Status of PADME activity

Paolo Iengo, Paolo Massarotti, Givi Sekhniaidze

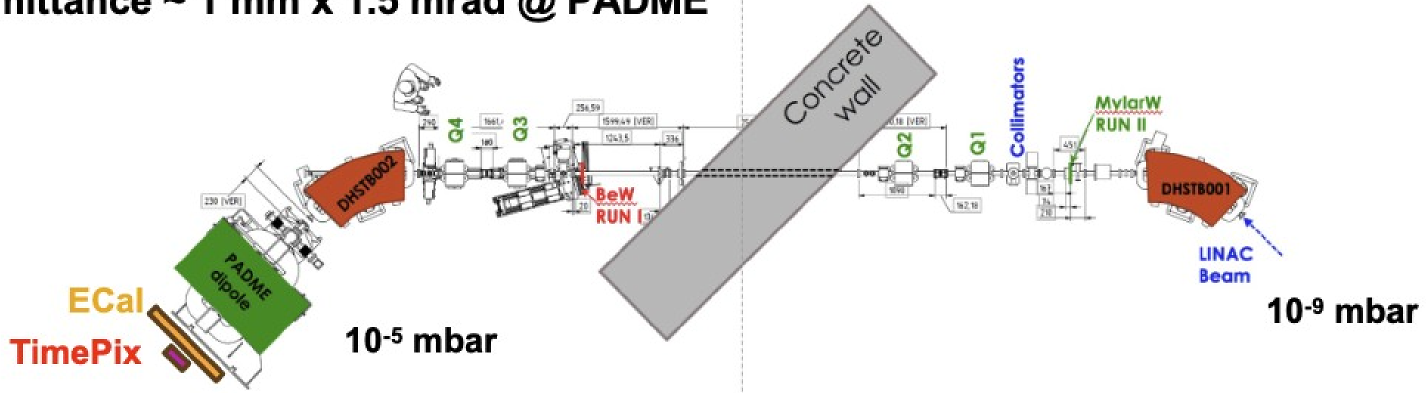
Positron Annihilation into Dark Matter Experiment (PADME)

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

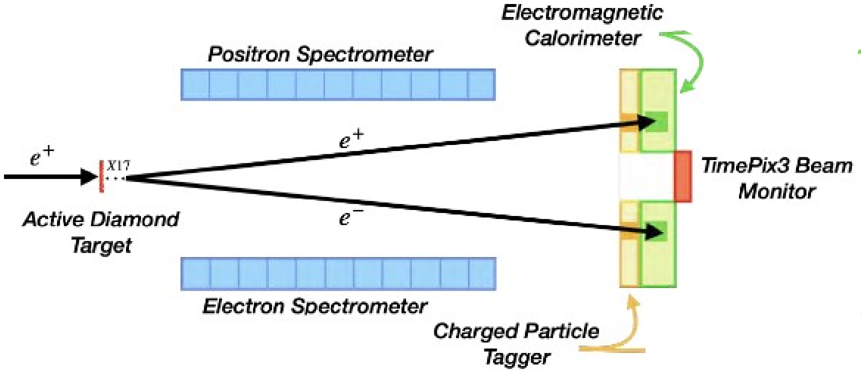
Emittance ~ 1 mm x 1.5 mrad @ PADME

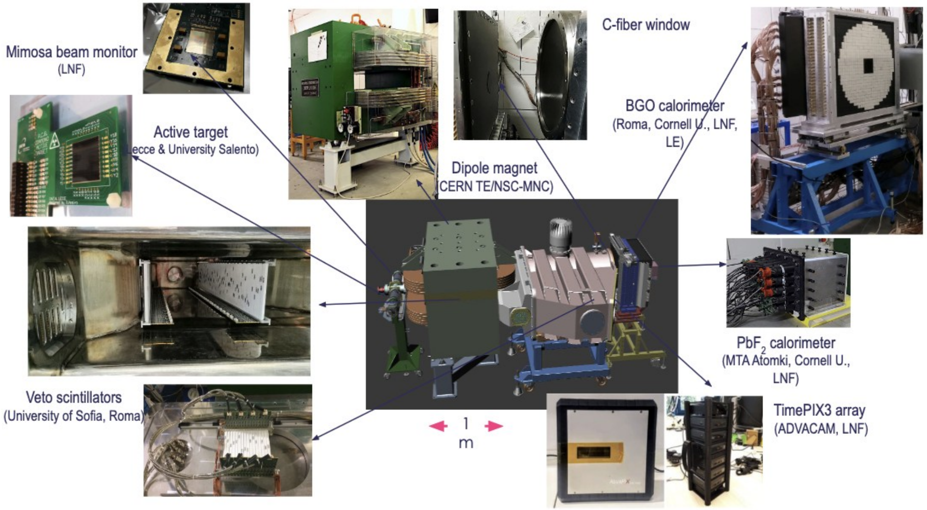


Past operations:

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, 47 scan points $s^{1/2}$ ~ 17 MeV [2022]

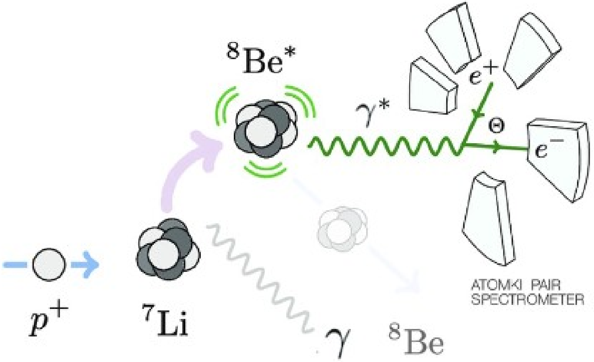
Positron Annihilation into Dark Matter Experiment (PADME)



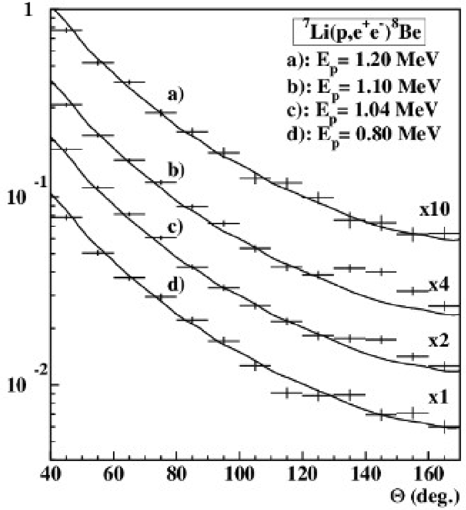


The X17 anomaly

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

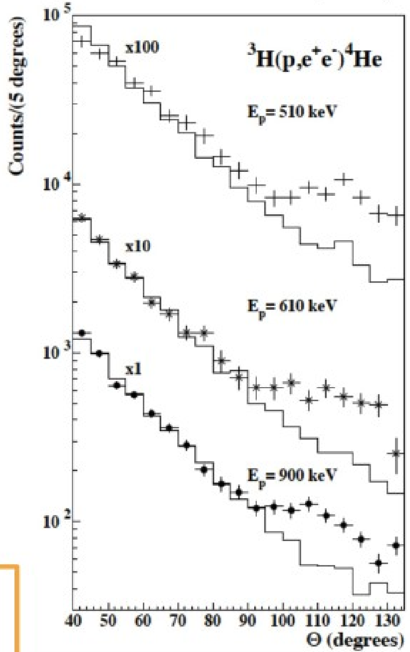


PRL 116, 042501 (2016)



$m_\chi = (17.01 \pm 0.16)$ MeV

Phys. Rev. C 104, 044003 (2021)



$m_\chi = (16.98 \pm 0.16 \pm 0.20)$ MeV

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Nuclear physics

Rekindled Atomki anomaly merits closer scrutiny

Feb 2020

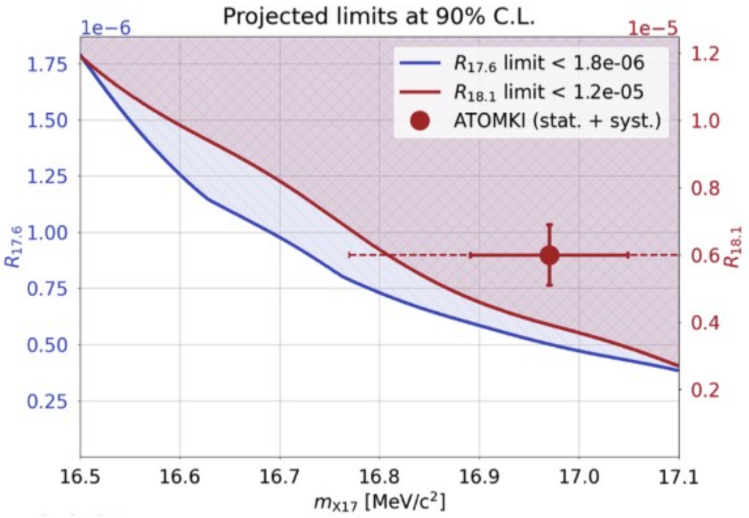
Observed at Atomki: ^{12}C [PRC 106, L061601], GDR of ^{8}Be [2308.06473]
Observed at HUS (Vietnam): ^{8}Be/^{12}C
Other efforts ongoing (e-, n beams, etc.)

Recent results from MEGII

7Li target for L1(P, y or y-→ee)8Be transition

- Using:
  - M_{X17} = 16.97(22) MeV and $R_{18.1}$ = 6 10^{-6}
  - Scaling $R_{17.6}$ = 0.46 $R_{18.1}$

- ATOMKI: X17 produced at 1.030 MeV **and not** at 0.440 MeV
  - → *p*-value : 6.2% (1.5σ)
  - **ATOMKI observation excluded at 94%**
- J.L.Feng et al.: X17 produced **both** at 1.030 MeV **and** at 0.440 MeV
  - → *p*-value : 1.8% (2.1σ)



X17 anomaly after MEGII result

On the Atomki nuclear anomaly after the MEG-II result

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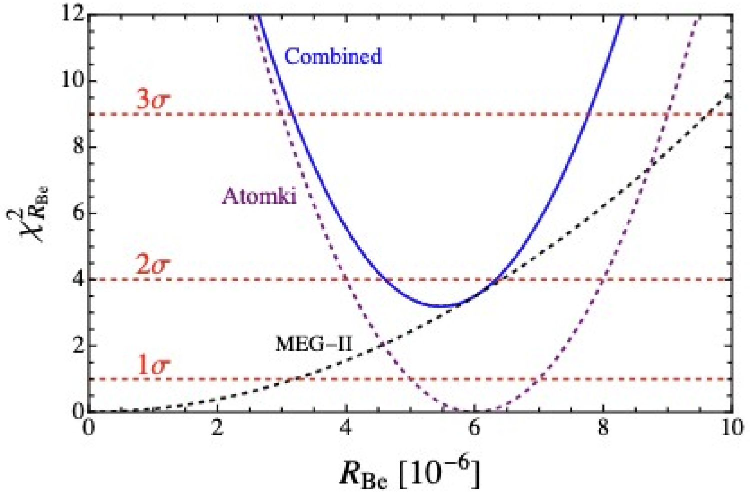


	R_{Be} [10^{-6}]	R_{He}	R_C [10^{-6}]
Atomki	6 ± 1 [1, 2]	0.2 ± 0.03 [3, 4]	3.6 ± 0.3 [5]
MEG-II	< 5.3 at 90% CL [38]		
Combined	5.5 ± 1.0		

Table 2. Experimental values at 1σ for the normalized decays rates from Atomki and the upper limit from MEG-II considering a mass value of 16.85 MeV for the X boson. We associate to the Atomki Helium experimental value a relative uncertainty equal to the Beryllium one, as this information is not reported by Atomki. The Atomki and MEG-II results in the Beryllium case are combined as explained in the text.

constraints from SINDRUM searches. Assuming future MEG-II results completely rule out the Beryllium anomaly, we have reconsidered the possibility of a pure CP-even scalar X state, a hypothesis previously dismissed due to its incompatibility with the Beryllium signal. Our results indicate that a pure CP-even scalar X can account for the Atomki anomalies in ^{4}He and ^{12}C, while remaining consistent with other experimental constraints.

X17 search with PADME Run-III

At PADME, X17 produced through resonant annihilation in diamond target:

- Scan around $E(e^+) \sim 283$ MeV
- Beam-energy spread ~0.25%, $\delta E(e^+)$ ~0.7 MeV → center of mass steps of 20 keV made
- Measure two-body final state yield N_2

Master formula for each scan point at c.m. energy $s^{1/2}$:

$$N_2(s) = N_{POT}(s) \times [\, B(s) + S(s; M_X, g)\, \varepsilon_S(s) \,] \quad \text{vs} \quad N_2(s) = N_{POT}(s) \times B(s)$$

Fundamental inputs:

- $N_{POT}(s)$ 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} = $\{M_X, g\}$
- $\varepsilon_S(s)$ signal acceptance and selection efficiency
- $s^{1/2}$ measured from magnetic field (Hall probe) run by run

Source	Expected uncertainty	Comment
$N_2(s)$	0.47—0.42% per point	statistical
B(s)	~ 0.5% per point	systematic
S(s; Mx, g)	< 3%	systematic
$\varepsilon_S(s)$	~ 0.5% per point	systematic
N_{POT}	0.5% per point	systematic
Data quality	TBD	systematic

$N_2(s)$ kept blind in the analysis

- Total systematic error per point 0.7 -- 0.9% at the moment
- Common errors working as a "scale" for the yield due to N_{POT} and $B + S\, \varepsilon_S$ are at 5%

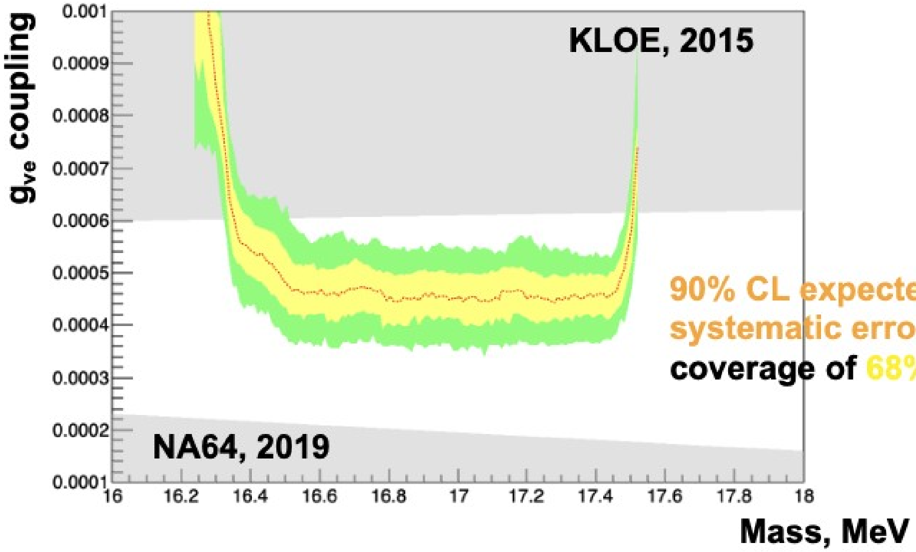
X17 search with PADME Run-III

Analysis still blind, expected sensitivity performed using MC

147 nuisance parameters: true values of N_{POT}, B, ε_S + signal shape and absolute scale

CLs limit with Tevatron-like likelihood [ATL-PHYS-PUB-2011-11/CMS NOTE-2011/005]

Full toy-of-toys for expected UL [130 pseudo-events, 200 toy events for each pseudo-event for each 20 keV-step mass and coupling]



90% CL expected exclusion with 0.9% systematic error and no signal: local coverage of 68% and 95%

1

Improving sensitivity: Nee/Nyy

- The results from PADME RUN III will be dominated by PoT systematics, two clusters acceptance acceptance systematics

  → Exploit a different normalization channel which could possibly cancel part of the systematic effects
- Natural candidate: $e^+e^- \rightarrow \gamma\gamma$
  - Same 2 body kinematics: similar ECal illumination, systematics due to bad ECal crystals largely cancels

- Back on the envelope estimation: need knowledge of $N_{\gamma\gamma}$ at 0.5 % for each scanning point
  - $\sigma(e^+e^- \rightarrow \gamma\gamma)_{E=300\ MeV}$ ~ 2 mb, Acc ($e^+e^- \rightarrow \gamma\gamma$) ~ 10 % ⇒ O(10k) γγ events per 10^{10} PoT
    - Need 4 times higher statistics per scan point
  - Less scan points due to the widening of X17 lineshape because of the electronic motion
  - Higher intensity – by a factor of 2
- Need good separation between charged and neutral final states

Plans for Run-IV

Increase sensitivity by:

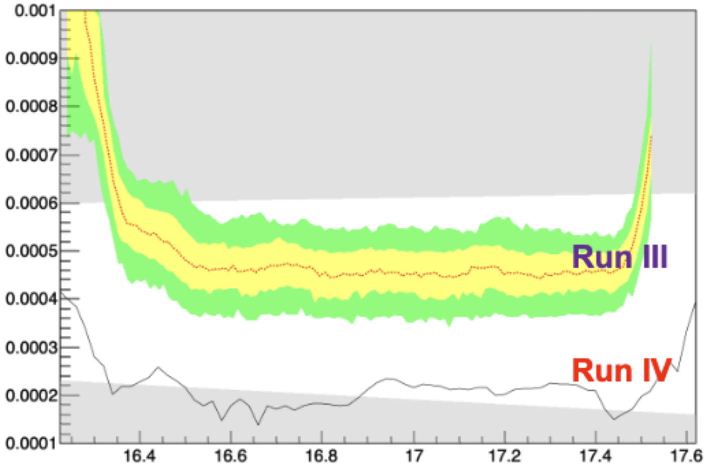
1. **Normalising to gamma-gamma final states, no use of N_{POT} whatsoever**
2. **Achieving an improved cancellation of systematic errors: data quality, selection efficiencies**
3. **Increasing the statistics per point by x4: run twice the time with half the scan points**

Gains:

- **Total statistical-systematic uncertainty down by x2, to 0.5%**
- **The purely statistical error on Nobs passes from 0.4% to 0.2%**
- **Fundamental improvement: the a-priori errors become statistical (γγ data counts) → can extrapolate vs $s^{1/2}$ bringing down the expected error by a factor of 5 or more**

Becomes a no-nuisance with 4 times the statistics

Point 1 above requires a detector upgrade

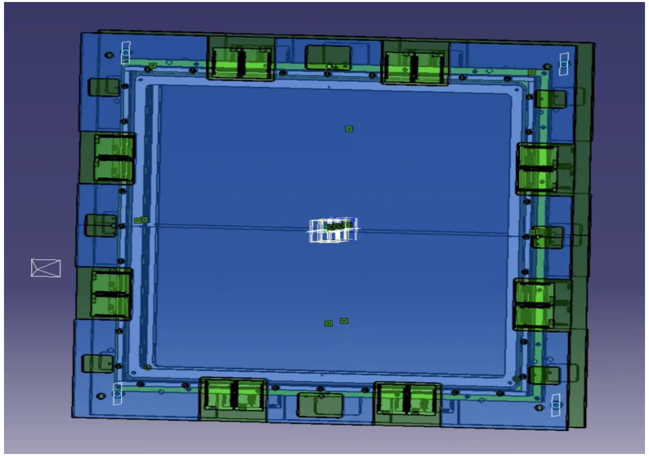


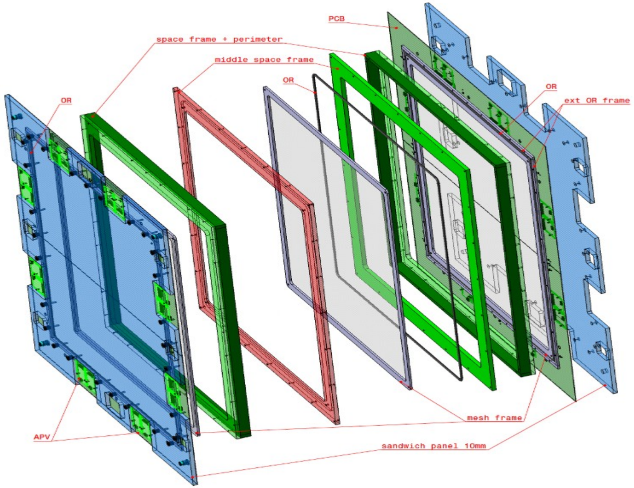
New tagger based on Micromegas detector

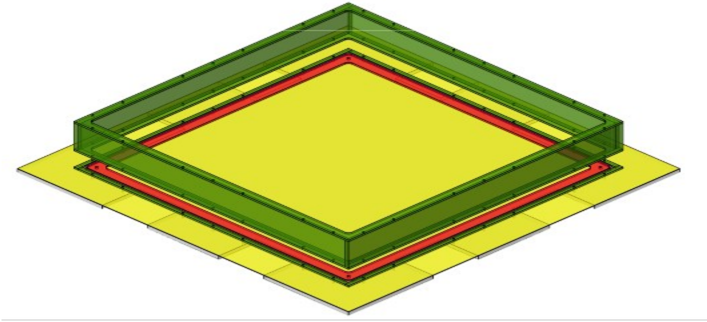
The Micromegas detector

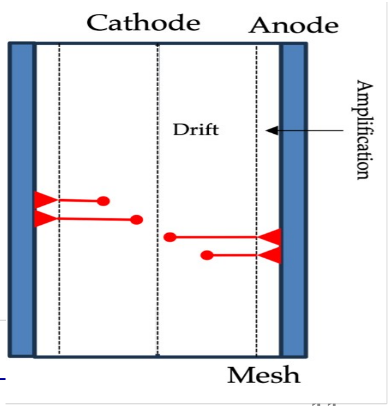
PadMMe detector:

- 65 cm x 65 cm
- TPC operation with 2 RO planes (2 views per plane) front-to-front
- Central drift cathode (stainless steel mesh)
- Single gas gap 10 cm long
- Gas mixture based on fast gas Ar:CF4:Iso=88:10:2; signals read using an APV-based frontend









PADME Micromegas: prototype test at BTF

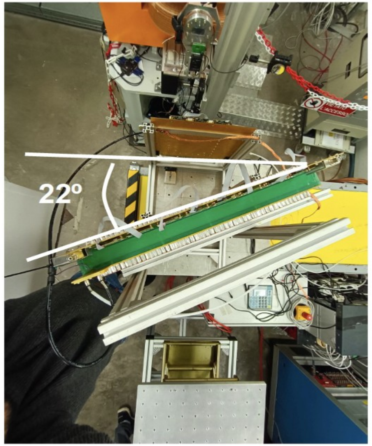
Proof of principle with old prototype chambers (from ATLAS) ay BTF on 05/24:

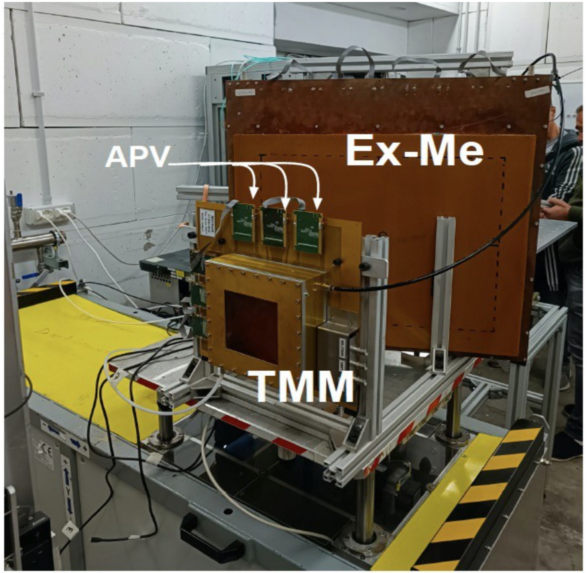
TMM 5cm drift gap 10x10cm^2 + ExMeMM 5cm drift gap (40x50 cm^2)

- Ar:CF4:Iso (88:10:2)
- Ex-Me chamber tilted by 22°
- Very narrow O(mm) positron beam
- Electronics: APV
- HV settings (nominal):

  TMM Amp: 460 V, Drift: 3 kV

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





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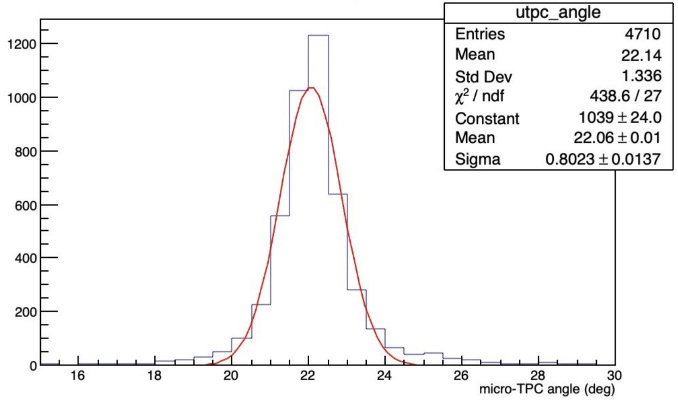
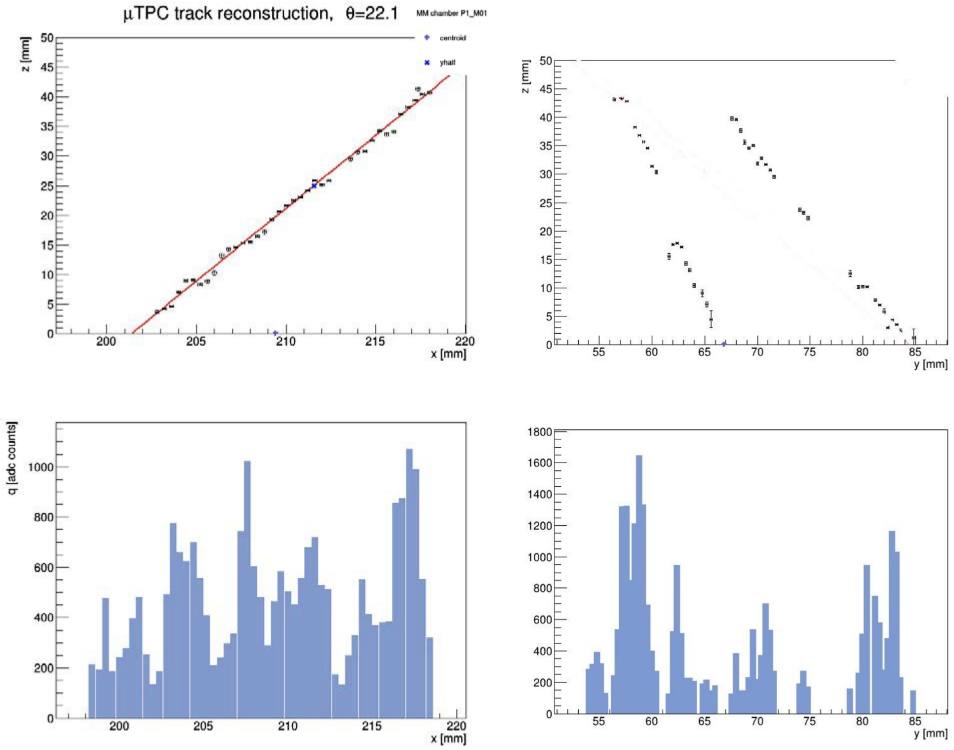
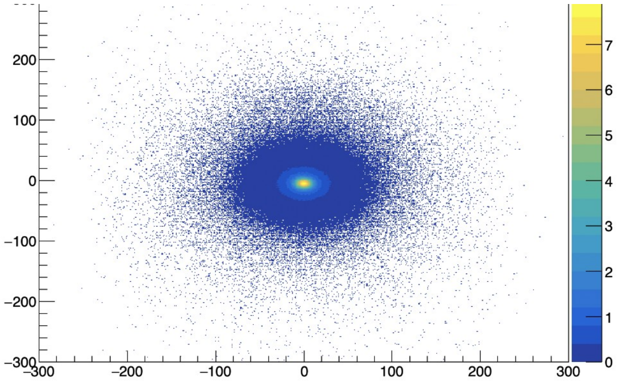


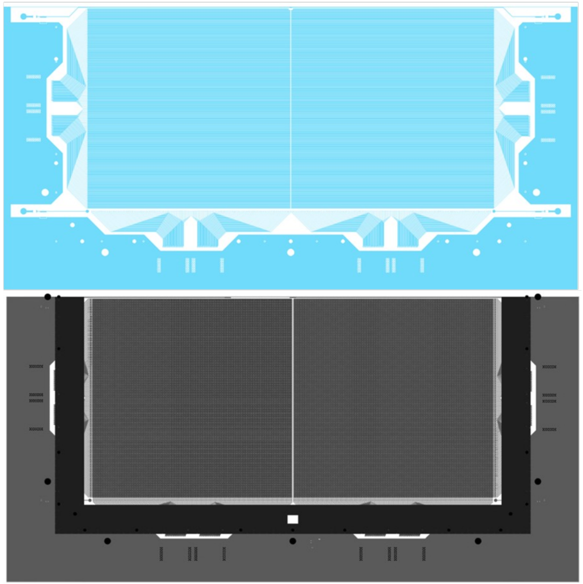


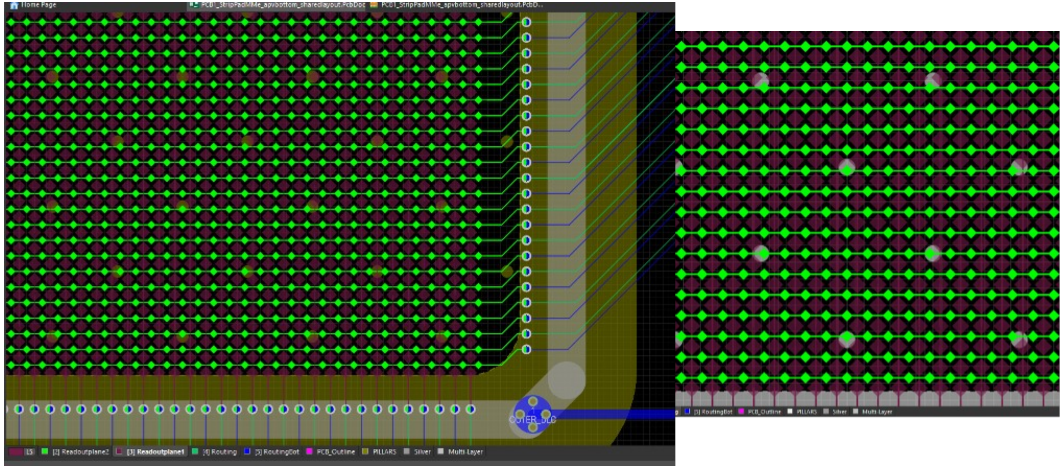
The Micromegas detector for PADME

PadMMe detector:

- 3 HV sections following expected occupancy
- Resistive DLC (diamond-carbon-like) layer
- 2 detectors with different RO electrodes design under construction
  - Diamond-like interconnected pads with pitch of 1.1 mm
  - ‘Standard’ 2D strip readout with pitch of 1.1 mm (spare/back-up)







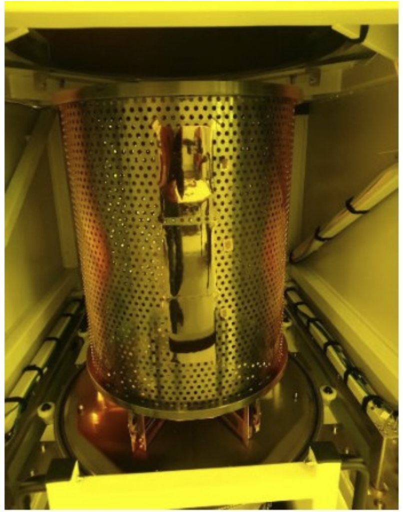
The CERN-INFN Sputtering machine

The **CID** (CERN-INFN-DLC) sputtering machine, a **joint project between CERN and INFN**, is used for preparing the **base material of the detector**. The potential of the DLC sputtering machine is:

- **Flexible substrates** up to **1.7×0.6m²**
- **Rigid substrates** up to **0.2×0.6m²**

In **2023,** the activity on CID focused on the **tuning** of the **machine on small foils: good** results in terms of **reproducibility and uniformity.**

In **2024**, the challenge is the **sputtering of large foils:**

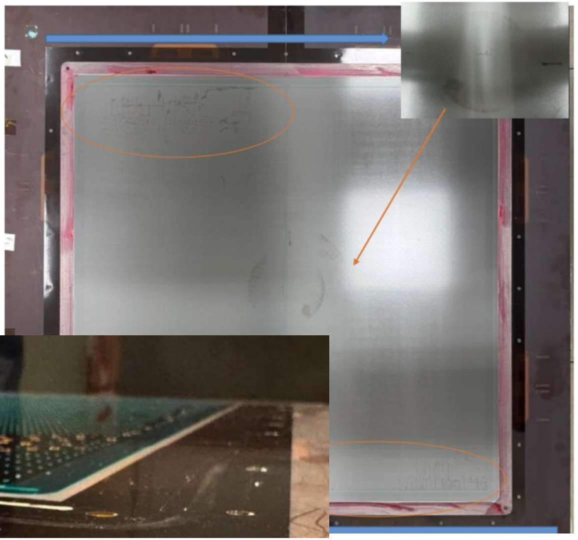


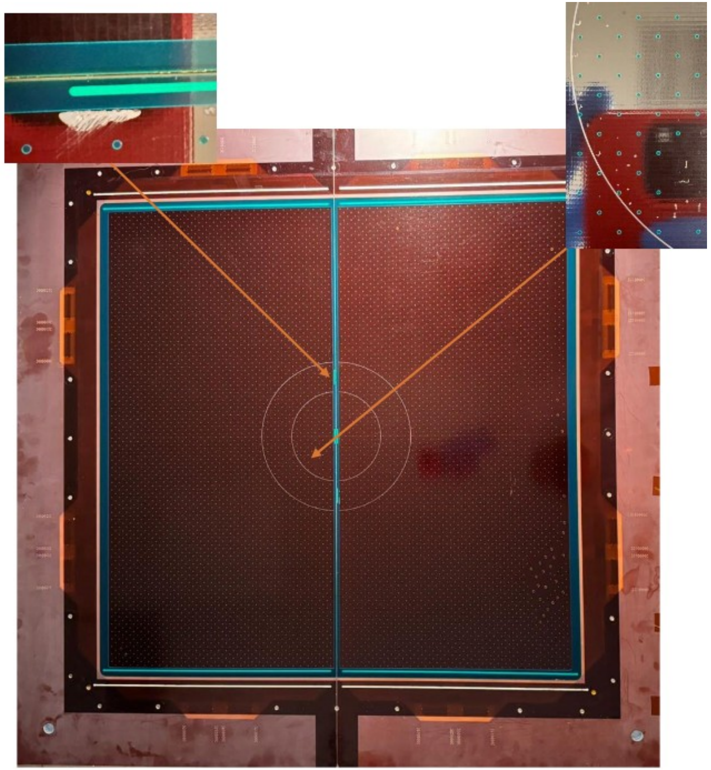
The Micromegas detector for PADME

PadMMe detector status:

- All material procured in 2024
- DLC produced in-house at CERN (CERN-INFN machine)
- PCB produced at ELTOS
- Micro-mesh 18/45 um pre-stretched on frame
- First detector (strip-type) assembled at LNF in November

New material used for pillar creation showed adhesion issues. Boards back to CERN for repair

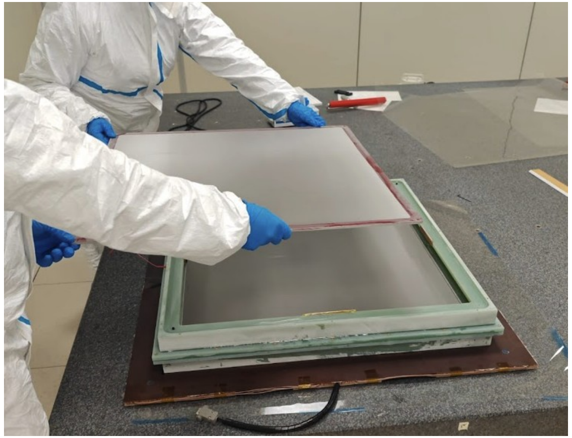


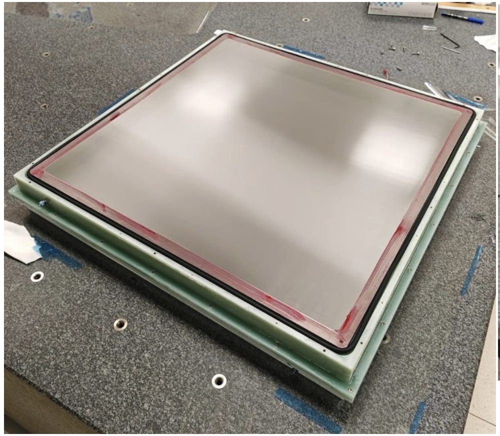


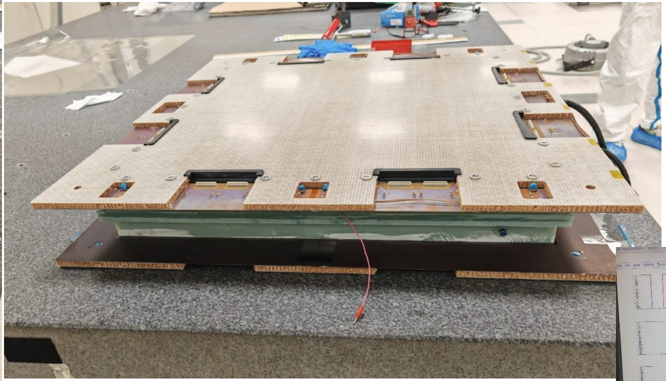
The Micromegas detector for PADME

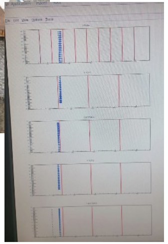
PadMMe detector status:

- All material procured in 2024
- DLC produced in-house at CERN (CERN-INFN machine)
- PCB produced at ELTOS
- Micro-mesh 18/45 um pre-stretched on frame
- Second detector (diamond-type) assembled and under preliminaty tests at LNF









Conclusions and outlook

- The search for X17 is still a relevant matter in DM searches
- PADME Run-III analysis close to unblinding
- Run-VI in preparation with Micromegas tracker
- Two detectors (1 main + 1 back-up) built and under evaluation; some issues during construction being addressed
- Relevant contribution of the (tiny) Napoli group in the Micromegas construction and operation
  - Detector design
  - Production follow-up and QC
  - Development and optimisation of VMM-based DAQ

Thank you