Combined Performance of the DHCAL with the Si-W ECAL

Talk could not be presented in time, added afterwards.

CALICE Collaboration Meeting

March 31st, 2023

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* McGill MSc Thesis, March 2023

Intent

Abstract

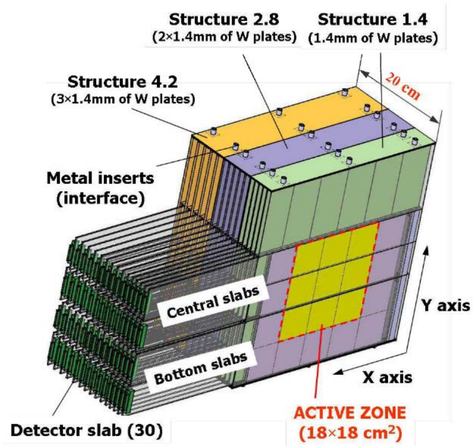
This thesis presents a study of the alignment and the energy response to pions of a combined electromagnetic and hadronic calorimeter system using two calorimeter prototypes from the CALICE international collaboration: the Digital Hadron Calorimeter (DHCAL) and the Silicon-Tungsten Electromagnetic Calorimeter (Si-W ECAL). The data was taken in April 2011 at the Fermilab test beam facilities. The experimental setup was exposed to a range of beam energies from 4 to 120 GeV. A first study and correction of the misalignment between detectors was performed using muon tracks. The linearity of DHCAL for hadronic and electromagnetic showers was next investigated. The prototype presented significant signal saturation effects for beam energies above 60 GeV. Finally, energy calibration factors for the calorimeters were obtained for hadronic events. Using the calibration, the hadronic energy resolution of the DHCAL was calculated to become 44%/sqrt{E/GeV}. This presents a 25% improvement from the energy resolution calculated with hit-to-energy conversion methods excluding ECAL.

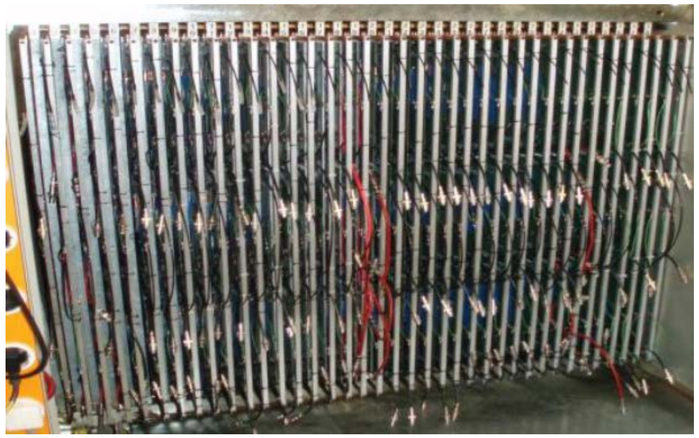
Goal

How does adding ECAL improve the DHCAL standalone pion energy resolution performance?

Detectors and Datasets

2011 versions of SiW ECAL and DHCAL (1x1 cm^2 cells)





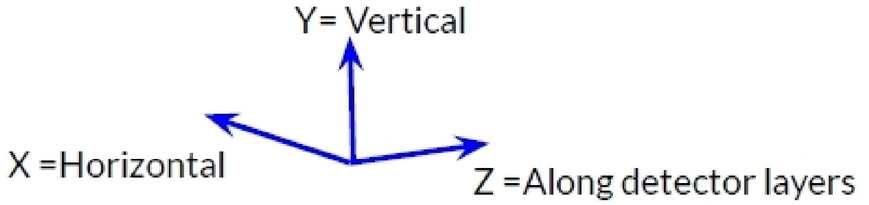
Testing period	Configuration	Combined detector layers	Collected μ events	Collected secondary beam events
October 2010	DHCAL	38	1.4M	1.7M
January 2011	DHCAL+TCMT	38+13=51	1.6M	3.6M
April 2011	Si-W ECAL+DHCAL+ TCMT	30+38+14=92	2.5M	5.1M
June 2011	DHCAL+TCMT	38+14=52	3.3M	2.7M
November 2011	MinDHCAL	50	0.6M	1.3M
Total			**9.4M**	**14.4M**

Data

April2011		
Beam energy (GeV)	Runs	Number of events
8	2	506095
12	5	216052
16	4	355449
25	2	183466
32	5	410833
40	5	386994
50	4	390220
60	5	157051
120	3	123693
Total	35	2729853

June 2011		
Beam energy (GeV)	Runs	Number of events
8	5	264770
16	4	312021
32	5	306665
40	8	379803
50	8	336071
60	6	306083
120	9	490413
Total	45	2395826

Event Examples

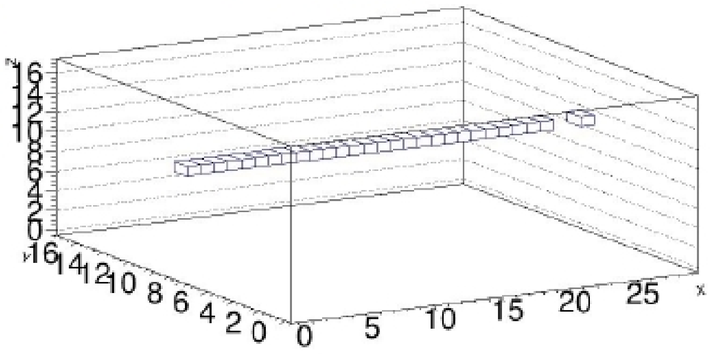


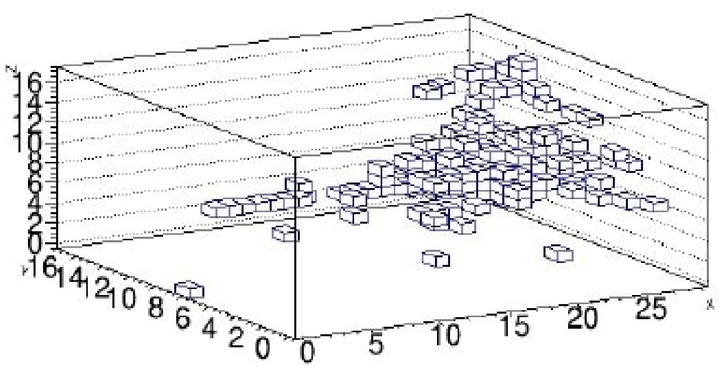
Muon

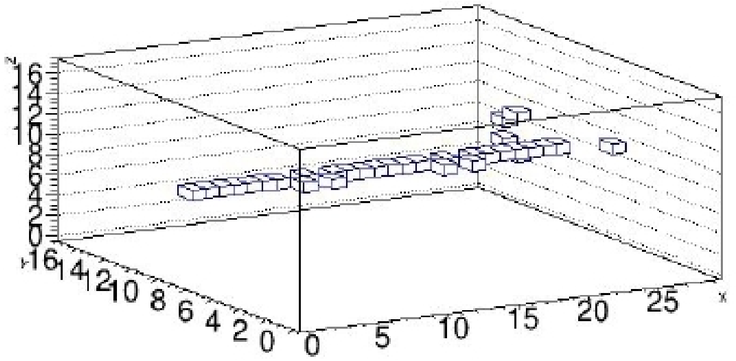
Positron

Pion

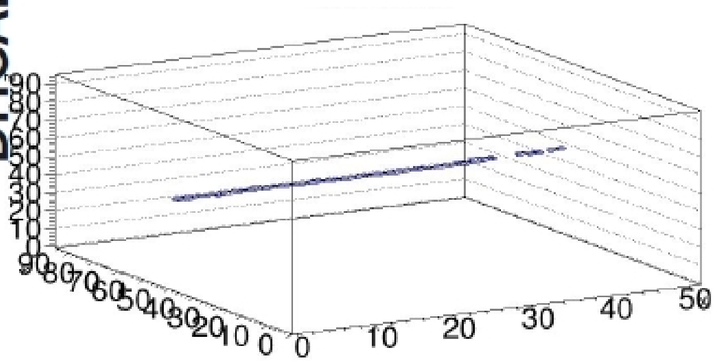
ECAL

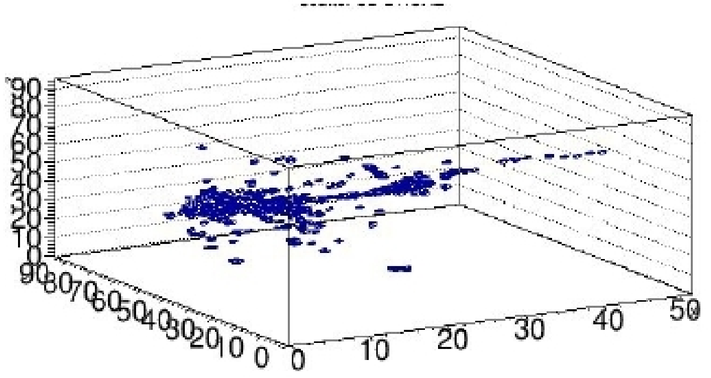


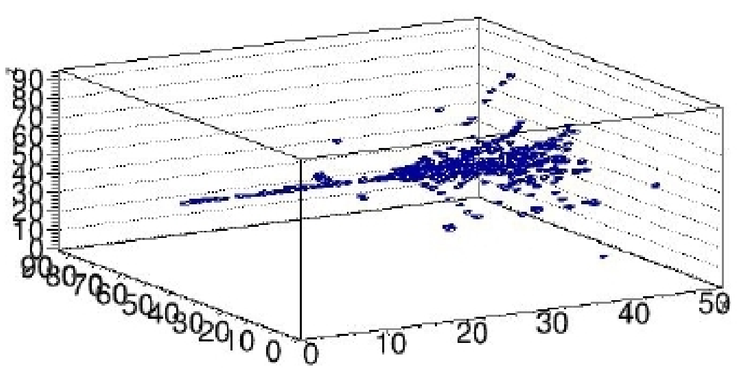




DHCAL

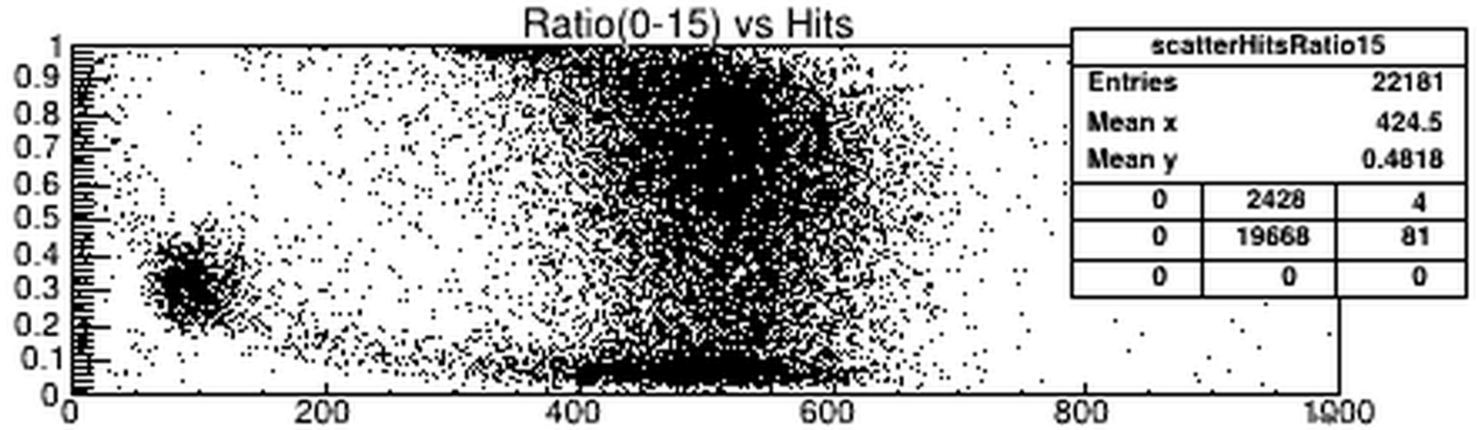


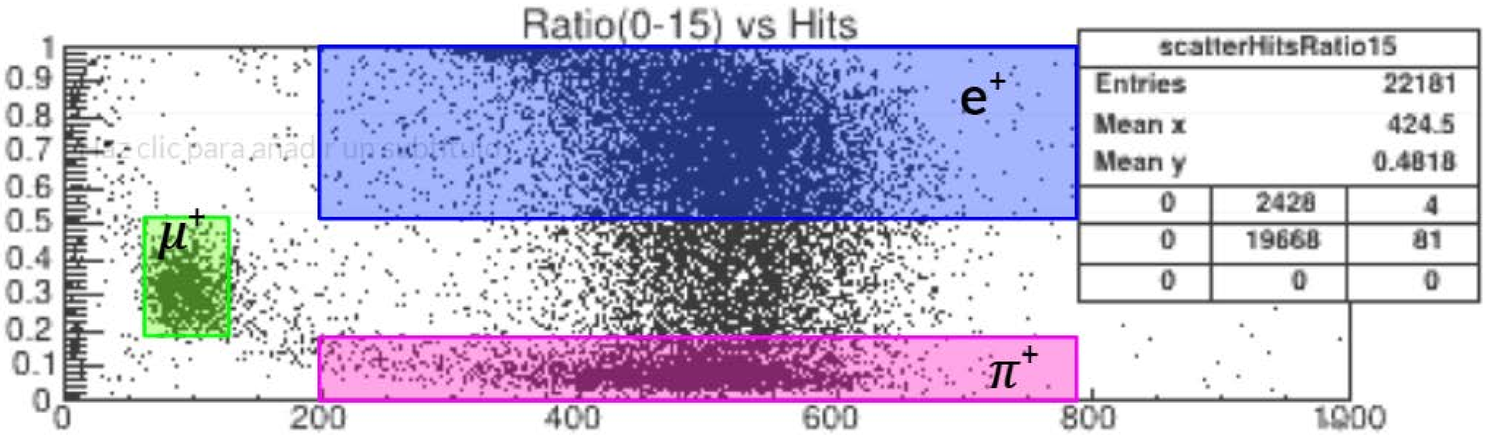




CALICE work in progress

Particle ID





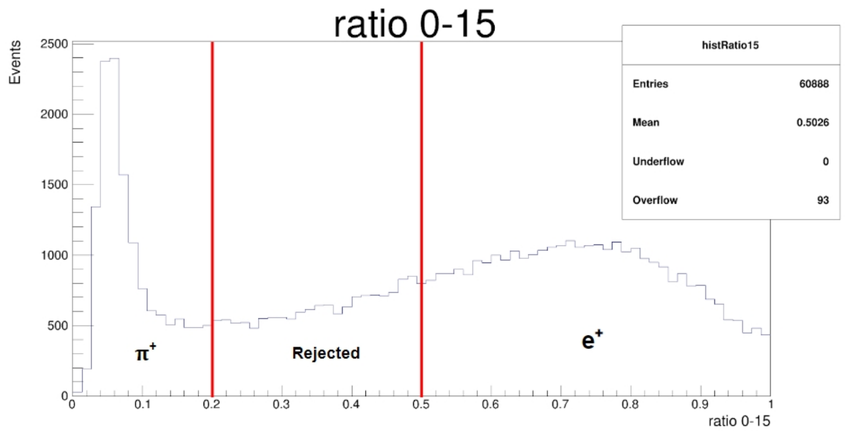
Caveats:

- SiW ECAL online calibration only
- ECAL+DHCAL at 50, 60, 120 GeV only, no dedicated muon run available.
- particle ID from the data itself (biased) since beam Cerenkov detectors were unavailable most of the time

But:

- this is a relative measurement study

$$r_{15} = \frac{hits_{first\,15\,layers}}{hits_{total}}$$



Event Selection

April 2011 Particle ID Cuts			
e^+	50 GeV	60 GeV	120 GeV
Number of hits DHCAL	<25	<75	<150
Number of hits ECAL	>120	>120	>120
Ratio ECAL	>0.95	>0.85	>0.8
π^+	50 GeV	60 GeV	120 GeV
Number of hits DHCAL	>50	>110	>200
Number of hits ECAL			
Ratio ECAL	<0.9	<0.75	<0.7
μ^+	50 GeV	60 GeV	120 GeV
Number of hits DHCAL	60<hits<100		
Number of hits ECAL	<120		
Ratio ECAL	0.2<ratioECAL<0.5		

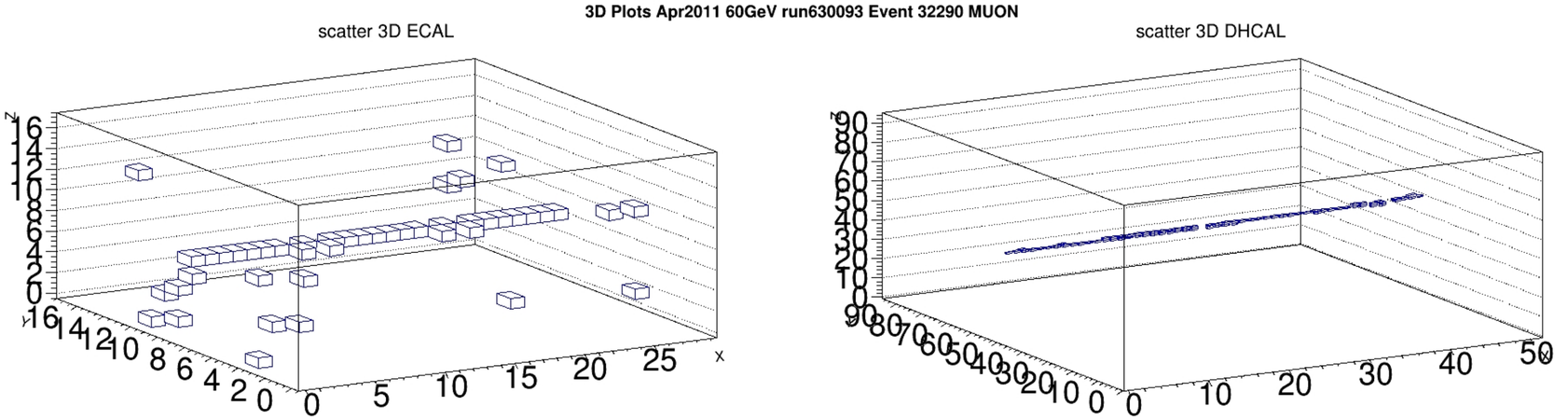
June 2011 Particle ID Cuts							
e^+	8 GeV	16 GeV	32 GeV	40 GeV	50 GeV	60 GeV	120 GeV
Number of hits	>50	>150	>200	>200	>250	>300	>500
Ratio(0-10)	>0.5	>0.5					
Ratio(0-15)			>0.5	>0.5	>0.5	>0.5	>0.5
π^+	8 GeV	16 GeV	32 GeV	40 GeV	50 GeV	60 GeV	120 GeV
Number of hits	>200	>200	>200	>200	>250	>300	>500
Ratio(0-10)	<0.3	<0.3					
Ratio(0-15)			<0.2	<0.2	<0.2	<0.2	<0.2
μ^+	8 GeV	16 GeV	32 GeV	40 GeV	50 GeV	60 GeV	120 GeV
Number of hits	60<hits<120		60<hits<130				
Ratio(0-10)	0.1<ratio10<0.4						
Ratio(0-15)			0.2<ratio15<0.5				

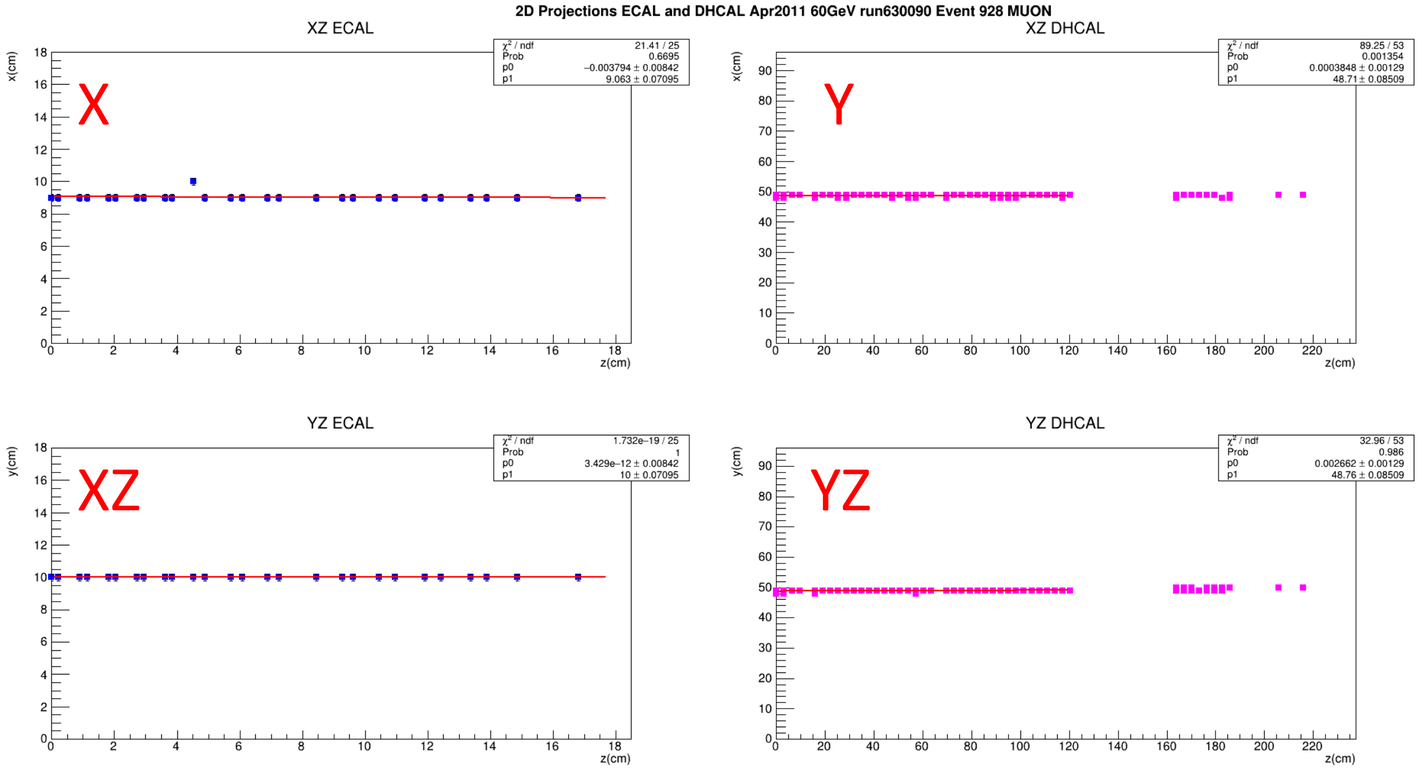
April 2011 Particle ID Cuts for Late showering pions					
π^+	12 GeV	16 GeV	25 GeV	32 GeV	40 GeV
Number of hits DHCAL	>120	>120	>120	>120	>150
Ratio(0-15)	<0.15	<0.2	<0.2	<0.2	<0.2

+ containment cuts on number of cuts in the last layers of DHCAL

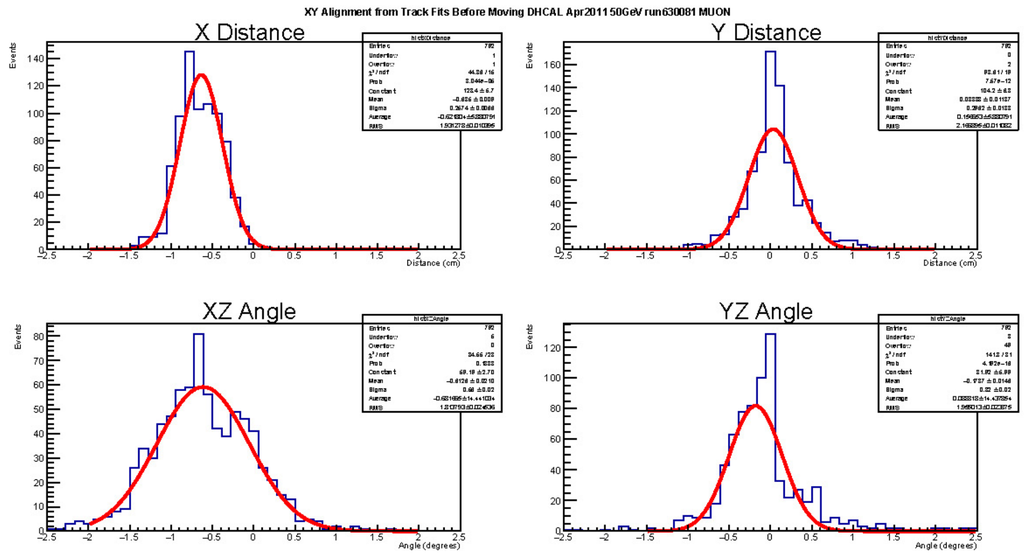
Before Alignment

Select muons from datasets
Reject hits outside of main track
(>4 hits/layer or at R>1 cm)

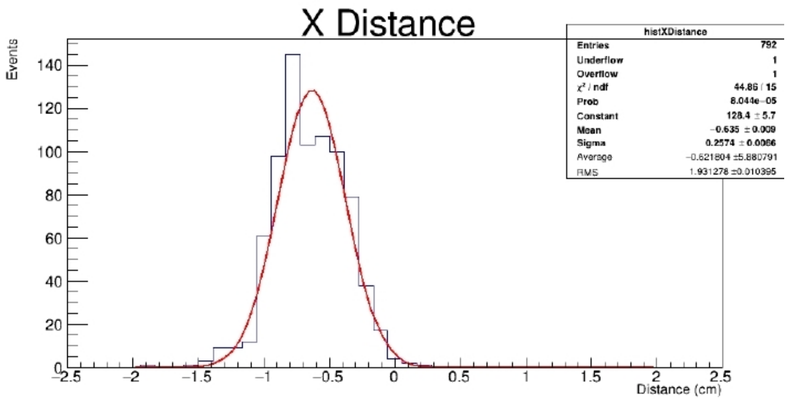


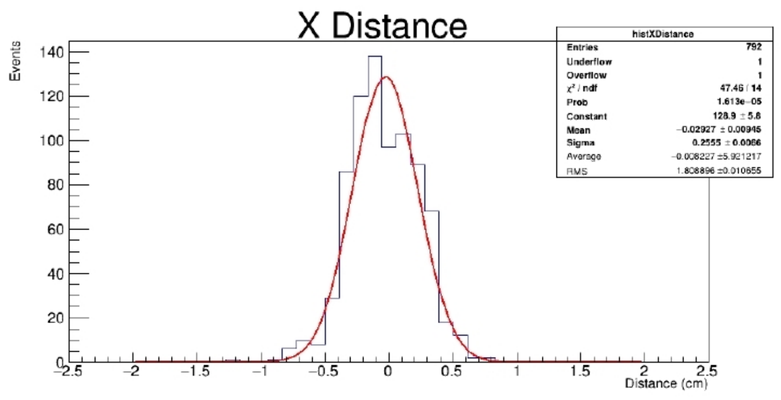


2 displacements (in X and Y) +
2 angles (in XZ and YZ planes)



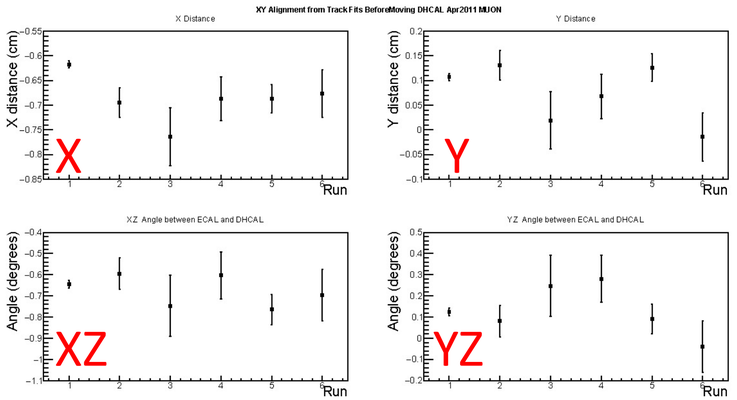
Before Alignment After

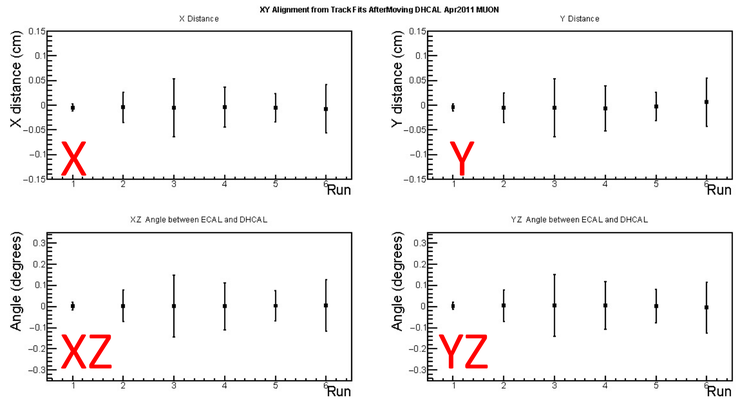




Beam energy	Run	Number of muon events
$50\ GeV$	630081	792
$60\ GeV$	630090	47
	630091	13
	630092	21
	630093	53
	630094	19
$120\ GeV$	630095	3
	630097	3

Results vs run number: 1x 50GeV and 5x 60 GeV
(not enough muons in 120 GeV data)





Global fits of the aligned tracks:

Position:
X/Y: ±0.013 (stat) ±0.016 (syst) cm

Angles
XY/YZ: ±0.013 (stat) ±0.064 (syst) °

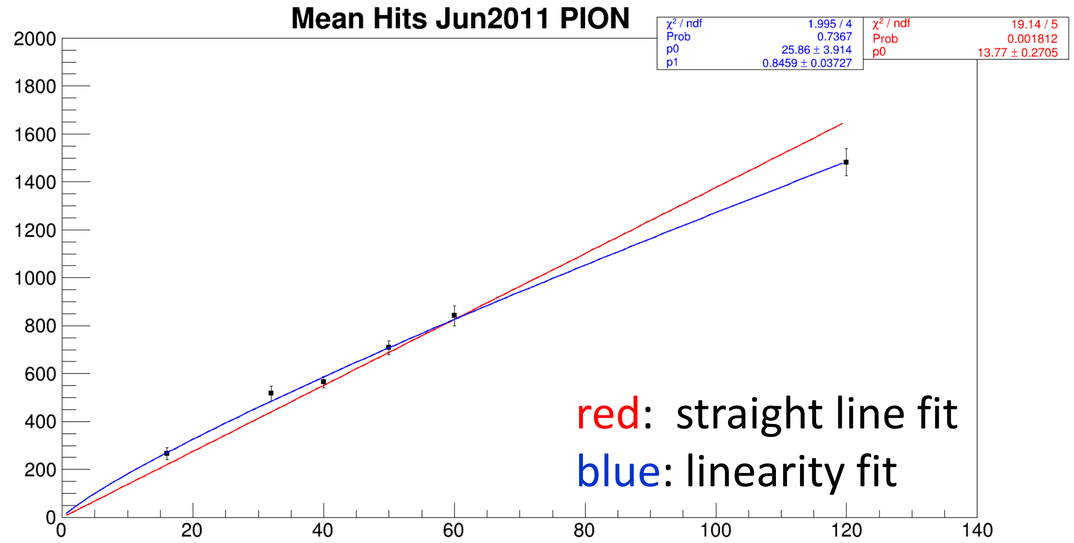
i.e. a few % of cell size

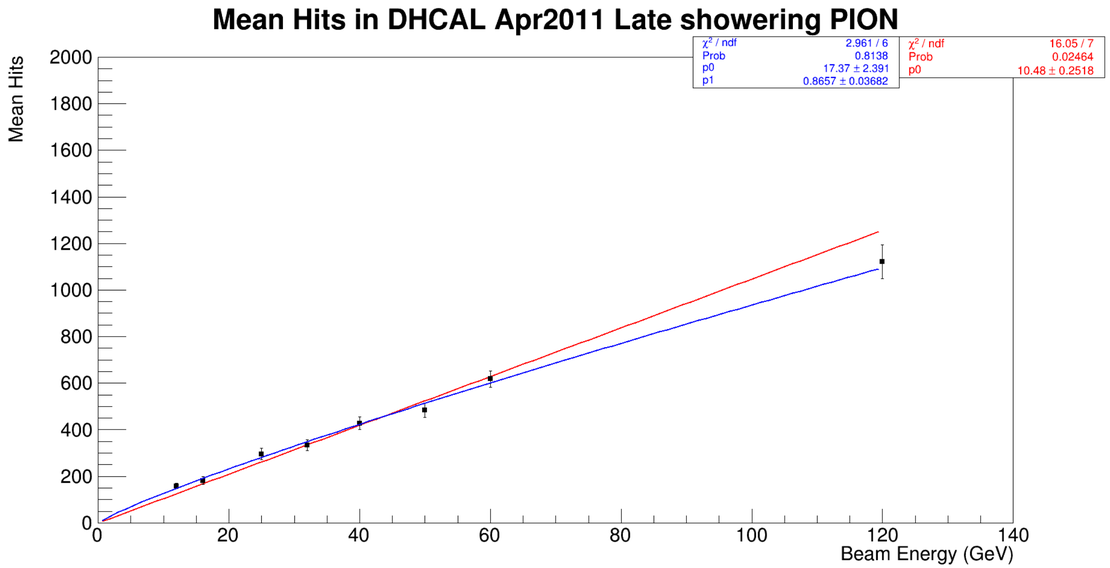
DHCAL Linearity

$$N_{Hits} = p_0 E_{Beam}{}^{p_1}$$

Period	p0	p1
June (DHCAL only)	25.9 ± 3.9	0.85 ± 0.04
April (DHCAL+ECAL)	17.4 ± 2.4	0.87 ± 0.04

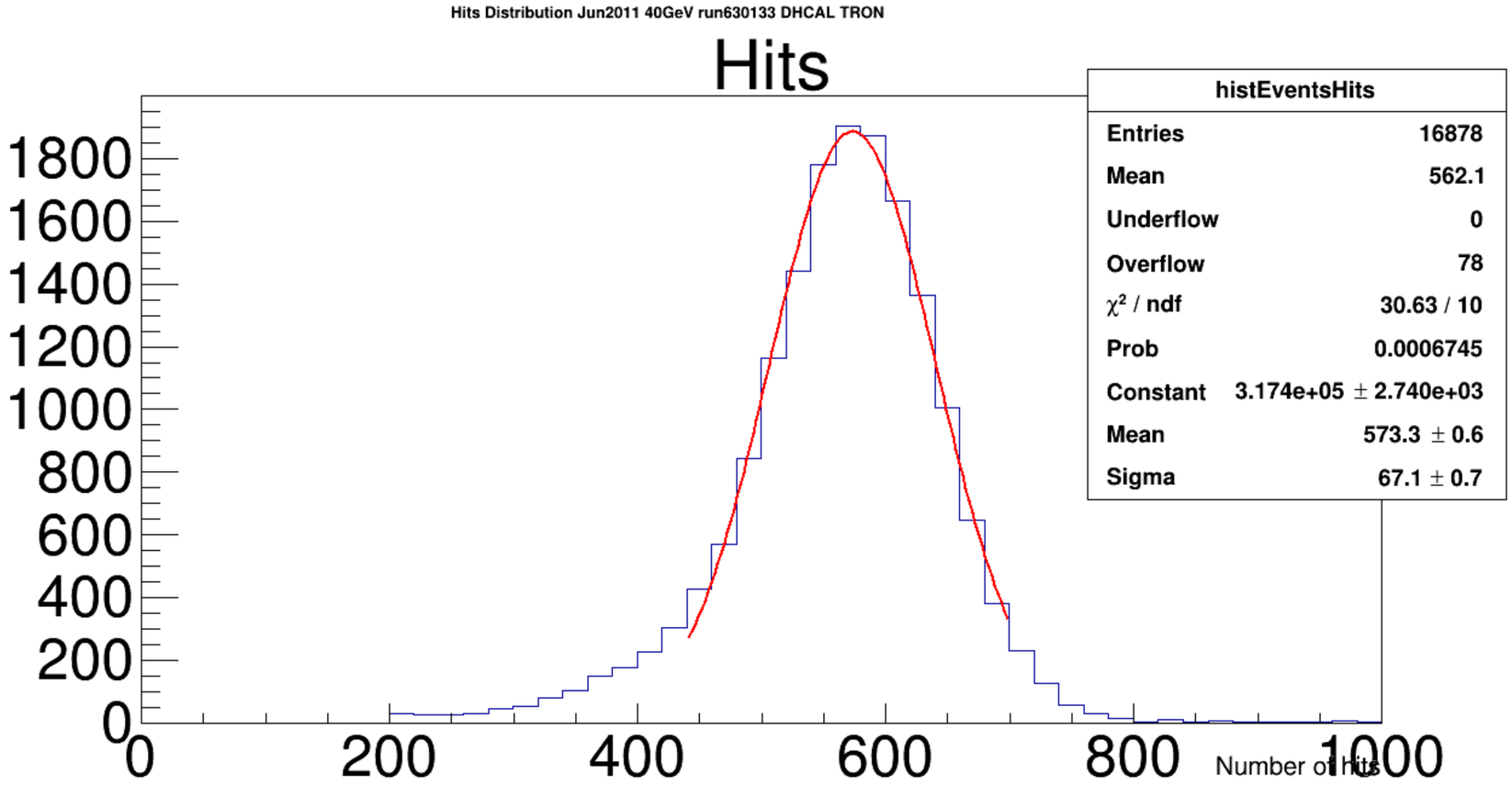
.. will be used for calibration





Resolution

June 2011 data
DHCAL only
40 GeV “electrons”:



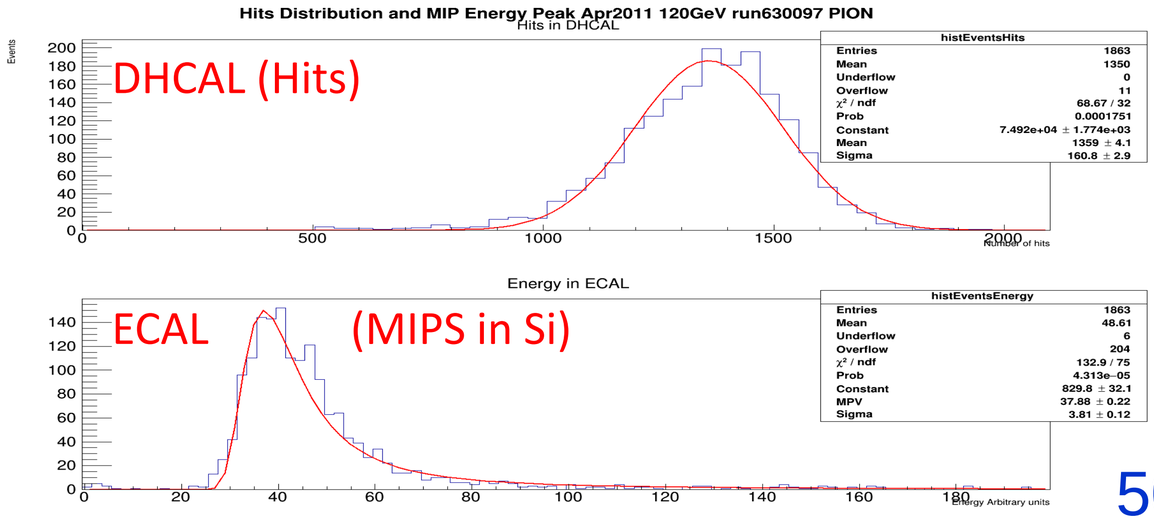
$$Resolution = \frac{\sigma}{E_{Mean}}$$

generic form
(E in GeV):

$$\frac{\sigma}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

Configurations for Pion Energy Resolution

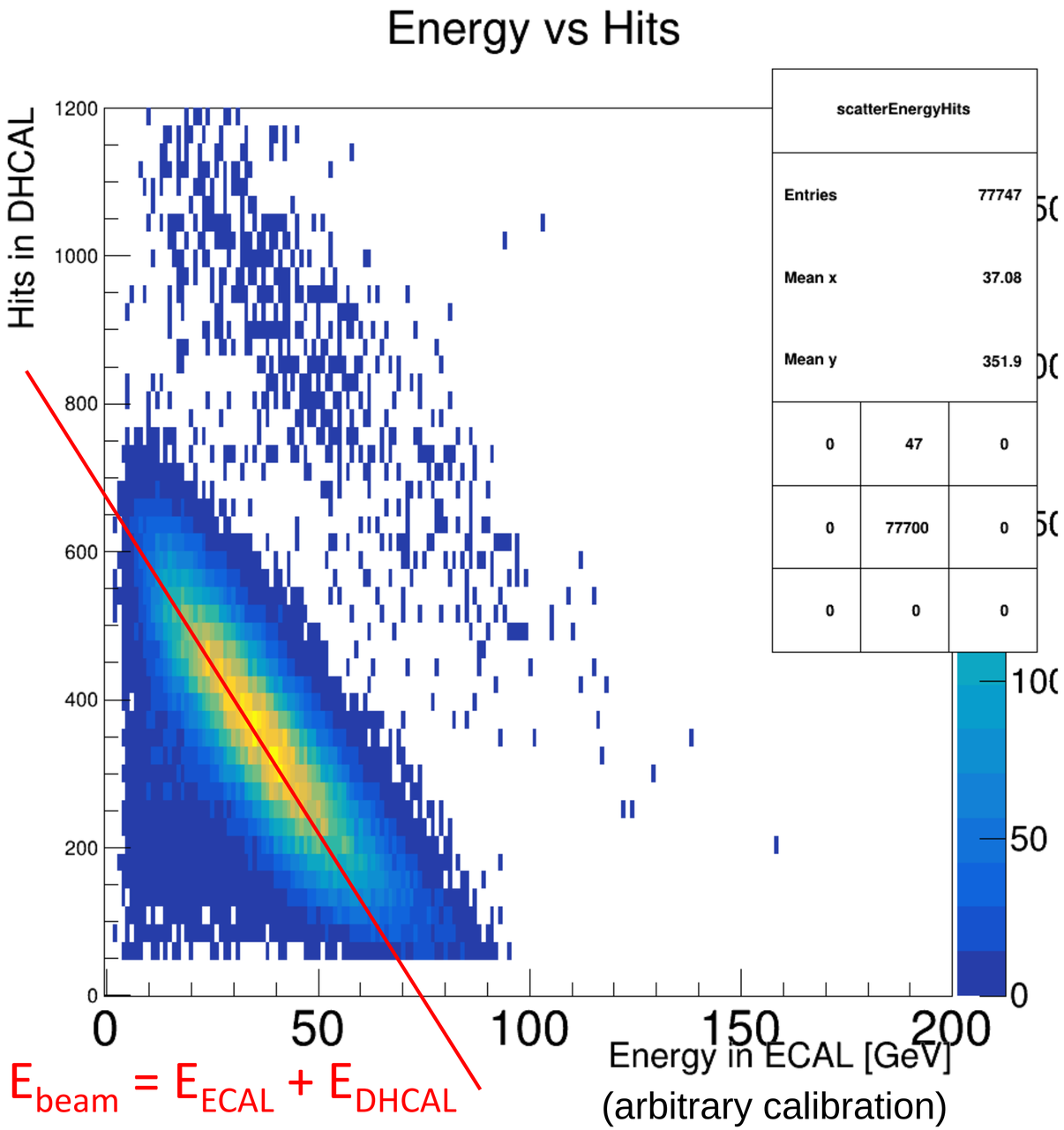
#	Period	Setup	Sample	DHCAL Calibration	Resolution
1	June	DHCAL	All	Linearity fit June	same?
2	April	DHCAL+ECAL	Late showers	Linearity fit April	
3	April	DHCAL+ECAL	Early showers	.. corrected by ECAL*	better?
4	April	DHCAL+ECAL	Early showers	Energy Sum	best?

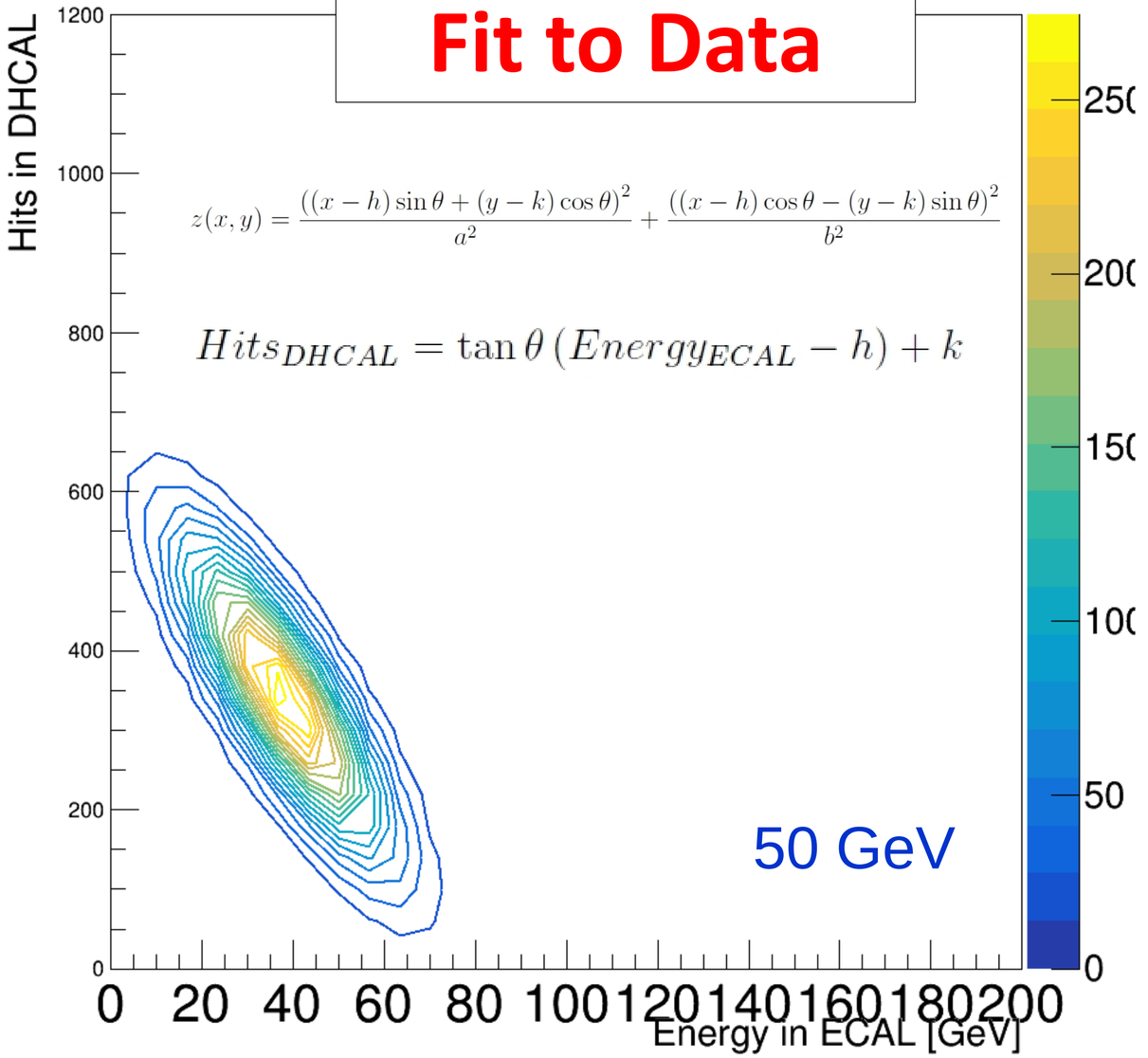


* ECAL online calibration for energy deposition in Silicon, completed by energy deposition in tungsten

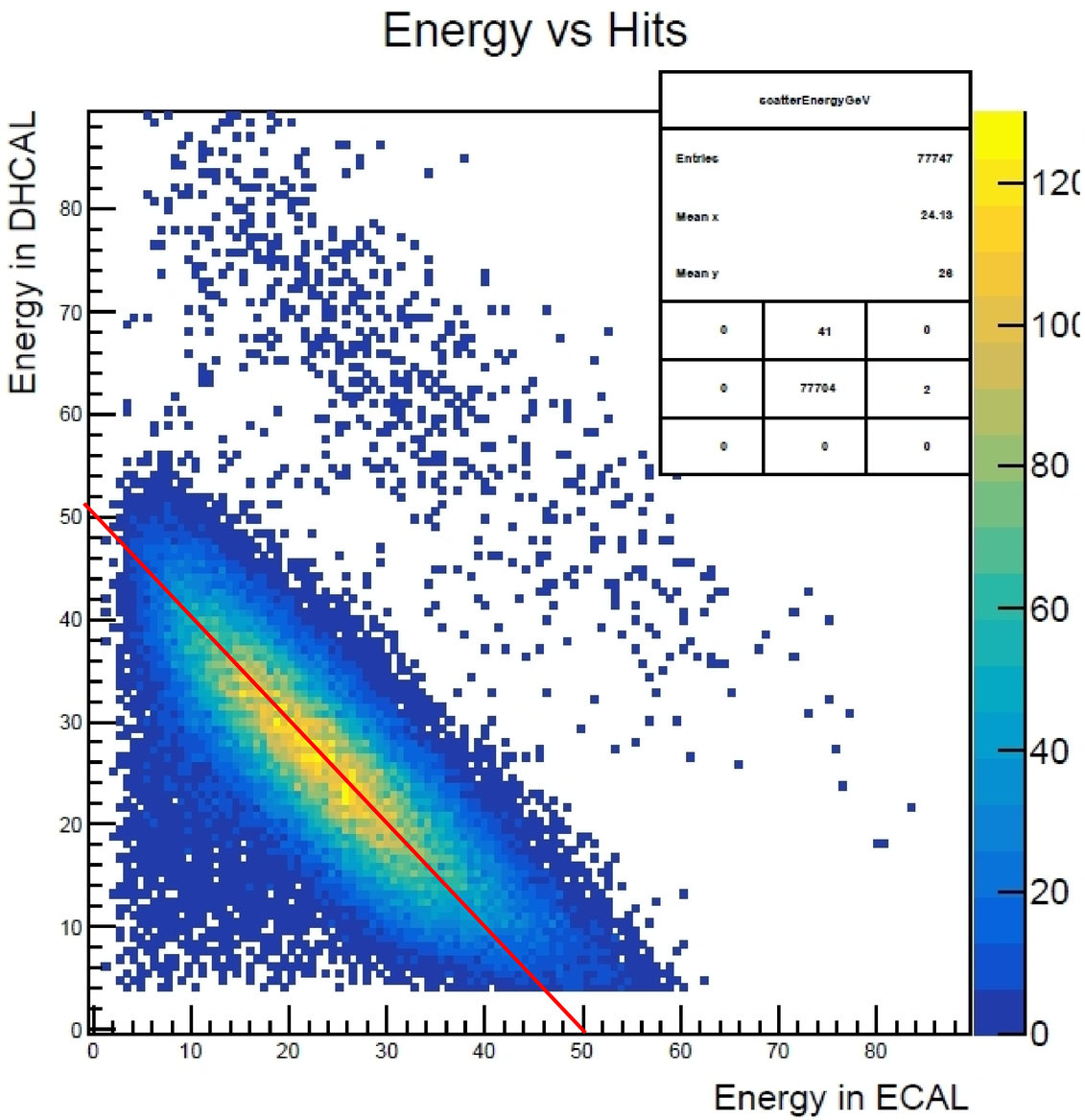
50 GeV sample

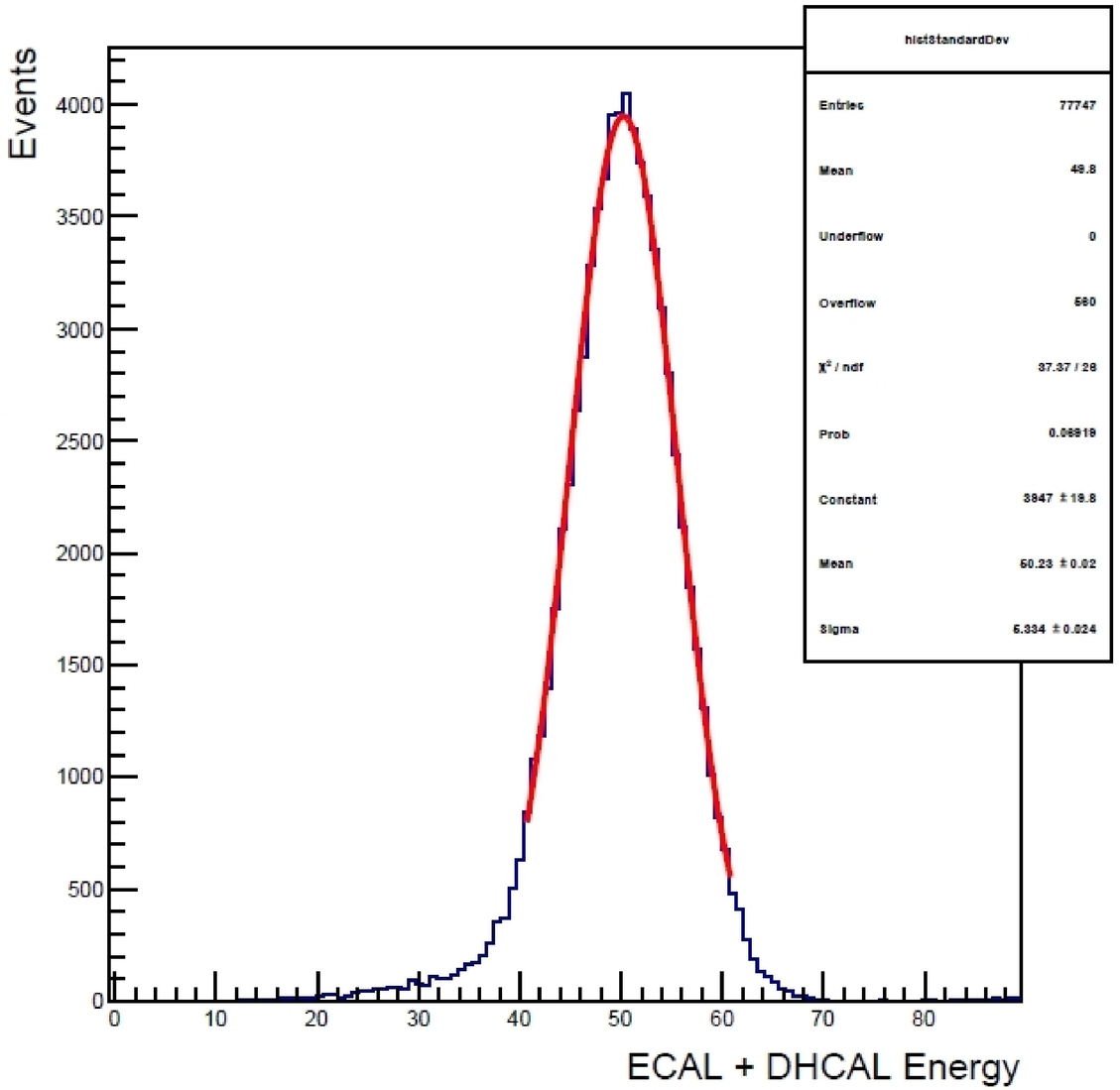
Paraboloid Fit to Data





Energy Calibrated to Beam





Resolutions per Dataset

#1

Results Energy Resolution June 2011		
Beam Energy	e^+Resolution	π^+Resolution
8 GeV	0.174 ± 0.004	
16 GeV		0.212 ± 0.003
32 GeV	0.148 ± 0.001	0.153 ± 0.002
40 GeV	0.123 ± 0.001	0.141 ± 0.002
50 GeV	0.120 ± 0.001	0.135 ± 0.002
60 GeV	0.126 ± 0.001	0.146 ± 0.002
120 GeV	0.119 ± 0.001	0.133 ± 0.002

#2

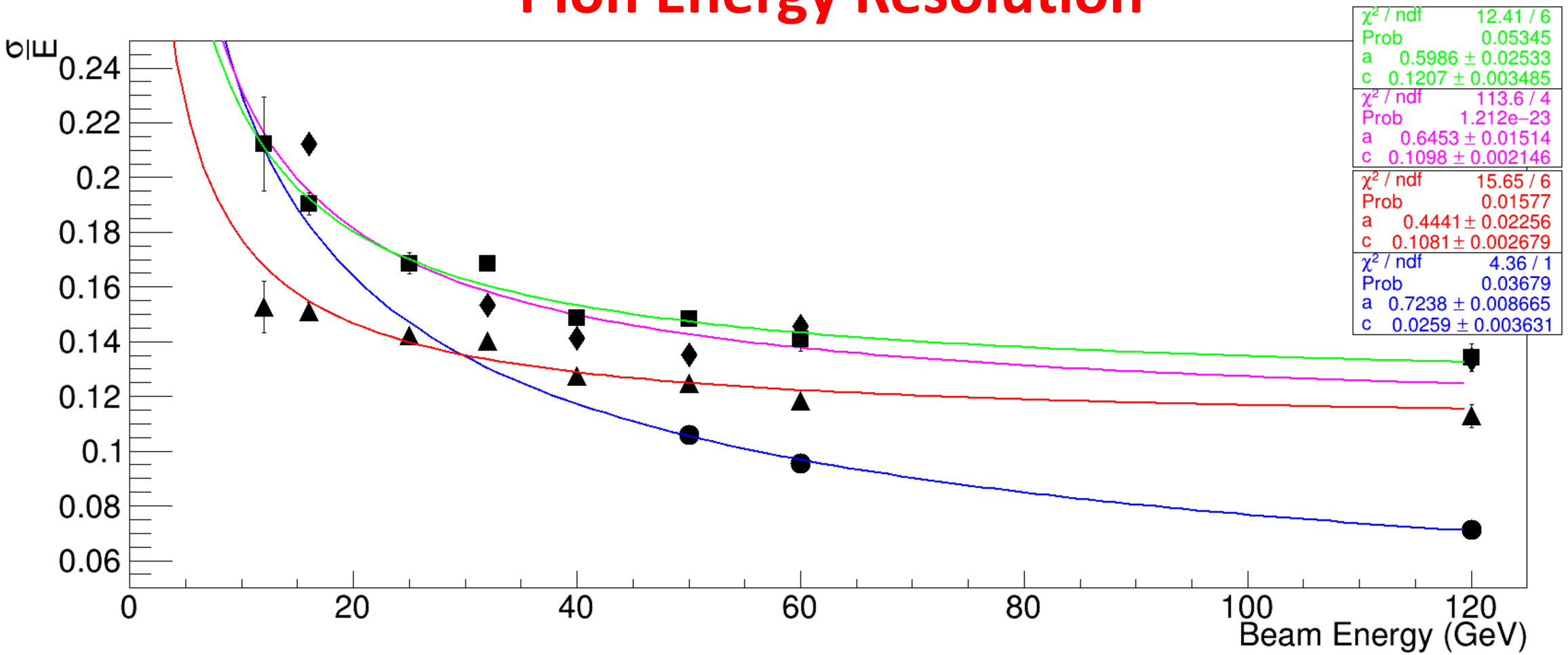
Results April 2011		
	DHCAL using Linearity fit	DHCAL using ECAL Correction
Beam Energy	Resolution	Resolution
12 GeV	0.210 ± 0.020	0.152 ± 0.009
16 GeV	0.190 ± 0.004	0.151 ± 0.003
25 GeV	0.169 ± 0.004	0.142 ± 0.003
32GeV	0.168 ± 0.003	0.14 ± 0.002
40 GeV	0.149 ± 0.002	0.127 ± 0.002
50 GeV	0.148 ± 0.002	0.125 ± 0.002
60 GeV	0.141 ± 0.004	0.118 ± 0.002
120 GeV	0.134 ± 0.005	0.113 ± 0.004

#3

#4

Beam Energy	Energy Resolution	a($GeV^{\frac{1}{2}}$)
50 GeV	0.1061 ± 0.0005	0.750 ± 0.004
60 GeV	0.095 ± 0.003	0.740 ± 0.006
120 GeV	0.071 ± 0.001	0.780 ± 0.008

Pion Energy Resolution



#2
#1
#3
#4

Fit function: $\frac{\sigma}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$ (with b=0)

Pion Energy Resolution

Period and Method	Marker	Energy Resolution PION			
		50 GeV	60 GeV	120 GeV	Average
DHCAL April 2011 Linearity fit	■	0.148	0.141	0.134	0.139
DHCAL June 2011 Linearity fit	♦	0.135	0.146	0.133	0.138
DHCAL April 2011 ECAL correction	▲	0.125	0.118	0.113	0.119
Si-W ECAL+DHCAL April 2011 Sum of energies	●	0.106	0.097	0.072	0.092

#2
#1
#3
#4

Compared periods	Difference between energy resolutions			
	50 GeV	60 GeV	120 GeV	Average
DHCAL April 2011 Linearity fit to DHCAL June 2011 Linearity fit	-6%	4%	-1%	-1%
DHCAL June 2011 Linearity fit to DHCAL April 2011 ECAL correction	-7%	-19%	-15%	-14%
DHCAL April 2011 ECAL correction to ECAL+DHCAL Sum of energies	-15%	-18%	-36%	-23%

#2 → #1

#1 → #3

#3 → #4

cumulative: ~40%

Conclusion and Outlook

The 2011 data of combined runs DHCAL and SiW-ECAL were analyzed. Several/severe caveats (e.g. limited energy range, particle ID).

- Muons could be used to align the detectors to ~0.02 cm in position and ~0.1 ° in angle.
- The presence of ECAL should improve the “pion” energy resolution. Better particle ID necessary.

DHCAL analysis plans: detailed better pion performance analysis from data and Monte-Carlo simulations (McGill and Beykent universities)

Extras

?