Analysis of DHCAL Data

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DHCAL Data Summary

Testbeam	Configuration	Muons	Secondary beam	Total
Fermilab[1]	DHCAL	6.9	9.3	16.2
	SiW ECAL + DHCAL	2.5	5.1	7.6
CERN[2]	DHCAL	5.6	23.4	29.1
TOTAL		**15.0**	**37.8**	**52.8**

[1]Contains a significant fraction of ‘calibration events’
[2]Contains no ‘calibration events’

Data taking about x4 more efficient at CERN due to

- Longer days (24 versus 12 hours)
- Higher spill frequency (every 45 versus every 60 seconds)
- Longer spills (9.7 versus 3.9 seconds)
- More uniform extractions (no detectable microstructure)
- Machine downtime similar at CERN and FNAL

DHCAL Data Analysis

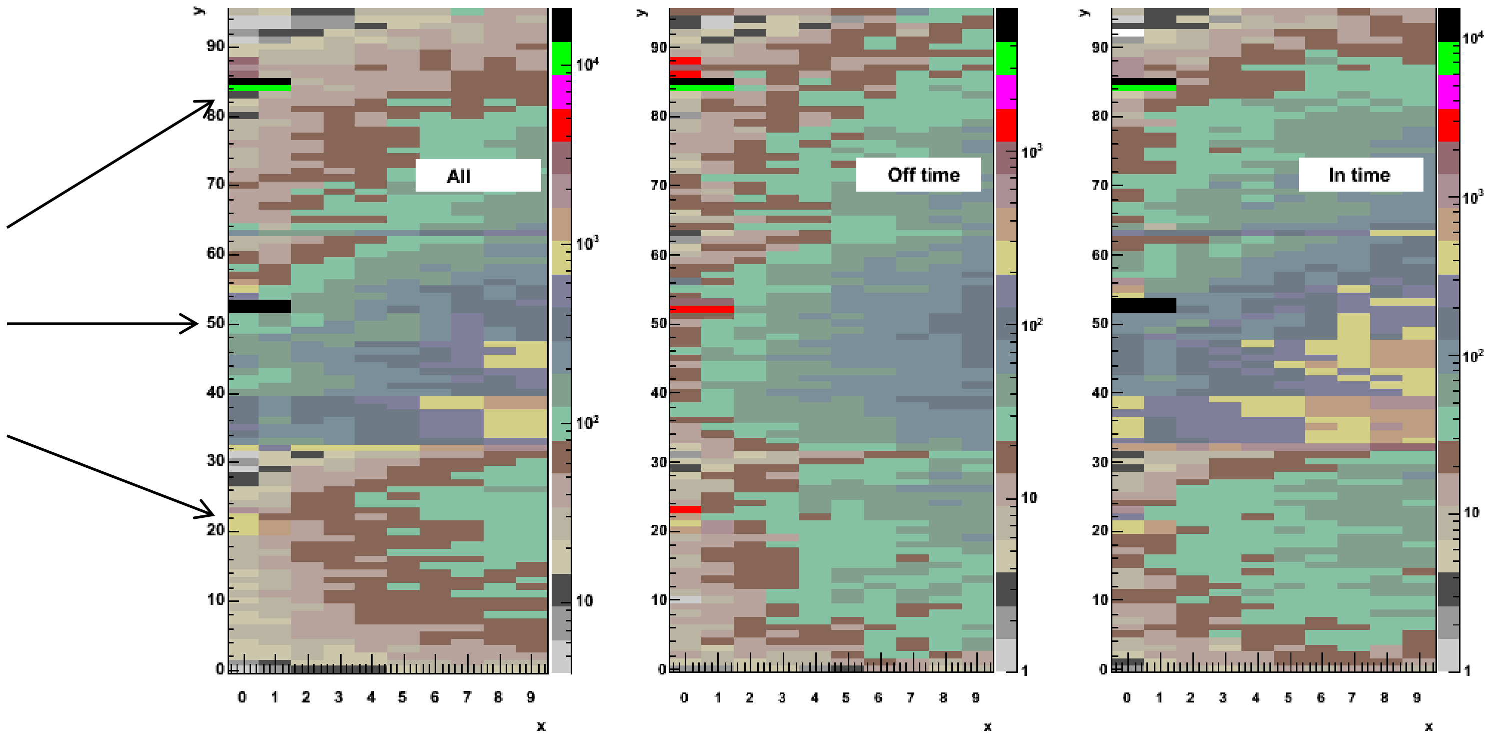
Topic	People
Noise studies	Guang Yang and Lei Xia Burak Bilki and José Repond
Calibration studies	Burak Bilki François Corriveau
Muon analysis	José Repond (Daniel Trojand)
Software compensation and weighting studies	Jacob Smith
RPC response simulation	José Repond Lei Xia
MC simulation	Burak Bilki Kurt Francis
Positron and Pion response (FNAL data)	Burak Bilki
CERN data quality	Kazuki Motohashi
Positron and Pion response (CERN data)	José Repond

Noise studies

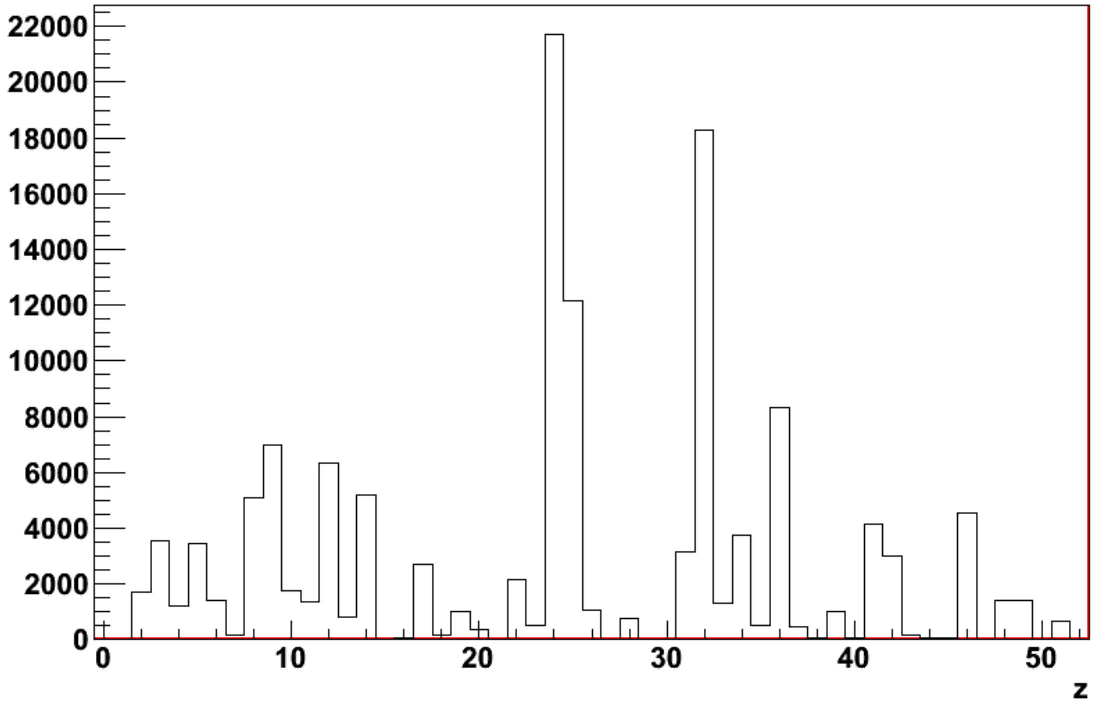
General comments

- Noise rates at the level of < 1 hits per event
- Response and resolution not affected by noise
- Possible effect on shower shapes

<u>Hits at ground connectors</u>



Events with hits in ground connector region

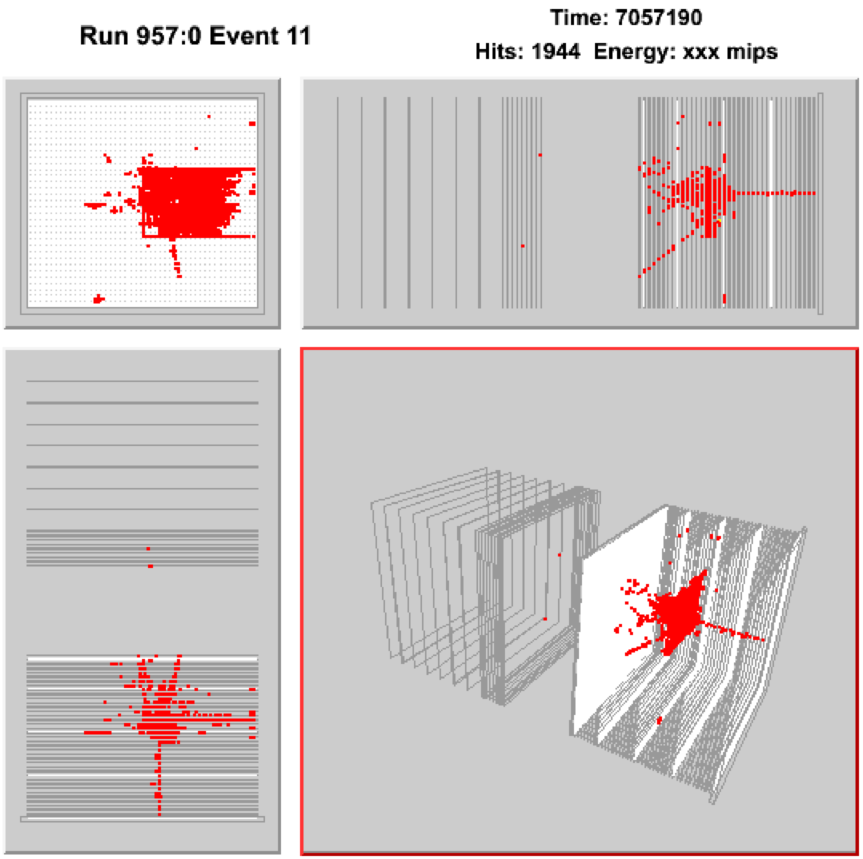


Some layers have no problems
Some layers are particularly bad

→ Reasons not entirely understood
→ Probably related to degraded contact between ground strip and resistive paint

Exclude x=0,1 and y=20-24, 52-56, 84-88 in all analyses

Box events



These events are **rare**, but seem to happen more often at high energies

Developed **two algorithms** to identify and eliminate events containing boxes

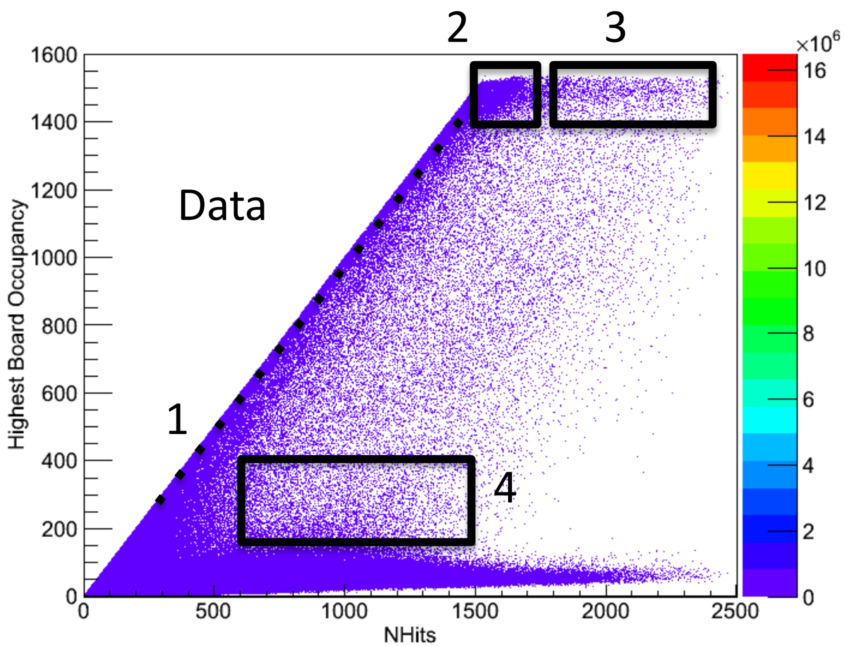
Burak: global analysis of all data

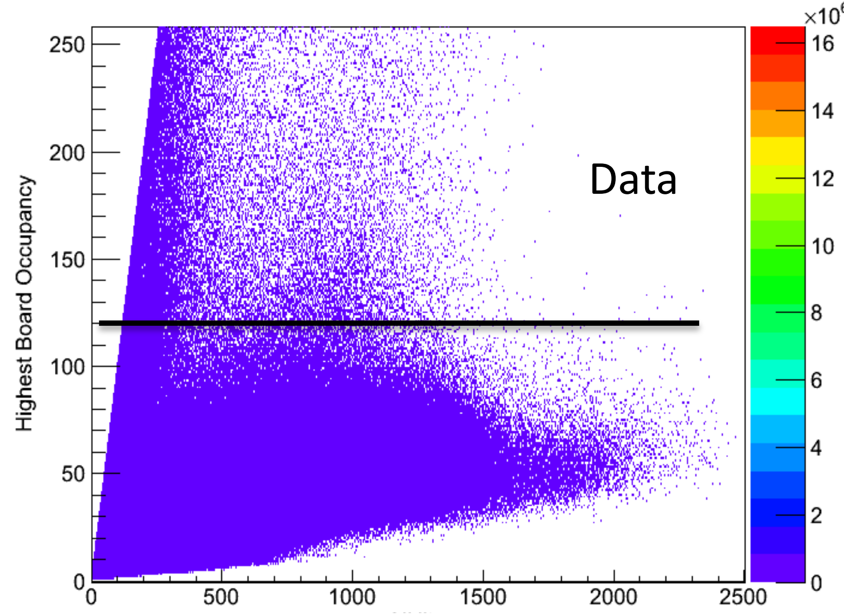
José: developed algorithm using runs with highest rate of box events

→ Useful for systematic studies

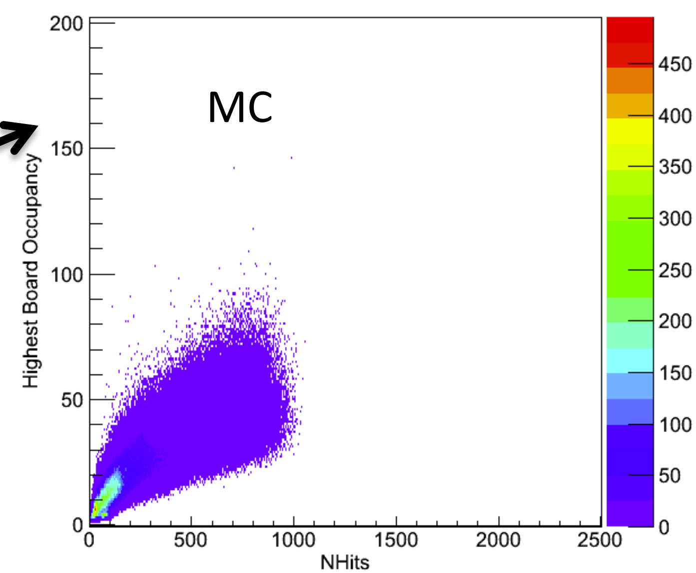
Conclusions from two approaches quite similar

Global analysis: Board occupancy versus N_{hits}





MC: DHCAL Oct10 setup, assume all hits in 1ΔTS
e+: 2, 4, 6, 8, 10, 12, 16, 20, 25, 32 GeV
pi+: 2, 4, 6, 8, 10, 12, 16, 20, 25, 32, 40, 50, 60 GeV



Cut if board occupancy>120

Global analysis

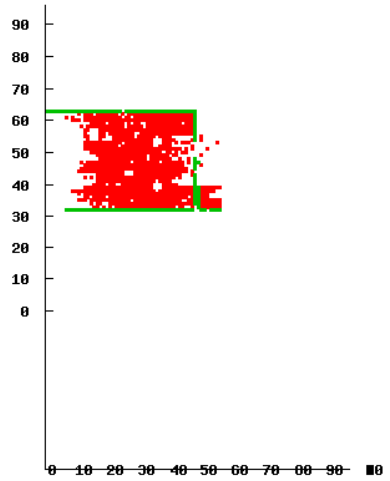
→ Further cuts depending on

Number of hits on edge of boards
Number of hits in ASICs
Number of hits on edge of ASIC

Analysis of 54,855,165 events (from FNAL and CERN)

608,909 rejected corresponding to 1.1%

Layers identified to have a box



Red hits inside border
Green hits on border of boards

Analysis of run 660505 (300 GeV)

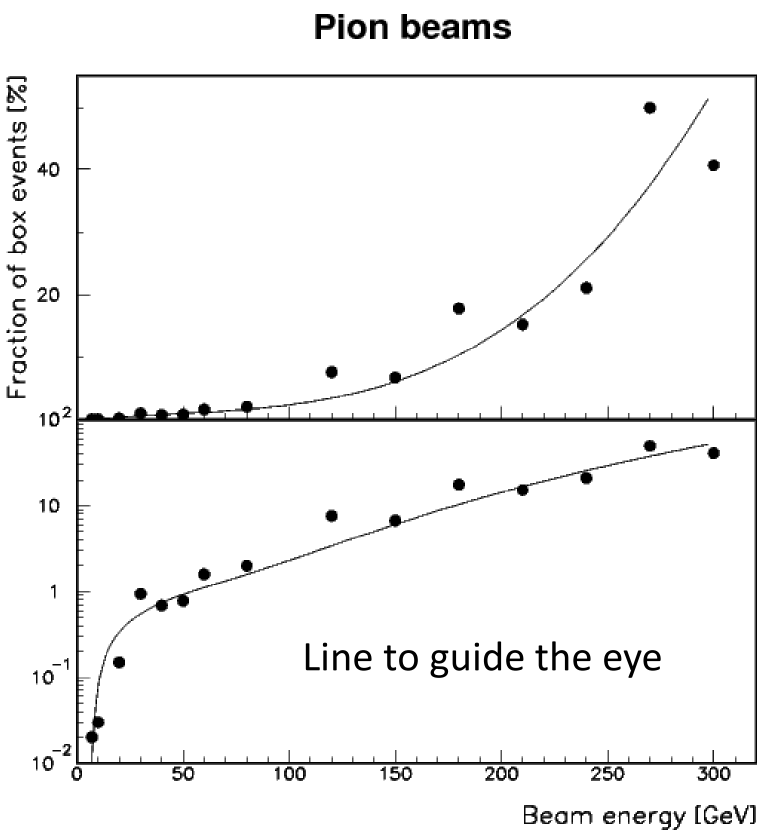
Use

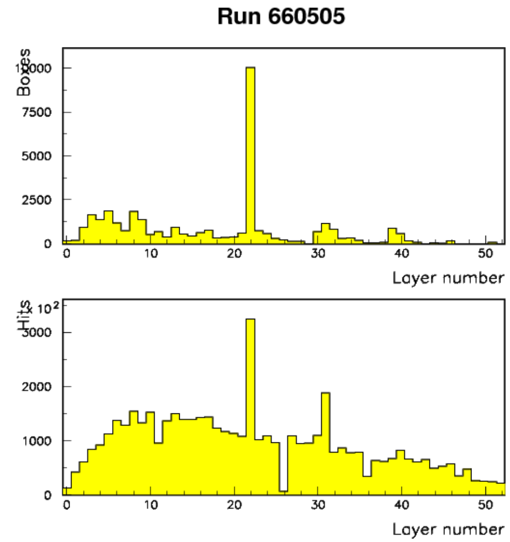
Number of hits on front-end board
Number of hits on edge of front-end board
Number of hits on neighboring rows of edges

to identify boxes

Analysis of run 660505

→ Applied to other runs





Below 100 GeV

Very low fraction of boxes

Above 100 GeV

Fraction increases dramatically

Scattering of box rates probably due to varying beam intensities

Reason for boxes

Not yet understood

Most likely related to grounding scheme

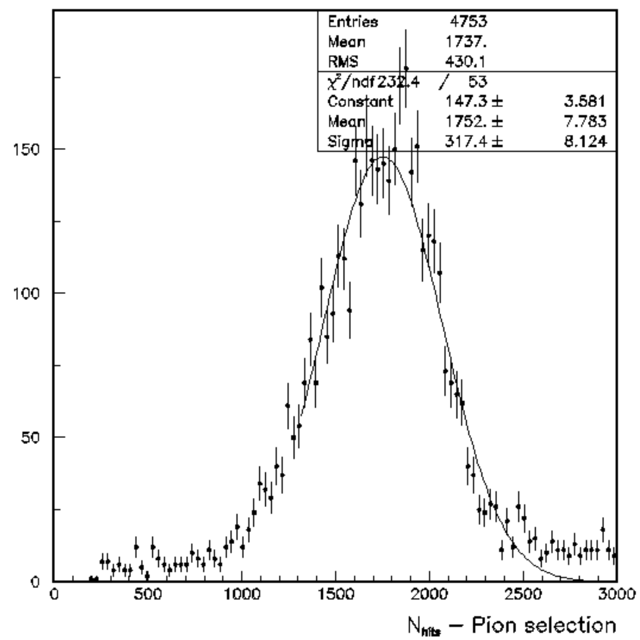
Applied to simulated 100 GeV pions

23 boxes found in 10,000 events

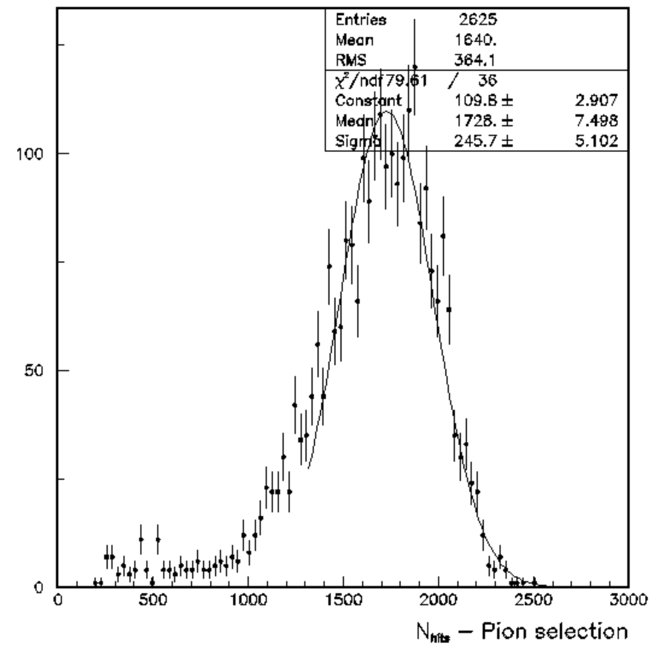
Assuming simulation close to reality → no bias introduced through box rejection

Effect of eliminating boxes on spectrum at 300 GeV

Before



After



Lost 45% of the events
Tail at high end disappeared
Width reduced by 22%

Simulation of RPC response

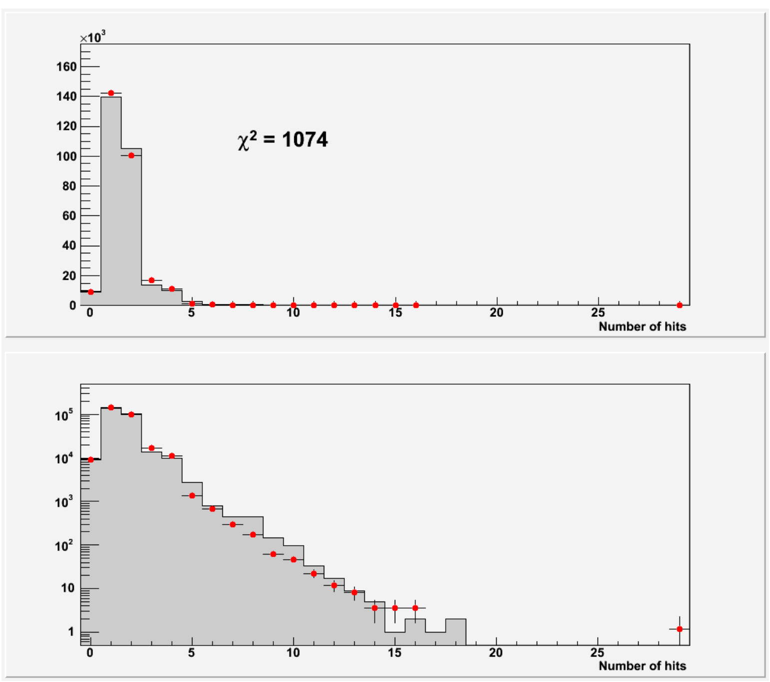
Use clean **muon** events
Tune to average response per layer
Two approaches (both useful for systematic studies)

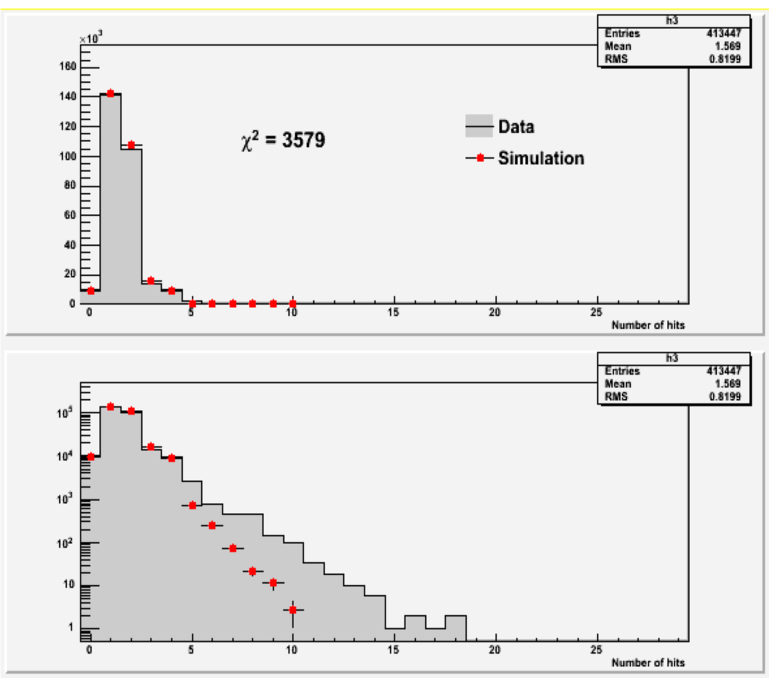
RPC_sim_3

Spread of charge in pad plane using 2 exponentials
6 parameters to be tuned
Reproduces tail towards higher pad multiplicities

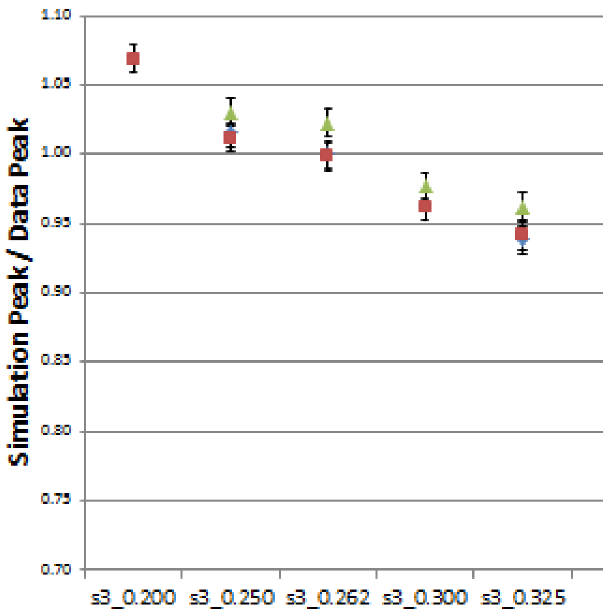
RPC_sim_4

Spread of charge in pad plane using 1 exponential
4 parameters to be tuned
Better reproduction of low multiplicity peak
Does not reproduce tail towards higher multiplicities





Simulation of Positrons



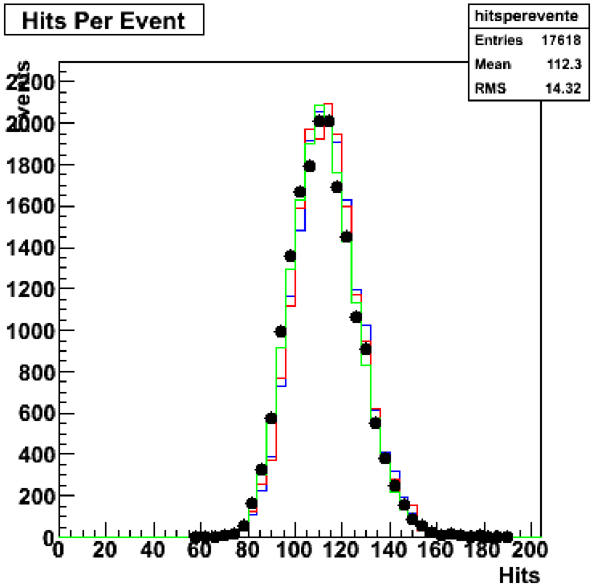
GEANT4

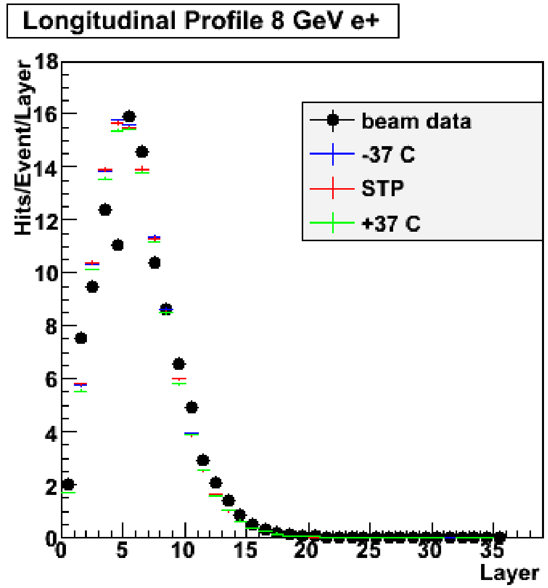
Physics list: QGSP _Bert
Within MOKKA framework

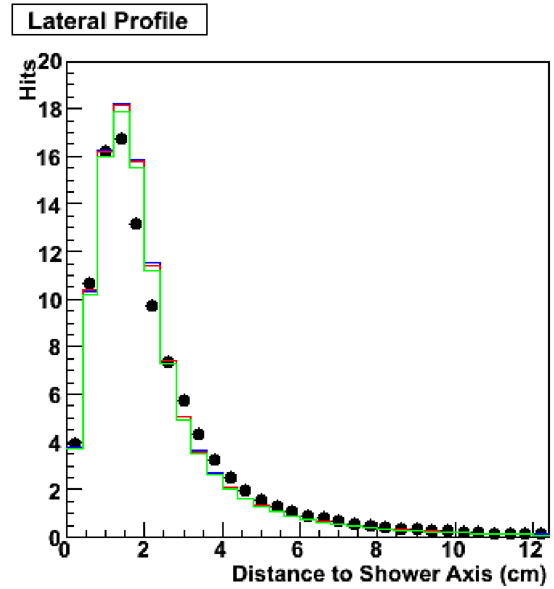
Fine tuning of the d_{cut} parameter

d_{cut}: Only 1 point (to be simulated) within a radius of d_{cut}
Muon simulation not sensitive to d_{cut}
Use 4/8/10 GeV positrons to determine best d_{cut} value

Study effect of changing gas density



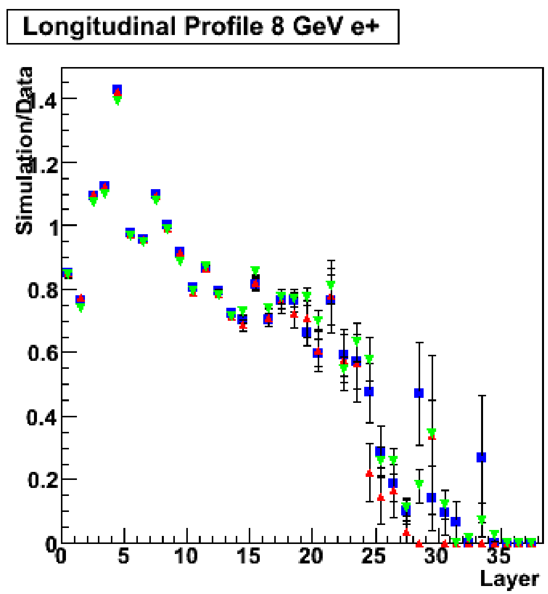


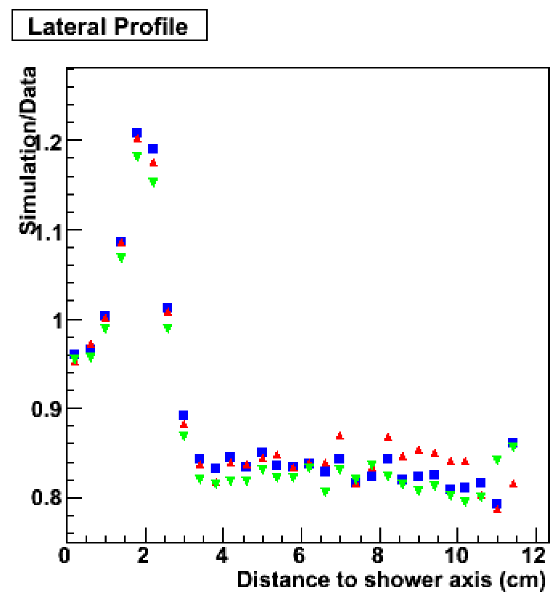


Note

Both longitudinal and lateral shapes not well reproduced

Is under investigation





Gas density affects

1) Cross section of interaction of photons in gas

→ to be simulated with GEANT4
→ no effect on muons

2) Gain of RPC

→ to be simulated by RPC_sim

Gas density in GEANT4

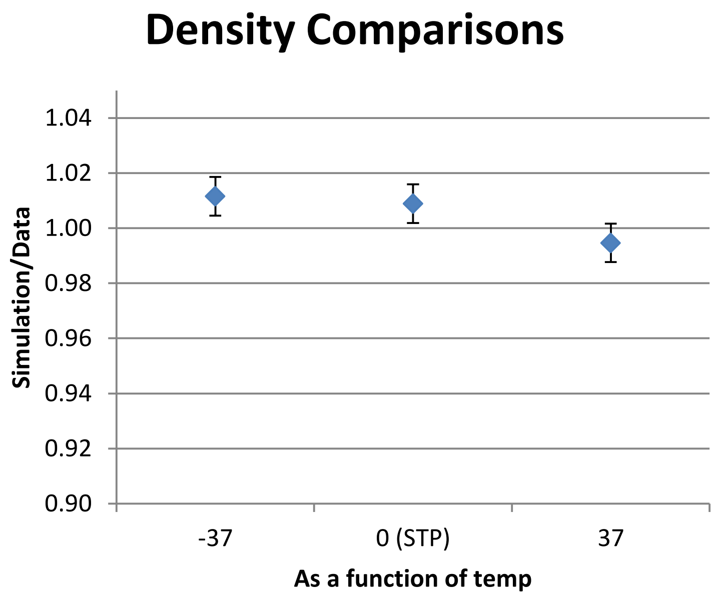
Changed corresponding to changes of $\pm 37^0$ C

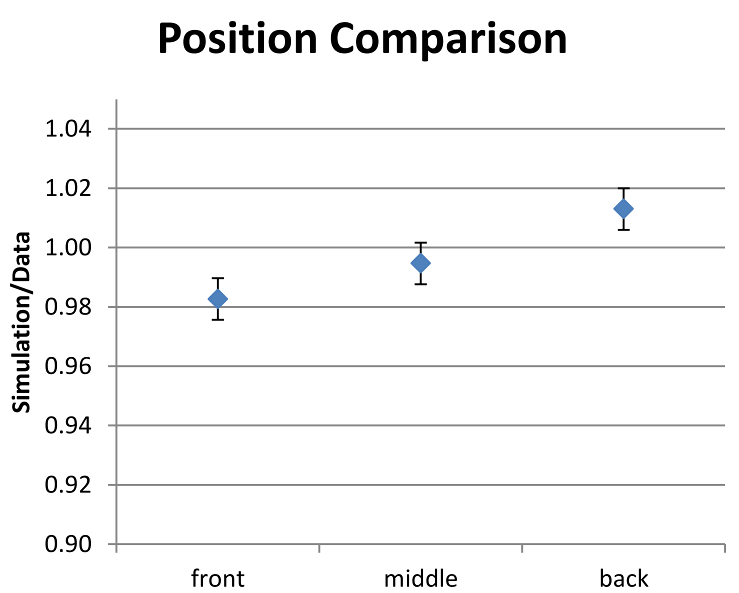
→ Minimal effect on mean of hit distribution

Effect of position of air gap in cassette

Moved air gap from back to front of layer

→ Minimal effect on mean of hit distribution

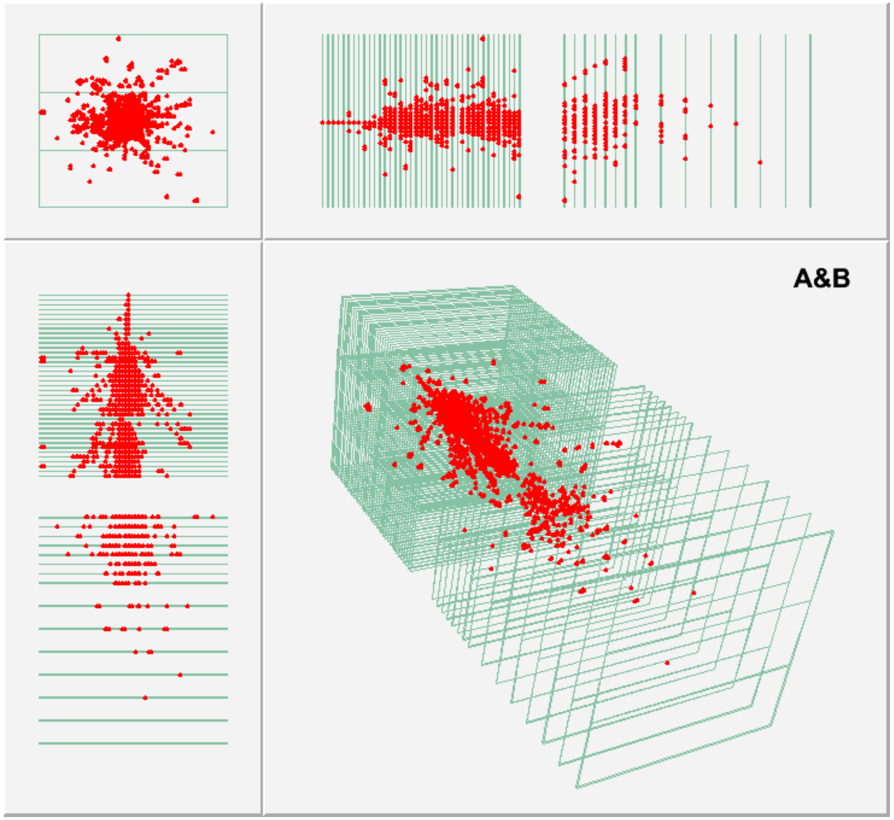


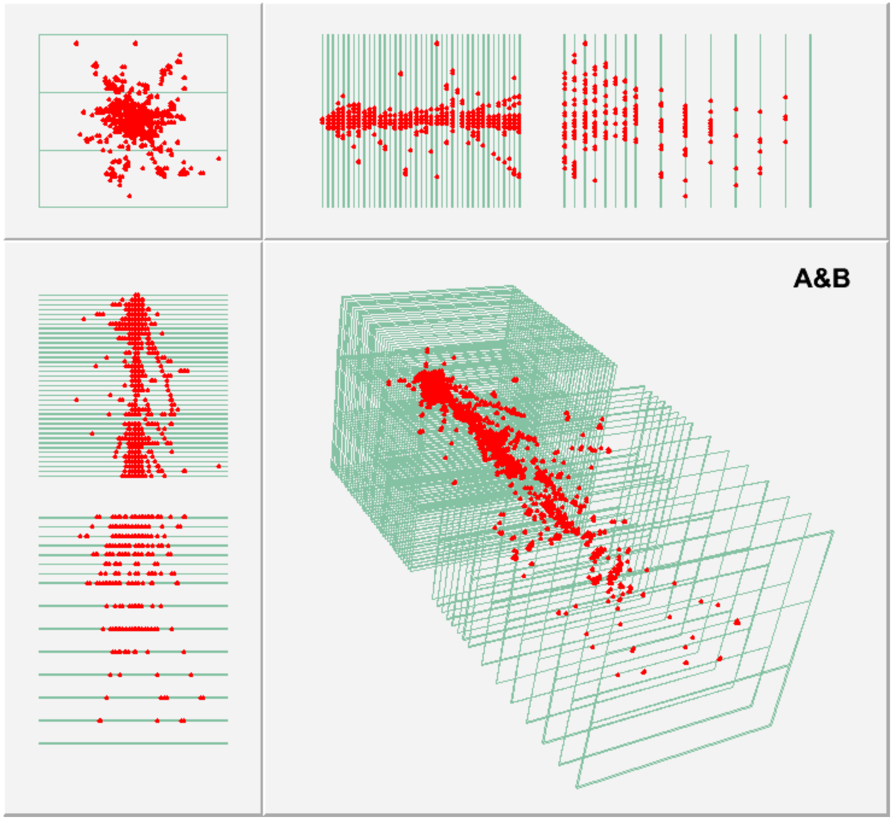


First analysis of CERN data

Polarity	Momentum	18 mm Pb absorber	No Pb absorber	Beam blocker	Total
Negative	1		540,660		540,660
	2		964,361		964,361
	3		1,006,185		1,006,185
	4		1,030,302		1,030,302
	5		1,185,235		1,185,235
	6		1,268,235		1,268,235
	7		1,546,744		1,546,744
	8		1,196,804		1,196,804
	9		2,044,224		2,044,224
	10		1,007,922		1,007,922
	12		300,666		300,666
	15	305,735			305,735
	20	465,904	438,356		904,260
	30	594,132	410,731		1,004,863
	40	510,736	303,020		813,756
	50	886,201			886,201
	60	497,739			497,739
	80	722,268			722,268
	100	526,323	64,658		590,981
	120	505,465			505,465
	180	123,448			123,448
	210	350,302			350,302
	240	283,554			283,554
	270	206,733			206,733
	300	436,133		704,141	1,140,274
	Total	6,414,673	13,308,103	704,141	20,426,917
Positive	4		1,137,898		1,137,898
	6		655,638		655,638
	8		527,234		527,234
	10		359,768		359,768
	60		10,125		10,125
	150	289,888	230,515		520,403
	180	303,917	211,482	4,920,679	5,436,078
	Total	593,805	3,132,660	4,920,679	8,647,144
Grand total		7,008,478	16,440,763	5,624,820	29,074,061

300 GeV pion showers





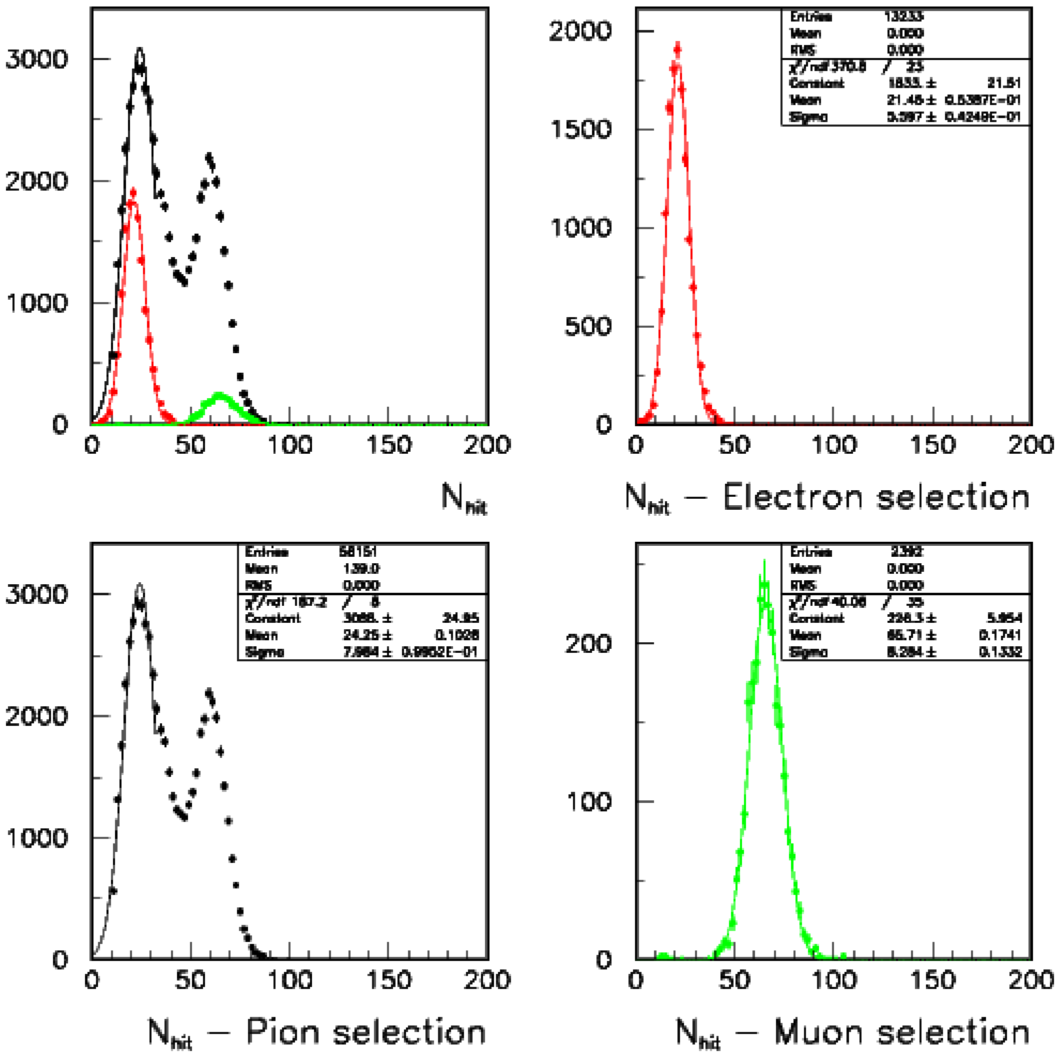
Event selection

General cut: 1 cluster in layer 0 with less than 12 hits

Particle	Cerenkov	BC	R	IL	N_0	$\sum_{i=last-4}^{last} N_i$	$\sum_{i=0}^{last} N_i$
Muons	$C_1+C_2=0$	>20	<3.0	-		>0	>10
Electrons	$C_1 \cdot C_2=1$	<8	>4.0 for E>12 GeV	-	>4 for E>12 GeV	-	-
Pions	$C_1+C_2=0$ or ($C_1=0$ and $C_2=1$)	-	>2.0 – 5.0	>2 for E>3 GeV		-	-
Protons	$C_1+C_2=0$	-	>2.0 – 5.0			-	

BC … Longitudinal barycenter
R … Average number of hits per active layer
IL … Interaction layer
N_0 … Hits in layer 0

Spectra at -2 GeV/c



Clean **electrons**

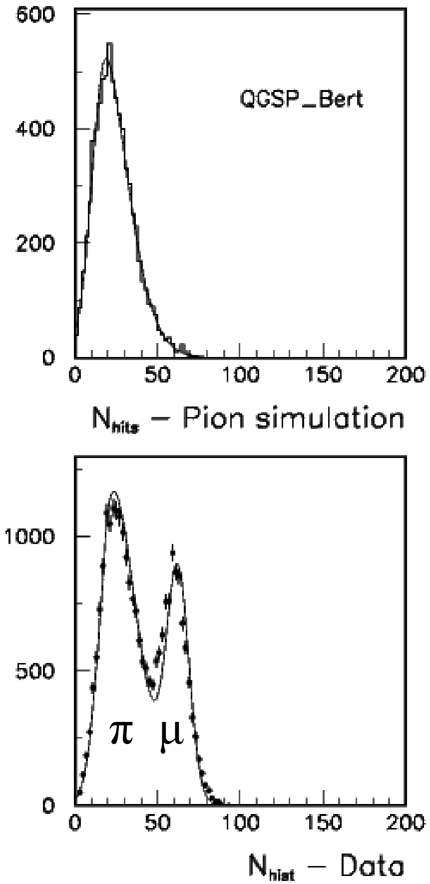
Clean through-going **muons**

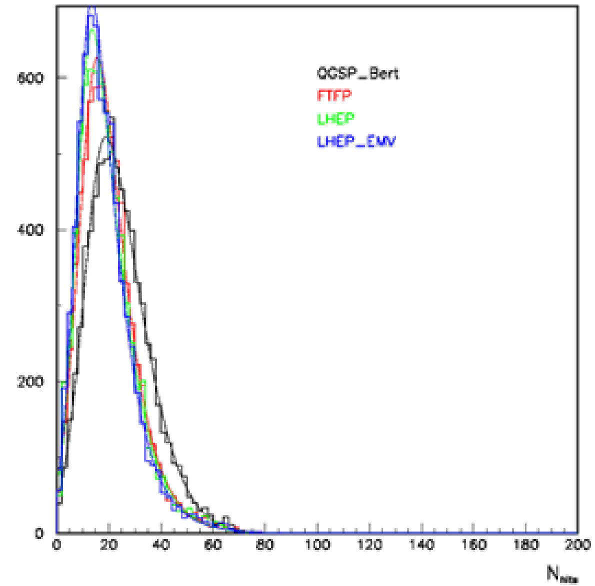
Two peaks in **pion** spectrum

→ What are they?

Simulation of -2 GeV/c pions and muons

-2 GeV/c Beam





Simulated pion/muon response fit with variable-width Gaussian

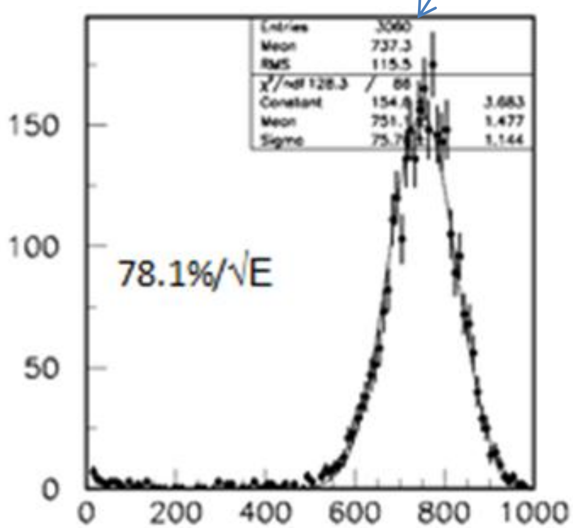
Data fit to sum of pion and muon response leaving only their normalizations free

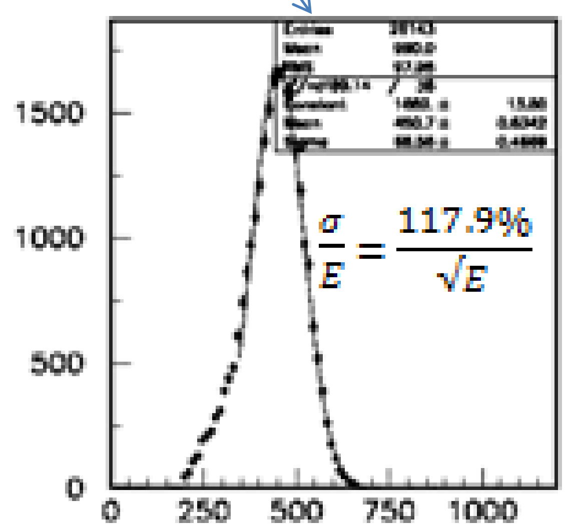
Muon response depends on assumed distribution of angle of incidence

Simulated pion response depends on physics list

Comparison with Steel at High Energy

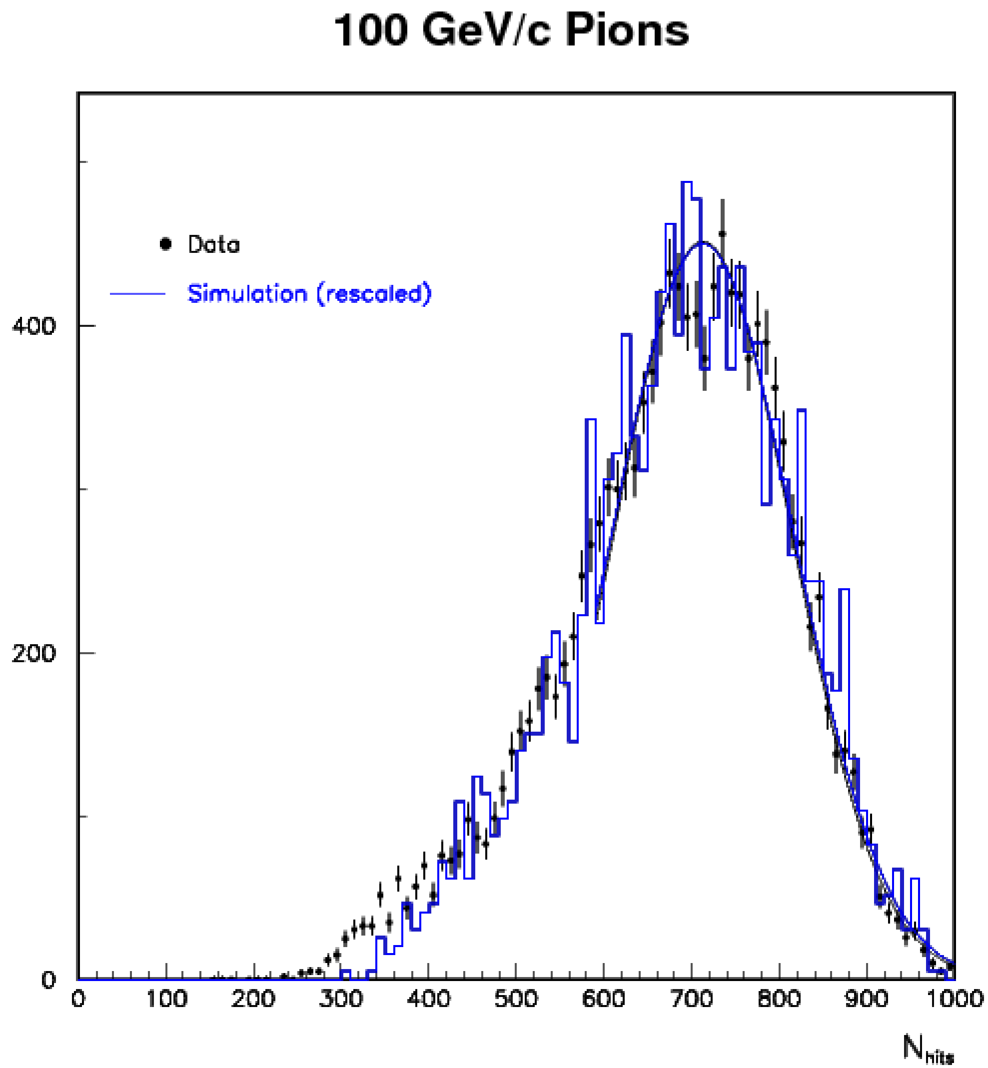
	Resolution $\alpha/\sqrt{E}$	
Energy	Steel absorber	W absorber
40	69%	97%
50	76%	106%
60	78%	118%





Better resolution with Steel
37% less hits in Tungsten
Note: tail towards low number of hits in Tungsten

Comparison with Simulation – RPC_sim_3



Peak positions

Data = 712.9
MC = 805.5

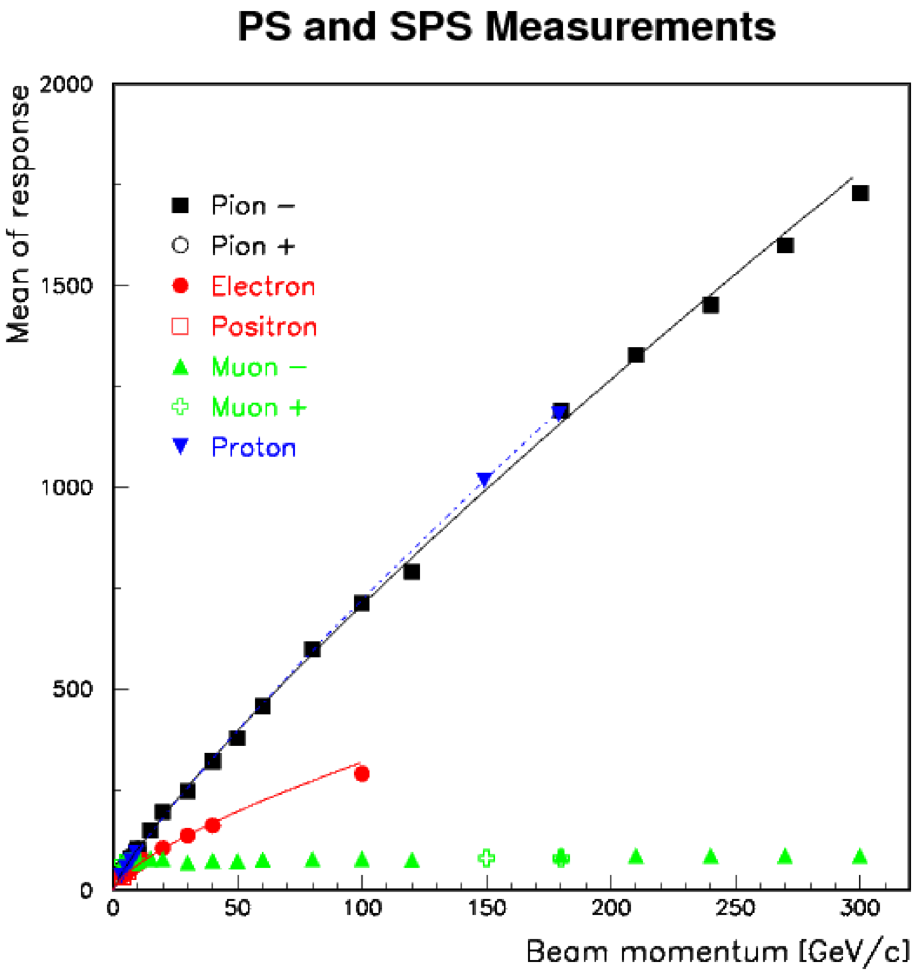
(data not calibrated yet)

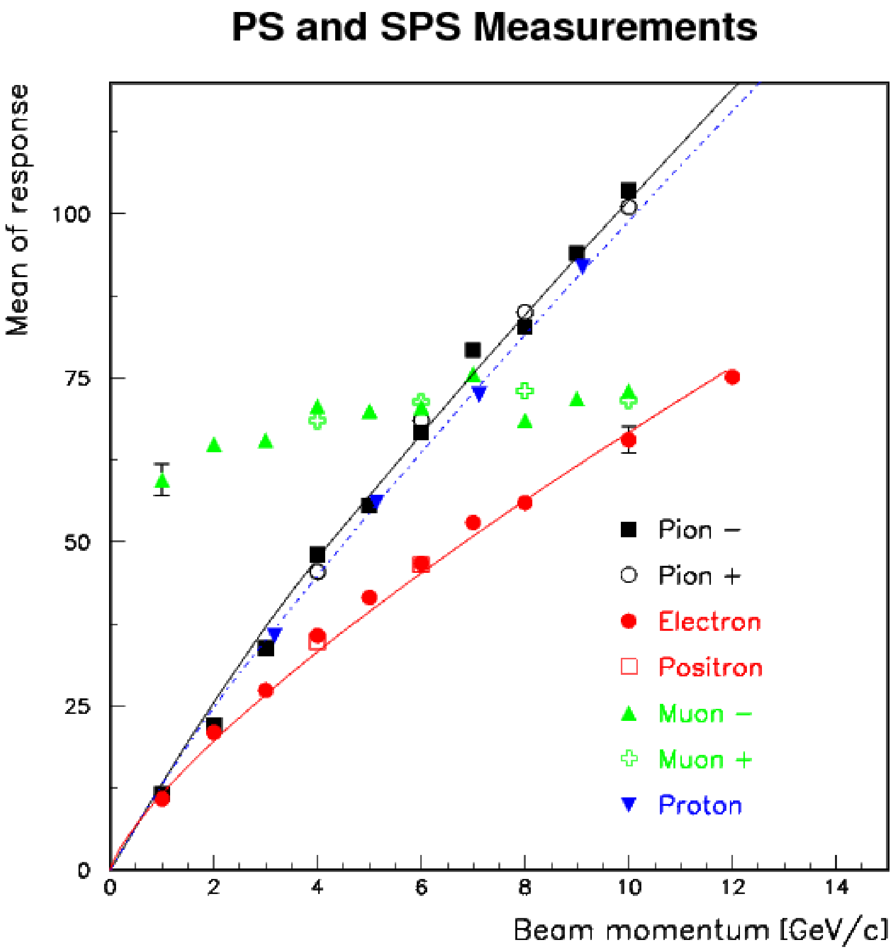
Rescaling for comparison

N_{MC} x 0.885

Tail observed in data also seen in simulation

Response from 1 – 300 GeV

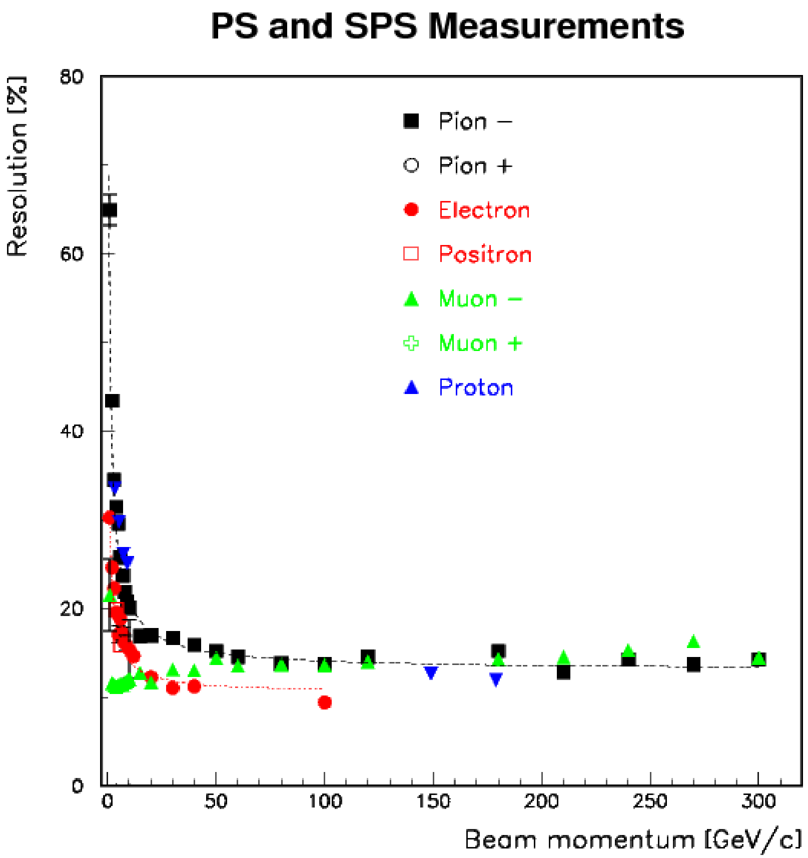


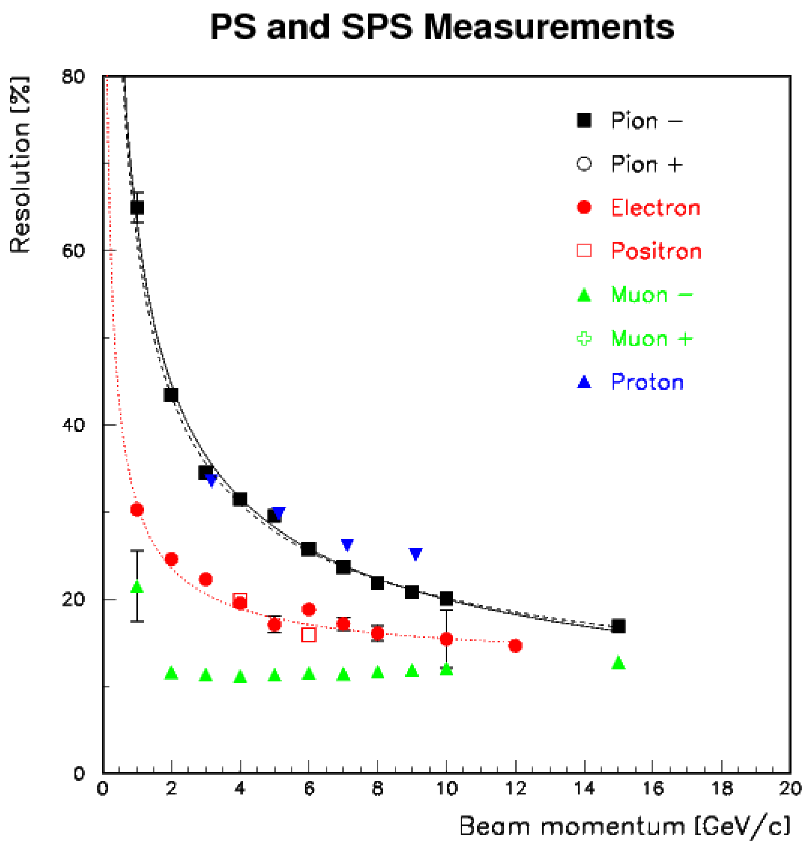


Fits to αE^{β}

Data not-calibrated yet

Resolution from 1 – 300 GeV

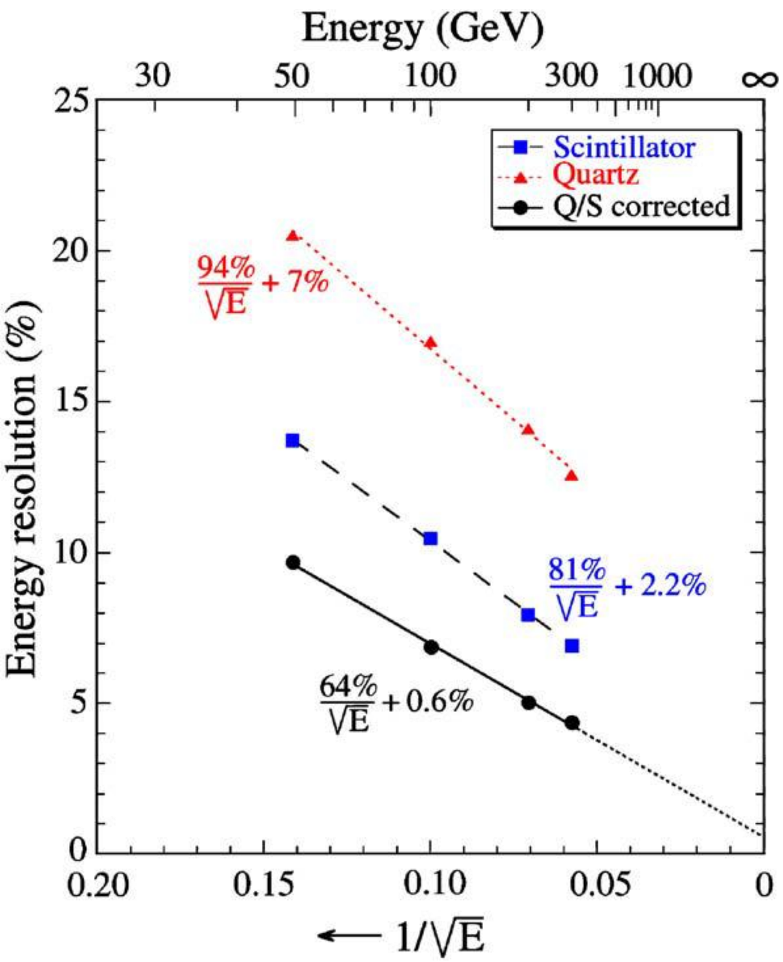




	β	α	c
Fit 1		73.1± 0.1	
Fit 2		51.21± 0.18	13.06± 0.04
e fit		29.73 ± 0.18	10.47 ± 0.08

	β	α	c
Fit 1		63.2± 0.1	
Fit 2		60.7± 0.3	6.0± 0.3
e fit		28.2 ± 0.2	12.6 ± 0.2

And what does Wigman's do….



Hadron and jet detection with a dual-readout calorimeter.

N. Akchurin, K. Carrell, J. Hauptman, H. Kim, H.P. Paar, A. Penzo, R. Thomas, R. Wigmans (Texas Tech. & Iowa State U. & UC, San Diego & INFN, Trieste).

Feb 2005

25 pp.

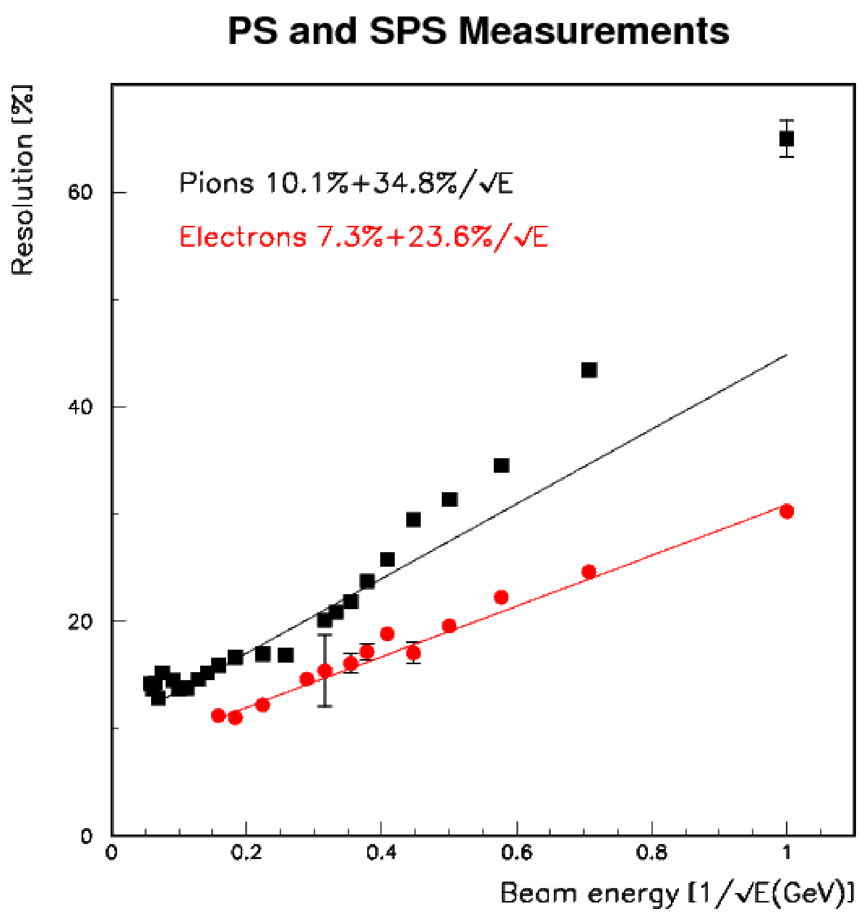
Nucl.Instrum.Meth. **A537** (2005) 537-561

DOI: 10.1016/j.nima.2004.07.285

Quote: '…constant term to be added *linearly* to the stochastic term.'

e.g. at E=100 GeV, assuming no constant term, σ = 70%/√E , σ = 110%/√E, σ = 175%/√E

DHCAL Resolutions à la Wigmans



Compare to fit to quadratic sum giving

$$\frac{\sigma}{E} = 13.1\% \oplus \frac{51.2\%}{\sqrt{E}}$$

Conclusions

We have a wonderful data set with 53 Million events spanning 1 – 300 GeV in energy

Detailed systematic studies of the data have begun (there is a lot to do and understand)

Simulations start to look like the data

The data from CERN look good

Wigmans is a cheat…

Backup Slides

Calibration of layers

Assign a weight w_i to each layer i

Method pioneered by ATLAS

$$N = \sum_i w_i N_i$$

Minimize resolution with w_i as parameters

$$w_i = \frac{\sum_k C_{ik}^{-1} \mu_k}{\sum_k C_{Mk}^{-1} \mu_k}$$

← Analytical expression to calculate weights

Where

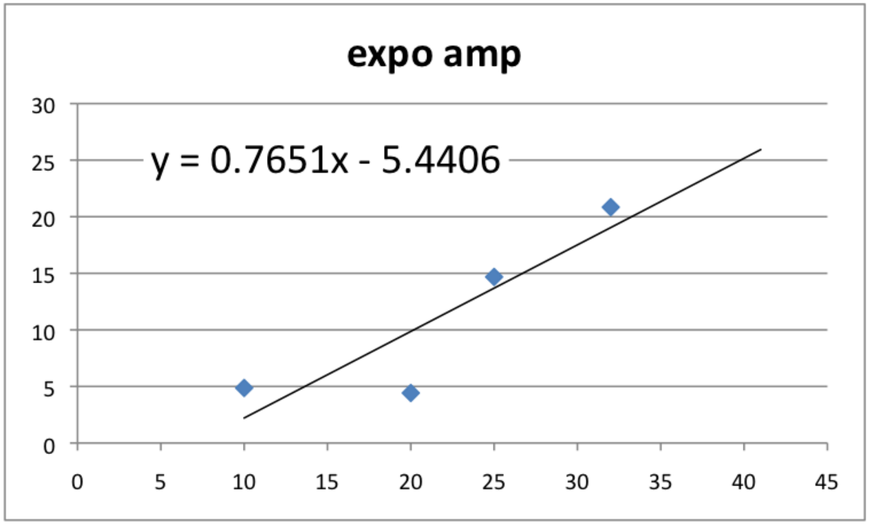
$$\mu_k = \frac{\sum_{j=1}^{n} N_k^{(j)}}{n}$$

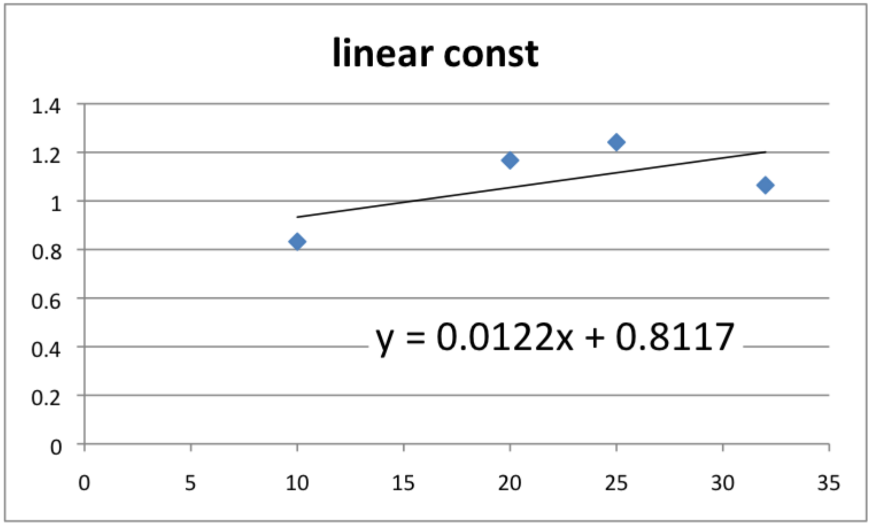
n….total number of events

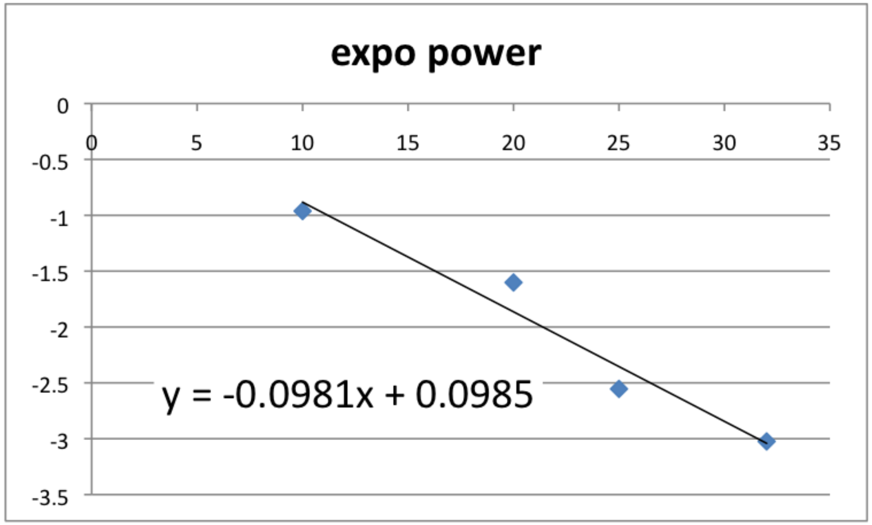
and

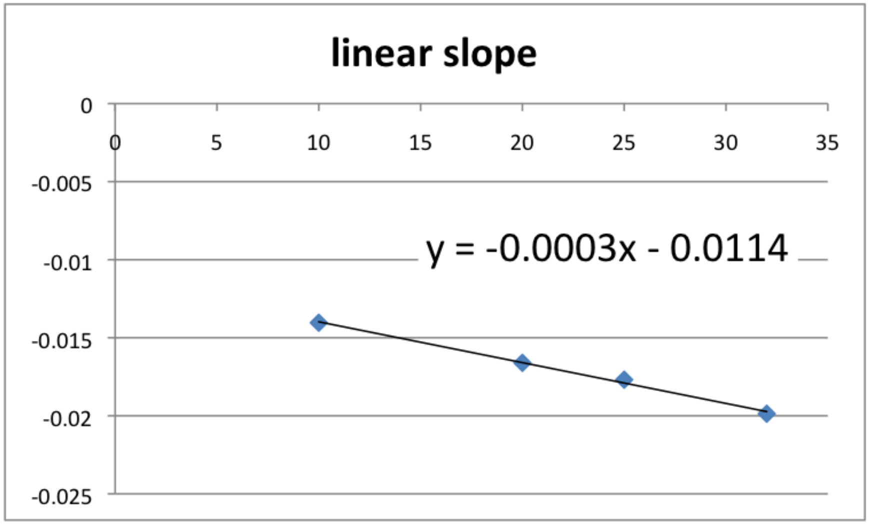
$$C_{ik} = \frac{\sum_{j=1}^{n} \left(N_i^{(j)} - \mu_i\right)\left(N_k^{(j)} - \mu_k\right)}{n-1}$$

Weight Parameters as a Function of Beam Energy



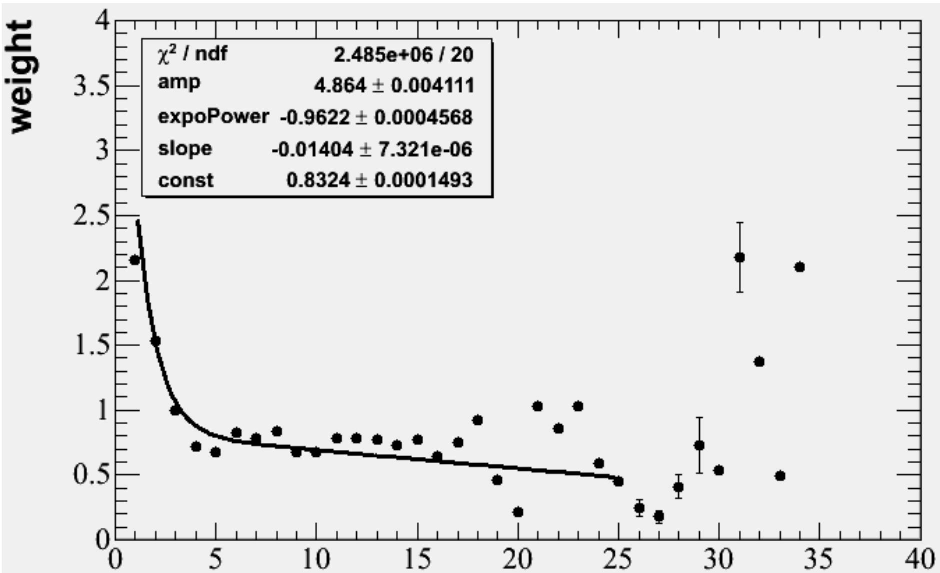






Fit value provides parameter values used in weights function at each energy

Layer Weights



Layer number – Layer number of first interaction

Weights as a function of shower-layer for 10 GeV/c pions

Fit to

$$w(i) = \alpha e^{-\beta i} + \gamma i + \delta$$

Currently errors on w_i are calculated via a Monte Carlo smearing technique, since uncertainties in μ_i and C_{ij} are correlated

These errors are still under study and not quite understood yet