The PADME experiment

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On behalf of the PADME Collaboration

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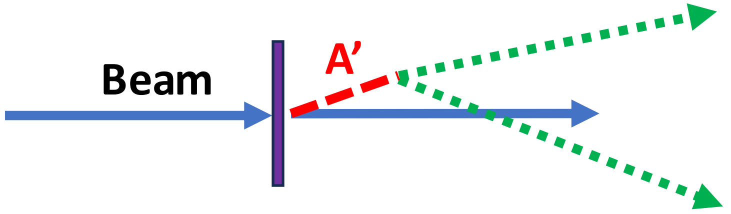
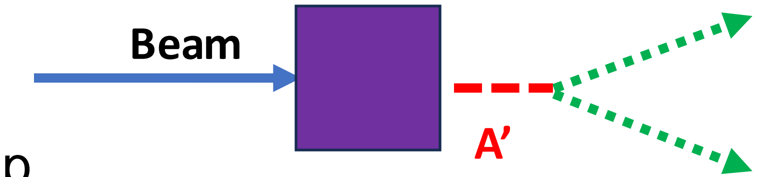
Light DM search techniques @ accelerators

Main techniques:

- **Fixed Target:**
  1. Thin target:
     - Direct production (usually X-strahlung)
     - Search for decays through event reconstruction (tracking)



  2. Secondary beam:
     - Usually in a thick target
     - Searching for new particles in meson decays → M_X usually limited by meson mass, coupling sensitivity and statistics
- **Beam Dump:**
  - Production: X-strahlung, shower, absorption of secondaries
  - Detection: everything is signal vs kinematics of the final state
  - The new particle has to survive the passage through the dump

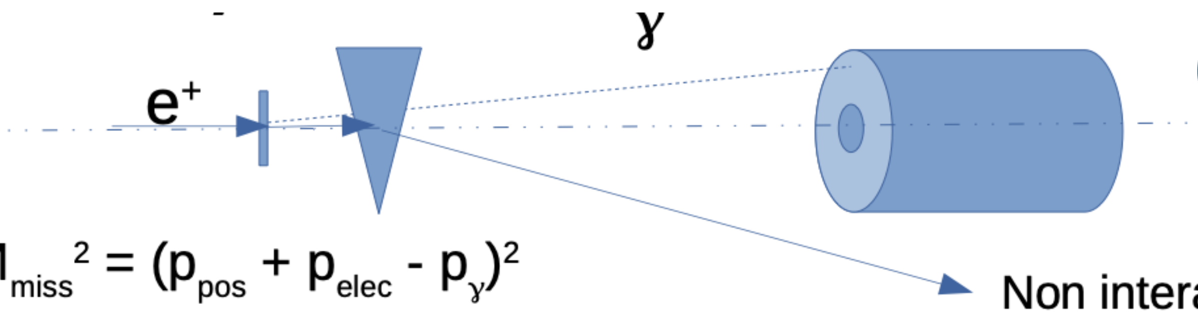


- **e^+e^- colliders:**
  - Associate production of new states
  - Sensitivity depends on the resolution on invariant/missing mass of the final state
  - Also searches through meson production and constrained initial state

PADME The PADME approach

- Positron Annihilation into Dark Matter Experiment: $e^+e^- \rightarrow \gamma A'$ based @ Frascati National Laboratories (LNF-INFN).
- e^+**beam** (E < 550 MeV) interacting with a diamond active target 2 cm × 2 cm ×100 µm
- **Final states particles**: e^+,e^-, photons
- **Aim**: Measure of ΔM^2_{miss} using a BGO ECal.
- Sensitive to sub-GeV new physics

PADME Physics case

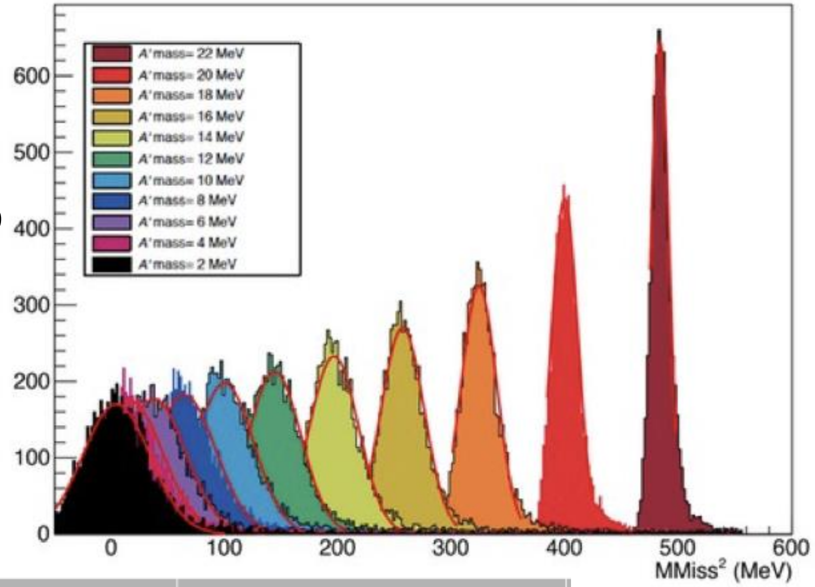


$$M_{miss}^2 = (p_{pos} + p_{elec} - p_\gamma)^2$$

- $e^+e^- \rightarrow \gamma A'$ → signal
- **Backgrounds:**

1. Bremsstrahlung in the field of the target nuclei
   - Photons mostly @ low energy, background dominates high missing masses
   - An additional lower energy positron that could be detected due to stronger deflection
2. 2 photon annihilation
   - Peaks at $M_{miss} = 0$
   - Quasi symmetric in gamma angles for $E\gamma > 50$ MeV
3. 3 photon annihilation
   - Symmetry is lost → decrease in the vetoing capability
4. Radiative Bhabha scattering
   - Topology close to bremsstrahlung

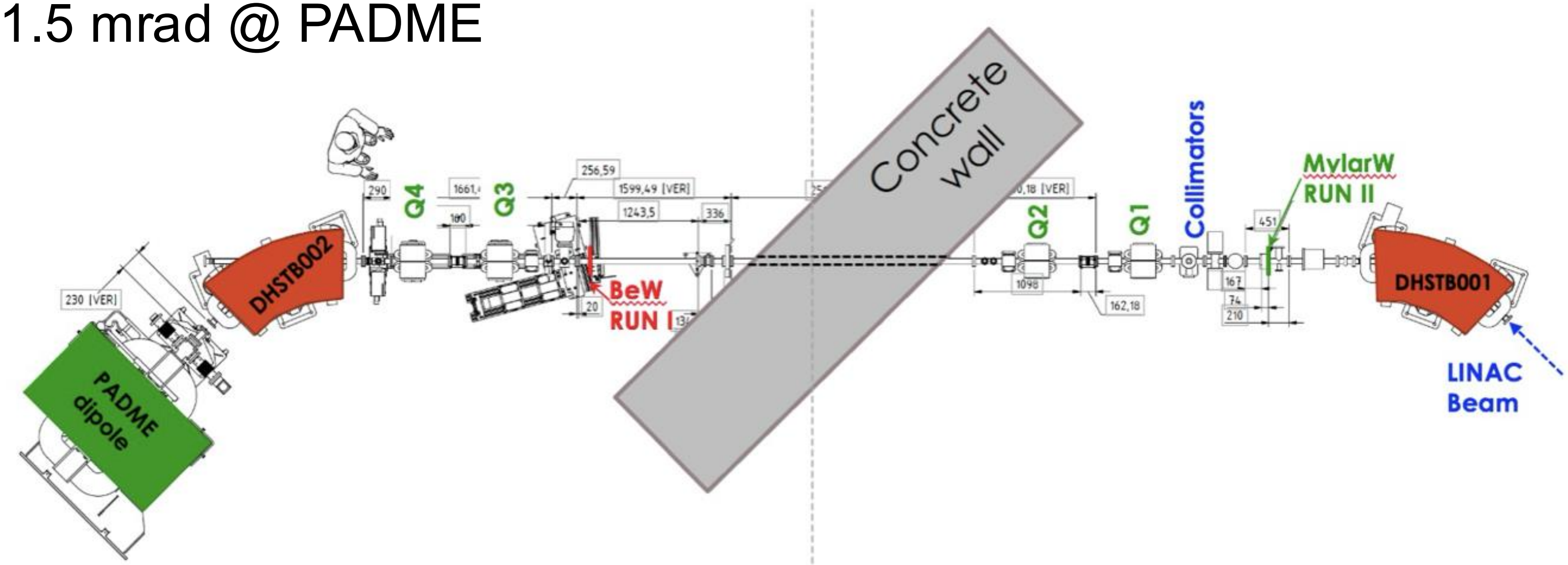
MMiss² for different $M_{A'}$



Background process	Cross section e^+@550 MeV beam
$e^+e^- \rightarrow \gamma\gamma$	1.55 mb
$e^+ + N \rightarrow e^+ N \gamma$	4000 mb
$e^+e^- \rightarrow \gamma\gamma\gamma$	0.16 mb
$e^+e^- \rightarrow e^+e^-\gamma$	180 mb

PADME – The facility

- Positrons from the DaΦNE LINAC up to 550 MeV, O(0.25%) energy spread
- Repetition rate up to 49 Hz, macro bunches of up to 300 ns duration
- Intensity must be limited below ~ 3 $\times 10^{4}$ 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)

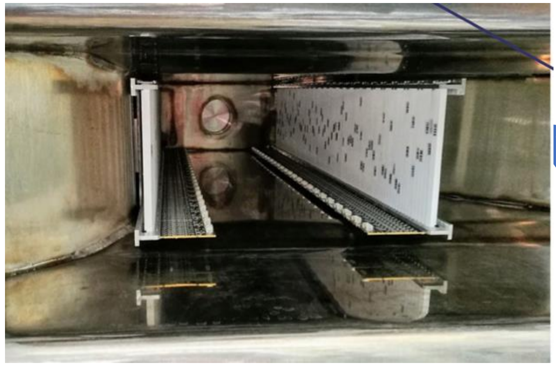
Run II e^+ primary beam, 125 μm Mylar™ vacuum separation, 28000 e+/bunch (2019-20)

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

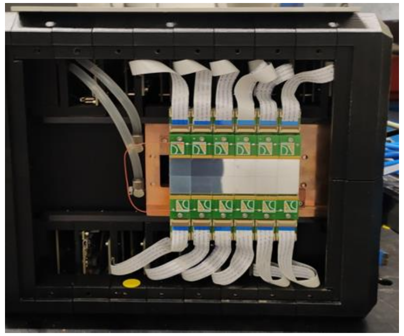
Run IV same conditions as Run III (Ongoing)

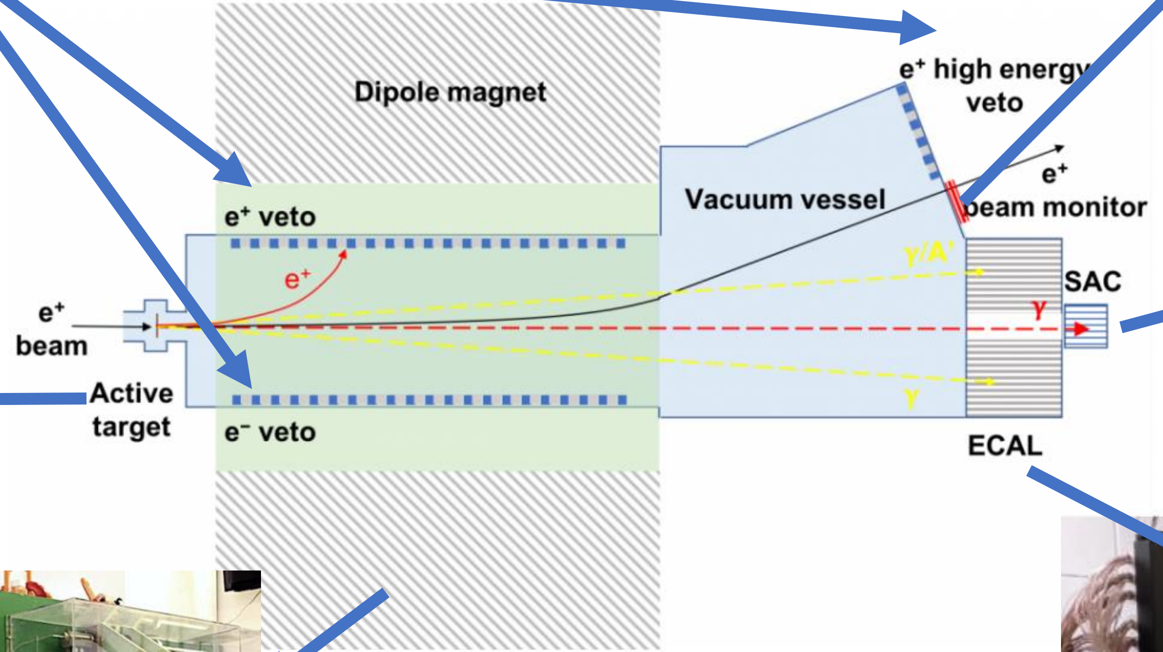
PADME – The detector

Scintillating e^+, e^- VETO

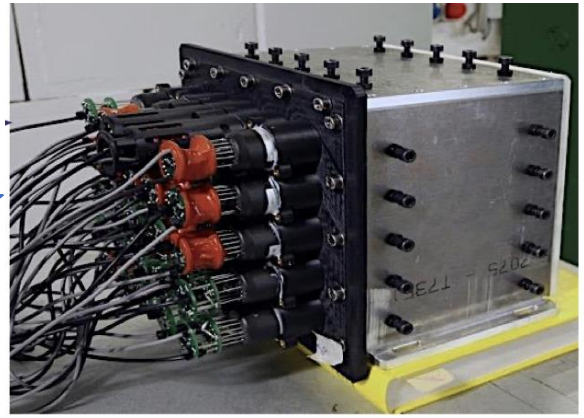


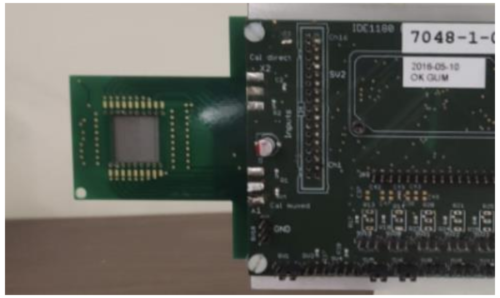
TimePix
Beam monitor



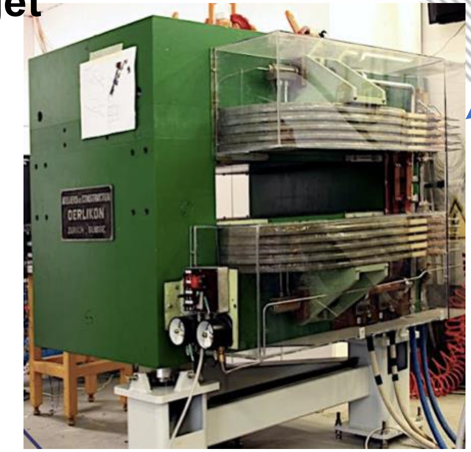


Small Angle PbF_2 calorimeter

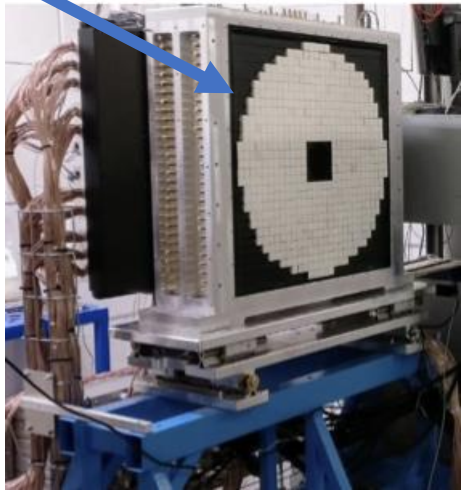




Active diamond target



Dipole Magnet

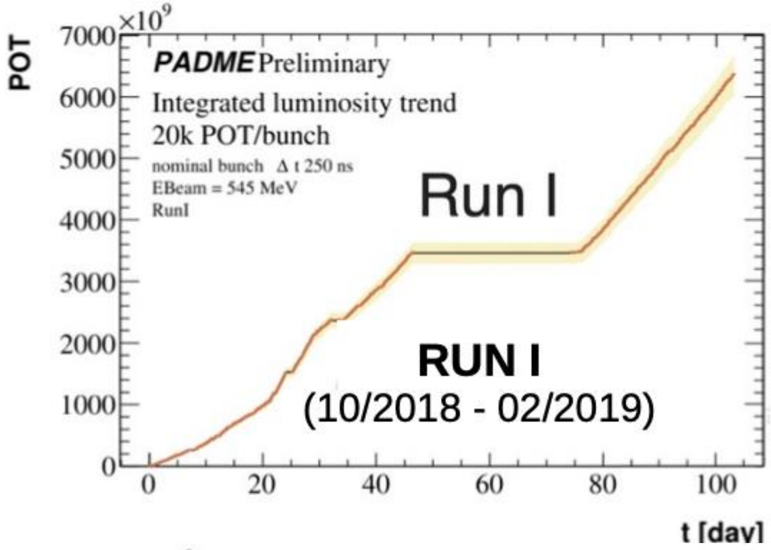


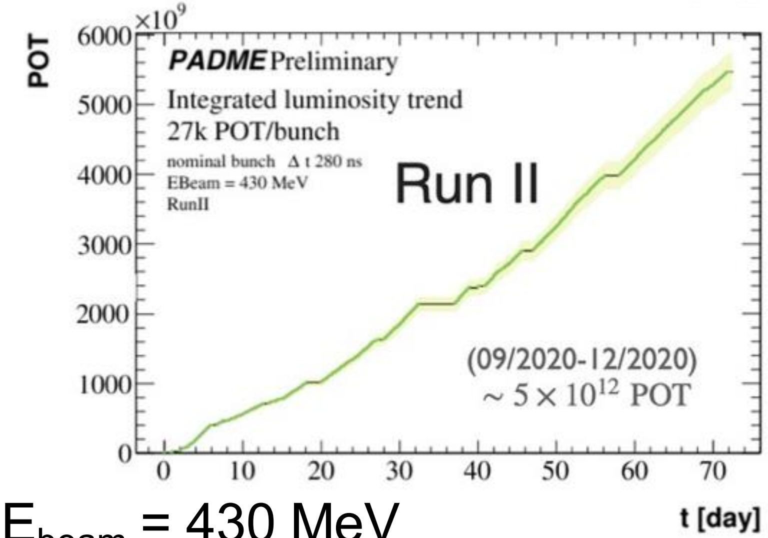
BGO ECAL

Run I and Run II

PADME Data taking

- PADME commissioning and **Run-1** started in Autumn 2018 and ended on February 25th
  - 7 x 10^{12} positrons on target recorded with secondary beam
  - PADME DAQ, Detector, beam, collaboration commissioning
  - Data quality and detector calibration
- PADME test beam data
  - July 2019, few days of valuable data
  - Certification of the primary beam
  - Detector performance/calibration checks
  - Primary beam with E_{beam} = 490 MeV
- July 2020 **Run-2**
  - New environment/detector parameter monitoring and control system
  - Remote operation confirmation

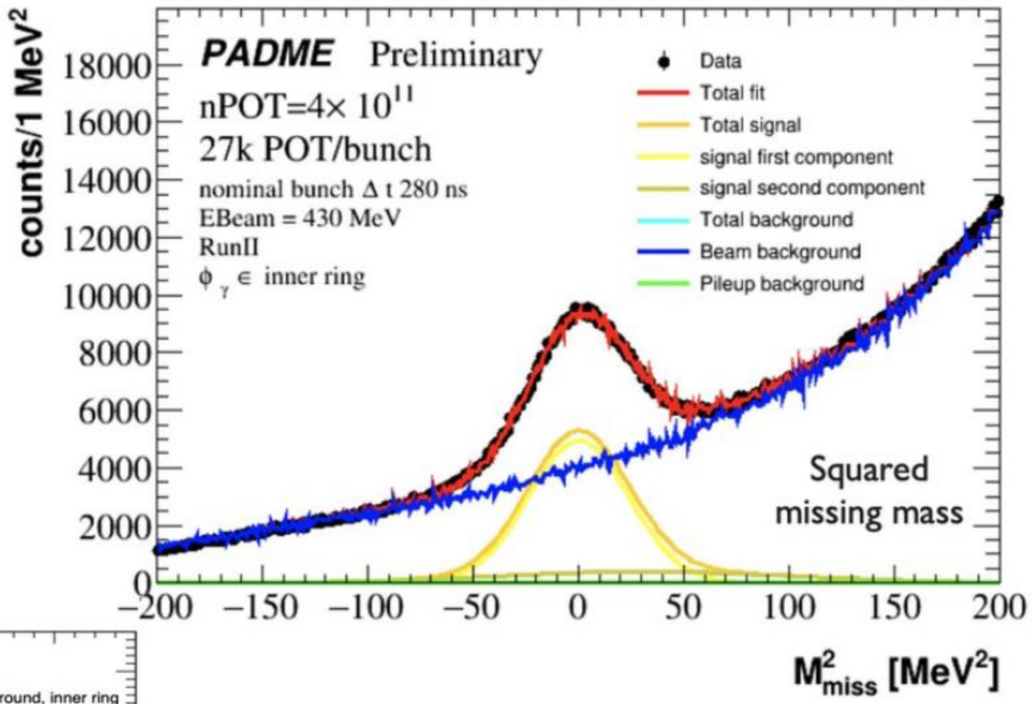


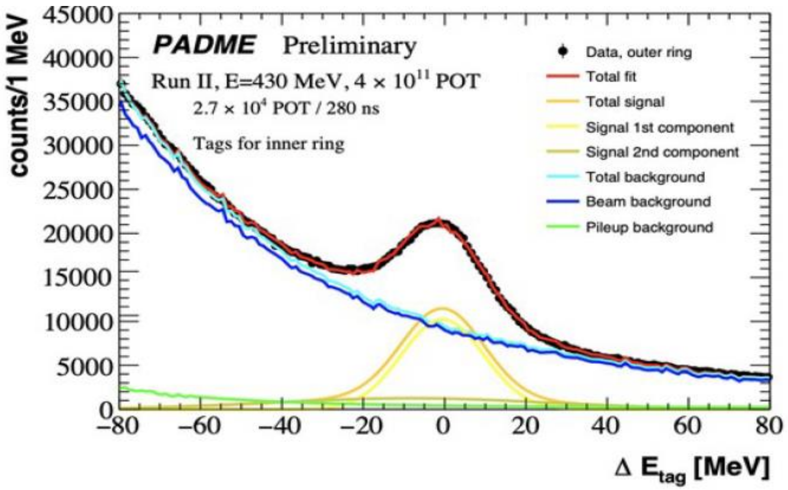


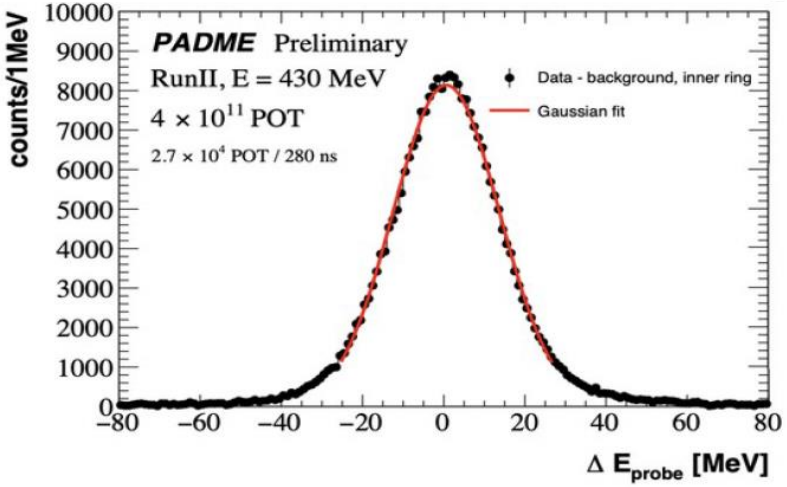
- Autumn 2020: A long data taking period with O(5x10^{12}) e^+ on target E_{beam} = 430 MeV

SM 2 photons events

- $e^+e^- \to \gamma\gamma$ cross section below 0.6 GeV known only with 20% accuracy
- Can be sensitive to sub-GeV new physics (e.g. ALP's)
- Using 10% of Run II sample
- **Tag-and-probe** method on two back-to-back clusters
  - Exploit energy-angle correlation
  - Count tag photons
  - Match using this correlation and count probes

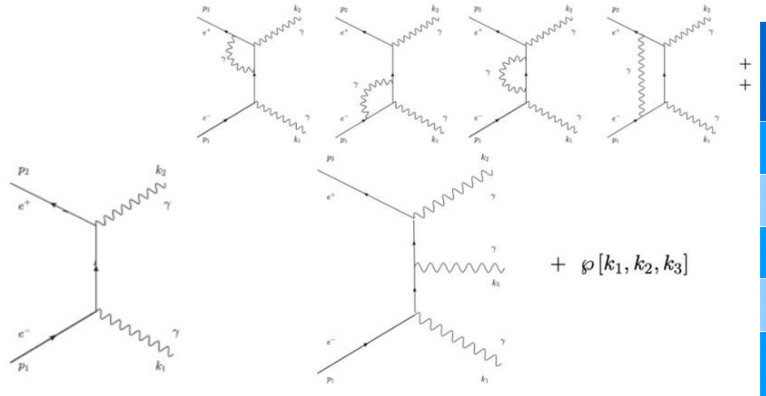






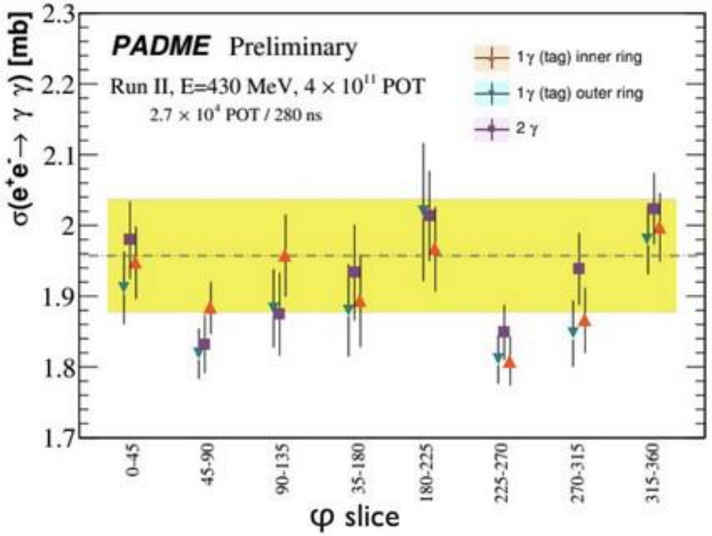
PADME SM 2 photons events → cross section

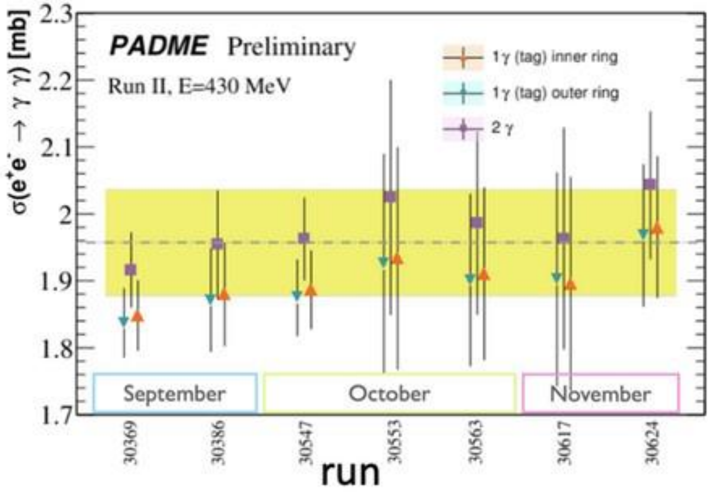
$$\sigma(e^+e^- \to \gamma\gamma(\gamma)) = 1.930 \pm 0.029(\text{stat}) \pm 0.099(\text{syst})\ \text{mb}$$

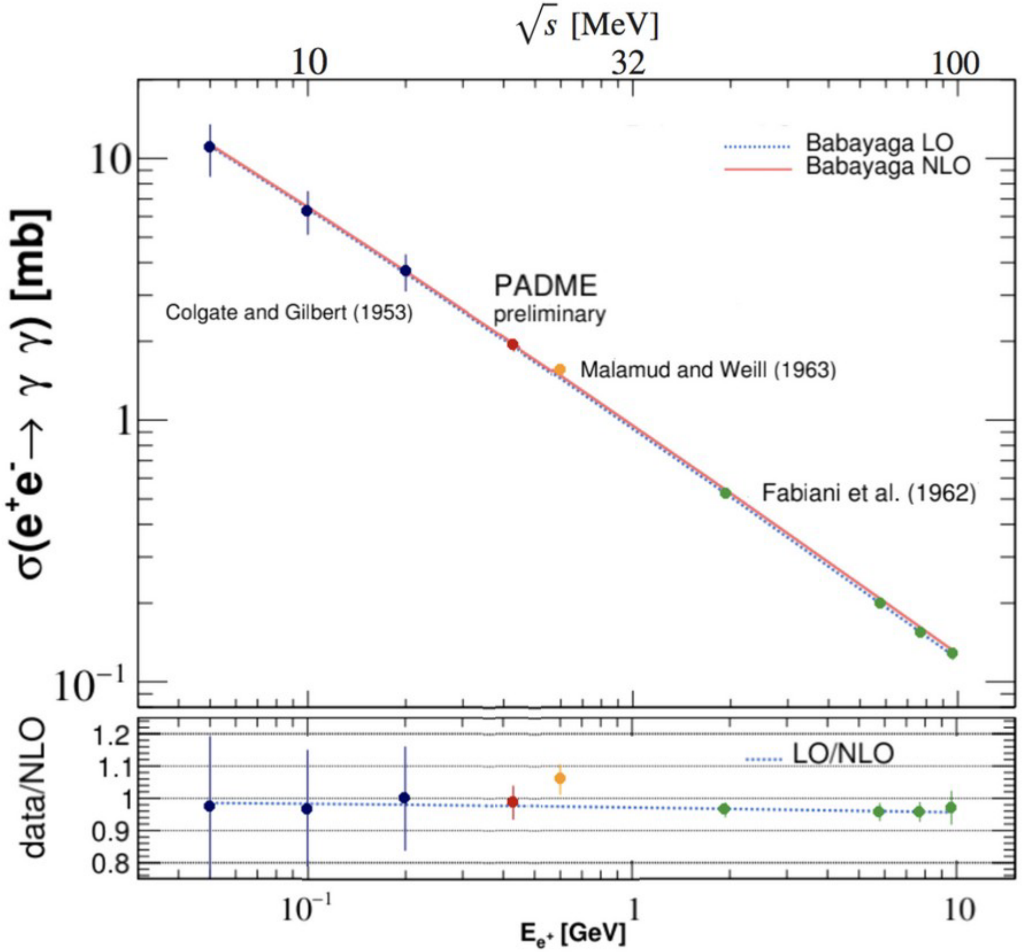


LO + NLO

Systematic effect	Contribution δ [mb]
Detector response uniformity	0.020
Background modelling	0.047
Acceptance	0.025
n POT: target calibration	0.079
Electron density (target thickness)	0.020







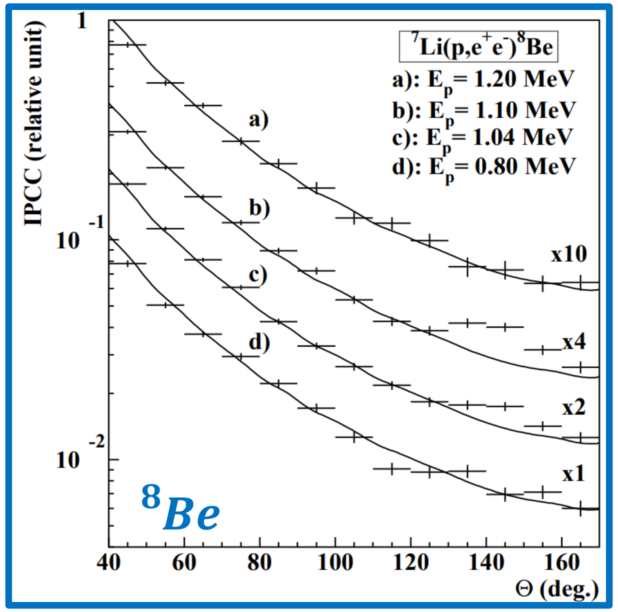
Run III

X17 anomaly @ ATOMKI

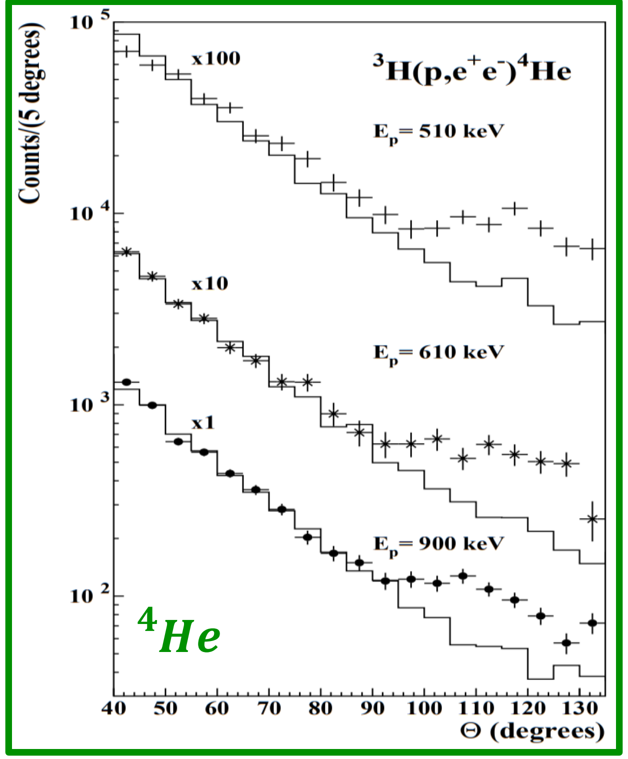
- Anomalous excesses in angular correlation of e^+e^- couples produced via IPC of ^8Be, ^4He e ^{12}C observed by the ATOMKI collaboration.

- The anomaly seems to be compatible with the production and successive decay of a **new ~17 MeV mass particle**

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



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



Phys. Rev. C 106, L061601

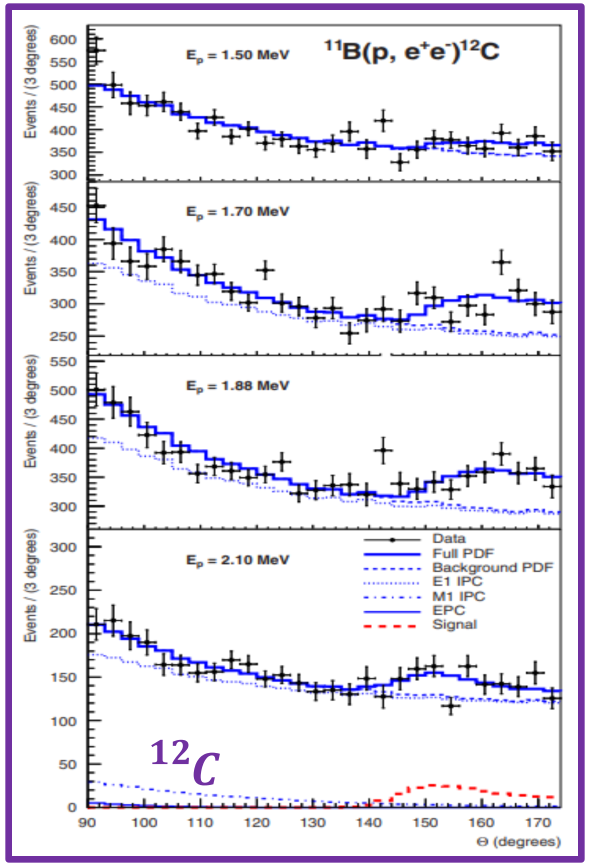
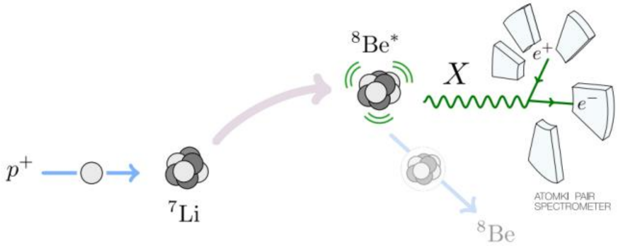


TABLE III. Nuclear excited states N_*, their spin-parity $J_*^{P_*}$, and the possibilities for X (scalar, pseudoscalar, vector, axial vector) allowed by angular momentum and parity conservation, along with the operators that mediate the decay and references to the equation numbers where these operators are defined. The operator subscripts label the operator's dimension and the partial wave of the decay, and the superscript labels the X spin. For example, $\mathcal{O}_{4P}^{(0)}$ is a dimension-four operator that mediates a P-wave decay to a spin-0 X boson.

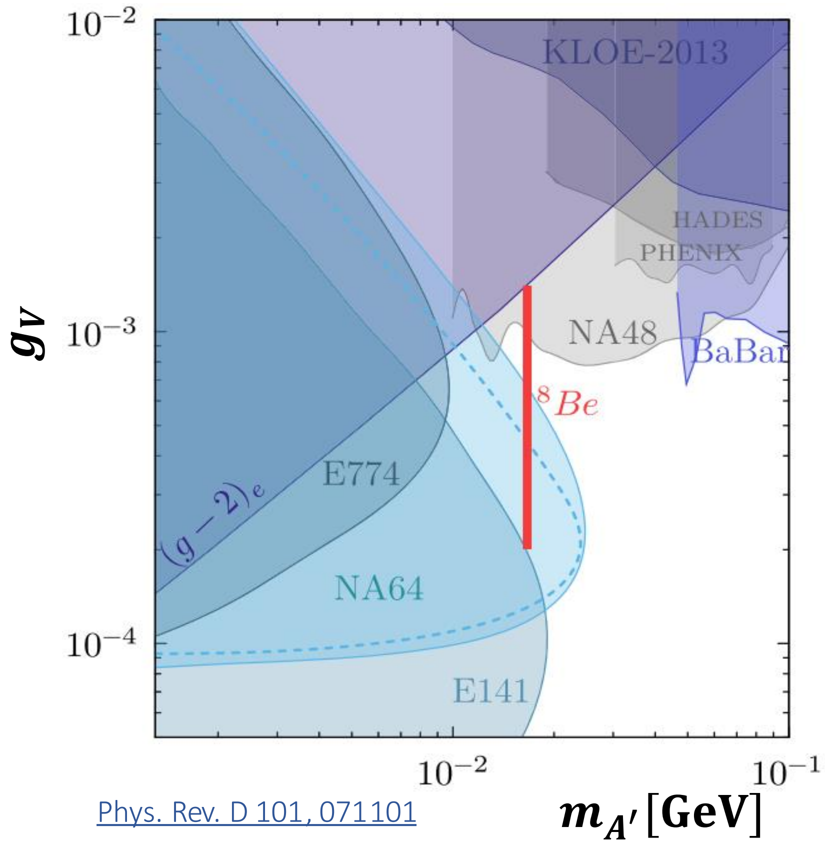
N_*	$J_*^{P_*}$	Scalar X	Pseudoscalar X	Vector X	Axial Vector X
^{8}Be(18.15)	1^+	...	$\mathcal{O}_{4P}^{(0)}$ (27)	$\mathcal{O}_{5P}^{(1)}$ (37)	$\mathcal{O}_{3S}^{(1)}$ (29), $\mathcal{O}_{5D}^{(1)}$ (34)
^{12}C(17.23)	1^-	$\mathcal{O}_{4P}^{(0)}$ (27)	...	$\mathcal{O}_{3S}^{(1)}$ (29), $\mathcal{O}_{5D}^{(1)}$ (34)	$\mathcal{O}_{5P}^{(1)}$ (37)
^{4}He(21.01)	0^-	...	$\mathcal{O}_{3S}^{(0)}$ (39)	...	$\mathcal{O}_{4P}^{(1)}$ (40)
^{4}He(20.21)	0^+	$\mathcal{O}_{3S}^{(0)}$ (39)	...	$\mathcal{O}_{4P}^{(1)}$ (40)	...



X17 as a vector or pseudo-scalar state

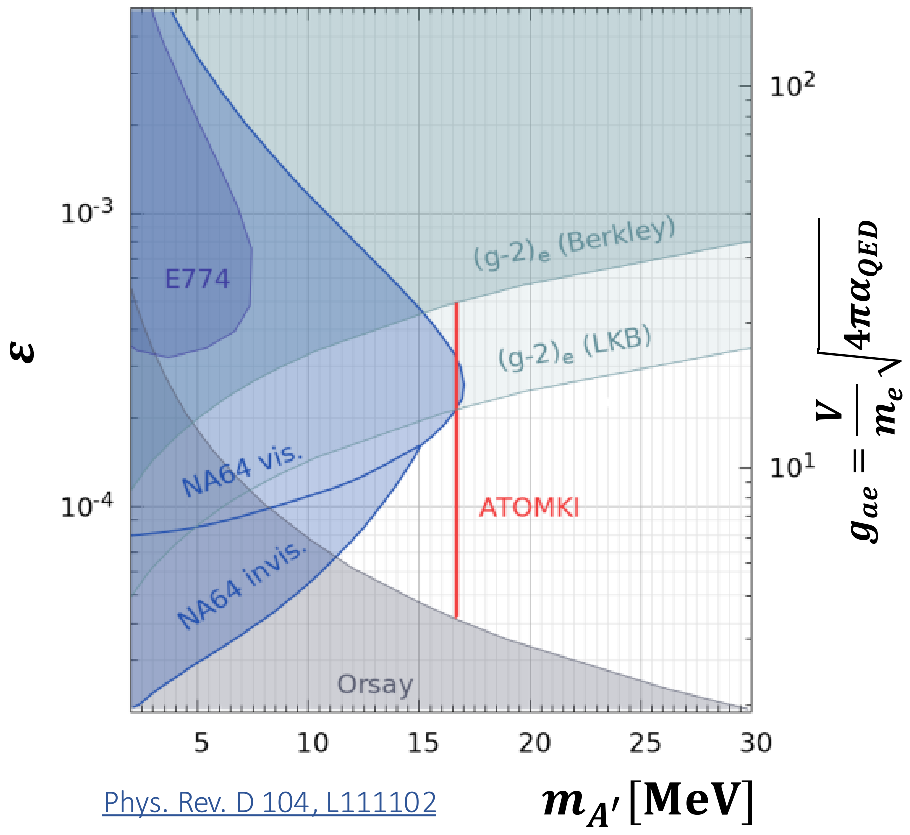
- New physics interpretations not fully excluded → still some phase-space available
- The PADME experiment is sensible to this mass range

Vector



Phys. Rev. D 101, 071101

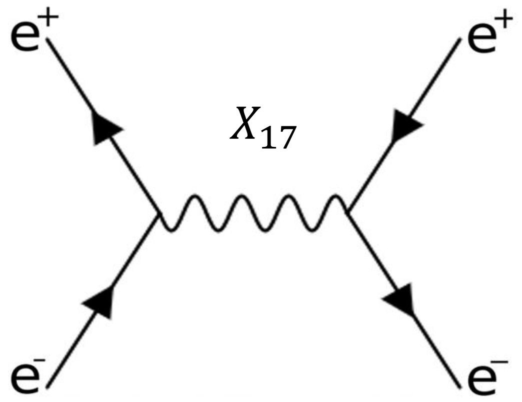
Pseudoscalar



Phys. Rev. D 104, L111102

Resonant search on fixed thin target

- $\sigma_{res} \propto \frac{g_{Ve}^2}{2m_e} \pi Z \, \delta(E_{res} - E_{beam})$ goes with Z → dominant process with respect to alternative signal production processes.
- $\sqrt{s}$ has to be as close as possible to the expected mass → fine scan procedure with the e^+ beam → expected enhancement in $\sqrt{s}$ over the standard model background



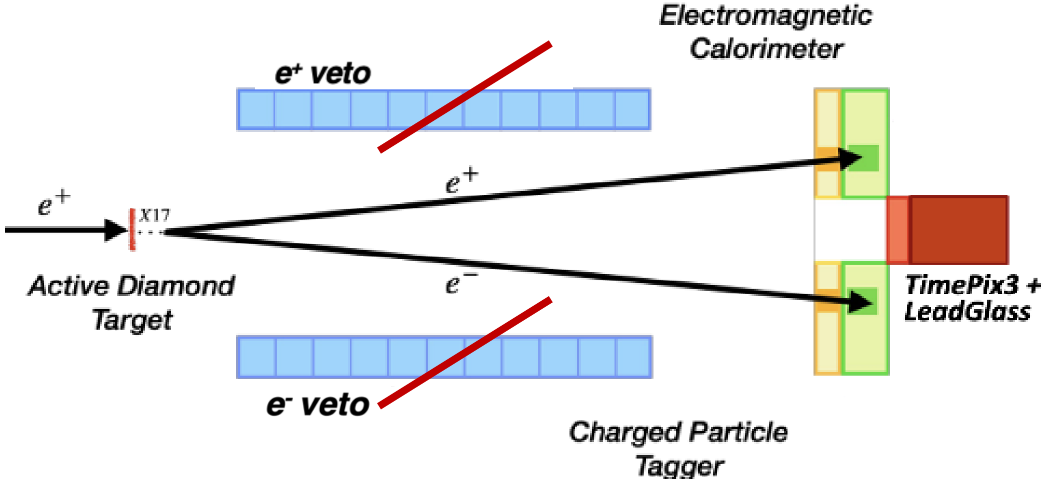
At PADME, X_{17} produced through resonant annihilation in diamond target:
Scan around $E(e^+) \sim 283$ MeV with the aim to measure two-body final state yield N_2

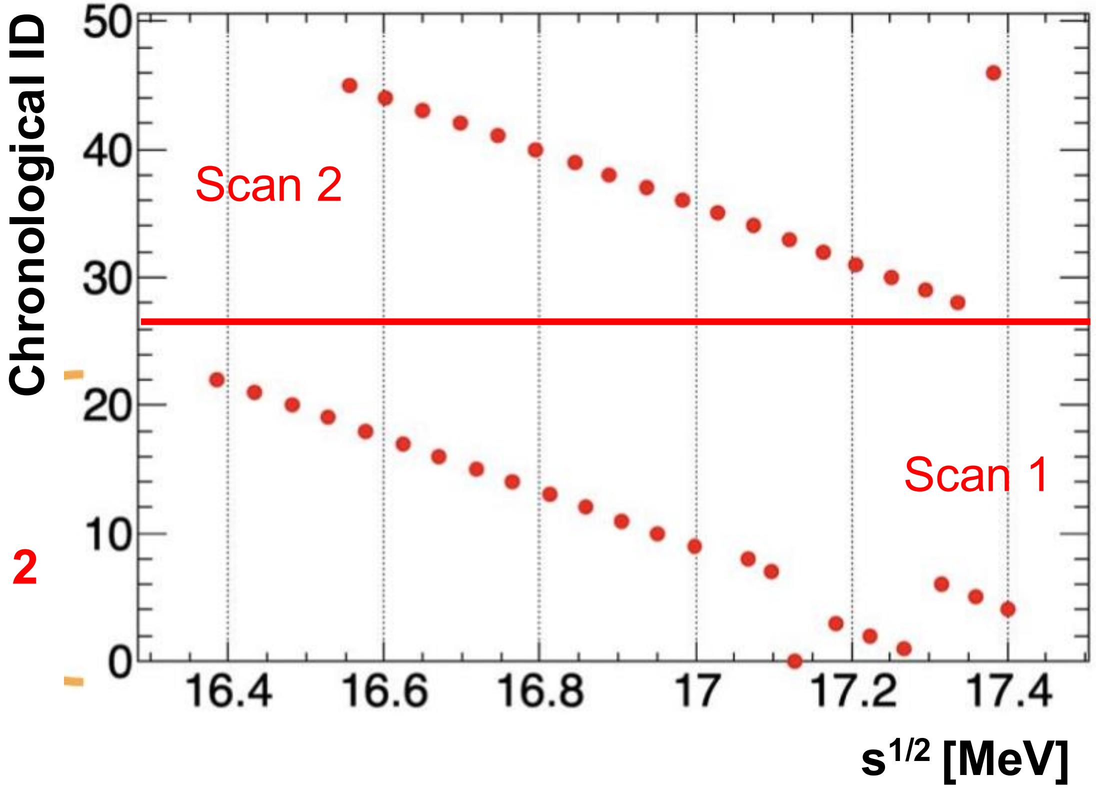
$$N_2(s) = N_{POT}(s) \times [\, B(s) + S(s; M_X, g)\, e_S(s) \,]$$ **to be compared to** $$N_2(s) = N_{POT}(s) \times B(s)$$

Run III

Main SM background are Bhabha scatterings and $\gamma\gamma$ pairs productions, fitted directly from data → needed some setup optimization:

- PADME dipole turned off
- ETagger added to identify charged particles
- SAC replaced with a TimePix3 beam monitor and a Leadglass luminometer





Data-taking divided in 3 parts:

- **On resonance: 47 points @ (263-299) MeV → scan 1 and 2**
- **Below resonance: 5 points @ (205-211) MeV**
- **Over resonance: 5 points @ 402.5 MeV**

Analysis inputs

$N_2(s) / (N_{POT}(s) \times B(s)) = K(s) [1 + S(s; M_X, g) e_S(s)]$ to be compared to $N_2(s) / (N_{POT}(s) \times B(s)) = K(s)$

Inputs:

- $N_2(s)$ number of two-cluster events selected
- $N_{POT}(s)$ number of e^+ on target from beam-catcher calorimeter
- $B(s)$ background yield expected per POT
- $S(s; M_X, g)$ signal production expected for {mass, coupling} = $\{M_X, g\}$
- $e_S(s)$ signal acceptance and selection efficiency
- **K(s)** DATA-MC scale factor with a possible dependence from s

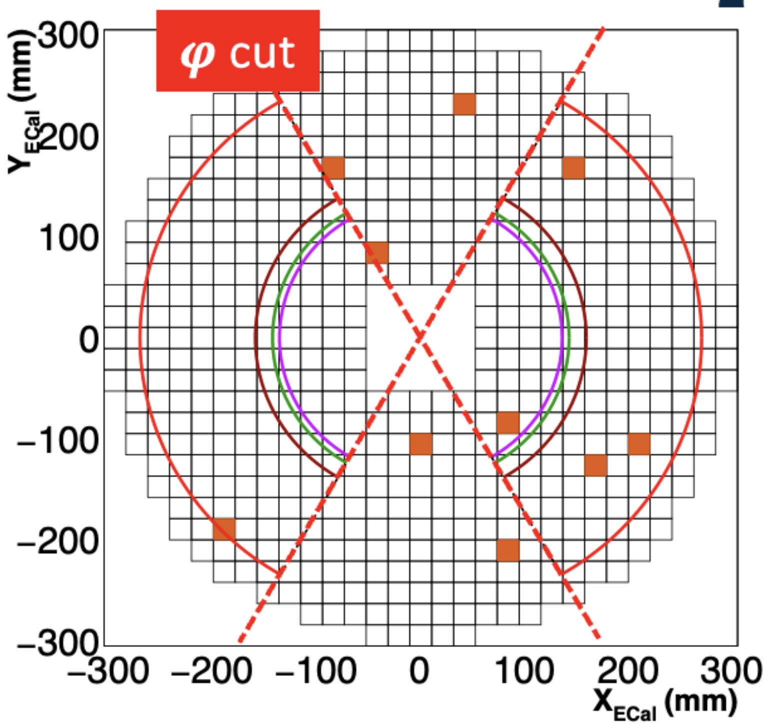
Aim: measure and evaluate systematic errors on:

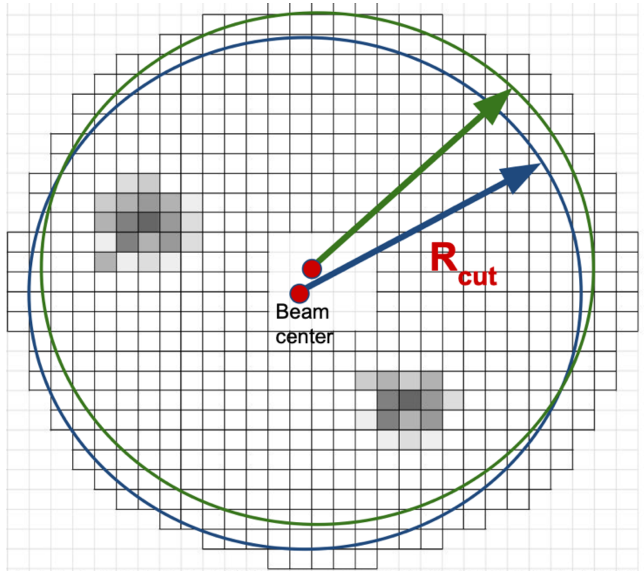
- N_{2Cl} (bkg subtracted) on data
- PoTs
- Signal Efficiency
- Signal shape
- MC Expected Yield

N_2 selection cuts

Selection algorithm as independent as possible on beam and detector conditions:

- **Selected a cluster pair with the following criteria**
  - Maximum radius defined by ECAL dimensions
  - Energy within the "two-cluster" kinematic range
  - Minimum radius within the "two-cluster" kinematic range → following the beam center conditions
  - ECAL Illumination affected by material along the beam line (below flange) → **Cut regions in φ**
- **Mutual cluster conditions:**
  - ΔT (clu0-clu1) < 5 ns
  - ΔR (clu0-clu1) > 60 mm (Minimum GG difference)
  - $\boldsymbol{\phi_1 - \phi_2}$ vs $\boldsymbol{\theta_1 + \theta_2}$ cut in the center of mass frame isolates the signal





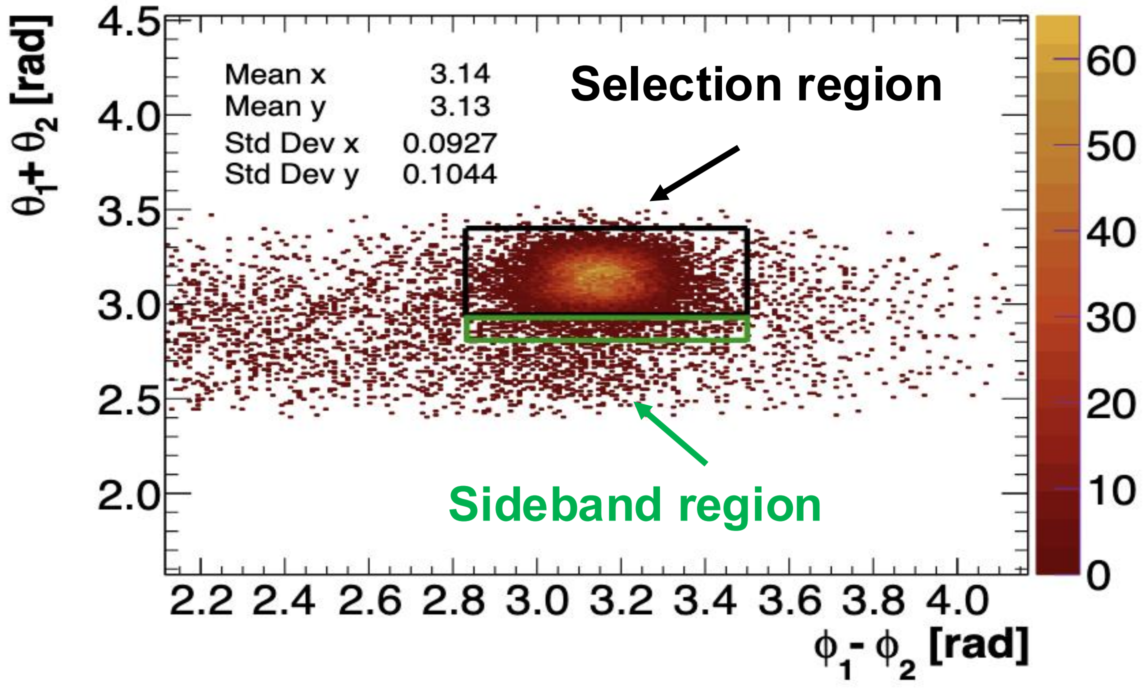
$\phi_1 - \phi_2$ vs $\theta_1 + \theta_2$ → $N_2(s)$

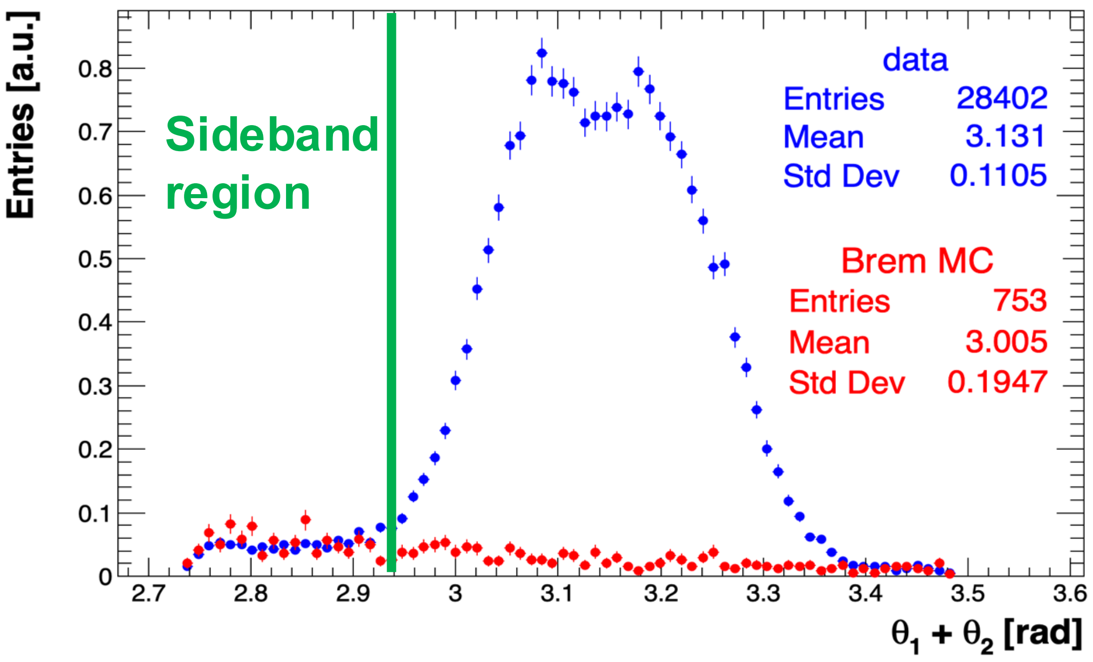
- $\boldsymbol{\phi_1 - \phi_2}$ vs $\boldsymbol{\theta_1 + \theta_2}$ cut isolates the signal
- **Cut range**: 3σ around the mean value
  - Flat beam bkg in $\boldsymbol{\phi_1 - \phi_2}$ → bkg level < 4%
  - Bremsstrahlung tail in $\boldsymbol{\theta_1 + \theta_2}$ → To be removed with MC shape using the sideband region

❖ Statistical error: **δN_2 ~0.6% up to 0.7%**

❖ Systematic uncertainty due to bkg subtraction: **δN_2 ~ 0.3%**

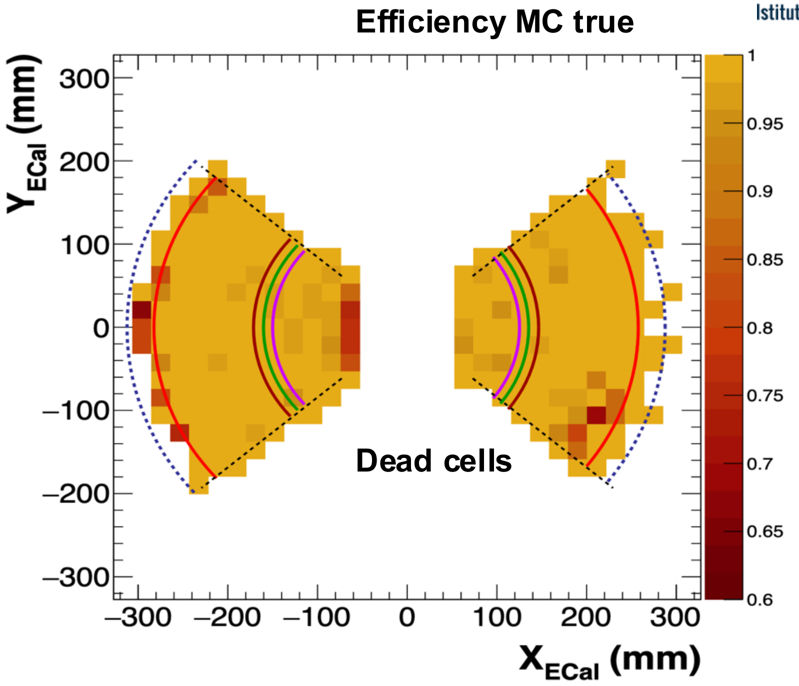
Source	Error on N_2 [%]
Statistics	~0.6
Background subtraction	0.3
Total	**0.65**

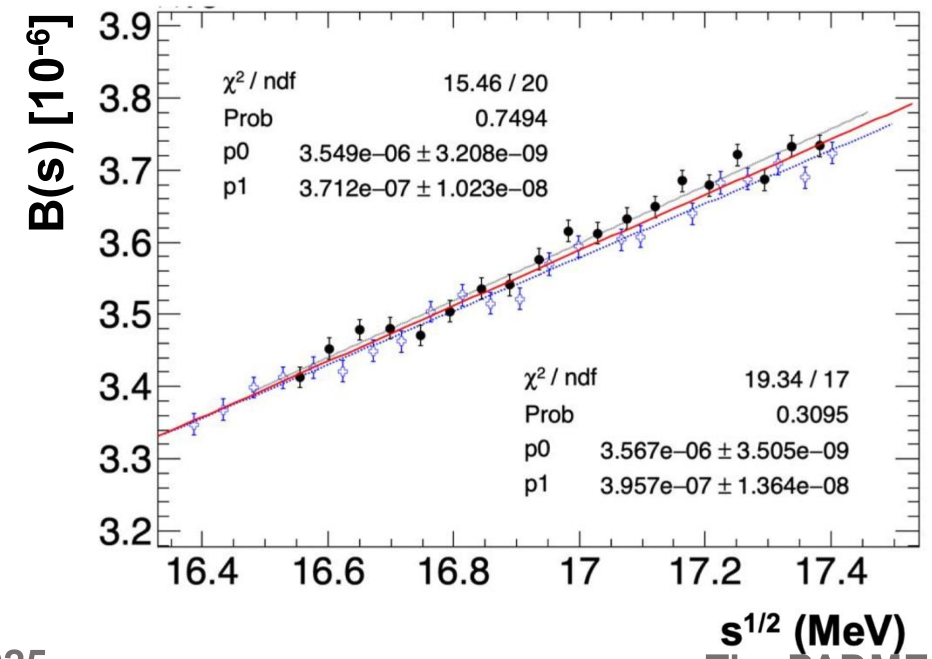




Expected Background → B(s)

The expected background / e+, B(s), is determined with MC + data-driven checks
Reconstruction efficiency taken into account:
- Data/MC efficiency with tag-and-probe technique
- bkg subtraction at tag level dominates the statistical-systematic error → **δB = 0.35%**
- Cut stability at MC and Data level also under control together with COG (beam) variations





Source	Error on B [%]
MC statistics	0.40
Data/MC eff. (Tag&Probe)	0.35
Cut stability	0.04
Beam spot variations	0.05
Total	**0.54**

Positron on target → NPoT(s)

- PoTs measured with the end-of-line lead glass calorimeter → 2% scale error on the calibration considered
- 2 main effects: **radiation induced loss + energy loss in passive material**
  - Run III radiation dose ~ 2.5 krad → transparency changes for O(krad)
    - Estimated from 3 flux proxy observables: $Q_{target\text{-}x}$, $\langle E_{ECal} \rangle$, period multiplets
    - LG yield decreases with relative PoT slope of 0.097(7) → Slope error included **δN_{PoT}=0.35%**
    - Constant term uncertainty of **δN_{PoT}=0.3%** added as scale error
  - Loss due to beam movements during the whole Run III → passive material crossing
    - Checked against data of October test beam + MC simulation → systematic correlated error **δN_{PoT}=0.5%**

Uncorrelated systematic errors

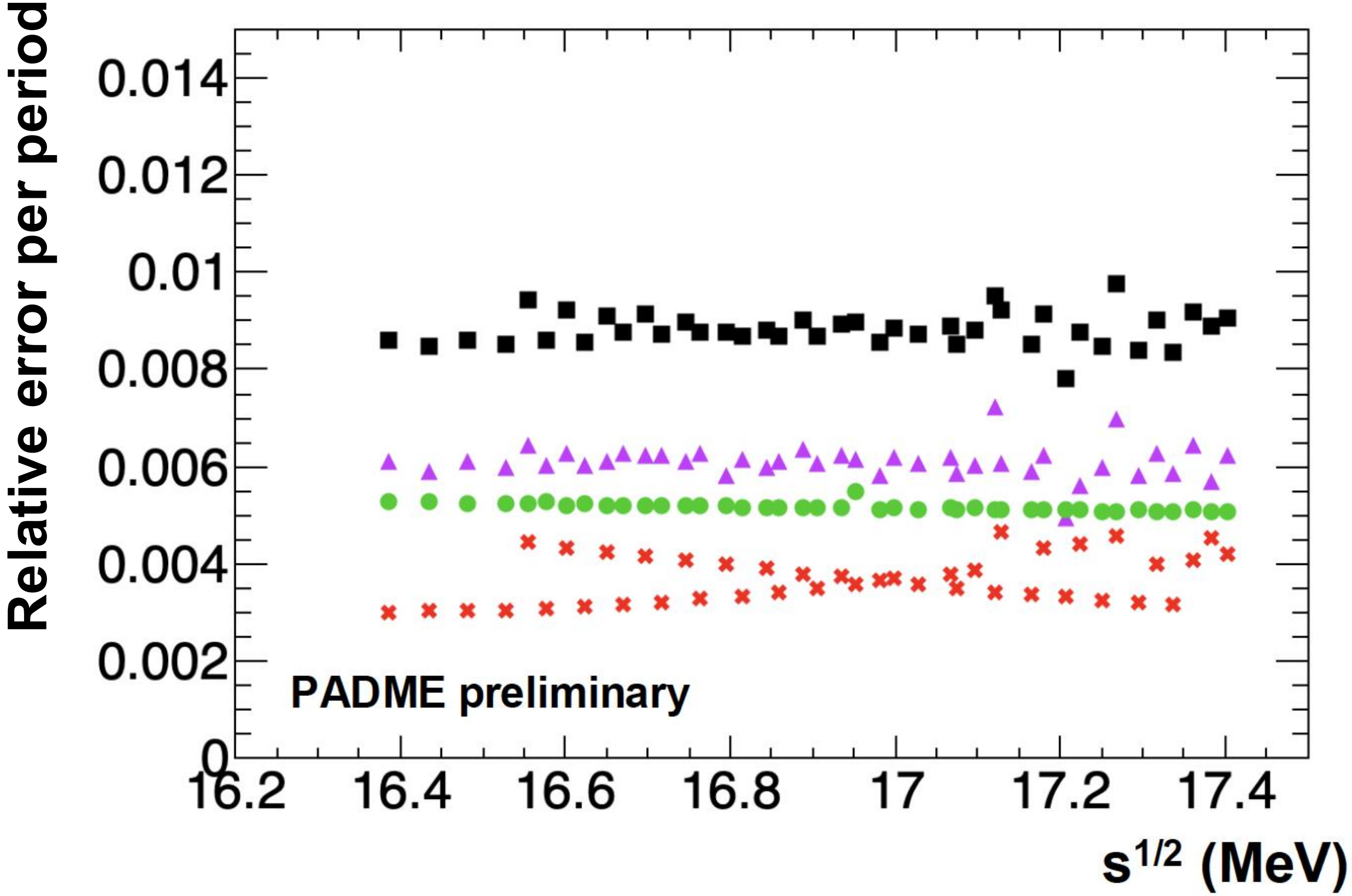
Source	Error on N_{POT} [%]
Statistics, ped subtraction	negligible
Energy scale from BES	0.3
Rad. induced loss, slope	Variable, ~0.35
Total	**0.45**

Common systematic errors

Source	Common error [%]
pC / MeV (JHEP 08 (2024) 121)	2.0
Energy Loss, data/MC	0.5
Rad. induced loss	0.3
Total	**2.1**

PADME Total error budget

- Uncorrelated uncertainty on $g_R(s)$ = $N_2(s)$ / (NPoT(s) B(s)):

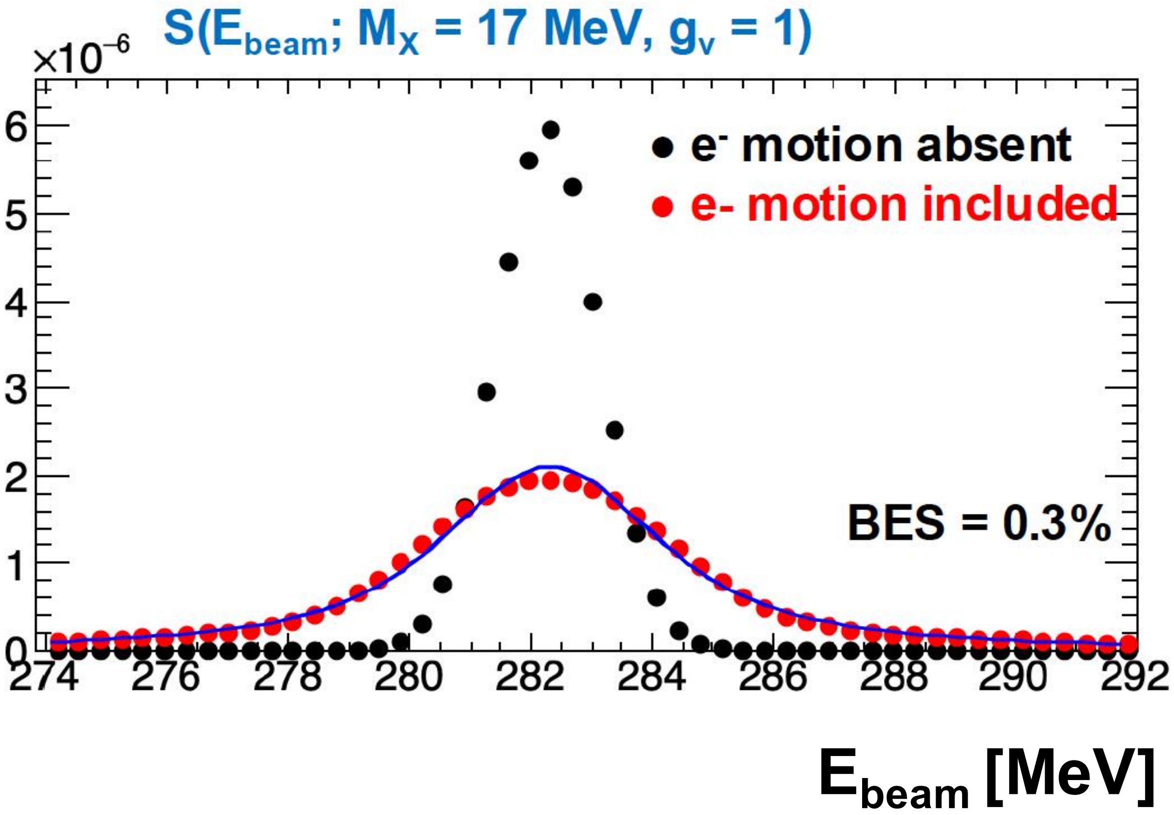


Uncorrelated errors	
Source	Uncertainty (% per energy point)
$N_2(s)$	0.60
$B(s)$	0.54
$N_{\rm PoT}(s)$	0.35
Total on $g_R(s)$	0.88
$K(s)$, constant term	
Source	Uncertainty (%)
Lead-glass calibration	2.0
Absolute B yield	1.8
Energy-loss correction to $N_{\rm PoT}$	0.5
Radiation-induced correction to $N_{\rm PoT}$	0.3
Total	2.8
$K(s)$, $\sqrt{s}$-slope	
Source	Expected value (%/MeV)
Radiative corrections	$-0.6 \pm 0.2 \pm 0.6$
Total	-0.6 ± 0.6

- **Next step:** is $g_R(s)$ compatible with **1** or **1+** S(s) $\varepsilon(s)$/B(s)?

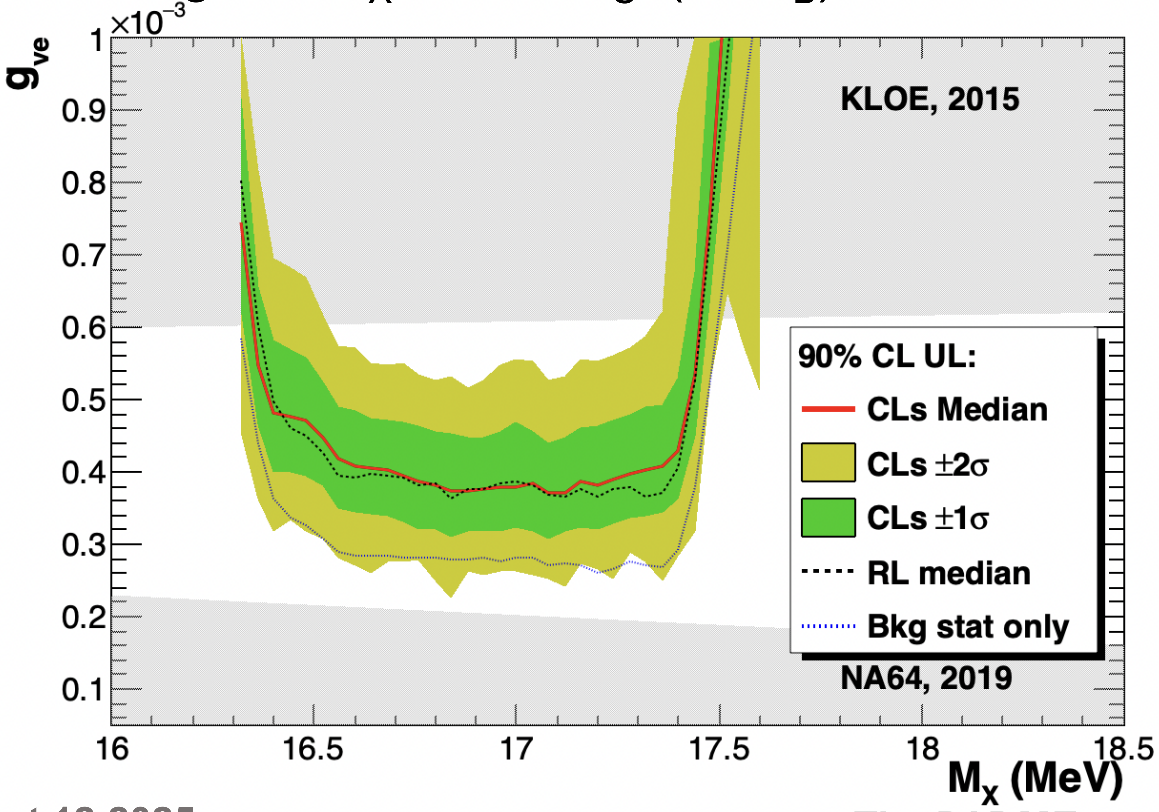
Signal shape and ε(s)/B

- Electron motion inside the target changes significantly the shape of the resonance → not anymore just a gaussian with σ equal to the beam energy spread
- Parameterized S vs E_{beam} with a Voigt function:
  - Convolution of the gaussian BES with the Lorentzian
- Uncertainty in the curve parameters as nuisances:
  - **Lorentzian width** around the resonance energy: 1.72(4) MeV
  - **Relative BES**: 0.025(5)%
- Expected background signal efficiency determined from MC:
  - Large cancellation of systematic errors seen using **ε/B**
- Fit ε(s)/B(s) with a straight line, include fit parameters as nuisances:
  - **Errors:** δP0/P0 ~ 0.1%, δP1/P1 = 3%, correlation = -2.5%



PADME Expected sensitivity

- Evaluate expected 90% CL UL in absence of signal
- Modified frequentist approach, LEP-style test statistic
- **Likelihood fits** performed for the separate assumptions of **signal + background vs background only,** define Q statistic based on Likelihood ratio: $Q = LS + B(g_{ve}, M_X)/ LB$. The likelihood includes terms for each nuisance parameter pdf
- For a given M_X, $CLs = P_S/ (1 – P_B)$ is used to define the UL on g_{ve}



Source	Uncertainty [%]
N_2	0.6
B	0.35
N_{PoT}	0.55
TOTAL on g_R	**0.88**
TOTAL on K(s)	**2.1**

Pseudo data (SM background) is generated accounting for the expected uncertainties of nuisance parameters + statistical fluctuations

PADME

Unblinding procedure

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Laboratori Nazionali di Frascati

To validate the error estimate, we applied the procedure in 2503.05650 [hep-ex]

- Aim to blindly define a side-band in $g_R(s)$, excluding 10 periods of the scan
- Define the masked periods by optimizing the probability of a linear fit in $s^{1/2}$
  1. Threshold on the χ^2 fit in side-band is $P(\chi^2)$ = 20%, corresponding to reject 10% of the times
  2. If ✅, check if the fit pulls are gaussian
  3. If ✅, check if a straight-line fit of the pulls has no slope in $s^{1/2}$ (within 2 sigma)
  4. If ✅, check if constant term and slope of the linear fit for $N_2(s)/B(s)$ are within two sigma of the expectations, i.e.: ±4% for the constant, ±2% MeV^{-1} for the slope

Successfully applied:

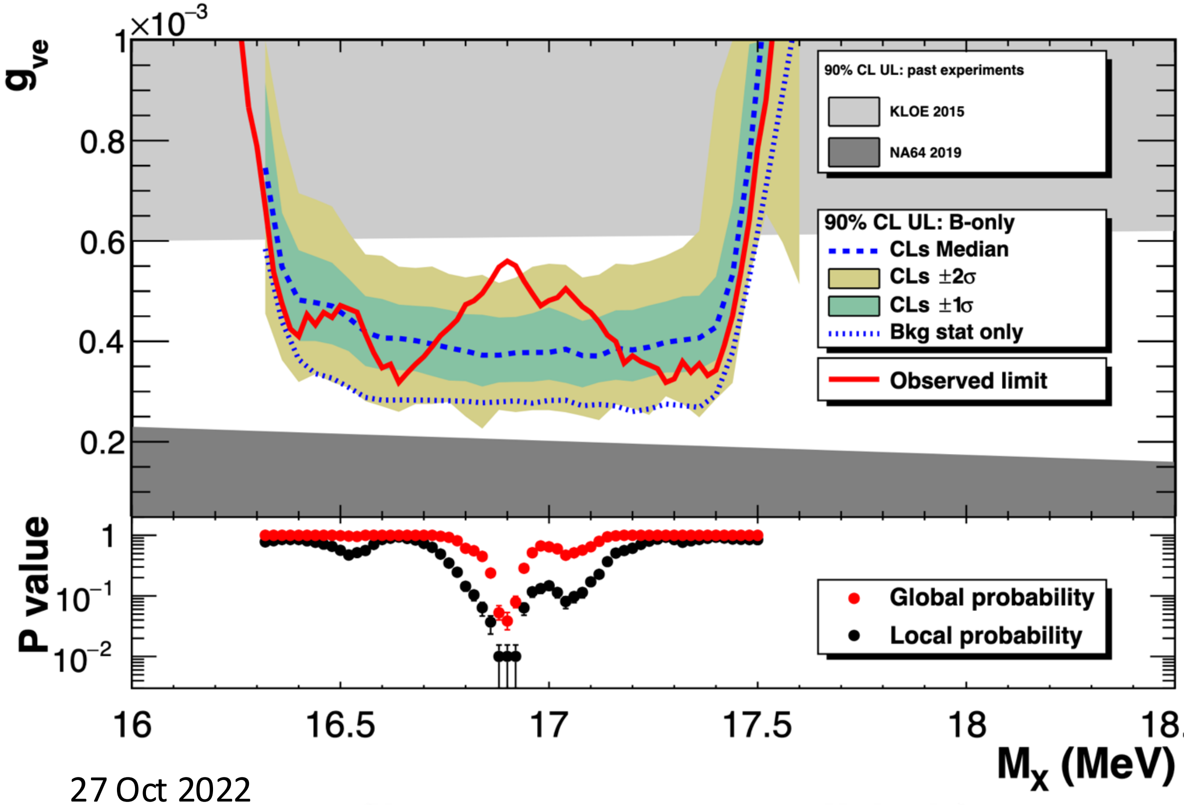
1. **$P(\chi^2)$ = 74%**
2. **Pulls gaussian fit probability 60%**
3. **Slope of pulls consistent with zero**
4. **Constant term = 1.0116(16), Slope = (-0.010 +- 0.005) MeV^{-1}**

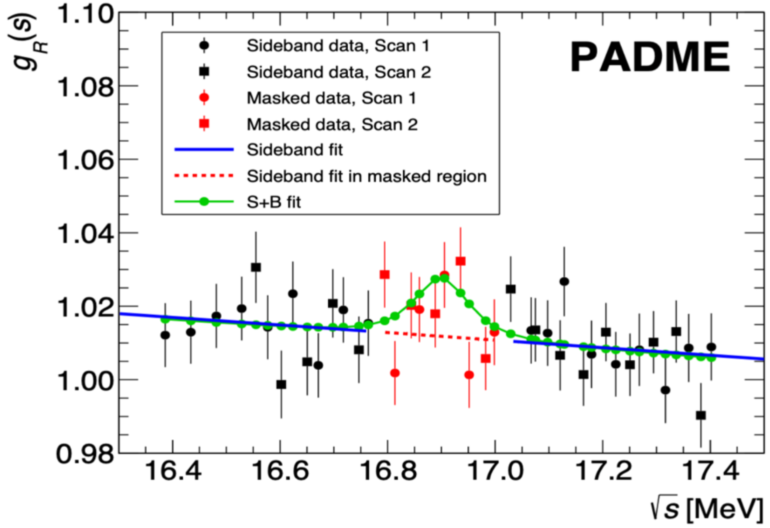
→ **Ready to unblind**

PADME Box opening

Some excess is observed a ~2.5σ local coverage

- At M_X = 16.90(2) MeV, g_{ve} = 5.6 x 10^{-4}, the global probability dip reaches $3.9_{-1.1}^{+1.5}$ %, corresponding to **(1.77 ± 0.15) σ** one-sided (look-elsewhere calculated exactly from the toy pseudo-events)
  - A second excess is present at ~17.1 MeV, but the absolute probability there is ~ 40%
- If a 3σ interval is assumed for observation following the estimate M_X = 16.85(4) MeV of PRD 108, 015009 (2023), the p-value dip deepens to $2.2_{-0.8}^{+1.2}$ % corresponding to (2.0 ± 0.2) σ one-sided

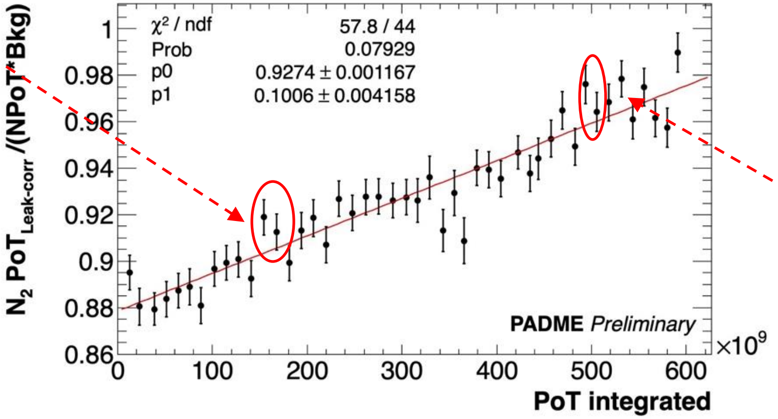




ArXiv:2505.24797 [hep-ex]

Minor revision from JHEP

27 Oct 2022



8 Dec 2022

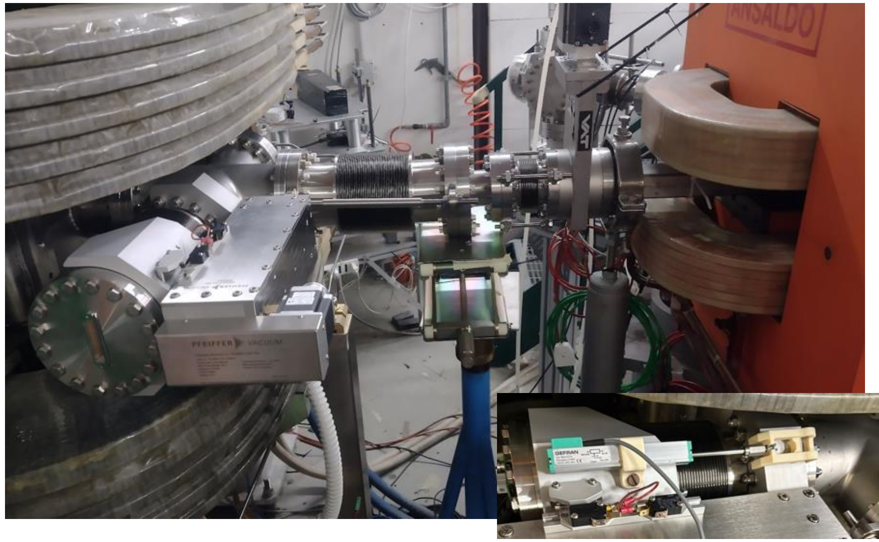
Run IV improvements overview

The Run IV paradigm → increase sensibility to confirm/disprove Run III result

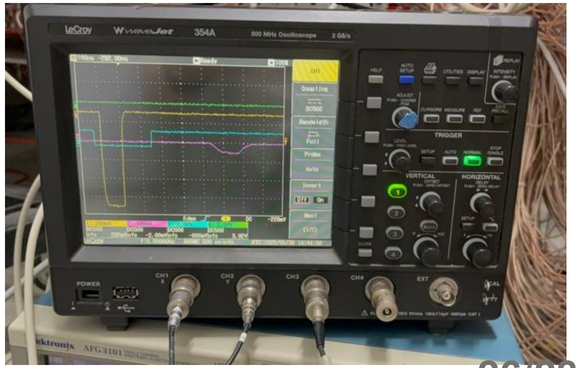
- **Diamond target** position moved downstream by ~30 cm
- Passive material removed and PADME Magnet fully degaussed → $B_{PADME} < 1$ G
- Beam stable in the central position along the whole data taking

  → **NO LATERAL LEAKAGE on the beam cathcer**
- **Led pulser** Tektronix AFG3101 to control the radiation induced loss
  - Independent trigger included in the DAQ
  - A second LG block installed (out of the acceptance and only acquiring the led trigger)
  - Online LG response renormalized to the not-fired-block
  - Reference for light yield response almost on the fly

Diamond target



Led pulser



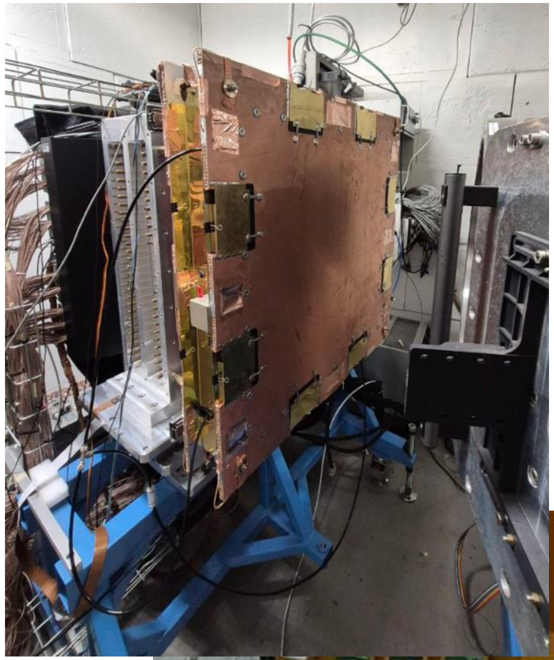
Run IV improvements overview

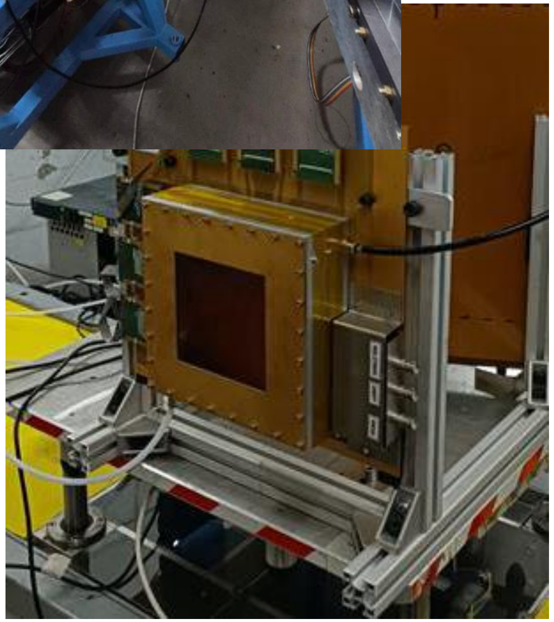
New detectors:

- **PadMMe** MicroMegas chamber replaced the Etagger:
  - e/γ discrimination → possible normalization to $e^+e^- \rightarrow \gamma\gamma$ process
  - Spatial resolution ~ 350 μm → angle disentanglement
  - Multitrack events can be collected
  - Beam spot monitor → Already implemented in the Run IV online monitor
- **TMM** Micromegas replace the TimePix beam monitor
  - Greater active area wrt TimePix and less passive material budget
  - Beam shape and spot monitor

Source	Uncertainty [%]		Improvement
	Run III	**Run IV**	
N_2	0.6	**0.3**	New target position → acceptance increased
B	0.35	**0.3**	PadMMe → ee/gg discrimination + better angular-momentum resolution
N_{PoT}	0.55	**0.3**	3 different beam spot monitor (target-PadMMe-TMM) + online LG calibration system
TOTAL	**0.88**	**0.5**	

PadMMe

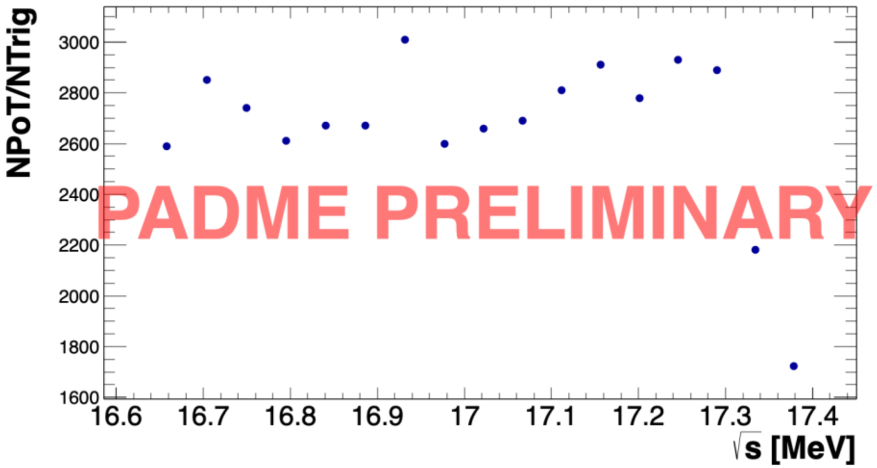




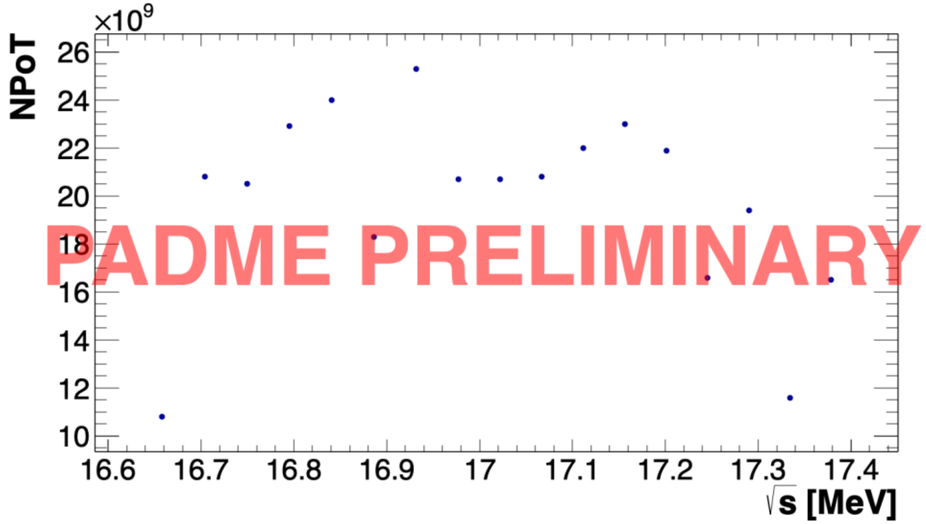
TMM

Conclusions

- PADME has collected about 5×10^{12} PoT with primary positron beam in Run II
  - Detectors performed as expected (and sometimes better)
- SM processes being looked at and used for experiment validation:
  - $e^+e^- \rightarrow \gamma\gamma$ cross section at Ee+ = 430 MeV measured with ~5% uncertainty
- Run III analysis has been completed: no indications of X_{17} well beyond two-sigma-equivalent global p-values, an excess has been observed, with global p-value equivalent to 1.77(15)σ
- New data acquired to better clarify:
  - Run IV-part 1 data already in the book: 18 energy scan points collected (~$2e^{10}$ PoTs each) equally separated by 1.5 MeV in the the E_{beam} = (269.5, 295) MeV / $\sqrt{s}$ = (16.60, 17.36) MeV region
  - Run IV-part 2 already scheduled for autumn 2025
    - Scan points = 18-20 + out-of-resonance below 16 MeV and above 18 MeV



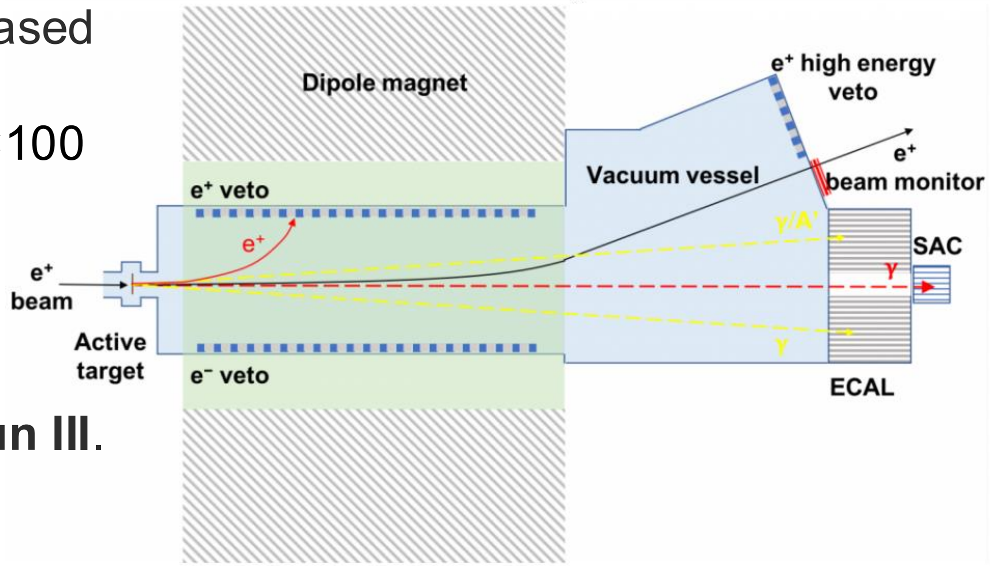
Run IV – Scan 1



Backup slides

The PADME experiment

- Positron Annihilation into Dark Matter Experiment: $e^+e^- \to \gamma A'$ based @ Frascati National Laboratories (LNF-INFN).
- e^+beam (E<550 MeV) on a diamond active target 2 cm × 2 cm ×100 μm
- Measure of ΔM^2_{miss} using a BGO ECal.
- Could be sensitive to sub-GeV new physics (e.g. ALPs)

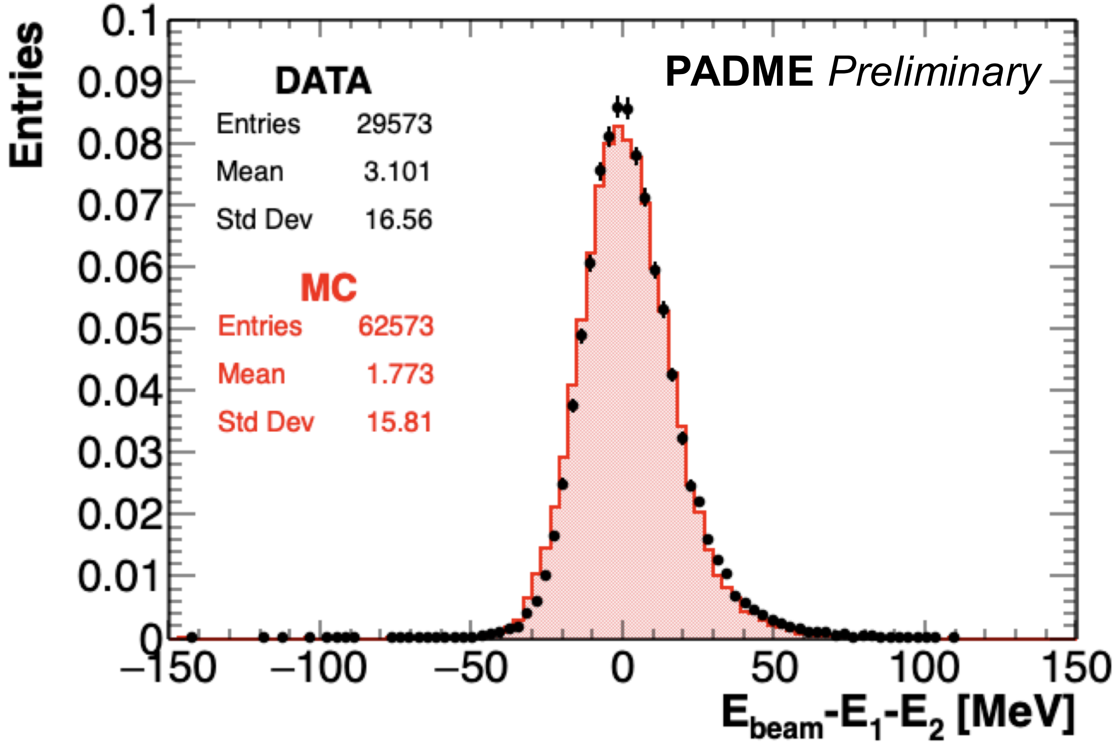


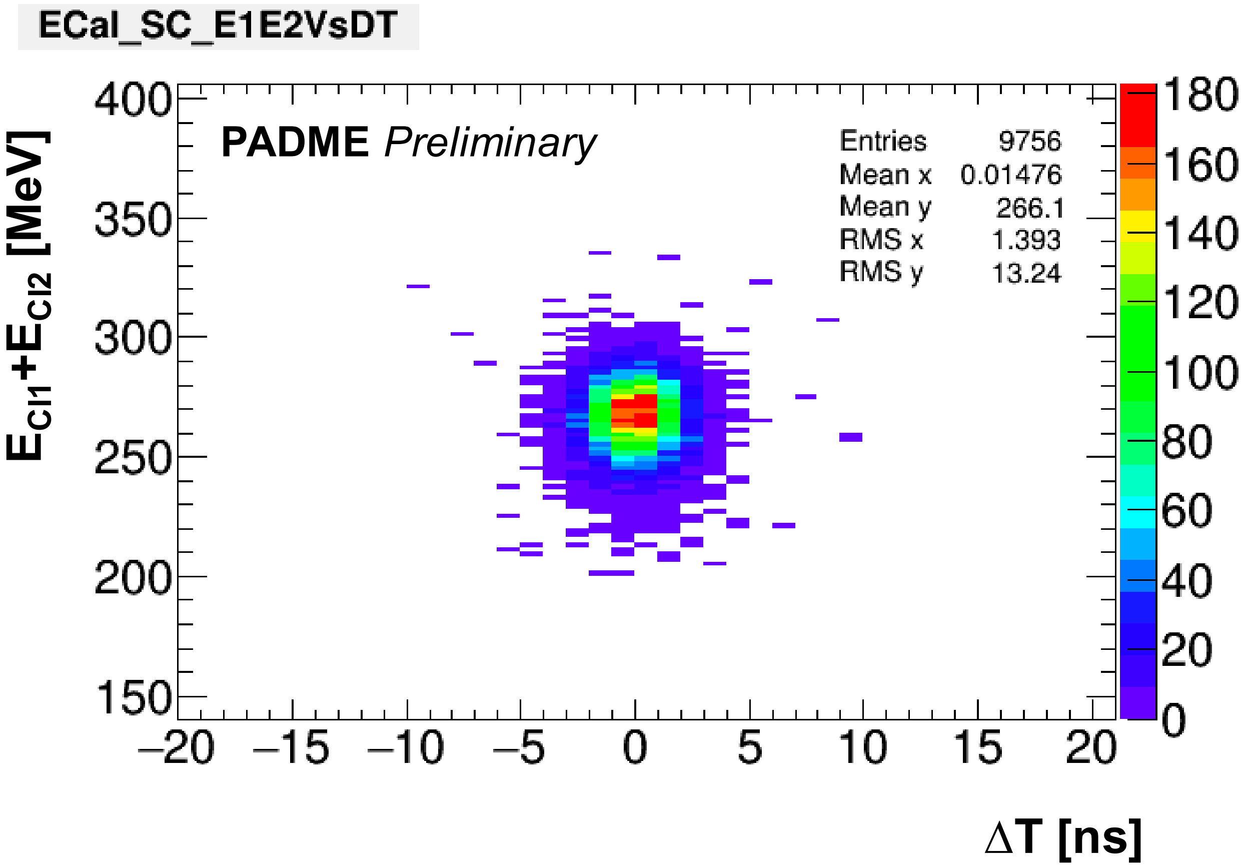
Can exploit the resonant production of X17 → fine scan: **PADME Run III**.

- Some modification to the setup were necessary

Events selected → $N_2(s)$

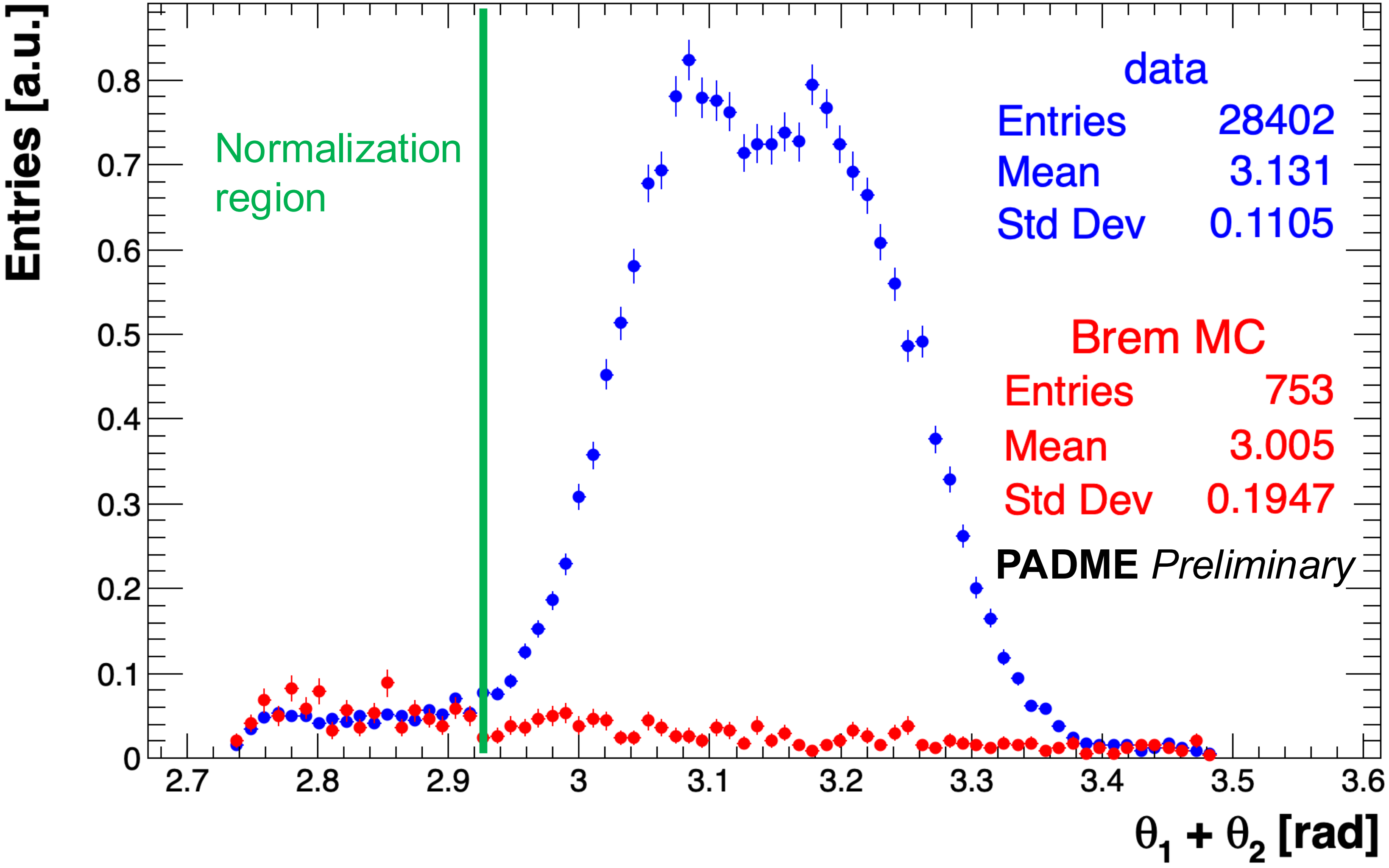
- Events surviving the whole set of cuts, also related to the time difference of the 2 Clusters
- Energy sum of the 2 clusters selected gives back the beam energy (as expected for a two-body final state)
- ECAL relative energy resolution ~ 5%





Bremsstrahlung bkg removal

- In the $\theta_{cm1} + \theta_{cm2}$ distribution of the selected event in data and MC shows a Brem tail in outside the signal
- By normalizing in the (0, 2.94 rad) regions and then using the ratio between the (2.94 rad, 4 rad) integrals it is possible to get an estimate of the Brem events under the signal

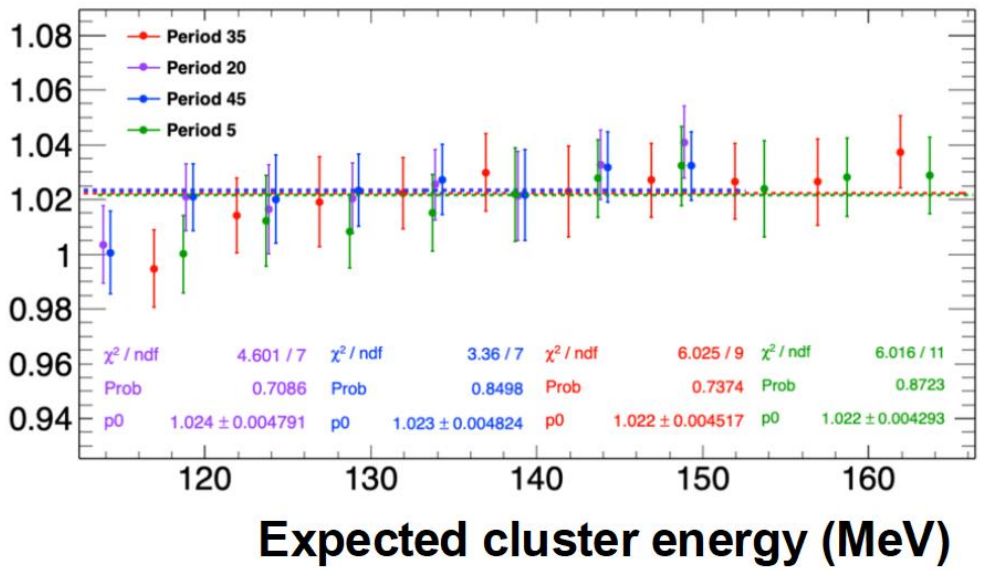


Tag and Probe → Reco efficiency

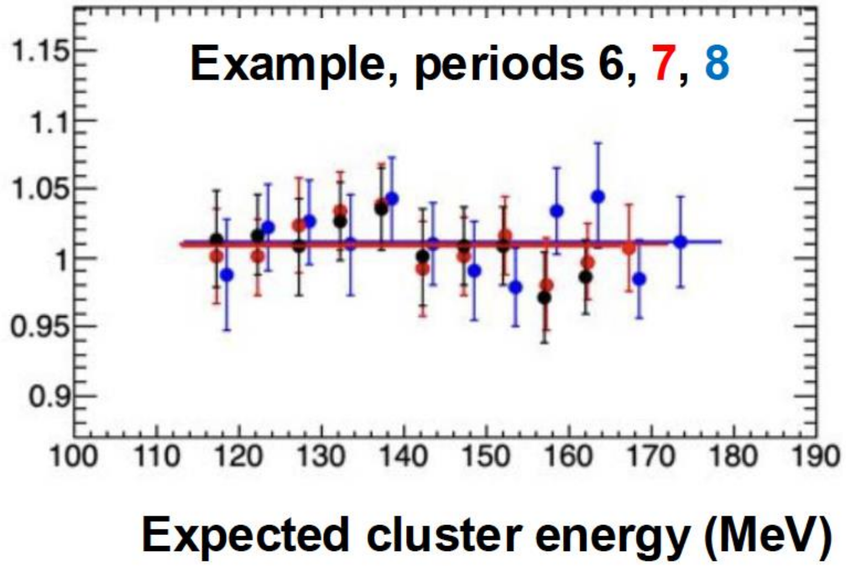
Tag and probe technique, the method-induced bias is 2.3(2)% and stable along the data set

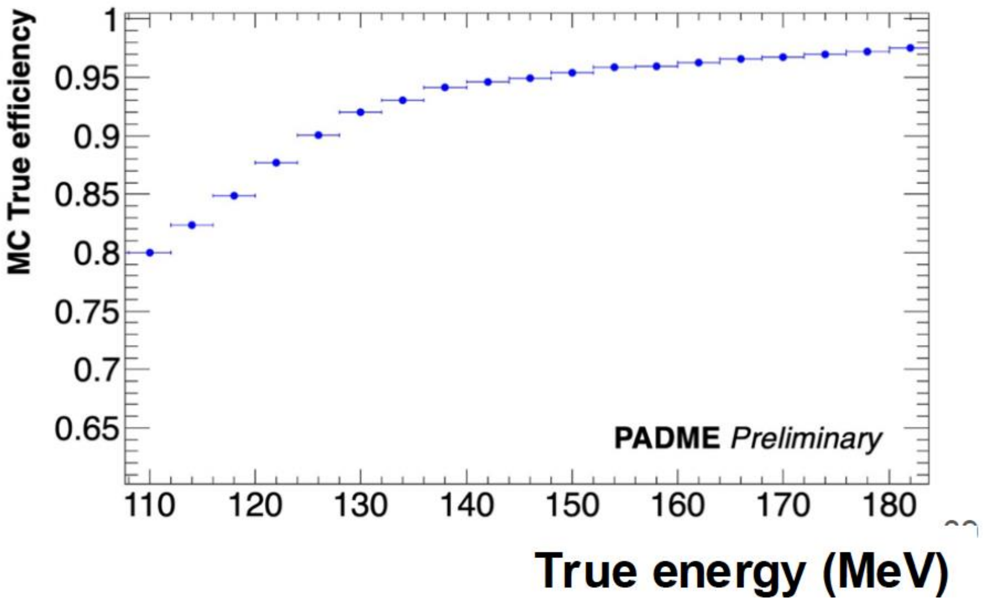
Data/MC method efficiency stable along the data set and at the few per mil

Efficiency <Method /MC true>



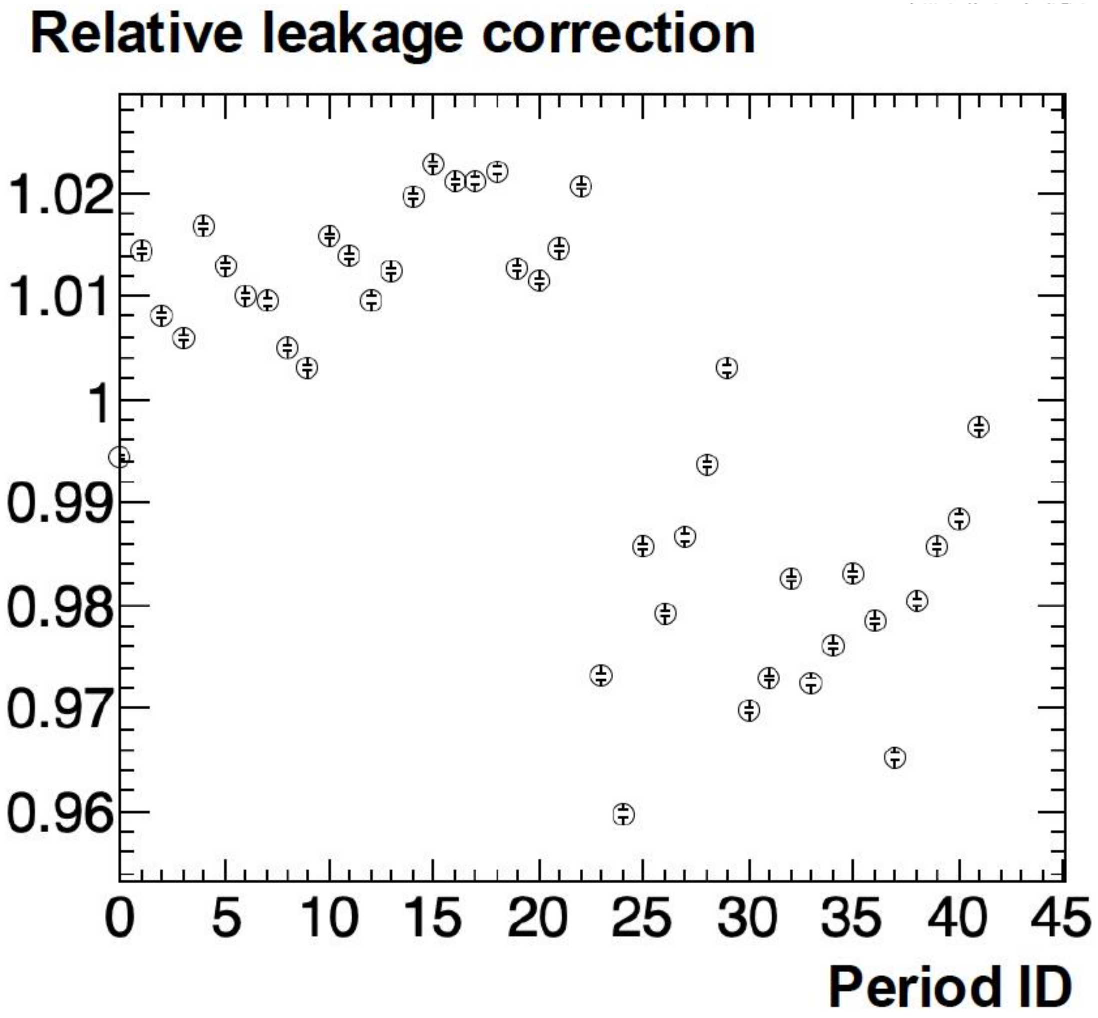
Efficiency Data/MC

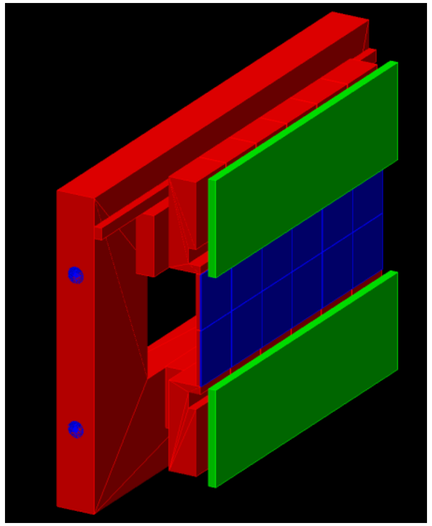




PbGl energy loss in passive material

- TimePix cooling geometry (mostly Cu) was described in detail in the MC simulation
- Replicate the loss due to the beam passing in the Cu in Run III is possible by using the beam spot
- Beam spot from TimePix is not available for all the periods → used the COG instead considering the Timepix-ECAL offsets and the intrinsic difference in resolution



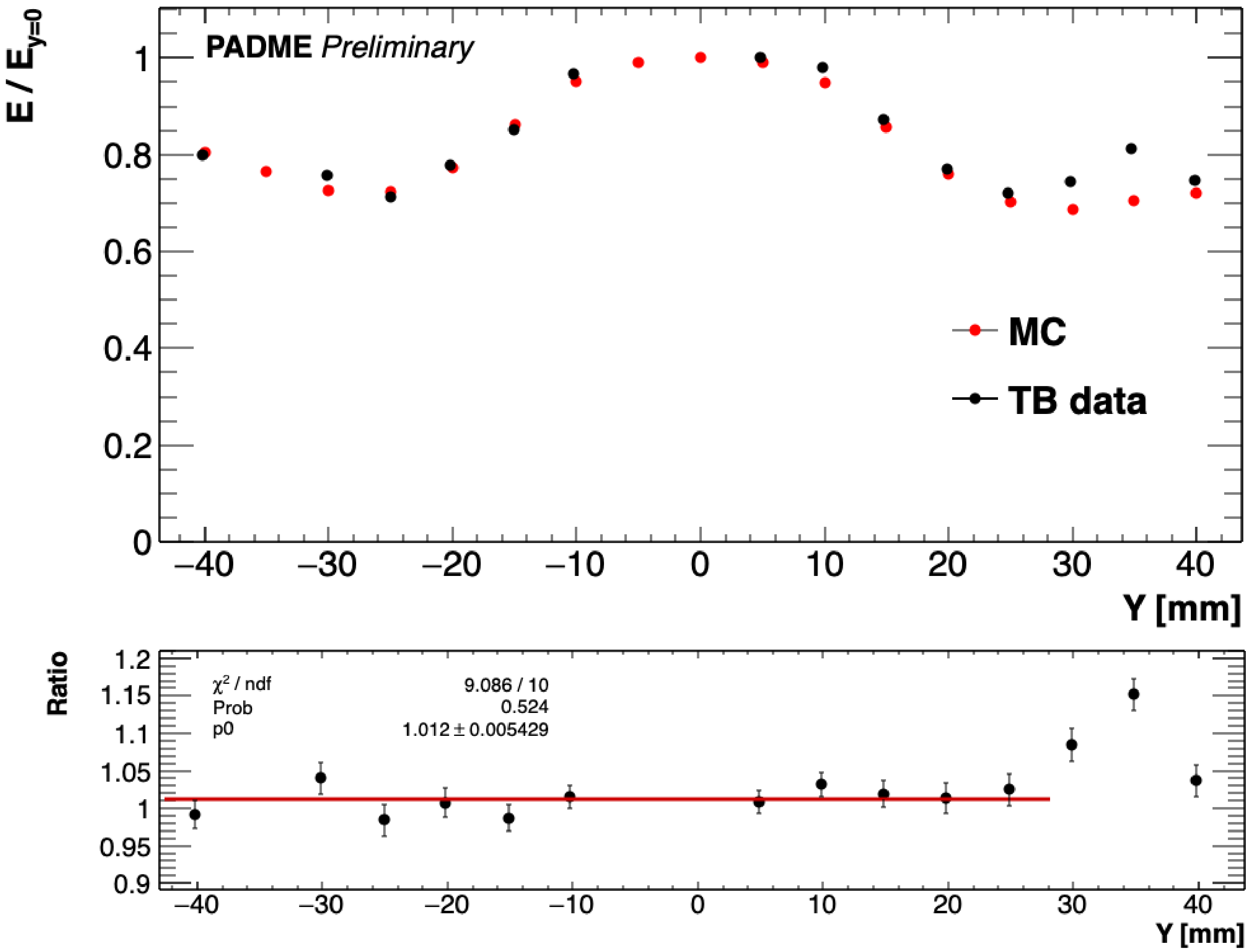


Significant period-by-period correction variation: -4% to +2%

Energy loss → Test beam

How much do we trust the correction?

- Dedicated test beam taking a Y scan at PbGl level. We tried to replicate it with the MC simulation
- Good Data/MC agreement in the region where the beam was scanned during Run III
- **1.2% overall scale correction** (included in the $g_R(s)$ scale) **with a 0.5% error**



Radiation damage

- Throughout Run III a total of 7e11 PoT(of ~300 MeV each) has passed through the PbGl block corresponding to a **TID of 25 Gy** (2.5 krad)
- The SF57 transmittance loss was never measured in literature, however for similar blocks (SF5-SF6) a significant loss is shown, especially near Cherenkov wavelengths
- Used of some proxy variables to understand the level of the LY loss:
  - Q_x-target
  - <E-ECAL>
  - Period multiplets

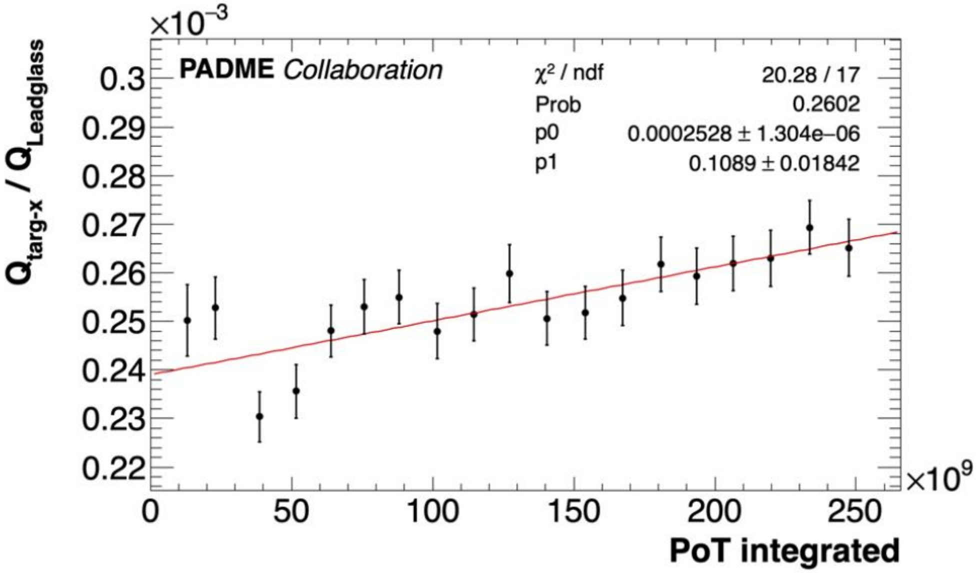
Quantity	PWO:R^{3+}	SF5 (PbO:50%) [4]	SF6 (PbO:75%) [4]
Density ($g\,cm^{-3}$)	8.28	4.07	5.19
Radiation length X_0 (cm)	0.89	2.55	1.69
Index of refraction	2.2	1.67	1.81
Cutoff in T (%) (nm)	320	340	360
Hygroscopicity	No	No	No
Melting point (°C)	1123	442	455
Radiation-hardness (rad)	10^{7-8}	10^{3-4}	10^{2-3}
Hardness (Mohs)	3		
Cleavage	(101)	None	None
Available length[a] (X_0)	30	Large	Large
Moliere radius (cm)	2.19		

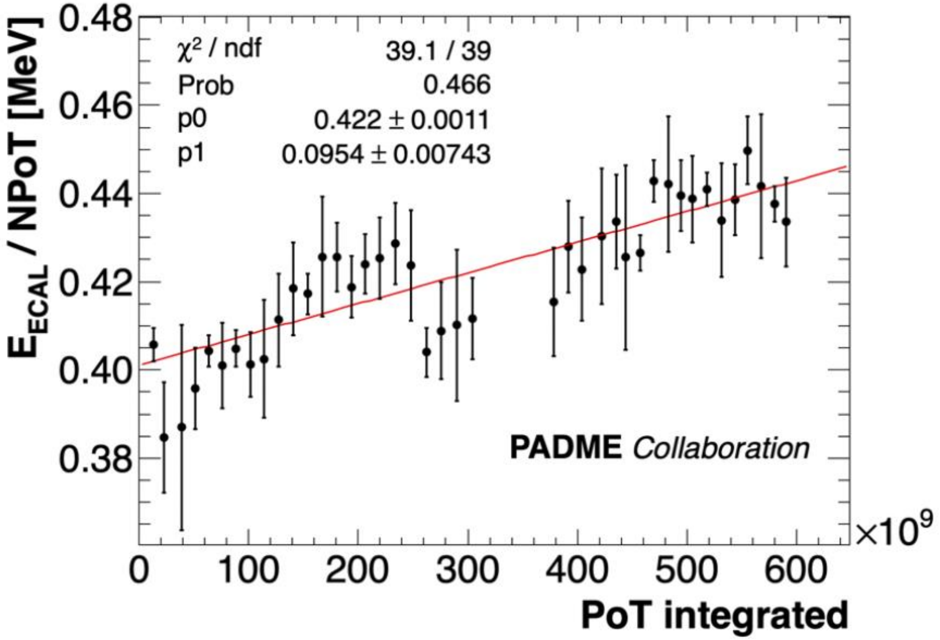
SF57 PbO concentration ~ 75%

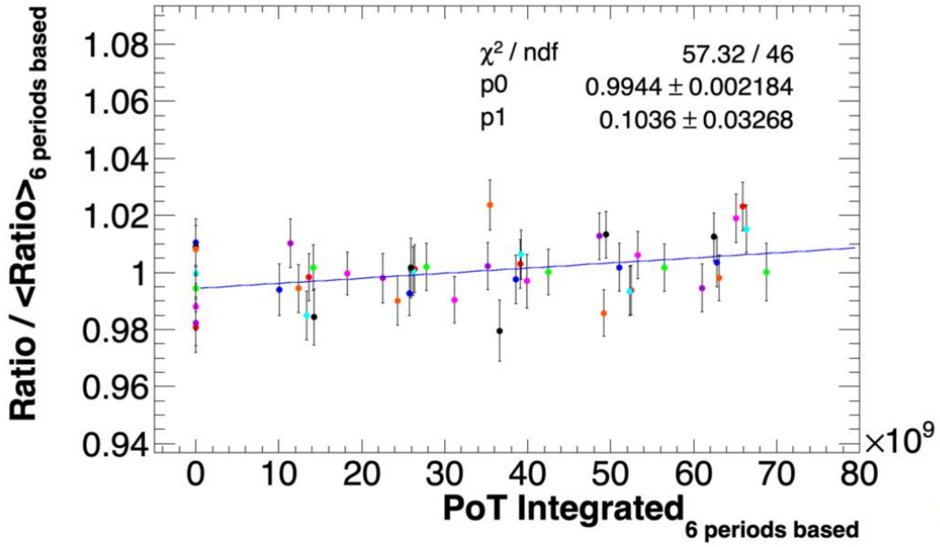
Radiation damage - 2

Proof of loss of LY:

- Target X strips are way more sensible than Y → their charge can be used for quantitative checks. **10% slope found**
- The overall energy on ECAL over the N_{PoT} should be a stable quantity, also here we see a **10% slope**
- Looking at the Data/MC ratio on resetting every 6 periods a compatible slope is found



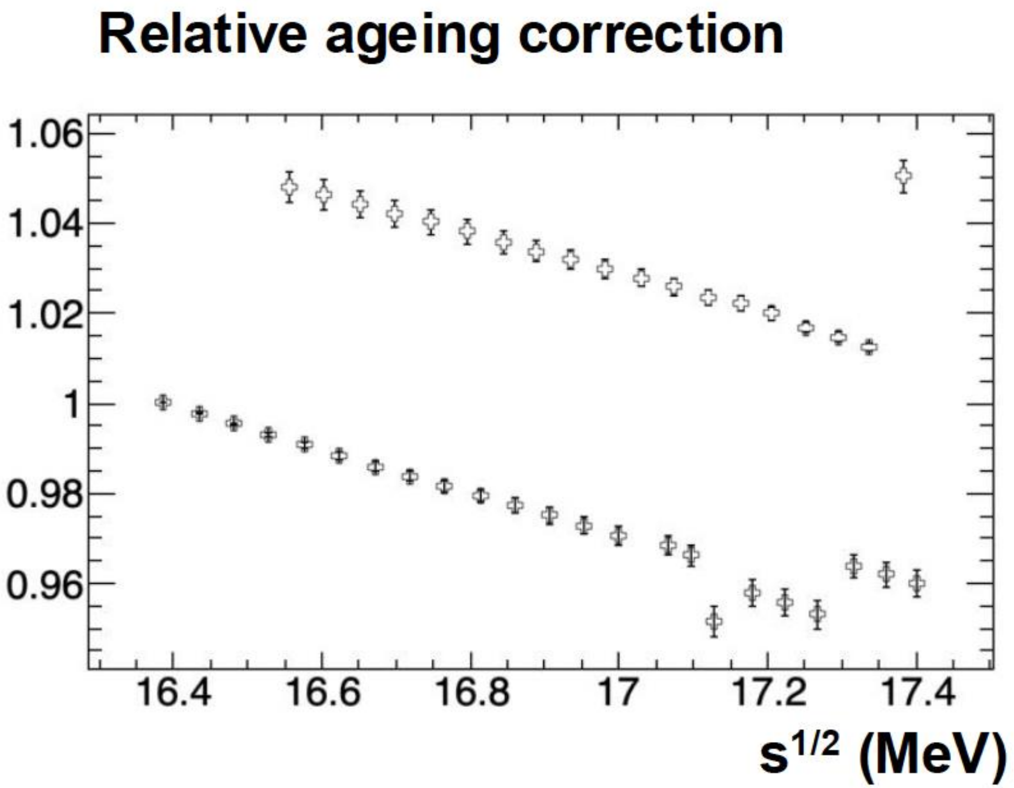




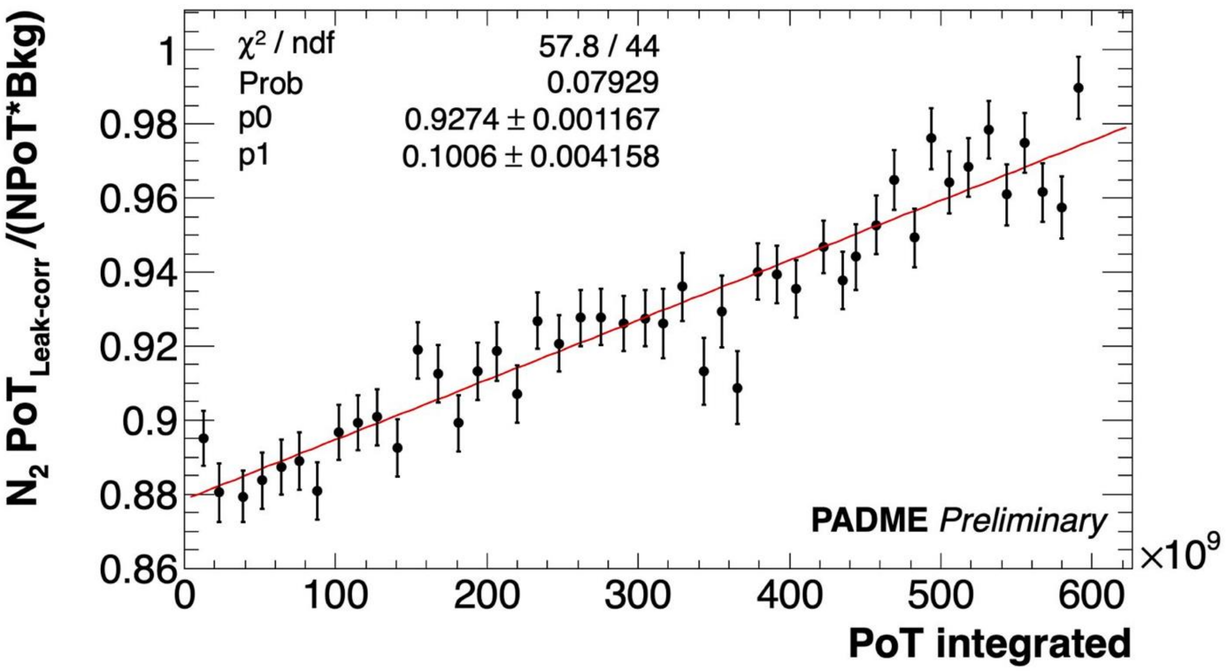
PbGl yield decreases with relative PoT slope of 0.097(7)

Radiation damage – 3

- **PbGl yield decreases with relative PoT slope of 0.097(7)**
- Constant term uncertainty of 0.3% added as scale error
- Slope error included in PoT uncertainty
- Checked the slope value on $g_R(s)$ after the unblinding→ totally compatible results

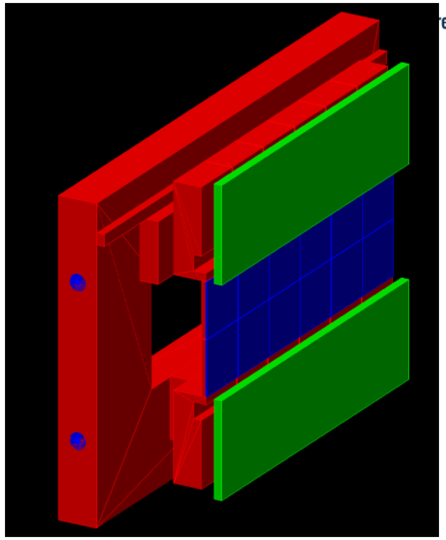


Post unblinding

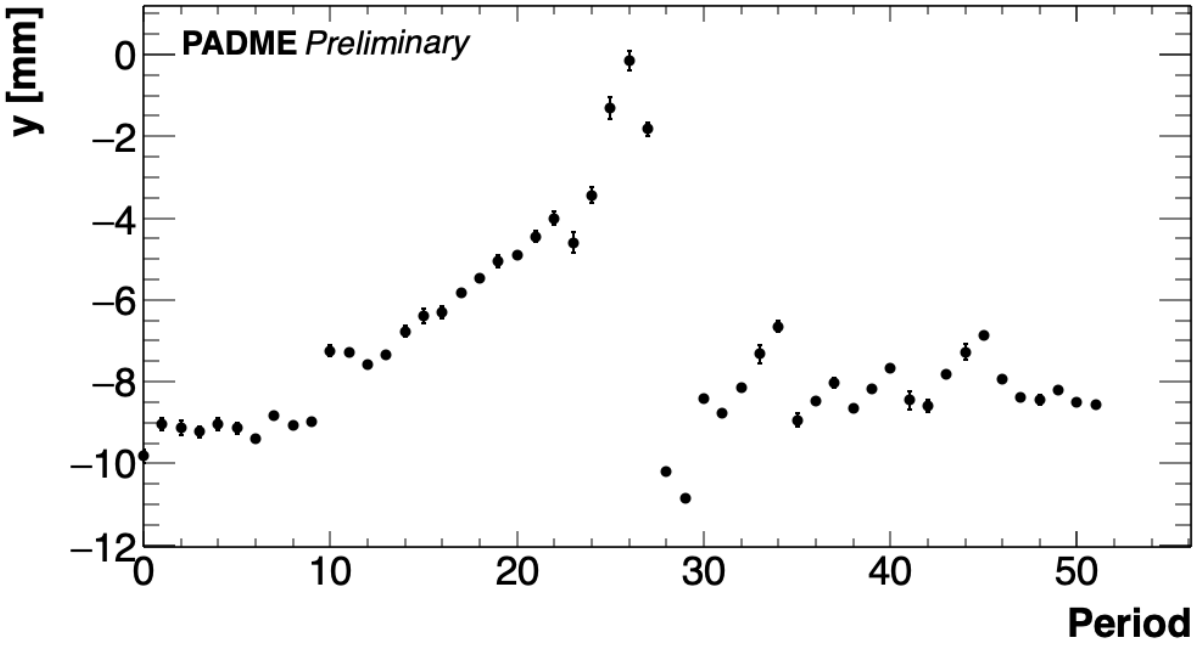


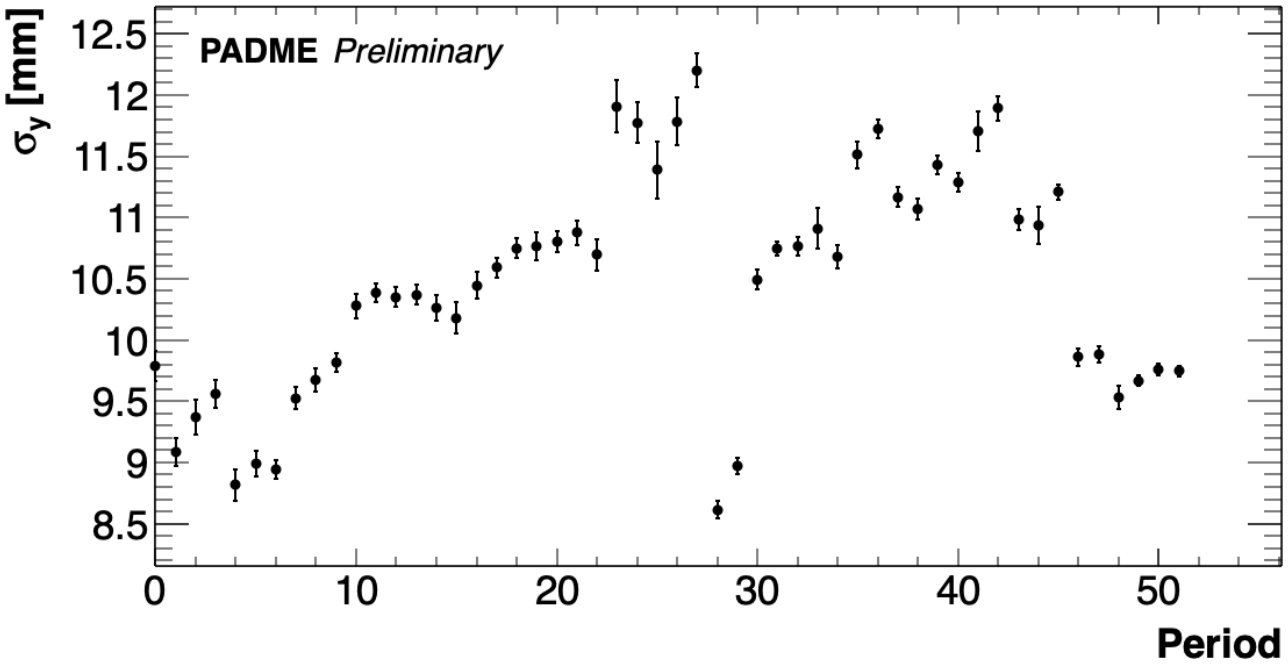
MC simulation in Run 3 (1)

- New Timepix geometry in PadmeMC to consider passive material (Cu)
- Using the Timepix beam spot it is possible to replicate the loss due to the copper also in Run 3
- Beam spot is not available for all the periods → we used the COG instead considering the Timepix-ECAL offsets and the intrinsic difference in resolution



MC inputs

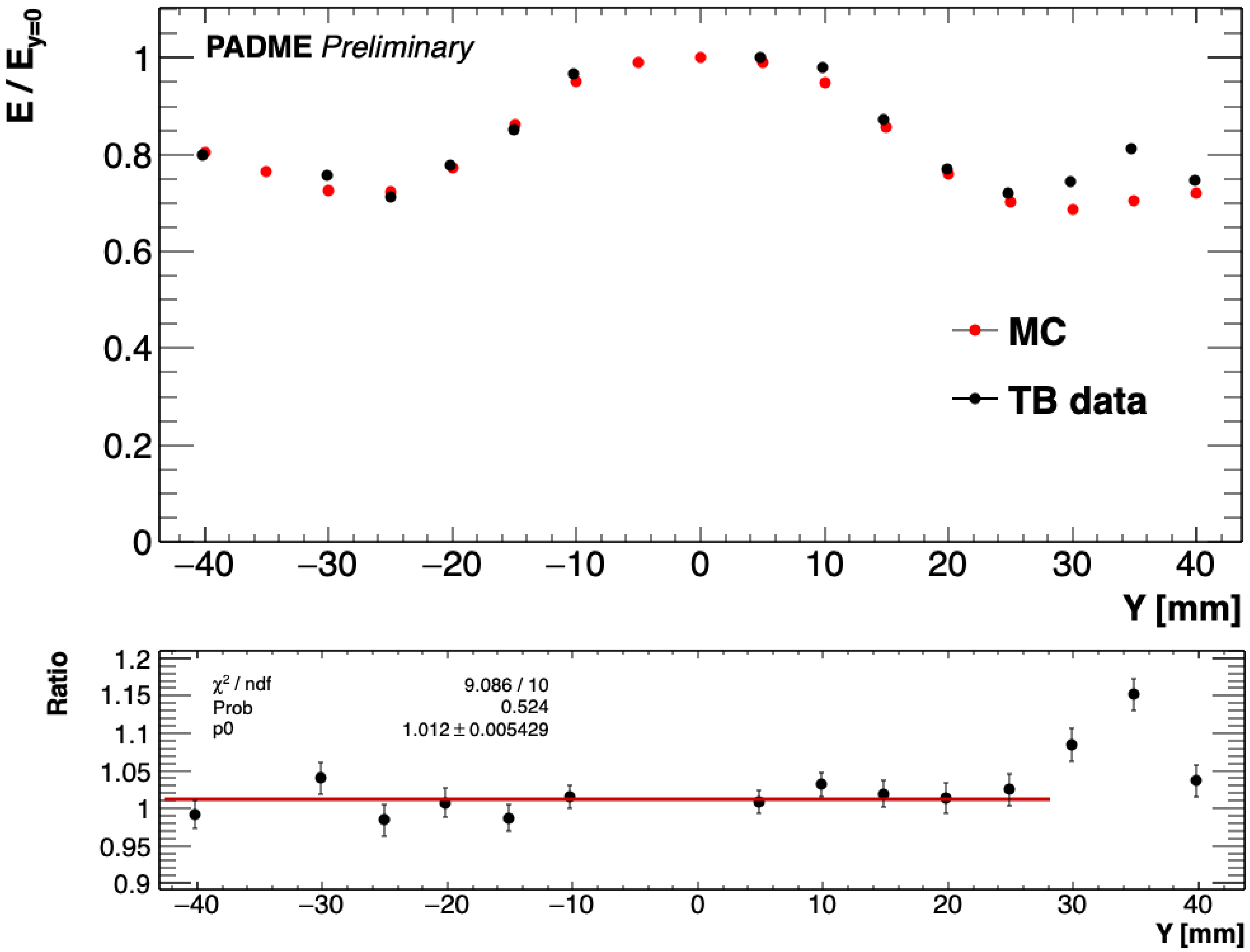




Energy leakage → Test beam

How much do we trust the correction?

- Starting from Katerina's data we tried to replicate the Y scan with PadmeMC
- Good data/MC agreement in the region where Run3 beam scanned
- **1.2% overall scale correction** (to address the Data/MC difference) **with a 0.5% error**



Radiation damage

- Throughout Run 3 a total of 70e10 PoT (of ~ 300 MeV each) has passed though the Leadglass block → in terms of radiation this corresponds to a TID of 25 Gy (2.5 krad)
- The SF57 transmittance loss was never measured in literature however for similar blocks SF5-SF6 a significant loss is shown, especially near Cherenkov wavelengths. Only samples doped with Ce (not our case) have shown a stronger resistance.

Quantity	PWO:R^{3+}	SF5 (PbO:50%) [4]	SF6 (PbO:75%) [4]
Density ($g\,cm^{-3}$)	8.28	4.07	5.19
Radiation length X_0 (cm)	0.89	2.55	1.69
Index of refraction	2.2	1.67	1.81
Cutoff in T (%) (nm)	320	340	360
Hygroscopicity	No	No	No
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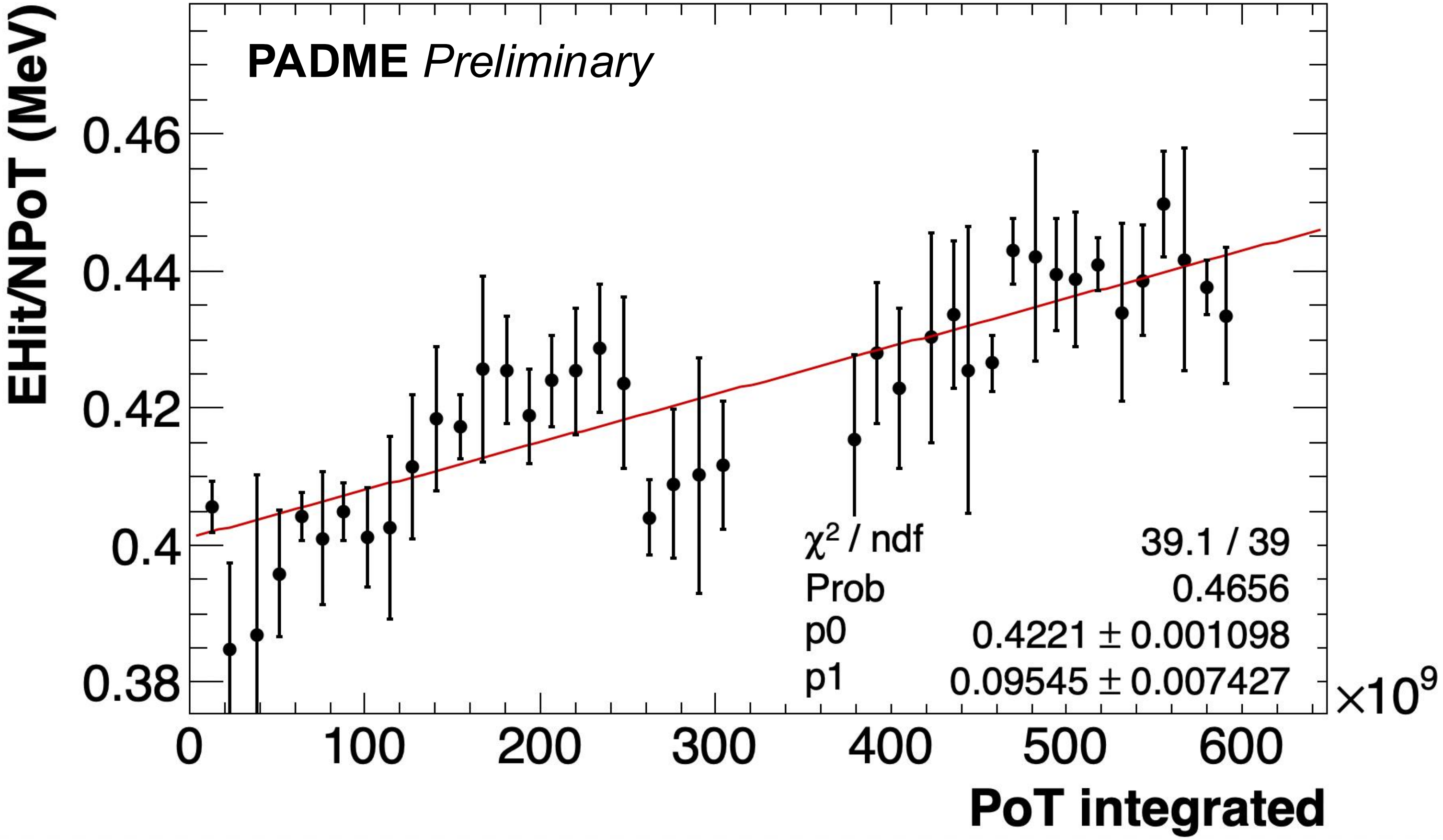
Radiation-hardness (rad)	10^{7-8}	10^{3-4}	10^{2-3}
Hardness (Mohs)	3		
Cleavage	(101)	None	None
Available length[a] (X_0)	30	Large	Large
Moliere radius (cm)	2.19		

SF57 PbO concentration ~ 75%

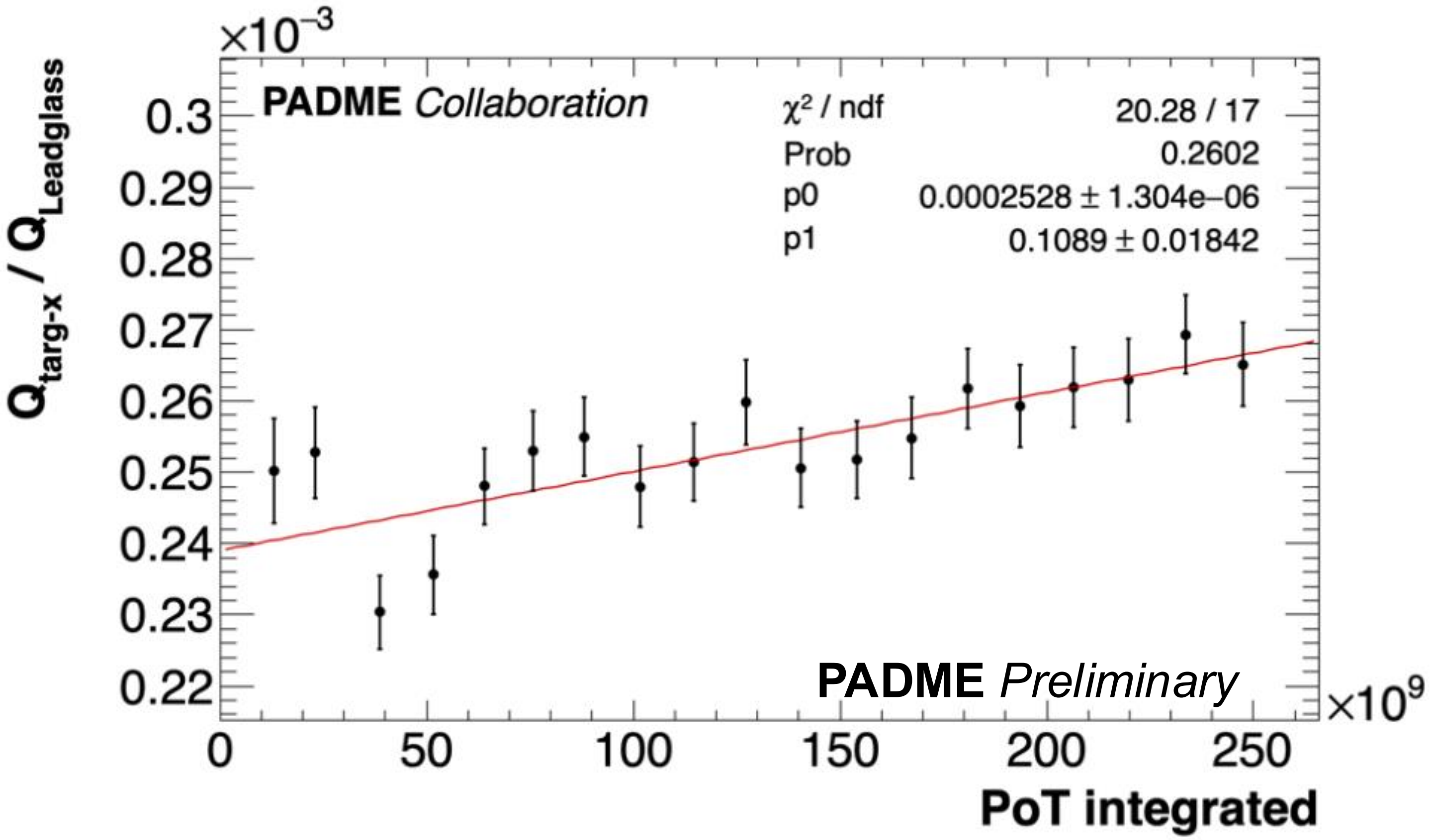
Radiation damage → Ehit/NPoT

- First proof of loss of LY:
  - By looking at the ratio between the total energy per bunch in ECAL and the NPoT an increasing slope is visible → order 10%
  - Notice that EHit is particularly sensible to the beam spot variation (beam e^+ might enter) hence is prone to significant jumps between periods



Radiation damage → $Q_{targetX}/Q_{Leadglass}$

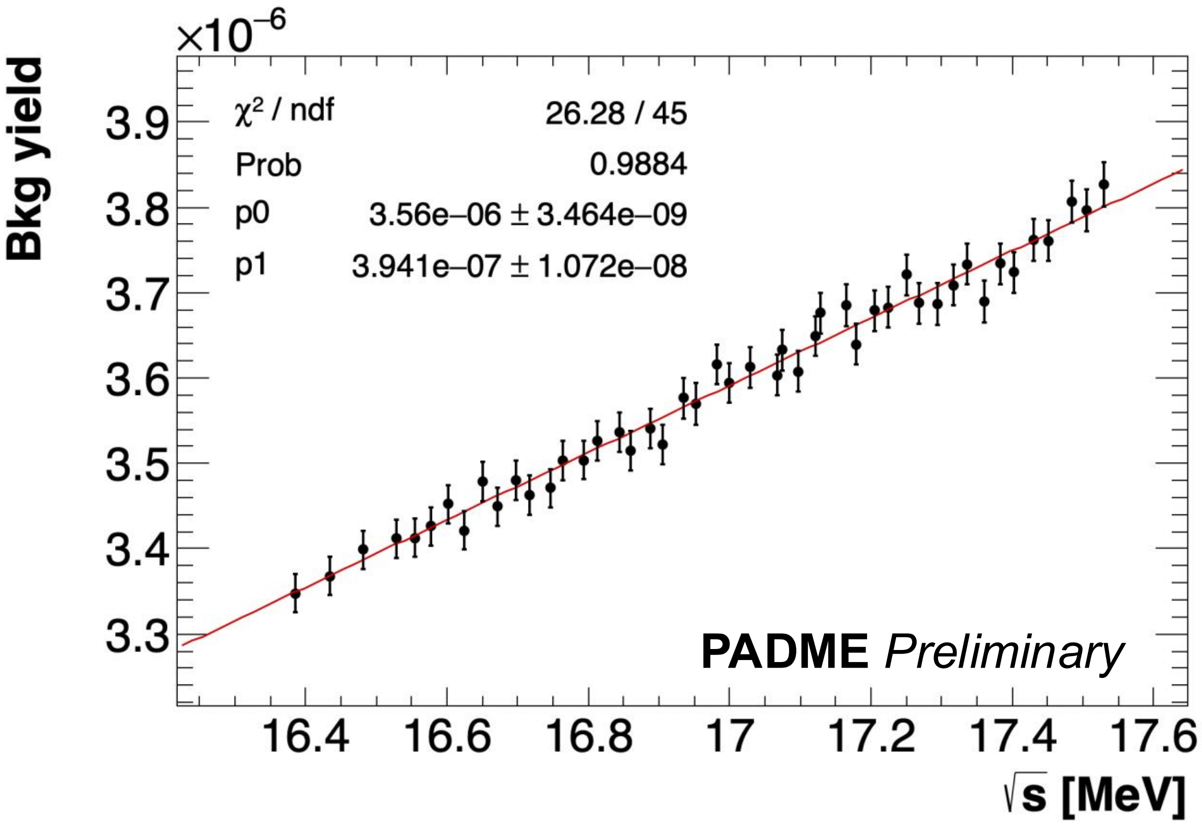
- Second proof of loss of LY:
  - Target X strips are way more sensible than Y → can be used for quantitative checks
  - Shows an increasing slope → order 10% also here
  - During scan 1 (fitted) there were no "no target runs" hence the Qx response is reliable just in that part of Run 3
- **Conclusion:** use the weighted mean of the two proofs as Integrated PoT correction → 0.0967 +/- 0.0068

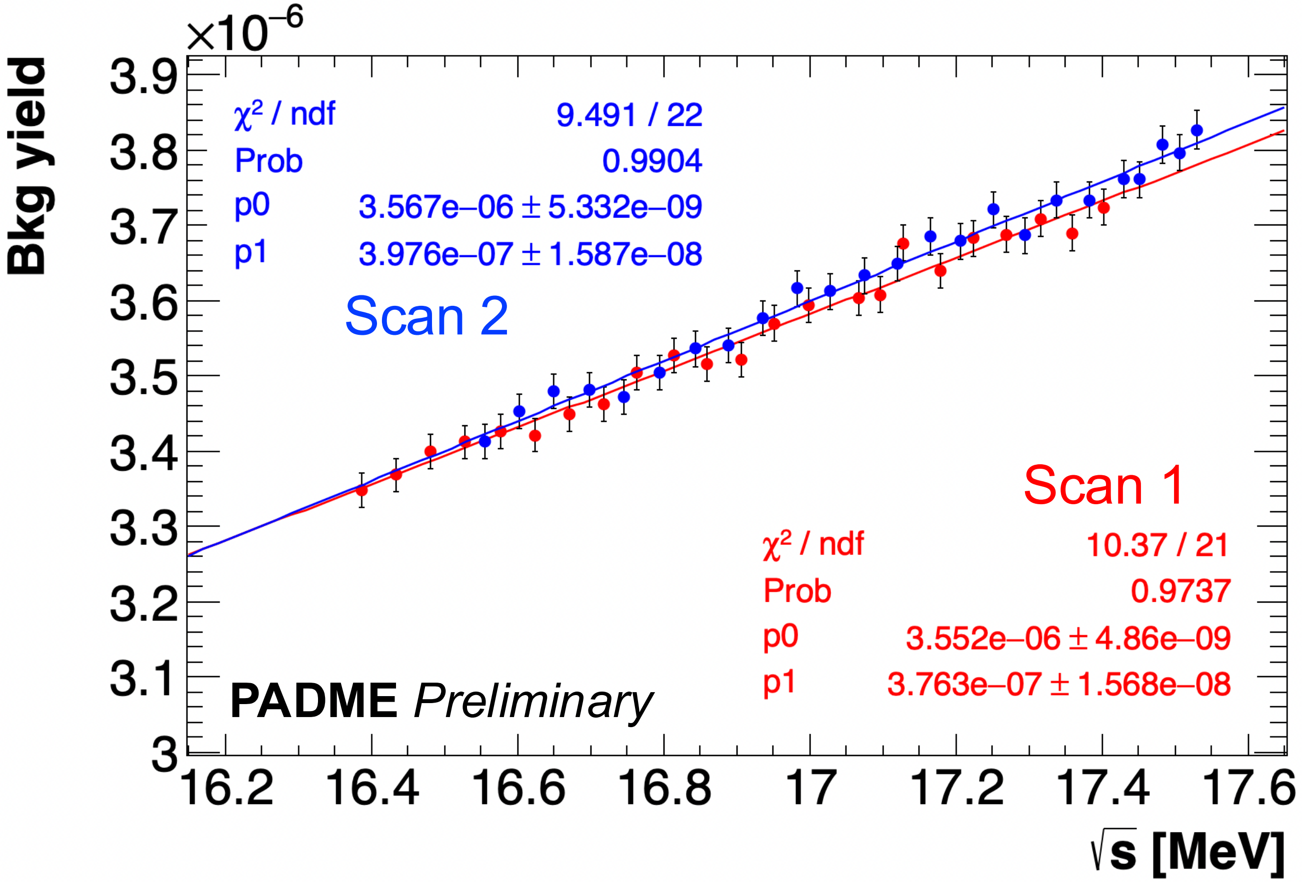


Bkg yield

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

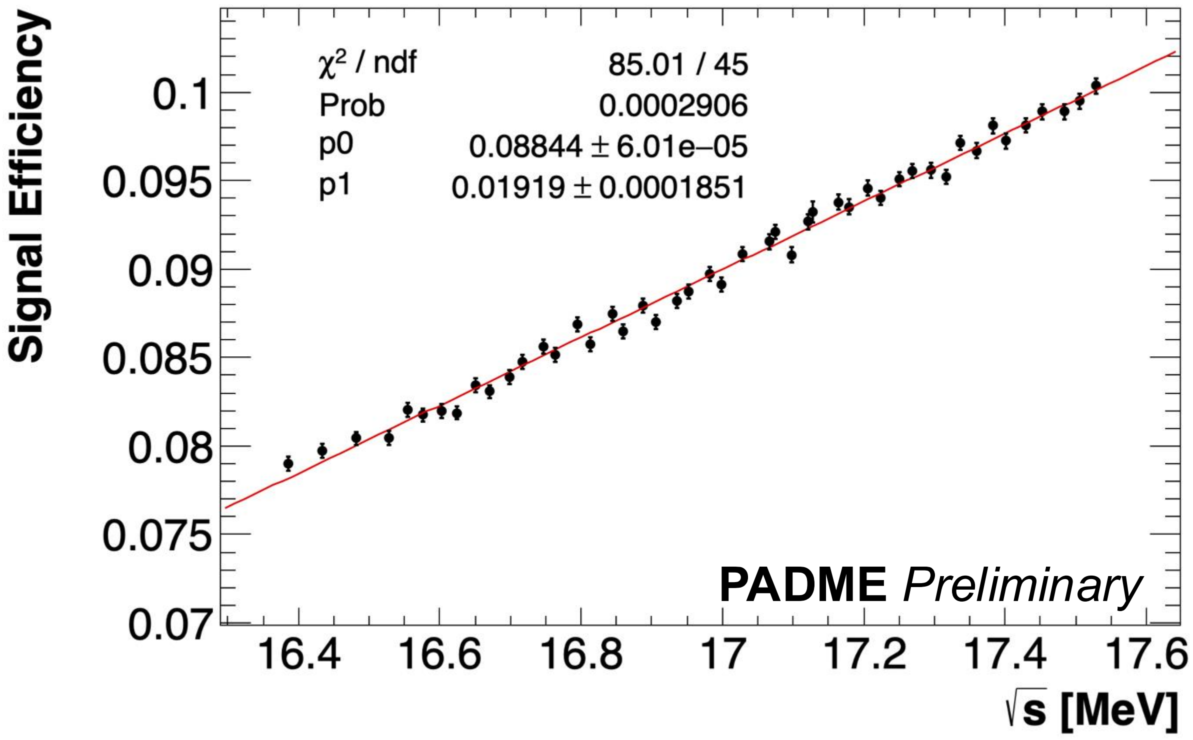
- 0.4% error → statistic, added 0.5% in quadrature to account the RMax cut systematics
- Possibility to treat separately the two scans in the sensitivity evaluation

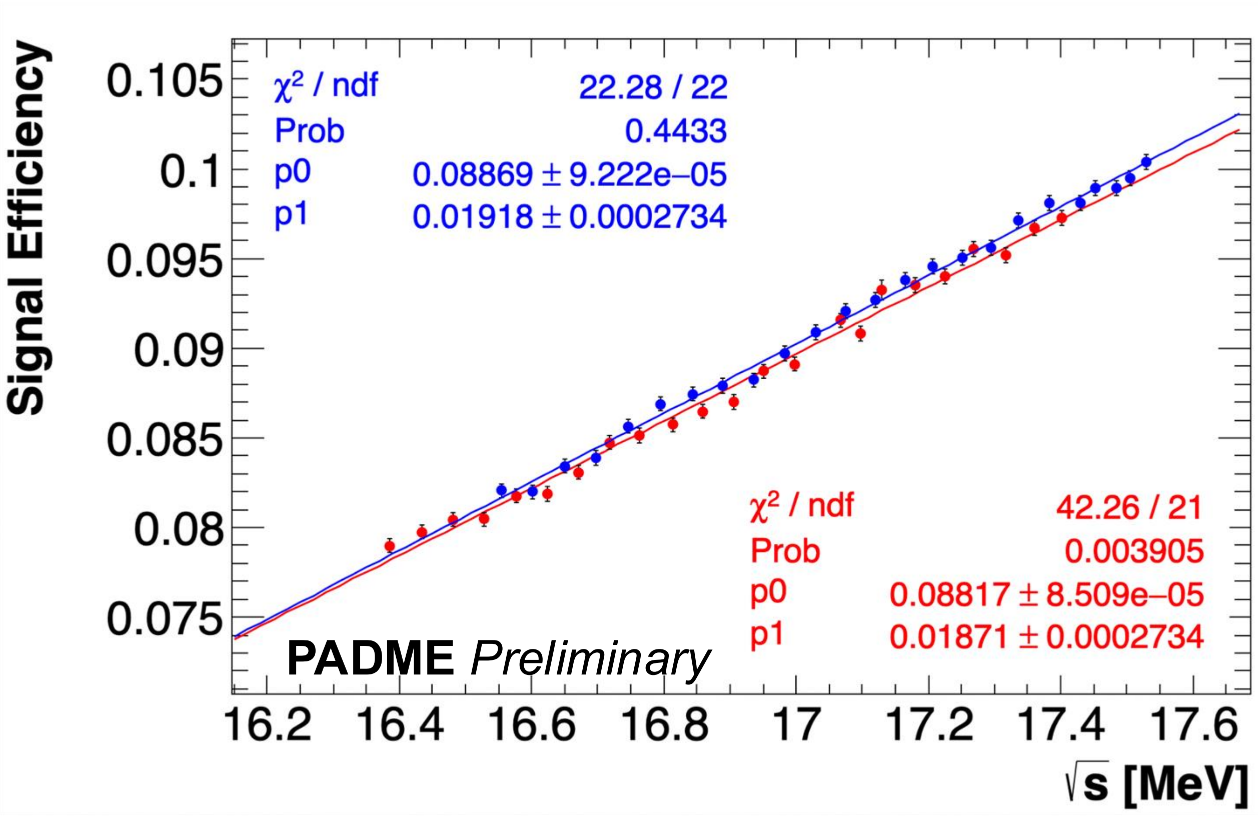




Signal efficiency

- 0.4% error → only statistic
- Possibility to treat separately the two scans in the sensitivity evaluation (better χ^2)





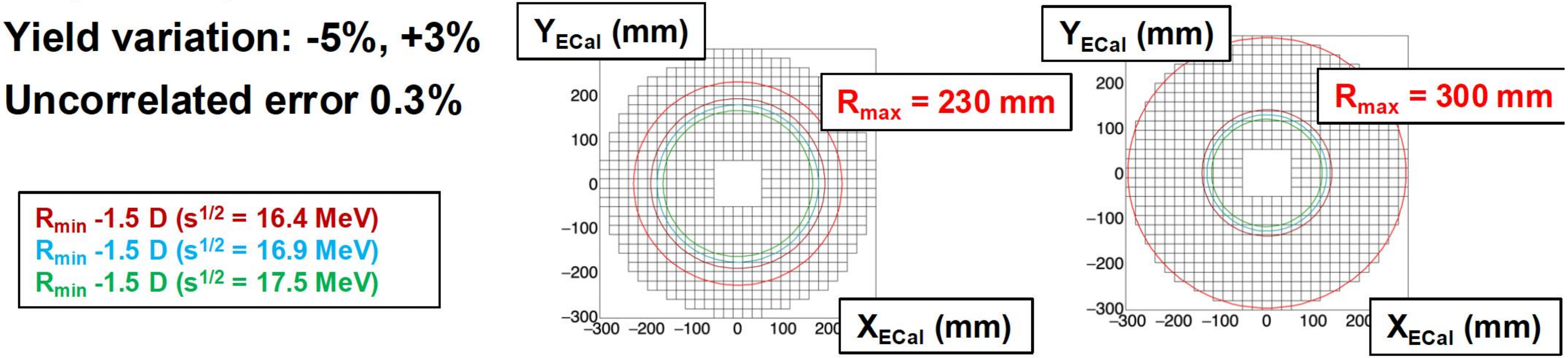
Rmax cut stability

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

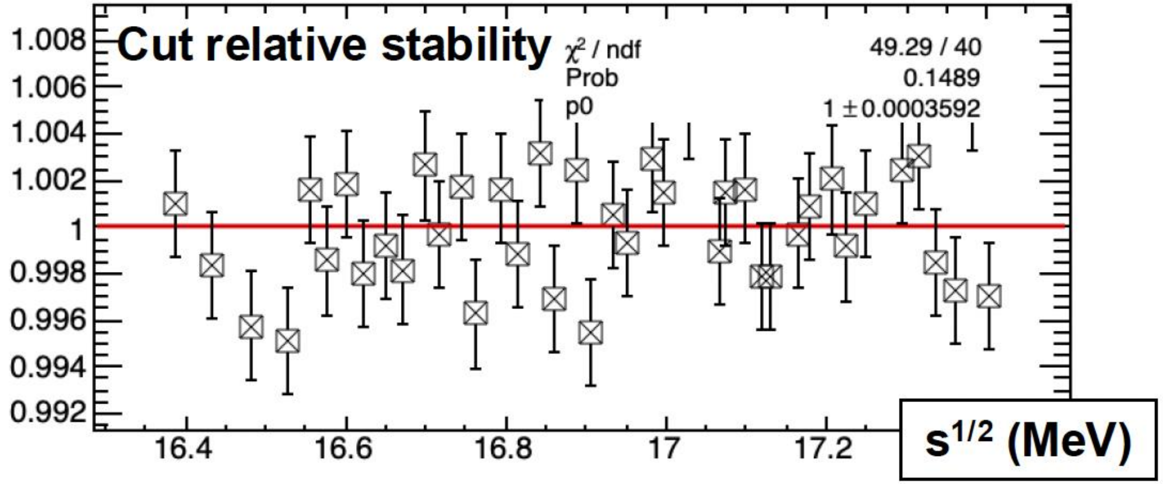
Vary R_{max} by +-2 E_{Cal} cells around nominal cut of 270 mm: 230 mm → 300 mm

Yield variation: -5%, +3%

Uncorrelated error 0.3%

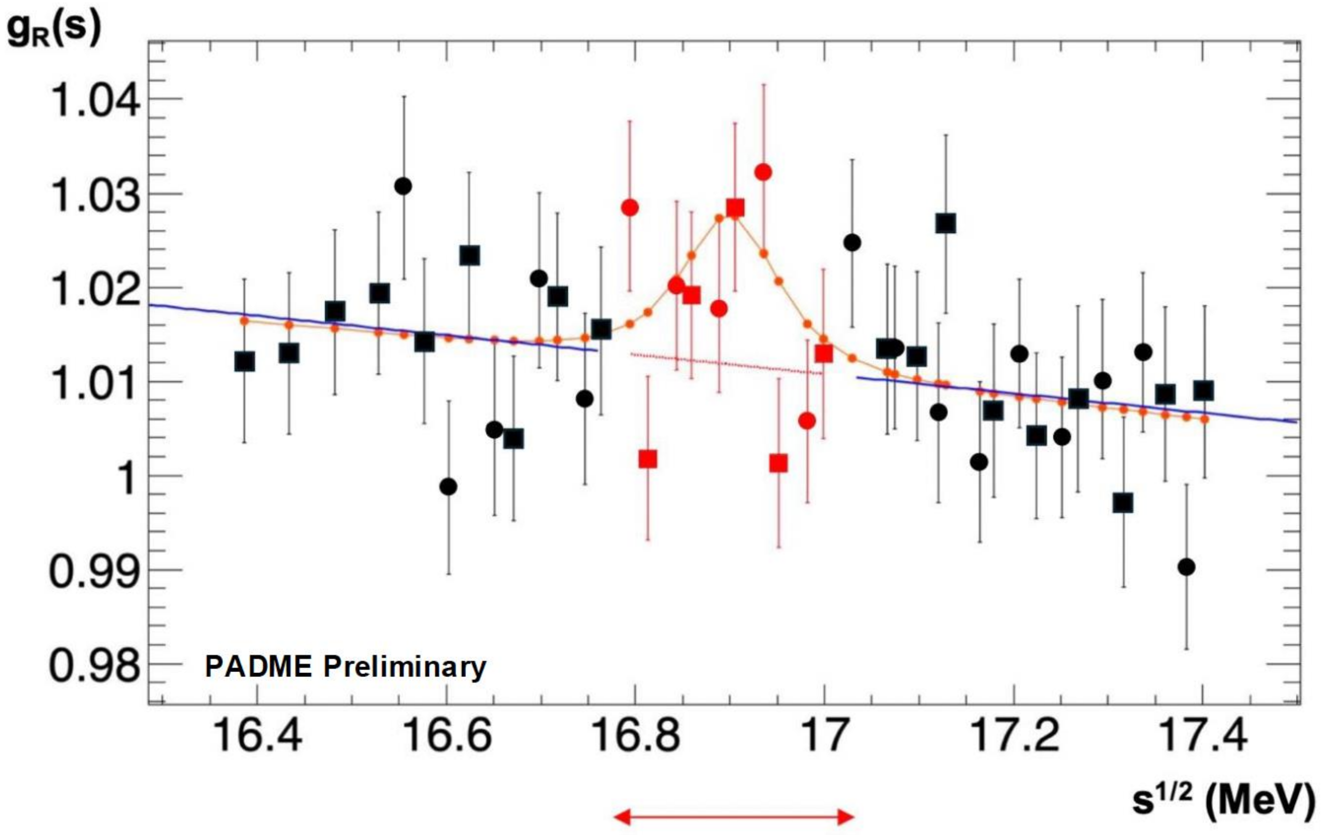


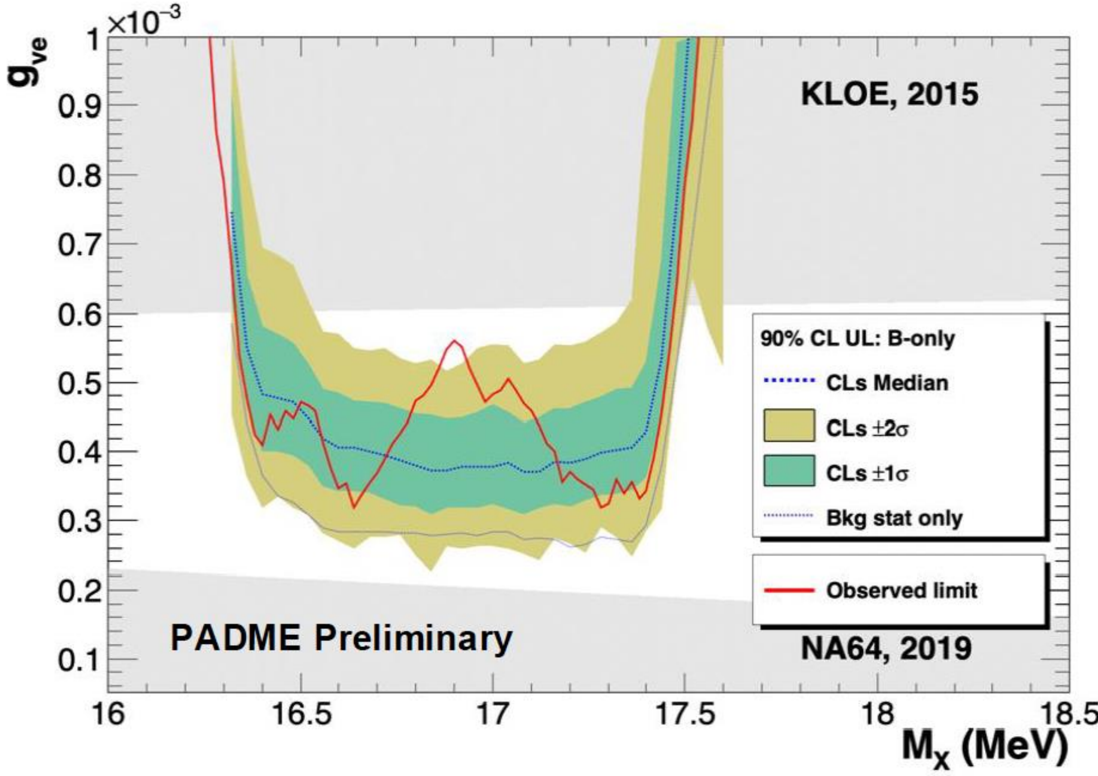
Stability is observed within a coverage band of +-0.2%, used as additional uncorrelated systematic error on B



Box opening - 2

- Check the data distribution vs likelihood fit done to evaluate $Q_{obs}(S+B)$
- Fit probability is 60%





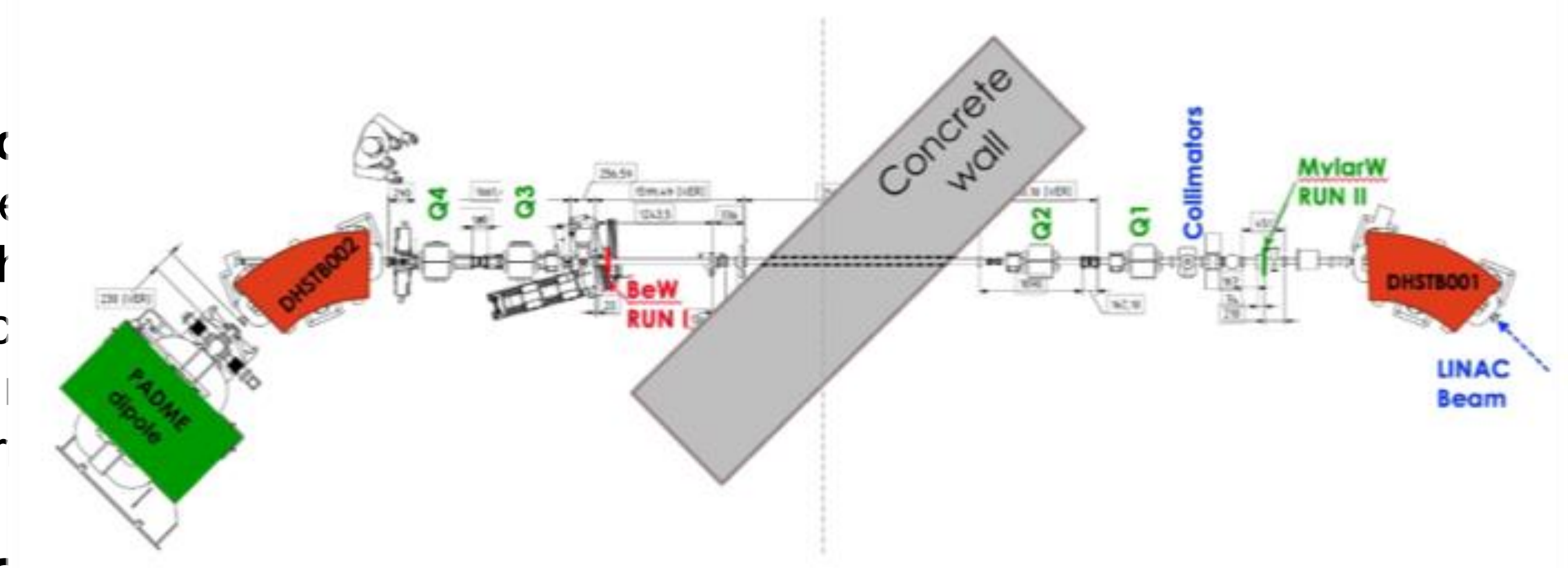
- Masked point of scan 1
- Masked point of scan 2
- Sideband point of scan 1
- Sideband point of scan 2

Sources of correlated error

B(s)

Correlated

- Absolute
- Target th
- B expec
  points, i
  scale er



NPoT(s)

Source	Common error on N_{POT} [%]
pC/MeV	2.0
Leakage, data/MC	0.5
Ageing, constant term	0.3
Total	2.1