POLARIMETRY AND HIGH-ANGULAR-RESOLUTION GAMMA-RAY OBSERVATIONS IN THE MEV REGIME USING A NOVEL DETECTOR CONCEPT

D. Horan[1]

for the HARPO Collaboration:*

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* Author list from recent publication: https://arxiv.org/abs/1706.06483

Polarimetry and high-angular-resolution gamma-ray observations in the MeV regime using a novel detector concept

ST3G

A PROTOYPE
BALLOON DETECTOR

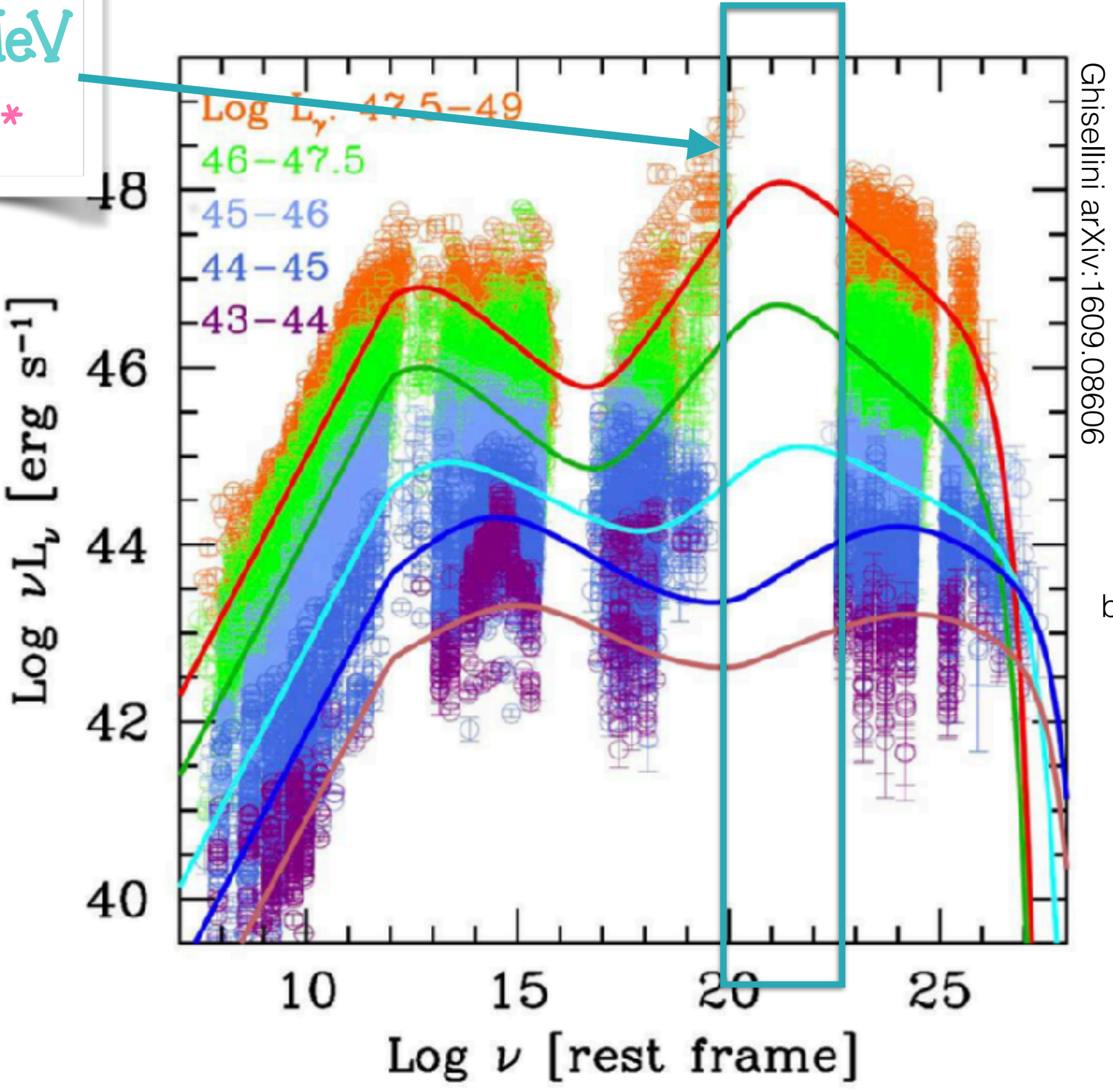
Self-**t**riggering **T**PC **t**elescope
for **g**amma-rays

Deirdre HORAN, Laboratoire Leprince Ringuet (IN2P3/CNRS), 7th International Fermi Symposium, Garmisch-Partenkirchen, 20.10.2017

Outline

- The sensitivity gap at MeV energies
- A TPC as an MeV telescope
- HARPO: ground phase / proof of concept
- ST3G : balloon phase / triggering in space
- MeV Science

The MeV Gap*



Ghisellini arXiv:1609.08606

* using blazars to illustrate the gap since these are broadband emitters from radio all the way up to gamma rays

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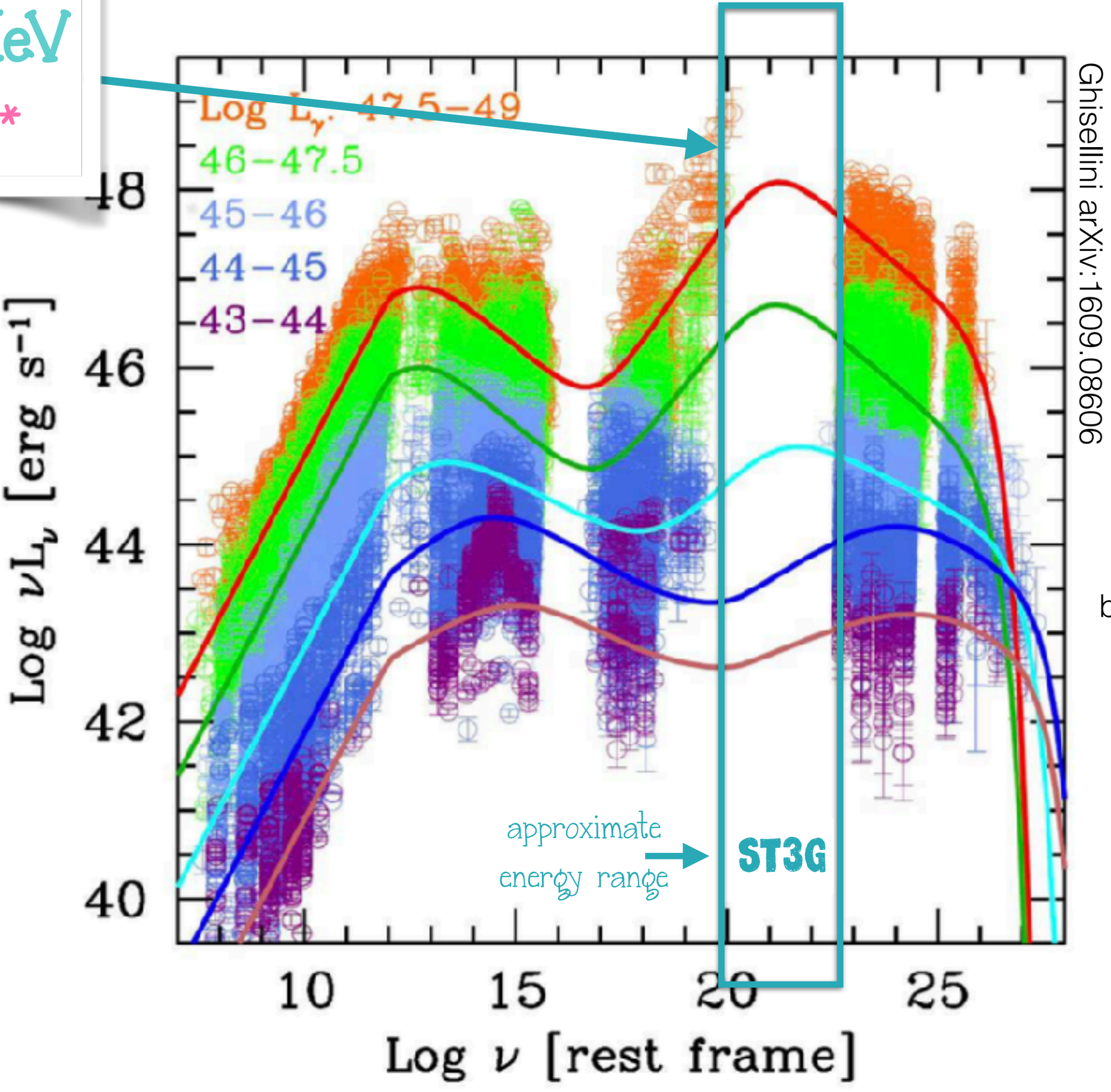

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The MeV Gap

The MeV sensitivity gap can be thought of as an angular-resolution issue ...

- At these energies (E>MeV), gamma rays interact predominantly by pair producing

- To increase the probability of pair production occurring (and therefore our effective area), we want the gamma ray to pass through as much matter as possible - we choose a high-Z material

- High-Z materials introduce multiple scattering of the e^+e^- pairs and we lose information about the geometry of the pair-production interaction

- This is not as significant a problem at energies above about 100 MeV (it becomes just about acceptable at 100 MeV: we are able to determine the direction of the gamma ray to within about 5°) but at lower energies, it renders the reconstruction of the gamma-ray direction, never mind the azimuthal information necessary to deduce the polarisation, infeasible - hence the sensitivity gap

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… what can we do?

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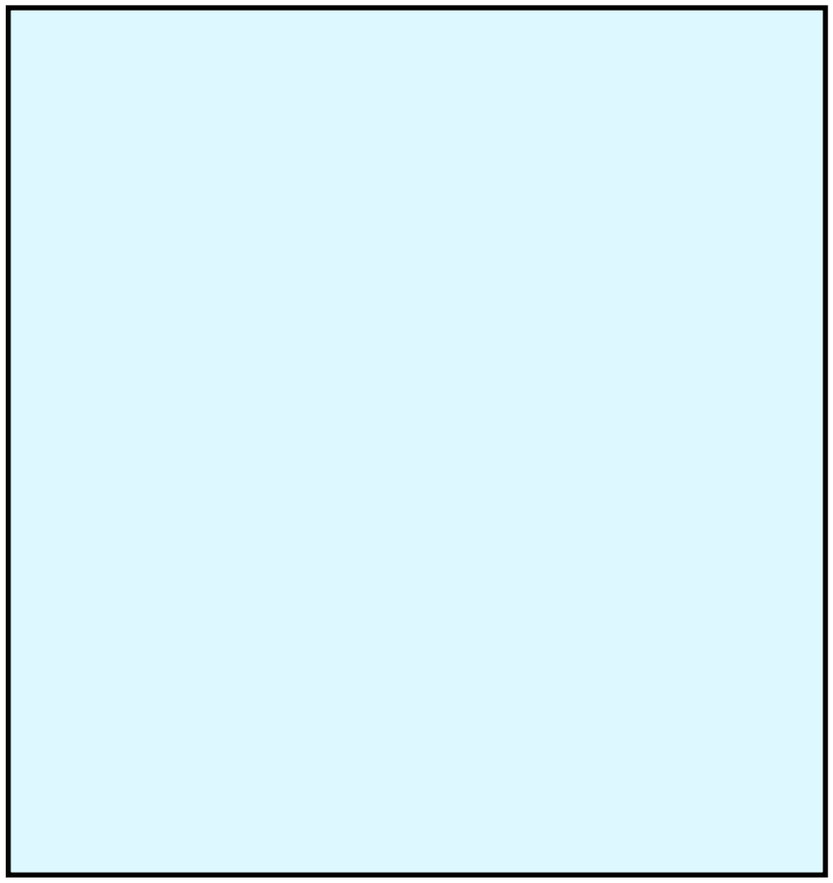
TPC



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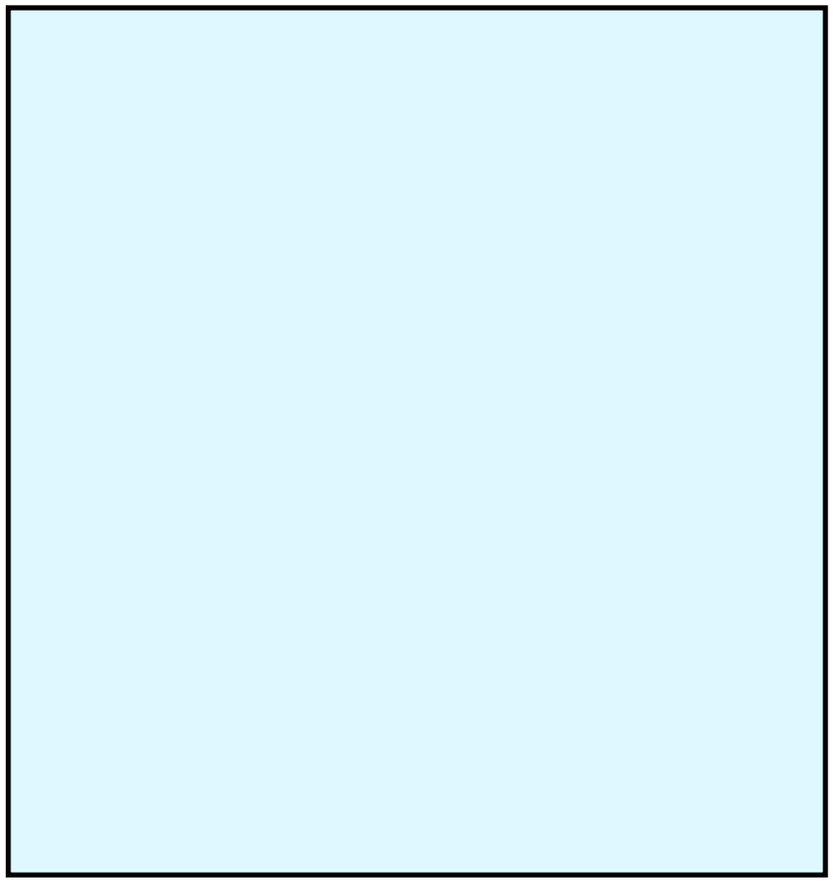
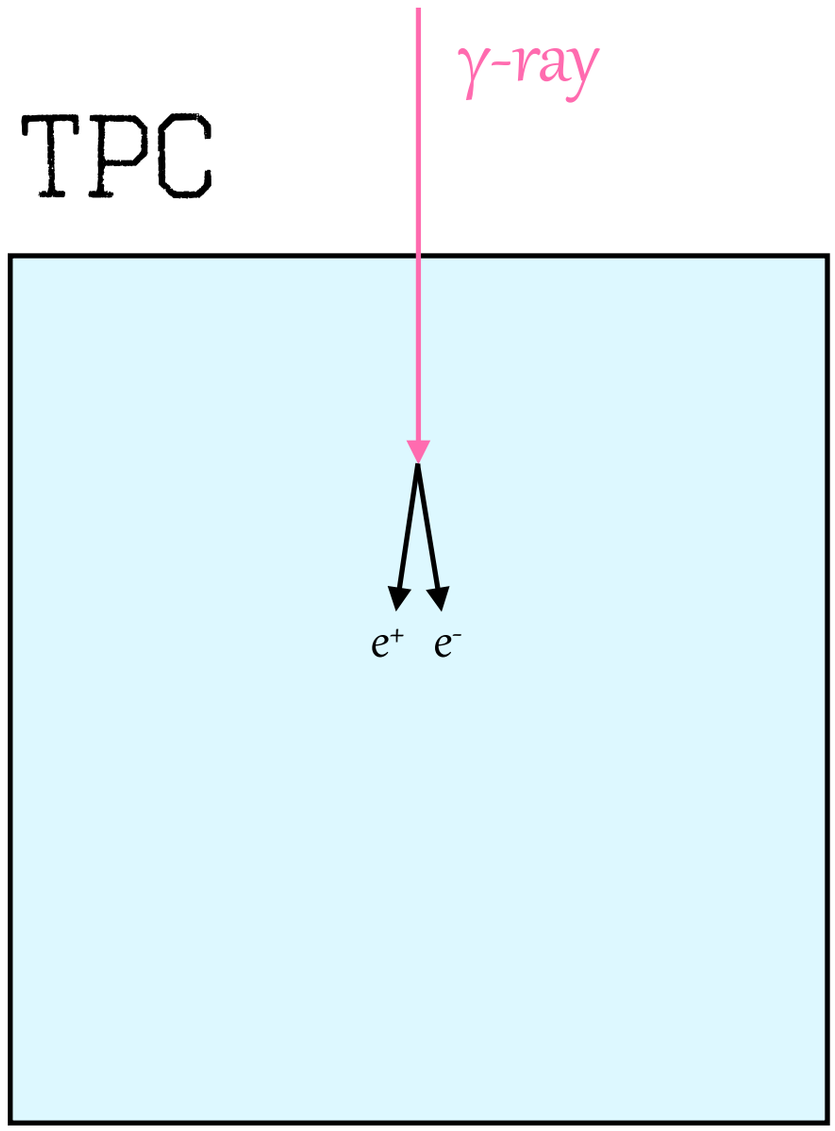


TPC (time projection chamber)

- simple robust particle detector
- widely used in HE physics
- a volume of matter is immersed in an E-field



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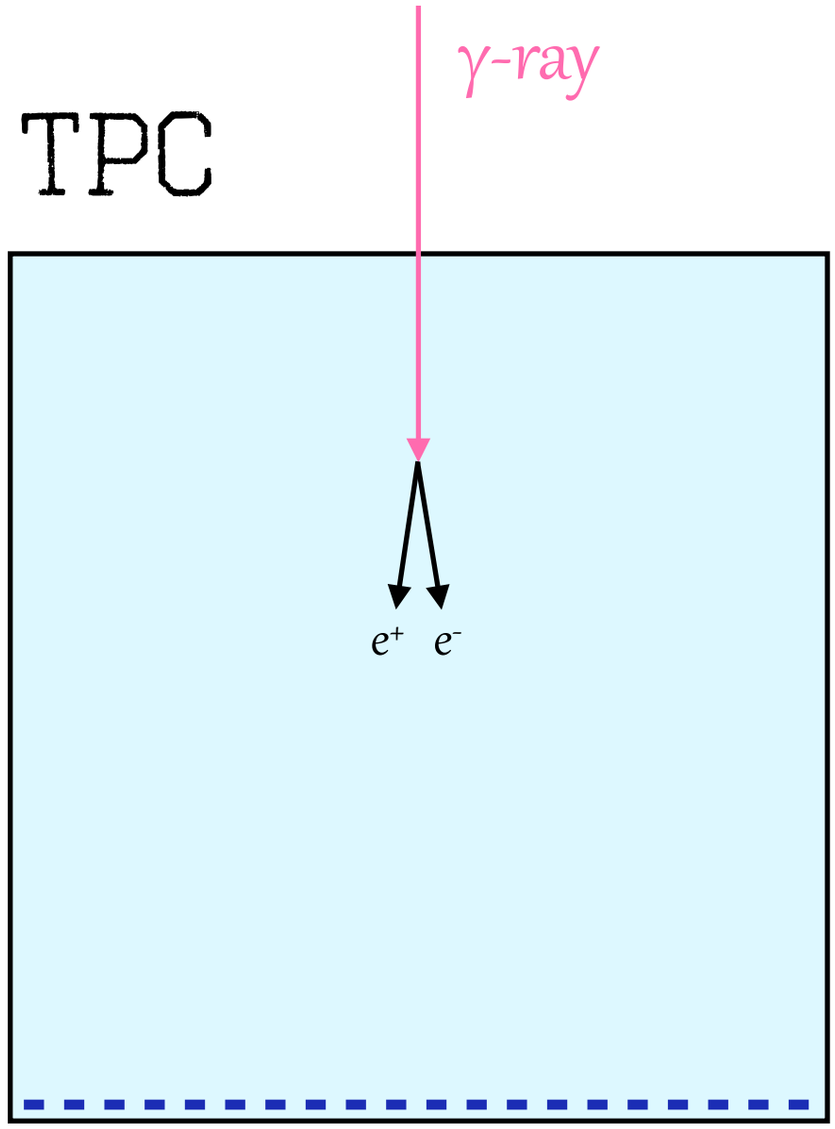

The anode is segmented (x-y coordinates)

- provides a "2D image" (2 x 1D slices) of the e^-s that drift on to it as a function of drift time
- the measurement of the drift time provides the third "z" coordinate

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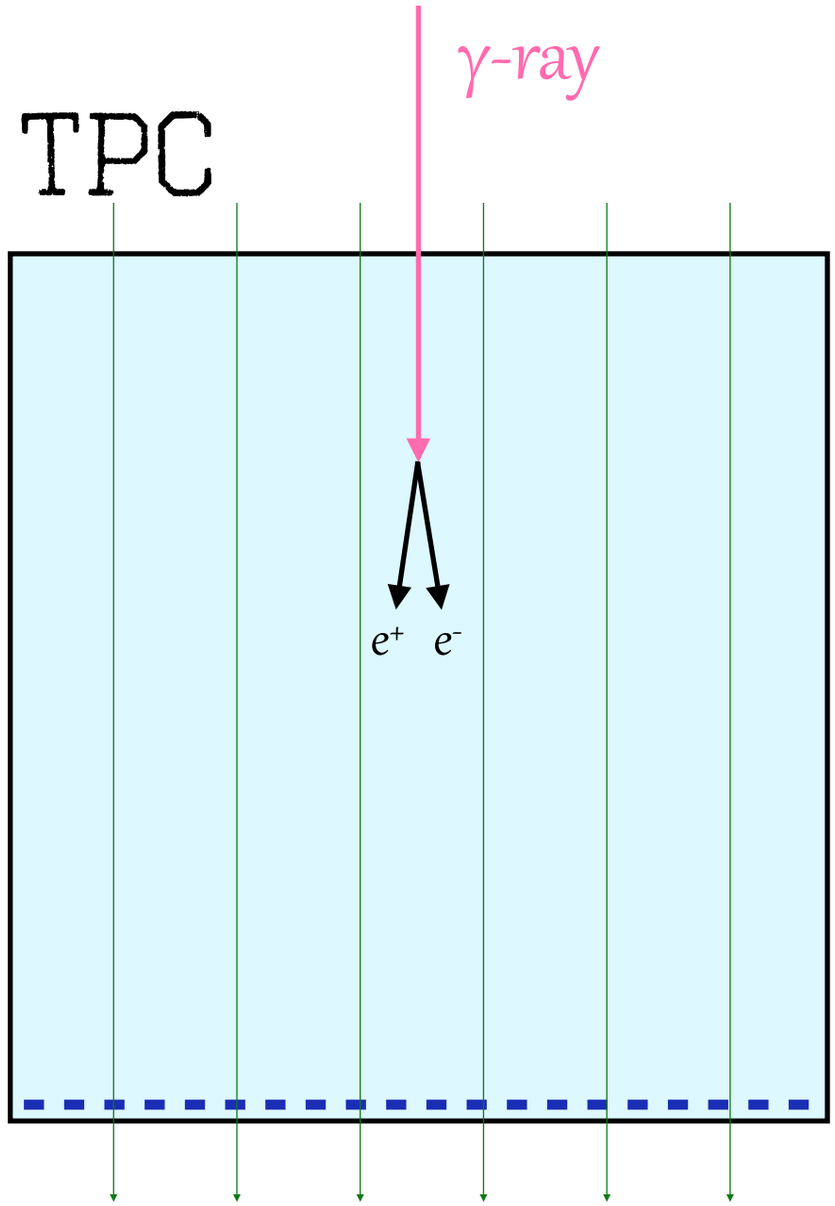

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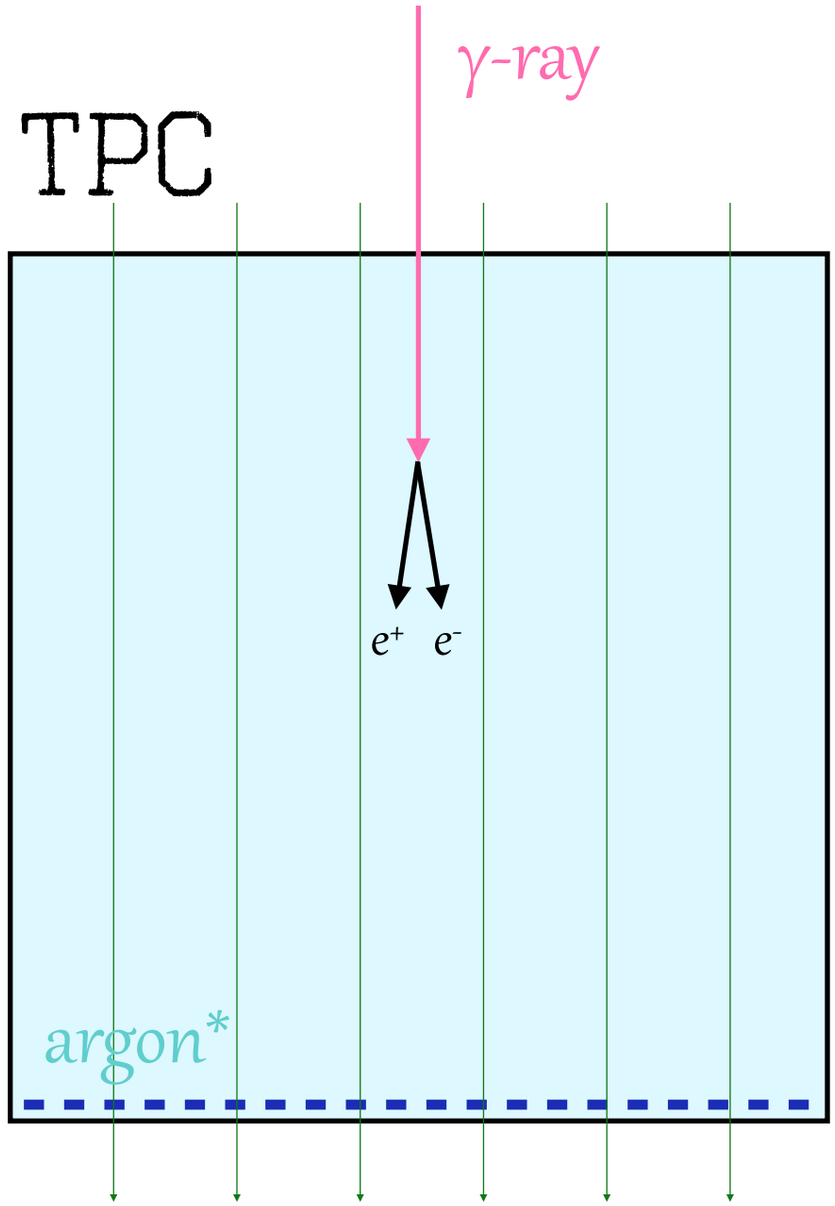

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Noble gases are very convenient as they allow free electrons to drift freely over long distances.

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*mostly

- **TPC = CONVERTOR + TRACKER → 100% "INSTRUMENTED"**

TPC is an active target - it is at the same time:

- the converter in which the gamma ray converts
- the tracker in which the two lepton trajectories are measured

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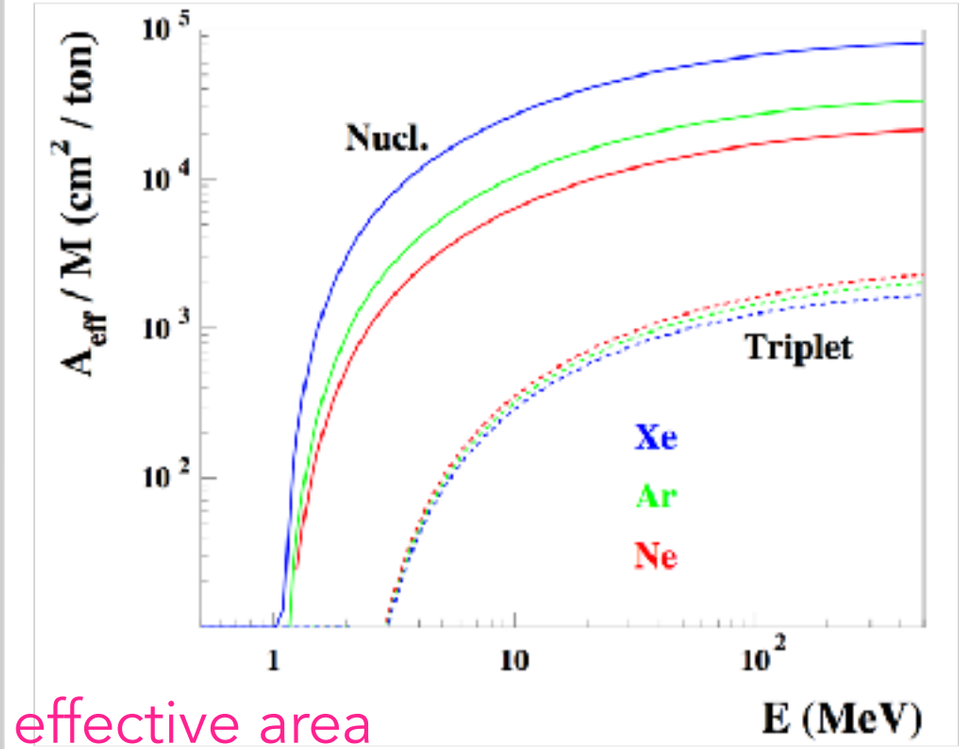

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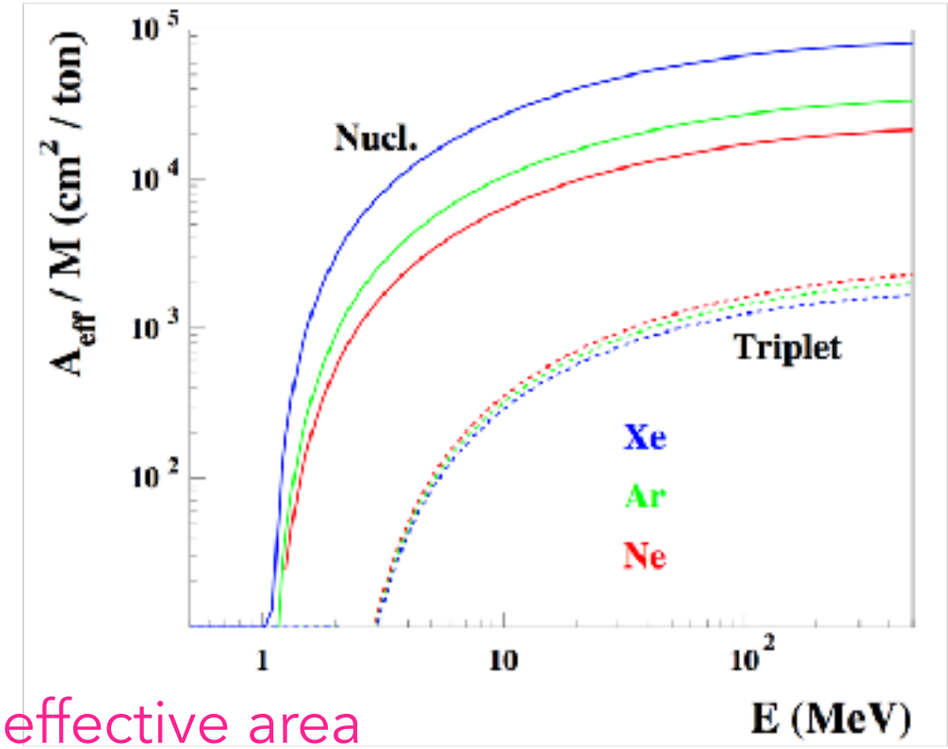
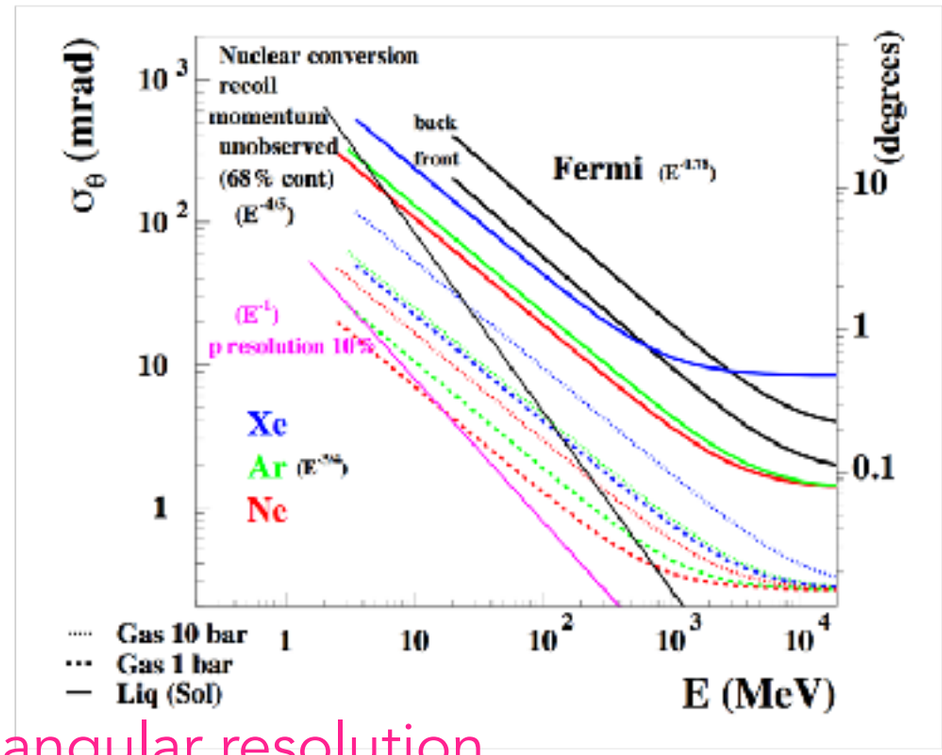
- but in so doing, the single-track angular resolution and therefore the single-photon angular resolution would degrade



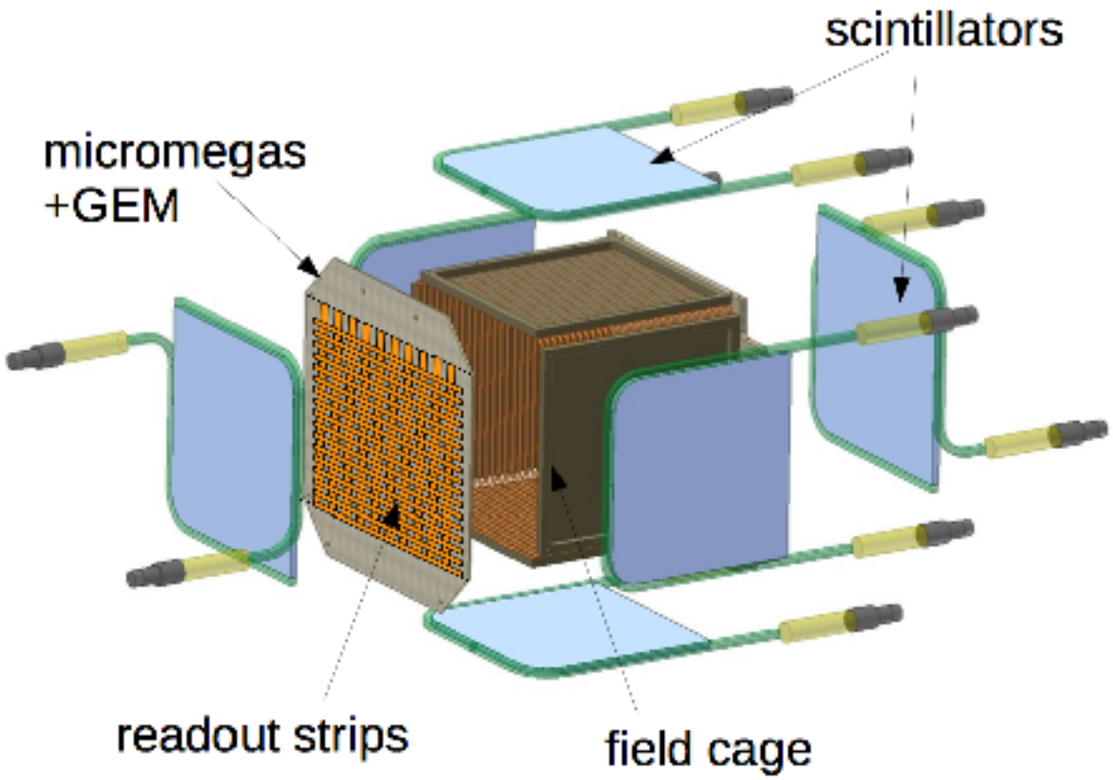
effective area

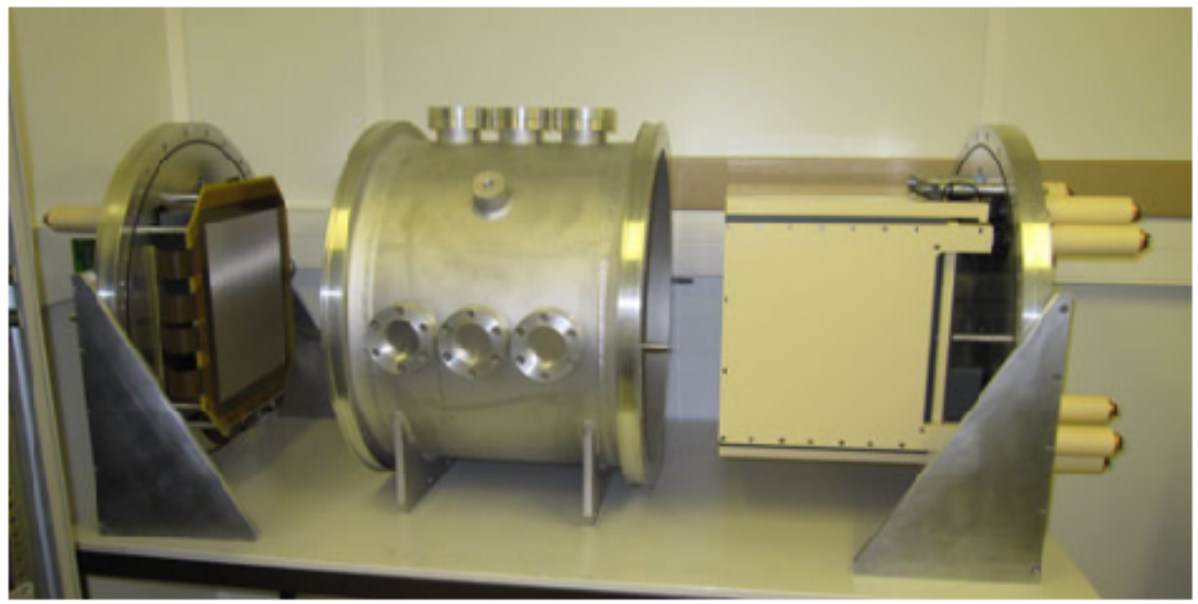


angular resolution

the Hermetic ARgon POlarimeter

a demonstrator of the performance of a TPC for measuring polarised gamma rays





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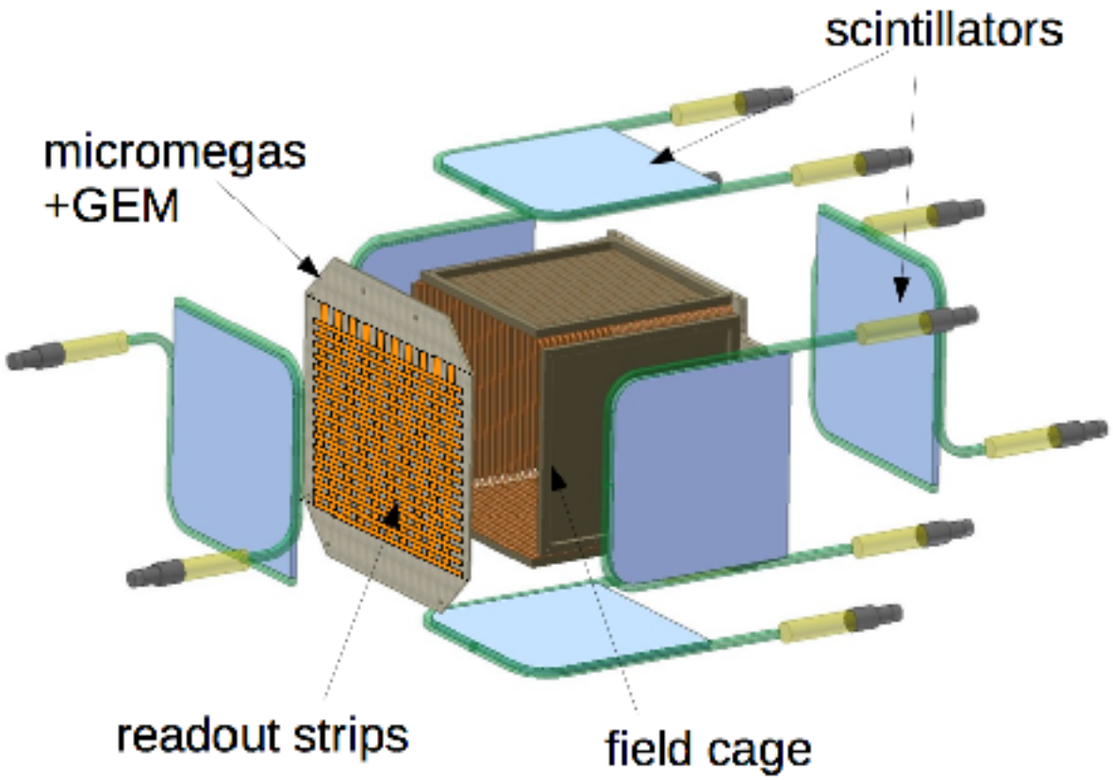

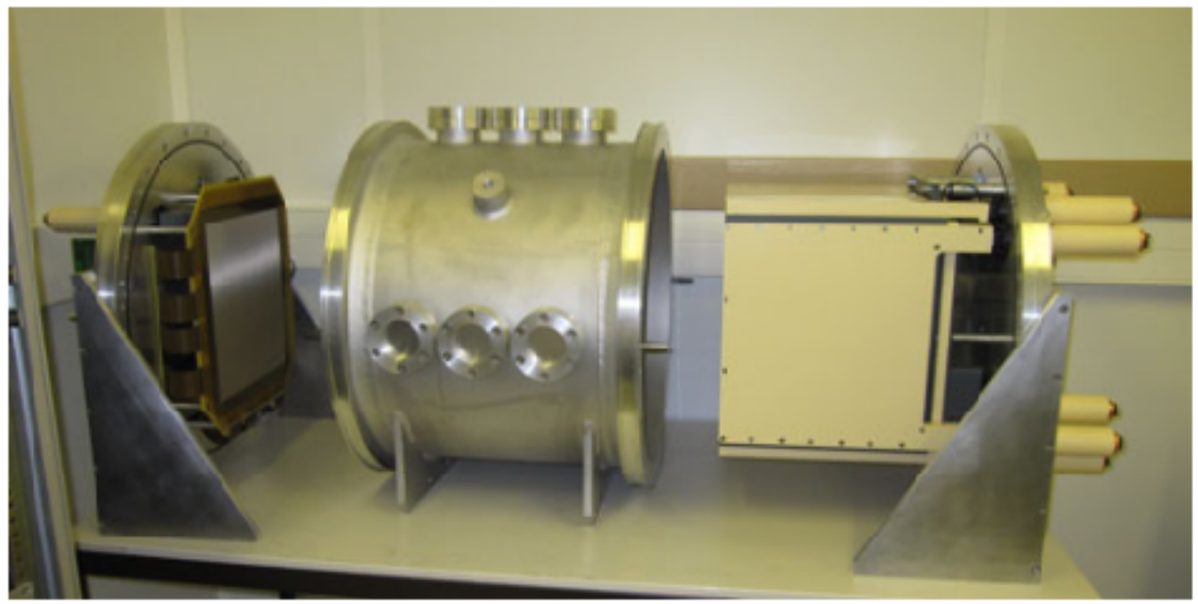

- designed for validation on the ground in a photon beam
- the most critical constraints related to space operation were taken into account
  - reduced no. channels, gas-quality preservation
- 30 cm^3 cubic TPC (Ar:isobutane, 95:5, @ 2.1bar)
- drift cage provided 220 V/cm drift field (v_{drift} approx. 3.3 cm/μs)
- readout plane: 2 Gas Electron Multipliers (GEMs) and one Micromesh Gas Structure (Micromegas)
- amplified e^- signal collected by 2 sets of perpendicular strips (1mm pitch; X-dir: strips; Y-dir: pads)
- signals read out and digitised with a set of AFTER chips and associated Front End Cards (FECs)

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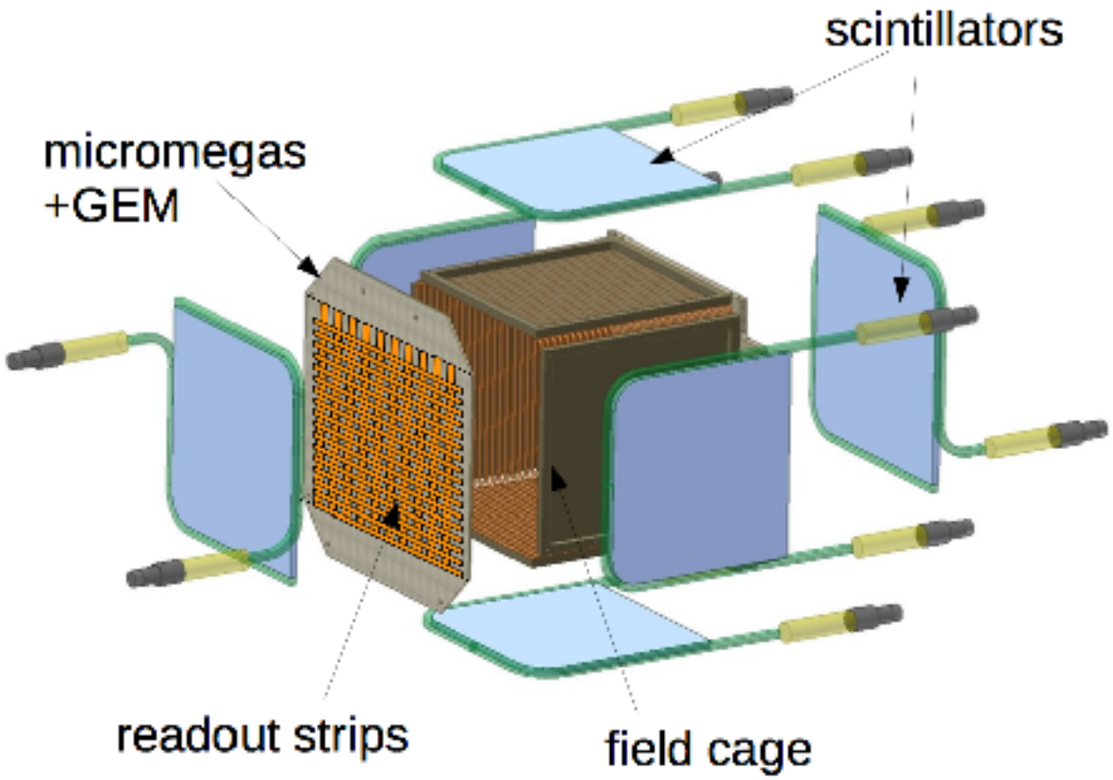
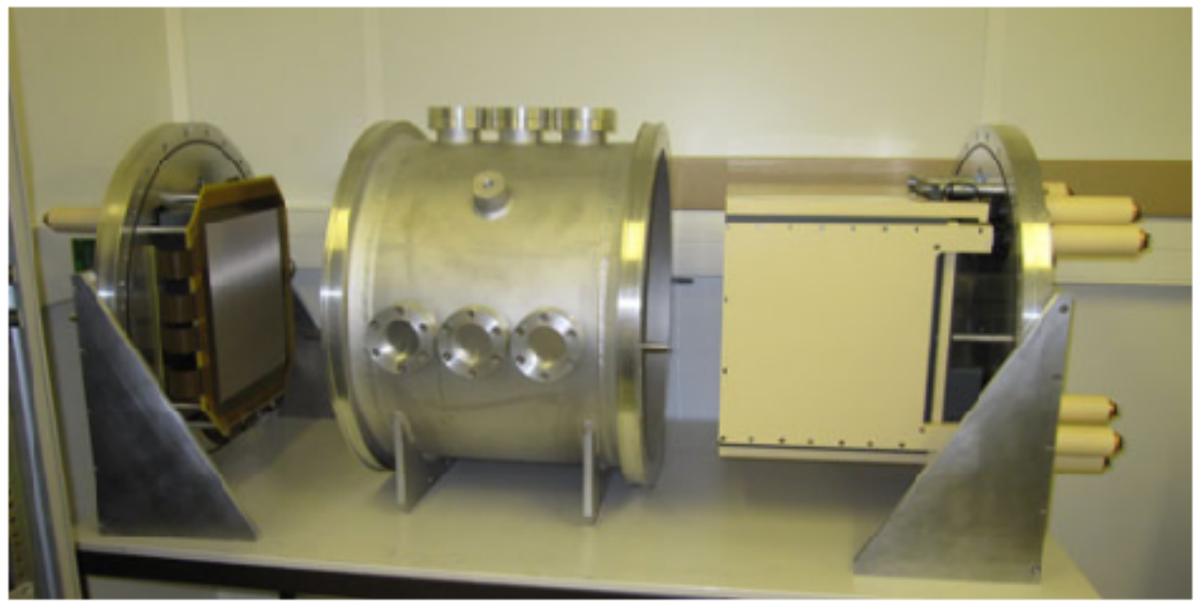
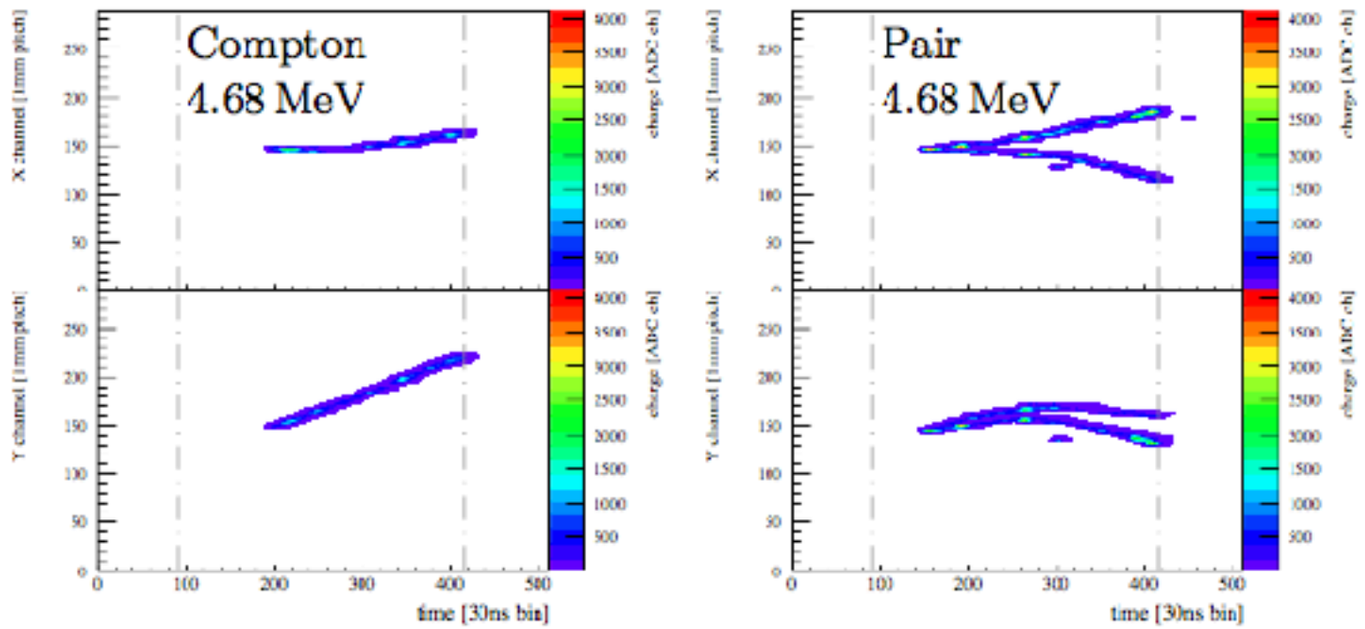
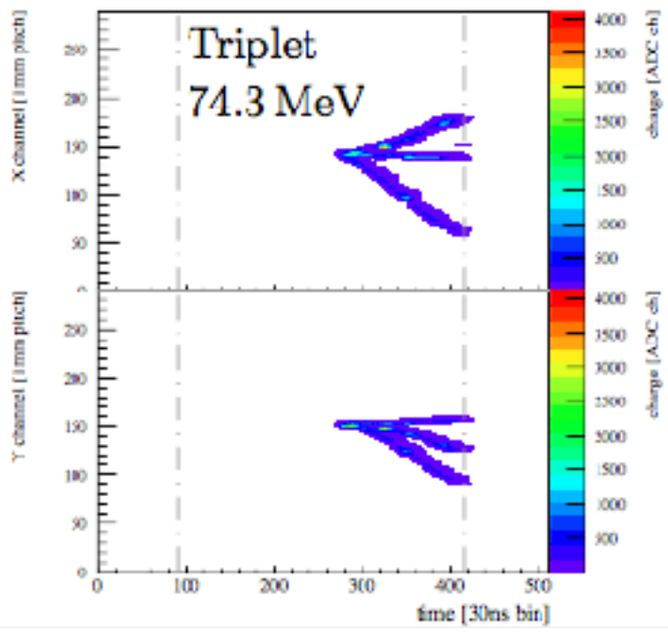




- set up in NewSUBARU polarised photon beam line in November 2014
- photon beam produced by Laser Compton Scattering of an optical laser on a high energy e^- beam
  - 0.6 - 1.5 GeV e^- beam
- lasers of different wavelengths + different energy e- beam
  - 13 photon energies from 1.74 MeV to 74.3 MeV

the Hermetic ARgon POlarimeter

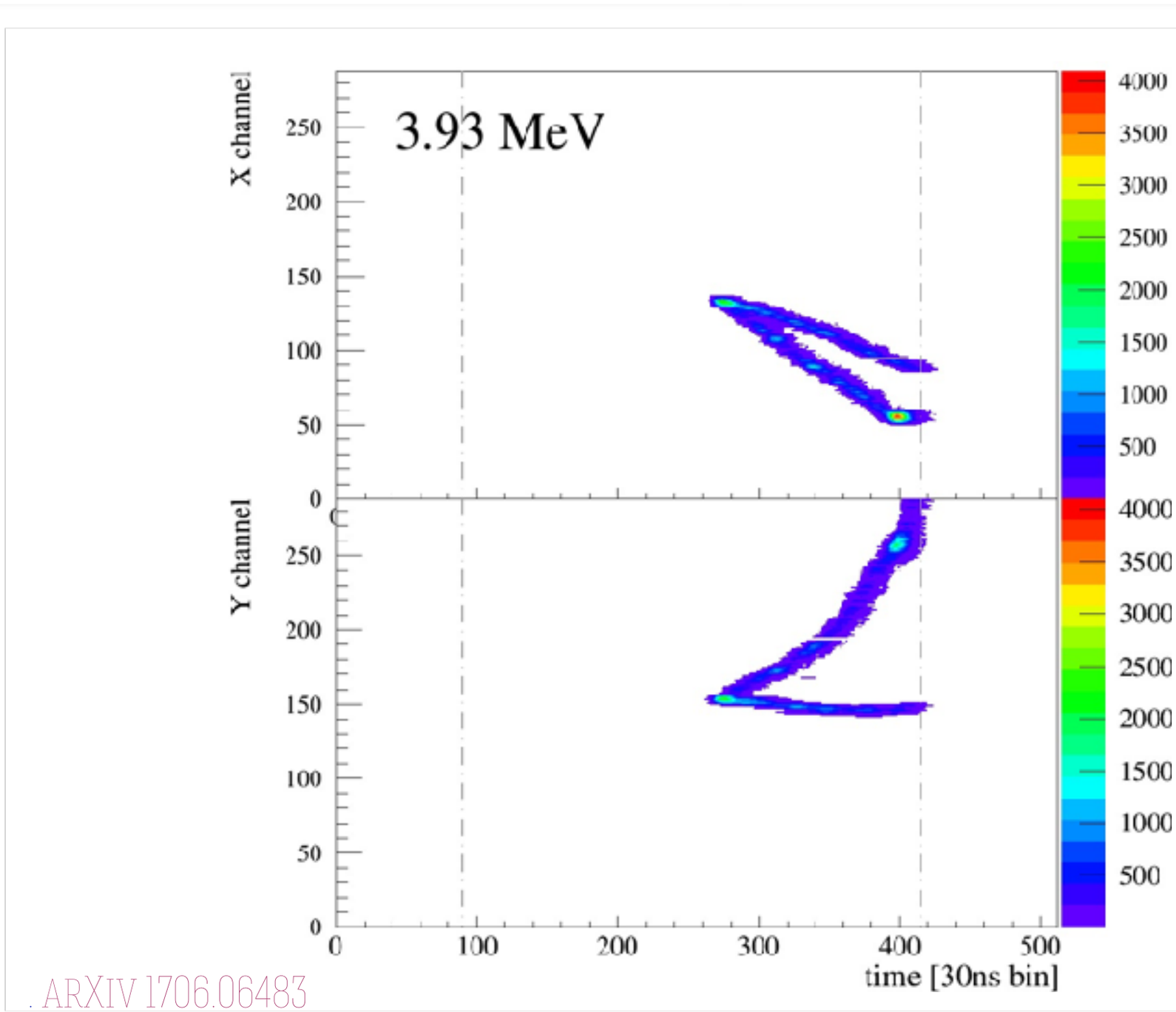




precise measure of e^+e^- tracks

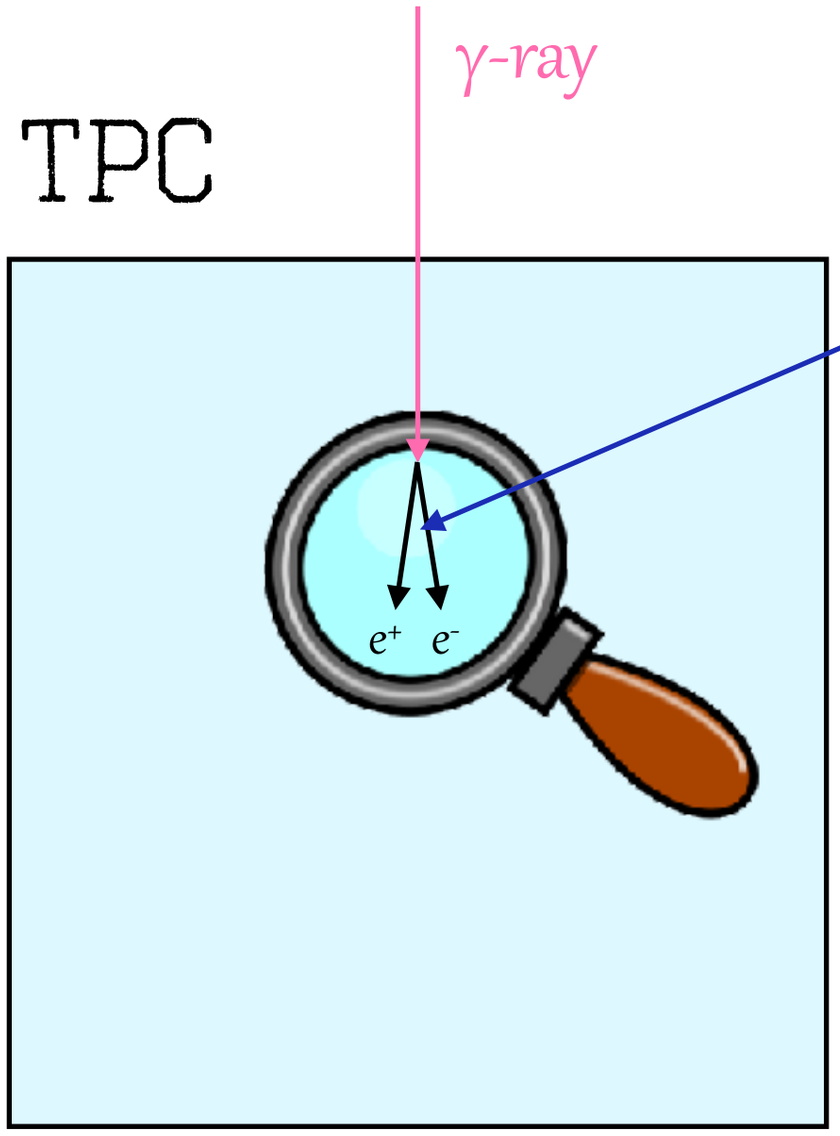
From "Performance measurement of HARPO: a Time Projection Chamber as a gamma-ray telescope and polarimeter", Gros P. et al. arXiv 1706.06483

the Hermetic ARgon POlarimeter

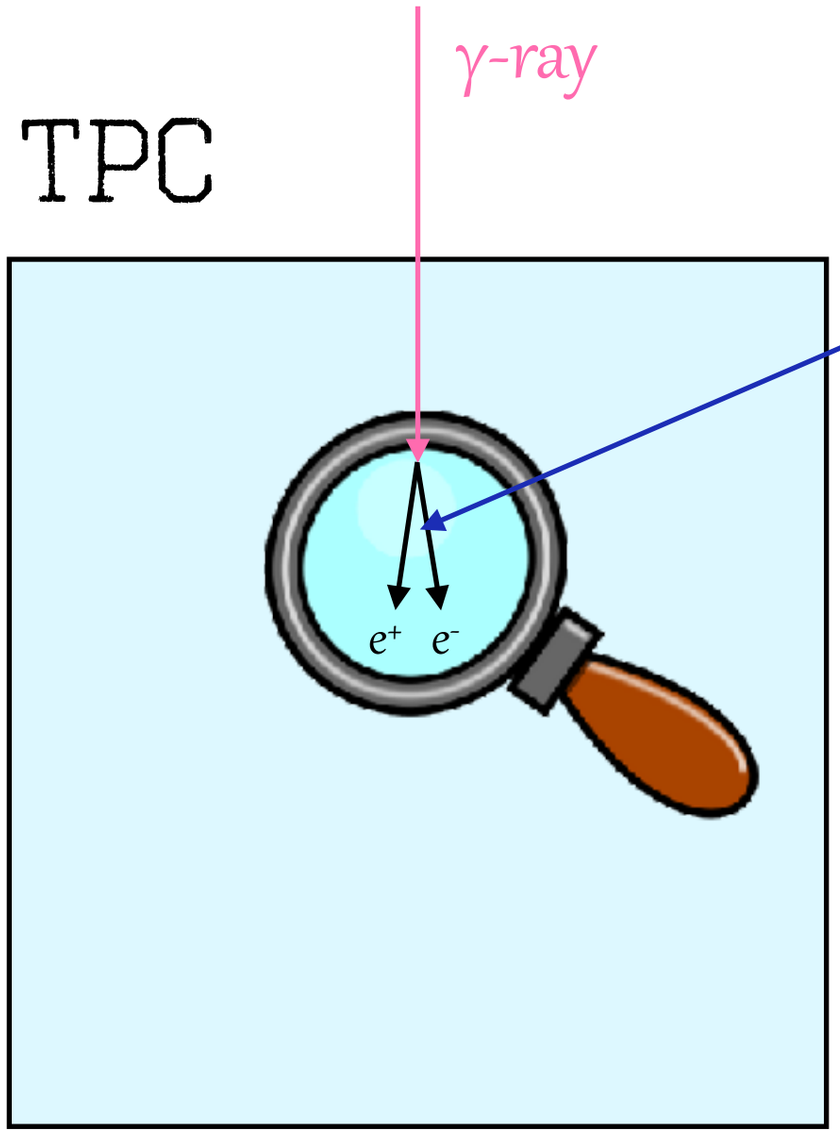


low-energy event: 3.93 MeV

. ARXIV 1706.06483



the measurement of the tracks enables us to reconstruct the angles of the pair production interaction thus giving us access to the polarisation information of the intitial gamma ray



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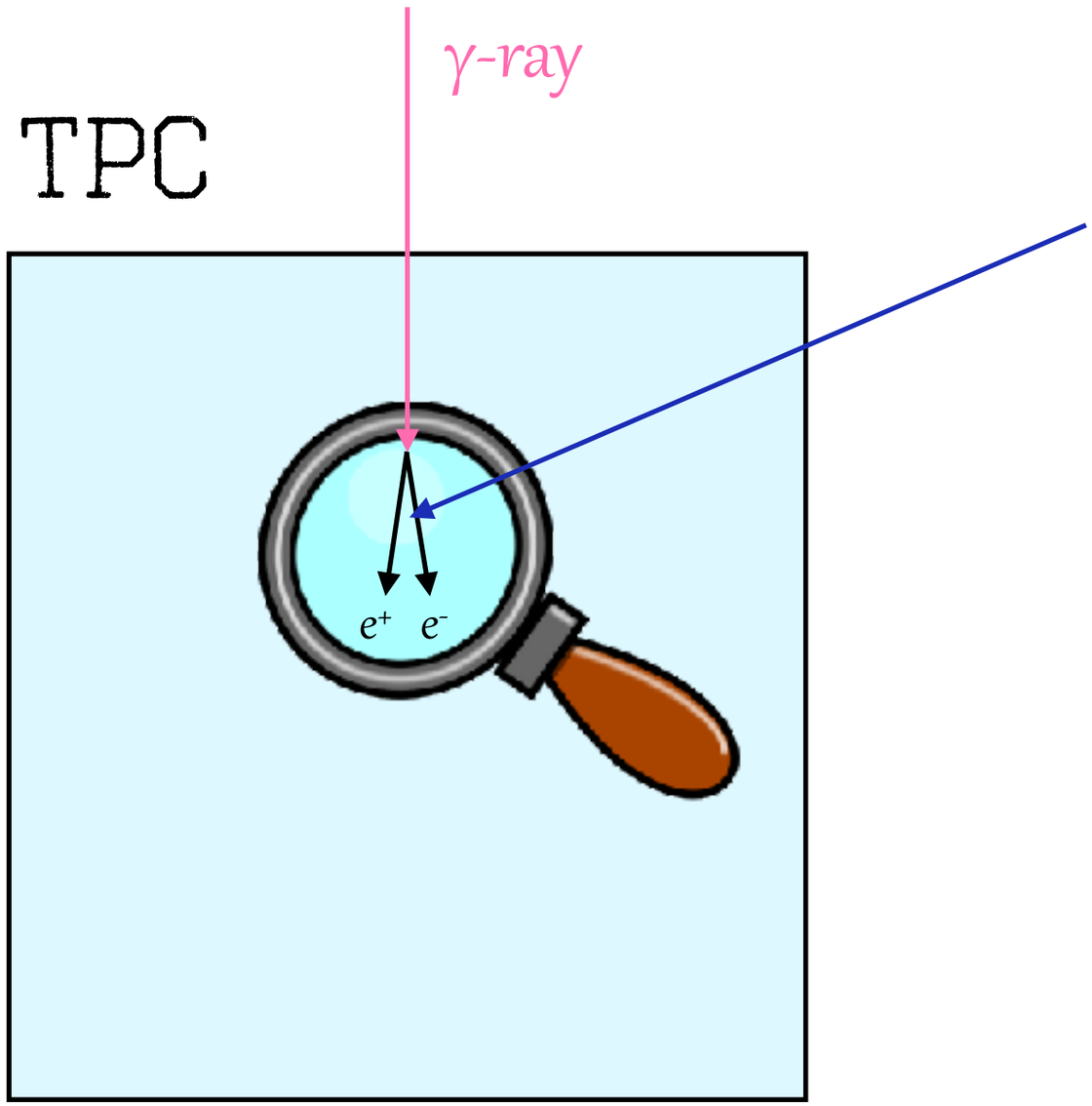
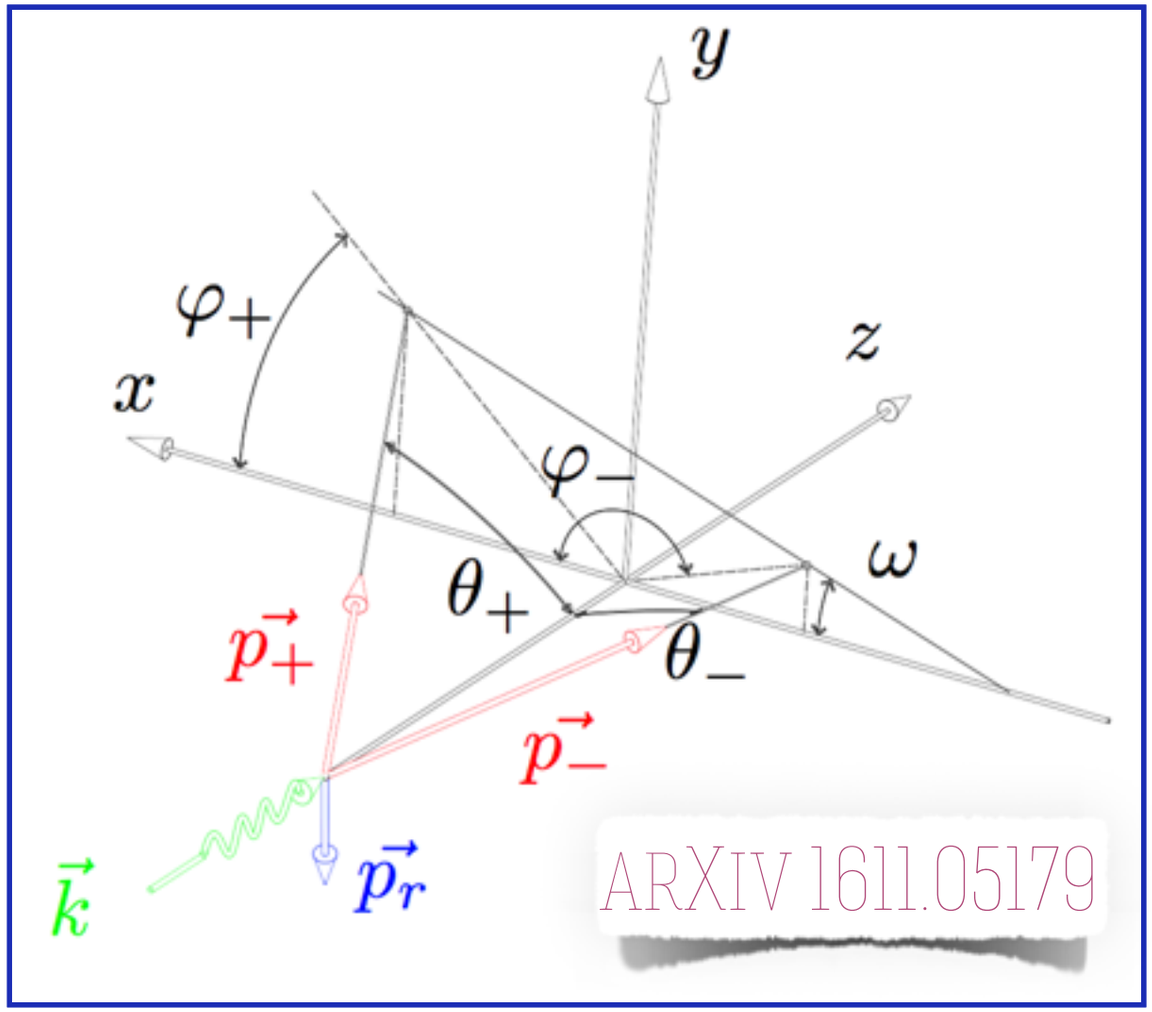
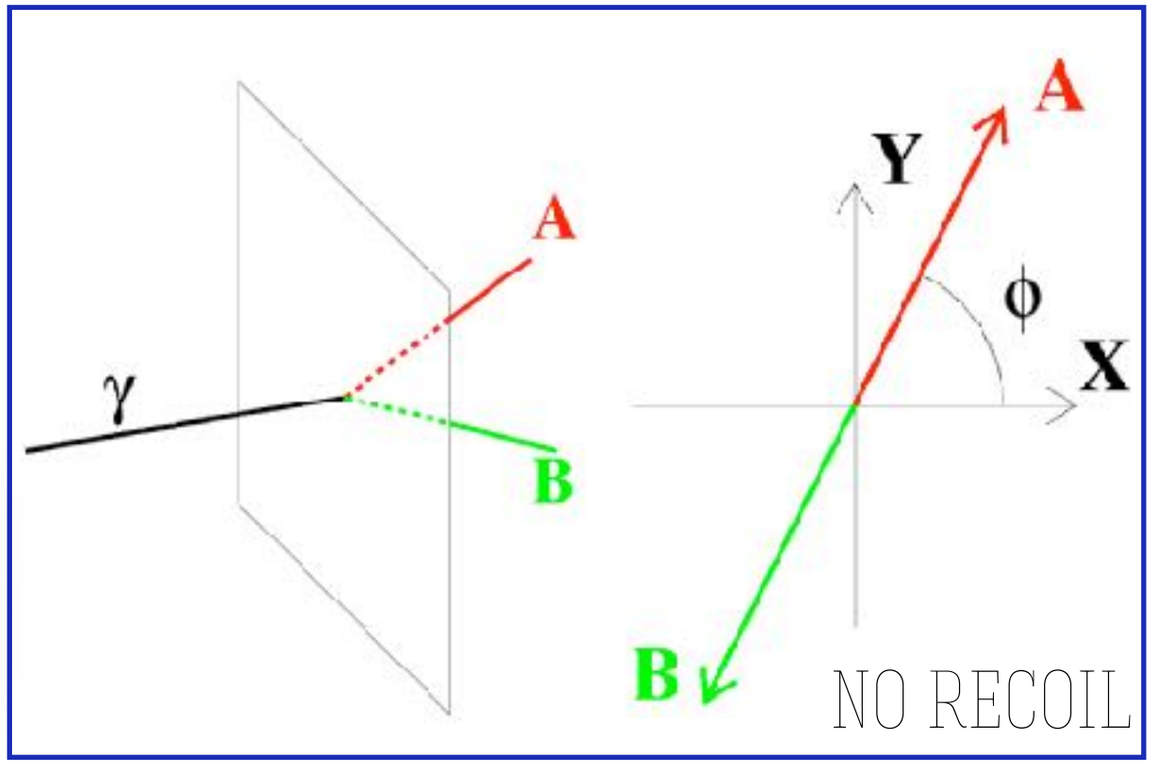
since the final state is determined by five variables, the definition of "the" azimuthal angle of the event can be done in several ways ... examination of the precision of the measurement shows that the optimal choice is the azimuthal angle of the bisectrix of the direction of the electron and of the positron







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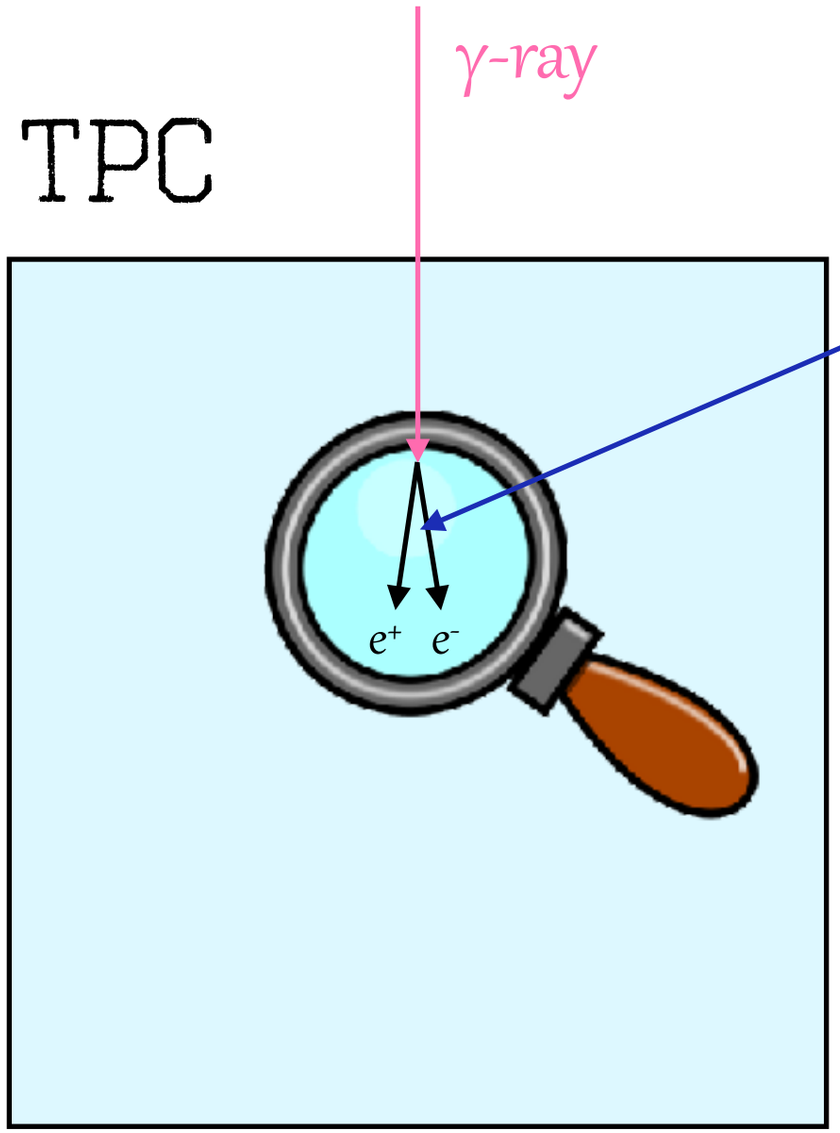

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$$\frac{\mathrm{d}\sigma}{\mathrm{d}\varphi} \propto (1 + A \times P \cos(2(\varphi - \varphi_0)))$$

A : polarisation asymmetry of conversion process

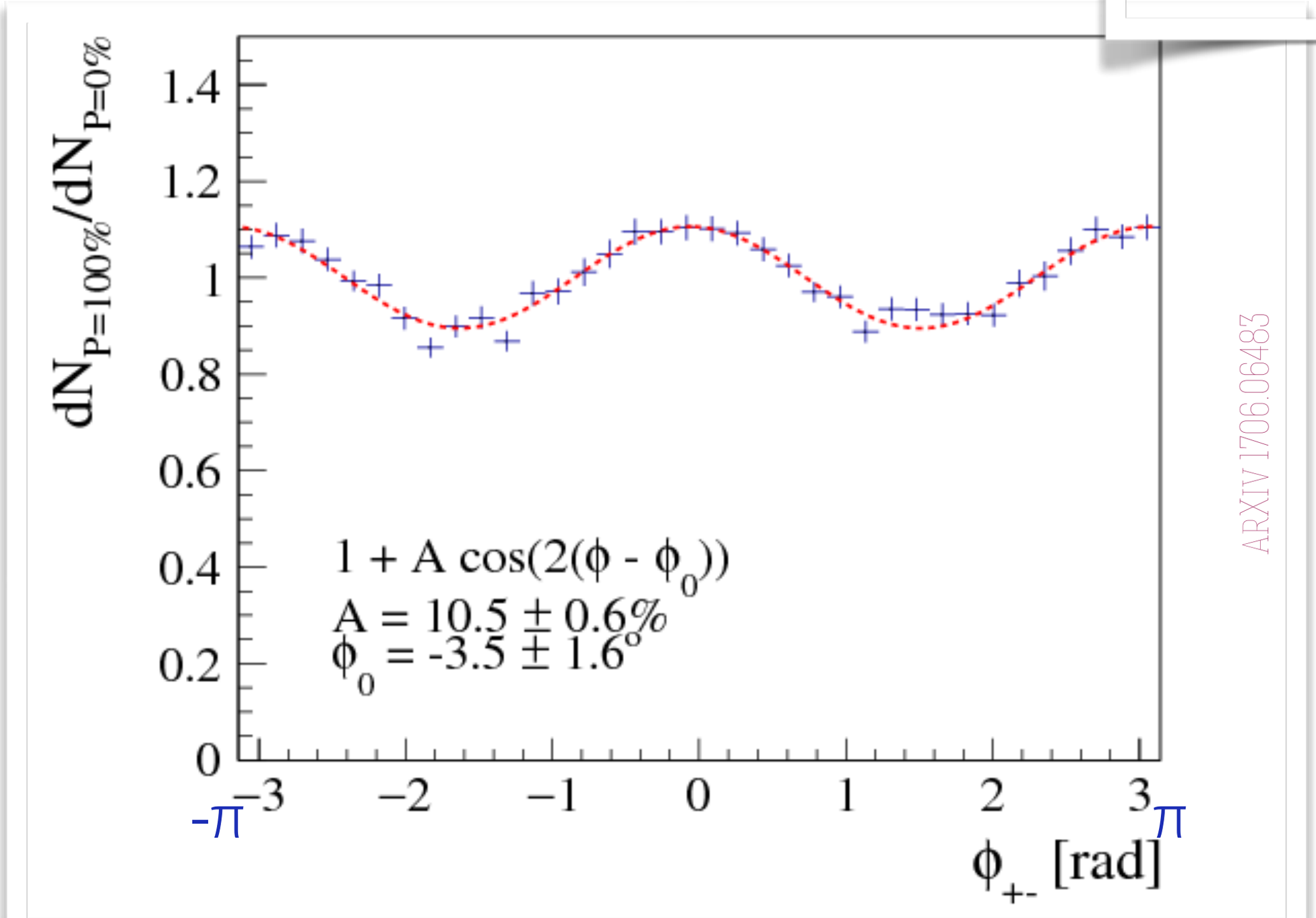
P : polarisation of incoming radiation

φ : azimuthal angle of the event

φ_0 : polarisation angle of incoming radiation

The first measurement of the polarisation of MeV gamma rays using a TPC

11.8 MeV



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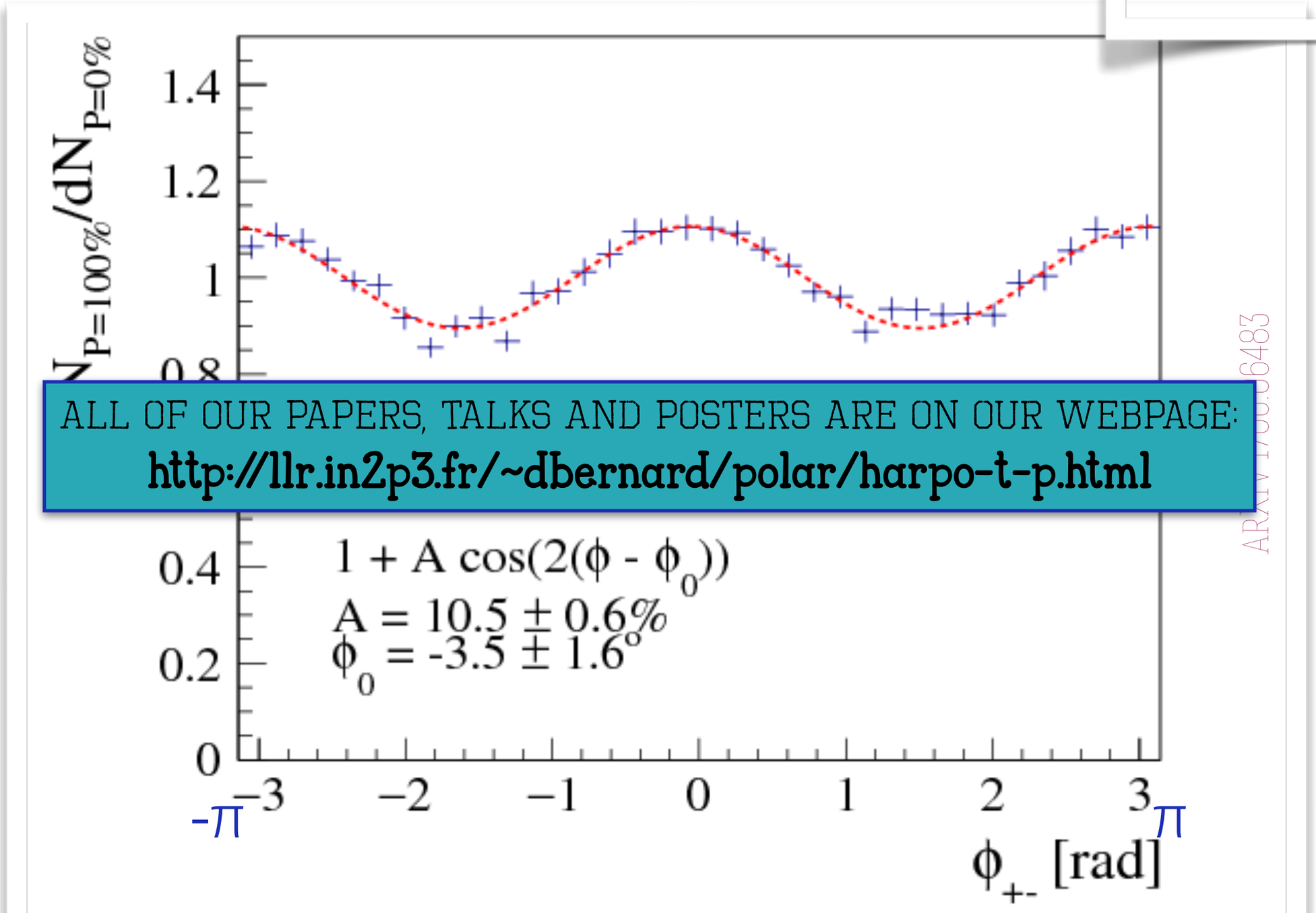


ALL OF OUR PAPERS, TALKS AND POSTERS ARE ON OUR WEBPAGE:

http://llr.in2p3.fr/~dbernard/polar/harpo-t-p.html

Ground phase

2009 bibliography

first validated event generator

2010 first (small) funding

prototype design

2011 protoype building

prototype commissioning

2012 first cosmic rays - characterisation as a tracker

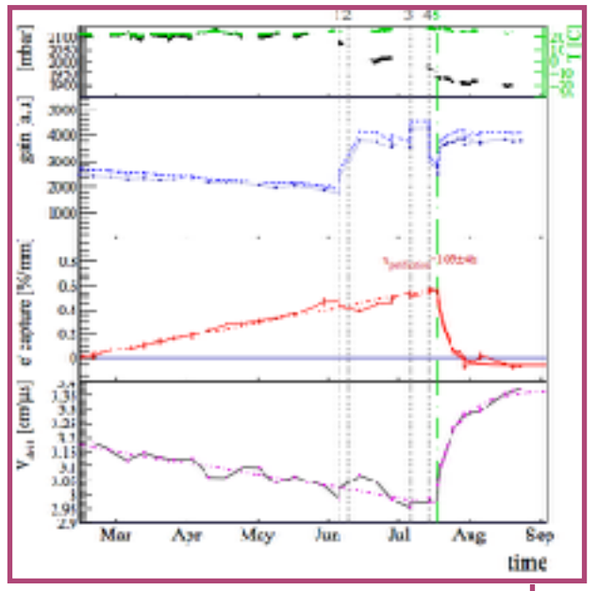
2012 2013 2014 2015 2016 2017

Ground phase

HARPO

2012 2013 2014 2015 2016 2017

the Hermetic ARgon POlarimeter (2012 - 2017)



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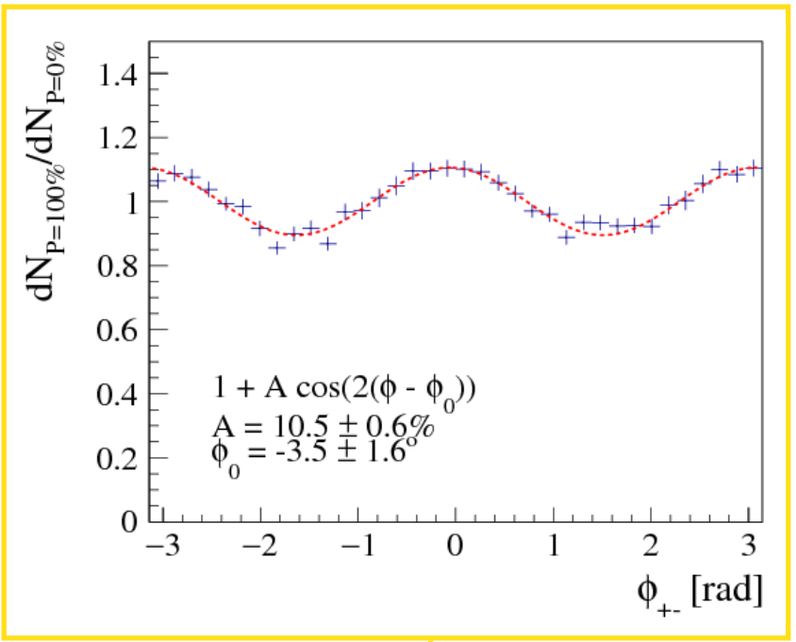

HARPO

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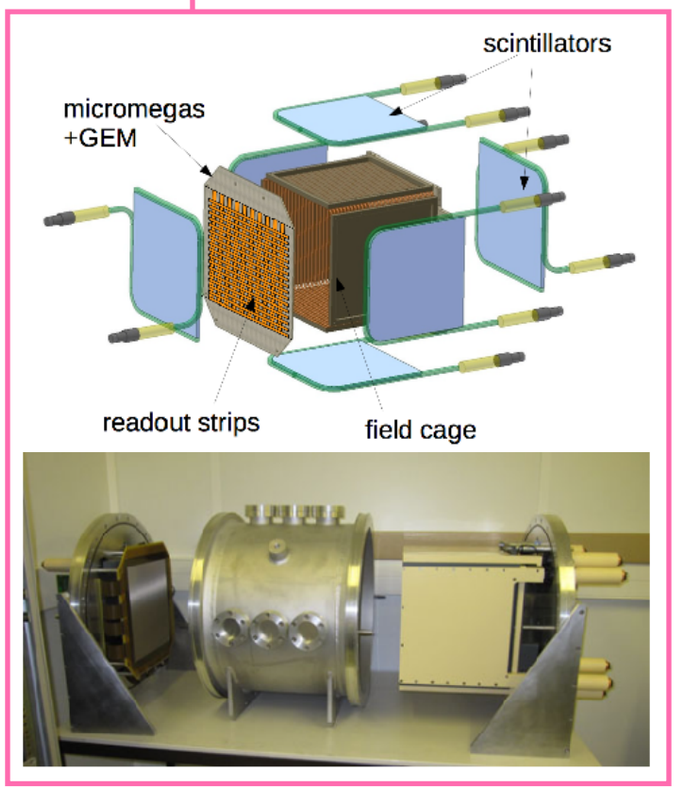

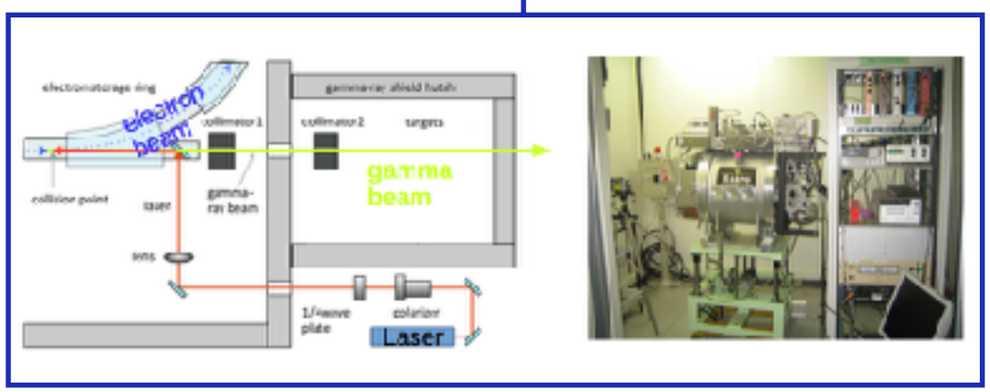

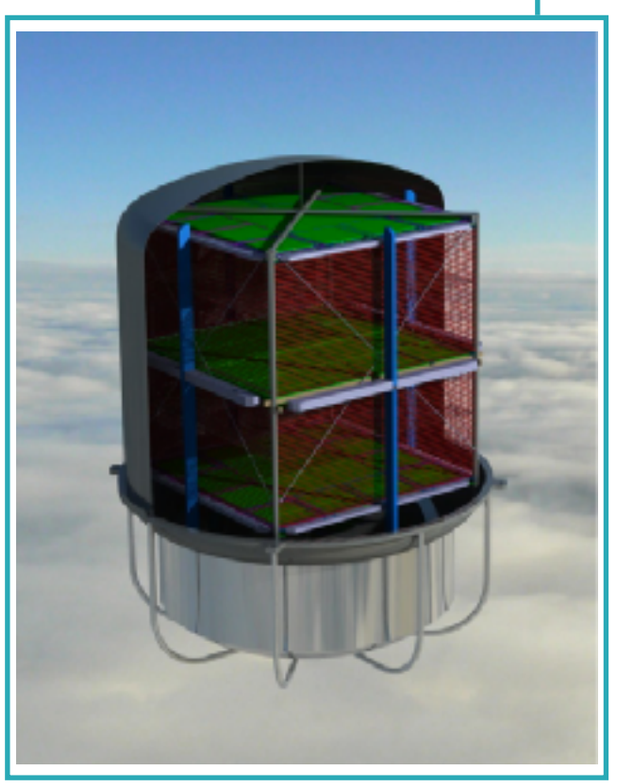

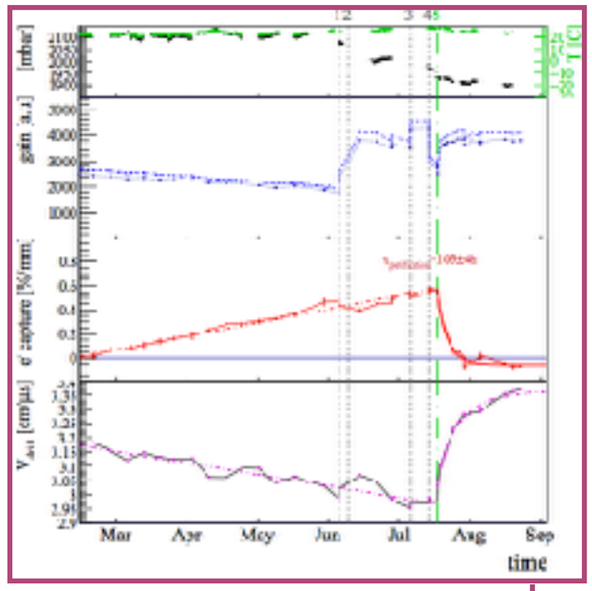

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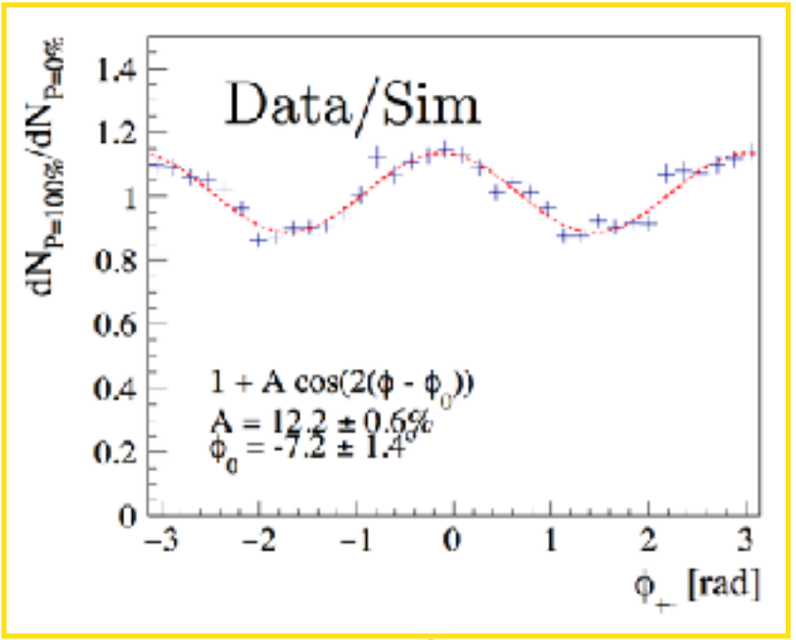

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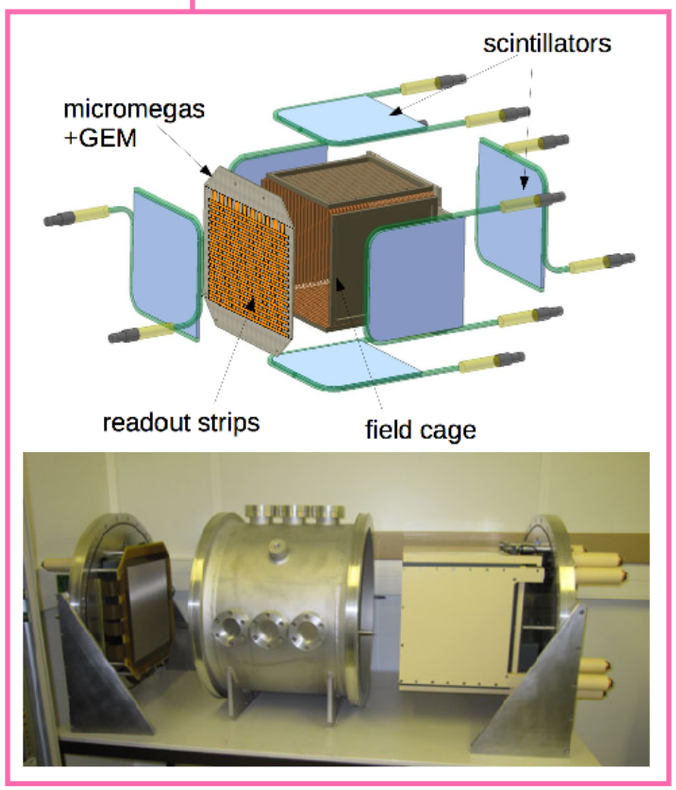

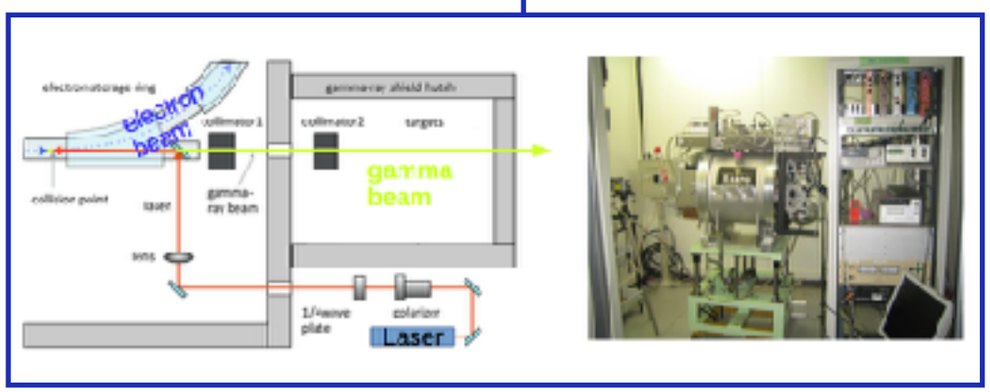

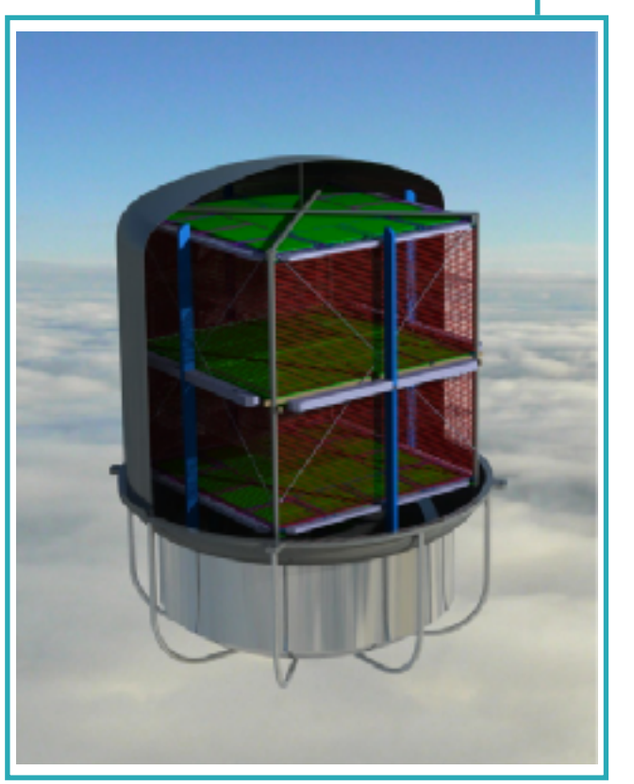

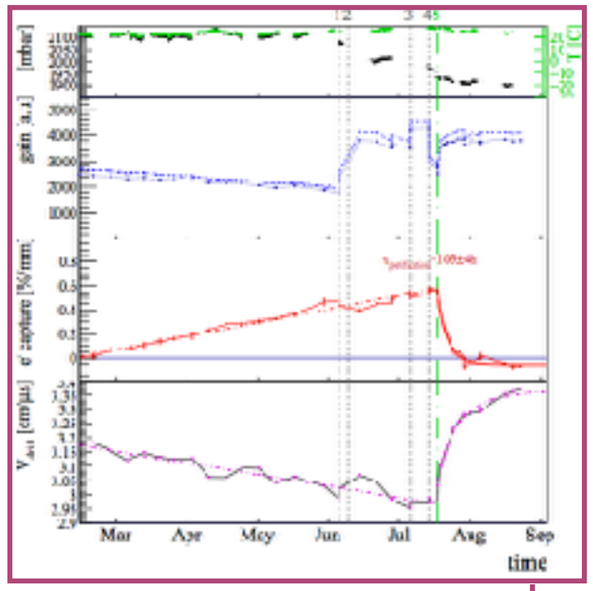

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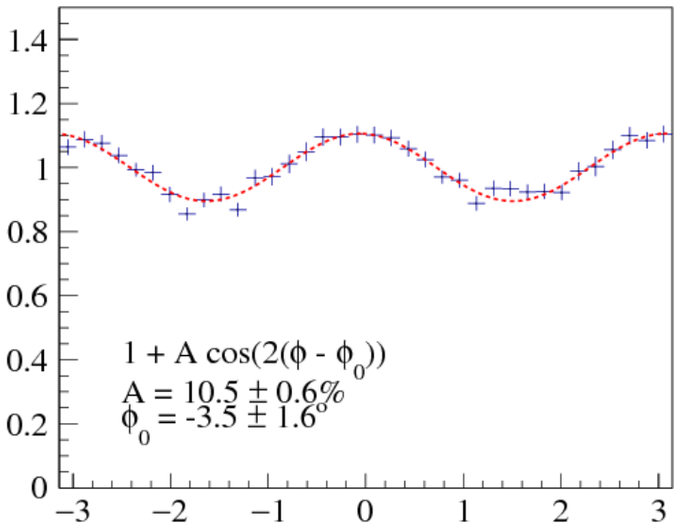

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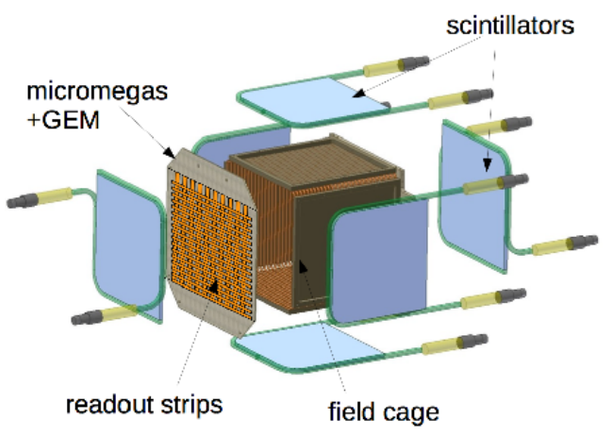
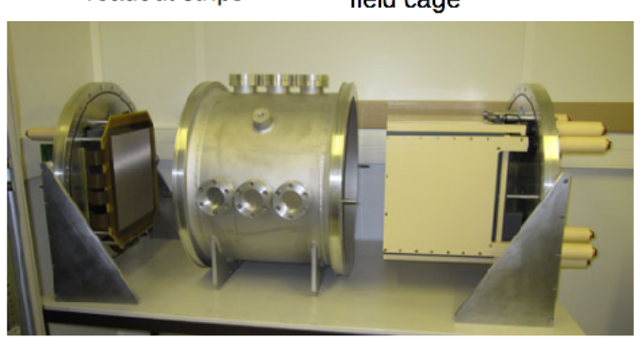
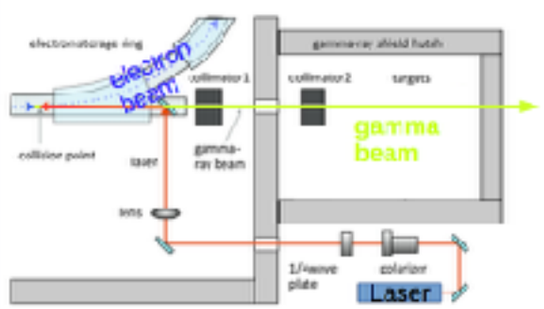
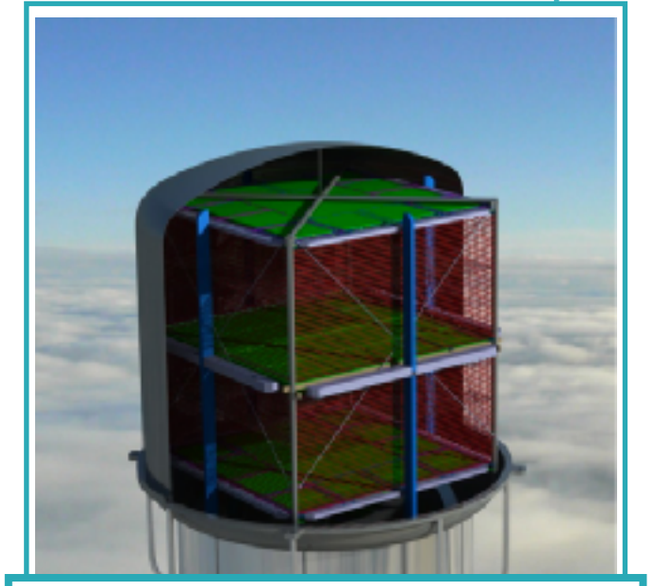
2012 2013 2014 2015 2016 2017

the Hermetic ARgon POlarimeter (2012 - 2017)









Balloon phase

Overview of project

Ground phase

HARPO

Proof of concept: use TPC to measure polarisation

Balloon phase

ST3G

Develop trigger system for TPC in space

Space phase

Design instrument for space flight

Overview of project

Ground phase

HARPO

ground

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ST3G

balloon

Develop trigger system for TPC in space

Space phase

Design instrument for space flight

Balloon phase

ST3G

DEVELOP TRIGGER SYSTEM FOR TPC IN SPACE

- develop scientific case
  - balloon flight
  - eventual space-based instrument
- perform simulations to develop trigger
  - design and build trigger system
  - test in lab
- build instrument for balloon flight
  - run trigger in "real" space environment
  - can we self-trigger a TPC efficiently?

Self-triggering TPC telescope for gamma-rays

ST3G

Key Characteristics

- Energy: a few MeV - GeV
- Polarisation capabilities
- High angular resolution

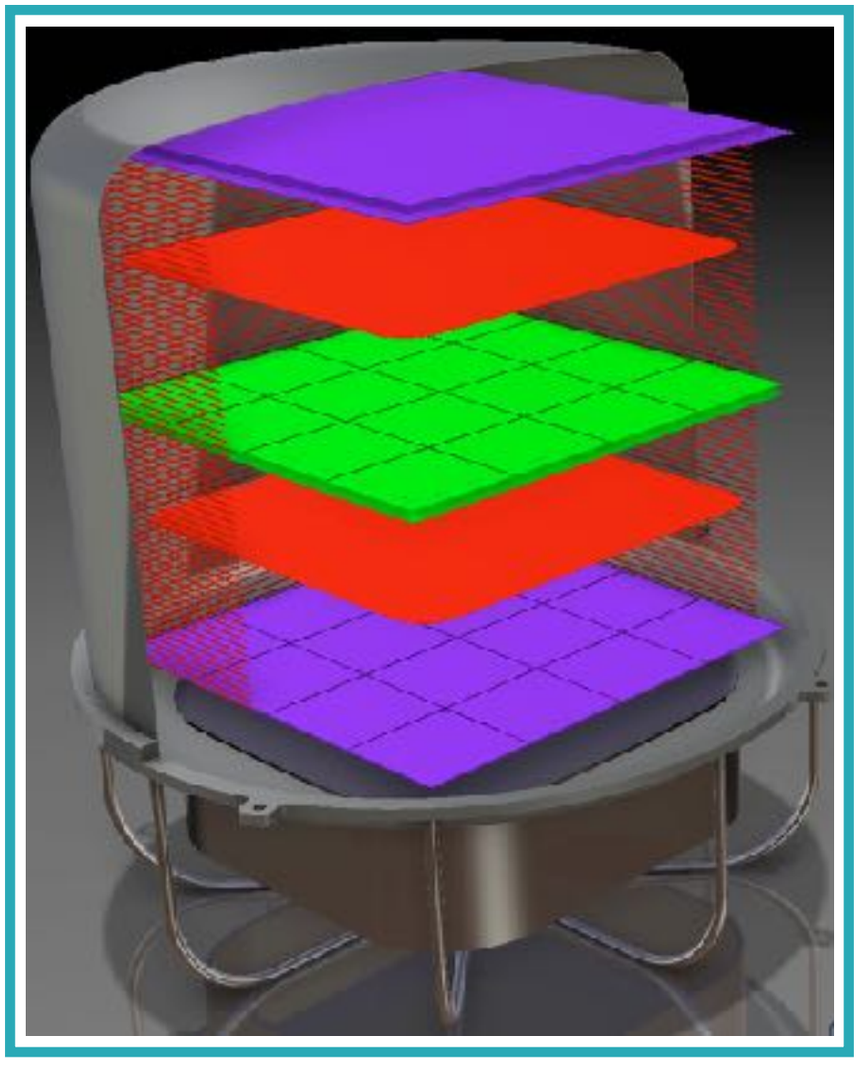
ST3G

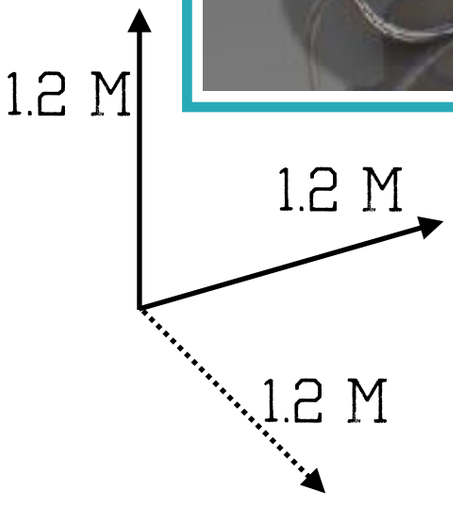
Key Characteristics

- Energy: a few MeV - GeV
- Polarisation capabilities
- High angular resolution

WE WILL ONLY HAVE
LIMITED CAPABILITIES
DURING A BALLOON FLIGHT

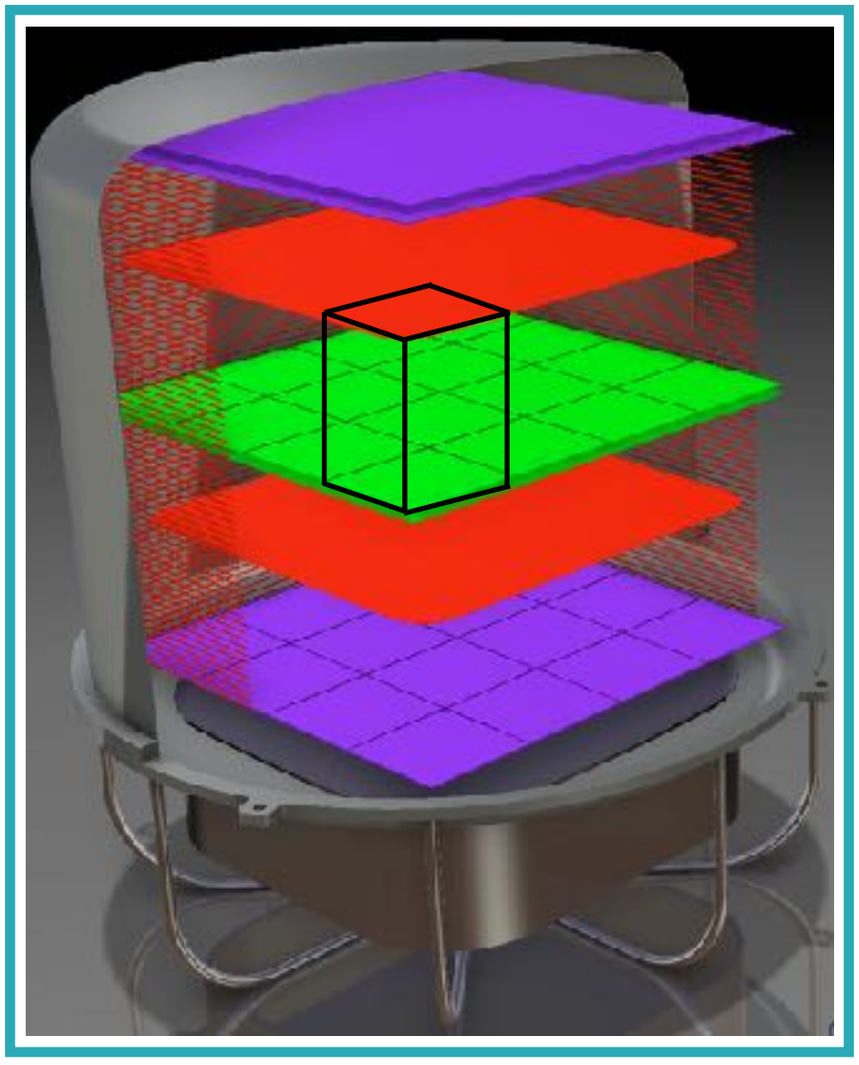
ST3G

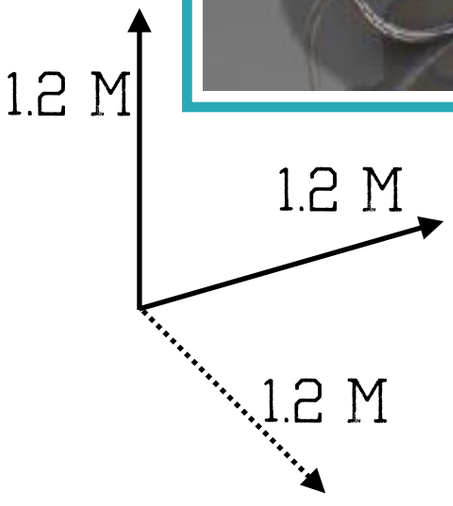




- 64 MODULES :
  - 1 MODULE = HARPO
- 32 TPCs :
  - 2 MODULES WITH A COMMON CATHODE
- 2 BAR ARGON GAS
- READOUT CHIP ASTRE

ST3G





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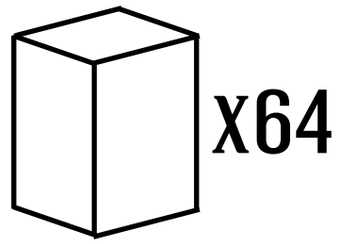
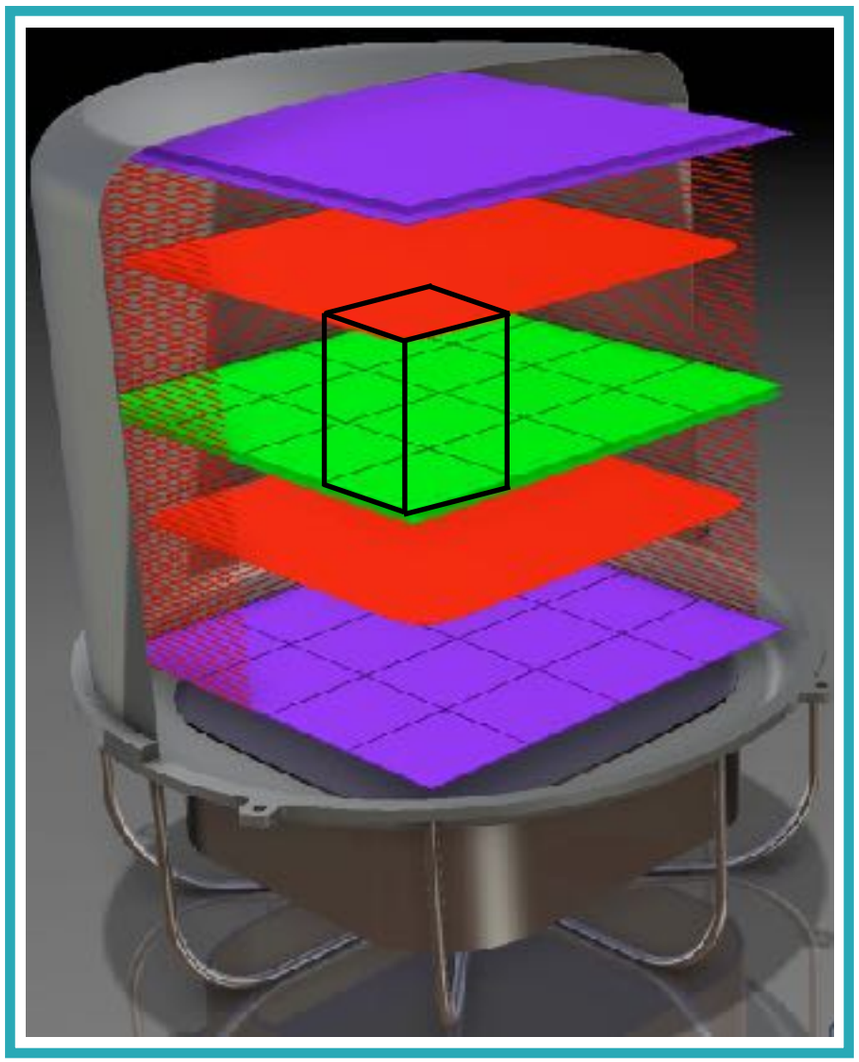


ST3G



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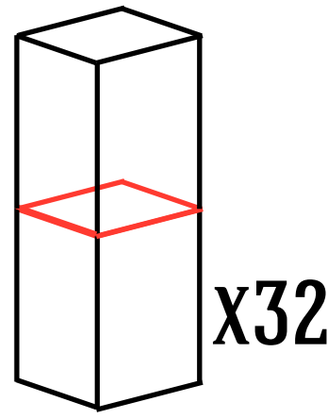
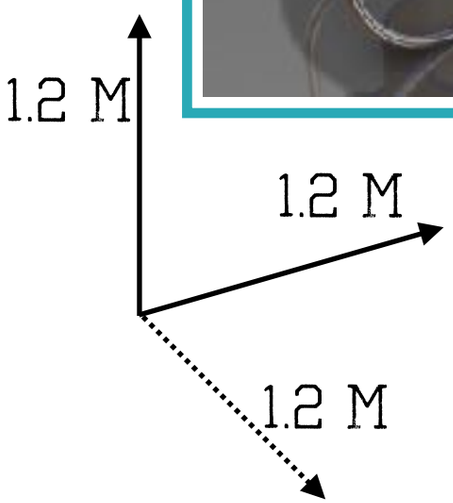
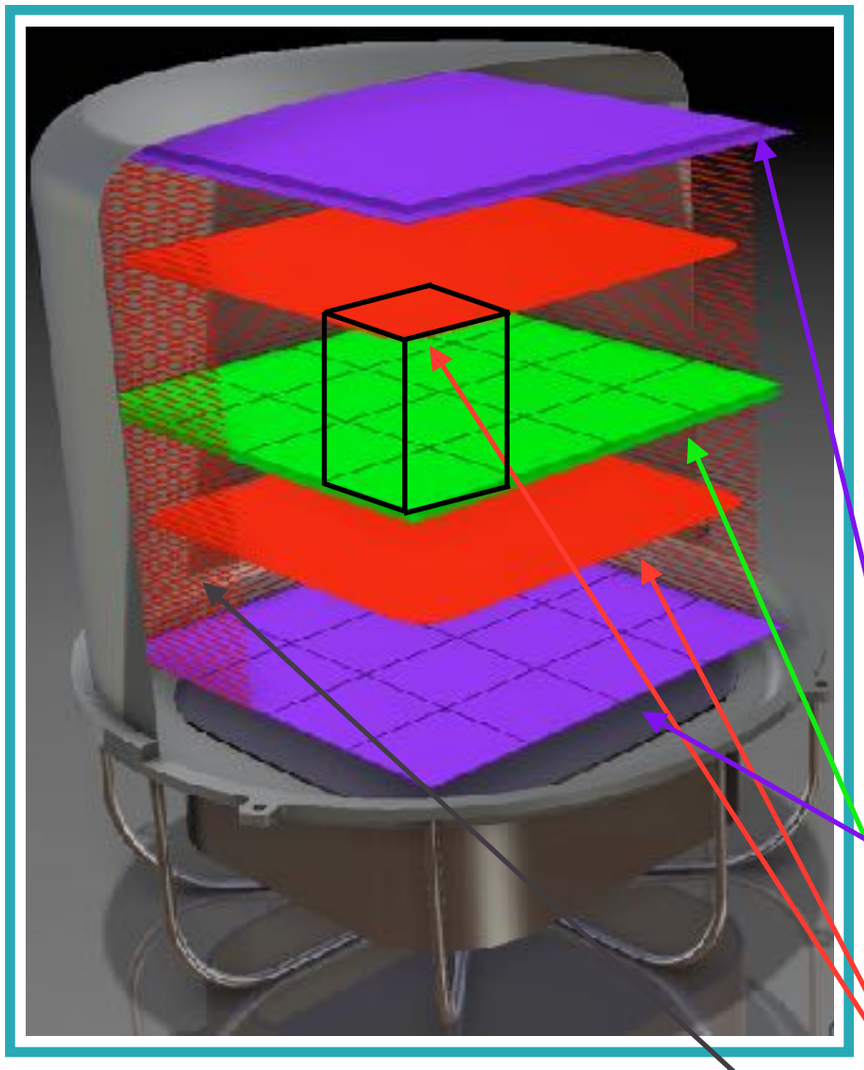




ST3G



- 64 MODULES :
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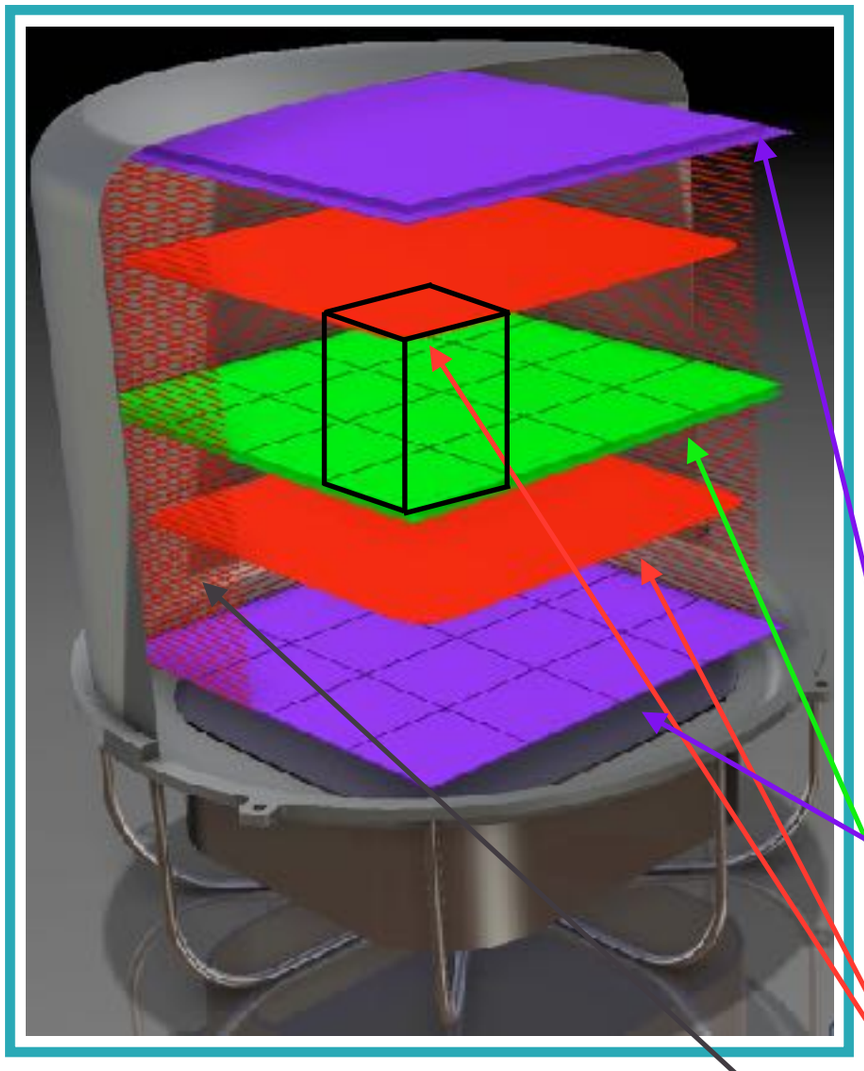
  - READOUT CHIP ASTRE

ST3G

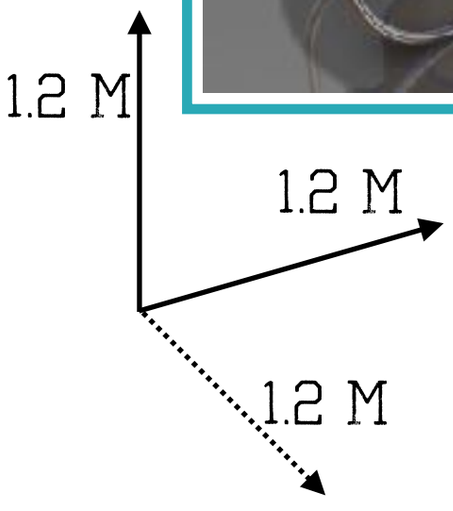


- 64 MODULES* :
  - 1 MODULE = HARPO
- 32 TPCs :
  - 2 MODULES WITH A COMMON CATHODE
- 2 BAR ARGON GAS
- READOUT CHIP ASTRE

single amplification plane

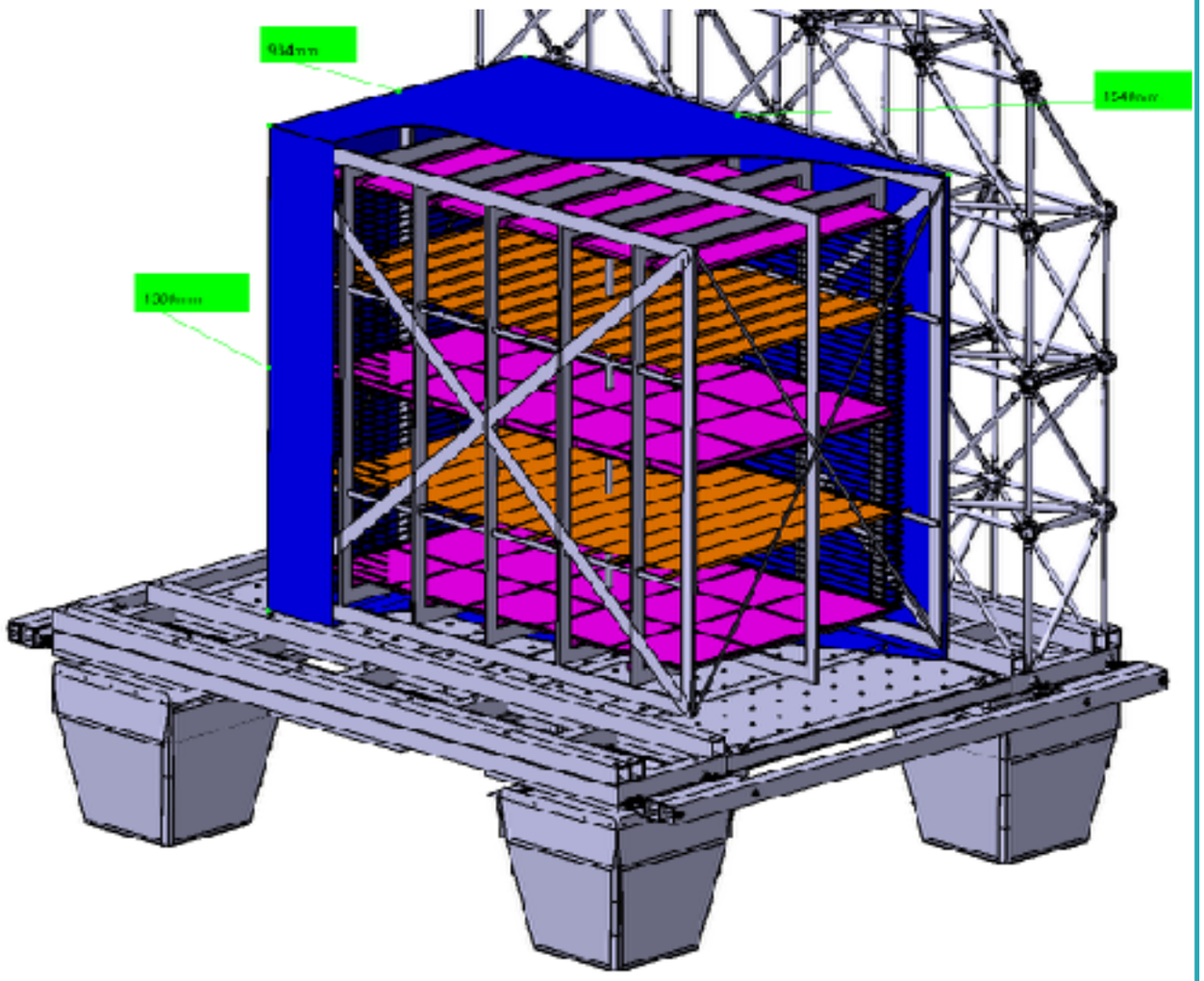
double amplification plane

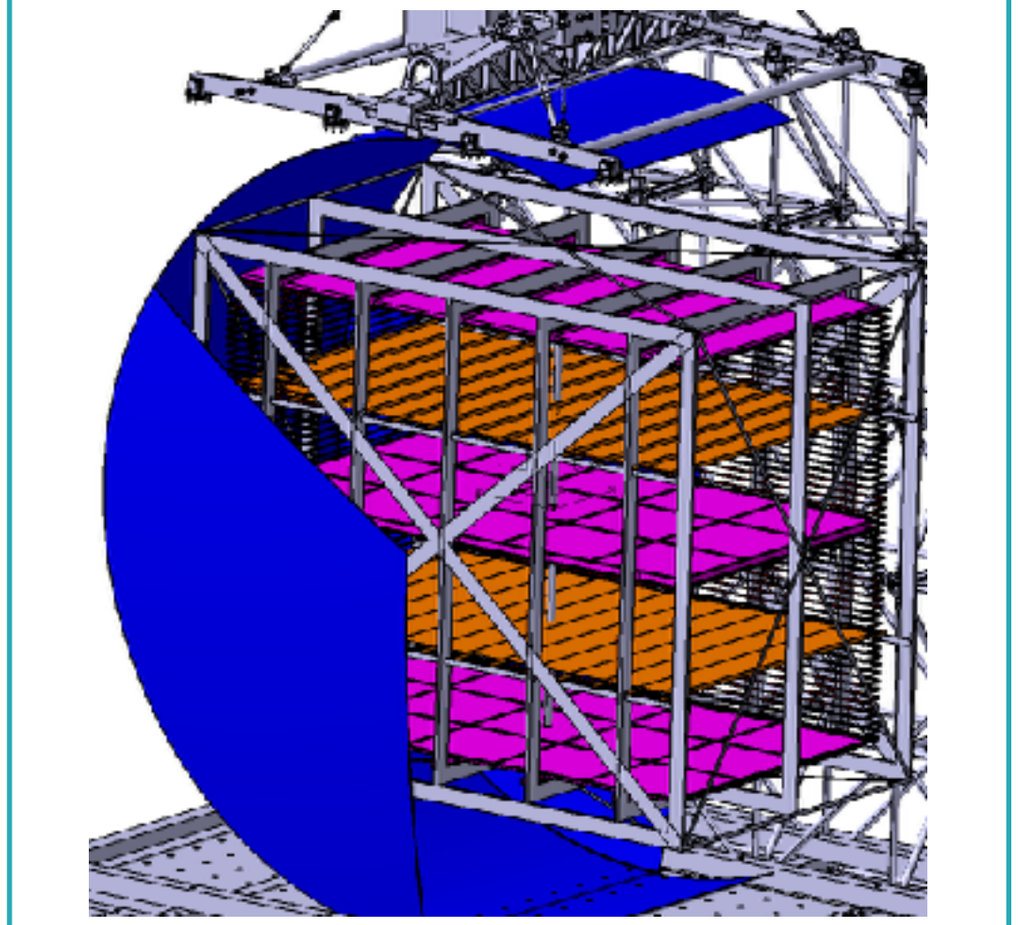
cathode(s)



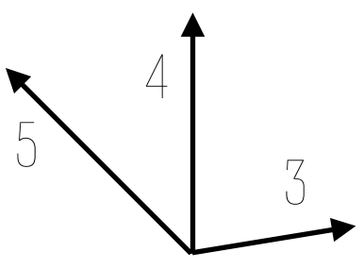
Note: * PLAN TO SWITCH TO 3X4X5 (60 MODULES) DUE TO THE PLATFORM THAT CNES PROPOSE (CARMEN)

ST3G



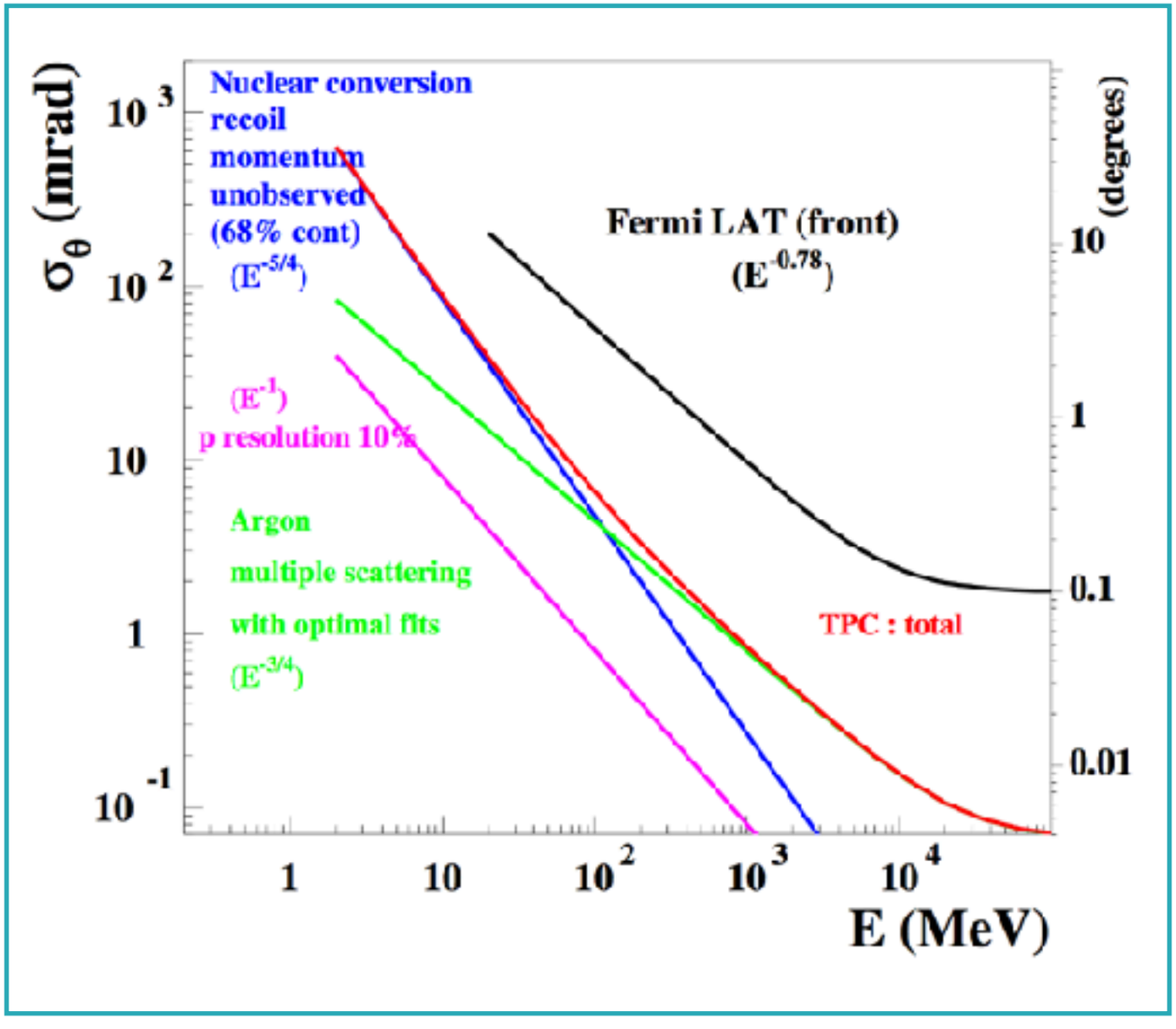


Credit: Mikaël Frotin



Note: * plan to switch to 3x4x5 (60 modules) due to the platform that CNES propose (CARMEN)

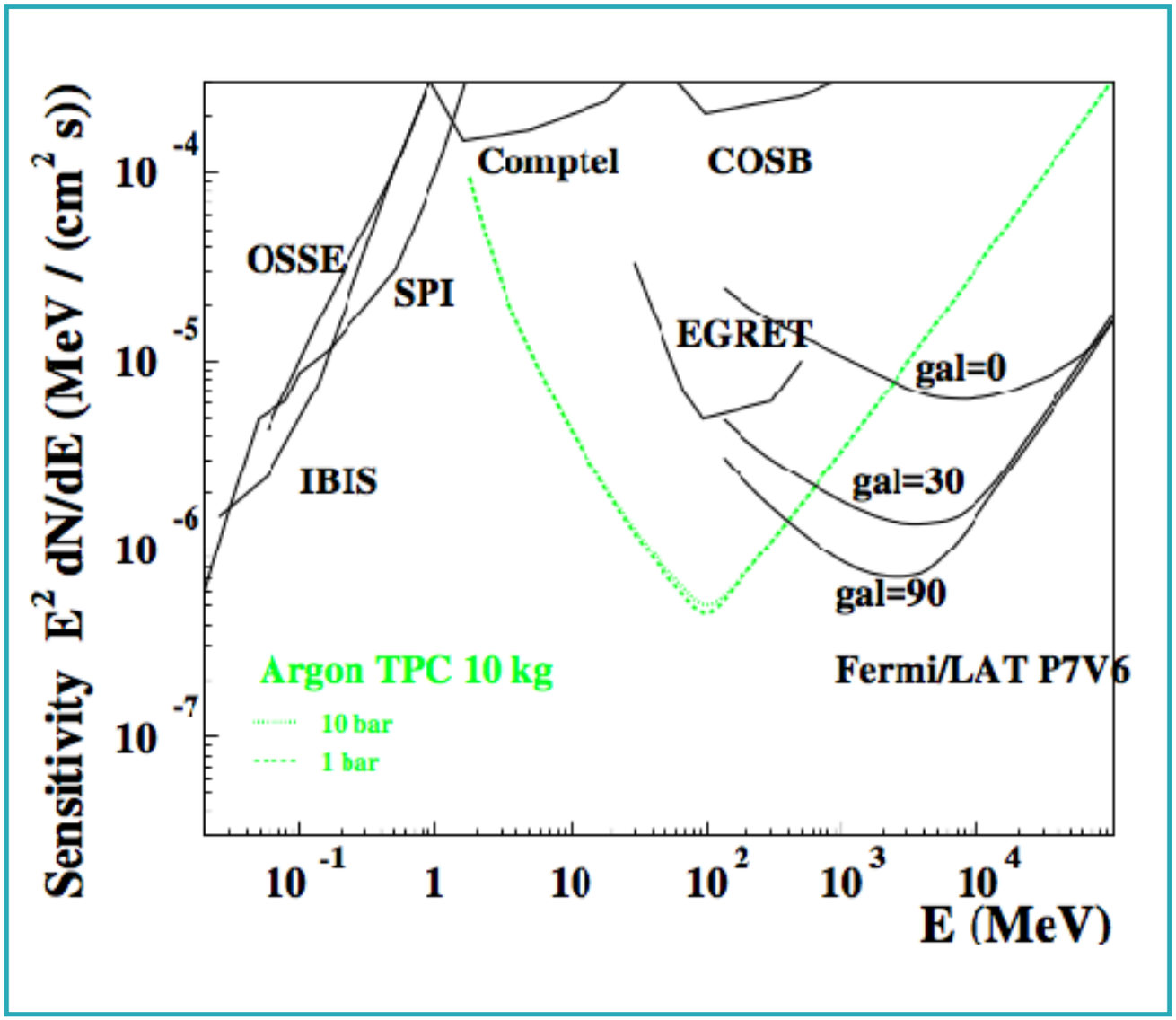
Angular Resolution



arXiv 1709.08544

ST3G

SENSITIVITY

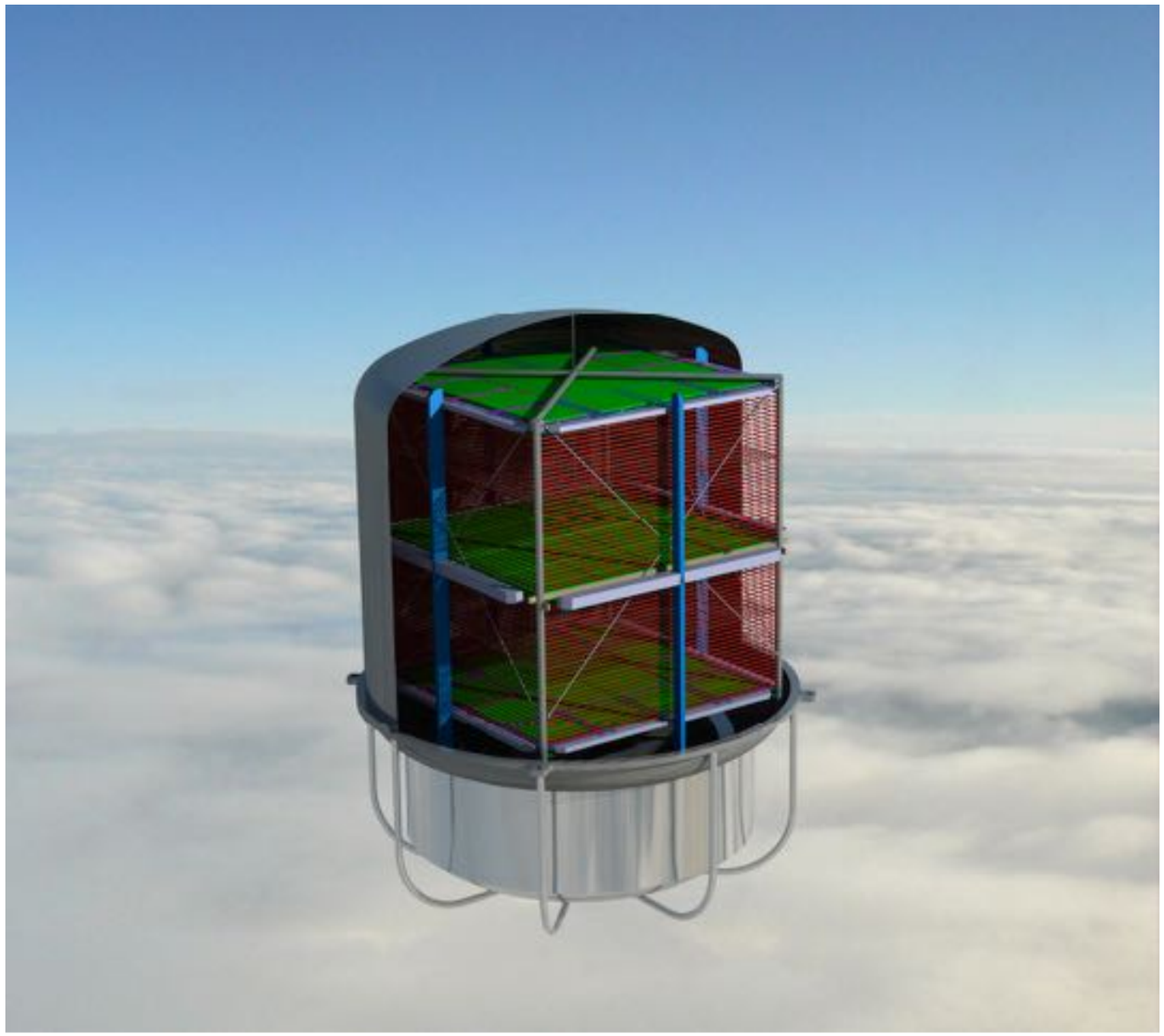


5 SIGMA
3 YEARS
10 PHOTONS
90 DEG FROM GAL. PLANE
4 ENERGY BINS PER DECADE

ARXIV 1709.08544

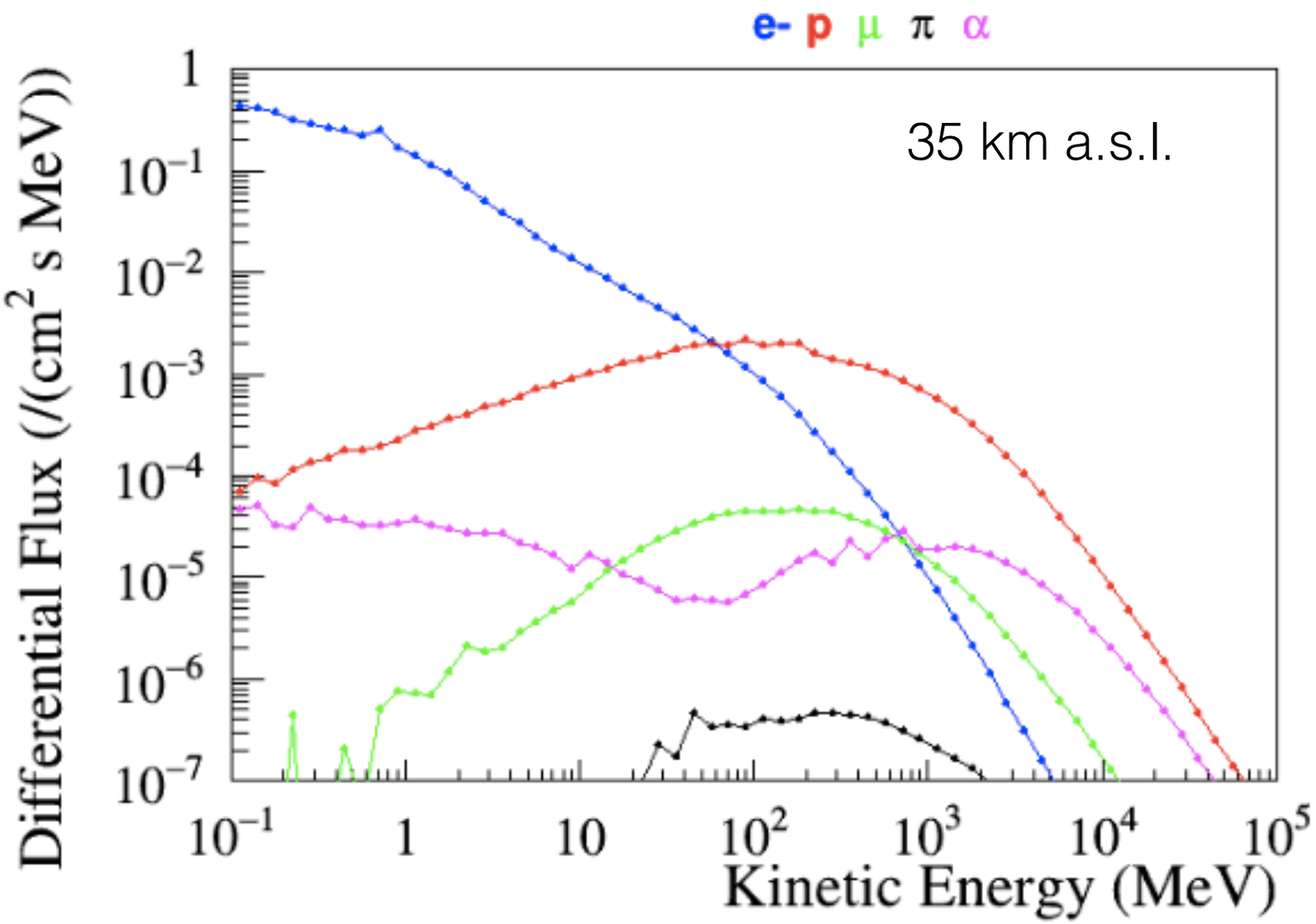
ST3G

Key challenge:



➡ Self triggering ... in real time ... in space

ST3G



Data recorded at Kiruna (Northern Sweden) 20.01.1996 (Quotid Atmospheric Radiation Model (QARM))

A.S.L. = above sea level

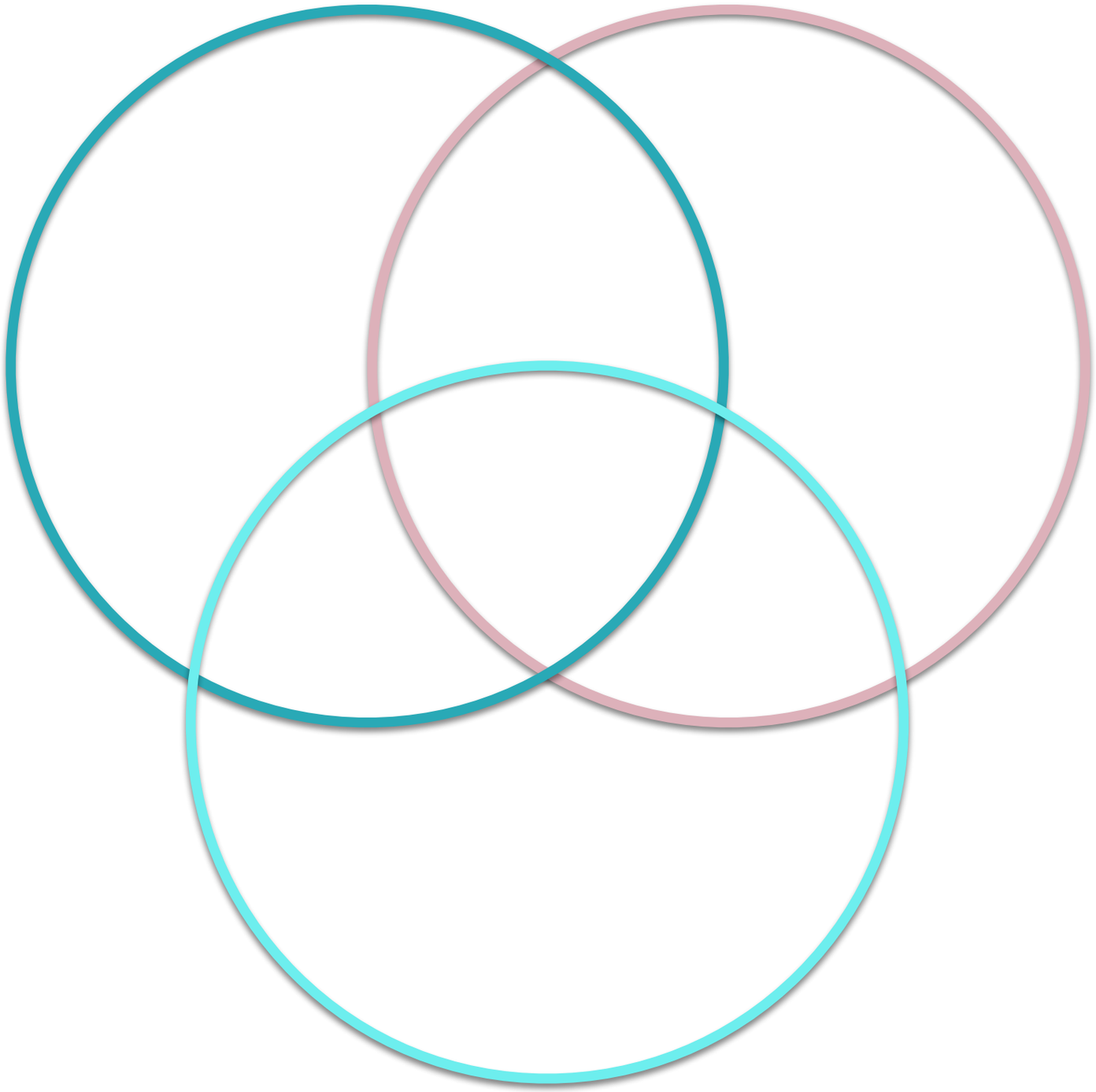
ST3G

- We want to fly ST3G on a balloon to:
  - Calibrate the instrument with actual cosmic data
  - Understand the background
  - **Run the trigger in its real environment**
    - ➡ Measure the combined sensitivity of the trigger/ detector system

Gamma-ray Astrophysics at MeV energies

MeV energy coverage

Polarization

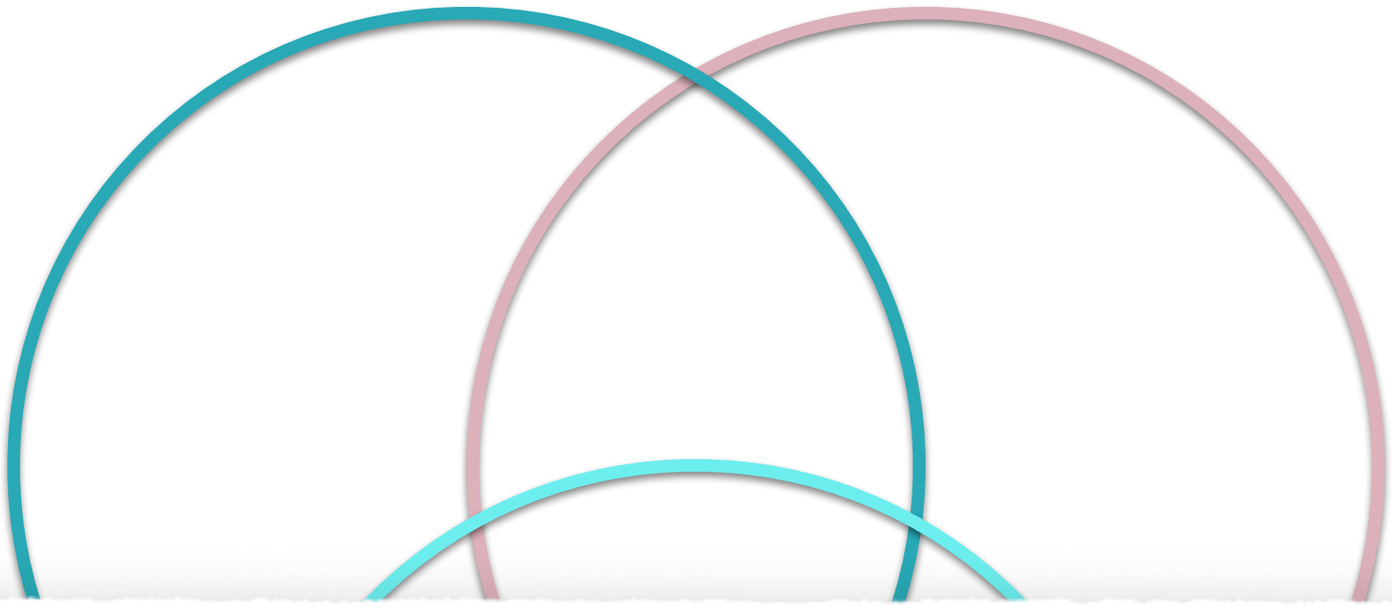


High Angular Resolution

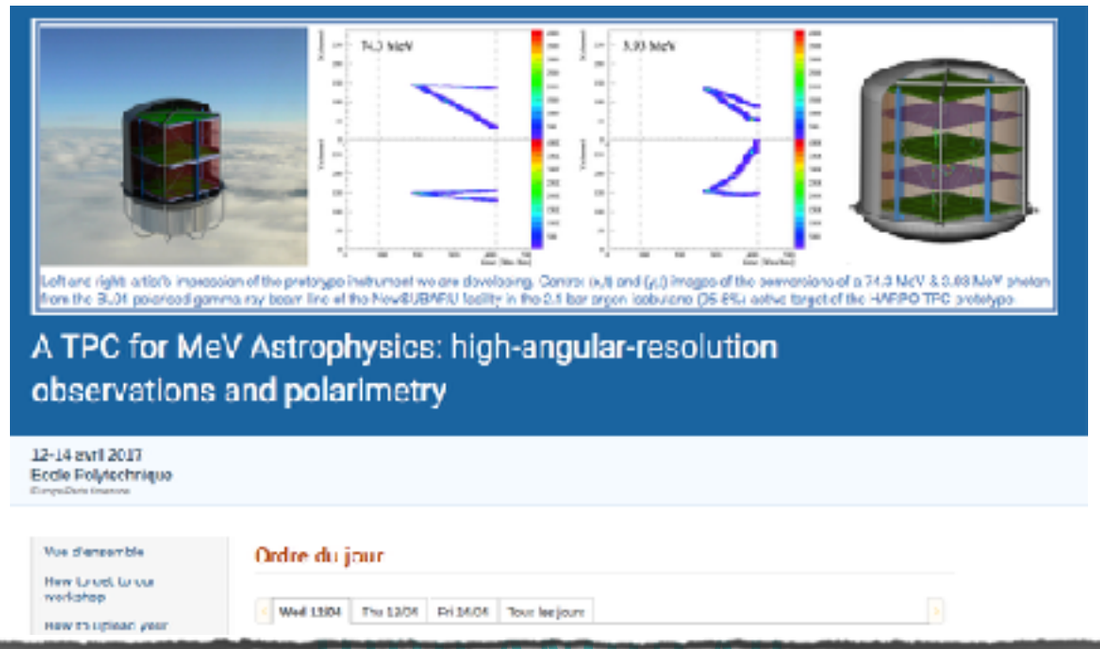
Gamma-ray Astrophysics at MeV energies

MeV energy coverage

Polarization



http://tpc-at-mev.in2p3.fr



High angular Resolution

Gamma-ray Astrophysics at MeV energies

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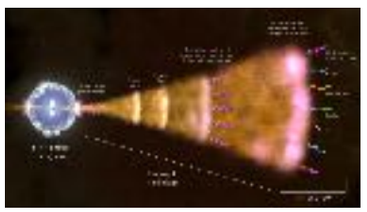
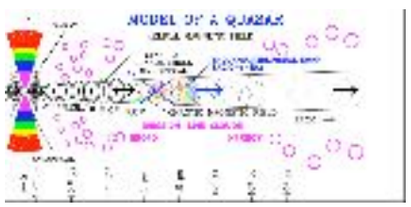
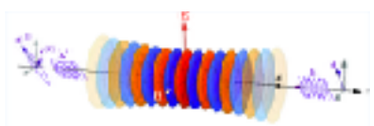
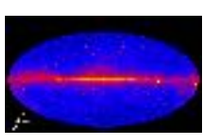
High Angular Resolution







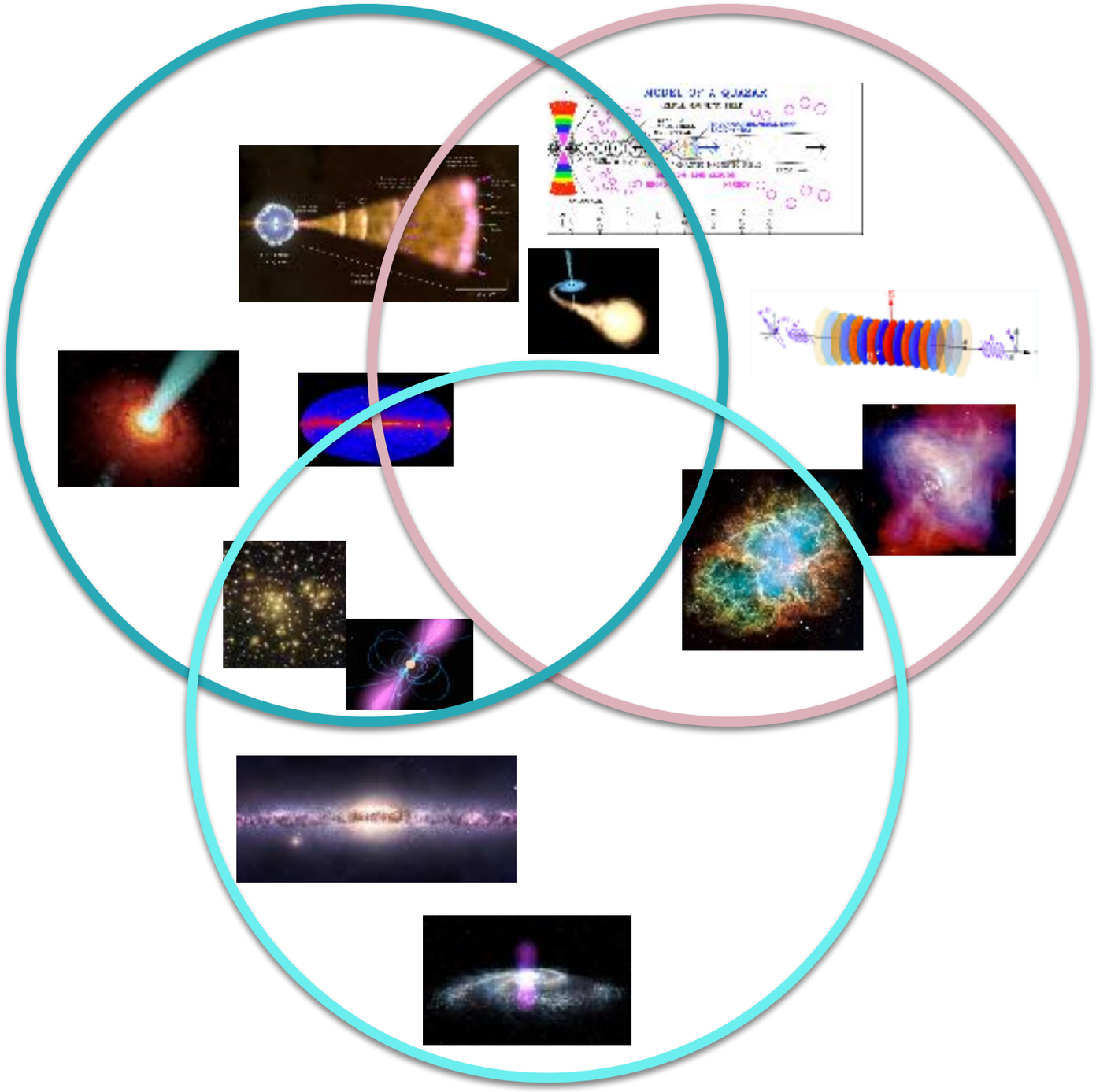




Blazars
Pulsars
Binaries
Cosmic rays
Dark matter
Fermi bubbles
MeV background
Gamma-ray bursts
Lorentz invariance
Supernova remnants

Deirdre HORAN, Laboratoire Leprince Ringuet (IN2P3/CNRS), 7th International Fermi Symposium, Garmisch-Partenkirchen, 20.10.2017

Gamma-ray Astrophysics at MeV energies

MeV energy coverage



Polarization

High Angular Resolution

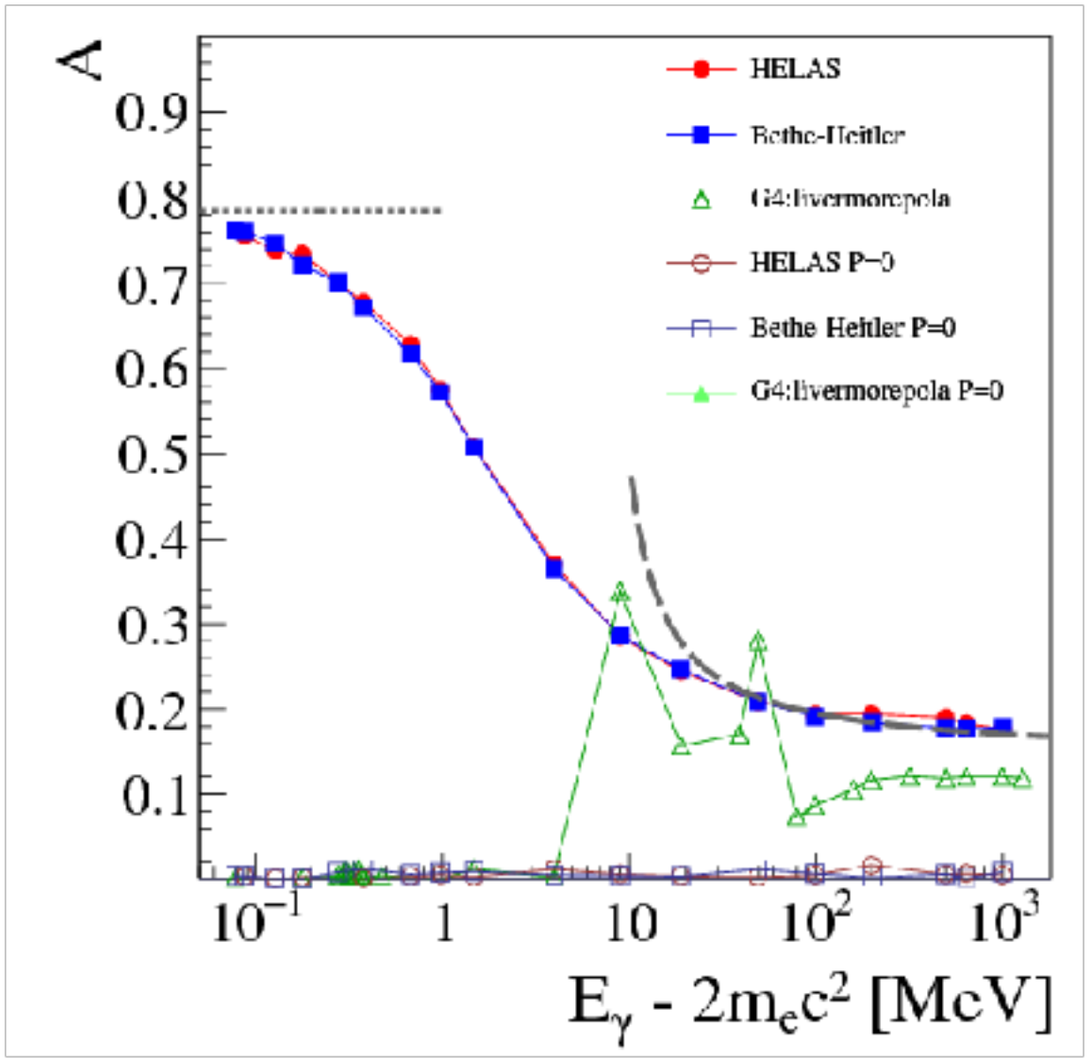
Thank you

http://llr.in2p3.fr/~dbernard/polar/harpo-t-p.html

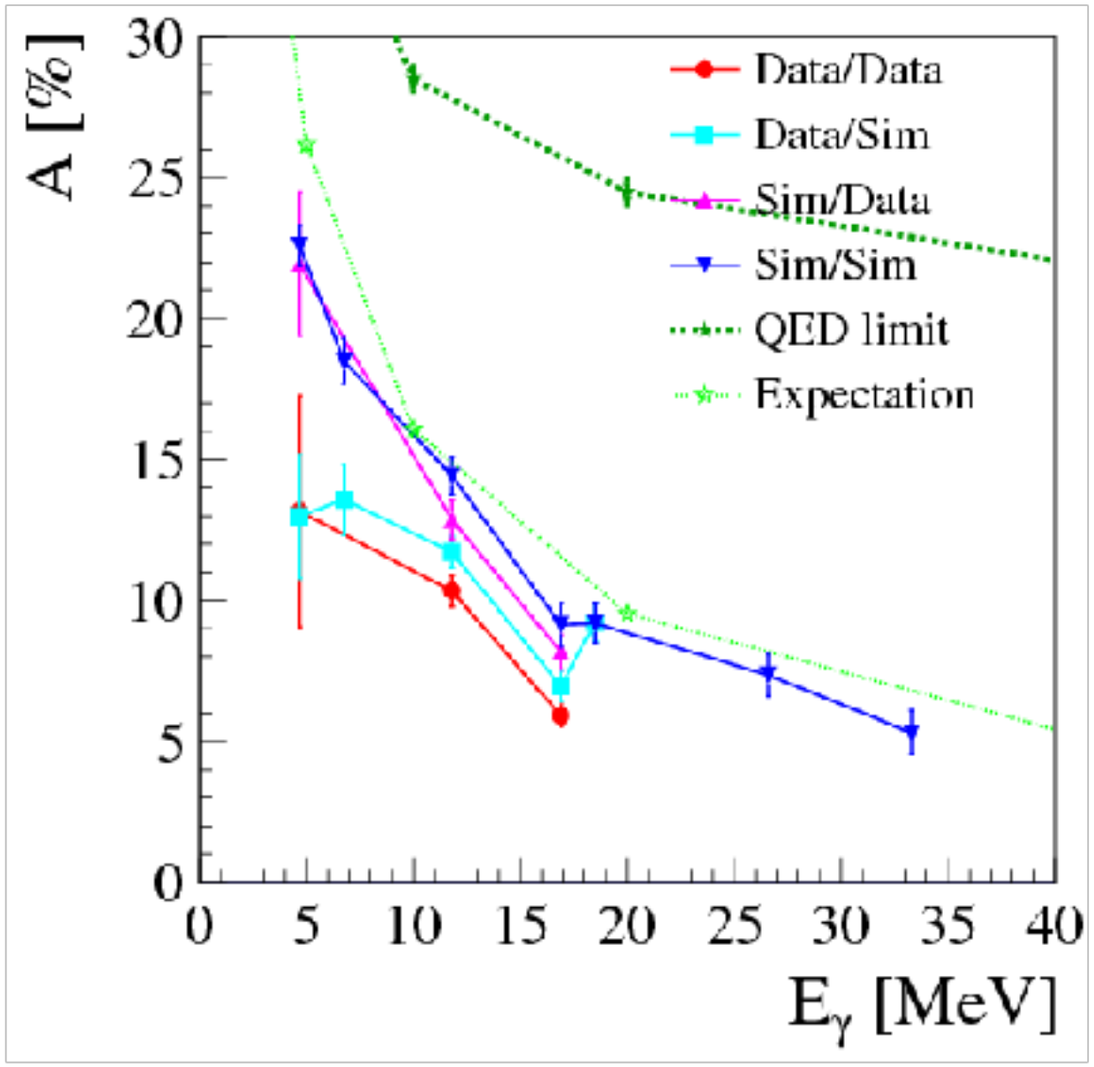
http://tpc-at-mev.in2p3.fr

Asymmetry as a function of energy ARXIV 1611.05179

Experimental effects affect the measurement of φ, which leads to an effective asymmetry, A_{eff} that is lower than the QED asymmetry, A. Their ratio $D \equiv A_{eff}/A$ is named the asymmetry dilution due to the experimental effects, $0 \leq D \leq 1$.



Theoretical



Measured