The PADME experiment

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on behalf of PADME collaboration

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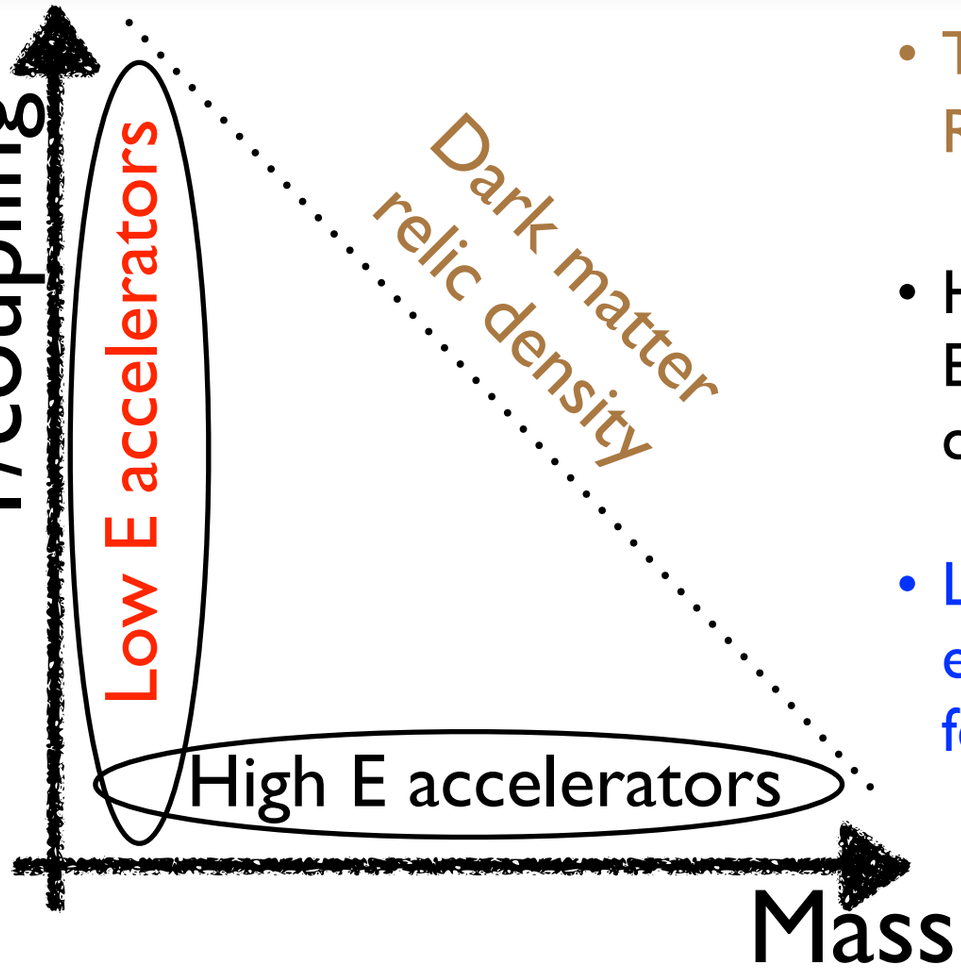
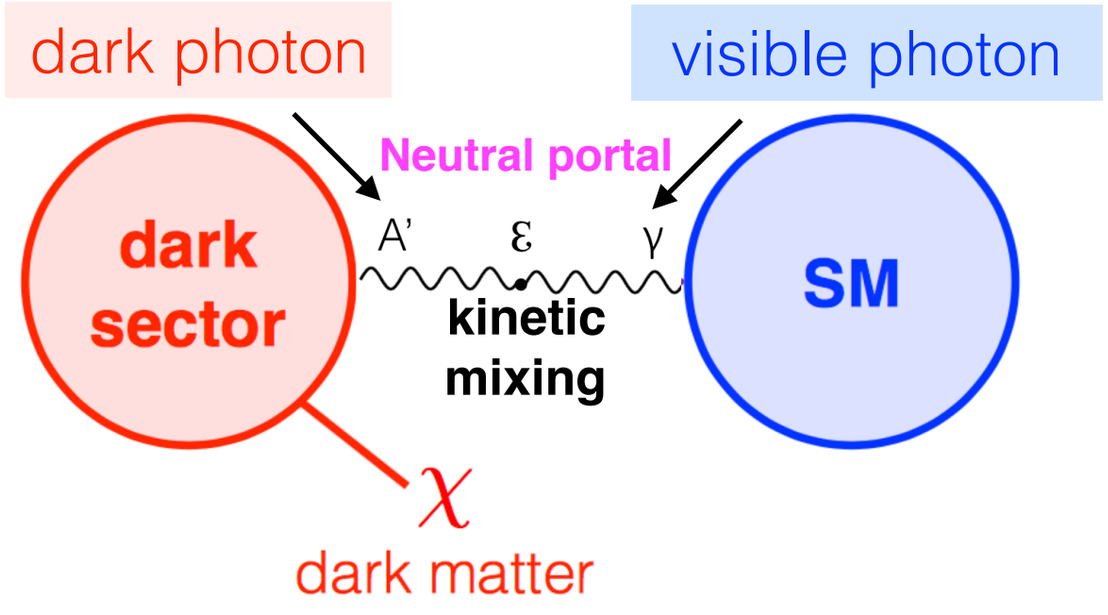
EUROPEAN PHYSICAL SOCIETY HEP2019

Outline and motivations



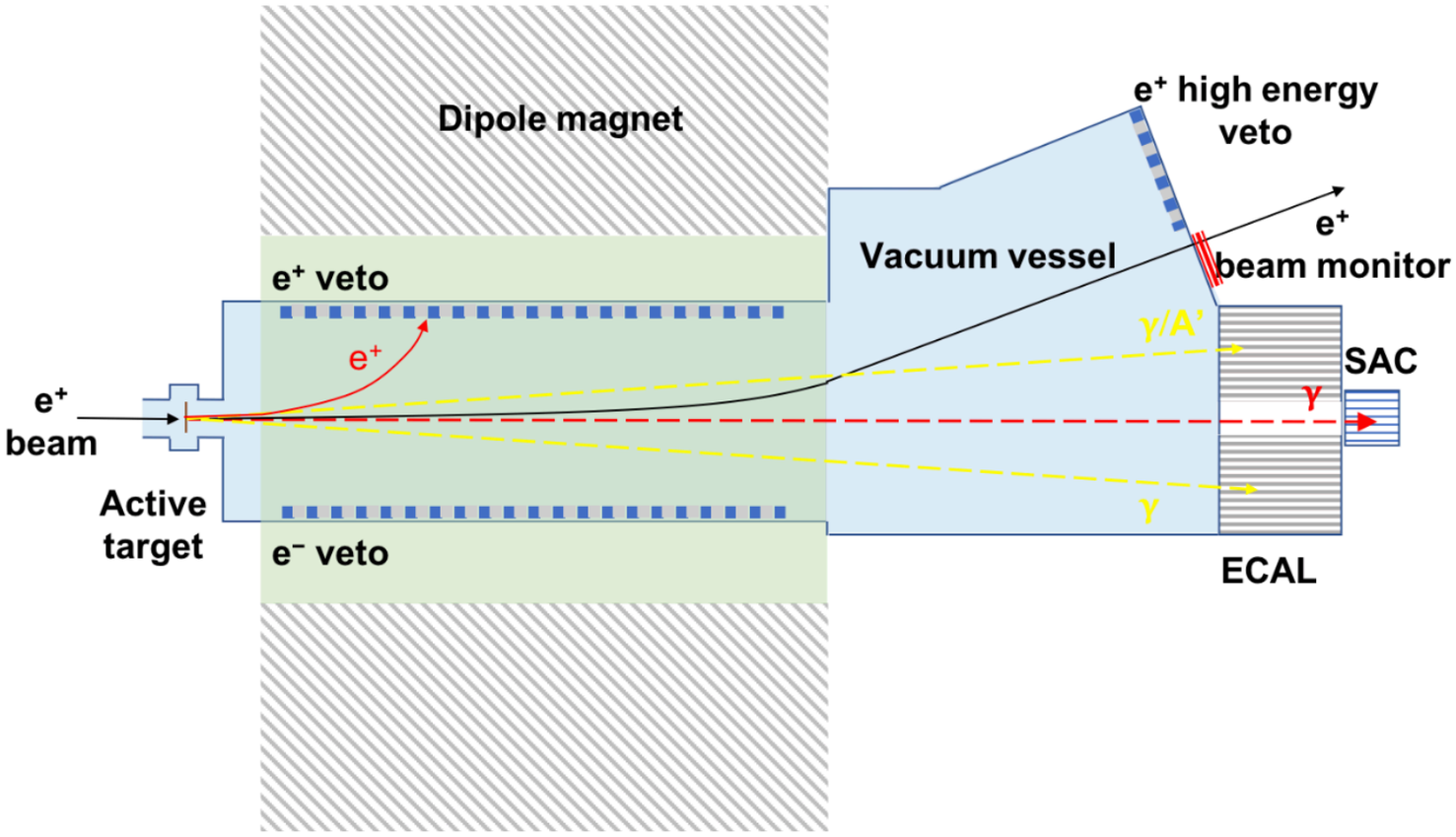
- THERE IS EVIDENCE OF DARK MATTER IN A WIDE RANGE OF DISTANCE SCALES $\Omega_{DM} = 0.1198 \pm 0.0015$
- HIGH ENERGY ACCELERATOR: thermally produced in Early Universe with masses at GeV-TeV and annihilation cross section of electroweak scale.
- LOW ENERGY ACCELERATOR Low-energy frontier experiments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

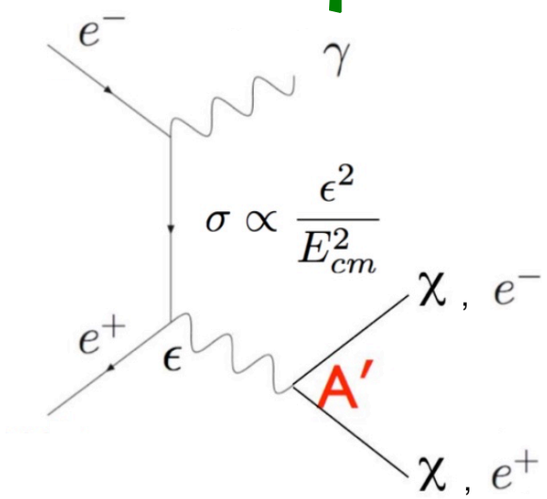


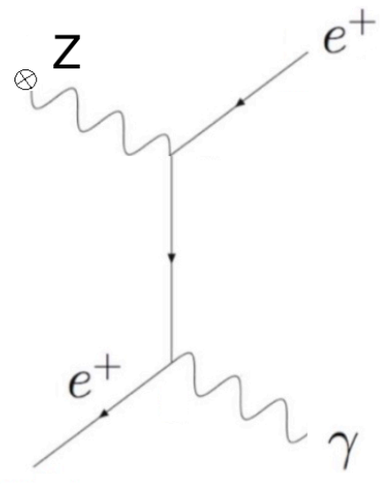
The experiment

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

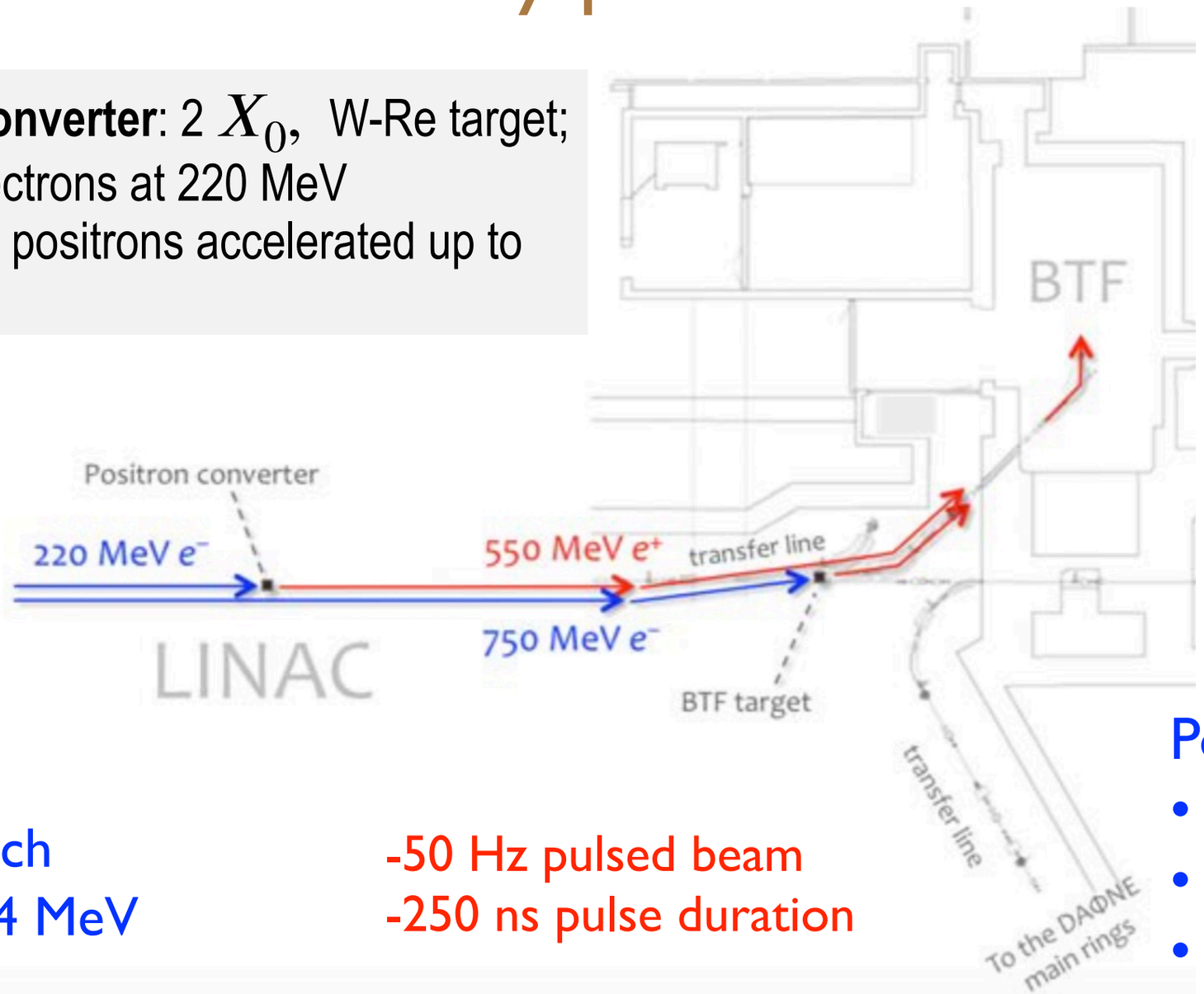
$$M^2_{\rm rec} = 2m_e\left(E_+ - E_\gamma(1+\frac{E_+}{2m_e}\theta^2_\gamma)\right)$$

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

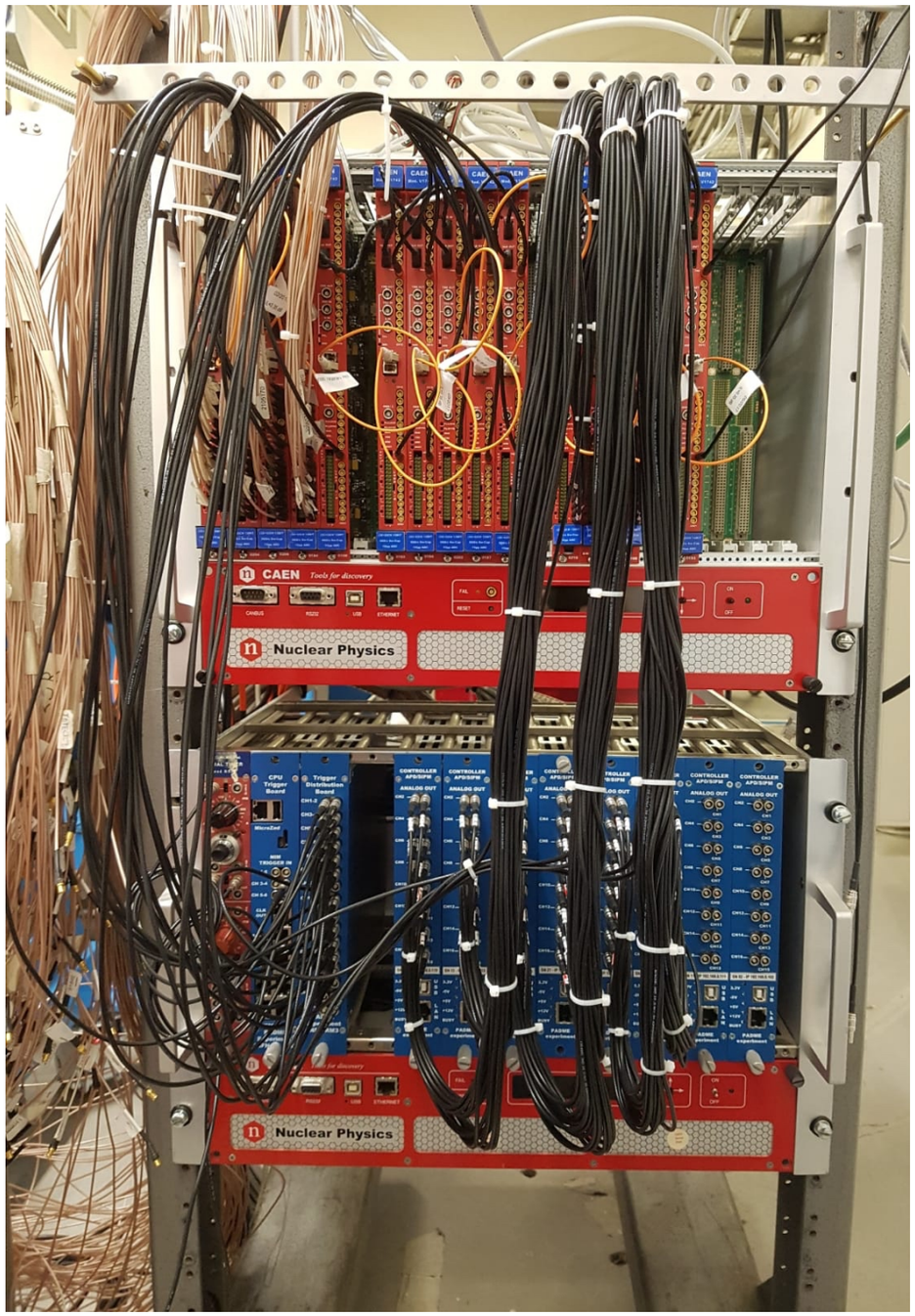
Positron beam parameters:
- 1% energy spread
- 1.5 mm beam spot size
- 1 mrad beam emittance

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)

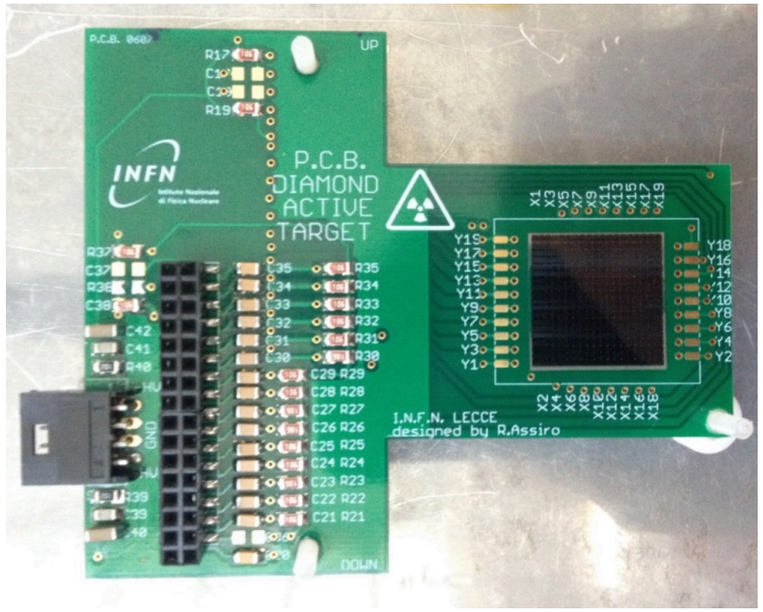
Two Trigger Levels

- 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



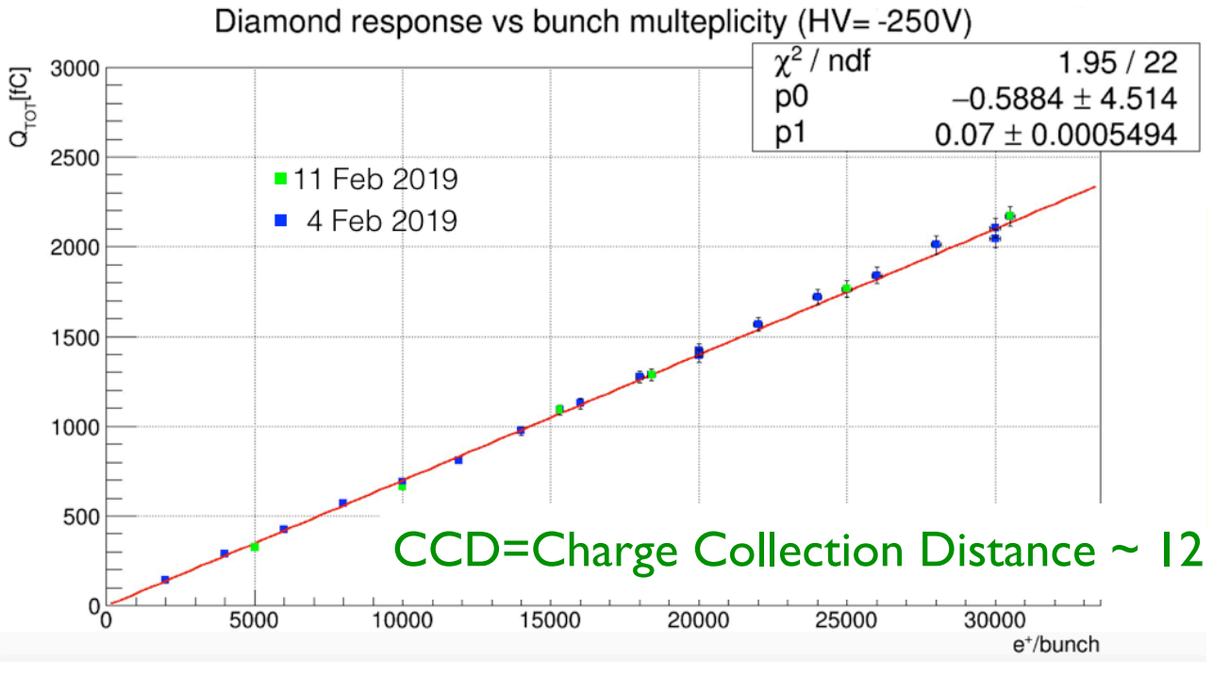
"FULL CARBON" ACTIVE TARGET

- CVD "as grown" diamond sensor:
- 2x2 cm² area
- 100 μm thickness.
- 19X+19Y Laser made graphite strips:, 1 mm pitch, 0.15 mm, inter-strip distance and electric resistance~2.5kΩ.

- In vacuum and not in B
- Moveable along x in/out beam

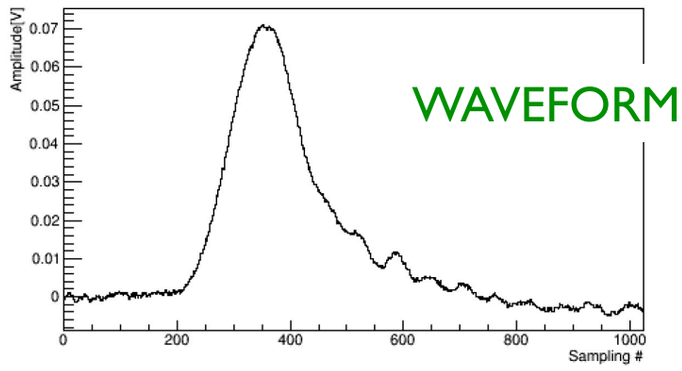
- X and Y profile/bunch
- Number of POT/ bunch

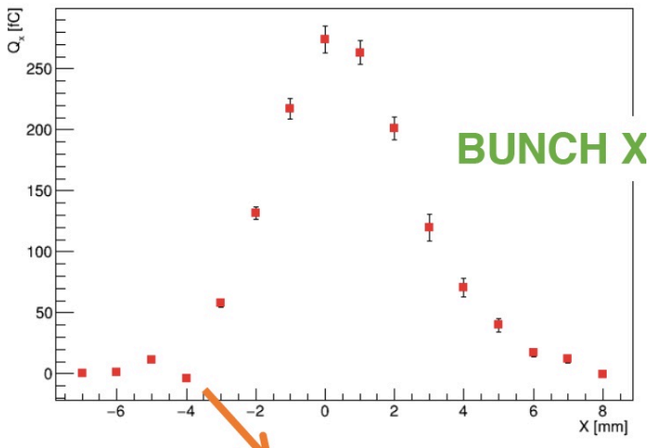
- Online beam monitoring
- Improve Missing Mass resolution
- Luminosity



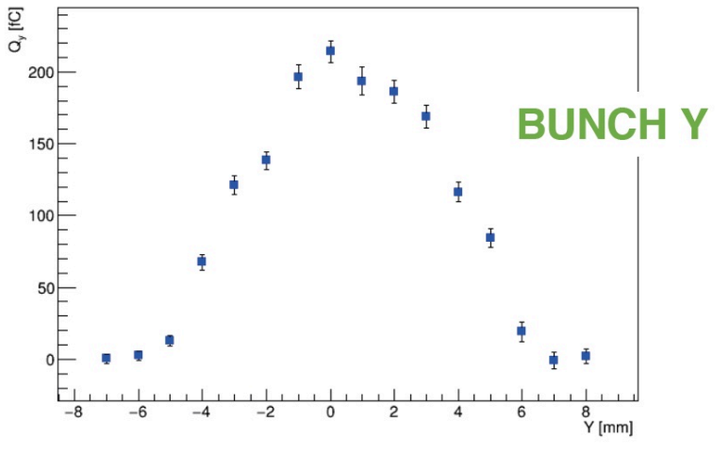
CCD=Charge Collection Distance ~ 12 μm

20000e⁺ / 250 ns

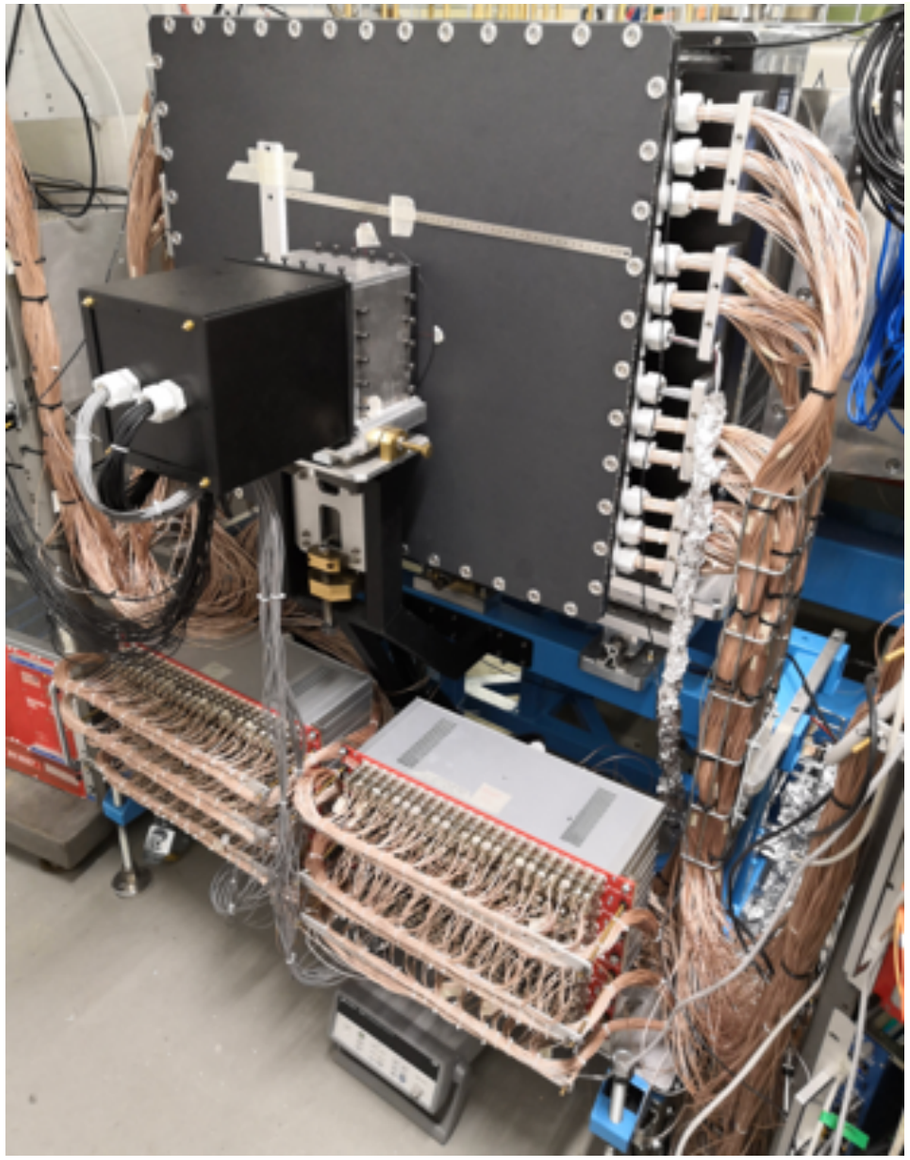




One dead strip out of 32



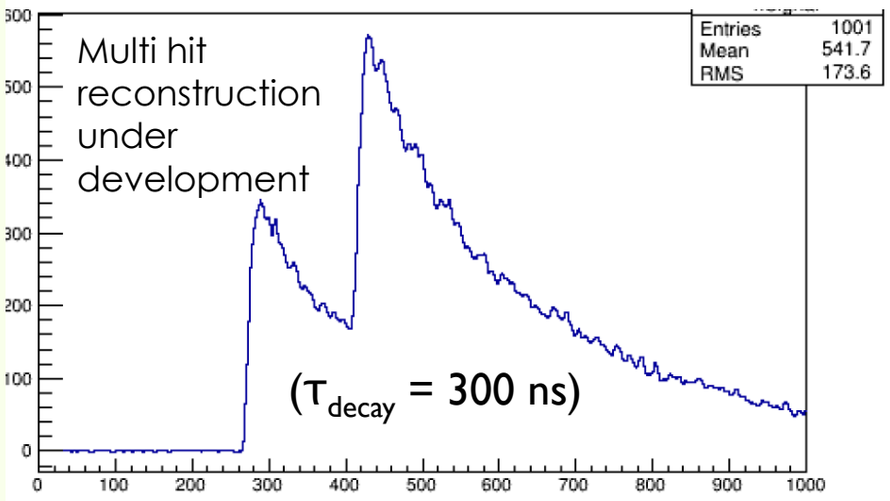
EM calorimeter system



ECAL (HIGH E RESOLUTION ECAL)

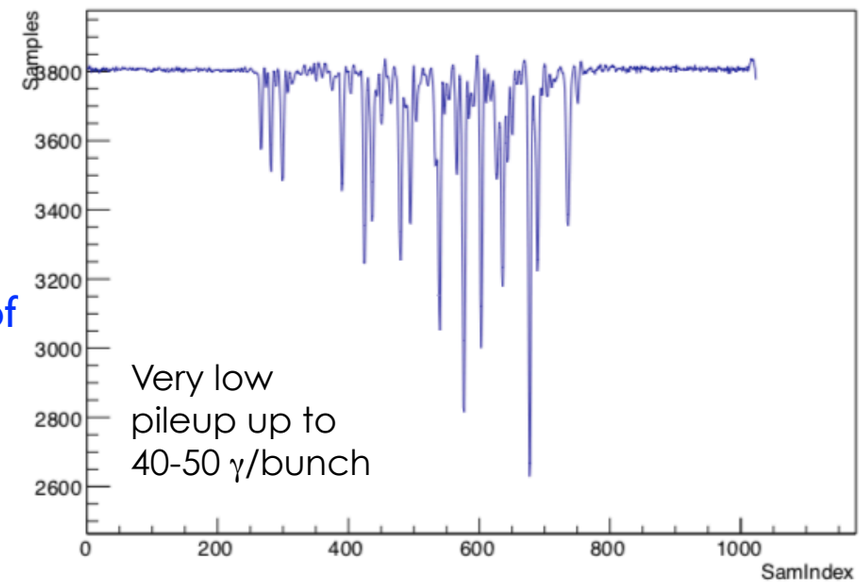
- 616 scintillating BGO crystals of 2.1×2.1×23 cm^3 size.
- PMT readout: HZC XP1911
- radius: ≈ 29 cm at 3.45 m from the target
- central hole (10.5×10.5 cm^2) for brems. to SAC (faster)
- angular coverage: [20,93] mrad acceptance: [26,83] mrad

Ecal 1 μs window, 1GHz sampling



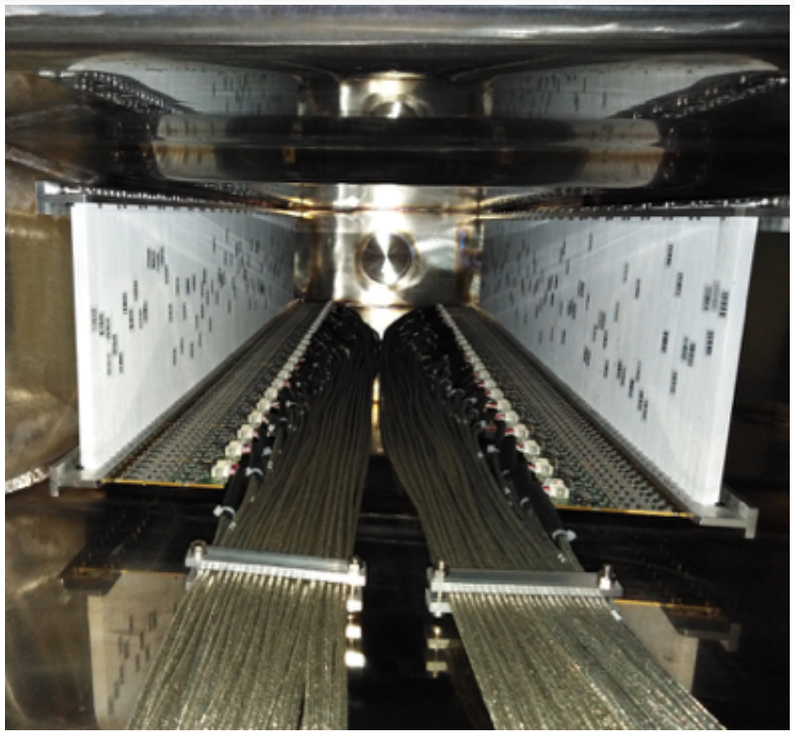
SAC (SMALL ANGLE CALORIMETER)

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



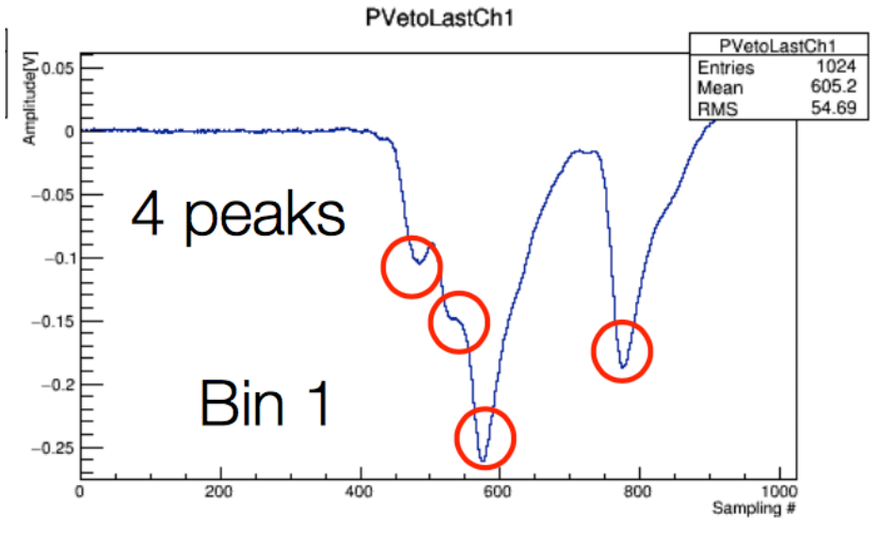
SAC 250ns window, 2.5 GHz sampling

Charged VETO system

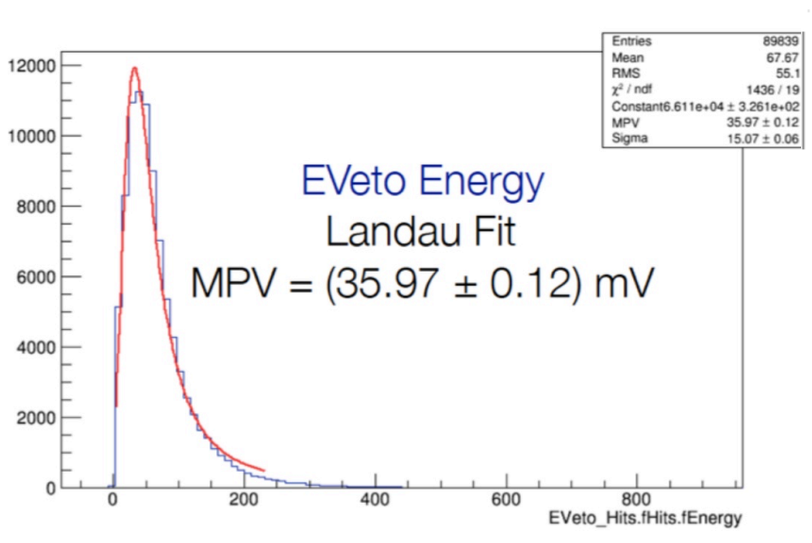


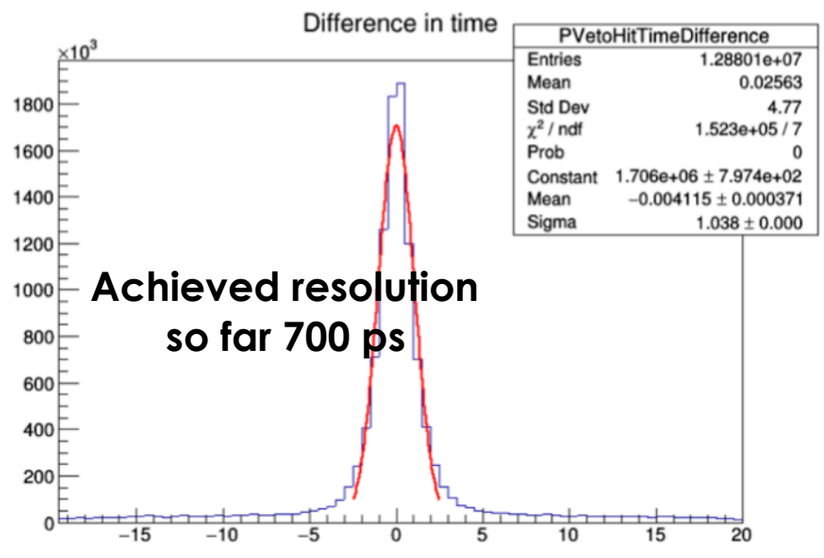
VETO's: 96 (e^- veto) + 90 (e^+ veto) + 16 (HEP veto):

- 1.1×1×17.8 cm^3 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 mm^2 25 μm cell
- custom RF amplifier with differential output



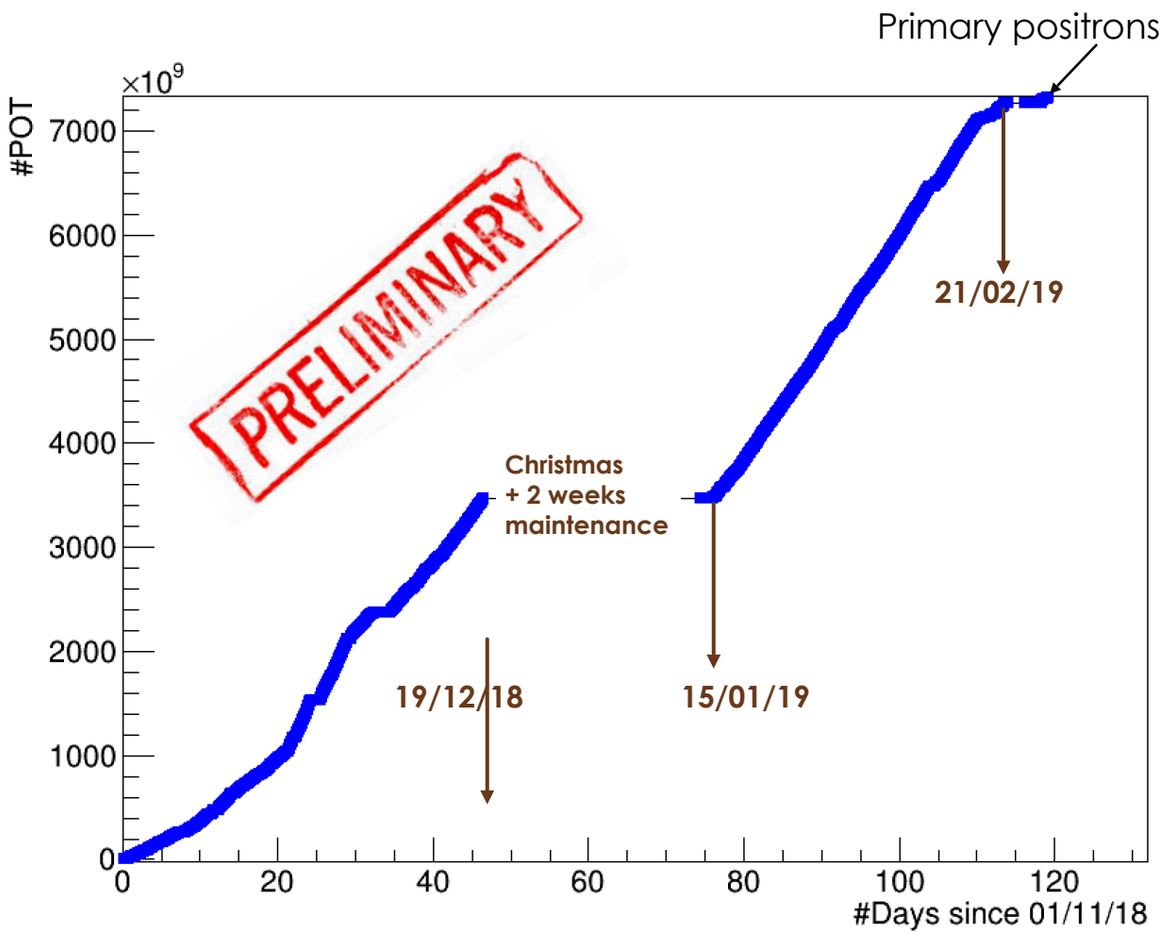
VETO 250ns window, 2.5 GHz sampling





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

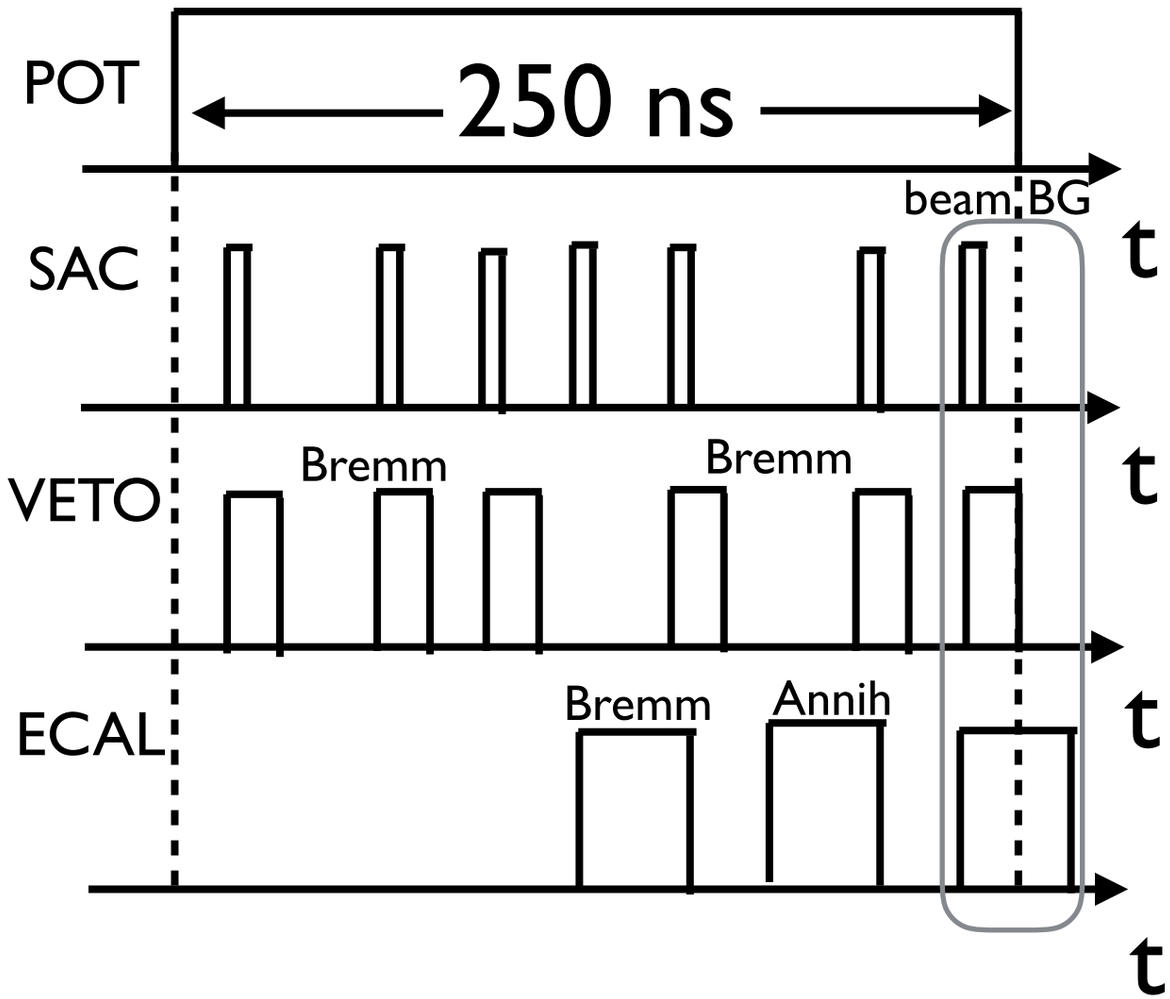
Data Analysis Strategy

- 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^+

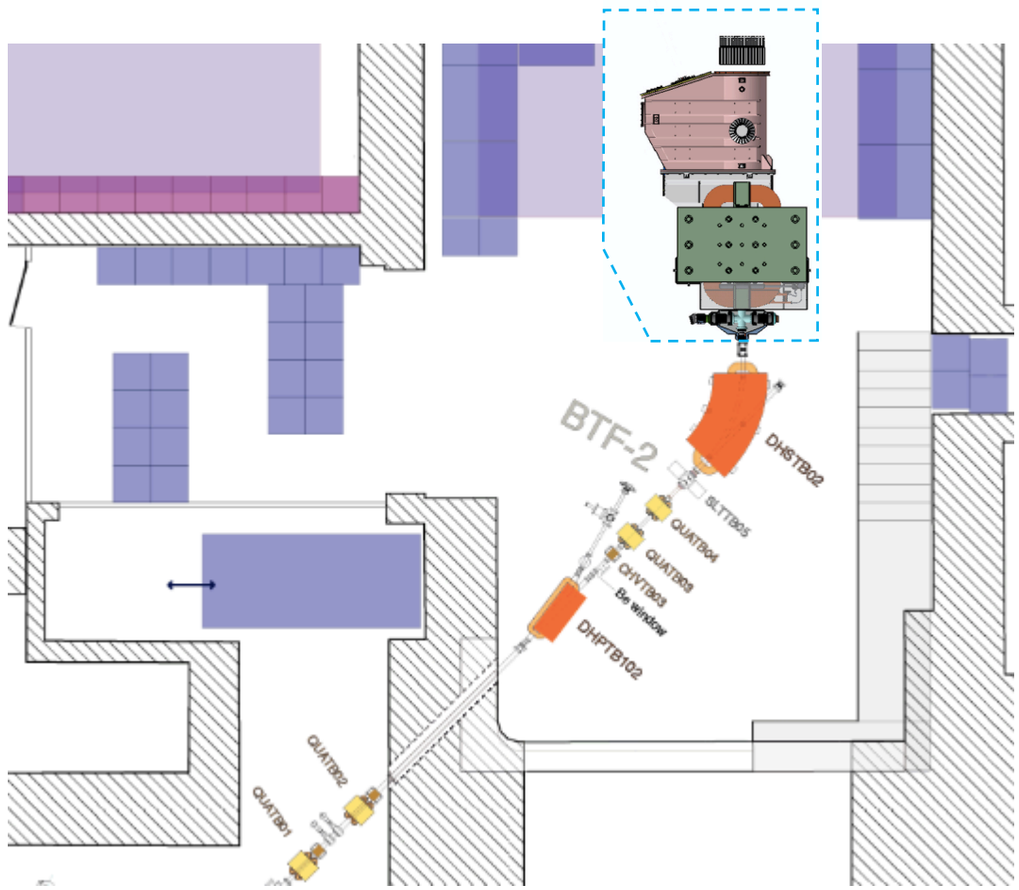
Temporal Pile-up

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



Catastrophic e^+

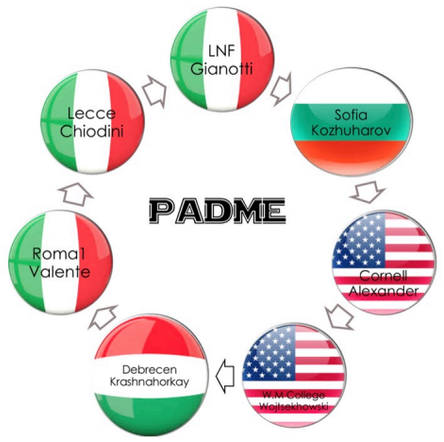
e^+ from non-gaussian energy tails of the beam might bent out of the ideal orbit and produce a splash of particles if they touch the beam pipe.

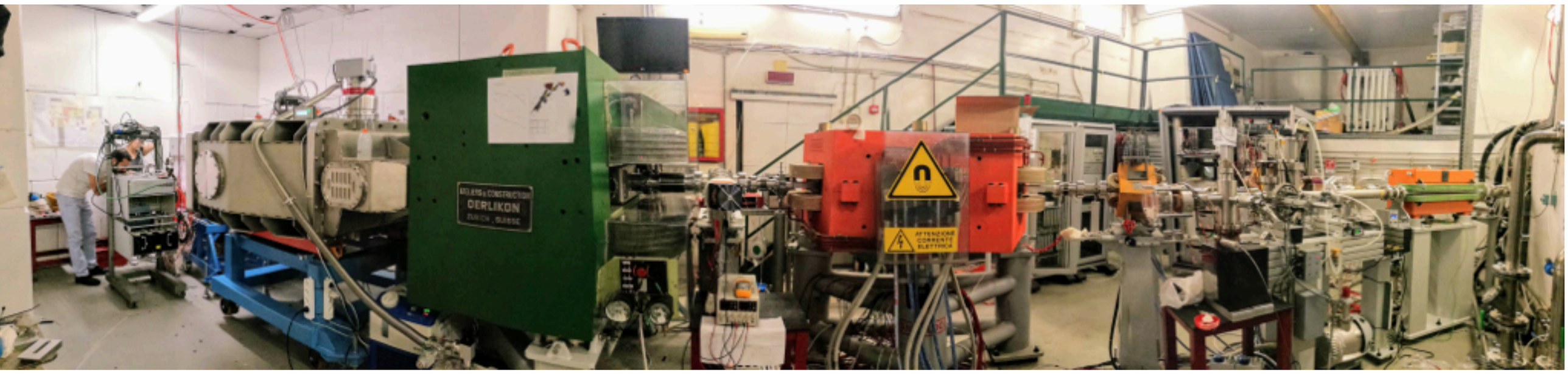


Catastrophic e^+ interaction must be VETOed.

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



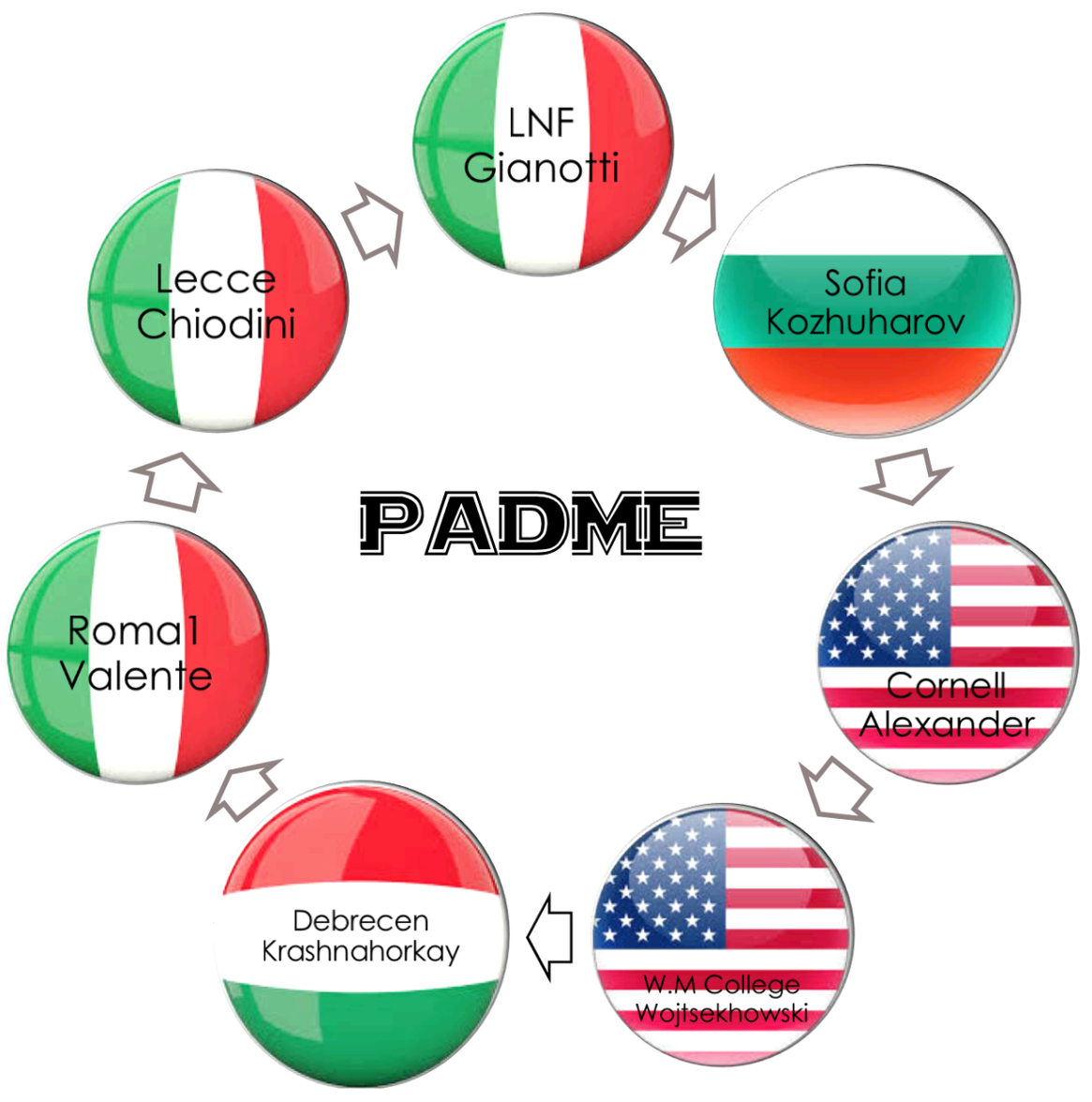


NEXT:

- 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

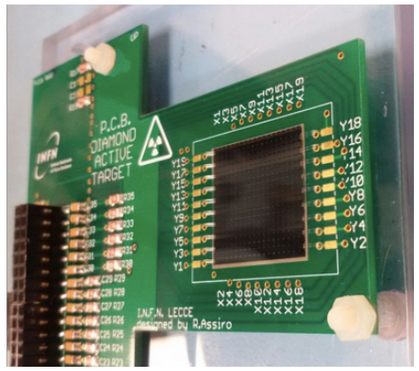
BACK-UP

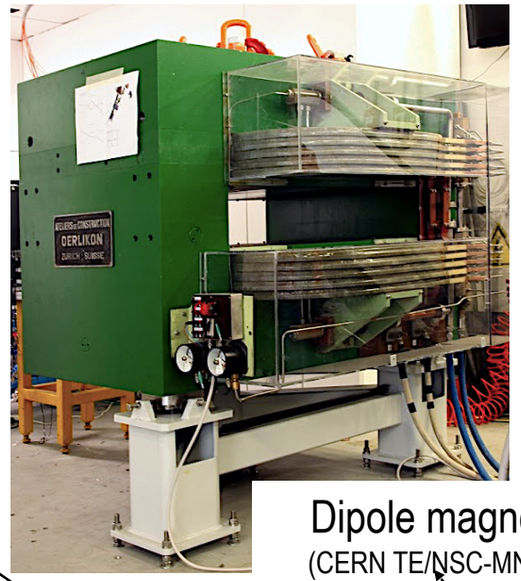
PADME COLLABORATION



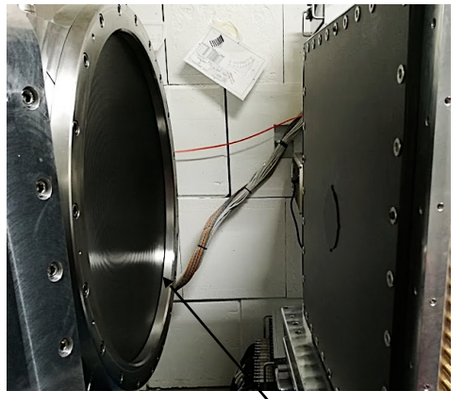
PADME IN A NUTSHELL

Active target
Lecce & University Salento

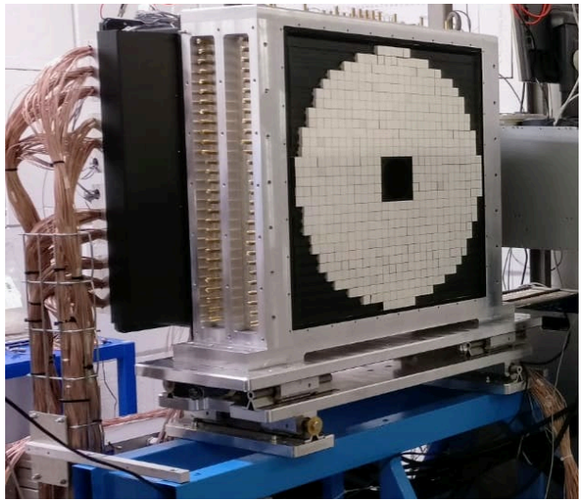




Dipole magnet
(CERN TE/NSC-MNC)

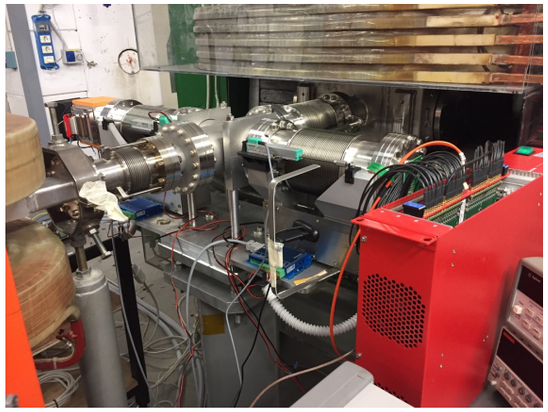


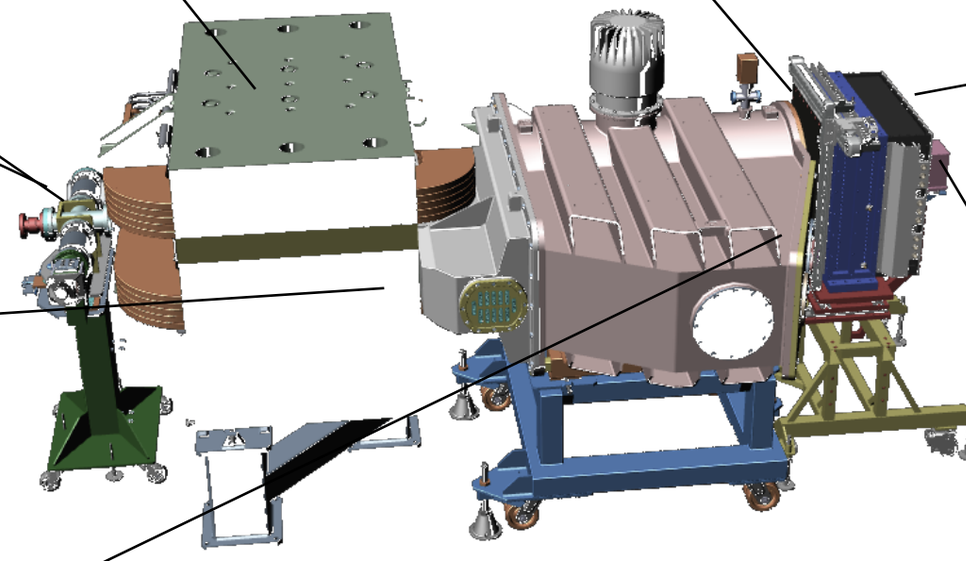
C-fiber window



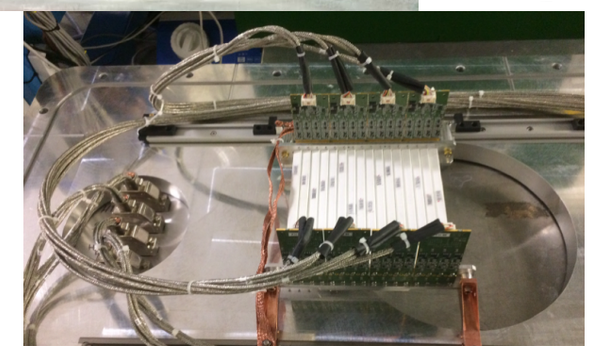
BGO calorimeter
(616 L3 endcap crystals:
Roma, Cornell U., LNF, LE)

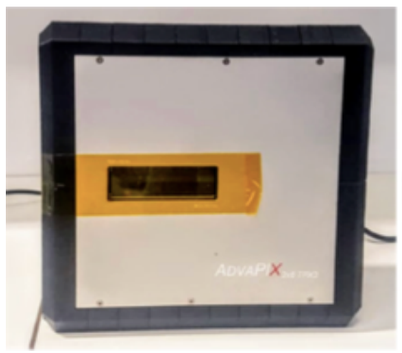
Vacuum Cross
Lecce & University Salento



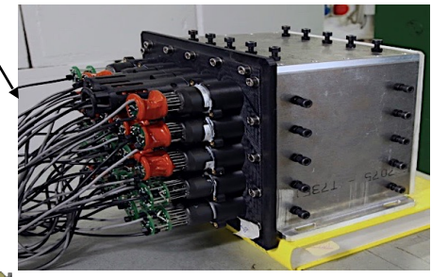


Veto scintillators
(University of Sofia, Roma)





TimePIX3 array
(ADVACAM, LNF)



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

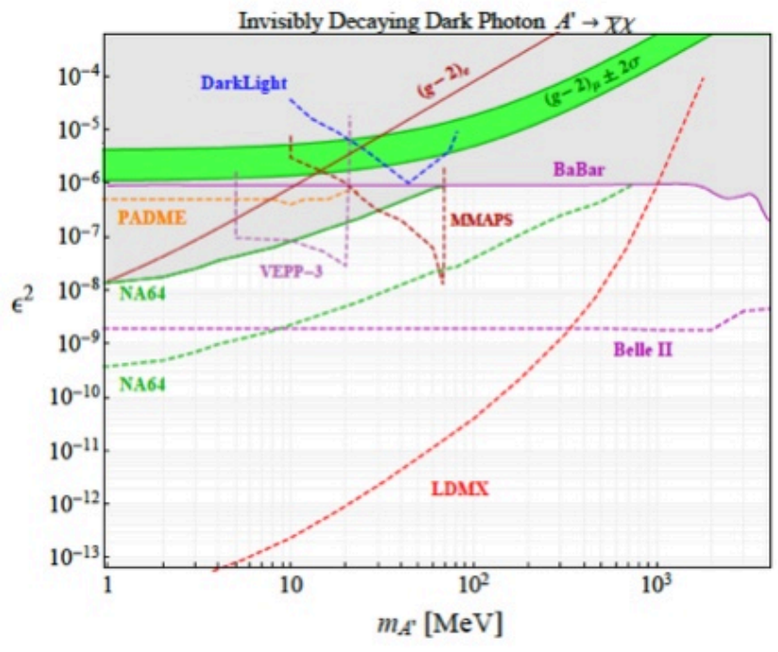
PADME physics

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

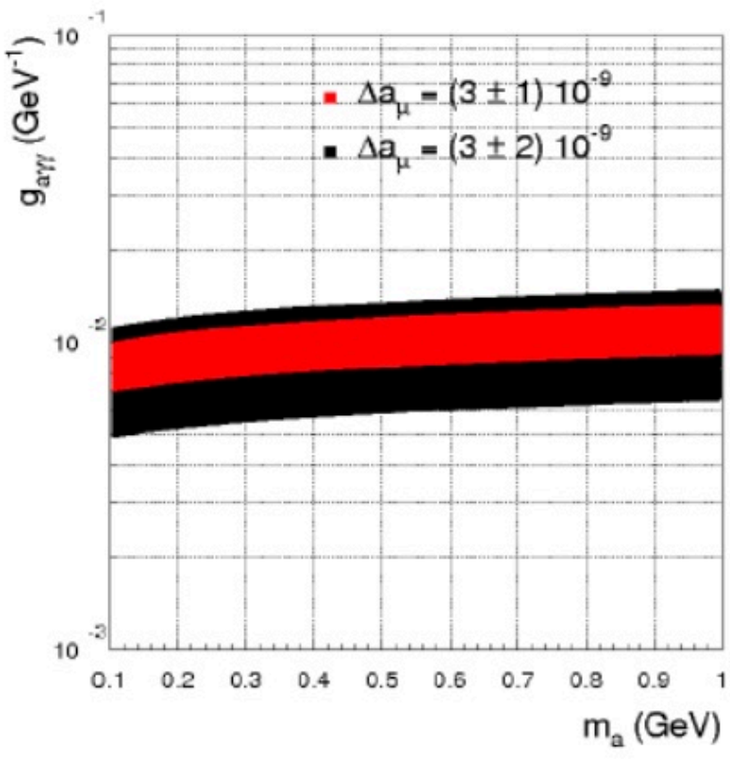
Main goal: **Invisible dark photon decays A → χχ**

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

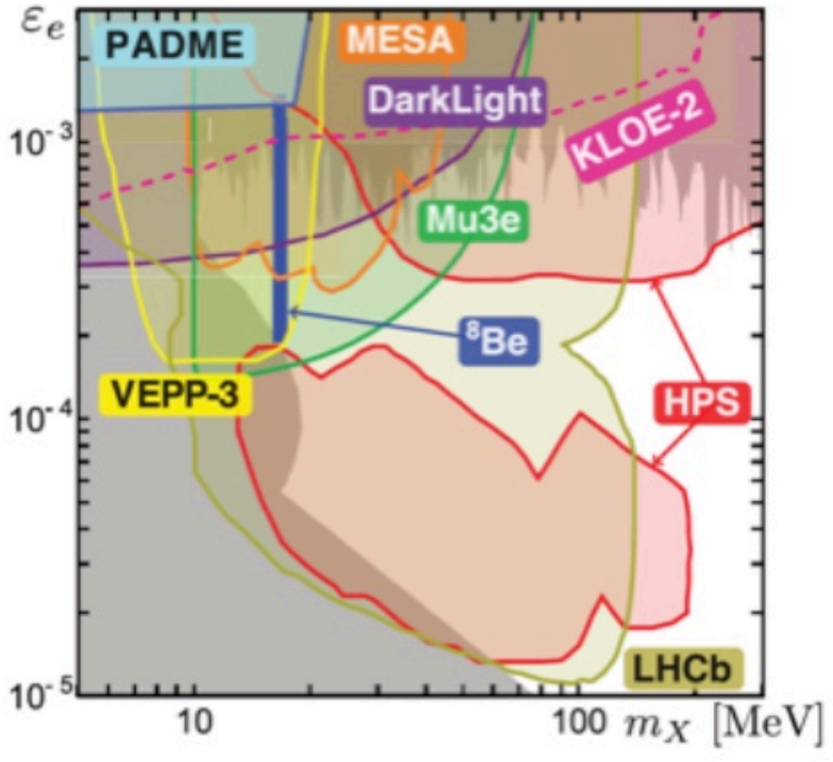
Dark Photon arXiv:1707.04591v1



ALPs and g-2 PRD 94, 115033,2016



Fifth force PRL 117, 071803 (2016)



Invisible final state *A'*→χχ
(γ+missing mass)

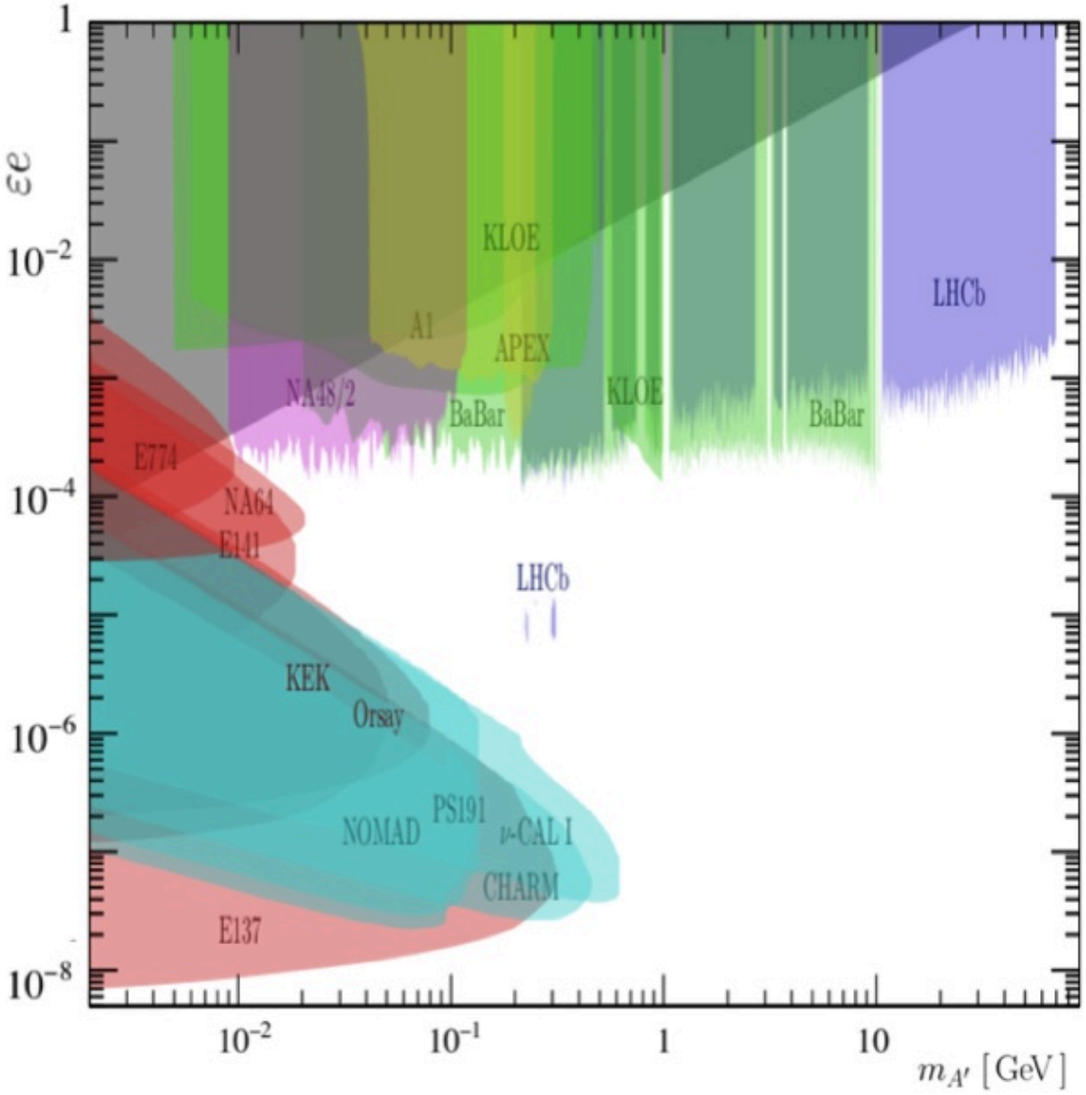
ALPs final state *a*→γγ
(γγγ or eγγ)

Final state *X*→e⁺e⁻

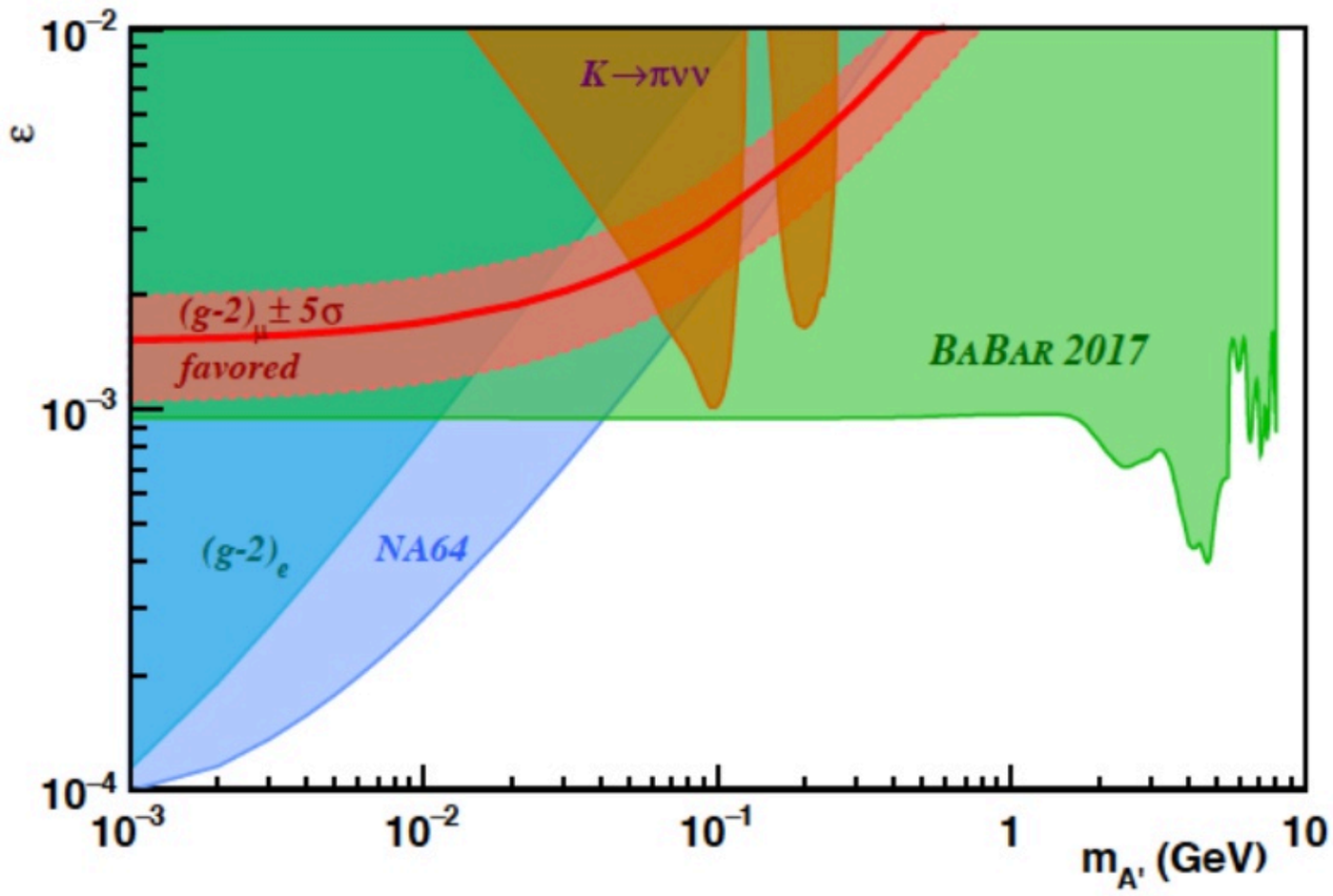
Running at LNF with 550MeV secondary beam 25K e+/bunch

Status of exclusion

Visible decays



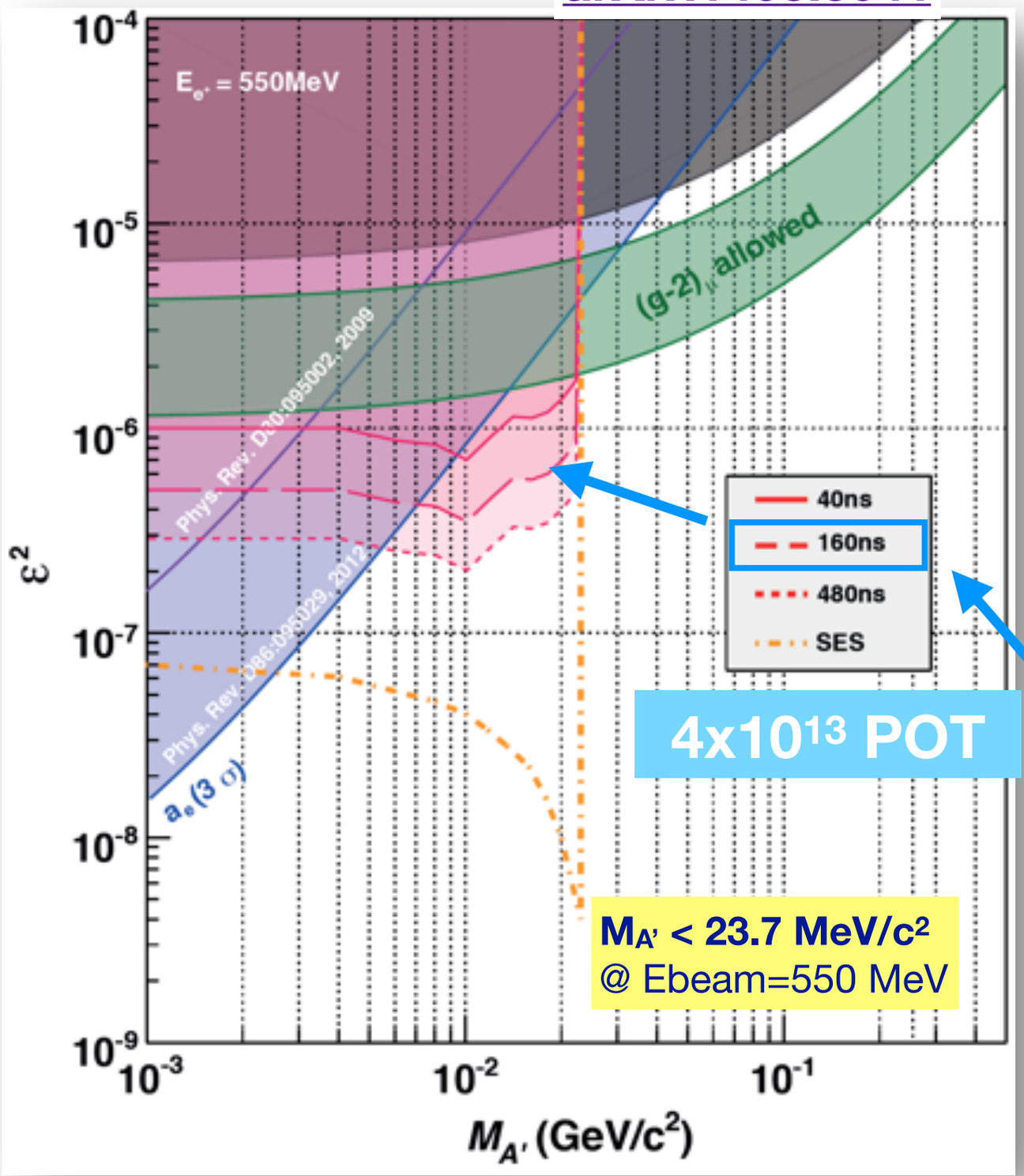
Invisible decays



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