Dark photon – experimental searches

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ФОНД
НАУЧНИ
ИЗСЛЕДВАНИЯ
МИНИСТЕРСТВО НА ОБРАЗОВАНИЕТО И НАУКАТА

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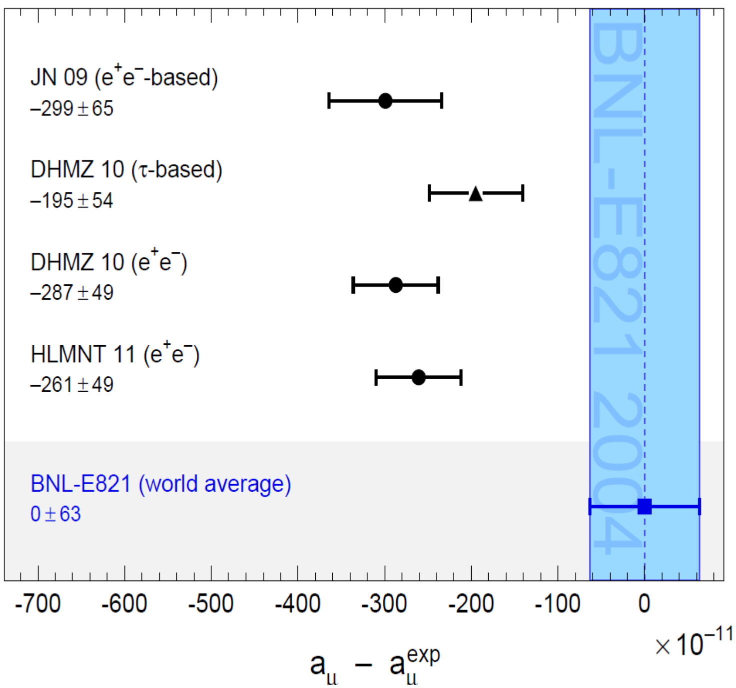
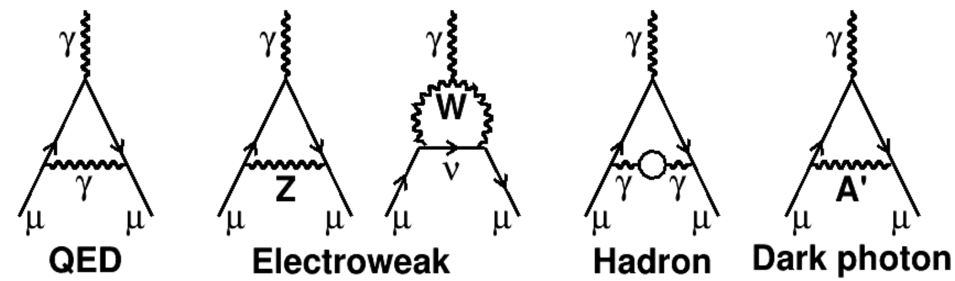
The Dark Photon @ LNF spring school

- Models
- Phenomenology
- Observables (or non-observables)
- When experiment meets theory
- Experiments … experiments … experiments

Why Dark Photon?





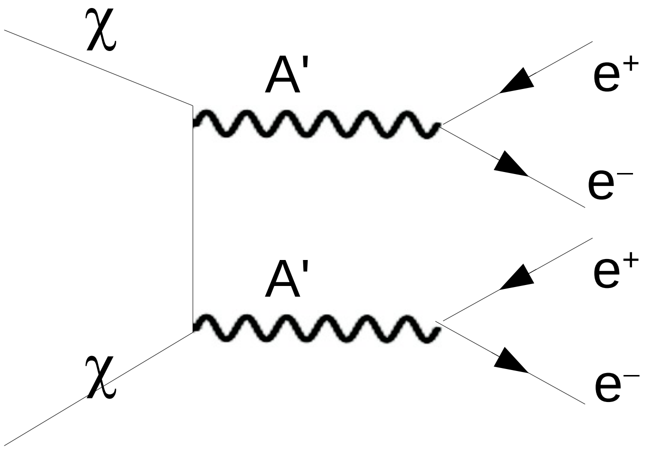
- About 3 σ discrepancy between theory and experiment (3.6 σ, if taking into account only $e^+e^- \rightarrow$ hadrons)

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

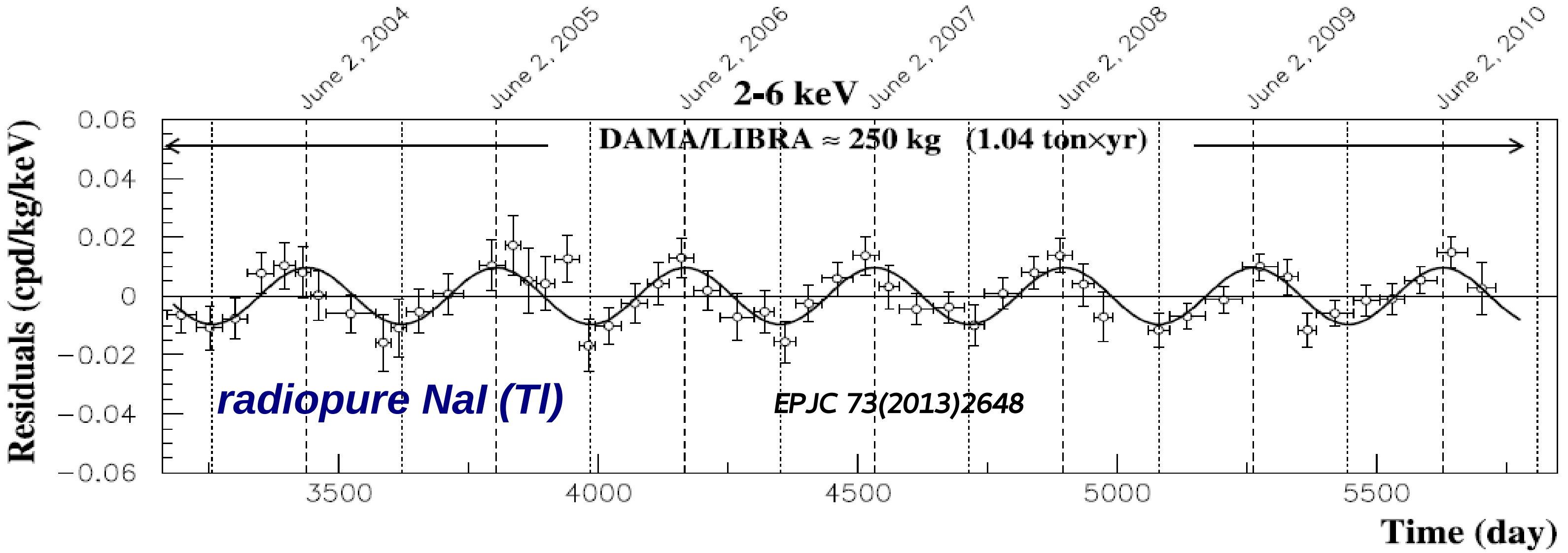
where $F(x) = \int_0^1 2z(1-z)^2/[(1-z)^2 + x^2 z]\,dz$. For values of $\varepsilon \sim 1\text{–}2 \cdot 10^{-3}$ and $m_V \sim 10\text{–}100\,\text{MeV}$, the dark photon, which was originally motivated by cosmology, can provide a viable solution to the muon $g-2$ discrepancy. Searches for the dark

Why Dark Photons

- Dark matter annihilation: positron, antiproton and 511 keV g excess

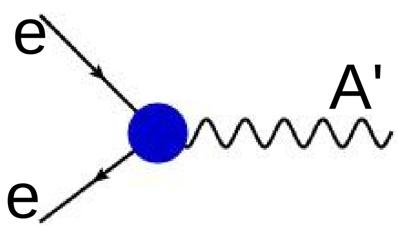


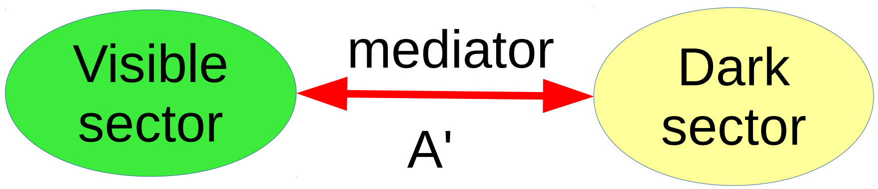
- Dark matter scattering



Why Dark Photon?

- The effective interaction that can be studied is





$$\mathcal{L} \sim g'q' \bar{\Psi} (\gamma_\mu + \alpha'_a \gamma_\mu \gamma^5) \Psi A'^\mu, \quad usually\ \alpha'_a = 0$$

  - $q_f \rightarrow 0$ for some flavours
- Textbook scenario, could address the (g_μ-2) discrepancy, abundance of antimatter in cosmic rays, signals for DM scattering
  - **General U'(1) and kinetic mixing with B (A', Z')**
    - Universal coupling proportional to the q_{em}
    - Just single additional parameter – ε

$$L_{mix} = -\frac{\epsilon}{2} F^{QED}_{\mu\nu} F^{\mu\nu}_{dark}$$

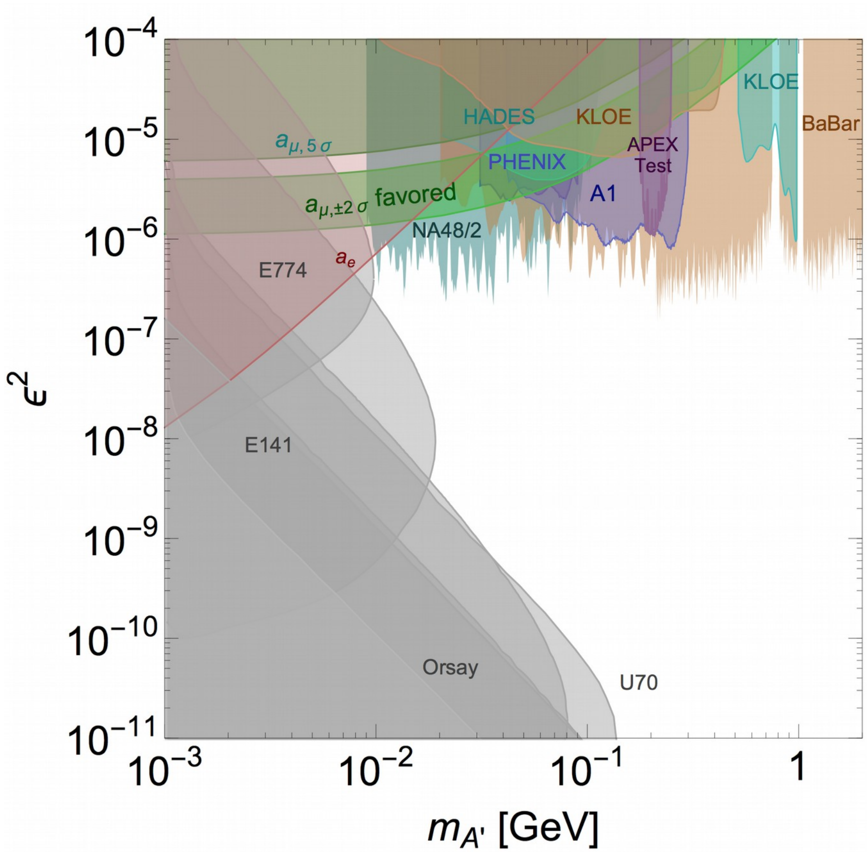
  - **Leptophilic/leptophobic dark photon**
  - **„Gauging“ SM accidental symmetries: (e.g. L_μ - L_τ , B - L)**

Variety of Dark Photons ...

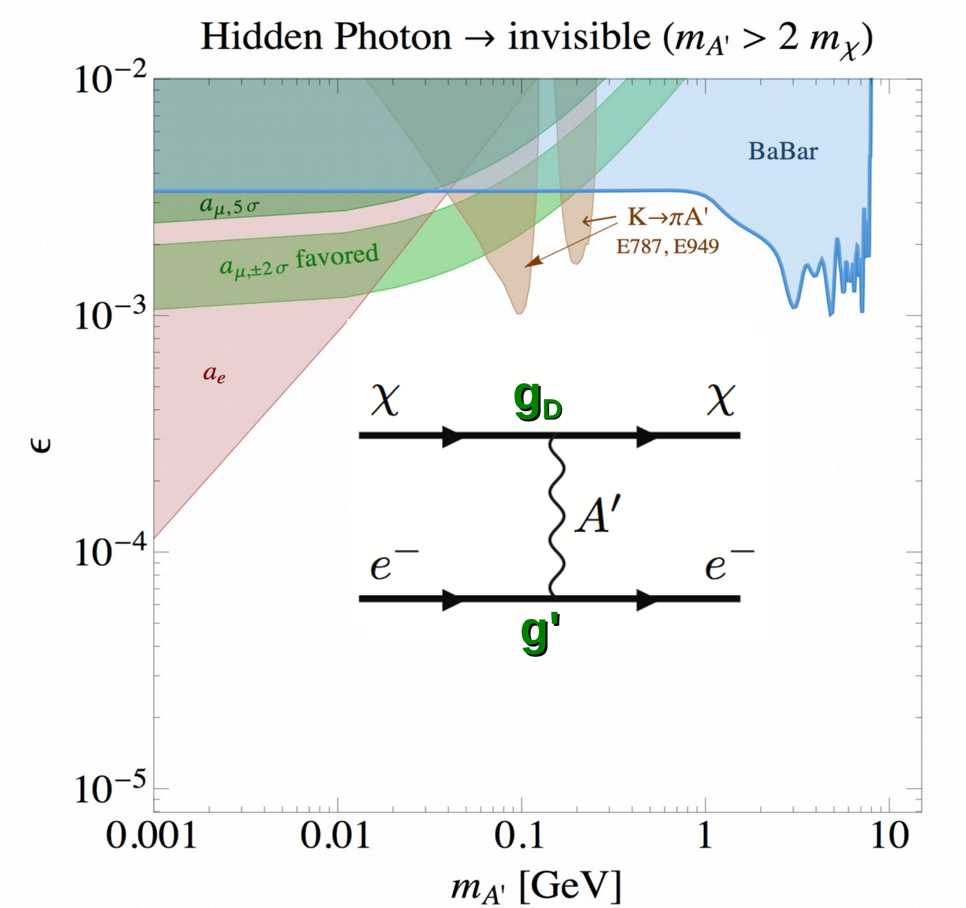
- Part of the phenomenology of the Dark Photon depends on what we don't know
  - Is it really a mediator between the visible and the hidden world?
  - Is it a manifestation of a Fifth Force?
  - How does it come to couple to SM particles?
    - Mixing with SM gauge boson?
    - Universal versus non-universal couplings?
- And moreover – what the hidden world looks like?
  - Light?
  - Heavy?
  - How many states?

Parameters with the Dark Photons

Dark photon is the only new light particle



- Two parameters
  - Mass M_A
  - Coupling constant



- At least four parameter space to be studied:

  $M_{A'}$, g', g_D, M_χ

Parameters with the Dark Photons

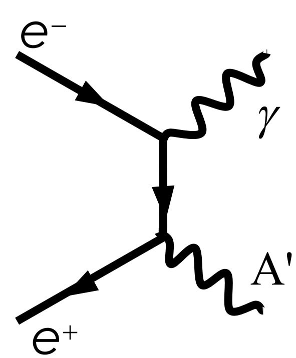
- The picture is quite simplified
  - Minimal extension of the Standard Model
- Shall we be minimal?
  - Multiparticle structure of the Standard Model
  - Why the DM should be composed of a single particle?

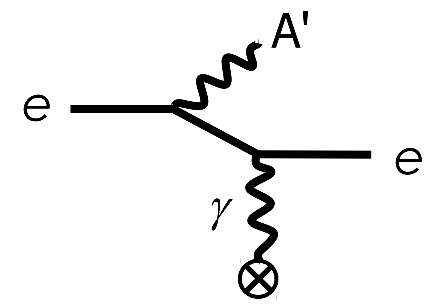
The picture should be simple, but not simpler than necessary

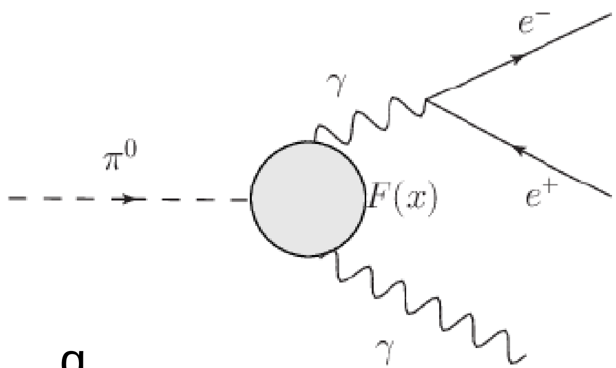
- Each coupling to the SM fermions might be flavour dependent
  - g' becomes g'_f, tuning to avoid anomalies
- Multiparticle structure of DM: $\chi \rightarrow \chi_i$, $M_\chi \rightarrow M_{\chi i}$
- DM coupling constants might be different: $g_D \rightarrow g_{Di}$

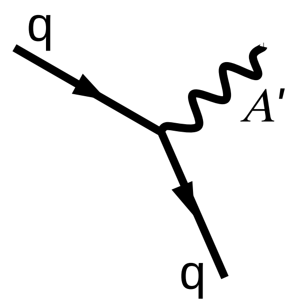
Dark Photon production

- In the general framework every SM particle can become a source of dark photons
- Type of the initial particles
  - A' from electrons
  - A' from hadrons
- Type of technique
  - Colliders
  - Beam dump
  - Thin targets
- Production mechanisms
  - Meson decays
  - Bremsstrahlung
  - Annihilation









Dark Photon decays

- Leptons

$$\Gamma_{A'\to l^+l^-} = \frac{1}{3}\alpha\epsilon^2 M_{A'}\sqrt{1-\frac{4m_l^2}{M_{A'}^2}}\left(1+\frac{2m_l^2}{M_{A'}^2}\right)$$

- Hadrons

$$\Gamma_{A'\to \mathrm{had}} = \frac{1}{3}\alpha\epsilon^2 M_{A'}\sqrt{1-\frac{4m_\mu^2}{M_{A'}^2}}\left(1+\frac{2m_\mu^2}{M_{A'}^2}\right)\times\frac{\Gamma(e^+e^-\to \mathrm{hadrons})}{\Gamma(e^+e^-\to\mu^+\mu^-)}(E=M_{A'})$$

- Dark matter fermions

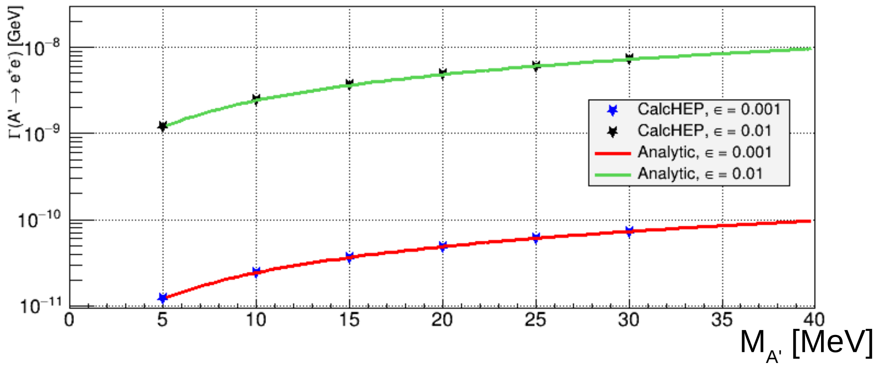
$$\Gamma_{A'\to \chi\chi} = \frac{1}{3}\alpha_D M_{A'}\sqrt{1-\frac{4m_\chi^2}{M_{A'}^2}}\left(1+\frac{2m_\chi^2}{M_{A'}^2}\right)$$

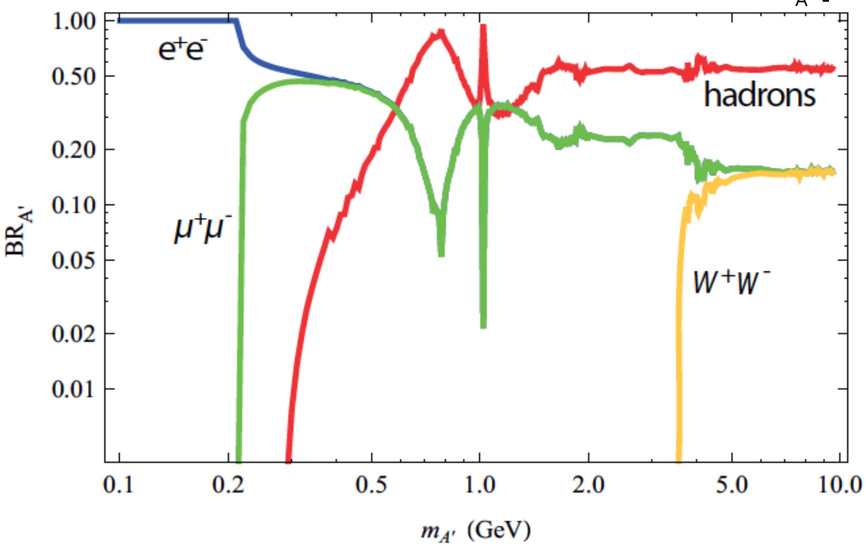
The Faith of the Dark Photon

- Decays to SM fermions
  - Depending on mass: e^+e^-, $\mu^+\mu^-$...

    For $M_{A'}$ = 40 MeV and $\varepsilon = 10^{-3}$,
    $\tau_{A'} \sim 10^{-15}$ s, ct ~ 2 μm

- Decay to hidden sector particles
  - If $M_{A'} > 2\ m_\chi$, then $A' \to \chi\chi$
    - Not suppressed by ε^2



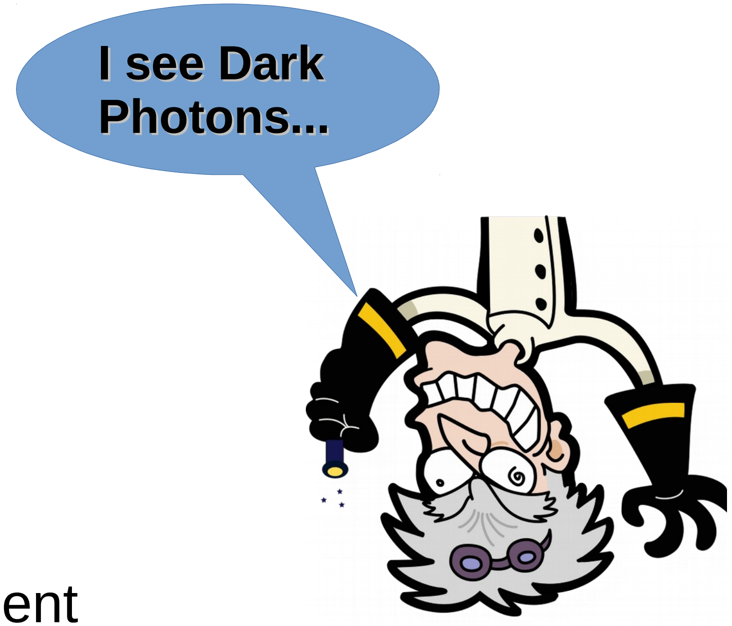


Batell, Pospelov and Ritz, PRD 80, 095024 (2009)

- Not decay at all (at least within the experim
  - For small ε^2 and $M_{A'} < 2\ m_\chi$
  - Decays into photons, if $M_{A'} < 2\ m_e$; $A' \to \gamma\gamma\gamma$

What do we see at experiments?

- The final detection is due to signals in the detectors that are generated only by the electromagnetic interactions!
  - Ionization and charge collection
  - Excitation and photons collection
  - We can detect charged particles (they ionize)



- Steps to consider when planning/doing an experiment
  - How the Dark Photon can be produced?
  - What would be the experimental signature?
  - What is the major background to it?
  - What is the model that the experimental setup is (is not) sensitive to

Experiment vs Theory

- Theory:
  transition rates
  and cross-sections

$$\Gamma = \int |M|^2 d\Phi$$

- Experiment:

  number of events

$$N_{events}$$

- In theory: $N_{events} \sim \int \Gamma dt = \int dt \int |M|^2 d\Phi$

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- Experiment (simplified)

$$N_{events} \sim \int dt \times \varepsilon_{trig} \times \left(\prod_i \varepsilon_i\right) \int |M|^2 d\Phi_{exp} + N_{bkg}$$

  - ε_{trig} – efficiency for recording the event
  - ε_i – efficiency for detecting the i-th final state particle
  - $d\Phi_{exp}$ – experimental phase space (or acceptance)
  - N_{bkg} – background contribution

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$$N_{events} \sim \int dt \times \varepsilon_{trig}(t) \times \left(\prod_i \varepsilon_i(t)\right) \int |M|^2 d\Phi_{exp}(t) + N_{bkg}(t)$$

  - ε_{trig} – efficiency for recording the event
  - ε_i – efficiency for detecting the i-th final state particle
  - $d\Phi_{exp}$ – experimental phase space (or acceptance)
  - N_{bkg} – background contribution

What do we measure

- Number of events, satisfying given requirements

$$N_{signal} = N_{measured} - N_{background}$$

- Sensitivity estimation: statistical uncertainty of the **simulated** (**determined from data**) background taken as a reference to determine the 90% (or 68 %) confidence level exclusion limits

- In case of modelling the events:

$$\sigma_{tot}(N) \sim (\sqrt{N})_{stat} \oplus (\delta_{model} * N)$$

  - Precision SM description of the processes

<u>Zero background (signal) experiments</u>

- Sensitivity scales as 1/N
- More difficult to convince why the detected number of events is 0

<u>Non background free experiments</u>

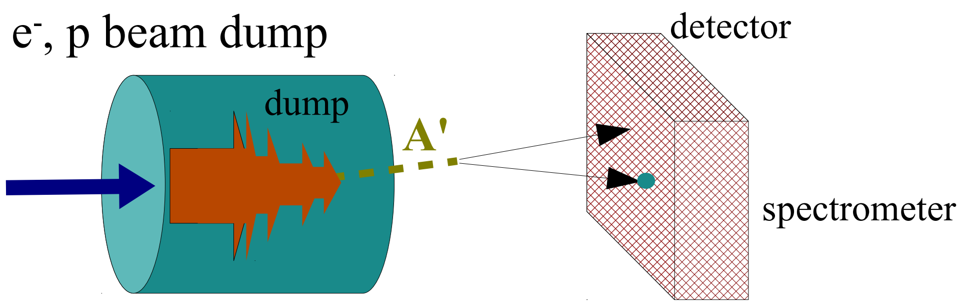
- Sensitivity scales as 1/ $(\sqrt{N})$
- Probe the technique and understanding through background modelling

Unconstrained initial process

- The initial kinematics quantities are not known
  - Cannot fix the initial state that creates the Dark Photon
    - $e^- + N \rightarrow e^- + N + A'$ (A'-strahlung)
    - Production in EM/hadronic showers
  - Thin target or beam dump experiments
- Reconstruct or look for specific signatures of the final state
  - Dark Photon decaying into SM particles
    - Thin target and beam dump
  - Dark Photon decaying into DM particles
    - Seek for DM particles scattering inside the detectors

Beam dump

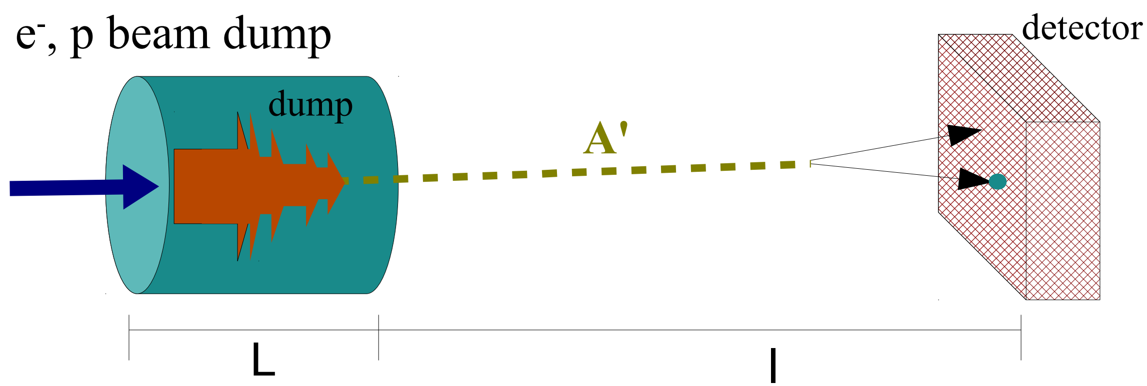
- Production: A'-strahlung, shower, absorption of secondaries



- Number of interactions depend on the total number of beam particles
  - Highest possible beam intensity
- The number of the events one should expect depends on
  - Total particles on target
  - A' coupling
  - A' mass
  - Geometry of the setup

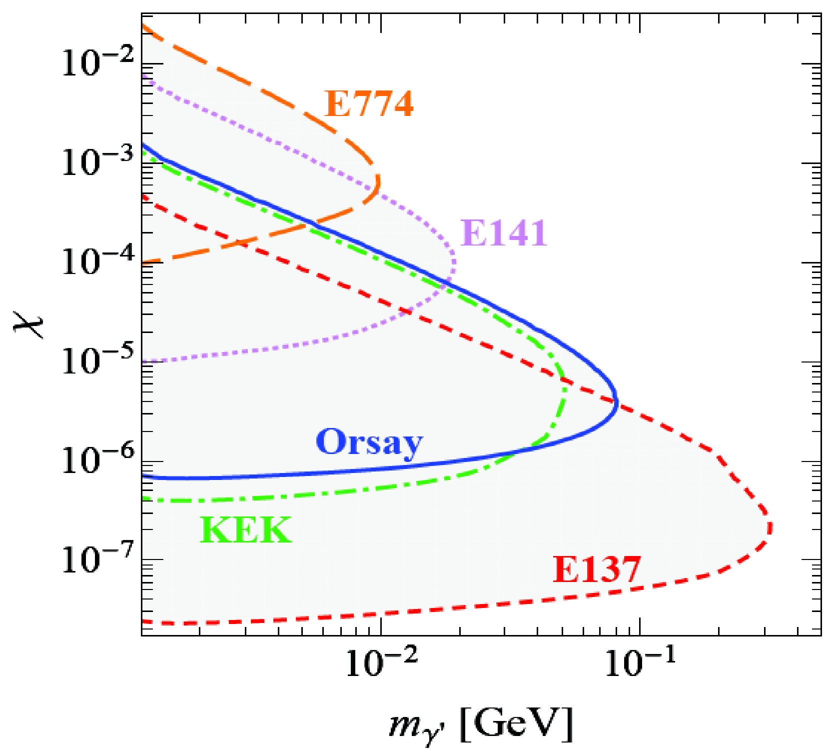
$$N \simeq \frac{N_e N_0 X_0}{A} \int dE_{\gamma'} \int dE_e \int dt \left[I_e \frac{1}{E_e} \left.\frac{d\sigma}{dx_e}\right|_{x_e = \frac{E_{\gamma'}}{E_e}} e^{-\frac{L_{\rm sh}}{l_{\gamma'}}} \left(1 - e^{-\frac{L_{\rm dec}}{l_{\gamma'}}}\right) \right] \mathrm{BR}_{l\bar{l}}$$

Beam dump



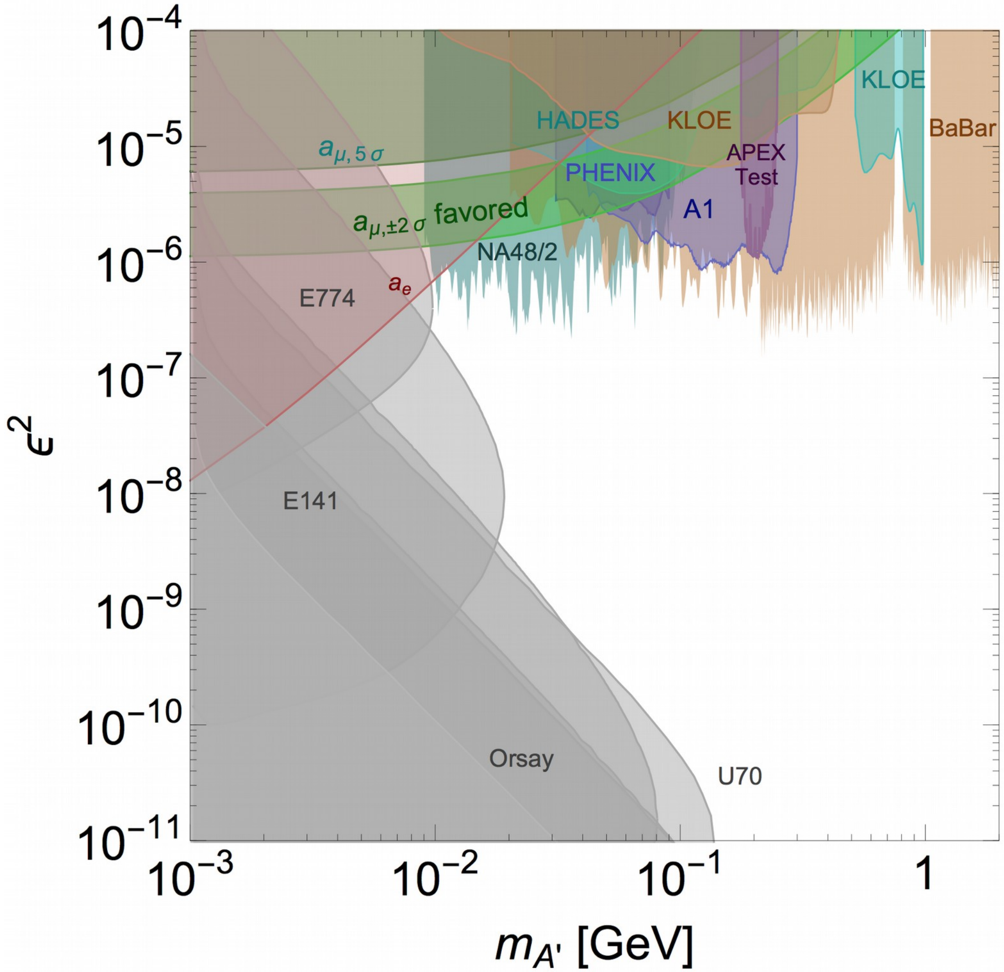
A' - strahlung

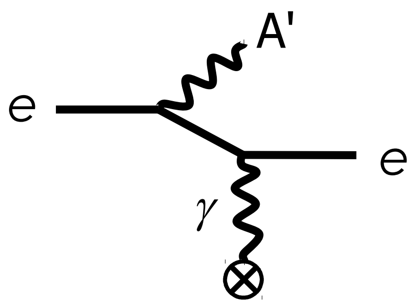
from S. Andreas

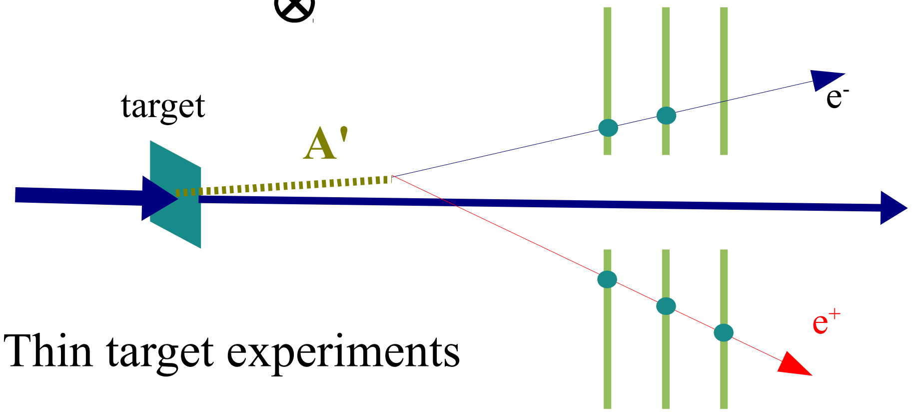


- Beam energy
  - Boosts the produced DP
  - Gives access to higher masses
- Initial flux
  - Dependence is weaker than on E_{beam}
- Inactive region length
  - Crucial for the access to high ε
  - But leakage from the target …

Thin target







Thin target experiments

- Fixed thin target:
  - Lower production rate
  - Bacground contribution

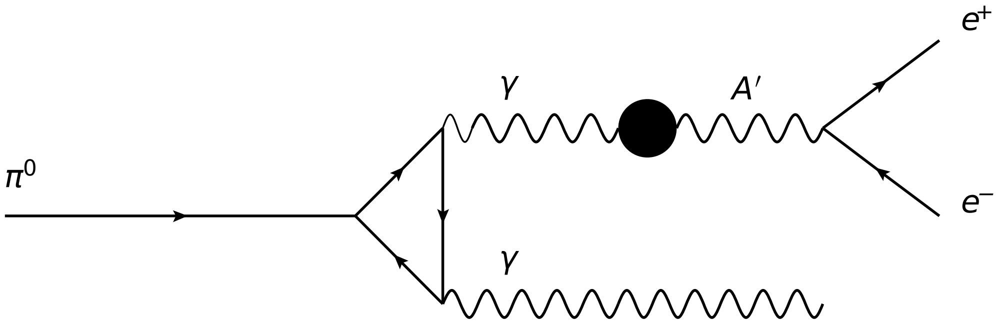
- Naive „everything is signal“ does not work
  - Kinematical reconstruction of the final state
  - Peaks in the e^+e^- invariant mass spectrum

Constrained initial process

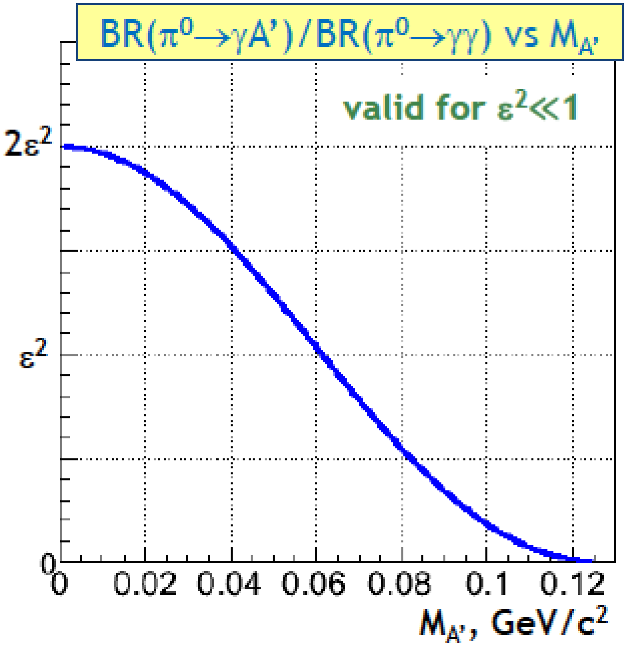
- Initial state is carefully prepared
  - A' as a product of SM particles decays: π^0, ρ, η….
  - e^+e^- colliders
  - Annihilation
- Possible A' final states
  - A' → SM particles, all states reconstruction
    - Provides significant background suppression
  - A' → DM particles
    - Determination of A' properties through missing momentum/energy/mass

Dark Photon in meson decays

Batell, Pospelov and Ritz, PRD 80, 095024 (2009)



$$\mathcal{B}(\pi^0 \to \gamma A') = 2\varepsilon^2 \left(1 - \frac{m_{A'}^2}{m_{\pi^0}^2}\right)^3 \mathcal{B}(\pi^0 \to \gamma\gamma)$$

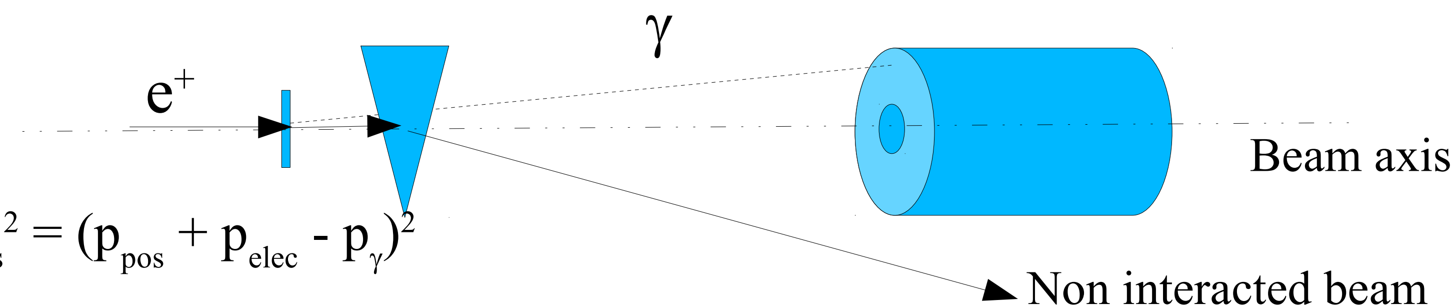


- Identify a solid source of π^0
  - @ colliders: $e^+e^- \to$ Υ, ρ, η, ϕ
  - In target production
    - Background from beam-target interaction
  - Use a cascade process, where π^0 is one of the products
    - $K^\pm \to \pi^\pm\pi^0$, $K^\pm \to \mu^\pm\pi^0\nu$ (Kμ3)

$\pi^0 \to ee\gamma$ (π^0_D)

- $Br(K^\pm \to \pi^\pm\pi^0 \to \pi^\pm e^+e^-\gamma) = 2.4 \times 10^{-3}$

A' in annihilation



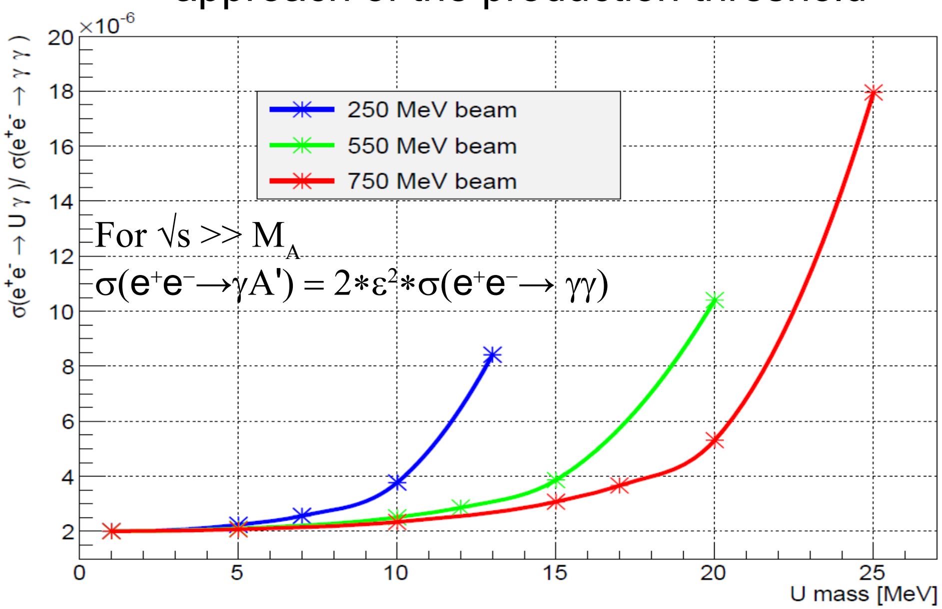
$M_{miss}^2 = (p_{pos} + p_{elec} - p_\gamma)^2$

- Positron beam on a thin target
- Positron momentum is determined by the accelerator characteristics
- Missing mass resolution: annihilation point, E_γ, φ_γ

$$\frac{\sigma(e^+e^- \to U\gamma)}{\sigma(e^+e^- \to \gamma\gamma)} = \frac{N(U\gamma)}{N(\gamma\gamma)} * \frac{Acc(\gamma\gamma)}{Acc(U\gamma)} = \epsilon^2 * \delta,$$

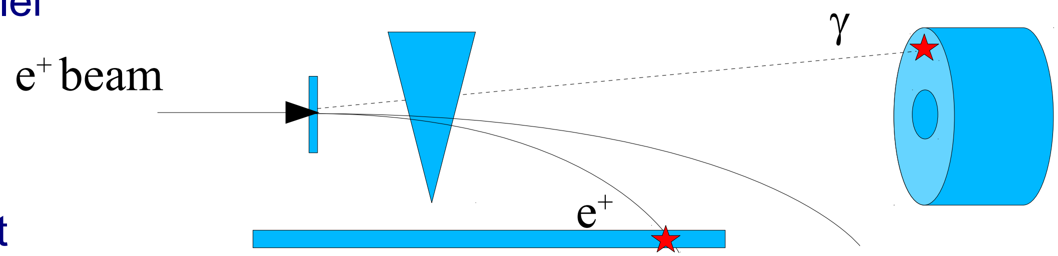
- Clear 2 body correlation
- Background minimization
  - Best possible resolution on energy/angle measurement
  - **Dominant process in e+/e- interactions with matter is bremsstrahlung**
  - Photons vetoing
  - Minimize the interaction remnants + vetoing

Cross section enhancement with the approach of the production threshold

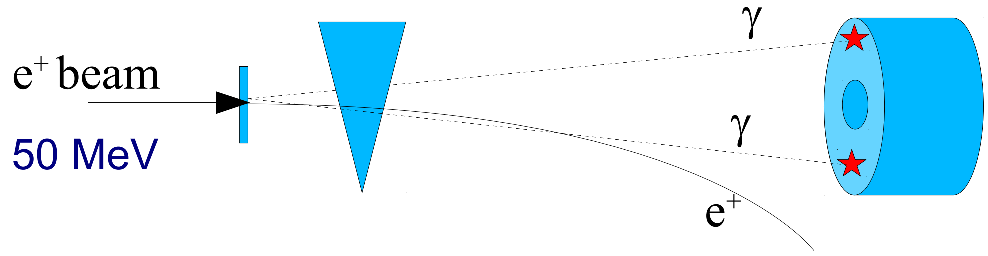


Backgrounds

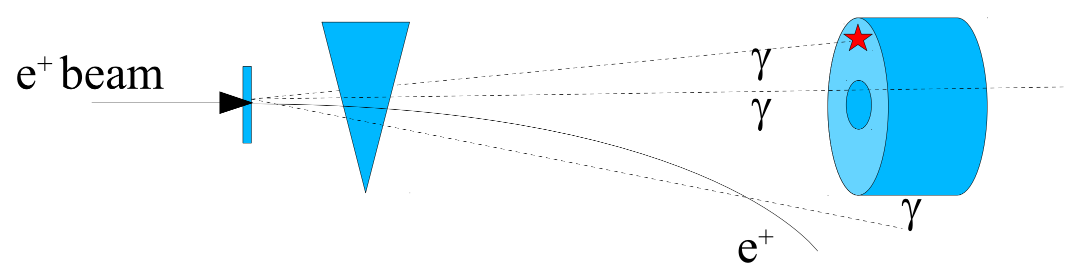
- Bremsstrahlung in the field of the target nuclei
  - Photons mostly @ low energy, background dominates the high missing masses
  - An additional lower energy positron that could be detected due to stronger deflection



- 2 photon annihilation
  - Peaks at $M_{miss} = 0$
  - Quasi symmetric in gamma angles for $E\gamma$ > 50 MeV

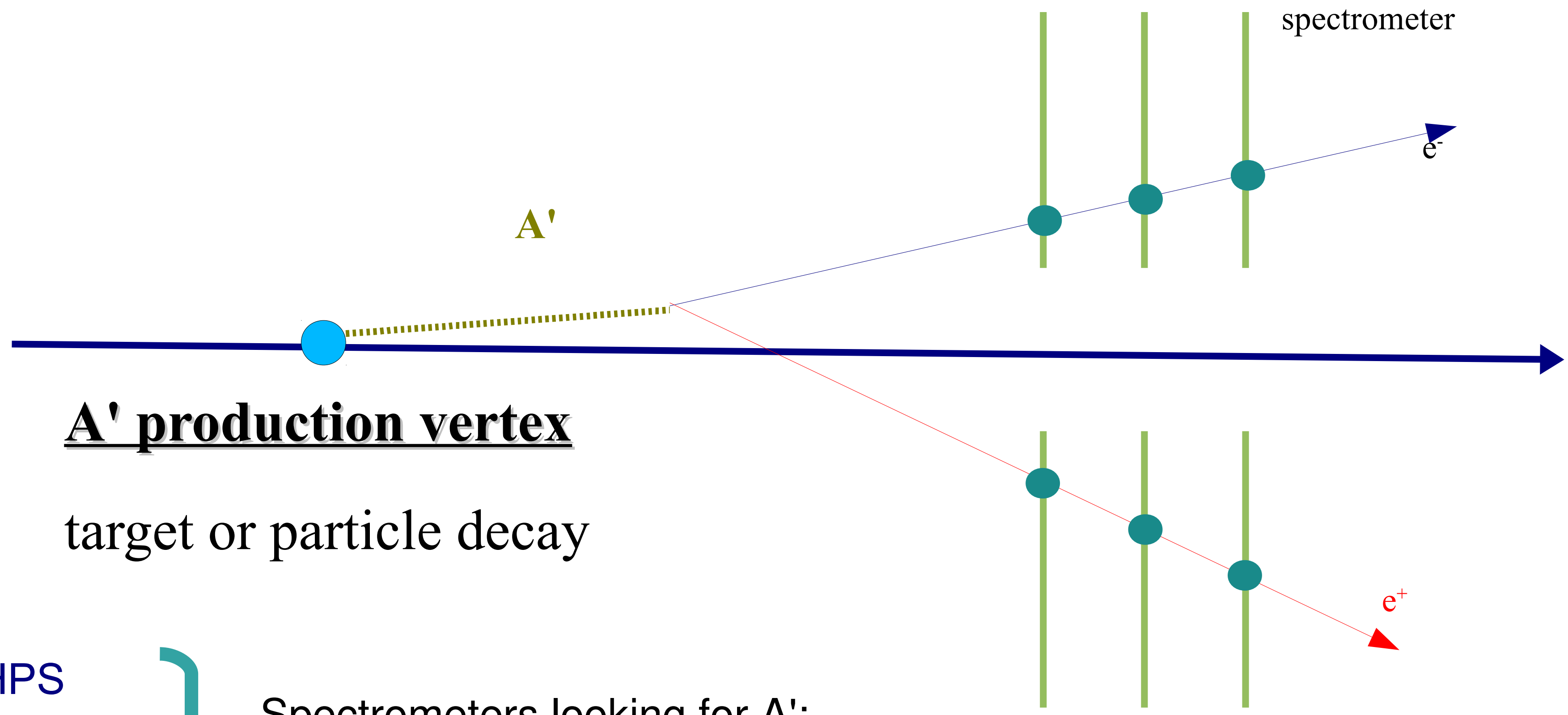


- 3 photon annihilation
  - Symmetry is lost – decrease in the vetoing capabilities
  - Does not peak
- Radiative bhabha scattering
  - Topology close to bremsstrahlung



Experiments

Thin target experiments



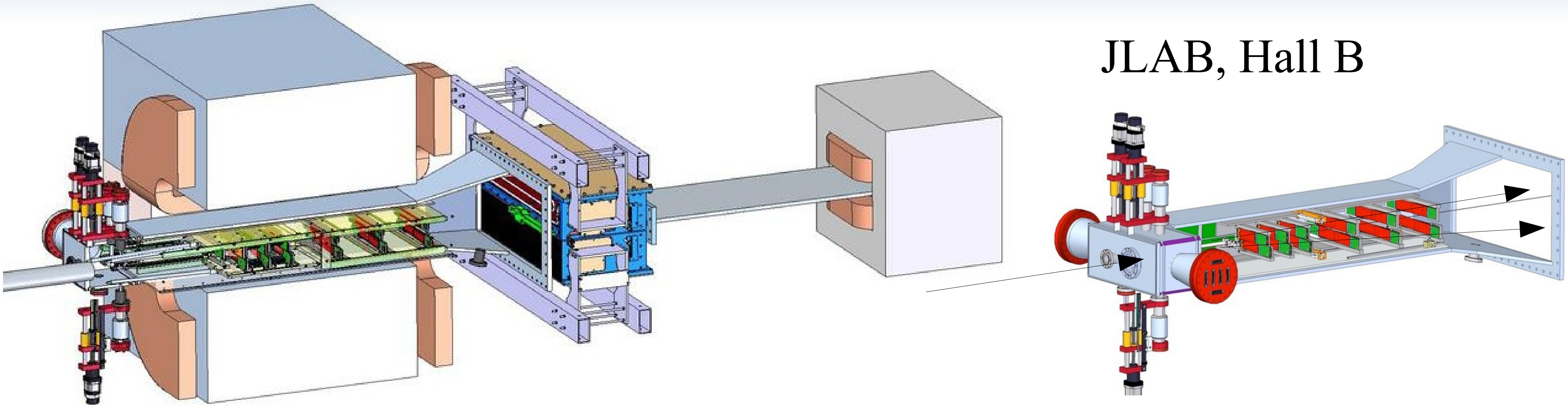
A' production vertex

target or particle decay

- HPS
- MESA

Spectrometers looking for A':
- produced in a thin target
- decaying to leptons

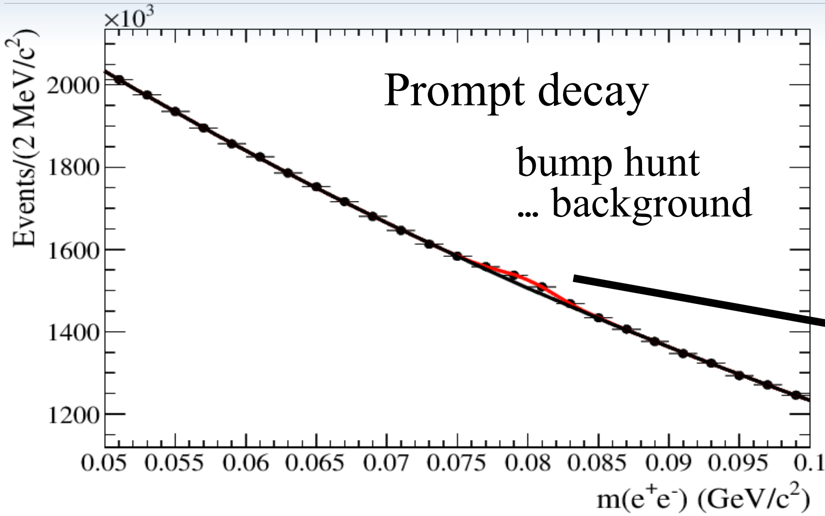
HPS experiment



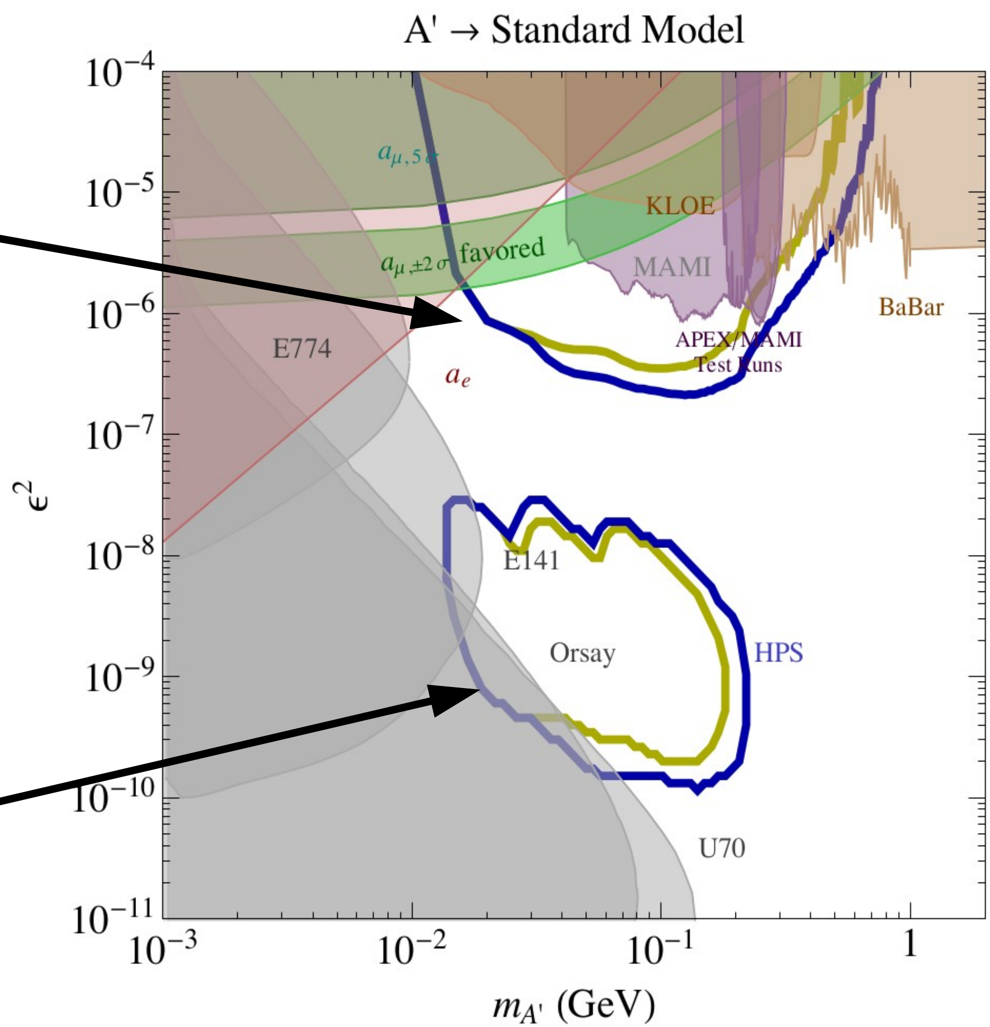
- Electron beam (2.2 and 6.6 GeV, up to 500 nA) on a thin tungsten target (0.25% X_0)
- A'-strahlung production
- Decay channel – $A' \rightarrow e^+e^-$
- Silicon vertex tracker (1 m long) inside dipole magnet, 6 layers (dual sensor)
  - Particle momenta, Vertices
  - 6.4 μm hit resolution, $\sigma(t)$ = 2.5 ns
- Lead tungstate electromagnetic calorimeter

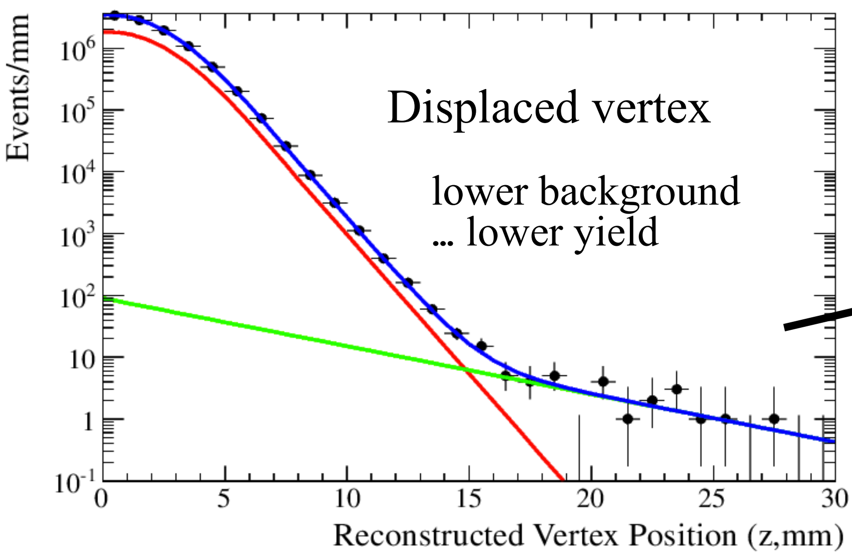
$\left\{ \begin{array}{l} \textbf{Fast energy measurement} \\ \textbf{Trigger definition} \end{array} \right.$

HPS sensitivity



Timothy Nelson, Dark Sectors Workshop, 28-30 Apr., SLAC

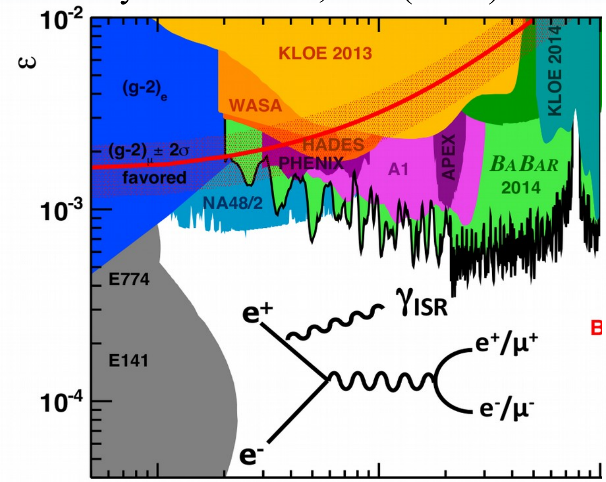




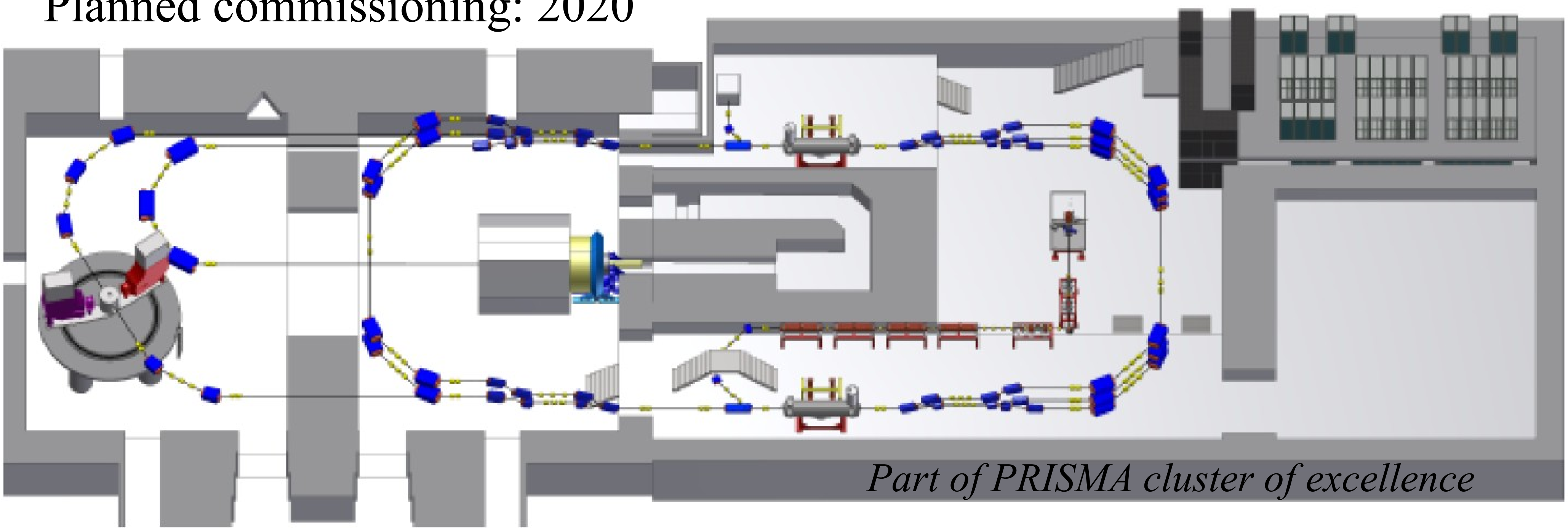
Dark photon @ Mainz

- Tradition in dark photon physics - A1 @ MAMI
- New accelerator: MESA (Mainz Energy-recovering Superconducting Accelerator)
  - Energy up to 155 MeV
  - Current > 1 mA

Phys. Rev. Lett., 112 (2014) 221802



Planned commissioning: 2020

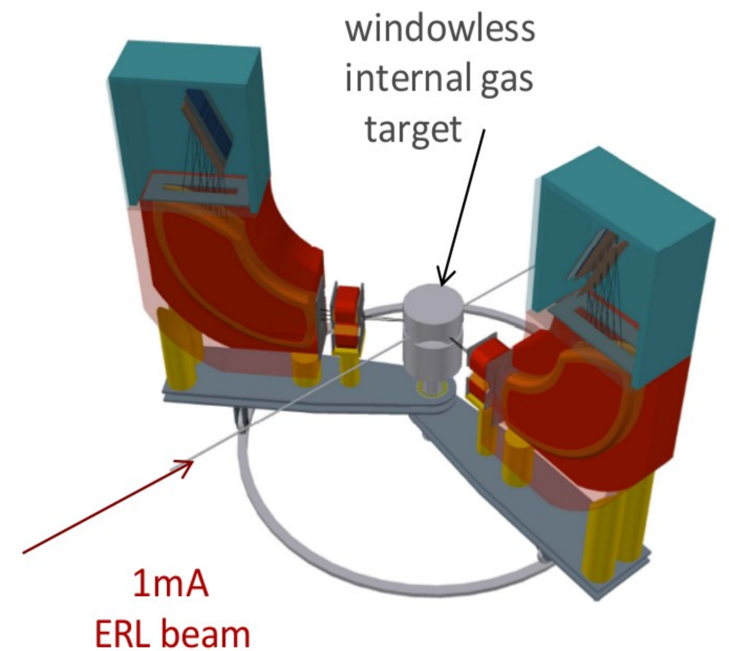


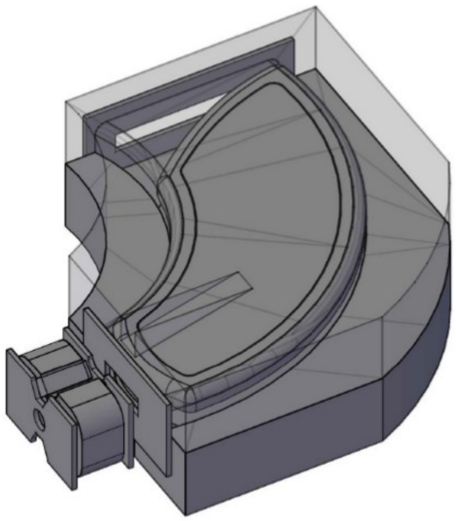
Part of PRISMA cluster of excellence

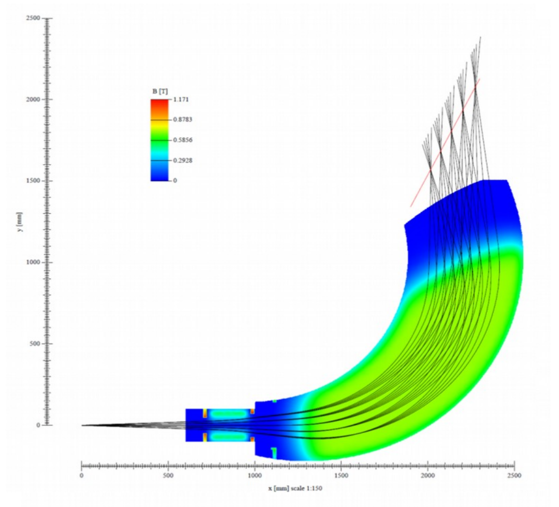
MAGIX @ MESA

The MAinz Gas Internal EXperiment

Achim Denig, Dark Sectors Workshop, 28-30 Apr., SLAC



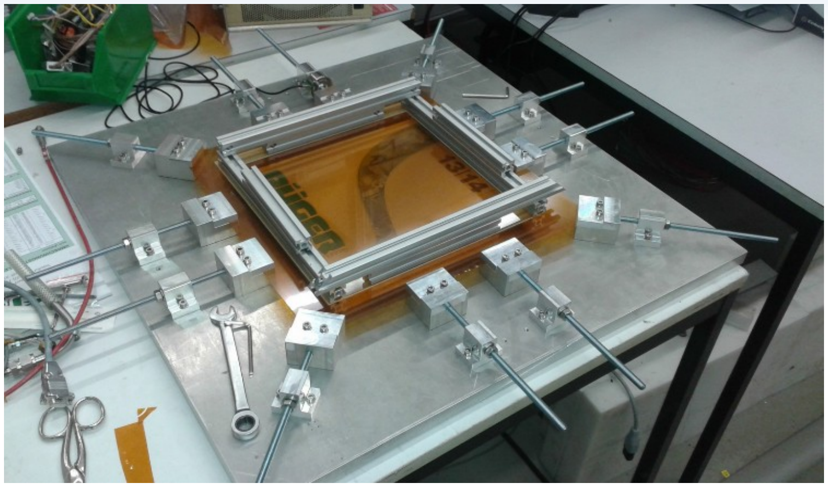


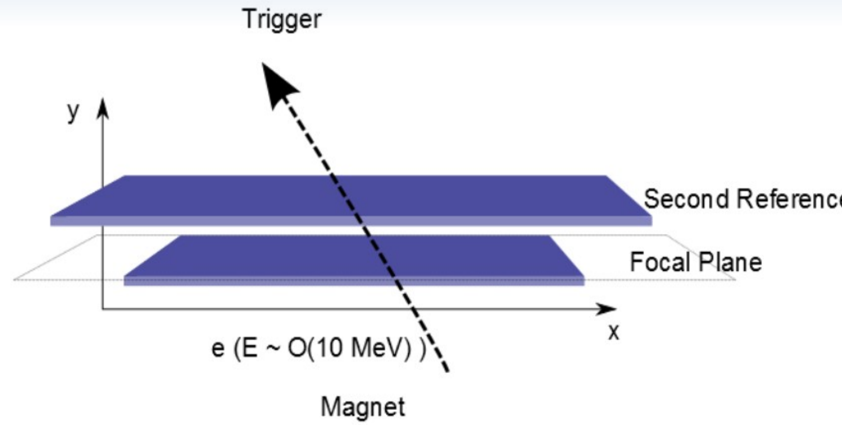


- Double arm high resolution spectrometers
  - Aim for $\Delta p/p \sim 10^{-4}$
  - Acceptance +- 50 mrad

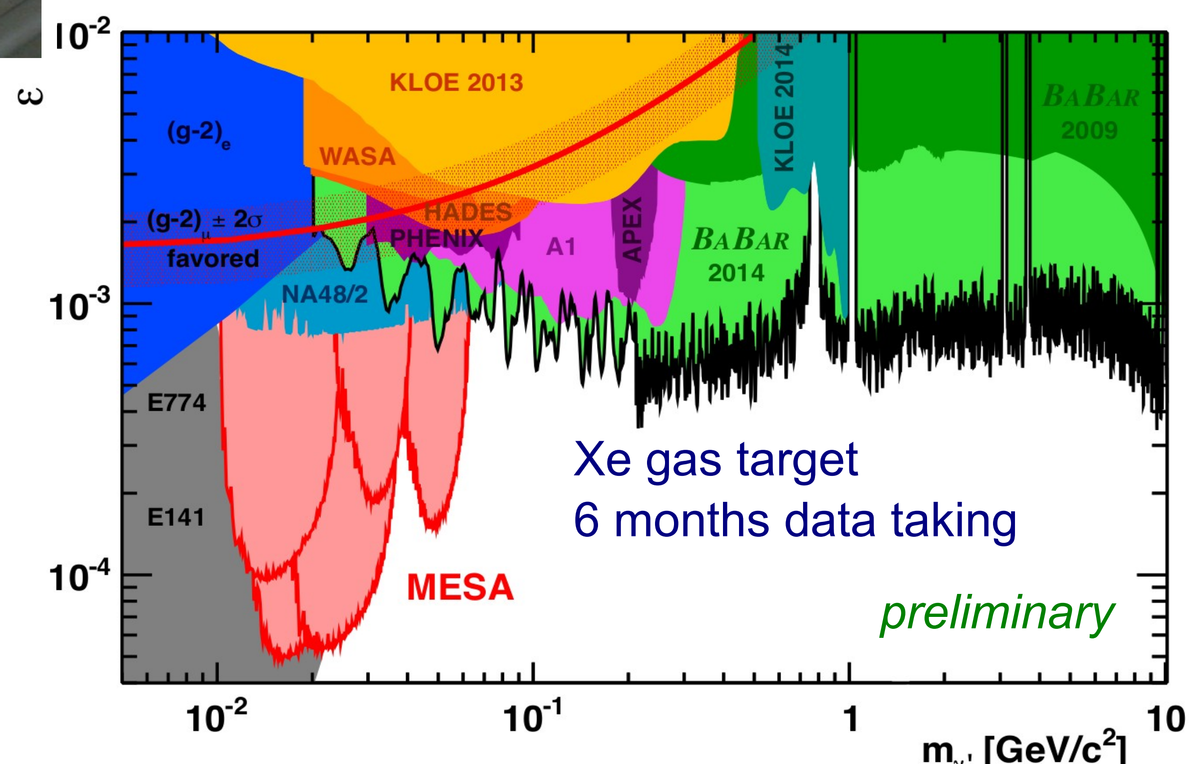
- Gas jet target
  - Supersonic gas /cluster jet
  - High gas density ($10^{19}/cm^2$)
  - O(mm) target length
  - Windowless

MAGIX @ MESA





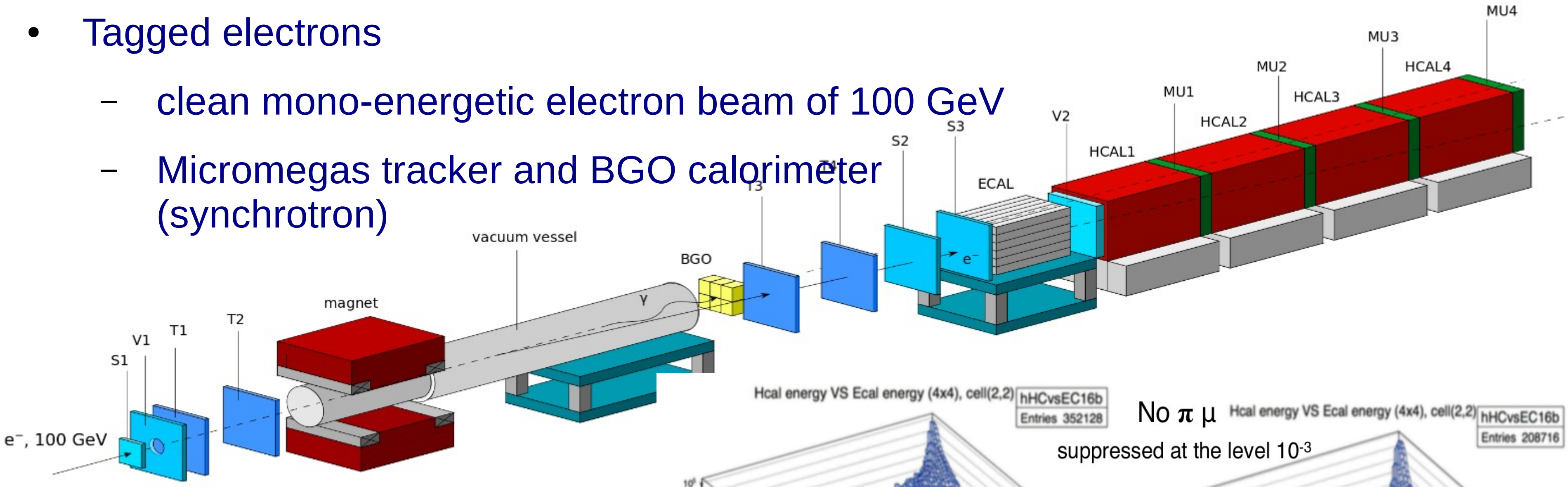
- Two position detectors
  - Focal plane
  - Direction measurement
- GEM detectors considered
  - 0.7% X0
  - High rate capability
  - 2D strip readout
    - Should aim for 50μm coordinate resolution

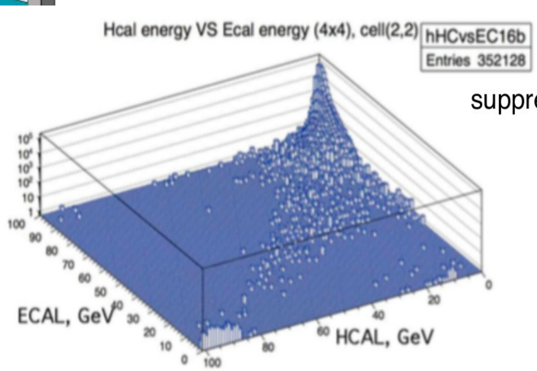


Missing energy technique

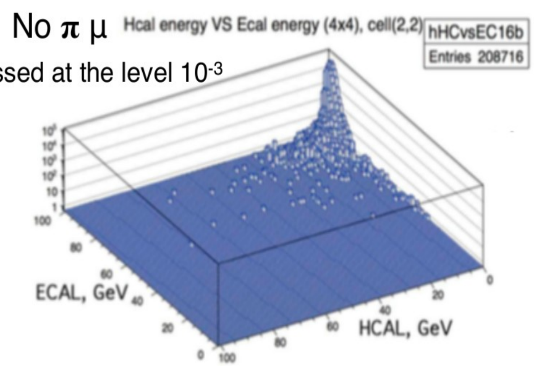
- NA64 experiment @ CERN SPS
- Tagged electrons
  - clean mono-energetic electron beam of 100 GeV
  - Micromegas tracker and BGO calorimeter (synchrotron)

Phys.Rev. D97 (2018) no.7, 072002



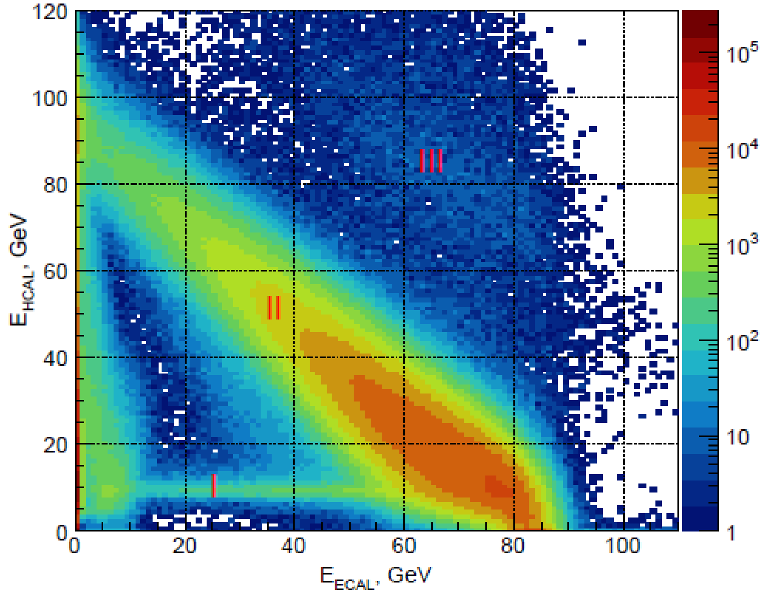


No π μ suppressed at the level 10^{-3}

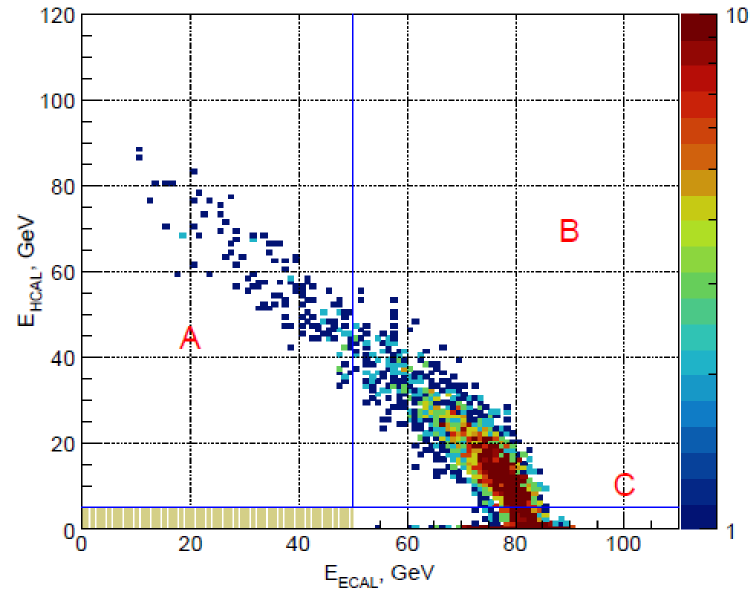


- Signature:
  - 100 GeV e^- track.
  - < 50 GeV EM shower in ECAL
  - no energy in Veto + HCAL

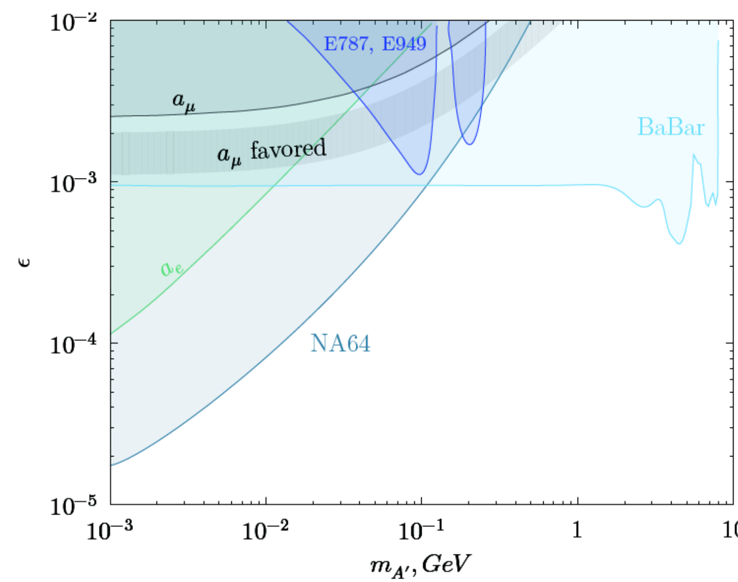
NA64 results



selection



- Perform the analysis in $E_{ECAL} – E_{HCAL}$ plane
- Sensitive to DP production through radiation in the shower development
- Using reweighting factors to account for differences between GEANT4 MC and DATA
- Zero events in the signal region
  - Expected 0.5 SM background

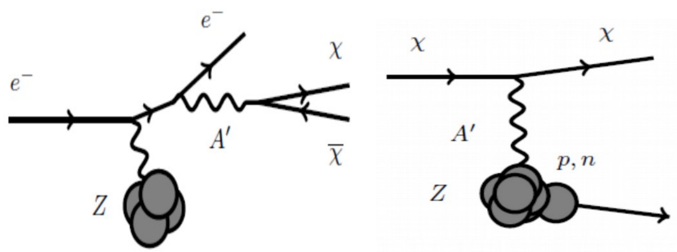


DM scattering: BDX

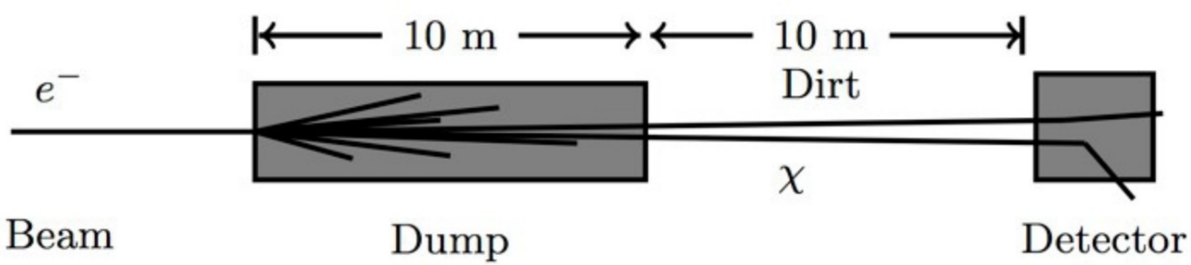
arXiv:1607.01390 [hep-ex]

Beam Dump eXperiment

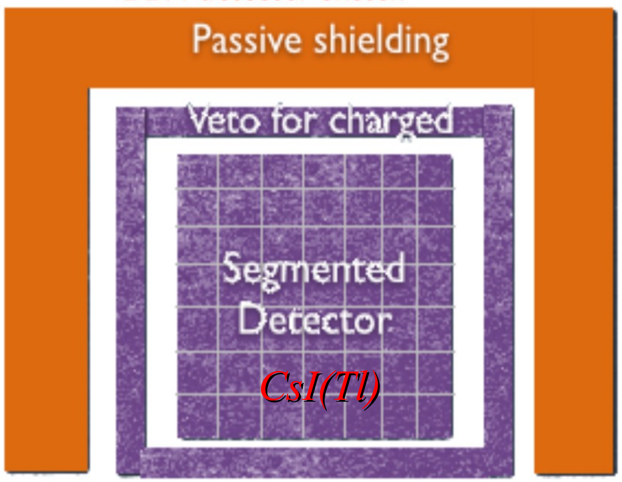
- χ production
  - High-energy, high-intensity e⁻ beam impinging on a dump
  - χ particles pair-produced radiatively, trough A'
- χ detection
  - Detector placed behind the dump, O(10m)
  - χ scattering trough A'
  - Different signals depending on the interaction (e⁻elastic, p quasi-elastic,.)

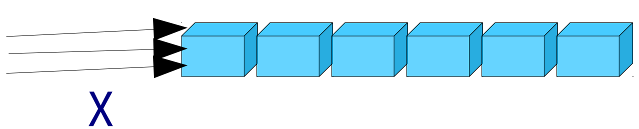


Number of events: $\frac{\alpha_D \epsilon^4}{M_A^4}$



BDX detector sketch





- LoI submitted to JLab PAC - positive feedback
- Preparation of a full Proposal ongoing
- Interesting opportunities for a phase-1 run @ other facilities

DM scattering: BDX

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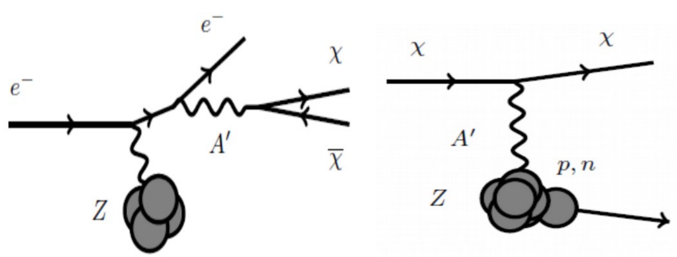
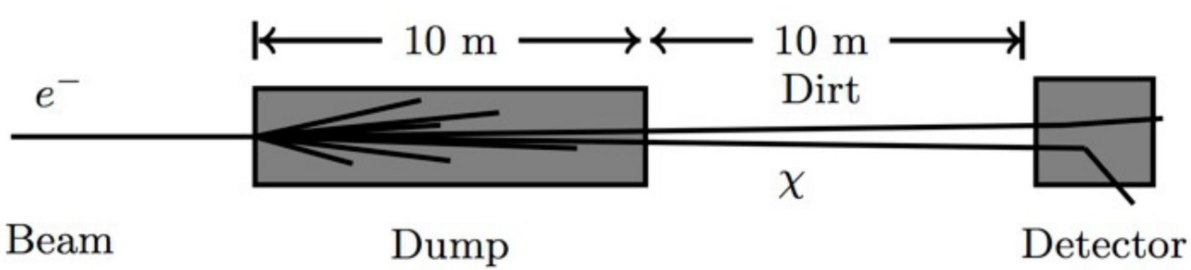
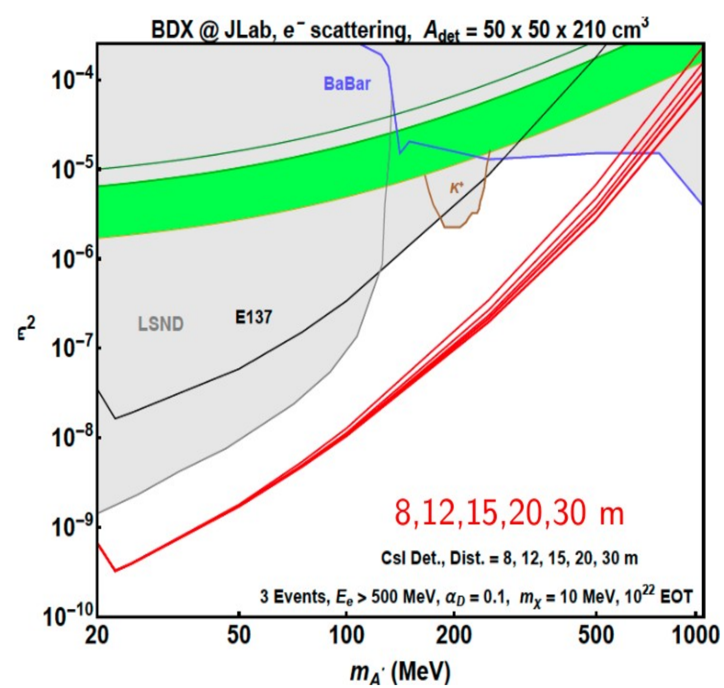


Number of events: $\frac{\alpha_D \epsilon^4}{M_A^4}$





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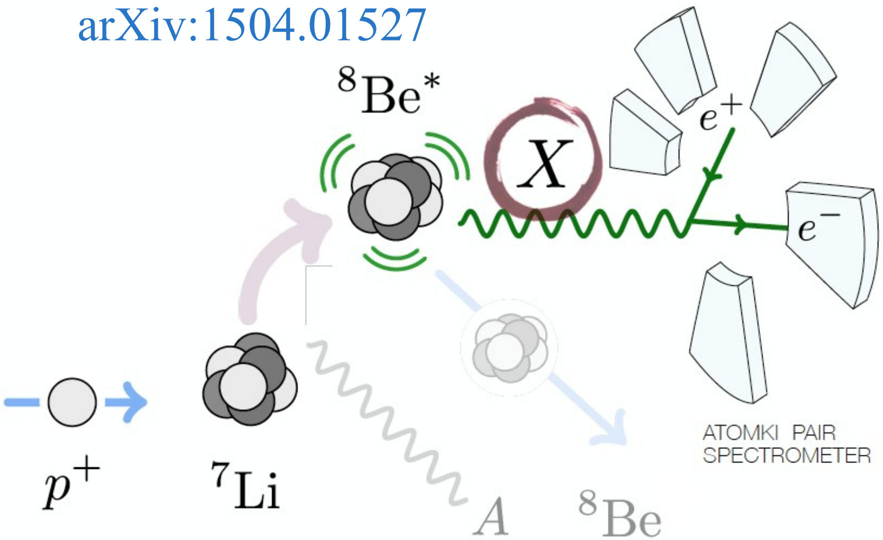
Constrained initial state

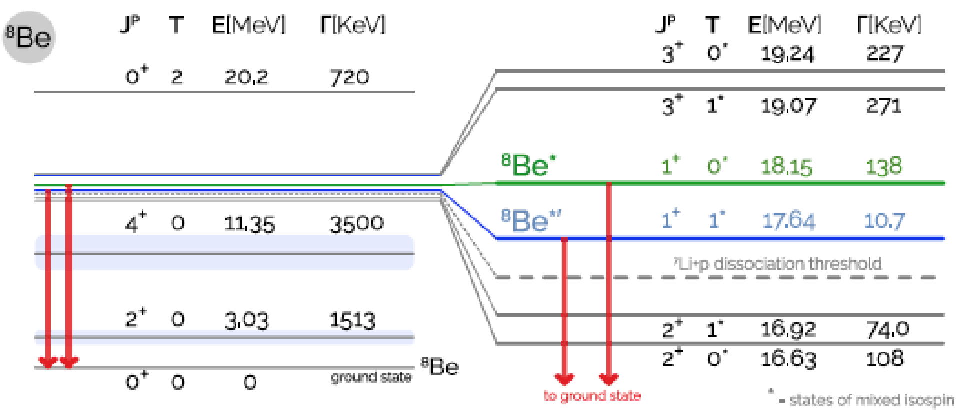
- Recall:
  - Initial state with fully determined kinematics
  - A single missing particle in the final state can be reliably identified
  - I case the full final state can be reconstructed → reduced background and consistency checks

Anomalies in nuclear transitions

arXiv:1504.01527



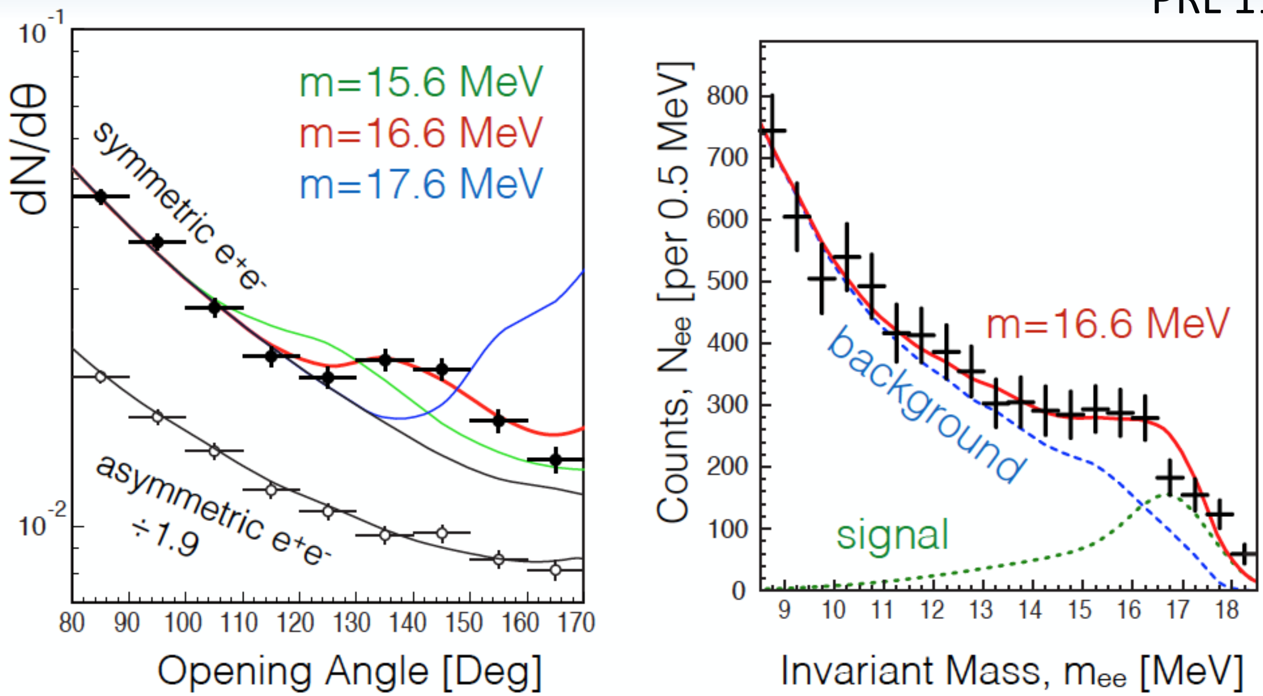
PRL 116, 042501 (2016)



- Carefully prepared initial state
  - p + ^{7}Li -> 8Be*, populating high energy excited state

Anomalies in nuclear transitions

PRL 116, 042501 (2016)

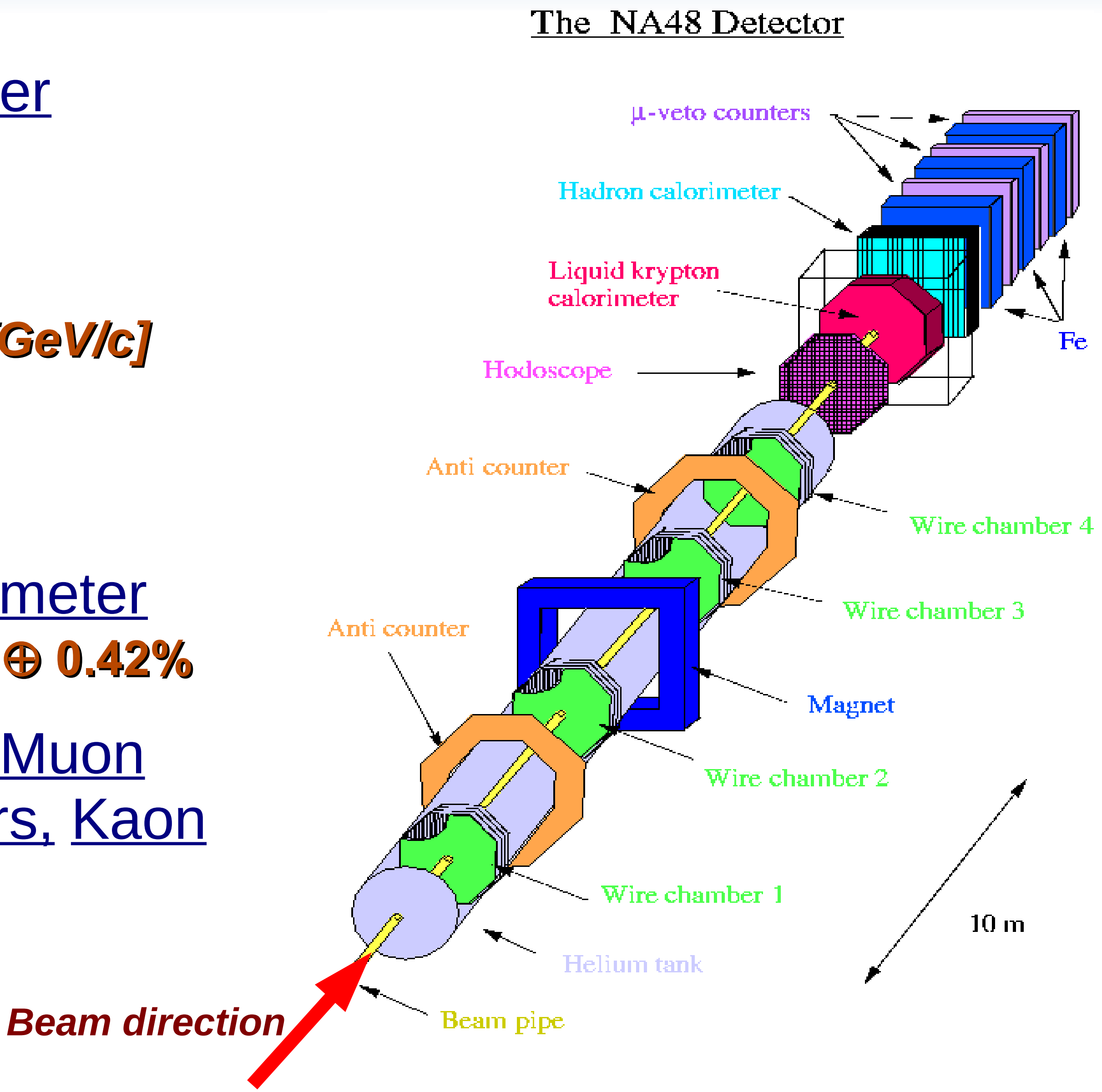


- Anomalous angular and invariant mass distributions in the IPC process
- Several indications in the last few decades
- New experiment to look for this effect exploiting He
- E-ΔE plastic scintillator detector, in the plane transversal to the beam
- The anomaly observed at ~17 MeV – difficult to be interpreted within nuclear physics so far...

NA48/2: $K^{\pm} \rightarrow \pi^{\pm}\pi^{0} \rightarrow \pi^{\pm} A'\gamma \rightarrow \pi^{\pm} e^{+}e^{-}\gamma$

- Magnetic spectrometer (DCH)
  4 drift chambers
  $p_{\perp}^{kick}$ = 120 MeV/c
  $\Delta p/p = 1\% \oplus 0.044\% * p$ [GeV/c]
- Hodoscope
  $\sigma(t)$ = 150 ps
- Liquid Krypton Calorimeter
  $\Delta E/E \cong 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$
- Hadron Calorimeter, Muon counters, Anticounters, Kaon Beam Spectrometer

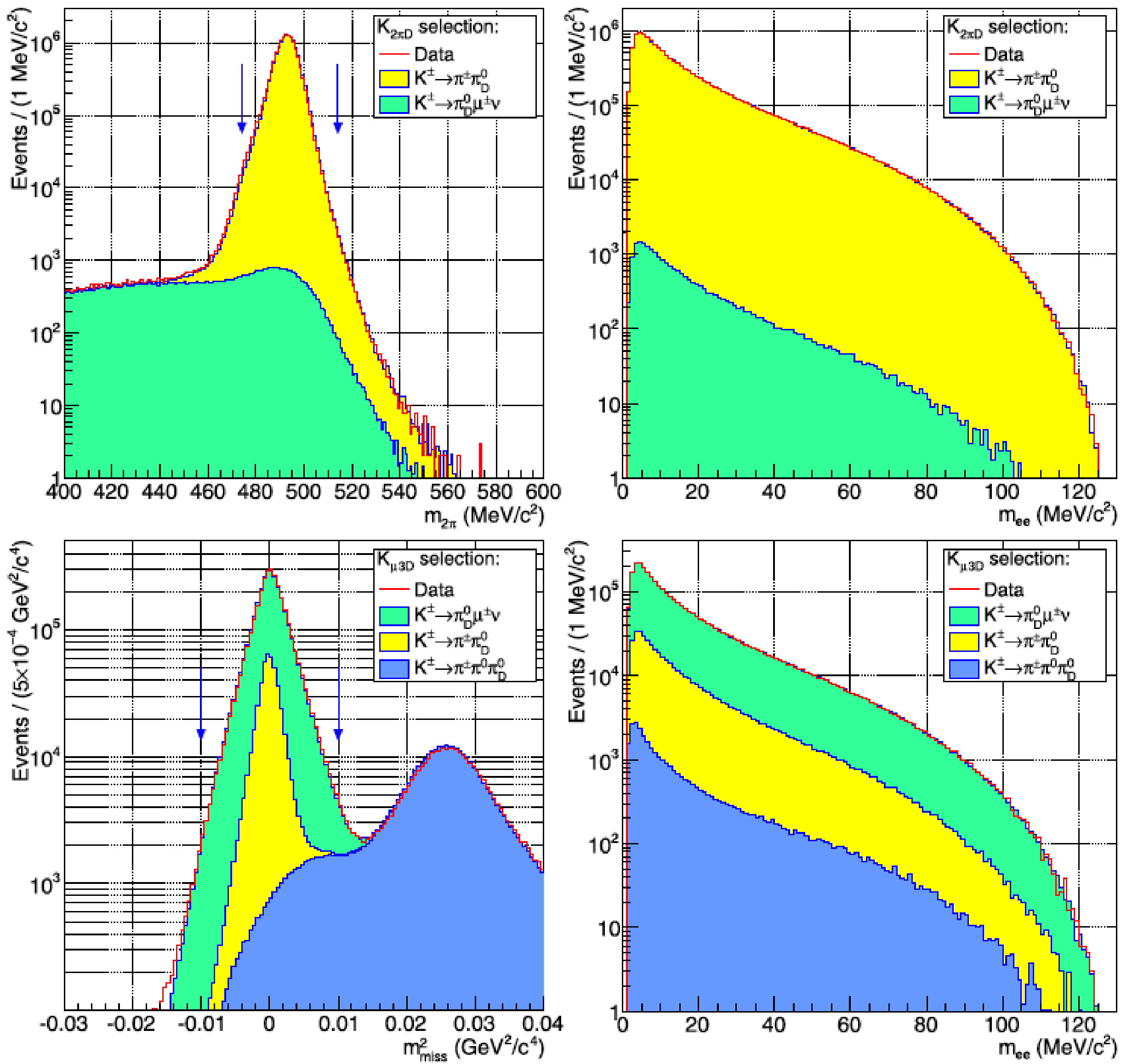
$N_{K\pm} \sim 2\times10^{11}$



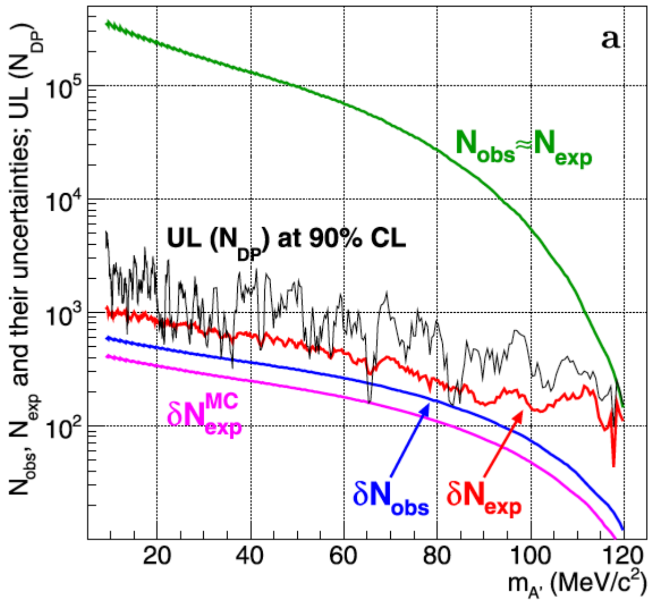
Dark Photon in meson decays

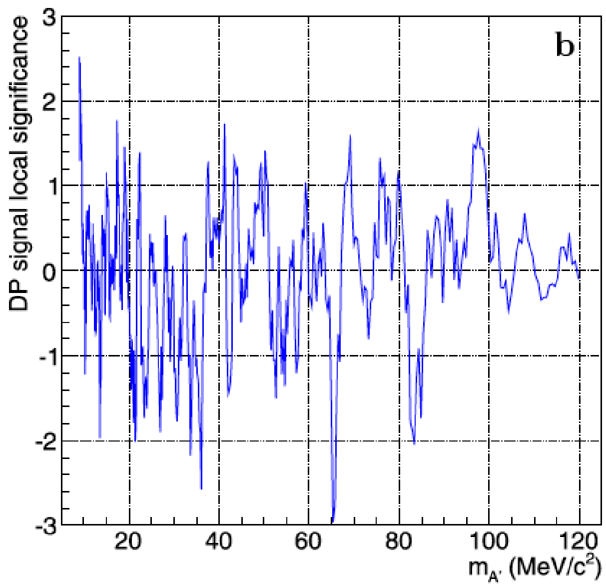
PLB746 (2015) 178

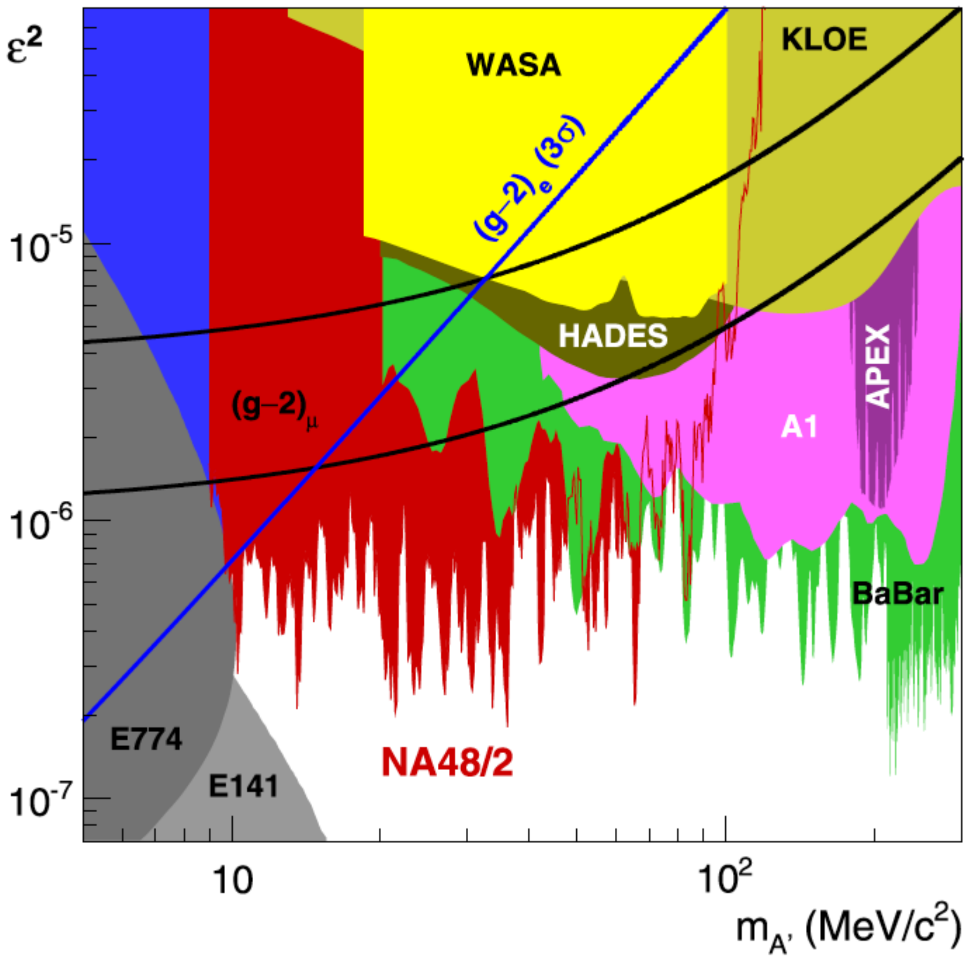
- Combined $\pi^0 \rightarrow ee\gamma$ reconstruction in $K \rightarrow \pi^+\pi^0$ and $K\mu3$
- Study the Mee distribution searching for excess
- Sample of 1.7×10^7 π^0
- Precise accounting for
  - Trigger efficiency
  - e^+e^- mass spectrum
  - Acceptance
  - Resolution



Dark photon in π^0 decay

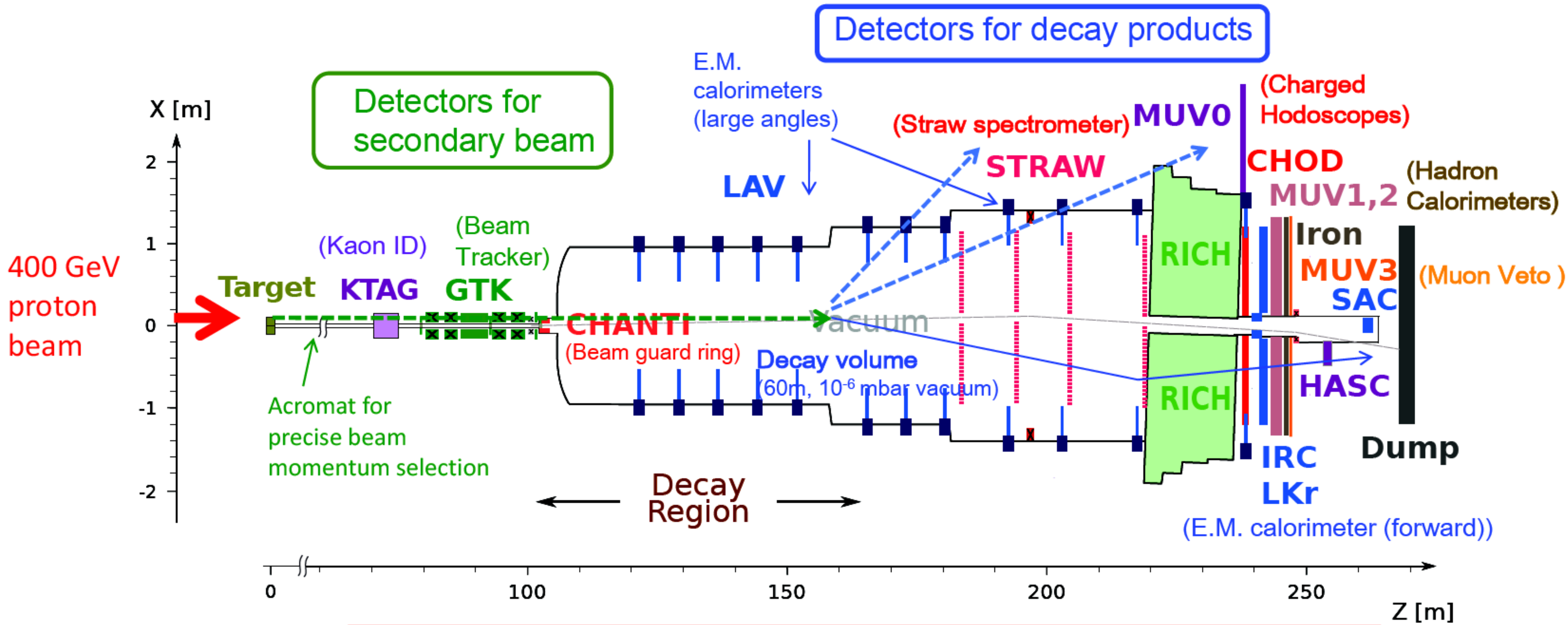






- Covering the gap for $(g_\mu$-2) in the visible DP decays

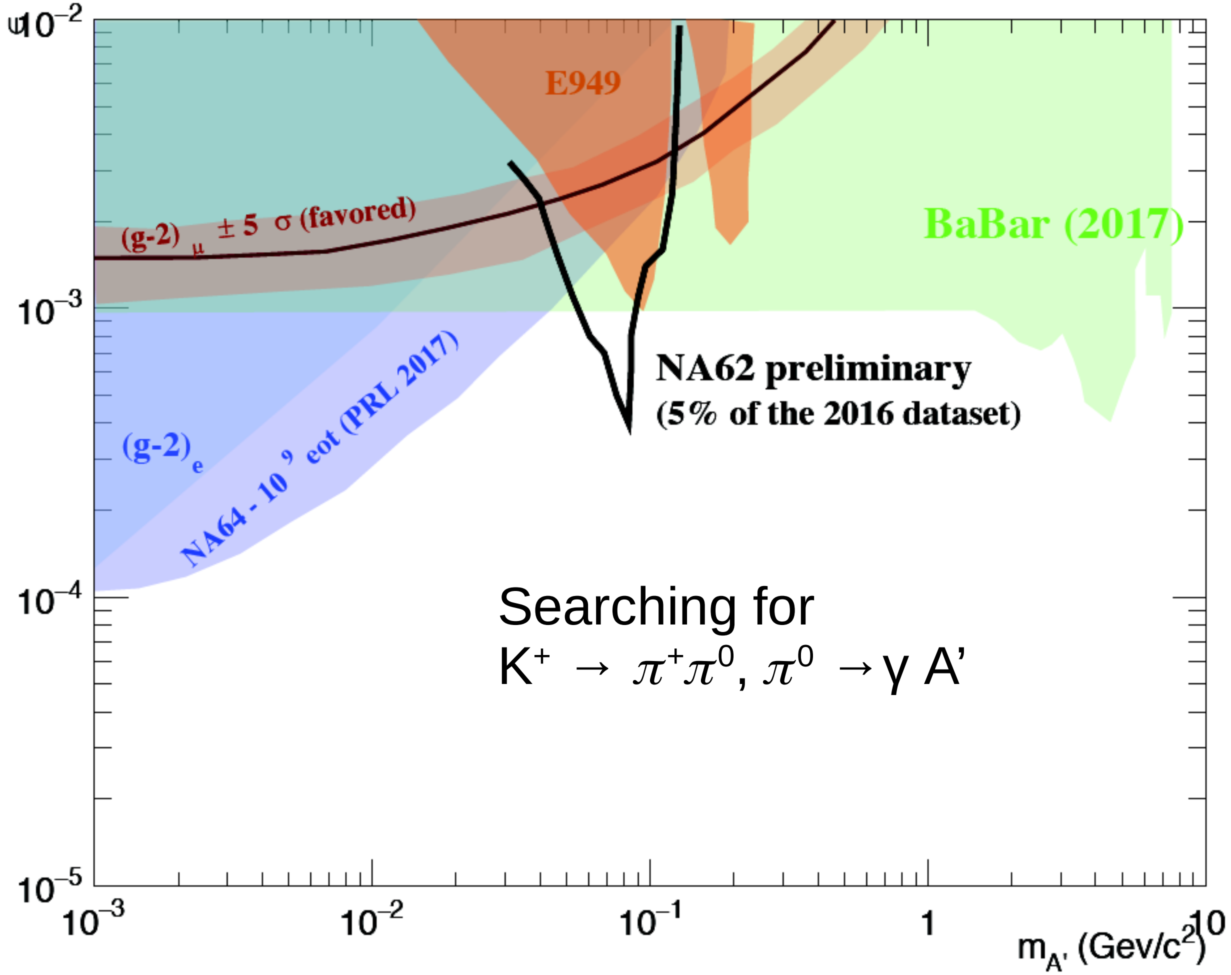
NA62: extensive search for NP



NA62 ~ (2.0-3.0)x10^{18} protons-on-target/year @ 400 GeV/c

JINST 12 (2017), P05025

NA62: extensive search for NP



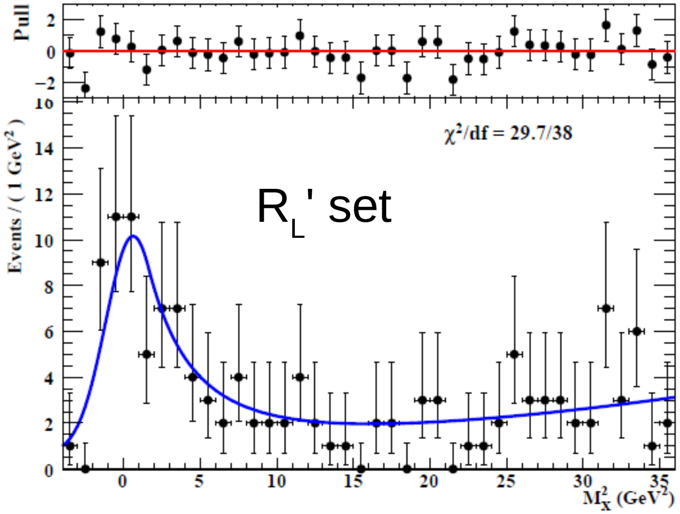
- Total number of kaons in the fiducial region – X*10[13]

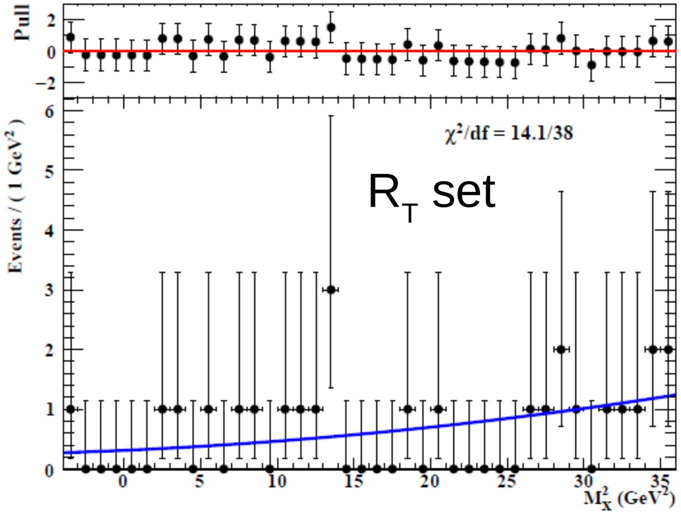
e^+e^- colliders

- The initial state is given by the beam energies
  - P_{e+} and P_{e-} are known
  - $M_{|i>}$ determines the event kinematics
- Final state:
  - A' associate production
  - Can study both scenarios
    - A' → f f , and A' → χχ

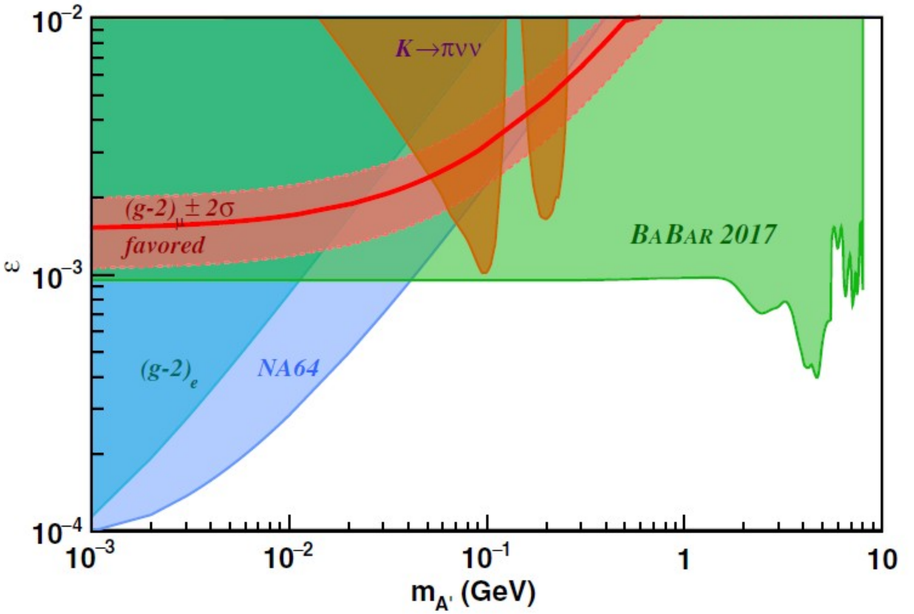
BaBar search for invisible DP

Y(3S) data

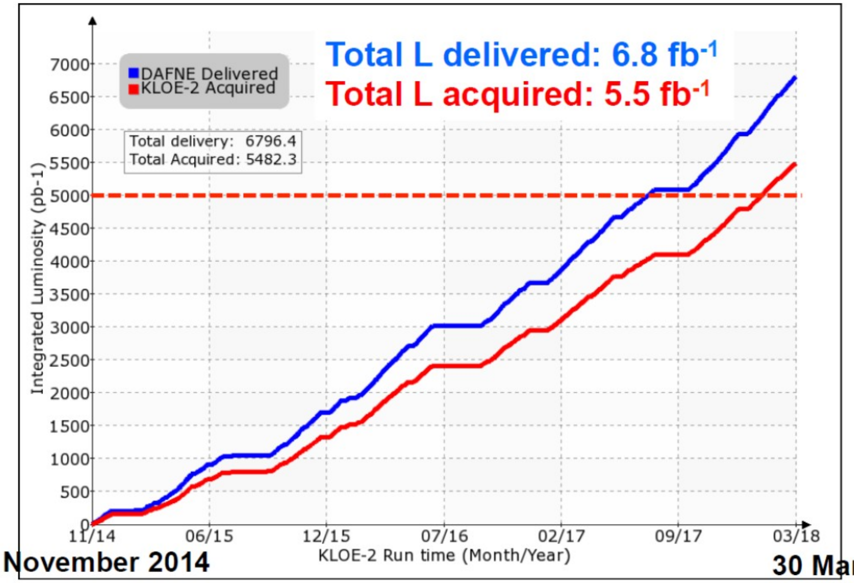




- 53 fb^{-1} of data close to Y resonances
- Single photon trigger
- BDT discrimination between signal and bacground
  - $e^+e^- \to \gamma\gamma$
  - $e^+e^- \to e^+e^-\gamma$ (radiative Bhabha)

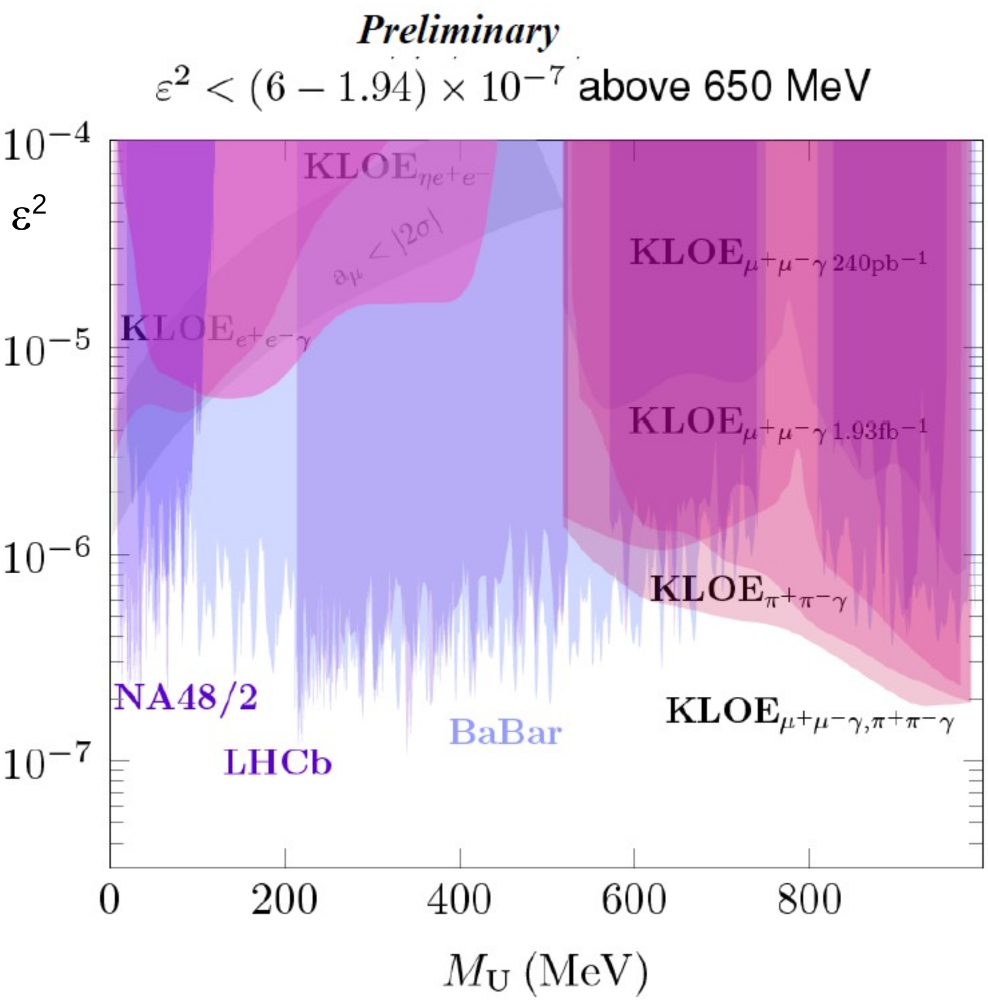


KLOE and Dark Photon



17 November 2014 30 March 2018

Talk of Elena Perez Del Rio



- Multimode searches for DP, including
  - muon final states
  - Dark higgs states
  - Hadron final states
  - Electron final states

KLOE and Dark Photon

Talk of Elena Perez Del Rio

$\varphi \to \eta U$ with $U \to e^+ e^-$ — Phys. Lett B 706 (2012) 251-255; Phys. Lett B 720 (2013) 111-115

$e^+ e^- \to U\gamma$ with $U \to \mu^+ \mu^-$ — Phys. Lett B 736 (2014) 459-464

$e^+ e^- \to Uh'$ with $h' \to$ invisible — Phys.Lett. B747 (2015) 365-372

$e^+ e^- \to U\gamma$ with $U \to e^+ e^-$ — Phys.Lett. B750 (2015) 633

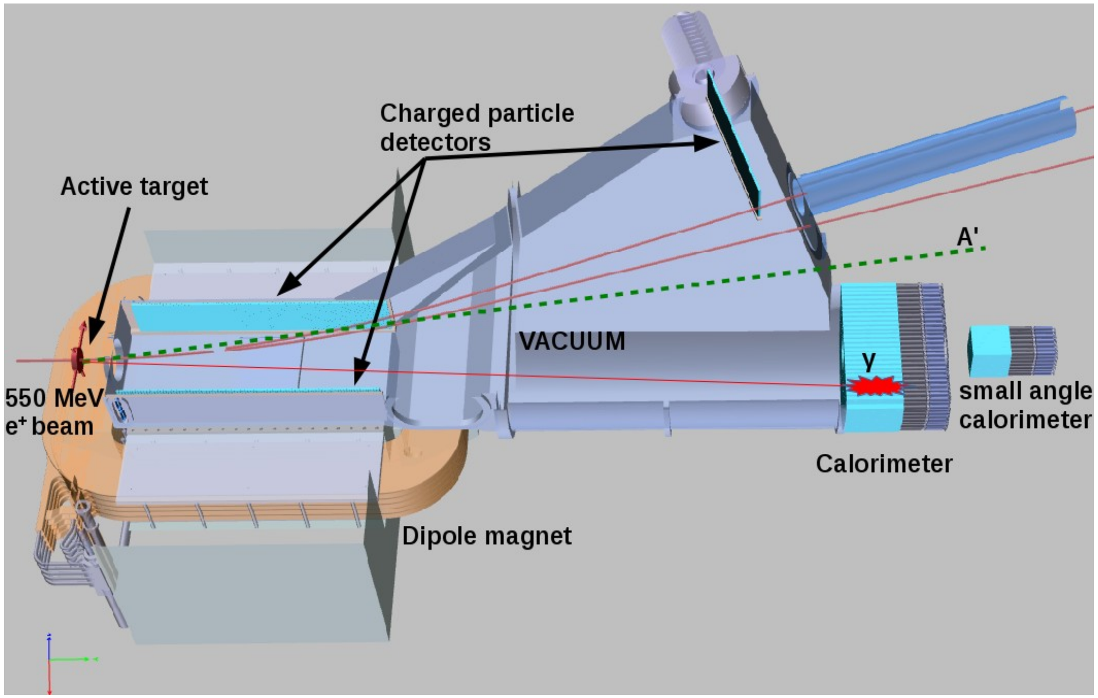
$e^+ e^- \to U\gamma$ with $U \to \pi^+ \pi^-$ — Phys.Lett. B757 (2016) 356-361

- LNF is already a Dark Sector physics laboratory
- New results to come
  - Including single photon detection

PADME

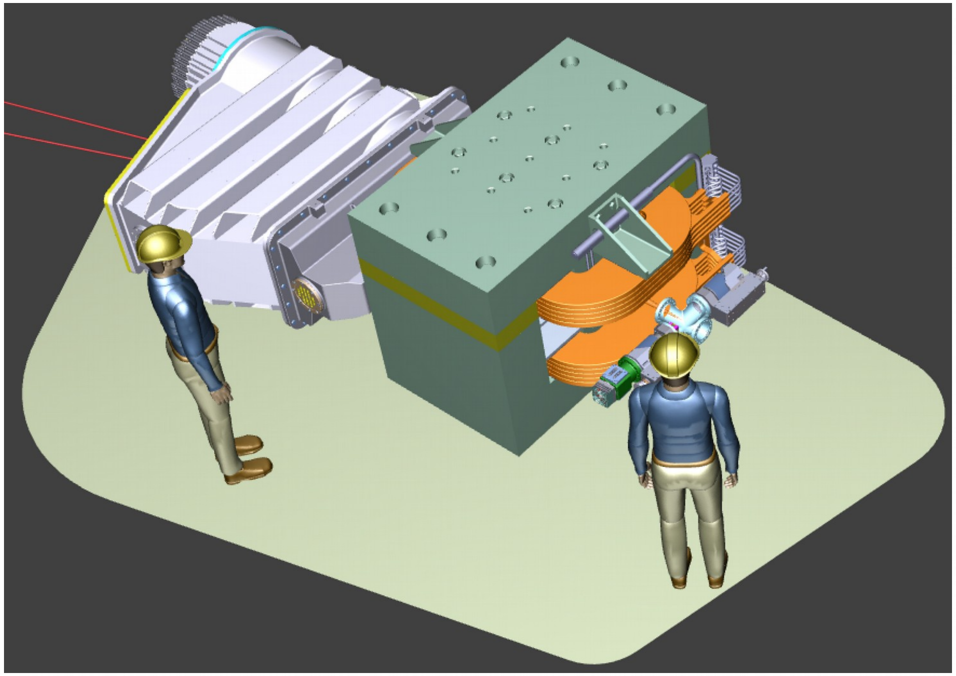
Positron Annihilation into Dark Matter Experiment

Adv. HEP 2014 (2014) 959802



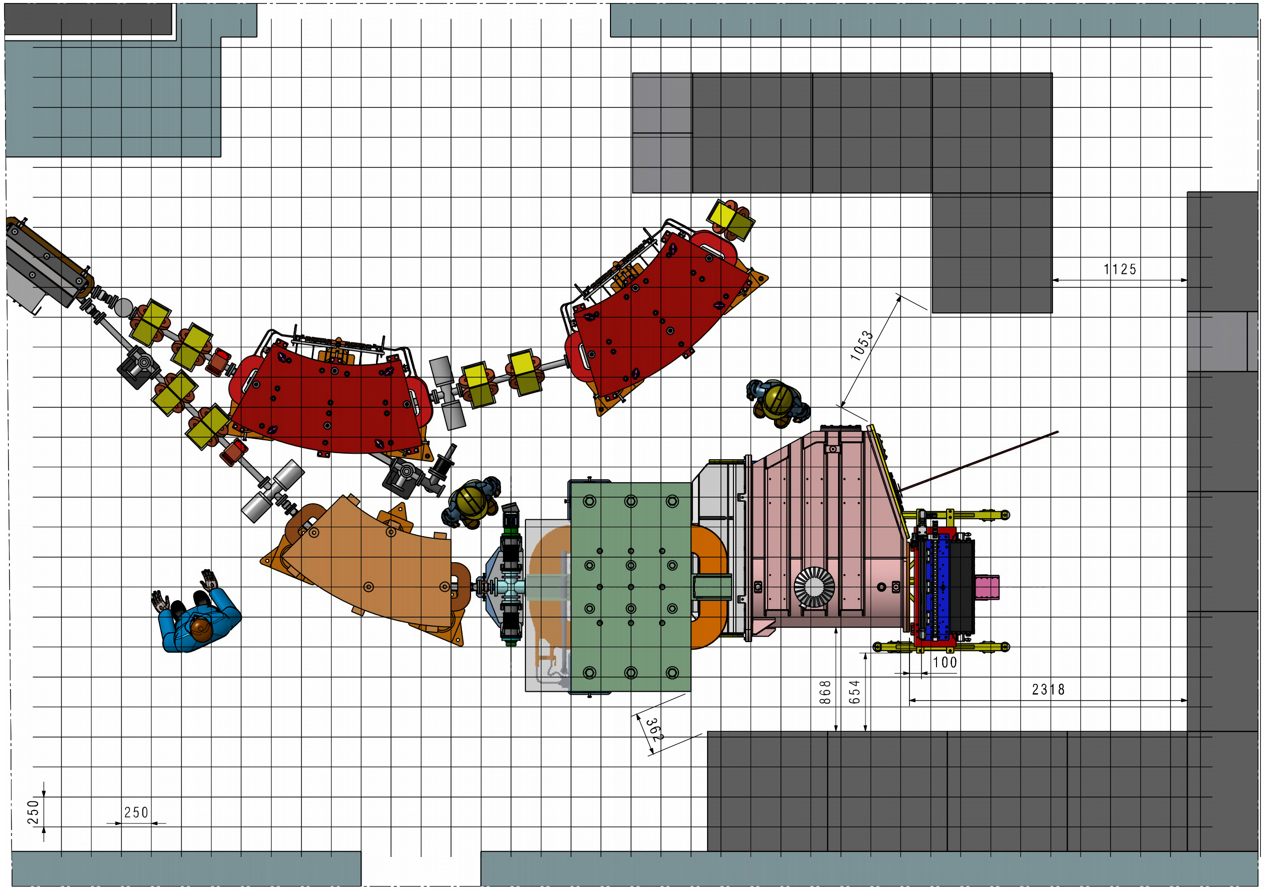
- Small scale fixed target experiment
  - e^+ @ Frascati Beam test facility
  - Solid state target
  - Charged particles detectors
  - Calorimeter

Talks of Clara Taruggi and Federica Oliva

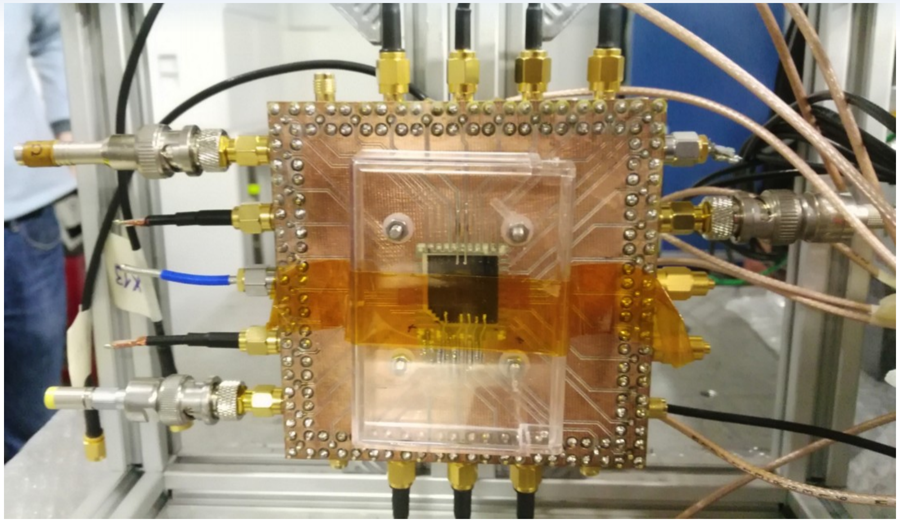


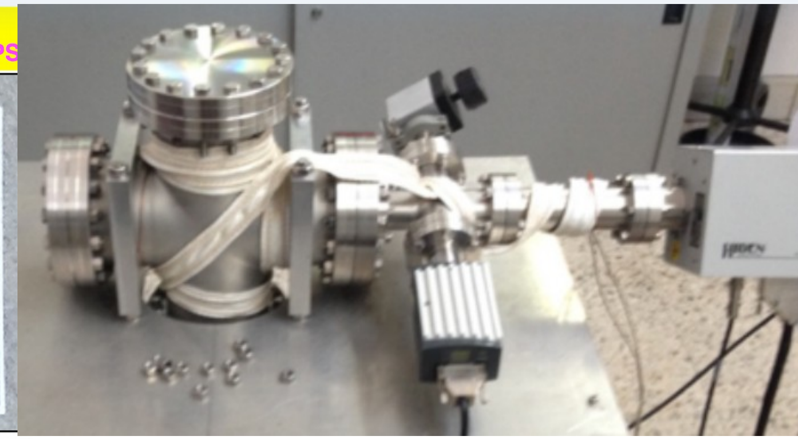
PADME @ BTF

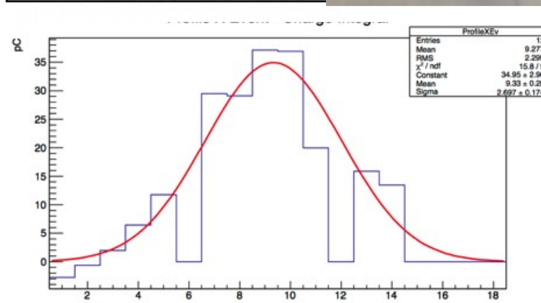
	Electrons	Positrons
Maximum beam energy (E_{beam})[MeV]	750 MeV	550 MeV
Linac energy spread [Dp/p]	0.5%	1%
Typical Charge [nC]	2 nC	0.85 nC
Bunch length [ns]	1.5 – 40 (can reach 200 in 2016)	
Linac Repetition rate	1-50 Hz	1-50 Hz
Typical emittance [mm mrad]	1	~1.5
Beam spot s [mm]	<1 mm	
Beam divergence	1-1.5 mrad	



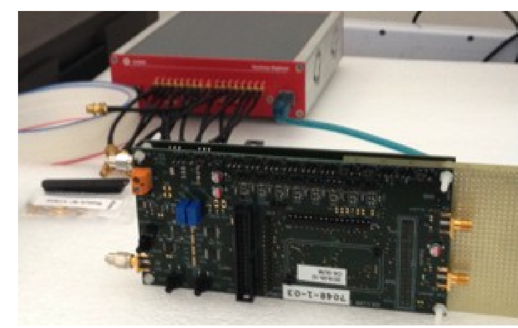
Diamond target







Motorized support structure read
vacuum tests ongoing



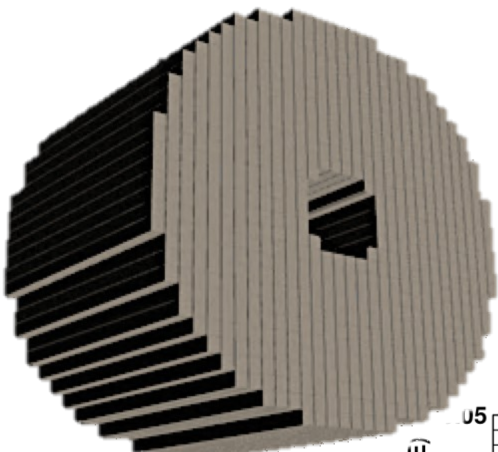
Polycrystalline diamonds

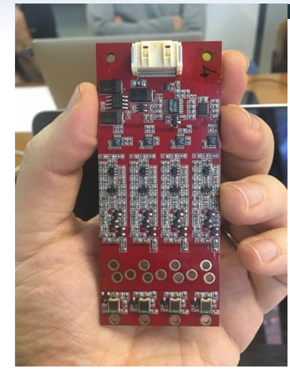
- 100 mm thickness:
- 16 × 1 mm² strip and X-Y readout in a single detector
- Samples with graphitized and metalized strips available
- PADME prototype 20 × 20 mm² produced and tested 2015
- Low noise CSA integrated in the 16 channel chip AMADEUS from IDEAS

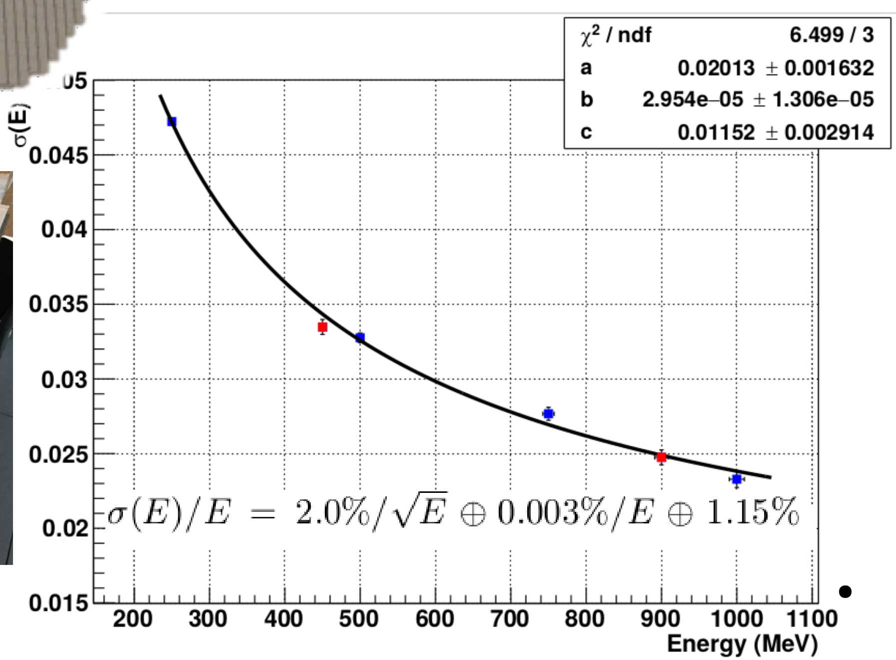
- Test beam results (~5000 e):
  - **good efficiency**
  - resolution on the position of the beam center **< 0.2 mm**
- FE electronics defined

Calorimeter and vetoes

616 BGO crystals, 2 x 2 cm^2 cross section



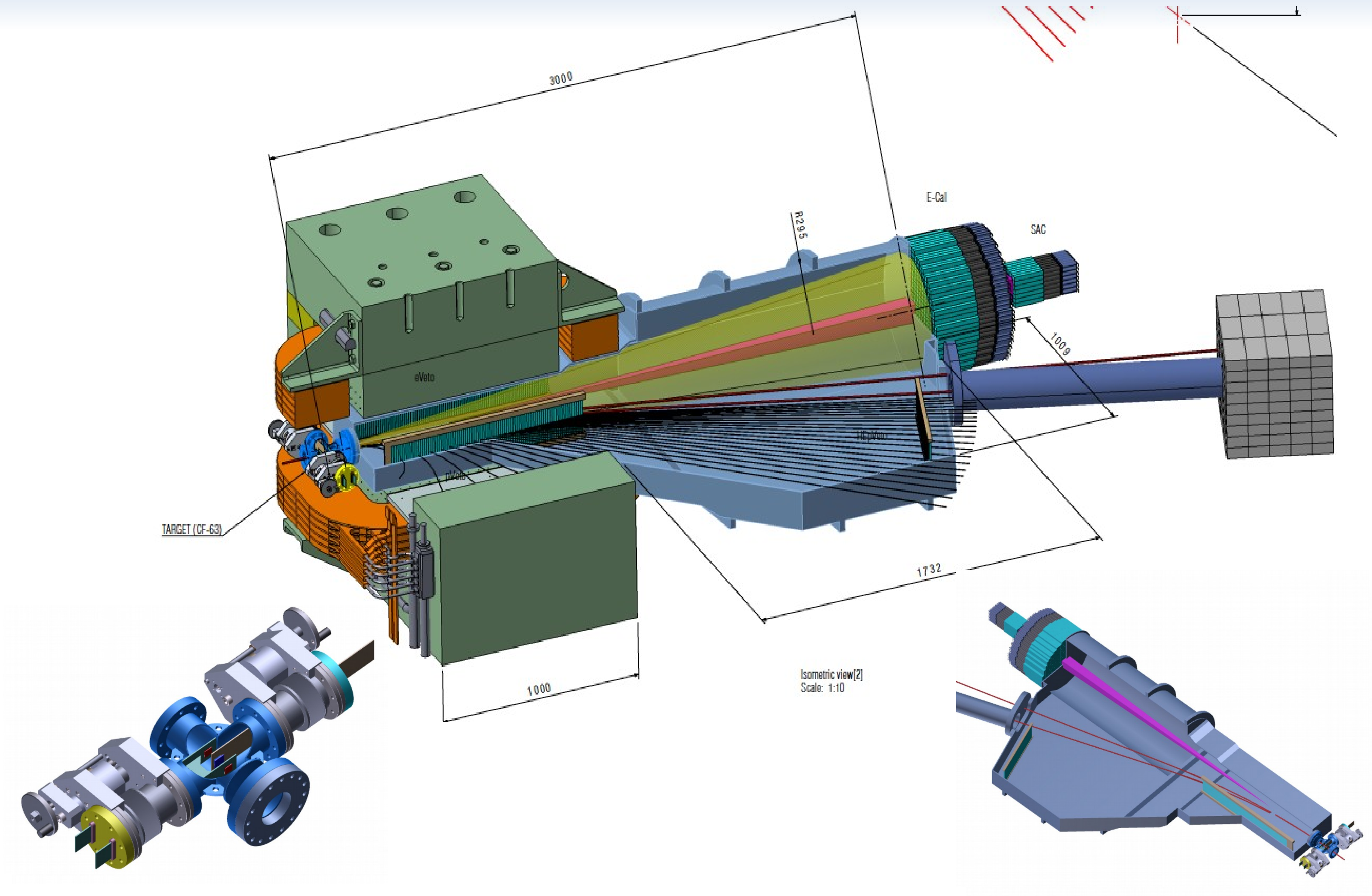




- Efficiency > 99%,
- $\sigma(t) < O(1\ \text{ns})$
- Momentum information through correlation with the particle position

Annular calorimeter to avoid high rate from bremsstrahlung

Construction



Sensitivity

2.5x10^{10} fully GEANT4 simulated 550MeV e+ on target events

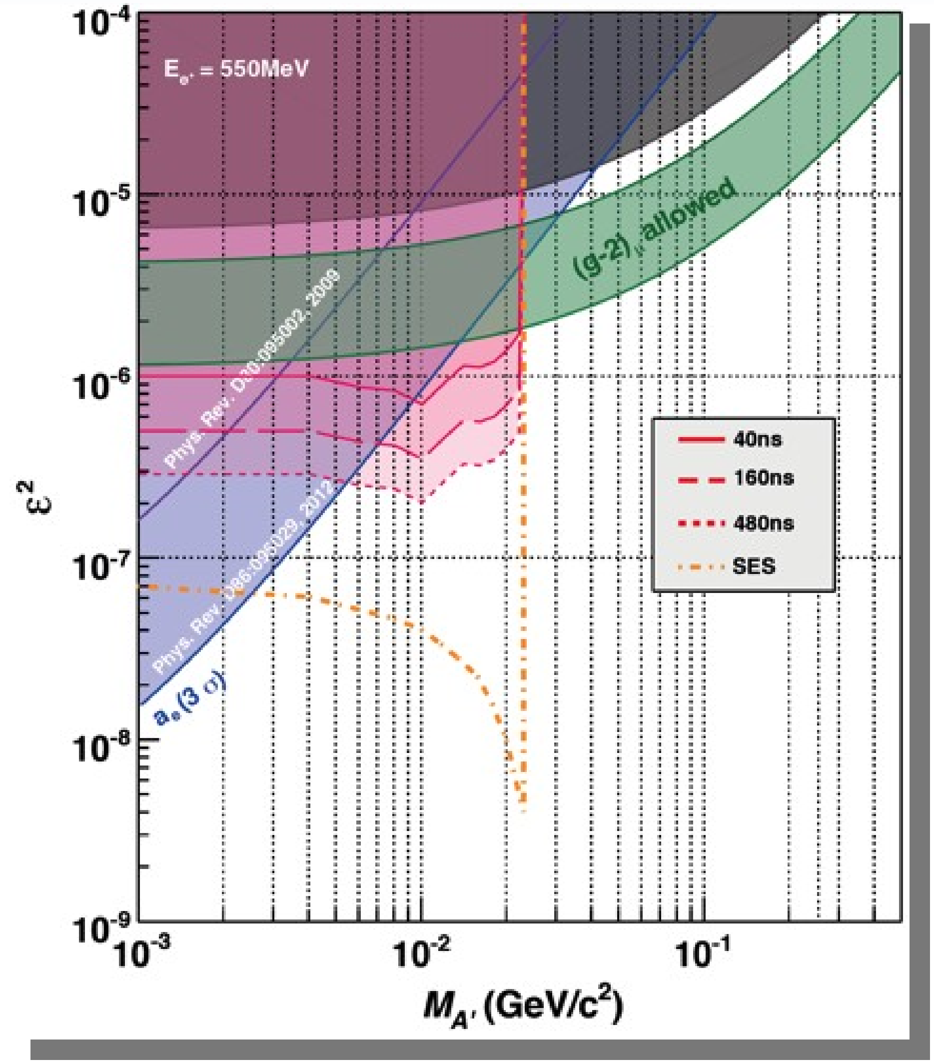
Number of BG events is extrapolated to 1x10^{13} electrons on target

$$\frac{\Gamma(e^+e^- \to A'\gamma)}{\Gamma(e^+e^- \to \gamma\gamma)} = \frac{N(A'\gamma)}{N(\gamma)} \frac{Acc(\gamma\gamma)}{Acc(A'\gamma)} = \varepsilon \cdot \delta$$

PADME:

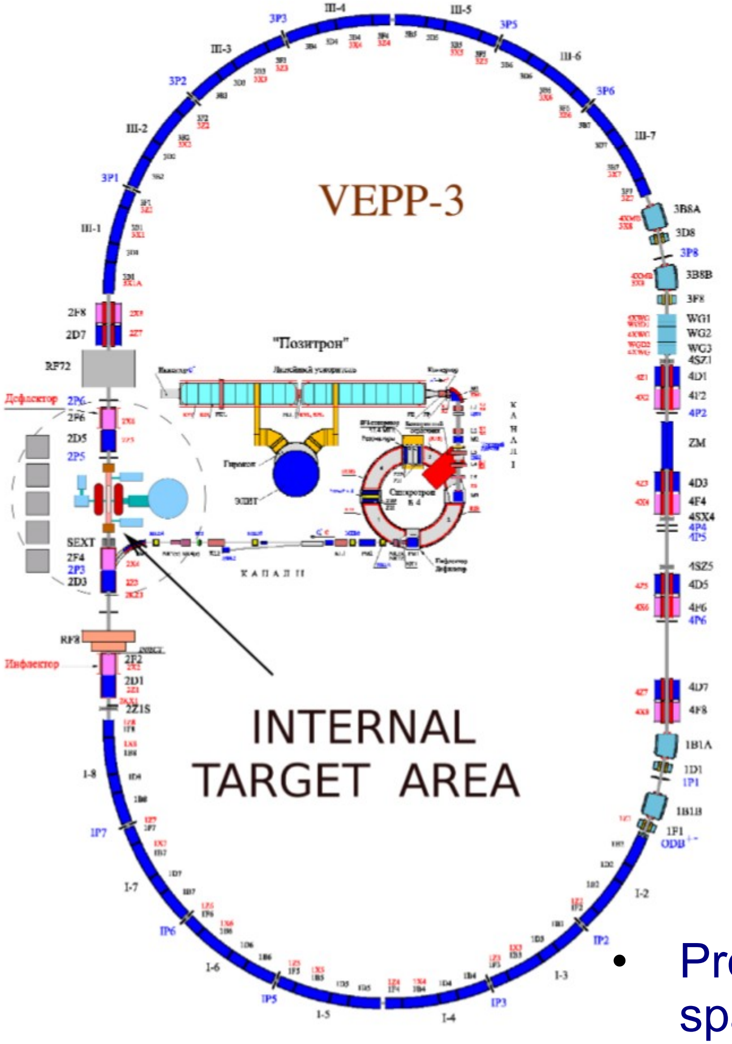
2 years of data taking at 60% efficiency with bunch length of 200 ns

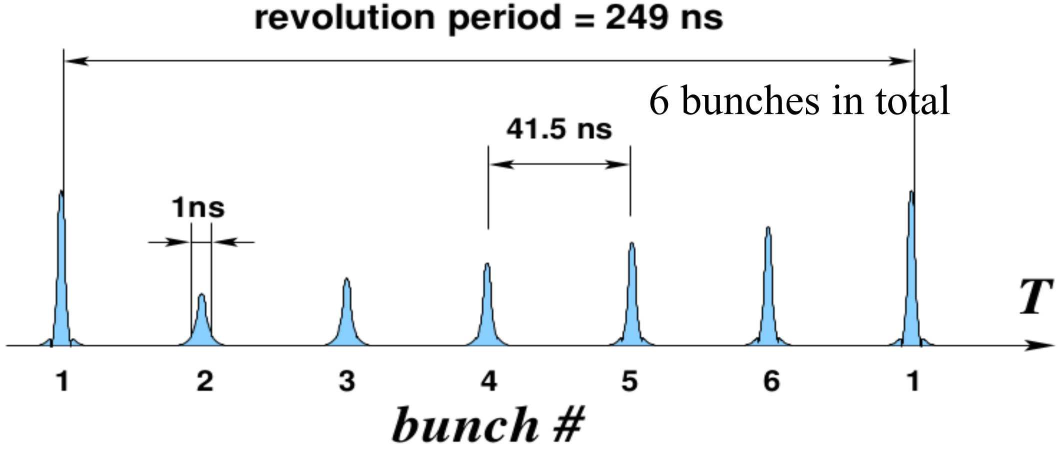
4x10^{13} EOT = **20000 e$^+$**/bunch × 2 × **3.1·10^7**s x 0.6 · **49 Hz**

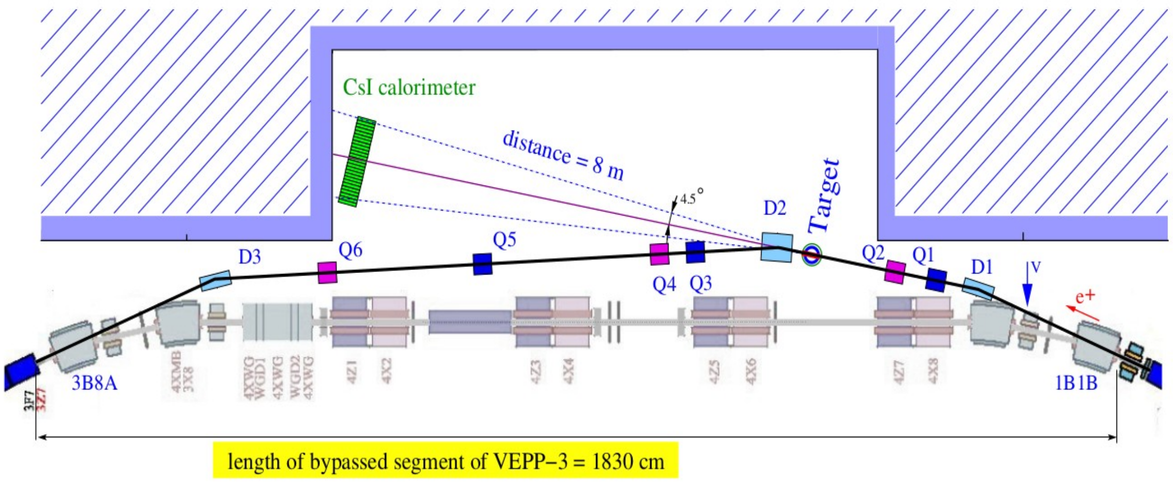


VEPP 3

- 500 MeV storage ring @ Novosibirsk



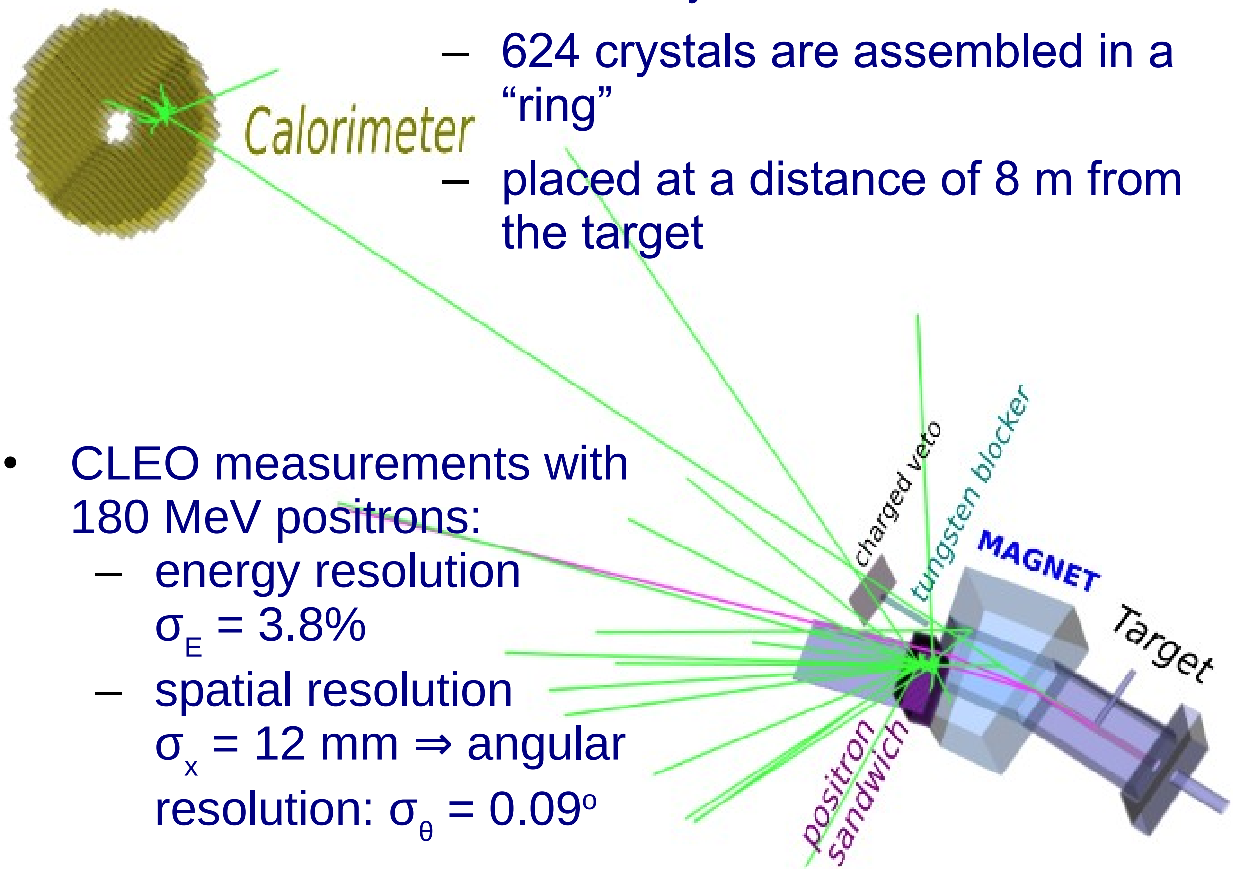




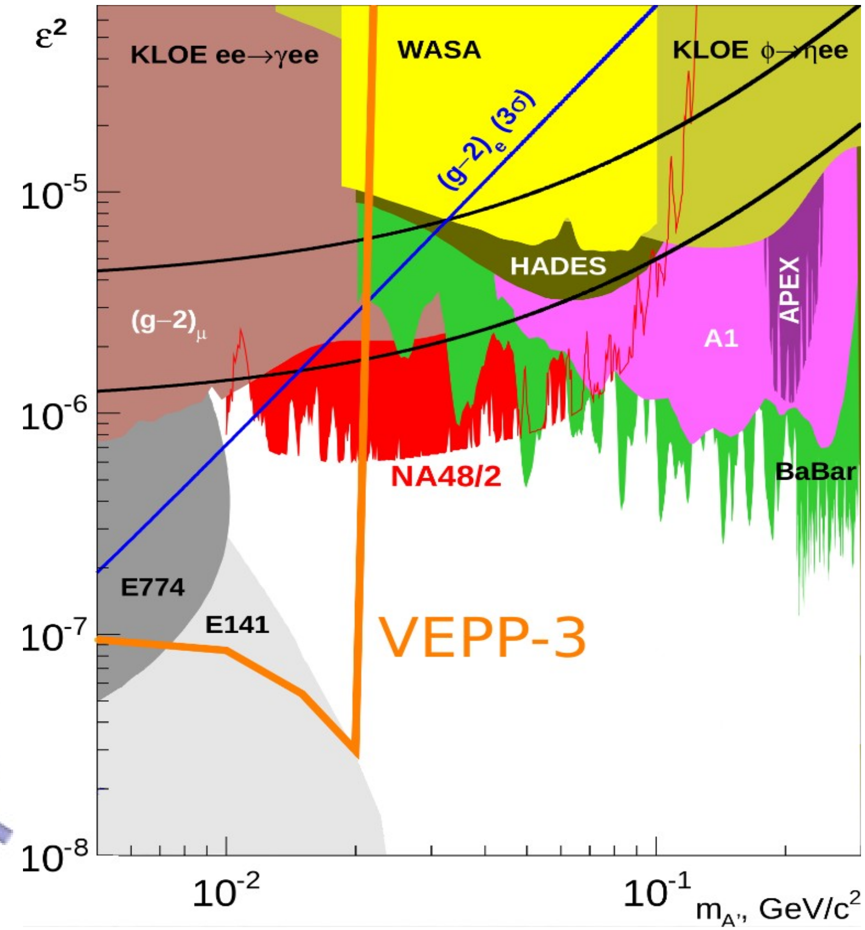
- Proposed to construct a ByPass, allowing to utilize available space for a crystal calorimeter and shielding
- Operating in paralel with the ongoing VEPP-3 activities

VEPP 3

- CLEO CsI crystals
  - 624 crystals are assembled in a "ring"
  - placed at a distance of 8 m from the target



- CLEO measurements with 180 MeV positrons:
  - energy resolution $\sigma_E = 3.8\%$
  - spatial resolution $\sigma_x = 12$ mm $\Rightarrow$ angular resolution: $\sigma_\theta = 0.09^o$



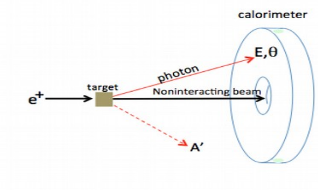
- Possible operation in 3-4 years with the by-pass beam line

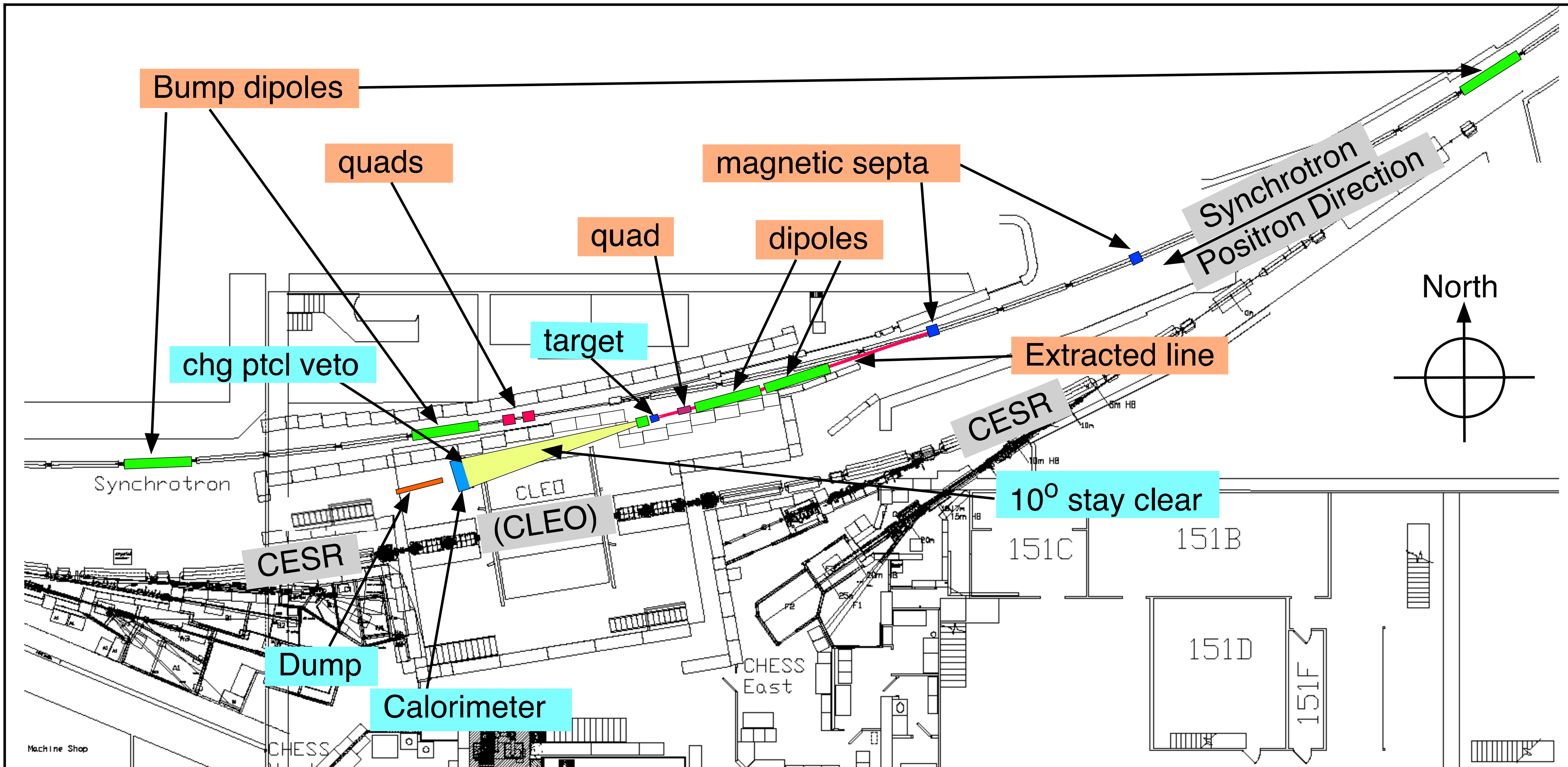
MMAPS

- Approach similar to PADME:

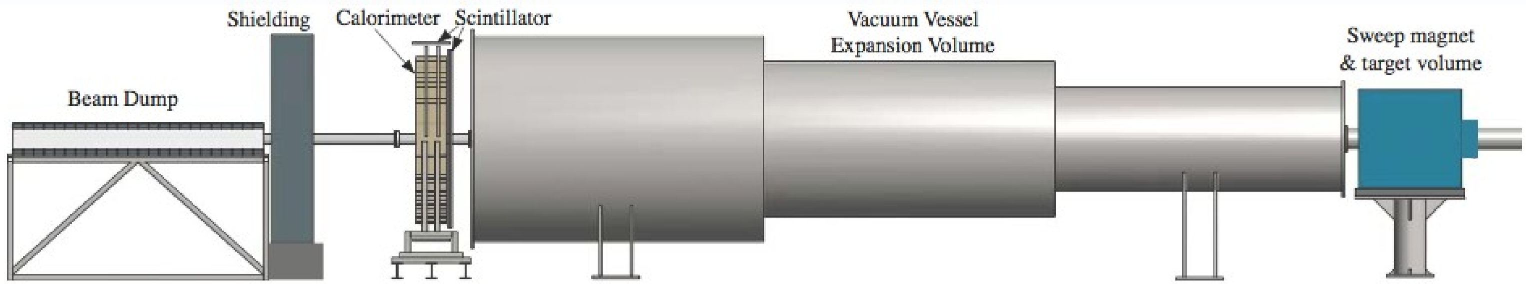
Missing Mass A-Prime Search

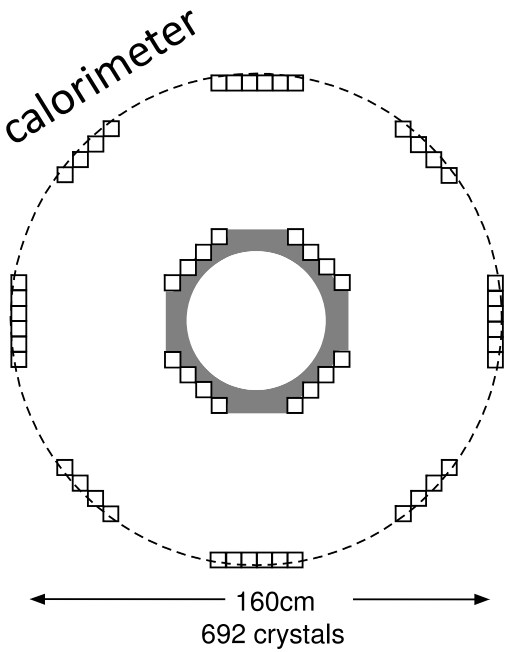
  - E_{beam} = 1.8 -- 5.3 GeV, I_{beam} ~ 2.3 nA at target,
  - ~millisecond spills @ 60Hz
  - pulse structure: 168ns

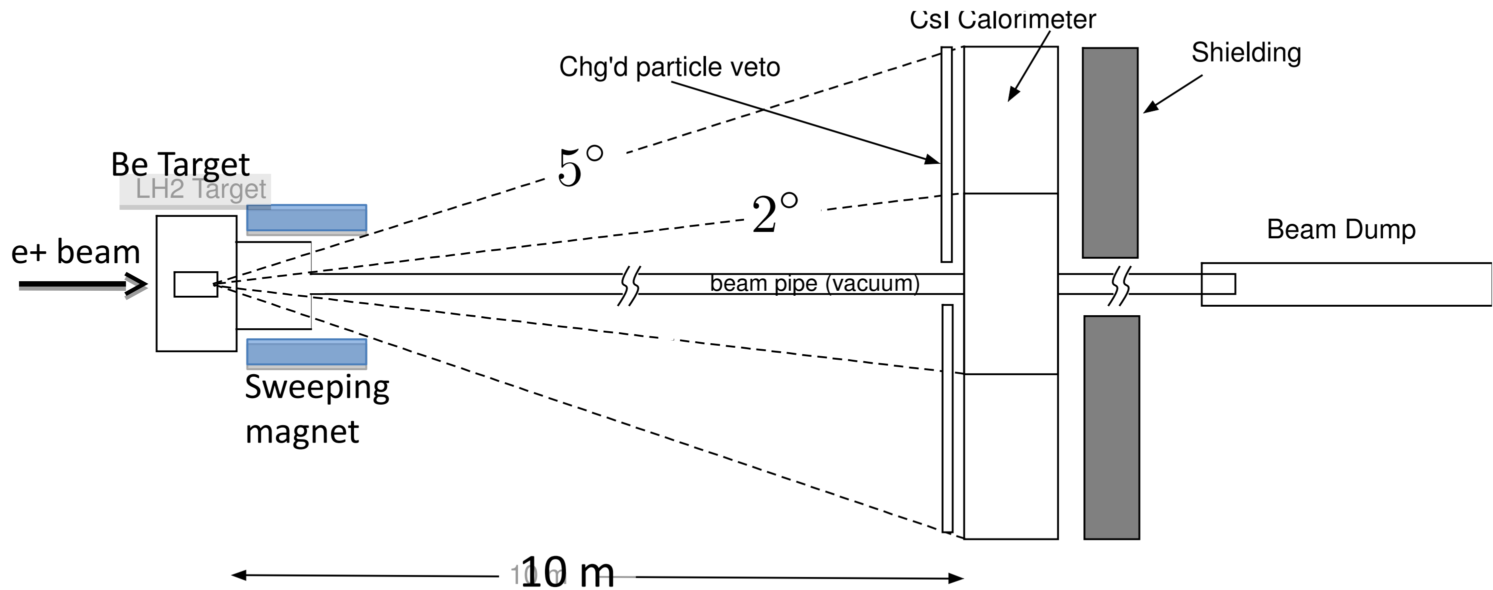




MMAPS design and sensitivity



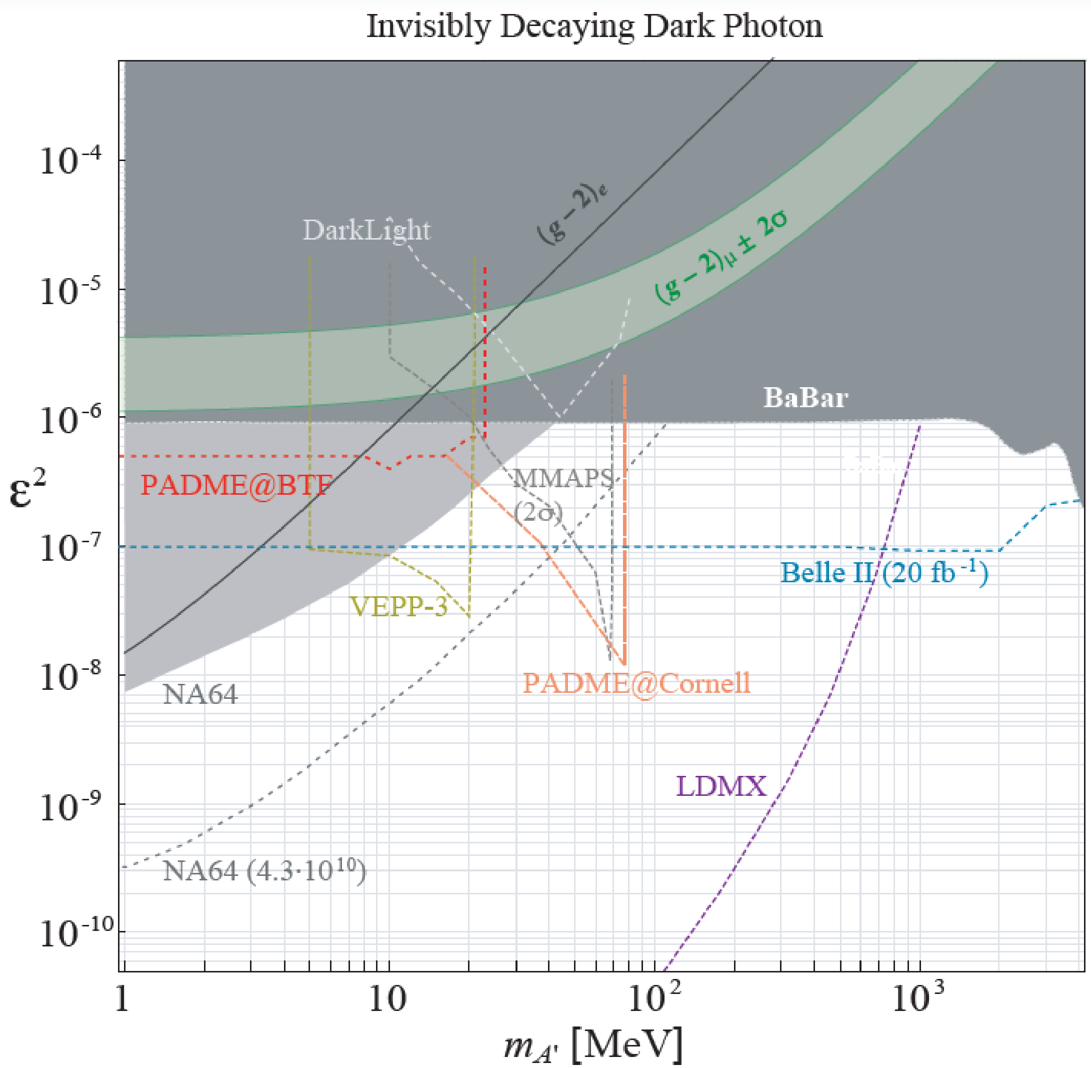




- Charged particle vetoes in front of the calorimeter
- CsI(Tl) crystal calorimeter (from CLEO), PMTs instead of photodiodes (time properties)
- Issues with **overlap @ maximal luminosity**: good double pulse separation necessary

Extend the accessible region up to $M_{A'} = 74$ MeV

Missing mass searches

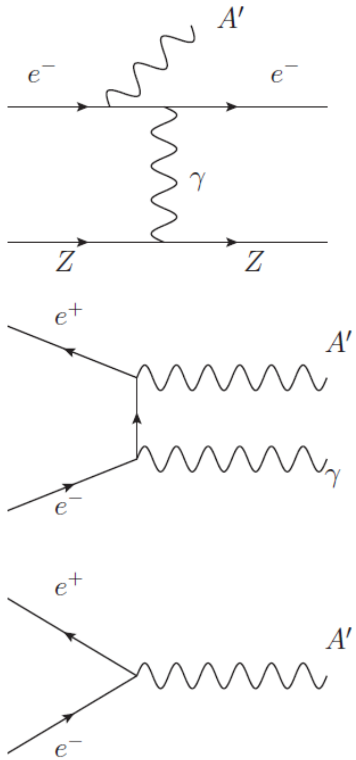


Missing mass searches

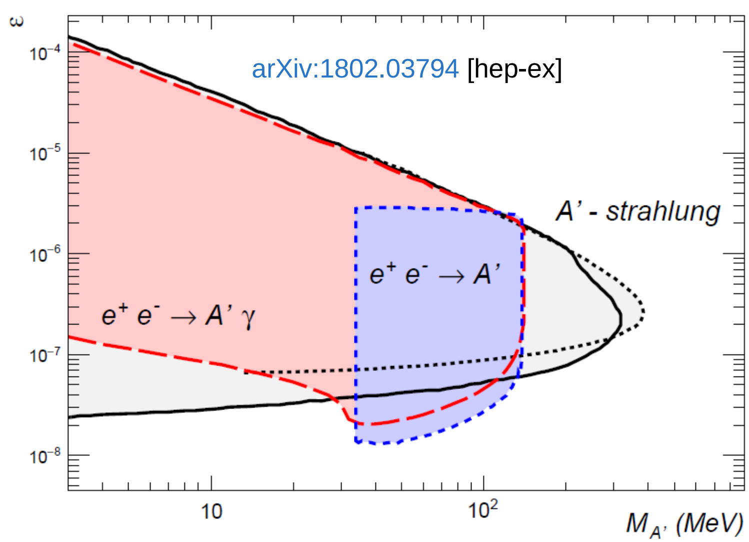
	PADME	MMAPS	VEPP3
Place	LNF	Cornell	Novosibirsk
Beam energy	550 MeV	Up to 5.3 GeV	500 MeV
$M_{A'}$ limit	23 MeV	74 MeV	22 MeV
Target thickness	$2x10^{22}$ e^-/cm^2	$O(2x10^{23})$ e^-/cm^2	$5x10^{15}$ e^-/cm^2
Beam intensity	8×10^{-11} mA	2.3×10^{-6} mA	30 mA
$e^+e^- \rightarrow \gamma\gamma$ rate [s^{-1}]	15	2.2×10^6	1.5×10^6
ε^2 limit (plateau)	**10^{-6} (*10^{-7} SES*)**	**$10^{-6} – 10^{-7}$**	**10^{-7}**
Time scale	2018	?	2020 (ByPass)
Status	**Preparation for run**	**Not funded by NSF**	**Proposal**

Exploiting further the annihilation

Talks of Anish Ghoshal and Cristian David Carvajal Ruiz



- Annihilation in beam dump and thin targets



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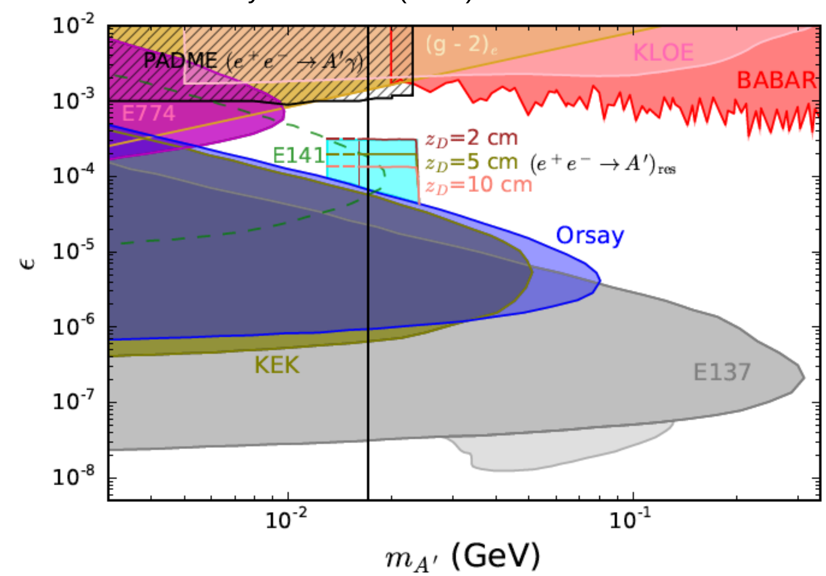
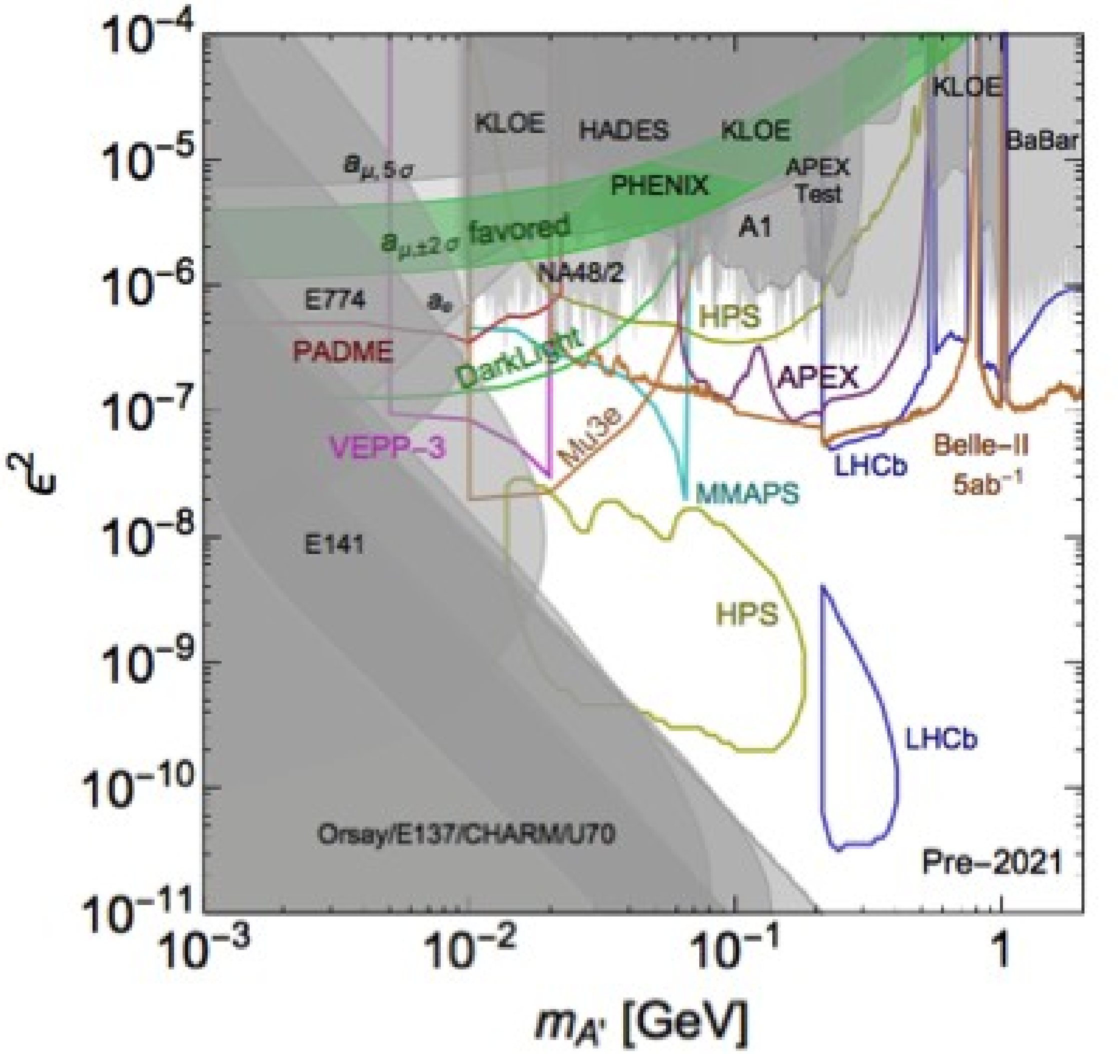


- Associate production of dark photon vs resonant annihilation
- A promising technique to cover the gap between dump and fixed (or no) target experiments
  - However, needs to control the leakage from the beam shower…

Conclusion



KLOE
HADES
KLOE
KLOE
BaBar
$a_{\mu,5\sigma}$
PHENIX
APEX Test
A1
$a_{\mu,\pm2\sigma}$ favored
NA48/2
E774
a_e
HPS
PADME
DarkLight
APEX
VEPP-3
Mu3e
LHCb
Belle-II $5ab^{-1}$
MMAPS
E141
HPS
LHCb
Orsay/E137/CHARM/U70
Pre-2021
ϵ^2
$m_{A'}$ [GeV]

Conclusion

- Dark photons may be just at the door
- Many projects in the past, many ongoing projects, many new to come on stage
- A variety of techniques applied to the Dark Photons studies
- Mass range from O(MeV) – O(GeV) covered
- And recall – most of the experimental searches are not only for DP, but for any excess of events with a specific topology