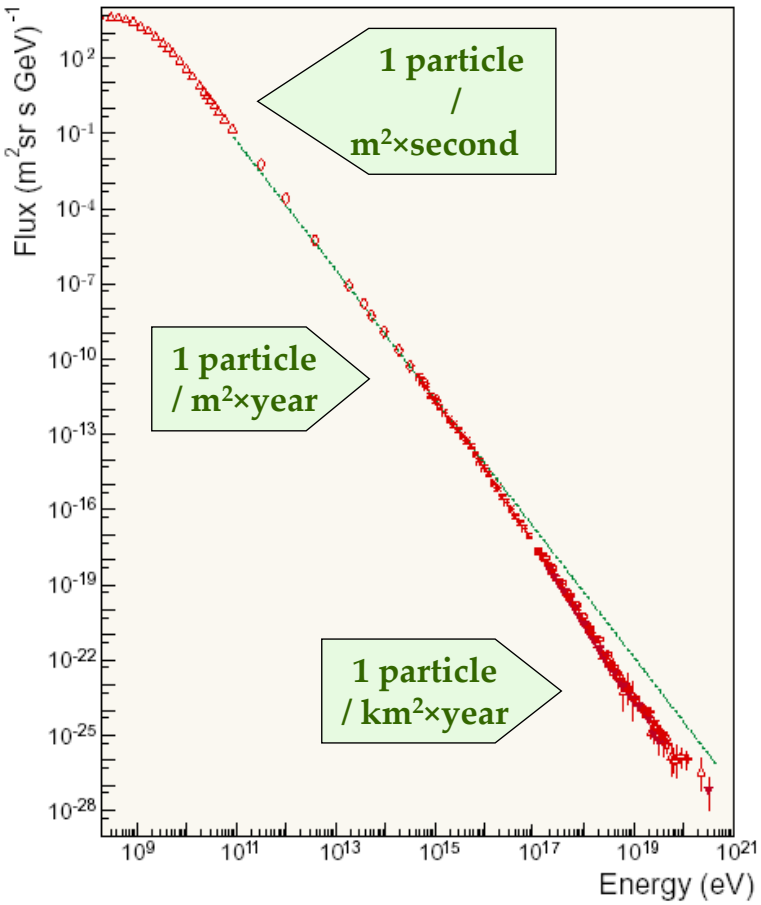
Calocube

Energy resolution and high dynamic range. System requirements and optimization

COSMIC-RAY SPECTRUM: SOME OPEN QUESTIONS



Scientific goal is the measurement of the energy spectrum of the nuclear component of cosmic rays in the region of the knee.

High energy nuclei

- **"Knee" structure around ~ PeV**
  - Upper energy of galactic accelerators (?)
  - Energy-dependent composition
- **Spectral measurements in the knee region up to now are only indirect**
  - Ground-based atmospheric shower detectors
  - High uncertainties

A direct spectral measurement in the PeV region with good energy resolution, at least ~40% for hadrons and ~ 2% for electons

DYNAMIC RANGE

Optical Signal

- Single crystal signal is up to 10% of a particle's energy that is 100 TeV.
- CsI(Tl) :

1MIP/cm = 1.25MeV/(g/cm^2) · 4.5g/cm^3 = 5.62 MeV/cm

- For 3.6 cm size 1 MIP≈20MeV (normal collisions)
- Dynamic range from 1 to 1·10^6 MIP
- CsI(Tl) light yield is 54 photons/keV
- 1 MIP ≈1080000 photons
- Dynamic range **1 ·10^6 – 1 ·10^{12}** photons.

Excelitas VTH2090 and VTP3310

Electrical signal

- Large PD

Size 9.2 x 9.2 mm^2 ➡ GF= 0.065
Q_{pd} = 0.6 , Q_{sc}=0.9

1MIP ≈ 10^6 ph · Q · GF ≈ 43 · 10^3 e$^-$ = 6.6 fC

Dynamic range
0.5-5·10^6 MIP = **3fC - 33 nC**

- Small PD

GF ~ 100 times lower
Max. signal – 330 pC

- Dynamic range with 2 PD

330pC/3fC ≈ 10^5
CASIS DR
50pC/0.1fC ≈ 5 - 10^5

Parameter	Area	Sens. range	Sens. peak	Q @ peak	Capacitance	Leakage
VTH2090	84,64 mm^2	400-1100 nm	960 nm	0.6 A/W	70 pF	10 nA max
VTP3320	0.684 mm^2	400-1150 nm	925 nm	0.55 A/W	25 pF	35 nA max

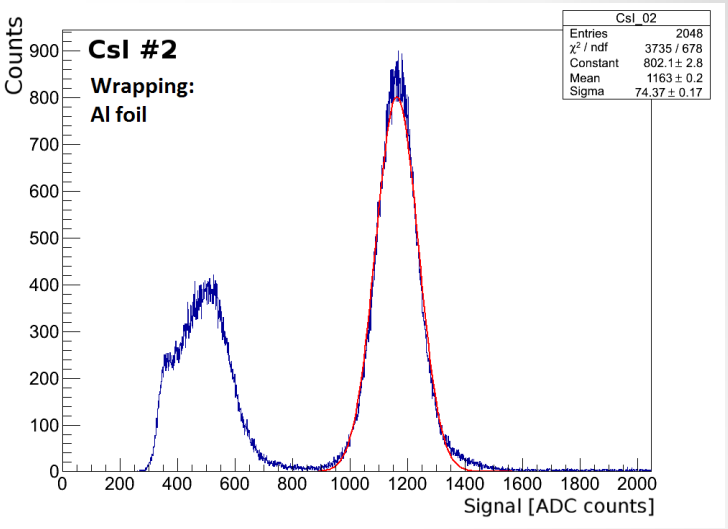
Requirements

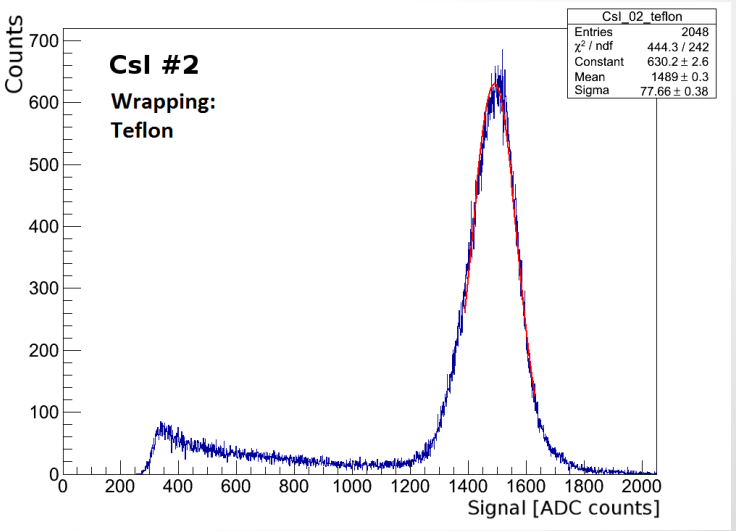
Requirements confrontation

Energy resolution → Light collection → Dynamic range

Energy resolution and light collection efficiency

- Light collection efficiency
- Simulations were performed for CsI(Tl) cube with 36 mm side. No wrapping, teflon and aluminized mylar with different surface roughness were studied. GEANT4 software was used. 100 GeV electrons and MIP were simulated.
- Measurement. Two CsI(Tl) cubes 25 mm side. 150 μm Teflon and 70 μm Al foil wrapping. VTH2090 PD and ^{241}Am α source.





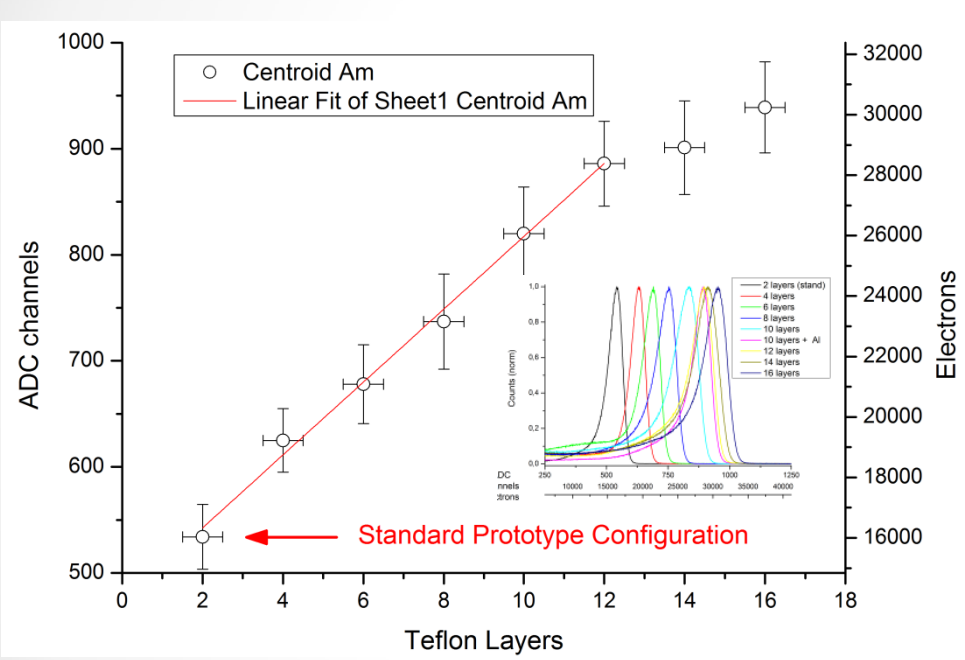
No wrapping Polished	Teflon Roughness 0.3	Al mylar Roughness 0.3
6.2%	14.3%	14.3%

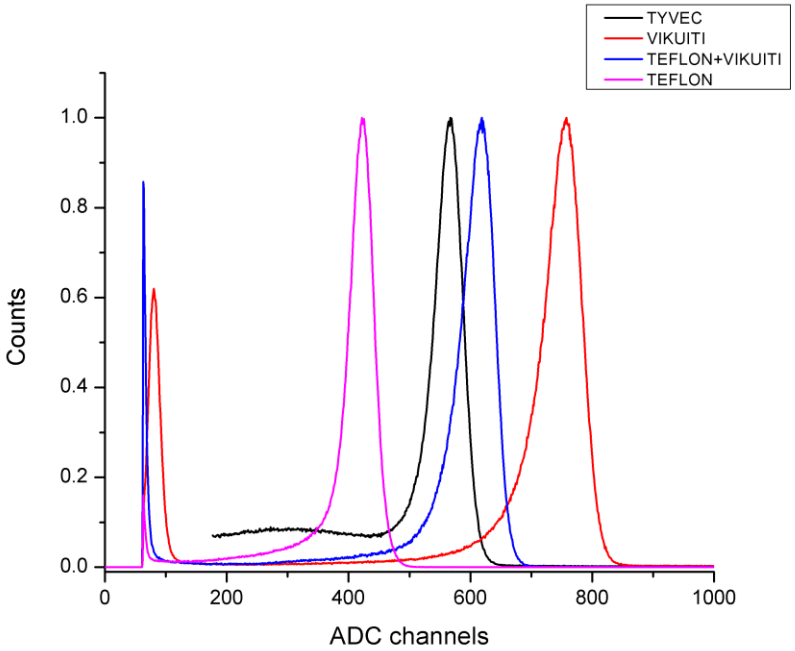
Crystal #	Wrapping	Peak[e^-]	Resolution[%]
2	Al	$1.96 \cdot 10^4$	19.0
	Teflon	$2.65 \cdot 10^4$	15.5
3	Al	$2.18 \cdot 10^4$	20.8
	Teflon	$2.93 \cdot 10^4$	12.5

Energy resolution and light collection efficiency

1. Light collection efficiency

Light collection was studied with different teflon width and Vikuiti wrapping. CsI(Tl) cubes 36 mm side. Teflon wrapping 50 μm/layer. VTH2090 PD and ^{241}Am α source.





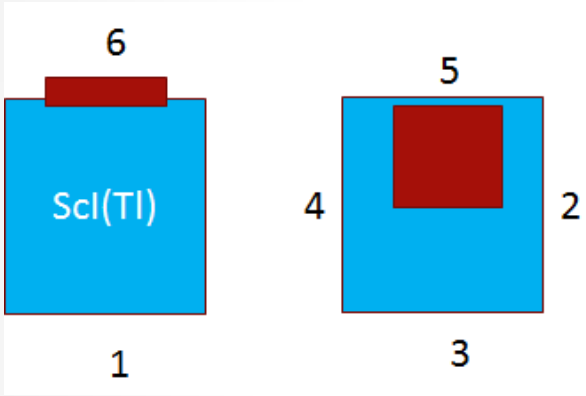
Layers	2	4	6	8	10	12	14	16
Peak	534	625	678	737	820	886	901	939

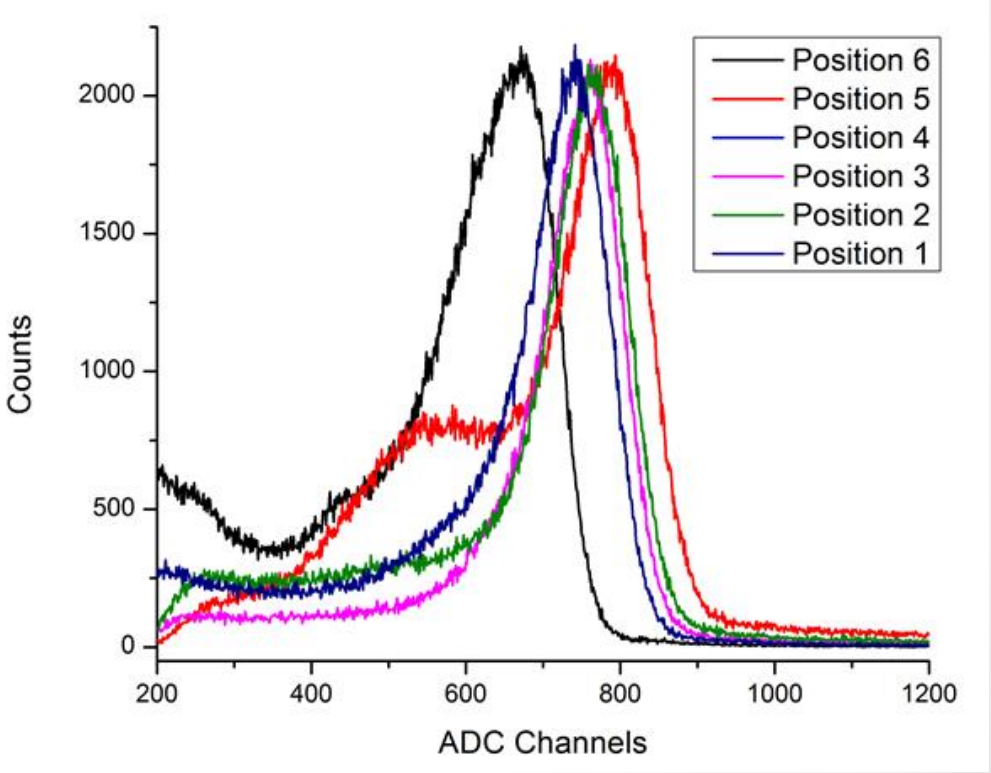
~80% signal increase with one Vikuiti layer

75% signal increase with 16 teflon layers (800 μm)

1. Light collection efficiency

Light collection was studied for different faces of the crystal. CsI(Tl) cubes 36 mm side. Teflon wrapping 800 μm. VTH2090 PD and ^{241}Am α source.



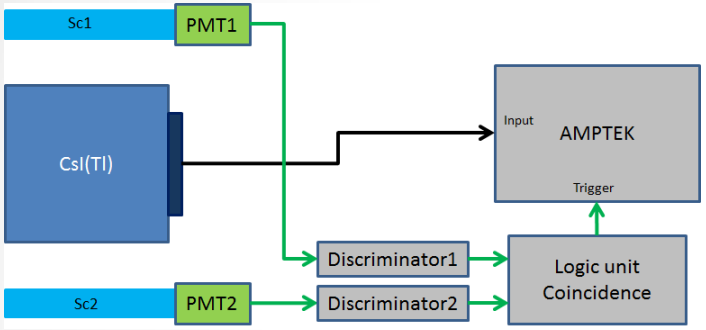


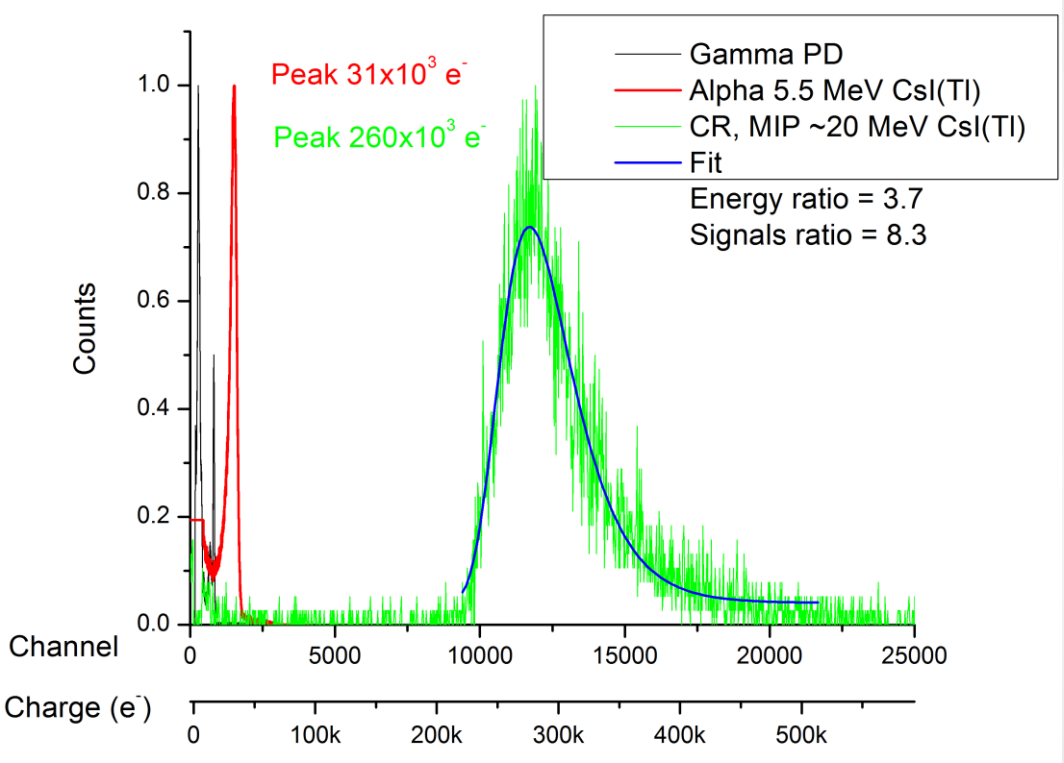
Face 6 - 650 ADC channels
Others – around 780 ADC channels

Energy resolution and light collection efficiency

1. Light collection efficiency

CsI(Tl) calibration with cosmic rays. CsI(Tl) cubes 36 mm side. Teflon wrapping ~150 μm. VTH2090 PD.





Signals ratio ≠ energy ratio
Resolution CR – 10.2%
5.5 MeV α particles – 5.2%

- different mechanism of scintillations
- geometry of the measurement

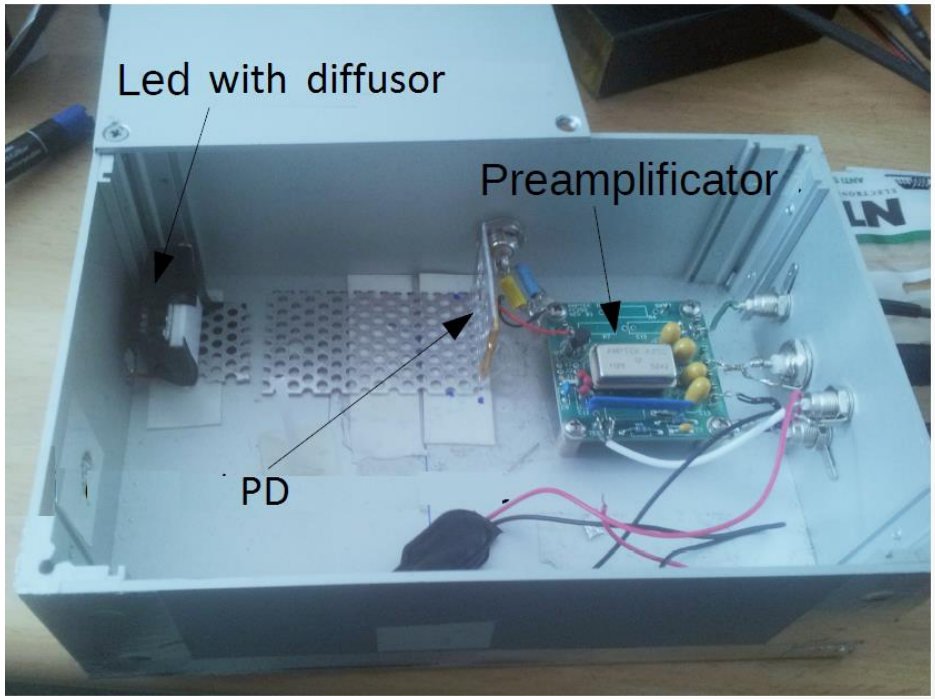
Dynamic range.

2 PDs with signal ratio at least 100

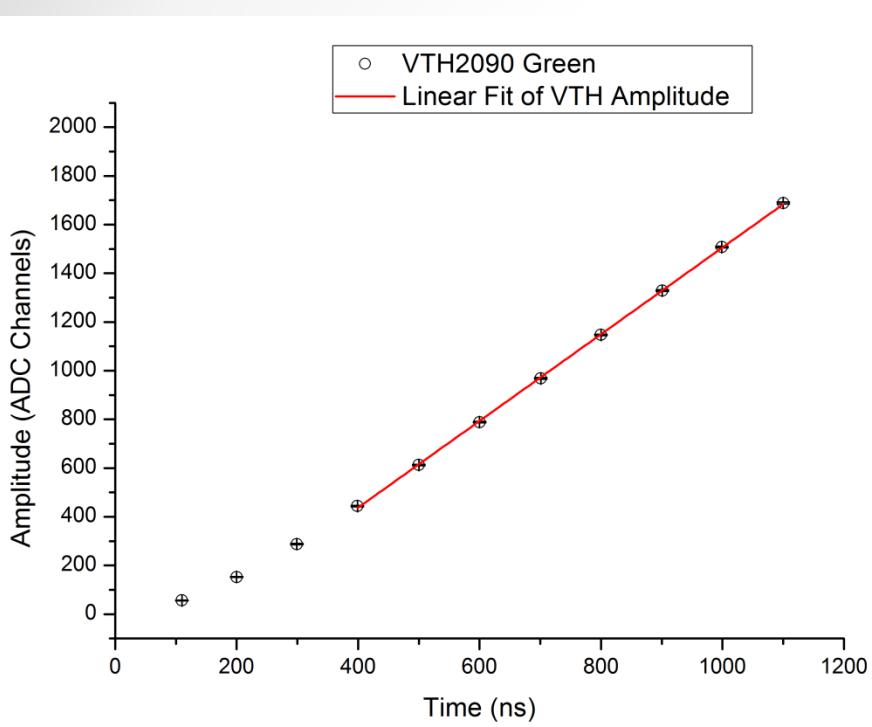
PD	Area	Sens. range	Sens. peak	Q @ peak
VTH2090	84,64 mm^2	400-1100 nm	960 nm	0.6 A/W
VTP3310	0.684 mm^2	400-1150 nm	925 nm	0.55 A/W

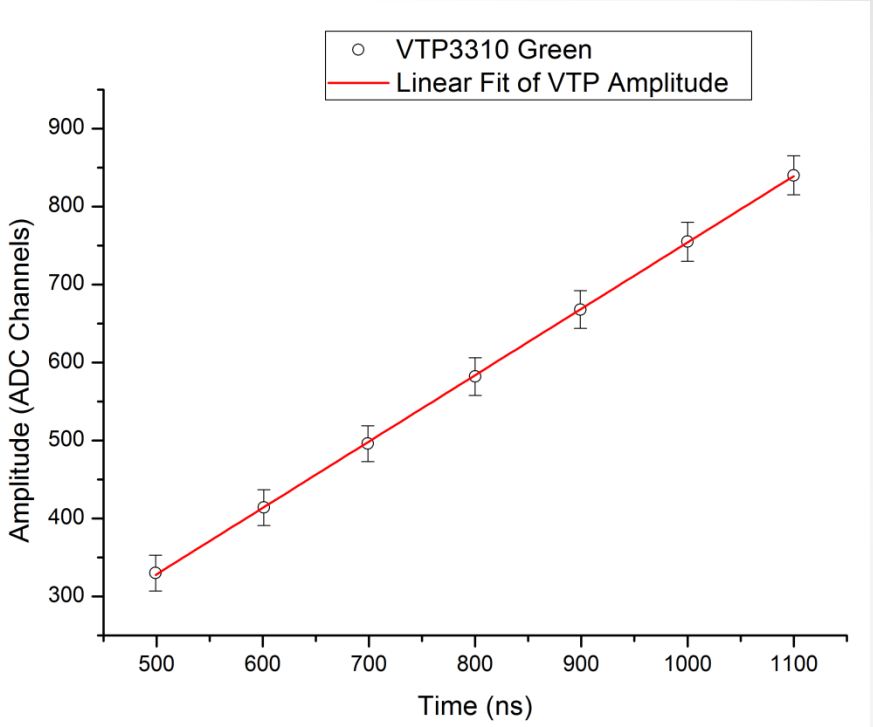
Measurements:
VTH2090
VTP3310

Green and red LED



Dynamic range

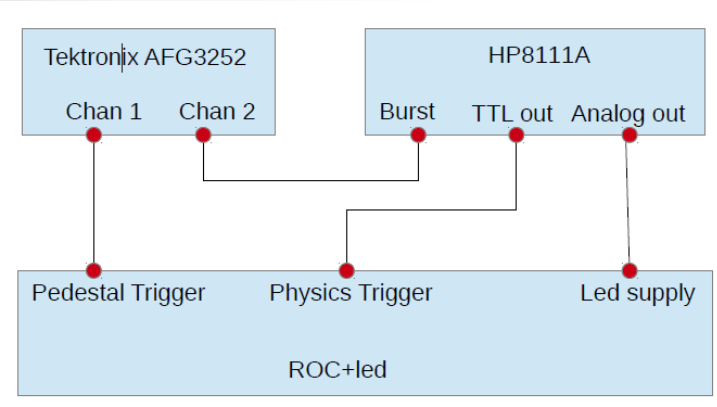


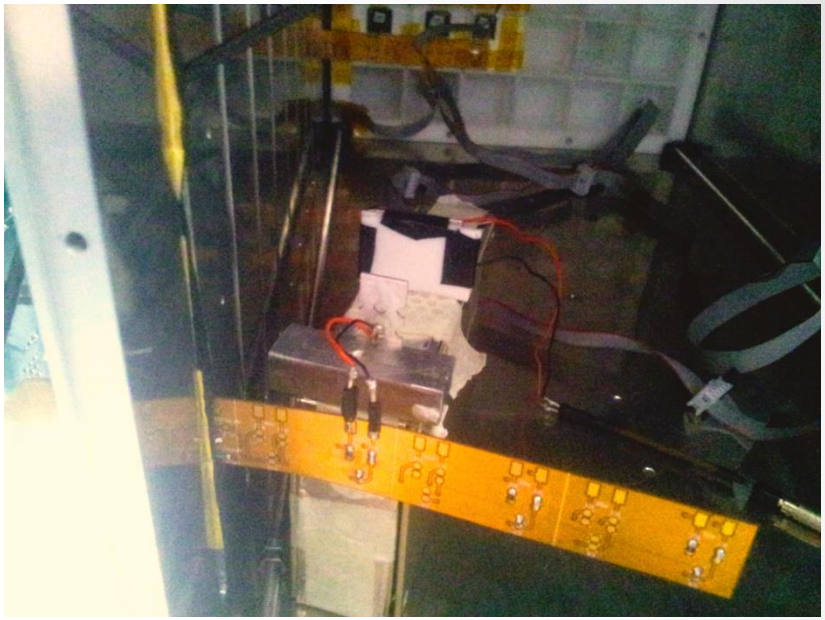


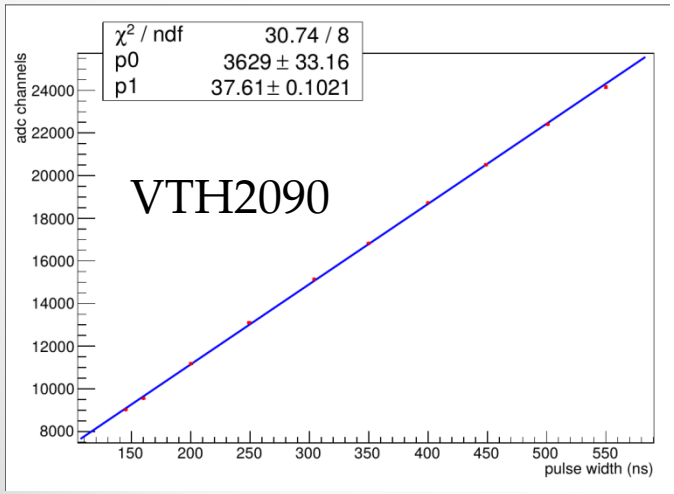
LED	VTP3310		VTH2090		Ratio	
	Signal	Gain	Signal	Gain	Meas.	Calc.
Green	0.851	171.867	1.7805	3.087	118 ±3	104±15
Red	1.245	1.949	156.48	1.949	125.7±1.6	111±16

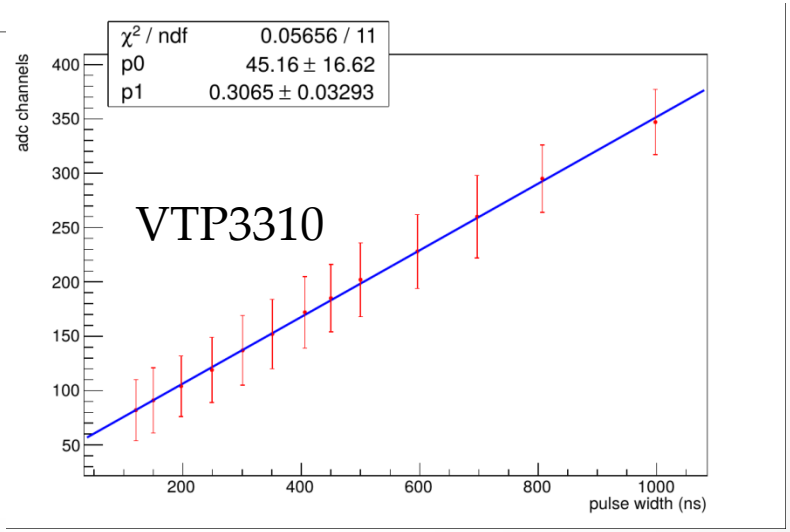
Dynamic range

CASIS









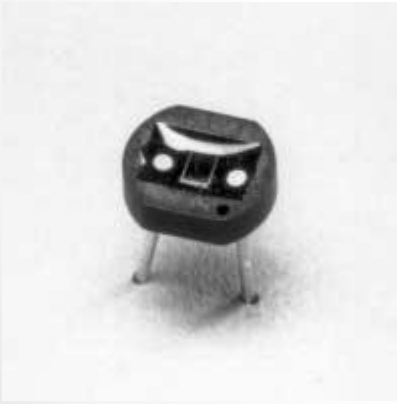
Ratio
108±16

Prototype

- 15 layers x 9 crystals
- Vikuiti wrapping with Tedlar cover
- 2 PD x crystal

- VTP9412 instead of VTP3310

Area ratio ~ 52.9



Results in the next talk!

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- Large PD

Size 9.2 x 9.2 mm^2 ⇒ GF= 0.065

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Dynamic range

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Max. signal – 330 pC

- Dynamic range with 2 PD

330pC/3fC ≈ 10^5

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Dynamic range estimation

Calculation

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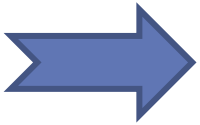

E^{l}_{max}=(50 pC/6.6fC)·20MeV =15 GeV
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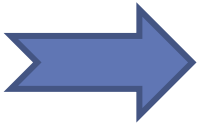

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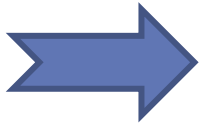
Measurements

ADC range = 700 000 ch
1 MIP = 20 MeV = 500 ch



E^{l}_{max}=(7 × 10^5/500)20MeV =28 GeV
E^{l}_{max}= 2.8 TeV

This estimation is in a good agreement with beam test data (next presebtation)

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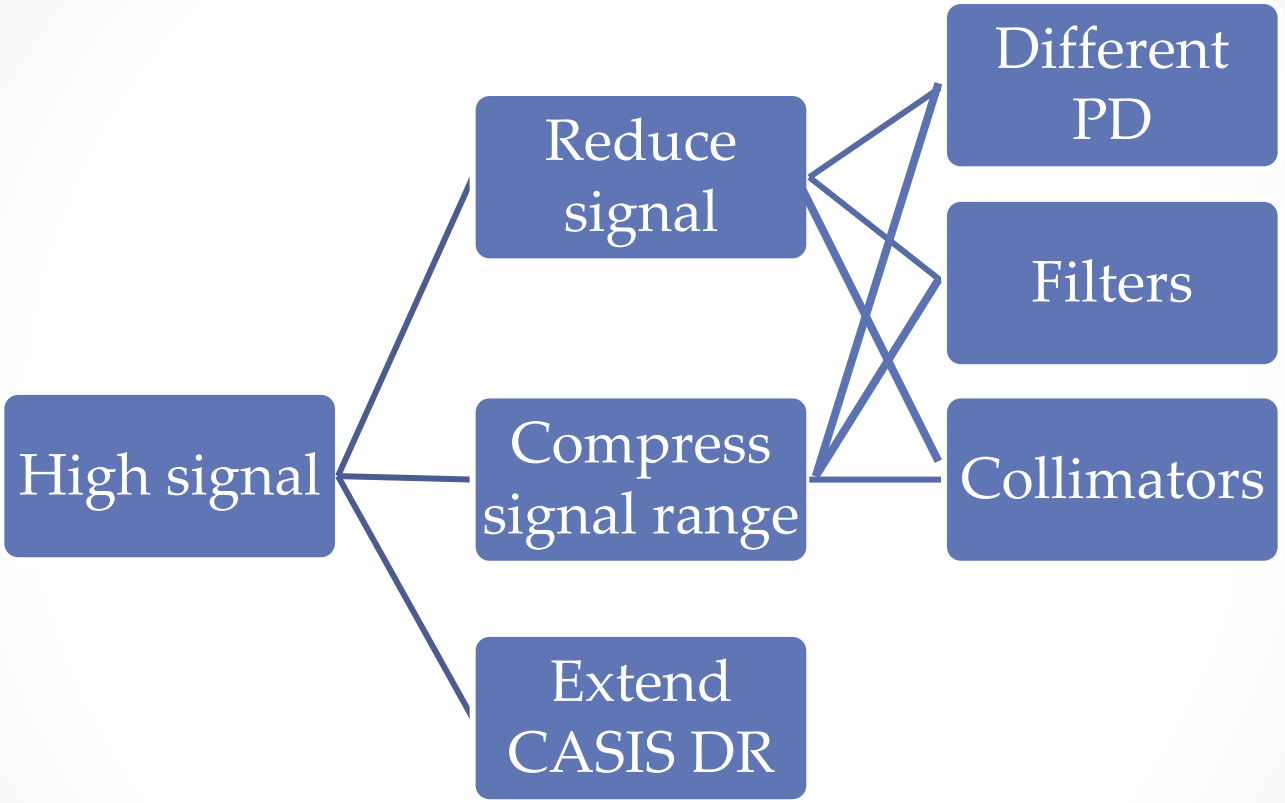

- New small PD with sensitivity 100 times lower!

Conclusions

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- Keep current or better energy resolution
- Cover all energy range

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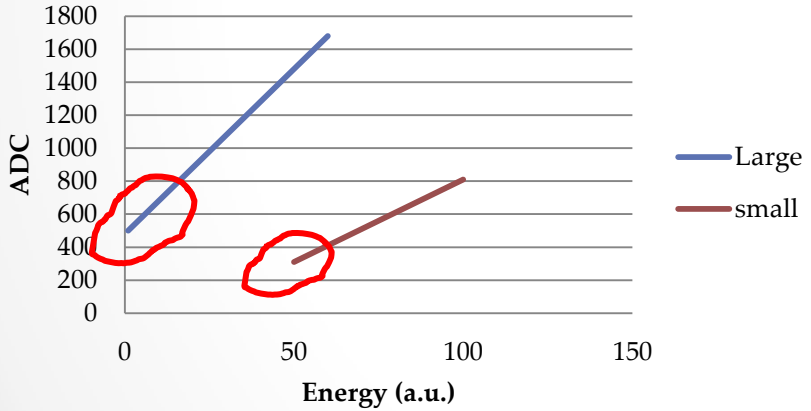

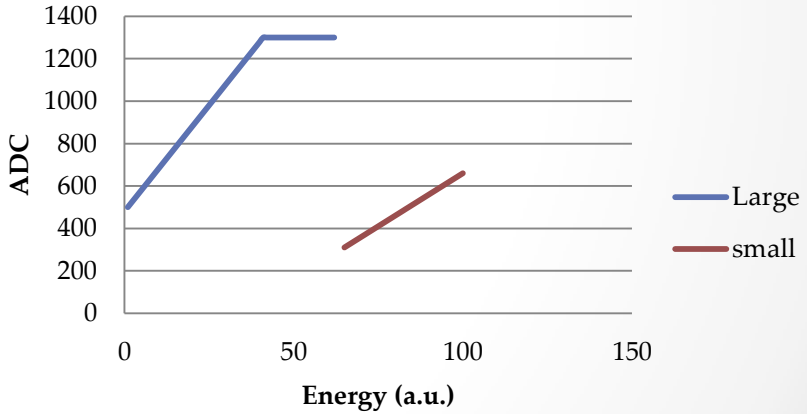

Conclusions

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- Cover all energy range