First experiments at the LEETECH facility at PHIL

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Orsay 2017

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LEETECH – Low Energy Electron Technology – facility at the PHIL to obtain quasi monochromatic electrons of variable low energy

Collaboration with: **LAL** (PHIL, general management and many other…); **CERN** (dipole magnet), **Kyiv U - TSNUK** (collimators, vacuum chamber, simulation), **IRFU** (gas system, setup calibration)

Motivation and history (shortly)

Development of new high-energy physics collider experiments, medical applications call for a rapid evolution of already established and development of new innovative detector techniques.

To characterize new types of detector systems and ensure quality of the already developed instruments high accuracy tests need to be performed (with high energy and time resolution, $\Delta E/E \leq 1\%$, $\Delta t \leq$ 20-30 ps).

Test beam facilities play a key role in such tests.

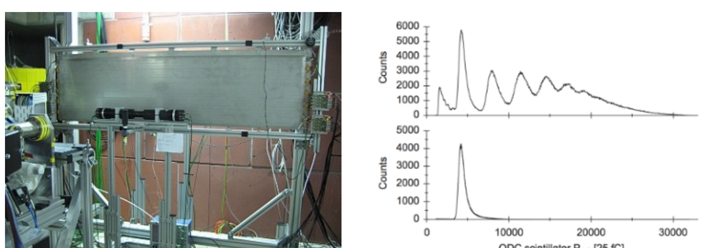
Majority of test facilities were built for specific experiments and after finish of these studies they were converted to the test tools. Therefore they have essential restrictions for effective using for many test tasks:

- Significant or very significant operating costs
- As rule large energies of beam particles
- Frequently the limit range and quality for energy variation
-

Some Scientific Centers, providing service of tests beam

Parameter	Values			
Maximum average flux	3.125 10^{10} particles/s			
Spot size	1–25 mm (y) 1–55 mm (x)			
Divergence	1–2 mrad			
	Parasitic mode		Dedicated mode	
Pulse duration	10 ns		1.5–40 ns Selectable	
Repetition rate	Variable between 10 Hz and 49 Hz Depending on DAFNE mode		1–49 Hz Selectable	
	With target	Without target	With target	Without target
Particle species	e^+ or e^- Selectable by user	e^+ or e^- Depending on DAFNE mode	e^+ or e^- Selectable	
Energy	25–500 MeV	510 MeV	25–700 MeV (e^-) 25–500 MeV (e^+)	250–730 MeV (e^-) 250–530 MeV (e^+)
Energy spread	1% at 500 MeV	0.5%	0.5%	
Intensity (particles/bunch)	1–10^5	10^7–1.5 10^{10}	1–10^5	10^3–3 10^{10}

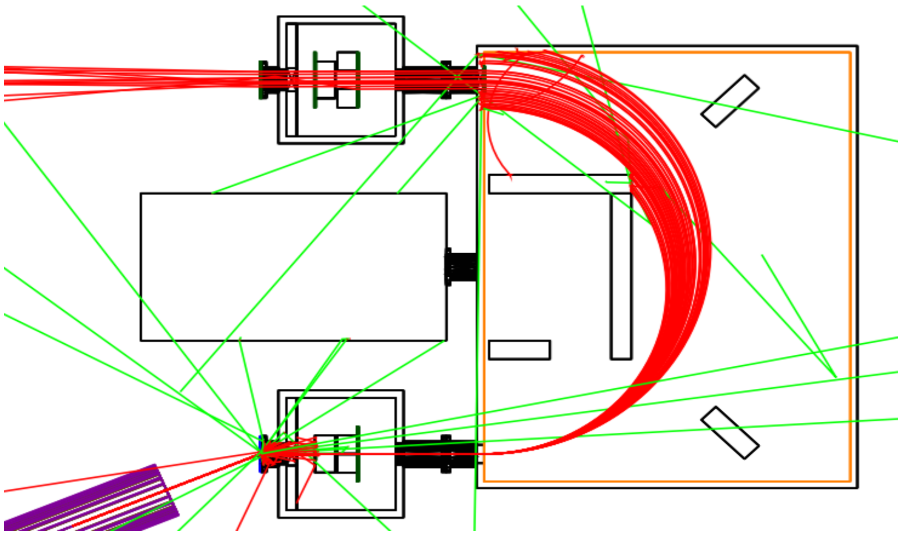
The DAFNE Beam-Test Facility (BTF)



Electron-beam testing station for detectors at the radiation source ELBE

Motivation and history (shortly)

In **Orsay** (Laboratory of Linear accelerator – **LAL**) it was decided to build the test tool on the base of electron linear accelerator PHIL - **LEETECH**

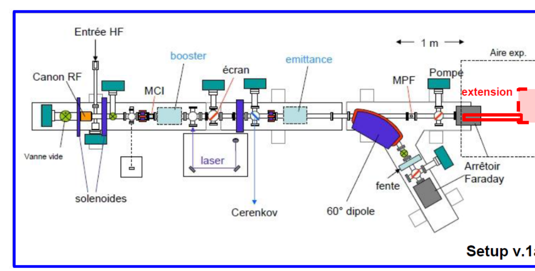


LeeTech

\- **L**ow **E**nergy **E**lectron **TECH**nique

Applications:

- Detector R&D
- Investigation single particle response
- Gaseous detectors calibration
- e^- dE/dx measurements



<u>Setup principle</u>

- ❑ Use electrons from PHIL, reduce energy/intensity using Al plug
- ❑ Select direction for electrons passing the plug with collimator 1
- ❑ Select required energy by **half-turn of electron in the magnetic field** (field value)
- ❑ Adjust intensity/energy spread using collimator 2, positioned in front of tested detector

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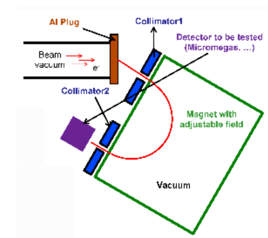
- ❑ **Multiplicity** at high electron flux (Intensity - **1-10^4 particles/bunch**)
- ❑ Particles type - **electrons,** or **positrons** with lower intensity
- ❑ Energy range - **from 0.5 MeV up to 5 MeV**
- ❑ Time resolution **–** better than **30 ps**

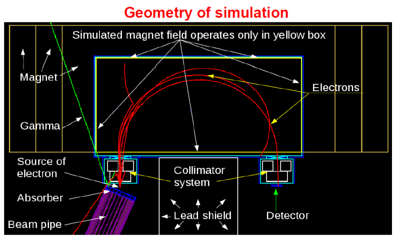
PHIL - **PH**oto-**I**njecteur au **L**AL

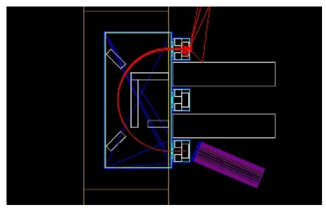


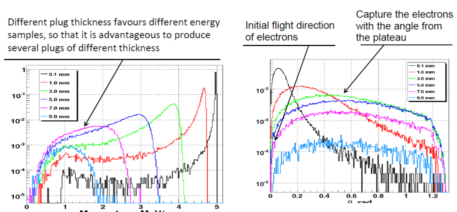
History (shortly)

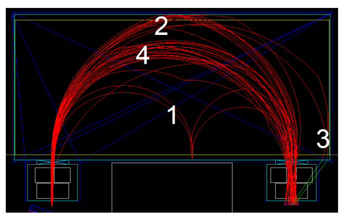
- Simulation, development, construction design, production, installation, commissioning - 2014-2015

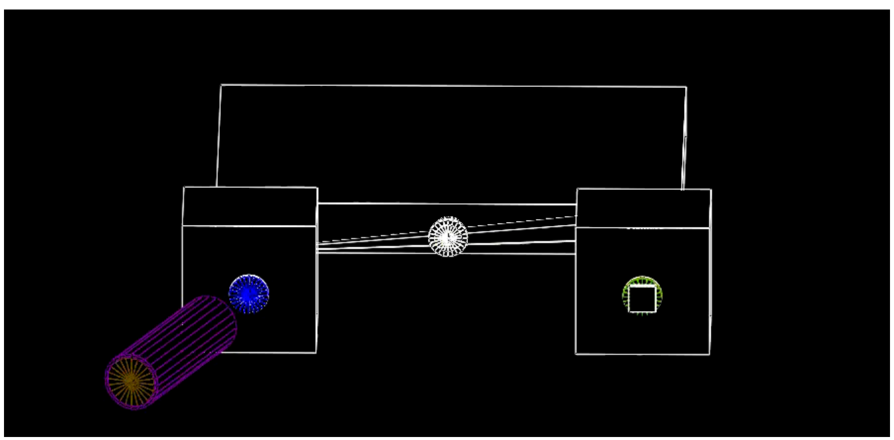
GEANT4 simulation





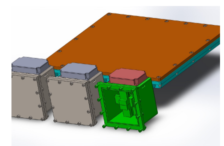


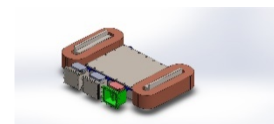


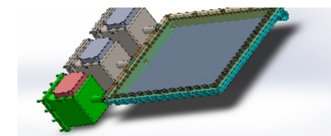


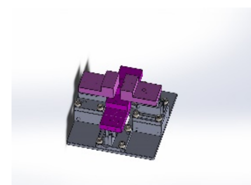
Video

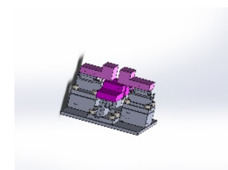
Development and construction design

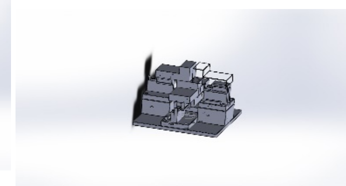


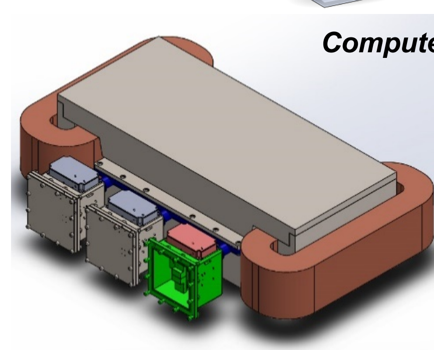


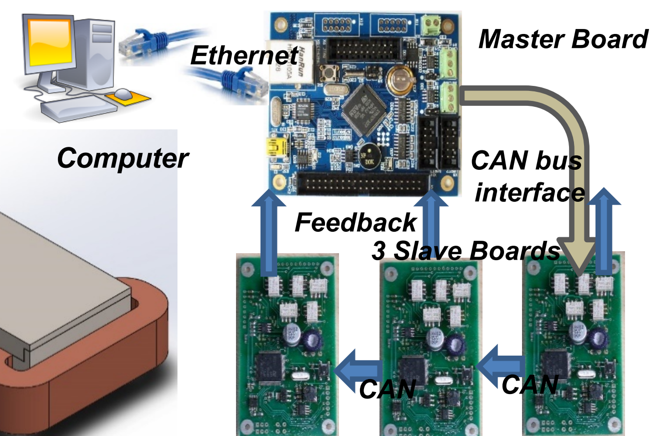








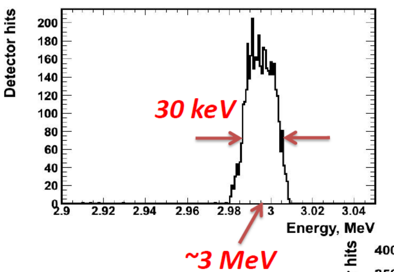




History (shortly)

- Simulation, development, construction design, production, installation, commissioning - 2014-2015

GEANT4 simulation - results

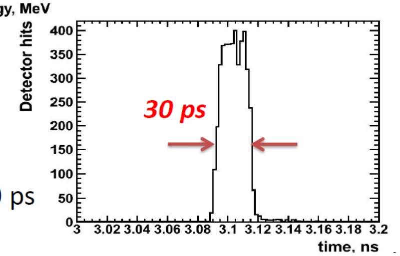


Energy resolution ≈ 1%

Primary electrons of E = 3.7 MeV

Collimators openings:

- entrance: 0.5x0.5 mm
- exit : 1.0x1.0 mm

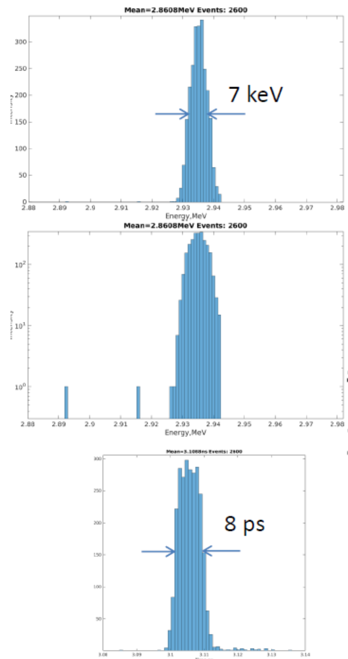


Time resolution ≈ 30 ps

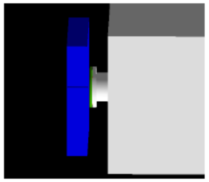
Acceptable geometry for manual alignment of LEETECH system

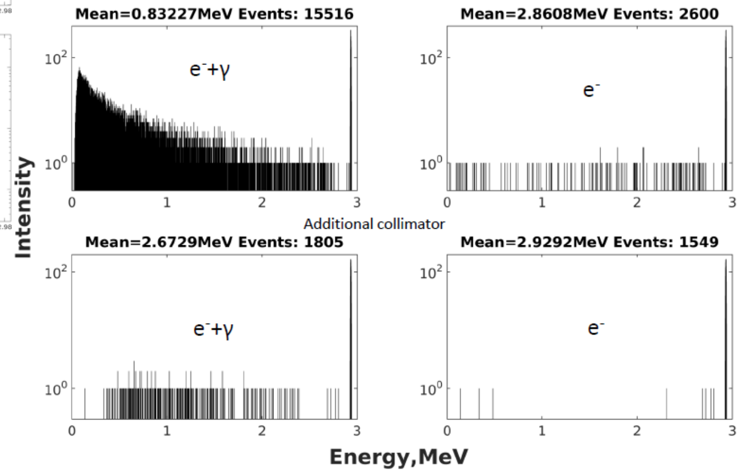
Simulations for real conditions in the "small" geometry

hole 0.2x0.2 mm (for future upgrade)



Additional collimator, lead, 110x110x20 mm hole diameter 1 mm



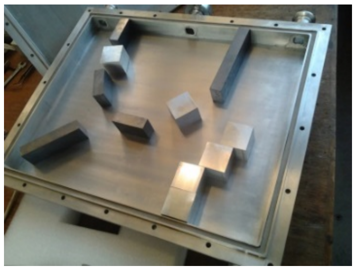


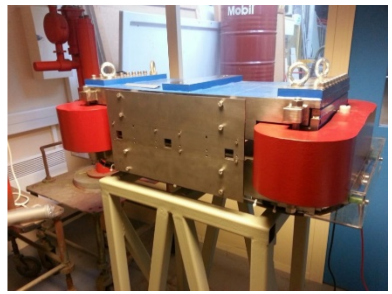
Enticing results, but one need special tools for alignment of LEETECH system

History (shortly)

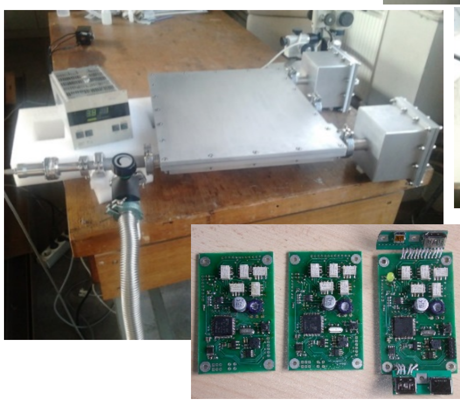
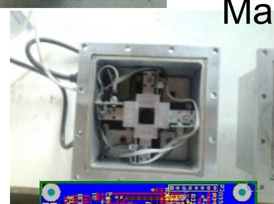
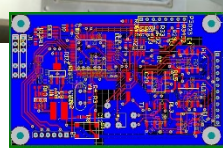
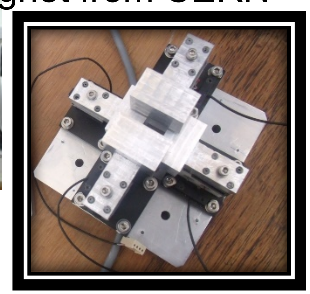
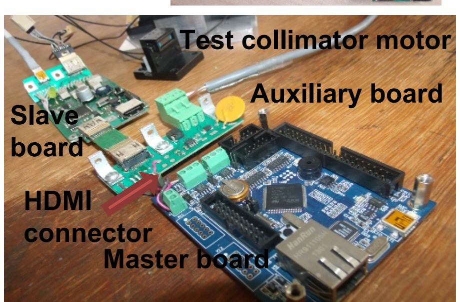
- Simulation, development, construction design, production, installation, commissioning - 2014-2015

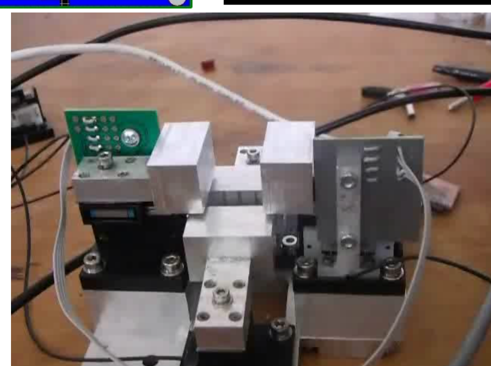
Design and production



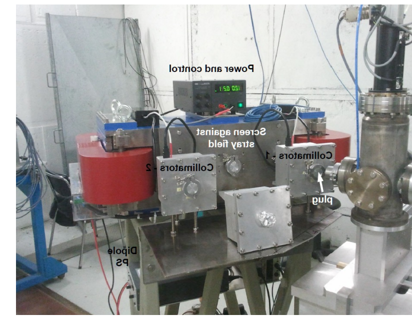
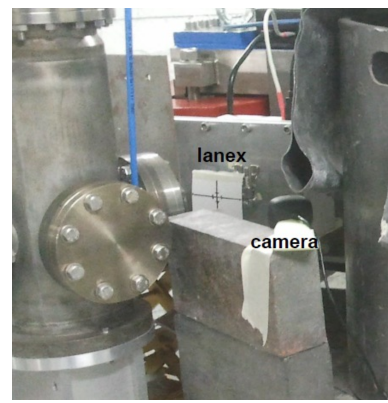
Magnet from CERN

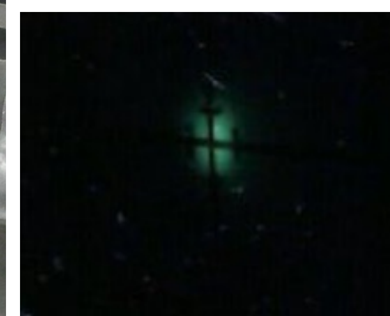








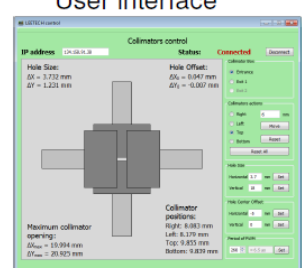
Video

Commissioning



User interface



All the mentioned above challenge (in the complex) with estimated good energy and time resolution in the "small" geometry lead to problem of the choice among the simple detector systems for experimental verification of calculated LEETECH characteristics ($\Delta E/E \sim 1\%$, $\Delta E \sim 30$ keV for $E \sim 3$MeV, $\Delta t \sim 20$-30 ps)

We consider such detector systems for studies:

1. Scintillator detector - NaJ(Tl)+PMT, width of crystal 5 mm, top window 1 mm (Al (0.5 mm) +TiO2 (0.5 mm)) (total energy deposition, reasonable energy resolution – a few %, influence of magnet field, not very thin top wall, sensitive to background gamma-photons)

2. Scintillator detector - CsJ(Tl)+p-i-n diode (SiPM), crystall 10x10x15 мм, thin top window (Al(<0.05 mm)) (total energy deposition, reasonable energy resolution – a few %, not sensitive to magnet field, very thin top wall, compact geometry, sensitive to background gamma-photons)

3. Semiconductor detector – **diamond detector**, crystal 4x4x0.5 мм, very thin top window (nanometers) (good energy resolution, not sensitive to magnet field, very thin top wall, compact geometry, not sensitive to background gamma-photons, not total energy deposition)

4. Semiconductor detector – Si p-i-n diode, crystal 3x3x0.3 мм (5x5x 0.3 мм), very thin top window. (very good energy resolution, not sensitive to magnet field, very thin top wall, compact geometry, not sensitive to background gamma-photons, not total energy deposition)

5. To study time characteristics – Cherenkov detector with MCP-PMT

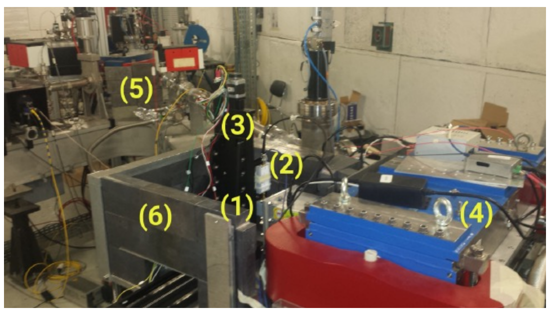
6. Compact magnet spectrometer (next steps)

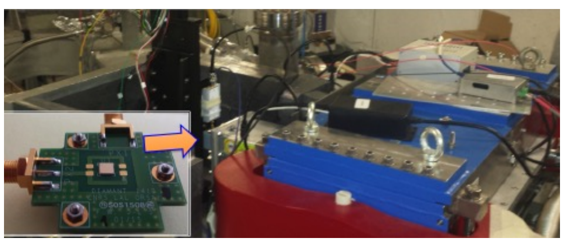
First experiments on the LEETECH – 2016 – start of 2017

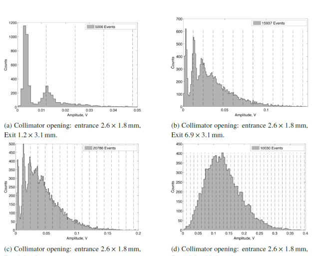
(in the frame of the PhD thesis work of Vladyslav Krylov)

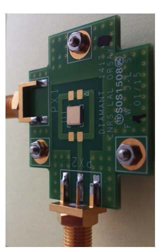
- Measurements with the diamond sensor - 2016
- dE/dx measurements with Micromegas/InGrid detector - 2017
- Measurements with quartz bar - 2017

Measurements with the diamond sensor

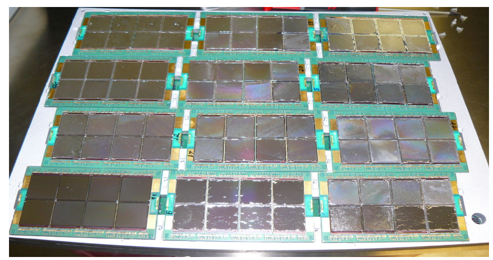


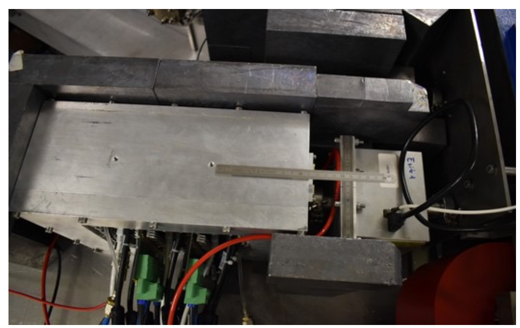


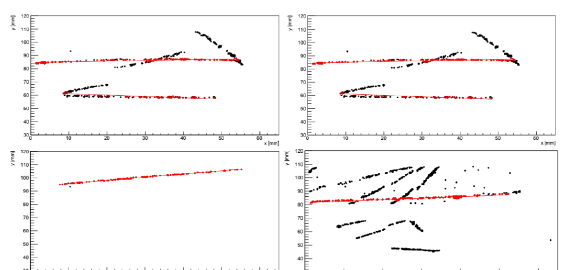




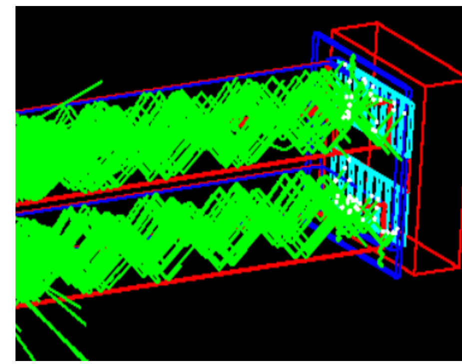
dE/dx measurements with Micromegas/InGrid detector

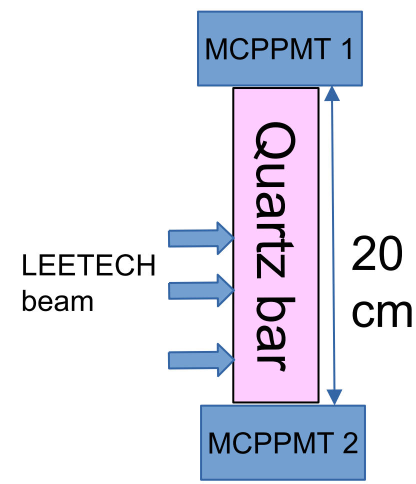




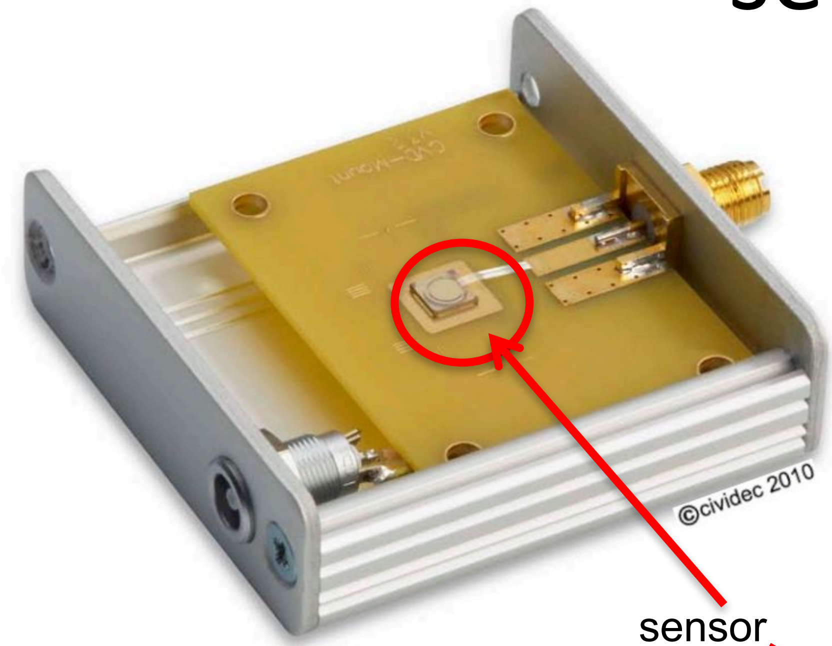


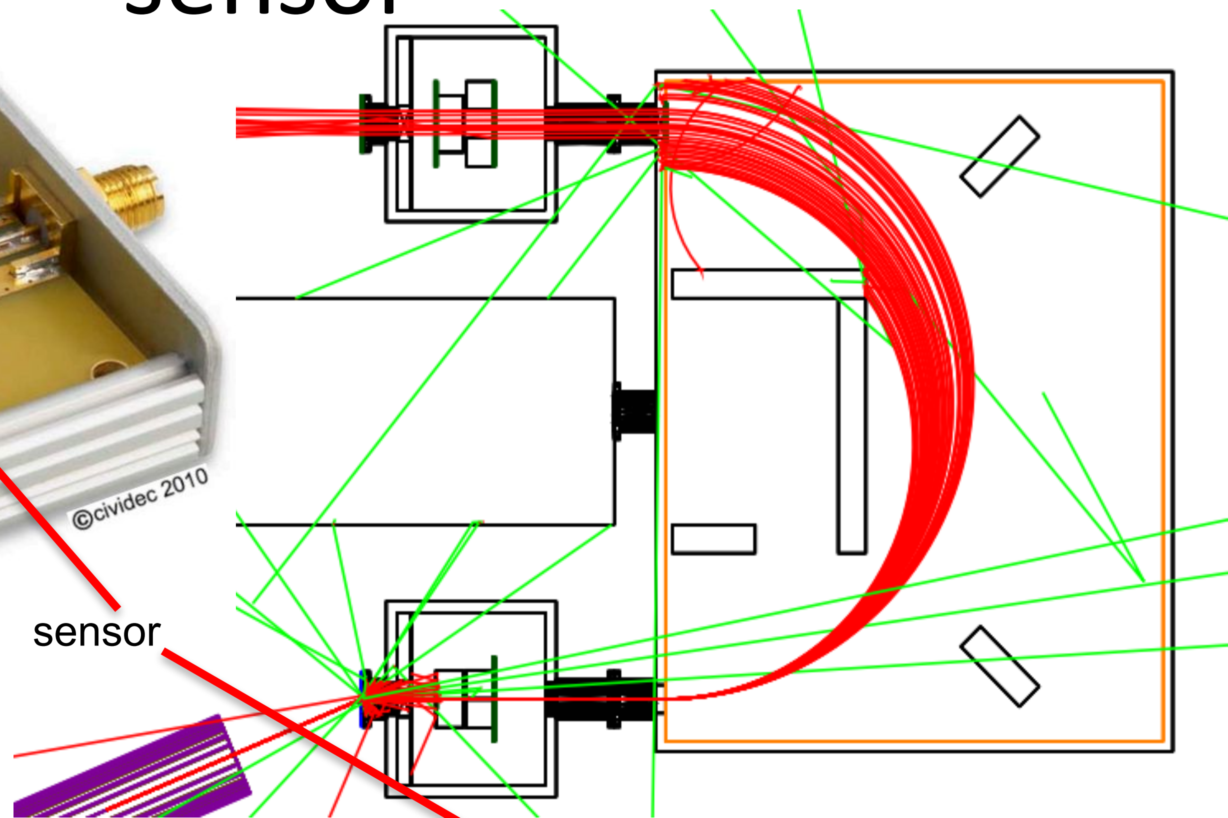
Measurements with quartz bar





Measurements with the diamond sensor

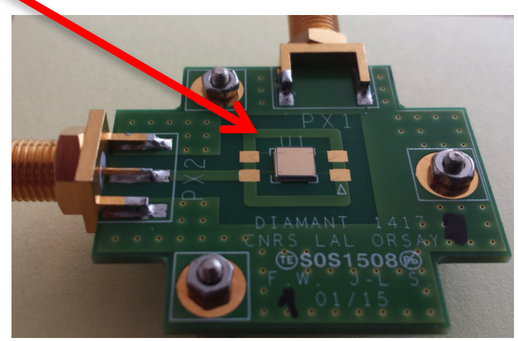




sensor

Diamond sensor:

- 4x4 mm^2
- 0.5 mm thickness
- wide dynamic range
  (up to 10^{15} protons/cm^2)
- very good radiation hardness



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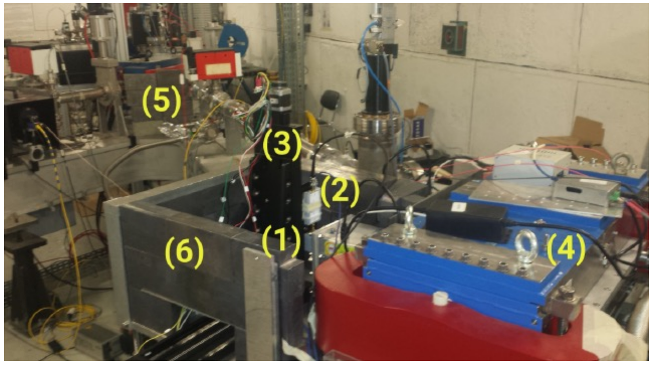
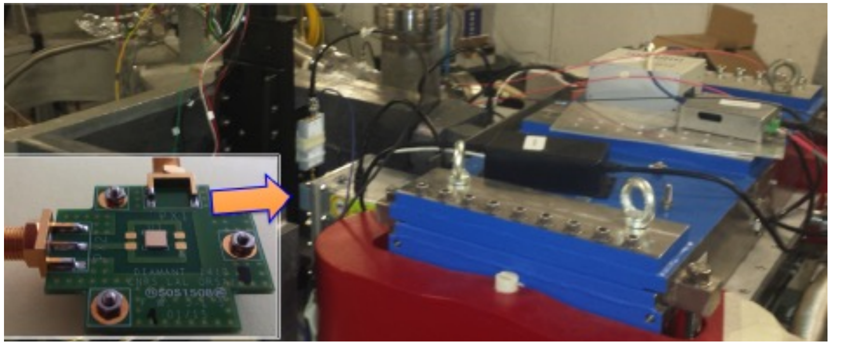
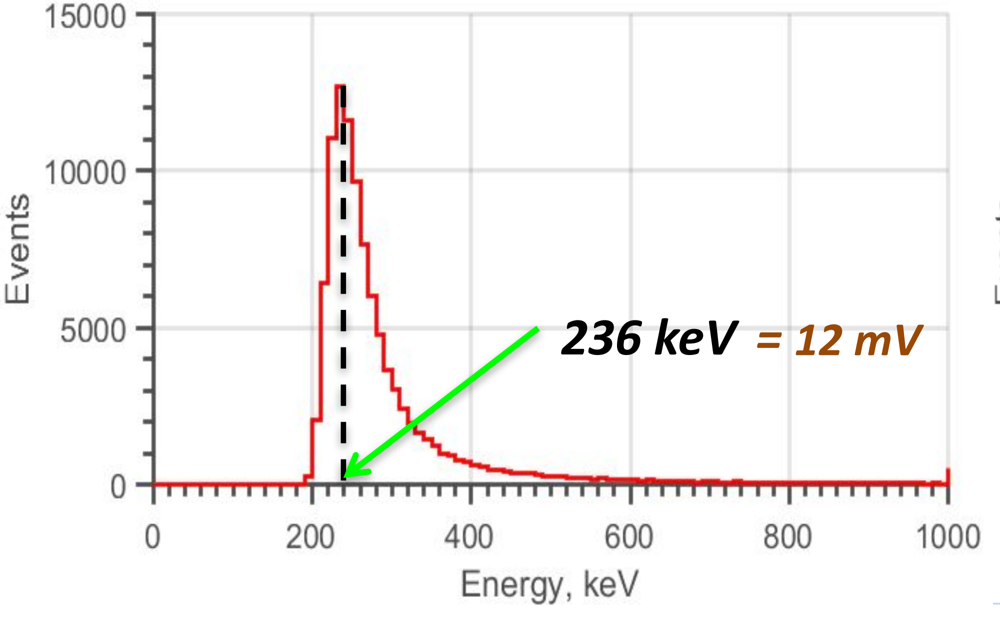


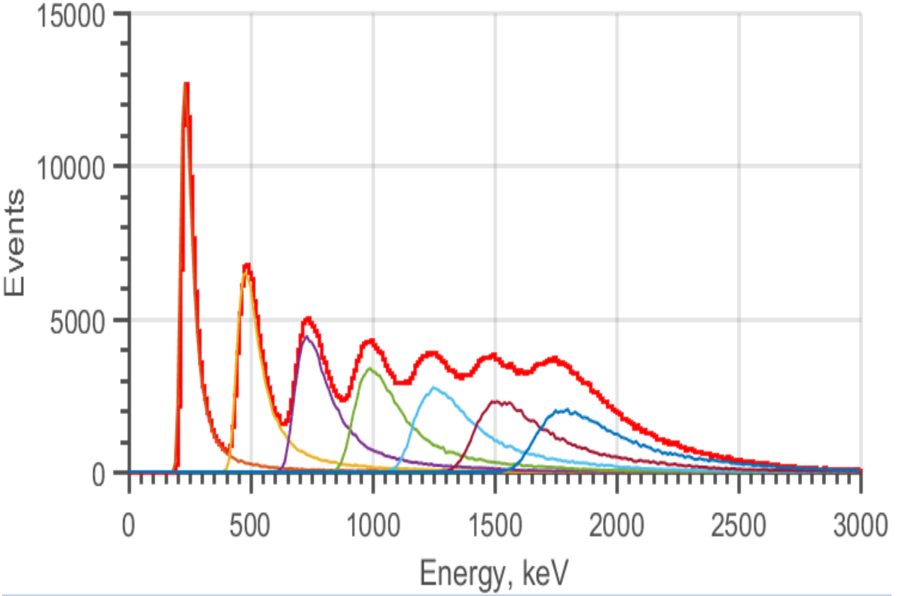


Geant4 simulation

single MIP response of detector

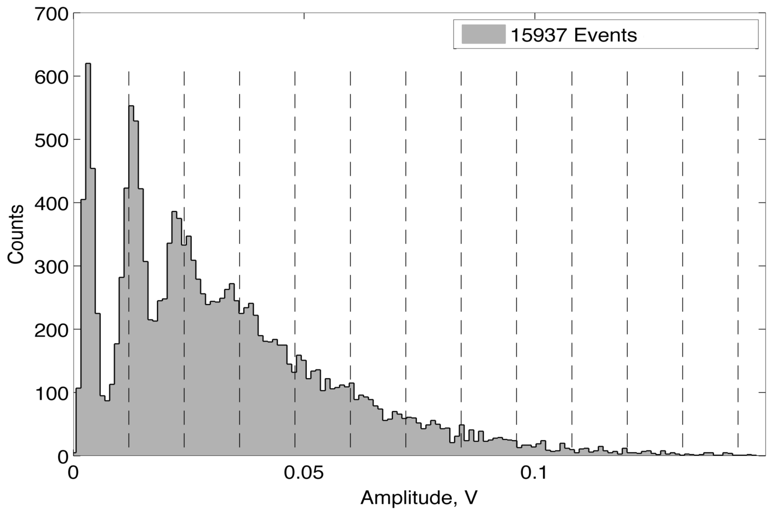


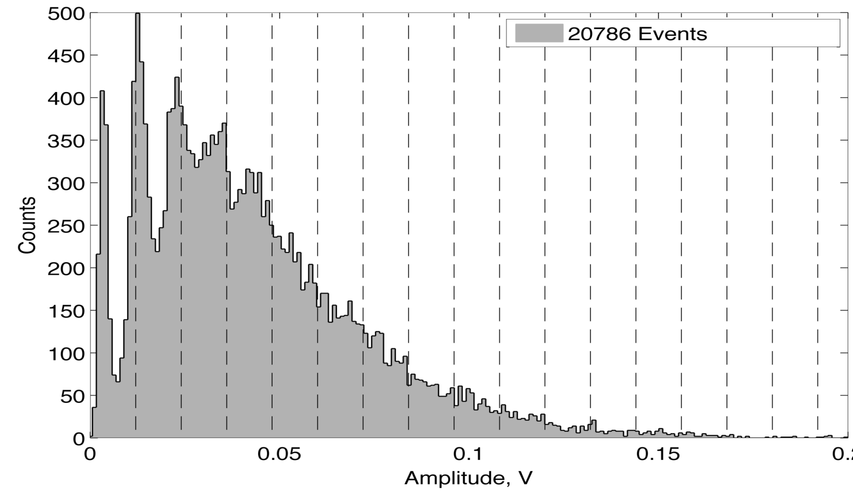
Detector response for a few of electrons (up to 7) and their sum



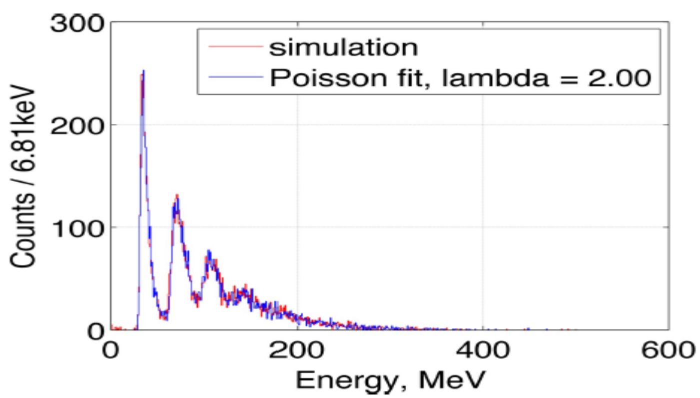
Low intensity mode on LEETECH. Measurements with the diamond sensor

Peaks from individual electrons are clearly resolved

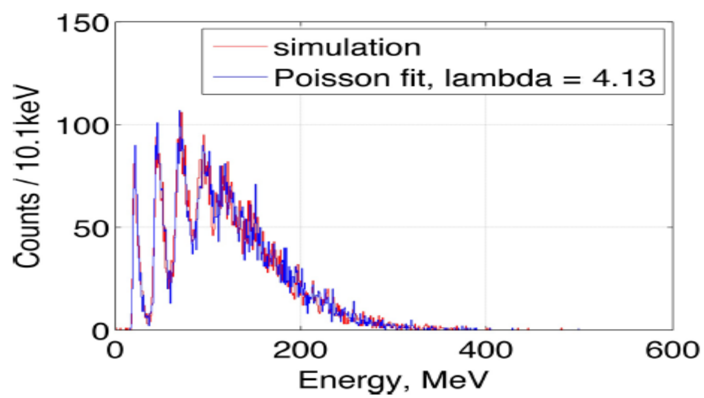




Number of electrons in output beam is distributed over Poisson distribution with mean value λ (Geant4 simulation and the Poisson fitting).

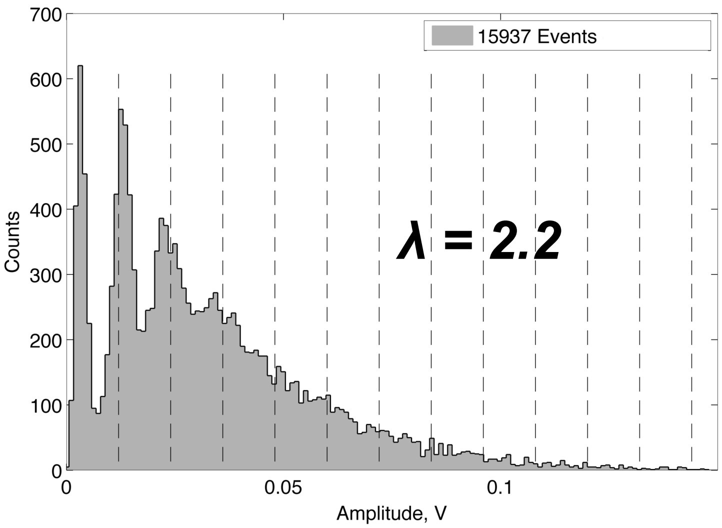


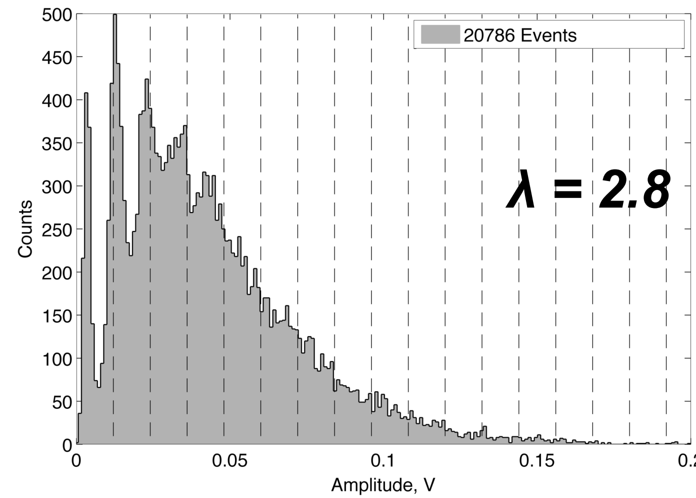
(a) Energy deposition for exit collimators openings of 1 × 1 mm.

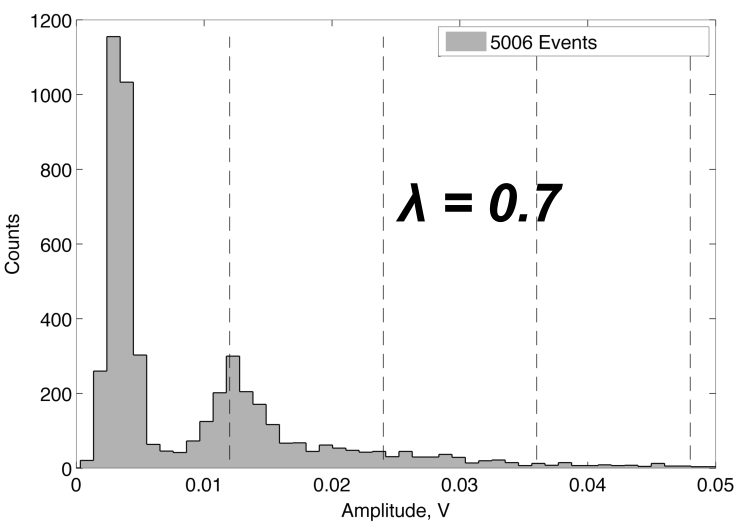


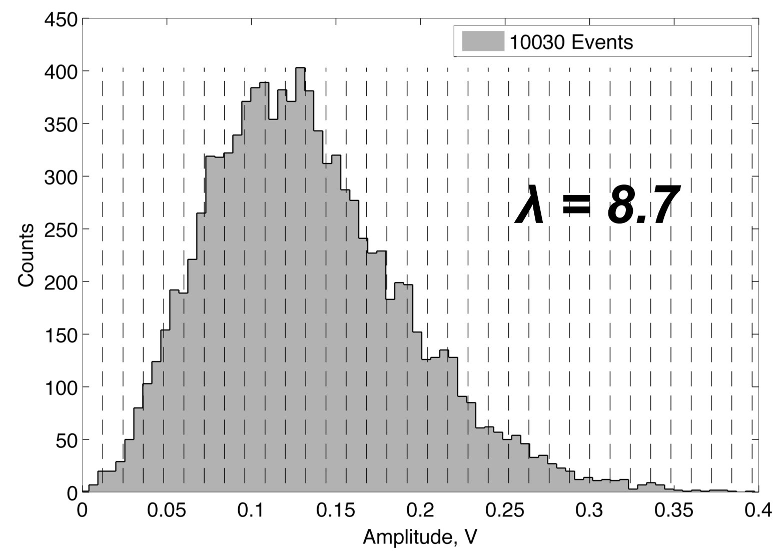
(b) Energy deposition for exit collimators openings of 1.4 × 1.4 mm.

Low intensity mode on LEETECH. Measurements with the diamond sensor

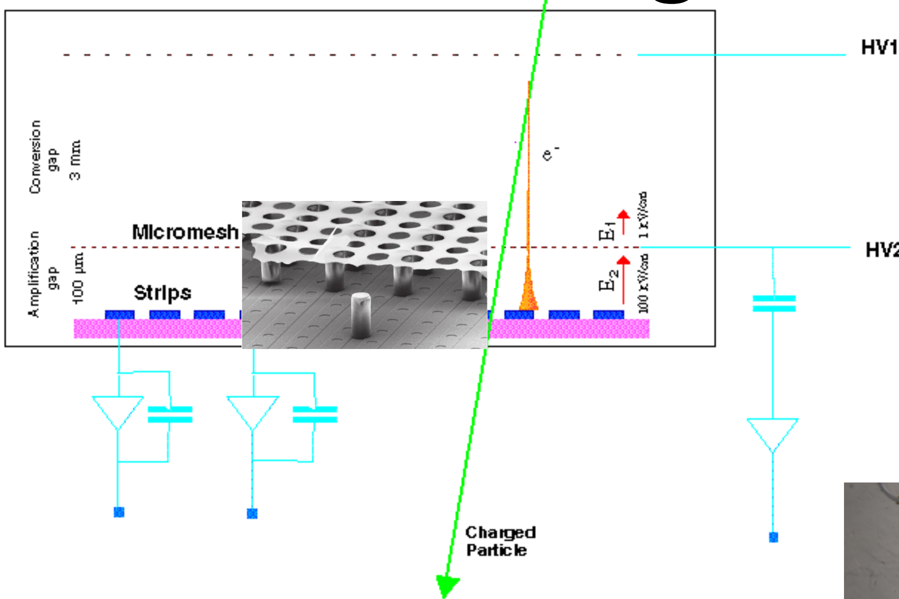






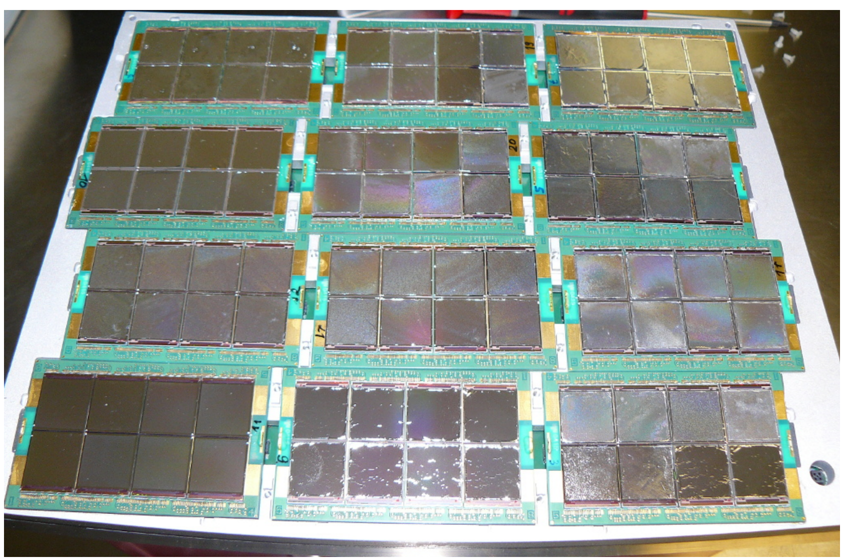


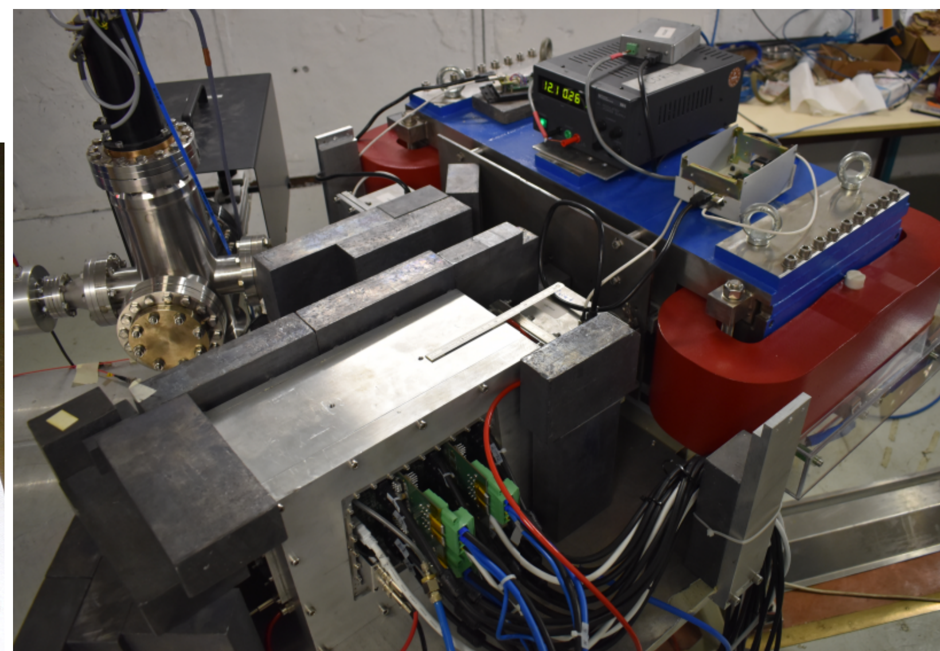
dE/dx measurements with Micromegas/InGrid detector

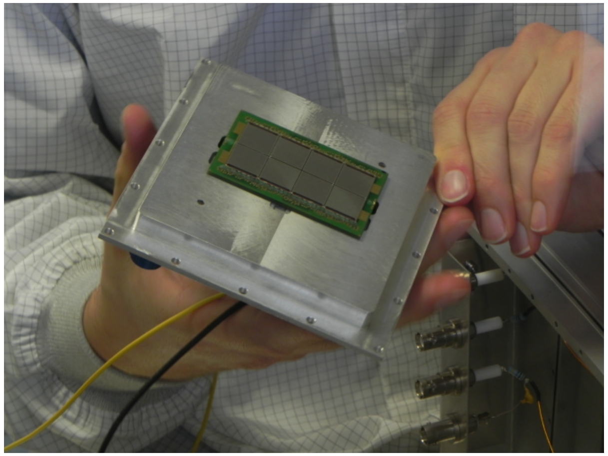


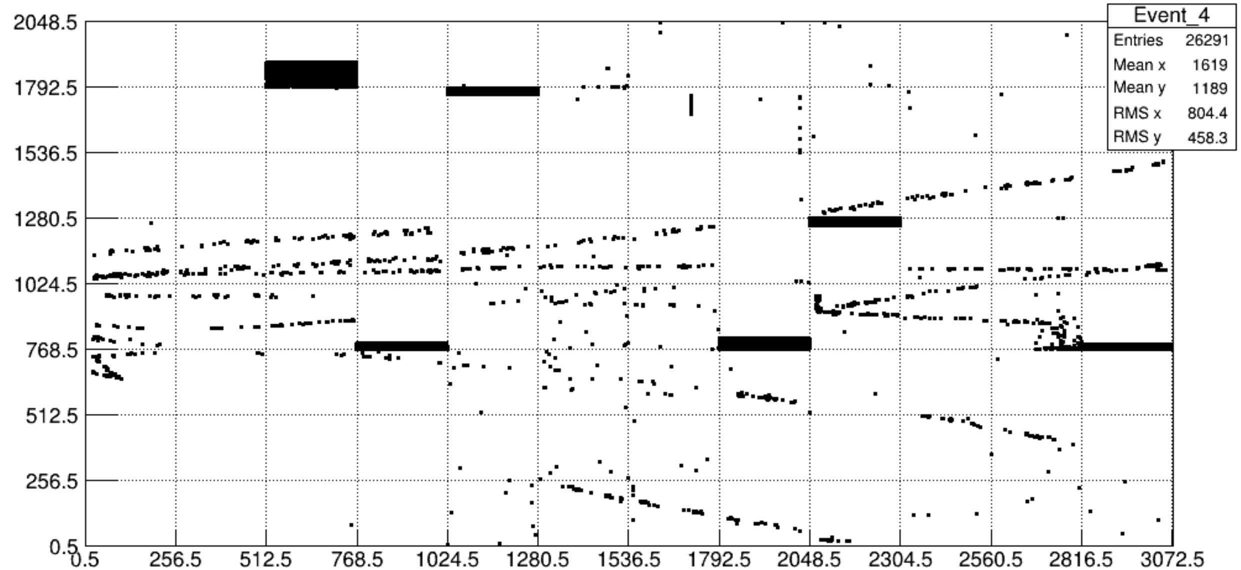
Gaseous detector with pixelated anode, a candidate for TPC at ILC

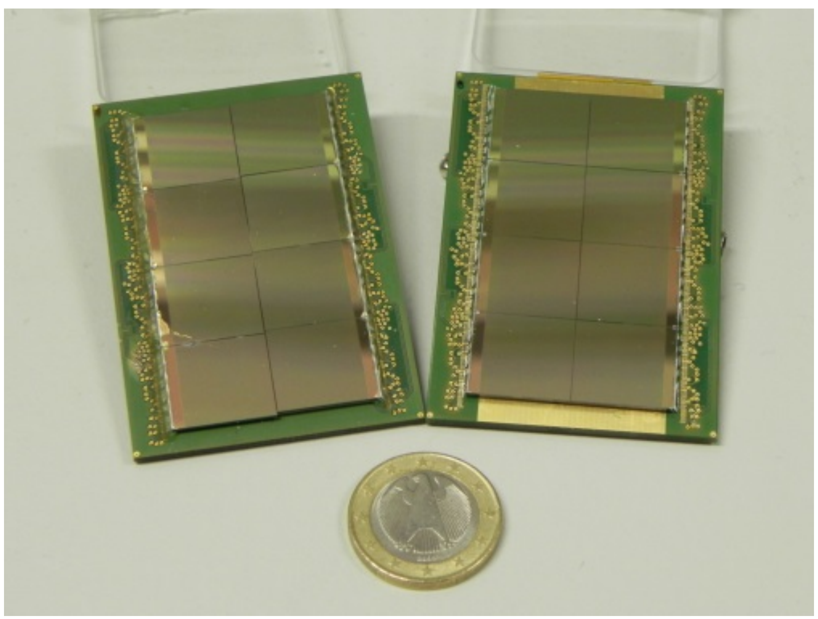
- pixel size of 55x55 µm
- chips assembled in Octoboards
- 12 Octoboards = 96 chips in a module
- provides possibility to resolve single secondary electrons counting

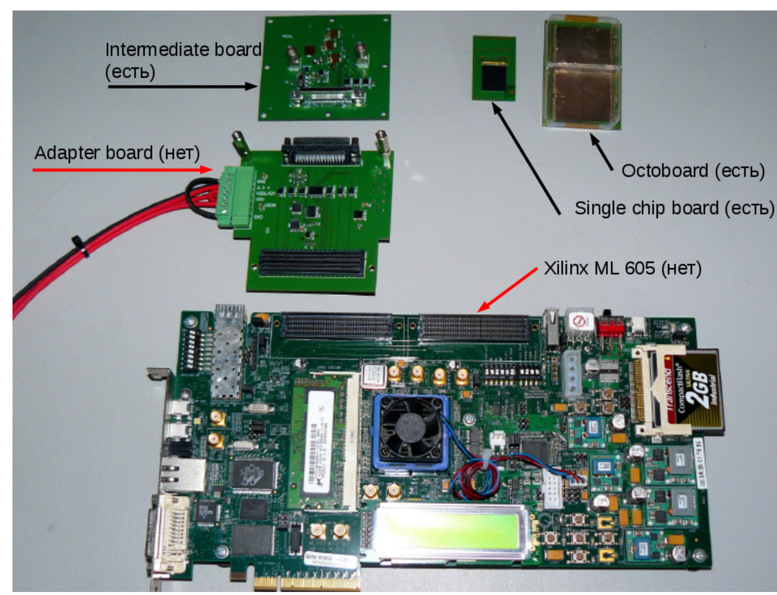




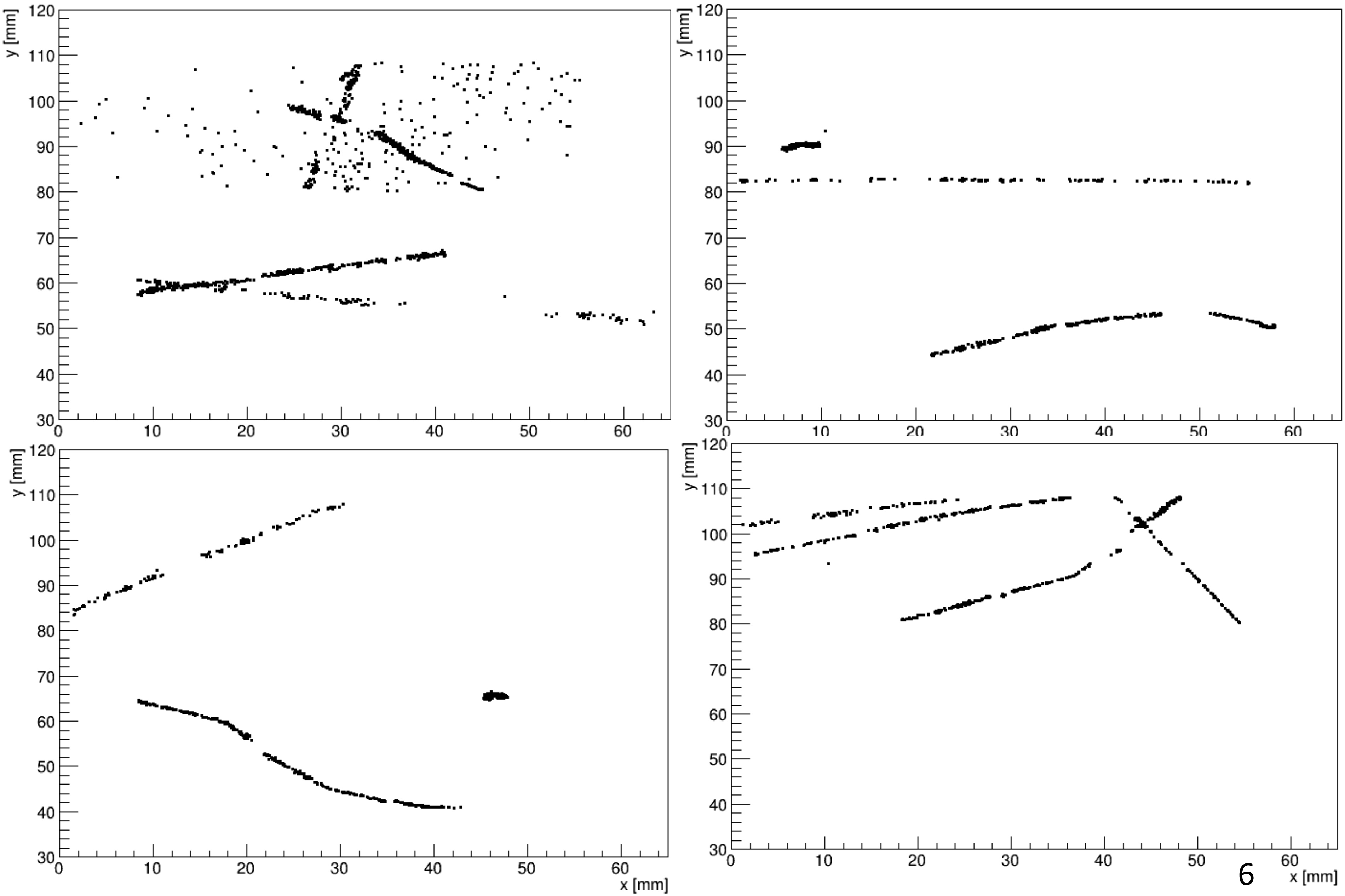



Event_4
Entries 26291
Mean x 1619
Mean y 1189
RMS x 804.4
RMS y 458.3
2048.5
1792.5
1536.5
1280.5
1024.5
768.5
512.5
256.5
0.5
0.5
256.5
512.5
768.5
1024.5
1280.5
1536.5
1792.5
2048.5
2304.5
2560.5
2816.5
3072.5



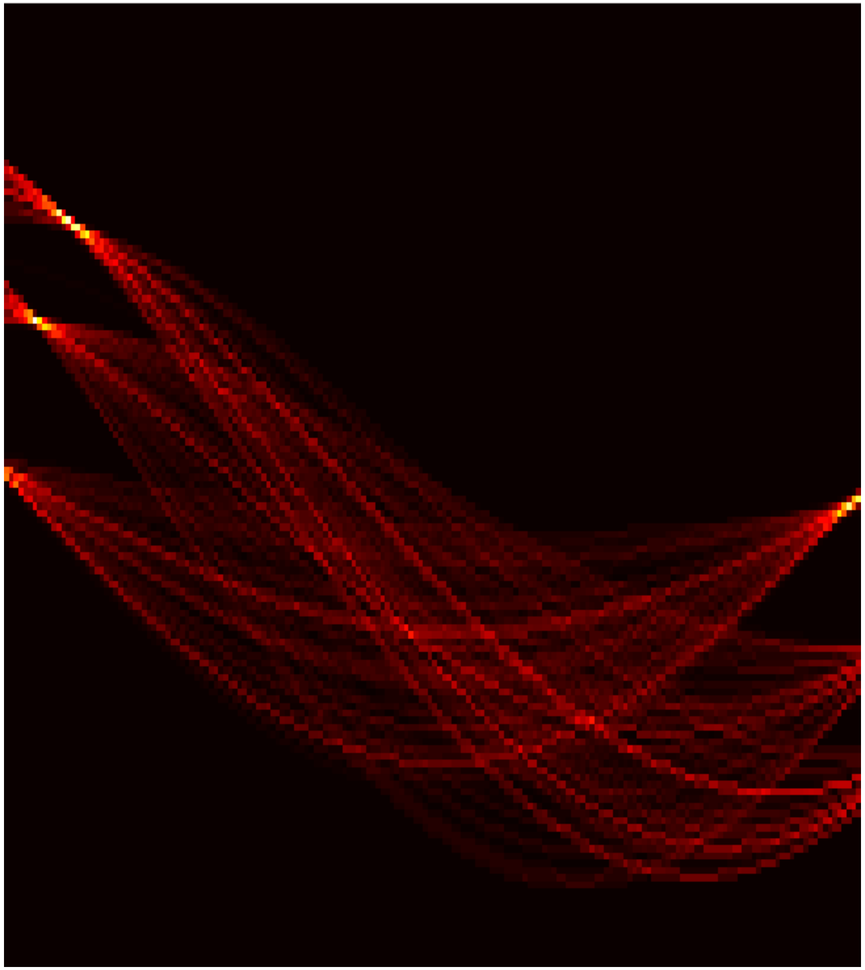

Intermediate board
(есть)
Adapter board (нет)
Octoboard (есть)
Single chip board (есть)
Xilinx ML 605 (нет)

Sample events

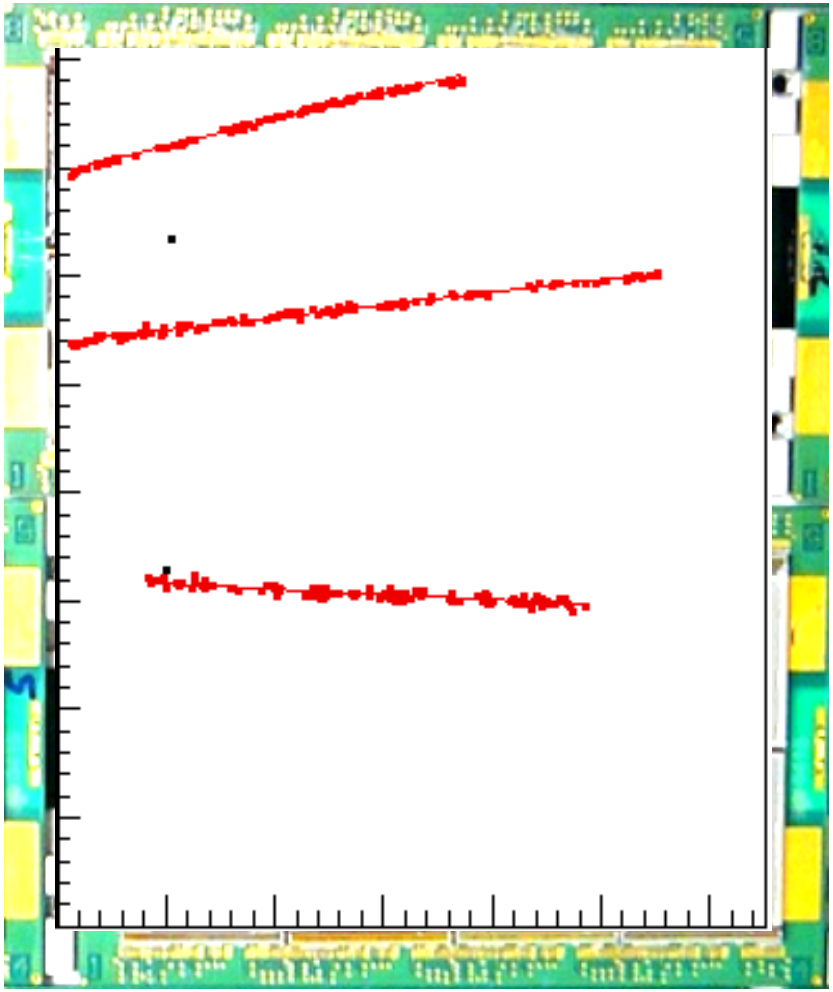


Sample track reconstruction

Hough transform
(histogram maxima indicate tracks)

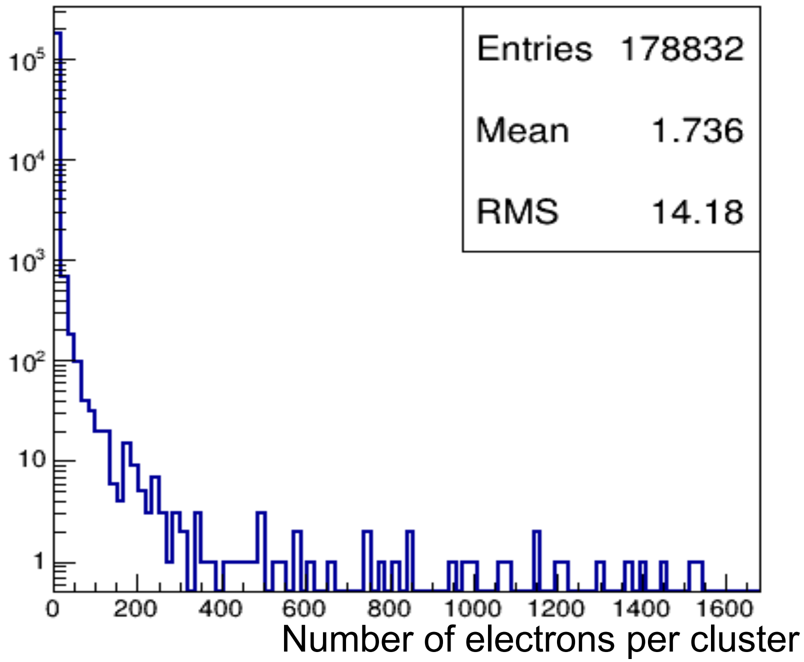


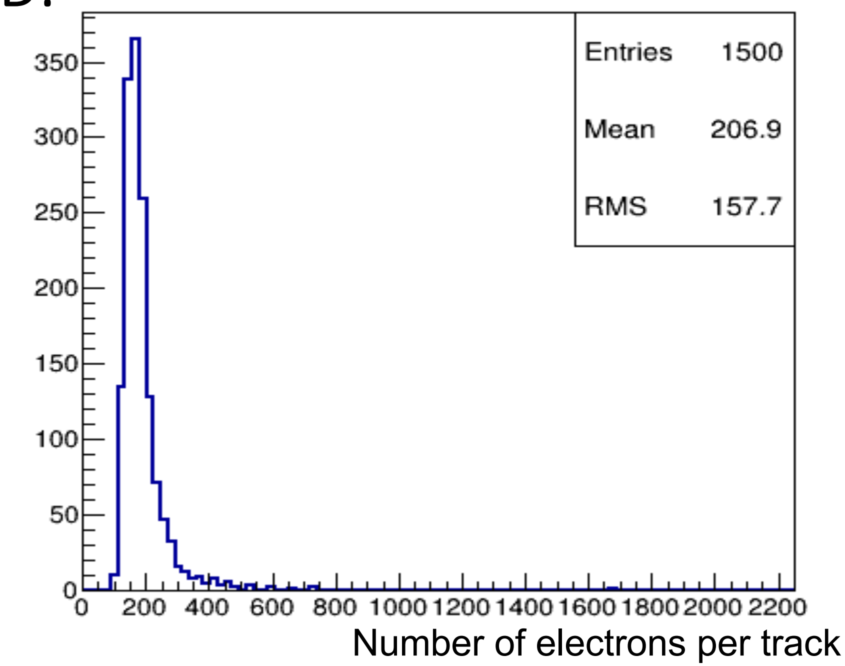
Reconstructed event



•Simulation: HEED and Degrad comparison

HEED:





$$\frac{N_{Collisions}^{HEED}}{1mm} = \frac{206.9/1.736}{56mm} = 2.128\frac{coll}{mm}$$

Degrad:

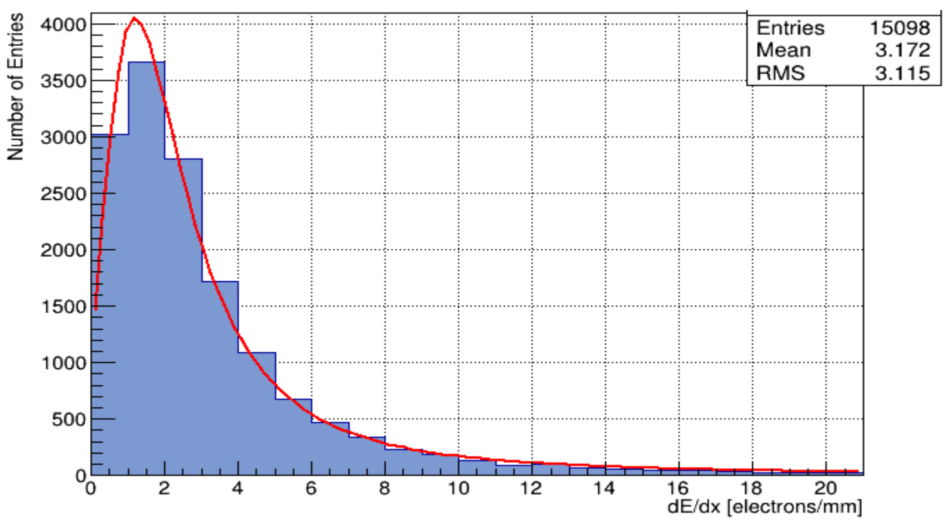
$$\frac{N_{Collisions}^{Degrad}}{1mm} = 0.2032D + 01 = 2.032\frac{coll}{mm}$$

4.6% difference

Experiment/Simulation comparison

N electrons per mm

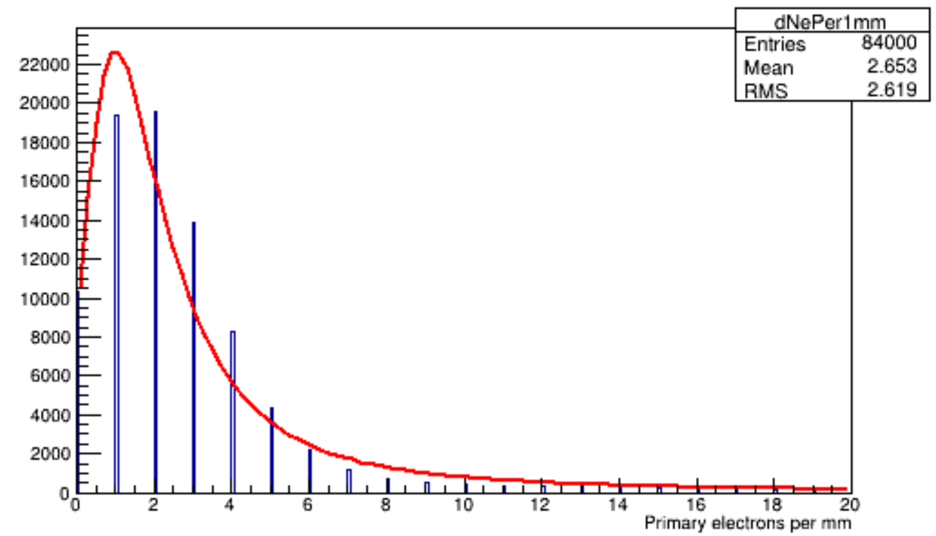
Experiment (Run 25)



FCN=106.874 FROM MIGRAD STATUS=CONVERGED 145 CALLS 146 TOTAL
EDM=1.43207e-08 STRATEGY= 1 ERROR MATRIX ACCURATE

EXT PARAMETER NO.	NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	Constant	2.24379e+04	2.90912e+02	9.36091e-01	-5.48178e-07
2	MPV	1.34327e+00	1.41382e-02	7.11146e-05	2.59889e-03
3	Sigma	6.88126e-01	8.05450e-03	5.68968e-06	-1.43932e-01

HEED simulation



FCN=6016.8 FROM MIGRAD STATUS=CONVERGED 82 CALLS 83 TOTAL
EDM=1.18104e-10 STRATEGY= 1 ERROR MATRIX ACCURATE

EXT PARAMETER NO.	NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	Constant	1.25713e+05	6.50862e+02	1.71295e+01	-6.96410e-09
2	MPV	1.13846e+00	5.03558e-03	1.65181e-04	3.44074e-03
3	Sigma	6.34863e-01	2.42261e-03	1.46258e-05	-2.30190e-02

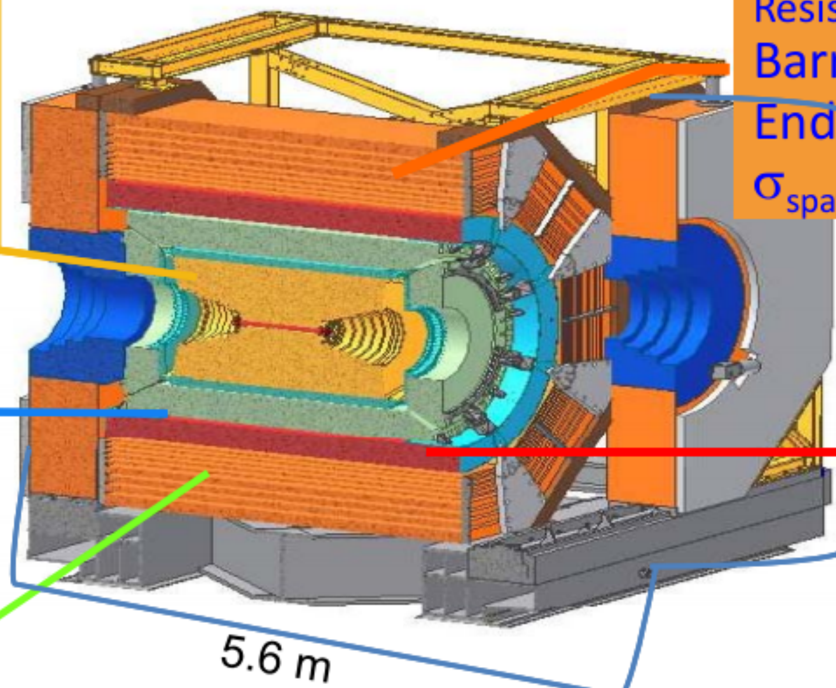
•Measurements with quartz bar

Quartz bar detector is a time-of-flight candidate for the upgrade of BESIII experiment and future HIEPA collider in China.

Drift chamber (MDC)
Small cell, 43 layer
Gas He/C_3H_8=40/60
σ_{xy}=115 μm, dE/dx~5%
σ_p/p = 0.5% @ 1 GeV

Time-of-flight (TOF)
Plastic scintillator/MRPC
σ_T(barrel): 68 ps
σ_T(endcap): 60 ps

ECAL calorimeter
CsI(Tl): L=28 cm ($15X_0$)
Energy range: 0.02-2GeV
$\sigma_E/\sqrt{E}$ = 2.5% @ 1GeV
σ_l = 0.5-0.7 cm/$\sqrt{E}$



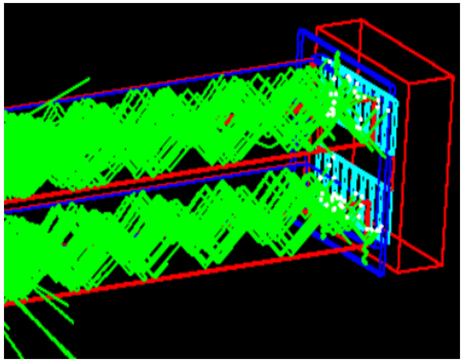
Muon counter
Resistive plate chamber
Barrel: 9 layers
Endcaps: 8 layers
$\sigma_{spatial}$: 1.4-1.7 cm

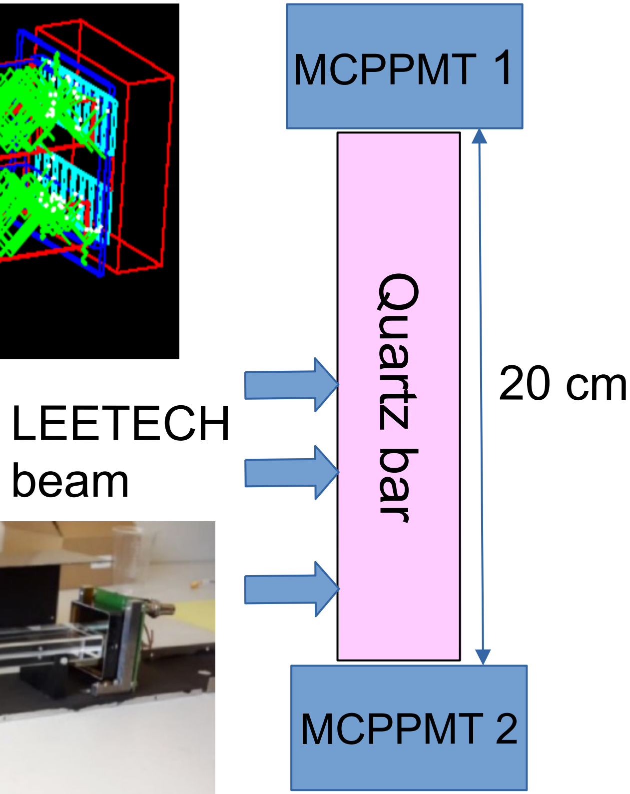
1T super-conducting magnet

RO channels: 10^4
Event rate: 4 kHz
Data size: 50 MB/s

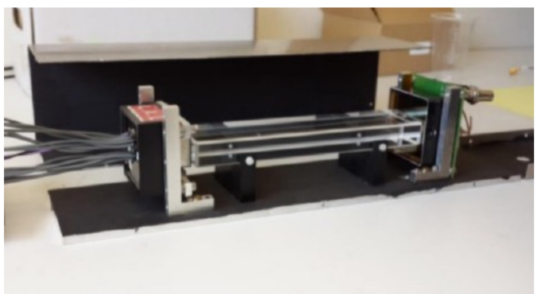
Grid computing
CPU: 3200 core
Storage: 2.2 pB

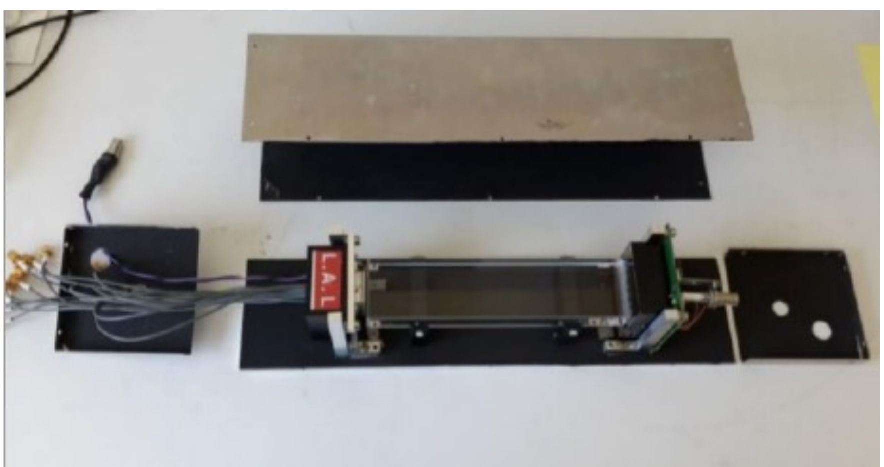
Measurements with quartz bar

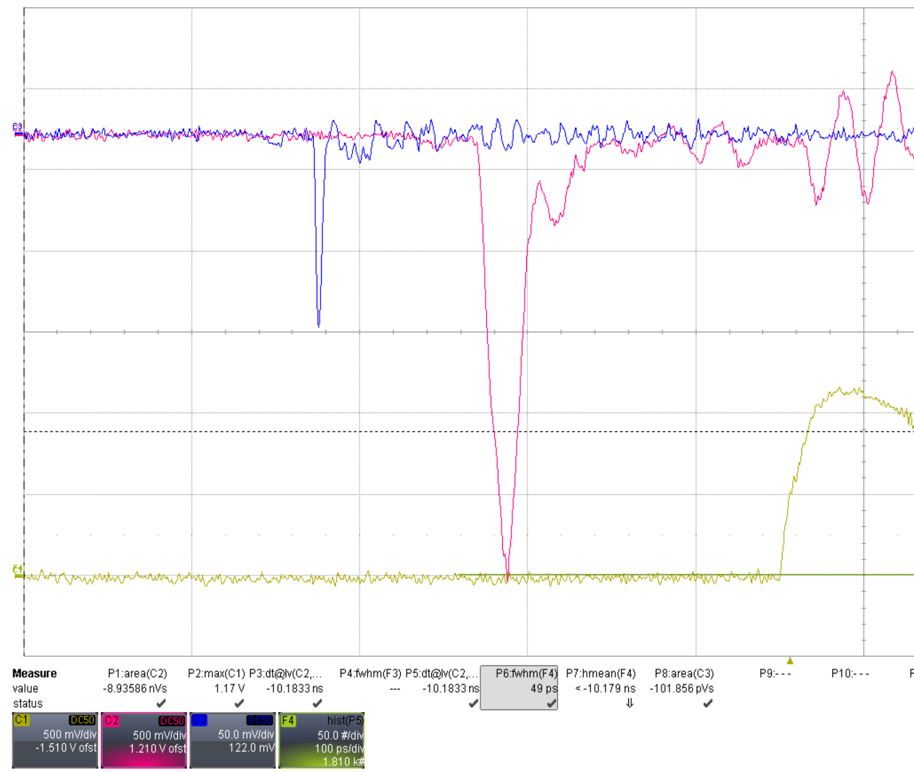




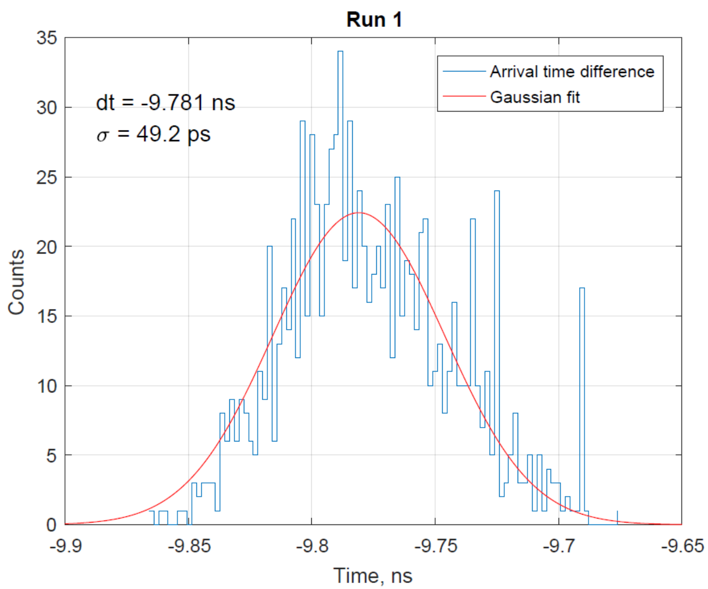
2 micro channel plate photomultipliers (Hammamatsu SL-10 and Burle XP85012) are placed at the ends of the quartz bar. The bar was closed with a dark box to reduce the light noise. The bar position was changed and time difference of MCPPMT signals was measured.

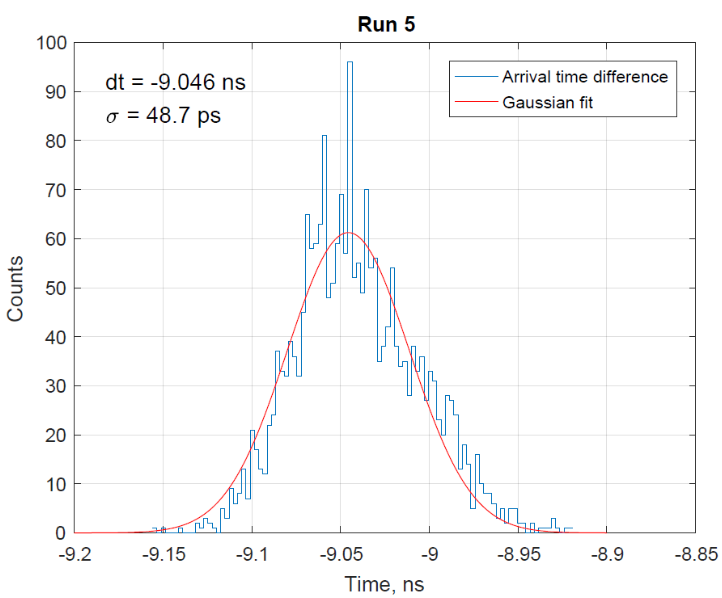


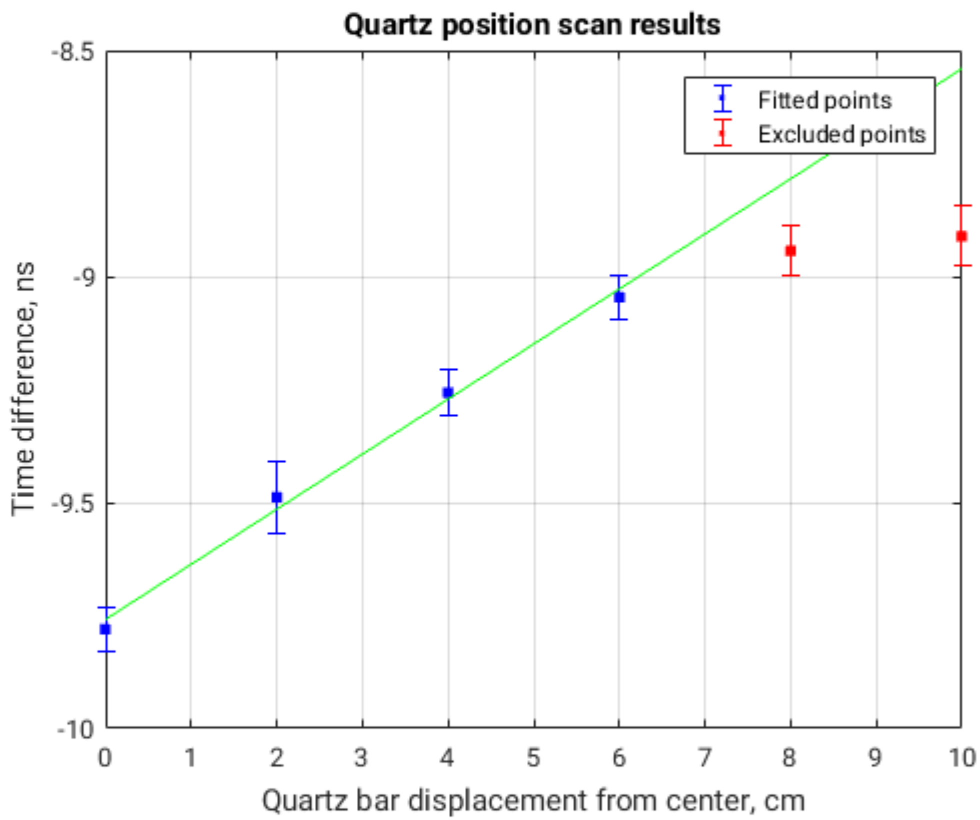




•Measurements with quartz bar



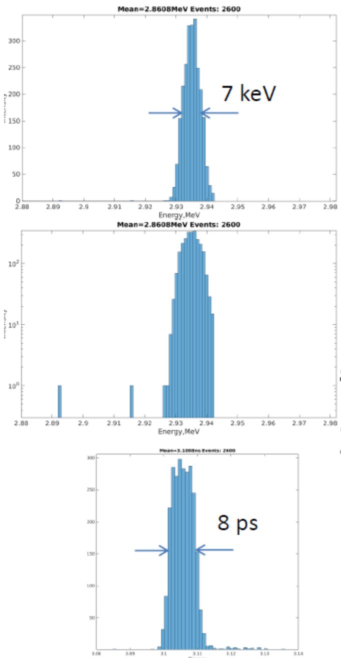




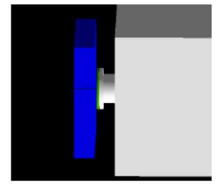
A promising result of σ = 50 ps time difference was obtained. Quartz bar position is recovered within errors.

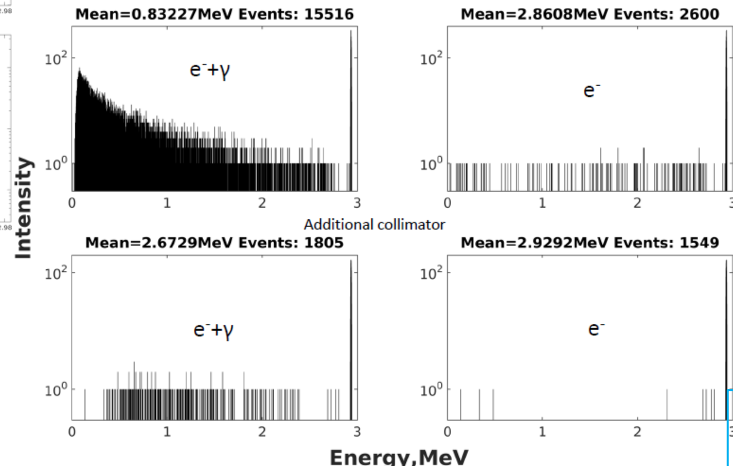
E_e=2.95 MeV

Simulations for real conditions in the "small" geometry
hole 0.2x0.2 mm (for future upgrade)

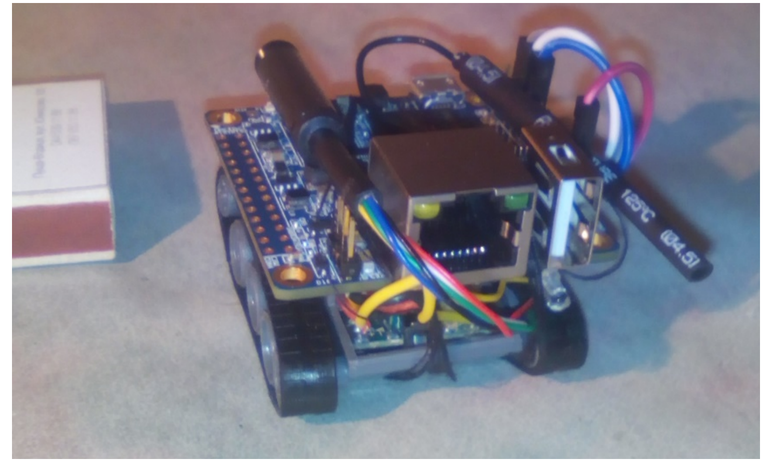


Additional collimator,
lead, 110x110x20 mm
hole diameter 1 mm

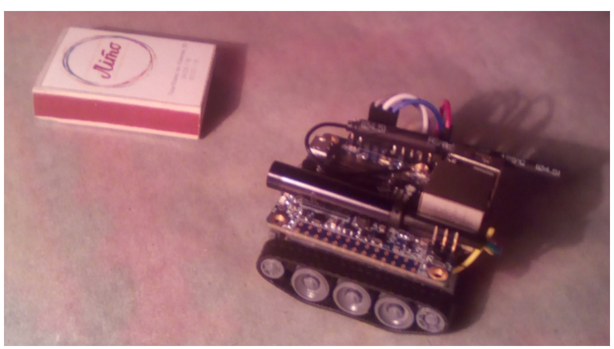




Enticing results, but one need special tools for the alignment of LEETECH system – we are developing micro-car for such tasks



Micro-car for measurements in the inner volume of the vacuum chamber of LEETECH (near the box for matches)



Micro-car for measurements in the inner volume of the vacuum chamber of LEETECH (near the box for matches)

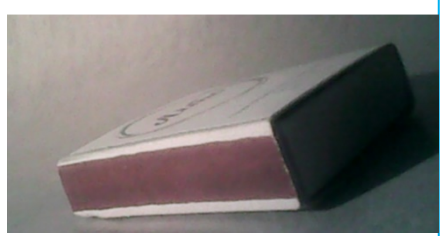


Photo from micro-video camera of Micro-car

Main features

- Size - L5.5mm*W4.5mm*H3.5mm
- Micro-video camera 640*480*30fps
- Micro-motors,
- Movement sensors (placement, accelerating, angles)
- Light-diode spotlight
- Micro - Battery
- Sensor of magnetic field
- CsJ+SiPM detector of ionizing beam (with vertical movement)
- Communication and control through WiFi,
- Power ARM processor (4 cores, 1.2 GHz) + ARM M3 microcontroller

Conclusions

- The test beam setup LEETECH at LAL was presented – motivation, history (simulations, development, production, installation and commissioning 2014-2015), first experiments
- Three measurement sessions were performed (2016-2017):
  - ❑ Low intensity mode was established with the diamond detector
  - ❑ A preliminary quartz bar characterization was performed
  - ❑ dE/dx for low energy electrons was measured, preliminary results are in agreement with simulation. Further work is ongoing to study the Bethe-Bloch curve.

Thank you for attention!