# The PADME experiment

PADME

INFN Istituto Nazionale di Fisica Nucleare

UNIVERSITÀ DEL SALENTO

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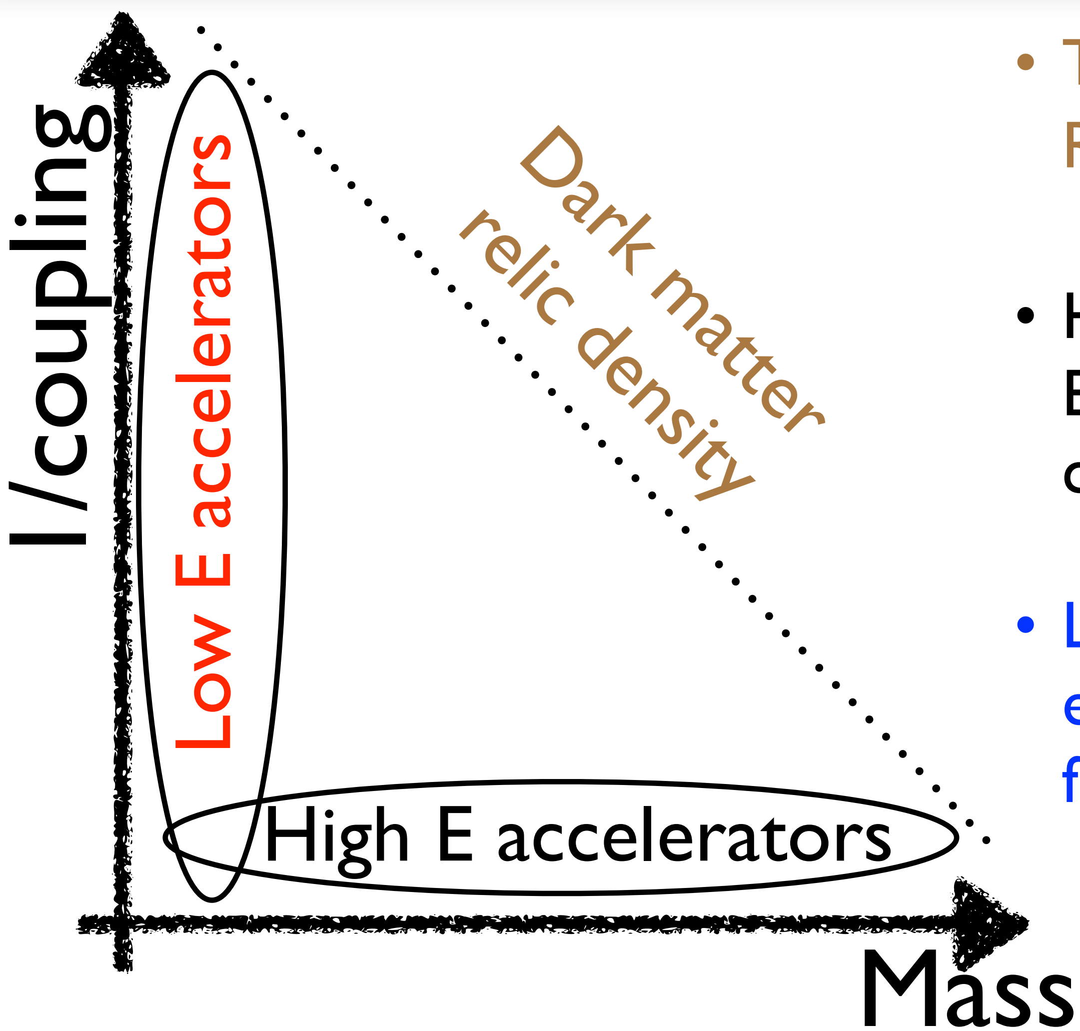
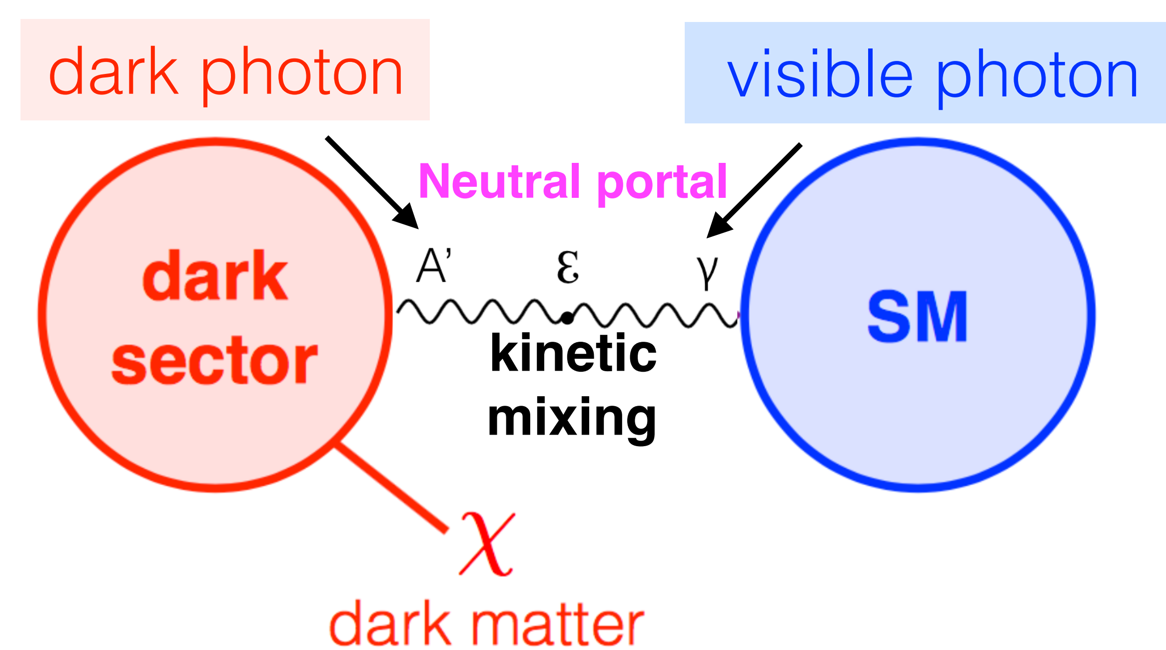
**on behalf of PADME collaboration**

July 10-17, Ghent - Belgium

# Outline and motivations



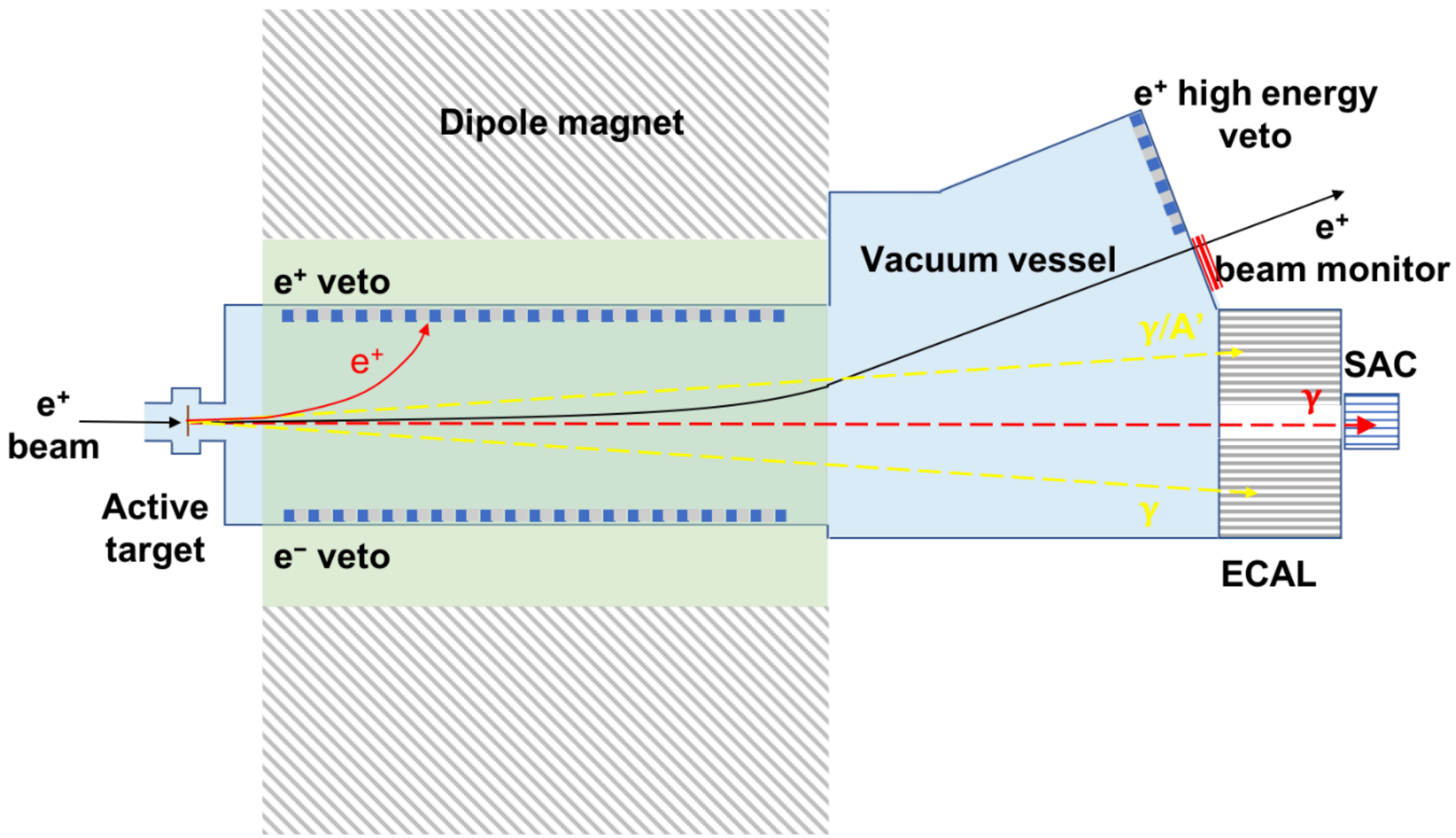

- THERE IS EVIDENCE OF DARK MATTER IN A WIDE RANGE OF DISTANCE SCALES $\Omega_{DM} = 0.1198 \pm 0.0015$
- HIGH ENERGY ACCELERATOR: thermally produced in Early Universe with masses at GeV-TeV and annihilation cross section of electroweak scale.
- LOW ENERGY ACCELERATOR Low-energy frontier experiments are starting to probe light masses and very feebly coupling to SM with high-intensity.



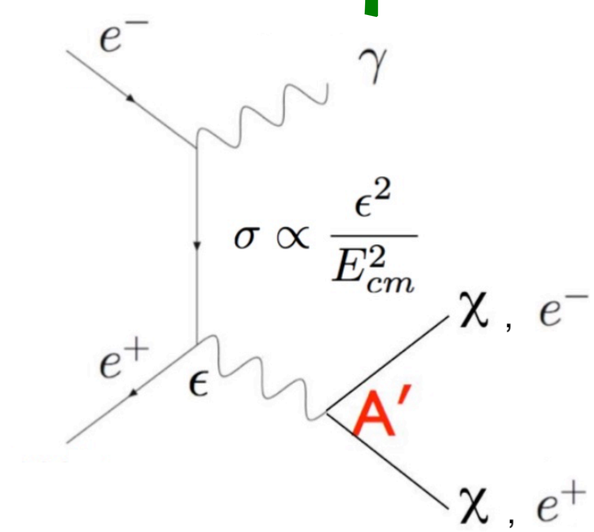

- Direct search of dark mediator without care what happens to UV-scale
- One of the simplest models is a dark photon A' associated to a new $U_{A'}(1)$ gauge symmetry

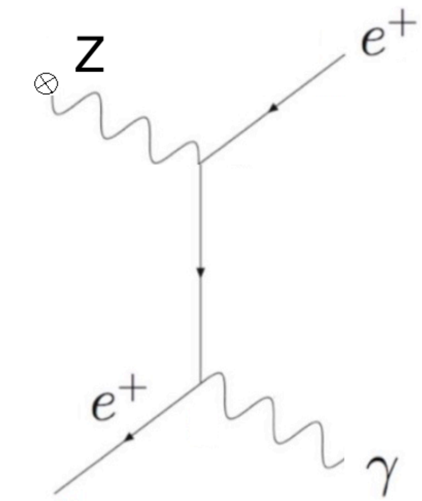
# The experiment

## PADME: Positron Annihilation into Dark Mediator Experiment




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




- Positron beam on active target
- B field bend not interacting positron out of ECAL acceptance
- Interacting positrons and electrons detected by charged veto system
- Dark photon reconstructed from Missing Mass in ECAL

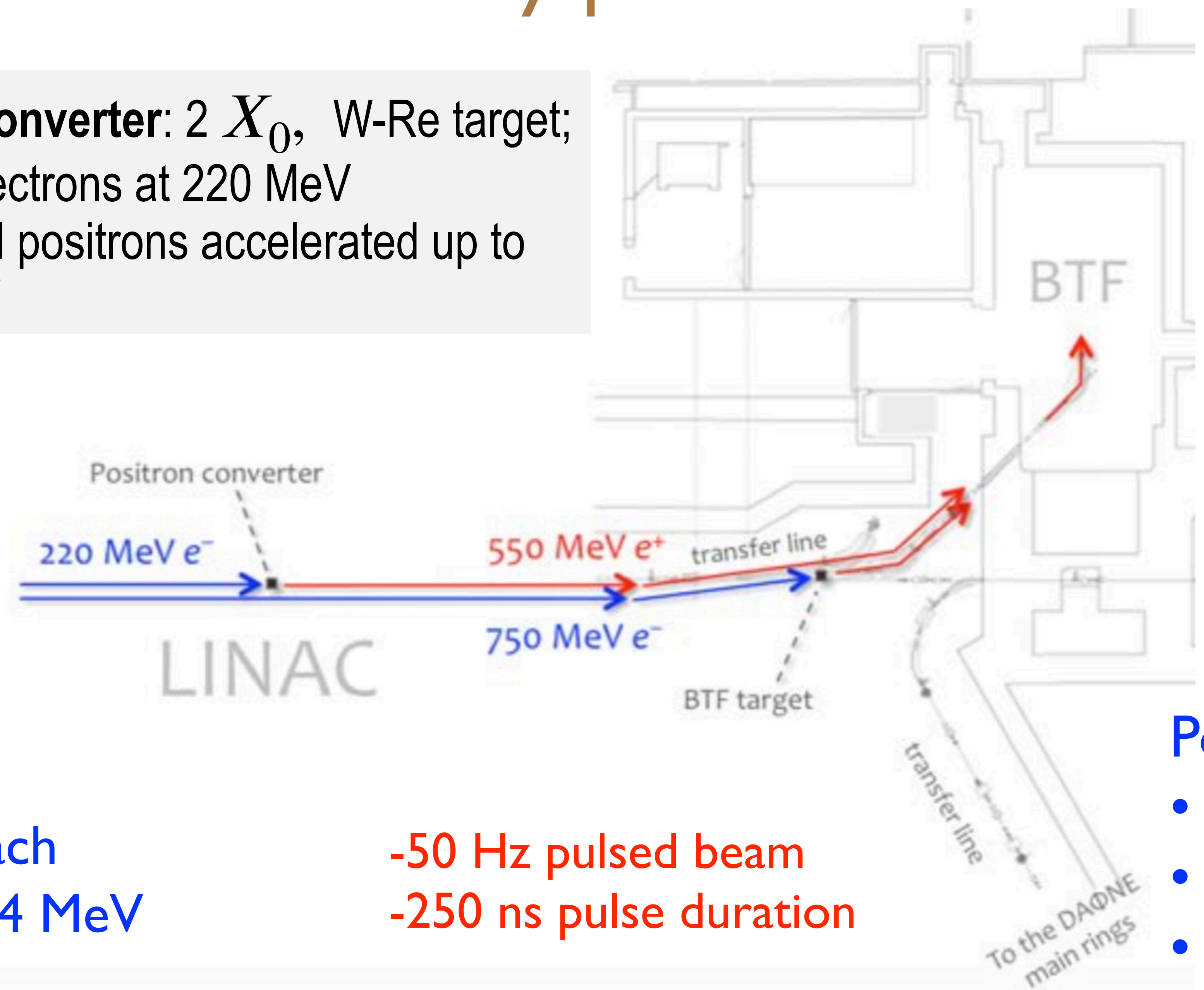
$$M^2_{\rm rec} = 2m_e\left(E_+ - E_\gamma(1 + \frac{E_+}{2m_e}\theta^2_\gamma)\right)$$

Main BG: $e^+Z \rightarrow e^+Z\gamma$

# The secondary $e^+$ beam

- Primary positrons from DAΦNE LINAC
- Secondary positron from BTF target

**Positron converter**: 2 $X_0$, W-Re target;
- Hit by electrons at 220 MeV
- Captured positrons accelerated up to **550 MeV**




**BTF target**: 1.7 $X_0$, Cu target
- Energy selection system and collimators on the BTF transfer-line for defining momentum, spot size, and intensity
- Transfer line: 2 FODO quadrupoles doublets for focussing

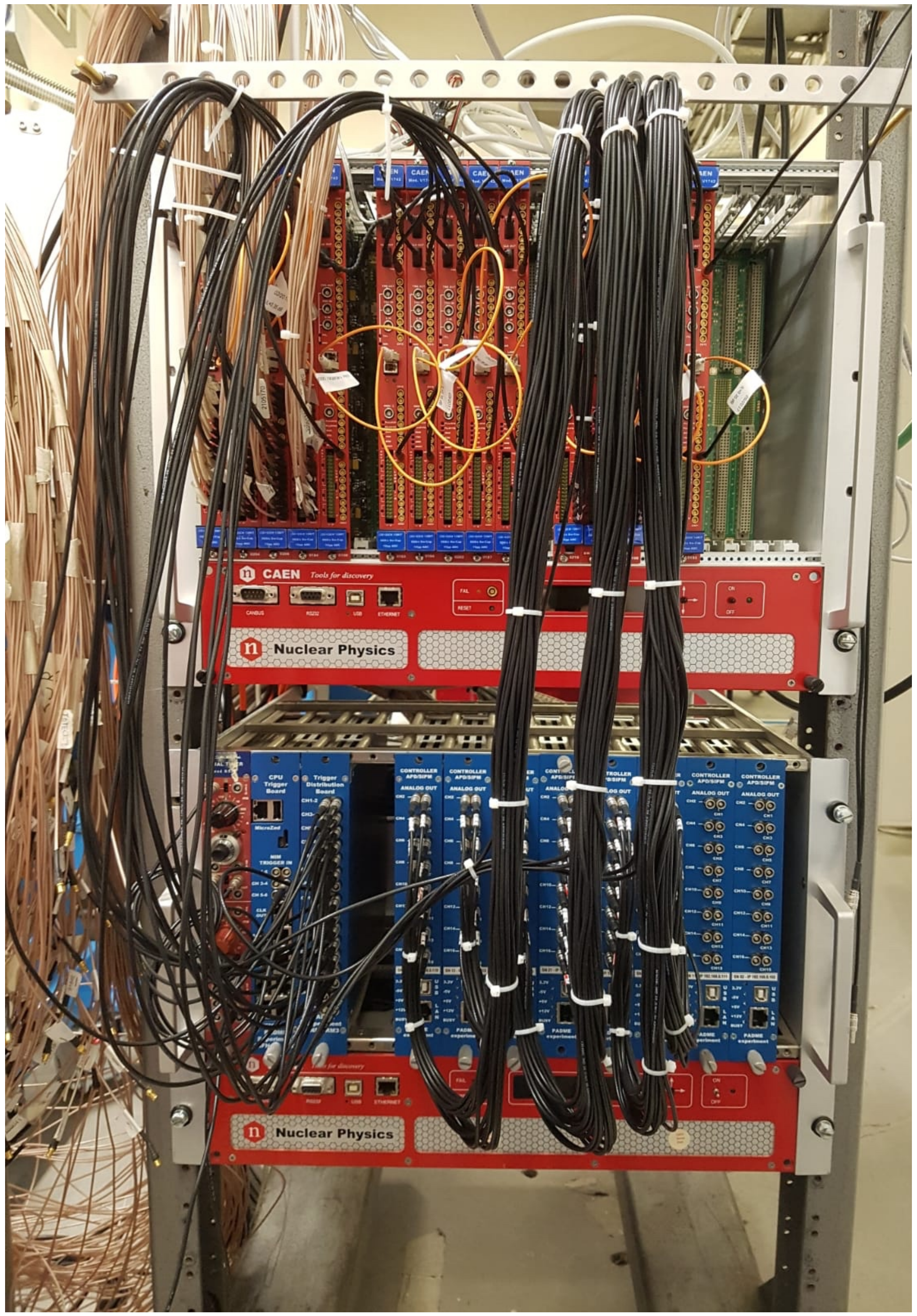
Positron beam parameters:
- 1% energy spread
- 1.5 mm beam spot size
- 1 mrad beam emittance

Mass reach
$M_{A'} \leq 23.4$ MeV

-50 Hz pulsed beam
-250 ns pulse duration

# DAQ and TRIGGER

All signal waveforms digitized for better pile-up suppressions and timing




- VME digitizers CAEN V1742
- 1-5 Gs/s sampling speed
- 12bit ADC signal range
- ~1000 channels
- 30 VME boards

Two Trigger Boards:

- - CPU Trigger Board generates the trigger signals: Physics, Cosmics, Random
- - Trigger distribution boards (2×32 channels)

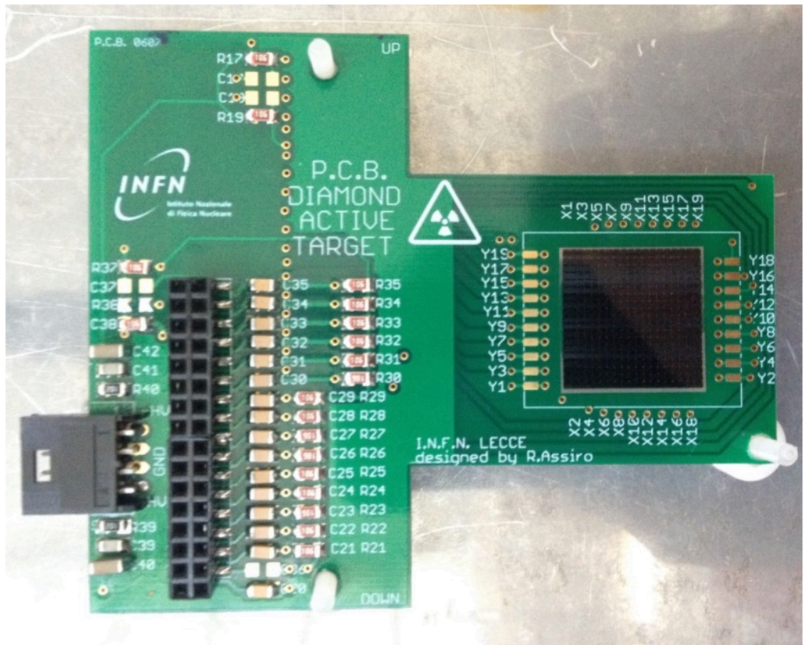
Two Trigger Levels

- L0 PCs perform data collection from single boards and zero suppression
- L1 PCs perform event merging and eventually further selection based on full event information

Data size:

- ~ 900 KB/bunch
- ~ 60 MB/s sustained data throughput

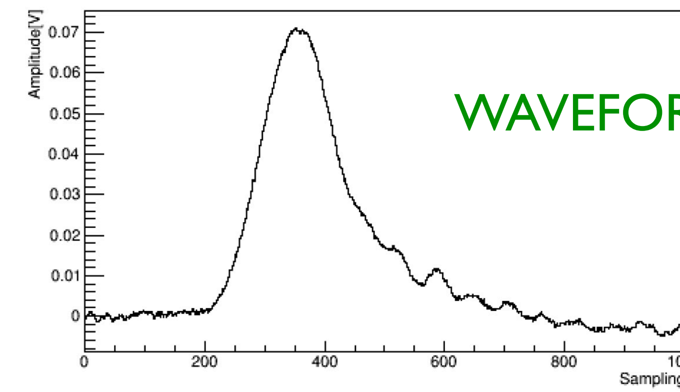
# Diamond Active Target

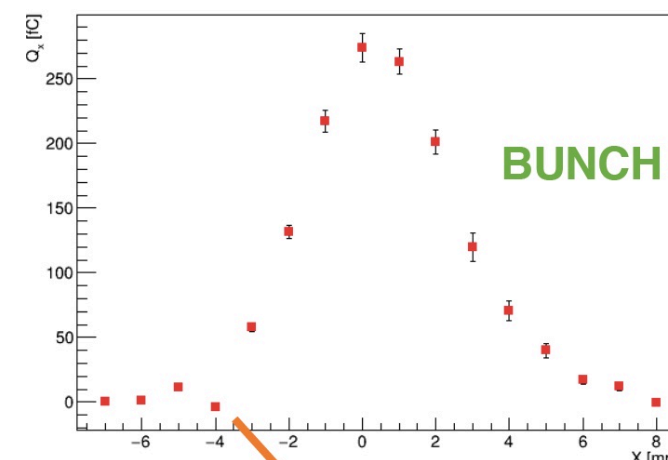



"FULL CARBON" ACTIVE TARGET

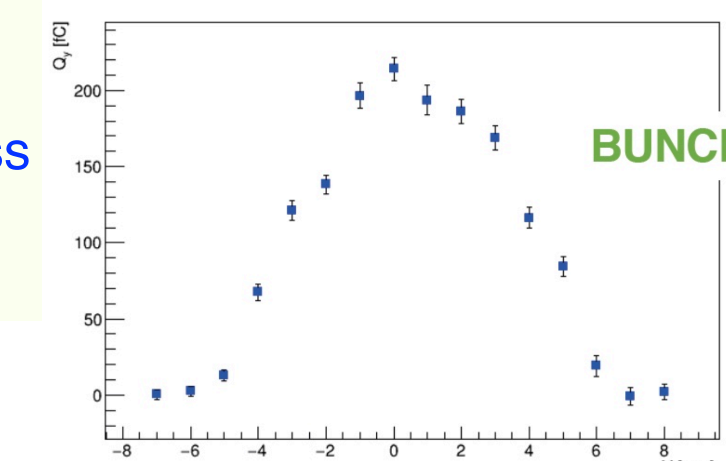
- CVD "as grown" diamond sensor:
- 2x2 cm$^2$ area
- 100 μm thickness.
- 19X+19Y Laser made graphite strips:, 1 mm pitch, 0.15 mm, inter-strip distance and electric resistance~2.5kΩ.

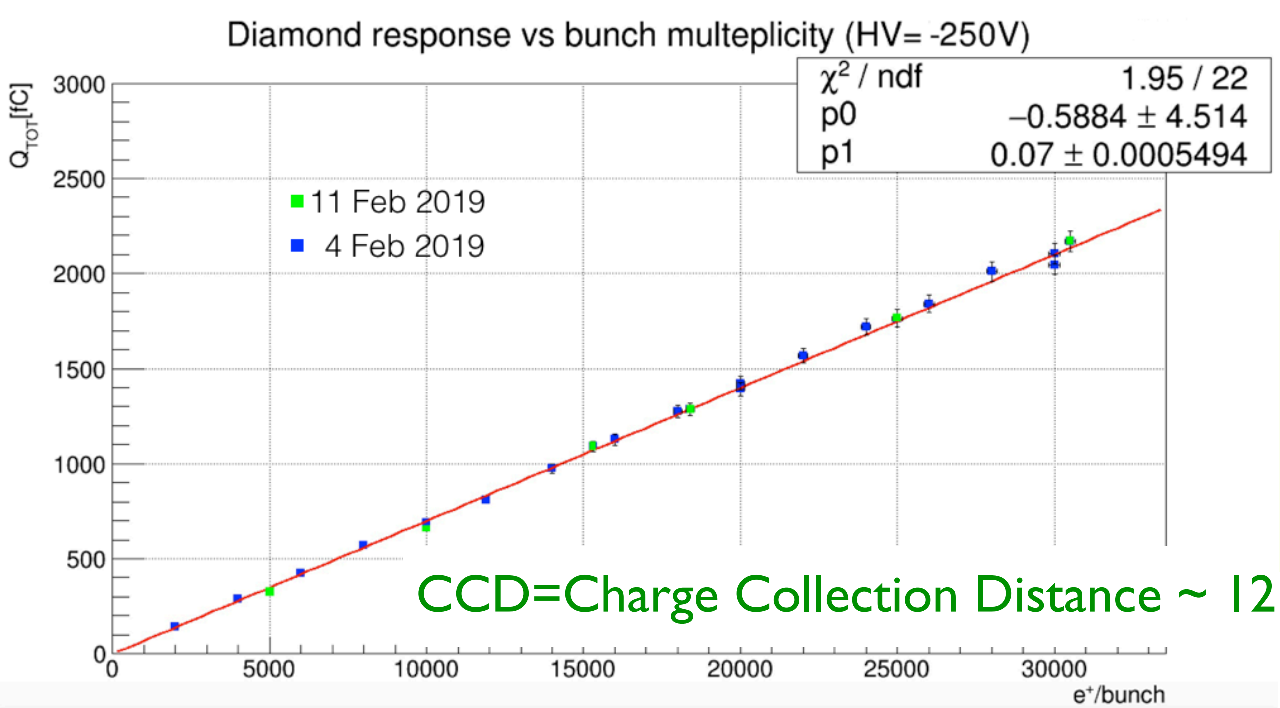
20000e$^+$ / 250 ns




One dead strip out of 32



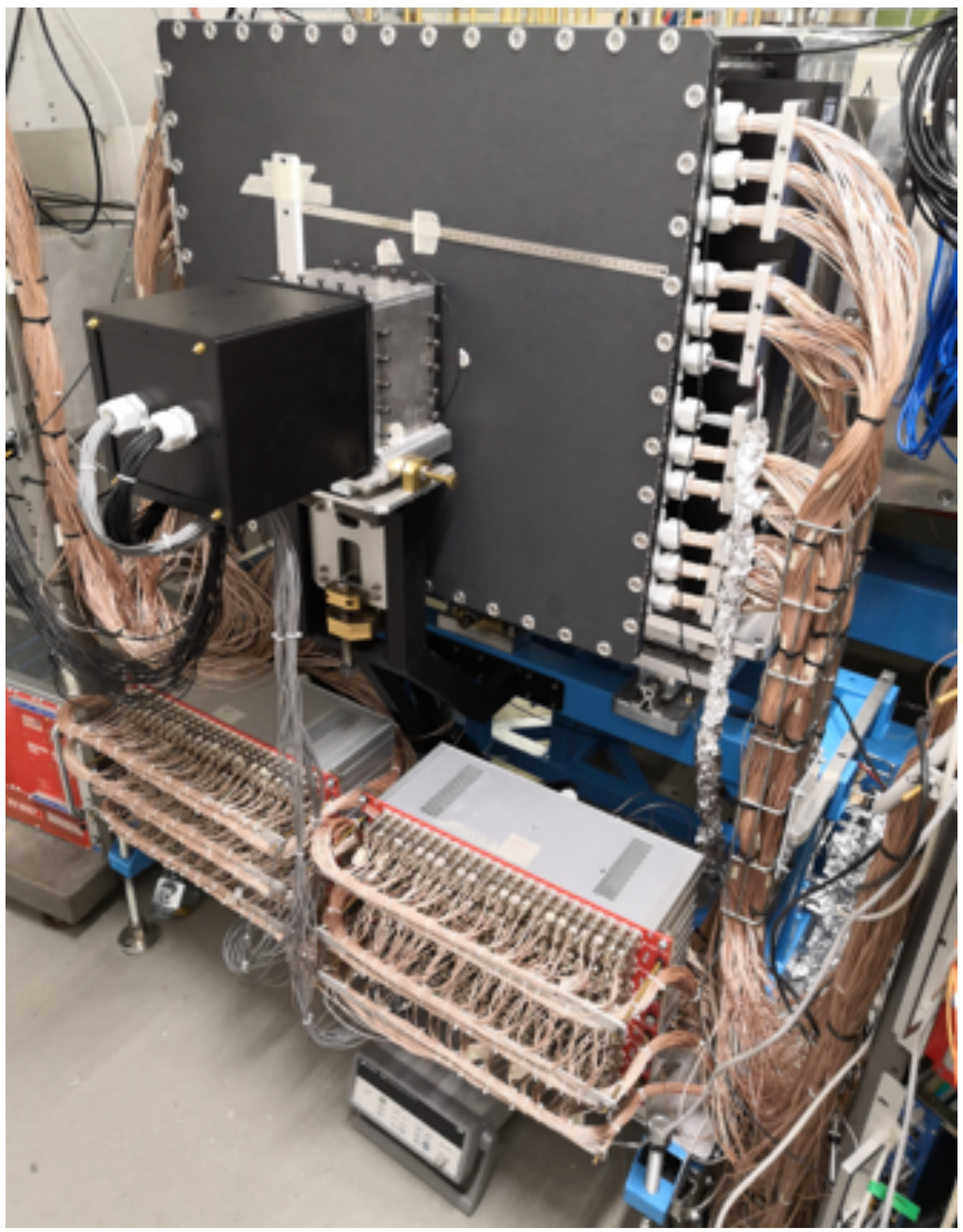




CCD=Charge Collection Distance ~ 12 $\mu$m

- X and Y profile/bunch
- Number of POT/ bunch

- Online beam monitoring
- Improve Missing Mass resolution
- Luminosity

# EM calorimeter system



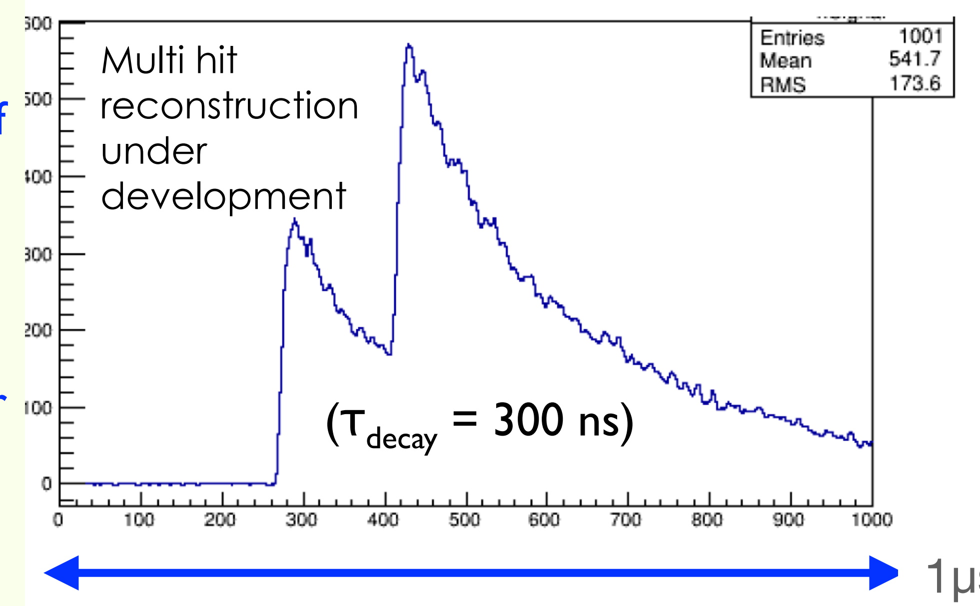
**ECAL (HIGH E RESOLUTION ECAL)**

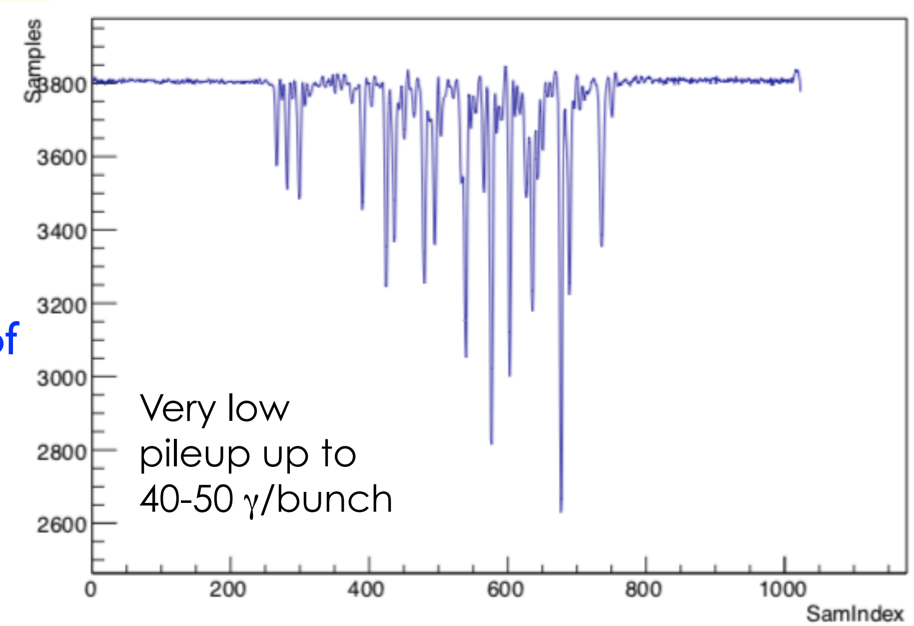
- 616 scintillating BGO crystals of 2.1×2.1×23 cm³ size.
- PMT readout: HZC XP1911
- radius: ≈ 29 cm at 3.45 m from the target
- central hole (10.5×10.5 cm²) for brems. to SAC (faster)
- angular coverage: [20,93] mrad acceptance: [26,83] mrad

**SAC (SMALL ANGLE CALORIMETER)**

- 25 Cherenkov PbF2 crystals of 3×3×14 cm³ size.
- 50 cm behind ECal
- PMT readout: Hamamatsu R13478UV
- angular coverage: [0,20] mrad

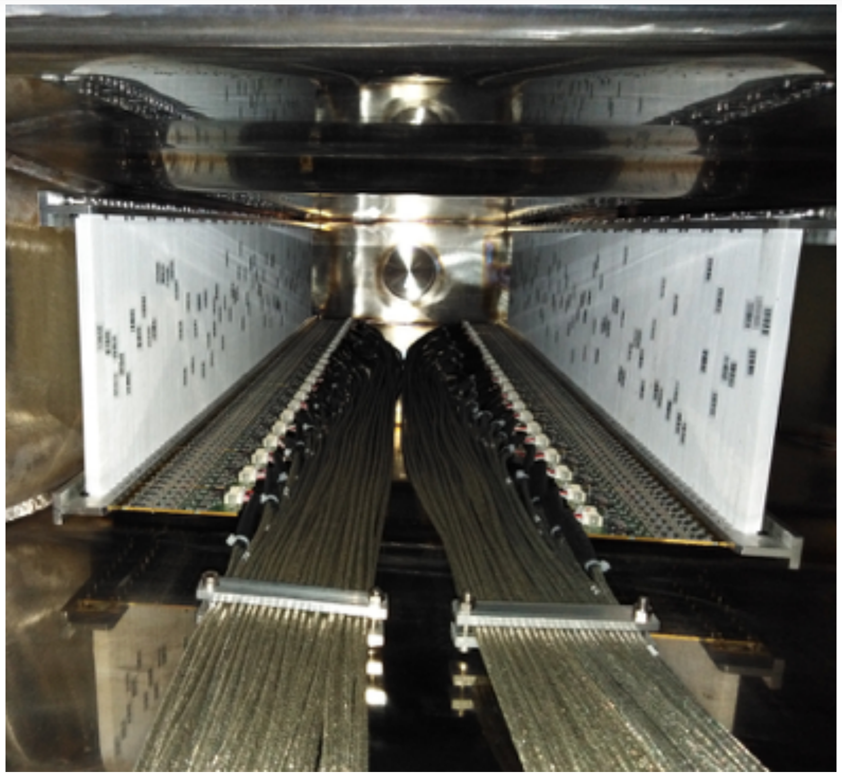
**Ecal 1 $\mu$s window, 1GHz sampling**



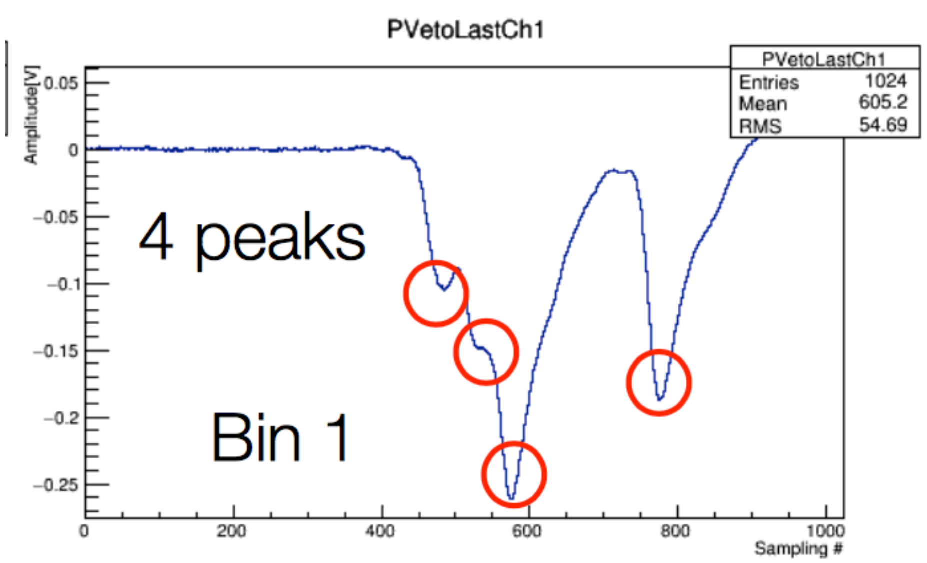

**SAC 250ns window, 2.5 GHz sampling**

# Charged VETO system

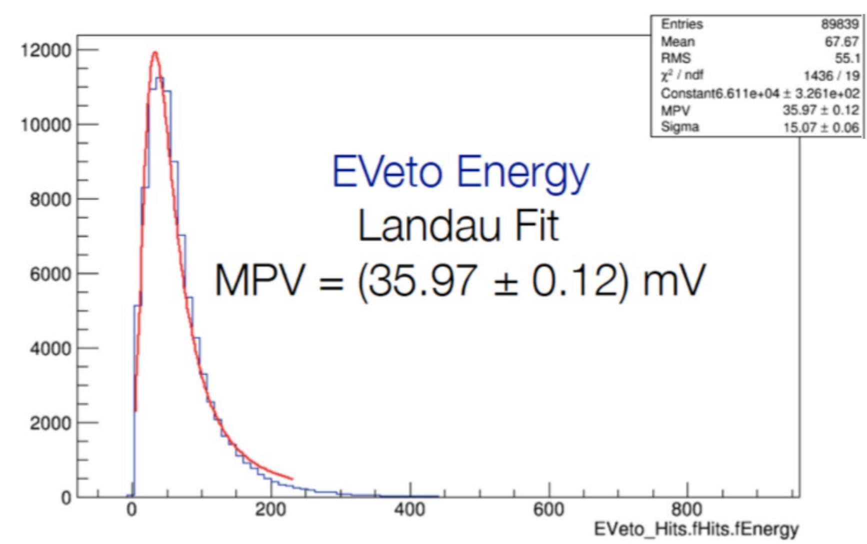


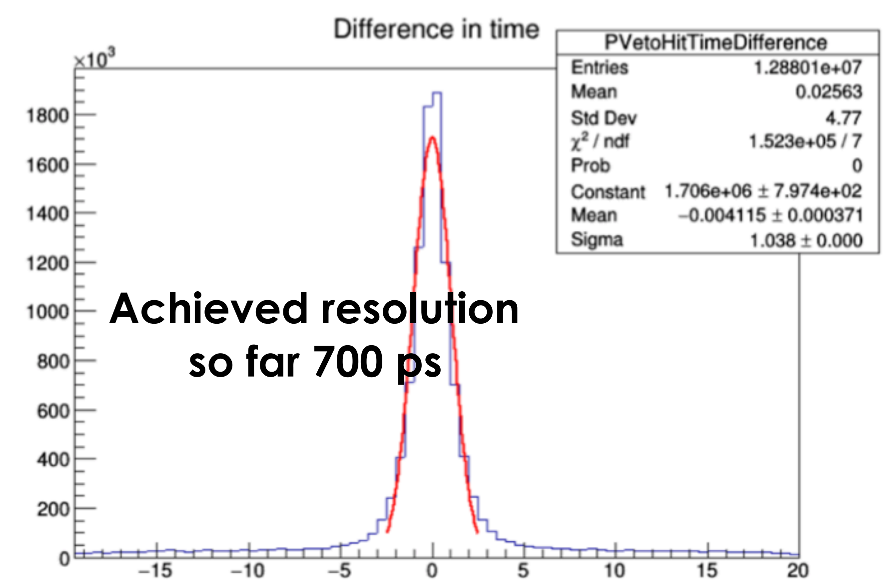
VETO's: 96 (e⁻ veto) + 90 (e⁺ veto) + 16 (HEP veto):

- $1.1 \times 1 \times 17.8$ cm³ scintillating plastic bars slightly rotated for 1.1 cm pitch
- WS fibers 1.2 mm in diameter glued to the scintillator
- In vacuum and magnetic field (no HEP veto)
- SiPM: Hamamatsu S13360 3x3 mm² 25 μm cell
- custom RF amplifier with differential output



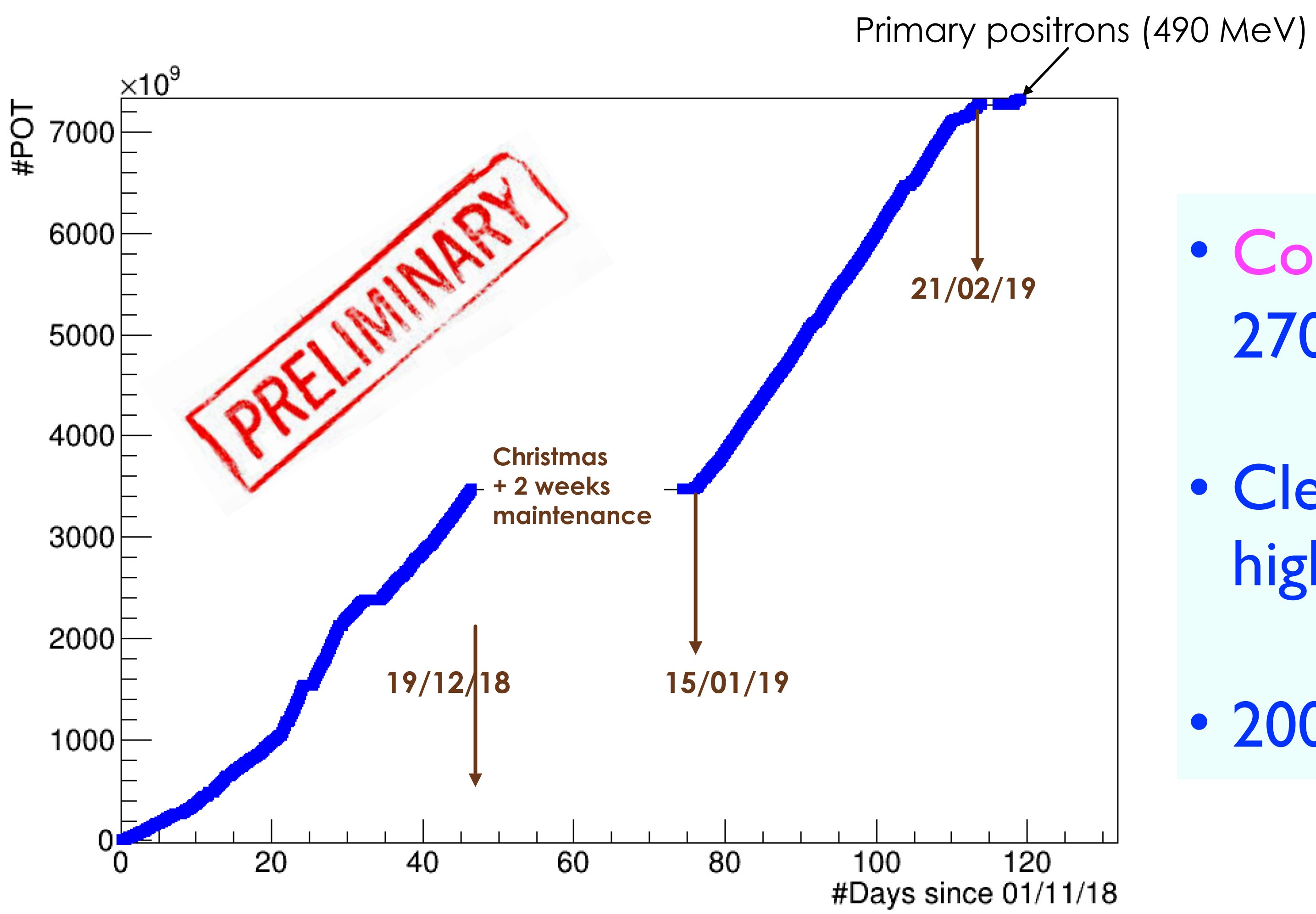

VETO 250ns window, 2.5 GHz sampling



# Run I data

## Successful RUN I: smooth 24 h data taken + remote shifts




- Collected $7 \cdot 10^{12}$ POT of data collected ~ 270 TB (mostly with secondary positron)
- Clear beam background in data (much higher with secondary positron)
- 20000 e+/bunch → $4 \cdot 10^{13}$ in 1.2 year.

In the absence of signal for $4 \cdot 10^{13}$ POT $\varepsilon \geq 5 \cdot 10^{7}$ is excluded

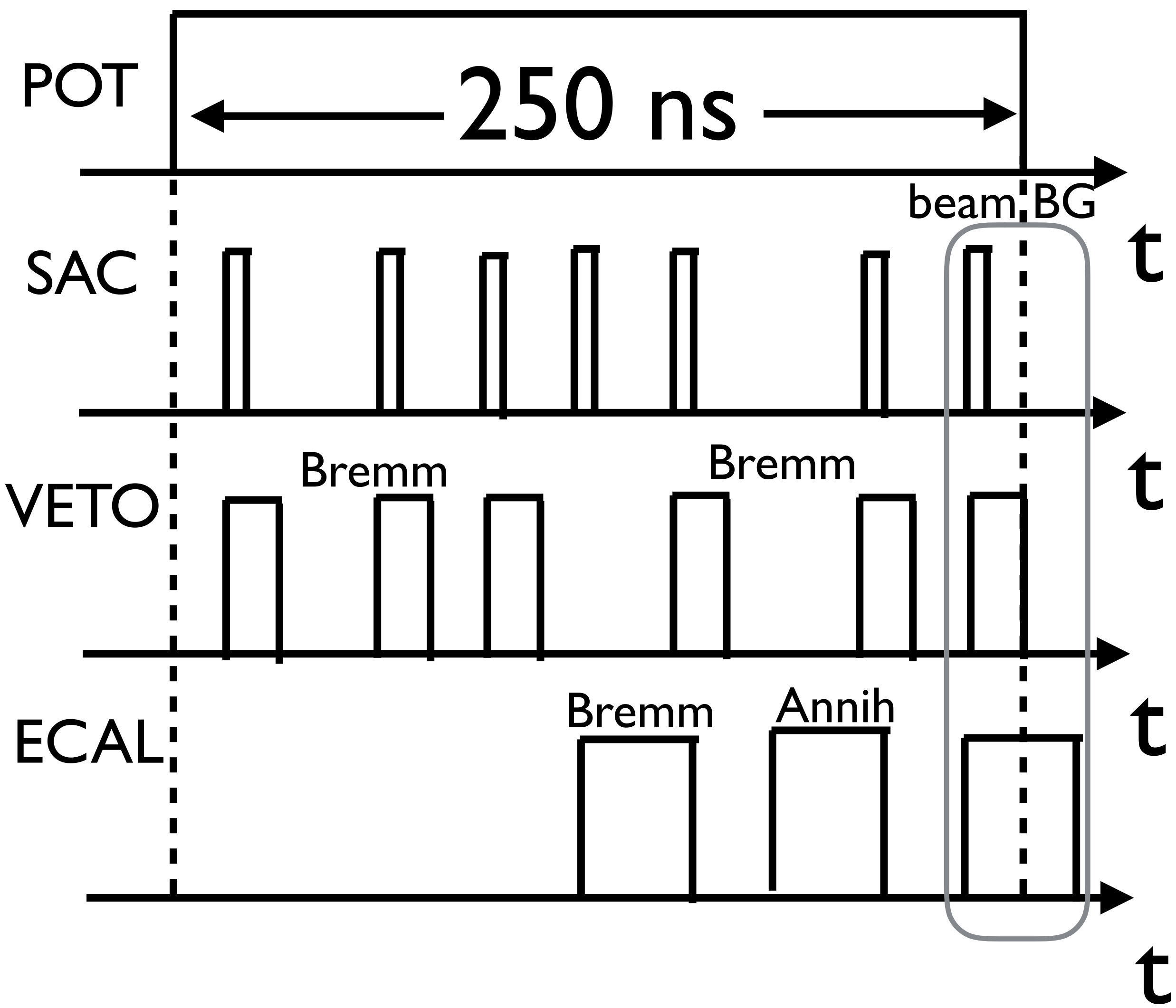
# Data Analysis Strategy

- ECAL and SAC absolute calibration with single positron per bunch
- VETO Momentum/B-Position calibration with single positron per bunch and B scan at fixed momentum
- Single channel time calibration
- establish pile-up performance for each detector
- determine beam-background and mitigation strategy
- develop high performance multi-hits reconstruction for each detector technology based on digitized waveforms:
    - hit efficiency
    - consecutive hit separation
    - hit time resolution

# Pile-up's and catastrophic $e^+$

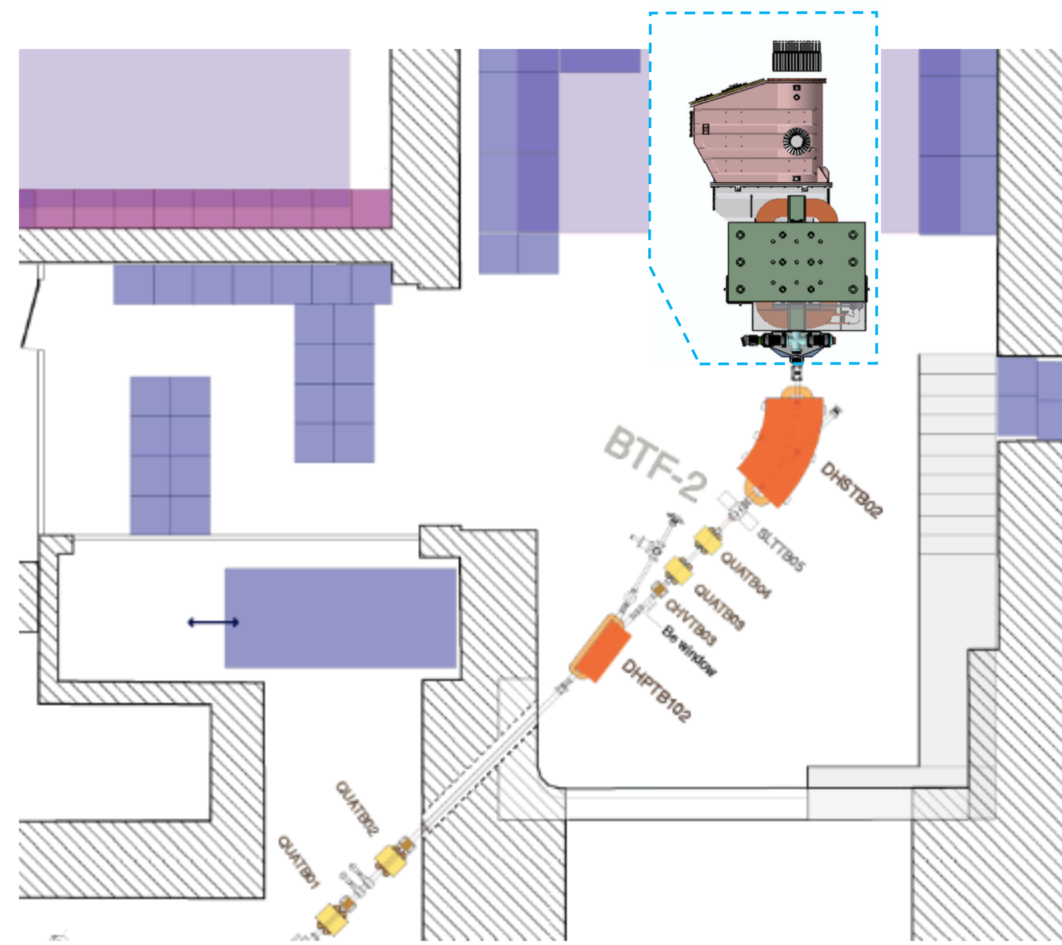
## Temporal Pile-up

The 50 Hz repetition rate impose large POT/bunch to increase intensity.
Necessary to handle multi-hits reconstructions and good timing.




## Catastrophic $e^+$

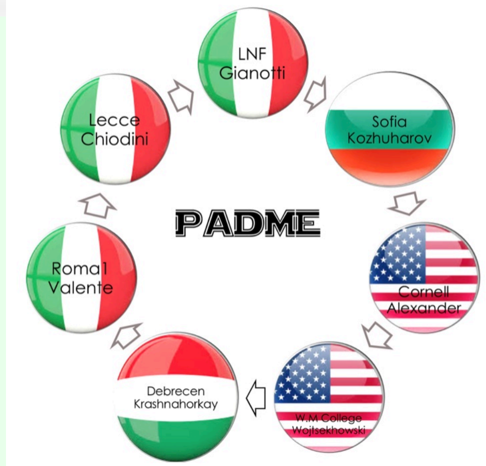
$e^+$ from non-gaussian energy tails of the beam might bent out of the ideal orbit and produce a splash of particles if they touch the beam pipe.

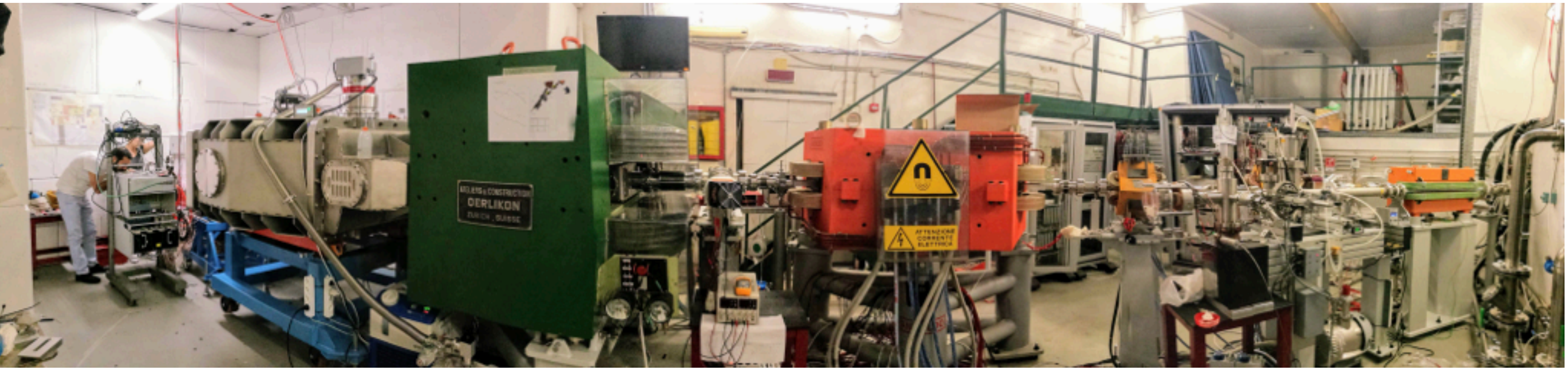



Catastrophic $e^+$ interaction must be VETOed.

# Conclusions

- PADME is the first experiment to search A' in invisible channel with:
  - missing mass technique
  - pulsed beam
- PADME detectors and DAQ reached TDR performances
- Stable positron beams from LINAC and BTF
- Collected $7 \cdot 10^{12}$ POT of data with secondary positrons



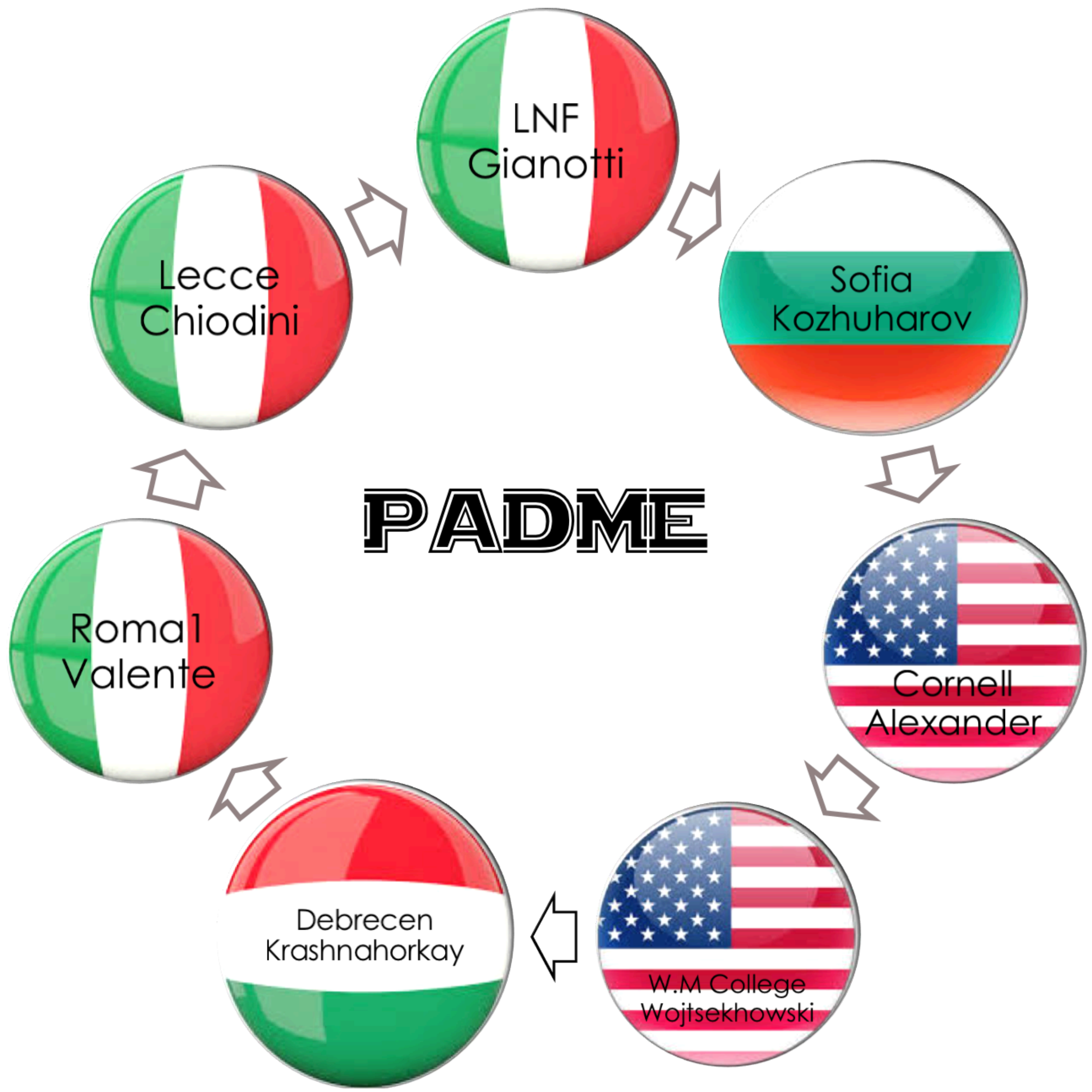



NEXT:

- finalize detectors absolute calibration
- measure physics signal (bremsstrahlung and annihilation) in data
- minimize beam-background along the beam line
- collect up to $4 \cdot 10^{13}$ POT

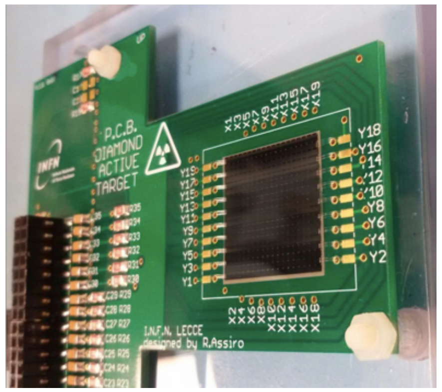
# BACK-UP

# PADME COLLABORATION

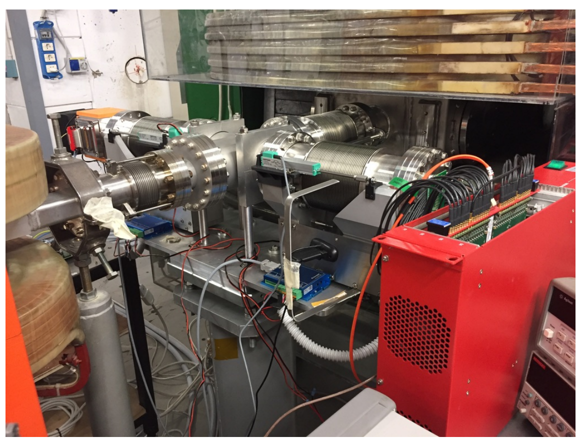


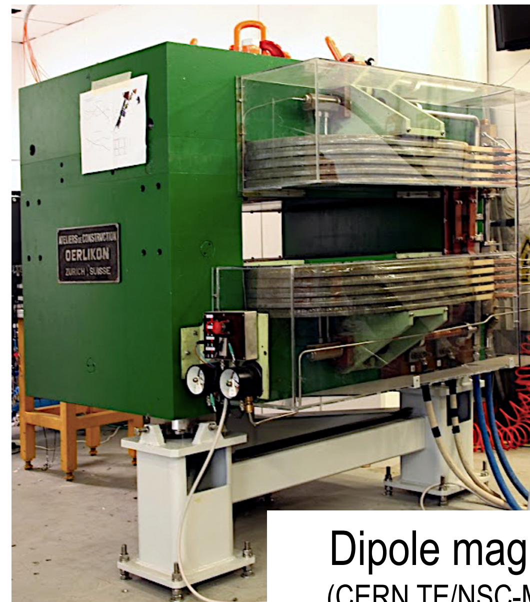
# PADME IN A NUTSHELL

Active target
Lecce & University Salento

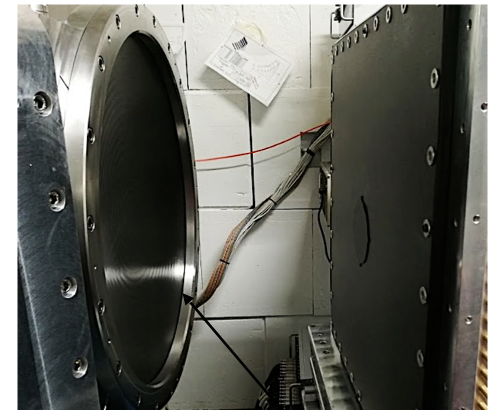


Vacuum Cross
Lecce & University Salento

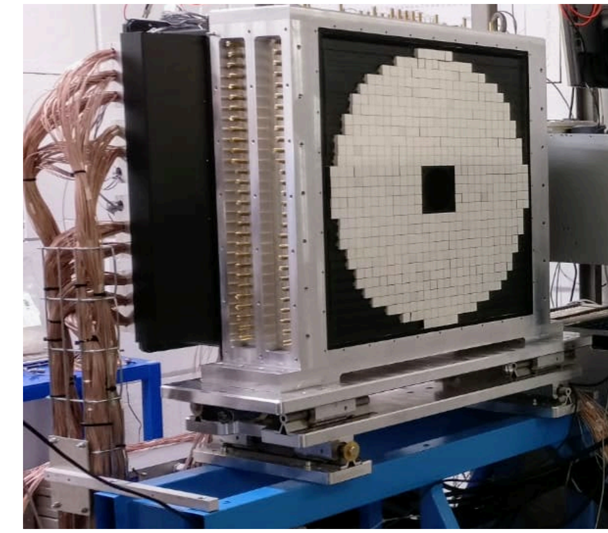




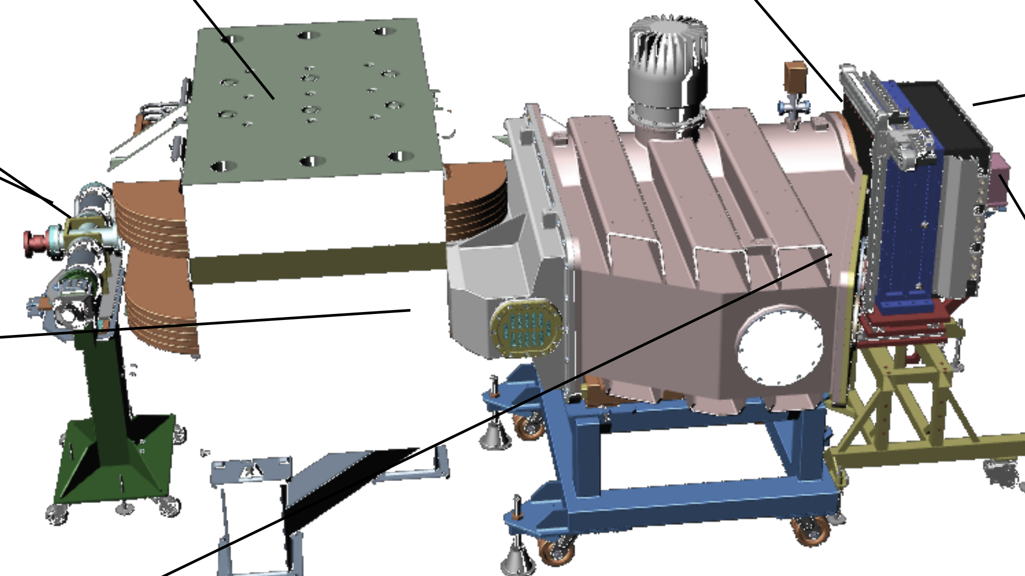
Dipole magnet
(CERN TE/NSC-MNC)

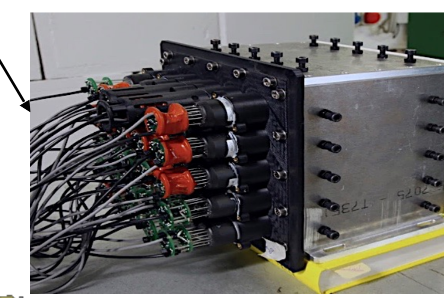


C-fiber window



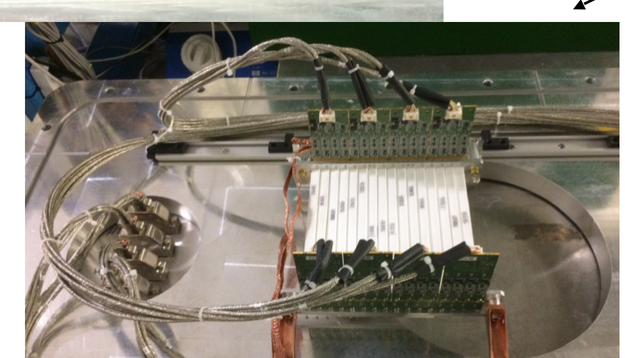
BGO calorimeter
(616 L3 endcap crystals:
Roma, Cornell U., LNF, LE)





$PbF_2$ calorimeter
(MTA Atomki, Cornell U., LNF)

Veto scintillators
(University of Sofia, Roma)



TimePIX3 array
(ADVACAM, LNF)

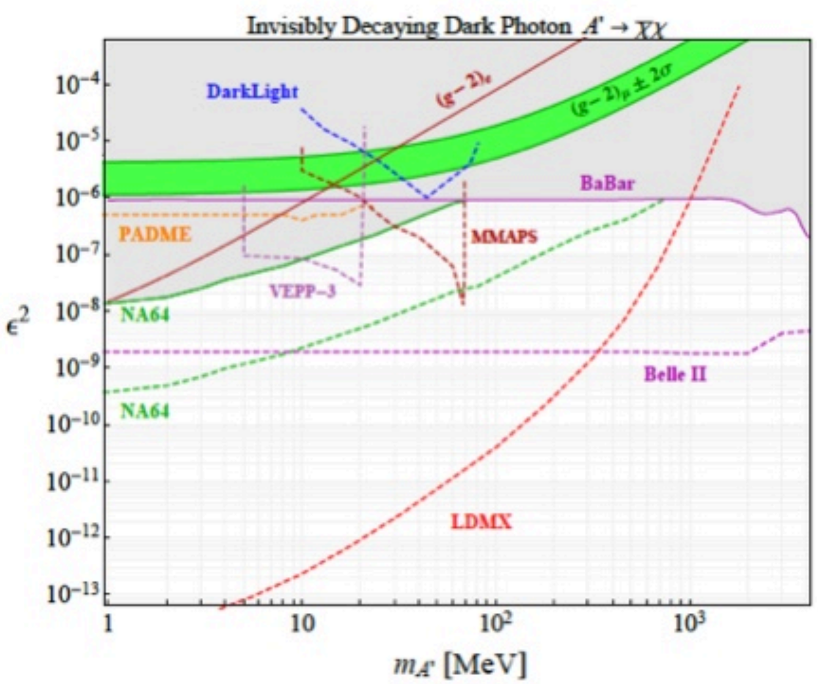
# PADME physics

**PADME** is a multipurpose dark sector search experiment with positrons on fixed target able to detect photons and charged particles:

Main goal: **Invisible dark photon decays A → χχ**

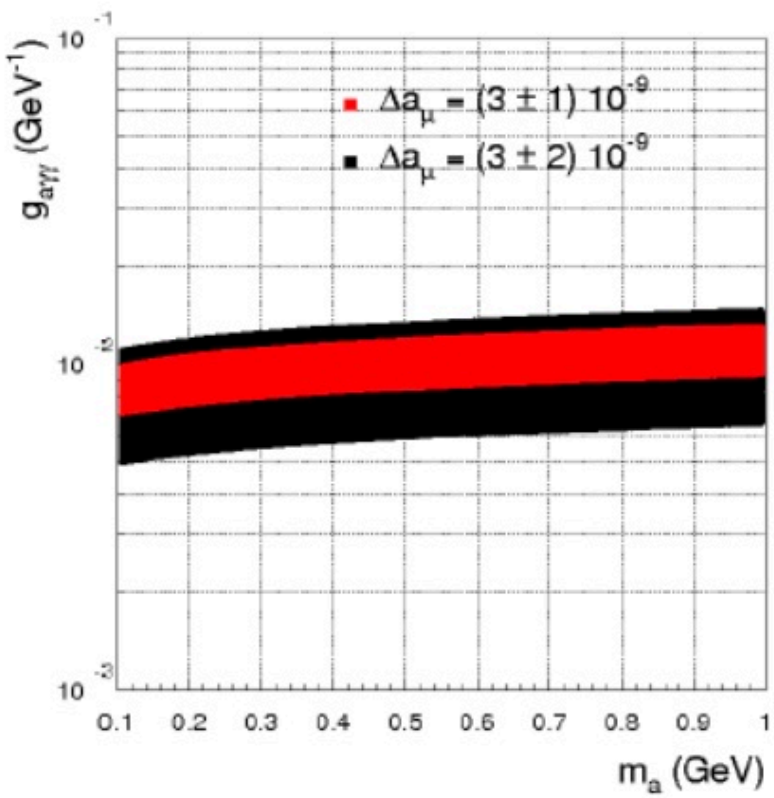
Aims to use annihilation production and missing mass searches. Several physics case under analysis

**Dark Photon** arXiv:1707.04591v1



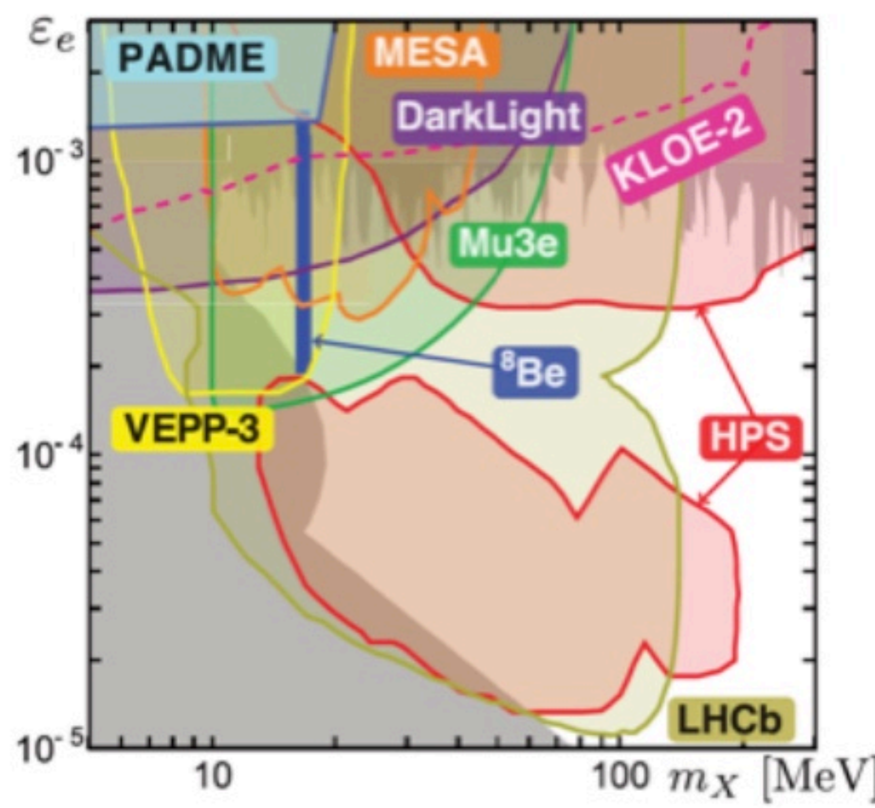

**Invisible final state $A' \to \chi\chi$ ($\gamma$+missing mass)**

**ALPs and g-2** PRD 94, 115033,2016




**ALPs final state $a \to \gamma\gamma$ ($\gamma\gamma\gamma$ or $e\gamma\gamma$)**

**Fifth force** PRL 117, 071803 (2016)

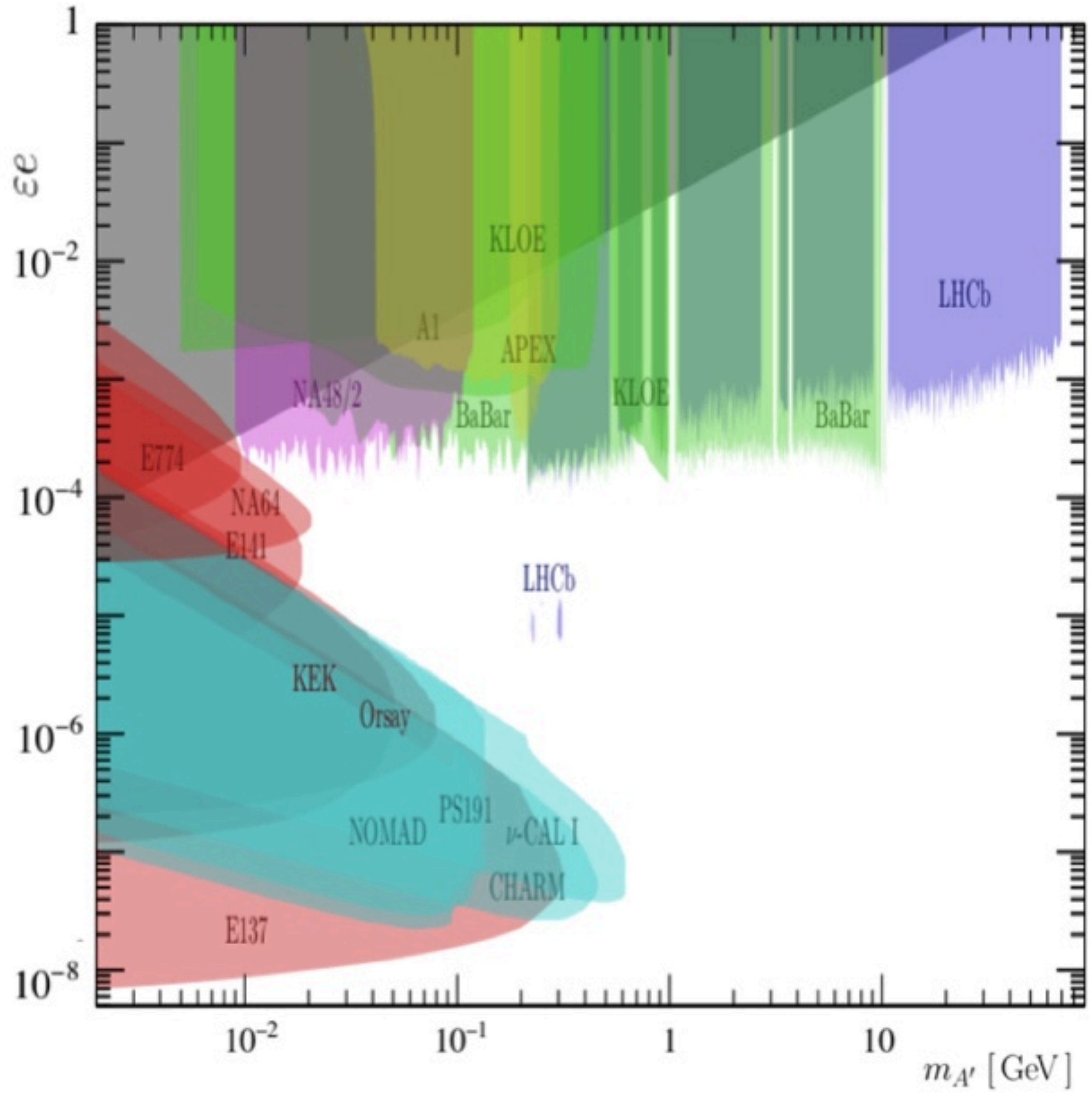



**Final state $X \to e^+e^-$**

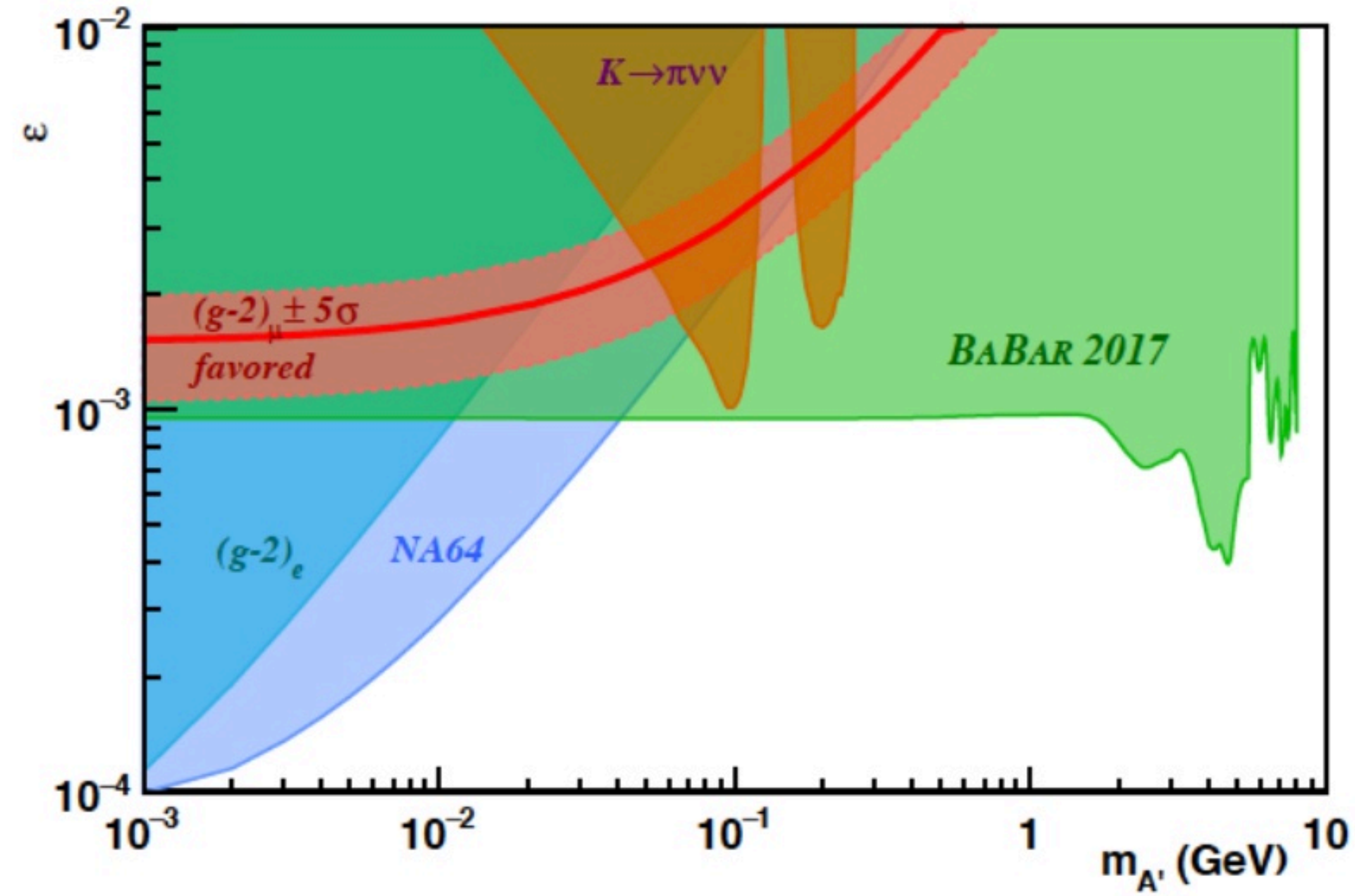
Running at LNF with 550MeV secondary beam 25K e+/bunch

# Status of exclusion

**Visible decays**



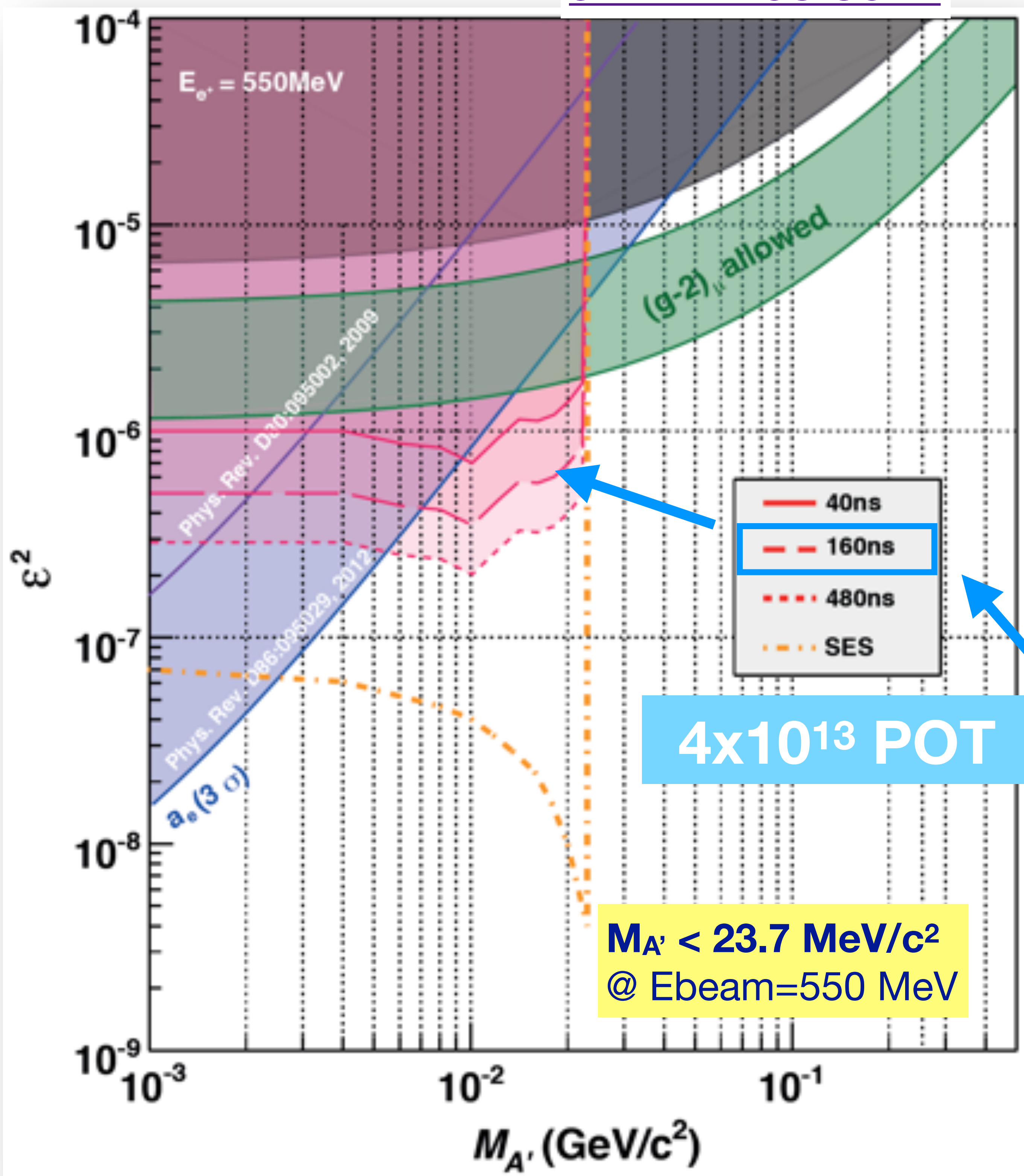

**Invisible decays**




Main competitors are now in standby or in commissioning.
APEX took 2 month of data for visible decays at the beginning of 2019

# PADME reach (from design)

arXiv:1403.3041




- in the absence of indications of signal events in data
- expected limits on $\varepsilon^2$ as a function of $m_{A'}$
  - from N(A'γ)=σ($N_{BkG}$)
- 2 years of data taking at 60% efficiency with bunch length of 160 ns
  - **$3.6 \times 10^{13}$ POT** = 20000 e+/bunch × 2 × $3 \times 10^7$s x 0.6 x 49 Hz
- Possible extension of the mass range ( < 32 MeV ) increasing beam energy < 1 GeV