



HARPO

(Hermetic ARgon POlarimeter)

A gas detector concept for photon detection and polarimetry in the MeV-GeV range

LLR (CNRS, École Polytechnique)/
Irfu (CEA Saclay)
funded by French ANR and Labex P2IO

TIPP 2014, Amsterdam

Philippe GROS
LLR, École polytechnique



Outline

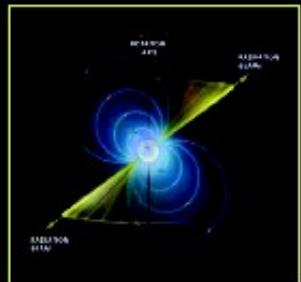
- Science case
- Proposed detector: TPC
- Results with a demonstrator
- Status and outlook



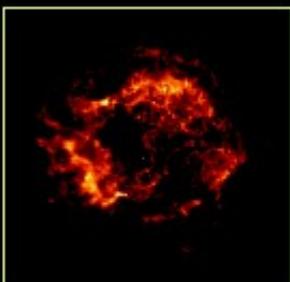
HARPO

Science case Gamma astronomy

- Galactic targets



Pulsar



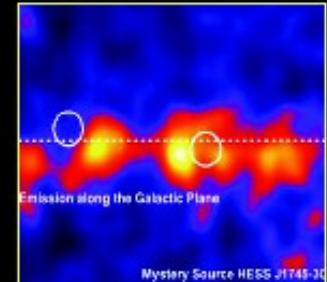
Supernova Remnants



Pulsar wind nebulae



Micro-quasars

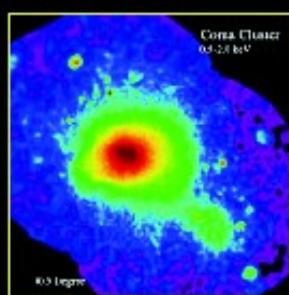


Galactic center

- Extragalactic targets



Active Galactic Nuclei



Galaxy Cluster



Starburst galaxies

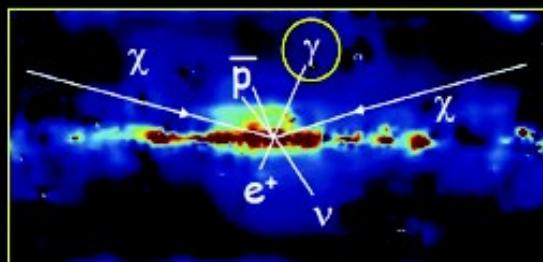


Merging Galaxies

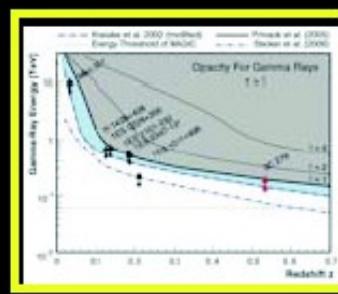


Gamma-ray Bursts

- Fundamental physics



Dark Matter annihilation

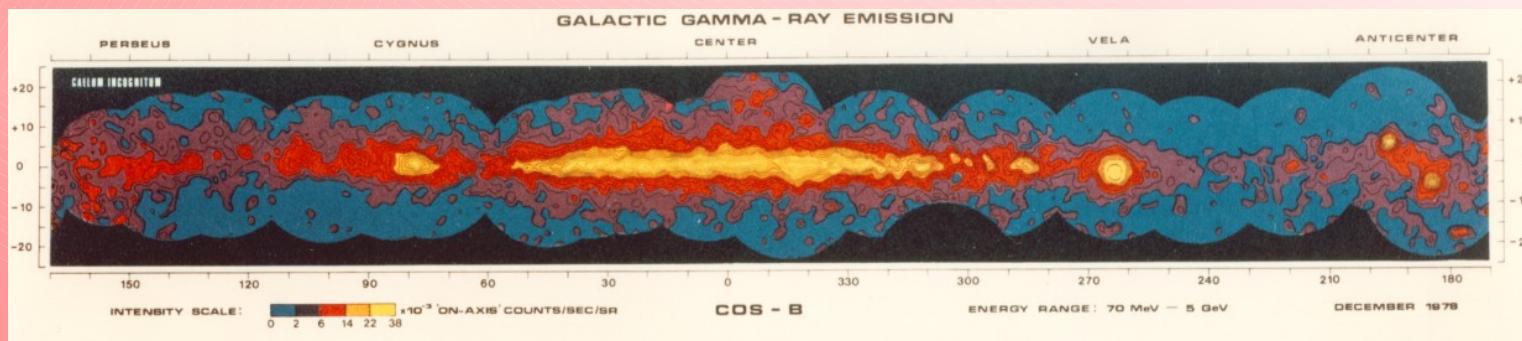


Universe transparency

- CR physics
- Lorentz invariance
- Quantum gravity
- Axion-photons obsr

Science Case Gamma telescopes performance

COS-B (1975-1982)
70MeV - 5GeV

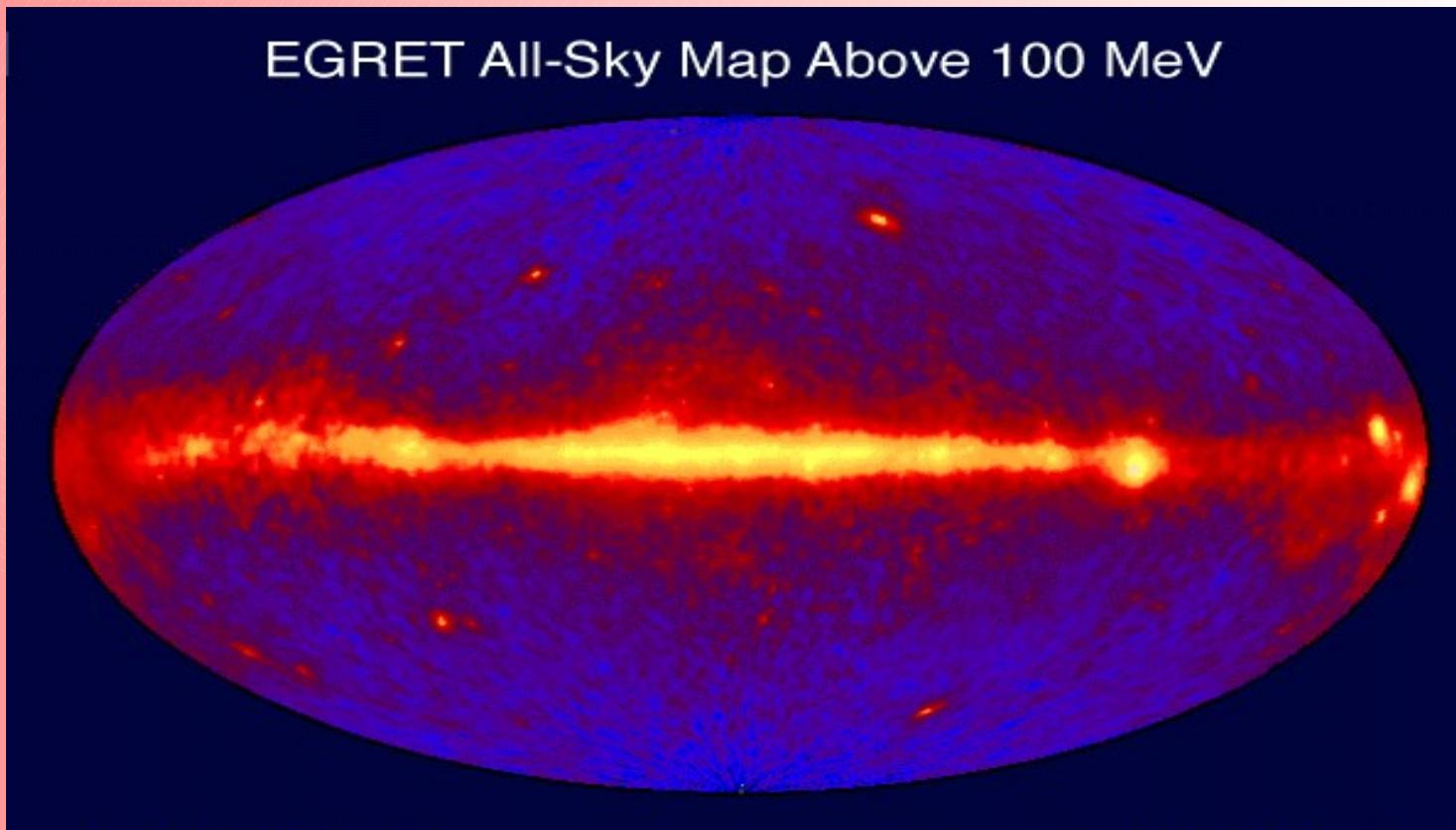


TIPP 2014: HARPO, TPC concept as gamma ray telescope and polarimeter
Philippe GROS, LLR École Polytechnique

Science Case

Gamma telescopes performance

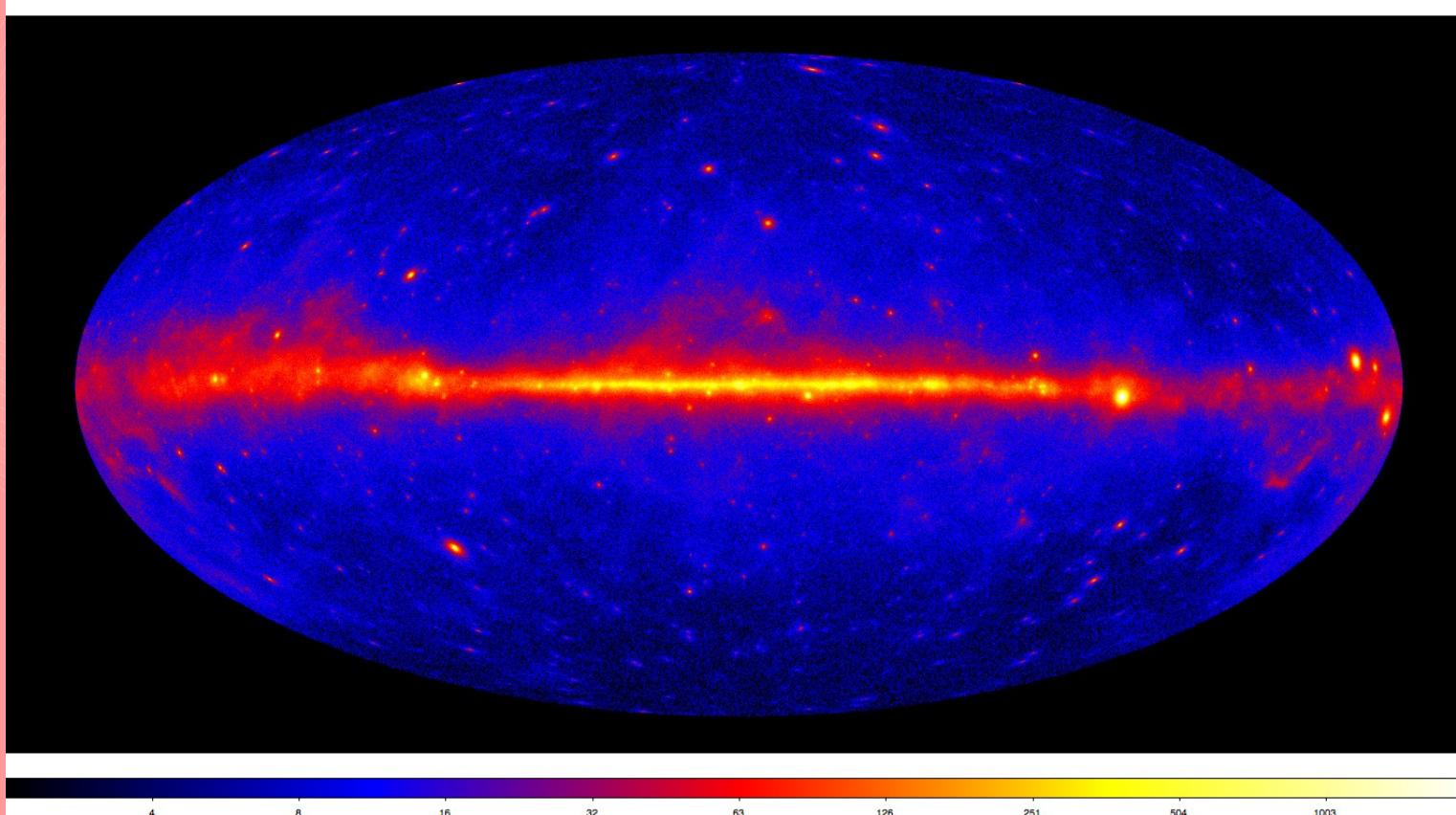
EGRET (1991-2000)
271 sources > 100 MeV



Science Case

Gamma telescopes performance

Fermi (2008-)
1873 sources > 100MeV

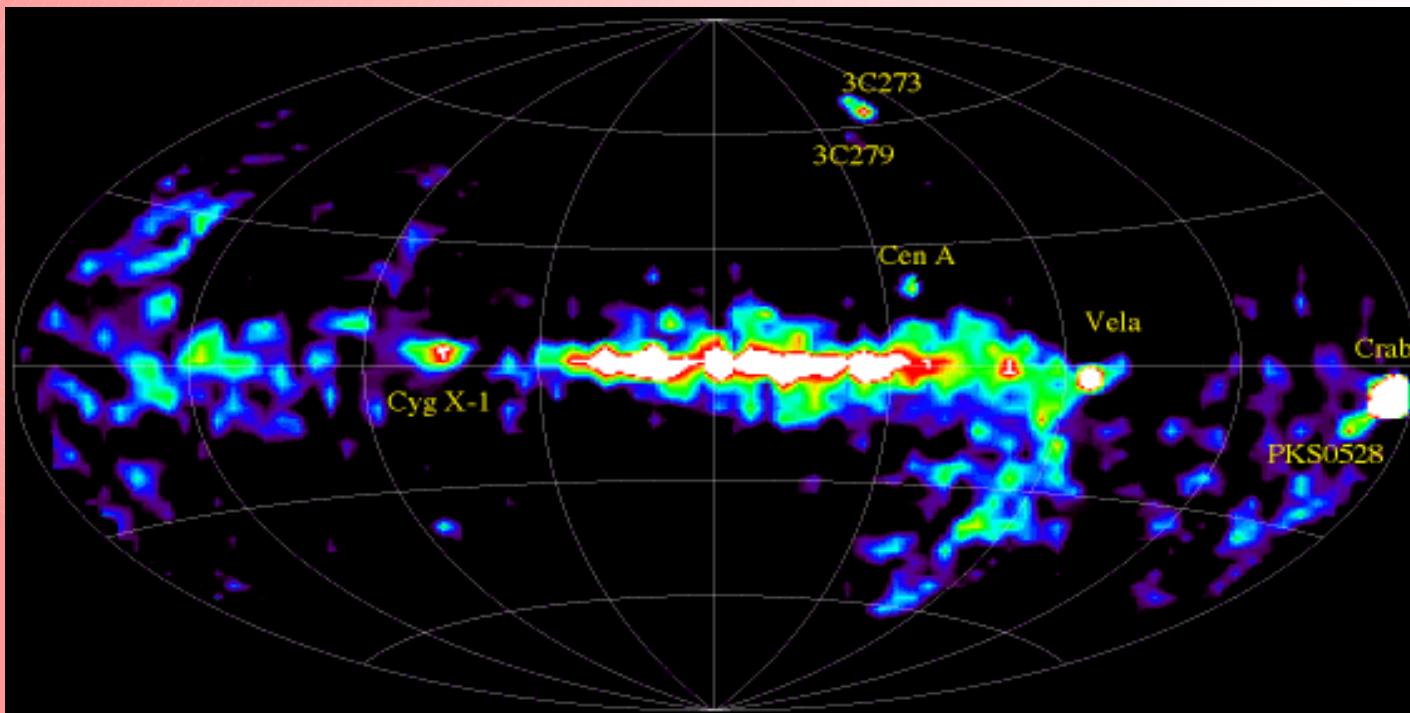


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Science Case

Gamma telescopes performance

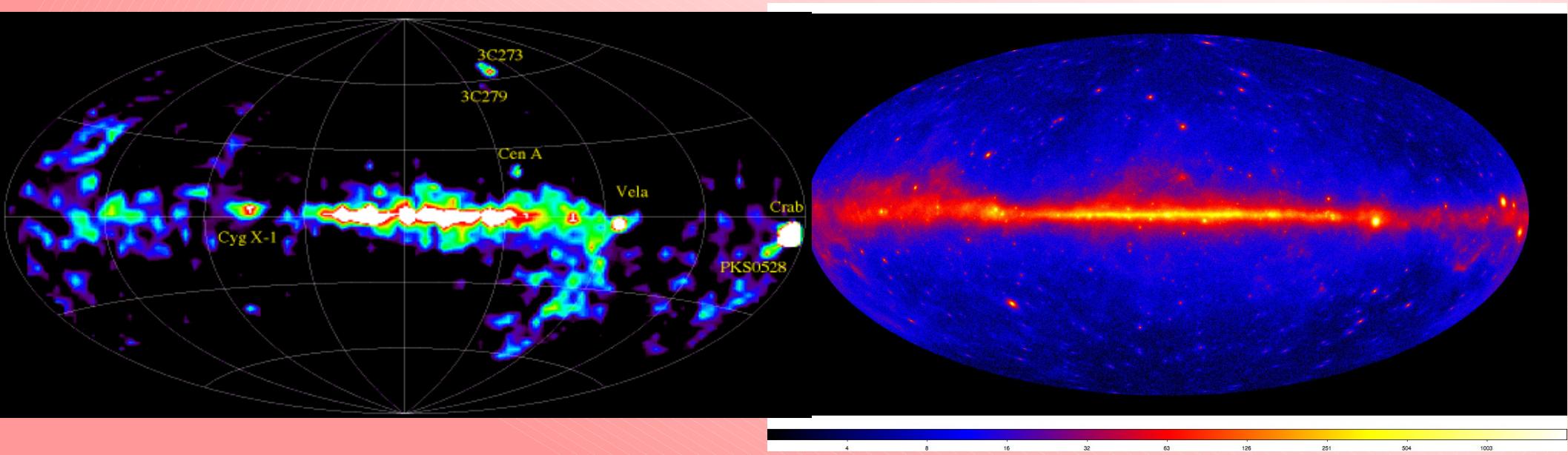
Comptel (1991-2000)
63 sources 1-30MeV



Science Case

Gamma telescopes performance

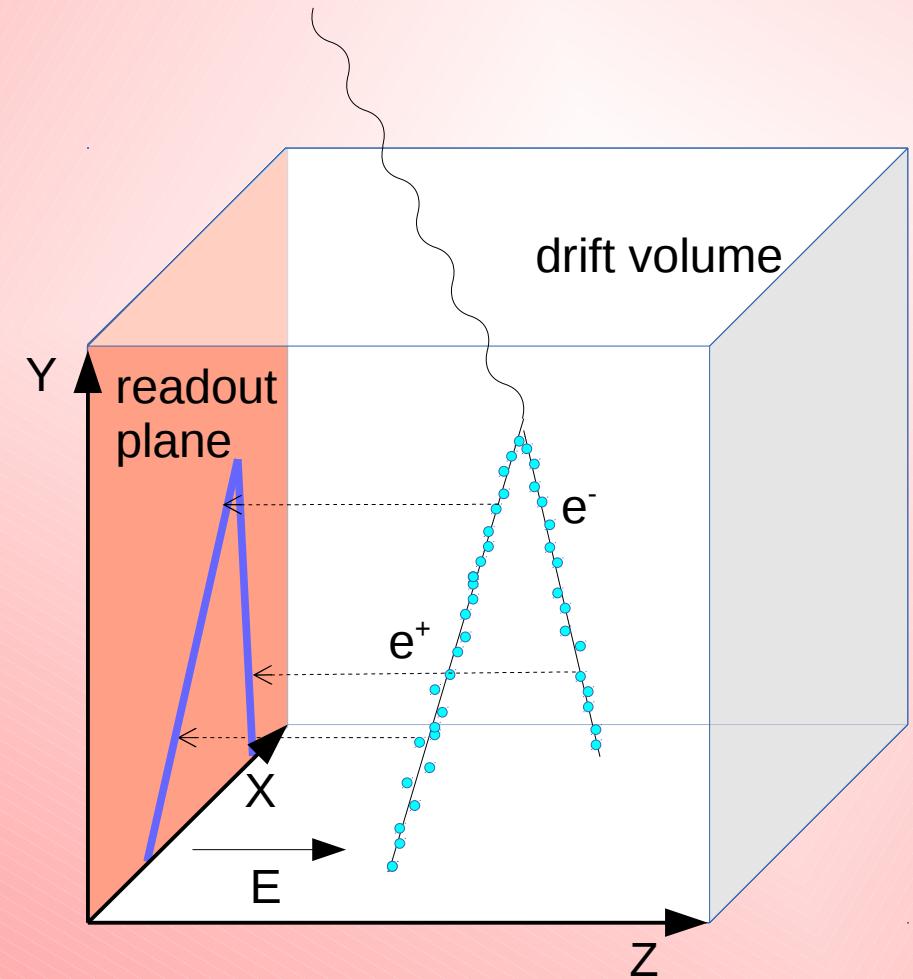
- There is important progress in gamma ray telescope at high energy ($>100\text{MeV}$)
- Still a big performance gap at lower energy



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Time Projection Chamber (TPC)

- photons are converted in the gas
- produced electrons ionise the gas
- ionisation electrons drift along E field
- electrons are amplified and measured on the xy-readout plane
- time gives a measure of the z coordinate
 - t_0 from external trigger
 - drift velocity





TPC Characteristics

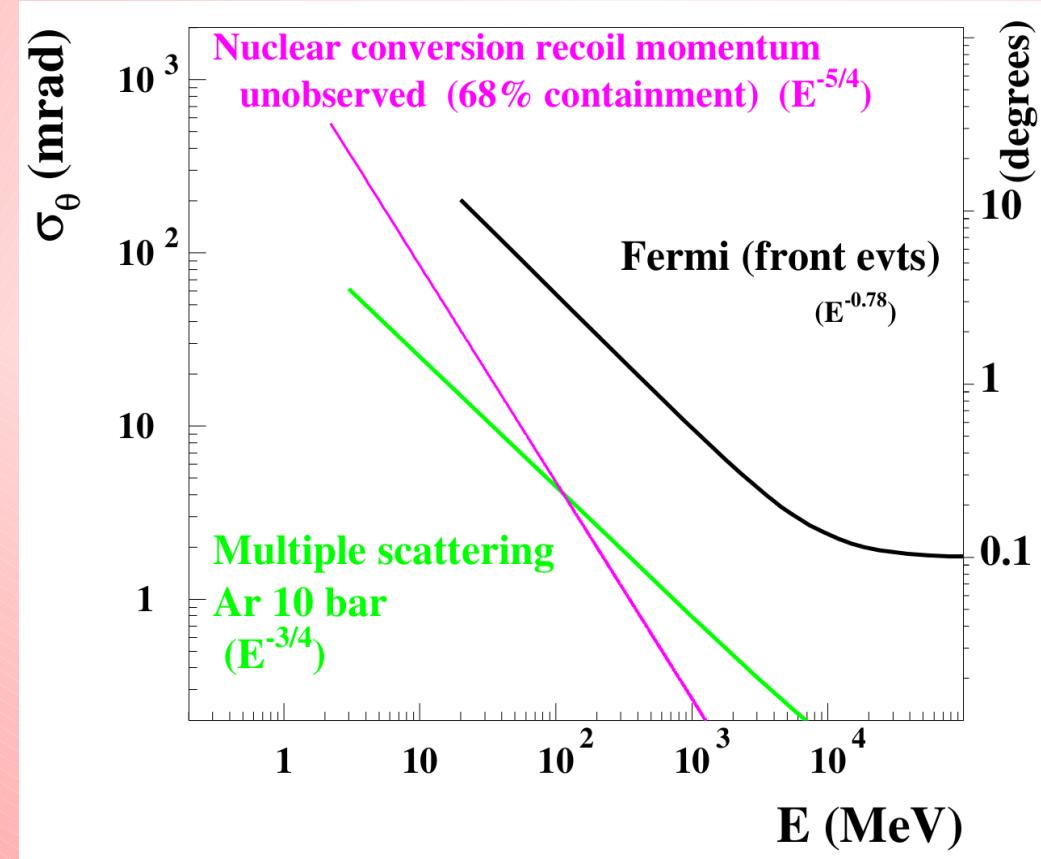
- A gaseous 3D tracking detector
 - Often used in particle physics
 - High spatial resolution (<1mm), excellent tracking
 - Low multiple scattering => tracking even for low momentum tracks
- “Thin” active target
 - sensitivity proportional to mass, not surface
 - Polarisation information accessible (thick detector, e.g. W/Si excluded)



HARPO

Expected Performance

- Angular resolution
 - limited by multiple scattering above 100MeV
 - limited by the unknown recoil nucleus momentum below 100MeV
 - only multiple scattering for triplet conversion, but very low efficiency
- Up to 1 order of magnitude better than Fermi!

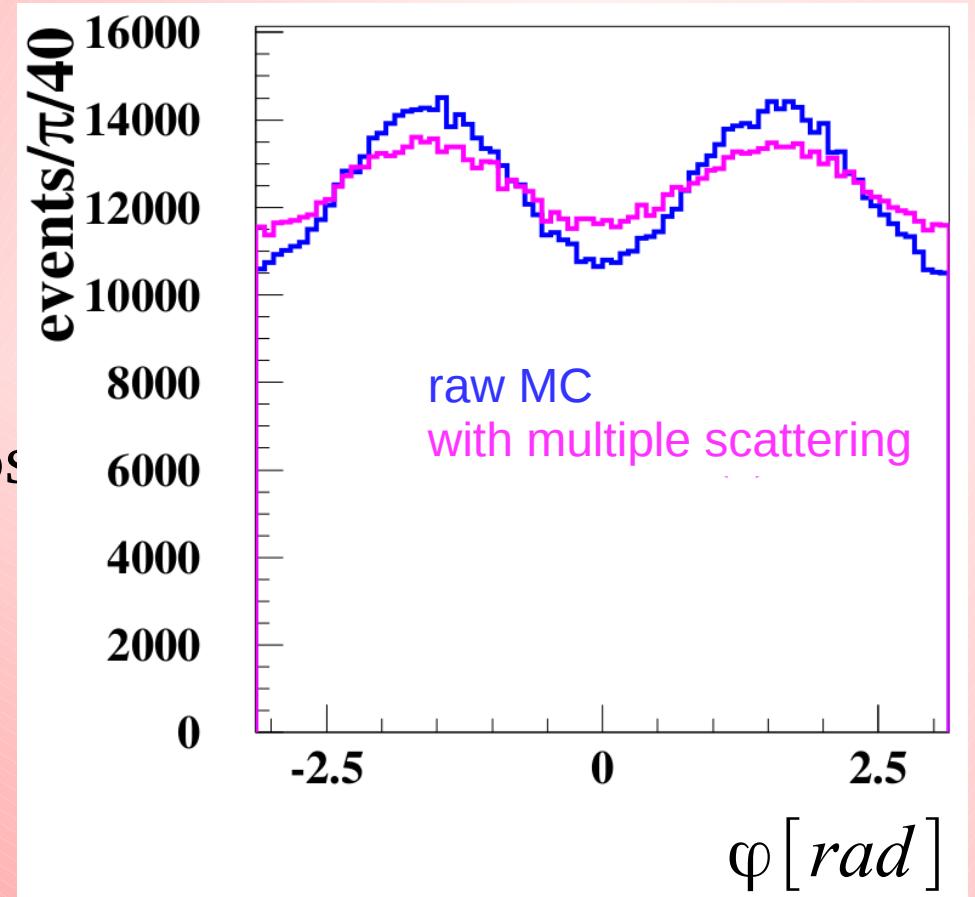




Polarimetry

$$2\pi \frac{d\sigma}{d\varphi} = \sigma_{tot}(1 - PA \cos 2\varphi)$$

- Multiple scattering dilutes the polarisation modulation
- In converters, it is very quickly lost
- In Argon at 5 bar:
(resolution 1mm, 1m³,
Crab-like, 1 year, exposure=efficiency=1)



Polarisation asymmetry $A \sim 15\%$

Polarisation resolution $\sim 1\%$

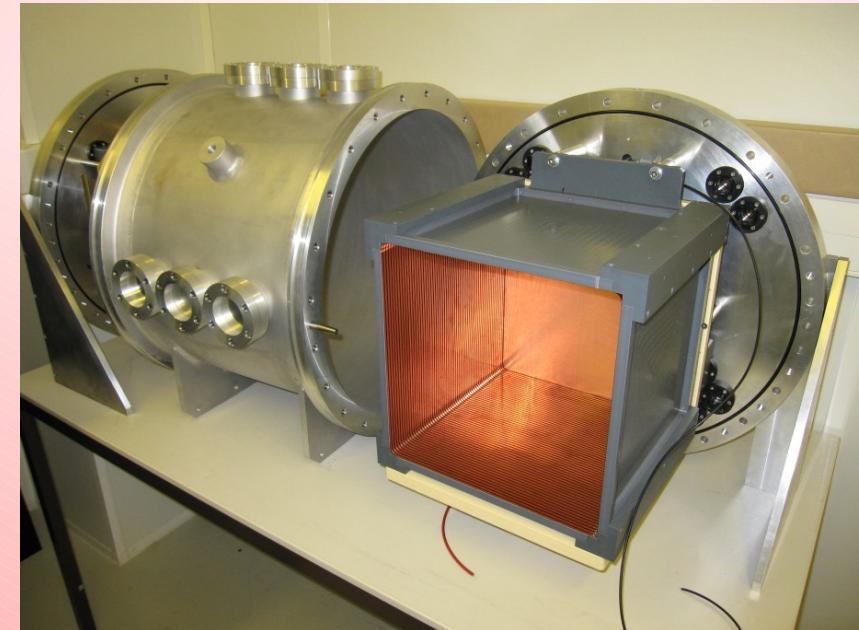
D. Bernard,
NIM A 701 (2013) 225



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HARPO Demonstrator

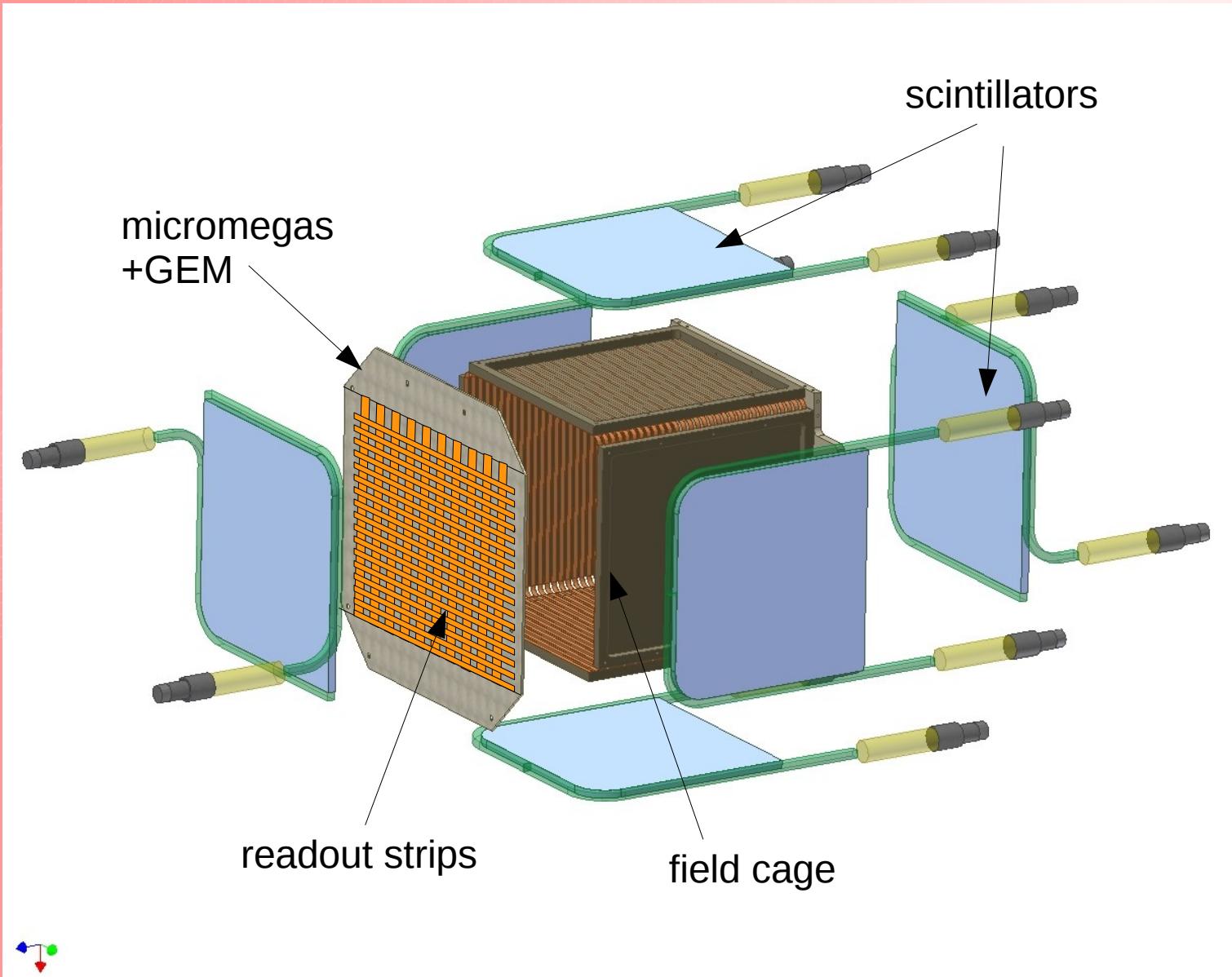
- Purpose
 - Assess challenges
 - Demonstrate performance in test beam
- Realisation
 - 30cm cubic TPC
 - Ar/iC₄H₁₀ 95/5 up to 5bar
 - micromegas+2GEM
 - 2x288 strips readout (x&y), ~0.5mm wide
 - AFTER readout electronics, 511 time bins, up to 50MHz
 - trigger: 6 scintillators





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HARPO Demonstrator

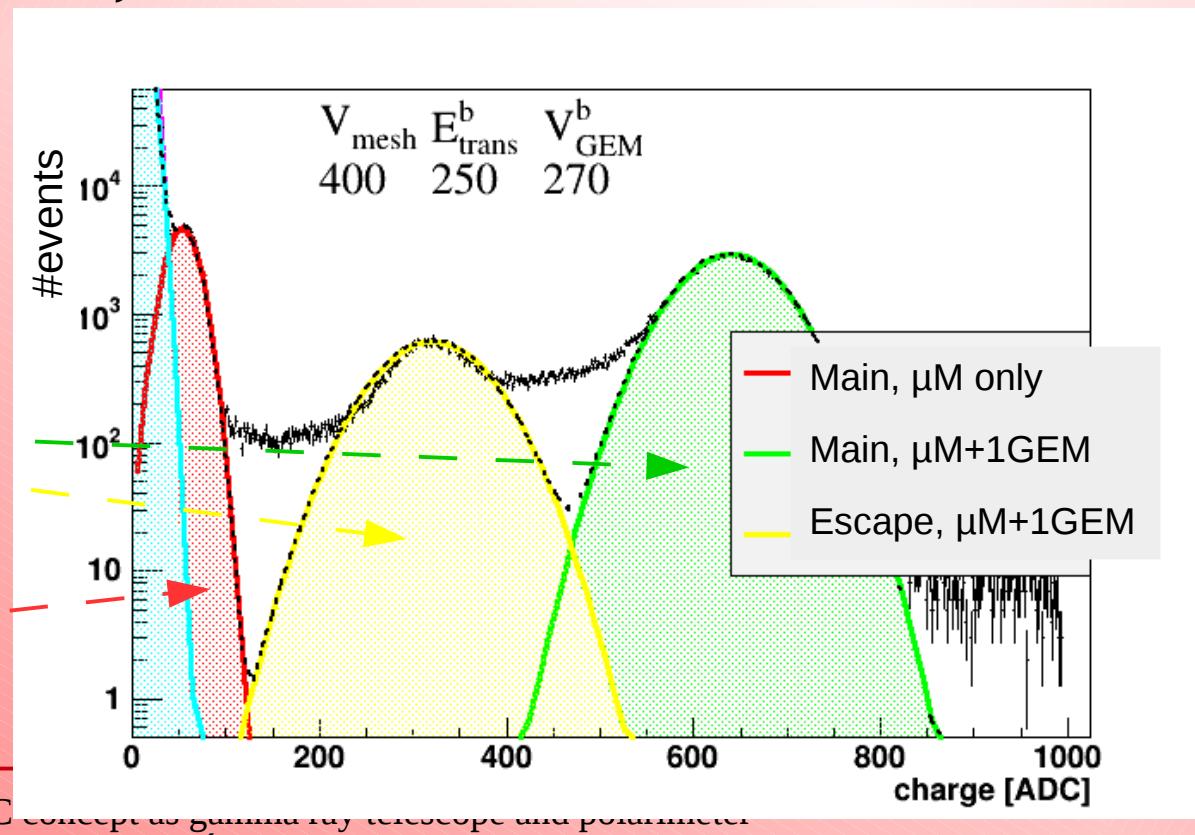
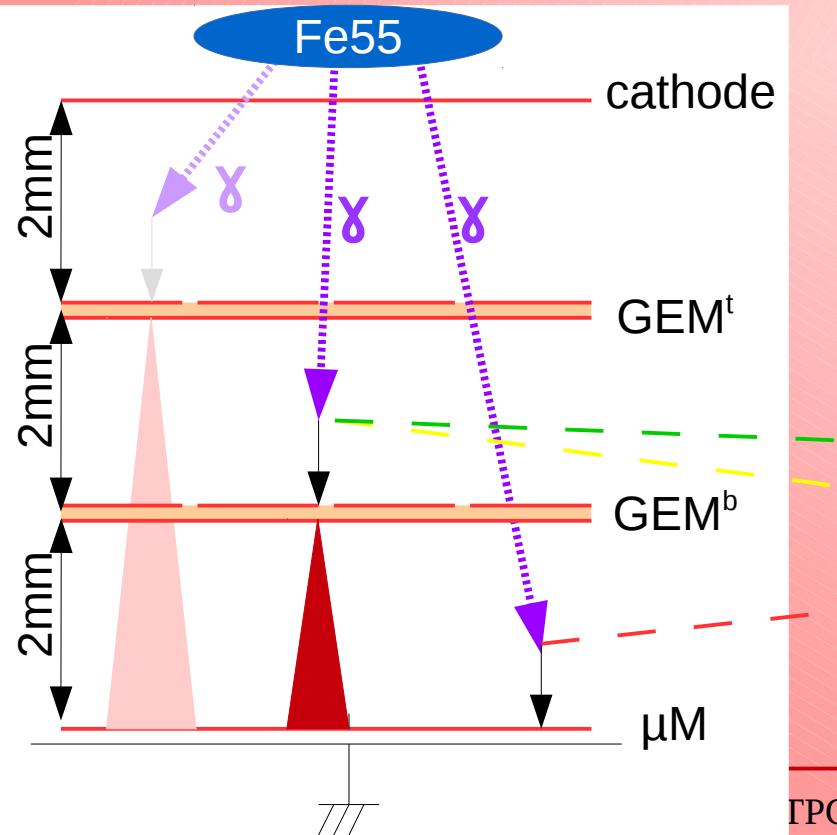




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Amplification Micromegas+GEM

- Limited gain with micromegas only
- Micromegas + 2GEM, produced at CERN
 - characterised at 1 bar, with ^{55}Fe source

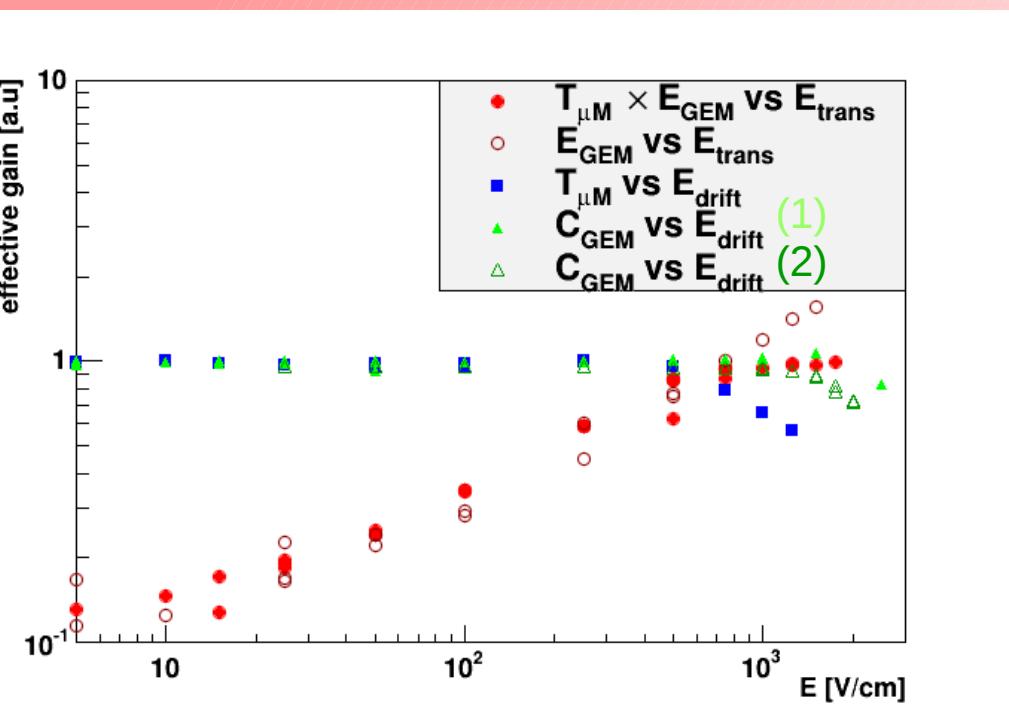


Micromegas + GEM Characterisation

- Many field parameters
- Gain factorisation:

$$\begin{aligned}
 & g_{\mu M}(V_{mesh}) \mathcal{T}_{\mu M}(E_{trans}^b) \\
 \times & E_{GEM}(E_{trans}^b) g_{GEM}^b(V_{GEM}^b) C_{GEM}(E_{trans}^t) \\
 \times & E_{GEM}(E_{trans}^t) g_{GEM}^t(V_{GEM}^b) C_{GEM}(E_{drift}^t)
 \end{aligned}$$

- Factorisation well understood (collection and extraction efficiencies)
- Effective gains up to a few 10,000



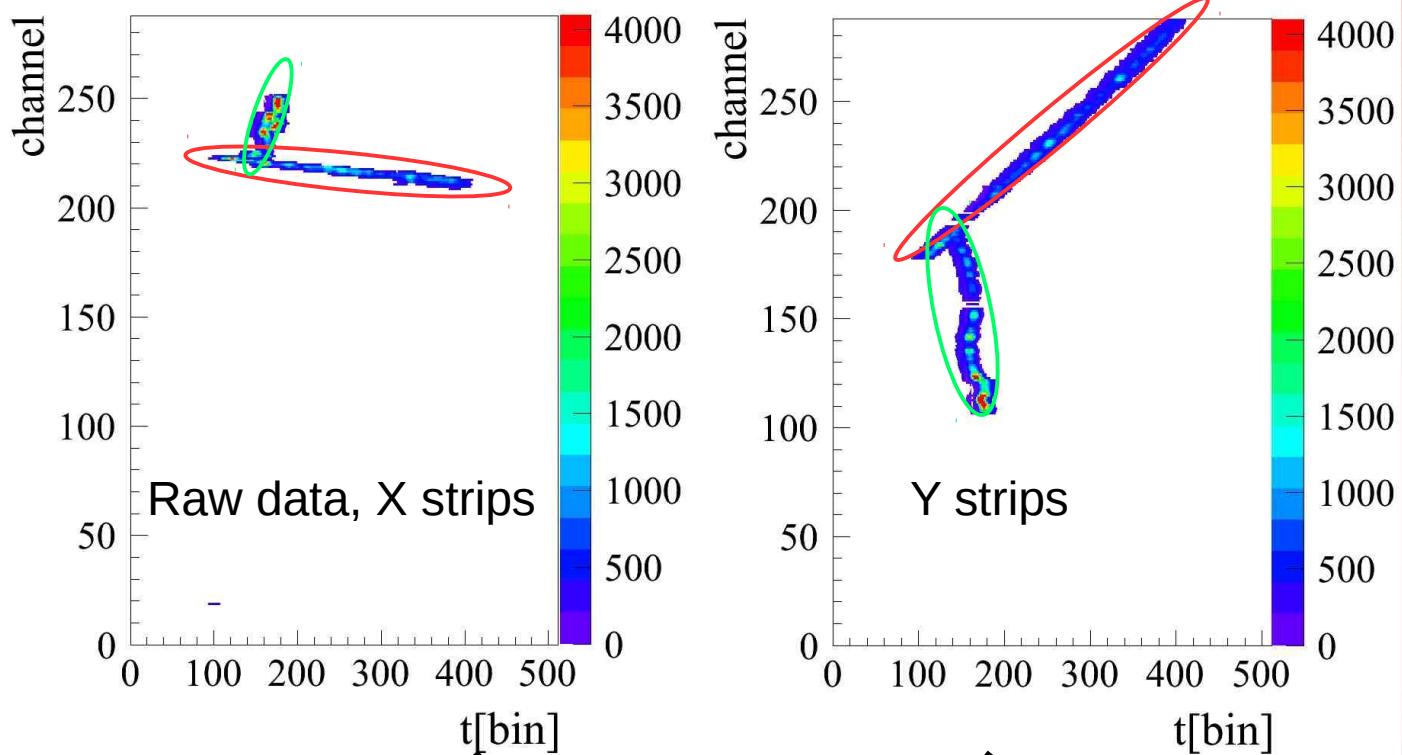


Cosmic Ray Test

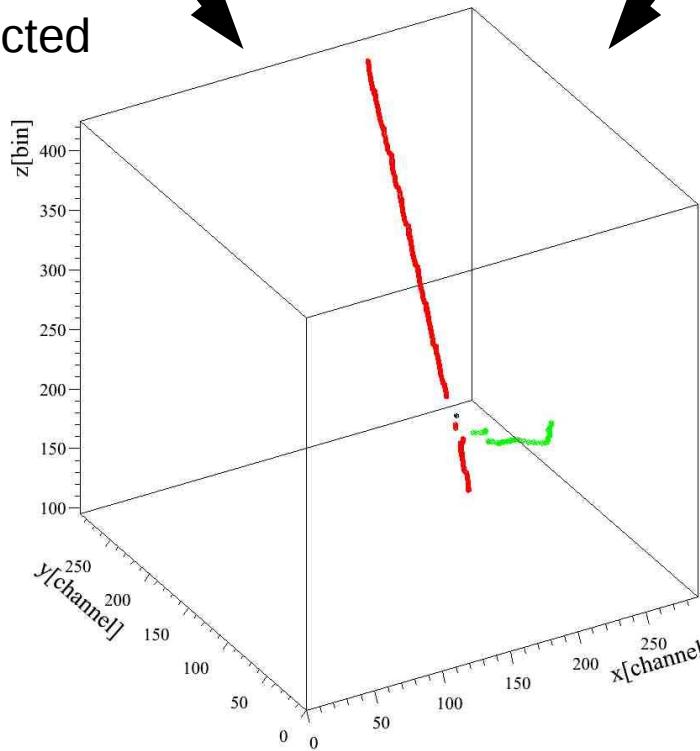
- Simple scintillator coincidence trigger
 - top/bottom coincidence
- Pressure from 0.5 to 2 bar
- Two planes readout
 - X and Time (Z)
 - Y and Time (Z)
- Track reconstruction and matching



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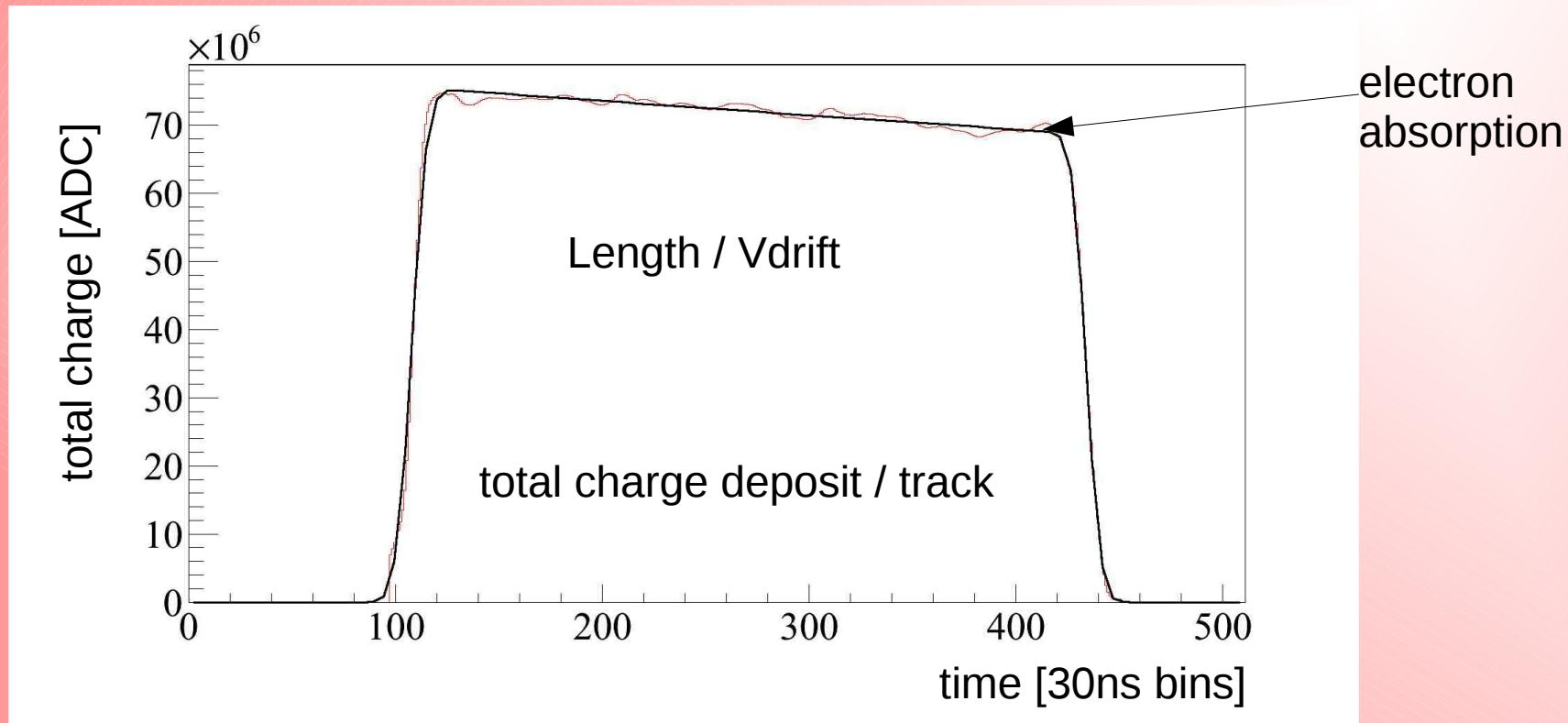


Reconstructed
tracks



Characterisation with traversing cosmic rays

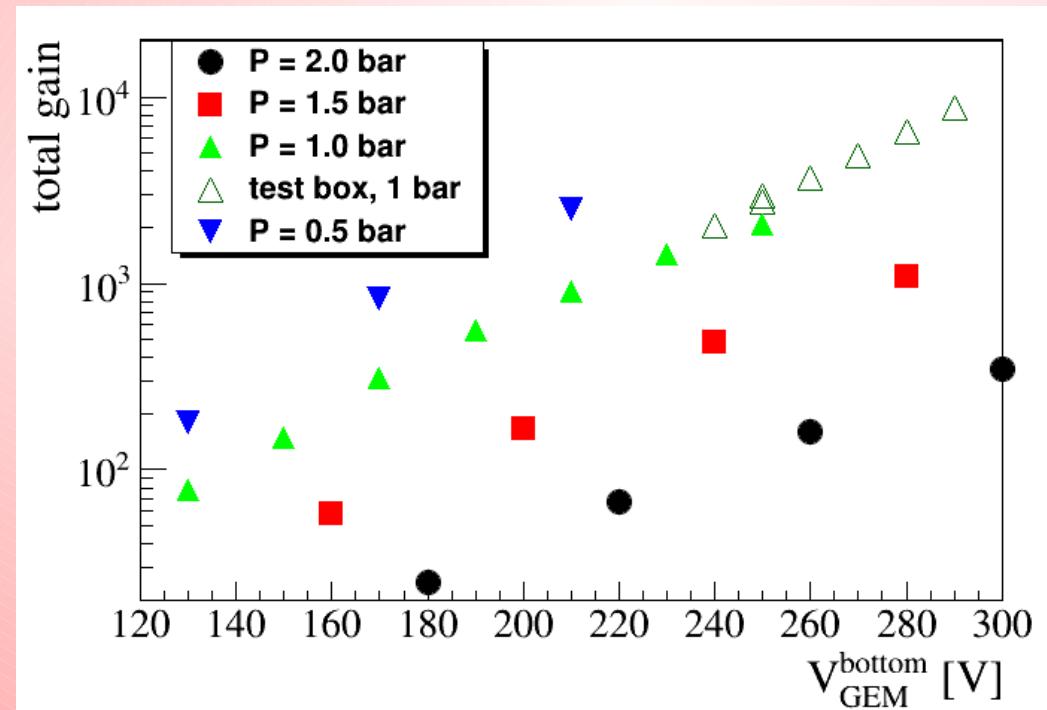
- Charge distribution from through tracks
 - easy access to drift velocity, gain and gas quality





Gain in cosmic run

- Preliminary gain study
 - compatible with test box results
 - data to be processed to optimize field configuration





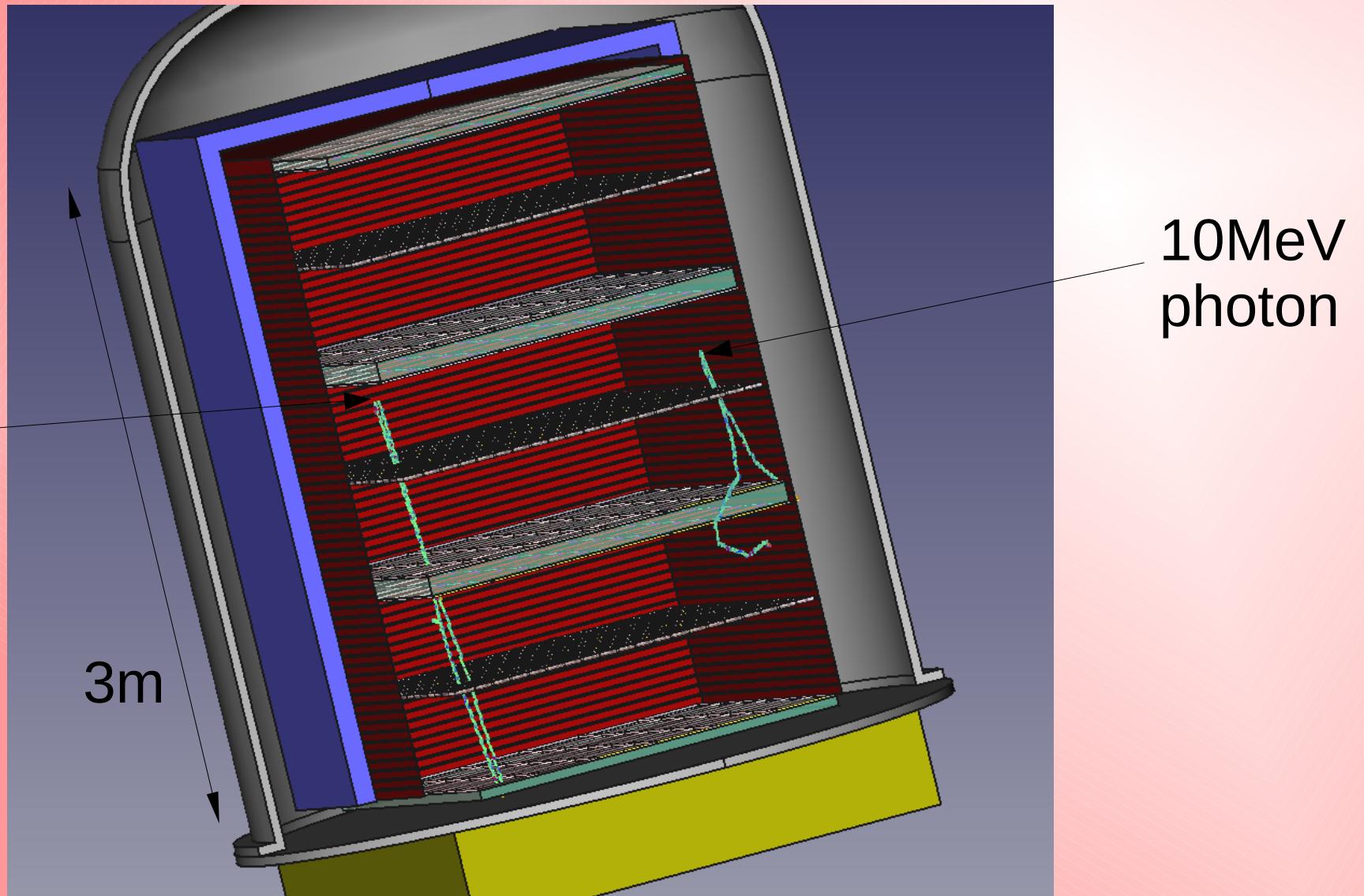
Status and Outlook

- Status
 - Encouraging simulations
 - Operational demonstrator
 - Scheduled test in polarised photon beam (NewSUBARU)
- Outlook
 - Upcoming beam test for concept validation
 - High pressure operation improvements (small gap)
 - Developments for space operation:
trigger, gas stability, radiation hard electronics



HARPO

Dreaming of the future



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Backup



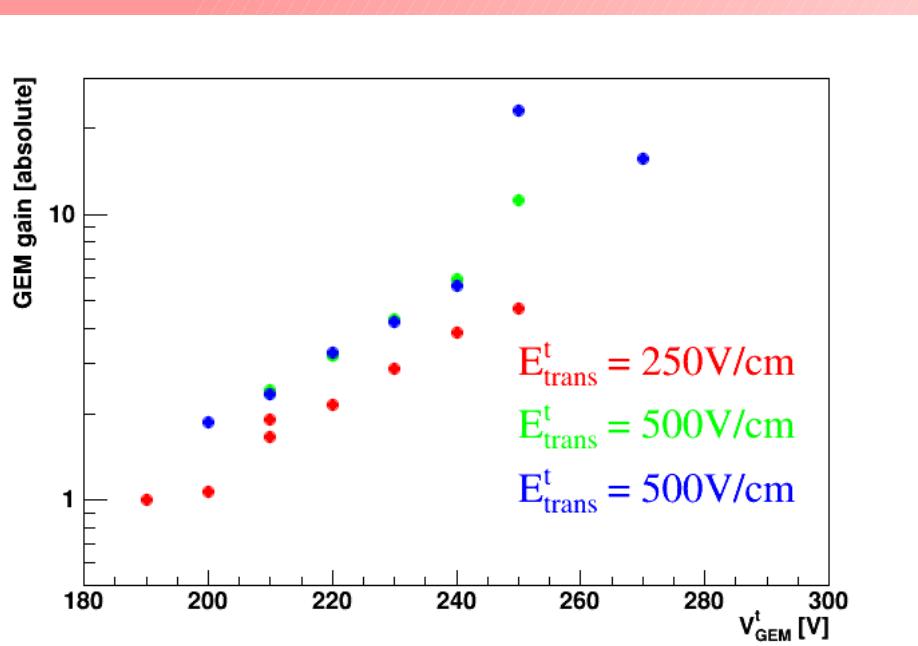
Space Challenges

- Trigger
 - heavy cosmic ray background (mostly protons)
 - non directional signal
 - self triggered TPC (AGET electronics)?
 - scintillators/silicon for T0
- Gas stability
 - maintained purity over several month/years
 - closed circuit purification loop?
- Radiation hard electronics

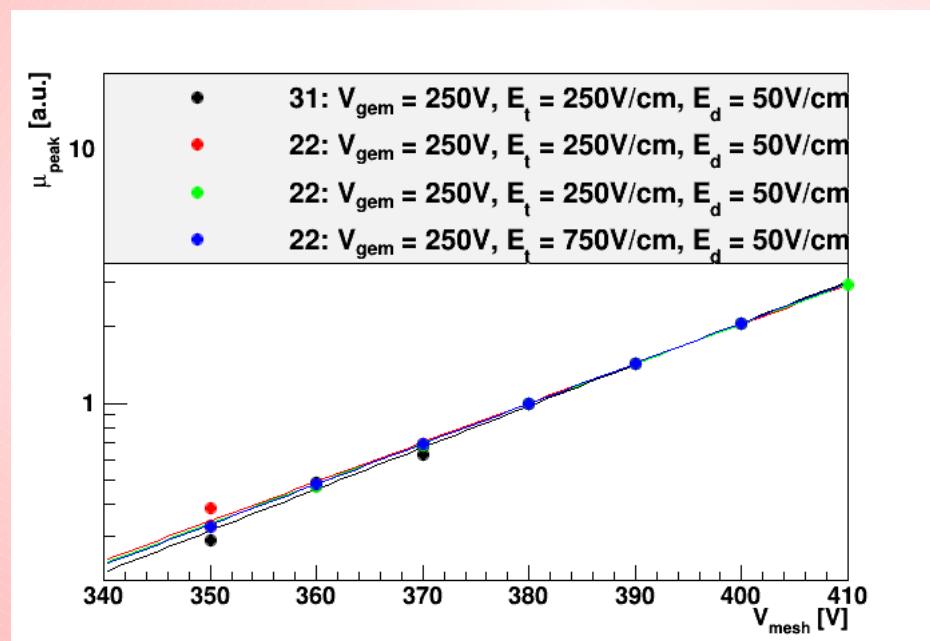


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Gain micromegas + GEM



absolute GEM gain measured up to ~ 10
(limited by dynamic range of ADC)
Maximum gain ~ 30 (extrapolated)



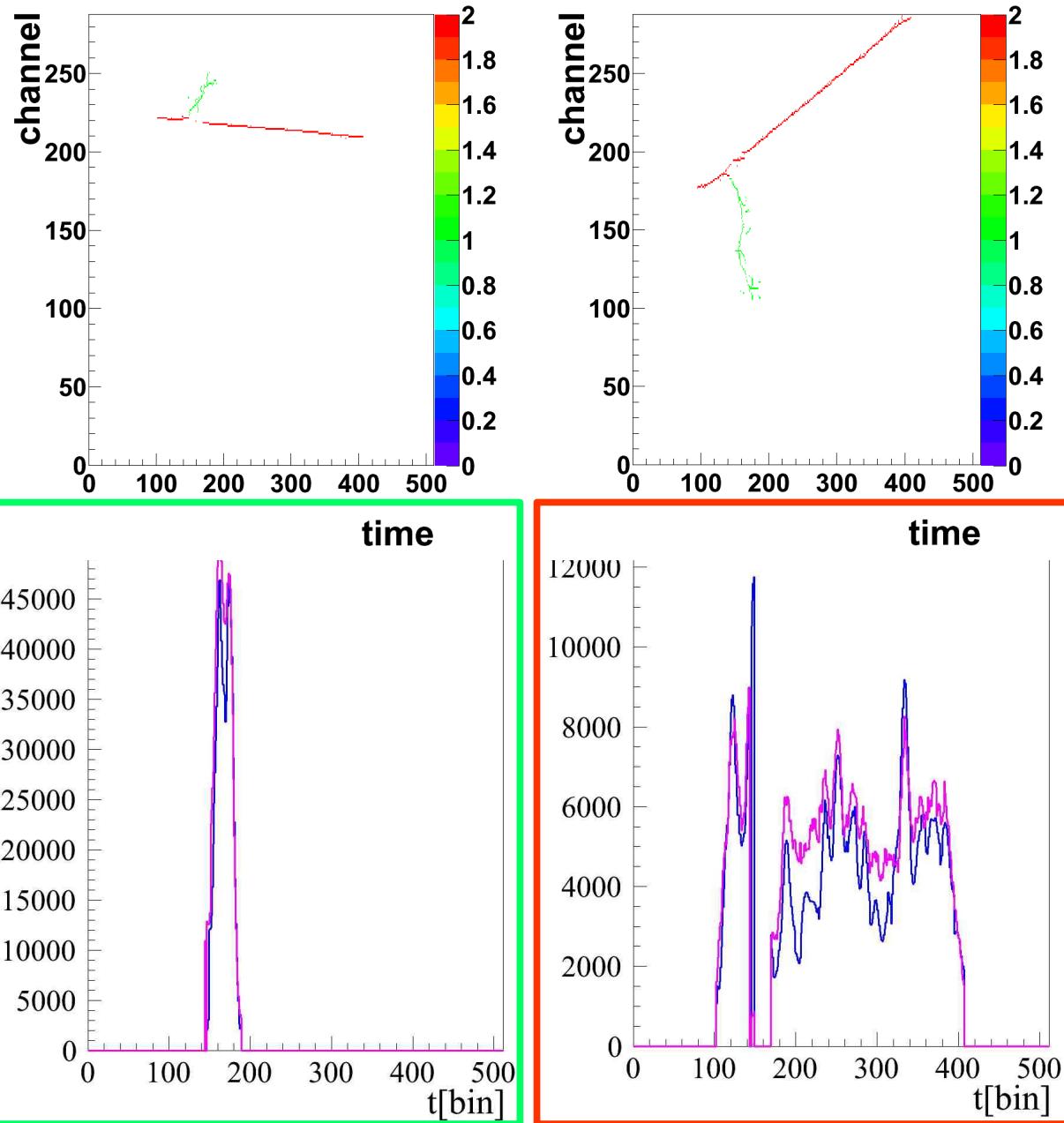
Micromegas gain up to ~ 2000

Total gain up to $\sim 40,000$



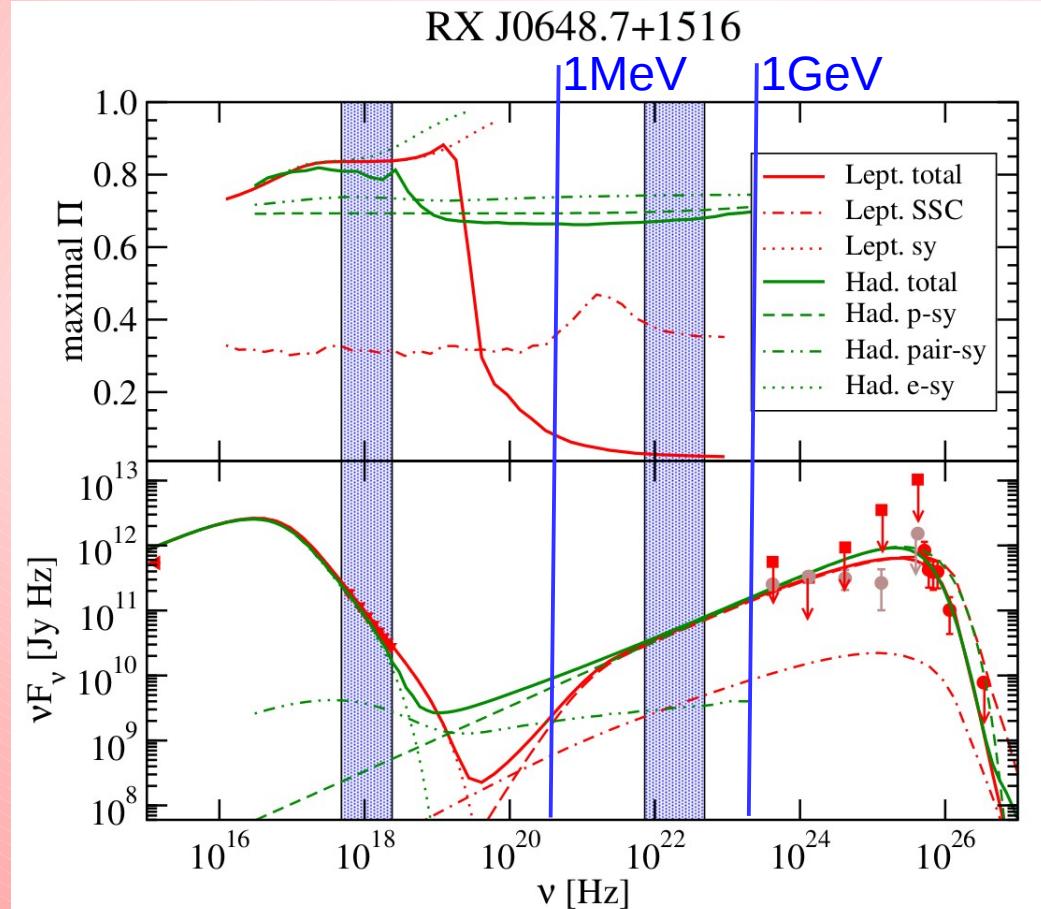
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Track matching



Science case example: Blazars

- Separating processes
 - Leptonic synchrotron self Compton (SSC)
 - Hadronic proton synchrotron
- Polarisation can give the answer
 - no difference in X
 - visible in gamma



H. Zhang and M. Böttcher,
A.P. J. 774, 18 (2013)



Polarimetry

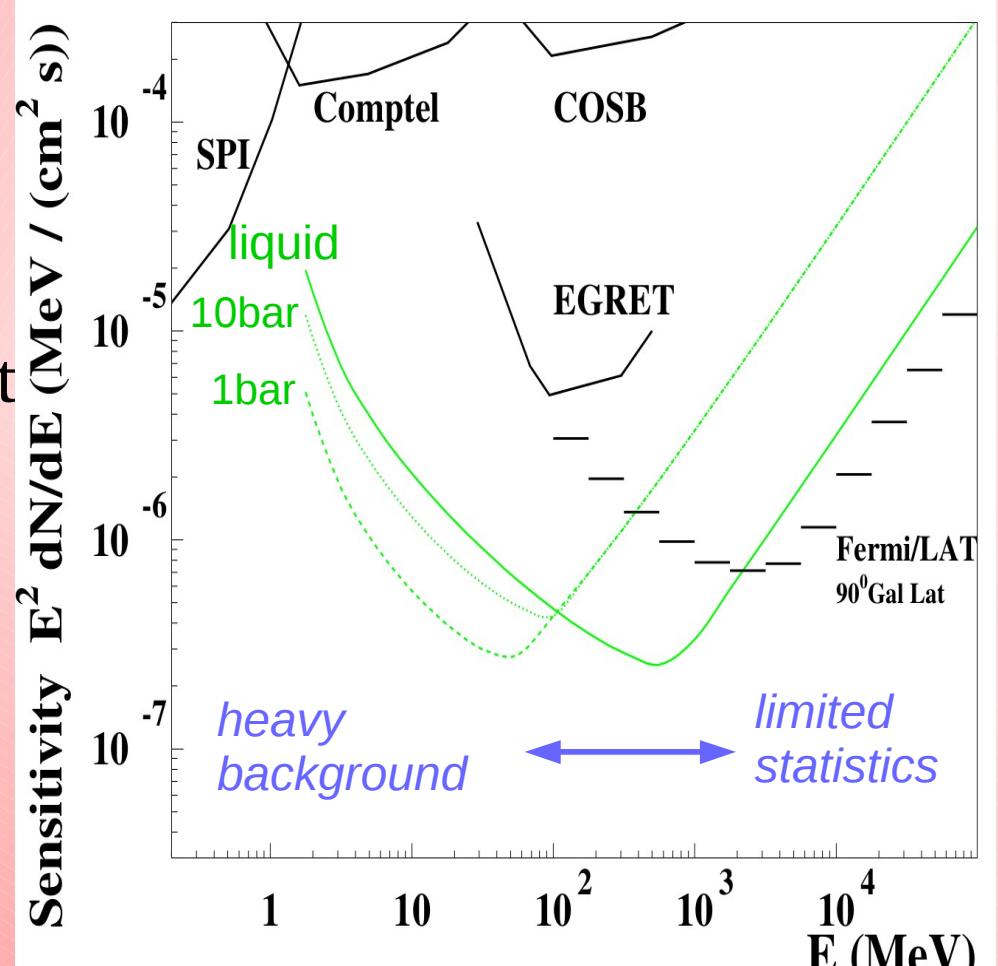
- Polarimetry capabilities depend on many parameters
 - energy, exposure, detector size, gas pressure...
- A simple example was used
 - Crab-like source, 1 year
 - size= 1m^3 , resolution=1mm
 - exposure fraction=1, efficiency=1



HARPO

Expected sensitivity

- At lower energies
 - $E < \sim 100\text{MeV}$
 - up to 2 orders of magnitude improvement
- Higher energy
 - $E > 100\text{MeV}$
 - Limited by low cross-section
 - still better than FERMI up to 400MeV



D. Bernard,
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FERMI pass7