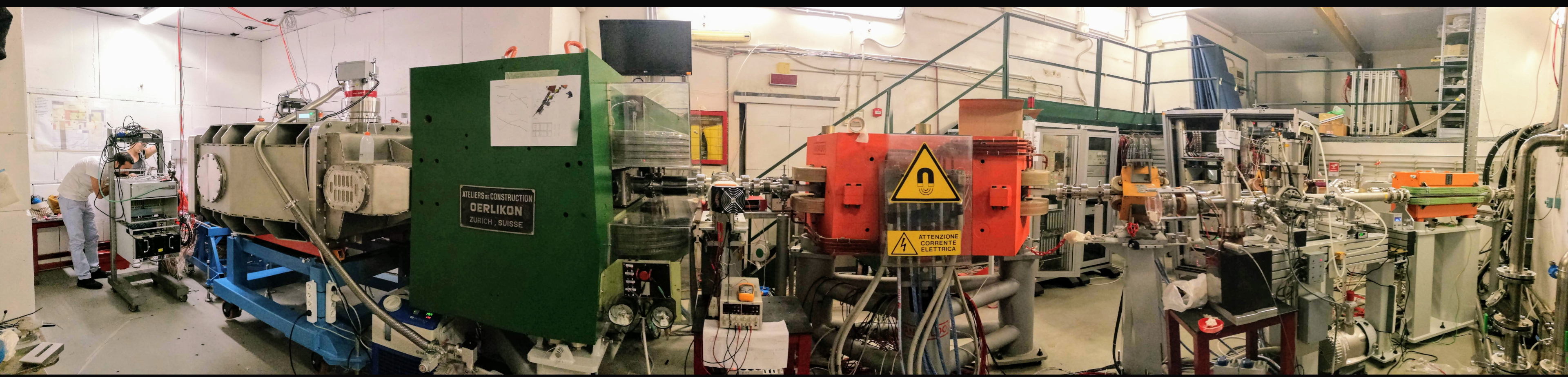
Status of the PADME experiment

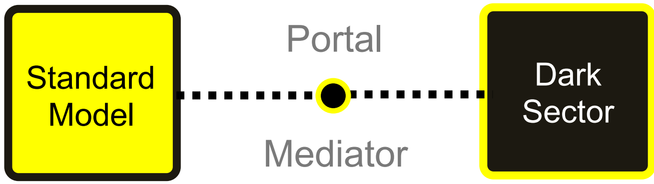


Mauro Raggi for the PADME collaboration,
Sapienza Università di Roma e INFN Roma
Meeting CNS1 Milano
LNF 13/07/2023

Outline

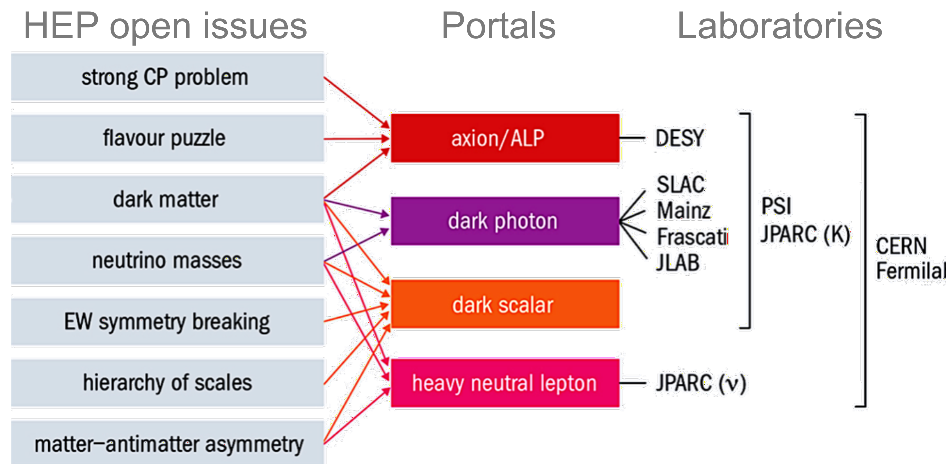
- Intro
- Status of Run II data analysis
- News on X17 word
- PADME searches for X17
- Conclusions

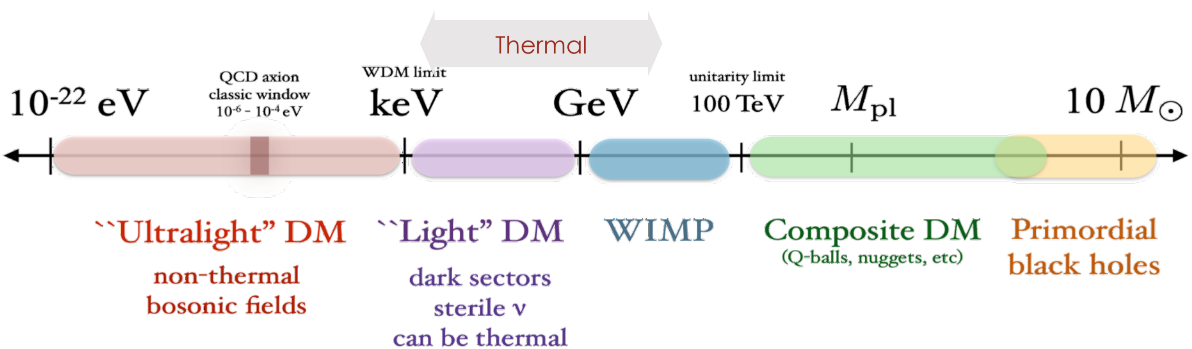
The dark sector paradigm



Feeble, non-gravitational interaction with ordinary matter

- **Dark matter**
- Dark forces
- Other dark particles





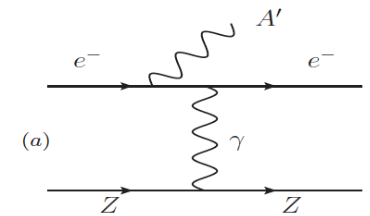
- Dark sector candidates can explain SM anomalies: (g-2)μ, ^{8}Be, proton radius
- The mediator can have a **small mass (MeV -100 MeV)**
- Due to its **small mass** the mediator can be **produced at low energy accelerators**
- It can **decay back to ordinary matter "visible"** on **not "invisible"**

Experimental approaches

- **Electron beam experiments production**
  - **Just A'-strahlung**
- **Positron based experiments**
  - **A'-strahlung**
  - **Associated production $e^+e^- \to A'(\gamma)$**
  - **Resonant production $e^+e^- \to e^+e^-$**

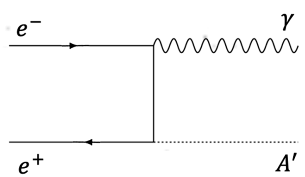
- **Visible decays**: $A' \to e^+e^-$ $A' \to \mu^+\mu^-$
  - **Thick target electrons/protons** beam is absorbed (NA64, old dump exp.)
  - **Thin target** searching for bumps in e^+e^- invariant mass
- **Invisible searches: $A' \to \chi\chi$**
  - **Missing energy/momentum**: A' produced in the interaction of an electron beam with **thick/thin target** (NA64/LDMX)
  - **Missing mass**: $e^+e^- \to A'(\gamma)$ search for invisible particle using kinematics (Belle II, **PADME**)

Brems.



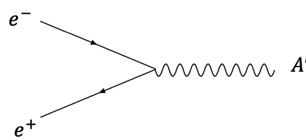
dump and thin target

Associated production



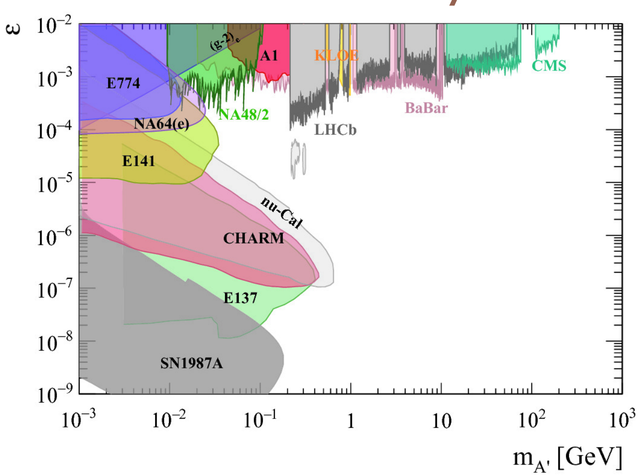
Colliders

Resonant

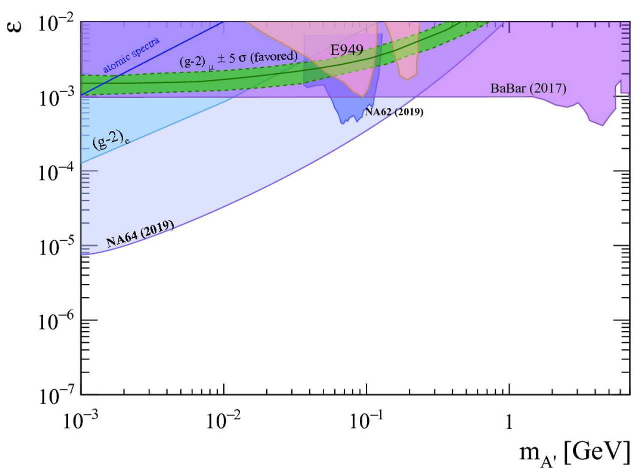


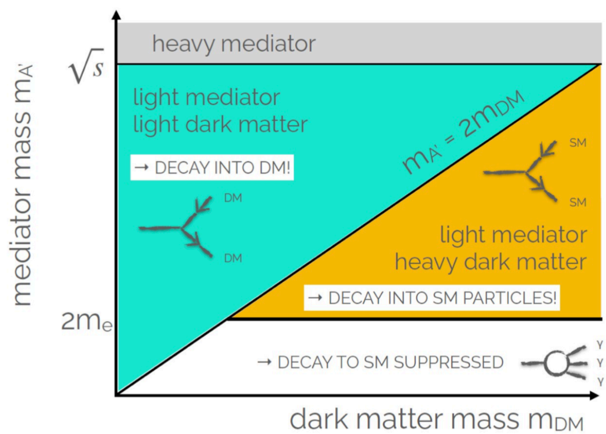
Never used!

Visible decay



Invisible decay



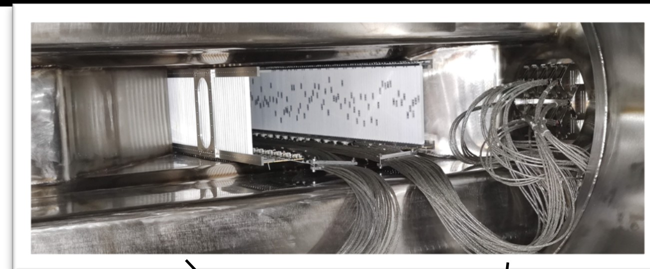


PADME Run I and Run II setup

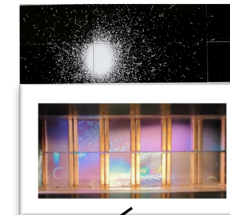
- Positron beam of ~**0.5 GeV/c**
  - LINAC repetition rate 50 Hz
  - Macro-bunches maximum length Δt ≲**300 ns**
- Number of annihilations proportional to:

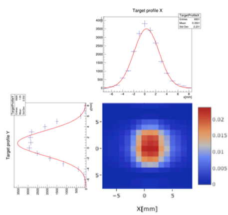
$$N^{e^+}_{beam} \times N^{e^-}_{target}$$

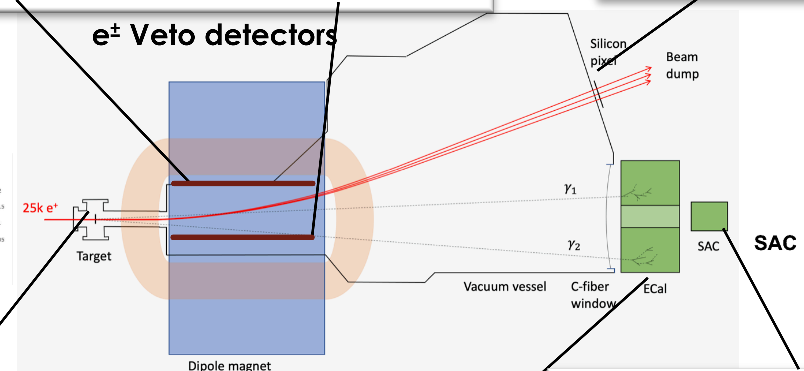
  - Limited **intensity**, due to pile-up, ~**3·10⁴ pot/pulse**
- Dipole **magnet** in order to
  - Sweep away non-interacting positrons
  - Tag positrons losing energy by Bremsstrahlung
- Scintillating bar **veto** detectors placed inside vacuum vessel
  - Positron and electron detectors inside the magnet gap
  - Additional veto for e^+ irradiating soft photons at beam exit

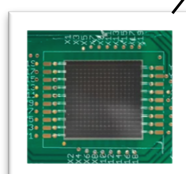


Silicon **pixel** (TimePix3)

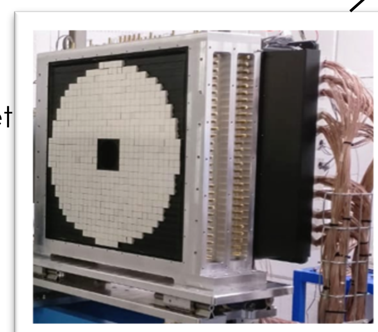




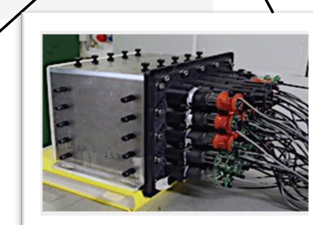




Active **diamond** target
100 μm thick

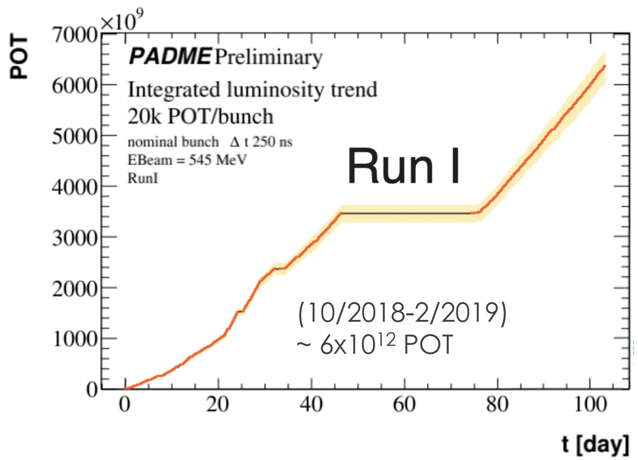


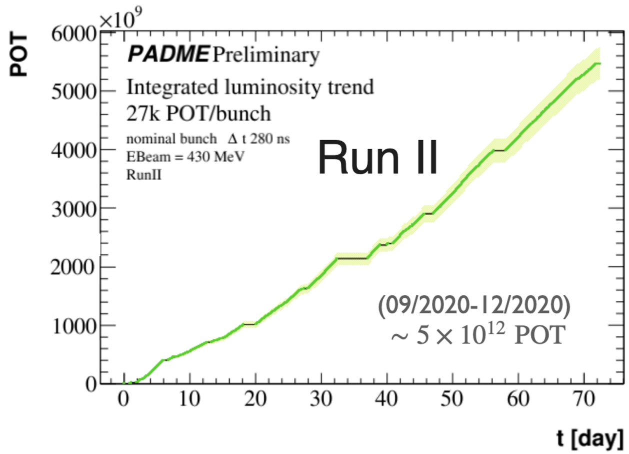
BGO calorimeter (ECAL)

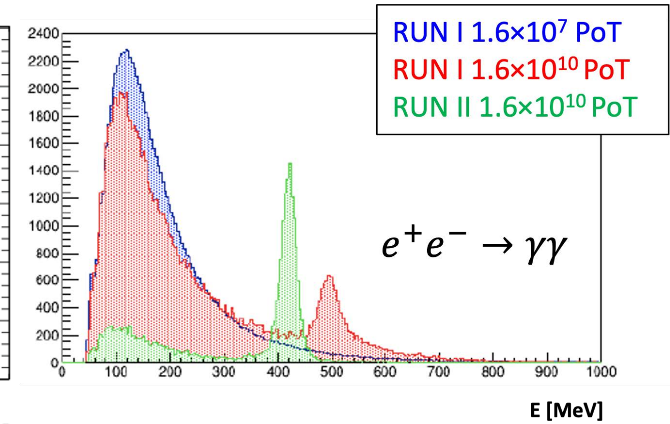


small angle calo
SAC PbF_2

PADME data taking periods 2018-20

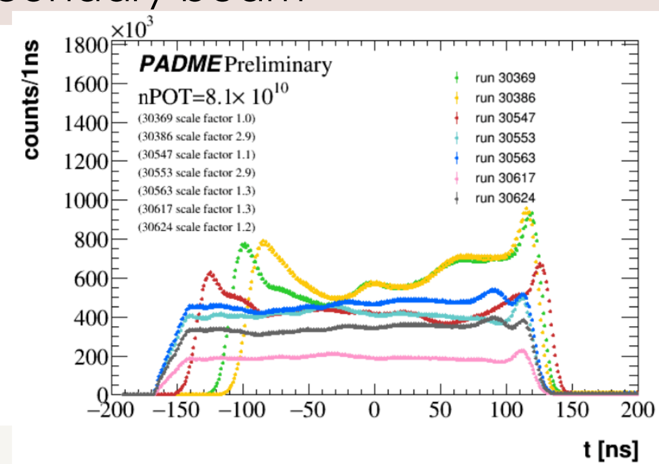






- Two physics runs **Run I Oct. 2018 Feb. 19** and **Run II Set-Dec 2020**
  - Hard simulation work to understand BG in between Run I and Run II.
- Run II wrt Run I
  - Slightly lower beam momentum in Run II, 430 MeV/c, wrt to Run I, 490 MeV/c
  - **Improved vacuum separation** between experiment and beamline
  - Less beam-induced background with primary wrt secondary beam

- During Run II itself
  - Improved bunch length and structure

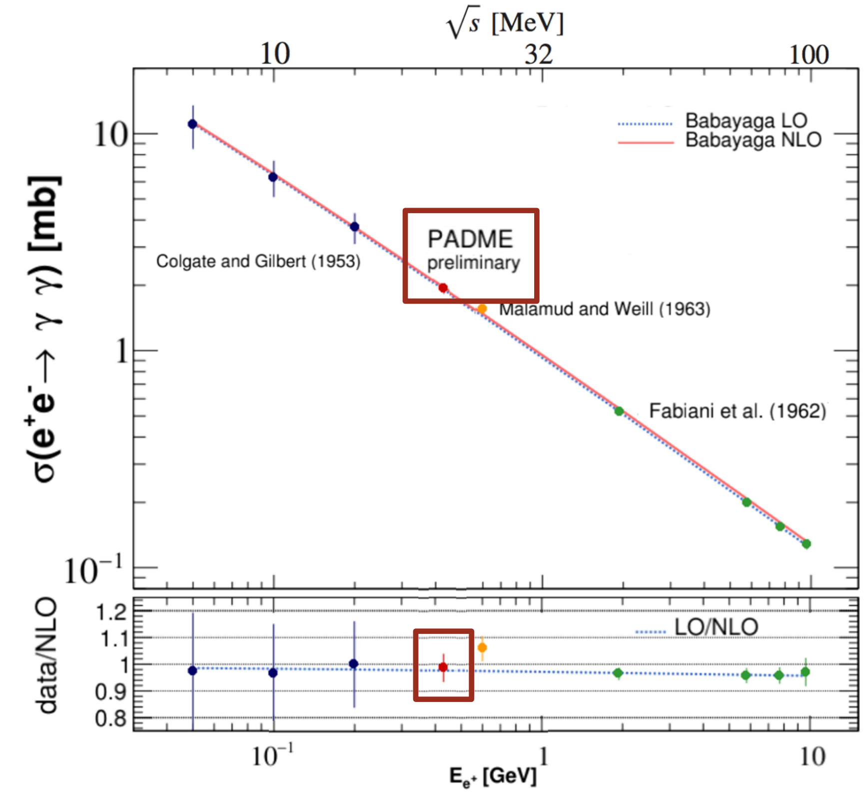


PADME σ(e⁺e⁻–>γγ) result in Run II

PADME 2020 (10% of 2020 data set)

$$\sigma(e^+e^- \to \gamma\gamma(\gamma)) = (1.977 \pm 0.018_{stat} \pm 0.119_{syst})\ \text{mb}$$

Phys.Rev.D 107 (2023)



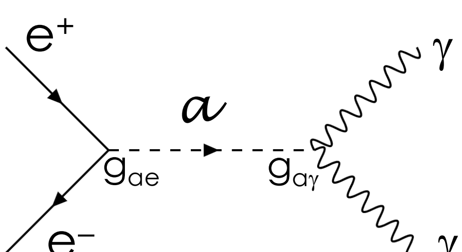
good agreement with NLO QED prediction:

QED @NLO $\sigma(e^+e^- \to \gamma\gamma(\gamma)) = 1.9573 \pm 0.0005\ (\text{stat}) \pm 0.0020\ (\text{syst})\ \text{mb}$

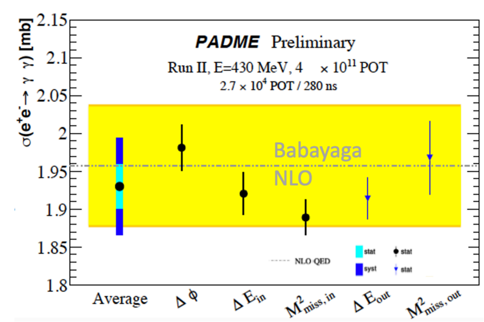
Phys.Lett.B 663 (2008) 209-213

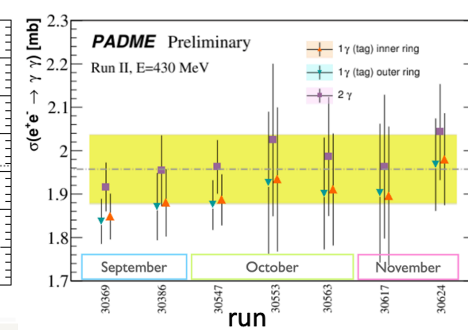
- **First direct measurement** of $e^+e^- \to \gamma\gamma$ below 1 GeV
- Both **Gilbert '53** and **Malamud '63** measure e^+ disappearance rates
- Error dominated by luminosity measurement large room for improving using 2022 data set.

- Can constrain ALPs with both g_e and g_γ couplings
- Including X17 with g_{ae} and $g_{a\gamma}$ couplings

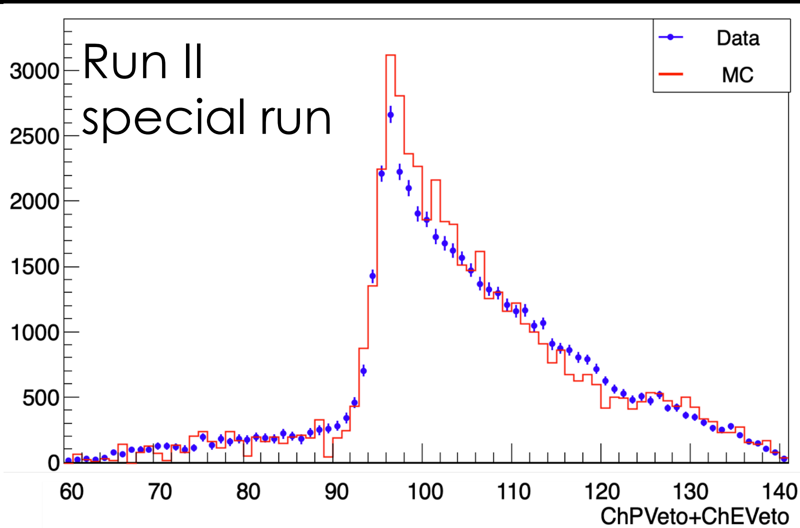


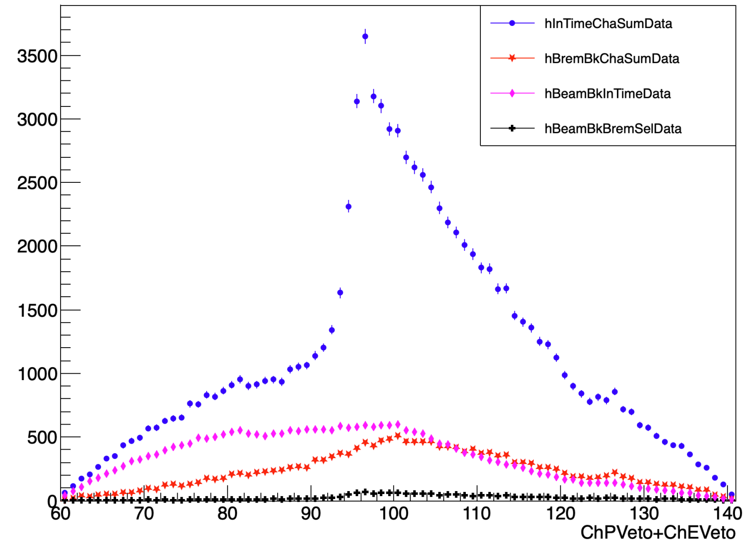
JHEP 06 (2021) 009





Status of σ(e⁺e⁻–> e⁺e⁻) in Run II

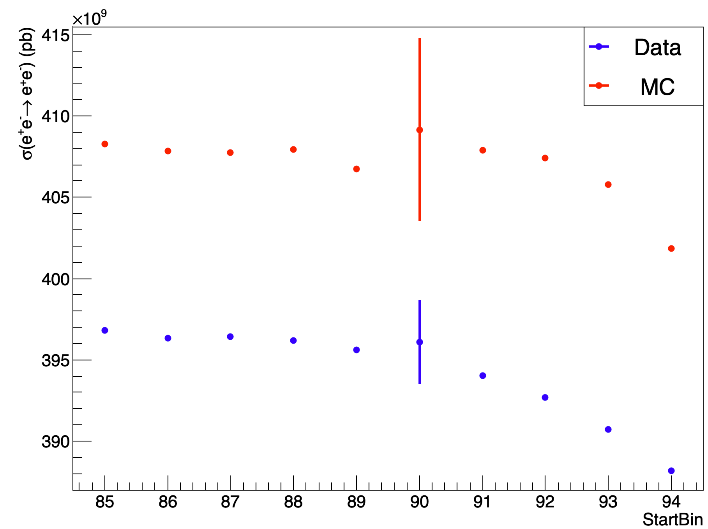




- Low intensity special run with 5K PoT/bunch
  - Very simple selection criteria
  - Error dominated by NPoT uncertainty
- Data driven BG subtraction using
  - No Target runs (beam related BG)
  - SAC tagged Bremsstrahlung from data sample.
- Measured cross section matching well the G4
  - G4 MC cross section: $(4.1 \pm 0.05) \times 10^{11}$ pB
  - Data: cross section : $(3.9 \pm 0.39) \times 10^{11}$ pB

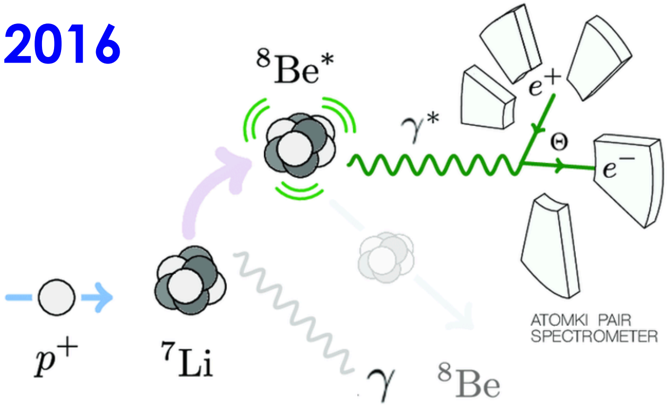
PRELIMINARY

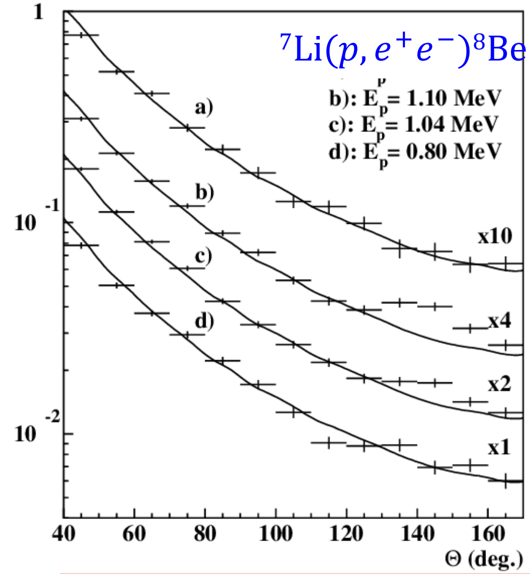
- Can be used to constrain g_{Ve}



The ^{8}Be and ^{4}He Atomki anomaly

2016

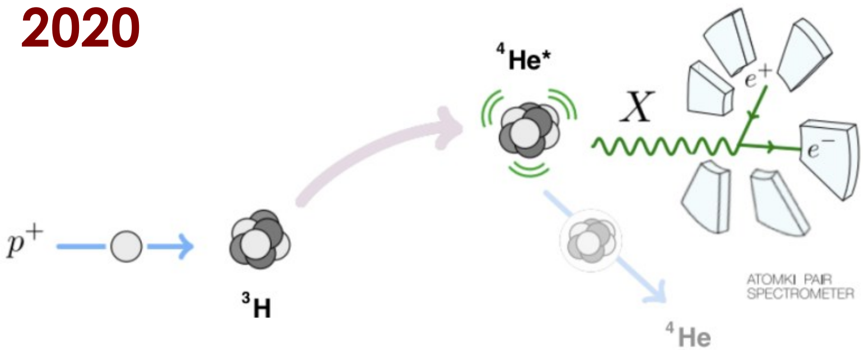


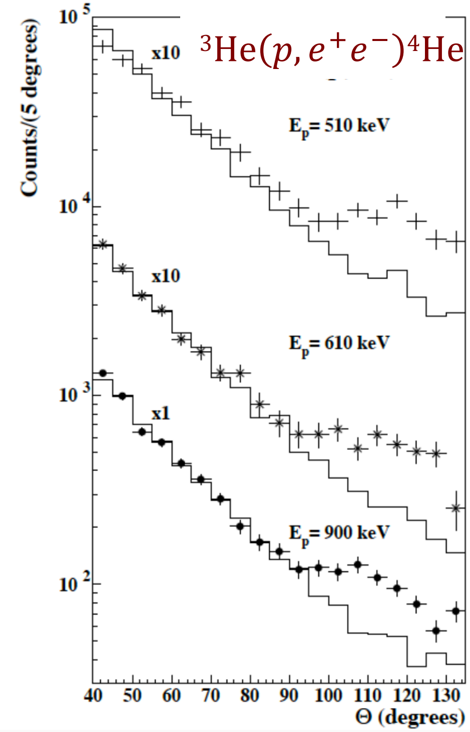


$m_X c^2 = 17.01 \ \pm 0.16(\mathrm{tot})$ MeV

PRL 116, 042501 (2016)

2020





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

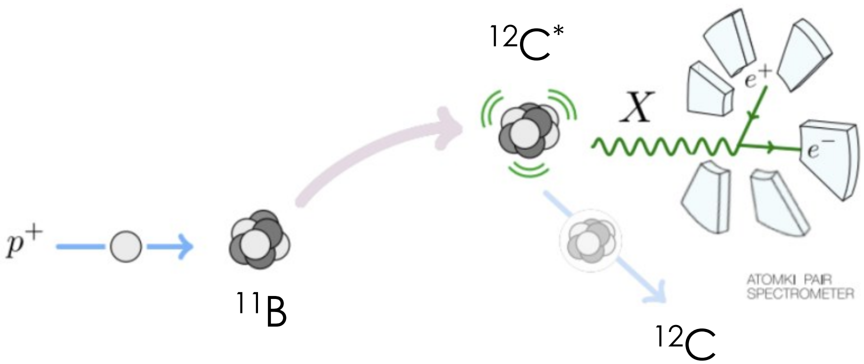
Phys. Rev. C 104, 044003 (2021)

ATOMKI has confirmed the anomalous peak in the angular distribution of internal pair creation in **^{8}Be with a similar** one in the **^{4}He** transitions, with different kinematics but at the **same invariant mass value.**

The ^{12}C anomaly and the vector portal

New anomaly observed in ^{12}C supports the existence and the vector character of the hypothetical X17 boson

Phys. Rev. C 106, L061601
Dec 2022



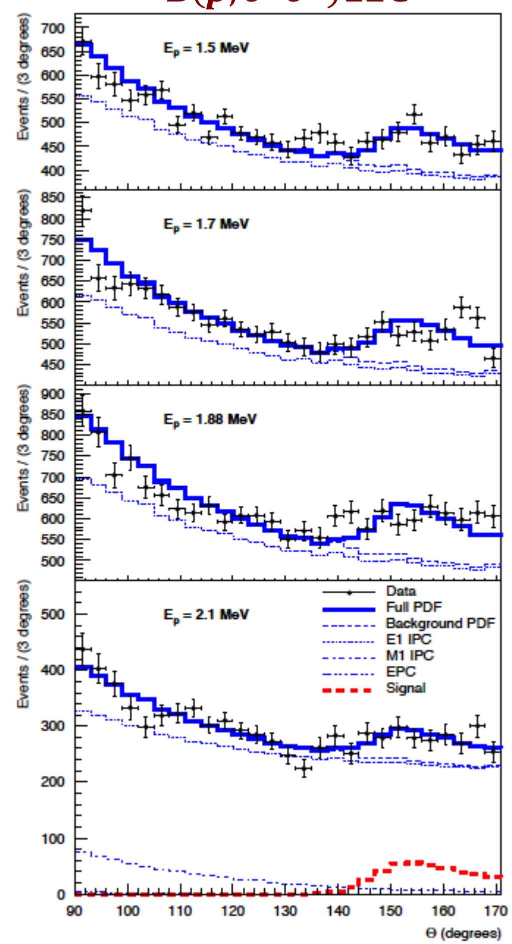
E = 17.23 MeV excited state of ^{12}C

TABLE I. X17 branching ratios (B_x), masses, and confidences derived from the fits.

E_p	B_x	Mass	Confidence
(MeV)	$\times 10^{-6}$	(MeV/c^2)	
1.50	1.1(6)	16.81(15)	3σ
1.70	3.3(7)	16.93(8)	7σ
1.88	3.9(7)	17.13(10)	8σ
2.10	4.9(21)	17.06(10)	3σ
Averages	3.6(3)	17.03(11)	
Previous [14]	5.8	16.70(30)	
Previous [31]	5.1	16.94(12)	
Predicted [33]	3.0		

4 different p bombarding energies with strong significance

$^{11}\mathrm{B}(p, e^+e^-)12\mathrm{C}$



On the nature of X17

PHYSICAL REVIEW D **102,** 036016 (2020)

Dynamical evidence for a fifth force explanation of the ATOMKI nuclear anomalies

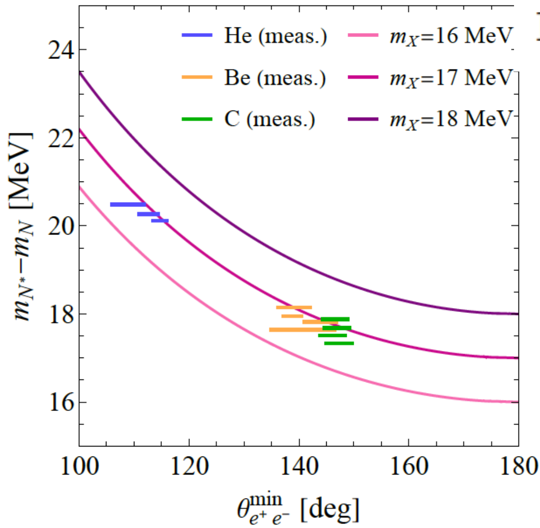
Jonathan L. Feng,* Tim M. P. Tait,† and Christopher B. Verhaaren‡
Department of Physics and Astronomy, University of California, Irvine, California 92697-4575, USA

Feng and collaborators suggested that the X17 should be observed in ^{12}C transitions
X17 observations in ^{12}C will point to a vector or axial vector nature for X17

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)	…

News from Phenomenology



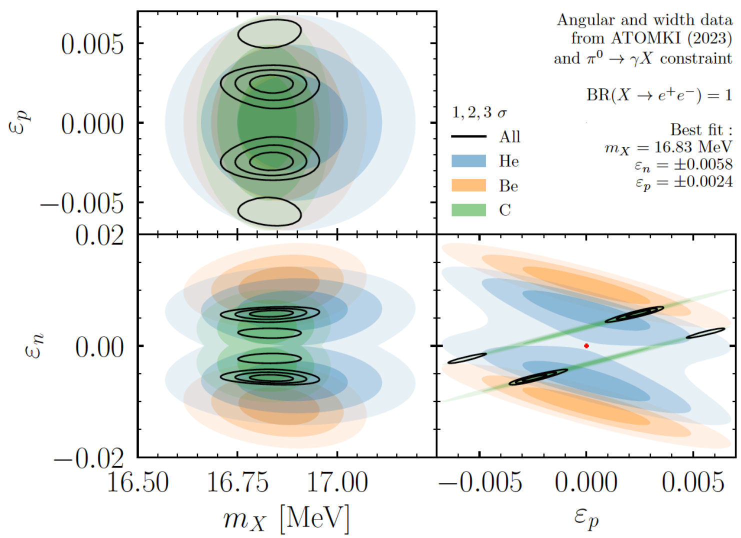
Neutrino Constraints and the ATOMKI X17 Anomaly

arXiv:2304.09877v1

Using angular data only: 11 measurements

An analysis with the angular data alone of 11 different measurements finds that the data is well described by a new particle of mass $m_X = 16.85 \pm 0.04$ MeV with an internal goodness-of-fit of 1.8σ calculated from Wilks' theorem at $\chi^2/dof = 17.3/10$. We use only the best fit

$$\theta_{ee}^{min} \approx 2\arcsin\left(\frac{m_{X17}}{m_{N*} - mN}\right)$$



Using width for each element: 3 measurements

Next, we add in to the analysis the latest width information from each element and include a prior on ε_p since X needs to couple to protons and/or neutrons on the production size. There is a stronger constraint

see the next section for more information. We find an okay fit to the data at the same mass $m_X = 16.83$ MeV, $\varepsilon_n = \pm 5.8 \times 10^{-3}$, and $\varepsilon_p = \pm 2.4 \times 10^{-3}$, see fig. 2. We note that the signs of ε_n and ε_p must be the same due to the non-trivial degeneracy structure shown clearly in the $\varepsilon_n - \varepsilon_p$ panel of fig. 2. We have confirmed that the

data are consistent and point to M_{X17}=16.85±0.04 MeV

SAPIENZA UNIVERSITÀ DI ROMA

Improving X17 production rates

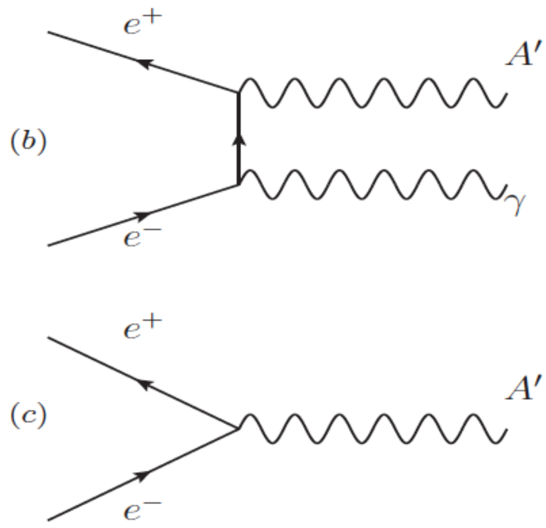
- We need higher production cross section!
- Can move from associated to resonant production
  - b) Radiative annihilation O(α^2)

$$\sigma_{nr} = \frac{8\pi\alpha^2}{s}\left[\left(\frac{s-m_{A'}^2}{2s}+\frac{m_{A'}^2}{s-m_{A'}^2}\right)\log\frac{s}{m_e^2}-\frac{s-m_{A'}^2}{2s}\right]$$

  - c) Resonant annihilation O(α)

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

Positron beams



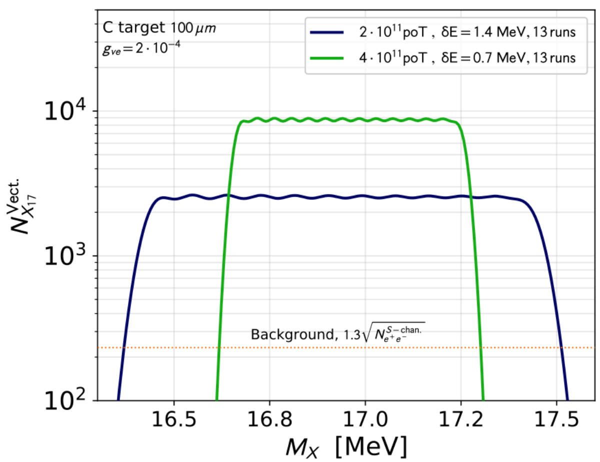
- **Resonant:** Profit for a higher production in a tiny mass region

$$\mathcal{N}_{X17}^{\text{Vect.}} \simeq 1.8\cdot 10^{-7} \times \left(\frac{g_{ve}}{2\cdot 10^{-4}}\right)^2 \left(\frac{1\ \text{MeV}}{\sigma_E}\right)$$

$$\mathcal{N}_{X17}^{\text{ALP}} \simeq 5.8\cdot 10^{-7} \times \left(\frac{g_{ae}}{\text{GeV}^{-1}}\right)^2 \left(\frac{1\ \text{MeV}}{\sigma_E}\right)$$

Darmé et al. Phys. Rev. D 106,115036

  - **Thousands** of X17 of events with just **1E10 PoT**
    - down to 2E-4 g_{ve}

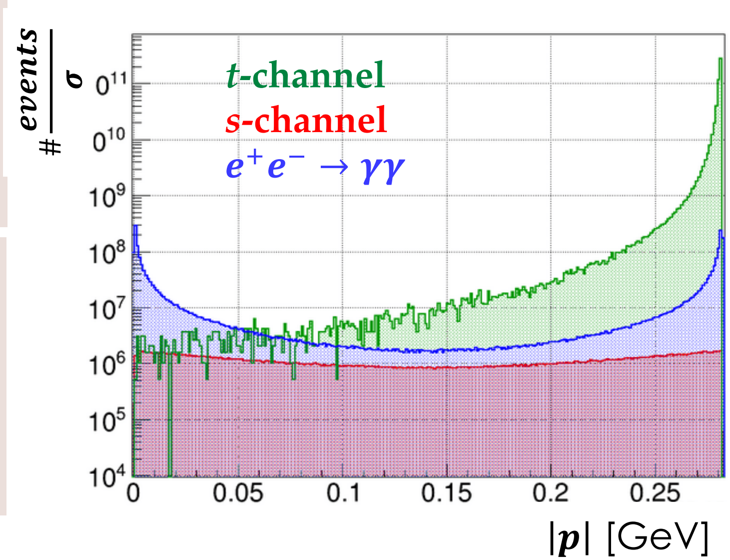


The mass scan X17 search strategy

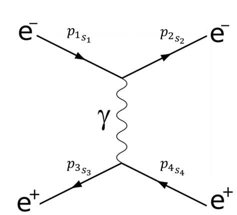
PADME, can use resonant X17 production process

- Extremely effective in producing X17 but in a very small mass range
- Scan E_{beam}=260–300 MeV in ~1.5 MeV steps

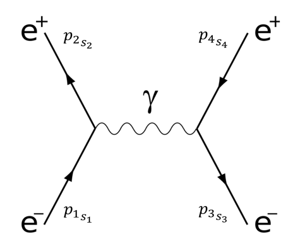
- Need only ~10^{10} POT per point
- Signal should emerge on top of **Bhabha** BG in one or more points of the scan.
- Critical parameter for signal to background optimization: **beam energy spread**



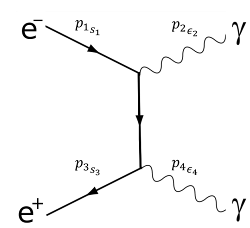
Bhabha scattering



t **channel**



s **channel**

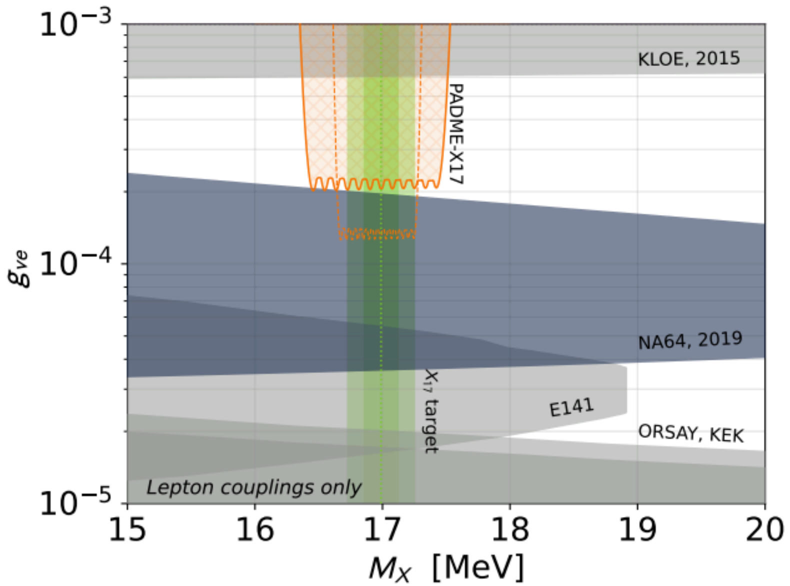


e⁺e⁻–>γγ

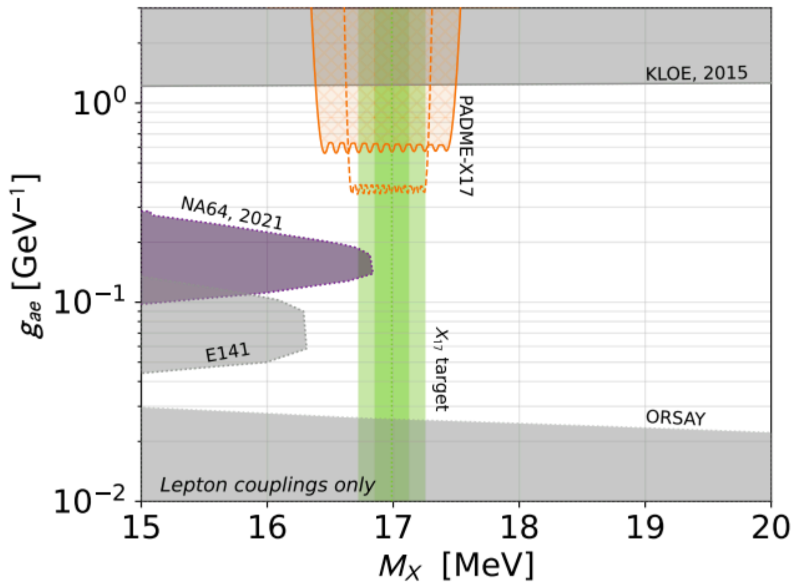
PADME expected limits

L. Darmé, M. Mancini, E. Nardi, M.R.
Darmé et al. Phys. Rev. D 106,115036

Vector X17



Pseudo scalar X17

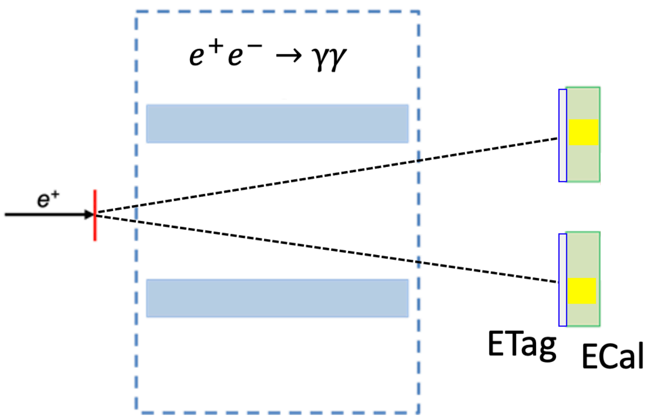


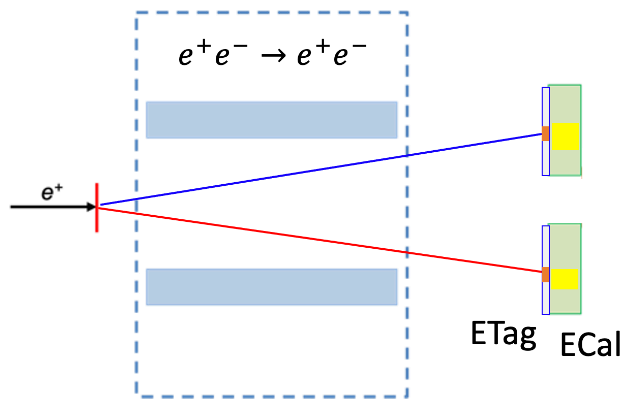
- BG from SM Bhabha scattering under control down to ε = few 10^{-4}
- Challenge is to achieve an extremely precise luminosity measurement and systematic errors control (<1%)
- Order 1E10 POT per each scan point
- PADME maximum sensitivity in the vector case
- Actual data set very close to optimistic scenario in the wide mass region

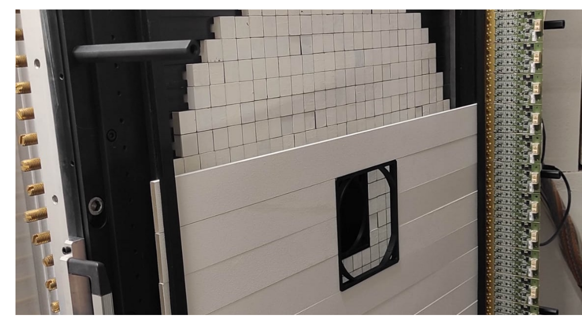
PADME Run III modified setup

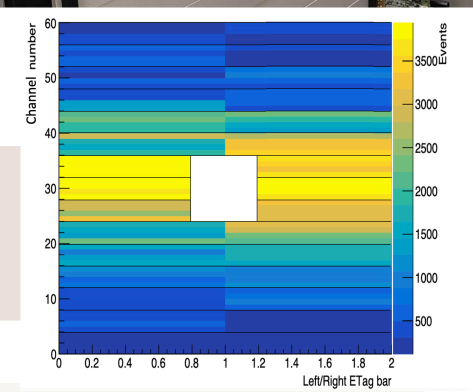
- Using PADME veto is impossible to reconstruct $e^+ e^-$ mass having no vertex info
- Idea: identify $e^+e^- \rightarrow e^+e^-$ using the BGO calorimeter only, as for $\gamma\gamma$ events in Run II

- Switch the PADME dipole **magnet off**
- Both positron and electron will reach the ECal
  - Can measure precisely (3%) electron-positron pair momentum and angles
  - Can reconstruct invariant mass of the pairs precisely (small pile-up)
- **Identify clusters** in ECal from photons or electrons
  - New detector, plastic scintillators, similar to PADME vetos (Electron tagger, ETag) with vertical segmentation and covering the fiducial region of ECal









- Thanks to the enhanced production cross section can reduce N_{POT}/bunch by factor 10.
- Much lower pile-up and better energy resolution

PADME Run III on resonance data set

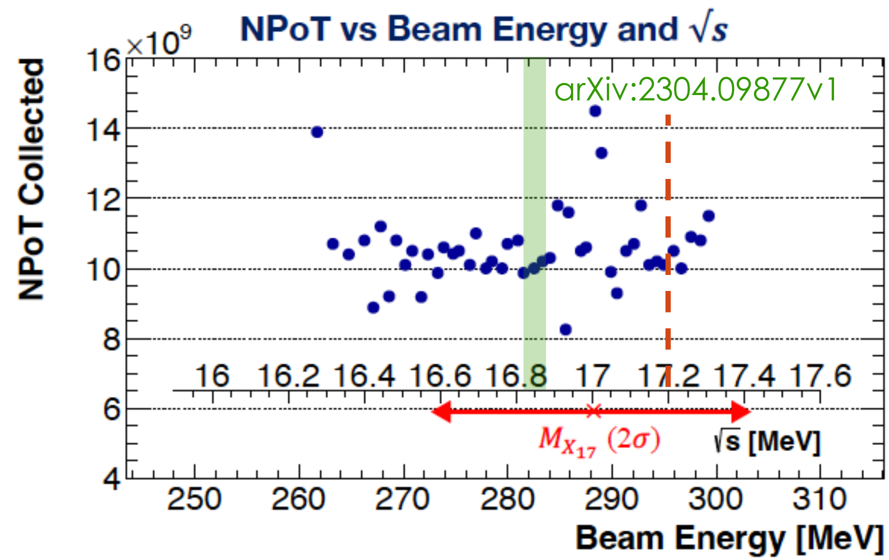
Collected 47 points at different energies

PADME data cover a region **1.1 MeV** in mass around the predicted region by Atomki

The collected statistics is enough to enter the NA64 coupling limit in the vector scenario.

The **PADME precision** on the $\mathbf{M_{X17}}$ measurement will be:

$\mathbf{\Delta M_{X17} = (17.47 - 16.36)/47 \sim 20\ KeV}$



RED Combined Be,He,C Atomki mass ranges
GREEN mass range fit results in arXiv:2304.09877v1
Dots mass points explored by PADME
I Mass limit imposed by ^{12}C observation

X17 observables at PADME

$\frac{N(e^+e^-)}{N^{PoT}}$ vs $\sqrt{s}$ $\frac{N(\gamma\gamma)}{N^{PoT}}$ vs $\sqrt{s}$

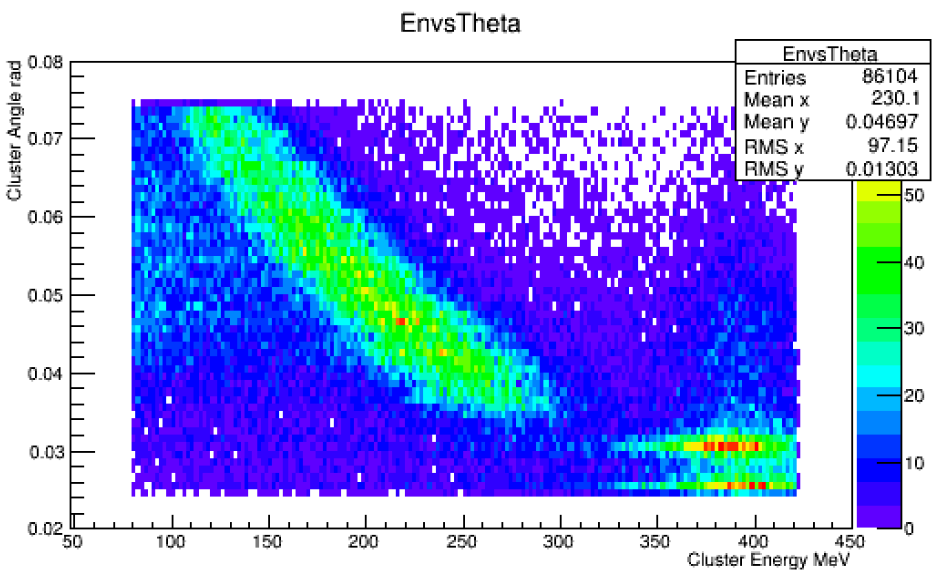
Osservabili $\frac{N(e^+e^-+\gamma\gamma)}{N^{PoT}}$ vs $\sqrt{s}$ N(2cl) selected for first step

$\frac{N(e^+e^-)}{N(\gamma\gamma)}$ vs $\sqrt{s}$

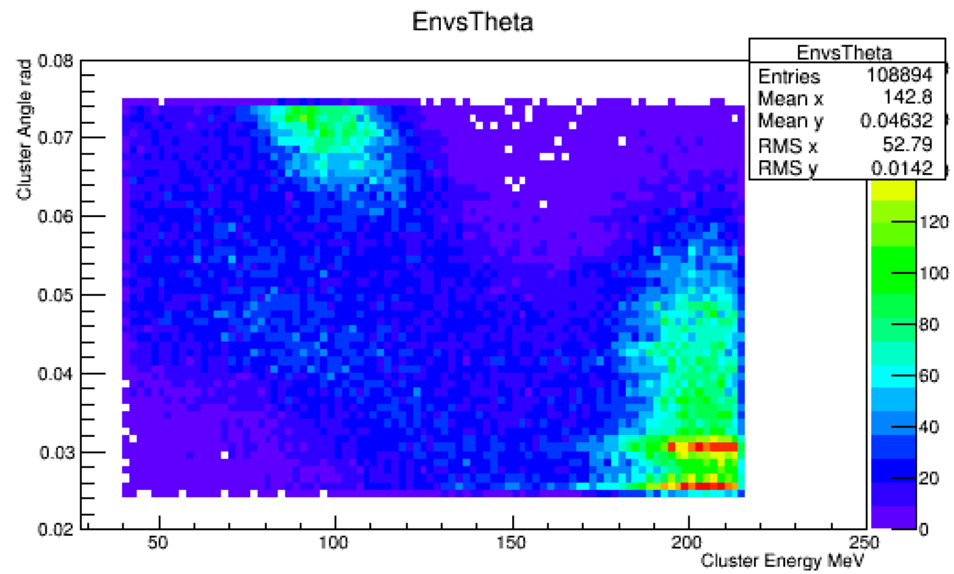
- Several different observables can be used with different outcomes:
  - **N(2cl)/N_{PoT}** = existence of X_{17}
    - Number of ee and $\gamma\gamma$ at the same time. High statistical significance
    - No particle ID -> no Etag related PID systematic errors
  - **N(ee)/N($\gamma\,\gamma$)** = existence of X_{17}
    - Lower statistical significance due to 2γ cross section
    - Independent from N_{PoT}, systematic due to E_{tag} PID
  - **N_{e+e-}/N_{PoT}** = vector nature of X_{17}
    - Systematic errors due to ETag tagging efficiency stability
  - **$N_{\gamma\gamma}/N_{PoT}$** = pseudo-scalar nature of X_{17}
    - Systematic errors due to ETag tagging efficiency stability

First look at Run III off resonance data set

- PADME collected **two off resonance** data sets:
  - **Over Resonance: 402 MeV:** 5 Runs for a total of **1.2E10 POT (collected October 2022)**
  - **Below Resonance: 205-211 MeV**: 5 energies for a total of **5E10 POT (December 2022)**
- PADME collected **few No Target Runs** for beam background studies.
- First selection aimed at **$N(2cl)/N_{PoT}$** studies:
  - 2 in time clusters in the $\Delta t < 5$ns in Ecal good radial region with reasonable Centre of Gravity
  - Cluster energy vs angle correlation compatible with a 2 body final state.

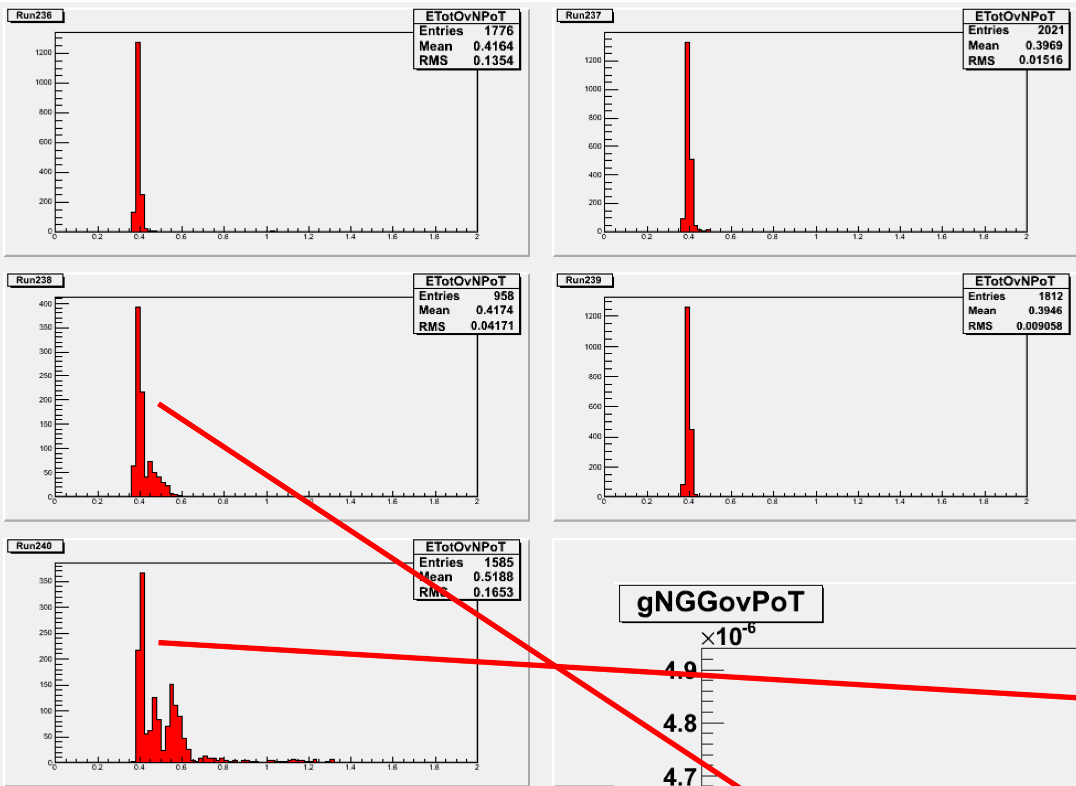


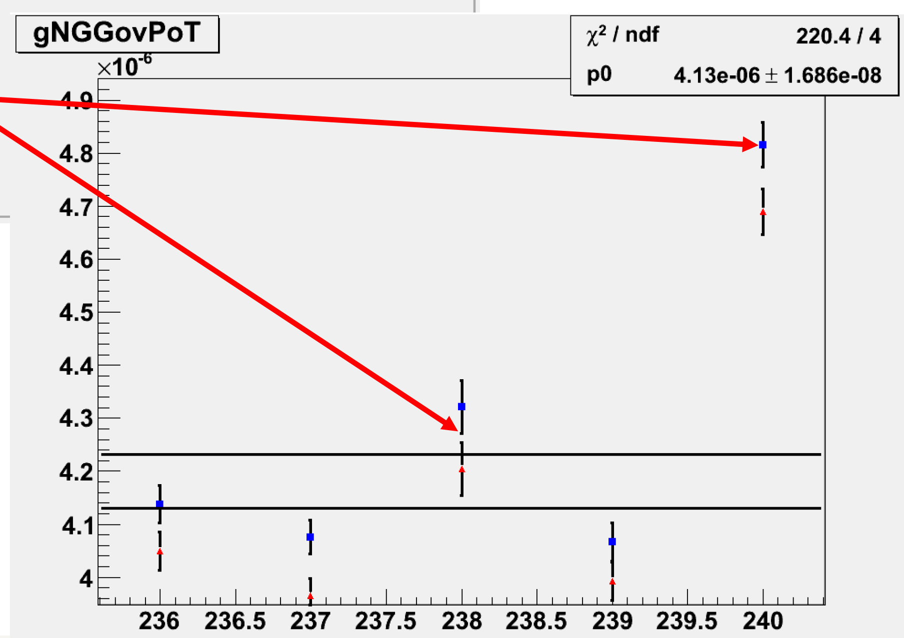
Over Resonance: 402 MeV



Below Resonance: 205 MeV

First results on Over resonance



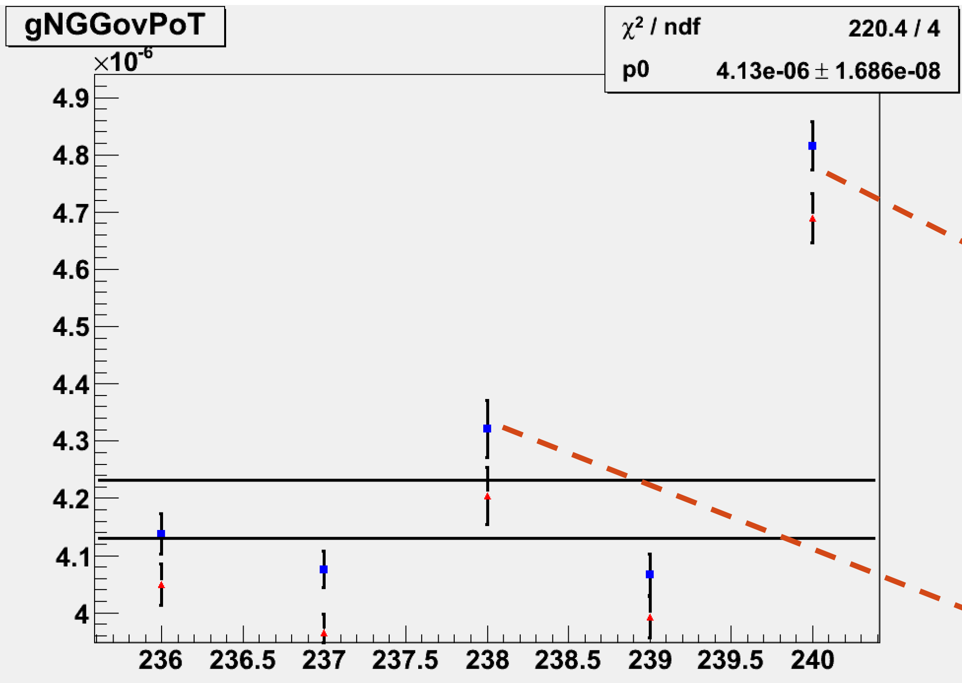


The variable E_{tot}^{ECal}/NPoT very sensitive to beam conditions.

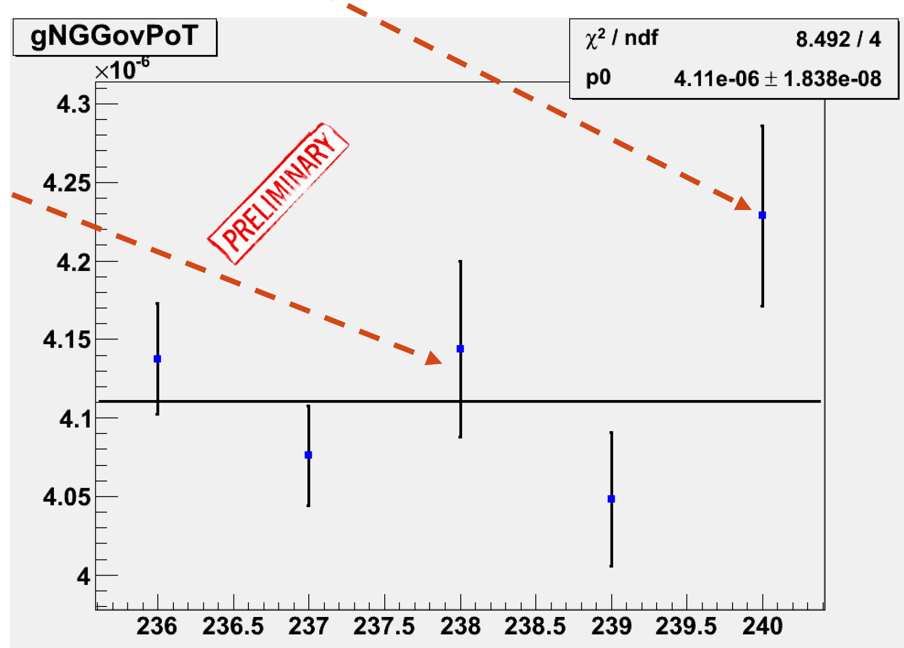
Measures the total BG on the PADME Ecal strongly related to beam background.

Cutting on the E_{Tot}/N_{PoT} ratio

- After introducing a cut on the ratio E_{tot}/N_{PoT} <0.43



- Values back in agreement with other runs!
- Beam quality cut very effective.



- Stability ~0.8% over the 5 runs
  - evidence of relative σ_{NPOT}<0.5%
- Good χ^2 means no significant systematic over statistical errors

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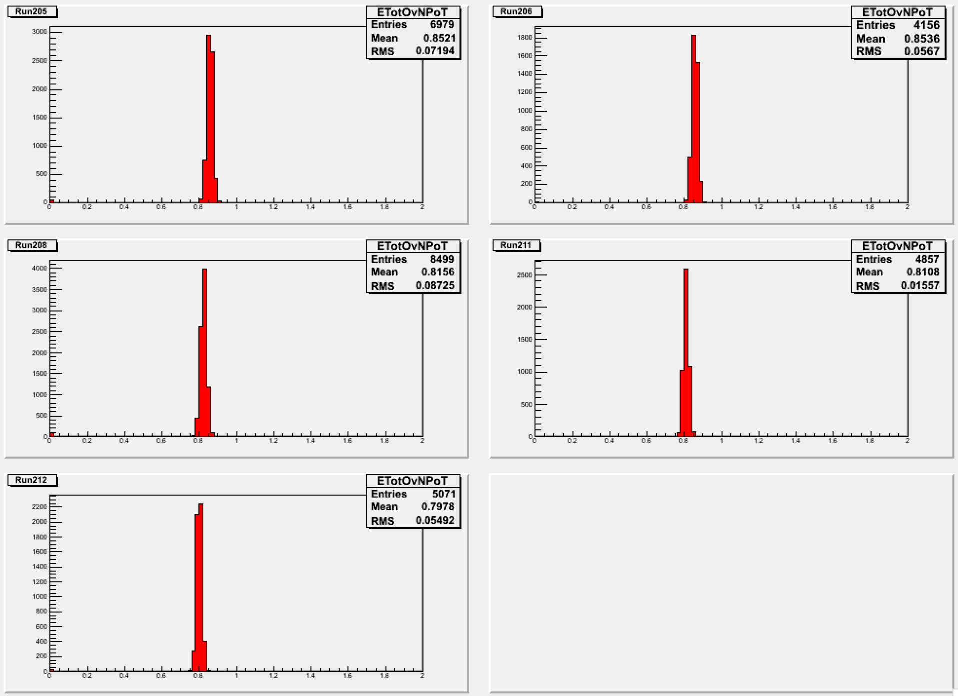
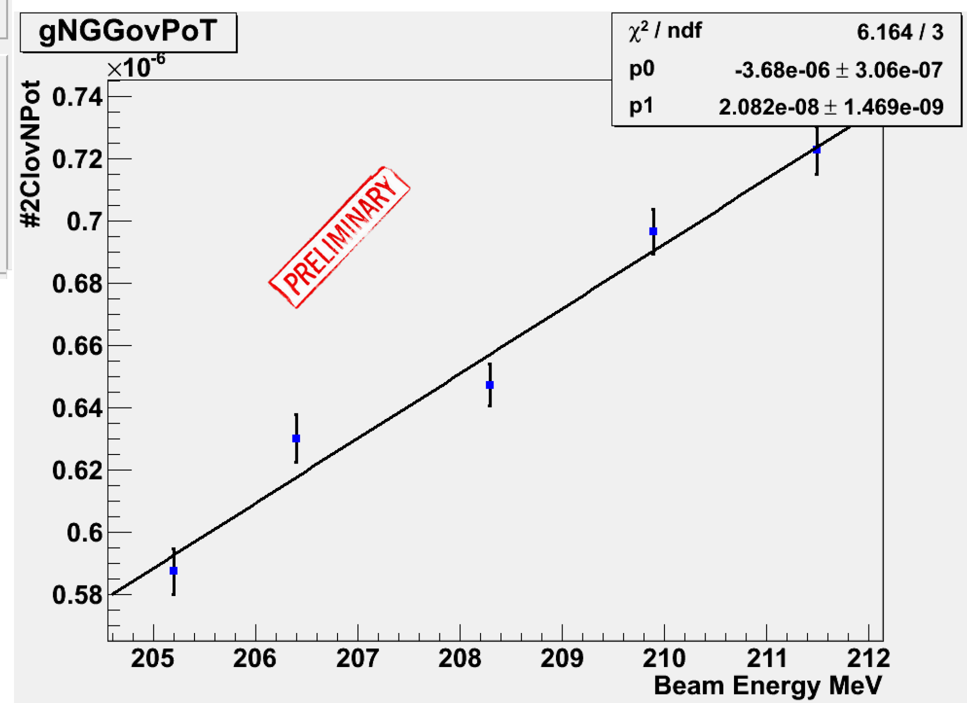
Below resonance scan

- Excellent beam stability no need for additional cuts.



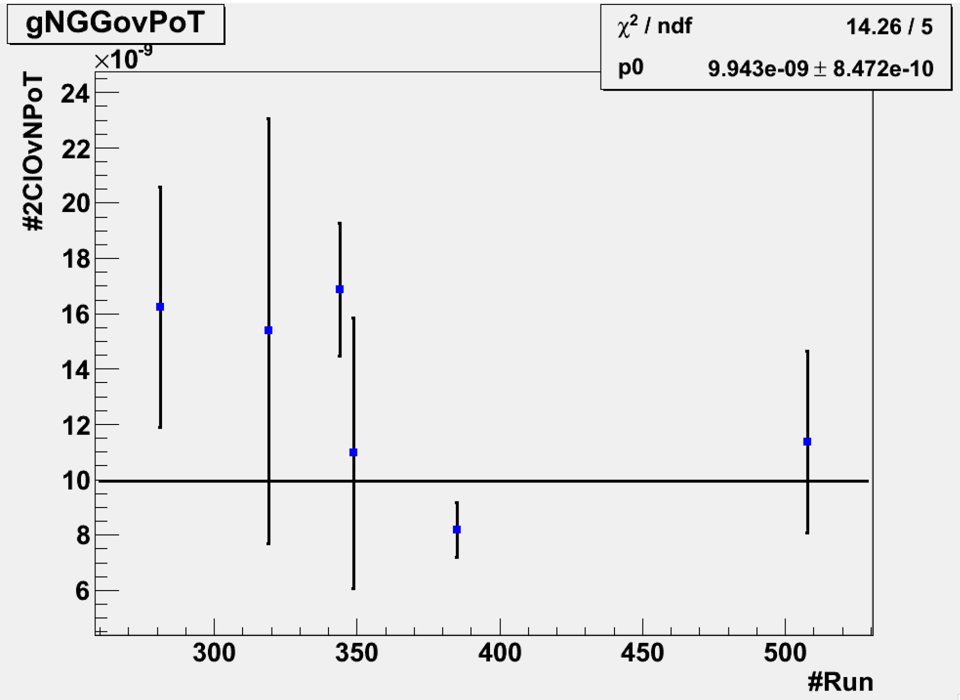
- Expect increasing value due to the different beam energy
  - Detector acceptance increases due to Lorenz boost



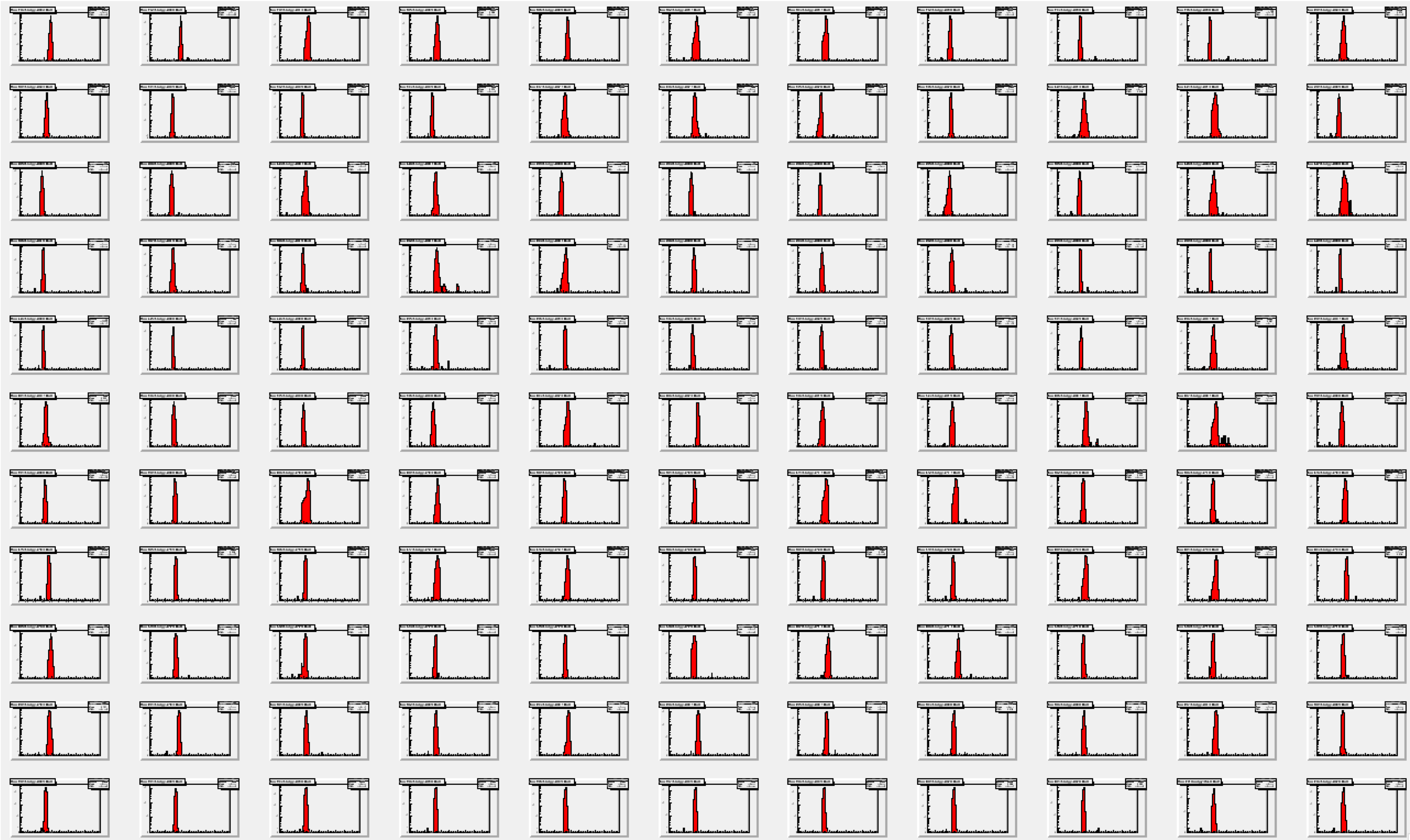
- Stability ~0.7% over the 5 energies
- Good χ^2 means no significant systematic over statistical errors

Beam BG contamination in #2cl

- No target data set are used to measure the beam background contamination in the data samples.
  - Running the same selection code on the no target runs we can get the beam background contribution to #2Cluster/N_{PoT}.
- Contamination form No Target Runs gives:
  - #2Cluster/N_{PoT} ~ 1.E-8 in no target Runs
  - #2Cluster/N_{PoT} ~ 1-3.E-6 in standard Runs
- Beam BG contamination in data is below <1%.



Data quality on the whole scan



All 121 runs in the X17 scans checked only a couple need checks

Possible 2024 data taking plan

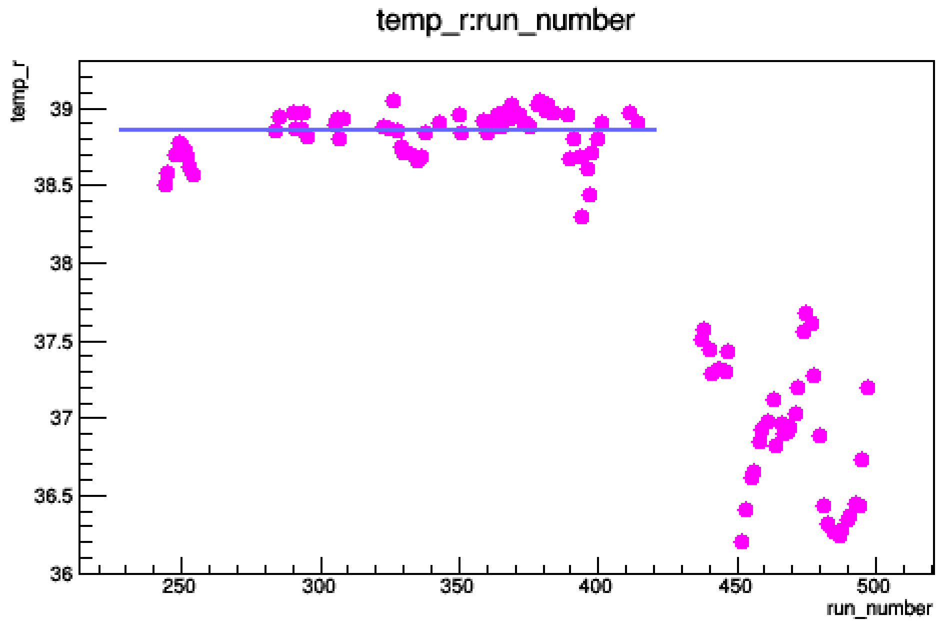
- Depending on the results obtained from Run III analysis
  - Perform additional data taking at sqrt(s)~17 MeV
  - Perform additional data taking with different sqrt(s)
- In any case we will ask for ~90 days of data taking in 2024 at the next LNF Scientific committee meeting
  - cost in ~10 Keuro travel to LNF
- Data taking period to be negotiated with the Laboratory
  - spring – autumn are the most favoured slots.

ECAL Temperature Correction in Run3 data

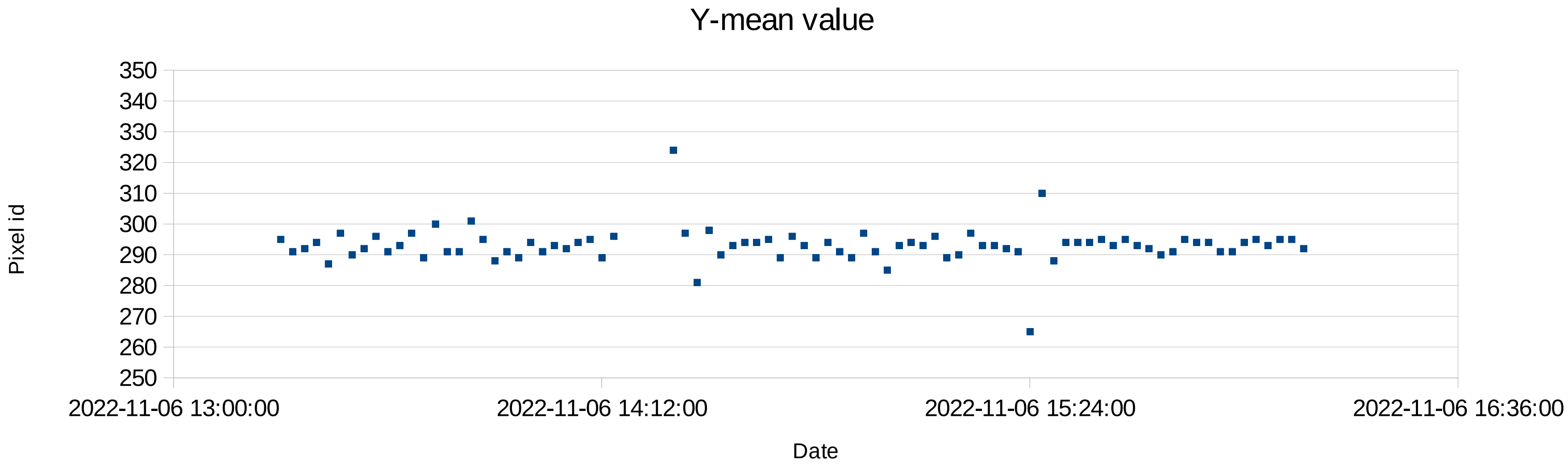
F. Ferrarotto

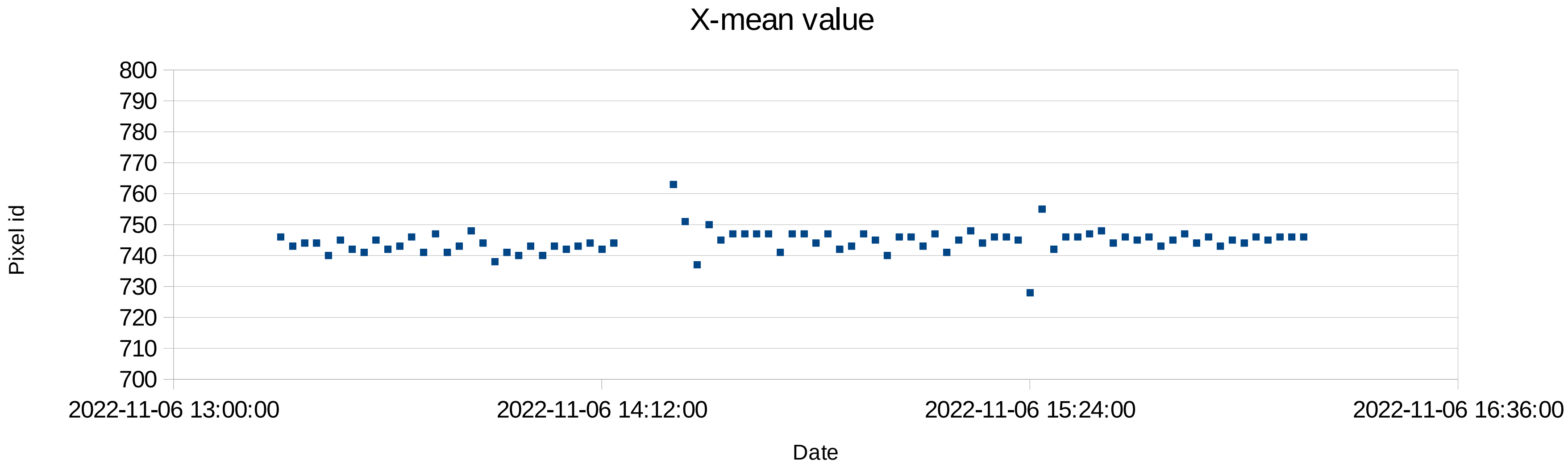
There's a large temperature variation between the first and the second part of the runs in Run3 → use a temp correction to improve the energy calibration discrepancy shown by Mauro

Preliminary : used only ECAL_Tleft_1 (read by Keysight) to make a global correction based on the average temp per run.
Reference temp used : global average of runs < 50414
Correction used : -0.95%*(trun_avg-t_tot_avg)

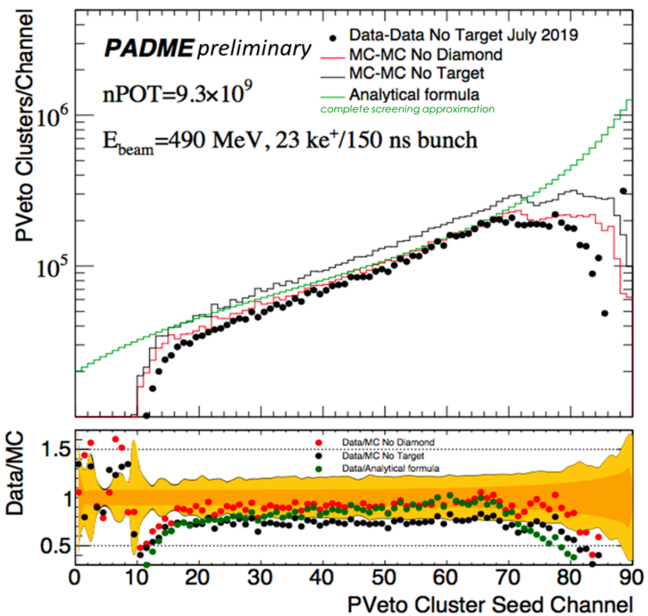


Timepix analysis – X- and Y- mean run_0050391_20221106_141153



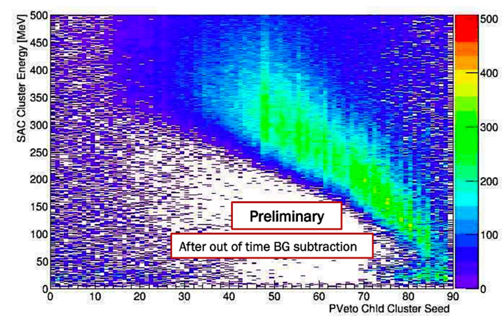


Single photon events

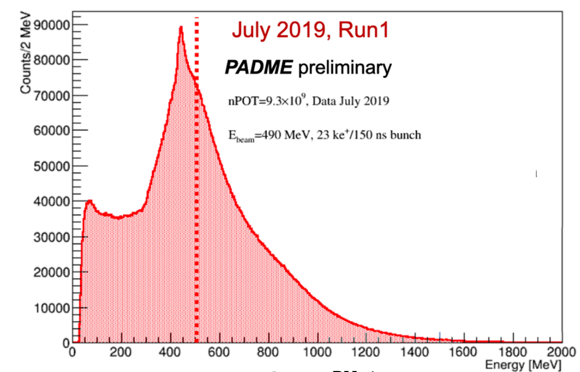


Physics backgrouns dominated by Bremsstrahlung:

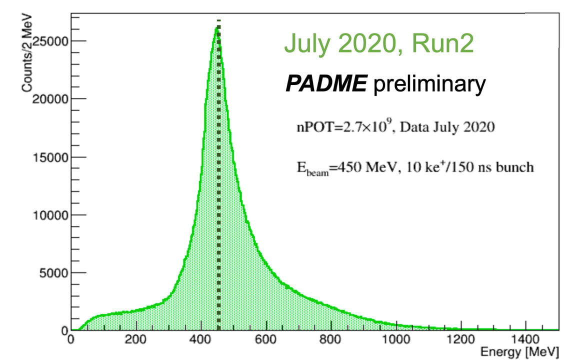
- Measured with no-target runs and subtracted
- Bremstrahlung photon distribution in agreement with **Monte Carlo simulation** and **analytical calculation**
- Main systematic uncertainties:
  - Background normalization
  - Positron momentum scale
  - n POT calibration



Veto momentum vs. SAC energy
490 MeV, primary beam, Δt <1 ns



$p_{\gamma}^{ECal} + p_{e^+}^{PVeto}$



$p_{\gamma}^{ECal} + p_{e^+}^{PVeto}$

- Essential for dark photon analysis

Conclusions

- PADME performed two physics runs, collecting ~$5 \cdot 10^{12}$ POT each
- PADME delivered its **first physics result on Run II** data
  - $\boldsymbol{\sigma(e^+e^- \rightarrow \gamma\gamma)}$**=** $\mathbf{(1.977 \pm 0.018_{\mathit{stat}} \pm 0.119_{\mathit{syst}})\ mb}$
  - Preliminary $\sigma(e^+e^- \rightarrow e^+e^-)$ on Run II @430 MeV exist
- **PADME Run III at the X_{17} anomaly**, successfully terminated
  - 47 different energy values acquired with N_{PoT}>1E10 each
  - High quality data collected for 16.35 MeV <M_{X17}<17.5 MeV
  - Beam Background and BhaBha are under control
- Stability of the ratio #2Clusters/N_{PoT} on off resonance data <1%
- Hope to have additional data taking in 2024 (X17 or different $\sqrt{s}$)

Directions in searching for X17

Atomki
$^{8}Be, ^{4}He, ^{12}C$
Nuclear

LNL,MEG, N-TOF ← Can we reproduce the effect?

NA64, FASER, NA62 ← Is the effect due to X17? → PADME $e^+e^- \rightarrow e^+e^-$

Is X17 a vector or a scalar? → PADME $e^+e^- \rightarrow e^+e^-$, $e^+e^- \rightarrow \gamma\gamma$

LNL,MEG, NTOF, NA62 ← What is the X17 exact mass? → PADME $e^+e^- \rightarrow e^+e^-$, $e^+e^- \rightarrow \gamma\gamma$

Summary on X17 constraints

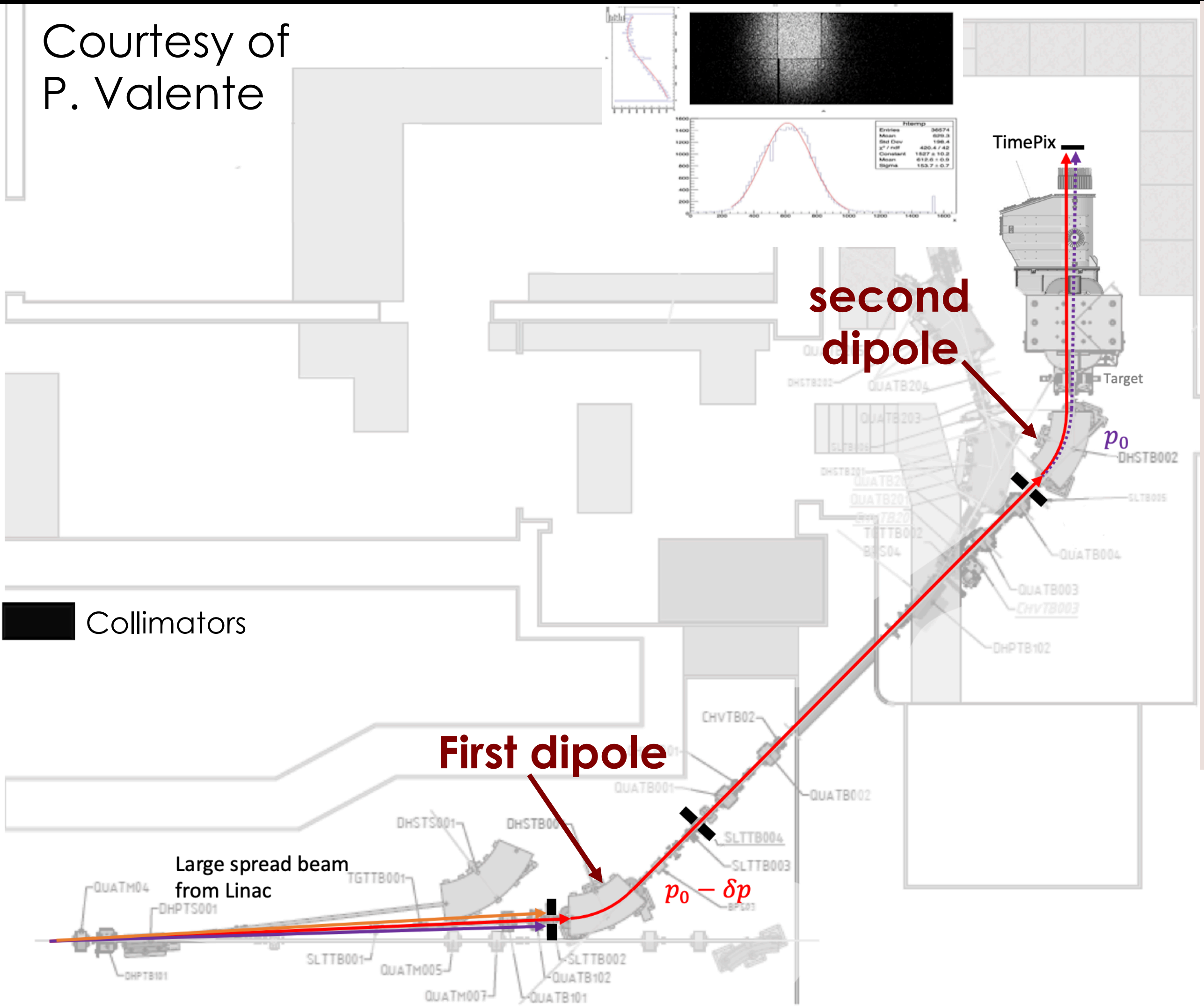
To summarize this section, a model with a vector mediator explaining the ATOMKI anomaly at a minimum needs to fulfill the following requirements:

- feature a vector mediator with mass $m_X \approx 17$ MeV,
- X needs to couple to neutrons with strength $|\varepsilon_n| \approx 0.0058$,
- X needs to couple to protons with strength $|\varepsilon_p| \approx 0.0024$,
- the product of neutron and proton couplings of X need to fulfill $\varepsilon_n \varepsilon_p > 0$,
- the coupling of X to electrons needs to be either $|\varepsilon_e| \in [0.63, 1.2] \times 10^{-3}$ or $|\varepsilon_e| < 10^{-12}$ for $\mathrm{BR}(X \to e^+e^-) = 1$, and
- the coupling of X to electron neutrinos needs to be smaller than $|\varepsilon_{\nu_e}| < 3 \times 10^{-6}$.

Finally, a new mediator that explains the ATOMKI anomaly is only required to couple to first generation fermions; if it also couples to the other generation potentially more constraints need to be taken into account.

Obtaining energy steps and resolution

Courtesy of
P. Valente



Use the first dipole magnet and collimators to select energy

- dp ∝ collimator aperture.

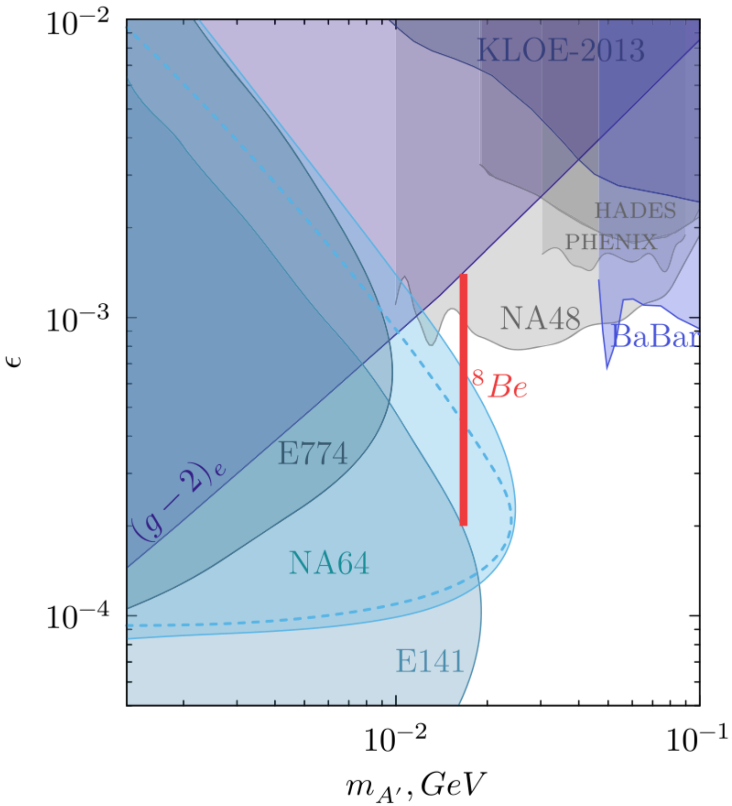
Change the first dipole magnet current to change the energy

Correct the trajectory using second dipole to put the beam back on axis at PADME

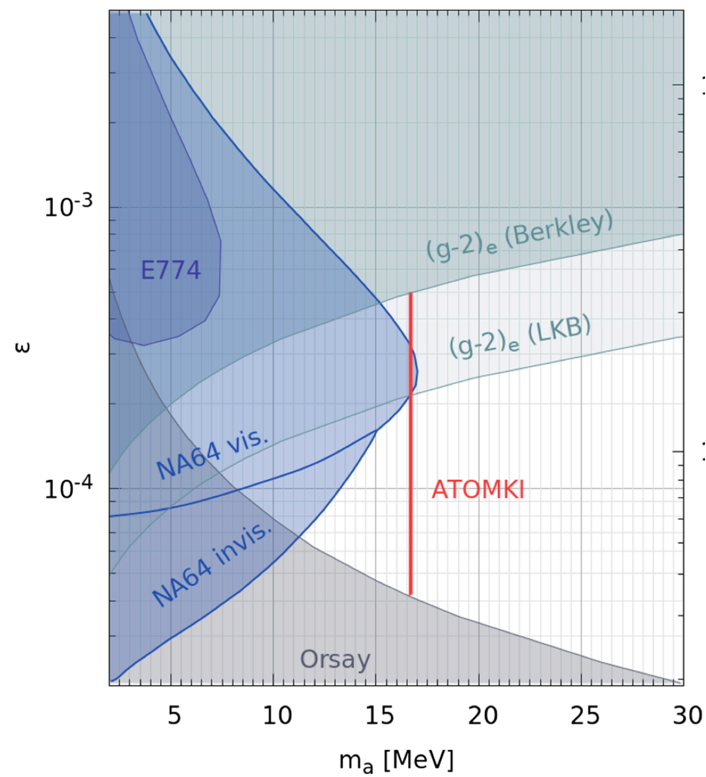
Measure the displacement at the target and timePix to measure the energy step performed

Current constraints on X17 from leptons

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



Phys. Rev. D 104, L111102 (2021)



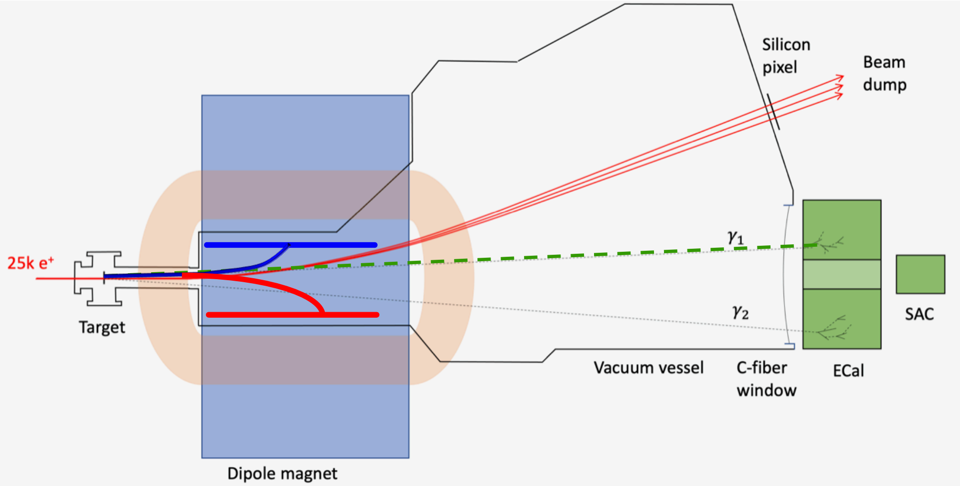
X17 as a vector particle:

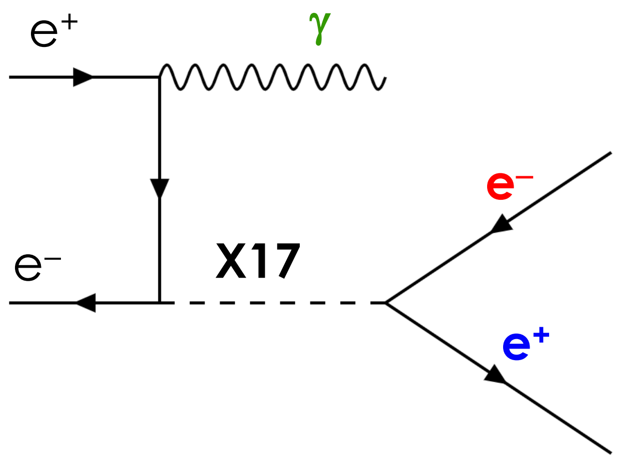
- LKB $(g\text{-}2)_e$ bound weaker for vector and model dependent
- NA48/2 bound not valid for “protophobic” X17
- Still a lot of free parameter space for vector X17

X17 as pseudo scalar particle:

- $(g\text{-}2)_e$ bound stronger for pseudo scalars
- Still model dependent and with big data uncertainties
- Almost unconstrained parameter space for X17

PADME X17 searches on Run II data





Final state $e^+e^- \rightarrow X_{17}\,\gamma \rightarrow e^+e^-\gamma$

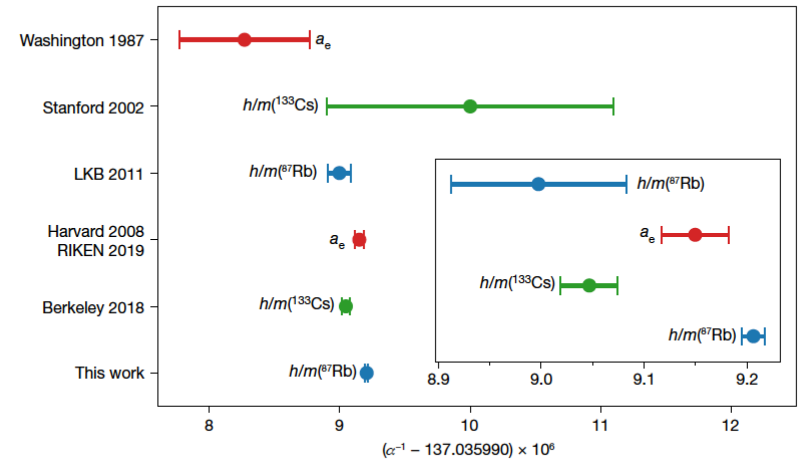
- Use radiative return E_{beam} =430 MeV
- small contribution from $\gamma\gamma$
- Large beam γ background reducing the sensitivity

Try to identify pairs of leptons using PADME veto

- Large BG from BhaBha scattering
- Large beam background increasing combinatorics BG
- Lepton invariant mass not accessible

g-2e anomaly

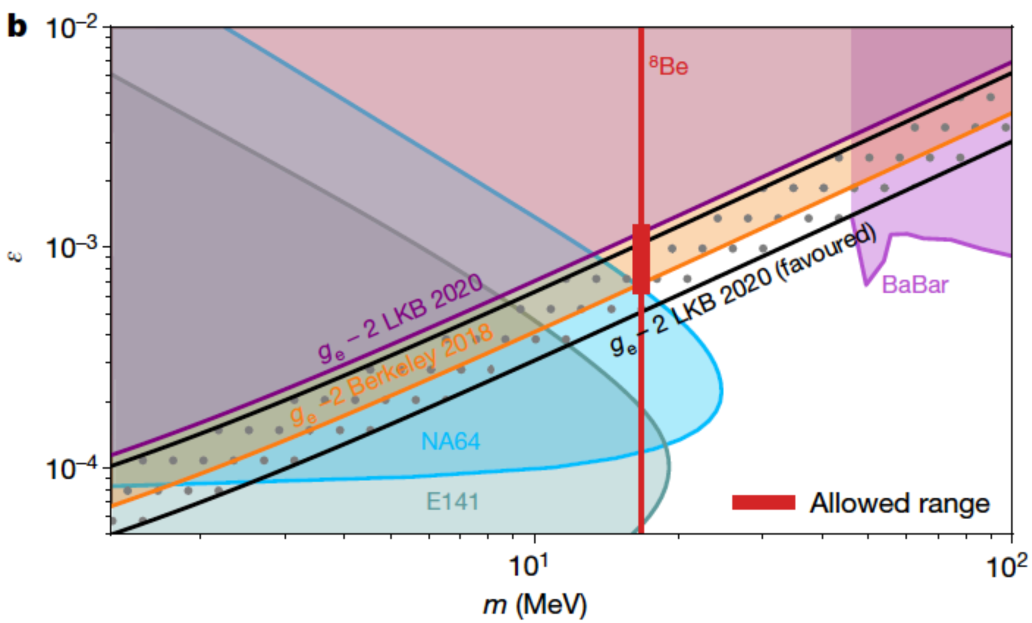
- Significant discrepancy in the last two results on the α determination
- Produce a modified $(g\text{-}2)_e$ exclusion which allows a region of existence of X17



$$\alpha^{-1} = 137.035999206(11).$$

The uncertainty contribution from the ratio $h/m(^{87}\mathrm{Rb})$ is 2.4×10^{-11} (statistical) and 6.8×10^{-11} (systematic). Our result improves the

https://www.nature.com/articles/s41586-020-2964-7



experimental measurement $a_{e,\mathrm{exp}}$ (ref. [9]) gives $\delta a_e = a_{e,\mathrm{exp}} - a_e(\alpha_{\mathrm{LKB2020}}) = (4.8 \pm 3.0) \times 10^{-13}$ ($+1.6\sigma$), whereas comparison with caesium recoil measurements gives $\delta' a_e = a_{e,\mathrm{exp}} - a_e(\alpha_{\mathrm{Berkeley}}) = (-8.8 \pm 3.6) \times 10^{-13}$ (-2.4σ). The uncertainty on δa_e is dominated by $a_{e,\mathrm{exp}}$.

X17 and g-2$_e$ anomaly

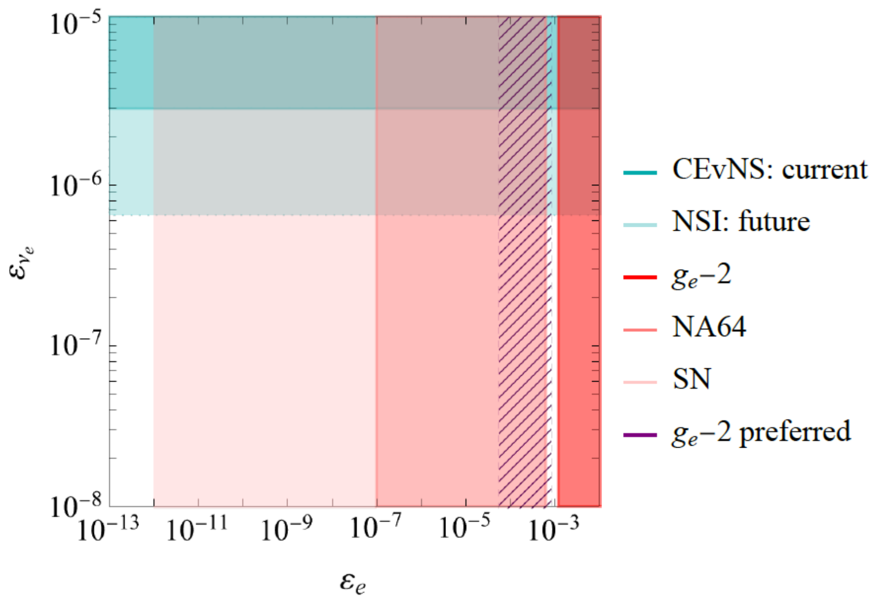
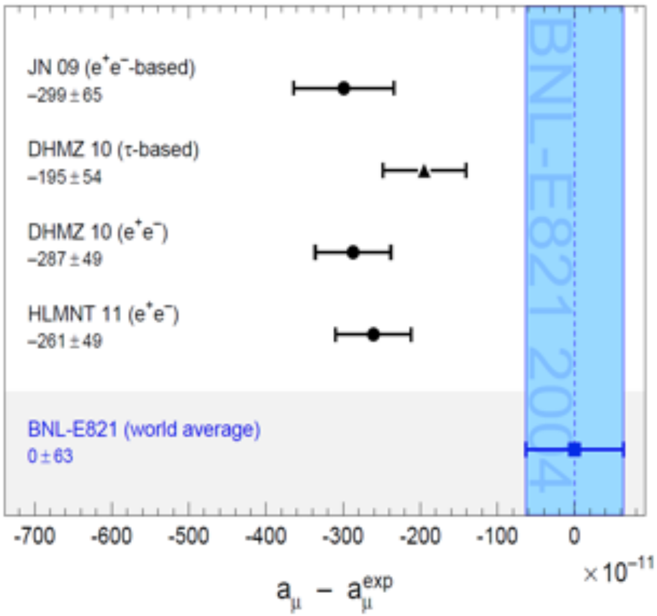
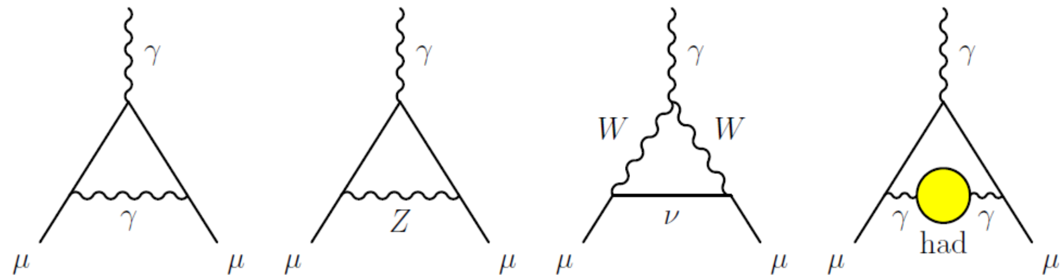


FIG. 3. Constraints on ε_{ν_e} and ε_e for $m_X = 17$ MeV. The dark cyan regions shows the current constraint from CEvNS setting $\varepsilon_n = 0.0058$, the lighter cyan regions shows the future constraints from NSI at upcoming oscillation experiments. The red and pink regions show the excluded regions from NA64 and $g_e - 2$, the lighter pink region to the left shows the constraint from SN. The purple hatched region shows the preferred region for ε_e from $g_e - 2$. The currently allowed region of parameter space is shown in white. The allowed region for ε_e can be probed with future collider and beam dump experiments [65–68].

Muon g-2 anomaly



g-2 in the standard model

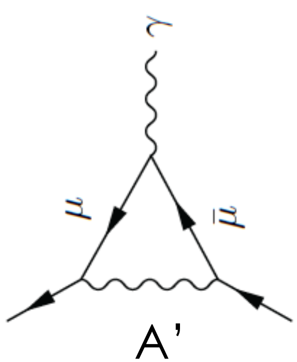


About 3σ discrepancy between theory and experiment (3.6σ, if taking into account only e+e–>hadrons)

Contribution to g-2 from dark photon

Additional diagram with dark photon exchange can fix the discrepancy (with sub GeV A' masses)

g-2 and A'



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

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