First analysis of DHCAL Data

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The DHCAL at CERN

Resistive Plate Chambers RPCs

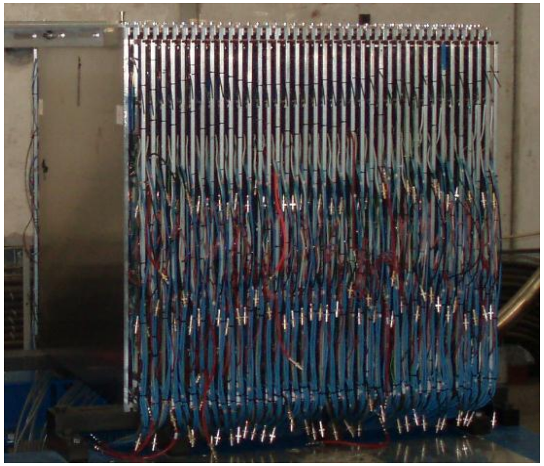
2-glass RPCs operated in avalanche mode

Digital Hadron Calorimeter DHCAL

54 layers (96 x 96 cm^2) of RPCs with 1 x 1 cm^2 readout pads
First large scale calorimeter with embedded front-end electronics
Up to 497,664 readout channels (world record for calorimetry and RPC systems)

Transport to CERN

Built spring-damped transport fixture
All RPCs survived intact



Installation at CERN

39 layers into Tungsten (1 cm ~ 3 X_0 plates) absorber structure
15 layers into Steel (2 cm and 10 cm plates) tail catcher

DHCAL Data Summary

Testbeam	Configuration	Muons[3]	Secondary beam[3]	Total[3]
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'
[3]Numbers in millions

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

Beams at CERN

PS

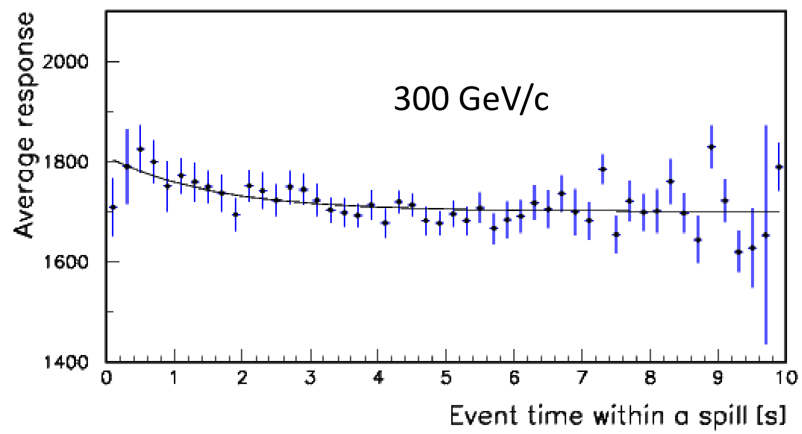
Covers 1 – 10 GeV/c
Mixture of pions, electrons, protons, (Kaons)
Two Cerenkov counters for particle ID
1-3 400-ms-spills every 45 second (RPC rate capability OK)
Data taking with ~500 triggers/spill

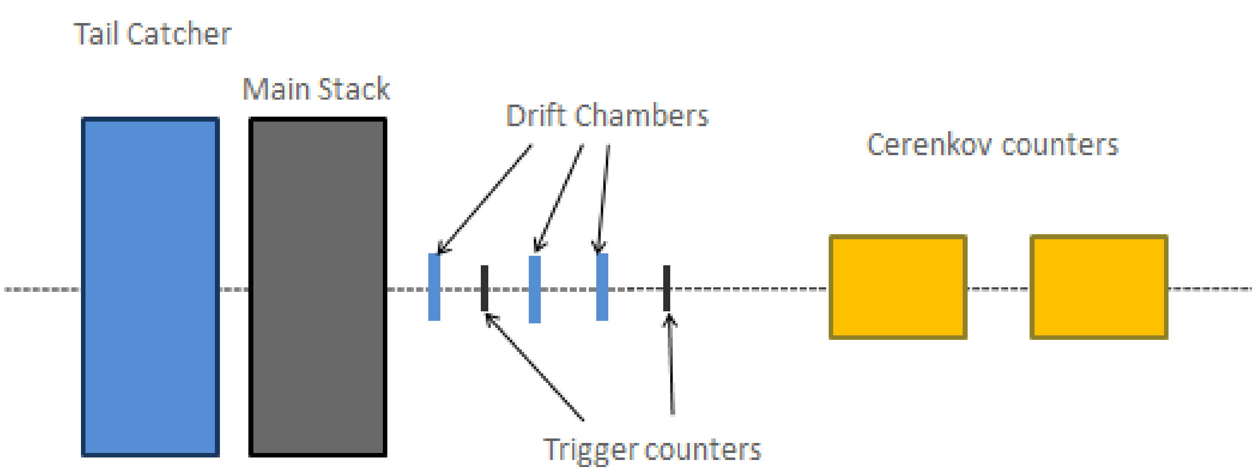
SPS

Covers 12 – 300 GeV/c
Mostly set-up to either have electrons or pions (18 Pb foil)
Two Cerenkov counters for particle ID
9.7-s-spills every 45 – 60 seconds
RPC rate capability a problem
(running with limited rate: 250 – 500 triggers/spill)

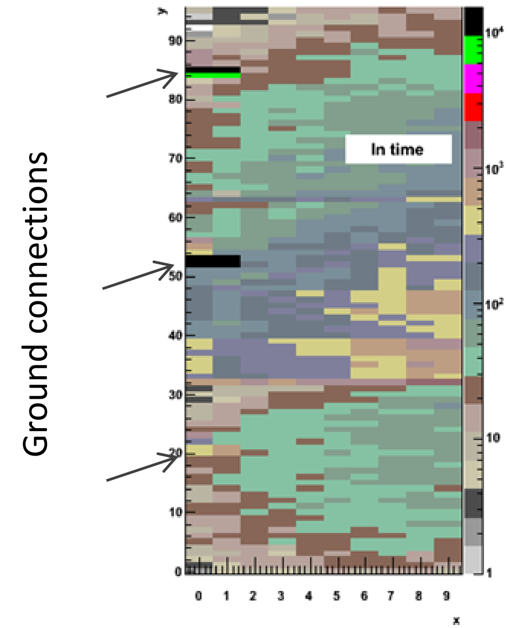
RPC rate limitations

~6 % loss of hits
(in the following not yet corrected)
Time constant ~ 1 second



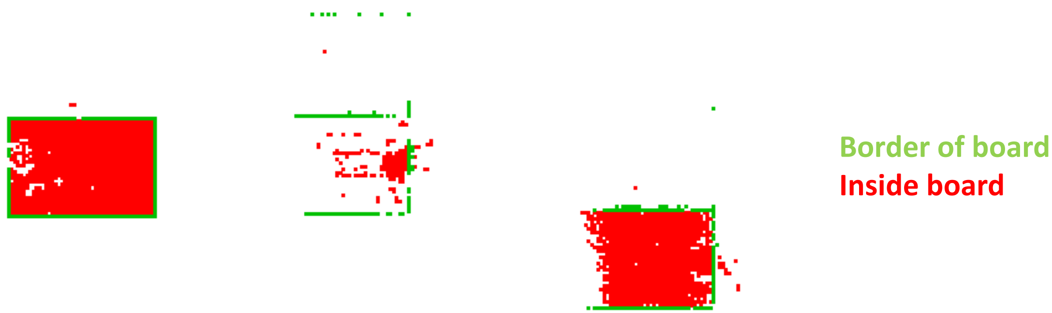


General data selection and preparation I



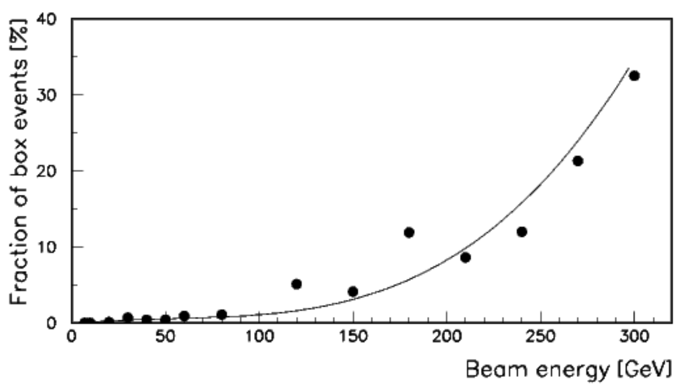
Random noise

Measured with trigger-less runs
Higher rate at ground connector (excluded from analysis)
In general < 1 hit/event
Noise has minimal effect on response
Noise needs to be studied carefully for the measurement of shower shapes



Box events

Large or small fraction of electronic board fires
Reason for boxes not entirely understood
Fraction of boxes <1% for E < 100 GeV
Significant fraction of boxes at E > 100GeV
Developed algorithm to identify boxes
Events with boxes rejected



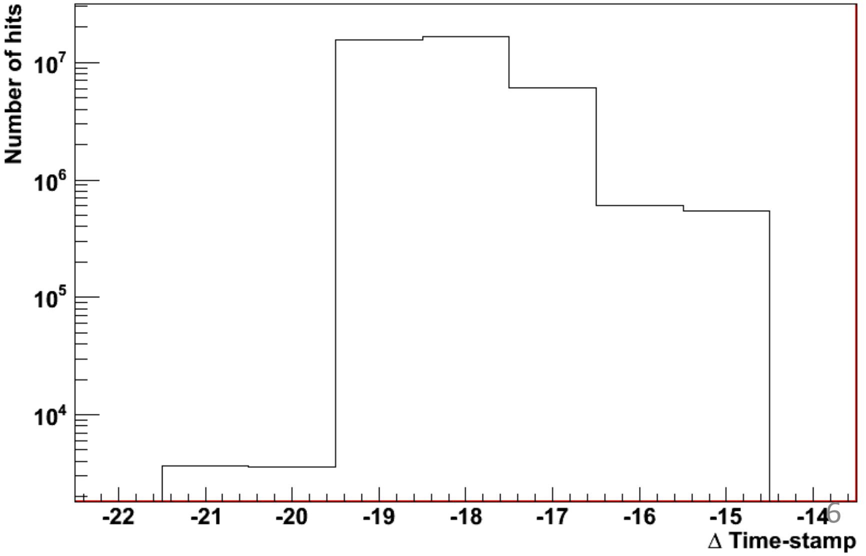
General data selection and preparation II

Double hits

Duplicate hits with the same coordinate, but different time-stamps are eliminated
This is a very small fraction of the hits

Time-stamp bins

Data are recorded in 7 time-stamp bins (each 100 ns)
First two time-stamps are before the trigger (→ estimation of the noise level)
Only hits in bins 3 and 4 included in analysis (← reduction of possible noise)



Simulation of RPC response

RPC simulation

Spread of charge in pad plane using 2 exponentials
6 parameters to be tuned

Use clean **muon events**

Tune to average response per layer
Able to tune 5 parameters

Muons not sensitive to d_{cut}
(Describes local inefficiency for 2nd avalanche close to 1st one)

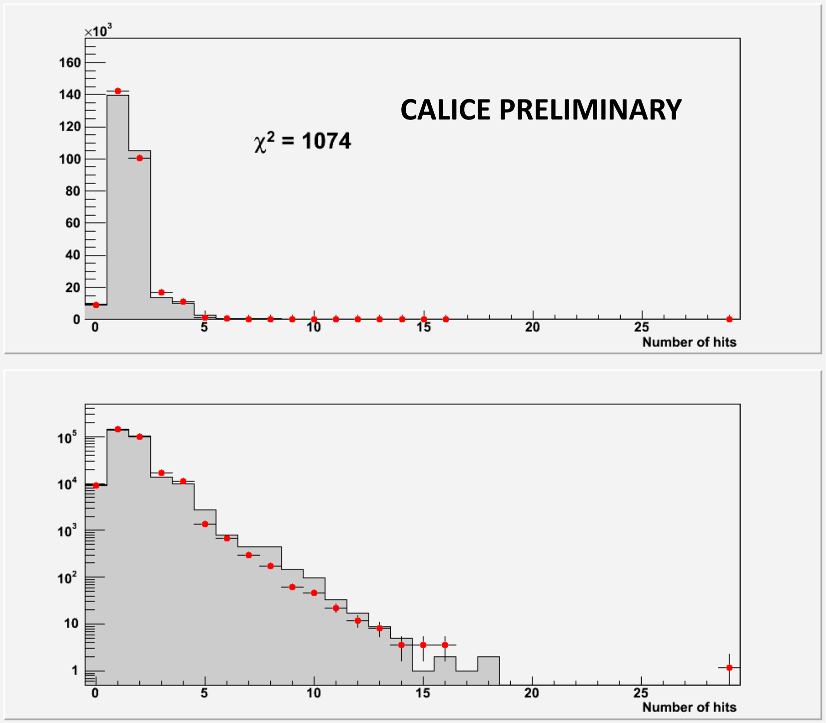
Use clean **positron events**

Tune last parameter: d_{cut}

Caveat

Tuning performed with Fermilab data
Slightly different operating conditions at CERN

Muon response

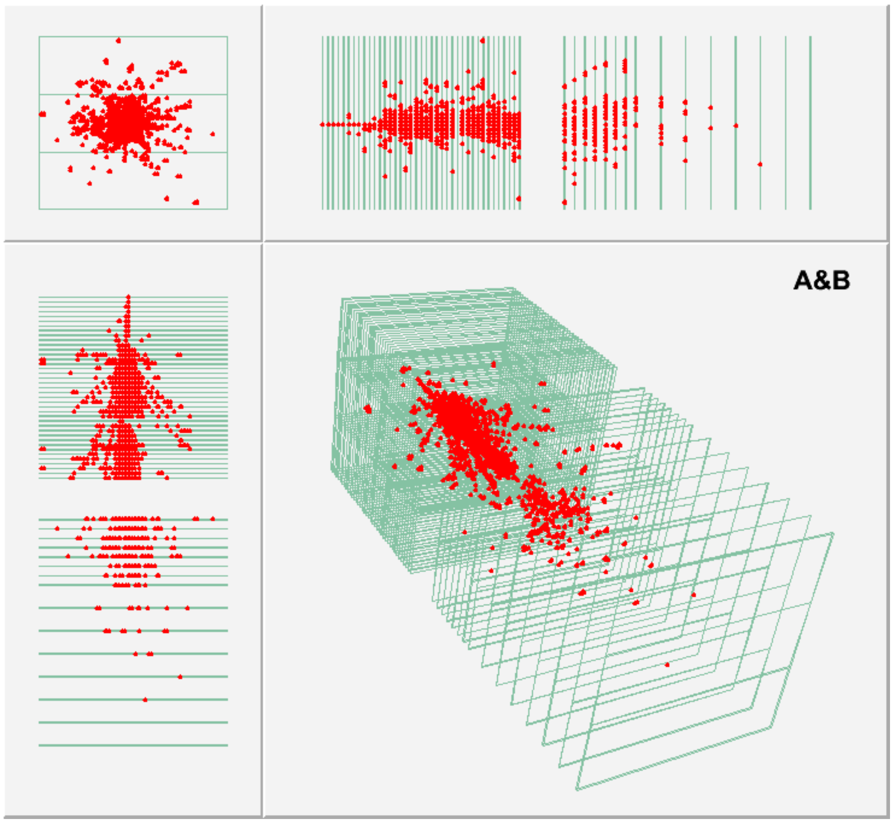


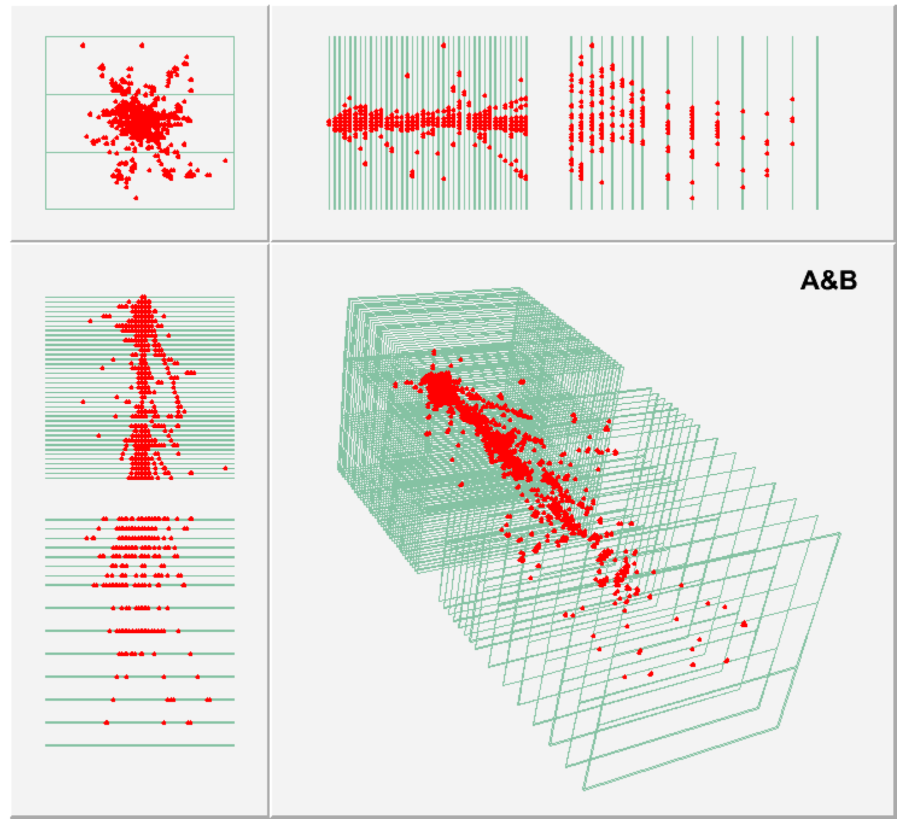
More details → L. Xia's talk

Overview of CERN data sample

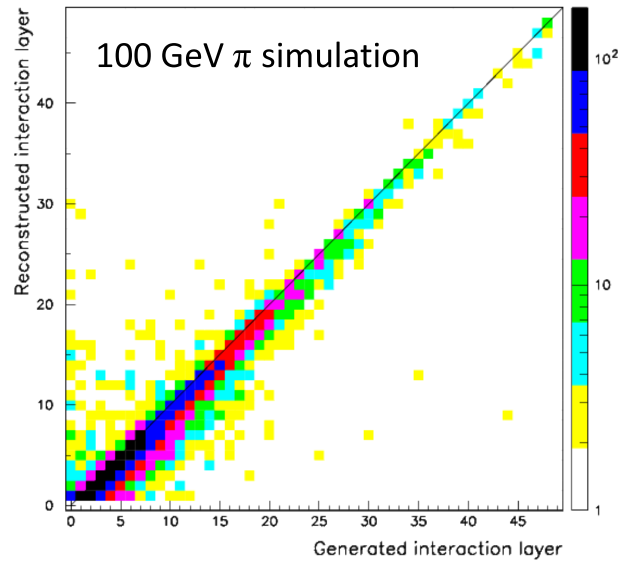
Polarity	Momentum	18 mm Pb absorber	No Pb absorber	Beam blocker	Total
Negative	1		540,660		540,660
	2		964,361		964,361
	3		1,006,185		1,006,185
	4		1,030,302		1,030,302
	5		1,185,235		1,185,235
	6		1,268,235		1,268,235
	7		1,546,744		1,546,744
	8		1,196,804		1,196,804
	9		2,044,224		2,044,224
	10		1,007,922		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





A few event variables



The interaction layer

Algorithm tuned with Monte Carlo events
Defined as first of two consecutive layers with more than 3 hits

Longitudinal barycenter

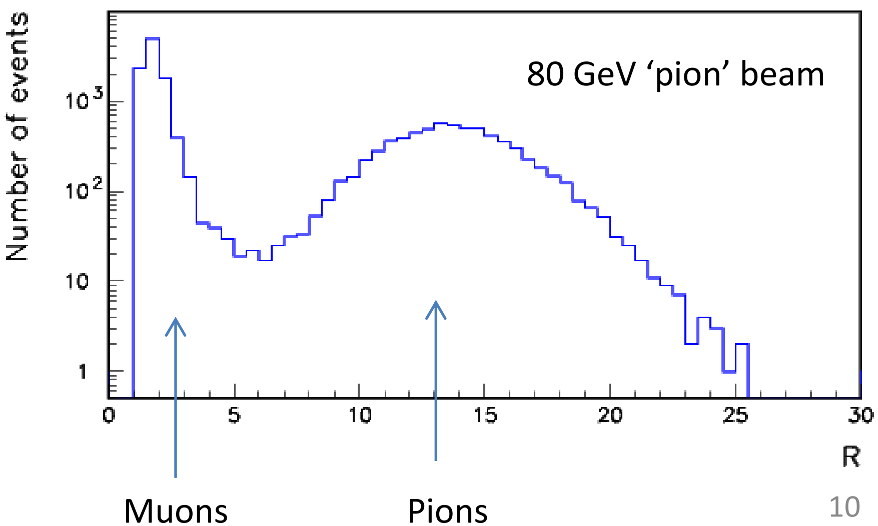
$$BC = \frac{\sum_{i=0}^{53} i \cdot N_i}{\sum_{i=0}^{53} N_i}$$

with N_i ... hits in layer I

Hit density R

$$R = \frac{\sum_{i=0}^{53} N_i}{\sum_{i=0}^{53} \mathrm{sgn}(N_i)}$$

with $\mathrm{sgn}(N_i) = 1$ for $N_i > 0$, $= 0$ for $N_i = 0$



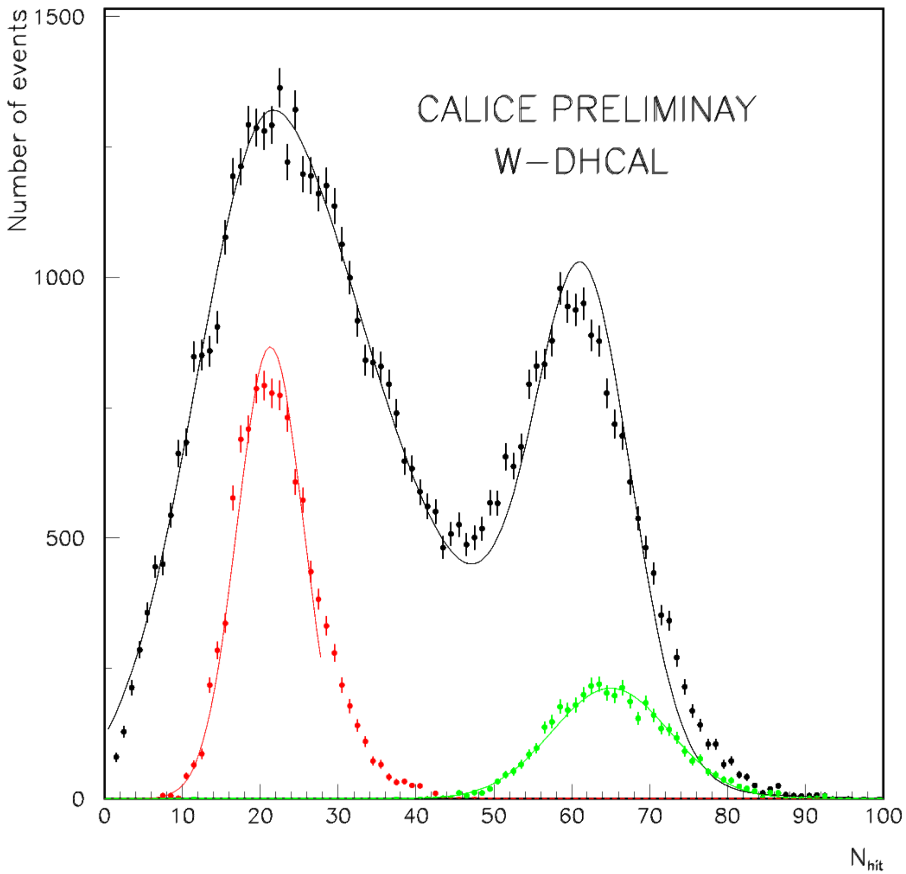
Event selection

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

Particle	Cerenkov	BC	R	IL	N_0	$\sum_{i=last-4}^{last} N_i$	$\sum_{i=0}^{last} N_i$
μ		>20	<3.0	-		>0	>10
$e^{\pm}$	$C_1 \cdot C_2=1$	<8	>4.0 for E>12 GeV	-	>4 for E>12 GeV	-	-
π^-	$C_1+C_2=0$	-	>2.0 – 5.0	>2 for E>3 GeV		-	-
π^+	$C_1=0$ and $C_2=1$ ($p \leq 10$ GeV/c) $C_1 \cdot C_2=1$ ($p > 10$ GeV/c)	-	>2.0 – 5.0	>2 for E>3 GeV		-	-
p	$C_1+C_2=0$	-	>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



Simulated spectra fit with modified Gaussian

$$x < \mu \qquad \sigma = \sigma_0$$

$$x \geq \mu \qquad \sigma = \sigma_0 + a(x-\mu)^b$$

or vice versa

Electron selection

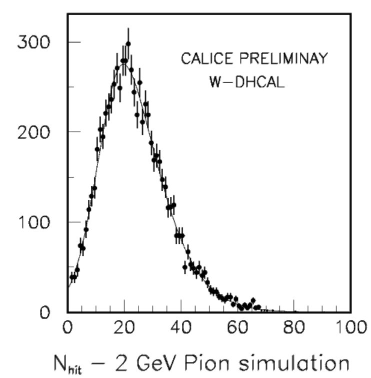
Through-going muon selection

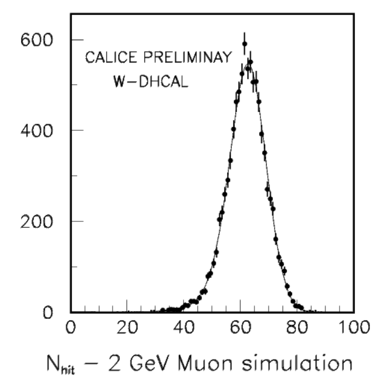
Pion selection

Double peak structure due to 2 GeV/c muons and pions

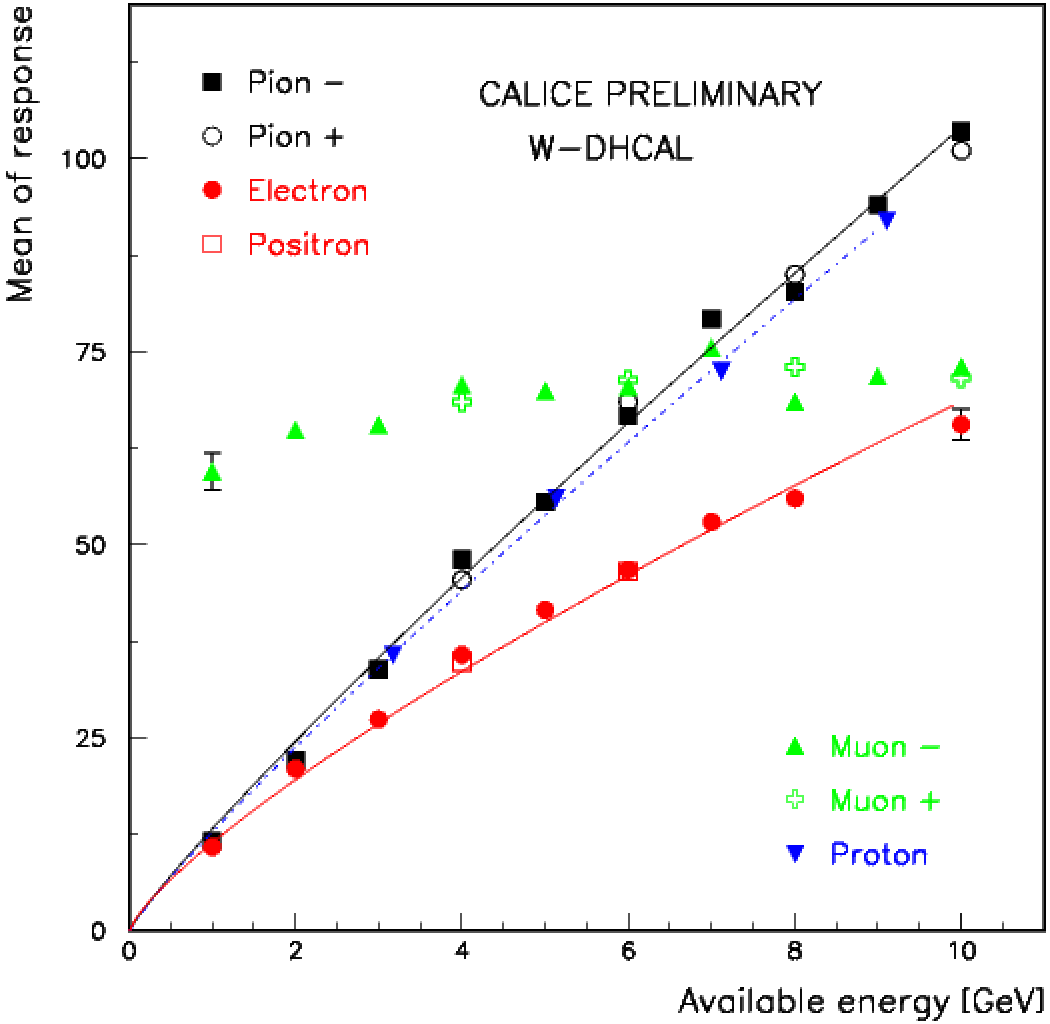
Both range out in the DHCAL

2 component fit adequate
(muon response sensitive to distribution of angle of incidence)
(pion response adjusted by 10%)





Response at the PS (1 – 10 GeV)



Fluctuations in muon peak

Data not yet calibrated

Response non-linear

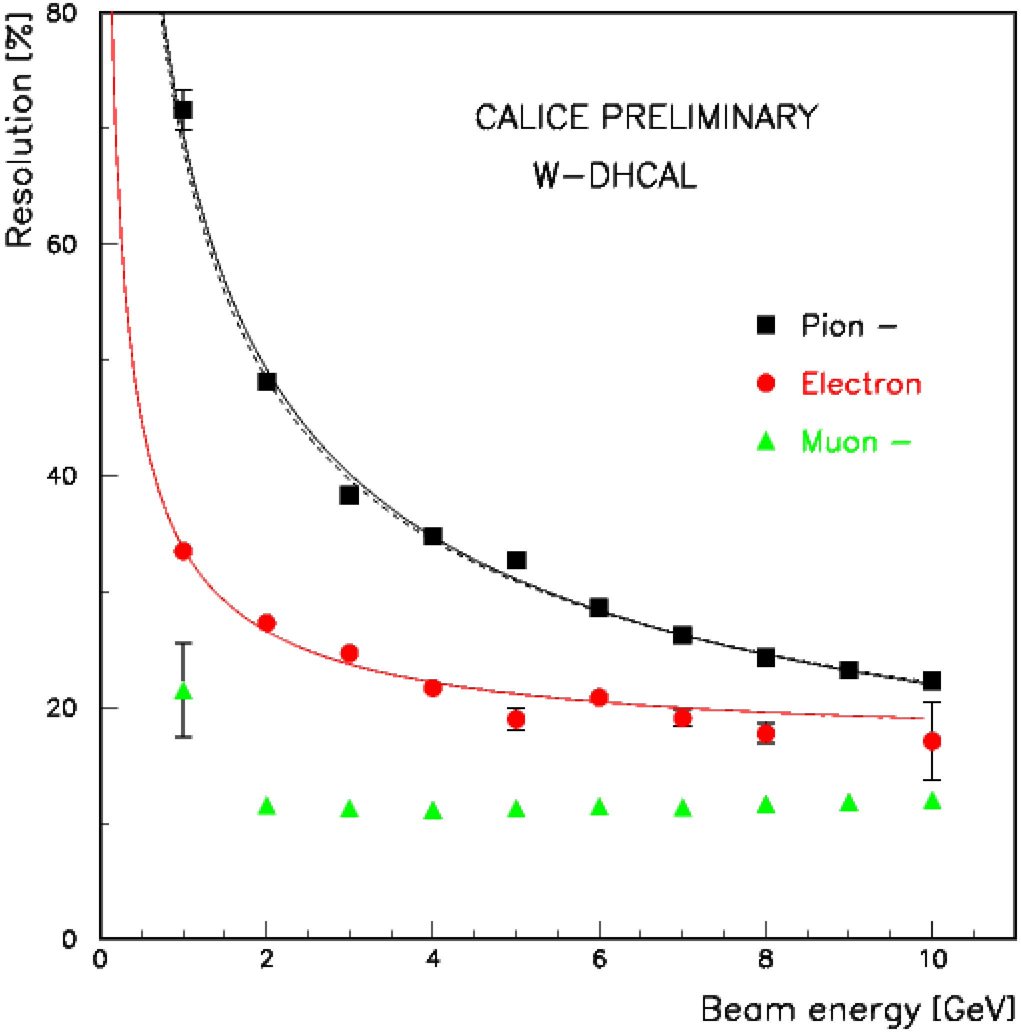
Data fit empirically with αE^{β}
β= 0.90 (**hadrons**), 0.78 (**electrons**)

W-DHCAL with 1 x 1 cm^2

Highly over-compensating
(smaller pads would increase the electron response more than the hadron response)

Remember: W-AHCAL is compensating!

Resolution at the PS (1 – 10 GeV)



Resolutions corrected for non-linear response

$$\frac{dE}{E} \sim \frac{1}{\beta}\frac{dN}{N}$$

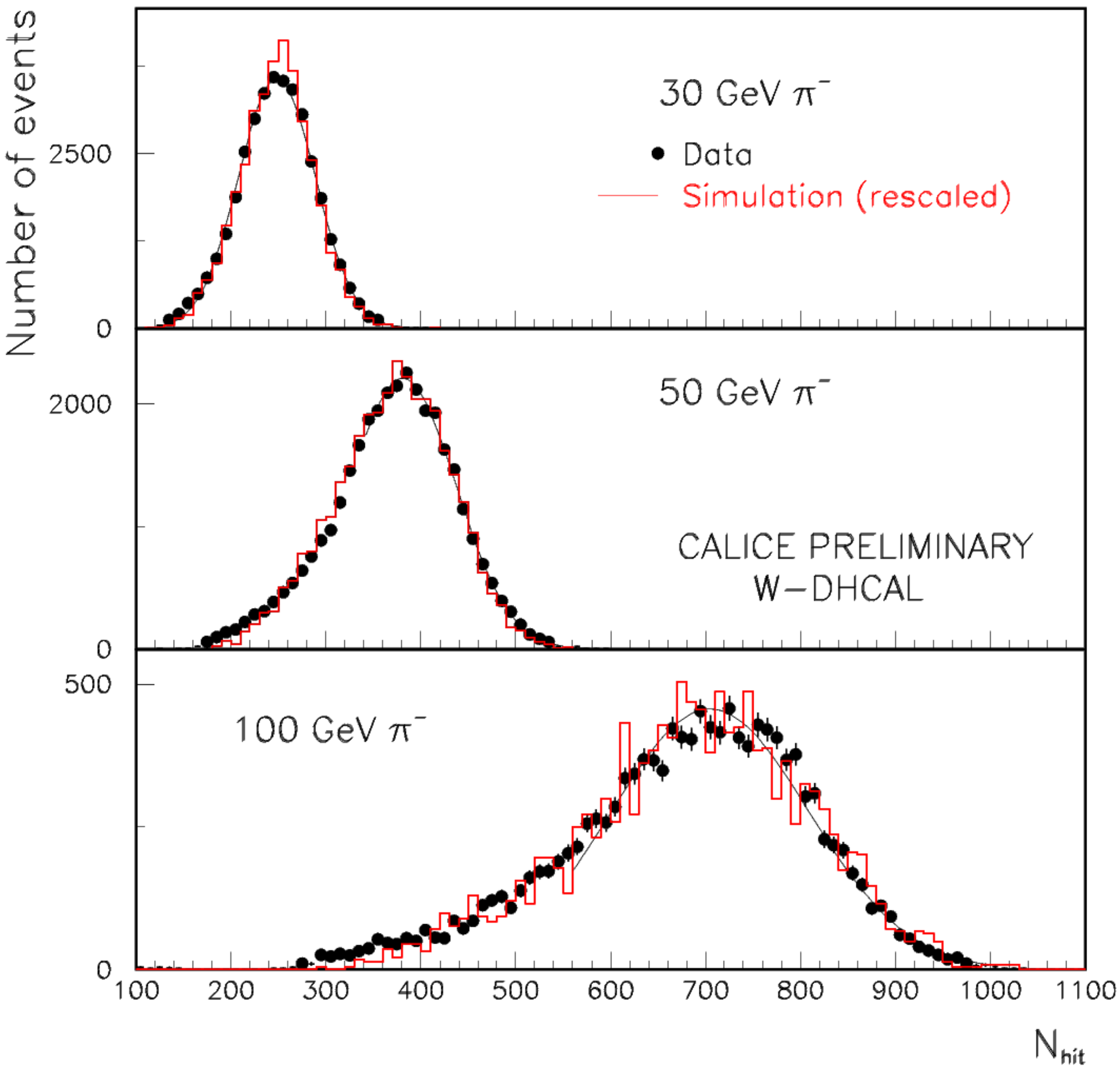
Data fit with quadratic sum of constant and stochastic term

$$\frac{\sigma}{E} = c \oplus \frac{\alpha}{\sqrt{E}}$$

Particle	α	c
Pions	(68.0±0.4%	(5.4±0.7)%
Electrons	(29.4±0.3)%	16.6±0.3)%

(No systematics yet)

Comparison with Simulation – SPS energies



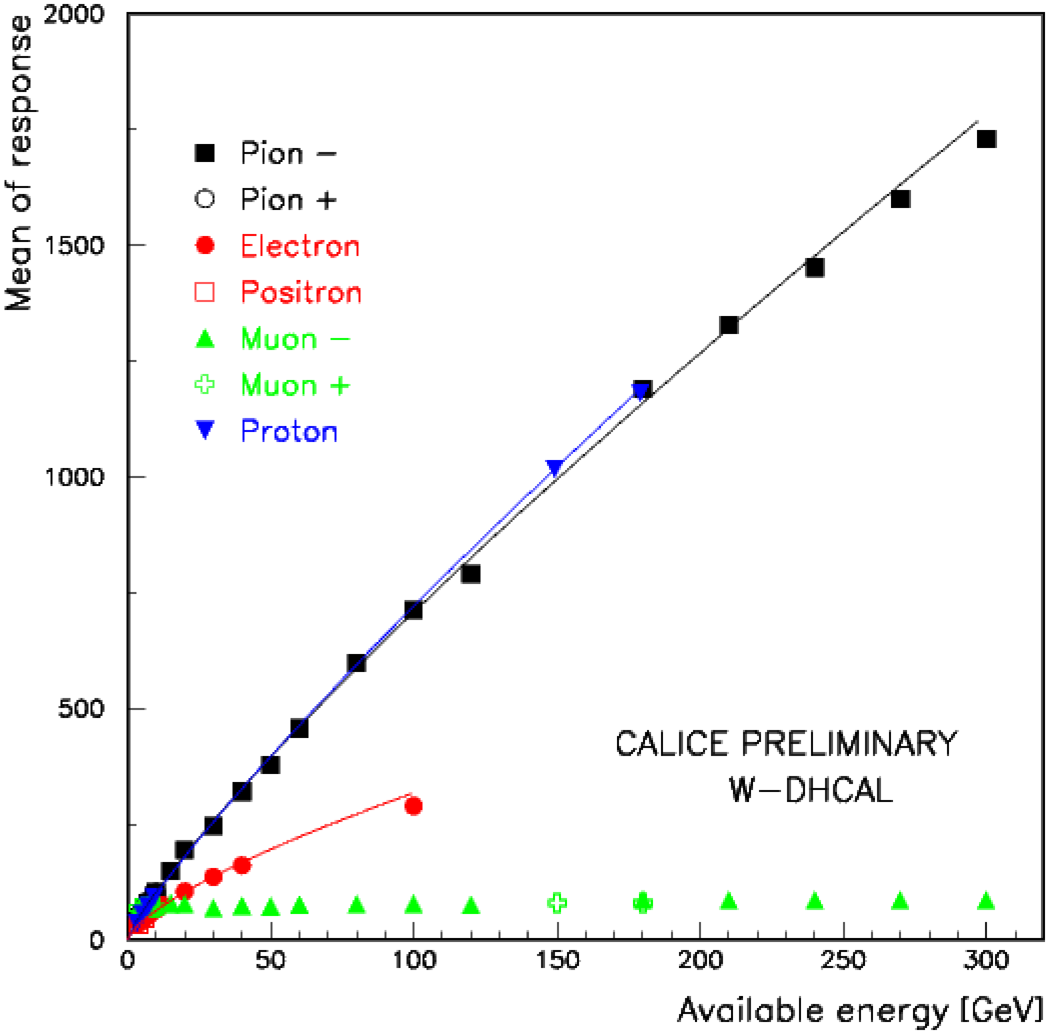
Data

Uncalibrated
Tails toward lower N_{hit}

Simulation

Rescaled to match peaks
Shape surprisingly well reproduced

Response at the SPS (12 – 300 GeV)



Fluctuations in muon peak

Data not yet calibrated

Response non-linear

Data fit empirically with αE^{β}
$\beta = 0.85$ (**hadrons**), 0.70 (**electrons**)

W-DHCAL with 1 x 1 cm^2

Highly over-compensating
(smaller pads would increase the electron response more than the hadron response)

Conclusions

W-DHCAL: **Great 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

Presented **preliminary look** at the W-DHCAL data

- Response saturates both at the PS (1 – 10 GeV) and the SPS (12 – 300 GeV)

  → Smaller readout pads needed for Tungsten absorbers

- Approximately 50% more hits with Steel absorbers

- Simulations start to look like the data

  → Major features of data understood