HARPO

A TPC as high performance gamma-ray telescope and polarimeter: polarisation measurement in a beam between 1.7 and 74MeV with HARPO

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8th International Symposium on
"Large TPCs for Low-Energy Rare Event Detection"
2016-12-07

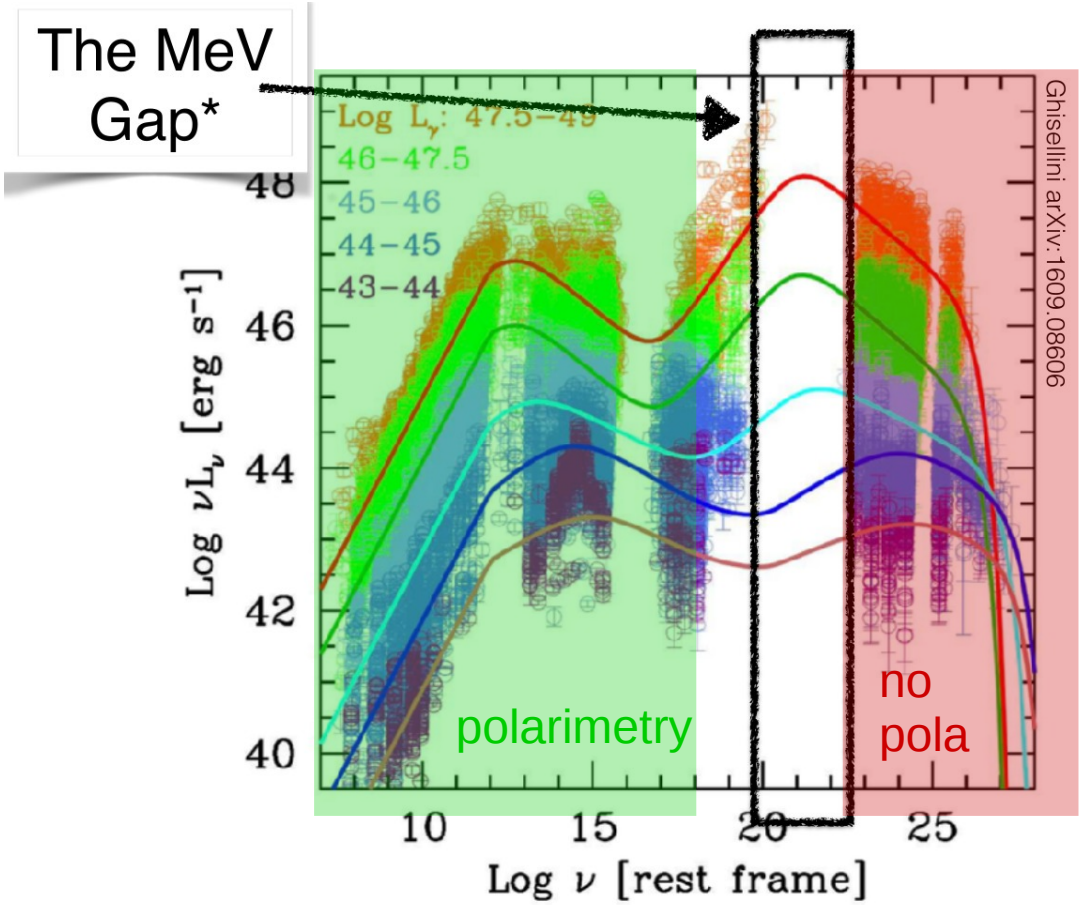
Irfu - CEA Saclay
Institut de recherche sur les lois fondamentales de l'Univers

NewSUBARU

- The HARPO detector
  - motivation
  - design
- Detector monitoring using cosmic rays
  - detector/gas stability over several months
- Polarisation measurement in a gamma ray beam
  - event reconstruction
  - modulation measurement
- Simulations
  - full detector simulation
  - systematics correction

HARPO Project

The MeV Gap

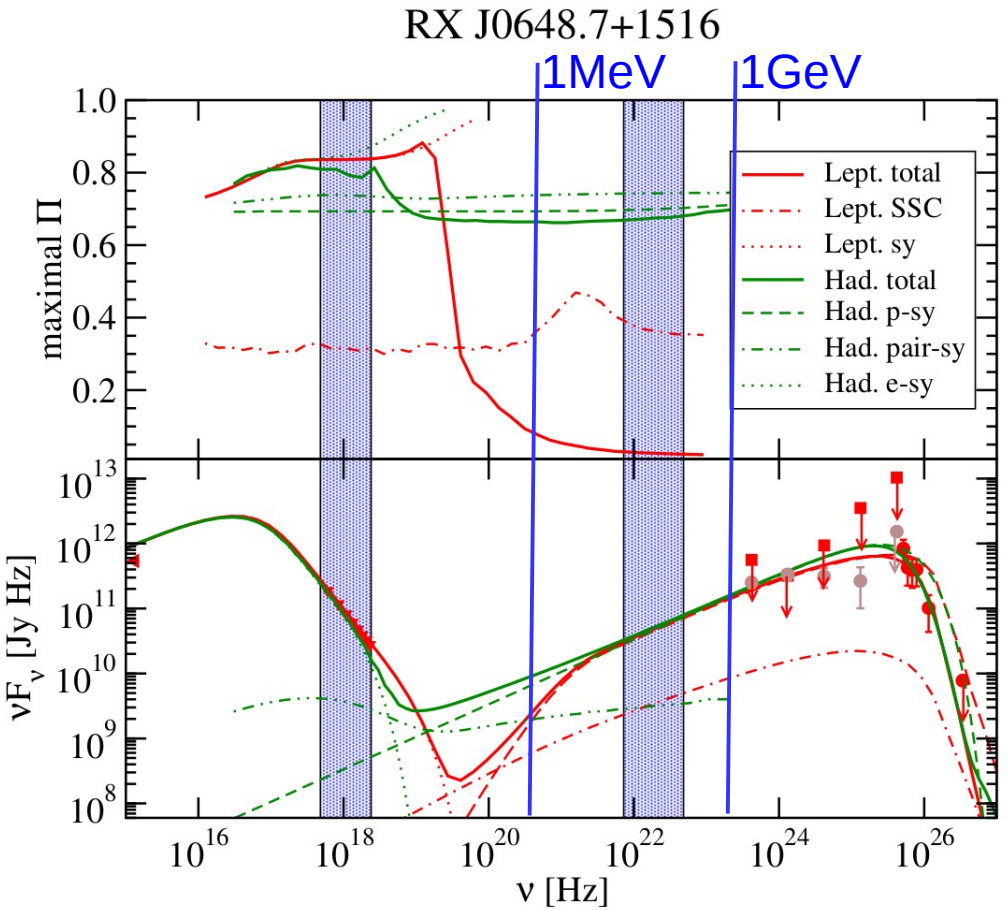


Spectra from blazars

- Sensitivity gap
  - no Compton above ~100keV
  - no Pairs below ~100MeV
- Polarimetry cut
  - no polarimetry above 1MeV

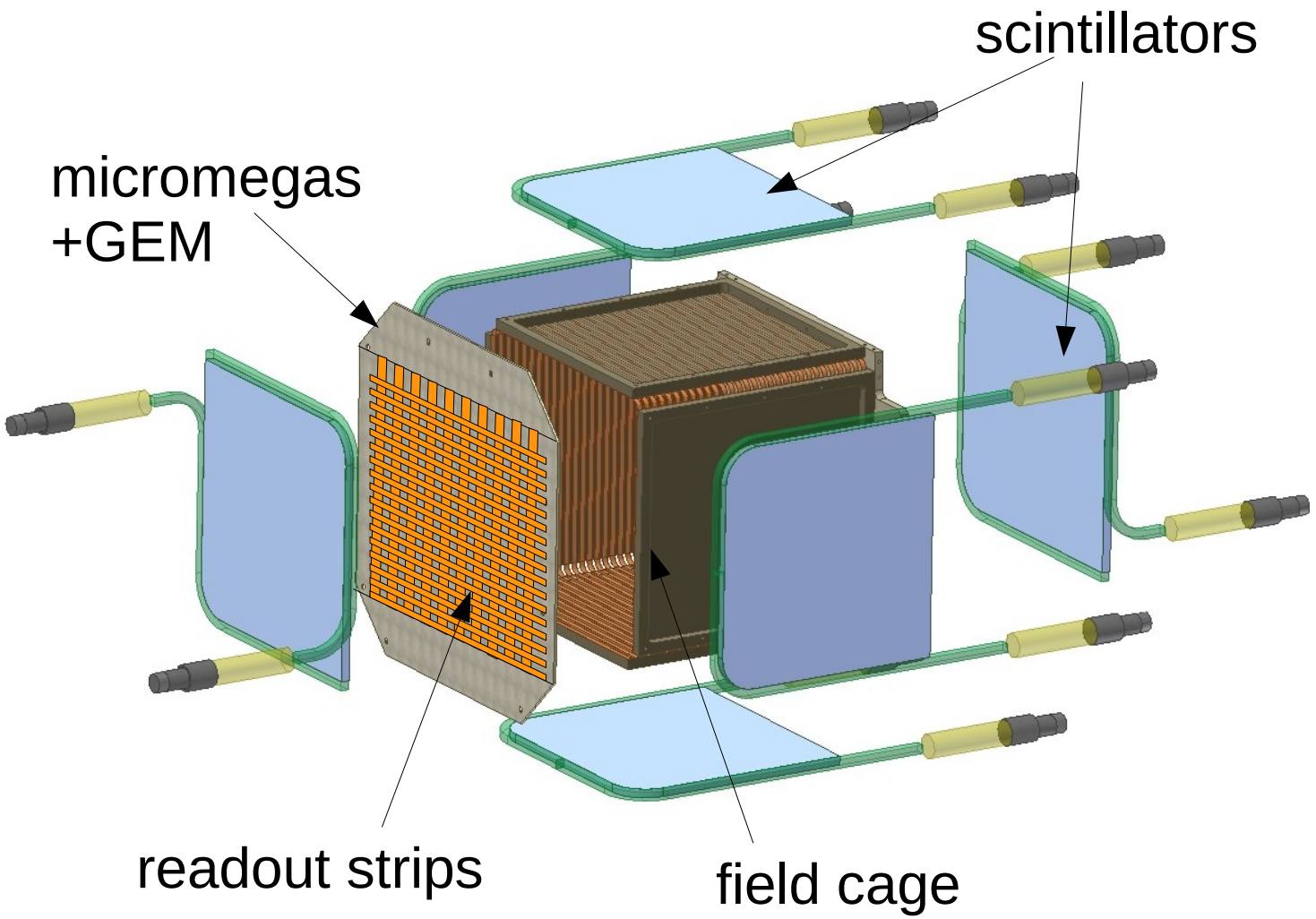
Polarimetry: example

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

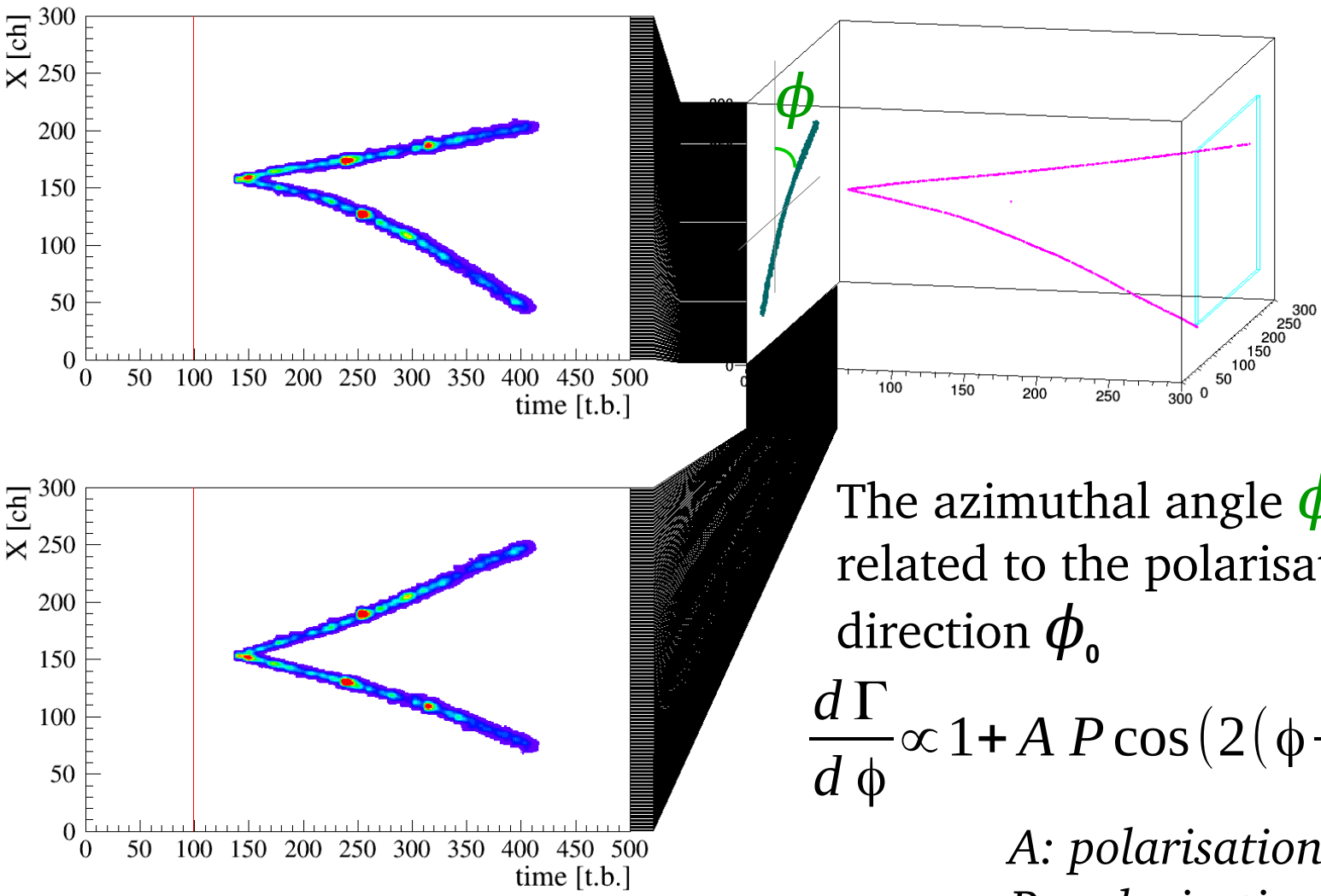


H. Zhang and M. Böttcher, A.P. J. 774, 18 (2013)

HARPO Demonstrator



Polarisation measurement



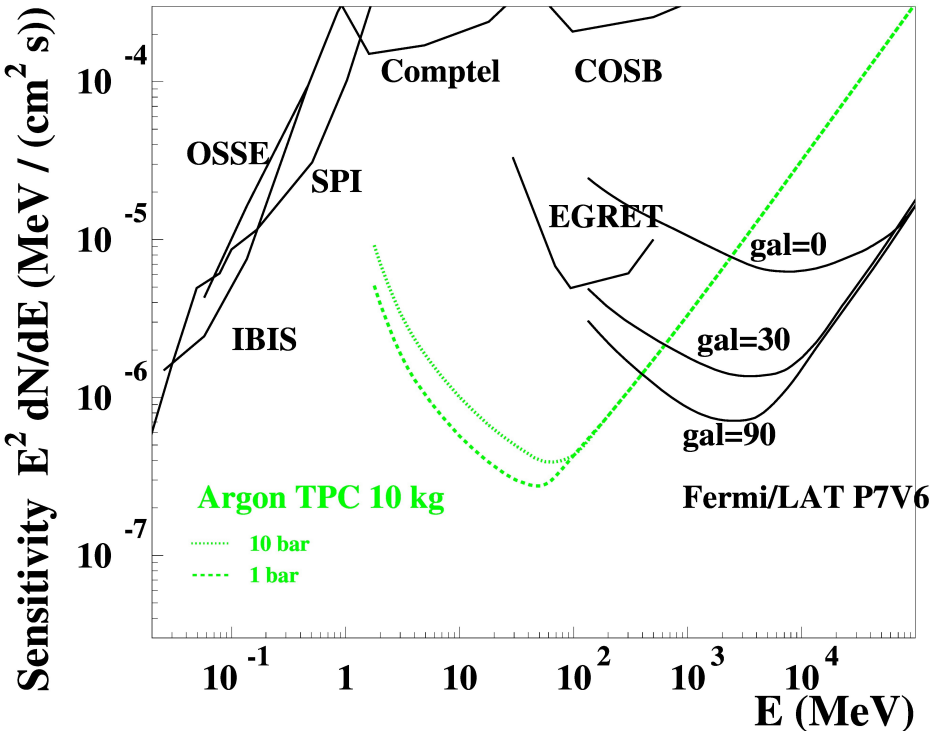
The azimuthal angle ϕ is related to the polarisation direction ϕ_0

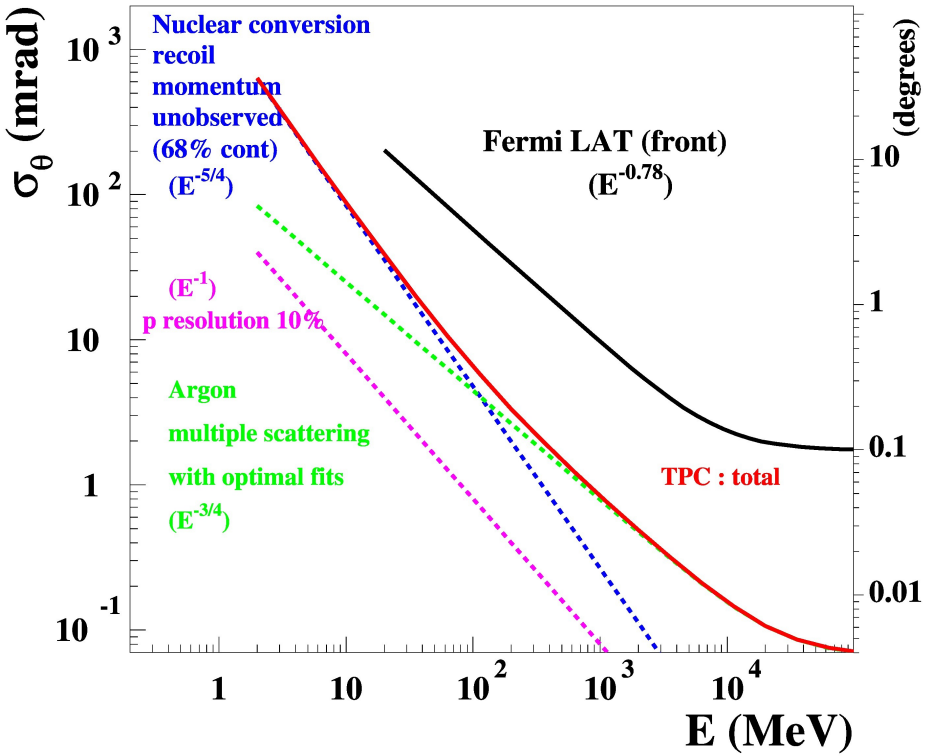
$$\frac{d\Gamma}{d\phi} \propto 1 + A\,P\cos\left(2\left(\phi - \phi_0\right)\right)$$

A: polarisation asymmetry

P: polarisation fraction

Expected performance

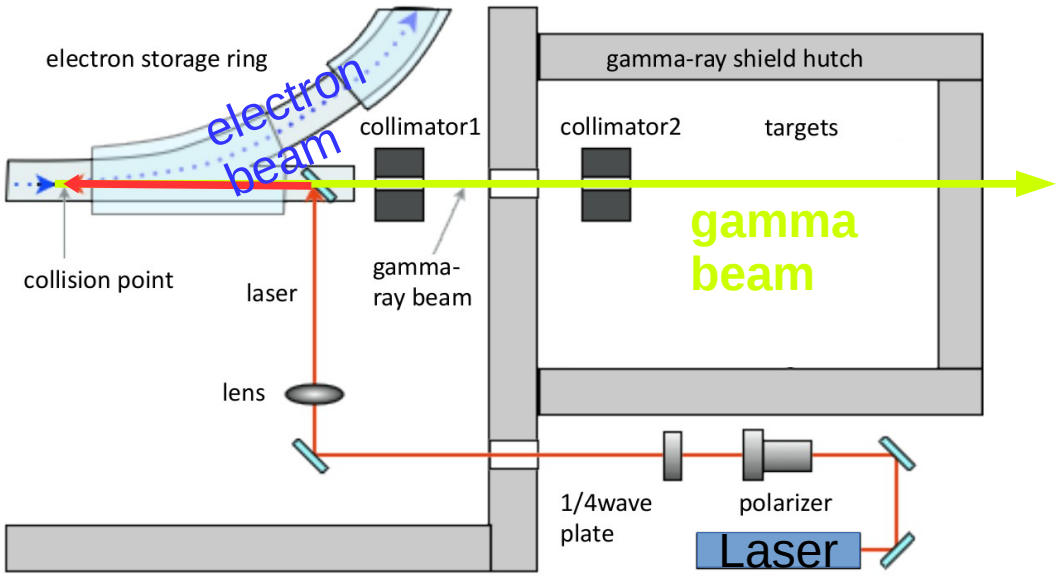


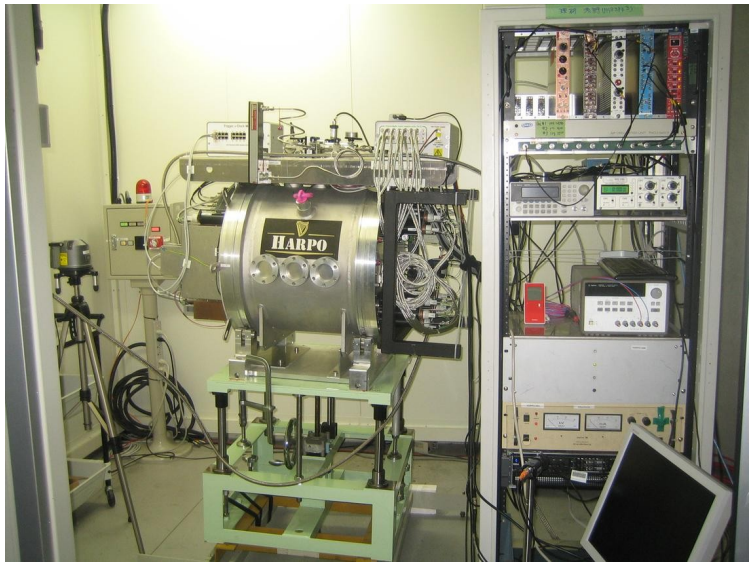


D. Bernard,
NIM A 701 (2013) 225

Measurement in polarised photon beam

- Demonstrator built and tested in polarised photon beam in NewSUBARU, Japan
  - 13 Energy points, 1.6 to 74MeV, ~60Mevents

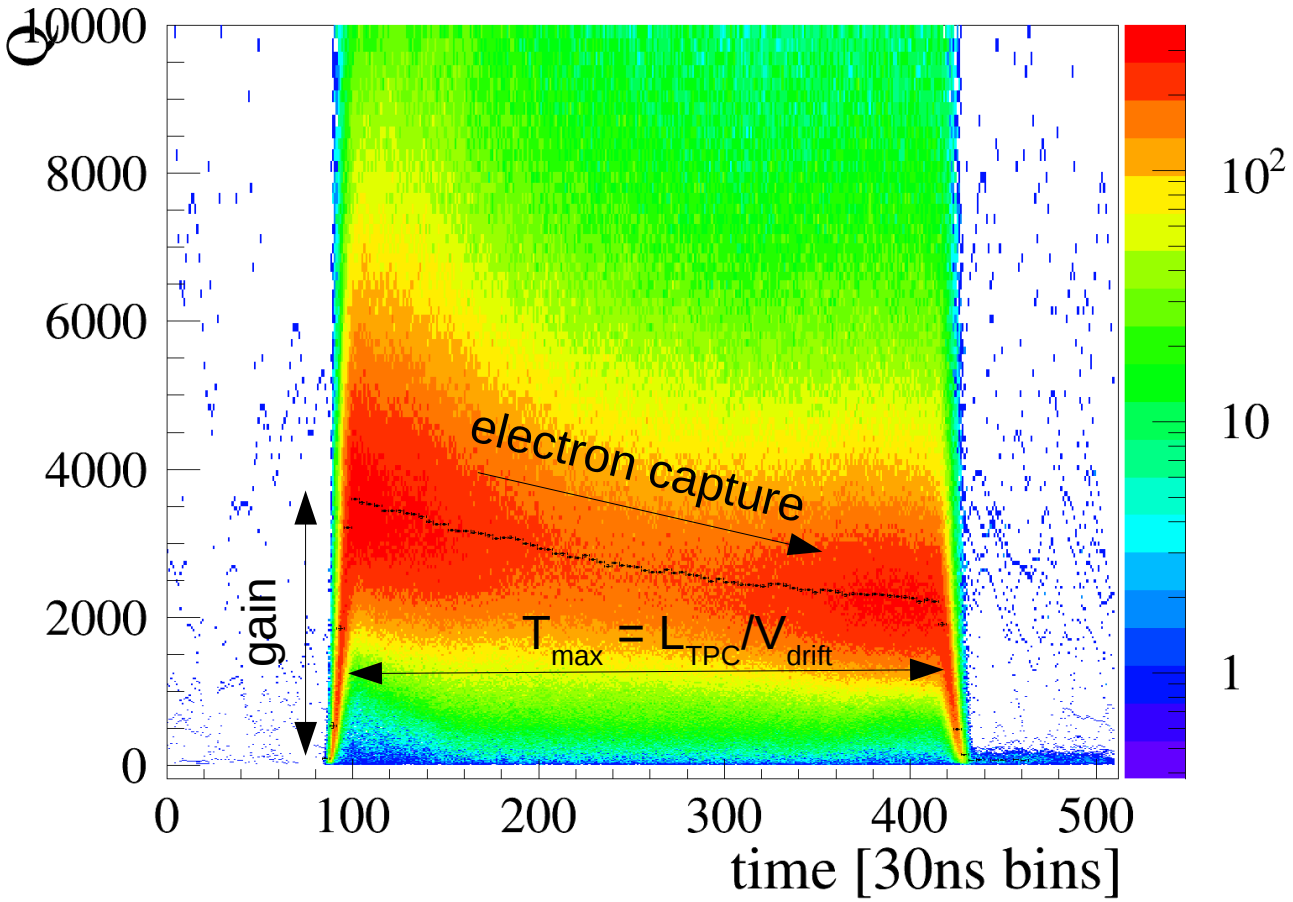




Detector monitoring using cosmic rays

Gas stability

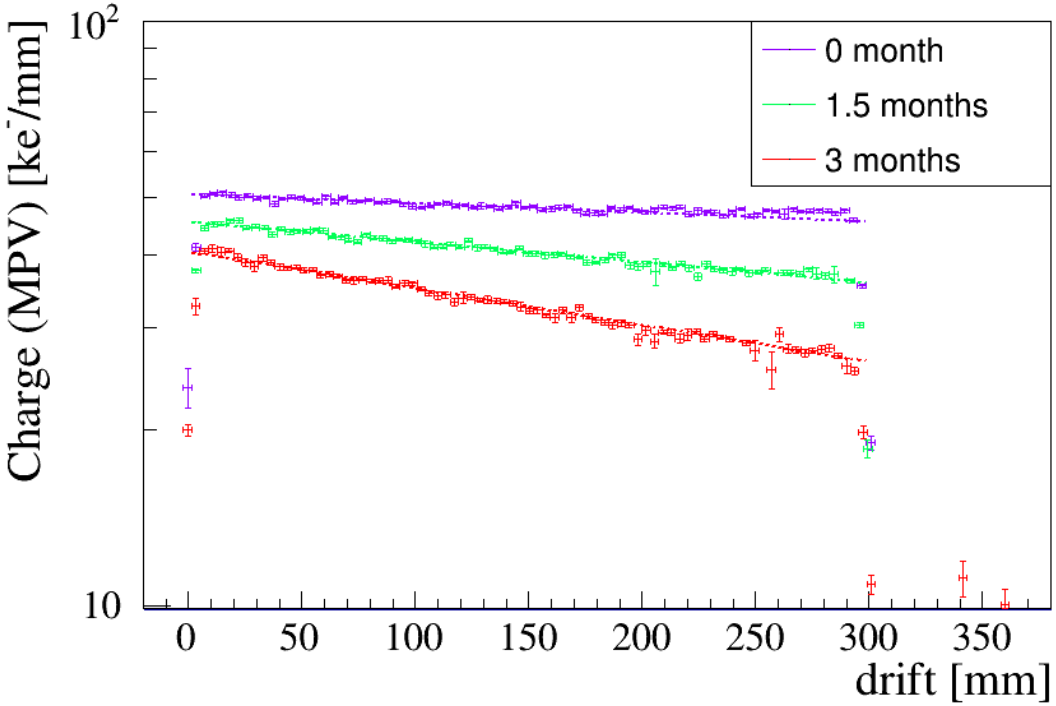
Diagnostics: Q vs T_{drift}



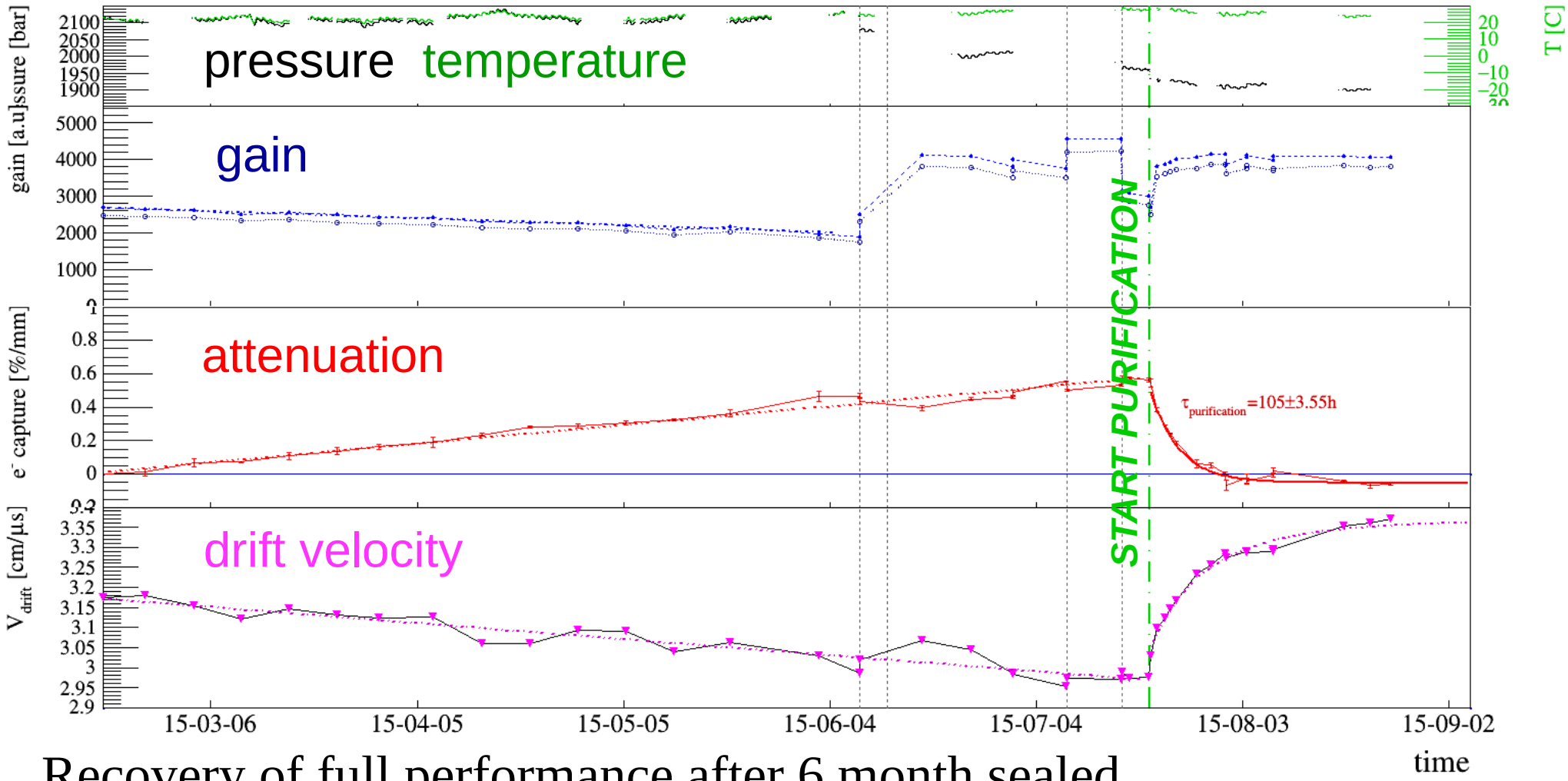
- The charge is normalised with regard to the track angle
- The profile is obtained from a Landau fit (of slices) (mean value affected by threshold/saturation effects)
- V_{drift} is also easily extracted from this plot

Cosmic runs LLR

- Relative measurements
  - First run as reference (“clean gas”)
- Weekly data taking of ~1.5h, for 6 months
- Clear degradation of gain and e- capture



Gas stability



Recovery of full performance after 6 month sealed

Frotin et al., MPGD2015, EPJ Web of Conferences, arXiv:1512.03248

Gas stability

- Very encouraging results
  - excellent performance after 6 month sealed
  - detector not optimised for outgassing
- Test done without HV
  - monitoring necessary: risk of damage on µM

    => HV turned on only for data taking ~1h/day
- New test ongoing
  - HV on all the time, data taking at regular interval
  - µM HV control using PYRAME

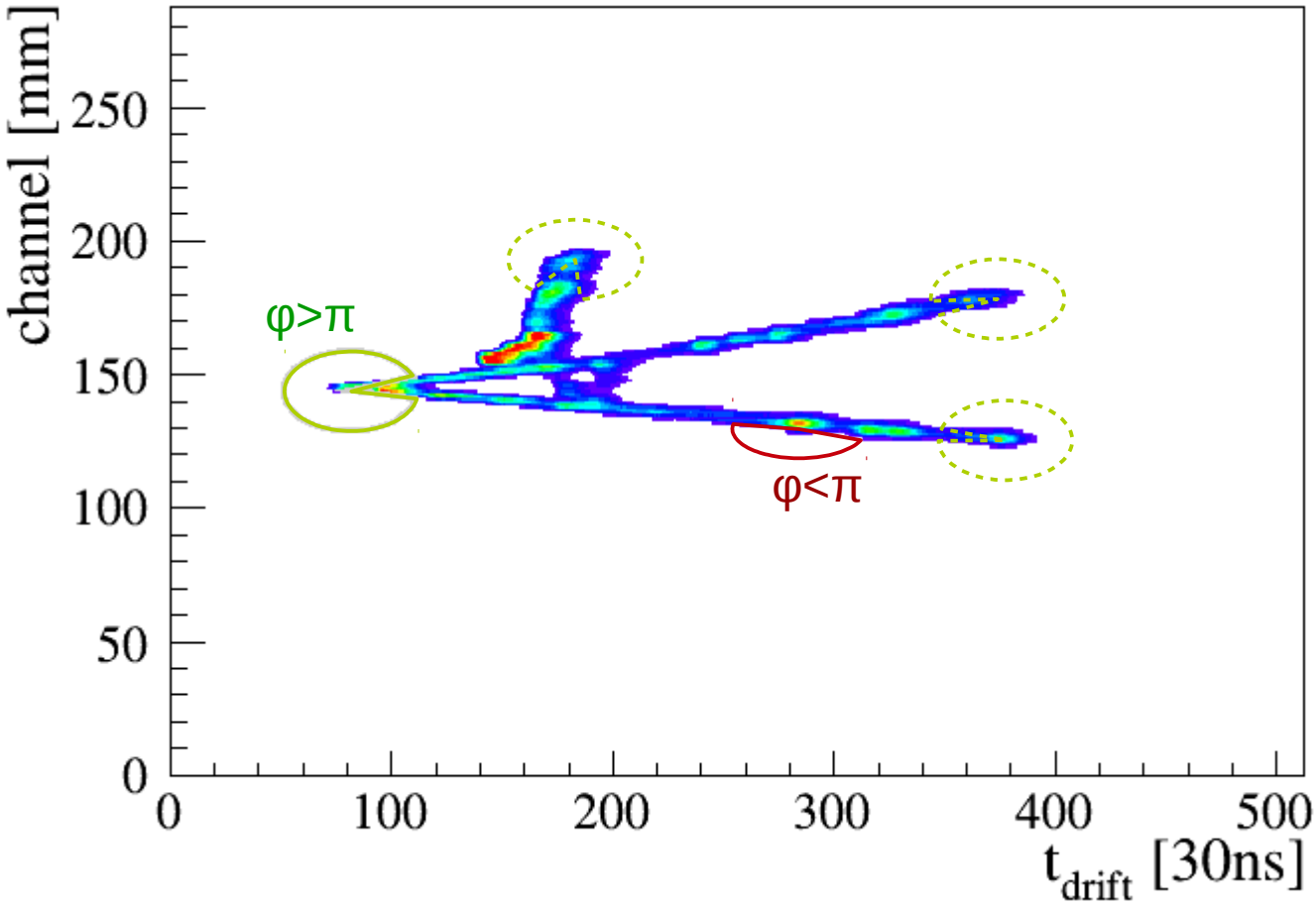
    http://llr.in2p3.fr/sites/pyrame

Gamma-ray beam Reconstruction and Analysis

Event reconstruction

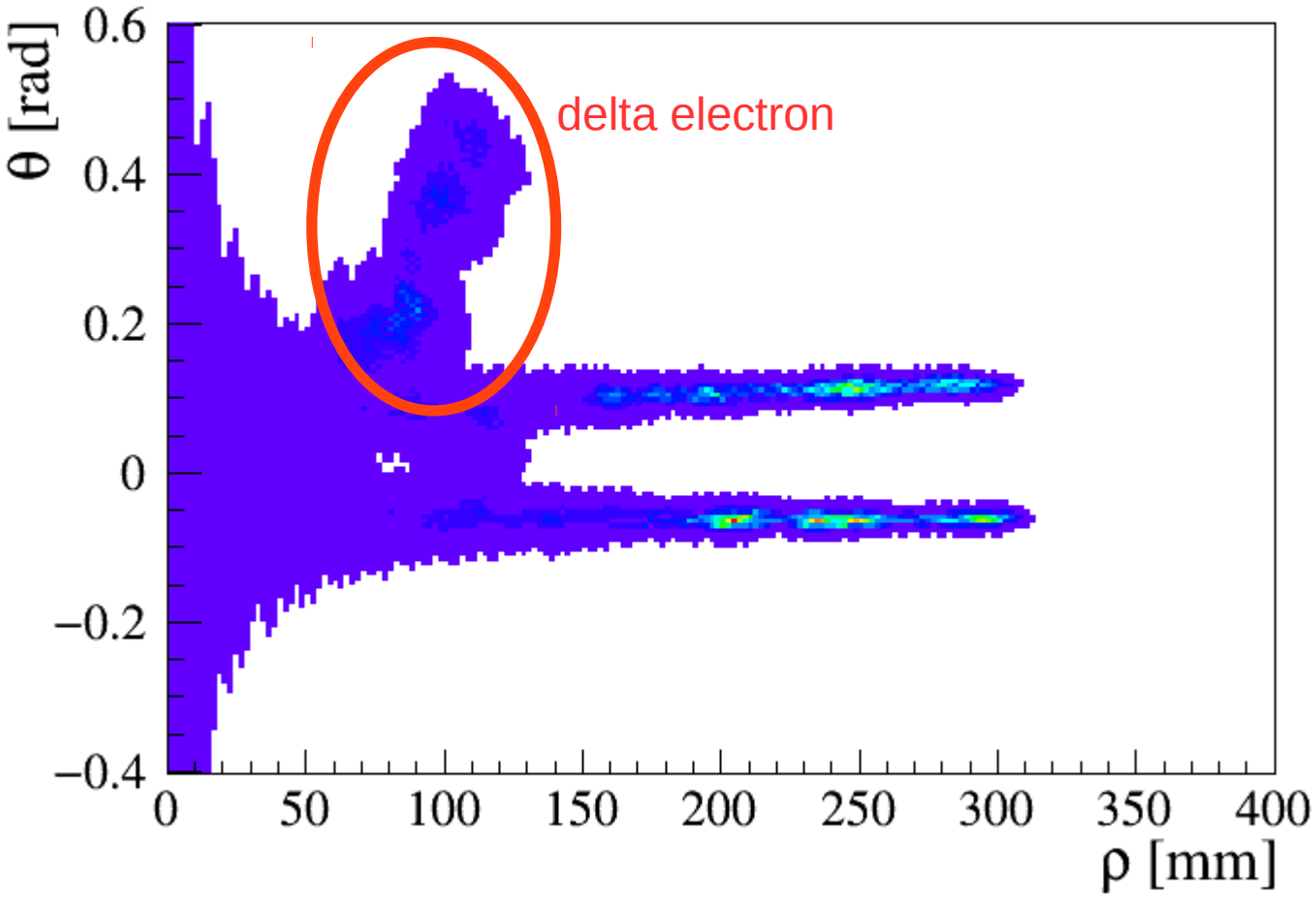
- Difficult with traditional HEP method
- v1: Hough track finding
  - good for cosmics (straight, separated)
  - <10% efficiency on low energy pairs
- v2: Kalman tracking
  - hard without layers
  - better at low energy, but still low efficiency
- v3: no clustering, no tracking
  - simple, robust and efficient
  - very specific to our event configuration

Vertex Finder



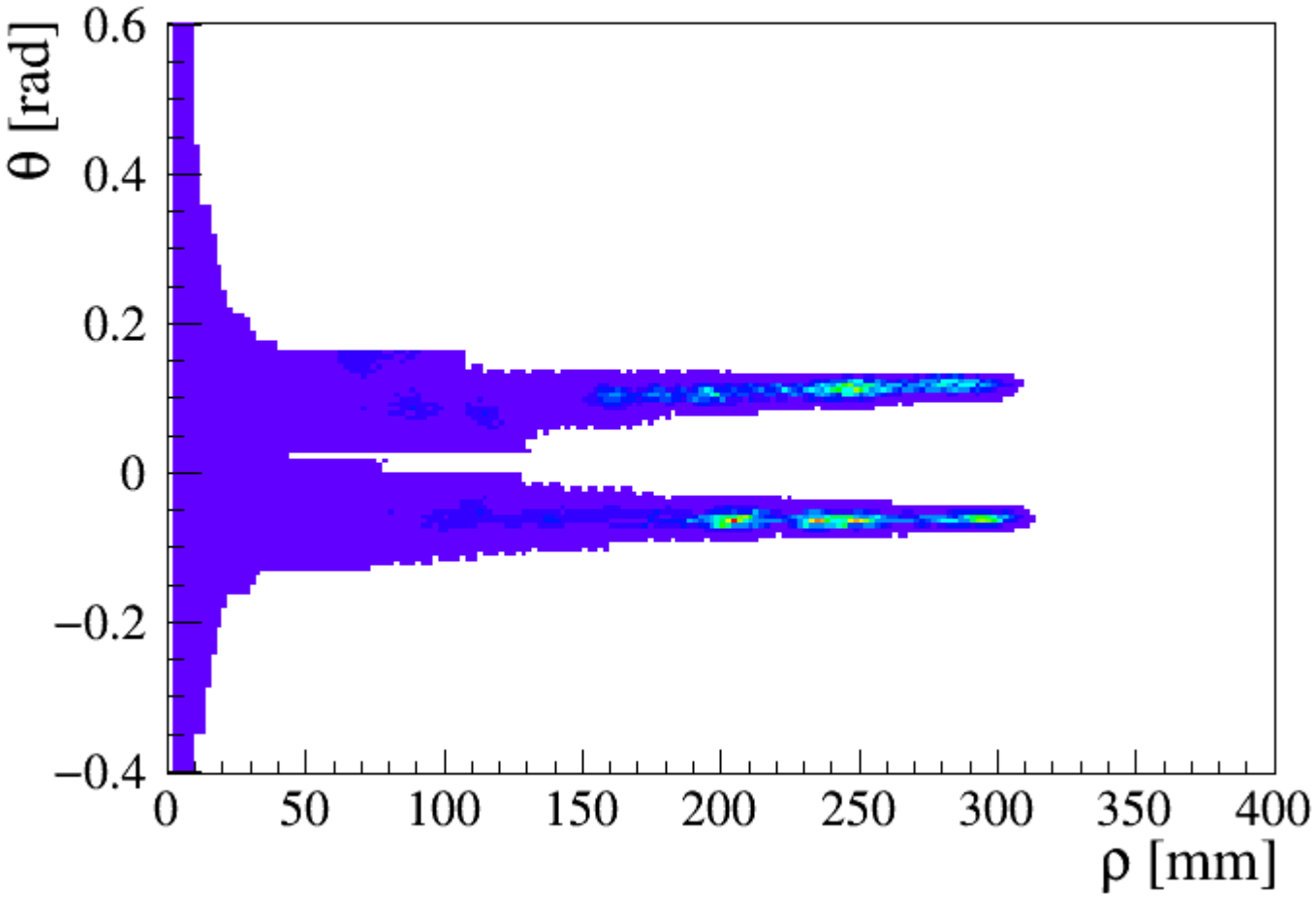
Vertex Fitting

- Polar charge distribution around vertex



Vertex Fitting

- Clean up: keep only straight lines

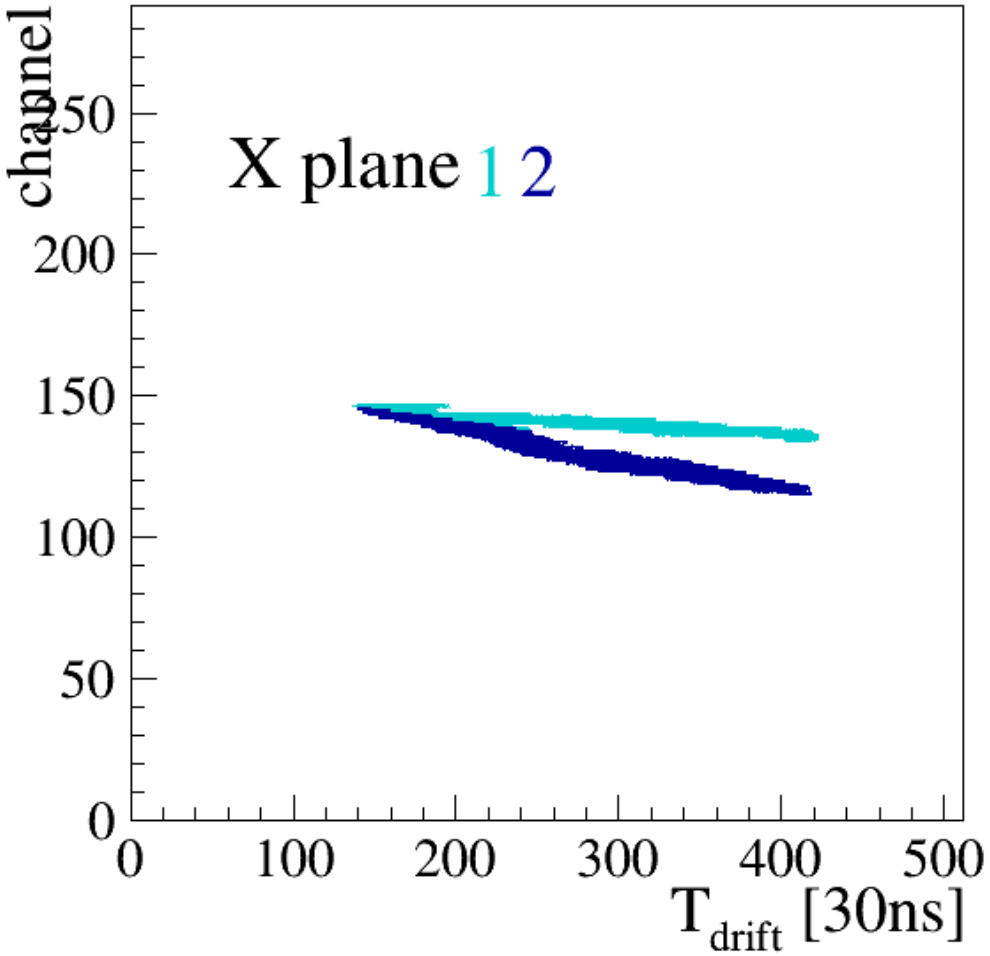


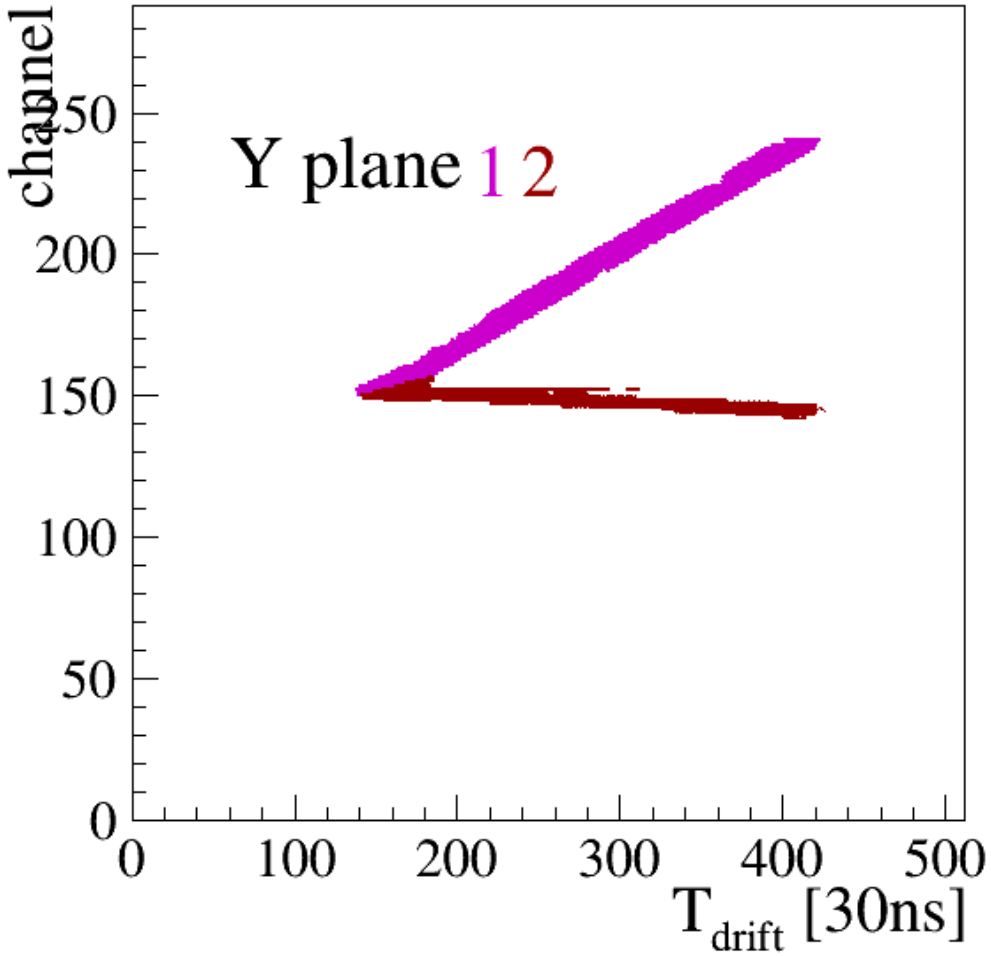
Vertex Matching

- As before: compare charge profile
  - 1: match vertexes if there are several with same Z position
  - 2: match the tracks in the vertex (simple: only 2 possibilities)

Vertex Matching

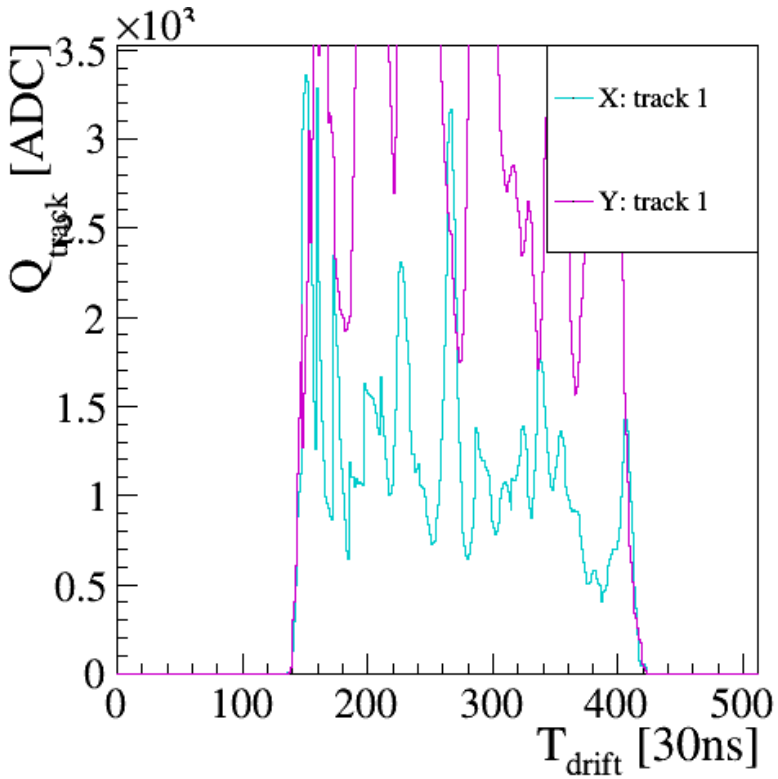
- Assign signal to tracks

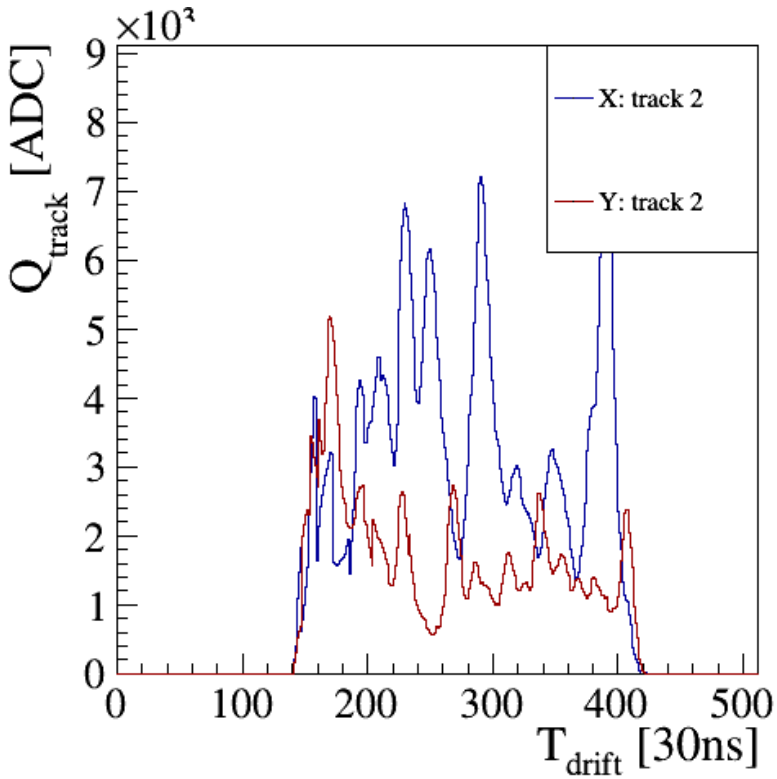




Vertex Matching

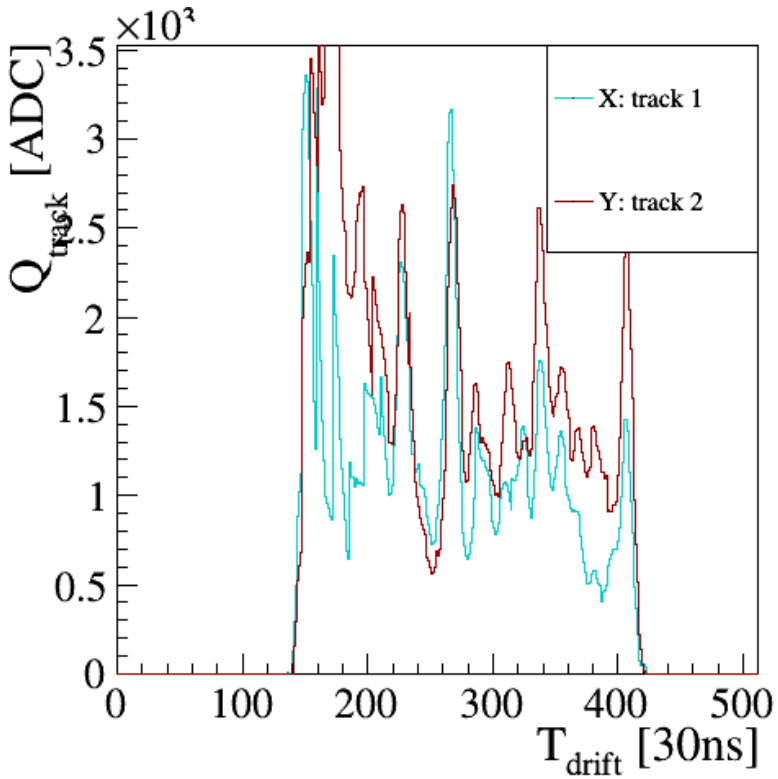
- Compare profiles: X(1,2) ↔ Y(1,2) "same"

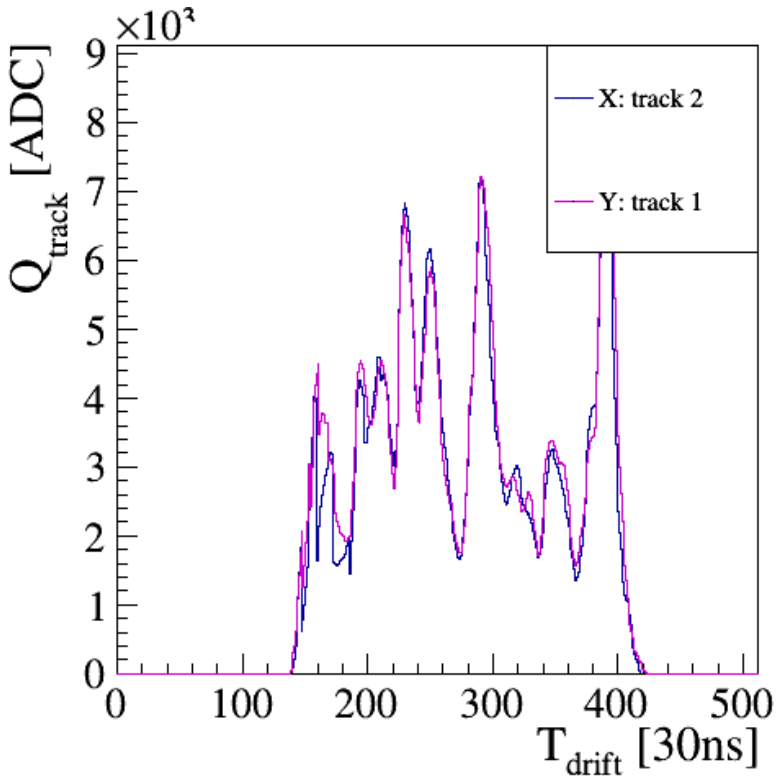




Vertex Matching

- Compare profiles: X(1,2) ↔ Y(2,1) "switch"



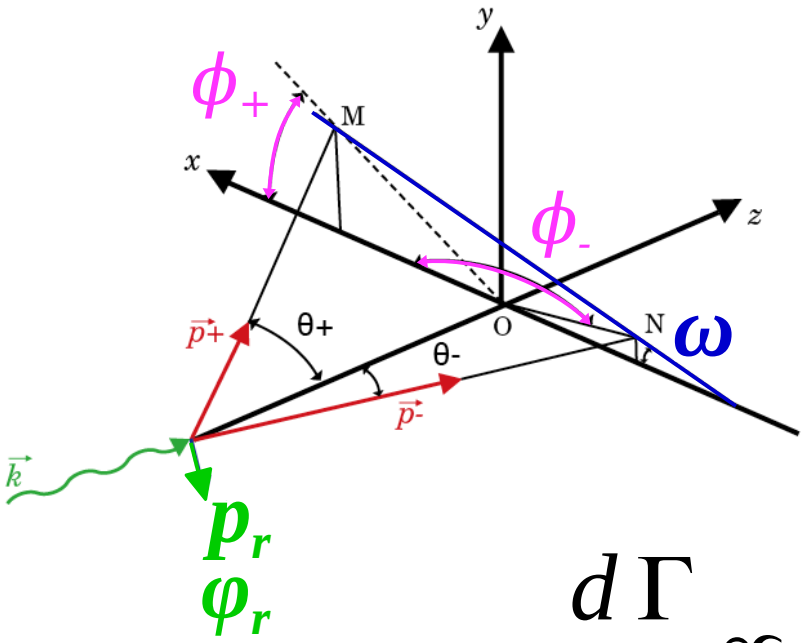


Vertex Fitting

- Simple
- Robust:
  - ignores obvious scattering and background
  - potential for small opening angle
  - resistant to electronics saturation

- Potential for improvement
  - better peak fitting
  - use as seed for Kalman tracking

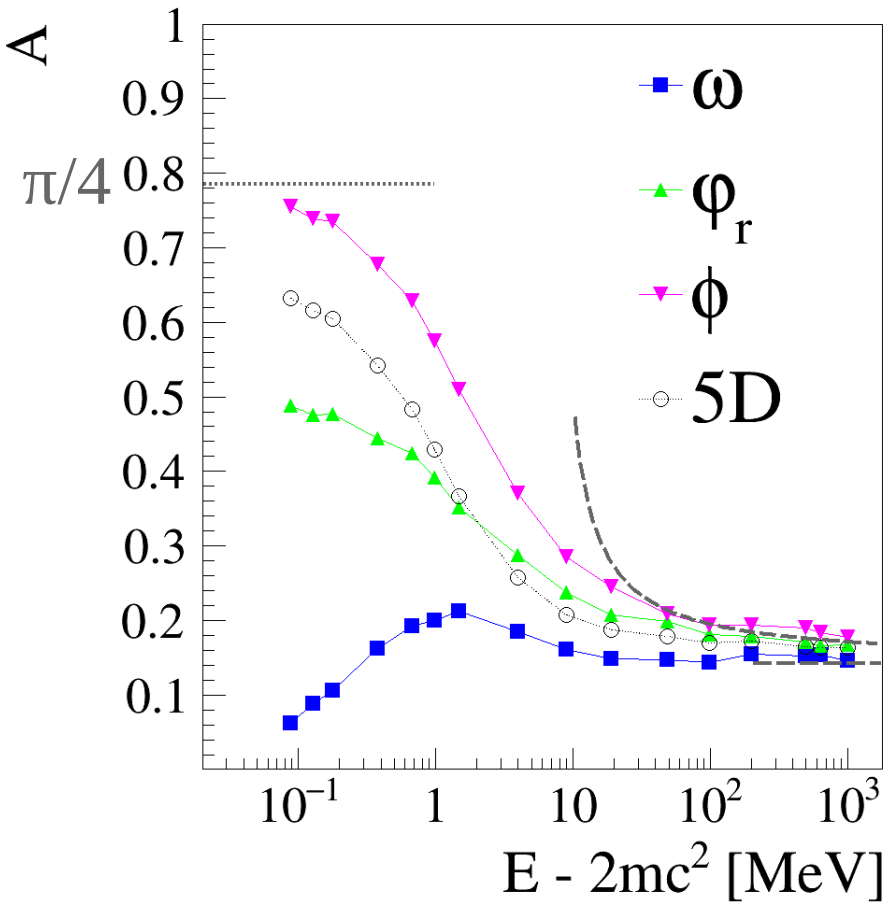
Azimuthal angle



- Azimuthal angle Ω definitions
  - recoil angle φ_r
  - pair plane angle ω
  - pair bisector $\Phi=(\phi_+ + \phi_-)/2$

$$\frac{d\Gamma}{d\Omega} \propto 1 + A\,P\cos\left(2\left(\Omega - \Omega_0\right)\right)$$

Azimuthal angle

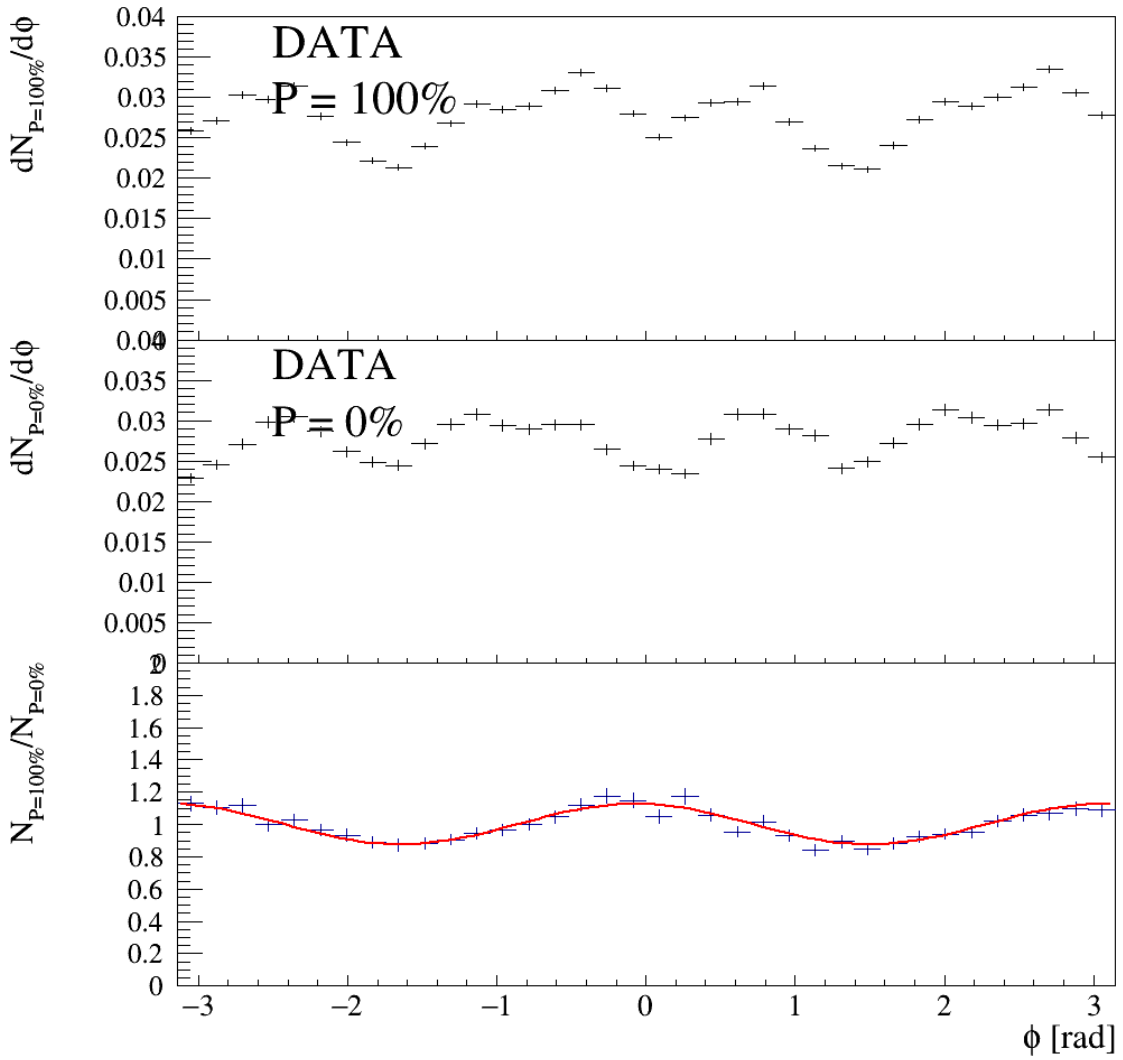


- Azimuthal angle Ω definitions
  - recoil angle φ_r
  - pair plane angle ω
  - pair bisector $\phi=(\phi_+ + \phi_-)/2$
- Angle ω used in previous publications underestimates *A* at low energy
- ϕ appears in Bethe-Heitler formula, agrees with asymptotic values

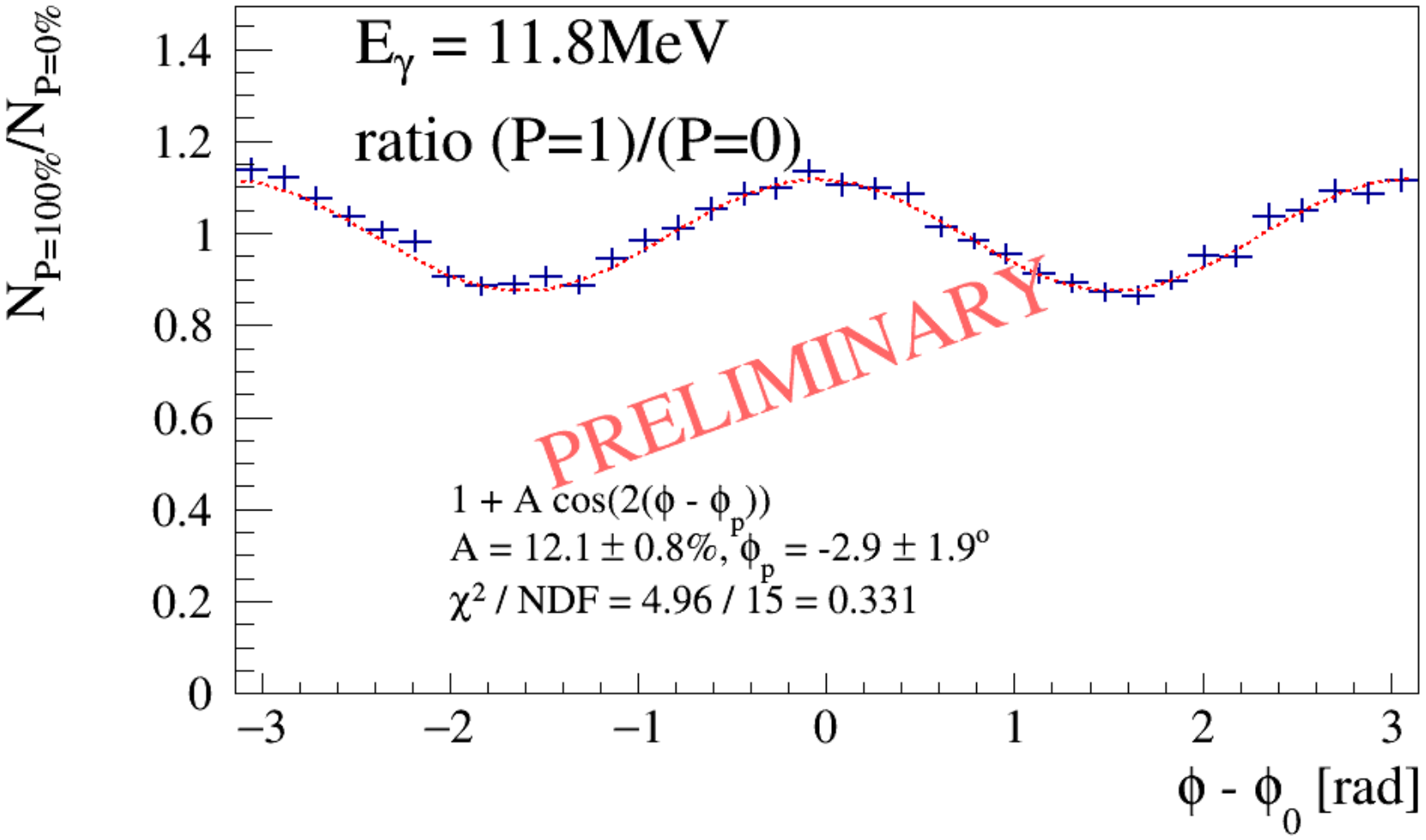
D.Bernard and PG arXiv:1611.05179 [astro-ph.IM]
submitted to astroparticle physics

Polarisation

- Large systematic bias
  - cubic geometry
  - fixed orientation
- Cancel systematic bias by taking the ratio between P=100% and P=0%



Azimuthal angle

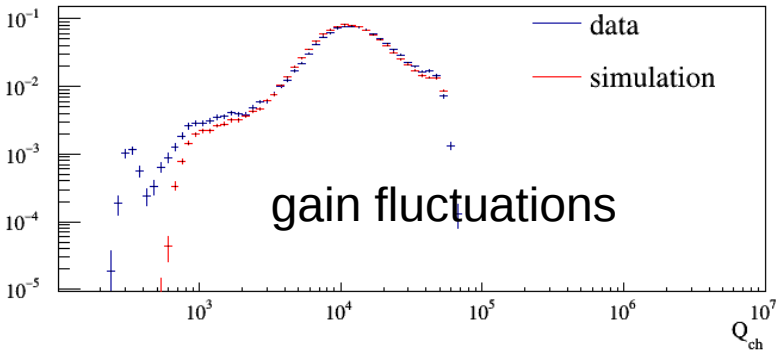


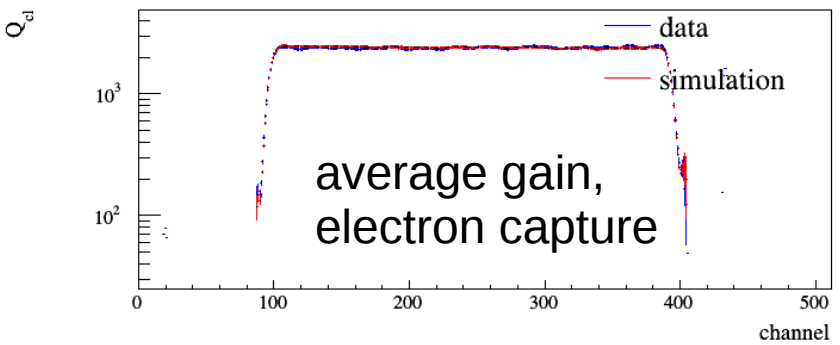
Simulation

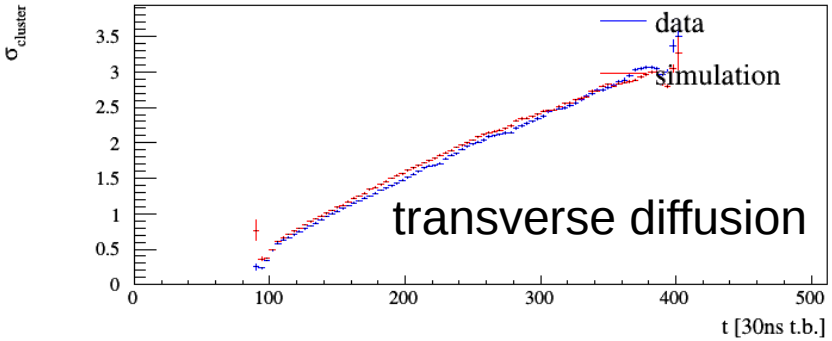
Detector simulation

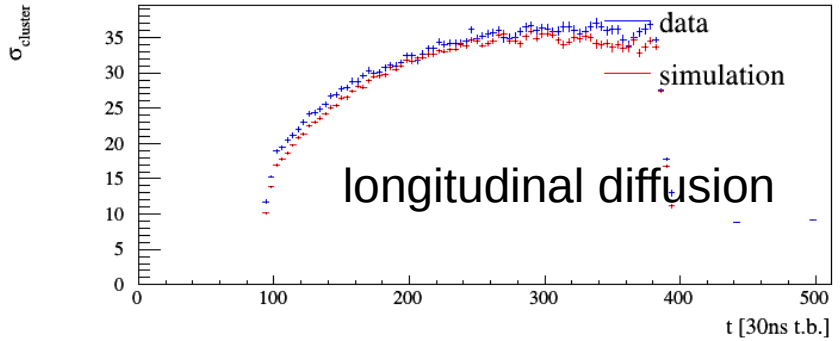
- Electron and positron 4-vectors from generator
- Track propagation and gas ionisation with Geant4
- Custom simulation of TPC
  - drift, diffusion, electron capture, gain fluctuations, electronics response
  - output same format as HARPO data, identical analysis

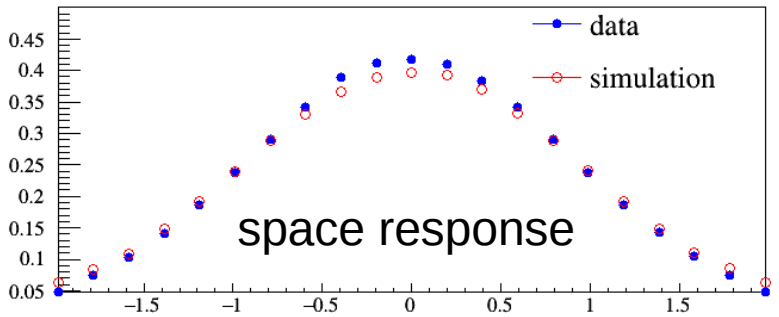
Validation/Calibration with cosmic rays

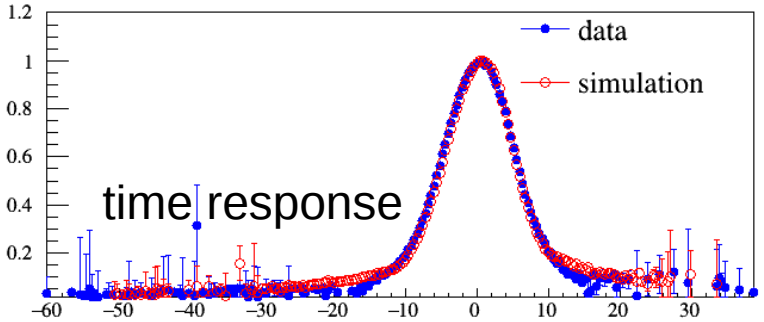




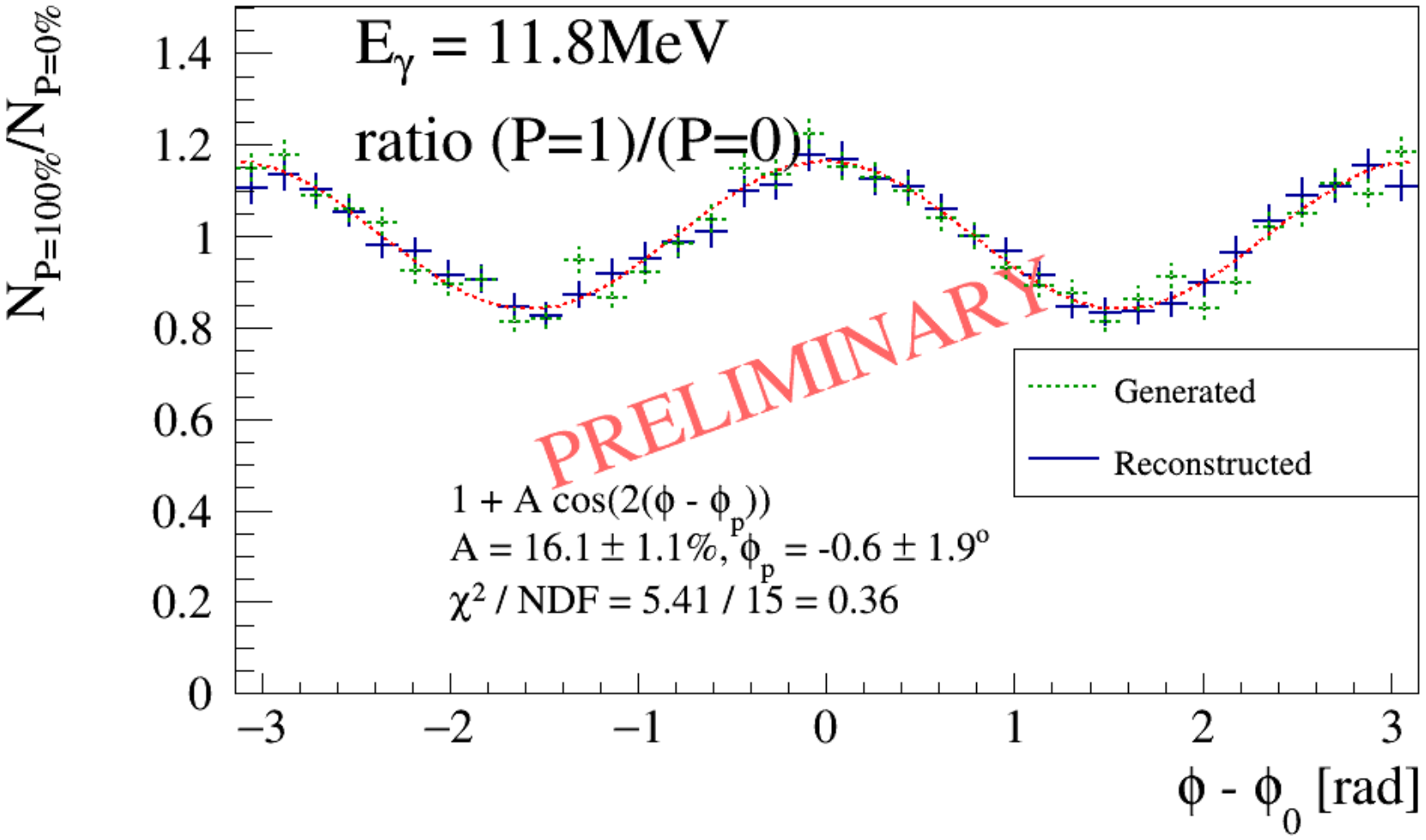




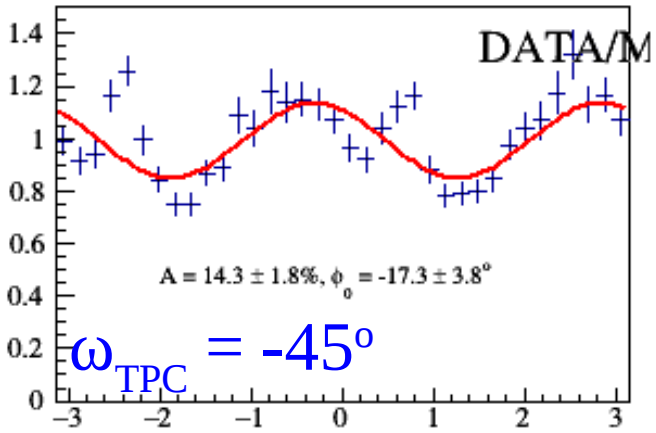


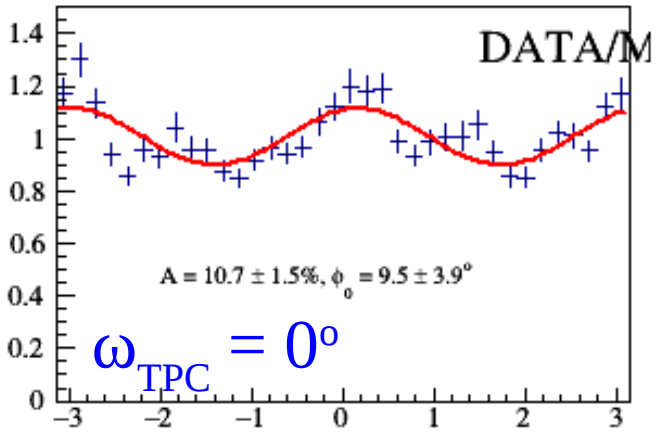


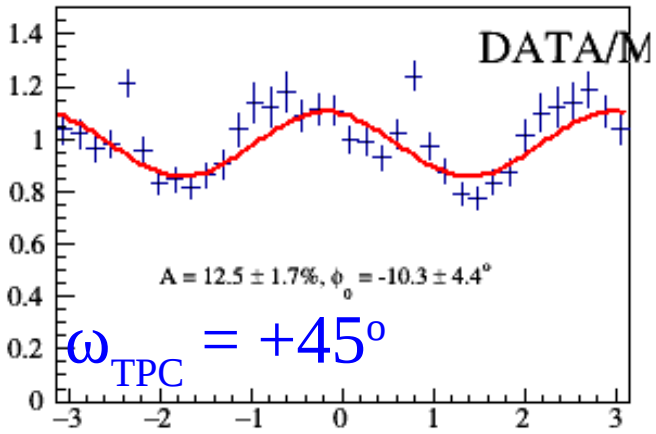
Polarisation: MC

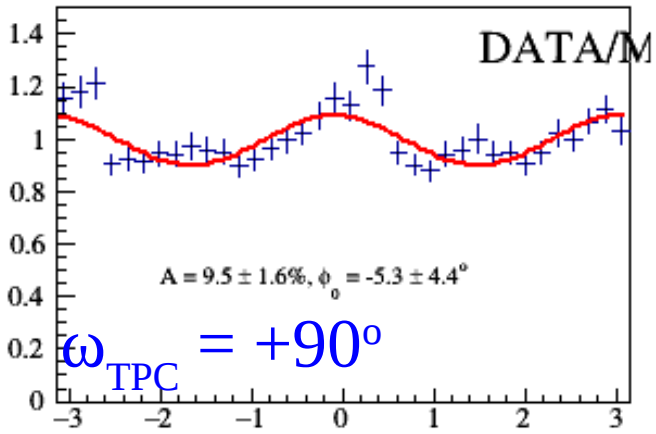


DATA/MC
4 TPC orientations







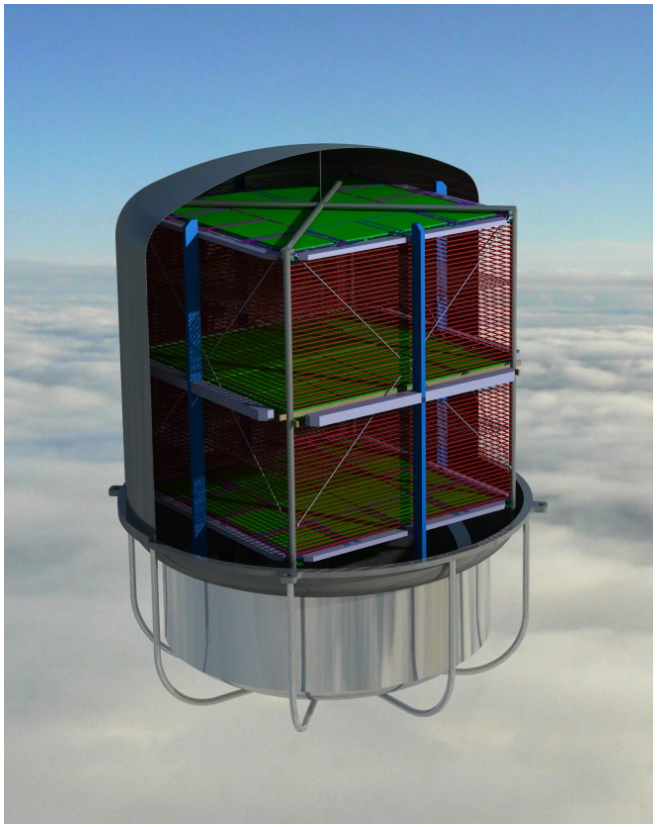


Very promising preliminary results:
systematic bias is well reproduced and corrected by the simulation

Perspective

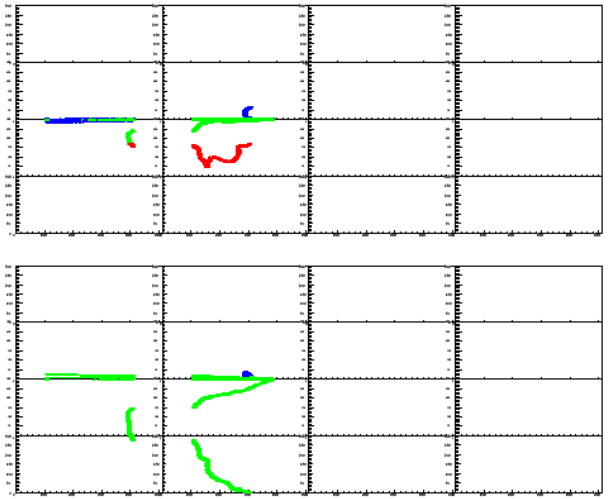
Balloon borne TPC: ST3G

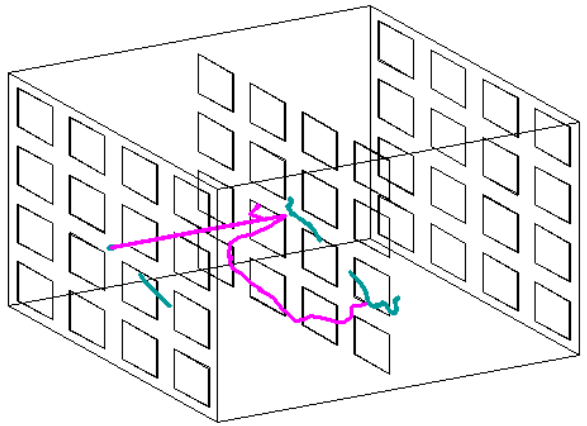
- Self Triggered Tpc Gamma-ray Telescope
- Validation of a trigger using TPC signal only
  - AGET/ASTRE self-trigger readout
- Stratospheric balloon
- 4x4x4=64xHARPO = $(1.2m)^3$

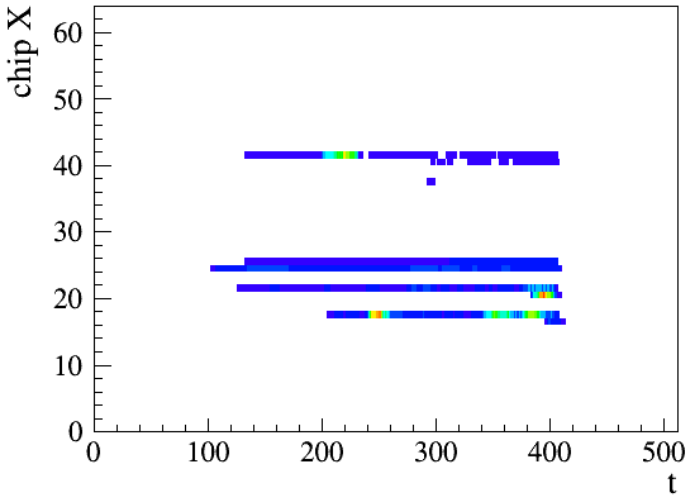


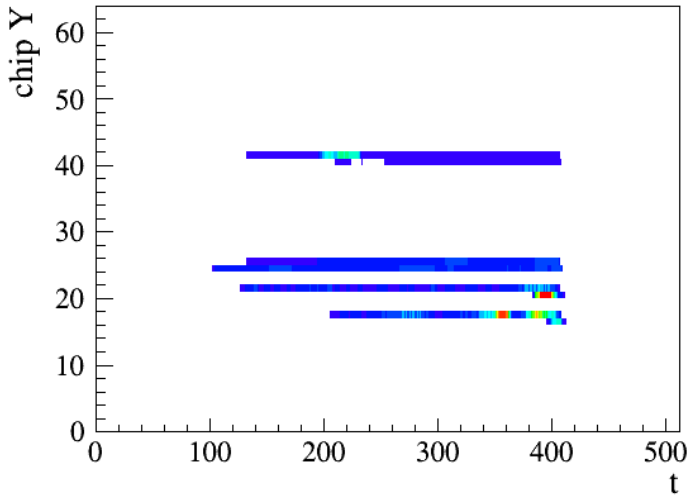
- Submission next year
  - concept defined
  - ongoing simulation study

Early simulation







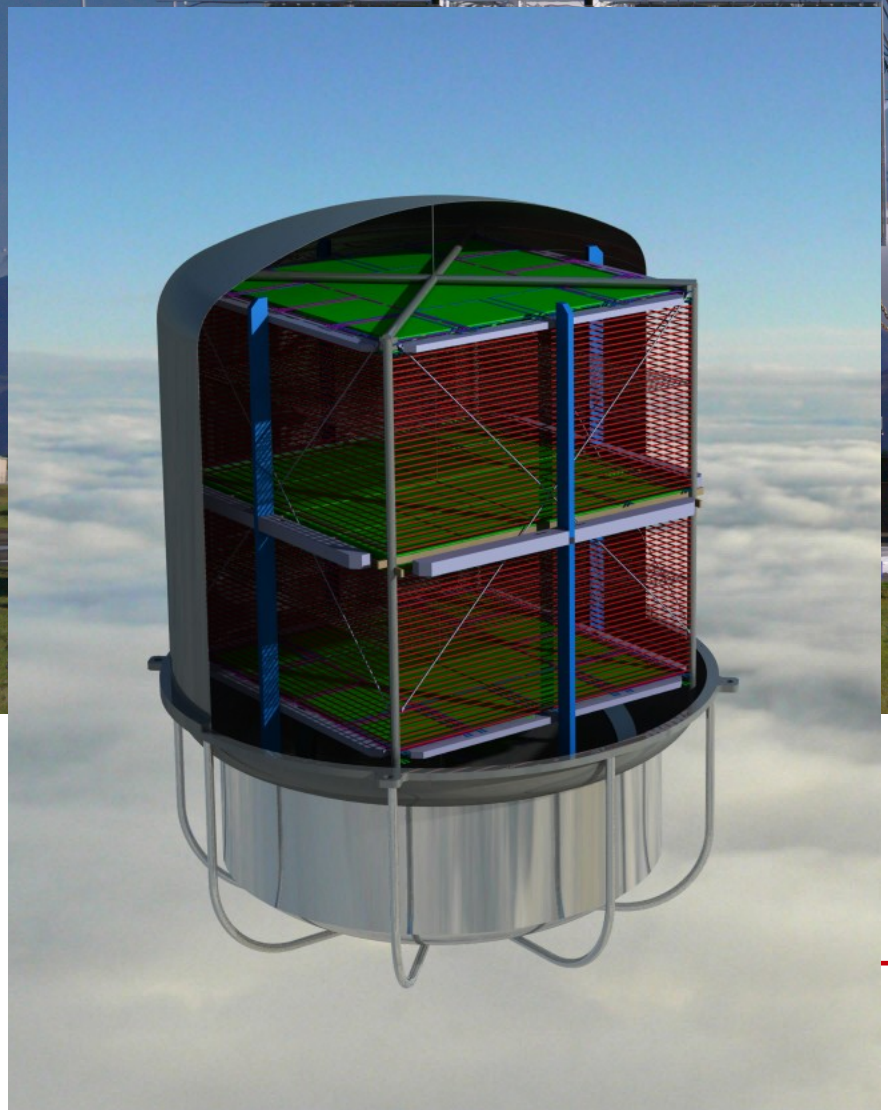


Conclusions

- A TPC is a good candidate for a **gamma-ray telescope and polarimeter in the 1-100MeV range**
- The HARPO demonstrator operated successfully in a gamma-ray beam
- **Excellent beam polarisation measurement**
- Detector can be well monitored with cosmic tracks
  - **long term as stability achieved** without HV, test on going with HV
- Good description with simulation for understanding and correcting the systematics
- Paves the way to future development for a **balloon borne experiment**

Acknowledgement, References

- The HARPO collaboration:
  - FRANCE: D. Attié, D. Baudin, D. Bernard, P. Bruel, D. Calvet, P. Colas, A. Delbart, M. Frotin, Y. Geerebaert, B. Giebels, D. Götz, P. Gros, D. Horan, M. Louzir, F. Magniette, P. Poilleux, I. Semeniouk, P. Sizun, S. Wang
  - JAPAN: S. Amano, S. Daté, T. Kotaka, S. Hashimoto, Y. Minamiyama, H. Ohkuma, A. Takemoto, M. Yamaguchi, S. Miyamoto
- References (http://llr.in2p3.fr/~dbernard/polar/harpo-t-p.html)
  - "Measurement of polarisation asymmetry for gamma rays between 1.7 to 74 MeV with the HARPO TPC", PG, et al., SPIE2016, arXiv:1606.09417
  - "ELECTRONICS FOR HARPO, Design, development and validation of electronics for a high performance polarized gamma-ray detector", Y. Geerebaert, et al., RT2016, 20th Real Time Conference
  - "Circulation and purification of gas in the sealed HARPO TPC", M. Frotin, PG et al. arXiv:1512.03248



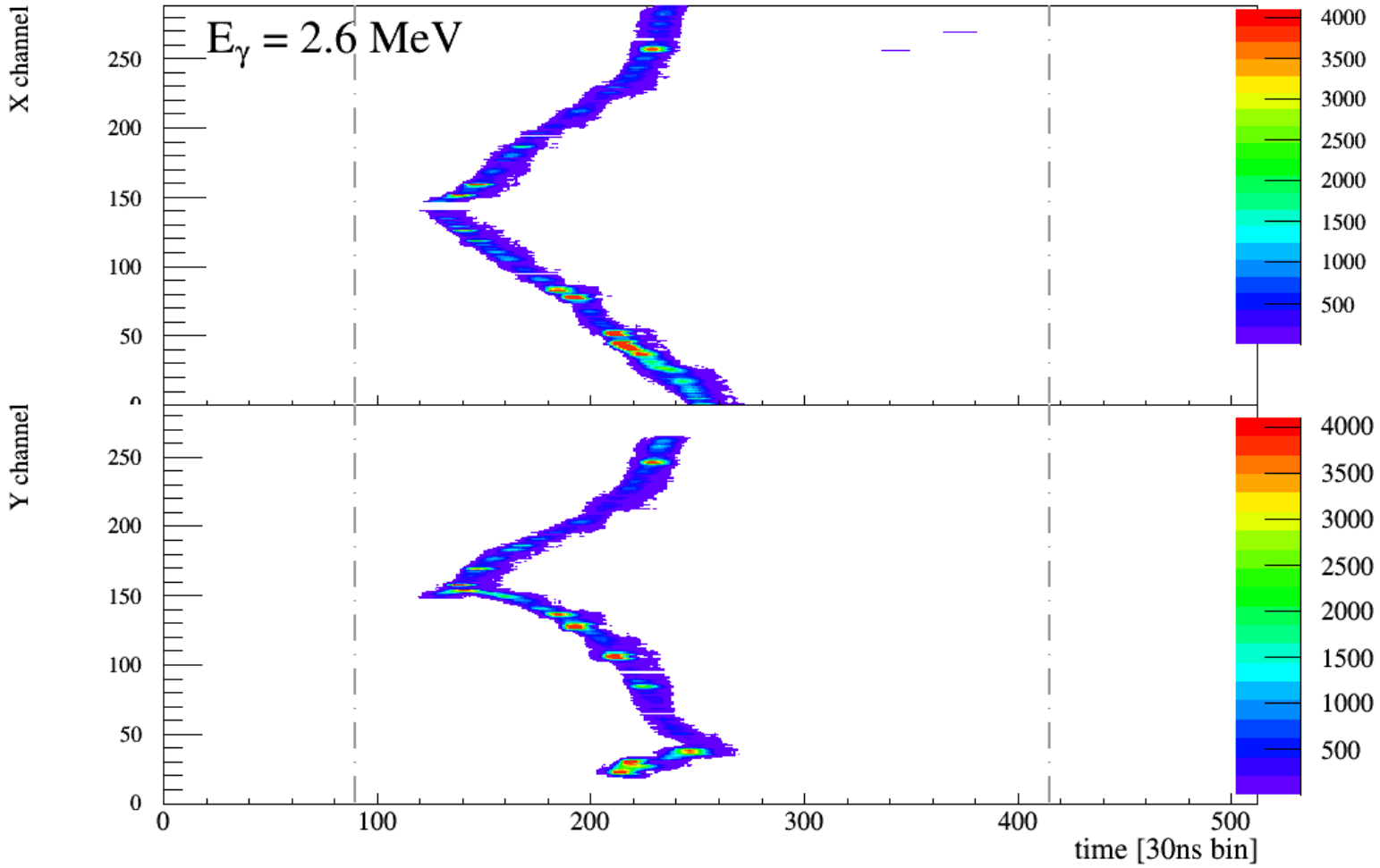
Dreams for the future

Backup

Examples of events

13 Energy points, 1.74 to 74 MeV

- *Experimental setup presented at TeVPA 2015 in Kashiwa*



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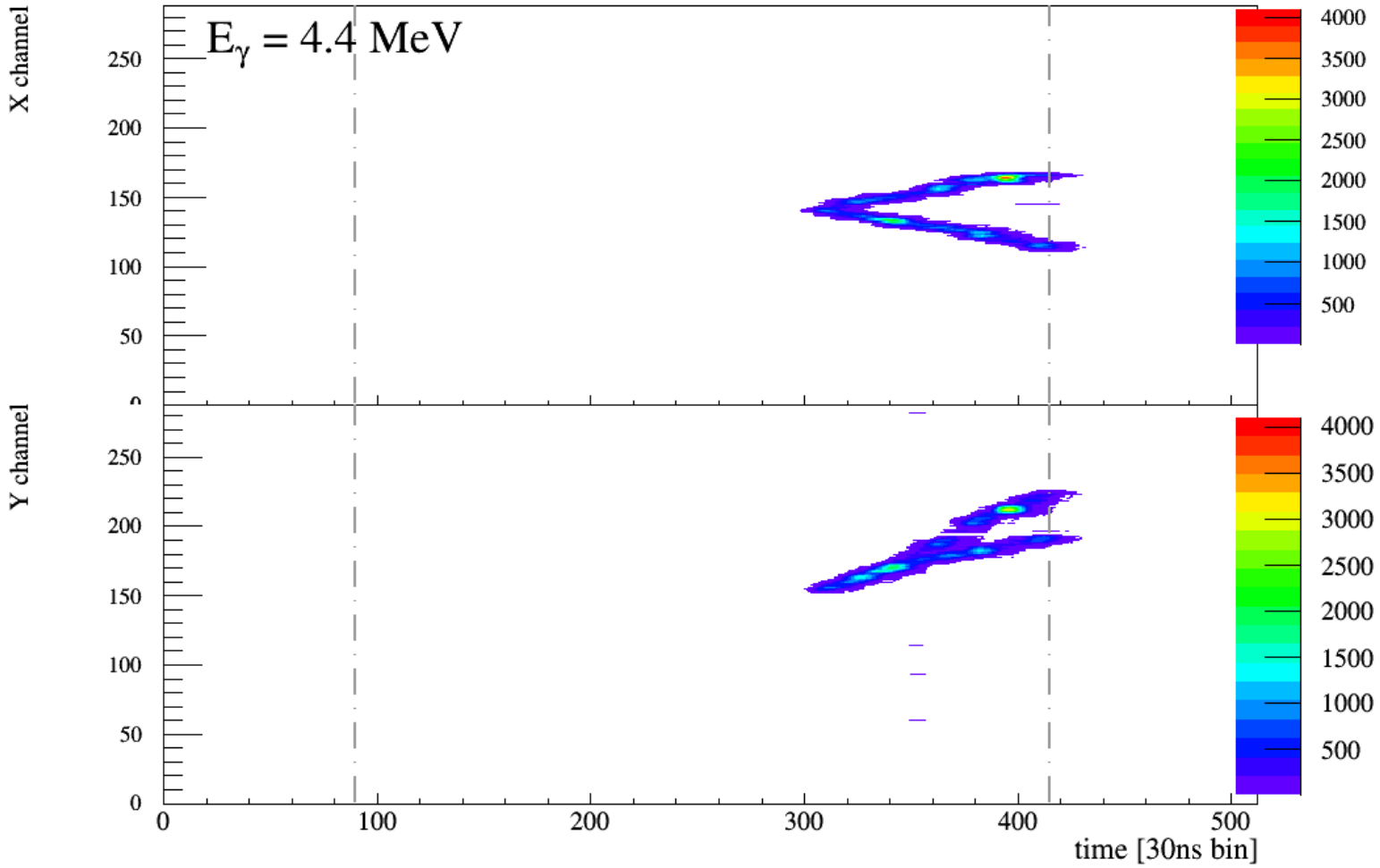

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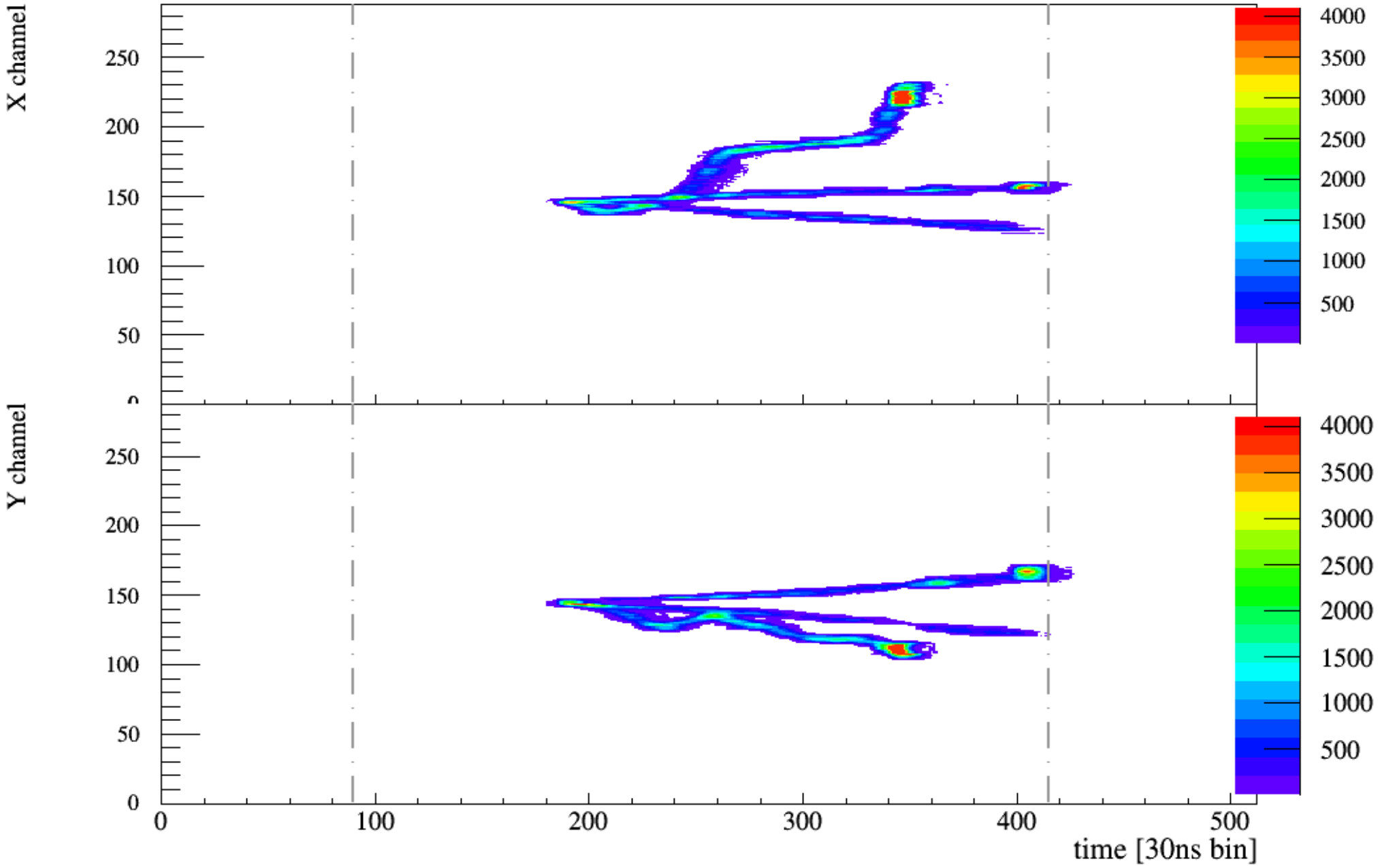

Examples of events

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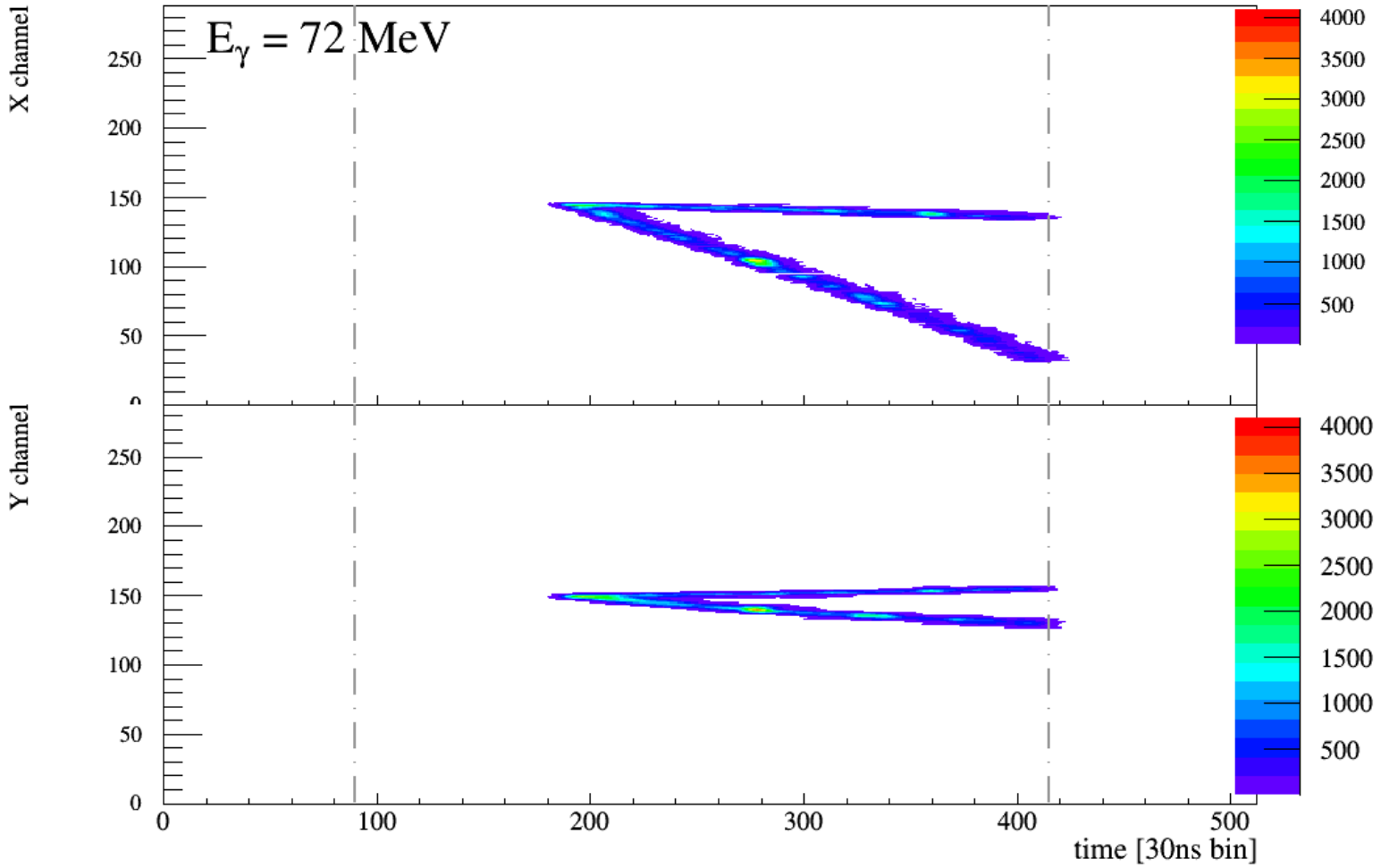
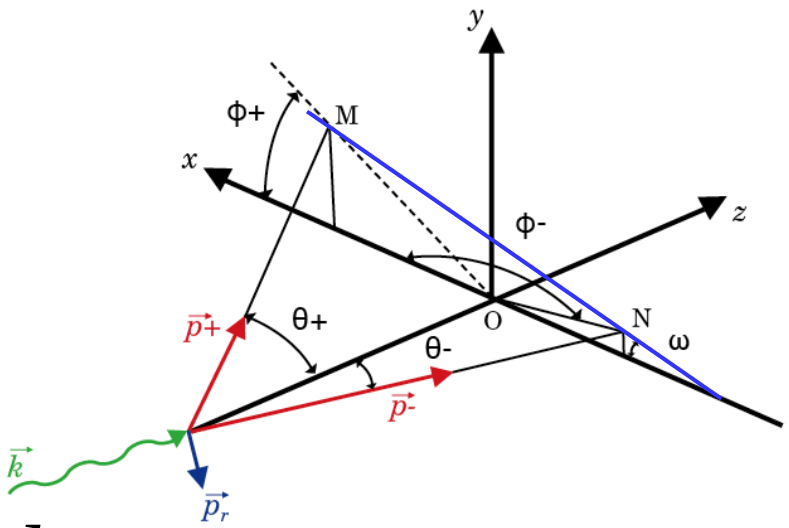


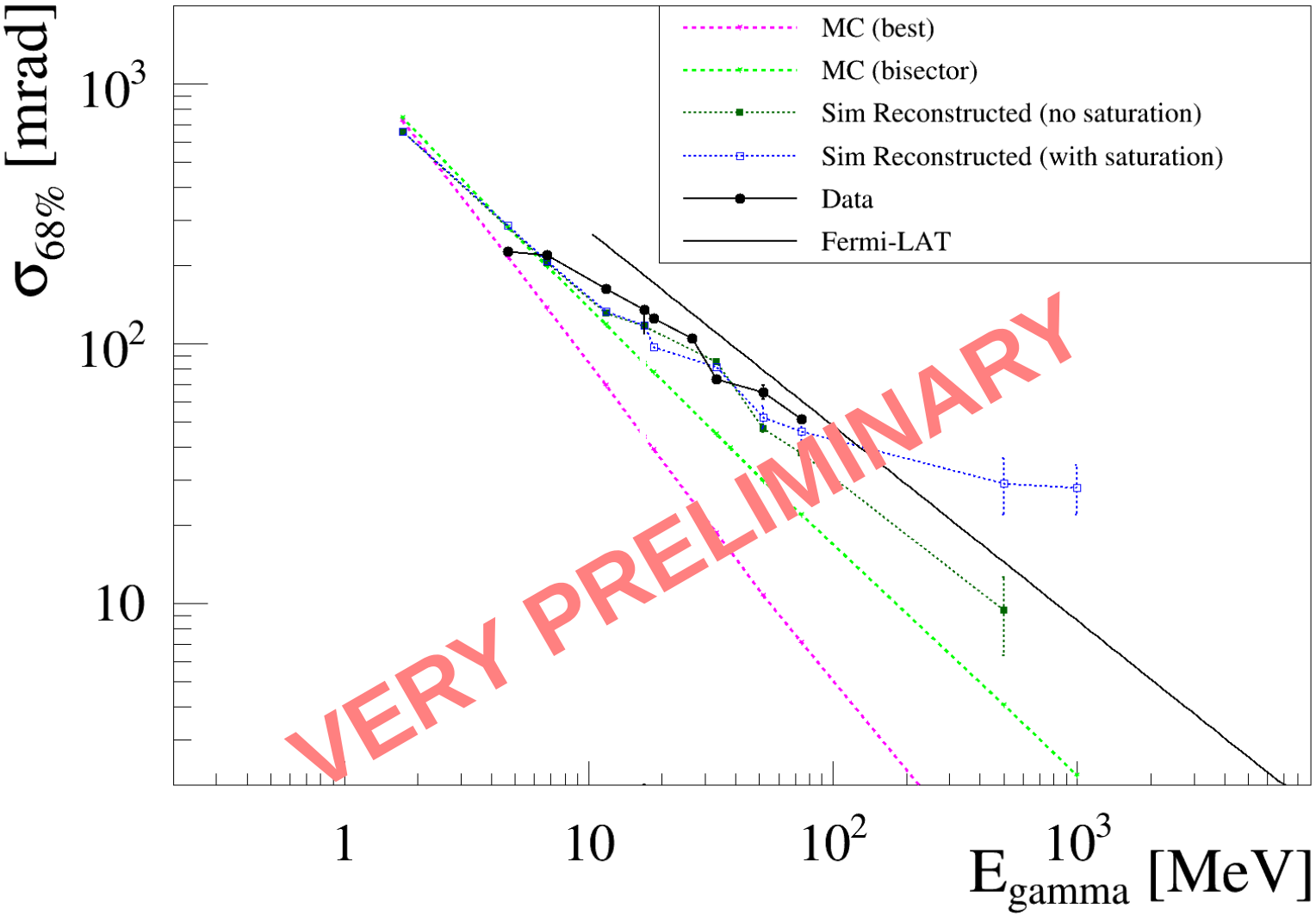
Polarisation

- Modulation of the azimuthal angle ω

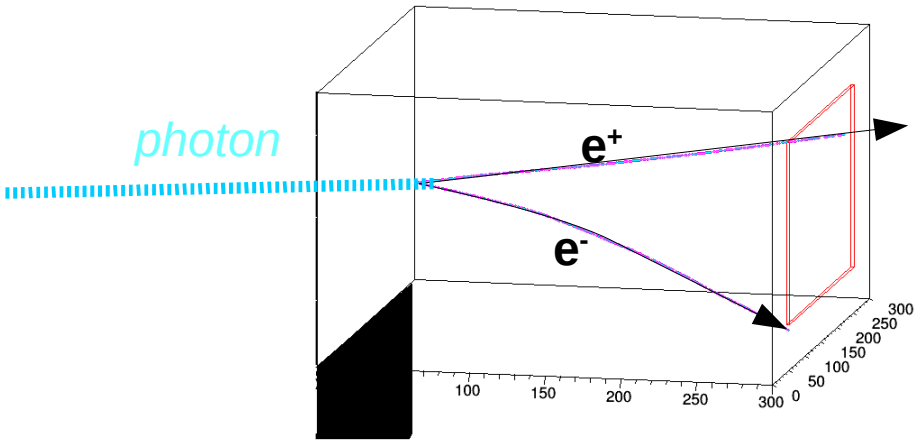


$$\frac{d\Gamma}{d\omega} \propto 1 + A\cos\left(2\left(\omega - \omega_0\right)\right)$$

Angular resolution



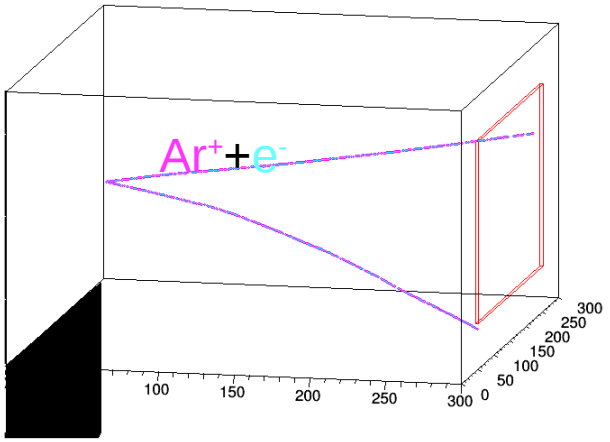
TPC: photon conversion



The incoming photon interacts with the gas and decays into an electron-positron pair

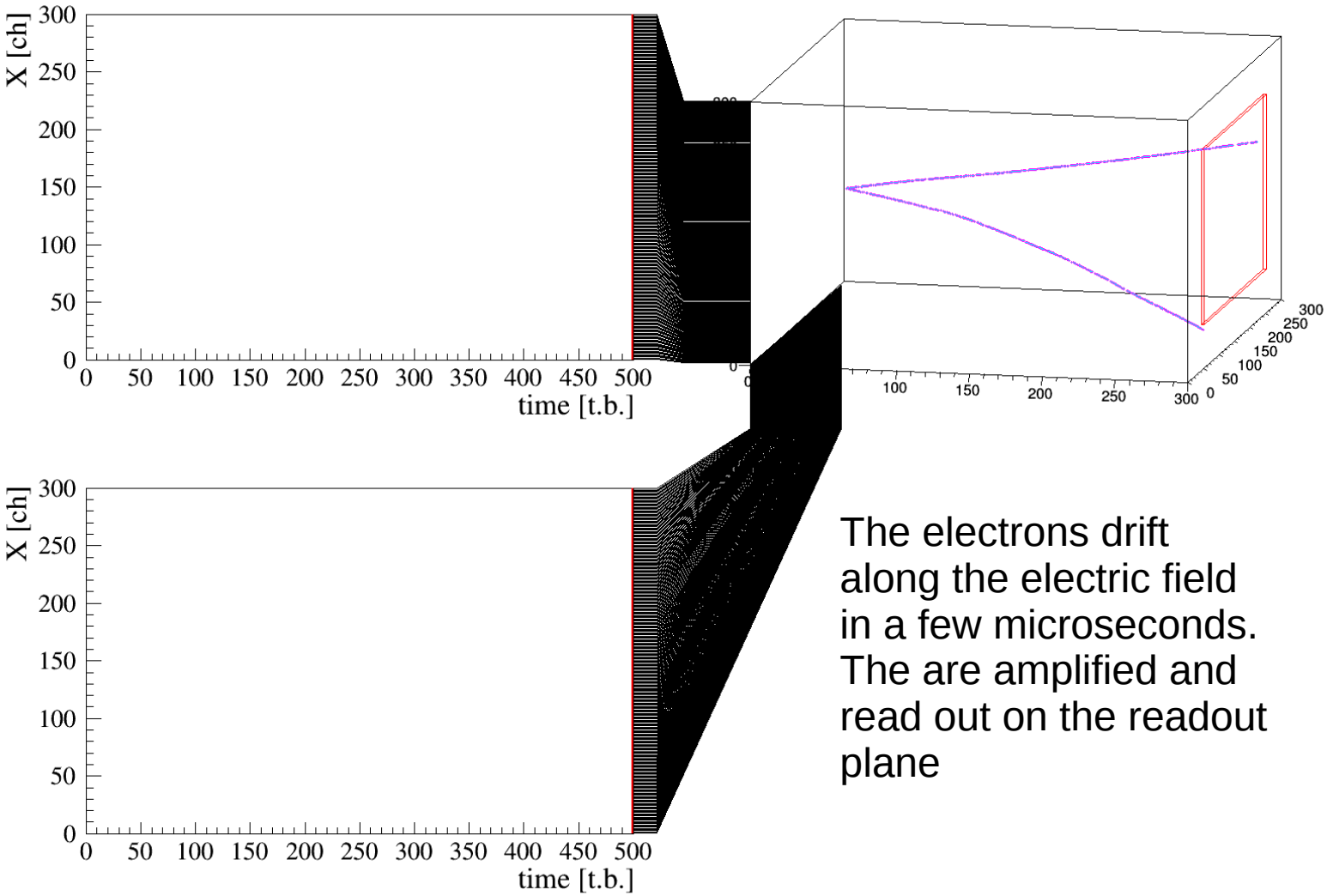
$$\gamma Z^{+} \rightarrow e^{+} e^{-} Z^{+}$$

TPC: Gas ionisation



The electron and positron travel through the gas (mostly Argon) and ionises it, freeing many electrons and positive ions
This takes a few nanoseconds

TPC: Drift and Readout

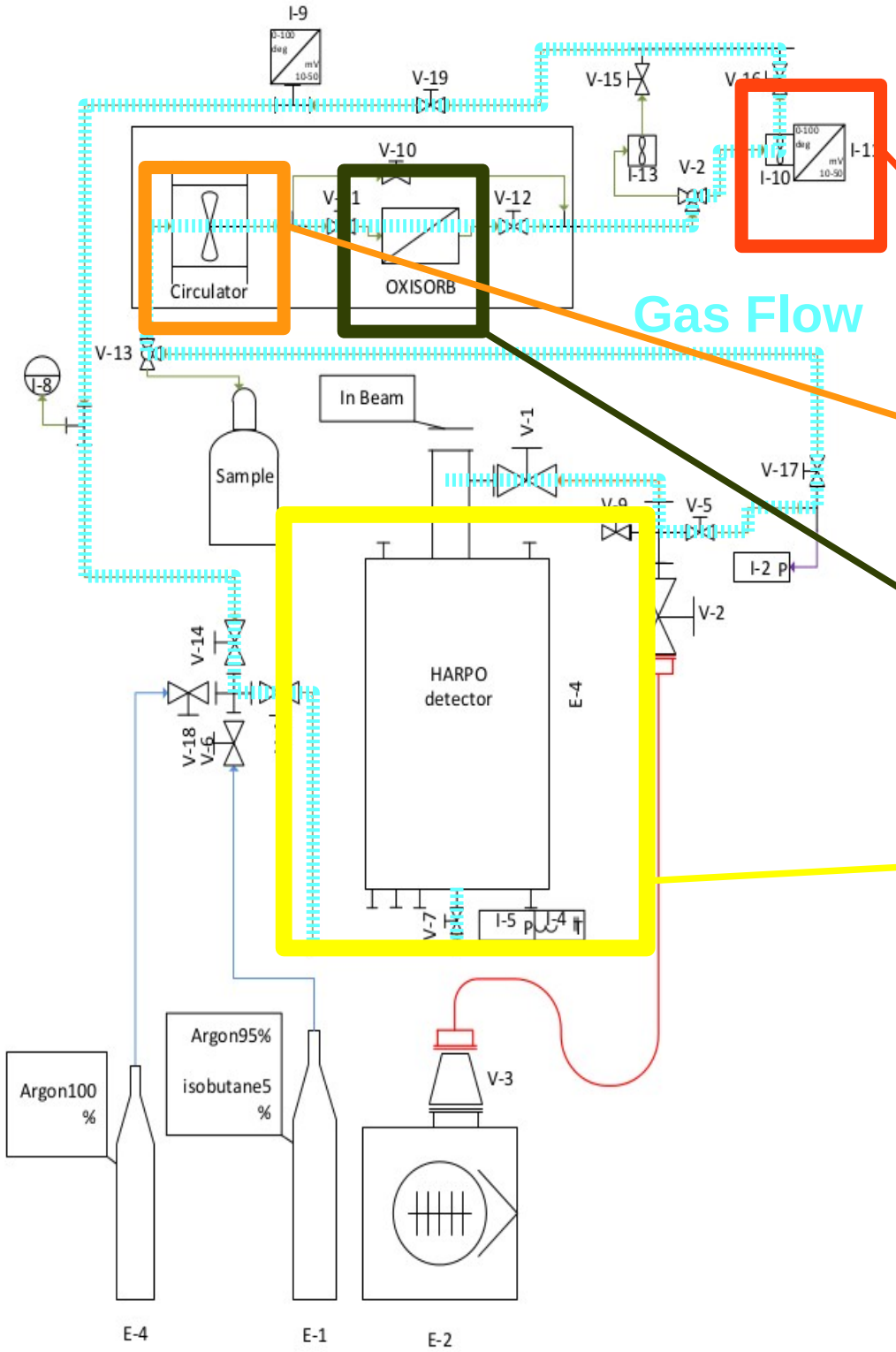


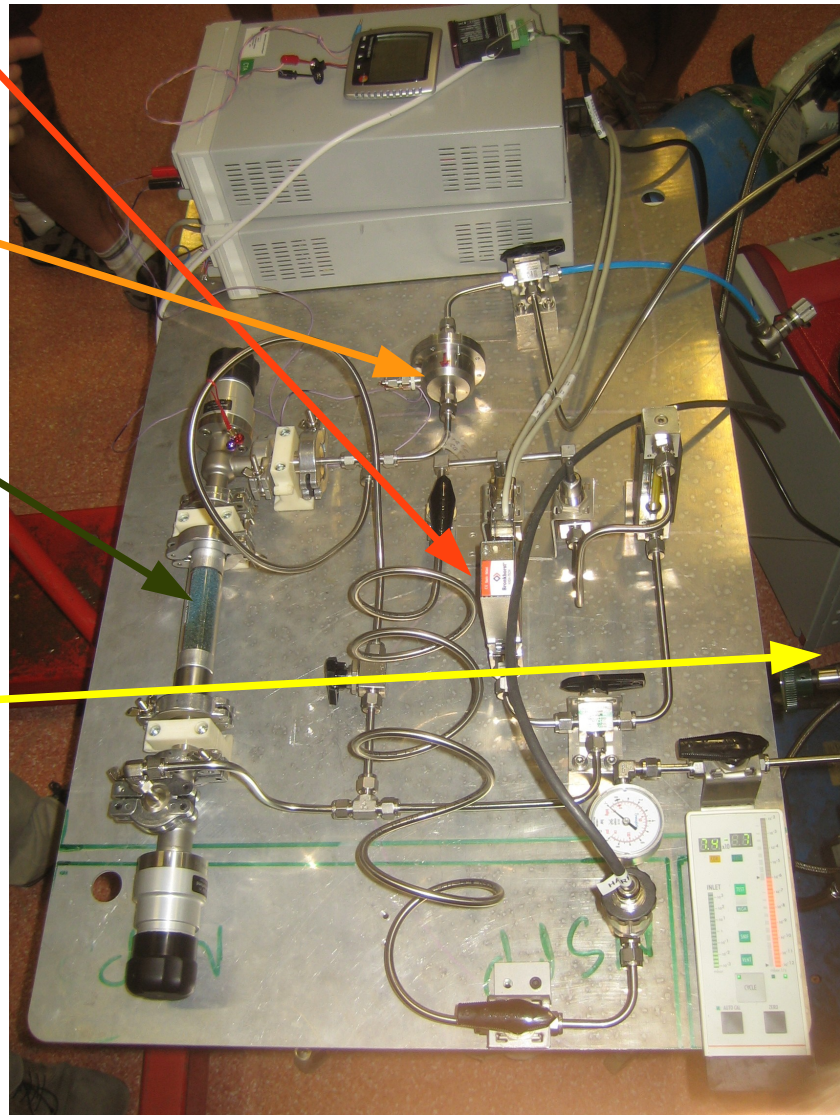
The electrons drift along the electric field in a few microseconds. The are amplified and read out on the readout plane

Angular resolution

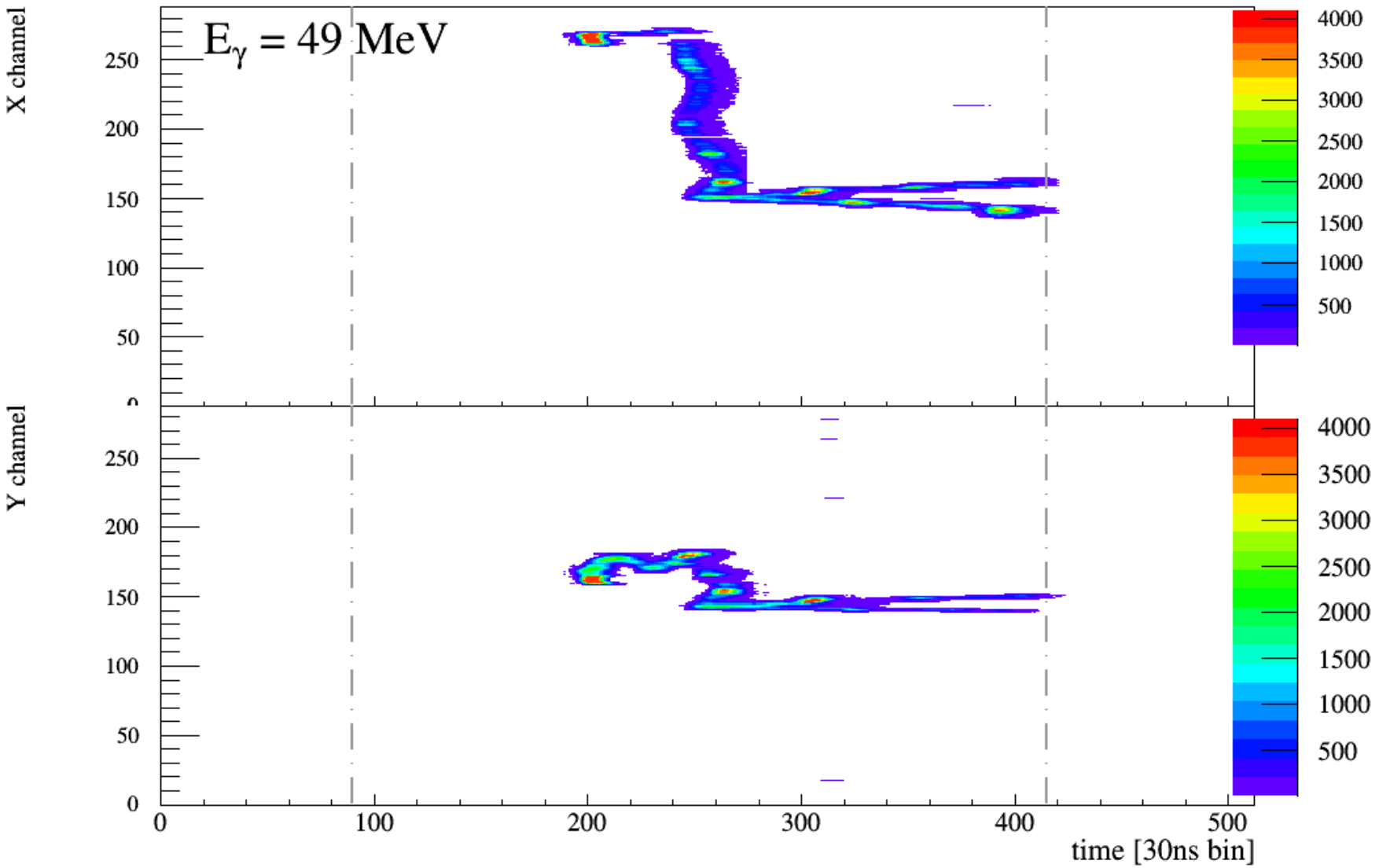
- Agreement with theoretical prediction
  - relatively small contribution of tracking
- Excellent agreement with simulation
  - effect of saturation dominates at high energy

- Potential for improvement
  - estimation of track momentum
  - even 100% resolution should significantly improve

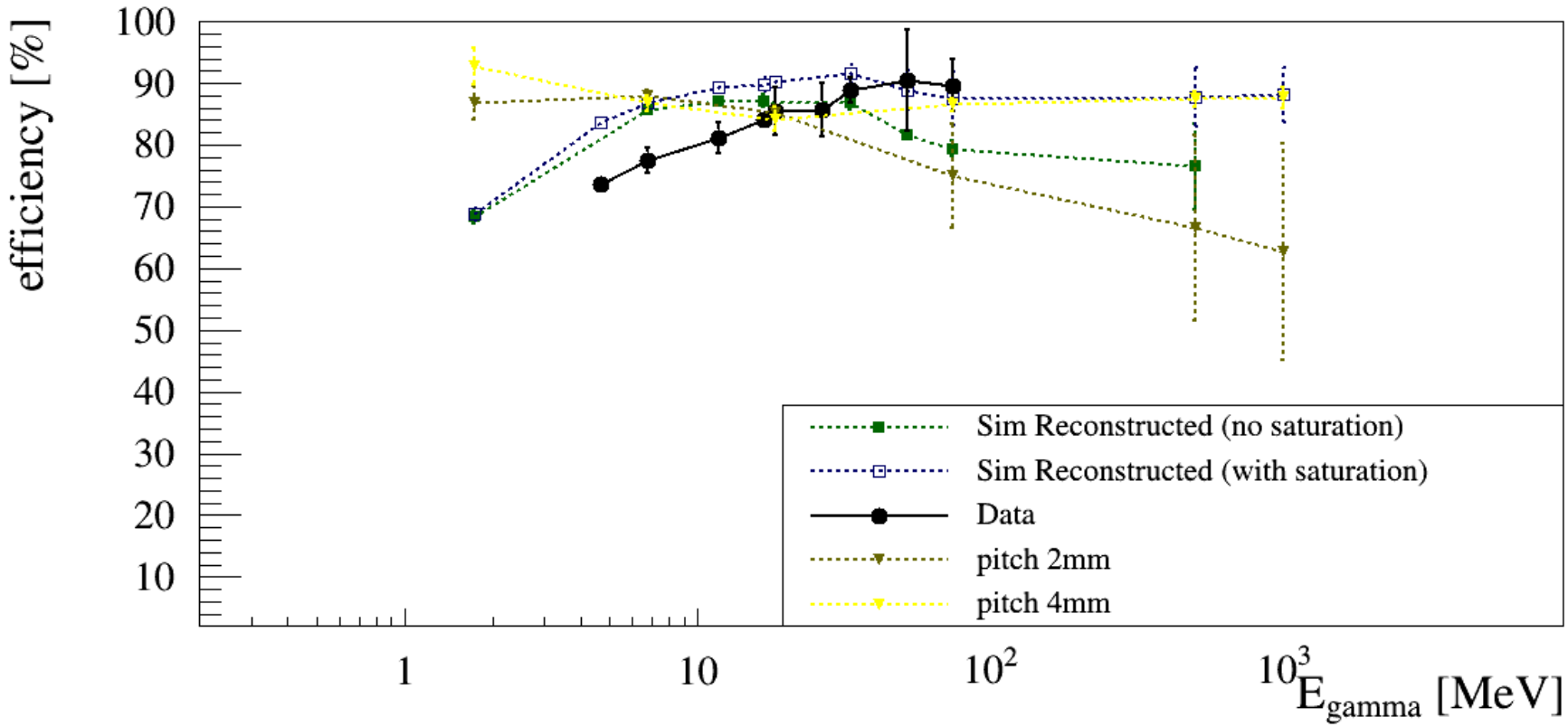

I-9
V-19
V-15
V-10
V-11
V-12
I-13
V-2
I-10
Circulator
OXISORB
Gas Flow
V-13
I-8
In Beam
V-1
Sample
V-17
V-9
V-5
I-2 p
V-2
V-14
V-18
V-6
HARPO
detector
E-4
V-7
I-5 p
I-4 T
Argon100
%
Argon95%
isobutane5
%
V-3
E-4
E-1
E-2



Triplet event



Efficiency


efficiency [%]
100
90
80
70
60
50
40
30
20
10
1
10
10^2
10^3
E_{gamma} [MeV]
Sim Reconstructed (no saturation)
Sim Reconstructed (with saturation)
Data
pitch 2mm
pitch 4mm

Polarisation asymmetry