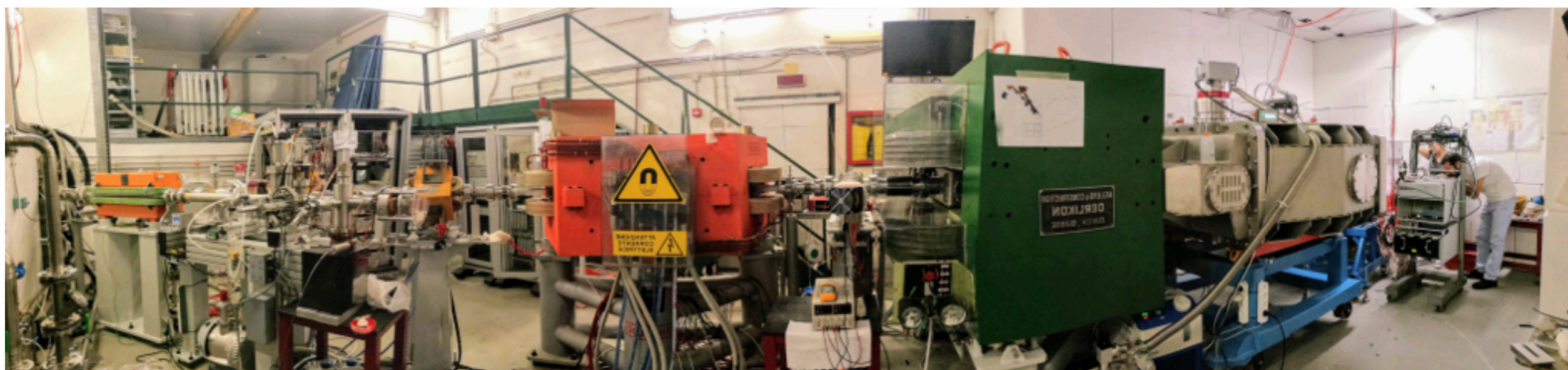


SEARCHING FOR DARK MATTER WITH THE PADME EXPERIMENT

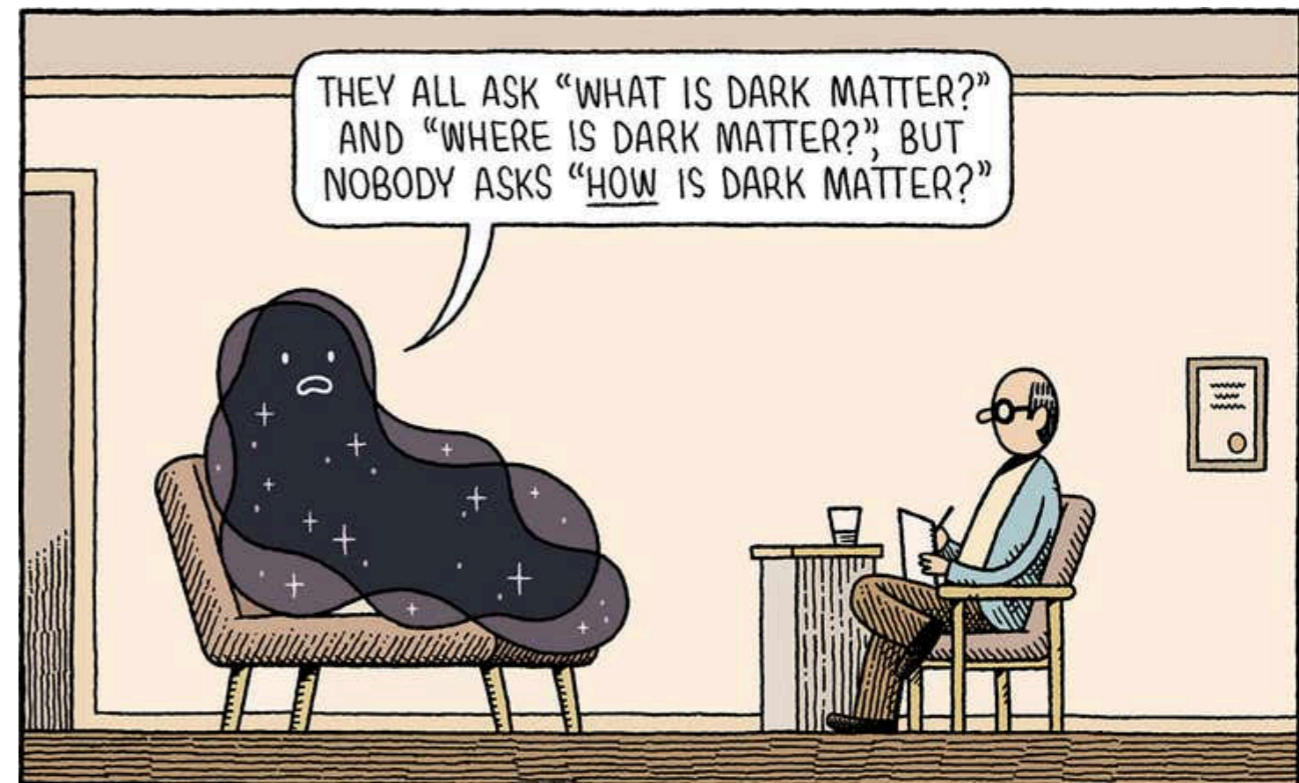
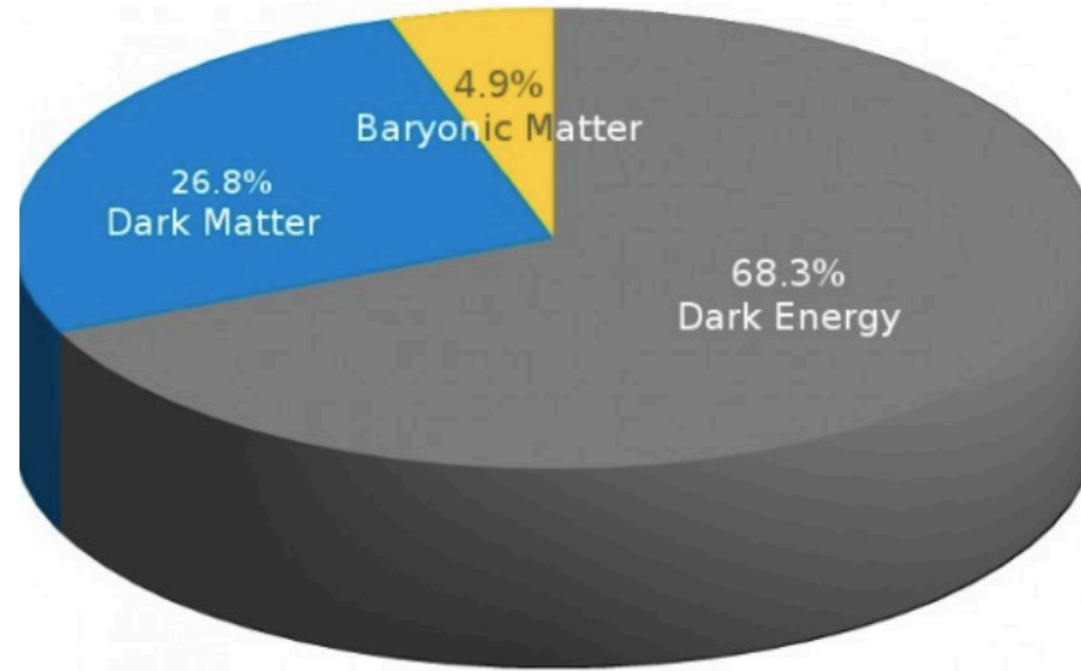
I.Oceano on behalf of PADME collaboration

International Conference on Topics in Astroparticle and Underground Physics



DARK MATTER EVIDENCES

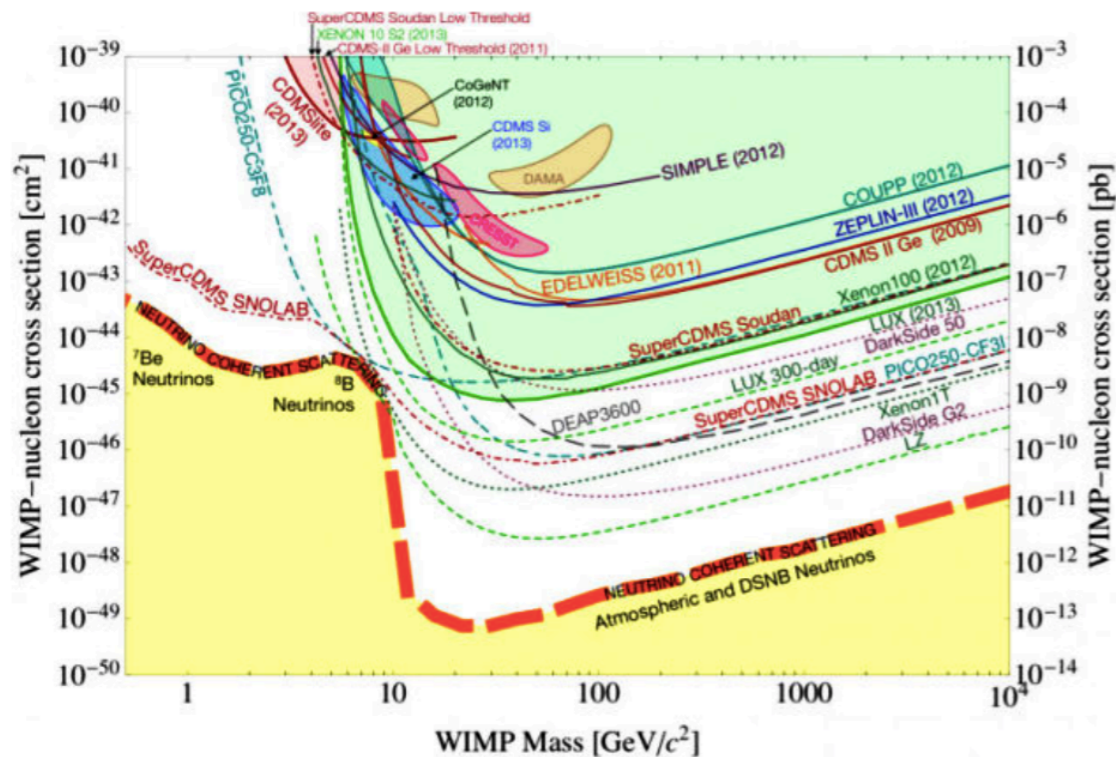
- Galactic rotation curves
- Galaxy clusters & GR lensing
- Bullet Cluster
- Velocity dispersions of galaxies
- Cosmic Microwave Background
- Baryon Acoustic Oscillations
- Type Ia supernovae distance measurements
- Big Bang Nucleosynthesis (BBN)
- Structure formation
- ...



A NEW GAUGE BOSON

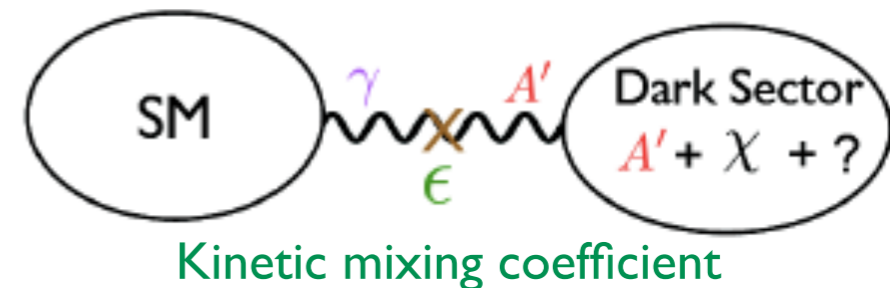


- Candidates challenged by LHC and direct detection experiments



- Introduction of a new Gauge symmetry $U_D(1)$

- New massive Gauge Boson A' : dark photon
- Weak interaction with SM throughout ϵ



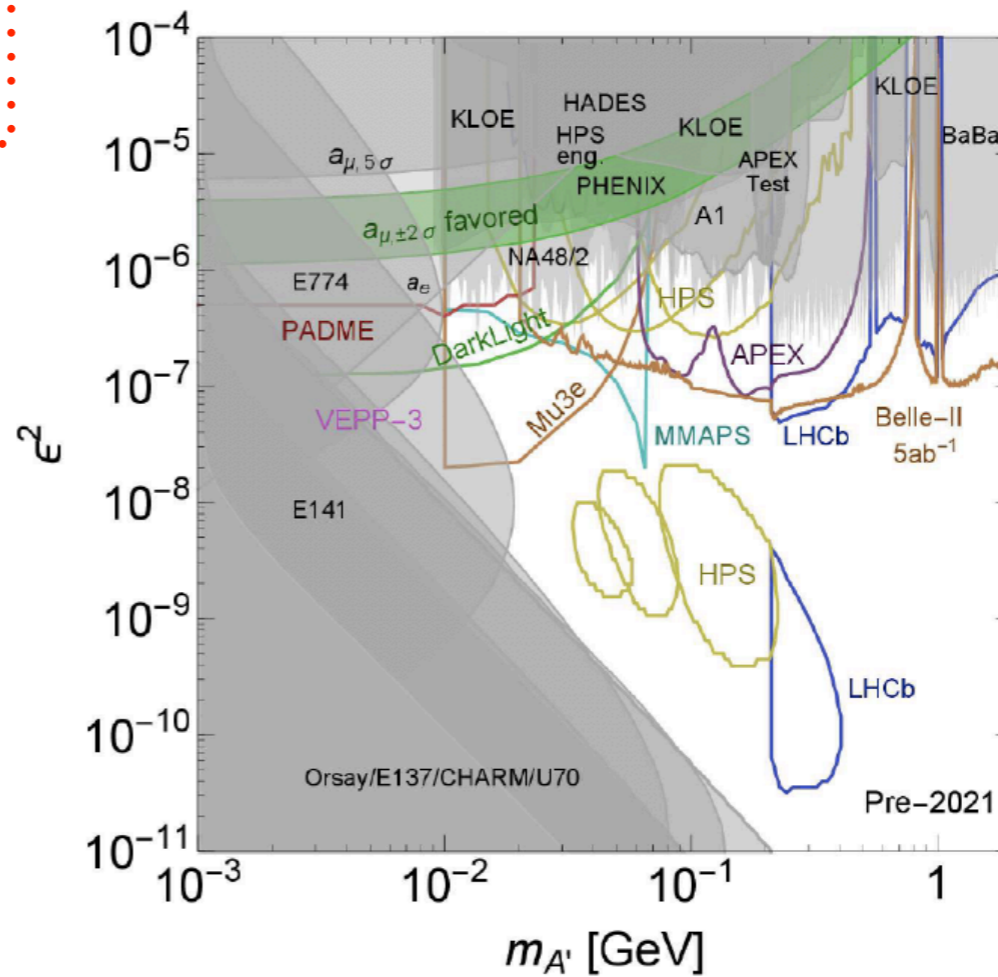
Decays

- To SM model particles if $M_{DM} > M_{A'} > 2m_e$
- To DM (invisible) particles if $2M_{DM} < M_{A'}$

A' search



- visible decay
- invisible decay



Model parameters

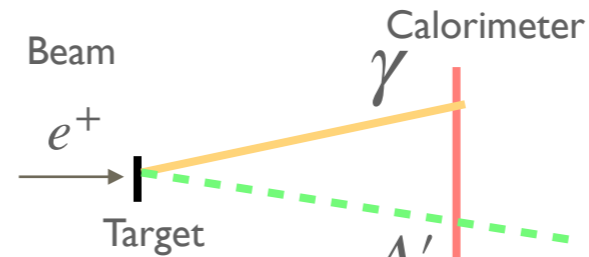
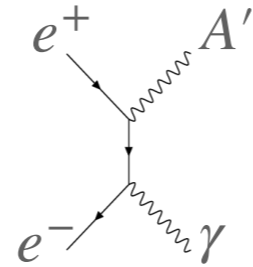
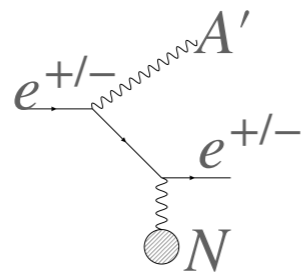
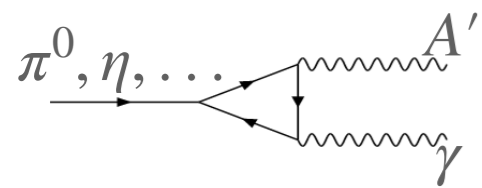
- ϵ
- $M_{A'}$

PADME DARK PHOTON SEARCH

Meson decay

Bremsstrahlung

Annihilation



$$e^+e^- \rightarrow \gamma A'$$

$$\sigma(e^+e^- \rightarrow A'\gamma) \sim \text{tens of nb}$$

$$M_{A'} = 10 \text{ MeV}$$

$$\epsilon^2 \simeq 10^{-6}$$

A' production mechanism

Annihilation

A' decay

Invisible

Technique

Missing mass

Beam energy

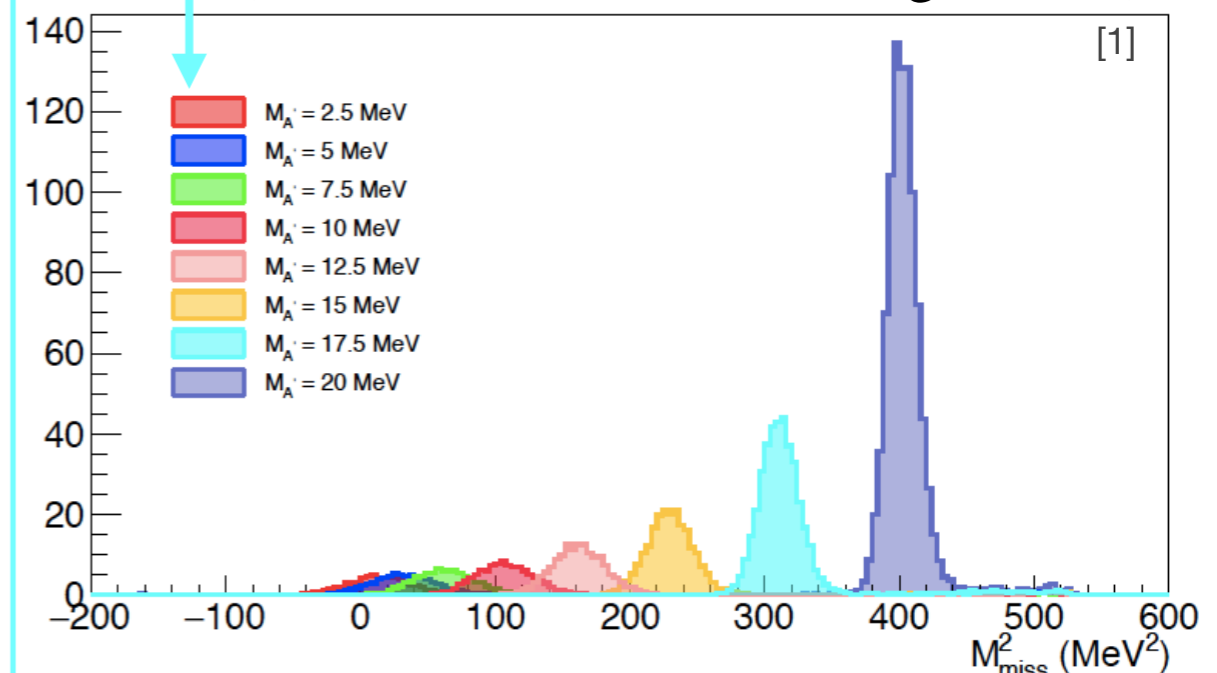
550 MeV

A' mass reach

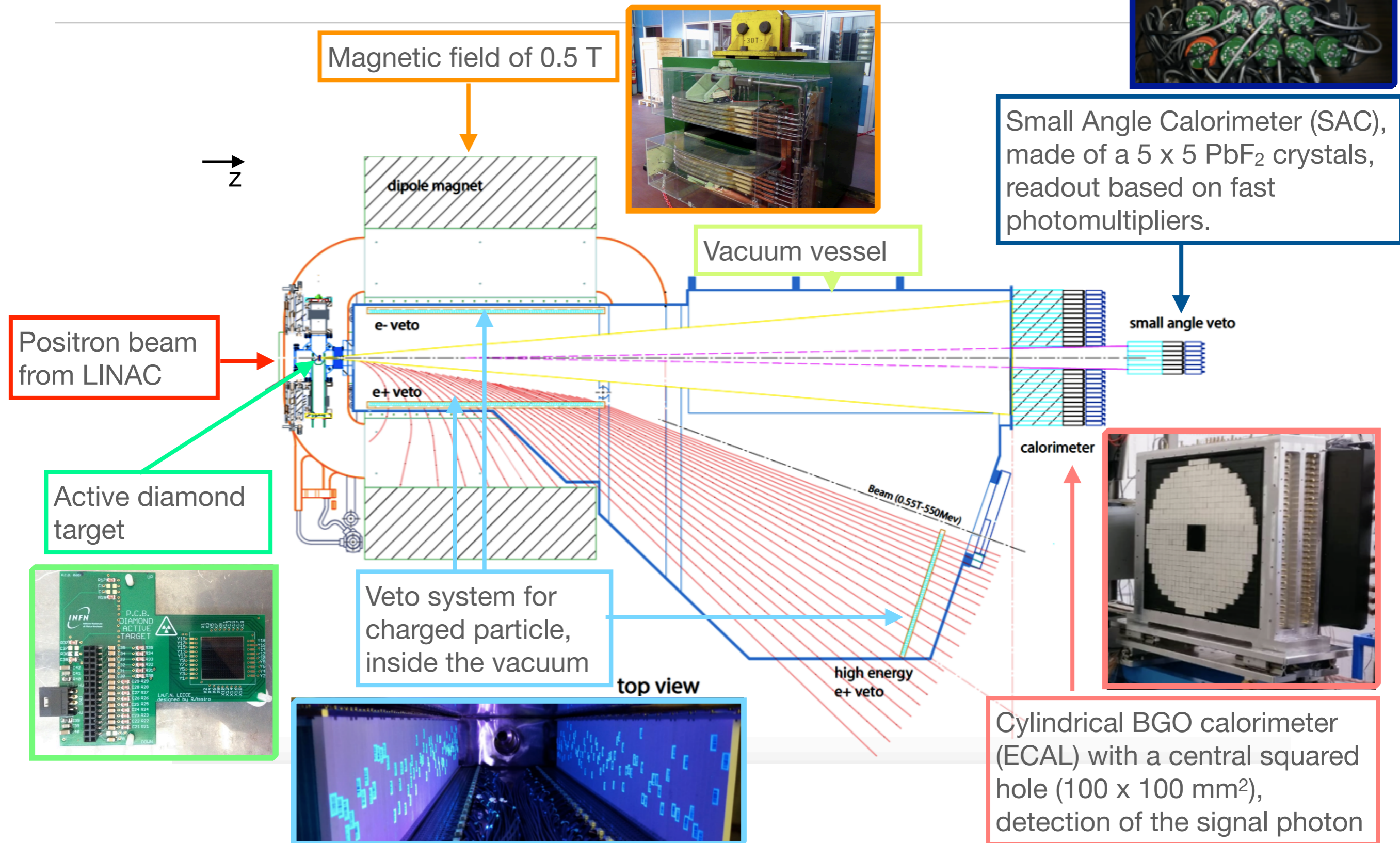
23.7 MeV

$$M_{miss}^2 = (p_{e^-} + p_{beam} - p_{\gamma})^2$$

(4×10^{13} Positron On Target POT)



PADME EXPERIMENT



SIGNATURES

- **Signal**

- One photon in ECAL

- SM backgrounds

- **Bremsstrahlung**

- One photon in ECAL + one positron in PVeto
 - If $E_\gamma > 1$ MeV and $E_{beam} = 550$ MeV, $\sigma(e^+N \rightarrow e^+N\gamma) = 4000$ mb

- **Annihilation**

- $e^+e^- \rightarrow \gamma\gamma$

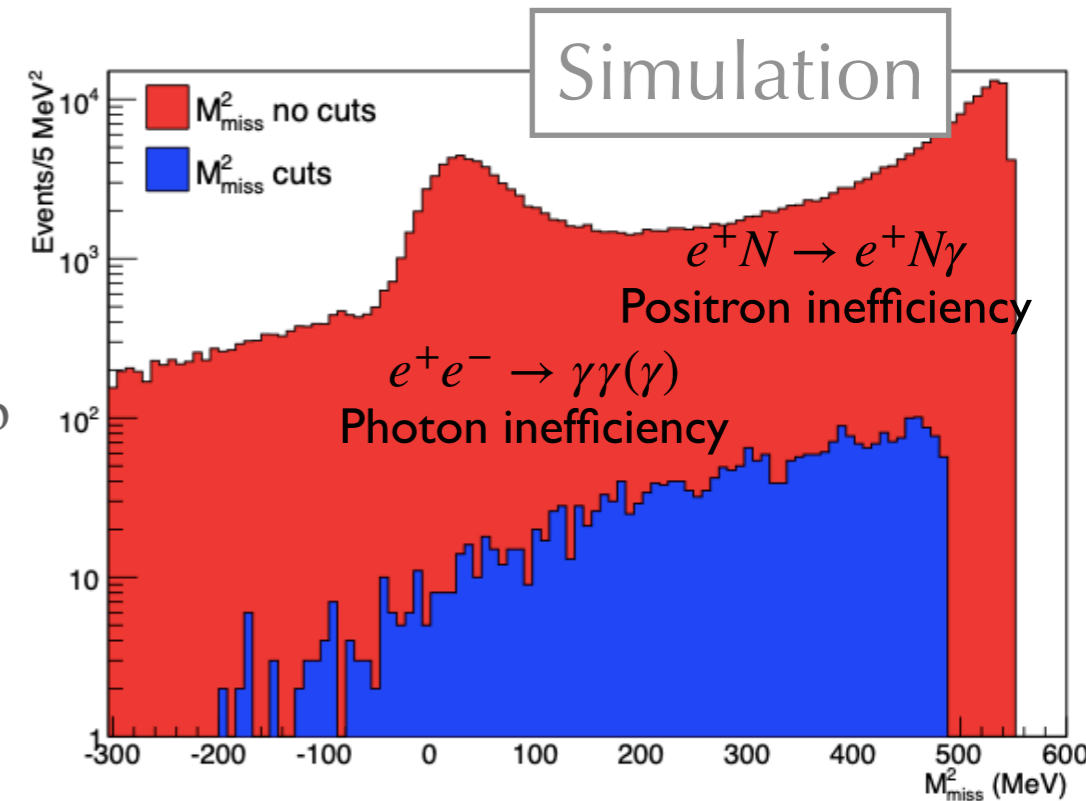
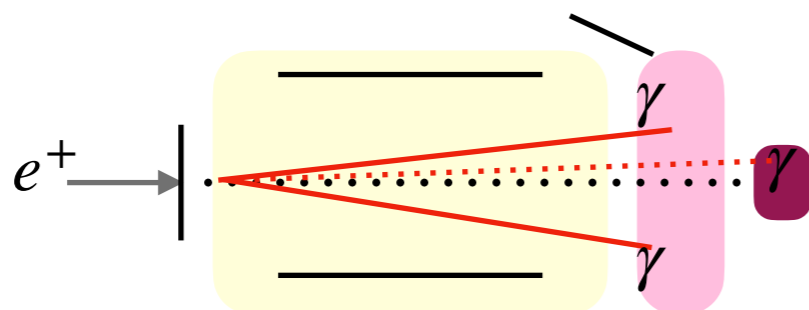
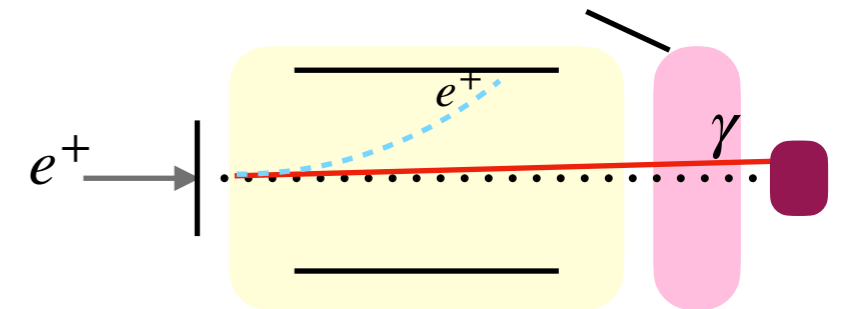
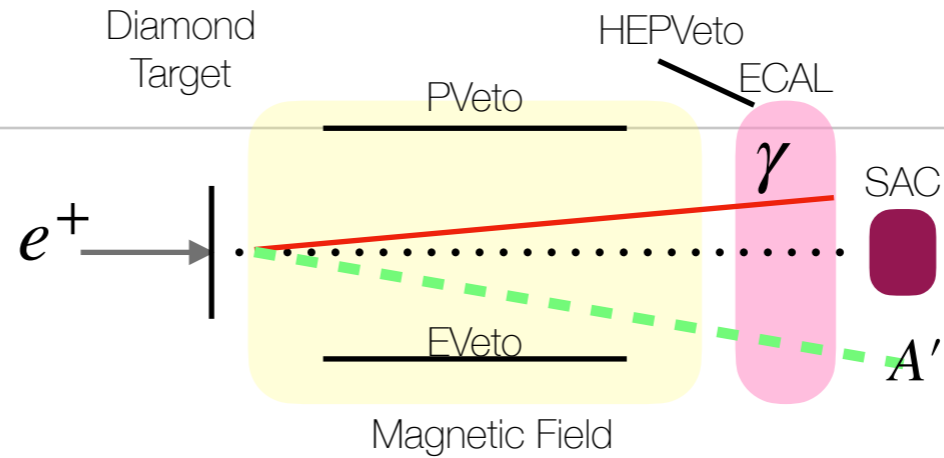
- Two symmetric photons in ECAL with correlated energy and polar angle

- If $E_{beam} = 550$ MeV, $\sigma(e^+e^- \rightarrow \gamma\gamma) = 1.55$ mb

- $e^+e^- \rightarrow \gamma\gamma\gamma$

- Symmetry lost

- If $E_{beam} = 550$ MeV, $\sigma(e^+e^- \rightarrow \gamma\gamma\gamma) = 7.5 \times 10^{-2}$ mb



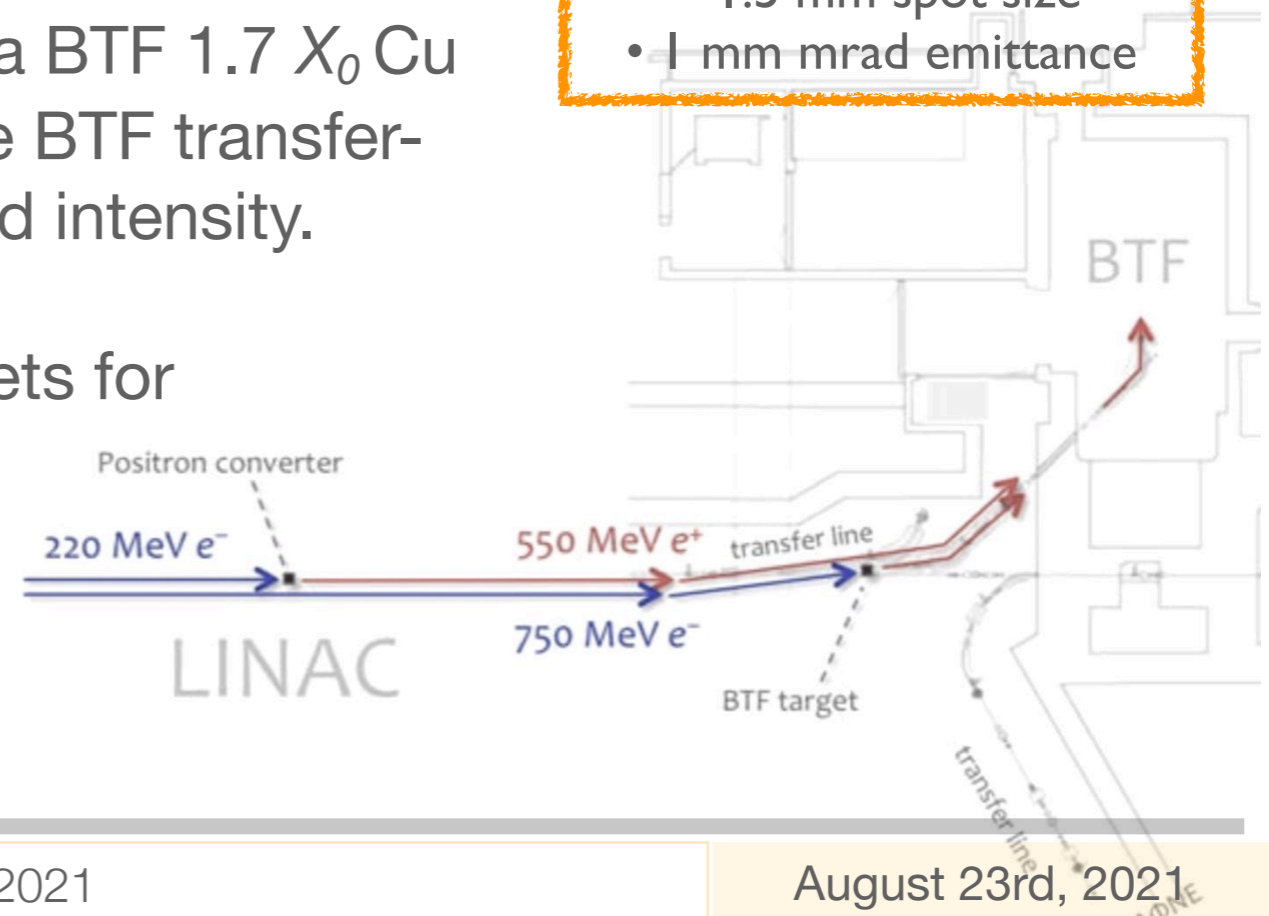
PADME POSITRON BEAM

- PADME uses the positron beam of the Beam Test Facility of the Laboratori Nazionali di Frascati
- Primary electrons from a gun can be accelerated up to 800 MeV
- **Primary positrons** are produced in a converter ($2 X_0$ W-Re target) by 220 MeV electrons
 - Captured positrons accelerated up to 550 MeV
- **Secondary positron** beam produced by a BTF $1.7 X_0$ Cu target. Energy selection collimation on the BTF transfer-line for defining momentum, spot size, and intensity.
- Transfer line: 2 FODO quadrupoles doublets for focussing

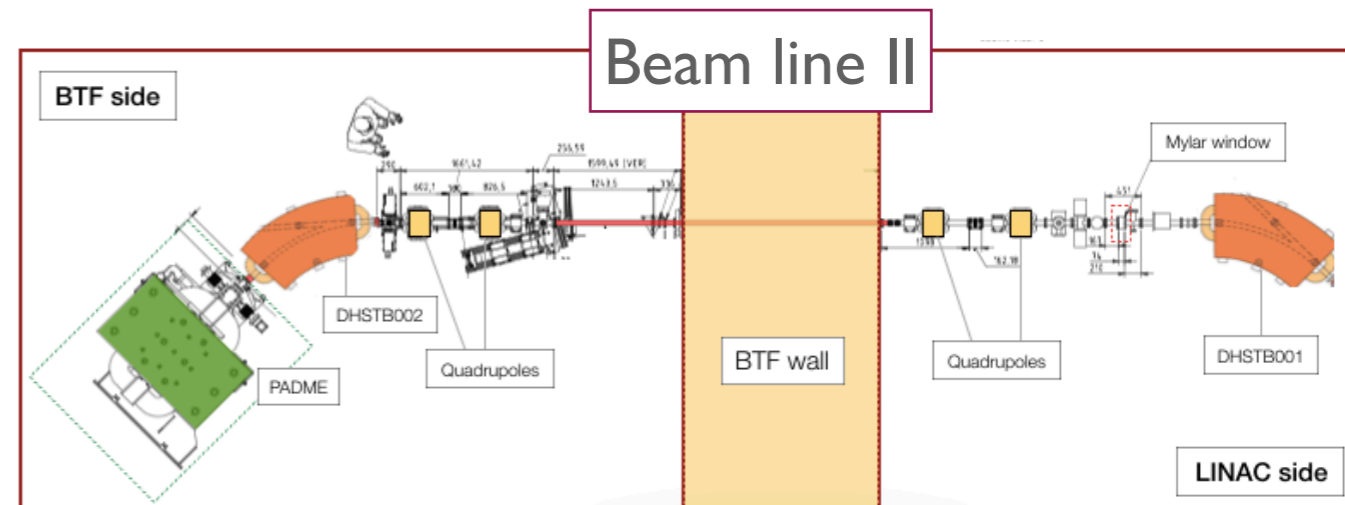
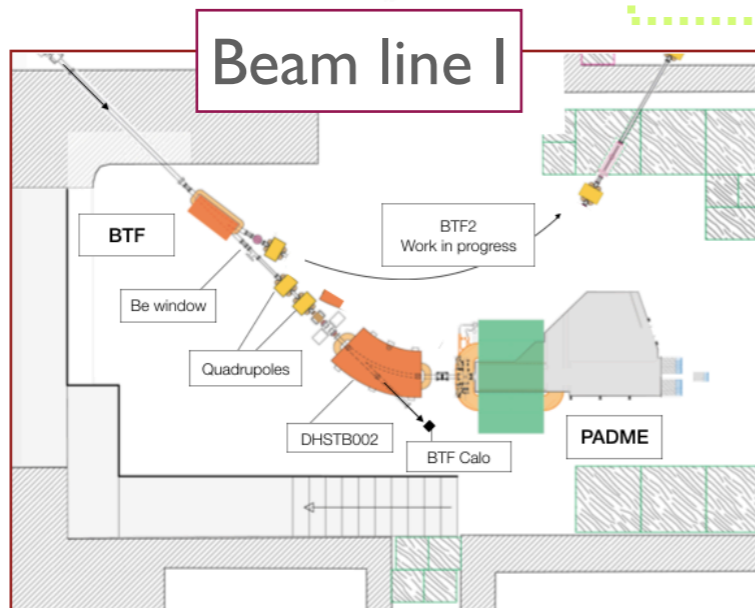
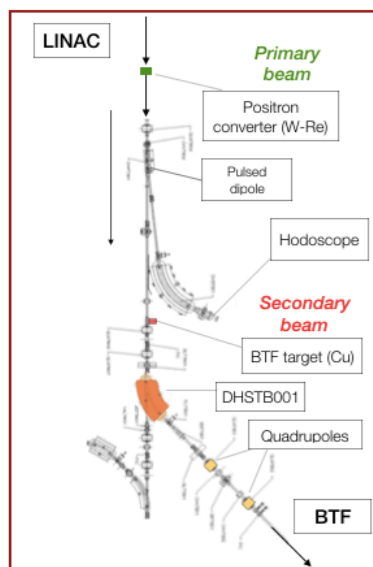
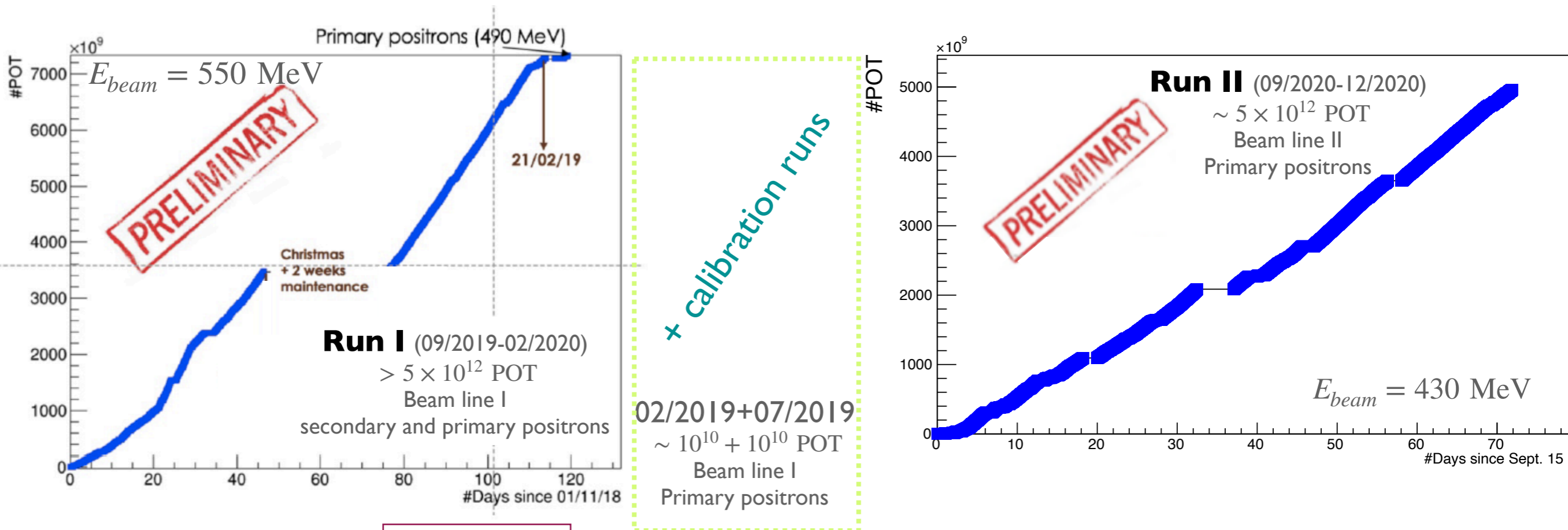
-50 Hz pulsed beam
-300 ns pulse maximum duration
-~10000 e+/pulse

Positron beam parameters:

- 1% energy spread
- 1.5 mm spot size
- 1 mm mrad emittance



PADME DATA TAKING



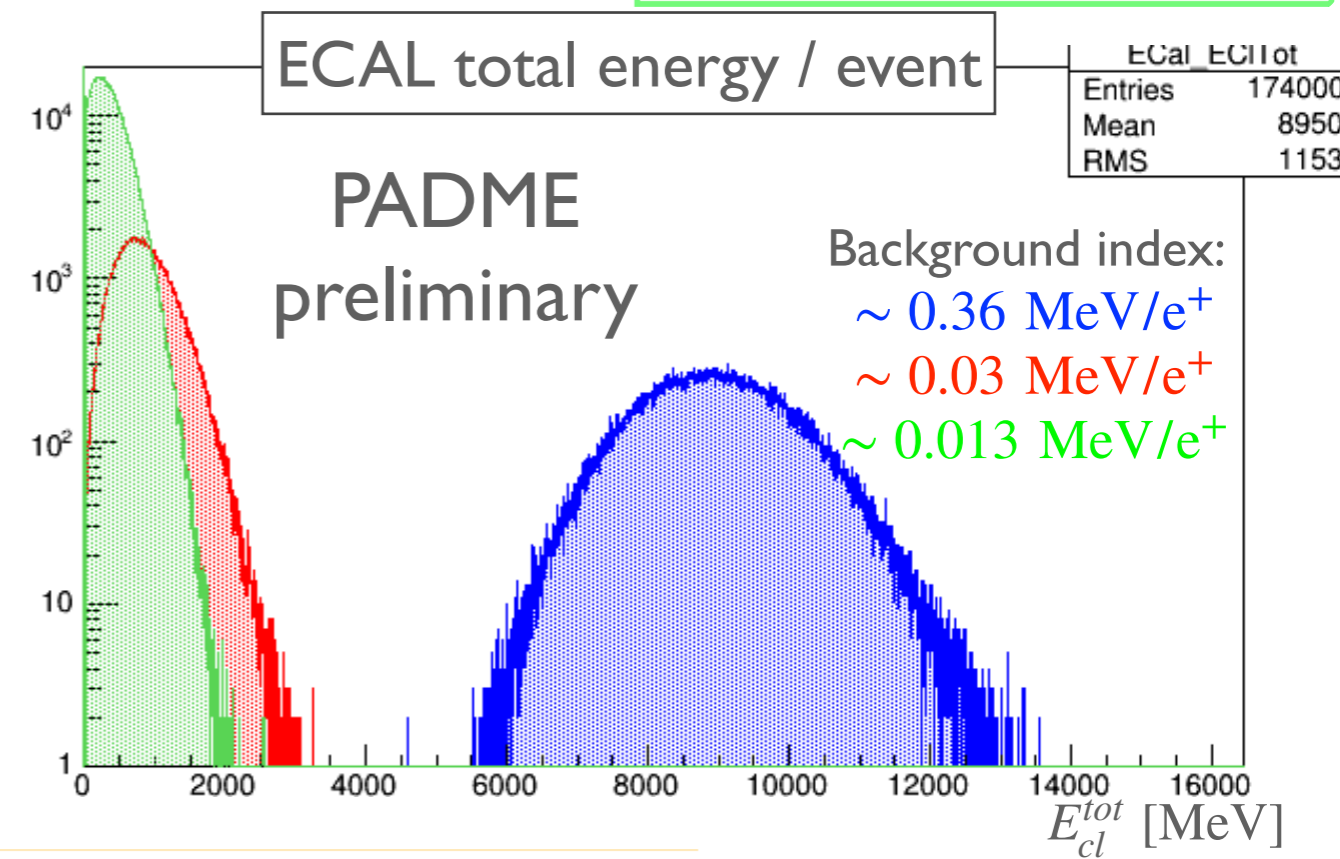
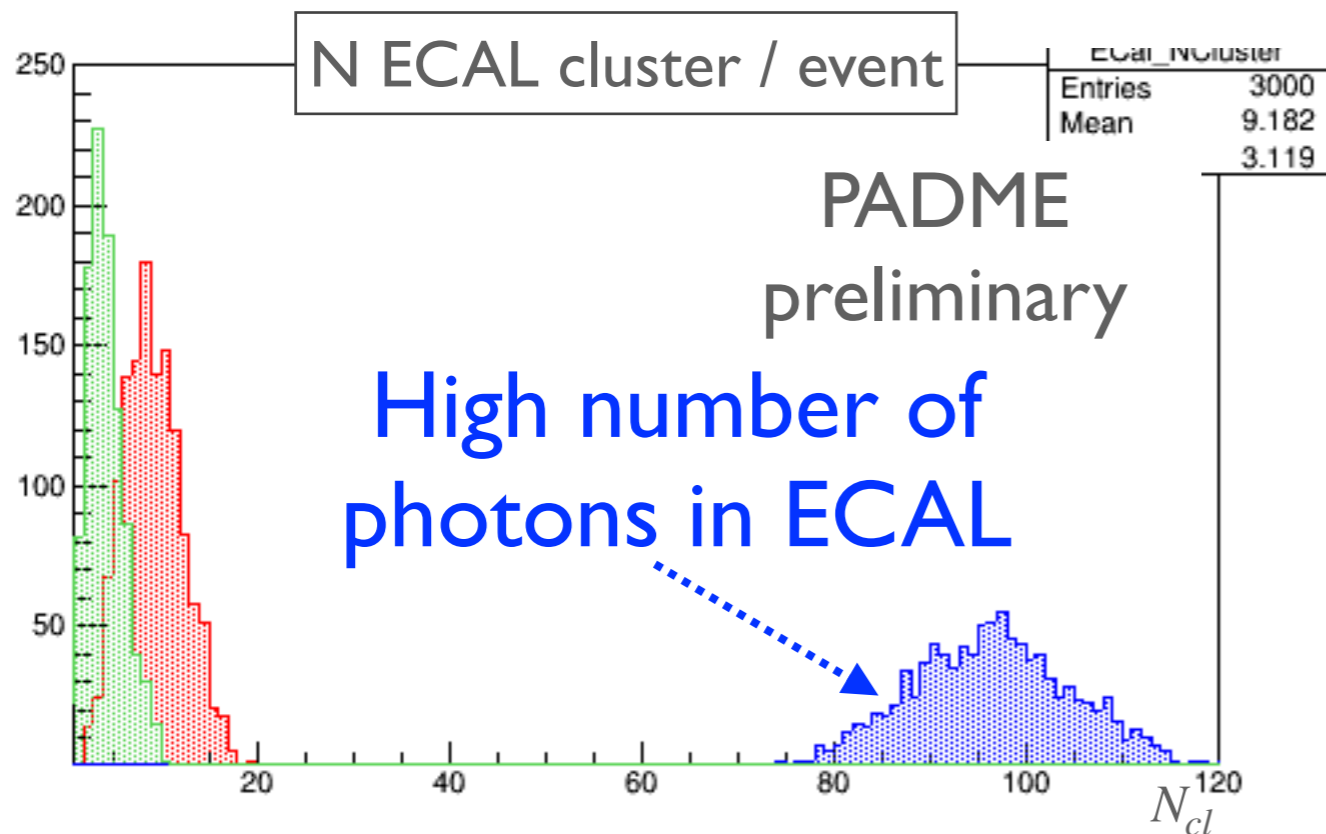
PADME DATA TAKING

- Due to the several condition of data taking, the quality of data is very different
 - Run I secondary beam:**
 - Huge background coming from the beam
 - Run I primary beam:**
 - Beam related background is observed.
 - Detailed beam line description in the MC used to investigate it.
 - With primary e^+ beam the beryllium window, used to separate the detector vacuum from the accelerator vacuum, produces a high beam momentum spread. As a consequence some particles can shower on the beam line;
 - Run II primary beam:**
 - Much cleaner beam. SM processes, like annihilation and bremsstrahlung, easy to identify

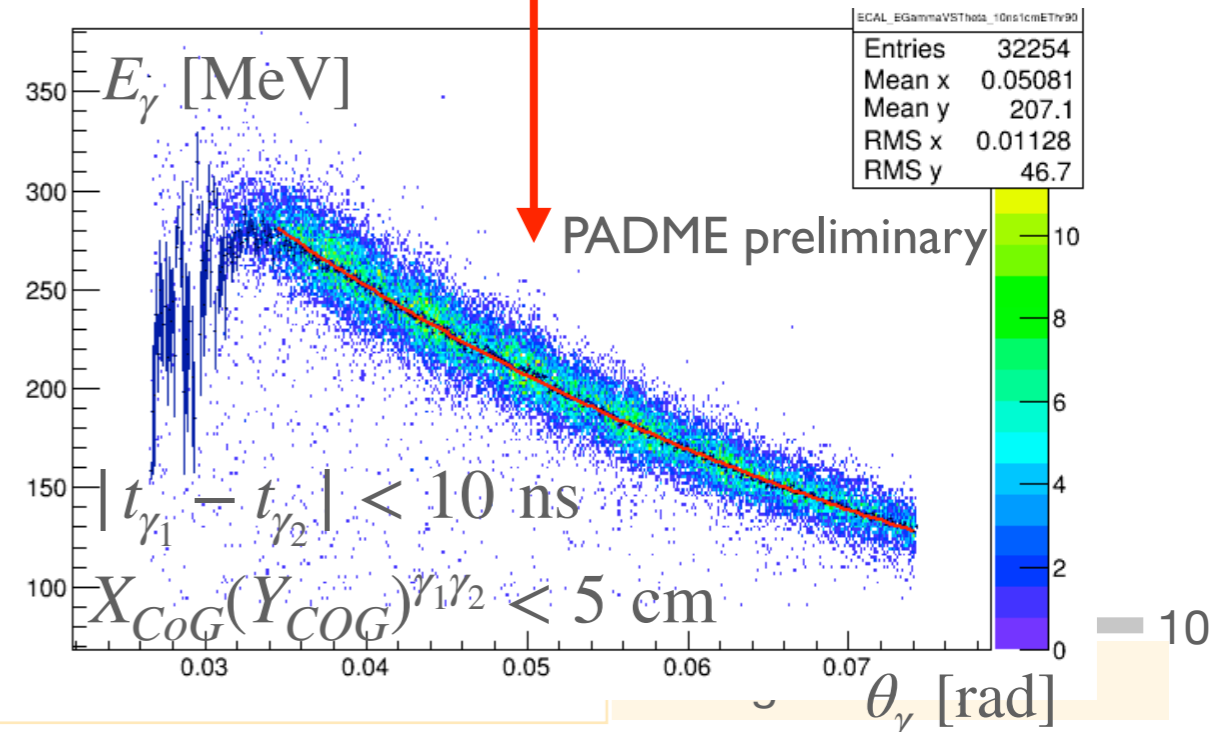
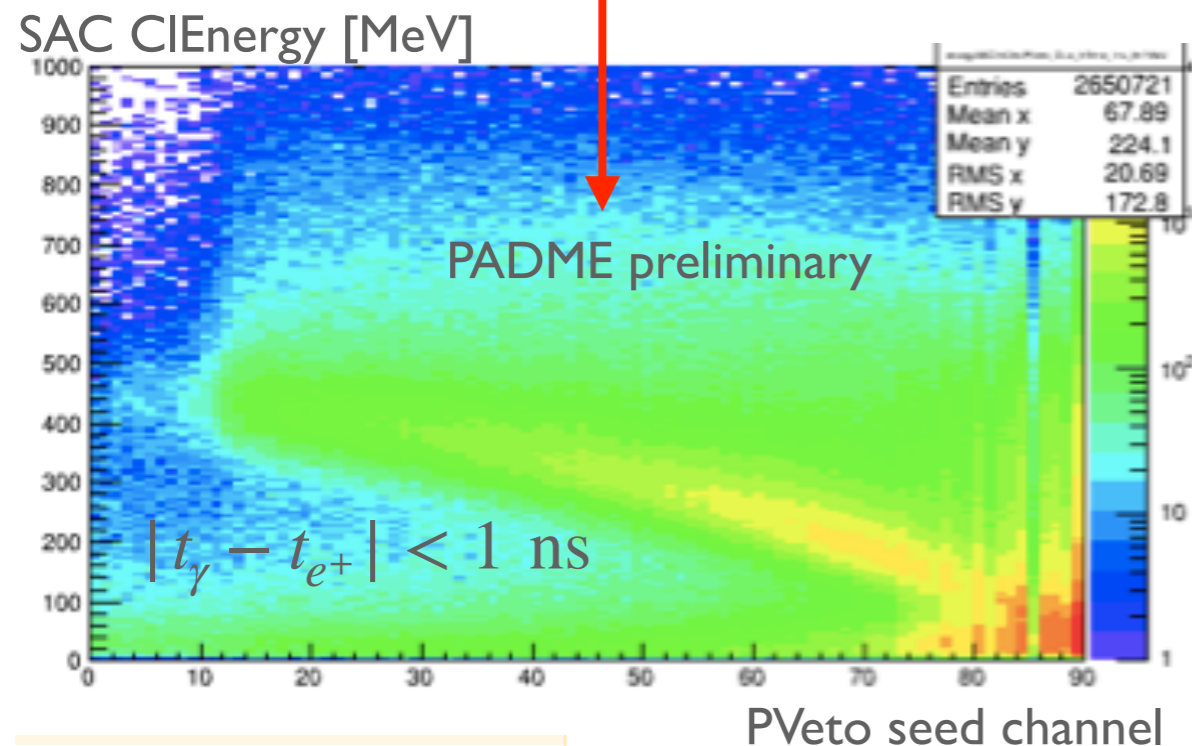
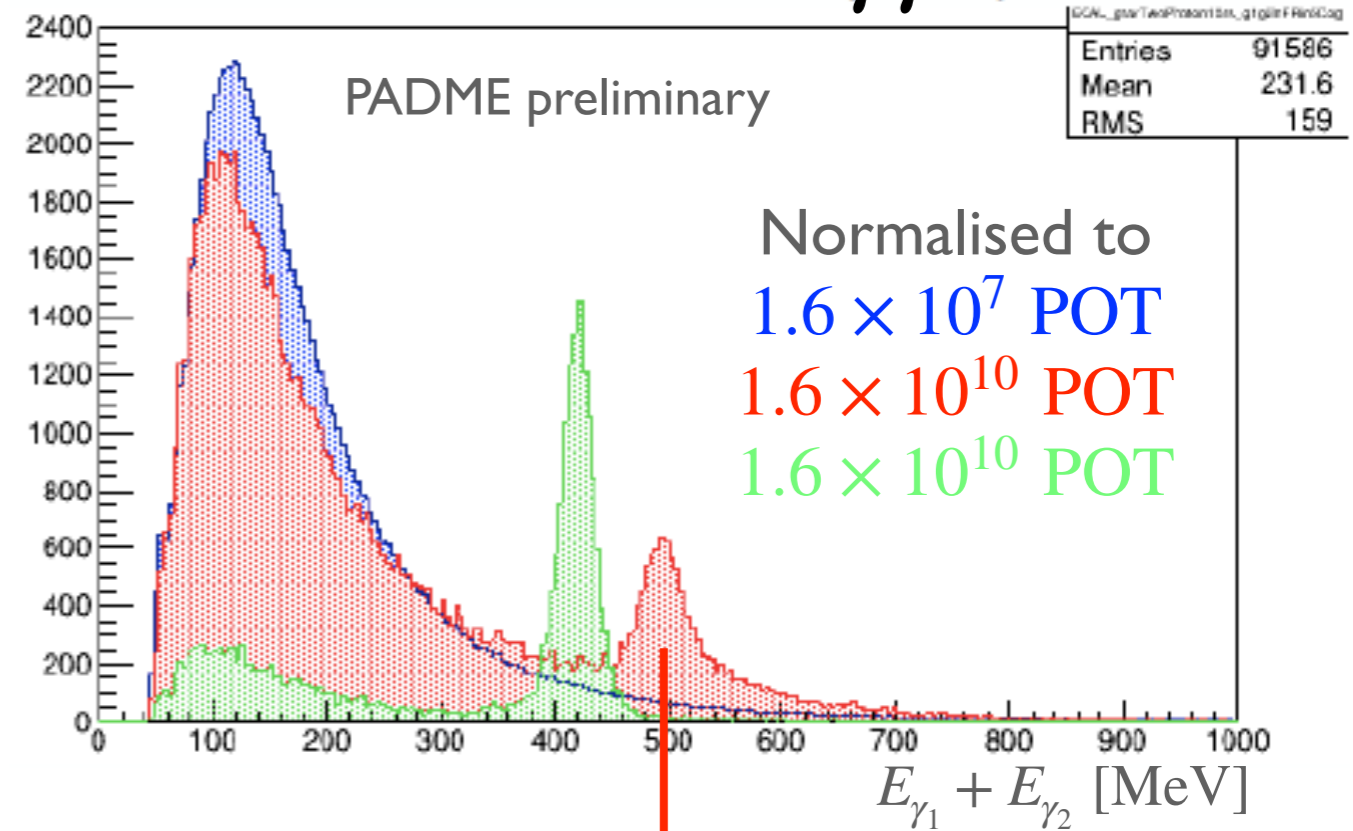
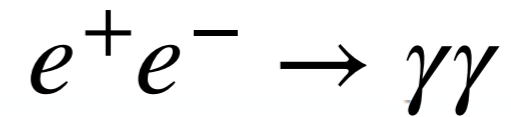
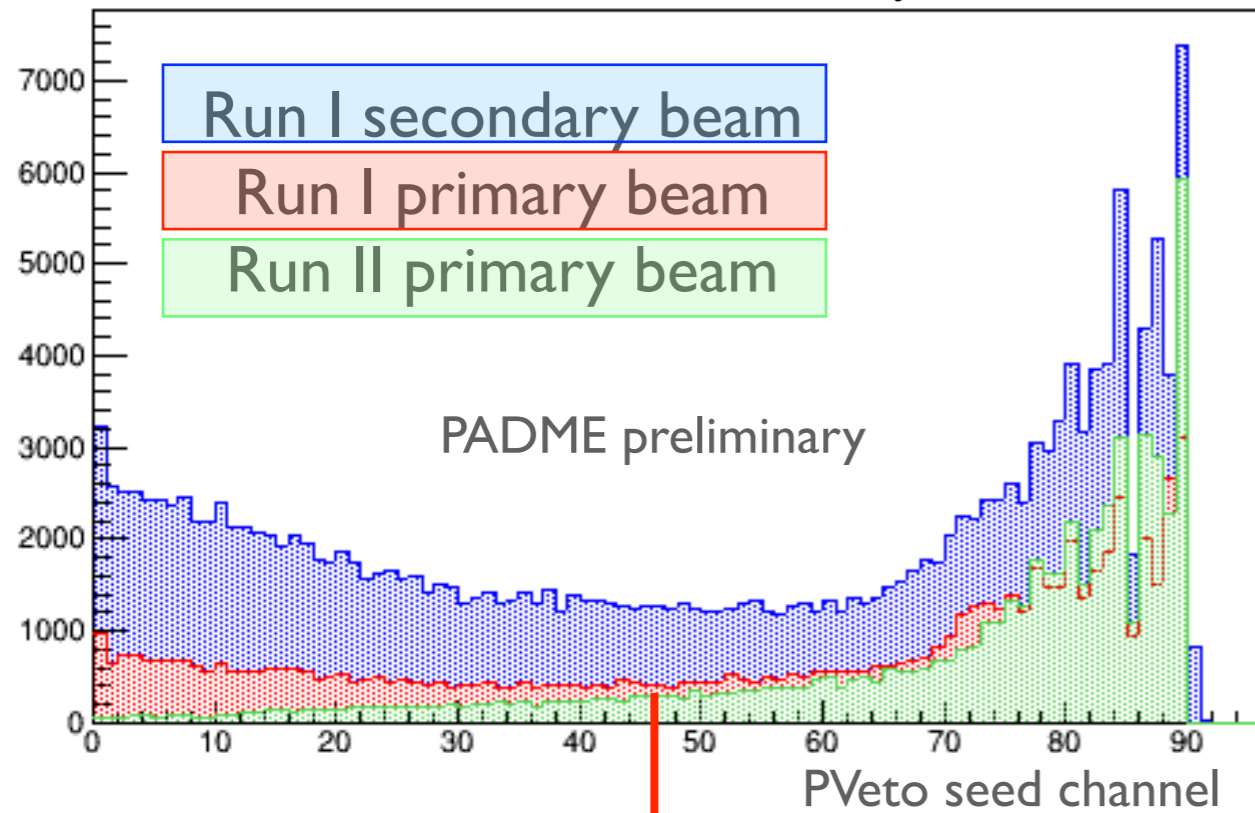
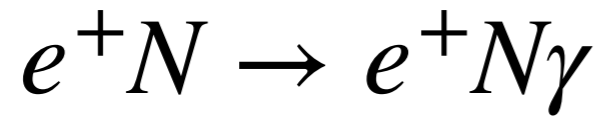
25000 kPOT/bunch
545 MeV beam energy
250 ns bunch length

25000 kPOT/bunch
490 MeV beam energy
250 ns bunch length

28000 kPOT/bunch
430 MeV beam energy
280 ns bunch length

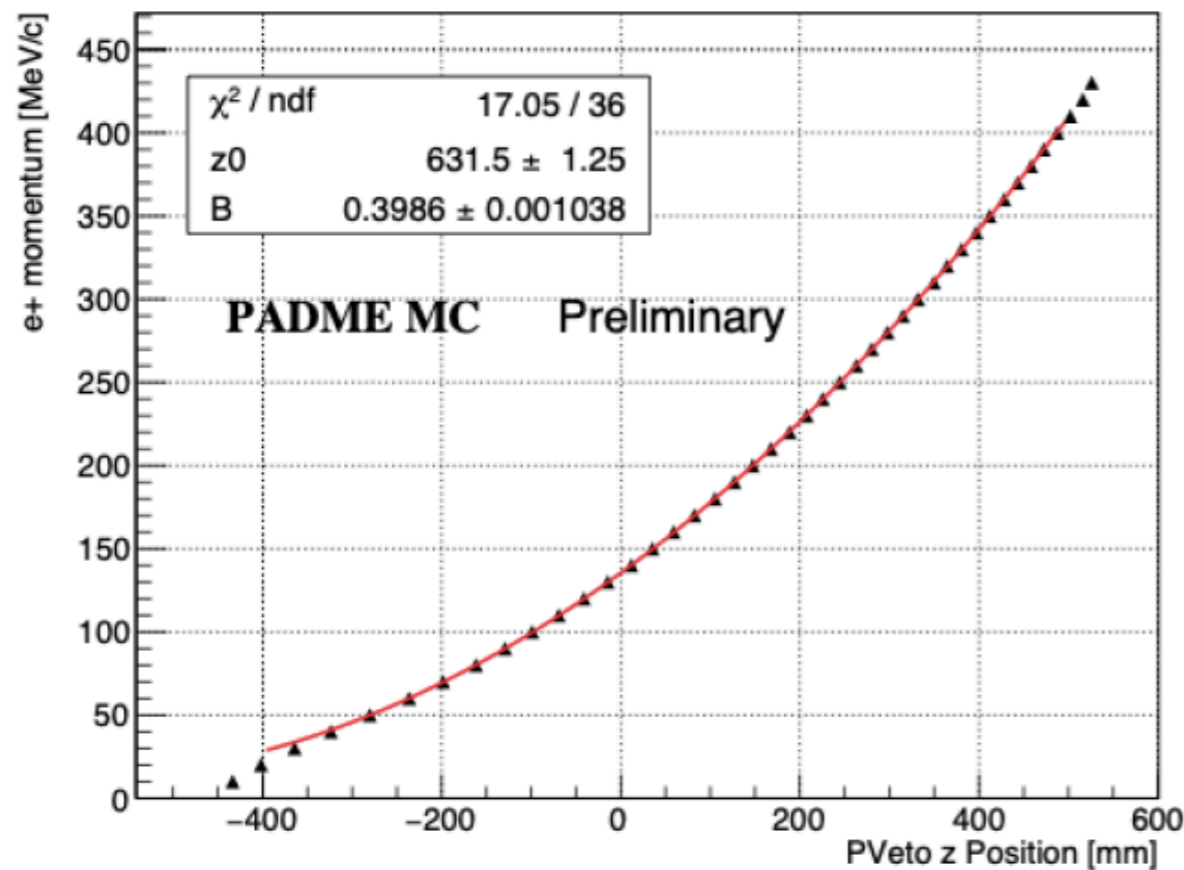


PADME DATA TAKING ON SM PROCESS



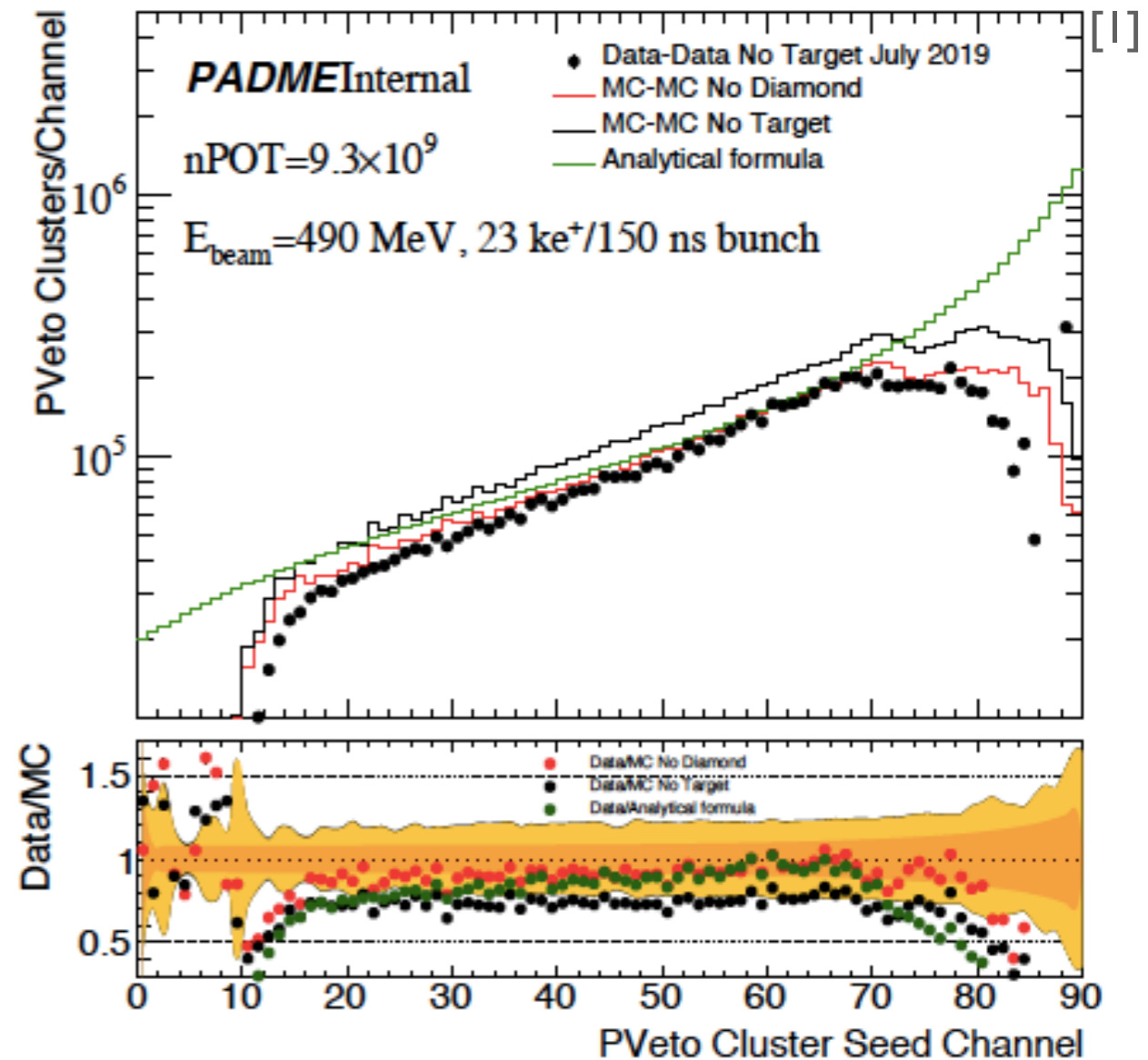
MOMENTUM CALIBRATION

- Momentum calibration using simulation
 - One single positron with different energies in PADME



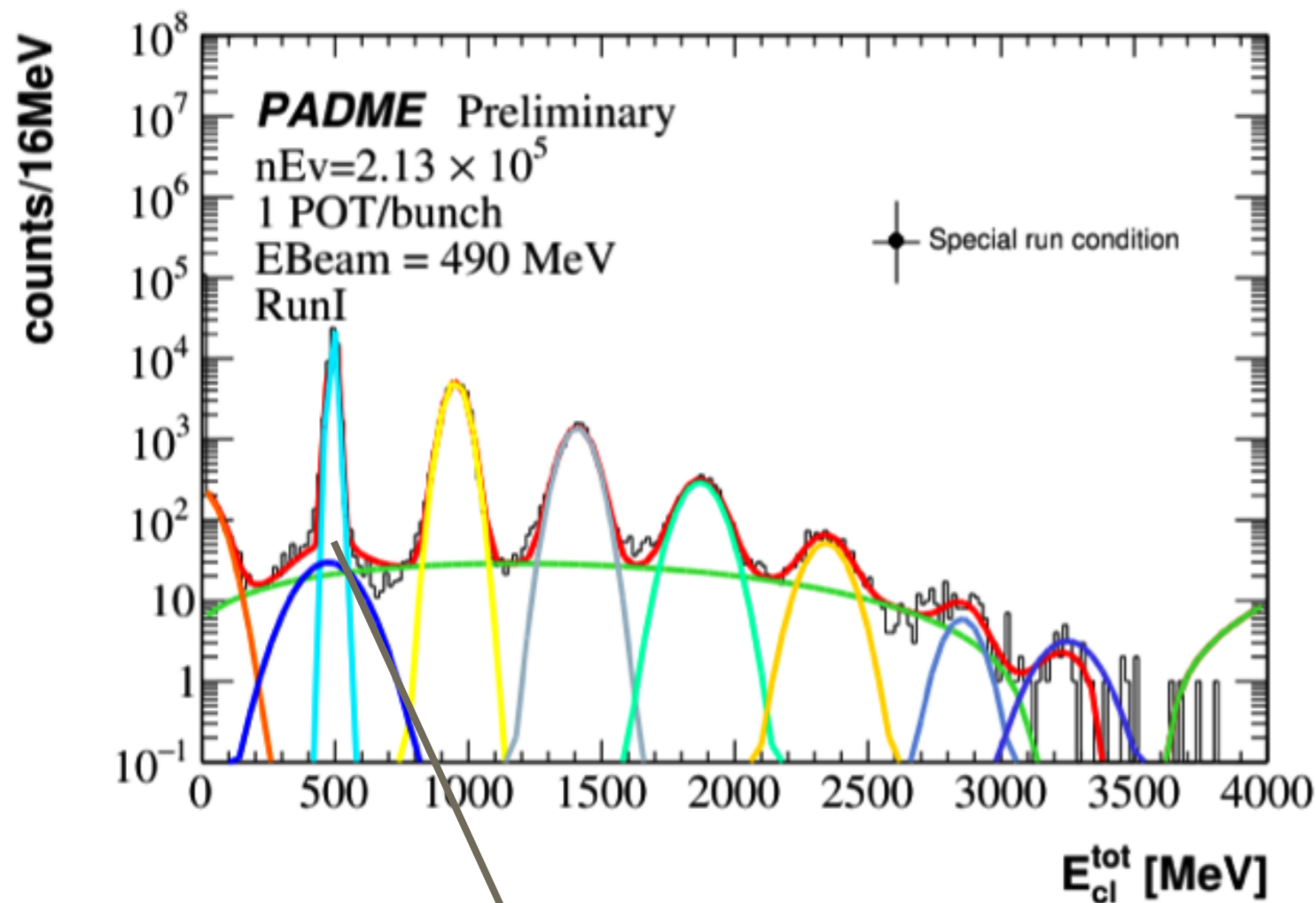
$$p(z) = \frac{0.3B[(z + z_0)^2] + x^2}{2x}$$

Bremsstrahlung positron profile on PVeto estimated by subtracting data with target and without target in data and MC compared to analytical formula (PDG)



CHALLENGING ECAL RECONSTRUCTION

ECAL energy resolution on $1e^+$ /bunch special run

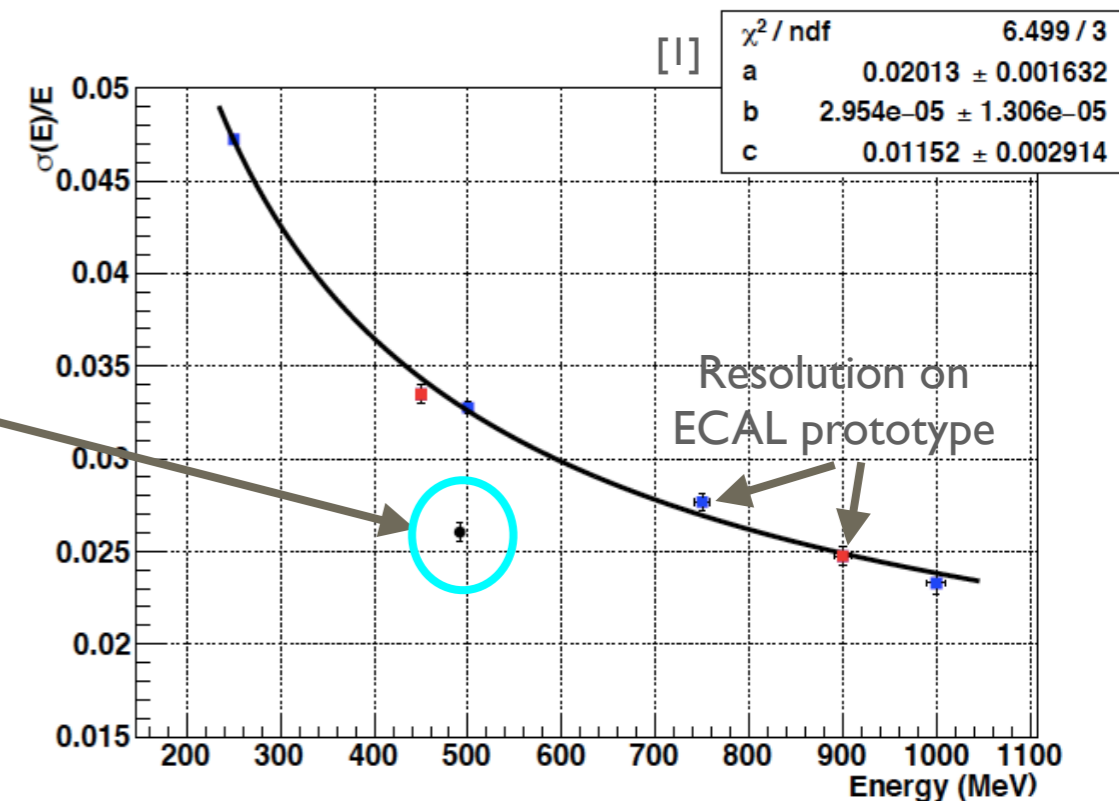


$$\sigma_E = 2.62 \pm 0.05(\text{stat}) \%$$

Time resolution, extracted using the 2γ annihilation photons, $\sim 1 \text{ ns}$

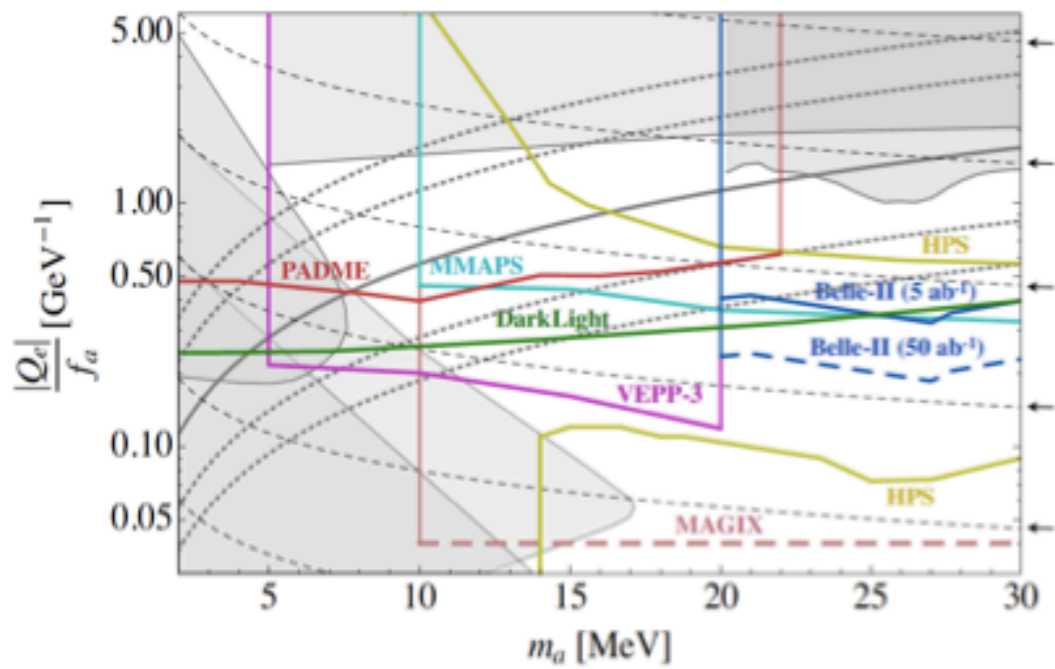
Multihit reconstruction

- Cluster total energy distribution well reproduced by a fit with gaussian peaks with Poissonian amplitudes distributed
 - $N_{e^+} = 1.18 \pm 0.22/\text{bunch}$



POSSIBLE FUTURE SEARCH

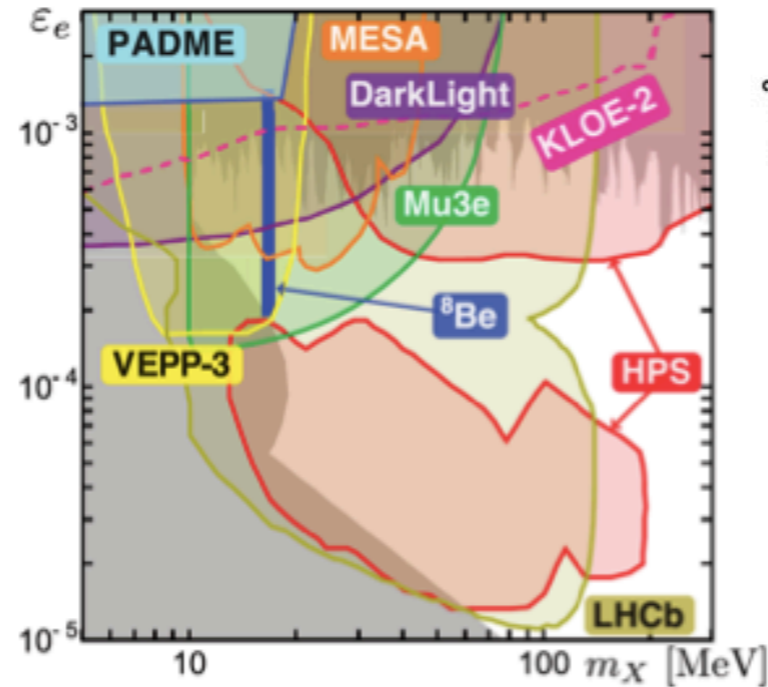
Axion Like Particle
[JHEP07(2018)092]



$$e^+e^- \rightarrow \gamma\alpha$$

$$\alpha \rightarrow \gamma\gamma, e^+e^-, \chi\chi$$

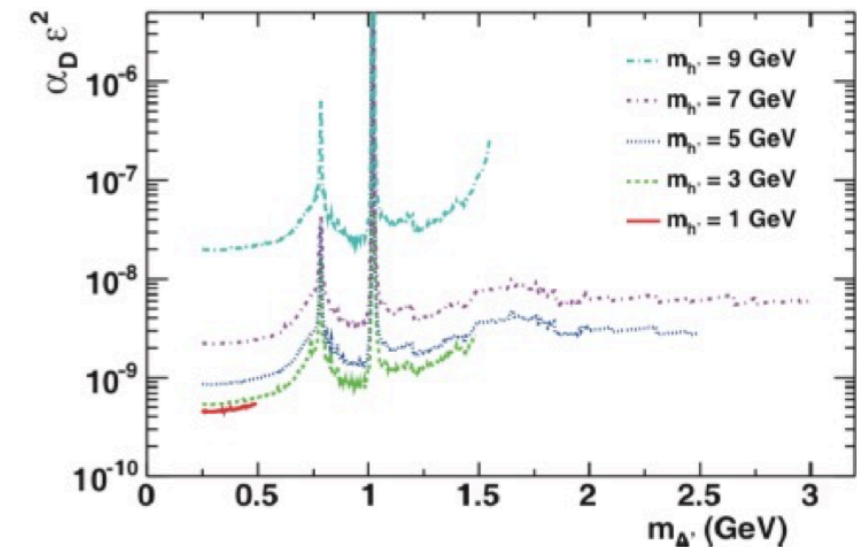
BE anomaly- X boson
[arXiv:1910.1045]



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

$$X_{17} \rightarrow e^+e^-$$

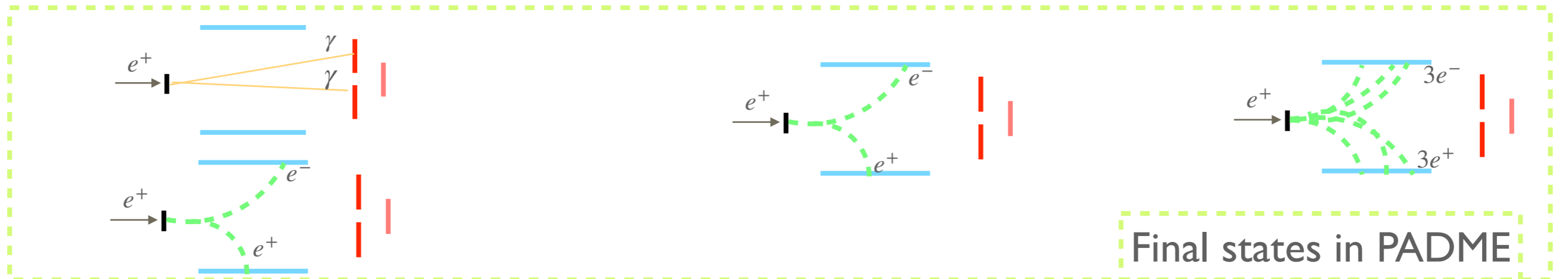
Dark Higgs
[arXiv:2012.04754]



$$e^+e^- \rightarrow h'A'$$

$$h' \rightarrow A'A'$$

$$A' \rightarrow \chi\chi, e^+e^-$$



Final states in PADME

CONCLUSION

- PADME is a **fixed-target, missing-mass** experiment to look for low-mass dark photons
- Model-independent (kinetic mixing)
- RUN I and RUN II acquired. The upgrade of the beamline in Run II helped to reduce the beam background.
 - PADME collected 5.58×10^{12} POT , about one half of the planned statistics, during the pandemics
 - Run II data analysis is ongoing: $e^+e^- \rightarrow \gamma\gamma$ (interesting by itself and a step towards the invisible dark photon analysis)
 - New runs are planned to test other DM hypothesis!