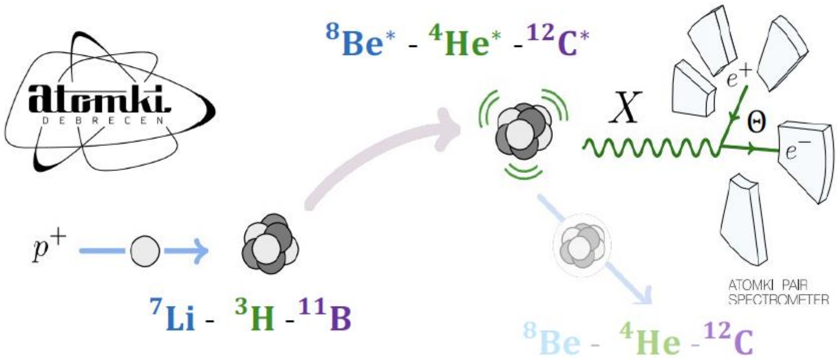
Status of the PADME X17 Search

Mauro Raggi, Sapienza Università di Roma & INFN Roma
on behalf of the PADME collaboration

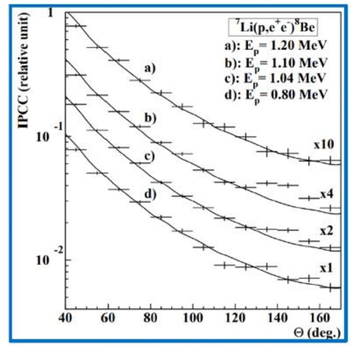
The X17 particles, status and new ideas
Trento 23-27 March 2026

The Atomki Anomaly



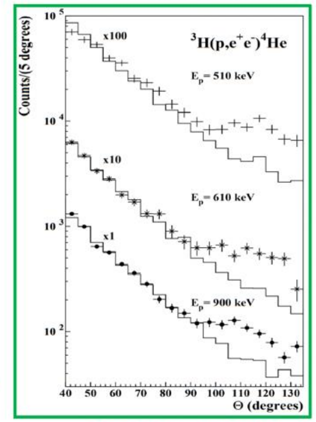
Solid experimental evidence: ^{8}Be, ^{4}He, ^{12}C each with high statistical significance

Phys.Rev.Lett. 116 (2016) 4, 042501



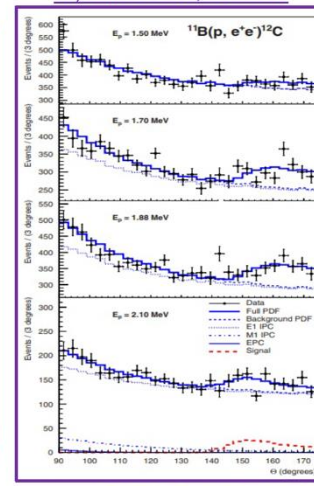
$m_X = (17.01 \pm 0.16)$ MeV

Phys.Rev.C, 104(4):044003



$m_X = (16.98 \pm 0.36)$ MeV

Phys. Rev. C 106, L061601



$m_X = (16.86 \pm 0.37)$ MeV

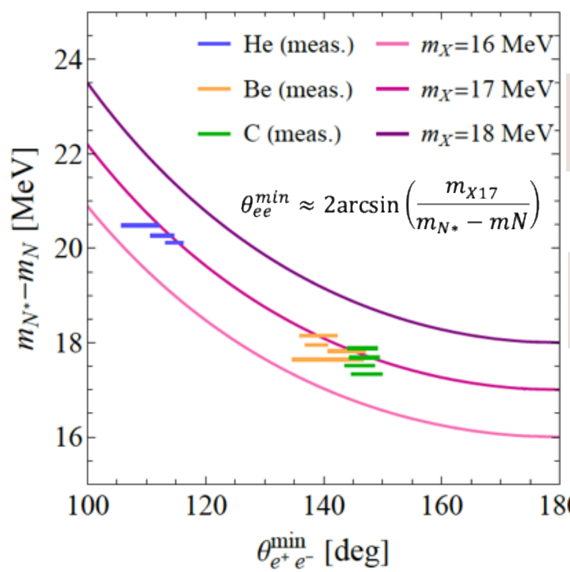
J. Feng et al. Phys. Rev. D 102, 036016 (2020)

N_*	$J_*^{P_*}$	Scalar X	Pseudoscalar X	Vector X	Axial Vector X
^{8}Be(18.15)	1^+	✗	✓	✓	✓
^{12}C(17.23)	1^-	✓	✗	✓	✓
^{4}He(21.01)	0^-	✗	✓	✗	✓
^{4}He(20.21)	0^+	✓	✗	✓	✗

- Vector and Axial Vector still viable after ^{4}He
- suggest to search in ^{12}C

plings. Last, we find that the protophobic vector boson could also be observable in the decays of the ^{12}C(17.23) 1^- excited state, and we have provided precise predictions for this rate.

Phys. Rev. D 108, 015009 (2023)



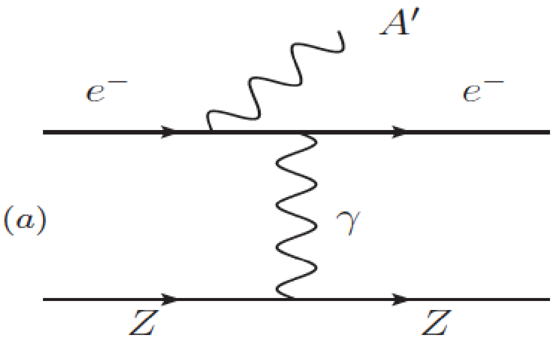
Using angular data only: 11 measurements

^{8}Be, ^{4}He, ^{12}C point to: M_{X17}=16.85±0.04 MeV

SAPIENZA UNIVERSITÀ DI ROMA

X17 in positron on target collisions

Electron beams



[M.R., E. Nardi et al. PRD 97, 095004 (2018)]

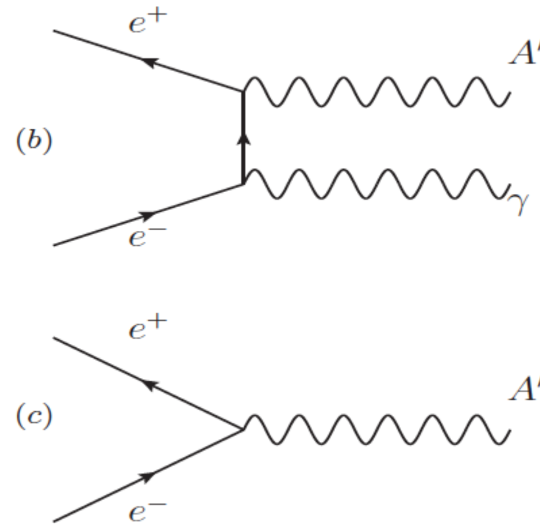
With e⁻ beams only Brems. production allowed

a) The Brems. process is O(α^3)

$$\frac{d\sigma}{dx\, d\cos\theta_{A'}} \approx \frac{8Z^2\alpha^3\epsilon^2E_0^2x}{U^2}\mathcal{L}og \times \left[\left(1-x+\frac{x^2}{2}\right) - \frac{x(1-x)m_{A'}^2(E_0^2x\theta_{A'}^2)}{U^2}\right]$$

With e⁺ beams add associated and resonant production

Positron beams



b) Radiative annihilation O(α^2)

$$\sigma_{nr} = \frac{8\pi\alpha^2}{s}\left[\left(\frac{s-m_{A'}^2}{2s}+\frac{m_{A'}^2}{s-m_{A'}^2}\right)\log\frac{s}{m_e^2} - \frac{s-m_{A'}^2}{2s}\right]$$

c) Resonant annihilation O(α)

$$\sigma_{\rm res}(E_e) = \sigma_{\rm peak}\frac{\Gamma_{A'}^2/4}{(\sqrt{s}-m_{A'})^2+\Gamma_{A'}^2/4} \qquad \sigma_{\rm peak} = 12\pi/m_{A'}^2$$

Profit for a higher production in a tiny mass region

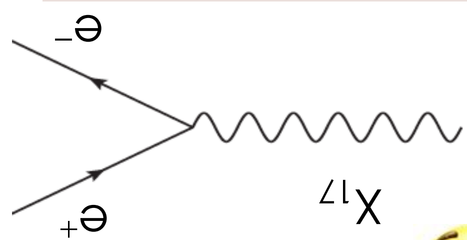
$$\mathcal{N}_{X_{17}}^{\rm Vect.} \simeq 1.8\cdot 10^{-7} \times \left(\frac{g_{ve}}{2\cdot 10^{-4}}\right)^2 \left(\frac{1\ {\rm MeV}}{\sigma_E}\right) \qquad \mathcal{N}_{X_{17}}^{\rm ALP} \simeq 5.8\cdot 10^{-7} \times \left(\frac{g_{ae}}{\rm GeV^{-1}}\right)^2 \left(\frac{1\ {\rm MeV}}{\sigma_E}\right)$$

Resonant production: X17 "Golden mode"

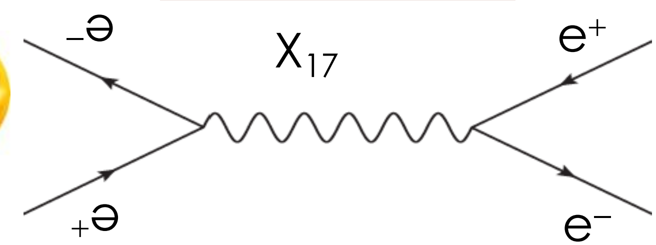
Atomki X_{17}

[M.R., E. Nardi et al. PRD 97, 095004 (2018)]

Just flip the diagram



and connect!



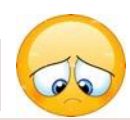
No model dependence just electron coupling!

Extremely high production rate Breit-Wigner enhancement

$$\sigma_{\text{res}}(E_e) = \sigma_{\text{peak}} \frac{\Gamma_{A'}^2/4}{(\sqrt{s} - m_{A'})^2 + \Gamma_{A'}^2/4} \qquad \sigma_{\text{peak}} = 12\pi/m_{A'}^2$$

Lowest possible α suppression

Extremely small Γ_{X17} $\quad \Gamma_{A'} \simeq \epsilon^2 \alpha m_{A'}/3 \quad$ $<10^{-2}$ eV



We need a lot of positrons in very limited COM energy range

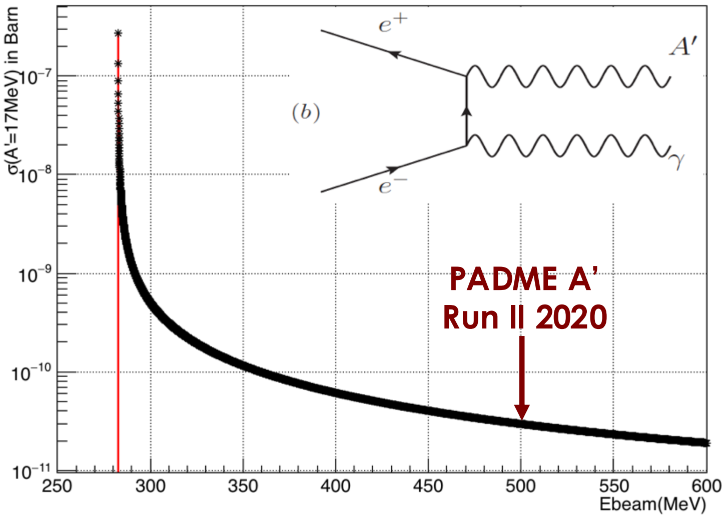
L. Darmé, M. Mancini, E. Nardi, M. Raggi
Phys. Rev. D 106,115036

We can **have >1E10 e⁺ in 20KeV** CoM energy at LNF!

Ok **let's do that at PADME**!

SAPIENZA
UNIVERSITÀ DI ROMA

Cross section enhancement

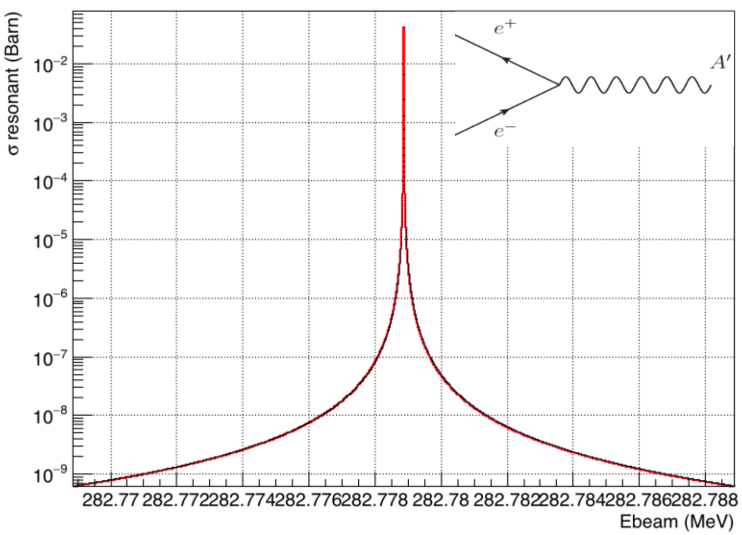


Associated production

$$\sigma_{nr} = \frac{8\pi\alpha^2}{s}\left[\left(\frac{s-m_{A'}^2}{2s}+\frac{m_{A'}^2}{s-m_{A'}^2}\right)\log\frac{s}{m_e^2}-\frac{s-m_{A'}^2}{2s}\right]$$

~ resonant production gives factor >1000 increase in X17 production with 1% beam energy resolution :)

But only very near to the resonance
500 MeV positrons will not help much



Resonant annihilation

$$\sigma_{\rm res}(E_e) = \sigma_{\rm peak}\frac{\Gamma_{A'}^2/4}{(\sqrt{s}-m_{A'})^2+\Gamma_{A'}^2/4}$$

$$\sigma_{\rm peak} = 12\pi/m_{A'}^2 \qquad \Gamma_{A'} = \tfrac{1}{3}m_{A'}\varepsilon^2\alpha$$

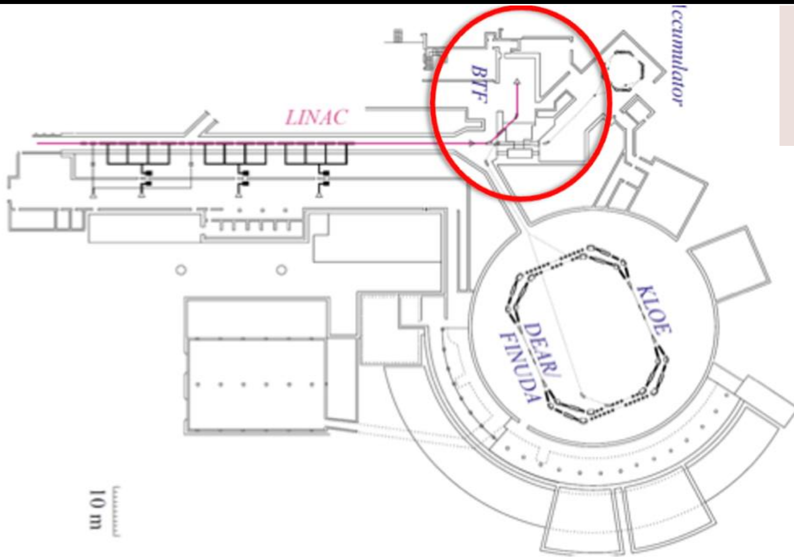
σ_{peak}~0.13 MeV^{-2}

Γ_{X17} ~ 0.04 eV for ε^2 =1x10^{-6} (vector case)

$$\mathcal{N}_{X_{17}}^{\rm Vect.} \simeq 1.8\cdot 10^{-7} \times \left(\frac{g_{ve}}{2\cdot 10^{-4}}\right)^2 \left(\frac{1\ {\rm MeV}}{\sigma_E}\right)$$

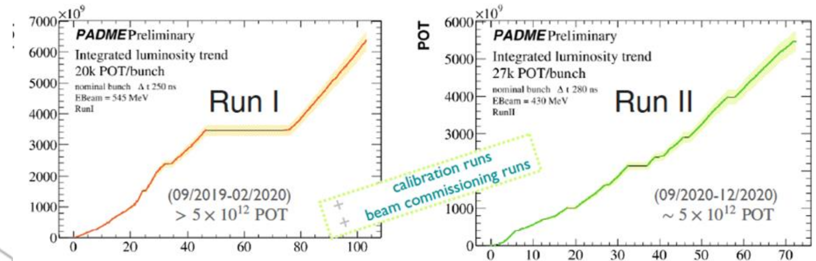
Need 282.7 MeV beam with <1% ΔP/P

The PADME experiment at LNF



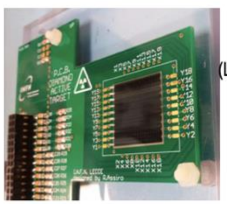
PADME is located at the Beam Test Facility of DAFNE

Data taking Invisible: Run I 2018, Run II 2020



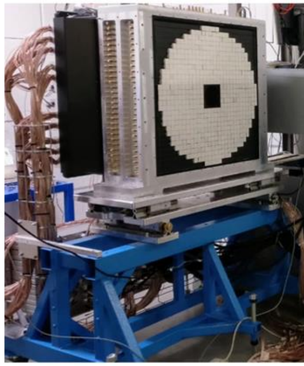
Run III 2022: dedicated search for X17

PADME detector setup



Active target
(Lecce & University Salento)

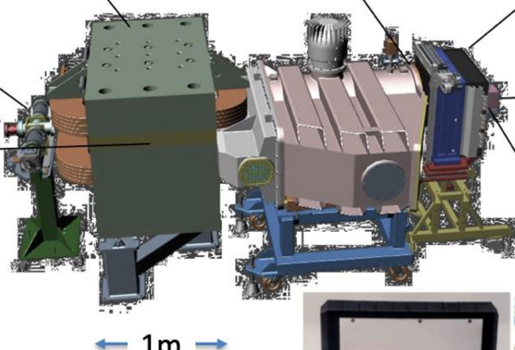
C-fiber window

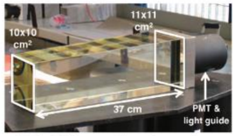


BGO calorimeter
(Roma, Cornell U., LNF, LE)

Dipole magnet
(CERN TE/NSC-MNC)

Veto scintillators
(University of Sofia, Roma)



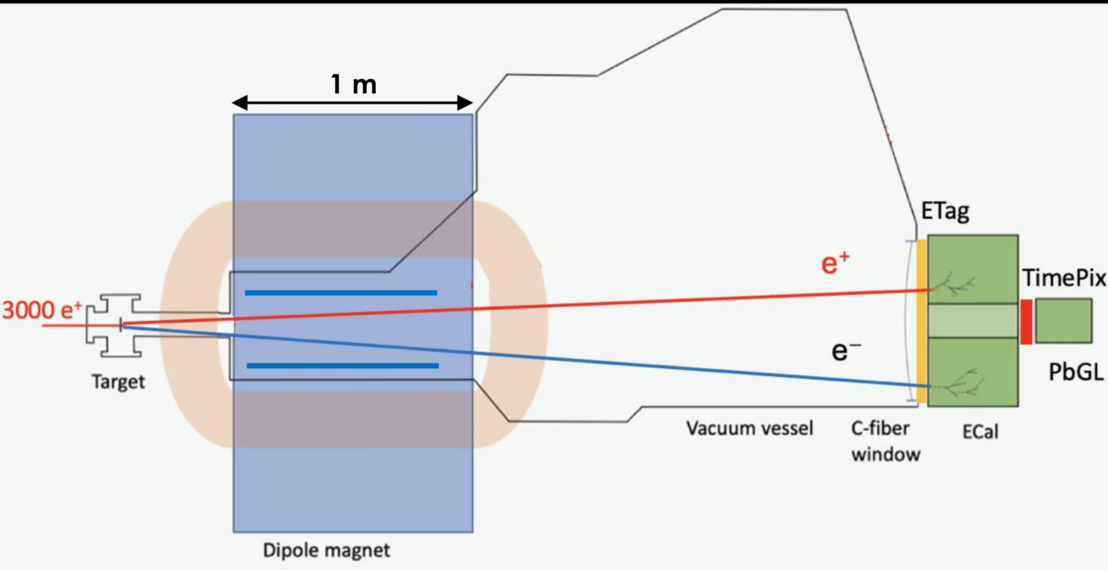


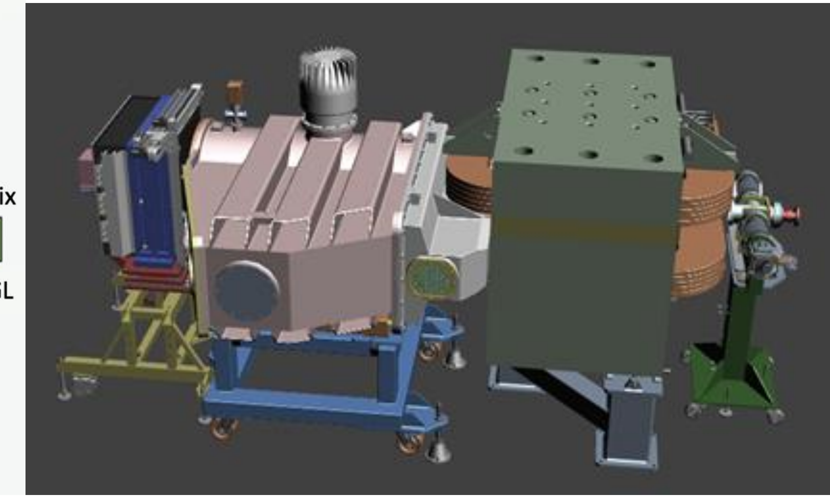
PbGL calorimeter

TimePIX3 array
(ADVACAM, LNF)

M.R and V. Kozhuharov
Adv. High Energy Phys. 2014 (2014) 959802

PADME detector in Run III





2022 Run-III setup adapted for the X17 search:

- Active target, CVD polycrystalline diamond with X,Y coordinates
- Dipole Magnet OFF
- Charged-veto detectors <u>not used</u>
- <u>ECal</u>, 616 21x21x230 mm^3 BGO crystals
- Newly built ETag in front of Ecal for e/γ
- <u>Timepix</u> silicon-pixel detector for beam spot imaging
- <u>Lead-glass</u> beam catcher (NA62 LAV spare block)

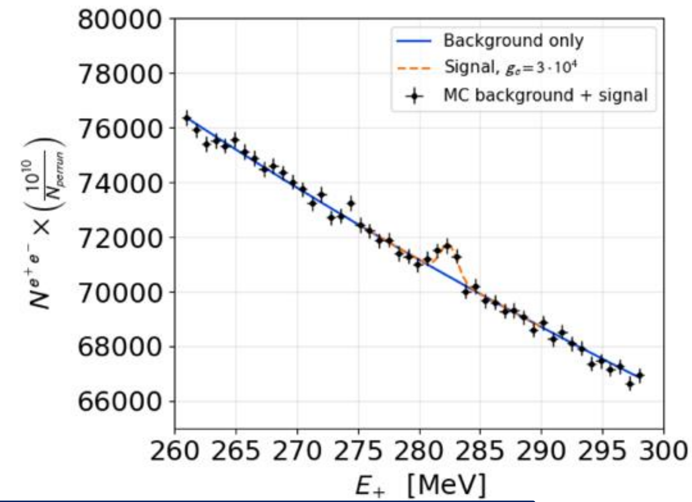
The mass scan PADME search strategy

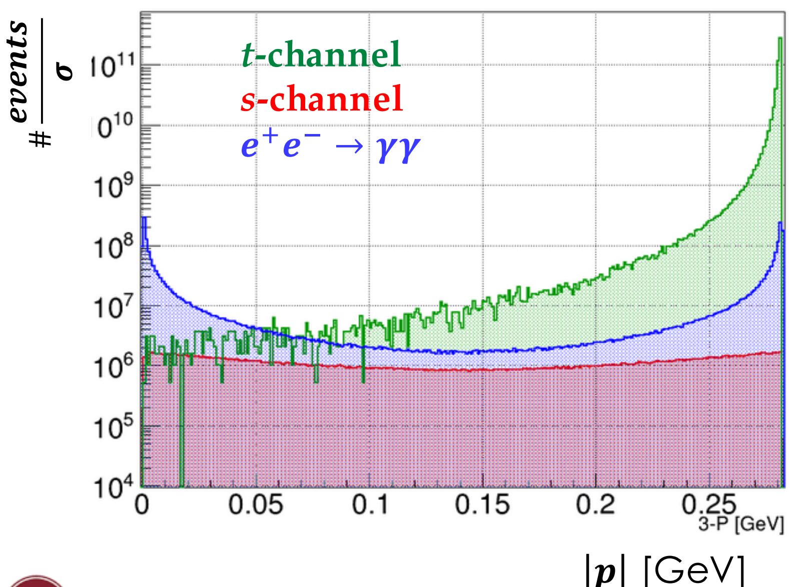
PADME, can use resonant X17 production process

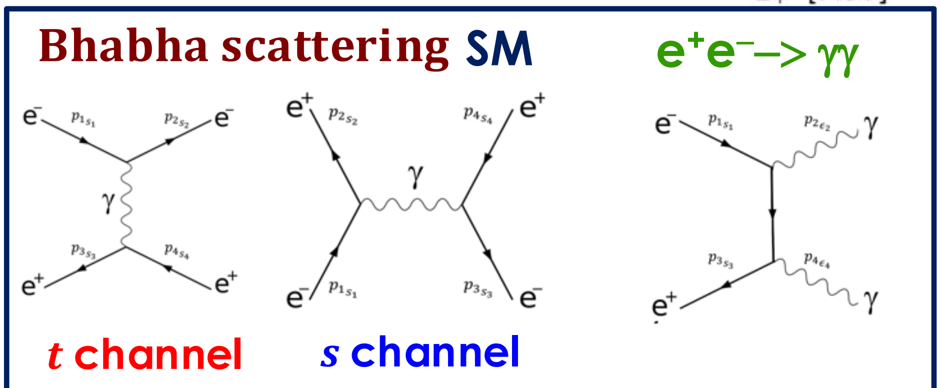
- Extremely effective in producing X17 but in a very small mass range
- Scan E_{beam}=260–300 MeV in <1 MeV steps

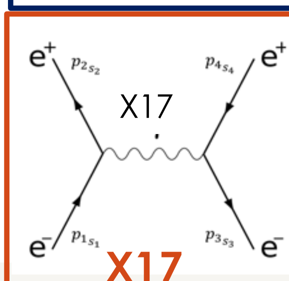
- Completely data driven no theory or MC inputs
- X17 signal should emerge on top of **Bhabha BG** in few points of the scan.
- Data driven BG estimated using surrounding bins

Cartoon view of the scan technique







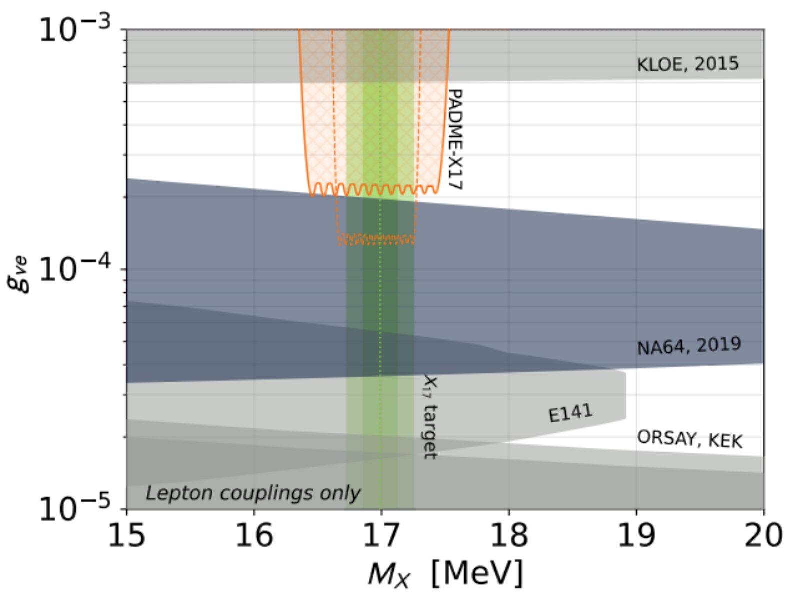


BSM

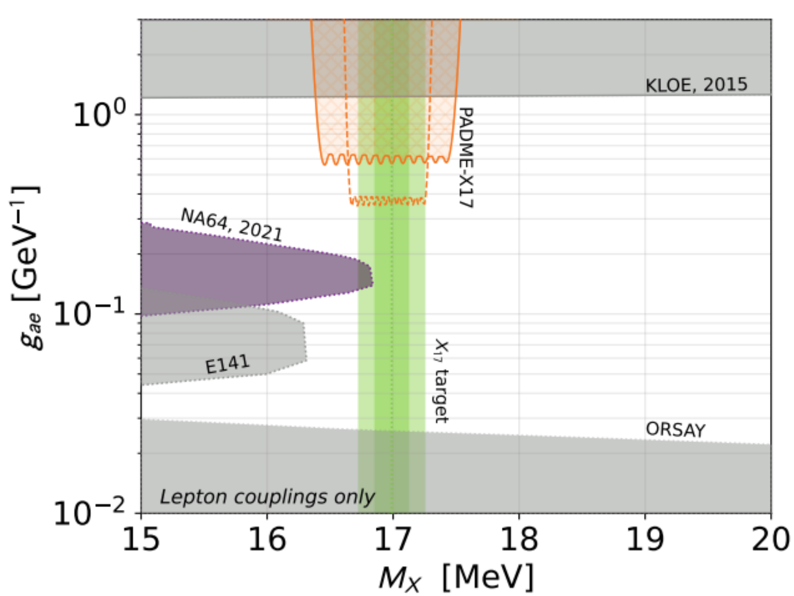
PADME expected limits

L. Darmé, M. Mancini, E. Nardi, M. Raggi
Phys. Rev. D 106,115036

Vector X17



Pseudo scalar X17



BG from SM Bhabha scattering under control down to ε = few 10^{-4}
Need precise luminosity measurement and systematic errors control (<1%)

Need ~1×10^{10} POT per each energy point
PADME maximum sensitivity in the vector case

X17 observables at PADME

Several different observables can be used with different systematics

Osservabili:

- $\frac{N(e^+e^-)}{N^{PoT}}$ vs $\sqrt{s}$ $\quad$ $\frac{N(\gamma\gamma)}{N^{PoT}}$ vs $\sqrt{s}$
- $\frac{N(e^+e^-+\gamma\gamma)}{N^{PoT}}$ vs $\sqrt{s}$
- $\frac{N(e^+e^-)}{N(\gamma\gamma)}$ vs $\sqrt{s}$

N(2cl)/NPoT ⟹ existence of X17
High statistical significance (small sensitivity loss due to small $\gamma\gamma$ BG)
No E/γ tagging related systematic errors

N(ee)/N($\gamma\gamma$) ⟹ existence of X17
Lower statistical significance due to smaller $\gamma\gamma$ cross section
Do not depend on N_{PoT} (no N_{PoT} systematic)
Error dominated by E/γ tagging efficiency

N_{e+e-}/N_{PoT} ⟹ vector nature of X_{17}
Systematic errors due to ETag tagging efficiency stability and N_{PoT}
$N_{\gamma\gamma}/N_{PoT}$ ⟹ pseudo-scalar nature of X_{17}
Systematic errors due to ETag tagging efficiency stability and N_{PoT}

PADME Run III data set: winter 2022

Run III PADME data set contains **3 subset**

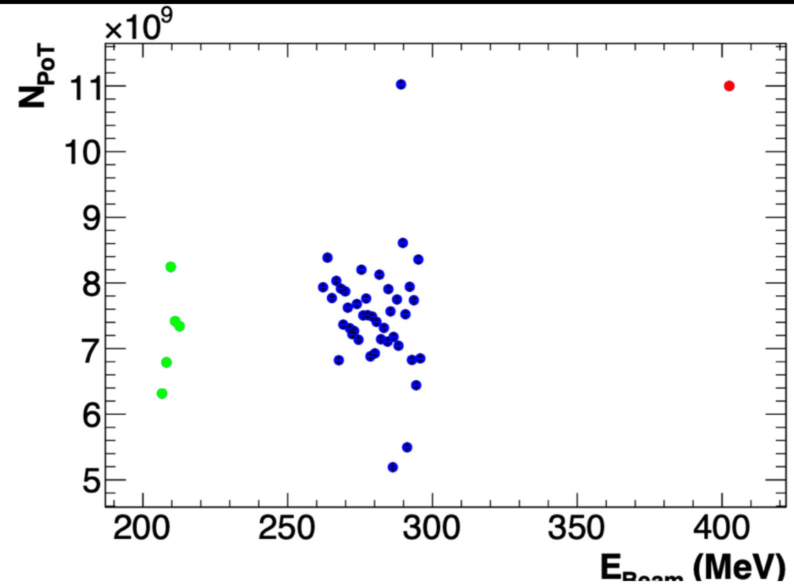
- **On resonance: E_B range (263-299) MeV**
- **Below resonance: E_B range (205-211) MeV**
- **Over resonance: single Energy 402. MeV**

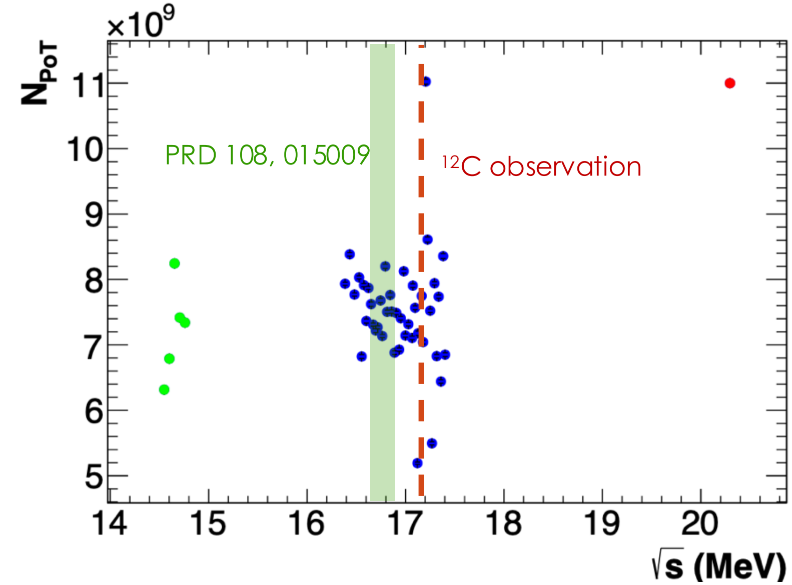
On resonance points **spaced** by **~ 0.75 MeV**
Point spacing equal to the energy resolution
Mass region 16.4 MeV <M_{X17}< 17.5 MeV
statistics ~1×10^{10} NPoT per point

Below resonance **spaced** by **~1.5 MeV**
Statistics ~ 1×10^{10} NPoT per point
Used to normalize absolute yield

1 over resonance energy **5 different runs**
Statistics ~0.4×10^{10} PoT per run ~2E10 total
Used to validate N_{PoT} measurement

Run III has already achieved ΔP/P~0.25%!





Dots mass points explored by PADME

Effect of e⁻ motion on the signal yield

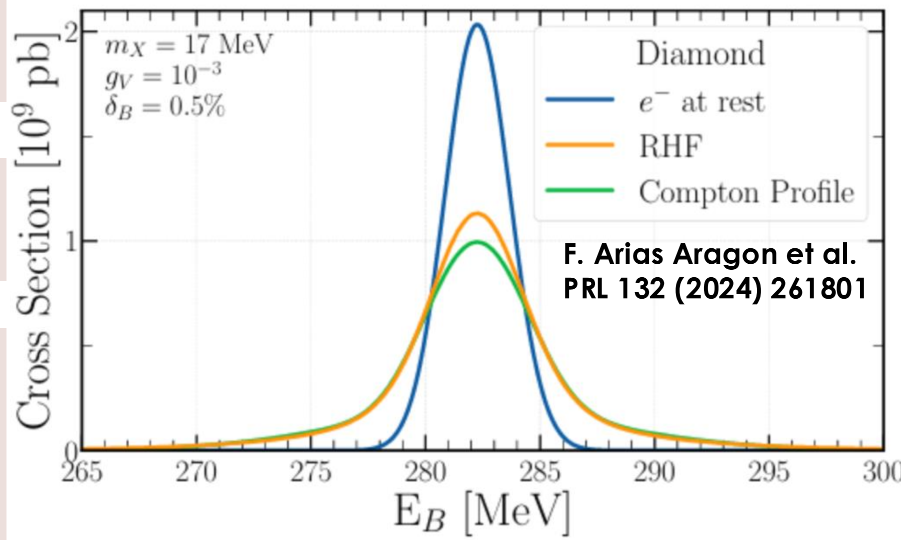
The energy resolution in Run III turned out **to be much smaller the 1%.** *JHEP 08 (2024) 121*

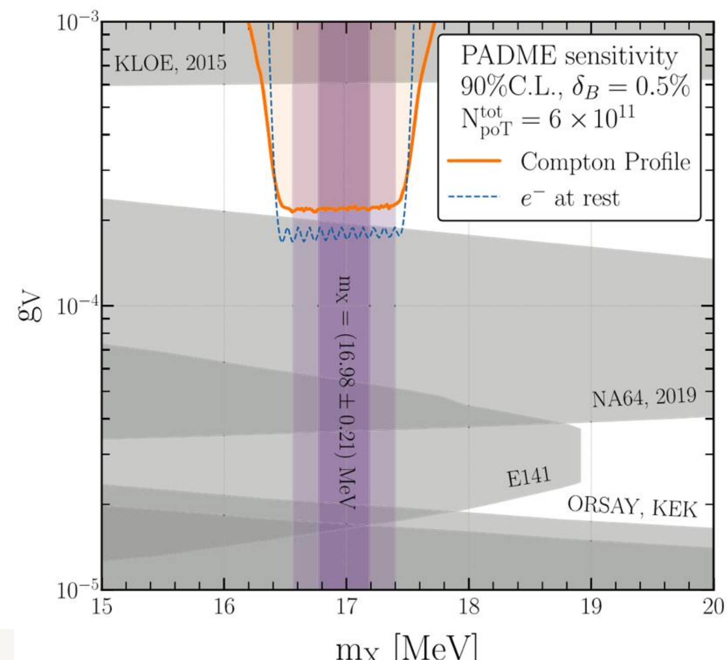
e⁻ at rest model in Phys. Rev. D 106,115036 was found to be inadeguate for such a small ΔP/P

New expected signal yield(s) provided from: **F. Arias Aragon et al. PRL 132 (2024) 261801**

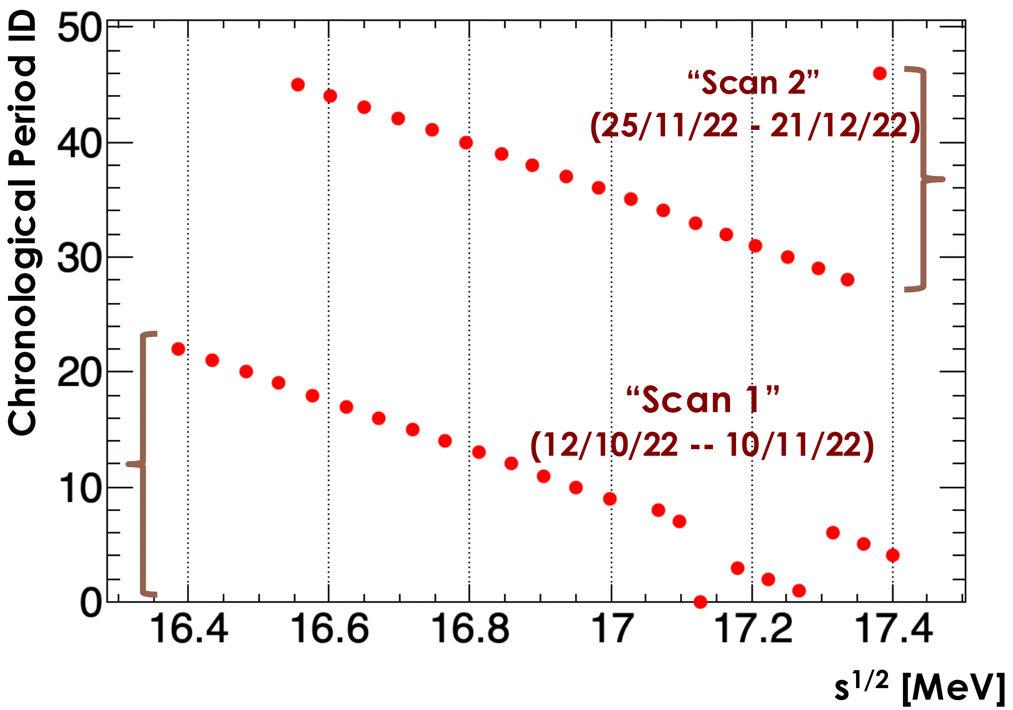
Includes effect of motion of the atomic electrons in the diamond target using Compton profiles data for diamond

PADME Resonant search sensitivity slightly reduced





Run III data taking strategy: 2 scans



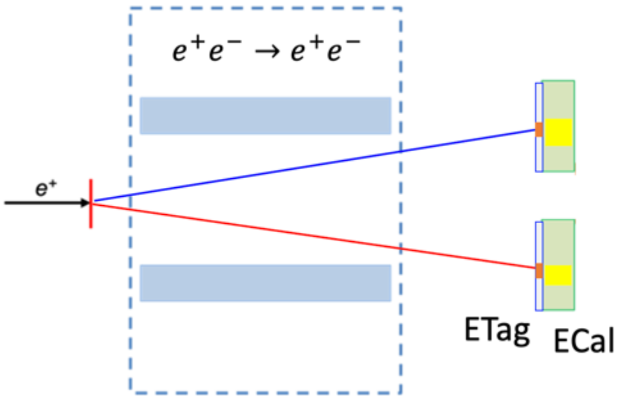
"**Run**": DAQ **for ~8 hours**, determine beam avg position/angle, ECal energy scale
"**Period**": a point at a **fixed beam energy**, typically lasts **24 hours**
"**Scan**" a **chronological set of periods** typically decreasing in energy

Scan 1 and 2 periods spaced ~ 1.5 MeV but interspersed in energy

Detailed GEANT4-based MC performed for each period

PADME Run III analysis scheme

Scatter e^+ on e^- in the diamond target to select $e^+e^- \to e^+e^-$ or $\gamma\gamma$ (2Cl)
Measure, direction and energy of each track with Ecal
Transform back to the Centre of Mass: e^+e^- are back-to-back.
Select events with $\theta_1+\theta_2=\pi$ and $\phi_1-\phi_2=\pi$



After selecting pure $e^+e^- \to e^+e^-$ search for unexpected excess from $e^+e^- \to X17 \to e^+e^-$ by scanning the X17 mass region.

Ultimately compare $N_2(s)$:

BG only hypothesis: $N_2(s) = N_{POT}(s) \times B(s)$

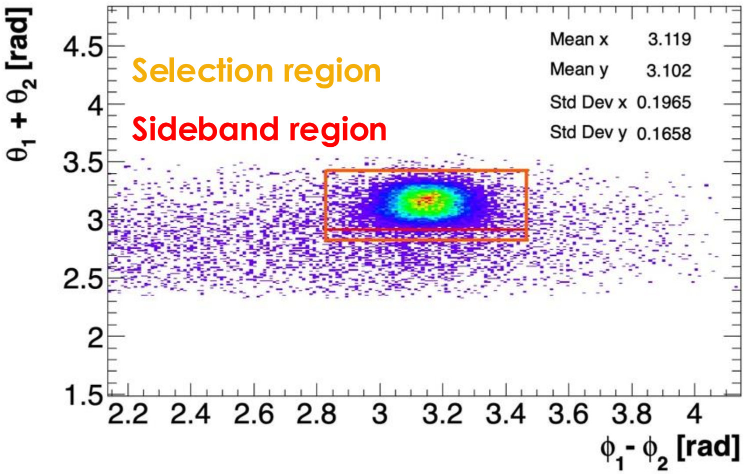
S+BG hypothesis: $N_2(s) = N_{POT}(s) \times [\, B(s) + S(s; M_X, g)\, \varepsilon_S(s)]$

Inputs:

- **$N_{POT}(s)$ number of e^+ on target from beam-catcher calorimeter**
- **$B(s)$ background yield expected per POT**
- **$S(s; M_X, g)$ signal production expected per POT for {mass, coupling} = {M_X, g}**
- **$\varepsilon_S(s)$ signal acceptance and selection efficiency**

$N_2(s)$: Number of 2Cl candidates

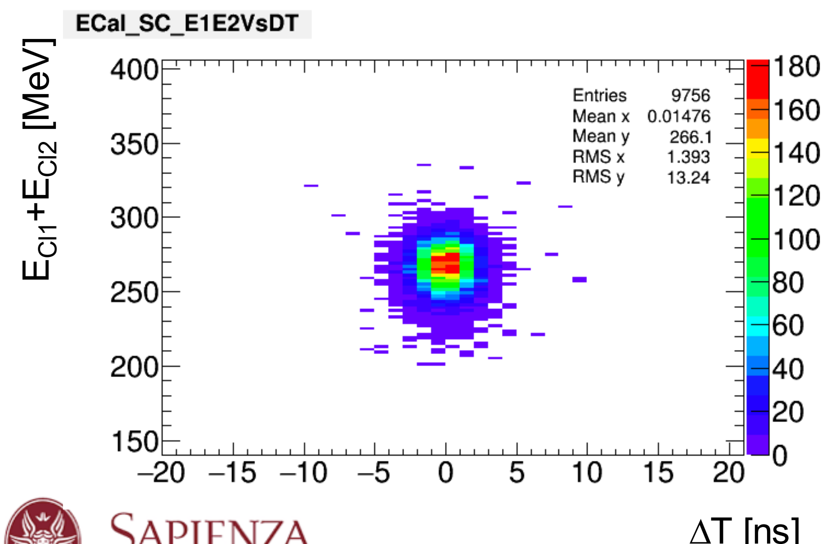
Neglecting m_e/E terms, the c.m. angles are independent on the lab energies



- Selection algorithm made as independent as possible on the beam variations:
- Retune beam center run by run with an error << mm
- Overall, make marginal use of the cluster energy
- Main analysis **cut based on CM angles only**:

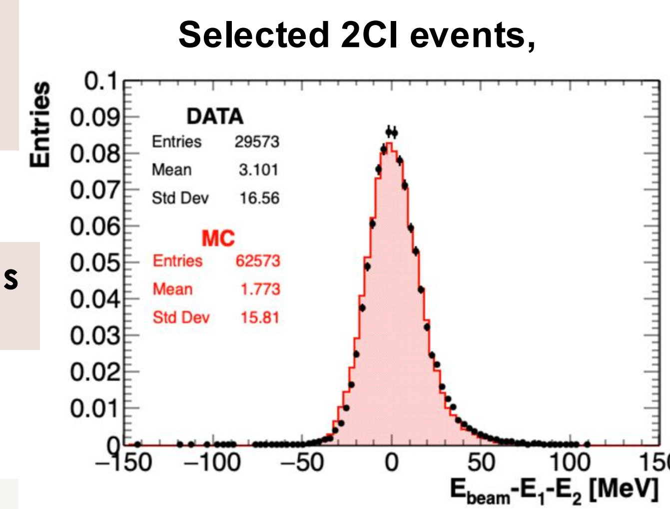
$(\theta_1+\theta_2=\pi)$ and $(\phi_1+\phi_2=\pi)$

E_{tot} and ΔT used as independent cross check



Brems BG down to 4% level can be measured in data

N_2~ 30K candidates per Energy point



Improving observable $g_R(s)$

Try to spot deviations from SM expected 2Cl yield define the analysis observable:
$g_R(s) = N_{obs}(s) / N_{exp}(s)$
If no BSM physics exist $g_R(s) = 1$

Rewrite the master formula dividing $N_{obs}=N_2$ by $N_{exp} = N_{POT}(s)\ B(s)$:

$$\underbrace{N_2(s) / (N_{POT}(s)\ B(s))}_{g_R(s)} = K(s)[\ 1 + S(s; M_X, g)\ \varepsilon_S(s) / B(s)\ ]$$

Different effects (see later) lead to a **linear scale deviation K(s)** from 1

The $\varepsilon_S(s) / B(s)$ cancel most of the systematic effect being the B and S acc. similar

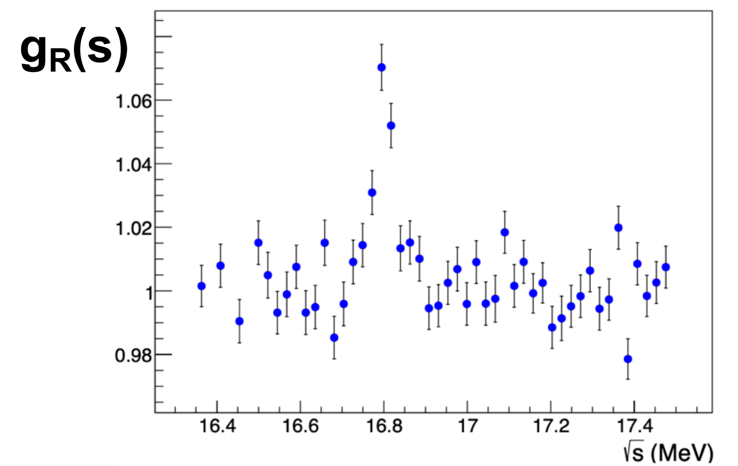
Question: is $g_R(s)$ more consistent with

- **BG only: K(s)**
- **S+BG = K(s) [1 + S(s; M_X, g) ε_S/B]**

Nuisance parameter count:

K(s) 2, S(s; M_X, g) 3, $\varepsilon_S(s)$ / B(s) 2. Total 7

MC with M_X = 16.8 MeV, $g_V = 8\times10^{-4}$



SAPIENZA
UNIVERSITÀ DI ROMA

$N_2(s)$ candidates error budget

- Selected around **30k 2Cl** candidates/period:
  Statistical error: **δN_2 ~ 0.6% up to 0.7%**
- SM Brems. **BG subtraction** using angular side-bands (bremsstrahlung, 4%)
  - additional statistical uncertainty **δN_2 ~ 0.3%**
- Data quality using time-averaged energy deposited on ECal:
  Overall systematic error from data quality, **δN_2 << %**

Source	Error on N_2 per period [%]
Statistics	**~0.6**
Background subtraction	**0.3**
Total	**0.65**

N_2 candidate count is statistically dominated!

B(s) expected BG/N_{PoT} error budget

B(s), the expected background/e^+, is determined with MC + data-driven checks

Source of uncorrelated error	Error on B per period [%]	Details
MC statistics	0.4	Next slide
Data/MC efficiency (Tag&Probe)	0.35	ⓘ
Cut stability	0.04	ⓘ
Beam spot position variations	0.05	ⓘ
Total	0.54	

Correlated (common) systematic errors on **B** enter in the scale K(s), e.g.:
Absolute cross section (rad. corr. at 3%), target thickness (known @ 5%)

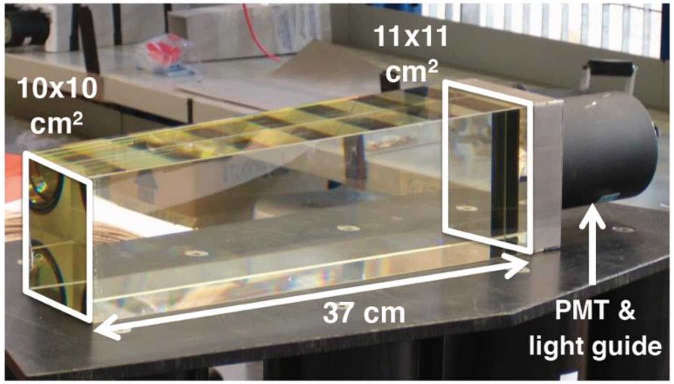
B expectation is compared to below resonance points, improving the systematic uncertainty

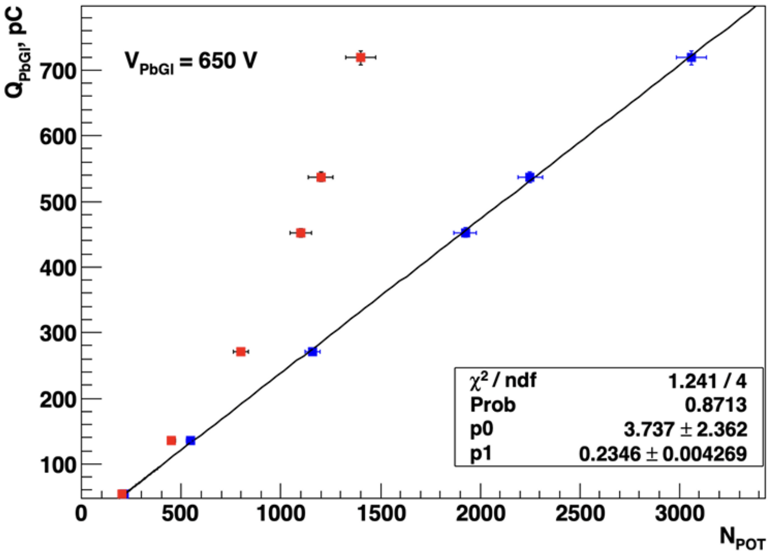
Scaling errors are accounted for

Source	Correlated B error [%]
Low-energy period statistics	0.4
Acceptance of low-energy, target thickness variations	0.5
Total	0.6

N_{PoT} calculation

Flux N_{POT} determined using Lead-glass detector charge, Q_{LG}:
$N_{POT} = Q_{LG} / Q_{1e+,\ 402\ MeV} \times 402 / E_{beam}$ [MeV]





Common systematic error dominated by Q_{1e+}
Known at 2%, see *JHEP* 08 (2024) 121

Uncorrelated systematic error due to value of E_{beam} from BES, 0.25%
Common scale error on beam energy, up to 0.5%, cancels @ 0.1%

Multiple analysis level corrections to be applied:

1. E_{Loss} @ E_{beam}/E_{Loss} @ 402 MeV: from data + MC, details
2. LG Radiation-induced response loss: from data, details

SAPIENZA
UNIVERSITÀ DI ROMA

N_{PoT} error budget

Uncorrelated uncertainty on N_{POT} :

Source	Error on N_{POT} per point [%]	Source
Statistics, ped subtraction	negligible	
Energy scale from BES	0.3	BES from timepix spot s_X
Error from ageing slope	Variable, ~0.35	
Total	**0.45**	

Correlated (common) systematic errors on N_{POT}:

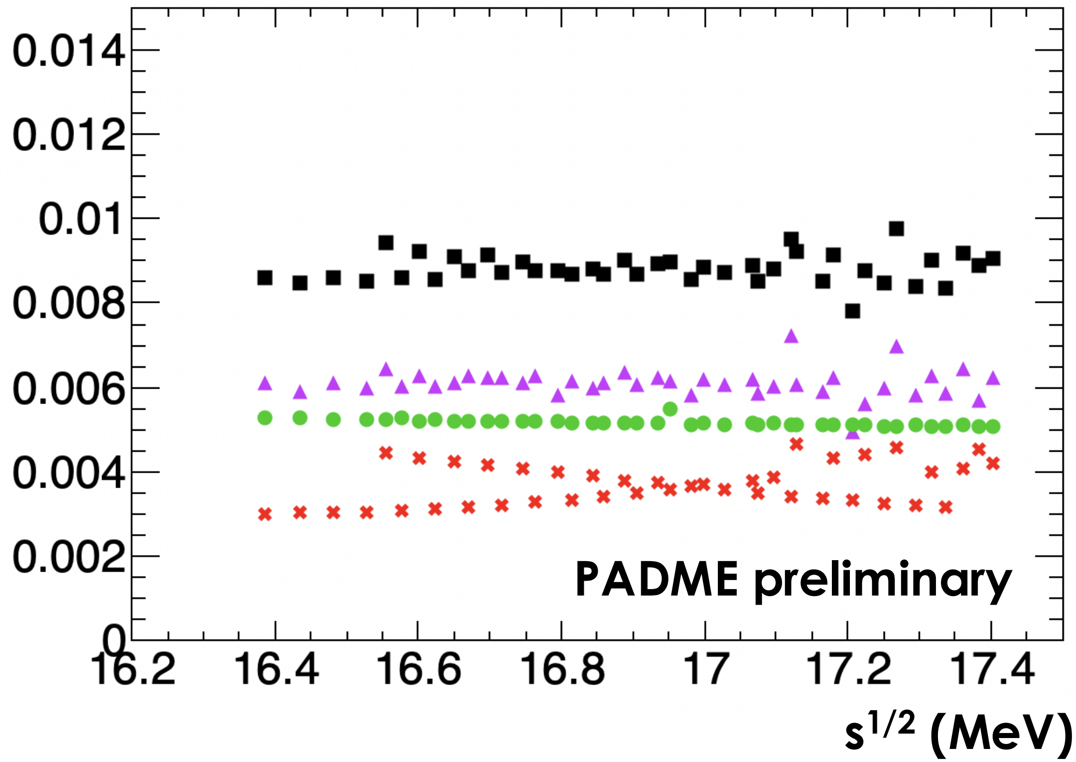
Source	Common error on N_{POT} [%]	Source
pC/MeV	2.0	Analysis in JHEP 08 (2024) 121
E_{Loss}, data/MC	0.5	
Ageing, constant term	0.3	
Total	**2.1**	

N_{PoT} error dominated by ageing correction!

Global $g_R(s)$ error budget

Uncorrelated uncertainty on $g_R(s) = N_2(s) / (N_{POT}(s)\, B(s))$:

Relative error per period



Source	Error [%]
$N^2(s)$	0.6
NPoT	0.35
B(s)	0.54
Total on $g_R(s)$	**0.88**
K(s) scale (common)	2.8

$S(s; M, g_v)$: Signal yield model

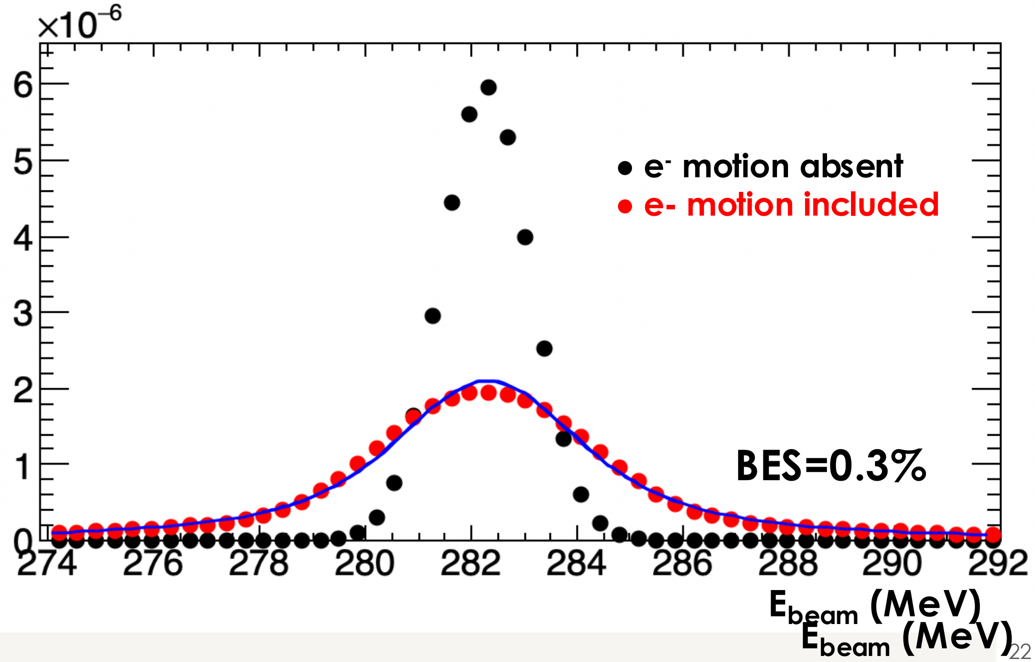
Parameterized S vs E_{beam} with a Voigt function:

- Convolution of the gaussian BES (0.3%) with the Lorentzian
- OK in the core within % with some dependence on BES

Uncertainty in the curve parameters as nuisances:

- Peak yield: 1.3%
- Lorentzian width around the resonance energy: 1.72(4) MeV
- Relative BES, as said: 0.025(5)%

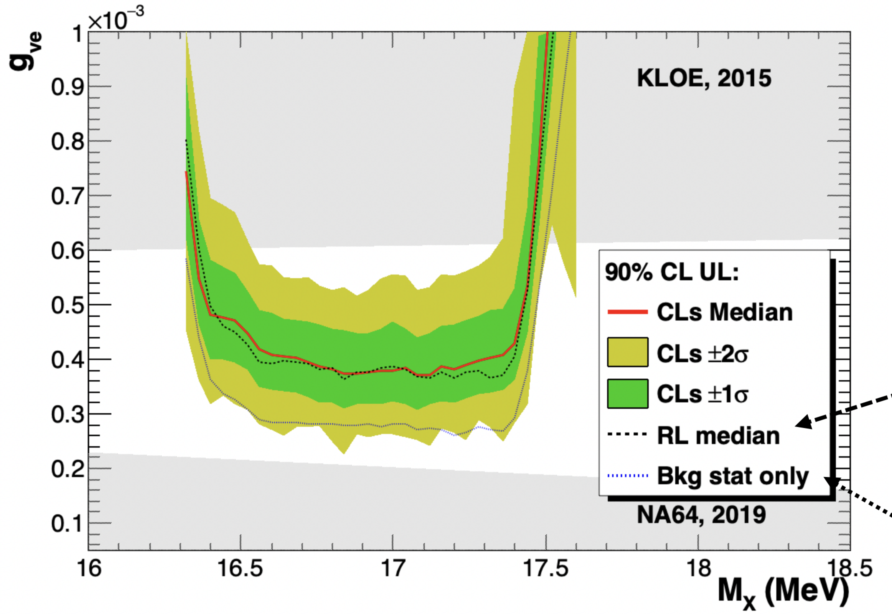
$S(E_{beam}; M_X = 17\ \text{MeV}, g_v = 1)$



SAPIENZA
UNIVERSITÀ DI ROMA

Expected sensitivity MC simulations

- Evaluate expected 90% CL UL in absence of signal
- Define Q statistic based on Likelihood ratio: $Q = L_{S+B}(g_V, M_X) / L_B$
- The likelihood includes terms for each nuisance parameter pdf
- For a given M_X, $CLs = P_S / (1 - P_B)$ is used to define the UL on g_V



The probabilities P_S and P_B are obtained using simulations, where the observables are always sampled, while the nuisance parameters stick to the B and S+B fits ("θ hat")

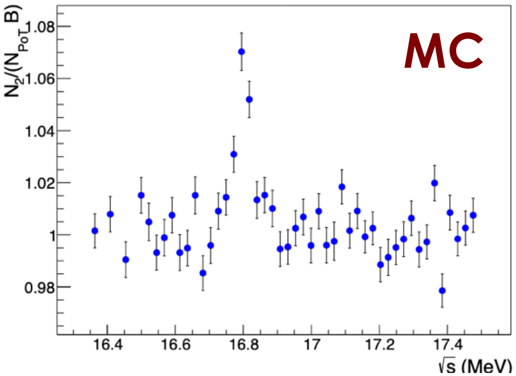
For comparison, we show also:

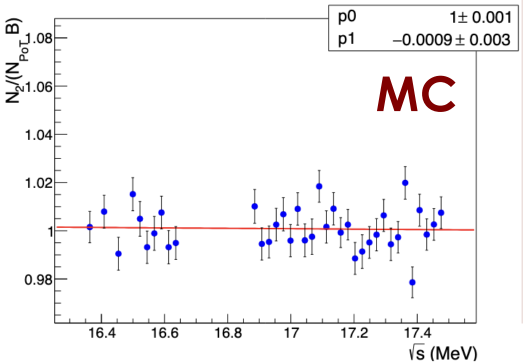
- the median of the limits obtained using the Rolke-Lopez likelihood-ranking method with the 5 periods with largest signal yield
- the purely statistical UL, $1.28\ N_2^{1/2}$

For details, **PADME collaboration** JHEP06(2025)040

SAPIENZA UNIVERSITÀ DI ROMA

The "blind unblinding" procedure





To validate the error estimate, in presence of signal in any region of the mass scan JHEP06(2025)040

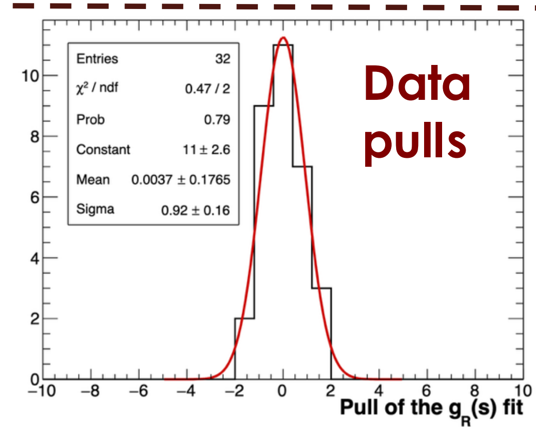
Aim to blindly define a side-band in $g_R(s)$, excluding 10 periods of the scan

Define the masked periods by minimizing χ^2 of a linear fit in $s^{1/2}$

1. Threshold on the χ^2 fit in **side-band is P(χ^2) = 20%,** corresponding to reject 10% of the times
2. If passed, check if the **fit pulls are gaussian**
3. If passed, check if a **straight-line fit of the pulls has no slope in $s^{1/2}$** (within 2 sigma)
4. If passed, check if constant term and slope of the linear fit for K(s) are within two sigma of the expectations, i.e.: ± 4% for the constant, ± 2% MeV^{-1} for the slope

Successfully applied, details in JHEP06(2025)040:

1. **P(χ^2) = 74%**
2. **Pulls gaussian fit probability 60%**
3. **Slope of pulls consistent with zero**
4. **Constant term = 1.0116(16), Slope = (-0.010 +- 0.005) MeV^{-1}**



Therefore, proceed with box opening

Observed limit after box opening

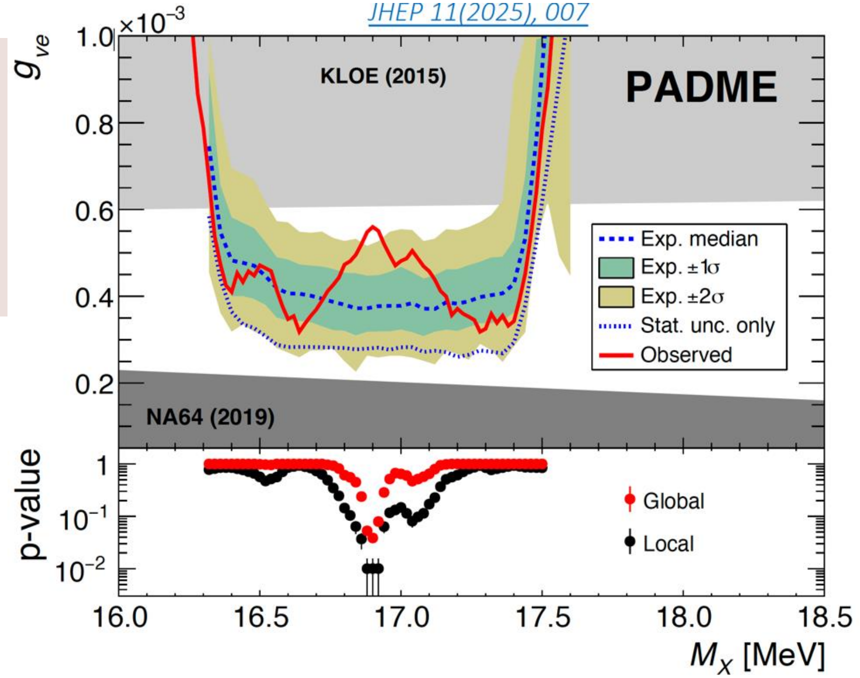
An **excess** is observed **beyond the 2σ local coverage** (**2.5 σ local**)

At **M_X = 16.90(2) MeV**, **g_{ve} < 5.6 x 10^{-4}**, the global probability dip reaches $3.9_{-1.1}^{+1.5}$ %, corresponding to (1.77±0.15) σ one-sided
(look-elsewhere calculated exactly from the toy pseudo-events)

If a 3σ interval is assumed for observation following the estimate M_X = 16.85(4) of PRD 108, 015009 (2023),

the p-value dip deepens to $2.2_{-0.8}^{+1.2}$% corresponding to (2.0±0.2) σ one-sided

[JHEP 11(2025), 007]

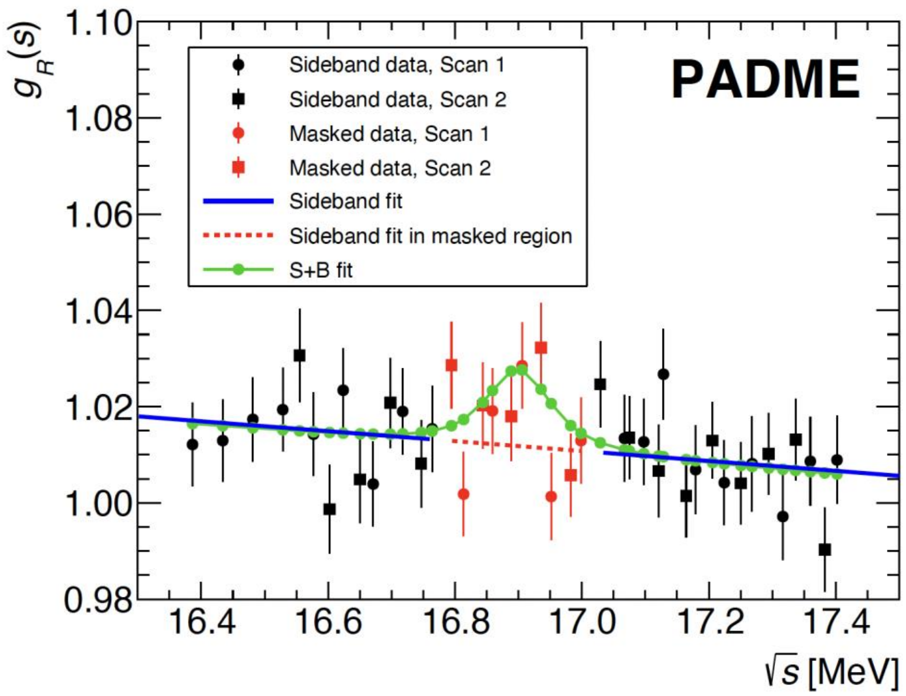


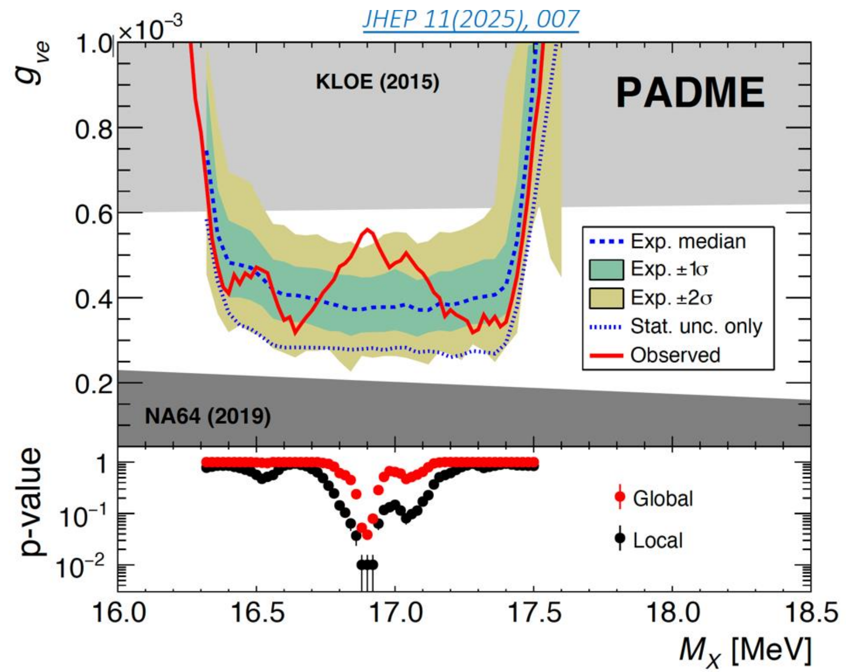
"Search for a new 17 MeV resonance via annihilation with the PADME Experiment"

JHEP 11 (2025) 007
arXiv:2505.24797
https://link.springer.com/article/10.1007/JHEP11(2025)007

Post unblinding checks: mass points

Check the data distribution against the likelihood fit used to evaluate Q_{obs}(S+B) Fit probability is 60%





Region masked by automatic procedure

S+B best fit

Masked point of scan 1

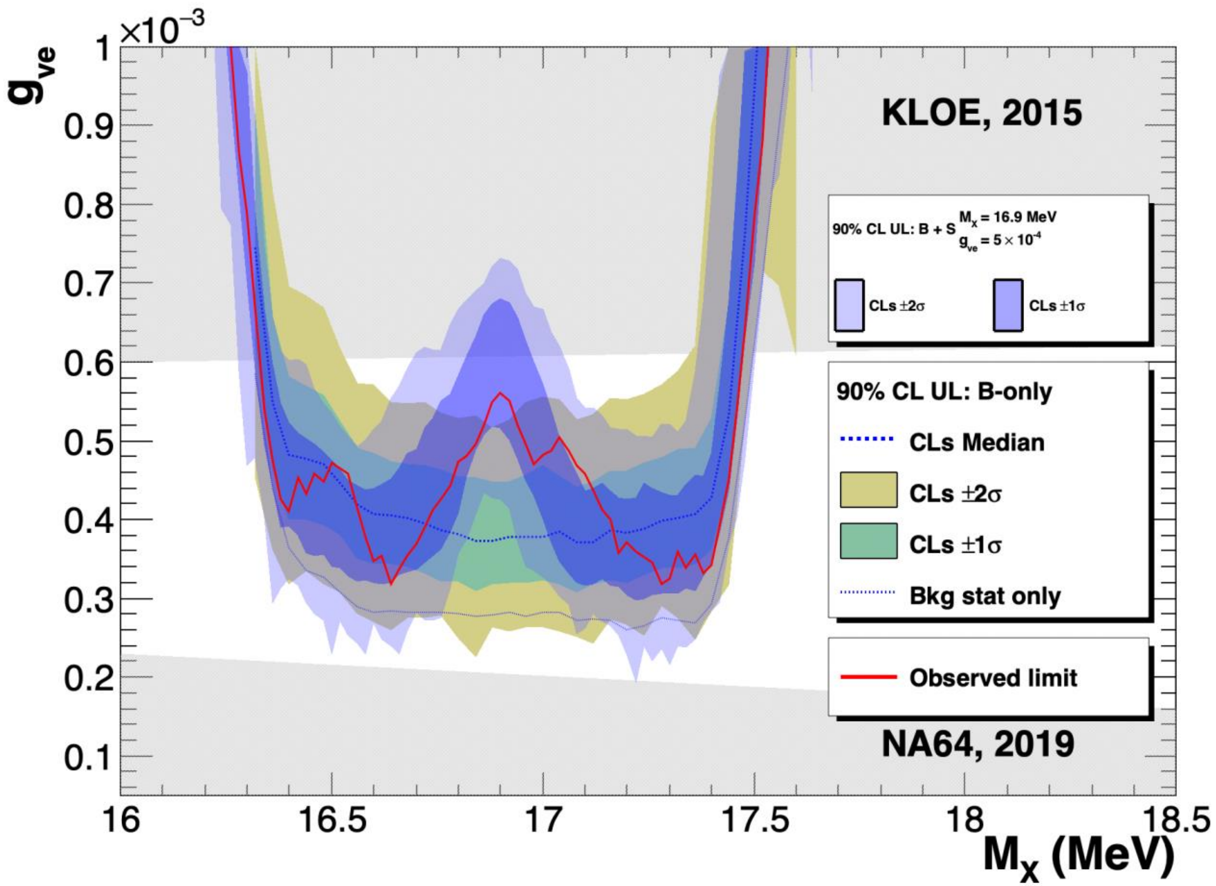
Masked point of scan 2

Sideband point of scan 1

Sideband point of scan 2

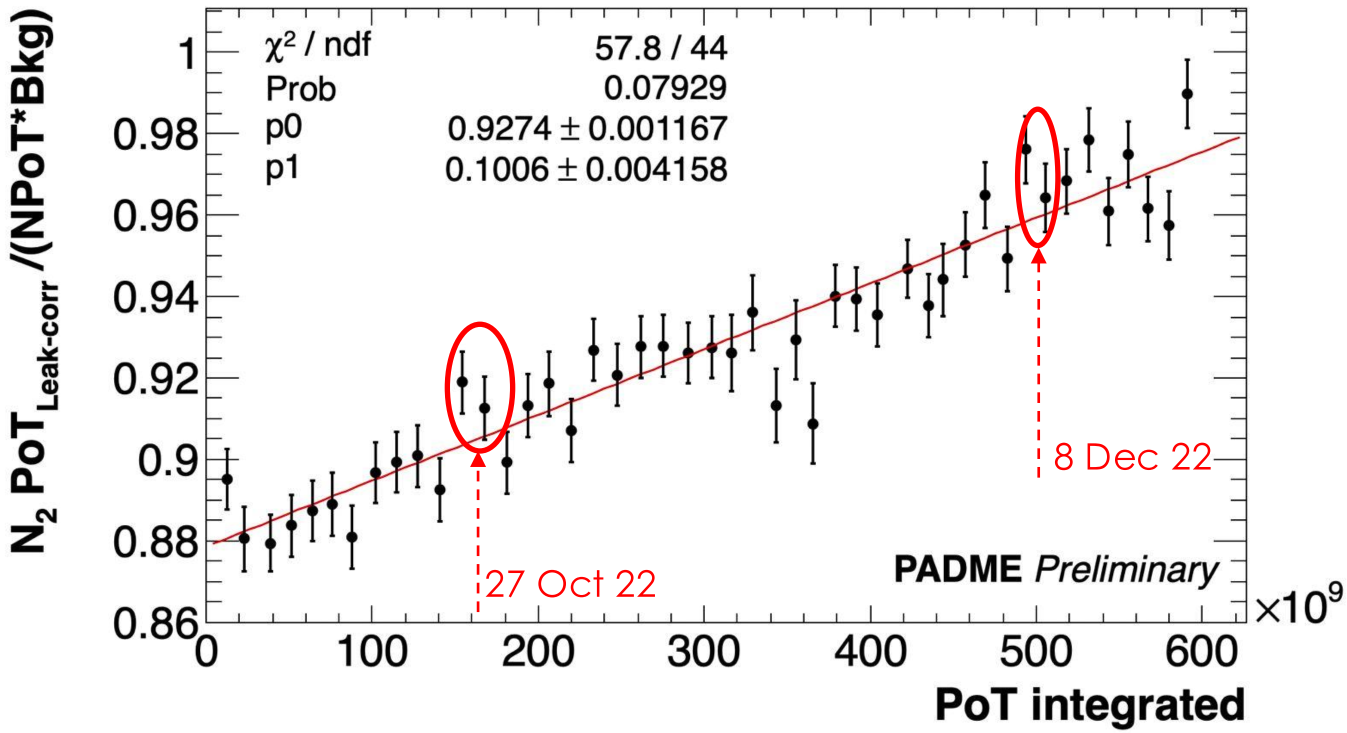
Post unblinding checks: excess shape

For comparison, check expected UL bands: **bkg-only** vs **B+S**(16.9 MeV, 5 × 10^{-4})



Post unblinding checks: LG ageing

After box opening, can check ageing correction applied, slope was 0.097(7)
Fully consistent (observed excess alters only marginally)

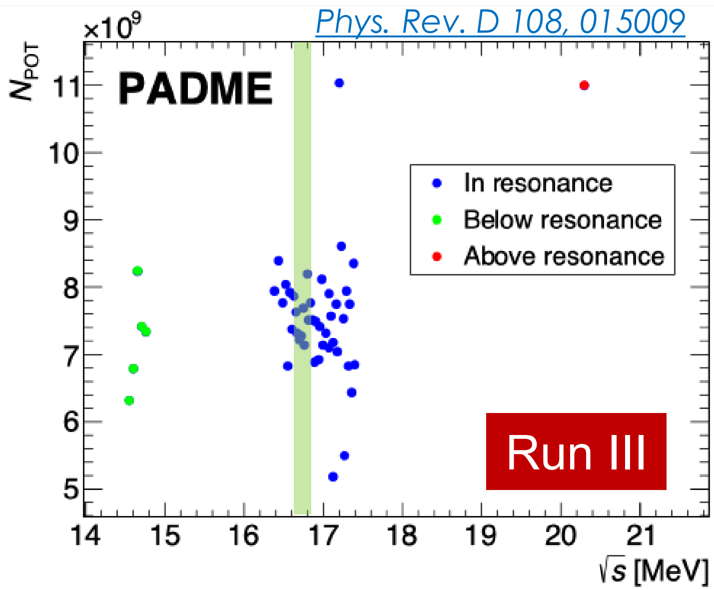


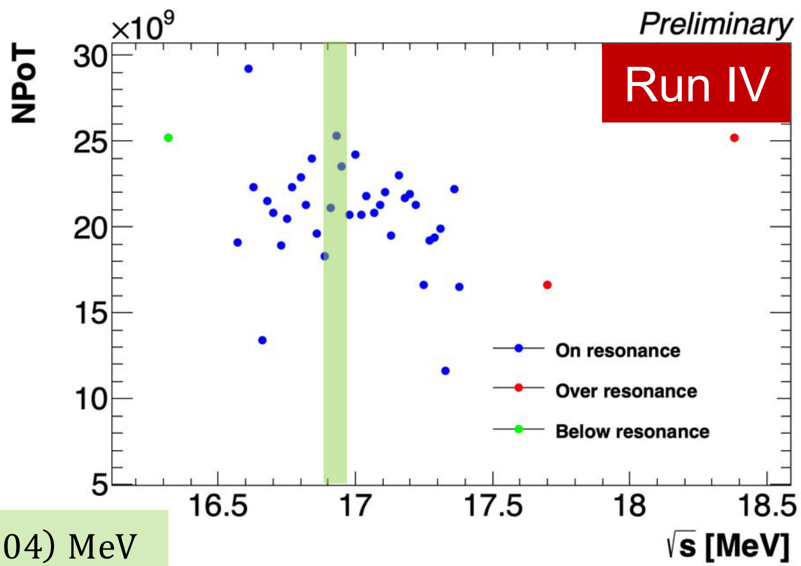
Run IV data taking

Run IV scan – 36 on resonance points +3 off resonance points +15 no-target runs

	Run III	Run IV
Scan points	42 on resonance S1 – 22 points S2 – 20 points	**36 on resonance S1=S2 – 18 points each**
N_{PoT}	$\sim 0.8 \times 10^{10}$PoT per on-resonance-point	$\sim \mathbf{2.2 \times 10^{10}}$**PoT per on-resonance-point**
E_{Beam}	$263\ MeV < E_B < 292\ MeV \quad \delta E_B \sim 0.75\ MeV$	$\mathbf{268\ MeV < E_B < 295\ MeV \quad \delta E_B \sim 0.75\ MeV}$
Below res.	**5 points @205 – 212 MeV**	**1 point @260 MeV**
Above res.	**1 point @402 MeV**	**2 points @300 – 330 MeV**

Phys. Rev. D 108, 015009





$m_{X_{17}} = (16.85 \pm 0.04)$ MeV

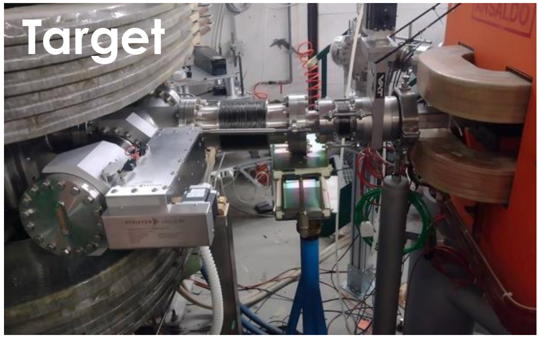
Run IV detector upgrades

<u>Diamond target</u> moved downstream by ~30 cm

PADME Magnet fully degaussed → remnant $B_{PADME} < 1\text{G}$

<u>New detectors added</u>:

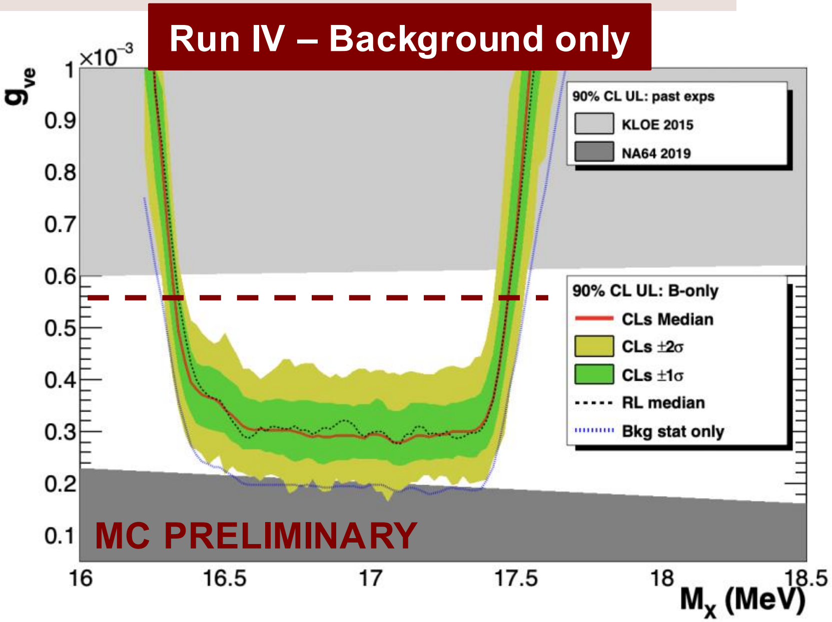
- **PadMMe** Micromegas chamber replaces the ETagger
- **TMM** Micromegas replaces the TimePix beam monitor
- Radiation loss monitor system for LG calibration (**<u>2nd LG block + LED pulser</u>**)



PadMMe
70x70x10 cm³

TMM
10x10x5 cm³

Source	Uncertainty [%]	
	Run III	Run IV
N_2	0.6 →	0.3
B	0.35	0.3
N_{PoT}	0.55 →	0.3
TOTAL	**0.88**	**0.5**

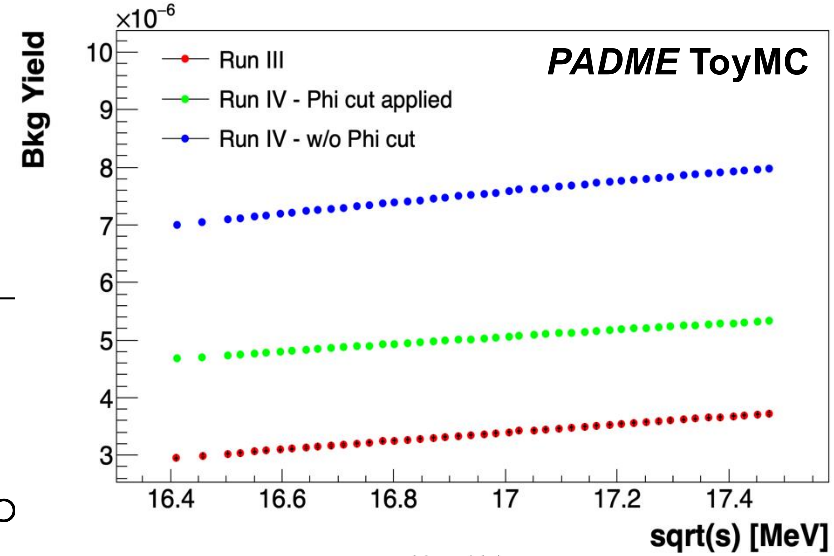


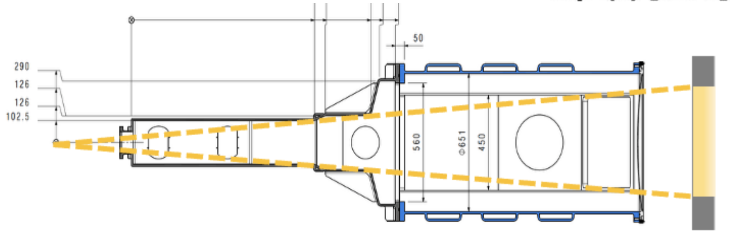
MC exclusion estimate:
4xRun III dataset + systematics lowered

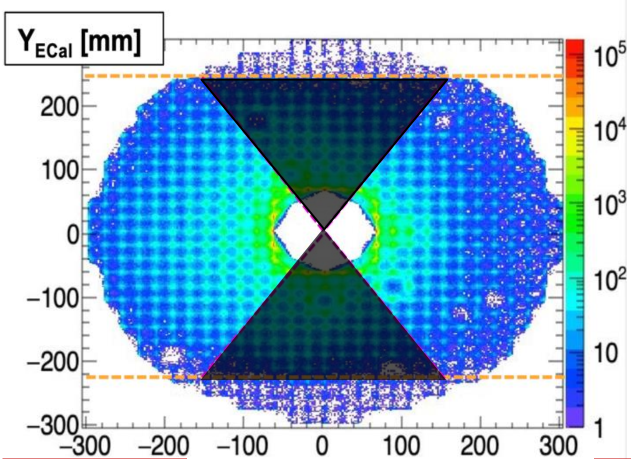
Run IV acceptance increase

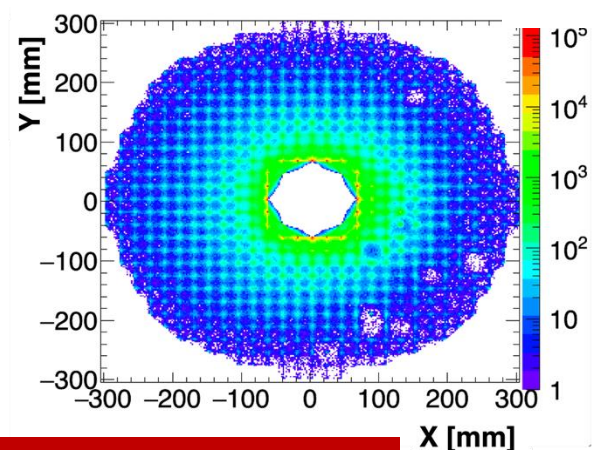
Run period	Target-ECal [mm]	Scattering θ_{lab} [mrad]	Magnet bore shadow
Run III	3700	24 - 73	249 mm
Run IV	3360	27 - 82	268 mm

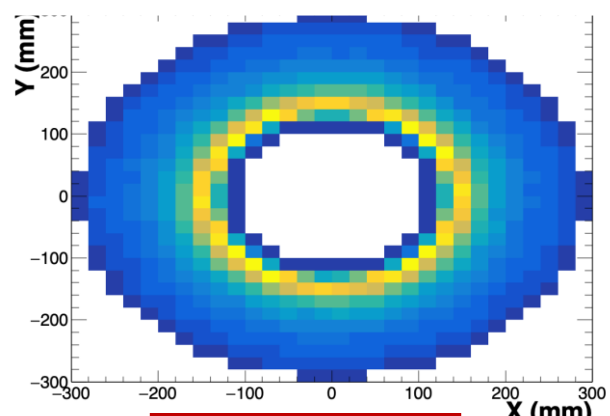
- Phi-cut can be totally removed or adapted
- Acceptance region widened → $\frac{Sig}{\sqrt{Bkg}}$ increases
- Run-by-run Run IV integrated luminosity increases b a factor of ~ 2.5 wrt Run III
  - Run III: $N_2 = 3.7 \times 10^{-6}$ (evaluated over 0.8×10^{10} PoT)
  - Run IV: $N_2 = 9.95 \times 10^{-6}$ (evaluated over 10^{10} PoT)











PADME MicroMega chamber

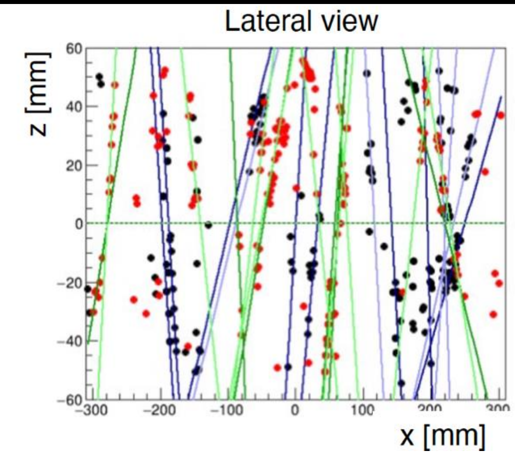
Double GAP MicroMega:

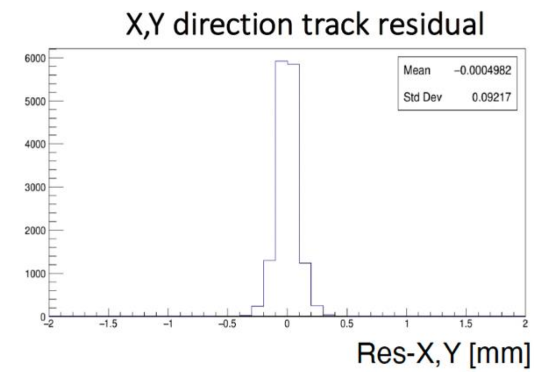
2x50 mm drift gap separated by mesh

2x readout planes

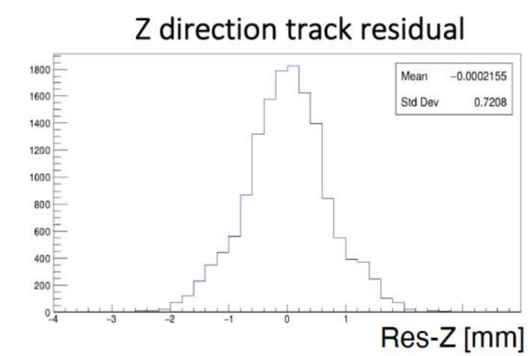
X,Y from readout strips $\sigma_{x,y}$~100μm

Z from drift time σ_Z ~700μm



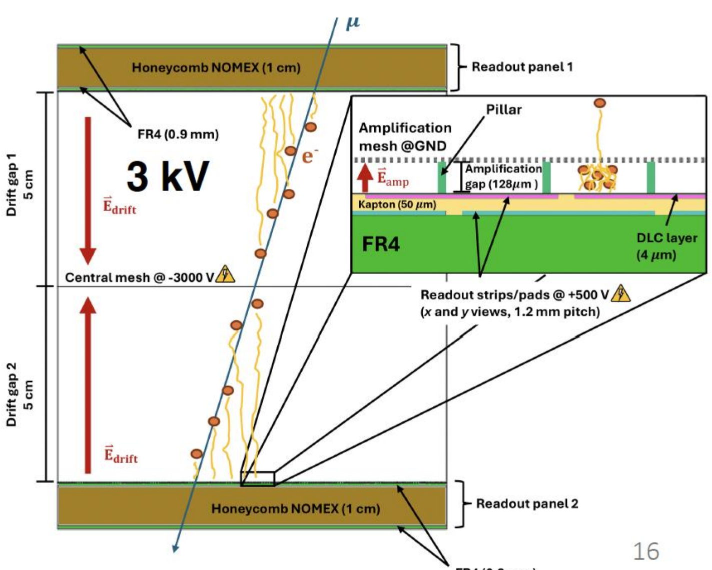


$\sigma_{x,y} \simeq 100$ μm



$\sigma_z \simeq 700$ μm

High occupancy due delta rays produced by the beam crossing in the cental region



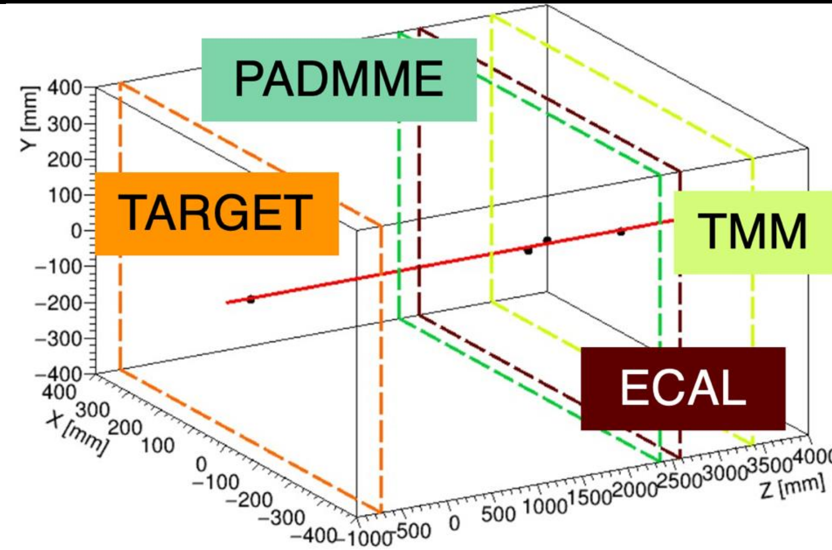
PadMMe ~70x70x10 cm³

Beam direction control

Diamond Target ⇨ TMM distance > 4m

$\sigma_{x,yBeam}$ @ TMM < 1mm
$\sigma_{x,yBeam}$ @ Target < 1mm

Angular resolution well below 1mrad



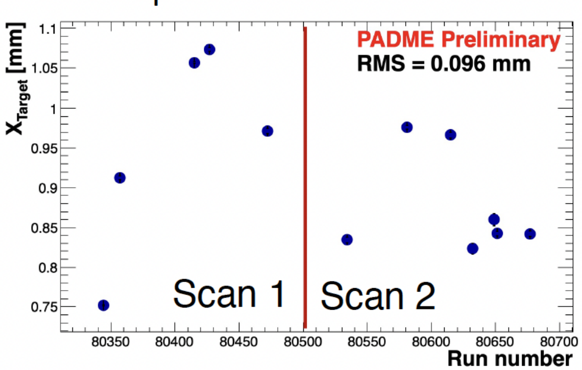
Additional informations:

ECal Center Of Gravity (x,y COG ~6mm)
MM beam positioning (~1-2 mm)

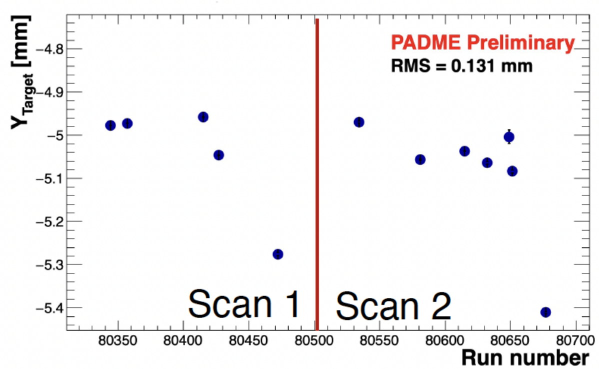
Precise alignement needed… ongoing

Target Run IV Preliminary

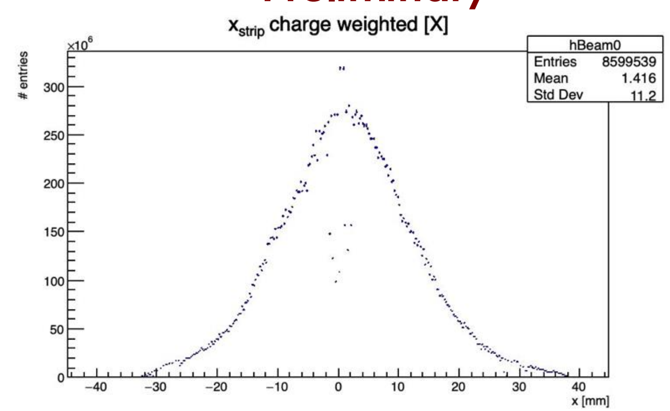
Beam position – X vs RunNumber



Beam position – Y vs RunNumber



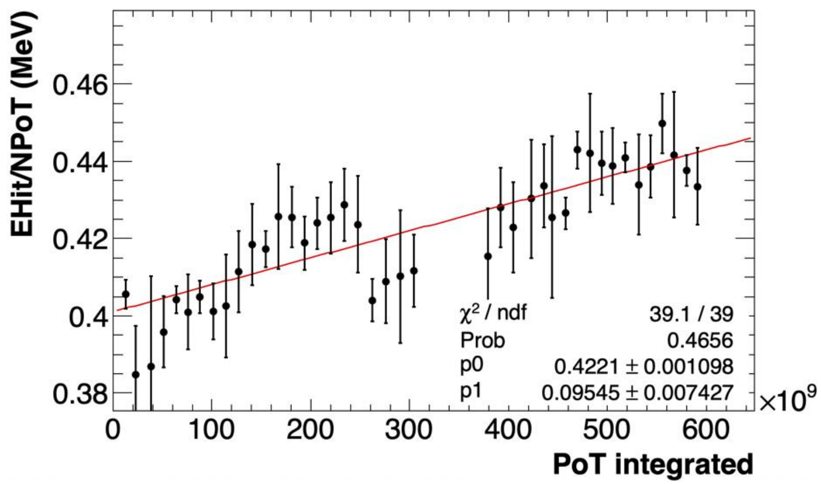
TMM Run IV Preliminary

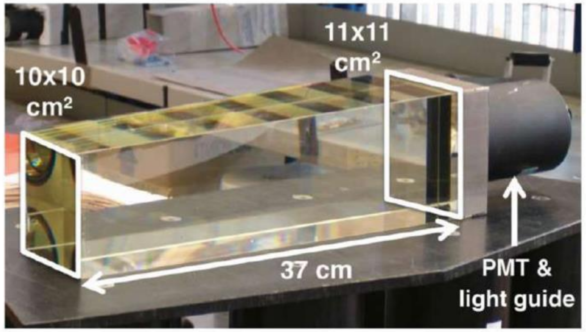


X at TMM

Radiation loss monitoring

In Run III N_{PoT} determination was affected by radiation-induced loss on LG beam monitor

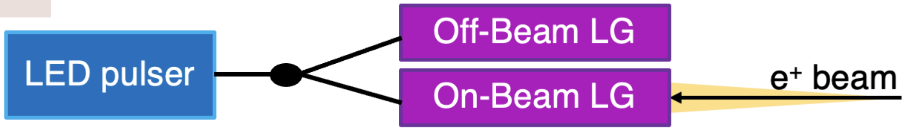




Run IV directly measure the LG ageing to correct N_{PoT}

LED pulser + 2nd LG block installed:
- Independent trigger integrated in DAQ
- 2nd LG block out of beam acceptance
- Run-per-run LG response compared to out-of-beam block

+3 additional independent measurements comparing to **total charge** in:
Target, padMMe, TMM

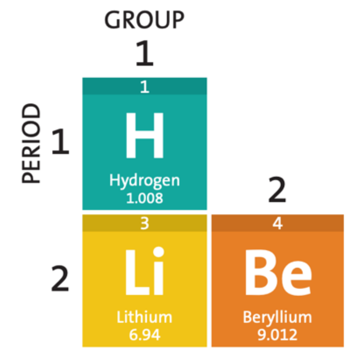


LED independent Trigger $\mathcal{O}$(2-4 Hz)

Future directions: new target material

Present situation (electron motion):

PADME :ΔP/P 0.25% + diamon target
Limiting factor: electrons motion



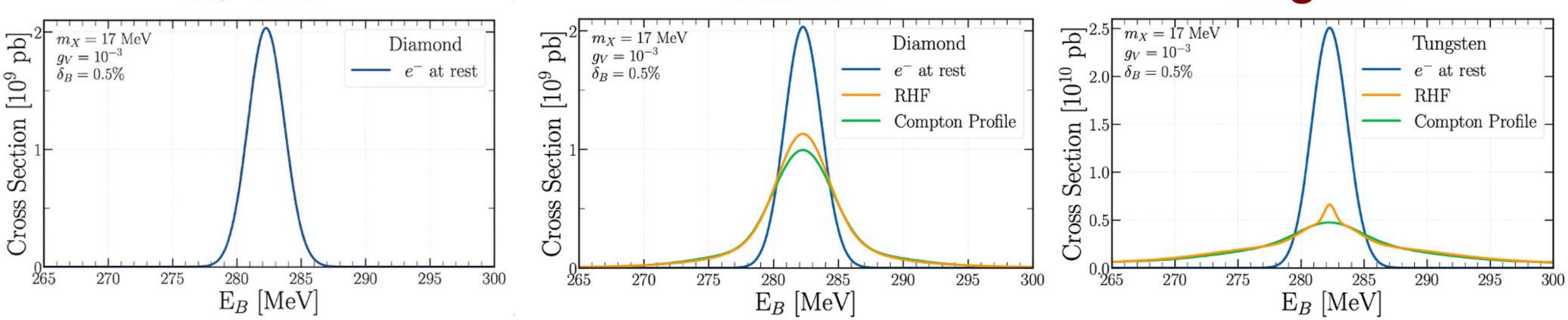
Future direction (electron motion):

Change target material –> reduce electron motion

Reduce the beam energy spread < 0.2%

Lower Z ← → Higher Z

Li, Be? **Carbon** **Tungsten**

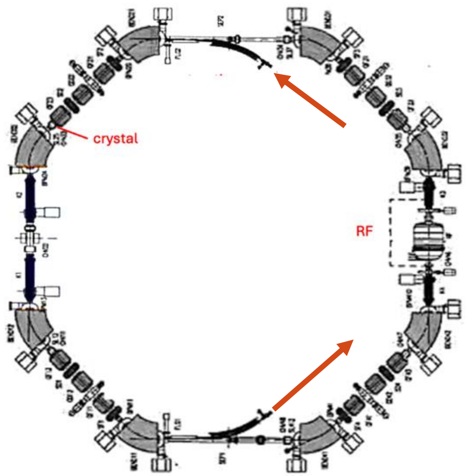


Gemini

[Phys. Rev. Lett. 132 (2024) 261801]

With ΔP/P < 0.2% and new target ⇢ RHF and Compton for Be, Li, …?

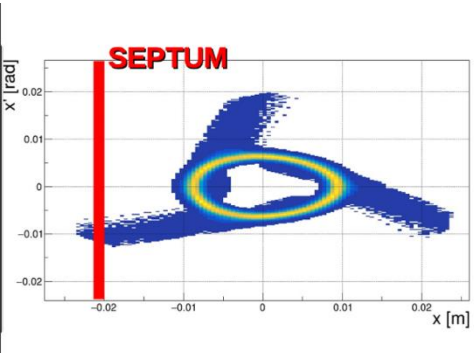
Future directions: dumping ring extraction

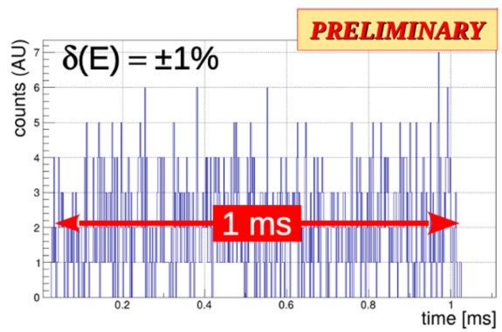


DAΦNE dumping ring

- 32 m long, 108 ns revolution period
- 4 arcs: 2 dipoles, 3 quadrupoles and 1 sextupole each
- 2 couples of magnetic septa
- Energy acceptance 1.5%, with low β

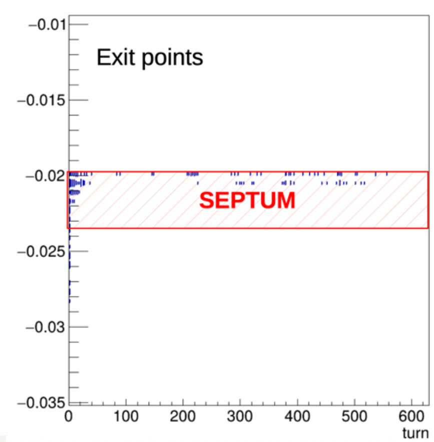
Monochromatic extraction at E= 300 MeV, RF off

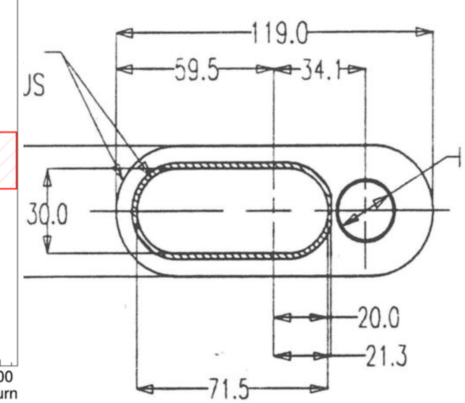




A. De Santis, Dafne Storage Ring group
LNF scientific committee Nov 2025

First simularions show potential 1ms bunch length (50x1ms ~5000x present lumi)





Not so easy septum too tick need thinner septum or assisted extraction scheme

Studies are ongoing …

Details in P. Valente, PADME future and prospects
https://agenda.infn.it/event/49565/timetable/#20260319.detailed

Conclusions

The **Run III analysis** has been completed using the blind-sideband method
Overall uncertainties at 0.88%
New exclusion limit region on X17 coupling to e^- covered in 16.5-17.5 MeV range
No X17 observation so far. Published **JHEP 11 (2025) 007**

An **excess** has been observed at **16.90(2) MeV**:

Local p-value equivalent to **2.5(1)σ**

Global p-value equivalent to **1.77(15) σ**

New data **set Run IV** acquired in 2025 to clarify the excess:

- **36 points** with **x4** expected statistic per point (**x2 NPoT and x2 Acc**.)
- A new micromegas-based trackers to improve beam monitoring
- First data check are positive

Ideas on how to **improve PADME statistics ~x10 to x1000** are under development

- Best solution: extraction from DAFNE dumping Ring

Acknowledgements…

Nothing of what I have shown would have been possible without the relentless effort of our colleagues of the LNF accelerator, theory division, technical division and the administrative service

Backup slides

Experimental directions

Atomki Nuclear
^{8}Be,^{4}He,^{12}C,GDR

It's the IPC result genuine

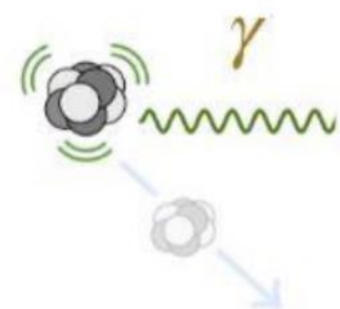
It's due to a new particle

Nuclear physics experiments			**Particle physics experiments**
MEGII @ PSI $p^7Li \to {}^8Be^* \to {}^8Be\ e^+e^-$ Eur.Phys.J.C 85(2025)7,763	**1st Result published** **New Run ongoing**		NA48/2 CERN $\pi^0 \to \gamma\ X17 \to \gamma\ e^+e^-$ PLB 746 (2015) 178-185
AN2000 @ LNL $p^7Li \to {}^8Be\ e^+e^-$	**Analysis of first data set**		NA64 CERN $eN \to eN\ X17 \to e^-e^+e^-$ PRD 101, 071101 (2020)
n_ToF @ CERN: $n^3He \to {}^4He\ e+e-$ PRC 105, 014001	Proposal		Prad X17 JLAB $eN \to eN\ X17 \to e^-e^+e^-$
U Montreal: $p^7Li \to {}^8Be^* \to {}^8Be\ e^+e^-$ arXiv:2211.11900	Running soon	**this talk**	PADME LNF $e^+e^- \to X17 \to e^+e^-$ JHEP 11 (2025) 007
???		**FDfDF**	DARK Light $eN \to eN\ X17 \to e^-e^+e^-$

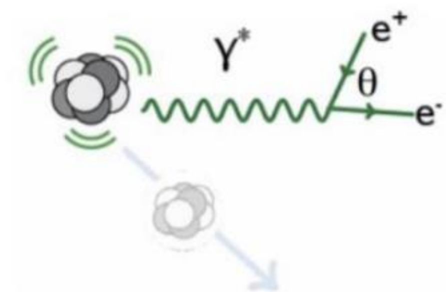
New physics in nuclear IPC transitions?

Excite the nucleus by proton capture:
choose the level by using appropriate p energy (few MeV)

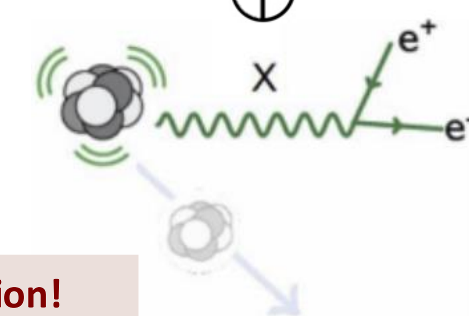
γ emission



IPC



⊕



Standard Model deexcitation mechanisms:
a) γ emission
b) Internal Pair Creation (IPC):
- **emit an off-shell photon γ***
- **γ* decays to e^+e^- pair**

New Physics (NP) deexcitation mechanisms:
- **Produce an intermediate on shell new particle X (mass M_X)**
- **X decays to e^+e^- pair**

NP produce enhanced IPC rate and different θ_{ee} distribution!

Need transitions with $\Delta E > M_X$

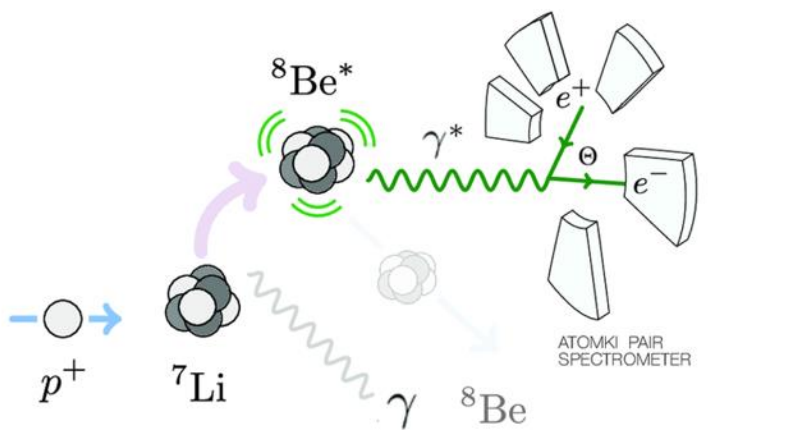
SAPIENZA
UNIVERSITÀ DI ROMA

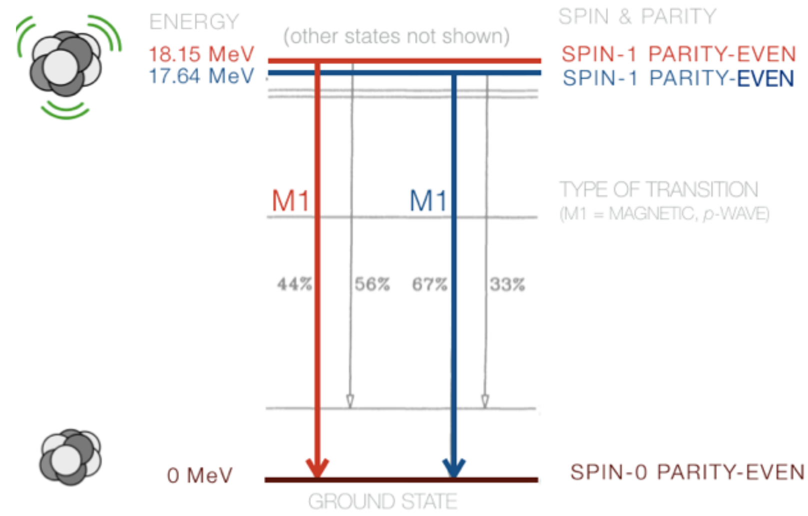
^{8}Be anomaly: first evidence 2016

PRL **116,** 042501 (2016) PHYSICAL REVIEW LETTERS week ending 29 JANUARY 2016

Observation of Anomalous Internal Pair Creation in ^{8}Be: A Possible Indication of a Light, Neutral Boson

A. Krasznahorkay et a
PRL 116, 042501 (20



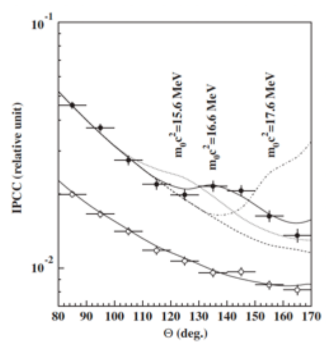


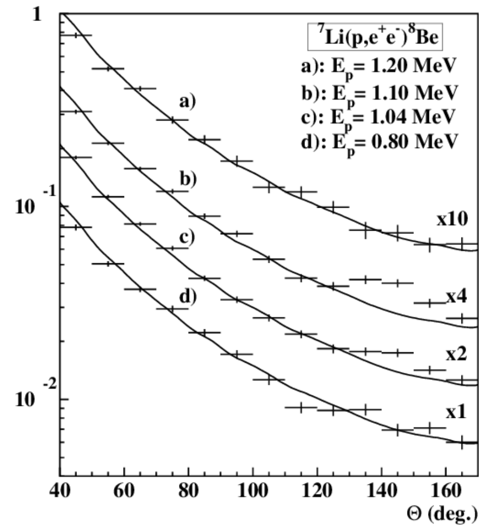
p + ^{7}Li —> ^{8}Be*(18.15 MeV) —> ^{8}Be + e^+e^-

Anomaly observed only in 2 over 4 proton energies

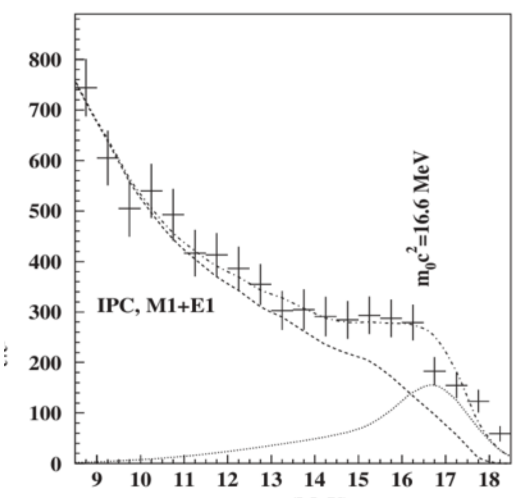
Anomaly observed only for symmetric track events

Anomaly observed only for ^{8}Be 18.15 MeV transition





6.8σ effect! not a fluctuation



$m_X c^2 = 16.70.35_{stat}0.5_{syst}$ MeV

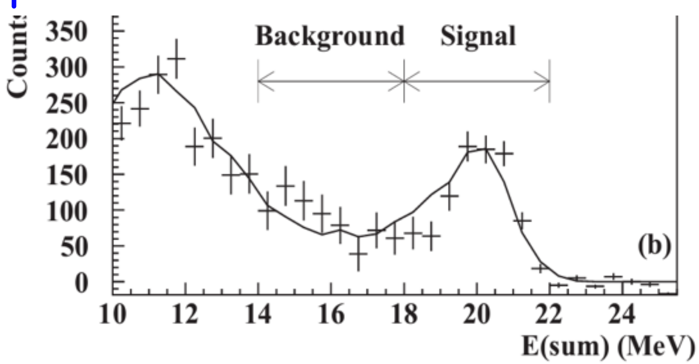
SAPIENZA
UNIVERSITÀ DI ROMA

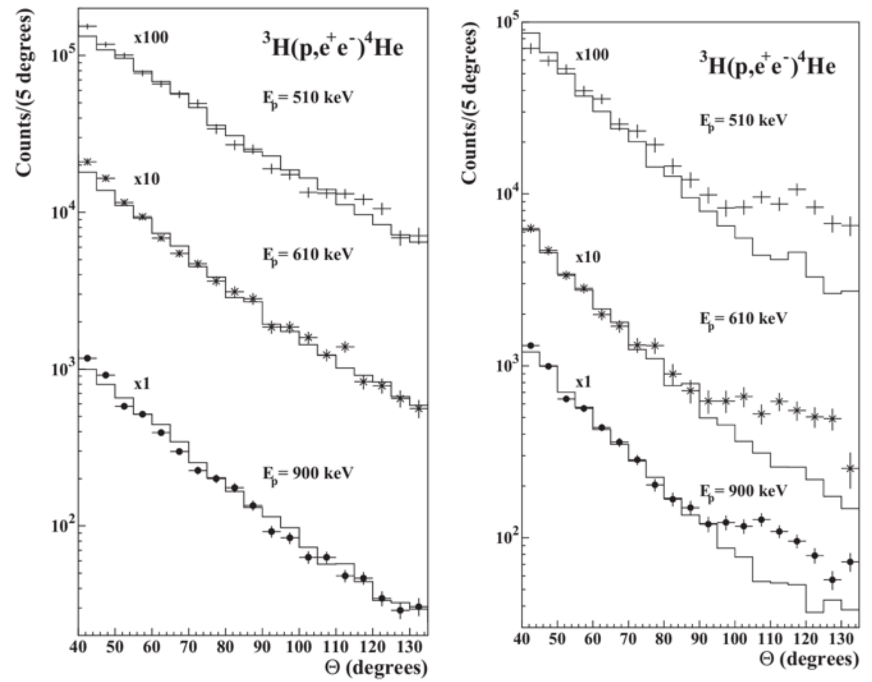
The ^{4}He Atomki anomaly: 2020

PHYSICAL REVIEW C **104**, 044003 (2021)

New anomaly observed in ^{4}He supports the existence of the hypothetical X17 particle

p + ^{3}H —> ^{4}He* —> ^{4}He + e$^+$e$^-$





Atomki has confirmed the anomalous peak in the angular distribution of ^{8}**Be** IPC in ^{4}**He** transitions at different angle. The difference was expected **due to the higher ΔE in ^{4}He**
The ^{4}He angle indicated **same X mass value.**

$$m_X c^2 = 16.94 \pm 0.12_{stat} \pm 0.21_{syst}\ \mathrm{MeV}$$

A. Krasznahorkay et al.

Phys. Rev. C 104, 044003 (2021)

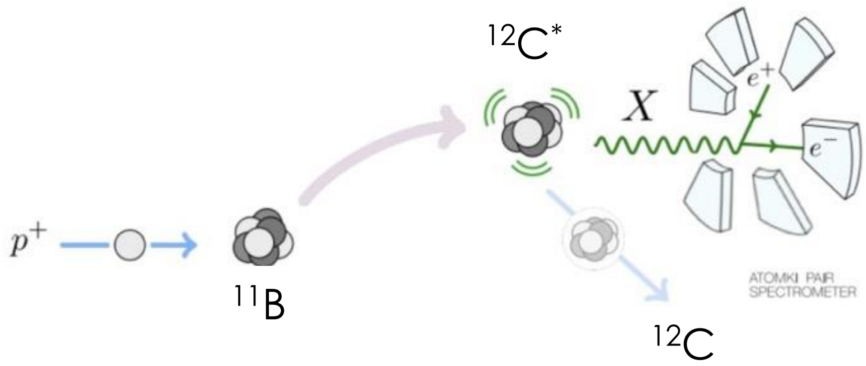
E_p (keV)	IPCC $\times 10^{-4}$	B_x $\times 10^{-6}$	Mass (MeV/c^2)	Confidence
510	2.5(3)	6.2(7)	17.01(12)	7.3σ
610	1.0(7)	4.1(6)	16.88(16)	6.6σ
900	1.1(11)	6.5(20)	16.68(30)	8.9σ
Averages		5.1(13)	16.94(12)	
^{8}Be values		6	16.70(35)	

The ^{12}C : September 2022

PHYSICAL REVIEW C **106**, L061601 (2022)

New anomaly observed in ^{12}C supports the existence and the vector character of the hypothetical X17 boson

A. Krasznahorkay et al.
Phys. Rev.C 106 (2022) 6



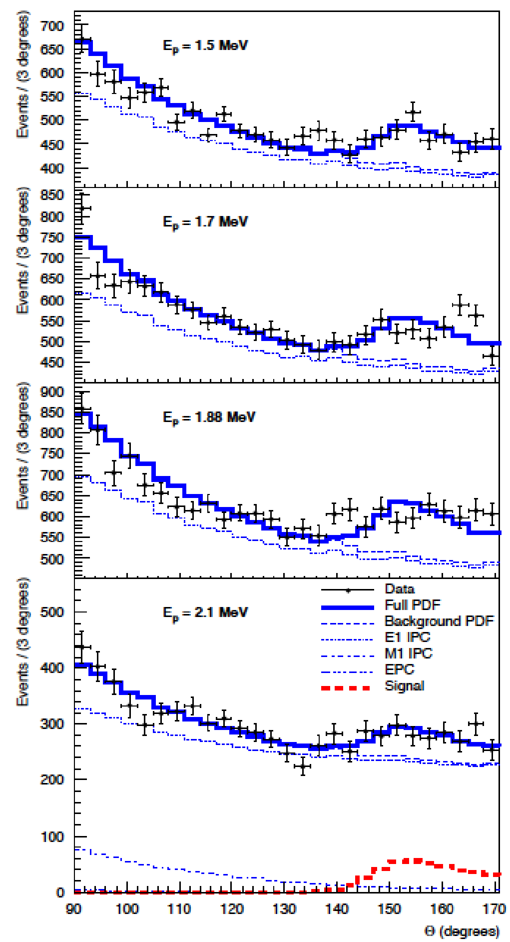
$p + {}^{11}B \to {}^{12}C^*(17.23\ \text{MeV}) \to {}^{12}C + e^+e^-$

E_p (MeV)	B_x $\times 10^{-6}$	Mass (MeV/c^2)	Confidence
1.50	1.1(6)	16.81(15)	3σ
1.70	3.3(7)	16.93(8)	7σ
1.88	3.9(7)	17.13(10)	8σ
2.10	4.9(21)	17.06(10)	3σ
Averages	3.6(3)	17.03(11)	
Previous [14]	5.8	16.70(30)	
Previous [28]	5.1	16.94(12)	

As predicted by J. Feng et al. excess at 160°

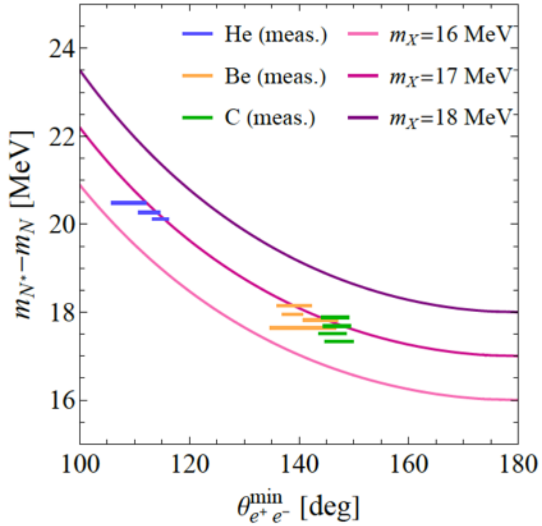
Same X17 particle suggested by the ^{8}Be and ^{4}He anomalies

$M_X = 17.03 \pm 0.11 \pm 0.20$ MeV



SAPIENZA UNIVERSITÀ DI ROMA

Global ΔE vs angle consistency



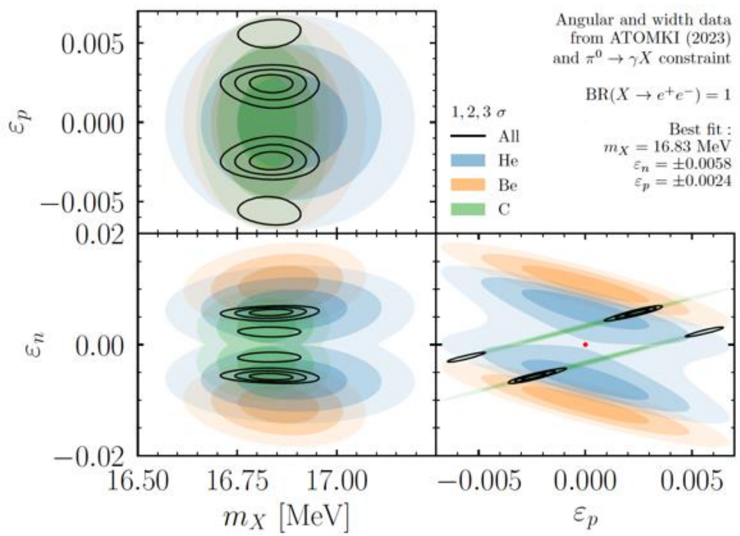
Neutrino Constraints and the ATOMKI X17 Anomaly

PHYS.REV. D 108, 015009 (2023)

Using angular data only: 11 measurements

An analysis with the angular data alone of 11 different measurements finds that the data is well described by a new particle of mass $m_X = 16.85 \pm 0.04$ MeV with an internal goodness-of-fit of 1.8σ calculated from Wilks' theorem at $\chi^2/dof = 17.3/10$. We use only the best fit

$$\theta_{ee}^{min} \approx 2\arcsin\left(\frac{m_{X17}}{m_{N*} - mN}\right)$$



Using width for each element: 3 measurements

Next, we add in to the analysis the latest width information from each element and include a prior on ε_p since X needs to couple to protons and/or neutrons on the production size. There is a stronger constraint

see the next section for more information. We find an okay fit to the data at the same mass $m_X = 16.83$ MeV, $\varepsilon_n = \pm 5.8 \times 10^{-3}$, and $\varepsilon_p = \pm 2.4 \times 10^{-3}$, see fig. 2. We note that the signs of ε_n and ε_p must be the same due to the non-trivial degeneracy structure shown clearly in the $\varepsilon_n - \varepsilon_p$ panel of fig. 2. We have confirmed that the

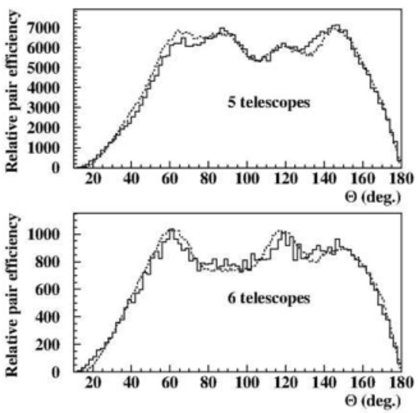
Data form ^{8}Be, ^{4}He, ^{12}C are consistent and point to: M_{X17}=16.85±0.04 MeV

SAPIENZA
UNIVERSITÀ DI ROMA

IPC experimental setup at Atomki

2 different setup used by Atomki for IPC measurements:
- **5 arms spectrometer (MWPC and 5 DE/E)**
- **6 arms spectrometer (Si strip and 6 DE/E)**

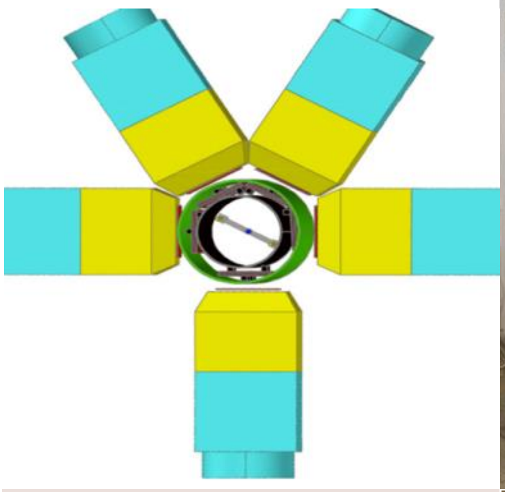
Different acceptance and detector types in ^{8}Be and ^{4}He



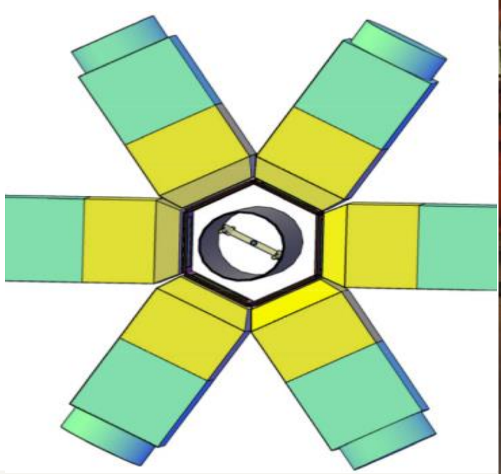
Tandetron Accelerator

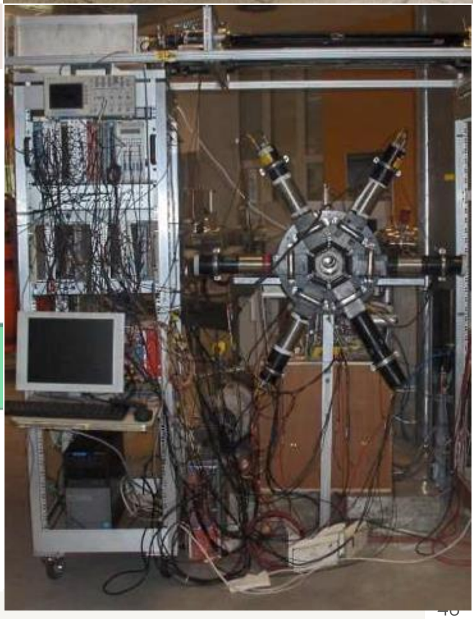
Beam current capability at 2 MV: 200 μA protons

5 arm spectrometer ^{8}Be 2016



6 arm spectrometer ^{4}He 2020





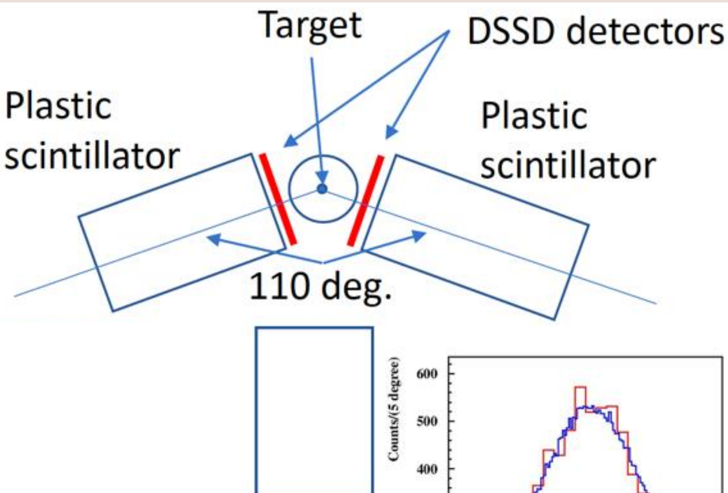
^{8}Be giant resonance anomaly: 2023

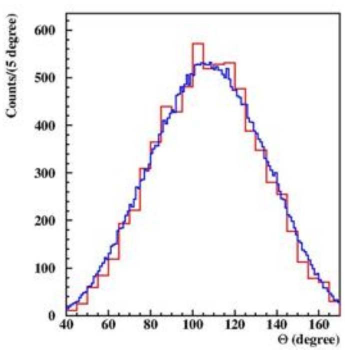
Observation of the X17 anomaly in the decay of the Giant Dipole Resonance of ^{8}Be

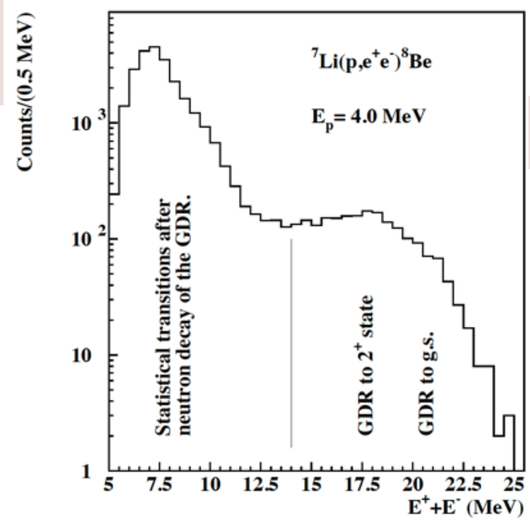
A. Krasznahorkay et al.
arXiv:2308.06473

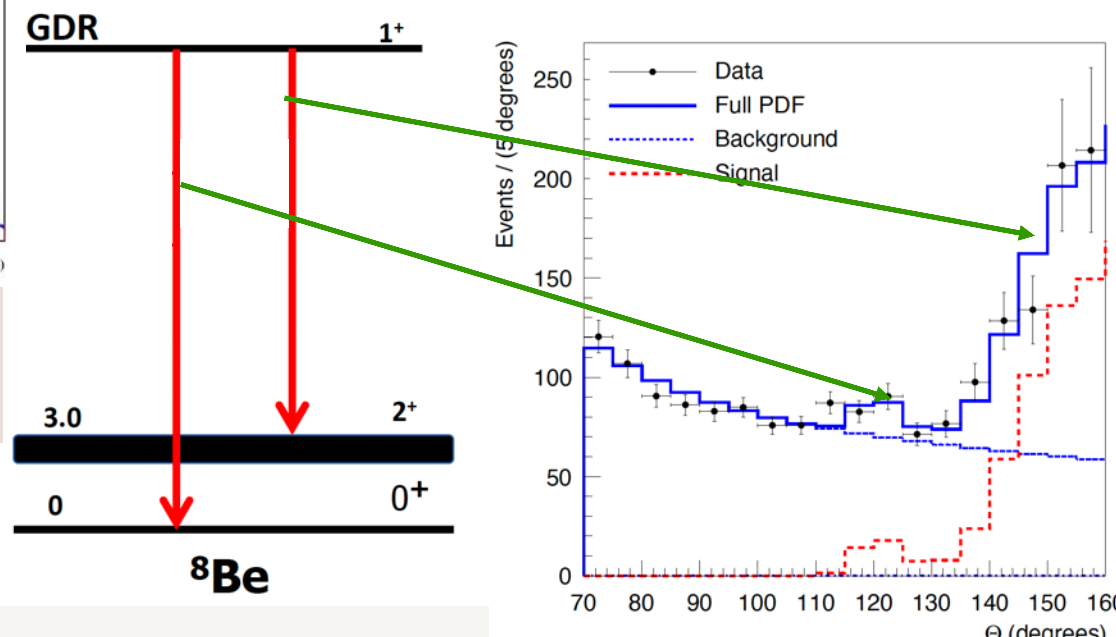
Atomki group: ^{8}Be experiment in GDR region
New 2 arm spectrometer closer to the target

- **E_P up to 4 MeV**
- **1^+ to 2^+ ~17.5 MeV**
- **1^+ to 0^+ ~20.5 MeV**









2 peak structure observed!
impressive angular agreement with particle hypothesis.

More information can be found here: ISMD 2023
https://indico.cern.ch/event/1258038/timetable/#20230822.detailed

SAPIENZA UNIVERSITÀ DI ROMA

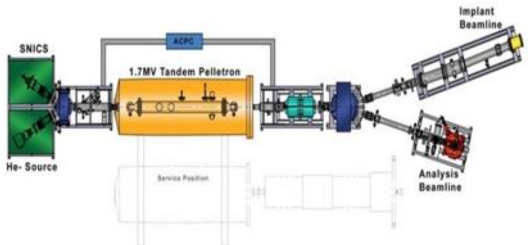
X17: the particle physics case

Theory insights based Atomki data: (assuming P conservation and resonance emission):
Scalar excluded by parity conservation in ^{8}Be
Pseudo scalar disfavoured by the ^{12}C observation

N_*	$J_*^{P_*}$	Scalar X	Pseudoscalar X	Vector X	Axial Vector X
^{8}Be(18.15)	1^+	✘	✔	✔	✔
^{12}C(17.23)	1^-	✔	✘	✔	✔
^{4}He(21.01)	0^-	✘	✔	✘	✔
^{4}He(20.21)	0^+	✔	✘	✔	✘

What next in particle physics experiments:
Explore the all-possible solution to search for signal outside nuclear physics
Concentrate attention on Vector and Axial Vector case. Theoretically favoured solutions
Don't forget Scalars and Pseudo scalars. Nature can always be different from what we expect!
Try to be as much model independent as possible

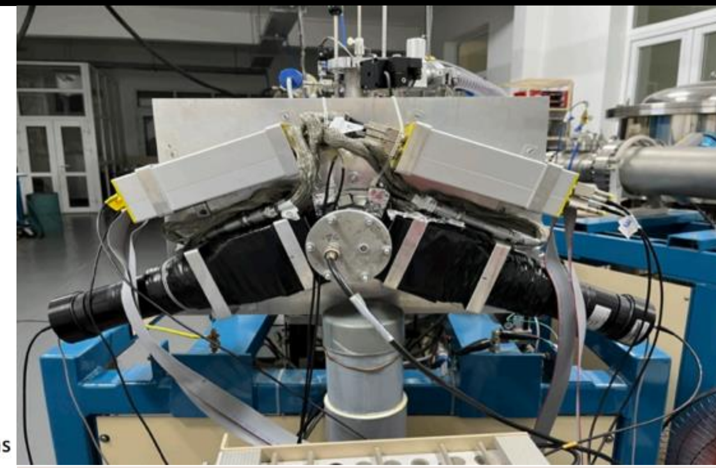
Confirmed in Vietnam 2023?



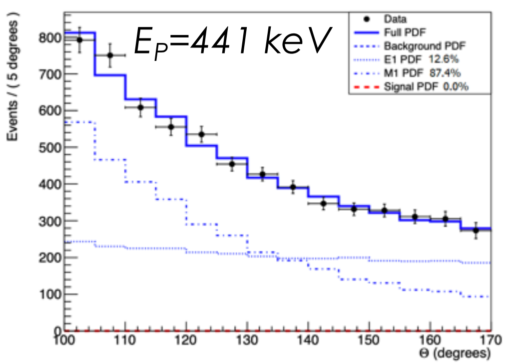
Pelletron Beamline, analysis beamline
Terminal Voltage: 1.7 MV
Ion: H^+, He^+, C^+, Si^+, Cu^+, Au^+...
Beam Current: 1nA – 2microA

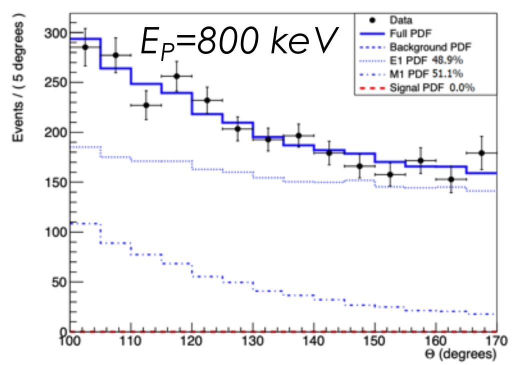
Main tasks:
RBS
PIXE
Ion implantaion
Astro nuclear reactions

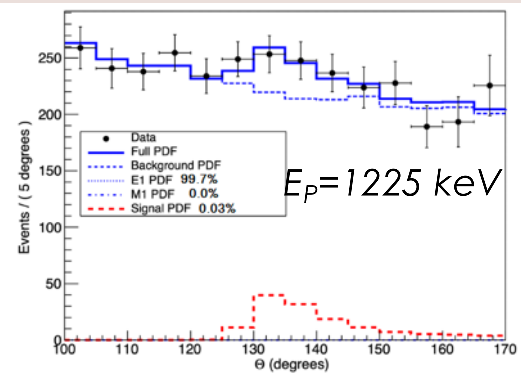
ISMD2023



2 arm spectrometer (ATOMKI like)
ATOMKI group participants
^{7}Li and ^{11}B target used.







Universe **2024**, *10*(4), 168;

Anomaly confirmed at 1225 KeV E_p. Not observed for lower bombarding energies.

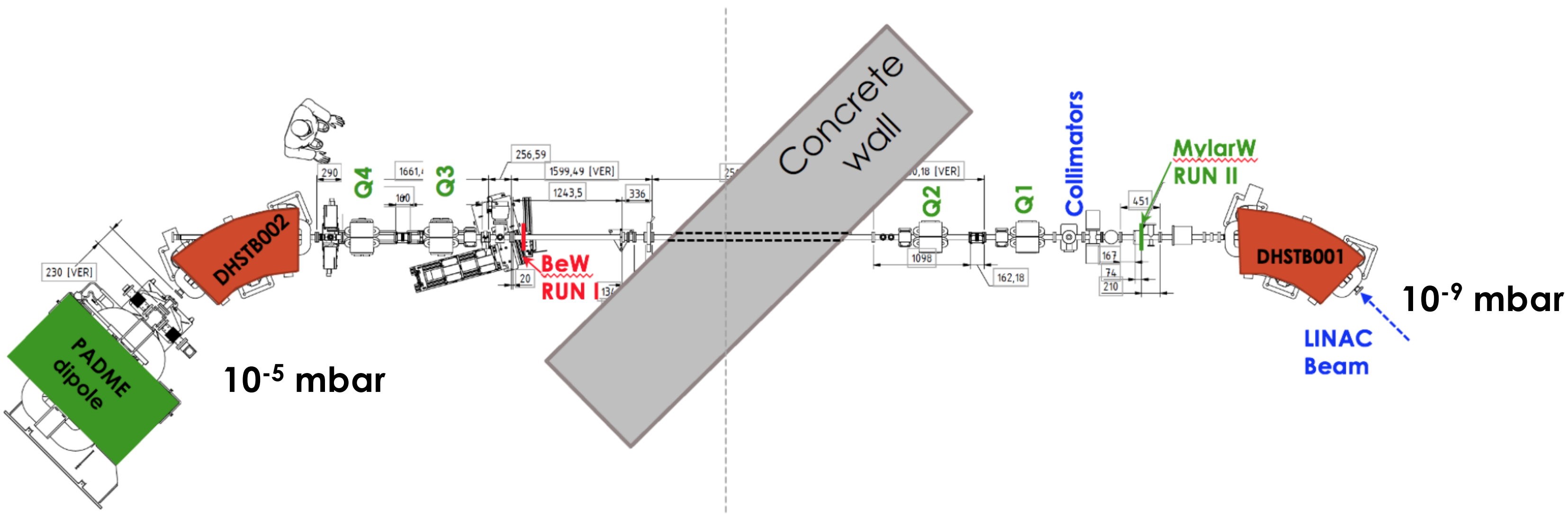
The BTF beam line and PADME

Positrons from the **DAΦNE LINAC 200 - 500 MeV**, O(0.25%) energy spread

Repetition rate up to **49 Hz**, macro bunches of up to **250 ns** duration

Intensity must be limited below ~ 3×10^4 PoT/spill to control pile-up

Emittance ~ 1 mm x 1.5 mrad @ PADME



Past PADME operations:

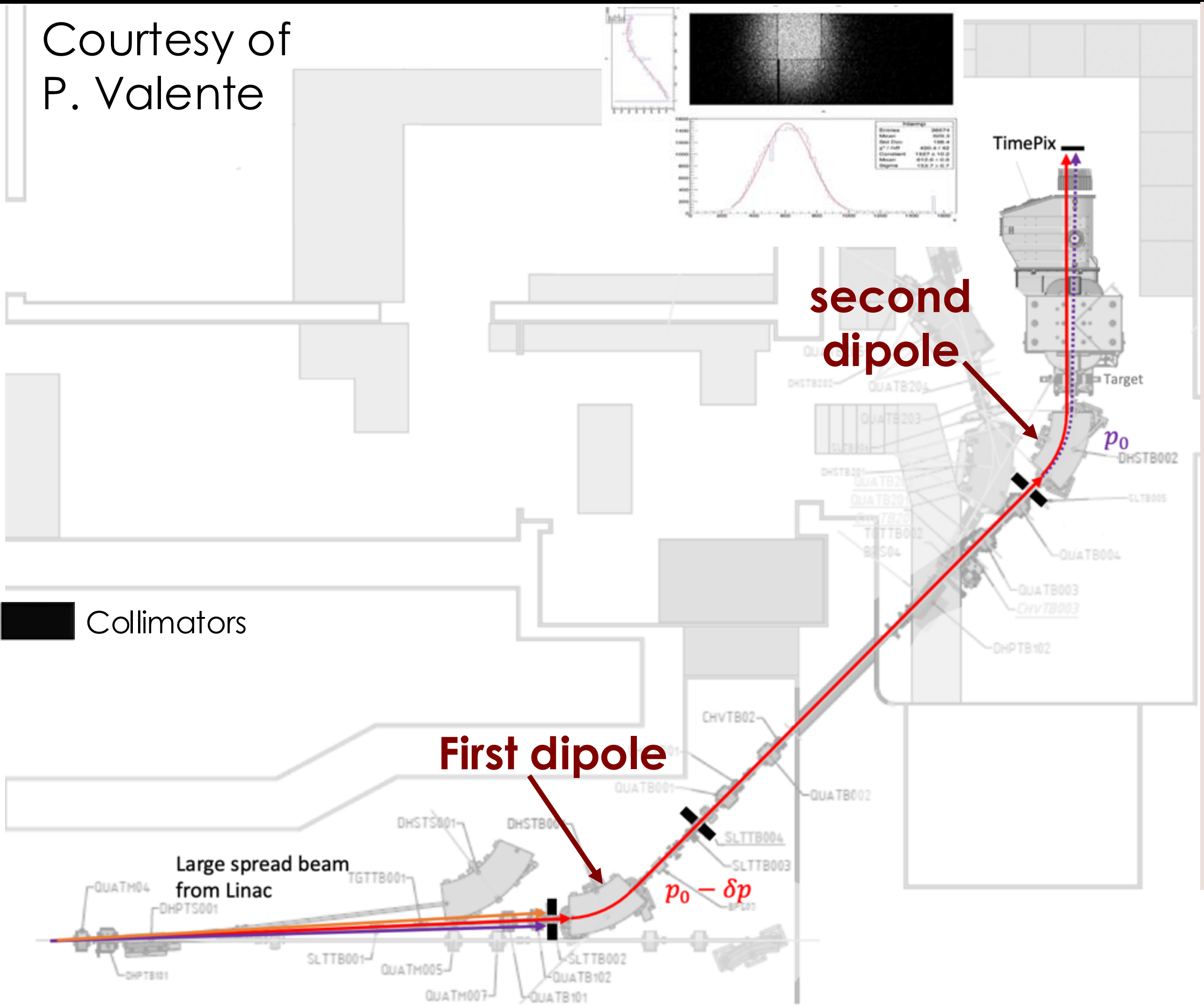
Run I 550 MeV e^+ secondary BTF target, 250 μm Be vac. wind. 28K e^+/bunch [Oct. 2018]

Run II 490 MeV e^+ primary beam, 125 μm Mylar™ vac. wind, 28K e^+/bunch [2019-20]

Run III dipole magnet off, ~3000 e^+/bunch, scan $s^{1/2}$ around ~ 17 MeV [End of 2022]

Obtaining energy steps and resolution

Courtesy of
P. Valente



Use the first dipole magnet and collimators to select energy

- dp ∝ collimator aperture.

Change the first dipole magnet current to change the energy

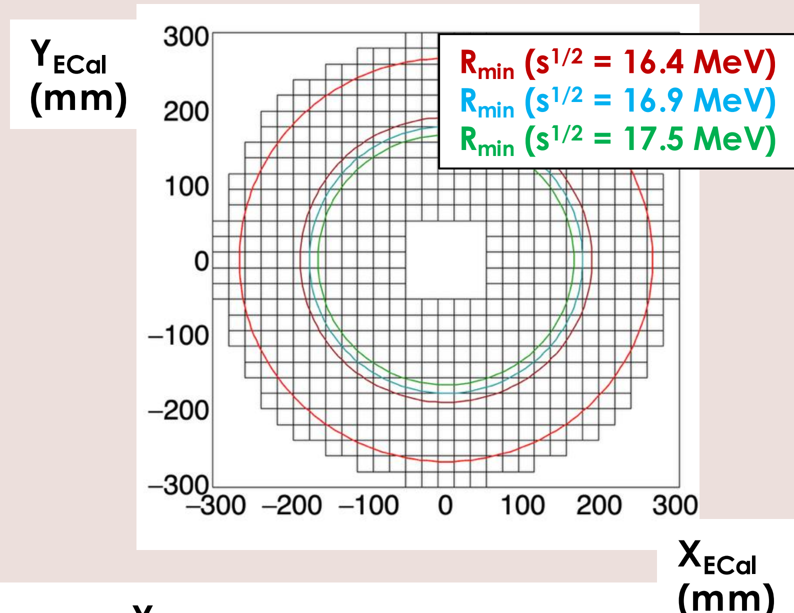
Correct the trajectory using second dipole to put the beam back on axis at PADME

Measure the displacement at the target and TimePix to measure the energy step performed

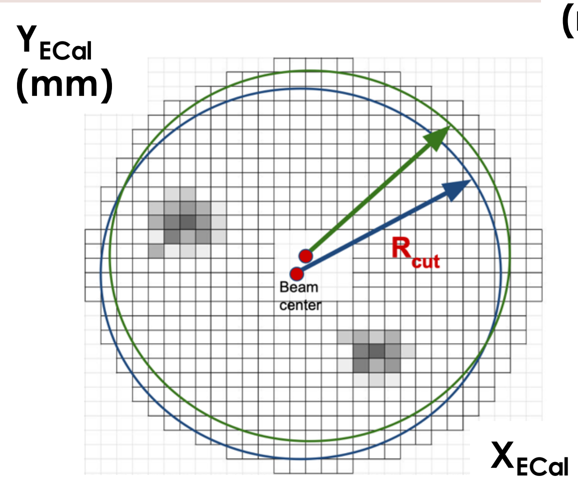
Run III concepts – N_2 selection

N_2 any two-body final state (ee + $\gamma\gamma$) with both particles in ECal acceptance:

1. Fix R_{Max} at Ecal, away from Ecal edges
2. Given s, compute R_{Min}, E_{Min}, E_{Max}
3. Select cluster pairs:
   - With Energy > E_{min} x 0.4
   - In time within 5 ns
   - Clus1: In (R_{min}- D, R_{max}), D = 1.5 L3 crystals
   - Clus2: R > R_{min}- D
4. Select pairs back-to-back in the c.m. frame



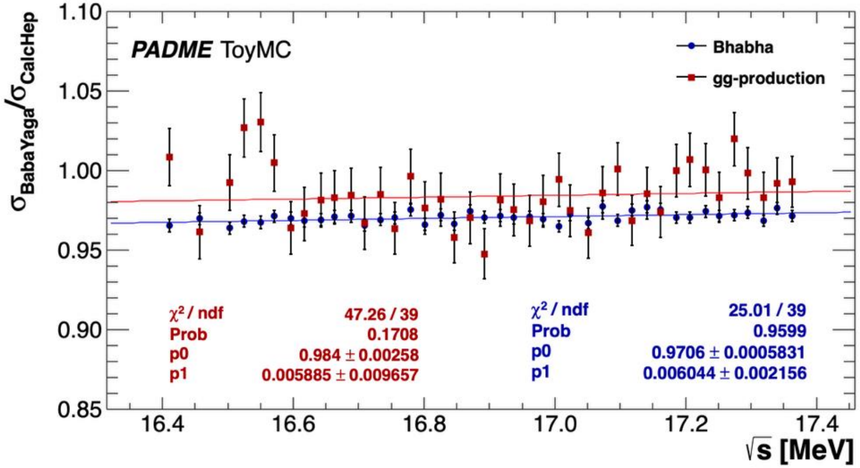
R_{max} chosen to be away from Ecal edges by more than the size of 1 crystal cell for any period in the data set



1 □ = 1 L3 crystal = 21.5 x 21.5 mm

Possible scale effects K(s)

Radiative corrections evaluated using Babayaga, ee(γ) and $\gamma\gamma$(γ)



Babayaga references:

Nucl. Phys. B 758 (2006) 227

Phys. Lett B 663 (2008) 209

Possible negative offset of ~ -2.3% → comparable to the scale error of 2.1%

Possible slopes with sqrt(s):

Radiative effects: slope of +0.6(2)% MeV^{-1}

Tag & probe correction: slope of -2.2(6)% MeV^{-1}

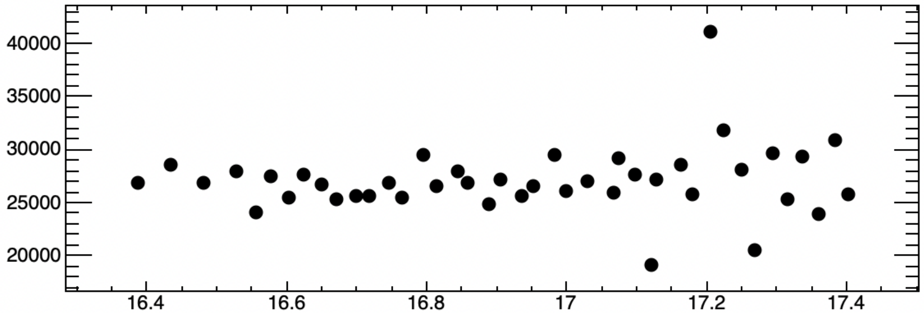
Total slope of -1.6(6)% MeV^{-1}

Details on the 2Cl count N2

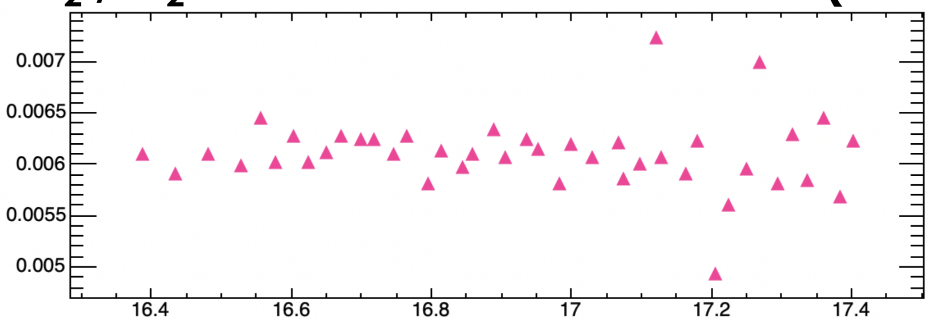
Background subtraction using side-bands (bremsstrahlung, ~4%)

Correction relative variation +-1%, statistical uncertainty on δN_2 ~ 0.3%

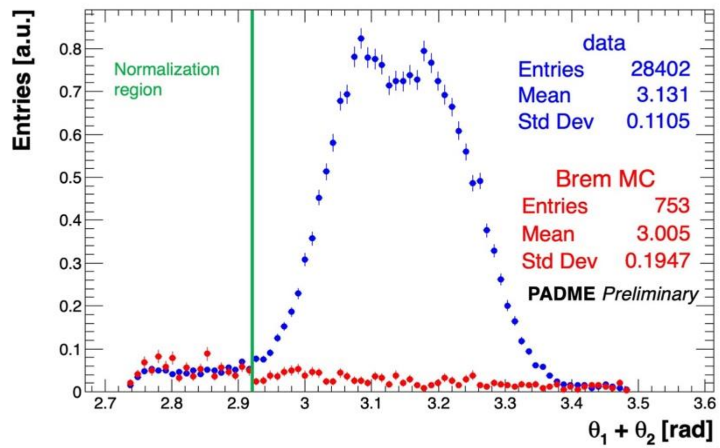
N_2



δN_2 / N_2 $s^{1/2}$ (MeV)



$s^{1/2}$ (MeV)



Shape of ee signal due to residual magnetic field (MNP CERN SPS type)

Fully modeled using MC + detailed map

SAPIENZA
UNIVERSITÀ DI ROMA

54

Details on background: cut stability

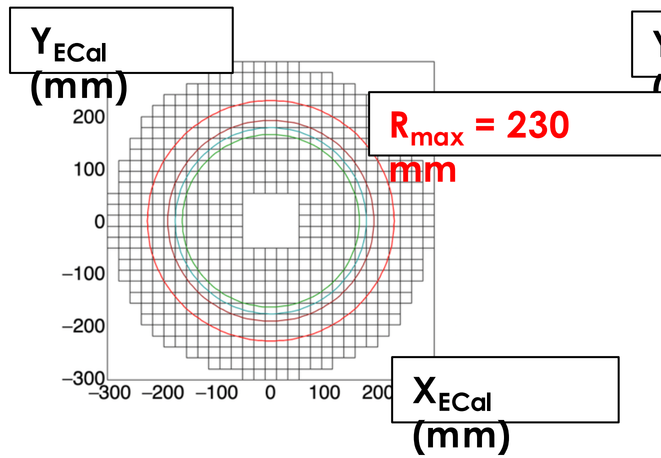
Check if MC and data yields stable vs R_{min}, R_{max} (edge effects, leakage)

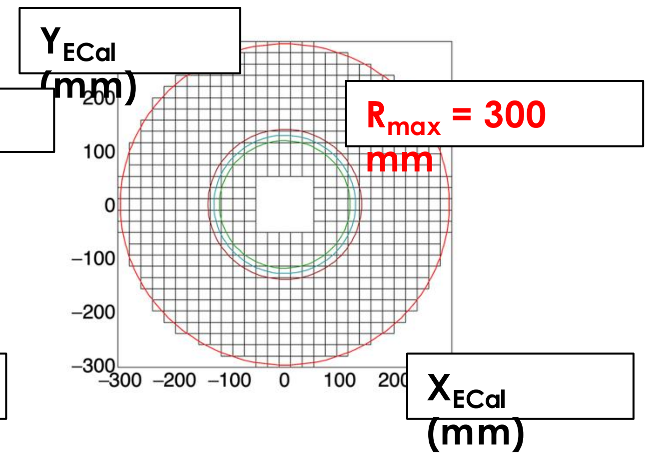
Vary R_{max} by +-2 E_{Cal} cells around nominal cut of 270 mm: 230 mm → 300 mm

Yield variation: -5%, +3%

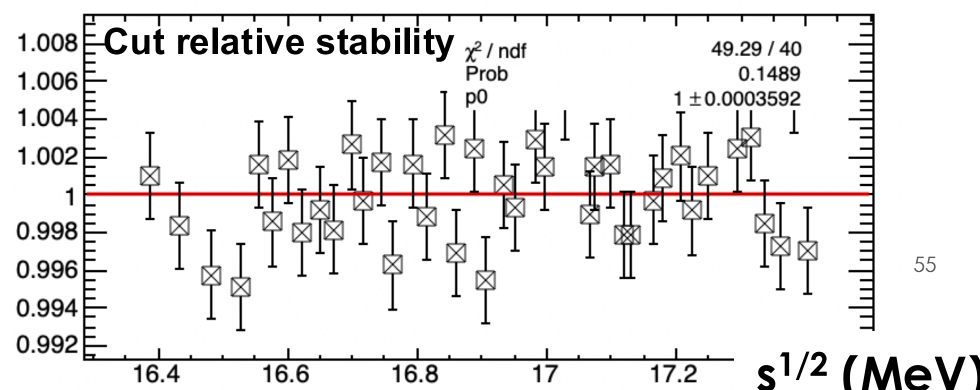
Uncorrelated error 0.3%

R_{min} -1.5 D ($s^{1/2}$ = 16.4 MeV)
R_{min} -1.5 D ($s^{1/2}$ = 16.9 MeV)
R_{min} -1.5 D ($s^{1/2}$ = 17.5 MeV)





Stability is observed within a coverage band of ±0.2%, used as additional uncorrelated systematic error on B



55

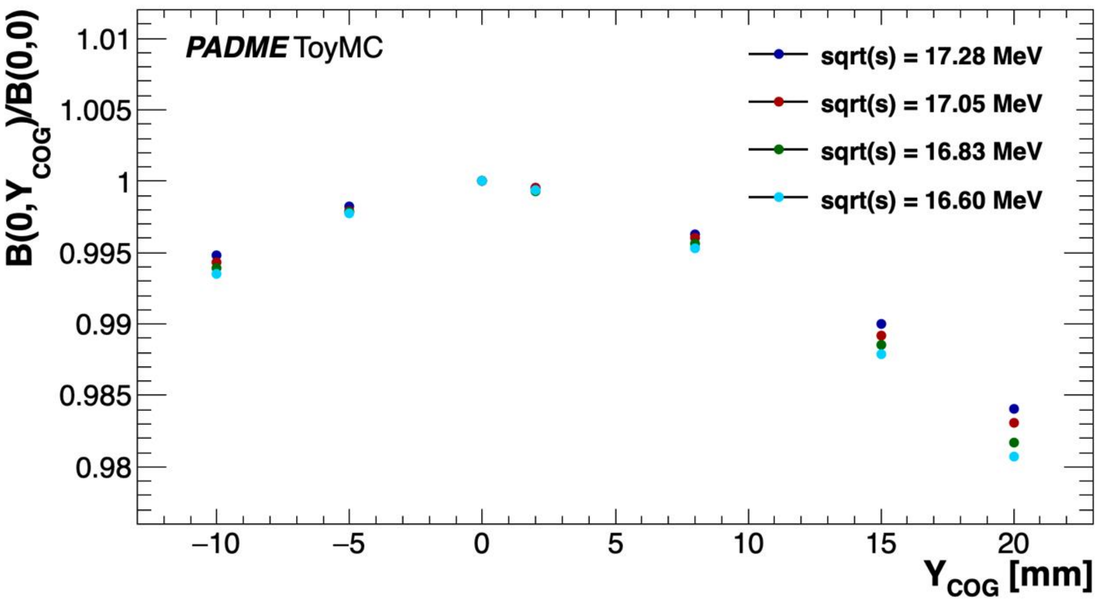
Details on BG: acceptance variations

The selection makes use of the expected beam direction, from the spot measured at the diamond target and the center of gravity (COG) of 2 body final states at ECal

Systematic shifts in the COG position translate into acceptance systematic errors

Largest effect in y due to acceptance limitations (rectangular magnet bore)
Fractional variations range from 0.08% to 0.1% mm^{-1} for $s^{1/2}$ from 16.6 to 17.3 MeV

An error of 1 mm in the COG is a conservative estimate → systematic error < 0.1%

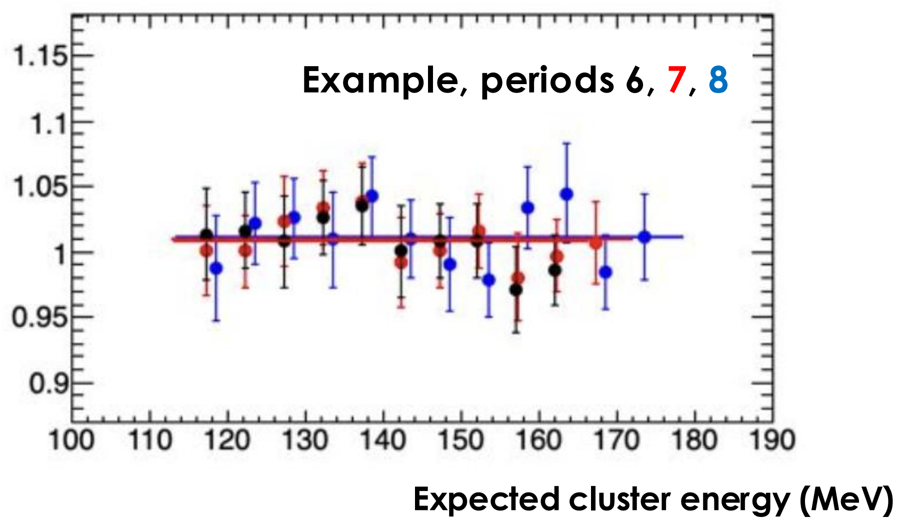


Details on BG: cluster reconstruction

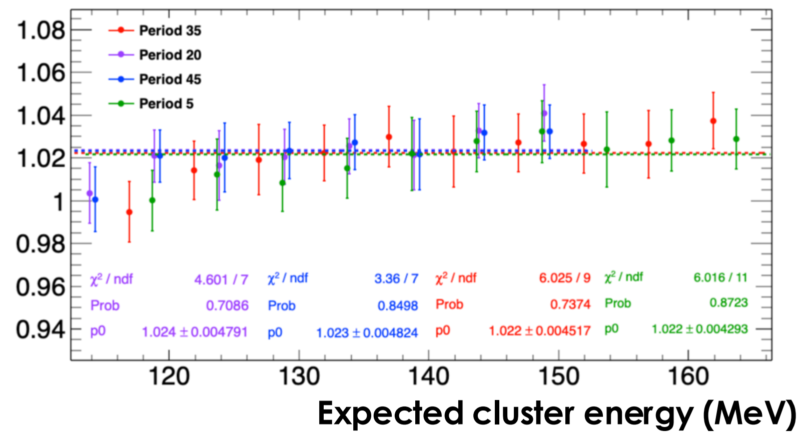
Tag and probe technique, the method-induced bias is 2.3(2)% and stable along the data set

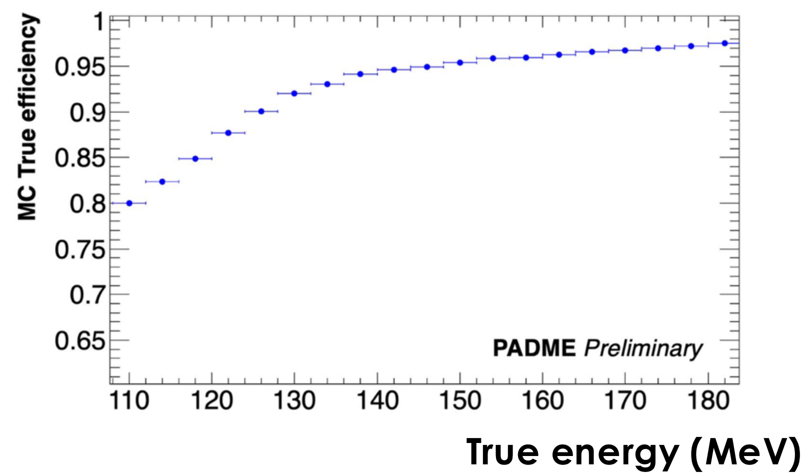
Data/MC method efficiency stable along the data set and at the few per mil

Efficiency Data/MC



Efficiency <Method /MC true>





Post unblinding checks: BG fit method

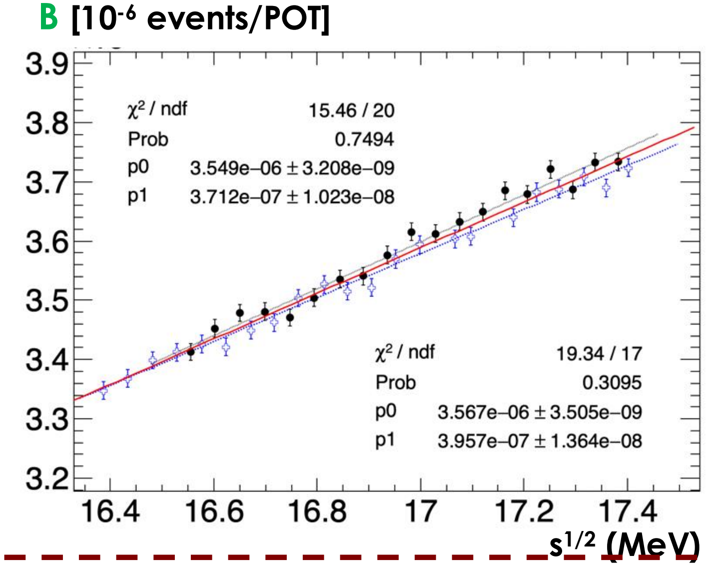
Perform the automatic procedure but fit SM BG with a constant:

Original version K(s) linear BG fit:
1. $P(\chi^2) = 74\%$
2. Pulls gaussian fit probability > 45%
3. Slope of pulls consistent with zero
4. Constant = 1.0116(16), Slope = (-0.010 ± 0.004) MeV^{-1}

Result using constant BG fit:
1. $P(\chi^2) = 37\%$
2. Pulls gaussian fit prob > 30%
3. Slope of pulls consistent with zero
4. Constant = 1.0112(14)

The center of the **masked region does not change**: 16.888 MeV
The **excess also remains** basically of the **same strength: 1.6σ**

Use scan1-scan2 separate parametrizations for B(s) instead of using B(s)/point:
The excess region is slightly affected but is equivalent to ~1.6 σ

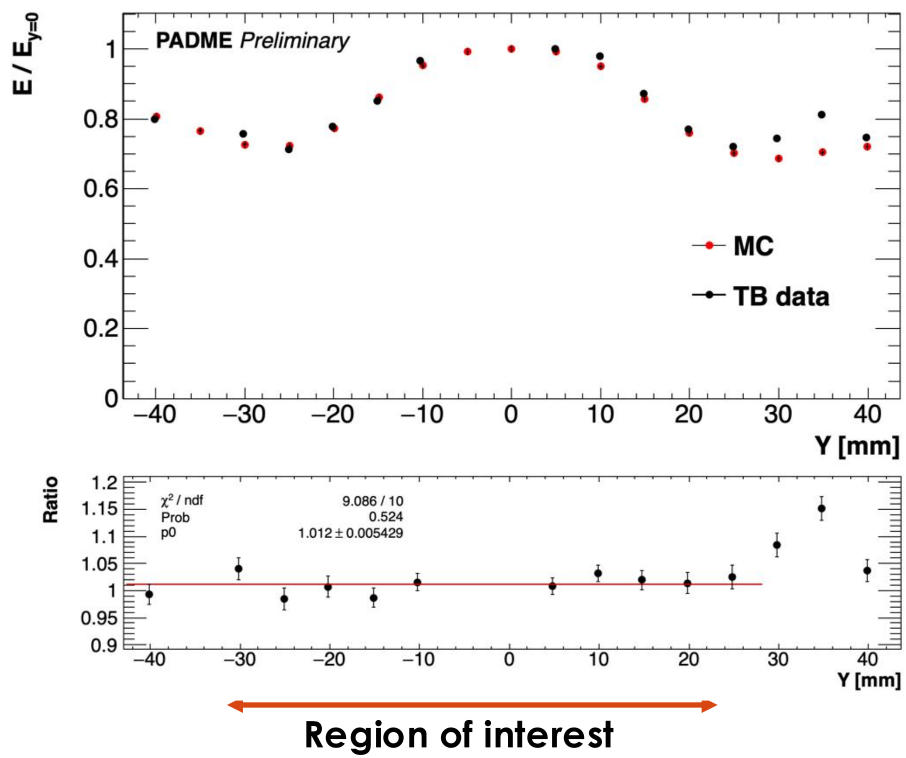


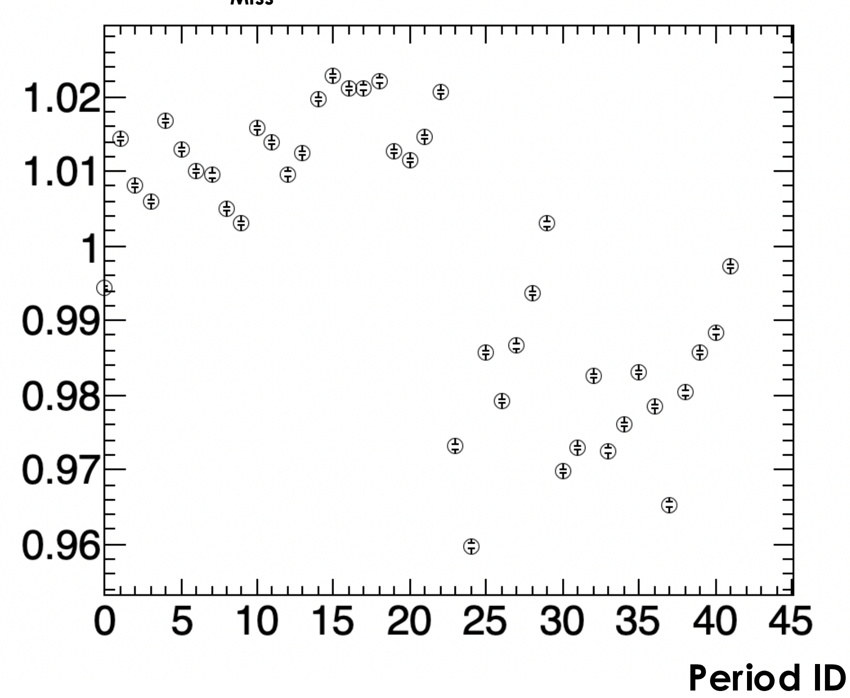
Check the PCL method using CLsb, equivalent number of σ = 1.62±0.13

SAPIENZA UNIVERSITÀ DI ROMA

LeadGlass E_{Lost} correction

LG E_{Lost} from detailed MC vs vertical position checked against data in test beam
Very good data-MC agreement, correction 1.2%, systematic error 0.5%
Significant period-by-period variation of the correction: -4% to +2%

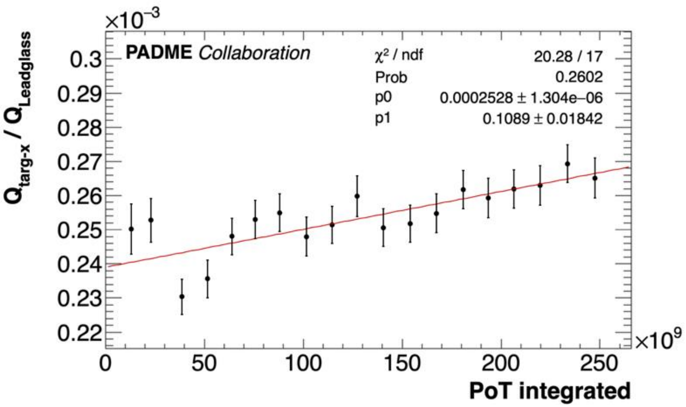


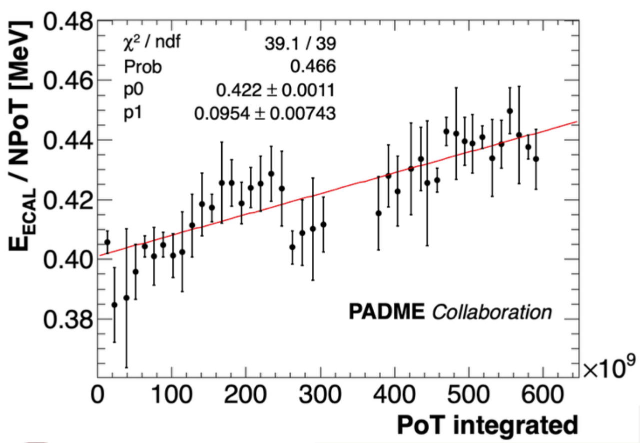


LeadGlass: ageing correction

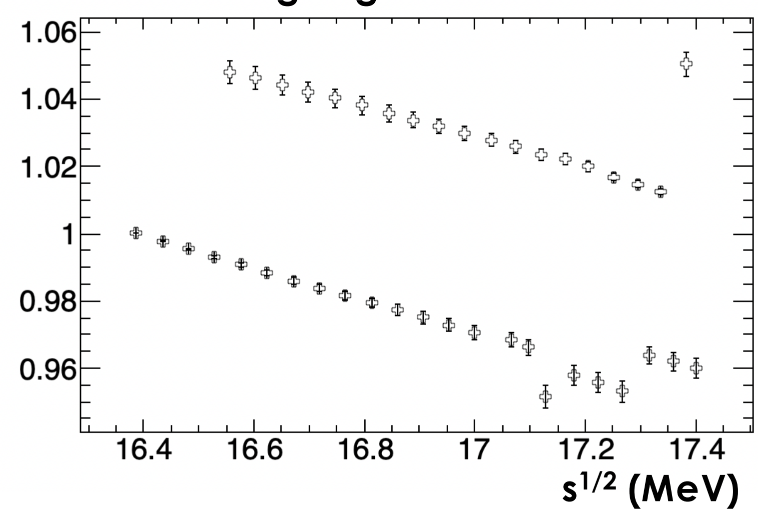
The literature indicates possible changes in SF57 transparency for O(krad)
Estimate of Run-III dose: 2.5 krad

Estimated from 3 flux proxy observables: $Q_{targ\text{-}x}/Q_{LG}$, $<E_{Ecal}>/N_{PoT}$
Leadglass yield decreases with relative N_{PoT} slope of 0.097(7)
Constant term uncertainty of 0.3% added as scale error
Slope error included in N_{PoT} uncertainty

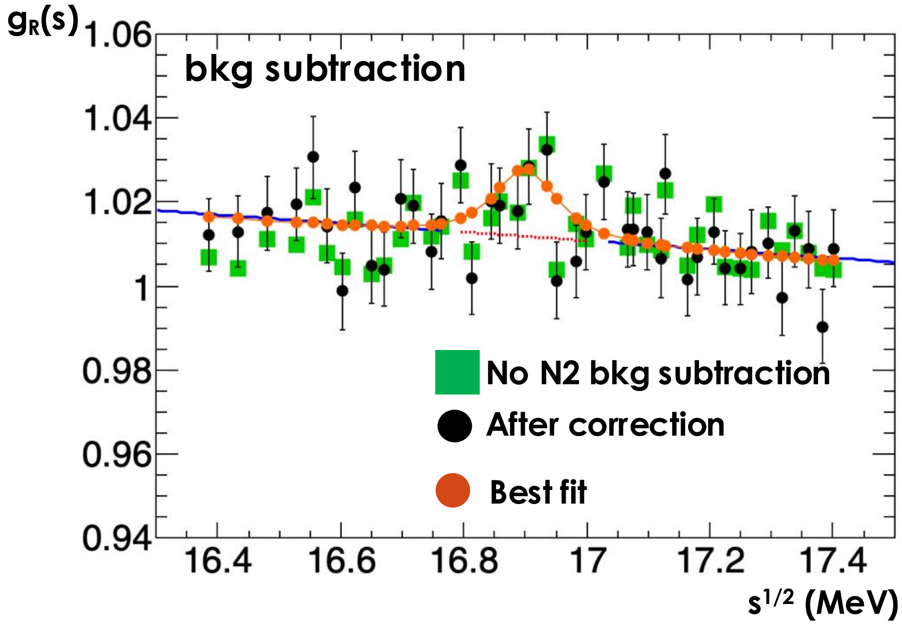


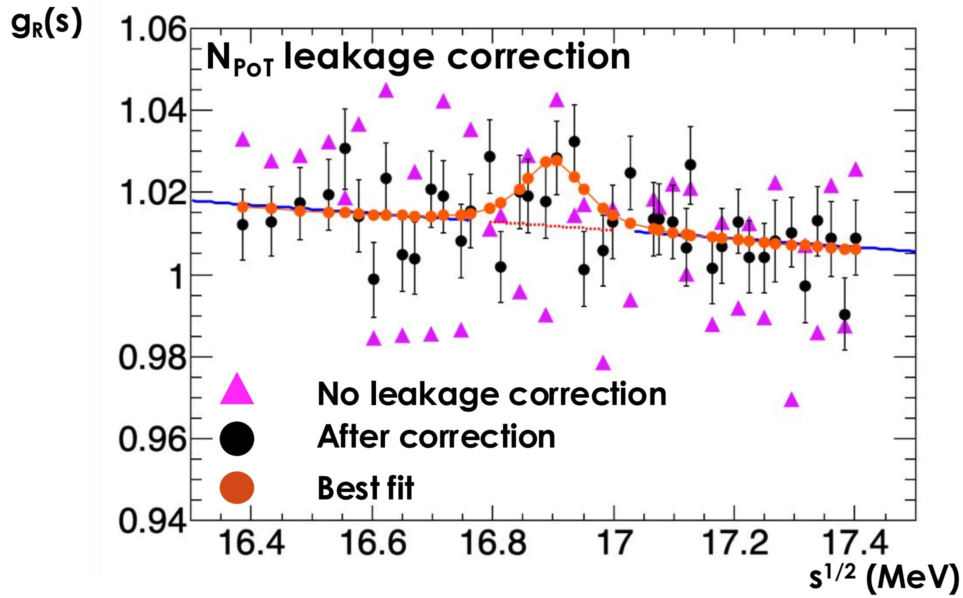


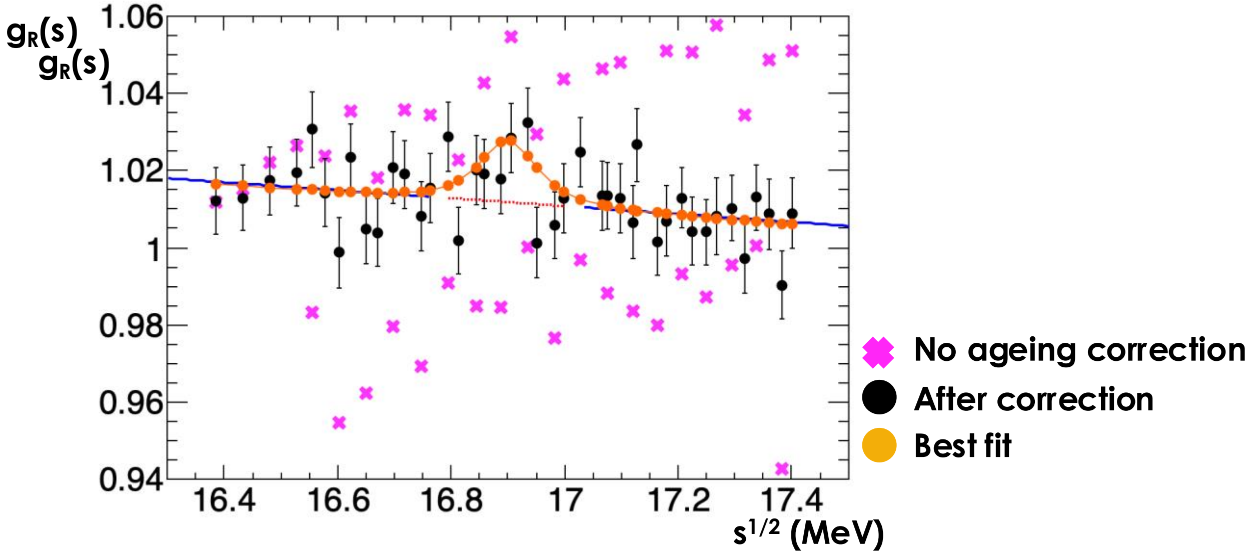
Relative ageing correction



Post unblinding checks: corrections



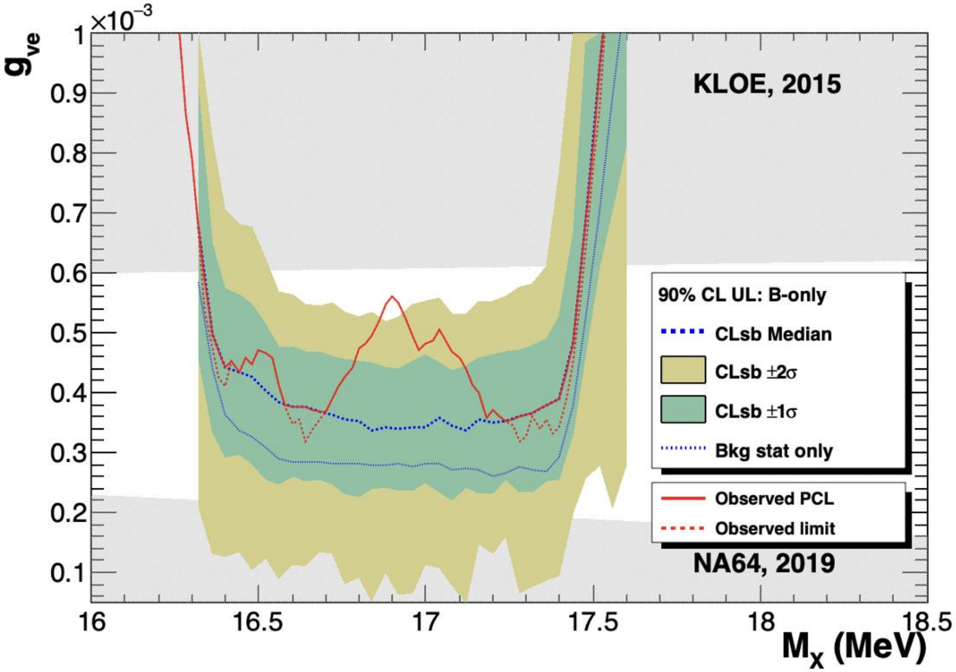




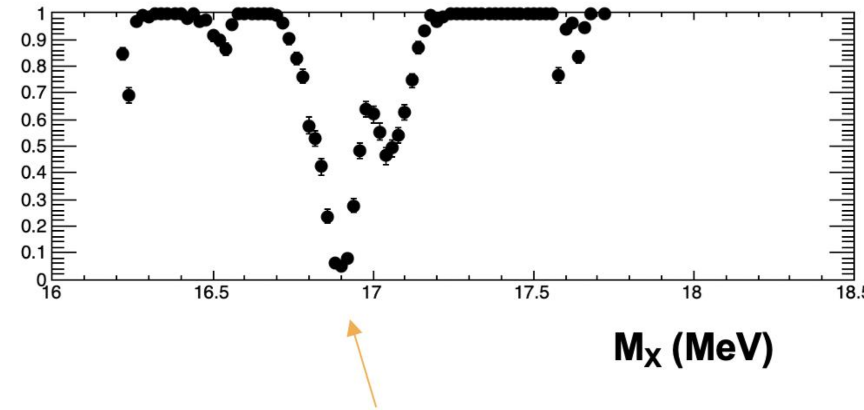
SAPIENZA
UNIVERSITÀ DI ROMA

CLSb

Using CLsb but clipping to the median every downward fluctuation of the limit



p-value



equivalent to (1.63 +- 0.13) σ

The p-value is only slightly affected, consistent with the coverage modifications of this method

Only P(signal)

^{8}Be and ^{4}He consistency and ^{12}C

PHYSICAL REVIEW D **102**, 036016 (2020)

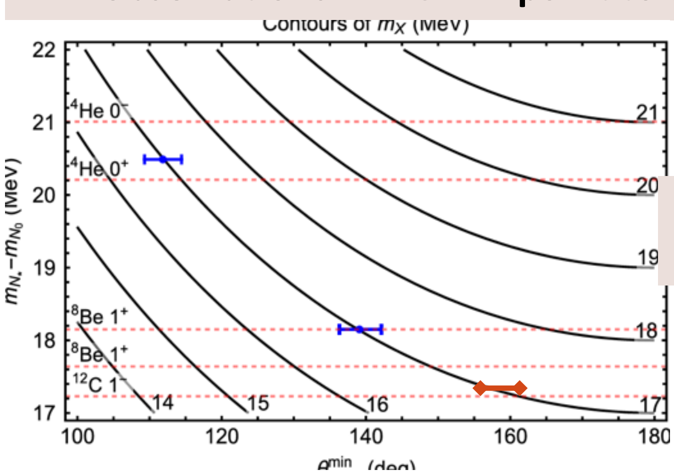
Dynamical evidence for a fifth force explanation of the ATOMKI nuclear anomalies

Feng et., Phys. Rev. D 102, 036016

Jonathan L. Feng,* Tim M. P. Tait,† and Christopher B. Verhaaren‡
Department of Physics and Astronomy, University of California, Irvine, California 92697-4575, USA

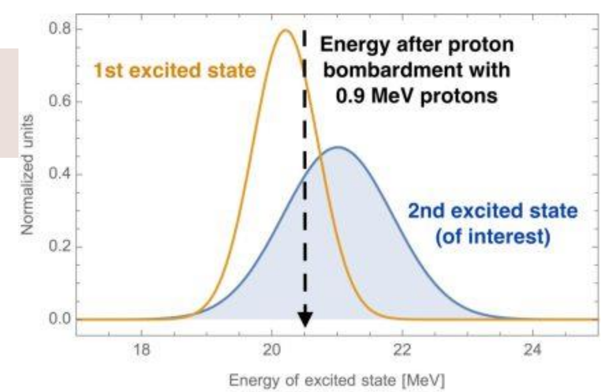
N_*	$J_*^{P_*}$	Scalar X	Pseudoscalar X	Vector X	Axial Vector X
^{8}Be(18.15)	1^+	✘	✔	✔	✔
^{12}C(17.23)	1^-	✔	✘	✔	✔
^{4}He(21.01)	0^-	✘	✔	✘	✔
^{4}He(20.21)	0^+	✔	✘	✔	✘

Feng et al., suggested that the X17 should be observed in ^{12}C transitions
X17 observations in ^{12}C will point to a vector or axial vector nature for X17



$$\theta_{ee}^{min} \approx 2\arcsin\left(\frac{m_{X17}}{m_{N*} - mN}\right)$$

^{12}C angle expected to be at ~160°



Can we trust the Atomki anomaly?

Evidence in favor:

- ✓ All the three anomalies $\gtrsim 6\ \sigma$, not a statistical fluctuation
- ✓ Bumps, not general excesses. Not a single bin or a last bin effect
  - ✓ Bumps disappear ΔE<17MeV and for asymmetric tracks
  - ✓ Bumps are produced by different detector configurations (2-5-6 arms)
- ✓ By introducing a single new particle, remarkable improvement of all the fits
- ✓ SM explanation theoretically strongly disfavored:
  - ✓ 8Be [Zhang+, (2017), Gysbers+, (2023)]; 4He [Viviani+, (2021)]
  - ✓ No explanation so far including all three anomalies at the same time
- ✓ ^{8}Be-^{4}He-^{12}C anomalies kinematically & dynamically consistent for V (and A): Barducci & Toni, Eur.Phys.J.C 83 (2023) 3, 230 [arXiv:2212.06453])
- ✓ For ^{12}C the effect was predicted, and confirmed by experimental data
- ✓ Additional recent evidence in GDR experiment
- ✓ Partially independent confirmation from Hanoi University

Odds against:

- ✓ No independent confirmation so far
- ✓ Strong constraints on the parameter space from particle physics experiments

Status of theoretical understanding

Can we explain the effect?	Not in within the SM	Zhang & Miller PLB 773, 2017 [nucl-th] Aleksejevs+, arXiv:2102.01127 [nucl-th] Viviani+ Phys. Rev. C 105, 014001
Is the effect due to X17?	Kinematic Dynamic consistent	Feng+, PRL 1604.07411 [hep-ph] Feng+, PRD 1608.03591 [hep-ph] Toni+ JHEP02(2023)154 [hep-ph]
Is X17 a vector or a scalar?	Vector or Axial vector	Feng+, PRD 1608.03591 [hep-ph] Toni+ JHEP02(2023)154 [hep-ph]
What is the best X17 mass value?	Mass fit: 16.85±0.04 Mev	B. Denton+ Phys. Rev. D 108, 015009
Is there a BSM solution?	Several different one	Feng+, PRL 1604.07411 [hep-ph] Phys. Rev. D 103, 055018

SAPIENZA
UNIVERSITÀ DI ROMA

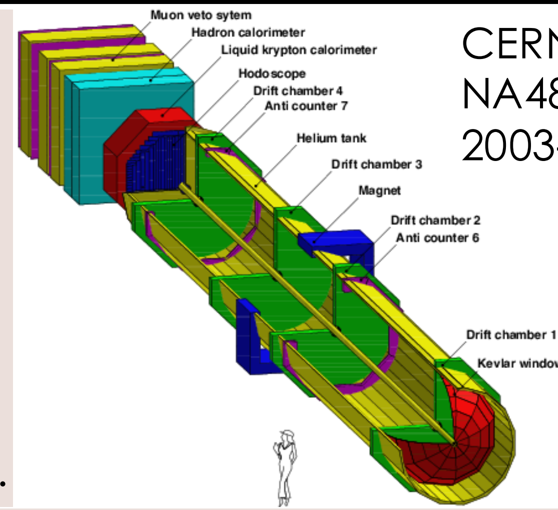
Pure dark photon: excluded NA48/2

For genuine A' $\varepsilon_f = \varepsilon q_f$ Feng et. al from the X17 rate:

$$\frac{B(^8\mathrm{Be}^* \to {}^8\mathrm{Be}\,X)}{B(^8\mathrm{Be}^* \to {}^8\mathrm{Be}\,\gamma)} = (\varepsilon_p + \varepsilon_n)^2 \frac{|\vec{p}_X|^3}{|\vec{p}_\gamma|^3} \approx 5.8 \times 10^{-6}$$

[PRL 117, 071803 (2016)]

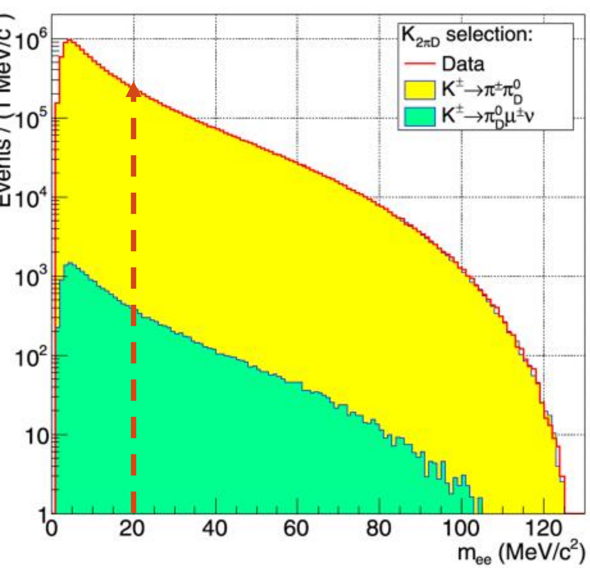
$$|\varepsilon_p + \varepsilon_n| \approx 0.011,$$

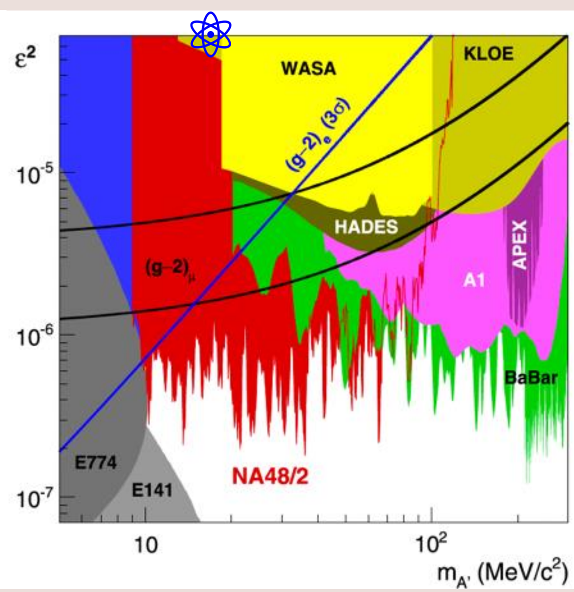


CERN NA48/2 2003-4

NA48/2 experiment limits for **A' in $K^{\pm}_{2pD}$**:
$K^{\pm} \to \pi^{\pm}\pi^0_D$ with $\pi^0_D = \gamma e^+e^-$ [PLB 746 (2015) 178-185]

In case X17 is a dark photon we should have in addition:
$\pi^0 \to \gamma X17 \to \gamma e^+e^-$
X17 should appear as a peak at 17 MeV in the m_{ee} spectrum.

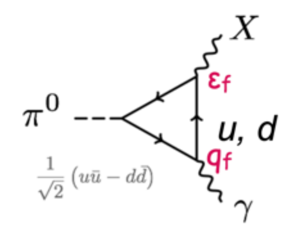




Universal coupled vector hypothesis A' firmly excluded

π-phobic/P-phobic vector particle:

[PRL 117, 071803 (2016)]



$\pi^0 \to X\,\square$: $|2\varepsilon_u + \varepsilon_d| < 8 \times 10^{-4}$ (NA48/2)

$B_{X17}/B_{\square}$: $|\varepsilon_u + \varepsilon_d| \approx 4 \times 10^{-3}$ (Atomki)

$\varepsilon_d \approx -2\,\varepsilon_u$ (±10%) ==> $\varepsilon_p = 2\varepsilon_u + \varepsilon_d \approx 0$;

$2\varepsilon_u + \varepsilon_d \approx 0$ ==> $\pi^0 \to X$© = 0

π-phobic vector still alive!

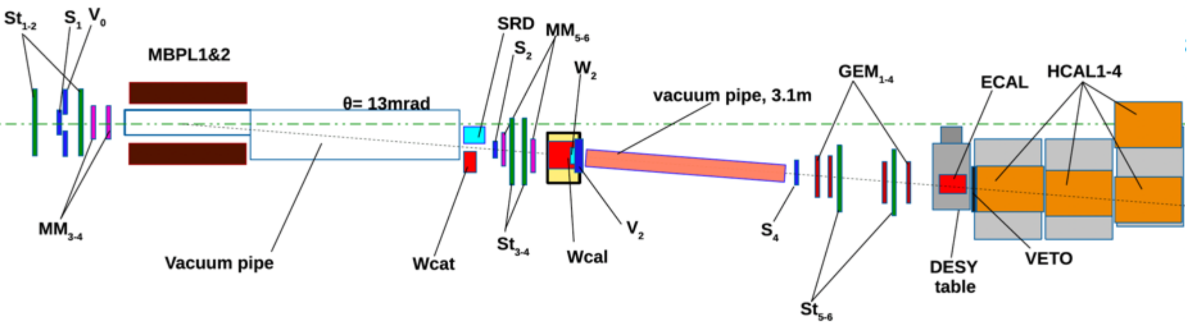
SAPIENZA UNIVERSITÀ DI ROMA

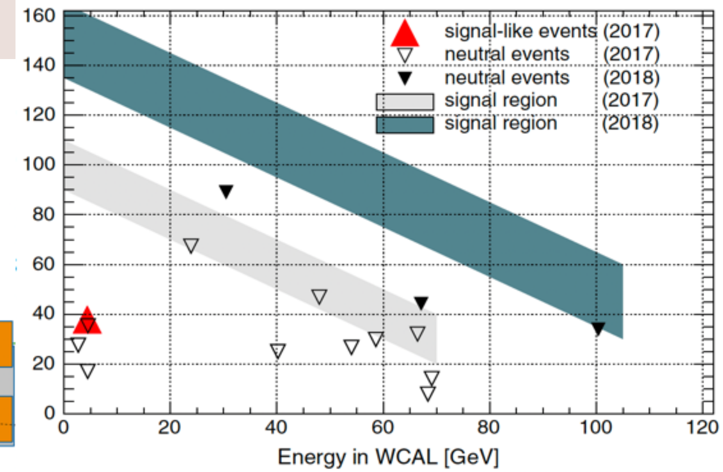
Generical vector constraints NA64

NA64 CERN NA, uses 150 GeV e^- beam on thick target.

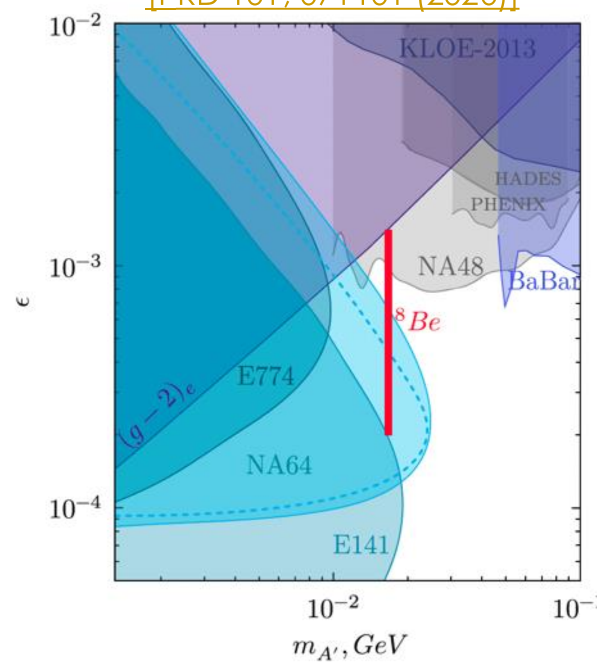
$$e^- + Z \rightarrow e^- + Z + A'(X), \qquad A'(X) \rightarrow e^+e^-$$

only e^- -> no problem with extra couplings!





[PRD 101, 071101 (2020)]



How it works:

1) Beam e^- losses part of its energy in W_{cal} before radiating.
2) After radiating A' is absrobed by W_{cal} depsiting all of its energy.
3) A' is radiated and decays after the W_{cal}
4) Energy of the ee pair from the A' decay is measured by ECal

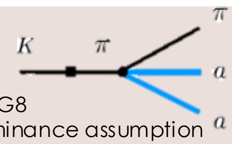
Dump experiment:

- limited in the high ε values by X17 lifetime
- No possibility to measure mass of eventually observed events
- just counts general event excess

Axion like X17: excluded by NA62

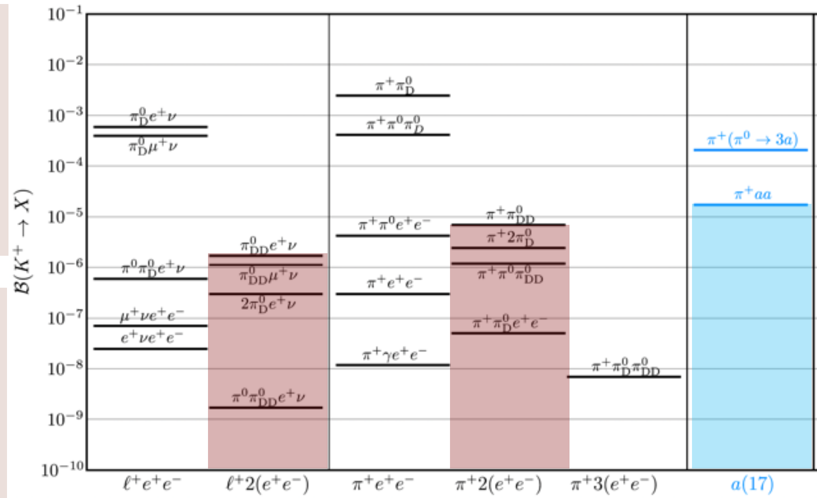
M. Pospelov noted: **[[PRD 105, 015017 (2022)]]**

$$BR(K^+ \to \pi^+ aa) \simeq 1.7 \times 10^{-5}$$



χPT G8 dominance assumption

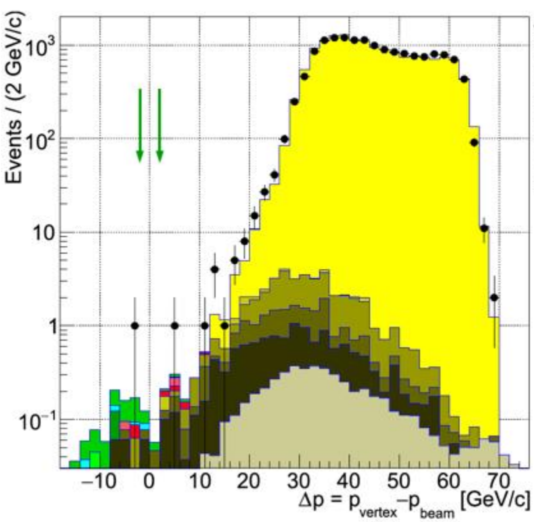
If a=X17 X17–>e⁺e⁻ and we have $\pi^+ 4e$ final state
a) main SM background $K^+ \to \pi^+ \pi^0_{DD}$ has lower rate
b) $m_{ee} = m_a$ is a strong kinematical constraint

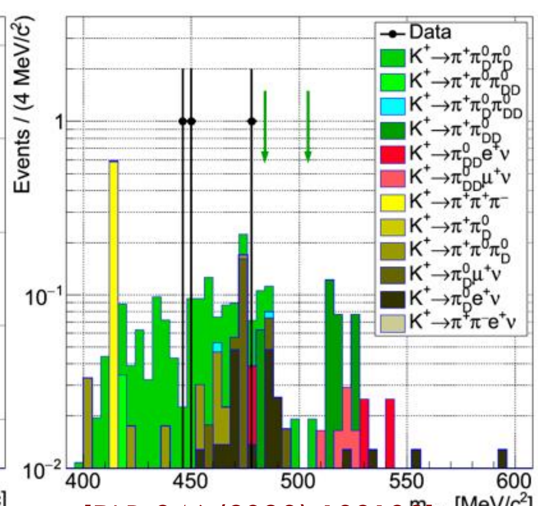


NA62 Search for $K^+ \to \pi^+ aa \to \pi^+ e^+ e^- e^+ e^-$ [PLB 846 (2023) 138193]

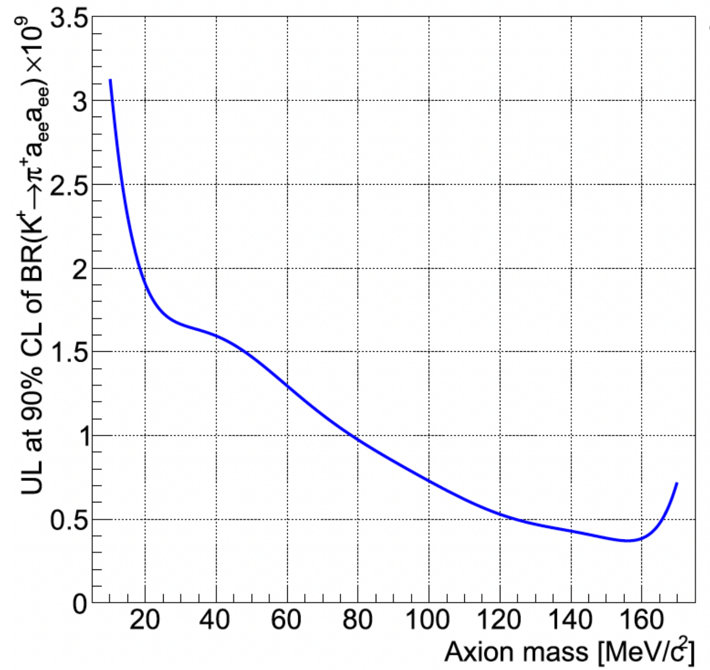
- Full NA62cdata set collected in 2017–2018
- Expected BG = 0.18±0.14 events
- No events are observed in the signal region $m_{\pi 4e} \sim m_{K+}$
- NA62 obtained: $BR(K^+ \to \pi^+ aa) \leq 2.1 \times 10^{-9}$ at 90% CL

which rules out the QCD axion hypothesis for the X17.



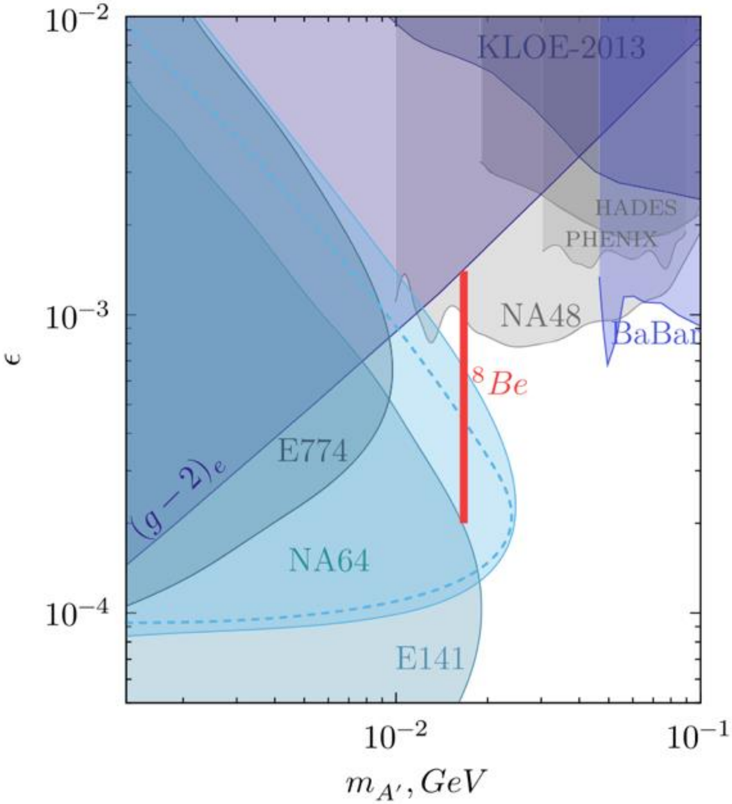


[PLB 846 (2023) 138193]

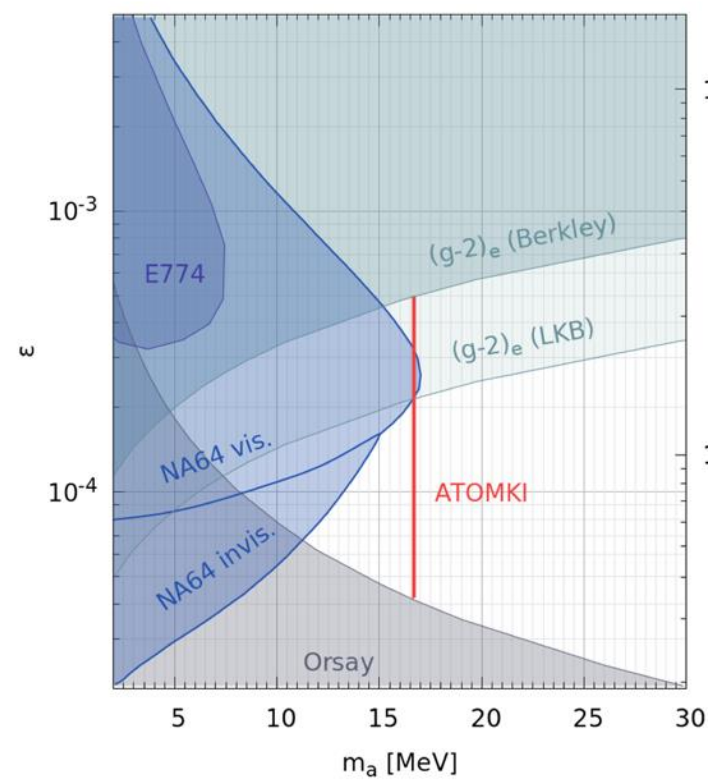


Constraints on X17: pure lepton

Phys. Rev. D 101, 071101 (R) (2020)



Phys. Rev. D 104, L111102 (2021)



X17 as a vector (V) or axial vector (A) particle:

- Theoretically favoured by ATOMKI oboservations.
- NA48/2 bound not valid for "protophobic" V and A
- $(g-2)_e$ bound weaker for vectors
- Still a lot of free parameter space for vector X17

X17 as pseudo scalar particle:

- Theoretically disfavoured by ^{12}C
- $(g-2)_e$ bound stronger for pseudo scalars
- Ruled out in pion decays ($\pi^0 \to aa$)
- Weak contraints in pure lepton-phillic models

SAPIENZA
UNIVERSITÀ DI ROMA

Is X17 a dark matter candidate?

Is X17 is a good DM candidate? NO

- Violates the rule 1) "It should be stable" X17 decays to SM e^+e^- pairs.

Is X17 is a good WIMP candidate? NO

- X17 mass in too low for a WIMP

Is X17 a good Dark Sector candidate? maybe (too early)

- X17 mass is in the correct mass range (few MeV to < 1 GeV)
- X17 is weekly coupled to SM fermions
- X17 is similar a light mediator particle for dark sectors

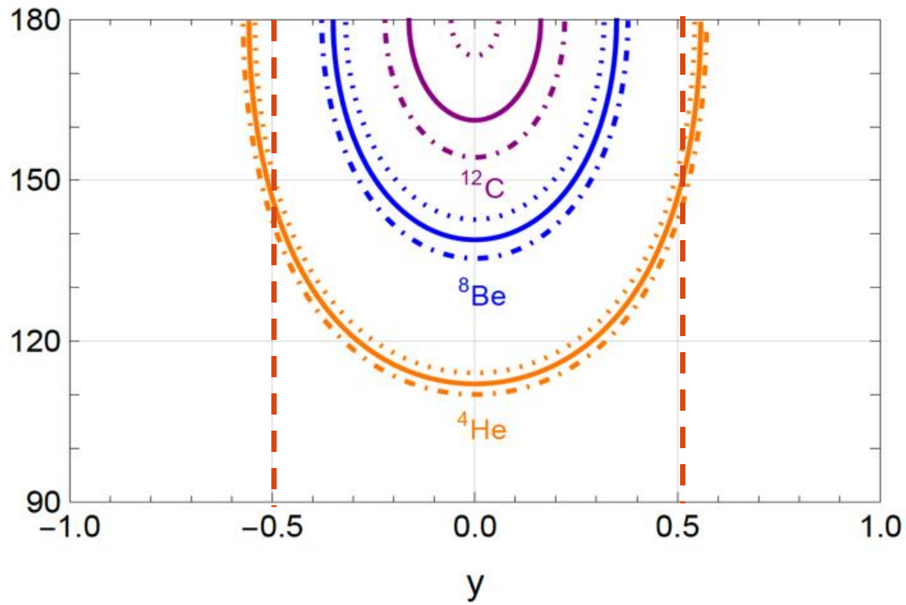
Could X17 be related to the DM problem?

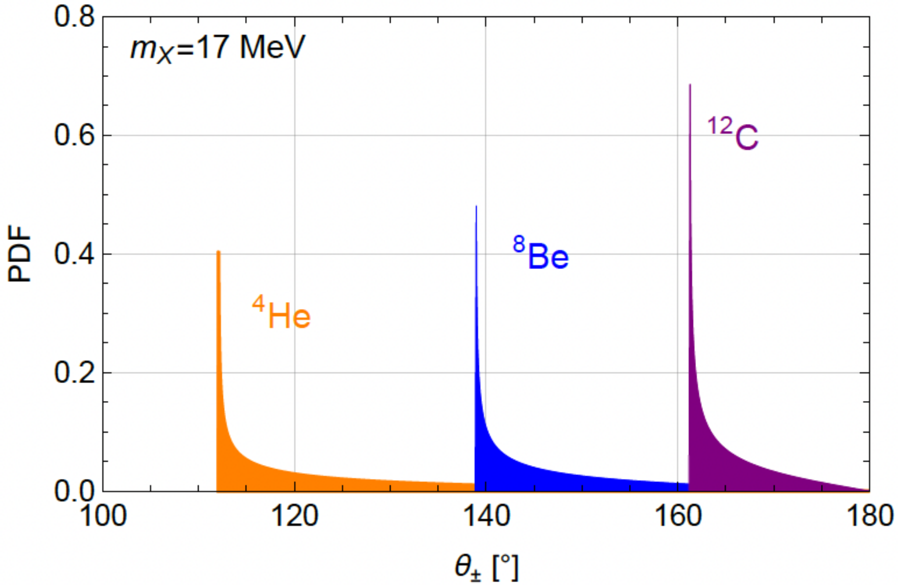
- If X17 it's a vector particle could act as mediator for a new $U(1)_D$ symmetry?
- In this case the DM fermions need to be at higher mass scales (M_χ >> 17MeV)

Could X17 help with other anomalies?

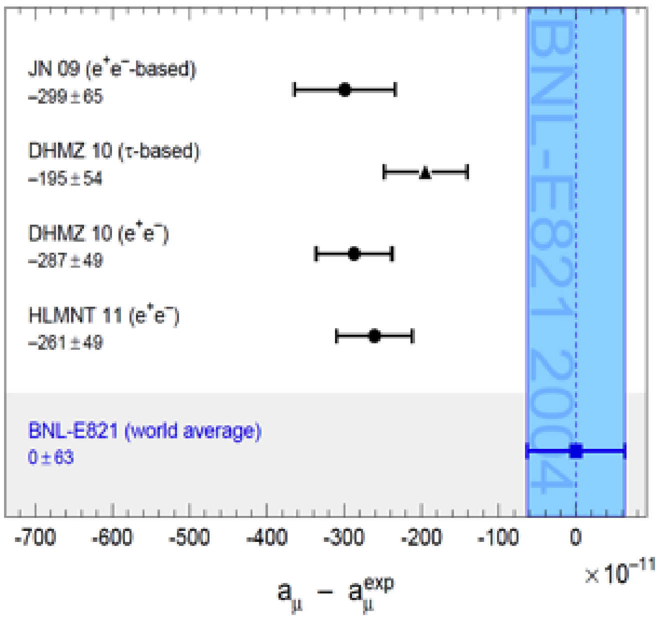
- If X17 it's a vector particle could help with $(g\text{-}2)_e$ and $(g\text{-}2)_\mu$ anomalies

Kinematics and the y cut.

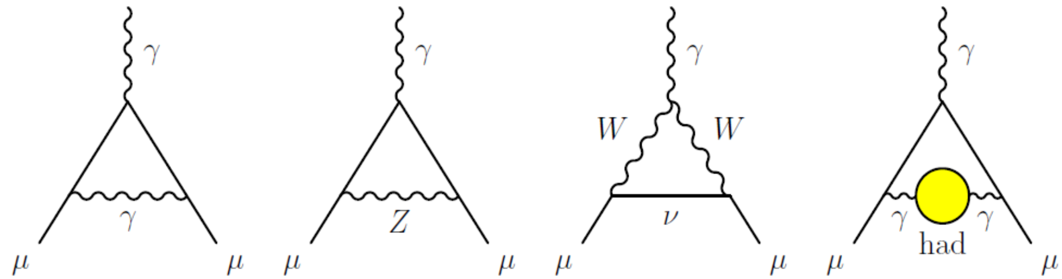




Muon g-2 anomaly



g-2 in the standard model

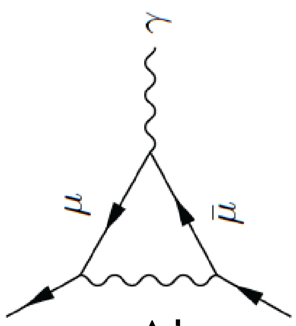


About 3σ discrepancy between theory and experiment (3.6σ, if taking into account only e+e–>hadrons)

Contribution to g-2 from dark photon

Additional diagram with dark photon exchange can fix the discrepancy (with sub GeV A' masses)

g-2 and A'



$$a_\mu^{\text{dark photon}} = \frac{\alpha}{2\pi}\varepsilon^2 F(m_V/m_\mu)\,, \qquad (17)$$

where $F(x) = \int_0^1 2z(1-z)^2/[(1-z)^2 + x^2 z]\, dz$. For values of $\varepsilon \sim 1\text{–}2 \cdot 10^{-3}$ and $m_V \sim 10\text{–}100$ MeV, the dark photon, which was originally motivated by cosmology, can provide a viable solution to the muon $g-2$ discrepancy. Searches for the dark

SAPIENZA UNIVERSITÀ DI ROMA