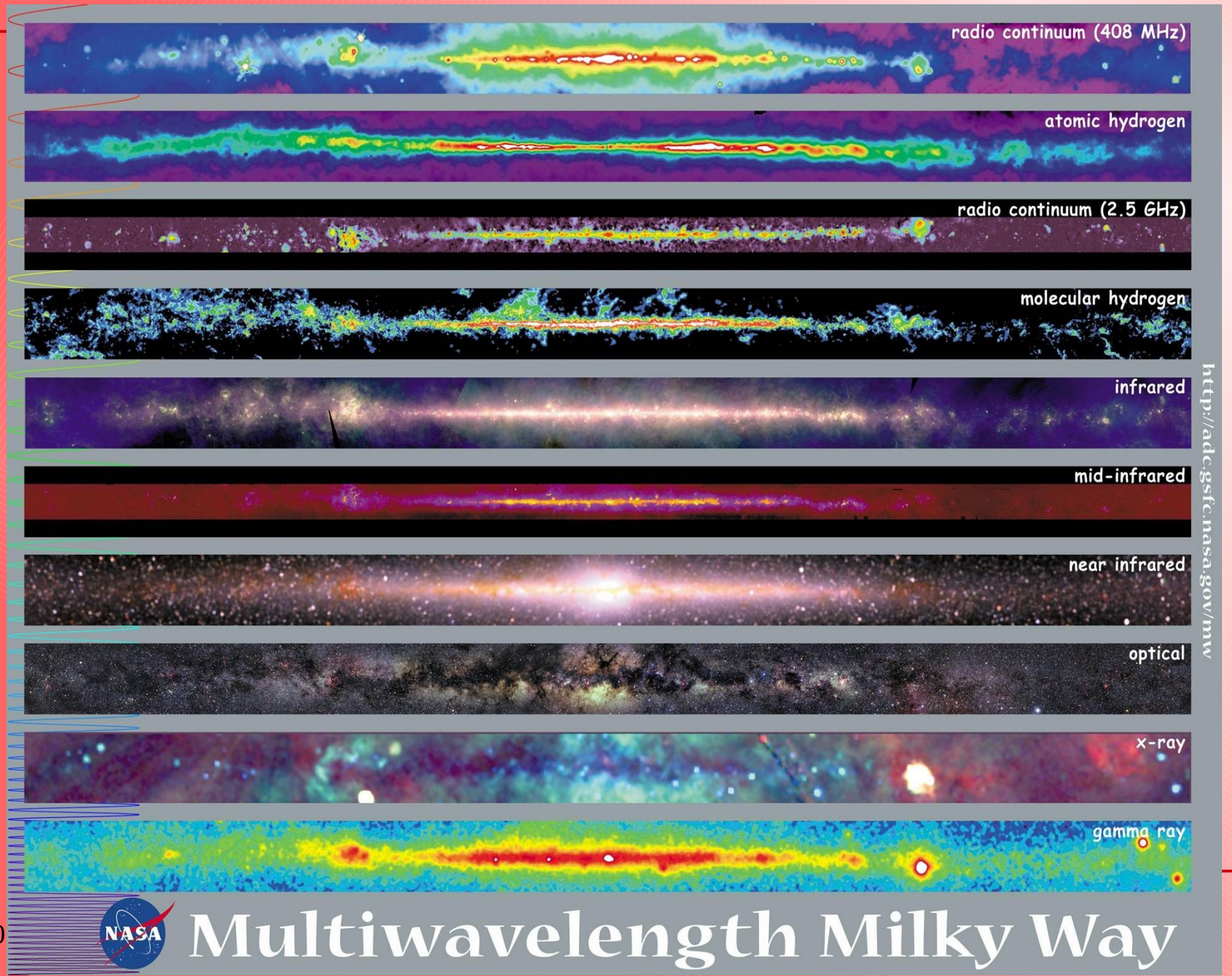
HARPO: Measurement of polarised gamma rays (1.7 to 72MeV) with the HARPO TPC

Philippe Gros
for the HARPO collaboration

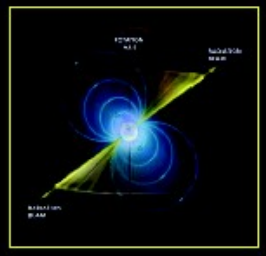
- Introduction to the HARPO project
- Setup at the NewSUBARU photon beam
- Gas monitoring
- Trigger with micromegas signal
- Other experiences
- Conclusions

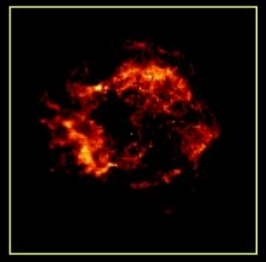
Milky Way / 天の河



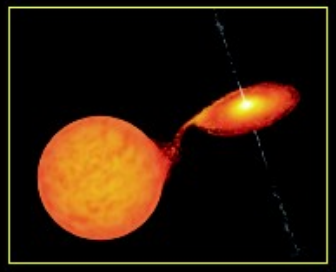
Gamma Astrophysics non thermal phenomena

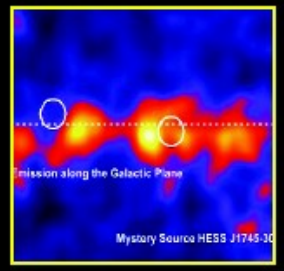
- Galactic targets


Pulsar


Supernova Remnants

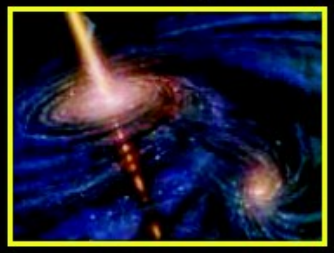
Pulsar wind nebulae

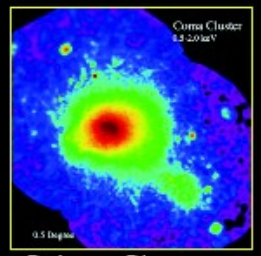

Micro-quasars



Galactic center

- Extragalactic targets


Active Galactic Nuclei



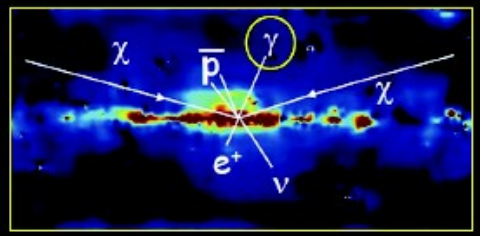
Galaxy Cluster

Starburst galaxies

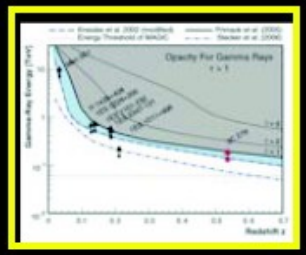
Merging Galaxies

Gamma-ray Bursts

- Fundamental physics



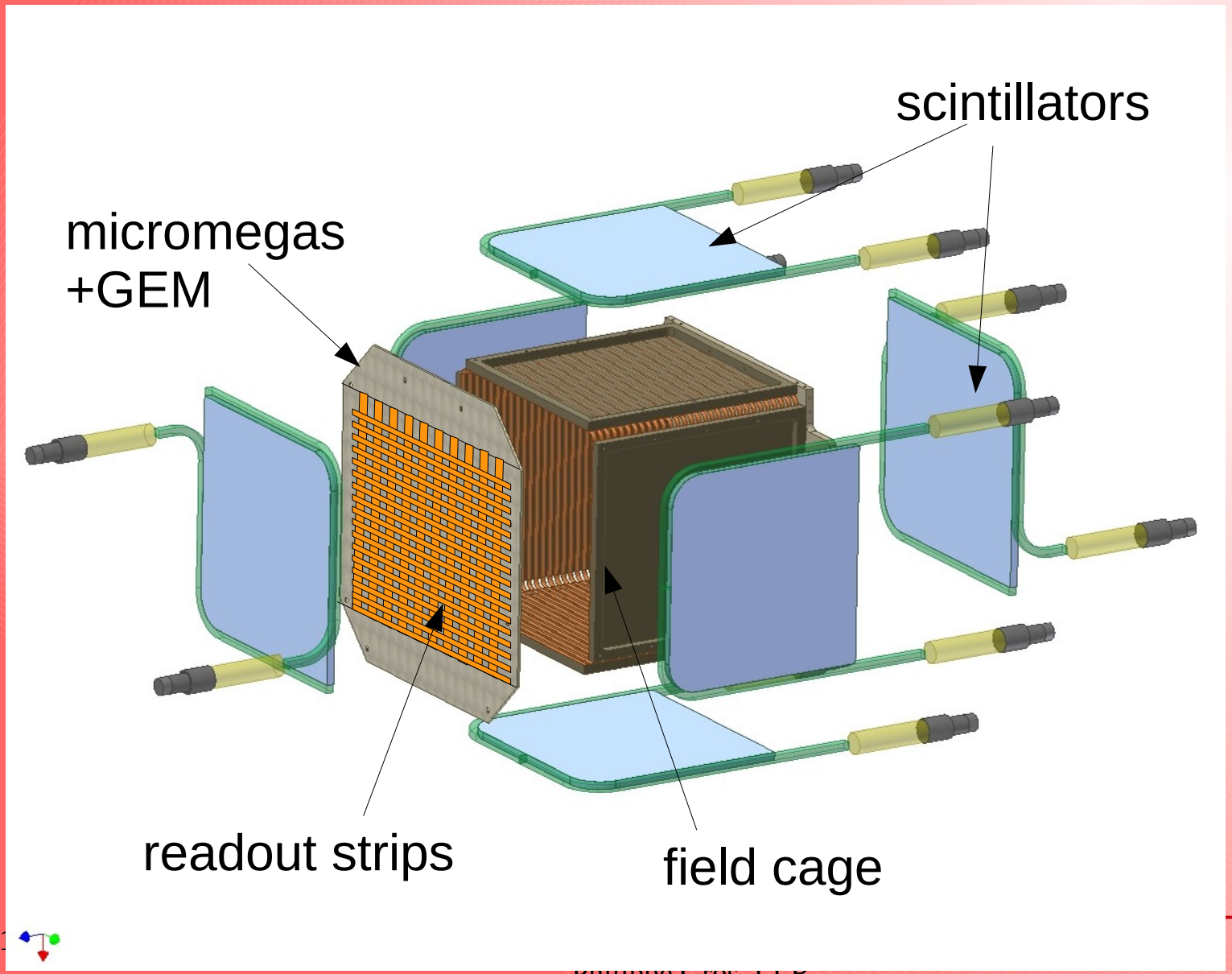
Dark Matter annihilation


Universe transparency

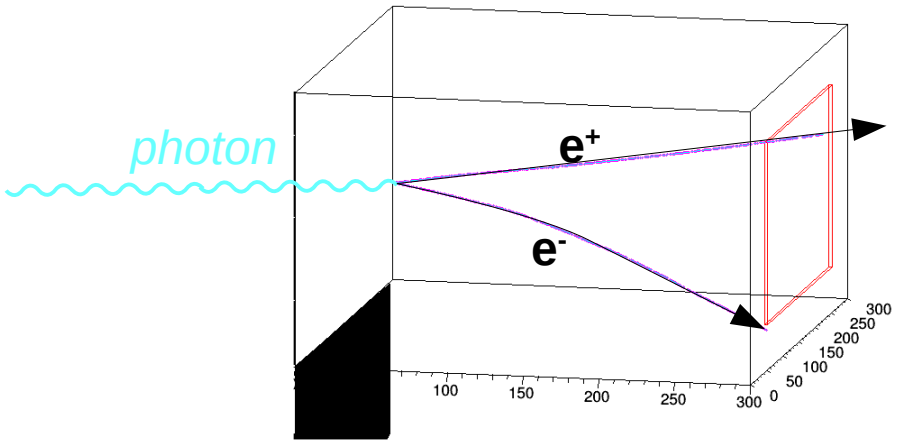
- CR physics
- Lorentz invariance
- Quantum gravity
- Axion-photons obsc

.....

HARPO Demonstrator

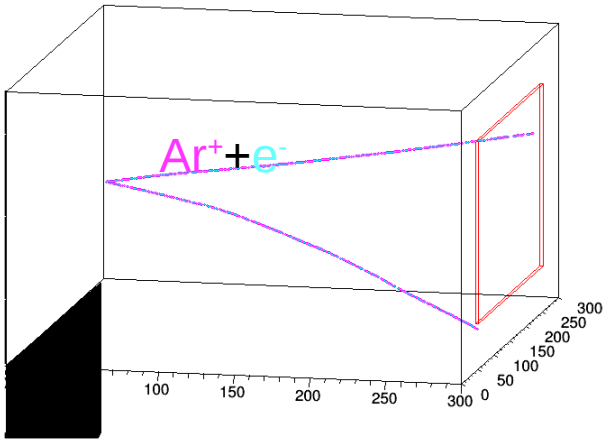


TPC: photon conversion



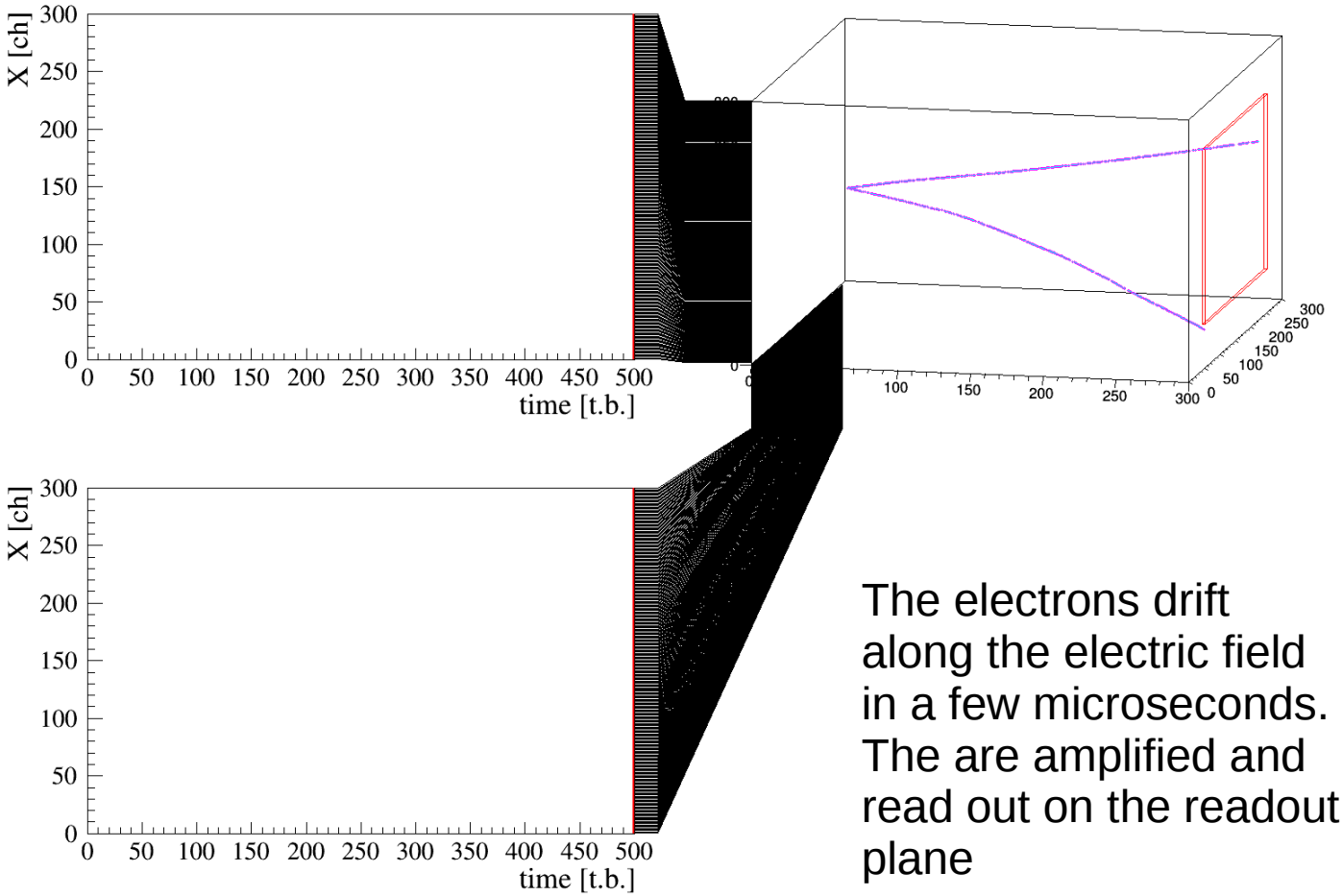
The incoming photon interacts with the gas and decays into an electron-positron pair

TPC: Gas ionisation



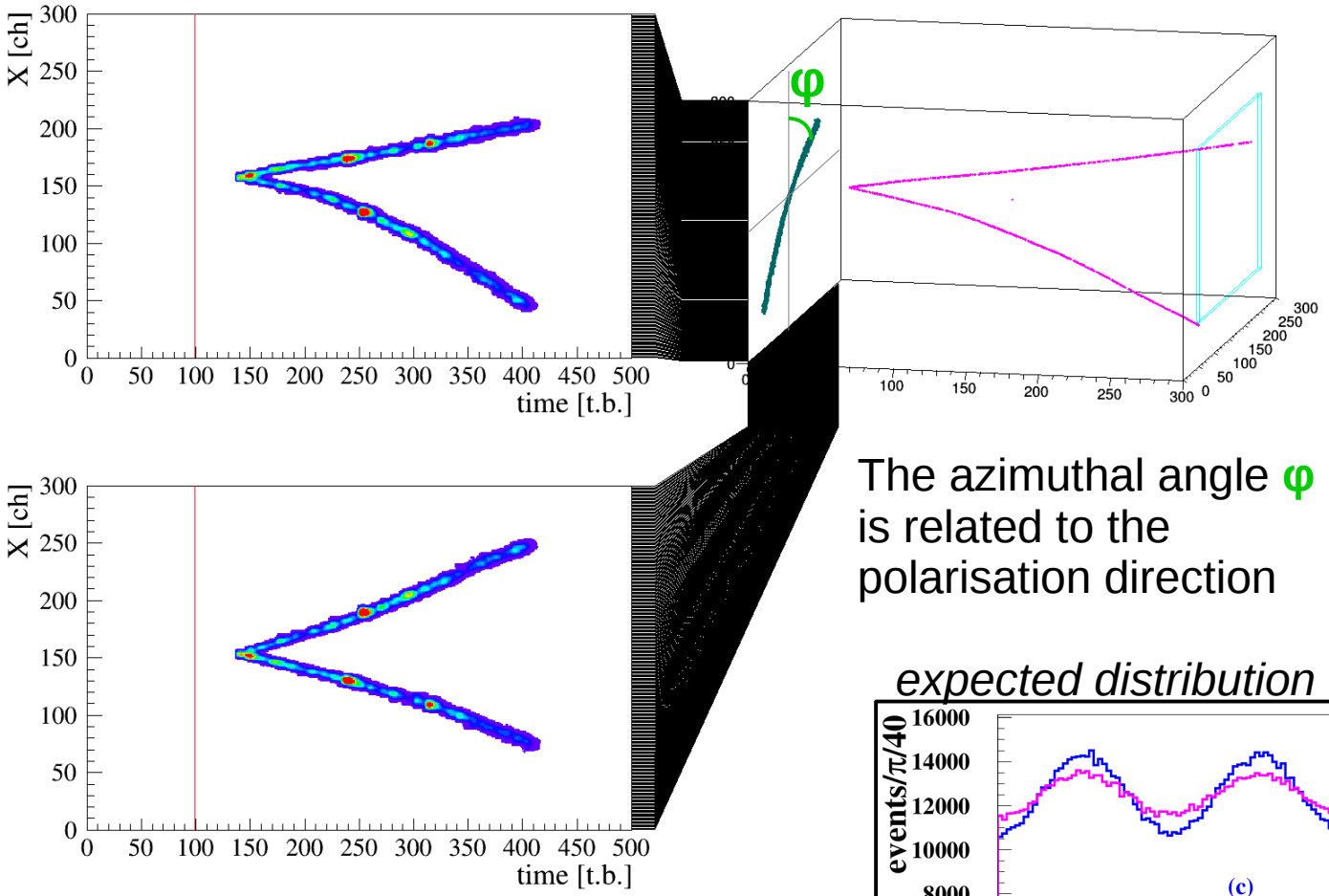
The electron and positron travel through the gas (mostly Argon) and ionises it, freeing many electrons and positive ions
This takes a few nanoseconds

TPC: Drift and Readout



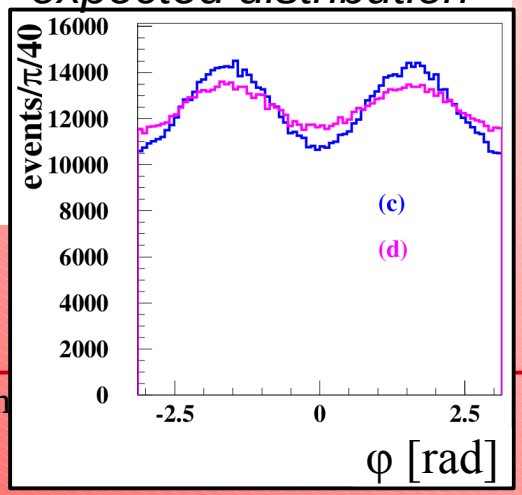
The electrons drift along the electric field in a few microseconds. The are amplified and read out on the readout plane

Polarisation measurement



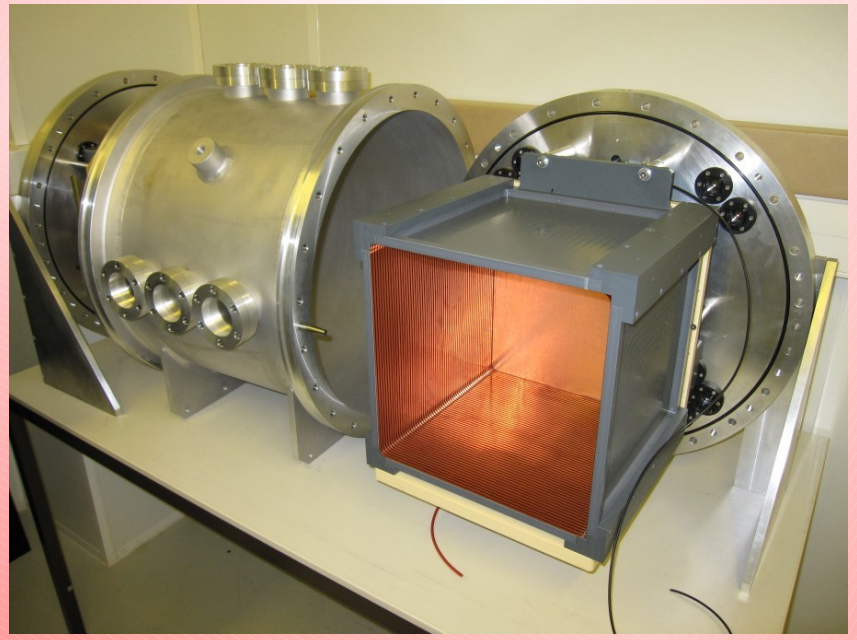
The azimuthal angle φ is related to the polarisation direction

expected distribution

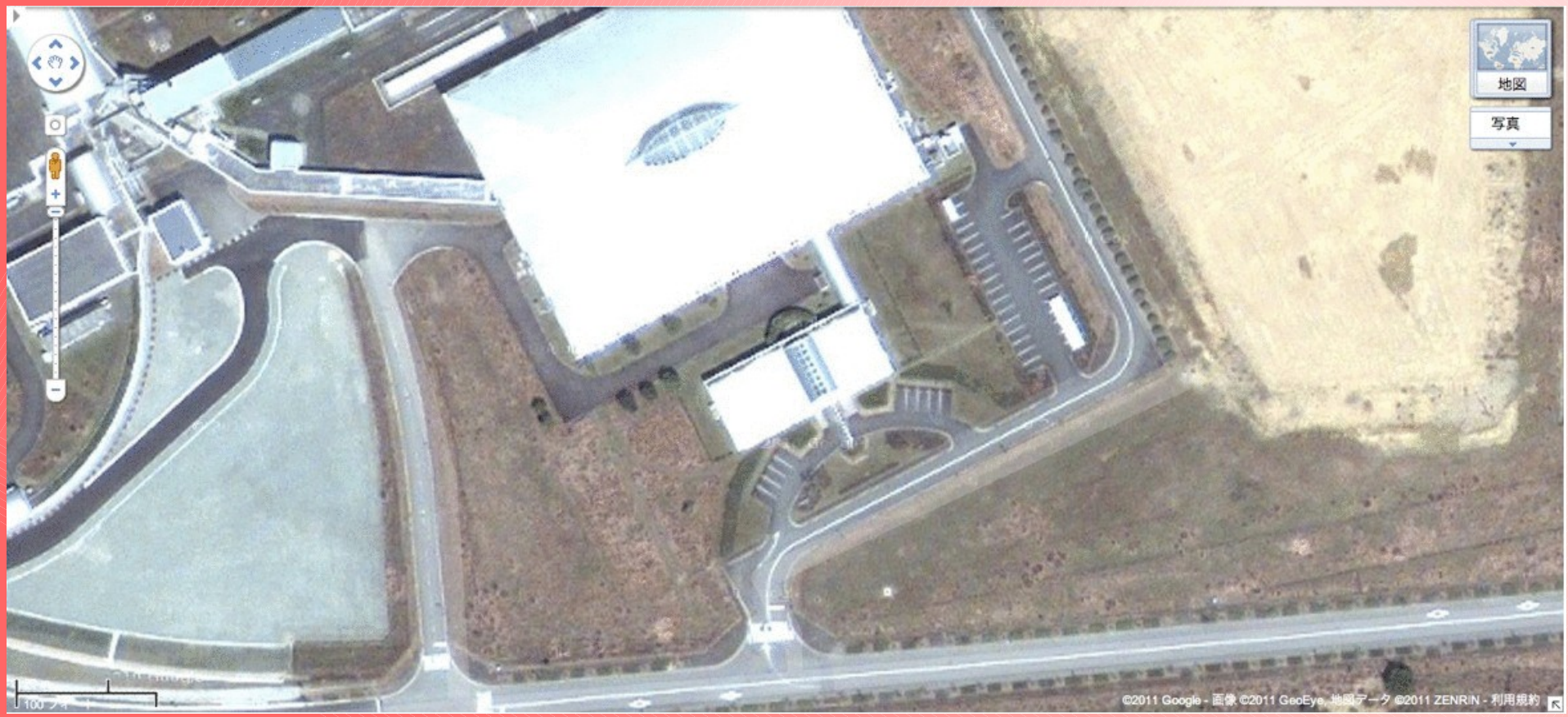


HARPO Demonstrator

- Purpose
  - Assess challenges
  - Demonstrate performance in test beam
- Realisation
  - 30cm cubic TPC
  - Ar/iC_4H_{10} 95/5 up to 5bar
  - micromegas+2GEM amplification
  - 2x288 strips readout (x&y), 1mm pitch
  - AFTER readout electronics,
    511 time bins, up to 50MHz (33 used)
  - trigger: 6 scintillators



Going to Japan



Shipping equipment

Departure from LLR

Arrival in NewSUBARU

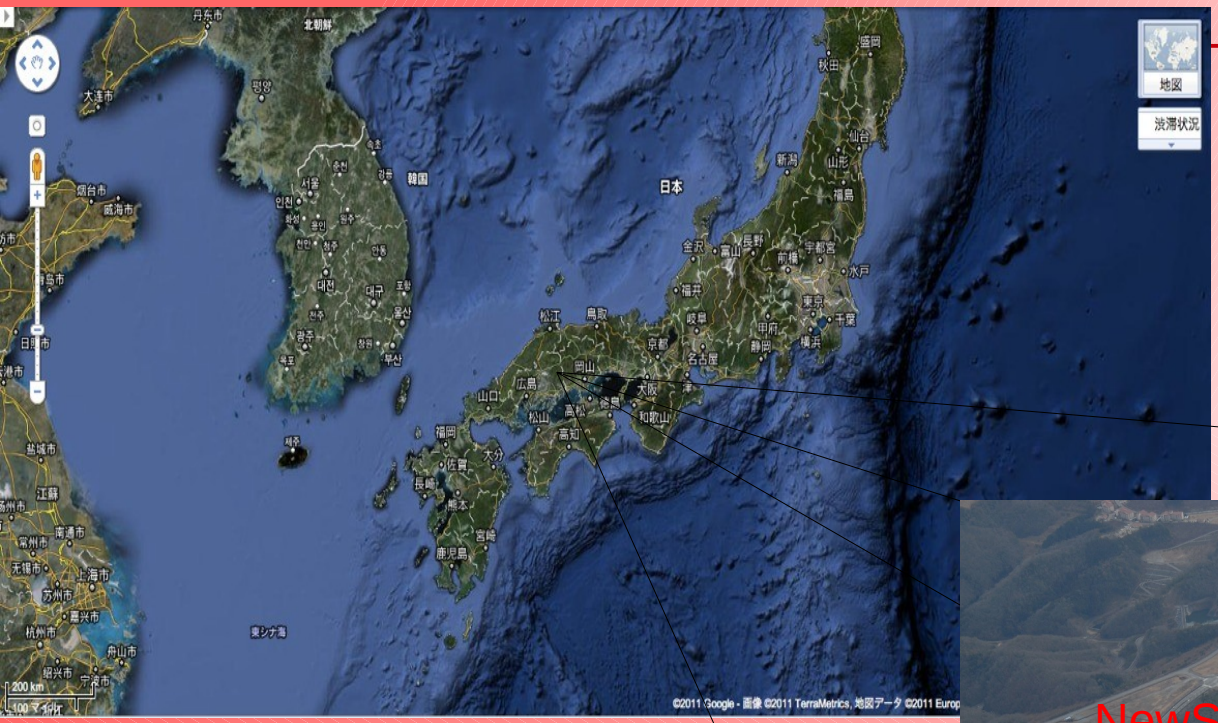
Shipping equipment

Departure from LLR

Arrival in NewSUBARU

Intermède animalier 1

NewSUBARU


日本
韓国
地図
渋滞状況

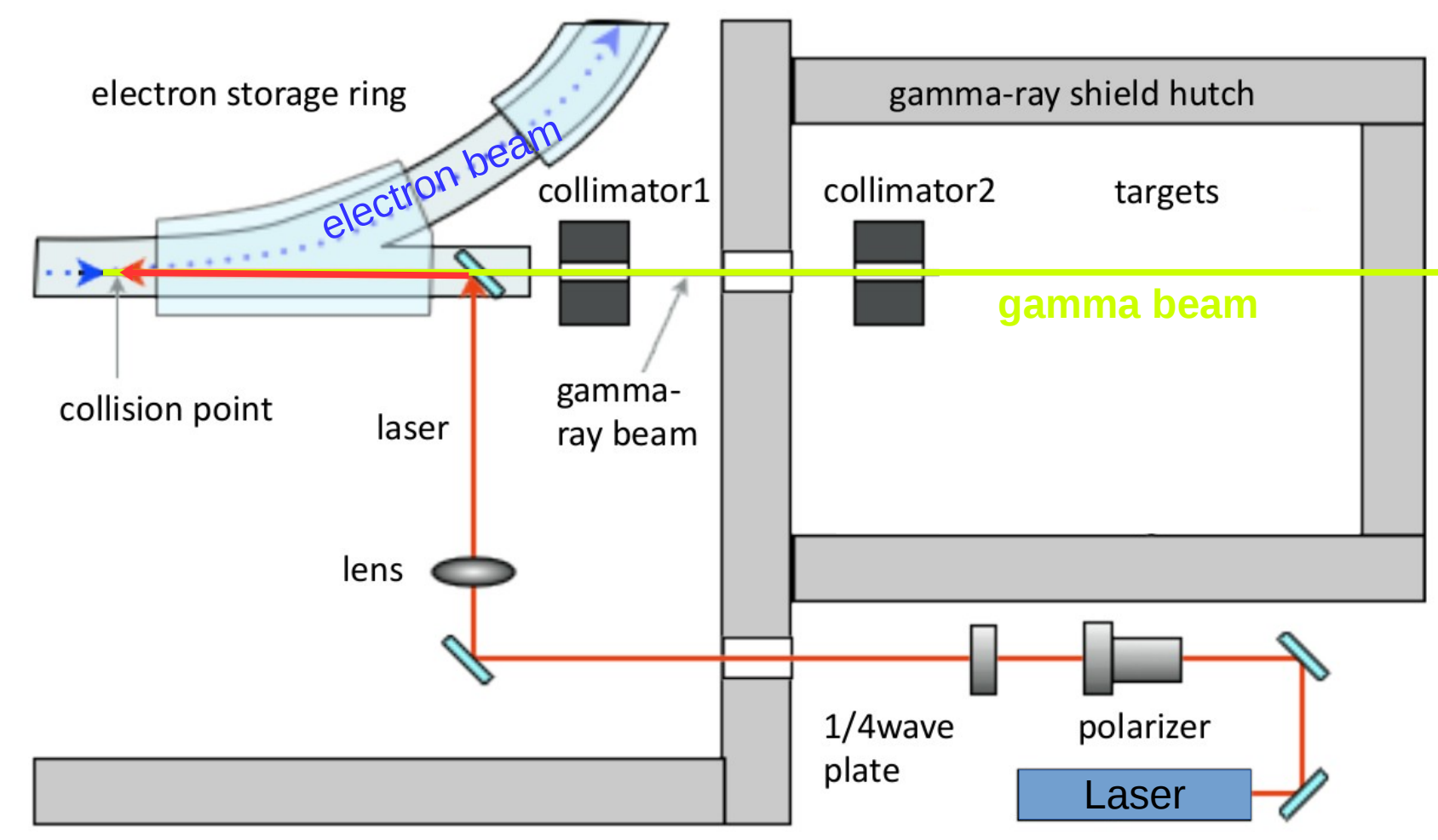
NewSUBARU
XFEL
Linac
Synchrotron
Storage
Ring

NewSUBARU photon beam

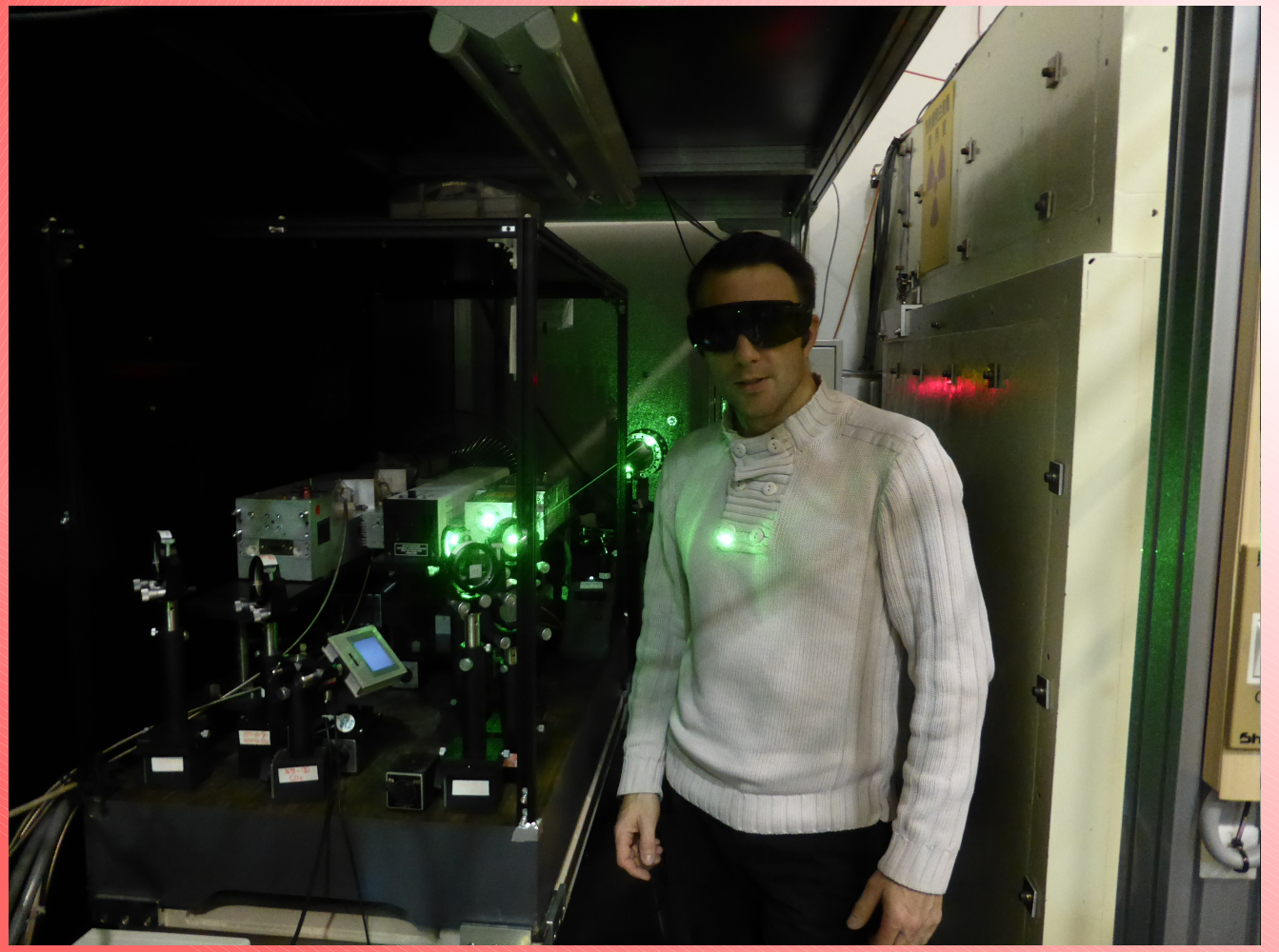
- Polarised gamma ray beam
  - Inverse Compton
  - electron beam 0.6, 1., 1.2 or 1.5 GeV
  - laser Nd (1ω or 2ω), Er or CO2

    => polarised photons 1.71 to 72.3MeV
- Pulsed mode
  - Nd: 20kHz, Er:200kHz, CO2: not

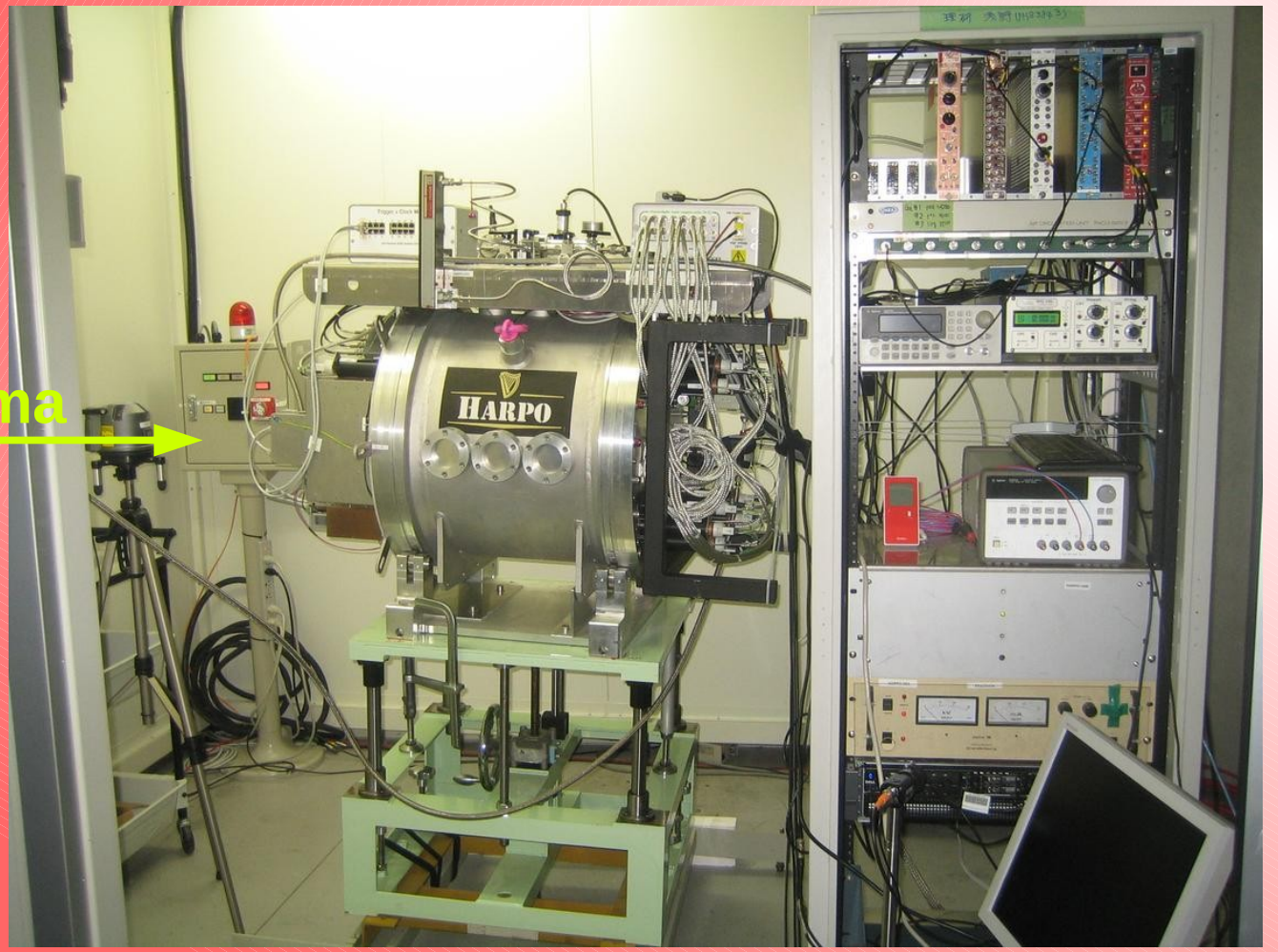
Gamma beam


electron storage ring
electron beam
collimator1
collimator2
targets
gamma-ray shield hutch
gamma beam
HARPO
collision point
laser
gamma-
ray beam
lens
1/4wave
plate
polarizer
Laser

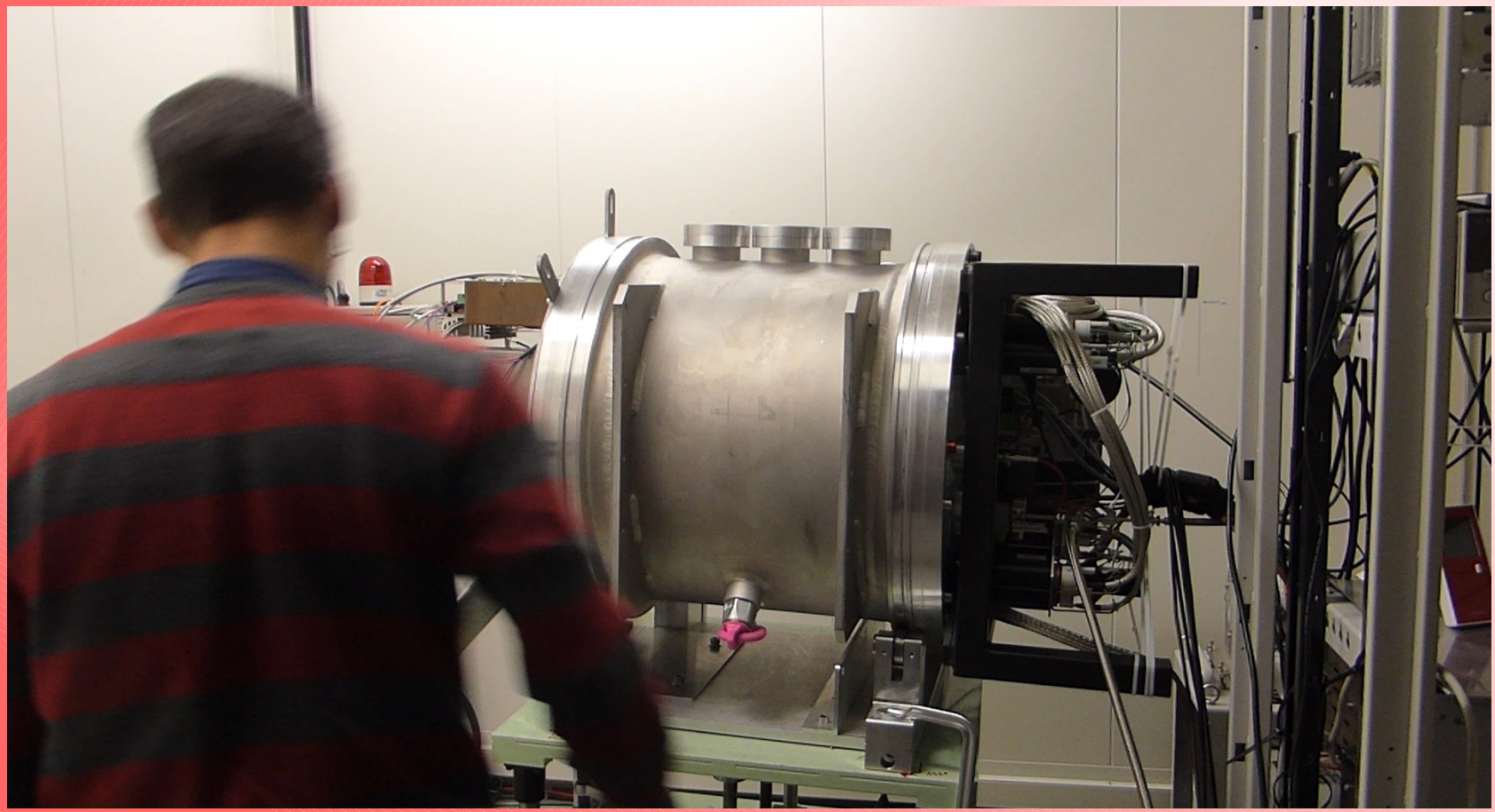
Laser beam



HARPO in beam

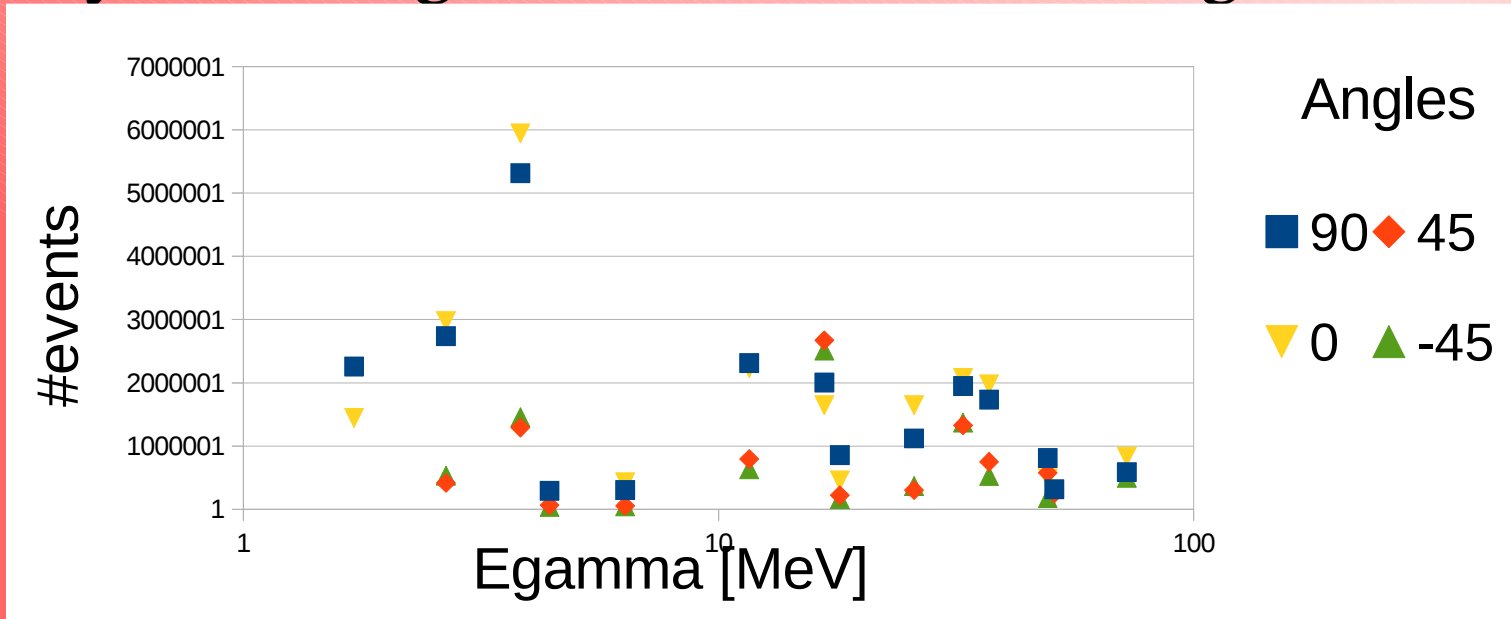


Rotation

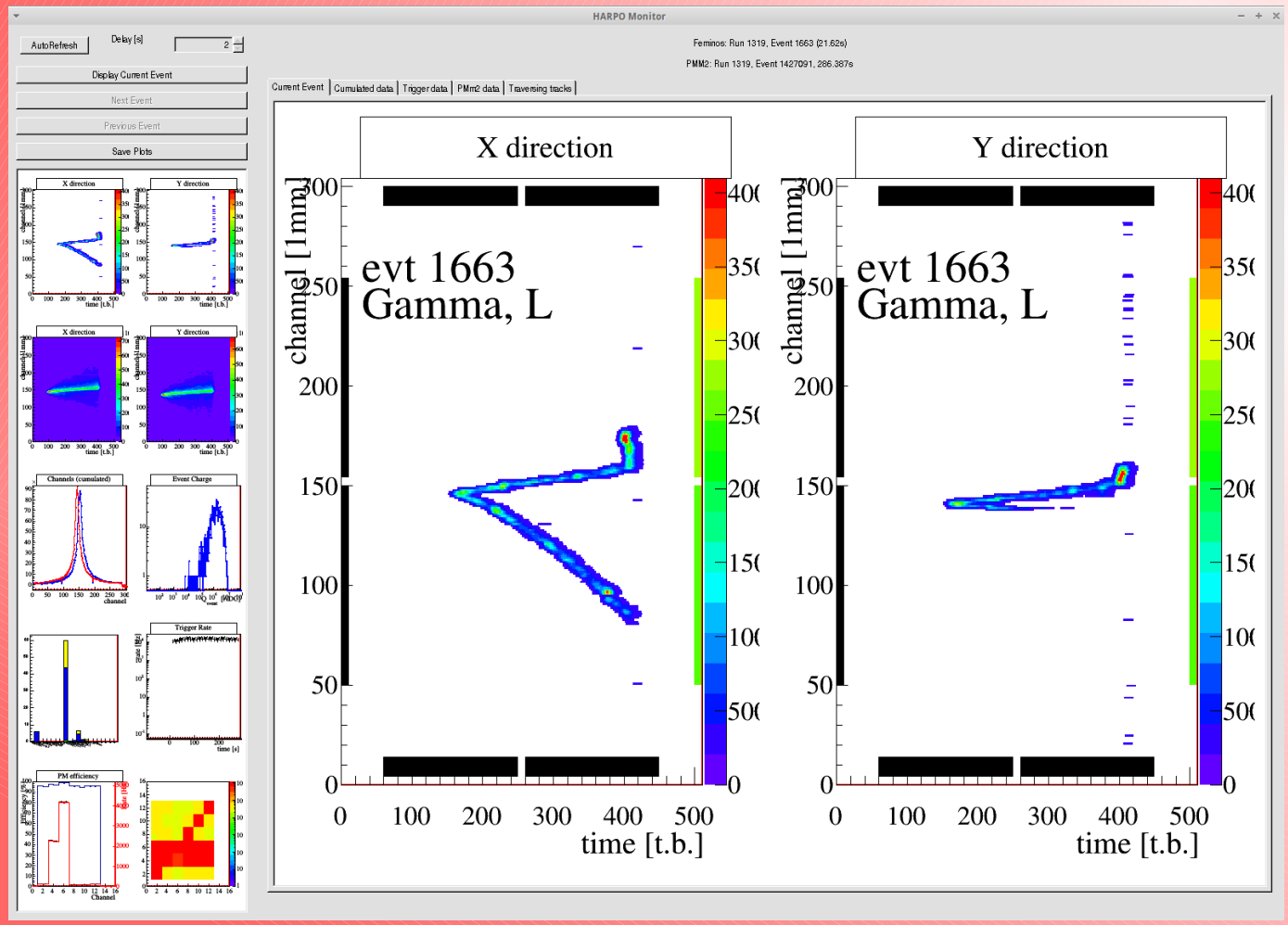


Beam campaign

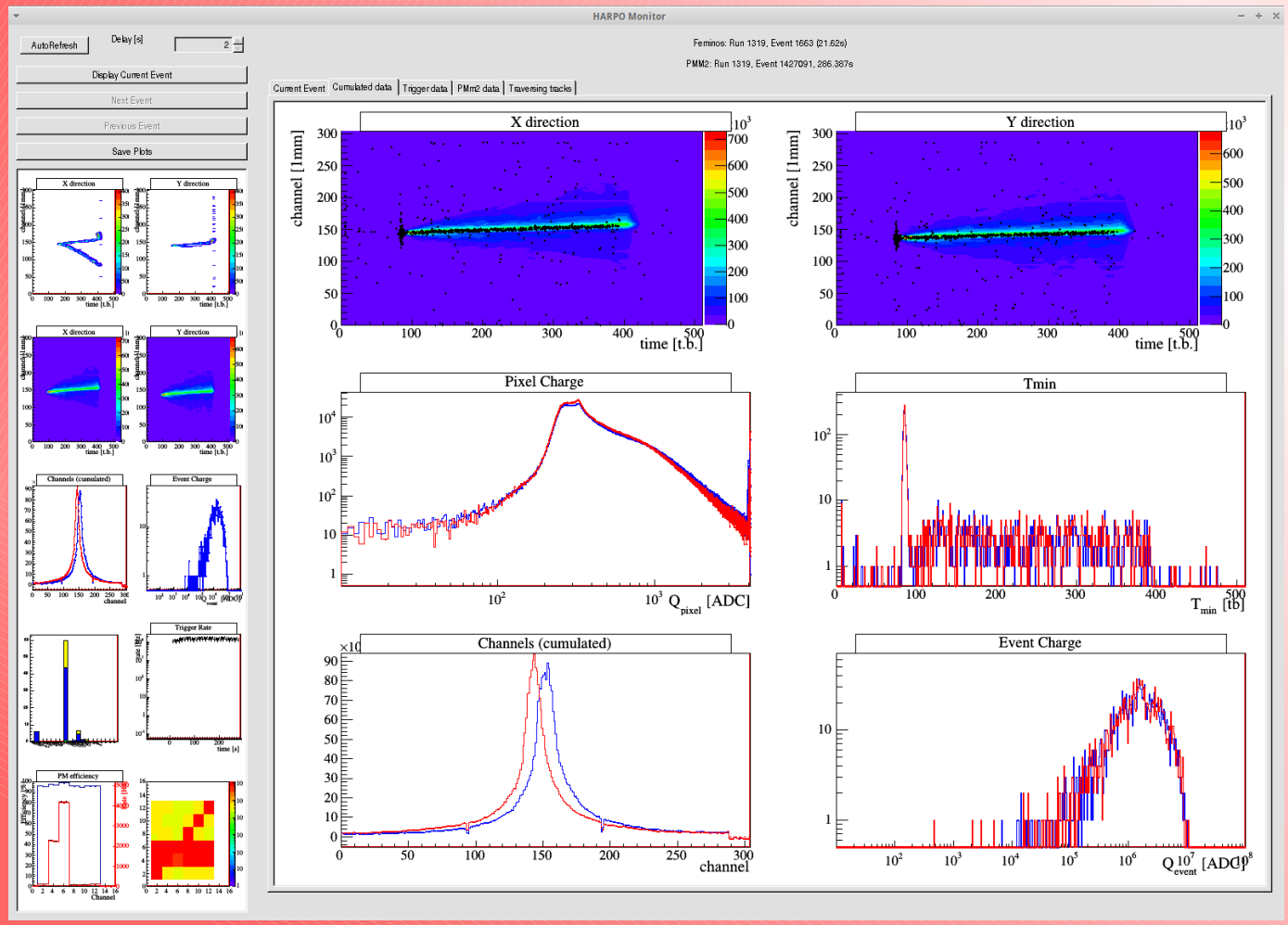
- ~20 days of data taking
- 13 gamma energies, beam polarised or not
- 4 TPC orientation for angle systematics
- >60Mevents, >1TB of data
- probably >20% gamma converted in gas



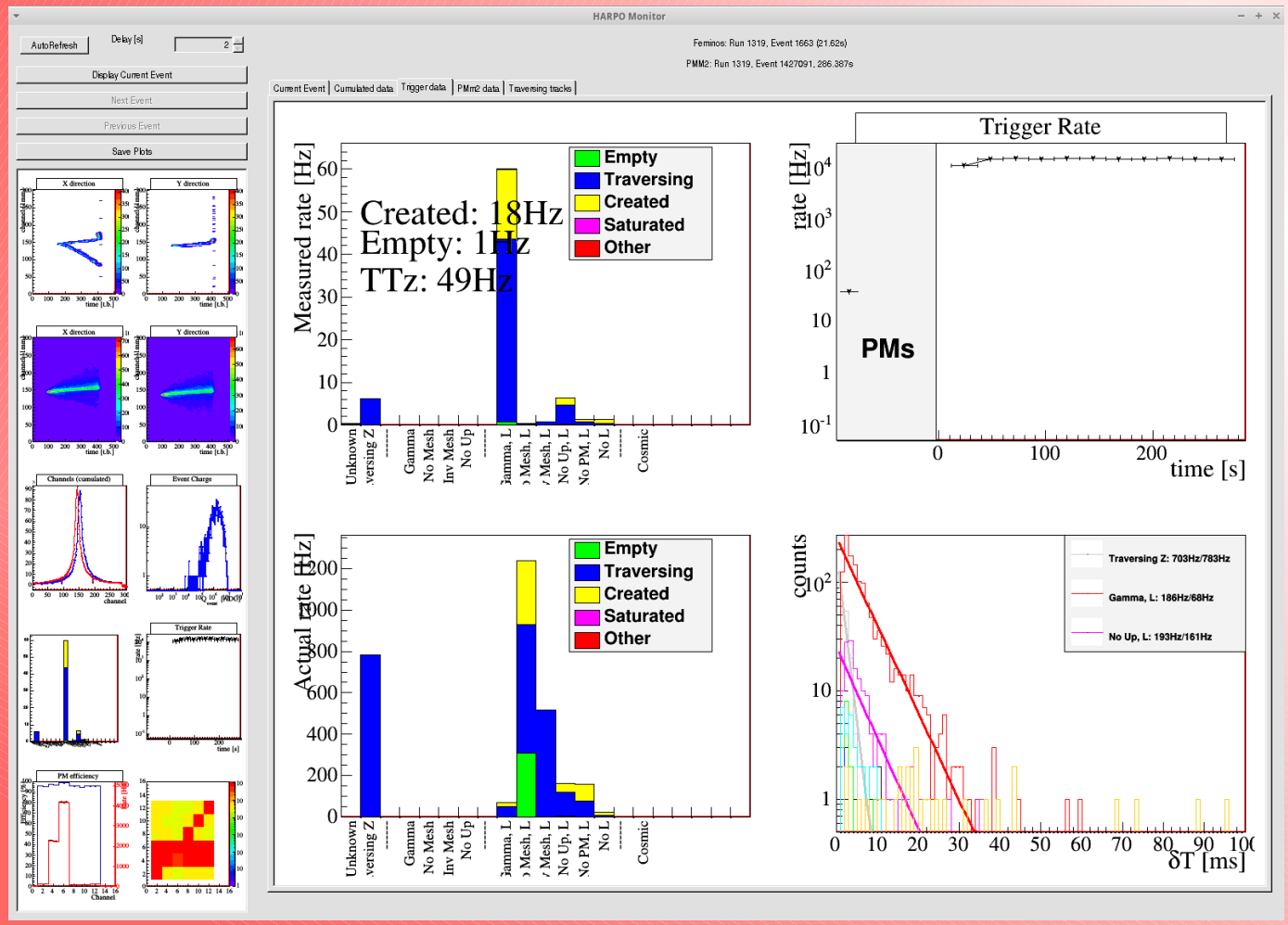
Monitoring


HARPO Monitor
AutoRefresh
Delay [s]
Display Current Event
Next Event
Previous Event
Save Plots
Feminos: Run 1319, Event 1663 (21.62s)
PMM2: Run 1319, Event 1427091, 286.387s
Current Event
Cumulated data
Trigger data
PMm2 data
Traversing tracks
X direction
Y direction
evt 1663
Gamma, L
channel [1mm]
time [t.b.]

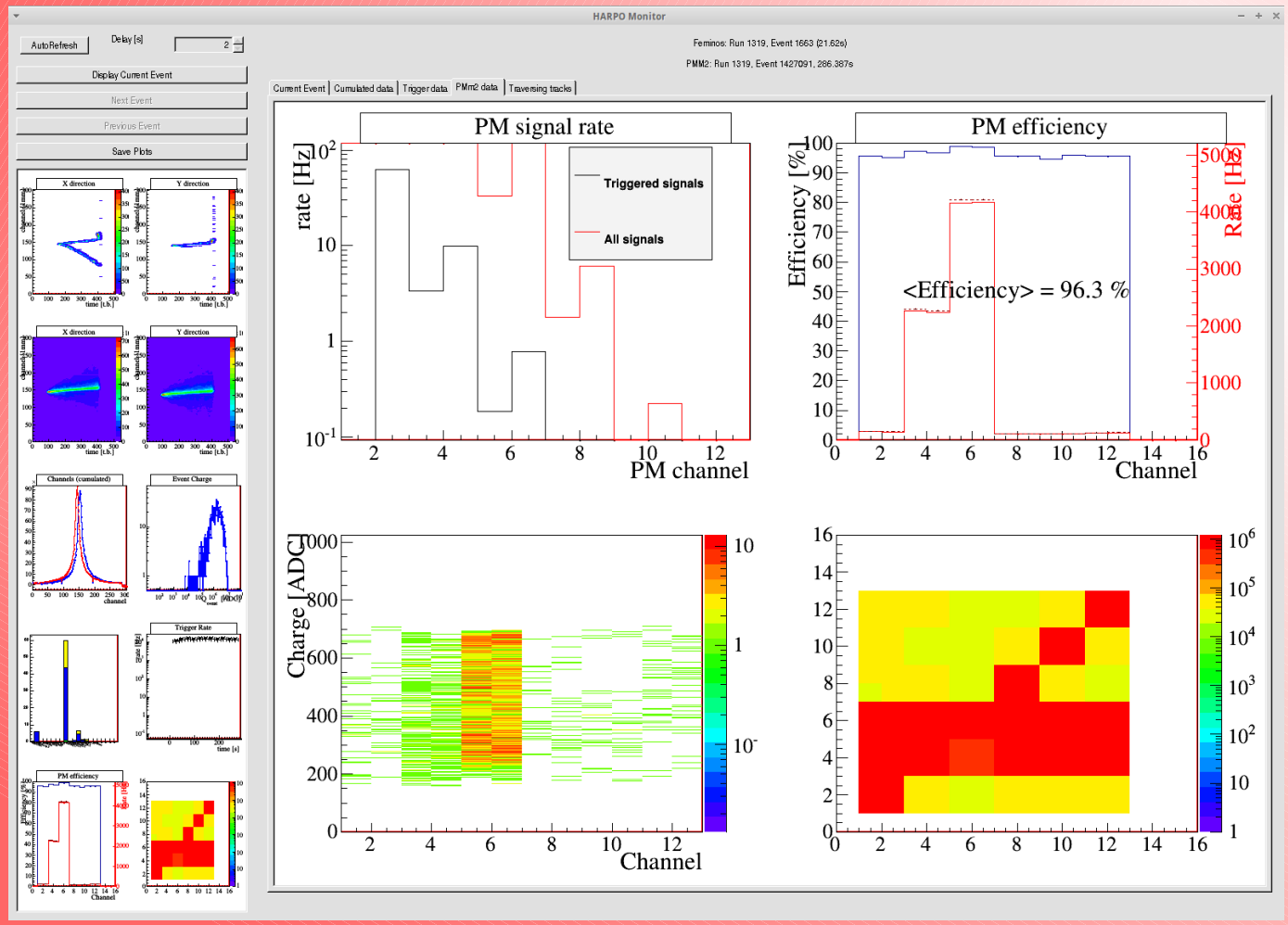
Monitoring


HARPO Monitor
AutoRefresh
Delay [s]
Display Current Event
Next Event
Previous Event
Save Plots
Feminos: Run 1319, Event 1663 (21.62s)
PMM2: Run 1319, Event 1427091, 286.387s
Current Event
Cumulated data
Trigger data
PMm2 data
Traversing tracks
X direction
Y direction
channel [1 mm]
time [t.b.]
Pixel Charge
Q pixel [ADC]
Tmin
T min [tb]
Channels (cumulated)
channel
Event Charge
Q event [ADC]

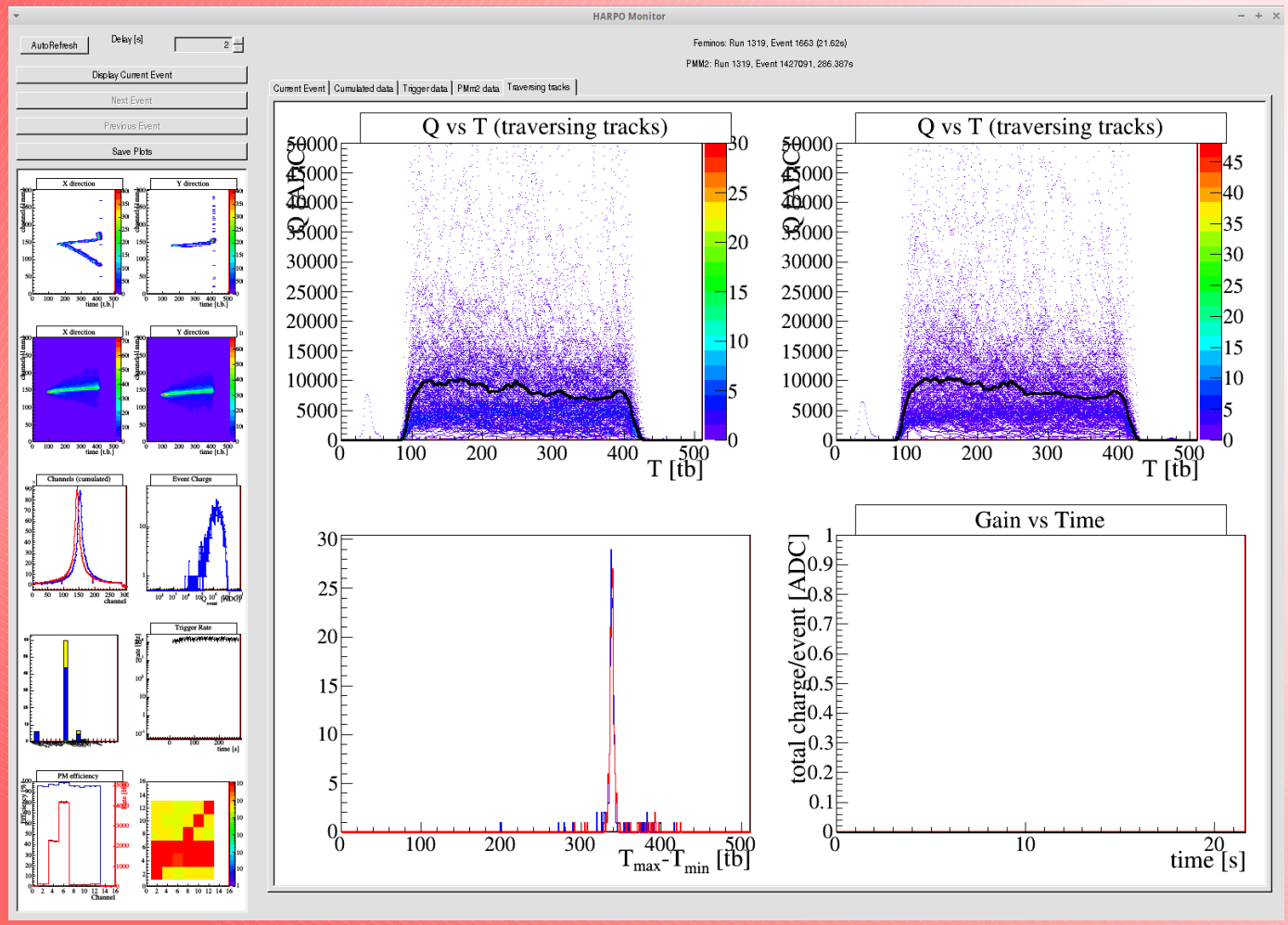
Monitoring


HARPO Monitor
AutoRefresh
Delay [s]
Display Current Event
Next Event
Previous Event
Save Plots
Feminos: Run 1319, Event 1663 (21.62s)
PMM2: Run 1319, Event 1427091, 286.387s
Current Event
Cumulated data
Trigger data
PMm2 data
Traversing tracks
Created: 18Hz
Empty: 1Hz
TTz: 49Hz
Measured rate [Hz]
Empty
Traversing
Created
Saturated
Other
Trigger Rate
rate [Hz]
PMs
time [s]
Actual rate [Hz]
counts
Traversing Z: 703Hz/783Hz
Gamma, L: 186Hz/68Hz
No Up, L: 193Hz/161Hz
δT [ms]
Unknown
Gamma
No Mesh
Inv Mesh
No Up
No L
Cosmic

Monitoring


HARPO Monitor
AutoRefresh
Delay [s]
Display Current Event
Next Event
Previous Event
Save Plots
Current Event
Cumulated data
Trigger data
PMm2 data
Traversing tracks
PM signal rate
Triggered signals
All signals
rate [Hz]
PM channel
PM efficiency
Efficiency [%]
<Efficiency> = 96.3 %
Rate [Hz]
Channel
Charge [ADC]
Channel

Monitoring


HARPO Monitor
AutoRefresh
Delay [s]
Display Current Event
Next Event
Previous Event
Save Plots
Feminos: Run 1319, Event 1663 (21.62s)
PMM2: Run 1319, Event 1427091, 286.387s
Current Event
Cumulated data
Trigger data
PMm2 data
Traversing tracks
Q vs T (traversing tracks)
Q [ADC]
T [tb]
Q vs T (traversing tracks)
Q [ADC]
T [tb]
Tmax-Tmin [tb]
Gain vs Time
total charge/event [ADC]
time [s]

Intermède animalier 2

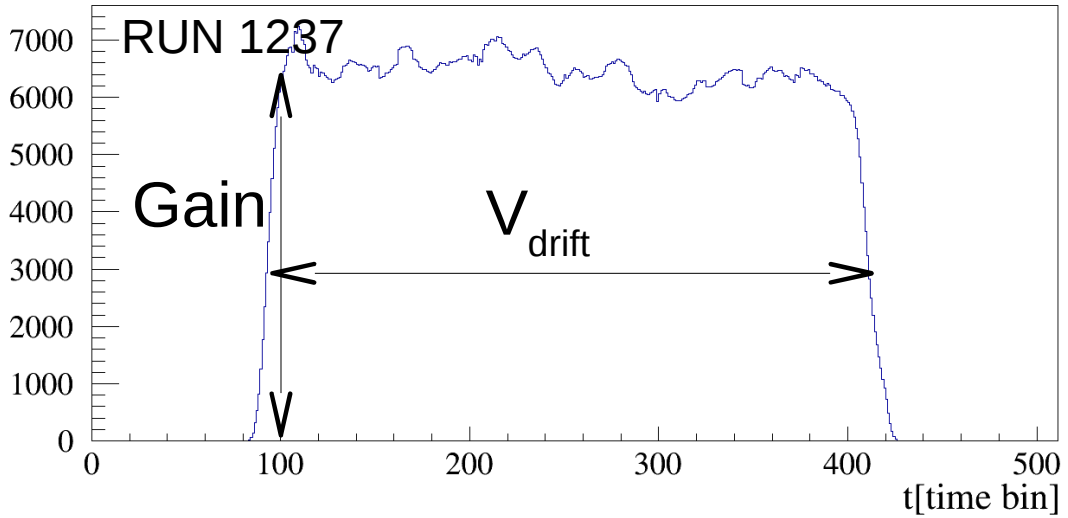
HARPO gas system

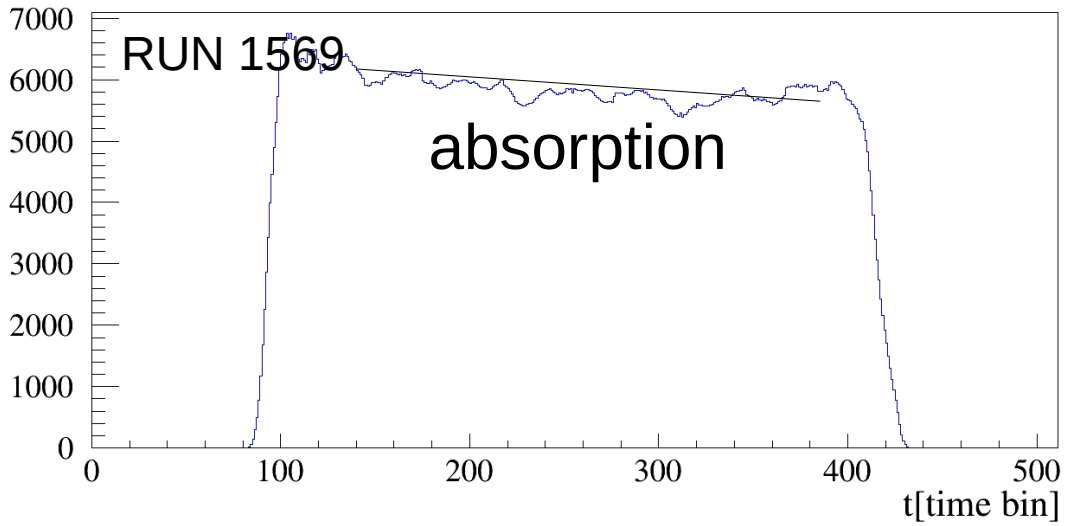
- Sealed vessel
- Leaks minimised in vacuum with He system
- Gas filling procedure
  - vacuum pumping ($<10^{-5}$bar)
  - “rinsing” with gas mixture ~100mbar
  - vacuum pumping ($\sim 10^{-7}$bar)
  - 2 bar fill

Gas monitoring

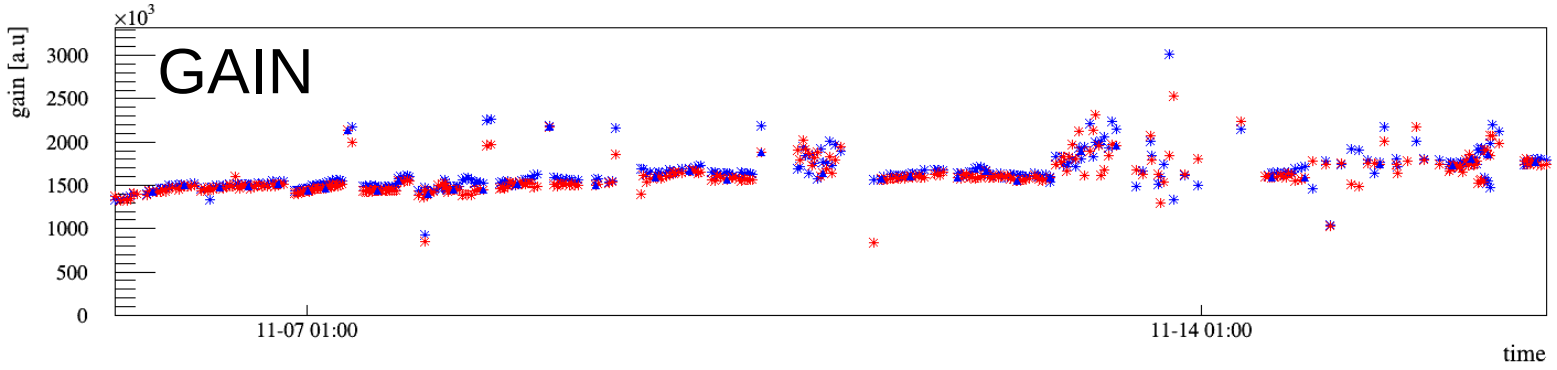
- No direct measurement of the gas
- Monitoring with track data
  - High momentum traversing tracks in Z
  - ~uniform energy deposition along Z (if corrected for angle)
  - Simple access to gain, drift velocity and absorption
  - Dedicated trigger line => ~2% of the events

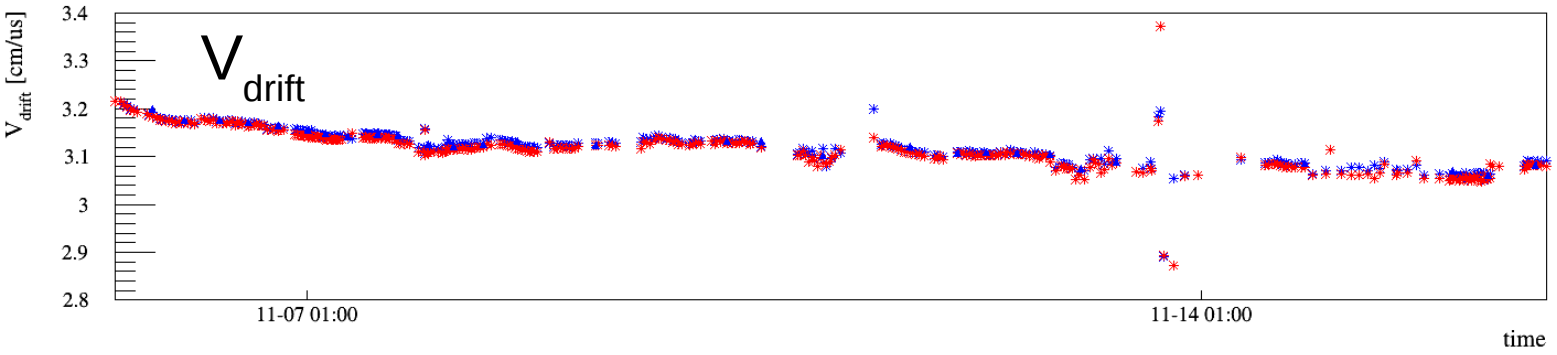
Cosmic rays

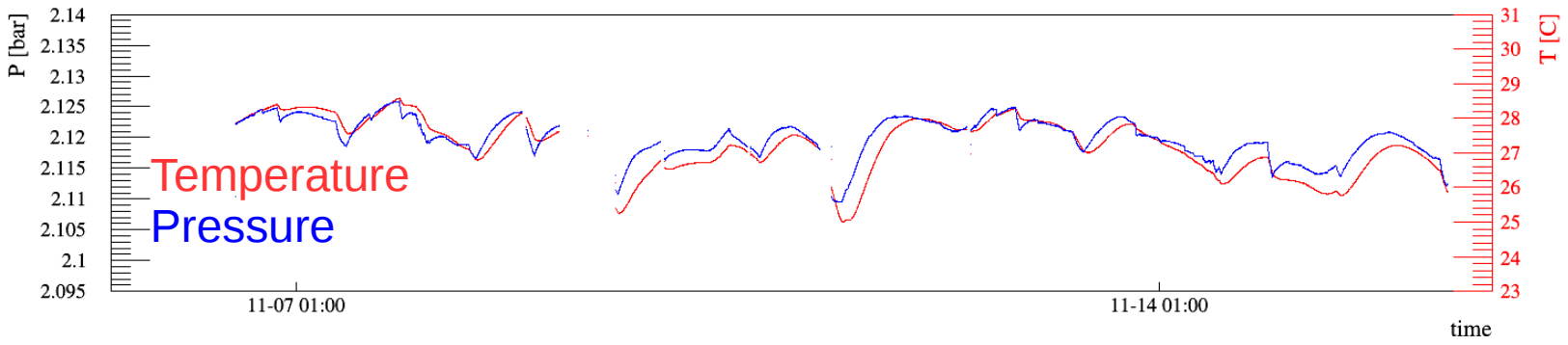

RUN 1237
Gain
V_{drift}
7000
6000
5000
4000
3000
2000
1000
0
0
100
200
300
400
500
t[time bin]


RUN 1569
absorption
7000
6000
5000
4000
3000
2000
1000
0
0
100
200
300
400
500
t[time bin]

Time evolution







T [°C]

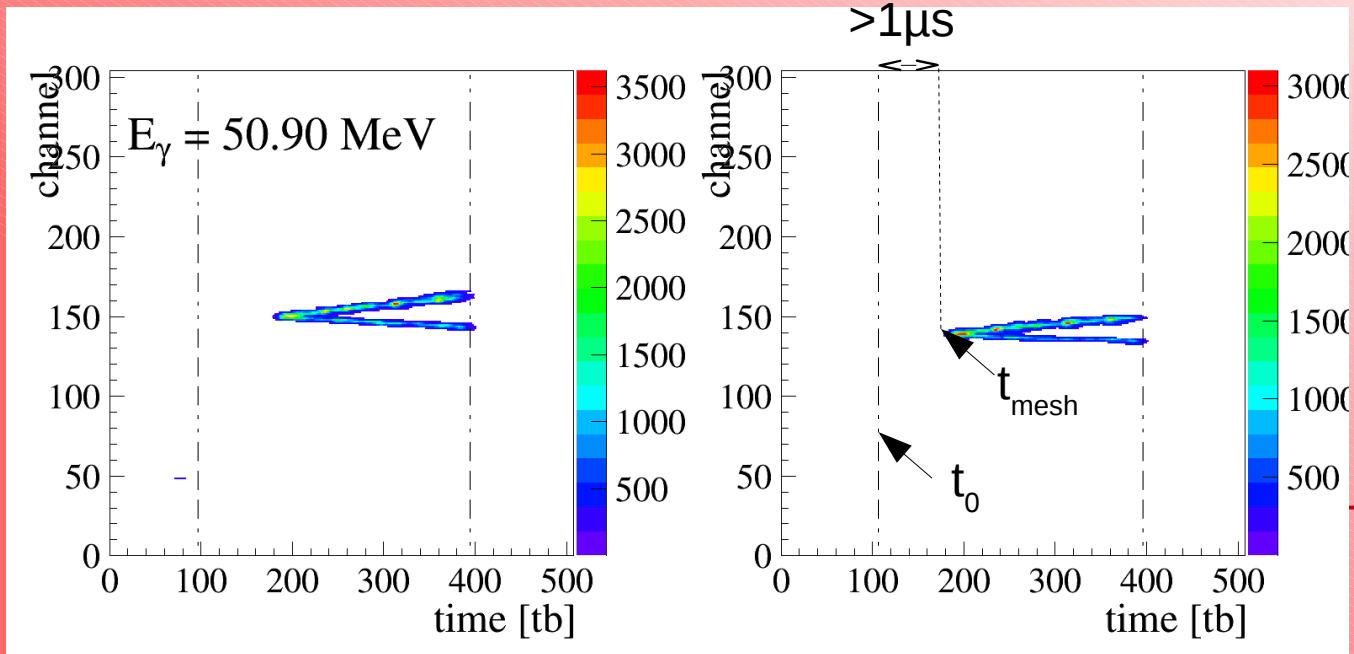
Gas stability

- 23 days in beam with same gas
- Almost no leak (no pressure loss)
- Slight decrease of Vdrift
- Stable gain
- Not much contamination (absorption). Longer analysis (with more statistics) necessary.

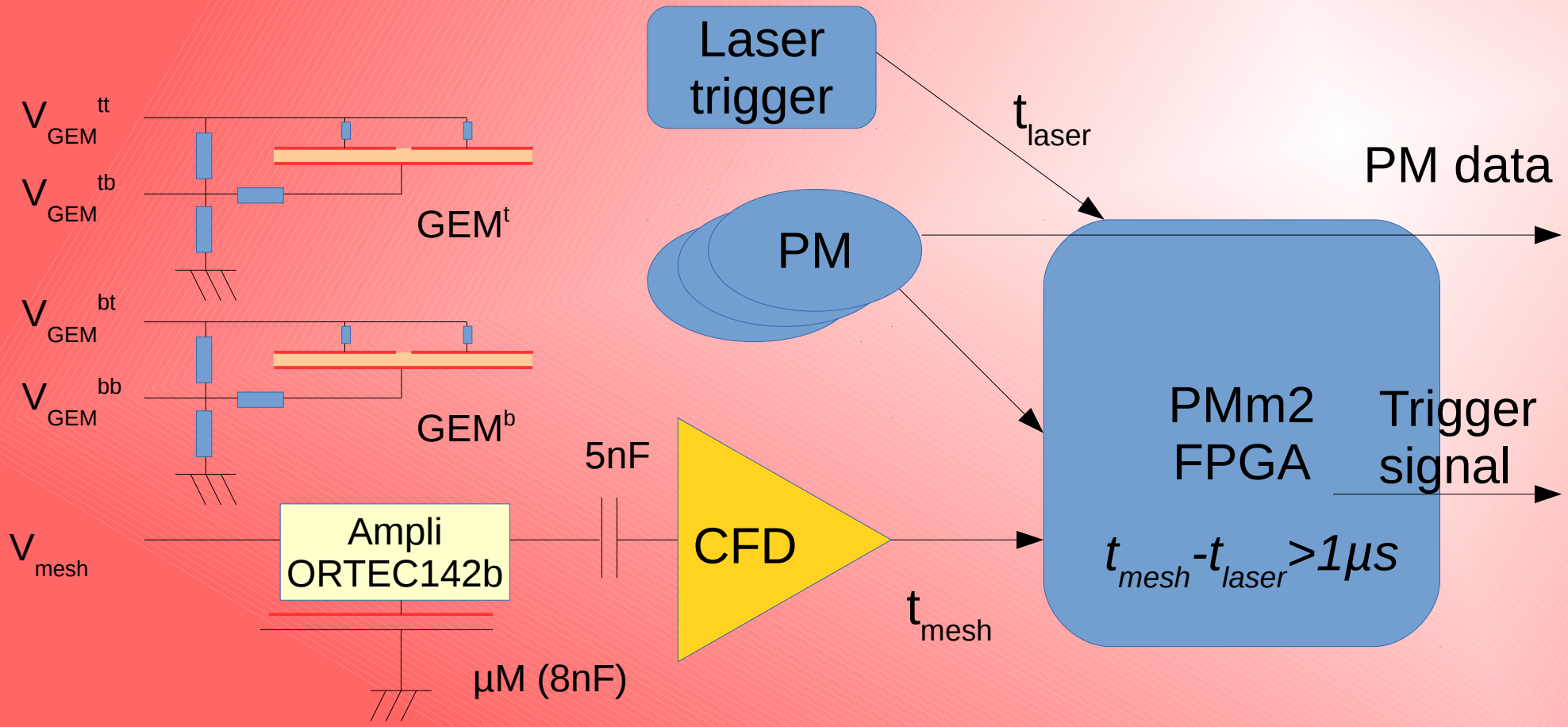
Gamma trigger

- Trigger on conversion in the gas volume
  - at least one scintillator (=> timing + trigger information)
  - if available, laser trigger signal
  - mesh signal >1us (→ 3cm) later

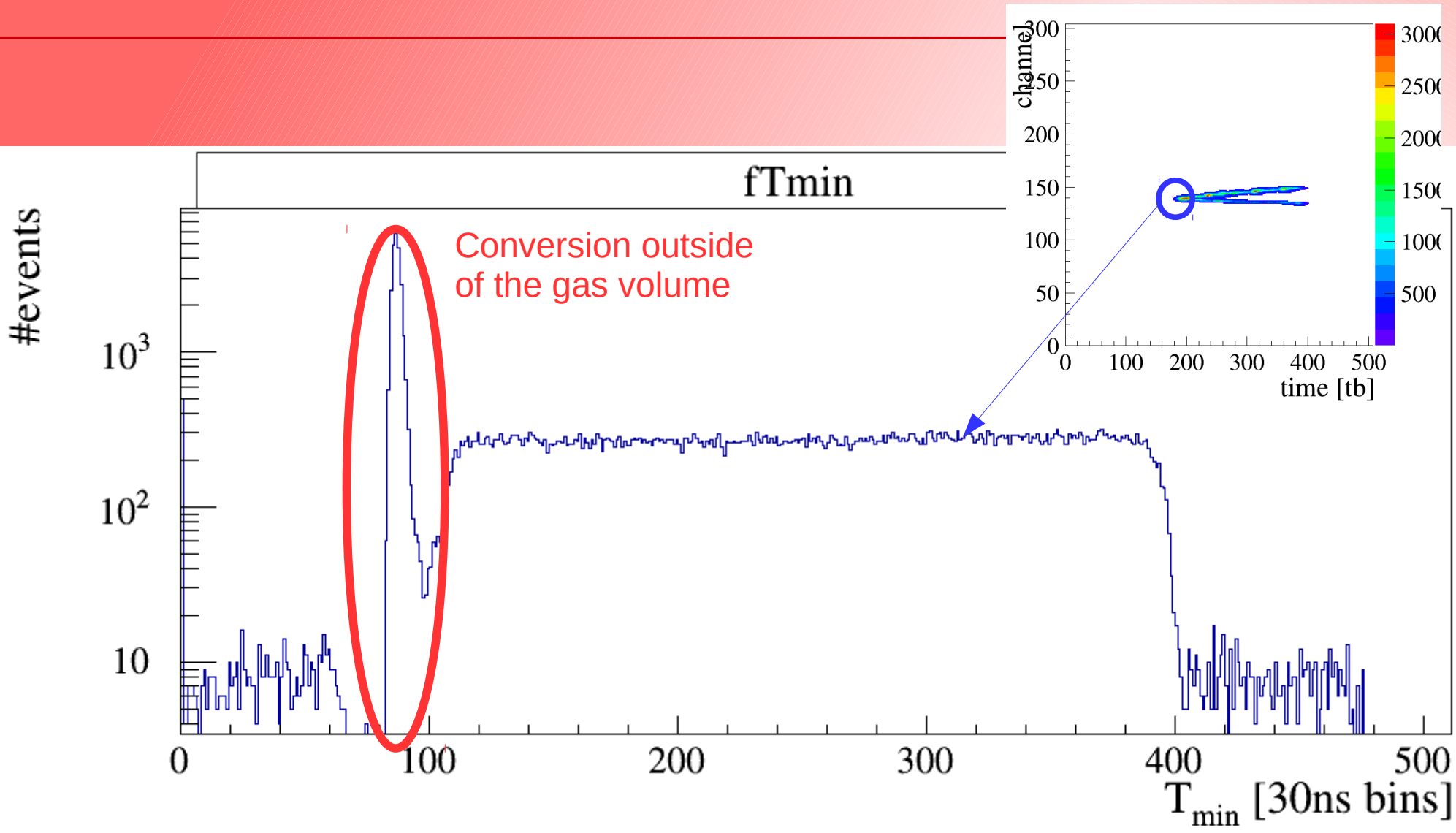
t_0



Micromegas trigger signal

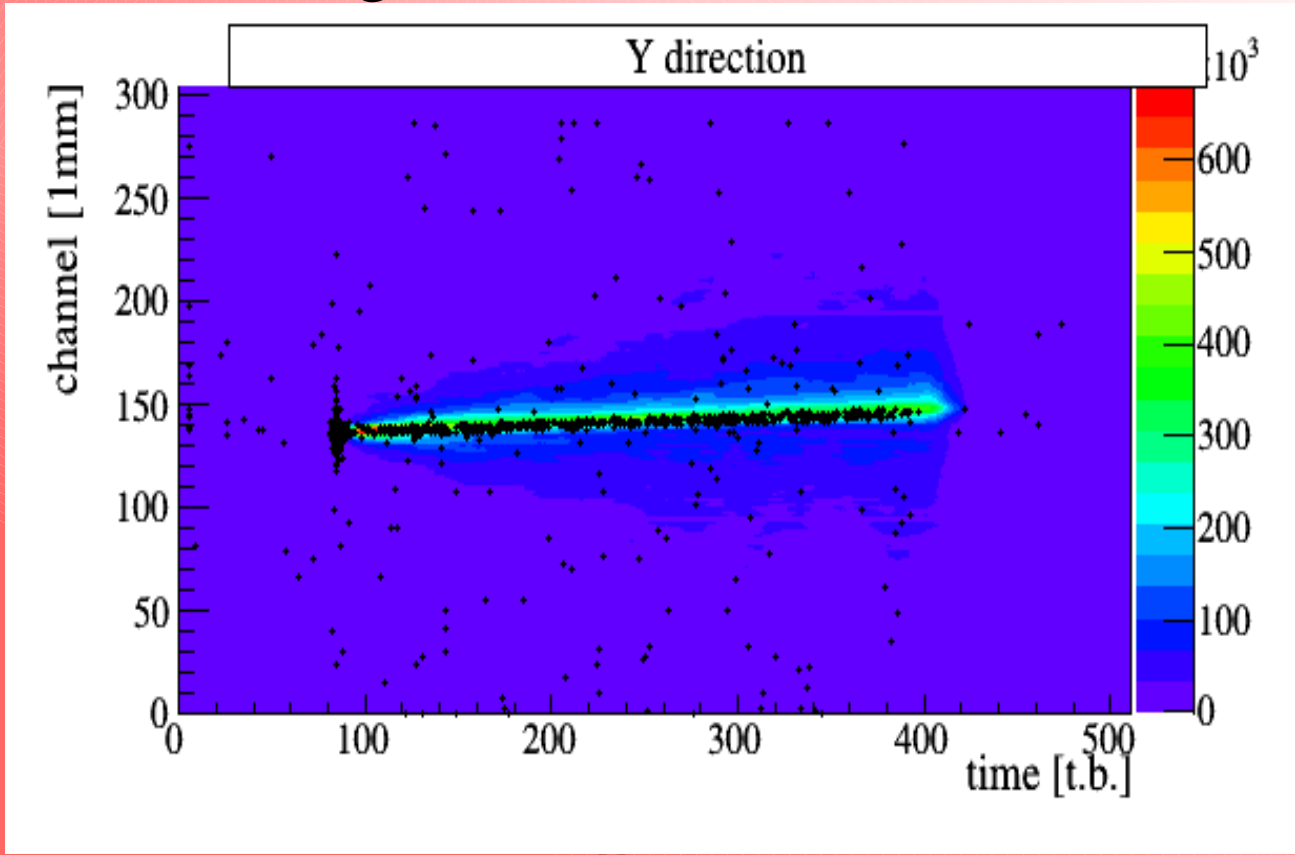


Trigger performance (?)

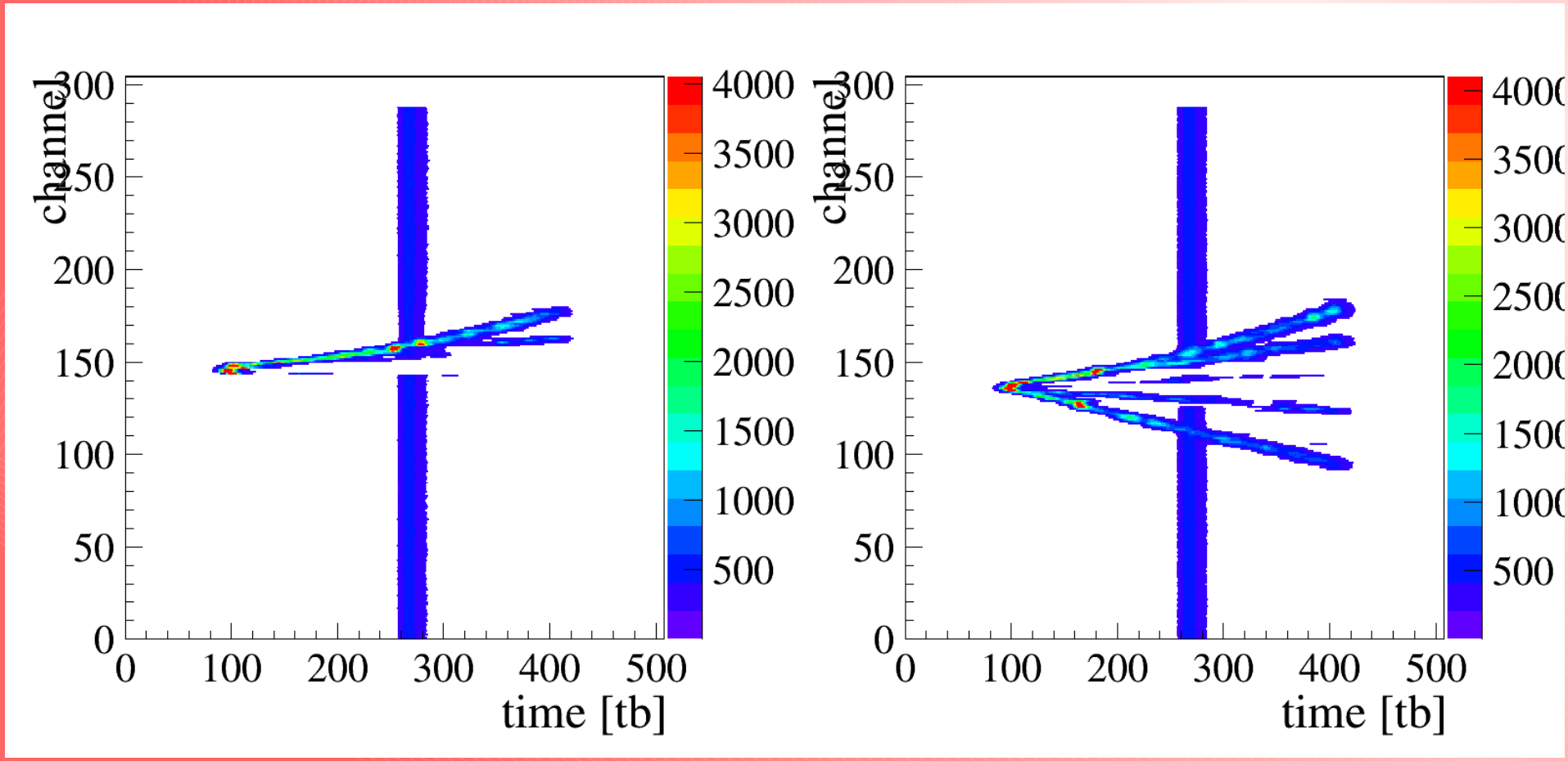


Trigger performance

- Further analysis of course needed
- “By eye” it worked well
  - Most events originate on the beam



A puzzling effect



Space charge? Ballistic deficit?

- Observed signal loss at the center of the detector (beam axis)
  - Only at high rate
  - space charge? ballistic deficit? other?
- “Ballistic deficit”
  - shaping 116ns
  - tracks in Z direction => several μs signals
- Improved by misaligning the detector

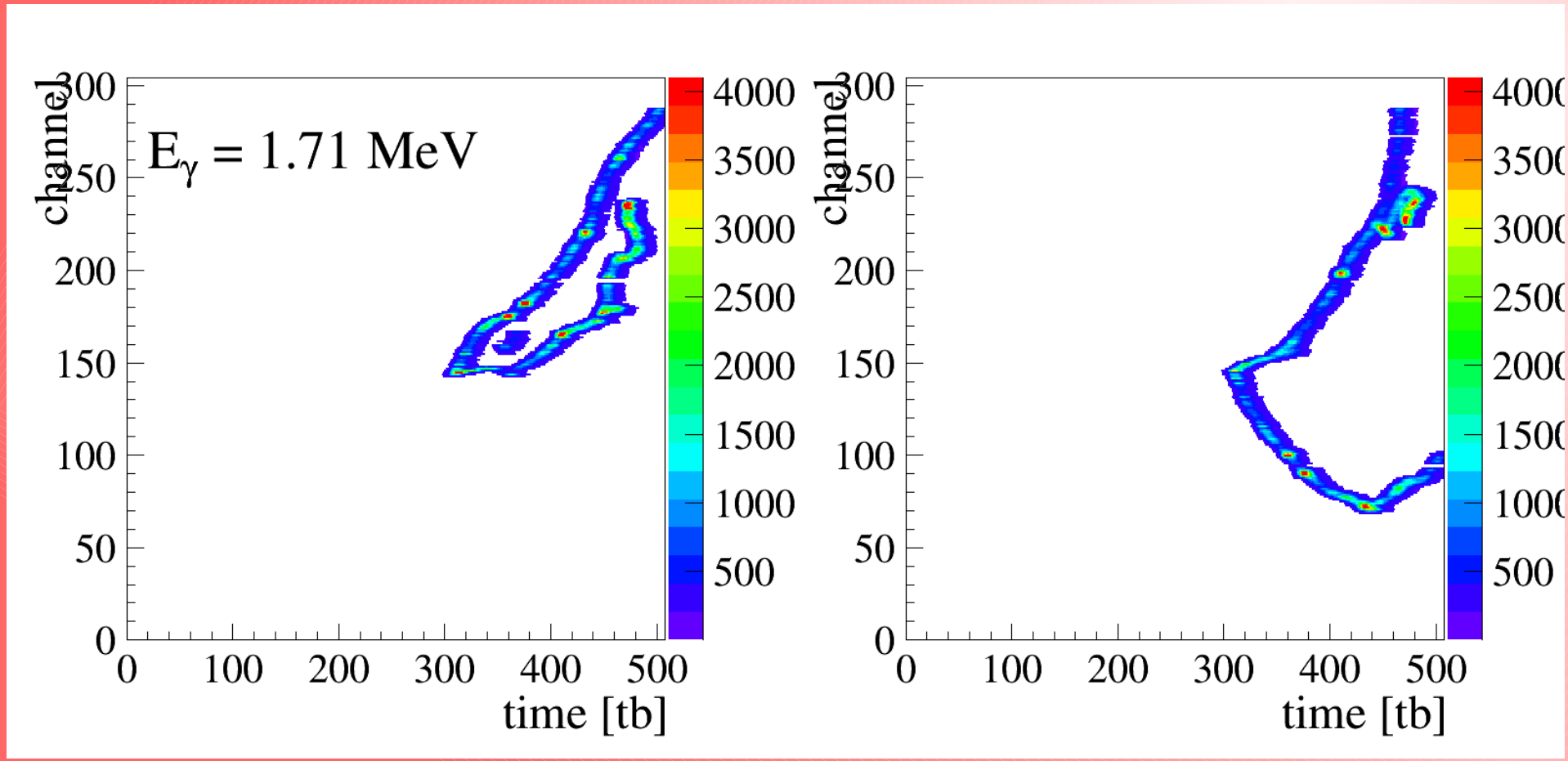
Intermède animalier 3

Conclusion and outlook

- Successful beam campaign with gamma rays
- Good gas stability over more than 20 days
- Good trigger performance
- Most issues related to high rate in beam
- Lots of work necessary for quantitative results…

Merci!

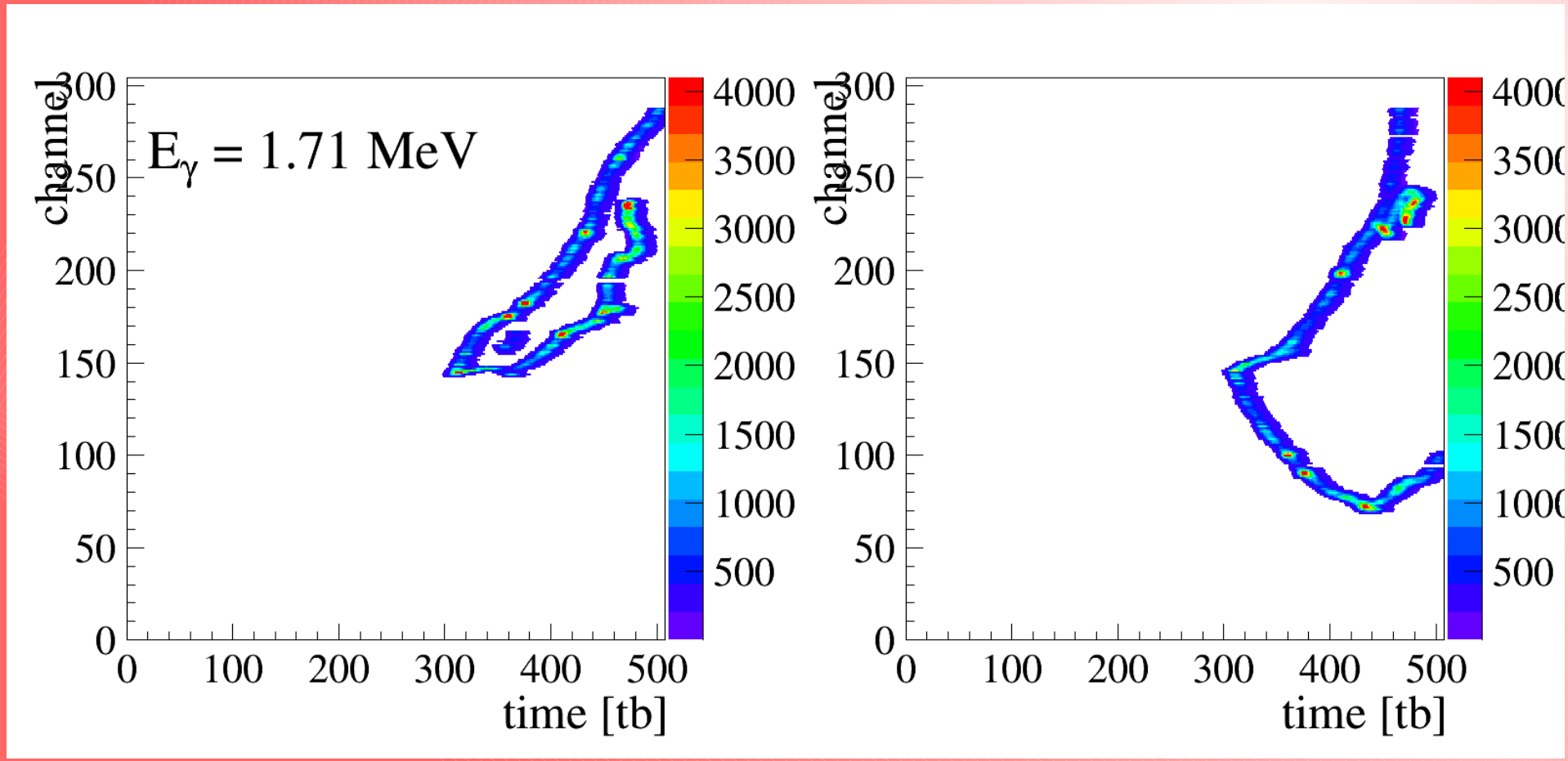
- Service de mécanique
  - conception, fabrication
- Service électronique
  -
- Service informatique
  -
- Service administratif
  - mission Japon, MoU, ...


E_γ = 1.71 MeV
channel
time [tb]
0
50
100
150
200
250
300
0
100
200
300
400
500
500
1000
1500
2000
2500
3000
3500
4000

Backup

Pressure scan

- One day dedicated to pressure scan
  - “Clean” gas at 1, 1.5, 2, 3 and 4 bar
  - Signal amplitude (dE/dx x gain) ~fixed (Adjusted on the fly)
  - At high pressure, cathode voltage was limited
- Good running condition at all pressures
- Increasing micromegas current spikes at high pressure
  - matching GEM over current => physics?


E_γ = 1.71 MeV
channel
time [tb]
0
50
100
150
200
250
300
0
100
200
300
400
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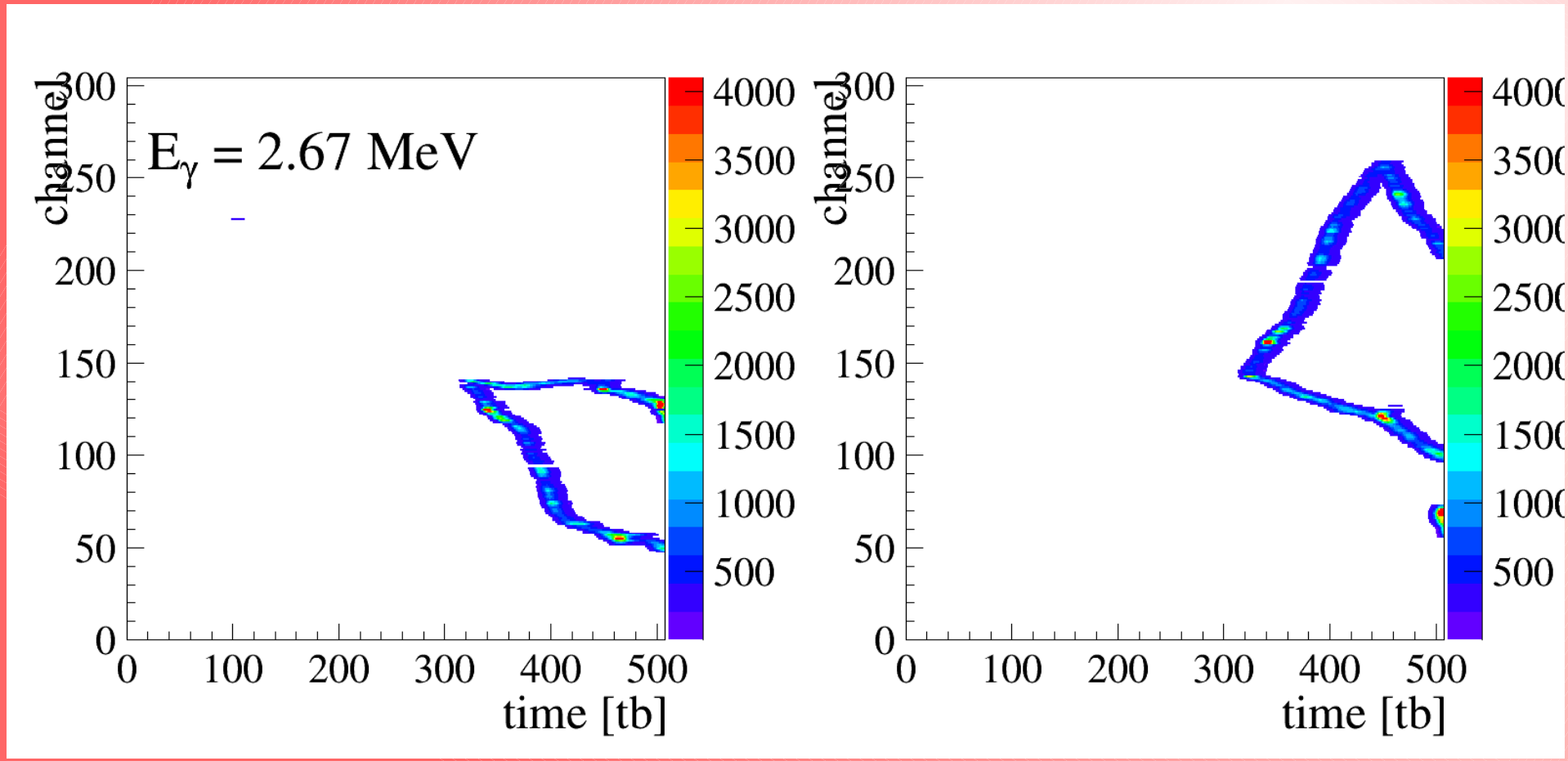
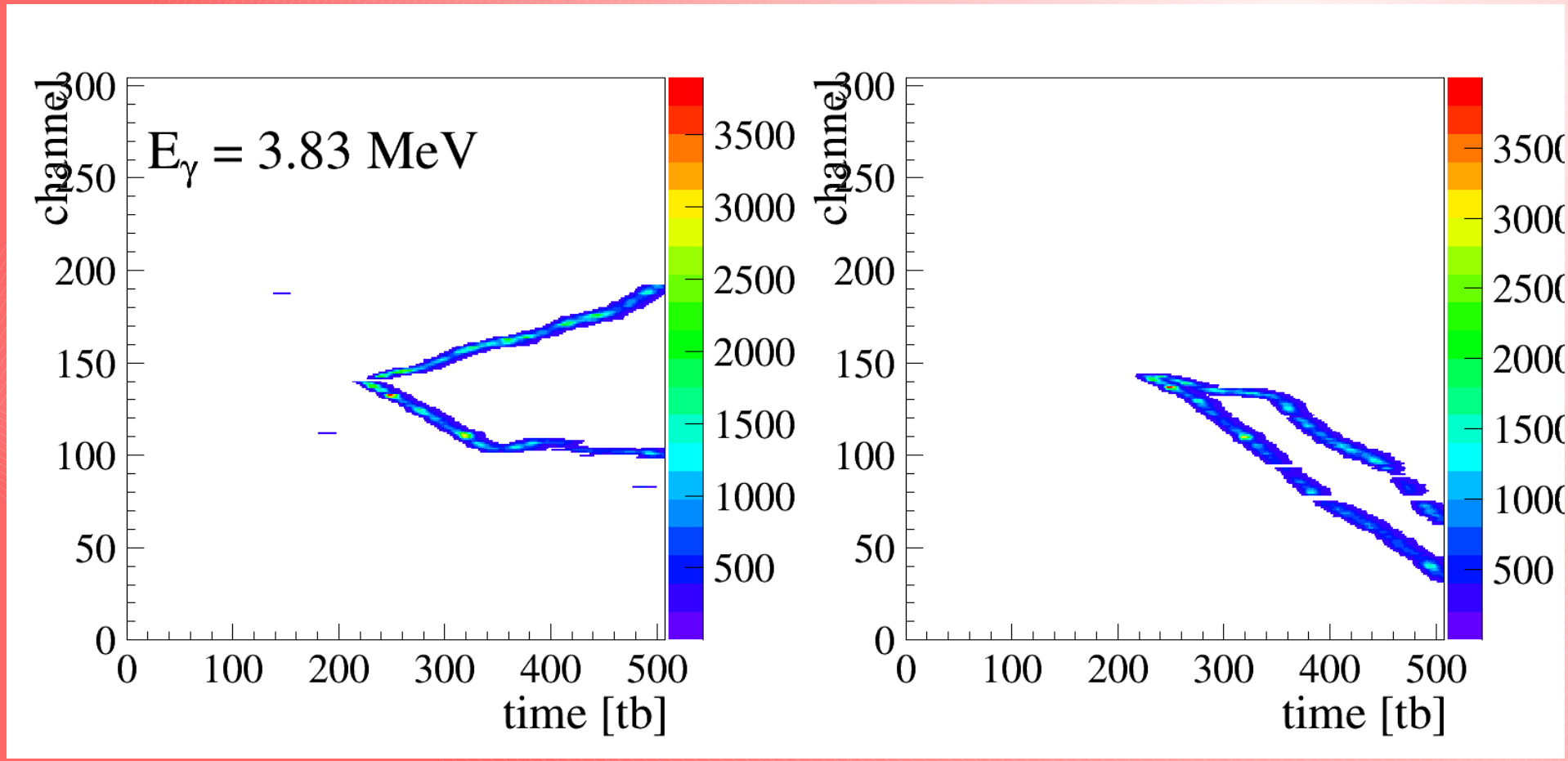
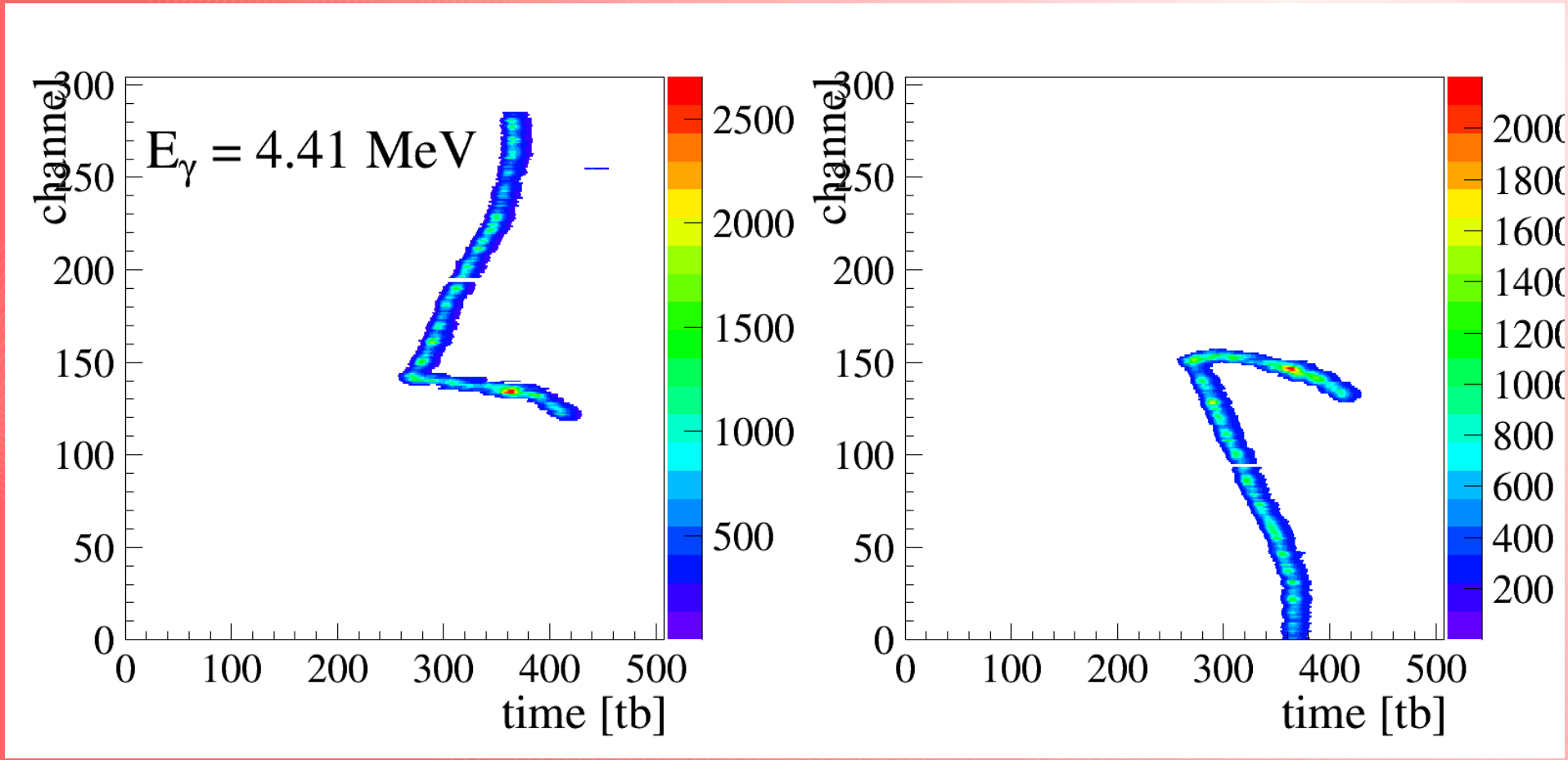
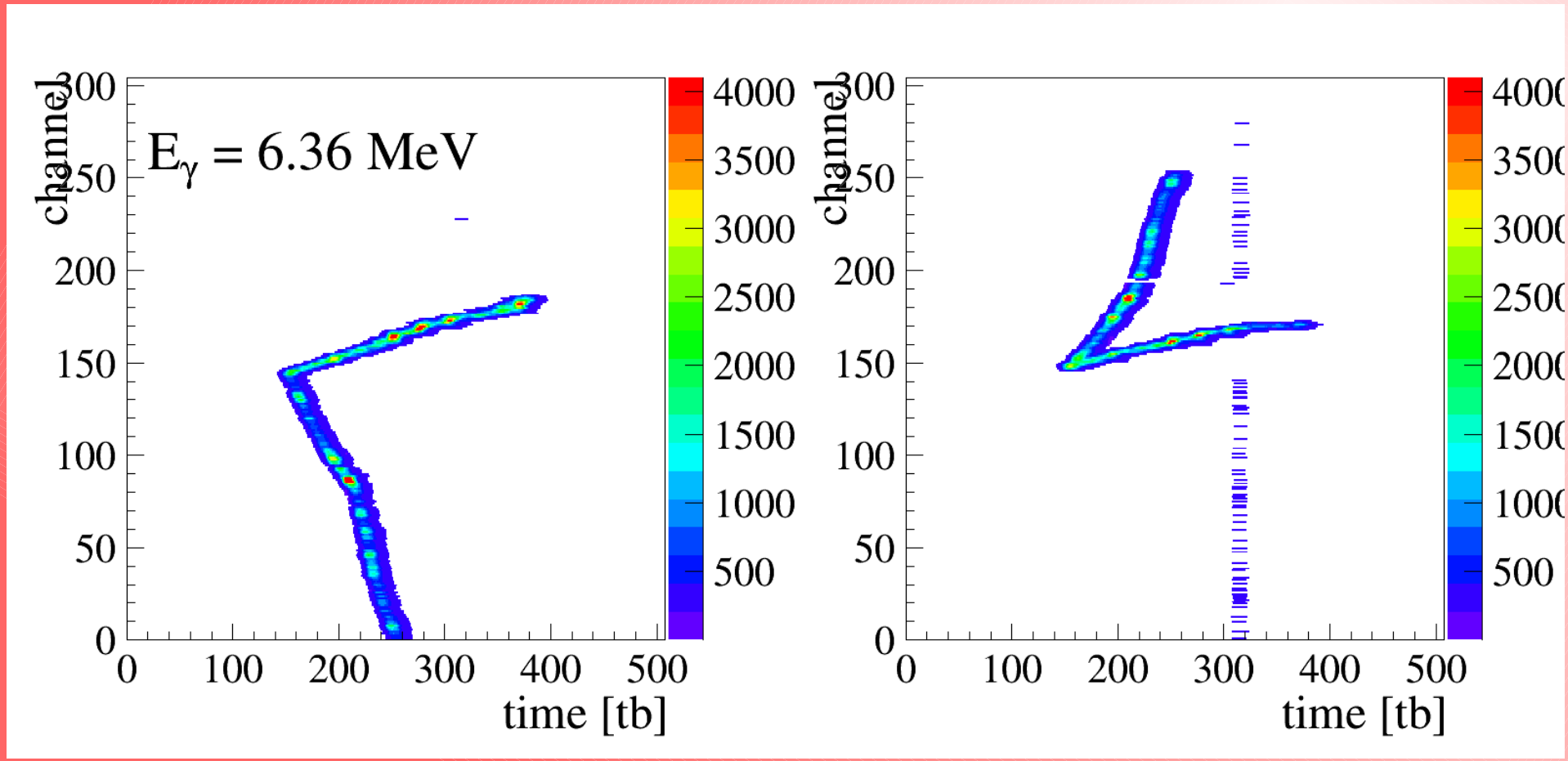
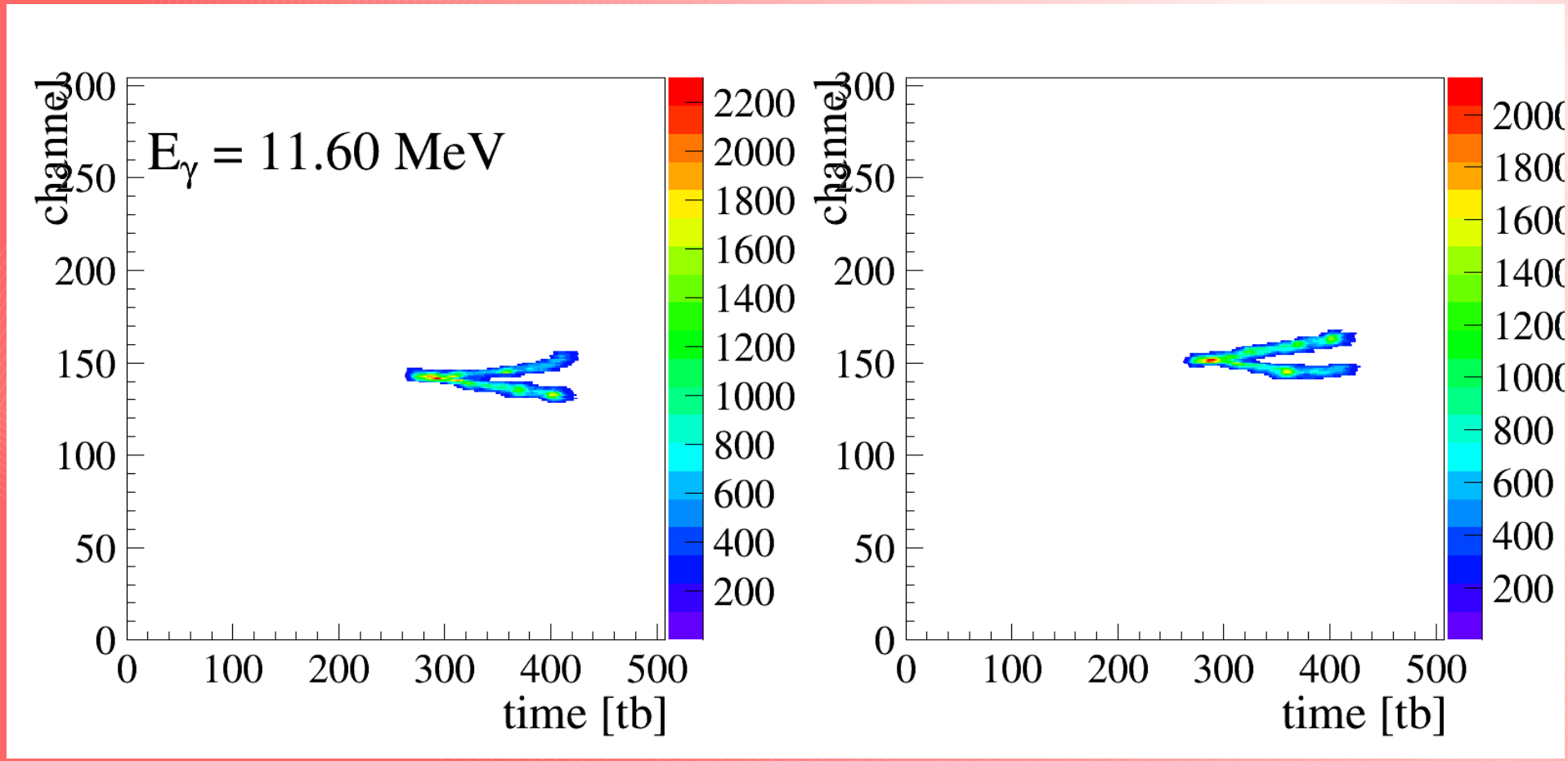
500
1000
1500
2000
2500
3000
3500
4000

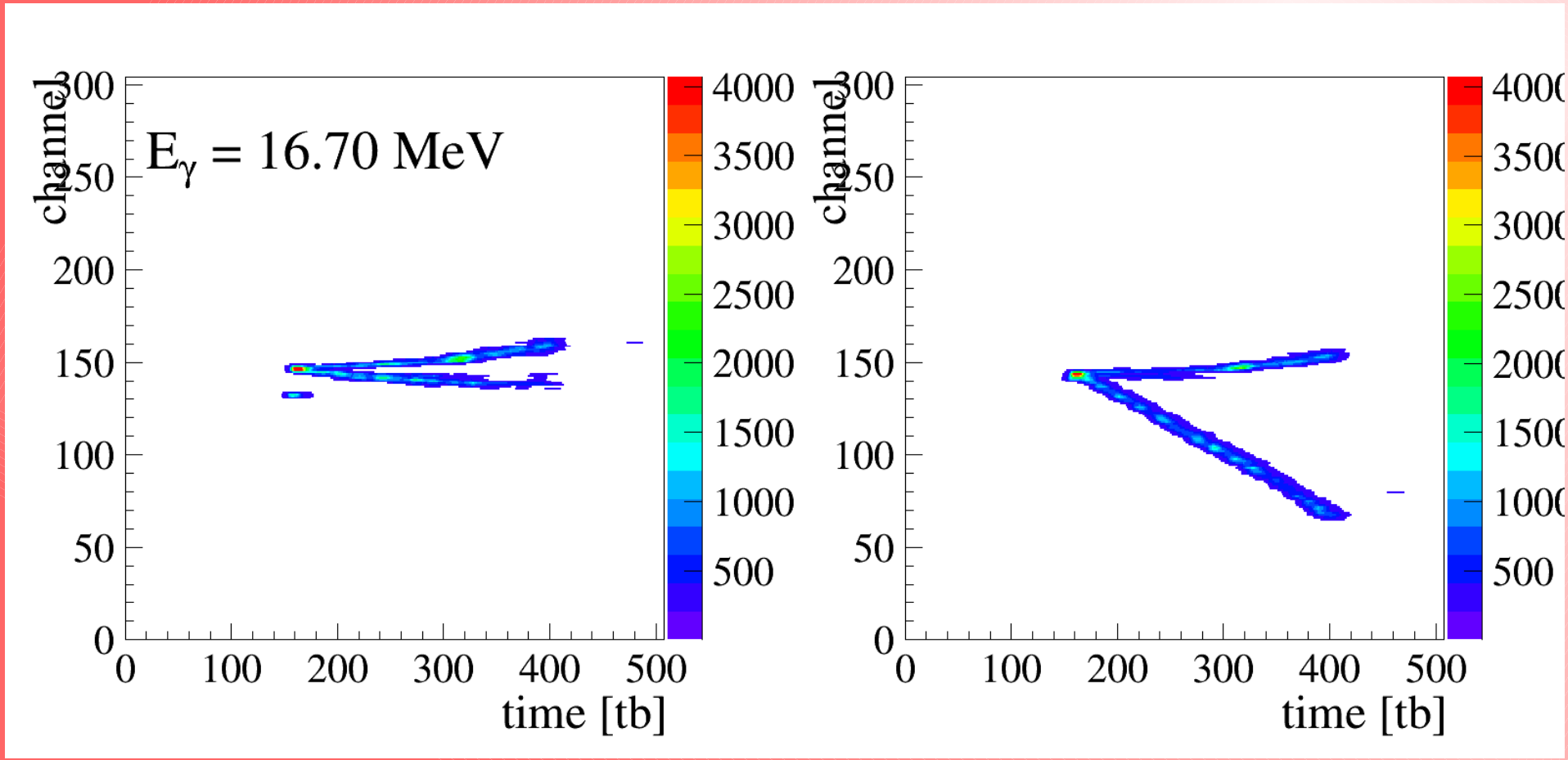

E_γ = 2.67 MeV
channel
time [tb]
0
50
100
150
200
250
300
0
100
200
300
400
500
500
1000
1500
2000
2500
3000
3500
4000

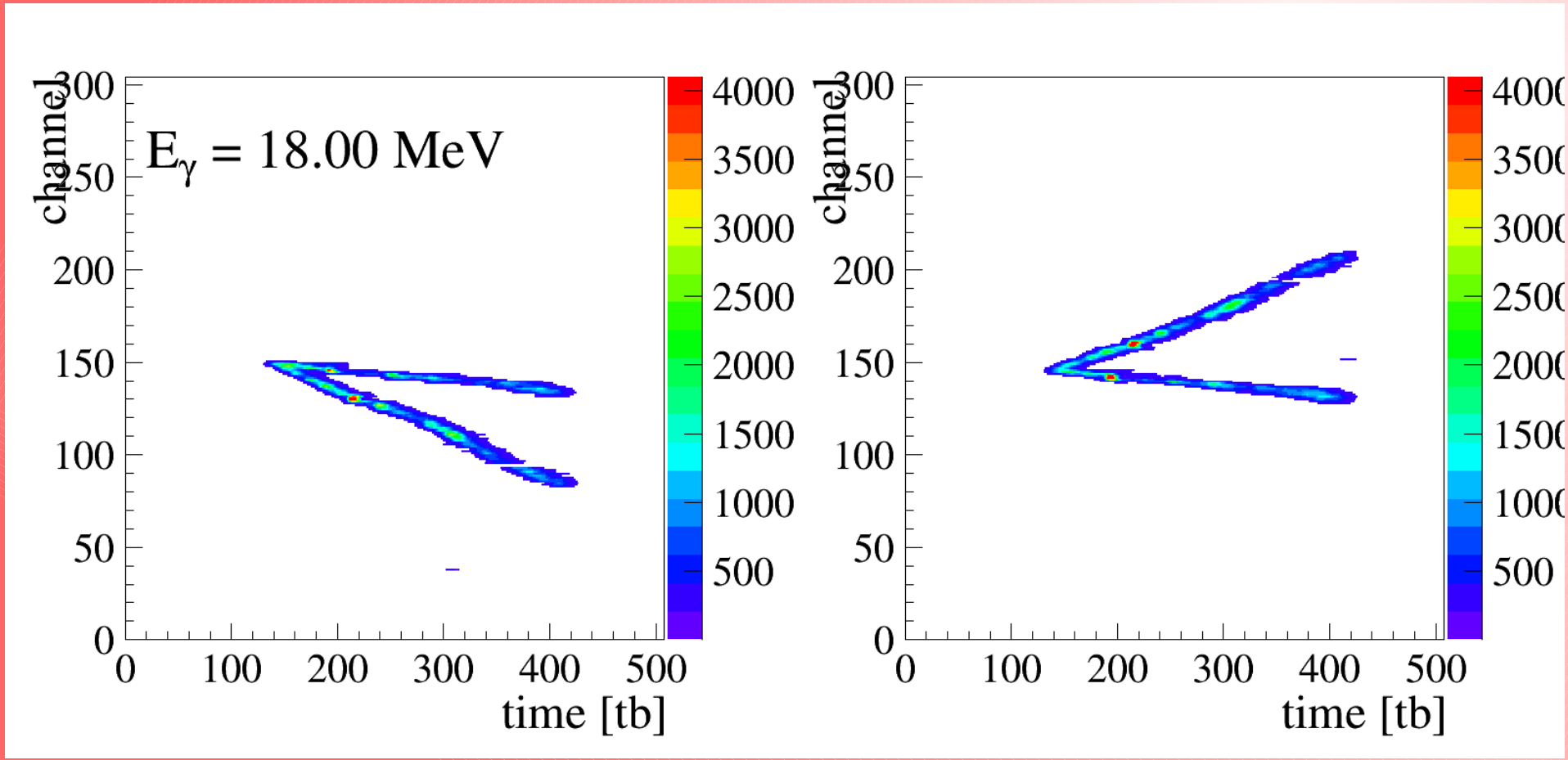

E_γ = 3.83 MeV
channel
time [tb]
0
50
100
150
200
250
300
0
100
200
300
400
500
500
1000
1500
2000
2500
3000
3500

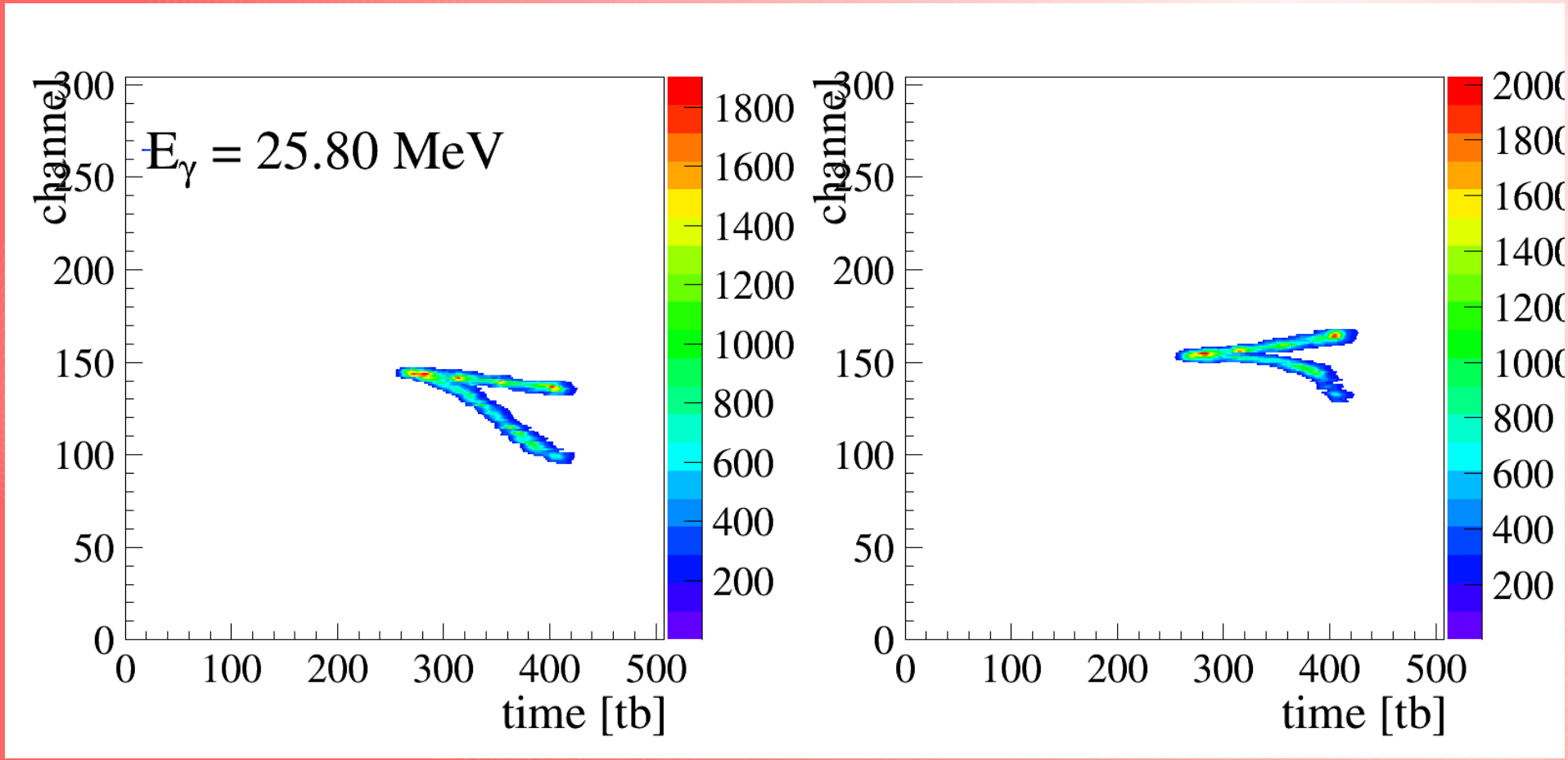

E_γ = 4.41 MeV
channel
time [tb]
0
50
100
150
200
250
300
0
100
200
300
400
500
500
1000
1500
2000
2500
200
400
600
800
1000
1200
1400
1600
1800
2000

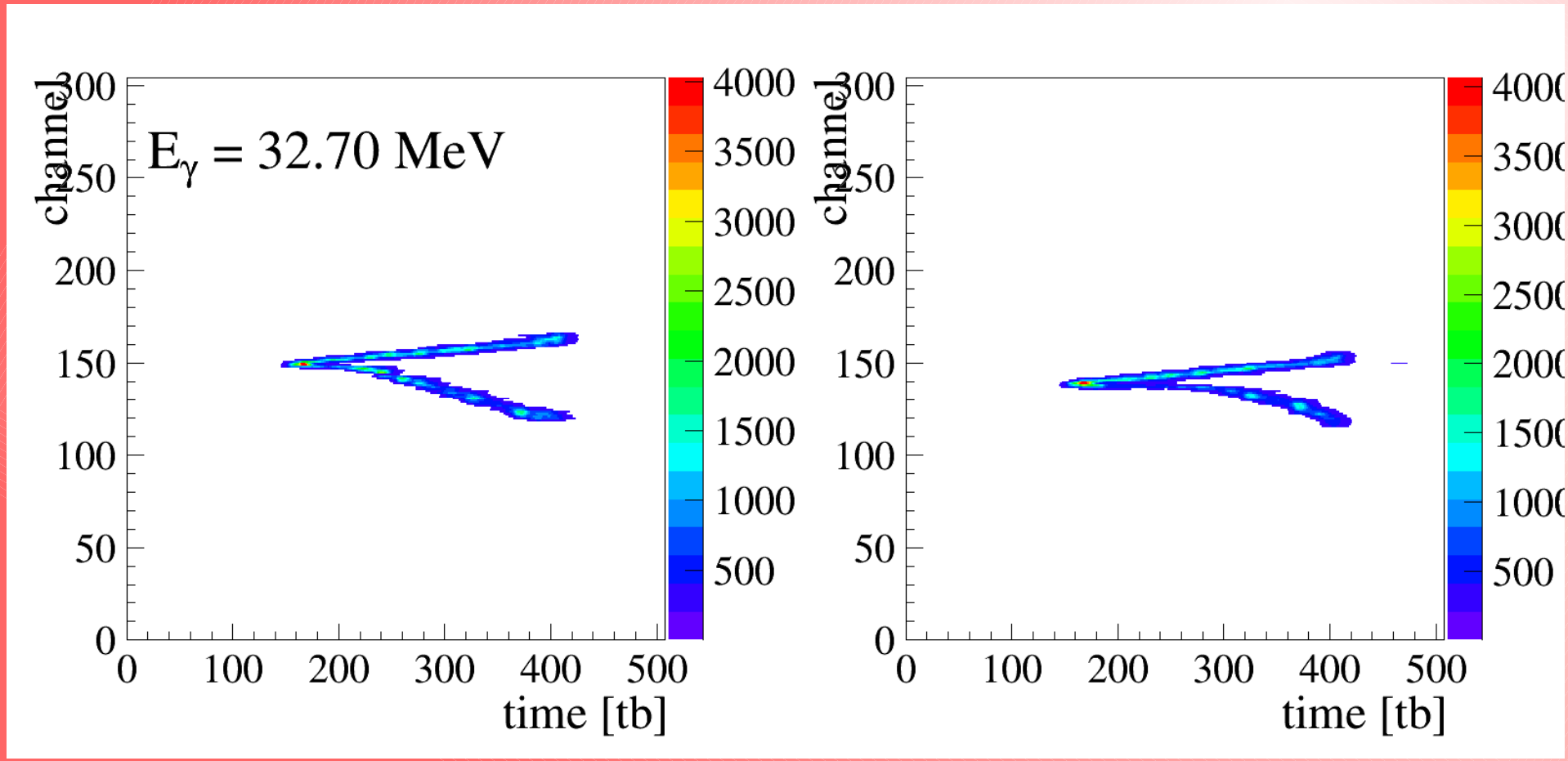

E_γ = 6.36 MeV
channel
time [tb]
0
50
100
150
200
250
300
0
100
200
300
400
500
500
1000
1500
2000
2500
3000
3500
4000

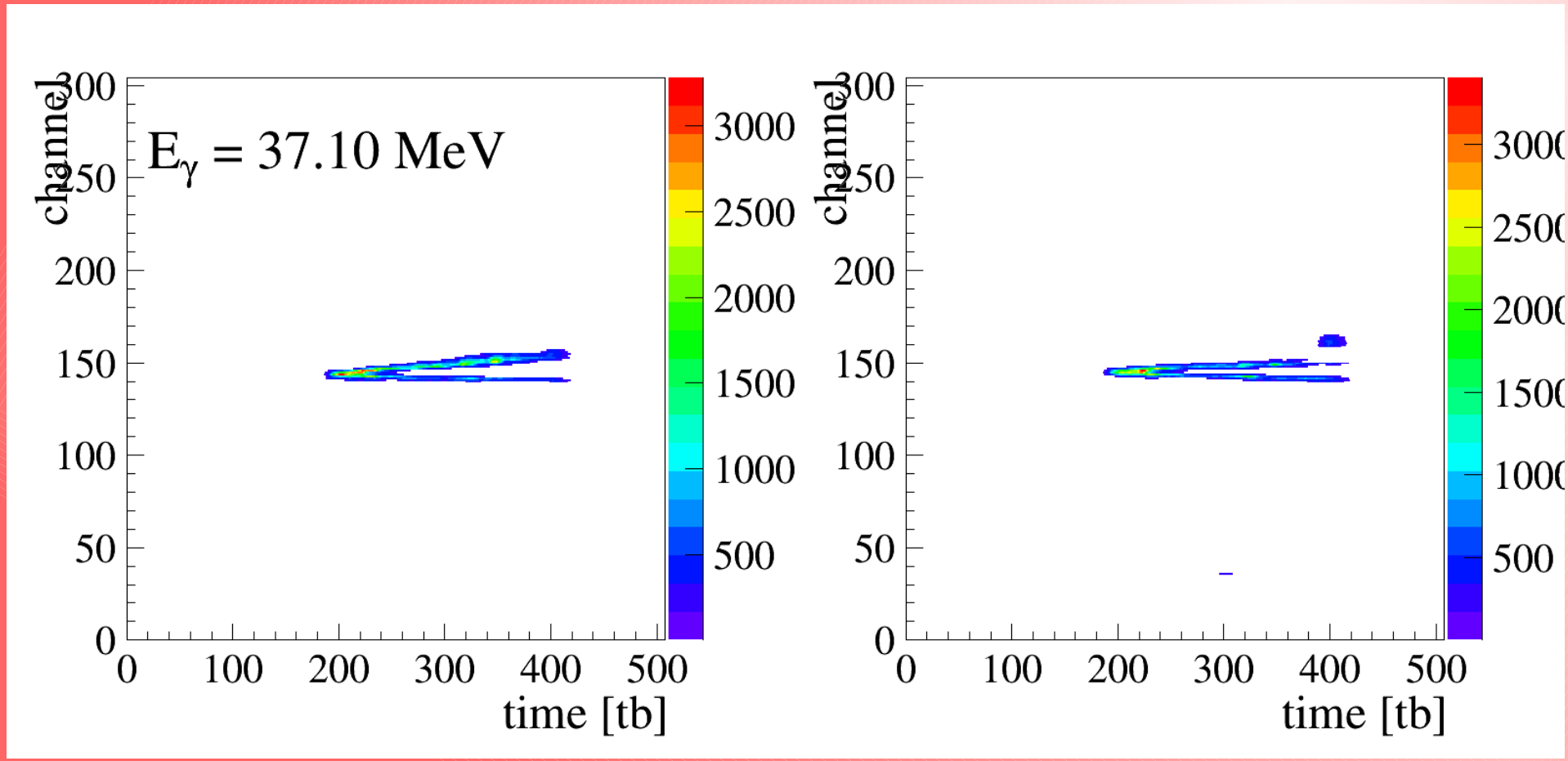

E_γ = 11.60 MeV
channel
time [tb]
0
50
100
150
200
250
300
0
100
200
300
400
500
2200
2000
1800
1600
1400
1200
1000
800
600
400
200

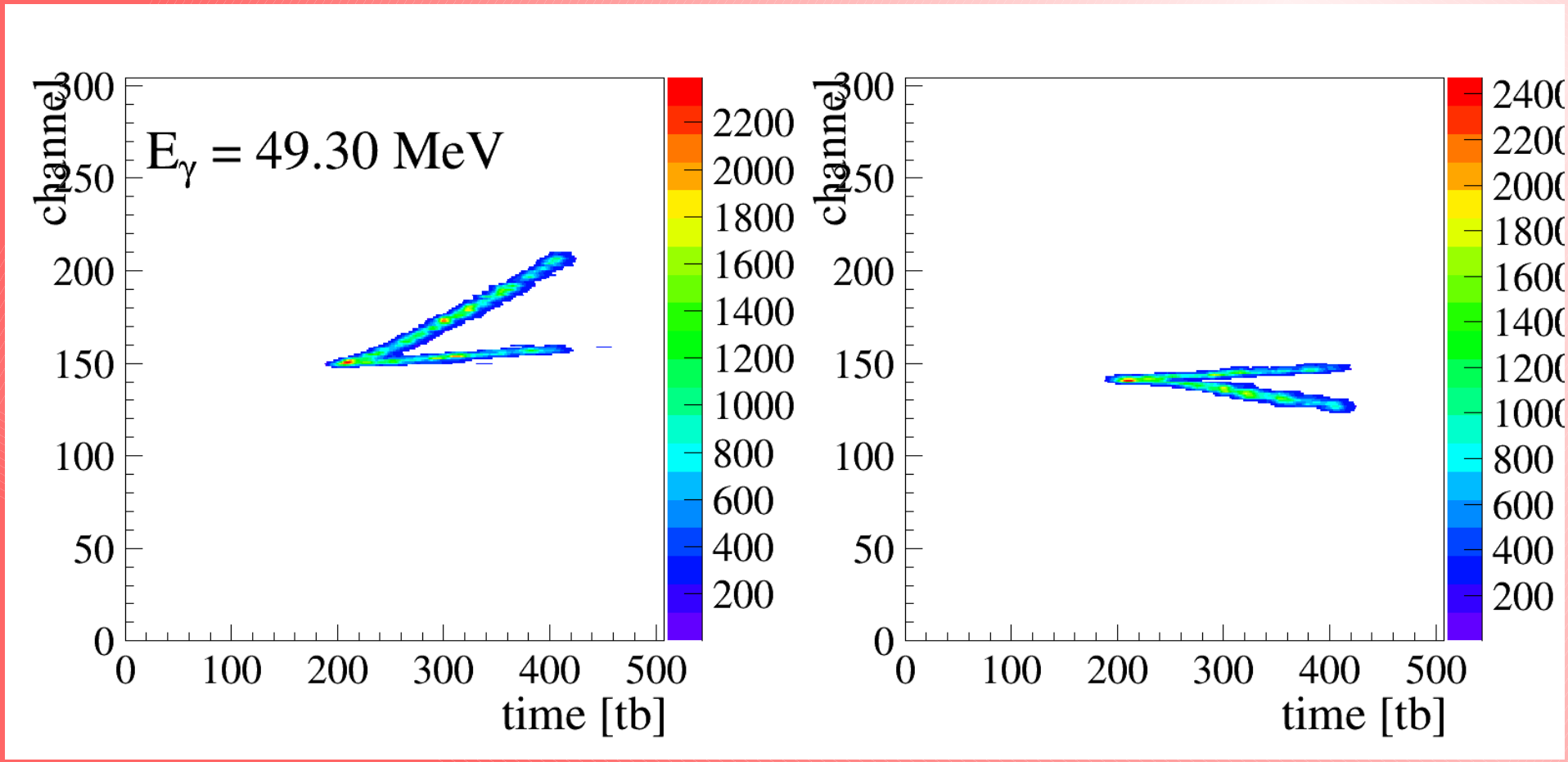

E_γ = 16.70 MeV
channel
time [tb]
0
50
100
150
200
250
300
0
100
200
300
400
500
500
1000
1500
2000
2500
3000
3500
4000

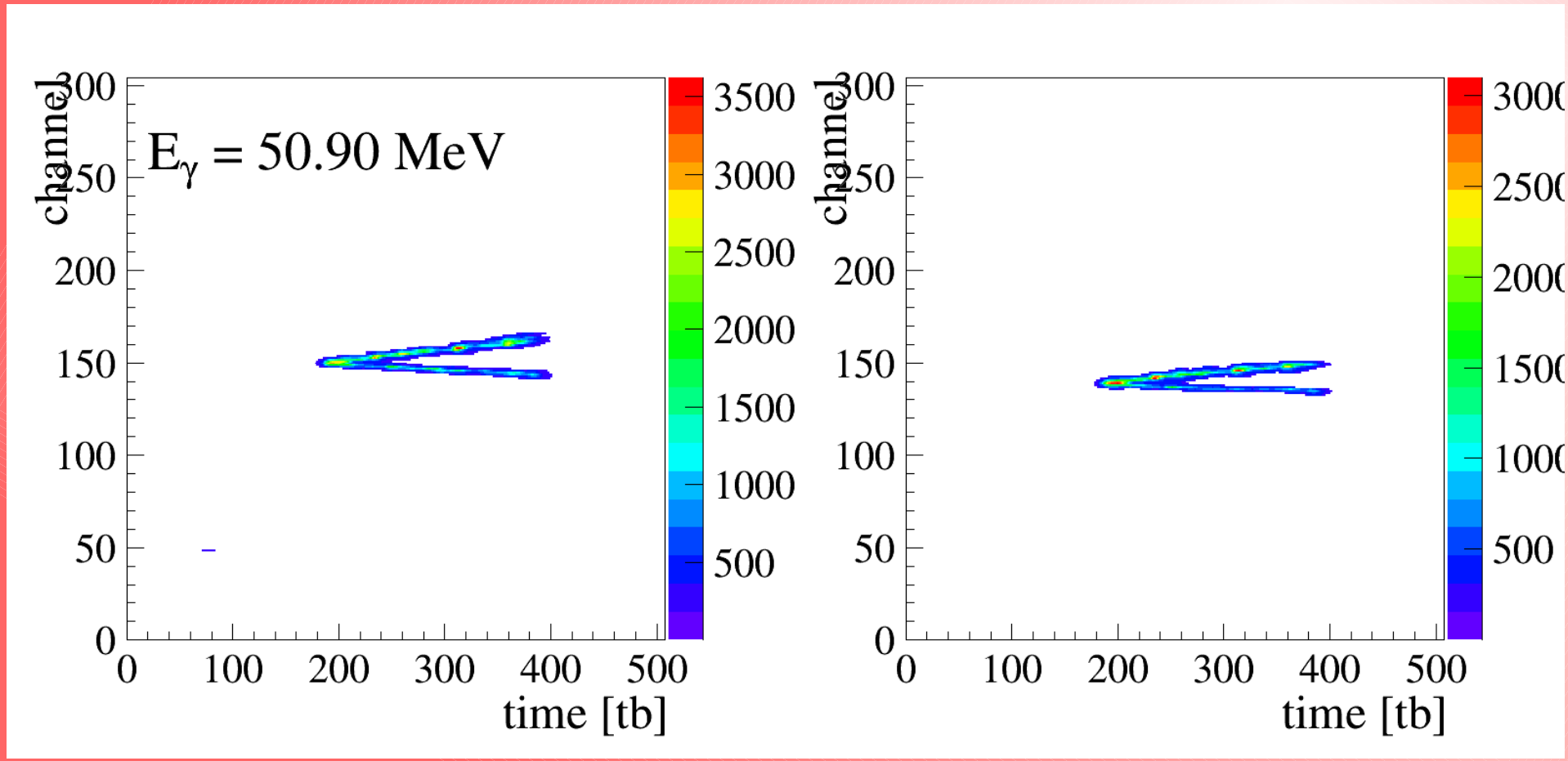

E_γ = 18.00 MeV
channel
time [tb]
0
50
100
150
200
250
300
0
100
200
300
400
500
500
1000
1500
2000
2500
3000
3500
4000

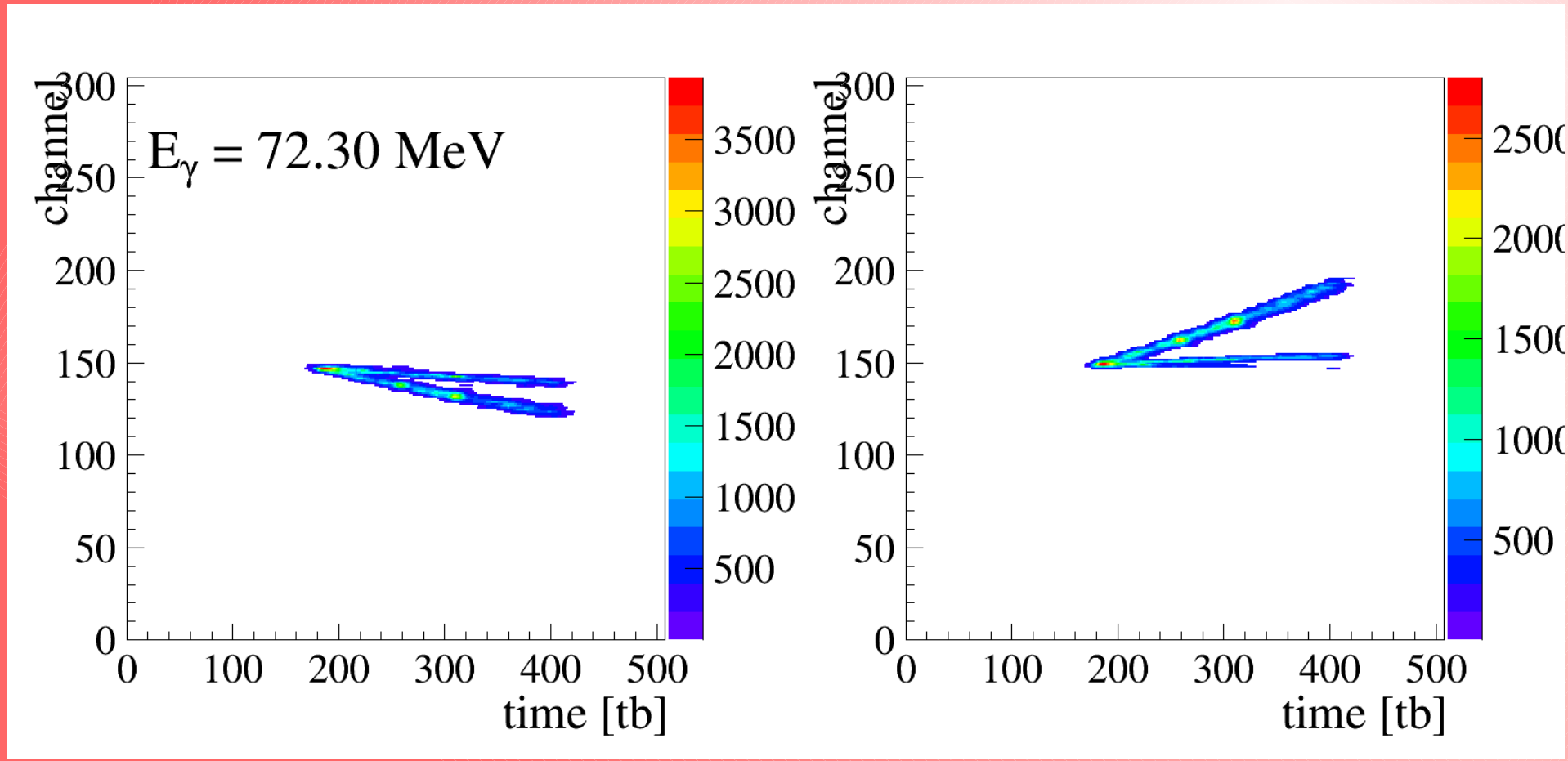

E_γ = 25.80 MeV
channel
time [tb]
0
50
100
150
200
250
300
0
100
200
300
400
500
200
400
600
800
1000
1200
1400
1600
1800


E_γ = 32.70 MeV
channel
time [tb]
0
50
100
150
200
250
300
0
100
200
300
400
500
500
1000
1500
2000
2500
3000
3500
4000


E_γ = 37.10 MeV
channel
time [tb]
0
50
100
150
200
250
300
0
100
200
300
400
500
500
1000
1500
2000
2500
3000


E_γ = 49.30 MeV
channel
time [tb]
0
50
100
150
200
250
300
0
100
200
300
400
500
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400


E_γ = 50.90 MeV
channel
time [tb]
channel
time [tb]


E_γ = 72.30 MeV
channel
time [tb]
0
50
100
150
200
250
300
0
100
200
300
400
500
500
1000
1500
2000
2500
3000
3500