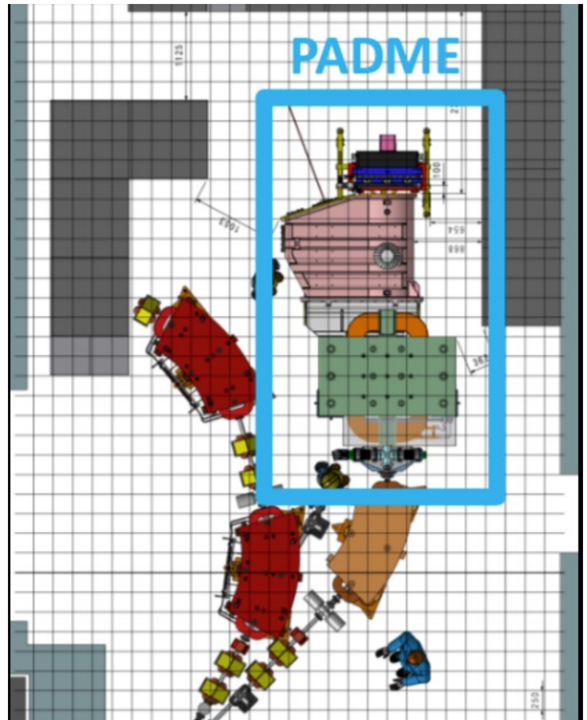
Dark sector studies at PADME



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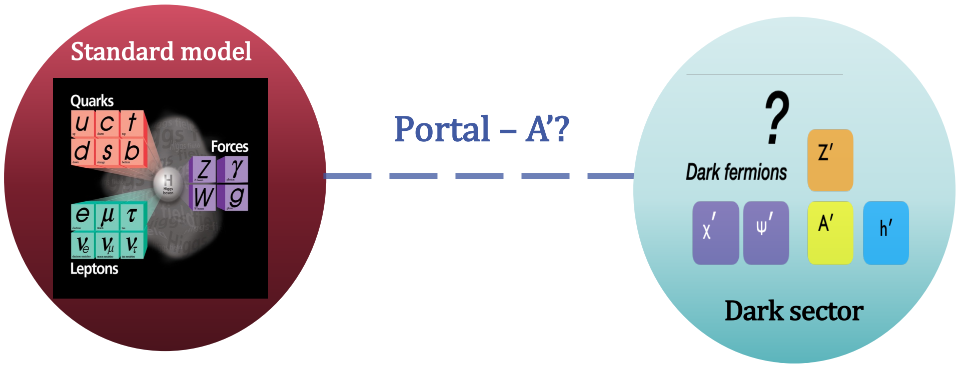
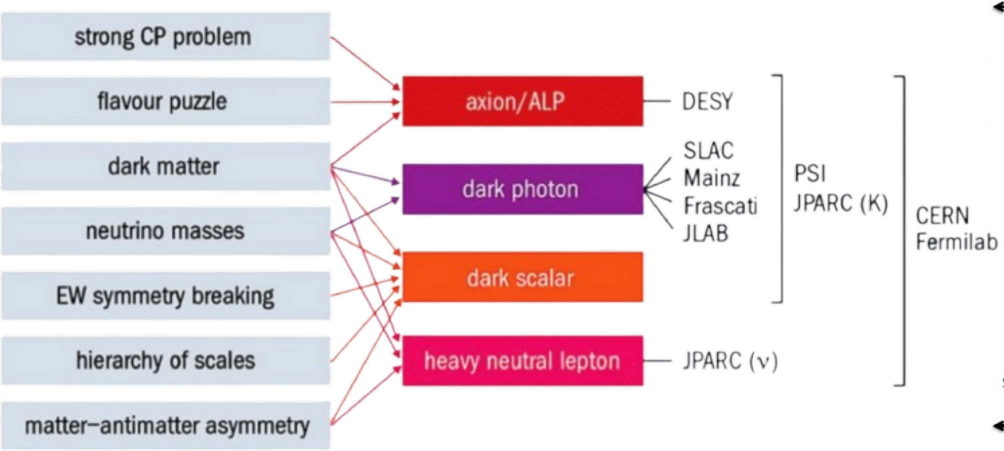
Outline

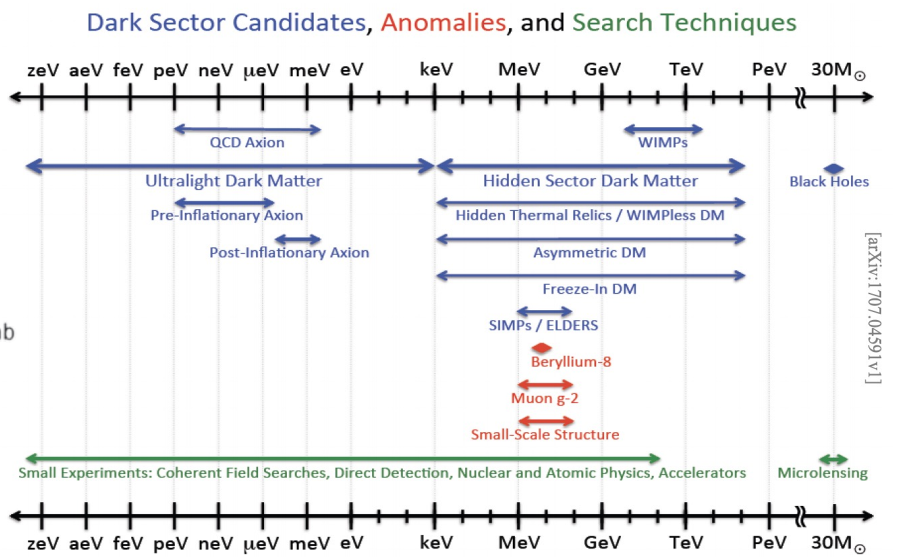
- Dark photon models
- Design of the PADME experiment
- Data taking at PADME
- First physics results
- The beryllium anomaly (X17 particle) and PADME Run 3
- Conclusions

The dark photon

- Dark photon (A') portal between Standard Model & Dark Sector
- Massive vector boson
- SM-A' coupling $\epsilon \ll 1$ => hidden
- Certain parameters could also explain other anomalies

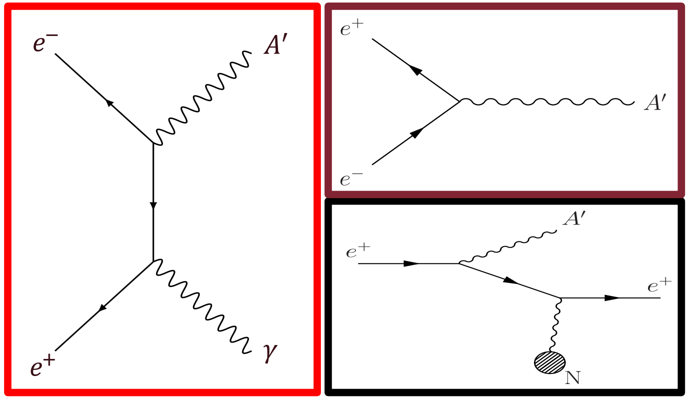


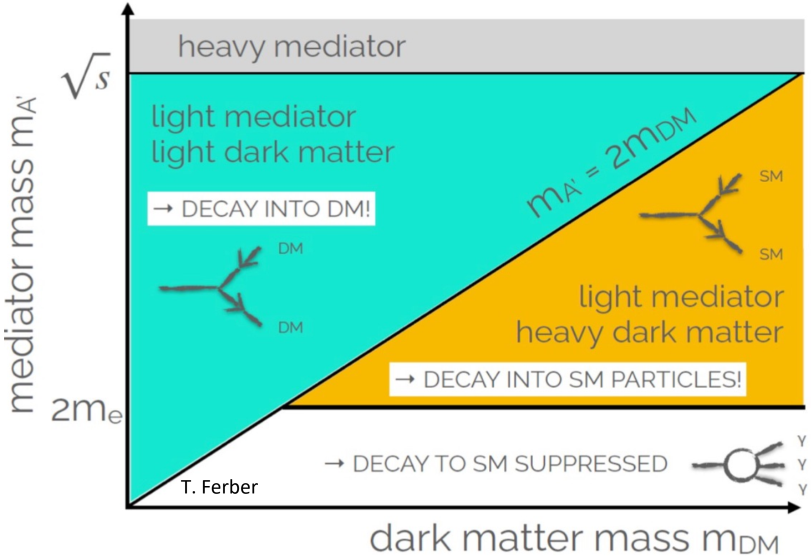




Experimental approaches

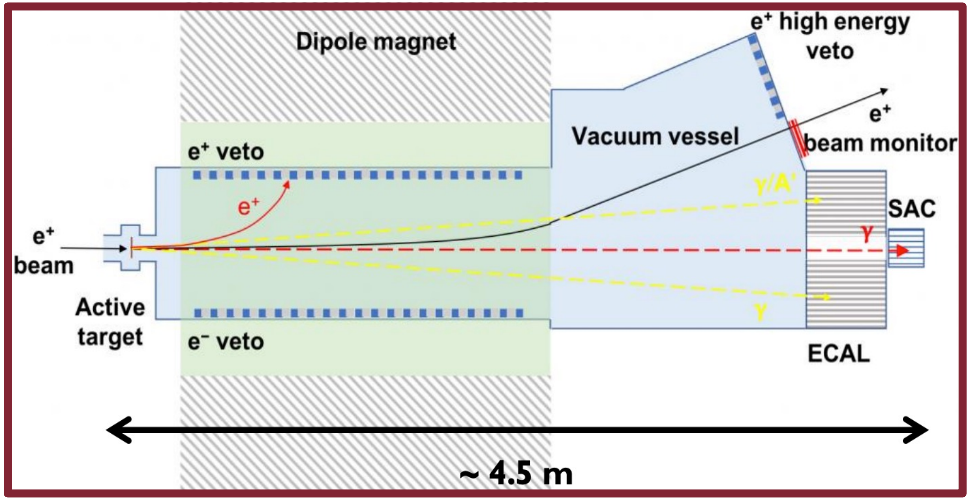
- Vector portal production at PADME:
  - Annihilation:
    - **Associated production: $e^+e^- \rightarrow \gamma A'$**
    - **Resonant annihilation: $e^+e^- \rightarrow A'$**
  - **A'-strahlung: $e^+N \rightarrow Ne^+A'$**
- **Visible searches**: detection of lepton pair in $A' \rightarrow l^+l^-$
- **Invisible searches**: don't rely on detection of decay products



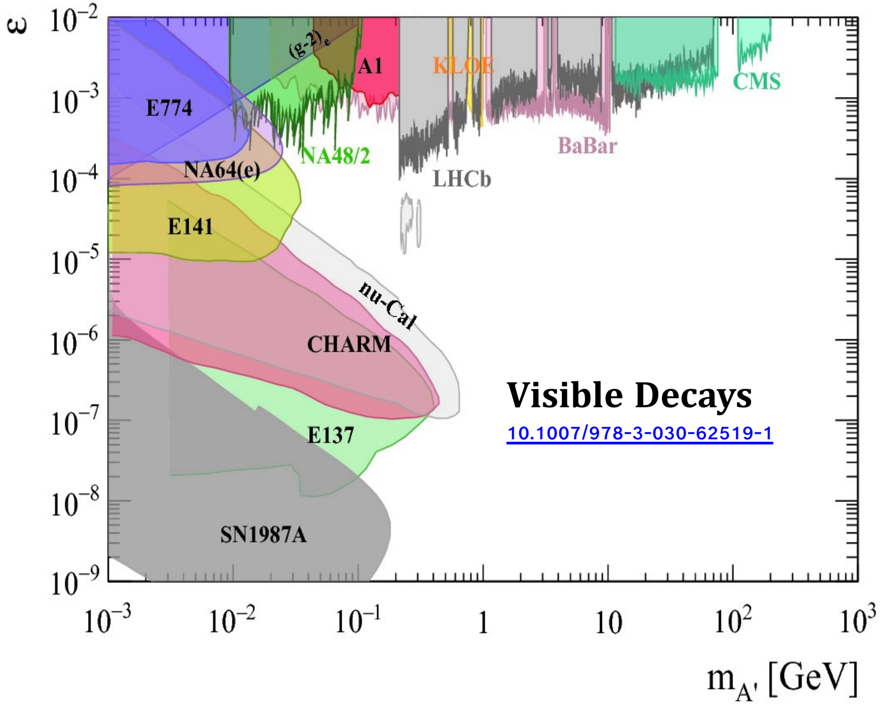


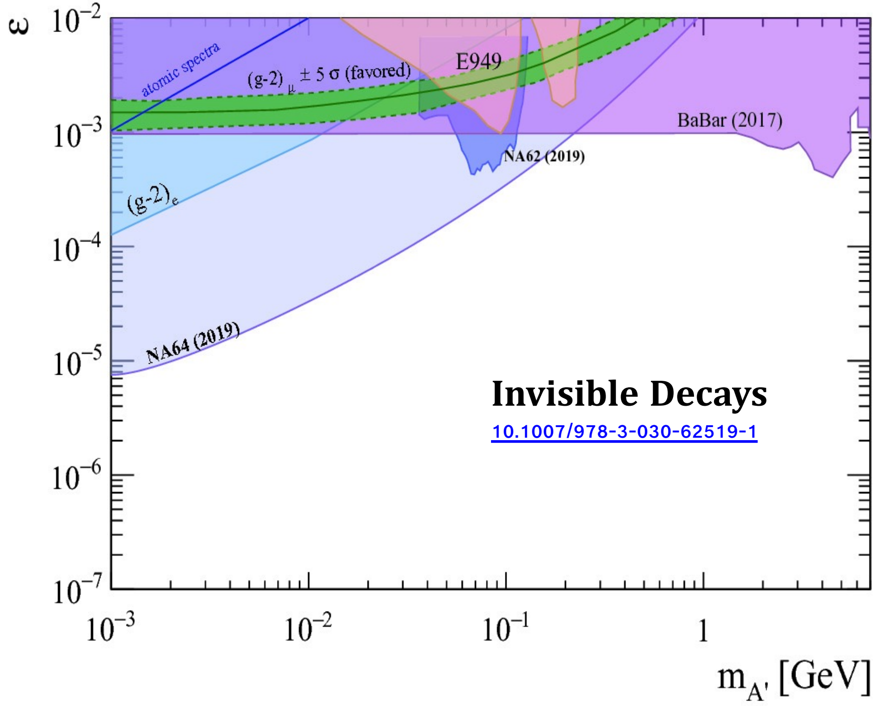
Dark photon production and detection at PADME

- Positron Annihilation to Dark Matter Experiment: $e^+e^- \rightarrow \gamma A'$ based at Laboratori Nazionali di Frascati (LNF)
- <550 MeV e^+ beam on 2cm×2cm×100μm active diamond target
  - 50 Hz pulsed beam
  - 300 ns pulse maximum duration
  - ~25000 e+/pulse
- Dipole B-field diverts un-interacted beam and charged final state particles
- Plastic scintillator bars as charged particle vetoes, in combination with the PbF_2 Small Angle Calorimeter
- Signal: 1 γ in BGO Electromagnetic Calorimeter & nothing elsewhere, ΔM^2_{miss} then gives access to $M_{A'}$



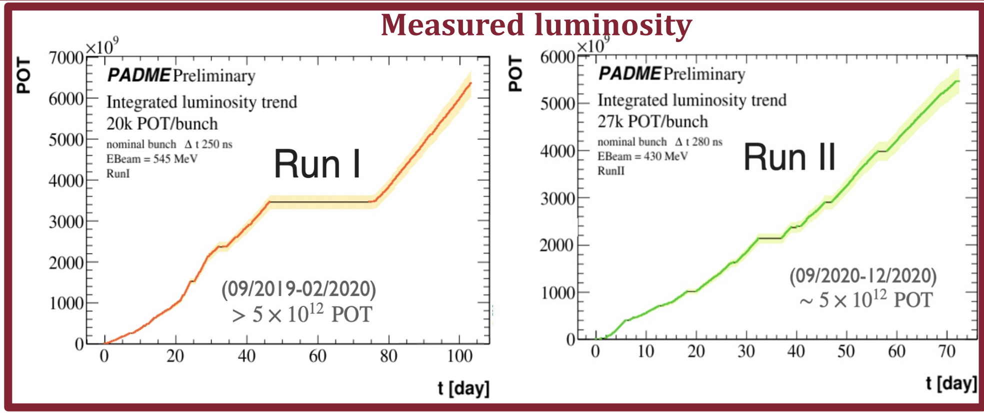
Current constraints

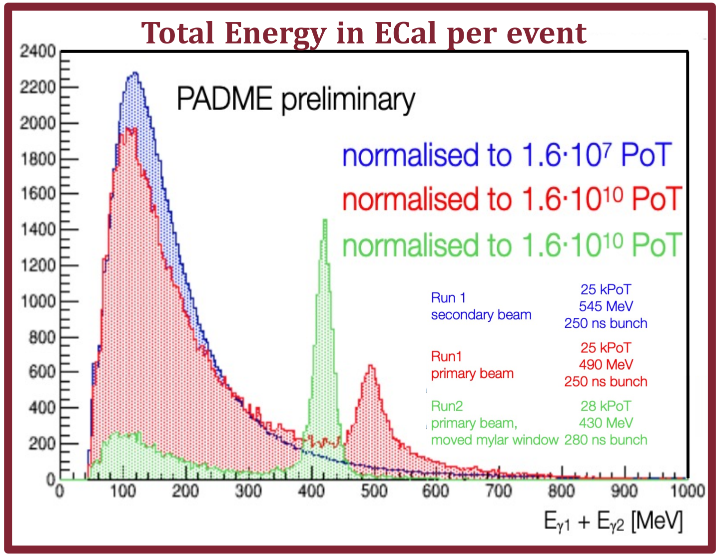




Data Taking

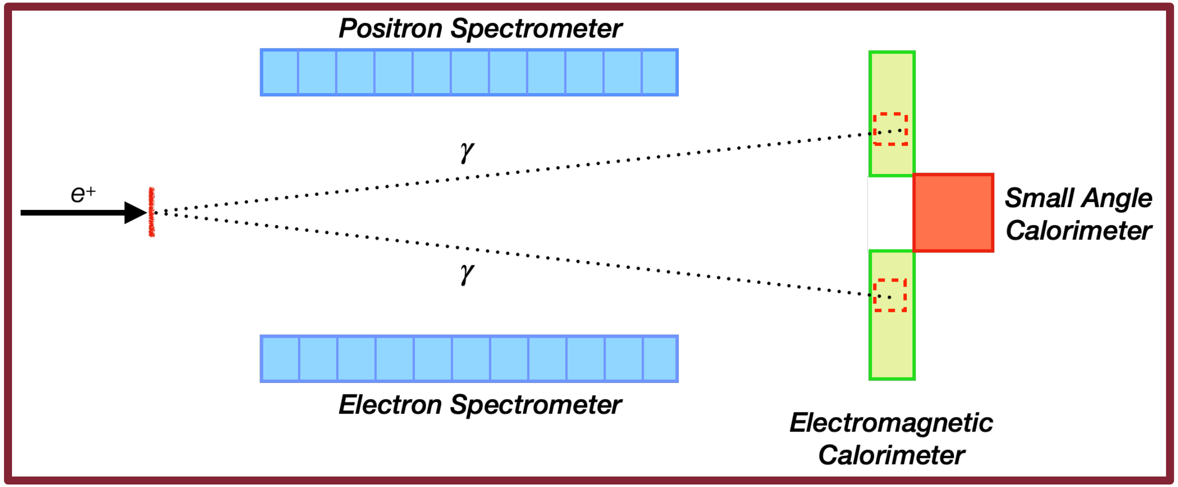
- Two runs in three configurations since installation in Sept. 2018
- Acquired luminosity measurement:
  - Run1 = 7×10^{12} POT
  - Run2 = 5.5×10^{12} POT
  - Precision = 5%
- Run 1a: secondary beam → Run 1b: primary beam
  - → Reduced beam-induced background
- Detailed MC simulation of beamline (https://arxiv.org/abs/2204.05616v1)
  - → Run 1b → Run 2: change of vacuum separation
    - → Significantly reduced background from vacuum window
  - → Run 1b → Run 2: longer beam (from 250 ns to 280 ns)
    - → Reduced pileup in detectors





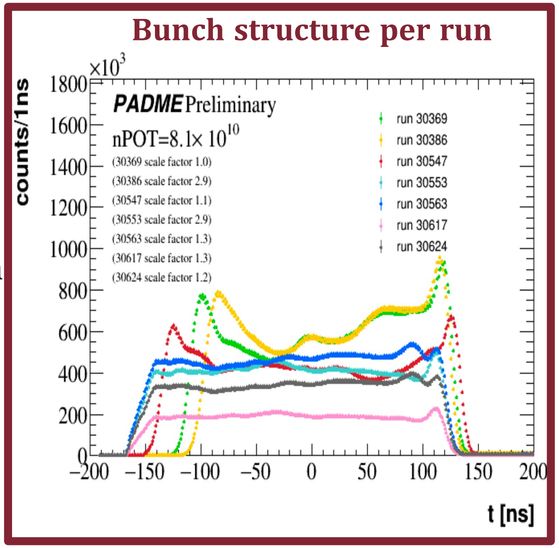
Multiple photon annihilation

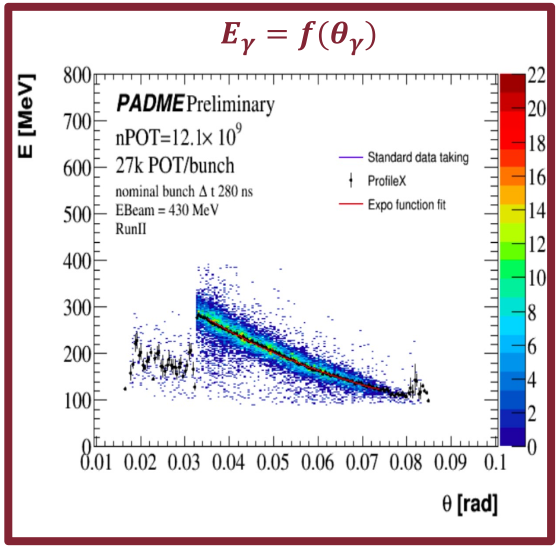
- $\sigma(e^+e^- \to \gamma\gamma(\gamma))$ measured
  - Characterisation of ECal
  - $\sigma(e^+e^- \to \gamma A') \propto \epsilon^2 \times \sigma(e^+e^- \to \gamma\gamma) \times \delta(MA')$
  - No measurements below 500 MeV with <20% precision (last measurements were e^+e^- disappearance from 1953)
  - Could be sensitive to sub-GeV new physics eg ALPs

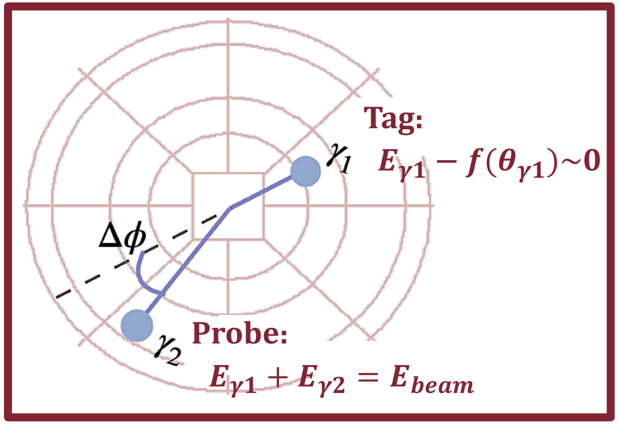


Tag and probe

- Measurement used 10% of Run 2 data
  - NPOT stable in time within each run
  - $19K - 36K$ POT/bunch
  - 4×10^{11} total POT
  - $E_{beam} = 430$ MeV
  - Bunch length ~200-280 ns
    - different time profile in each run
- Tag and probe method, exploiting two-body kinematics → $E_\gamma = f(\theta_\gamma)$
  - Count tag photons with $E_\gamma - f(\theta_\gamma) \sim 0$
  - Match using $E_{\gamma 1} + E_{\gamma 2} = E_{beam}$ and count probes



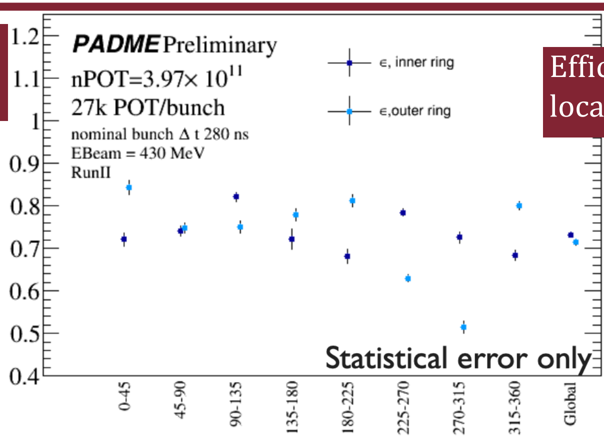




Event selection

- At least two good quality ECAL clusters:
  - $|\Delta t| < 10$ ns
  - $E_{\gamma 1} > 90$ MeV, $E_{\gamma 2} > 90$ MeV
  - $\Delta E = E_{\gamma} - f(\theta_{\gamma})$:
    $|\Delta E(\theta_1)| < 100$ MeV $|\Delta E(\theta_2)| < 100$ MeV
  - For the leading photon $R_{\gamma 1} \in FR$ ($115.8 < R < 285$ mm
    ~6% acceptance)

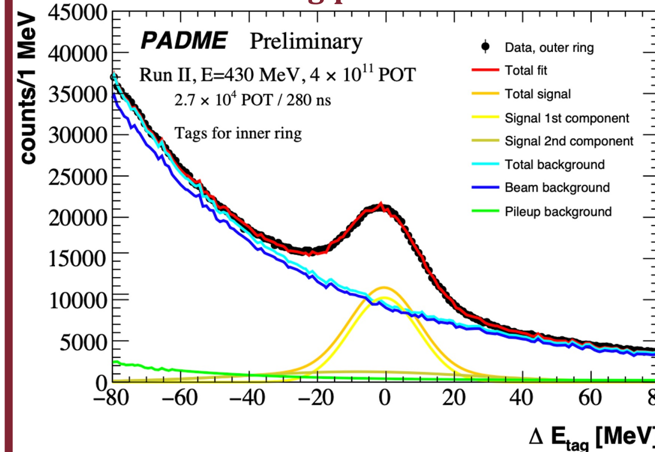
$$\epsilon = \frac{N_{probe}}{N_{tag}}$$



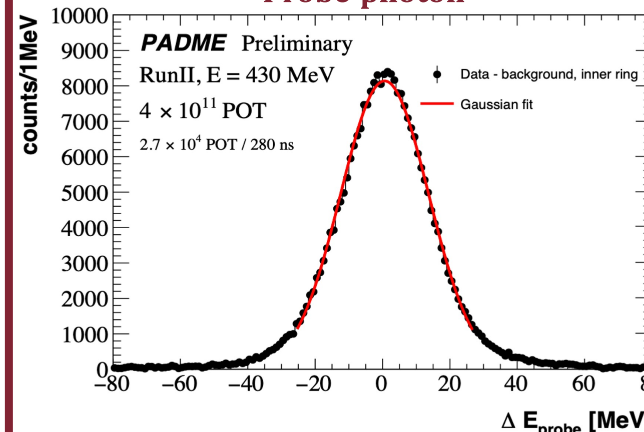
Efficiency trend matches local detector acceptance

ϕ sector of ECal

Tag photon



Probe photon



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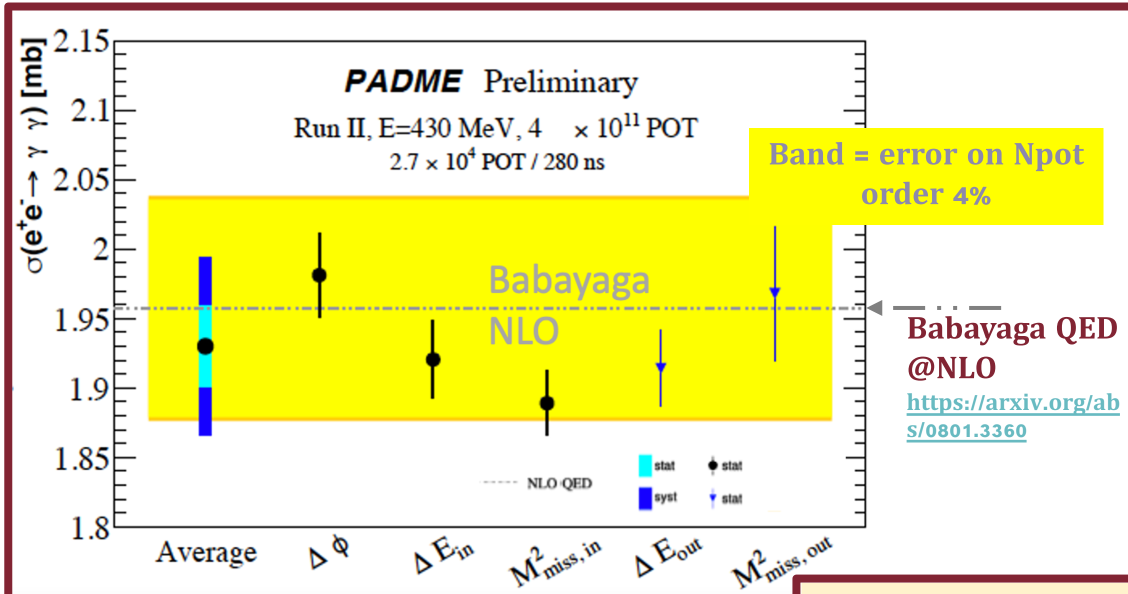
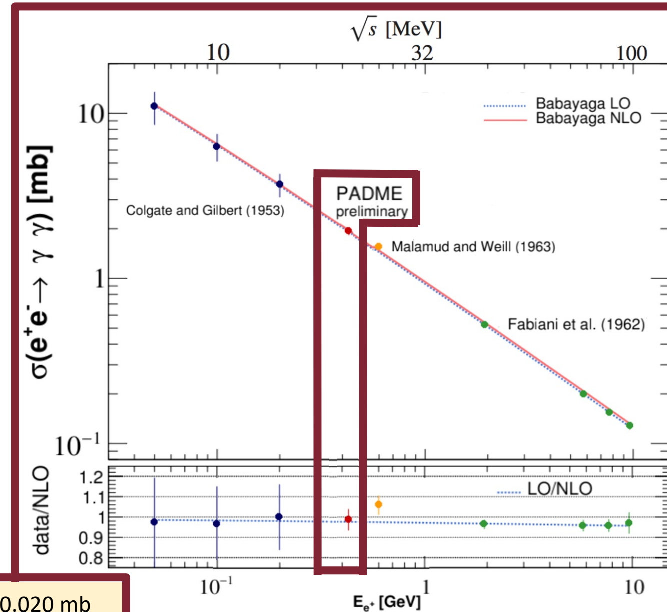
PADME

Cross section measurement

$$\sigma(e^+e^- \rightarrow \gamma\gamma(\gamma)) = 1.930 \pm 0.029\,(stat) \pm 0.057\,(syst) \pm 0.020\,(target) \pm 0.079\,(lumi)\,mb$$

QED @NLO $\sigma(e^+e^- \rightarrow \gamma\gamma(\gamma)) = 1.9573 \pm 0.0005\,(stat) \pm 0.0020\,(syst)\,mb$





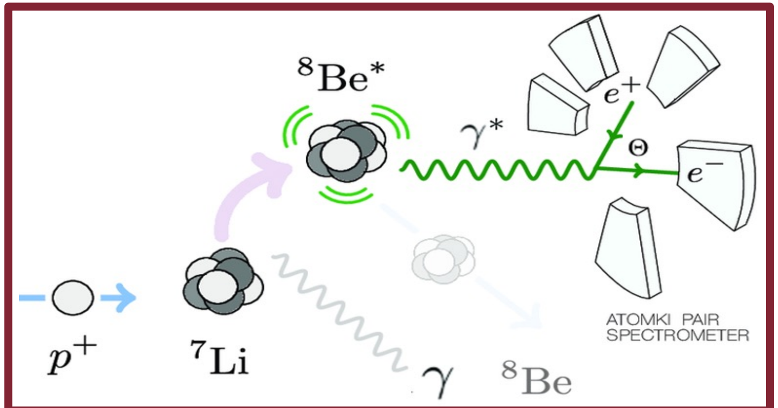
Detector response uniformity	0.020 mb
Background modelling	0.047 mb
Acceptance	0.025 mb
n POT: target calibration	0.079 mb
Electron density (target thickness)	0.020 mb

Full details: I. Oceano @ Moriond

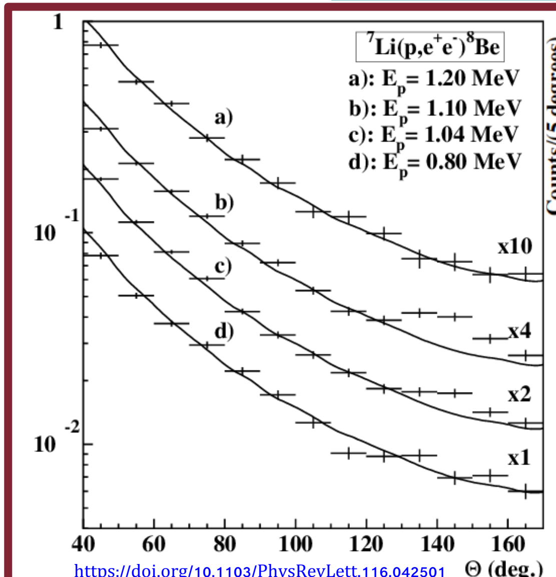
Paper in progress

The beryllium anomaly

- Collaboration at ATOMKI institute in Hungary studying IPC decays of excited ^{8}Be (2016)/^{4}He (2020) nuclei
- Found anomaly compatible with new particle of 17 MeV mass
- LNF is the only facility in the world with a positron beam capable of this measurement at 282 MeV resonance

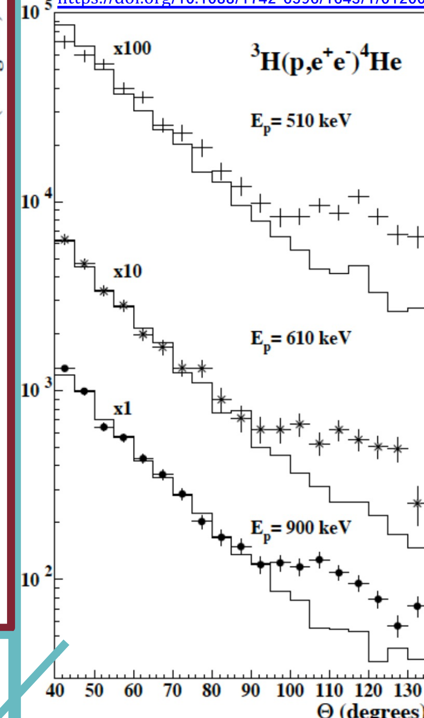


$m_X c^2 = 16.98 \pm 0.16(\text{stat}) \pm 0.20(\text{syst})$ MeV



https://doi.org/10.1103/PhysRevLett.116.042501

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



https://doi.org/10.1088/1742-6596/1643/1/012001

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

More info & new (preliminary) results:

- 2021 A. J. Krasznahorkay X17 Workshop
- 2022 $^7Li(p,e^+e^-)^8Be$ proton capture update
- Frankenthal Particlebites

$X17$ as vector or pseudo-scalar

- Interpretation as vector or pseudo-scalar not totally excluded

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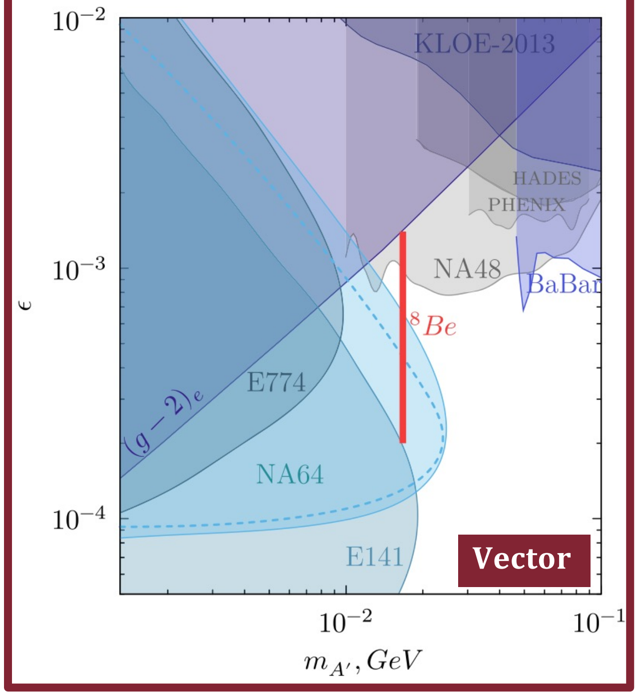
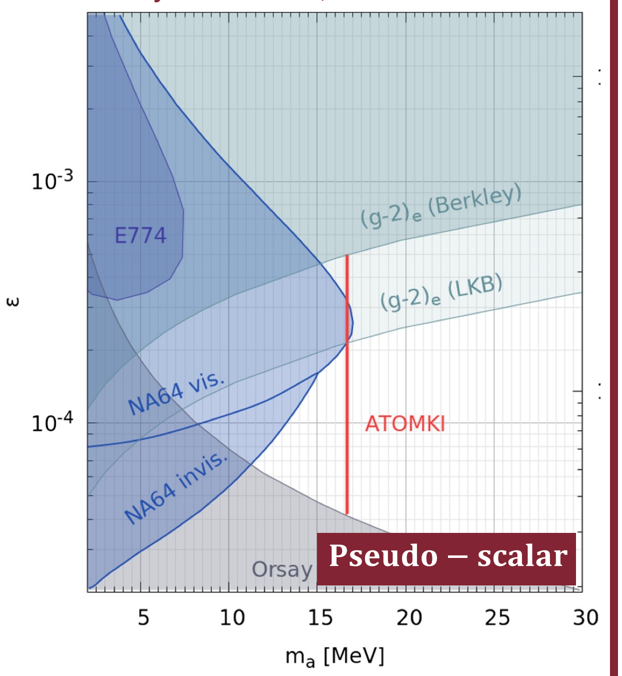
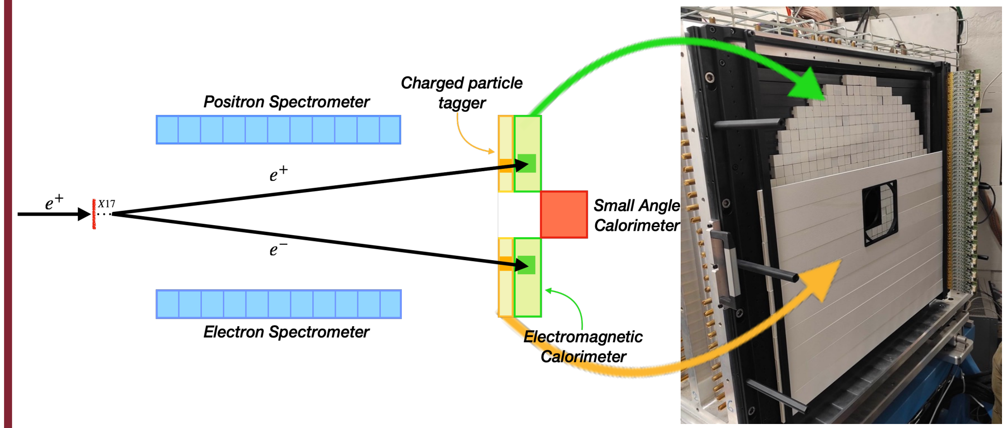


Phys. Rev. D 104, L111102 (2021)



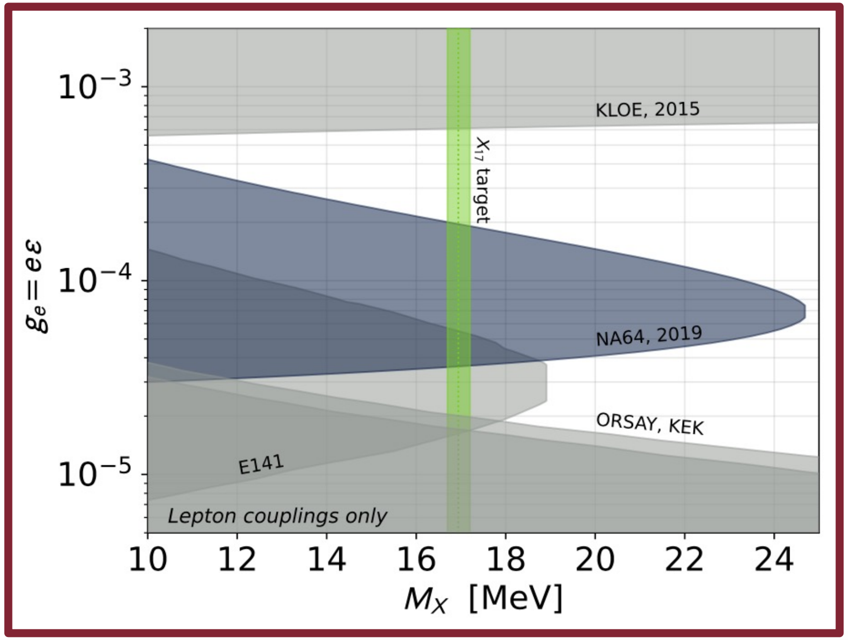
PADME Run 3

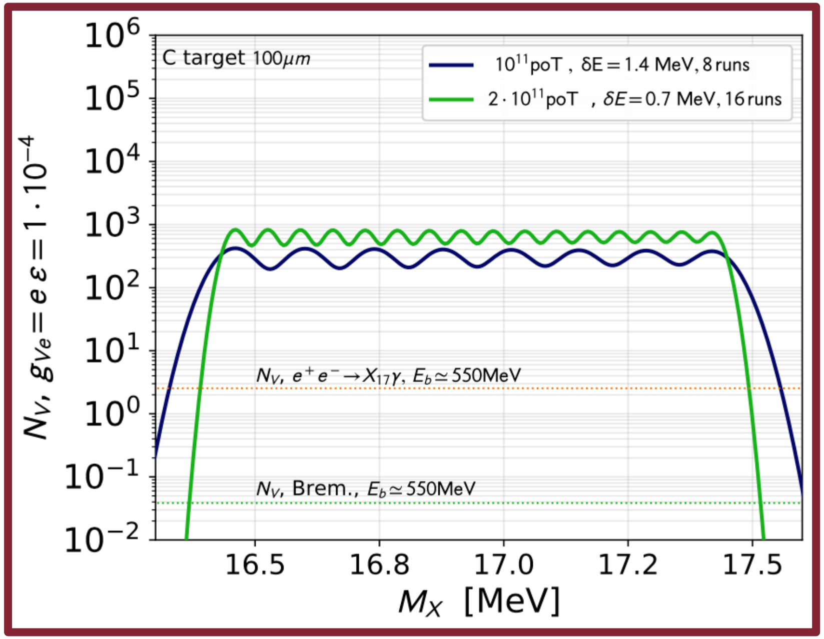
- Knowing from ATOMKI that $X17 \rightarrow e^+e^-$, we reverse the Feynman diagram so that $e^+e^- \rightarrow X17$, and then search for $X17 \rightarrow e^+e^-$ decays
- Studies from Run 2 show difficulty of charged final state measurements with vetoes
- Taking confidence from $e^+e^- \rightarrow \gamma\gamma$ measurement we're looking for X17 with the **ECal**
- Built **ETagger** detector of 5mm thick plastic scintillator to distinguish $e^{+/-}$ from γ



X17 at PADME

- Couplings of $(2-6)\times10^{-4}$ represents an open window for X17 searches, especially for protophobic models
- PADME can generate several thousand X17 even with these small couplings





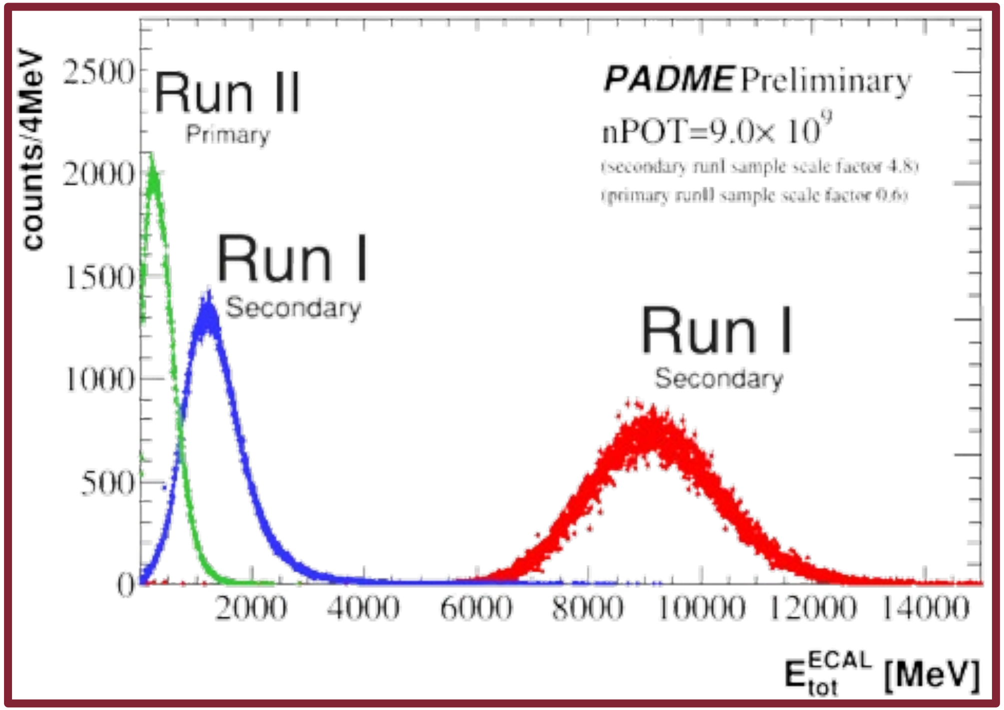
Conclusions

- PADME's 2 runs between 2018 and 2020 PADME have allowed us to optimise running conditions and detector reconstruction
  https://arxiv.org/abs/2205.03430 (accepted JINST)
- We've created a detailed and reliable Monte Carlo simulation of the beam-line https://arxiv.org/abs/2204.05616v1 (accepted JHEP)
- We've performed the most precise measurement of $\sigma(e^+e^- \to \gamma\gamma(\gamma))$ below 1 GeV (article on its way)
- We're preparing for Run III during which we hope to shine light on the X17

Thank you for your attention
and
turn the dark on!

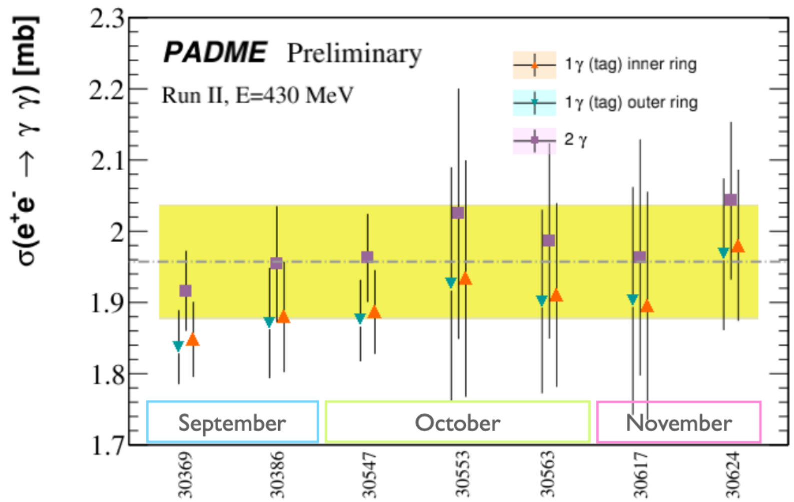
Data Taking

- Two runs in three configurations since installation in Sept. 2018
  - Run 1a) (Oct 2018-February 2019)
    - Secondary e^+ from e^- on Cu target before the entrance of BTF
  - Run 1b) (February -March 2019)
    - Primary e^+ from W-Re e^+ converter immediately after e^- production
  - Run 2 (Sept 2020-Dec 2020)
    - primary e^+ beam and improved beamline setup
- Acquired luminosity measurement:
  - Run1 = 7×10^{12} POT
  - Run2 = 5.5×10^{12} POT
  - Precision = 5%



Run 1 secondary beam	25 kPoT 545 MeV 250 ns bunch
Run1 primary beam	25 kPoT 490 MeV 250 ns bunch
Run2 primary beam, moved mylar window	28 kPoT 430 MeV 280 ns bunch

Cross section measurement: run variation



Band = error on # POT

← Babayaga NLO

No emerging systematic effects

Not-unif, typical # POT/bunch
Not-unif, Low # POT/bunch
~ unif, High # POT/bunch
Unif, Very high # POT/bunch
Unif, Typical # POT/bunch
Unif, Very high # POT/bunch
Unif, Typical # POT/bunch

ECal geometry