Stable charged particle identification in 4th

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The main problem addressed here is the identification of a track (through a tracking system and into a calorimeter) with a very high efficiency and a very low mis-identification rate.

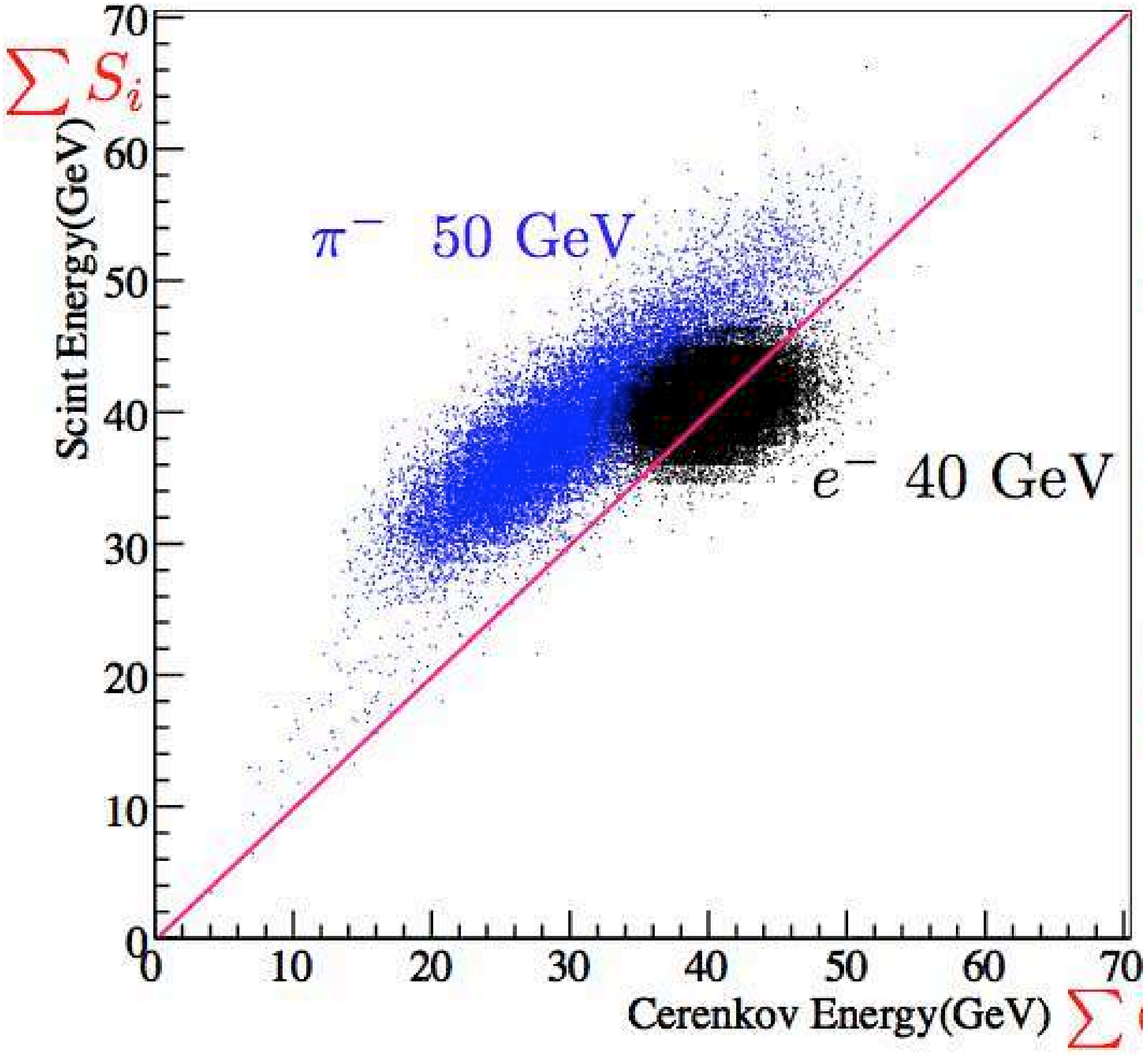
Valuable physics tracks are μ and *e*, and dominant background tracks are $\pi^{\pm}$ from high-x *q*/*g* fragmentation, but also $\tau \rightarrow \pi^{\pm}$.

μ and e sources are W,Z and also speculative exotic particles.

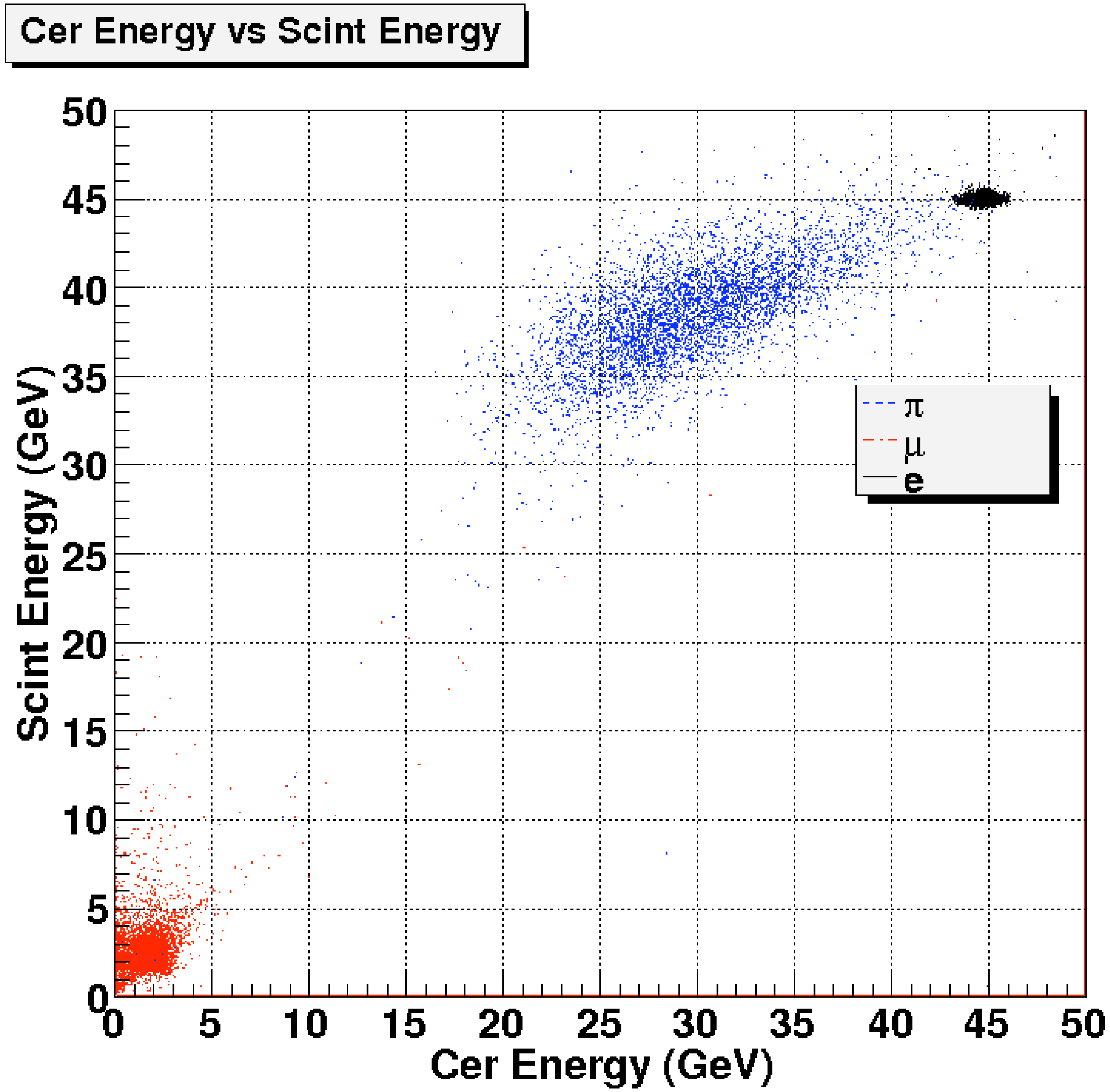
Telling an e from a π

e vs. π direct dual-readout

DREAM data



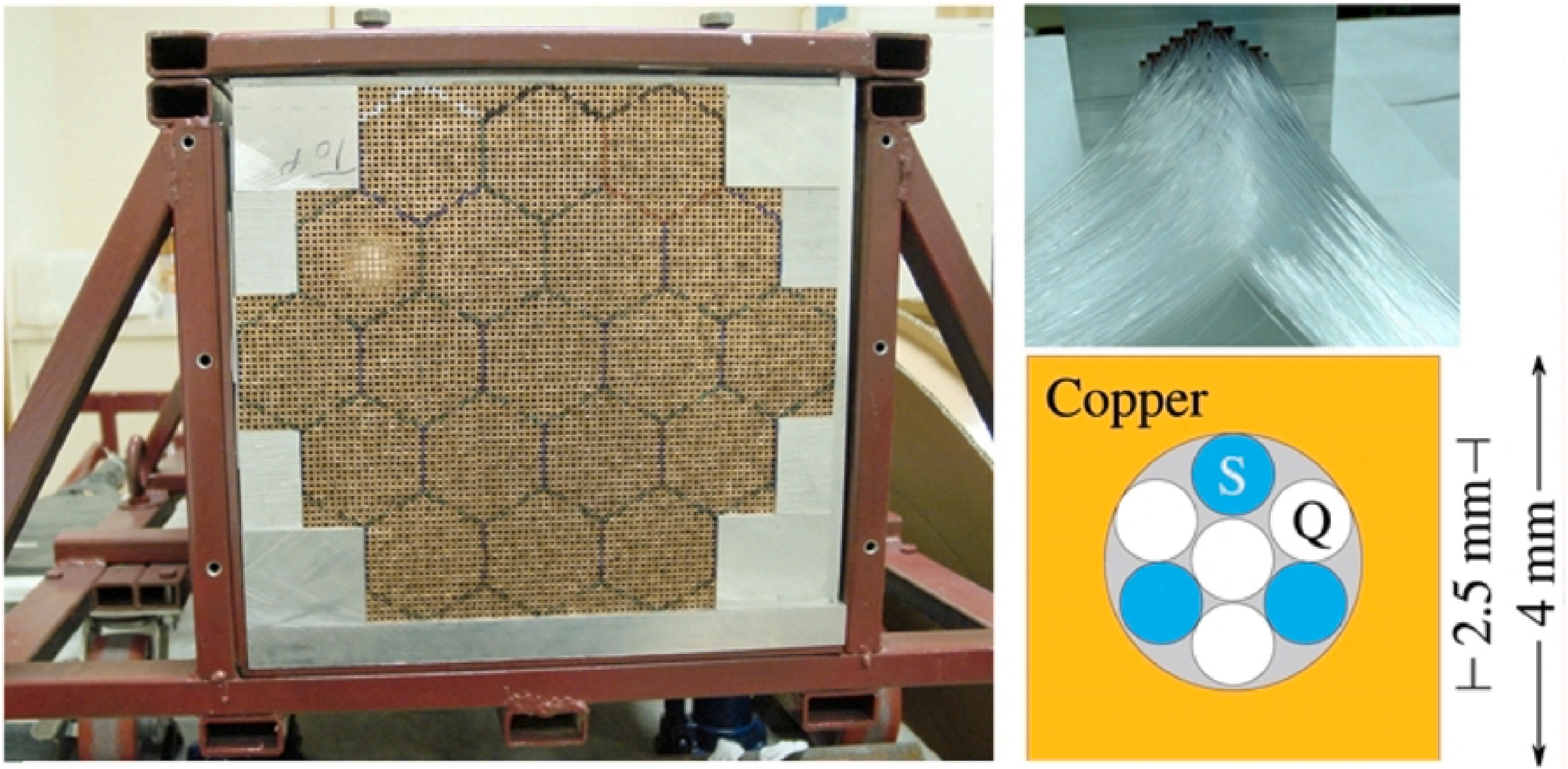
4th simulation (45 GeV)



The “proof-of-principle” DREAM module

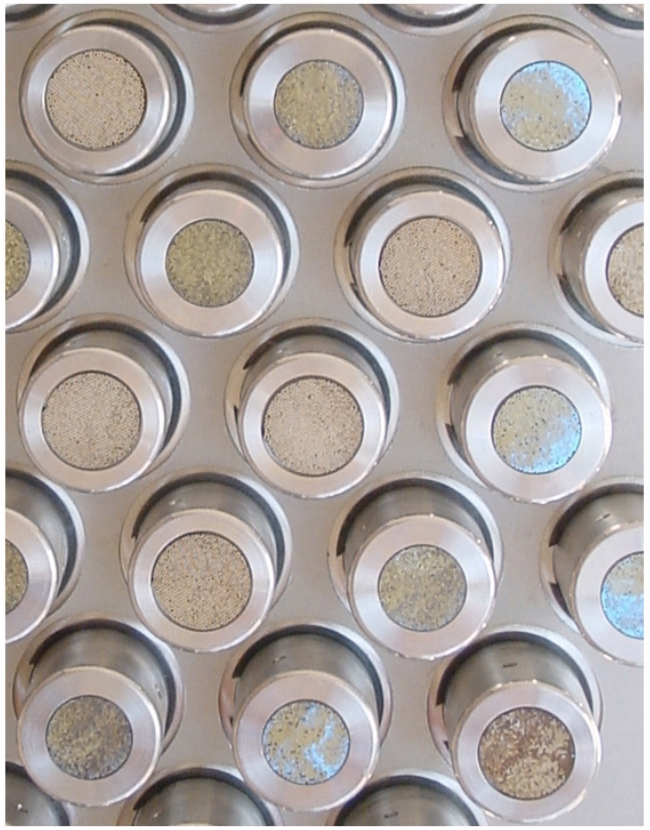
S = scintillating fibers
Q = quartz (clear) fibers

DREAM: Structure



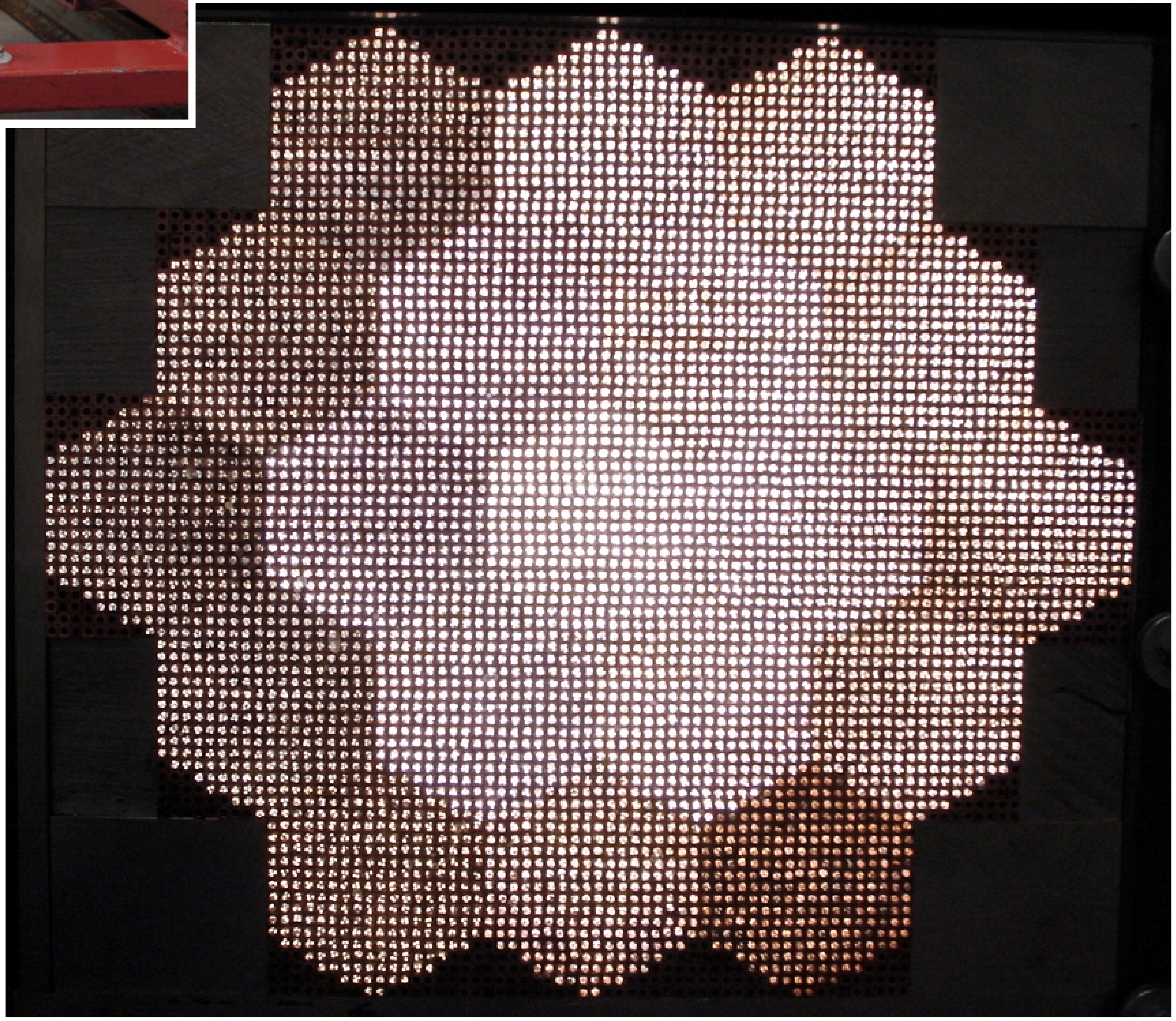
- *Some characteristics of the DREAM detector*
  - Depth 200 cm (10.0 λ_{int})
  - Effective radius 16.2 cm (0.81 λ_{int}, 8.0 ρ_M)
  - Mass instrumented volume 1030 kg
  - Number of fibers 35910, diameter 0.8 mm, total length $\approx$ 90 km
  - Hexagonal towers (19), each read out by 2 PMTs

DREAM readout

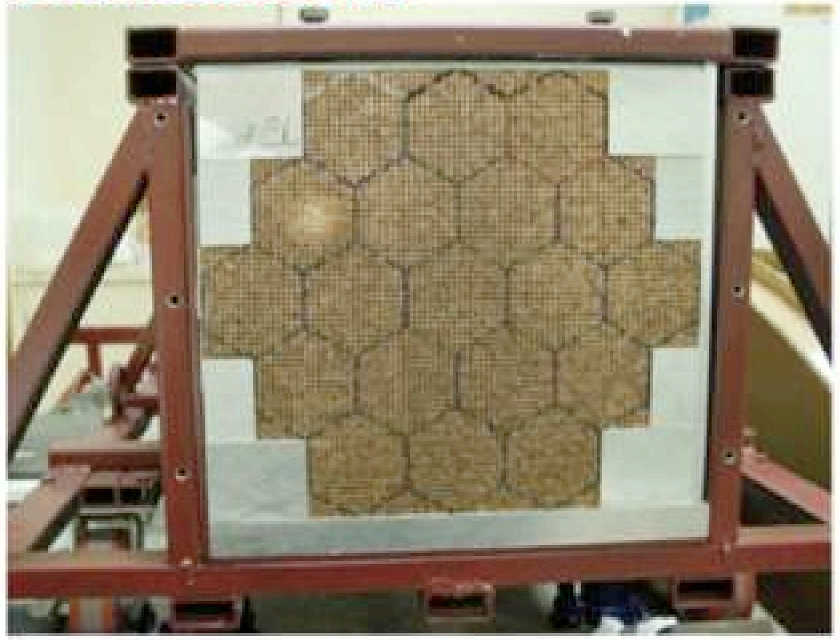


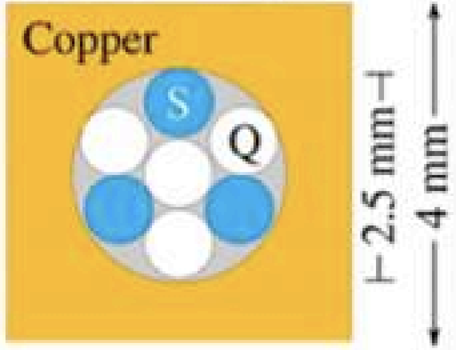
Channel structure defined by bundled scintillation and Cerenkov fibers

Shine light through module



Dual-readout DREAM: Structure





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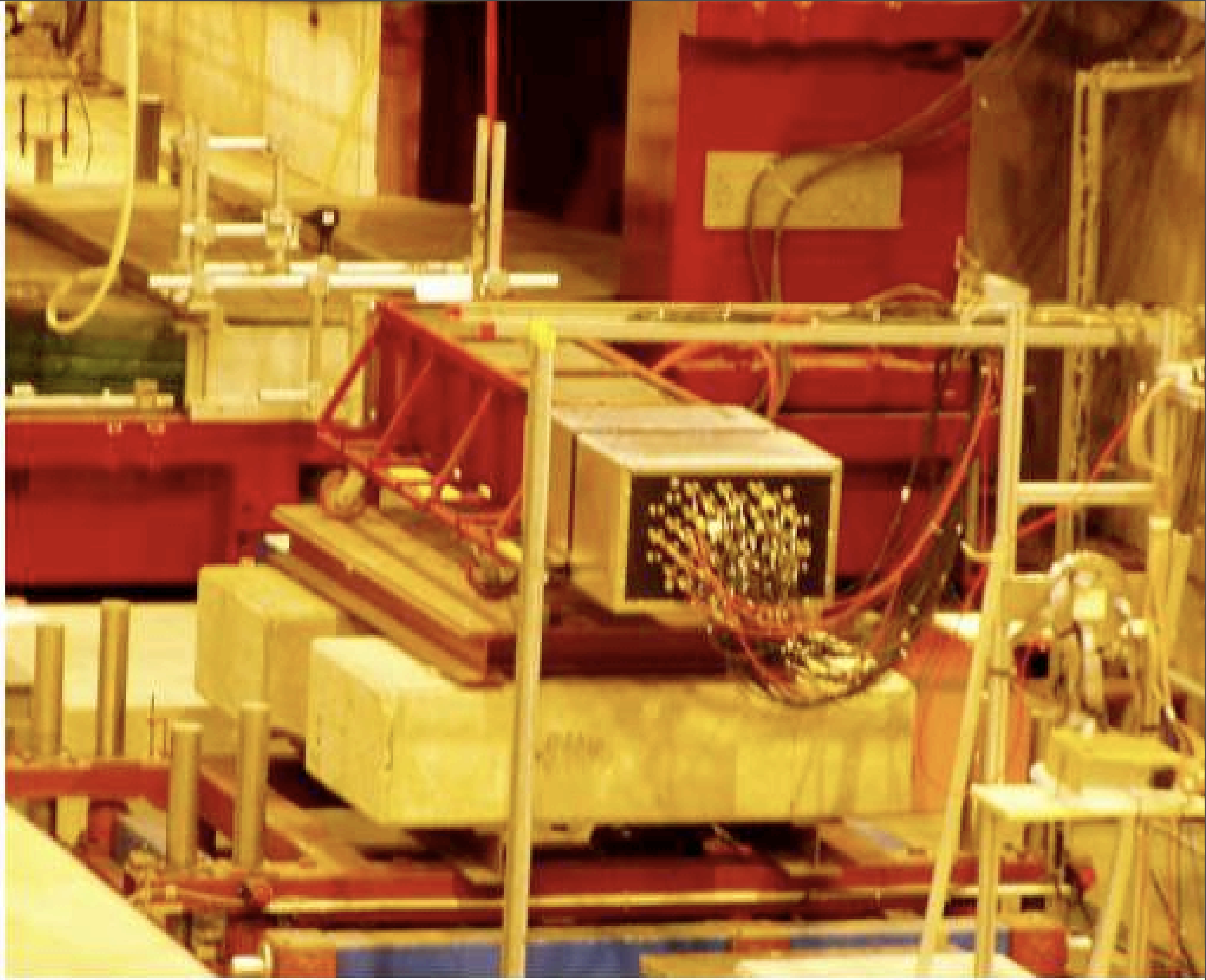

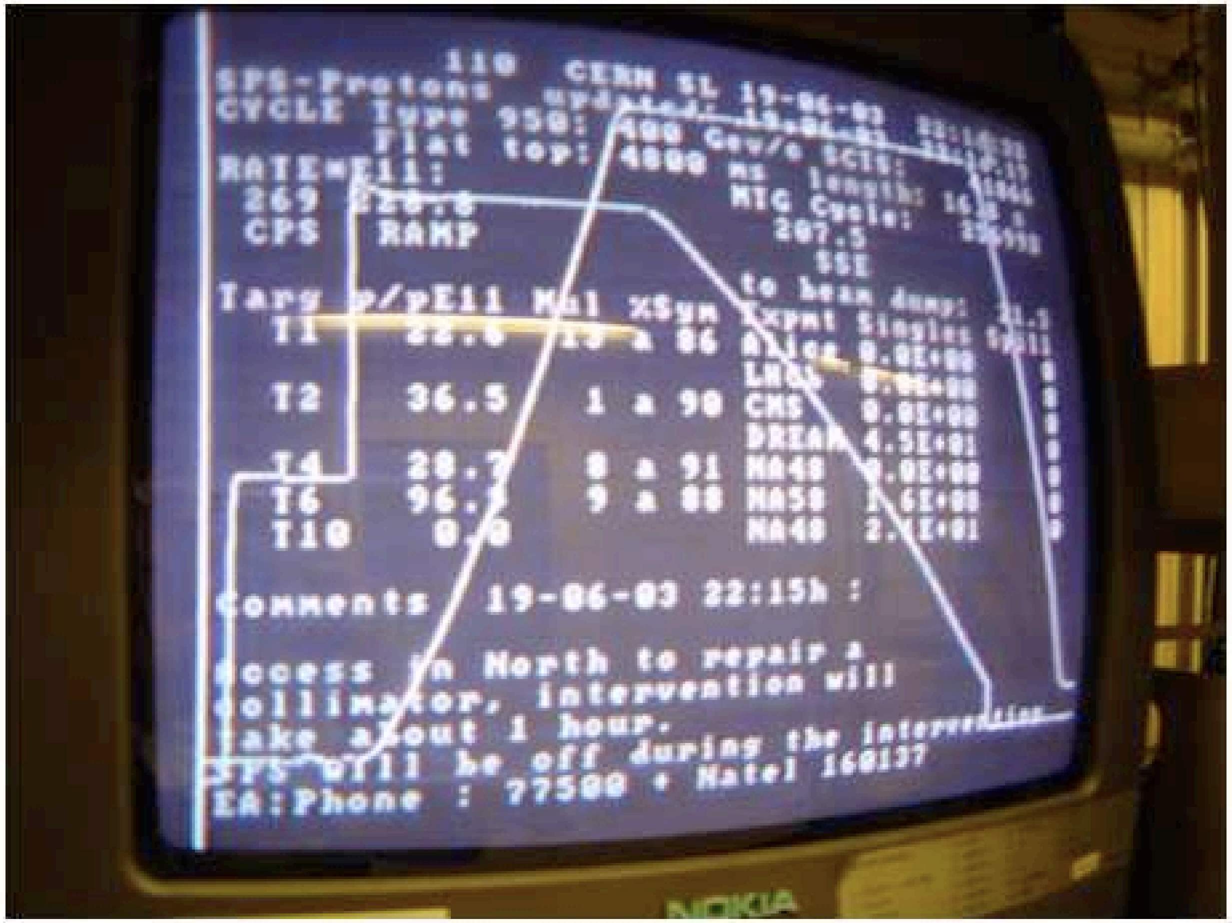

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             110   CERN SL 19-06-03 22:1[illegible]
SPS-Protons    updated: 19-06-03 22:1[illegible]
CYCLE Type 950: 400 GeV/c SCIS: [illegible]
       Flat top: 4800 ms  length: 16.8 [illegible]
RATE=E11:              MTC Cycle: [illegible]
 269  220.8                 207.5
 CPS  RAMP                   SSE
                        to beam dump: 21.1
Targ p/pE11 Mul %Sym Expmt Singles Spill
 T1    22.6  13 a 86 Alice 0.0E+00
                     LHCb  0.0E+00
 T2    36.5   1 a 90 CMS   0.0E+00
                     DREAM 4.5E+01
 T4    28.7   8 a 91 NA48  0.0E+00
 T6    96.[illegible]   9 a 88 NA58  1.6E+00
 T10    0.0          NA48  2.[illegible]E+01

Comments   19-06-03 22:15h :

Access in North to repair a
collimator, intervention will
take about 1 hour.
SPS will be off during the intervention
EA:Phone : 77500 + Natel 160137
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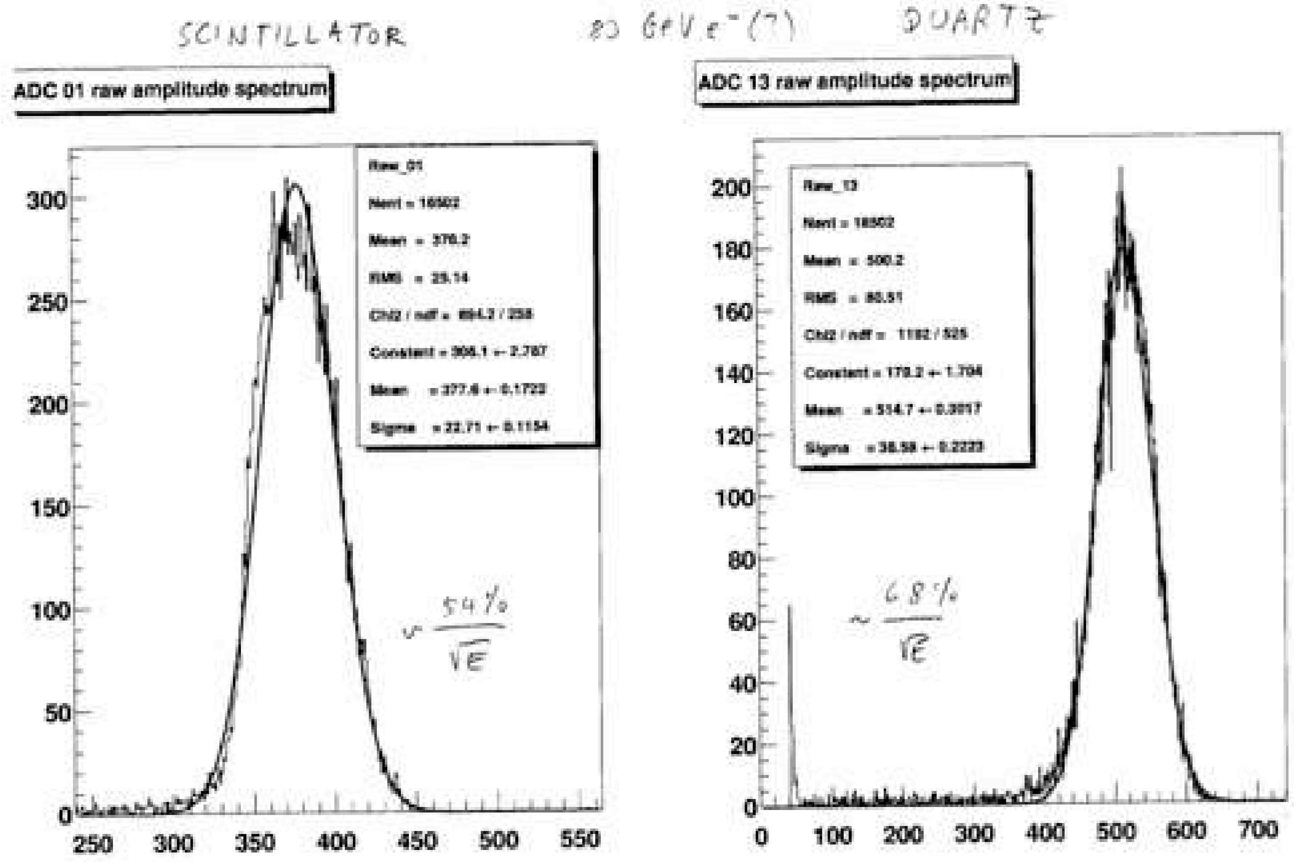
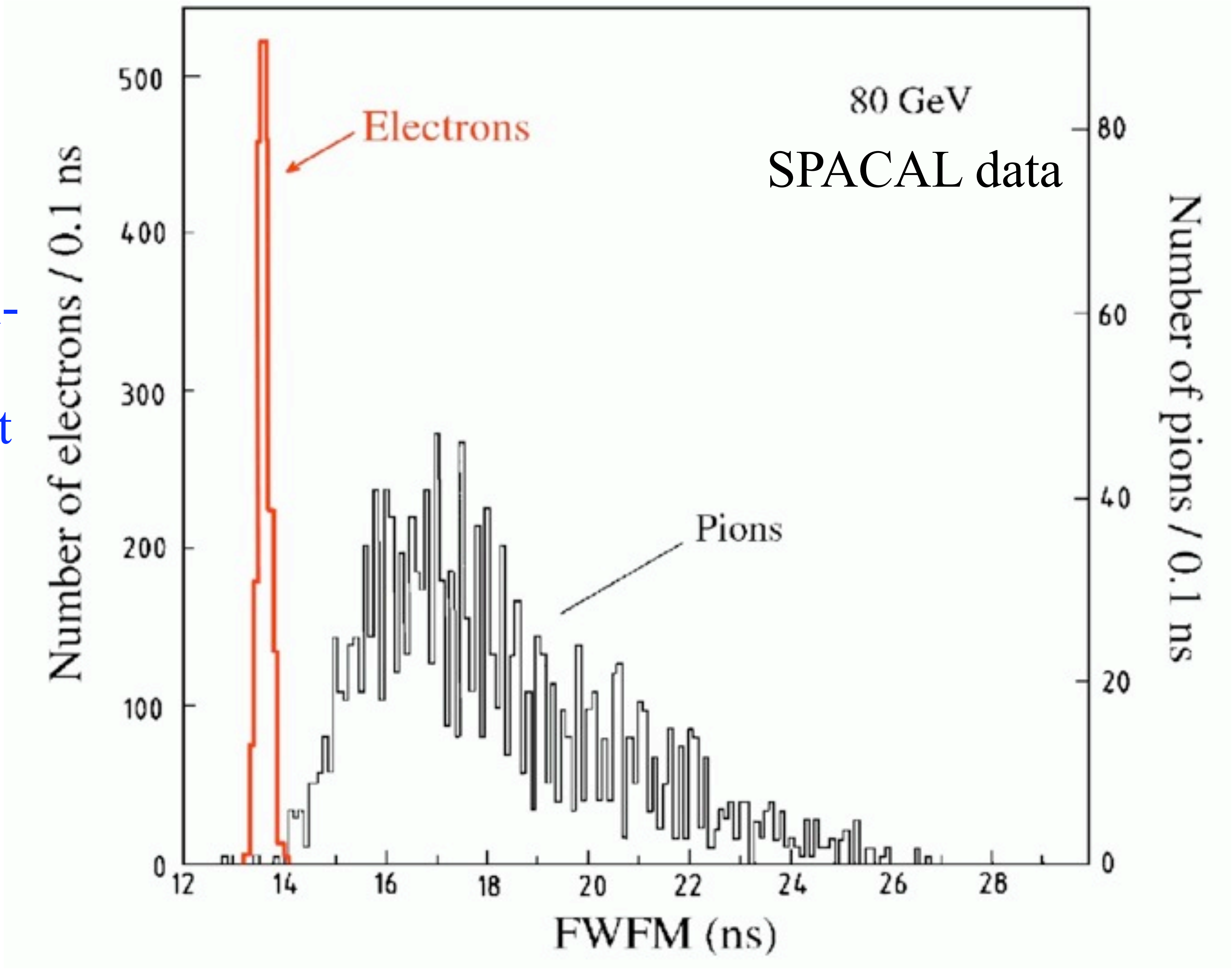


e vs. π time-history of scintillation fibers

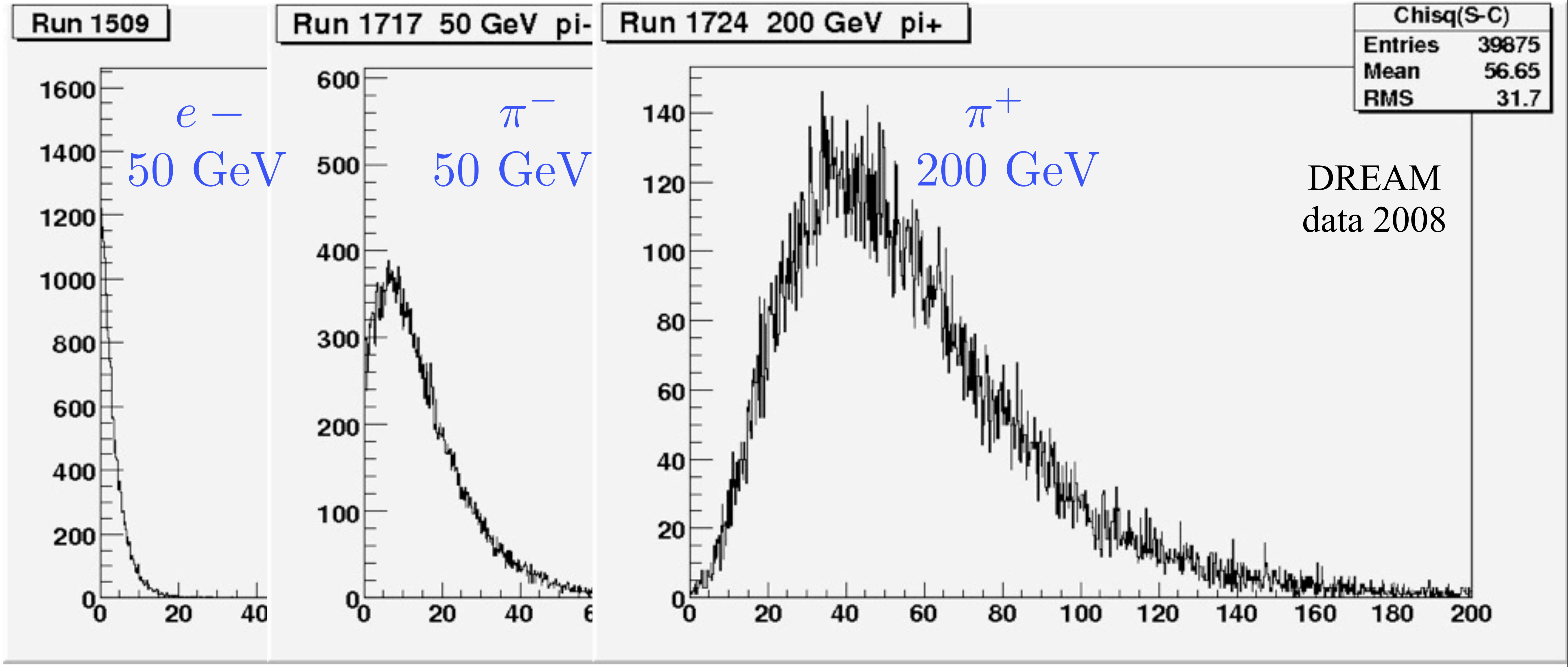


Distribution of pulse full-width at 1/5-maximum for electrons and pions at 80 GeV in SPACAL

e vs. π dual-readout channel-to-channel fluctuations

Chi-squared of S-C fluctuations among the channels of a shower:

$$\chi^2_{C-S} = \Sigma\left(\frac{S_k - C_k}{\sigma_k}\right)^2 \approx \Sigma_k \frac{(S_k - C_k)^2}{0.1(S_k + C_k)}$$



$$\chi^2_{C-S} \rightarrow$$

Telling a μ from a π

(More-or-less isolated track, but could be near a jet, too.

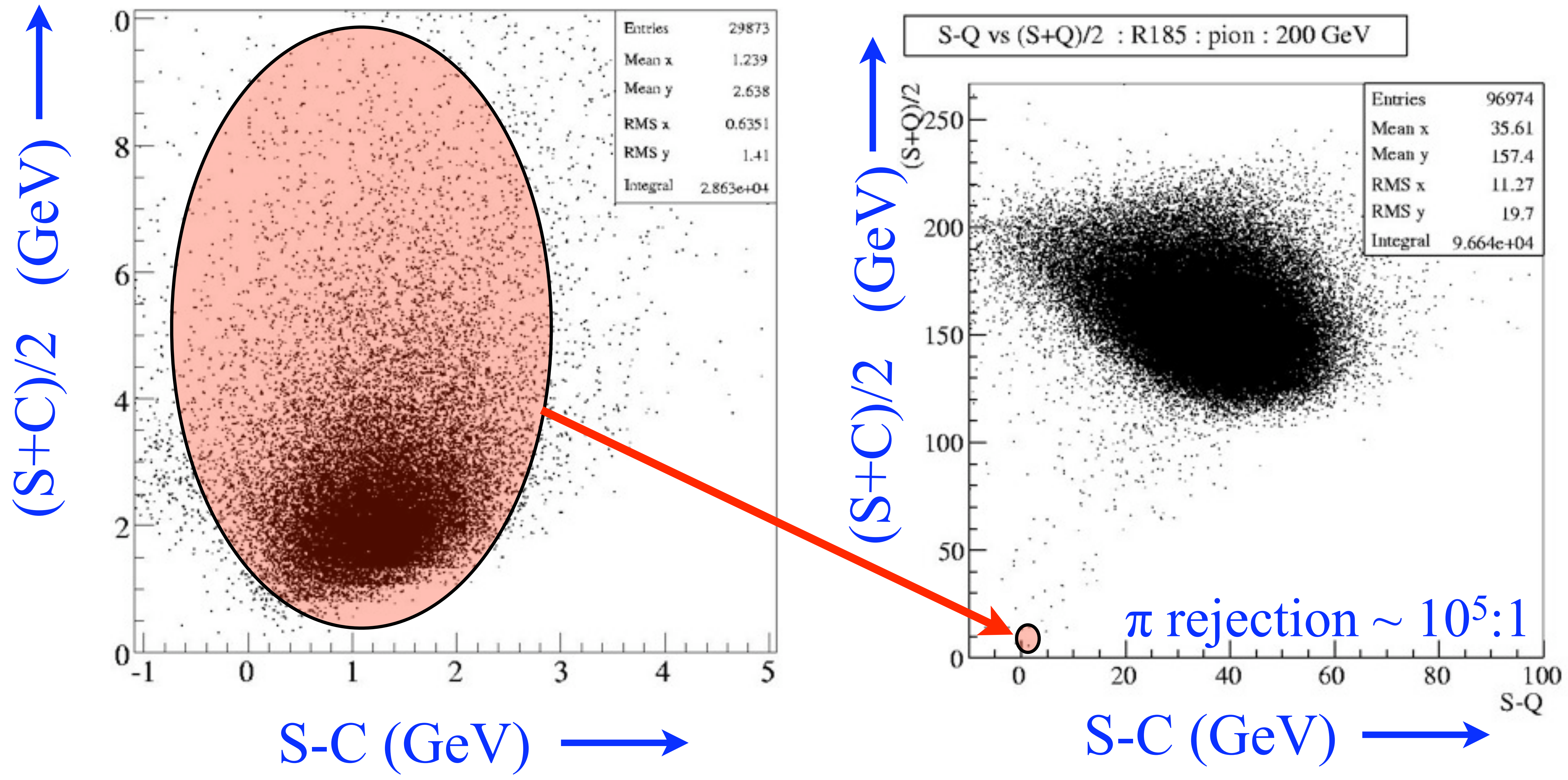
μ vs. π dual-readout: $\theta_{\text{Cher}} > \theta_{\text{num. aperture}}$

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

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

200 GeV μ^-

200 GeV π^-

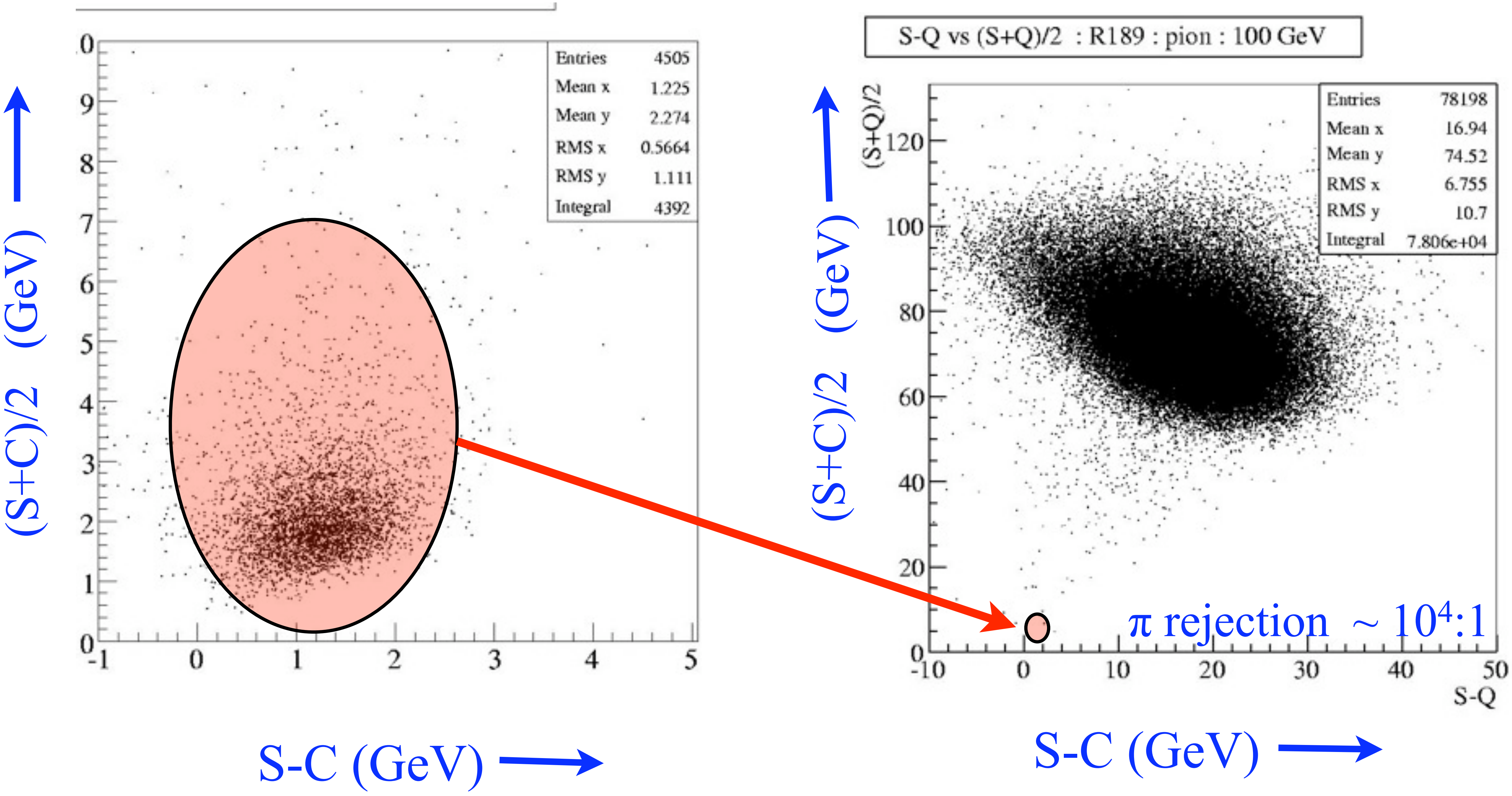


π rejection ~ 10^5:1

μ *vs.* π dual-readout: $\theta_{\mathrm{Cher}} > \theta_{\mathrm{num.\ aperture}}$

100 GeV μ^-

100 GeV π^-

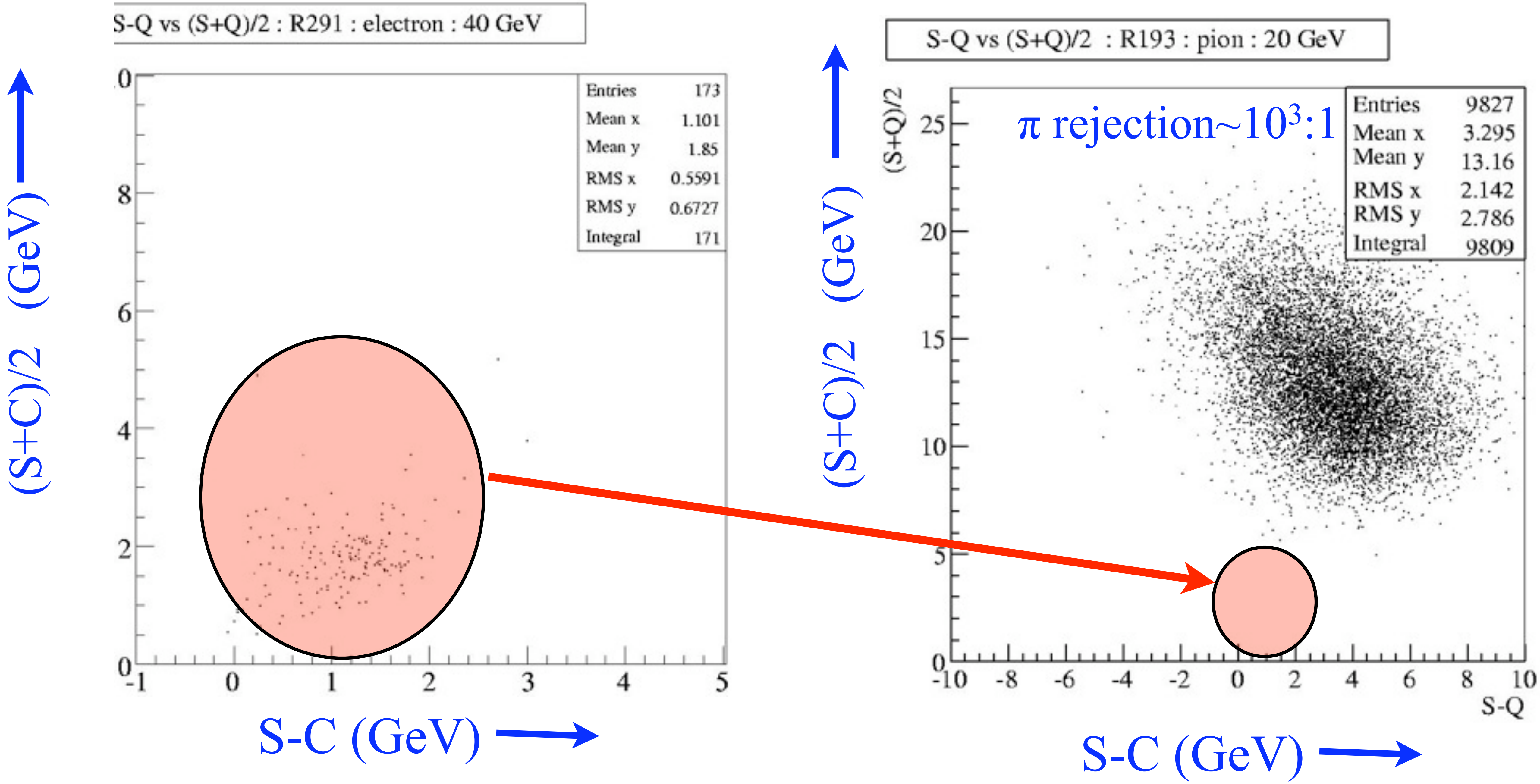


π rejection ~ 10^4:1

μ vs. π dual-readout: $\theta_{\text{Cher}} > \theta_{\text{num. aperture}}$

40 GeV μ^-

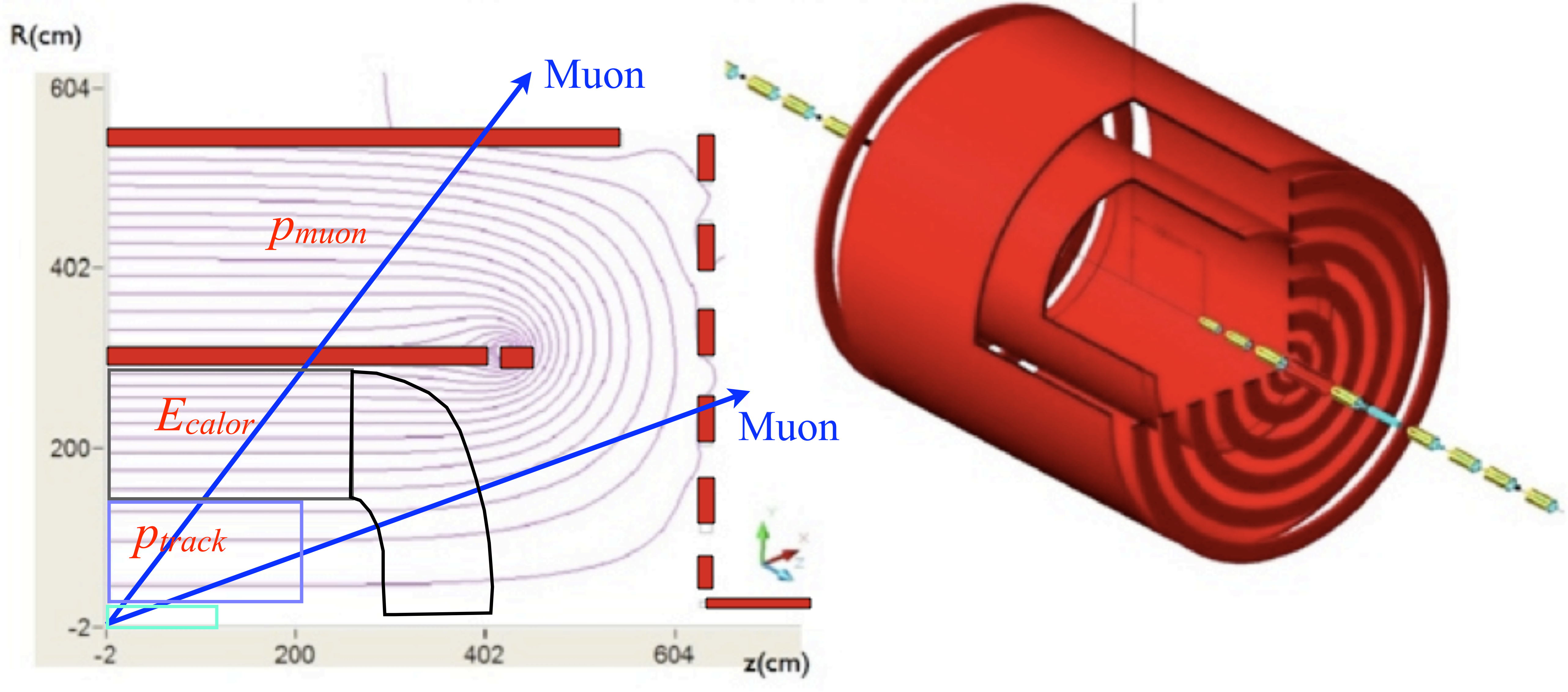
20 GeV π^-

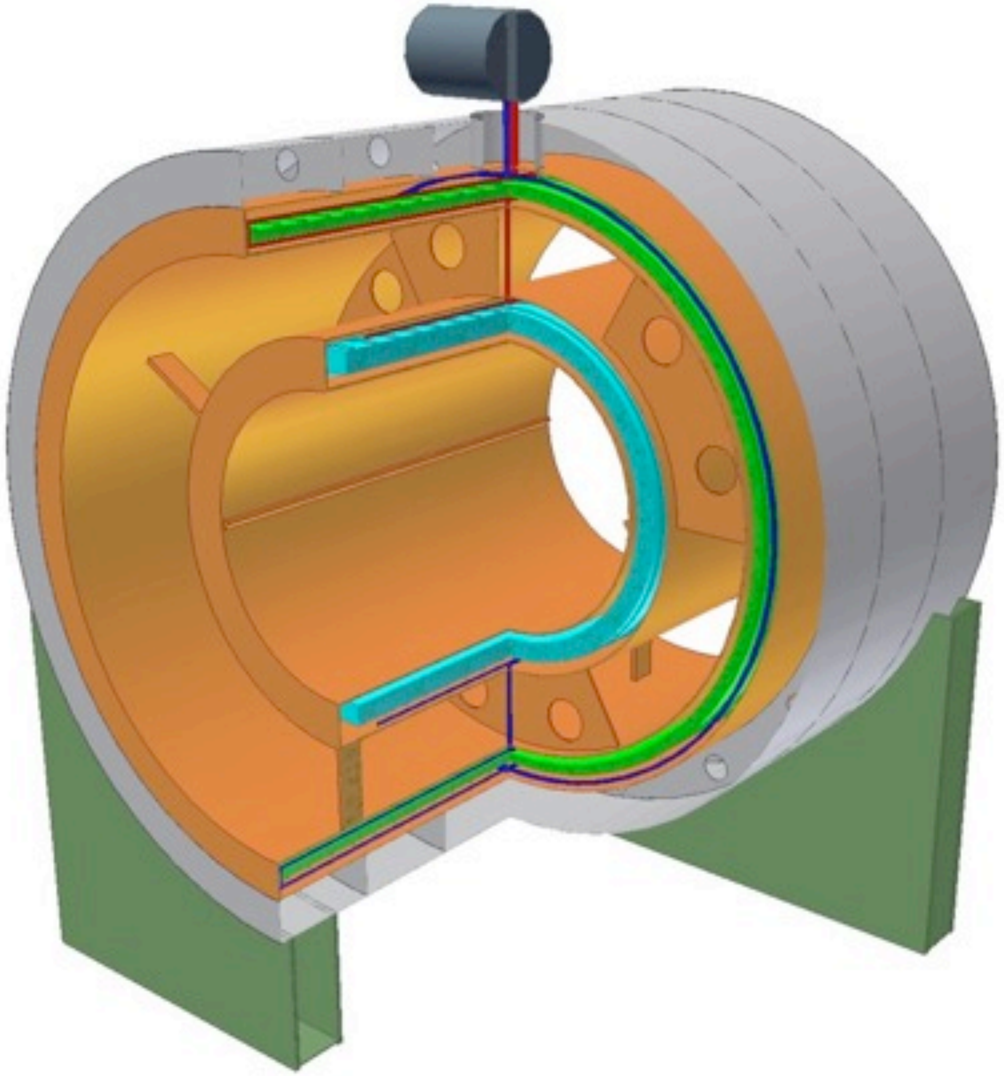


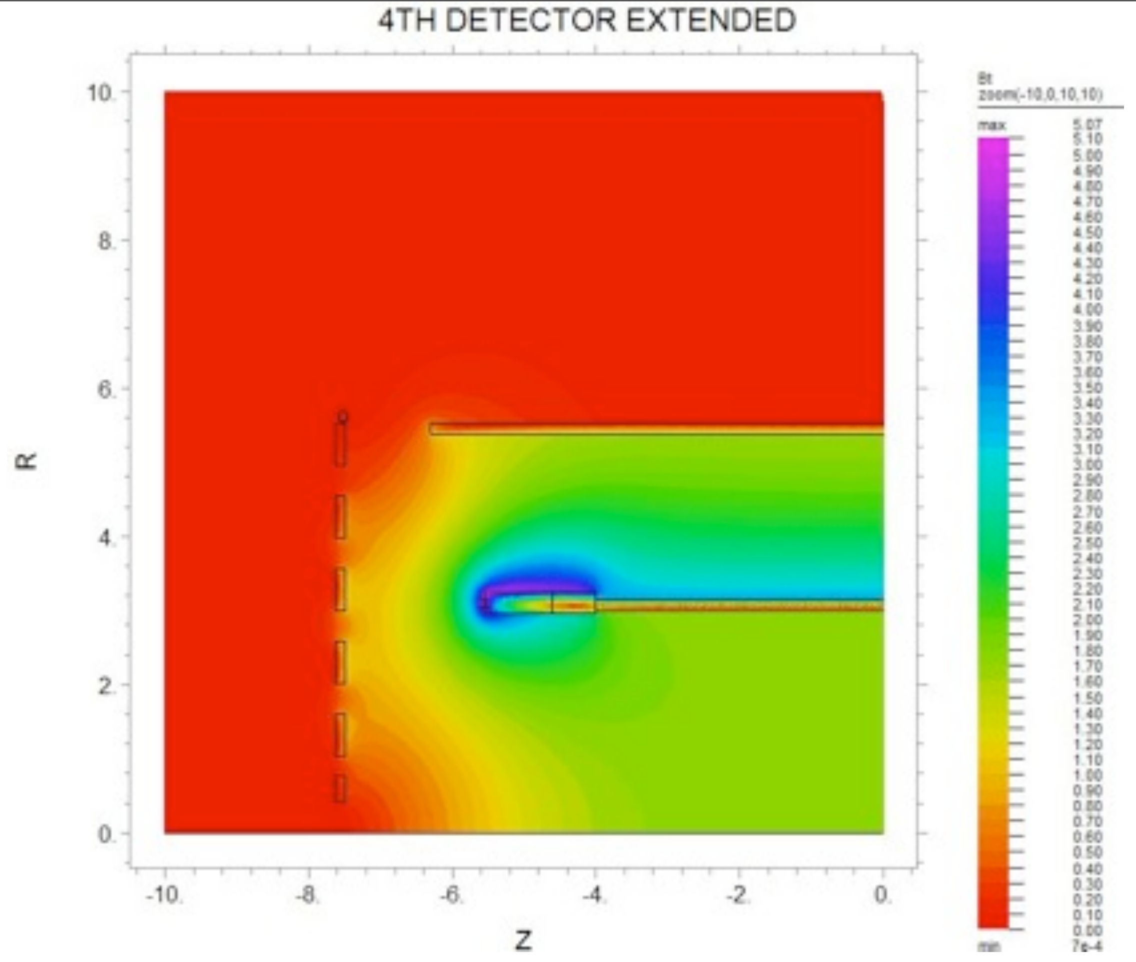
μ *vs.* $\pi_{\text{punch-through}}$ E-p balance: dual-solenoids

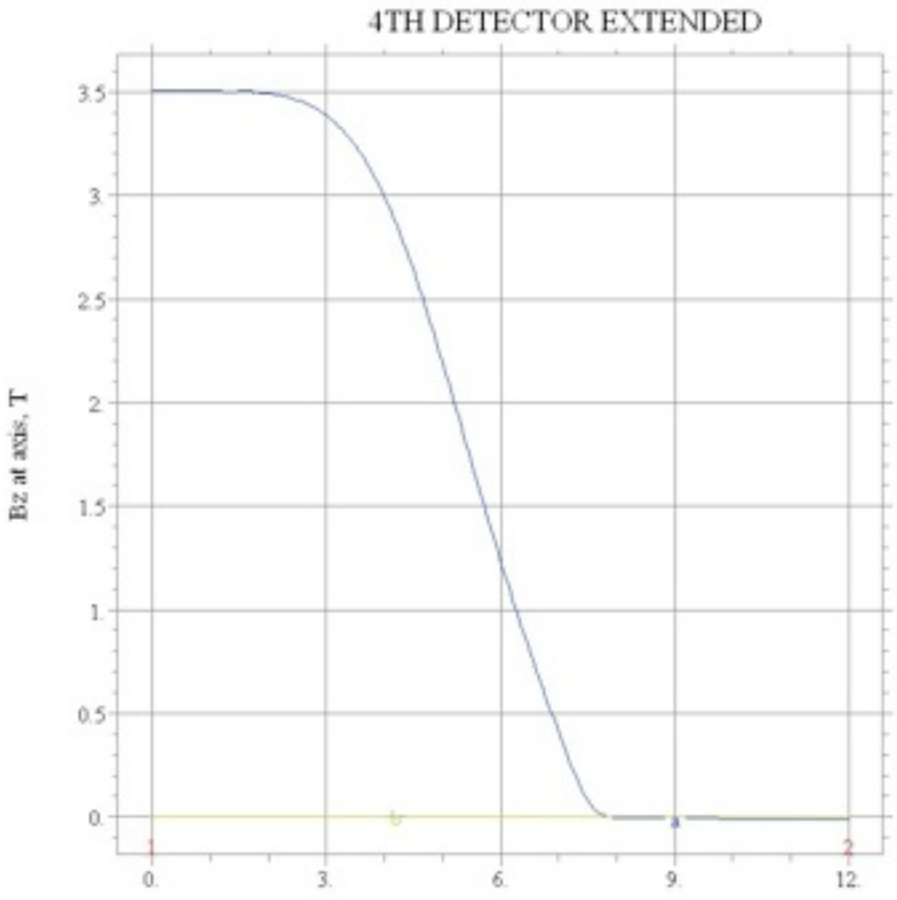
$$p_{track} = E_{calor} + p_{muon}$$

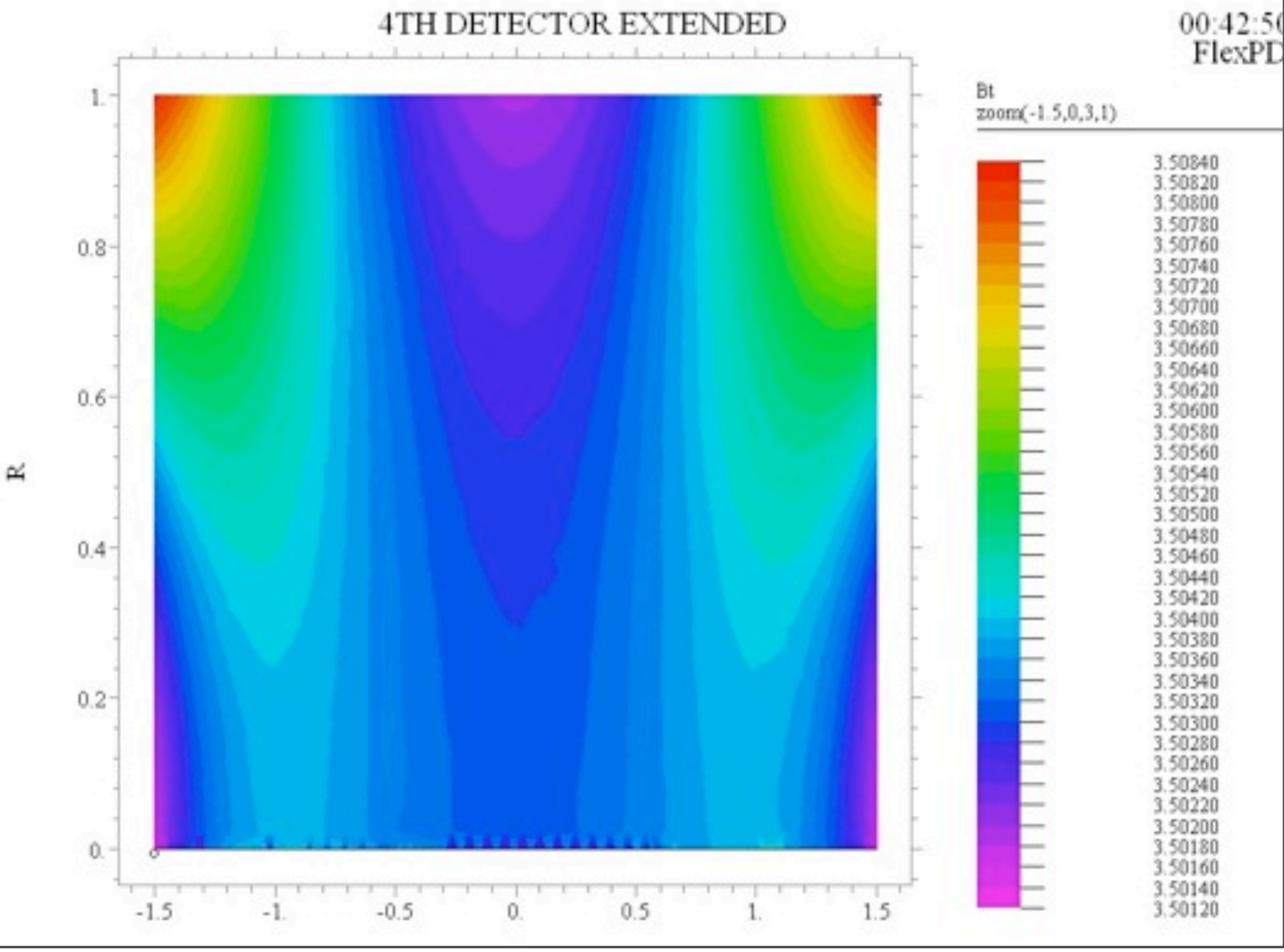
Magnetic field of dual solenoid and wall of coils






4TH DETECTOR EXTENDED

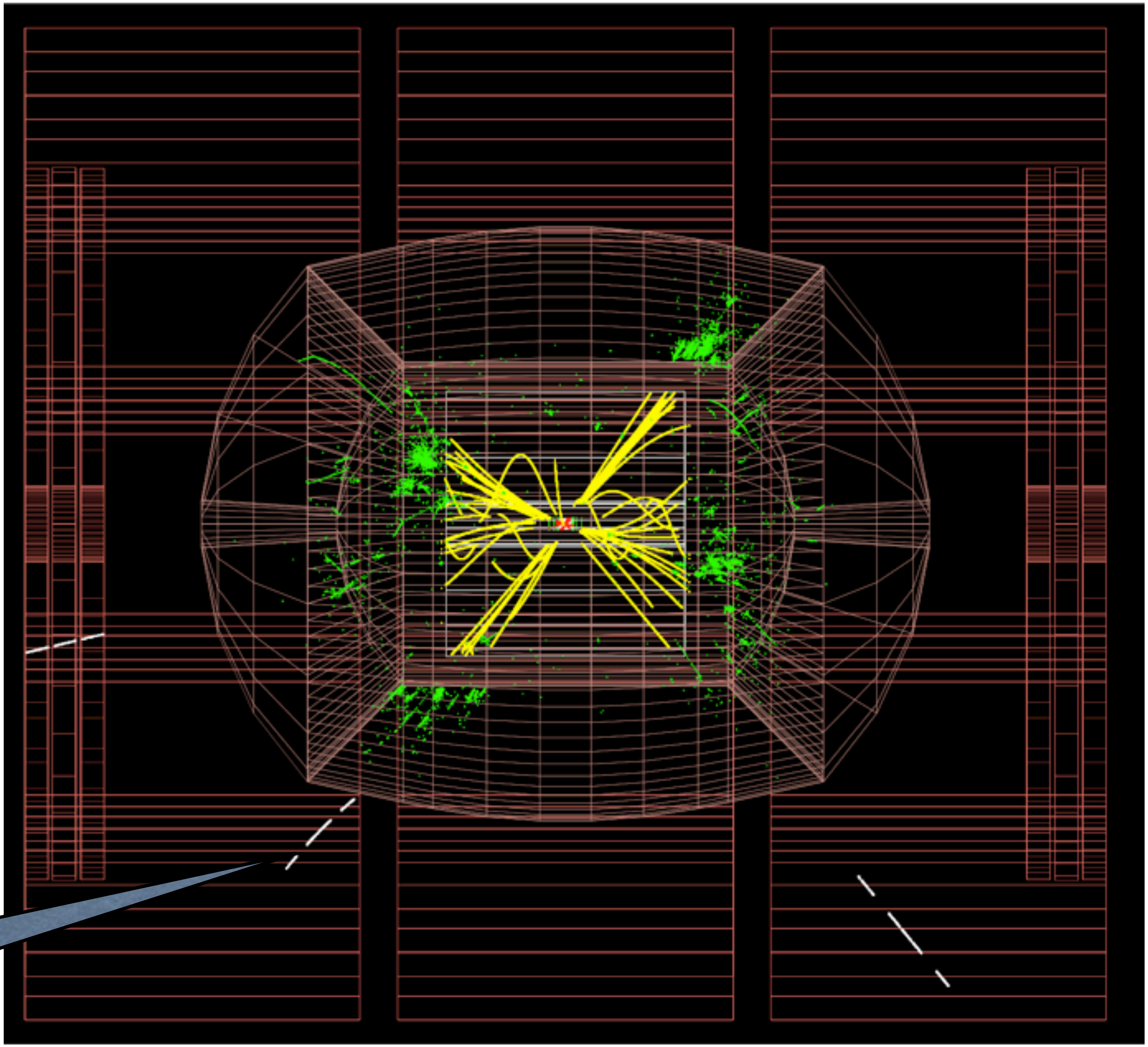

4TH DETECTOR EXTENDED


4TH DETECTOR EXTENDED

Event Display in ILCroot

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

E_{CM} = 500 GeV

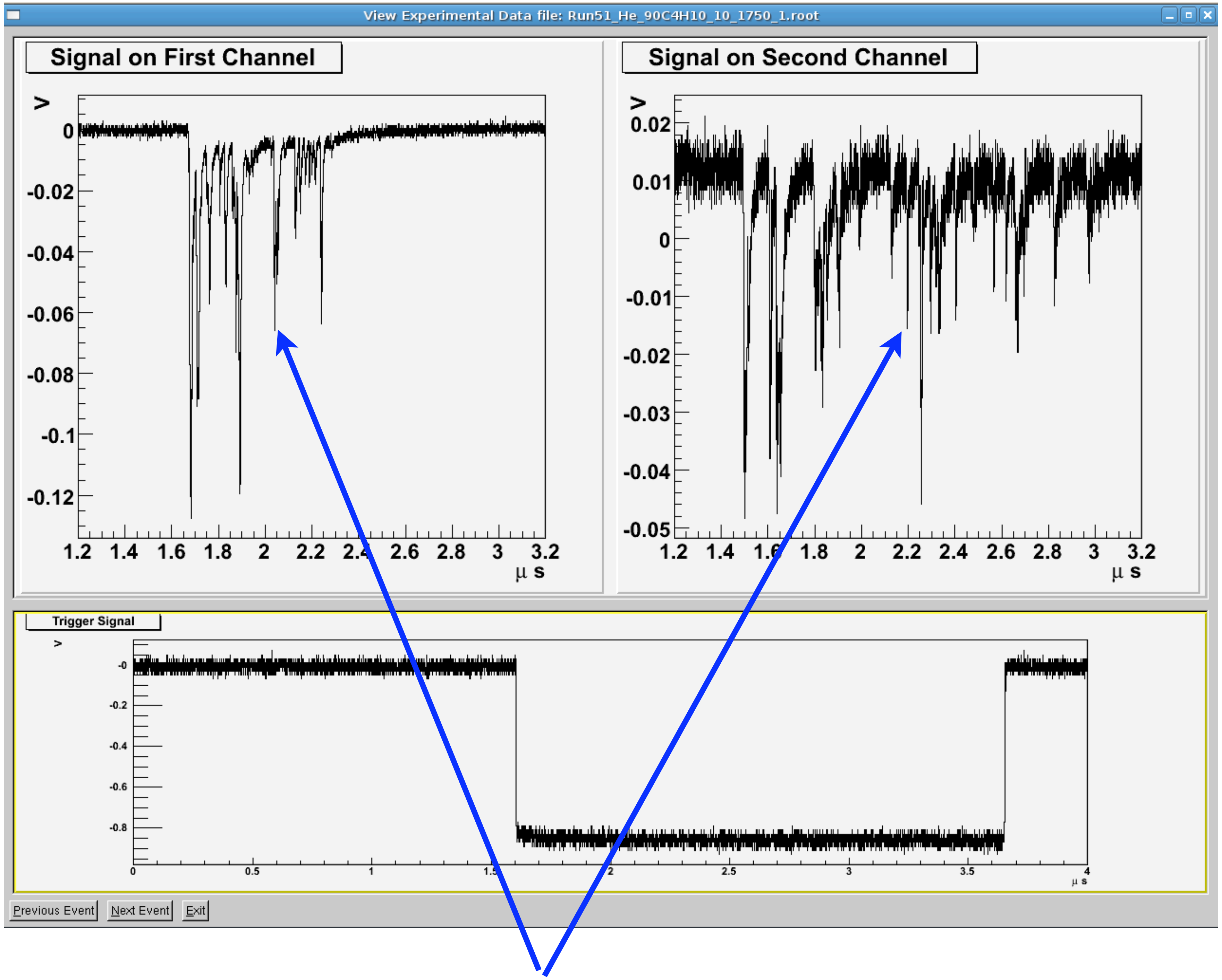


Low pt secondary muon

Telling *e*-μ-π-*K*-*p* from each other

(Few GeV region)

e-μ-π-K-p in few-GeV region



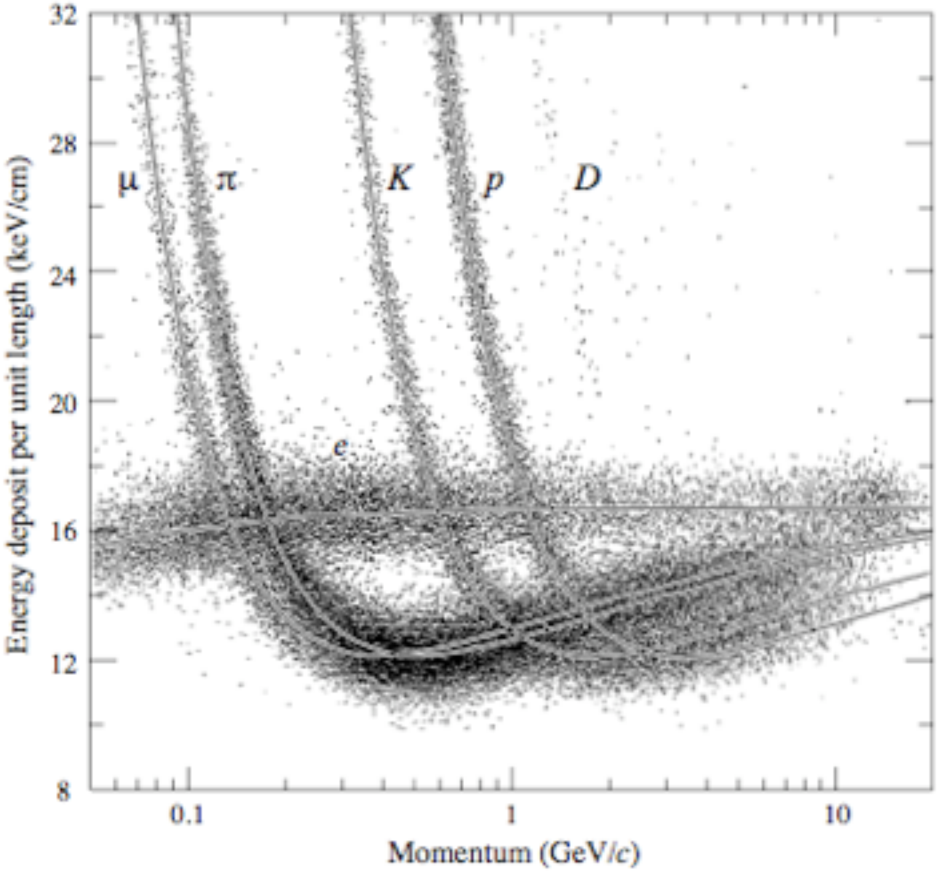
Measured CluCou clusters on two different wires: cluster count is Poisson (no Landau fluctuations), expect 3.5% measurement of specific ionization

dN/dx
by cluster-timing:

specific ionization resolution ~ 3.5%

TPC with ~6%
dE/dx resolution

This TPC built by Dave Nygren, LBL, in 1970's, analyzed by Gerry Lynch.



Summary:

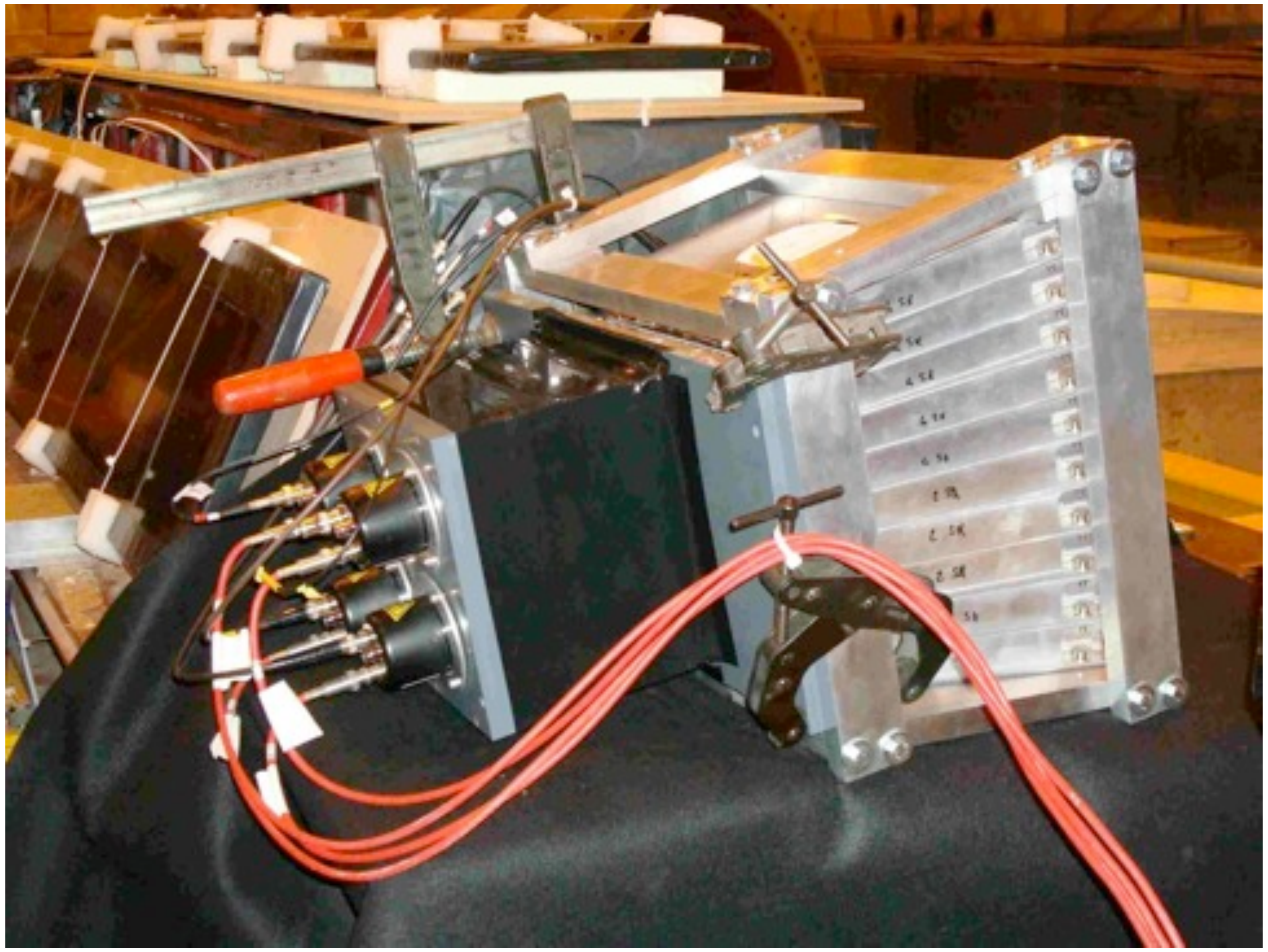
4th has many particle ID measurements, including handles on all fundamental partons. These are the ones for stable charged tracks.

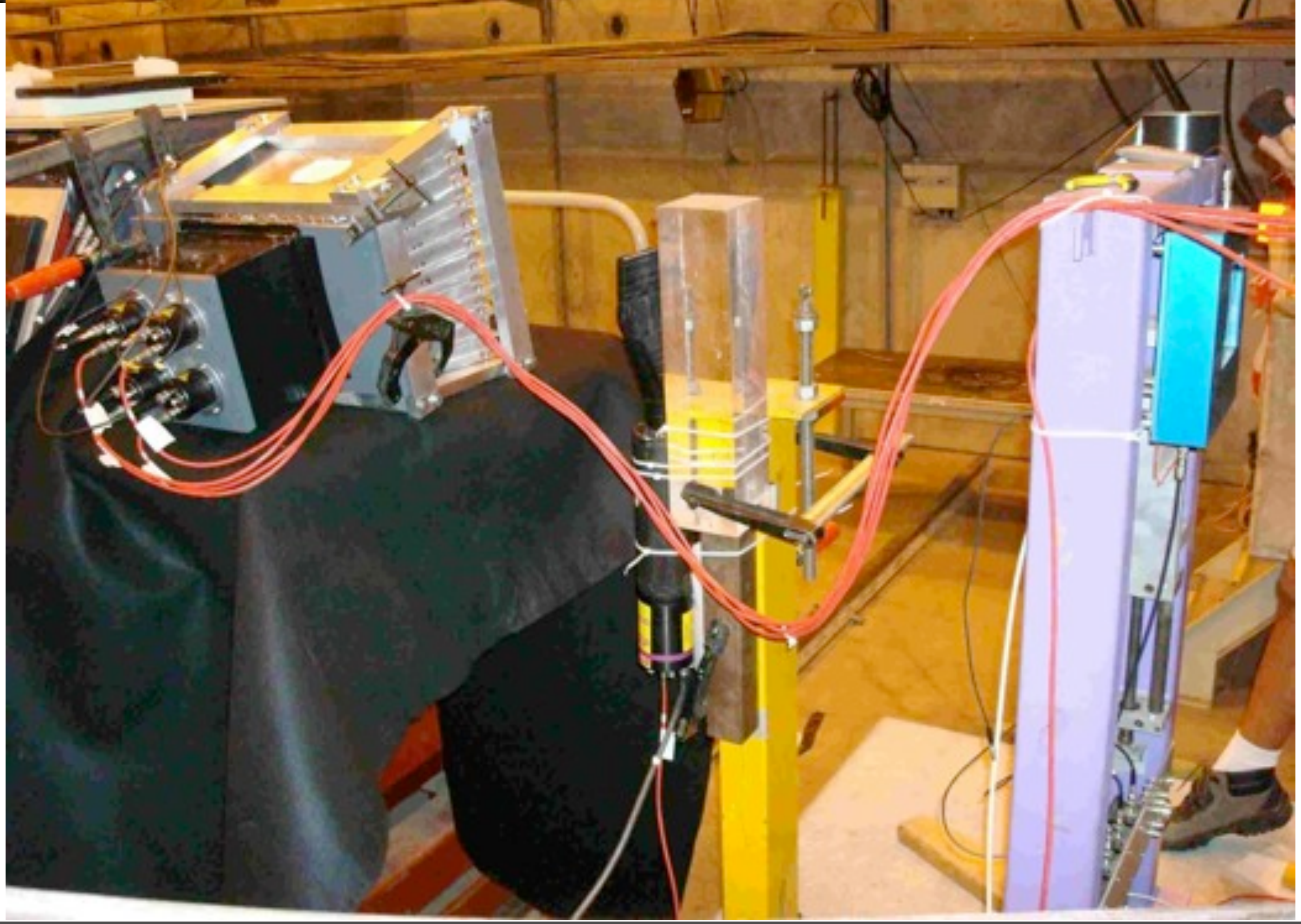
- *Leptons: e, mu, tau & neutrino (by subtraction)*
- *Quarks: uds & t ➔Wb (by reconstruction)*
- *Bosons: W, Z, and gamma*
- *Hadrons: pi-zero (by mass), charged pi, K, p (by dE/dx)*

Extras

Test beam setup

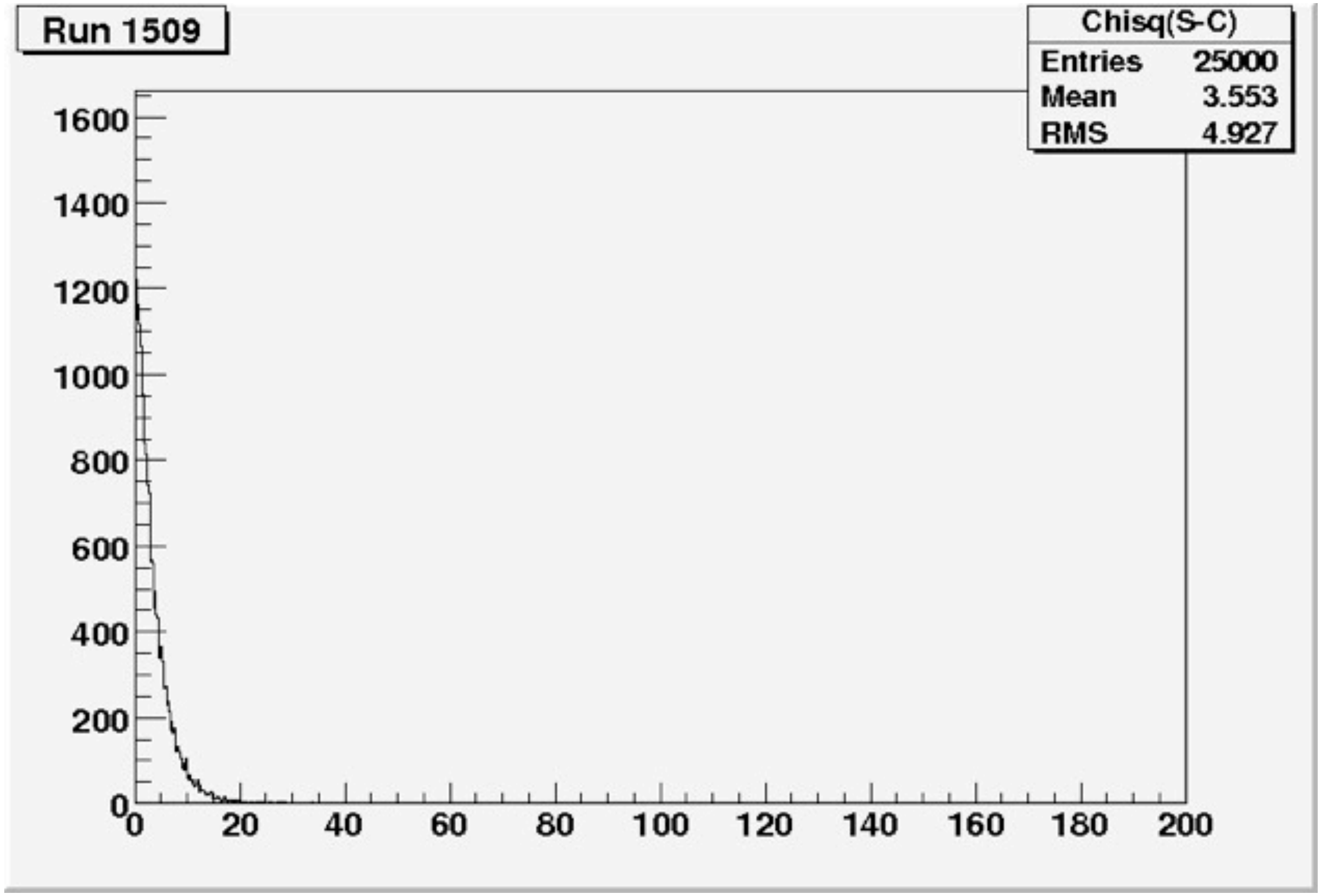
(July-Aug '08)



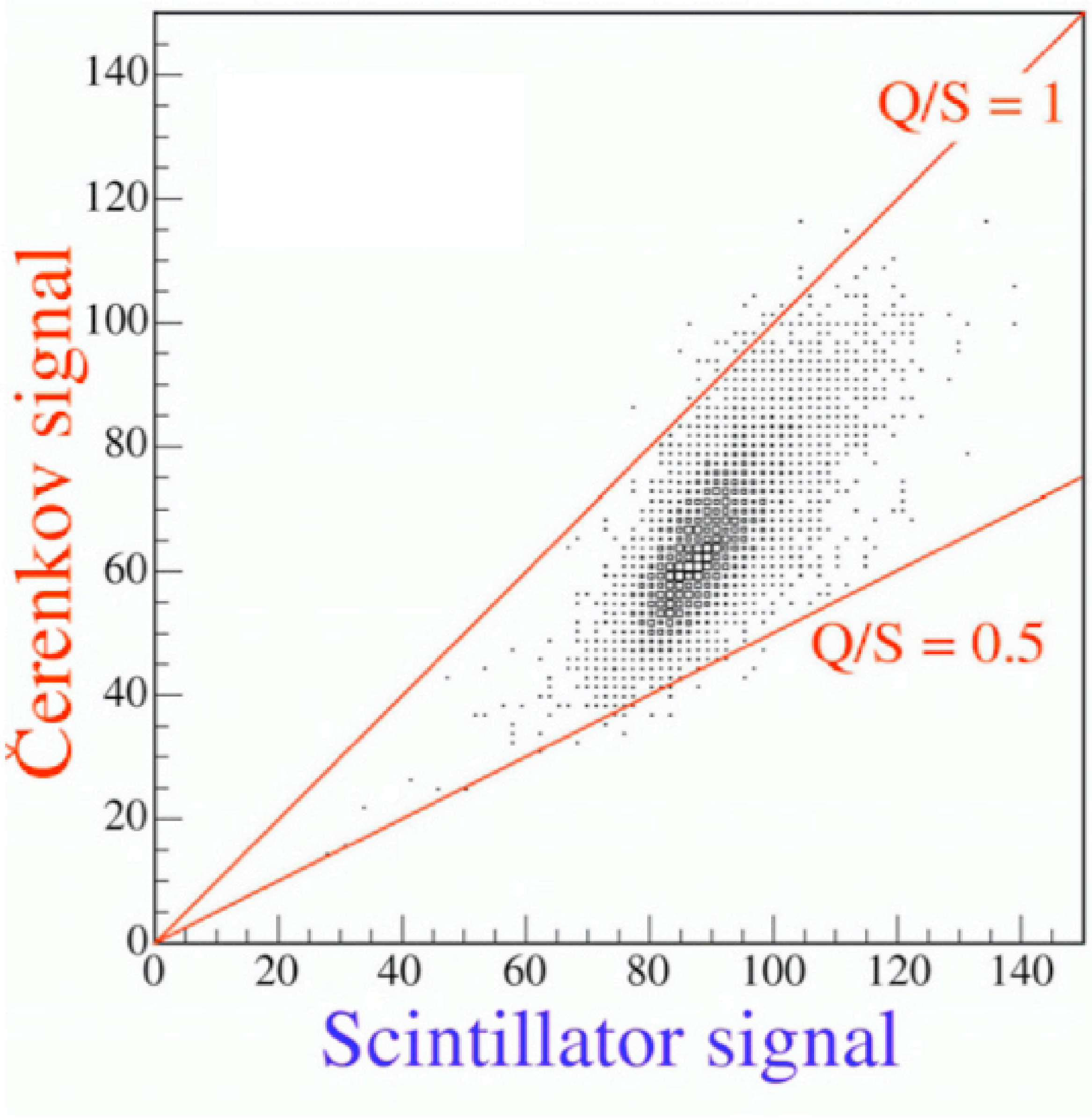


ID discrimination	*measurement*	*item*
e - pi - mu	S *vs.* C	#1 *(measured - beam test data)*
EM vs. hadronic	*channel-to-channel* *S-C fluctuations*	#2 *(measured - beam test data)*
"neutronic" *(hadronic vs. non-hadronic)*	f_n	#3 *(measured - beam test data)*
mu vs. e,pi	$(S-C)$ *vs.* $(S+C)$	#4 *(measured - beam test data)*
n & e vs. pi	$S_{pe}(t)$	#5 *(measured - beam test data)*
e-pi-K-p (few GeV)	$dN_{clusters}/dx$	#6 *(bench measurements data)*

ID discrimination	*measurement*	item
e vs. gamma	*Tracking, BGO*	#7 *(ILCroot)*
mu vs. punch-through hadrons	$P_{mu} + E_{dual} + P_{tracking}$	#8 *(ILCroot)*
tau --> rho nu	*BGO + fiber dual readout*	#9 *(ILCroot)*
Massive SUSY, etc.	*Cerenkov light timing (BGO+fibers)*	#10 *(ToF from beam test data)*
W--> jj	*ILCroot, Tracking, dual-readout*	#11 *(achieved with ILCroot)*


Run 1509
Chisq(S-C)
Entries 25000
Mean 3.553
RMS 4.927
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140
160
180
200

Dual readout (in optical fibers of DREAM module)



$$Q = E\left[f_{em} + \frac{1}{(e/h)_Q}(1-f_{em})\right] \qquad (1)$$

$$S = E\left[f_{em} + \frac{1}{(e/h)_S}(1-f_{em})\right] \qquad (2)$$

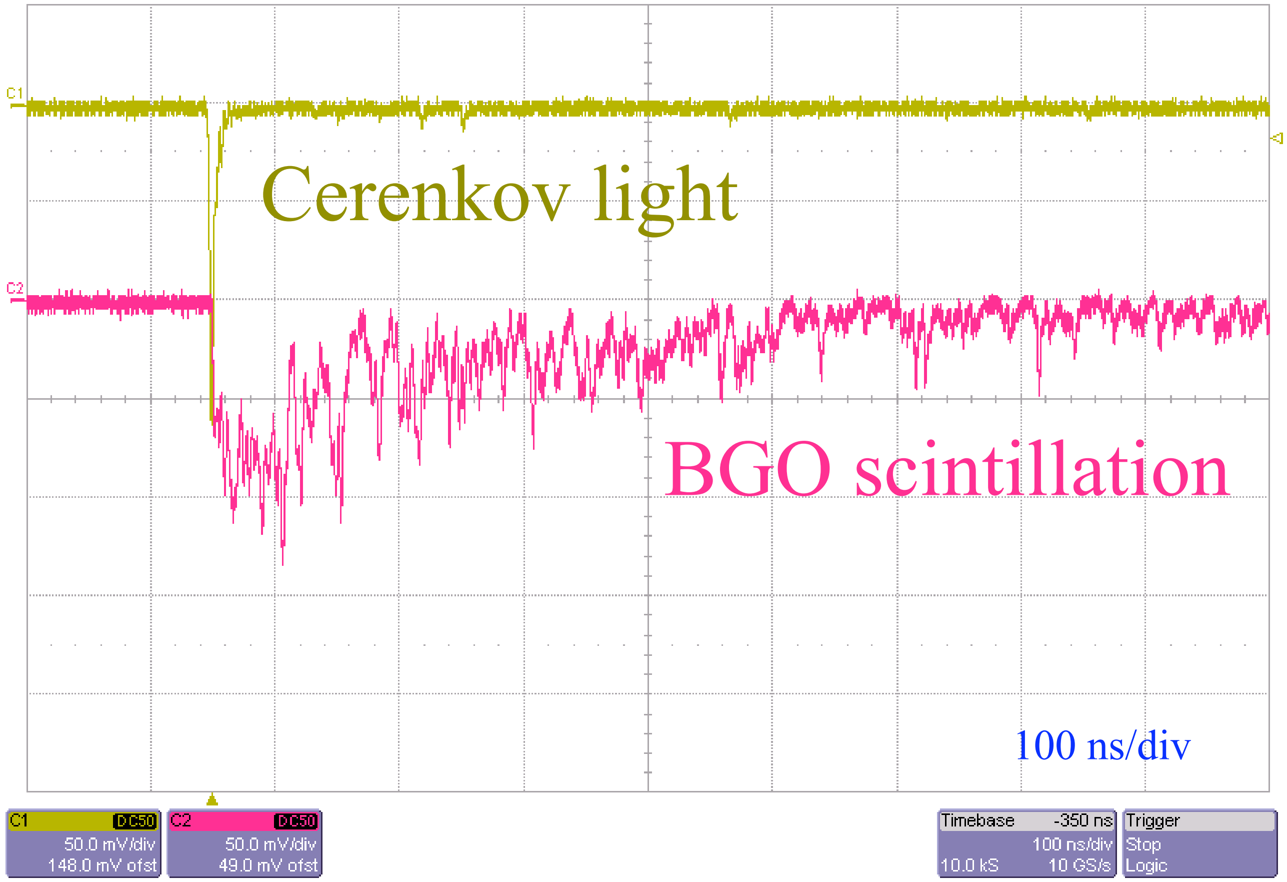
e.g. If $e/h = 1.3\ (S),\ 4.7\ (Q)$

$$\boxed{\frac{Q}{S} = \frac{f_{em} + 0.21\,(1-f_{em})}{f_{em} + 0.77\,(1-f_{em})}} \qquad (3)$$

$$\boxed{E = \frac{S - \chi Q}{1 - \chi}} \qquad (4)$$

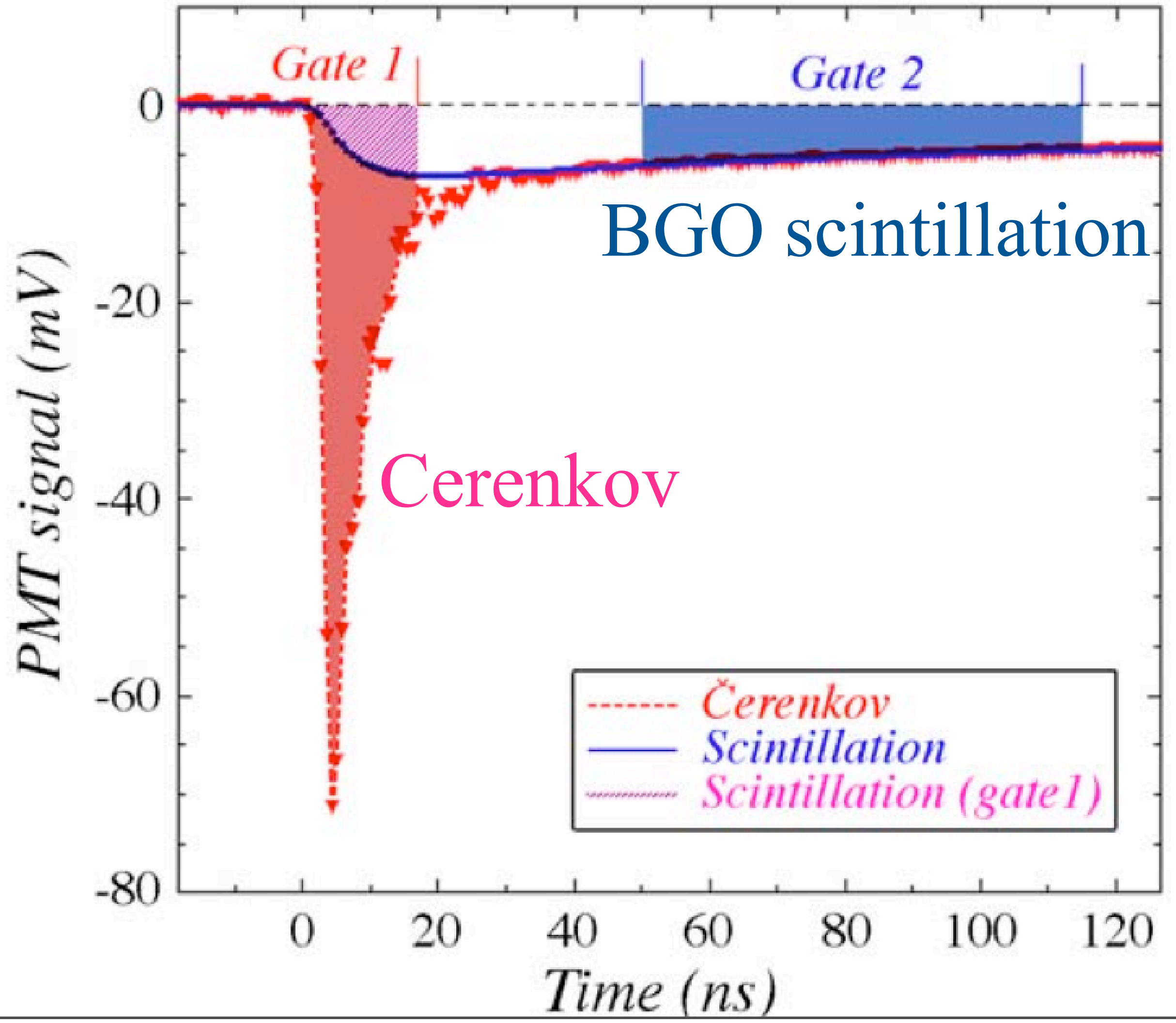
with $\chi = \dfrac{1-(h/e)_S}{1-(h/e)_Q} \sim 0.3$

Dual readout (in BGO crystals tested with DREAM module)

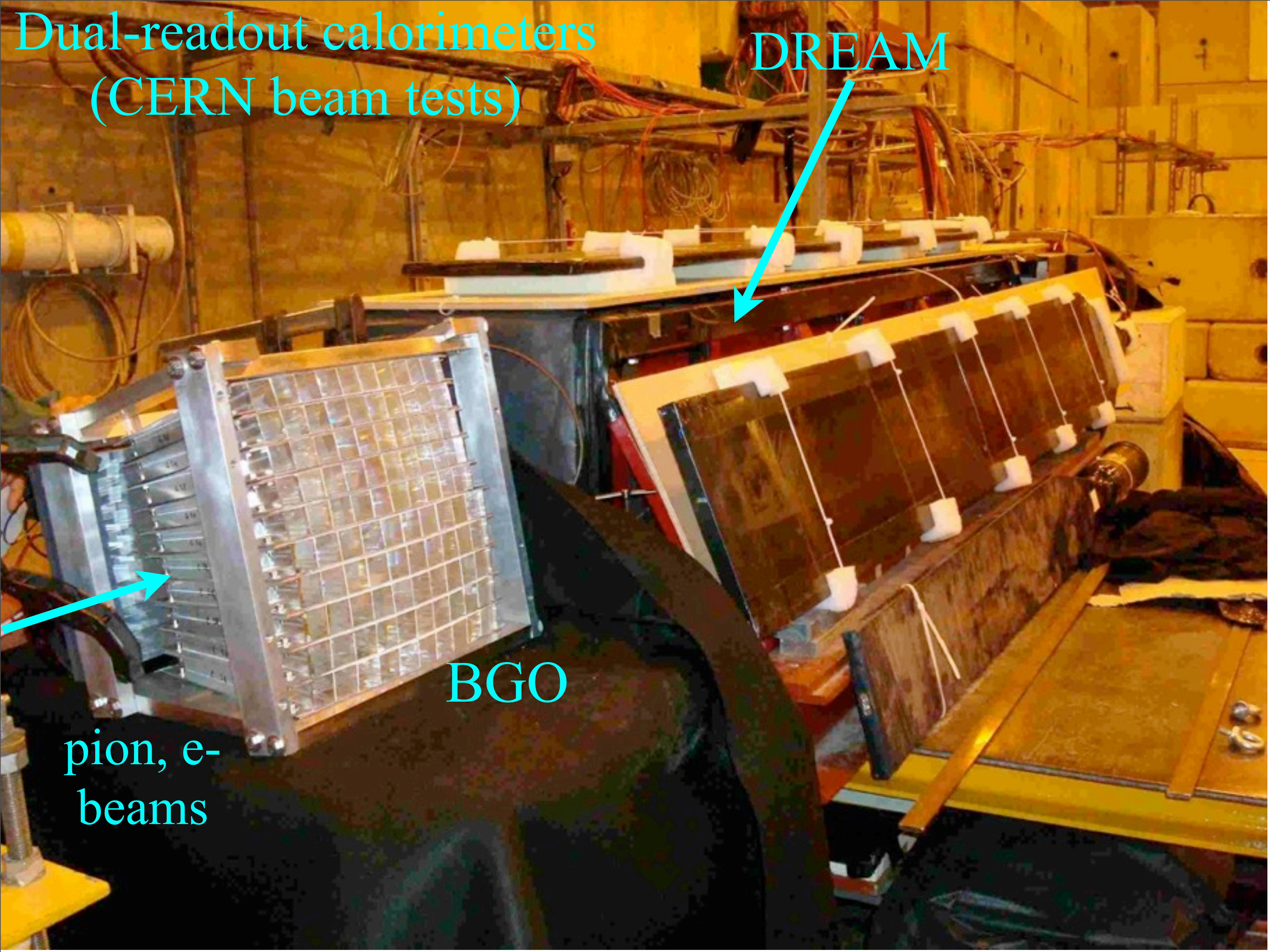


Single cosmic muon

electron beam:
C and S from
one PMT



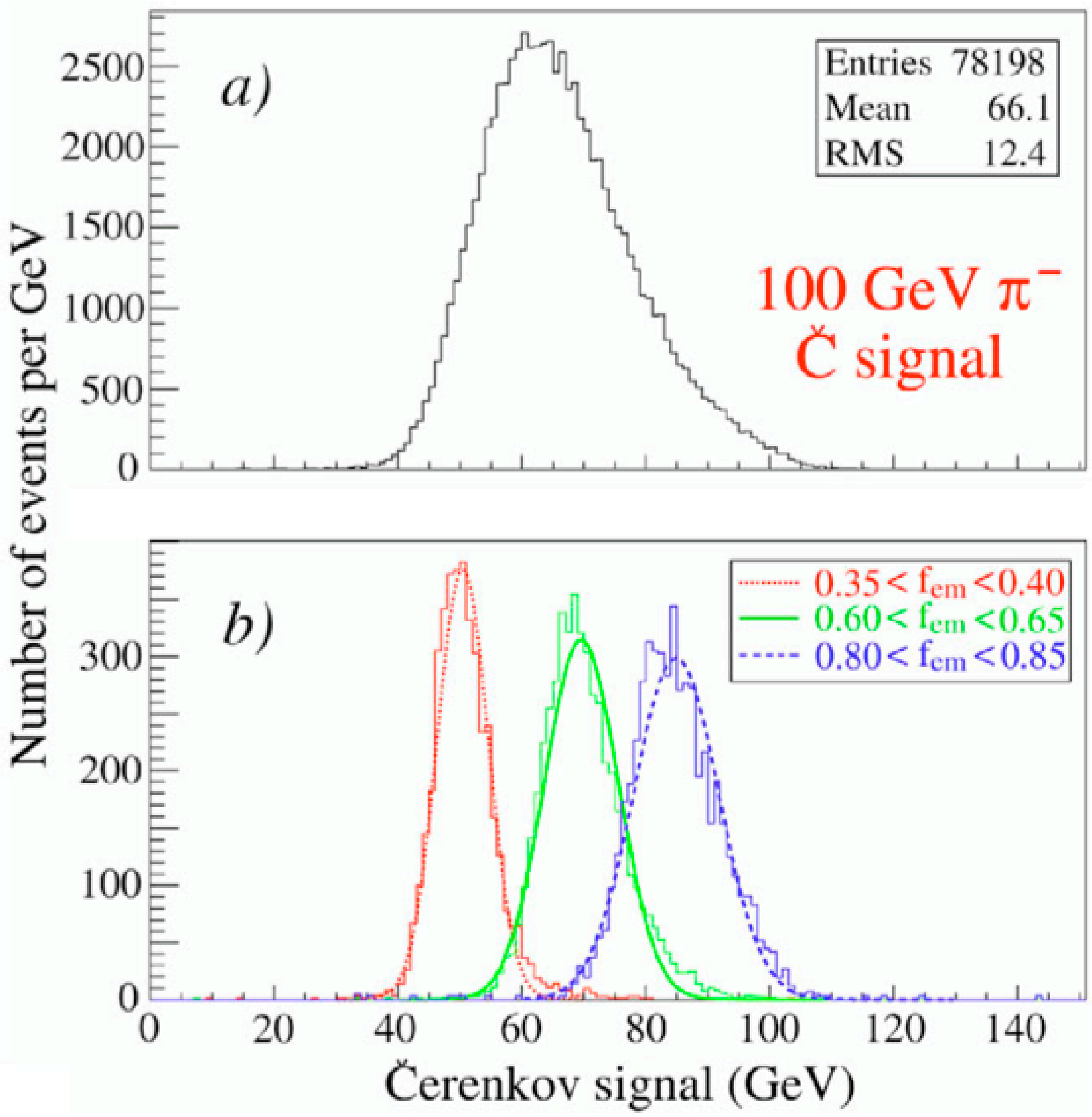
Dual-readout calorimeters (CERN beam tests)

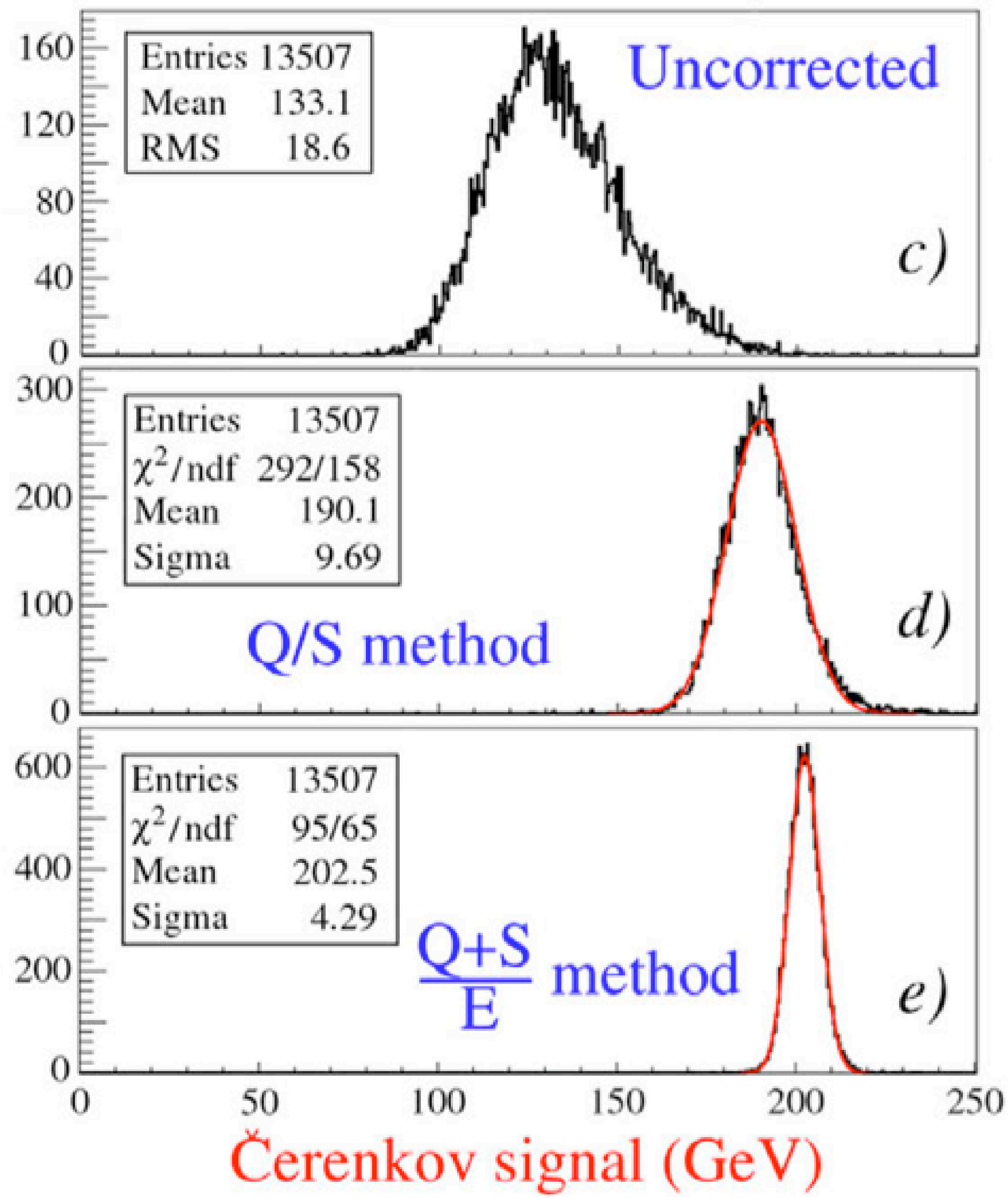


The DREAM Collaboration (Cagliari, CERN, Cosenza, Iowa State, Pavia, Pisa, Rome, Texas Tech)

(Will answer K. Hara's question.)

Why dual-readout works so well (and so easily)





🔴 Achieved in test beam data

🟢 Achieved in cosmic mu test data

🔵 Achieved in ILCroot simulation and analysis

ID	Physical measurement	Partons/particles identified	Subsystems used	
1	C *vs.* S	$e^\pm$ *vs.* $\pi^\pm$ *vs.* $\mu^\pm$	S and C	🔴 🔵
2	$\chi^2 \sim \frac{1}{N}\Sigma_i^N[(C_i - S_i)/\sigma_i]^2$	EM *vs.* non-EM *vs.* "hadronic"	S_i and C_i channels	🔴
3	$(S-C)$ *vs.* $(S+C)$	μ *vs.* π	fiber S and C	🔴
4	$f_n \sim E_n/E_{\mathrm{shower}}$ (MeV neutrons)	"hadronic" *vs.* non-"hadronic"	scintillating fibers $S_{pe}(t)$ long-time history	🔴 🔵
5	S_{pe} time duration	EM *vs.* non-EM *vs.* "hadronic"	S fibers time-history	🔴
6	dN/dx, specific ionization (cluster counting)	$e-\mu-\pi-K-p$ (few GeV region)	CluCou tracking	🟢
7	EM calor + tracking	$e-\gamma$	CluCou tracking + dual-readout calor's	
8	$p_{\mathrm{track}} \approx E_{\mathrm{calor}} + p_\mu$	μ *vs.* punch-through π	CluCou, calor, muon	
9	$\tau^\pm \to \rho^\pm\nu \to \pi^\pm\gamma\gamma$	τ *vs.* hadronic debris	BGO and fiber dual-reaout, CluCou	🔵
10	Time-of-flight (sub-ns)	massive SUSY object	Čerenkov pulses in BG and fiber calorimeter	🔴
11	$W, Z \to jj$ mass	W, Z *vs.* QCD jj	CluCou, jet finding, dual-readout calor's	🔵