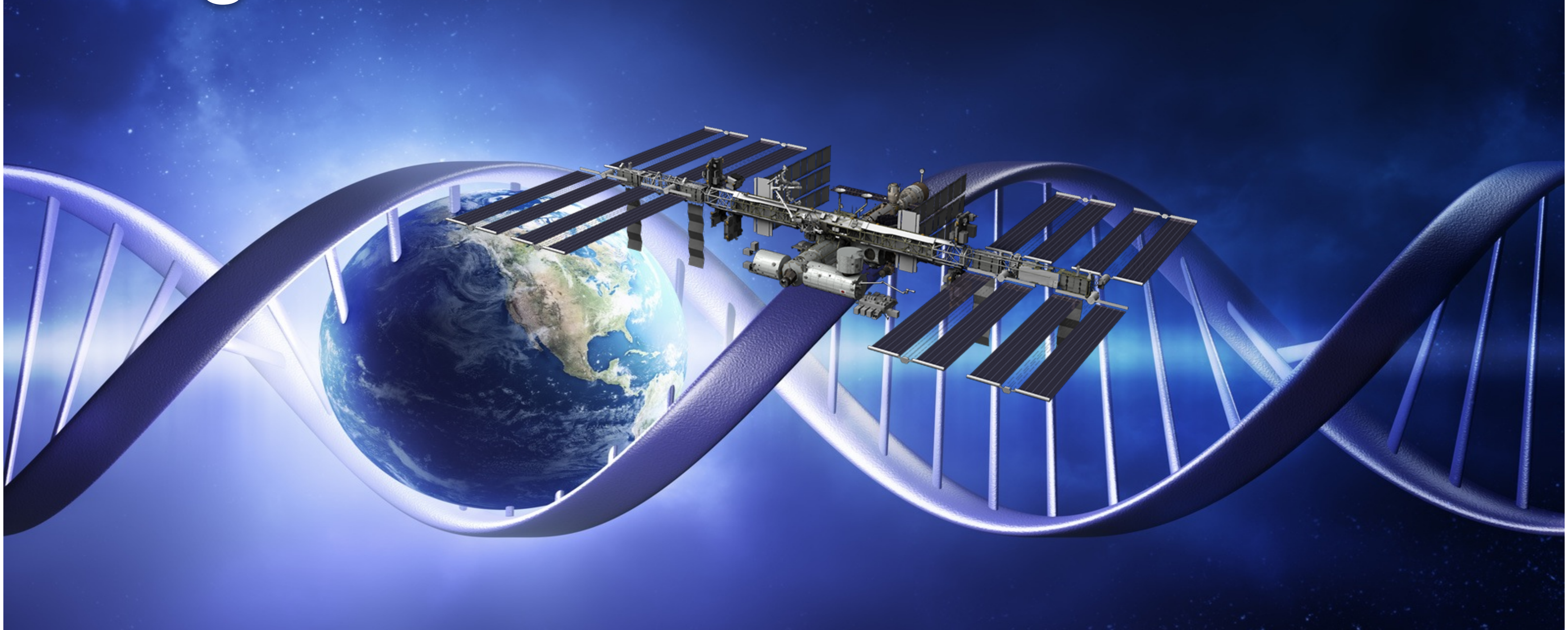
LIDAL

Light **I**on **D**etector for **AL**TEA



Workshops on **R**adiation **M**onitoring for the **I**nternational **S**pace **S**tation

Turin, 5-7 September 2017

Alessandro Rizzo for LIDAL-ALTEA collaboration

agenzia spaziale italiana

UNIVERSITA' degli STUDI di ROMA TOR VERGATA

LIDAL team

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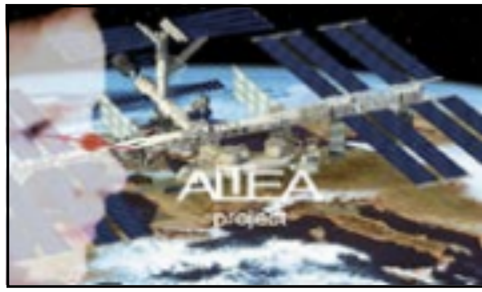
Eddie Semones Larry Pinsky Raphael Mastrangelo	MEDIPIX NASA - UoH
Elisa Carruba	PD Kaiser Italia
Marino Crisconio	PM ASI



Outline

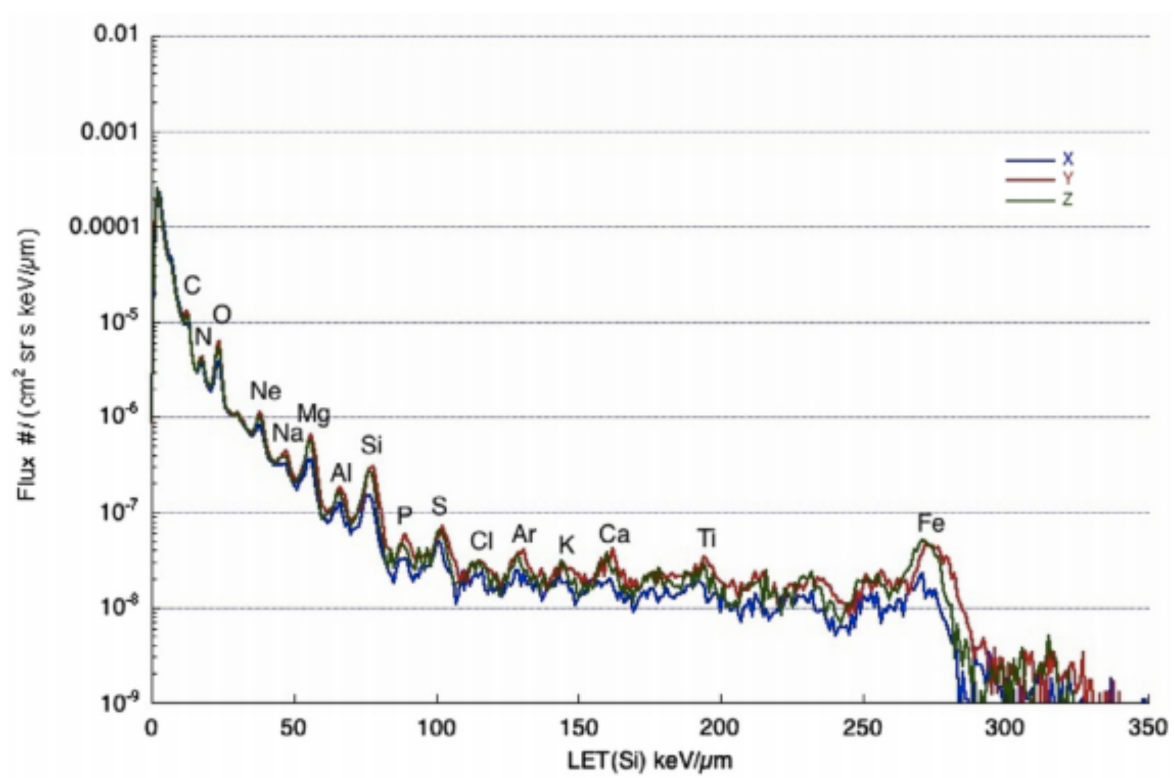
- LIDAL-ALTEA System: how to study in detail the low-Z part of ion spectrum onboard the ISS
- Time of Flight measurements
- Toward LIDAL detector realization
- Test Beam @Trento ProtonTherapy Center: First Results
- What we have learned
- Toward LIDAL-ALTEA apparatus realization
- TimePix Integration

LIDAL-ALTEA System: how to study in detail the low-Z part of ion spectrum onboard the ISS

Spectrum seen by ALTEA detector

Protons: most abundant particles of the spectrum → GCR (Galactic Cosmic Rays) / Solar (SPE)

They account for the 99% particle of the spectrum (with He)



"Radiation survey in the International Space Station" - L. Narici et al. J. Space Weather Space Clim., 5, A37 (2015)

The risk is mitigated by the small quality factor Q for protons

ALTEA Kinetic Energy Window acceptance: 25-45 MeV

hardly measure GCR protons, mostly secondaries and albedo protons are detected by ALTEA

"Performances of Kevlar and Polyethylene as radiation shielding on-board the International Space Station in high latitude radiation environment" - L. Narici et al. Scientific Reports 7, Article number: 1644

LIDAL detector

LIDAL is a detector designed to perform **Time of Flight** (**ToF**) measurements working paired to ALTEA detector

In order to:

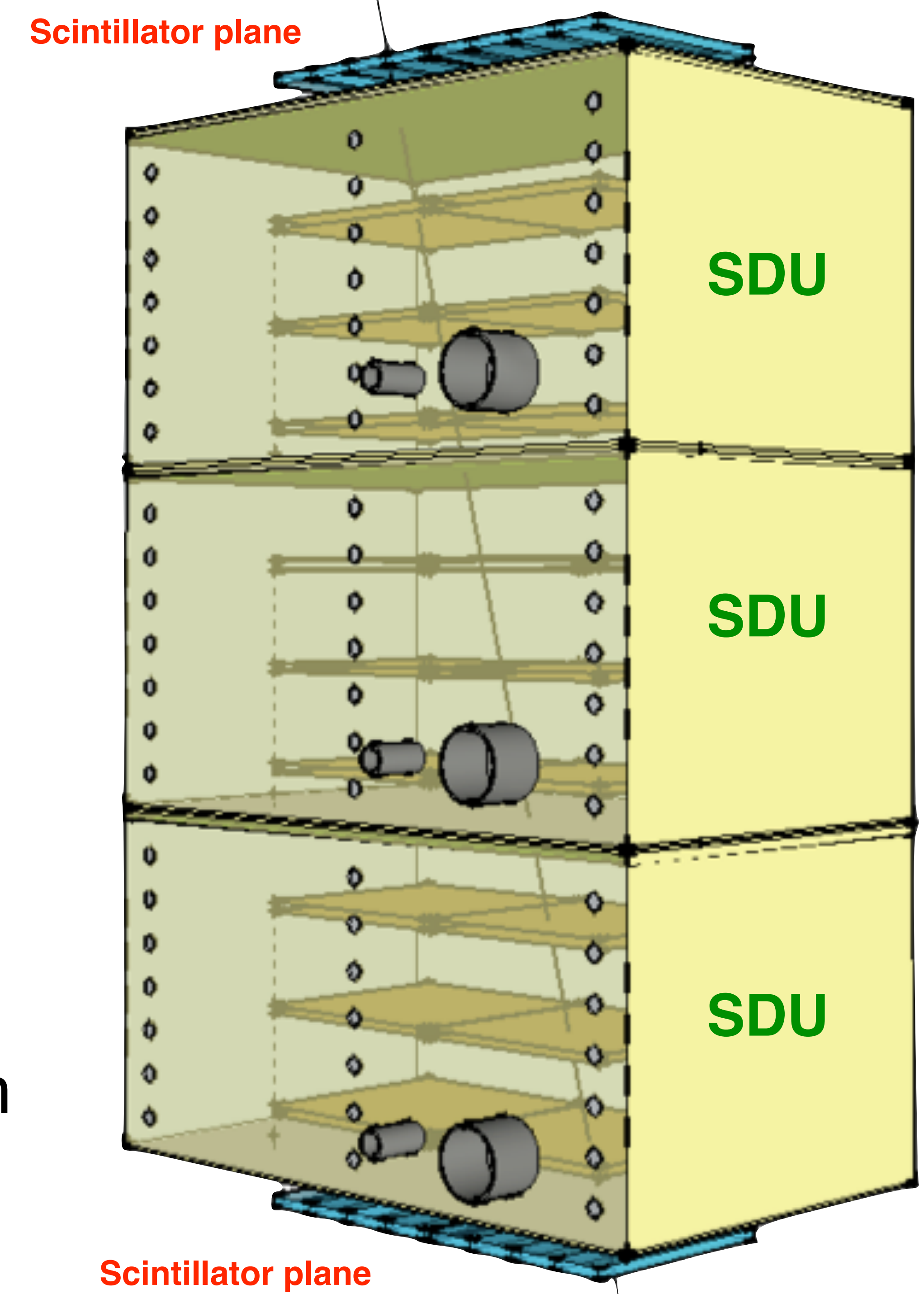
- Study in detail (kinetic energy) the low-Z part of the spectrum on ISS, in particular protons

by product results:

- Enhance ALTEA acceptance window for low Z particles
- Enhance ALTEA discrimination power

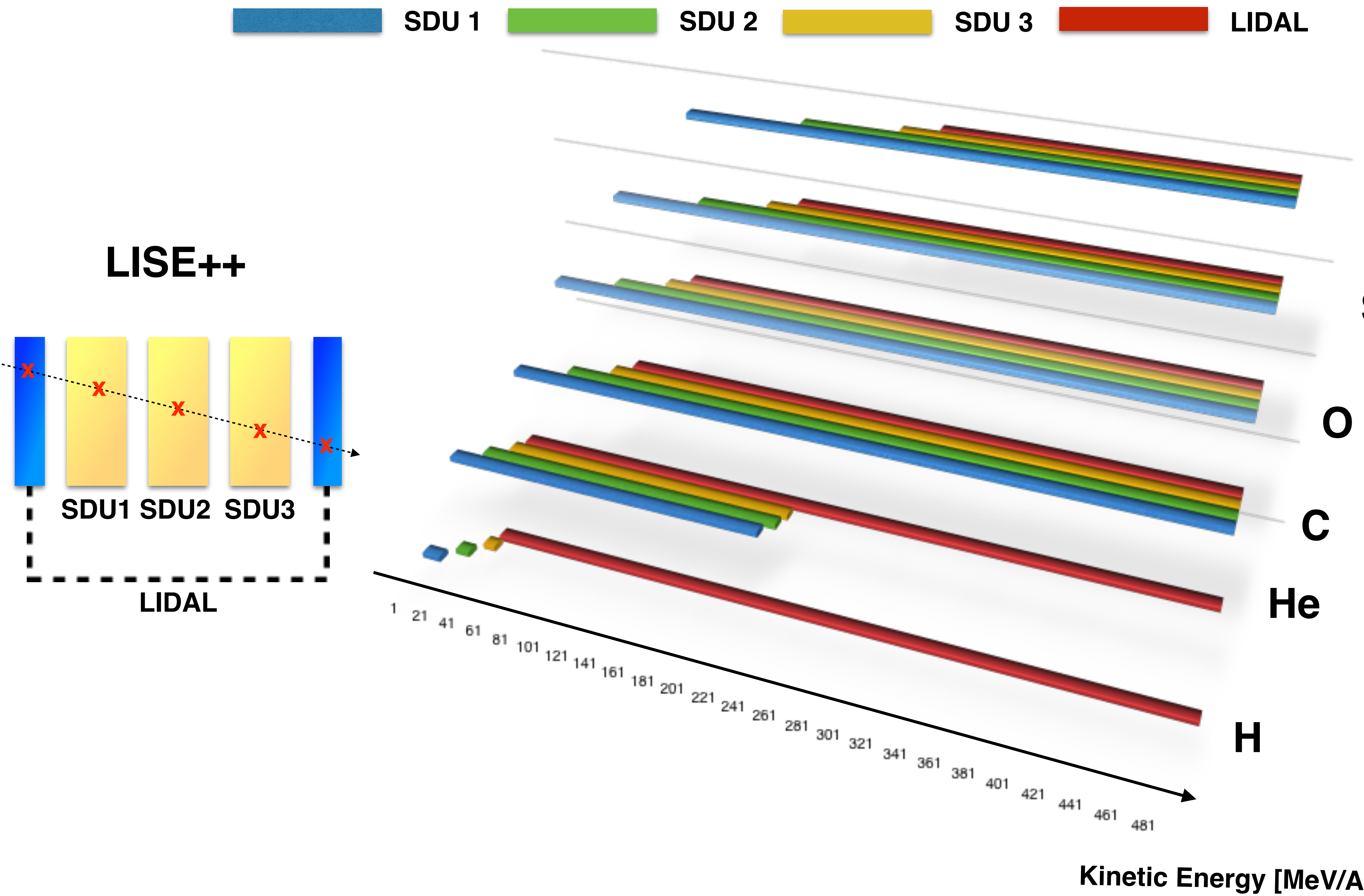
Duties

- taking data independently from ALTEA
- Triggering ALTEA acquisition
- Merging measures with ALTEA ones



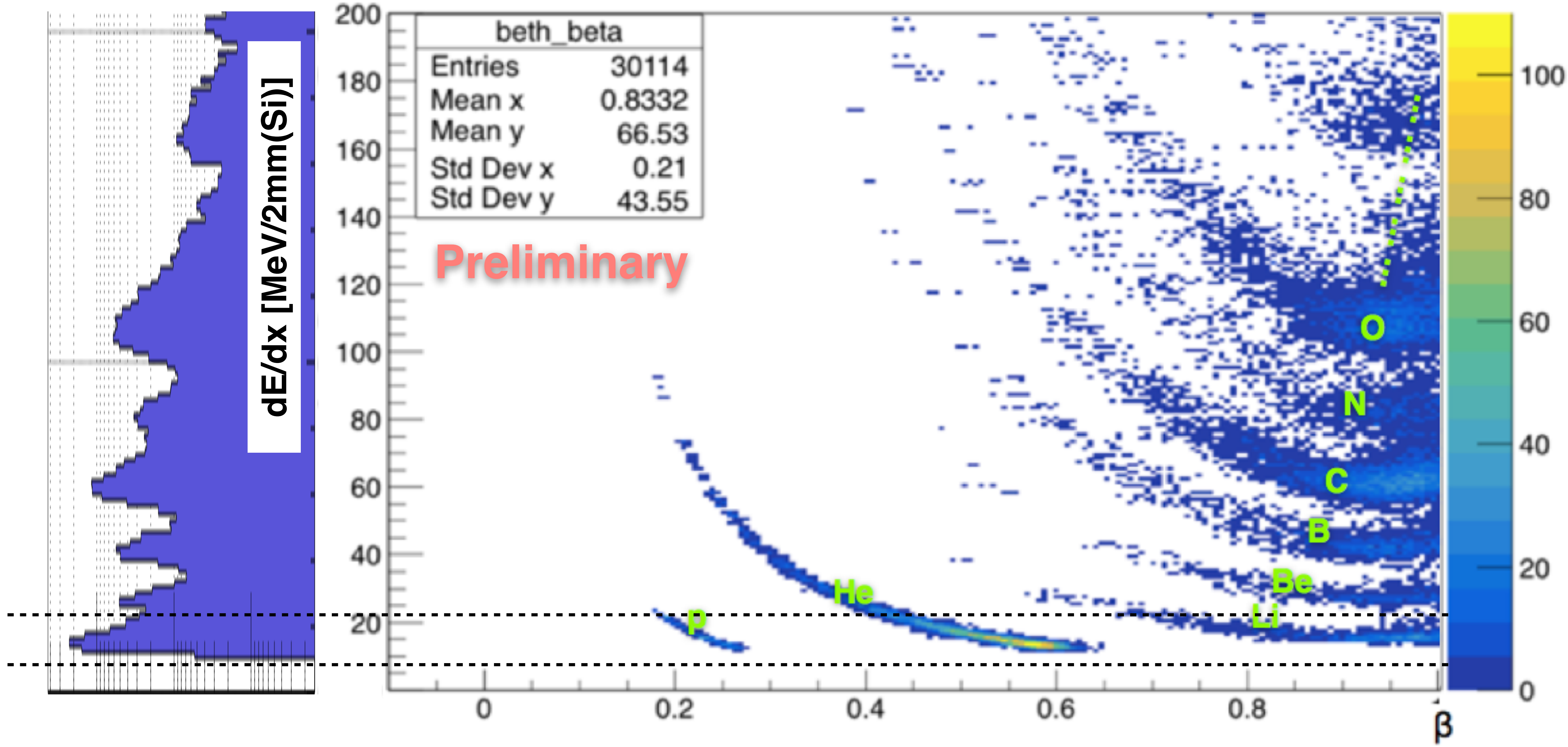
LIDAL-ALTEA trigger: Kinetic Energy

Kinetic Energy that ion should have to start the trigger in:



Discrimination Power

Asked for TIME RESOLUTION better than 120 ps (here 80 ps)



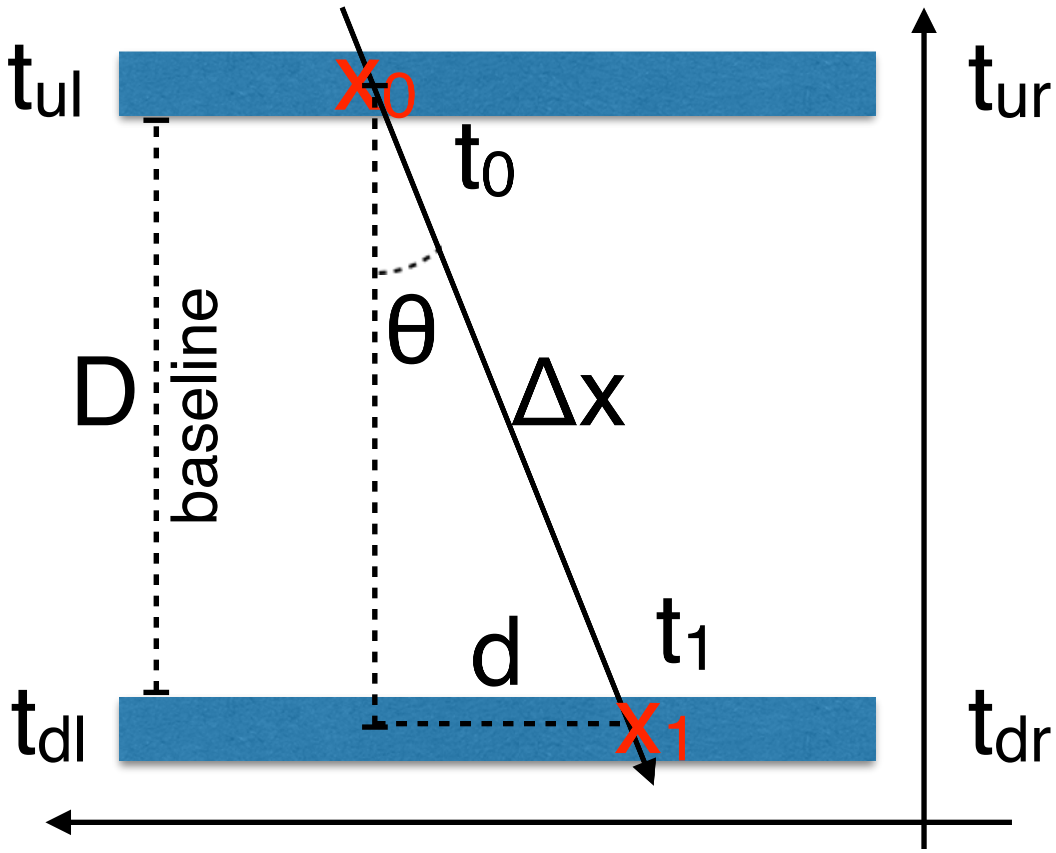
LIDAL-ALTEA apparatus: expected discrimination power

ALTEA acceptance windows have been included

- Distribution generated (accept/reject method) accordingly to CREME96 ones
- Deposited energy on silicon plane smeared with straggling

Time of Flight measurements

ToF Measurements



v= speed of light in the medium= c/n

$$t_{ur} = t_0 + v x_0 \qquad t_{dr} = t_1 + v x_1$$

$$t_{ul} = t_0 + v(L - x_0) \qquad t_{dl} = t_1 + v(L - x_1)$$

position (time difference)

$$x_0 = \frac{t_{ur} - t_{ul} + vL}{2v} \qquad x_1 = \frac{t_{dr} - t_{dl} + vL}{2v}$$

time (sum)

$$t_0 = \frac{t_{ur} + t_{ul} - vL}{2} \qquad t_1 = \frac{t_{dr} + t_{dl} - vL}{2}$$

Kinetic Energy from ToF Measurements

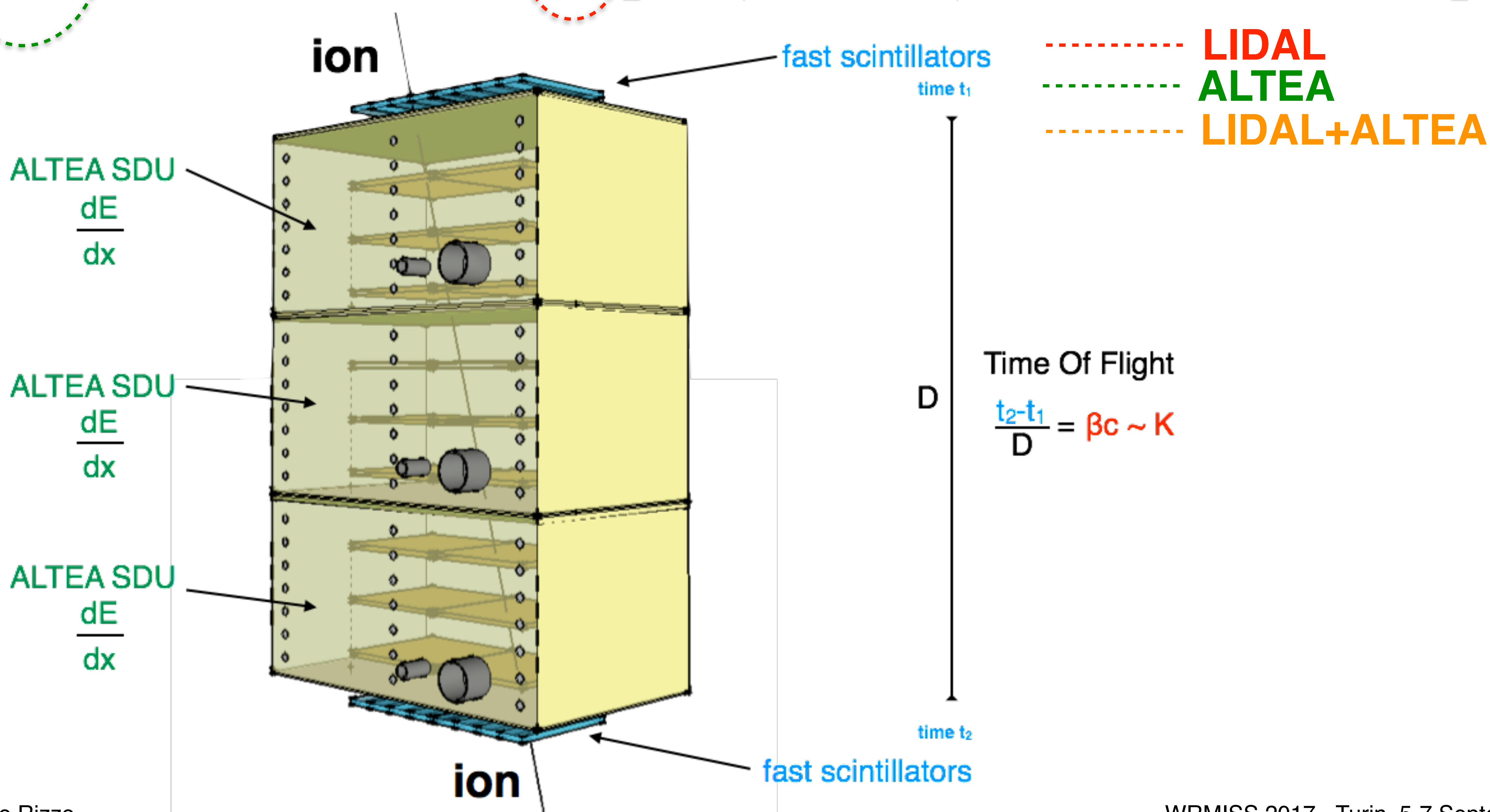
$$\Delta t = t_1 - t_0 = \frac{t_{dr} + t_{dl} - t_{ur} - t_{ul}}{2} \qquad d = x_1 - x_0 = \frac{t_{dr} - t_{dl} - t_{ur} + t_{ul}}{2v}$$

$$\Delta x = \sqrt{d^2 + D^2}$$

$$\beta = \frac{v_{part}}{c} = \frac{\Delta t}{c\Delta x} \rightarrow \gamma = \frac{1}{\sqrt{1-\beta^2}} \quad E = \gamma m c^2 \rightarrow T = \sqrt{\frac{m^2c^4}{1 - \frac{\Delta x^2}{c^2 \Delta t^2}}} - mc^2$$

Risk assessment: ToF measurements and Bethe-Bloch parameters

$$\frac{dE}{dx} \approx \rho N_e m_e c^2 r_e^2 \frac{Z}{A}\frac{z^2}{\beta^2}\left[ln\left(\frac{\gamma^2\beta^2 W}{I^2}\right) - 2\beta^2 - \delta - \frac{2C}{Z}\right]$$



Toward LIDAL detector realization

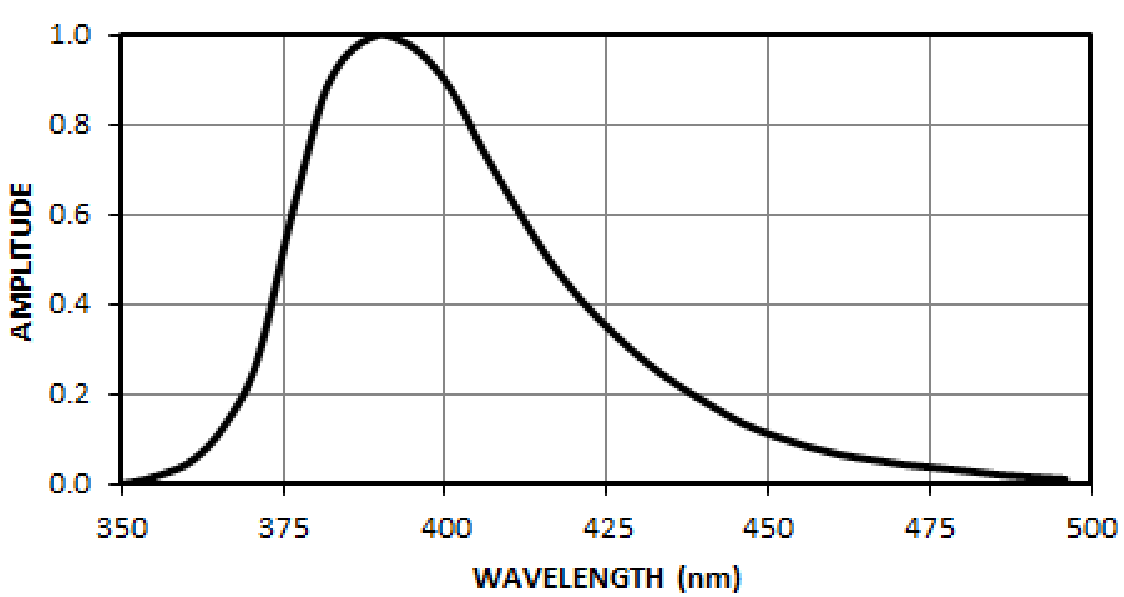
LIDAL detector

How to reach a **TOF resolution ≤ 120 ps (σ) ?**

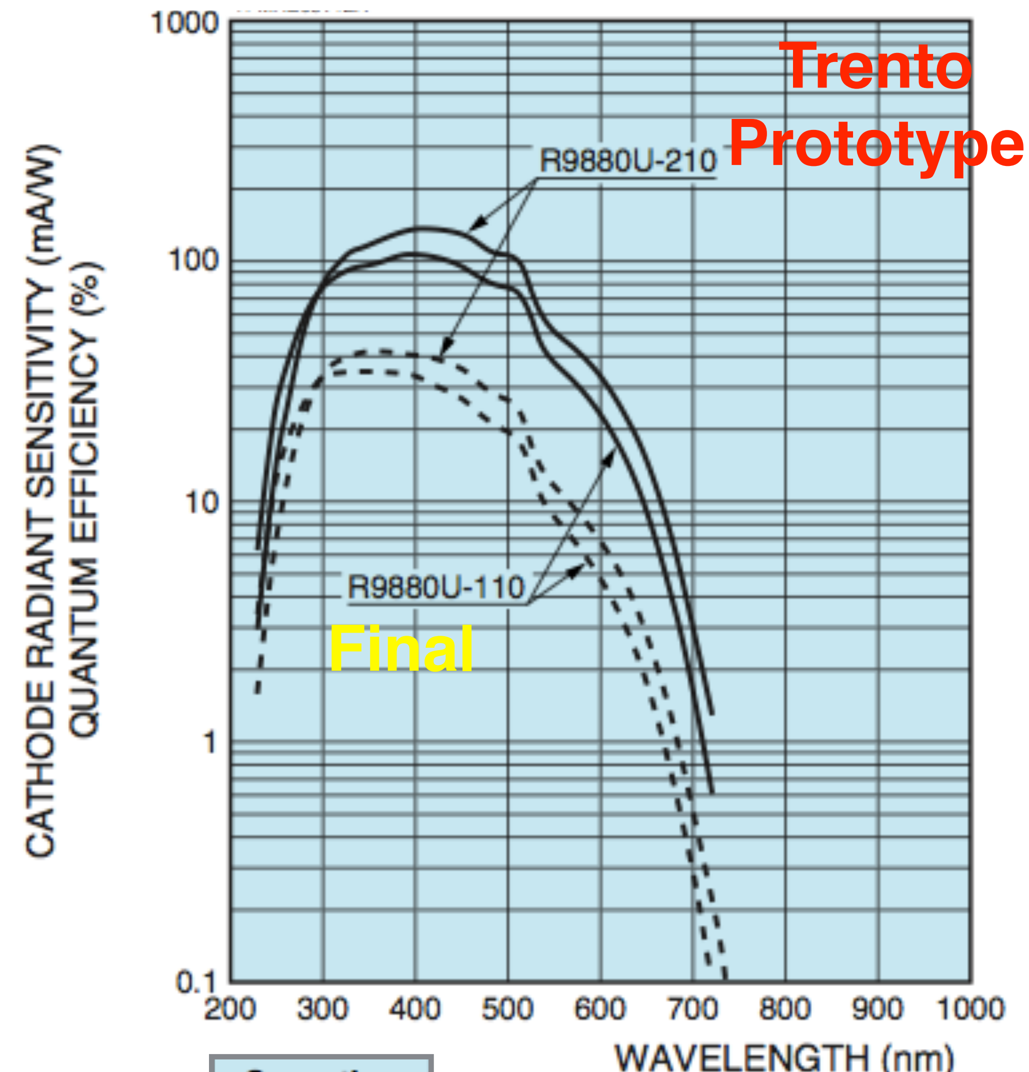
EJ-230 ELJEN technology

PROPERTIES	EJ-230
Light Output (% Anthracene)	64
Scintillation Efficiency (photons/1 MeV e^-)	9,700
Wavelength of Maximum Emission (nm)	391
Light Attenuation Length (cm)	120
Rise Time (ns)	0.5
Decay Time (ns)	1.5
Pulse Width, FWHM (ns)	1.3

EJ-228 AND EJ-230 EMISSION SPECTRUM



HAMAMATSU R988OU-110



Operating Ambient Temperature (°C)
-80 to +50

Time Response		
Rise Time	Transit Time	TTS
0.57	2.7	0.2

LIDAL Scintillators

Scintillator Dimensions and Thickness

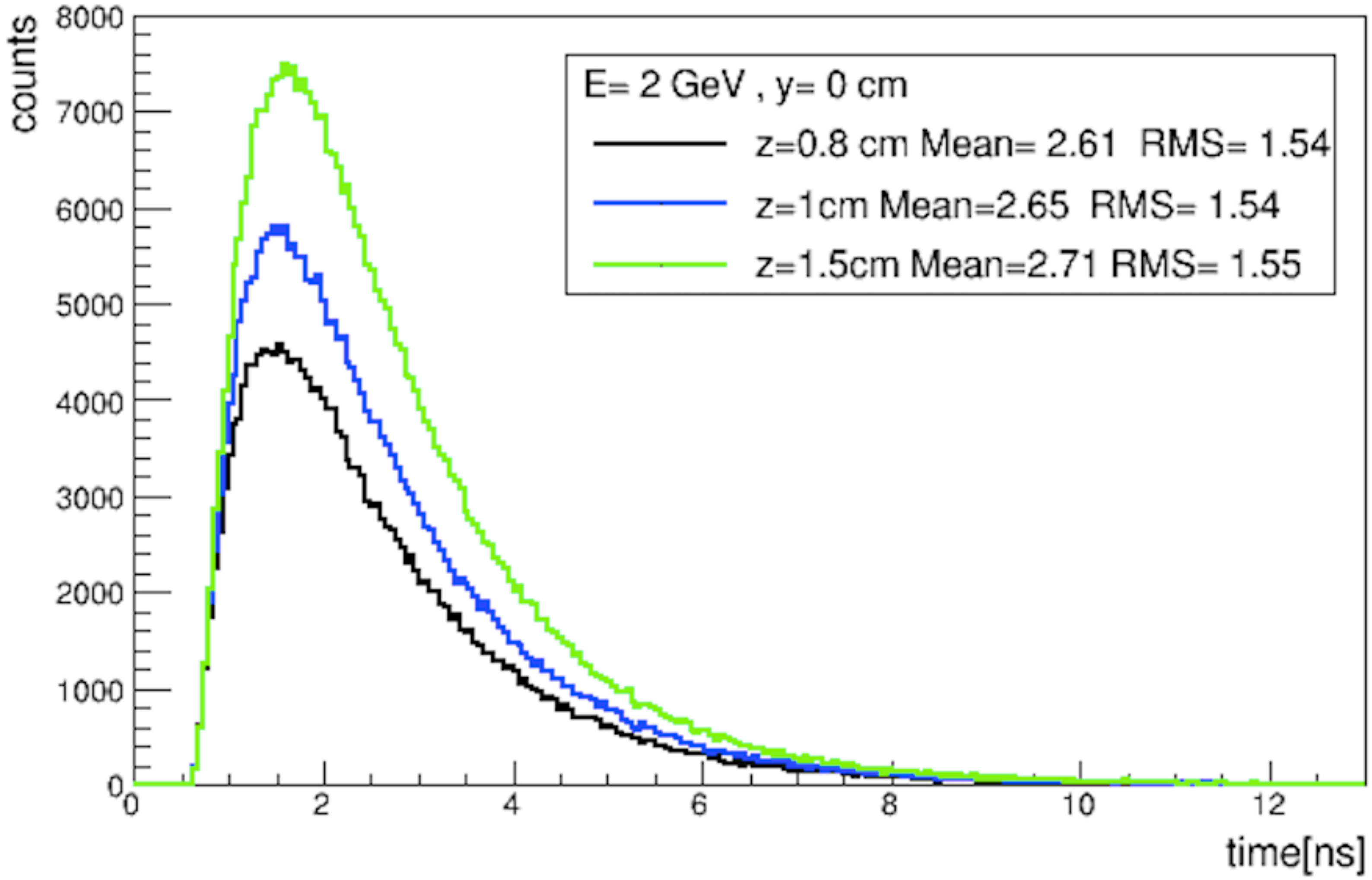
LIDAL tasks

Trigger →	High Collected Light better S/B discrimination	LARGE
TOF →	Fast Signals short light propagation path	SMALL

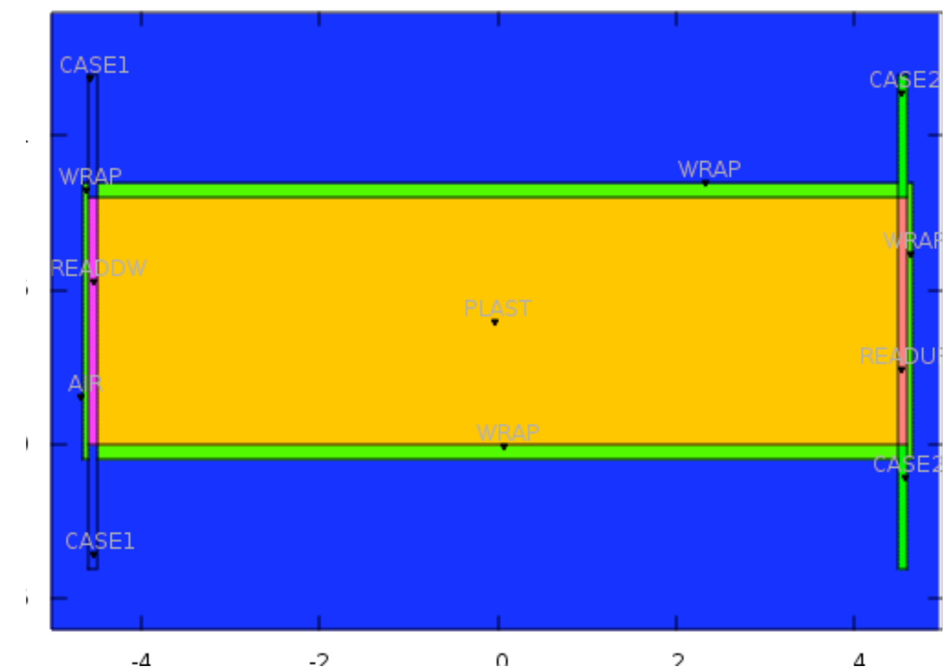
Three different step have been done to define the final scintillator dimensions

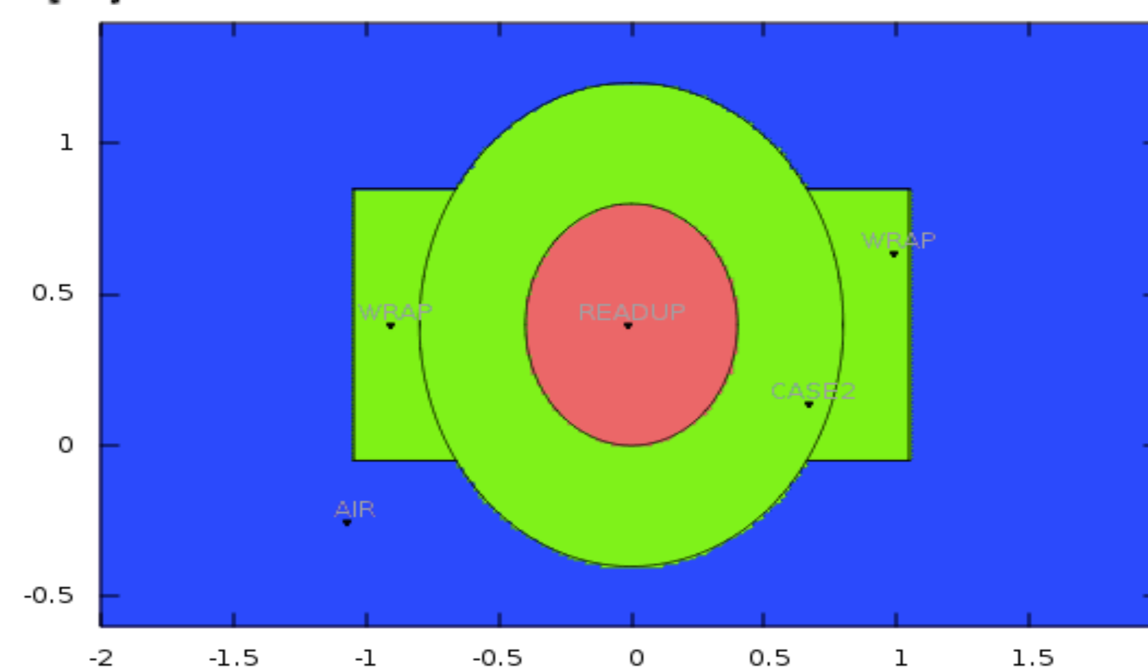
	Fluka simulations	Trento Test	Final dimensions
dimensions	18.0x2.4x0.8/1.0/1.5 cm 9.0x2.4x0.8/1.0/1.5 cm	9.0x2.4x0.8 cm	8.0x2.0x0.4 cm
issues	• Number of collected photons at both sides • Temporal structure of the signal (internal reflections)	• Time Resolution and light collection	• Solving Cross-Talk and FEE Saturation

LIDAL scintillators: Simulations



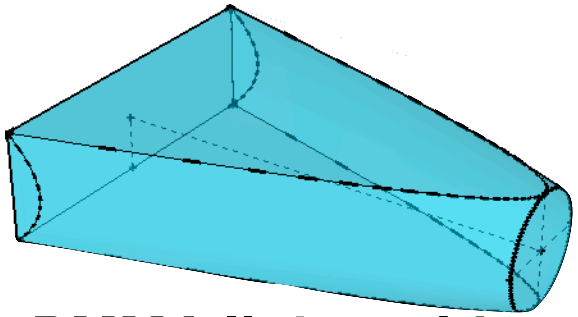
Simulated geometry:



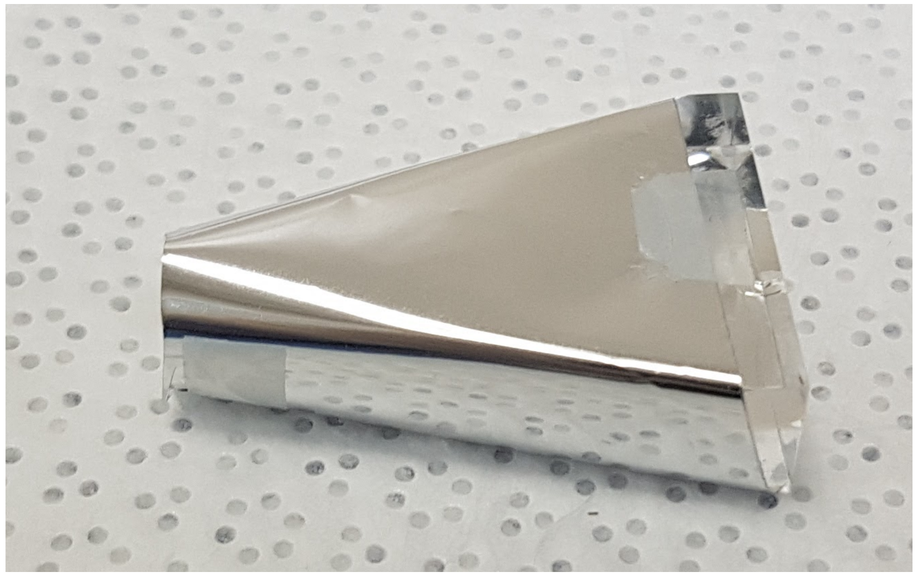


- Plastic Scintillator (EJ-230)
- Reflective (85%) Mylar
- Readout area
- Air

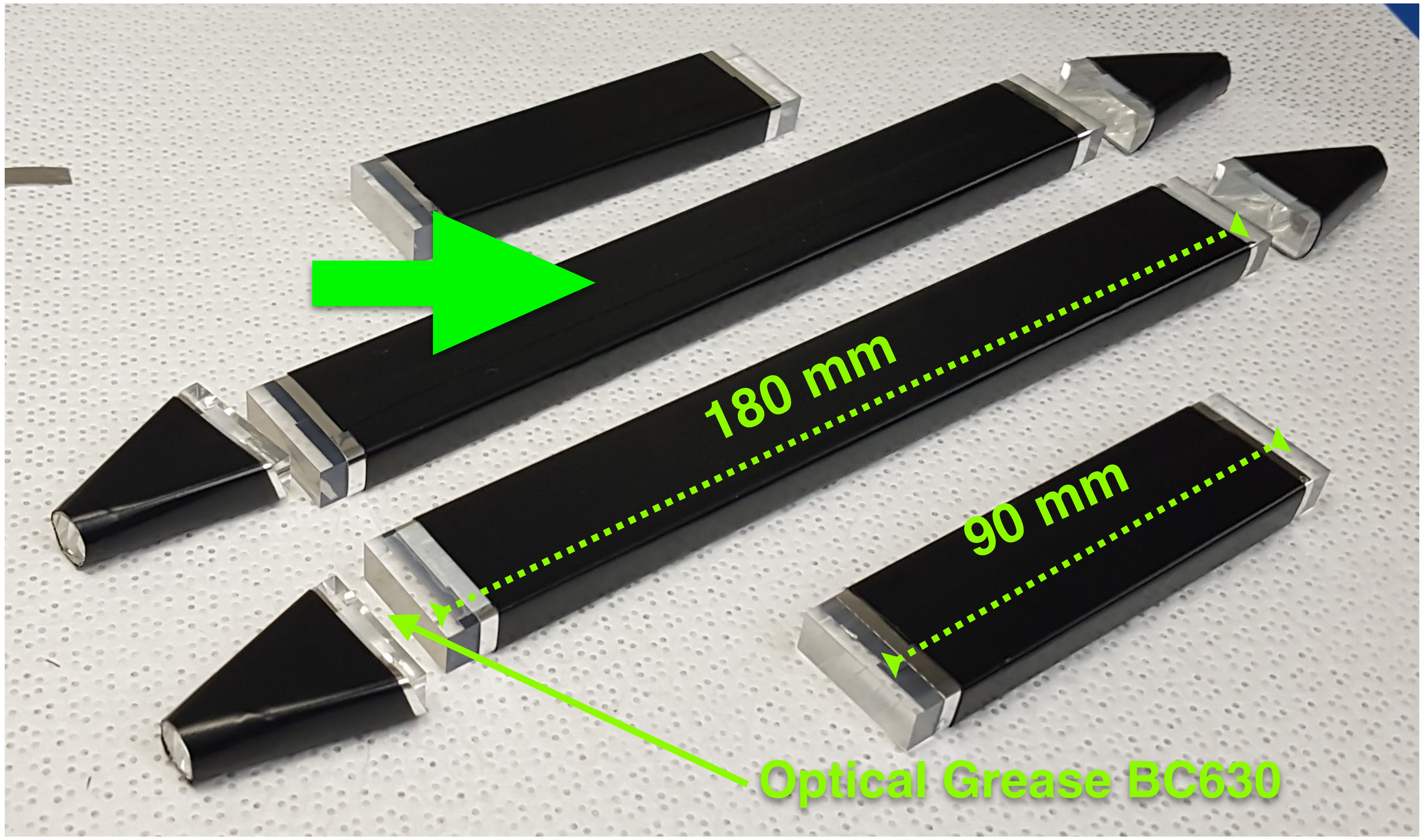
LIDAL scintillators: Trento Tests



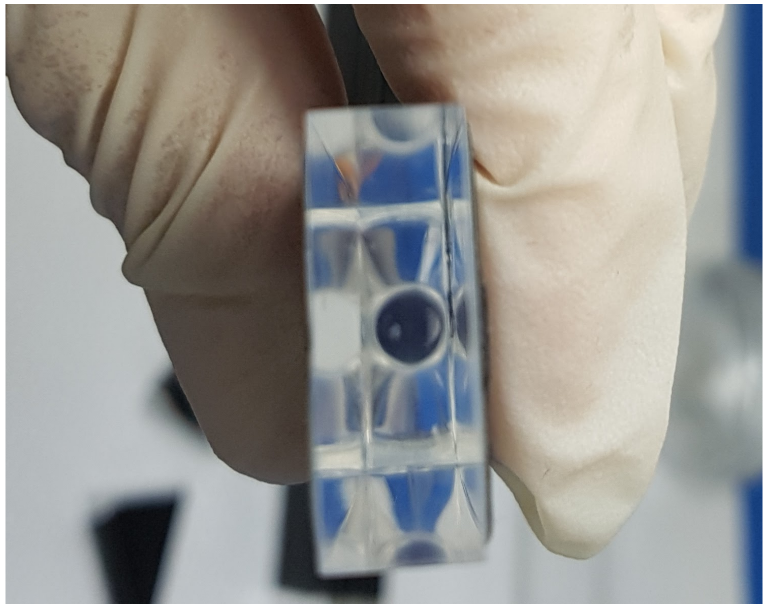
- **PMMA light guides**

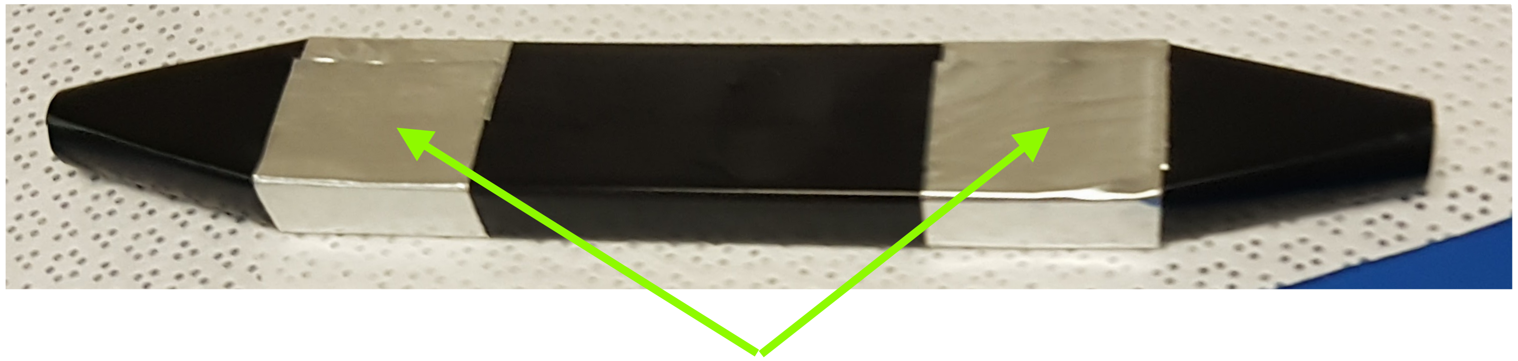


- **Aluminized Mylar (1 side)**
- **Black tape (1 wrap)**



- **Optical Contact**

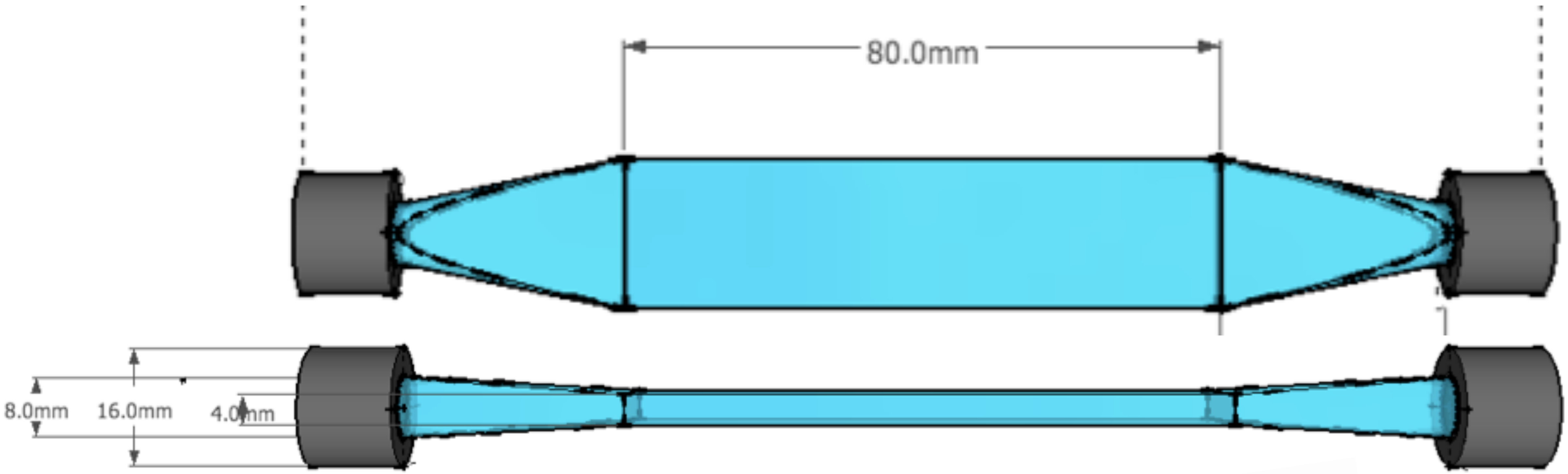


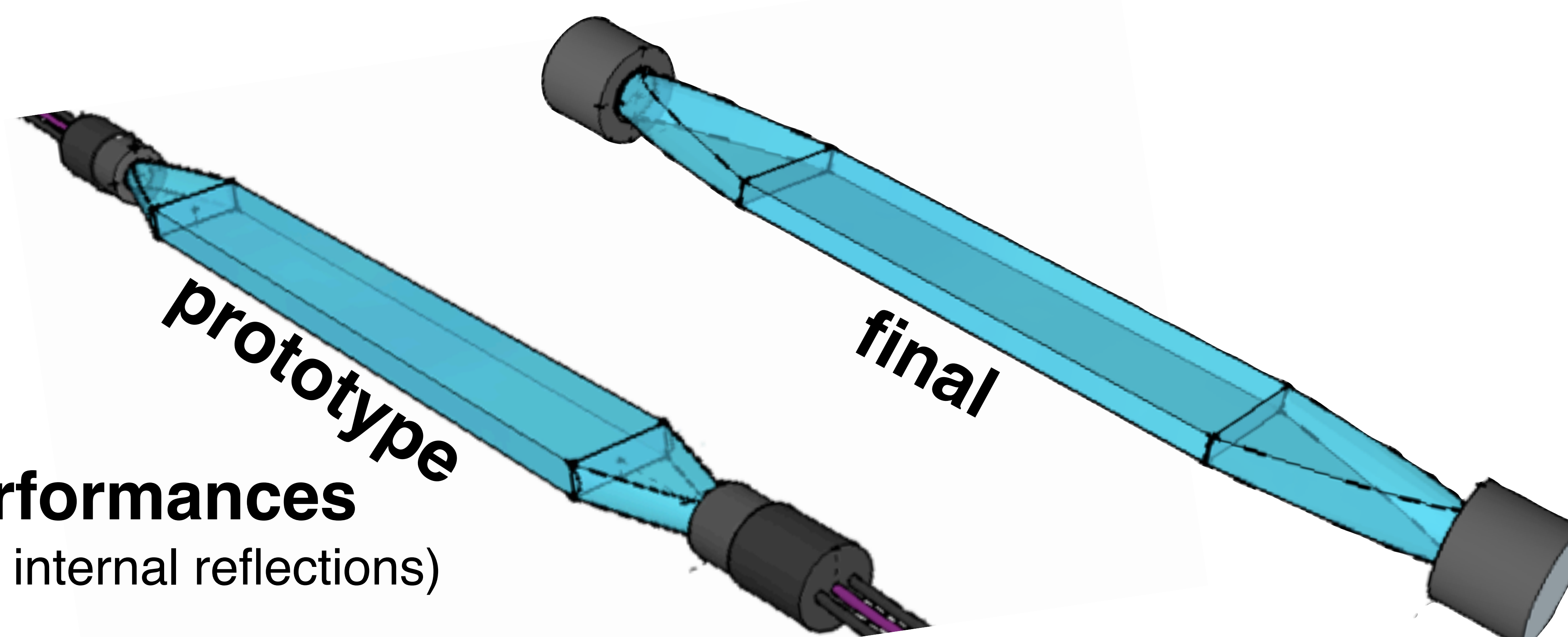


- **Aluminum tape (1 wrap)**

LIDAL scintillators: Final

Designed to reduces the signals (cross-talk issue**)**



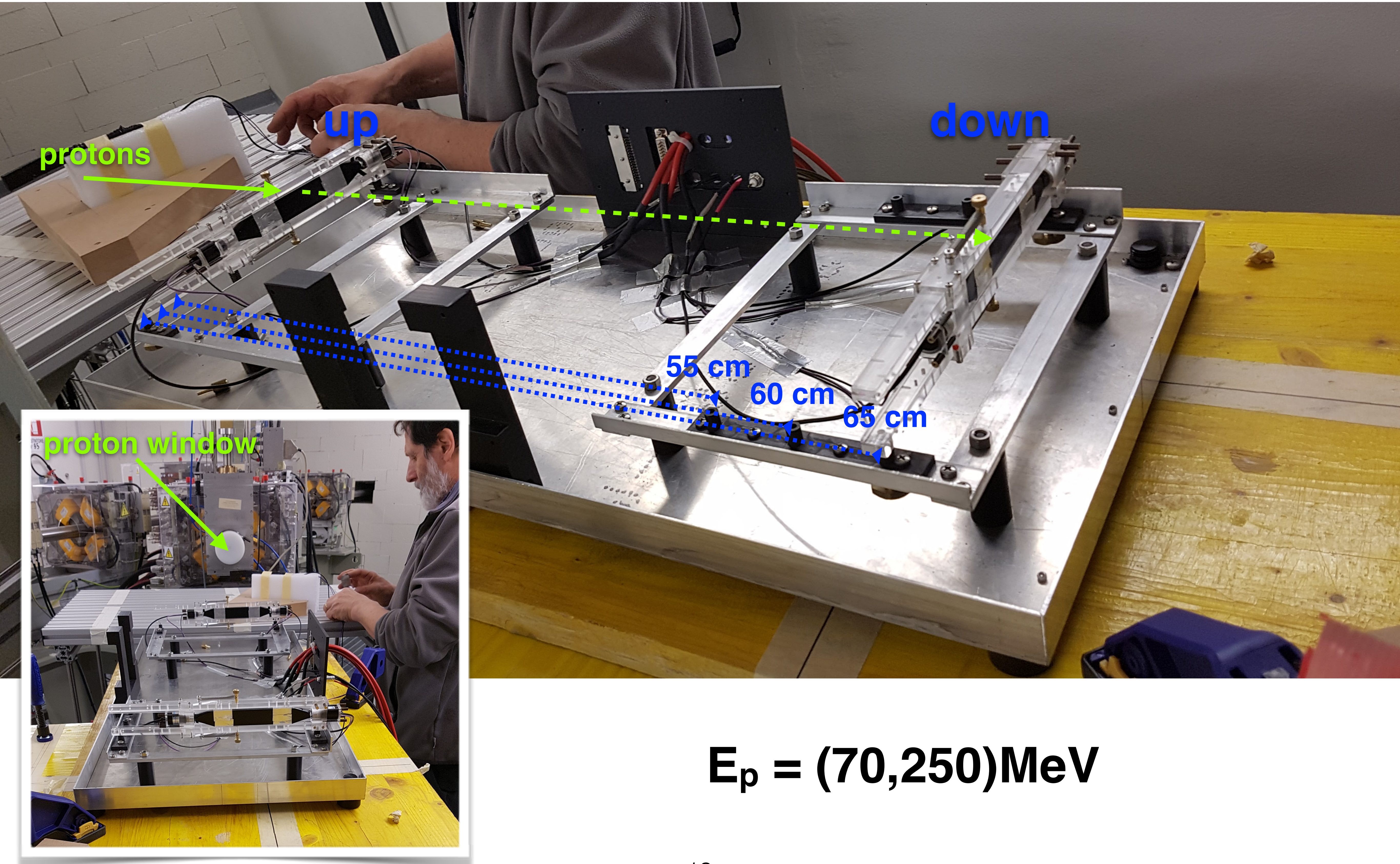


best timing performances

(reduction the number of internal reflections)

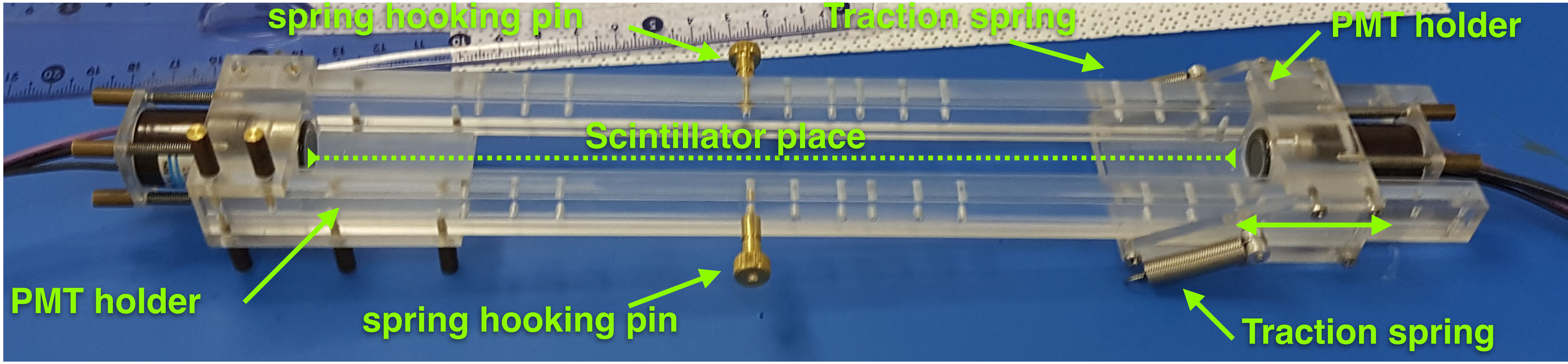
Test Beam @Trento ProtonTherapy Center: First Results

LIDAL prototype 0@TIFPA

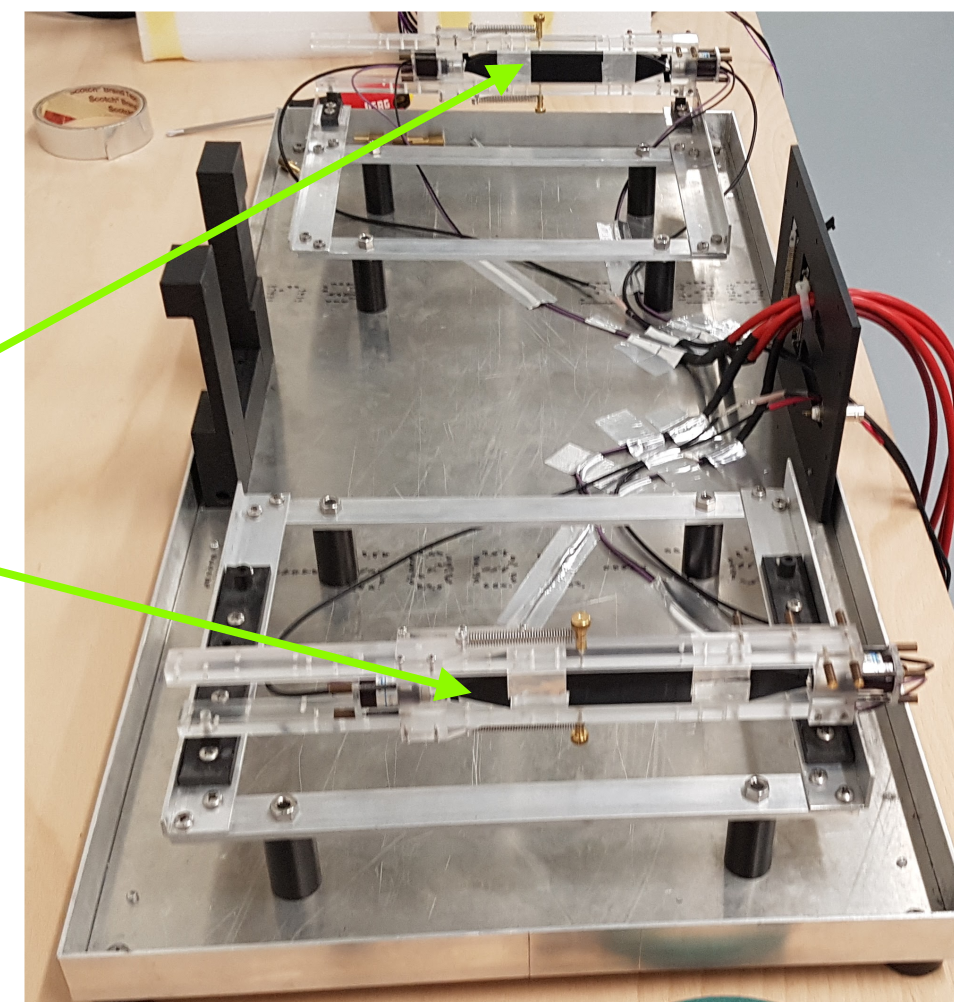


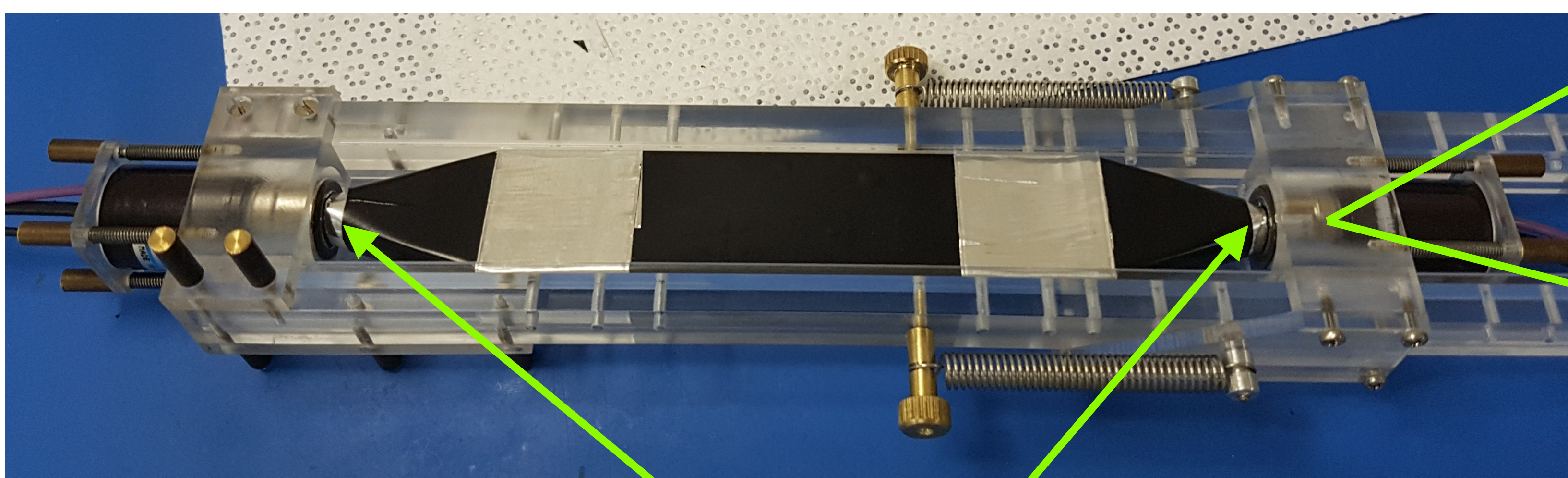
E_p = (70,250)MeV

Socket Assembly



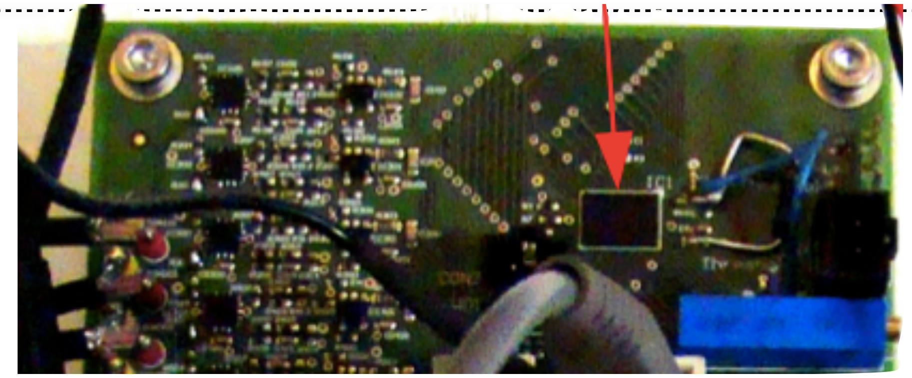
Designed and Realized by Tor Vergata Mechanical Workshop



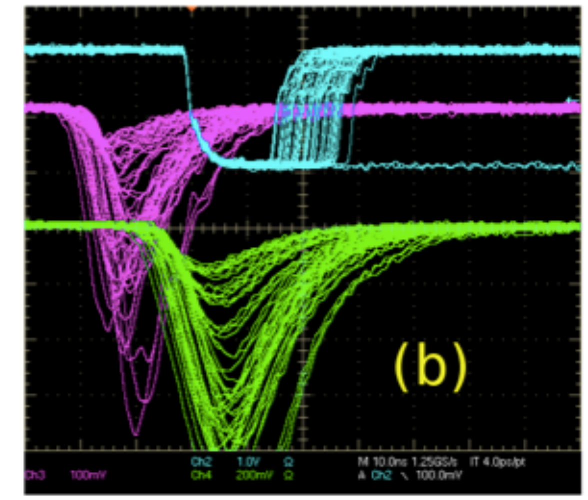


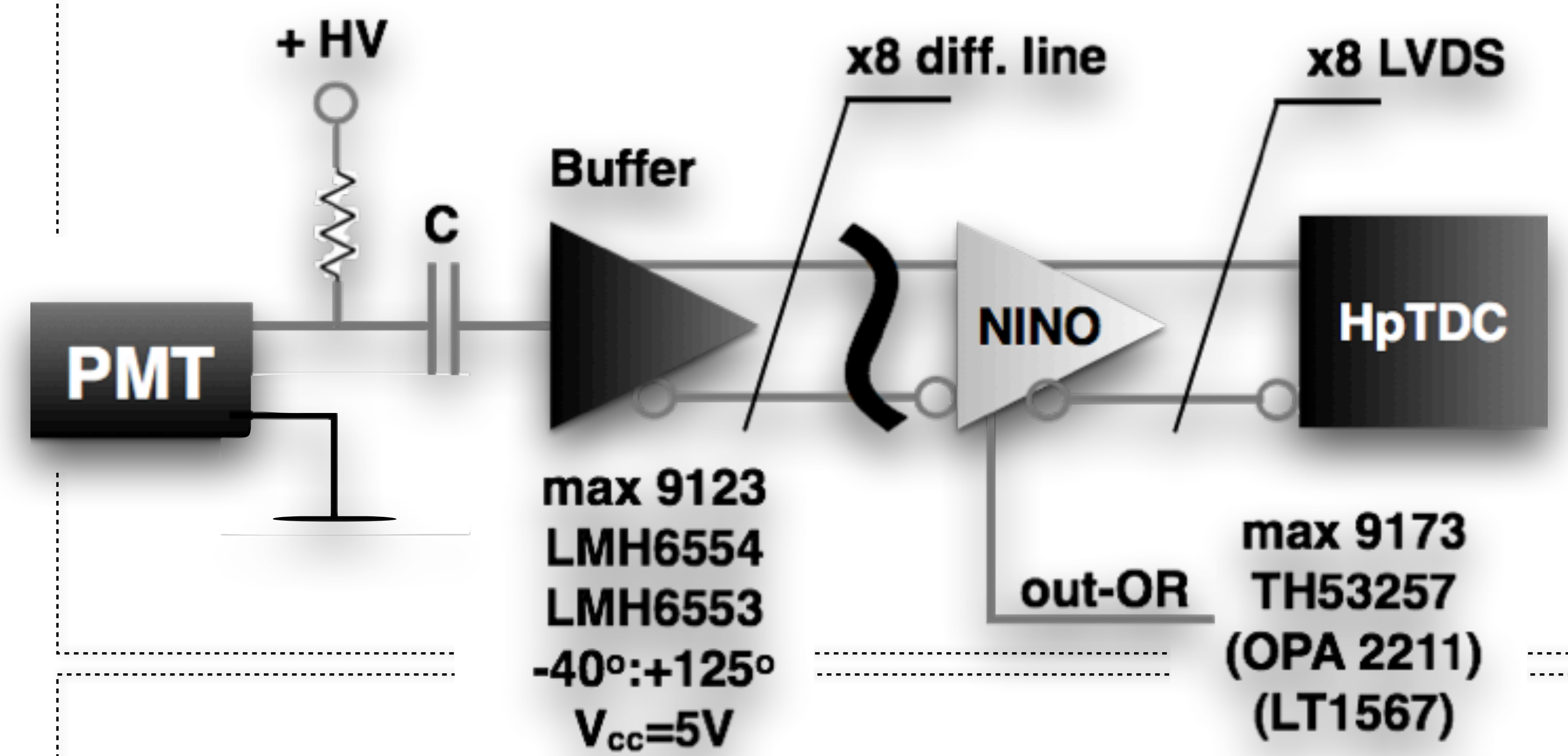
LIDAL electronics sketch

Front End Electronics
NINO



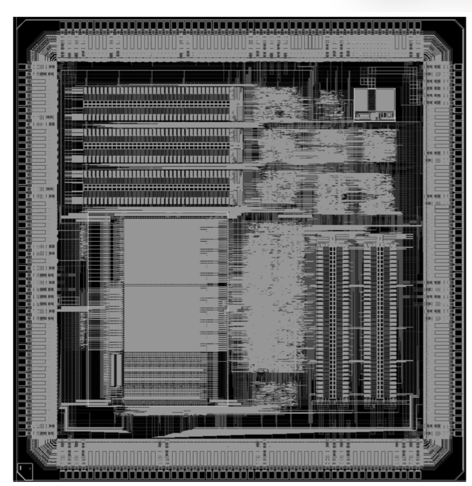
Pre-amp and **Discriminator**





Magenta = input pulse from scint.
Cyan = LVDS output from NINO
Green = MAX 4412 amplifier out

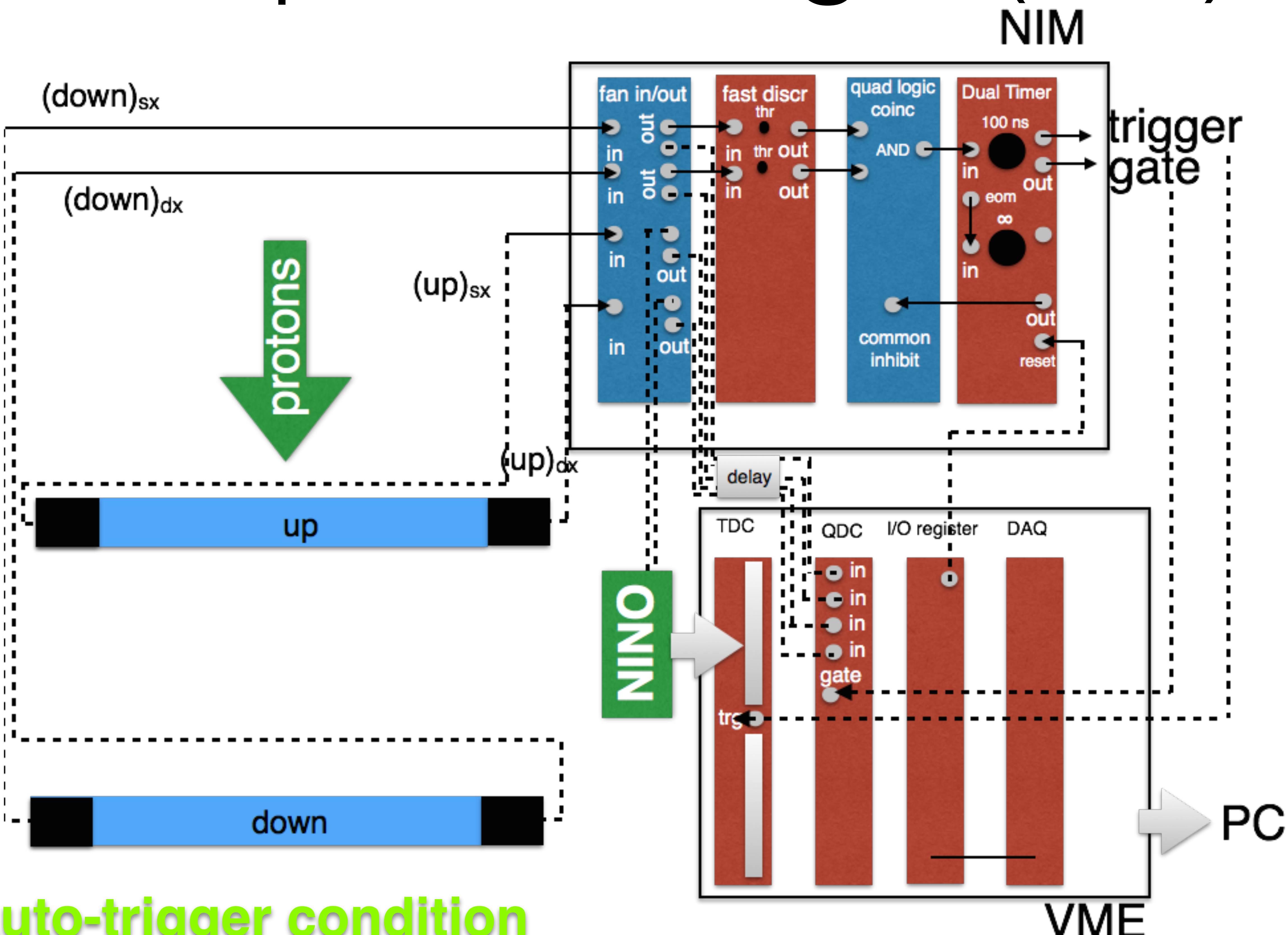
TDC
CERN HpTDC



High Resolution Mode:
8 TDC **channels** with **res=25 ps**

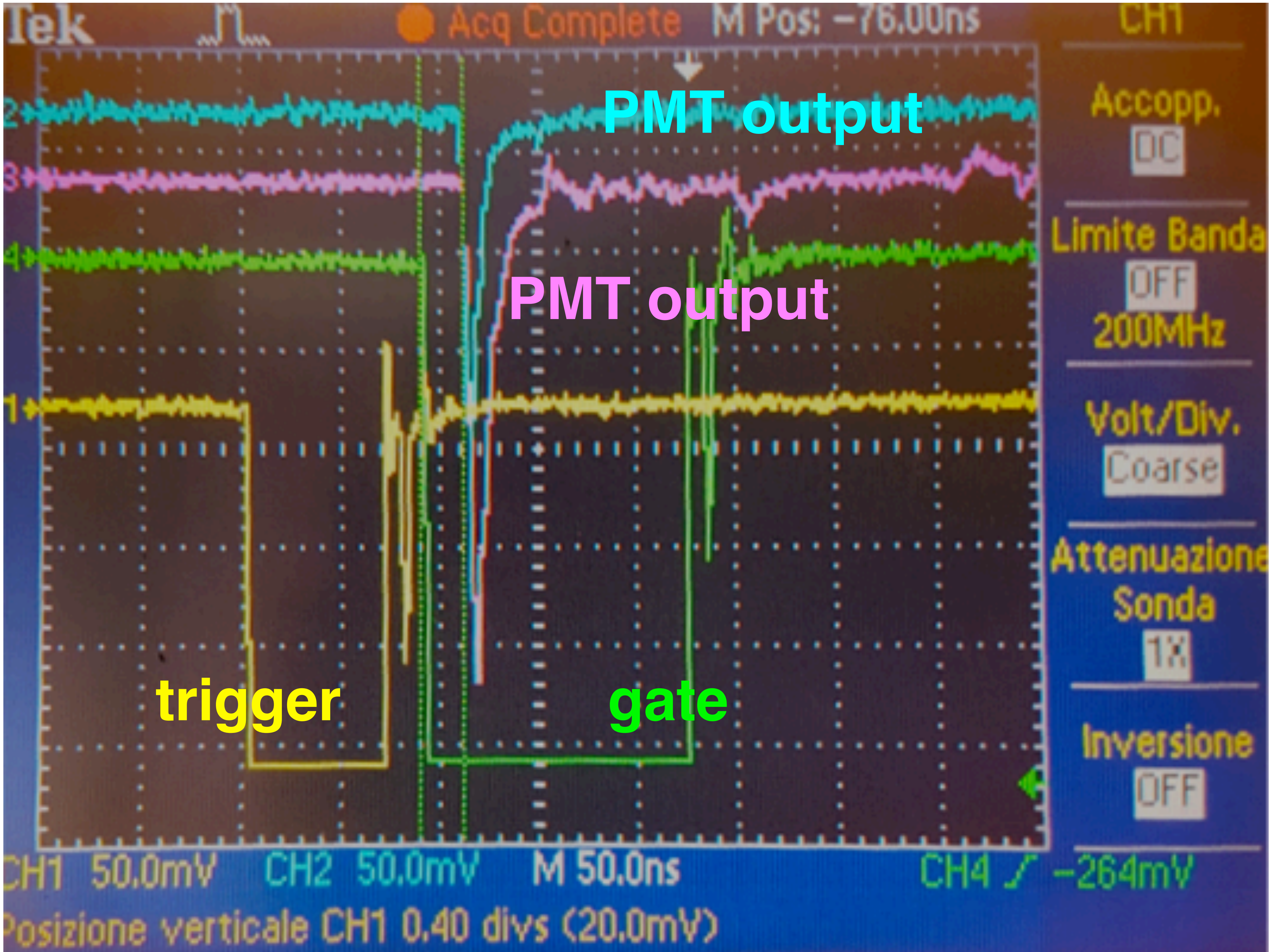
Fully differential Input

Acquisition logic (1/2)



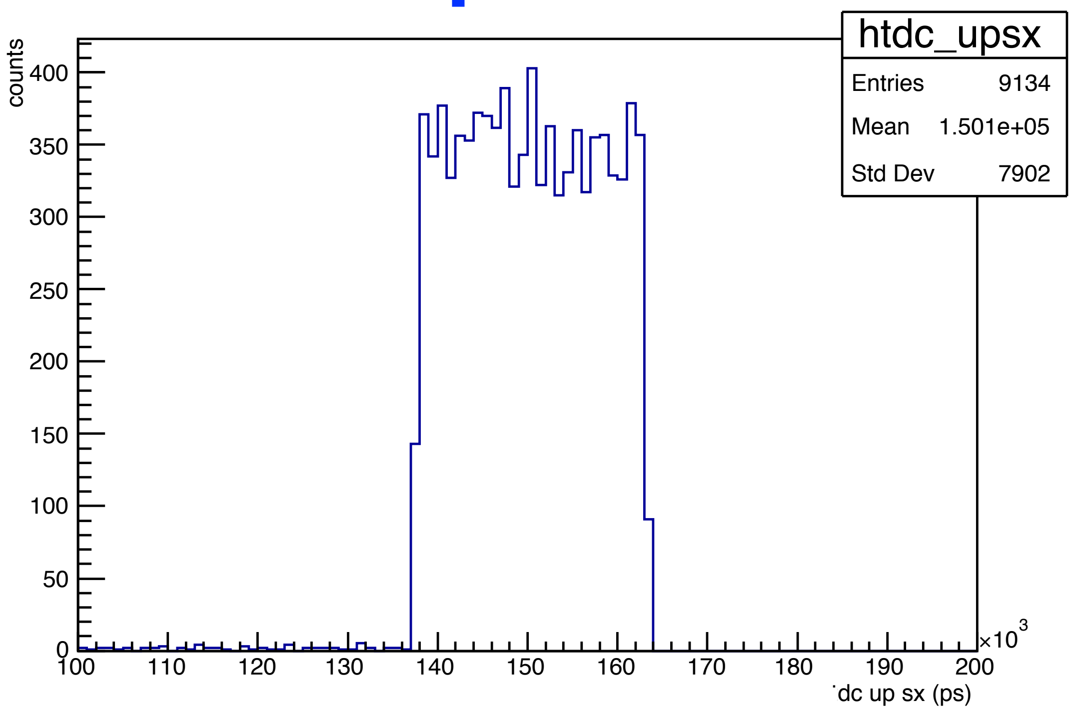
Auto-trigger condition

Acquisition logic (2/2)

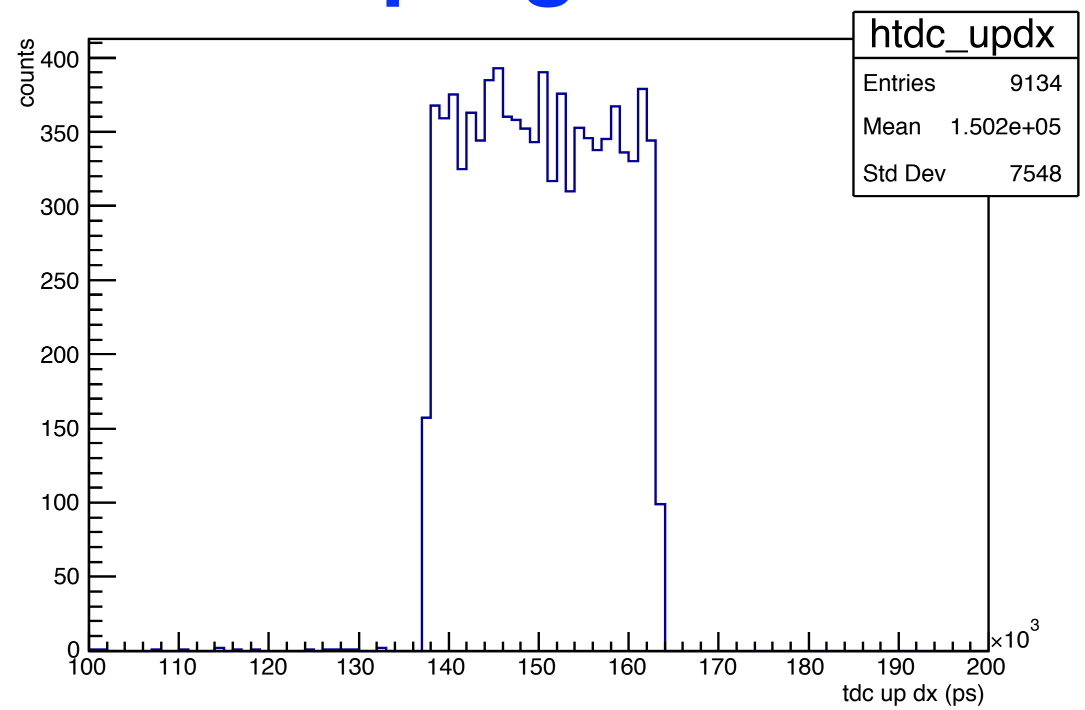


HpTDC (multihit)

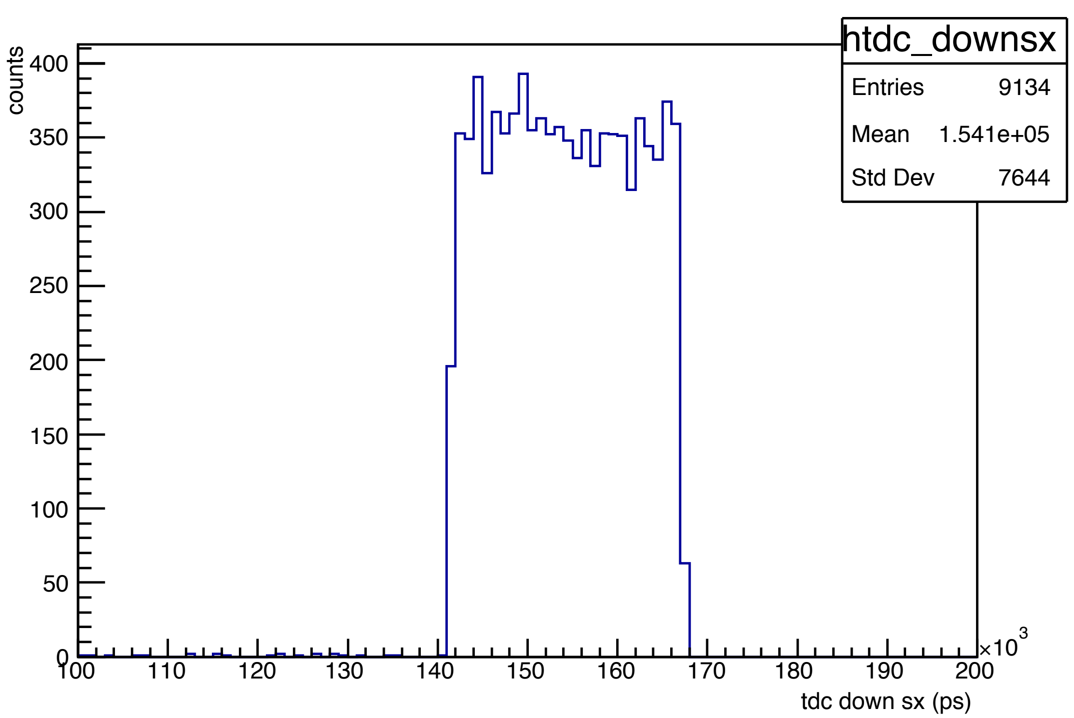
up left



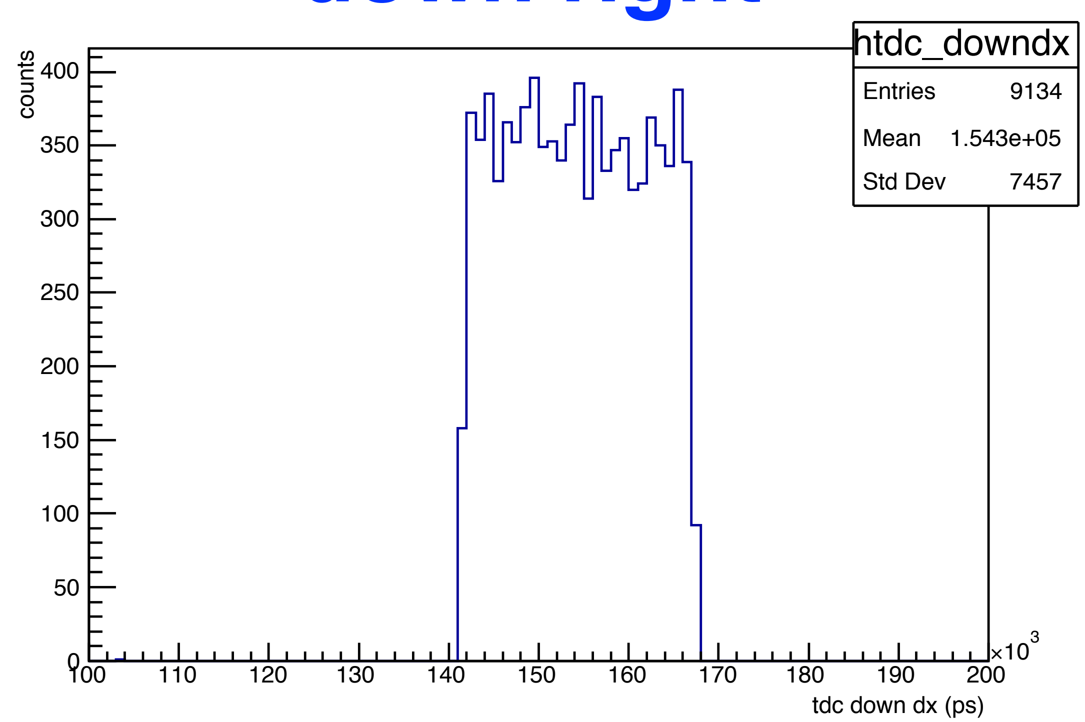
up right



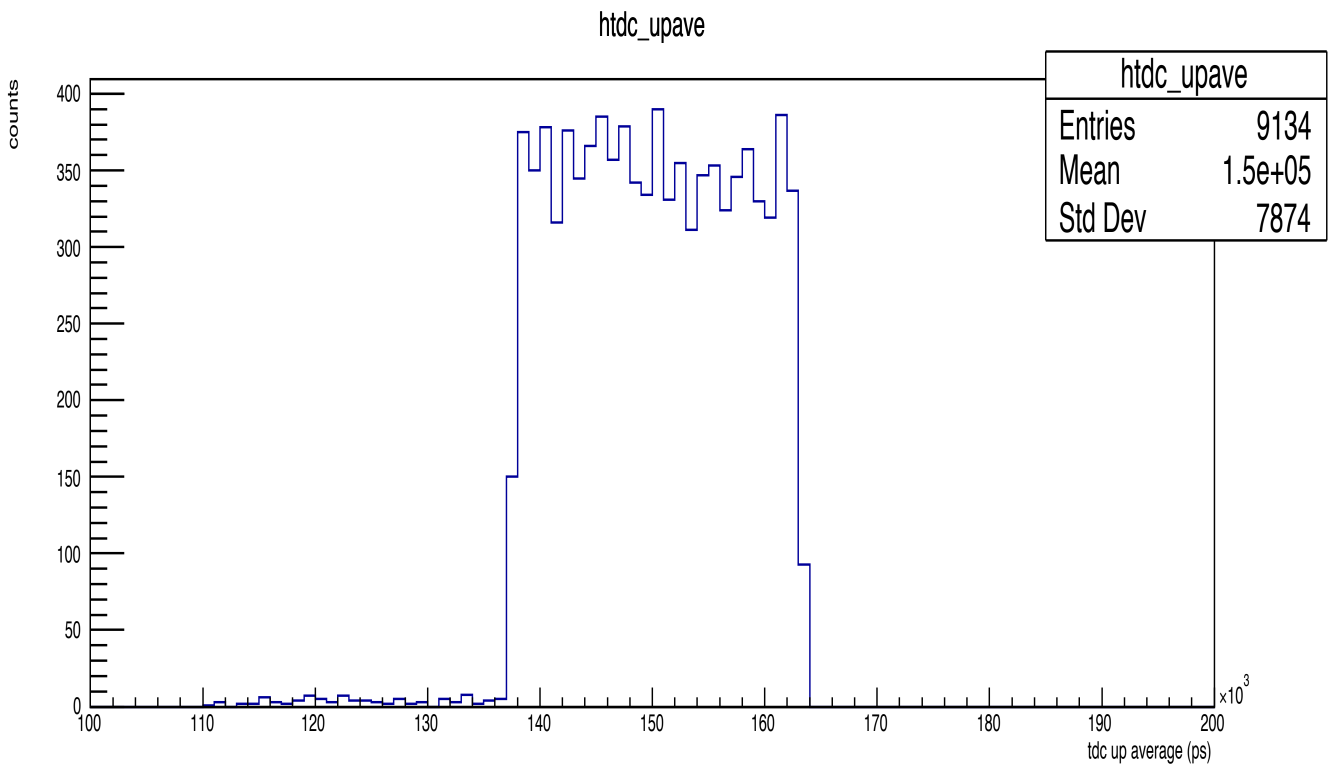
down left

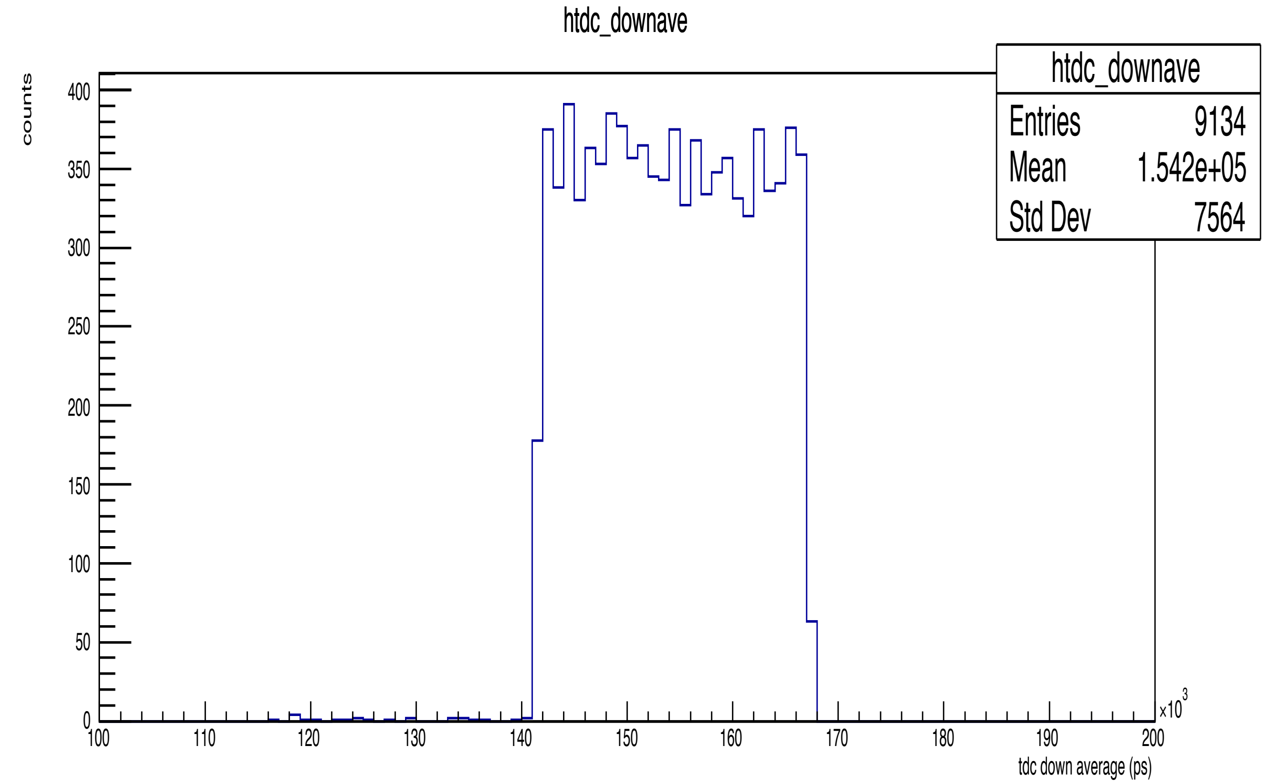


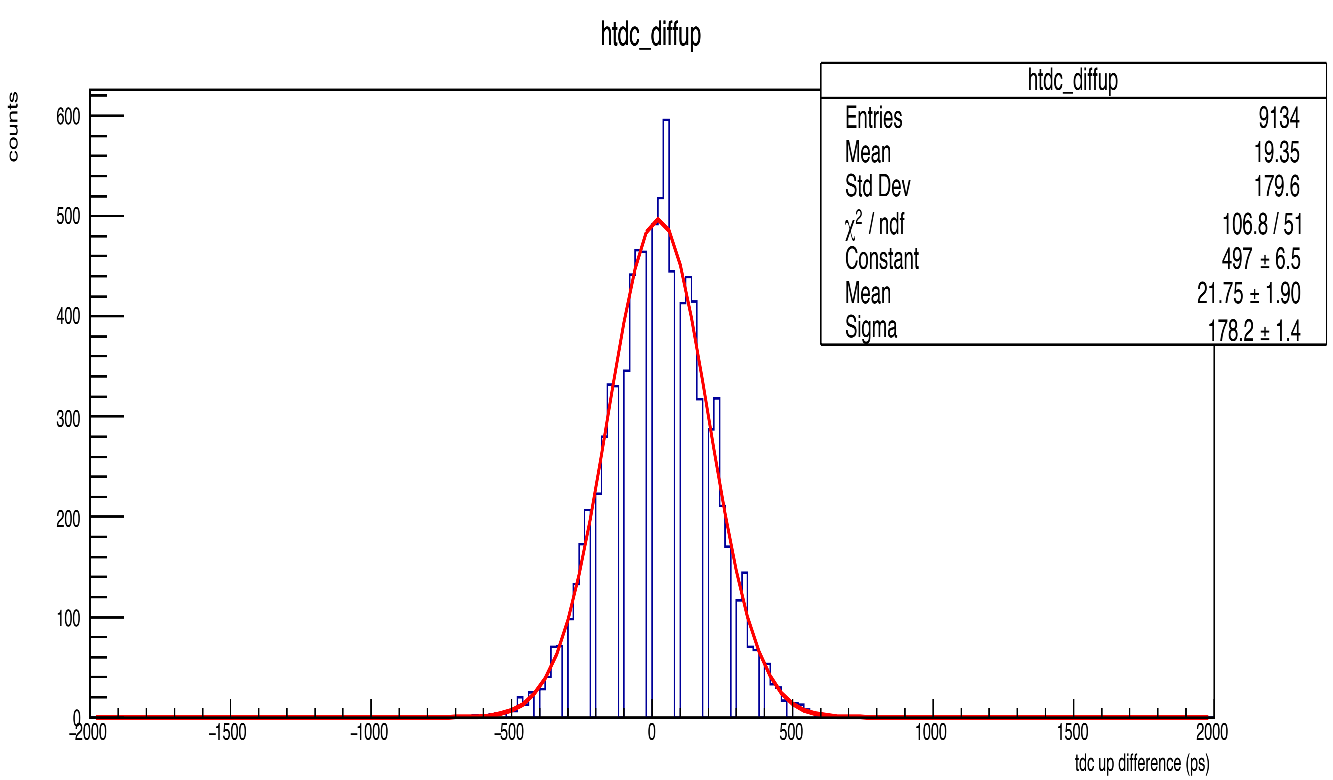
down right

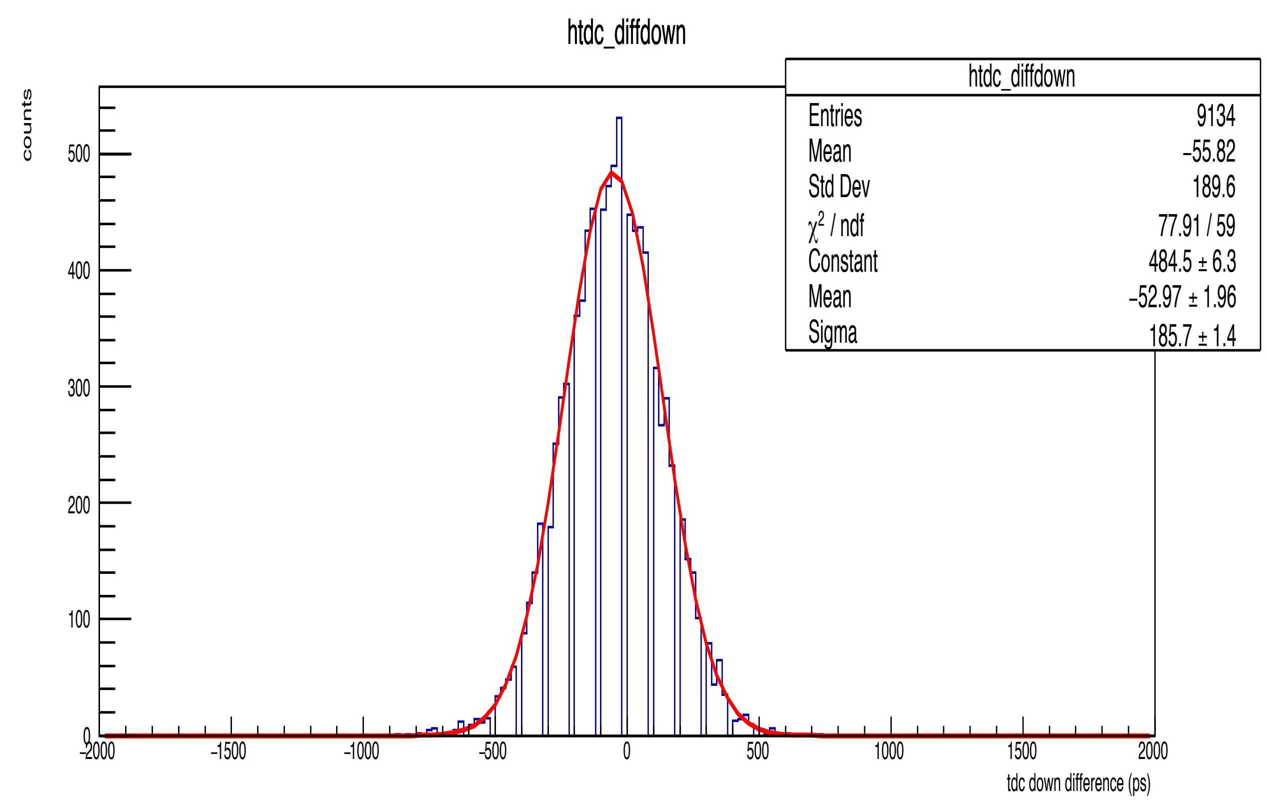


Average and difference

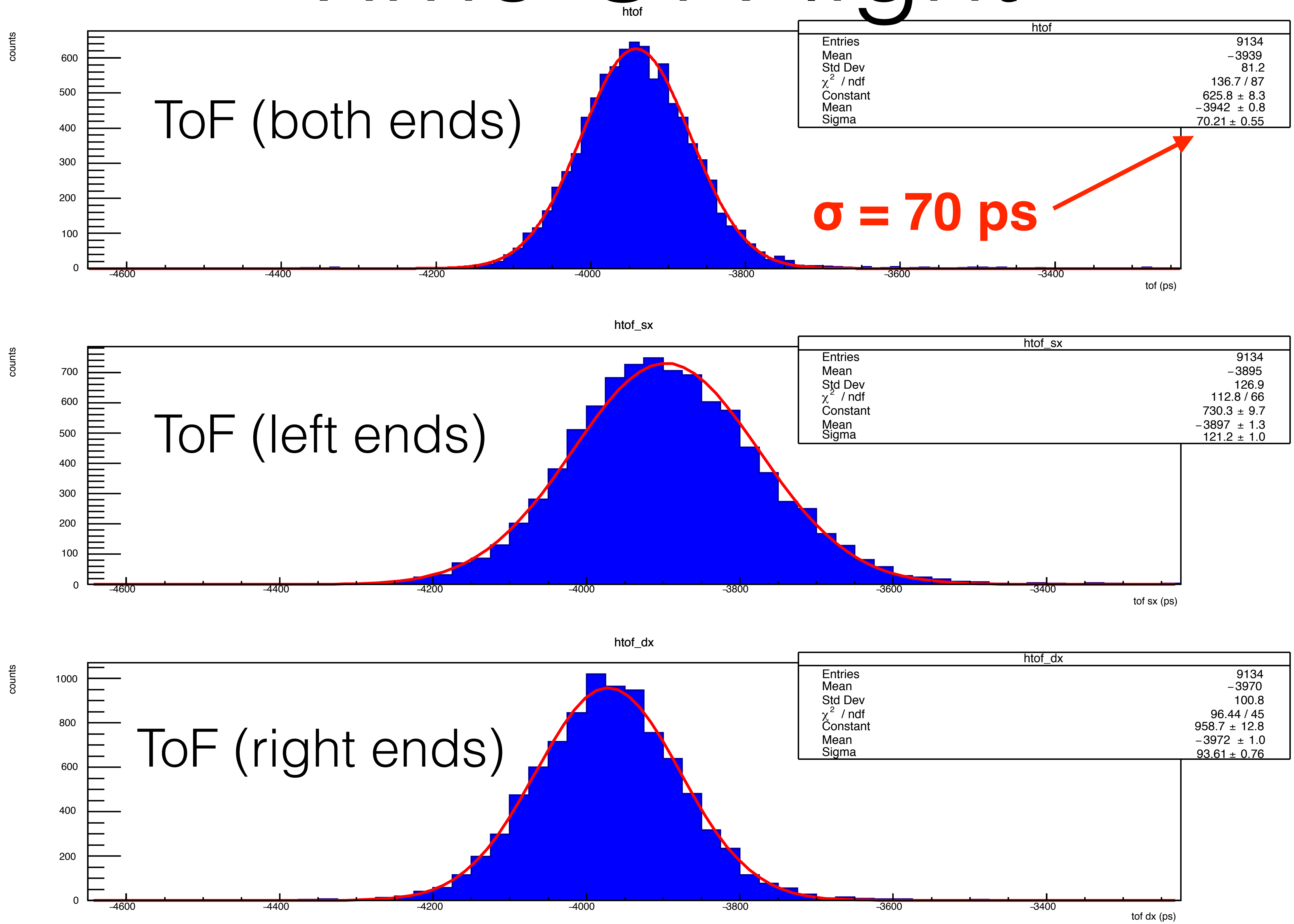




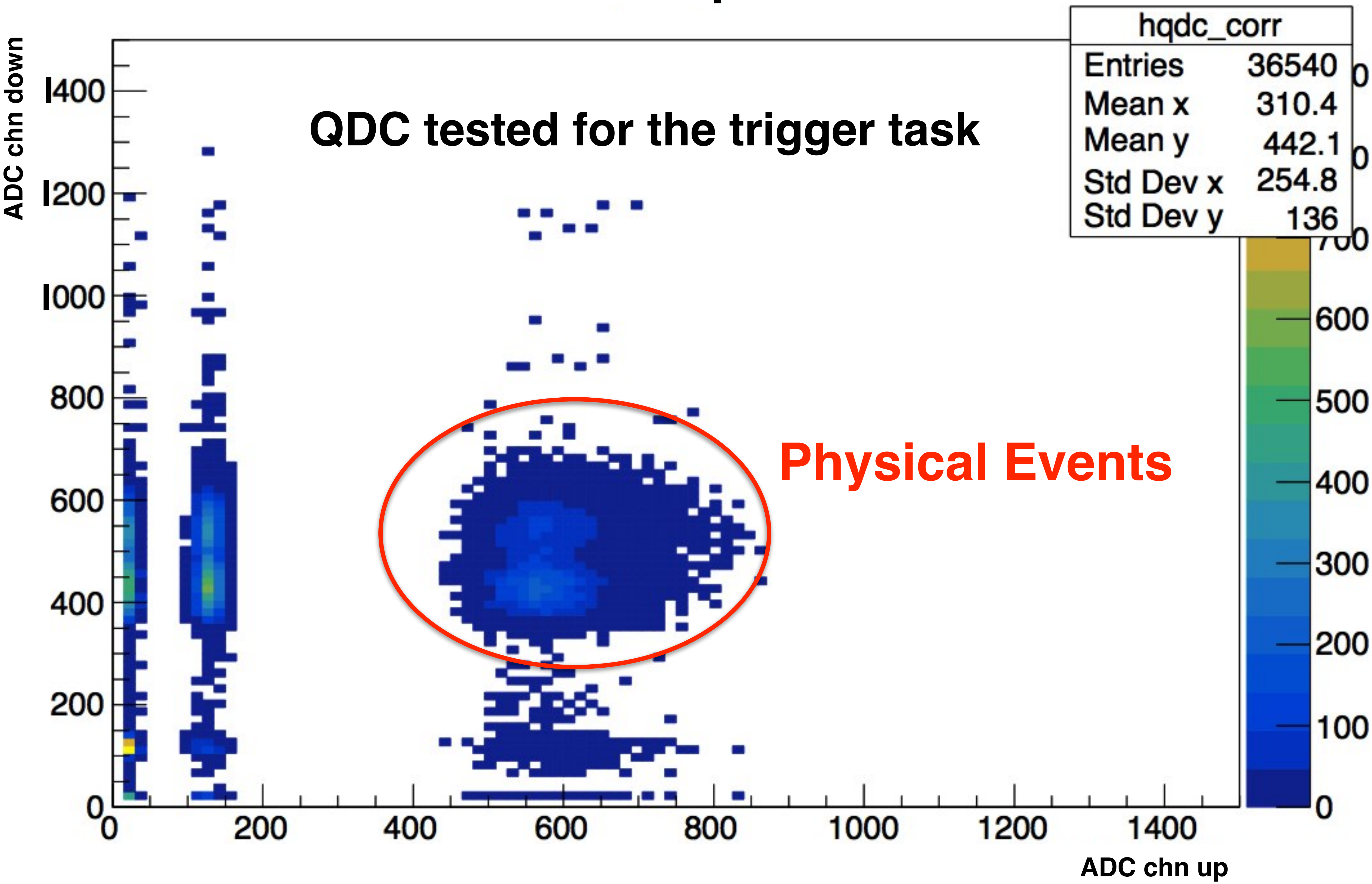




Time Of Flight

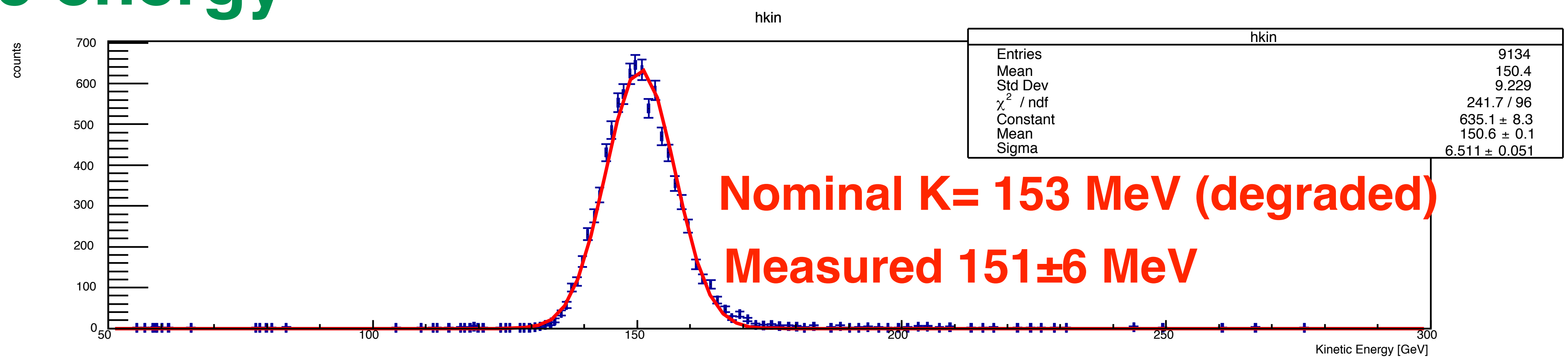


QDC acquisition

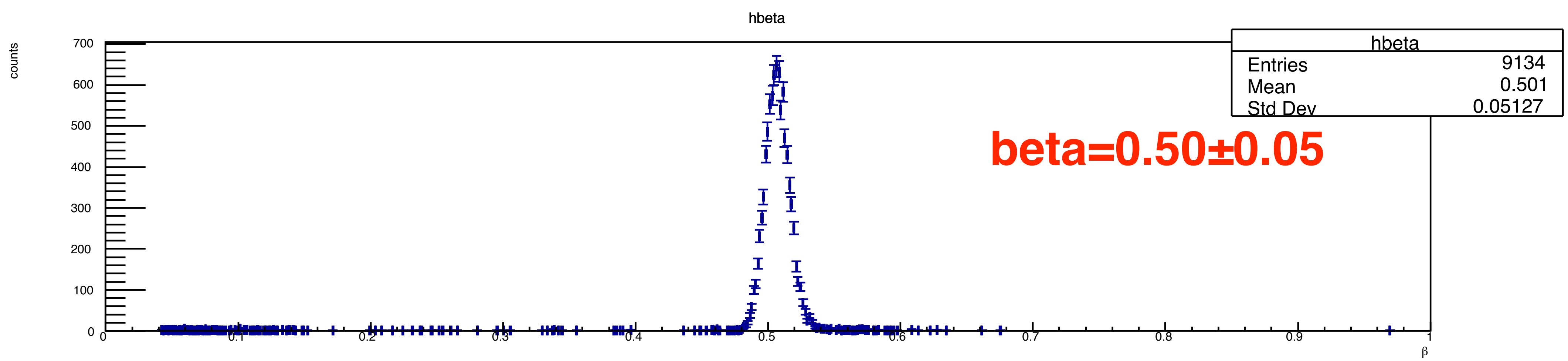


Test on beam parameters: kinetic energy

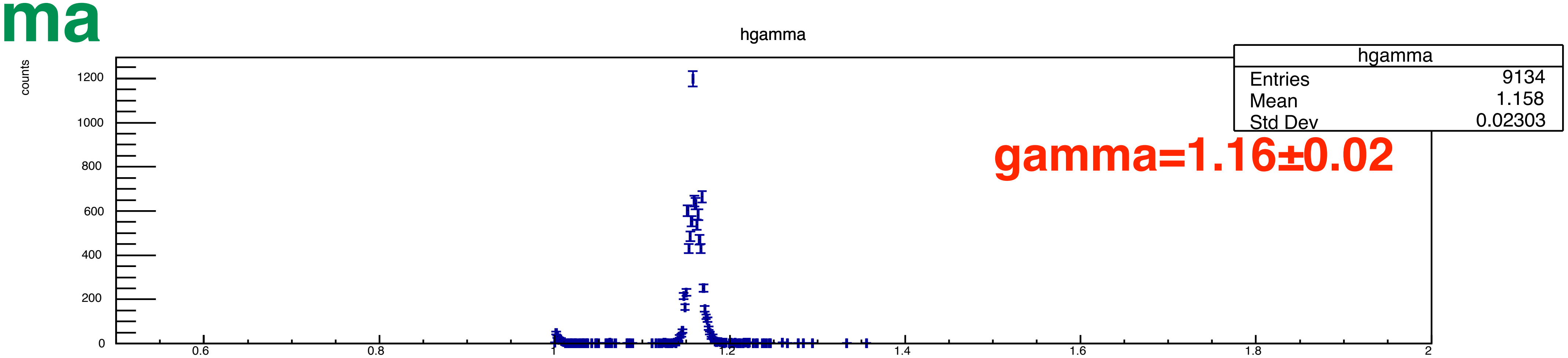
kinetic energy



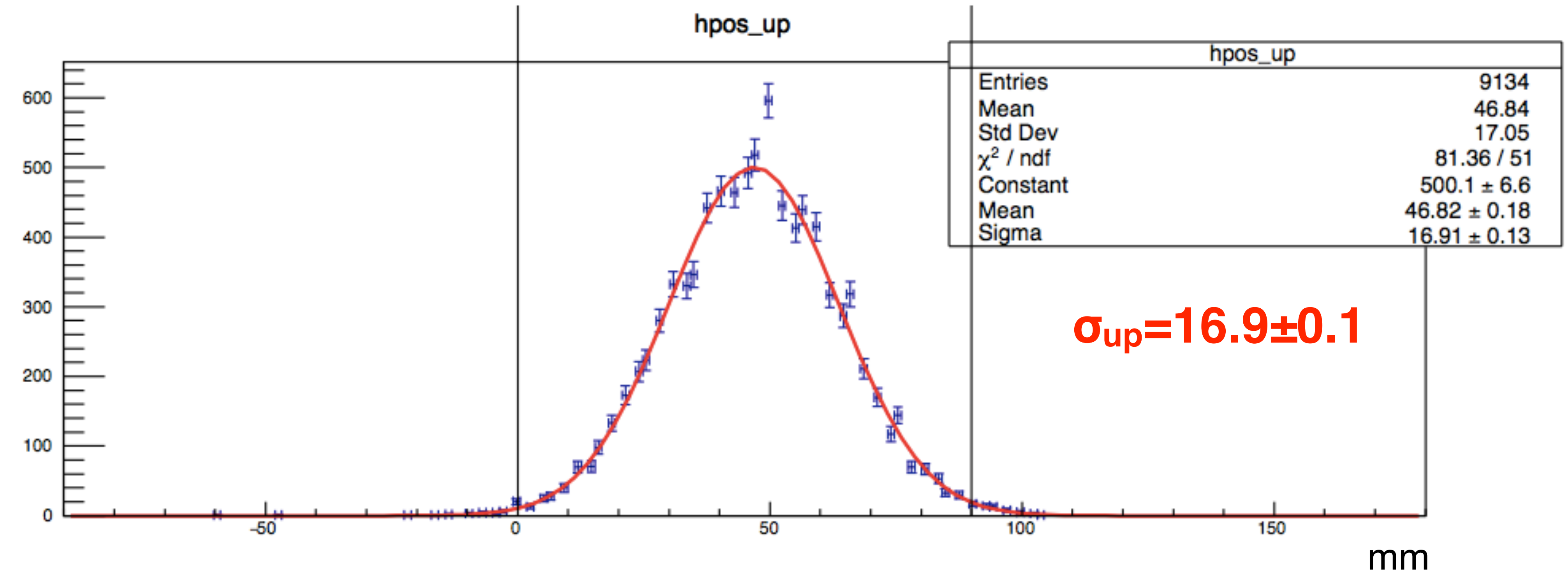
beta

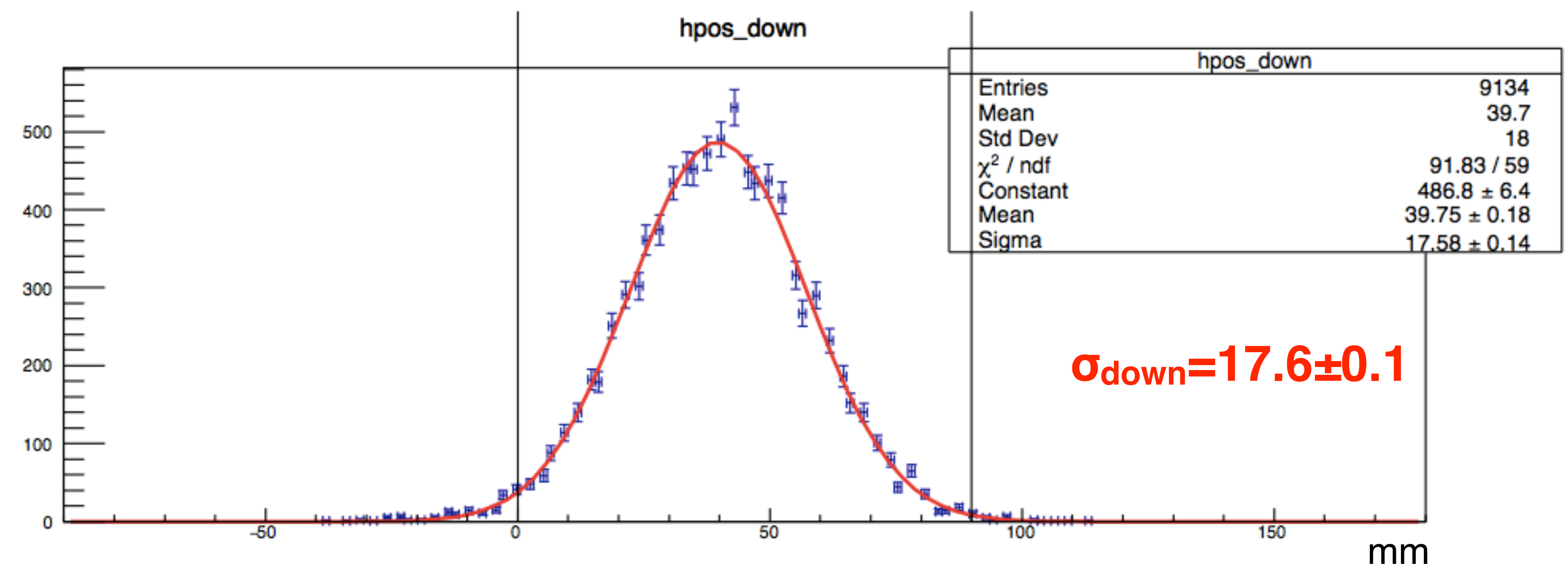


gamma



Test on beam parameters: sigma of the beam

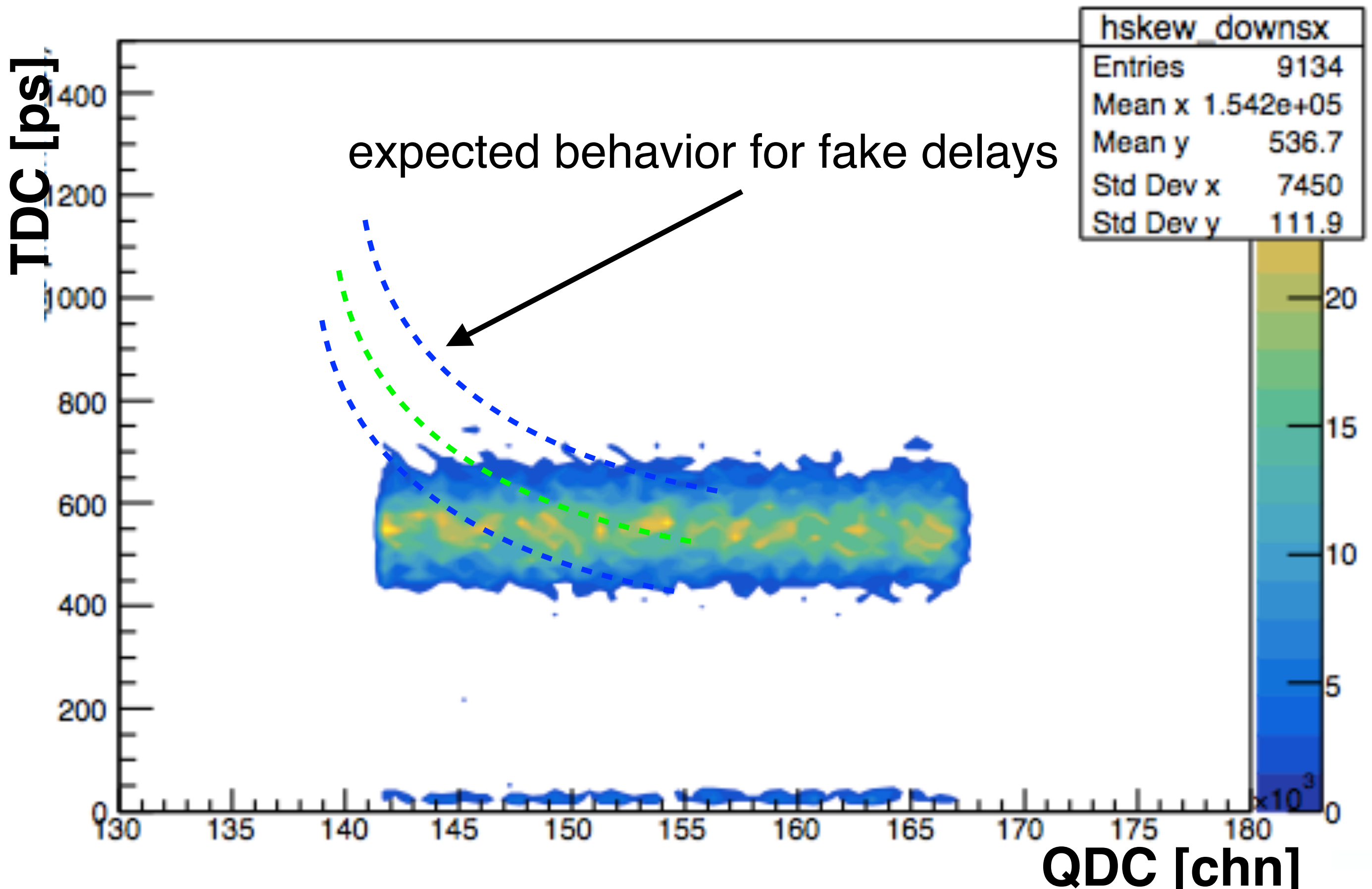




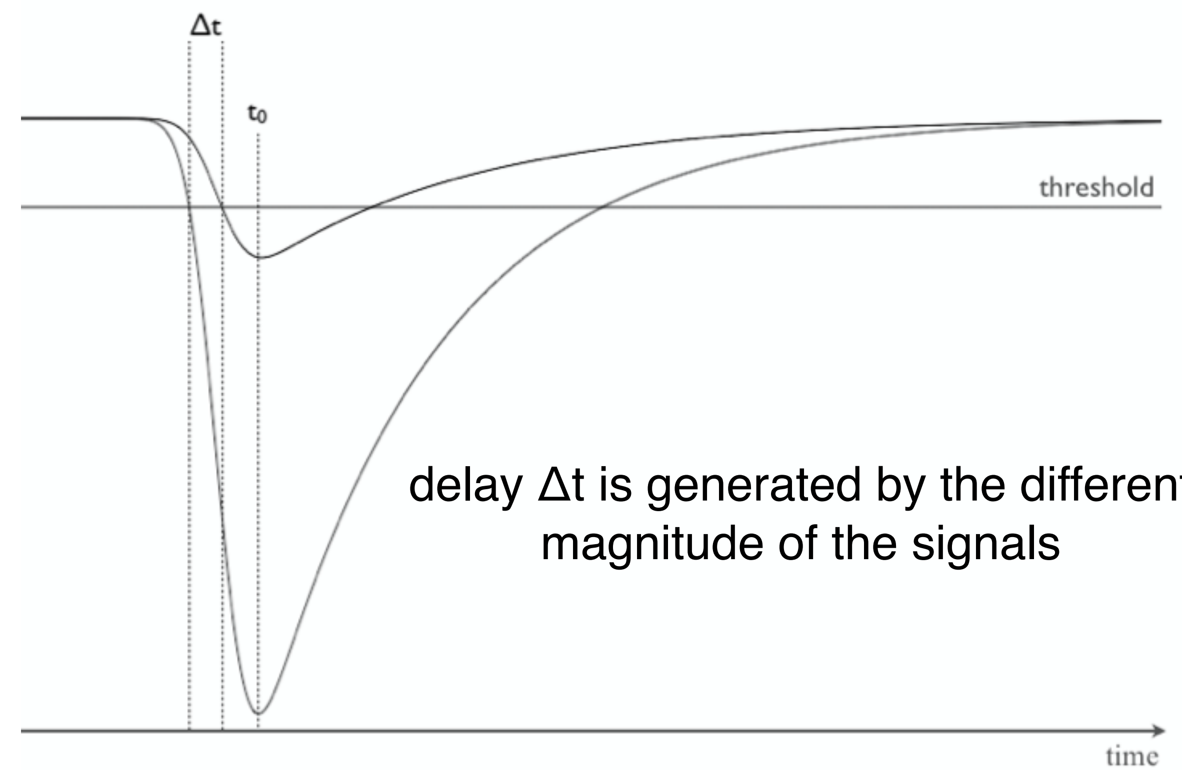
$\sigma_{machine}$ ~ 15mm at the isocenter (without any material in between)

What we have learned

NINO behavior

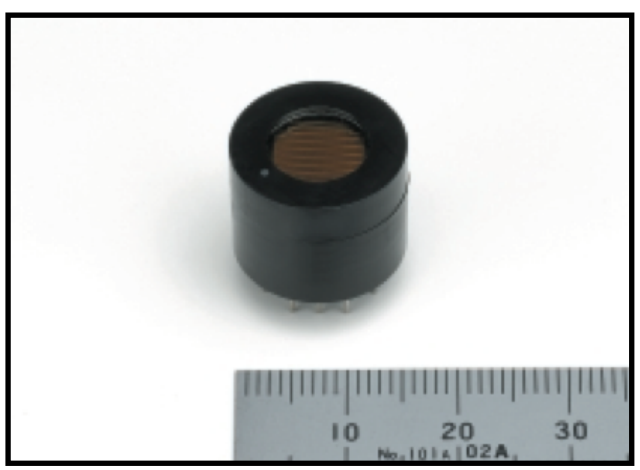


No evidences of **fake delays**



Meaning: **NINO** acts as **CFD**

Reduce signals



PMT R9880-U110

QE~30%
(U210 ~40%)

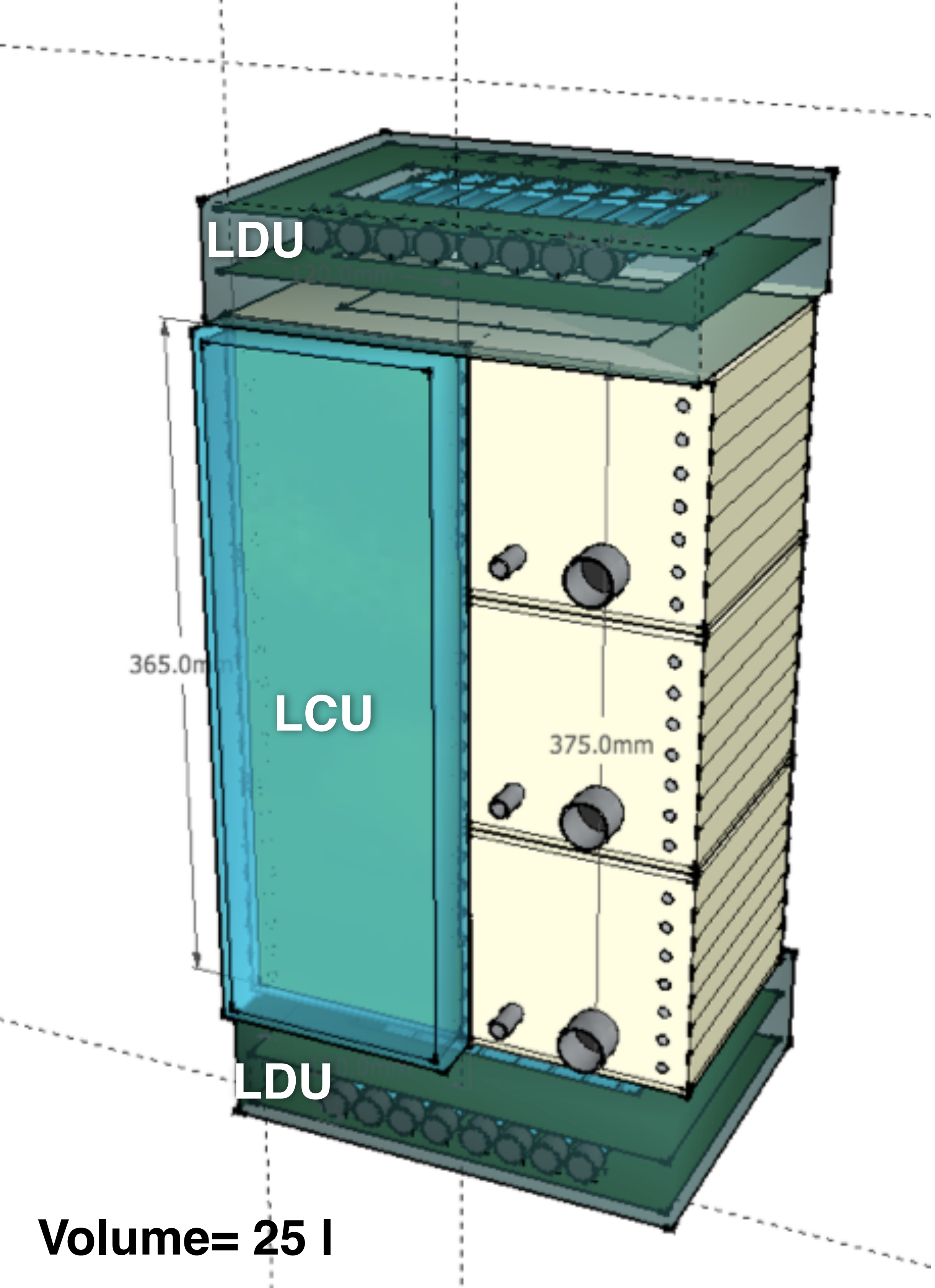
but at the same time this behavior could be due to NINO saturation

We observe a lot of cross talk
Confirmed at workbench tests

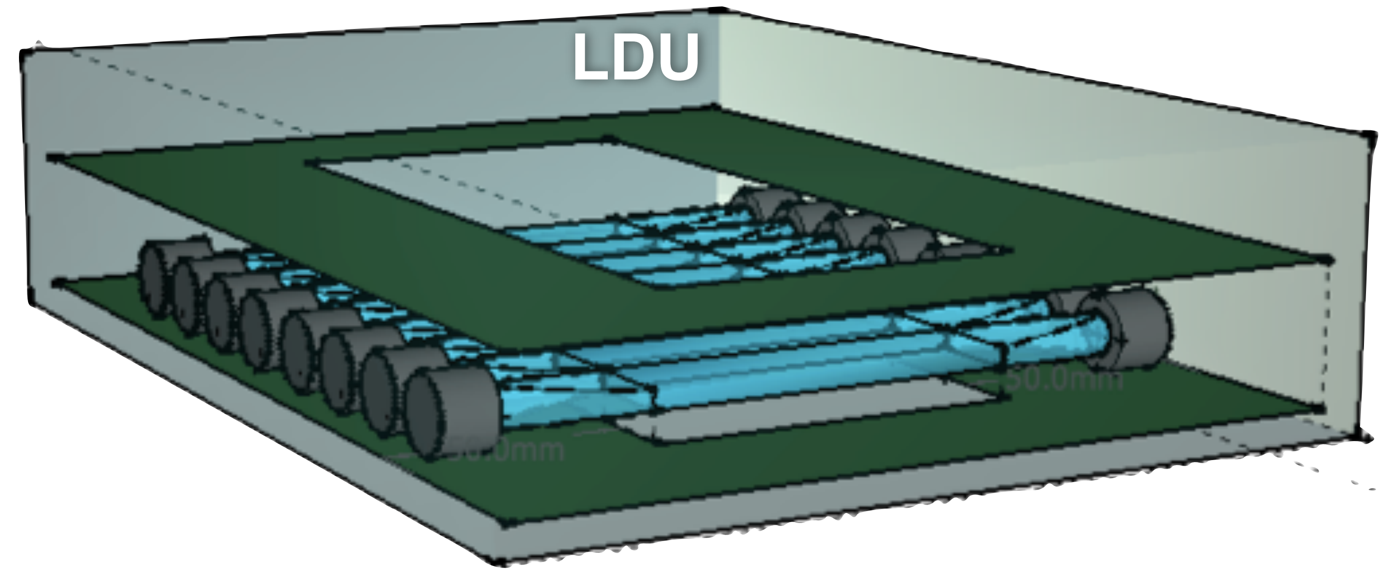
Smaller Scintillators 4 mm thickness

Toward LIDAL-ALTEA apparatus realization

LIDAL-ALTEA first sketches



Volume= 25 l



LDU (**L**IDAL **D**etector **U**nit)

- Scintillator Units
- NINO chip
- Trigger ALTEA circuit
- HV supply chips

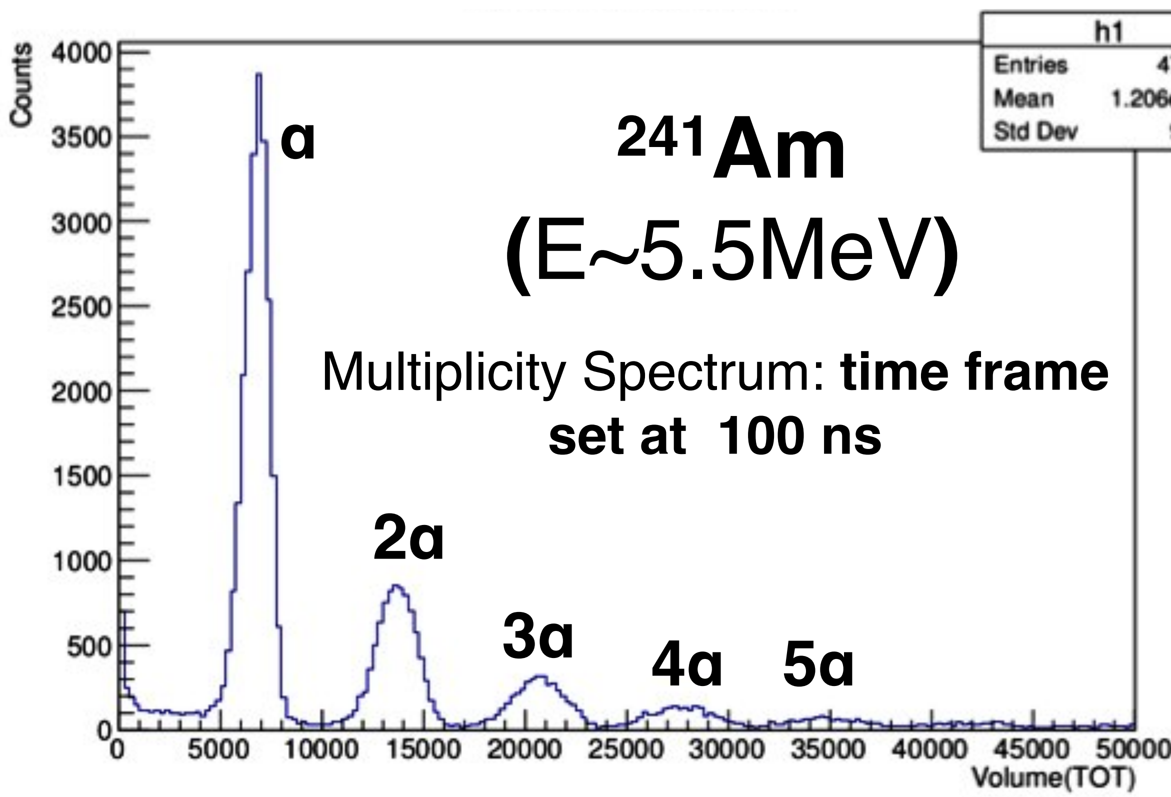
LCU (**L**IDAL **C**ollector **U**nit)

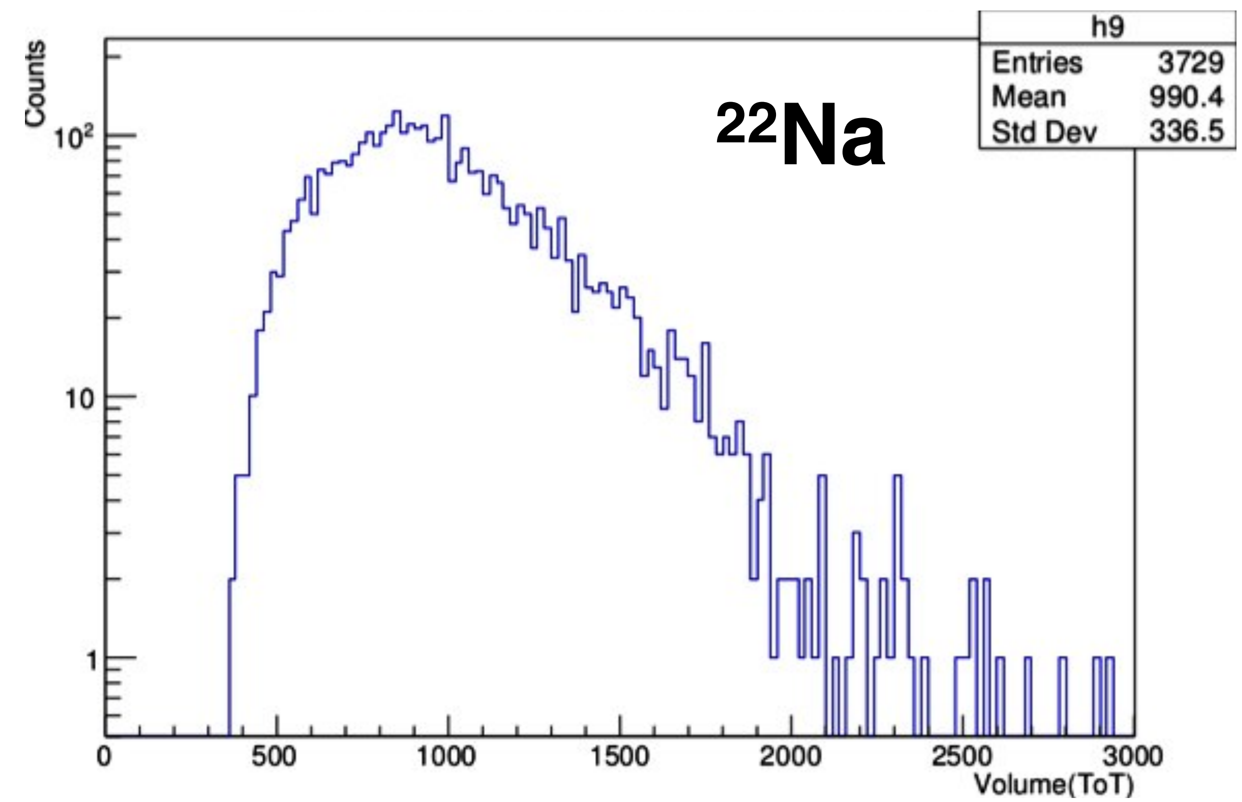
- HpTDC (sync issue)
- FPGA
- Power Supply distribution

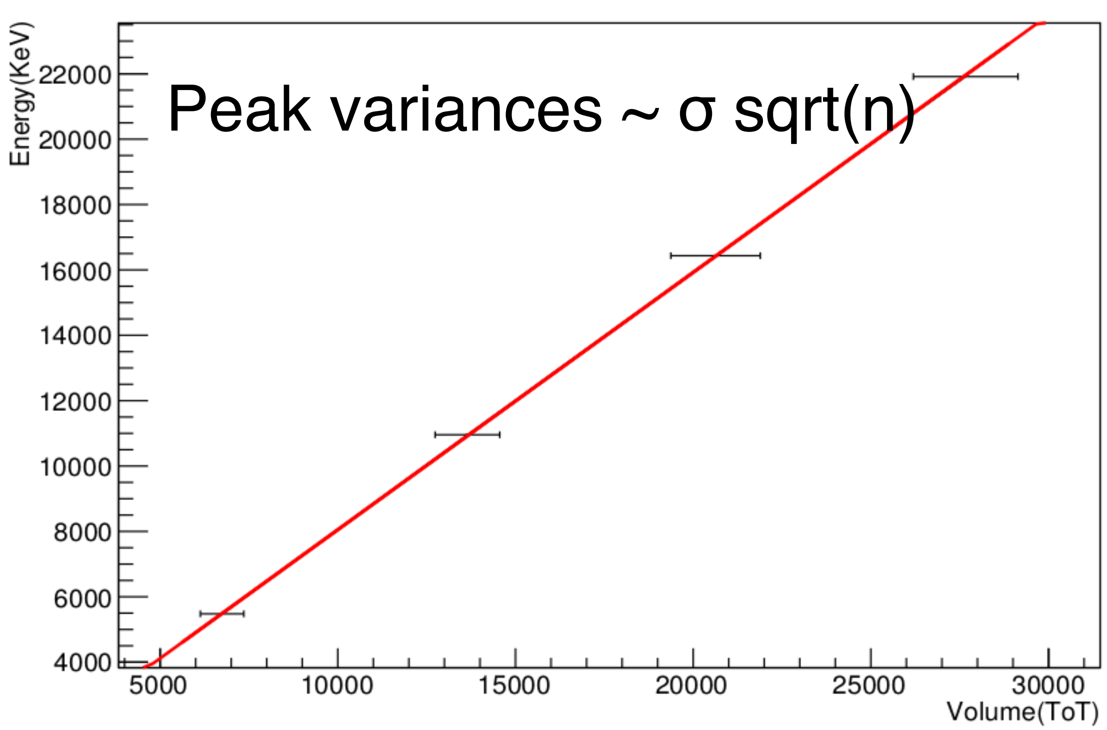
TimePix integration

TimePix Integration (1/2)

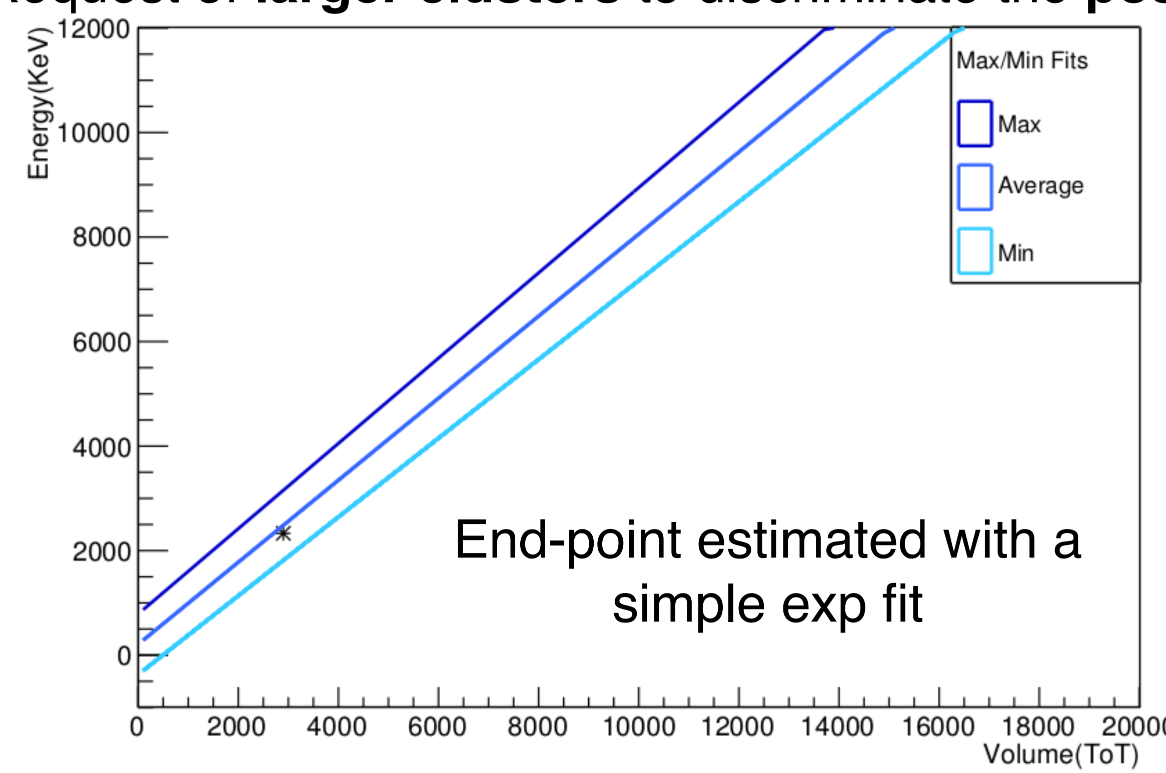
First calibrations @Tor Vergata



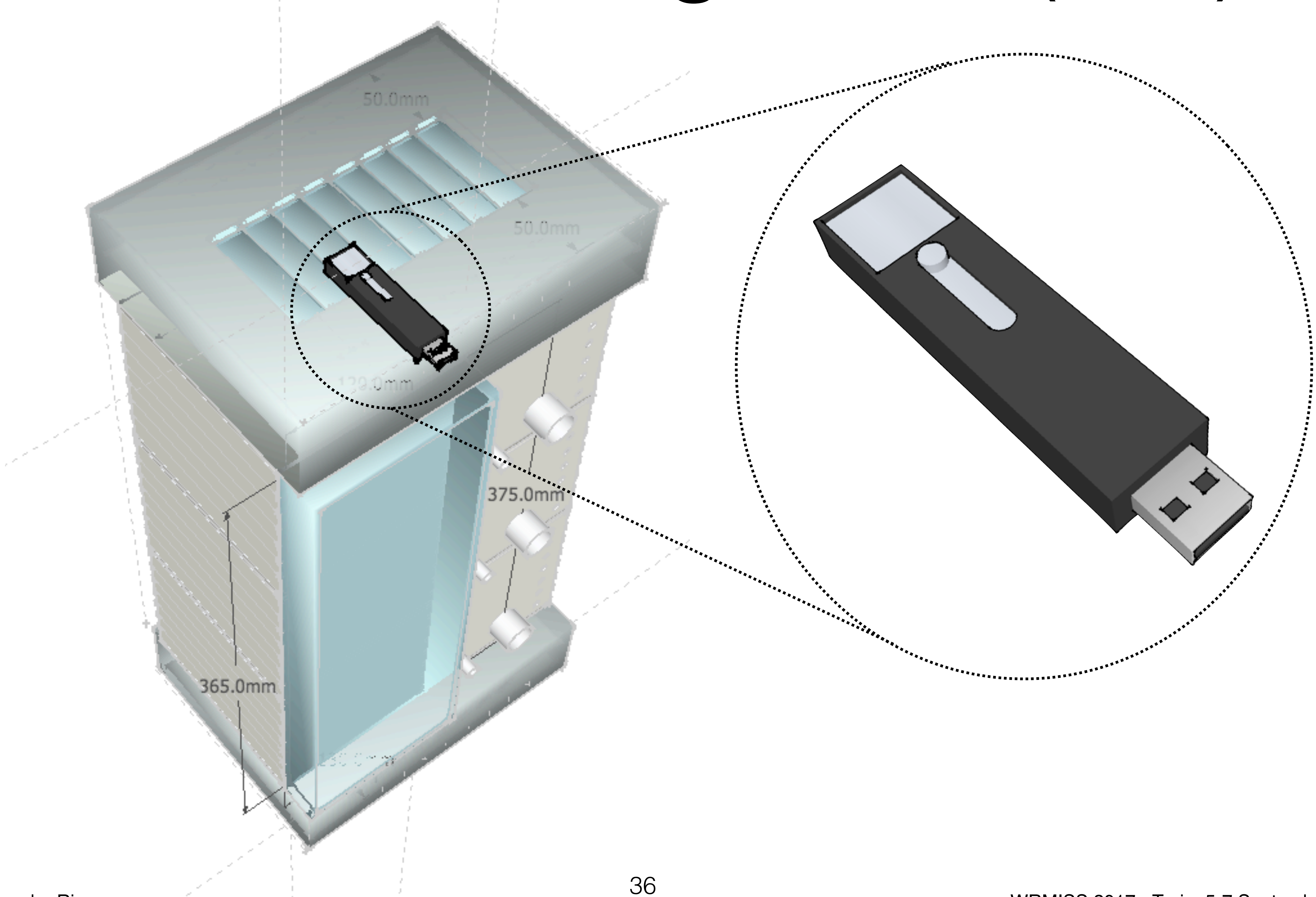




Request of **larger clusters** to discriminate the **positrons**



TimePix Integration (2/2)



Thanks for your attention!

LIDAL project

Università di Tor Vergata:

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	Piergiorgio Picozza
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Christian Manea
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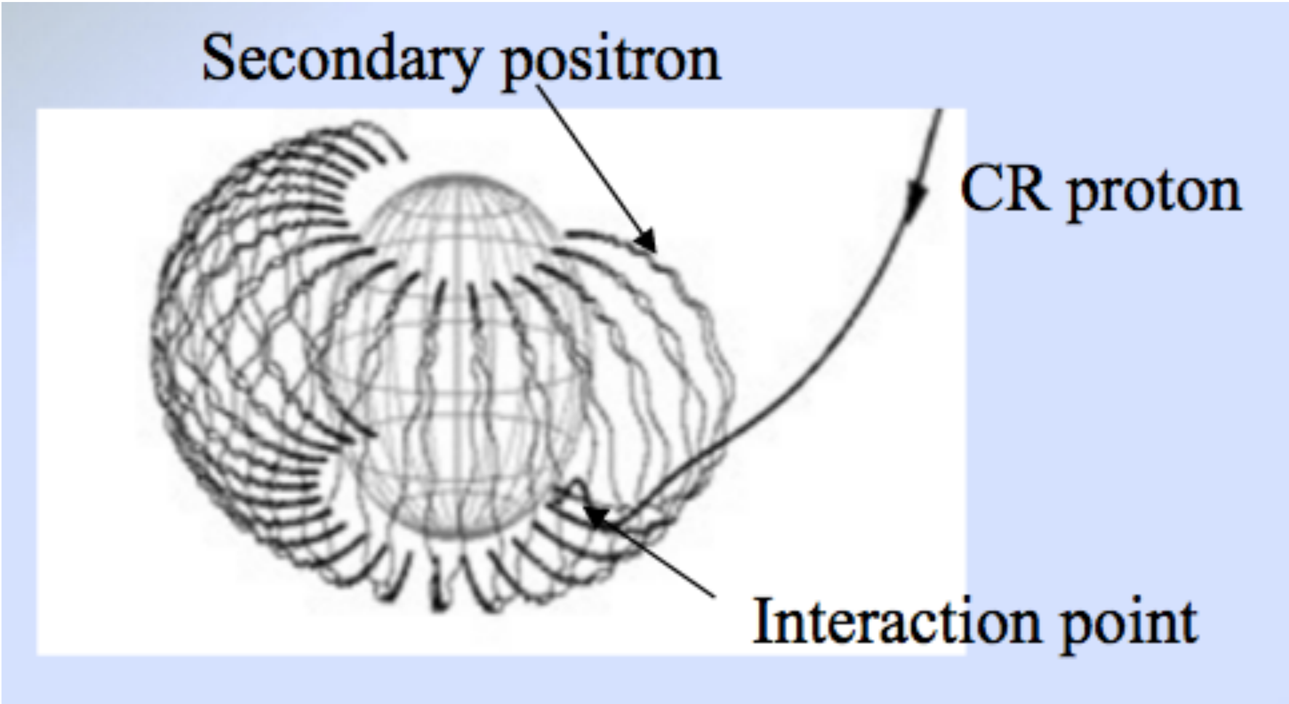
ALTEA acceptance windows

ALTEA Acceptance

Albedo Proton



We loss a considerable part of the proton spectrum, important for risk assessment for next manned missions in space

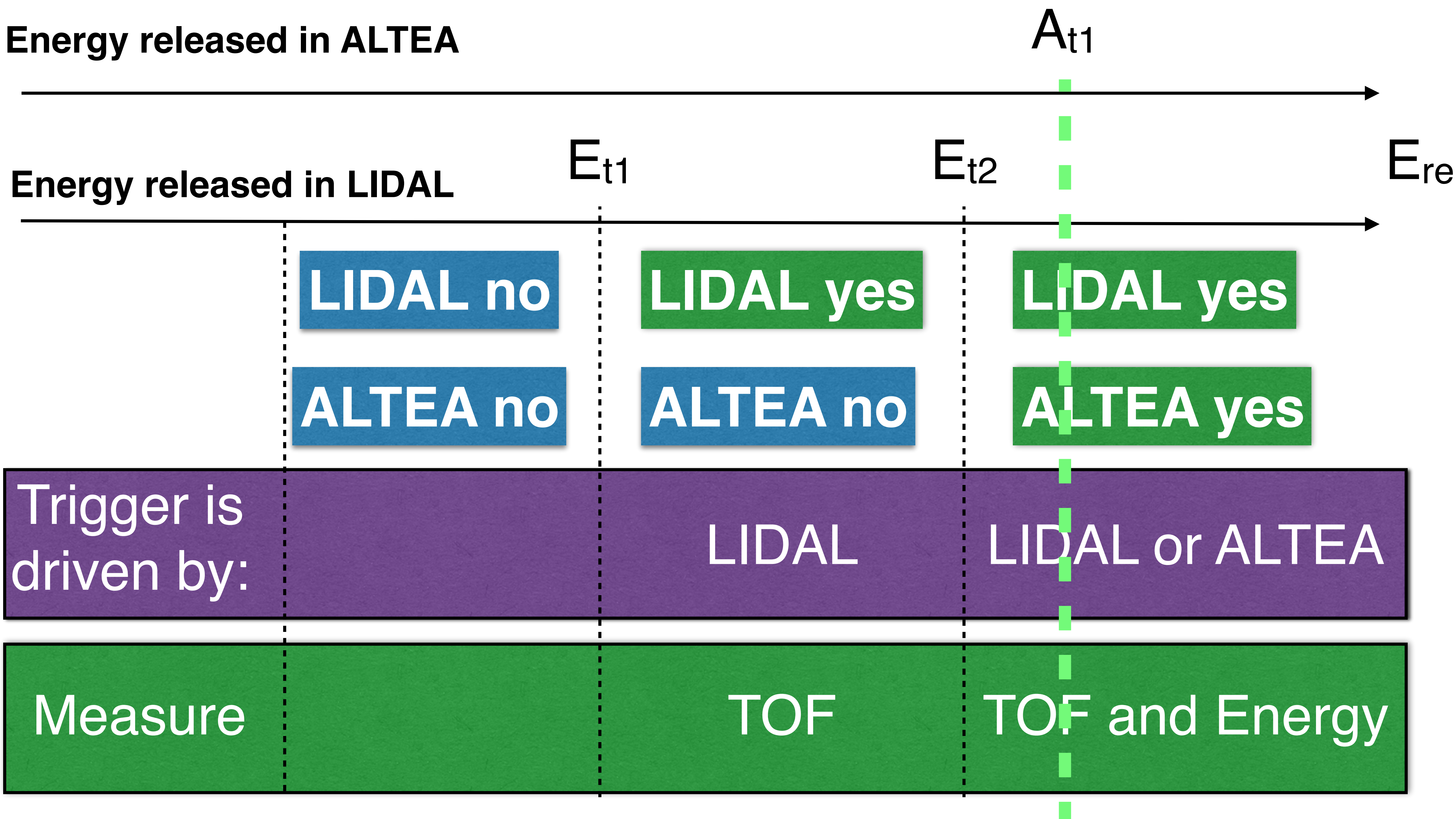
An enhancement of the ALTEA detecting power for protons and alphas is needed

LIDAL trigger logic sketch

LIDAL thresholds: $\mathbf{E_{t1}}$ $\mathbf{E_{t2}}$

ALTEA threshold: $\mathbf{A_{t1}}$

Cross-Calibrations LIDAL-ALTEA



Risk assessment in space VS the standard dosimetry

Approach	Physical Quantities (Measured)	Dosimetric Quantities (Evaluated)	
Standard Dosimetry	**Averaged quantities (d<E>/dm)**	**weighting factors w_r, w_t: epidemiological analysis**	**E** Effective Dose
Dosimetry in Space (active detectors)	**Punctual quantities (per particle)**	**Quality factor Q (energy dependent)**	**H_T** Equivalent Dose

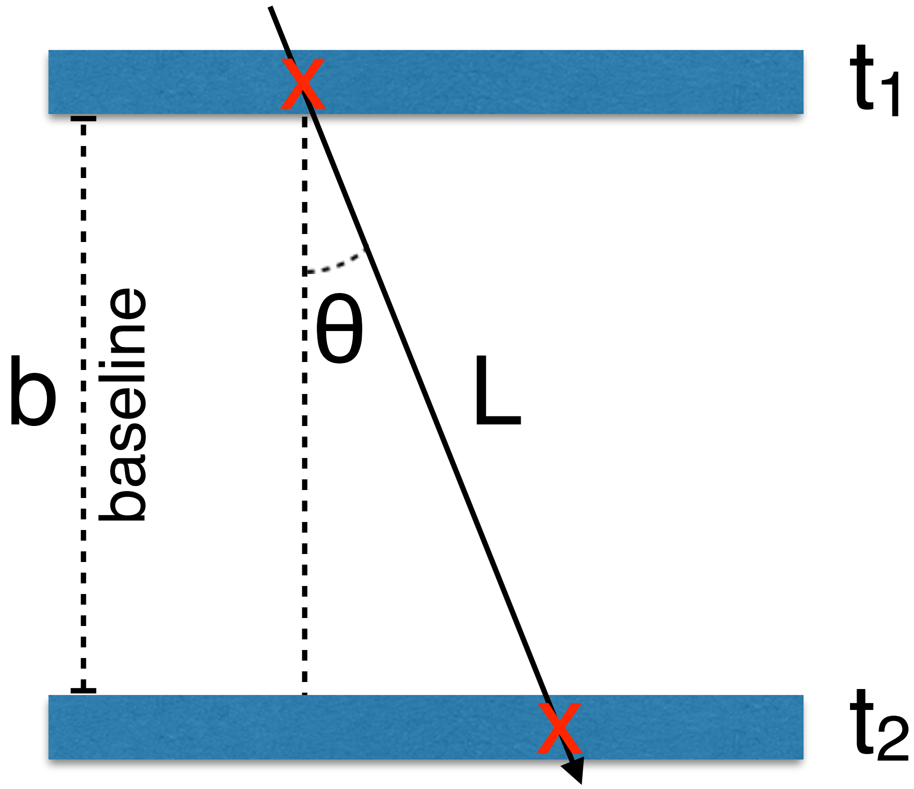
H_T in space (active detector) is a strictly physical quantity!

$$\frac{dE}{dx} \approx \rho N_e m_e c^2 r_e^2 \frac{Z}{A}\frac{z^2}{\beta^2}\left[ln\left(\frac{\gamma^2\beta^2 W}{I^2}\right) - 2\beta^2 - \delta - \frac{2C}{Z}\right]$$

Important parameters for risk assessment in space

- - - - - - - - - - **ALTEA**
- - - - - - - - - - **LIDAL**
- - - - - - - - - - **LIDAL+ALTEA**

ToF Measurements



Lorentzian Factors	$\beta = v/c$ $\gamma = (1-\beta^2)^{-1/2}$
Energy	$E = \gamma m c^2$

Kinetic Energy from ToF Measurements

$$\Delta t = t_2 - t_1 \;\rightarrow\; \beta = \frac{L}{c\Delta t} \;\rightarrow\; T = \sqrt{\frac{m^2c^4}{1-\frac{L^2}{c^2\Delta t^2}}} - mc^2$$

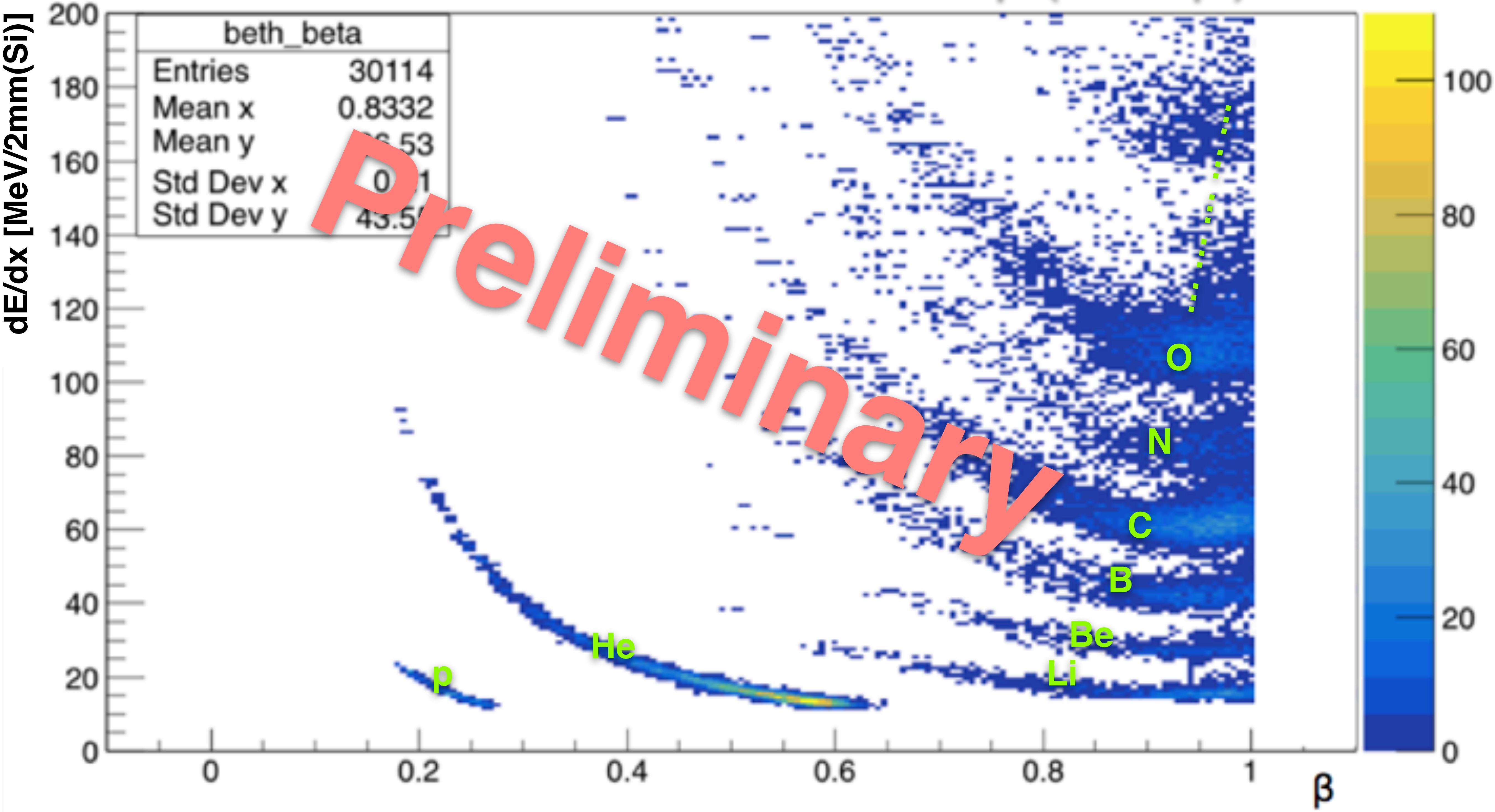
Time Difference for 2 particles with the same momentum and different masses (m_1 and m_2)

$$\Delta t = \frac{L}{cp}\left[\sqrt{p^2 + m_2^2c^2} - \sqrt{p^2 + m_1^2c^2}\right] \xrightarrow[m \ll p]{} \frac{Lc}{2p^2}\left[m_2^2 - m_1^2\right]$$

Taylor expansion for $m_{1,2} \ll p$

Discrimination Power

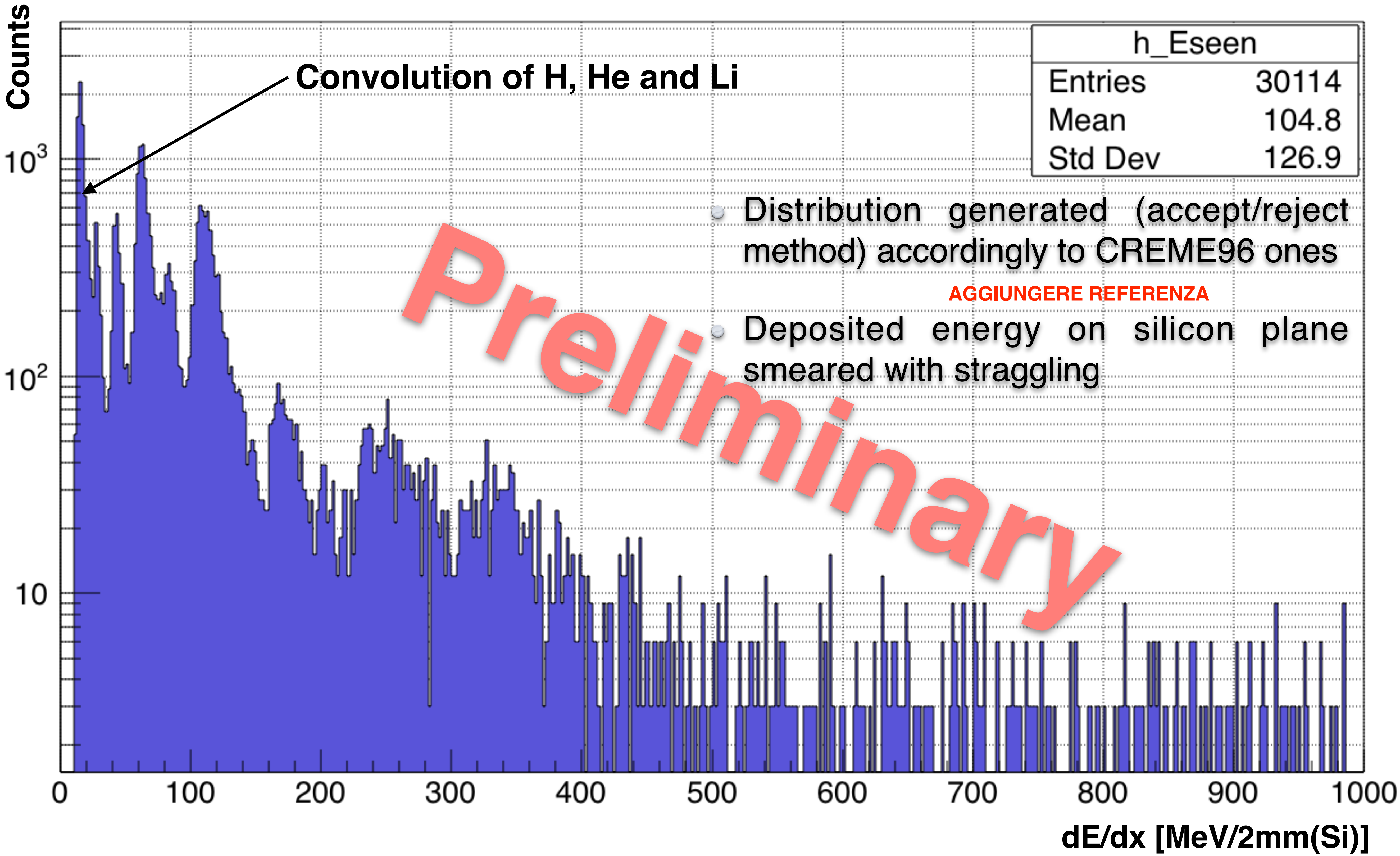
Asked for TIME RESOLUTION better than 120 ps (here 80 ps)



LIDAL-ALTEA apparatus: expected discrimination power

ALTEA acceptance windows have been included

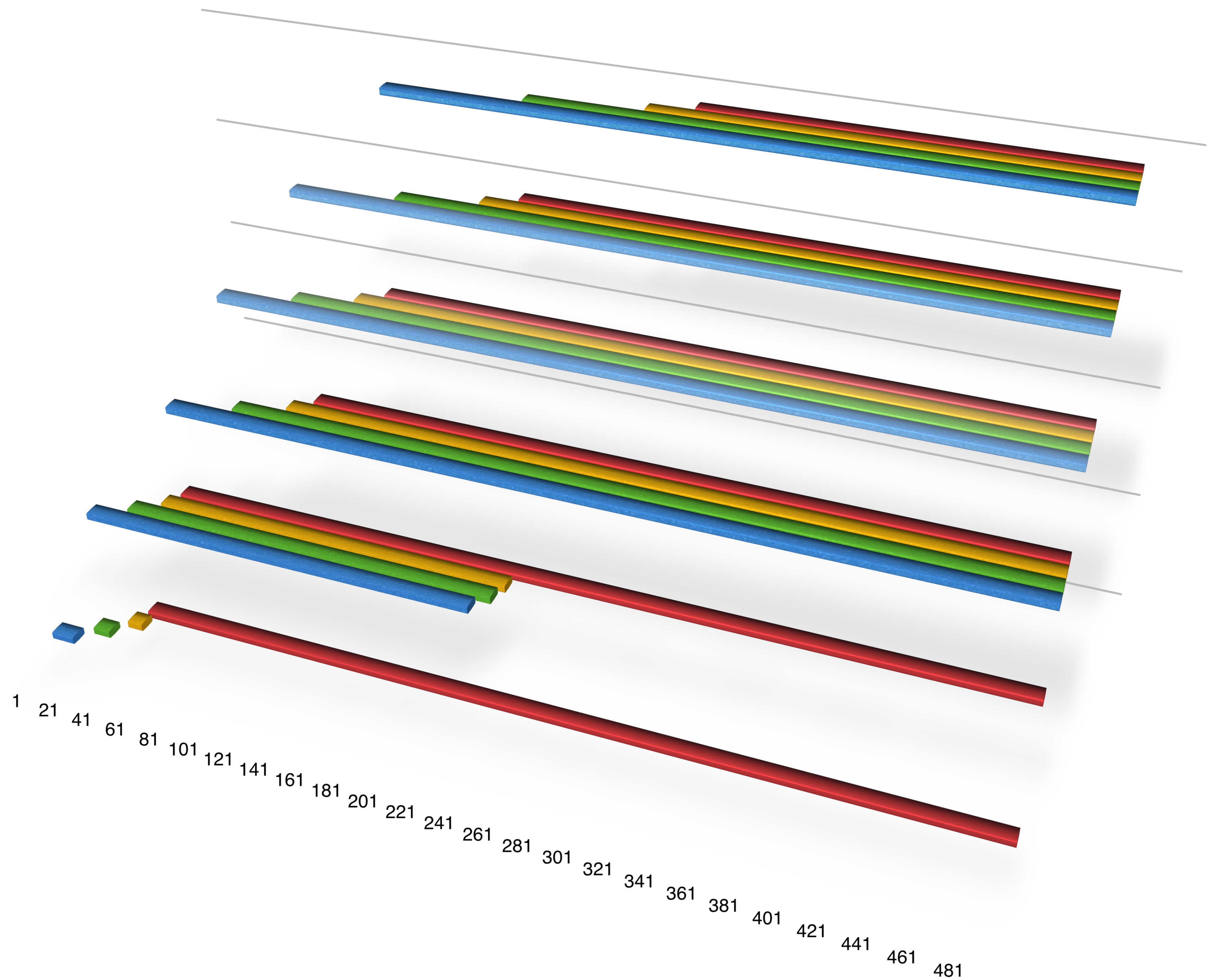
Simulated ALTEA spectrum



- Distribution generated (accept/reject method) accordingly to CREME96 ones

AGGIUNGERE REFERENZA

- Deposited energy on silicon plane smeared with straggling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