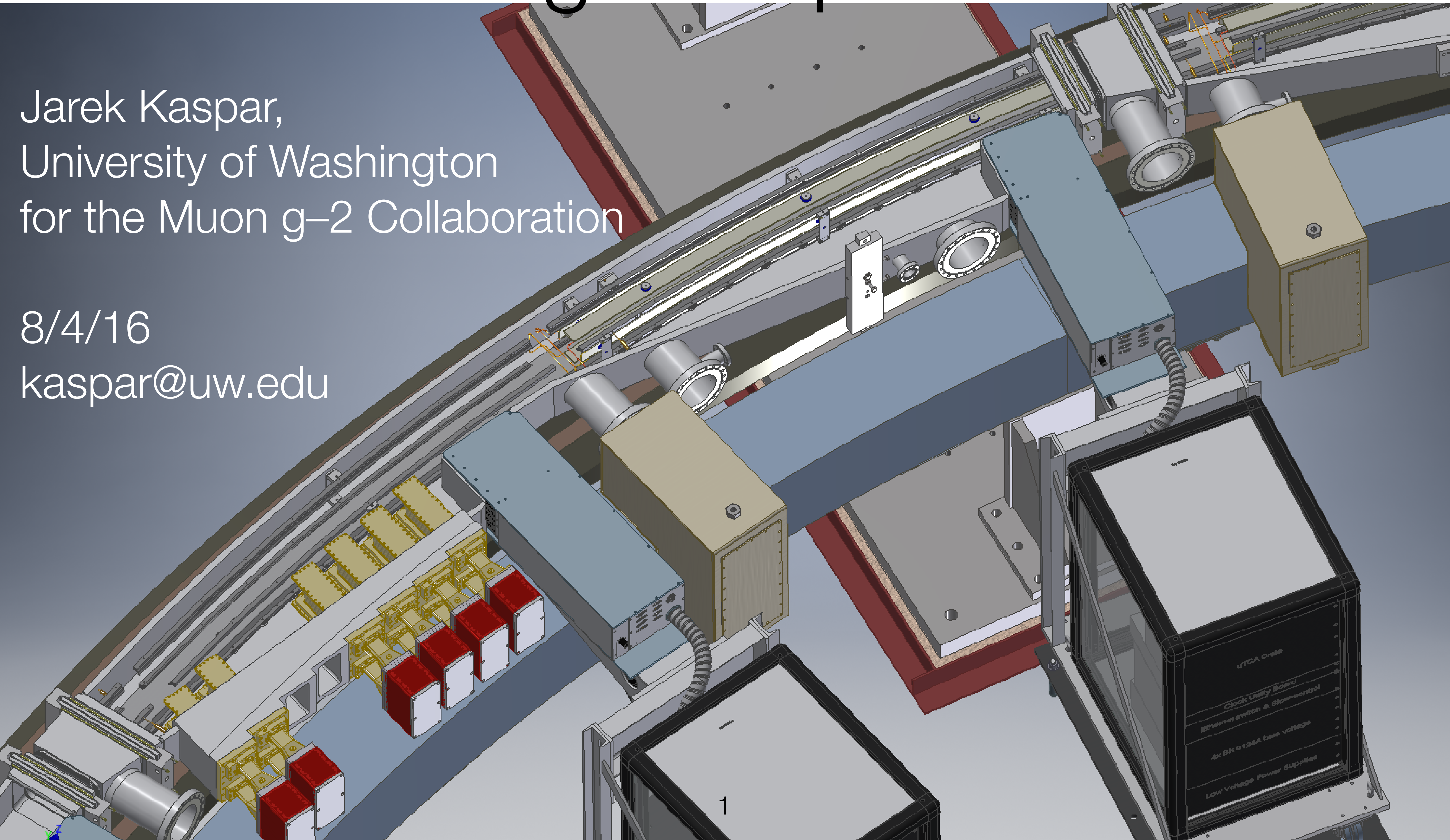
Detector systems for the Muon g–2 experiment

Jarek Kaspar,
University of Washington
for the Muon g–2 Collaboration

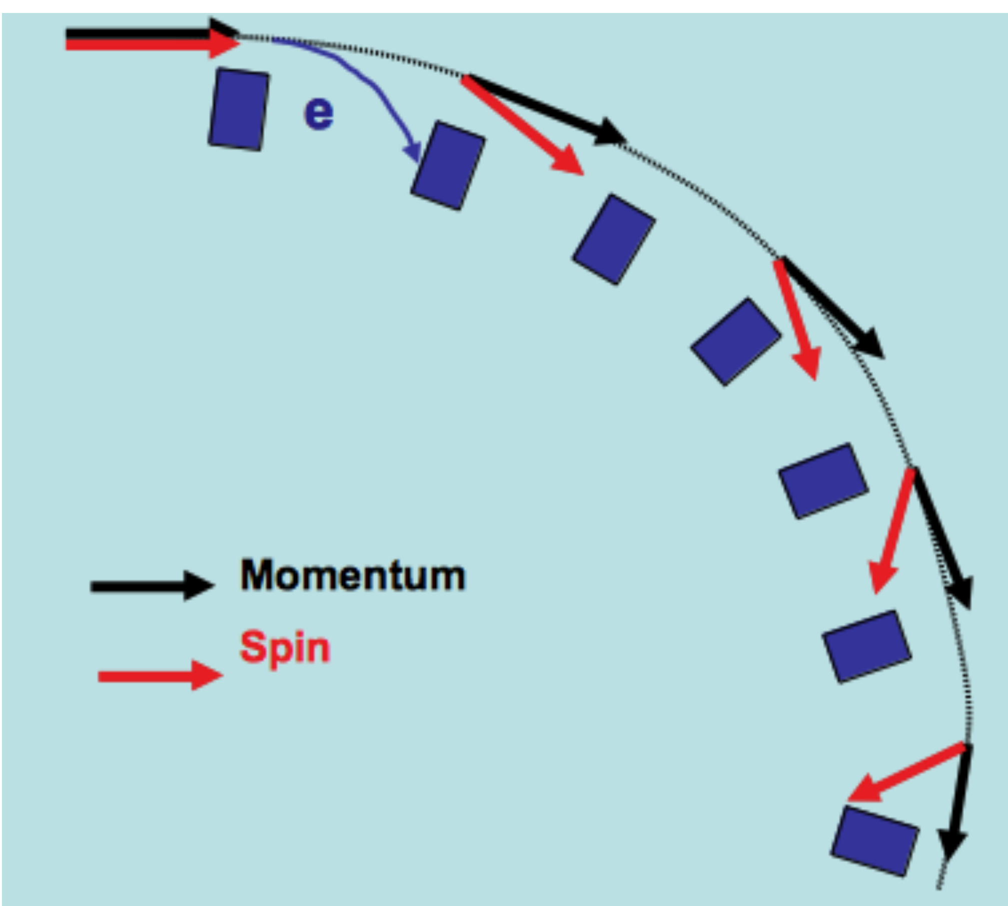
8/4/16

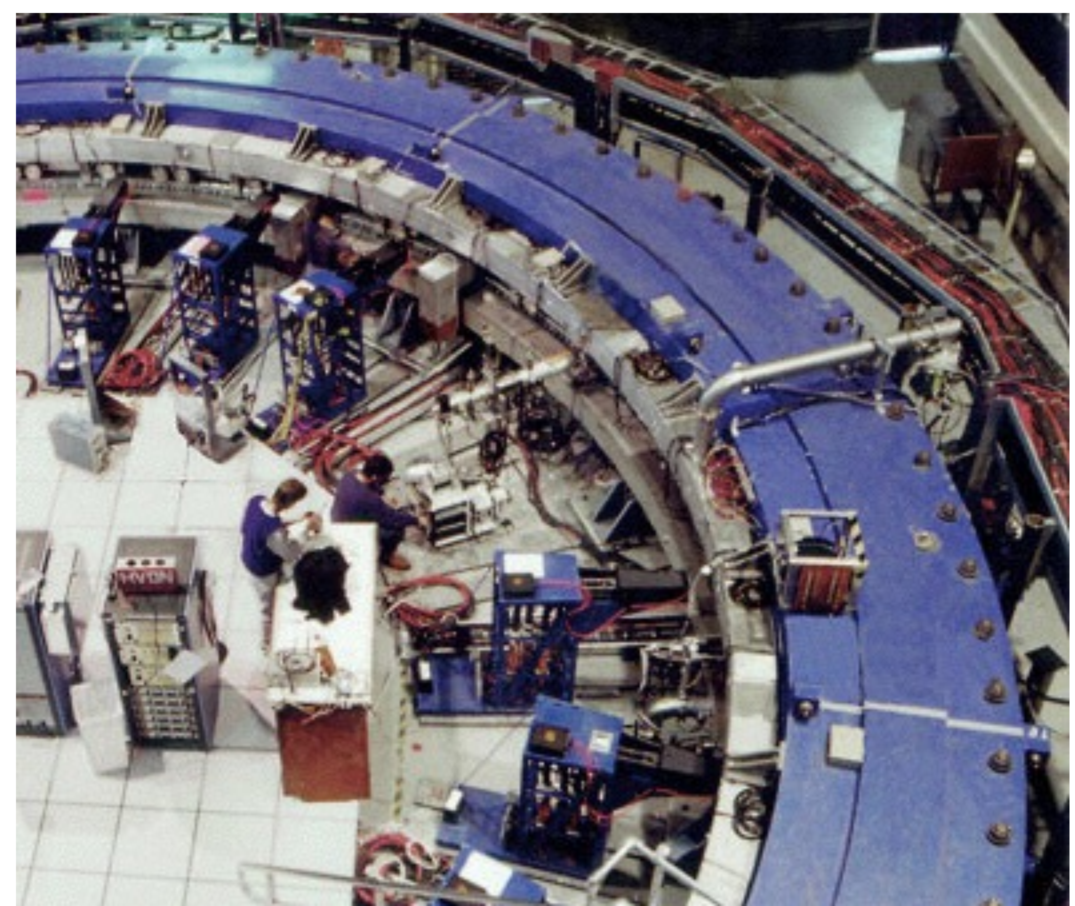
kaspar@uw.edu



magnetic dipole moment of muon

- torque experienced in external magnetic field
- spin → intrinsic magnetic dipole moment
- experiment measures the anomalous part of magnetic dipole moment



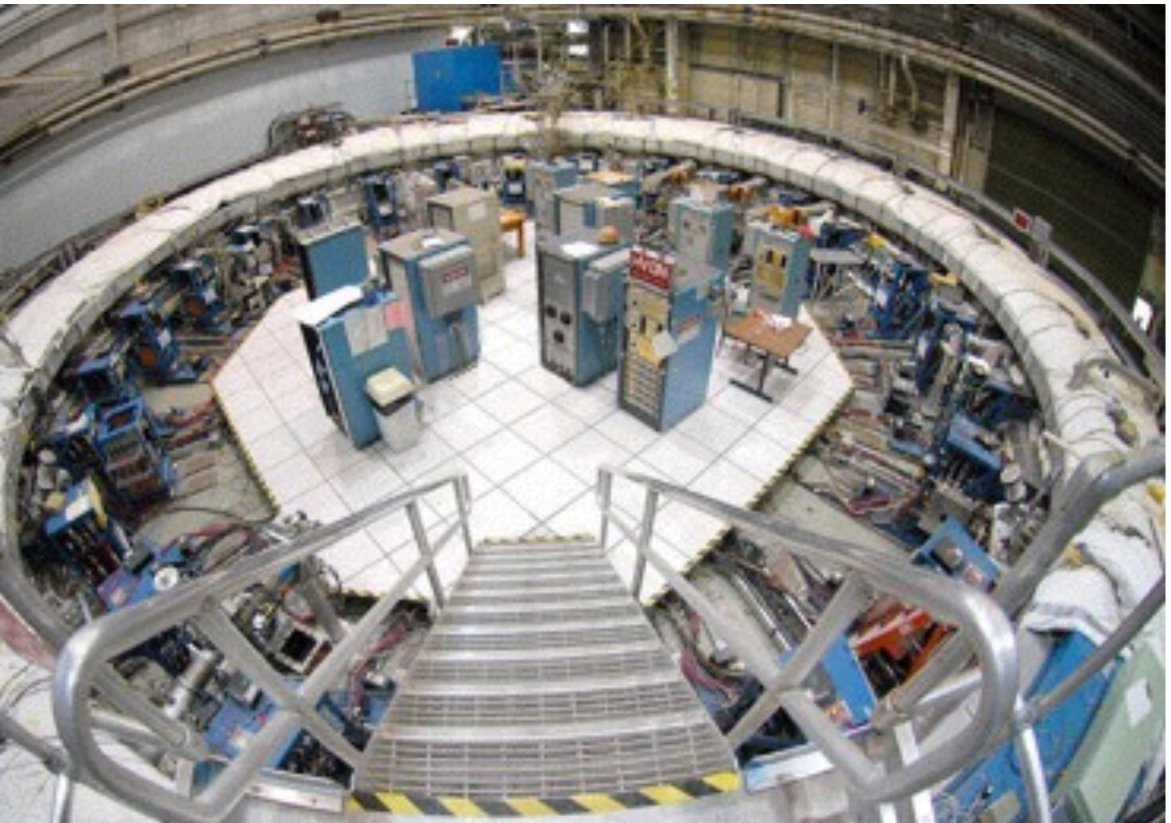


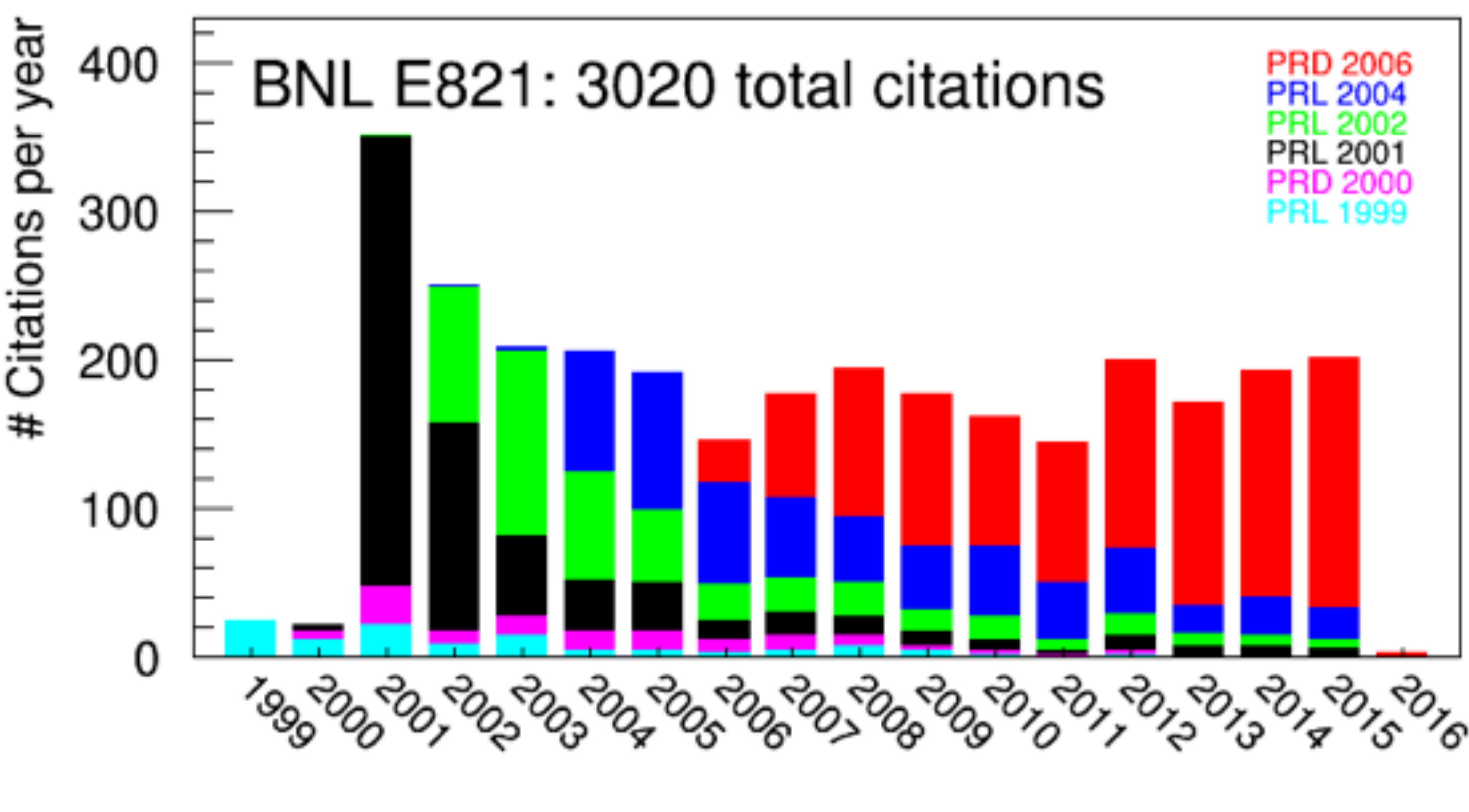
$g - 2$ experiment at BNL

E821 (1999 - 2006):

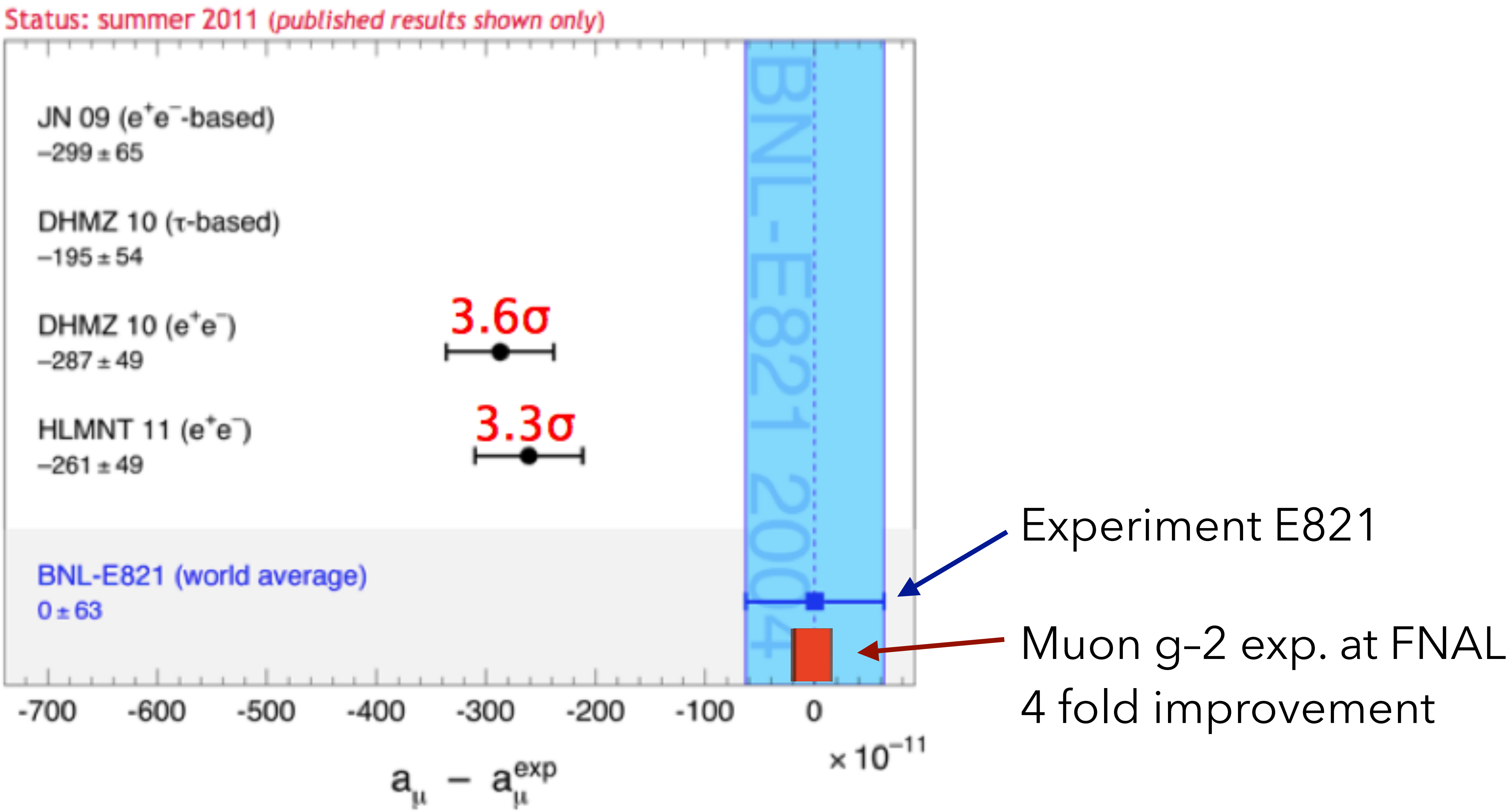
$a_\mu = 0.001\ 165\ 920\ 89\ (63)\ (\pm 0.54\ \text{ppm})$

And a hint of New Physics ?

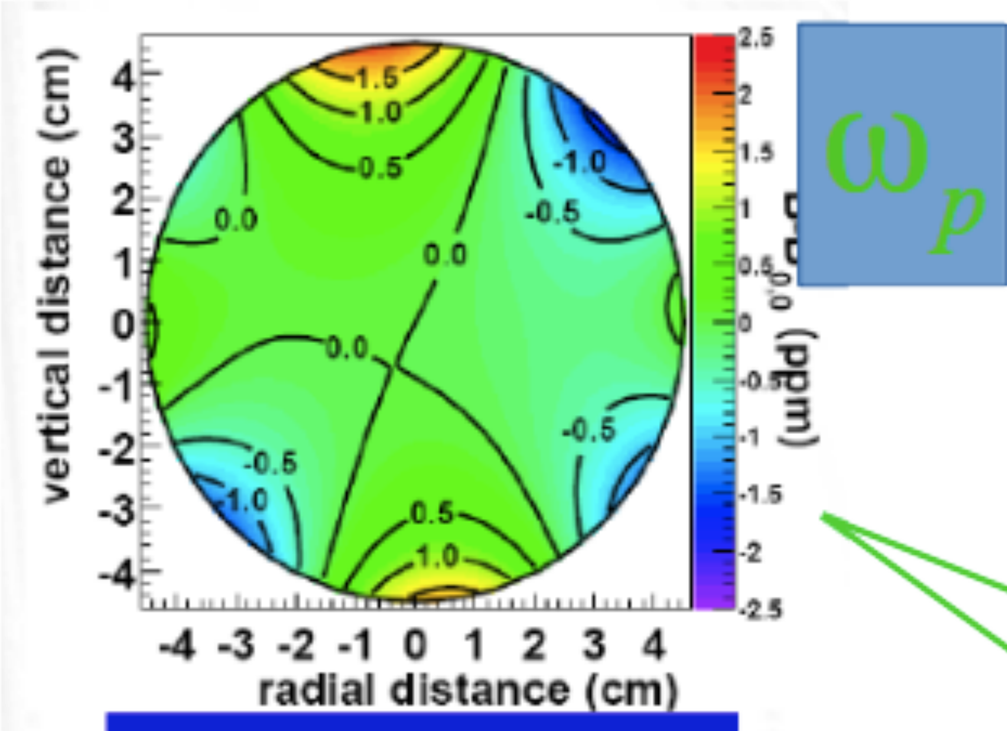




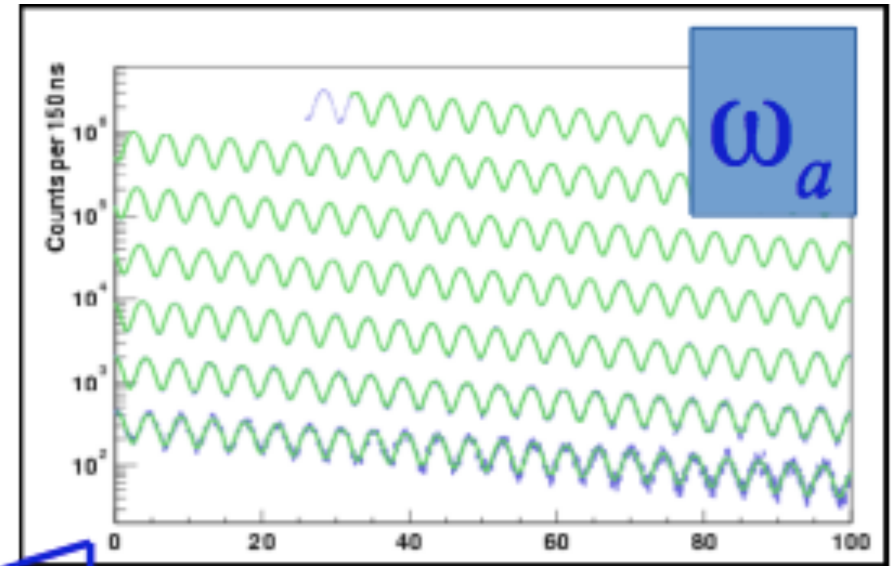
Standard Model prediction



Talk by Polly, C. & Swanson, E. The Muon g–2 Experiment at Fermilab

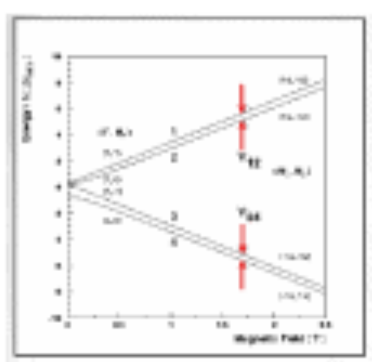


Our "Magnet"



Our conventional Detector, Electronics, and DAQ systems

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



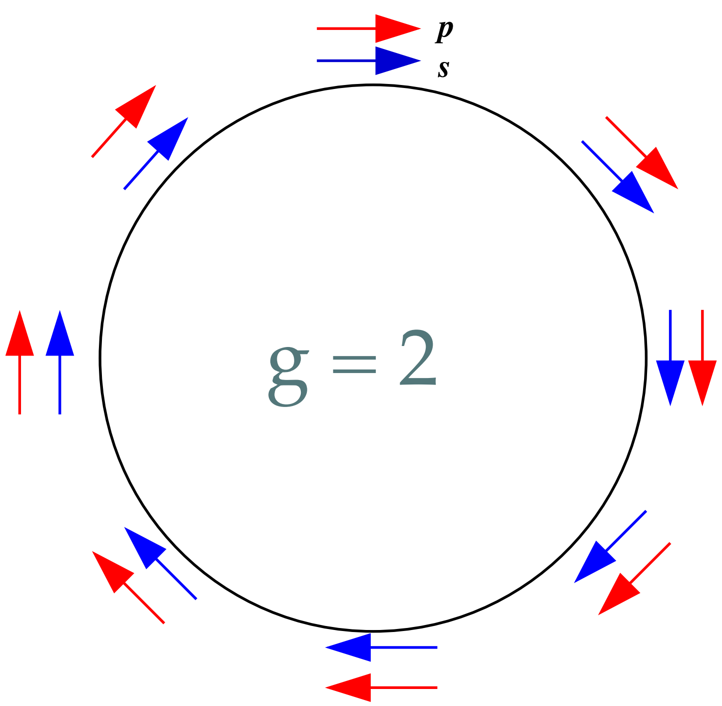
μ_μ/μ_p = 3.183 345 24(37) (120 ppb)
= *3.183 345 39(10) (31 ppb)*

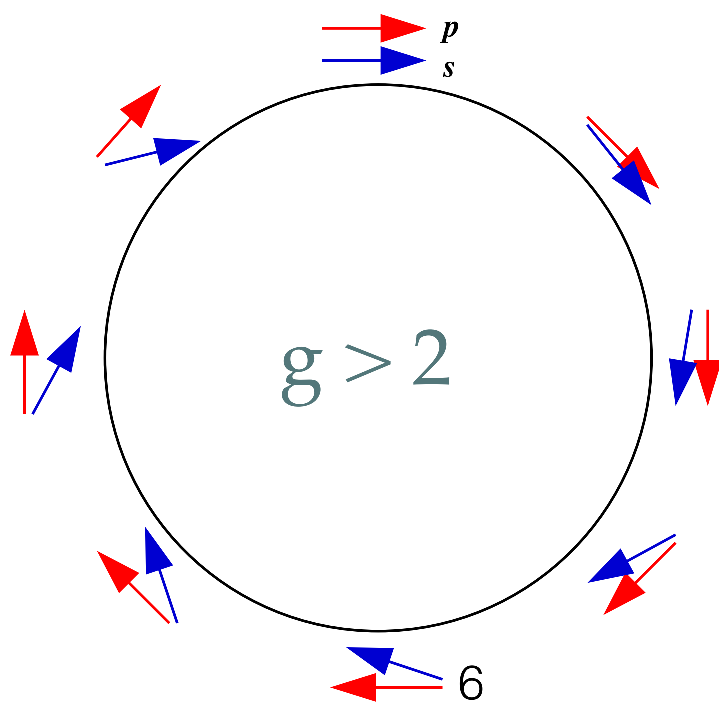
External Muonium Hyperfine Expt.

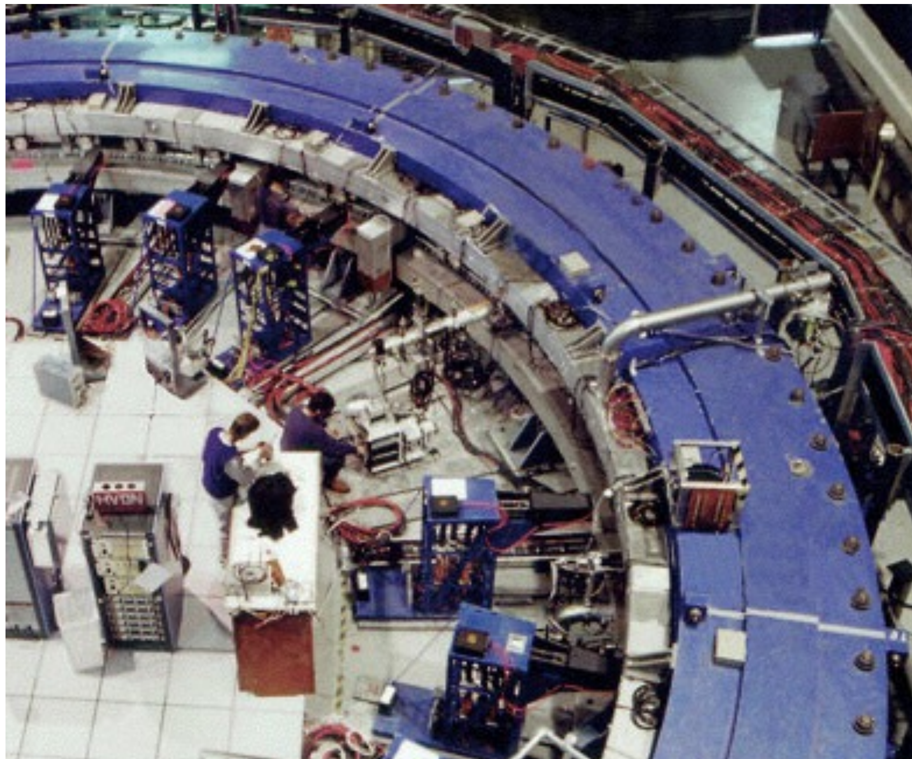
Poster by Kiburg, B. Maximizing Magnetic Field Uniformity in the 1.45-Tesla Muon g–2 Storage Ring

principles of ω_a measurement

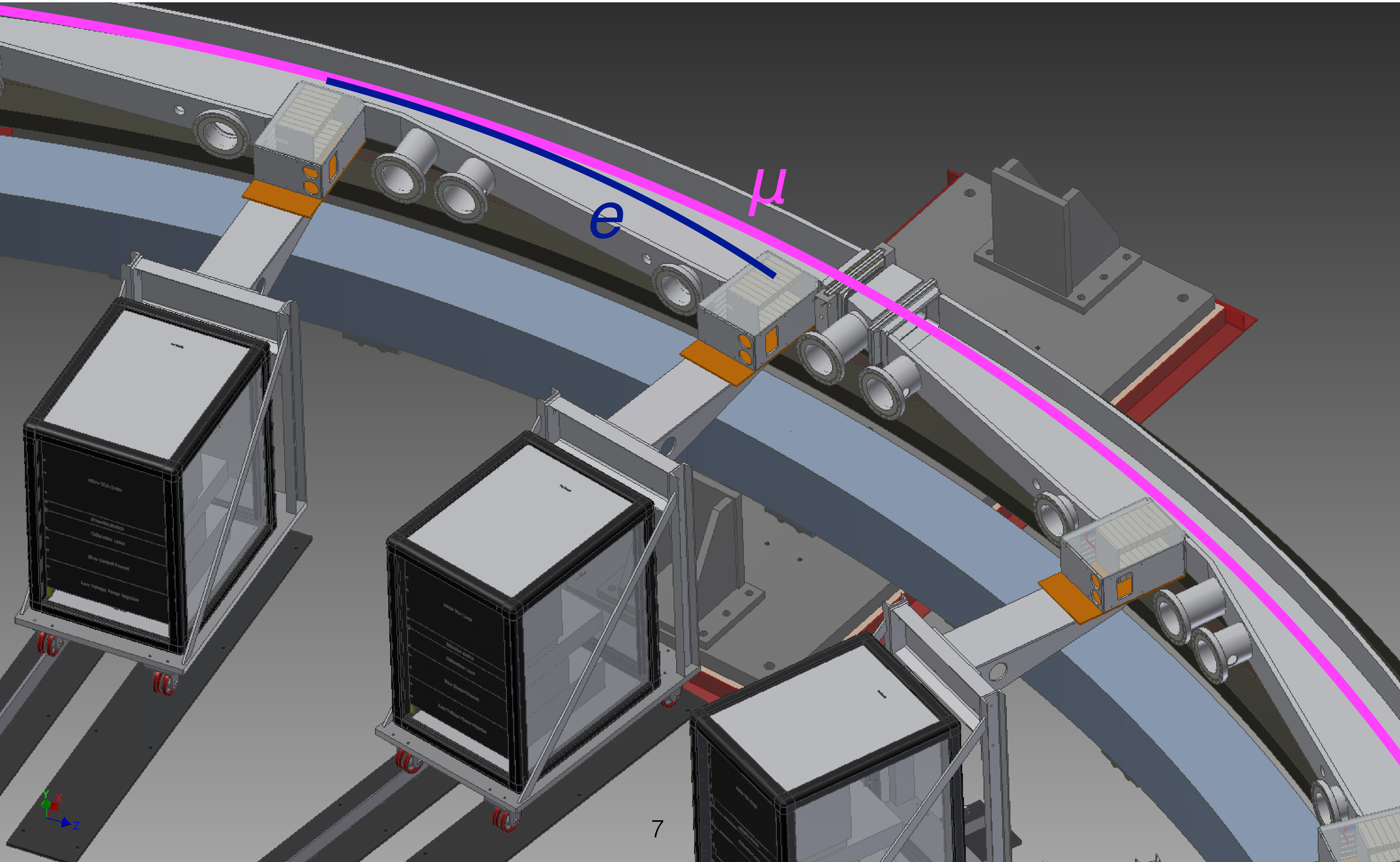
1. source of polarized muons (parity violating pion decay)
2. precession proportional only to the anomalous part of magnetic dipole moment *(g-2)*
3. magic momentum gets rid of $\beta \times E$ term
4. parity violating decay (positron reports on spin)
   Lorentz boost maps spin direction onto energy



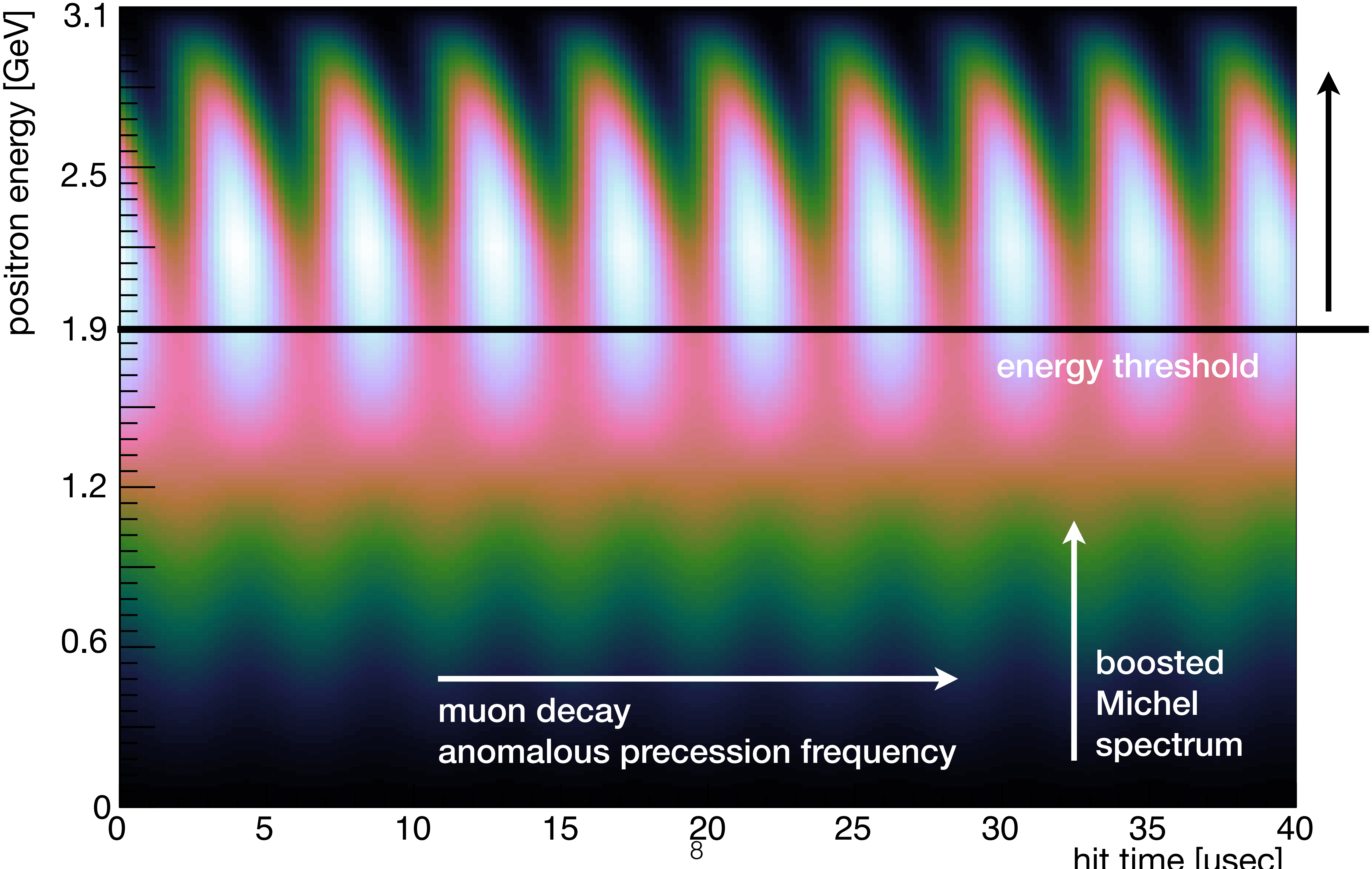


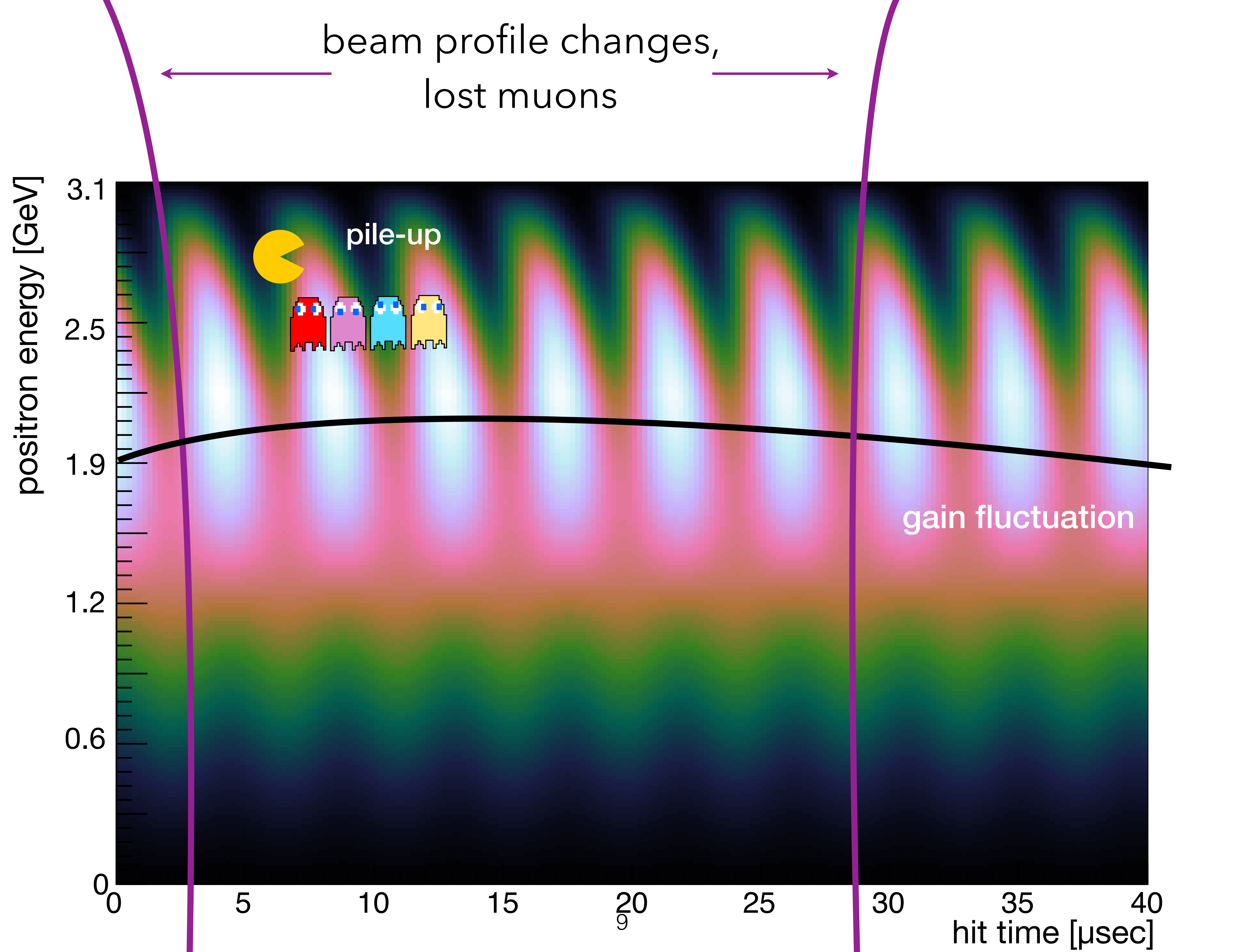


a lighthouse riding a carousel



what does a calorimeter see




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]

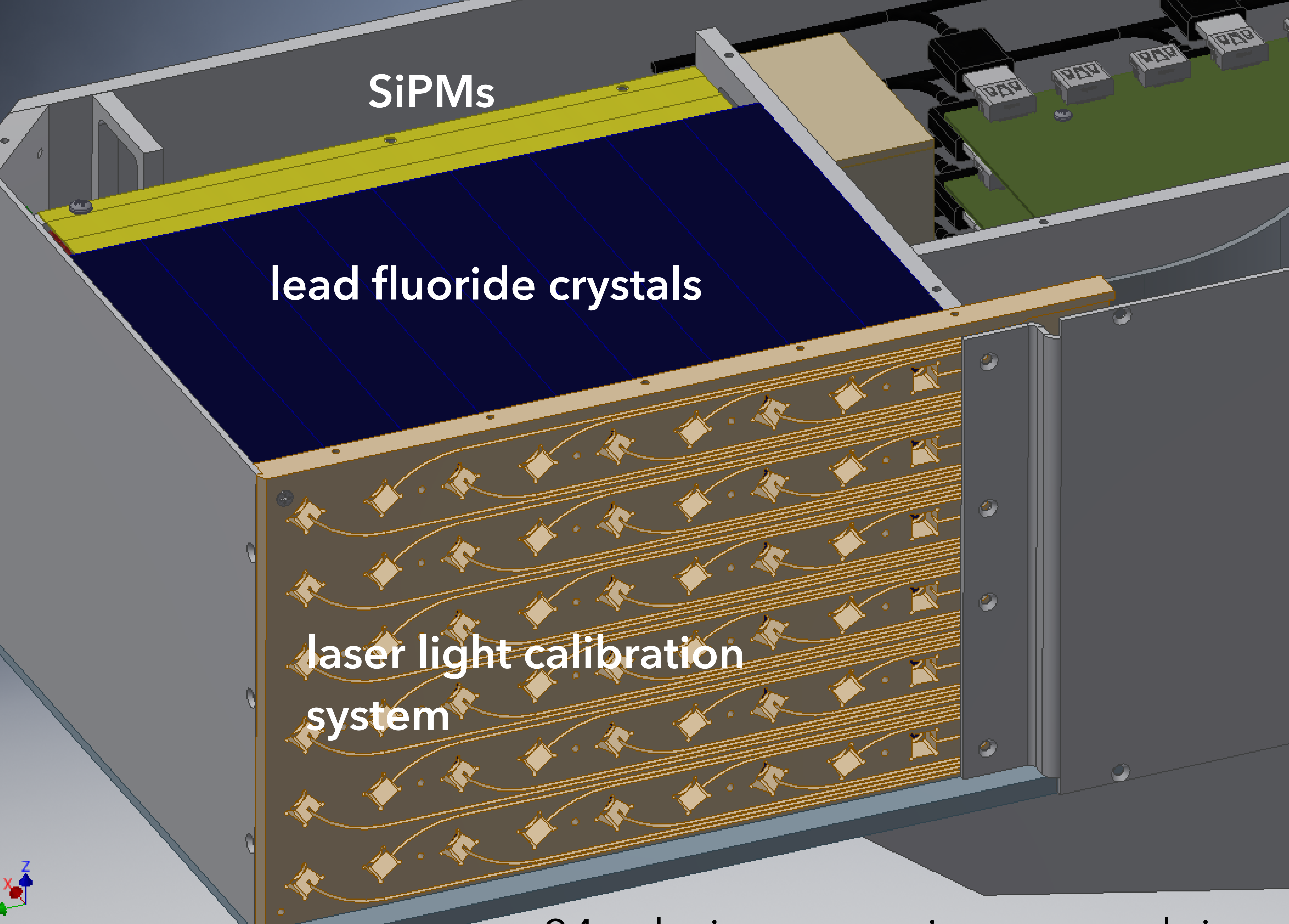
Calorimeter design goals

1. Positron **hit time** measurement with accuracy of (100 psec above 100 MeV)

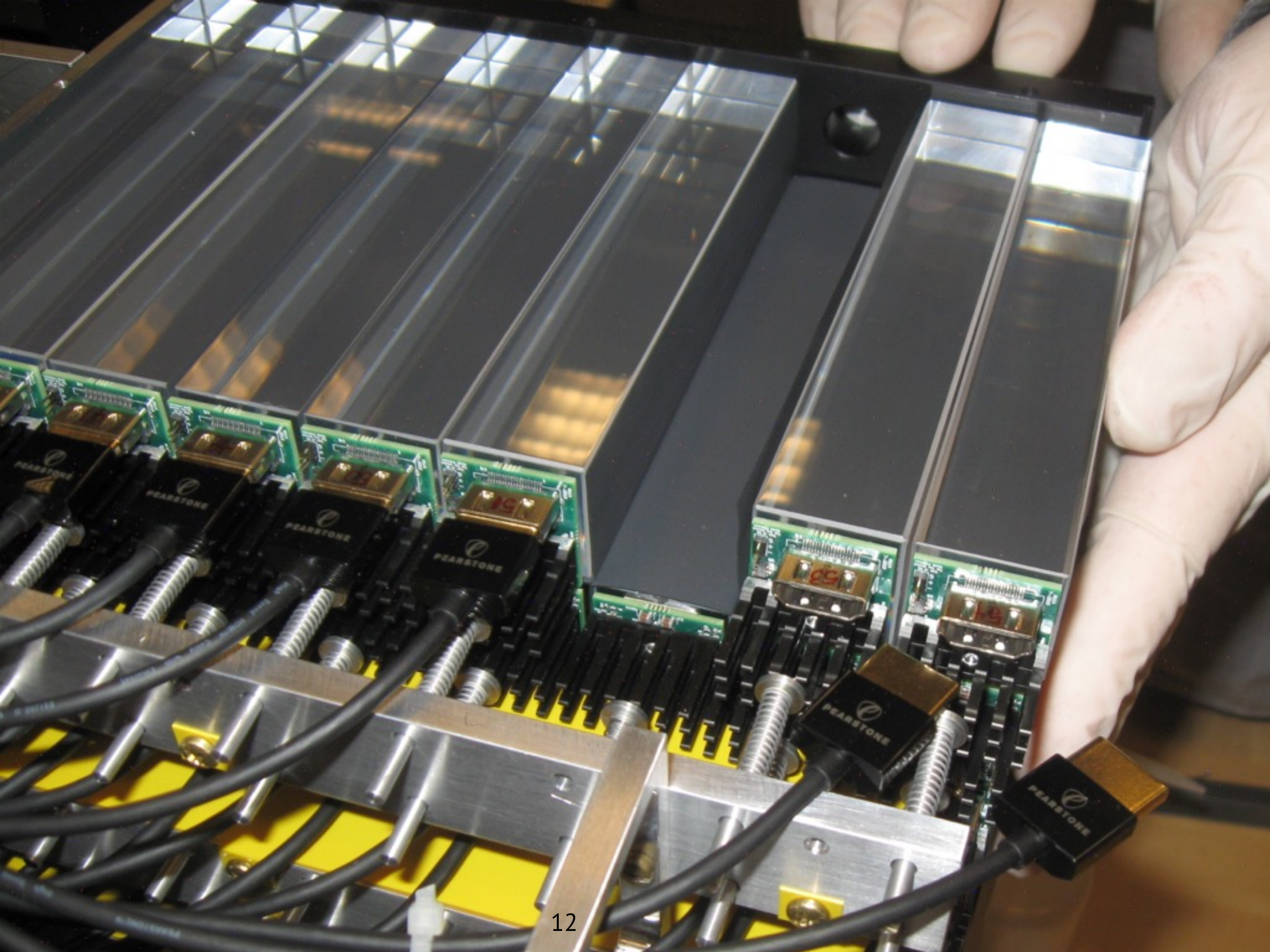
2. **Deposited energy** measurement with resolution better than 5 % at 2 GeV

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.



24 calorimeter stations around ring

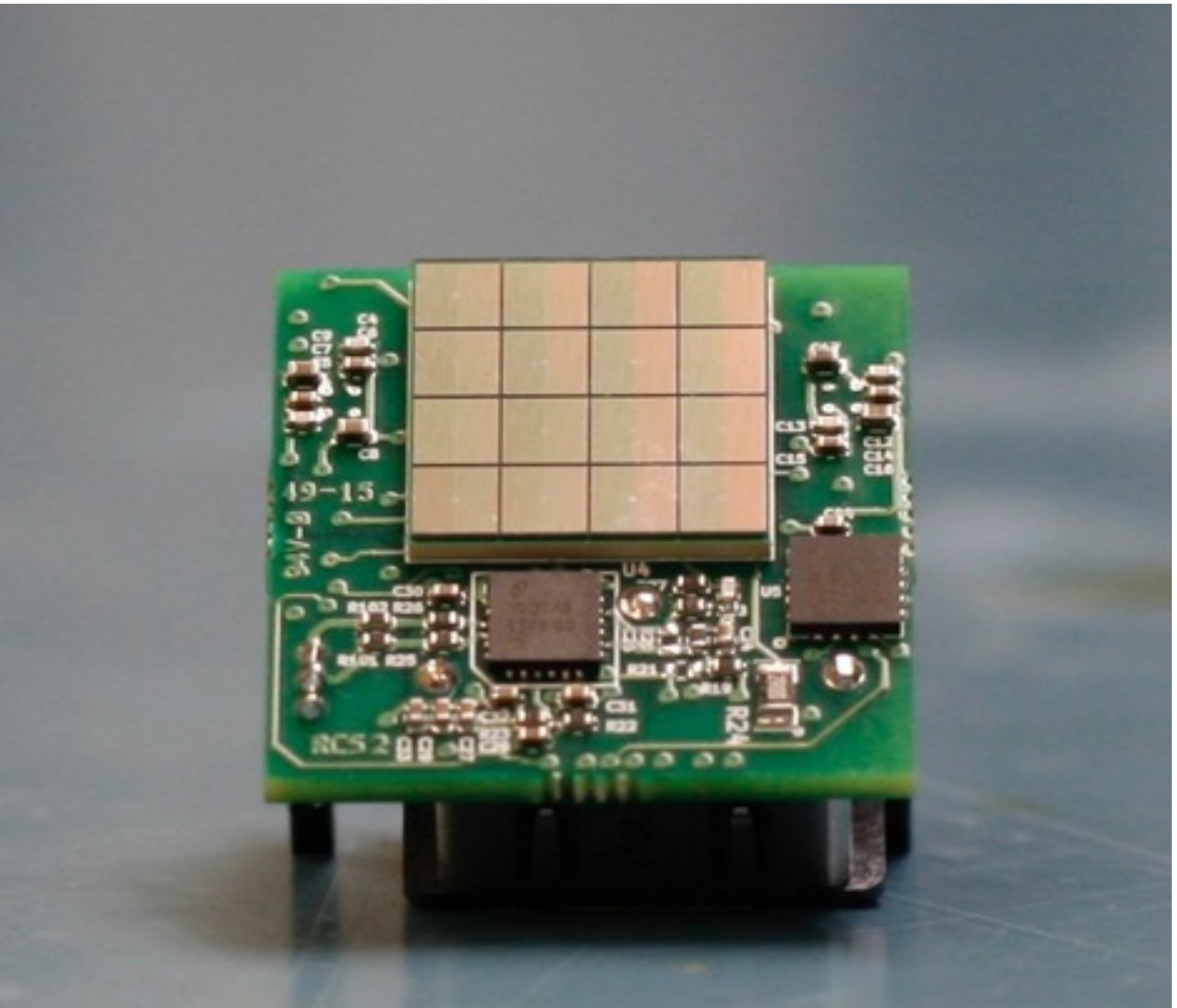

PEARSTONE

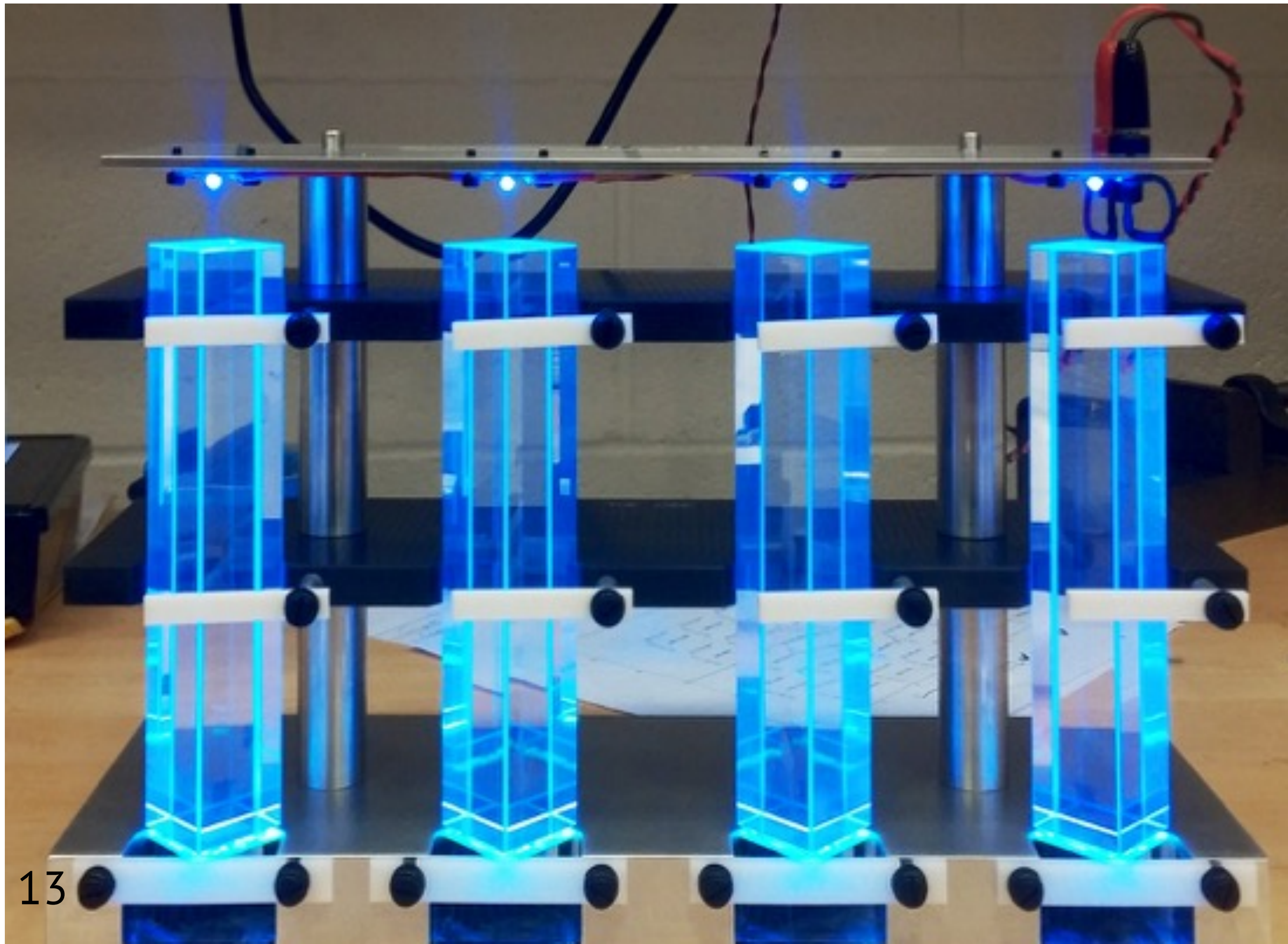
positron detection in calorimeter

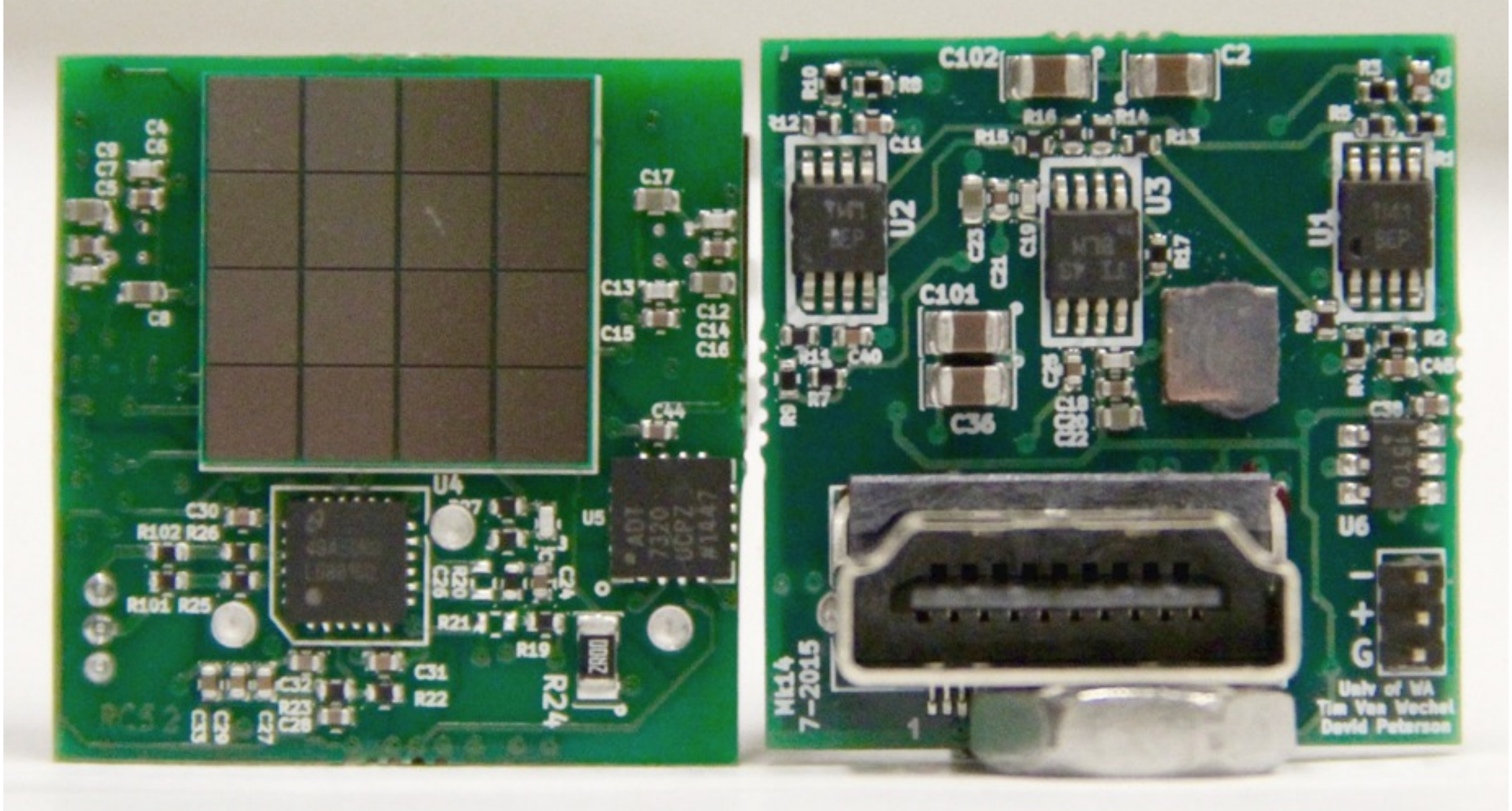
PbF2 – pure Cherenkov radiator

SiPM – counts photons; magnetic field compatible

A.T. Fienberg, et al. Nucl.Instrum.Meth. A783 (2015) 12-21, arXiv:1412.5525



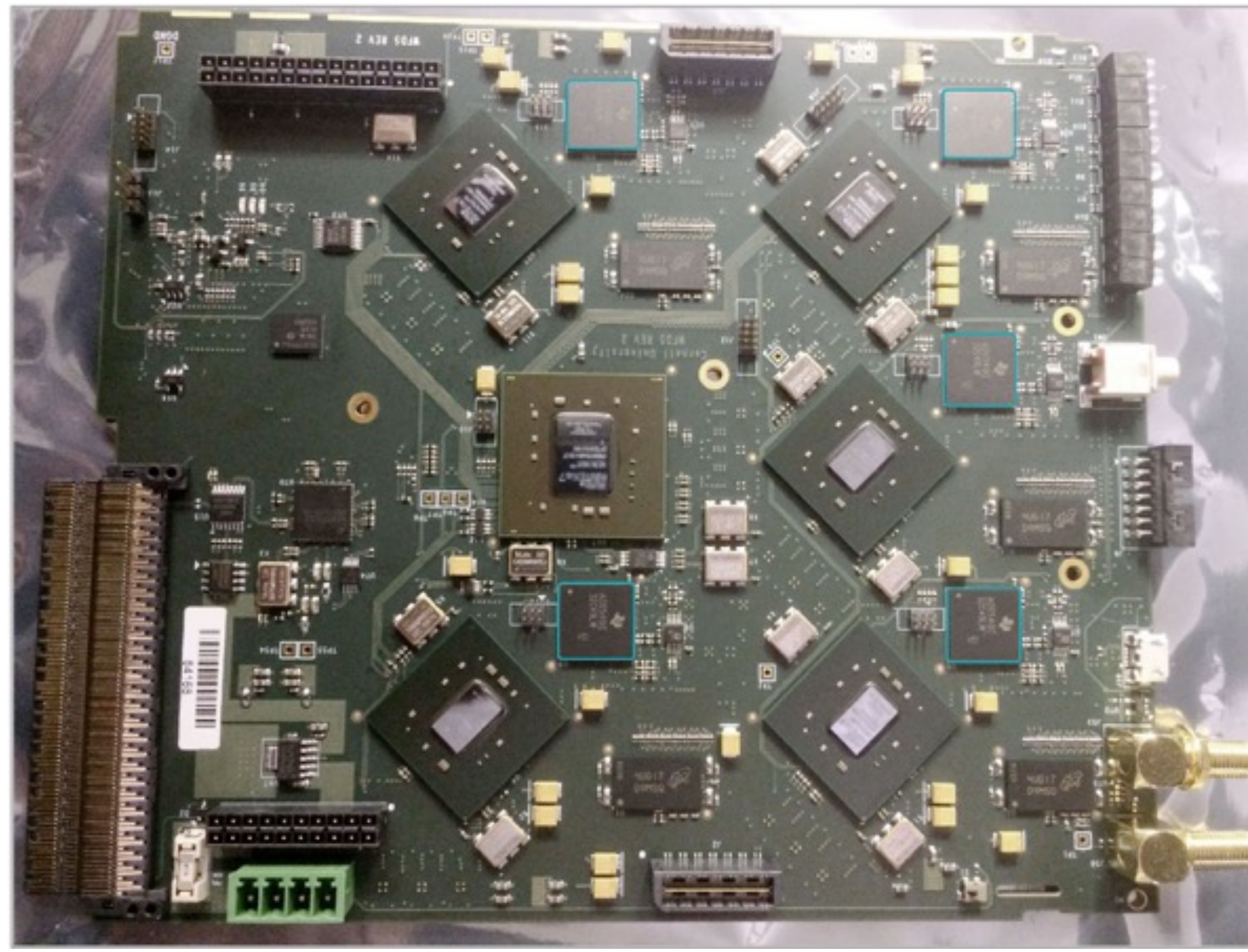




- based on a trans-impedance amplifier (no shunt resistor) PMT-like pulse shape
- programmable gain amplifier to equalize 1400 boards
- DC coupled differential signal to digitizers
- temperature sensor on board for offline gain calibration

custom made 800MHz digitizer

- 5ch, 800 MSpS
- 12 bit, TI ADS5401
- 1 V dynamic range
- <1 mV noise
- µTCA format



Poster by Sweigart, D. A new µTCA-based waveform digitizer for the Muon g-2 experiment

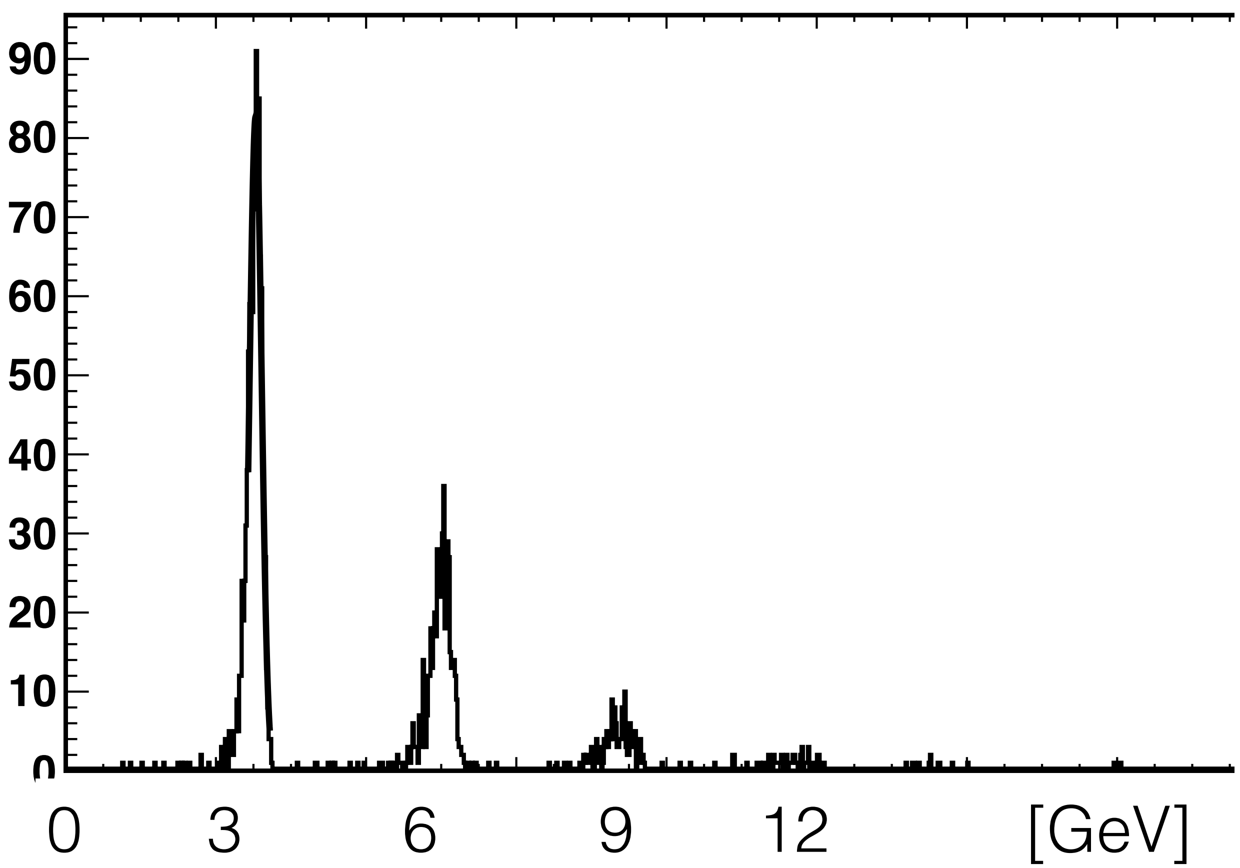
Talk by Gohn, W. Data Acquisition with GPUs: The DAQ for the Fermilab Muon g-2 Experiment

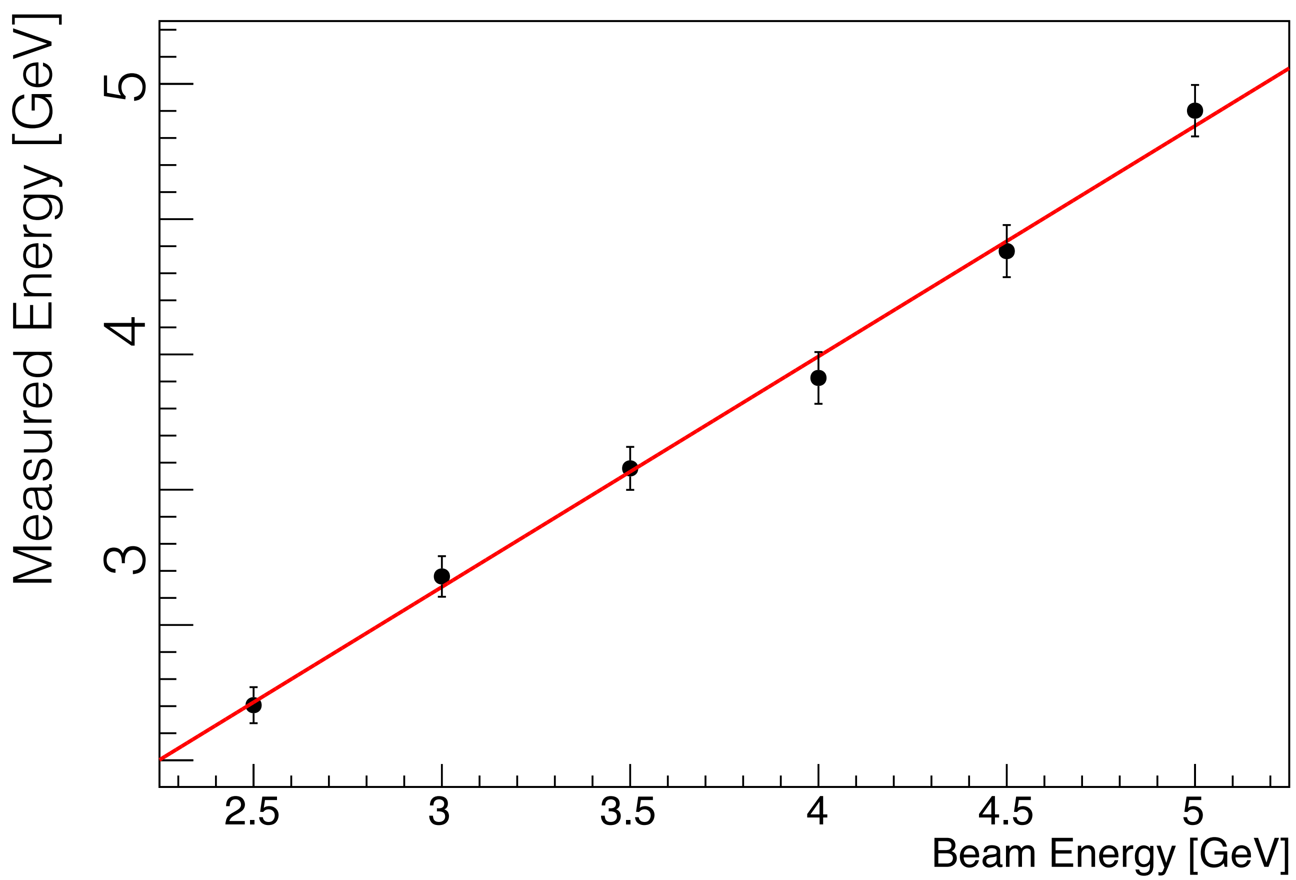
calorimeter at SLAC test beam

energy resolution 3% at 3GeV

both from data, and understanding of
photo statistics and electronics contributions

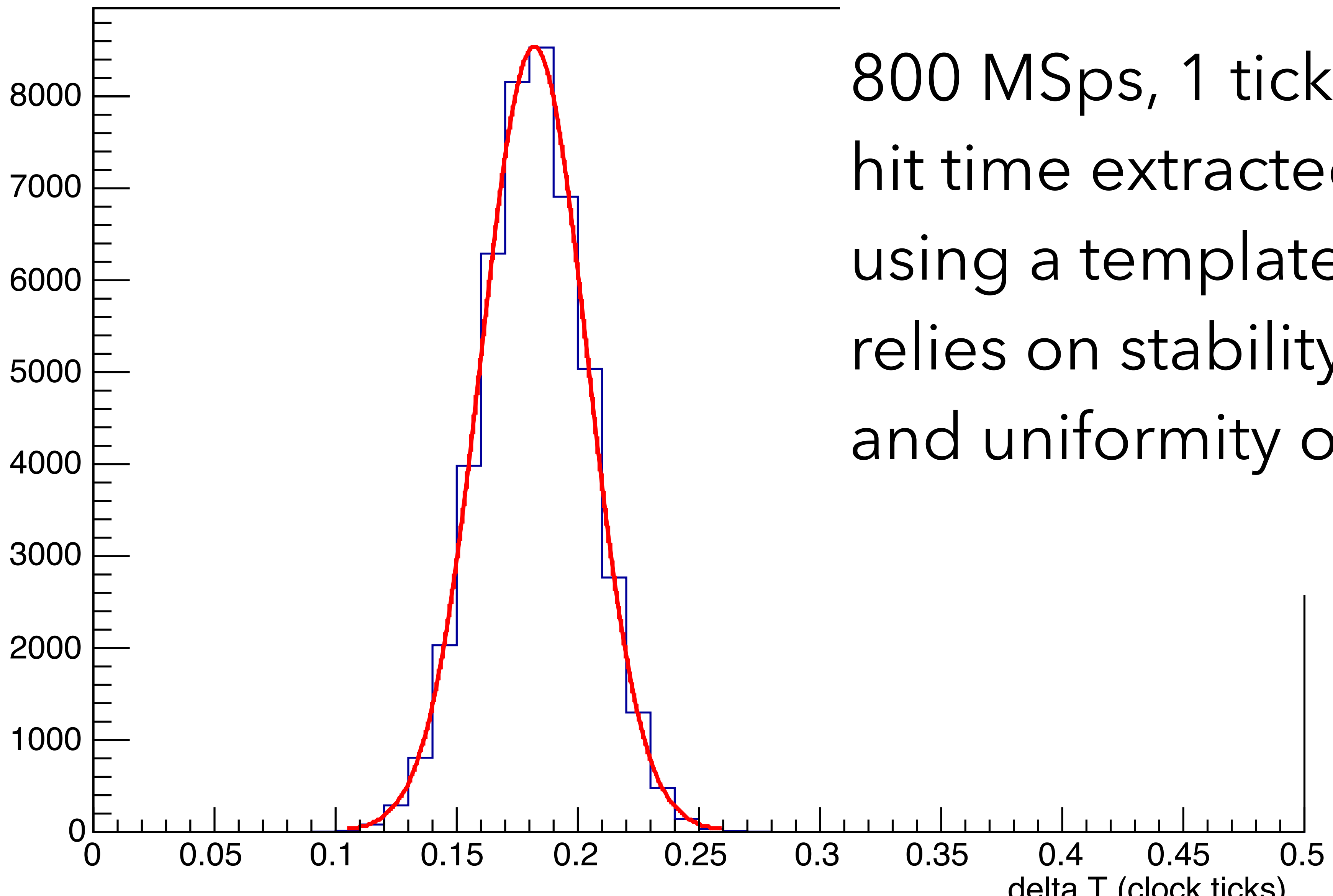
Poisson comb of hit energies, 3 GeV electron beam





timing resolution 25ps at 3GeV

1. time differences within digitizer channels
2. time differences across channels

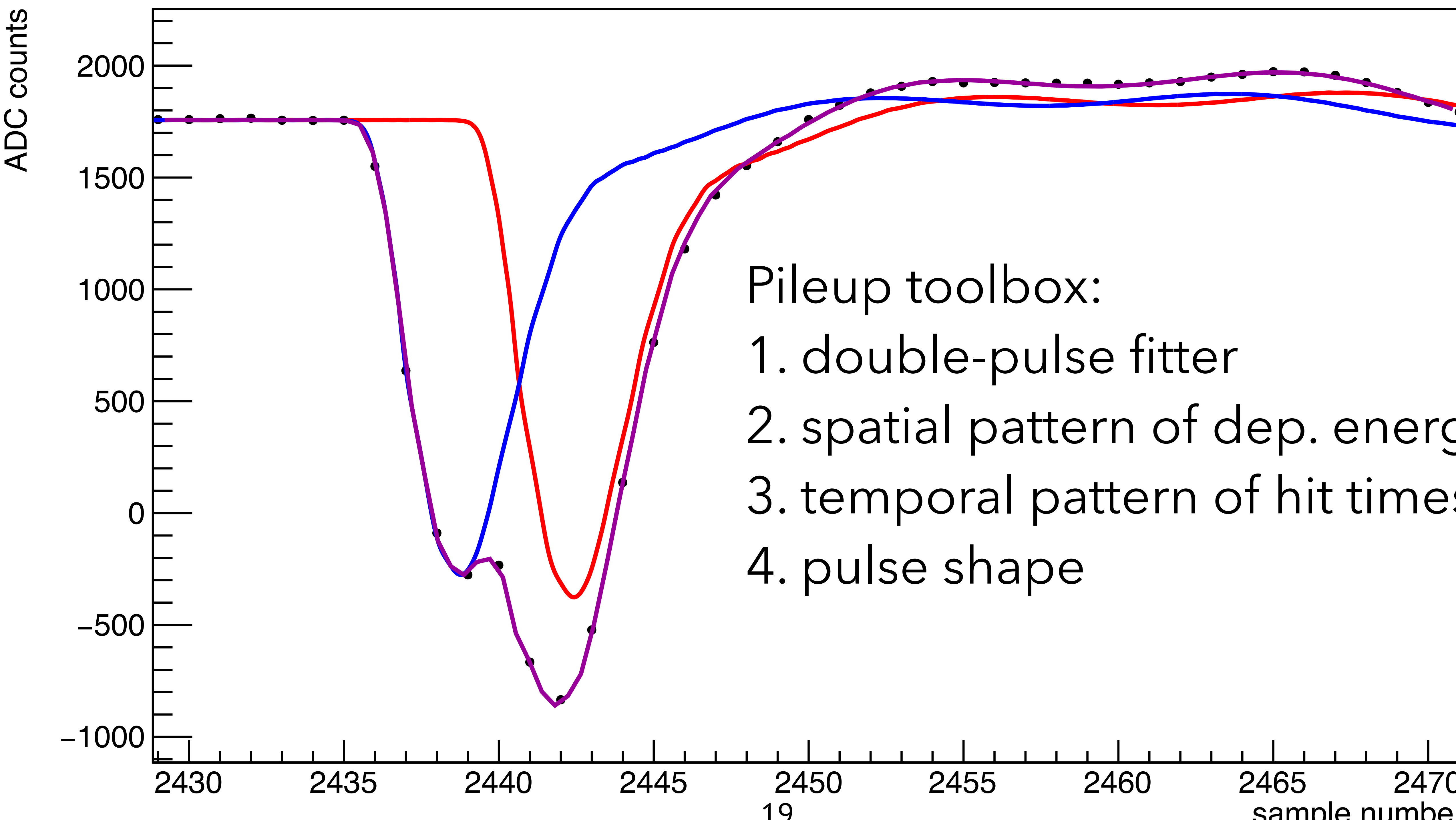


800 MSps, 1 tick is 1.25nsec

hit time extracted from leading edge using a template fitter

relies on stability of pulse shape, and uniformity of SiPM boards

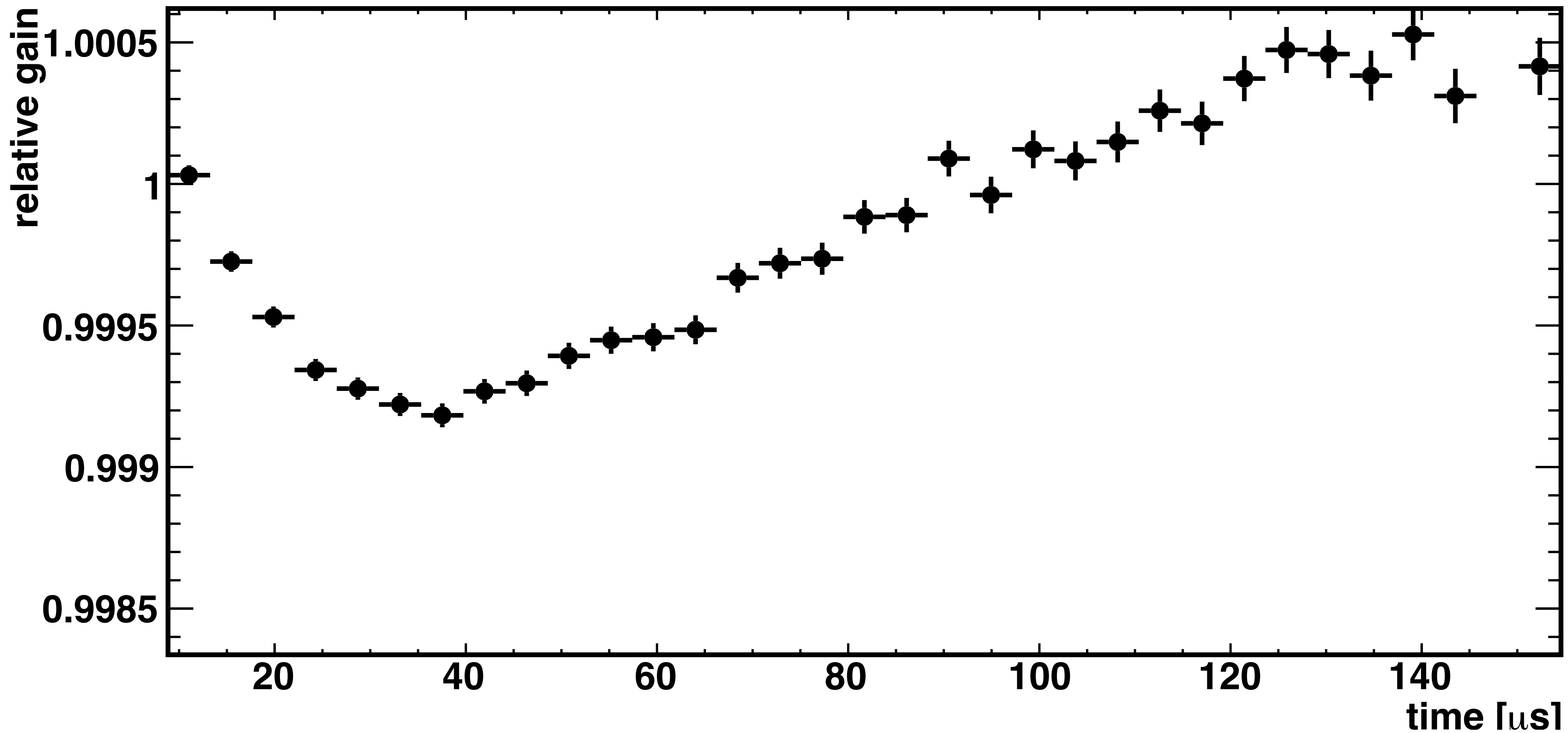
pileup separation: double bunches 4.5 nsec separation



Pileup toolbox:

1. double-pulse fitter
2. spatial pattern of dep. energy
3. temporal pattern of hit times
4. pulse shape

energy scale stability



Three different timescales:

1. months, 2. muon fill of 700 μsec, 3. pileup ~10 nsec

load using laser:

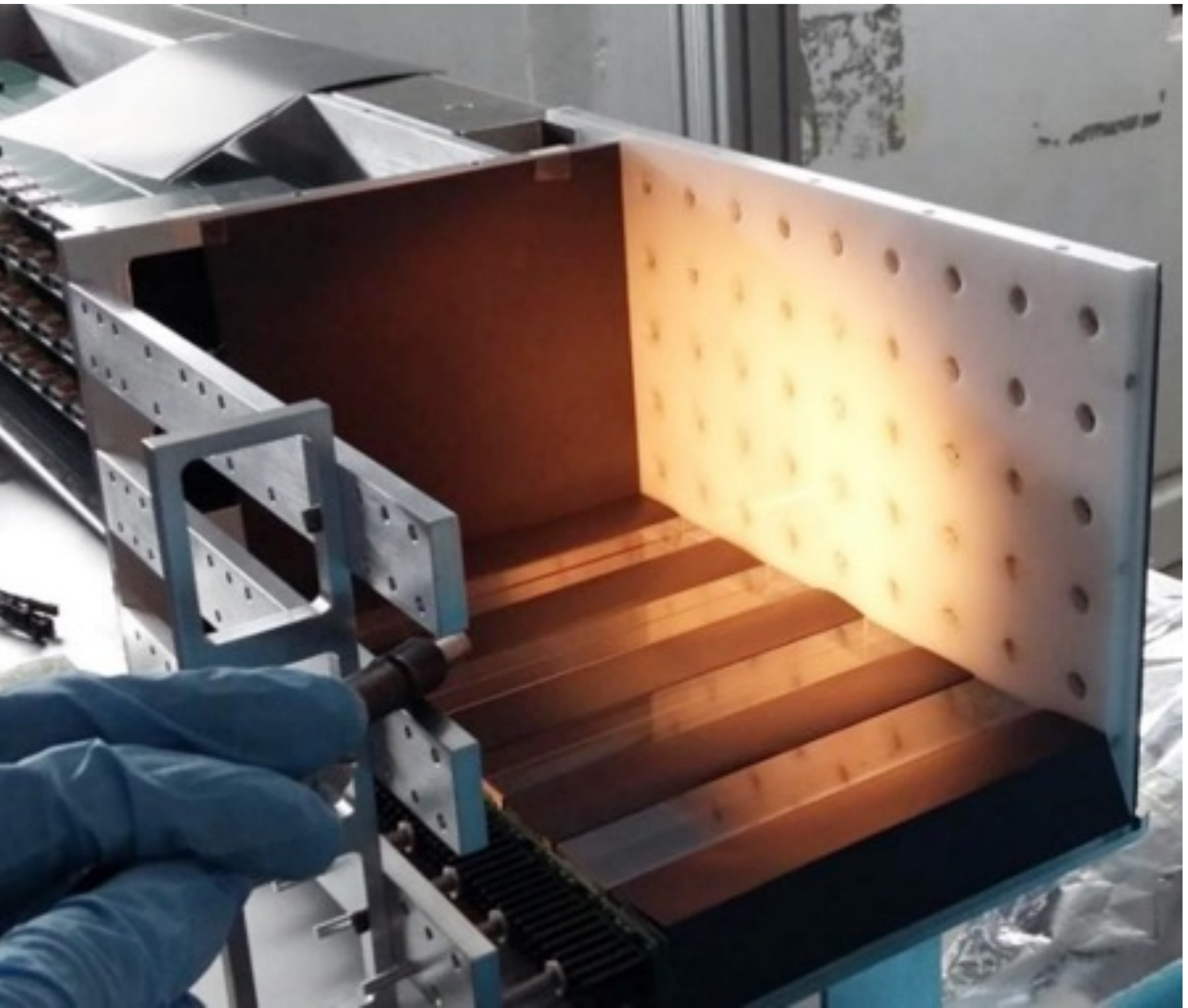
~100 times more photons than a regular muon fill,

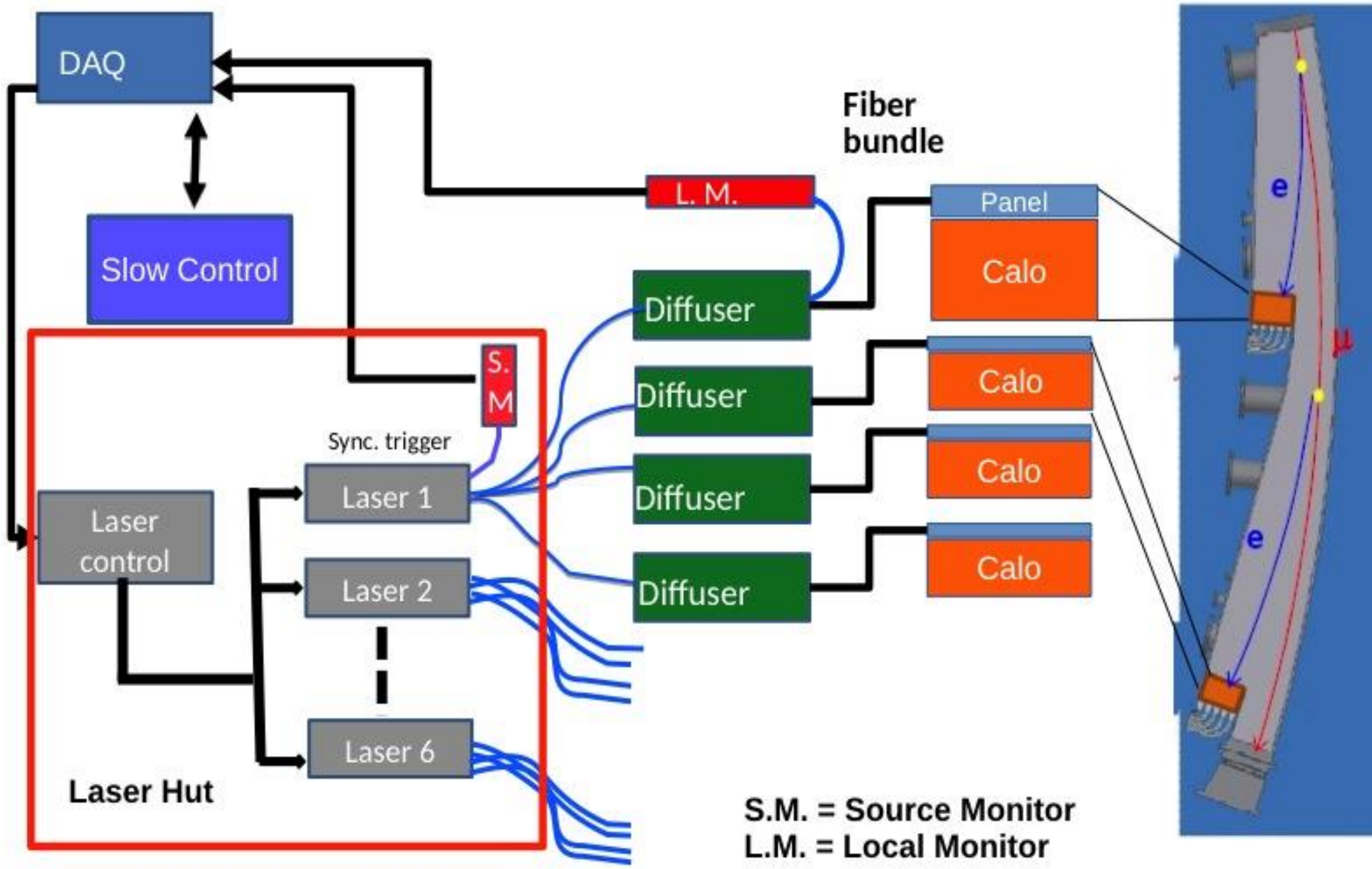
64 μsec exp decay in intensity, factor 1e4 over muon fill

probe with beam, specs: 1e-3, met.

laser calibration system

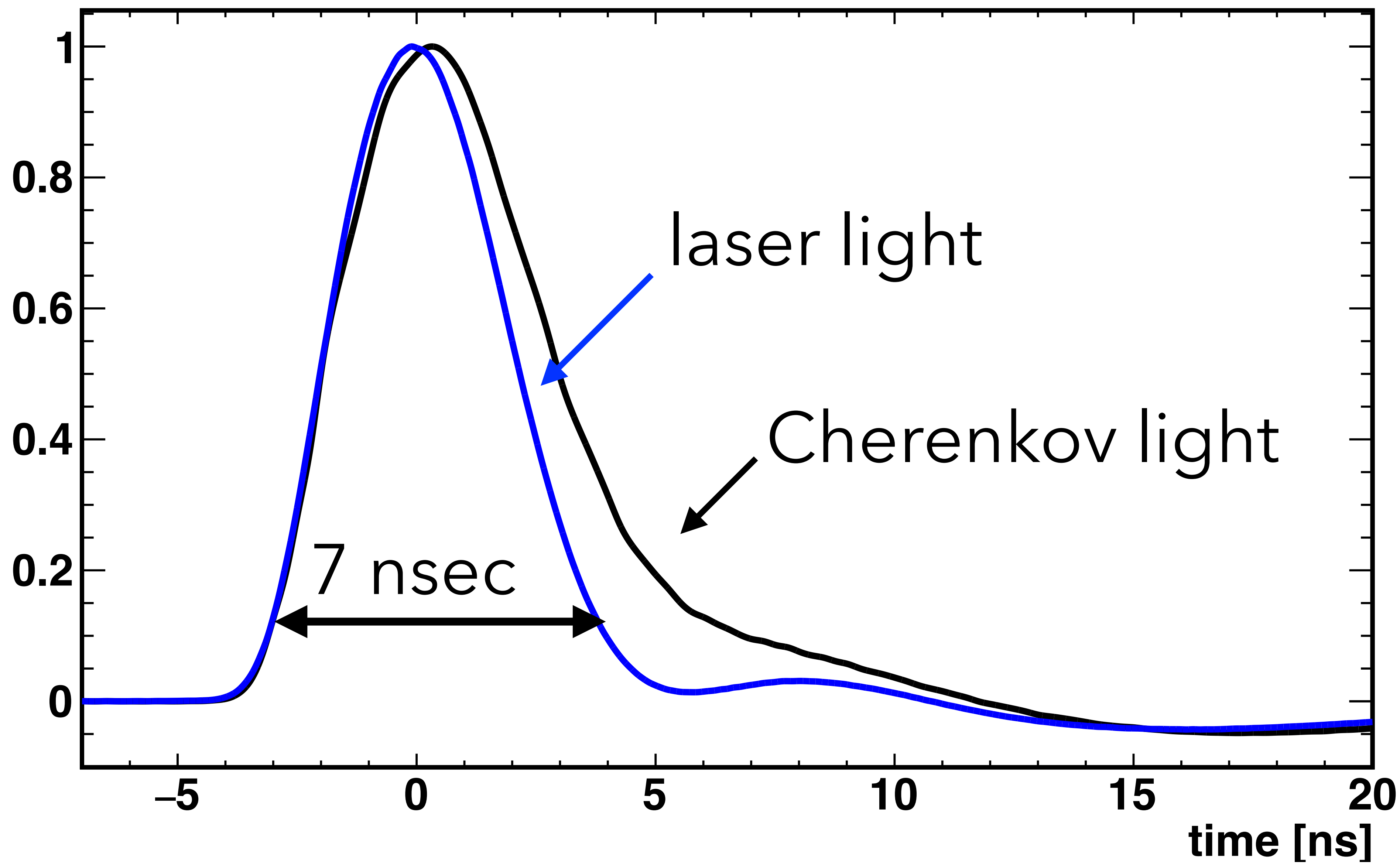
- gain stability of 0.04% in "offline" mode,
- 405 nm, same pulse shape and path as physics,
- laser monitors with Am/NaI reference,
- and local calorimeter monitors





pulse shape comparison

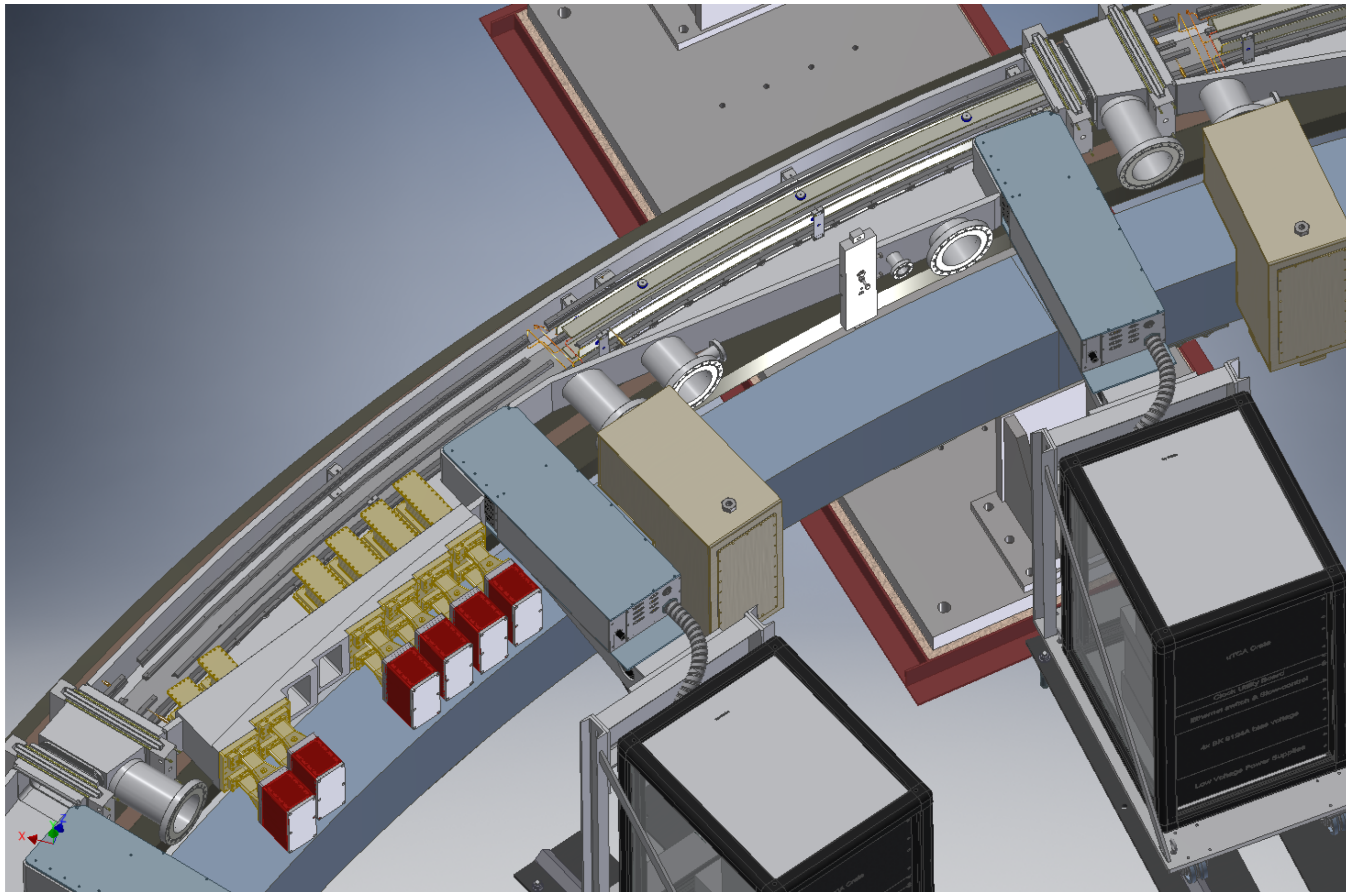
crystals wrapped in black Tedlar,
to limit photon propagation to total internal reflection only



Beam related systematics, and EDM

Calorimeter acceptance is a function of decay vertex position, and positron momentum;

- coherent betatron oscillations
- muon momentum spread
- muons escaping storage region
- other early to late effects



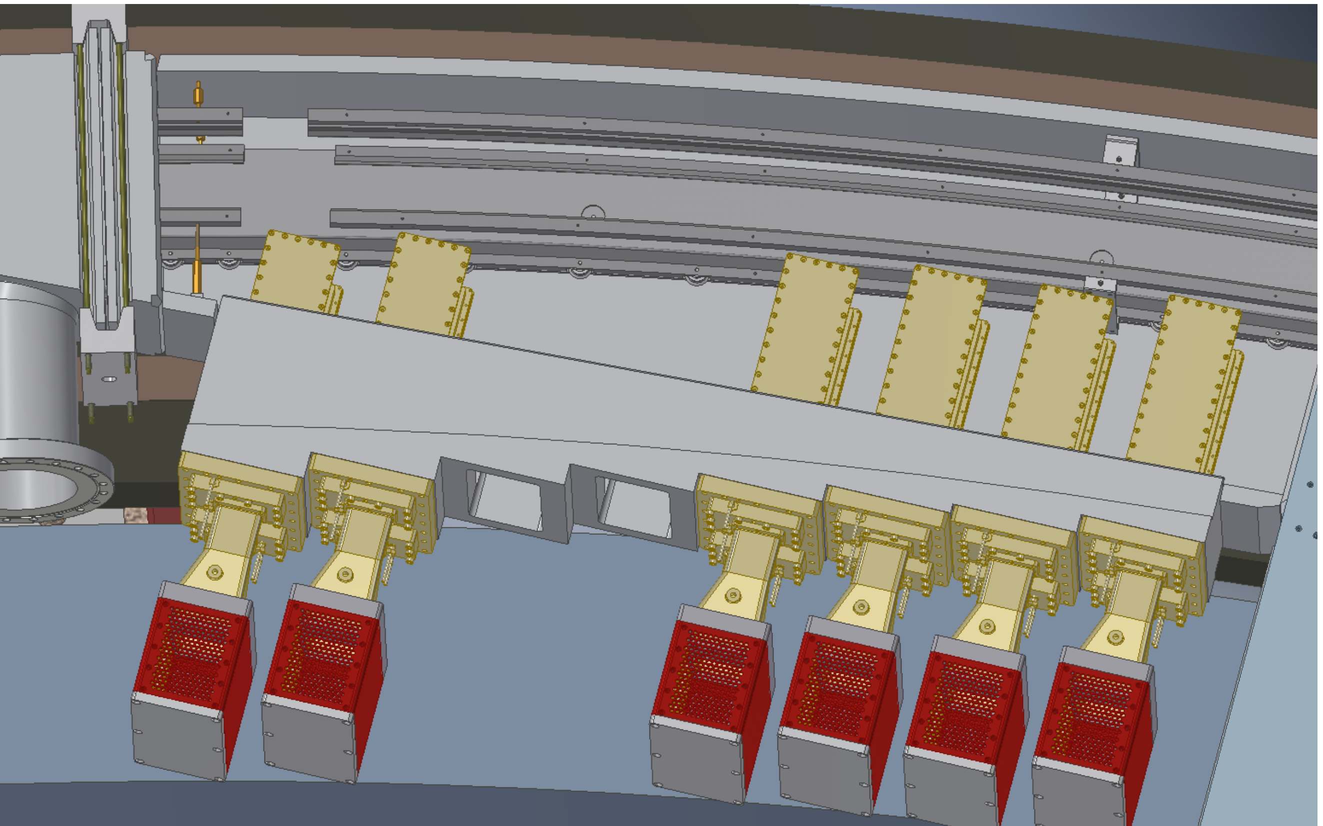
Talk by Tishchenko, V. Muon storage for the Muon g-2 Experiment at Fermilab

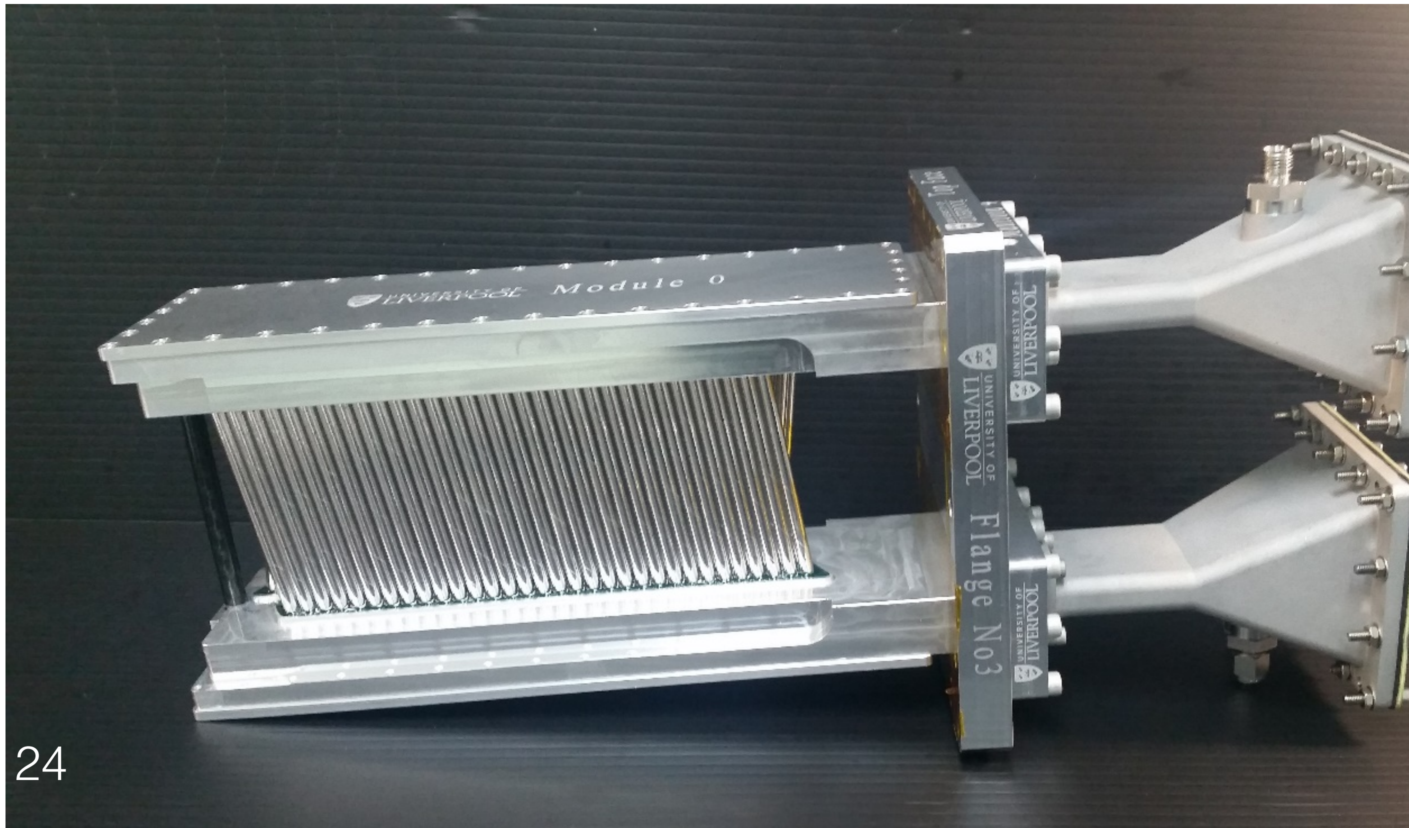
Poster by Bjorkquist, R. Evaluating the Muon g-2 calorimeters as a beam diagnostic tool

Straw tracker design

- At 3 points around ring,
- 8 modules per station
- high-gain Ar:Ethane

Large azimuthal acceptance with low material (15μm Mylar)



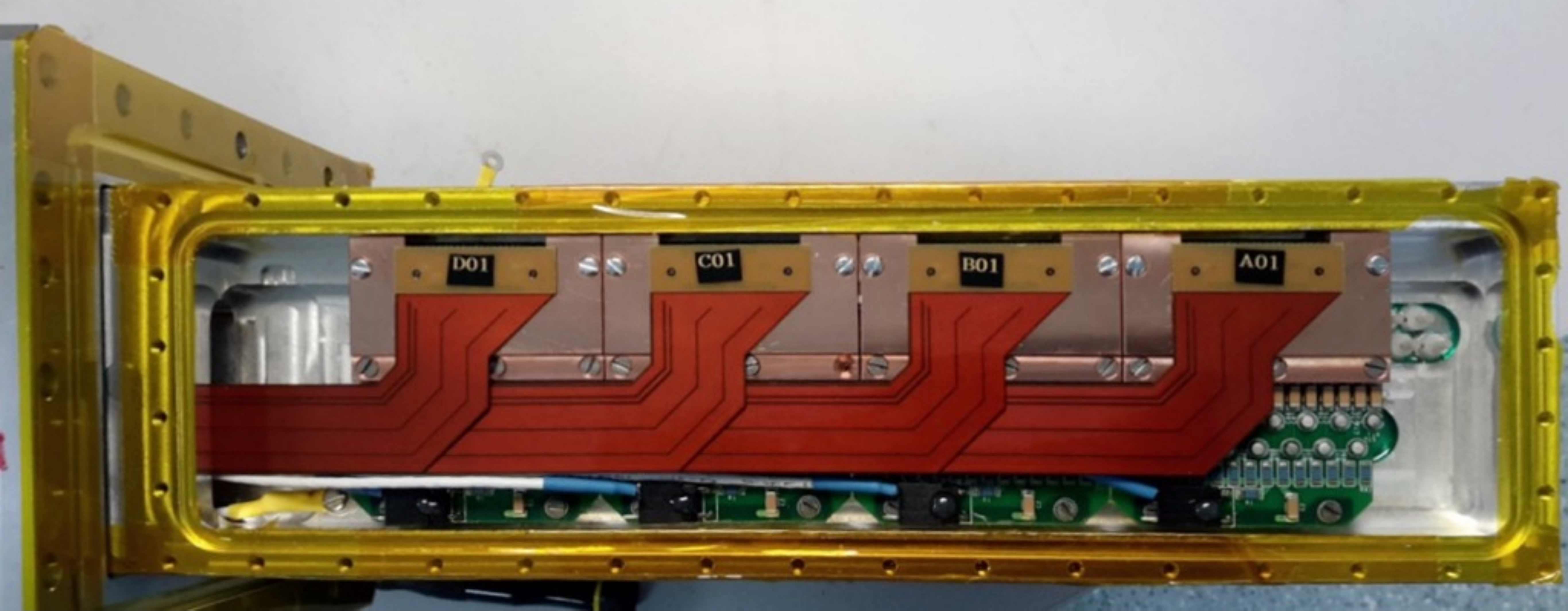


Swiss-knife of Muon *g*–2 experiment

Measures stored muon profile and its time evolution.
Addresses pile-up systematics, measure positron momentum.
Detects lost muons escaping storage region.
Measures vertical pitch of decay positrons → EDM measurement.

Determines area of magnetic field map seen by the muons
Limits the size or radial and longitudinal magnetic fields

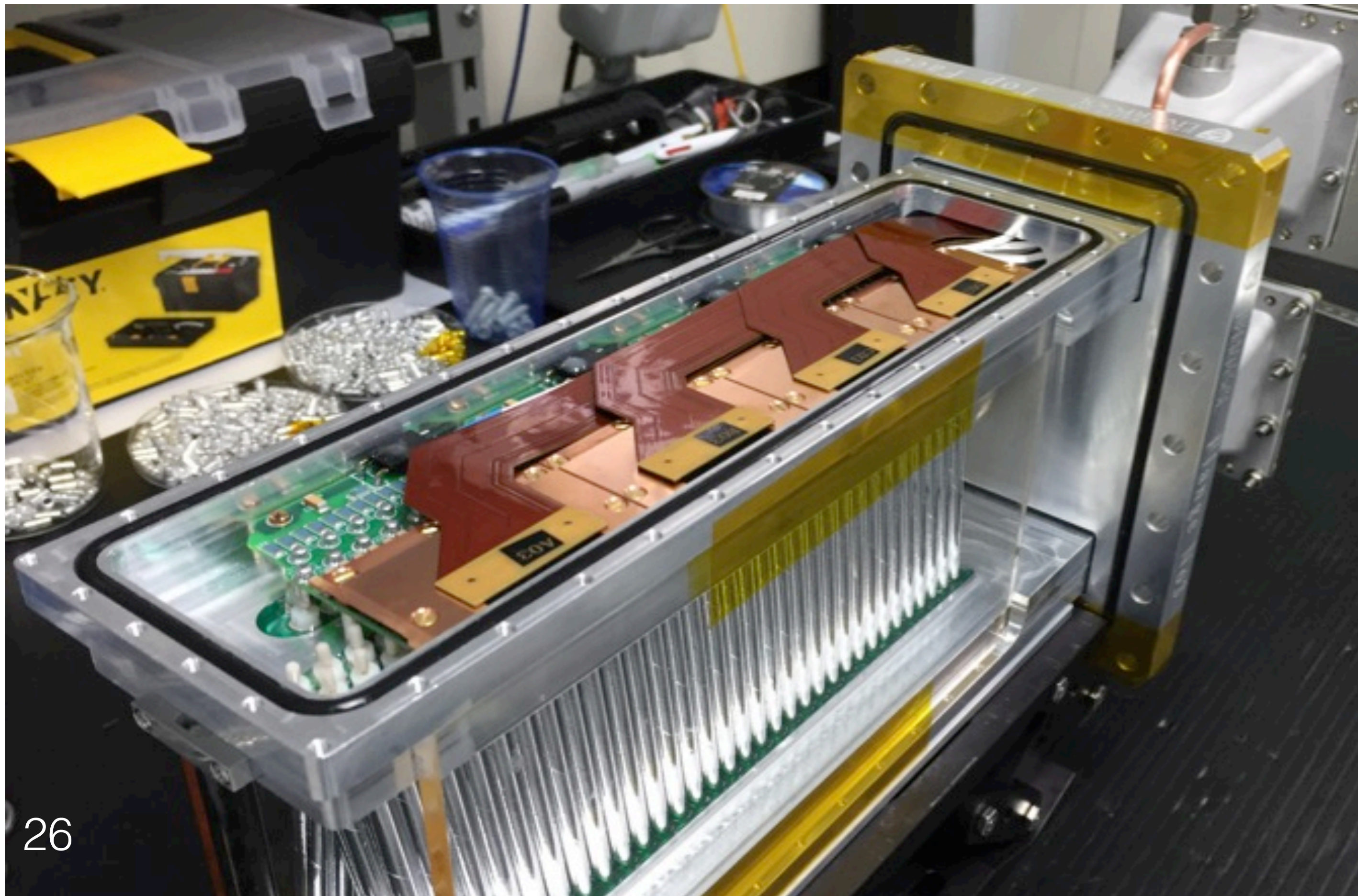
Makes an independent measurement of positron momentum.



Poster by Mott, J. The readout system for the Fermilab Muon g-2 straw tracking detectors

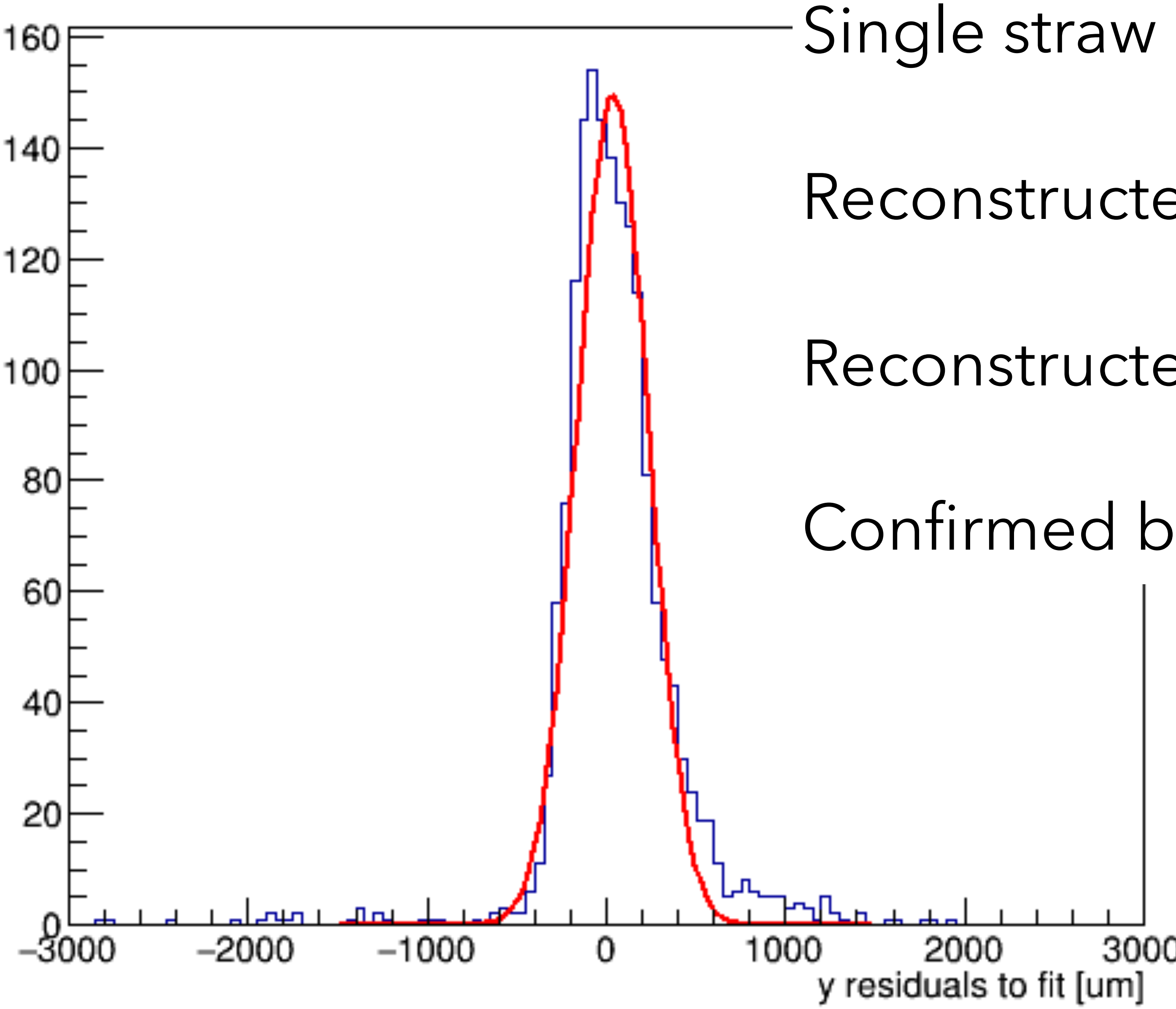
Poster by Epps, A. The construction and quality assurance testing of the Fermilab Muon g-2 straw tracking detectors

Poster by McEvoy, M. The slow control system for the Fermilab Muon g-2 experiment



Test run at FNAL MTest beam

120 GeV protons, Silicon telescope, MWPC



Single straw radial resolution = 200 μm

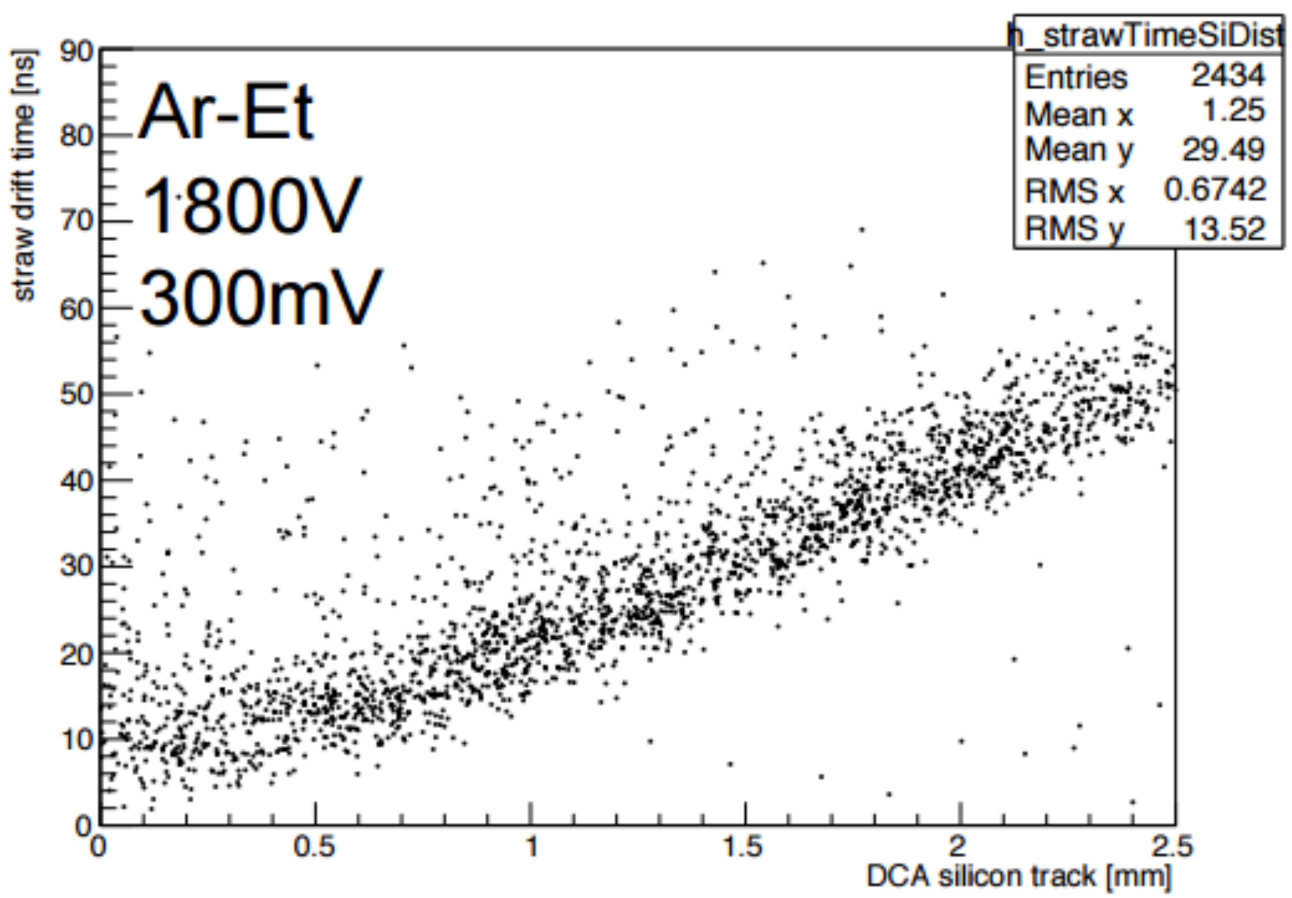
Reconstructed hit **radial resolution = 100 μm**

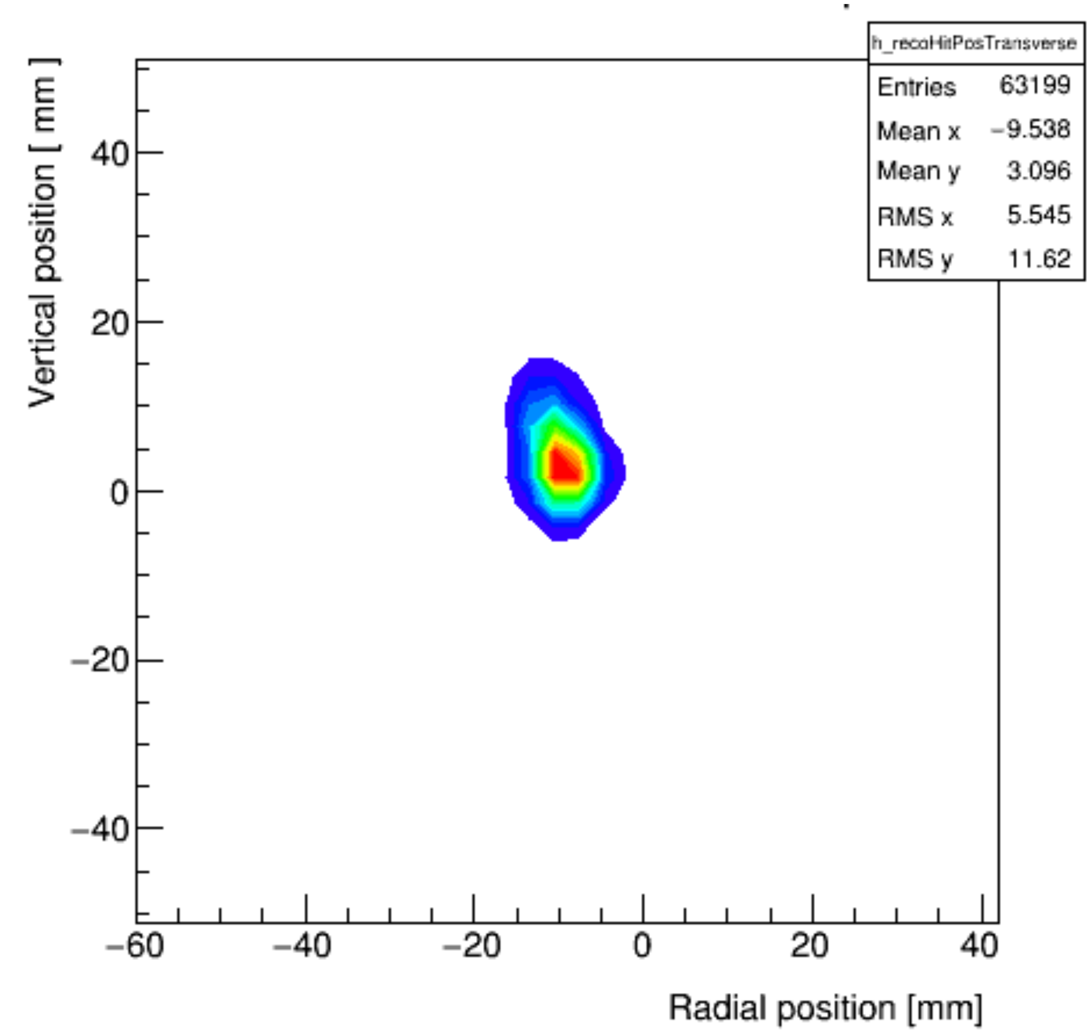
Reconstructed hit vertical resolution = 750 μm

Confirmed by comparing to silicon tracks

Tracker performance met goals

hit position compared to wire chamber
drift time compared to silicon detector





Poster by Stuttard, T. The track reconstruction software and performance studies of the Fermilab Muon g-2 straw tracking detectors

Conclusions

Four fold improvement in determination of Muon g-2 requires new instrumentation.

Calorimeters and trackers are in production.

Detector installation in ring begins in Fall 2016

First beam arrives in Spring 2017.

Thank you very much!