



# Gamma-ray polarimetry in the $e^+e^-$ pair regime with the HARPO TPC

*Philippe Gros*  
LLR, Ecole Polytechnique & CNRS/IN2P3, France  
for the HARPO collaboration

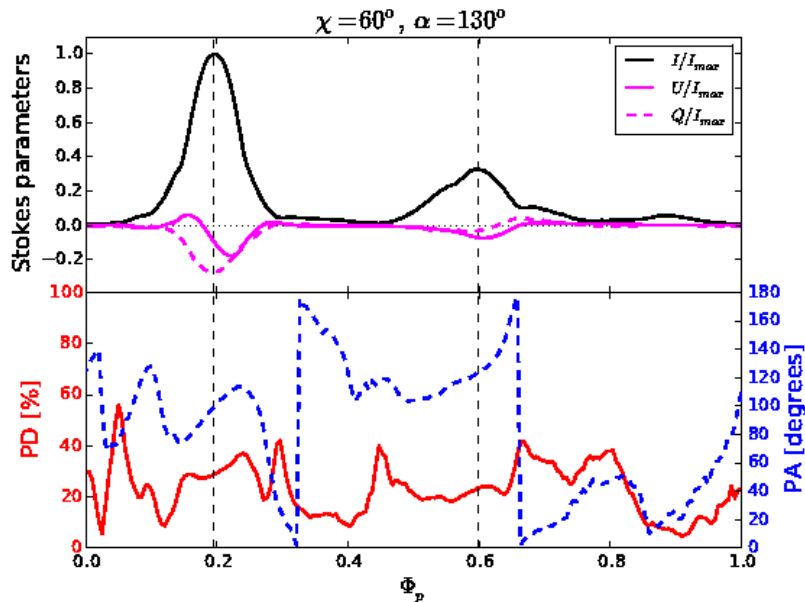
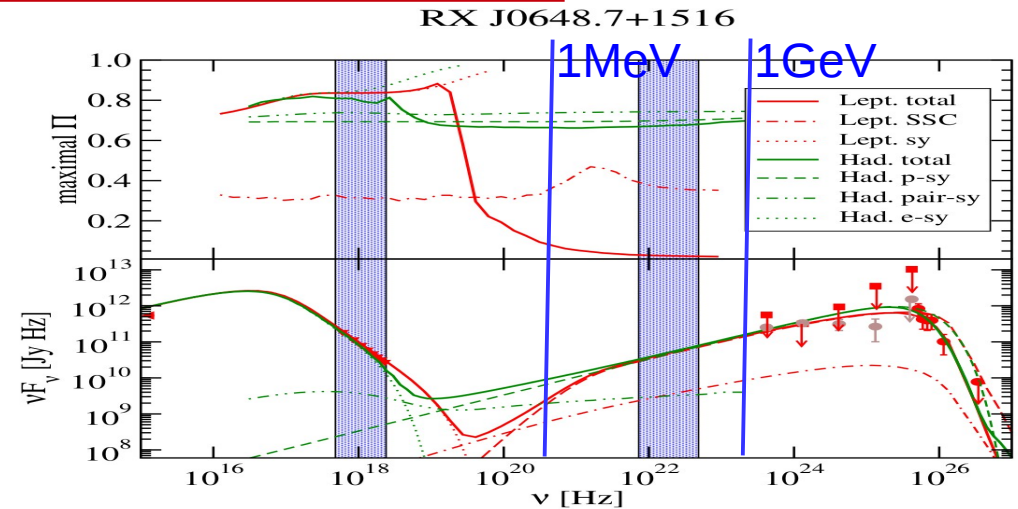
**TeV Particle Astrophysics (TeVPA2016), CERN,  
12 September 2016**



- Motivation for a MeV-GeV high performance telescope and polarimeter
- Working principles of the HARPO detector
- Polarisation measurement in a gamma ray beam
- Gas stability
- Conclusions and Perspectives

- Separating leptonic and hadronic processes
- Difference only  $> 1\text{MeV}$

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

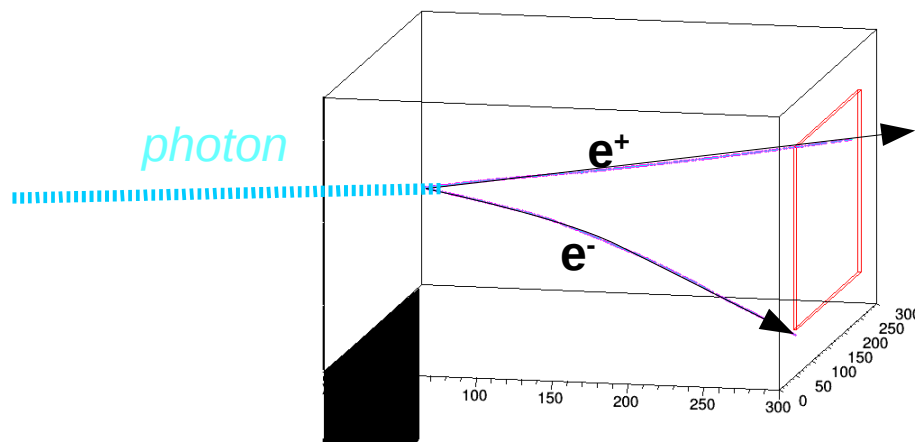


- More sensitive to EM geometry and location of emission

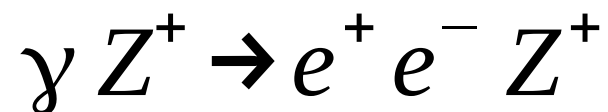
- Predicted by PIC models

**B. Cerutti et al.,**  
**arXiv:1609.00021 (2016)**

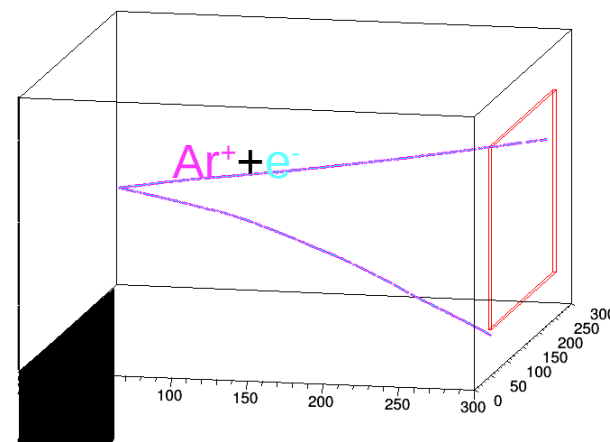
# TPC: photon conversion



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

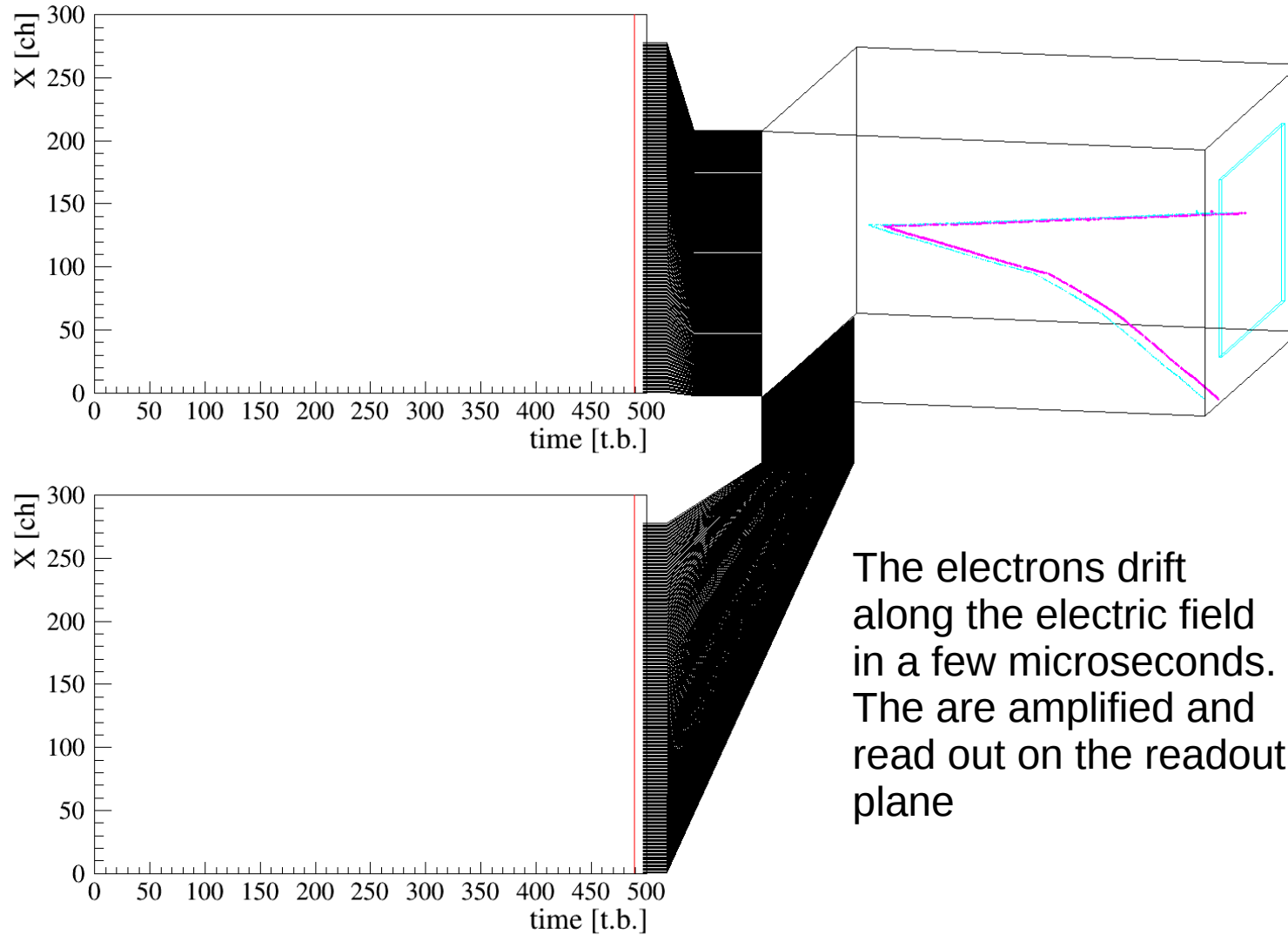


# TPC: Gas ionisation



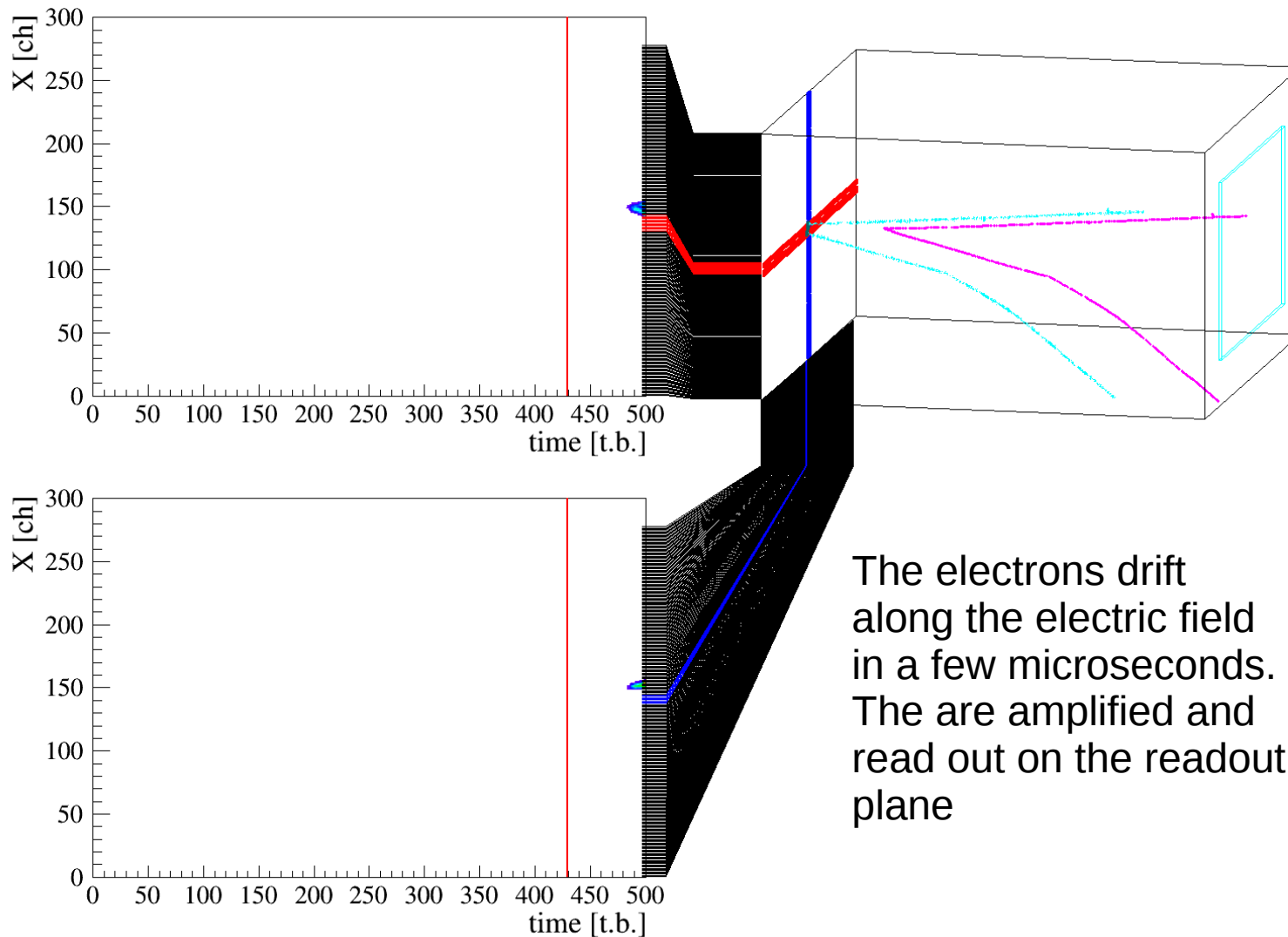
The electron and positron travel through the gas (mostly Argon) and ionises it, freeing many electrons and positive ions  
This takes a few nanoseconds

# TPC: Drift and Readout



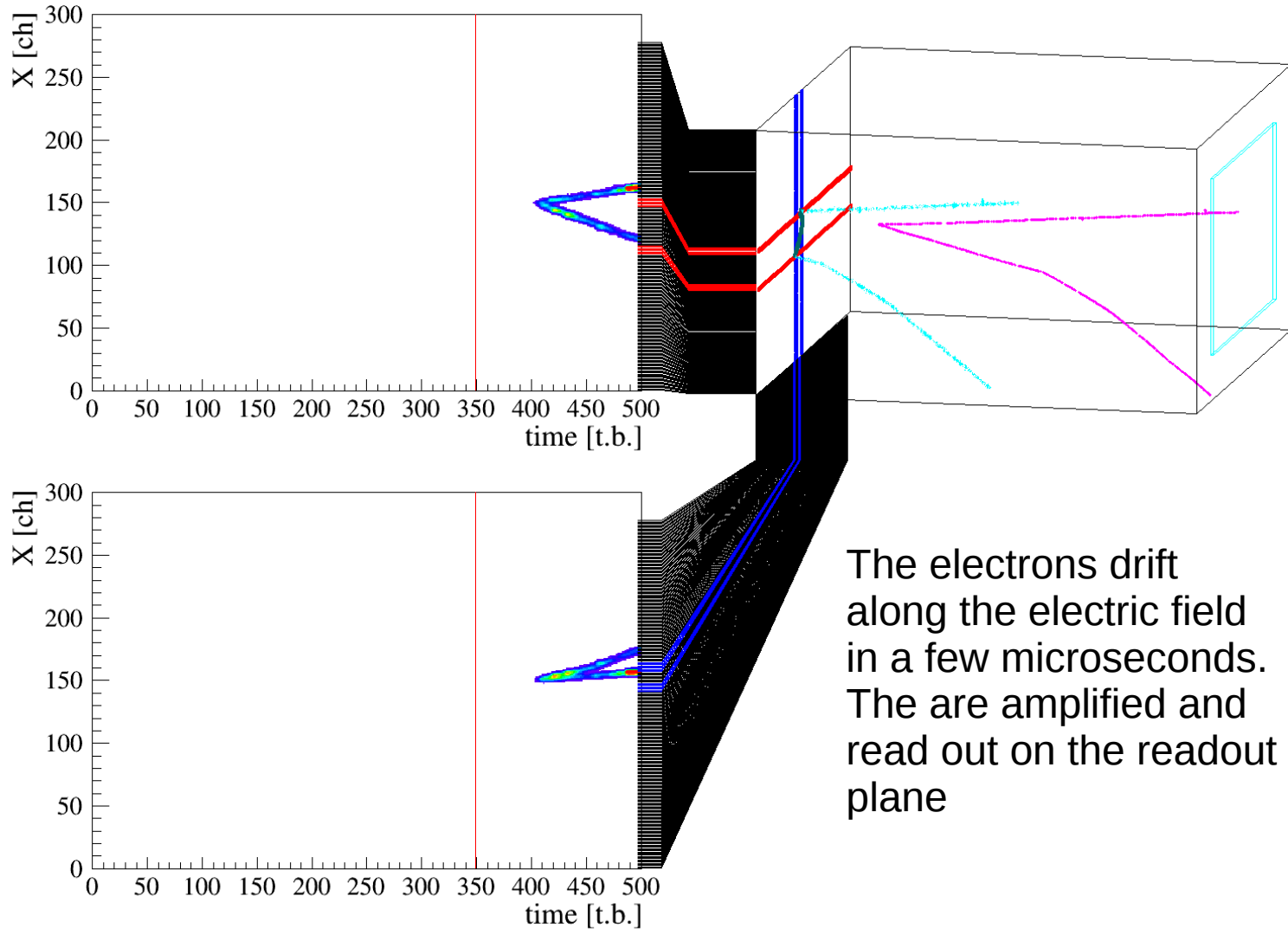
The electrons drift along the electric field in a few microseconds. They are amplified and read out on the readout plane

# TPC: Drift and Readout



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

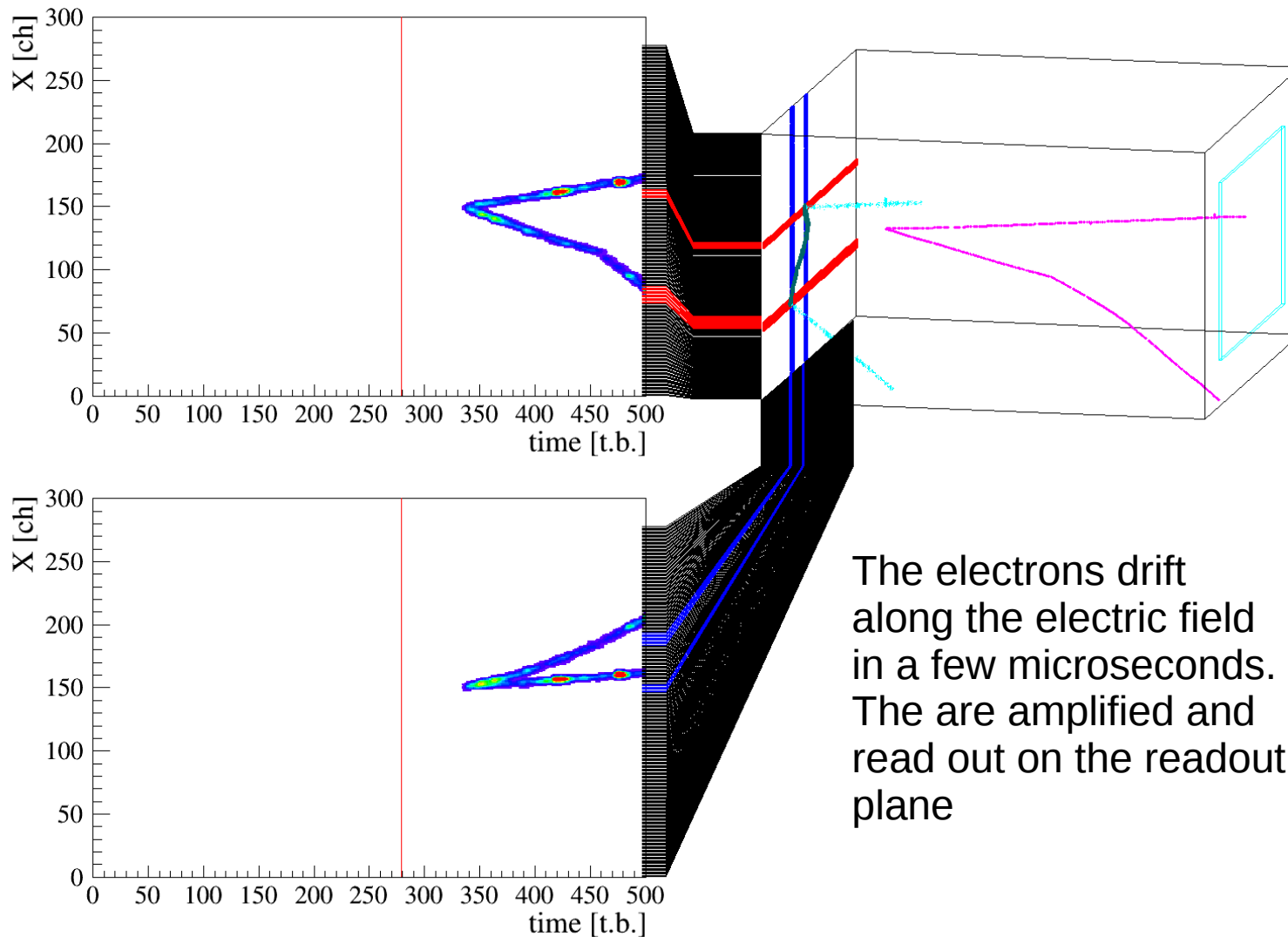
# TPC: Drift and Readout



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

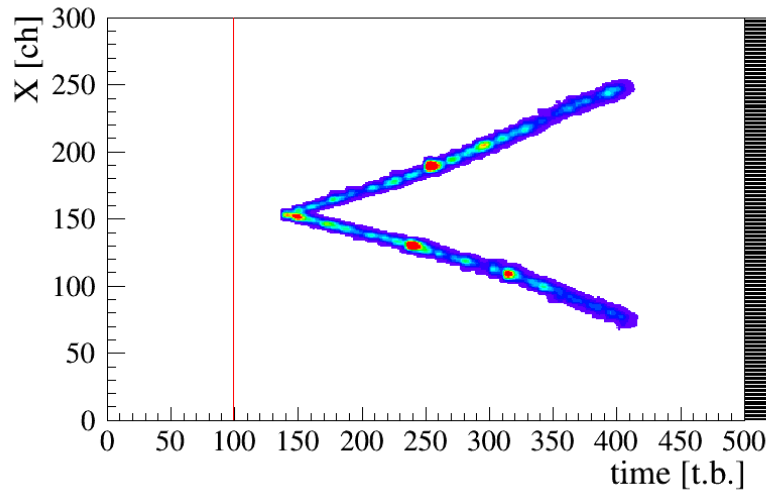
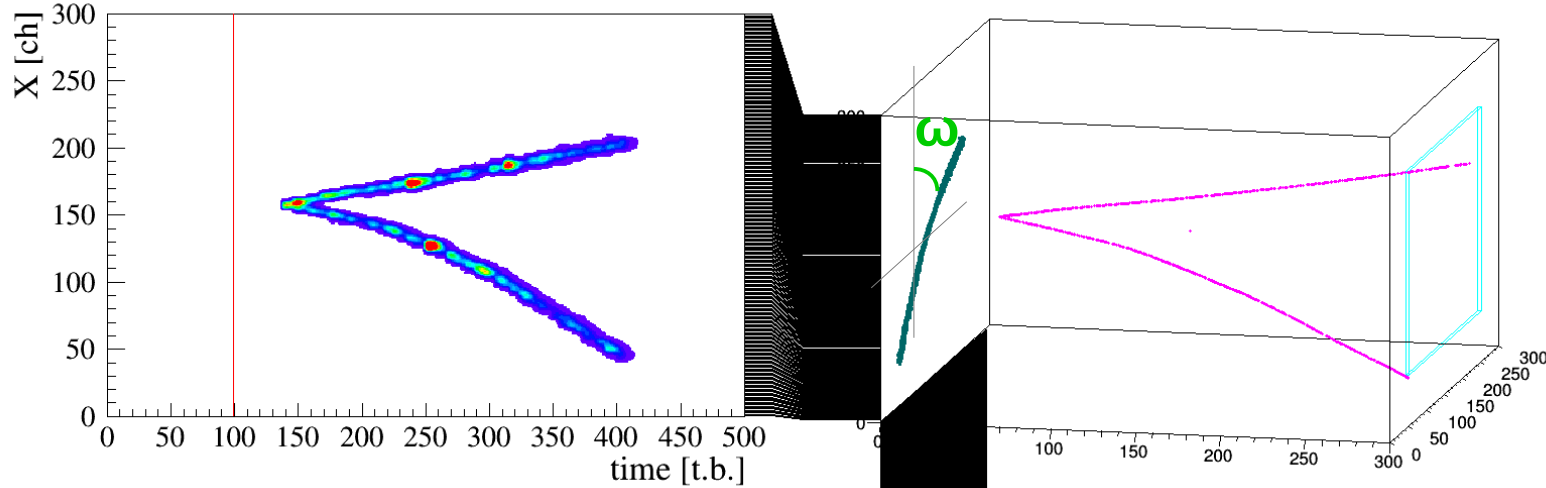


# TPC: Drift and Readout



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

# Polarisation measurement



The azimuthal angle  $\omega$  is related to the polarisation direction  $\omega_0$

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

$A$ : polarisation asymmetry

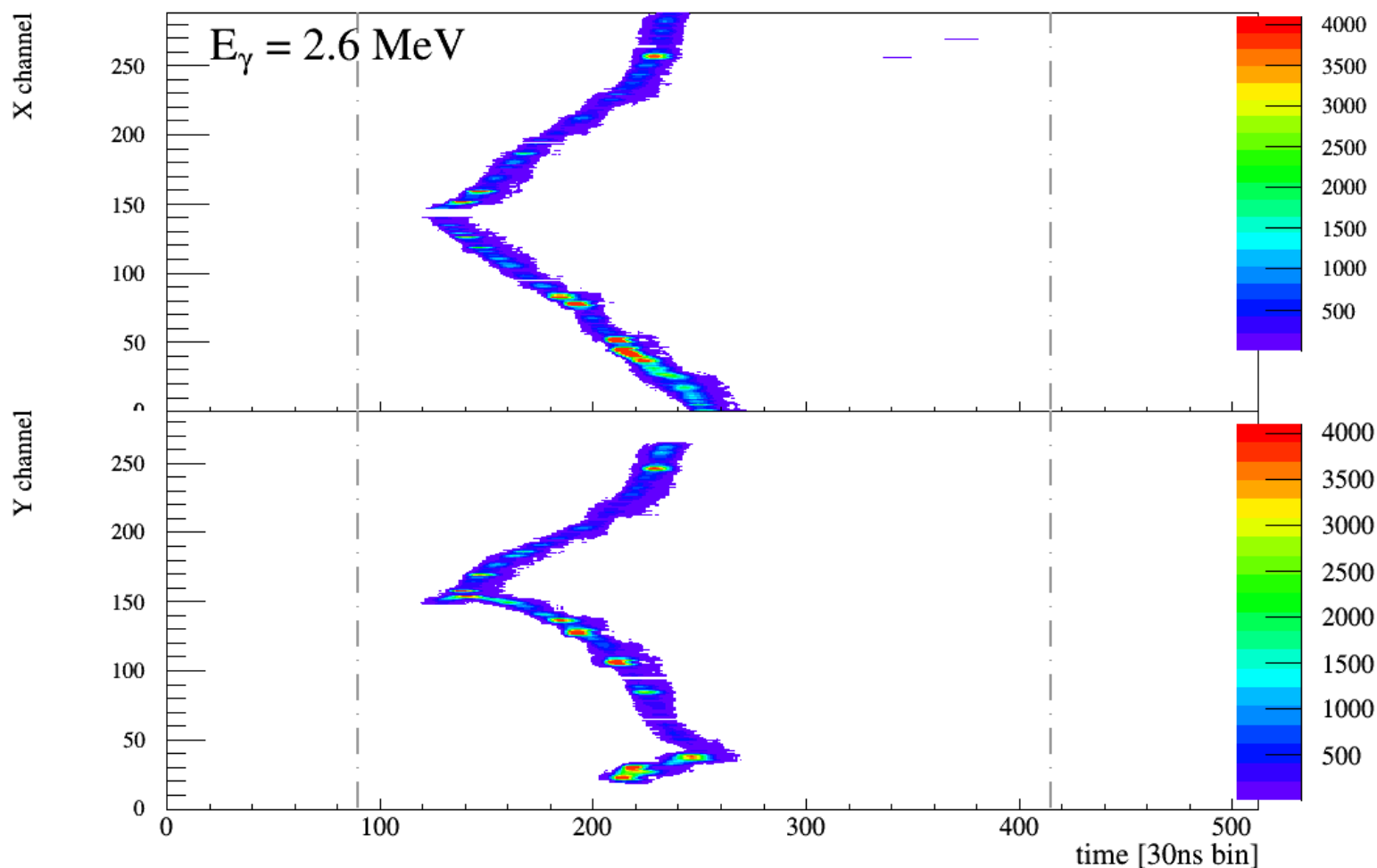
$P$ : polarisation fraction

# Examples of events

13 Energy points, 1.74 to 74 MeV



- *Experimental setup presented at TeVPA 2015 in Kashiwa*



Polarimetry in the pair regime with HARPO

Philippe Gros, LLR, CNRS/IN2P3, France

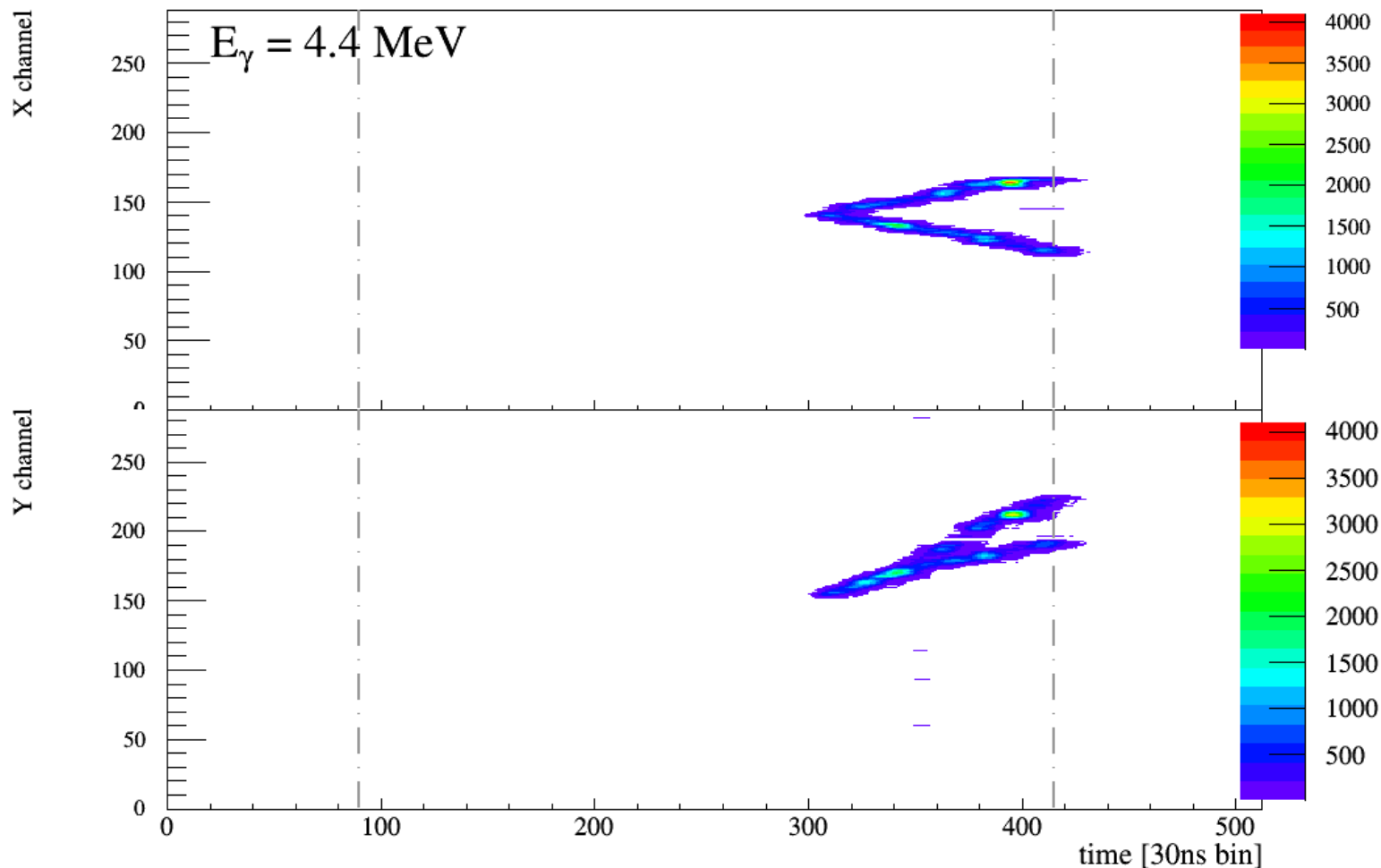
TeVPA2016, CERN

# Examples of events

13 Energy points, 1.74 to 74 MeV



- *Experimental setup presented at TeVPA 2015 in Kashiwa*

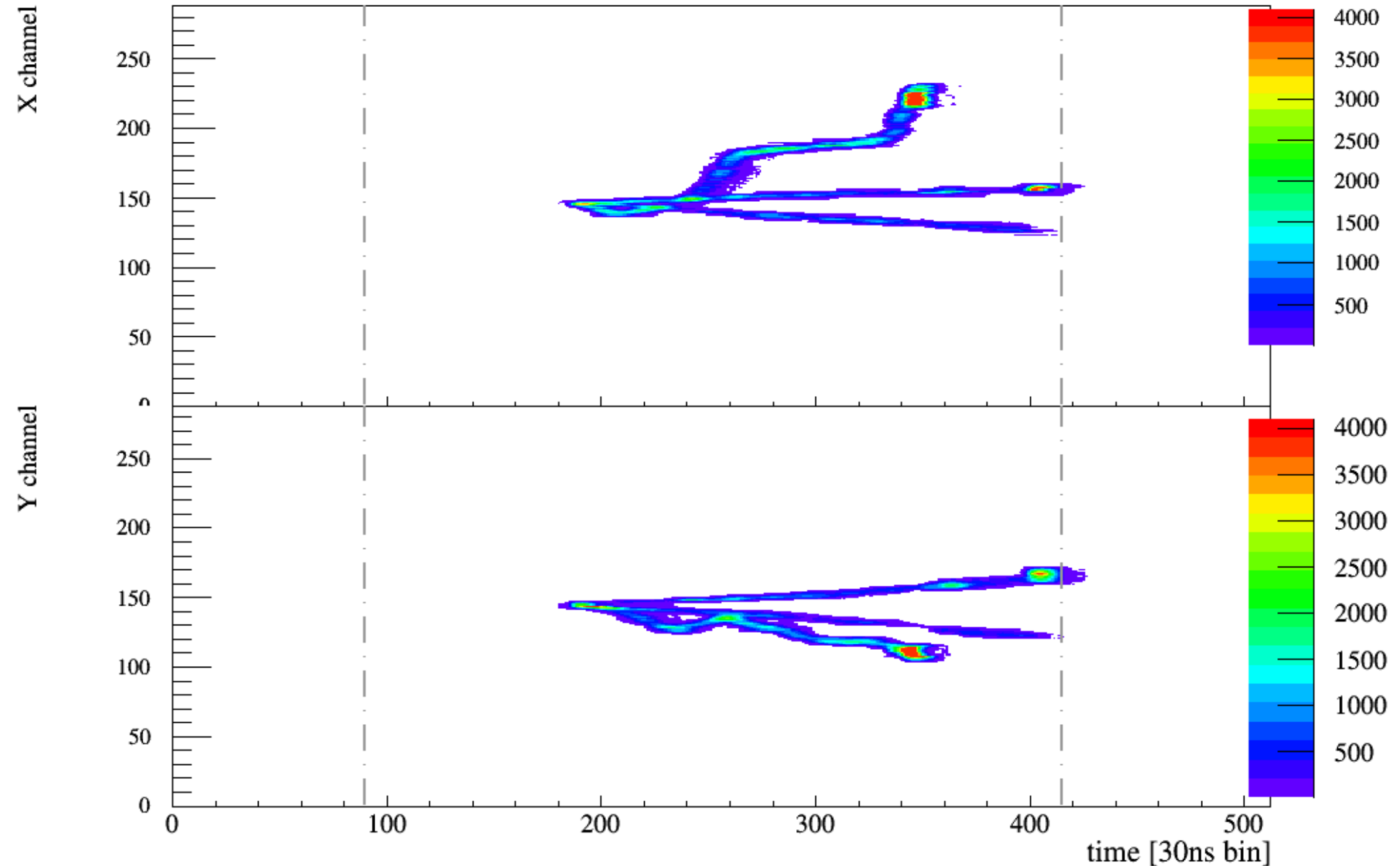


Polarimetry in the pair regime with HARPO

Philippe Gros, LLR, CNRS/IN2P3, France

TeVPA2016, CERN

# Examples of events



Polarimetry in the pair regime with HARPO

*Philippe Gros, LLR, CNRS/IN2P3, France*

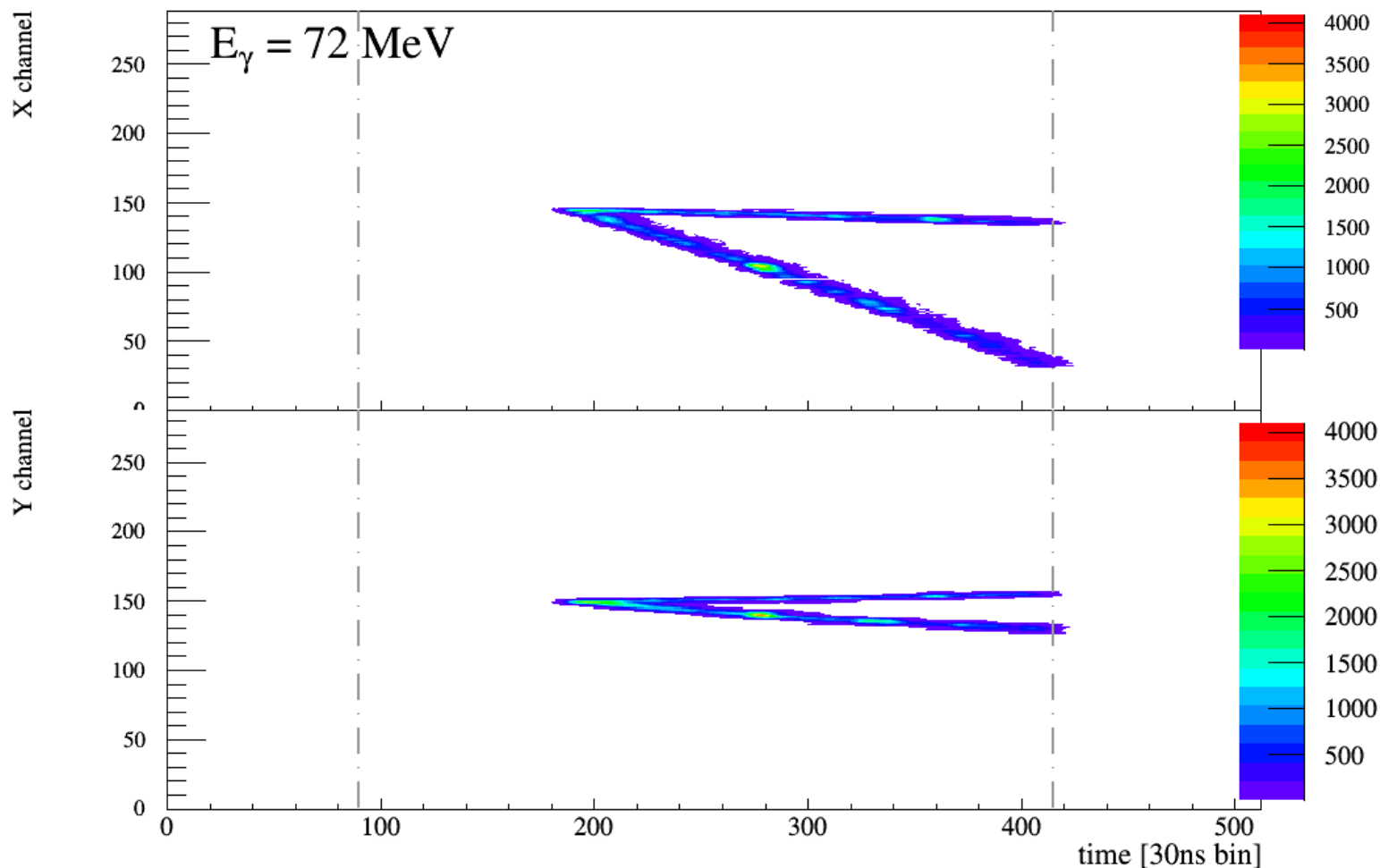
TeVPA2016, CERN

# Examples of events



13 Energy points, 1.74 to 74 MeV

- *Experimental setup presented at TeVPA 2015 in Kashiwa*



Polarimetry in the pair regime with HARPO

Philippe Gros, LLR, CNRS/IN2P3, France

TeVPA2016, CERN

# Reconstruction

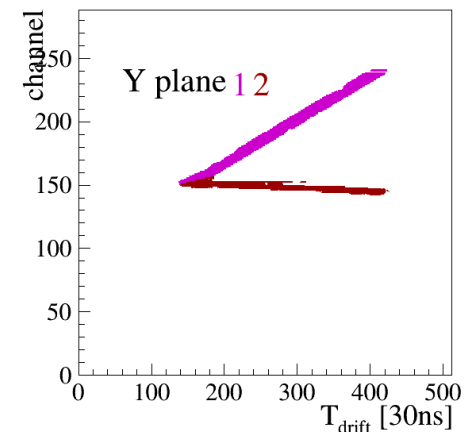
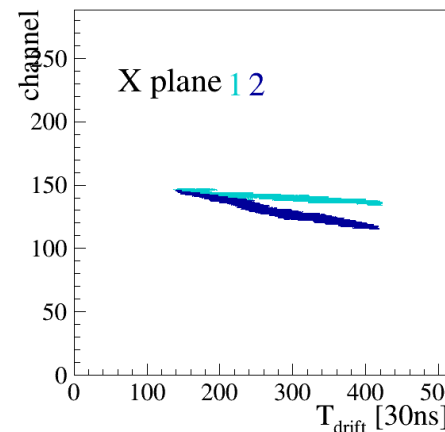
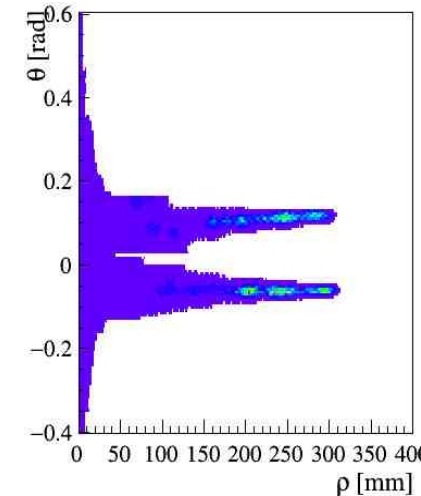
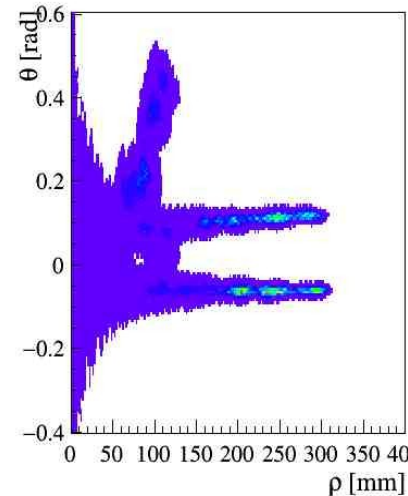
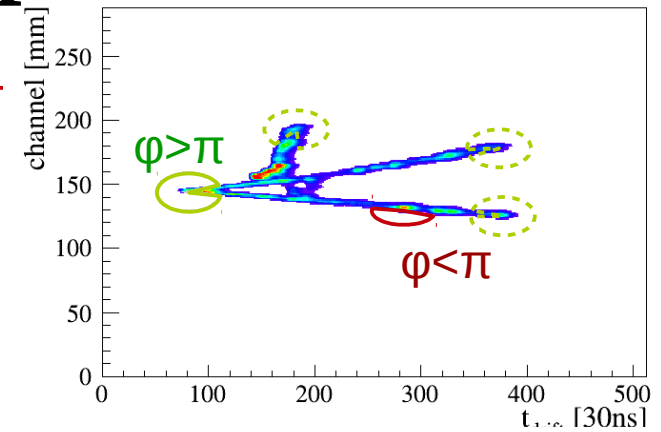


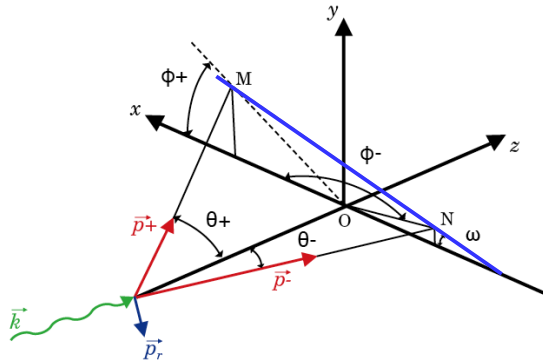
- No tracking: local vertices

- Find ROI

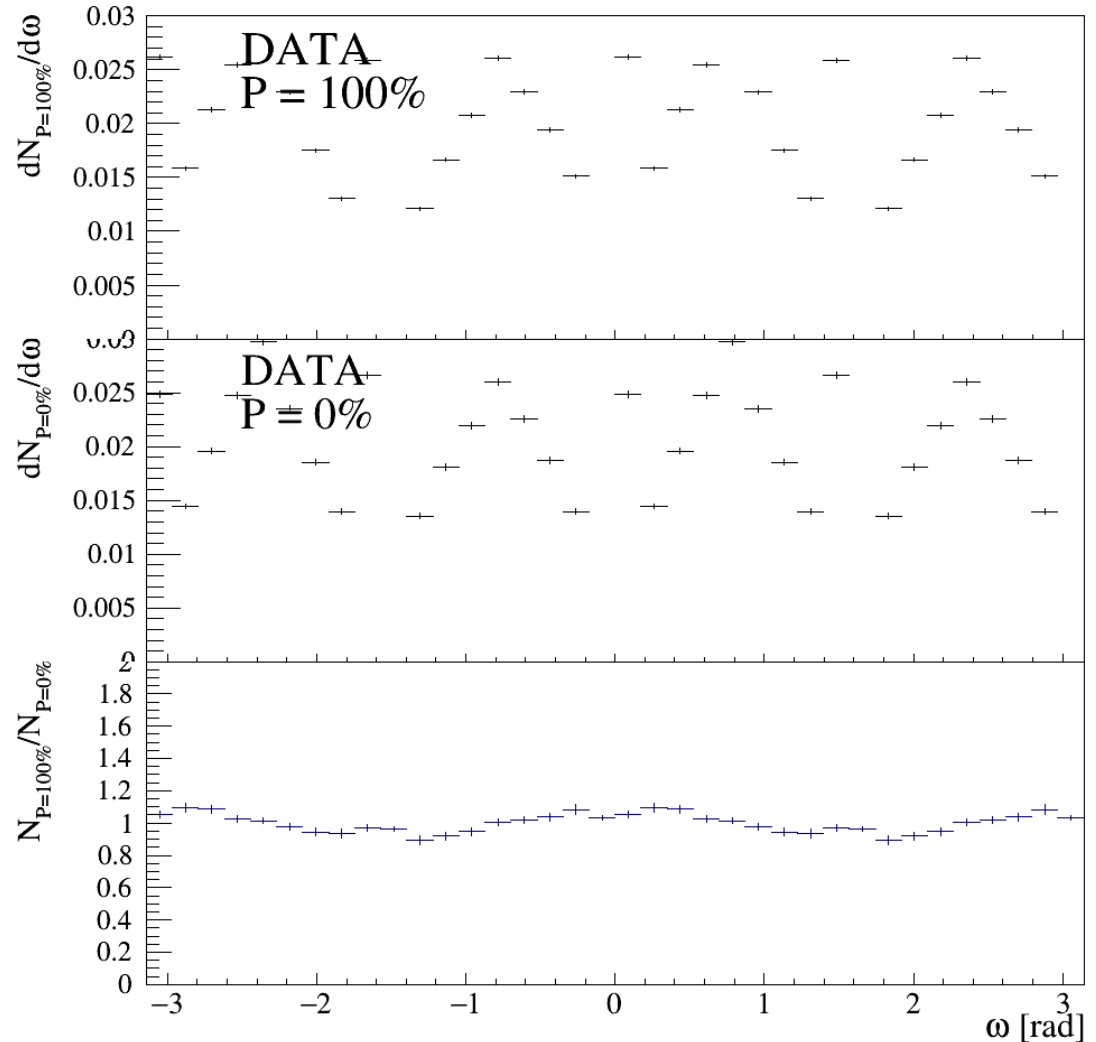
- Find peaks in polar distribution around point

- match 2D vertices to get 3D picture

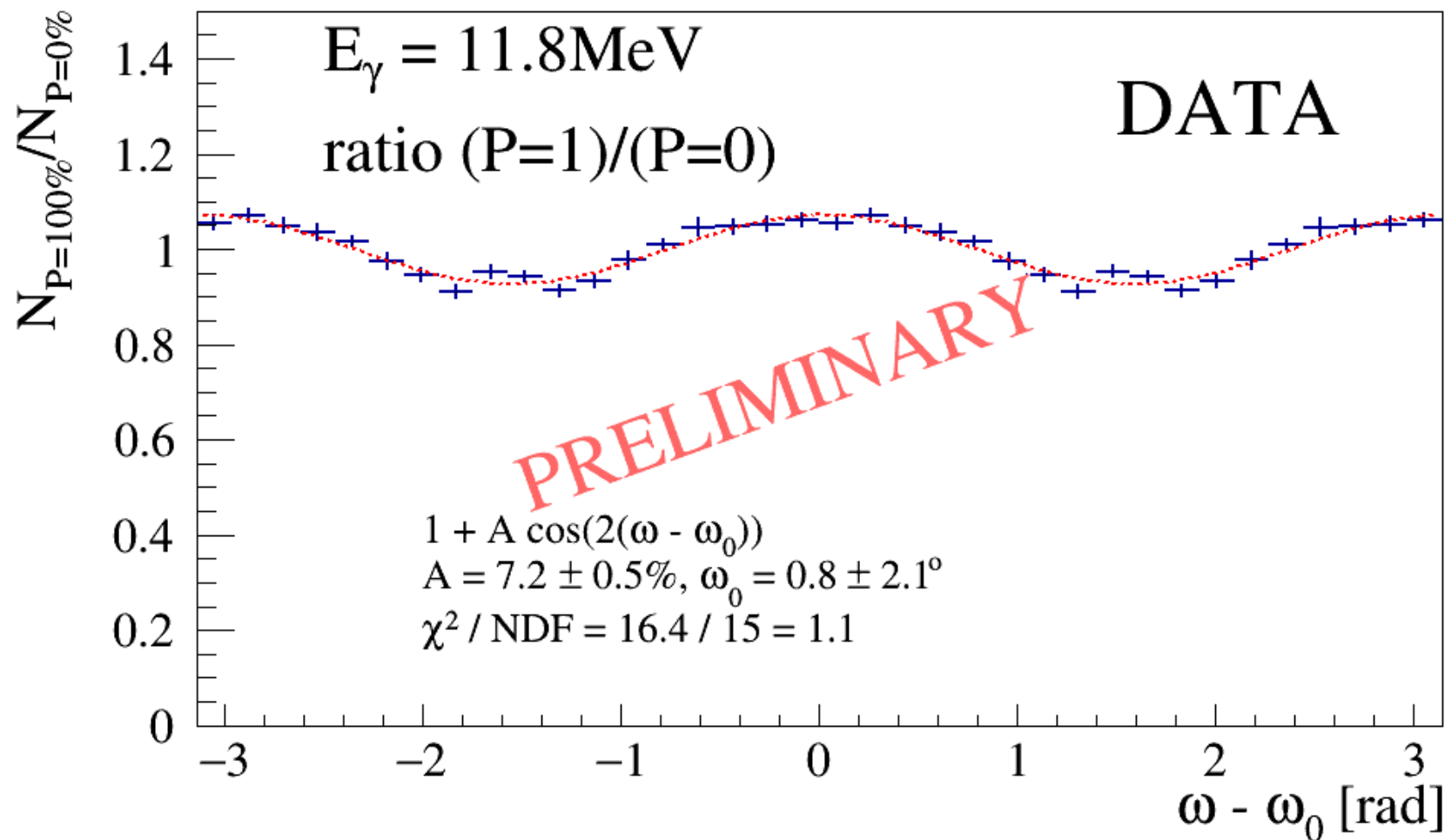


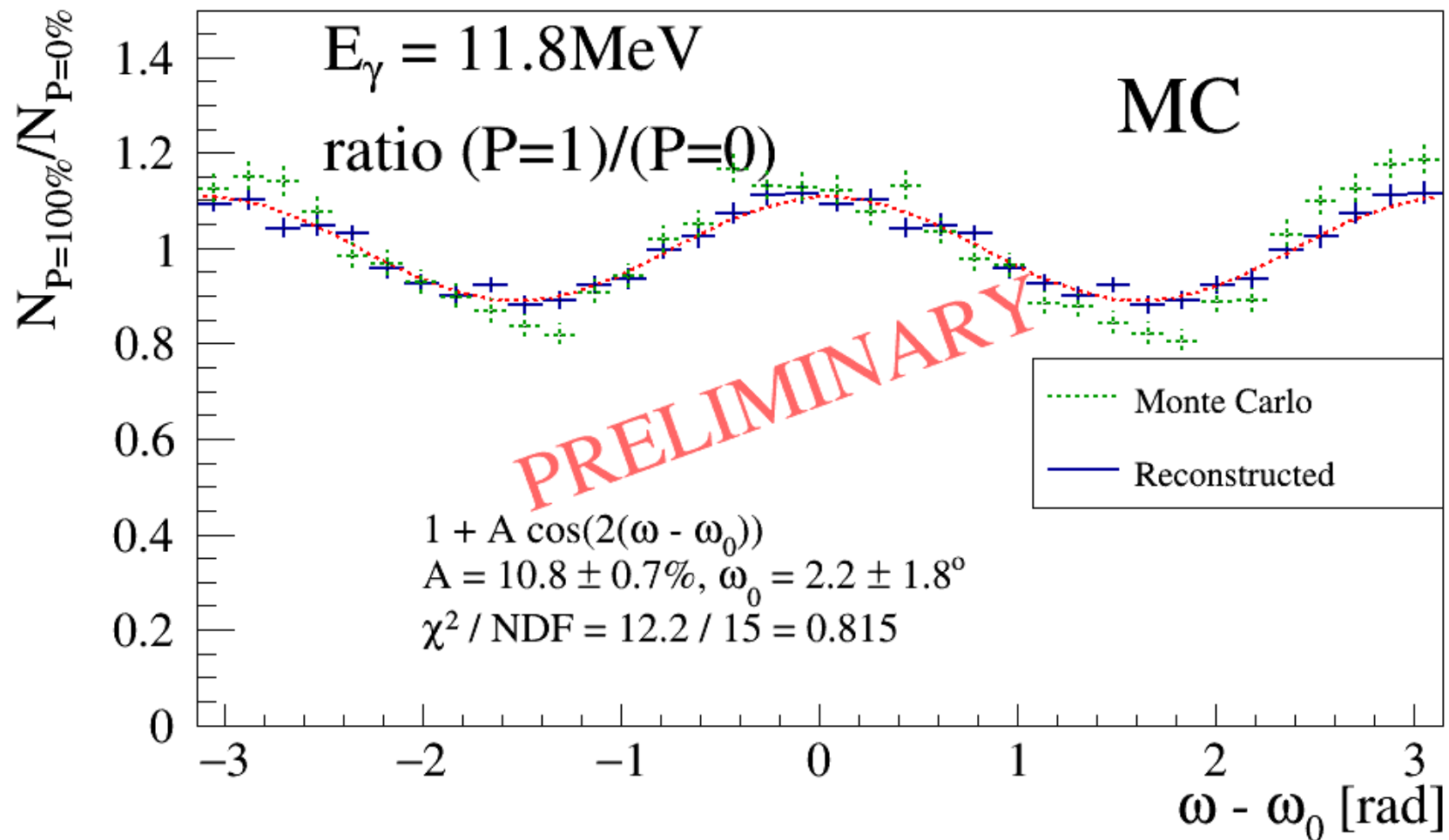


- Large systematics due to cubic geometry
- Cancel systematic errors by taking the ratio between  $P=100\%$  and  $P=0\%$



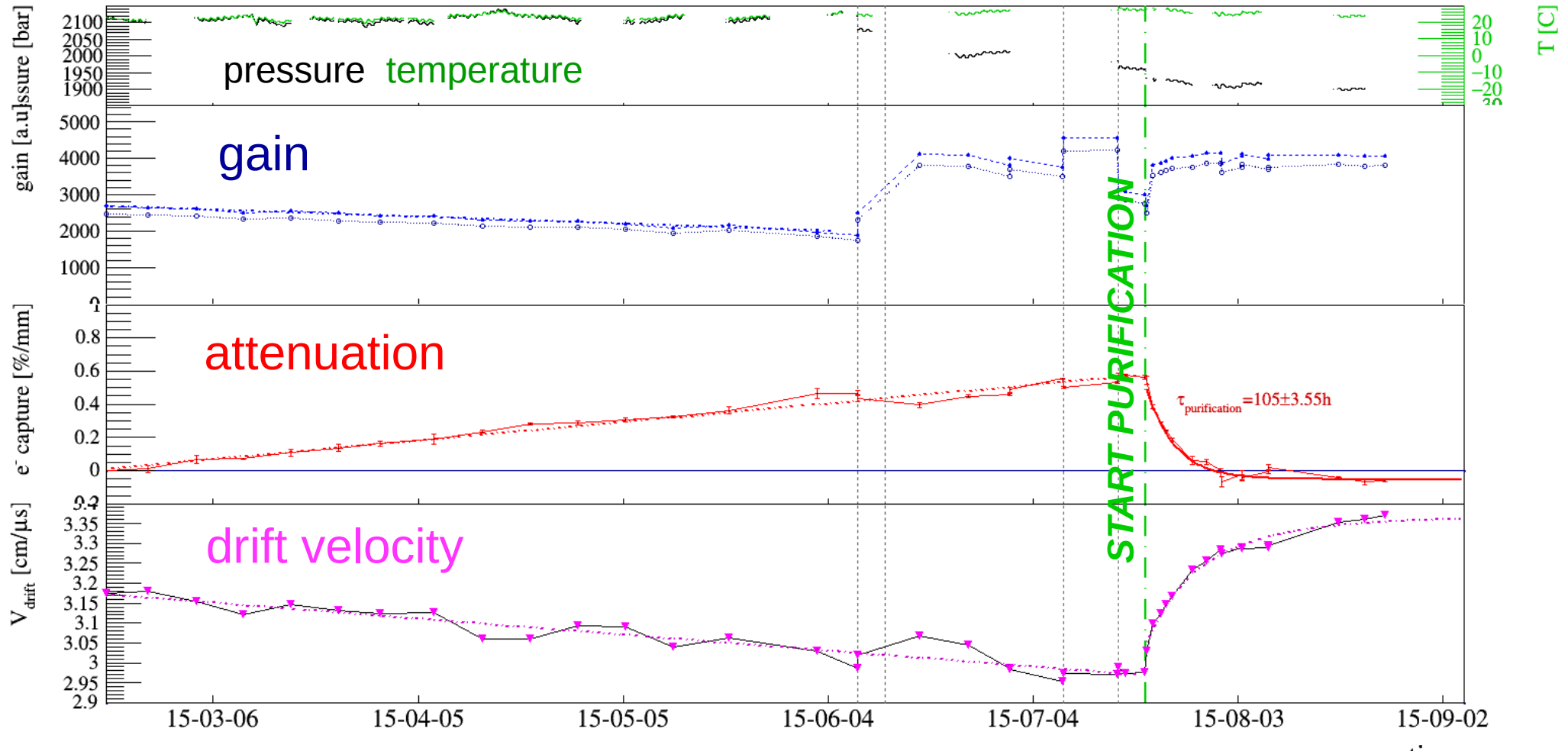








# Gas stability



Recovery of full performance after 6 month sealed

Frotin et al.,  
arXiv:1512.03248



- A gaseous detector such as a TPC is a good candidate for high resolution telescope and polarimeter in the MeV-GeV range
- A demonstrator has been successfully operated in a polarised beam 1.74-74 MeV and maintain with good gas quality over > 6 months
- Polarisation modulation has been measured with high precision, with good agreement with simulation
- *This paves the way for a high resolution gamma-ray space telescope and opens the field of gamma polarimetry!!!*



- The HARPO collaboration:
  - FRANCE: D. Attié, D. Bernard, P. Bruel, D. Calvet, P. Colas, A. Delbart, M. Frothin, Y. Geerebaert, B. Giebels, D. Götz, P. Gros, D. Horan, M. Louzir, 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. Frothin, PG et al. arXiv:1512.03248



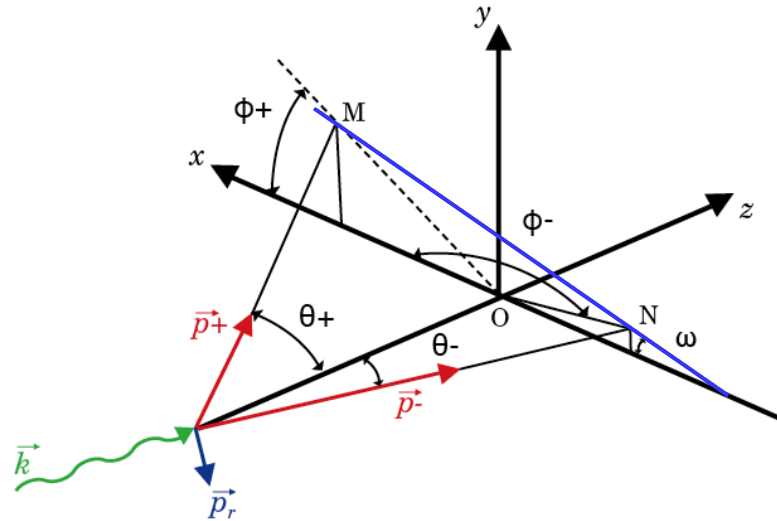
## *Dreams of the future*

the pair regime with HARPO  
s, LLR, CNRS/IN2P3, France  
VPA2016, CERN

---

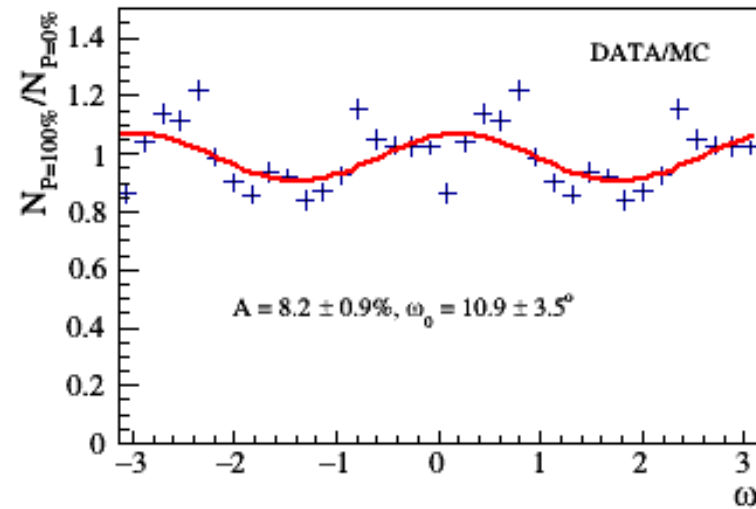
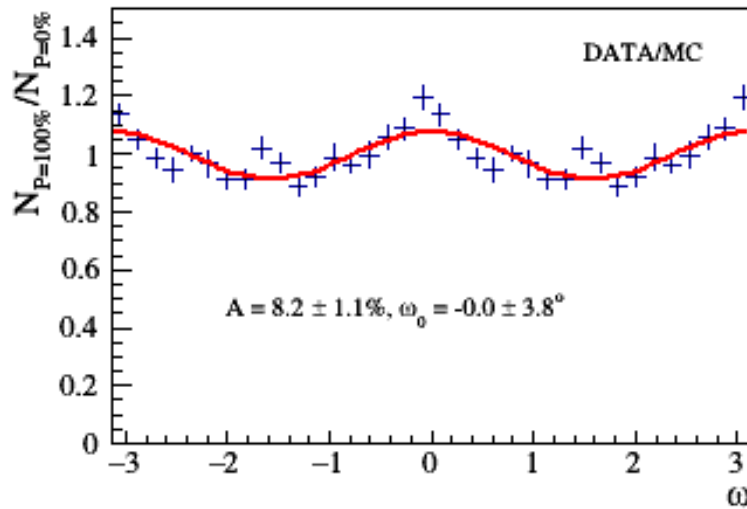
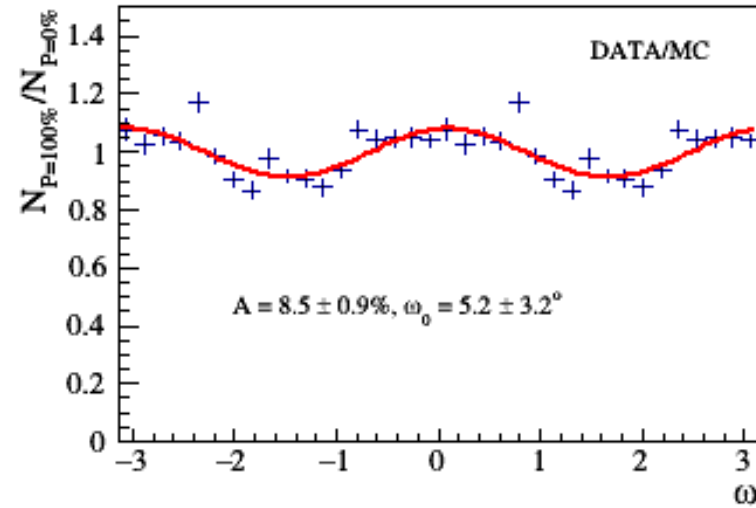
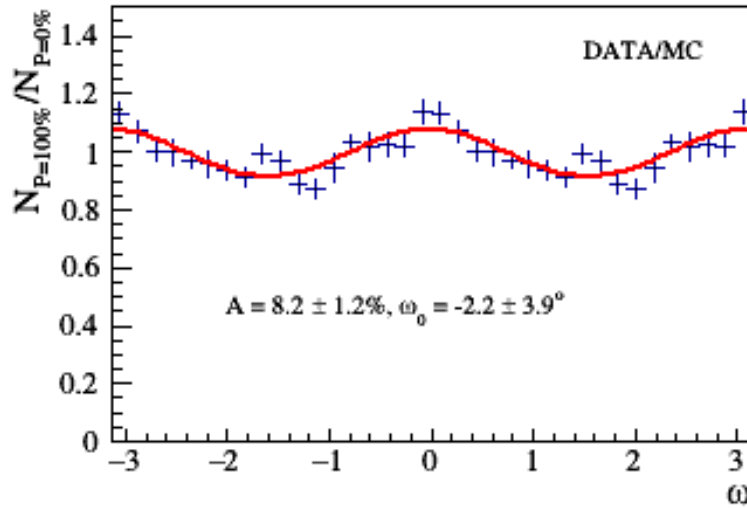
# Backup

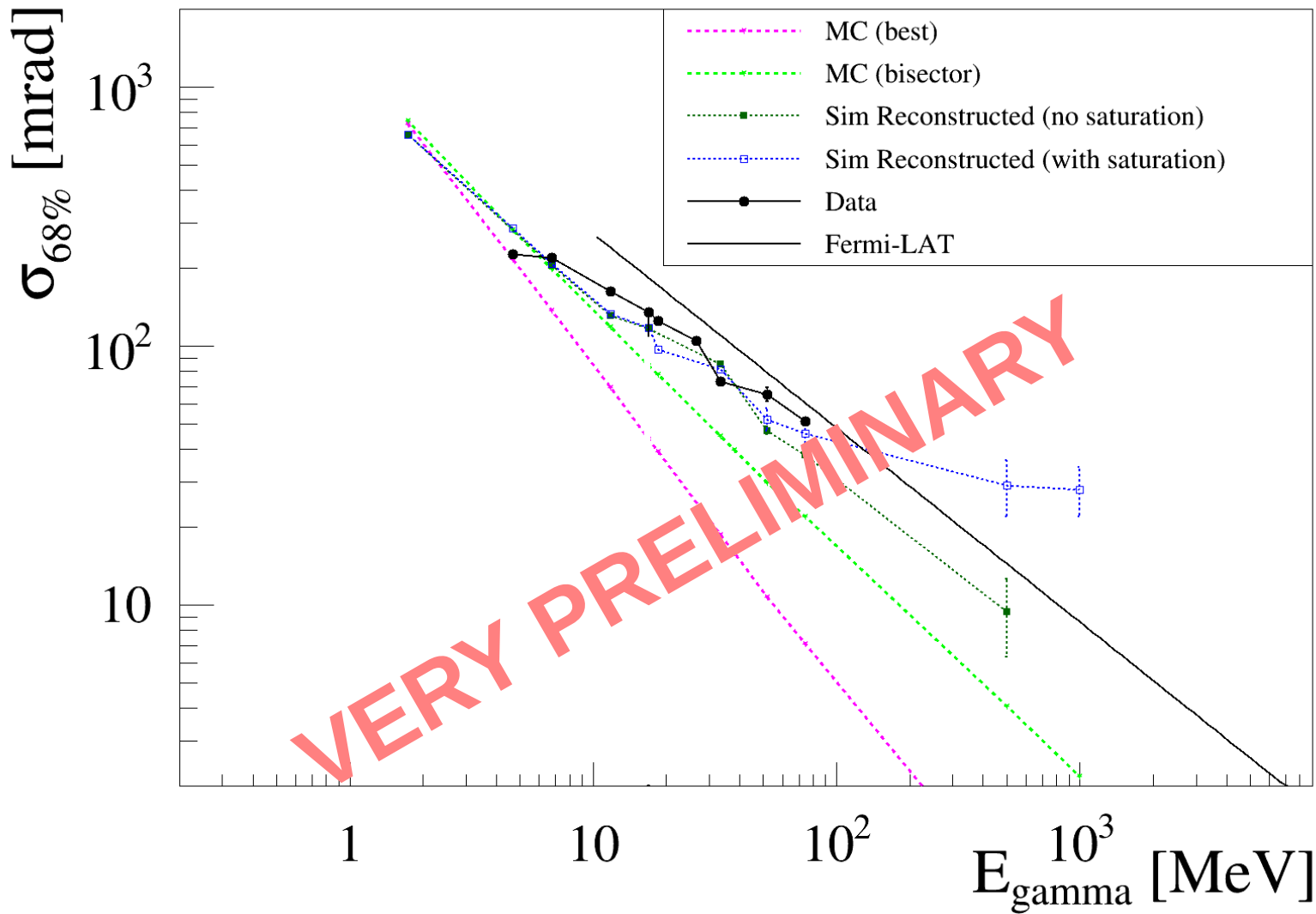
- Modulation of the azimuthal angle  $\omega$



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



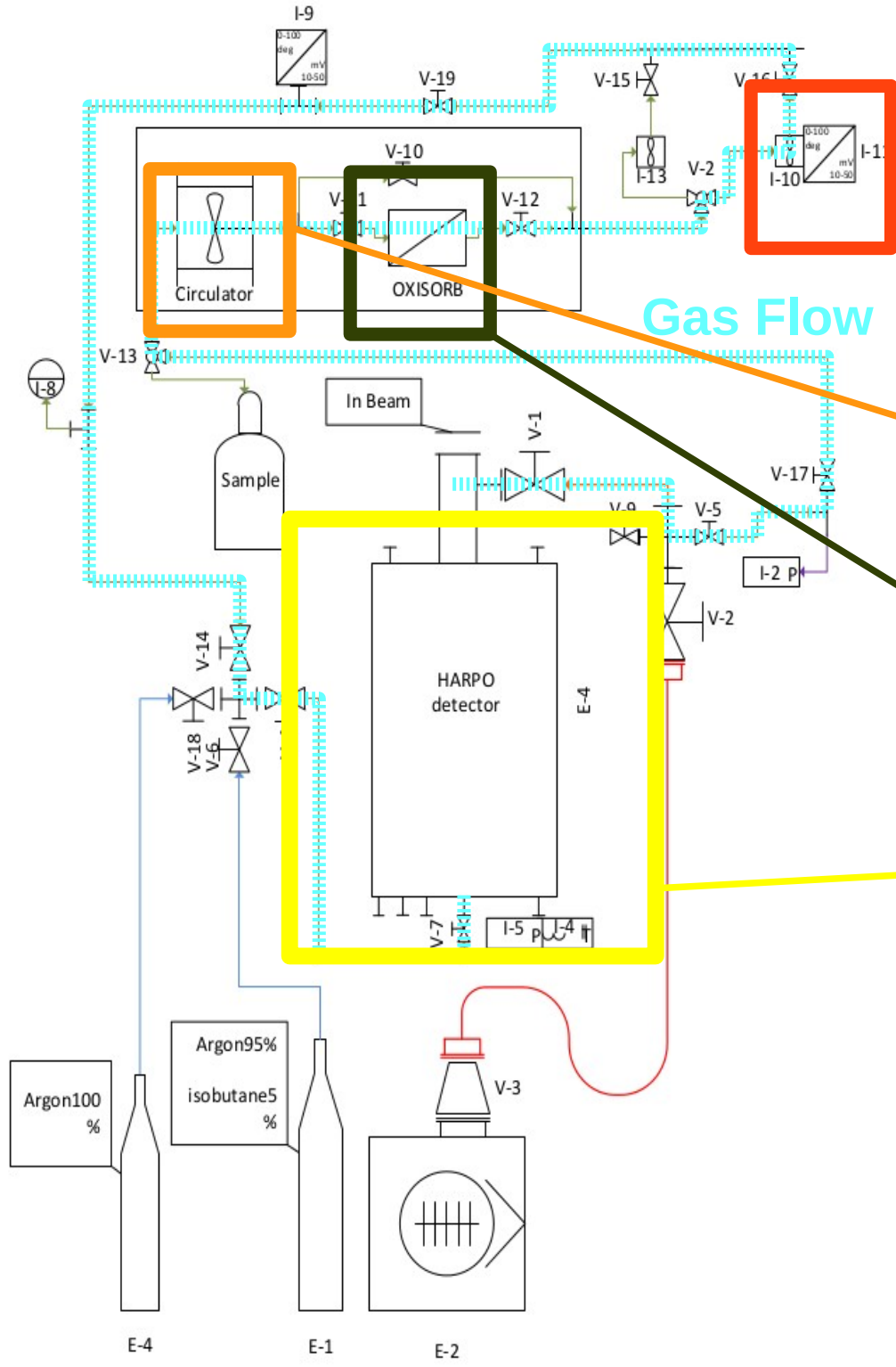




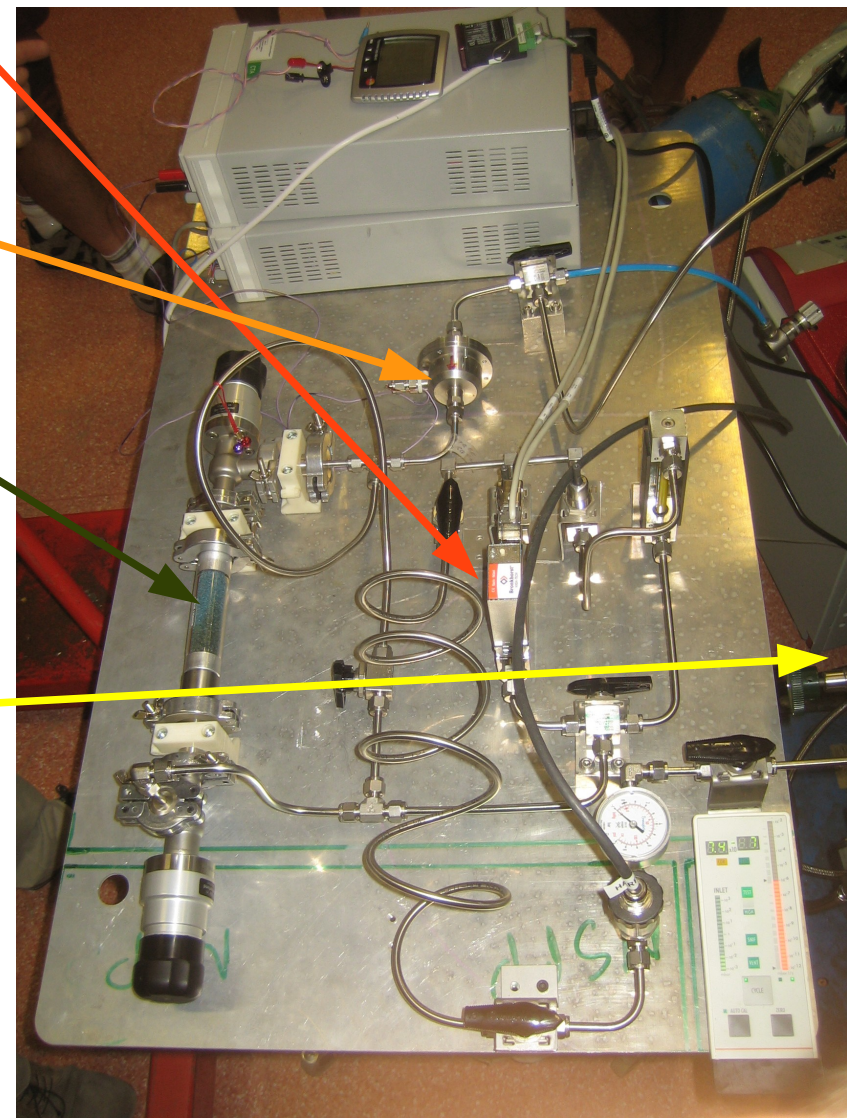


- Agreement with theoretical prediction
  - relatively small contribution of tracking
- Excellent agreement with simulation
  - effect of saturation dominates at high energy
- Potential for improvement
  - estimation of track momentum
  - even 100% resolution should significantly improve

LM

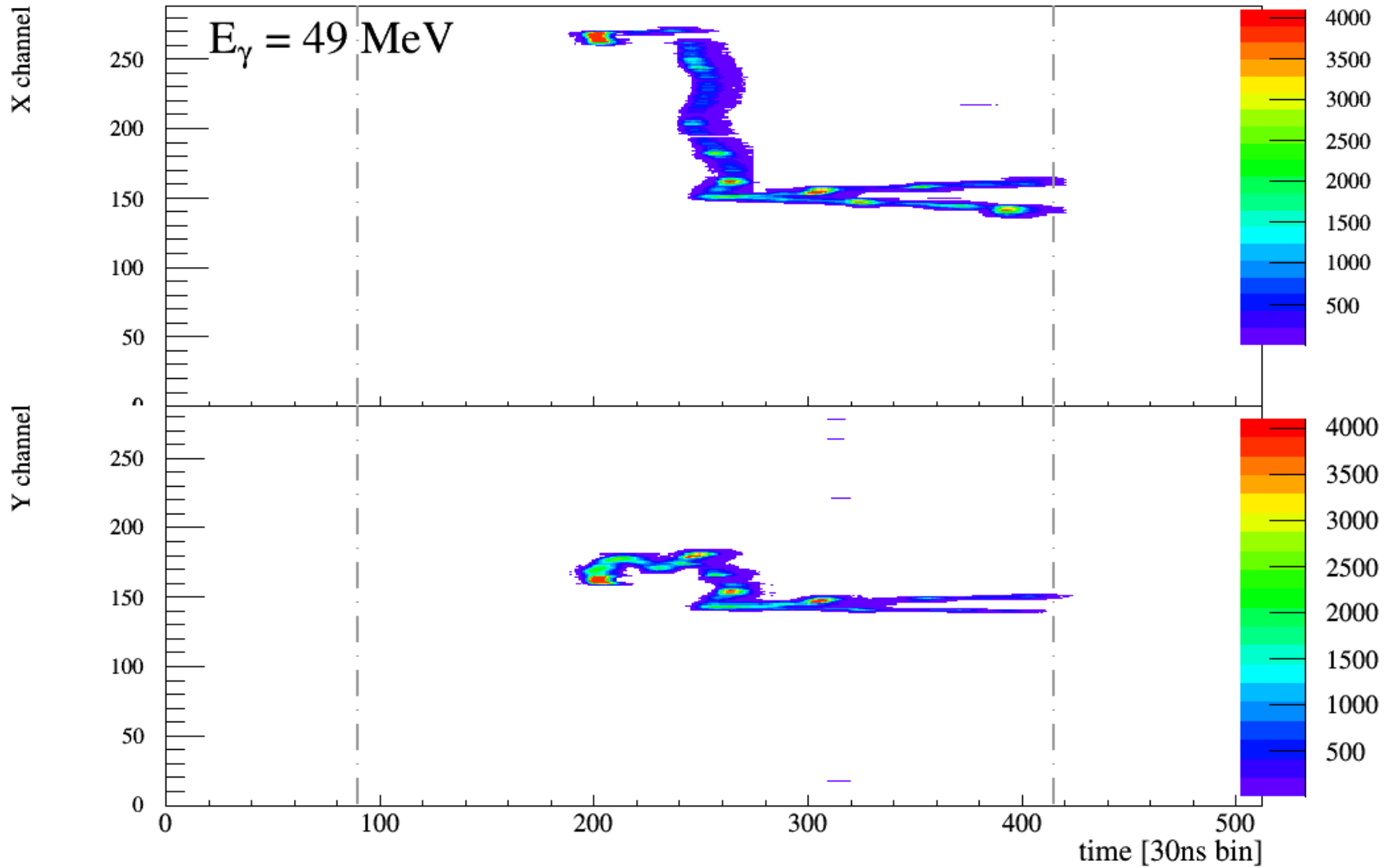


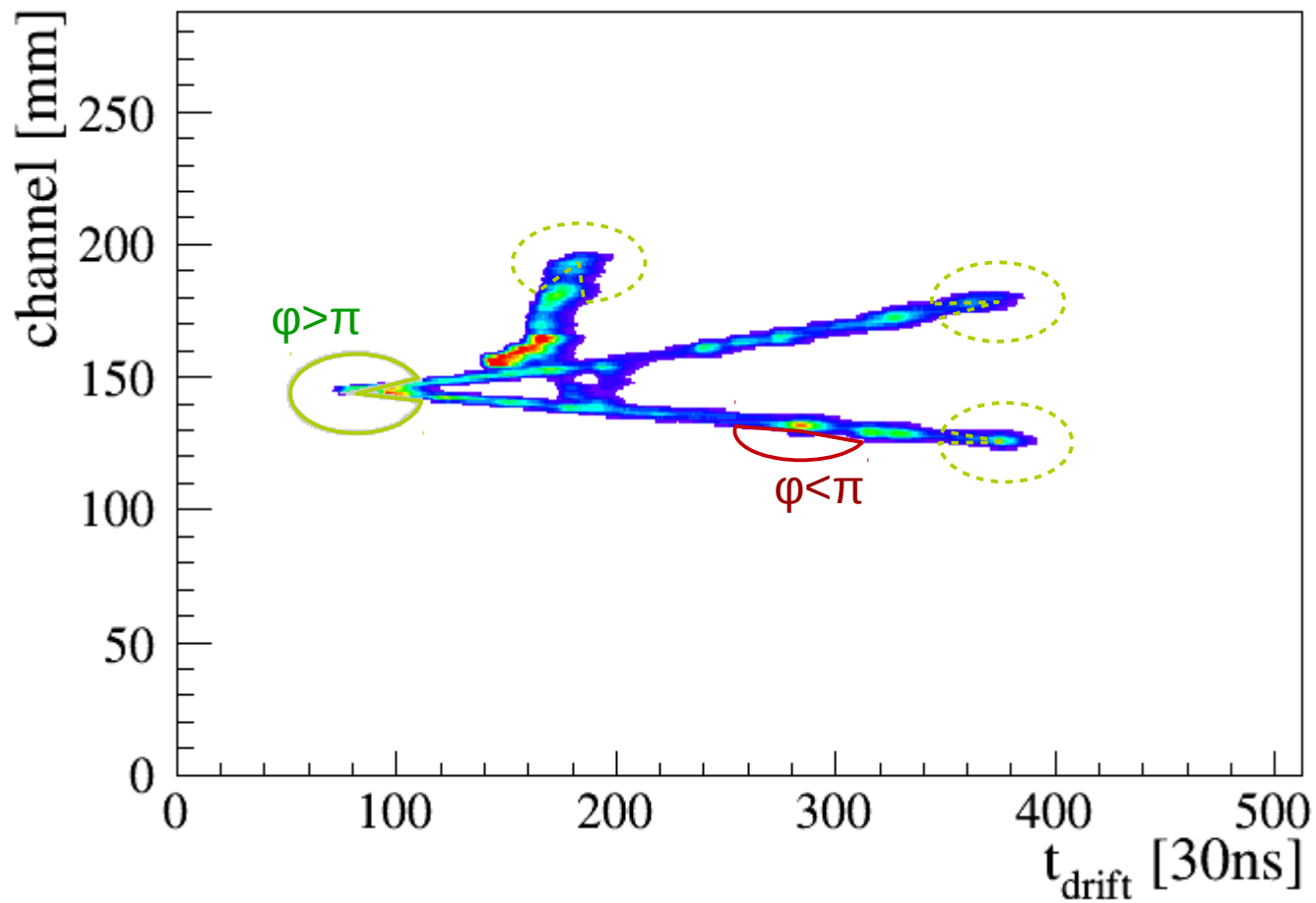
Gas Flow



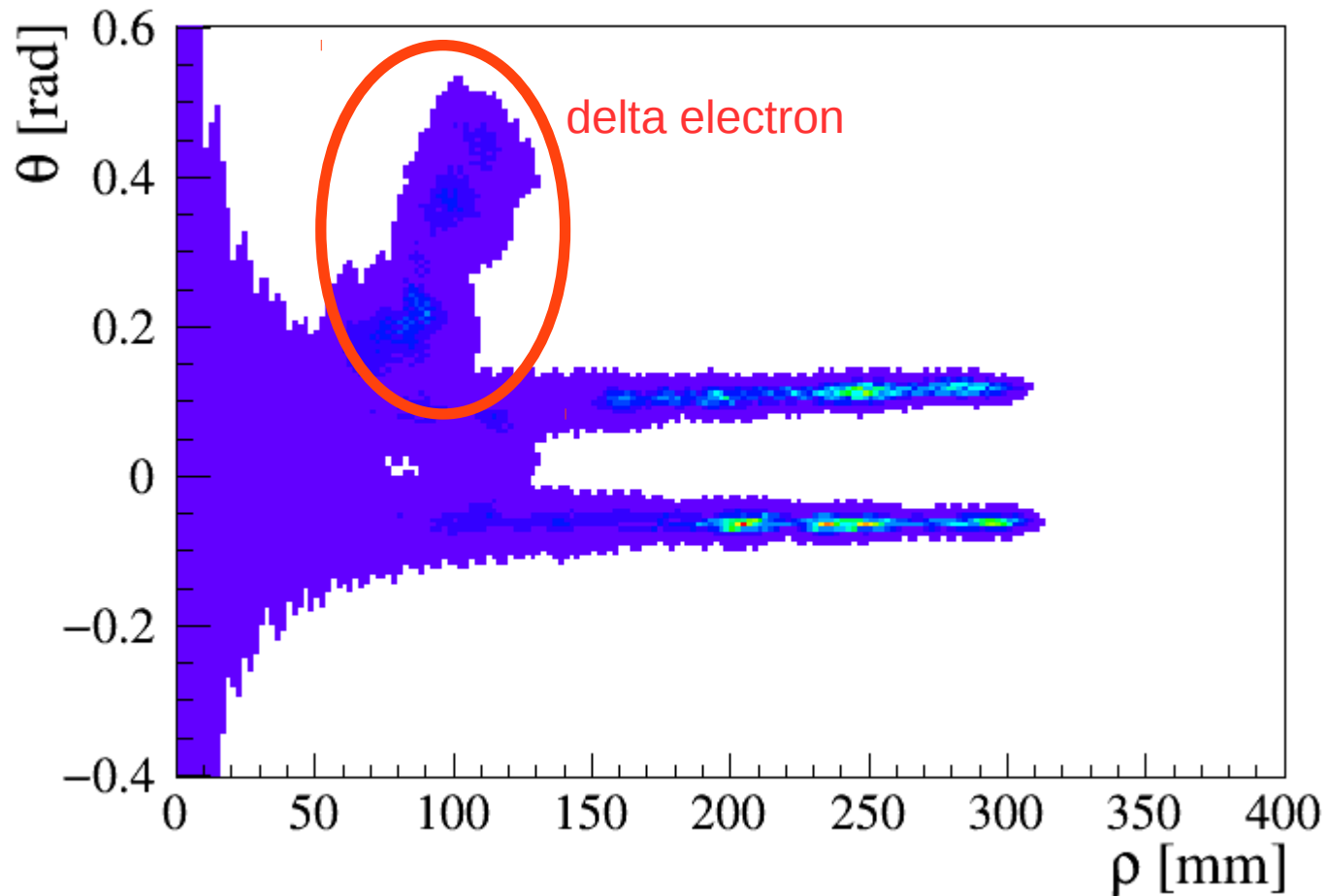
with HARPO  
2P3, France  
LN

# Triplet event



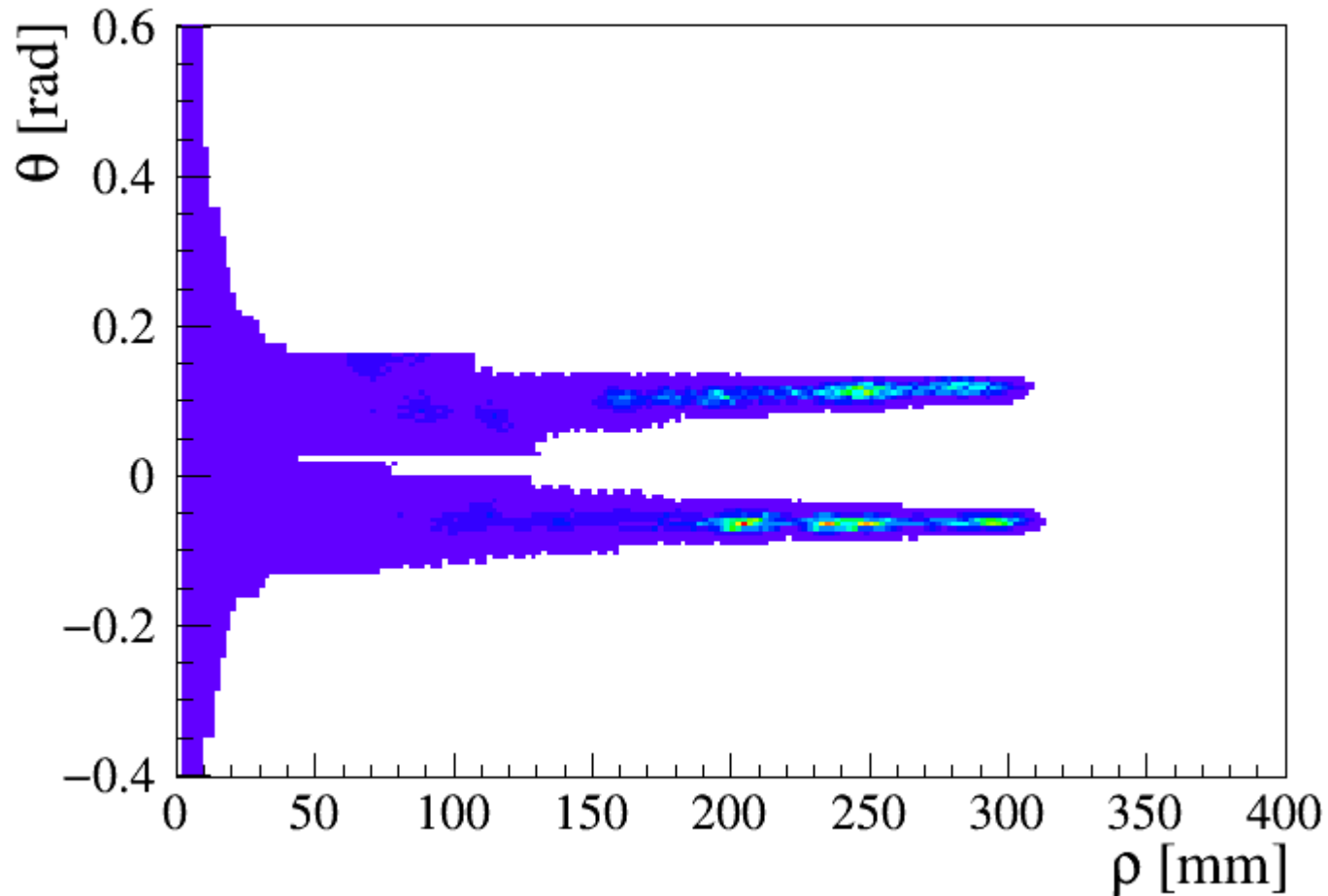


- Polar charge distribution around vertex





- Clean up: keep only straight lines





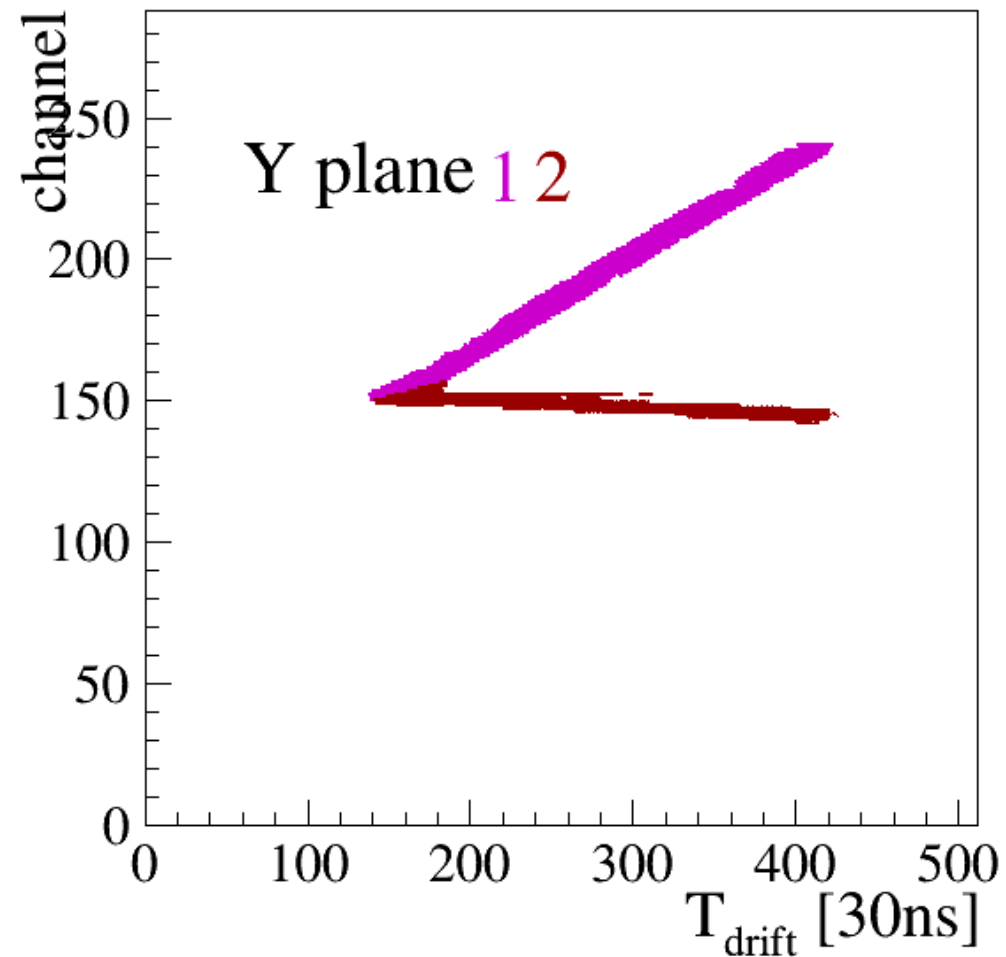
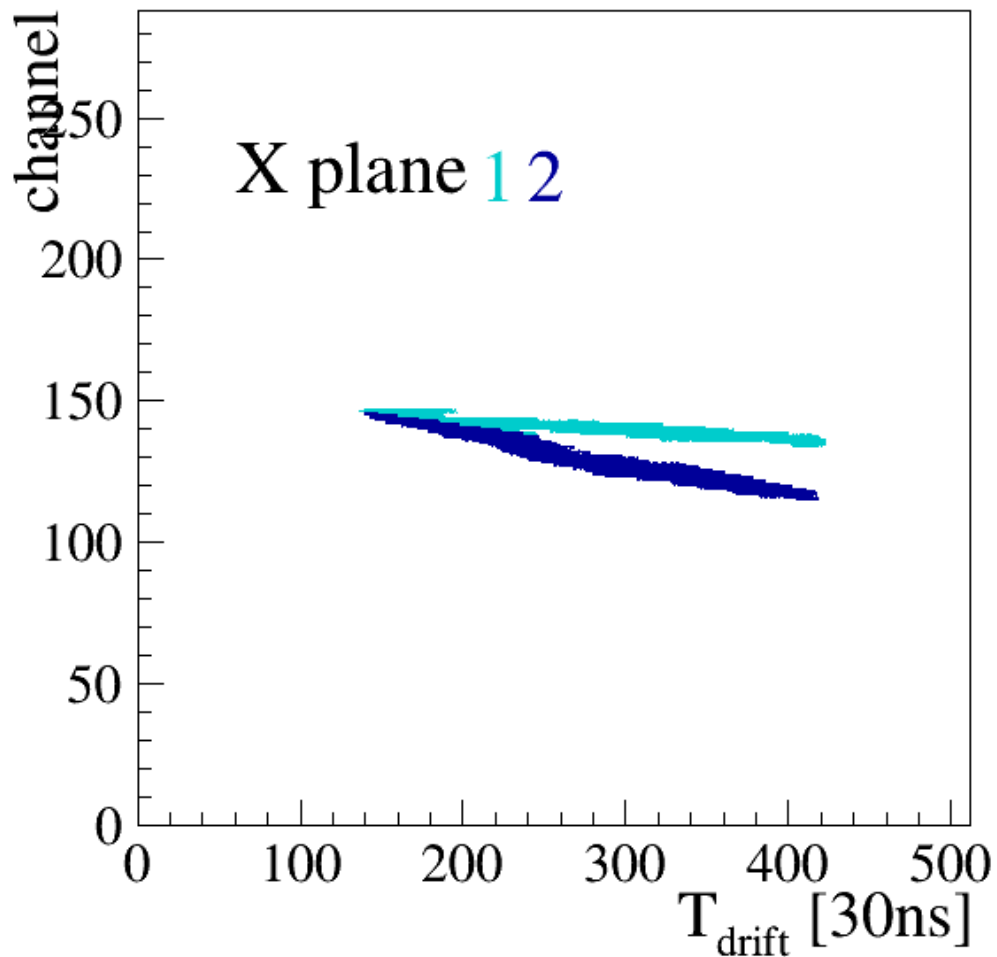


- Simple
- Robust:
  - ignores obvious scattering and background
  - potential for small opening angle
- Potential for improvement
  - better peak finding
  - use of distance info (focus on short distance for large opening angle, long distance for small)

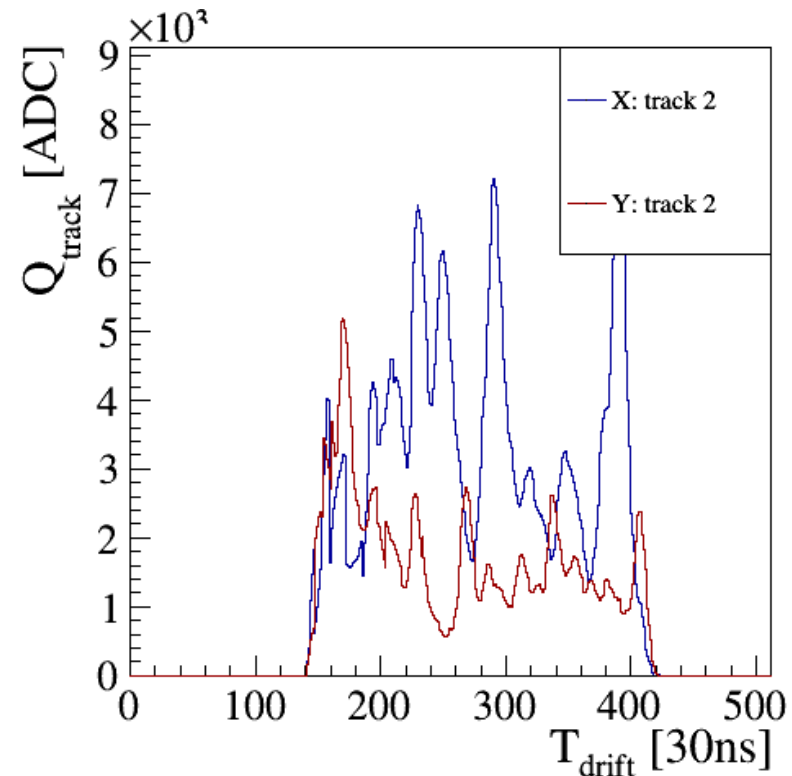
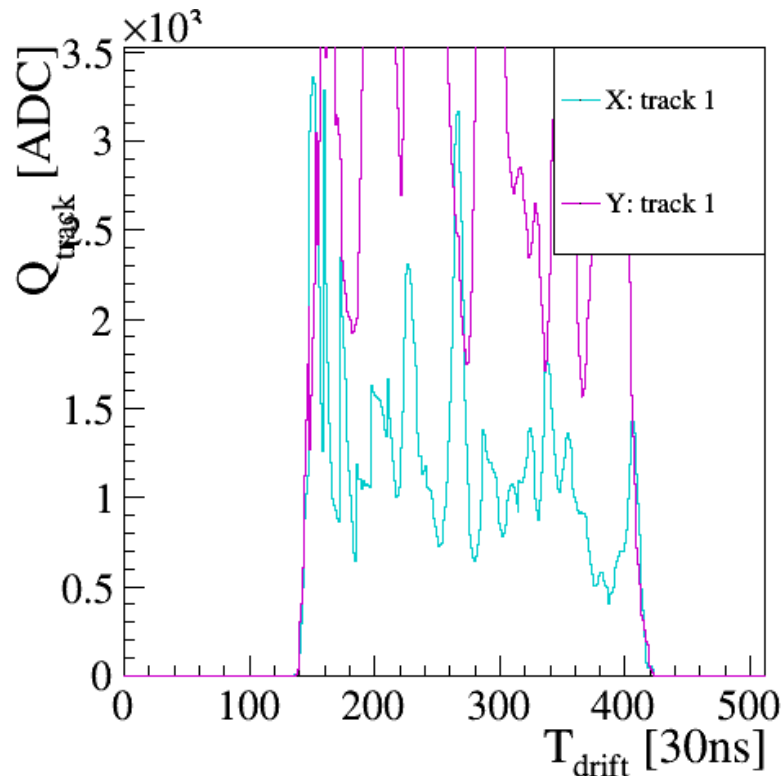


- As before: compare charge profile
  - 1: match vertexes if there are several with same Z position
  - 2: match the tracks in the vertex (simple: only 2 possibilities)

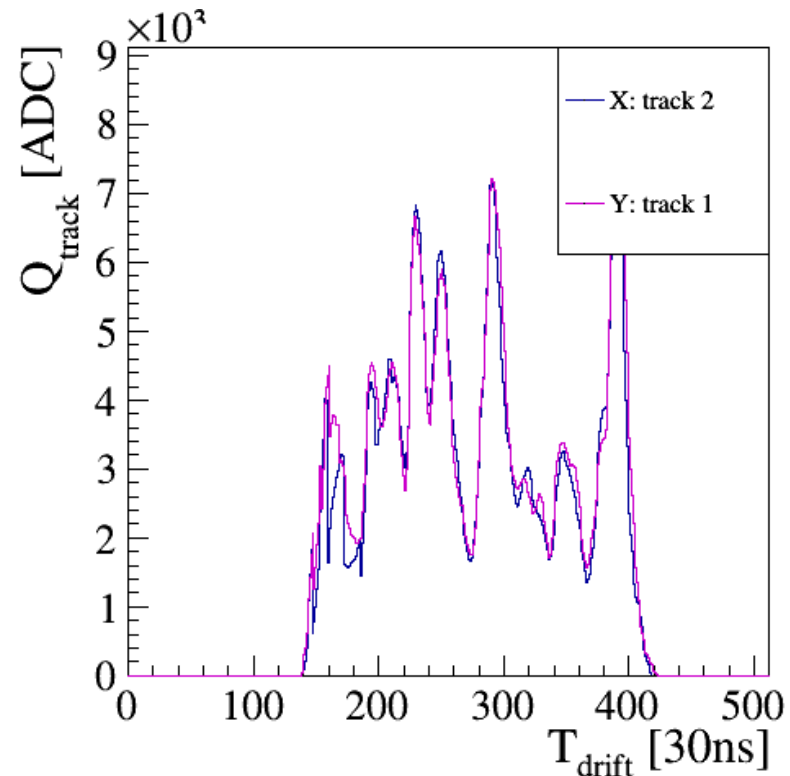
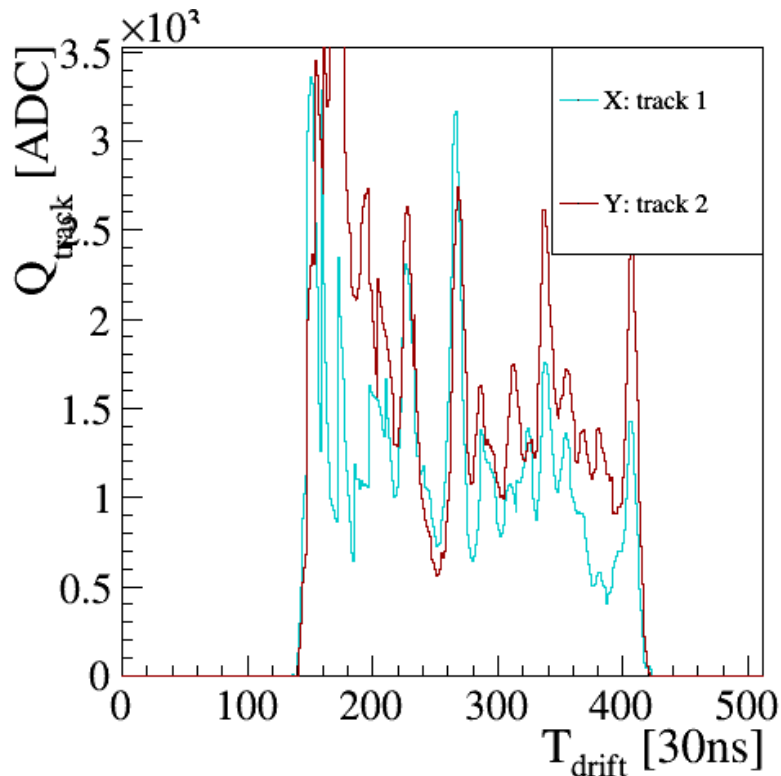
- Assign signal to tracks

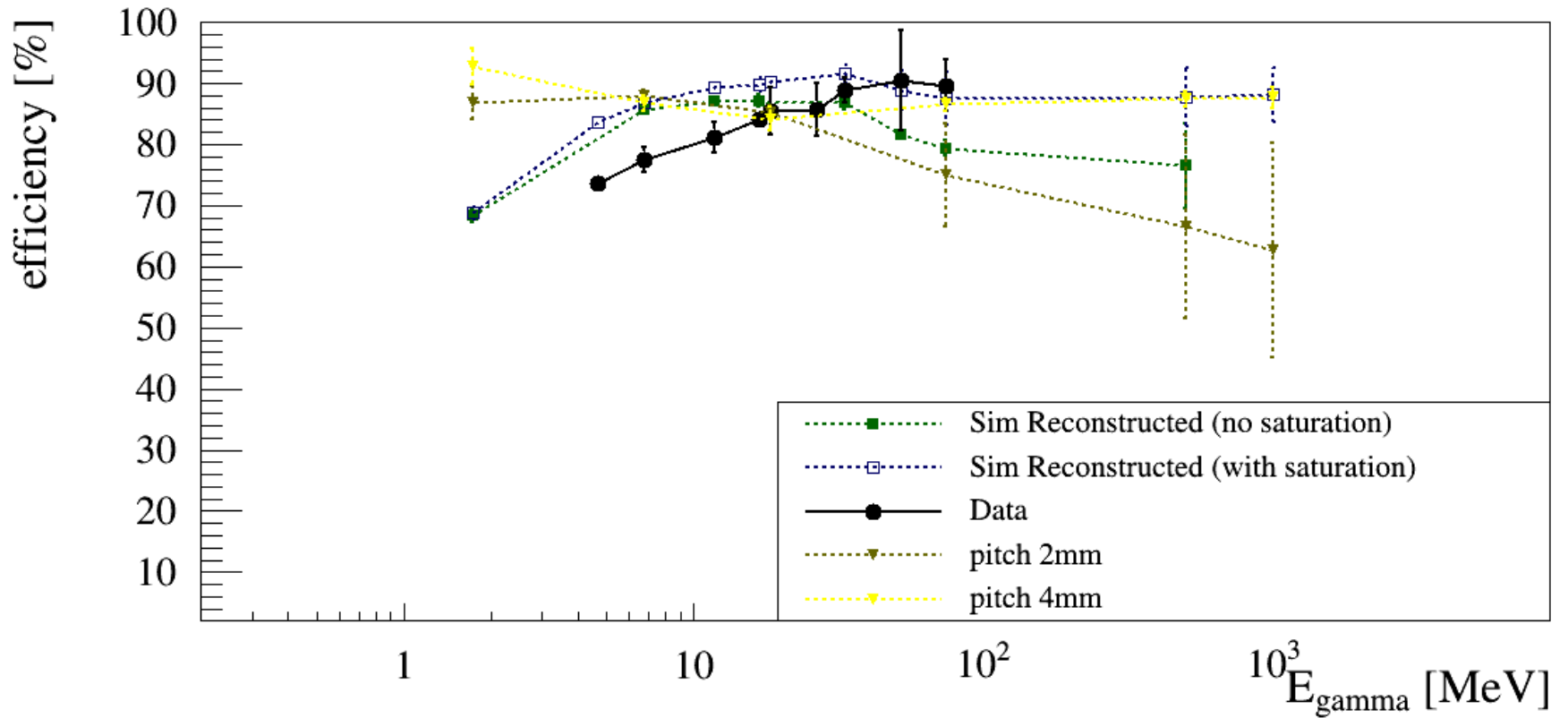


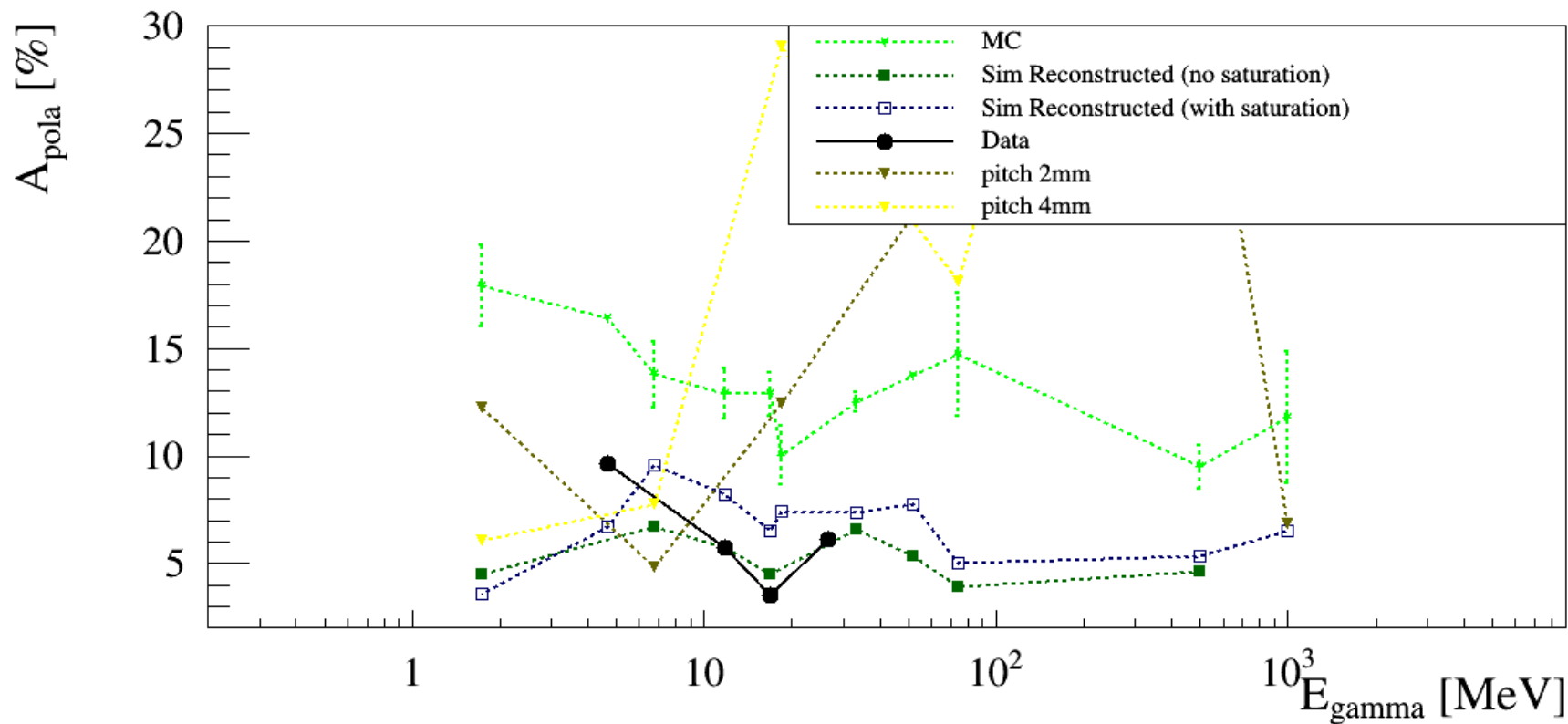
- Compare profiles:  $X(1,2) \leftrightarrow Y(1,2)$  “same”

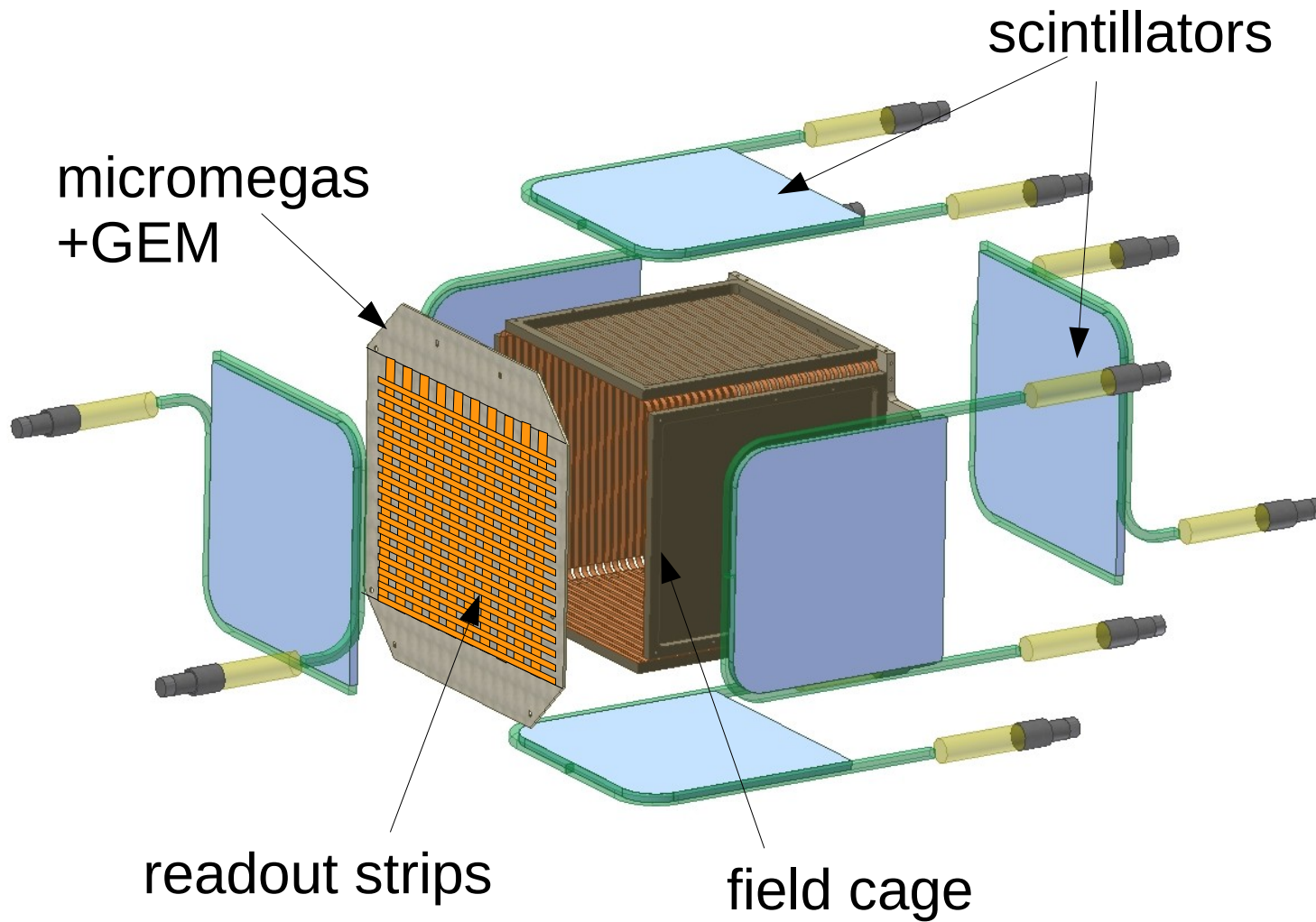


- Compare profiles:  $X(1,2) \leftrightarrow Y(2,1)$  “switch”





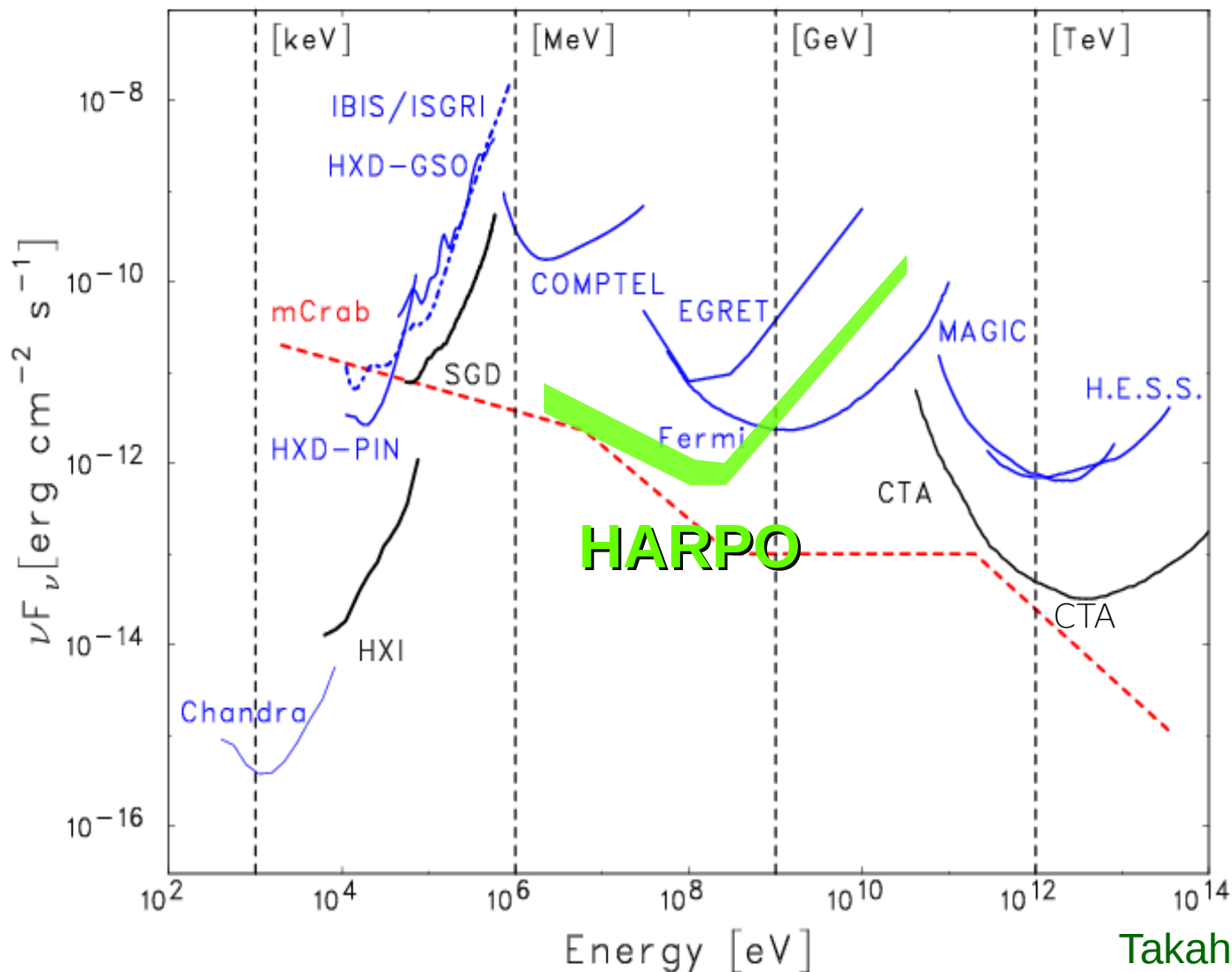








# Gamma source sensitivity

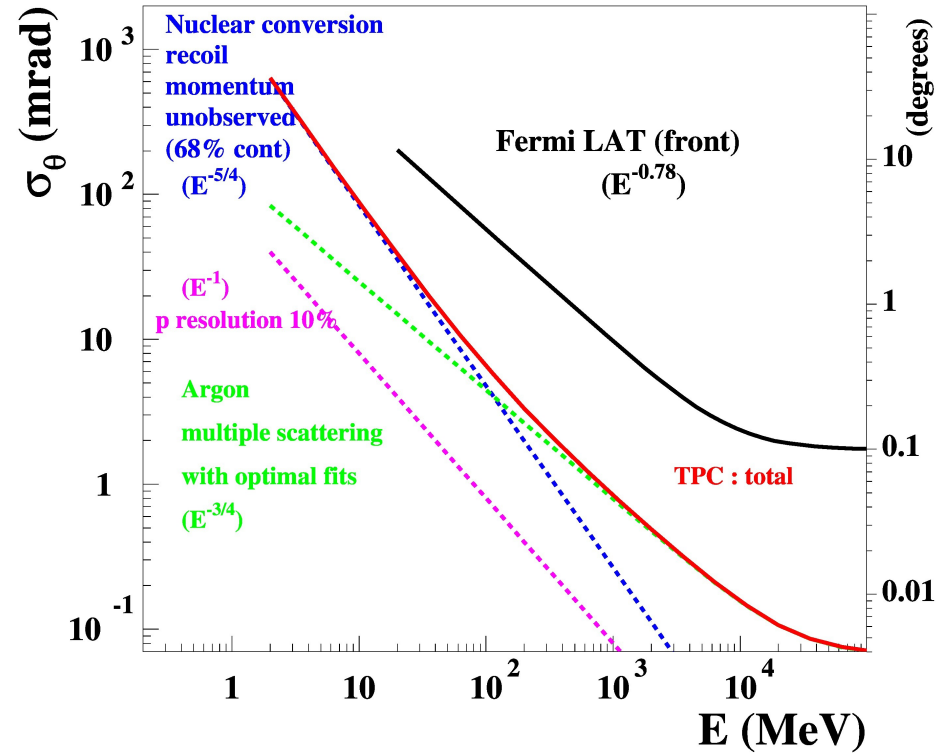
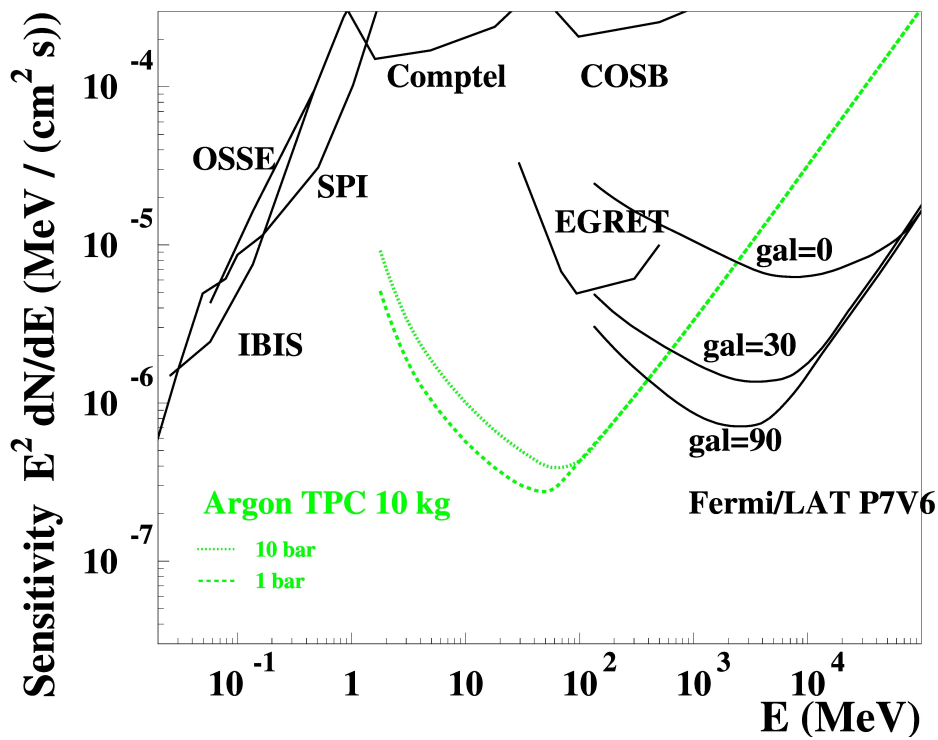


Takahashi 2012

Polarimetry in the pair regime with HARPO  
Philippe Gros, LLR, CNRS/IN2P3, France  
TeVPA2016, CERN

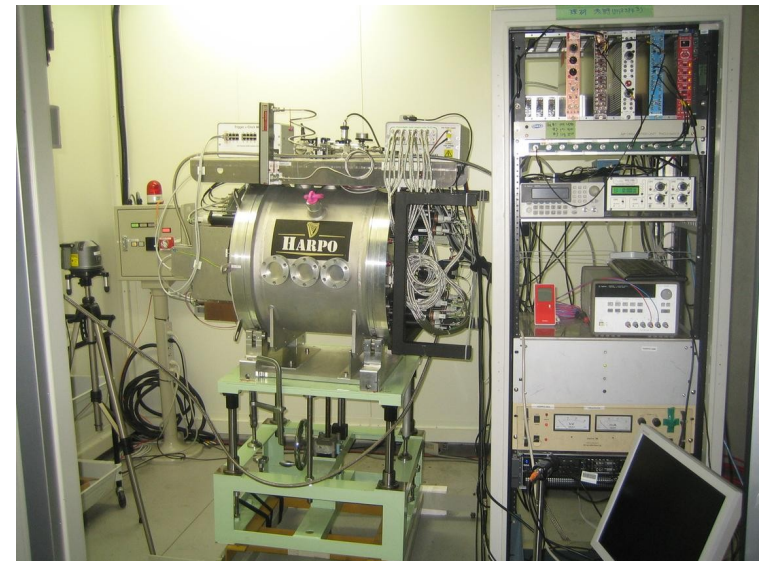
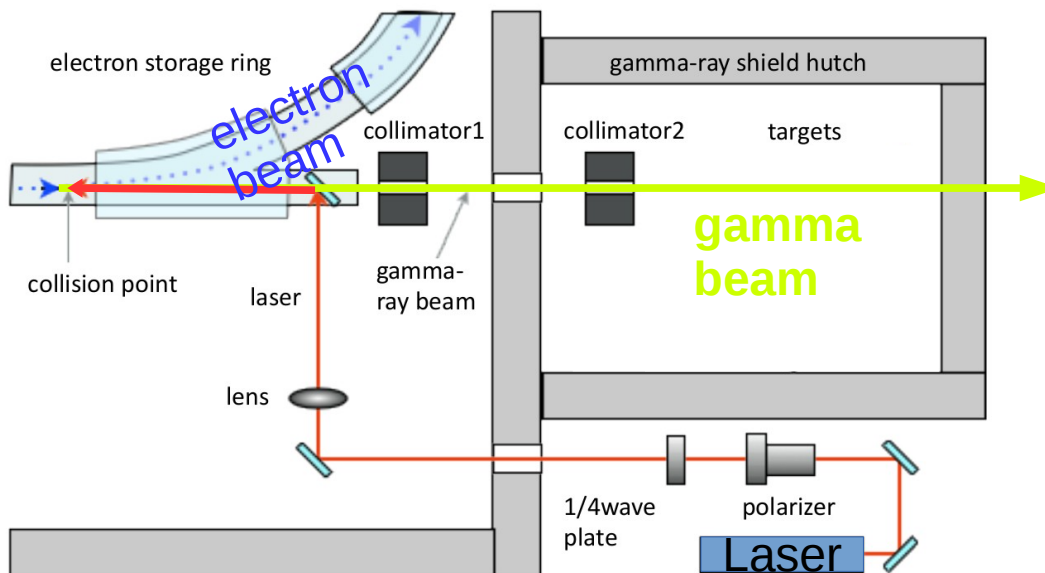


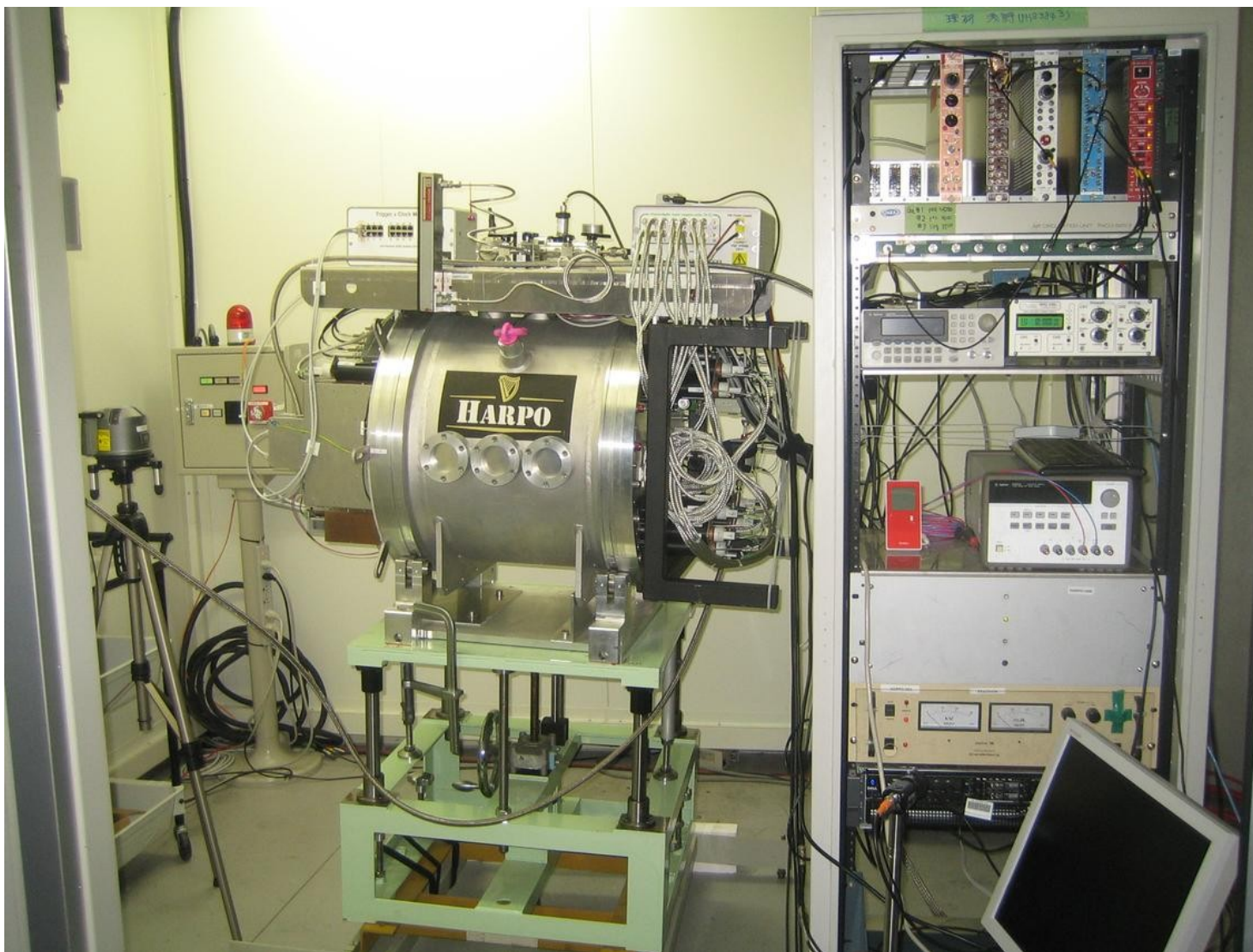
# Expected performance



D. Bernard,  
 NIM A 701 (2013) 225

- Demonstrator built and tested in polarised photon beam in NewSUBARU, Japan
  - 13 Energy points, 1.74 to 74MeV,  $\sim 60$  Mevents





Polarimetry in the pair regime with HARPO  
*Philippe Gros, LLR, CNRS/IN2P3, France*  
 TeVPA2016, CERN