A massive, fine grain scintillating fiber calorimeter for the CERN to Gran Sasso LBL project (CNGS)

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for the NOE Collaboration

The goal of the CNGS beam is the direct appearance of the n_t

A possibility is the “NOMAD” approach:
Search for $n_m \rightarrow n_t$ appearance in $t \rightarrow enn$ channel using event kinematics

NOE R&D motivated by:

Kinematical tagging of n_t

high detector performance

good E and E_t resolution (s_E, s_{Et})

Long Base Line ⟶ Low n flux
Low n cross section

Large mass detector

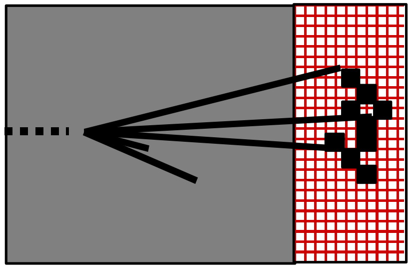
Cost

Read out channels

Long Baseline (LBL) neutrino detector

Basic hardware

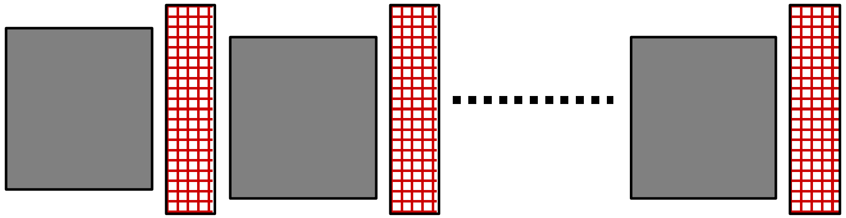
Target: vertex, tracking, particle id, energy losses.



Calorimeter:
Hadronic energy measurement
Shower containment
μ analysis (if magnetized)

Strategy for a multi-kiloton LBL apparatus

*** multi module-apparatus:**



- **enough modules to reach a sensitive mass & ν rates**
- **events confined in each module**
- **each module works indipendently**
- **E_{μ} & charge sign**

Proposed up to now:

$$\text{NOE} = \sum_{\text{N-modules}} (\text{TRD (target)} + \text{CAL})$$

$$\text{ICANOE} = \sum_{\text{N-modules}} ((\text{ICARUS-L.Ar. target}) + \text{M.CAL})$$

How can we build a large mass calorimeter (few Ktons), while obtaining the required performances ?

How much can we limit the sampling fraction, the number of electronics channels, while manteining an hadronic energy resolution s/E~40%/E ?

<u>Our choice was a scintillating fiber/iron calorimeter (SPACAL, CHORUS, H1,KLOE,etc.))</u>

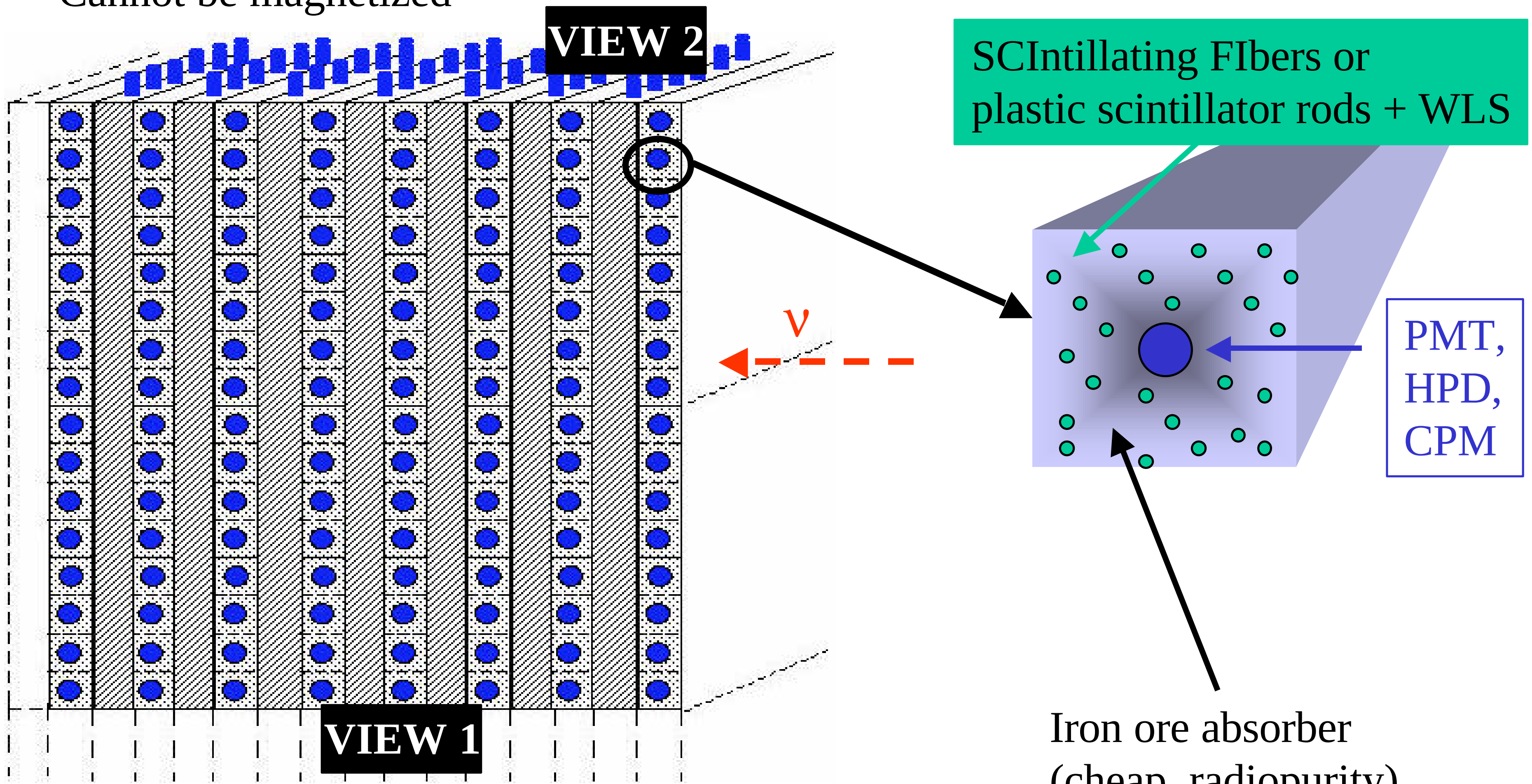
NOE R&D: started in ‘95, long R&D on SCIFI, Scintillator +WLS fibers, several read out (PMTs,HPDs, CPMs):
<u>a first calo prototype (4 tons) exposed to PS T7</u>

Nowadays NOE/ICANOE in no more on the floor, but we believe this was an interesting R&D , possibly fruitful for the CALO Community

We developed 2 different options:

1) CROSSED BARS Option (Basis for NOE Calorimeter)

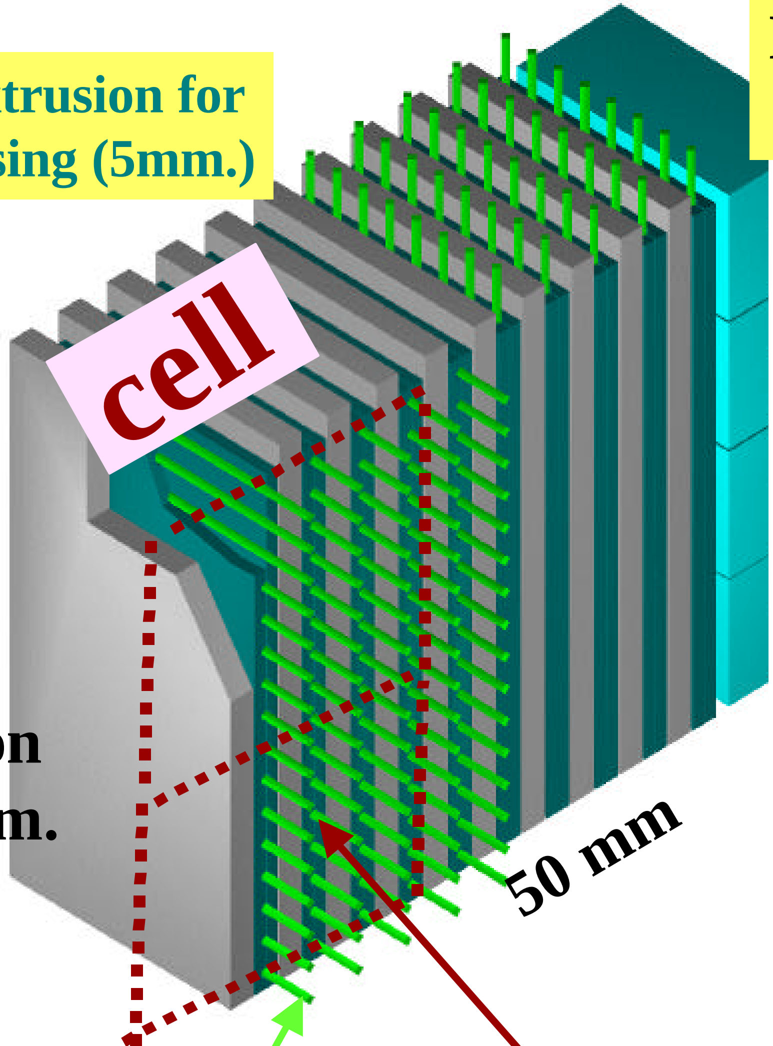
Easy to build, mounting quite simple
Cannot be magnetized

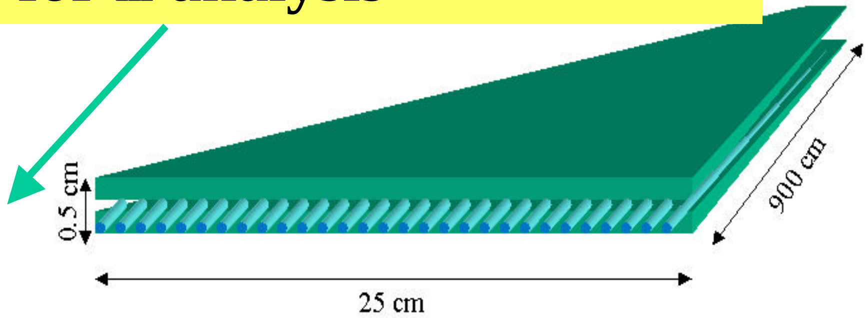


2) CROSSED FIBERS option (ICANOE Calorimeter)

Plastic extrusion for fiber housing (5mm.)

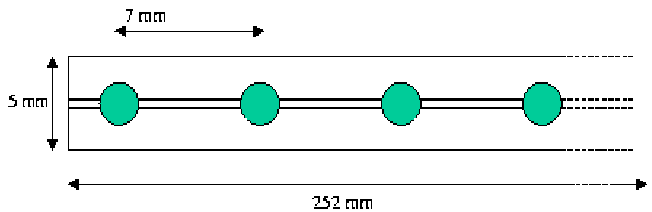
Drift tubs for (3cm. x 3cm.) for m analysis





plastic extrusion for fiber housing

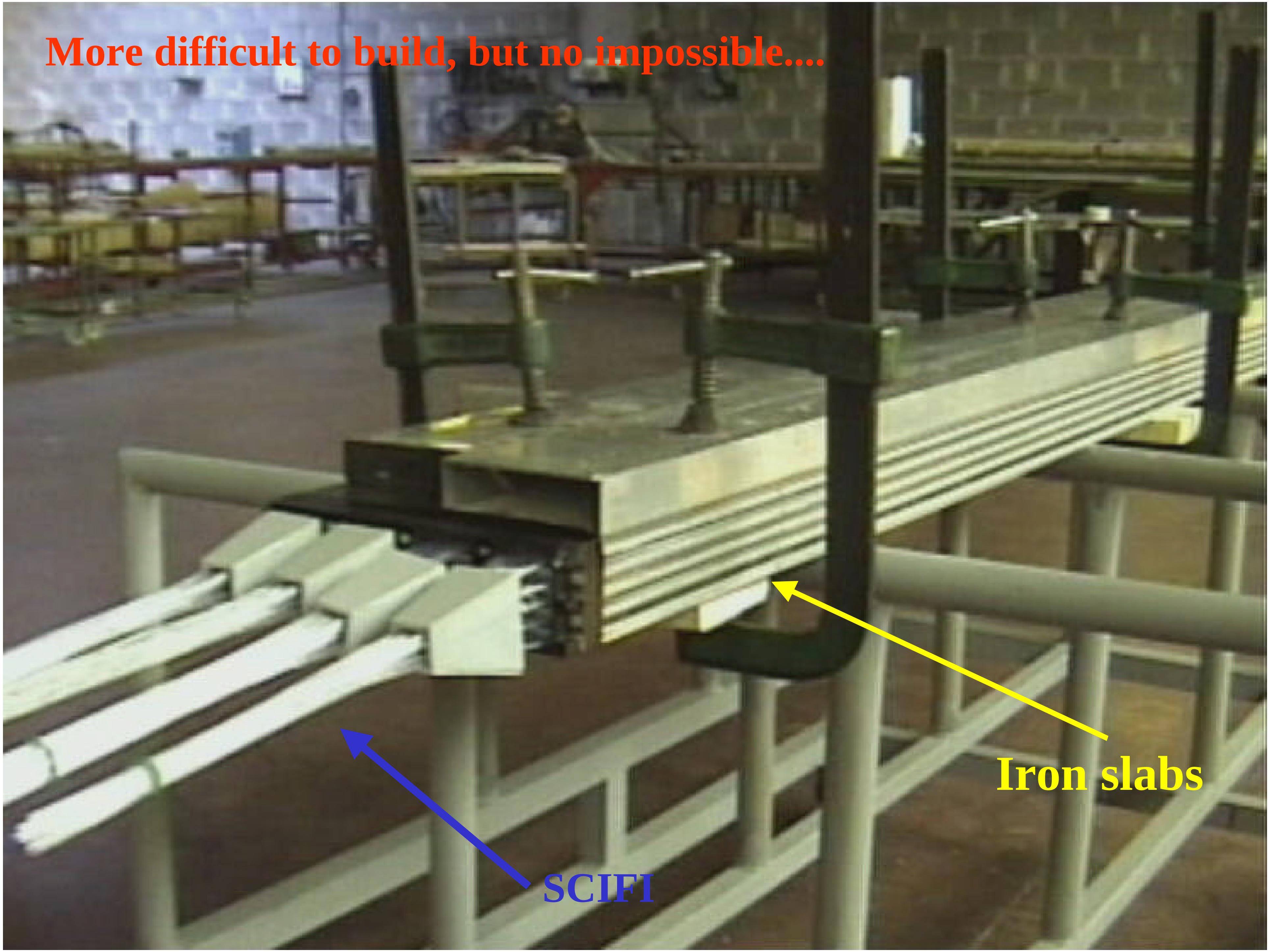
Iron 5mm.

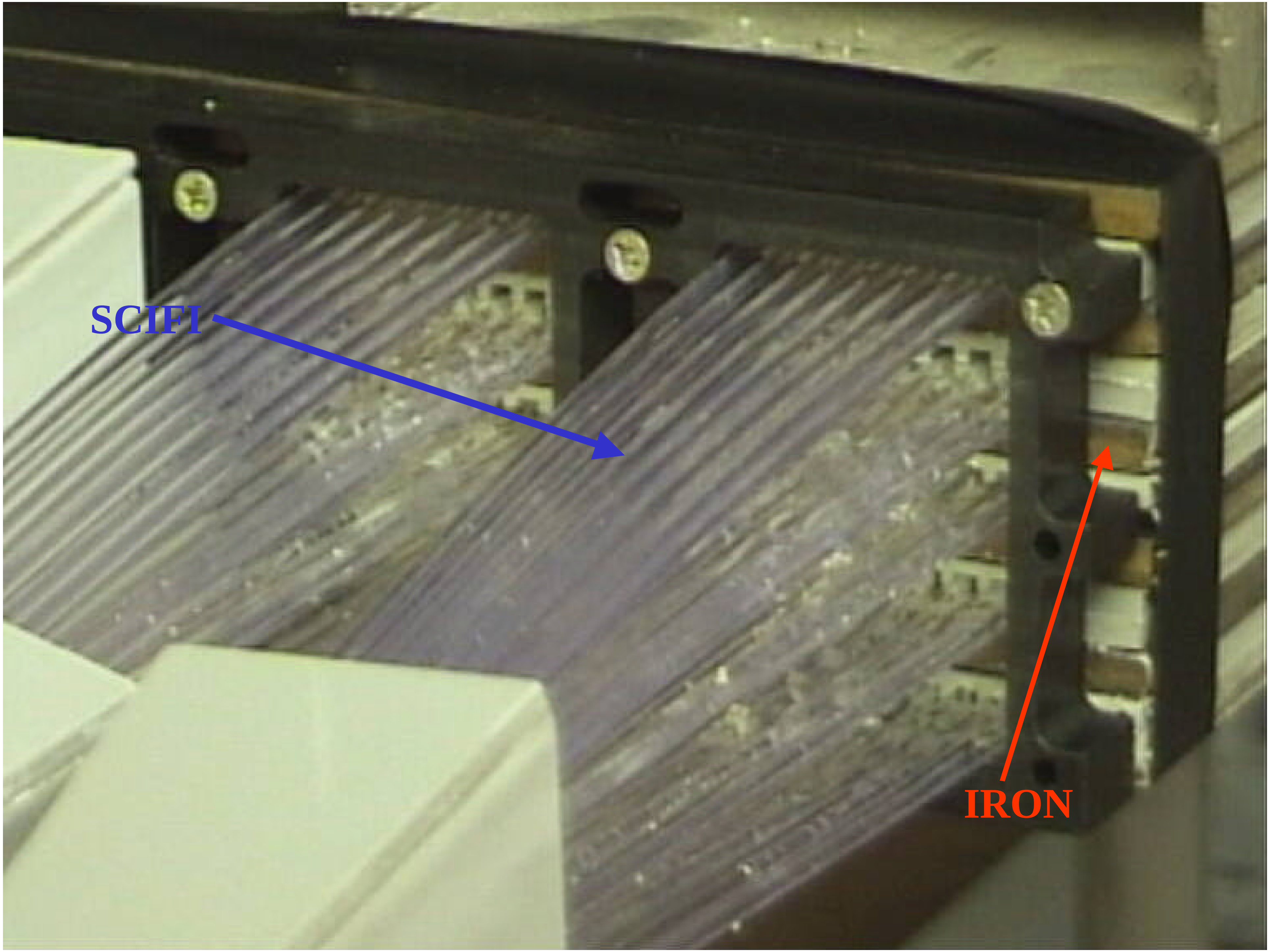


Fibers 2mm.

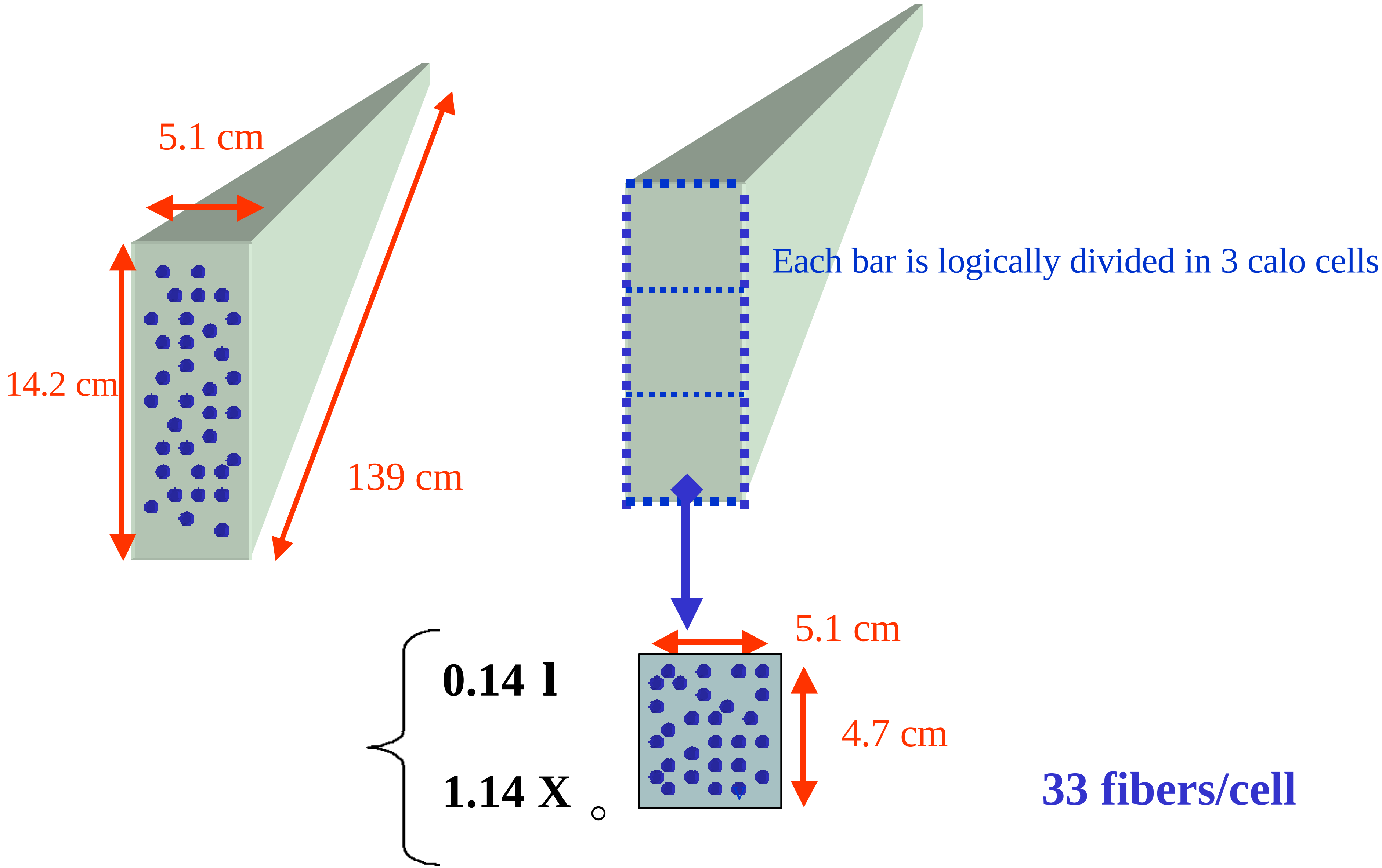
Calorimetric cell 5x5cm^2 (optimized)

Calorimetric layer: 50 mm thick
5 Iron plates: (5 mm thick)
5 SCIFI plane: 5 (2 mm Ø fiber)
$0.18\lambda_i$/cell - $1.47X_0$/cell


More difficult to build, but no impossible....
Iron slabs
SCIFI

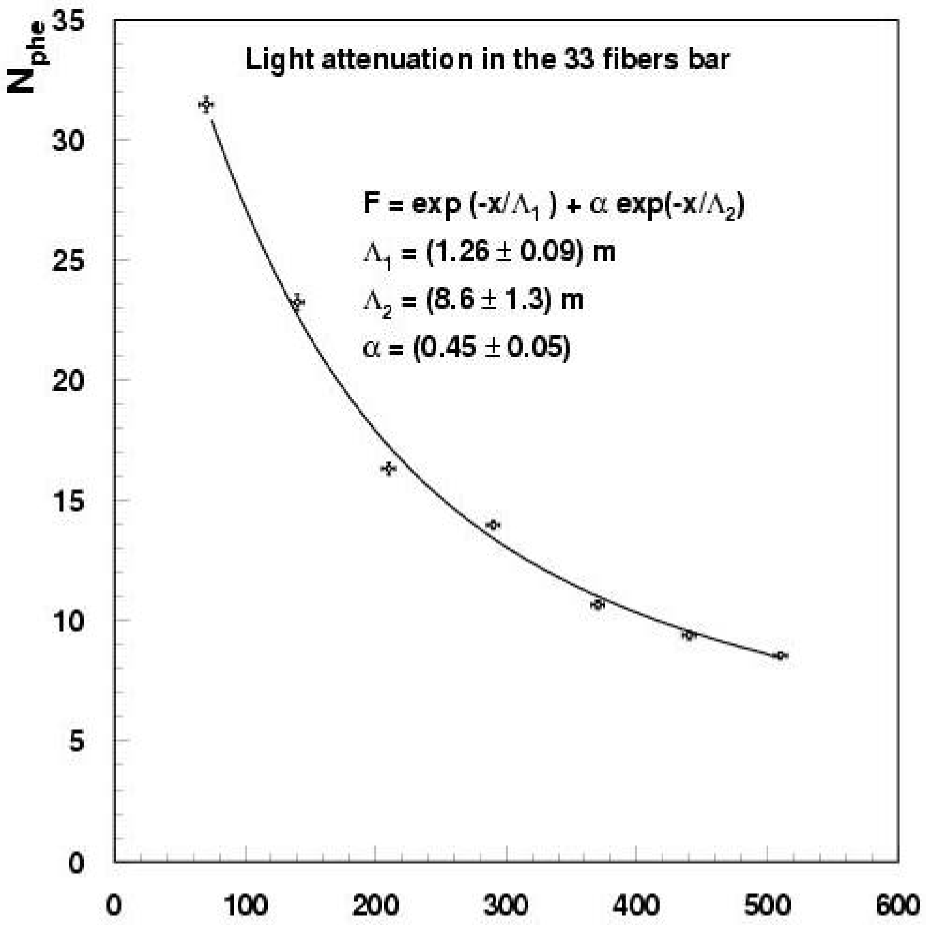

SCIFI
IRON

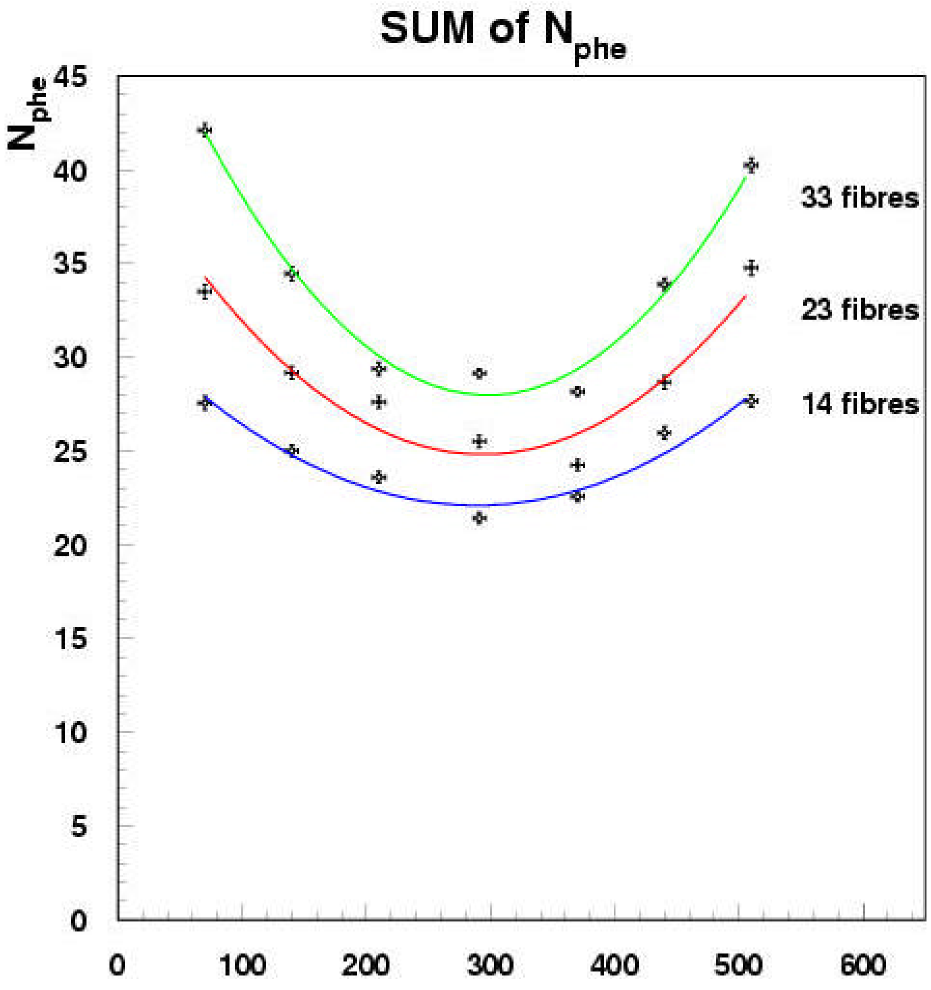
Calorimeter bars (5.1 x 14.2 x 139) cm^3 filled with iron ore



1.9 mm diameter Polithech (POLIFI 0244-3-200)

Double cladding	first cladding	n=1.49	Ø = 3% of external
	second cladding	n=1.43	Ø = 2% of exteranl cladding
Emission peak		420 nm	
Core		n=1.59	





Each cell is read out by a PMT Hamamatsu R4125 working @ G=10^7

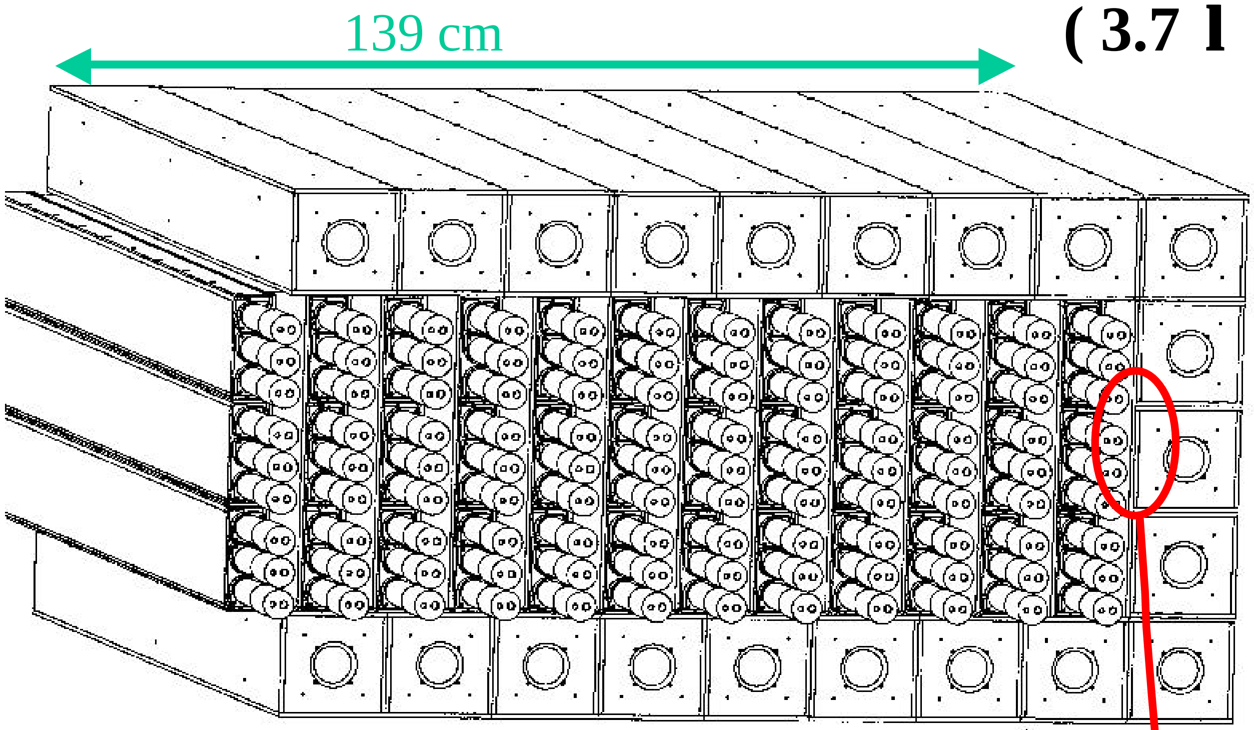
- High Gain
- Very good linearity (~5% @ 150 mA)
- Reasonable cost
- Good match with SCIFI emission spectrum
- 3/4 `` is ok for our fiber spot

A green LED, coupled to a optical fiber, sends light pulses to the PMT

All the 129 PMT's read out using ADC Lecroy 2249A,
fast gate (170 ns) generated by four fold scintillator coincidence; DAQ with Labview
~ 130 events/spill recored

4 tons prototypwe exposed to PS test beam on Dec. 98 (Crossed Bars option)

(3.7 l , 29.8 X̊)

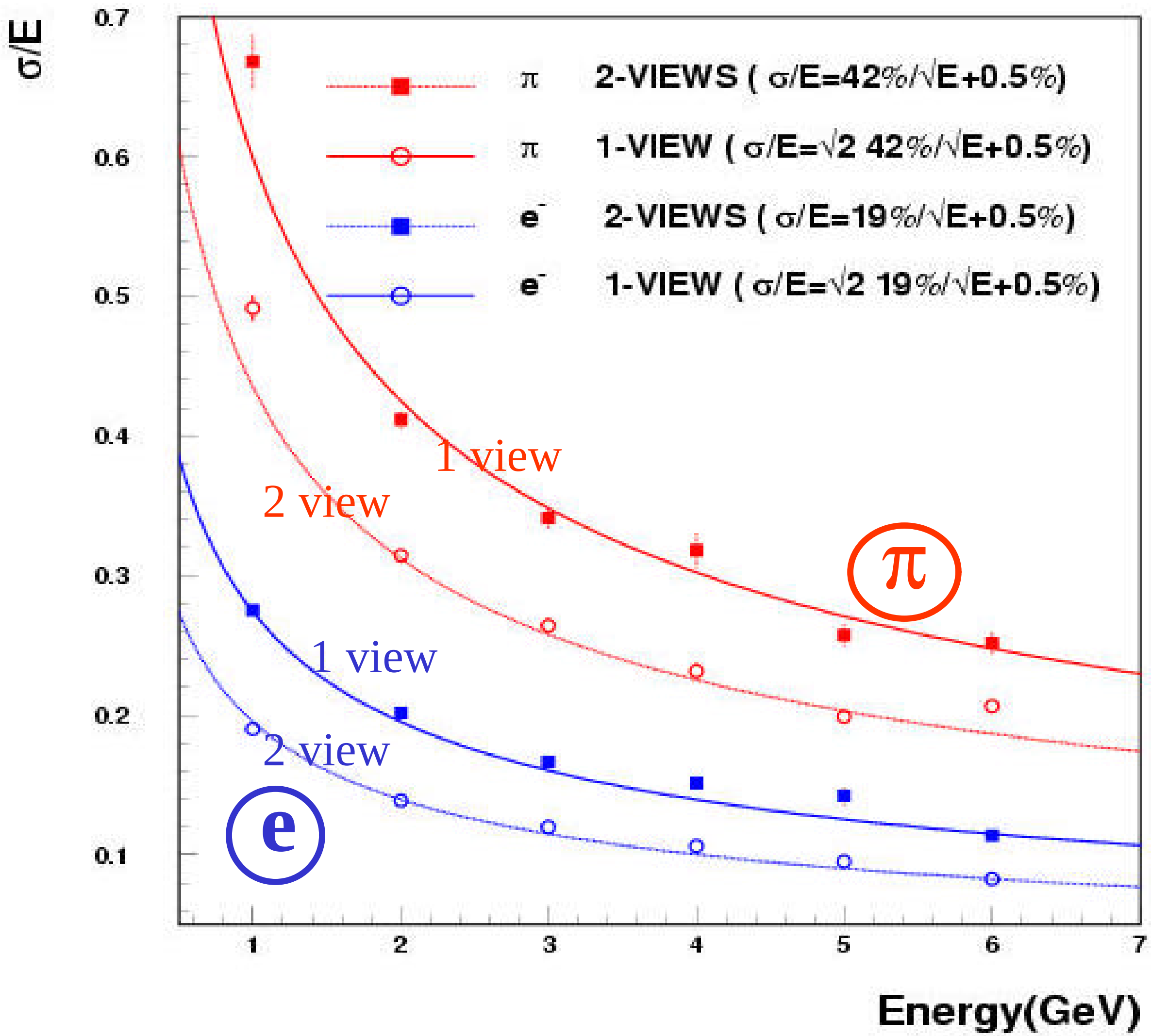


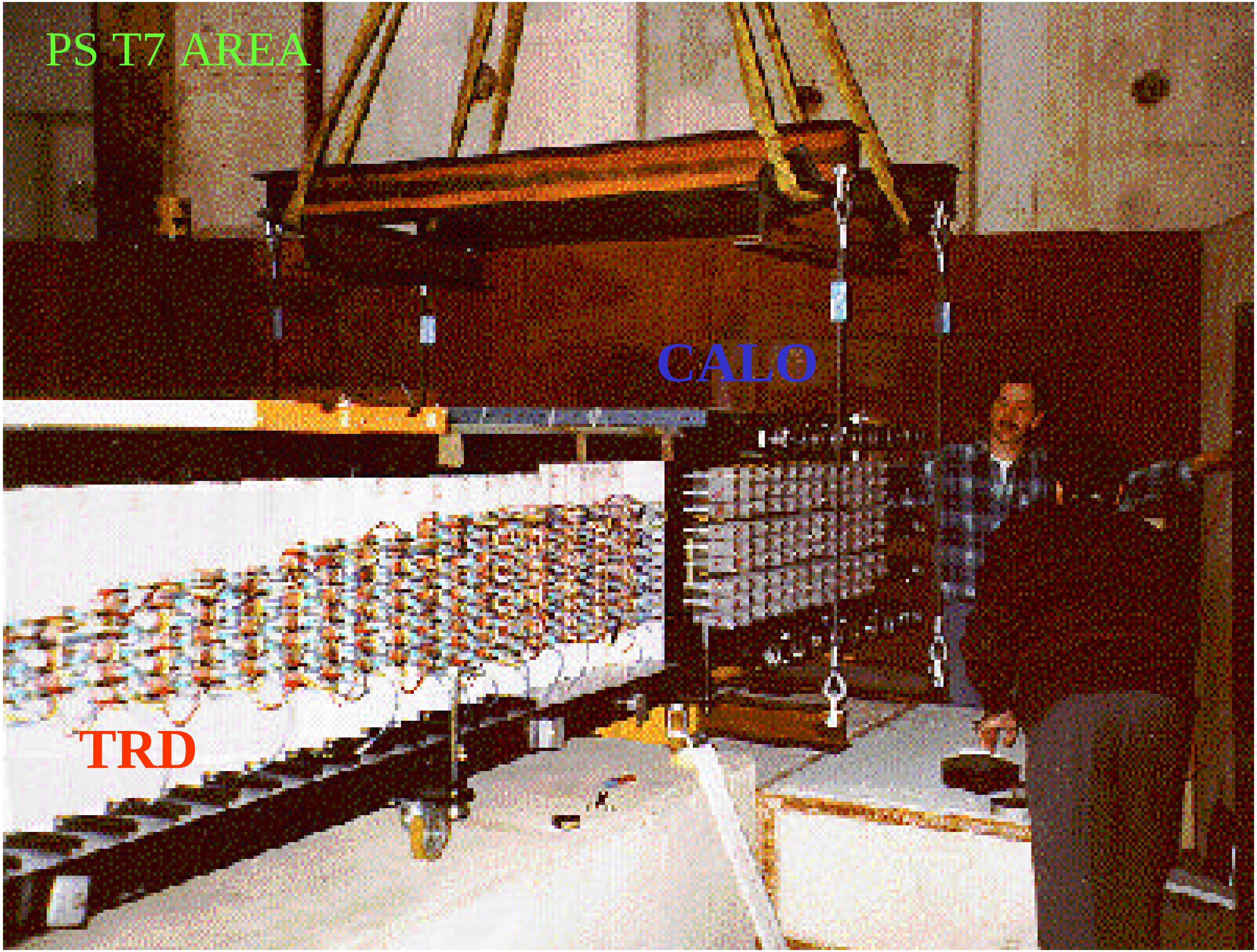
1 view instrumented

119 PMT Hamamasts R4125
+ 21 Hamamatsu R5686

Both the electromagnetic and hadronic energy resolution scales as $\sqrt{2}$ (since σ/E for Iron Calorimeter with $abs_{thick} > 2$ mm working at E~ 10 GeV is dominated by samplig fluctuations)

GEANT 3.21 CALO Simulation

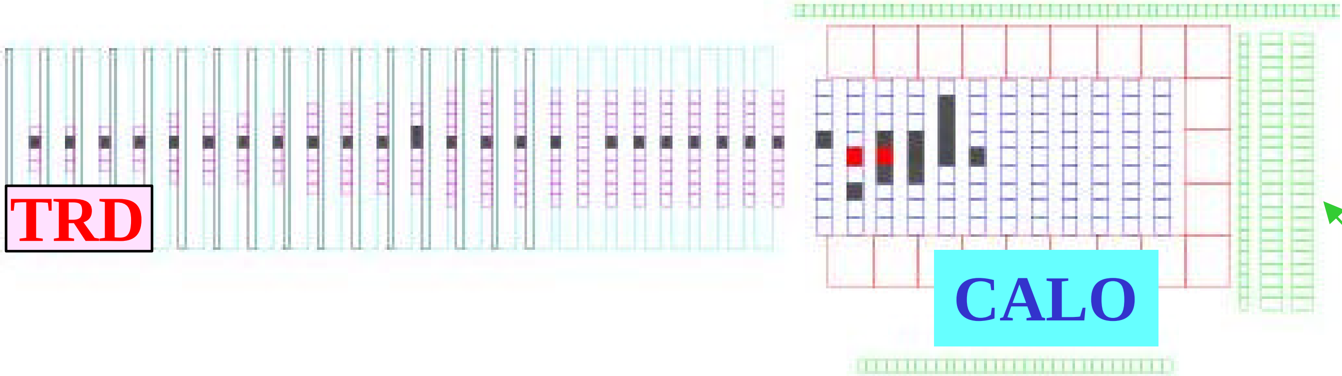




PS T7 AREA
CALO
TRD

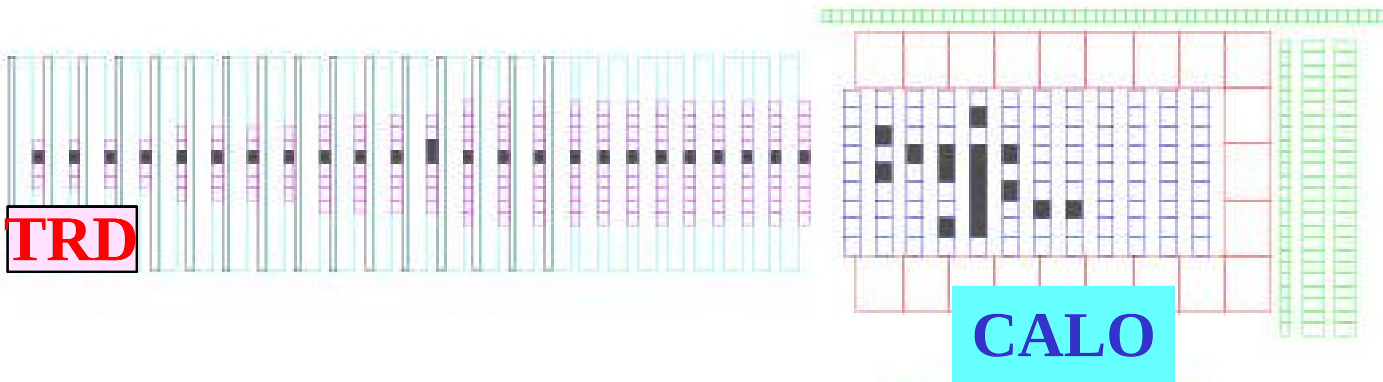
NUE
Neutrino Oscillation
Experiment

evt. 81
Particle type ele

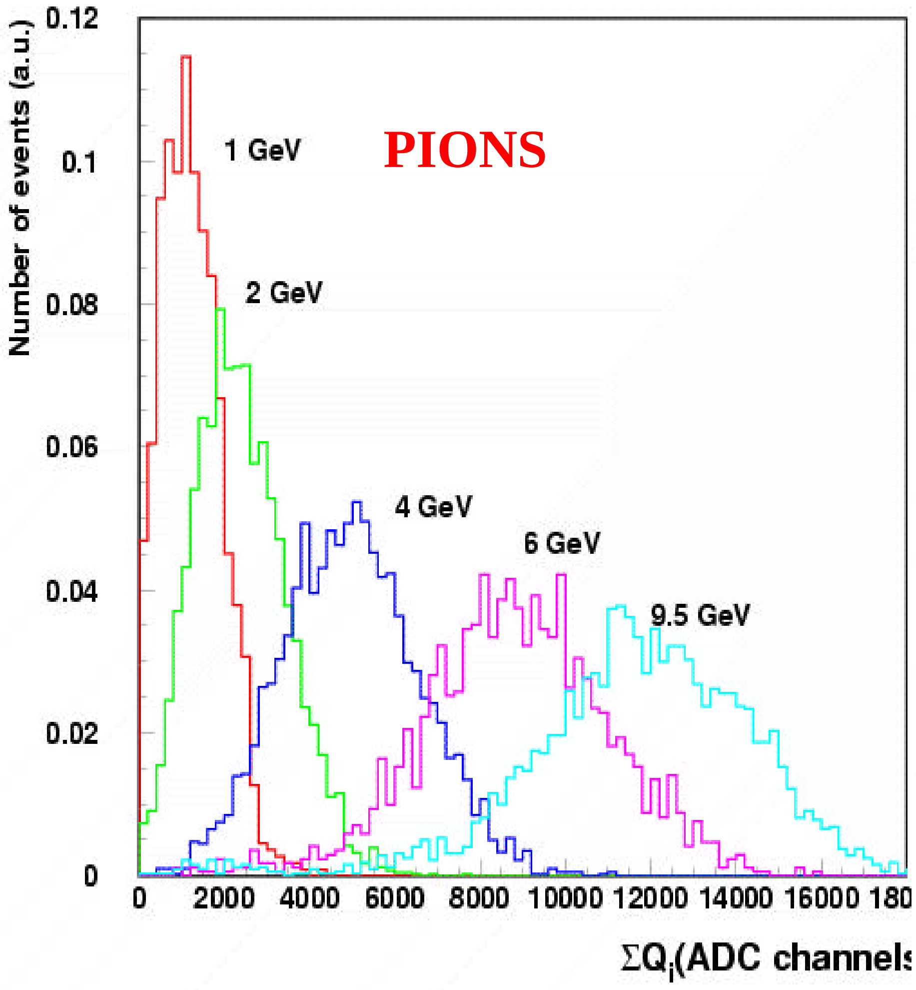


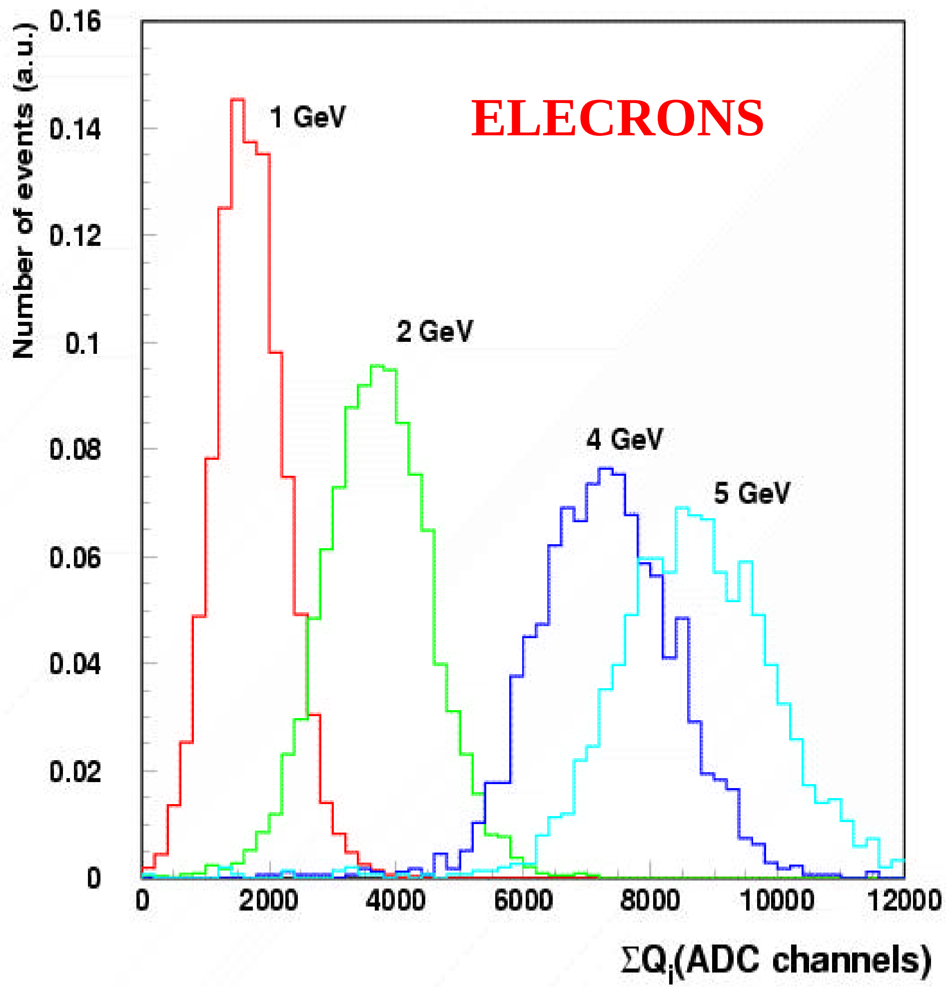
Limited streamer
tube tail catcher

evt. 198
Particle type pion

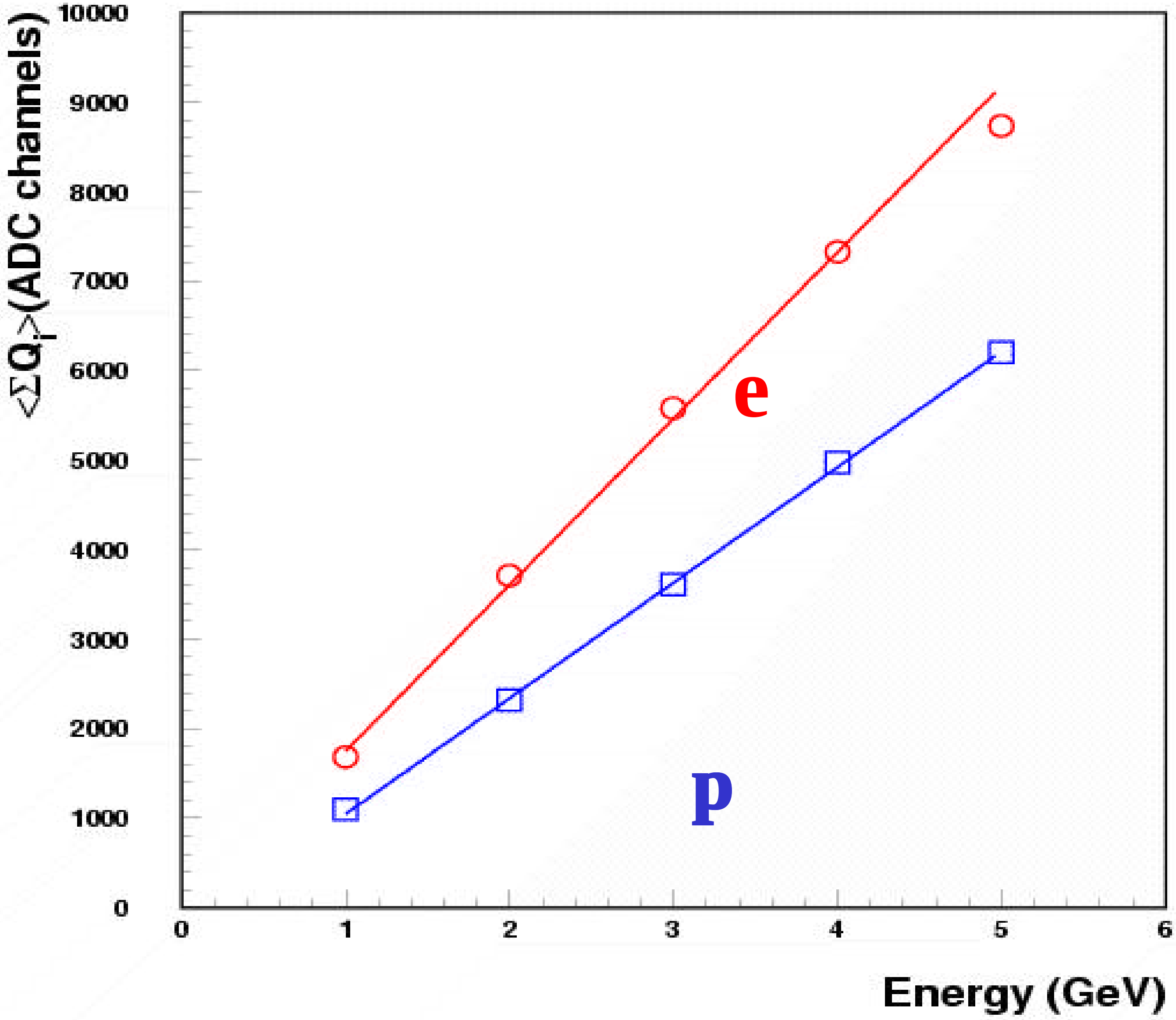


$$Q_{tot} = \sum_i (ADC_i - Ped_i)$$





Calorimeter linearity for electrons and pions:

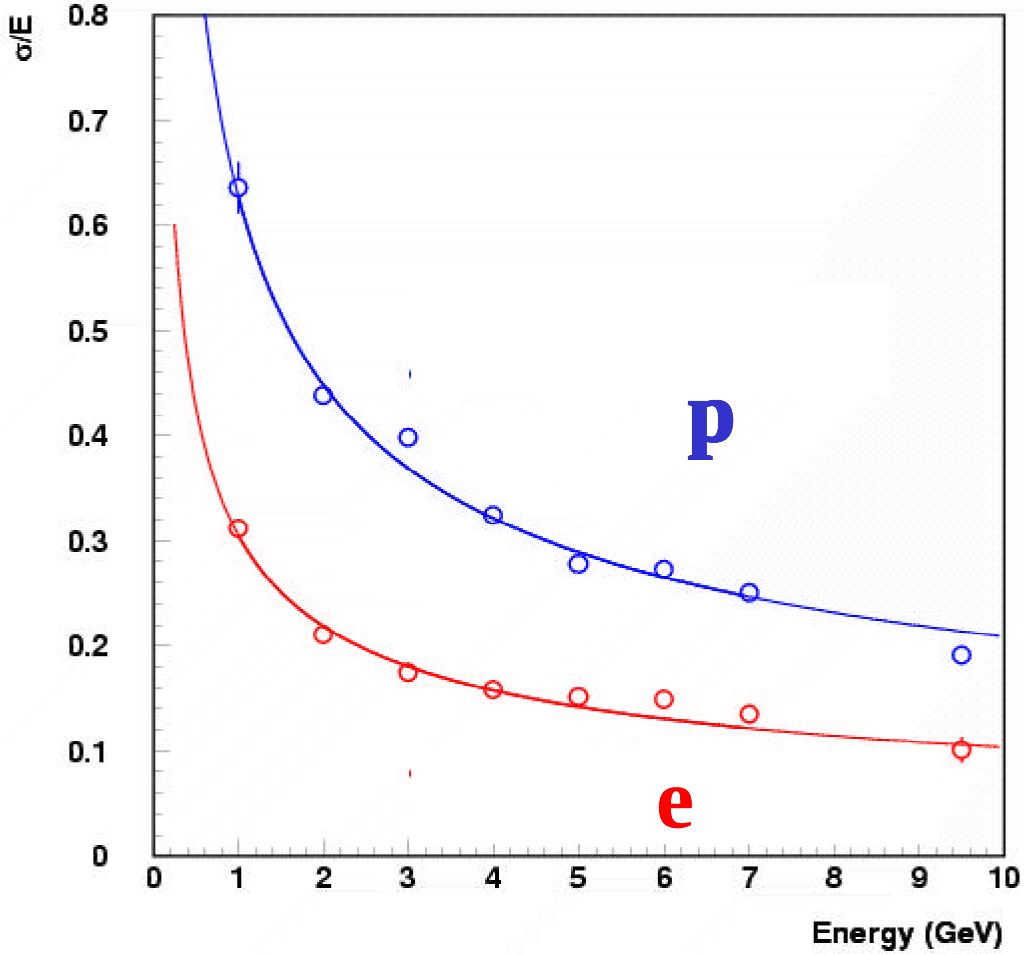


$$\frac{\sigma}{E} = \frac{\sqrt{2}\,(43. \pm 1.)\%}{\sqrt{E}} + (1.5 \pm 0.9)\%$$

p

$$\frac{\sigma}{E} = \frac{\sqrt{2}\,(20.9 \pm 0.3)\%}{\sqrt{E}} + (1.0 \pm 0.3)\%$$

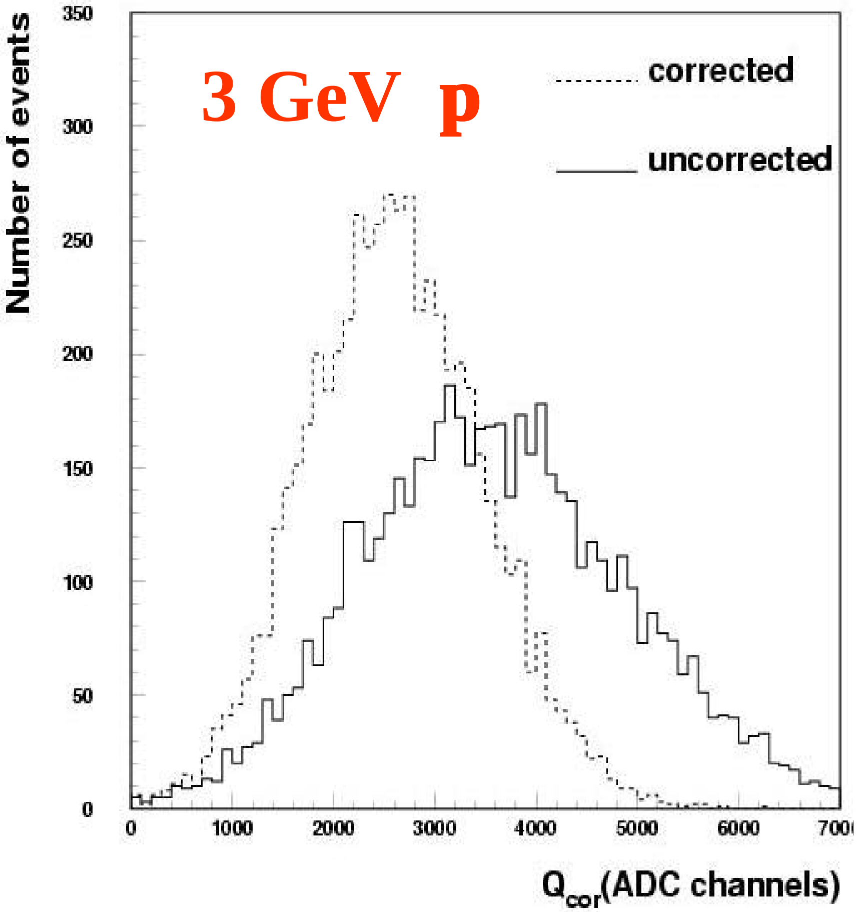
e

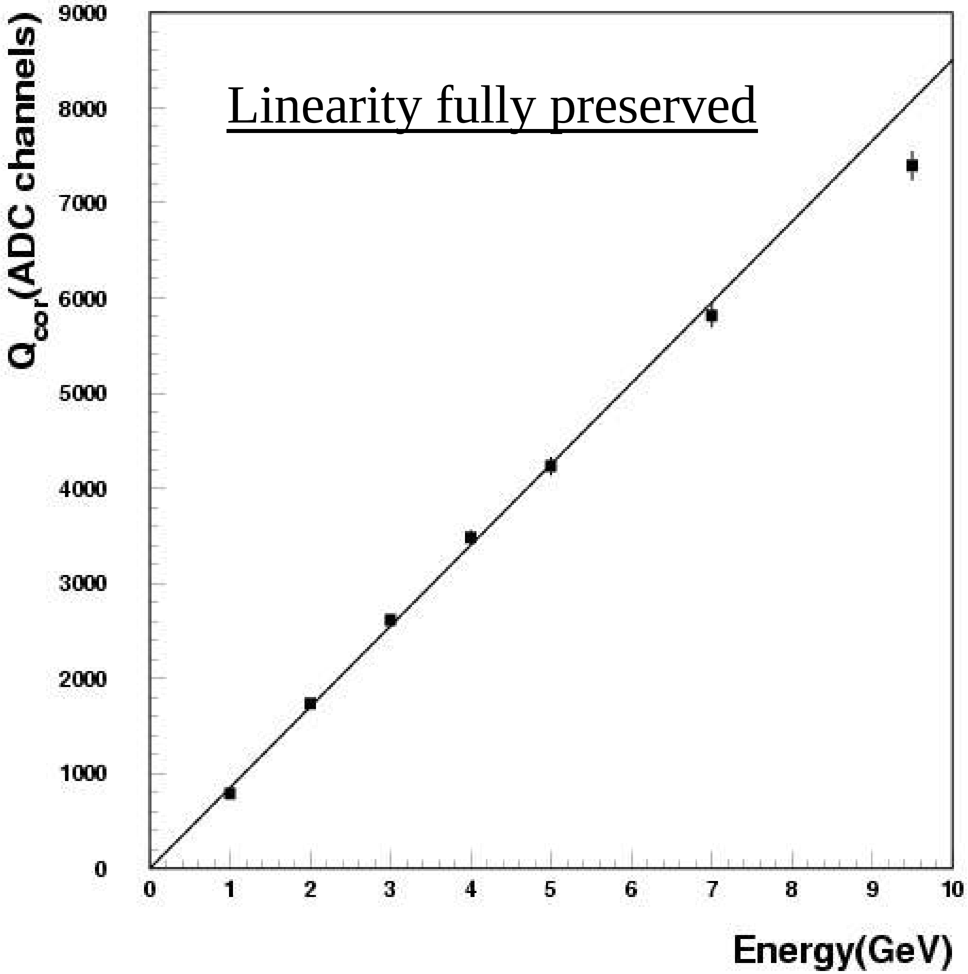


Software compensation

$$Q_{corr} = S\, Q_i * (1 - K * Q_i)$$ → K evaluated by data minimizing s(Q)/Q

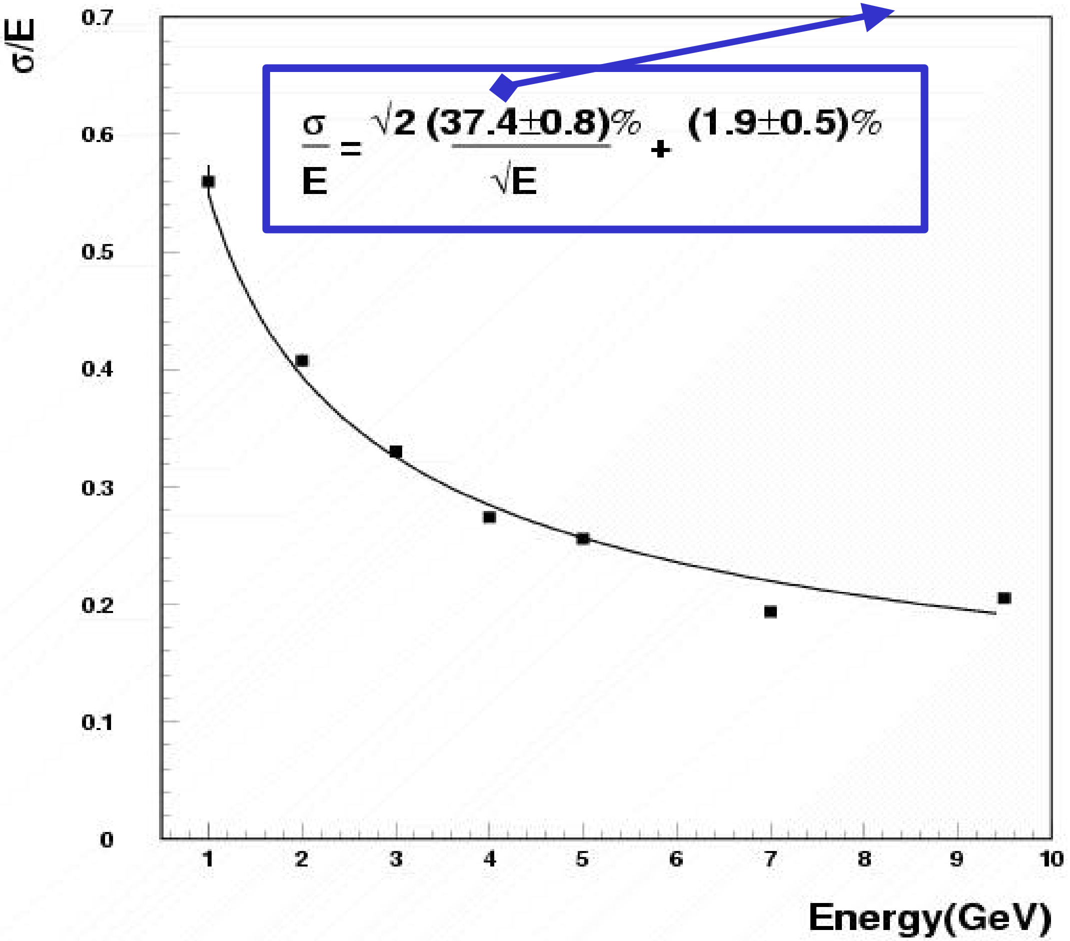
In CDHS K was running with E ; in NOE Calo K is almost constant (K=0.008)





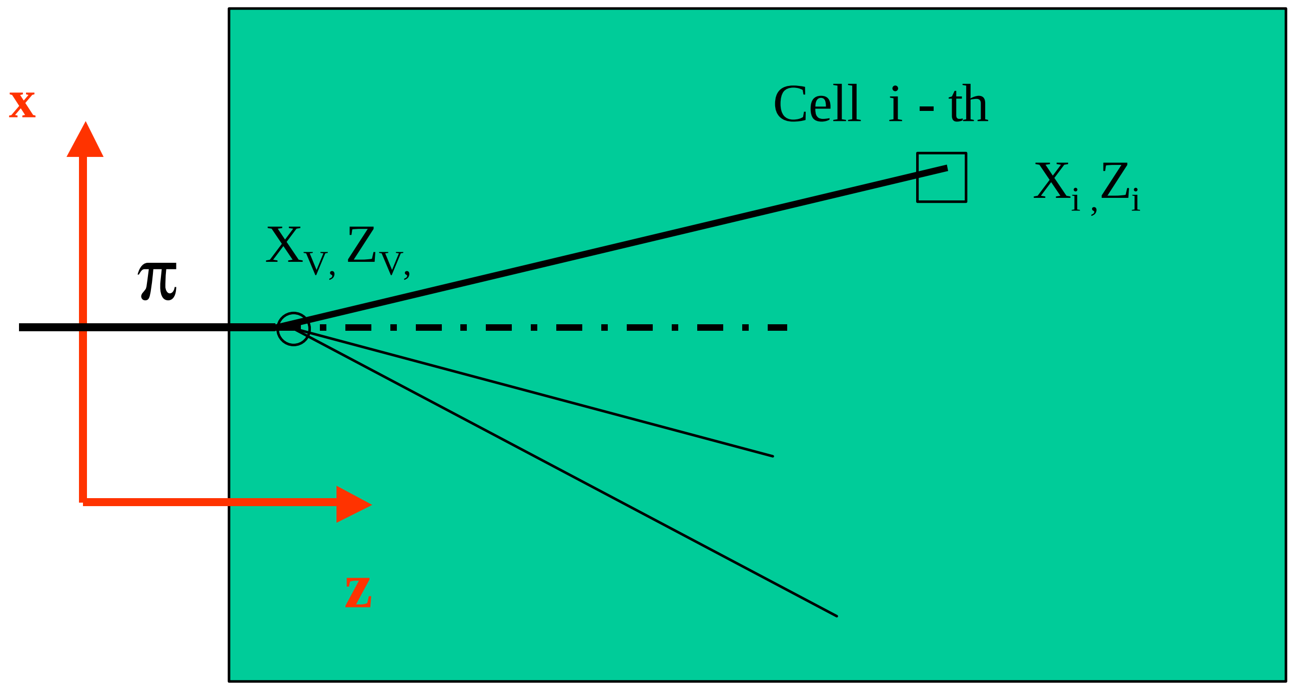
Energy resolution improvement after sotware correction:

Stocastic term improved of ~ 15%

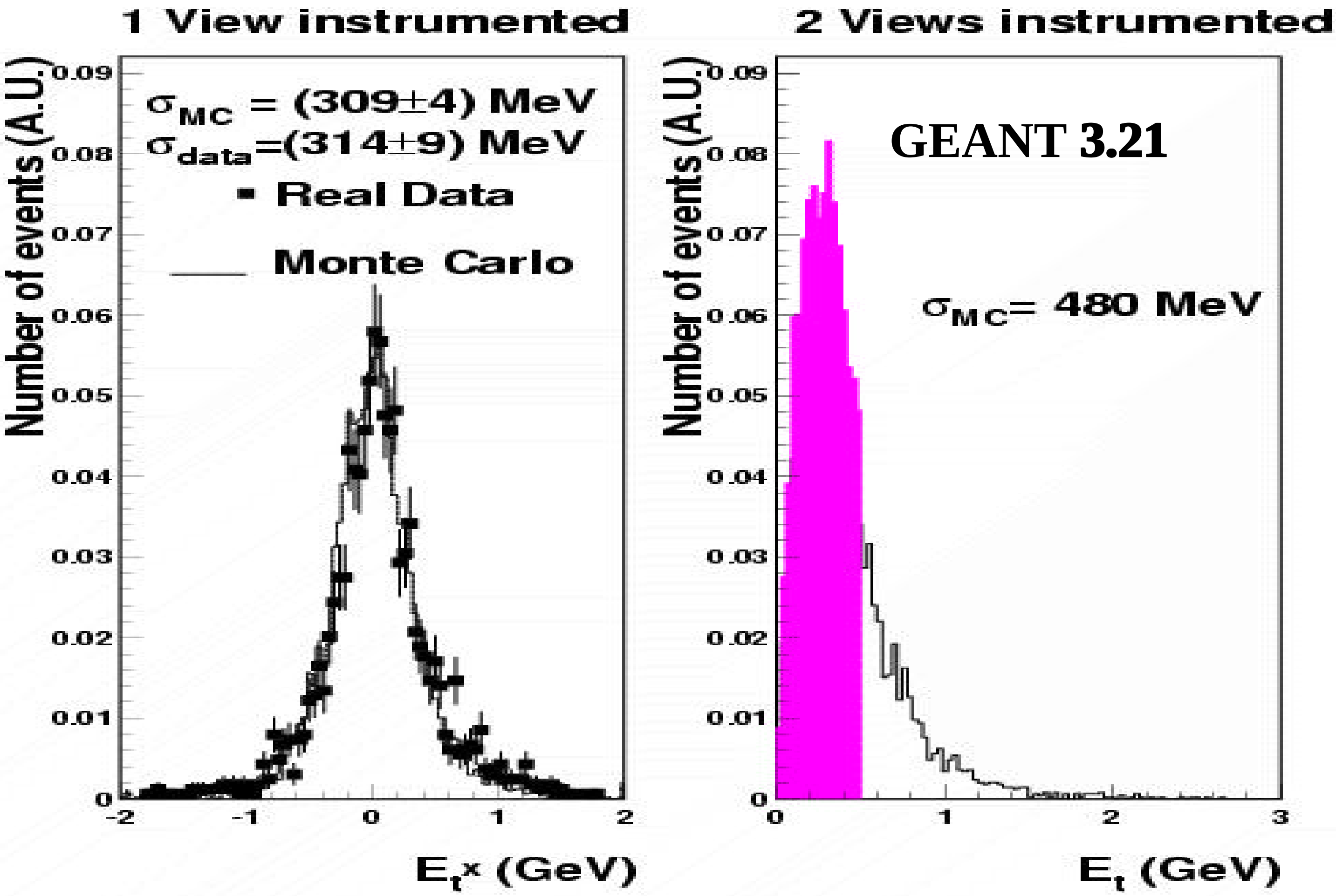


$$\boxed{E_t^X = E \sin\Theta_x}$$

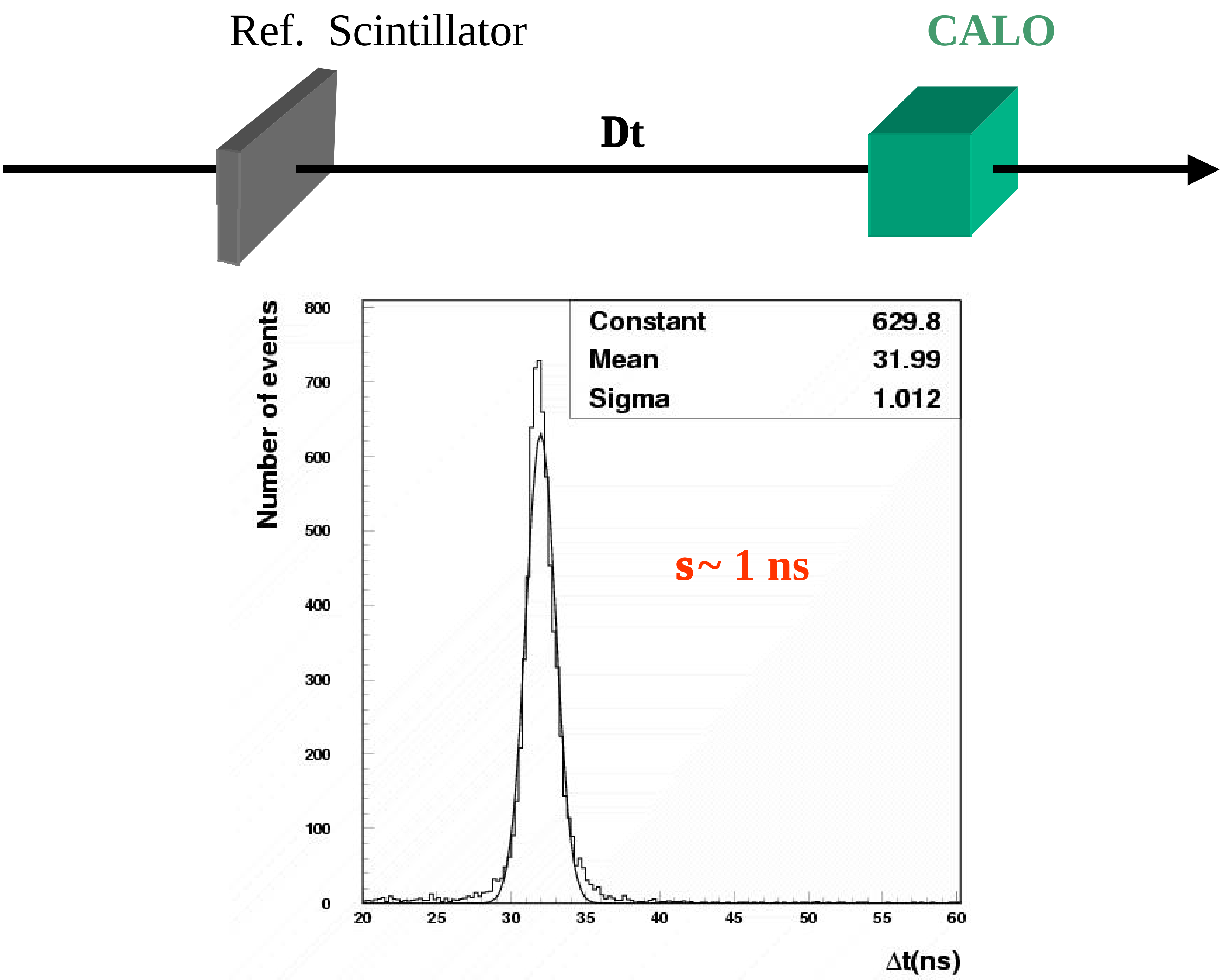
$$\Theta_x = \frac{1.}{\Sigma Q_i} \Sigma Q_i \arcsin \frac{(X_i - X_V)}{\left((X_i - X_V)^2 + (Z_i - Z_V)^2 \right)^{0.5}}$$



3 GeV p



1 View instrumented
2 Views instrumented
σ_{MC} = (309±4) MeV
σ_{data}=(314±9) MeV
Real Data
Monte Carlo
GEANT 3.21
σ_{MC}= 480 MeV
Number of events (A.U.)
E_t^x (GeV)
E_t (GeV)


Ref. Scintillator
CALO
Dt
Number of events
Constant 629.8
Mean 31.99
Sigma 1.012
s~ 1 ns
Δt(ns)

CONCLUSION

2 POSSIBLE SOLUTIONS FOR A MASSIVE , FINE GRAIN CALORIMETER HAVE BEEN STUDIED.

TEST BEAM RESULTS ON 4 TONS PROTOTYPE SHOW A GOOD CALORIMETER PERFORMANCE, WITH $\sigma/E \sim 43\%/\sqrt{E}$, IMPROVED BY SOFTWARE CORRECTIONS TO $\sim 37\,\% / \sqrt{E}$

TRANSVERSE ENERGY RESOLUTION MEASURED IN 1 - dim, (E_T^X) : RESULTS IN GOOD AGREEMENT WITH MC..