Muon measurement and identification in 4th concept

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Two innovations:

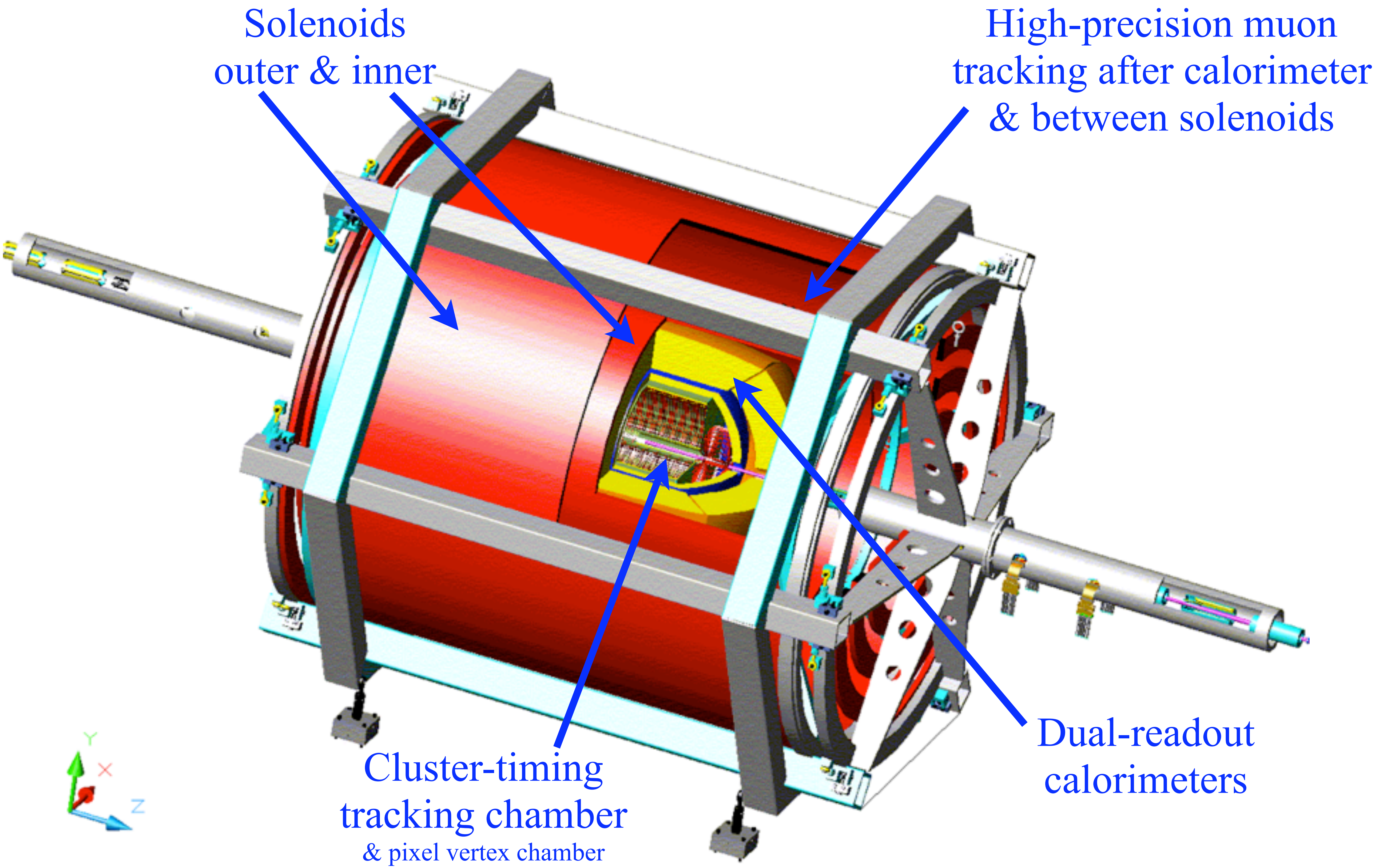
1. No iron: flux return by second solenoid

- (many benefits in MDI, push-pull, access, 2-gamma, etc.)
- for muons, precision momentum measurement after solenoid in a large-volume spectrometer.
- use energy conservation from main tracker, calorimeter, and spectrometer for muon ID tagging.

2. Dual-readout fiber calorimeter: unique muon ID

- Cerenkov angle is larger than numerical aperture caapture angle of fiber, therefore S = *dE/dx + bremsstrahlung*, *C = bremsstrahlung*
- *S-C = dE/dx* ~ 1.1 GeV in 10 int-length DREAM module.

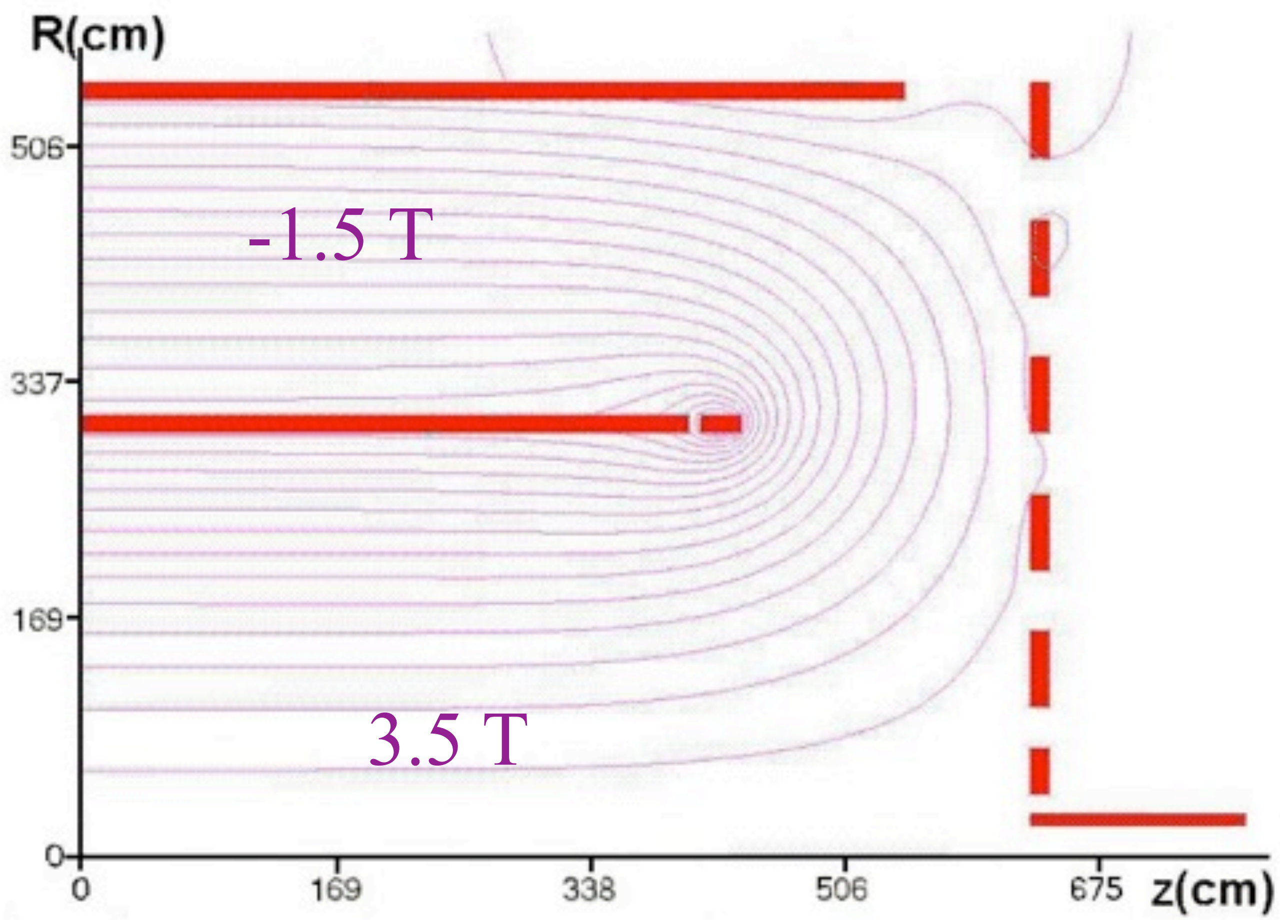
Necessarily, muons are measured by all systems of a detector

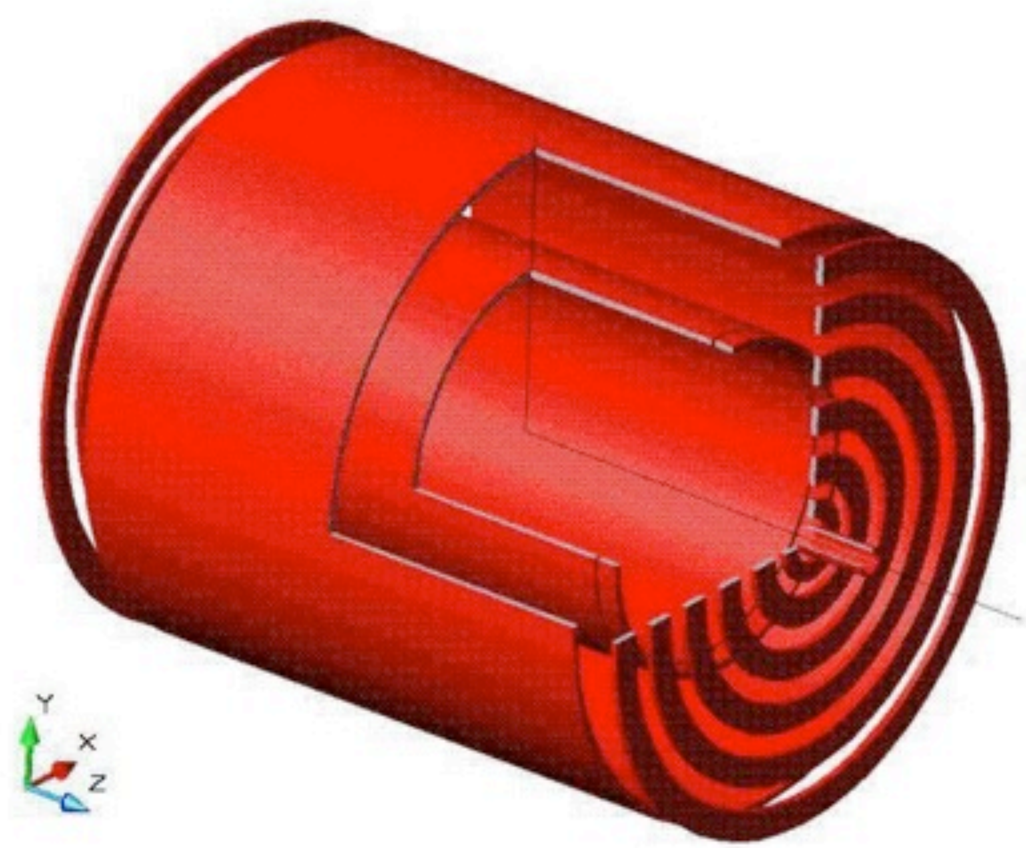


Muon spectrometer measurement (iron-free)

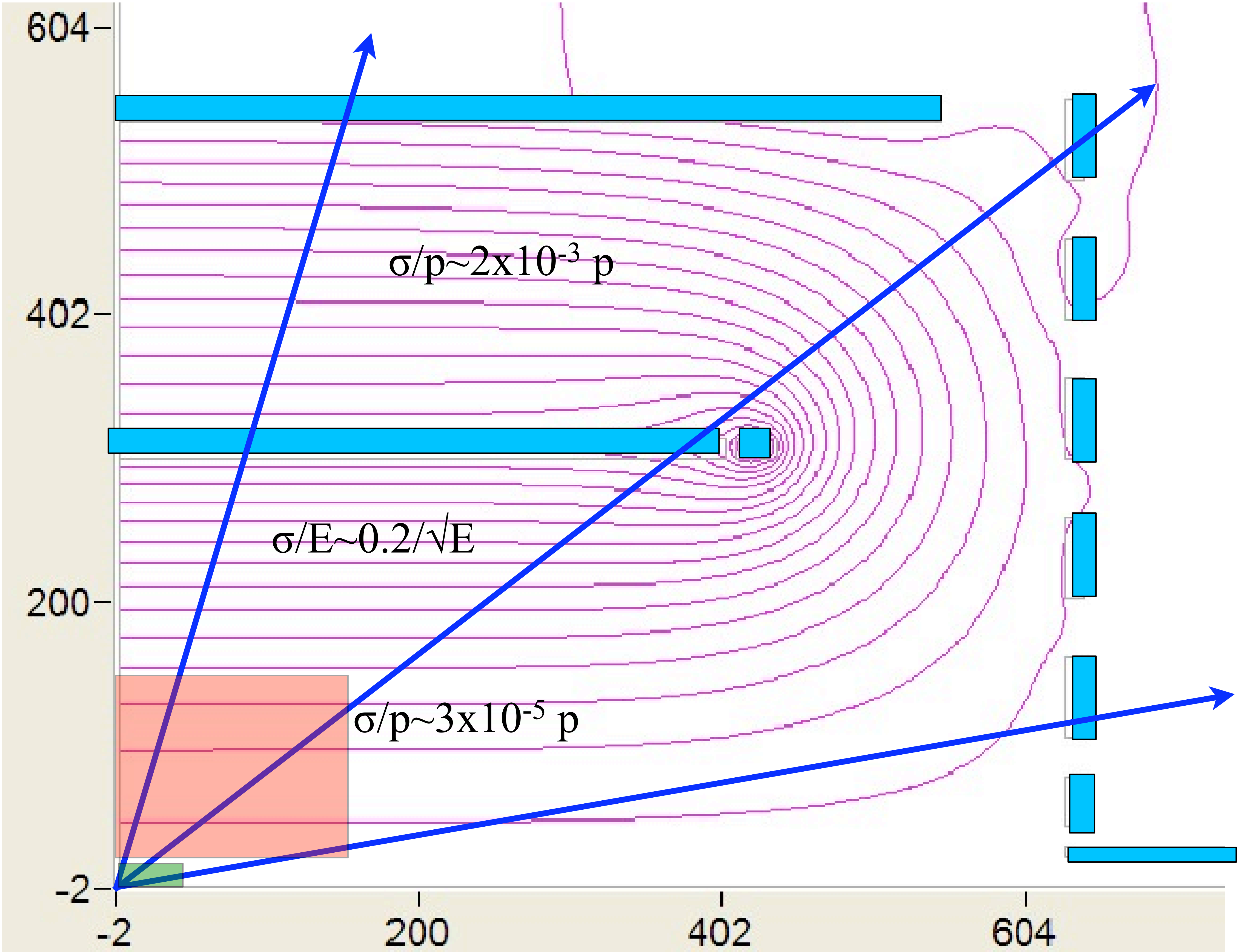
Dual-solenoids (A. Mikhailichenko, Cornell)

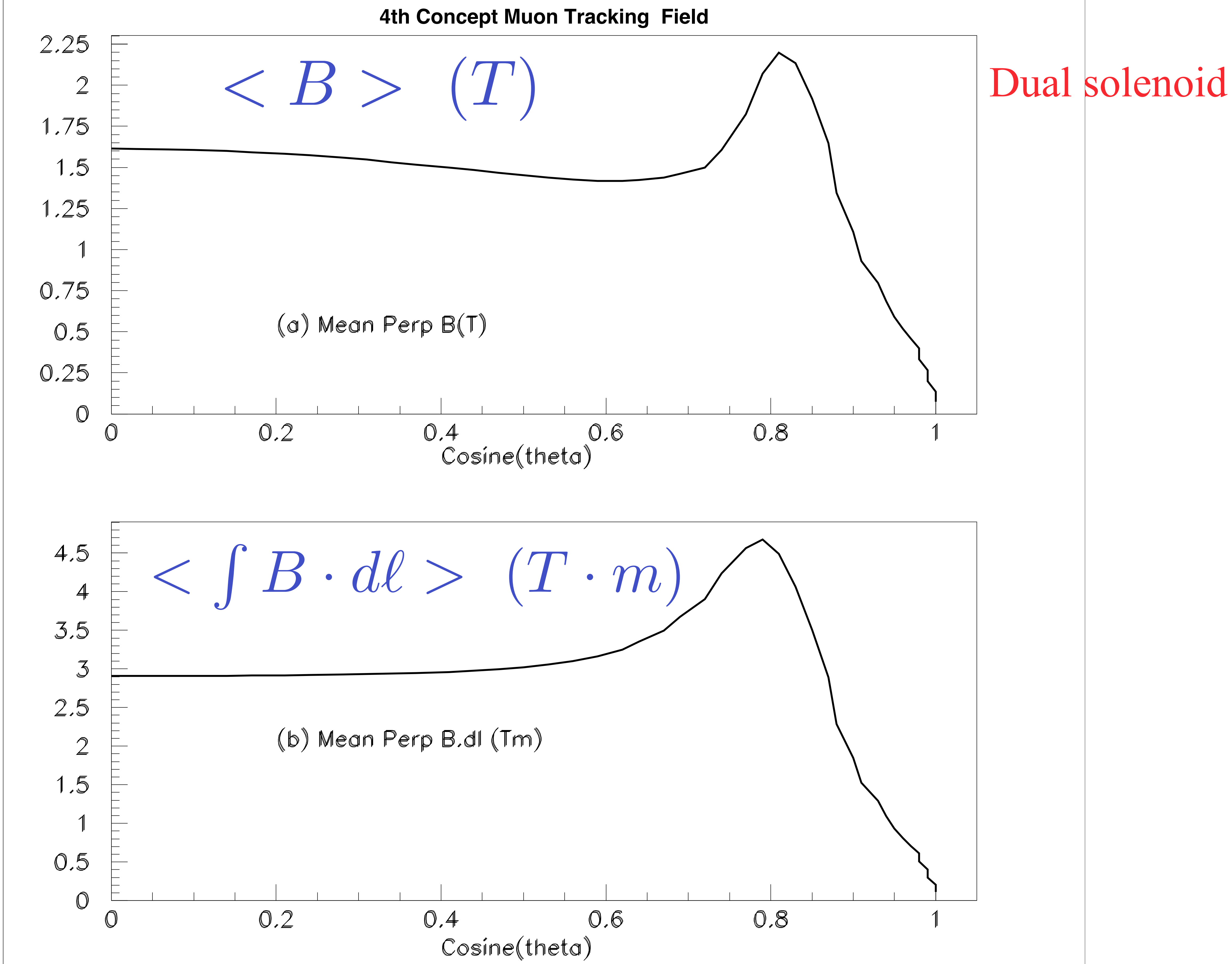
- inner solenoid like CMS
- outer solenoid and end coils driven in opposite direction
- essentially no fringe field
- outer solenoid is big, but not a problem





Muon trajectories from the interaction point

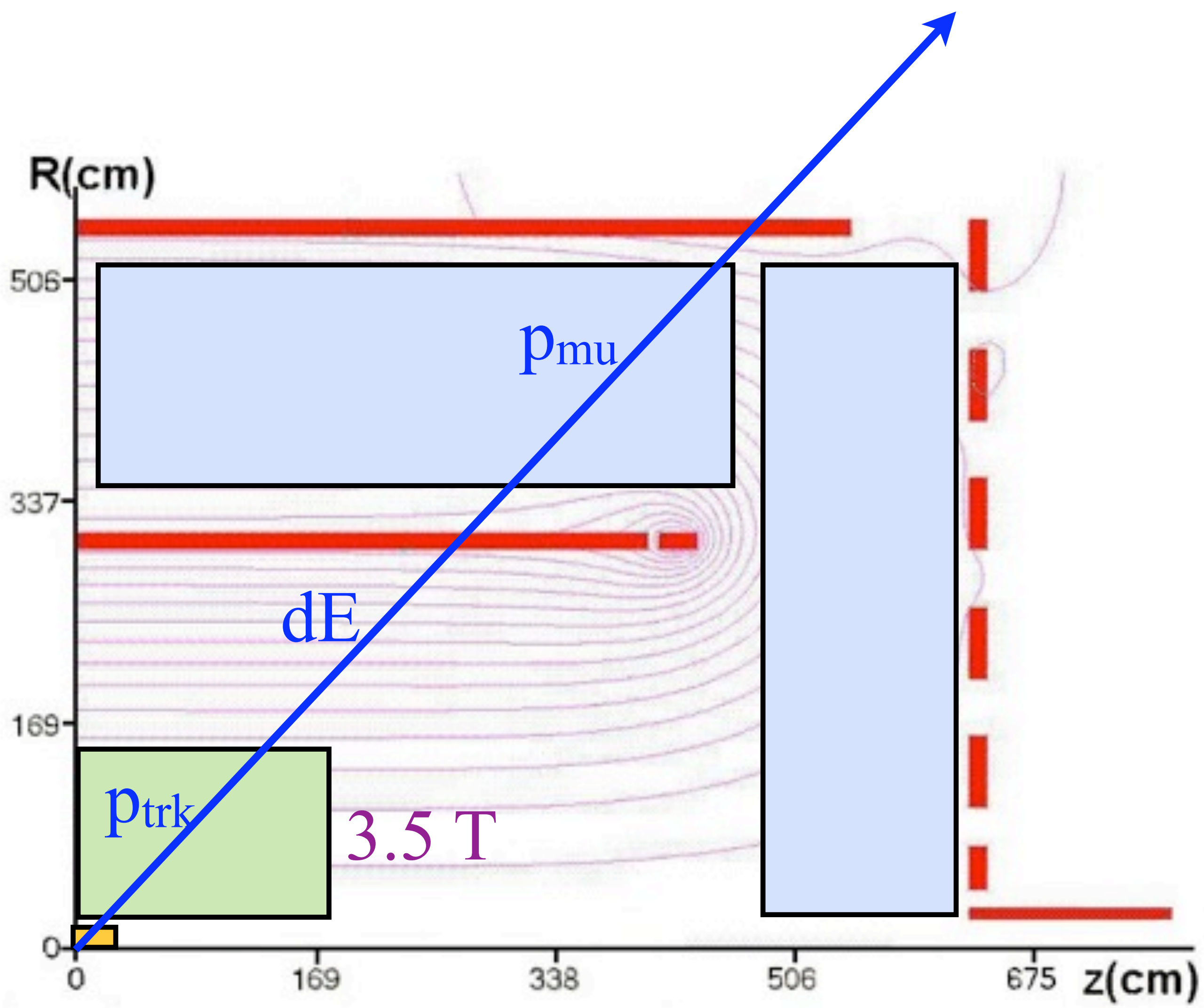


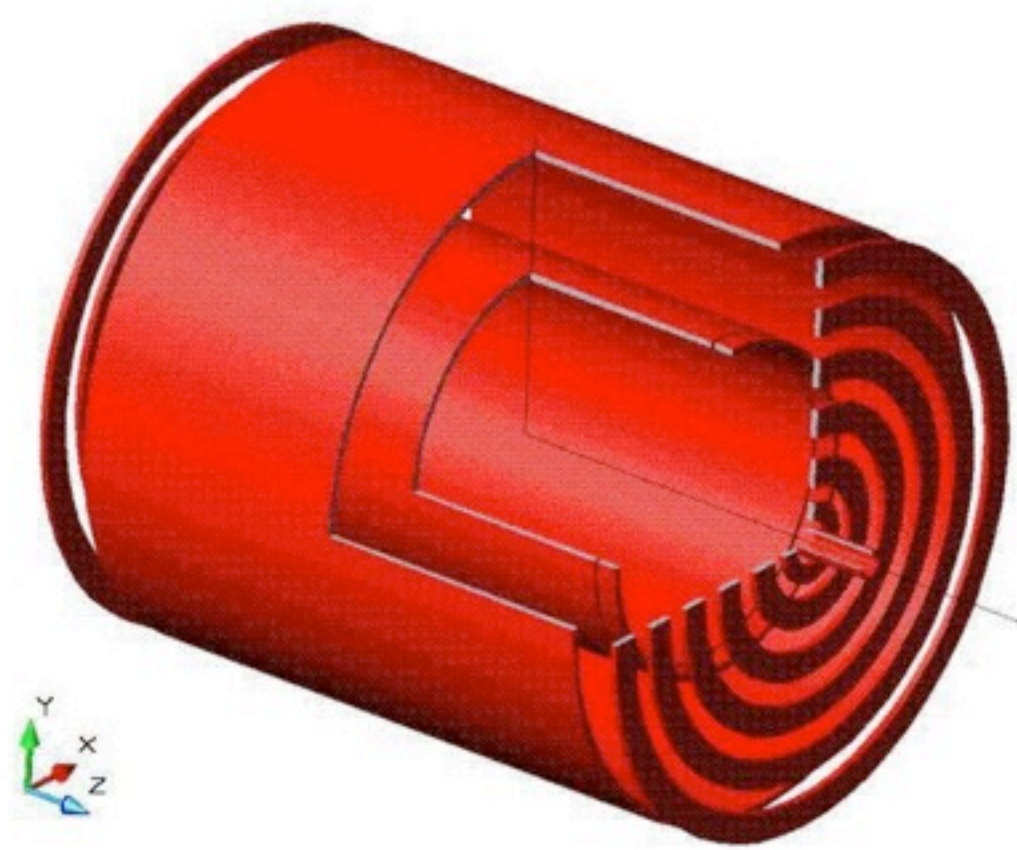

4th Concept Muon Tracking Field
$< B > \ (T)$
(a) Mean Perp B(T)
Cosine(theta)
$< \int B \cdot d\ell > \ (T \cdot m)$
(b) Mean Perp B.dl (Tm)
Cosine(theta)
Dual solenoid

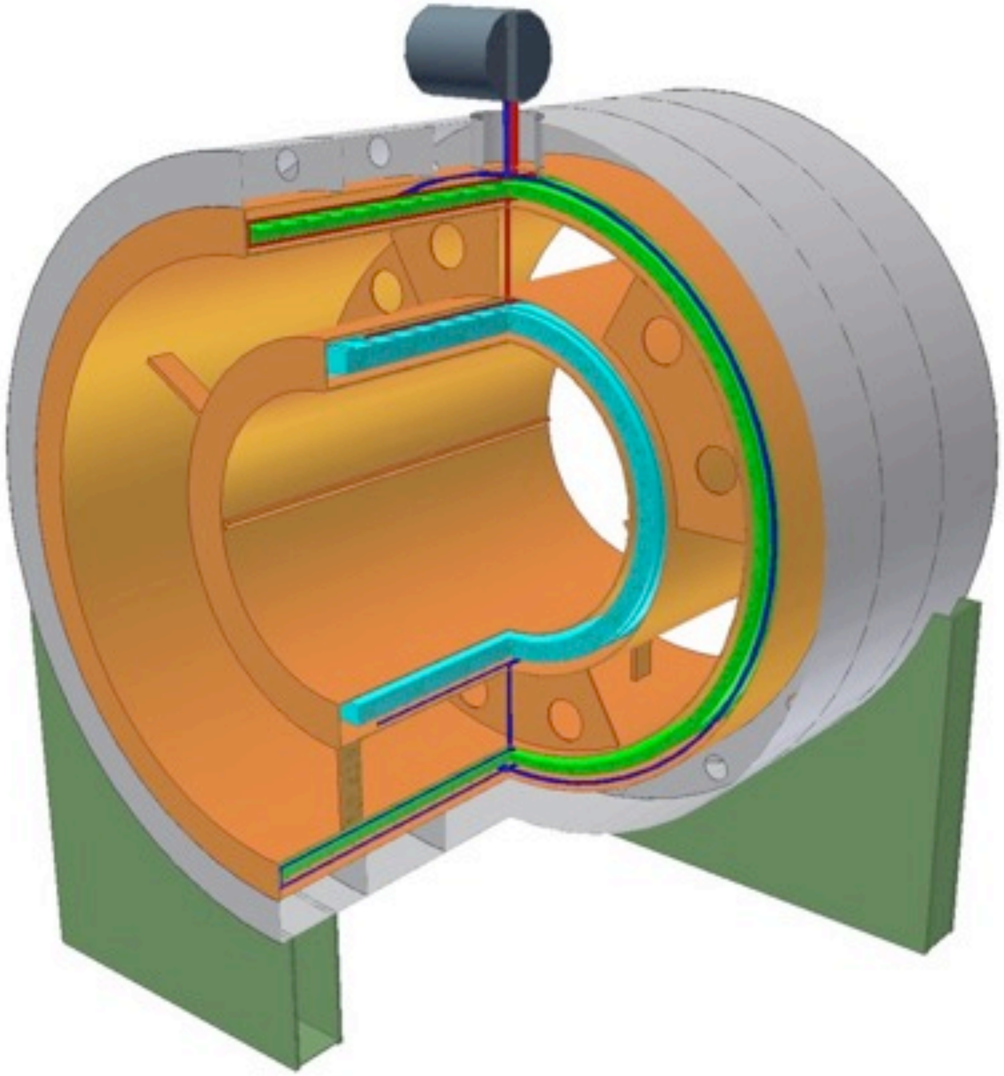
Muon energy-momentum measurements

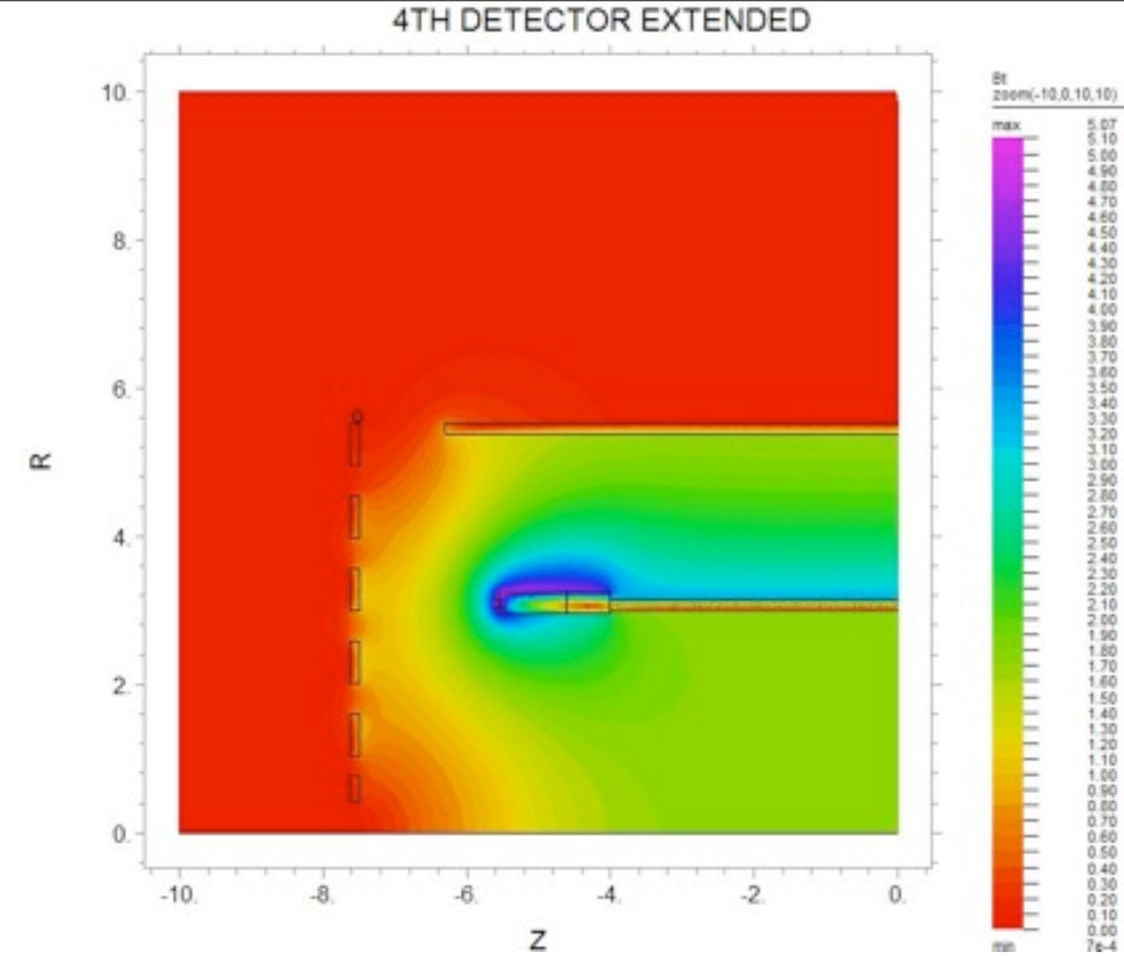
For
$p_{trk} \sim 100$ GeV/c in central tracker
$dE \sim 20$ GeV bremsstrahlung in calorimeter
$p_{mu} \sim 80$ GeV/c in muon spectrometer

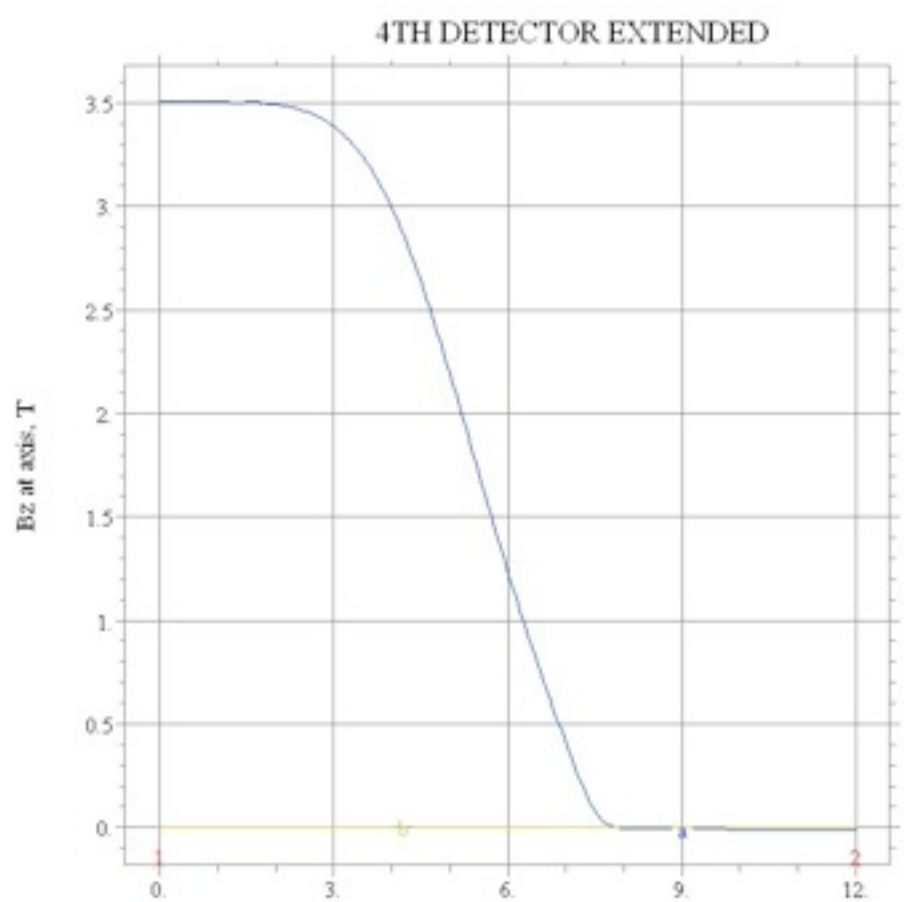
⇨ Muon is measured to better than few % in every system:

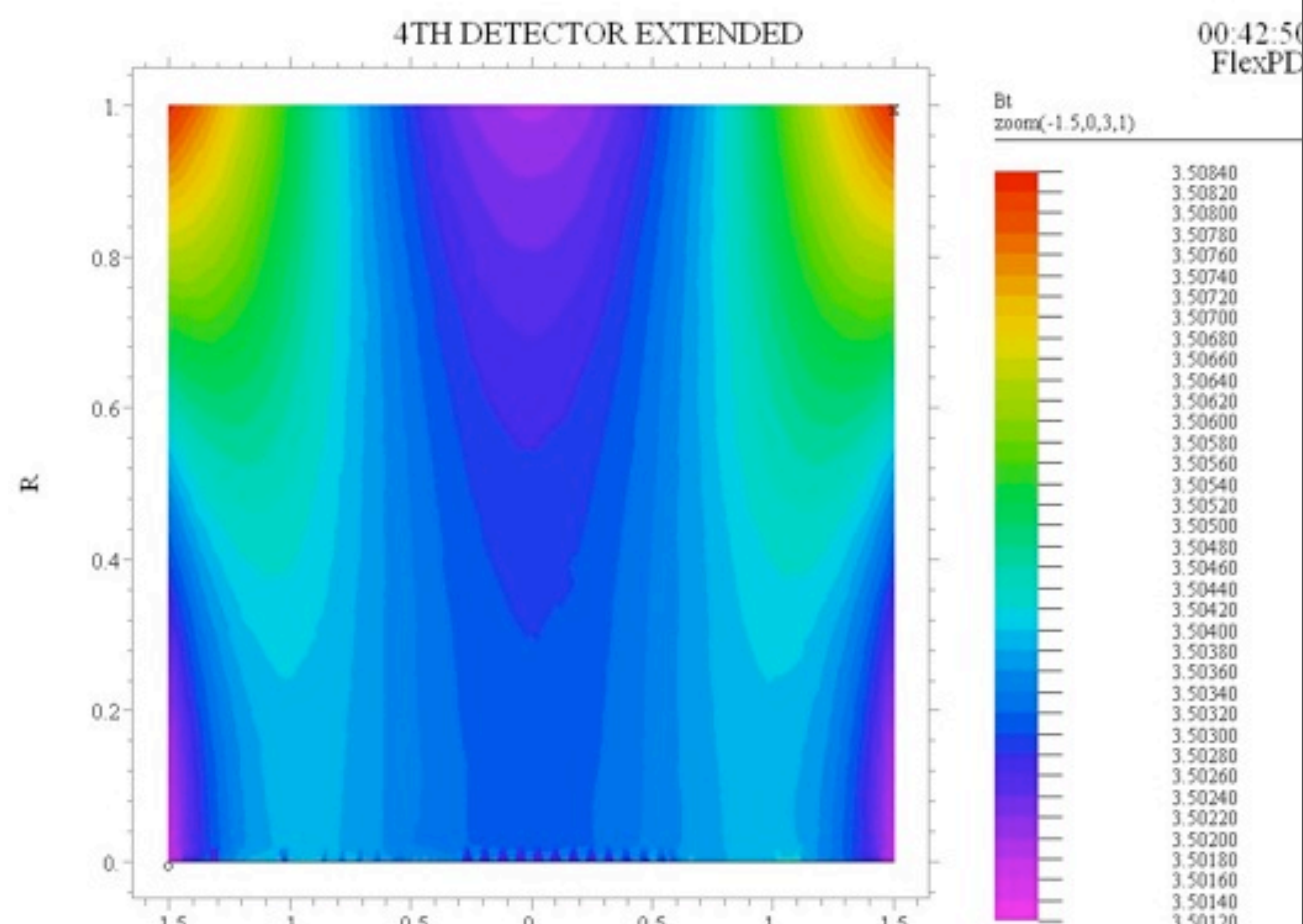






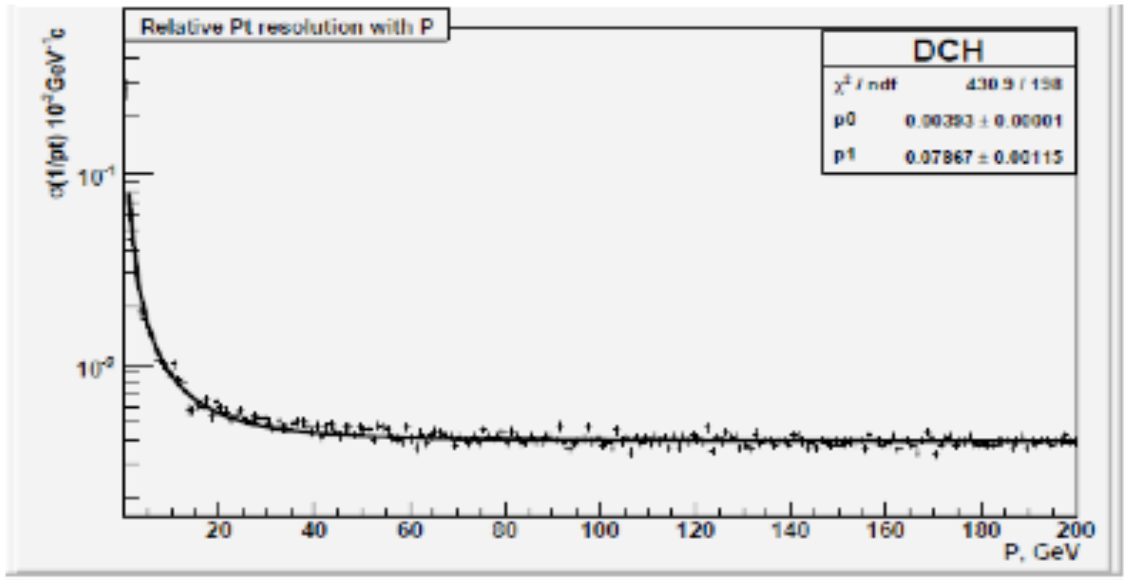

4TH DETECTOR EXTENDED
R
Z
10.
8.
6.
4.
2.
0.
-10.
-8.
-6.
-4.
-2.
0.

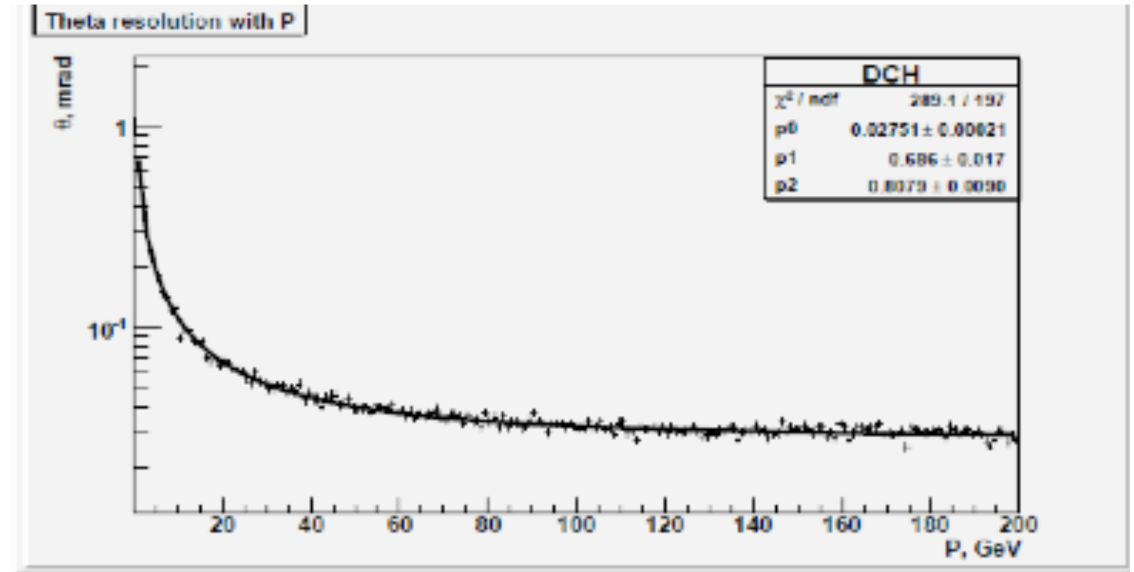

4TH DETECTOR EXTENDED
Bz at axis, T
3.5
3
2.5
2
1.5
1
0.5
0
0.
3.
6.
9.
12.

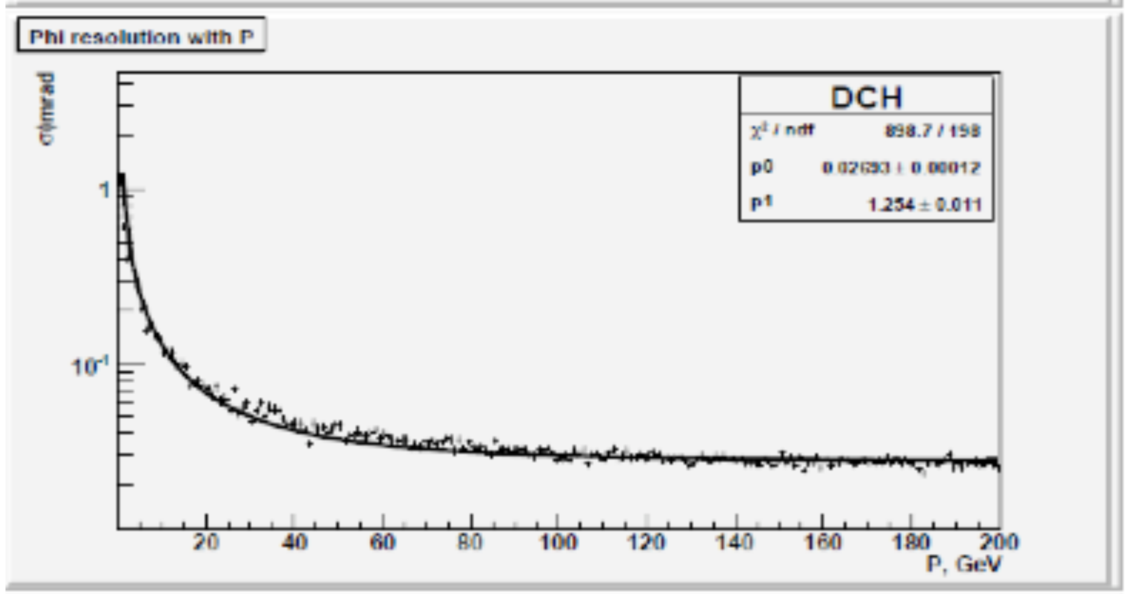

4TH DETECTOR EXTENDED
R
Bt
zoom(-1.5,0,3,1)
1.
0.8
0.6
0.4
0.2
0.
-1.5
-1.
-0.5
0.
0.5
1.
1.5
3.50840
3.50120

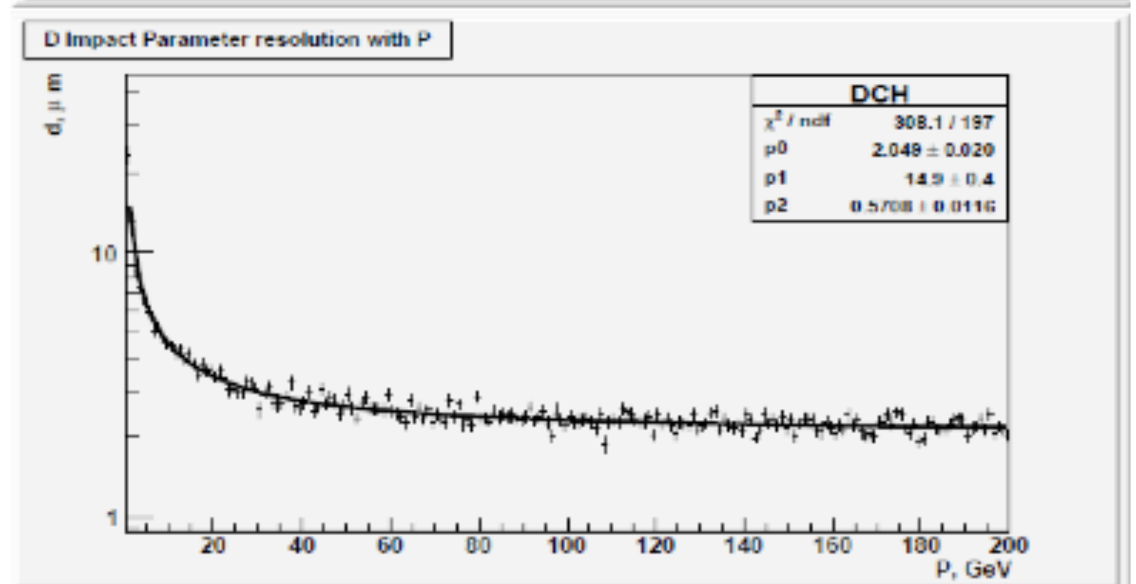
Single muons
No beam bkg

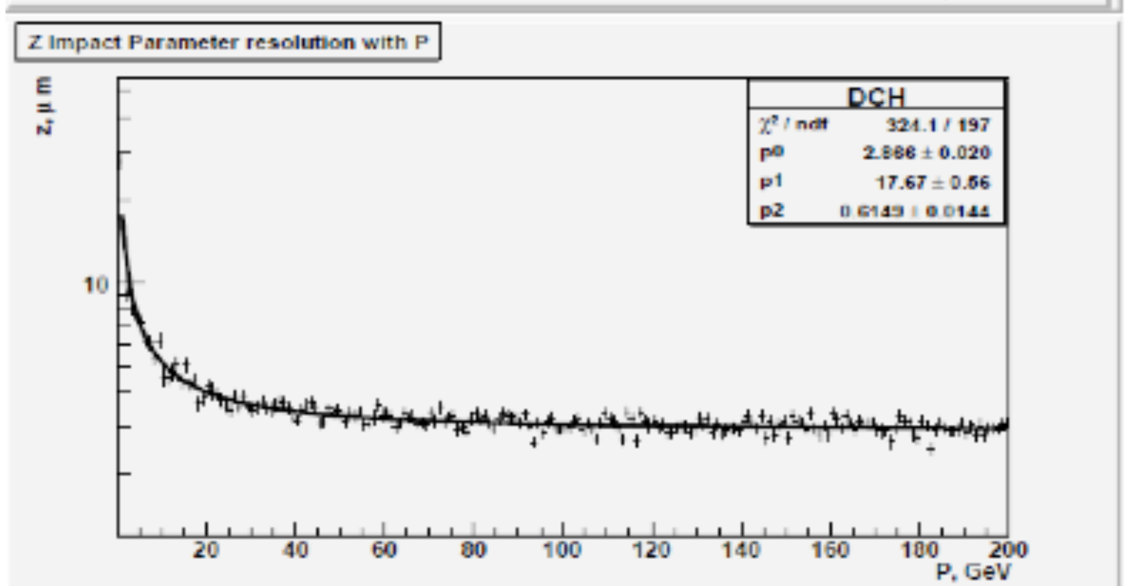
Tracking resolutions vs. P(GeV/c)







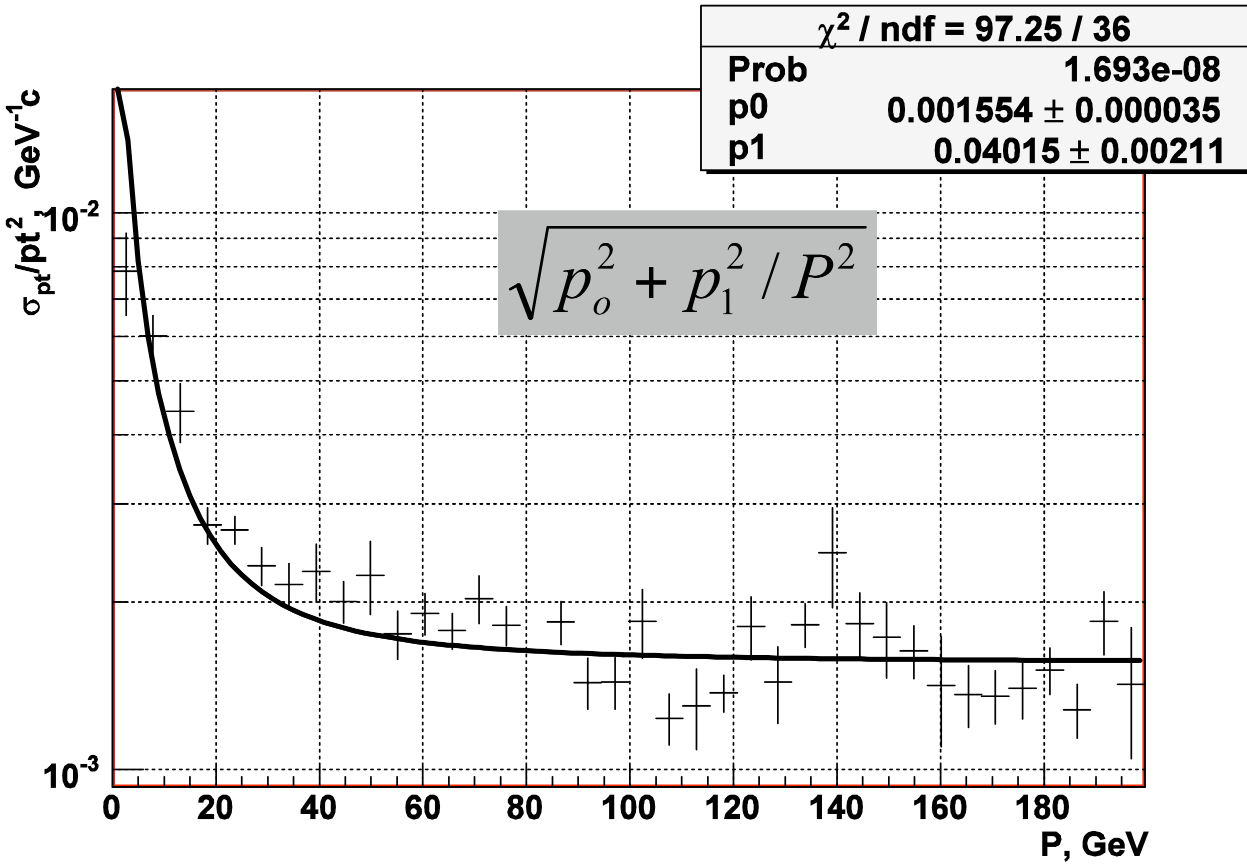




track parameter	fit results stochastic term	multiple scattering term
$\sigma(1/p_T)$	$3.9 \times 10^{-5}\ (\mathrm{GeV}/c)^{-1}$	$\oplus\ 7.9 \times 10^{-3}/p_T$
σ_θ	$0.69\ \mathrm{mrad}/p_T^{0.80}$	$\oplus\ 0.027\ \mathrm{mrad}$
σ_ϕ	$1.25\ \mathrm{mrad}/p_T$	$\oplus\ 0.027\ \mathrm{mrad}$
σ_d	$14.9\ \mu\mathrm{m}/p_T^{0.57}$	$\oplus\ 2.0\mu\mathrm{m}$
σ_z	$17.7\ \mu\mathrm{m}/p_T^{0.58}$	$\oplus\ 2.9\mu\mathrm{m}$

Muon Spectrometer tracking performance

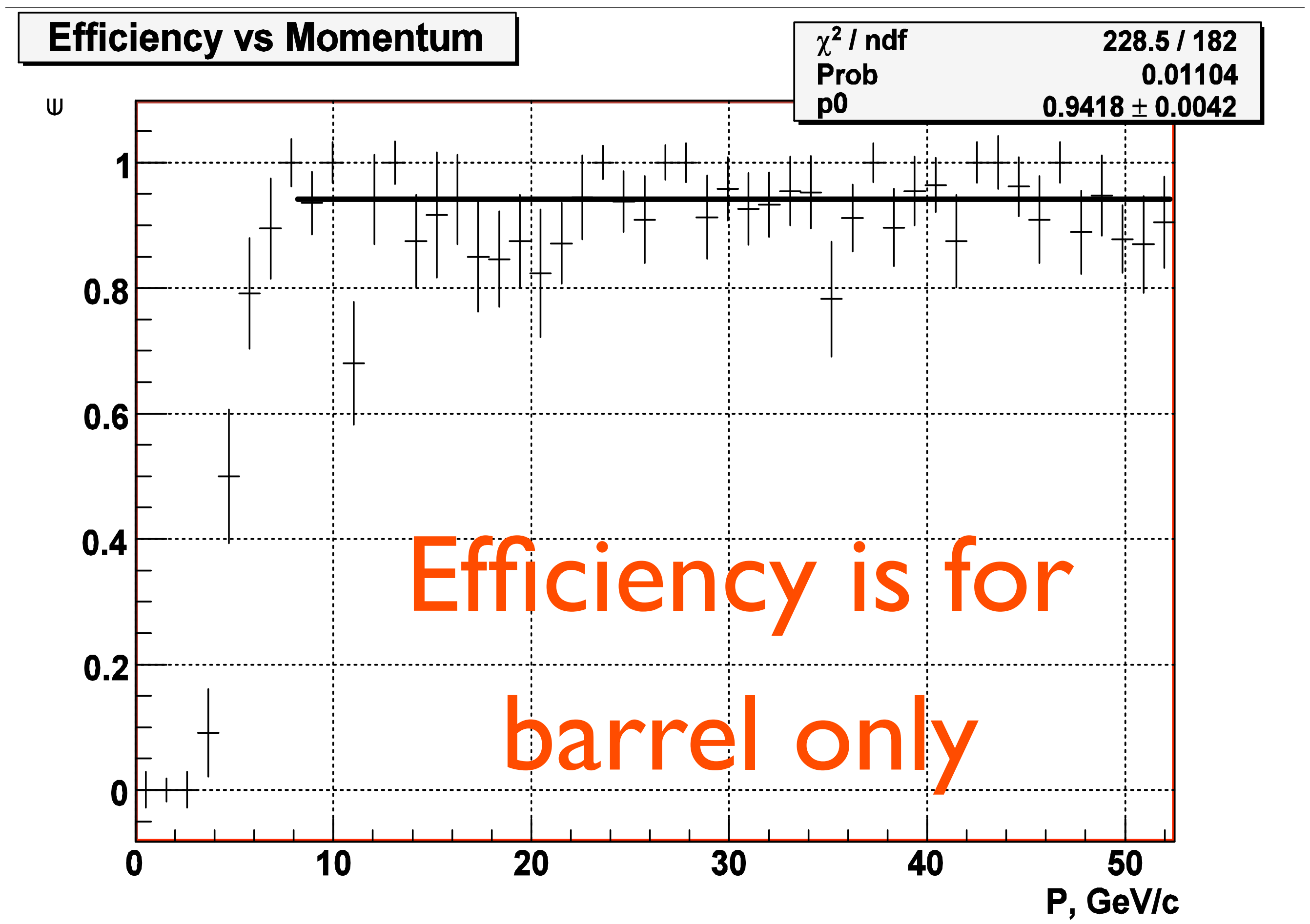
(same cluster-timing tracking as in main tracker)



Cracks excluded

Requires tracks already reconstructed in DCH

$$\sigma(P_t^{-1}) = 0.04 / P \oplus 1.5 \times 10^{-3} GeV^{-1} c$$

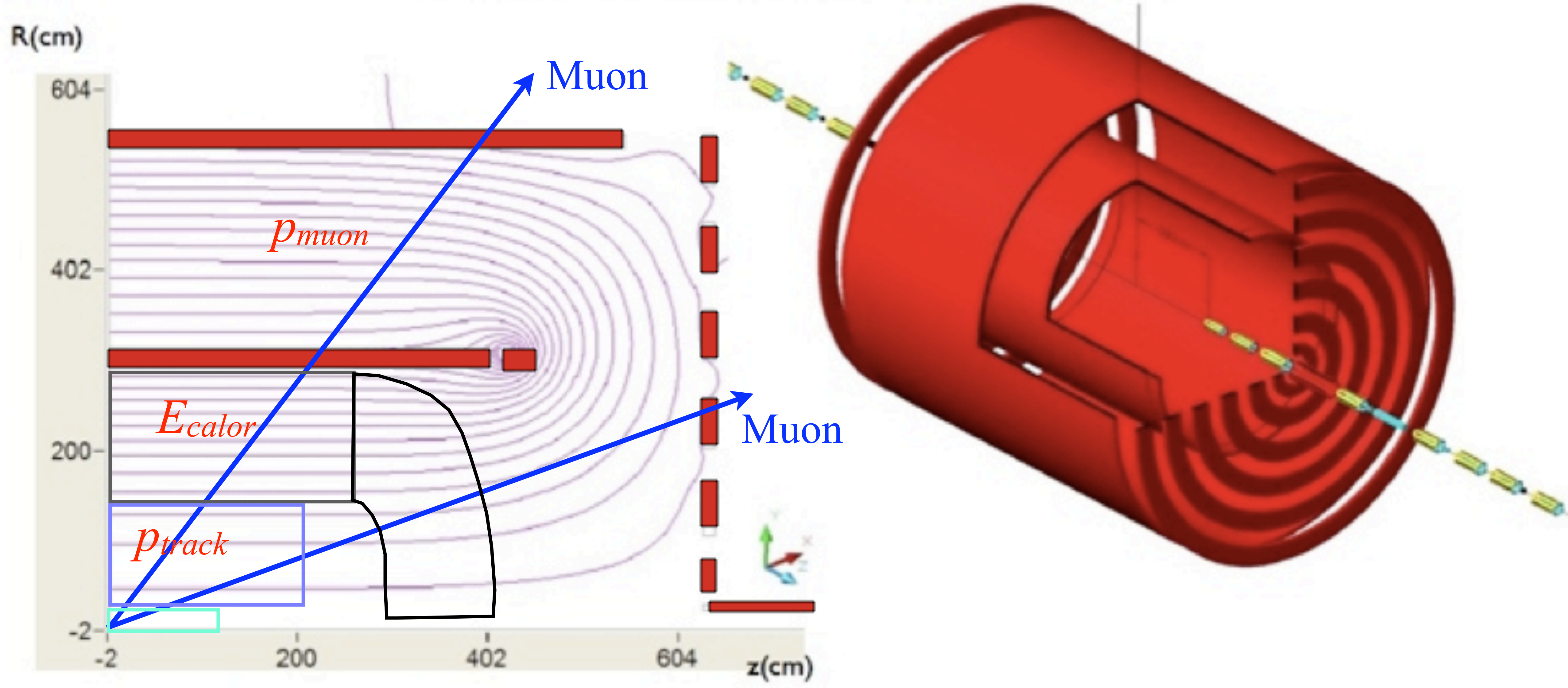


μ vs. $\pi_{\text{punch-through}}$ E-p balance: dual-solenoids

$$p_{track} = E_{calor} + p_{muon}$$

σ/p ~ 3x10^{-5} p   0.04/√E   1.6x10^{-3} p

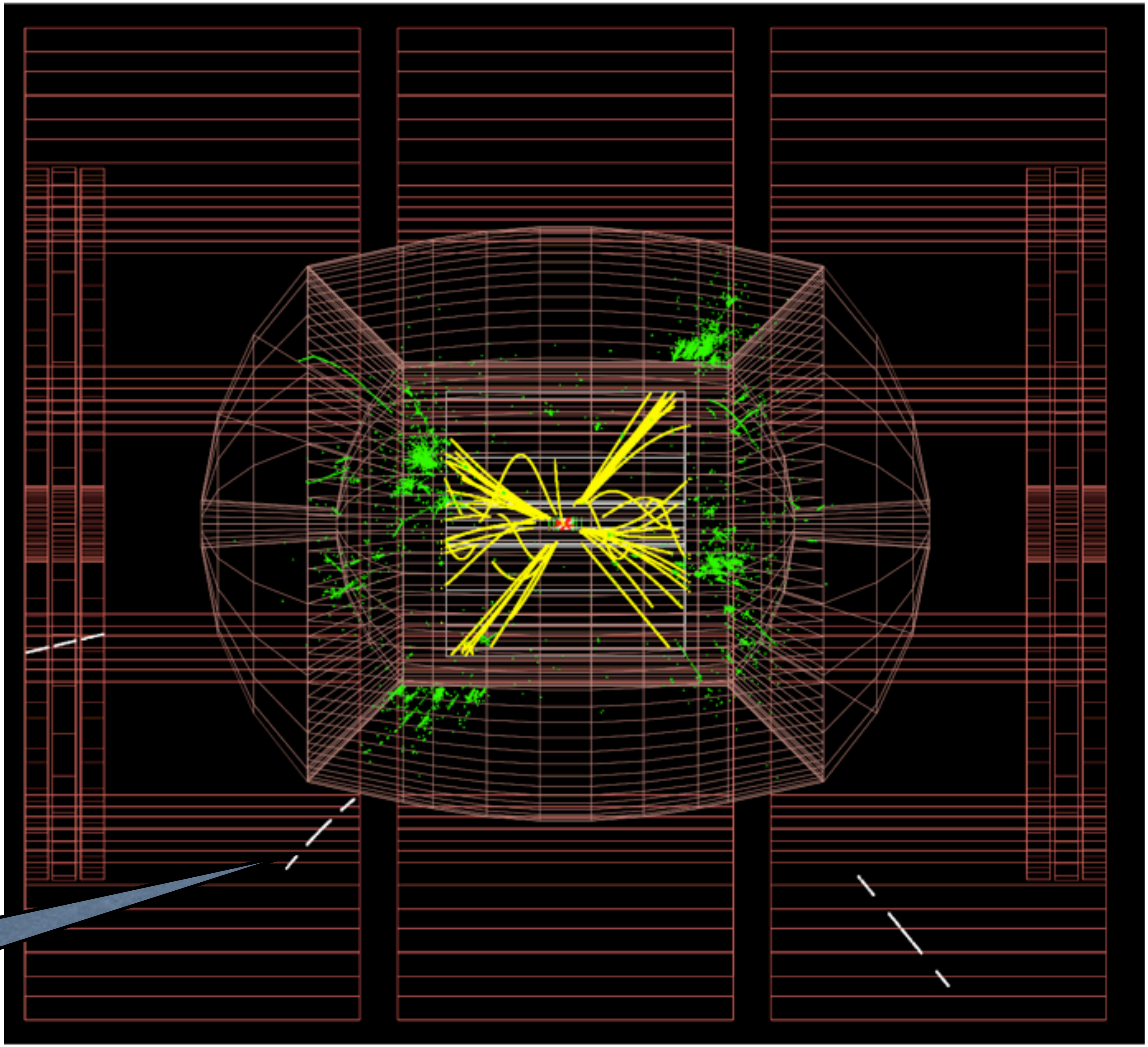
Magnetic field of dual solenoid and wall of coils



Event Display in ILCroot

$e^+e^- \to H^oH^oZ^o$
$\to$ 4 jets
+ 2 muons

E_{CM} = 500 GeV



Low pt secondary muon

Can the momentum resolution in the annulus be improved?

- This would provide a tighter energy constraint
- Pion rejection increasing to 50-100
- Might also be useful for "new physics" that appears at long times, leaving tracks behind the calorimeter.

The resolution depends on the point resolution in the tracking chambers, $\sigma_x \sim 200\mu m$. We assumed this for practical reasons and with a careful look at the ATLAS muon system. In the spirit of a "concept" we could have assumed $\sigma_x \sim 50\mu m$.

Also, on B and L^2 between the solenoids. It turns out that BL^2 is independent of the radius of the outer solenoid, so we cannot easily gain in L^2, and B from the inner solenoid is at the CMS-limit for current densities. This invariant is because the inner solenoid flux density is 3.5T = 3.5 Webers/m^2. This number of Webers must fill the annulus of area $[\pi R^2_{outer} - \pi R^2_{inner}]$. Increasing R_{outer} increases L linearly and decreases the flux density as the square, so BL^2 is approximately constant.

Dual-readout (fiber) identification

μ *ID* in dual-readout: $\theta_{Cerenkov} > \theta_{num.\ aperture}$

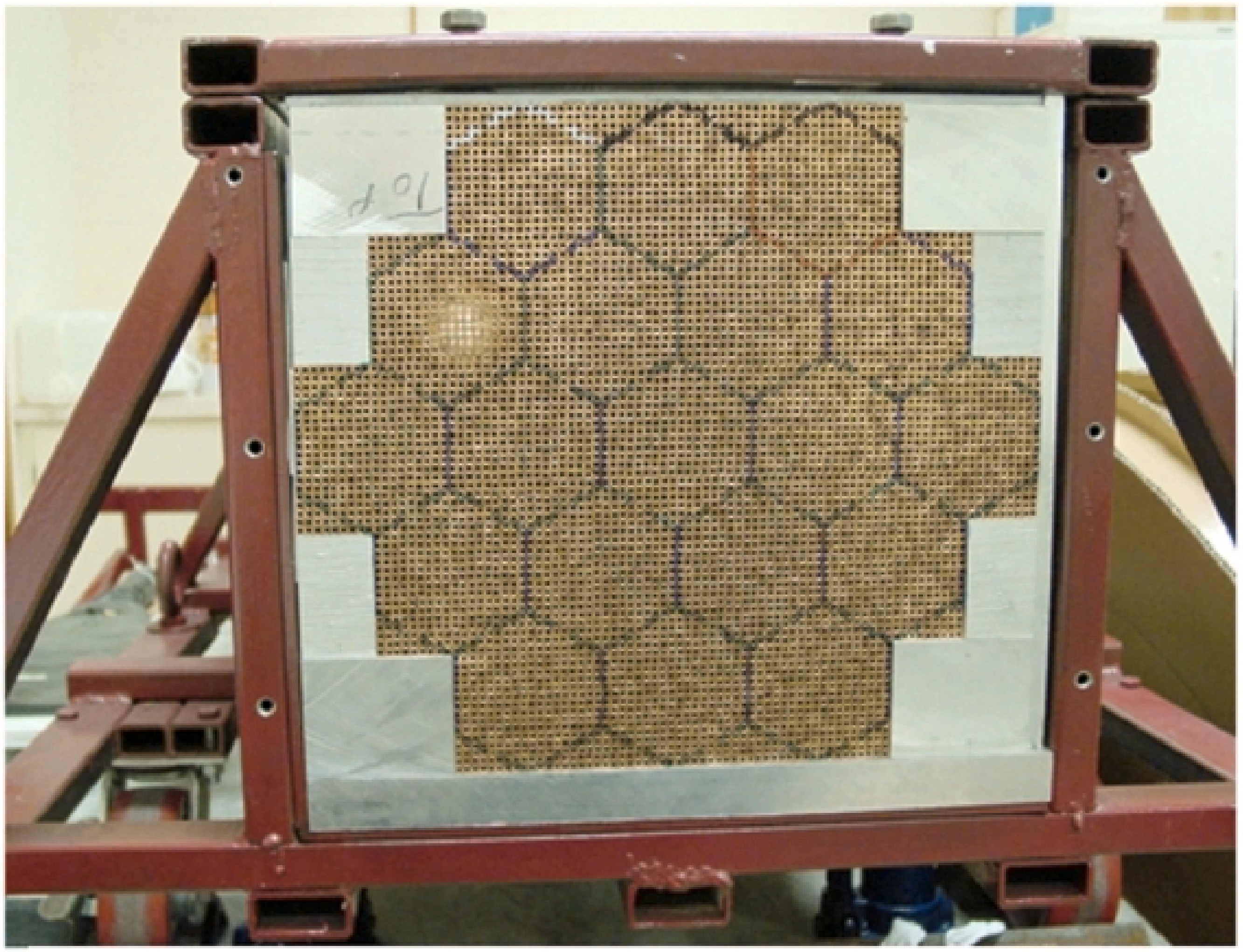
(S~*dE/dx+brems* & *C~brems)*

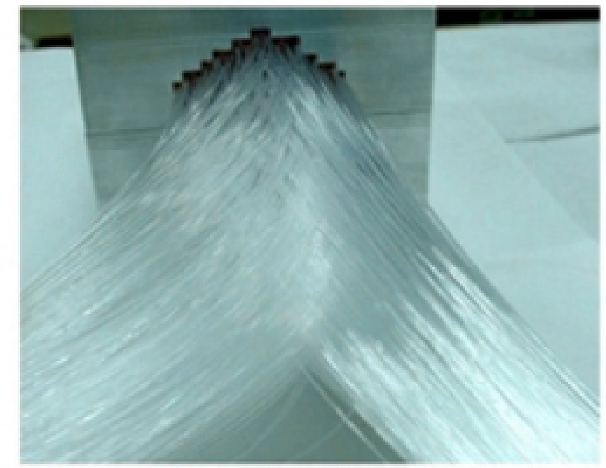
S-C ~ *dE/dx* ~ 1.1 GeV (in DREAM) for μ

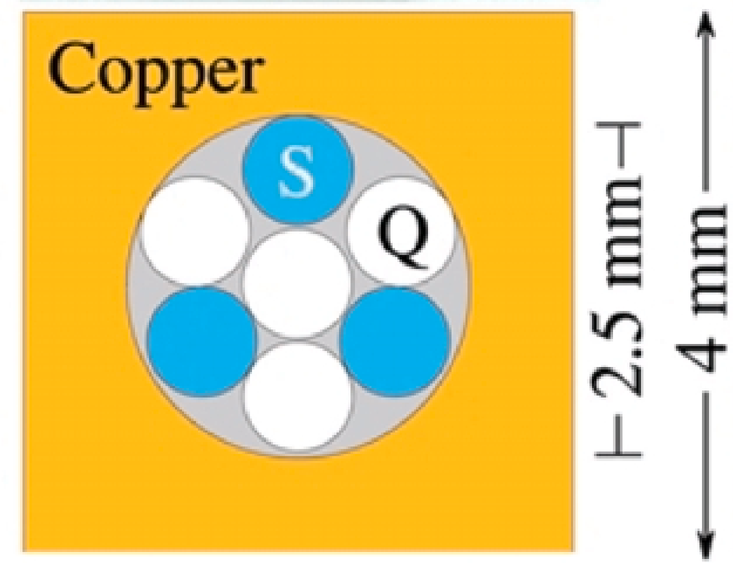
The “proof-of-principle” DREAM module

S = scintillating fibers
Q = quartz (clear) fibers

DREAM: Structure

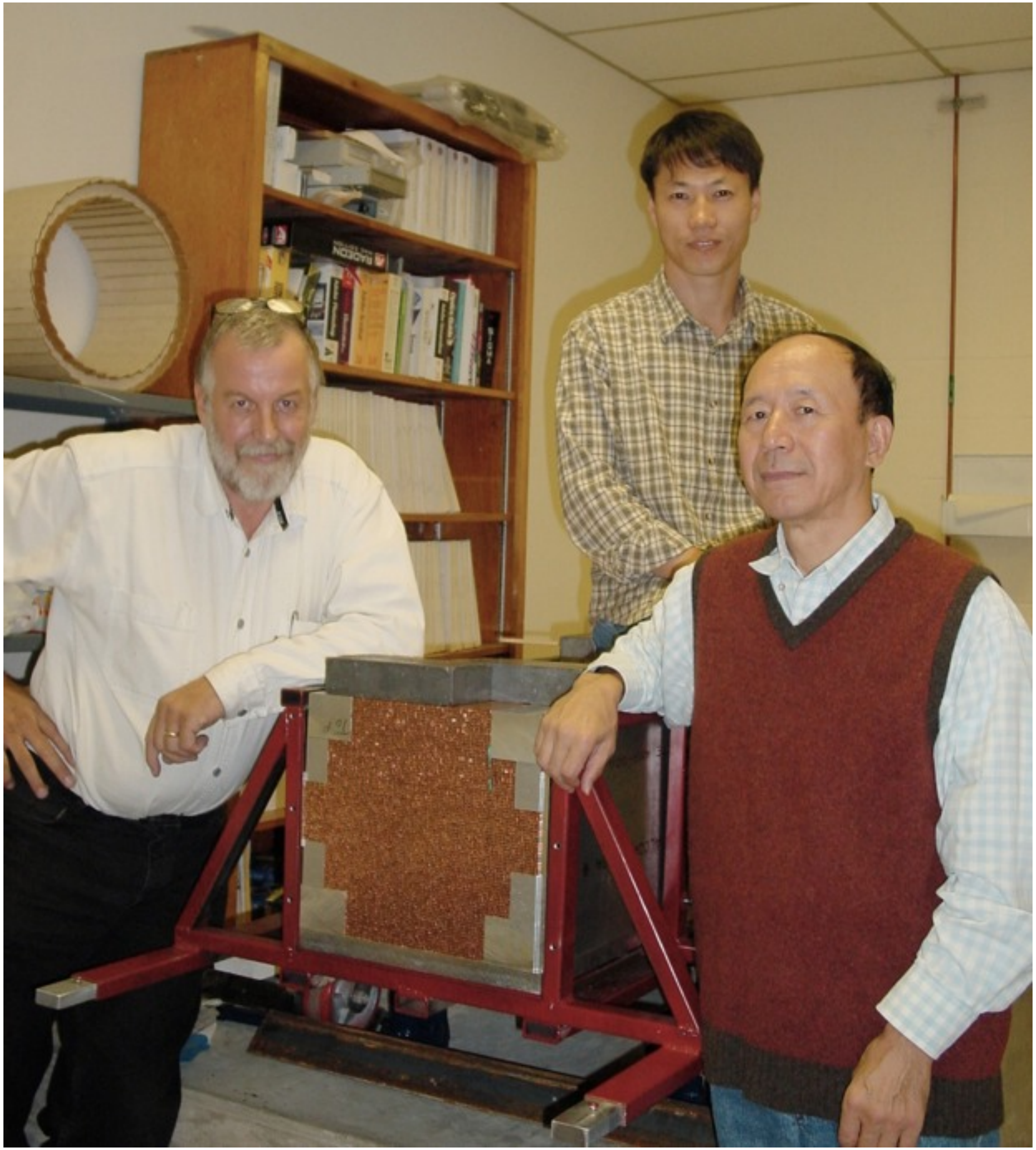






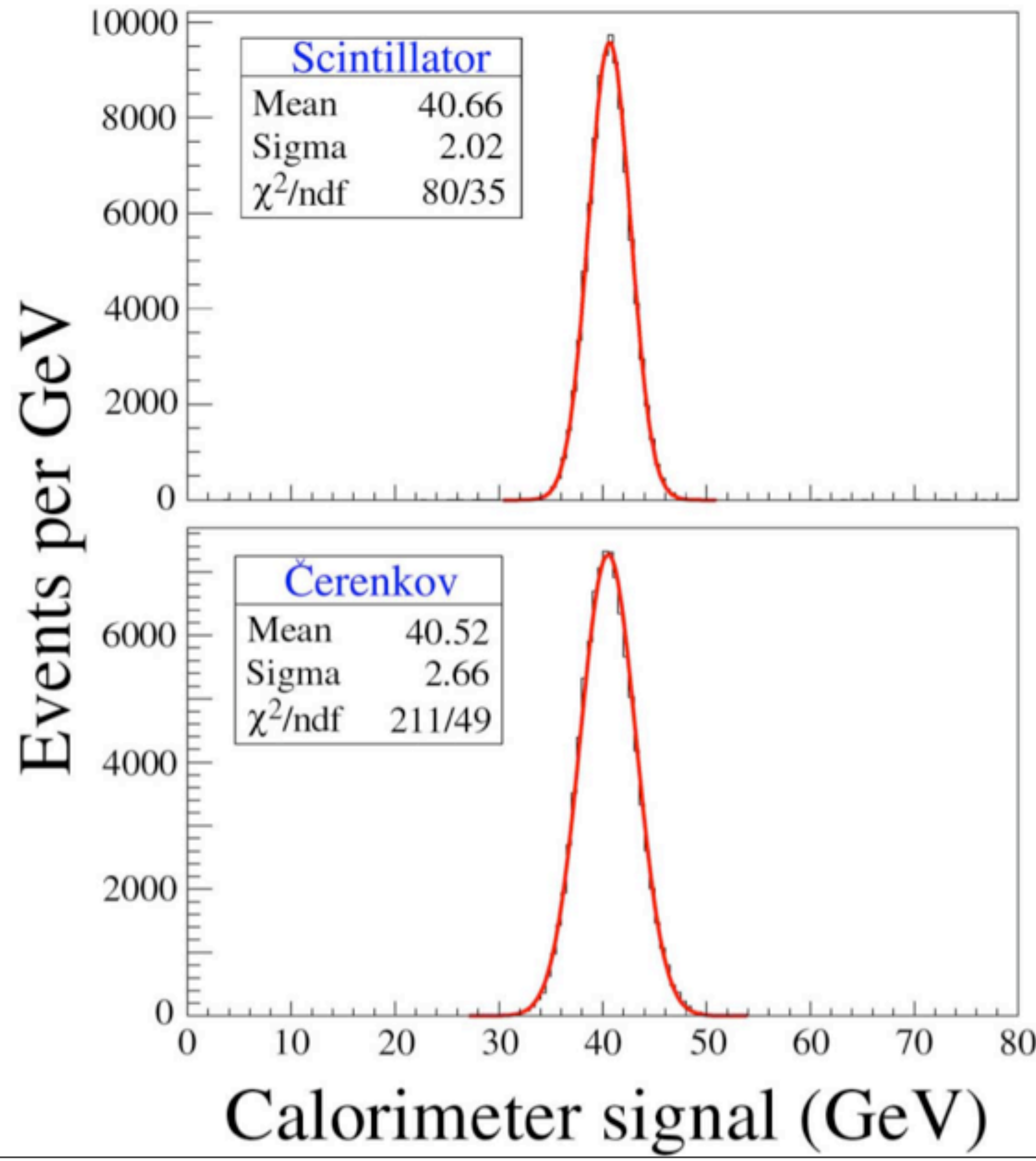
- *Some characteristics of the DREAM detector*
  - Depth 200 cm (10.0 λ_{int})
  - Effective radius 16.2 cm (0.81 λ_{int}, 8.0 ρ_M)
  - Mass instrumented volume 1030 kg
  - Number of fibers 35910, diameter 0.8 mm, total length $\approx$ 90 km
  - Hexagonal towers (19), each read out by 2 PMTs

Simply built, inexpensive, proof-of-principle DREAM module ($10\ \lambda_{INT}$)



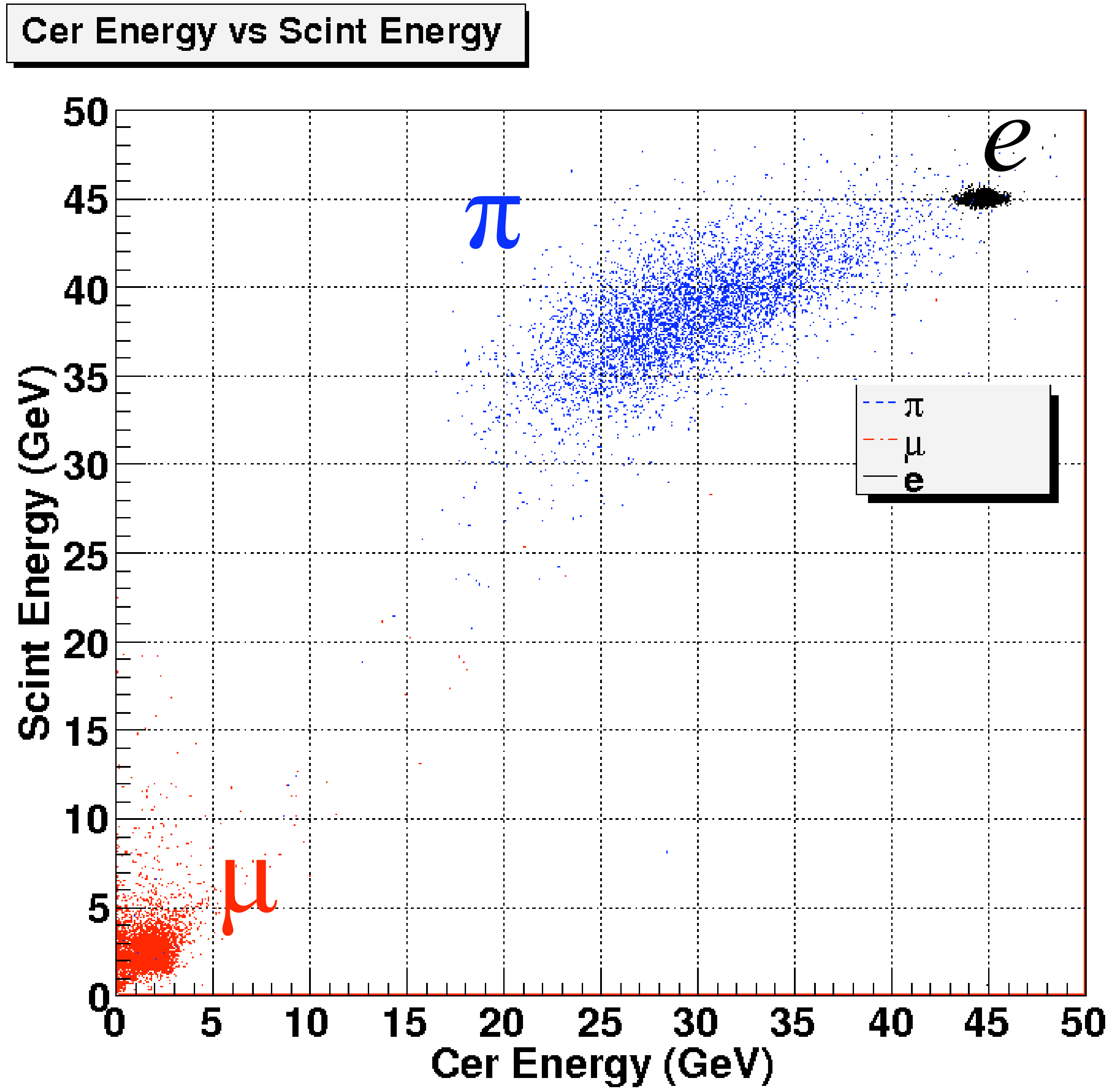
Muons tagged by scintillation counter downstream and behind an additional $8\ \lambda_{INT}$ of concrete

Calibrate with 40 GeV electrons: set GeV/ADC for both scintillation and Cerenkov to get <data> = 40 GeV

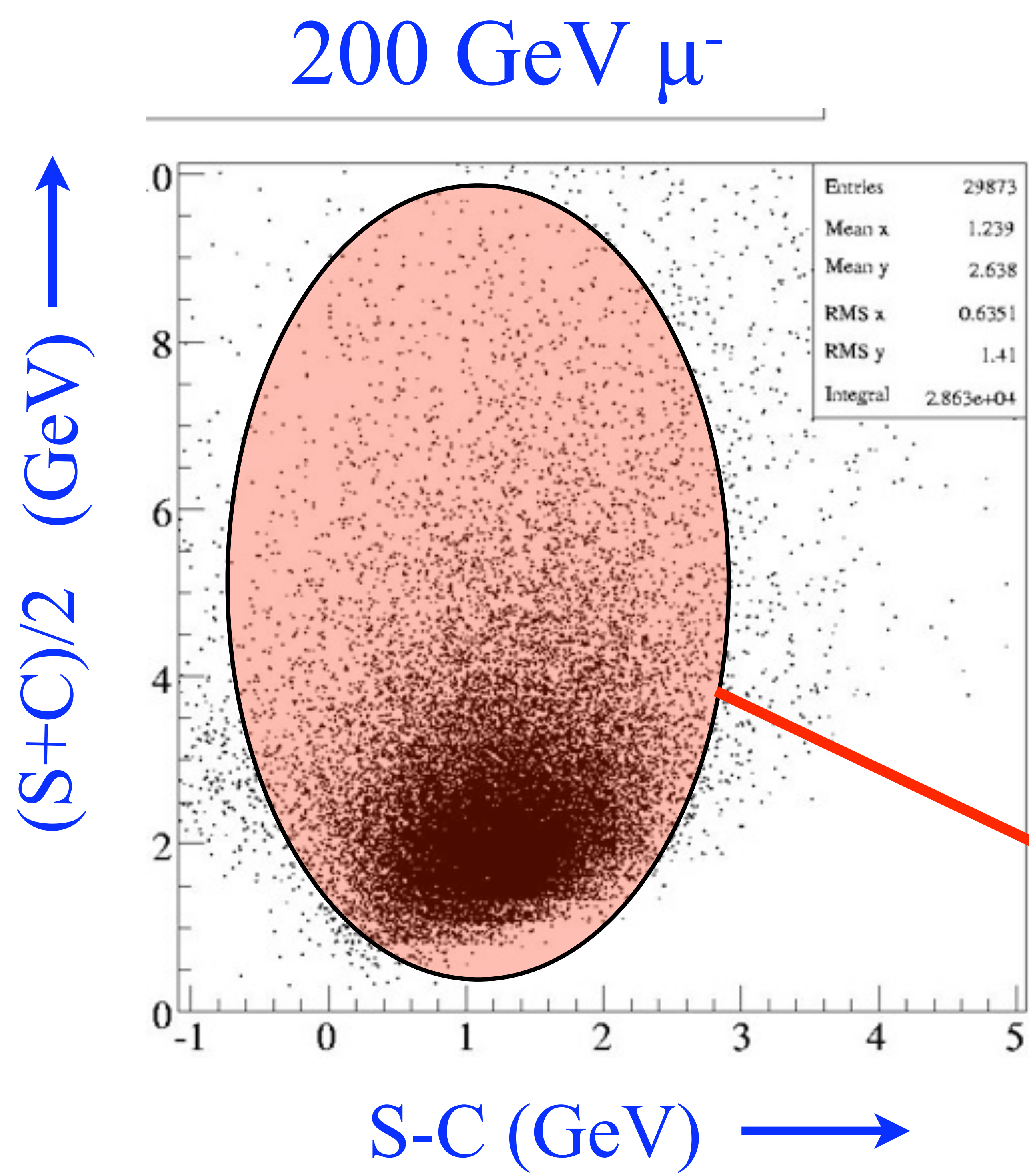


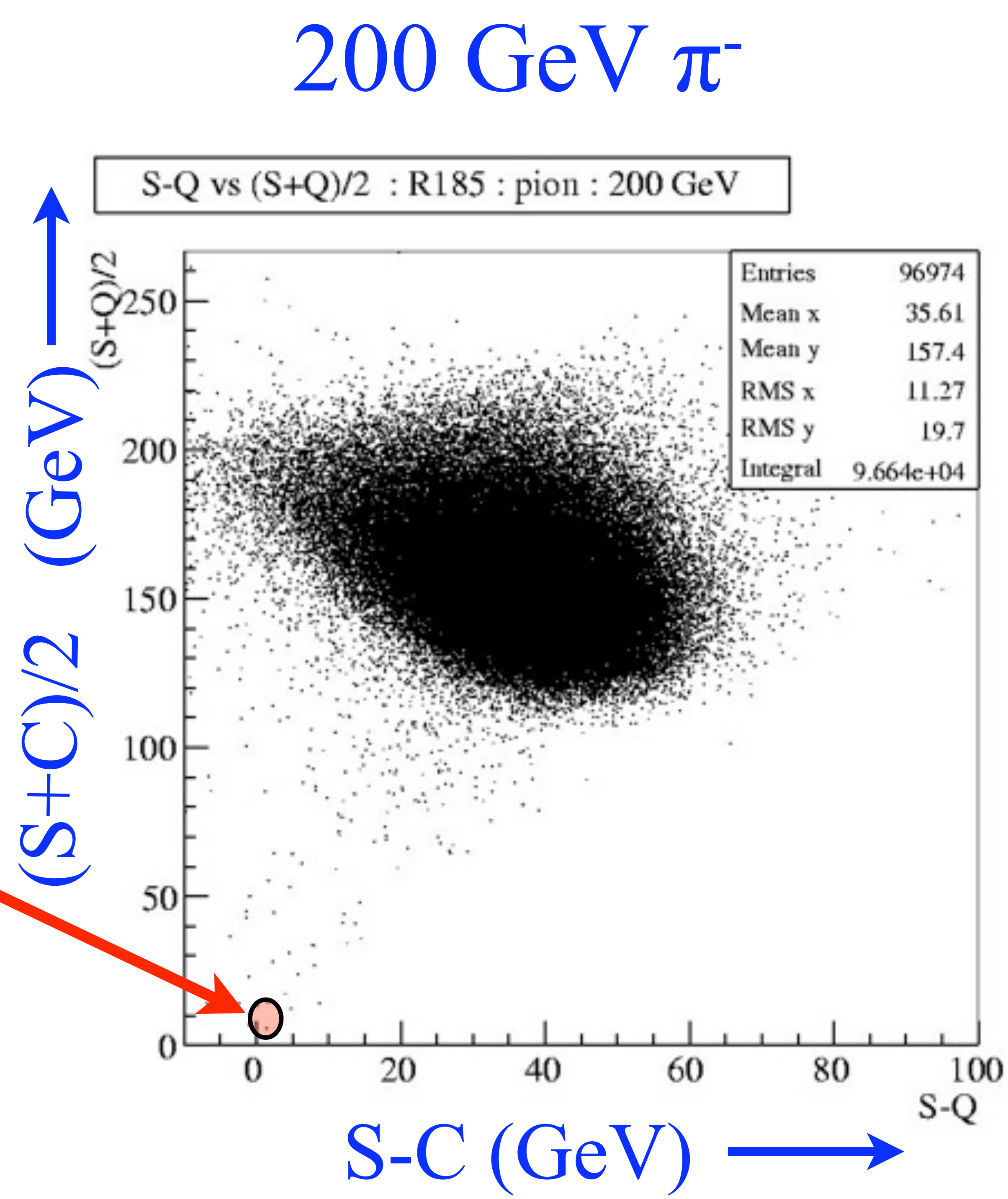
Dual-readout: Scintillation vs. Cerenkov plot

4th simulation (45 GeV)



μ-π descrimination (DREAM data) π rejection ~ 10^5:1

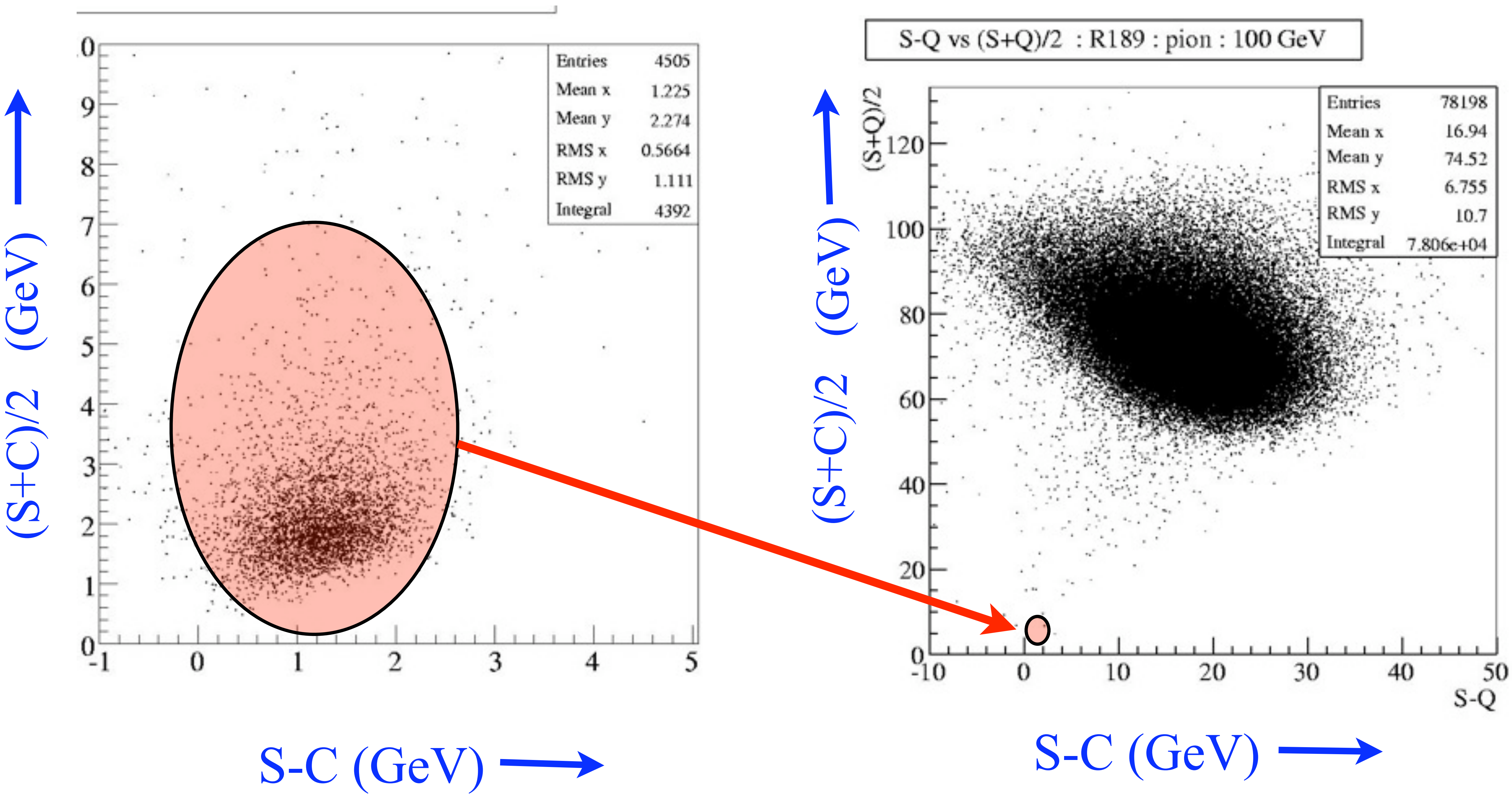




π rejection ~ 10^4:1

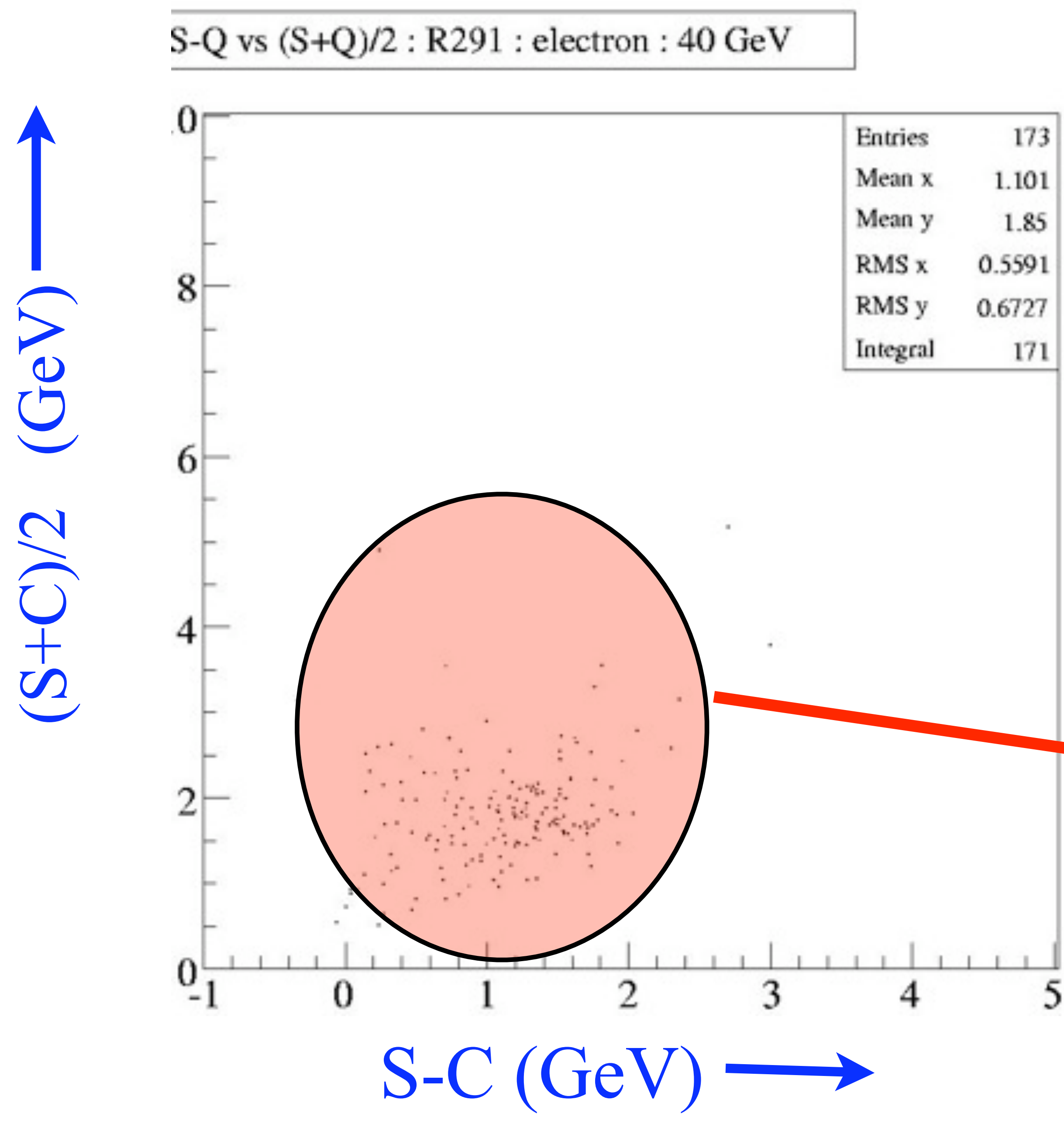
100 GeV μ^-

100 GeV π^-

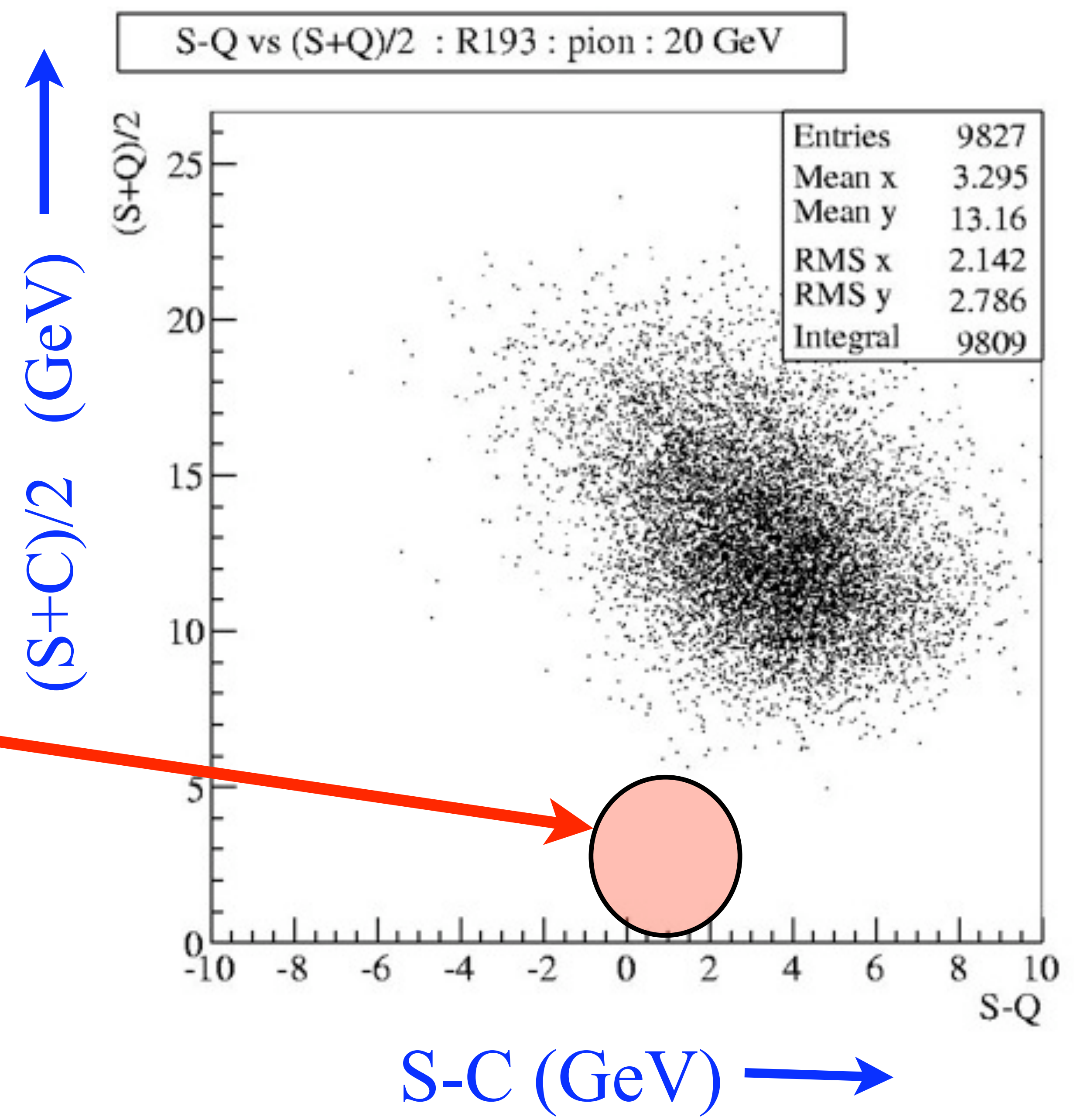


π rejection $\sim 10^3$:1

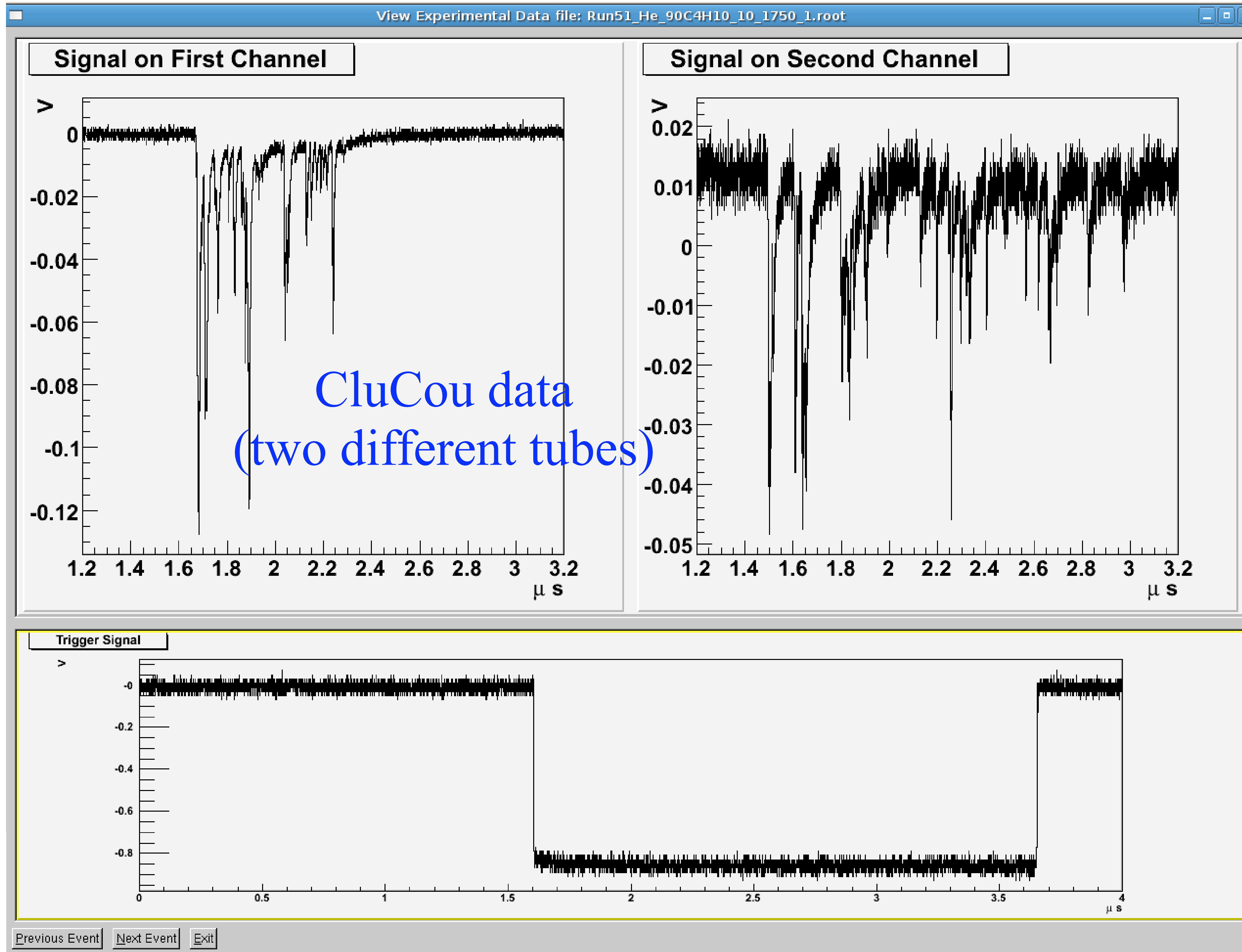
40 GeV μ^-



20 GeV π^-

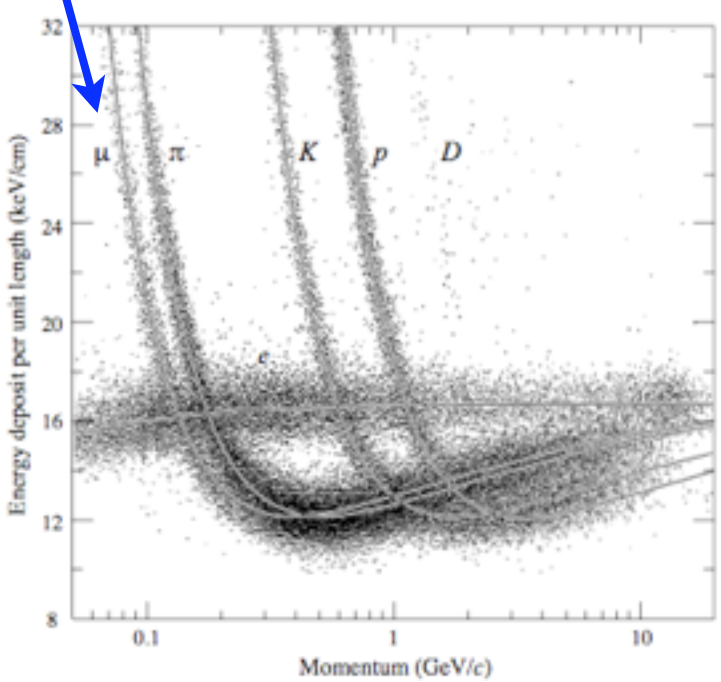


Weak muon ID at low momenta: CluCou cluster-counting is Poisson: better *dE/dx* specific ionization resolution ~3% (no Landau tail)



CluCou data
(two different tubes)

μ^-



dE/dx resolution TPC LBL/PEP4
(using truncated mean ~6%)

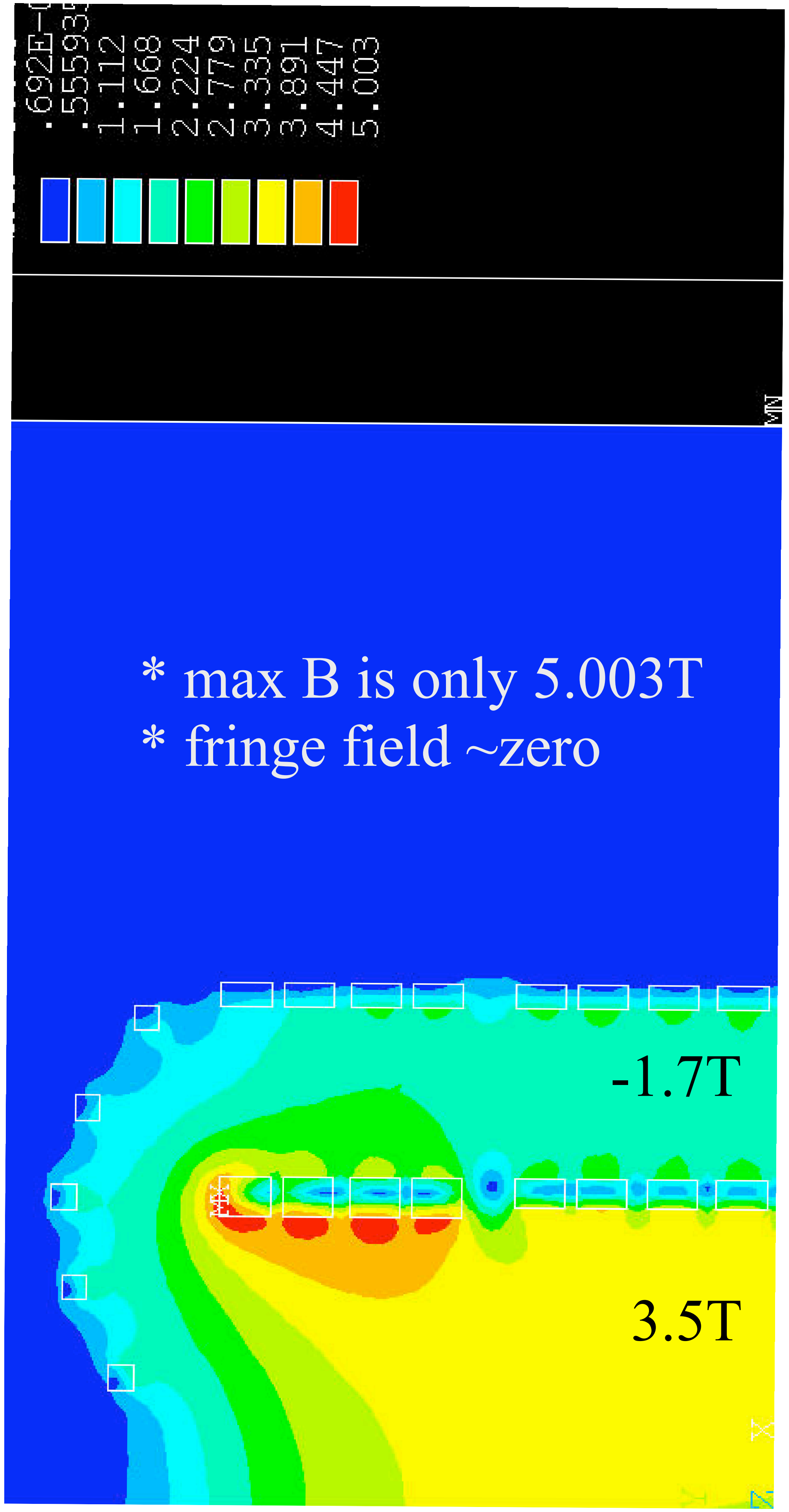
Summary

Good kinematic fix on muons after solenoid; pion rejection ~ 10-50

Dual-readout ID (most effective for isolated, or nearly isolated, tracks)

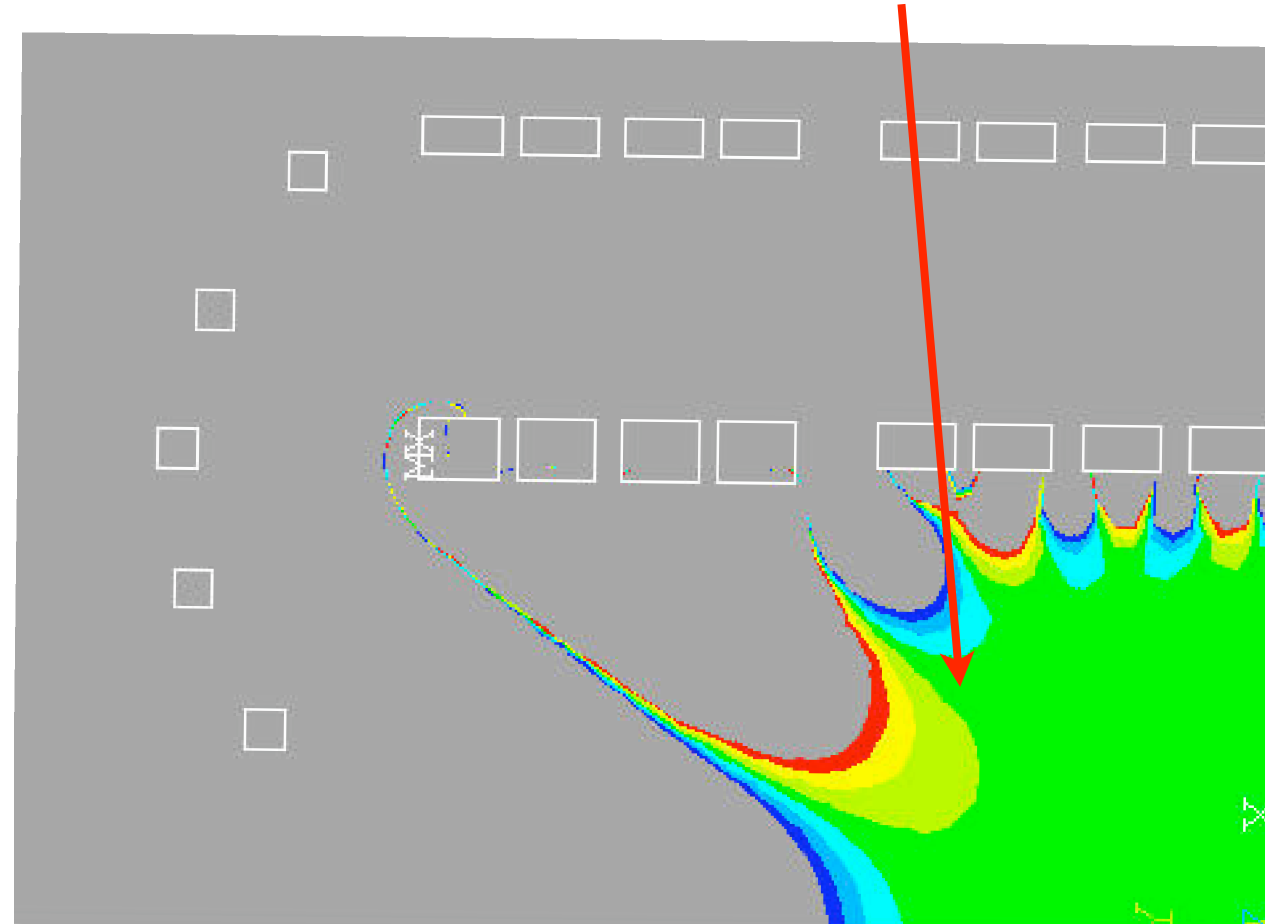
Spares

M. Wake solution for dual solenoids



Wake's solutions, compared to Mikhailichenko's, means there is a continuum of interesting solutions available.

Tracking field quality is excellent: each color is dB/B=0.001



Particle Identification:

must be a priority for any new detector at a precision collider

- *uds* quarks (jet energy resolution)
- *c,b* quarks (vertex tagging)
- *t* quark (reconstruction)

- *electron* (dual-readout)
- *muon* (dual-readout and iron-free field)
- *tau* (reconstruction)
- *neutrino* (by subtraction; resolution)

- *W,Z* (hadronic jet reconstruction)
- *photon* (BGO dual readout)