Study of the X17 anomaly with the PADME Experiment

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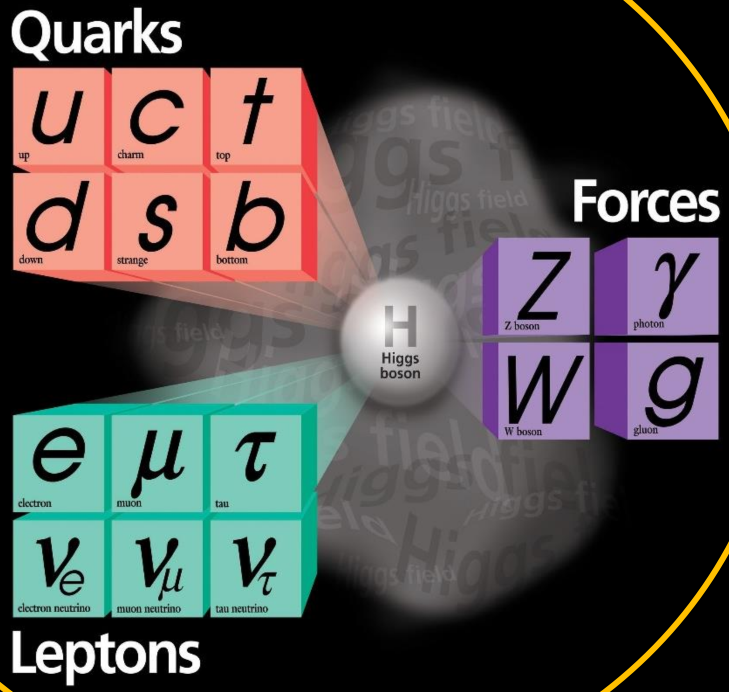
The Dark Sector Paradigm

Standard Model

Portal

Dark Sector

$$\mathcal{L} \sim g_V q_f \bar{\psi}_f \gamma^\mu \psi_f A'_\mu$$



$g_V \ll 1$

Feeble interaction with ordinary matter

dark bosons

dark fermions

Z′

A′

h′

χ′

ψ′

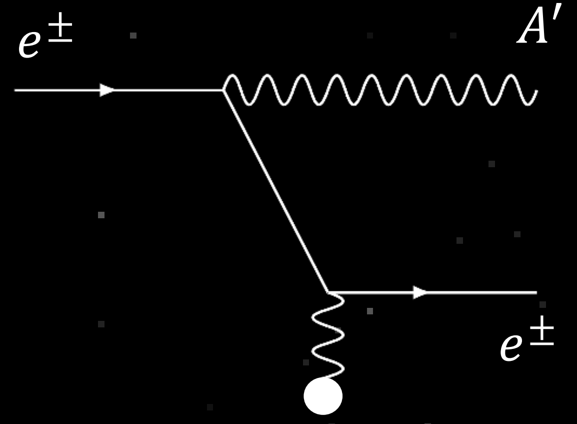
can address g-2, antimatter in cosmic rays, dark matter

can be produced at accelerators
can decay back to ordinary matter

Dark Photon Production

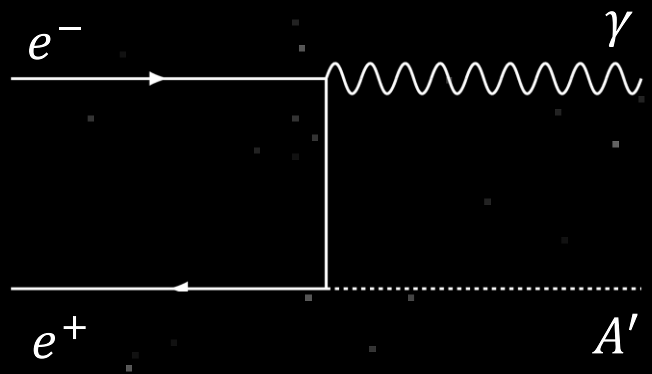
electron and positron beam experiments

A'-strahlung

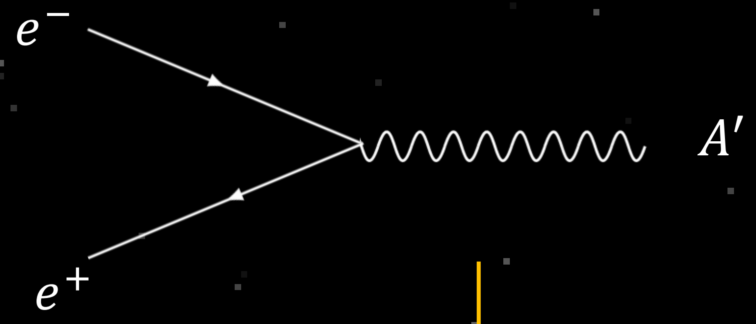


only positron beam experiments

Associated Production



Resonant production



Cross-section enhancement
if $m_{A'}$ known and $\sqrt{s} = m_{A'}$

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

Dark Photon Decay and Experimental Approaches

Visible decays to SM particles

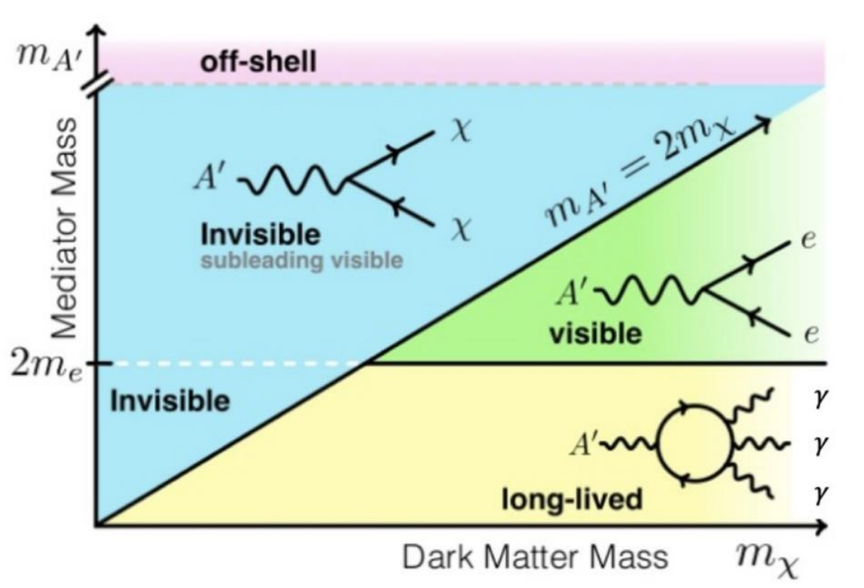
$A' \rightarrow e^{+}e^{-}$; $A' \rightarrow \mu^{+}\mu^{-}$

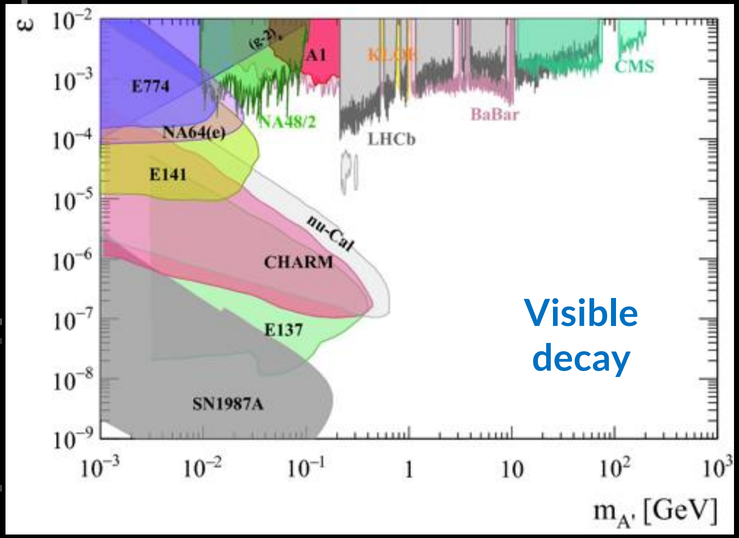
- Thick target electron/proton beam (NA64)
- Thin target beam and search peak in $e^{+}e^{-}$ invariant mass

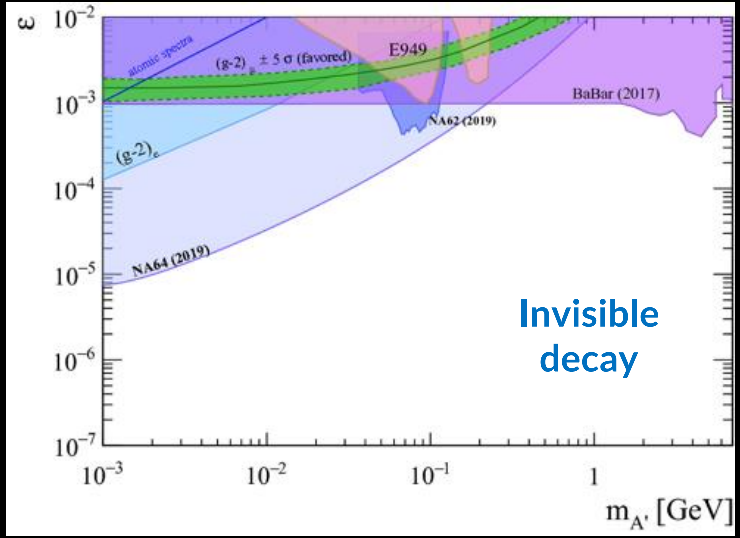
Invisible decays
(+ visible but long-lived mediators)

$A' \rightarrow \chi\chi$

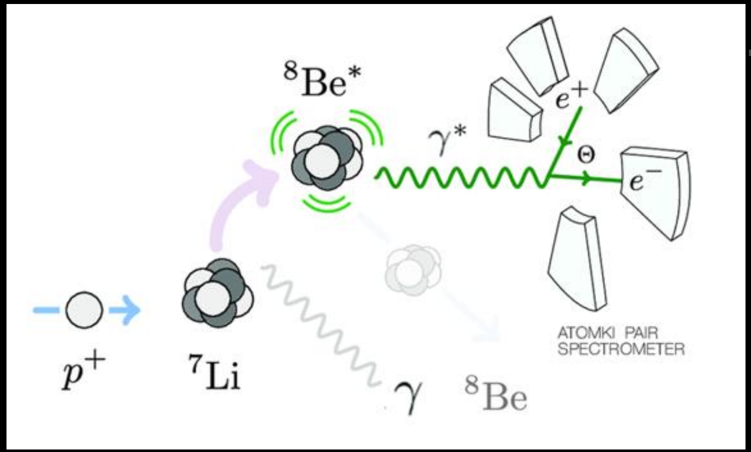
- Missing energy/momentum: A' produced in the interaction of an electron beam with thick/thin target (NA64/LDMX)
- Missing mass: $e^{+}e^{-} \rightarrow A'(\gamma)$ search for invisible particle using kinematics (Belle II, PADME)



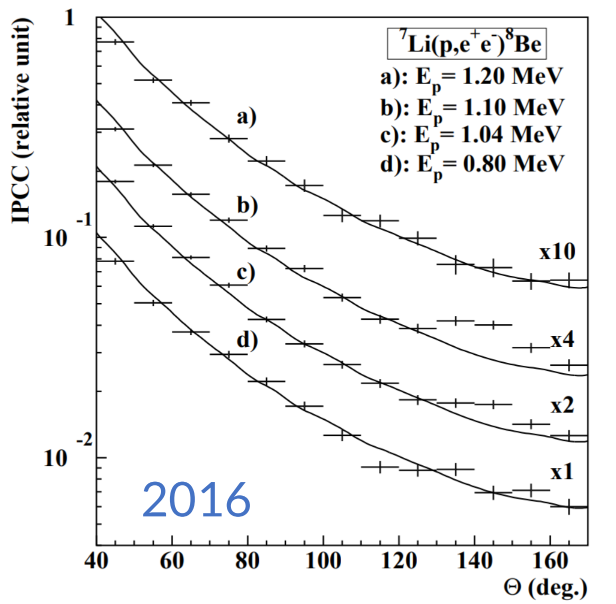




The ATOMKI Anomaly



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

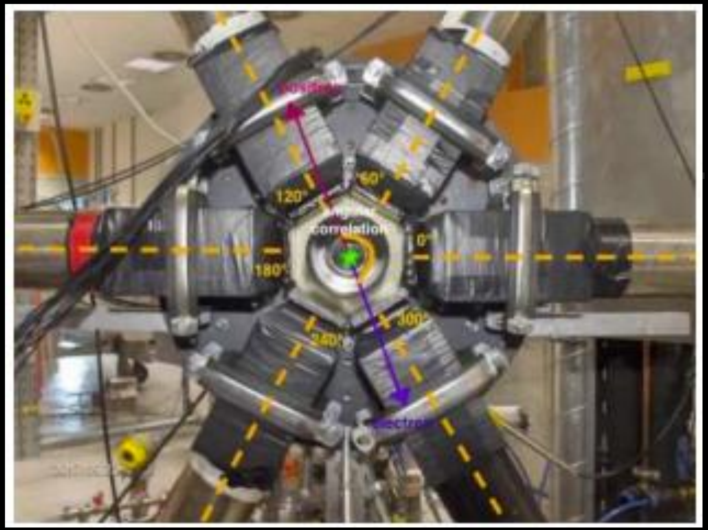


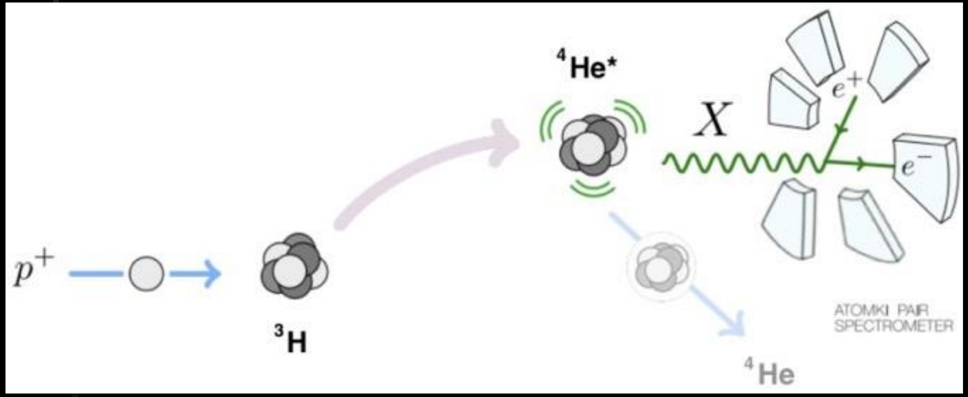
$m_X c^2 = 17.01 \pm 0.16(\text{tot})$ MeV

De-excitation of light nuclei via Internal Pair Creation shows anomalous peak in angular distribution of e^+e^-

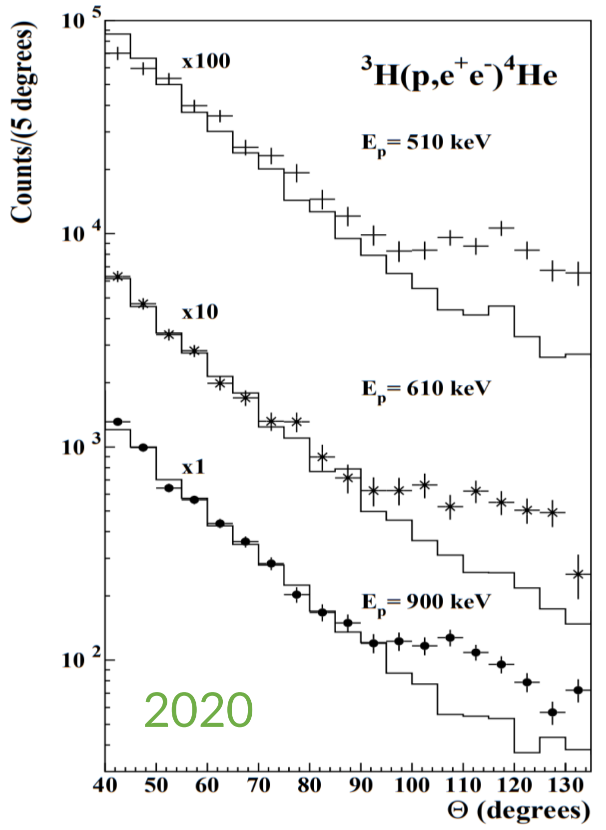
different kinematics but same invariant mass

ATOMKI Spectrometer





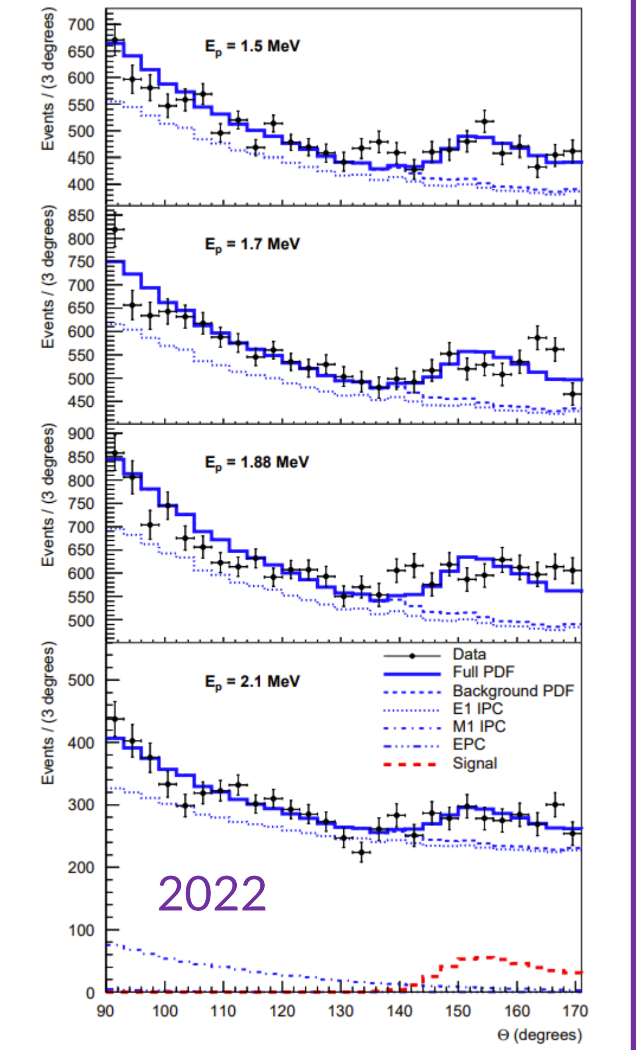
Phys.Rev.C, 104(4):044003

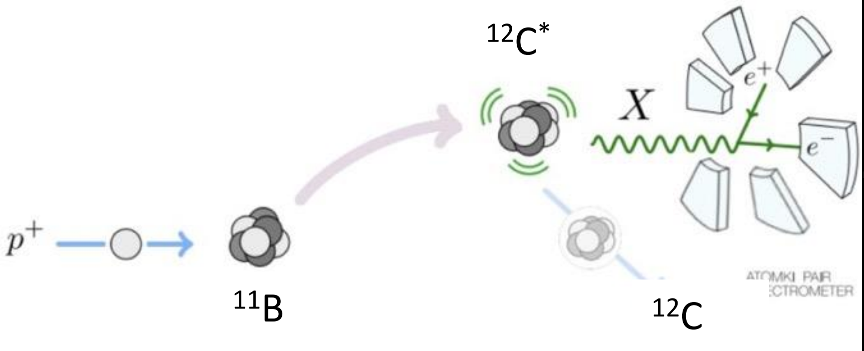


$m_X c^2 = 16.98 \pm 0.25(\text{tot})$ MeV

The Hypothetical X17 Boson

Phys. Rev. C 106, L061601





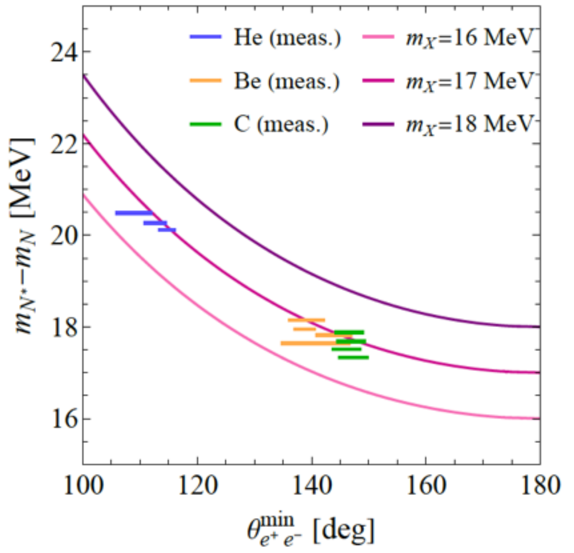
All anomalies are explainable with the existence of a **new boson** dubbed **X17** with these characteristics:

$$m_X c^2 = 16.84 \pm 0.16(\text{stat}) \pm 0.20(\text{syst})\ \text{MeV}$$

$$J^P = 1^-\ (\text{vector})\ \text{or}\ 1^+\ (\text{axial-vector})$$

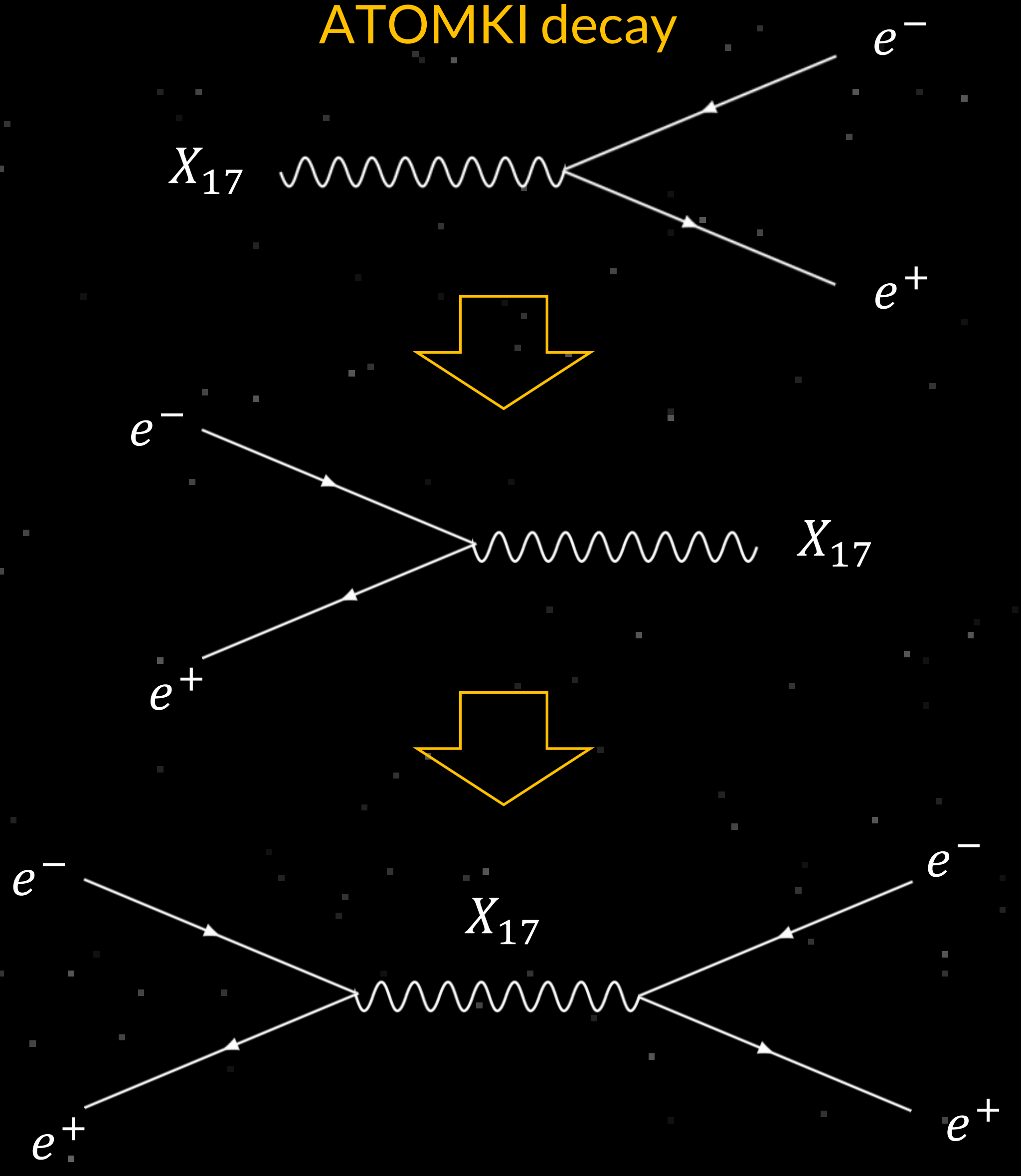
$$Br(e^+e^- \to X_{17}) \simeq 5 \times 10^{-6}\, Br(e^+e^- \to \gamma\gamma)$$

$$\Gamma_{A'} \simeq \epsilon^2 \alpha m_{A'}/3\ < 10^{-2}\text{eV}$$



X17 Resonant Production at PADME

ATOMKI decay



No model dependence just electron coupling!

High production rate expected at the resonance

$$\sigma_{peak} = \frac{12}{m_{A'}^2}$$

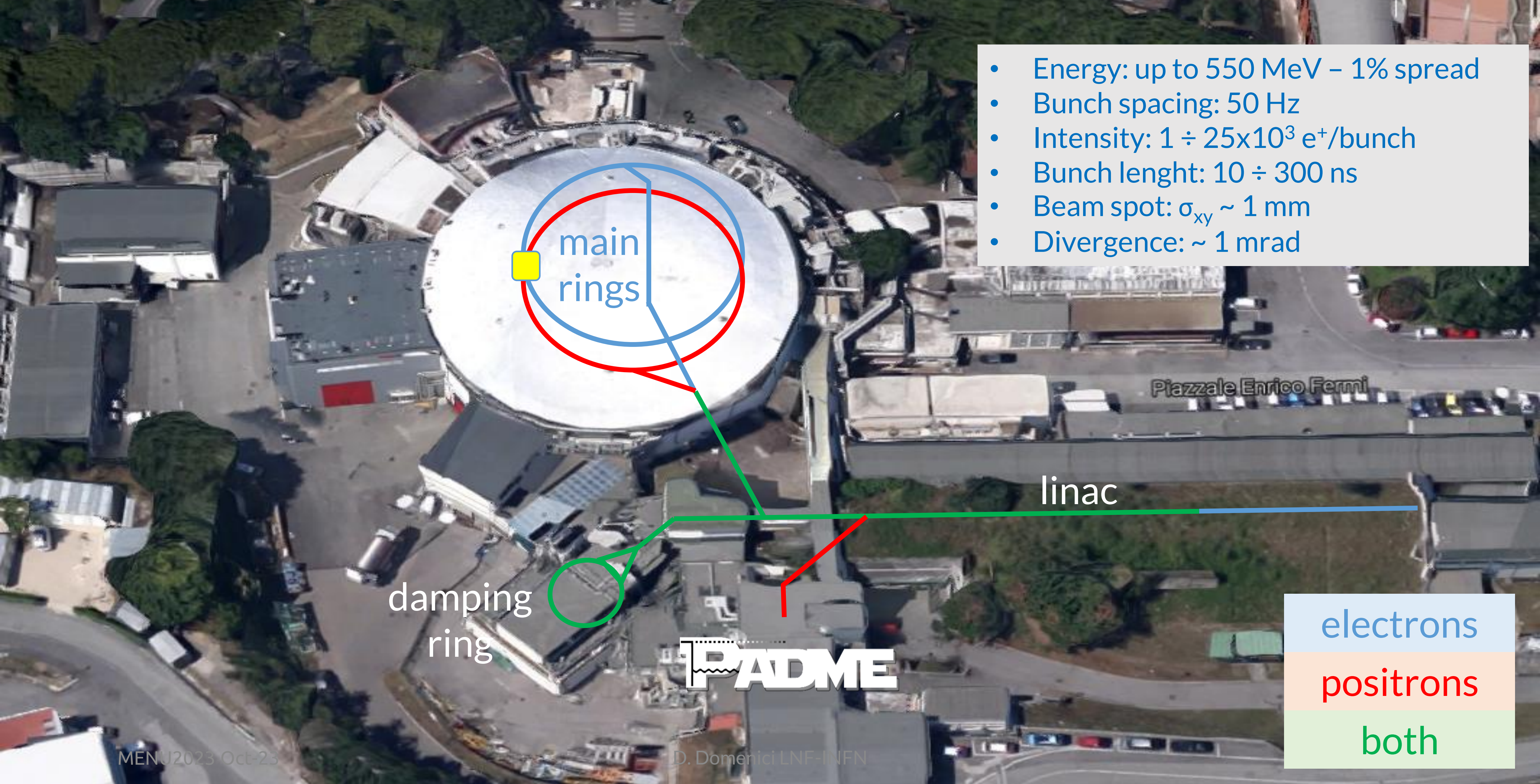
Extremely small width $\Gamma_{A'} < 10^{-2}\,\mathrm{eV}$

We need a lot of positrons in a narrow energy range

The Frascati LINAC can produce $> 10^{10}$ positrons in 20 keV range around $\sqrt{s} = 17$ MeV (beam energy around 282 MeV)

the accelerator complex of INFN Frascati National Laboratory

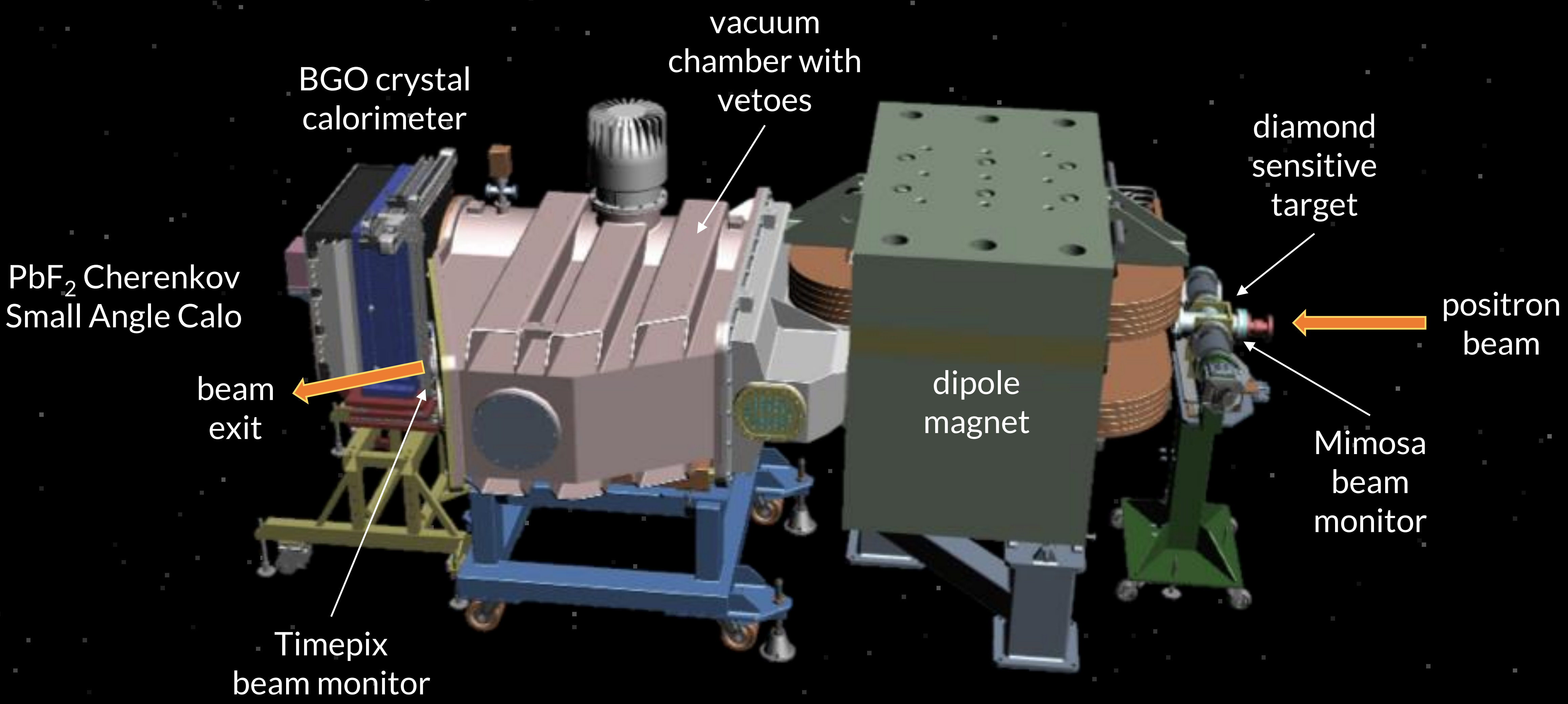
- Energy: up to 550 MeV – 1% spread
- Bunch spacing: 50 Hz
- Intensity: 1 ÷ 25x10^3 e$^+$/bunch
- Bunch lenght: 10 ÷ 300 ns
- Beam spot: σ_{xy} ~ 1 mm
- Divergence: ~ 1 mrad



A PADME Picture

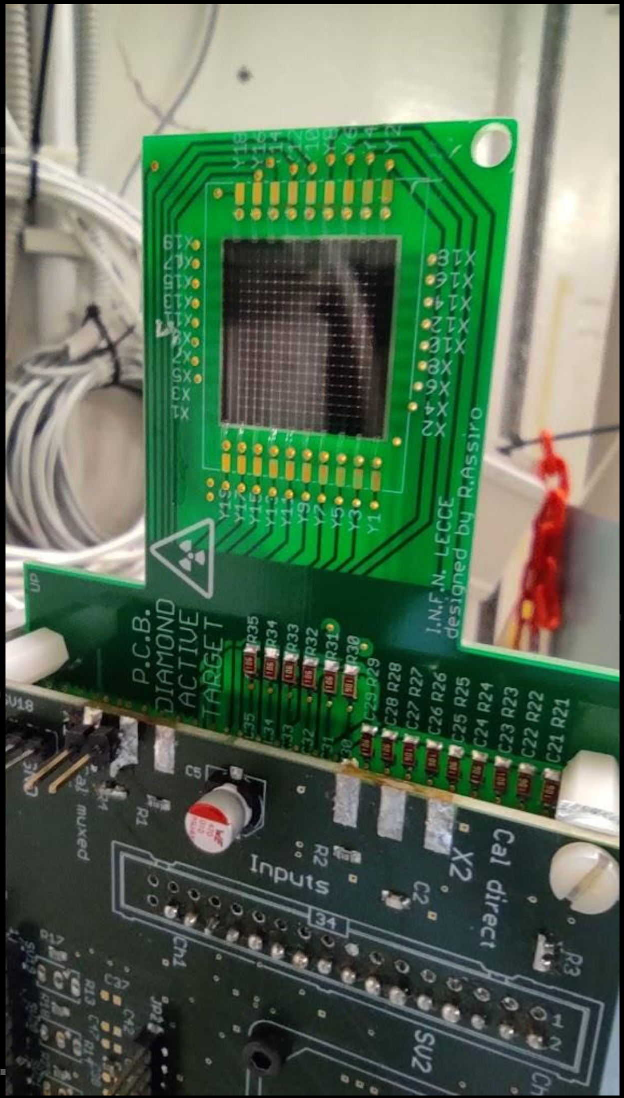
[2022 JINST 17 P08032]

The PADME Detector



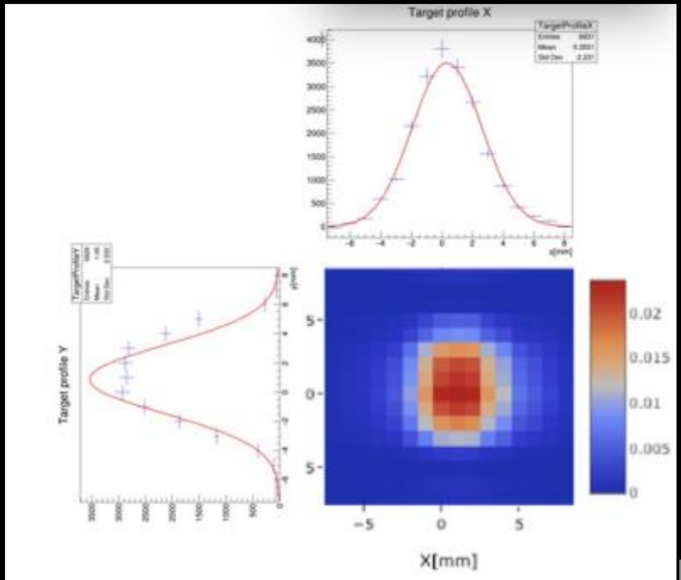
Detector: Beam Monitors

Diamond active annihilation target

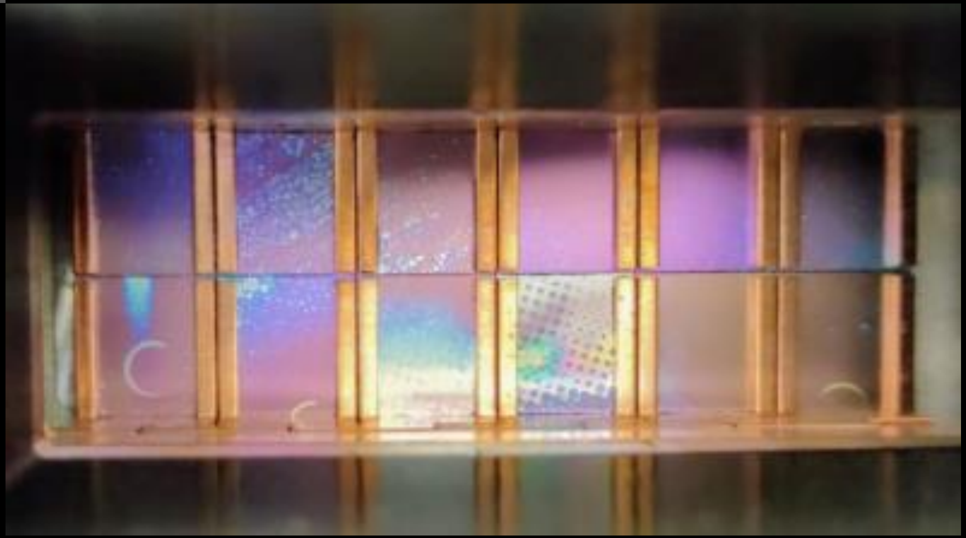


single bunch XY profile
and beam multiplicity

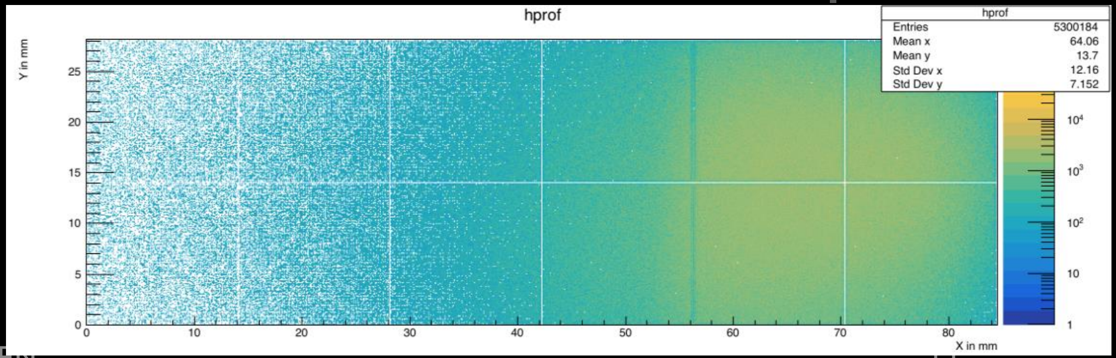
20x20x0.1 mm^3 pCVD sensor
16+16 XY graphite strips
1 mm pitch
60 μm resolution
10% intensity measurement
[NIM A 162354 (2019)]



Downstream Timepix



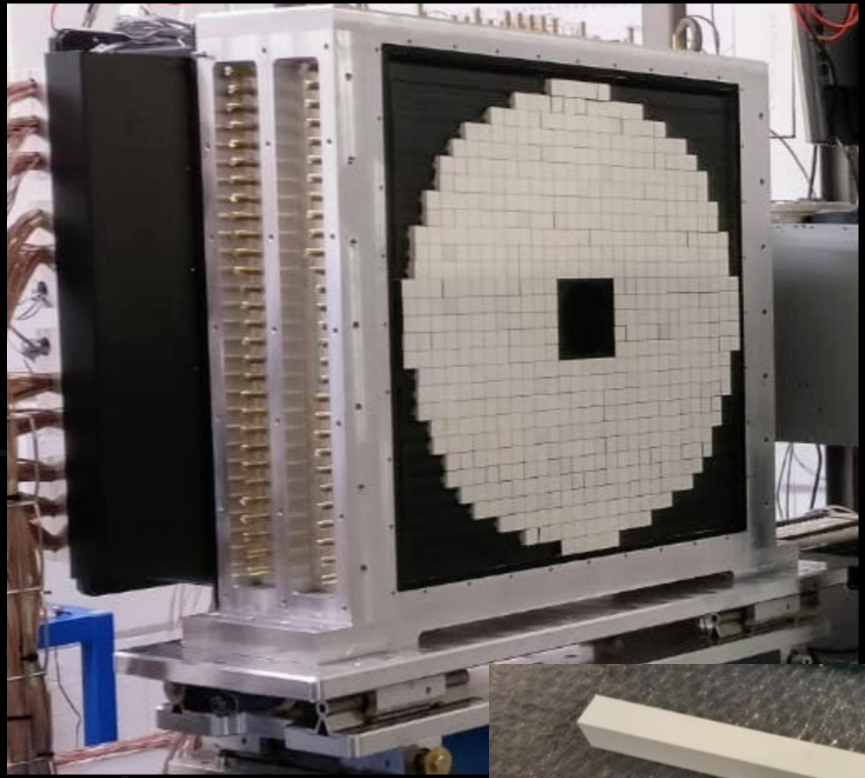
2x6 matrix of 14x14 mm^2 Timepix3
0.13 μm CMOS technology
256x256 pixel matrix, 55x55 $μm^2$



Detector: Calorimeter and Tagger

Electromagnetic Calorimeter
ECAL

annihilation events
bremmstrahlung suppression



616 scintillating BGO crystals
$21 \times 21 \times 230$ mm^3
PMT readout
$\sigma E/E$ = 2.8% at 490 MeV
BGO decay time = 300 ns
Radiation length = 20.5 X_0
[JINST 15 (2020) T10003]

Electron Tagger
ETAG

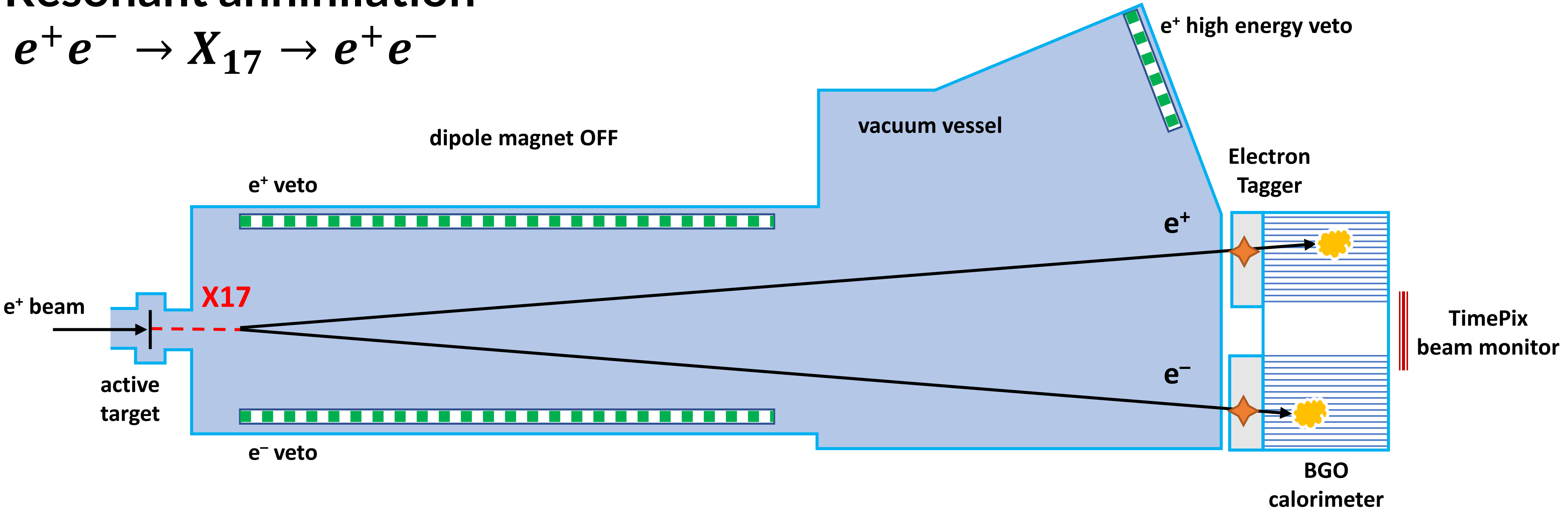
photon veto for X17 run

16 scintillators 600x45x5 mm^3
4 SiPM direct readout on both sides
installed in 2022

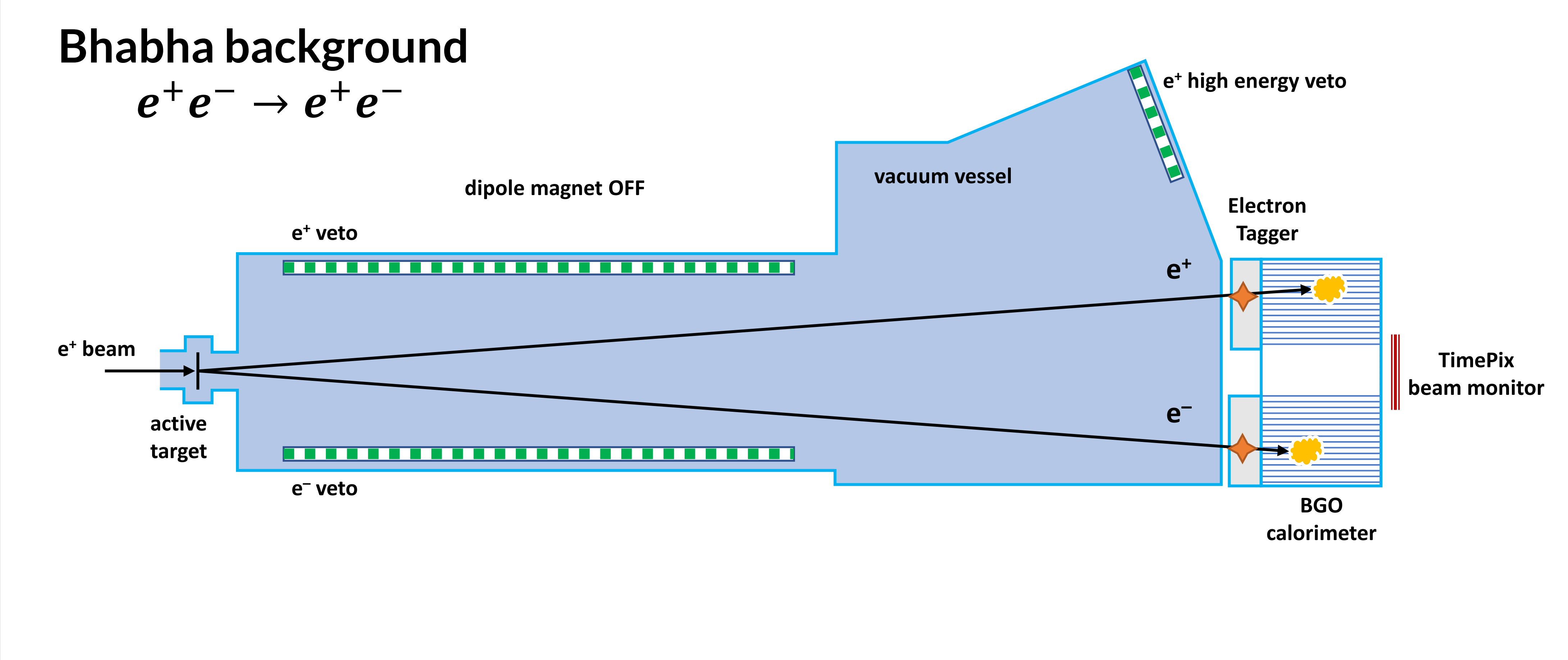
PADME Detector for X17 Boson

Resonant annihilation

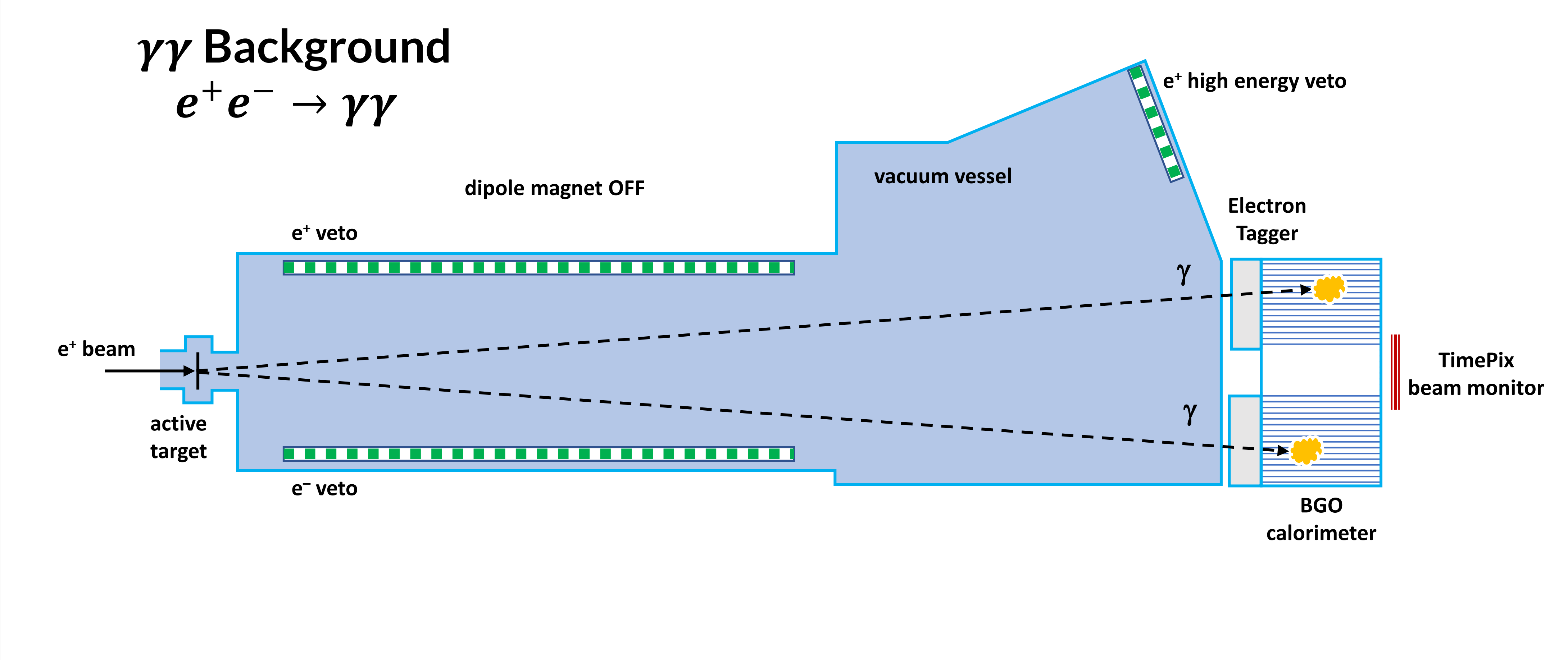
$$e^+e^- \rightarrow X_{17} \rightarrow e^+e^-$$



PADME Detector for X17 Boson



PADME Detector for X17 Boson



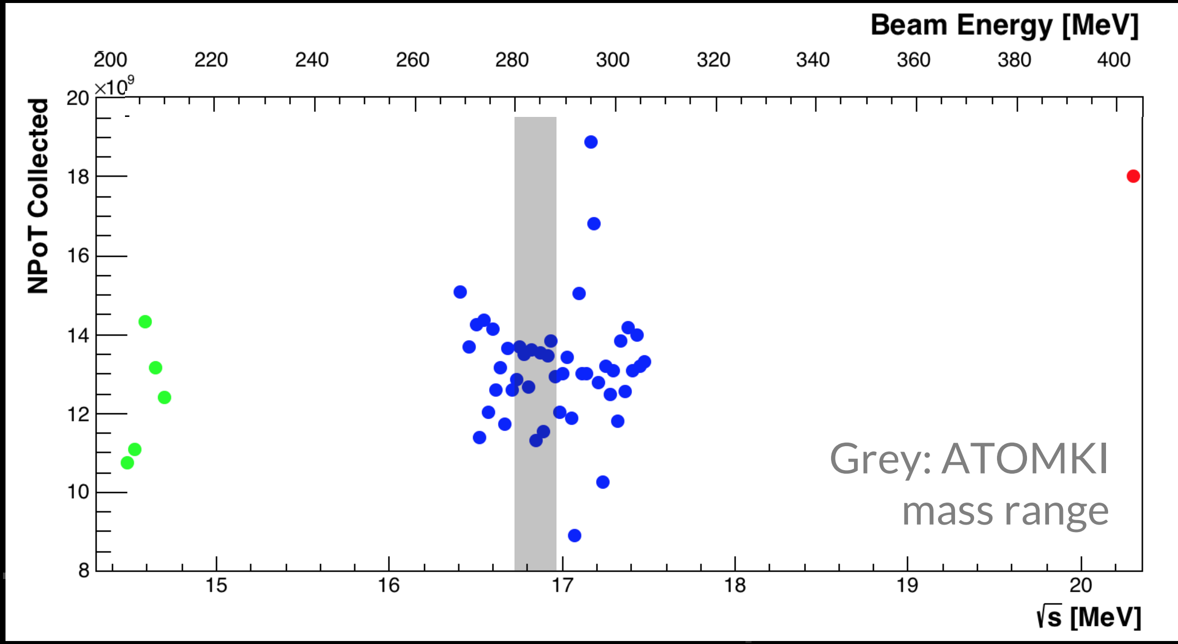
X17 Resonance Scan

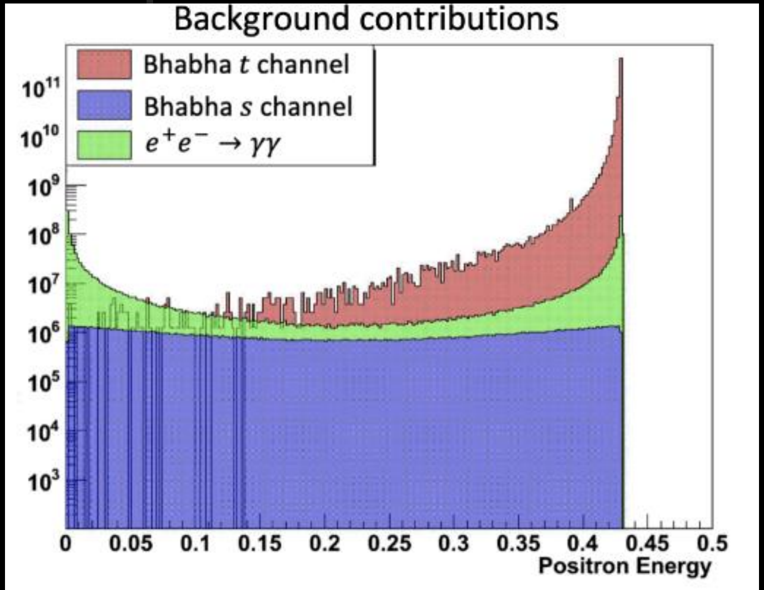
PADME Run3
September – December 2022
Energy scan around X17 Mass

5 points below resonance: 205 ÷ 211 MeV
Spacing: 1.5 MeV
Statistics: 10^{10} POTs/point
Used to validate analysis

47 points on resonance: 263 ÷ 299 MeV
Mass region 16.4 MeV < M_{X17} < 17.5 MeV
Spacing: 0.75 MeV (equal to the energy resolution)
Statistics: 10^{10} POTs/point
Precision on M_{X17} measurement: ~20 keV

1 point above resonance: 402 MeV
Statistics: $2x10^{10}$ POTs
Used to validate NPOT measurement



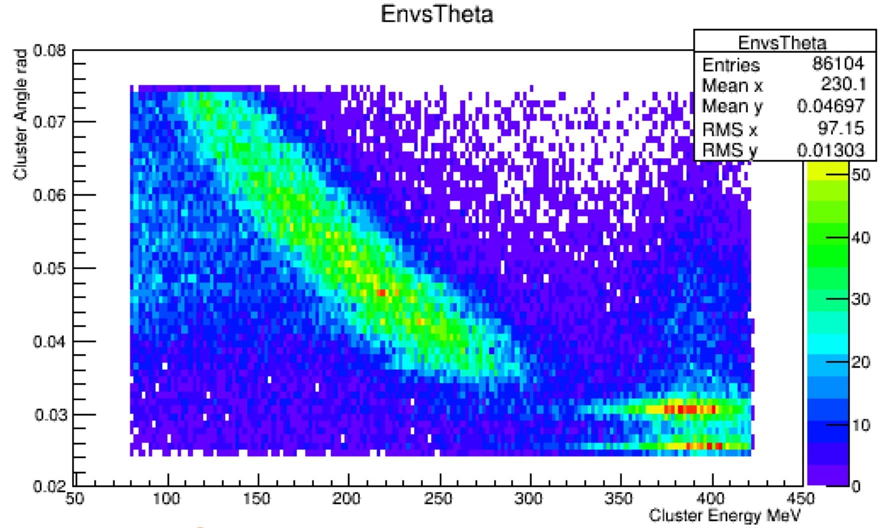


Signal should emerge on top of Bhabha and $\gamma\gamma$ backgrounds

First Look at Off-Resonance Data

Selection of 2 clusters in ECAL within 5ns
(no need to rely on Etag efficiency)
&&
Energy vs Angle compatible with a 2 body final state.

$$\frac{N(e^+e^- + \gamma\gamma)}{N_{POT}}$$

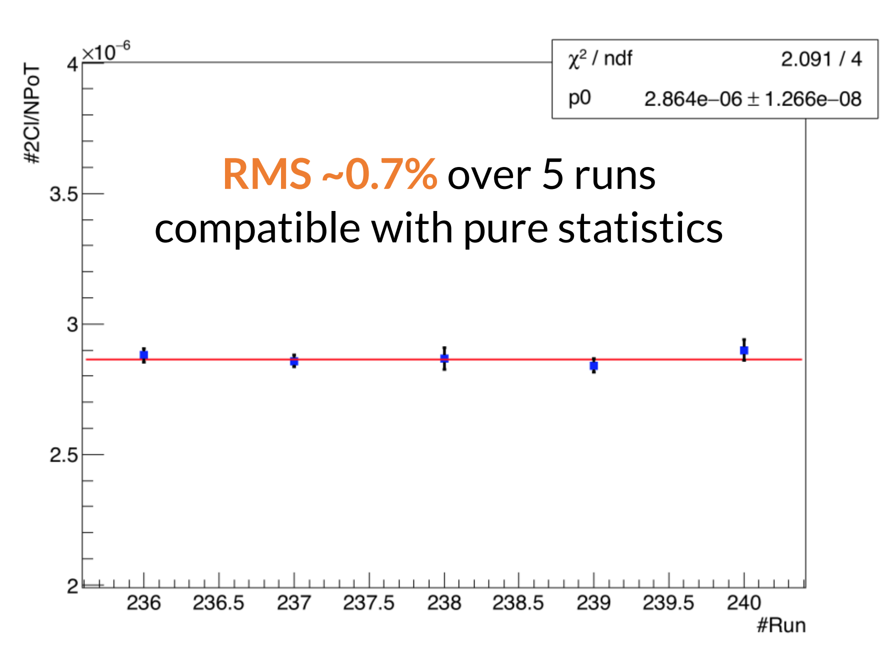


Above Resonance: 402 MeV

Combining with other observables

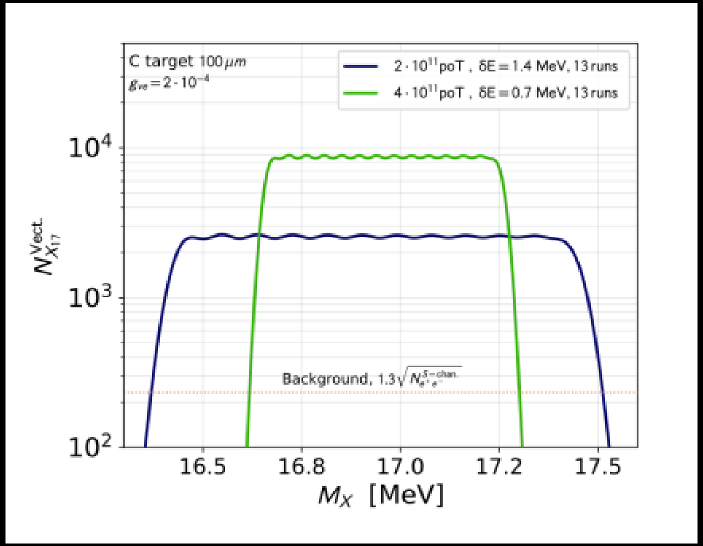
$$\frac{N(e^+e^-)}{N_{POT}} \qquad \frac{N(\gamma\gamma)}{N_{POT}} \qquad \frac{N(e^+e^-)}{N(\gamma\gamma)}$$

Existence of X17 and its spin-parity can be assessed

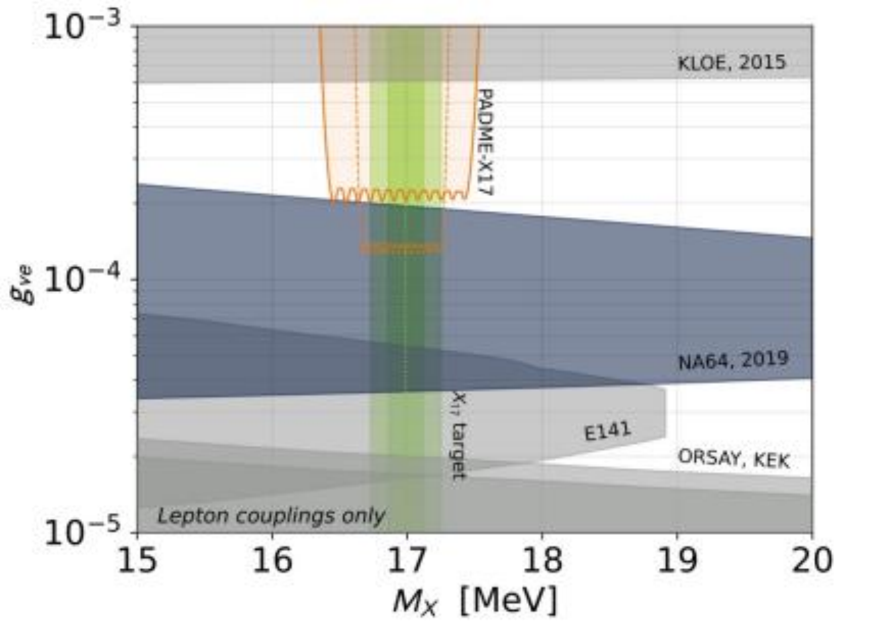


RMS ~0.7% over 5 runs
compatible with pure statistics

X17 Expected Limits

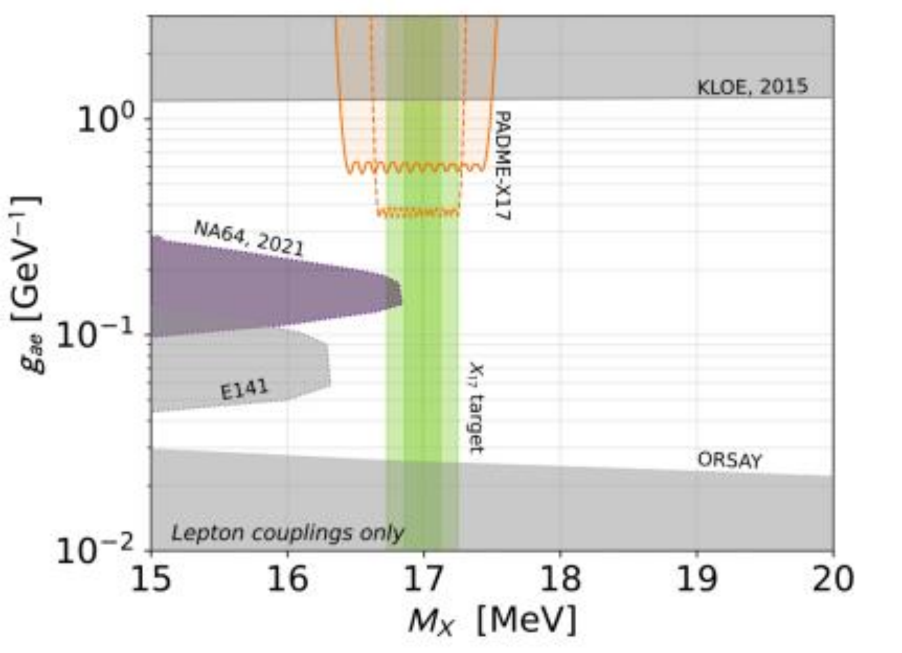


projected sensitivity for vector



Darmé et al. Phys. Rev. D 106,115036

projected sensitivity for pseudo-scalar



We made a unique scan with width of blu and density of green

New plots coming soon

Conclusions

In 2022 the PADME experiment, with a modified setup, was dedicated to the search of X17 with resonant production of a positron beam on target

Energy scan performed in range 16.35 MeV $< M_{X17} <$ 17.5 MeV

Current analysis on off-resonance data shows <1% observable stability and very good background separation

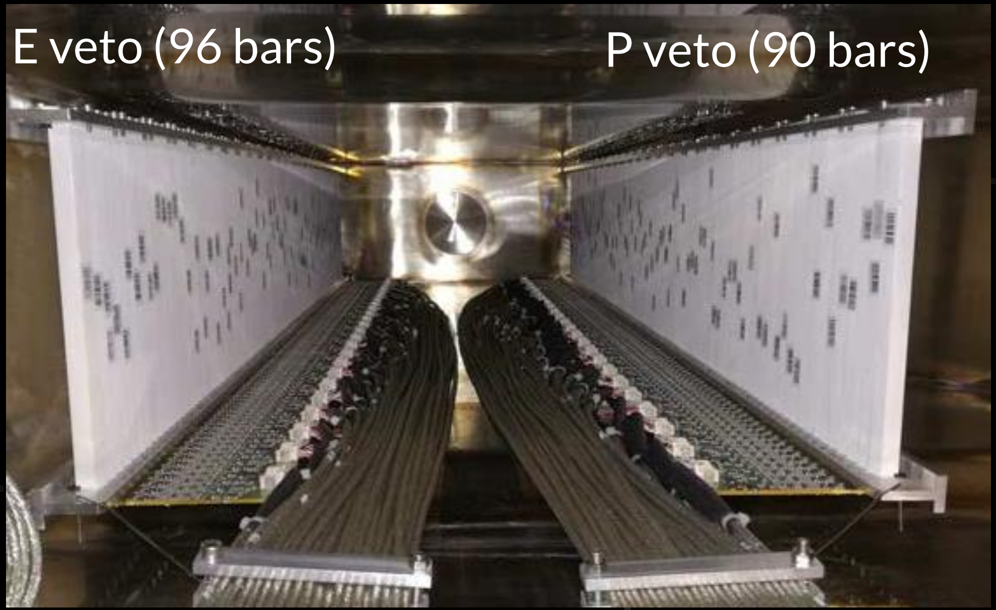
Next step is move to sidebands closer to M_{X17}

PADME results on X17 coming soon. Stay tuned!

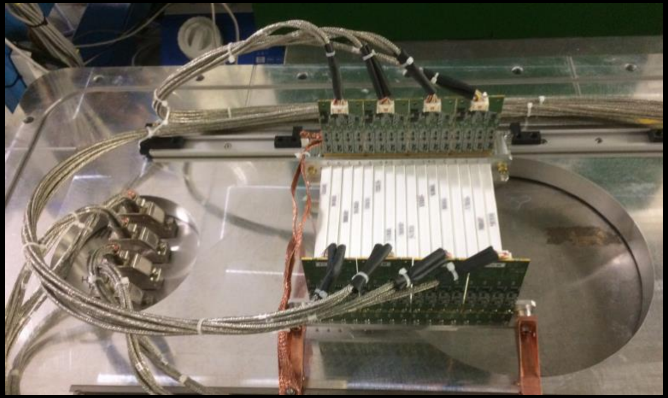
SPARES

Detector: Vetoes and SAC

Electron-Positron Vetos
EVETO-PVETO



HEP veto
(16 bars)



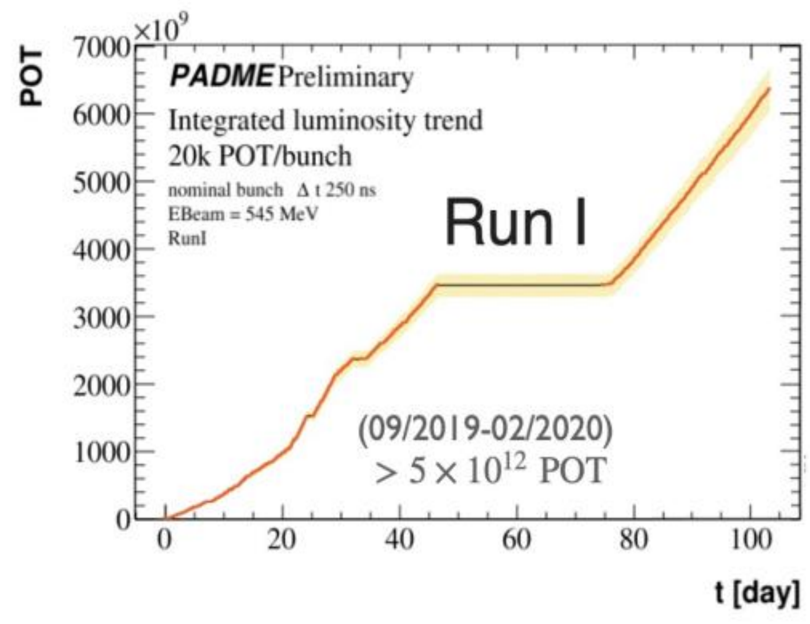
bremmstrahlung suppression
detection of visible decays

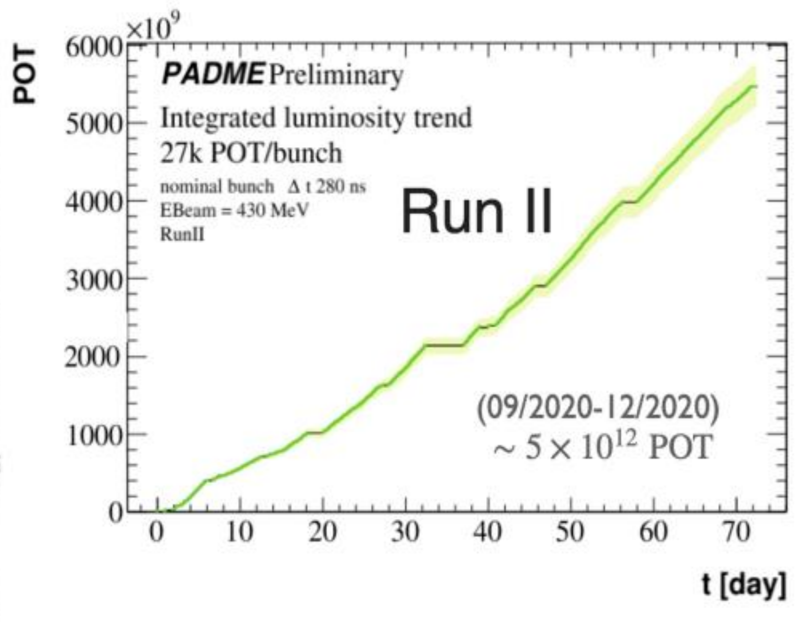
plastic scintillators bars
10x10x178 mm^3
WLS fiber + 3x3 mm^2 SiPM
500 ps time resolution
2% momentum resolution
[NIM A 936 (2019) 259]
[JINST 15 (2020) 06, C06017]

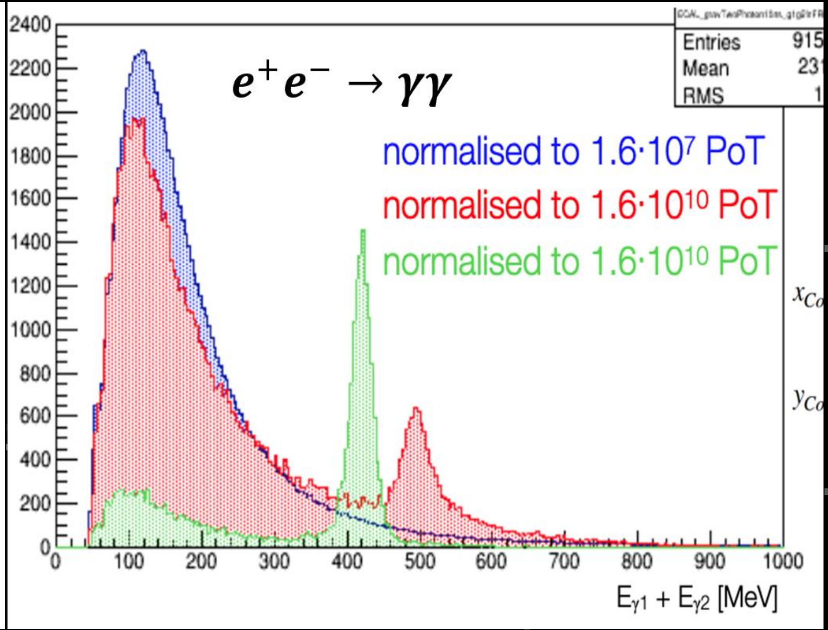
Small Angle Calorimeter
SAC

25 Cherenkov PbF_2 crystals
30×30×140 mm^3
PMT readout
PbF_2 signal time = 3 ns
Time resolution = 80 ps
Rate capability = 40 cluster/bunch
[NIM A 919 (2019) 89]

Data Taking Runs







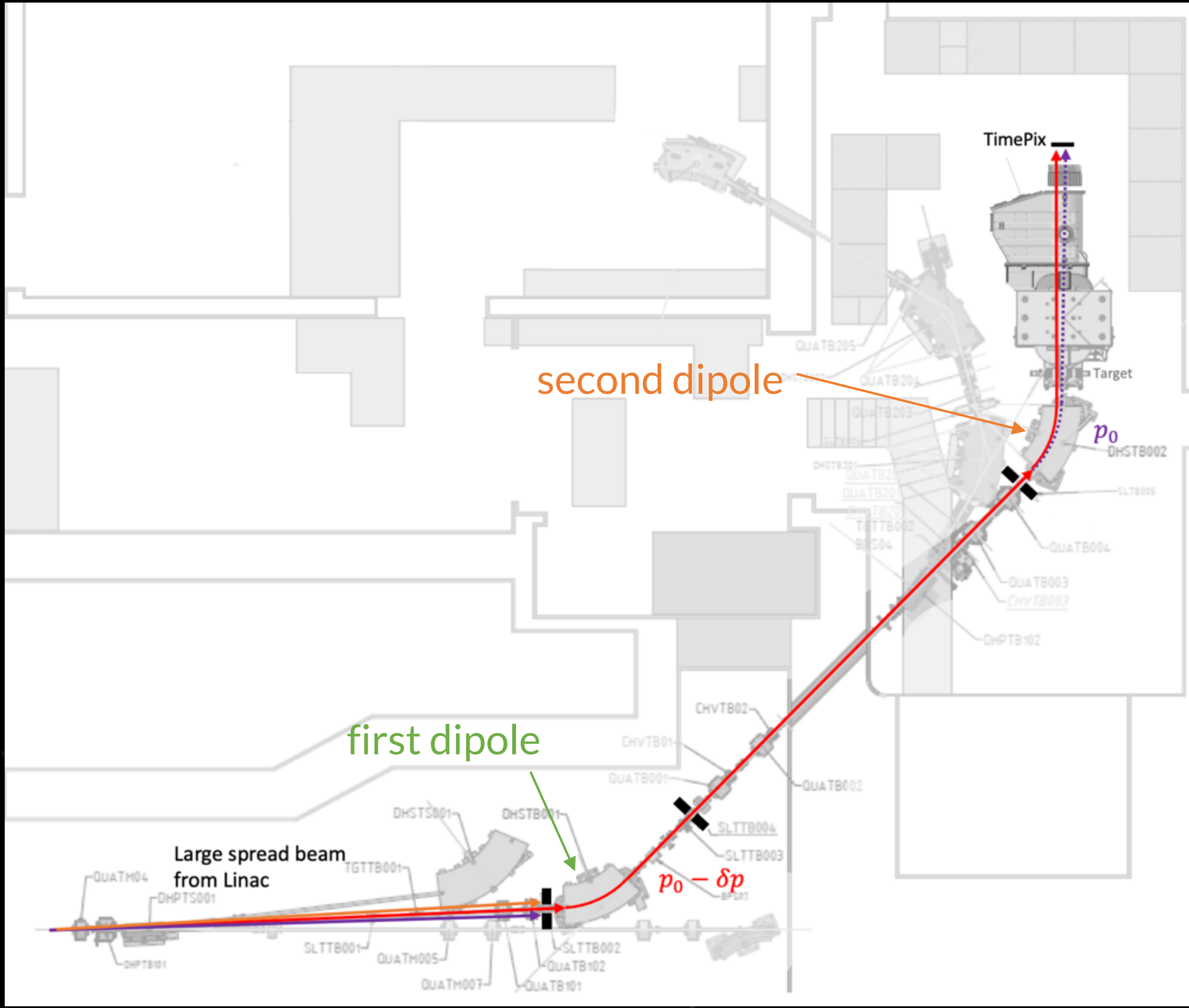
RUN1 – 2019
Secondary Beam
7×10^{12} POT
250 µm Be window
545 MeV
25kPOT / 250 ns bunch

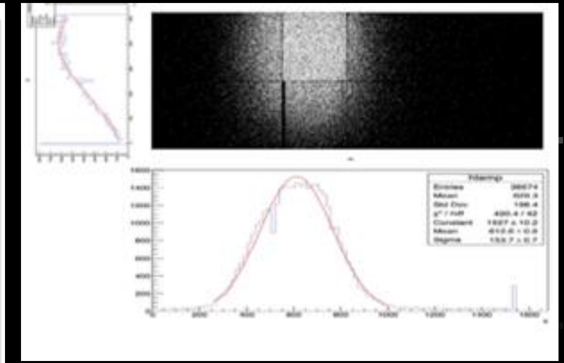
RUN1 – 2019
Primary Beam
250 µm Be window
490 MeV
25kPOT / 250 ns bunch

RUN2 – 2020
Primary Beam
6×10^{12} POT
125 µm Mylar window
430 MeV
28kPOT / 280 ns bunch

RUN3 – 2022 – X17 search
Primary Beam
6×10^{11} POT
125 µm Mylar window
283 MeV
2kPOT / 260 ns bunch

Energy beam selection and Resolution





TimePix monitor

First dipole used to select energy

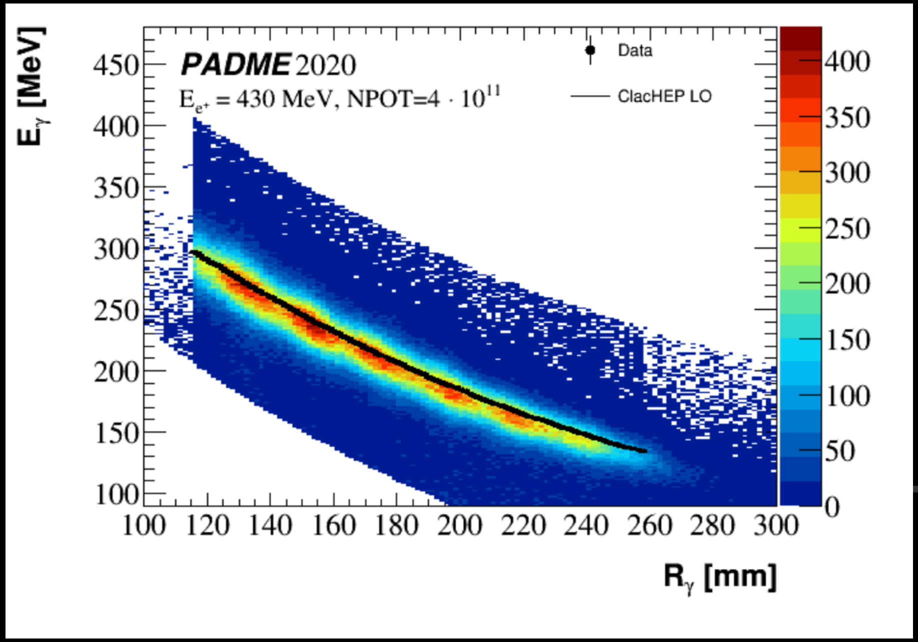
Second dipole used to correct trajectory and center beam on PADME axis

Measure displacement with TimePix to compute energy step

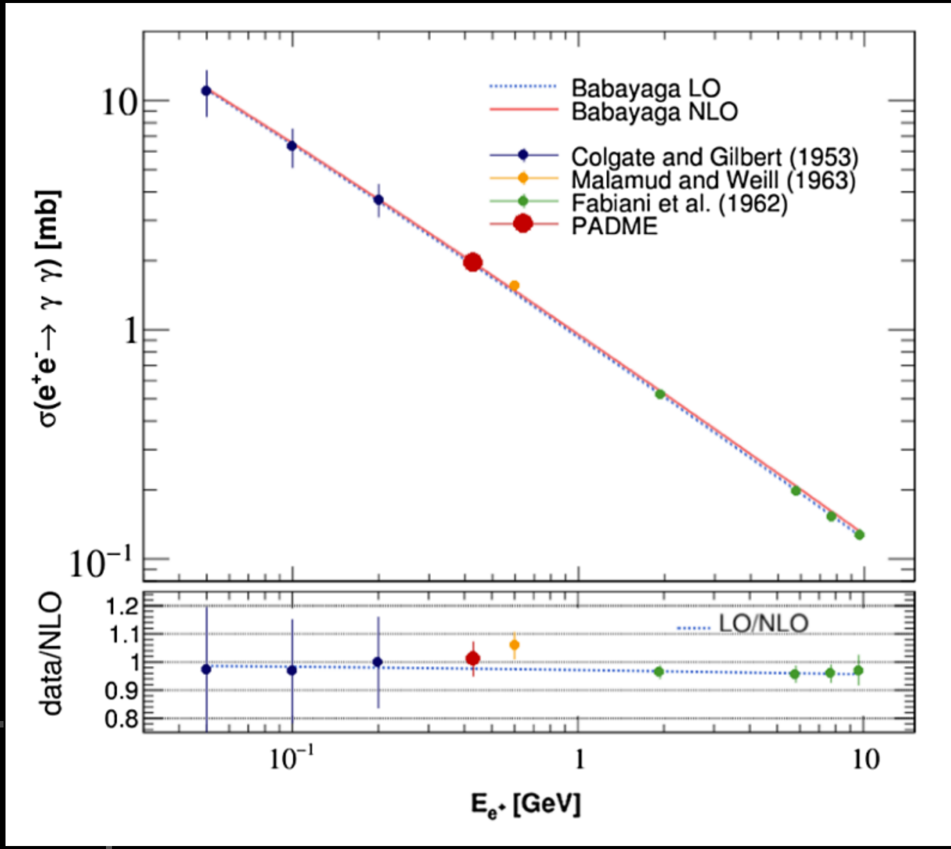
$e^+e^- \to \gamma\gamma$ Cross-Section

Physics case:

- known only with 20% accuracy below 0.6 GeV
- Most recent measurement is 60 y old
- Used data of Run2



Exploit energy vs polar angle correlation to select photons



$\sigma(e^+e^- \to \gamma\gamma) = (1.930 \pm 0.029_{stat} \pm 0.156_{syst})$ mb

most precise measurement in this energy regime