Status of the PADME experiment and future plans

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on behalf of the PADME collaboration

INFN CSN1 meeting

Rome, Centro Fermi, February 23, 2024

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The dark matter problem and its implications

Dark matter indirect evidence from a number of observations

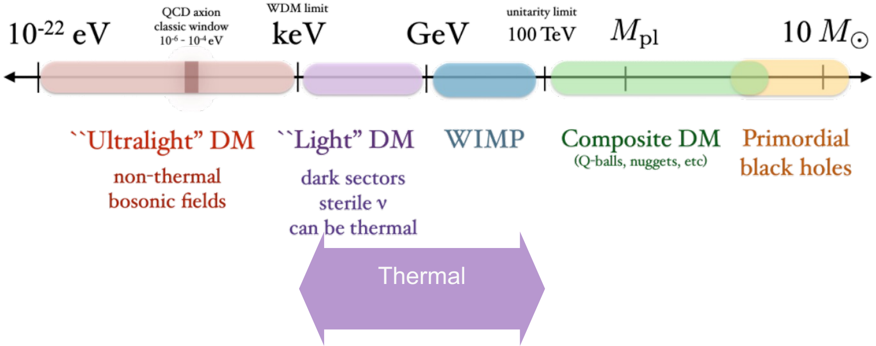
CMB anisotropies, rotational curves of galaxies, milky way rotation, …

Problem might be solved with new massive weakly interacting particles (WIMPs)

None observed up to now

Or via light dark matter (LDM)

MeV-GeV "hidden-sector" states, neutral under SM interactions, interacting with SM via new forces



Portals and broad phenomenology

New forces classified on an effective-interaction basis, e.g.:

Portal	Coupling
Dark photon, A_μ	$-\frac{\epsilon}{2\cos\theta_W}F'_{\mu\nu}B^{\mu\nu}$
Dark Higgs, S	$(\mu S + \lambda S^2)H^\dagger H$
Axion, a	$\frac{a}{f_a}F_{\mu\nu}\tilde{F}^{\mu\nu}$, $\frac{a}{f_a}G_{i,\mu\nu}\tilde{G}_i^{\mu\nu}$, $\frac{\partial_\mu a}{f_a}\overline{\psi}\gamma^\mu\gamma^5\psi$
Sterile neutrino, N	$y_N LHN$

J. Phys. G: Nucl. Part. Phys. **47** 010501

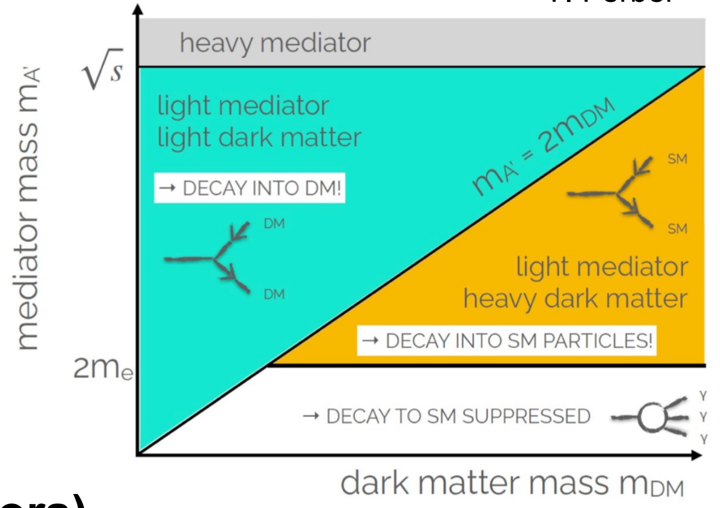
Phenomenology can hugely vary on the basis of

- **structure of the hidden sector**
- **simultaneous presence of many mediators**
- **mass structure, e.g. 2 Mχ < or > mediator mass**

Broadly speaking:

- **Visible decays to SM particles**
- **Invisible decays (+ visible but long-lived mediators)**

T. Ferber



The PADME approach

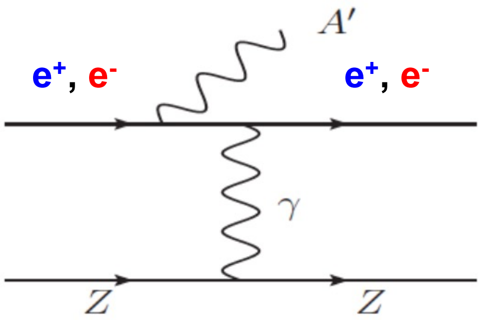
Dedicated experiment sensitive to NP coupling to e or γ @ $\sqrt{s} \sim 20$ MeV

Model-independent and redundant as much as possible:

use e^+ beam + fixed target, kinematics highly constrained

Exploit an existing facility: the Beam Test Facility (BTF) of the LNF complex

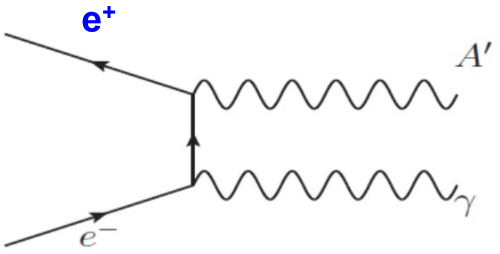
Positron vs electron beams, A' example



A' strahlung: ~ $\alpha^3\ \varepsilon^2 / m_A^2$, ~ $\varepsilon^2 (m_A / m_e)^2$ × SM

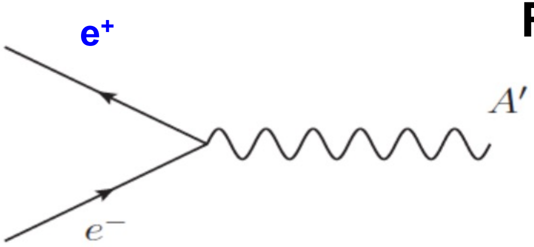
$$\frac{d\sigma}{dx\,d\cos\theta_{A'}} \approx \frac{8Z^2\alpha^3\epsilon^2E_0^2x}{U^2}\,\mathcal{L}og\left[\left(1-x+\frac{x^2}{2}\right)-\frac{x(1-x)m_{A'}^2(E_0^2x\theta_{A'}^2)}{U^2}\right]$$

with $U(x,\theta_{A'}) = E_0^2x\theta_{A'}^2 + m_{A'}^2\frac{1-x}{x} + m_e^2x$



Rad. annihilation ~ $\alpha^2\ \varepsilon^2 / (s - m_A^2)$, ~ $2\varepsilon^2$ ($m_A << s$) × SM(γγ)

$$\frac{d\sigma(e^+e^-\to\gamma A')}{d\cos\theta} = \frac{\alpha\epsilon^2}{2s^2(s-m_{A'}^2)}\left(\frac{s^2+m_{A'}^4}{\sin\theta^2}-\frac{(s-m_{A'}^2)^2}{2}\right)$$



Resonant annihilation ~ α, high but extremely narrow

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

σ_{peak} ~ 0.2 b (M_A = 17 MeV) but Γ_A ~ 0.04 eV × ($\varepsilon^2 / 10^{-6}$)

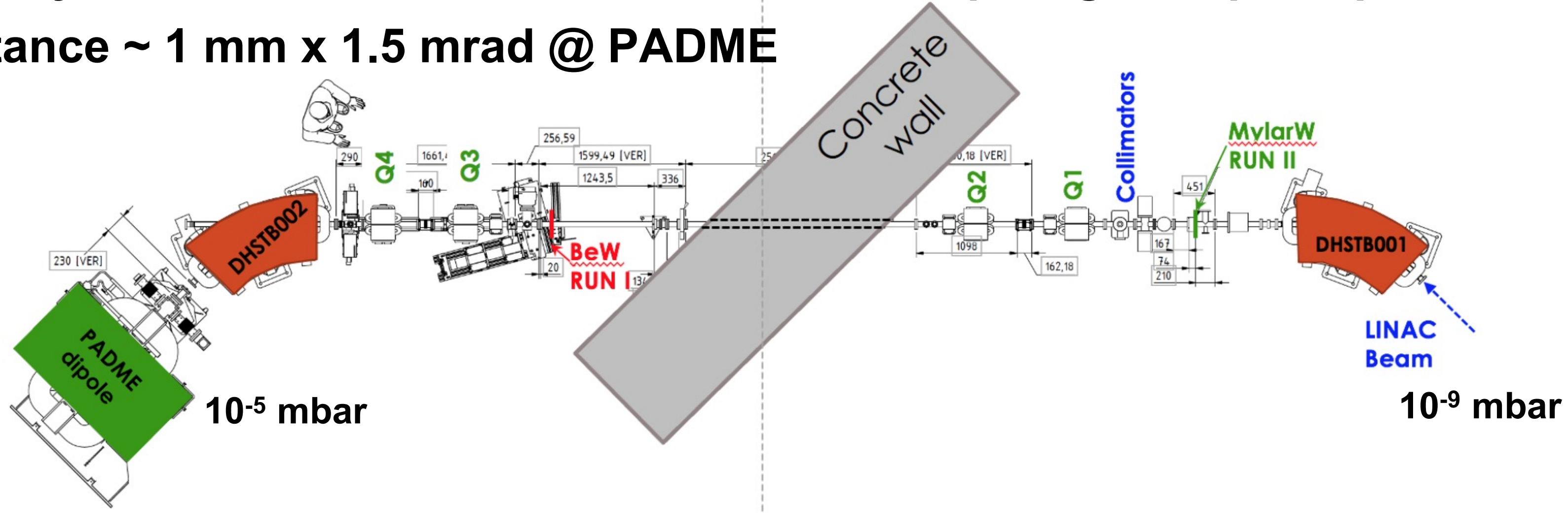
What's PADME – the facility

Positrons from the DAFNE LINAC up to 550 MeV, O(0.5%) energy spread

Repetition rate up to 49 Hz, macro bunches of up to 300 ns duration

Intensity must be limited below ~ 3 × 10^4 POT / spill against pile-up

Emittance ~ 1 mm x 1.5 mrad @ PADME



Past operations:

Run I	e^- primary, target, e^+ selection, 250 μm Be vacuum separation [2019]
Run II	e^+ primary beam, 125 μm Mylar™ vacuum separation, 28000 e^+/bunch [2019-20]
Run III	dipole magnet off, ~3000 e^+/bunch, scan $s^{1/2}$ around ~ 17 MeV [End of 2022]

Data quality and goals for Run II data

Background reduced to 0.013 MeV / e^+, finally allowing precision analyses, broadly divided in terms of final states

Two-body:

- $e^+e^- \rightarrow \gamma\gamma$, absolute cross section, luminosity [PRD 107 (2023) 1, 012008]
- $e^+e^- \rightarrow e^+e^-$, absolute cross section [concluded]
- Single photon: $e^+e^- \rightarrow \gamma X$, X as invisible A' [ongoing, new ML-based reco]

Three body:

- Three photons: $e^+e^- \rightarrow \gamma\gamma\gamma$, search for prompt $a \rightarrow \gamma\gamma$ [ongoing]
- Single photon: $e^+e^- \rightarrow \gamma e^+e^-$, search for prompt a/A' $\rightarrow e^+e^-$ [conceived]

Many body:

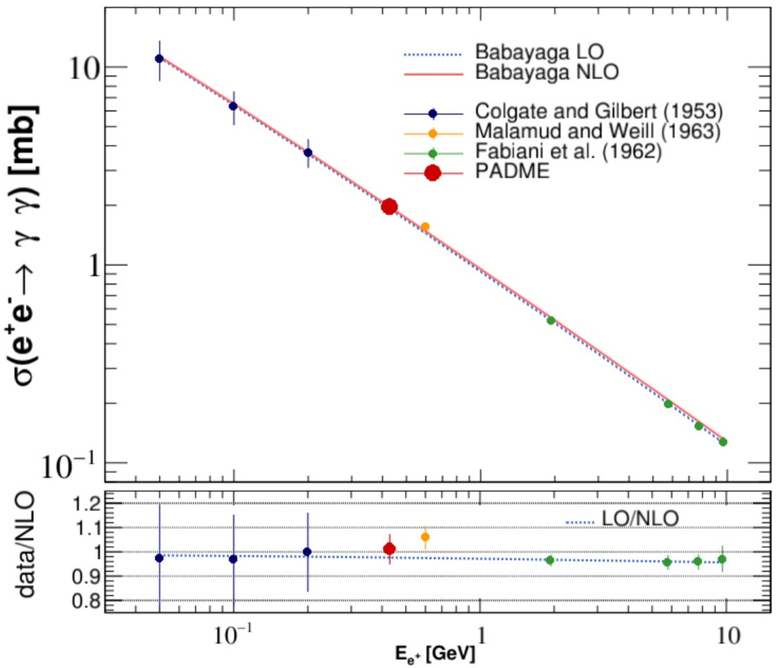
- Single photon: $e^+e^- \rightarrow 3(e^+e^-)$, search for prompt $e^+e^- \rightarrow$ h' A' $\rightarrow$ 3A'

ee → γγ: result

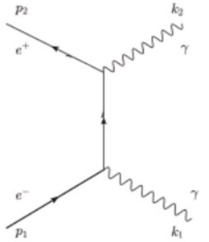
Result compatible with SM expectation: Babayaga at NLO

Only measurement below GeV made matching the 2 γ's: other measurements made with e^+ disappearance → implication on New Physics sensitivity

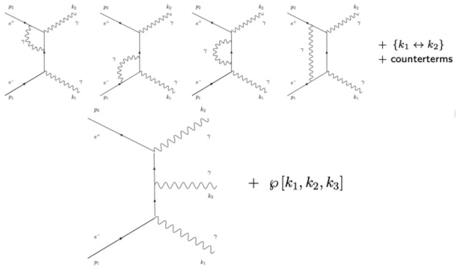
Measurement can be re-interpreted as a search for prompt decays of an ALP state, a → γγ



LO

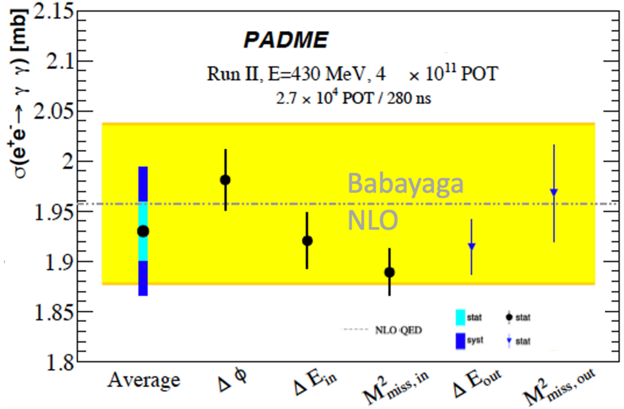


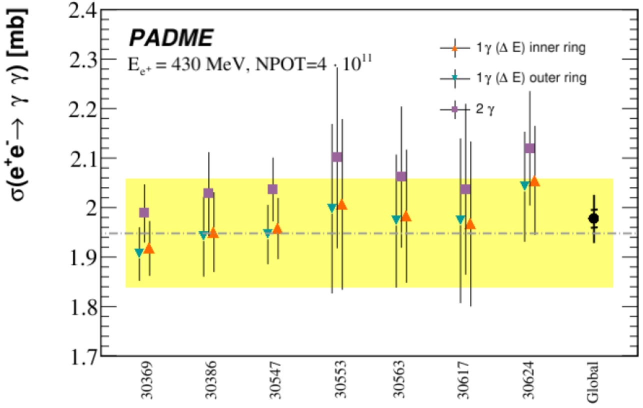
NLO

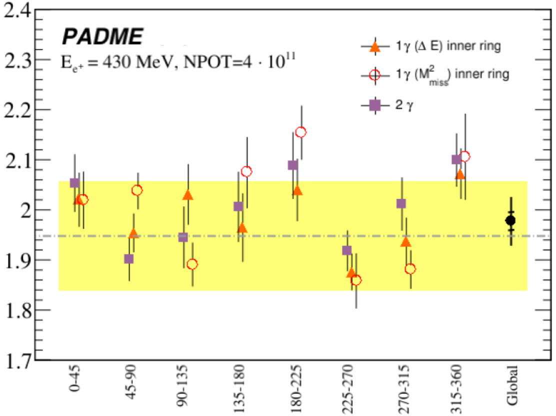


$e^+e^- \rightarrow \gamma\gamma$: results

Systematic tests: identification method, stability with data taking and R vs φ







Final result with 5.5% uncertainty:

$$\sigma(ee \rightarrow \gamma\gamma) = (1.977 \pm 0.018_{stat} \pm 0.118_{syst})\ \text{mb}$$

Uncertainty down to 3.7%* when ee → γγ is used as normalization for other searches

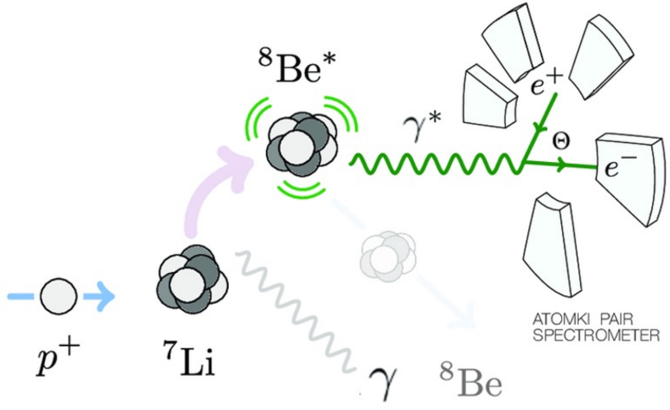
Uncertainty summary	
Detector uniformity	0.024 mb
Background modelling	0.009 mb
Acceptance	0.037 mb
N_{POT}	0.079 mb
Electron density	0.073 mb

***Expected down to 1% if intensity down by x10**

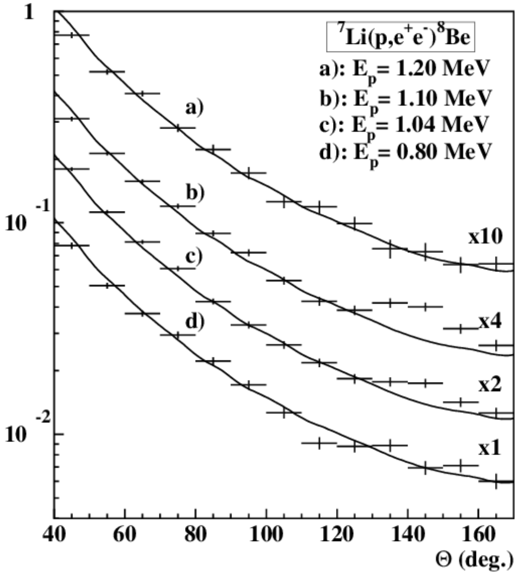
Run III

Standing anomalies in the game: “X17”

De-excitation of light nuclei via IPC, an anomaly in the decay of ^{8}Be and ^{4}He

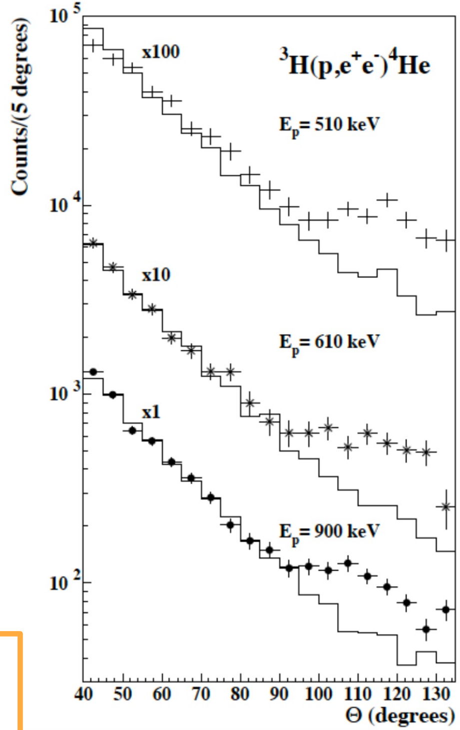


PRL 116, 042501 (2016)

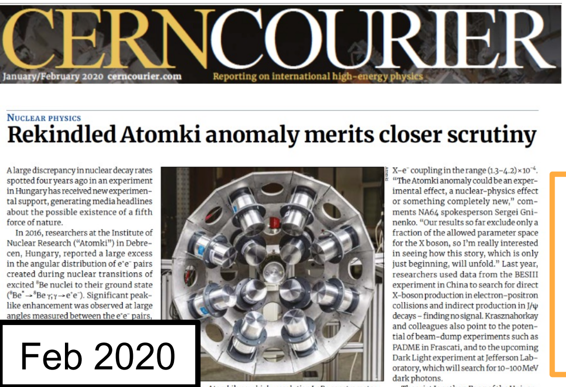


m_χ = (17.01 ± 0.16) MeV

Phys. Rev. C 104, 044003 (2021)



m_χ = (16.98 ± 0.16 ± 0.20) MeV



CERNCOURIER

January/February 2020 cerncourier.com Reporting on international high-energy physics

NUCLEAR PHYSICS

Rekindled Atomki anomaly merits closer scrutiny

A large discrepancy in nuclear decay rates spotted four years ago in an experiment in Hungary has received new experimental support, generating media headlines about the possible existence of a fifth force of nature.

In 2016, researchers at the Institute of Nuclear Research (“Atomki”) in Debrecen, Hungary, reported a large excess in the angular distribution of e^+e^- pairs created during nuclear transitions of excited ^{8}Be nuclei to their ground state ($^{8}Be^* \rightarrow {}^{8}Be\,\gamma; \gamma \rightarrow e^+e^-$). Significant peak-like enhancement was observed at large angles measured between the e^+e^- pairs,

X–e^- coupling in the range (1.3–4.2)×10^{-4}. “The Atomki anomaly could be an experimental effect, a nuclear-physics effect or something completely new,” comments NA64 spokesperson Sergei Gninenko. “Our results so far exclude only a fraction of the allowed parameter space for the X boson, so I’m really interested in seeing how this story, which is only just beginning, will unfold.” Last year, researchers used data from the BESIII experiment in China to search for direct X-boson production in electron–positron collisions and indirect production in J/ψ decays – finding no signal. Krasznahorkay and colleagues also point to the potential of beam-dump experiments such as PADME in Frascati, and to the upcoming Dark Light experiment at Jefferson Laboratory, which will search for 10–100 MeV dark photons.

Feb 2020

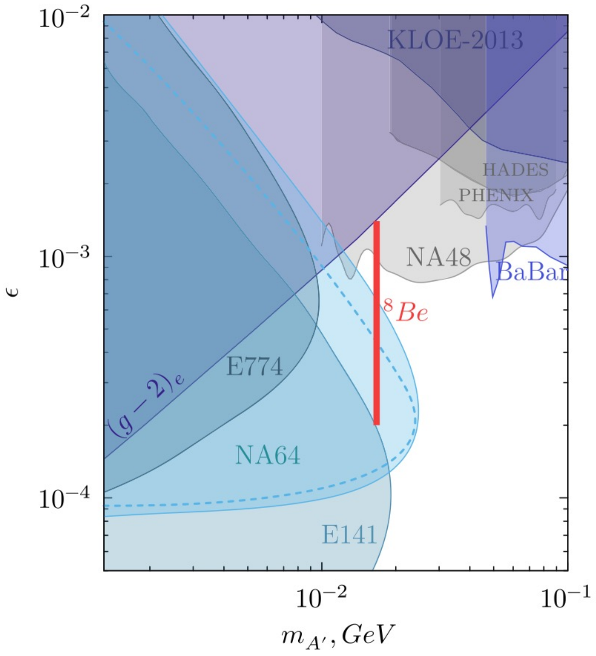
In ^{12}C [PRC 106, L061601], GDR of ^{8}Be [2308.06473], in ^{8}Be/12C at HUS (Vietnam)

Other efforts ongoing (e-, n beams, etc.)

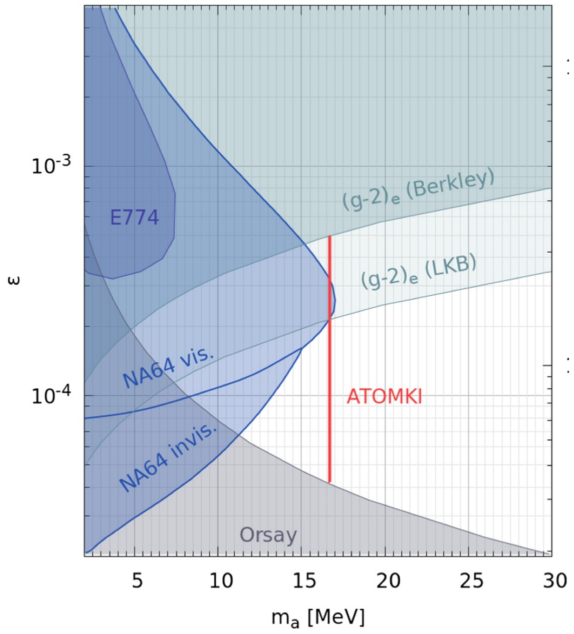
“X17” as a vector or pseudo-scalar state

New physics interpretations not fully excluded

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



Phys. Rev. D 104, L111102 (2021)

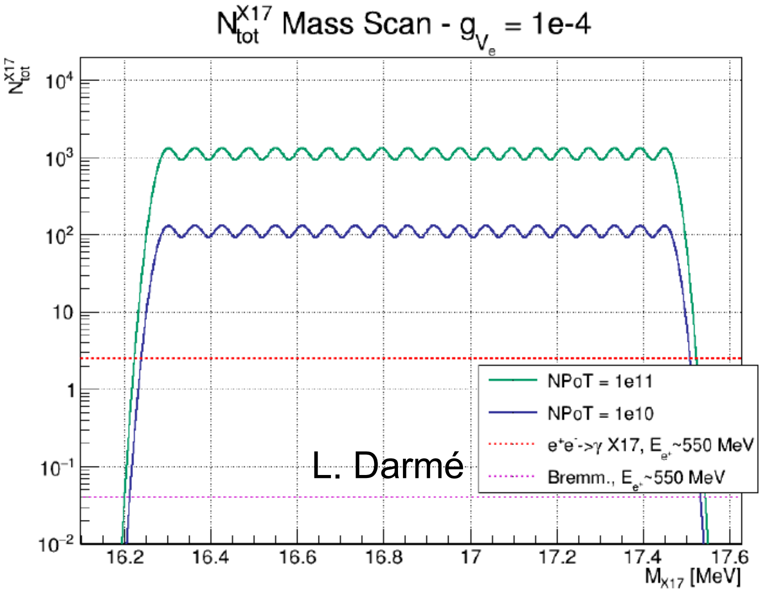


Novel QCD interpretations exist, too [hexadiquark states for He4, 2206.14441]

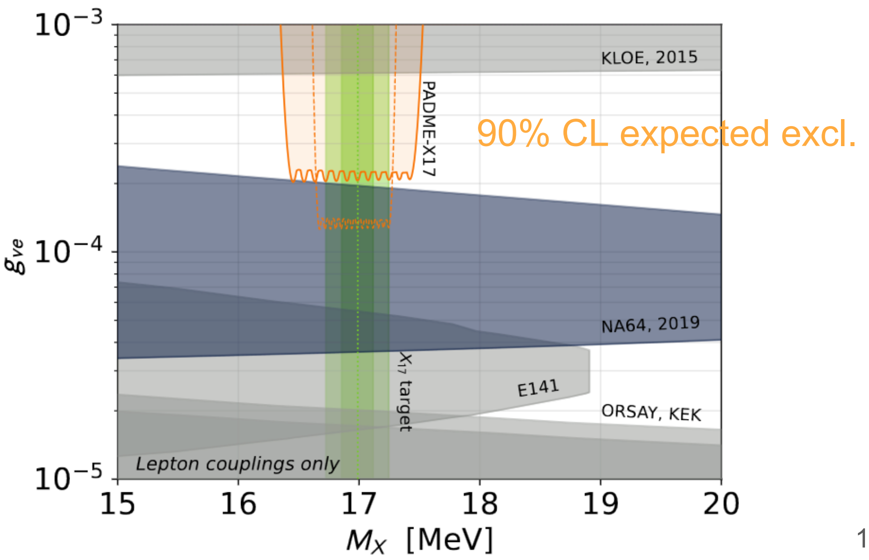
Data quality and goals for Run-III data: X17

At PADME, an independent production mode to test existence of X17

Resonant production with $E(e^+) \sim 283$ MeV: signal should emerge on top of Bhabha s and t-channel bkg, intrinsic width ~0.01 eV [Darmé, et al., PRD 106 115036]



Run-III corresponds to the upper curve, with higher density of scan points (0.5% BES, 12 points, 2E11 POT)

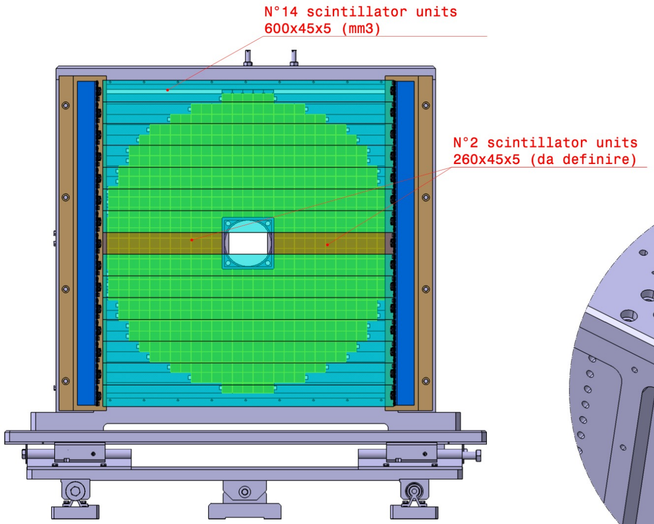


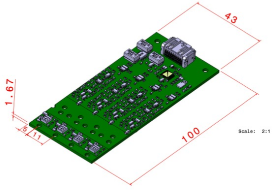
X17 via resonant-production: detector upgrade

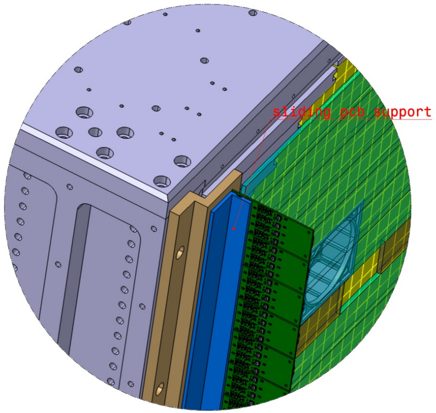
The setup for an e^+e^- resonance search is modified with resp. to Run II

Switch off the PADME dipole → increase acceptance

Distinguish e/γ in the ECAL with a new hodoscope, the E_{tag}







Built, commissioned July 2022, to be used for systematic cross checks

Overall analysis scheme

Analysis pillars:

- Measurement of e^+ beam quadri-momentum
- Measurement of beam energy spread
- Selection of $e^+e^-/\gamma\gamma$ final states
- Independent measurement of POT

Open possibilities:

N (e^+e^-) / POT vs √s as in Darmé et al., PRD 106 (2022) 11 , 115036

N (e^+e^- + $\gamma\gamma$) / POT vs √s

N (e^+e^-) / N ($\gamma\gamma$) vs √s

Goal: % level total systematic error (excl. components indep. of √s)

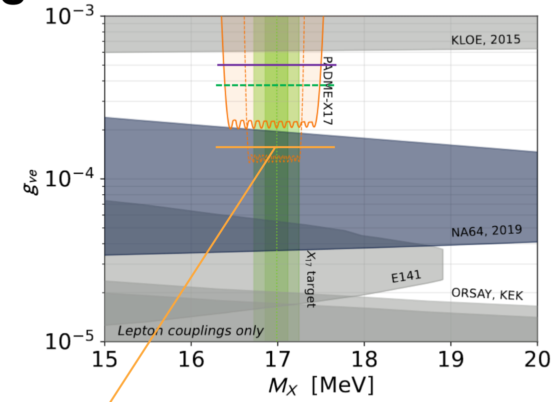
Basic assumptions [N (e^+e^- + $\gamma\gamma$) / POT]

Statistics collected (after data quality cuts): O(10^{10} POT) / point

Beam momentum spread: σ_E = 0.7 MeV/c → 0.25% relative beam spread

47 points spaced by ΔE = 0.75 MeV/c ~ σ_E, reduce span due to binning

- **Signal counts (S) expected per point: S = 350 x (g_{ve} / 2 × 10^{-4})^2**
- **Background (B) expected per point: B ~ 45000 events**



S / √B ~ 1.6 x (g_{ve} / 2 × 10^{-4})^2

- **5σ discovery for g_{ve} > 3.5 × 10^{-4}**
- **If no signal, 90% CL excl. for g_{ve} > 0.9 × 10^{-4}**

Systematic σ_B negligible if σ_B / B << 1/√B = 0.5%

If σ_B / B = 1%:

- **sensitivity worsens by √3 → 5σ, 3σ obs. 5 (3.8) × 10^{-4}, excl. 1.5 × 10^{-4}**
- **expected exclusion in absence of NP would remain within NA64**

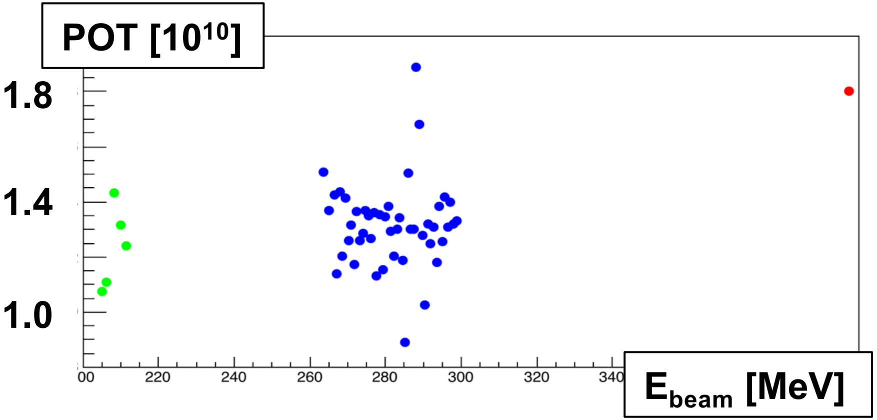
X17 via resonant-production: run III

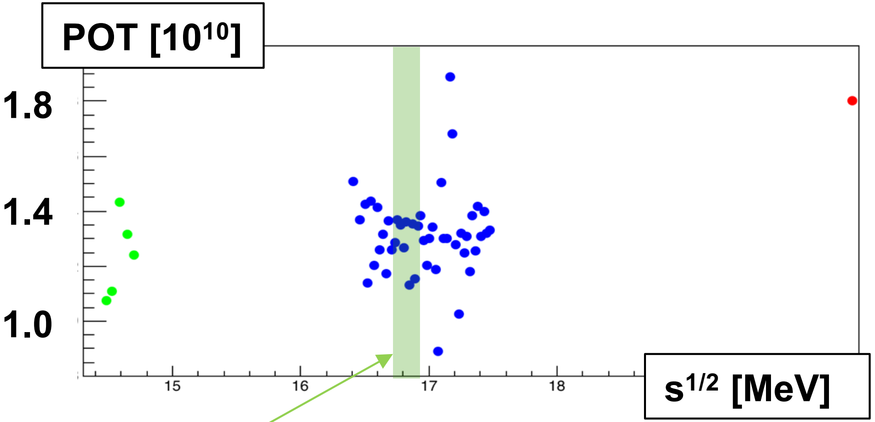
Run III PADME data set contains **3 subset**
- **On resonance: 47 points (263-299) MeV**
- **Below resonance: 5 points (205-211) MeV**
- **Over resonance: 1 energy 402. MeV**

On resonance points, mass range 16.4 — 17.5 MeV
Beam energy steps ~ 0.75 MeV ~ beam energy spread
Spread equivalent to ~ 20 KeV in mass
Statistics > 10^{10} POT per point

Below resonance points
Beam energy steps ~1.5 MeV
Statistics > 10^{10} POT per point
Used to validate analysis method

1 over resonance energy point
Statistics ~2 x 10^{10} total
Used to validate POT measurement



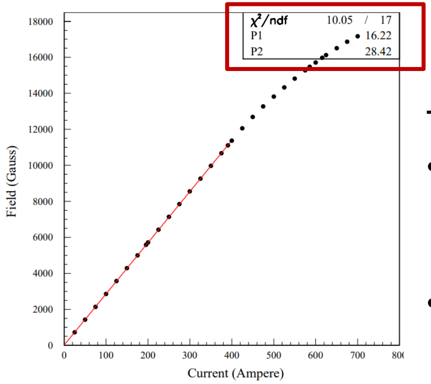


Fit result from ATOMKI data
[PRD 108, 015009 (2023)]

Measurement of beam 4-momentum in Run III

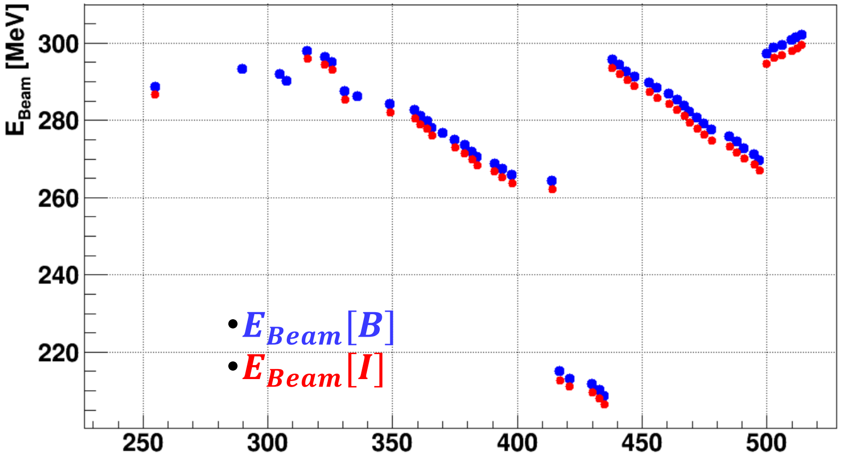
Two measurements of the energy available

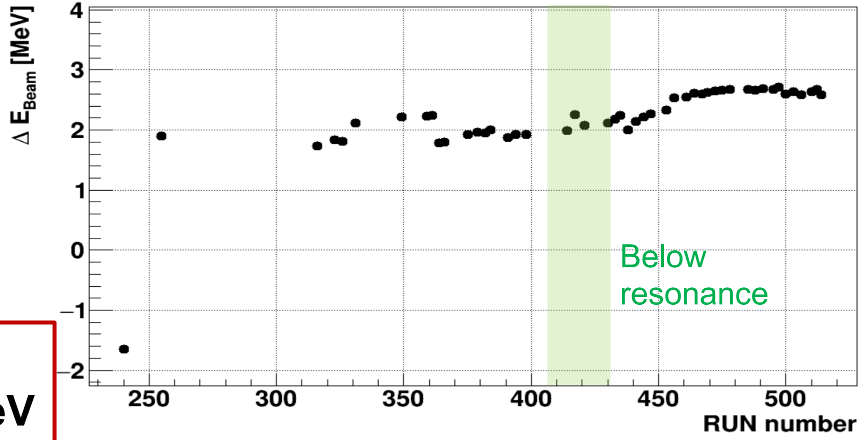
- Magnetic field (B) from Hall probe at DHSTB001: P_{Beam} [MeV] ~ 0.0551 x B[G]
- Current of DHSTB001 coils from power supply: P_{beam} [MeV] ~ 0.0551 x (K + 28.42 x I[A])



The *offset K* depends on:

- Residual magnetization – variable during the data taking
- Position of the Hall probe

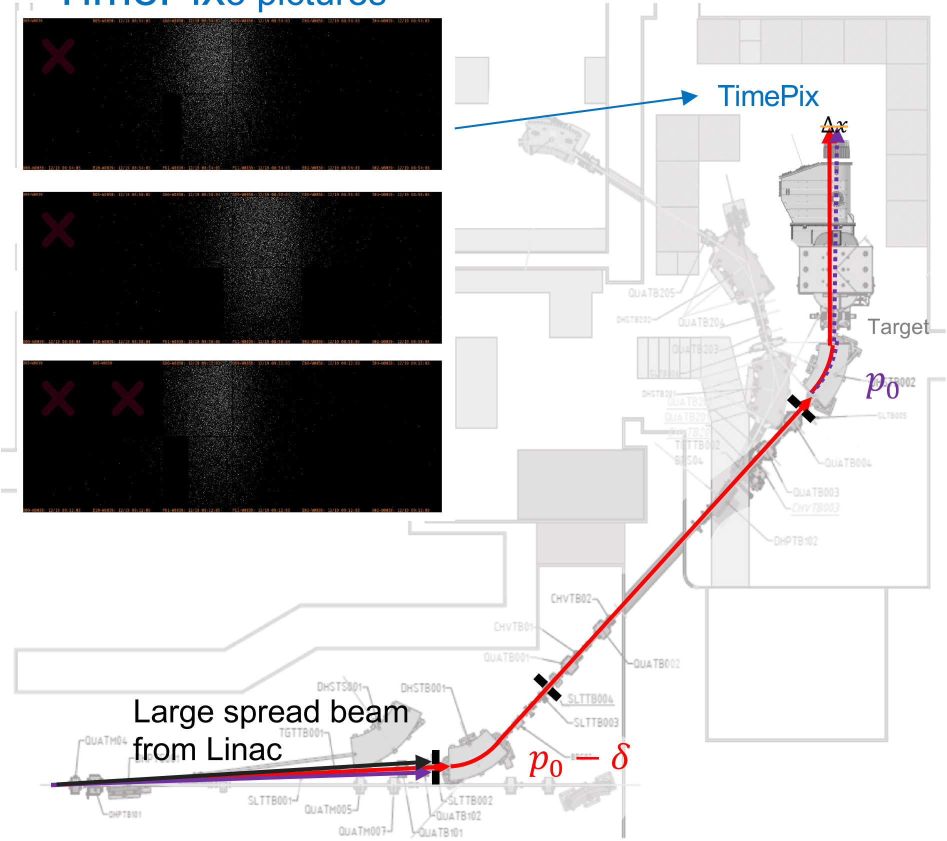




Beam energy known with ~ 2 MeV uncertainty,
conservative systematic uncertainty $\delta m_{X_{17}} \sim 30$ keV

Beam energy spread

TimePix3 pictures



In a spectrometer line the horizontal position of a particle with momentum $p = p_0(1+\delta)$ with $\delta = \sigma_p/p_0$, will be offset by $\Delta x = D_x\delta$, where D_x is the dispersion function; $D_x \approx L\varphi$ (L is the arm length and φ the deflection angle)

The beam spot size is given by: $\sigma_x = \sqrt{\varepsilon\beta + \left(\frac{D_x\sigma_p}{p}\right)^2}$

If the geometric beam size in absence of dispersion can be neglected, $\sqrt{\varepsilon\beta} \ll \frac{D_x\sigma_p}{p}$, we can get the spread from: $\frac{\sigma_p}{p} \approx 1/D_x \cdot \sigma_x$ NIM A515 (2003) 524

From a **run without the PADME target** (no Coulomb scattering) we estimate: $\frac{\sigma_p}{p} \approx$ **0.24%**

- Can also be computed from collimators' gaps/distances from MC, JHEP 09 (2022) 233

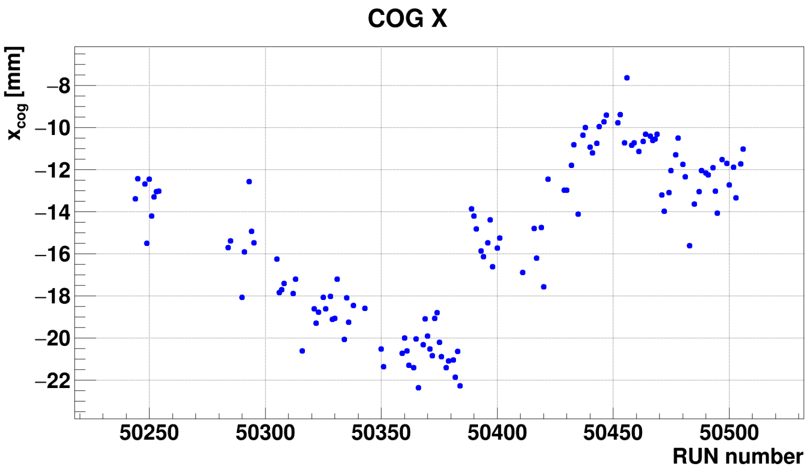
$$\left|\frac{\Delta E}{E}\right| = \frac{h}{2\rho} + \sqrt{2}\left(\frac{R_x}{L_1} + \frac{H}{2L_1}\right) \cong \frac{h}{2\rho} + \sqrt{2}\frac{H}{L_1}$$

- With H=h=2 mm we get **0.22%**

Signal selection: variation of beam positions

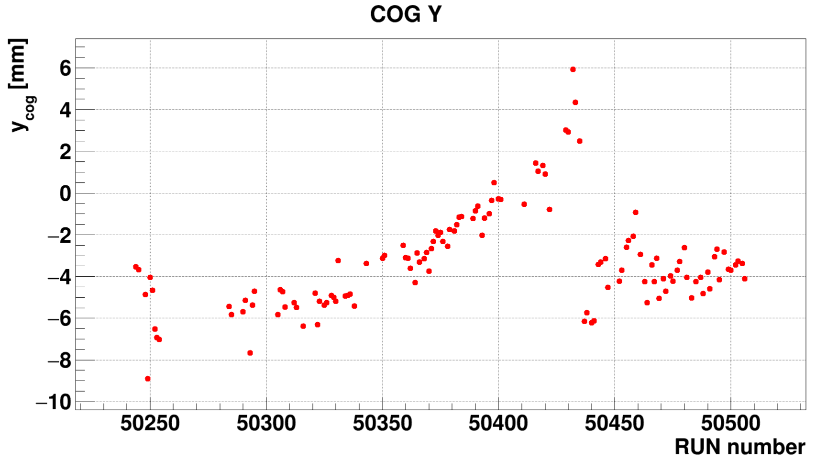
Beam position measured run by run in data from the center of gravity (COG) of 2 EM clusters at Ecal:

$$x_i^{COG} = \frac{x_i^1 E_1 + x_i^2 E_2}{E_1 + E_2}$$



The beam position slightly moves run by run

Acceptance cuts defined to follow the variations

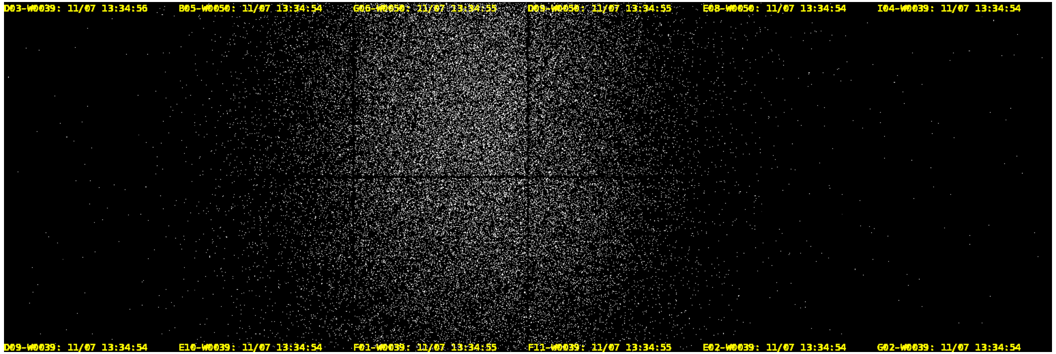


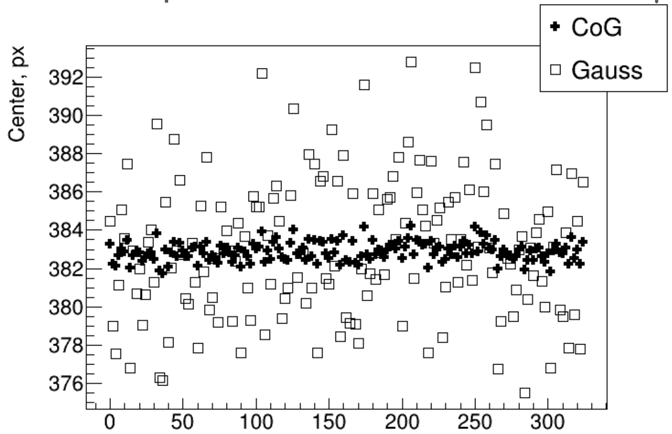
2 clusters in ECAL in a range R_{min} -- R_{max} of radius centered at $(x,y)_{COG}$:

- R_{max} = 270 mm (1.5 blocks from ECal edge)
- R_{max} is a known function of beam energy

Beam monitor with TimePix

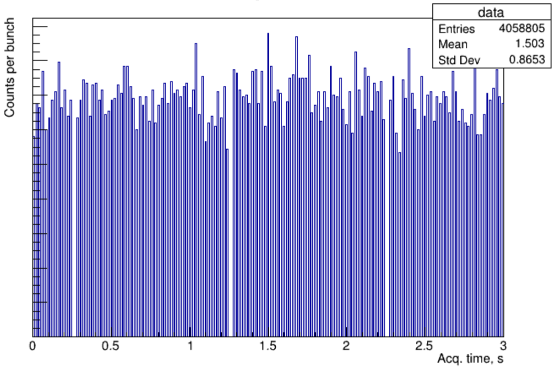
Pixel size: 55 μm,
Y beam position variation - within 100 μm



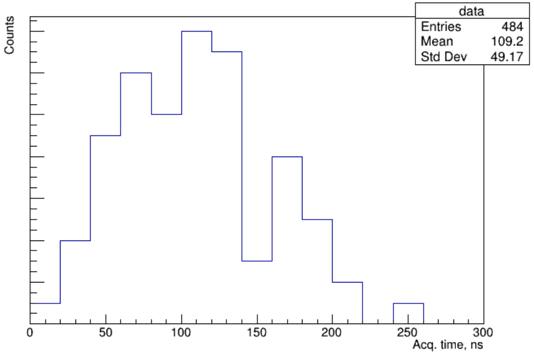


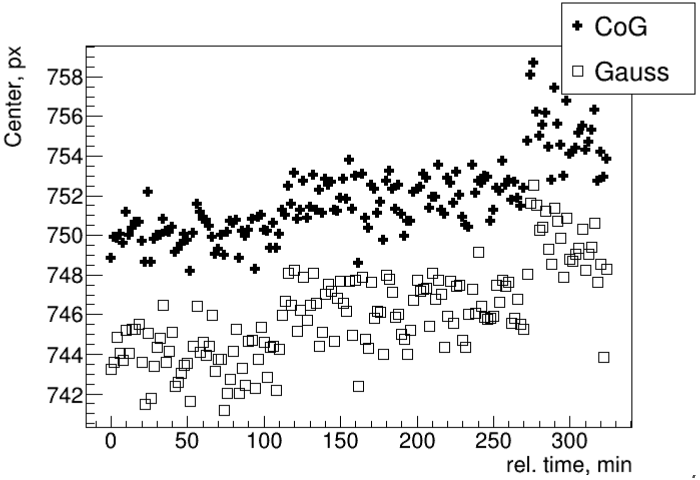
STREAMING MODE ACQUISITION

Bunch sequence



Bunch structure

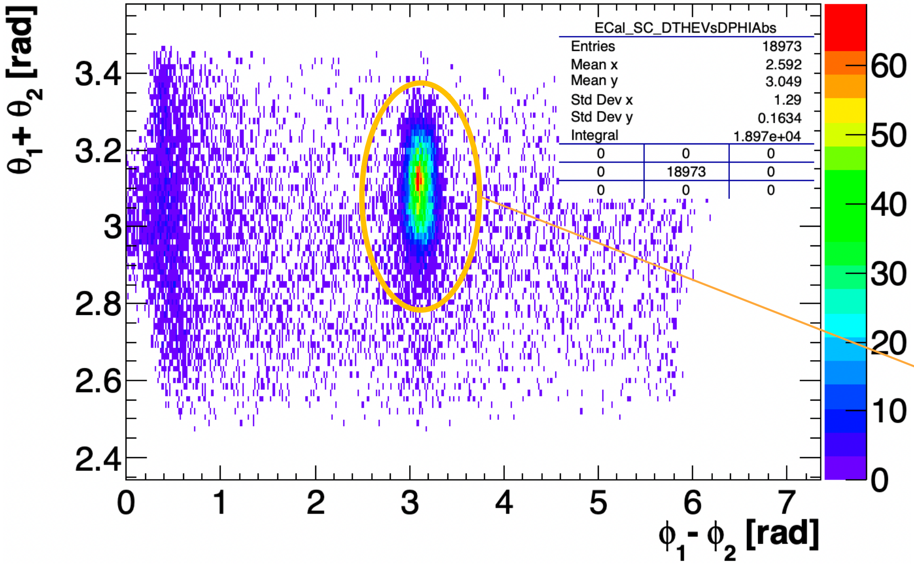


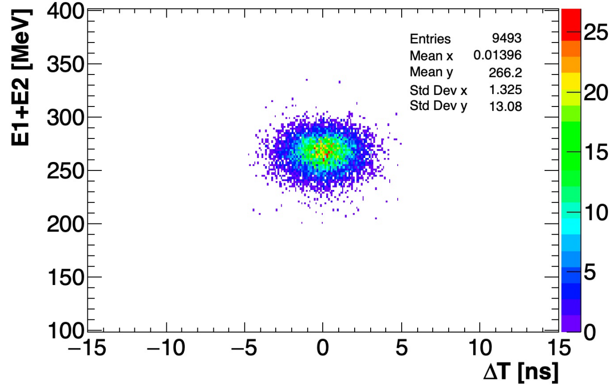


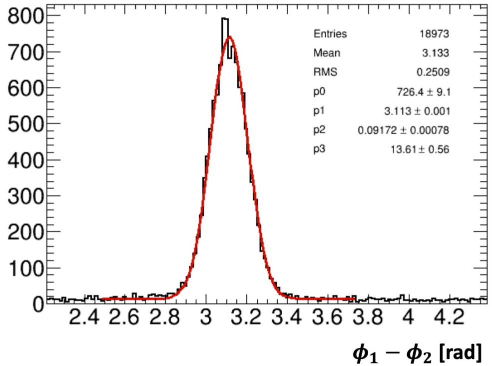
Signal selection

Selection of two clusters mutually in time [within 5 ns], in the ECAL region of interest

Enforce the kinematics expected for a two body production in the center of mass frame (no use of ECAL energy response beyond the cluster reconstruction)







Background estimation ~ 4%, taken under control from data

ECAL efficiency

ECAL efficiency from tag-and-probe technique

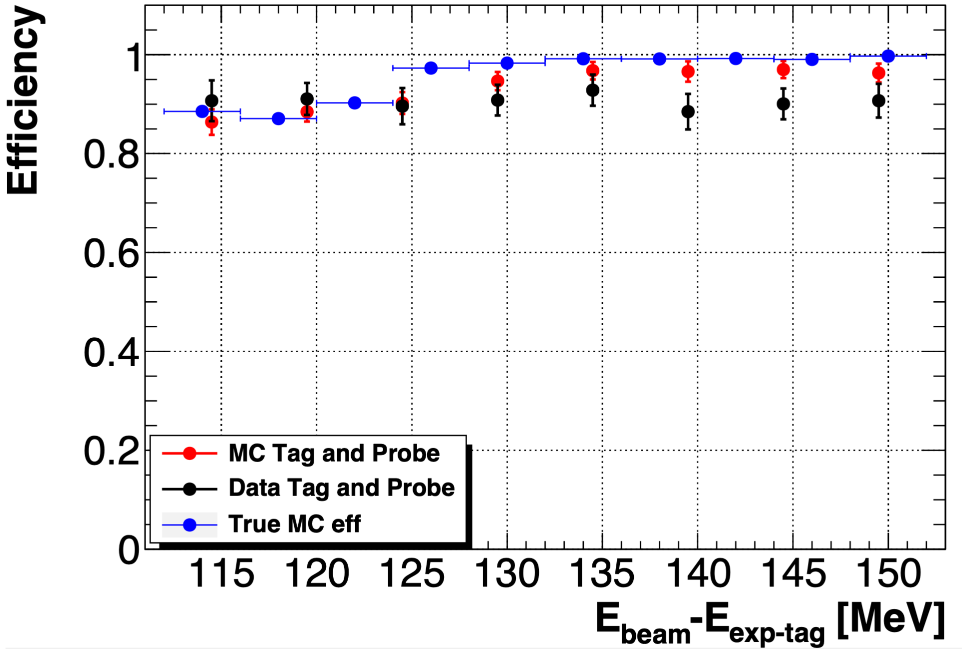
Much less background than in Run II thanks to reduced intensity

Low-energy inefficiency dominated by 15 MeV threshold on single hits

Method bias extremely limited [MC truth vs MC T&P]

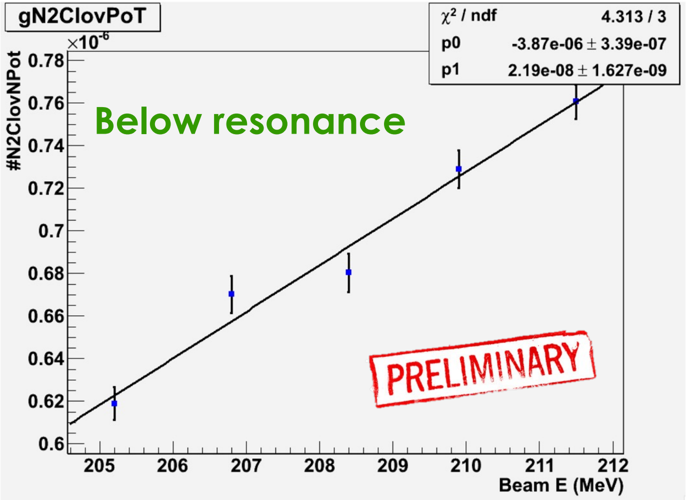
Data over MC correction limited to a few % overall

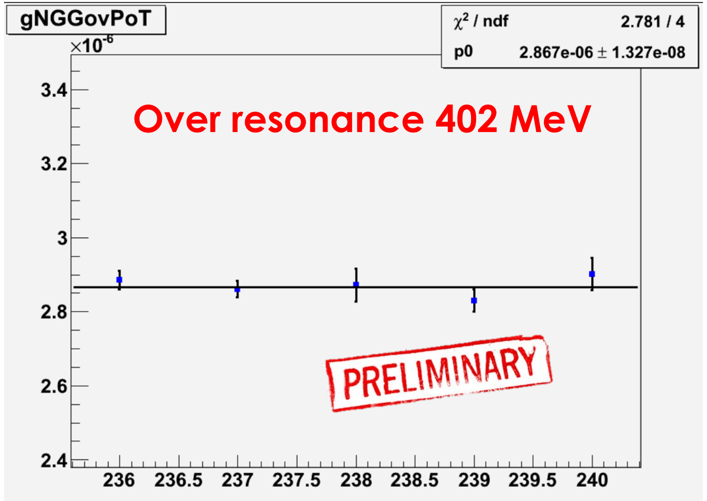
Good control of selection efficiency at the % level



Signal selection: stability

Stability proved to be better than 1% from out of resonance points



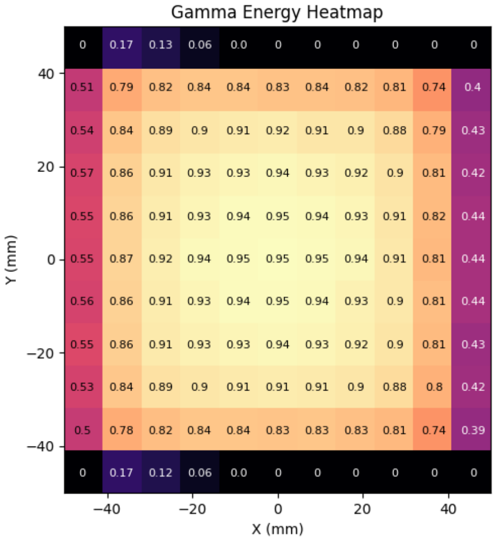


- **RMS <1%** over the 5 energies, computed on residuals wrt the fit
- Good χ^2 of the linear fit: trend due to acceptance, reproduced by MC

- **RMS ~0.7%** over the 5 runs, compatible with pure statistics
- **Fit to a constant with good χ^2**, no evidence of systematic errors, even in absence of acceptance corrections

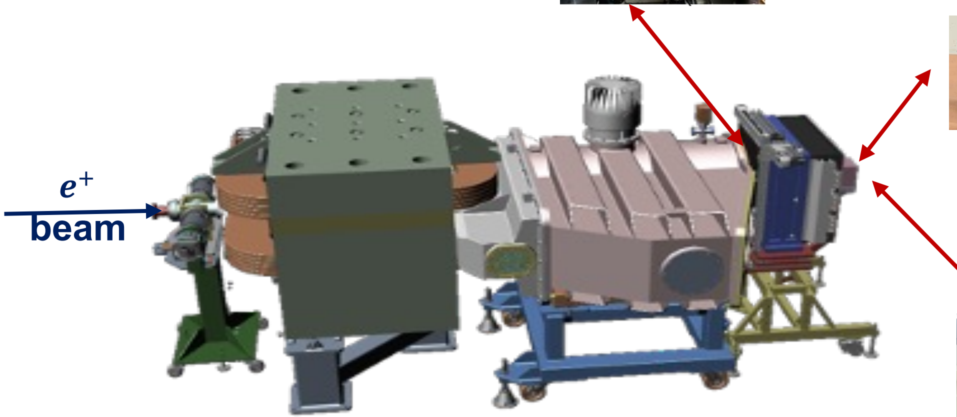
POT determination

Absolute scale of POT is not relevant for X17, only needed for absolute xs
We know the absolute scale to better than 10%, working to improve it
The beam variations induce a correction point-by-point of **several %**

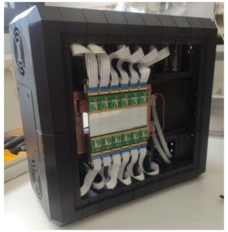


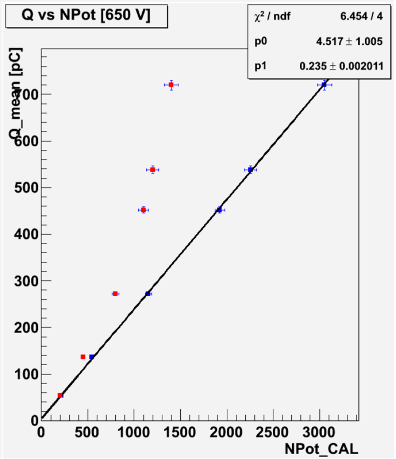
Carbon fiber window

PbGl luminometer



TimePix3 + support structure



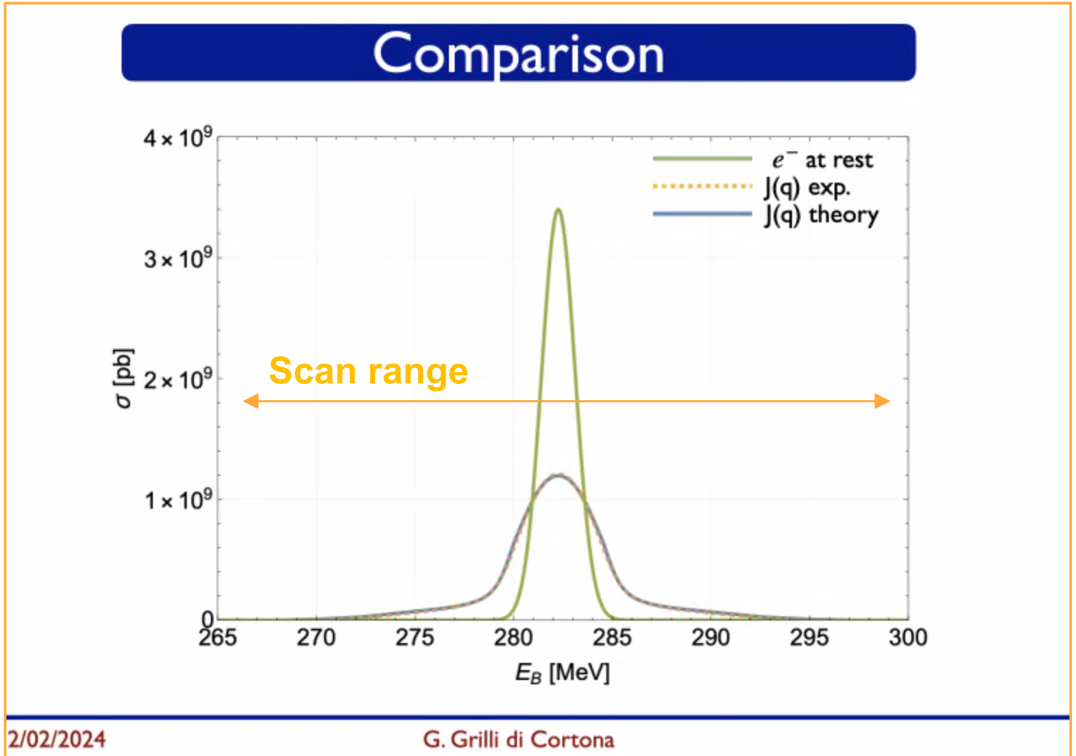


X17 via resonant-production: effect of e- motion

The motion of e^- in the diamon target spreads the resonance xs
See presentation by G. Grilli da Cortona, main effects:

1. **Peak σ down by x3, S/B down by x2**

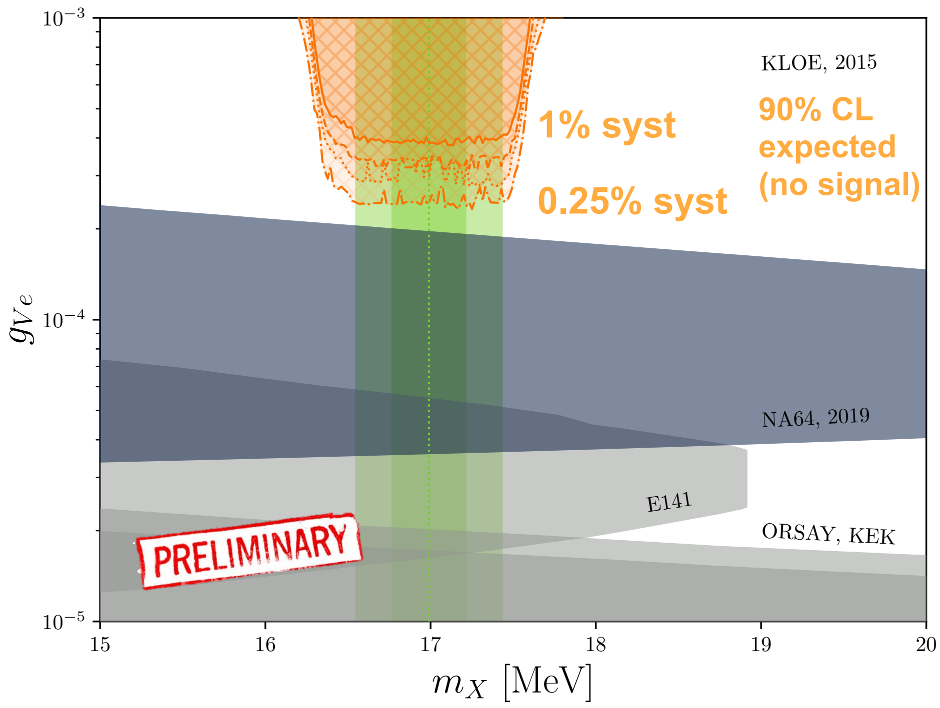
2. **Side bands for background scaling down by x4, still part of the acquired points can be used**



X17 via resonant-production: effect of e- motion

The motion of e^- in the diamon target spreads the resonance cross section
See presentation by G. Grilli da Cortona for details. The main effects are:

1. **Peak σ down by x3, S/B down by x2**
2. **Side bands for background scaling down by x4, still can be used**
3. **Sensitivity depends on the background uncertainty more than expected for the same statistics, systematic error should be reduced from 1% to 0.3% to keep the same sensitivity (!)**



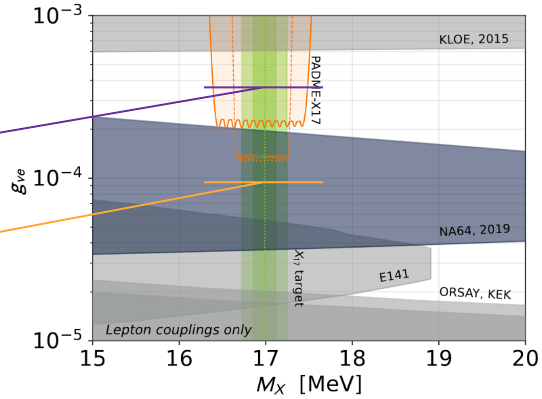
How can we improve and close?

A new data taking needed, probing X17 through N(ee)/N(γγ), not N(ee/γγ)/POT:
No systematic error on POT, reduced systematic on ECAL selection

Must improve by x4 in statistics to reduce statistical error on N(γγ) to 0.5%:
e.g.: ~x2 in intensity, fewer points needed

In this assumption: $1/\sqrt{B} \sim 0.3\%$, $1/\sqrt{N(\gamma\gamma)} \sim 0.5\%$,
$S/\sqrt{B} \sim 1.6 \times (g_{ve} / 2 \times 10^{-4})^2$

- **Discovery for $g_{ve} > 3.5 \times 10^{-4}$**
- **If no signal, 90% CL excl. for $g_{ve} > 0.9 \times 10^{-4}$**



Mis-tagging probability should be kept at few per mil
Present Etag is not suited for a per-mil stability, being rate-limited

The conclusion is that a new tagger is needed

The idea for a new tagger

A micro pattern gas detector has a number of advantages:

- **Very high segmentation**
- **Tracking capabilities**
- **Very low X0**
- **Good resolution in xy**

Exploit the available expertise from ATLAS groups

The test beam of a micromega prototype

We already had a successful test beam in Nov23 (1week) with MM detector adapted with a 5cm drift gap, extended for TPC purposes

Experimental Setup at BTF (LNF)
2 MM chambers with 5 cm drift gap

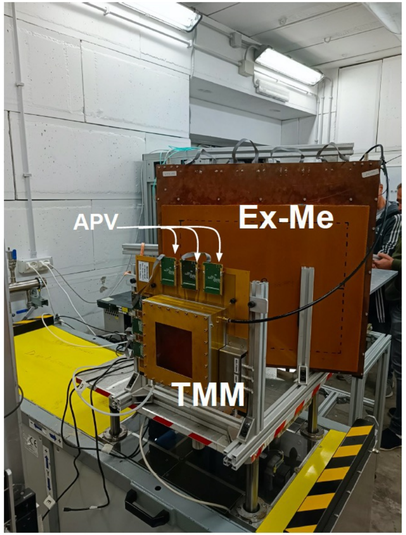
- 10x10 cm^2 TMM (x,y view)
- 40x50 cm^2 Ex-Me (1 coord.)
- Gas mixture, Ar:CF4:isobutane 88:10:2 vol%
- Electronics: APV

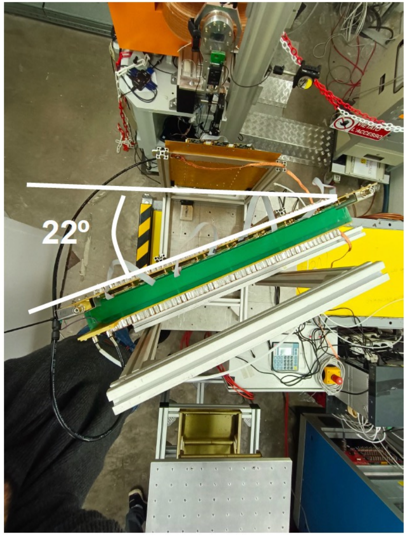
HV (nominal):

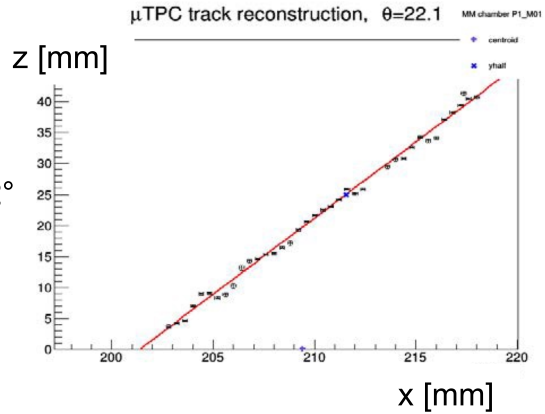
- TMM Amp: 460 V, Drift: 3 kV
- Ex-Me Amp: 490 V, Drift: 3 kV

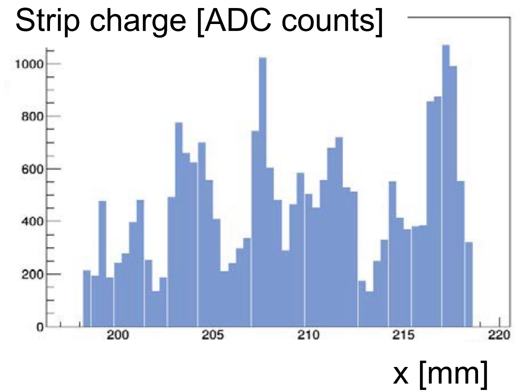
Cost of gap extension: 5 kE

- Ex-Me chamber tilted by 22°
- O(mm) e^+ beam spot



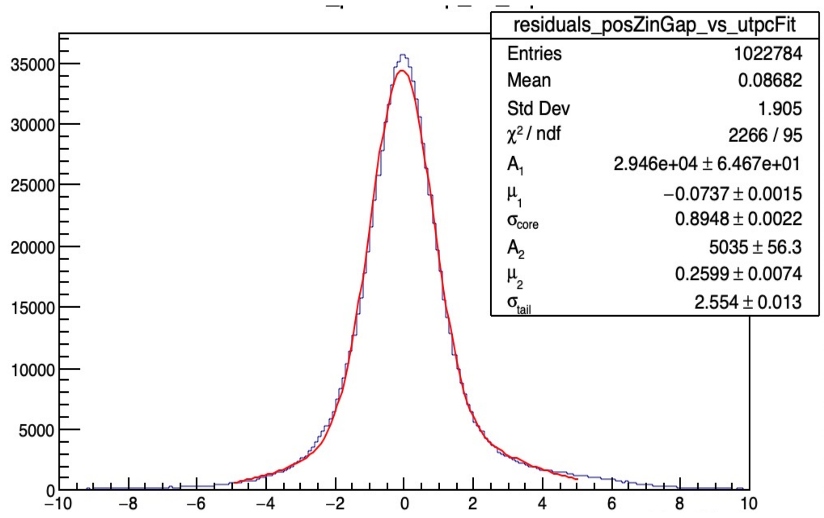




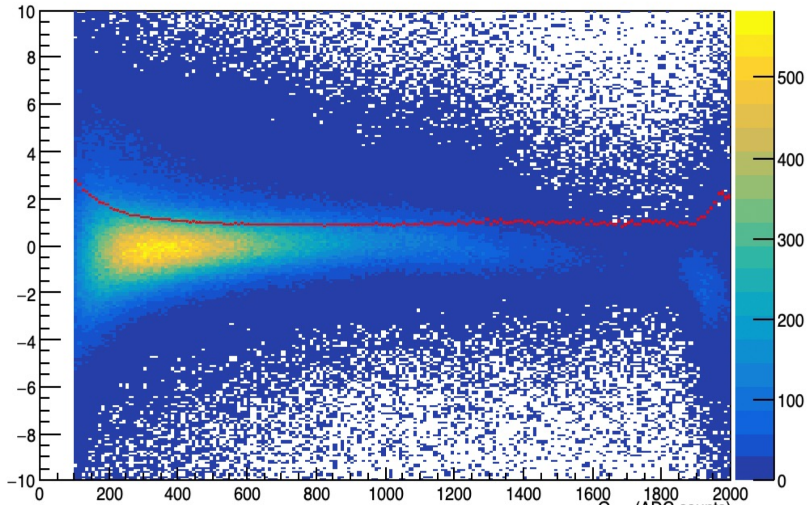


The test beam of a micromega prototype

The micro TPC operation is proved, the core resolution on the hit z coordinate depends on the charge and is around 1 mm



Fit residuals in z [mm]

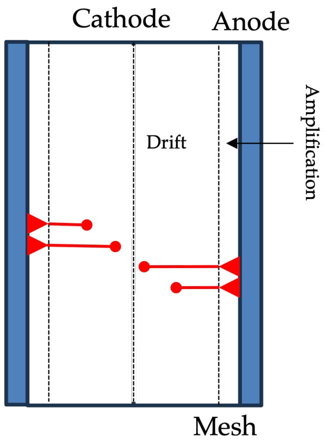


Charge in the strip [ADC counts]

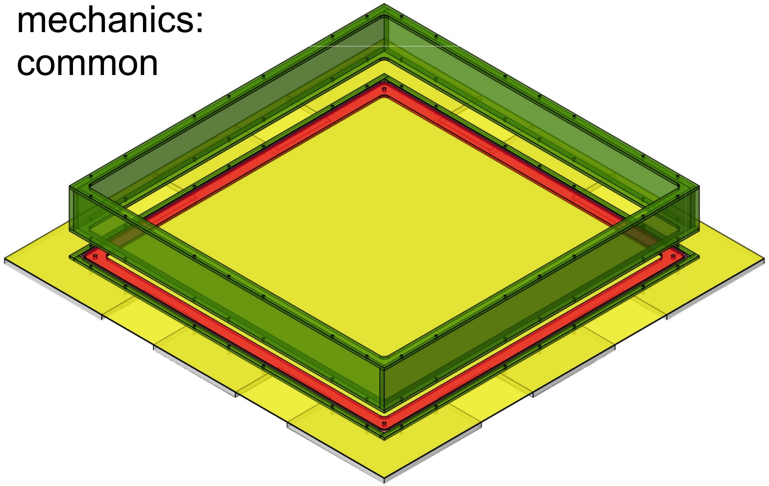
The design of a micromega tagger

Design: 2 detectors have been proposed (same mechanics to reduce costs)
- x,y strips as a baseline detectors
- diamond shaped pads read in raws: brand new design that could allow for better performances

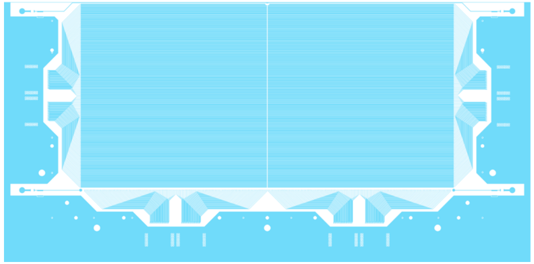
Those 2 detectors are to be tested in a 2-week test beam in May24



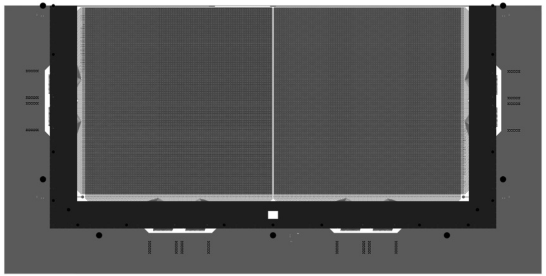
mechanics: common



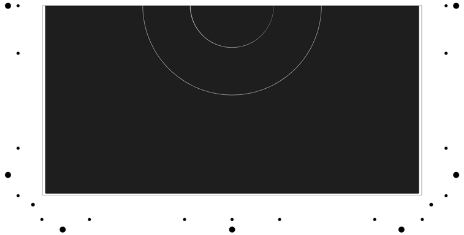
strip layout



diamond layout



resistive circuit (common, **3HV zones**)

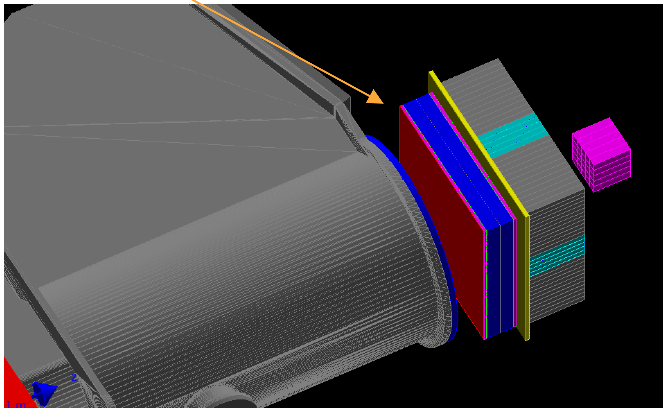


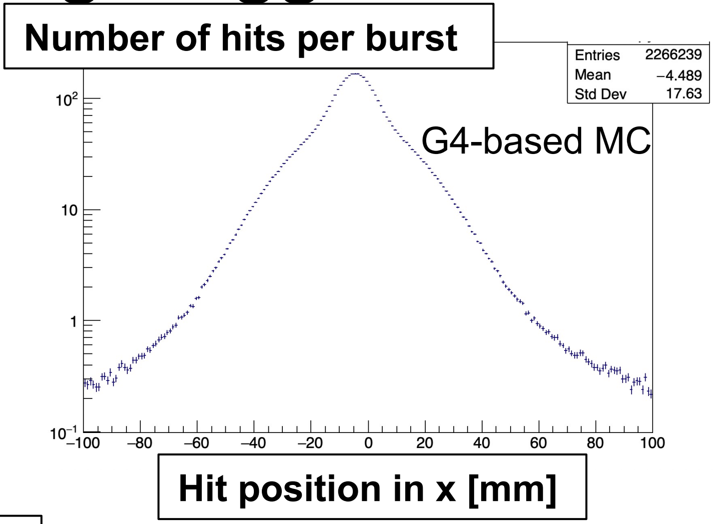
The design of a micromega tagger

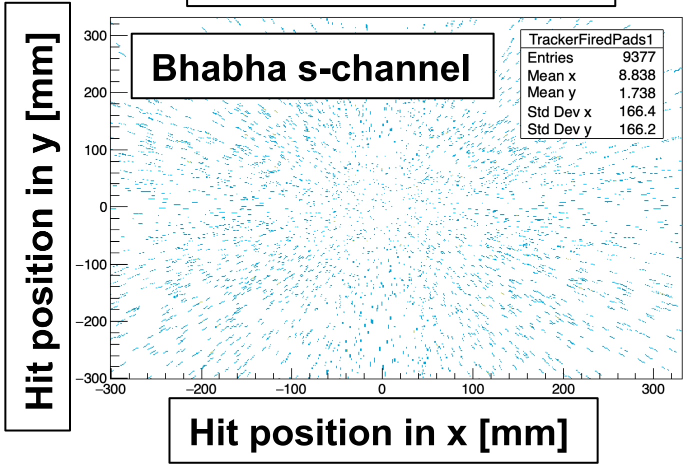
3 HV regions have been designed to cope with the higher occupancy in the central region and to operate the detector at lower amplification voltage

As determined with the test beam, this is still allowing it to act as beam monitor

The new tagger provides a reconstruction of the vertex of origin, allowing to extend the PADME program with the search for long-lived particles







The organization for a new tagger

Obviously, we need a significant addition in terms of man-power and expertise:
researchers, tecnological personnel, and expert technicians

People available to join (or already joined) the effort:
(LNF) M. Antonelli, G. Mancini, C. Arcangeletti, M. Beretta, B. Ponzio, E. Capitolo, G. Pileggi, B. Buadze, L. Gongadze

(RM1) F. Anulli
(NA) P. Massarotti, (NA-CERN) G. Sekhniaidze, (NA-CERN), P. Iengo,
(Munich LMU) R. Hertenberger, V. D'Amico,
Interest from Saclay (to be confirmed) and NTUA (to be confirmed), members of SOFIA CMS

Fine tuning of the FTE will be determined in July

Timeline and costs

Timeline of the project:

- **Aim** for detectors to be ready for the May24 test beam at LNF
- Detector drawings: available, ready to be sent for production
- Gas: to be ordered now to be ready for May24 [3 months delivery time]
- Sync of MM acquisition with PADME DAQ: to be completed in May 2024
- Green light to be ready to start integration in PADME: Jul-Aug 2024

Costs and request to CSN1: 37 kE [APP] + 14 kE [CON]

- PCB preparation **27k Euro** [Bid Rui de Olivera, CERN]
- Mechanics and other components: **4k Euro** [ELTOS, etc.]
- PC* for DAQ **10k Euro** [Informal quote, ITM Pomezia]
- Gas**: **10 kEuro** [Nippon gas]
- FEE: no cost, material available already worth 20kE →

Items	Cost per unit	Quantity	Total
master apv	135	32	4320
slave apv	135	32	4320
connection cables	15	32	480
fec v3 + adc	2460	2	4920
crate fec srs	1000	1	1000
cavi hdmi	10	16	160
piedini di massa per APV	10	64	640
panasonic	10	64	640
transceiver	100	2	200
SY5527	2900	1	2900
HV board	4760	1	4760
total			19580

* Downgraded version of PC in use for nSW QC: 24 kE

**1 bottle of premixed gas costs ~300 Euros and lasts 7-10 days, studies on the gas flow to be performed in May

Conclusions

The quality of the PADME Run III data is in line with the expectations:

1% overall systematic error within reach

Aim of opening the box in time for summer conferences

Unfortunately, the sensitivity is reduced by the effect of the e- motion more than anticipated

Closing the gap with NA64 requires a new run with an upgraded detector

A tracker based on micromegas allows precision measurement of ee/$\gamma\gamma$

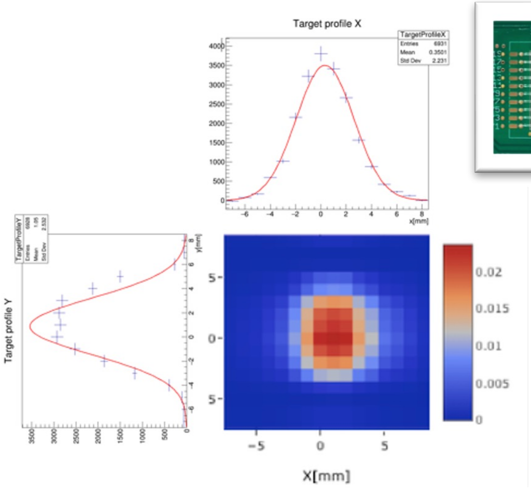
POT-independent and experimentally clean

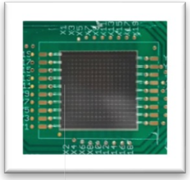
Need x4 in statistics to reduce statistical error on $\gamma\gamma$ to 0.5%

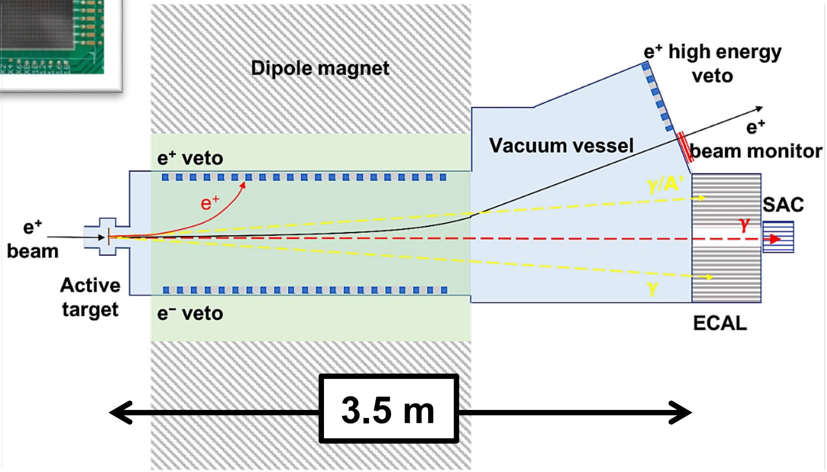
Spare slides

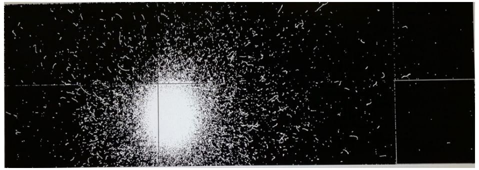
What's PADME – the detector: beam monitors

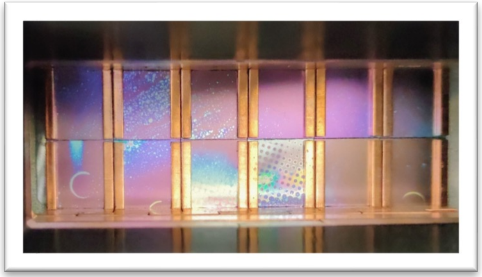
1.5 × 1.5 mm² spot at active, 100 μm diamond target: position, multiplicity
1 × 1 mm² pitch X,Y graphite strips [NIM A 162354 (2019)]









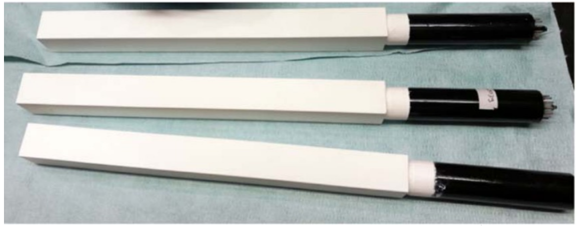


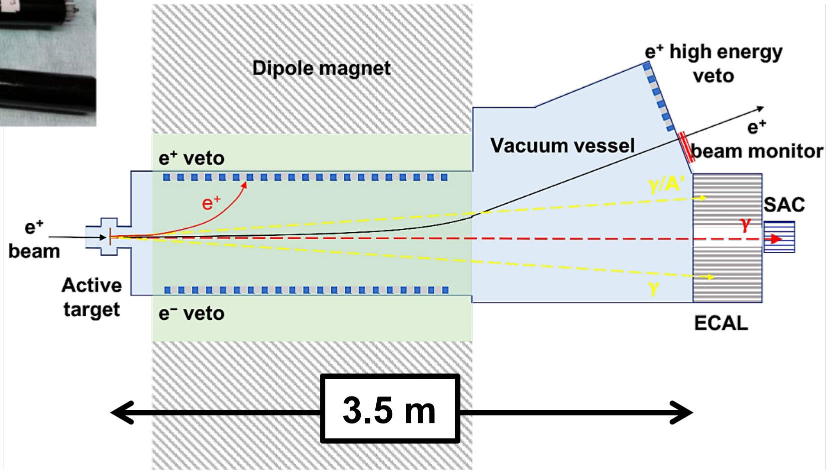
Bend by CERN MBP-S type dipole: 0.5 T field, 112×23 cm² gap, 70 cm long
Beam monitor (Si pixels, Timepix3) after bending: $\sigma_P/P_{beam} < 0.25\%$

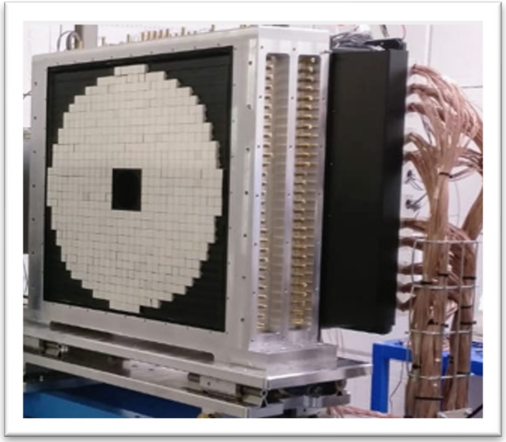
What's PADME – the detector: calorimeters

Forward calorimeter: $\sigma_E/E = 2\% / \sqrt{E[GeV]} + 0.003\% / E[GeV] + 1.1\%$

616 BGO crystals (LEP L3), 2.1 × 2.1 × 23 cm^3 [JINST 15 (2020) T10003]







Forward photons detected by fast PbF_2 small angle calorimeter (SAC)

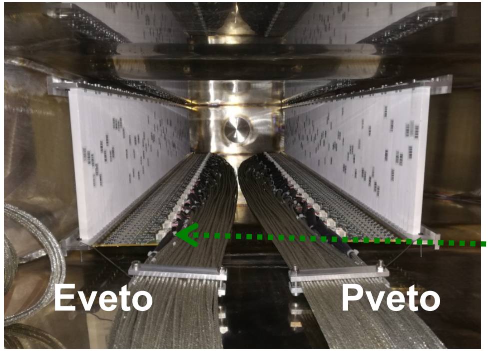
σ_T ~ 80 ps, double-pulse separation < 2 ns [NIM A 919 (2019) 89]

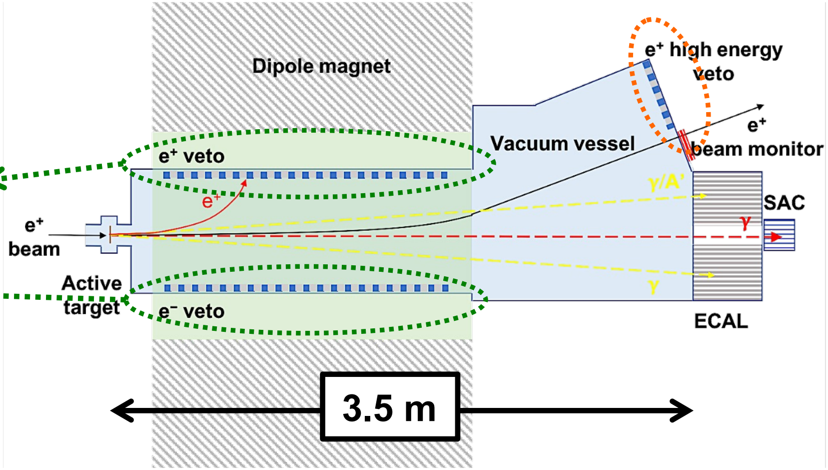
What's PADME – the detector: vetoes

Veto for e^+/e^- with scintillating bars, 1 × 1 × 17.8 cm^3 [JINST 15 (2020) 06, C06017]

Inside vacuum vessel

on the sides (186 ch's) of the dipole magnet gap + forward (16 ch's)





For collinear e^+ (brems), the scintillating bar hit gives the e^+ momentum

Time resolution ~ 0.5 ns, inefficiency < 0.1% [NIM A 936 (2019) 259]

What's PADME – the TDAQ concepts

Three trigger lines: Beam based, Cosmic ray, Random

Trigger and timing based on custom board [2020 IEEE NSS/MIC, doi: 10.1109/NSS/MIC42677.2020.9507995]

Most detectors acquired with Flash ADC's (CAEN V1742), O(10^3) ch's:

- **1 μs digitization time window**
- **1 V dynamic range, 12 bits**
- **sampling rates at 1, 2.5, 5 GS/s**

Level 0 acquisition with zero suppression, ×10 reduction → 200 KB / ev.
Level 1 for event merging and processing, output format ROOT based

First experiment goal (A' invisible search) required 10^{13} POT, O(80 TB)

Measurement of $e^+e^- \rightarrow \gamma\gamma$: data set and concept

Using < 10% of Run II data, N_{POT} = (3.97 ± 0.16) ×10^{11} positrons on target

- **Expect $N_{ee\rightarrow\gamma\gamma}$ ~0.5 M, statistical uncertainty < 1%**
- **Include various intensities, e^+ time profiles for systematic studies**
- **Evaluate efficiency corrections from MC + data**

Master formula:

$$\sigma_{e^+e^-\rightarrow\gamma\gamma} = \frac{N_{e^+e^-\rightarrow\gamma\gamma}}{N_{POT} \cdot n_{e/S} \cdot A_g \cdot A_{mig} \cdot \epsilon_{e^+e^-\rightarrow\gamma\gamma}}$$

N_{POT} from diamond active target

Uncertainty on e^- density $n_{e/S} = \rho N_A Z/A\ d$ depends on thickness d

Run #	NPOT [10^{10}]	e^+/bunch [10^3]	length [ns]
30369	8.2	27.0 ± 1.7	260
30386	2.8	19.0 ± 1.4	240
30547	7.1	31.5 ± 1.4	270
30553	2.8	35.8 ± 1.3	260
30563	6.0	26.8 ± 1.2	270
30617	6.1	27.3 ± 1.5	270
30624	6.6	29.5 ± 2.1	270
30654	No-target	~ 27	~ 270
30662	No-Target	~ 27	~ 270

$e^+e^- \rightarrow \gamma\gamma$: POT, target thickness

N_{POT} from active target, uncertainty is 4%:

1. **Absolute calibration by comparing with lead-glass calorimeter fully contained from 5k to 35k e+/bunch**
2. **When focusing beam into 1-2 strips, non-linear effects observed**

$n_{e/S}$ from target thickness, uncertainty is 3.7% (i.e., ~3.7 μm)

1. **Measured after assembly with profilometer with 1 μm resolution as difference with respect to the supporting surface**
2. **Correction due to roughness (quoted as 3.2 μm by producer): compare precision mass and thickness measurements on similar diamond samples**

$e^+e^- \rightarrow \gamma\gamma$: analysis strategy

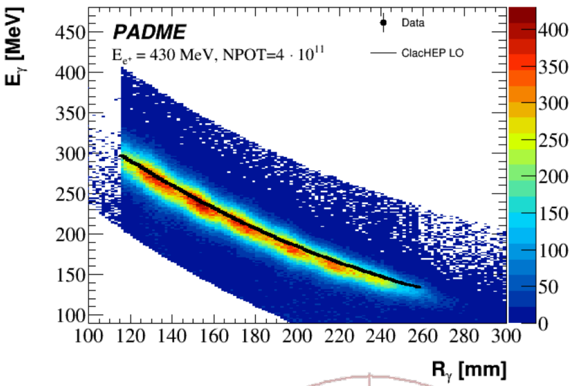
Exploit E vs θ correlation for selection, $E_{exp} = f(\theta)$

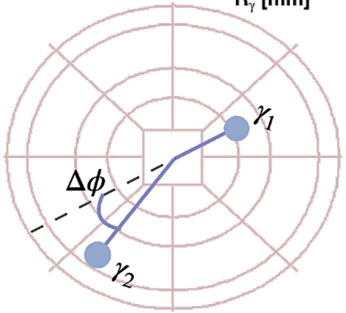
Background templates from no-target runs

Signal samples: 2γ (bkg/sig ~ %), 1γ (bkg/sig ~1)

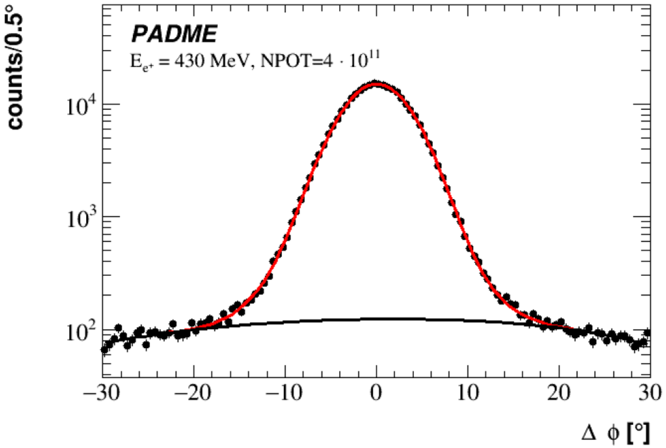
Data-driven Tag&Probe corrections

Independent measurements 2 R-bins × 8 φ-bins: bkg varies by x7

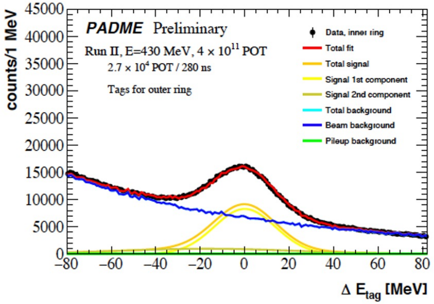


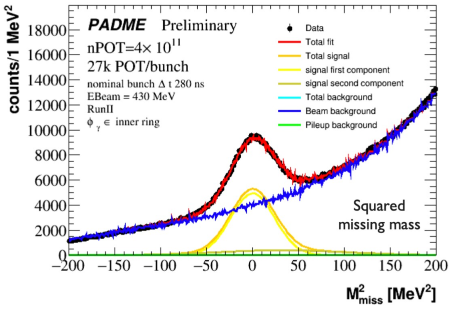


Two-photon selection

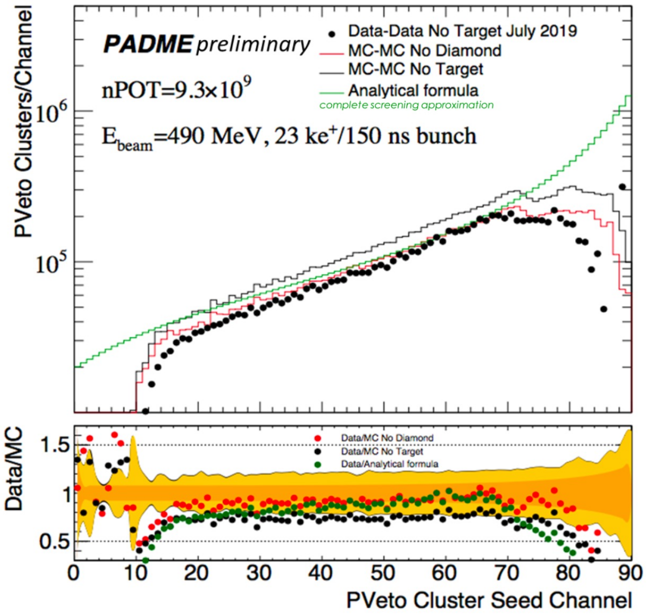


Single photon selection



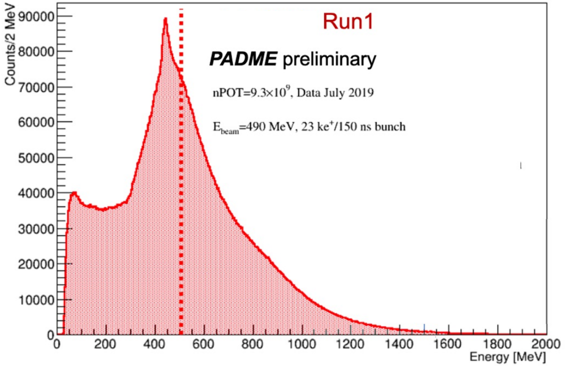


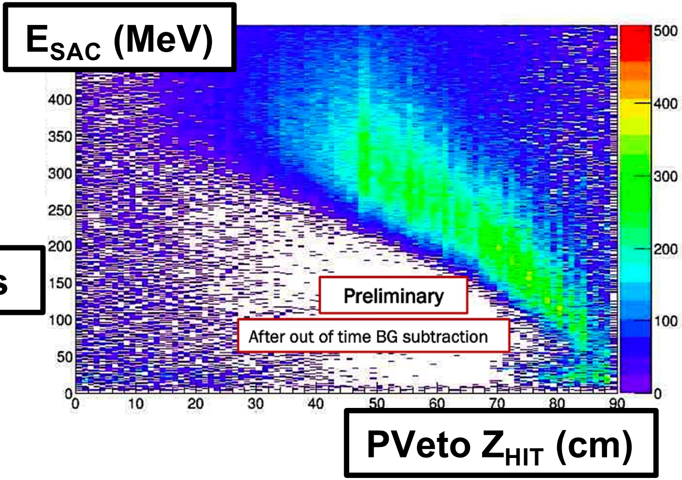
The single γ search: veto capability



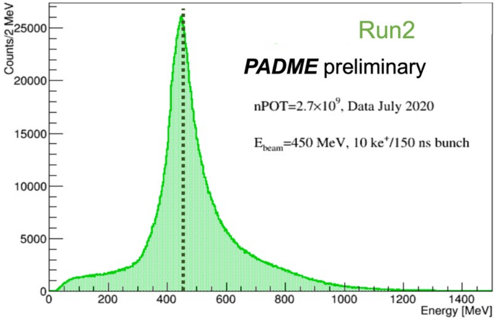
Beam background dominated by Bremsstrahlung:

- Measured with no-target runs and subtracted
- Bremsstrahlung photon distribution in agreement with **MC** and **analytical calculation**
- Main systematic uncertainties:
  - Background normalization
  - e^+ momentum scale
  - N_{POT} calibration

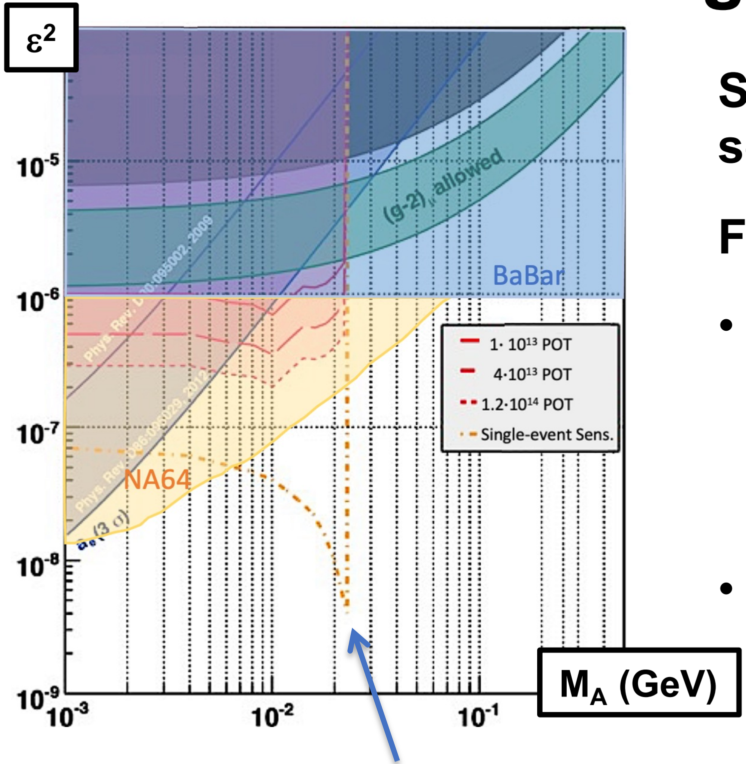




ΔT(SAC-PVETO) < 1 ns



The single γ search: status



Search presently background dominated, sensitivity scales as √bkg

For background reduction with Run II data:

- Improved, AI-assisted ECAL reconstruction: promising double-pulse separation, time resolution, linearity [see Instruments 6 (2022) 4, 46 and talk by K. Stoimenova at CALOR 2022]
- Improved veto conditions using ML

A single-particle experiment with a (quasi-) continuous beam: stretch the LINAC beam pulse using the DAFNE ring, 10^{16} POT achievable in 2 years [arXiv:1711.06877, Phys. Rev. Accel. Beams 25 (2022) 3, 033501]