The 4th Concept detector for the International Linear Collider

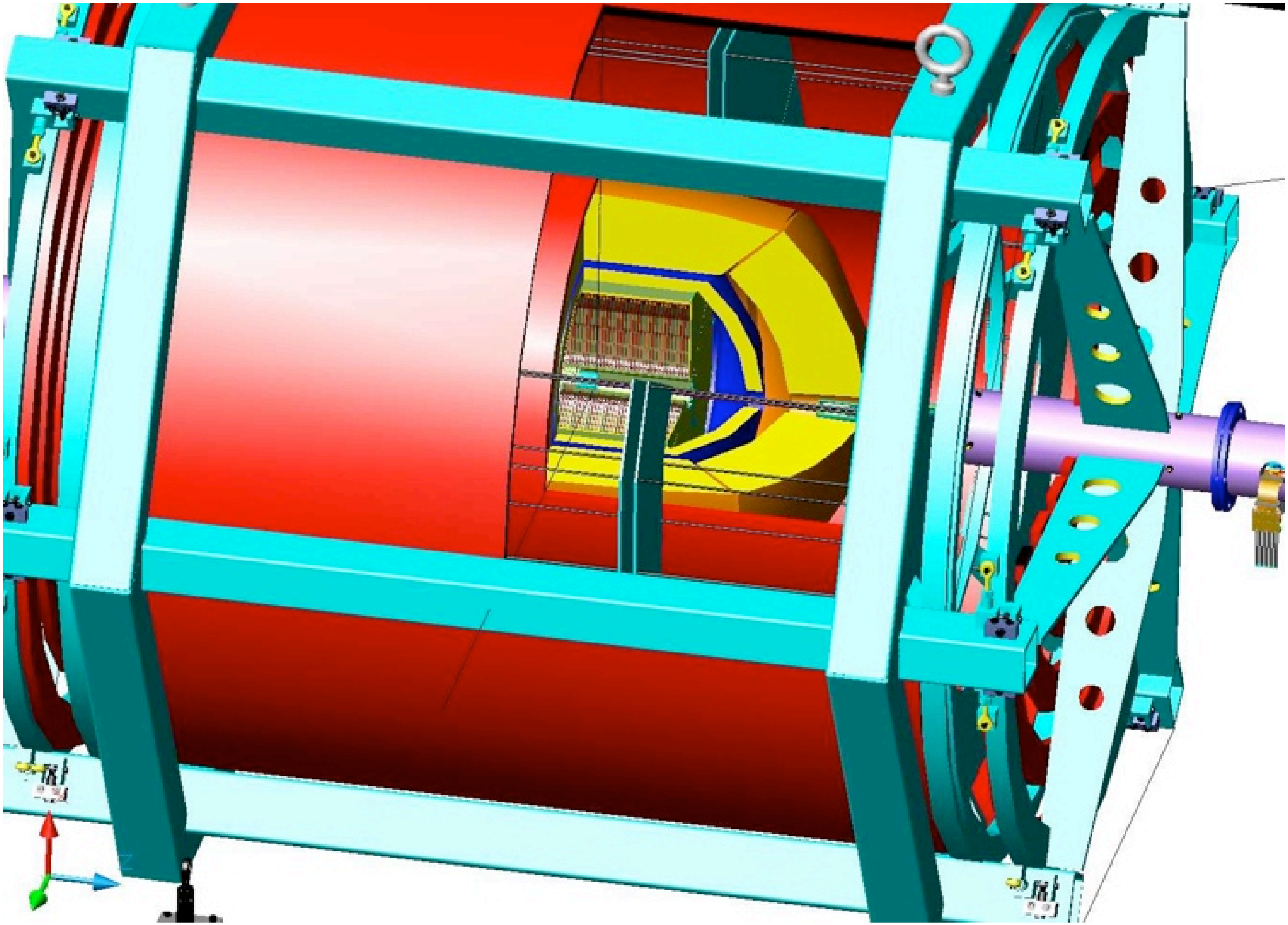
High energy physics is aggressive: Tevatron is running past 2 inverse-fb in 2 TeV proton-antiproton collisions, the LHC is almost ready for pp collisions at 14 TeV, and already the community is designing the next machine: a 1 TeV $e+e-$ collider, the International Linear Collider.

And the detectors are in a "concept" phase somewhere between "wild ideas" and "engineering design".

This is the "4th" concept detector since previous to 1.5 years ago, there were three long-standing concepts:

- GLD - "Global Large Detector" (JLC/KEK, mostly Japanese)
- LDC - "Large Detector Concept" (TESLA/DESY, mostly European)
- SiD - "Silicon Detector" (NLC/SLAC, mostly US)

Pixel vertex - TPC - dual readout calor - dual solenoid muon



4th Concept People ~1/3 Asia, ~1/3 US, ~1/3 Europe

Mostly orthogonal to other three concepts

Basic design principle: only four basic, powerful systems, each as simple as possible. Obviate any need for tail-catchers, pre-showers detectors, end-cap chambers, or silicon blankets to augment performance of main detector.

- •Pixel Vertex (PX) 20-micron pixels (like Fermilab/SiD thin pixel)
- •TPC (like GLD or LDC) or KLOE-like cluster counting drift chamber (new)
- •Triple-readout fiber calorimeter: scintillation/Cerenkov/neutron (new)
- •Muon dual-solenoid iron-free geometry (new), cluster counting (new)

Measure *all* partons with high precision

$$e, \mu, \tau \rightarrow e/\mu/\pi; \quad uds \rightarrow j; \quad c, b\ (\lambda_{decay}); \quad t \rightarrow Wb;$$
$$W \rightarrow jj \text{ and } Z \rightarrow jj, \mu\mu, ee \text{ (mass)}; \ \nu \text{ (subtraction)}$$

The GLD "Global Large Detector" ... mostly iron!

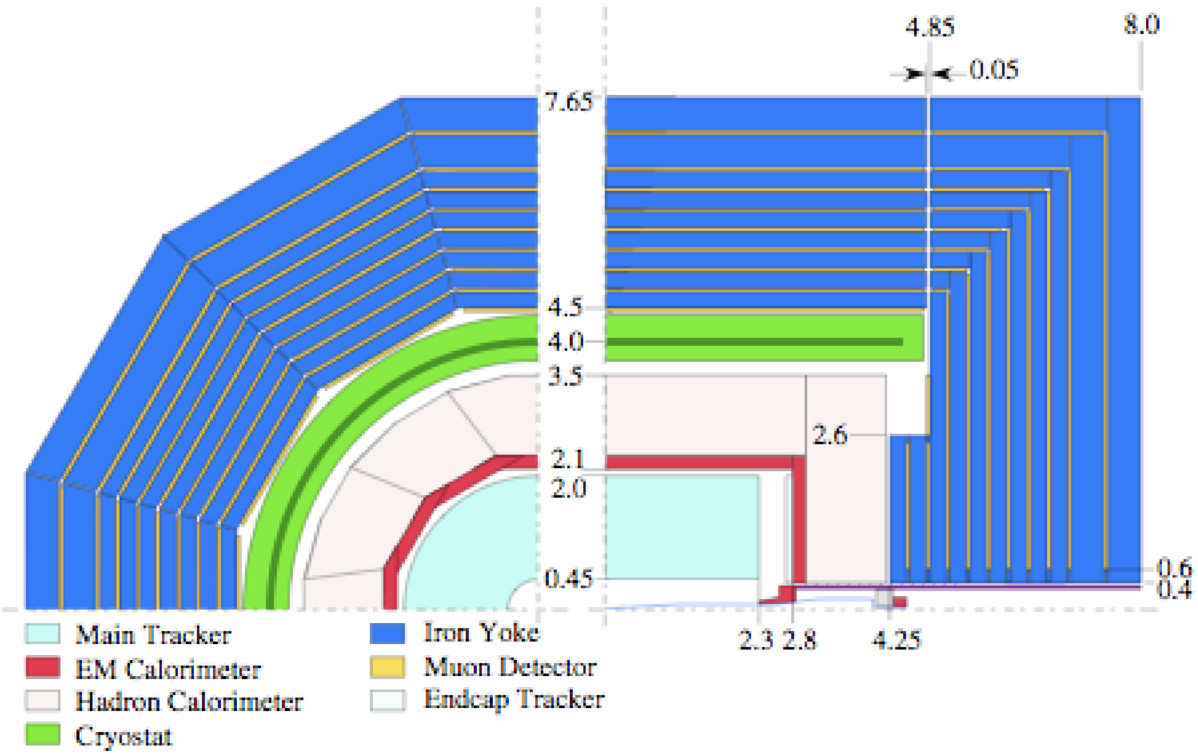


Figure 1.2: Schematic view of two different quadrants of GLD Detector. The left figure shows the $r\phi$ view and the right shows the rz view. Dimensions are in meter. The vertex detector and the silicon inner tracker are not shown here.

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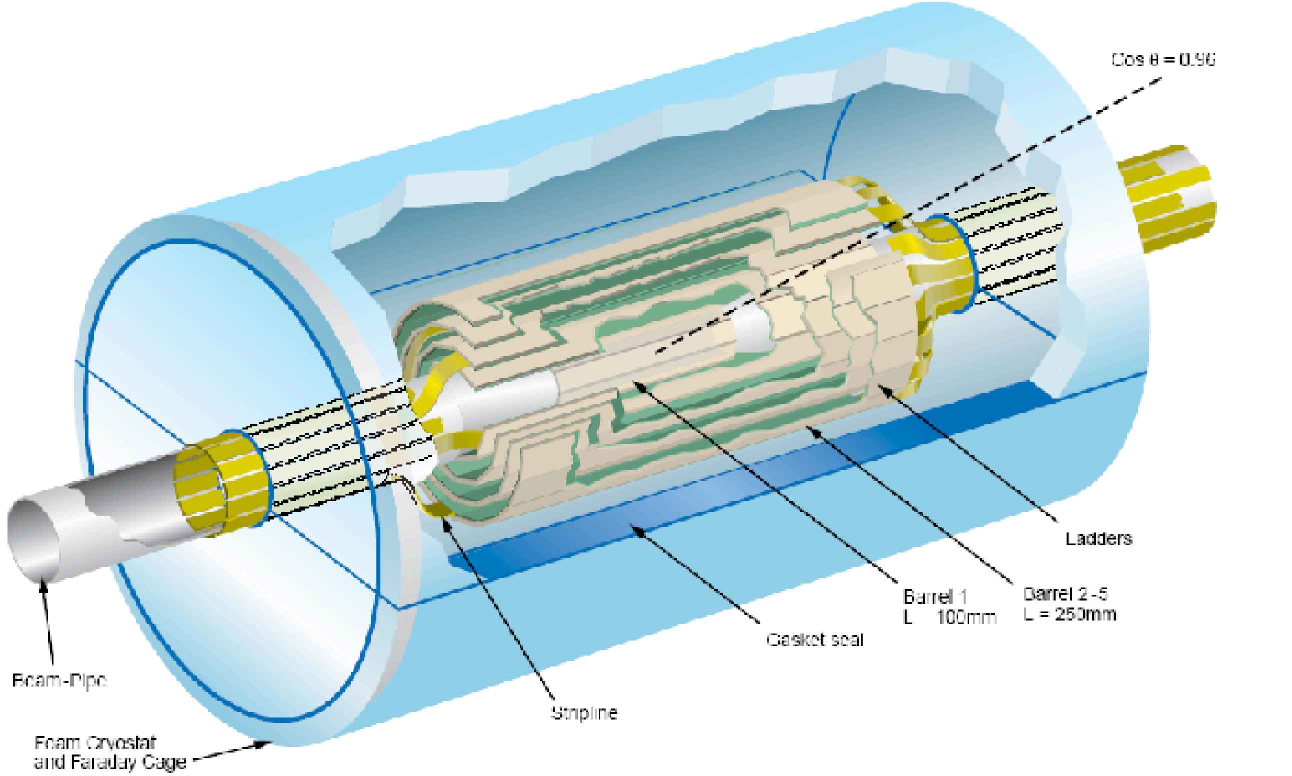
Pixel vertex detector is "conventional"

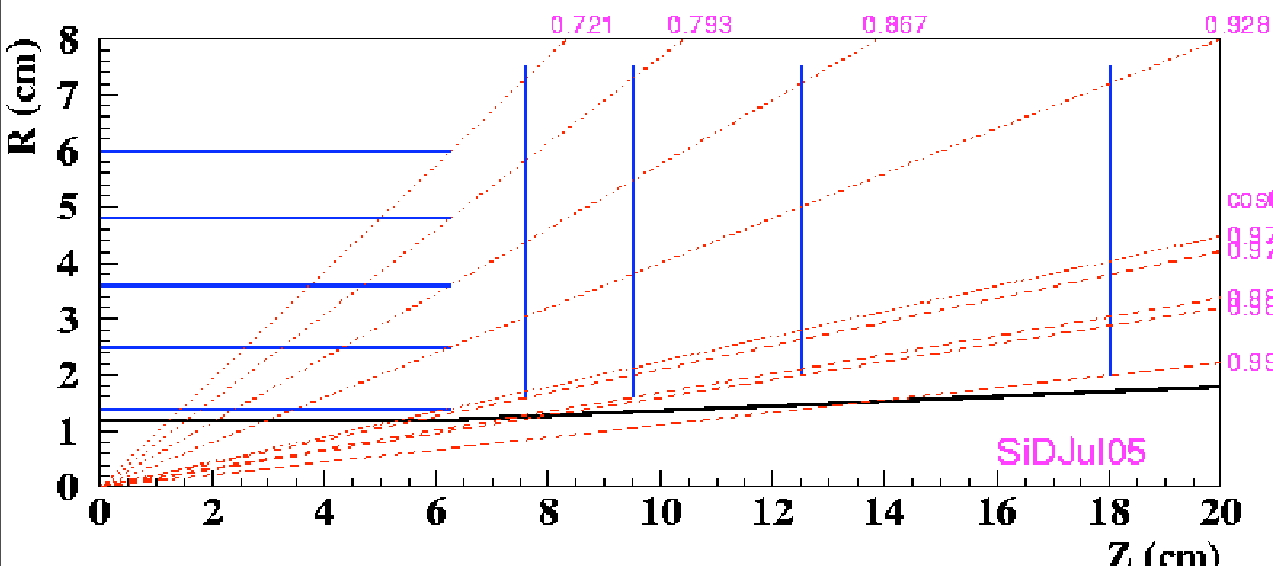
Scientific goal is identification of *b,c* quarks and tau leptons with high efficiency and purity, and hit occupancy reduction (by brute force) to about 1%. This requires ...

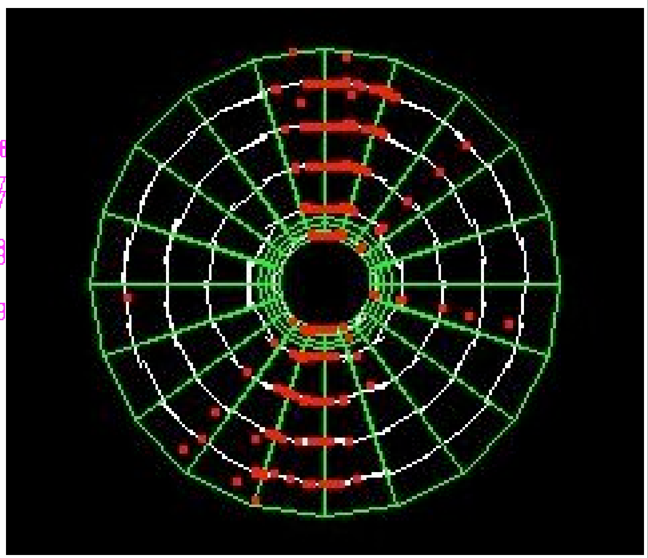
* 15-micron, or so, square pixels
* a billion, or so, channels
* several competing technologies
* we do not have "a dog in this fight"

We design with the SiD/Fermilab "thin pixel" vertex chamber.

Pixel vertex detector design







Time Projection Chambers (TPCs)

Truly extraordinary advances are being made with these large volume, low mass, 3-dimensional tracking chambers. Dan Peterson is at the center of this world-wide work:

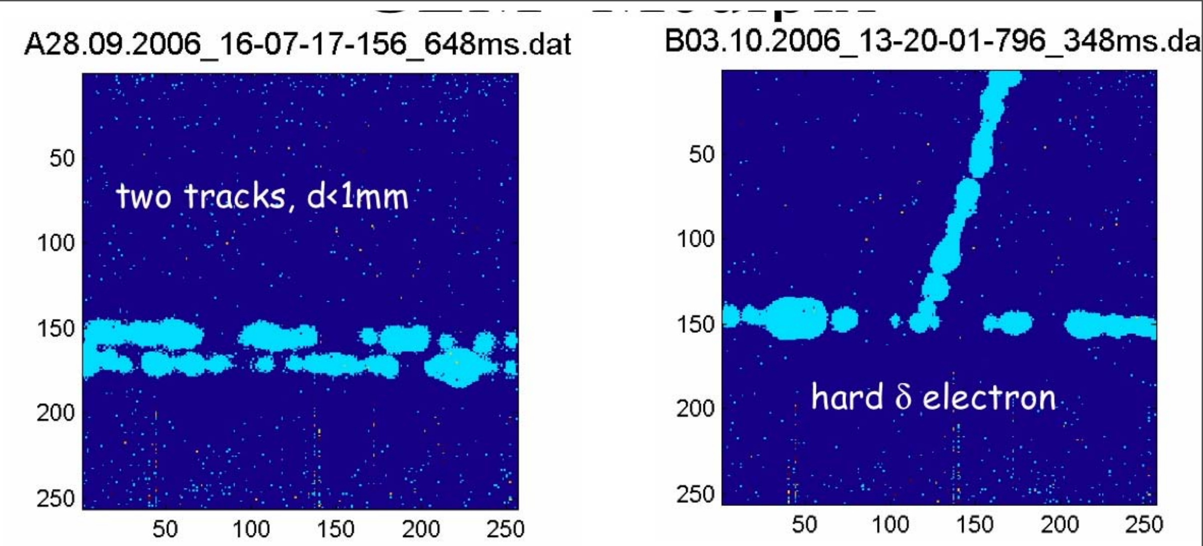
* single-electron sensitive
* 50-micron spatial precision

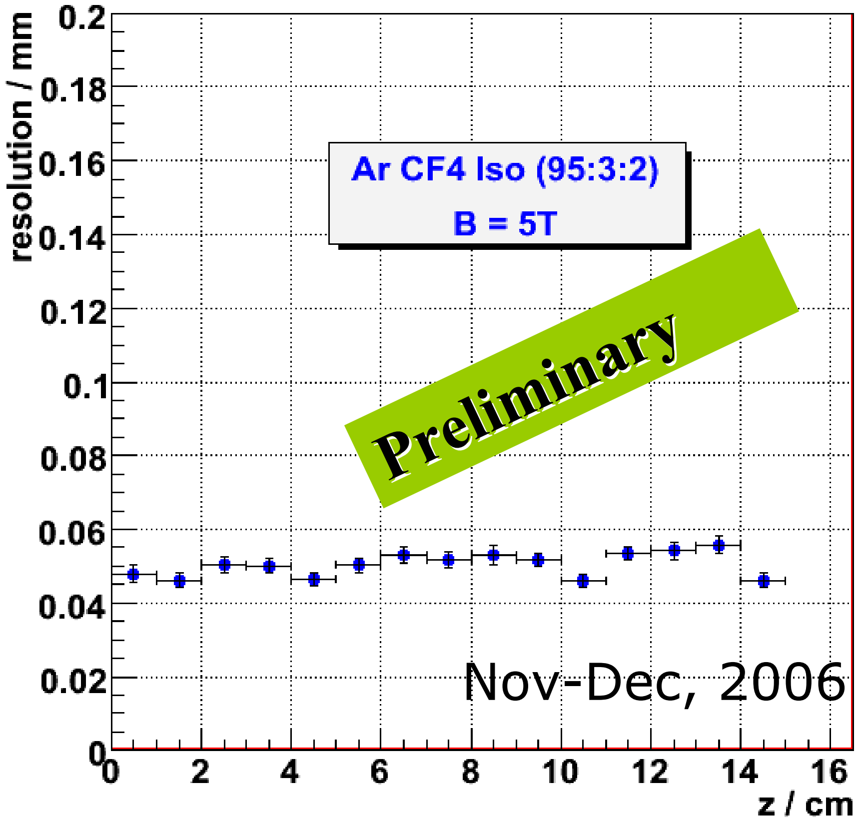
Concern: long time integration, background tracks, and positive ion loading of drift volume

GLD, LDC and 4th advocate using TPC; 4th also considers KLOE cluster counting DC (Franco Grancagnolo).

New TPCs

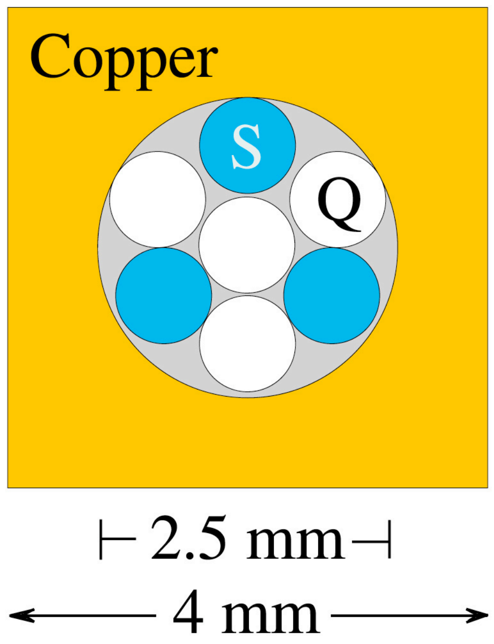
DESY test beam data:
digital TPC, GEM endplane, MediPix chip





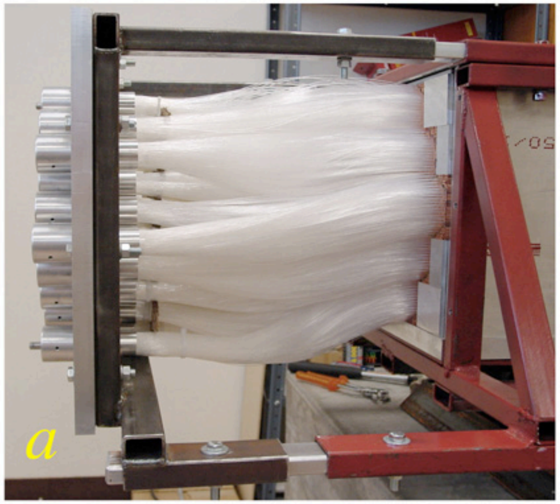
~ 50 μm av. resolution (diffusion negligible over 15 cm)
100 μm over 2 meters appears feasible
(~ 30 μm systematics Aleph TPC experience)

Calorimeter is new: a "dual readout" fiber calorimeter, first developed by R. Wigmans

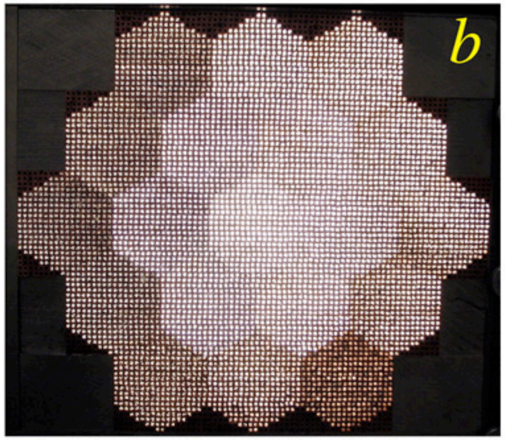


Unit cell

Back end of 2-meter deep module

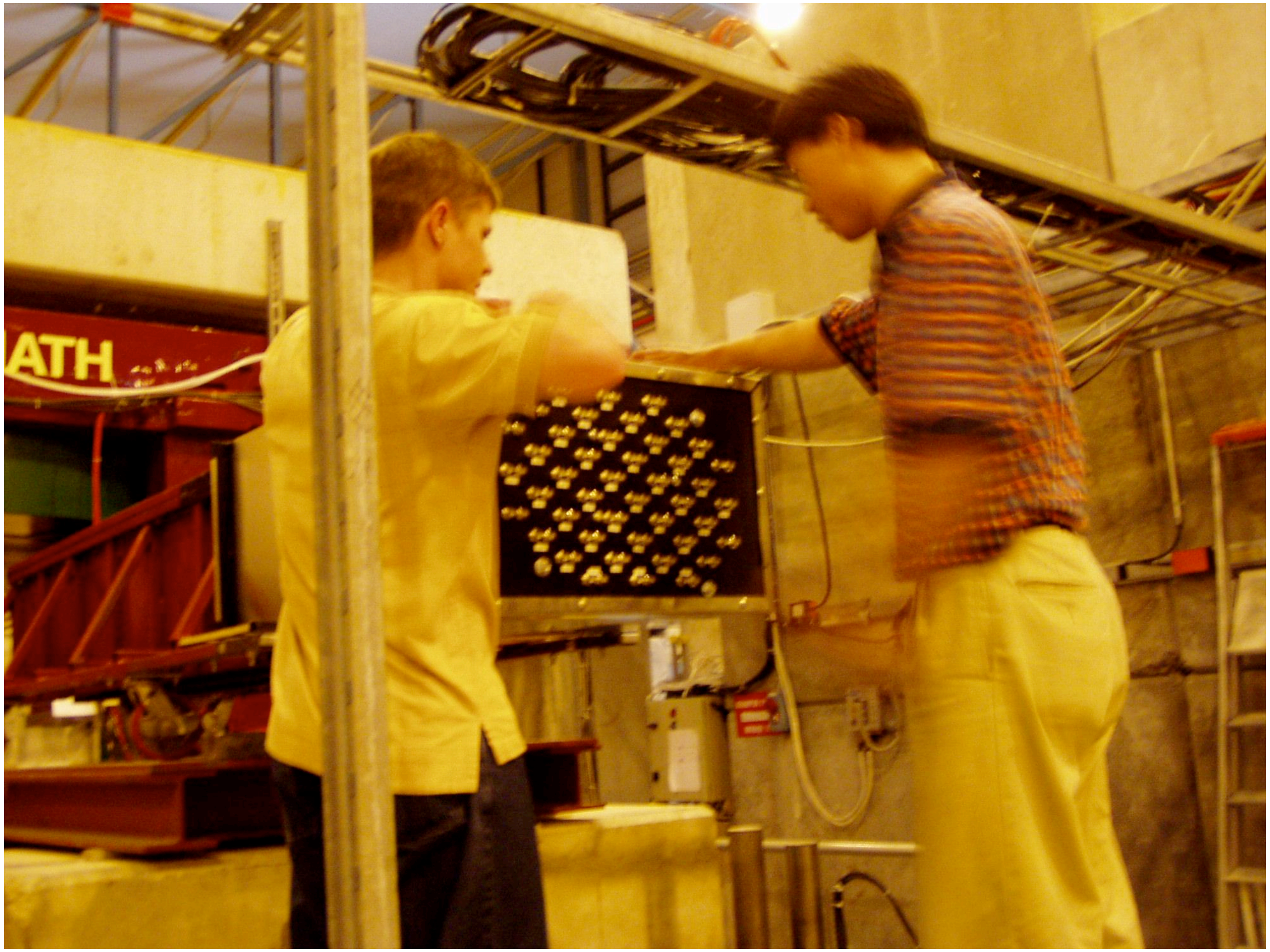


Physical channel structure



http://www.phys.ttu.edu/dream

Downstream end of DREAM (Dual REAdout Module) showing HV and signal connectors to ordinary PMTs



Scintillation: all charged particles - *e,pi,K,p*

Cerenkov: predominantly *e* from *photon showers* from *pi-zeros*

Hadronic showers suffer from large fluctuations in "EM fraction", that is, from fluctuations in neutral and charged pion production within the shower. This leads to

- poor energy resolution
- non-Gaussian response, high-side tail
- non-linear response with energy

Common characteristics of "non-compensating" calorimeters in which electromagnetic and hadronic responses differ, "$e/h \neq 1$"

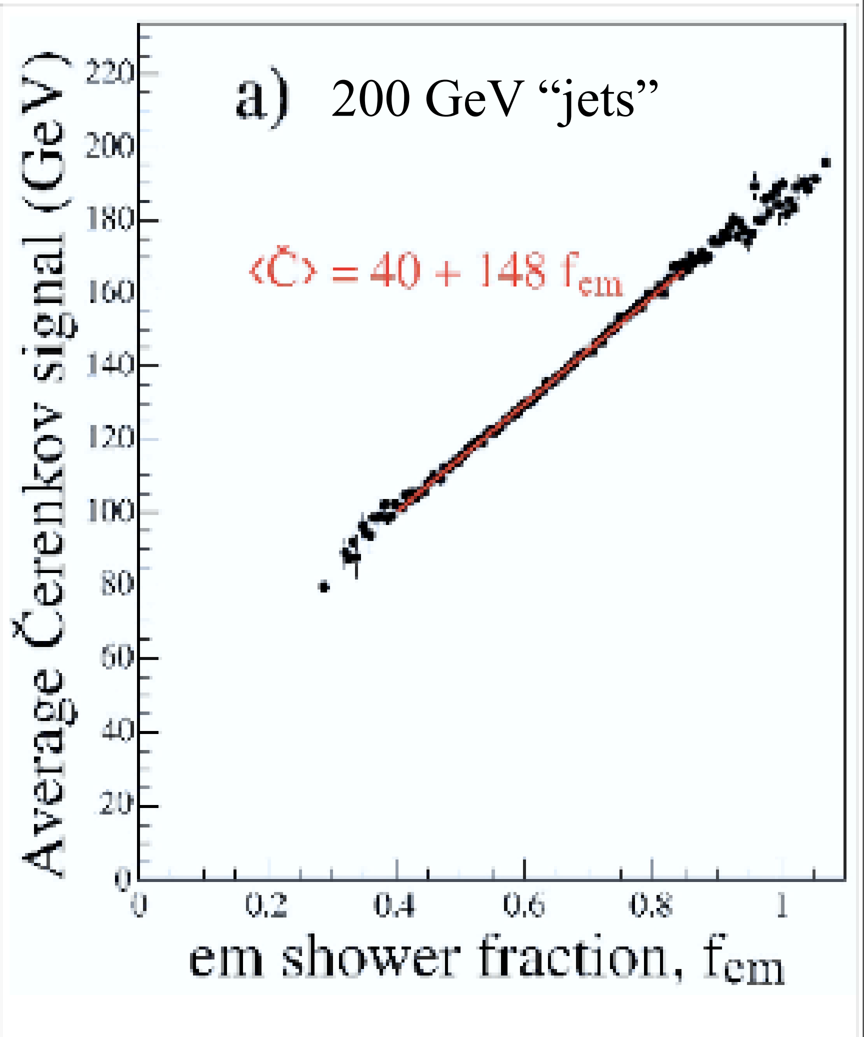
Dual-Readout: Measure

every shower twice - in scintillation light and in Cerenkov light. Calibrated with 40 GeV electrons into the center of each tower.

$$(e/h)_C = \eta_C \approx 5$$
$$(e/h)_S = \eta_S \approx 1.4$$

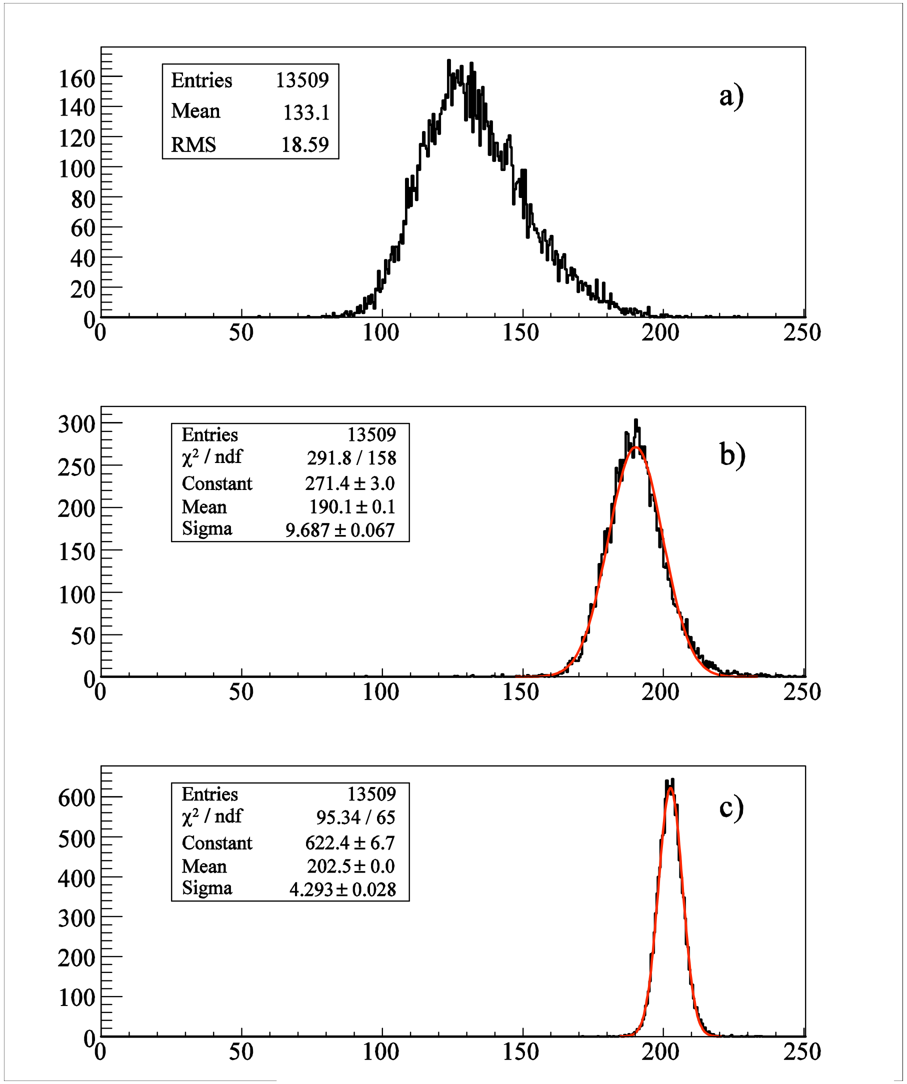
$$C = [f_{em} + (1 - f_{em})/\eta_C]E$$
$$S = [f_{em} + (1 - f_{em})/\eta_S]E$$

$$\rightarrow C/E = 1/\eta_C + f_{em}(1 - 1/\eta_C)$$



Data NIM A537 (2005) 537.

DREAM data 200 GeV π^-: Energy response



Scintillating fibers

Scint + Cerenkov

$f_{EM} \propto (C/E_{shower} - 1/\eta_C)$

(4% leakage fluctuations)

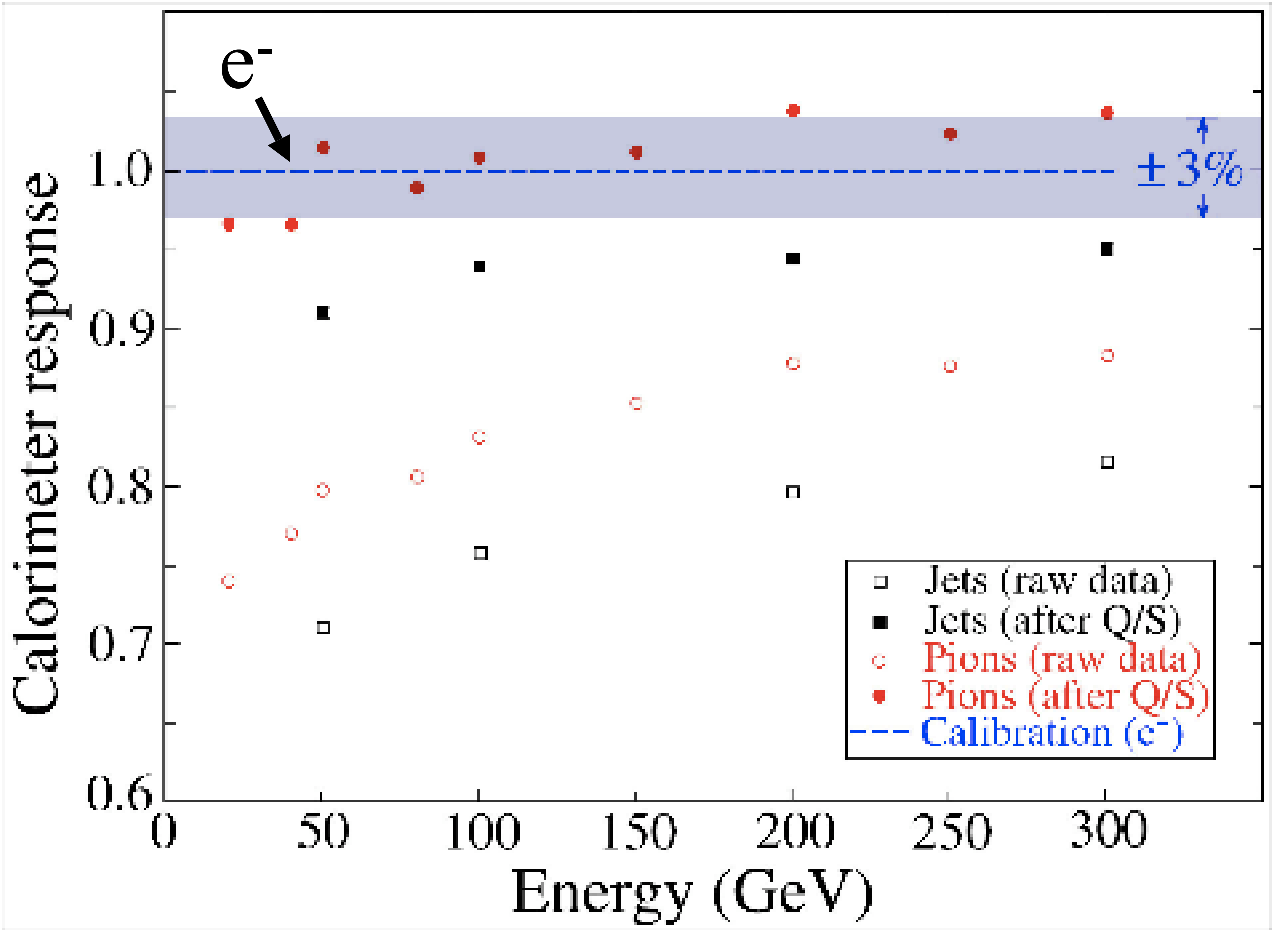
Scint + Cerenkov

$f_{EM} \propto (C/E_{beam} - 1/\eta_C)$

(suppresses leakage)

Data NIM A537 (2005) 537.

More important than good Gaussian response: DREAM module calibrated with 40 GeV e^- into the centers of each tower responds linearly to π^- and "jets" from 20 to 300 GeV.



Hadronic linearity may be the most important achievement of dual-readout calorimetry.

↑ ILC

Data NIM A537 (2005) 537.

Go after the neutrons, improve geometry, make it scalable

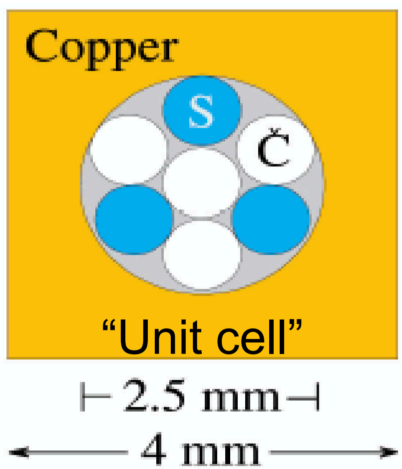
DREAM module

3 scintillating fibers
4 Cerenkov fibers

ILC-type module

2mm Pb or brass plates;
fibers every 2 mm

(Removes correlated fiber hits)



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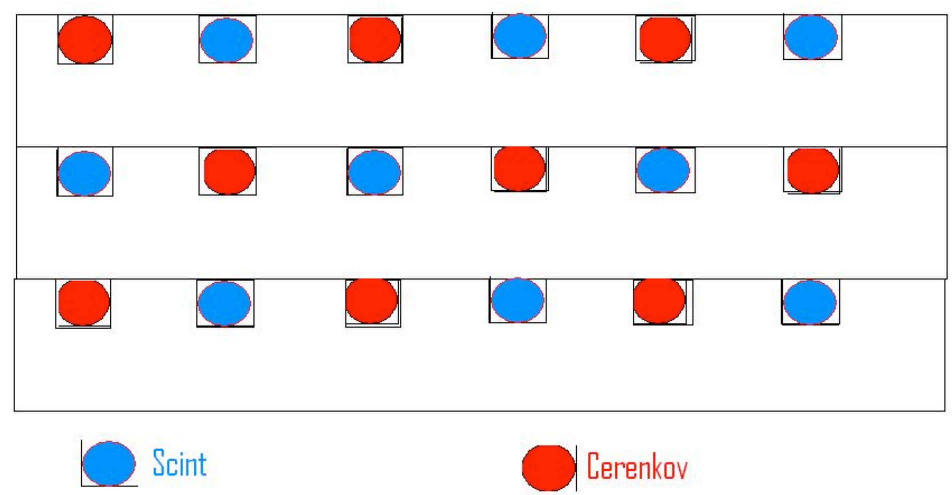
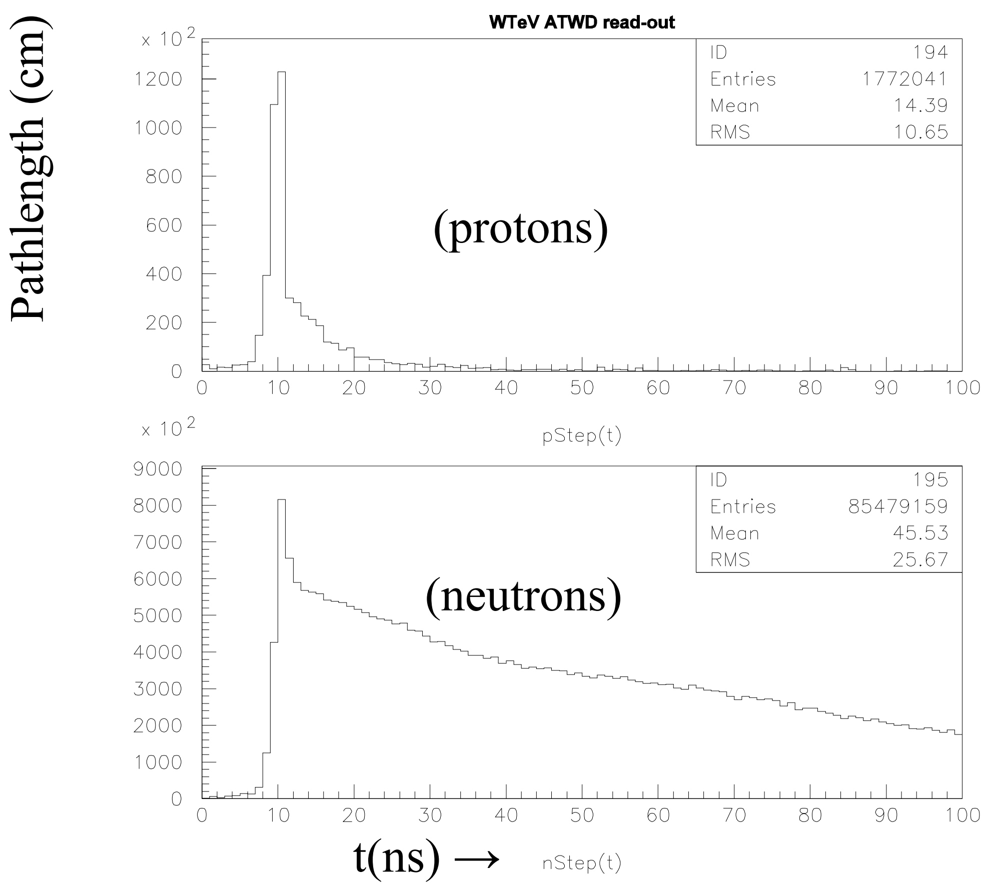


Binding energy loss fluctuations: next largest hadronic shower fluctuation after EM fraction, correlated with MeV neutrons

(1) Measure MeV neutrons by time. ~



Velocity of MeV neutrons is ~ 0.05 c

(1) Scintillation light from np→np scatters comes late; and,

(2) neutrons fill a larger volume

(2) Measure MeV neutrons by separate hydrogenous fiber

- A hydrogenous scintillating fiber measures proton ionization from np→np scatters;
- A second scintillating non-hydrogenous fiber measures all charged particles, but does not see protons from np → np elastic scatters;
- This method has the weakness that the neutron component is the difference of two signals.

(3) Measure MeV neutrons with a neutron-sensitive fiber

- Lithium-loaded or Boron-loaded fiber (Pacific Northwest Laboratory has done a lot of work on these)
- Some of these materials are difficult liquids
- Nuclear processes may be slow compared to 300 ns.
- But, most direct method we know about.

(4) Measure MeV neutrons using different Birk's

- Birk's constant parameterizes the reduction in detectable ionization from heavily ionizing particles (essentially due to recombination)
- Use two scintillating fibers with widely different Birk's constants.
- Two problems: (i) hard to get a big difference, and (ii) neutron content depends on the difference of two signals.

“Ultimate calorimetry” ?

The theoretical limit (Wigmans) for hadronic energy resolution is

$$\frac{\sigma_E}{E} \approx \frac{13\%}{\sqrt{E}}$$

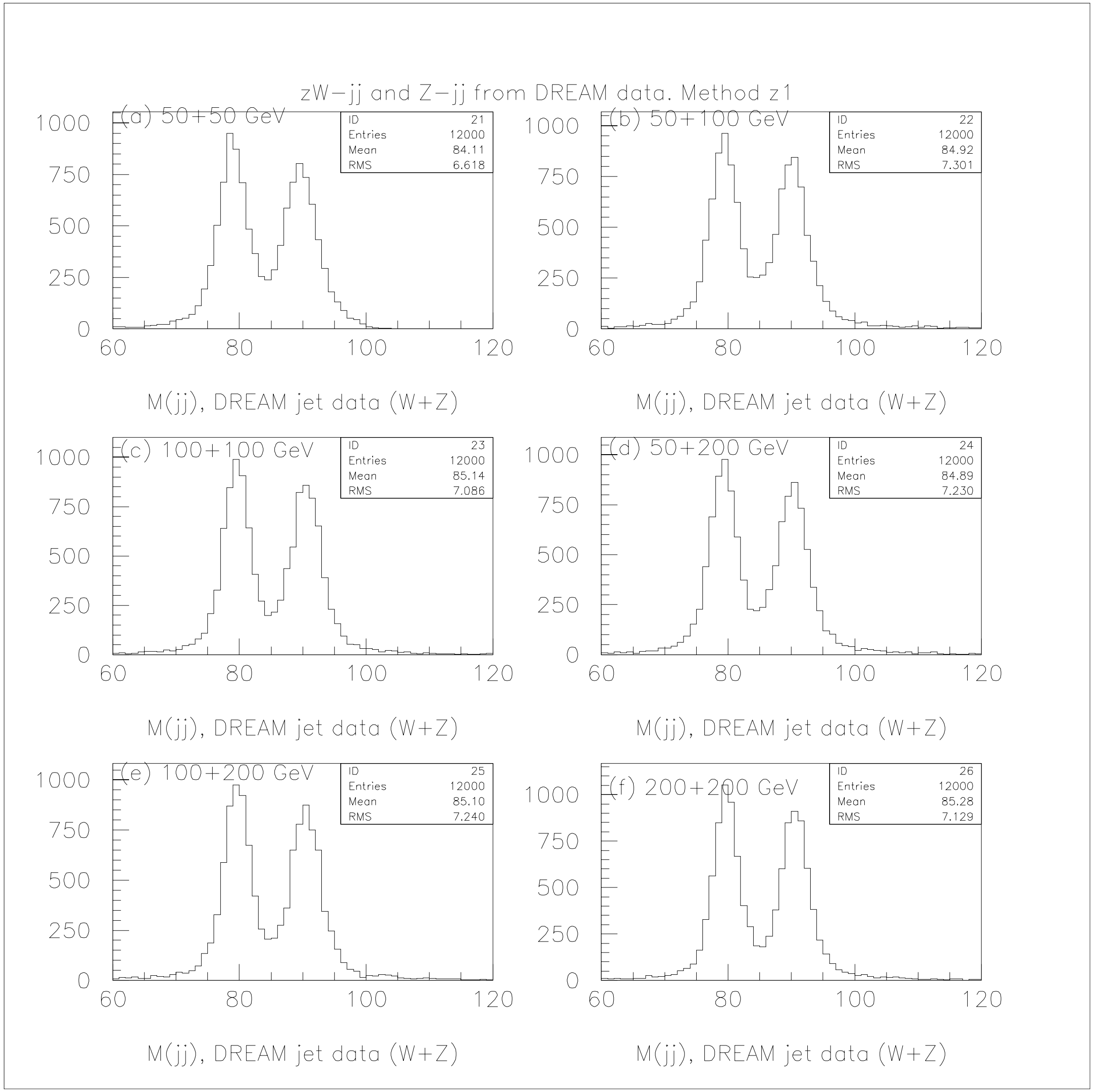
when leakage, EM fraction fluctuations and binding energy loss fluctuations are suppressed. We would be happy to achieve

$$\frac{\sigma_E}{E} \approx \frac{20\text{--}25\%}{\sqrt{E}}$$

in a test module.

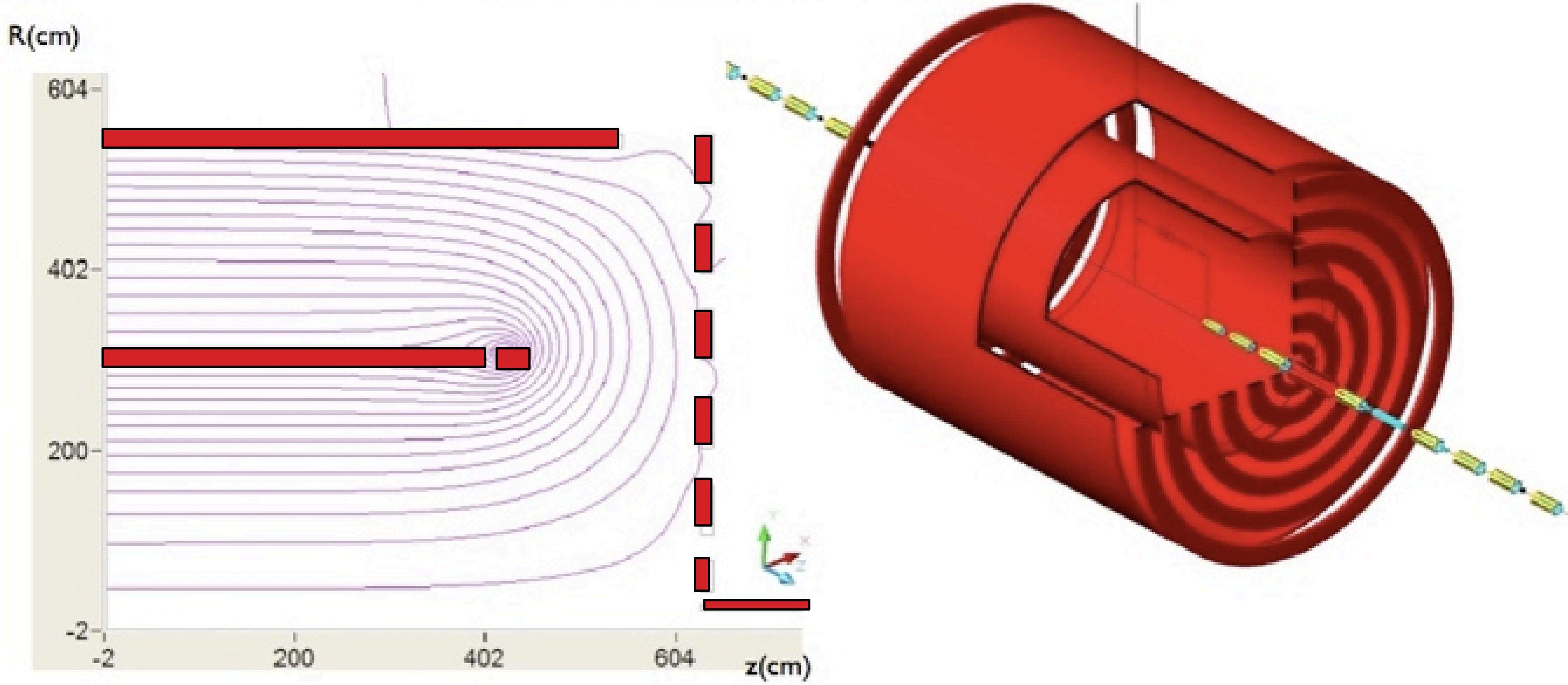
What 20% buys you for W and Z decay to 2-jet mass reconstruction:

Both jets are sampled from DREAM data with measured spatial and energy fluctuations



Dual Solenoid: new magnetic field, new ``wall of coils", iron-free. Many benefits to muon detection and MDI (Machine Detector Interface)

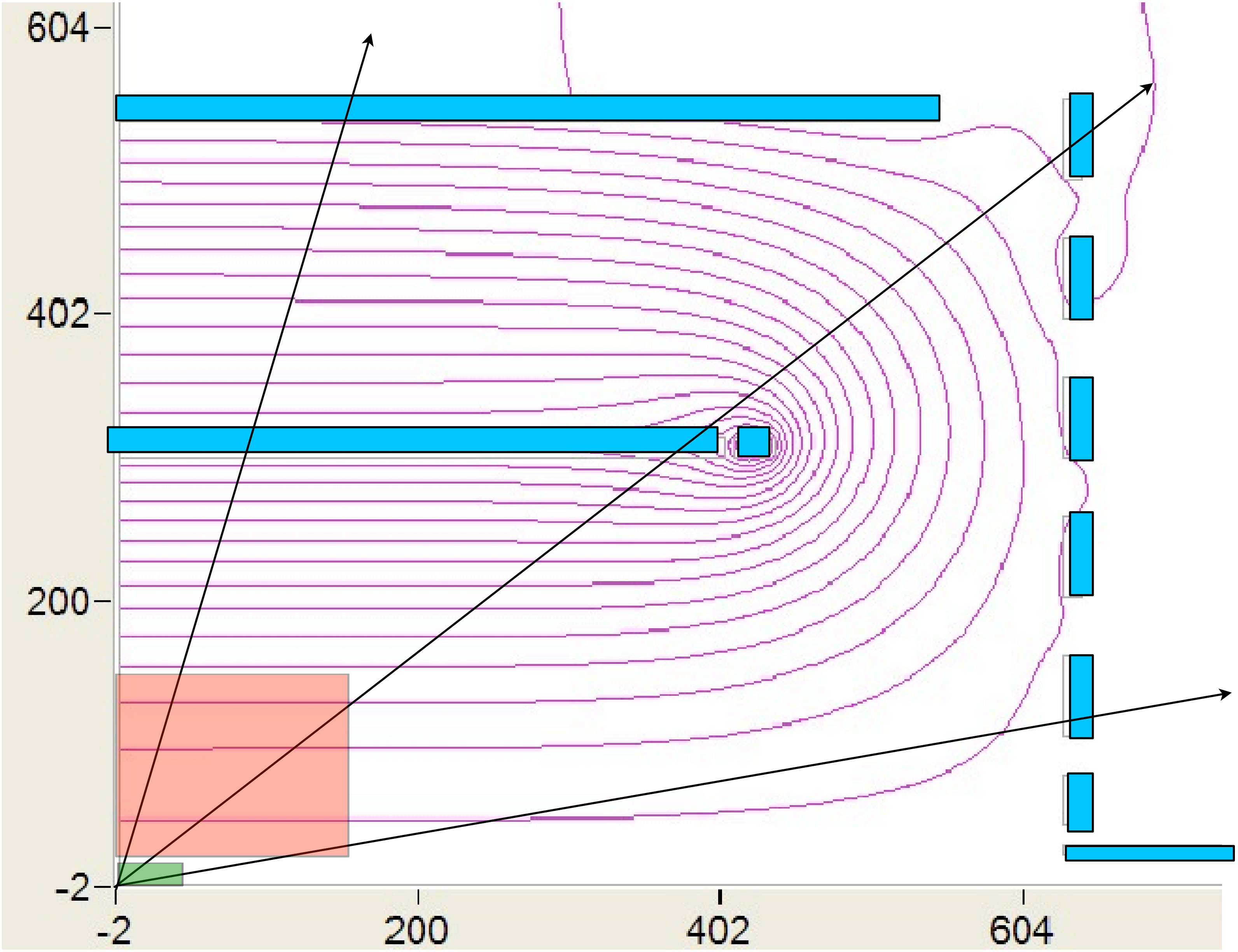
Magnetic field of dual solenoid and wall of coils

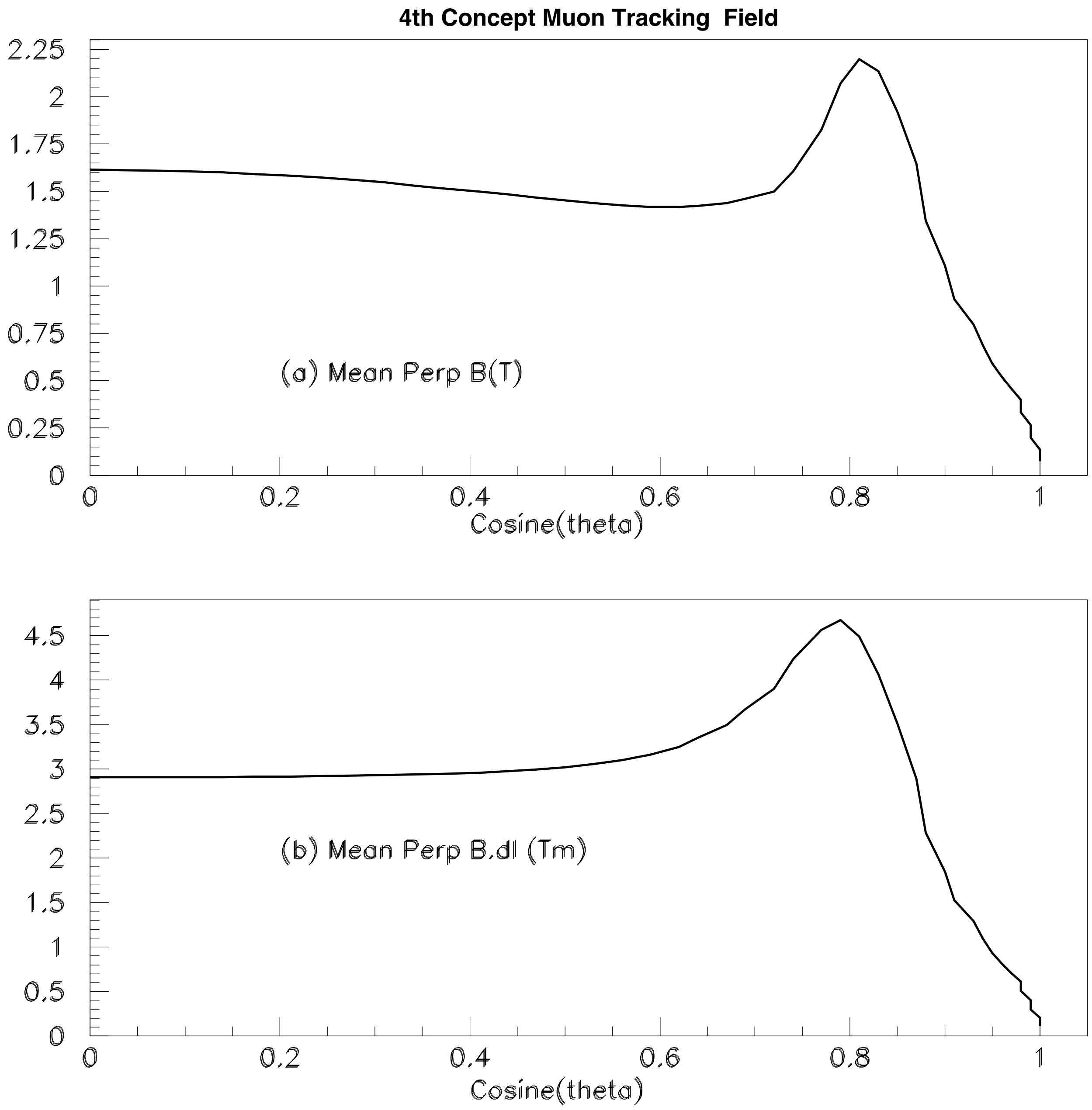


Dual solenoid: scientific advantages

- no iron: cheaper, more flexible detector
- precision measurement of muons
- can reverse B field: cancel detector asymmetries in precision *b,c* asymmetry measurements
- can insert specialized detectors in the annulus between the solenoids for new searches, new ideas, ...
- exceedingly flexible: can move calorimeter in *z*, reconfigure geometry for asymmetric beam energy running, re-configuration of detector, etc.
- can insert a toroid to measure small angle tracks ...

Muon trajectories from the interaction point

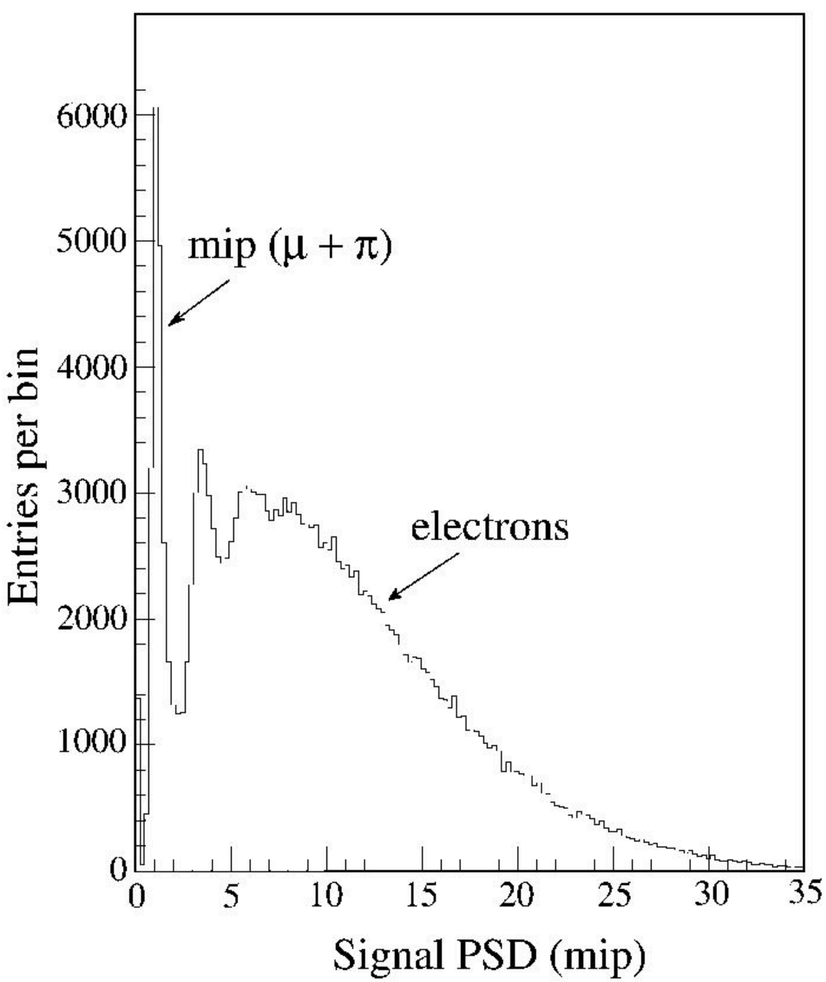


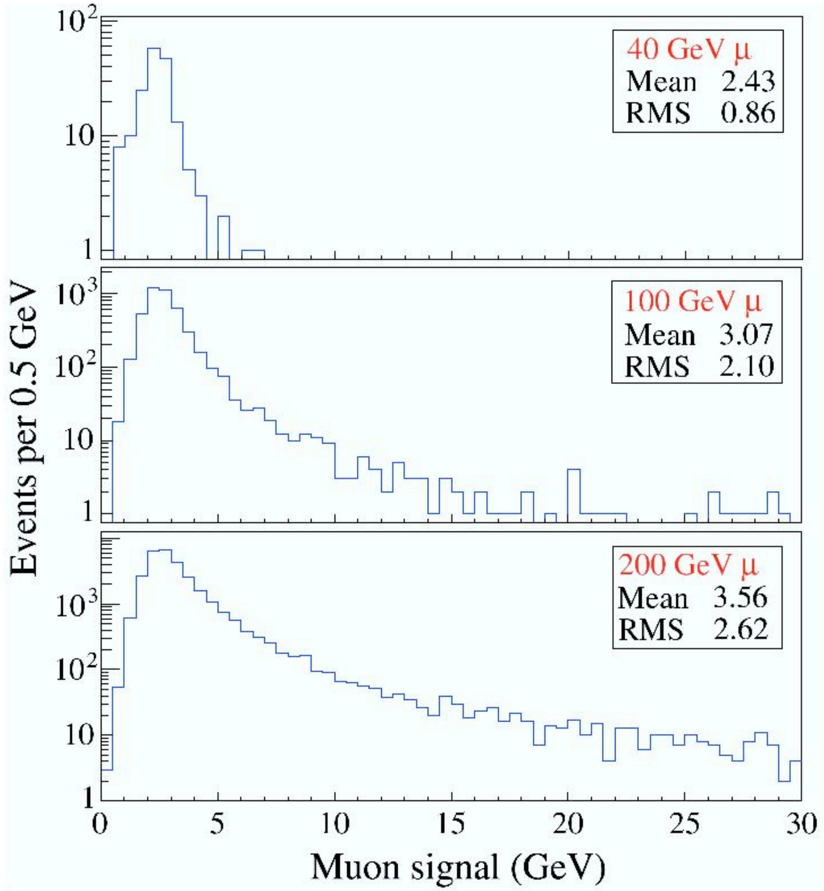


Dual solenoid

tracking along muon trajectories in the annulus between solenoids.

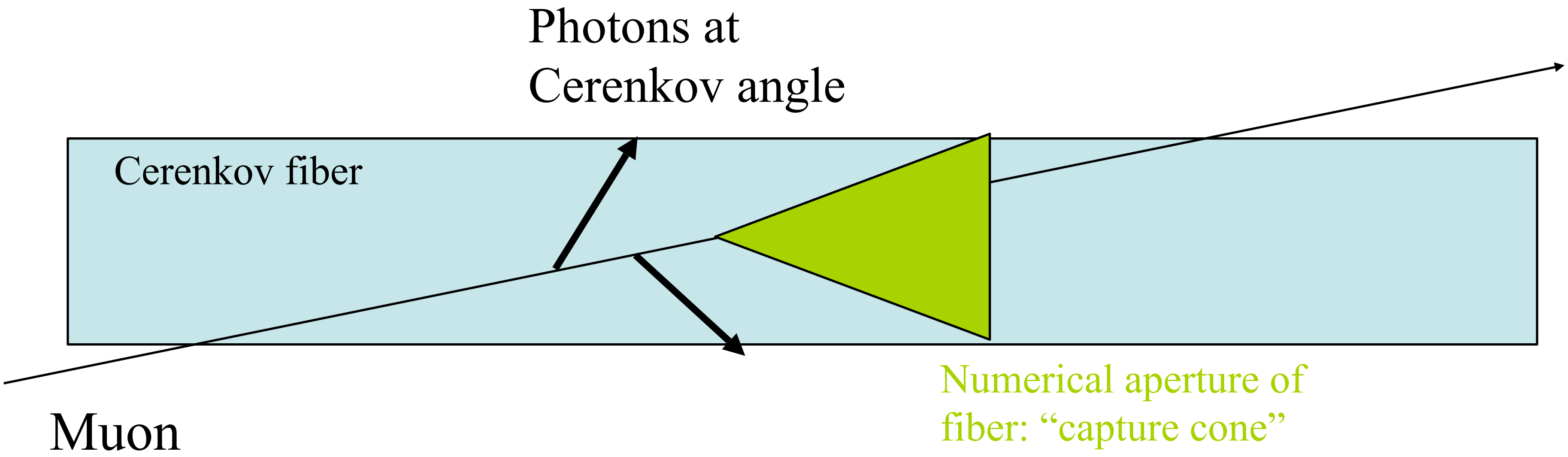
cluster counting drift tubes for muon tracking.





NIM A533 (2004) 305-321.

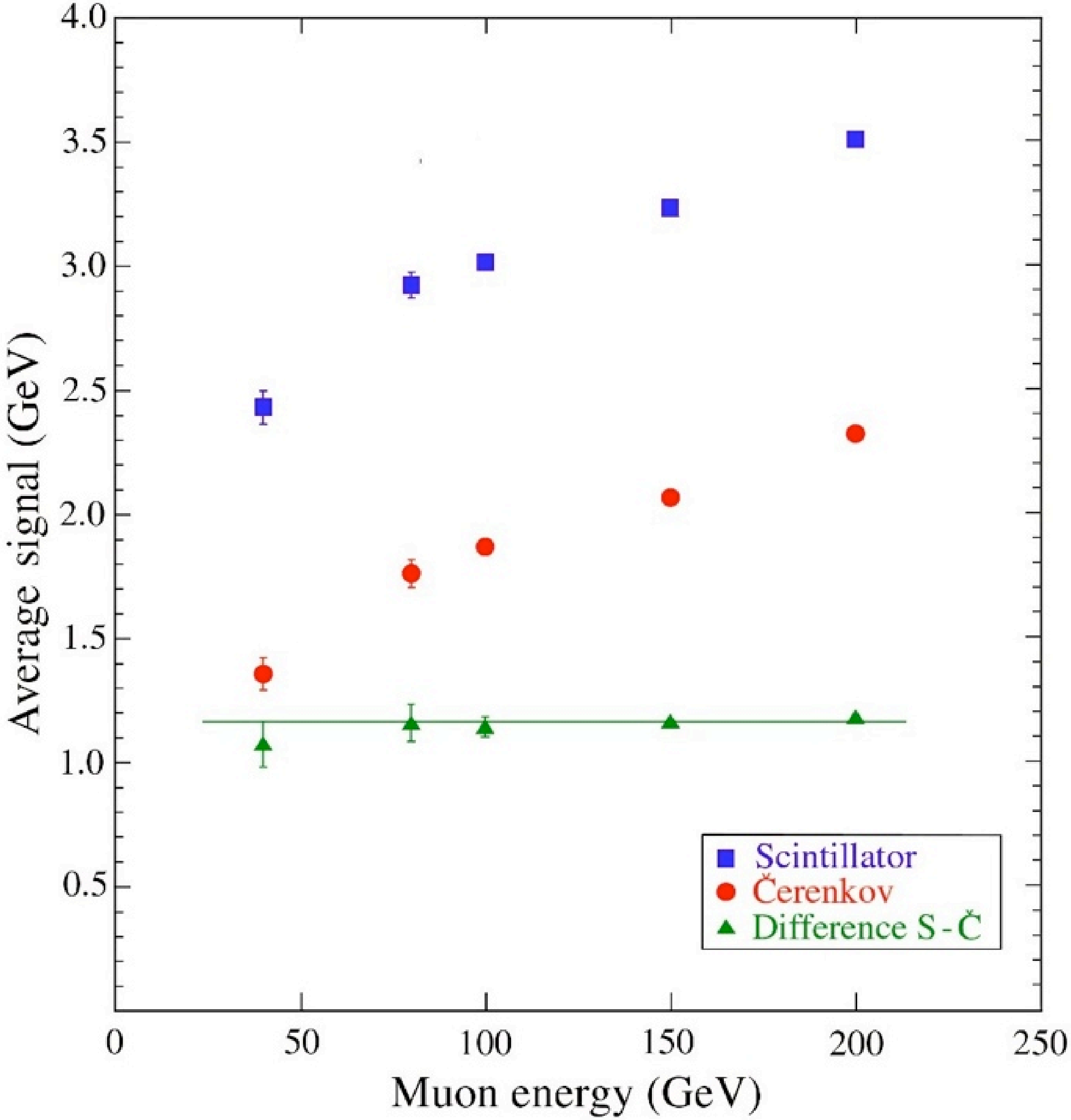
The Cerenkov signal from an aligned, non-radiating muon is zero



All of the Cerenkov light of an approximately aligned muon falls outside of the numerical aperture of the fiber.

C ~ 0 S ~ *dE/dx*

First measurement of separate ionization and radiation of muons in a medium



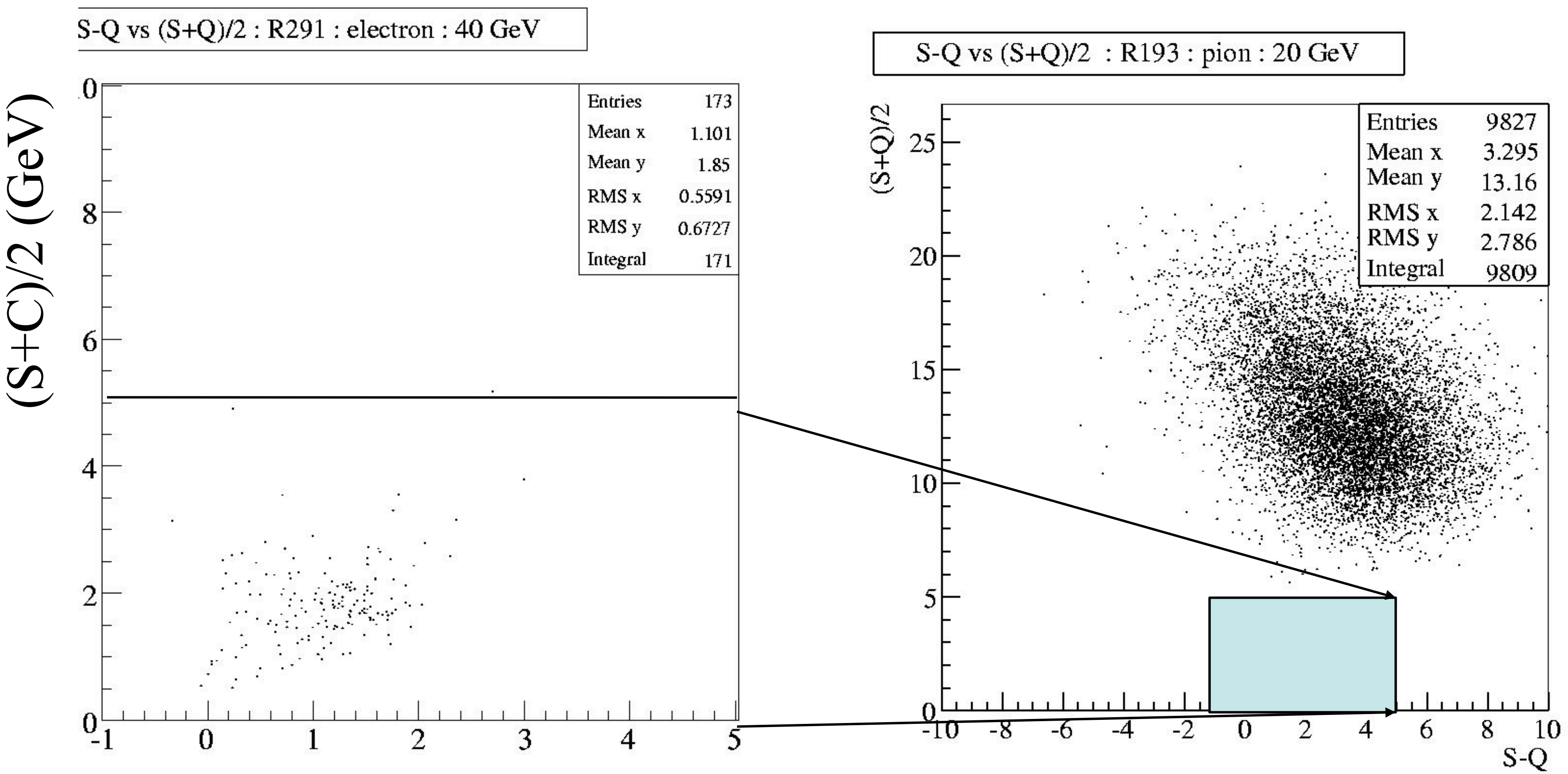
S = *dE/dx* + radiation

C = radiation

S-C = *dE/dx* ~ 1 GeV

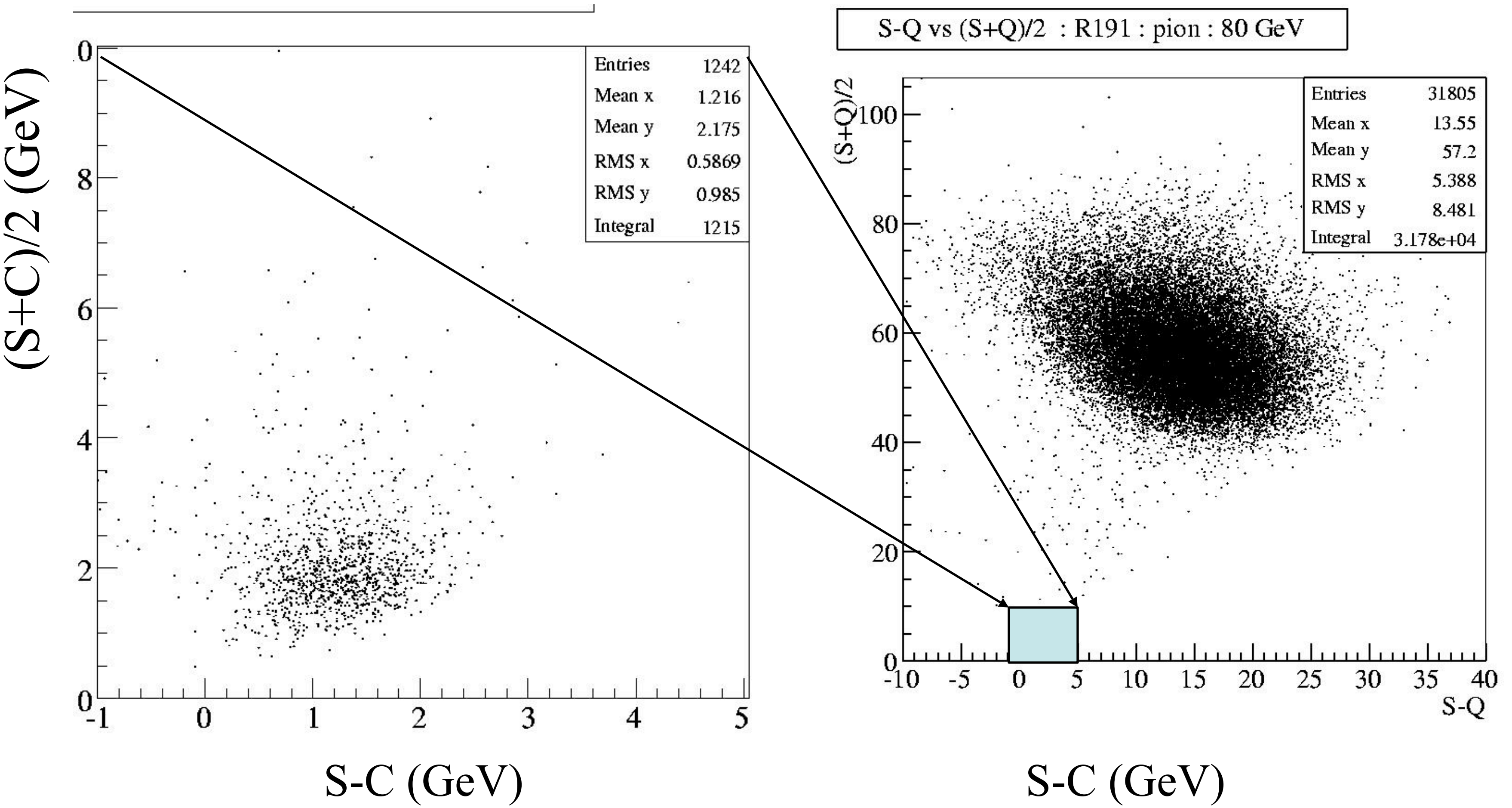
Use it for muon identification

Muons (40 GeV) & Pions (20 GeV)

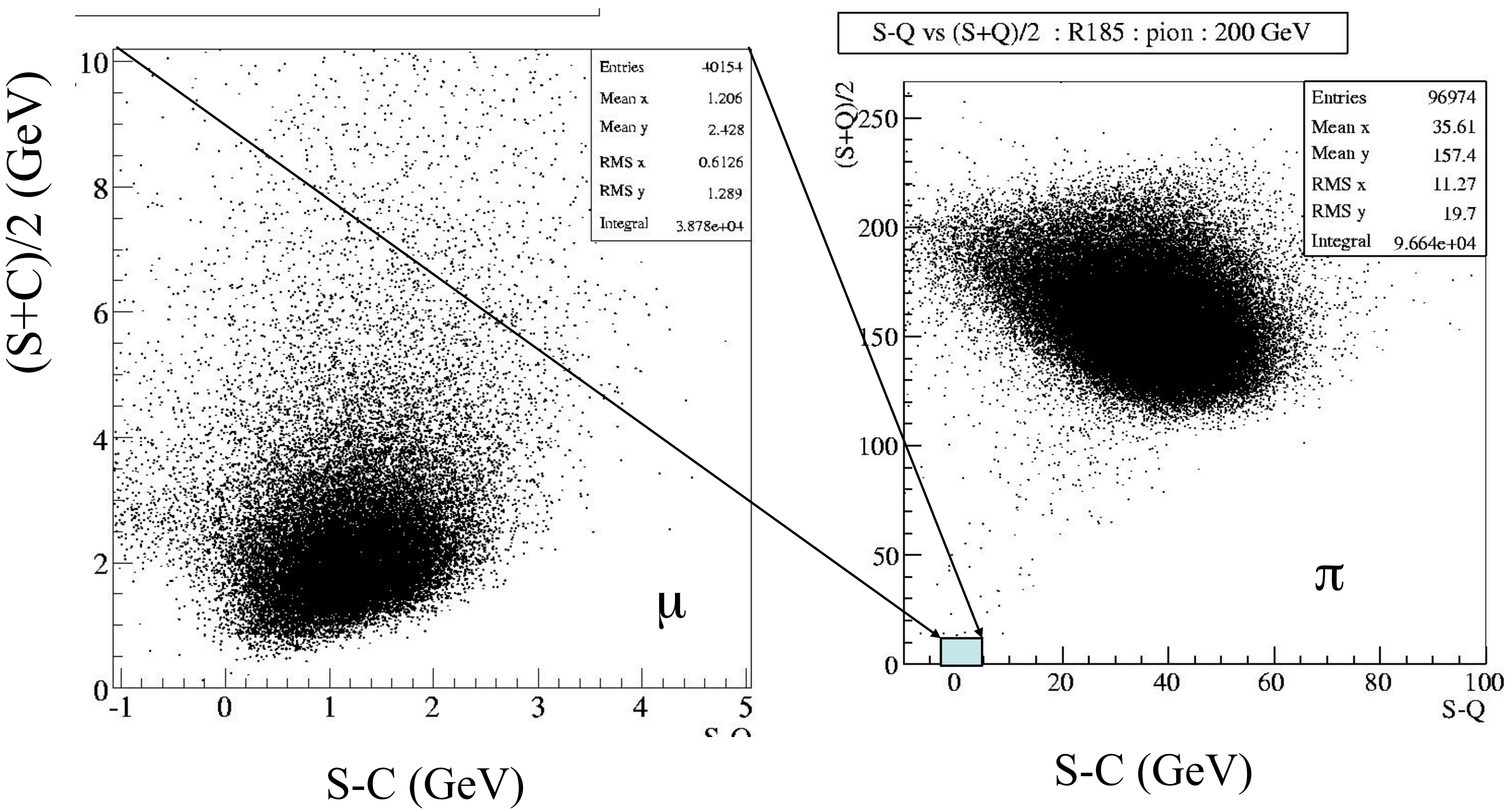


S-C (GeV) S-C (GeV)

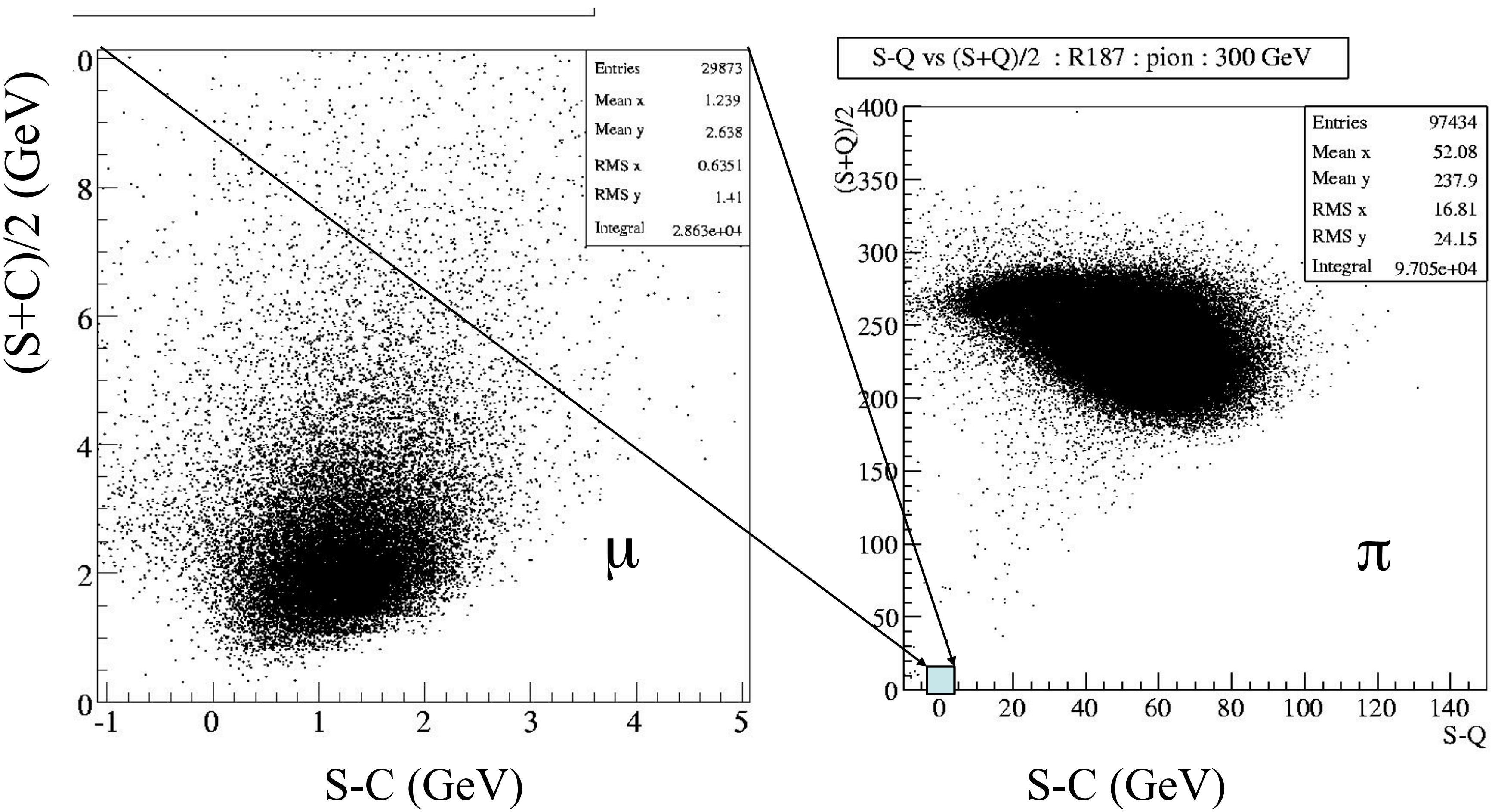
Muons and Pions (80 GeV)



Muons and Pions (200 GeV)



Muons and Pions (300 GeV)



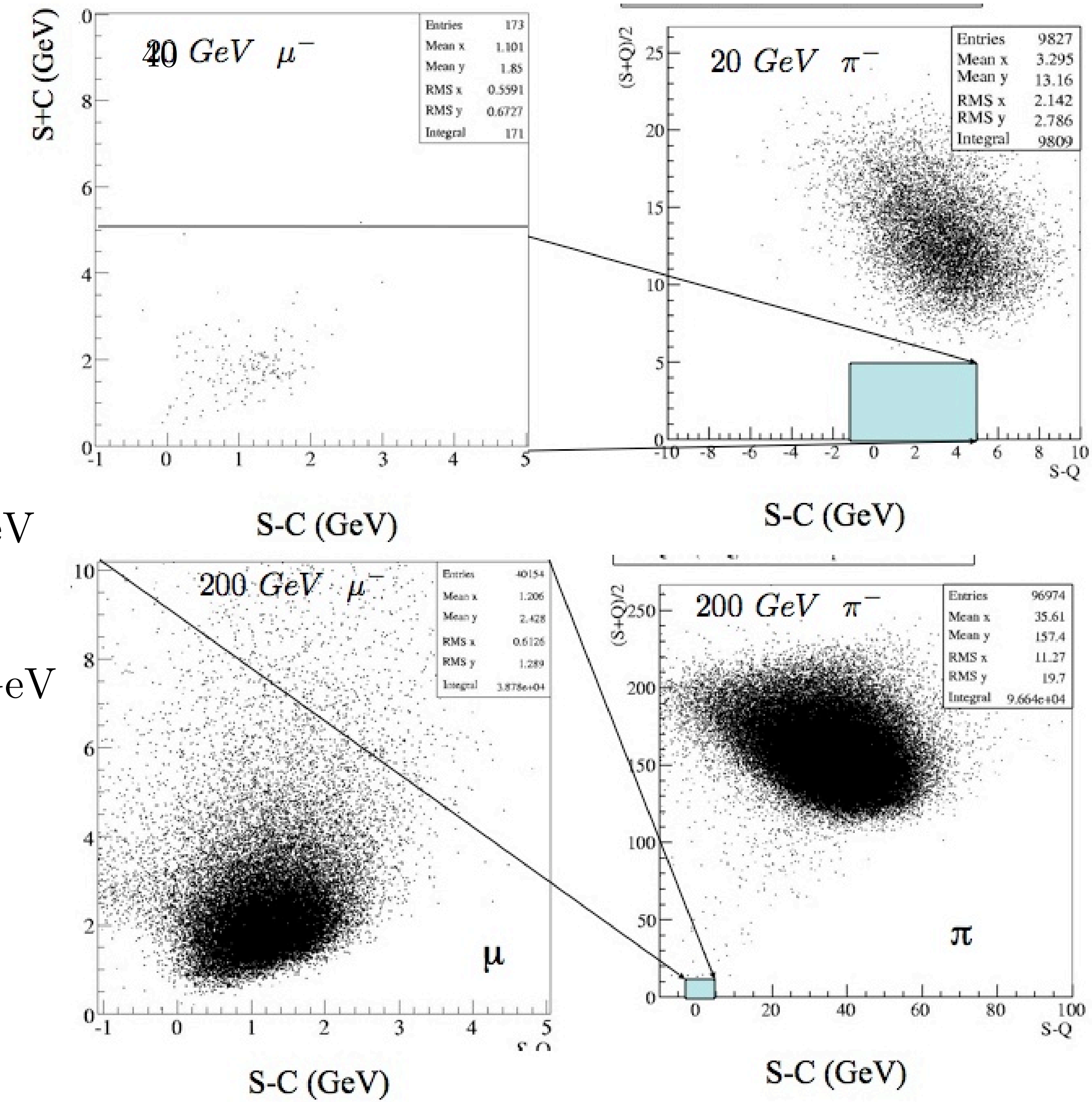
Dual readout of muons in DREAM module

$\pi^{\pm}$ rejection:

10^{-3} at 20 GeV

10^{-4} at 200 GeV

(or better)



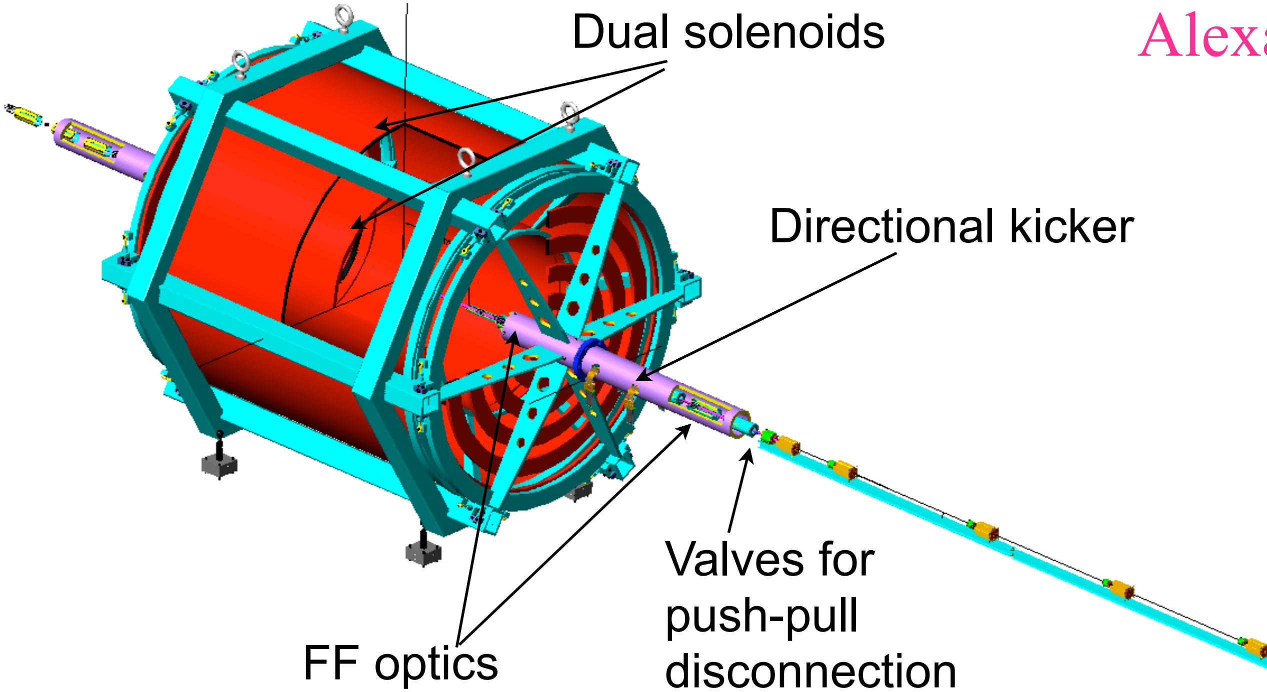
Muon as a "perfect parton" in 4th Concept.

- momentum measured in TPC + vertex
- ionization energy loss and radiative energy losses measured separately in the dual readout calorimeter
- near-positive identification of muon in calorimeter
- momentum measured again in annulus between the solenoids: energy balance of muon in detector $E_{TPC} \sim E_{CALOR} + E_{MU\text{-}SPECTR}$
- pion rejection against muons is huge: use both calorimeter identification and energy balance
- muons inside a jet, however, have not yet been studied

Dual solenoid: machine-detector interface advantages

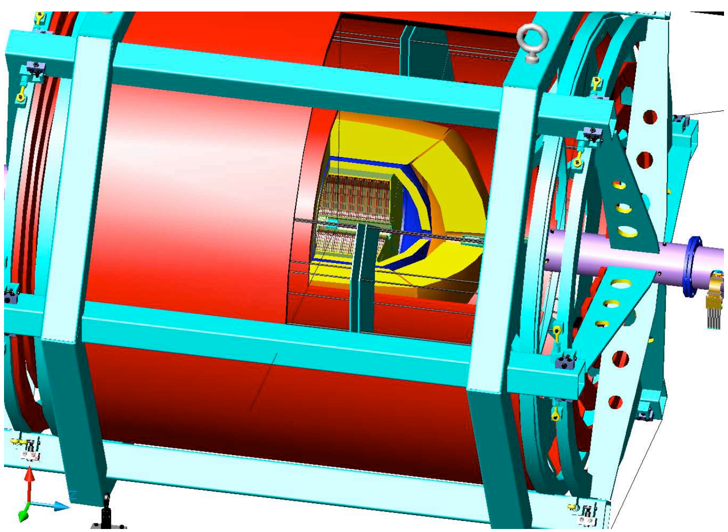
- control of B on and near beam line
- "push-pull" of two detectors in one IR
- installation and re-installation
- costs and infrastructure in interaction hall
- FF optics, compensation, quads up to and inside the detector
- can accomodate adiabatic focusing, monochromatization, any crossing angle, etc.

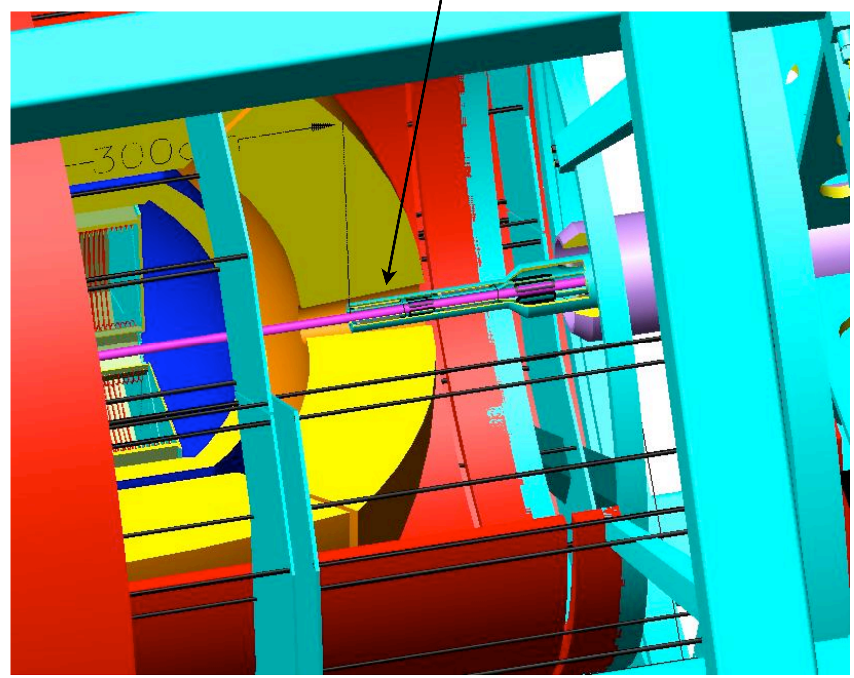
Alexander Mikhailichenko



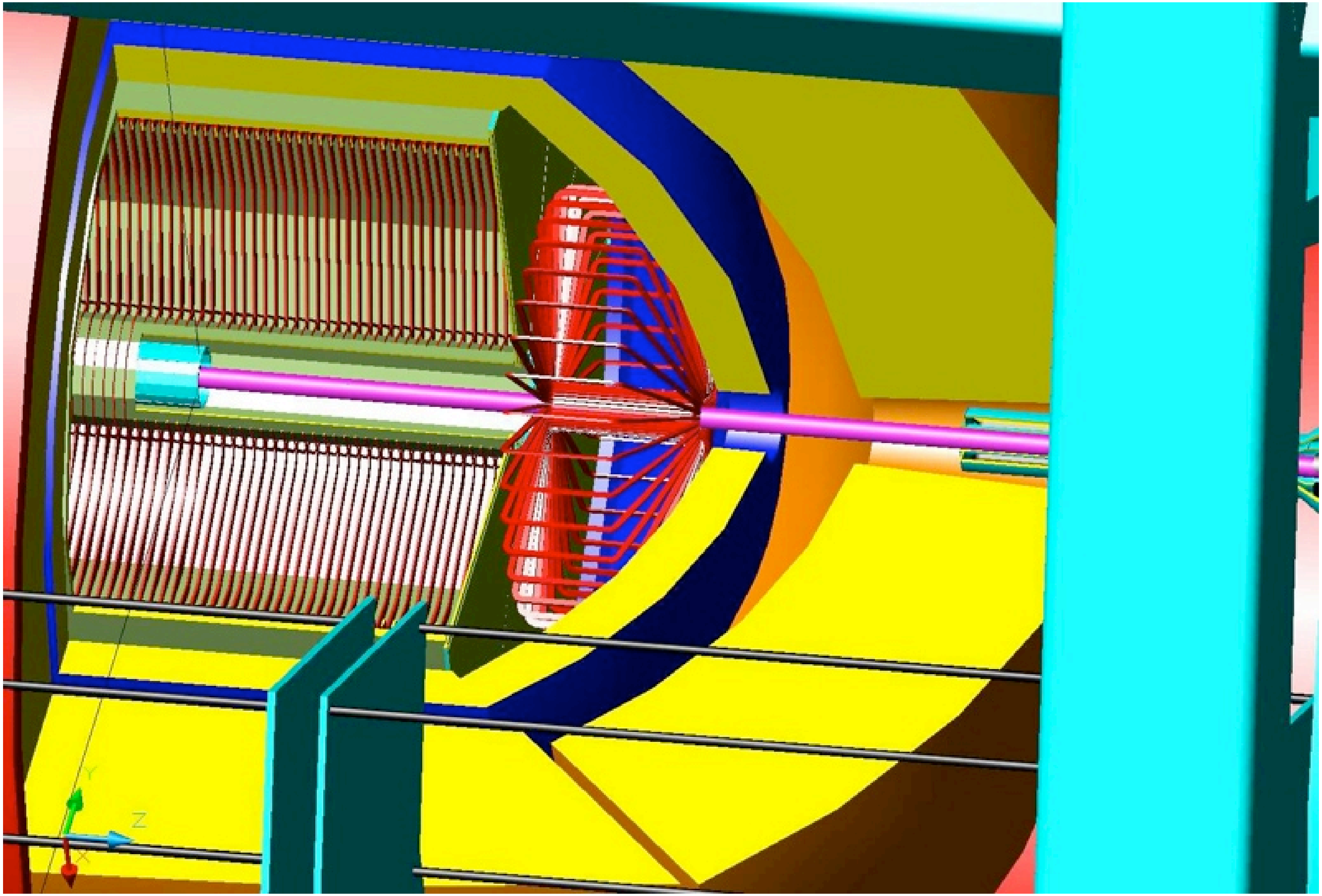
Final focus optics, mounted inside a cylinder attached to the detector by consoles.

This reduces influence of ground motion.



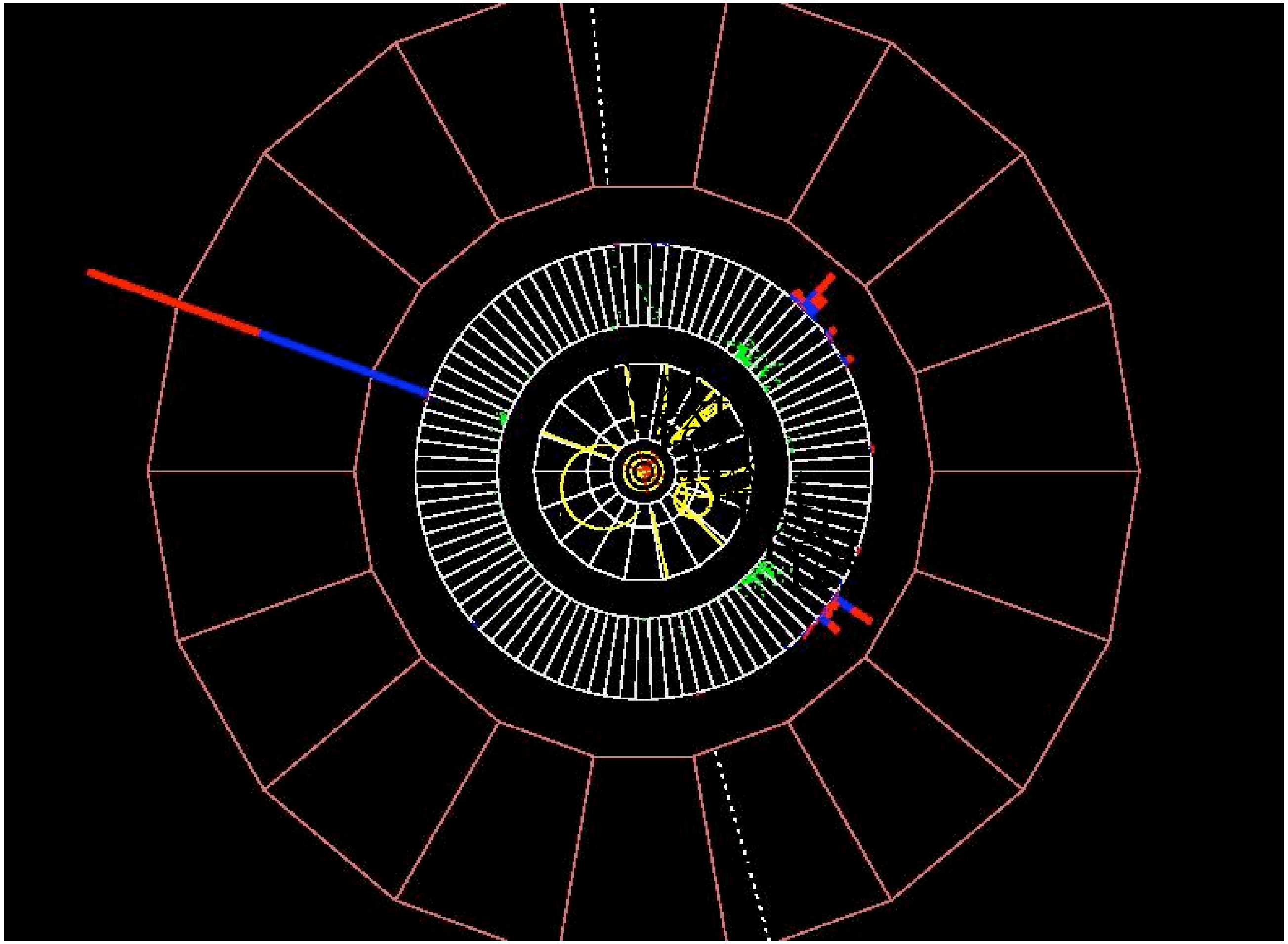


Another new idea: we are toying with the design of a toroid between the TPC and calorimeter for small angle tracks



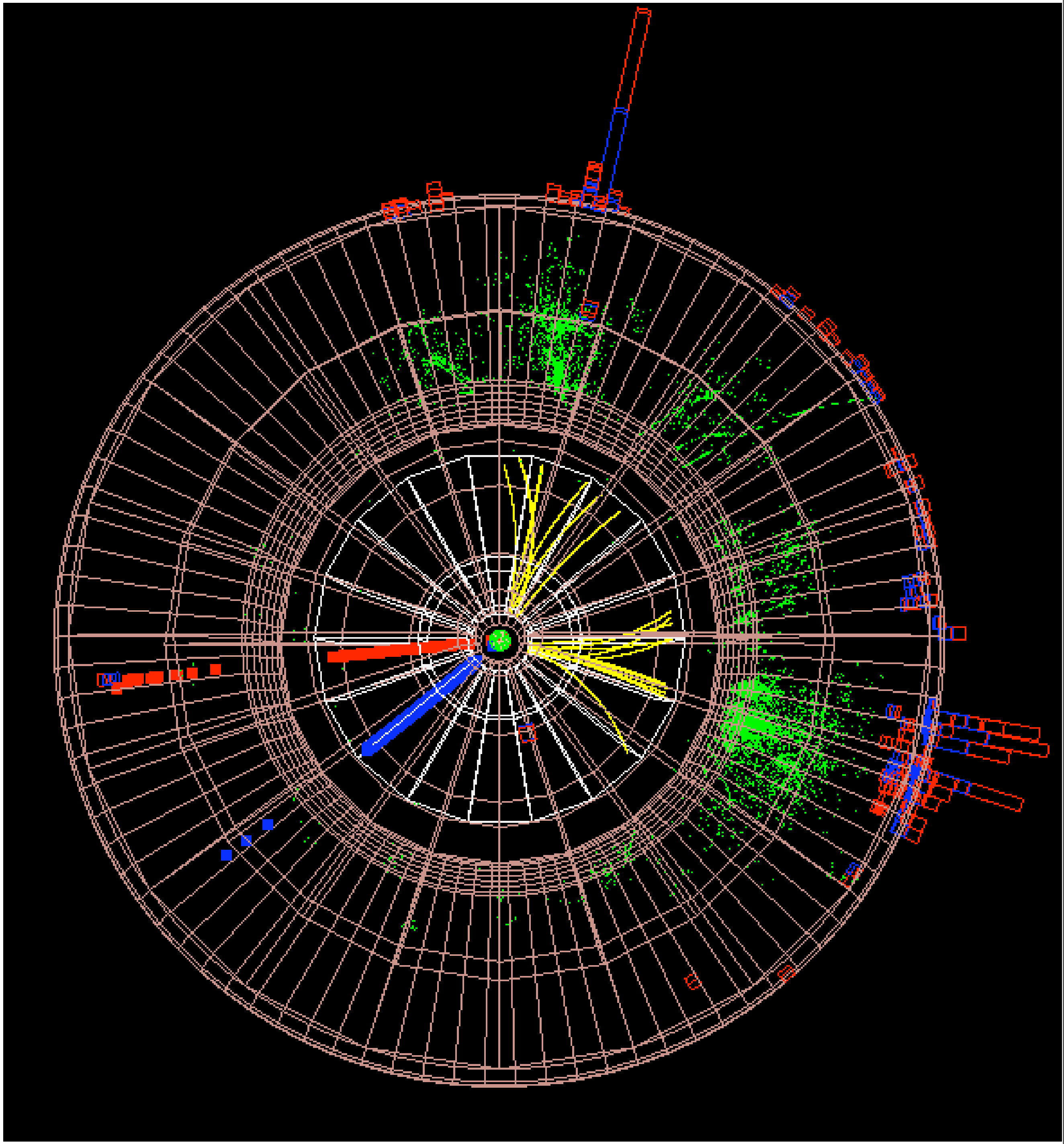
ILCroot software

$$e^+e^- \to H^0 Z^0 \to W^+W^- \mu^+\mu^- \to jj \;\; e^-\nu \;\; \mu^+\mu^-$$

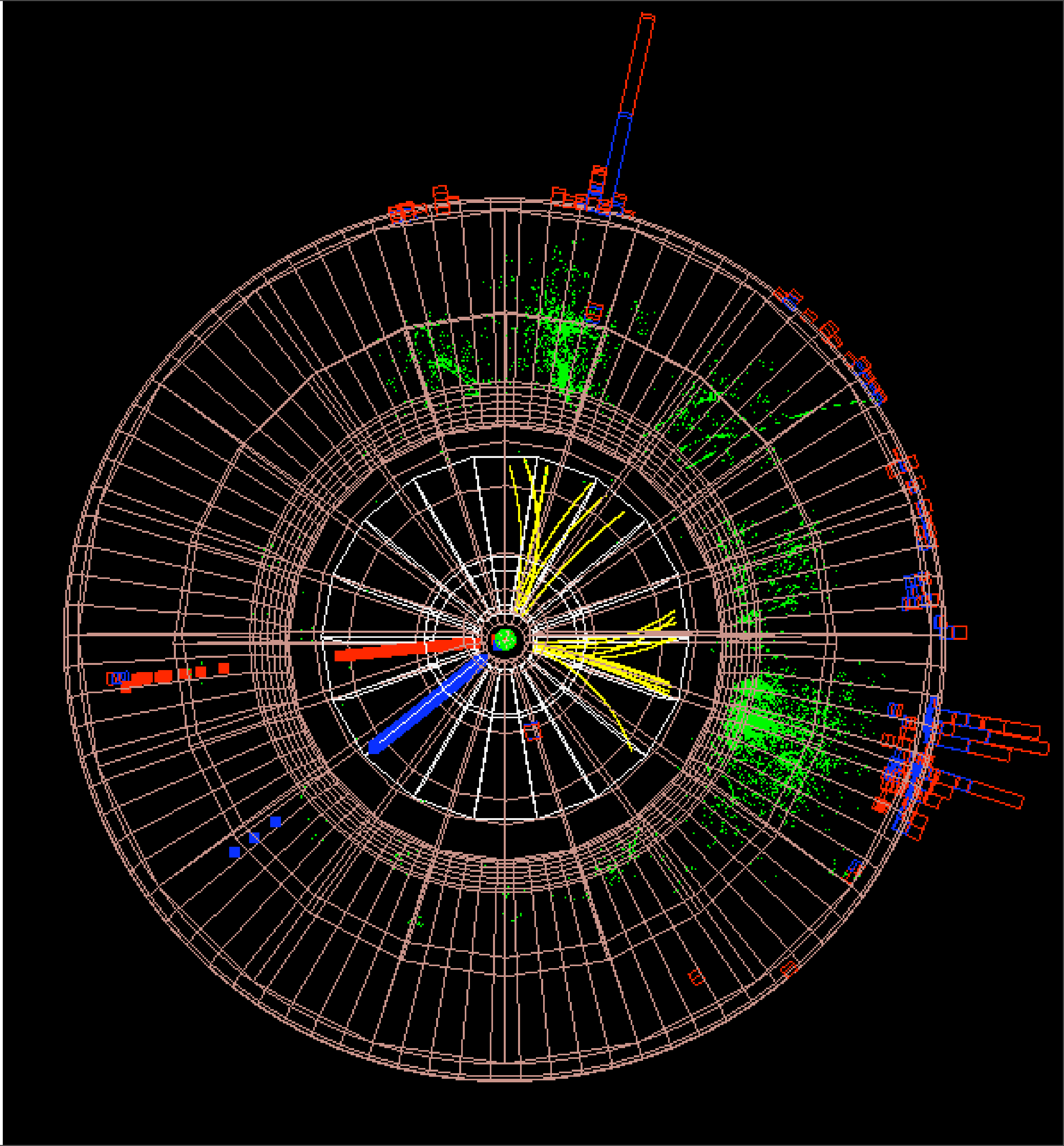


Illustrates all the detectors of 4th Concept … particle ID “obvious”

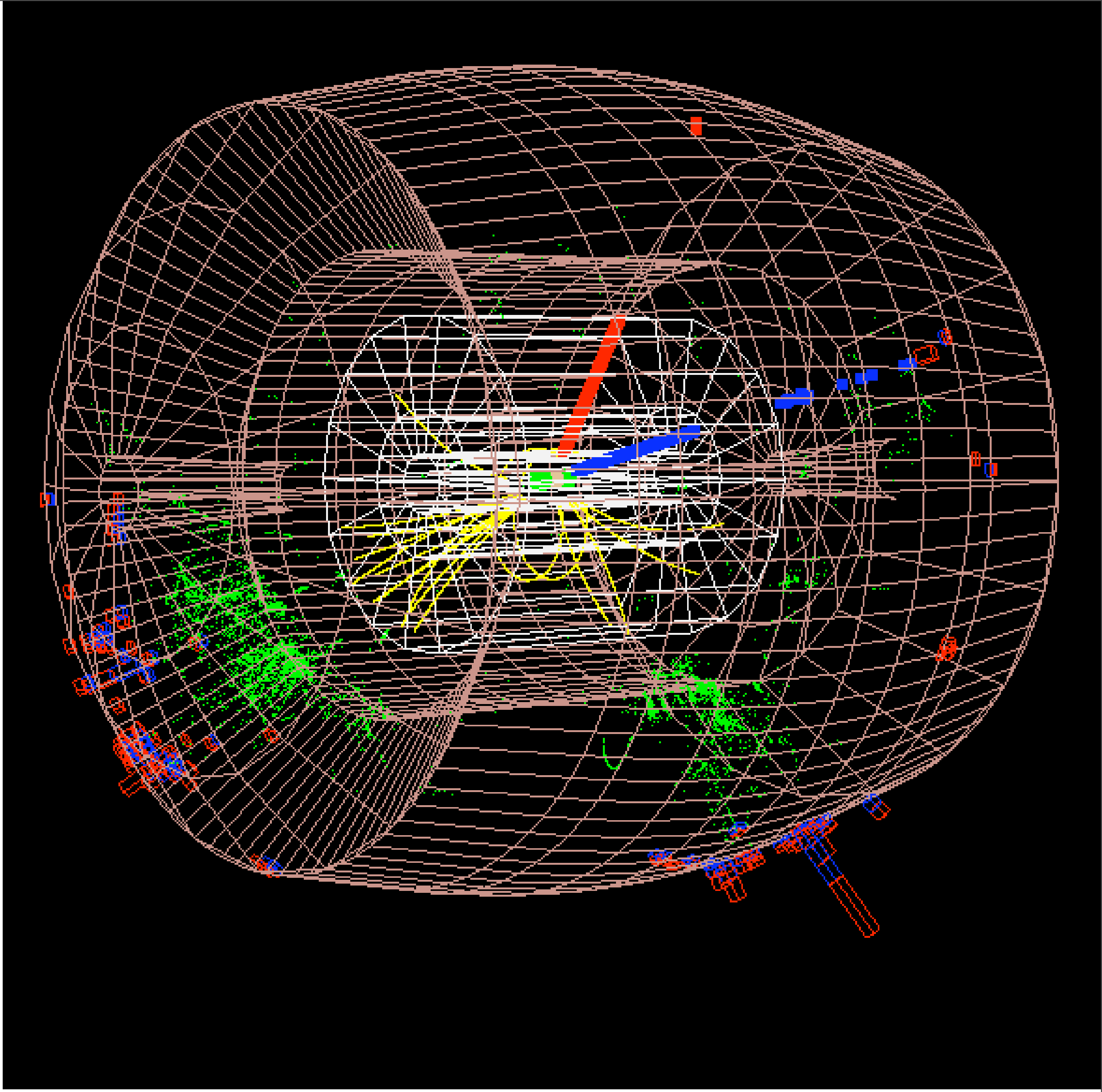
$$e^+e^-$$
$$\to H^0 Z^0$$
$$\to b\bar{b}\mu^+\mu^-$$



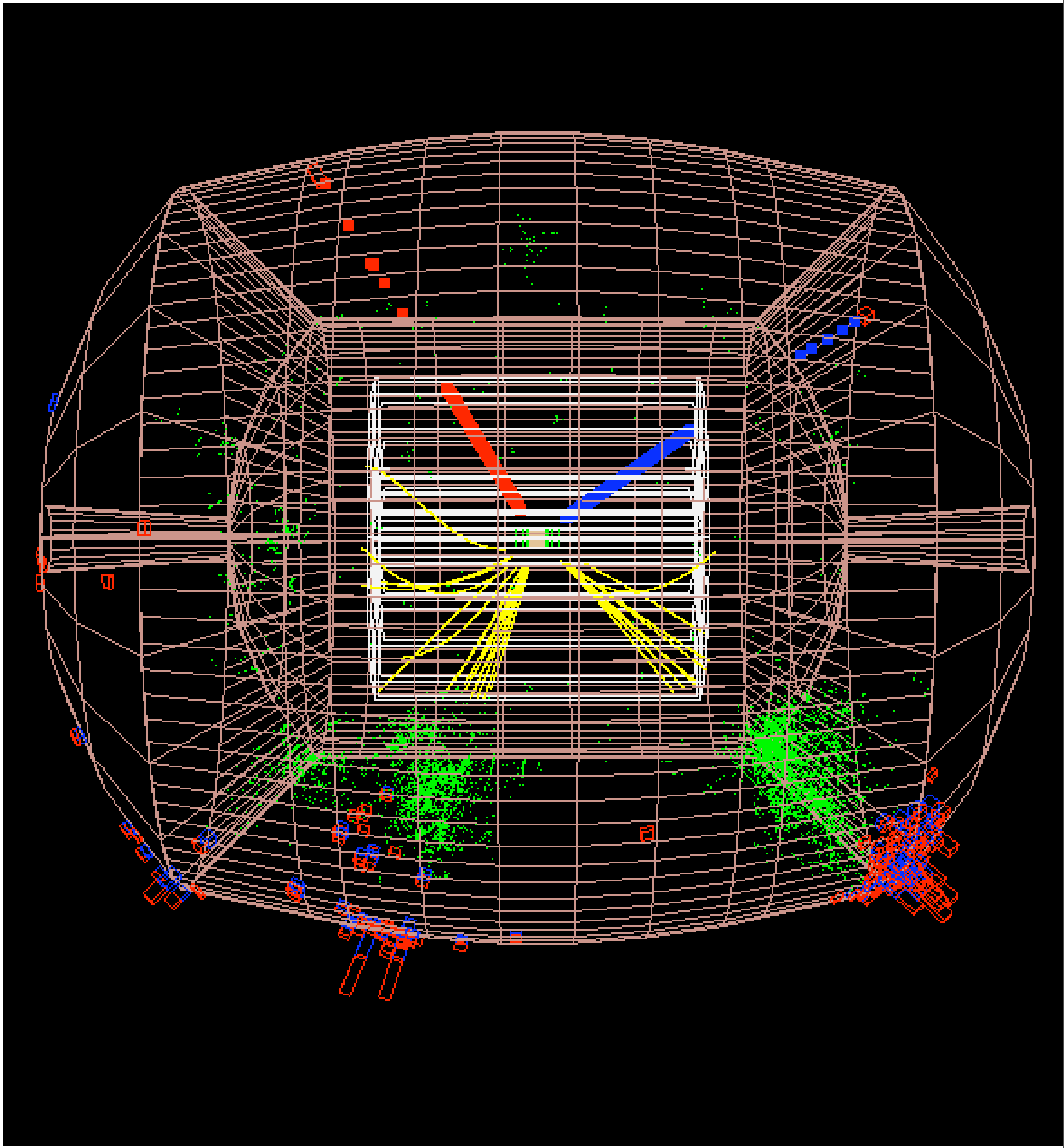
$$e^+e^- \rightarrow H^0 Z^0 \rightarrow b\bar{b}\mu^+\mu^-$$



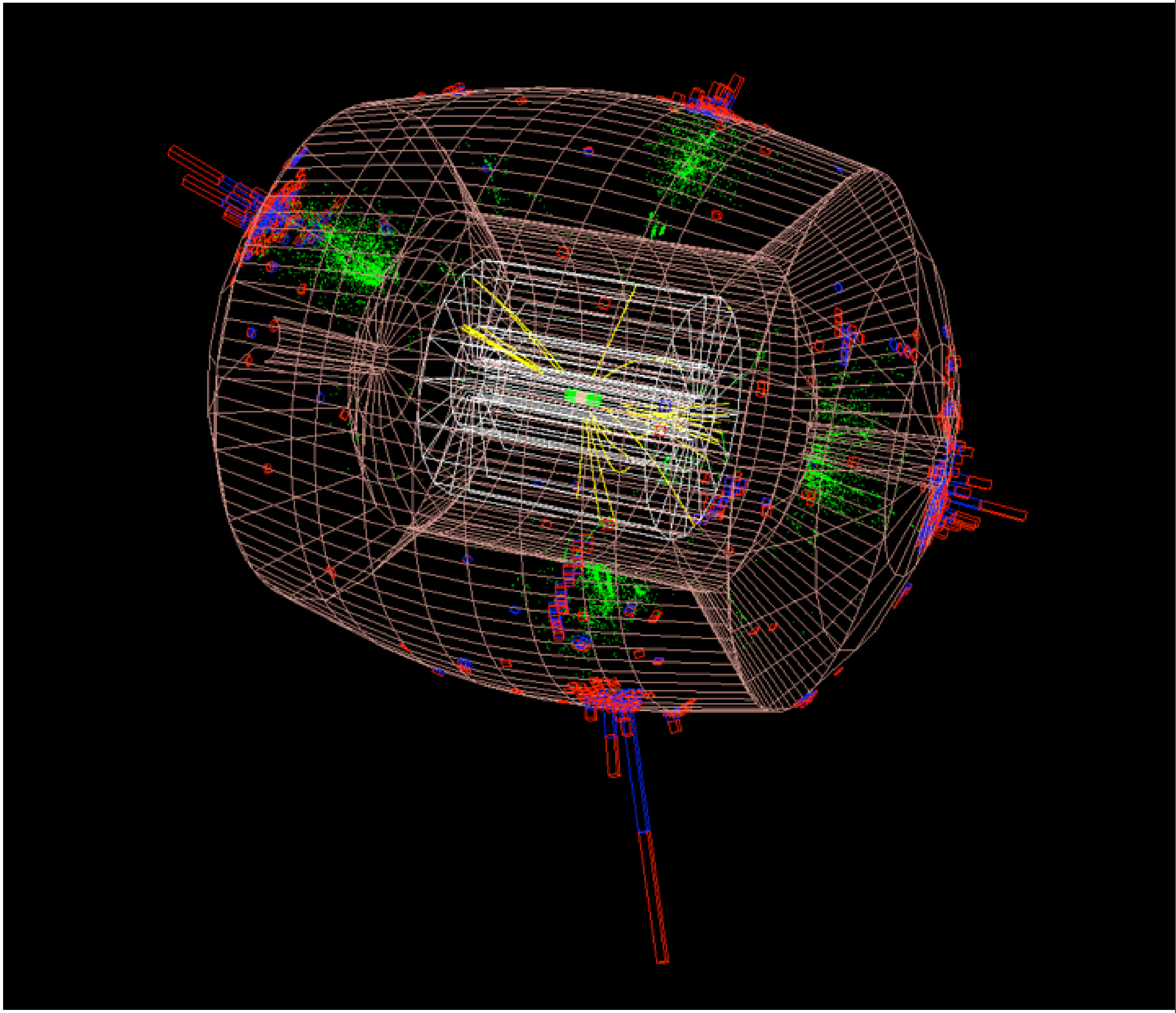
$$e^+e^- \to H^0 Z^0 \to b\bar{b}\mu^+\mu^-$$



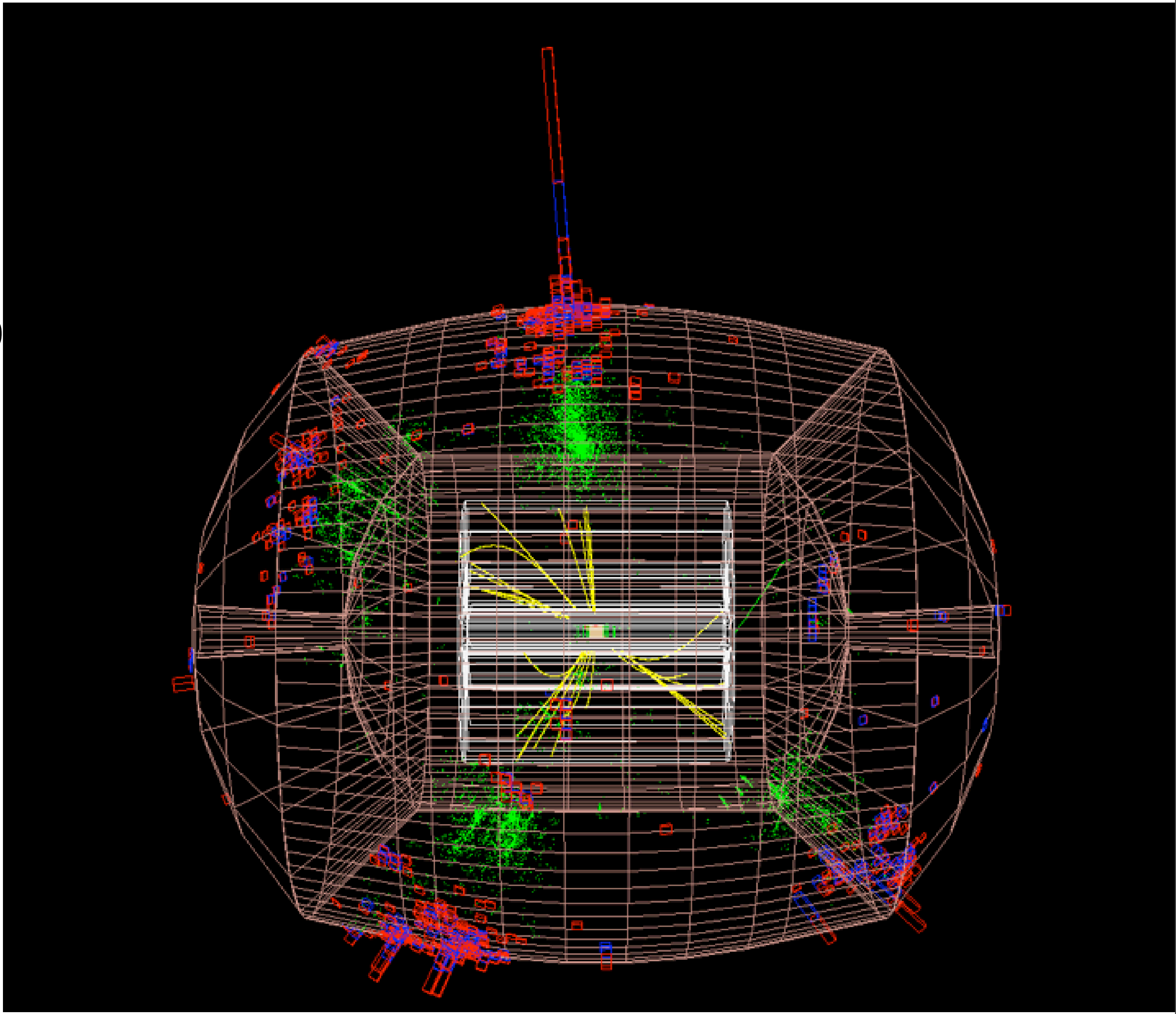
$$e^+e^-$$
$$\rightarrow H^0 Z^0$$
$$\rightarrow b\bar{b}\mu^+\mu^-$$



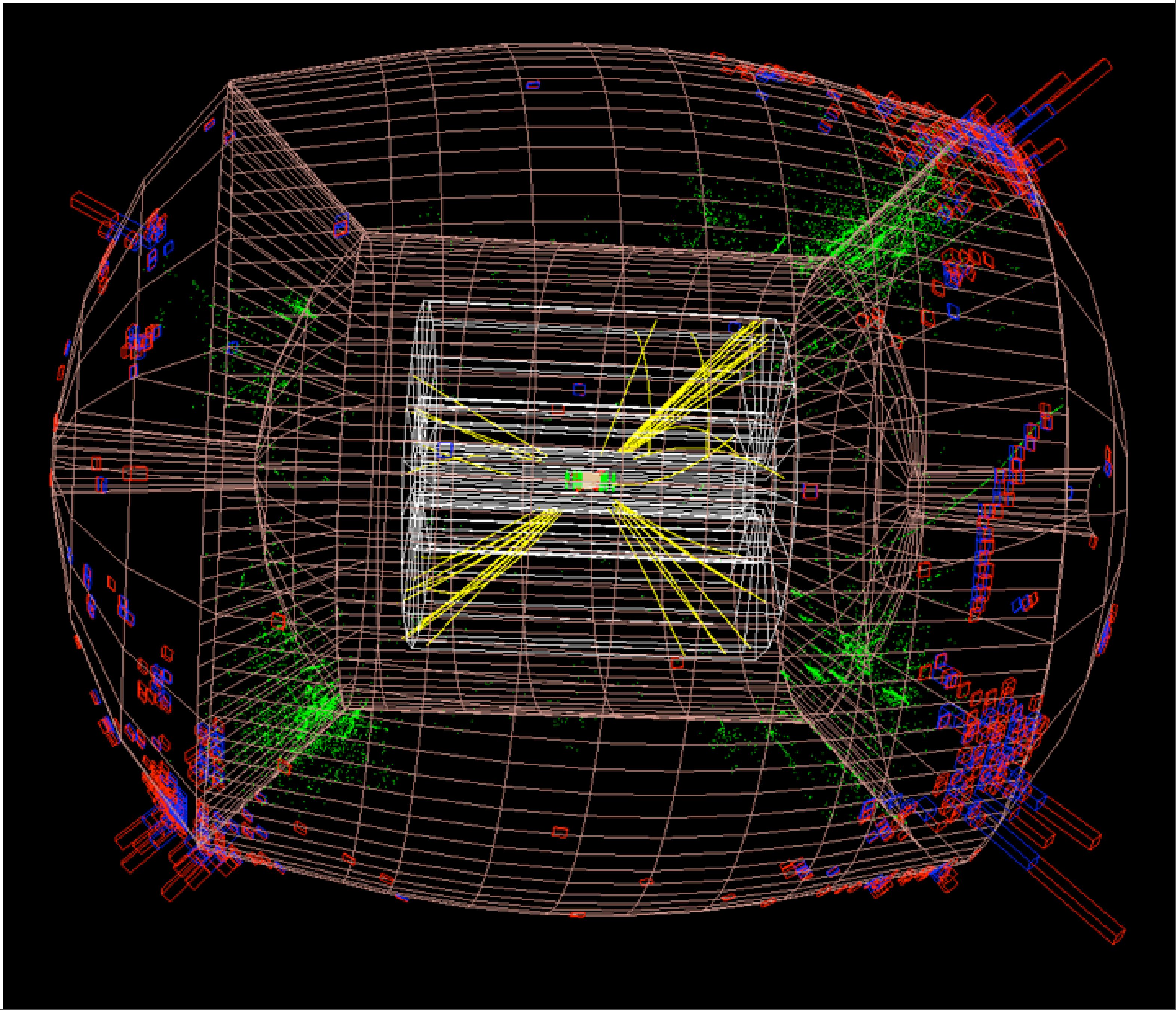
$$e^+e^- \to H^0Z^0 \to b\bar{b}q\bar{q}$$



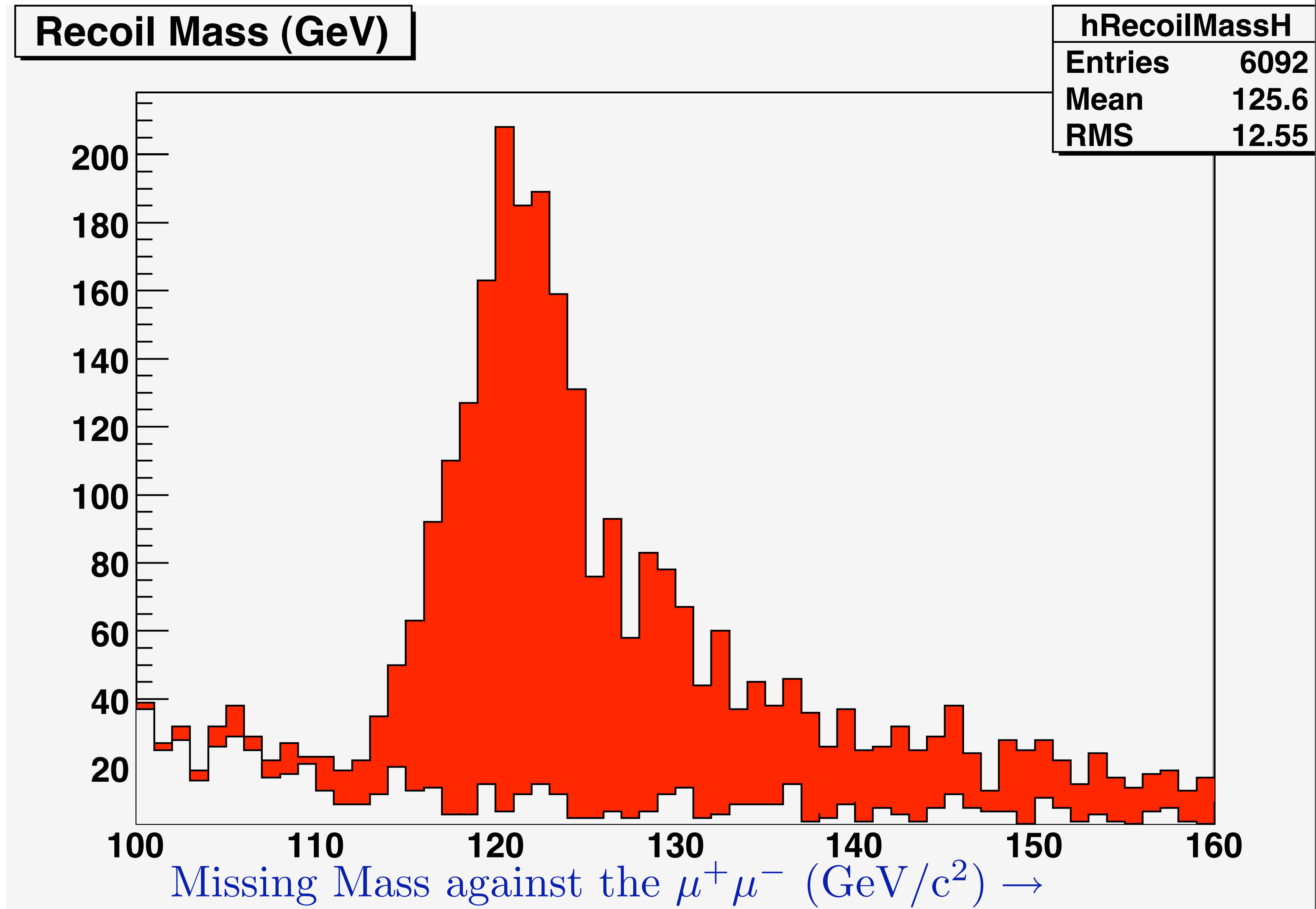
$$e^+e^- \rightarrow H^0 Z^0 \rightarrow b\bar{b}q\bar{q}$$



e^+e^-
$\rightarrow H^0 Z^0$
$\rightarrow b\bar{b}q\bar{q}$



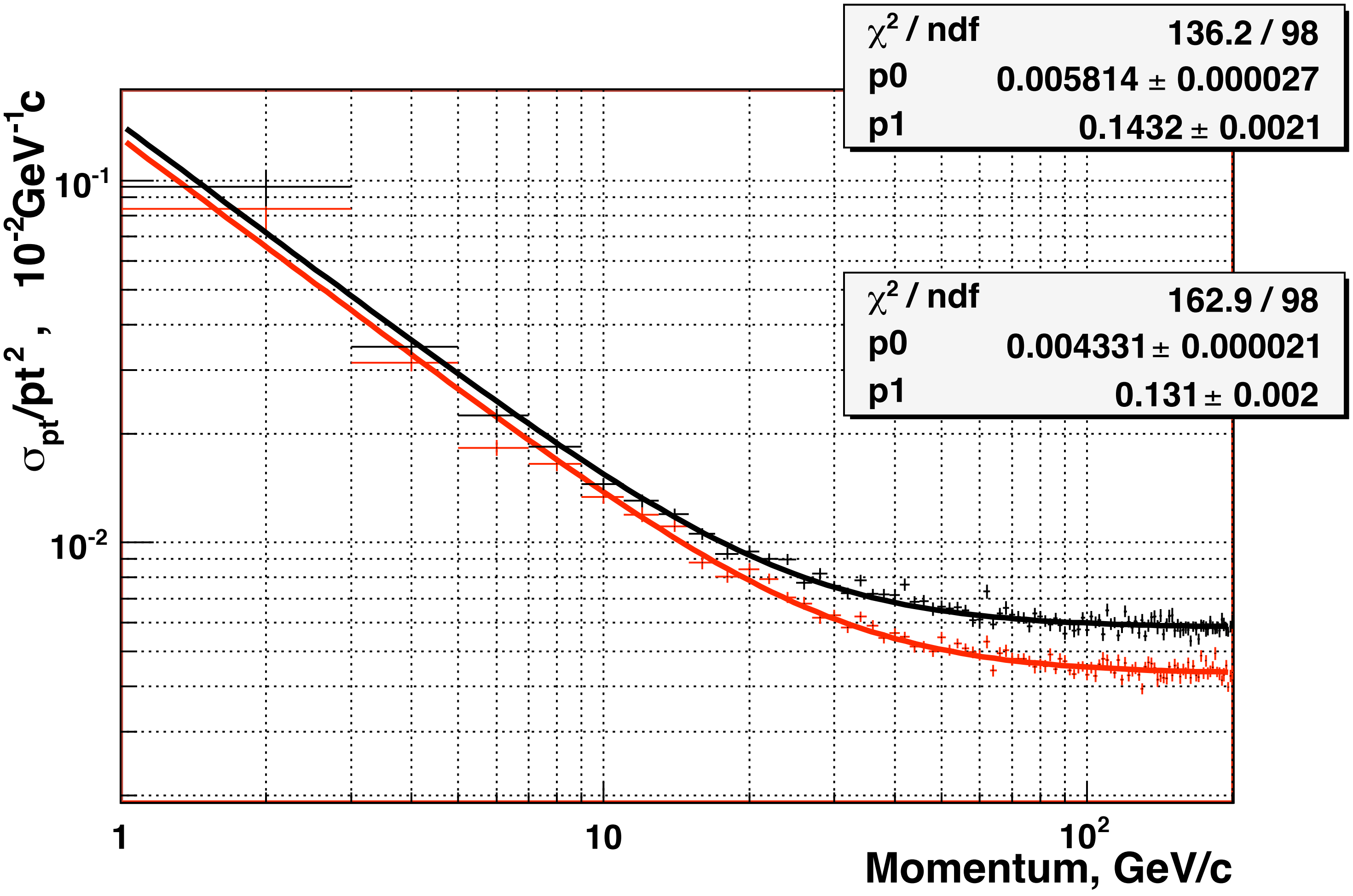
$$e^+e^- \to H^0 Z^0 \to H^0 + \mu^+\mu^-$$



Where to ?   What next ?

- Main ILC detector goal: design and build a detector that is 2-to-10 times better than the already excellent LEP detectors.
- I have not mentioned “physics”. The intent of the 4th Concept is to measure all partons of the standard model with high precision, say, 1-2% in four-vector components. Having accomplished this, all physics is accessible.
- About six months from now, these four concepts will merge into two concepts--presumably the two future detectors at the ILC. This will be tricky.
- We are small (a mouse in a room with three elephants), having fun with new ideas, and have about two years to think-optimize-finalize the design.

spares...



χ^2 / ndf 136.2 / 98
p0 0.005814 ± 0.000027
p1 0.1432 ± 0.0021
χ^2 / ndf 162.9 / 98
p0 0.004331 ± 0.000021
p1 0.131 ± 0.002
σ_{pt}/pt^2, $10^{-2}GeV^{-1}c$
10^{-1}
10^{-2}
1
10
10^2
Momentum, GeV/c

Toroid for low angle tracks