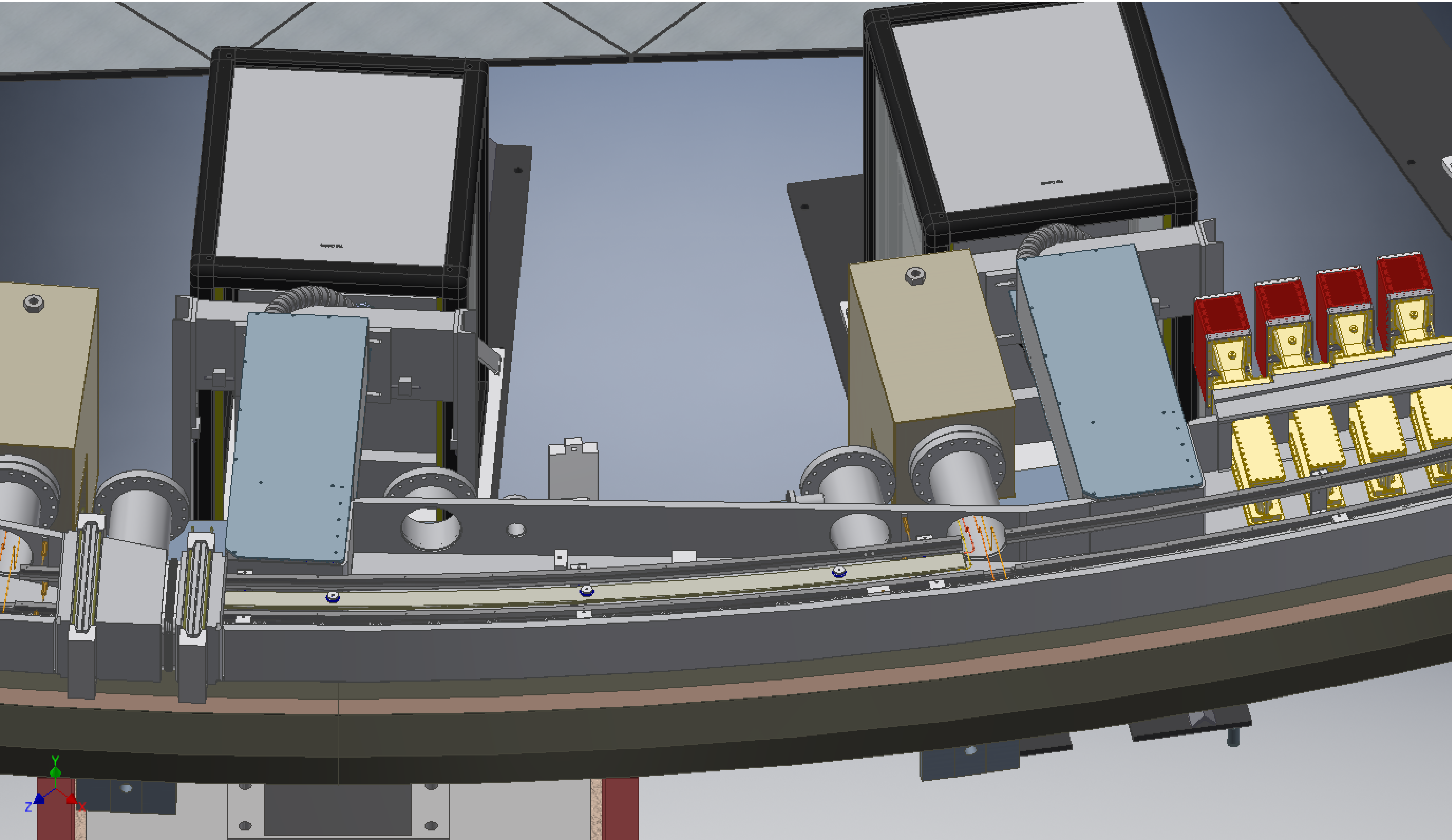
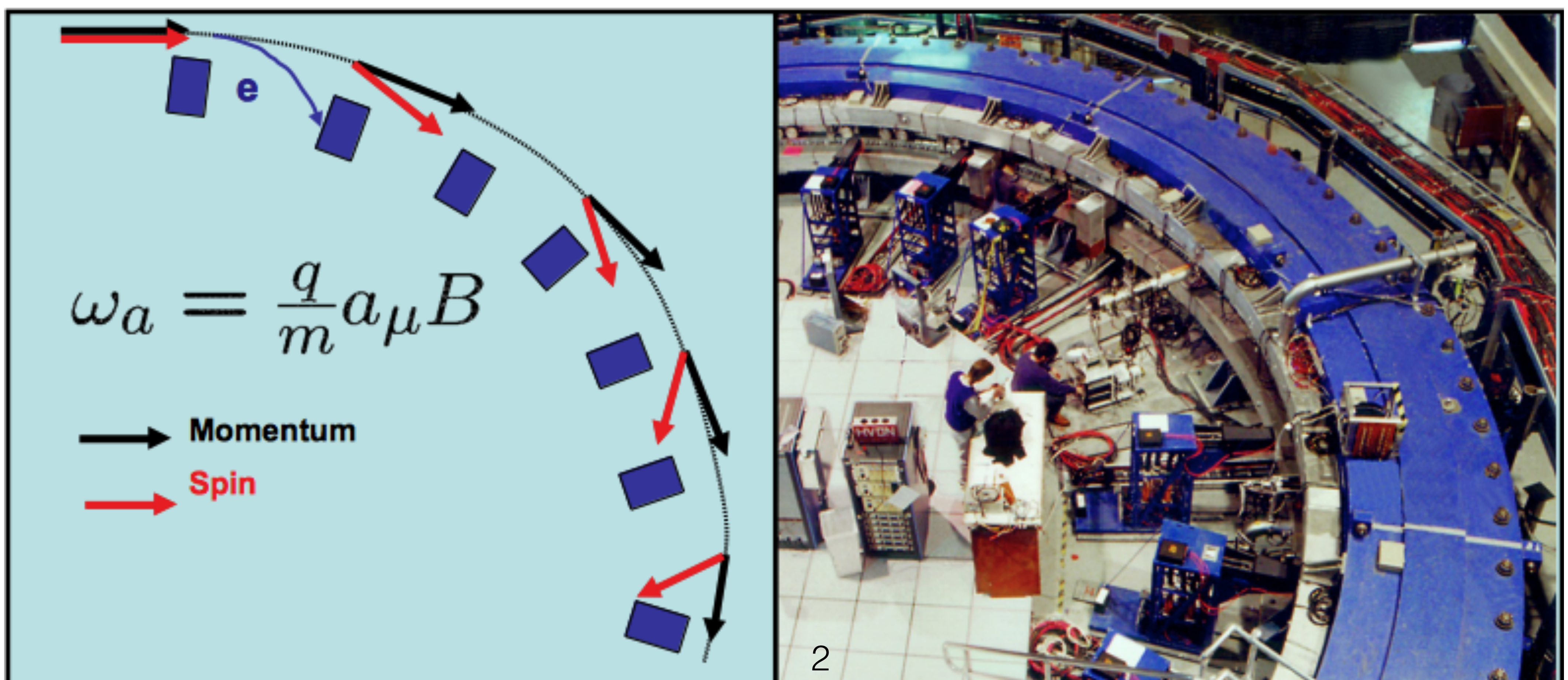
The calorimeter of Muon g-2 experiment

J. Kaspar, University of Washington

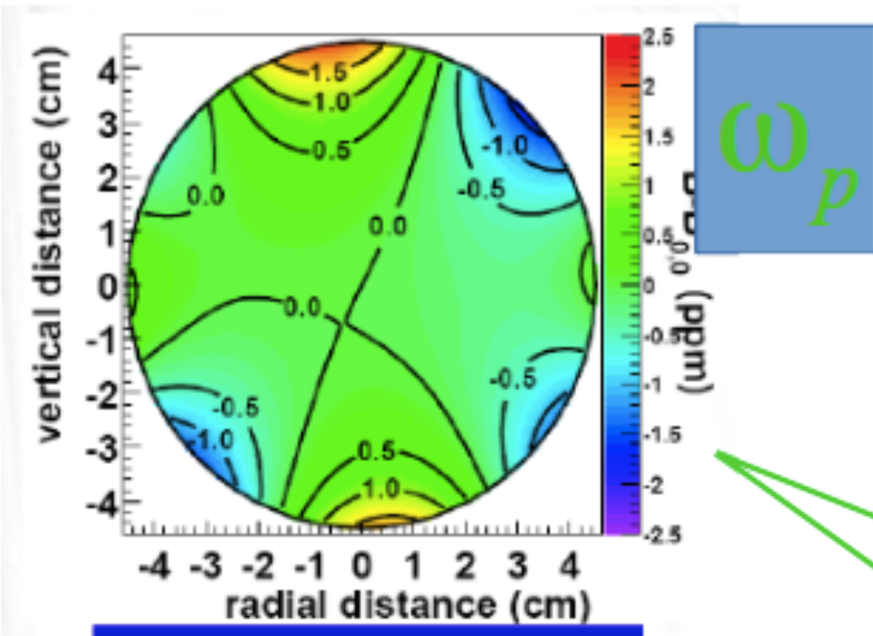


magnetic dipole moment of muon

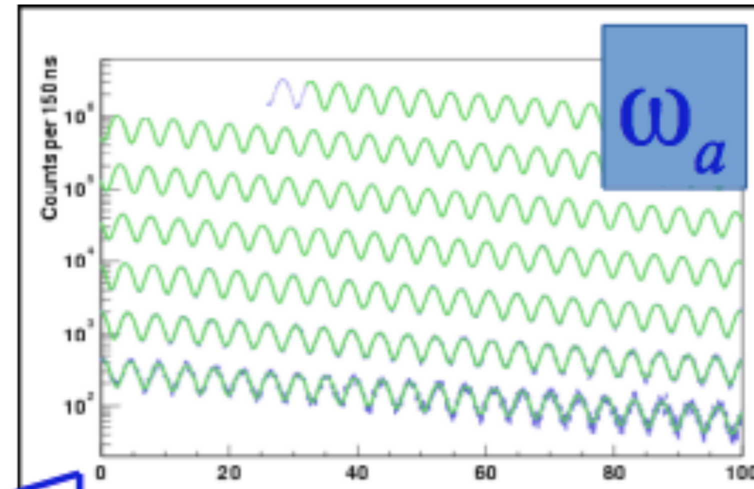
- torque experienced in external magnetic field
- spin -> intrinsic magnetic dipole moment
- experiment measures how fast spin rotates



measurement recipe

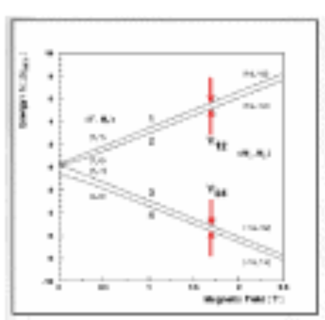


Our “Magnet”



Our conventional Detector, Electronics, and DAQ systems

$$a_\mu = \frac{\dfrac{\omega_a}{\omega_p}}{\dfrac{\mu_\mu}{\mu_p} - \dfrac{\omega_a}{\omega_p}}$$

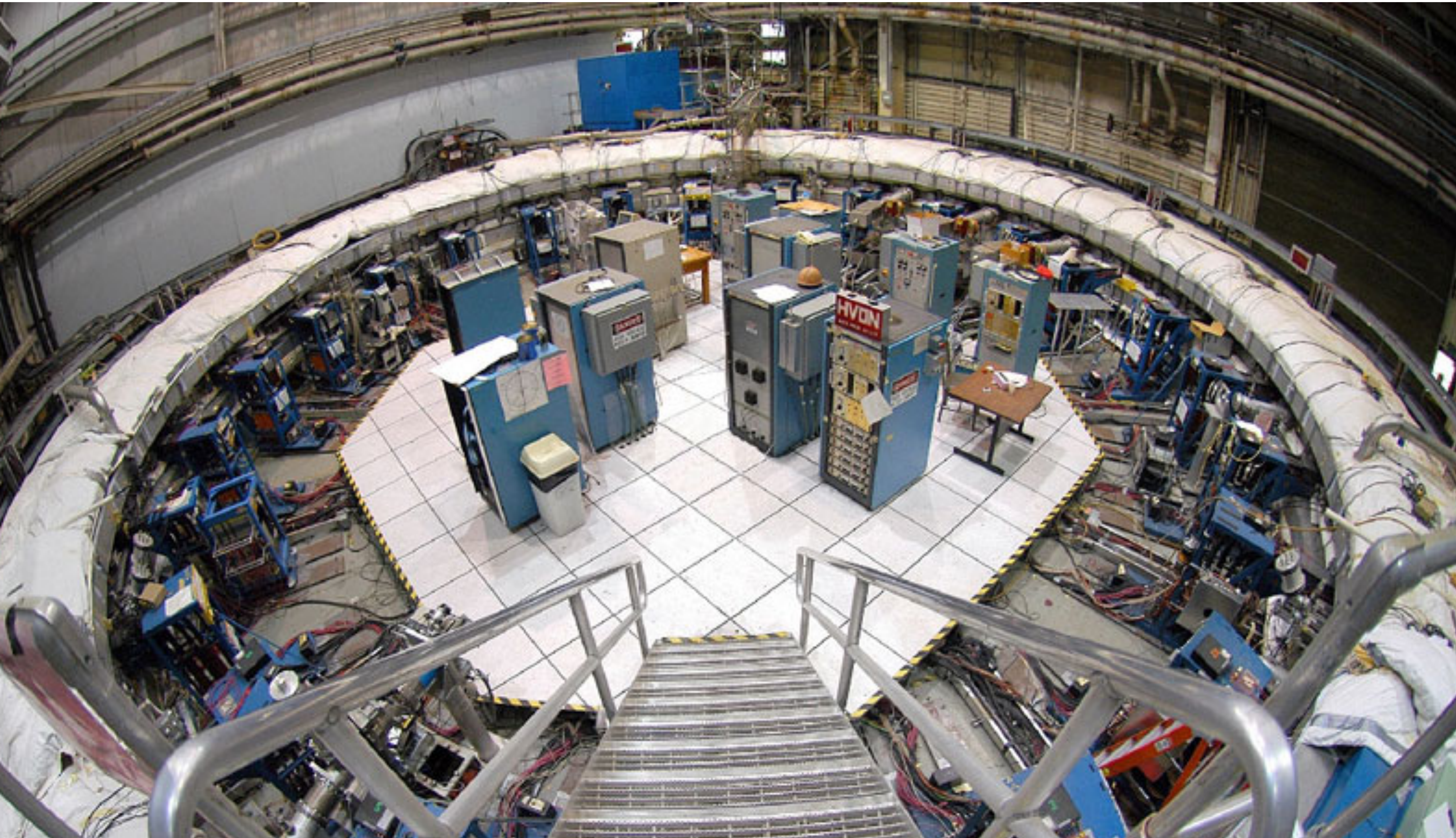


μ_μ/μ_p = 3.183 345 24(37) (120 ppb)

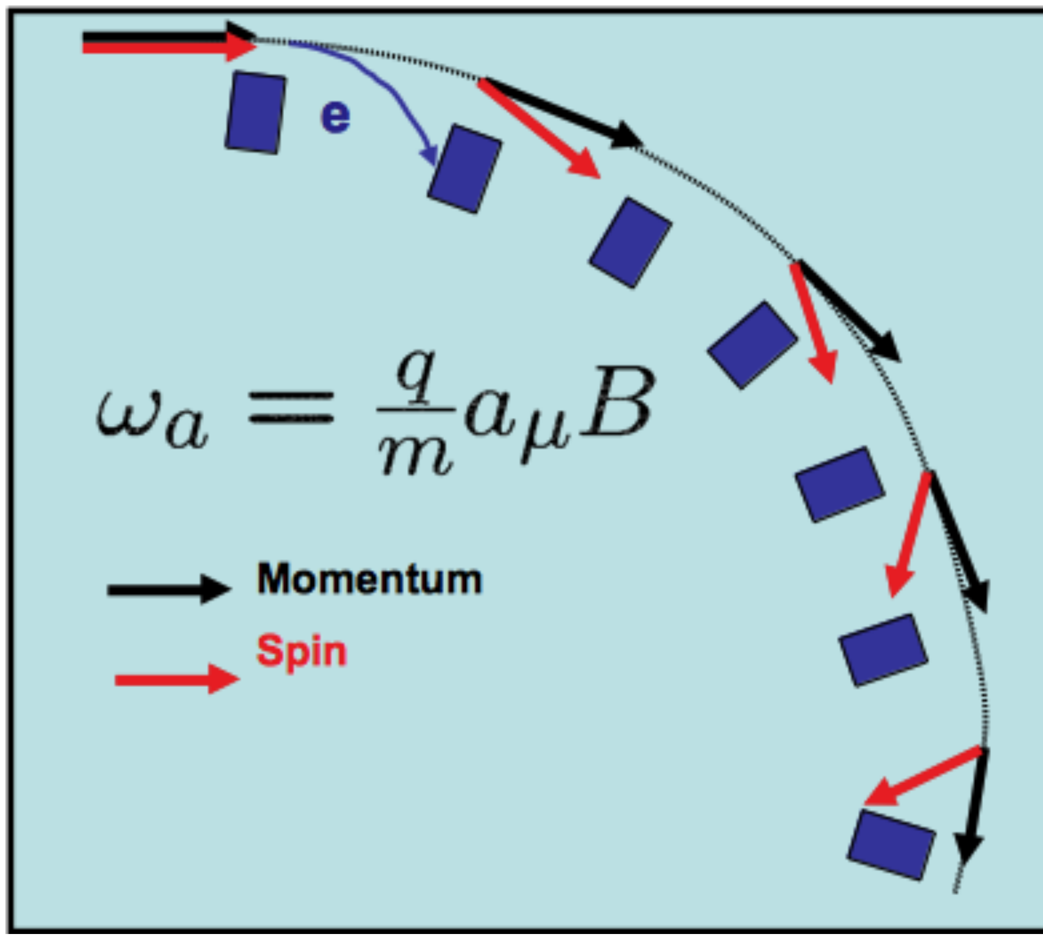
= *3.183 345 39(10) (31 ppb)*

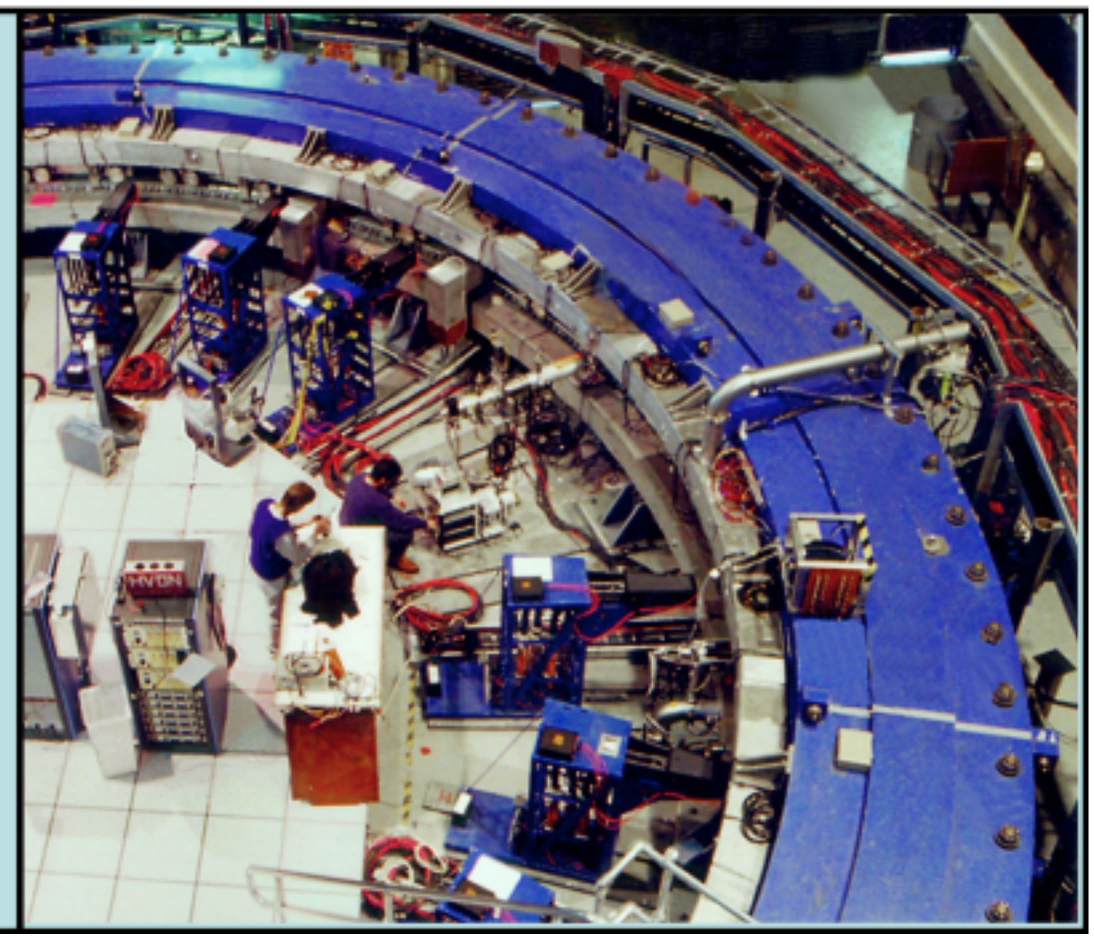
External Muonium Hyperfine Expt.

old ring, new instrumentation and beam



principles of the experiment





principles of the experiment

1. source of polarized muons
2. precession proportional to (g – 2)
3. magic momentum
4. parity violating decay (positron reports on spin)

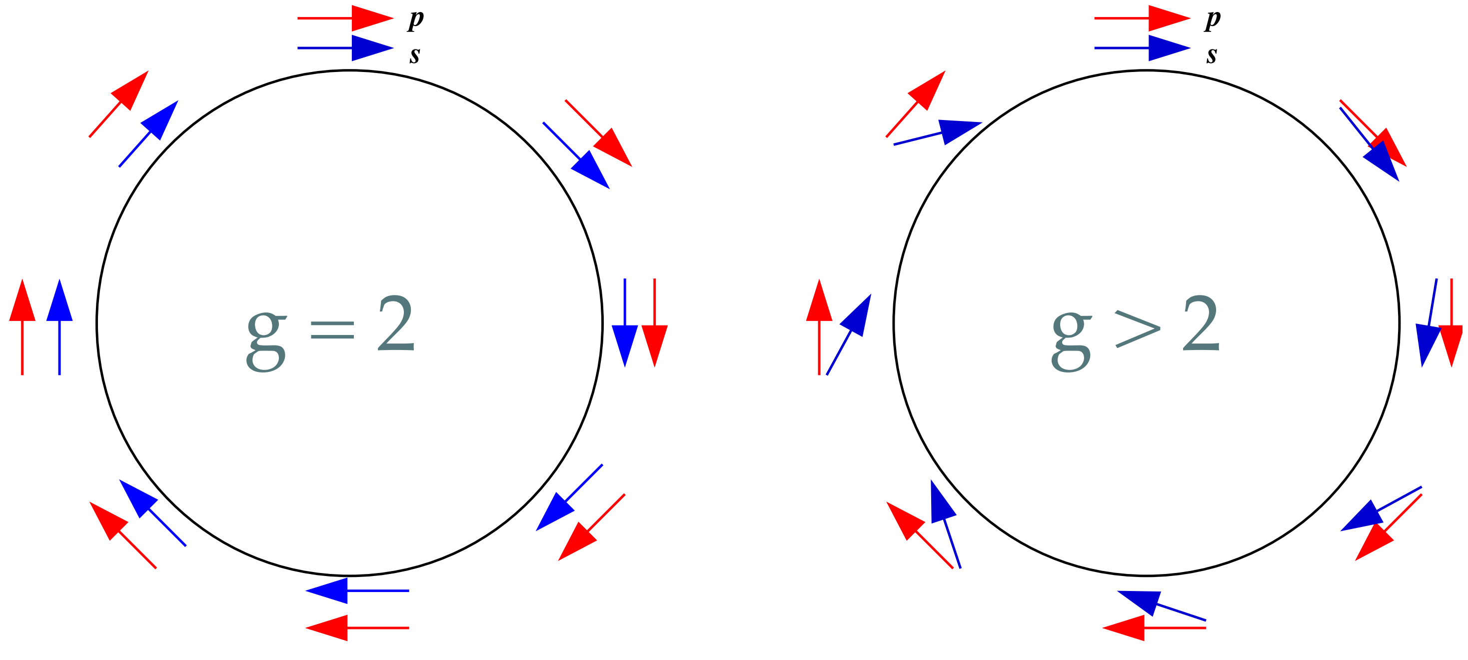
1. source of polarized muons

- pion decay into muon
- it's parity violating decay
- spin prefers opposite direction to momentum (for positive pion)
- pions come from protons hitting Li target

2. precession proportional to g – 2

$$\omega_C = \frac{eB}{mc\gamma} \qquad \omega_S = \frac{geB}{2mc} + (1-\gamma)\frac{eB}{\gamma mc}$$

$$\omega_a = \omega_S - \omega_C = \left(\frac{g-2}{2}\right)\frac{eB}{mc} = a\frac{eB}{mc}$$



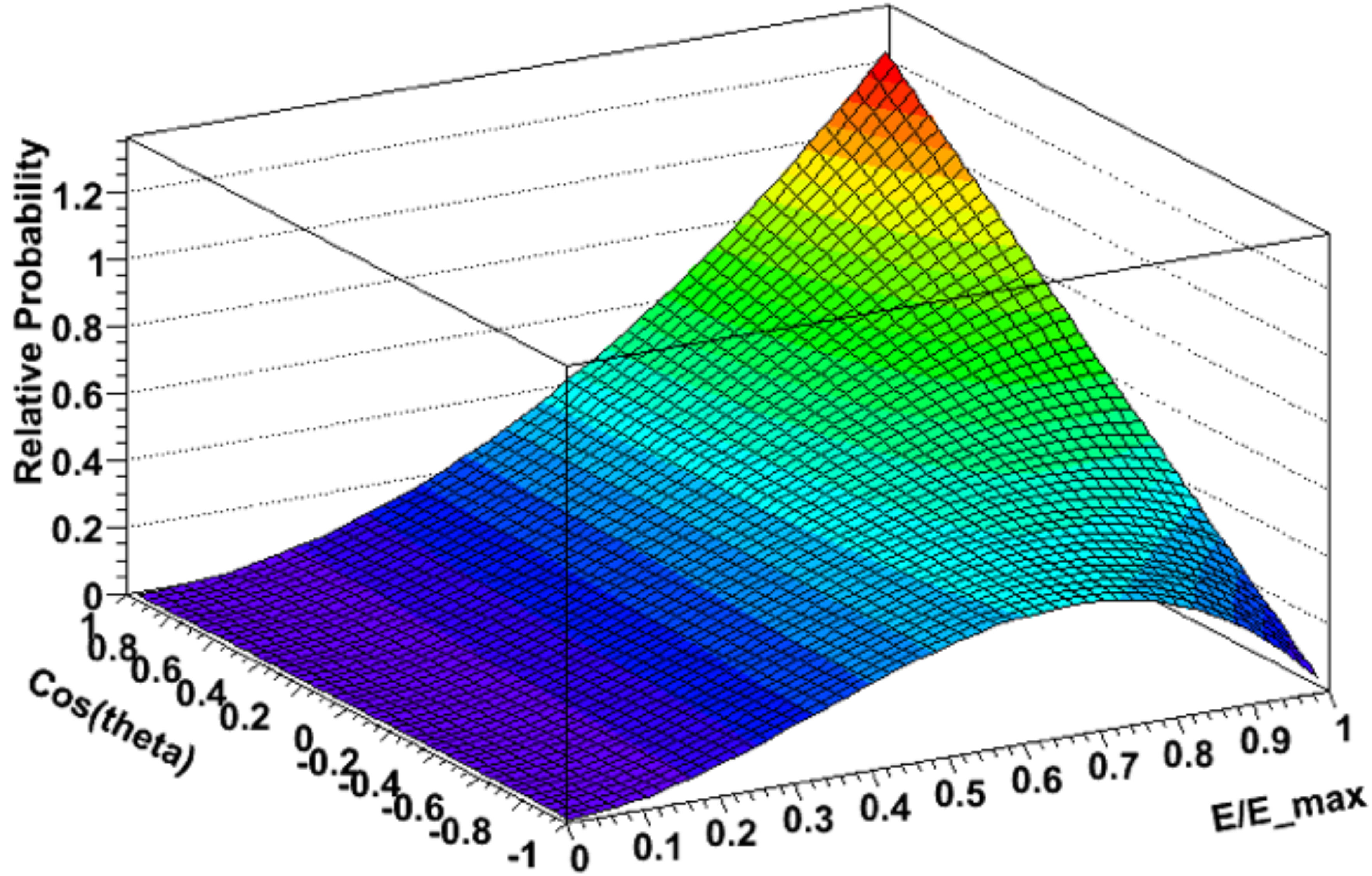
3. magic momentum

- electric quadrupole used for vertical focusing

$$\vec{\omega}_a = -\frac{e}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c}\right]$$

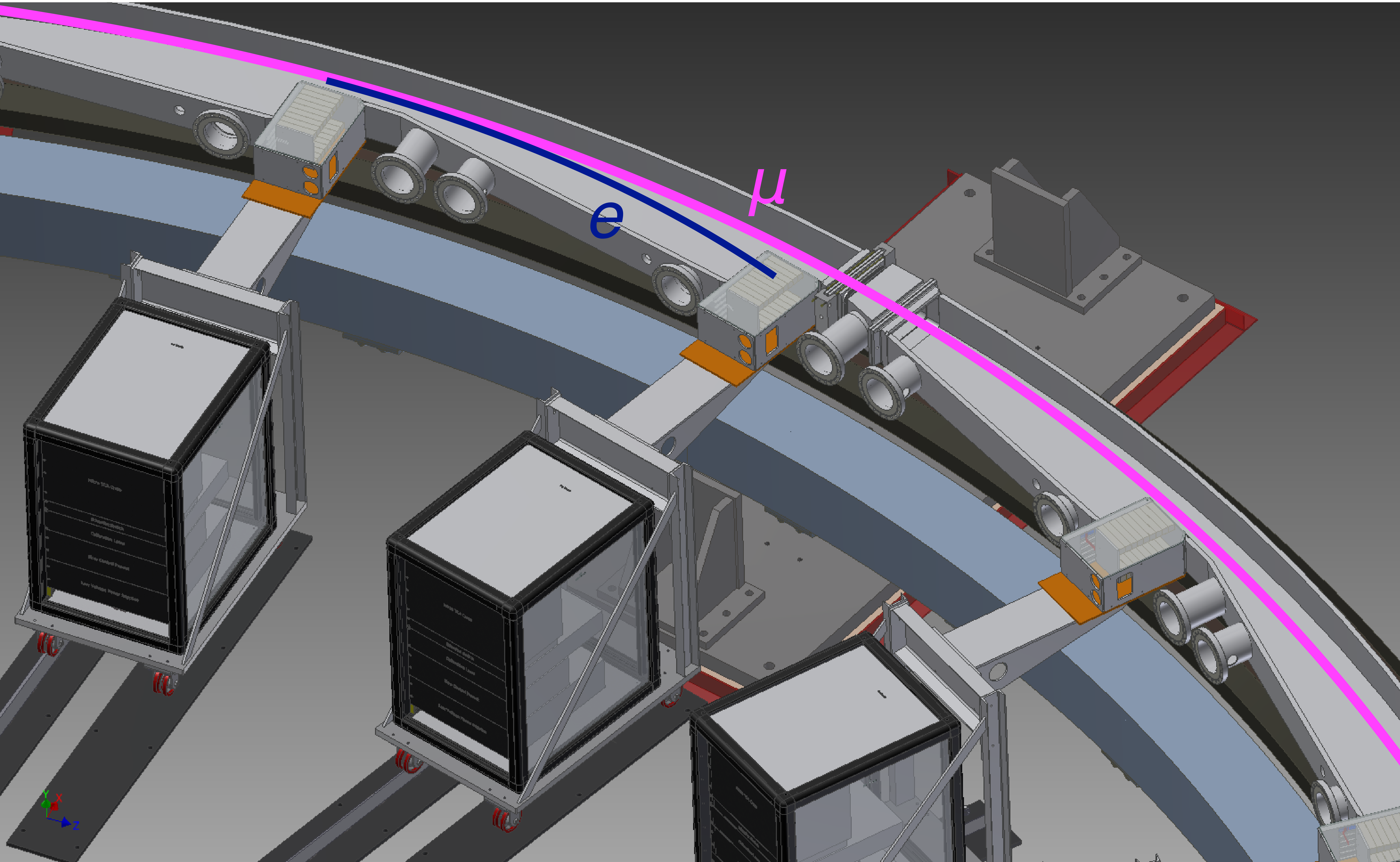
- select $\gamma = 29.3$, muon momentum 3.094 GeV

4. parity violating decay

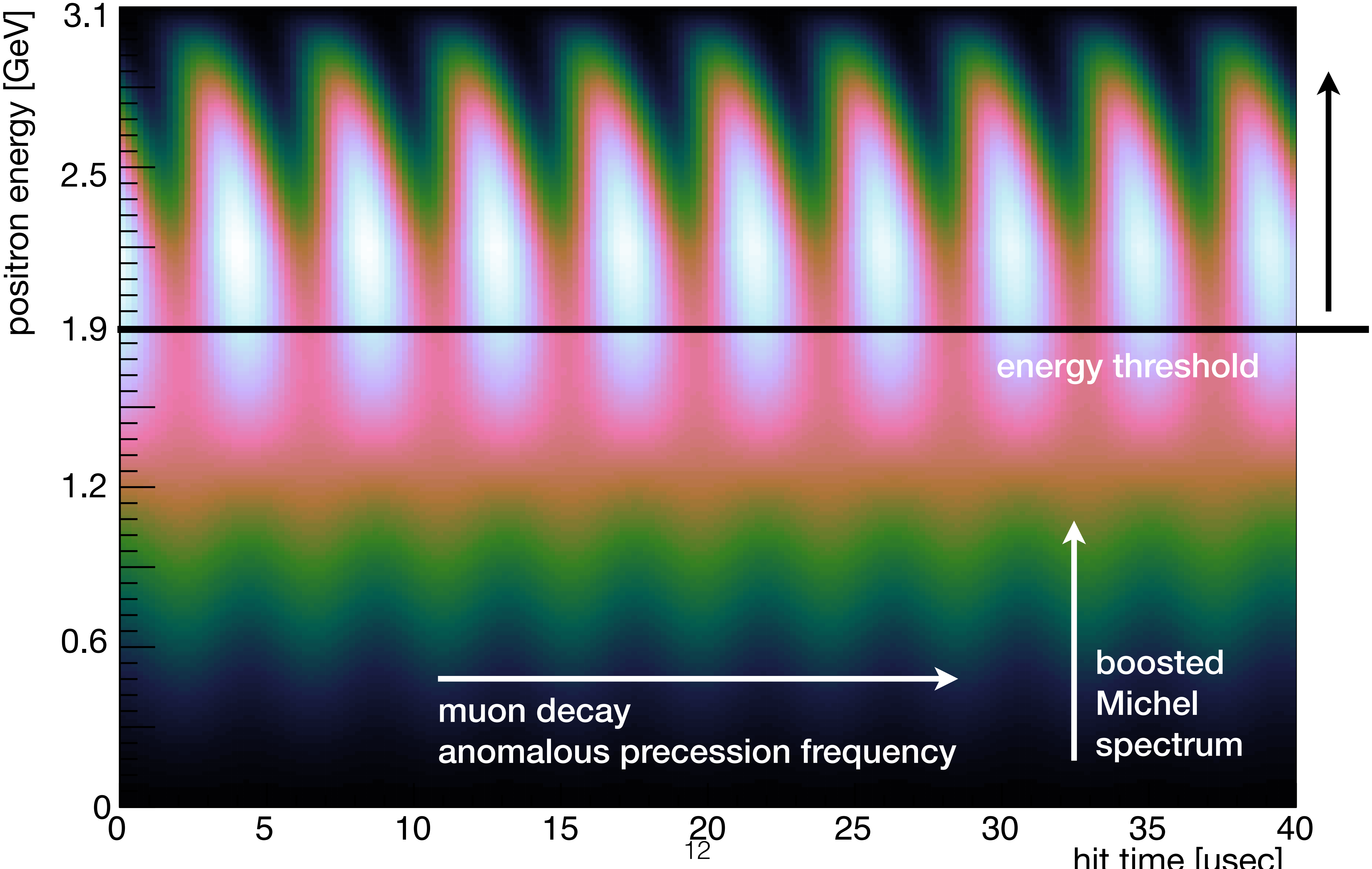


- muon -> electron and two neutrinos
- electron carries information on muon's spin
- positron prefers spin direction
- electron would prefer opposite direction

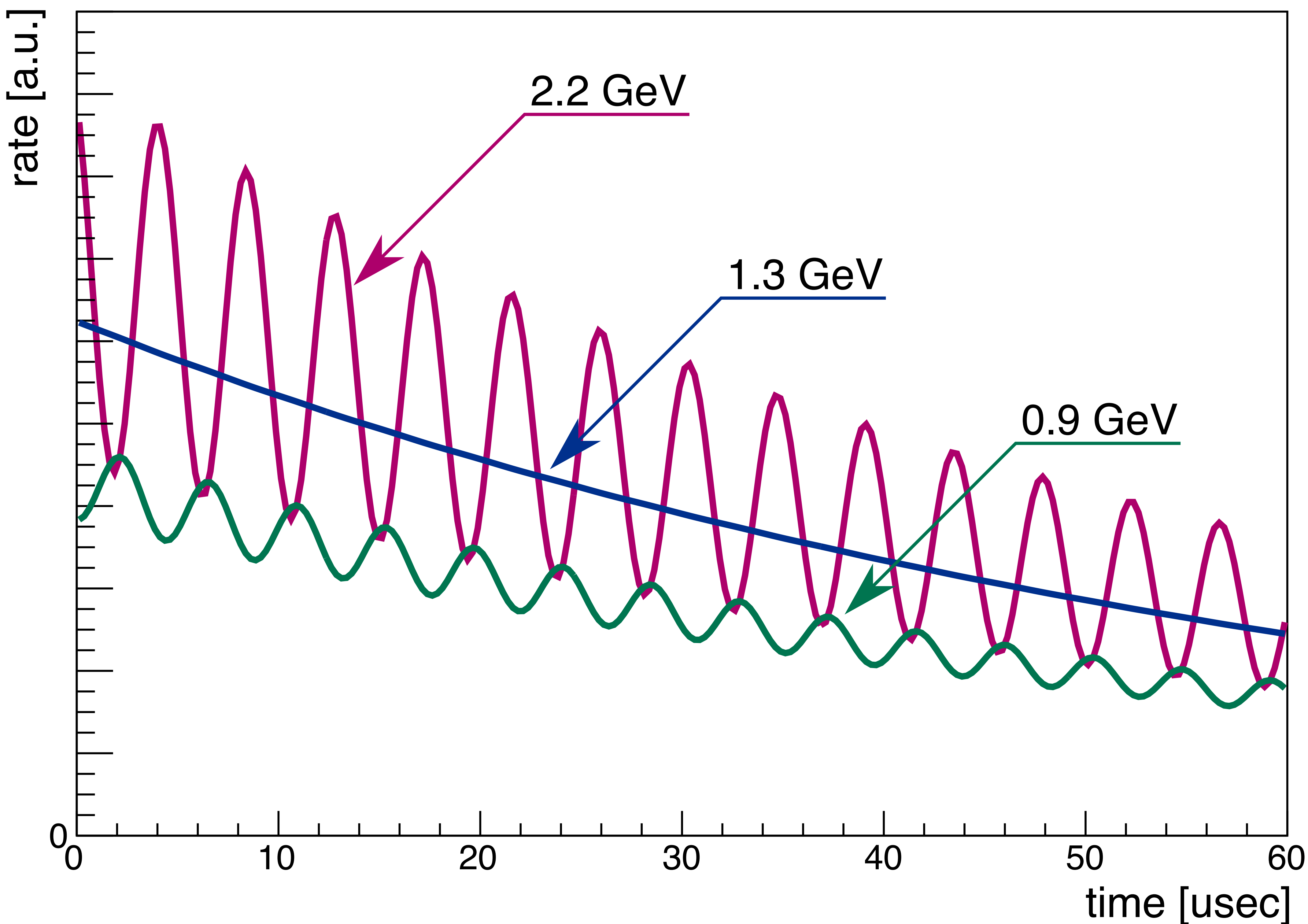
a lighthouse riding a carousel

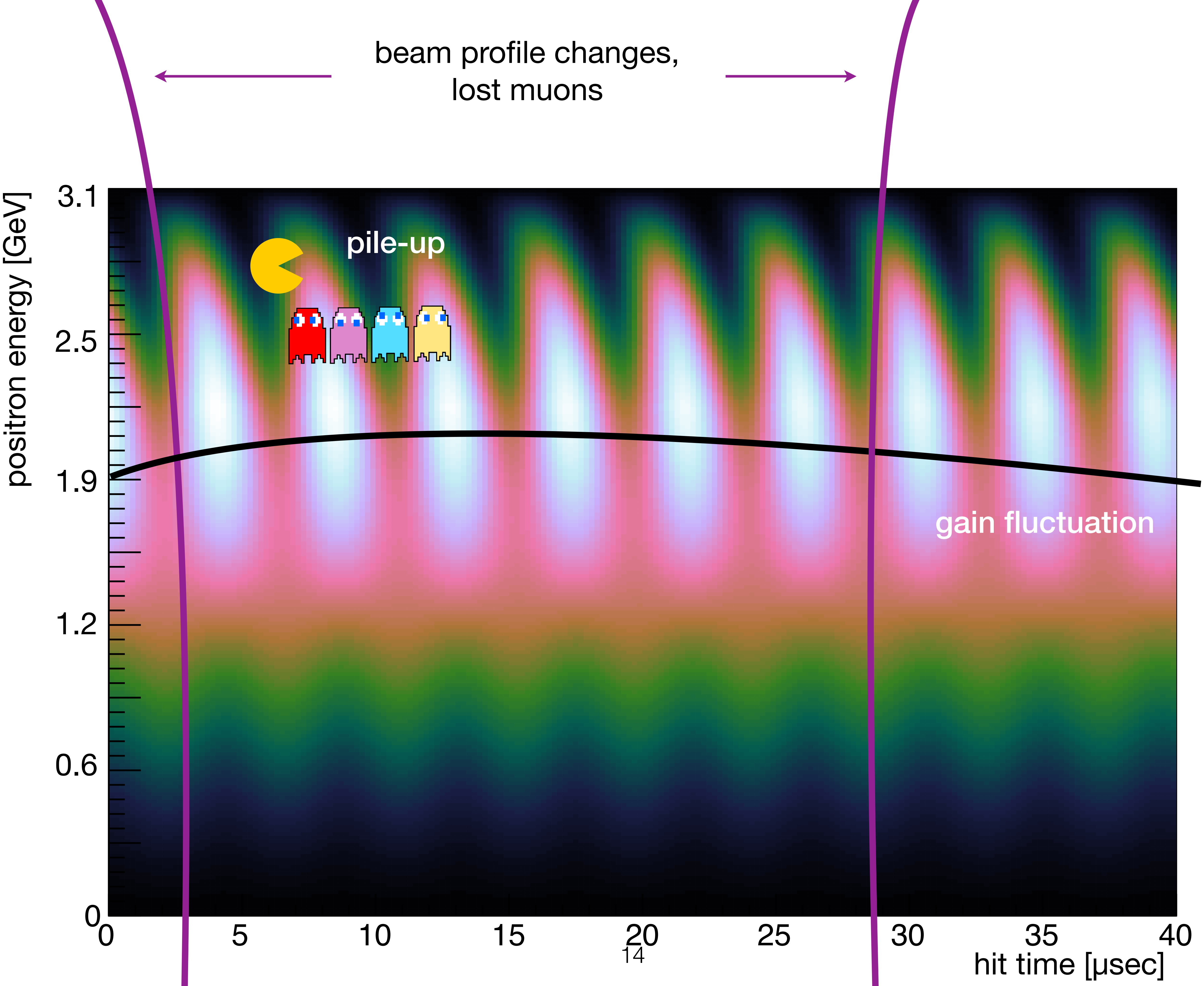


what does a calorimeter see



1D slices at a fixed energy




beam profile changes,
lost muons
pile-up
gain fluctuation
positron energy [GeV]
3.1
2.5
1.9
1.2
0.6
0
0
5
10
15
20
25
30
35
40
hit time [μsec]

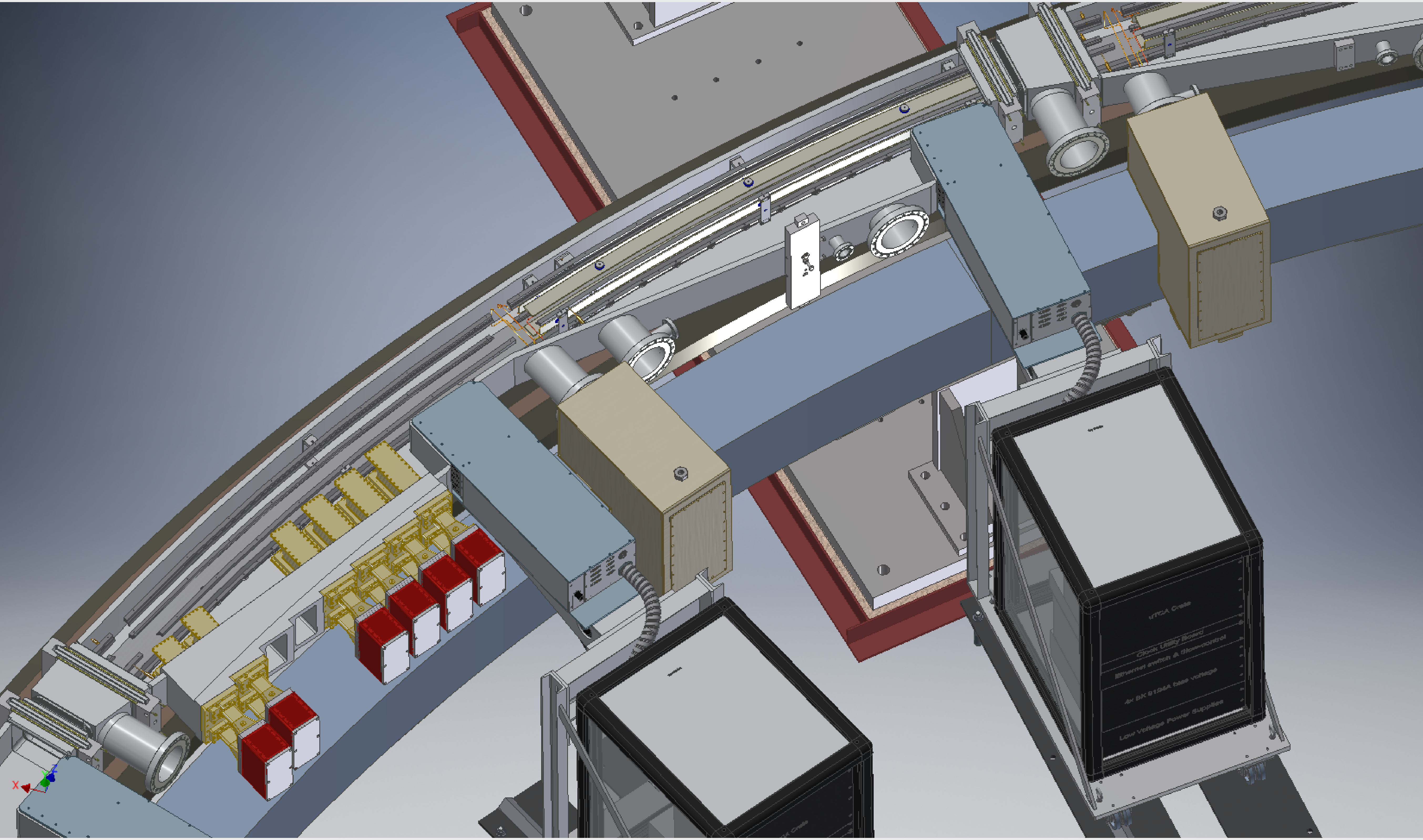
What a calorimeter is supposed to do

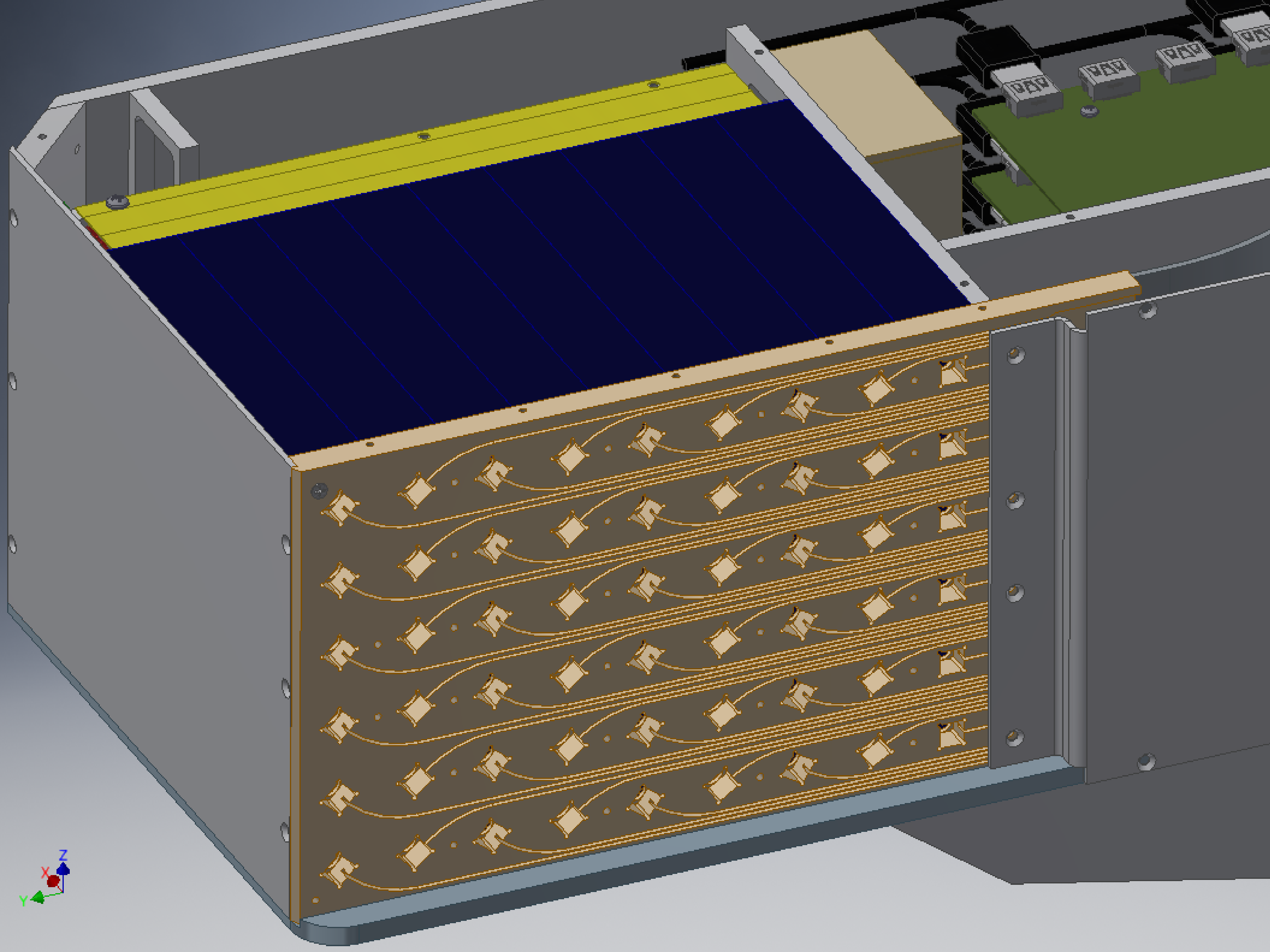
1. Measure positron hit time accurately (100 psec above 100 MeV)

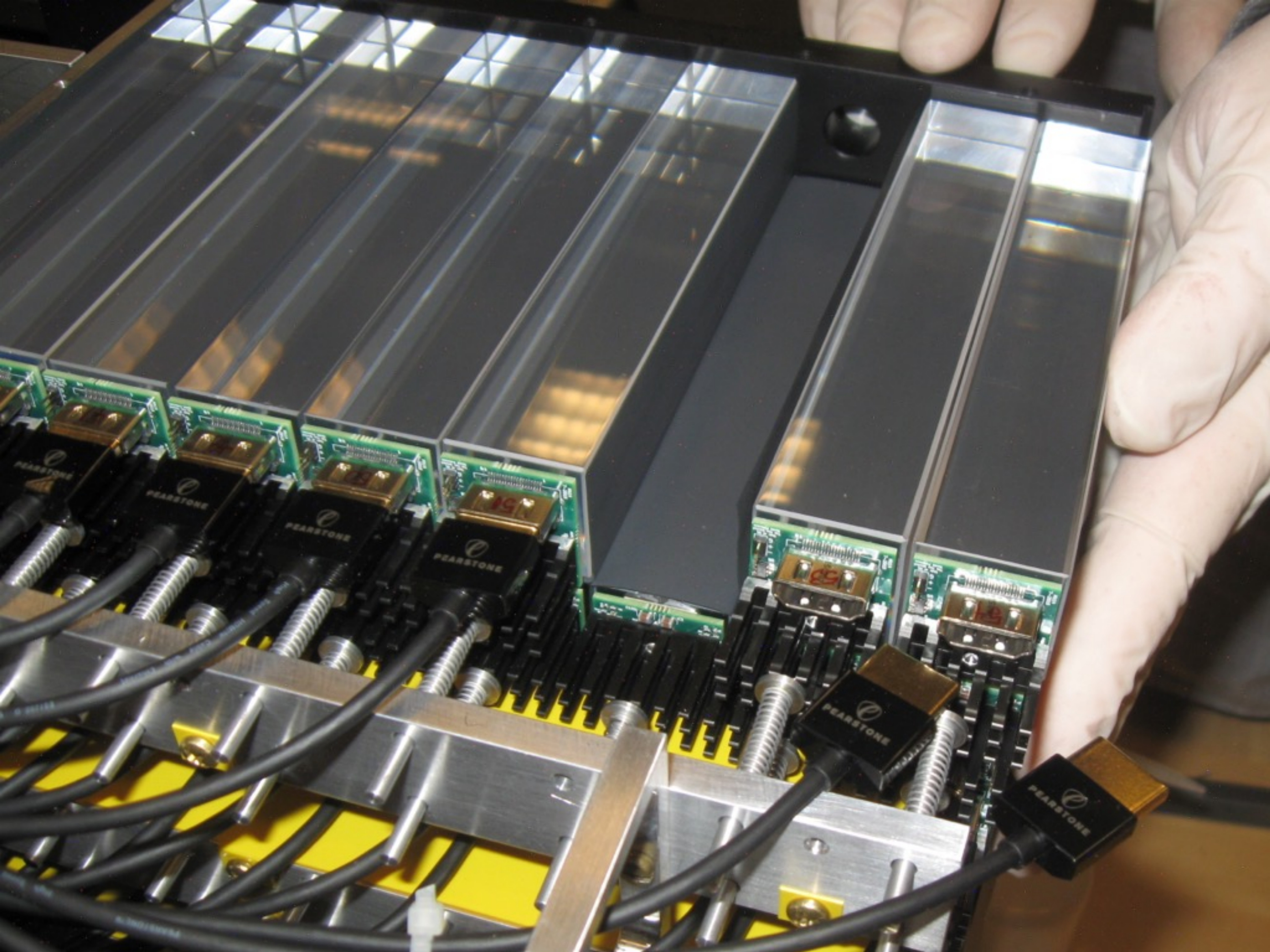
2. Measure deposited energy with resolution better than 5 % at 2 GeV

3. Energy scale (gain) stability in 1e−3 range, over the course of 700 μsec fill where rate varies by 1e4.

4. 100 % pile-up separation above 5 nsec, and 66 % below 5 nsec.


uTCA Crate
Clock Utility Board
Ethernet switch & Slow-control
Low Voltage Power Supplies


Z
X
Y

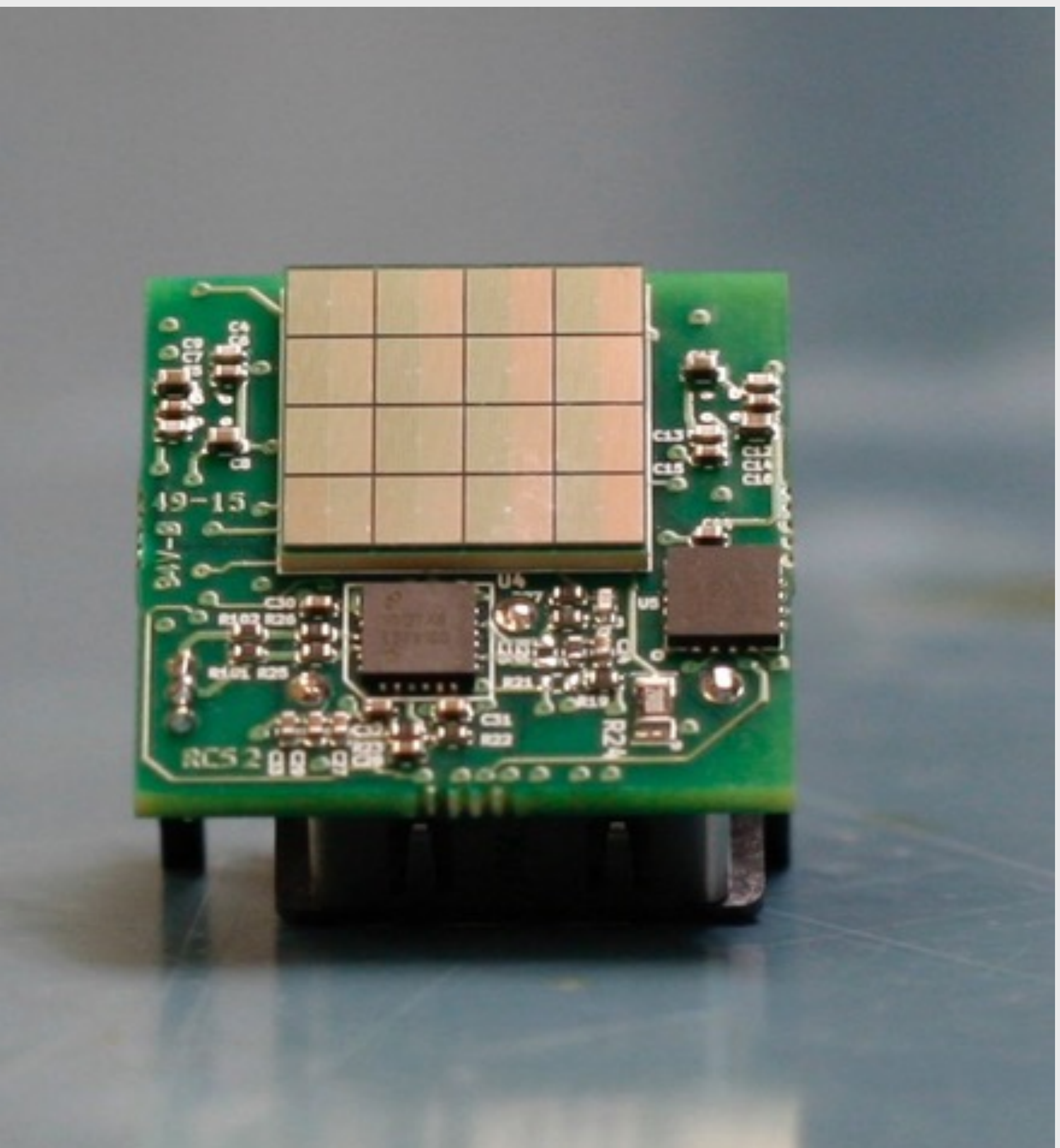

PEARSTONE
PEARSTONE
PEARSTONE
PEARSTONE
PEARSTONE
PEARSTONE
PEARSTONE

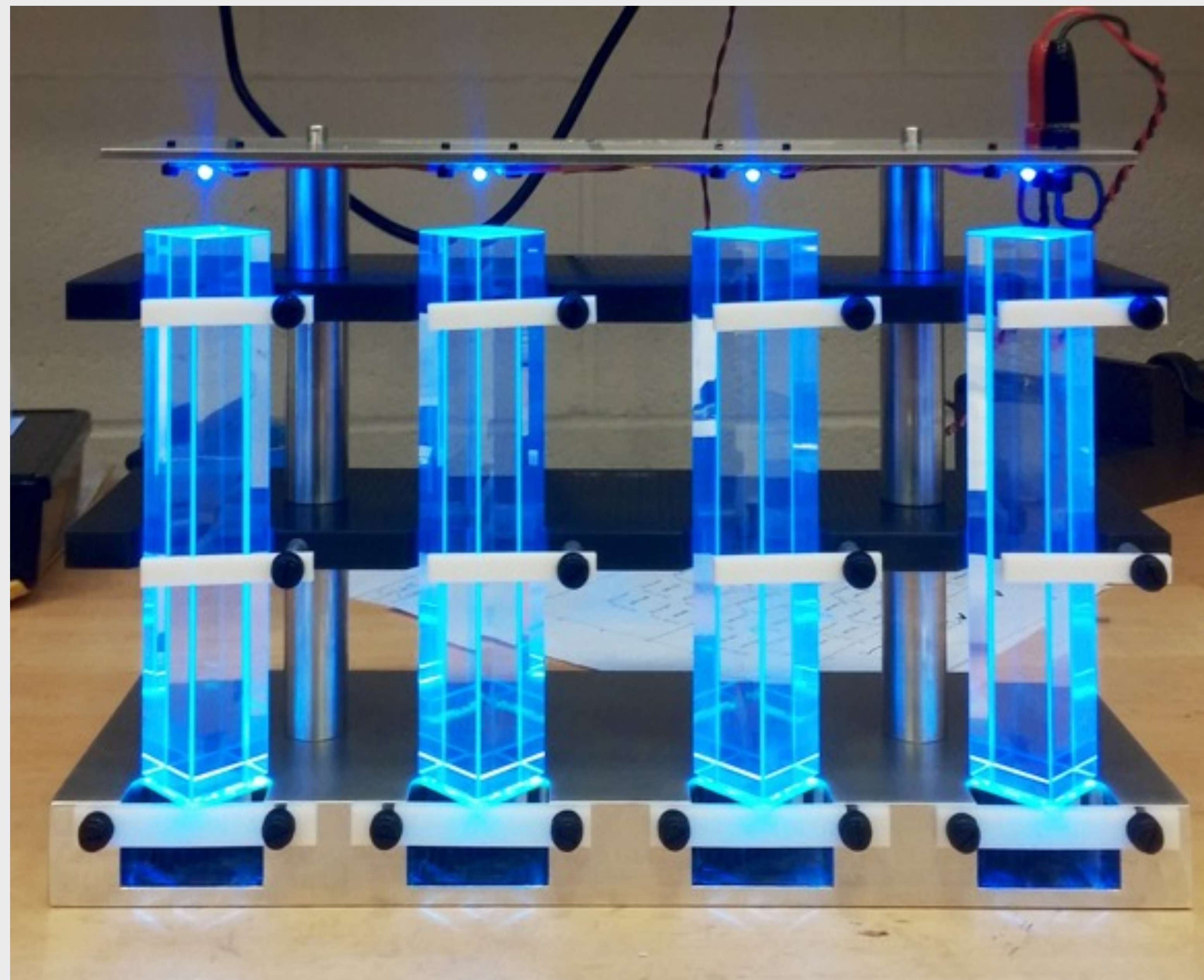
Calorimeter test run at SLAC in June 2016

principles of particle detection

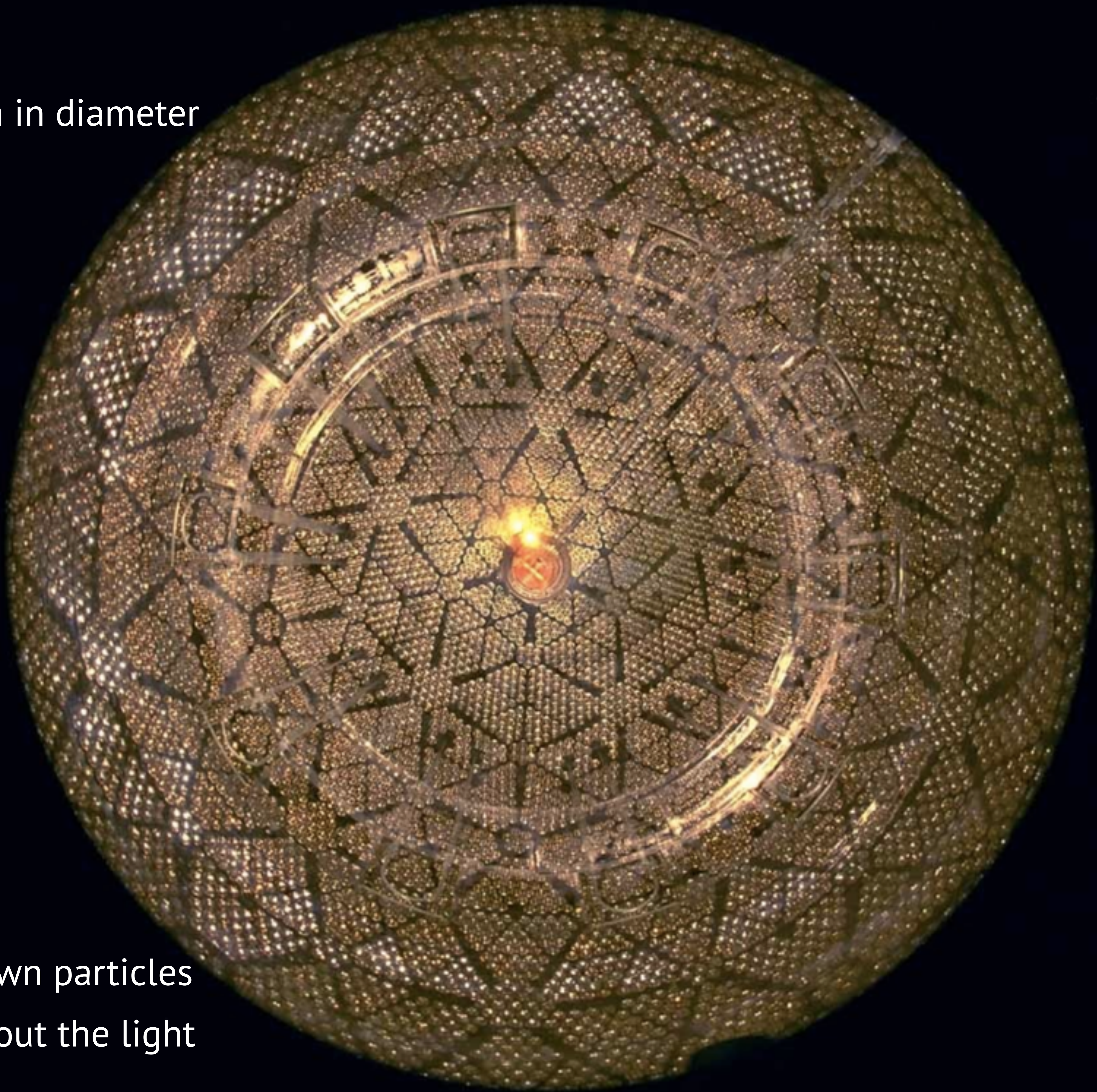
PbF2 – stops down the particle, and converts deposited energy into light

SiPM – reads the light out (counts photons); operates in magnetic fields.





SNO+ detector, 12m in diameter



scintillator stops down particles

10 000 PMT’s read out the light

how SiPM works

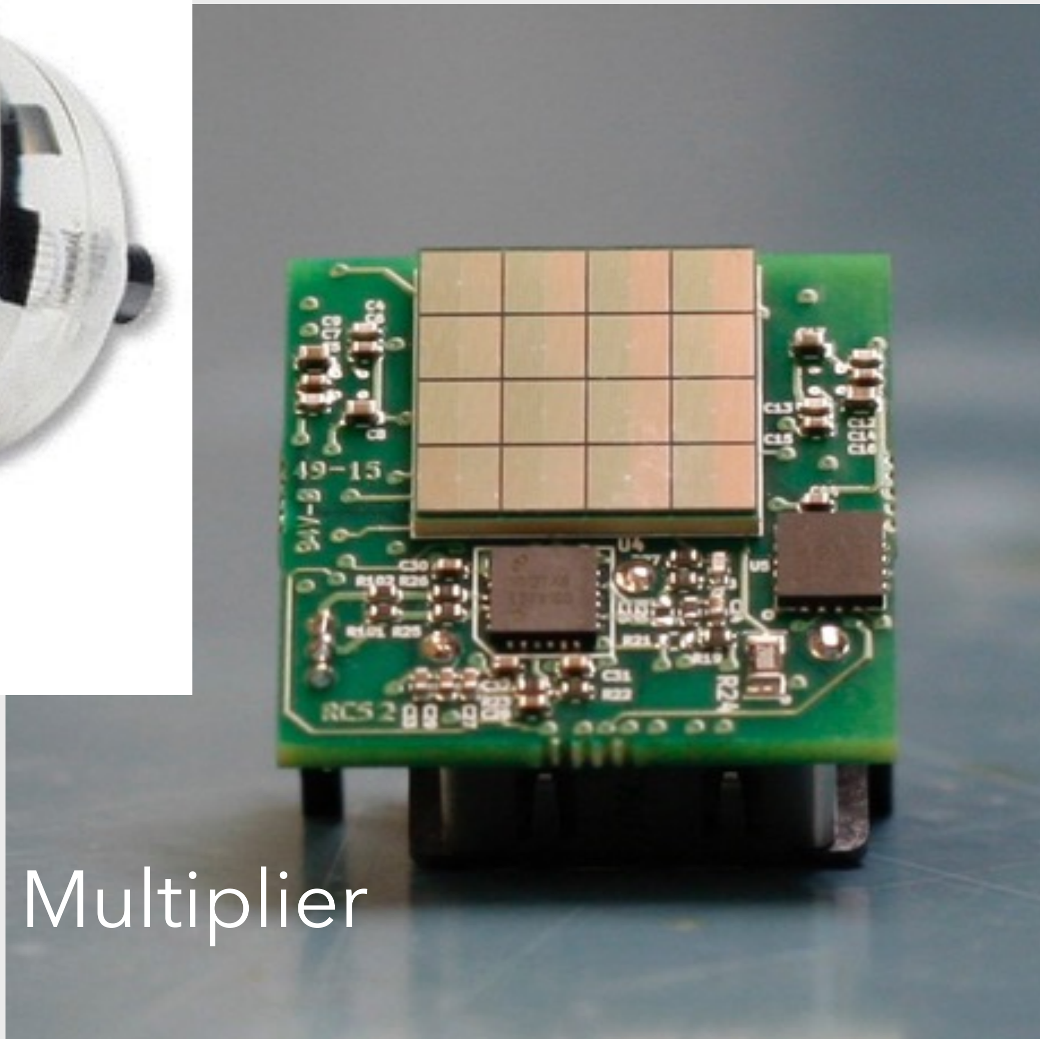
invert

shrink and repeat

56 000 times

CRT TV set

Photo Multiplier Tube



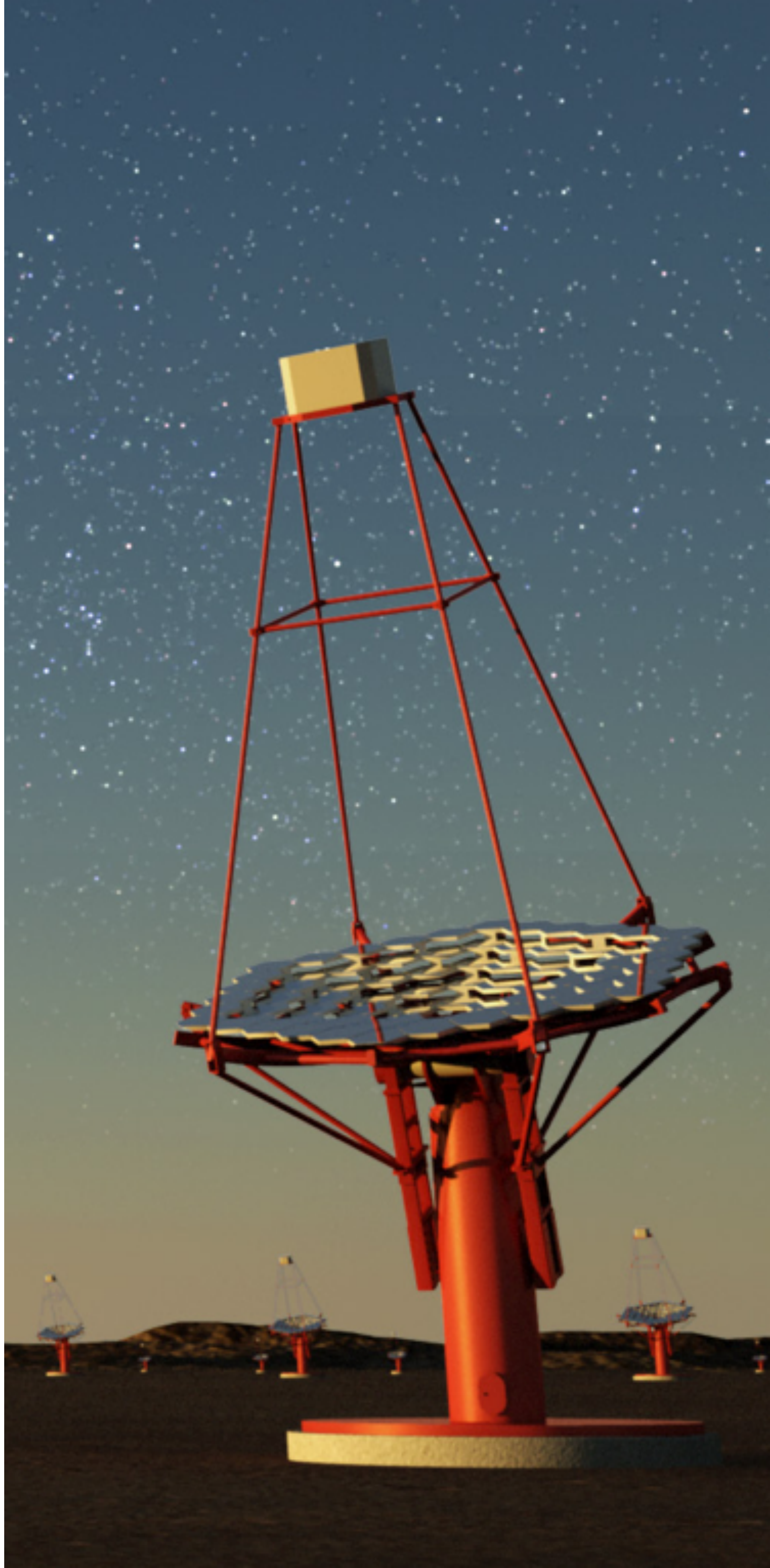
Silicon Photo Multiplier

other examples of use

- Cerenkov telescopes (CTA)
  single photons, shaping, clipping,
  pole-zero correction

- hadron calorimeters
  ~1000 photons
  Cerenkov, fast scint, or both

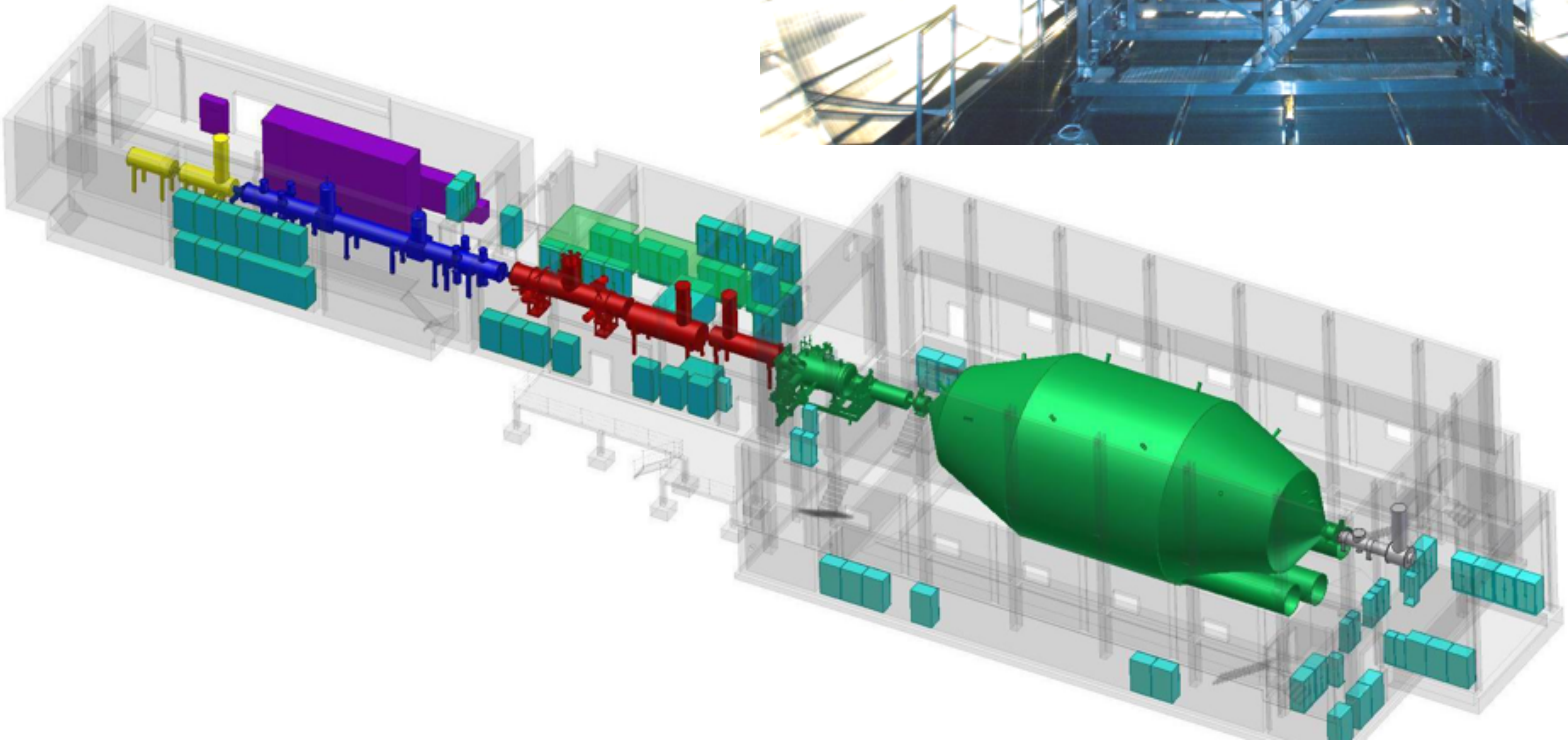
- positron emission tomography
  TOF



KATRIN neutrino mass exp

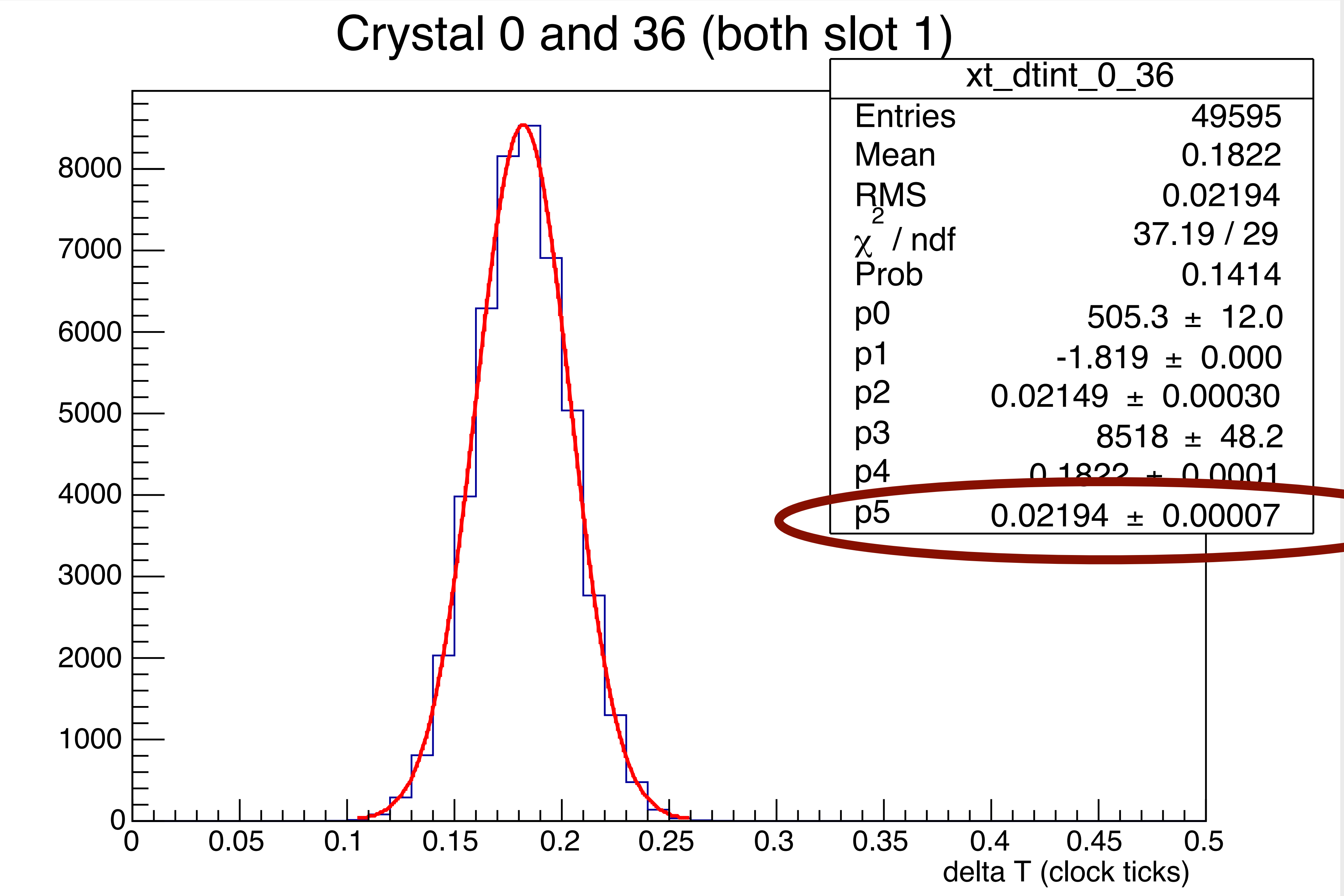
charged particle propagation

in electro-magnetic field



timing resolution 25ps at 3GeV

1. time differences within digitizer channels (two pulses in the same channel)
2. time differences across channels (a single pulse in two channels)



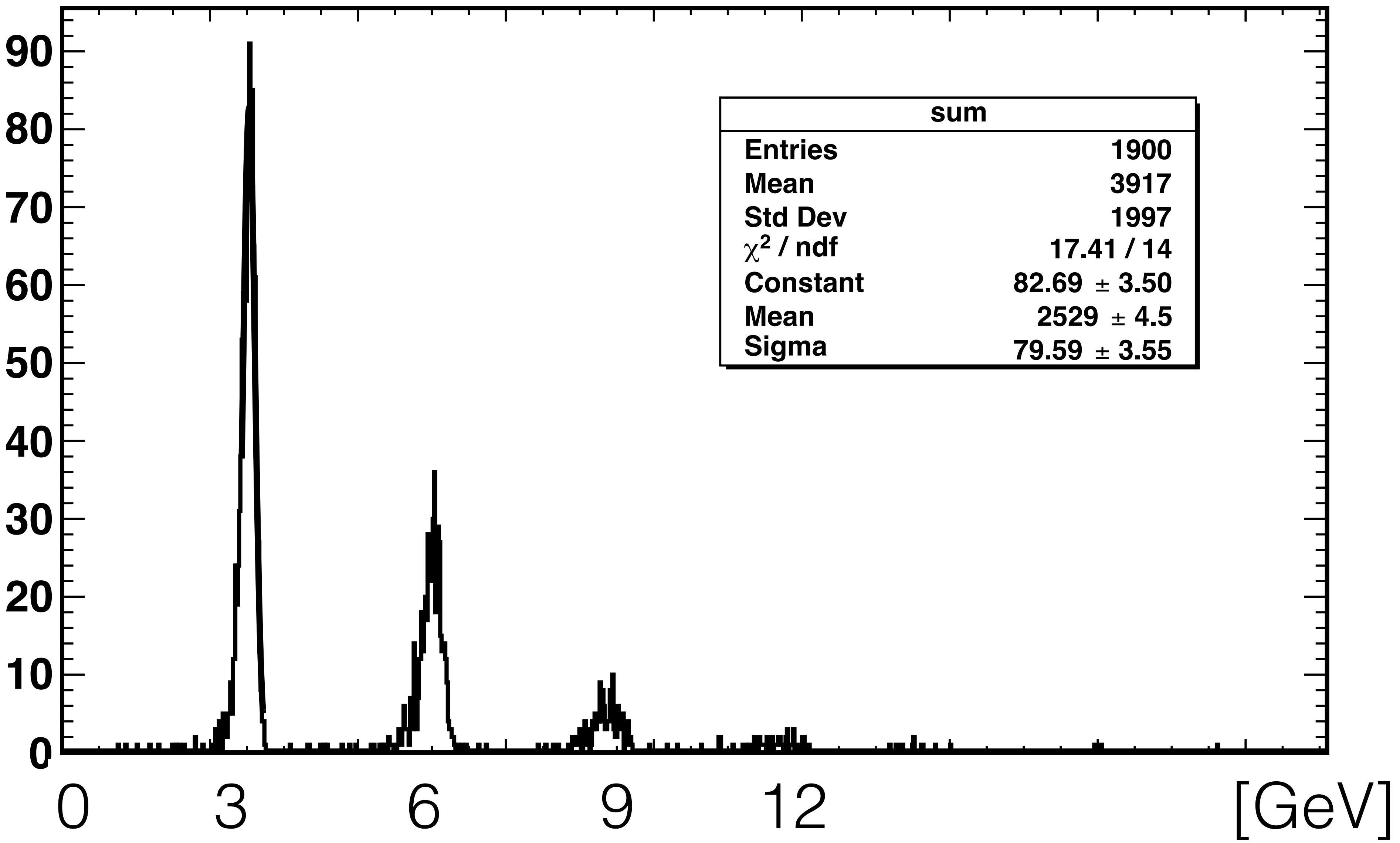
800 MHz clock

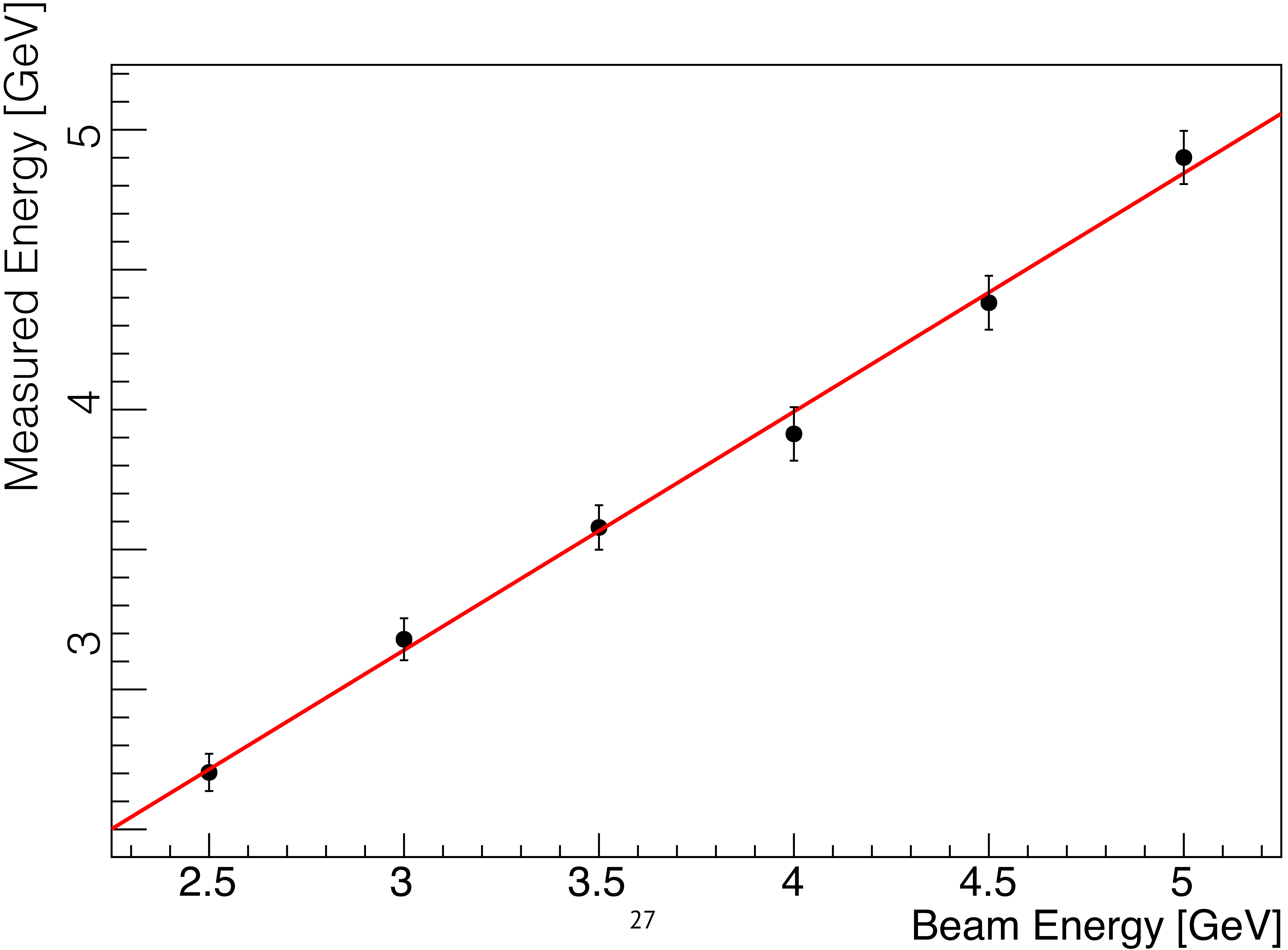
1 tick is 1.25nsec

reproduced eng resolution 3% at 3GeV

both from data, and photo statistics and electronics contributions

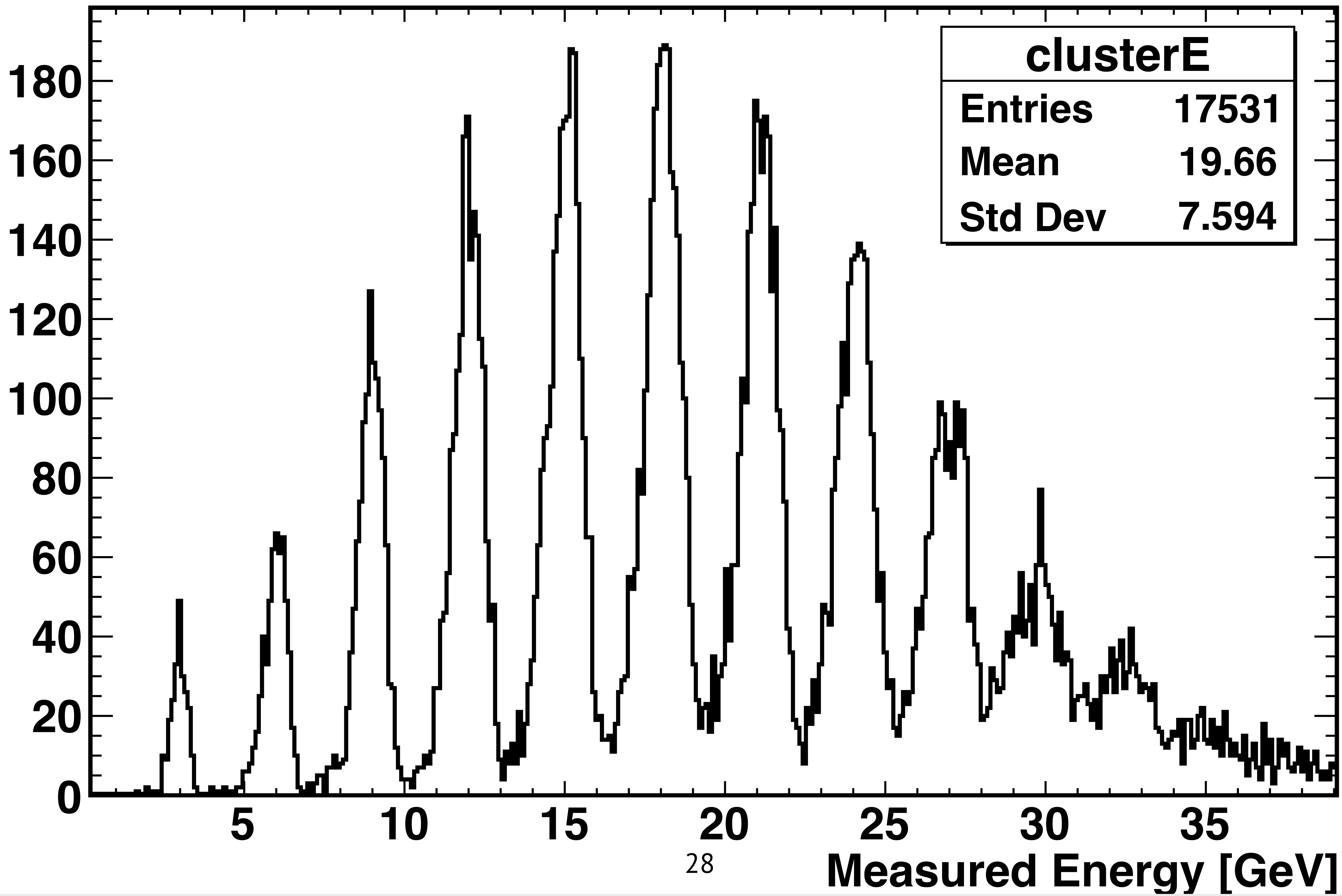
Poisson comb of hit energies



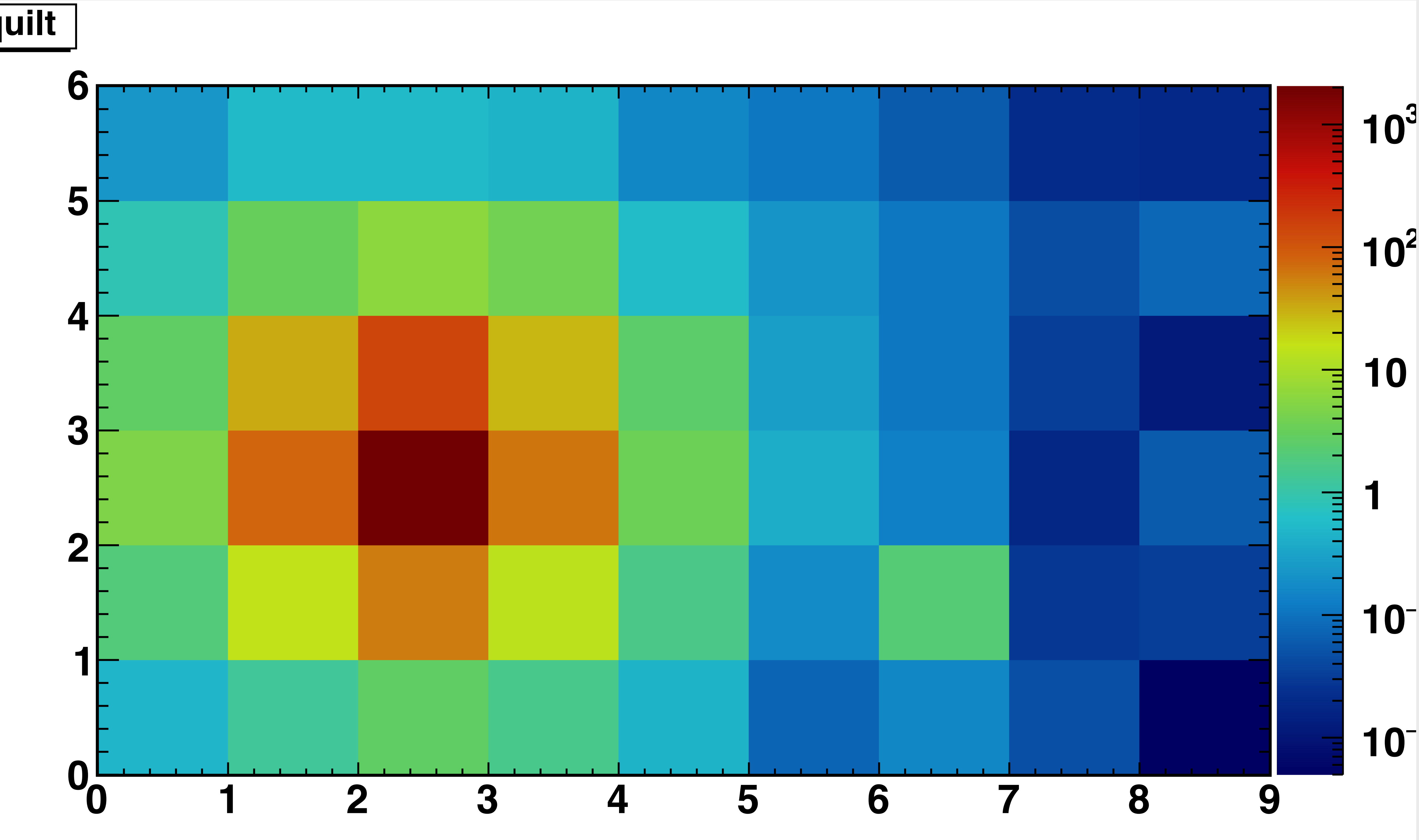


Measured Energy [GeV]
5
4
3
2.5
3
3.5
4
4.5
5
Beam Energy [GeV]

low QE runs

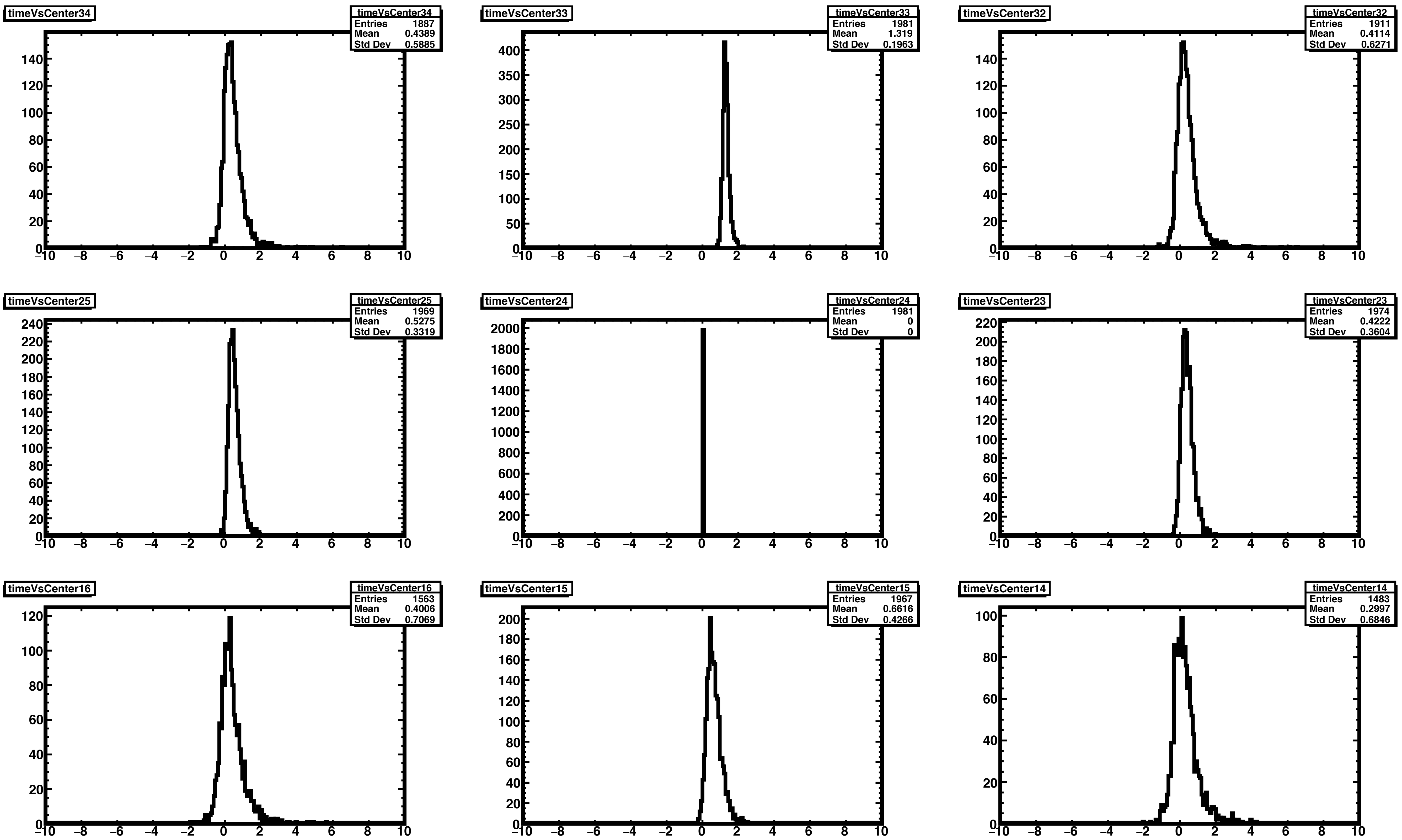

clusterE
Entries 17531
Mean 19.66
Std Dev 7.594
0
20
40
60
80
100
120
140
160
180
5
10
15
20
25
30
35
Measured Energy [GeV]

1e-3 effects in shower propagation



timing for angle reconstruction

Cherenkov photons slower than EM shower propagation



Energy scale (gain) stability on 3 time scales

The goal is in the *1e-3* range

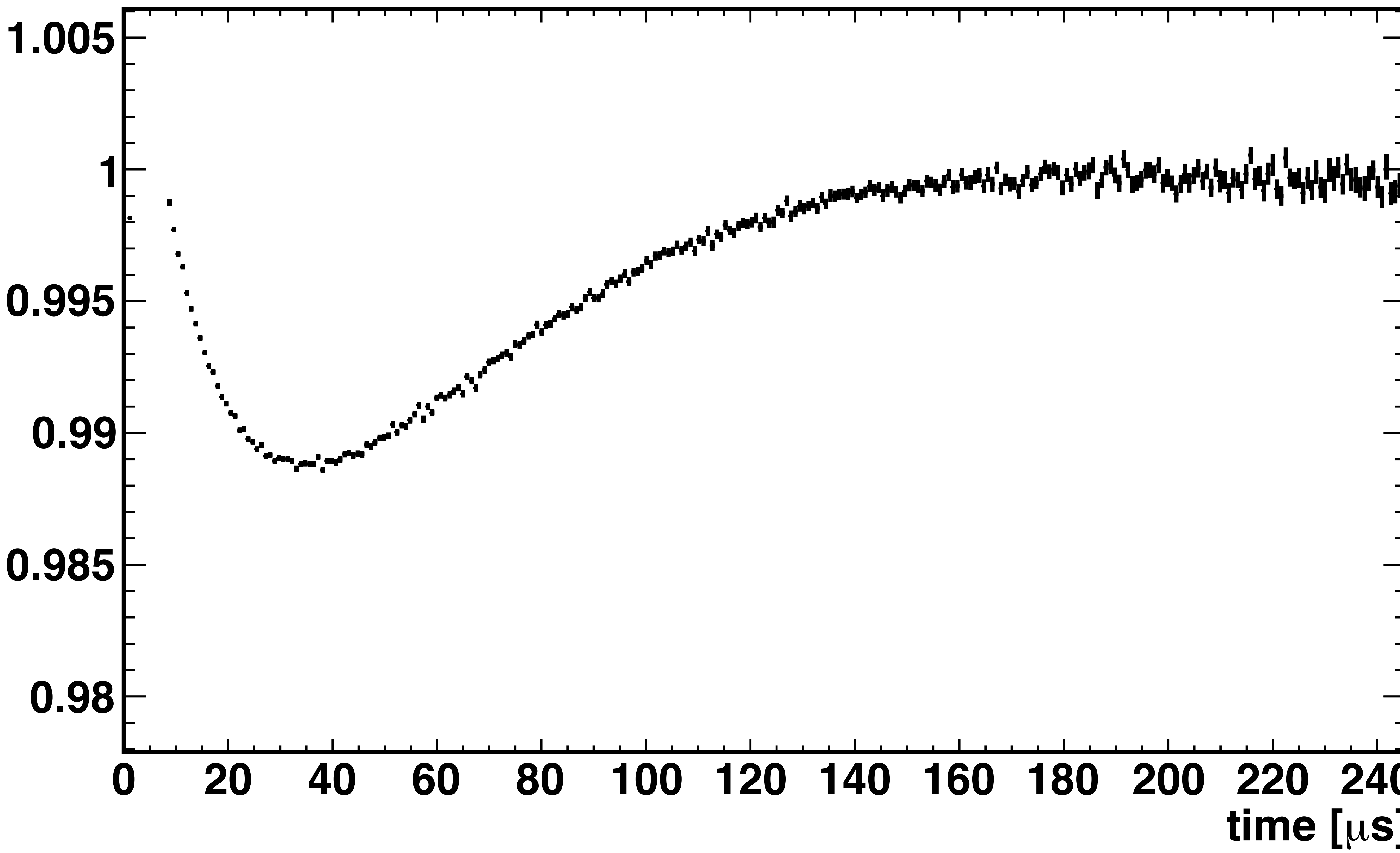
1. Long term hours, days, years (laser calibration)

2. within a muon fill which lasts 700 μsec (laser calibration)

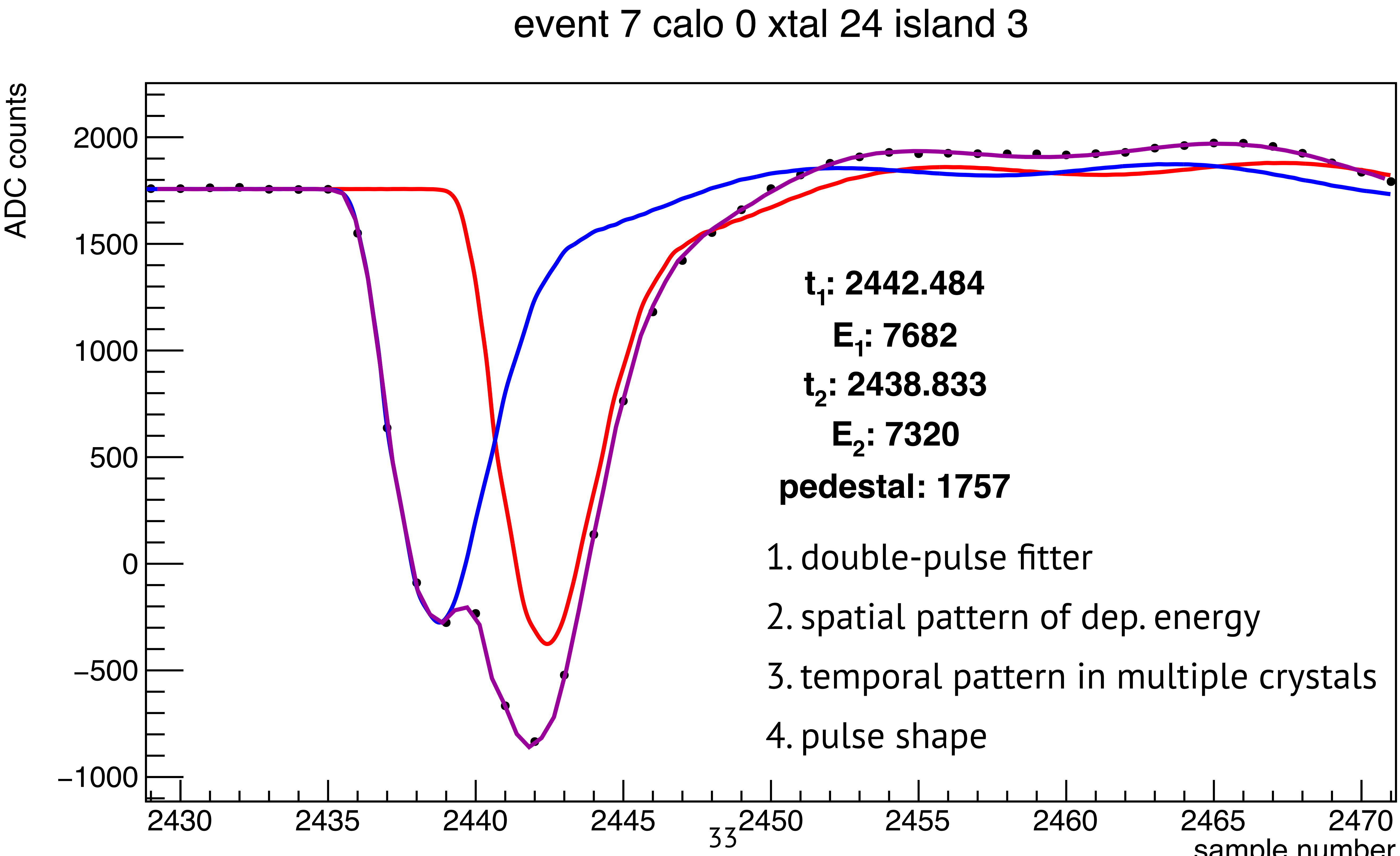
3. pile-up separation of pulses 10 nsec wide (lasers very difficult here)???

You come to SLAC.

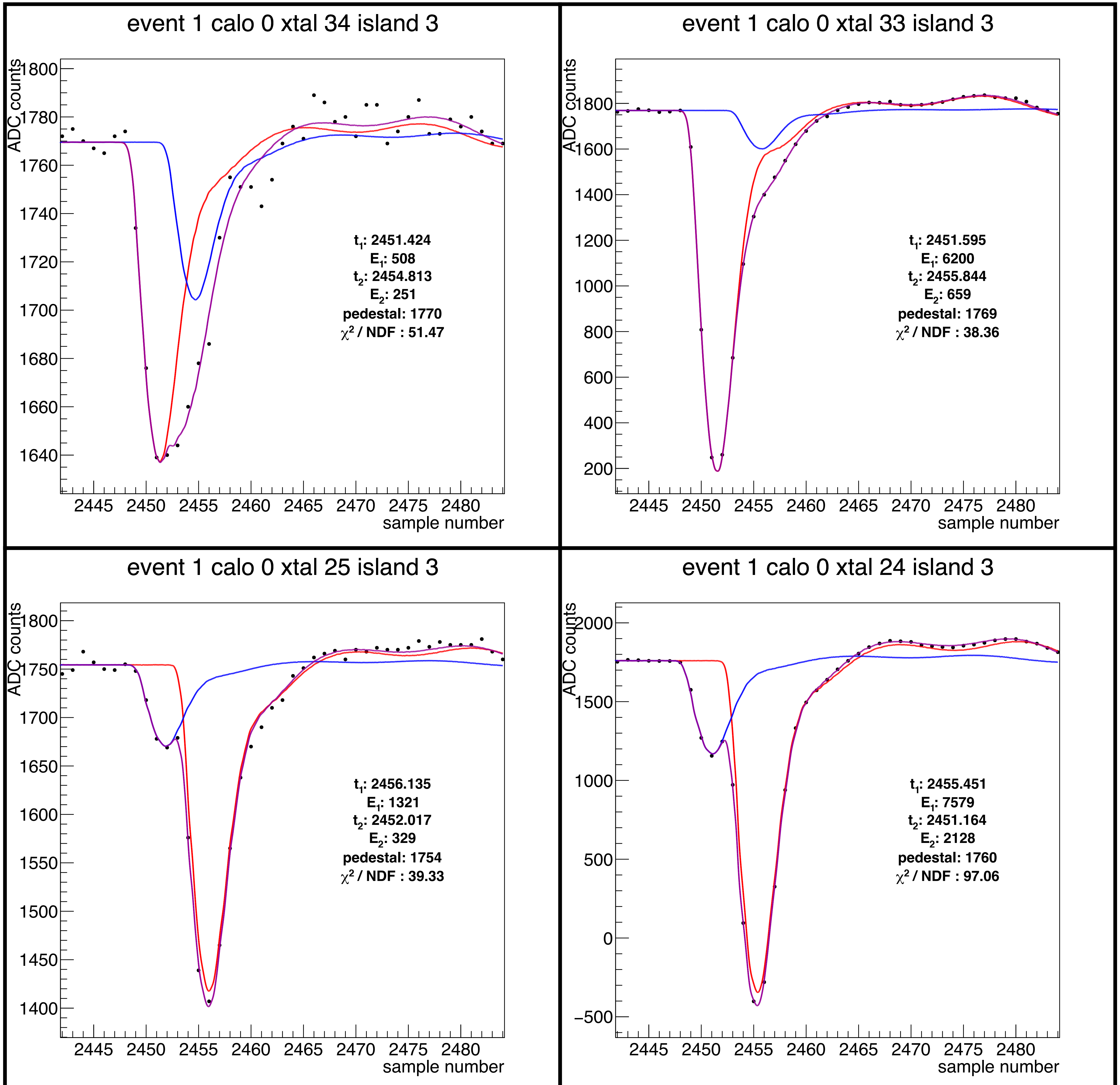
gain sagging with 1,000 times more light than physics



pileup separation: double bunches with 4.5nsec separation



1. double-pulse fitter
2. spatial pattern of dep. energy
3. temporal pattern in multiple crystals
4. pulse shape


event 1 calo 0 xtal 34 island 3
ADC counts
sample number
t1: 2451.424
E1: 508
t2: 2454.813
E2: 251
pedestal: 1770
χ2 / NDF : 51.47
event 1 calo 0 xtal 33 island 3
ADC counts
sample number
t1: 2451.595
E1: 6200
t2: 2455.844
E2: 659
pedestal: 1769
χ2 / NDF : 38.36
event 1 calo 0 xtal 25 island 3
ADC counts
sample number
t1: 2456.135
E1: 1321
t2: 2452.017
E2: 329
pedestal: 1754
χ2 / NDF : 39.33
event 1 calo 0 xtal 24 island 3
ADC counts
sample number
t1: 2455.451
E1: 7579
t2: 2451.164
E2: 2128
pedestal: 1760
χ2 / NDF : 97.06

Next steps: installation at FNAL

Move everything and everybody to FNAL: September 2016

Calorimeter installation in ring: October 2016

First beam in Spring 2017.

Thank you very much!