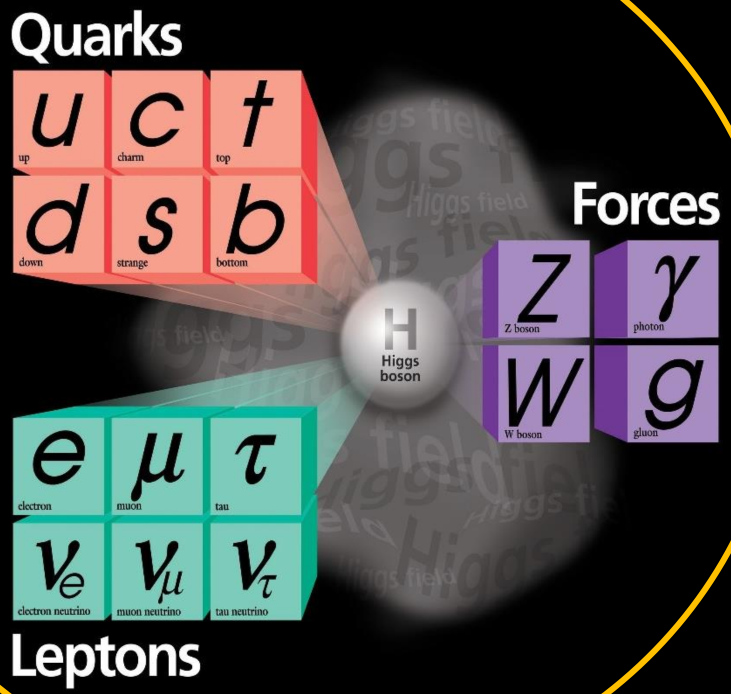
Search for feebly interactive particles: the PADME experiment

Danilo Domenici
on behalf of the PADME collaboration

Dark Sector extension to SM

Standard Model



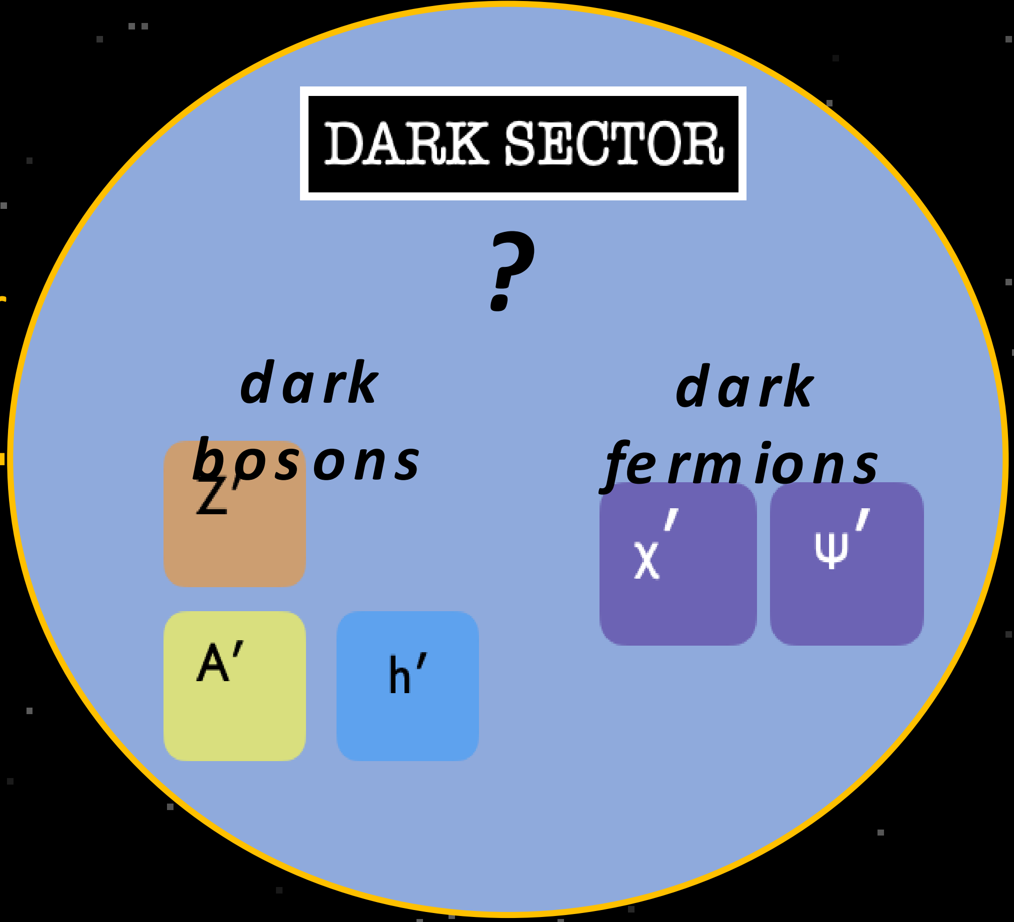
PORTAL

vector A'
pseudo-scalar
ALPs

$$\mathcal{L} = \frac{\varepsilon}{2} F^{\mu\nu} F'_{\mu\nu}$$

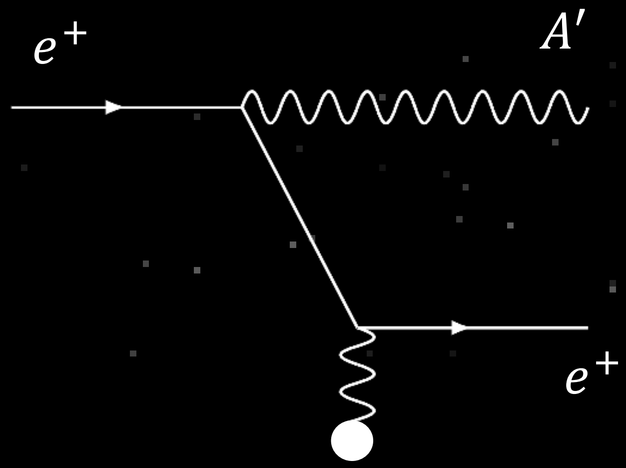
$$\varepsilon \ll 1$$

can address g-2, antimatter in cosmic rays, dark matter

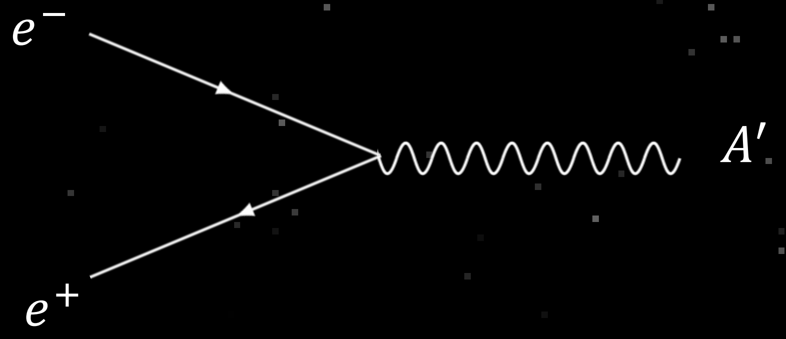


Production mechanisms

A'-strahlung

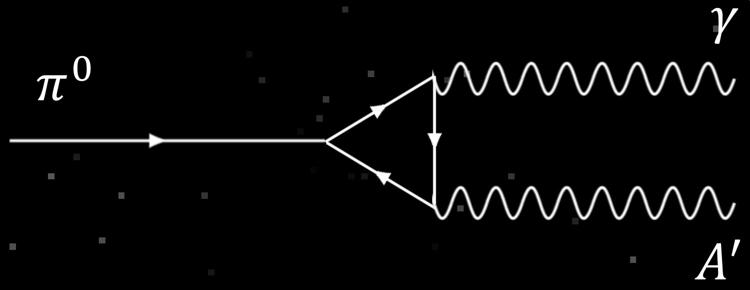


resonant annihilation

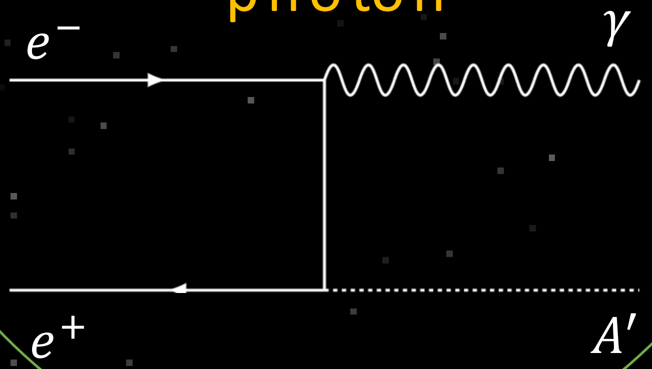


cross-section enhanced if mass is known

meson decay



annihilation with SM photon



coupling constant can be extracted

$$\frac{\sigma(e^+e^- \to A'\gamma)}{\sigma(e^+e^- \to \gamma\gamma)} \sim \varepsilon^2$$

PADME Technique

Positron Annihilation into Dark Matter Experiment

PRODUCTION

A' produced in e^+e^- annihilation

positron (beam) ↔ electron (target)

DECAY

A' invisible channel

missing mass technique

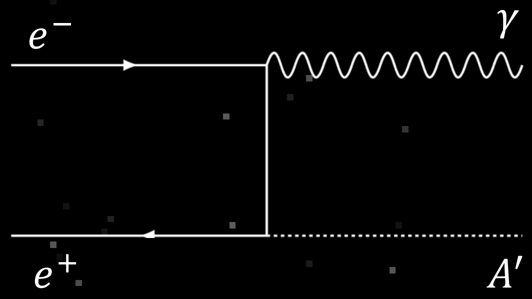
$$M^2{}_{A'} = (\bar{P}_{e^+} + \bar{P}_{e^-} - \bar{P}_{\gamma})^2$$

visible channel in SM particles

A' → e^+e^-

Signal

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

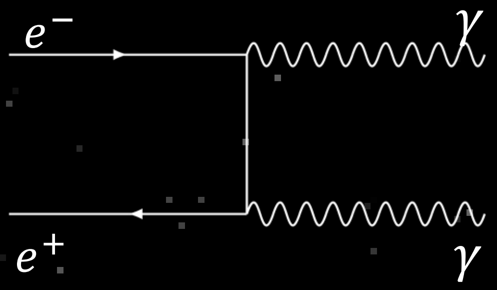


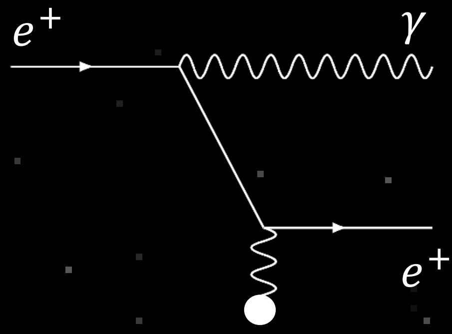
Background

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

$e^+N \rightarrow e^+N\gamma$

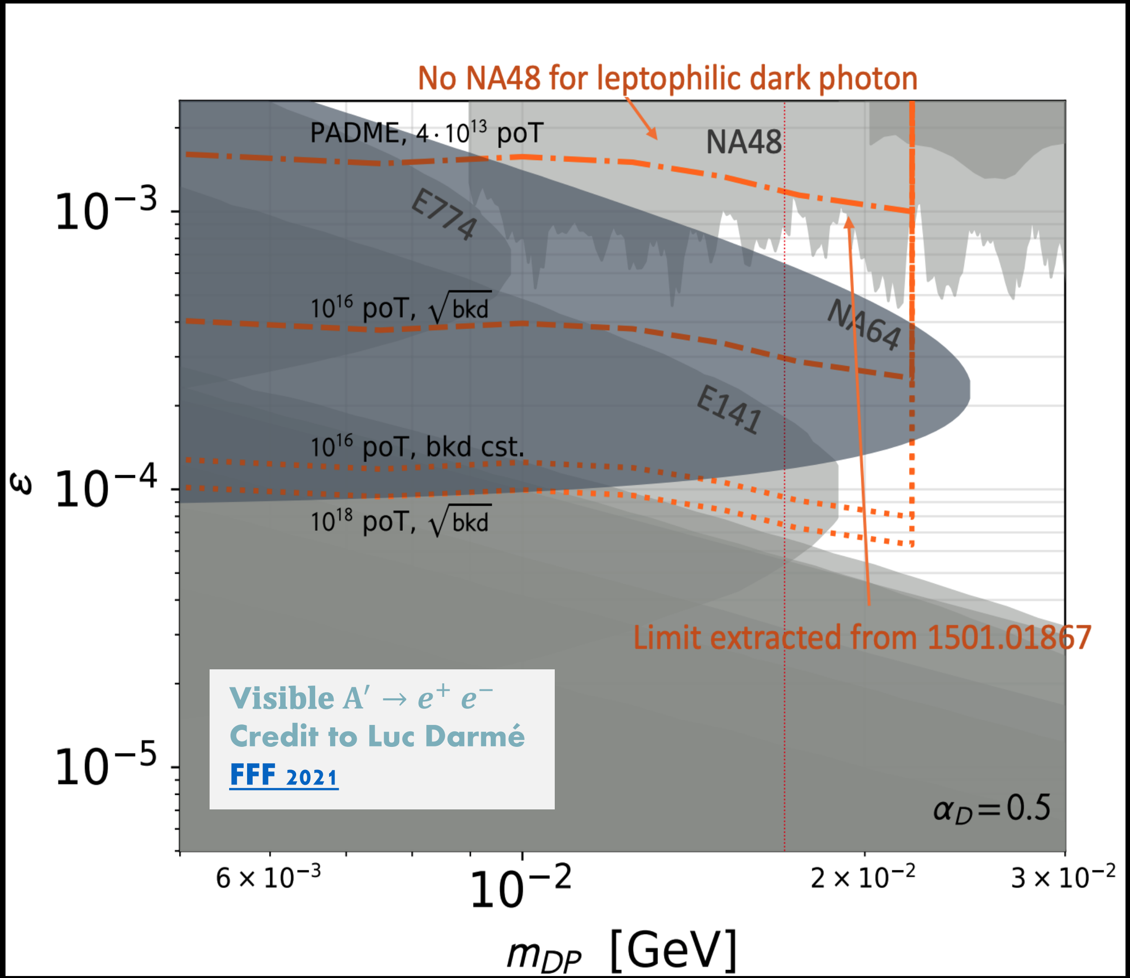
beam induced



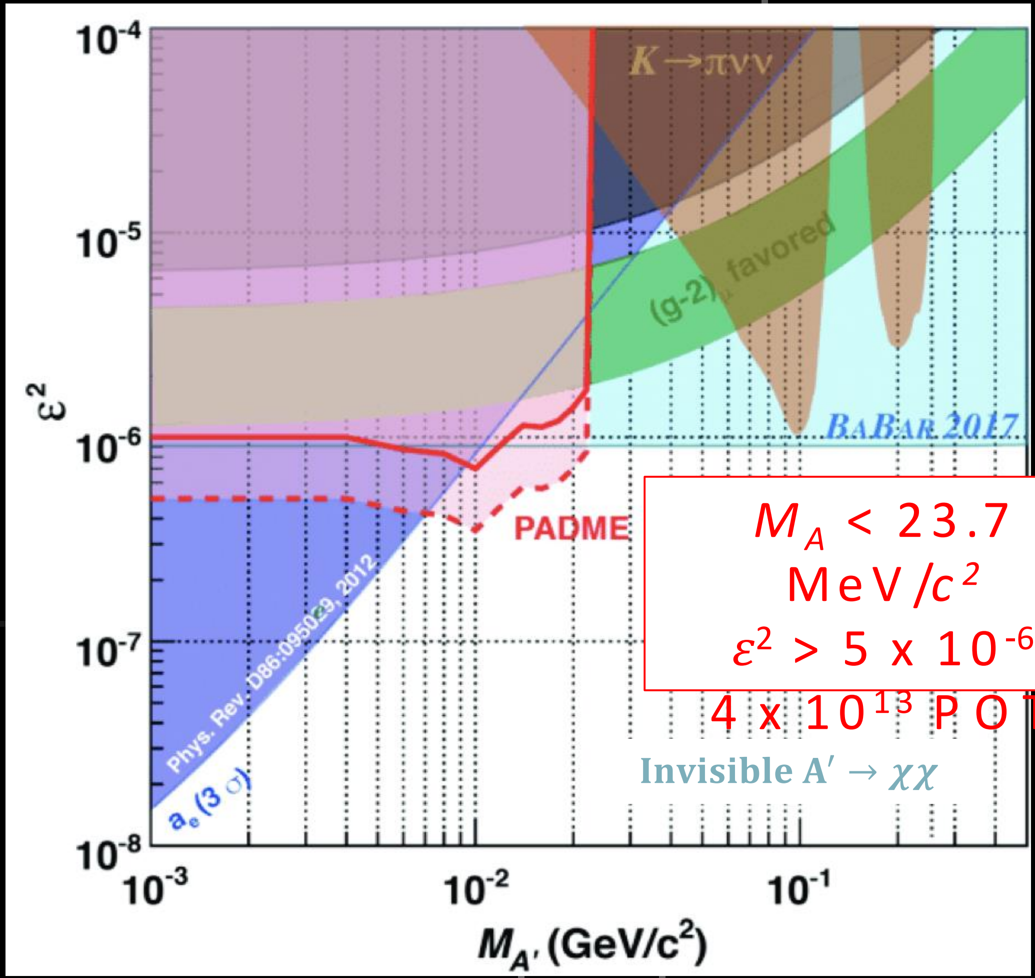


PADME Sensitivity

VISIBLE CHANNEL



INVISIBLE CHANNEL

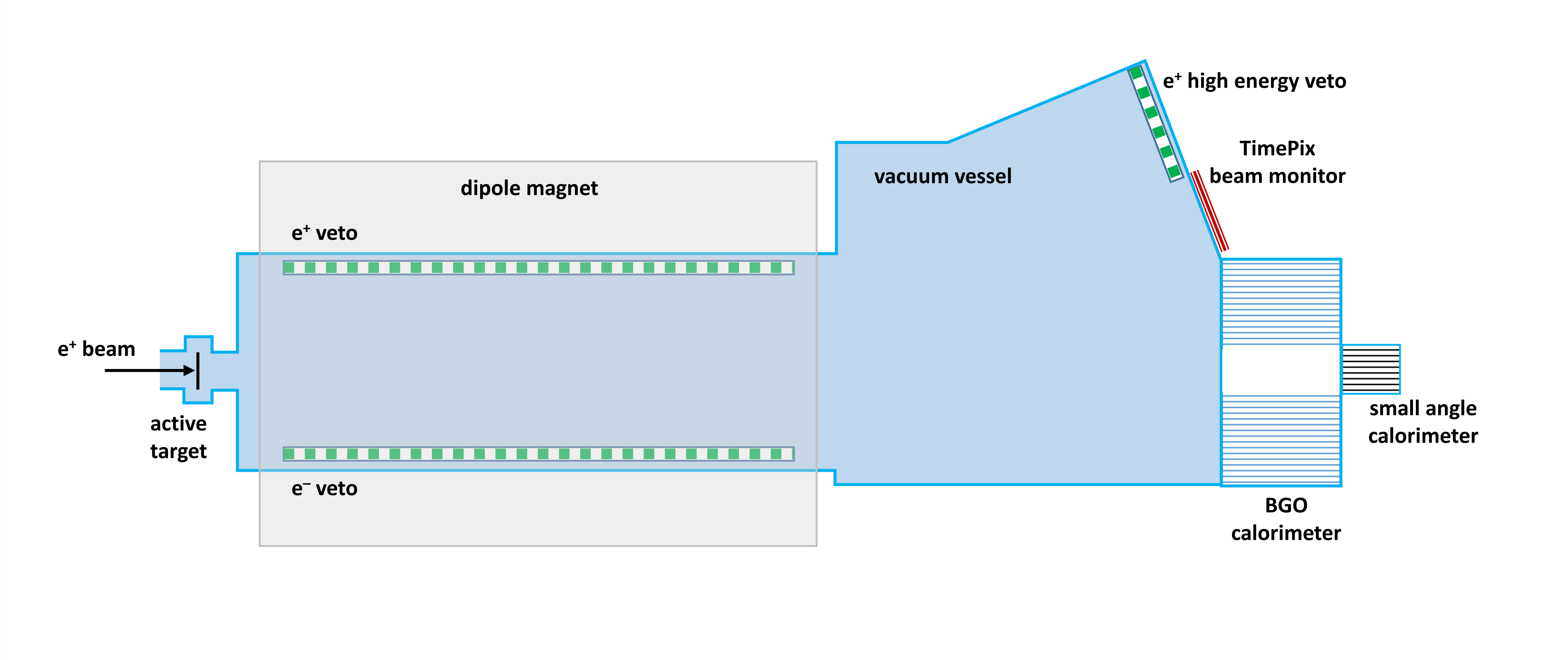


$M_A < 23.7$ MeV/c^2

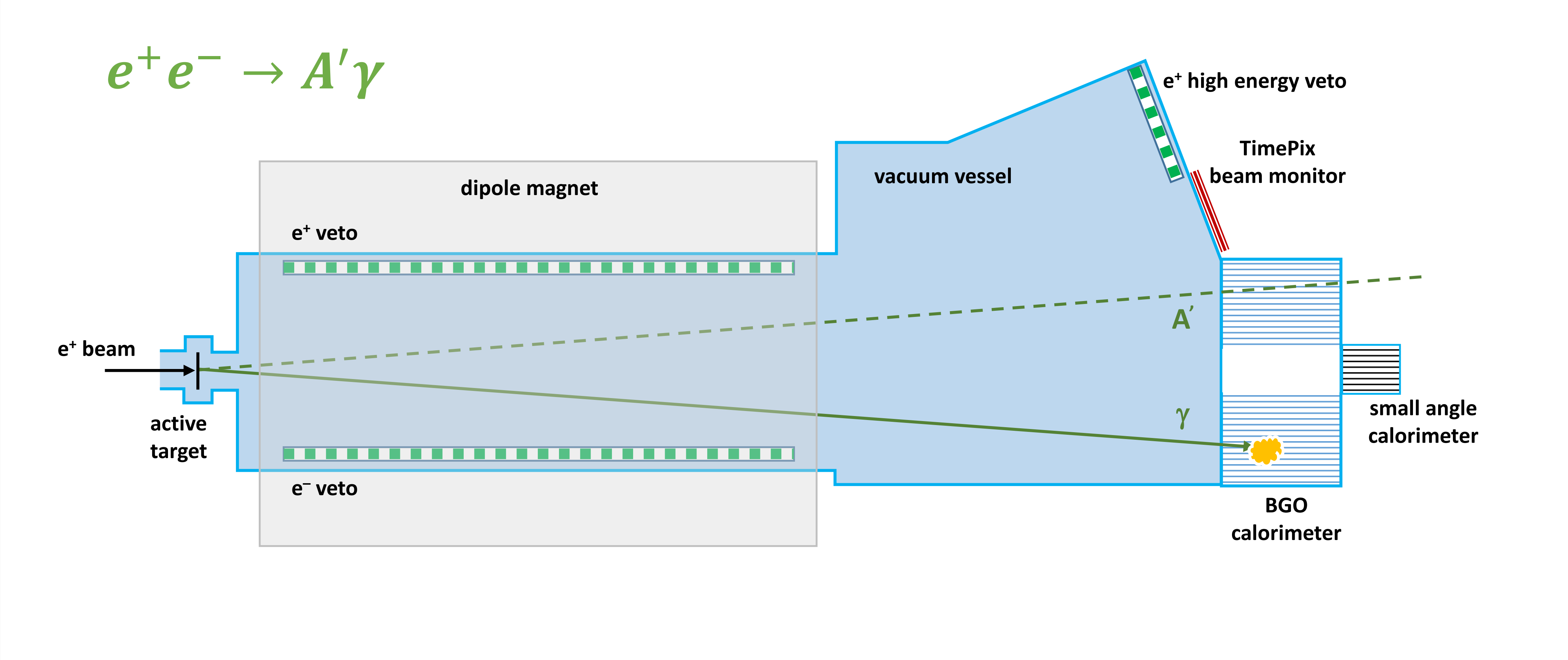
$\varepsilon^2 > 5 \times 10^{-6}$

4×10^{13} POT

PADME Outline



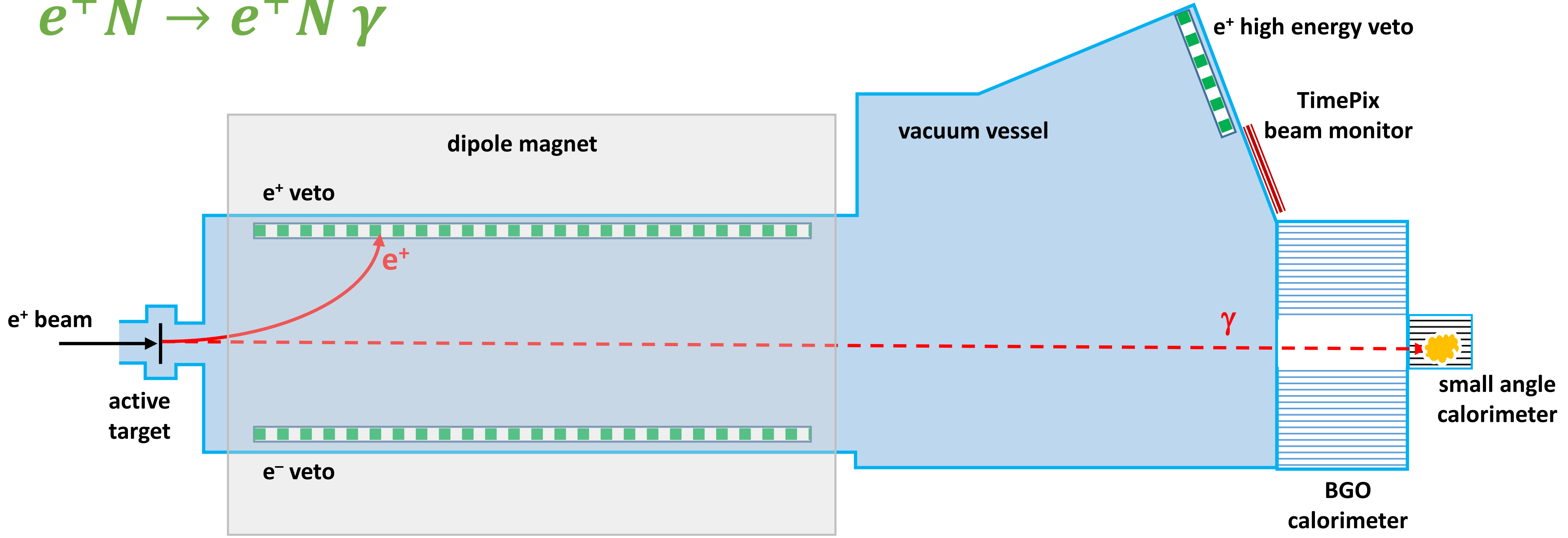
Dark Photon Signal



one γ and no in time activity in the detectors

Background: Bremmstrahlung

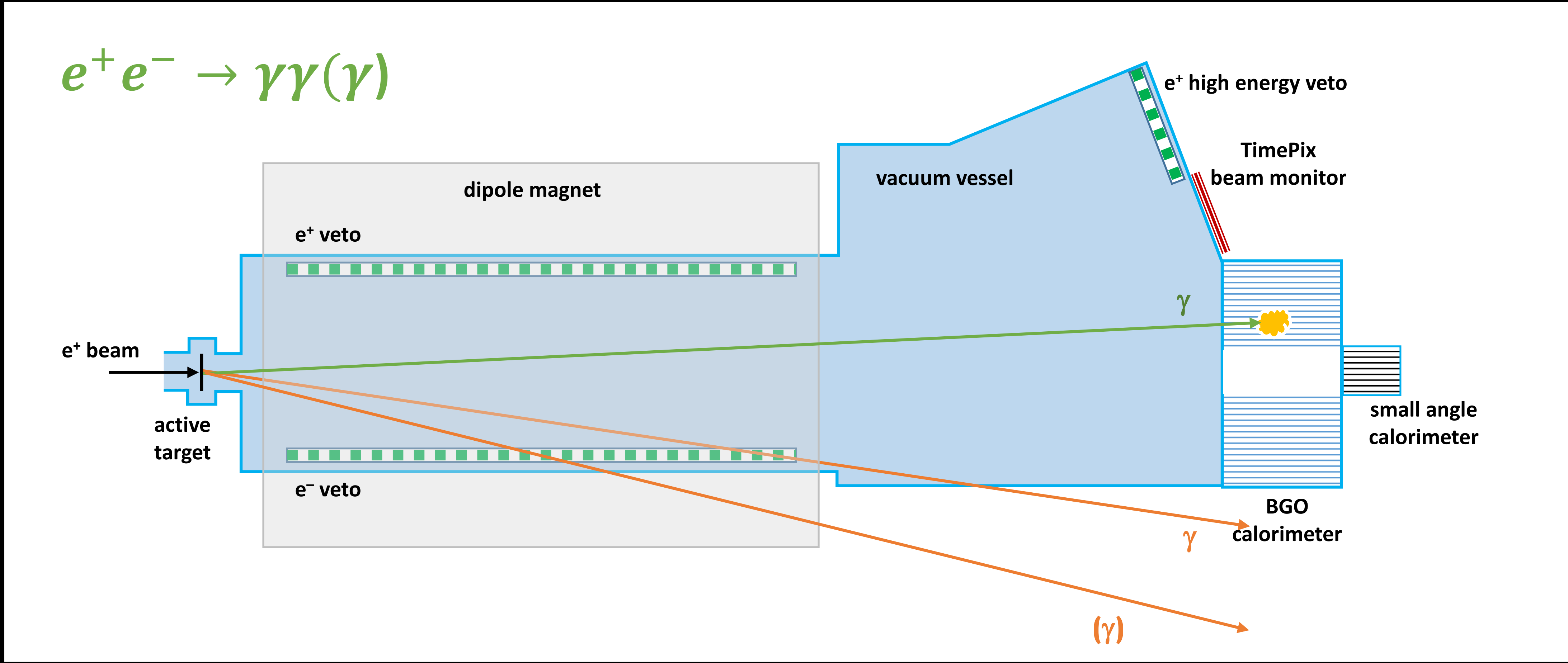
$$e^+ N \rightarrow e^+ N \gamma$$



one γ but in time low energy e^+ in the spectrometer

$\sigma = 4b/C$ atom @ $E_\gamma = 1 MeV$

Background: annihilation

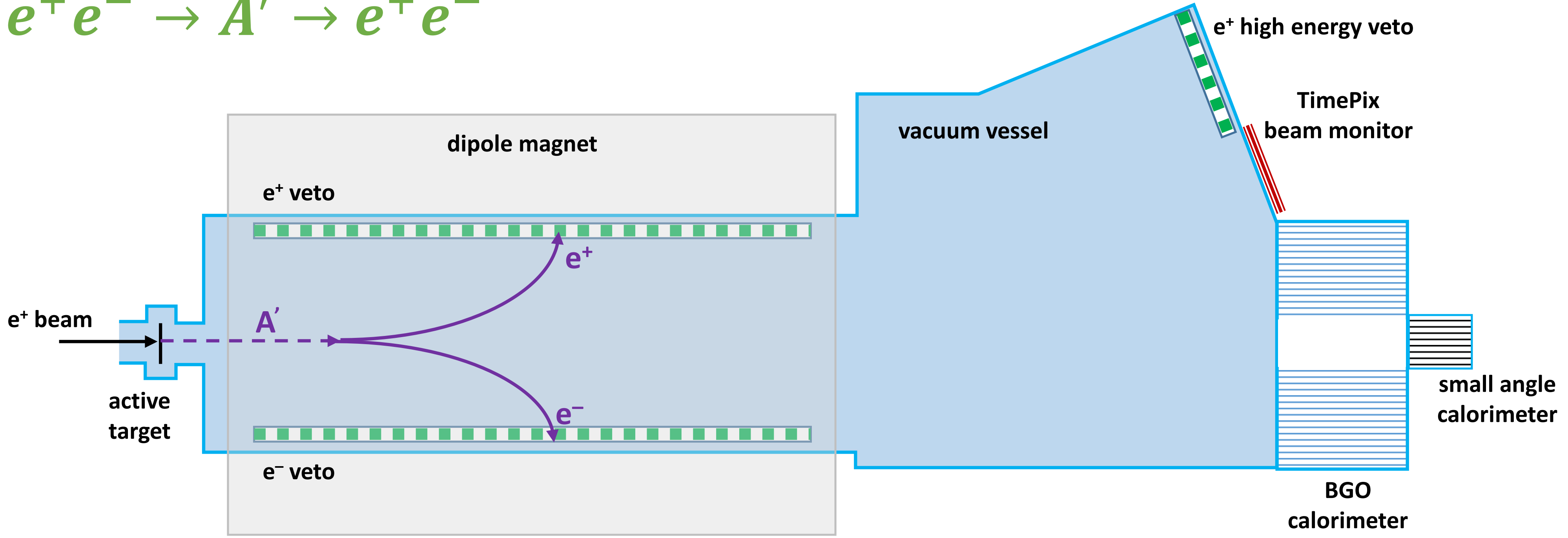


one (or two) γ not in detector acceptance

$\sigma = 0.15\,\text{mb}\ @\ E_\gamma > 1\,\text{MeV}$

Visible decay

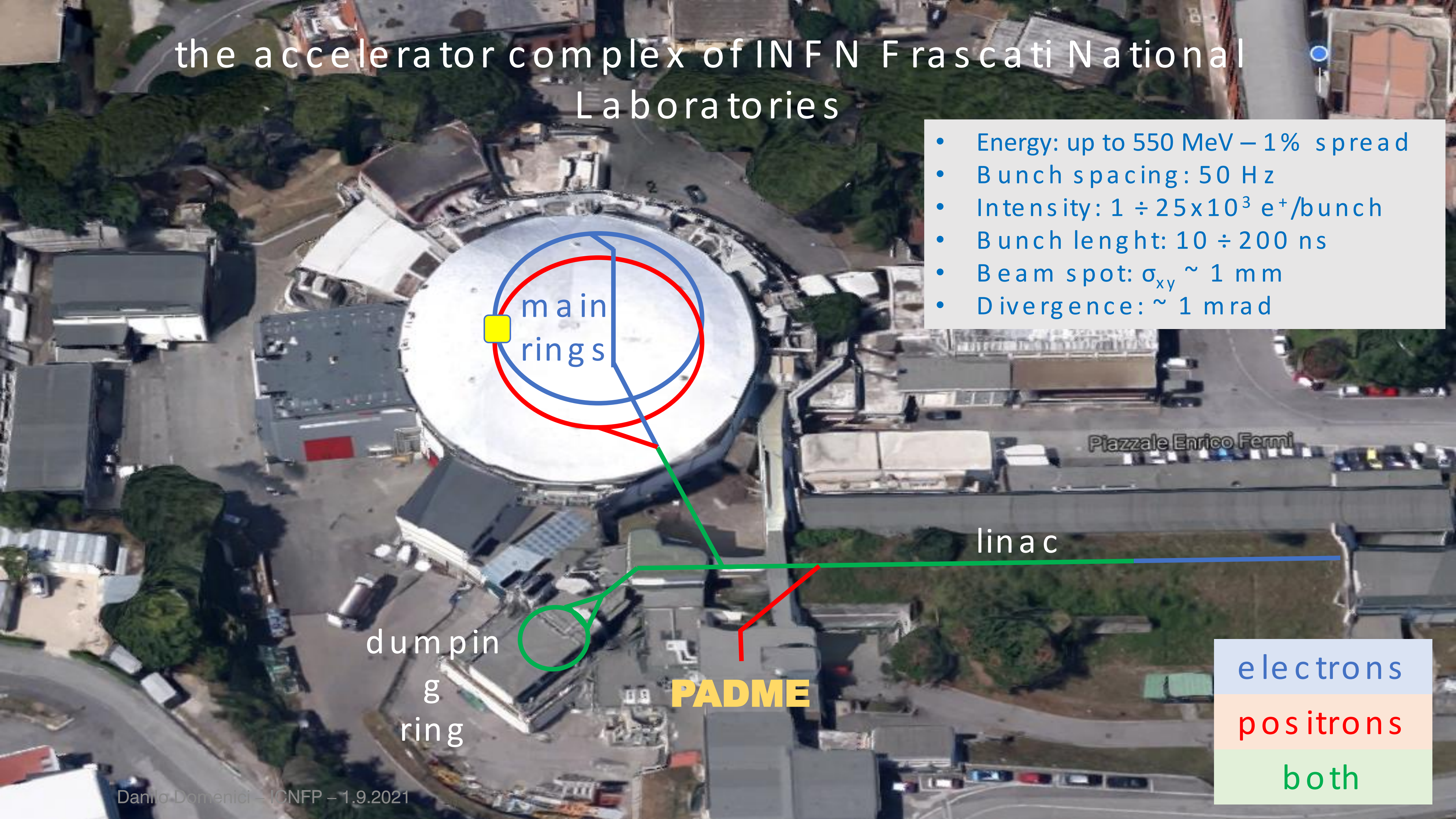
$$e^+e^- \to A' \to e^+e^-$$



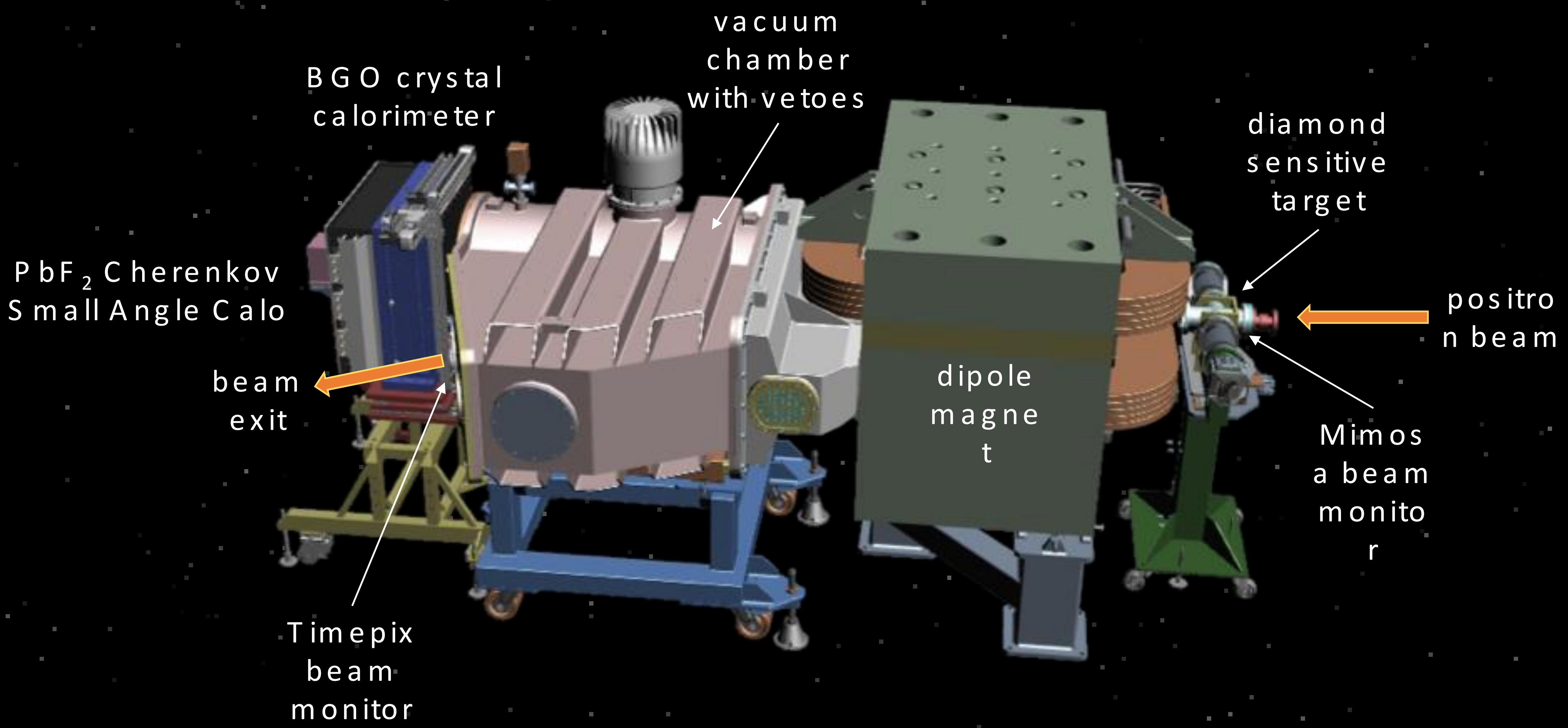
lepton pair detected in the spectrometer

the accelerator complex of INFN Frascati National Laboratories

- Energy: up to 550 MeV – 1% spread
- Bunch spacing: 50 Hz
- Intensity: 1 ÷ 25x10^3 e$^+$/bunch
- Bunch lenght: 10 ÷ 200 ns
- Beam spot: σ_{xy} ~ 1 mm
- Divergence: ~ 1 mrad



the PADME Detector



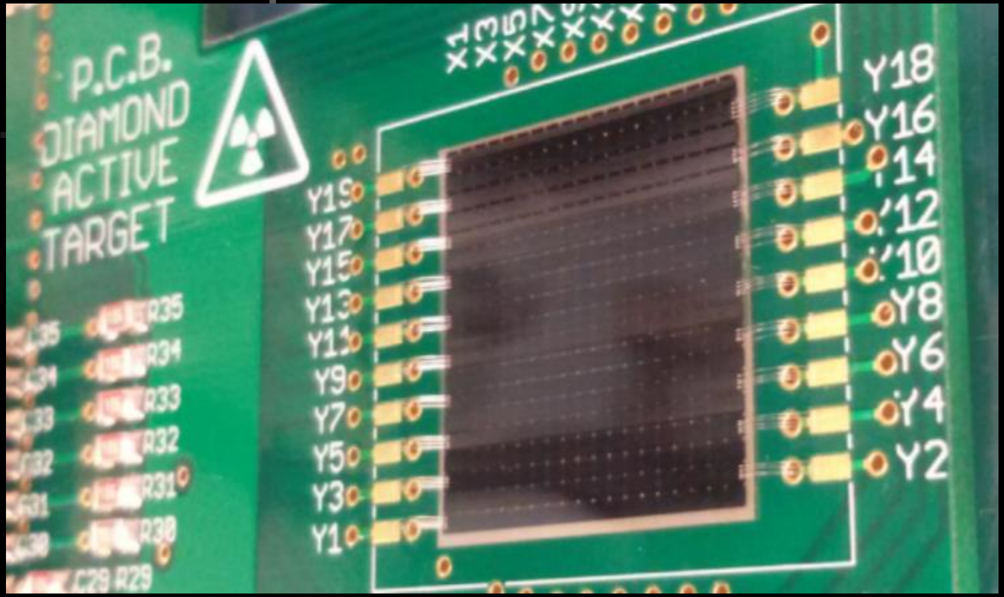
a PADME Picture

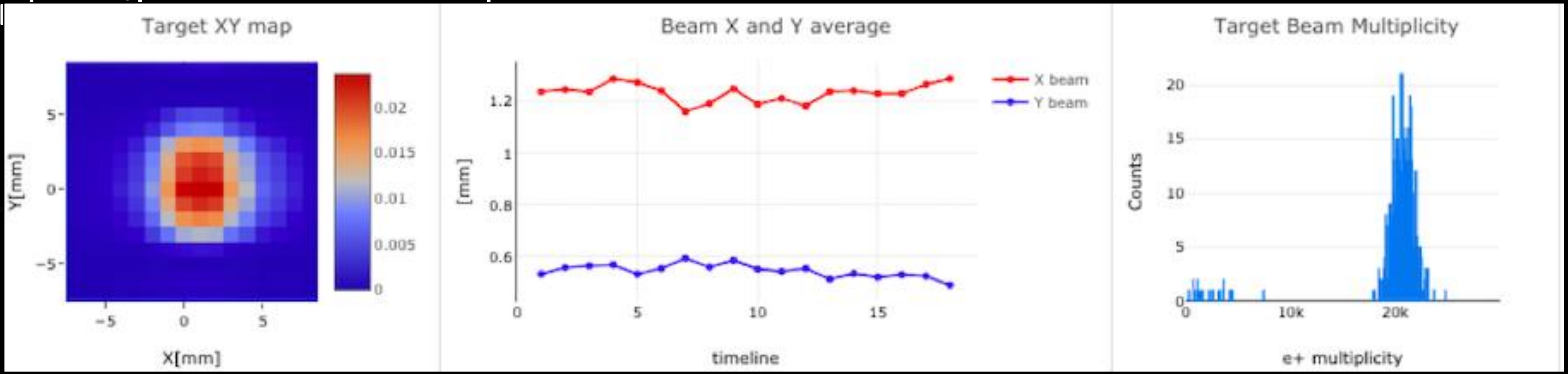
Diamond Active Target

annihilation target
provides single bunch XY profile
provides beam multiplicity

$20 \times 20 \times 0.1\ mm^3$ pCVD sensor
16+16 XY graphite strips
1 mm pitch
60 µm charge cetroid resolution

10% i





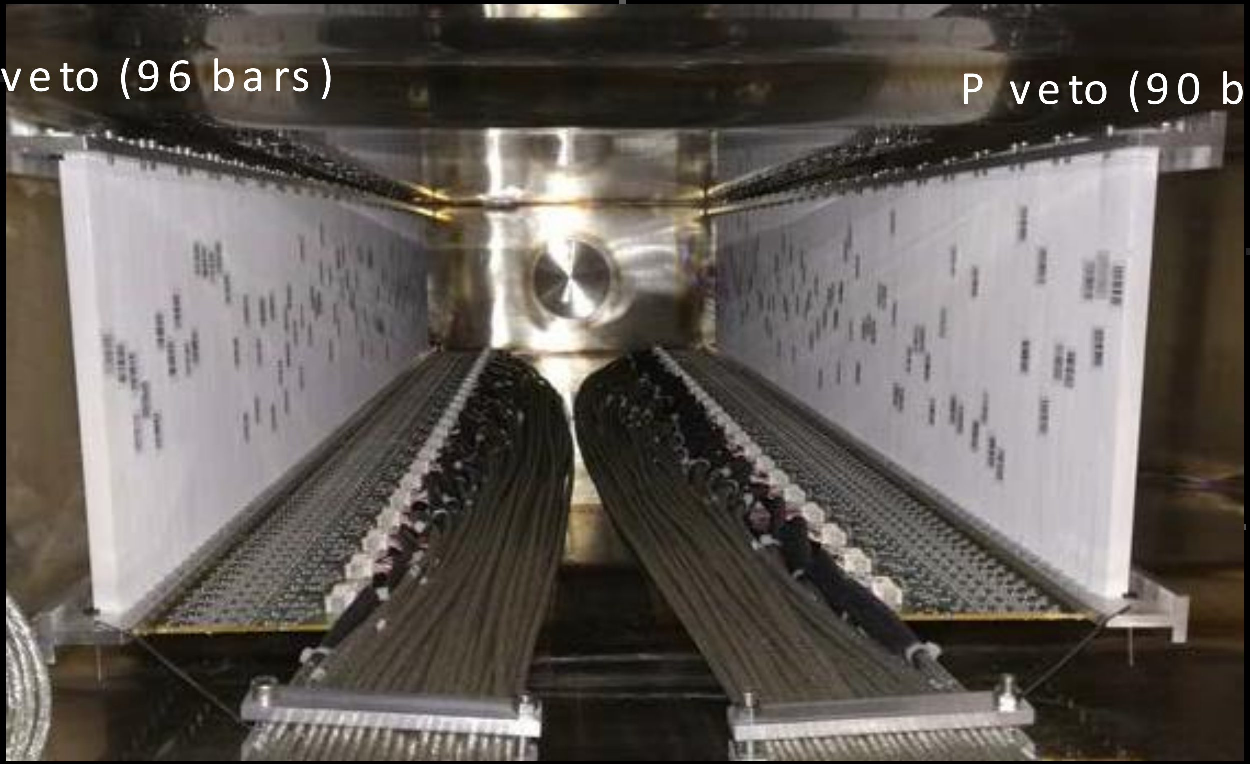
Charged Particle Veto

bremmstrahlung suppression
detection of visible decays

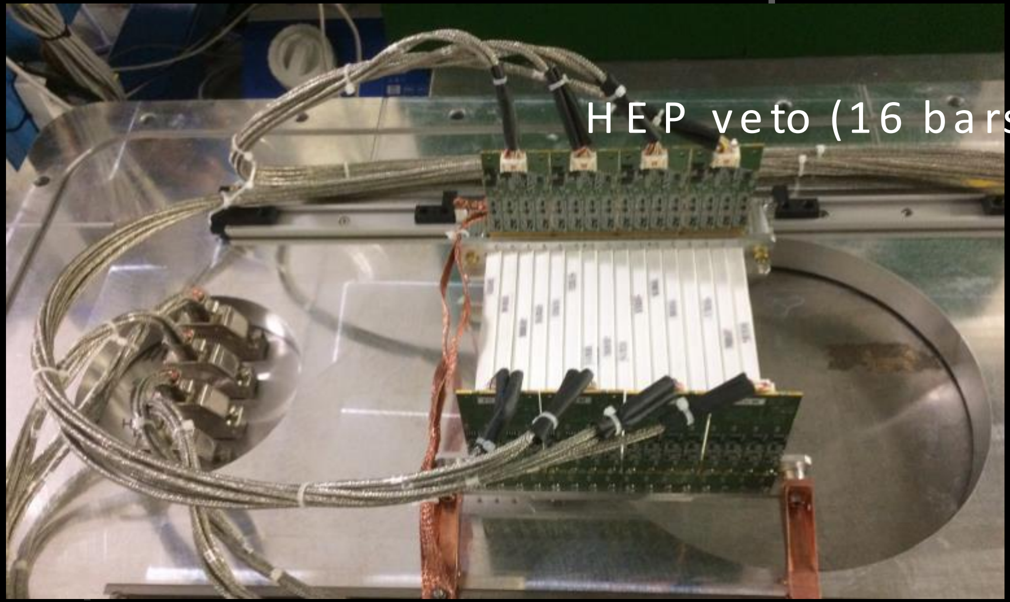
plastic scintillators bars
10x10x178 mm^3
WLS fiber + 3x3 mm^2 SiPM
700 ps time resolution
2% momentum resolution

E veto (96 bars)

P veto (90 bars)

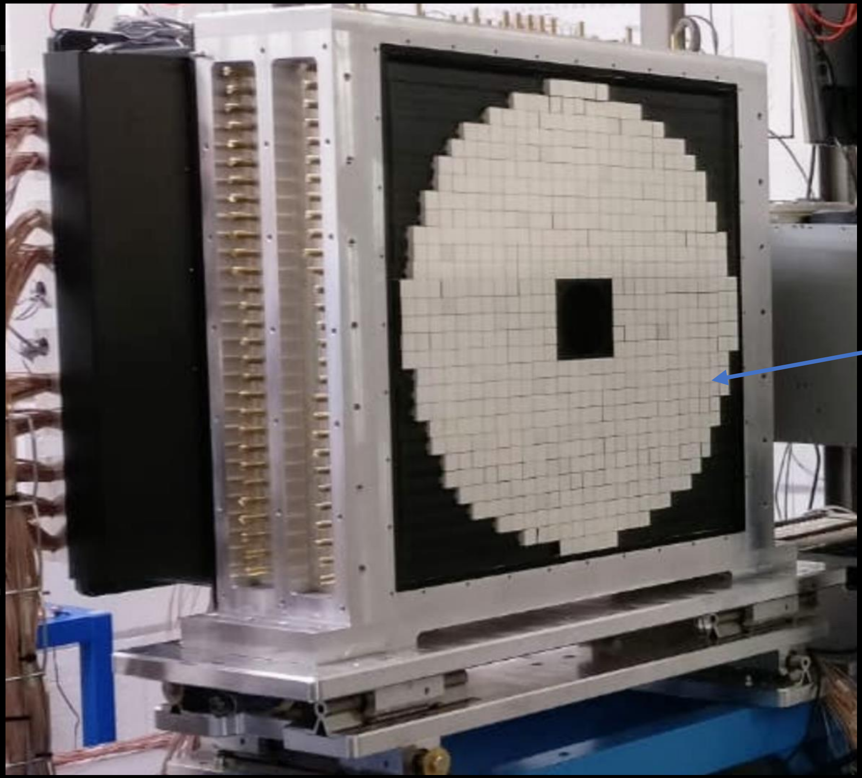


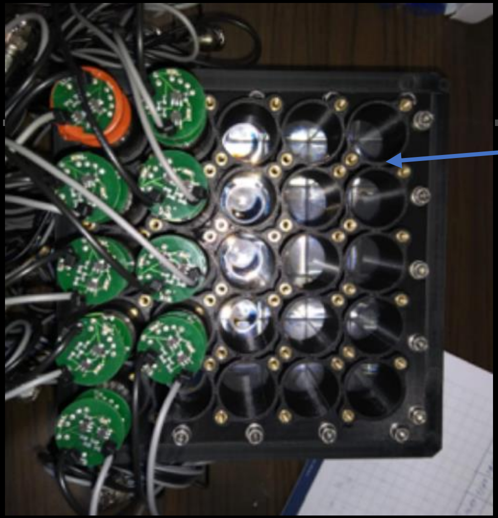
HEP veto (16 bars)



Electromagnetic Calorimeters

detection of annihilation events
bremmstrahlung suppression

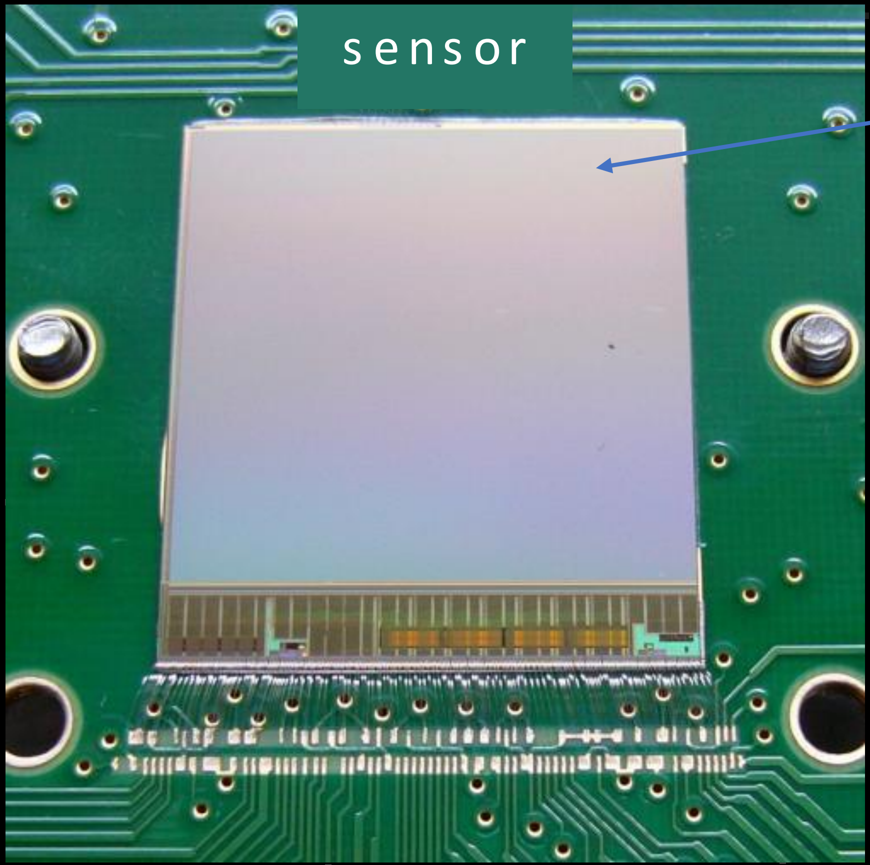




ECAL - Electromagnetic Calorimeter
616 scintillating BGO crystals 21×21×230 mm^3
PMT readout
σE/E = 2.7% at 490 MeV
BGO decay time = 300 ns
Radiation length = 20.5 X0

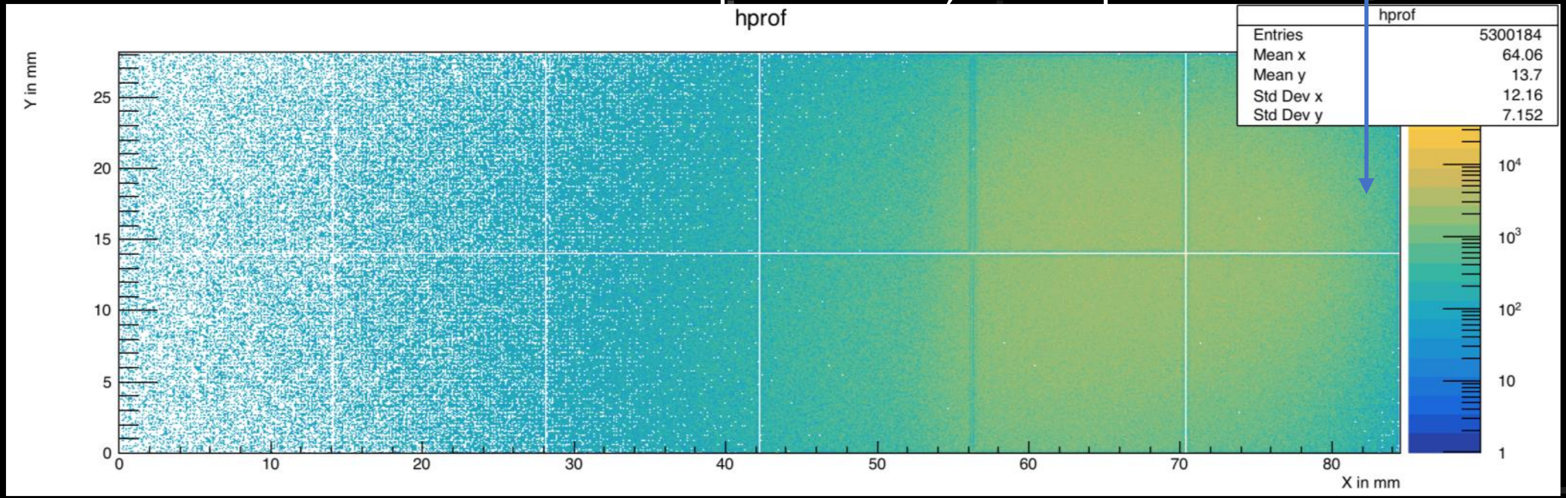
SAC – Small Angle Calorimeter
25 Cherenkov PbF_2 crystals 30×30×140 mm^3
PMT readout
PbF2 signal time = 3 ns
Time resolution = 86 ps
Rate capability = 40 cluster/bunch

Beam Monitors

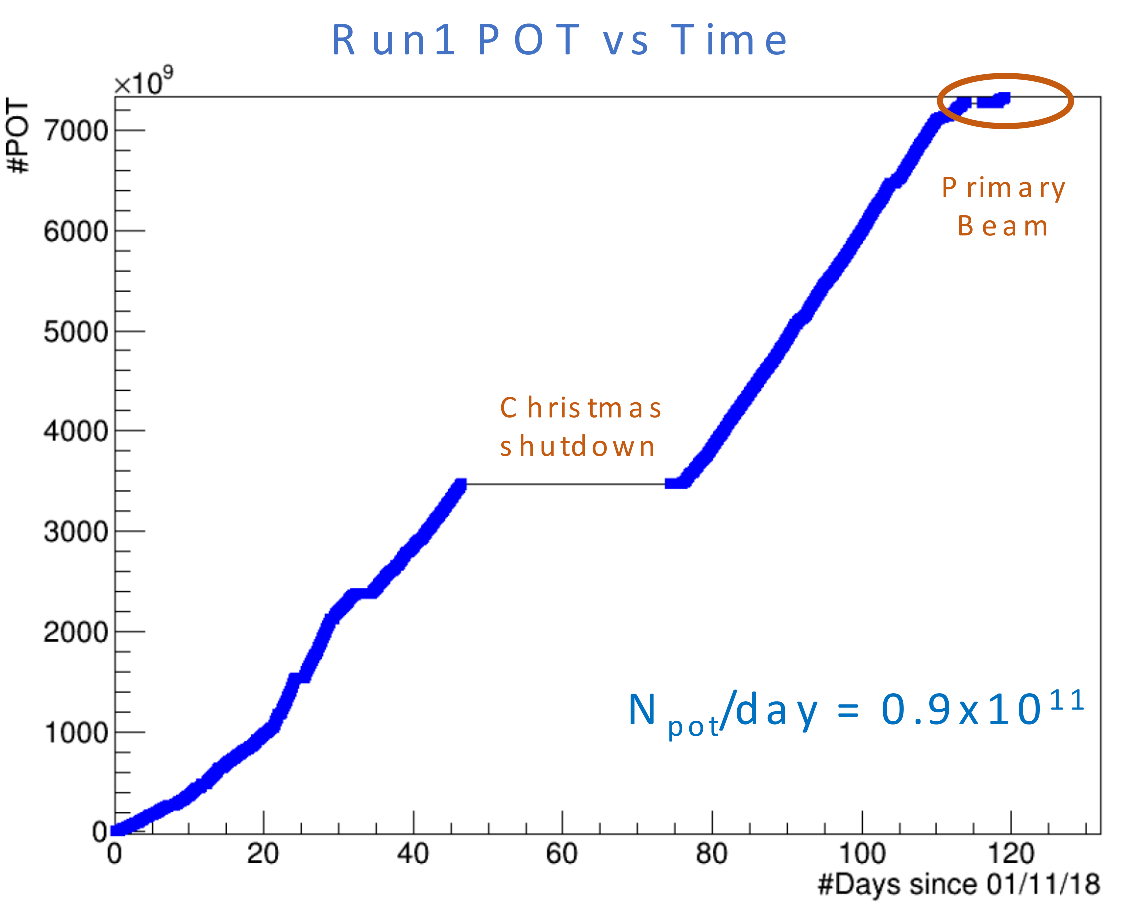


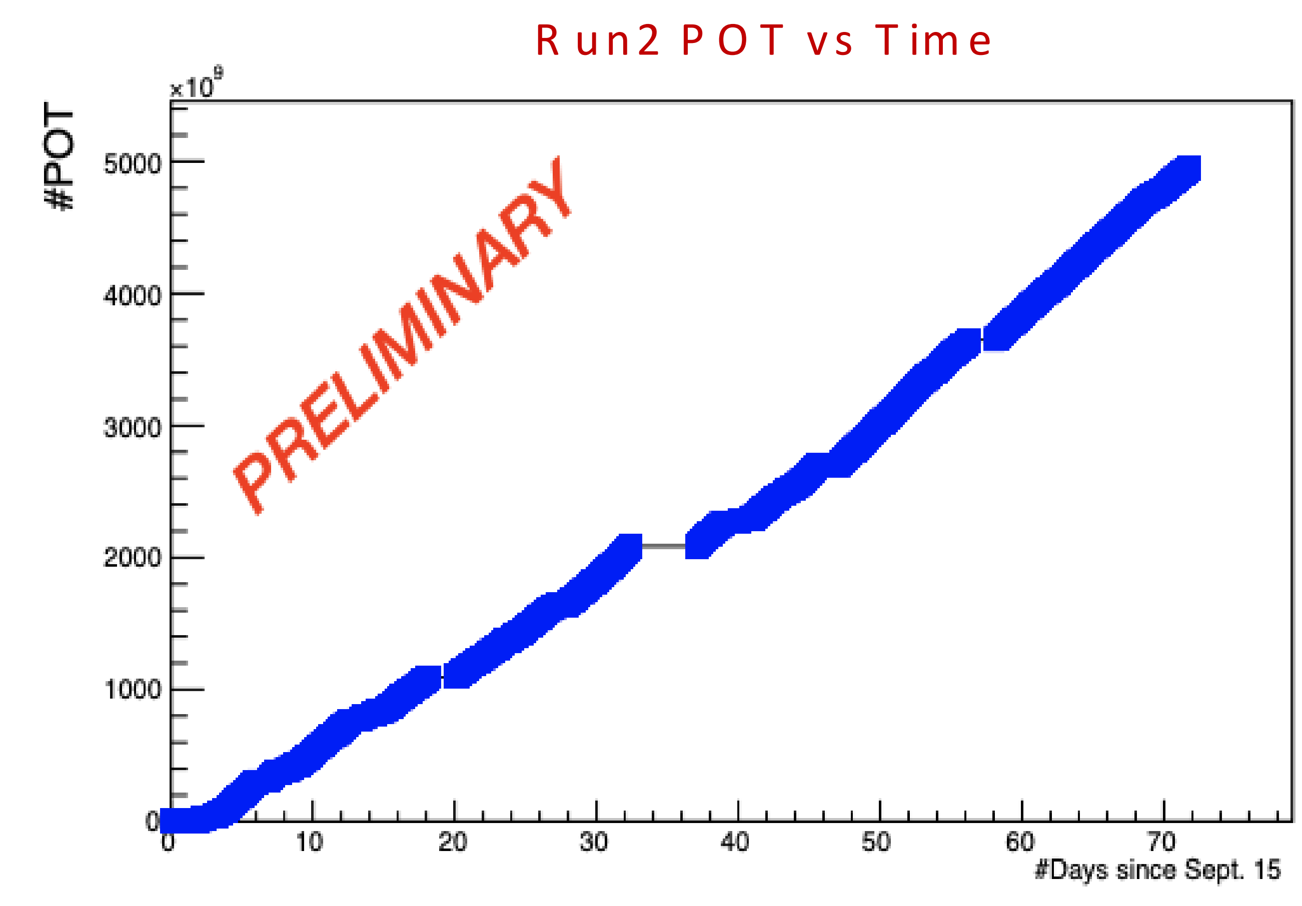
UPSTREAM - MIMOSA
Monolitic pixel tracker in vacuum
19.9x19.2 mm^2 sensor area
960x928 pixel array
20.7 µm pitch – 0.9 million pixels
Single point resolution= 3 µm
Readout time = 200 µs

DOWNSTREAM - TIMEPIX
2x6 matrix of 14x14 mm2
Timepix3
0.13 µm CMOS technology
256x256 pixel matrix, 55x55 μm^2



Data Taking





RUN1 (Oct 18 – Feb 19)
$7x10^{12}$ POT

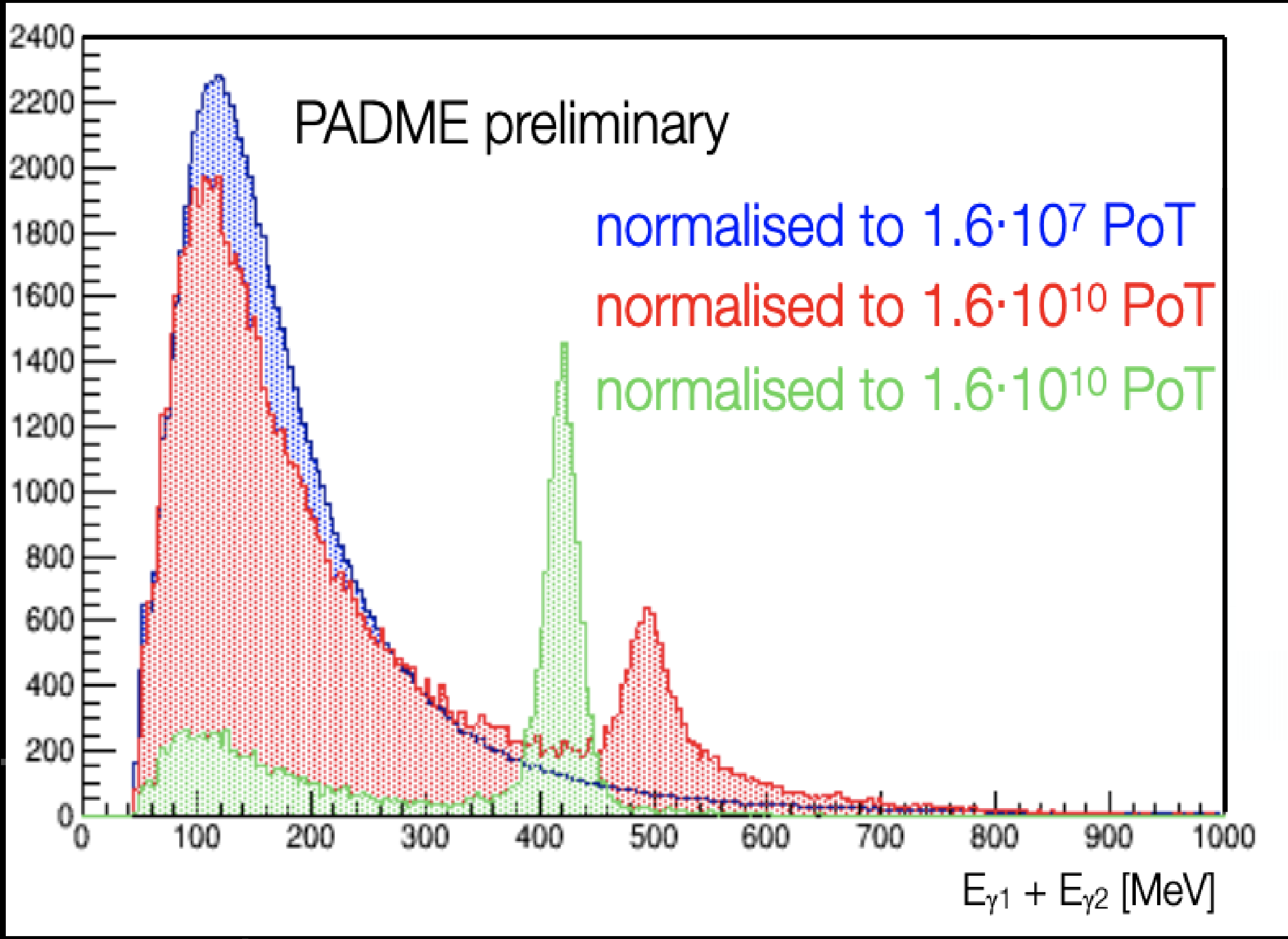
RUN2 (Sep 20 – Dec 20)
$5.6x10^{12}$ POT

Beamline Characteristics

RUN1 – Secondary Beam
250 µm Be window
545 MeV
25kPOT / 250 ns bunch

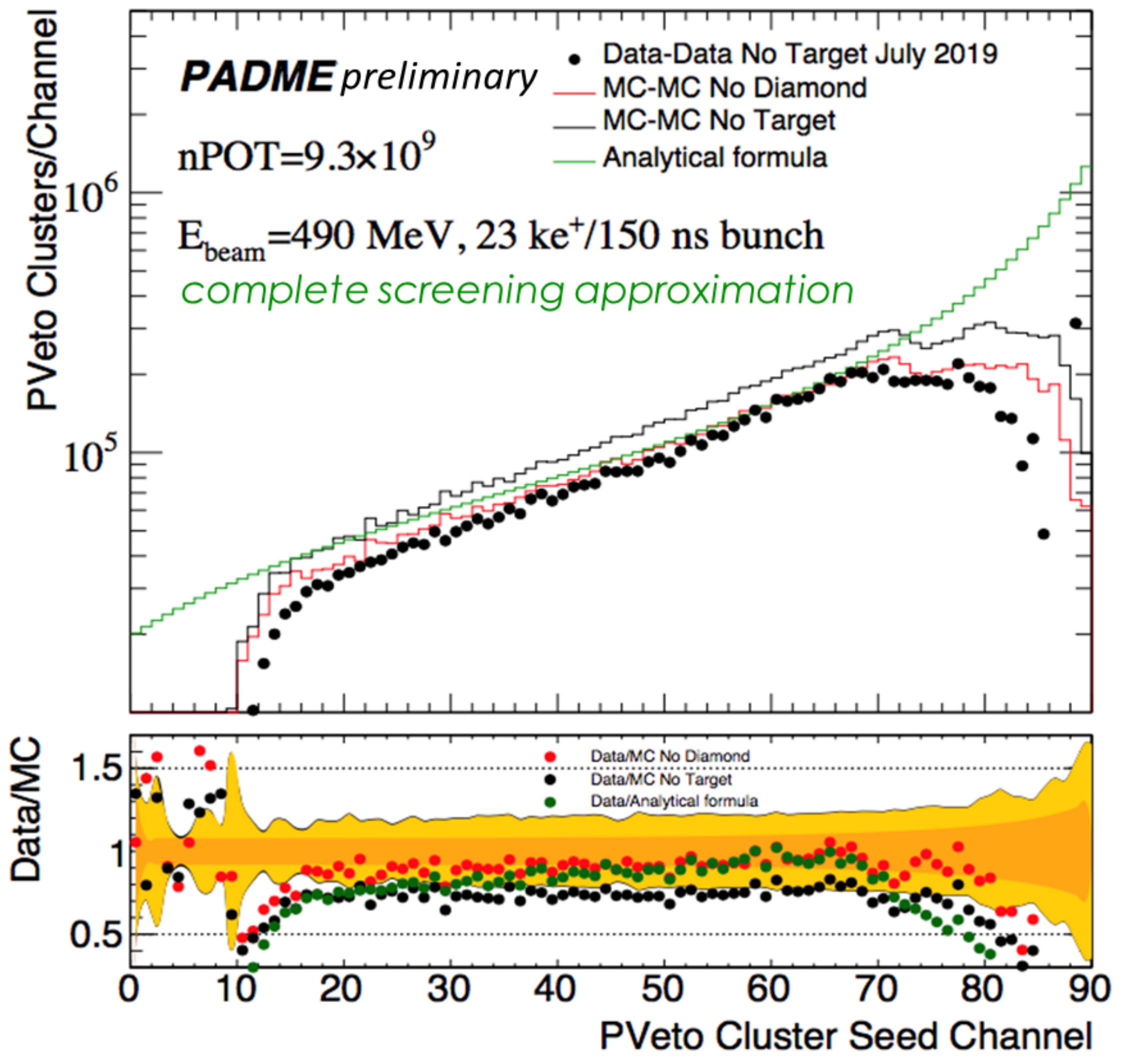
RUN1 – Primary Beam
250 µm Be window
490 MeV
25kPOT / 250 ns bunch

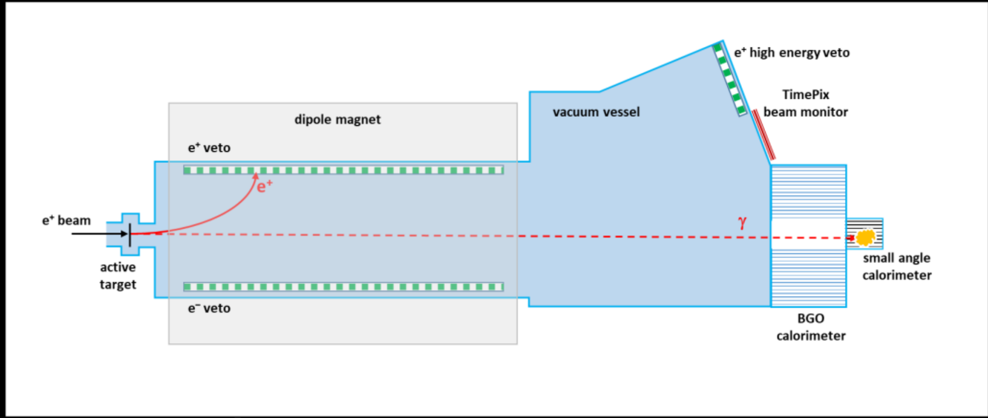
RUN2 – Primary Beam
125 µm Mylar window
430 MeV
28kPOT / 280 ns bunch



Positron Bremmstrahlung

Cluster distribution in PVeto



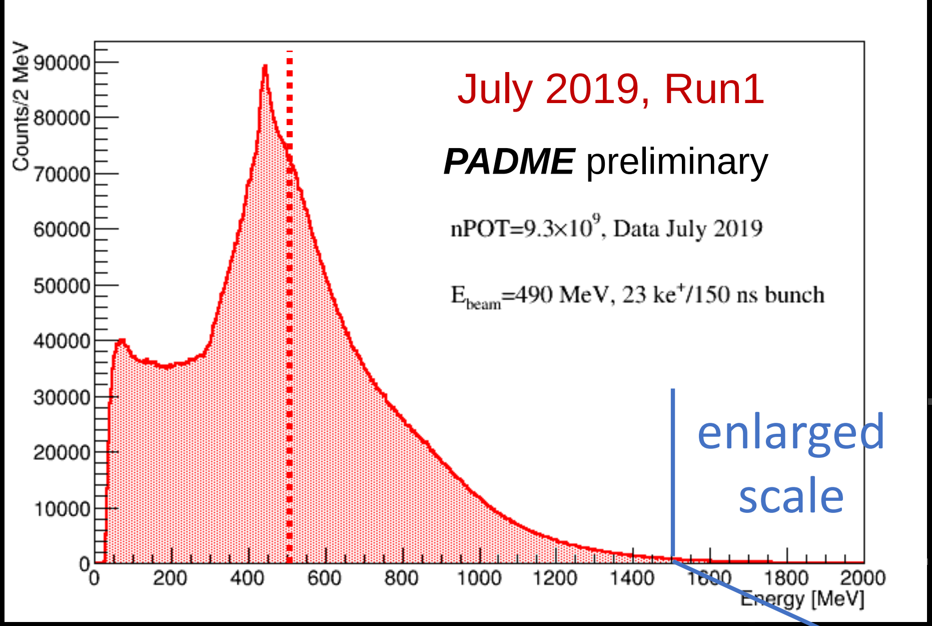


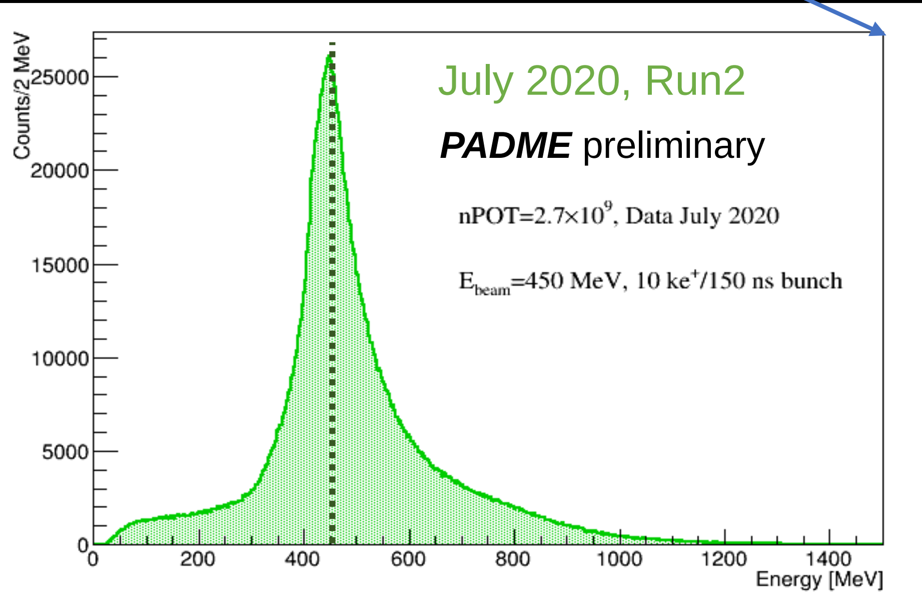
beam background measured w/o target and subtracted

bremmstrahlung photon distribution in agreement with simulation and analytical calculation

systematic uncertainties dominated by background normalization, positron momentum scale, POT measurement calibration

Beamlines Comparison

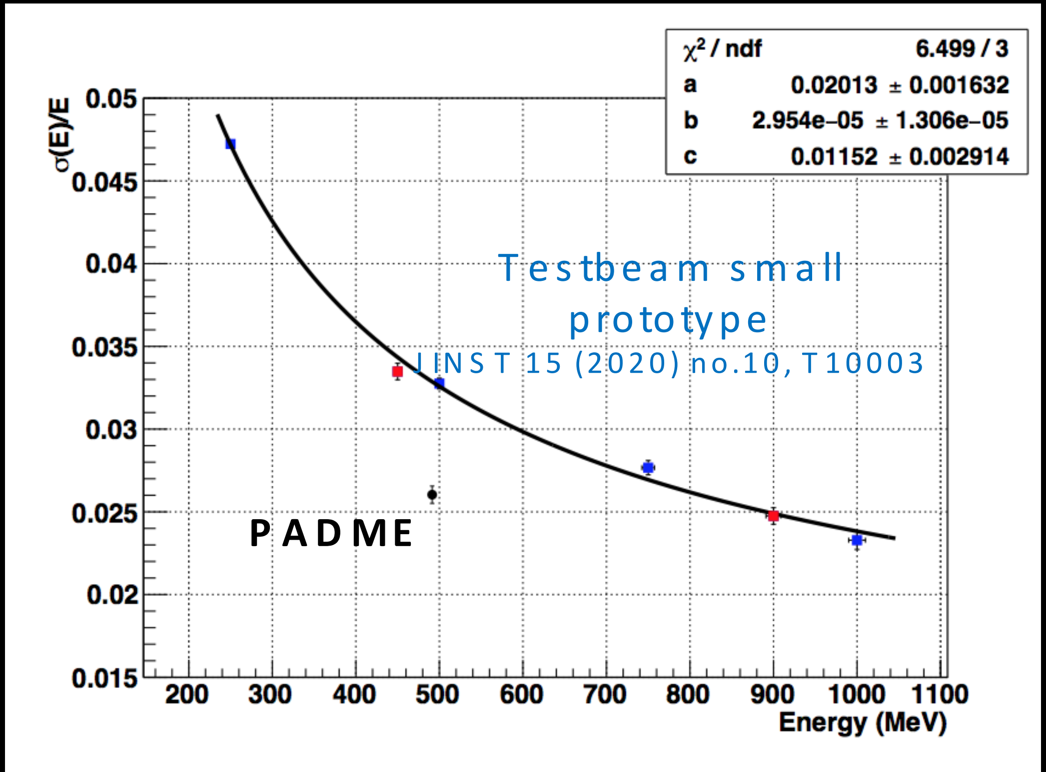




photon energy in calorimeter
+
e+ energy computed by PVeto position
(in time within 1ns)

much cleaner distribution evident in Run2

Calorimeter Performance



Energy resolution

$\sigma_E/E = (2.62 \pm 0.05)\%$ @ 490 MeV

in 1 POT/bunch calibration run

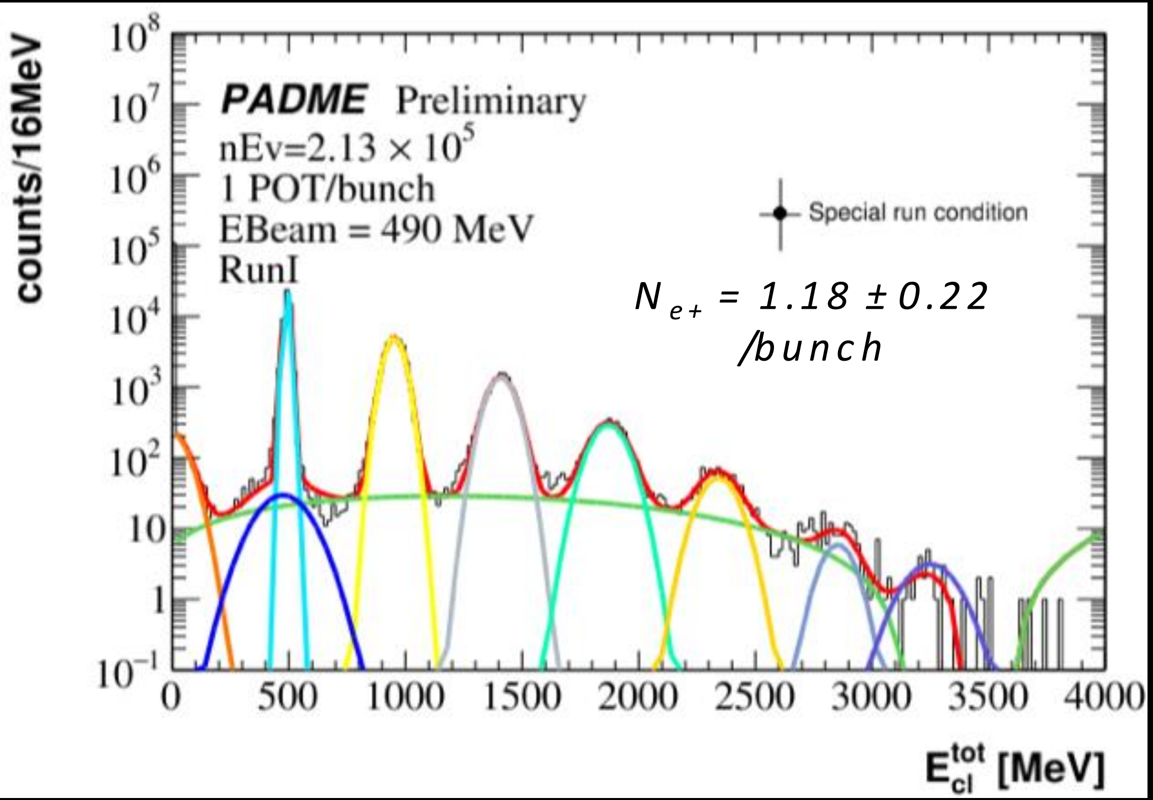
Multihit reconstruction

in 1 POT/bunch calibration run

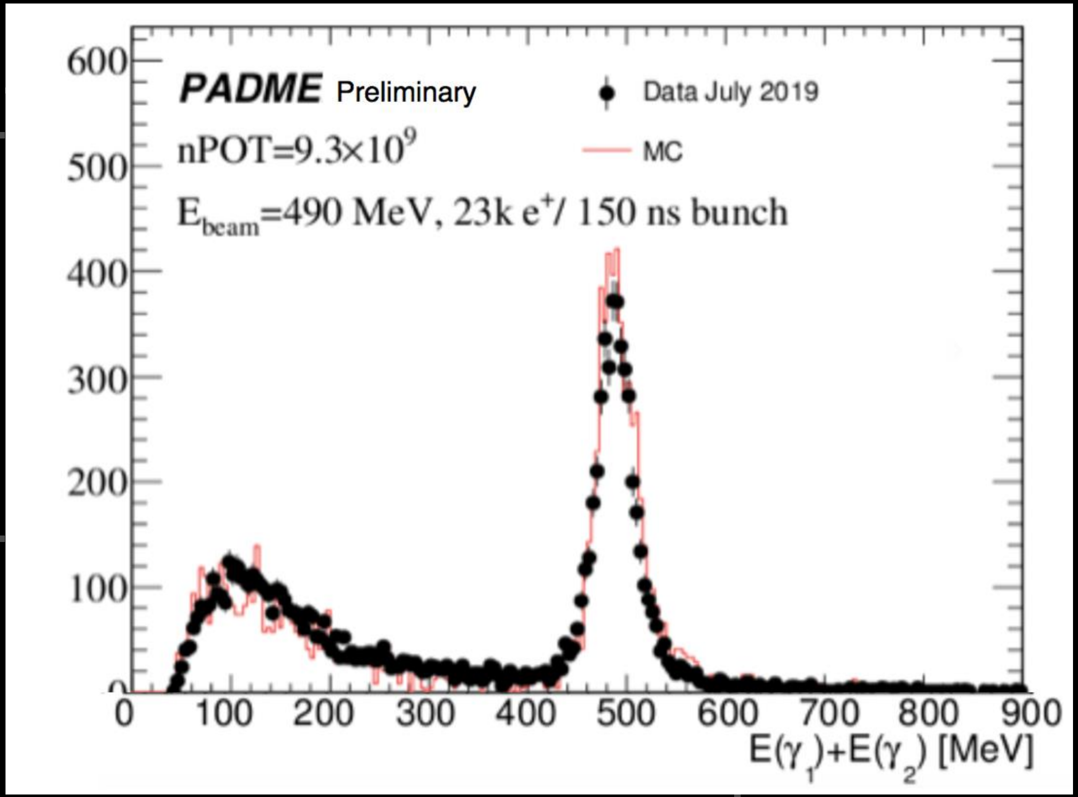
Time resolution

$\sigma_t \sim 1$ ns

for photons > 100 MeV

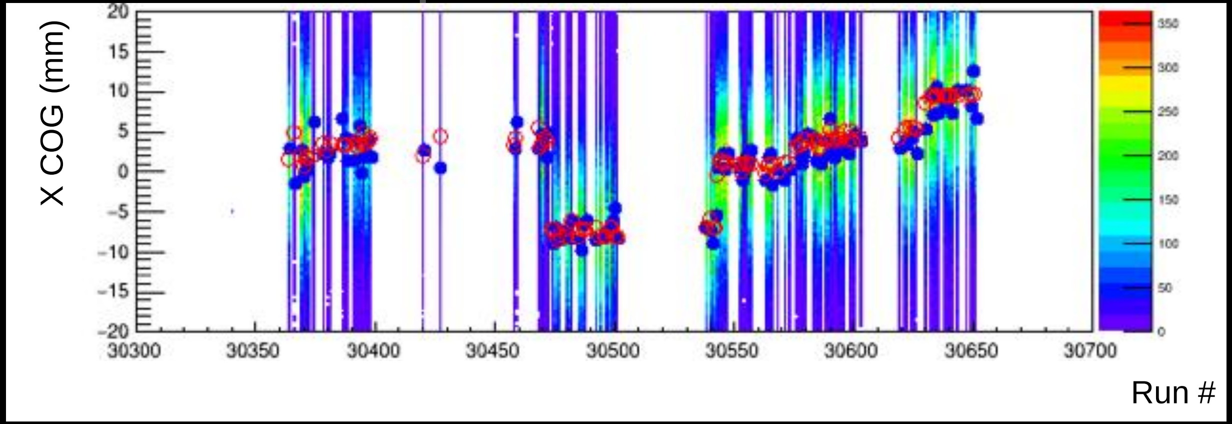


SM Signal Analysis



SM annihilation signal
$\Delta t < 10$ ns
$\Delta\phi < 25°$
$\gamma\gamma$ COG < 1 cm from nominal beam

powerful run-dependent monitor
of the luminous point



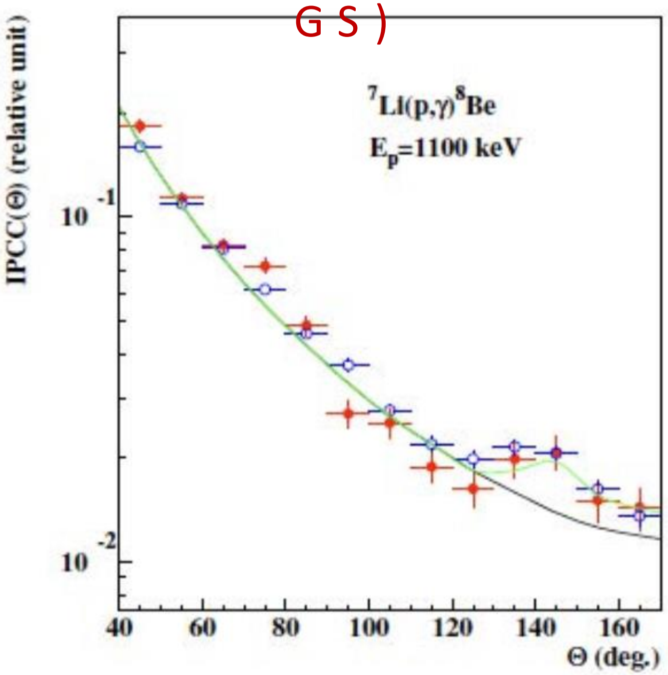
Cross-section measurement with
clear Run2 sample
in progress

Run3: hunt to X17

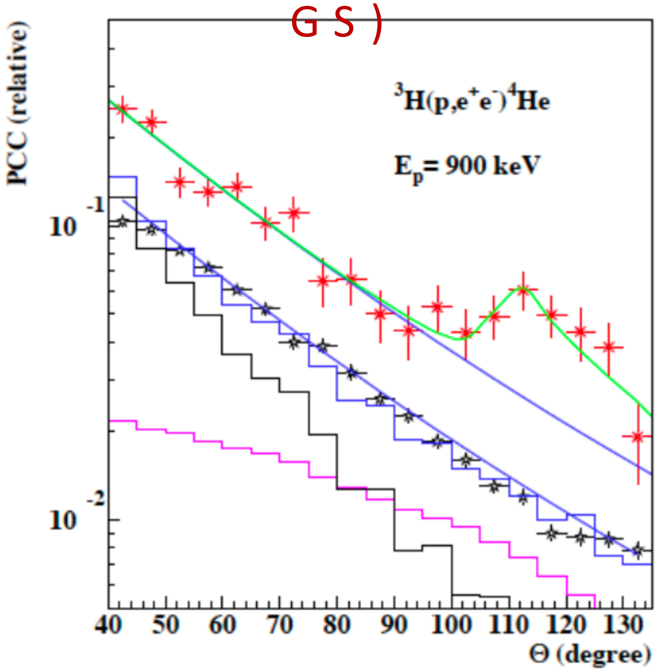
PADME

INFN LNF

^{8}Be anomaly (18 MeV to GS)



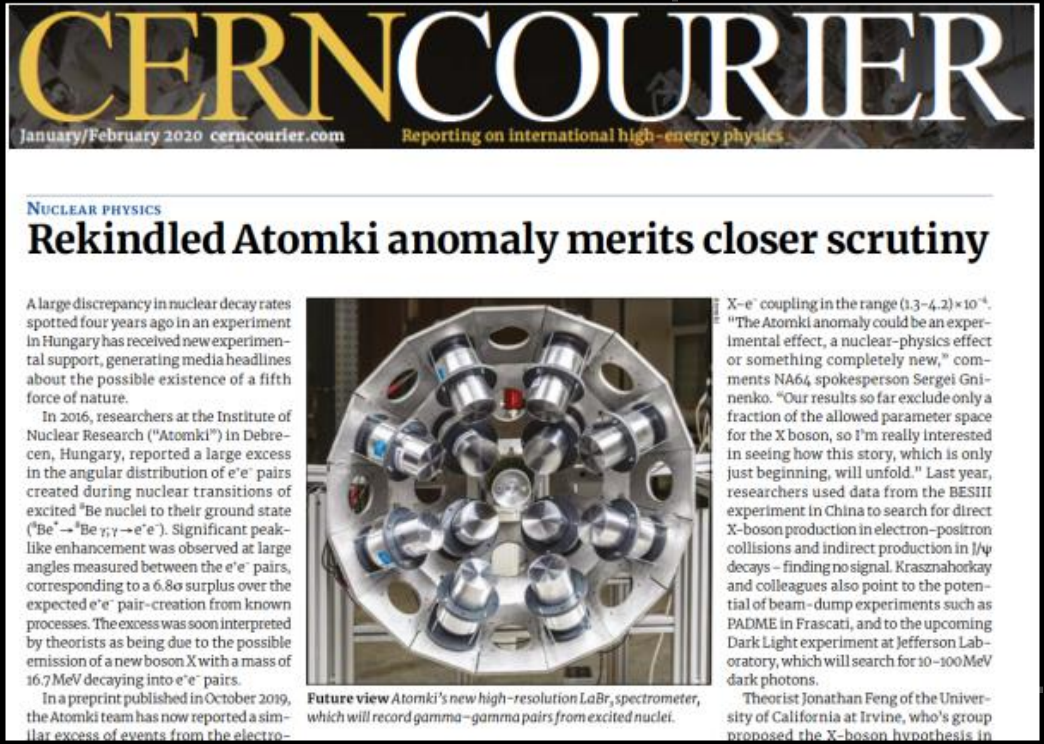
^{4}He anomaly (21 MeV to GS)



$m_X = 16.84 \pm 0.16(stat) \pm 0.20(syst)$ MeV

$\Gamma_X = 3.9 \times 10^{-5}$ eV

PRL 116, 052501 (2016)



CERN COURIER

January/February 2020 cerncourier.com Reporting on international high-energy physics

NUCLEAR PHYSICS

Rekindled Atomki anomaly merits closer scrutiny

A large discrepancy in nuclear decay rates spotted four years ago in an experiment in Hungary has received new experimental support, generating media headlines about the possible existence of a fifth force of nature.

In 2016, researchers at the Institute of Nuclear Research ("Atomki") in Debrecen, Hungary, reported a large excess in the angular distribution of e⁺e⁻ pairs created during nuclear transitions of excited ^{8}Be nuclei to their ground state (^{8}Be* → ^{8}Be γ; γ → e⁺e⁻). Significant peak-like enhancement was observed at large angles measured between the e⁺e⁻ pairs, corresponding to a 6.8σ surplus over the expected e⁺e⁻ pair-creation from known processes. The excess was soon interpreted by theorists as being due to the possible emission of a new boson X with a mass of 16.7 MeV decaying into e⁺e⁻ pairs.

In a preprint published in October 2019, the Atomki team has now reported a similar excess of events from the electro-

Future view *Atomki's new high-resolution LaBr₃ spectrometer, which will record gamma–gamma pairs from excited nuclei.*

X–e⁻ coupling in the range (1.3–4.2)×10⁻⁴. "The Atomki anomaly could be an experimental effect, a nuclear-physics effect or something completely new," comments NA64 spokesperson Sergei Gninenko. "Our results so far exclude only a fraction of the allowed parameter space for the X boson, so I'm really interested in seeing how this story, which is only just beginning, will unfold." Last year, researchers used data from the BESIII experiment in China to search for direct X-boson production in electron–positron collisions and indirect production in J/ψ decays – finding no signal. Krasznahorkay and colleagues also point to the potential of beam-dump experiments such as PADME in Frascati, and to the upcoming Dark Light experiment at Jefferson Laboratory, which will search for 10–100 MeV dark photons.

Theorist Jonathan Feng of the University of California at Irvine, who's group proposed the X-boson hypothesis in

Phys. Rev. D97 (2018) 095004

PADME Run3 (Spring-Summer 2022)

search for X17 in resonant production with 282.7 MeV e^+ beam and e^+e^- decay

Conclusions

PADME has started to explore the Dark Sector

Run1 (2019) has been very fruitful to understand and optimize the positron beam

Run2 (2020) clean data sample is under analysis to give first physics results

Run3 (2022) will be devoted to the hunt of the hypothetical X17 boson from Be anomaly