PADME results on X17 searches

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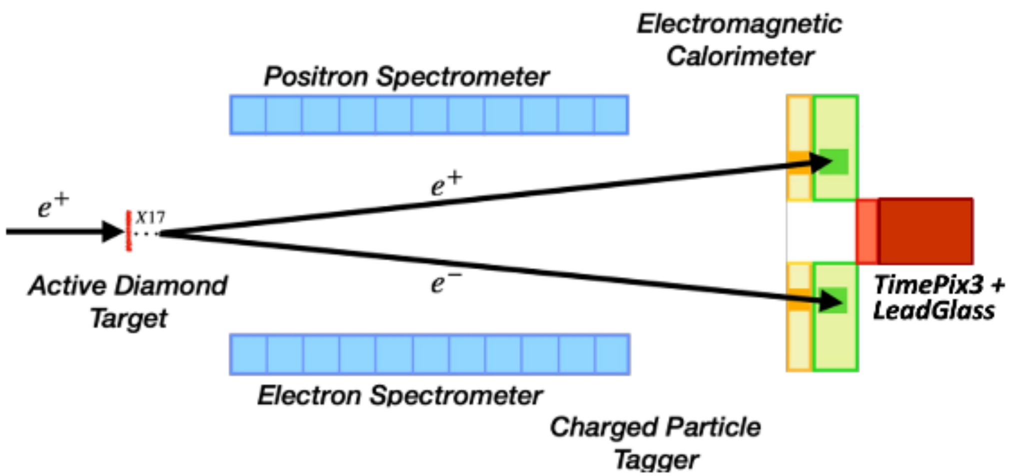
Run III setup

2022 Run-III setup adapted for the X17 search:

- **Active target, polycrystalline diamond**
- **No magnetic field**
- **Charged-veto detectors <u>not used</u>**
- **ECal: 616 BGO crystals, each 21x21x230 mm^3**
- **Newly built hodoscope in front of Ecal for e/γ**
- **Timepix silicon-based detector for beam spot**
- **Lead-glass beam catcher (NA62 LAV spare block)**

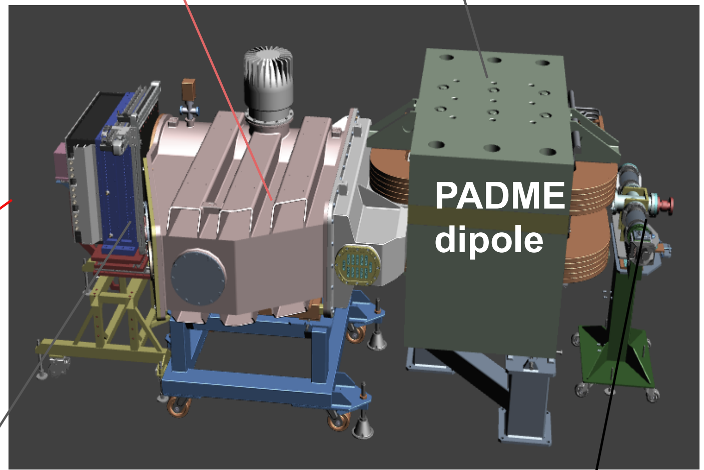


Charged particle detectors in vacuum

Vacuum tank, 10^{-6} – 10^{-7} mbar

Lead glass

Timepix



Electromagnetic calorimeter

Diamond target

Run-III concepts: the observable

At PADME, search for a resonance with e^+ annihilation in diamond target:

- Scan around $E(e^+) \sim 283$ MeV
- Beam-energy spread ~0.25%, $\delta E(e^+) \sim 0.7$ 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

$g_R(s) = N_2(s)/[\, N_{POT}(s) \times B(s)\,]$ kept blind in the analysis

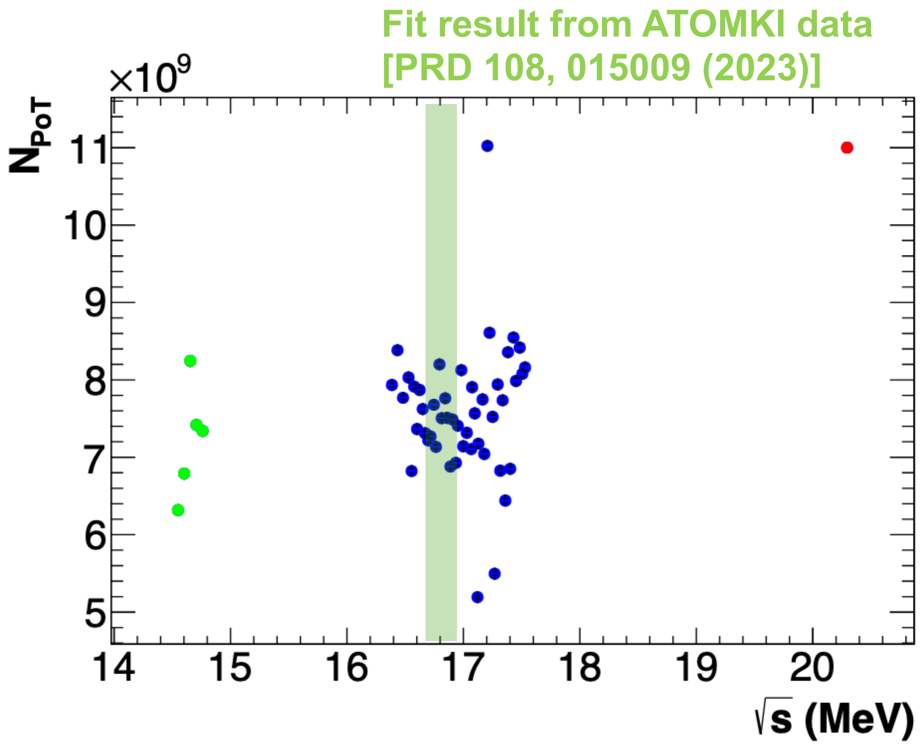
Run-III concepts: the data set

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

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

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

Below resonance points
Beam energy steps ~1.5 MeV
Statistics ~ 0.8 x 10^{10} POT per point
Used to cross-check the flux scale



Run III beam performance:
JHEP 08 (2024) 121

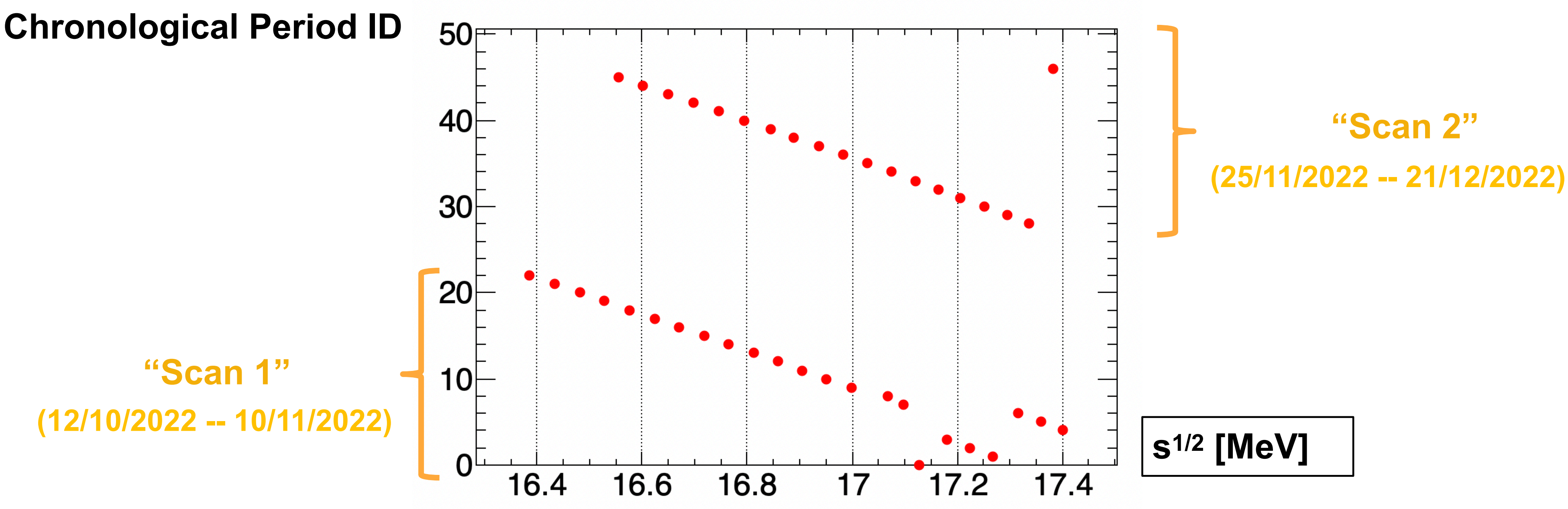
Run-III concepts: redundancy

"Run": DAQ for ~8 hours, determine beam avg position/angle, ECal energy scale

"Period": a point at a fixed beam energy, typically lasts 24 hours

"Scan" a chronological set of periods typically decreasing in energy

Scan 1 and 2 periods spaced ~ 1.5 MeV but <u>interspersed in energy</u>

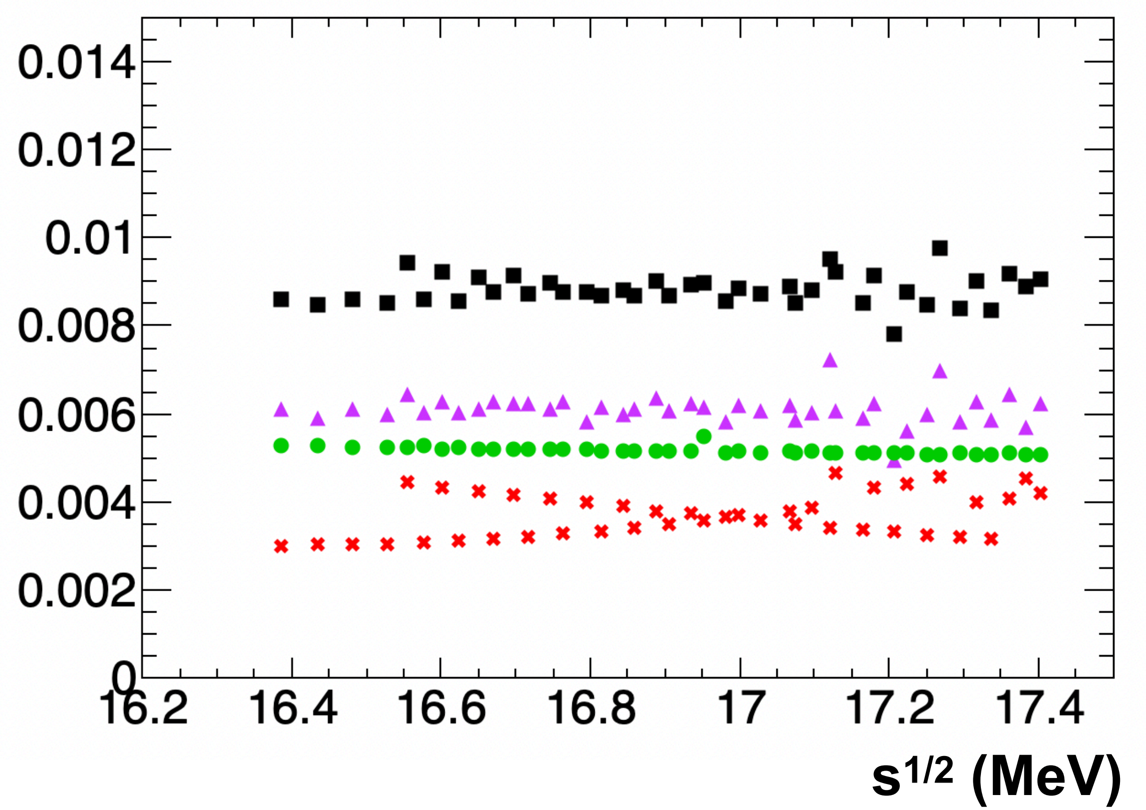


Detailed GEANT4-based MC performed for each period

Run-III result, gR error budget

Uncorrelated uncertainty on $g_R(s) = N_2(s) / (N_{POT}(s)\ B(s))$:

Relative uncorrelated error per period



Uncorrelated errors

Source	Uncertainty (% per energy point)
$N_2(s)$	0.60
$B(s)$	0.54
$N_{\mathrm{PoT}}(s)$	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_{PoT}	0.5
Radiation-induced correction to N_{PoT}	0.3
Total	2.8

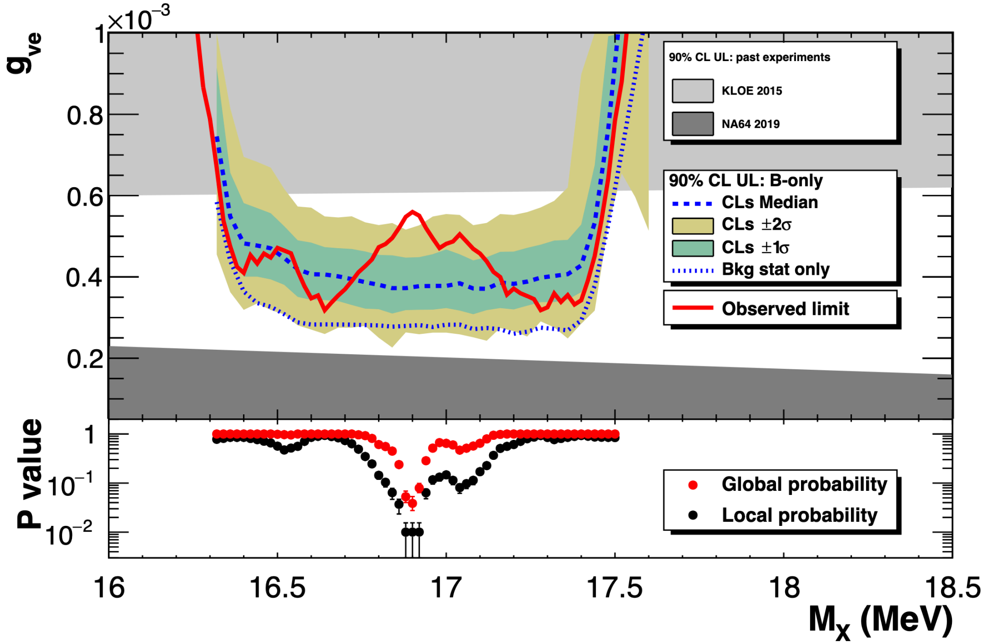
$K(s)$, $\sqrt{s}$-slope

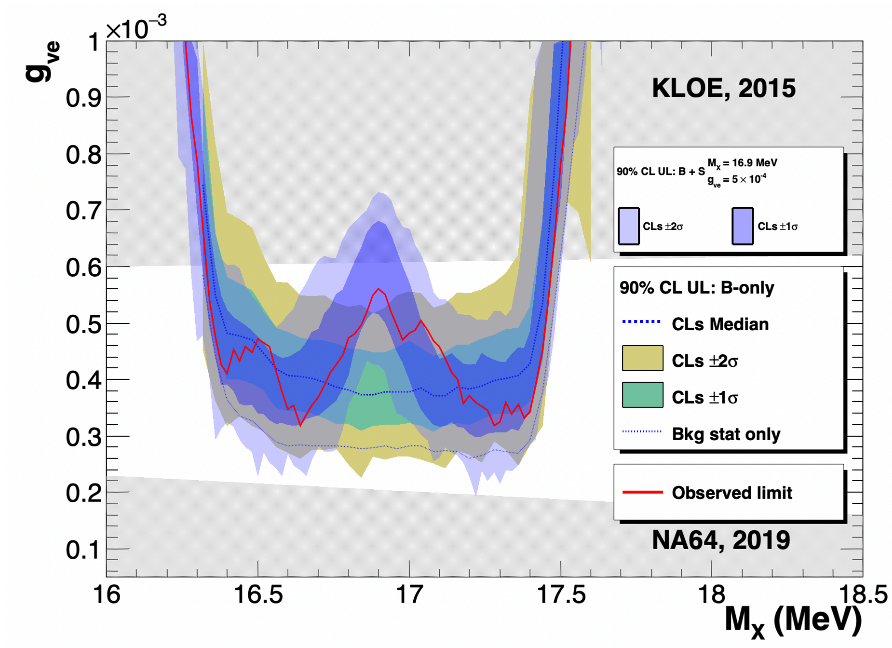
Source	Expected value (%/MeV)
Radiative corrections	$-0.6 \pm 0.2 \pm 0.6$
Total	-0.6 ± 0.6

Estimated errors validated still preserving blind-analysis concept: JHEP 06 (2025) 040

Run-III result

Search for a X17 with Run III data completed: arXiv:2505.24797, paper submitted



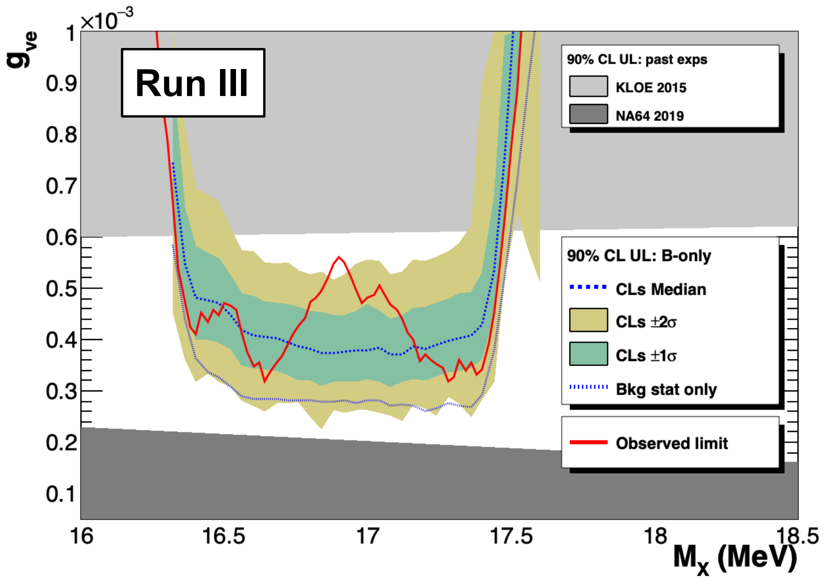


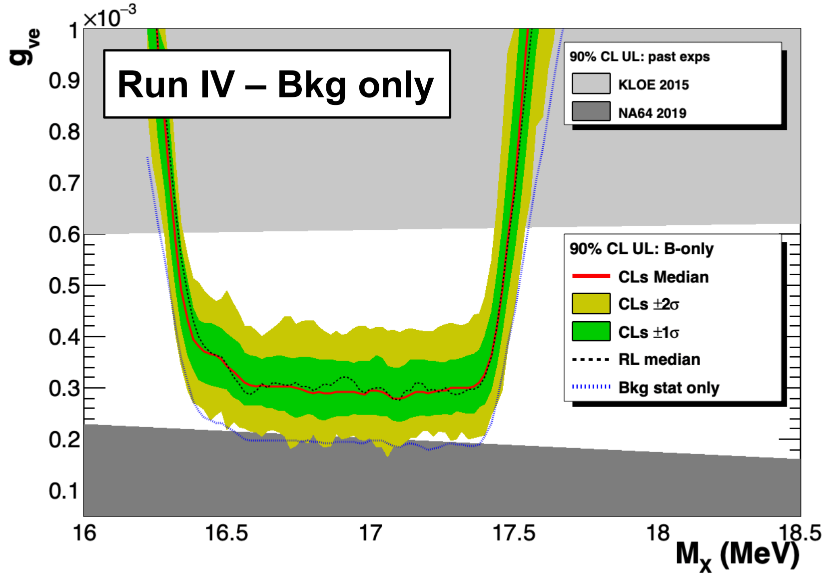
Excess observed, 2.5 σ local, 1.8(2) σ global significance

Just for comparison, check expected UL bands: bkg-only vs B+S(16.9 MeV, 5 × 10^{-4})

Run IV to clarify

See also the CERN EP seminar, https://indico.cern.ch/event/1553077/





Source	Uncertainty [%]		Note
	Run III	Run IV	
N_2	0.6	0.3	Uncorrelated
N_{PoT}	0.35	0.3	Uncorrelated
B	0.55	0.3	Uncorrelated
Total	0.89	0.5	Uncorrelated

Separately measure e^+e^- and $\gamma\gamma$ yield in Run IV

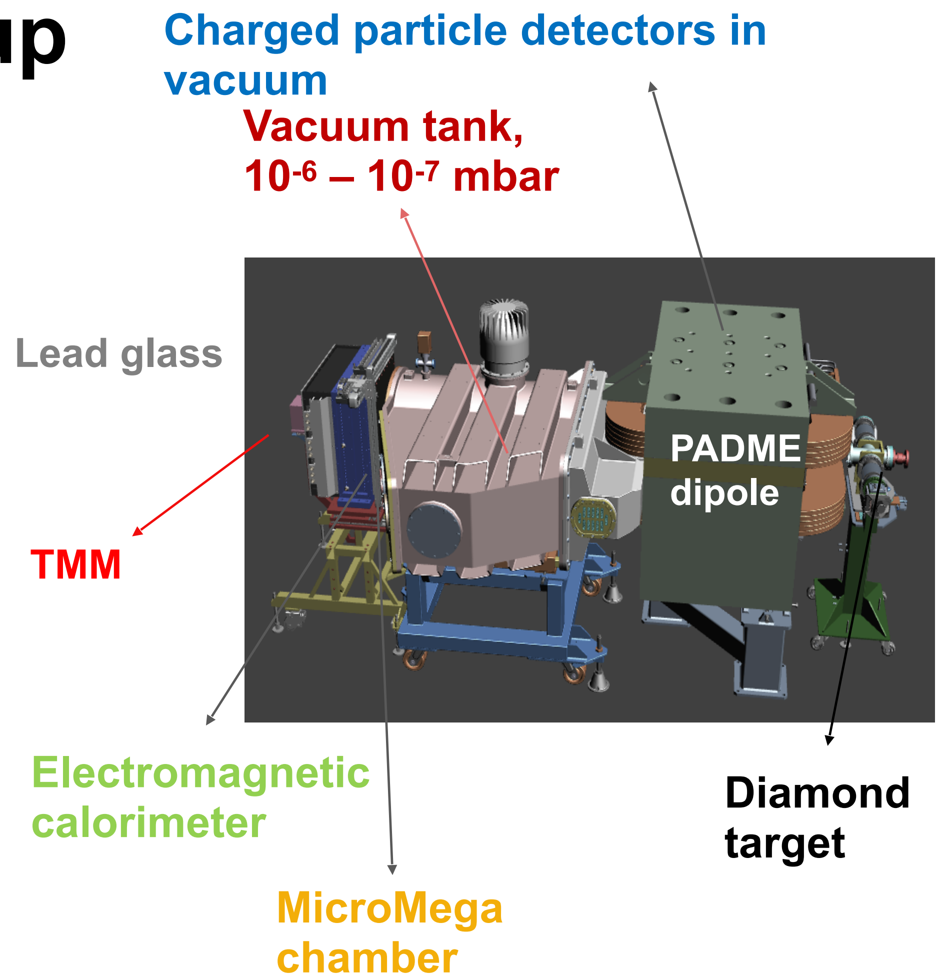
Presently taking data (Run IV, up to Nov 2025), goal of x4 in statistics with reduced systematics:

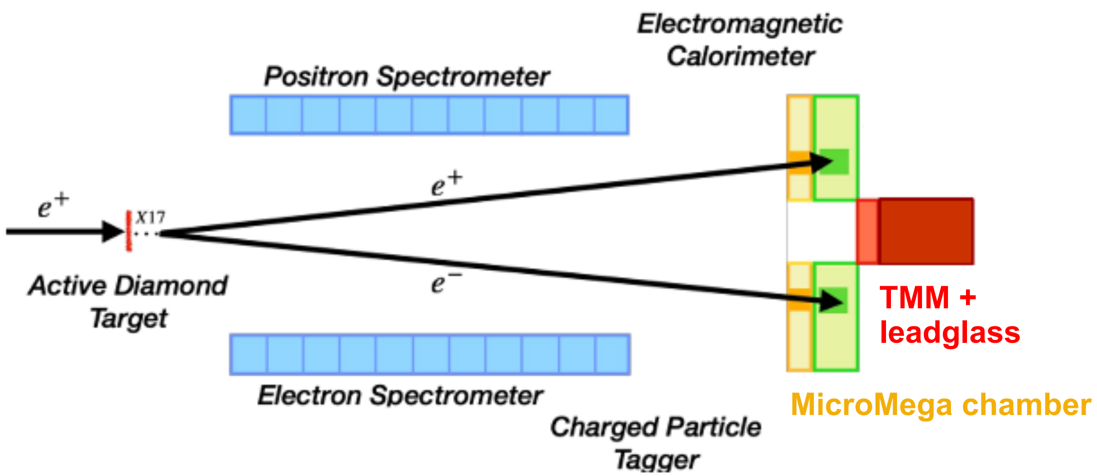
- Tuned position of target with respect to Ecal to improved acceptance
- New micromega-based chamber for e^+/e^- directions and e^+/e^- vs γ ID, installed Feb 2025
- New micromega-based chamber for beam spot monitoring in front of beam catcher, Apr 2025
- Improved monitoring of beam catcher response stability

Run IV setup

2022 Run-III setup adapted for the X17 search:

- **Active target moved downstream by 300 mm**
- **No magnetic field**
- **Charged-veto detectors not used**
- **ECal: 616 BGO crystals, each 21x21x230 mm^3**
- ~~Hodoscope~~ **MicroMega in front of ECal for e/γ**
- ~~Timepix~~ **Micromega TMM for beam spot**
- **Lead-glass beam catcher now LED monitored**

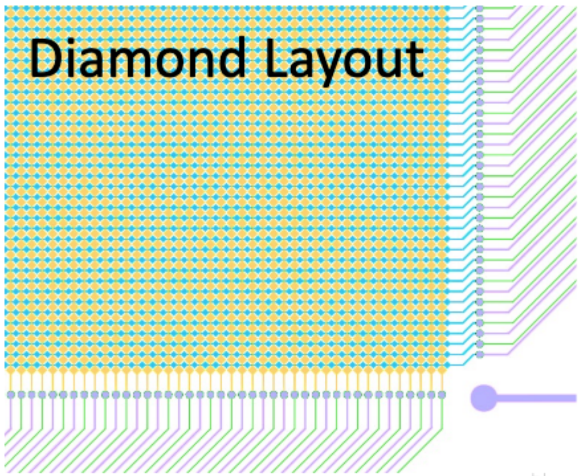


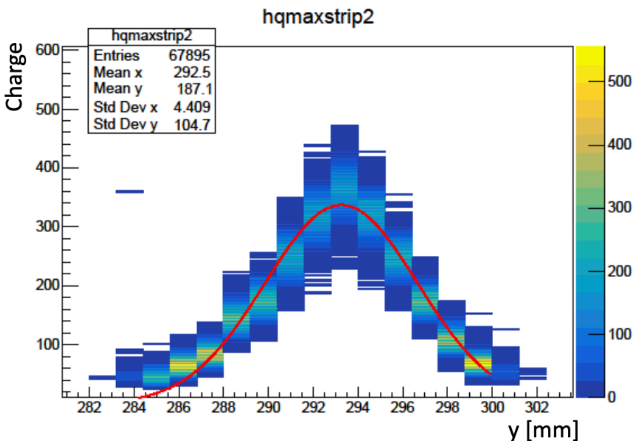


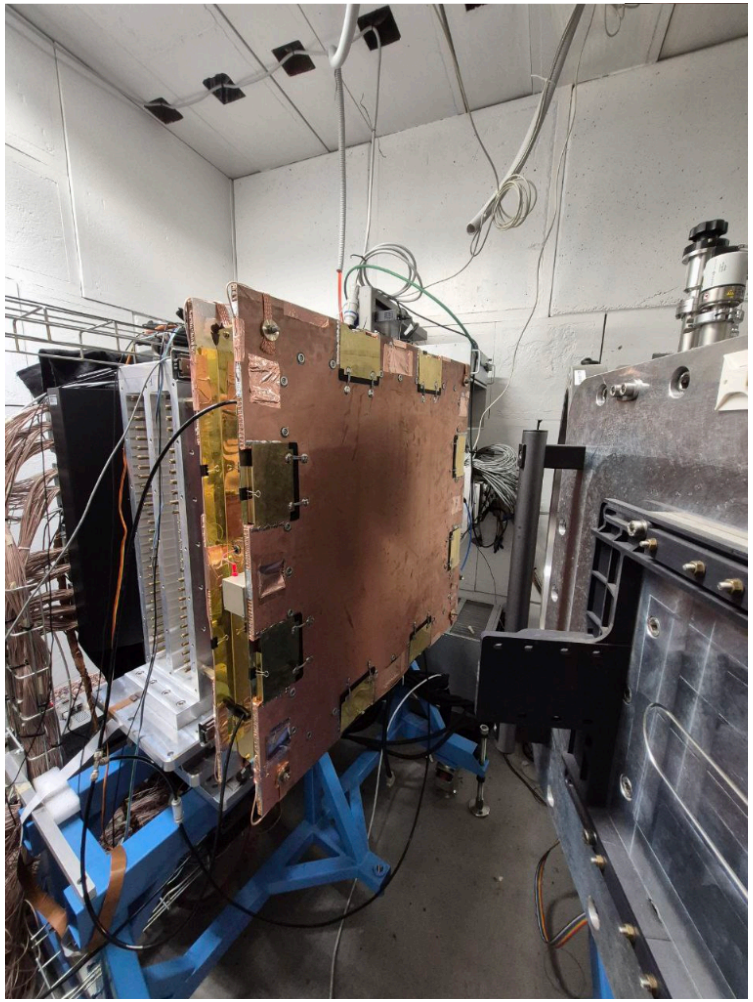
Micromega chamber in Run IV

Detector installed with the novel diamon-shaped readout

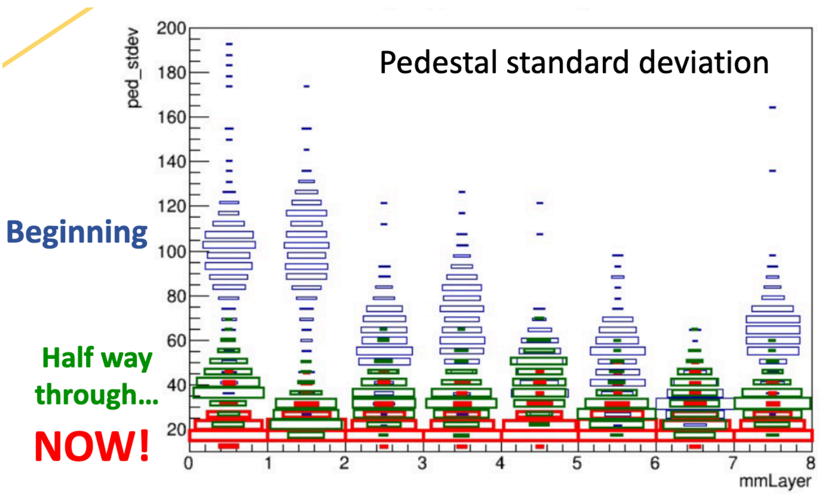
- Outer dimensions 88 x 88 cm^2
- Readout by APV25
- Time window up to 675 ns (drift time ~500 ns)
- Gas mixture: Ar:CF_4:Isobutane = 88:10:2
- Provides beam spot with uncertainty $\sigma_{x,y}$ ~ 30 μm
- Track points with $\sigma_{x,y}$ ~ 350 μm and σ_z ~ 2 mm per point







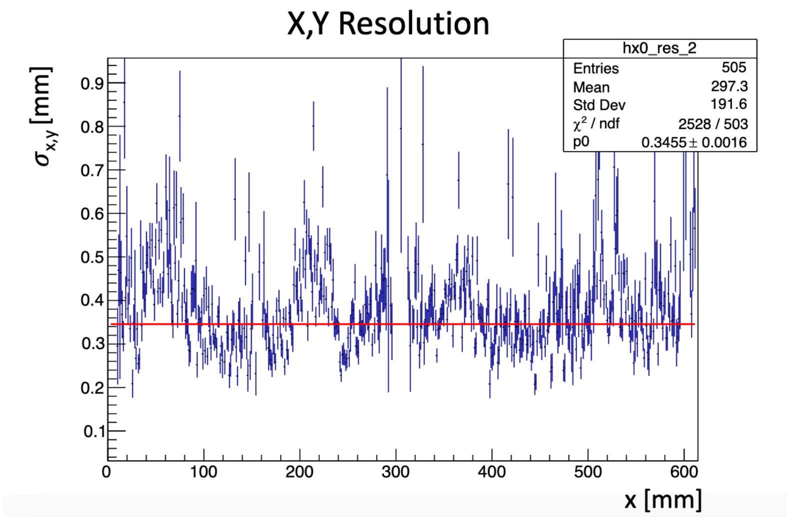
Micromega chamber in Run IV

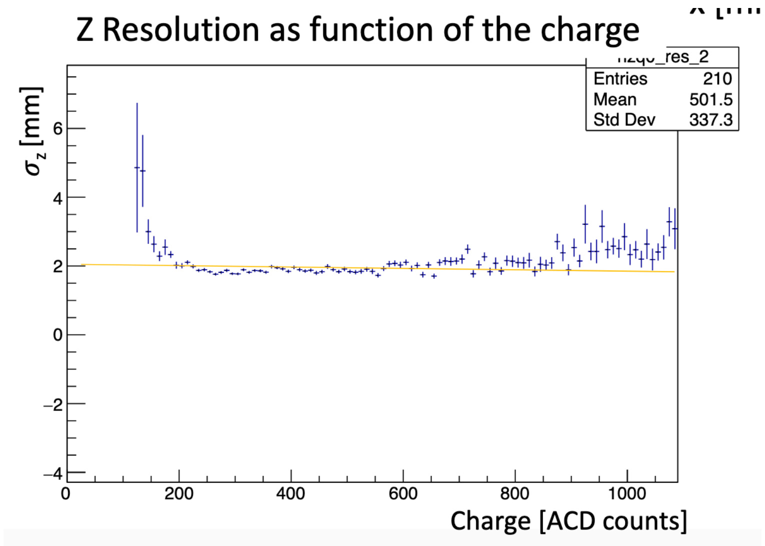


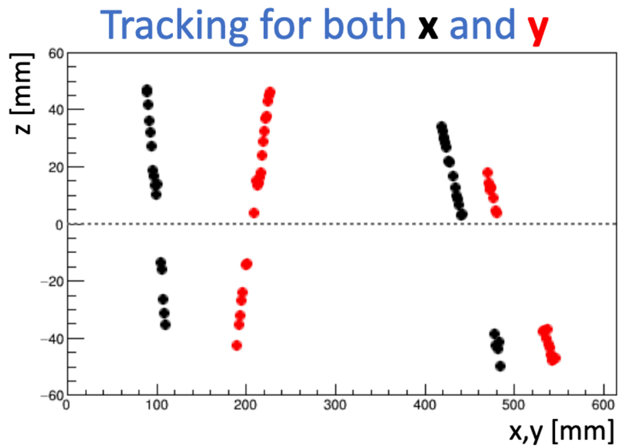
Commissioning using CR events:

- $\sigma_{x,y}$ ~ 350 μm, σ_z ~ 2 mm
- Hit efficiency > 90%

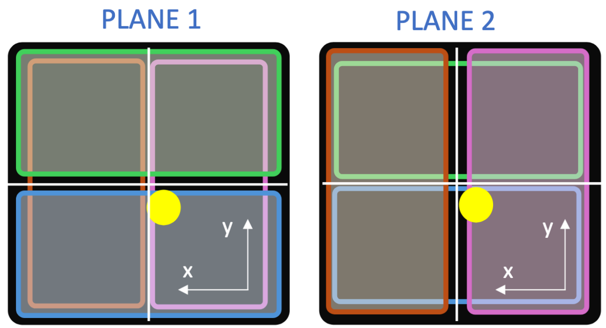
TPC mode works sarisfactorily







MM chamber in Run IV



Beam monitoring using beam events:

Beam Monitoring

- Charge vs Position

P1 position

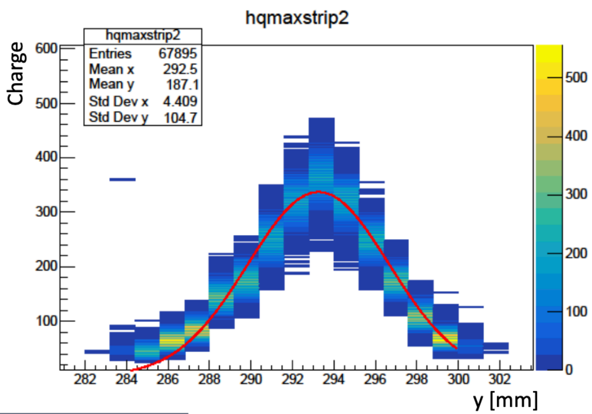
- X_{mean} = 293.26 ± 0.02 mm
- **σ_x = 3.41 ± 0.03 mm**
- y_{mean} = 332.25 ± 0.02 mm
- **σ_y = 3.43 ± 0.02 mm**

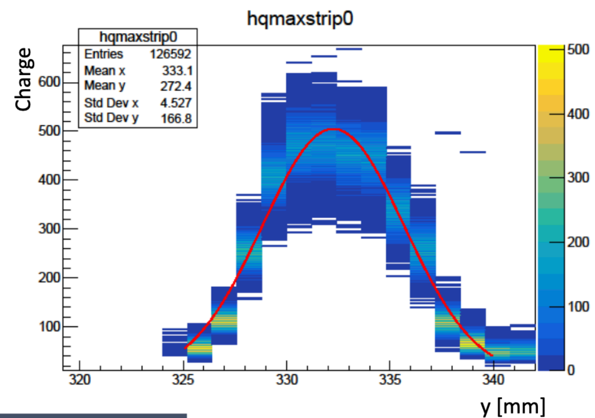
P2 position

- X_{mean} = 295.71 ± 0.04 mm
- **σ_x = 4.14 ± 0.05 mm**
- y_{mean} = 341.51 ± 0.03 mm
- **σ_y = 3.37 ± 0.04 mm**

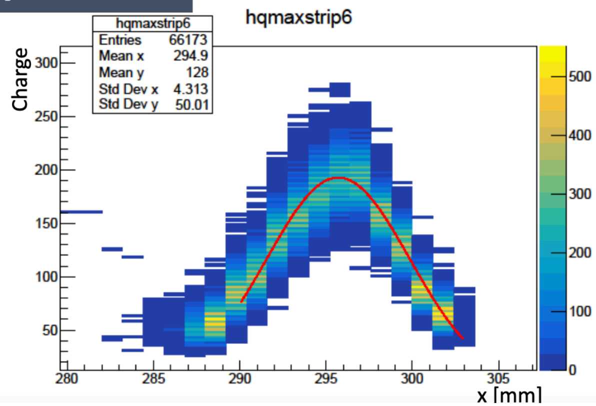
X position | **Y position**

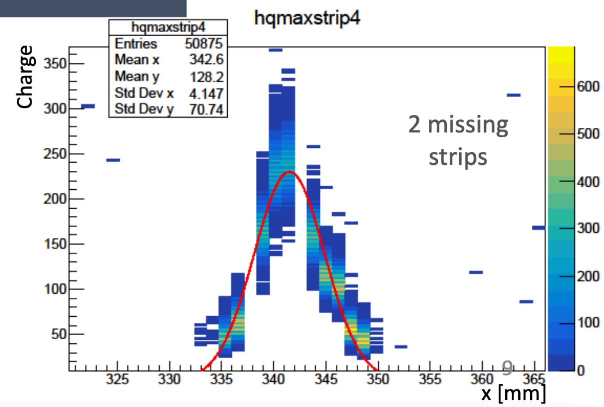
P1





P2



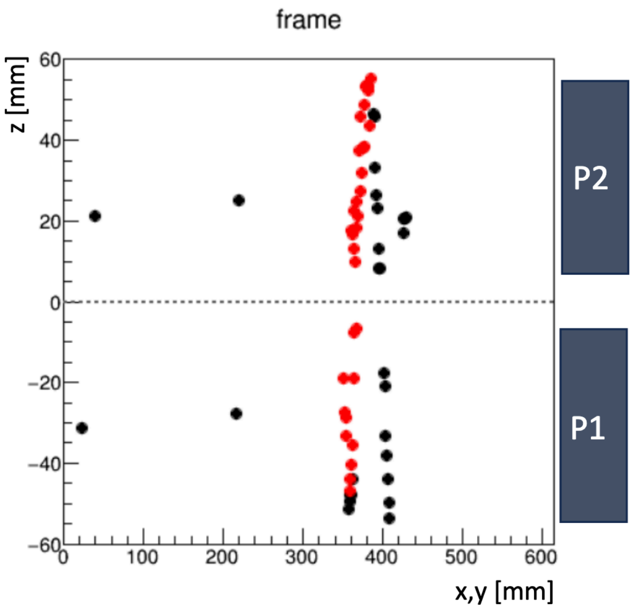


MM chamber in Run IV

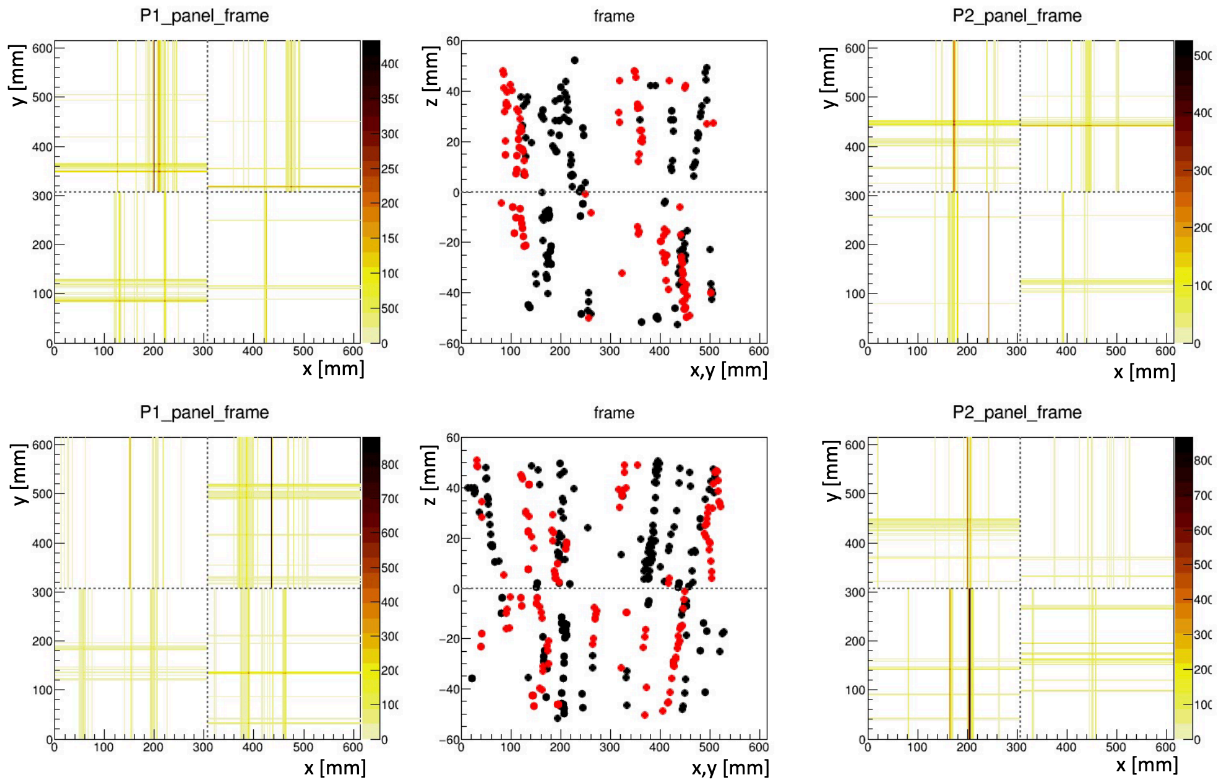
Tracking in beam conditions, occupancy as high as 50%
Working for a robust track reconstruction

Tracking

Single Particle run (no target)



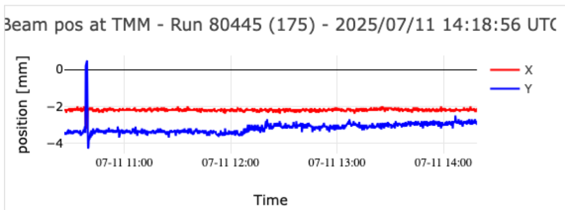
3000 Particles run (with target)

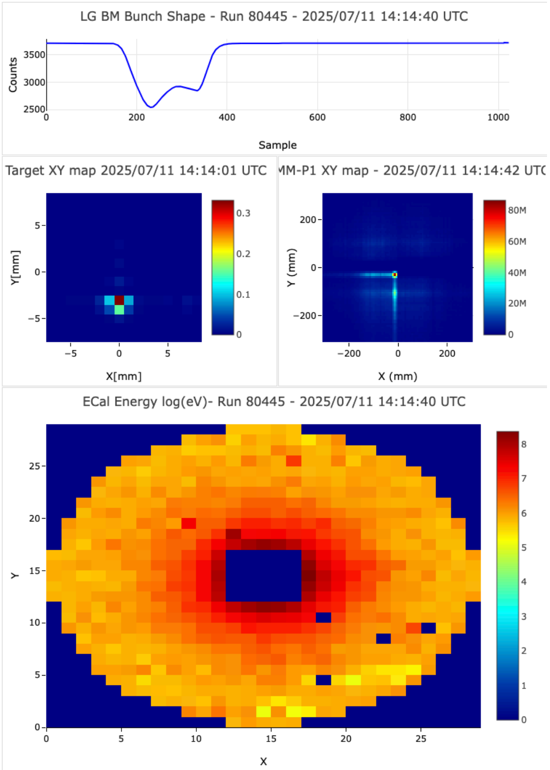


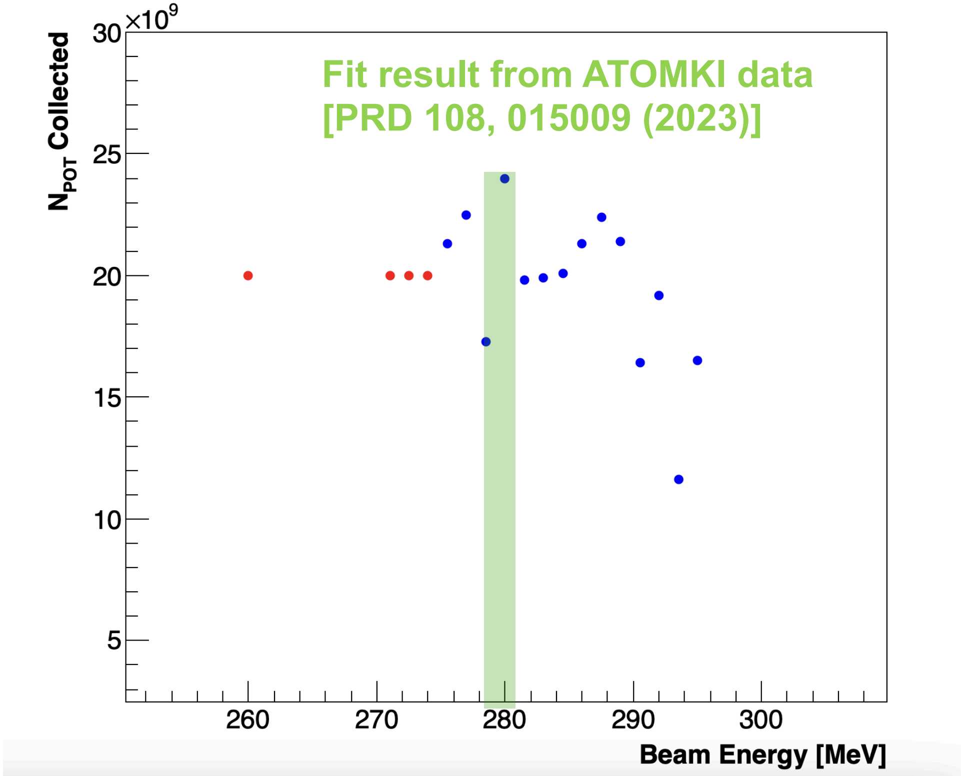
Overview of Run IV status

Online monitor info:

- **Beam spill vs time**
- **Beam spot @ target**
- **Beam spot @ micromega**
- **Beam halo @ calorimeter**
- **Beam spot @ TMM**







Conclusions

Analysis of Run III done in a blind way

"Blind unblinding" procedure published as a separate paper
Validation of total uncertainty at 0.9% per energy point
Result presented and made public on the arXiV, submitted to journal

Run IV planned to significantly improve sensitivity:

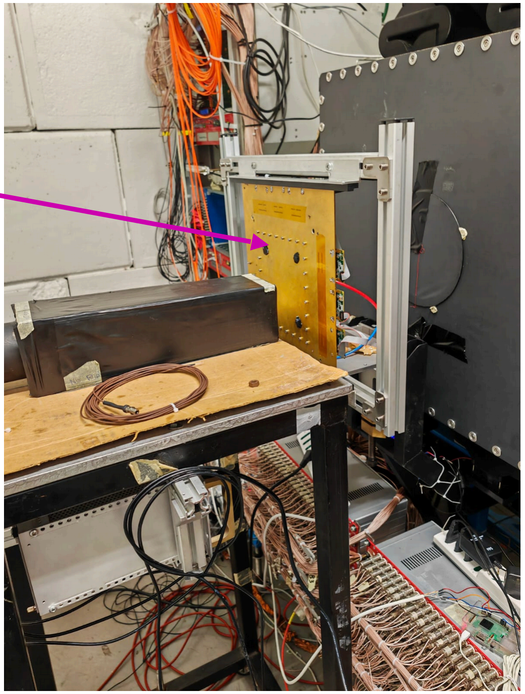
Detector upgraded with new micromega tracker + TMM end of line monitor
6 months of data taking

- Run IV-part 1 data already in the book: 18 energy scan points collected (~2e10 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

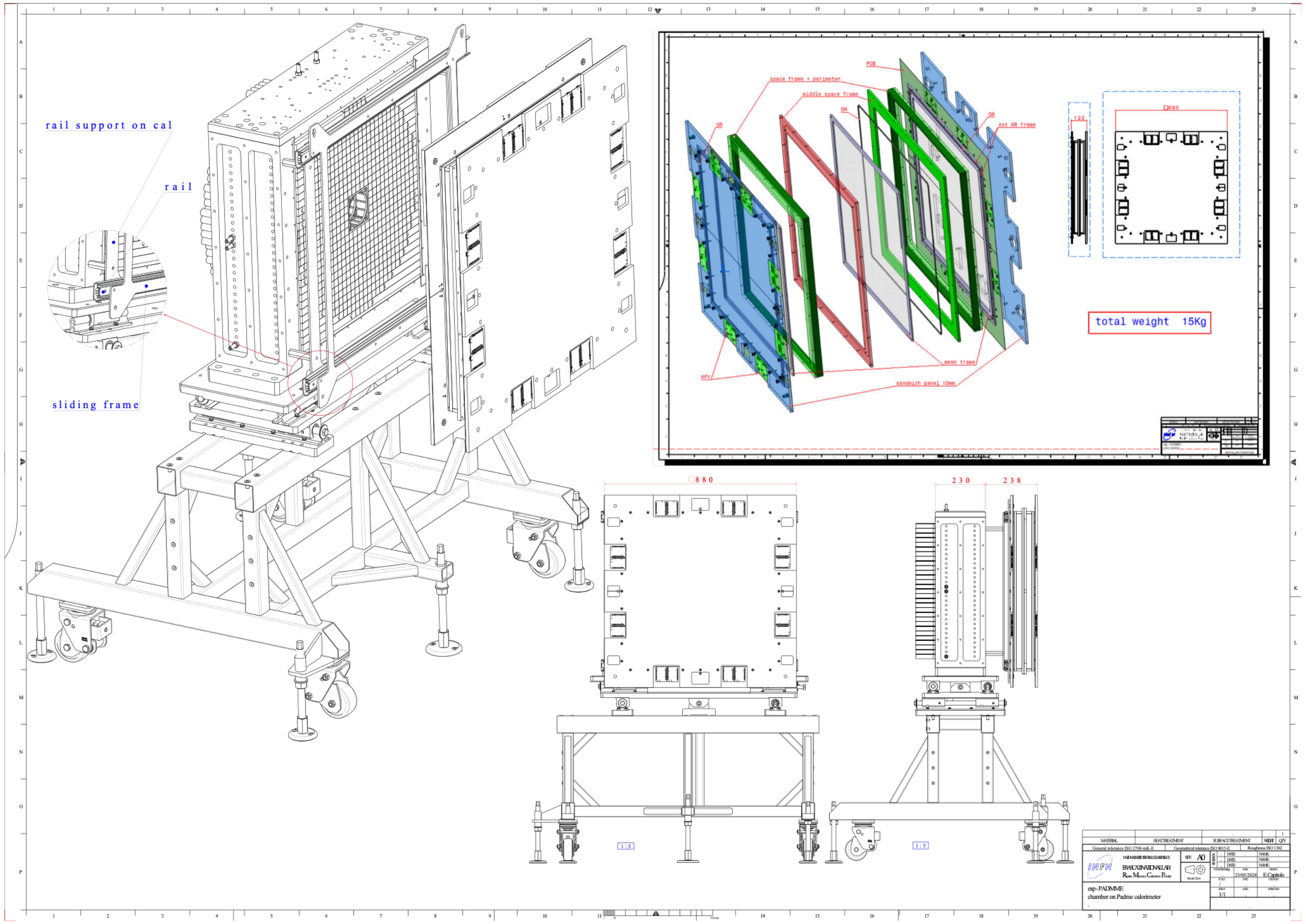
Status of the Run IV data taking - commissioning

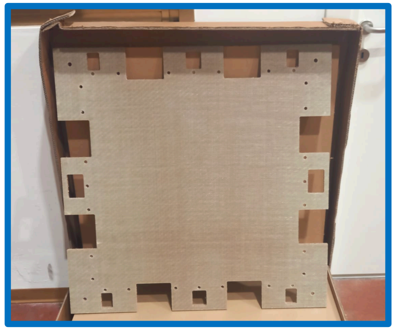
Commissioning bit longer than expected due to:

- **Problems with TimePix detector: albeit working perfectly up to Nov. 2024, internal trigger transmission problems appeared in Feb. 2025**
- **Problems with diamond target motor driver, replaced with a new Ethernet controller (bought by Sofia U.)**
- **TimePix sent to Advacam (Prague) for repair, waiting for cost estimate**
- **TimePix replaced with a 10 x 10 cm^2 active-area MM chamber: so-called TMM**

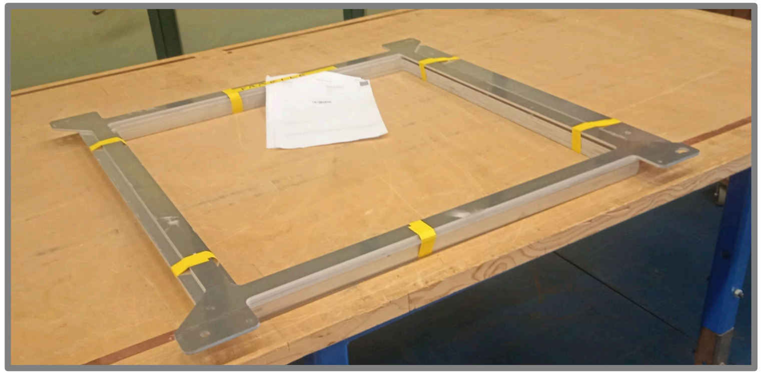


The design of the micromega chamber





Pannelli sandwich
Mesh frame
Space frame
Middle space frame
PCB



Installed and precisely aligned at the beginning of Run IV