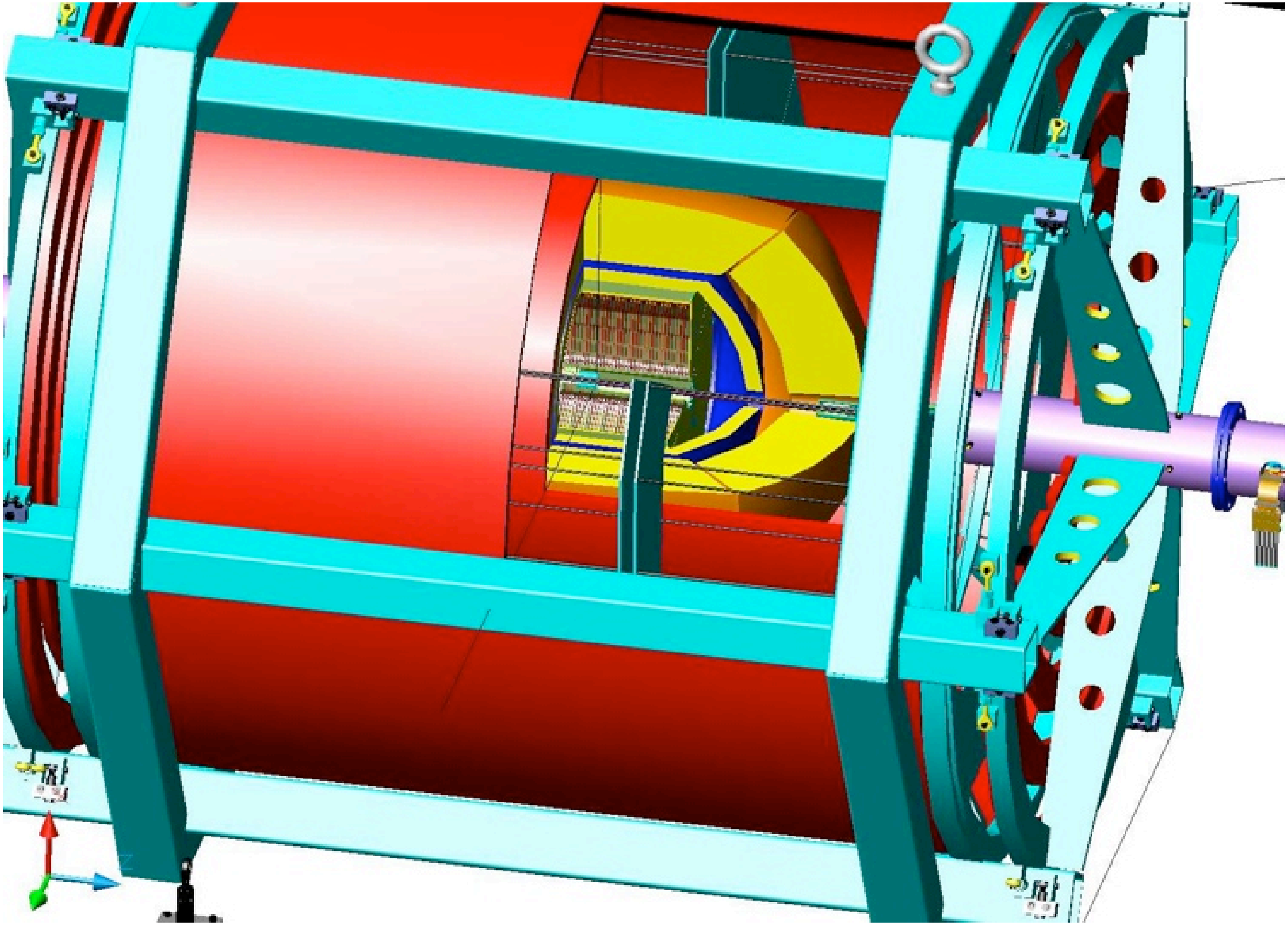
4th Concept detector: Pixel vertex-TPC-triple readout calorimeter-dual solenoid(no iron)-beam delivery

(J. Hauptman, BILCWS7, 4-7 February 2007)



4th Concept People

~1/3 Asia, ~1/3 US, ~1/3 Europe

Mostly orthogonal to other three concepts

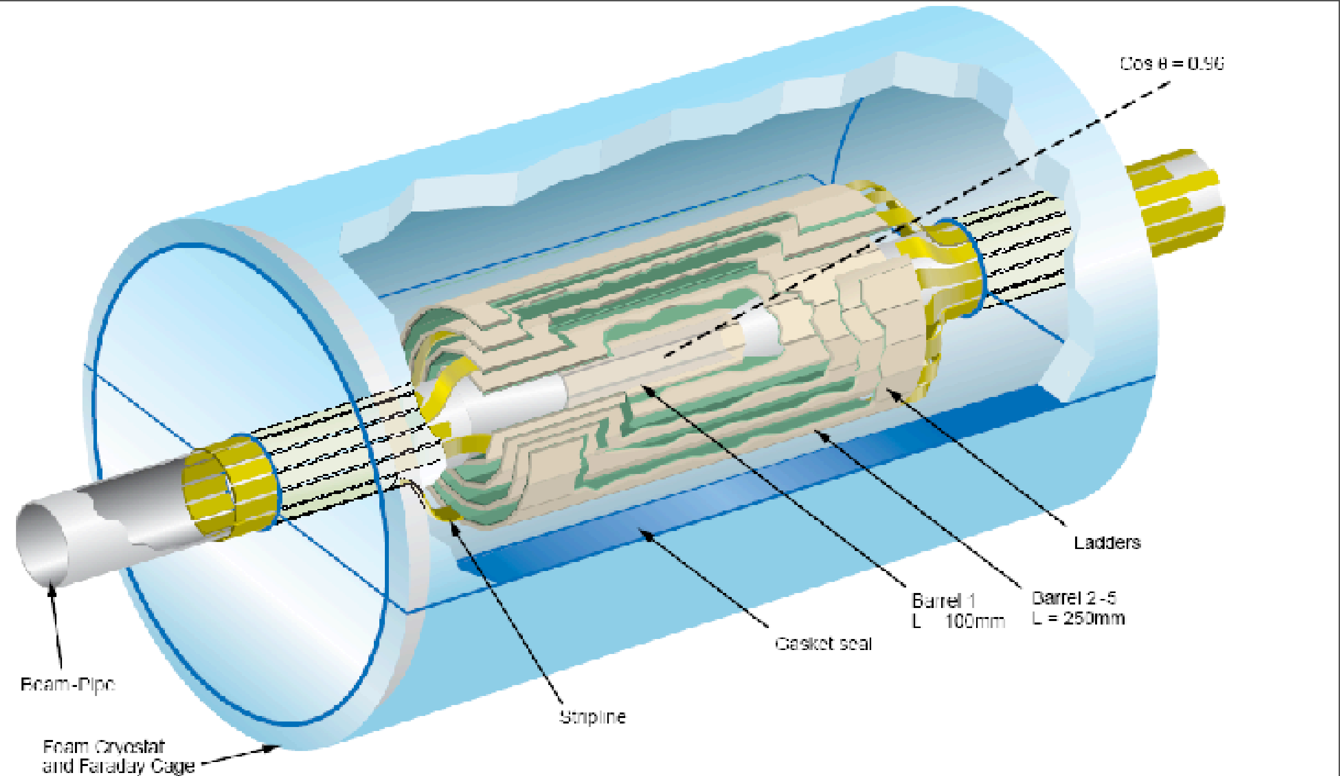
Basic design principle: only four basic, powerful systems, each as simple as possible. Obviate any need for tail-catchers, pre-showers detectors, end-cap chambers, or silicon blankets to augment performance of main detector.

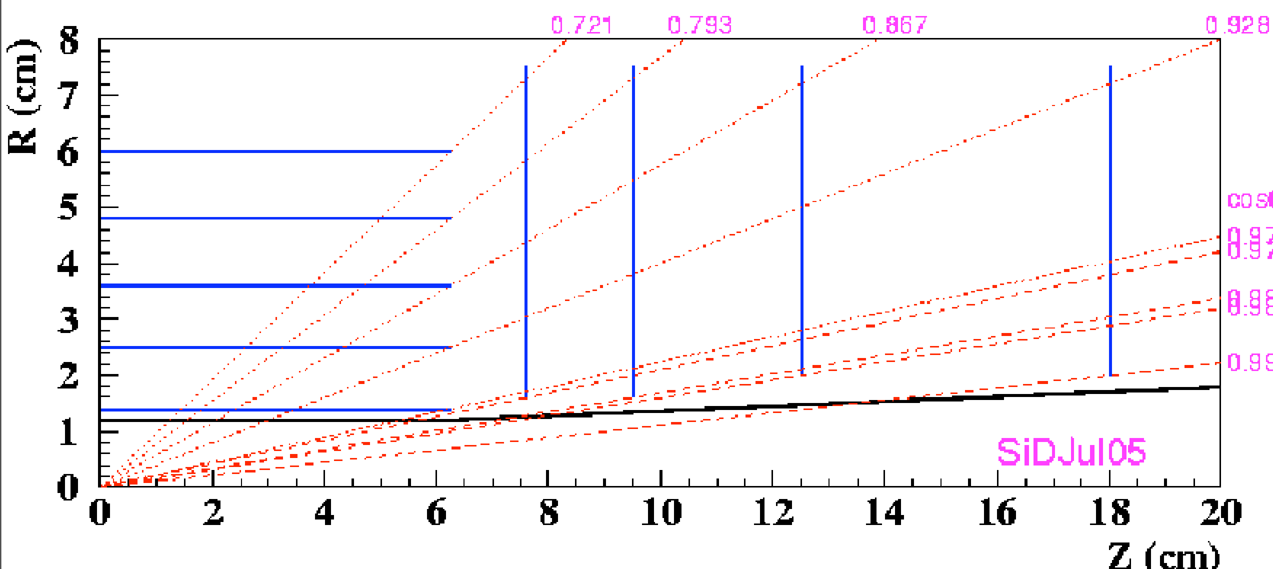
- Pixel Vertex (PX) 20-micron pixels (like Fermilab/SiD thin pixel)
- TPC (like GLD or LDC) “gaseous club sandwich” (Paul Colas)
- Triple-readout fiber calorimeter: scintillation/Cerenkov/neutron (new)
- Muon dual-solenoid iron-free geometry (new), cluster counting (new)

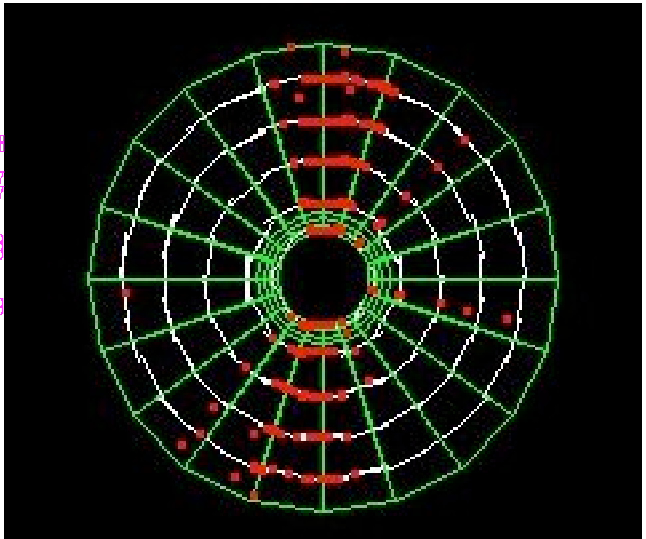
Measure *all* partons with high precision

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

New pixel vertex detector: SiD / Fermilab

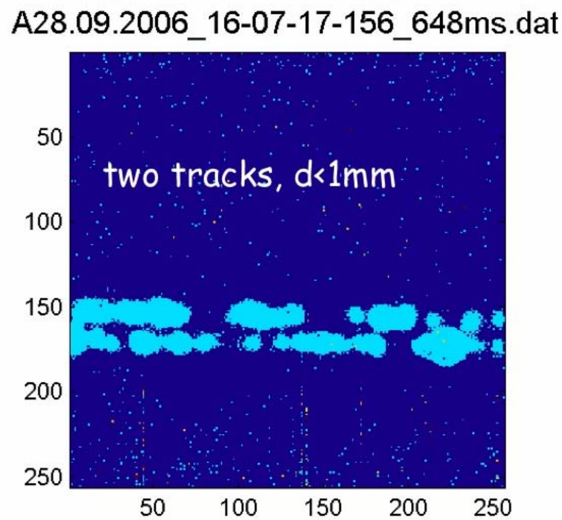


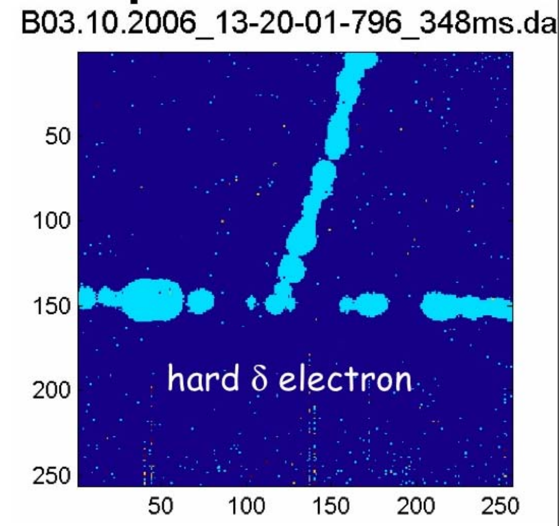


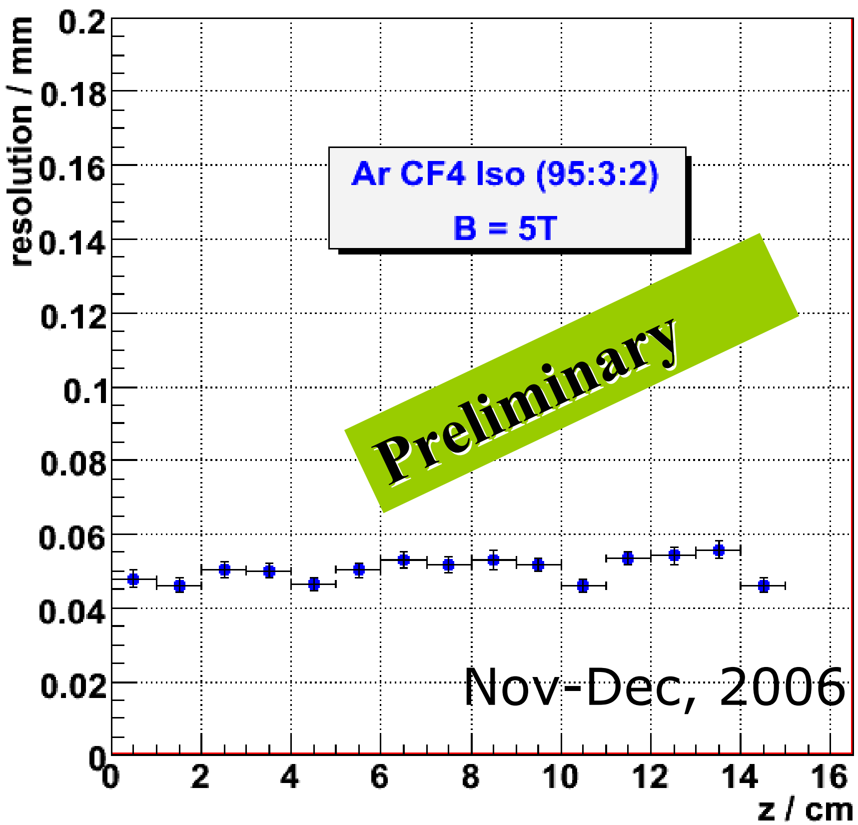


New TPCs

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

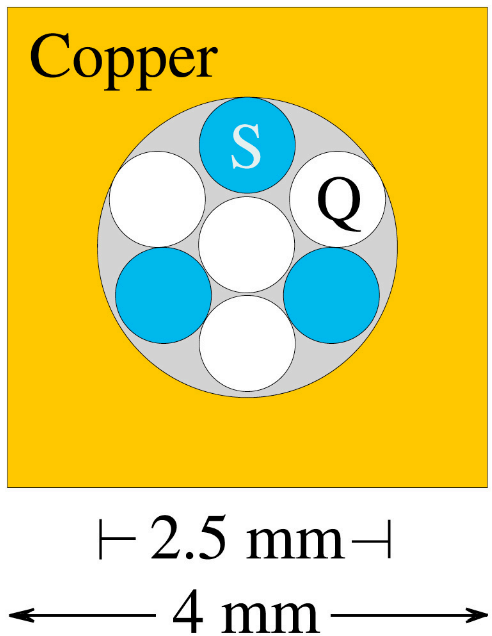






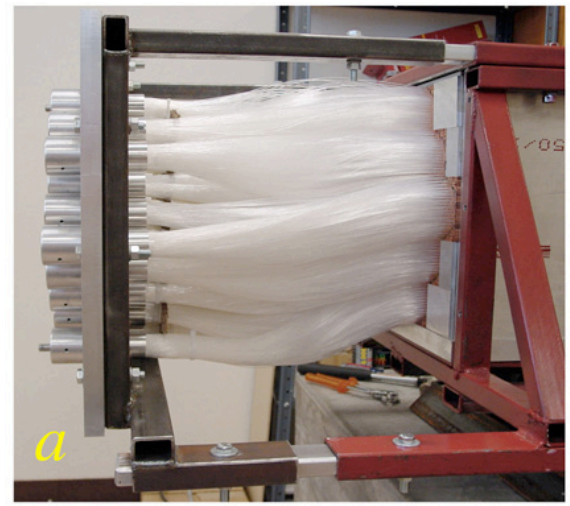
~ 50 μm av. resolution (diffusion negligible over 15 cm)
100 μm over 2 meters appears feasible
(~ 30 μm systematics Aleph TPC experience)

Calorimeter is new: a “dual readout” fiber calorimeter to measure EM fraction fluctuations, first developed by R. Wigmans

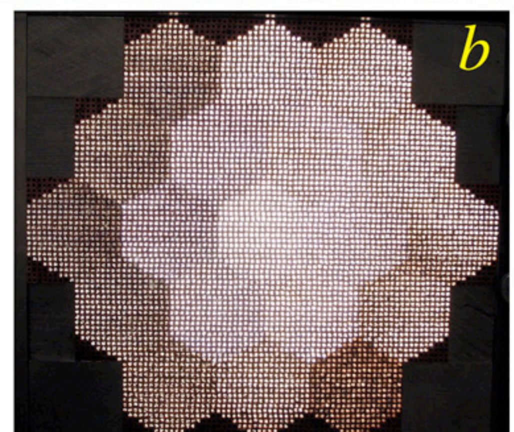


Unit cell

Back end of 2-meter deep module

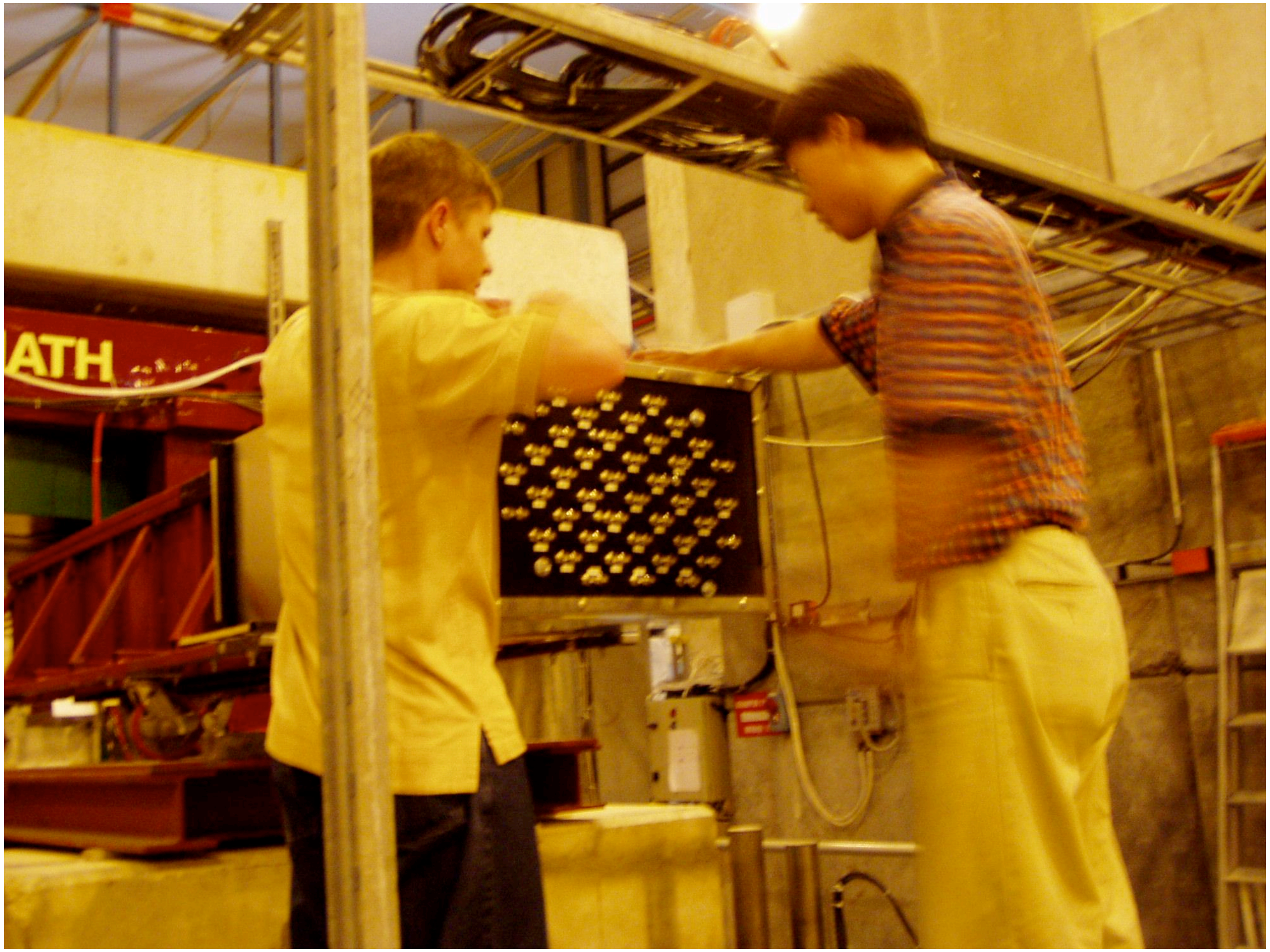


Physical channel structure



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*

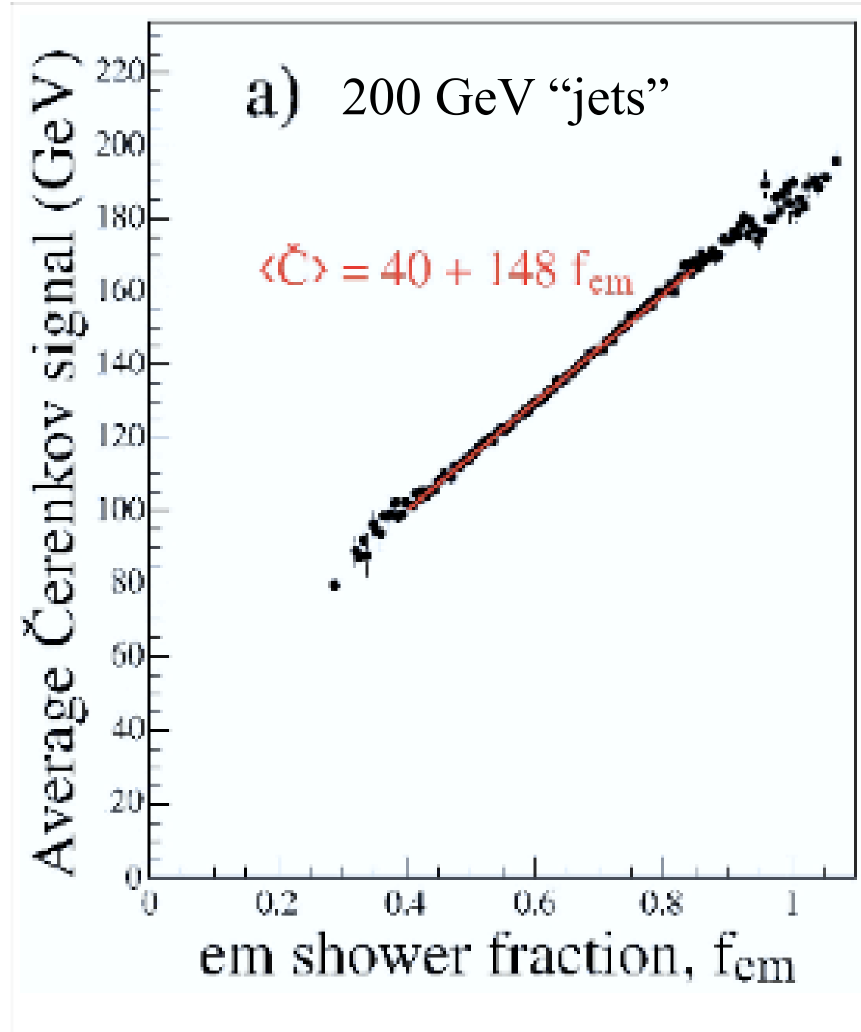
Cerenkov: predominantly *e* from *photon showers* from *pi-zeros*

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

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

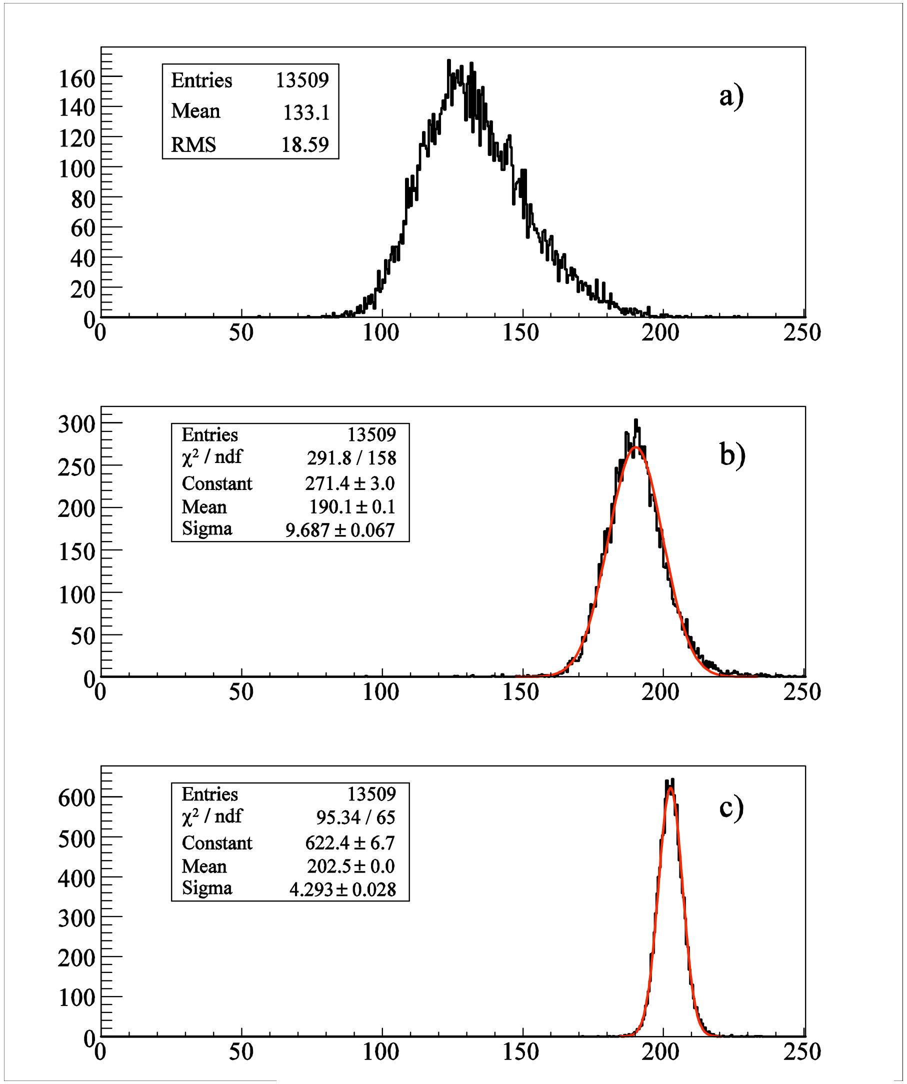
$$C = [f_{em} + (1 - f_{em})/\eta_C]E$$
$$S = [f_{em} + (1 - f_{em})/\eta_S]E$$

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



Data NIM A537 (2005) 537.

DREAM data 200 GeV π^-: Energy response



Scintillating fibers only

Scintillation + Cerenkov

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

(4% leakage fluctuations)

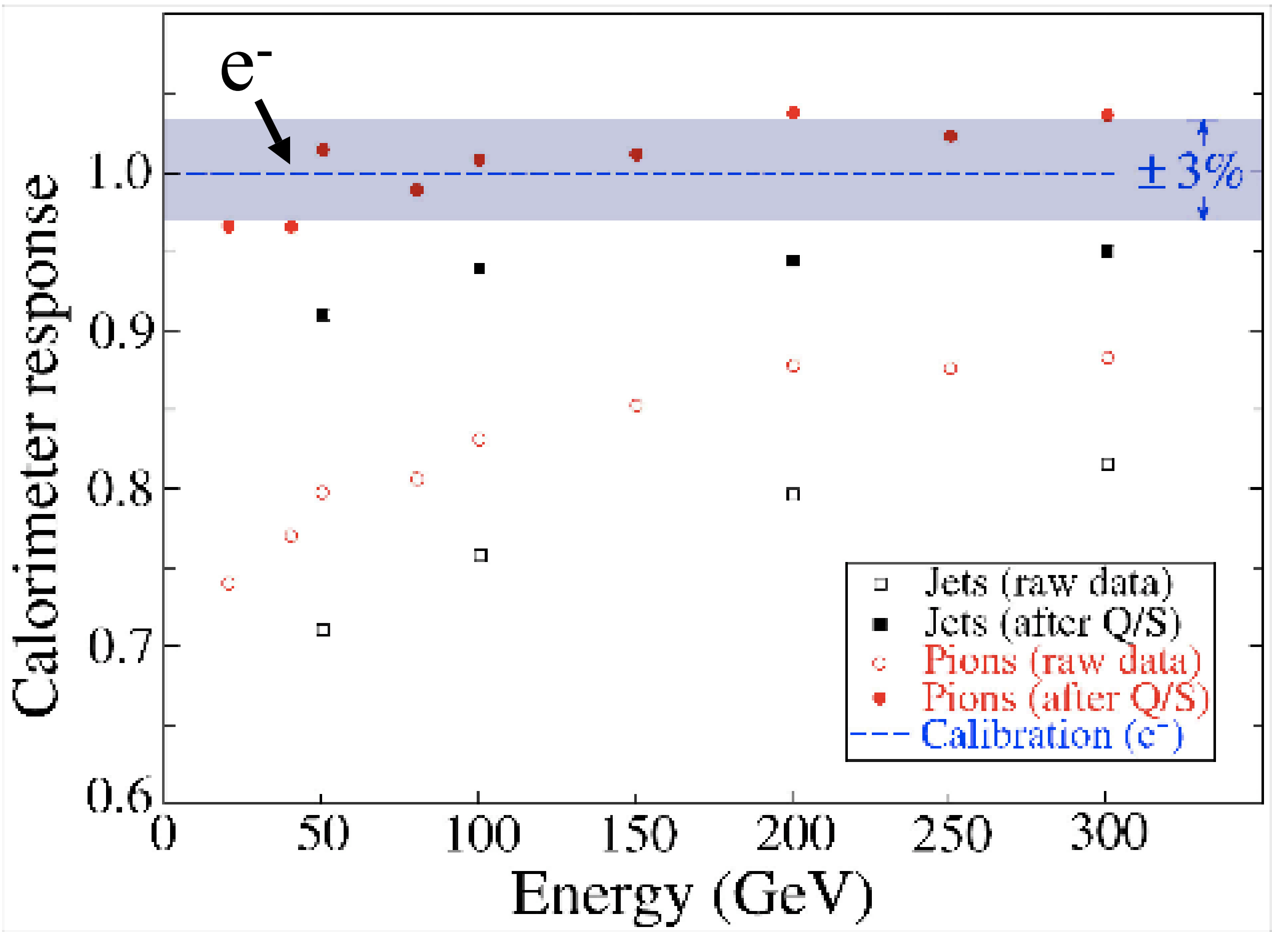
Scintillation + Cerenkov

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

(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.

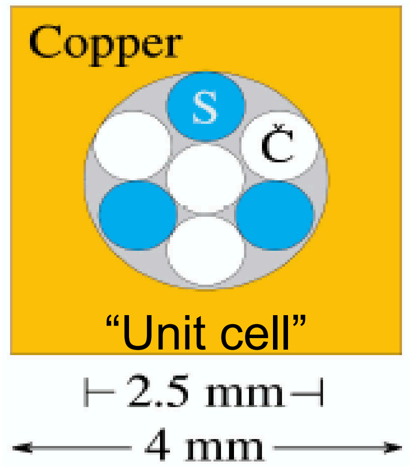
ILC

Data NIM A537 (2005) 537.

Go after the neutrons, improve geometry, make it scalable

DREAM module

3 scintillating fibers
4 Cerenkov fibers

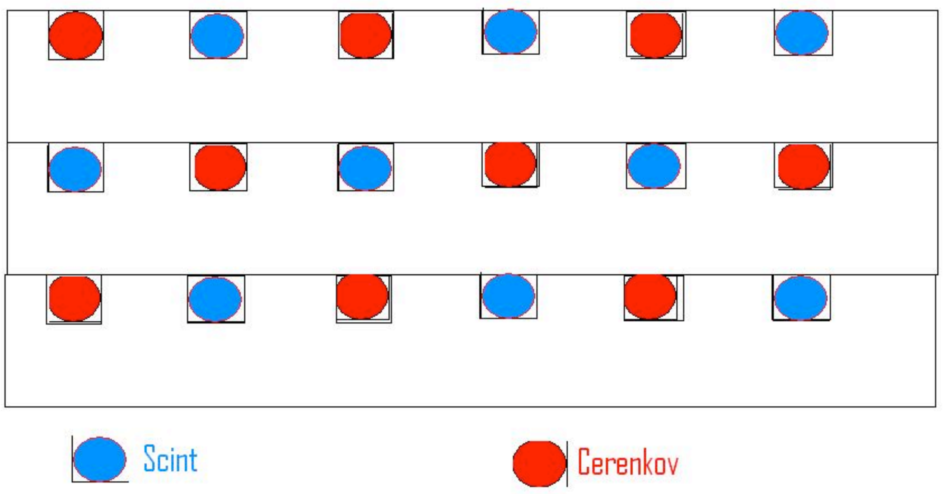


→

ILC-type module

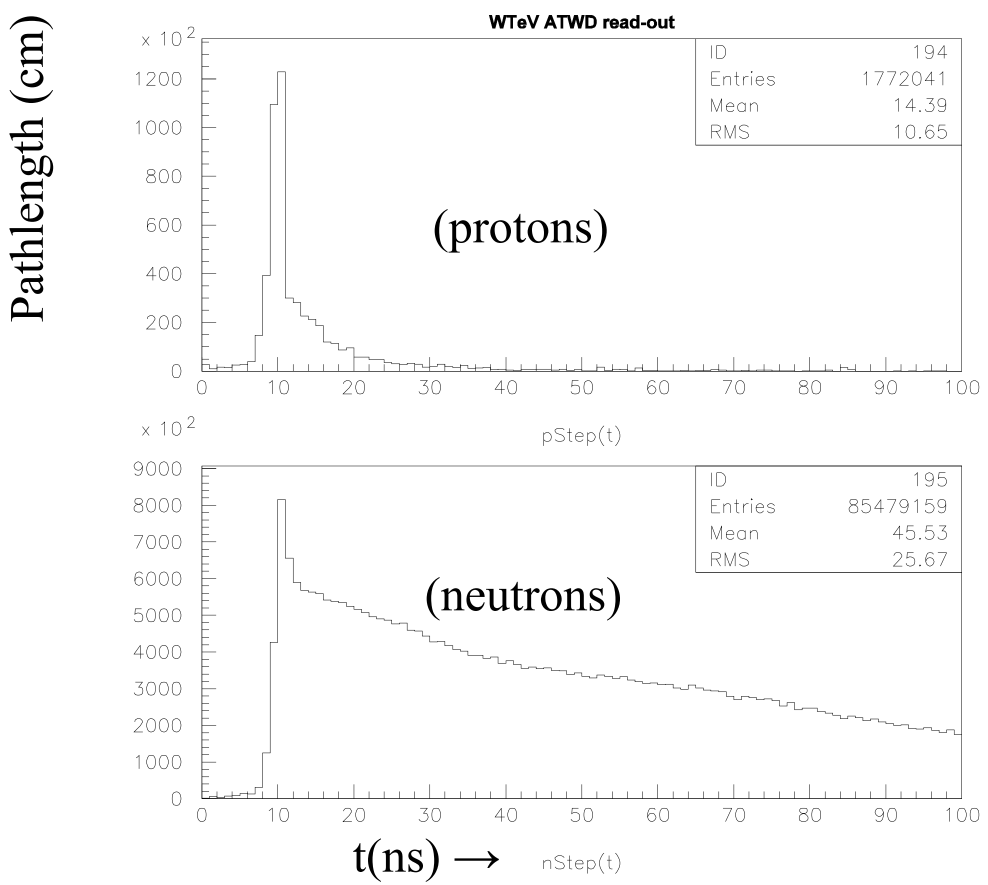
2mm Pb or brass plates;
fibers every 2 mm

(Removes correlated fiber hits)



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

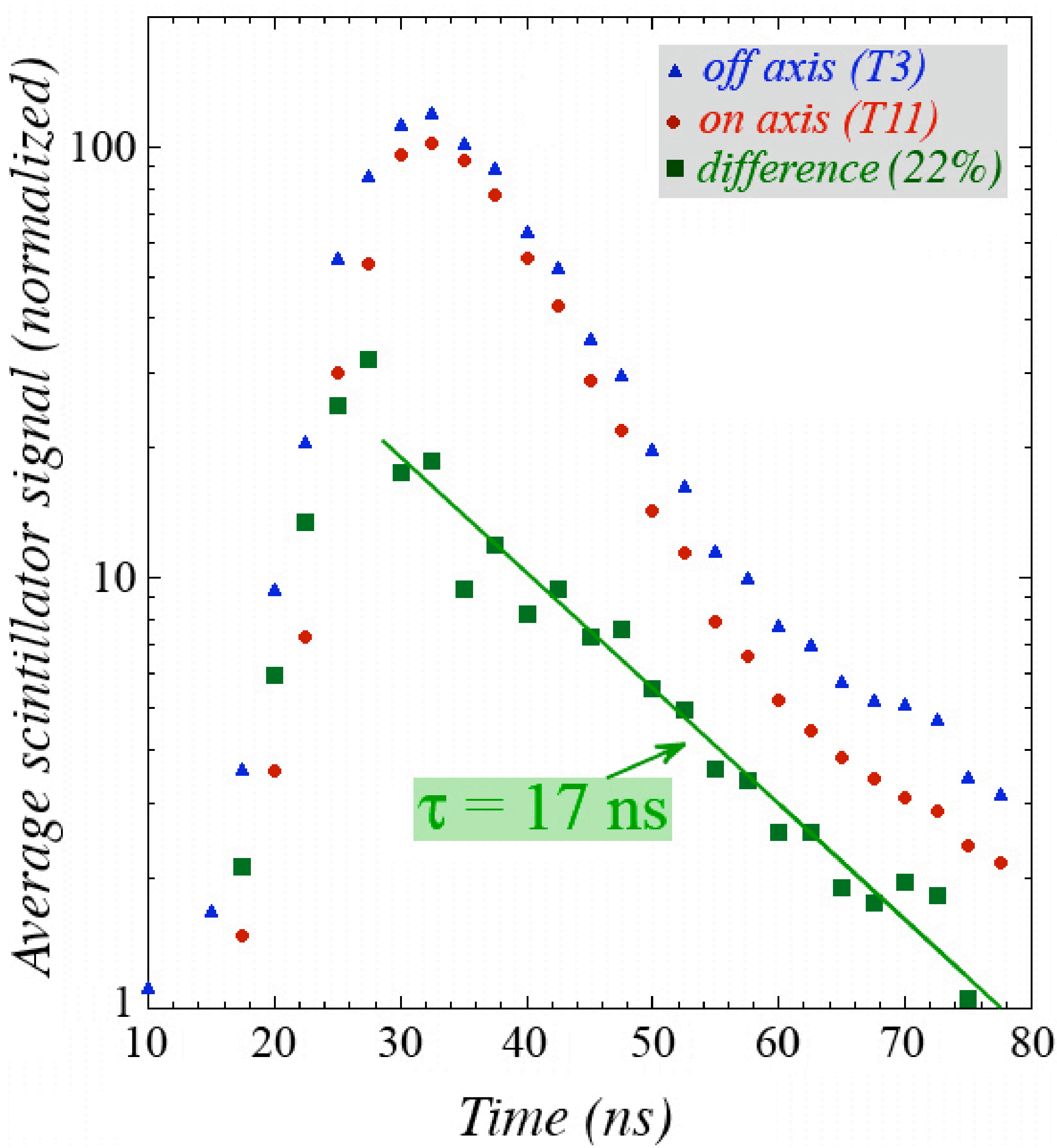
- Birk's constant parameterizes the reduction in detectable ionization from heavily ionizing particles (essentially due to recombination)
- Use two scintillating fibers with widely different Birk's constants.
- Two problems: (i) hard to get a big difference, and (ii) neutron content depends on the difference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

LCRD $10K- measure neutrons:

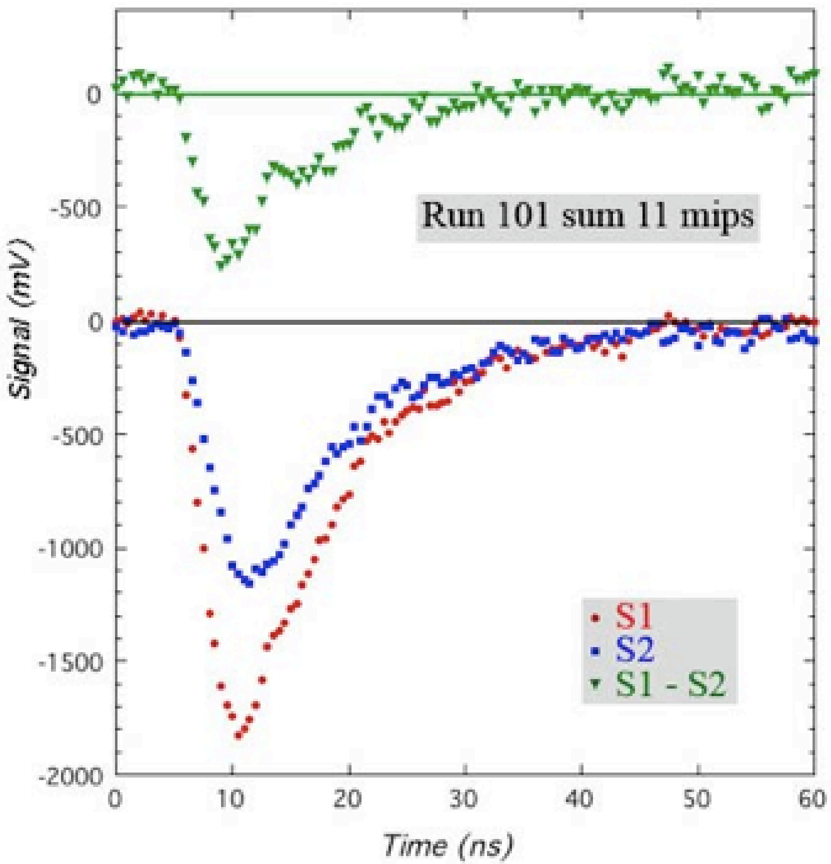
pions into one channel, clock out neighboring channel

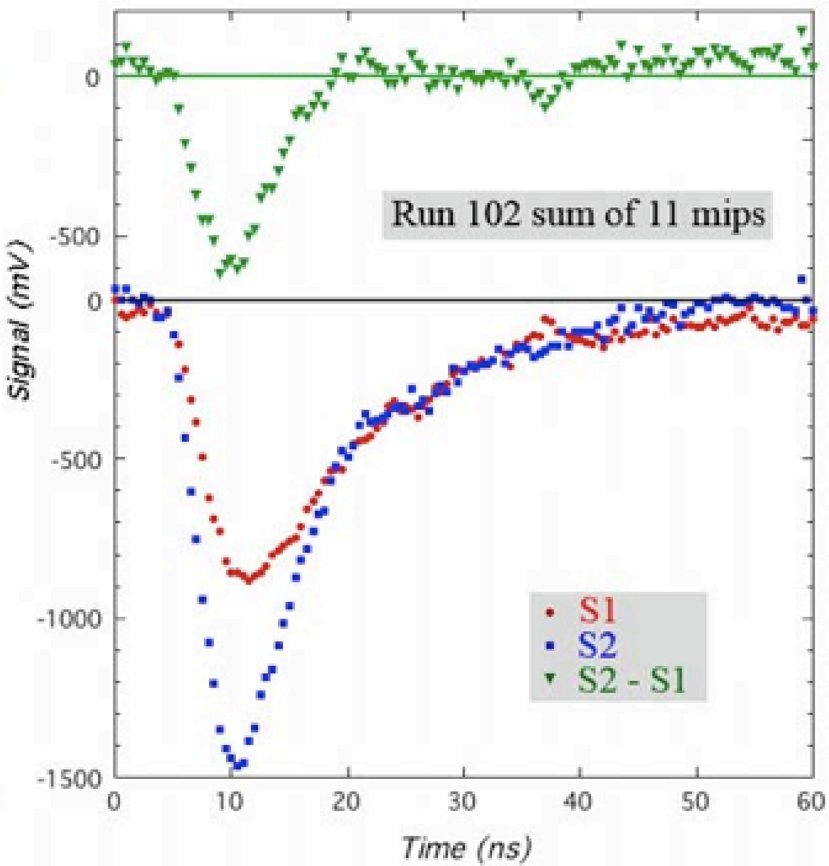
Also, test dual readout of a single crystal

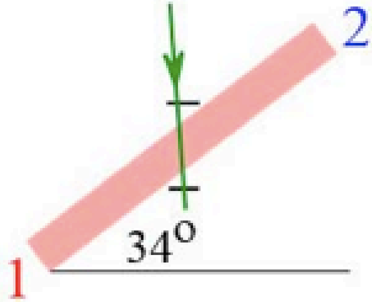
(CERN test, Oct 2006)



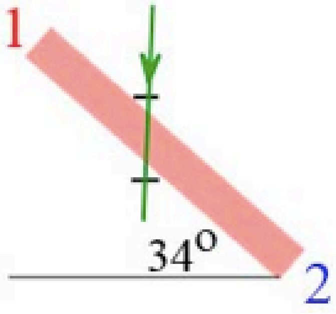
Time structure of cosmic ray events in $PbWO_4$ ($\Delta E = 25$ MeV)



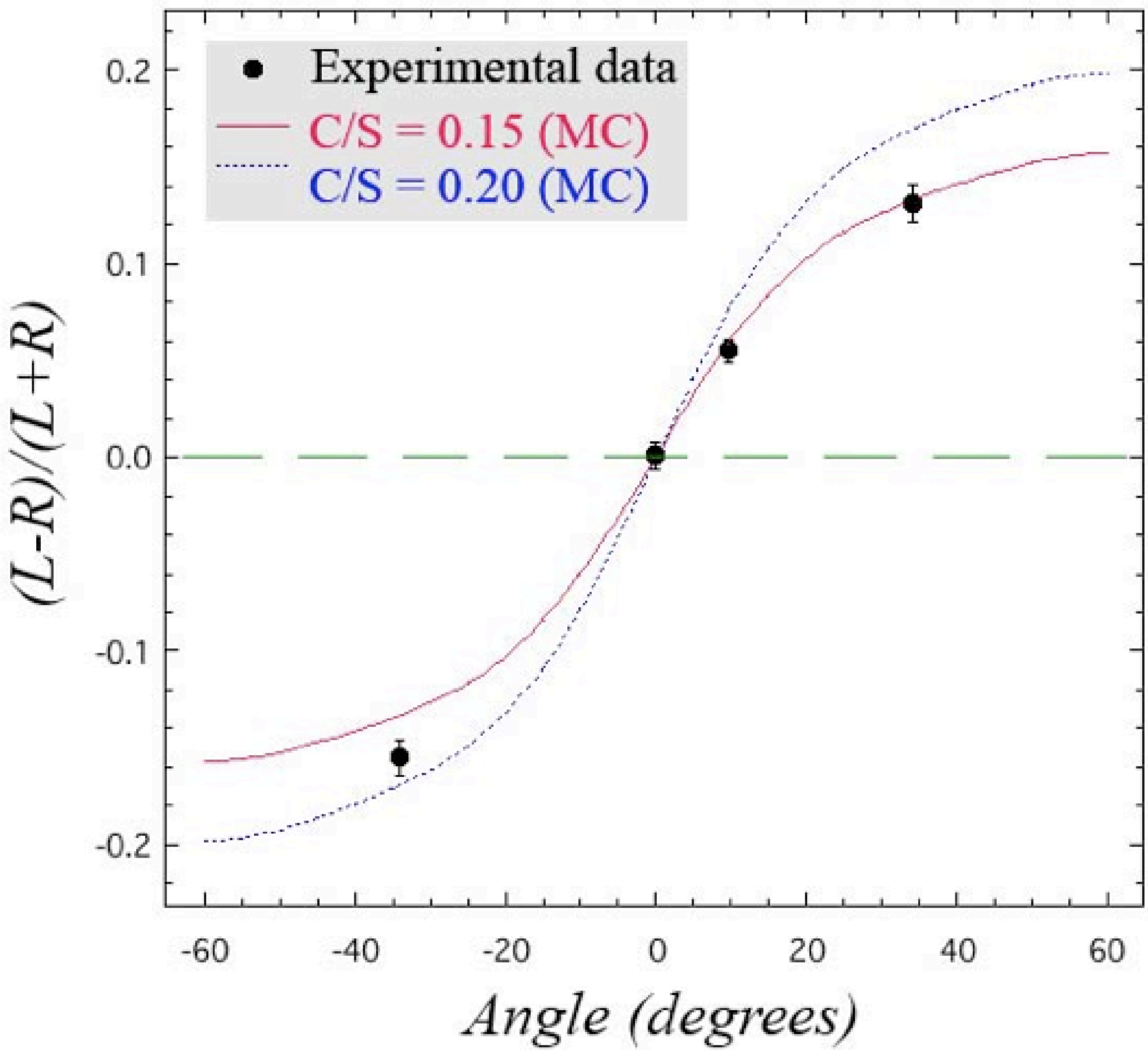




Slope *dL/dt*
measures C/S



Experimental results, light directionality in $PbWO_4$



“Ultimate calorimetry” ?

The theoretical limit (Wigmans) for hadronic energy resolution is

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

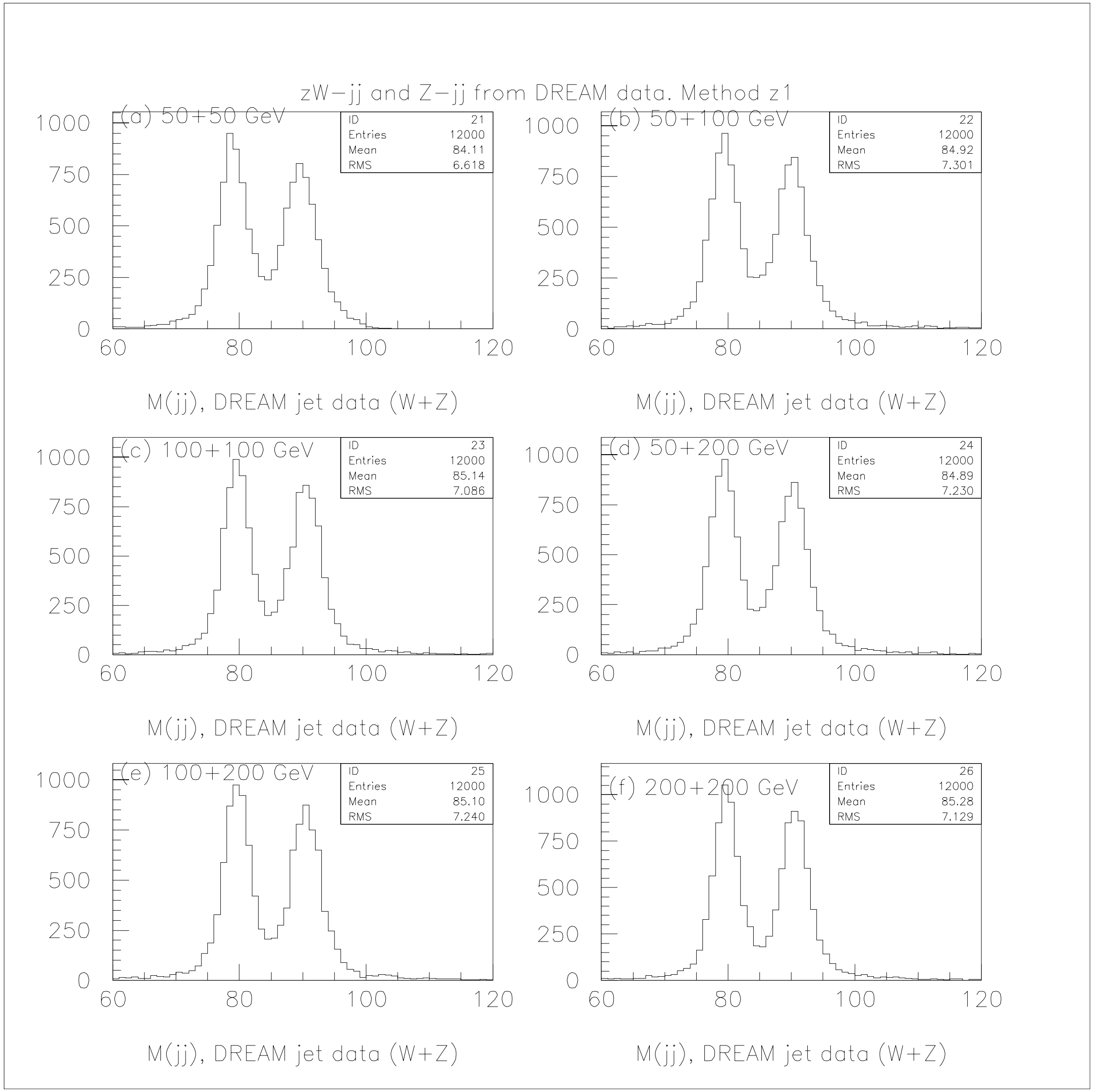
when leakage, EM fraction fluctuations and binding energy loss fluctuations are suppressed. We would be happy to achieve

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

in a test module.

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

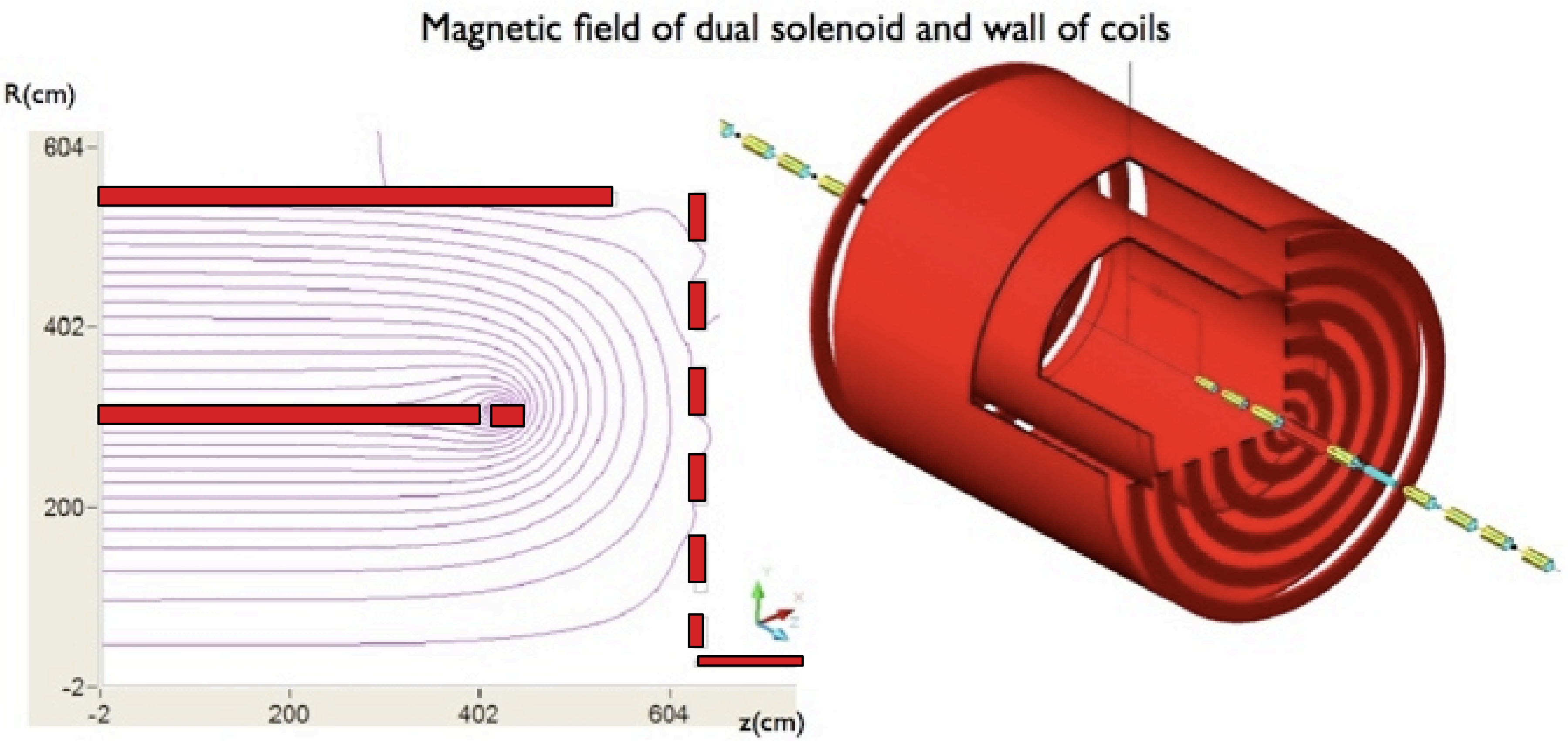
Both jets are sampled from DREAM data with measured spatial and energy fluctuations

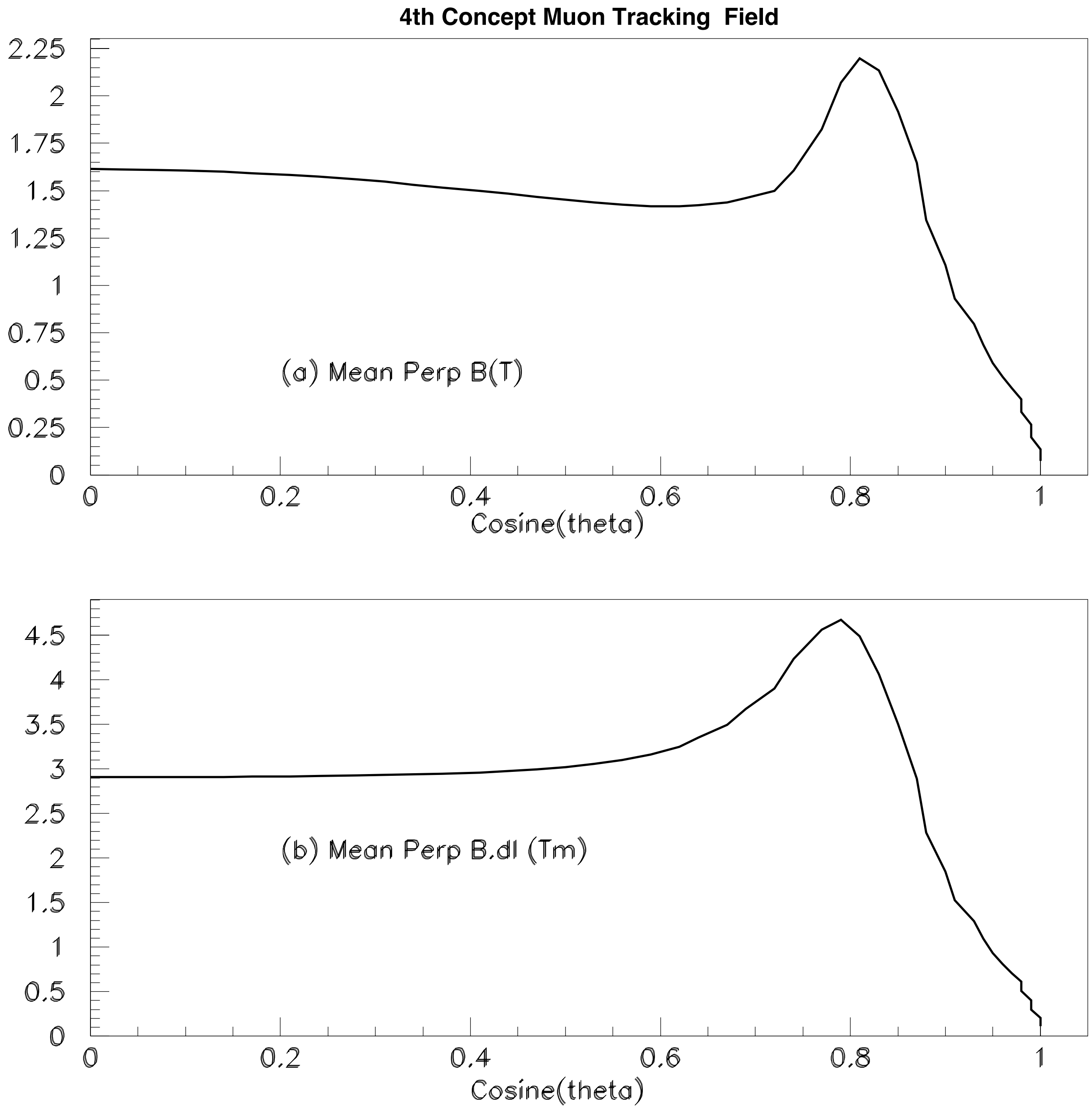


Dual solenoid: scientific advantages

- 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 ...

New magnetic field, new ``wall of coils", iron-free:
many benefits to muon detection and MDI,
Alexander Mikhailichenko design

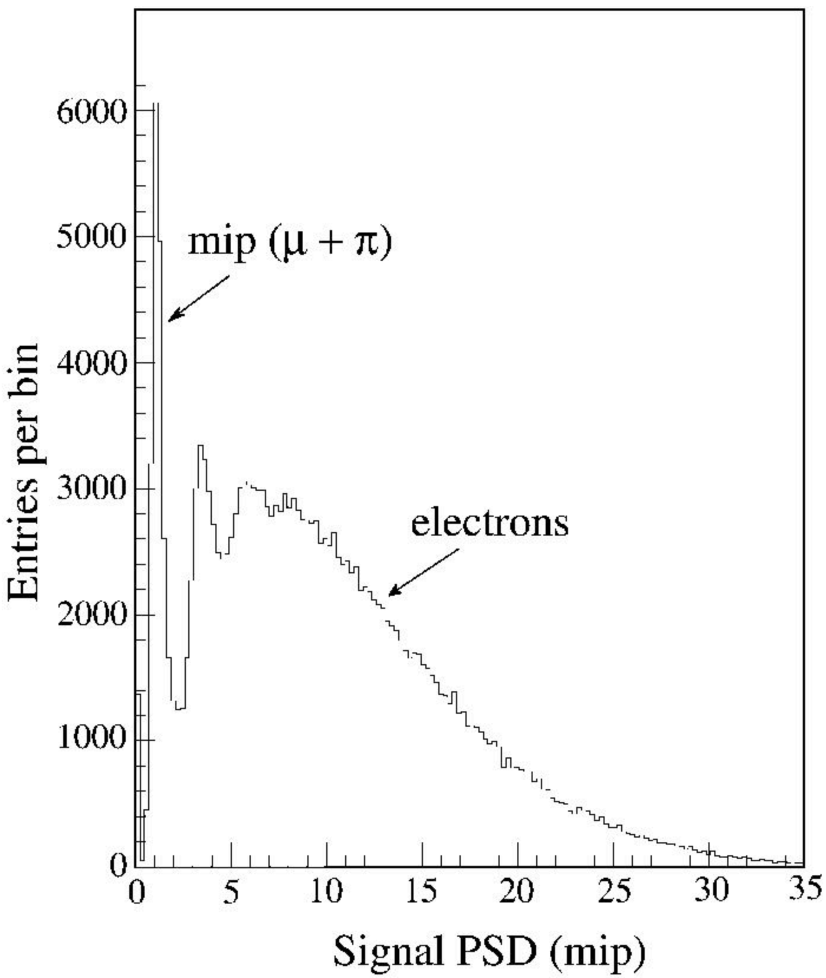


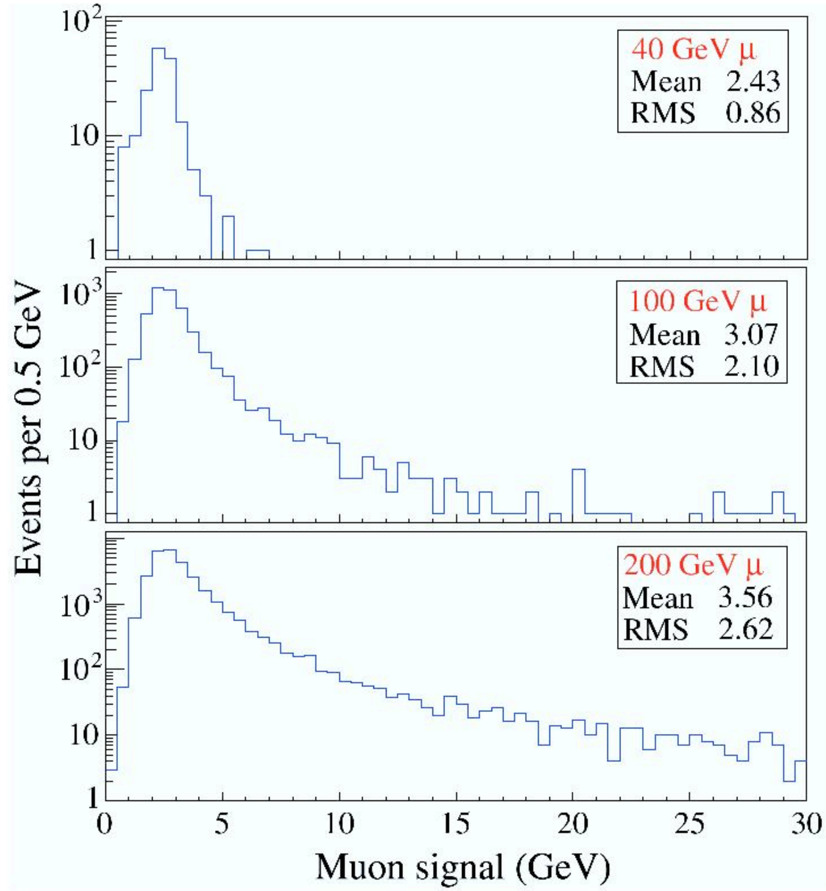


Dual solenoid

tracking along muon trajectories in the annulus between solenoids.

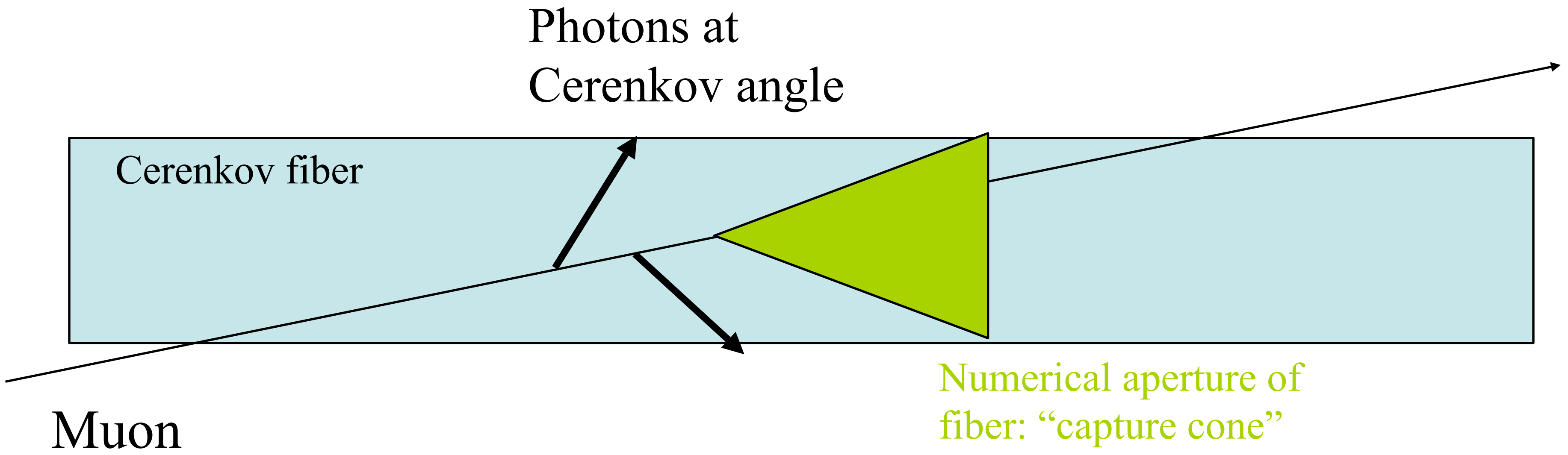
cluster counting drift tubes for muon tracking.





NIM A533 (2004) 305-321.

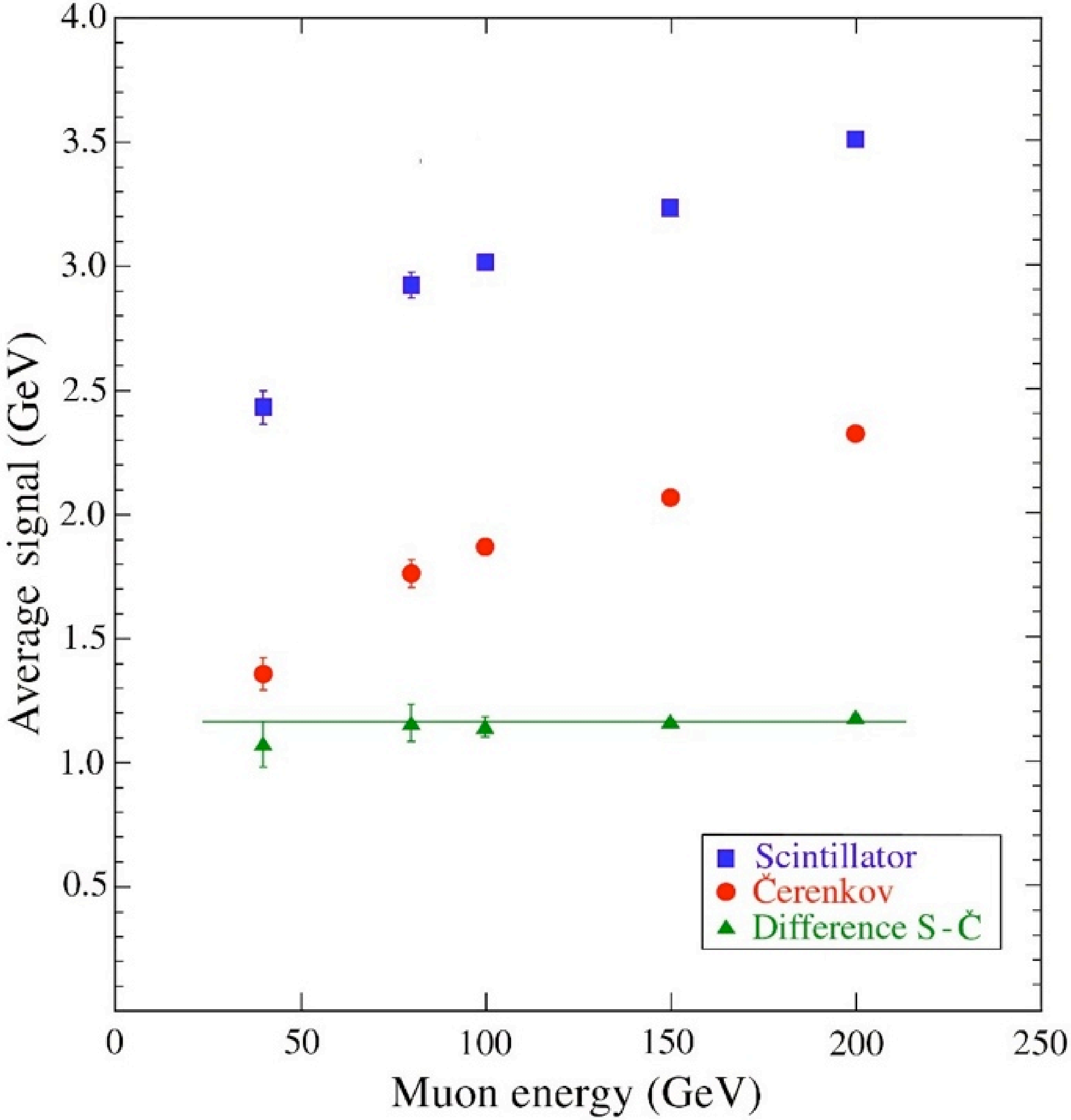
The Cerenkov signal from an aligned, non-radiating muon is zero



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

$C \sim 0$ $S \sim dE/dx$

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



S = dE/dx + radiation

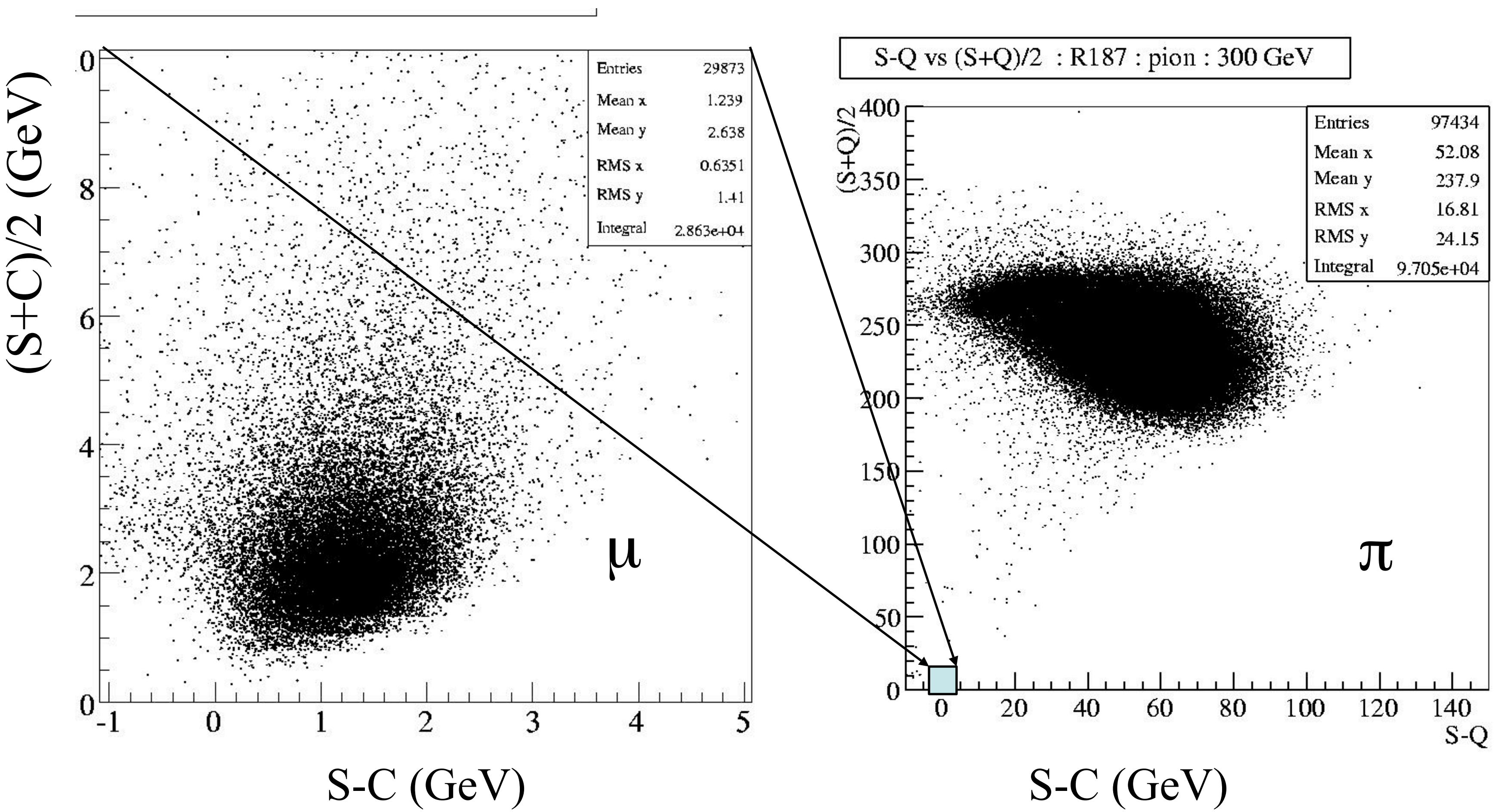
C = radiation

S-C = $dE/dx \sim 1$ GeV

Use it for muon identification

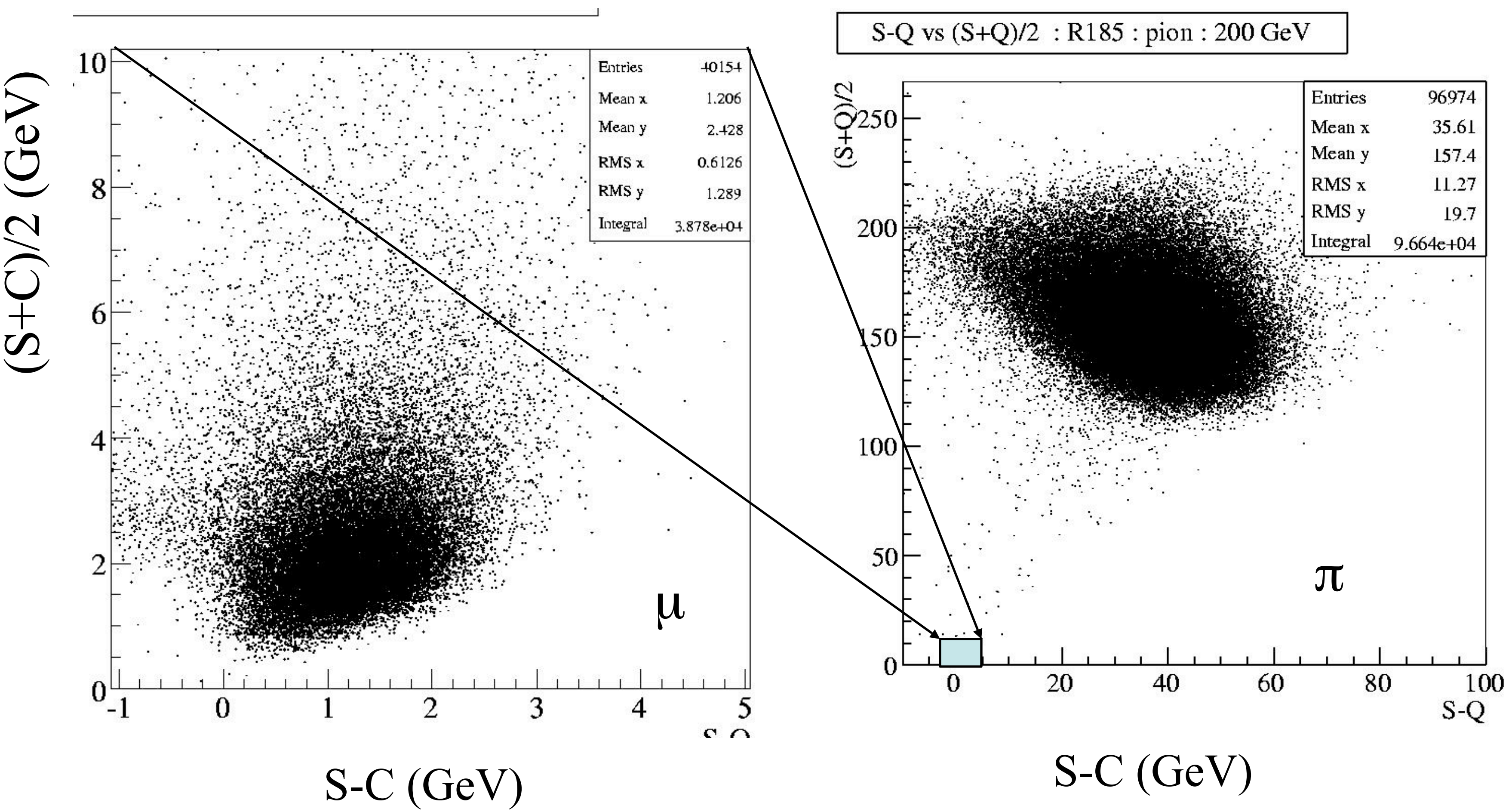
Muons and Pions (300 GeV)

NIM A533 (2004) 305-321.



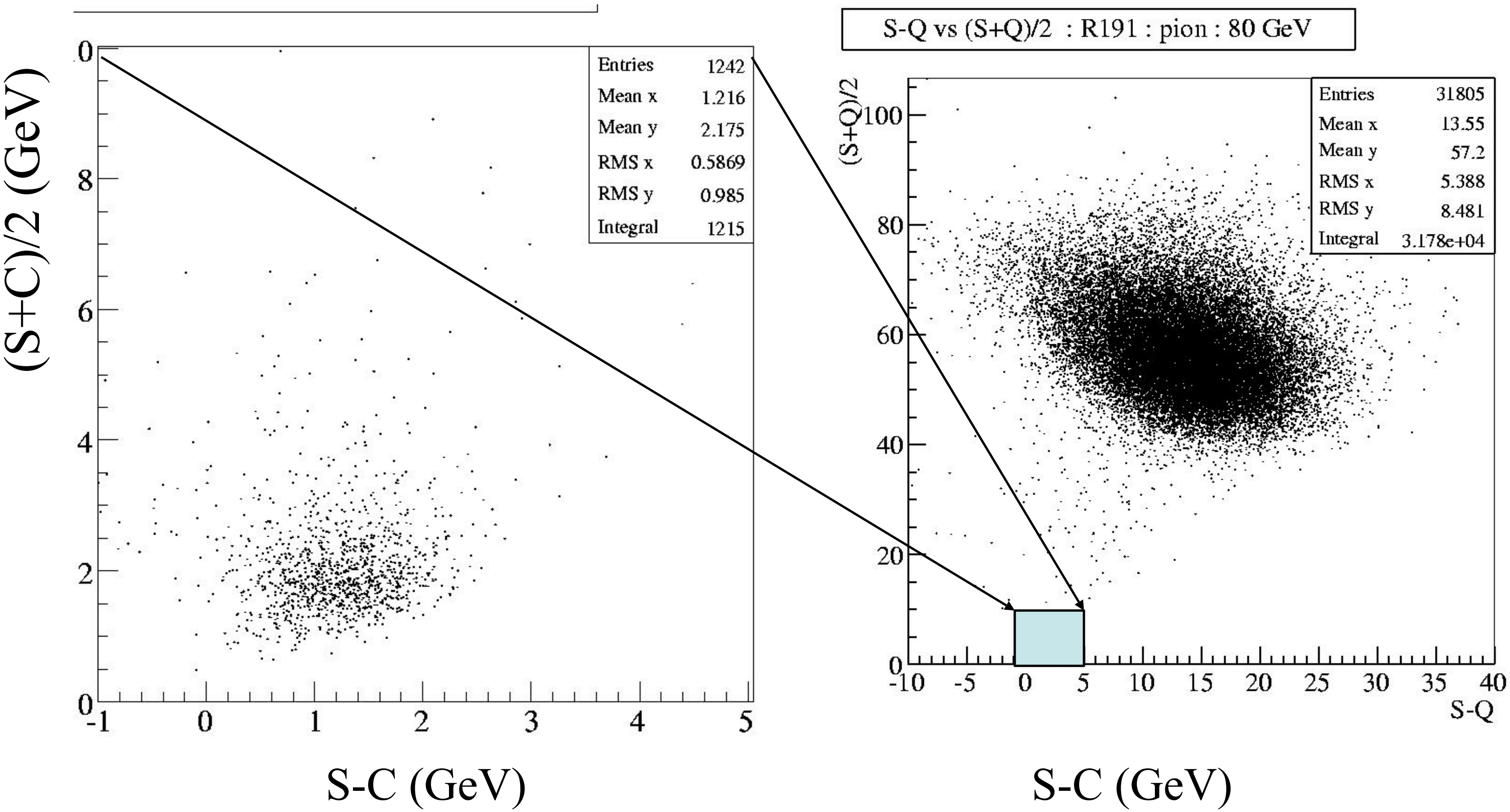
Muons and Pions (200 GeV)

NIM A533 (2004) 305-321.

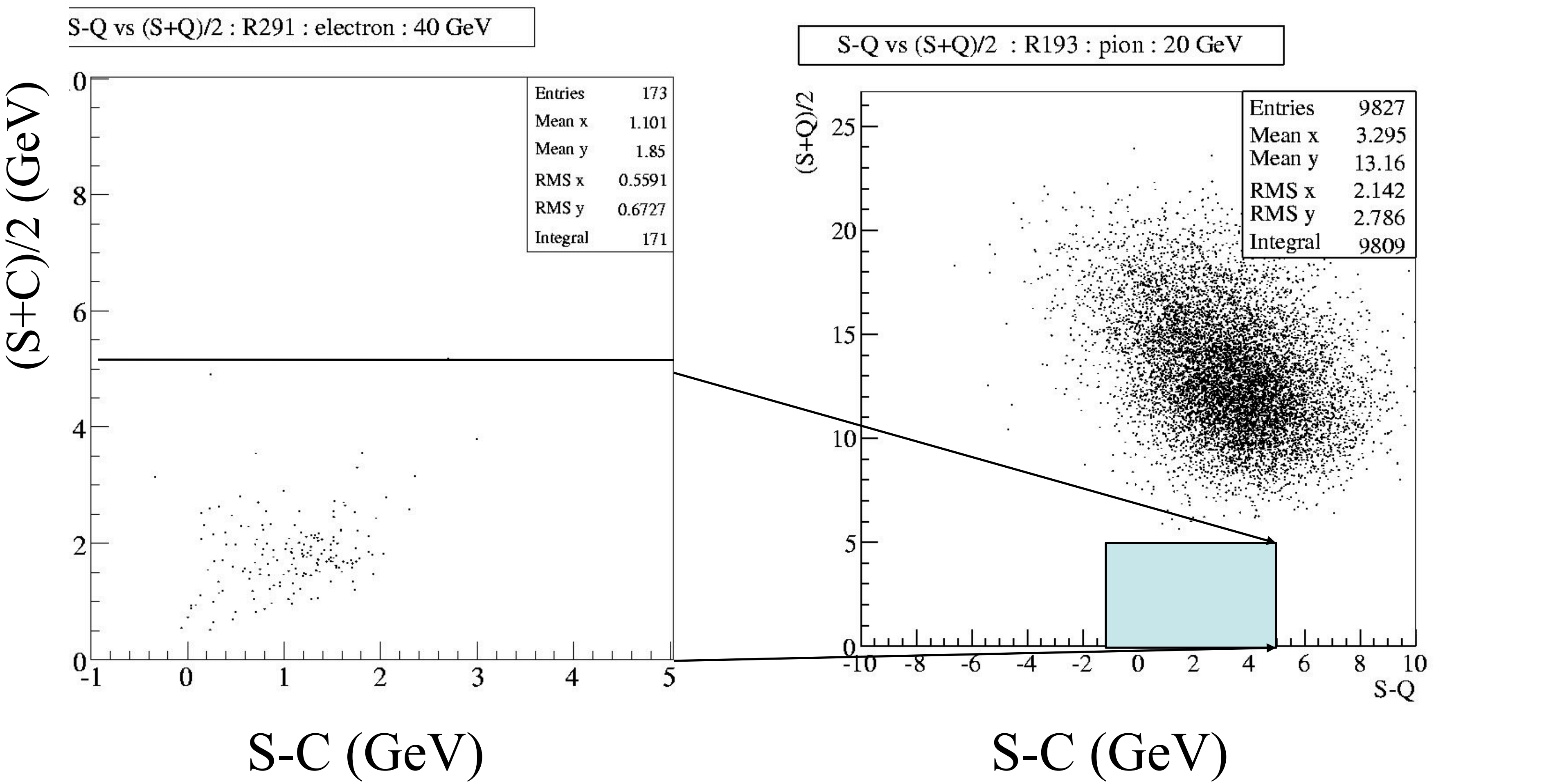


Muons and Pions (80 GeV)

NIM A533 (2004) 305-321.



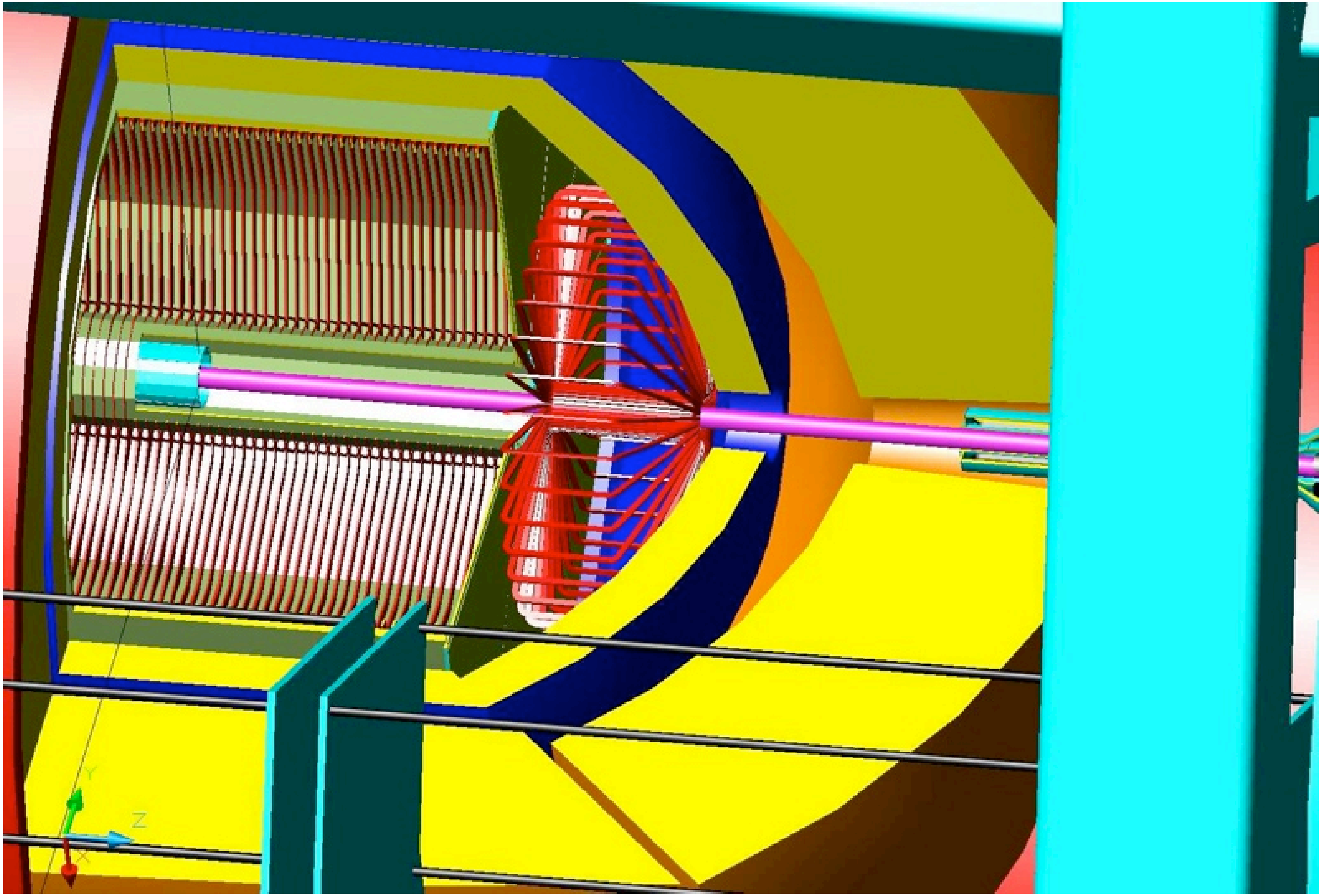
Muons (40 GeV) & Pions (20 GeV) NIM A533 (2004) 305-321.



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 $E_{TPC} \sim E_{CALOR} + E_{mu\ annulus}$
- pion rejection against muons is huge: use both calorimeter identification and energy balance
- *muons inside a jet, however, have not yet been studied*

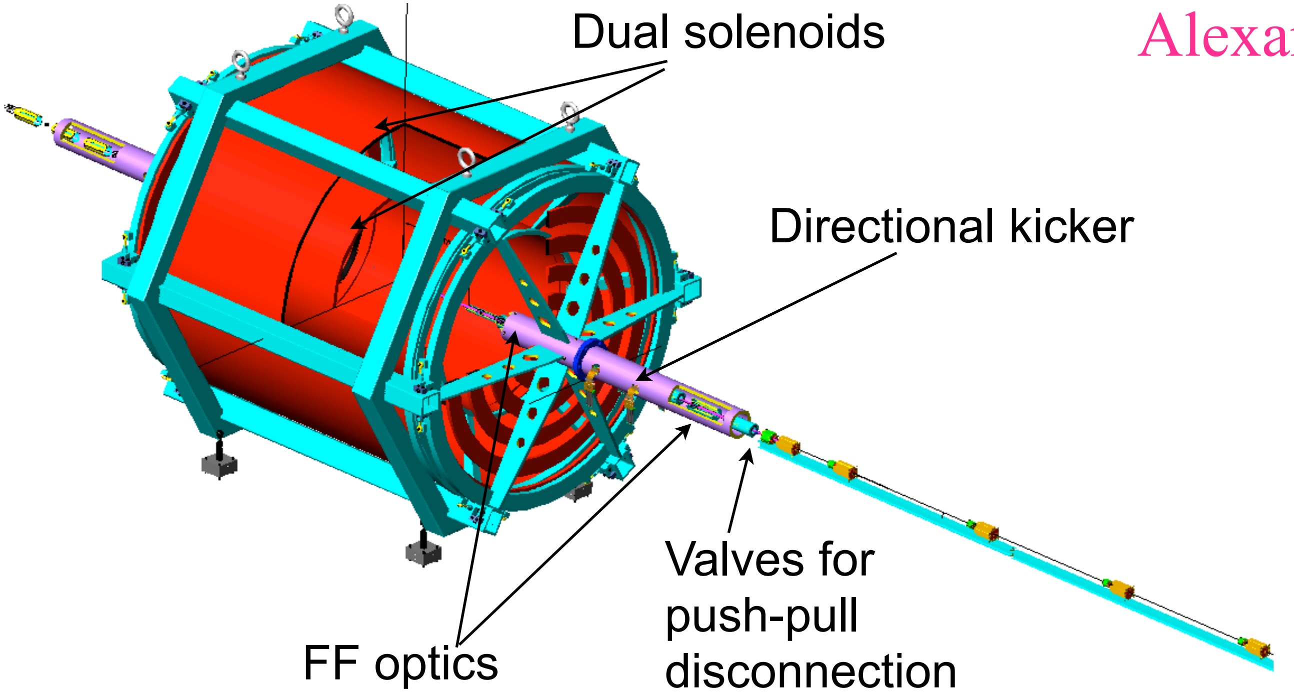
Another example of flexibility: we are toying with the idea of a toroid between the TPC and calorimeter for small angle tracks



Dual solenoid: machine-detector interface advantages

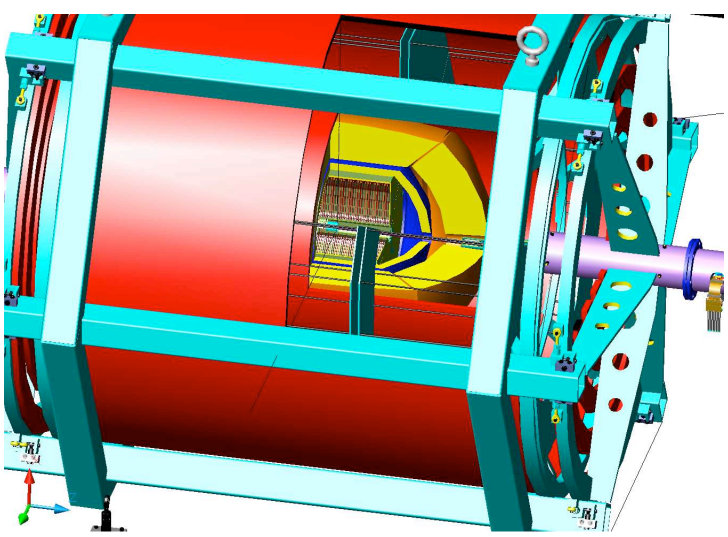
- control of B field on and near beam line
- “push-pull” of two detectors in one IR
- installation and re-installation
- costs and infrastructure in interaction hall
- FF optics, compensation, quads up to and inside the detector
- can accomodate adiabatic focusing, monochromatization, any crossing angle,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

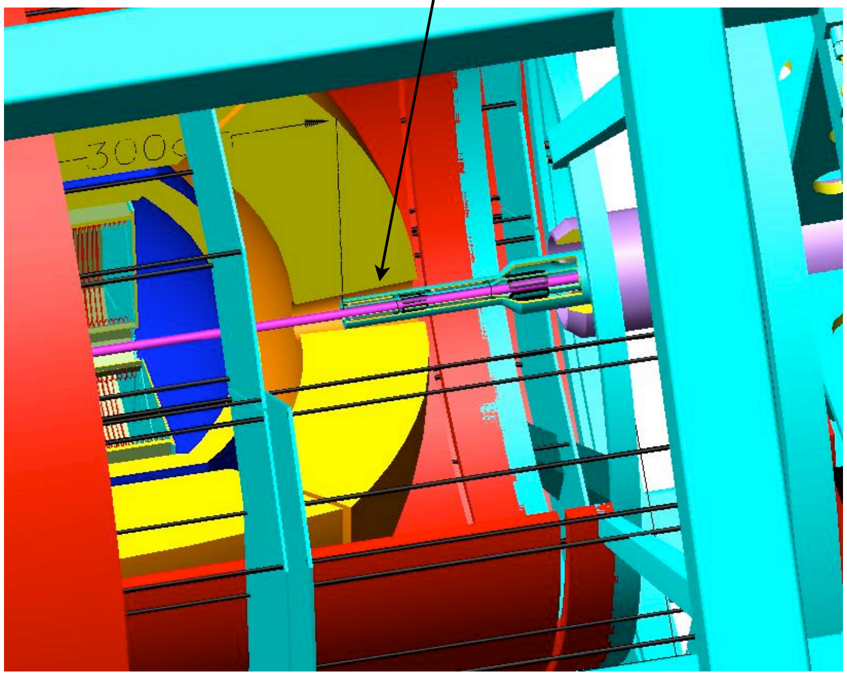
Alexander Mikhailichenko



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

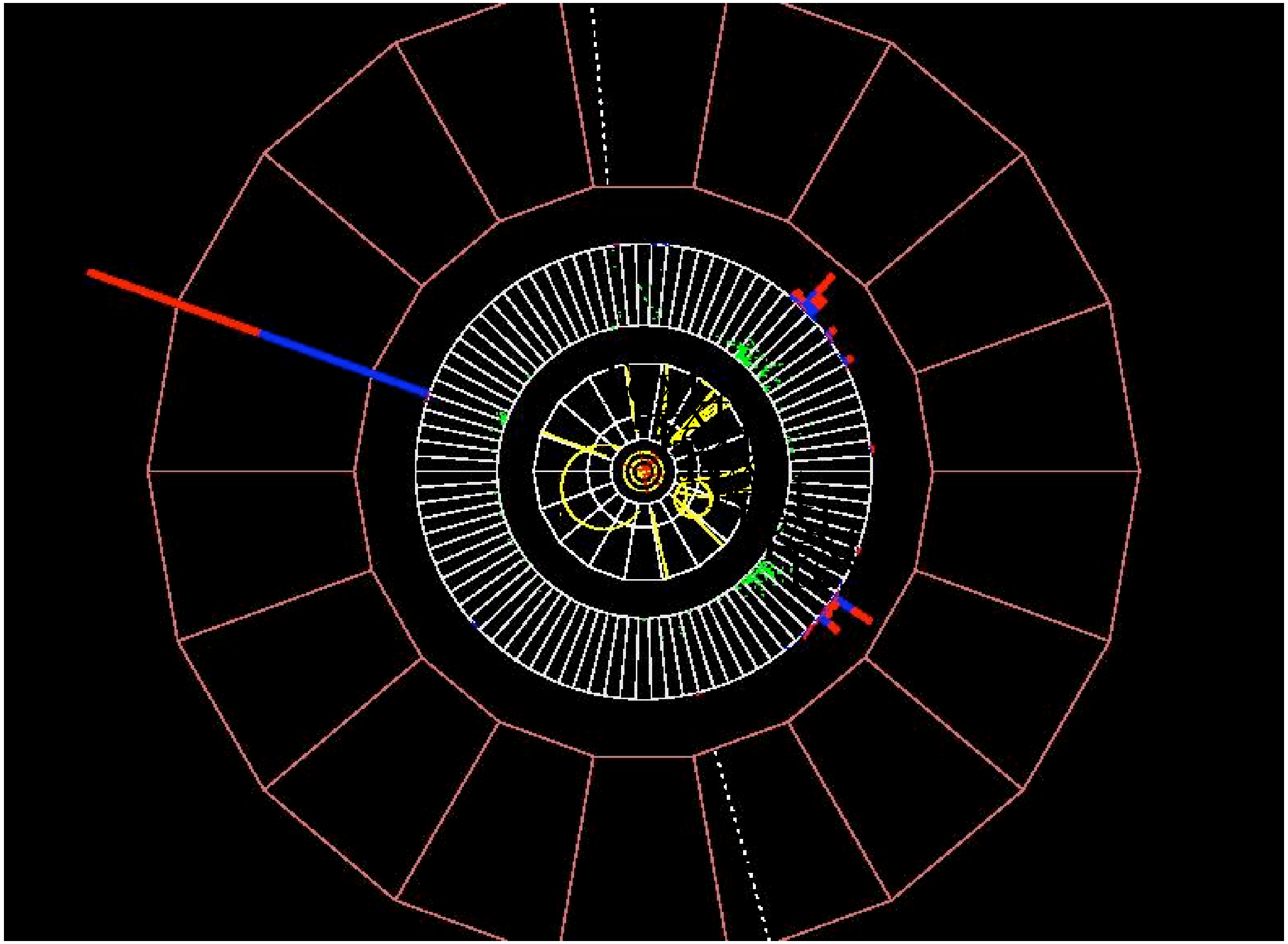
This reduces influence of ground motion.





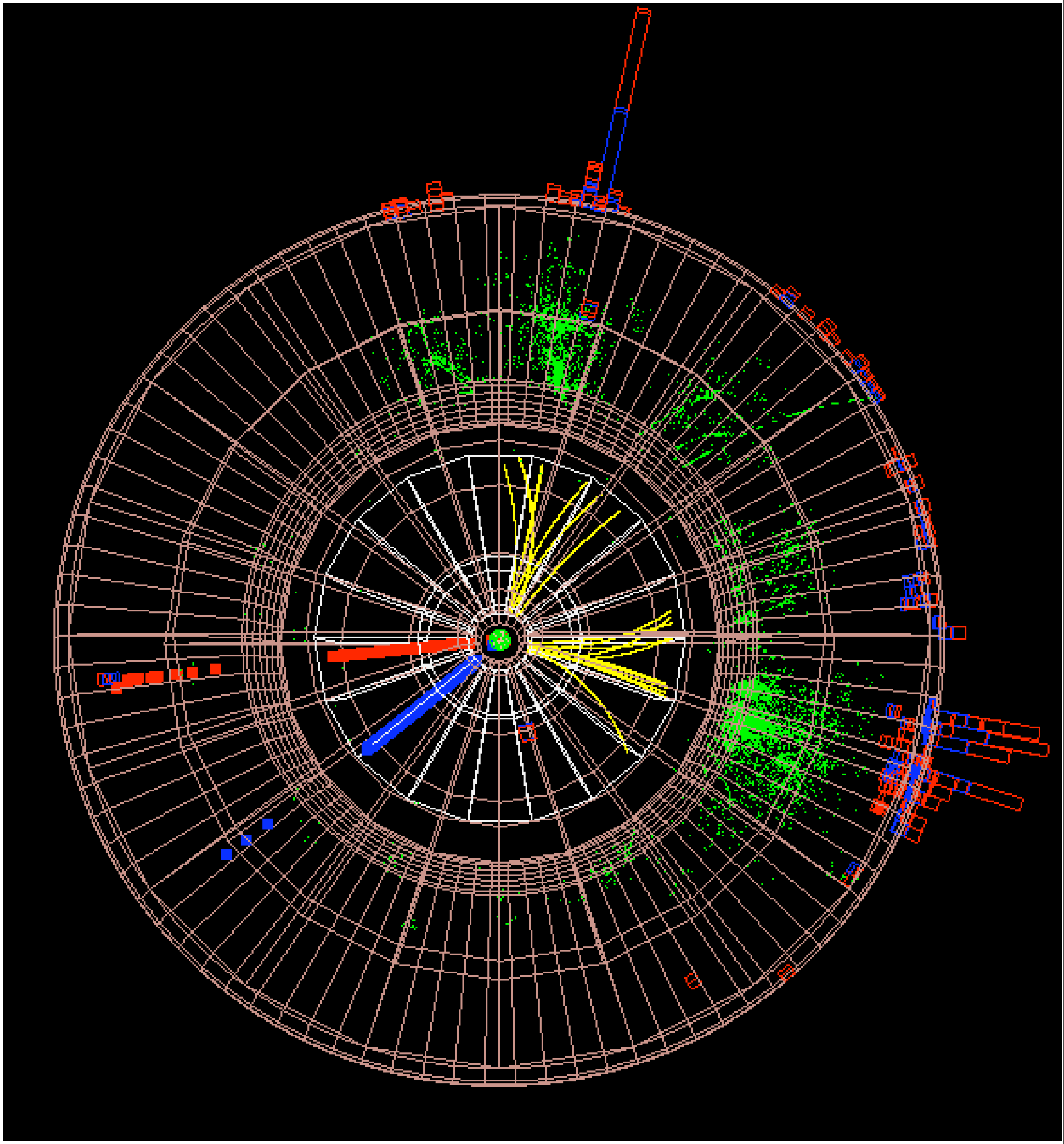
ILCroot software developed by the Lecce group, Corrado Gatto

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

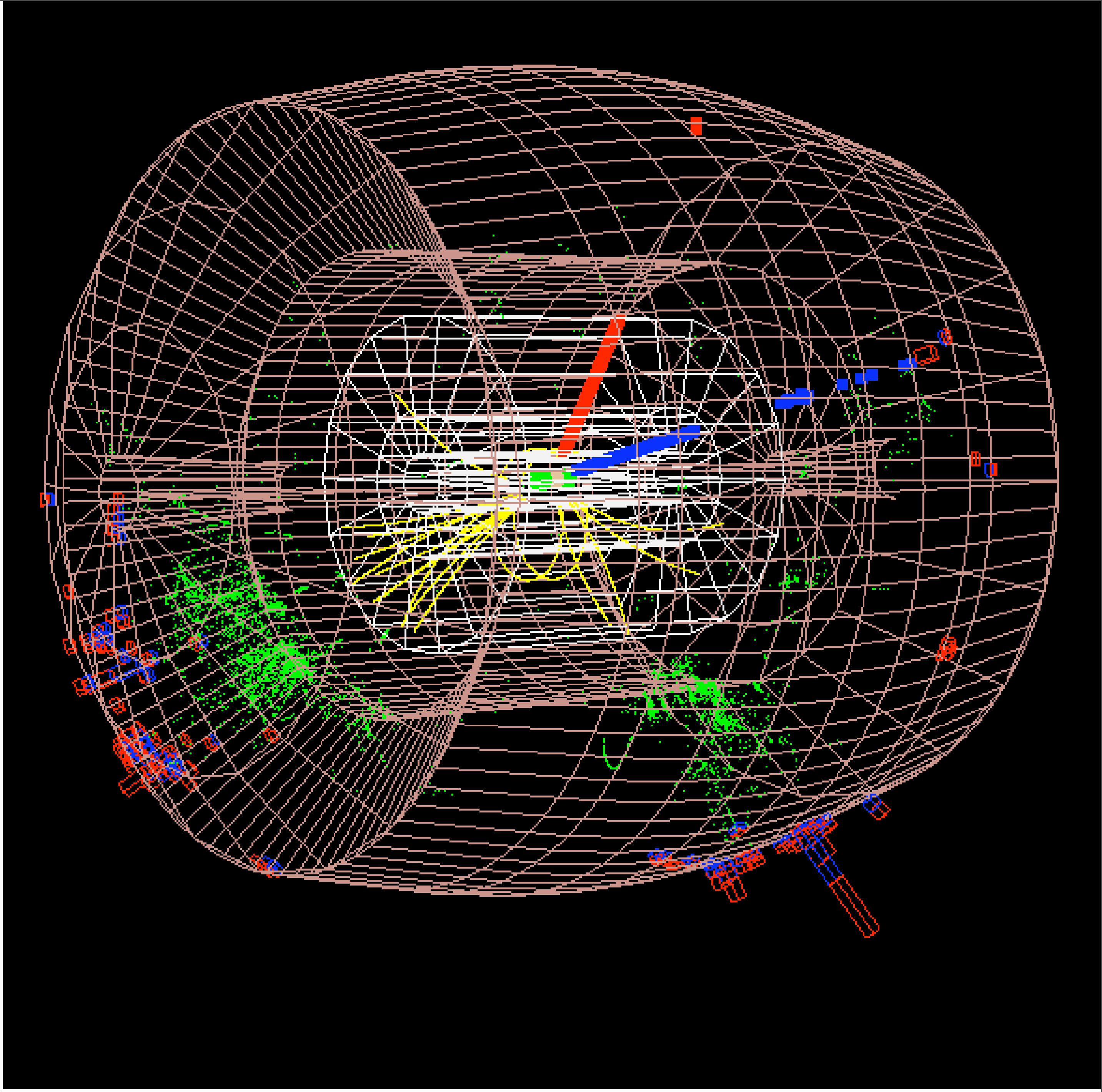


Illustrates all the detectors of 4th Concept … particle ID “obvious”

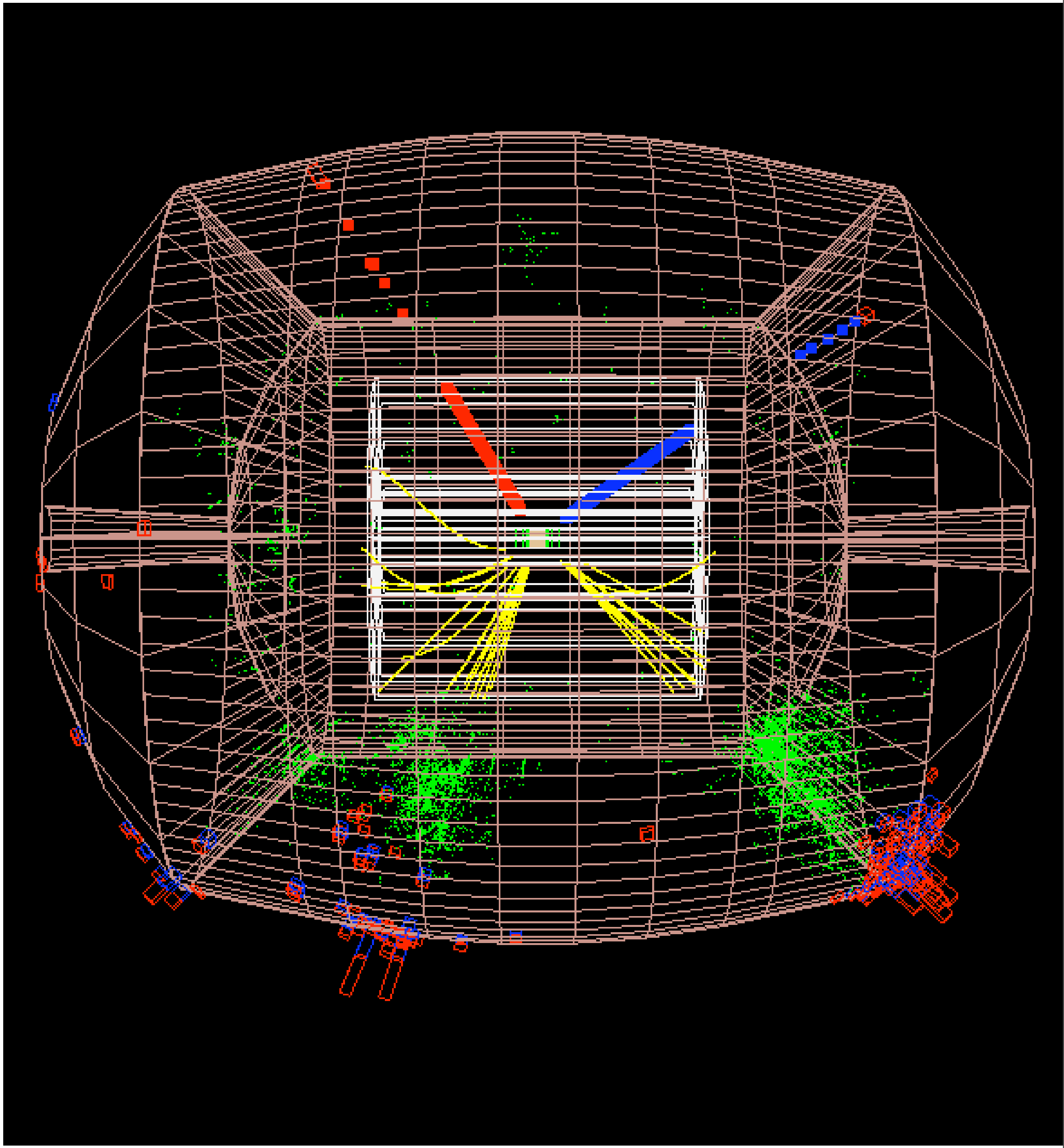
$$e^+e^- \to H^0 Z^0 \to b\bar{b}\mu^+\mu^-$$



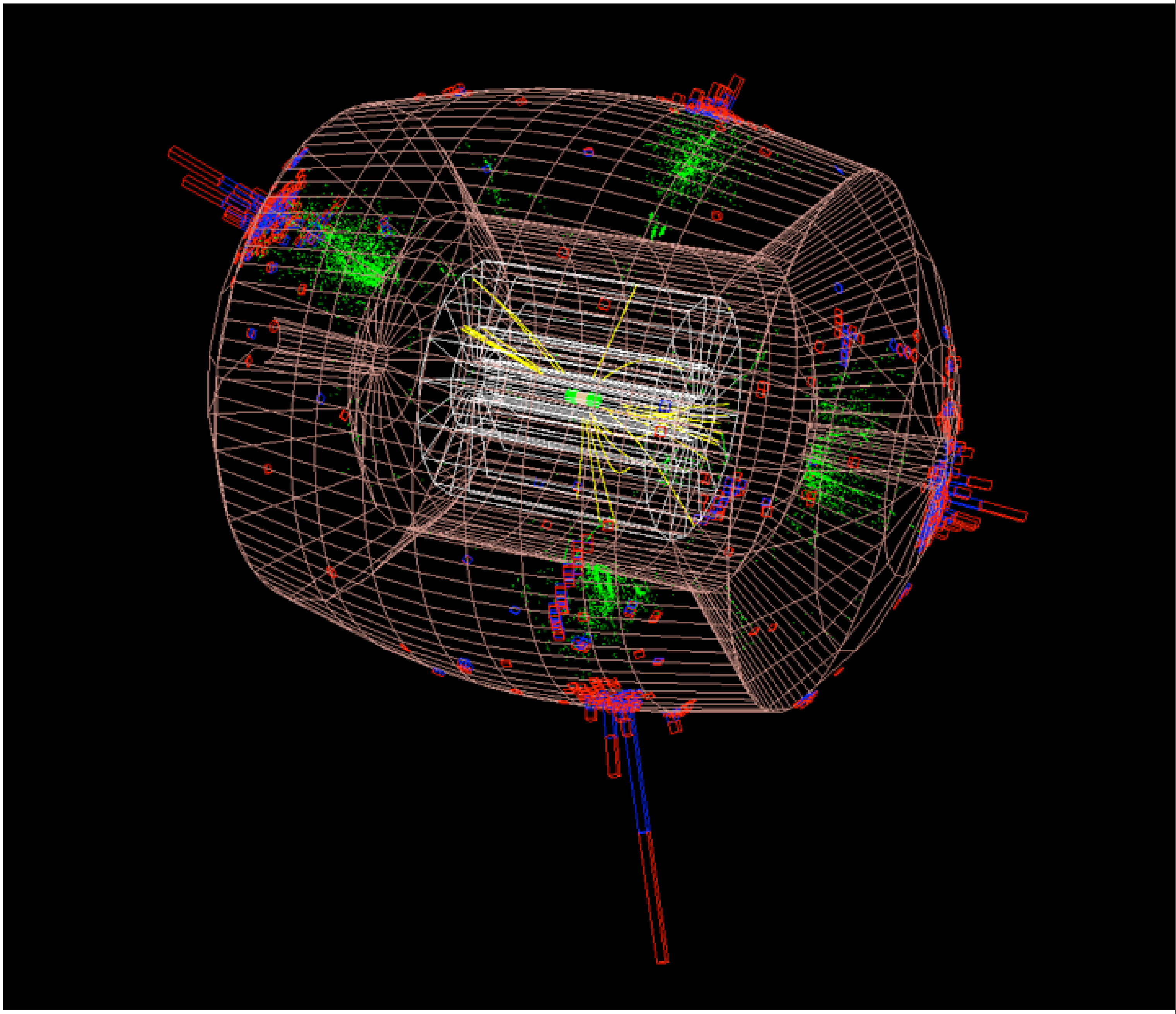
$$e^+e^- \to H^0 Z^0 \to b\bar{b}\mu^+\mu^-$$



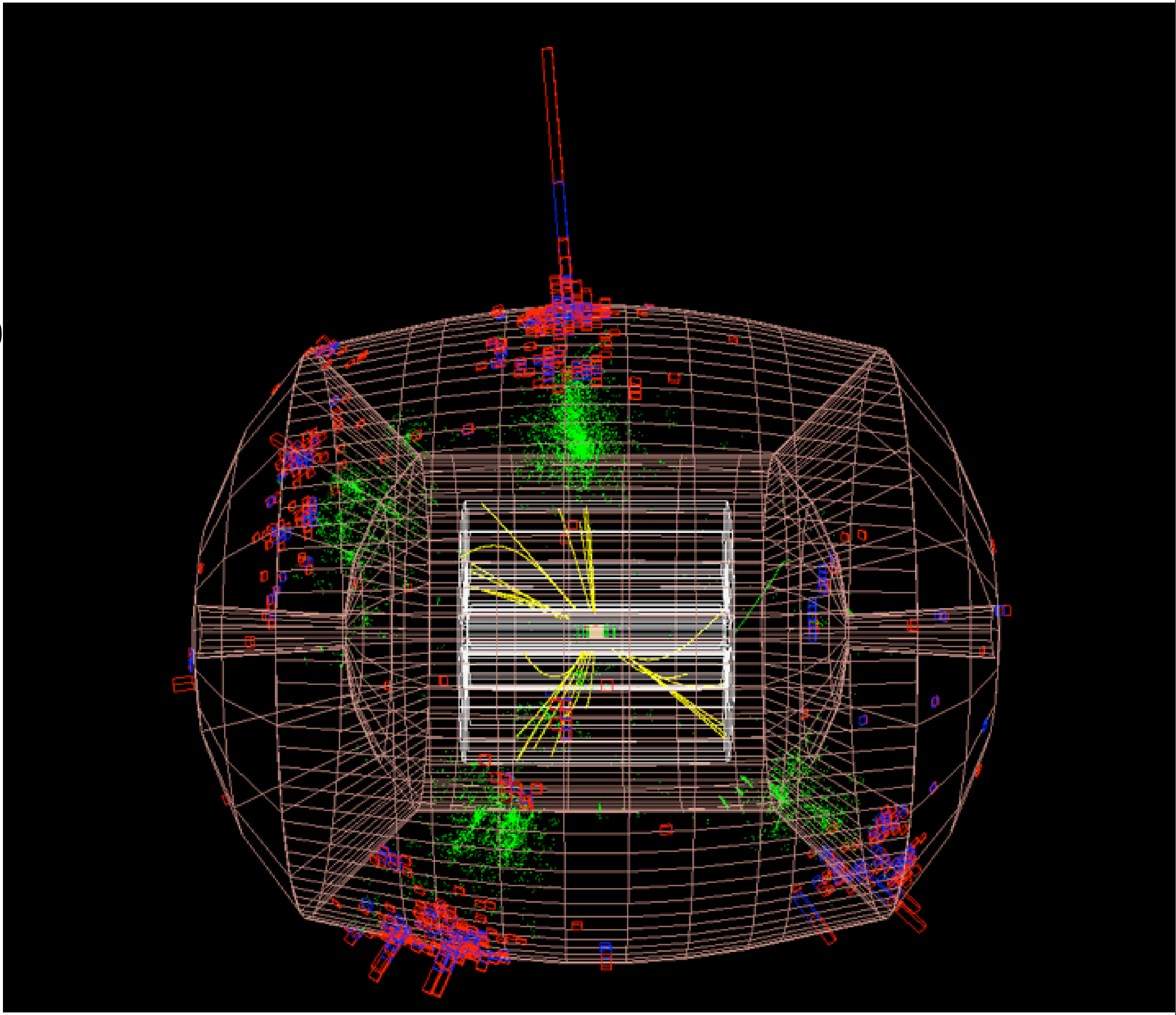
$$e^+e^- \to H^0 Z^0 \to b\bar{b}\mu^+\mu^-$$



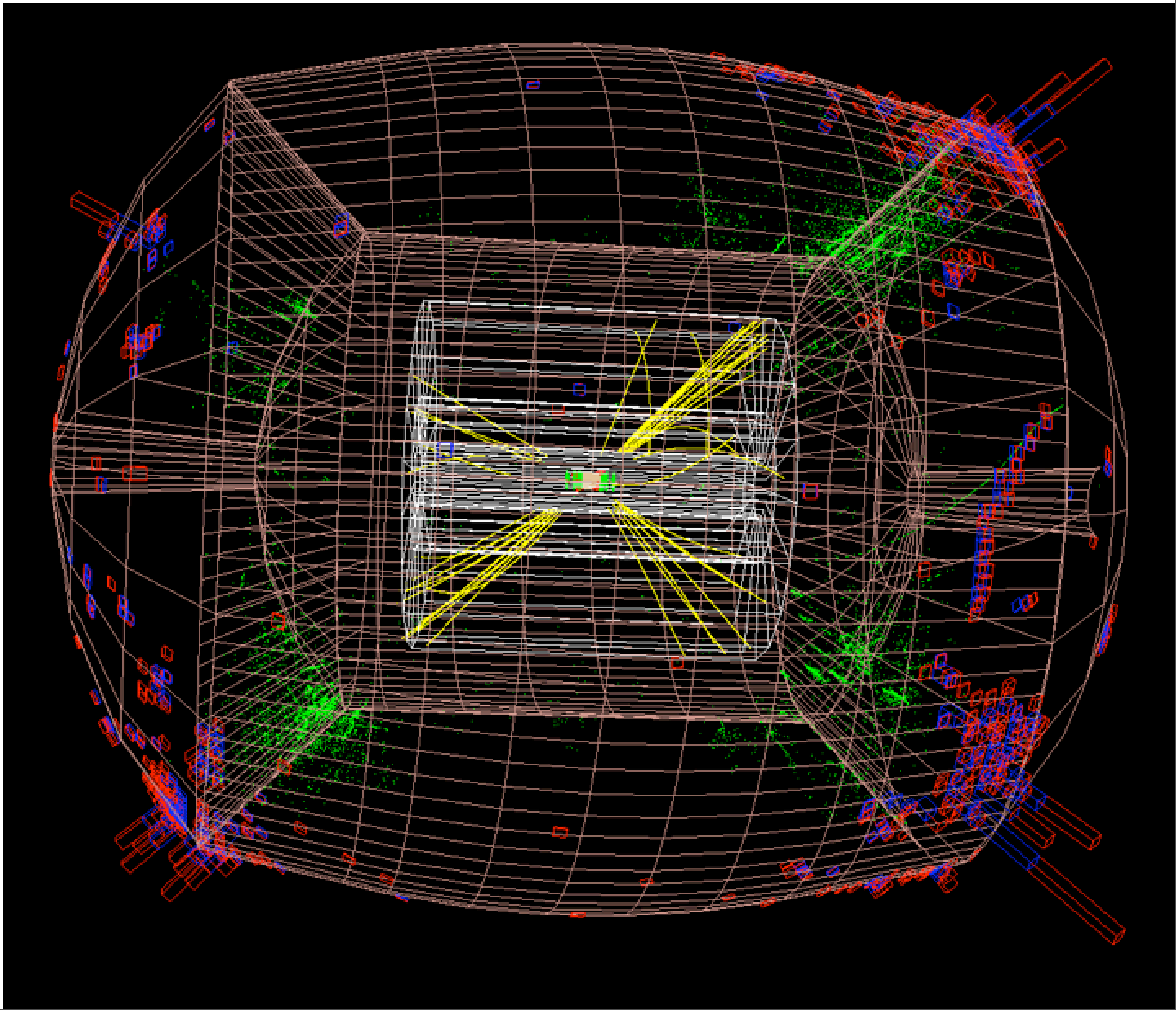
$$e^+e^- \rightarrow H^0 Z^0 \rightarrow b\bar{b}q\bar{q}$$



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

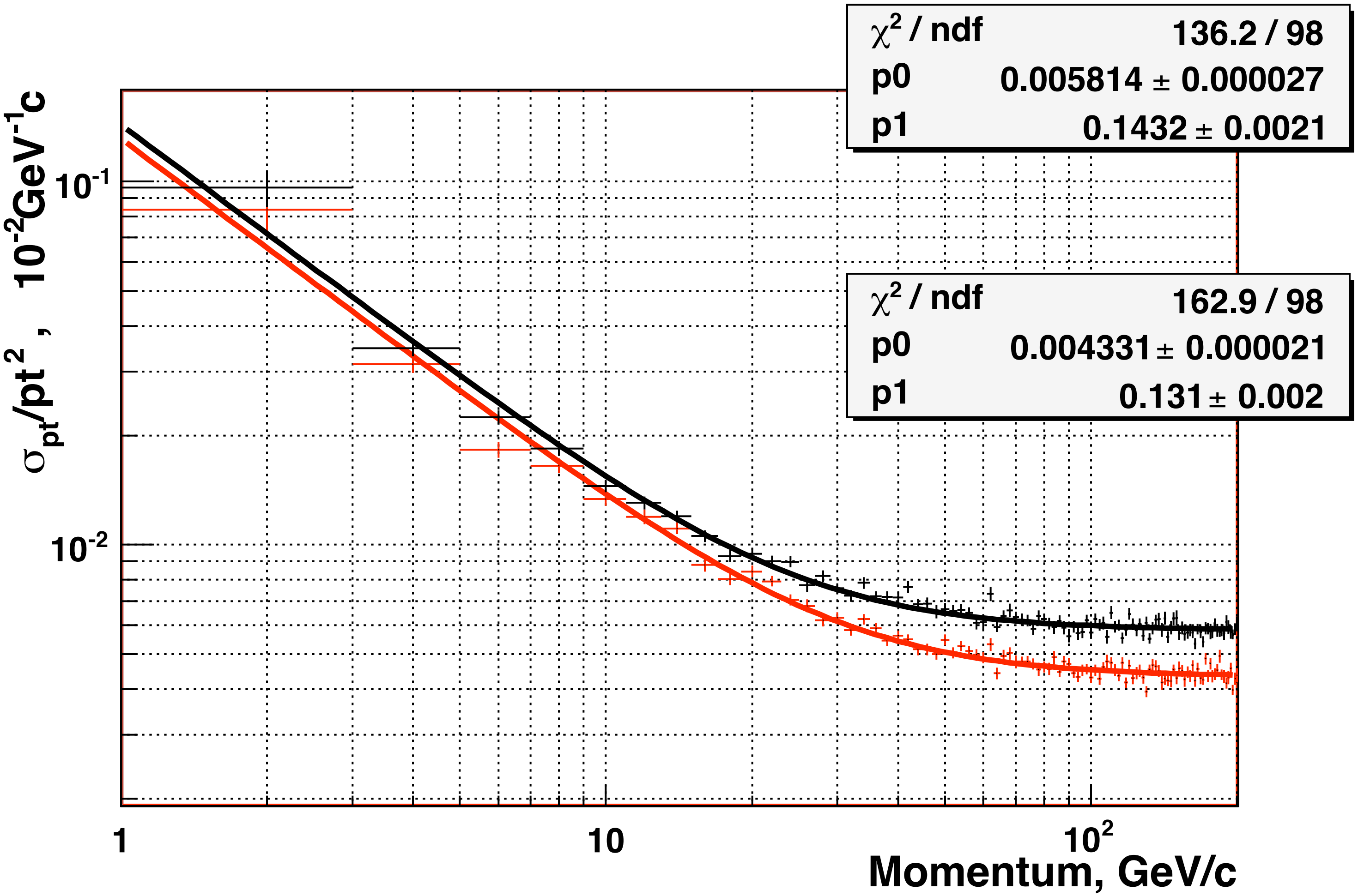


$$e^+e^- \rightarrow H^0 Z^0 \rightarrow b\bar{b}q\bar{q}$$



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.
- Dual readout of single crystal (tested CERN, Oct’06)
- Design scalable triple readout module



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

Problems to work on

- asymmetric energies: physics and detector
- monochromatization of beams
- both beams polarized
- muon tagging down to 1 GeV/c
-