Status of the prototype beam-test analysis

E.Vannuccini (INFN Florence)
On behalf of the collaboration

Test	Particles	Energy (GeV)	CaloCube	Notes	Results
SPS 2013-02	Ions Pb+Be	13×A - 30×A	v1.0 3×3×14	• Optical cross-talk • No CASIS time correction • MC model (fine tuning)	Energy resolution $H_2 \div Si_{28}$ <40%
BTF 2014-xx	1÷22 e 50÷400 e	0.491 0.295	v1.0 3×3×5		
SPS 2015-03	Ions (Ar+Poly) Ar	19×A - 30×A 648 -1080	v1.1 3×3×14	• No optical cross-talk • Time-correction	(work in progress)
SPS 2015-09	μ π e	150 50-100-150-180 50-75-180	v1.2 3×3×14	• Sensors along the beam • Few crystals with double-PD readout	Energy resolution (LPD) e @50-75 GeV
SPS 2016-09	μ π e	150 50-100-150-300 50-100-150-200	v2.0 5×5×18	• Full double-PD readout • Lateral sensors • Incomplete μ calibration scan • Anti-	Energy resolution (LPD+SPD) e @50÷200 GeV (work in progress)
BTF 2016-10	1÷40000 e	0.300	v2.0 5×5×18	• Full dynamic range scan	(work in progress)

h ⇒ ~ 10 MIP/GeV
e ⇒ ~ 40 MIP/GeV
High/low gain @ ~32 kMIP
LPD saturation @ ~70÷80 kMIP
SPD ~ LPD/100

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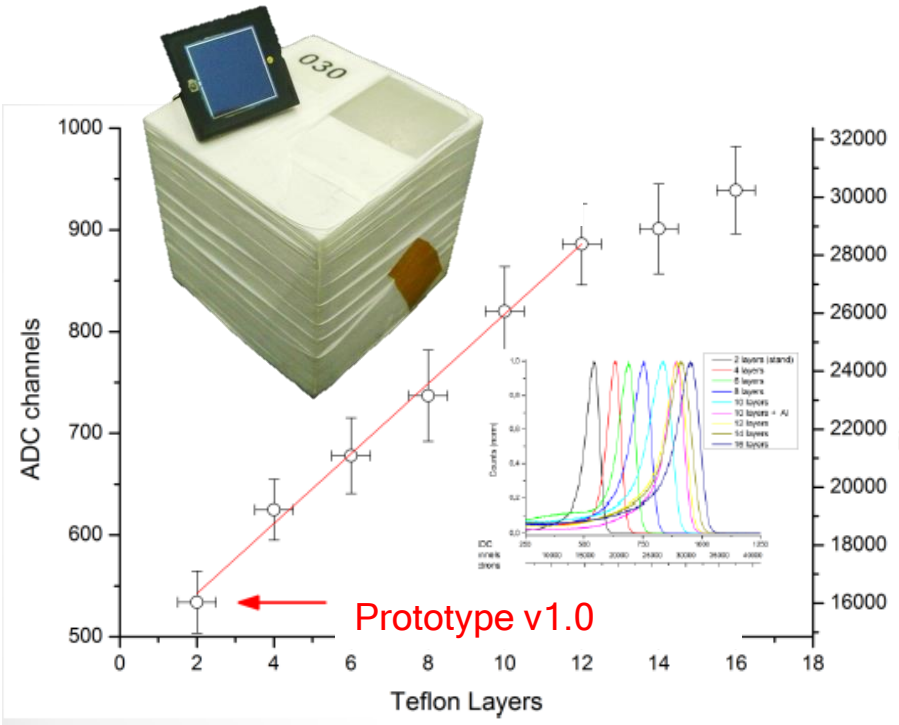
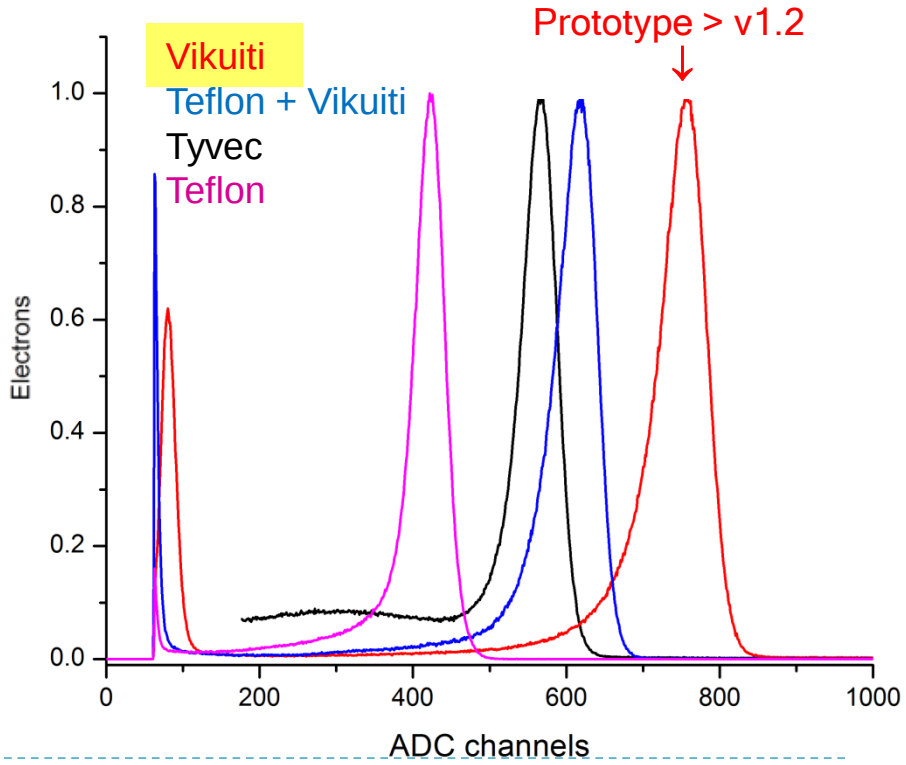
Light-collection optimization

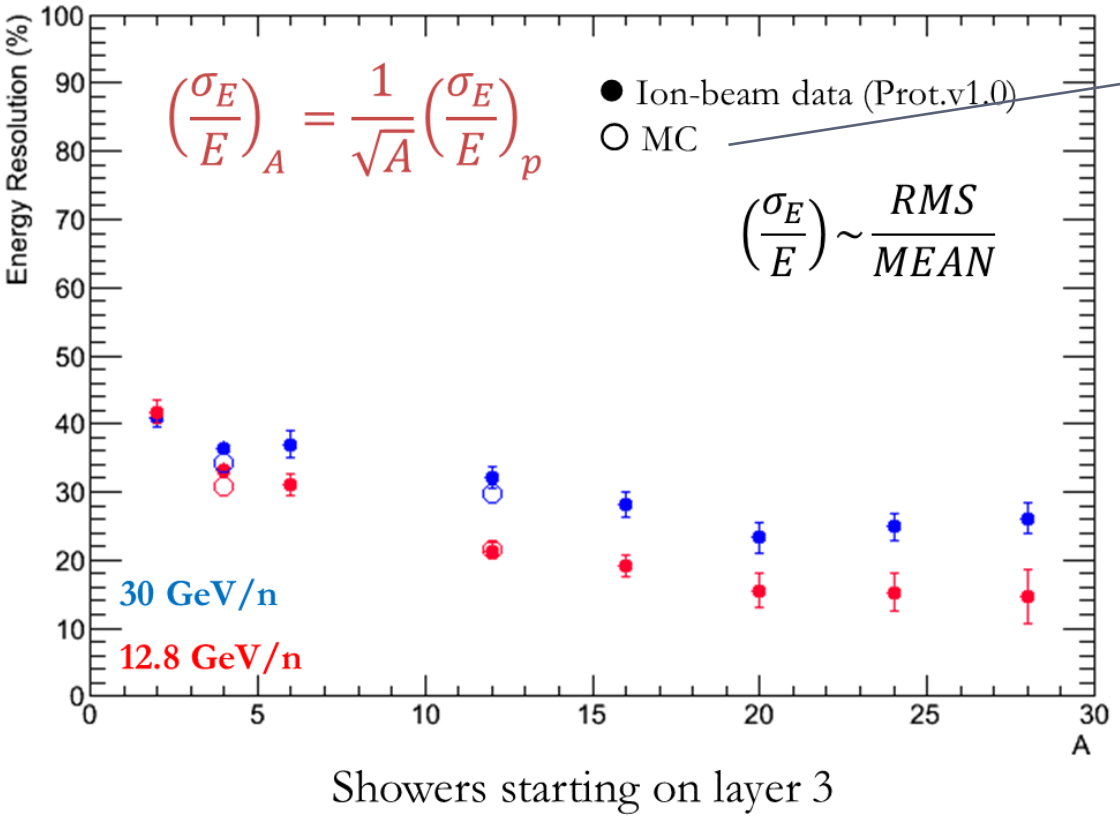
- Studied with signal induced by 5,5 MeV α from Am source
- Setup:
  - single cube (matte) coupled to VTH2090 PD
  - Readout by commercial CSA and DPA modules (Amptek)





SPS 2013-02

Energy resolution for showers induced by ions



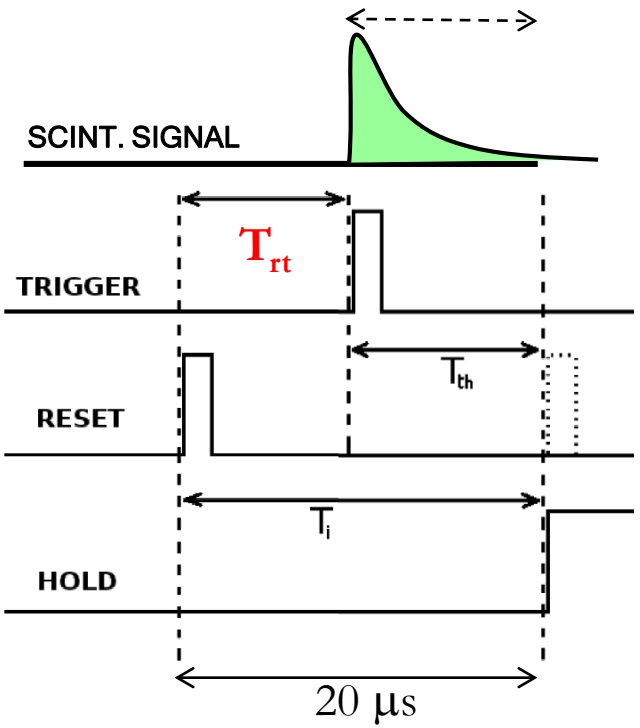
- Prot. v1.0 affected by instrumental effects → MC fine tuning:
  - 14% optical cross talk
  - 4.5% additional gaussian spread to single-crystal signal

- Agreement with MC prediction at few % level
- Measured energy resolution systematically worse than expected
- Instrumental effects understood and fixed:
  - CASIS-time effect
  - optical cross-talk

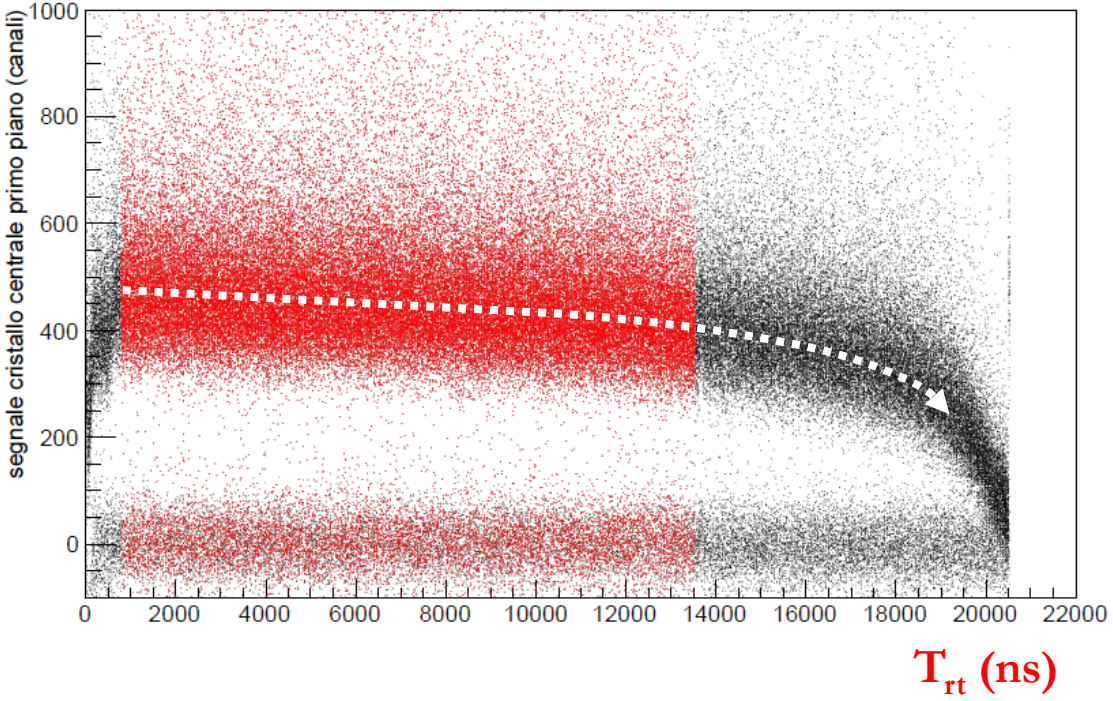
CASIS-time effect

Particle trigger signal asynchronous wrt CASIS acquisition cycle → variable integration time

Integration time



Muons 180 GeV



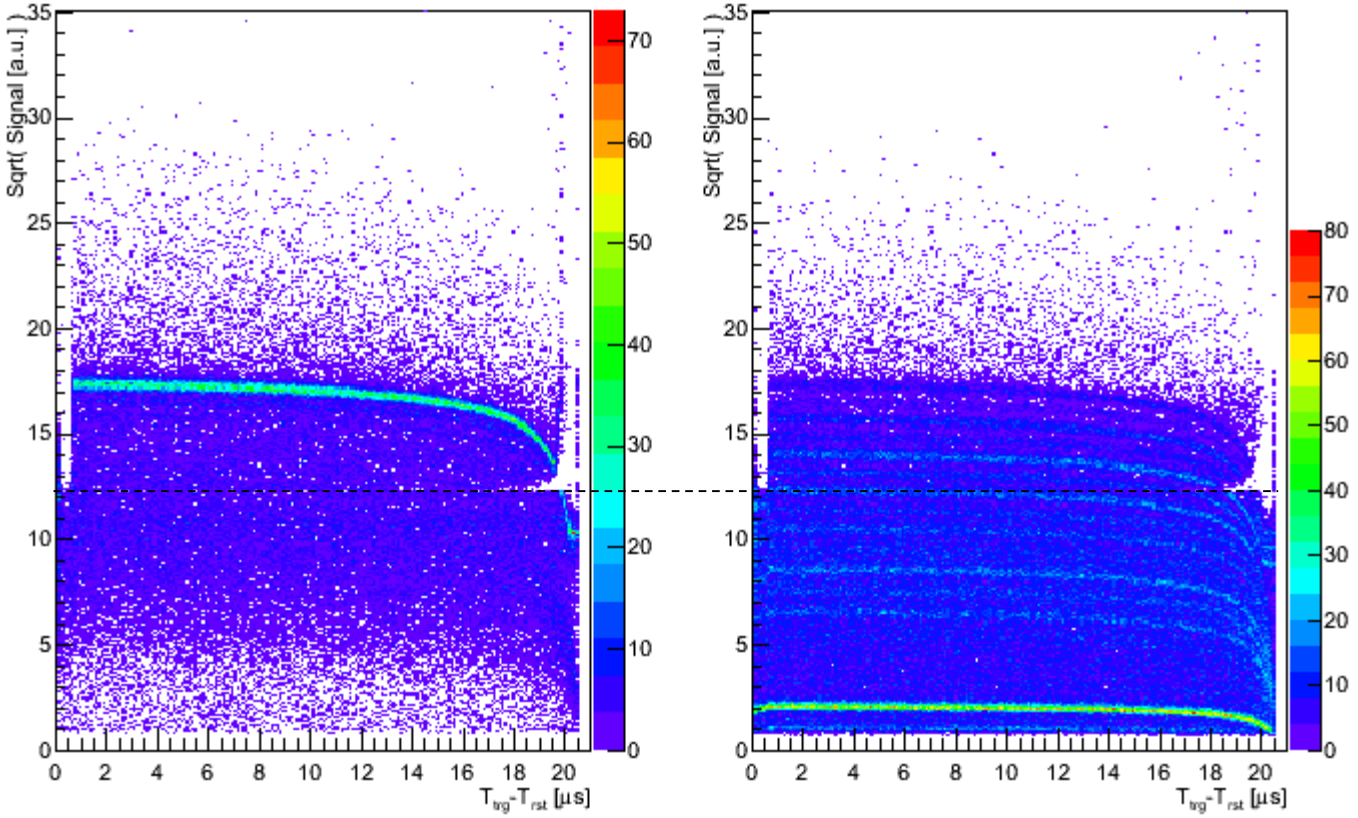
Signal attenuation consistent with ~30% slow scintillation component of ~8µs decay time

SPS 2015-03

Ar beam 30GeV/u

Ar+Polyethylene beam 30GeV/u

high gain ← | → low gain

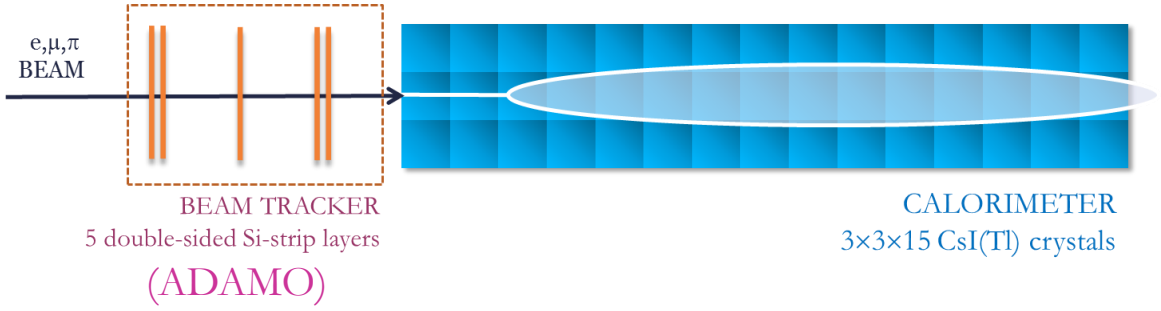


Prototype v1.1

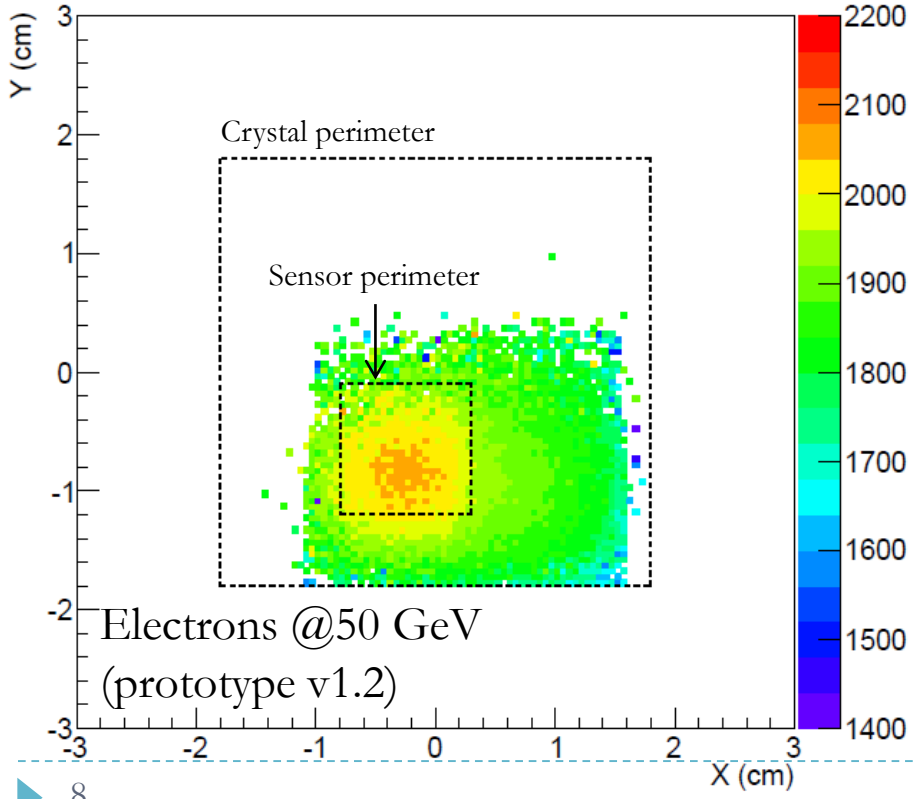
- No optical cross-talk
- Time correction

Work in progress

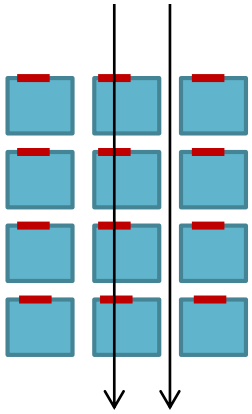
Test with high-energy electrons



- Prototype v1.2 exposed to e,μ,π beams of 50÷180 GeV (Sep-2015 @CERN-SPS)

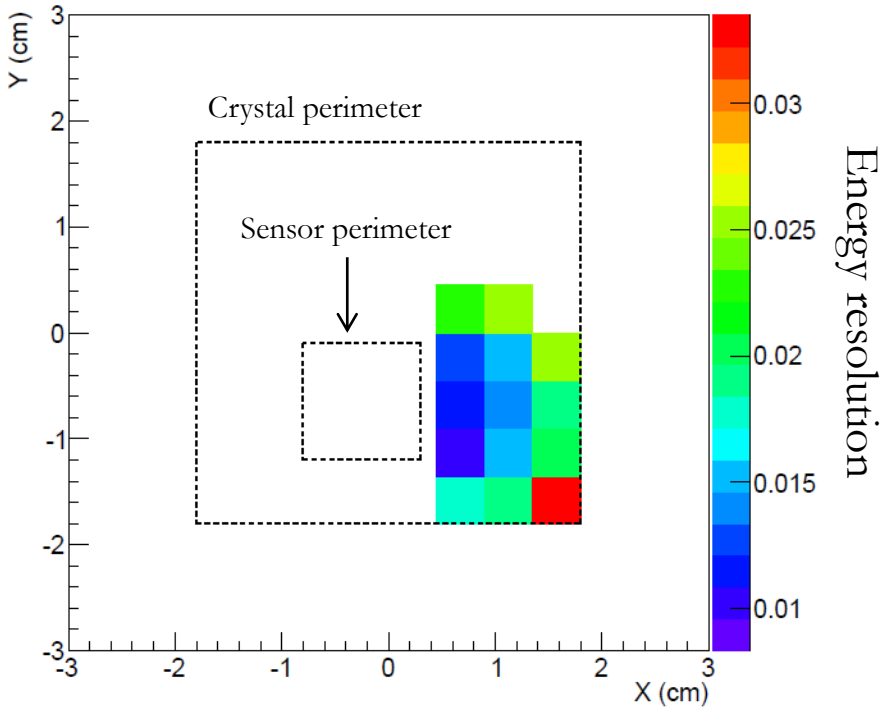


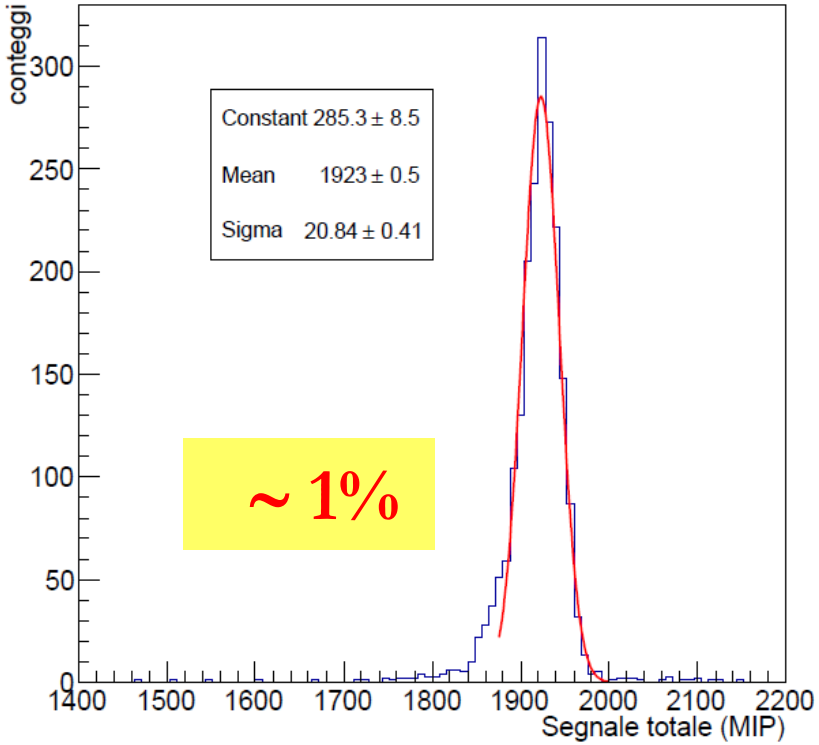
- Large variations (~10%) on the collected signal depending on inpact position: crystal bulk, sensor, borders (known geometrical effect, not a surprise)



Energy resolution – e.m. showers

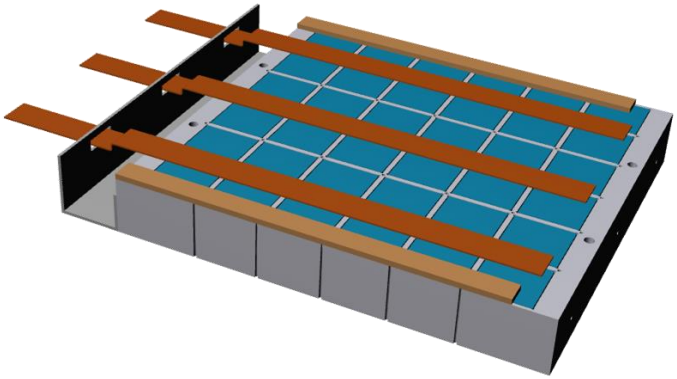
50 GeV electrons – prototype v1.2

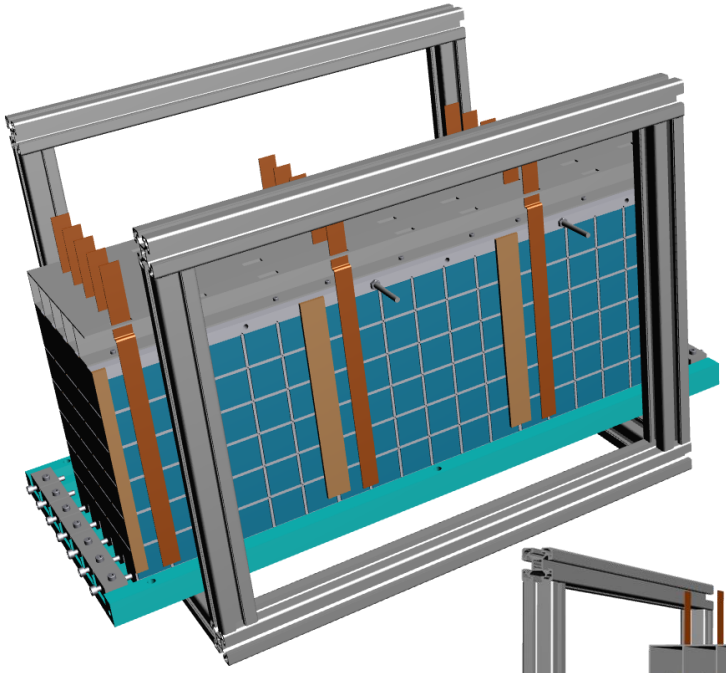


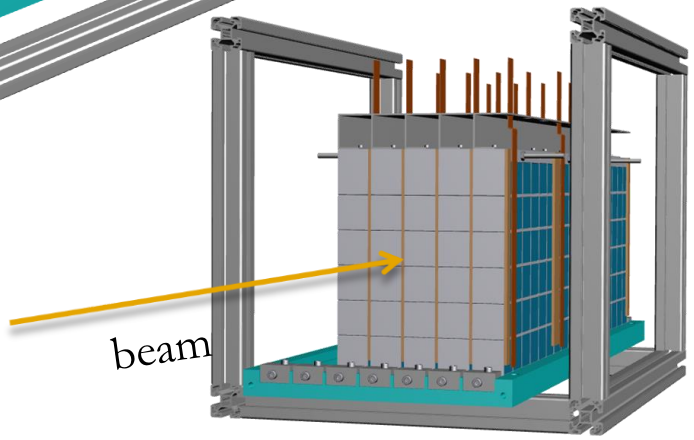


- **1% energy resolution** (locally)
  - Good agreement with MC prediction (no fine tuning required)

Prototype upgrade (v2)



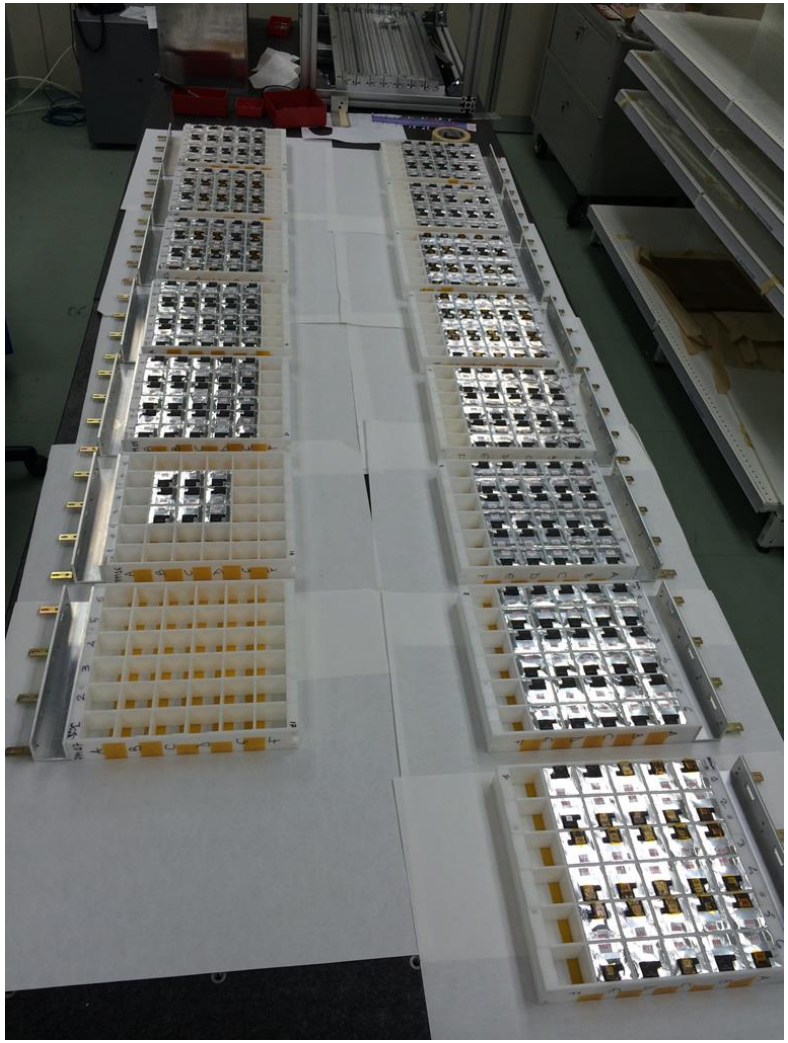


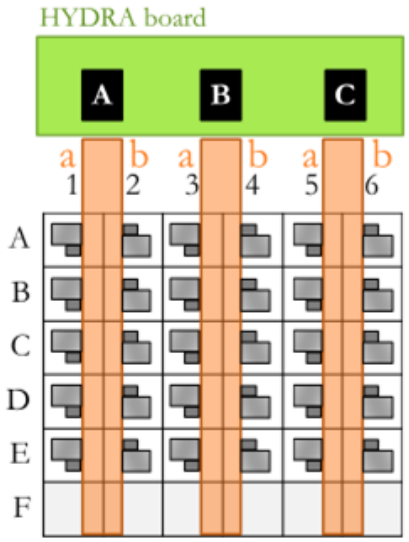


- Prototype mechanics completely redesigned
  - Sensor placed sideways!
  - Up to 18 trays × 36 crystals each
  - active depth **35.0 X_0 → 1.6 λ_I**

• Mechanics: INFN Pisa

Prototype upgrade (v2)





- First version of HYDRA chip (28 channels)
- Two-PD redout
- V2.0 → 5×5×18 instrumented elements

Sep 2016	v2.0	μ,π,e 50÷200 GeV
Oct 2016	v2.0	(3÷40000) e 300MeV

• Data analysis: INFN Florence+Pisa, CIEMATMadrid

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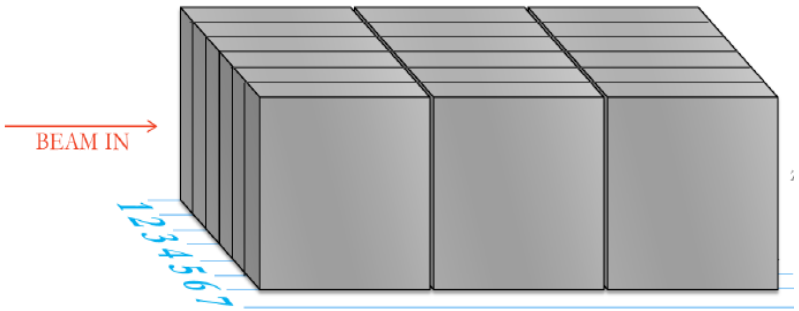
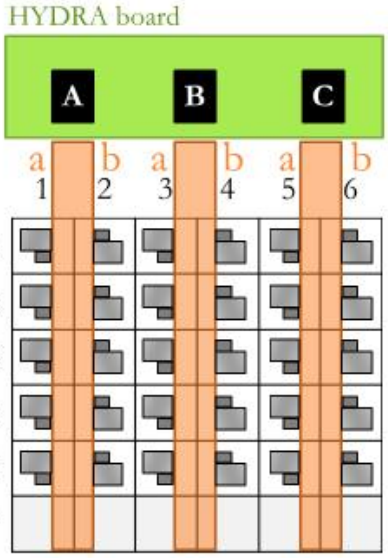
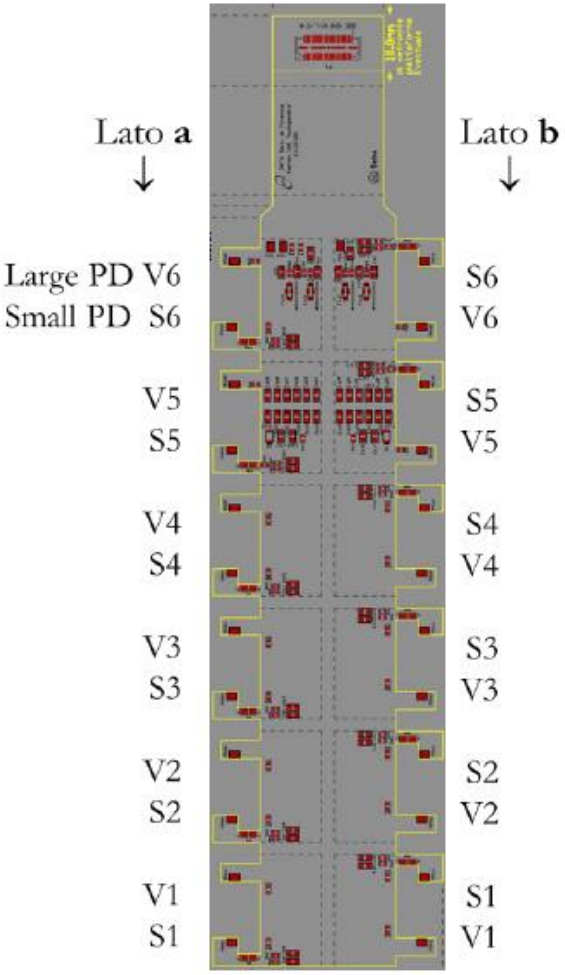
Readout board







HYDRA Channel	PD
1	-
2	CNa
3	V6a
4	V5a
5	V4a
6	V3a
7	V2a
8	V1a
9	S1a
10	S2a
11	S3a
12	S4a
13	S5a
14	S6a
15	S1b
16	S2b
17	S3b
18	S4b
19	S5b
20	S6b
21	CNb
22	V6b
23	V5b
24	V4b
25	V3b
26	V2b
27	V1b
28	-

Common-noise model

HYDRA Channel	PD
1	-
2	CNa
3	V6a
4	V5a
5	V4a
6	V3a
7	V2a
8	V1a
9	S1a
10	S2a
11	S3a
12	S4a
13	S5a
14	S6a
15	S1b
16	S2b
17	S3b
18	S4b
19	S5b
20	S6b
21	CNb
22	V6b
23	V5b
24	V4b
25	V3b
26	V2b
27	V1b
28	-

$CN_a = (ADC - PED)_a$

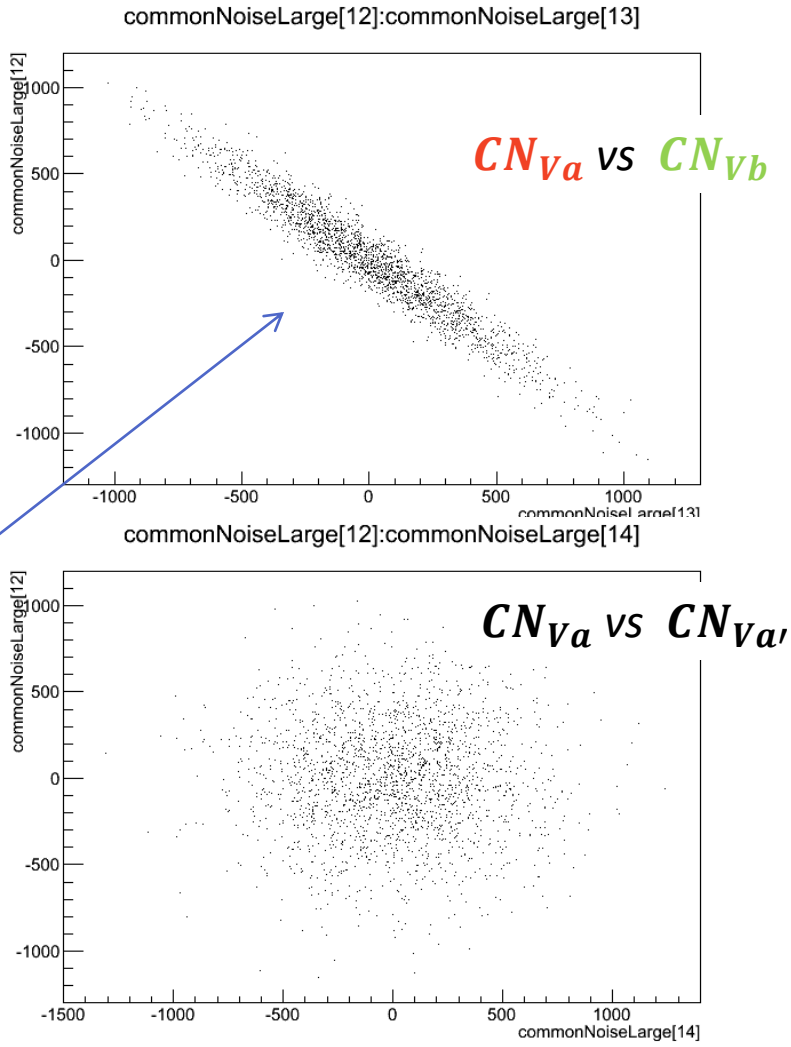
$\boldsymbol{CN_{Va} = \langle ADC - PED \rangle_{Va}}$

$CN_{Sa} = \langle ADC - PED \rangle_{Sa}$

$CN_{Sb} = \langle ADC - PED \rangle_{Sb}$

$CN_b = (ADC - PED)_b$

$\boldsymbol{CN_{Vb} = \langle ADC - PED \rangle_{Vb}}$



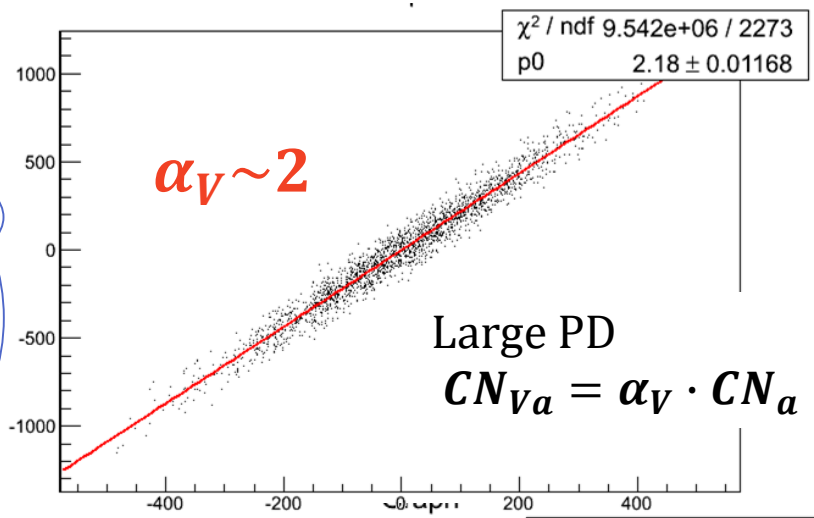
Common-noise model

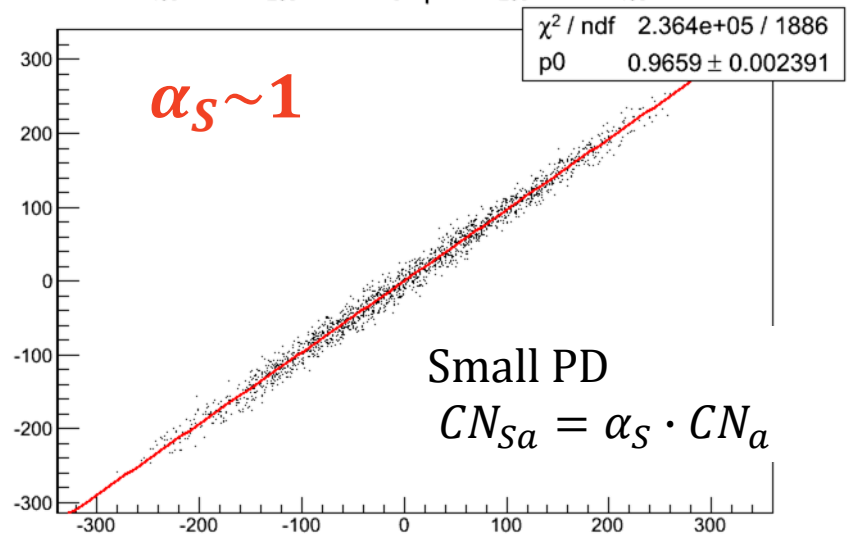
HYDRA Channel	PD
1	-
2	CNa
3	V6a
4	V5a
5	V4a
6	V3a
7	V2a
8	V1a
9	S1a
10	S2a
11	S3a
12	S4a
13	S5a
14	S6a
15	S1b
16	S2b
17	S3b
18	S4b
19	S5b
20	S6b
21	CNb
22	V6b
23	V5b
24	V4b
25	V3b
26	V2b
27	V1b
28	-

$CN_a = (ADC - PED)_a$

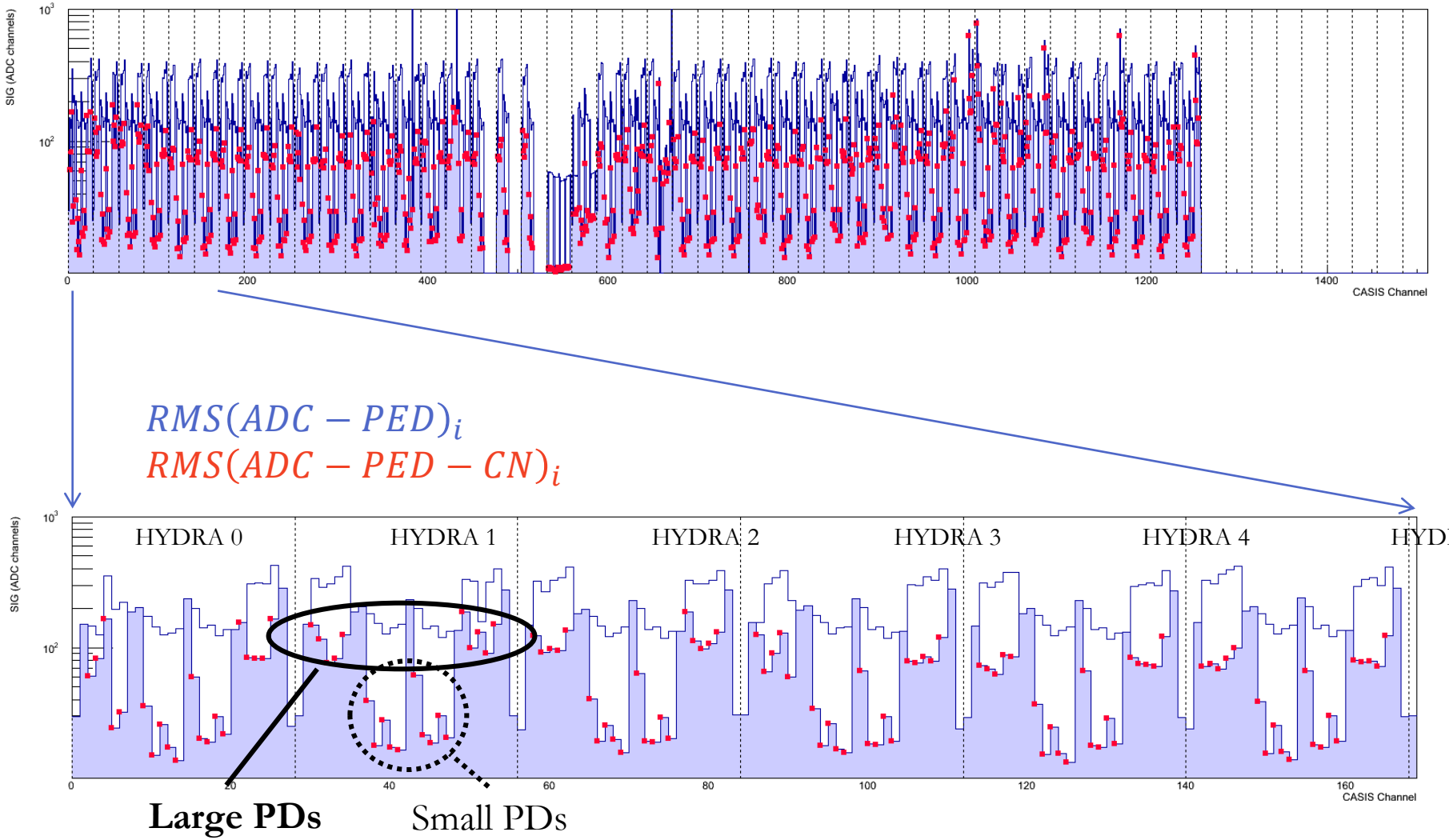
$\boldsymbol{CN_{Va} = \langle ADC - PED \rangle_{Va}}$

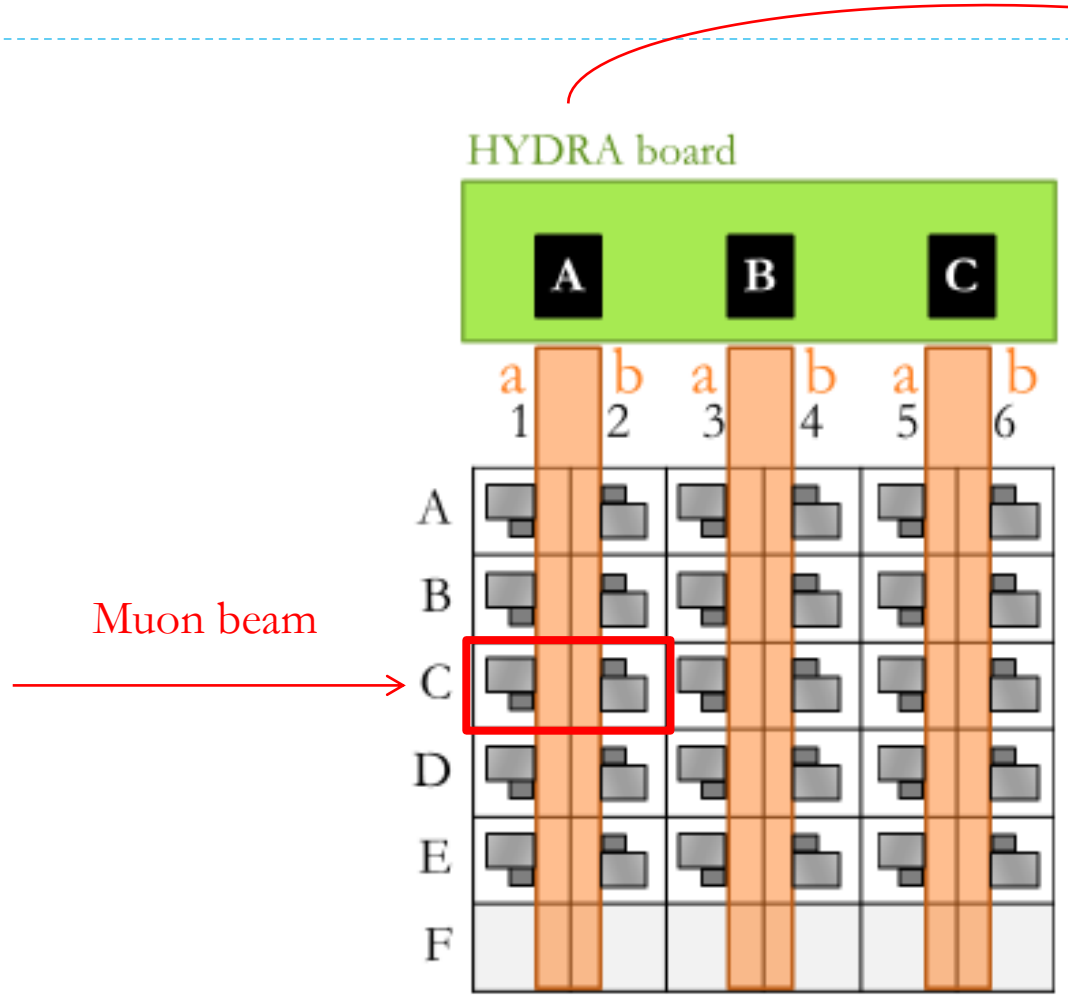
$CN_{Sa} = \langle ADC - PED \rangle_{Sa}$



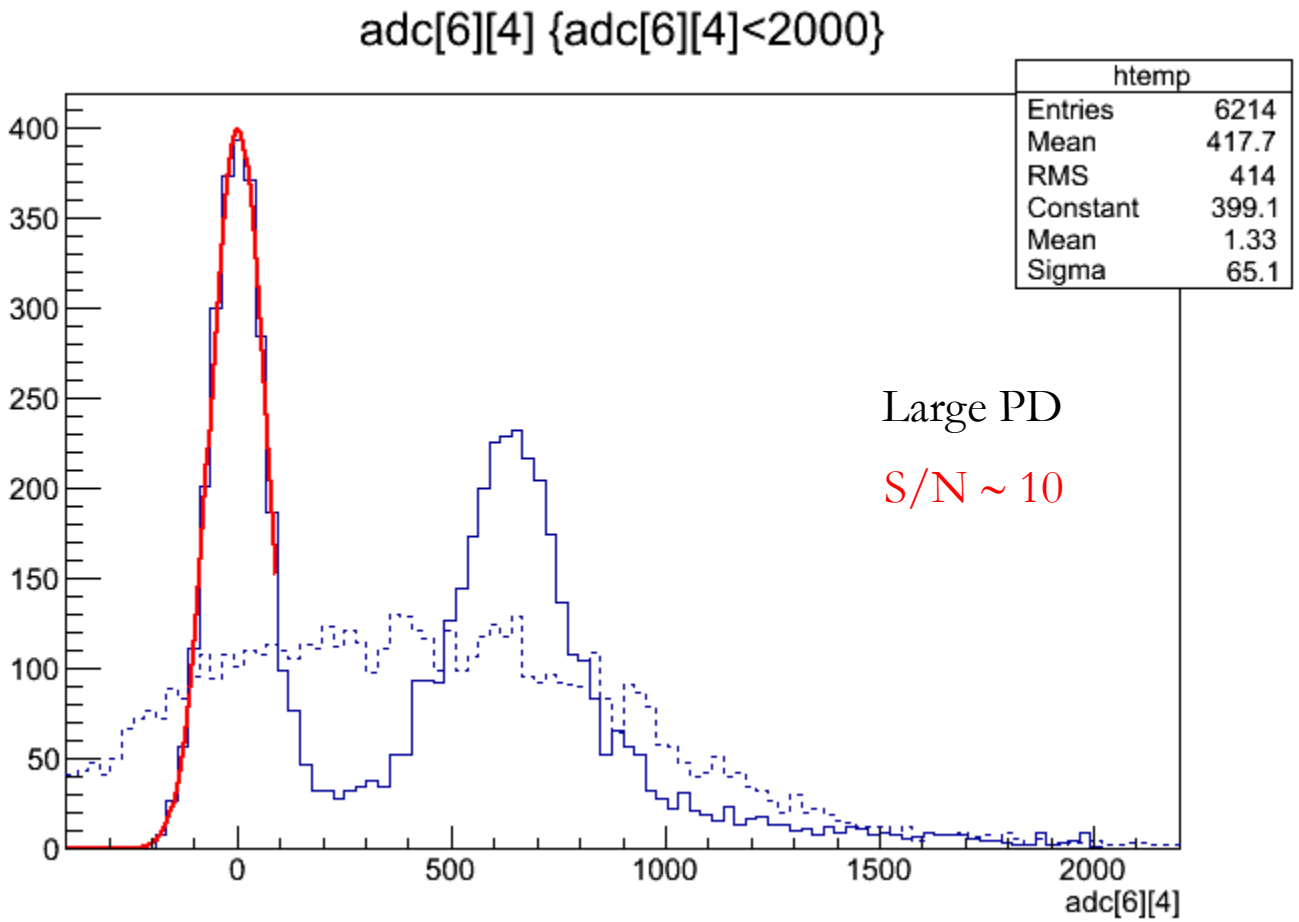


Noise

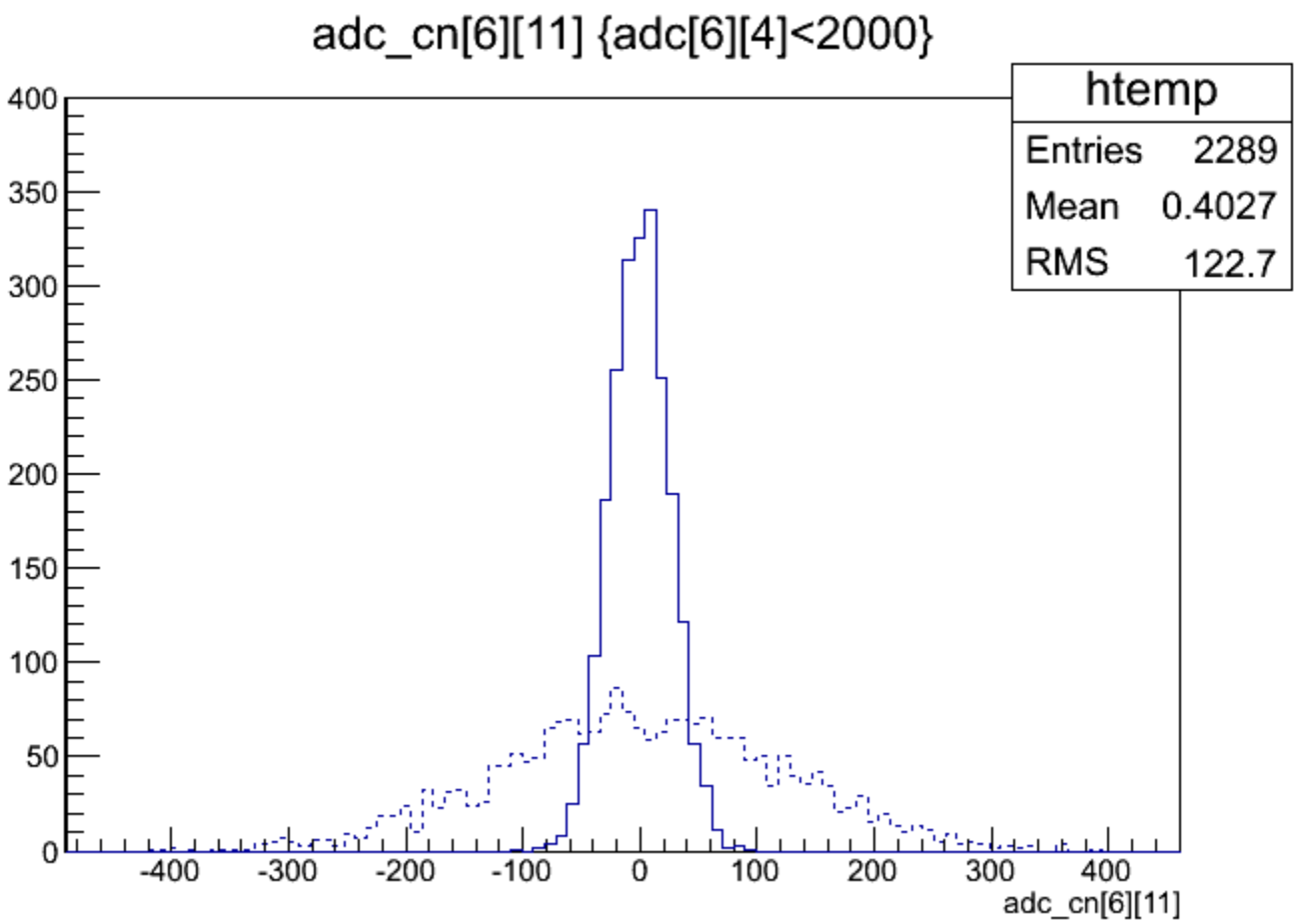

SIG (ADC channels)
CASIS Channel
$RMS(ADC - PED)_i$
$RMS(ADC - PED - CN)_i$
HYDRA 0
HYDRA 1
HYDRA 2
HYDRA 3
HYDRA 4
HYDRA 5
Large PDs
Small PDs



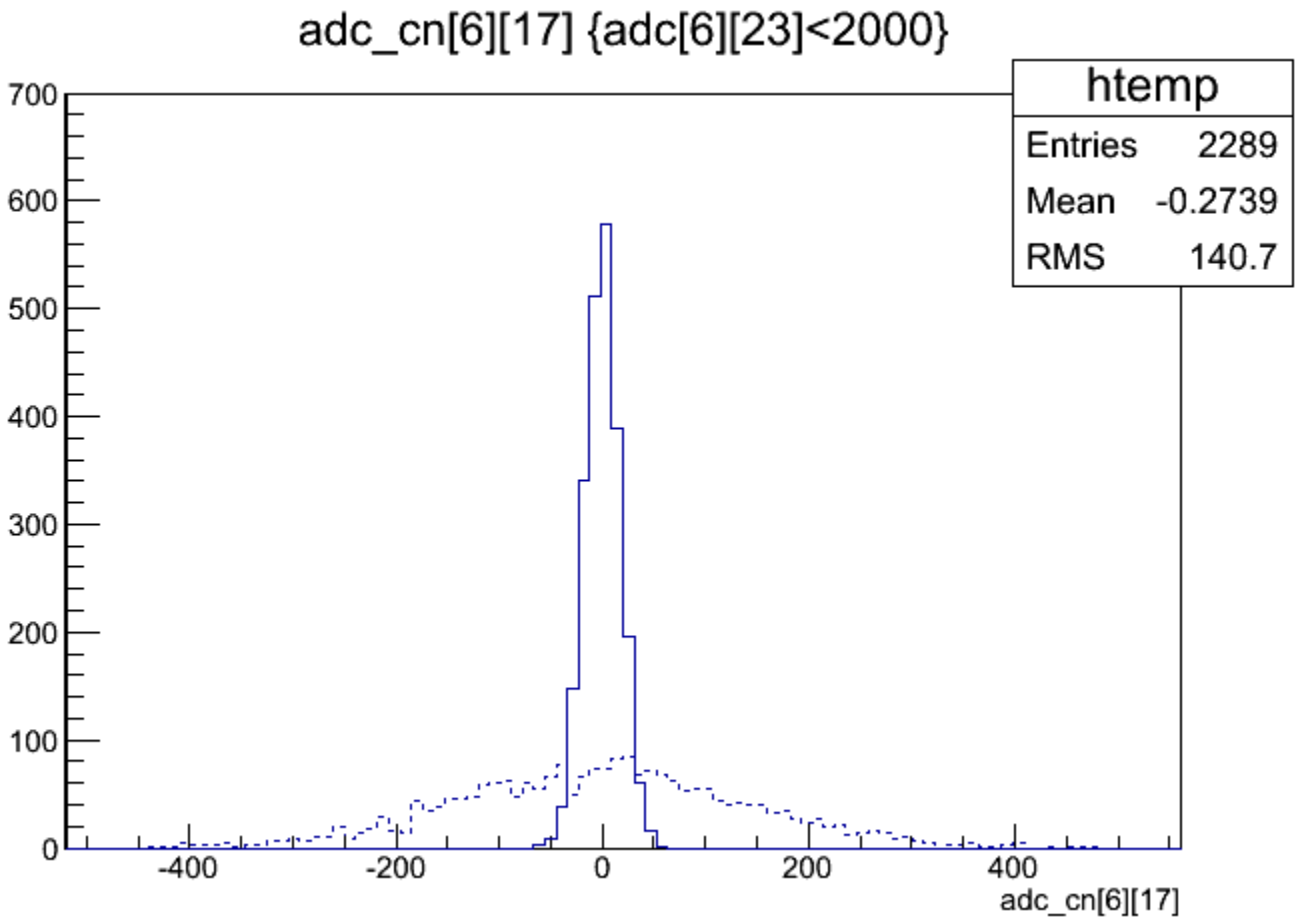
HYDRA Channel	PD	
1	-	
2	CNa	
3	V6a	
4	V5a	
5	V4a	←
6	V3a	
7	V2a	
8	V1a	
9	S1a	
10	S2a	
11	S3a	
12	S4a	←
13	S5a	
14	S6a	
15	S1b	
16	S2b	
17	S3b	
18	S4b	←
19	S5b	
20	S6b	
21	CNb	
22	V6b	
23	V5b	
24	V4b	←
25	V3b	
26	V2b	
27	V1b	
28	-	



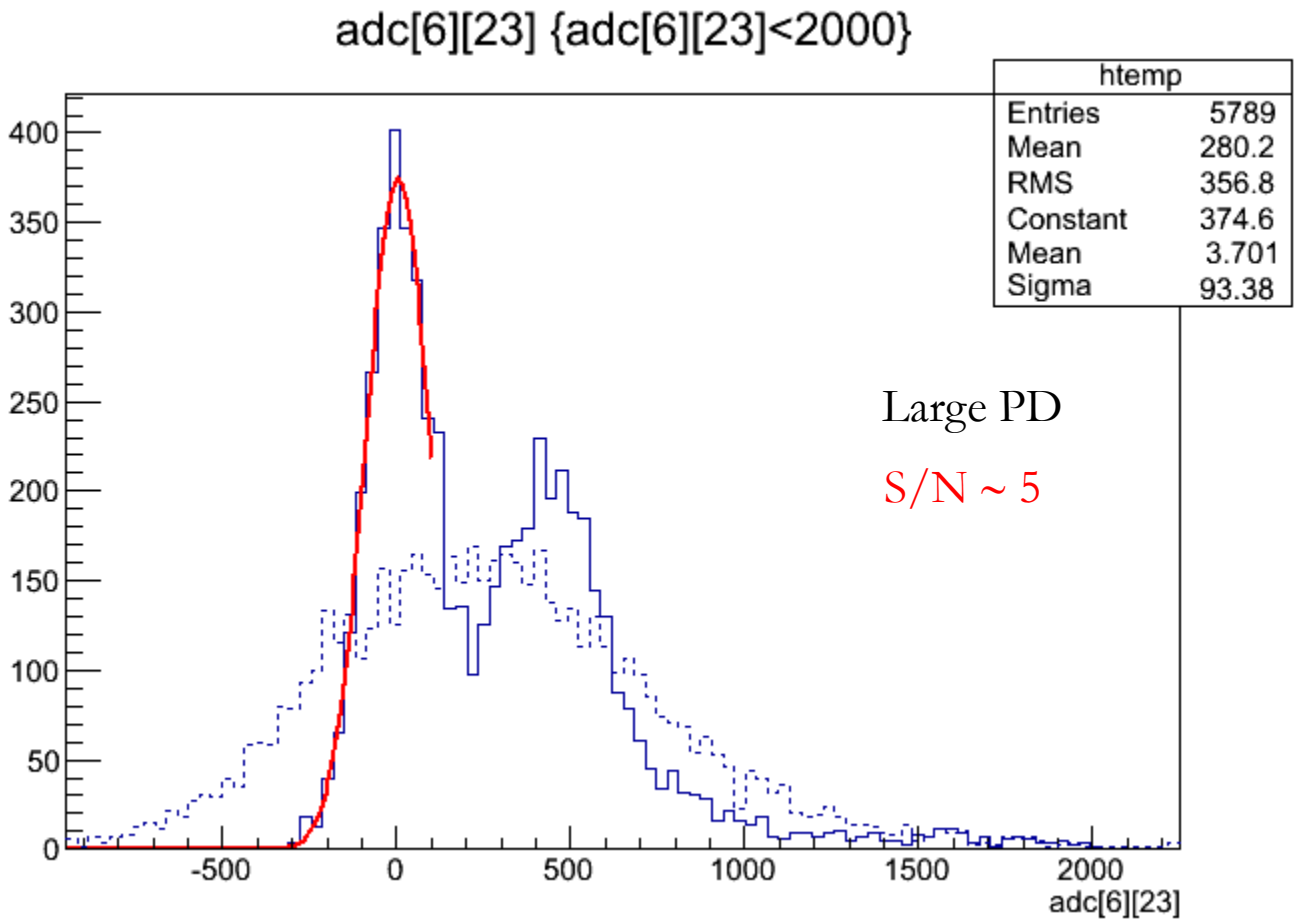
Muons 150 GeV



Muons 150 GeV

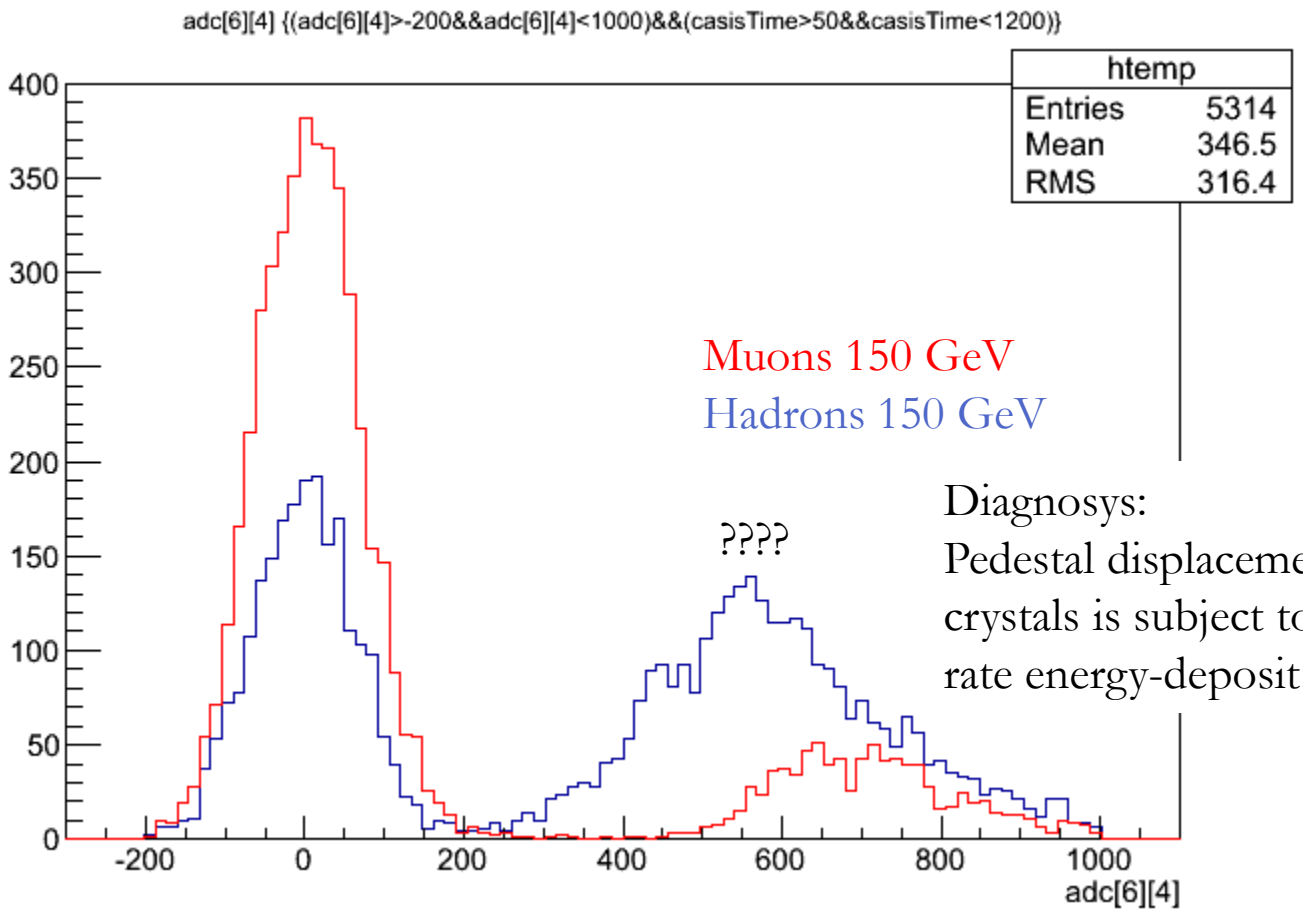


Muons 150 GeV



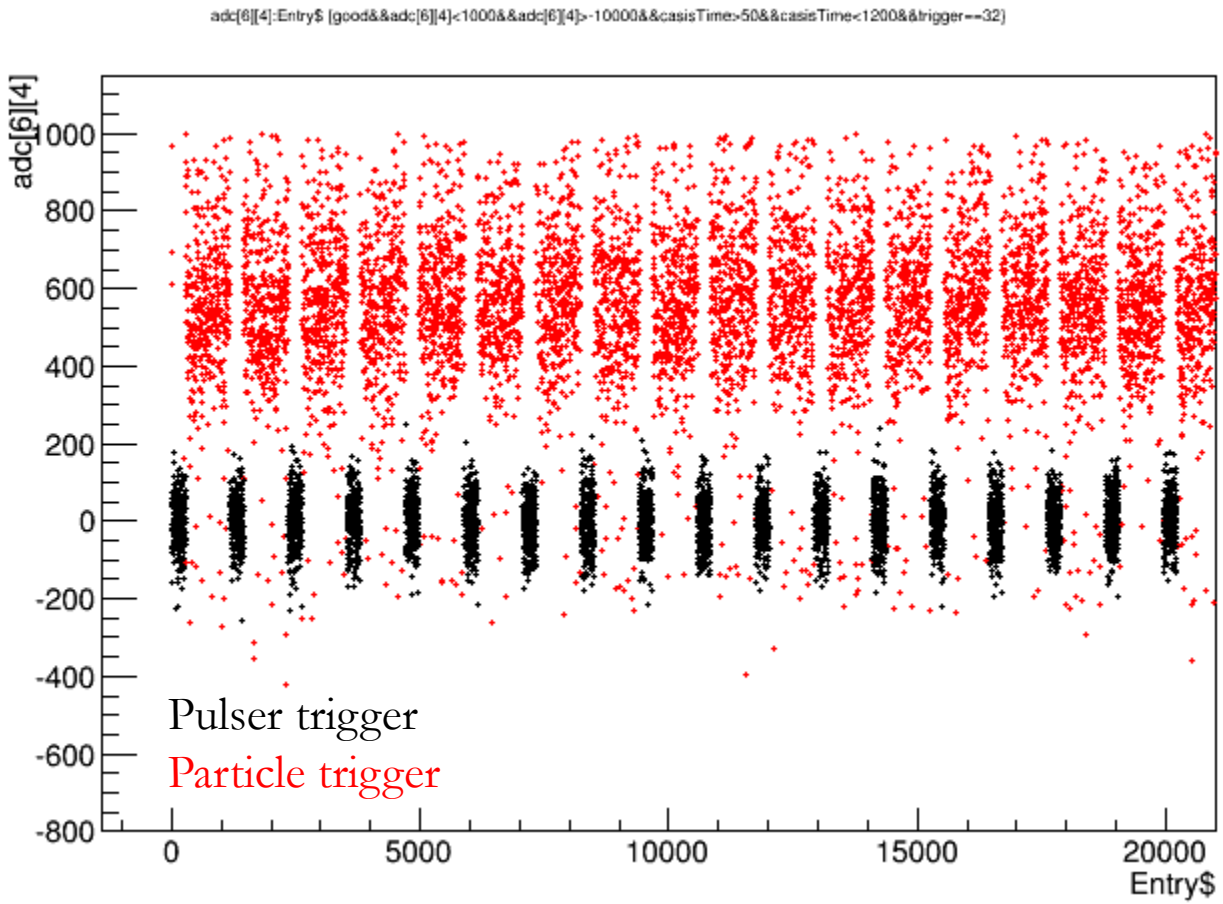
Muons 150 GeV

Ionization signal

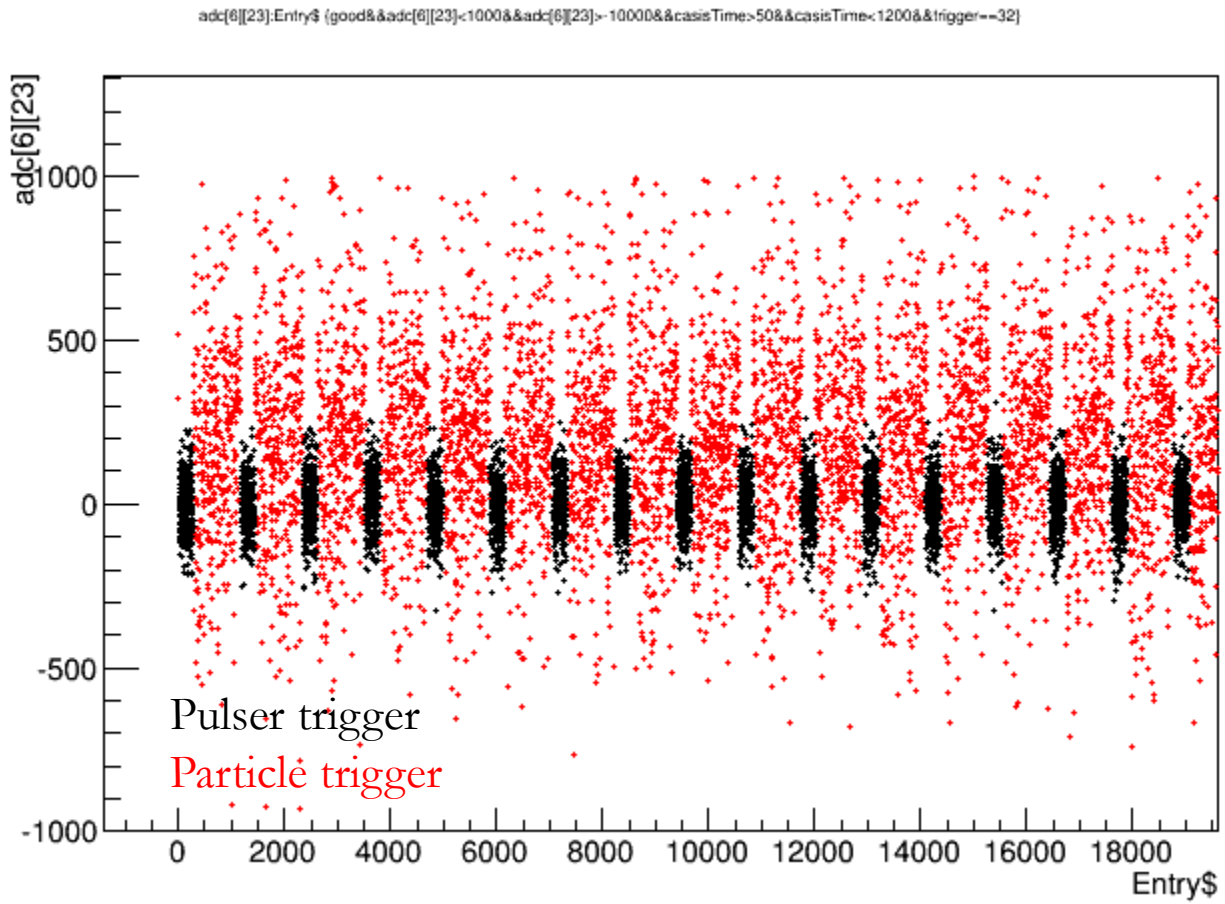


Diagnosys:
Pedestal displacement when the crystals is subject to large high-rate energy-deposit…

Central cube, layer 0



Central cube, layer 0



Central cube, layer 1

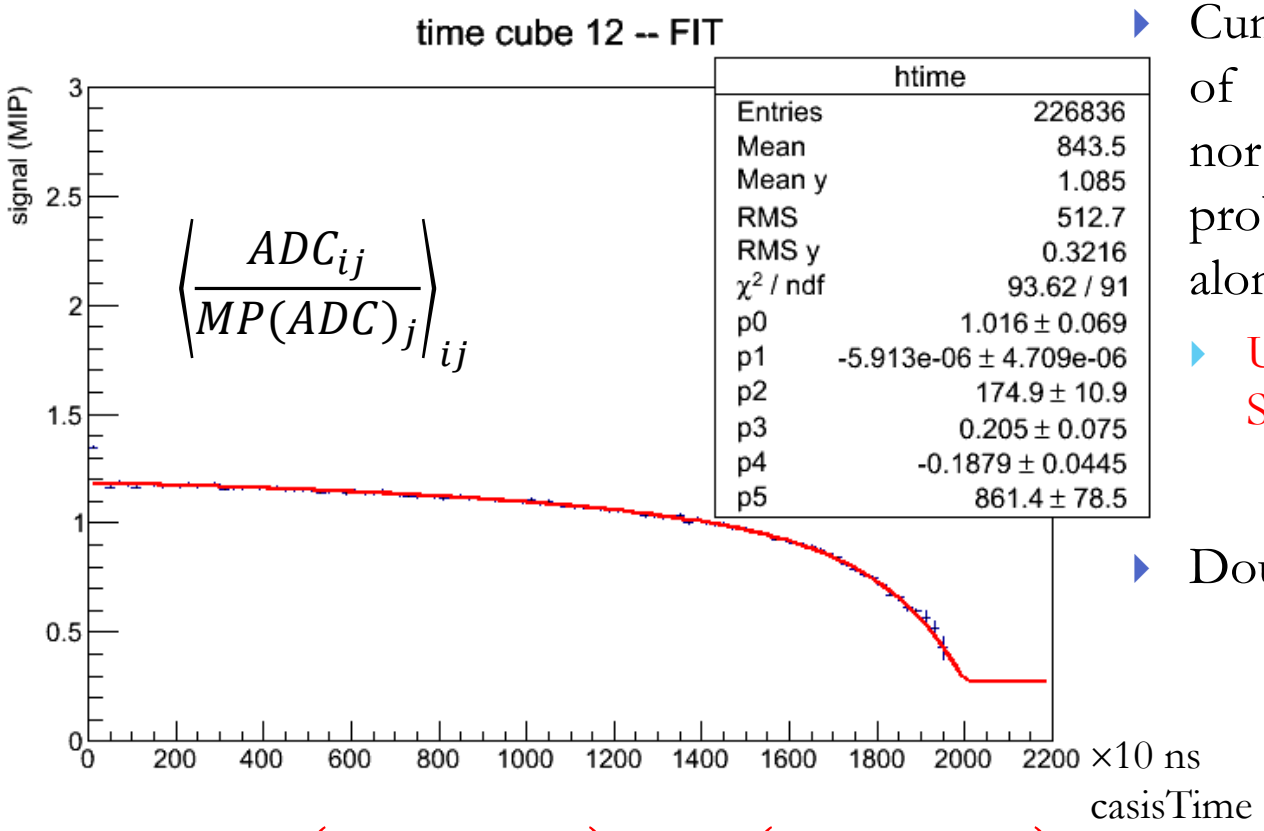
Channel equalization

- Muon beam, 150 GeV
  - Beam covering only some columns →

0	1	2	3	4
5	6	7	8	9
10	11	12	13	14
15	16	17	18	19
20	21	22	23	24

- Iterative procedure
  1. MIP-peak(0) gaussian fit of MIP signals
  2. time-corr(0) evaluate t.correction
  3. MIP-peak(1) apply t.correction + landau fit of MIP signals
  4. time-corr(1) evaluate t.correction →final
  5. MIP-peak(2) apply t.correction + landau fit →final

Time correction



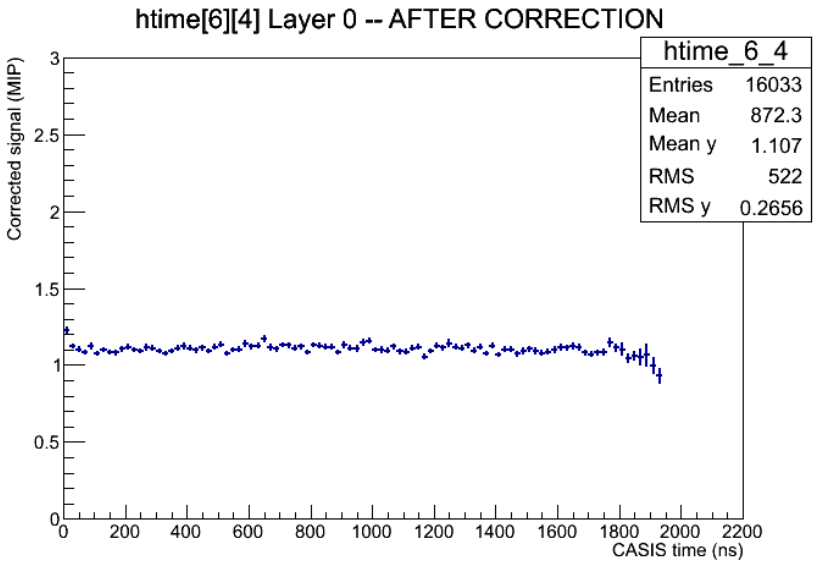
- Cumulative distribution of all signals (ADC), normalized to most probable value (MP), along the central column
  - Up to a time such that S/N>4
- Double-exponential fit

$$f(t) = P_0 \cdot \left(1 + P_1 \cdot e^{t/P_2}\right) + P_3 \cdot \left(1 + P_4 \cdot e^{t/P_5}\right)$$

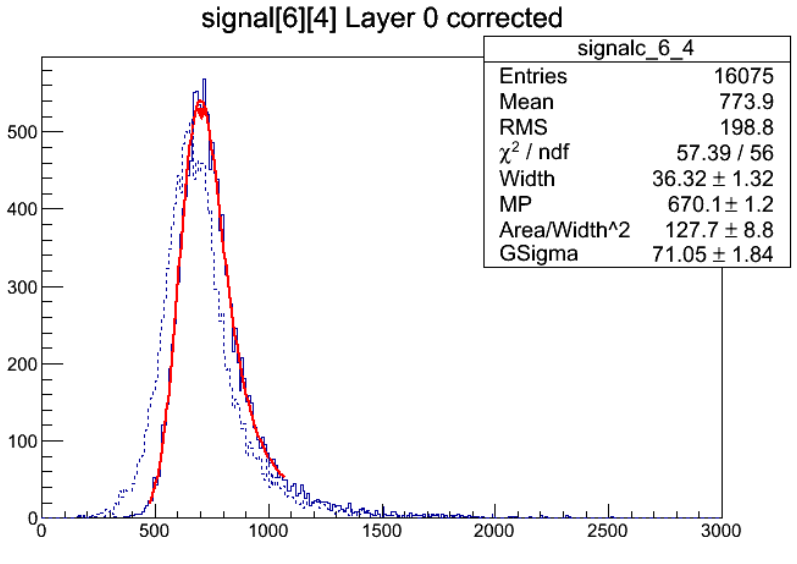
Time correction $\longrightarrow \frac{f(0)}{f(t)}$

Time correction

Central column, layer 0



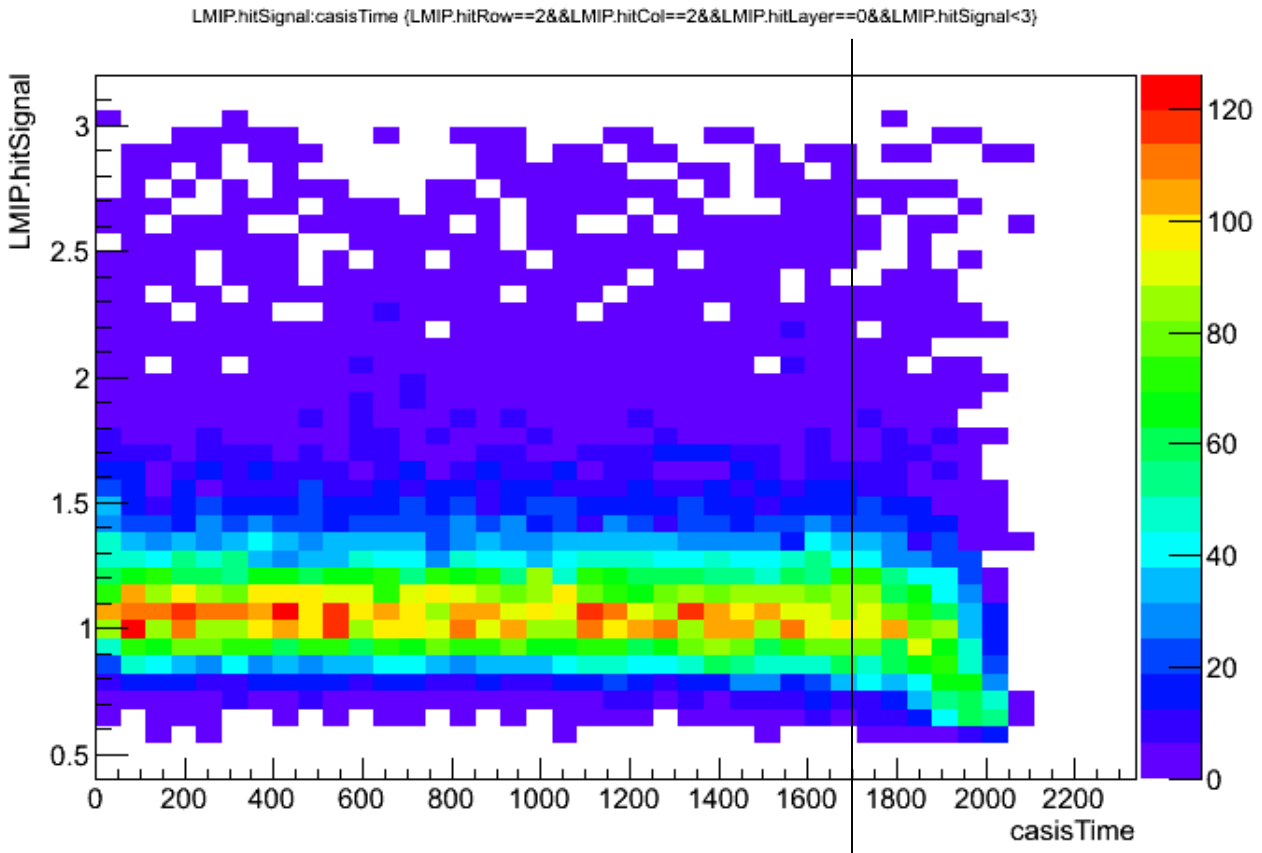
Check of time correction



- Landau⊗gauss fit after time correction
- GSigma ~consistent with channel noise
- Signals normalized to MP

Time correction

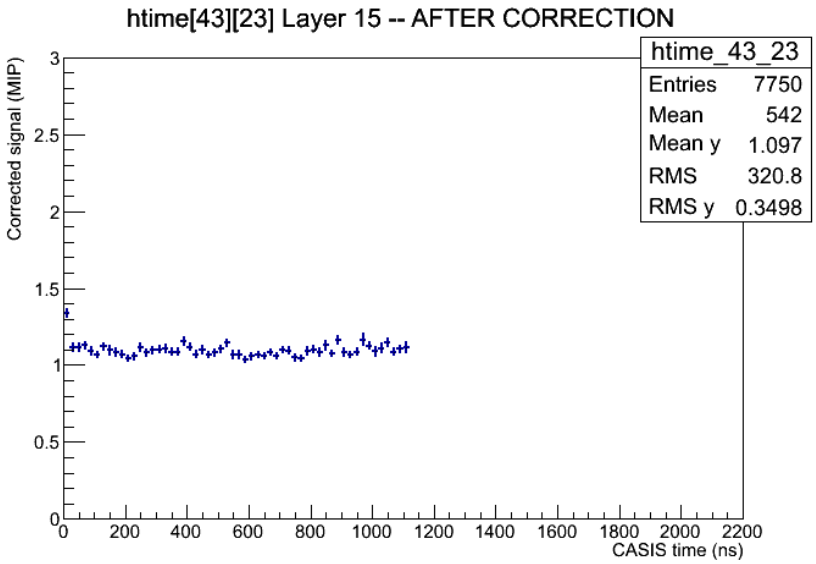
Central column, layer 0



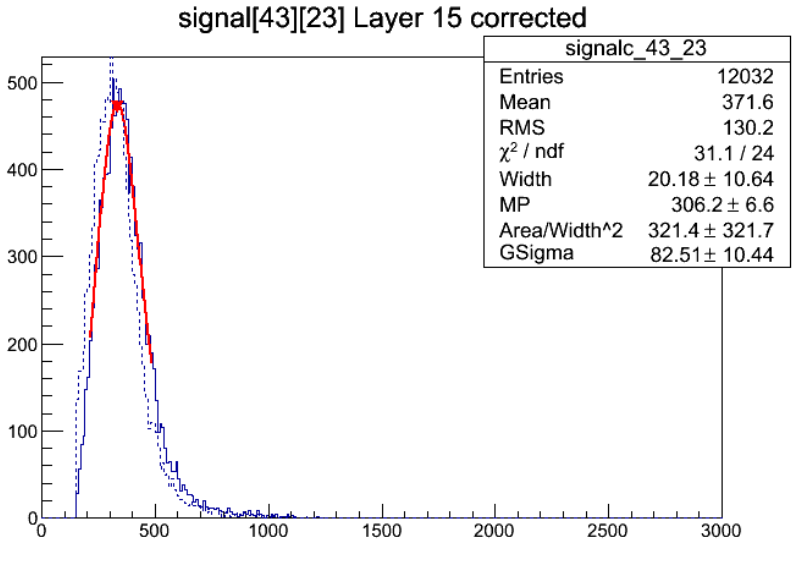
Time-correction not reliable above 17 µs due to low S/N ratio

Time correction

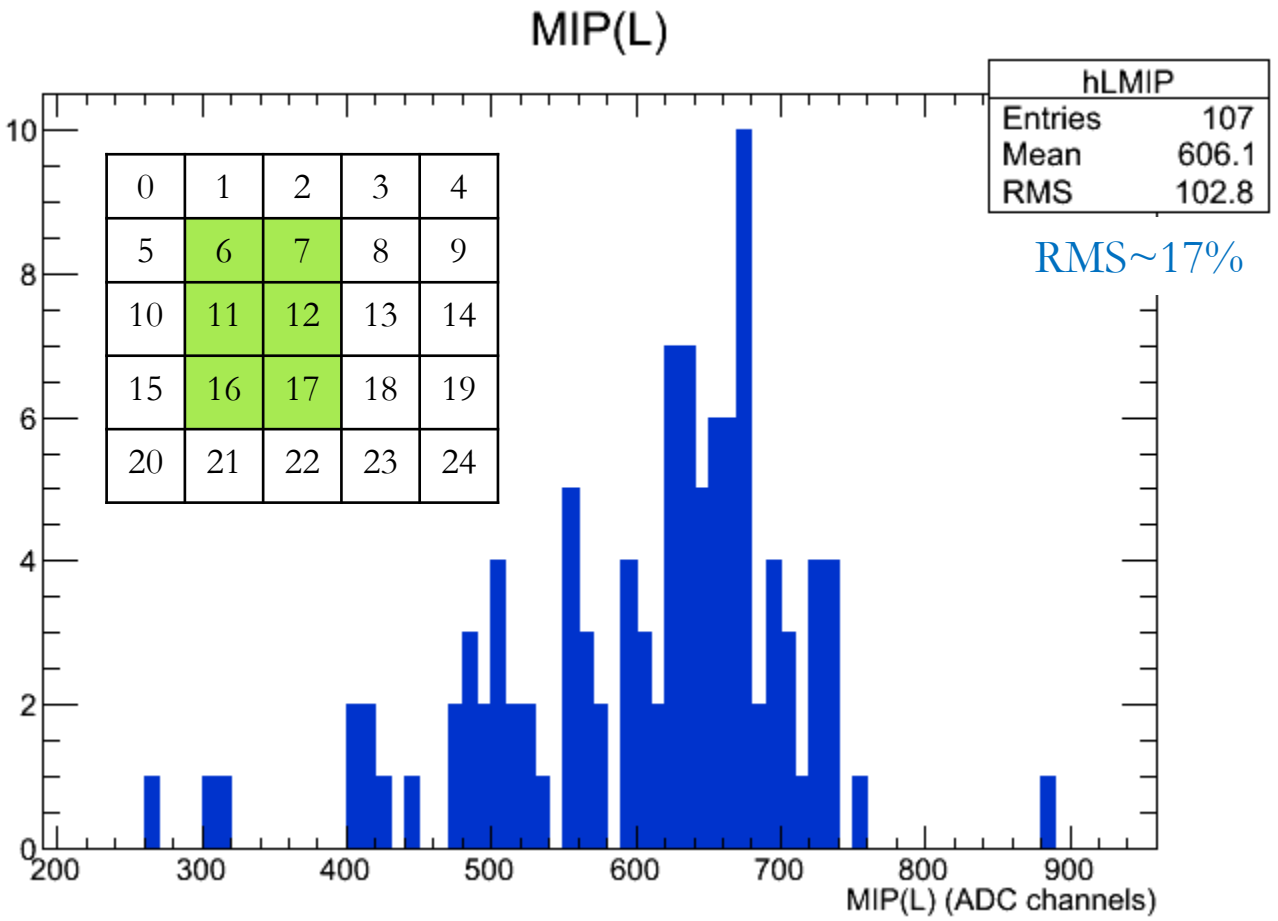
Central column, layer 15 (low S/N !!)



Check of time correction

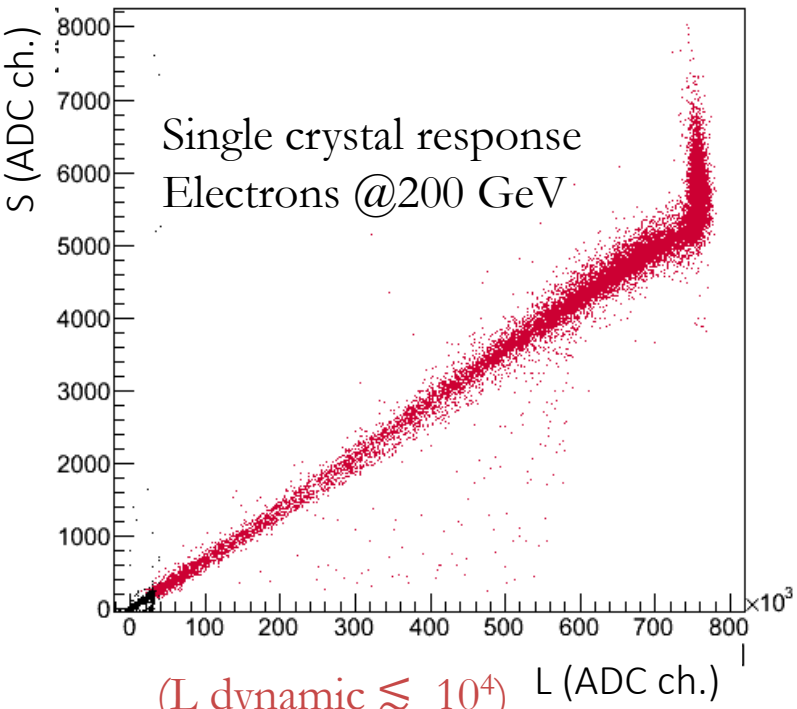


- Landau⊗gauss fit after time correction
- GSigma ~consistent with channel noise
- Signals normalized to MP


MIP(L)
hLMIP
Entries 107
Mean 606.1
RMS 102.8
RMS~17%
0 1 2 3 4
5 6 7 8 9
10 11 12 13 14
15 16 17 18 19
20 21 22 23 24
0
2
4
6
8
10
200
300
400
500
600
700
800
900
MIP(L) (ADC channels)

Single-crystal calibration

- Signal induced by MIPs used to equalize crystal responses
  - v2.0 setup: noise~60÷80 ADCch. $\Rightarrow \langle S/N \rangle_{1MIP} \lesssim 10$
- Signal induced by showers used to equalize relative sensor responses R=L/S



(L dynamic $\lesssim 10^4$)

SPD
LPD

Study of S-vs-L correlation

- Straight-line fit → $S = L/P_0$
- Indipendent fit for low- and high-gain
  - Check systematics
- Cumulative electron sample to cover the full dynamic range
  - 50 +100 + 150 + 200 GeV

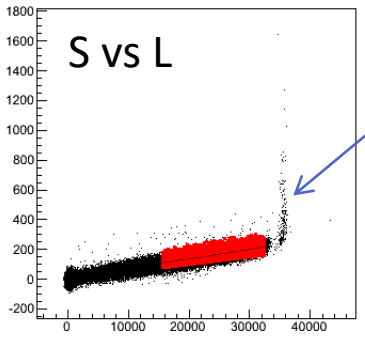
L/S gain ratio

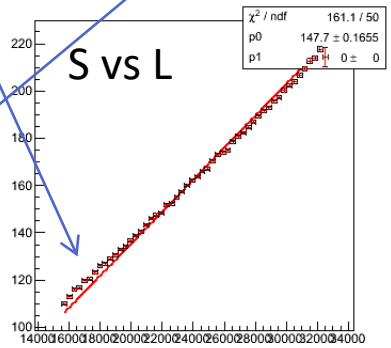
0	1	2	3	4
5	6	7	8	9
10	11	12	13	14
15	16	17	18	19
20	21	22	23	24

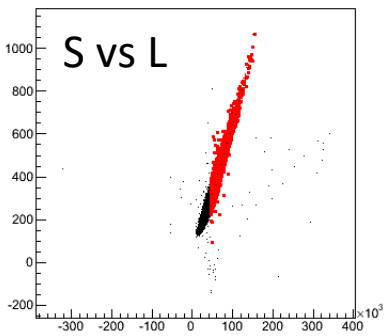
Column 12, layer 0

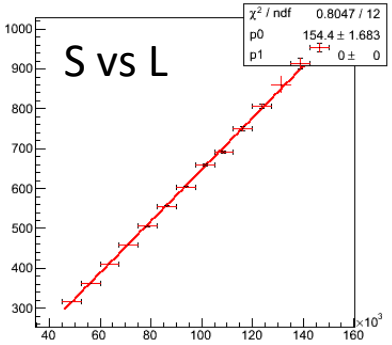
High-gain saturation

Pedestal displacement??



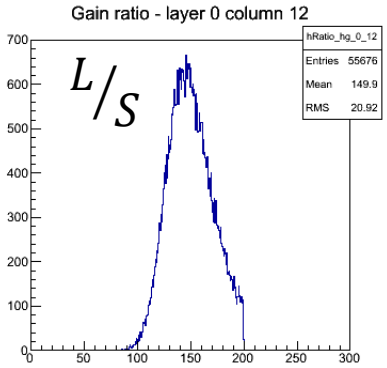






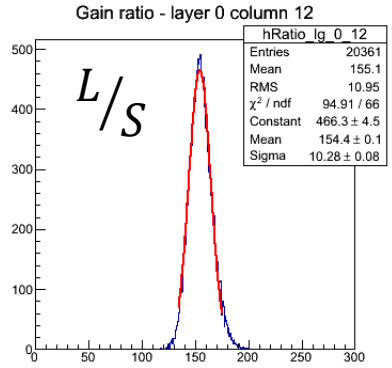
S vs L (high-gain)

- All hits
- Fit range



S vs L (low-gain)

- L=20·ADC-2000
- All hits
- Fit range

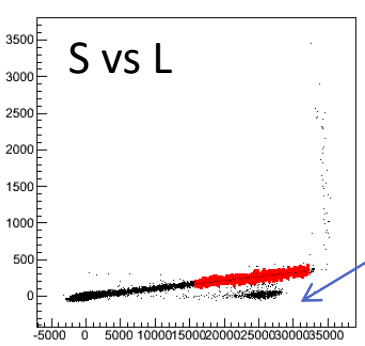


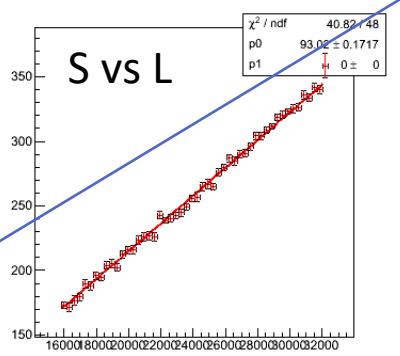
L/S gain ratio

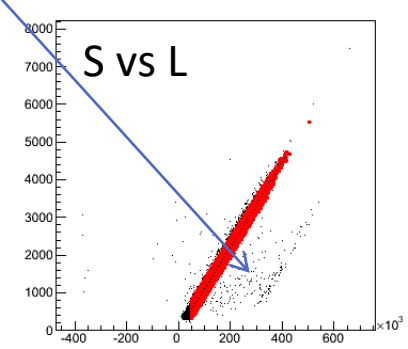
0	1	2	3	4
5	6	7	8	9
10	11	12	13	14
15	16	17	18	19
20	21	22	23	24

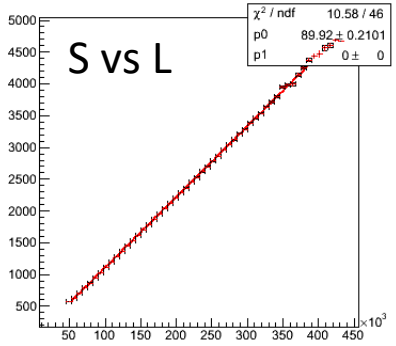
Column 12, layer 2

Direct ionization of PDs!!

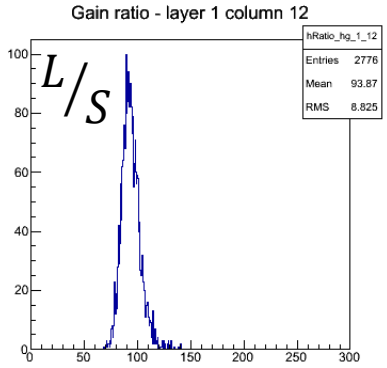




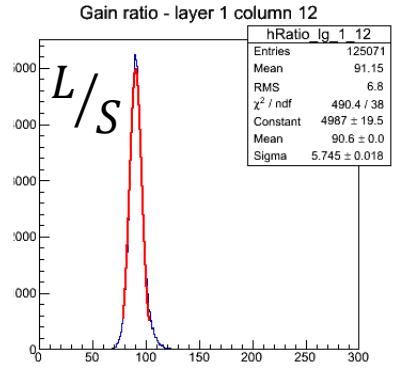




S vs L (high-gain)
- All hits
- Fit range



S vs L (low-gain)
- L=20·ADC-2000
- All hits
- Fit range



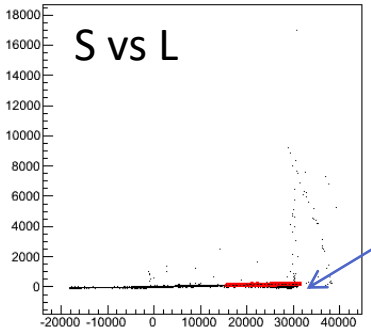
L/S gain ratio

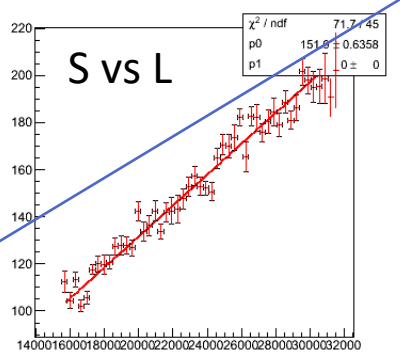
0	1	2	3	4
5	6	7	8	9
10	11	12	13	14
15	16	17	18	19
20	21	22	23	24

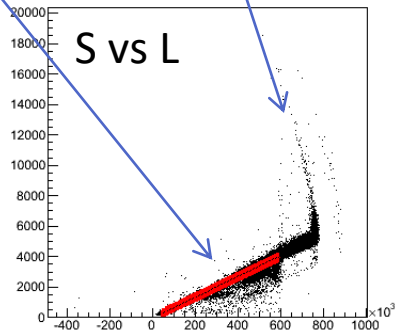
Column 12, layer 3 (~shower maximum)

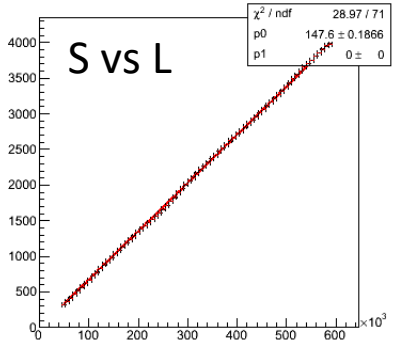
Low-gain saturation

Direct ionization of PDs!!

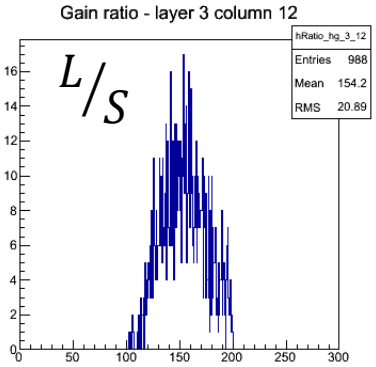




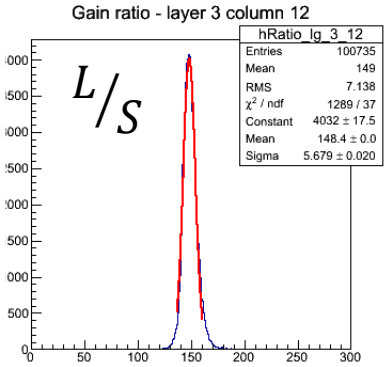




S vs L (high-gain)
- All hits
- Fit range



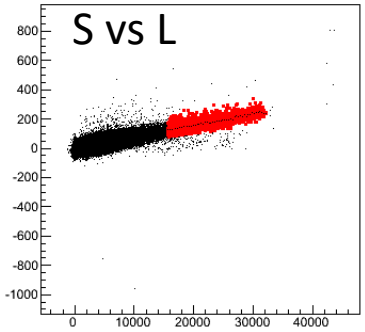
S vs L (low-gain)
- L=20·ADC-2000
- All hits
- Fit range

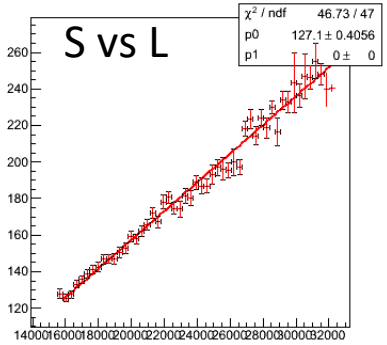


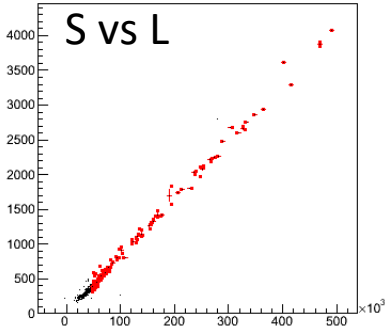
L/S gain ratio

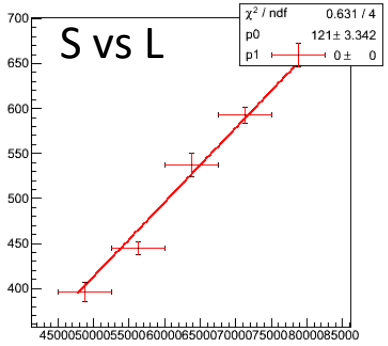
0	1	2	3	4
5	6	7	8	9
10	11	12	13	14
15	16	17	18	19
20	21	22	23	24

Column 6, layer 3 (~shower maximum)

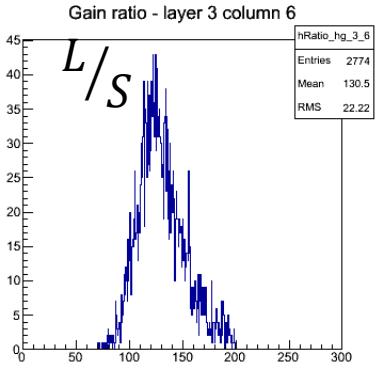




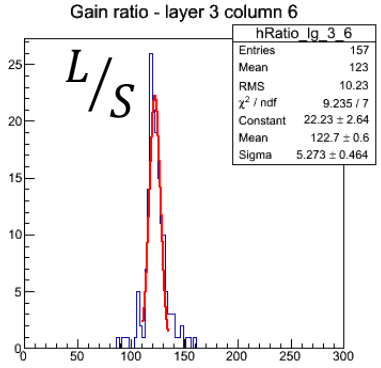




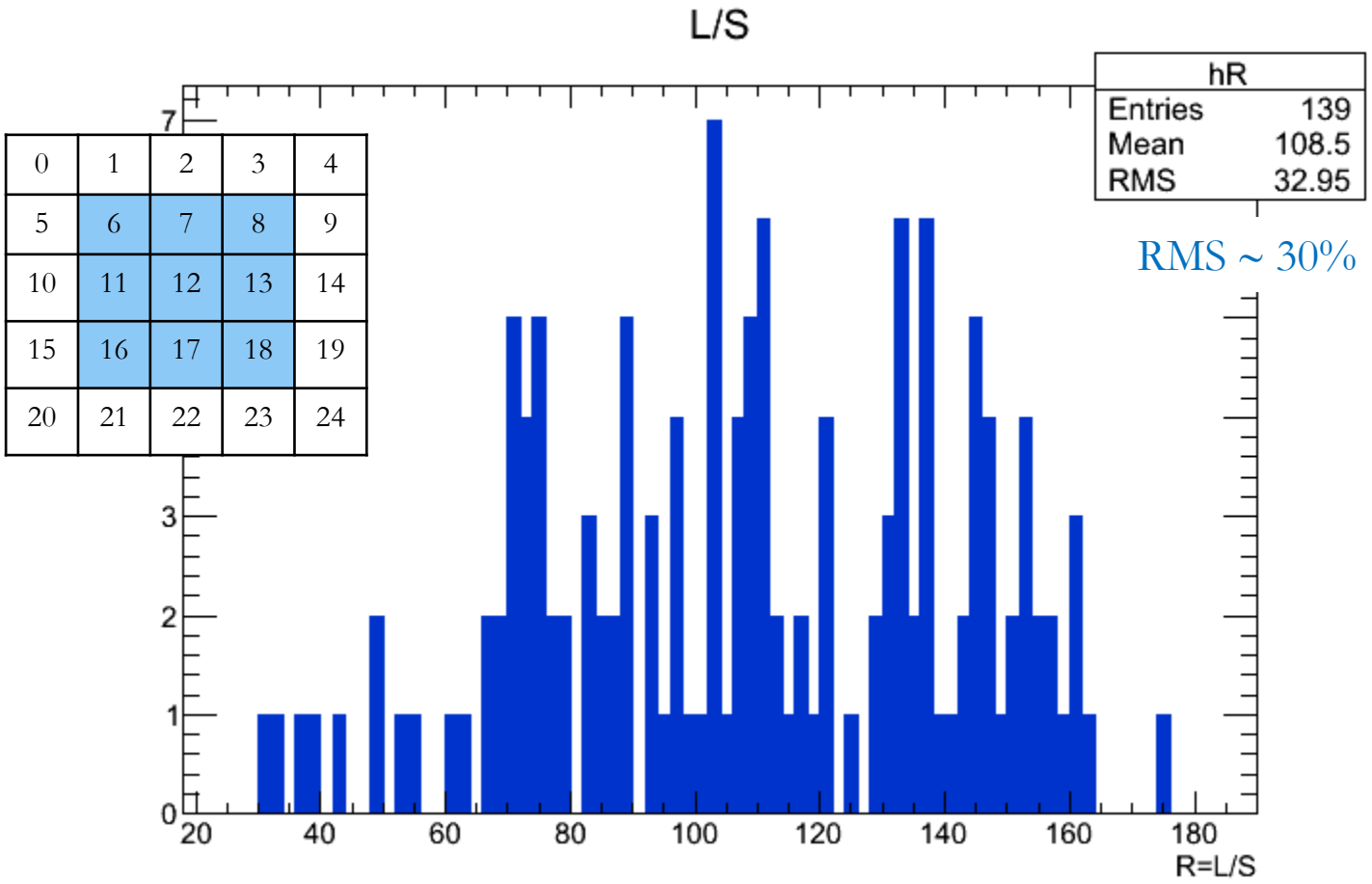
S vs L (high-gain)
- All hits
- Fit range



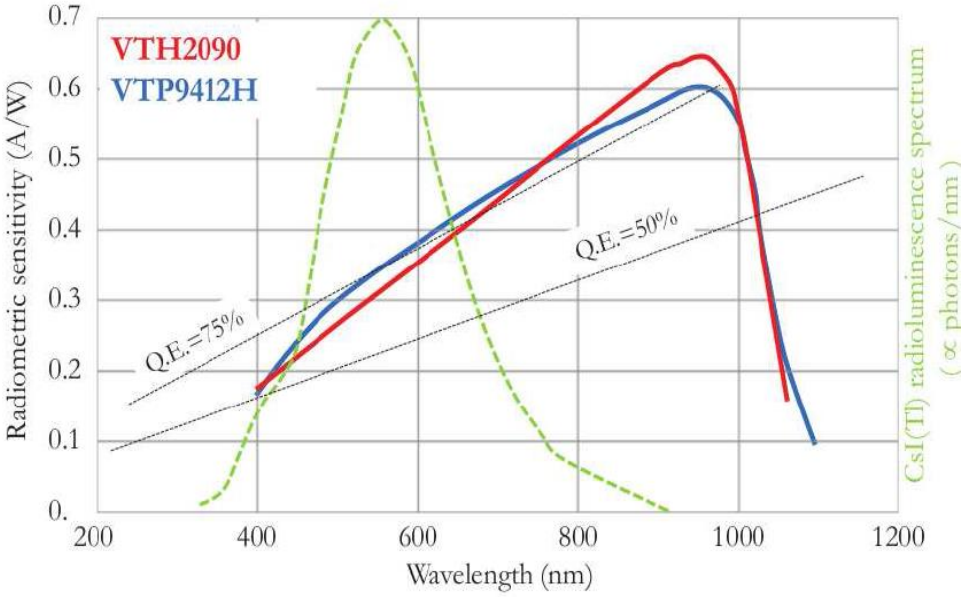
S vs L (low-gain)
- L=20·ADC-2000
- All hits
- Fit range



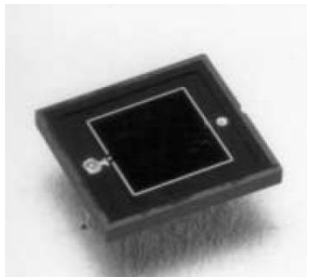
Final calibration parameters

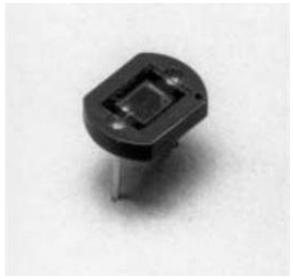


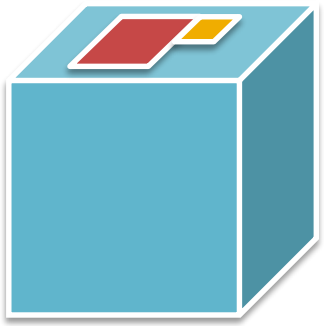
Two-sensor readout



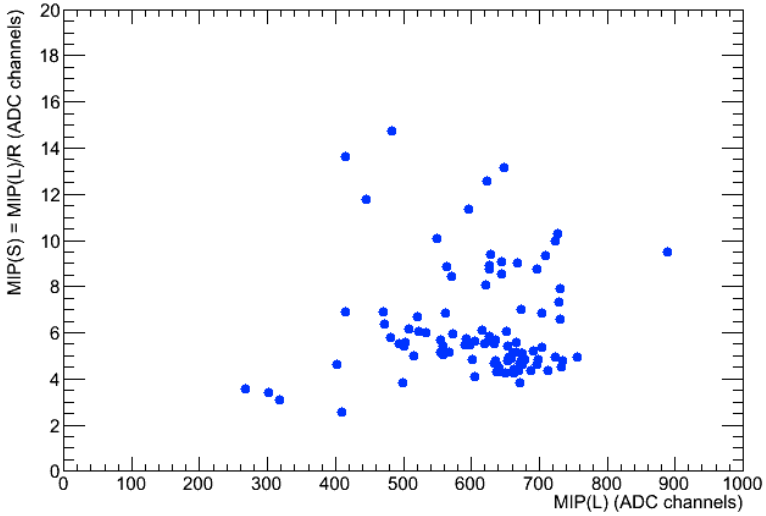
- Relative gain studied with signal induced by atmospheric muons
- Setup:
  - Single cube coupled to both PDs
  - Readout by low-noise CSA and DPA modules (Amptek)
- Measured ratio ~ 55 (expected ~ 49)

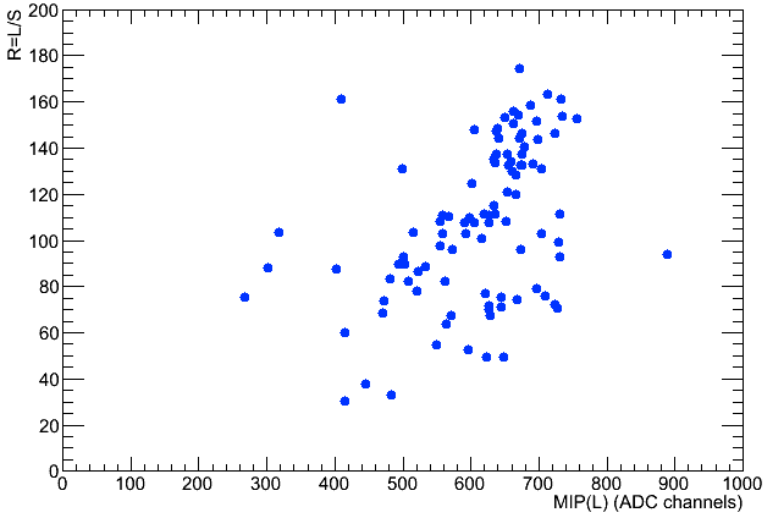






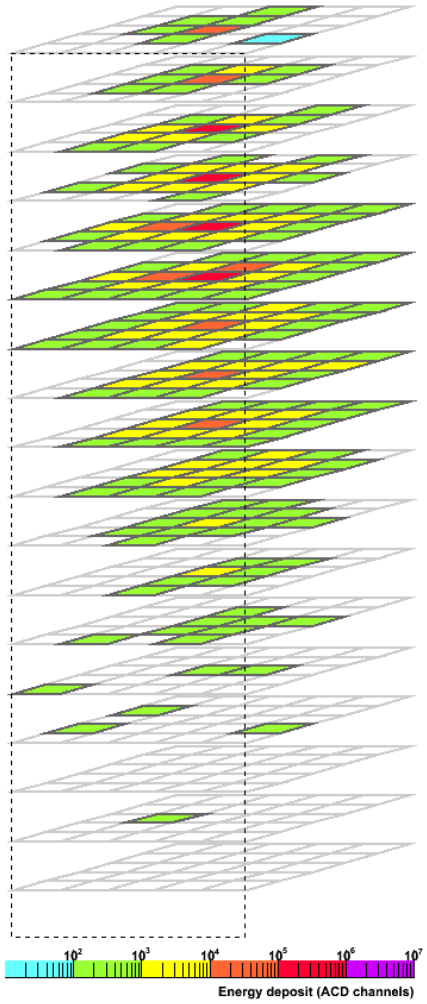
	VTH2090	VTP9412H
Active area (mm^2)	84.6	1.6
Sp.response range/peak (nm)	400÷1100 / 960	400÷1150 / 925
C_J(pF)	70 @30V	6 @15V

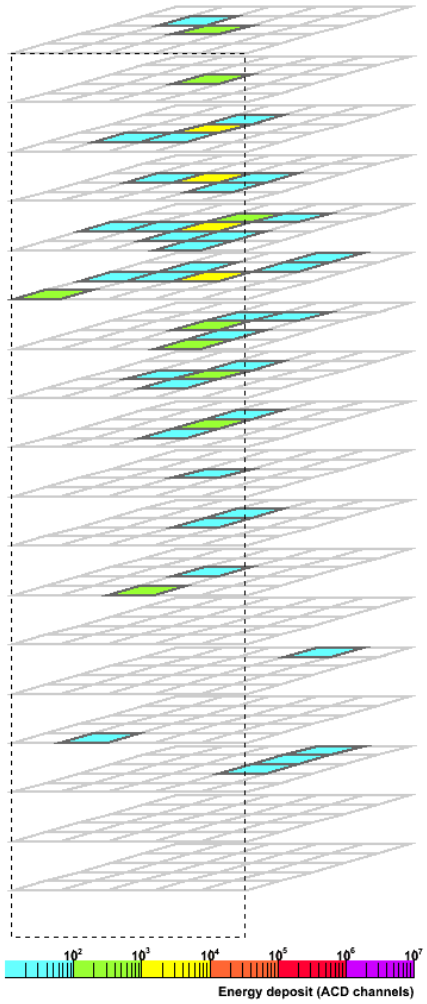

MIP(S) = MIP(L)/R (ADC channels)
MIP(L) (ADC channels)
0
2
4
6
8
10
12
14
16
18
20
0
100
200
300
400
500
600
700
800
900
1000


R=L/S
MIP(L) (ADC channels)
0
20
40
60
80
100
120
140
160
180
200
0
100
200
300
400
500
600
700
800
900
1000

e^- 50 GeV

Large PDs

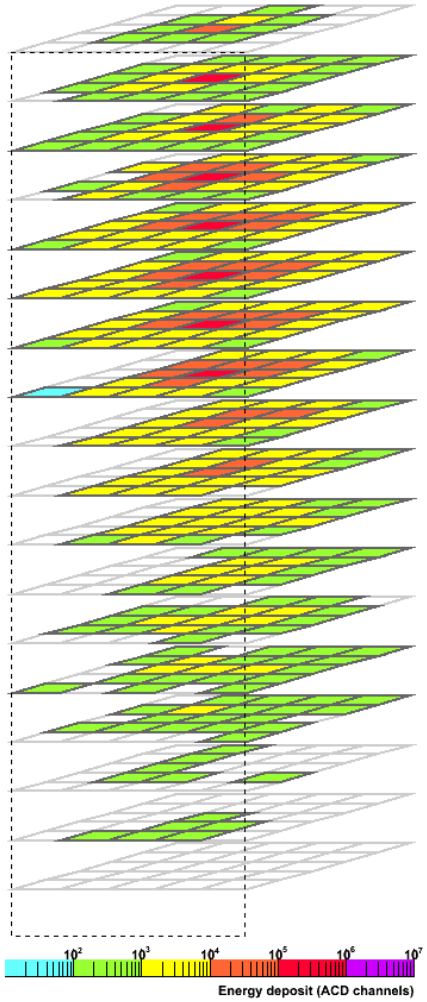


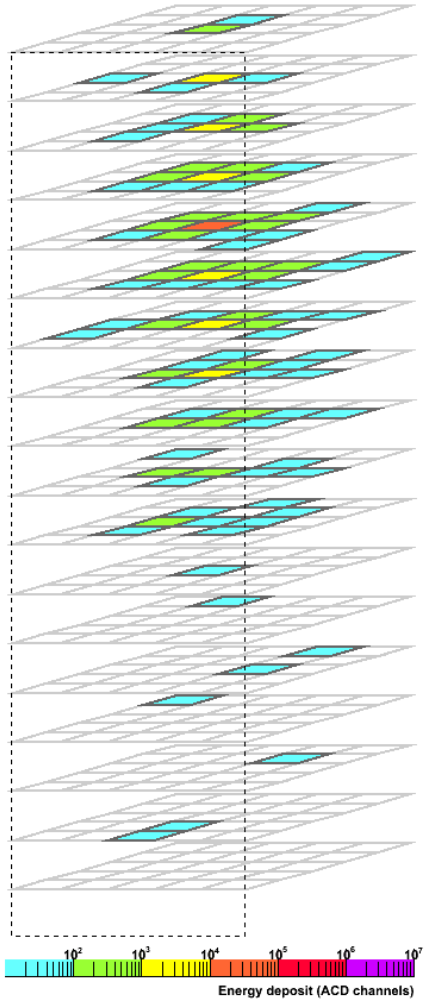


Small PDs

e^- 200 GeV

Large PDs

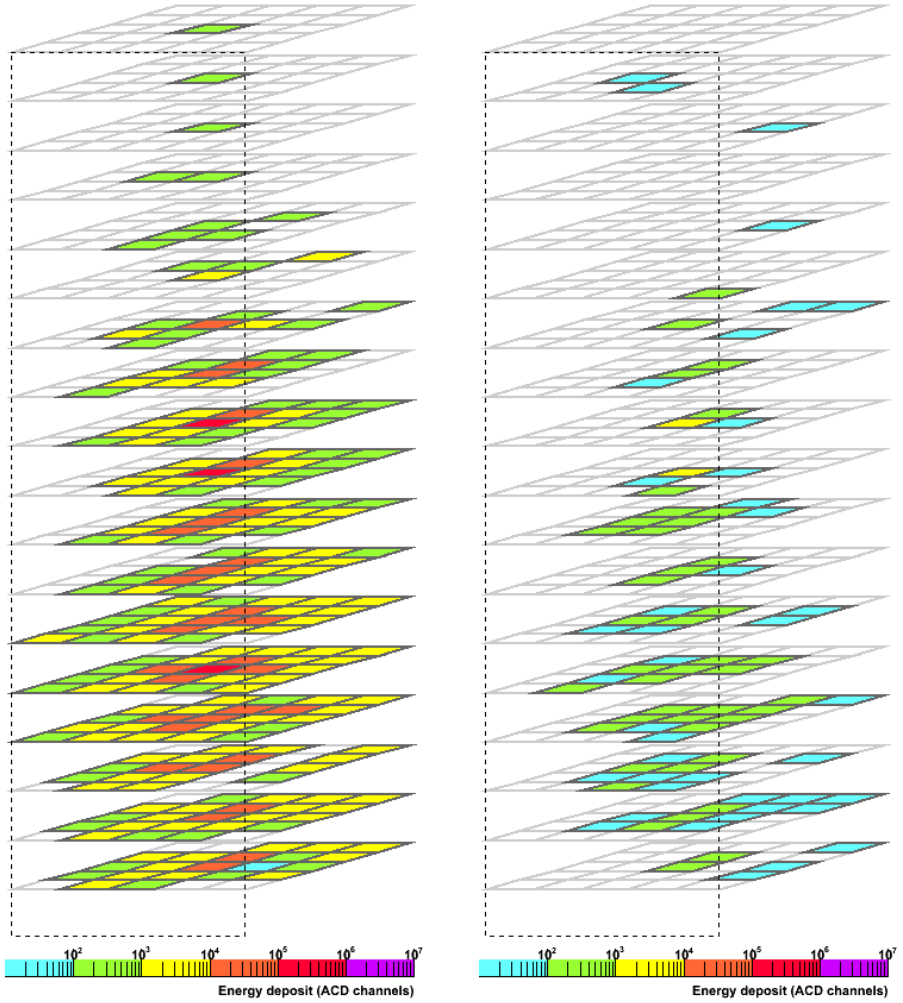




Small PDs

π^- 150 GeV

Large PDs



Small PDs