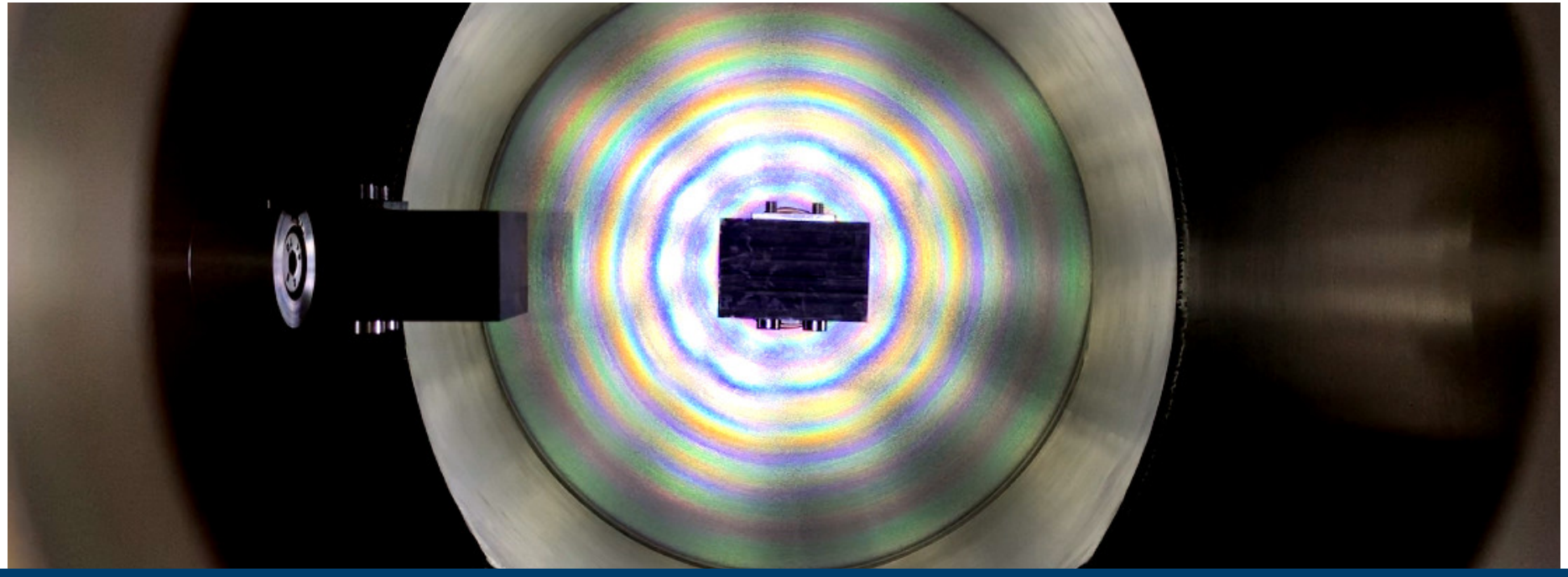


DEVELOPMENT OF A DEDICATED PRECISION POLARIMETER FOR CHARGED PARTICLE EDM SEARCHES AT COSY

Speaker: Irakli Keshelashvili

PSTP 2019 — Oak Ridge National Laboratory

OUTLINE

- Goals of ***srEDM Polarimetry***

  challenges for srEDM case

- **COSY** Accelerator Facility

  Spin gymnastic & operating polarimeters

- New Polarimeter Concept

  MC Simulation & Installation

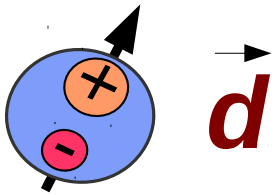
- Experimental Results

  Results since last PSTP 2017

- Summary

STORAGE RING – EDM

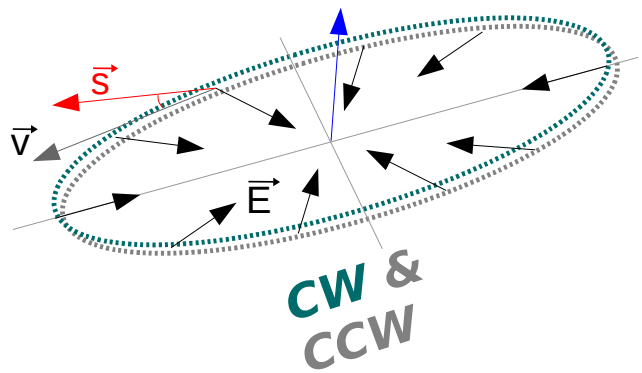
method differs strongly from nEDM



$\vec{d}$

For all ***EDM*** experiments
Interaction of ***d*** with ***E***
is necessary!

$$\frac{d\vec{s}}{dt} \propto d \cdot \vec{E} \times \vec{s}$$



a) Store longitudinally polarized ***protons***

b) Interact with a radial E-field

c) *Analyze Polarization Build-up (this talk)*

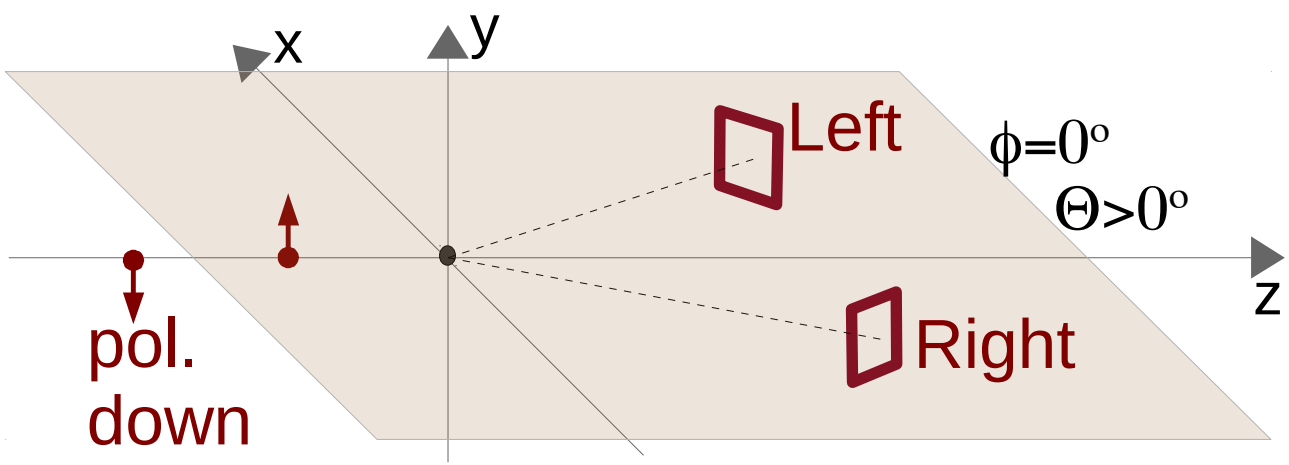
build-up of vertical polarization $\vec{s}_{\perp} \propto |d|$

GENERAL FORMALISM

$$PA_y(\theta) = \frac{\sigma^L(\theta) - \sigma^R(\theta)}{\sigma^L(\theta) + \sigma^R(\theta)} \approx \frac{N^L(\theta) - N^R(\theta)}{N^L(\theta) + N^R(\theta)}$$

$$\text{for } \vec{d}: \sigma^{\mathbf{pol}}(\theta, \phi) = \sigma_0(\theta)[1 + \tfrac{3}{2} PA_y(\theta) \cos\phi \quad + \{\tfrac{1}{3} \sum P_{ii} A_{ii}\} \ ]$$

$$CR(\theta) = \frac{\sqrt{N^{L\uparrow} N^{R\downarrow}} - \sqrt{N^{R\uparrow} N^{L\downarrow}}}{\sqrt{N^{L\uparrow} N^{R\downarrow}} + \sqrt{N^{R\uparrow} N^{L\downarrow}}} \approx PA_y - \text{known } A_y : \text{measure } \vec{P}$$



$$FOM(\theta) = \sigma A_y^2 - \text{max. } FOM : \text{monitor } \frac{d\vec{s}}{dt}$$

General Requirements for the Polarimeter

srEDM – *Precision Experiment !*

- Reaction with Large ***FOM*** (σA_y^2) & ($\sigma_{ela}/\sigma_{tot}$): Best $dC \rightarrow dC$
- Maximum Detection & Data Taking Efficiency
- Full ϕ in Reasonable ***FOM***(θ) region
- No strong Magnetic / Electric Field
- Stability – Long / Short Term

JEDI POLARIMETER SETUP @ COSY

Energy range (min.-- max.):

0.045 – 2.8 GeV (p)

0.023 – 2.3 GeV (d)

Max. momentum ~ **3.7 GeV/c**

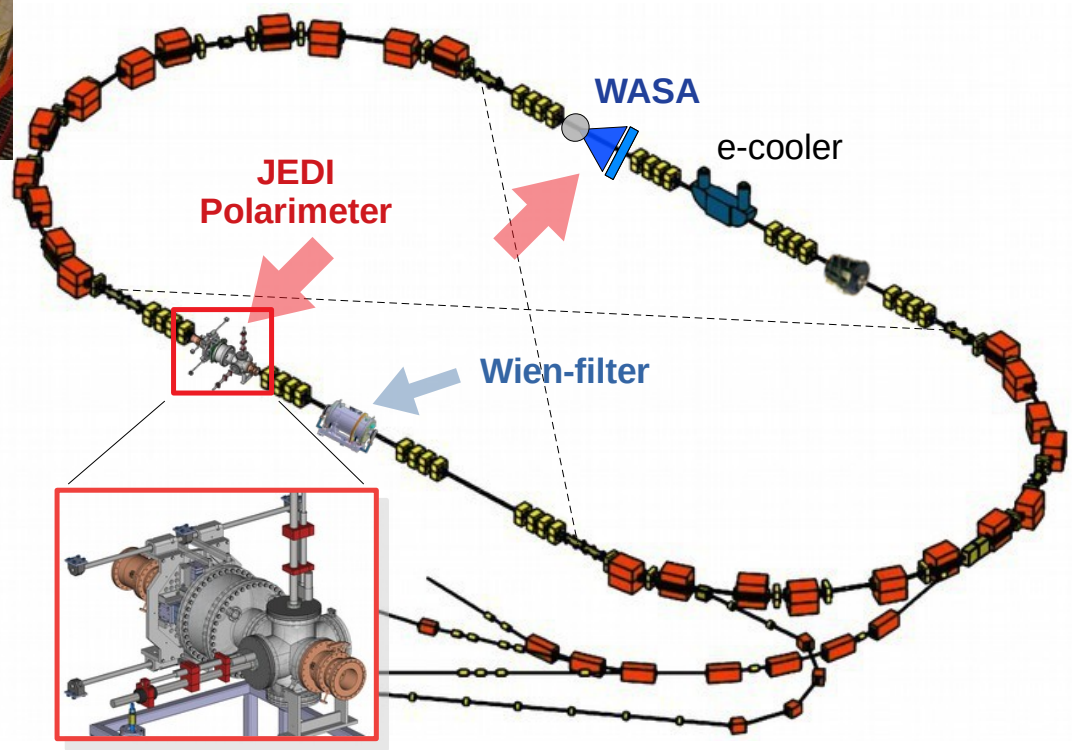
Internal & **external** beams

Electron & ***Stochastic*** cooling

Feed-forward machine

High **polarization** (***p, d***)

Spin manipulation !!!

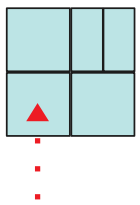


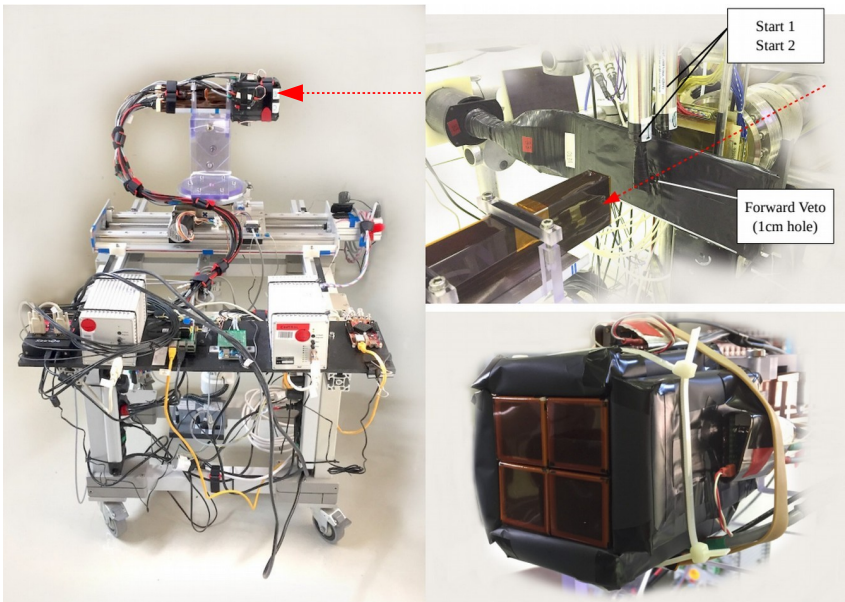
HISTORY

Steps-by-Step

Exp. E002.1 March 2016

First test of:
- LYSO
- PMT
- SiPM
- FADC
- Scans
- ...





HISTORY

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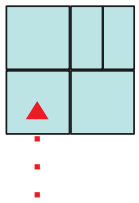
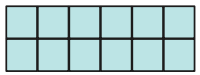
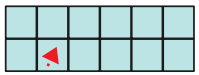


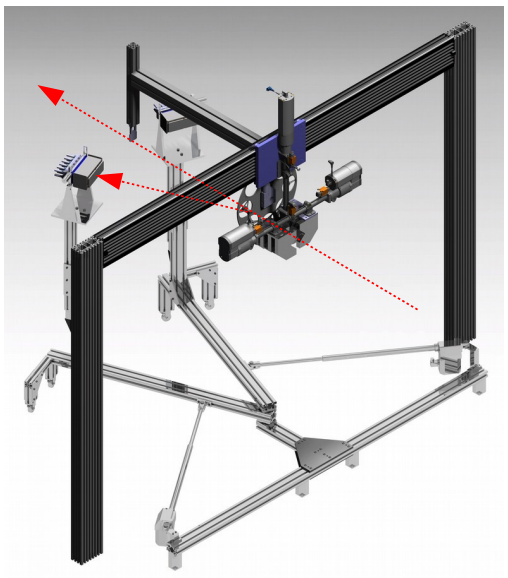
Exp. E002.2 Dec. 2016





Test of:
- 24x LYSO
- New SiPM
- ΔE 5mm
- Software
- Power supply
- ...

C, CH_2, Mg, Al, Si

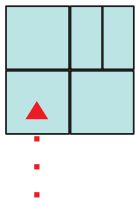


HISTORY

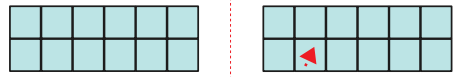
Steps-by-Step

Exp. E002.1 March 2016

First test of:
- LYSO
- PMT
- SiPM
- FADC
- Scans
- ...



Exp. E002.2 Dec. 2016



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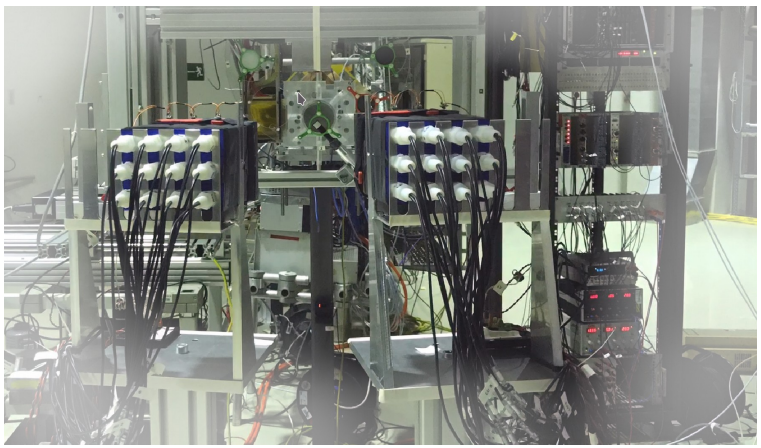
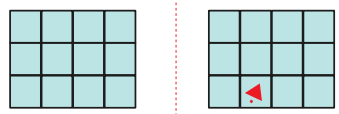
- New SiPM
- ΔE 5mm
- Software
- Power supply
- ...

C, CH_2, Mg, Al, Si



Exp. E002.3 March 2017



Test of:
- Cross sections
- Software
- ΔE 10mm
- V readout
- ...

C, CH_2, Mg, Al, Si

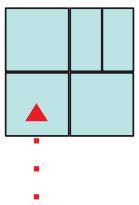
JÜLICH Forschungszentrum

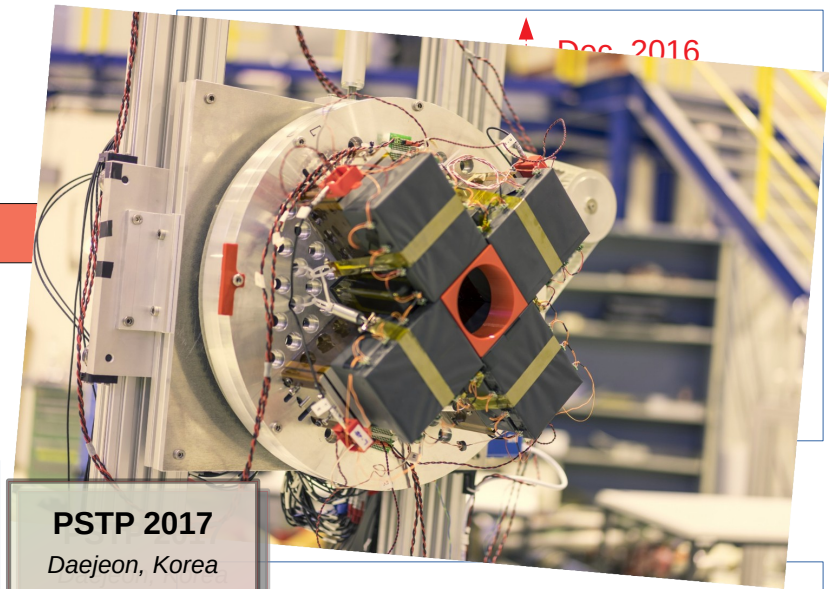
HISTORY

Steps-by-Step

Exp. E002.1 March 2016

First test of:
- LYSO
- PMT
- SiPM
- FADC
- Scans
- ...





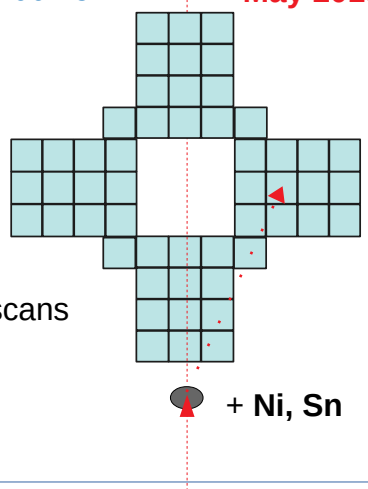
Dec. 2016

PSTP 2017
Daejeon, Korea

Exp. E002.4 Dec. 2017
E002.5 **May 2018**

Test 1 :
- 52x LYSO
- ΔE 20mm
- Mechanics
- 6x FADC
- Timing

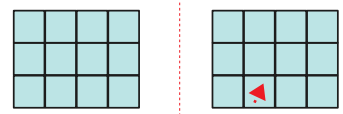
Test 2:
- Front face scans ***2D maps***
- Tracker ΔE
- ...



+ **Ni, Sn**

Exp. E002.3 March 2017

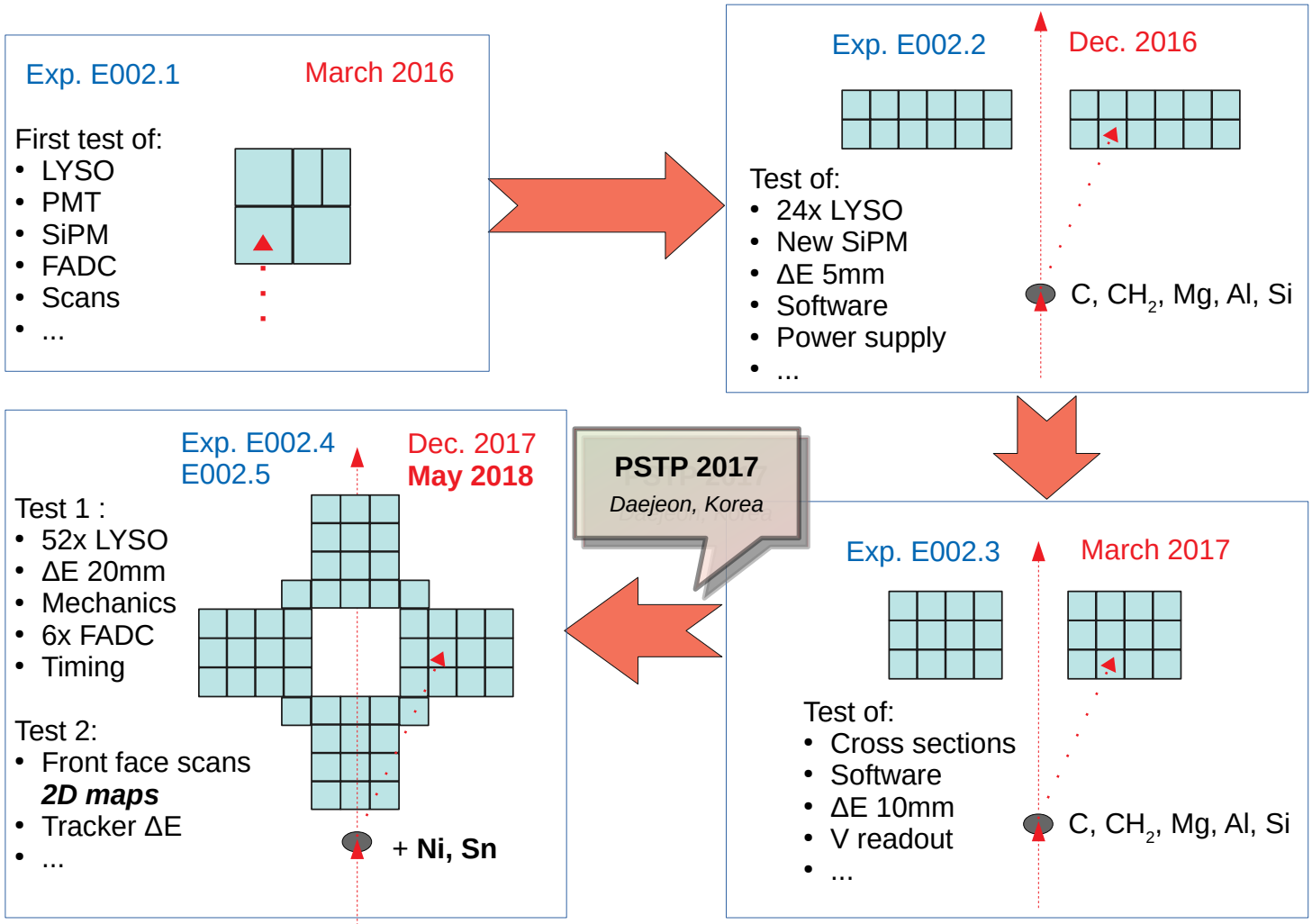
Test of:
- Cross sections
- Software
- ΔE 10mm
- V readout
- ...



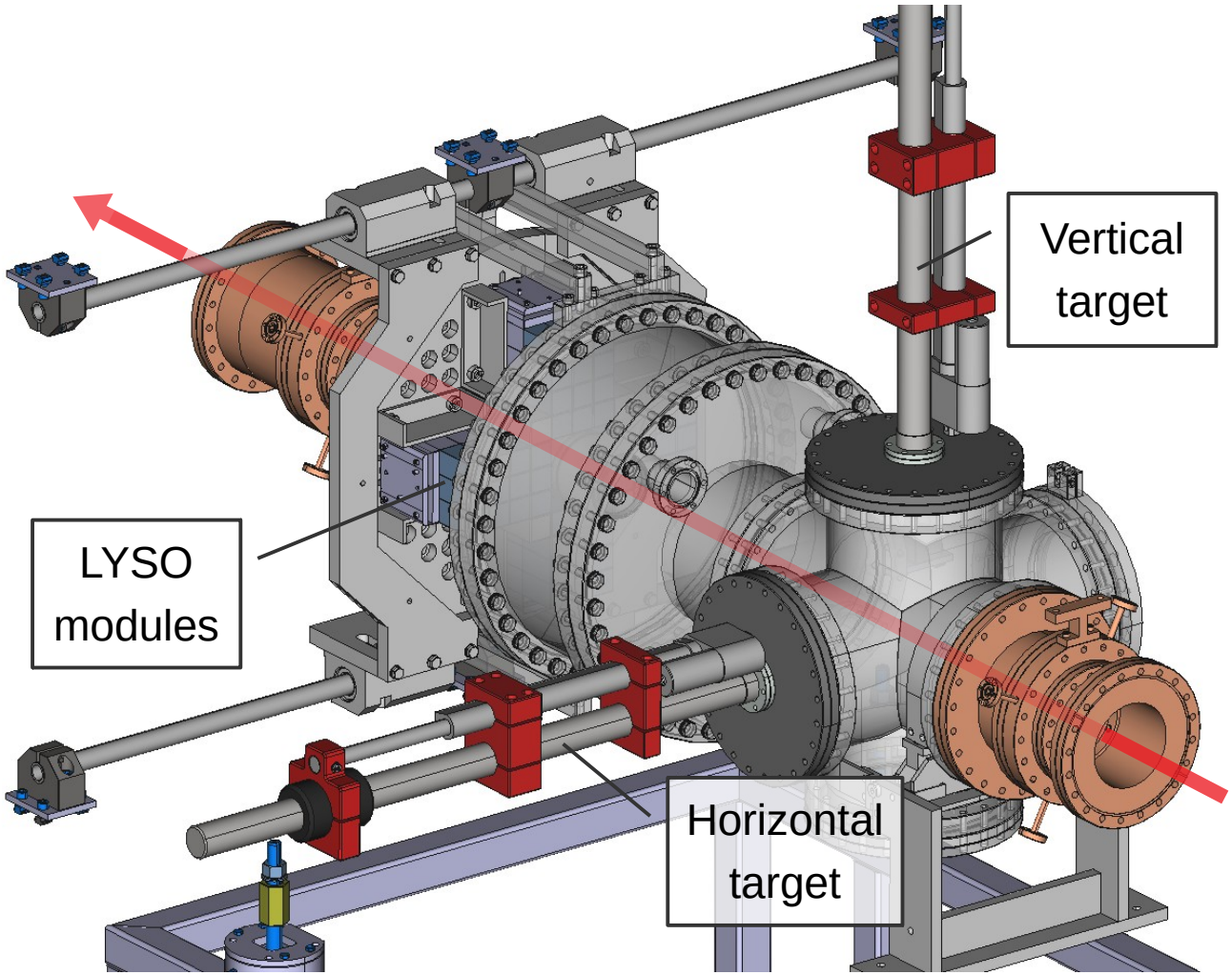
C, CH_2, Mg, Al, Si

HISTORY

Steps-by-Step

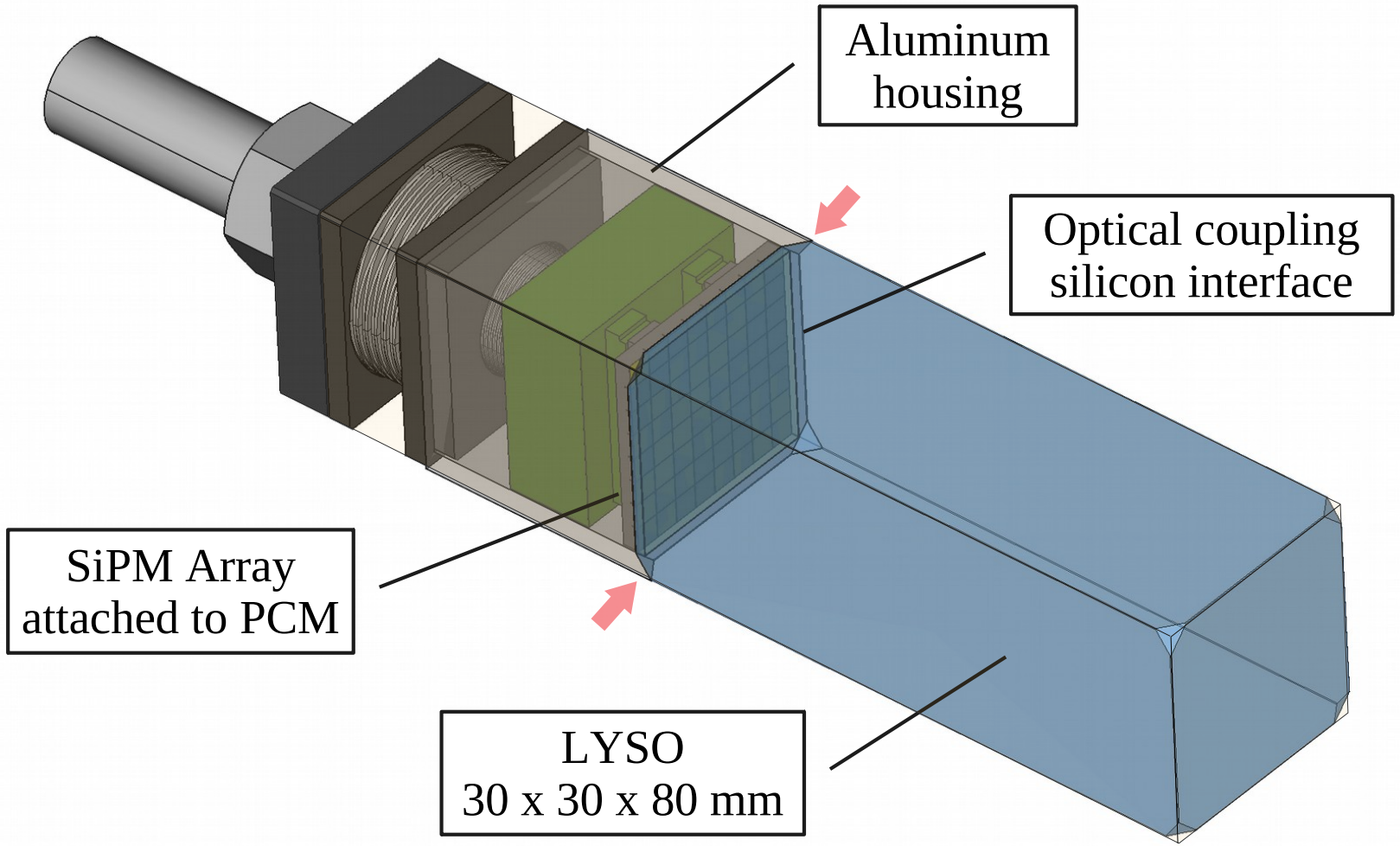


JEDI POLARIMETER



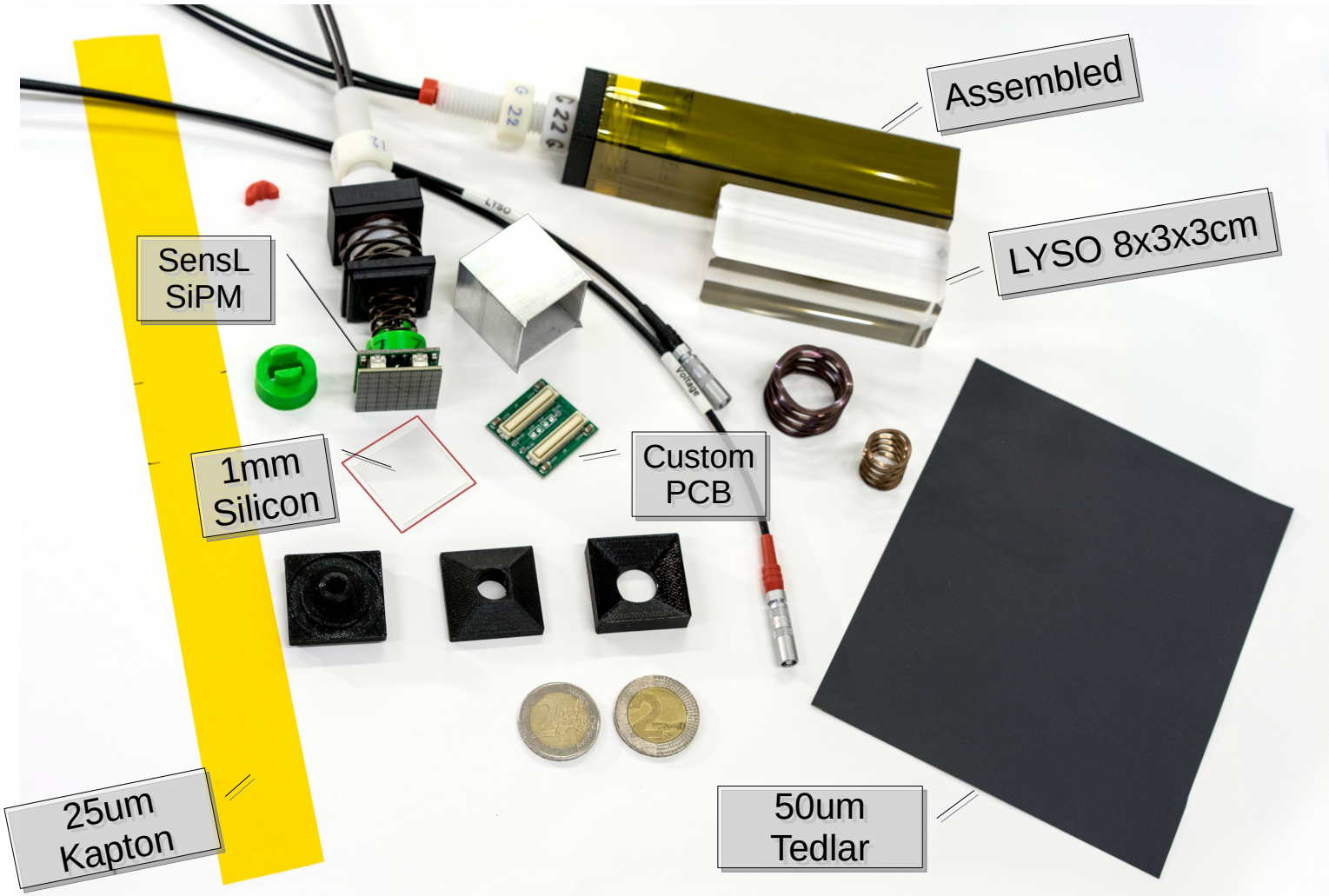
POLARIMETER MODULES

LYSO coupled to 8x8 SiPM Array



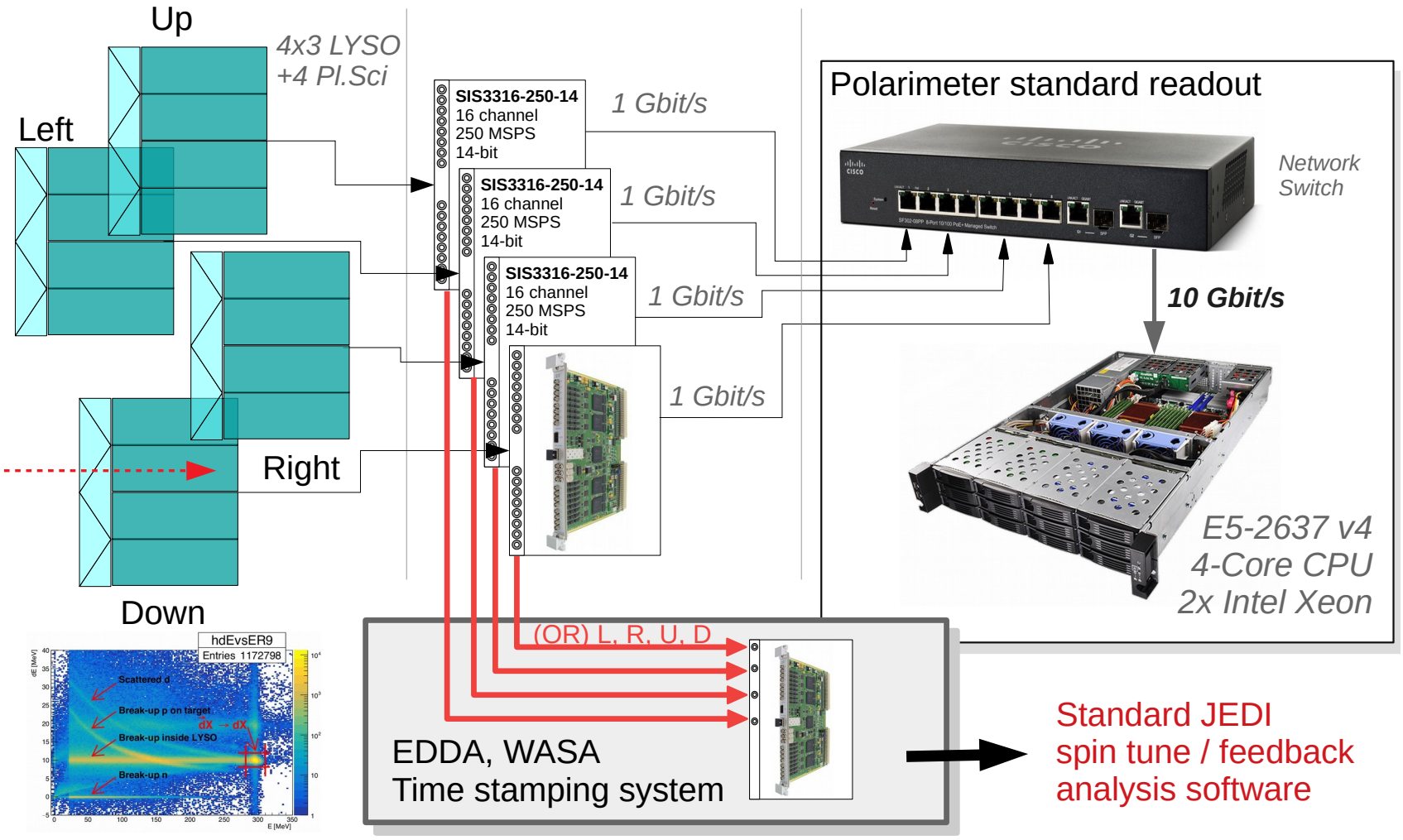
LYSO MODULE MK-2

New improved mechanics and electronic components



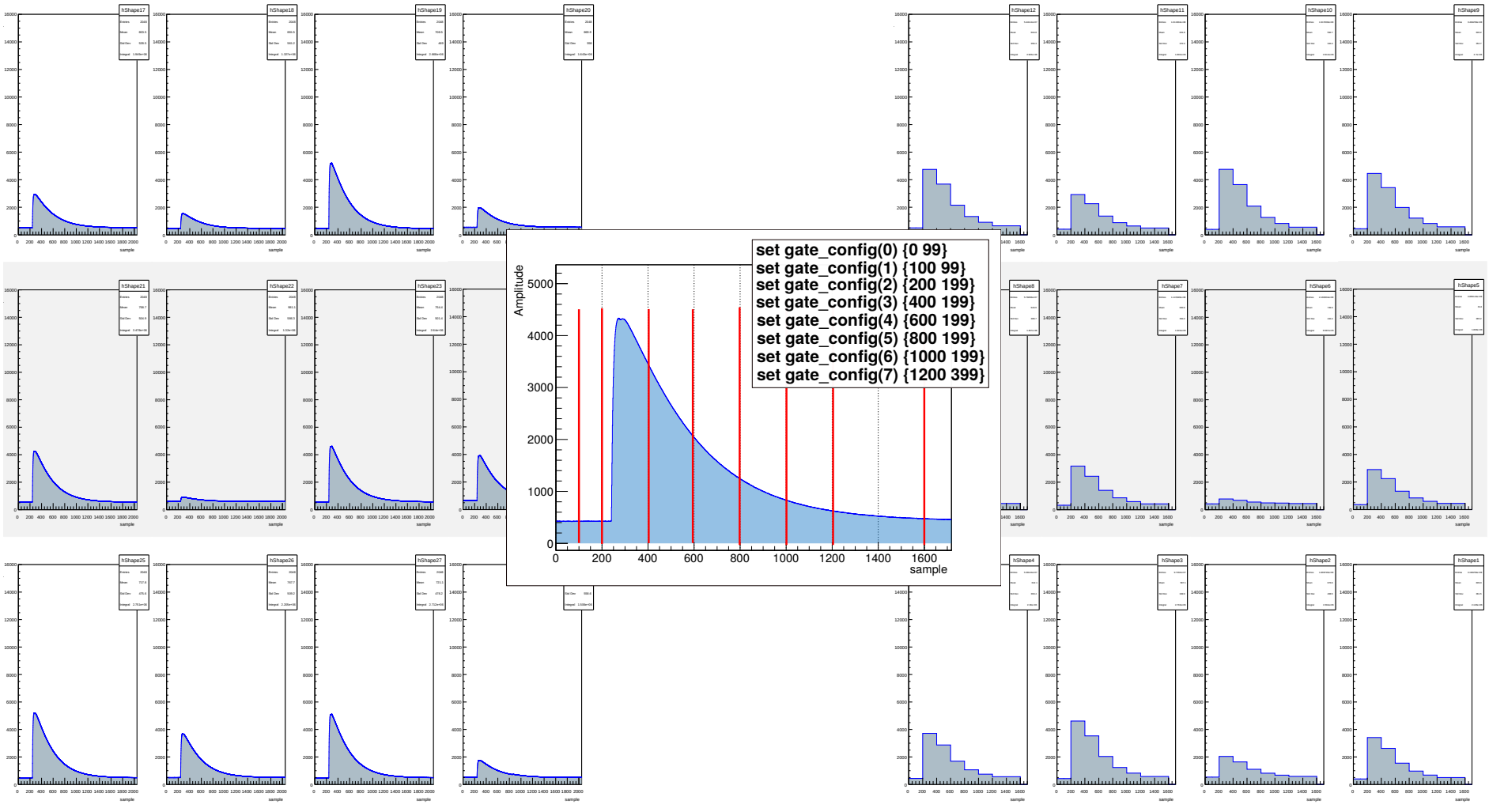
SADC BASED DAQ SYSTEM

Maximum efficiency + time-stamping



SIGNAL SHAPES

Full signal shape vs 8 accumulator/integral region



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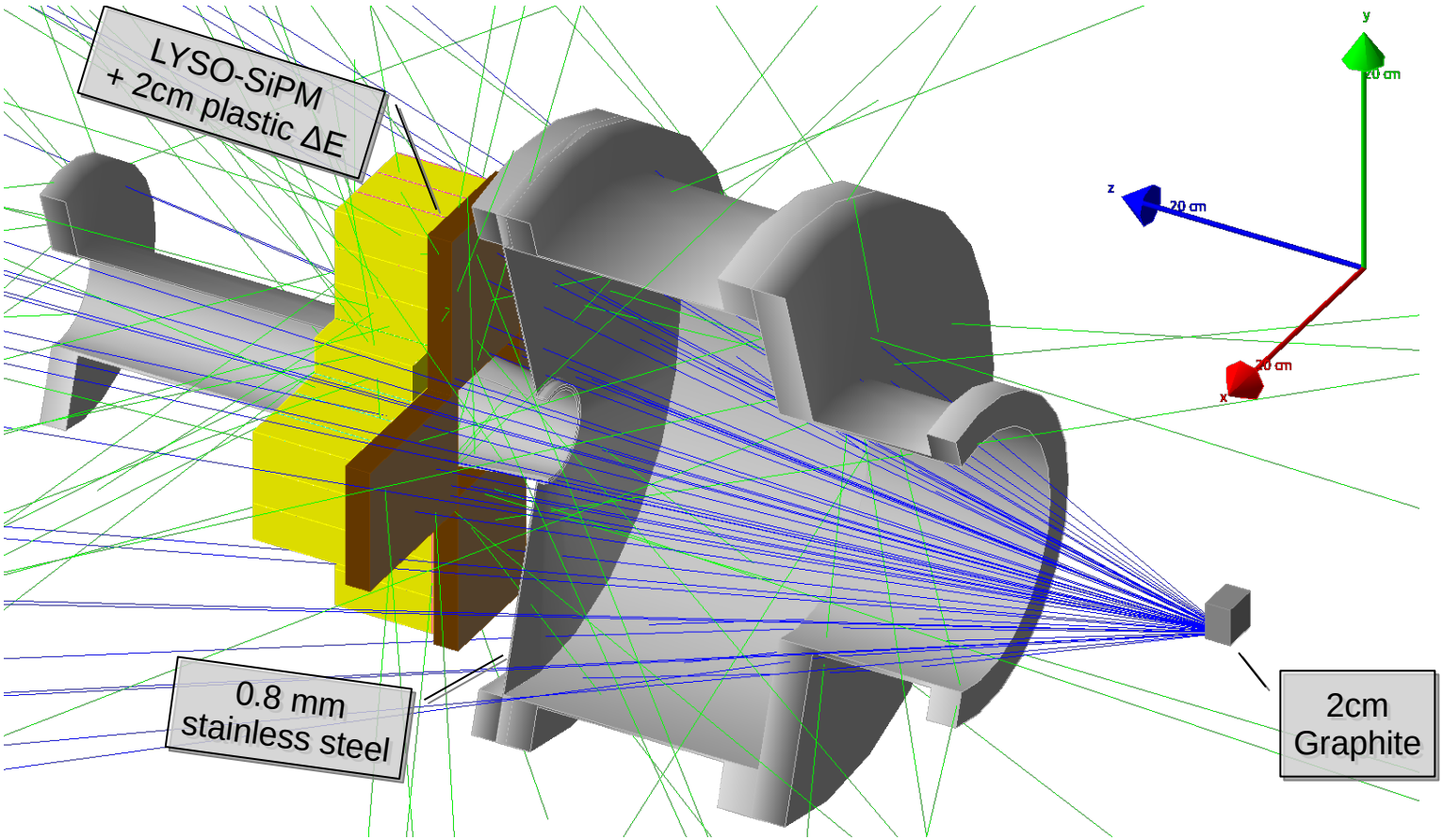
GEANT4 SIMULATION

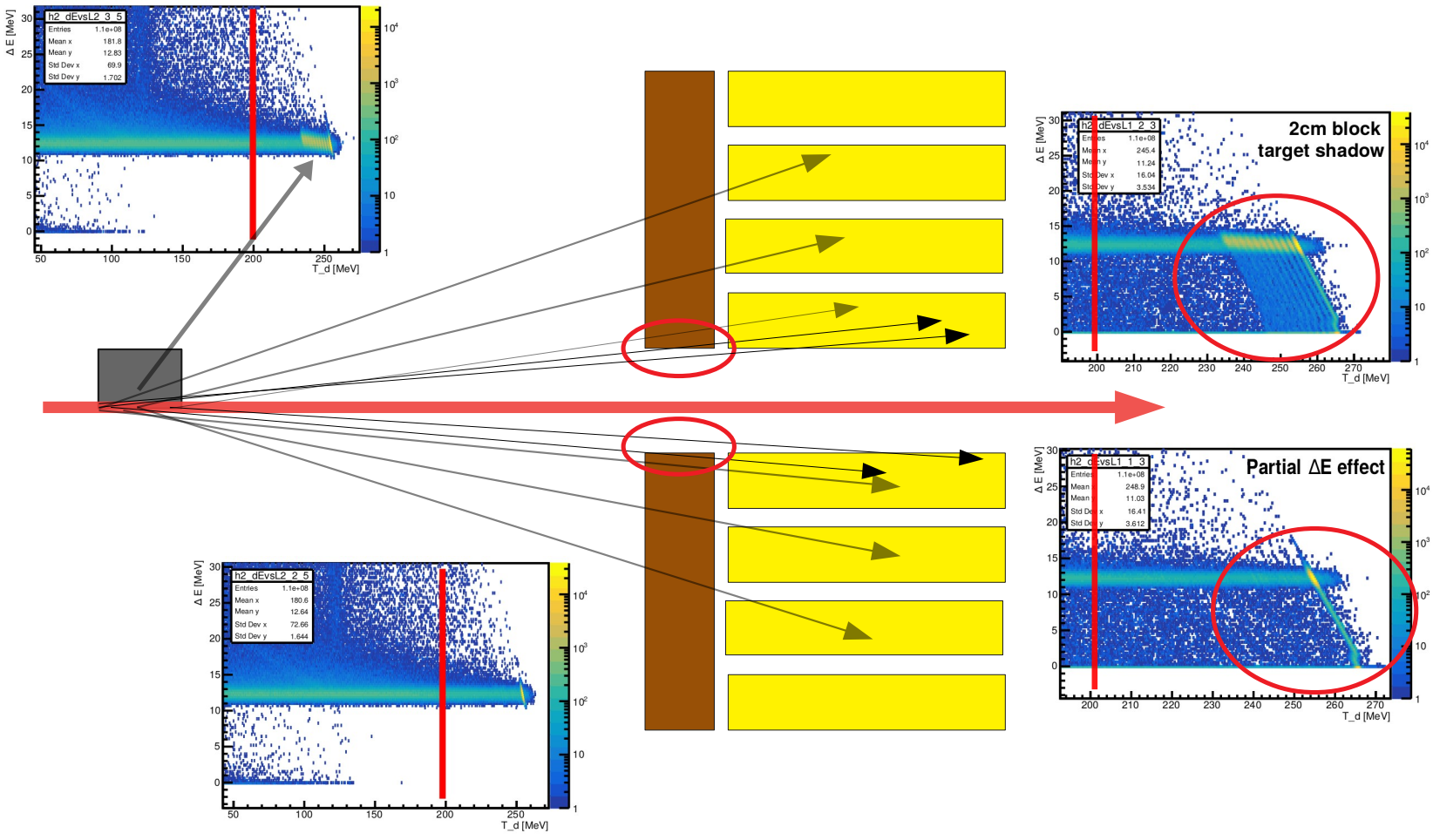
Full model of actual setup (Master thesis of M. Abuladze)



To investigate artificial asymmetry due to multiple scattering inside the target material

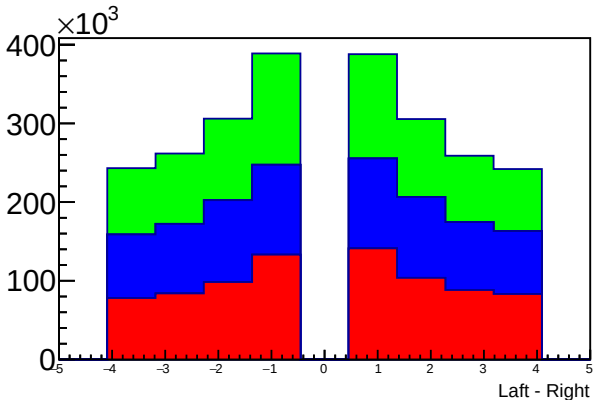
GEANT4 SIMULATION

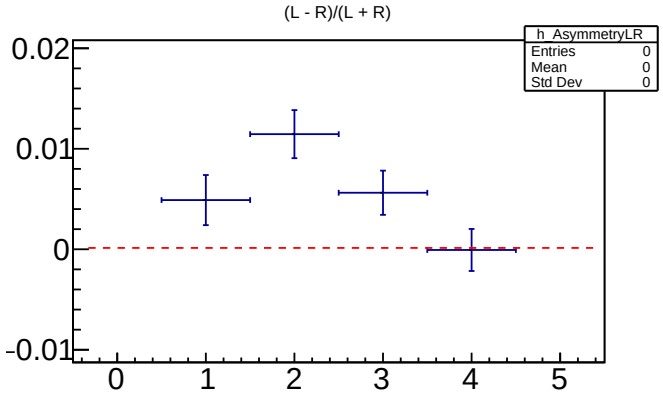
Expected track distribution

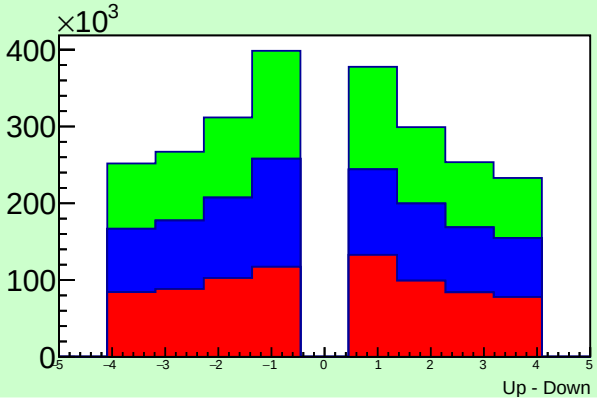


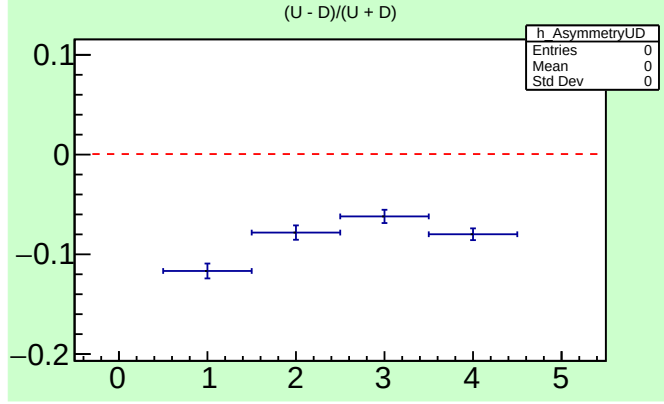
GEANT4 RESULTS

2 cm graphite target





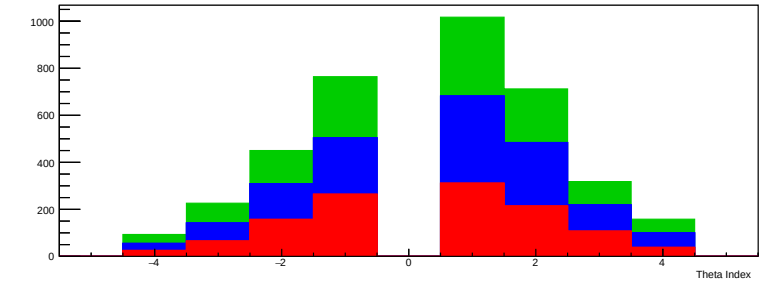


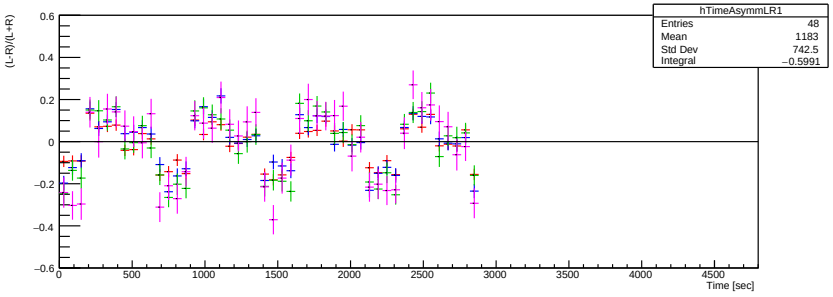


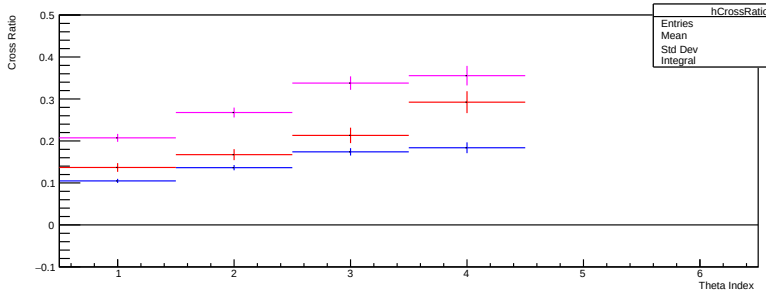
Asymmetry due to multiple scattering inside the target material

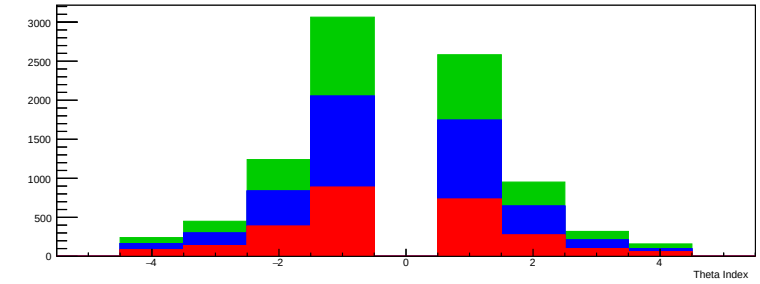
ASYMMETRY

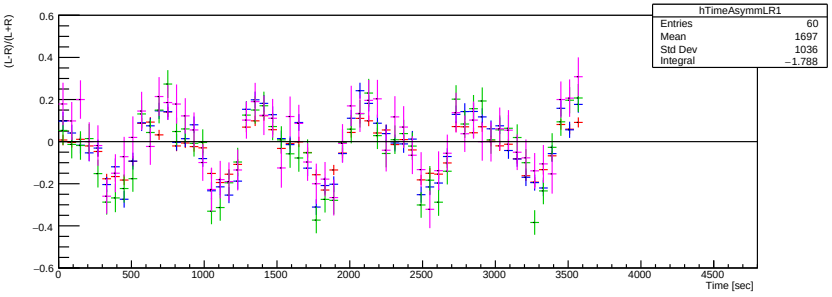
Carbon at $\Theta_{max} = 10^o$ and $\Theta_{max} = 15^o$

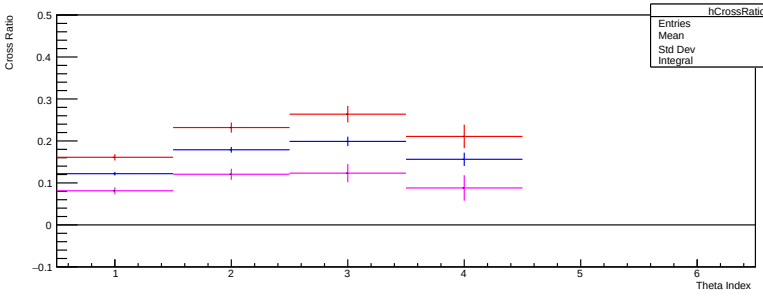






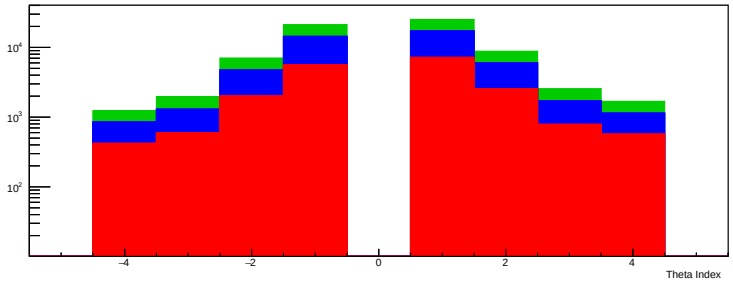


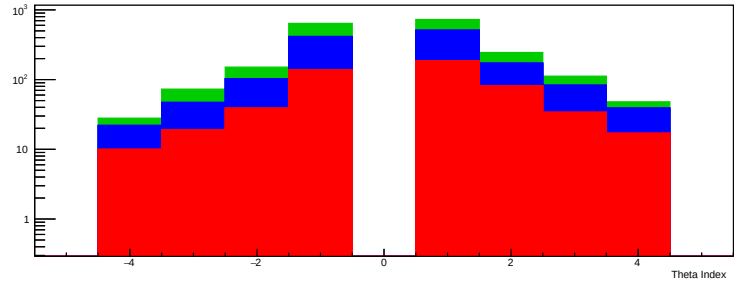


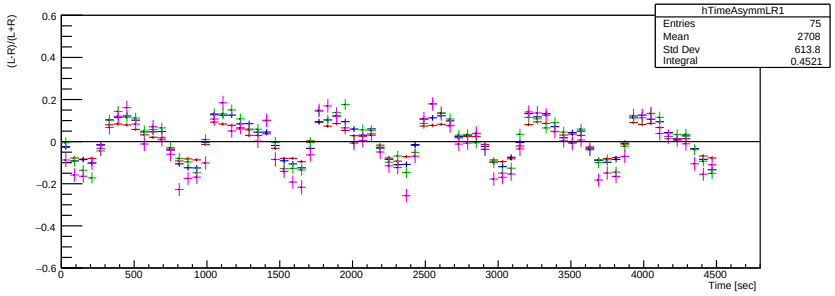


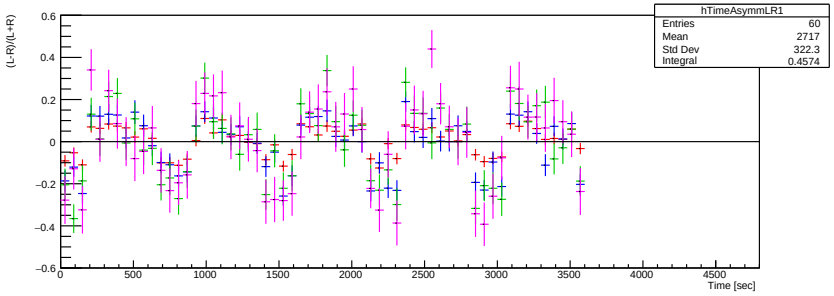
ASYMMETRY

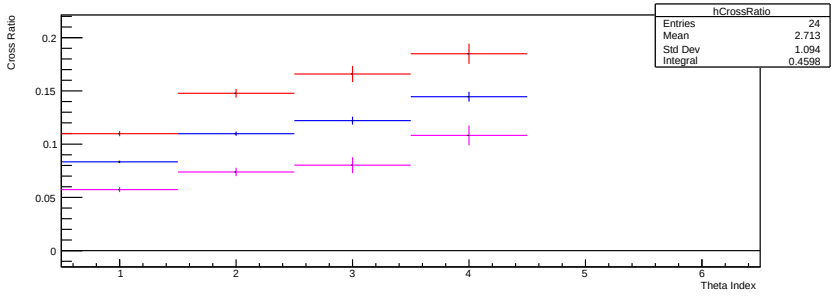
Different target materials (left Nickel; right Tin)

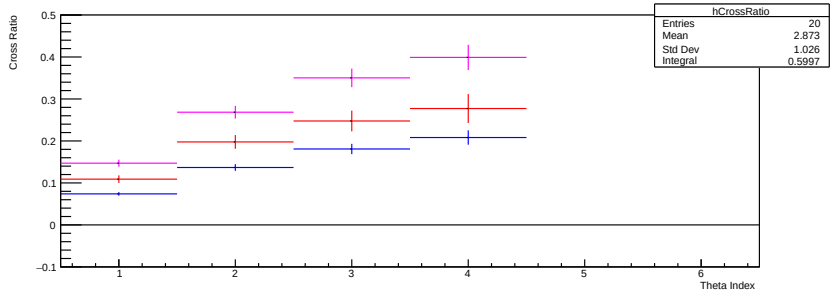






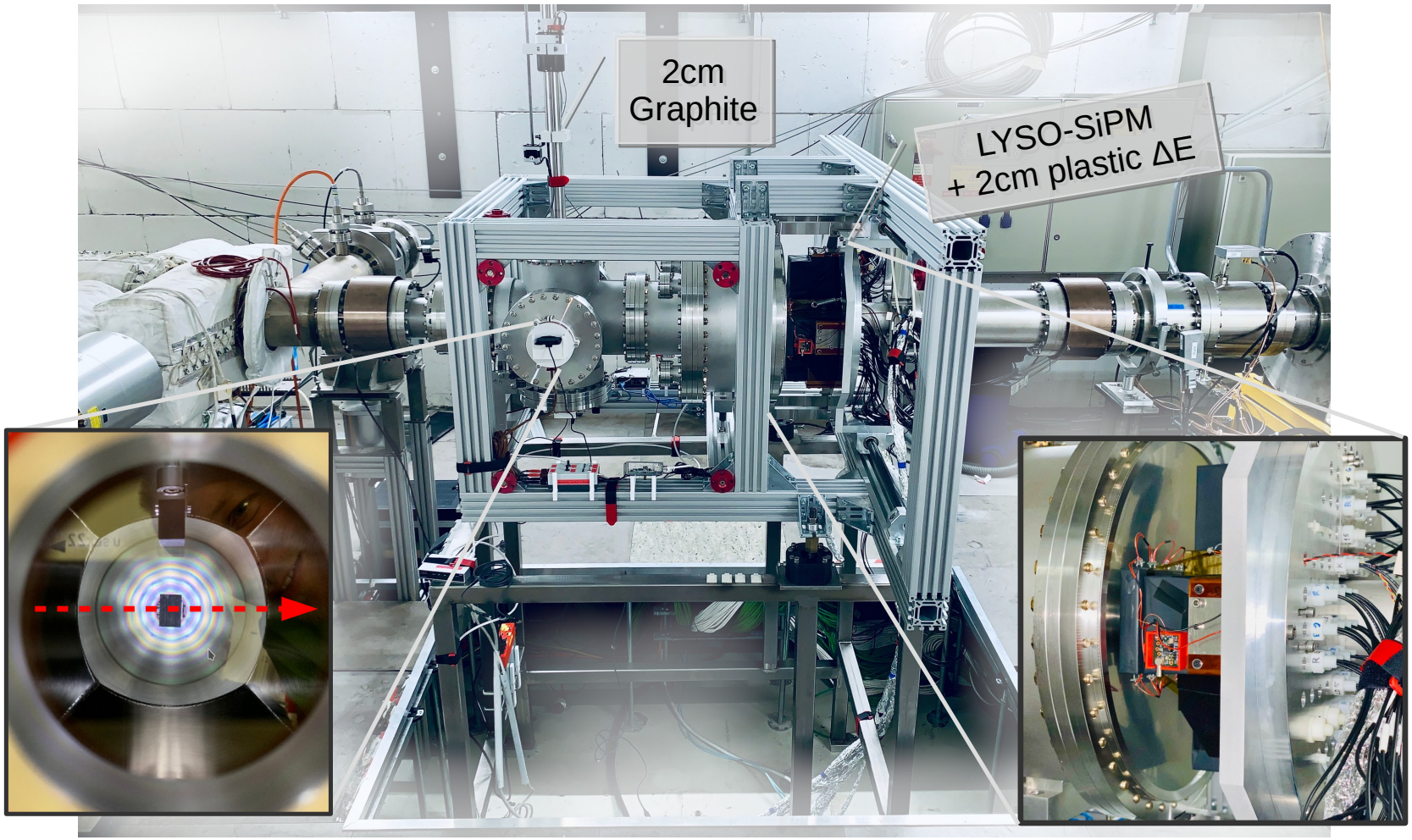






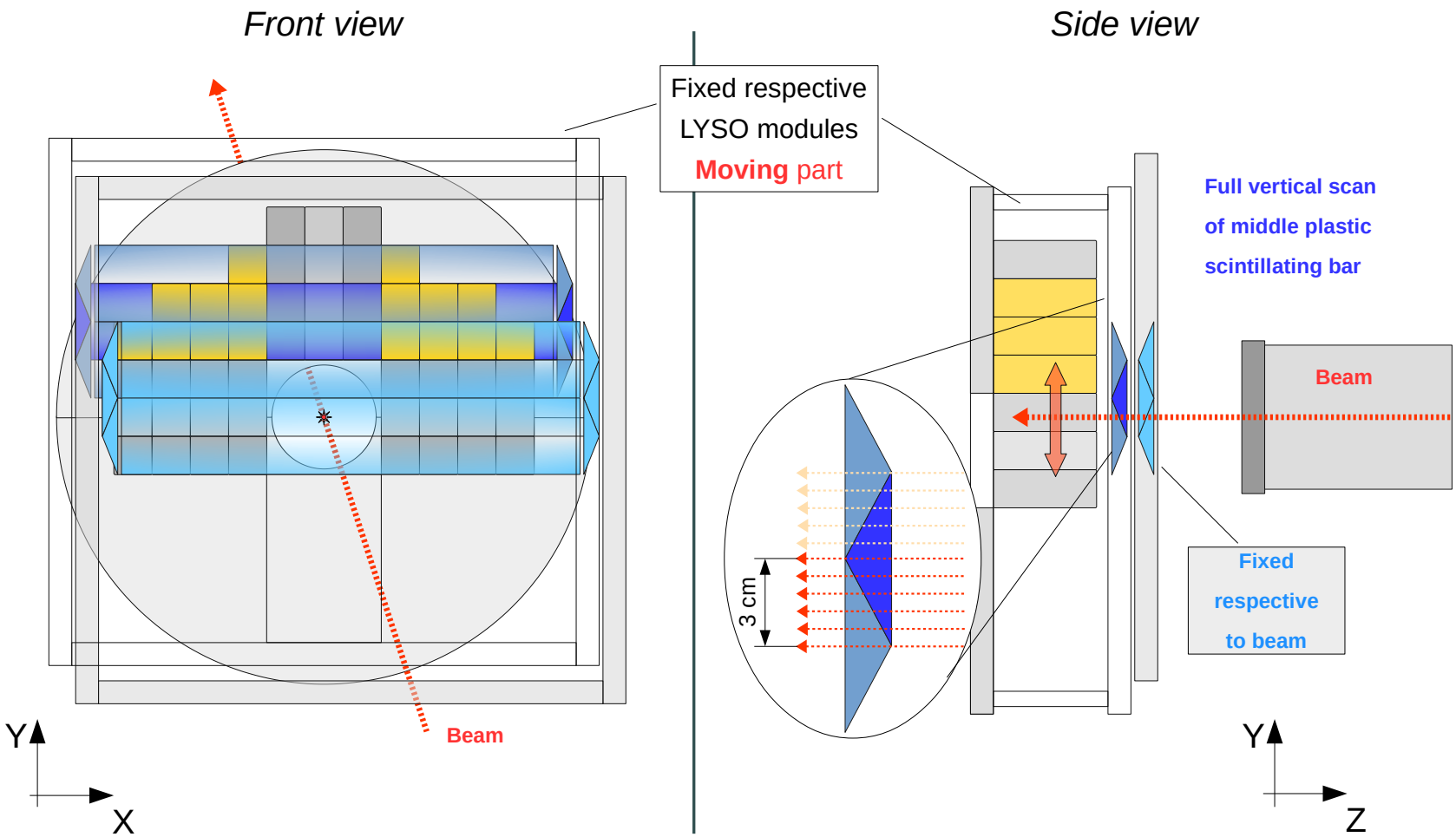
JEDI POLARIMETER – JEPO

September 20th, 2019



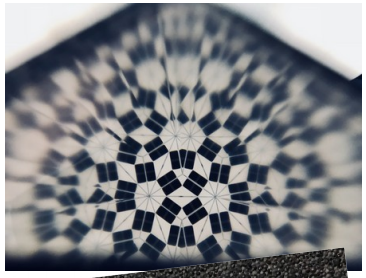
JEPO TRACKING SYSTEM

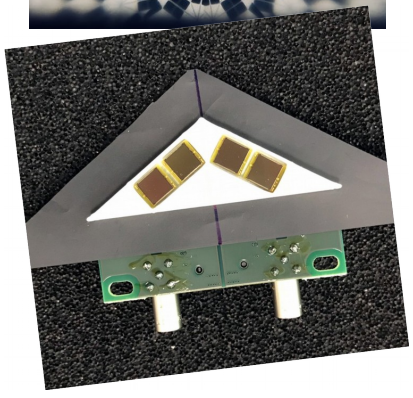
Tested and 1 mm space resolution achieved

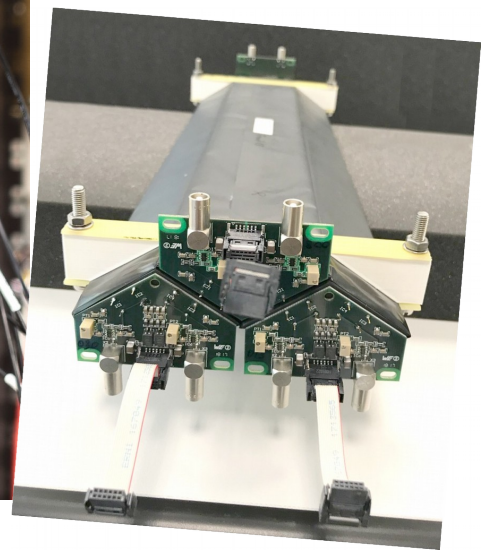


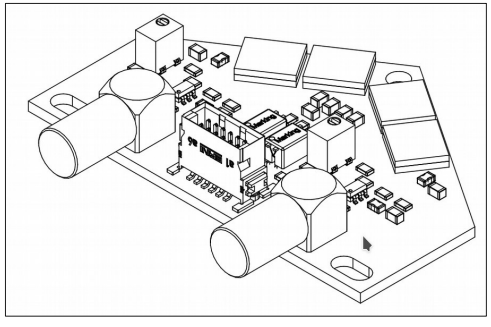
JEPO TRACKING SYSTEM

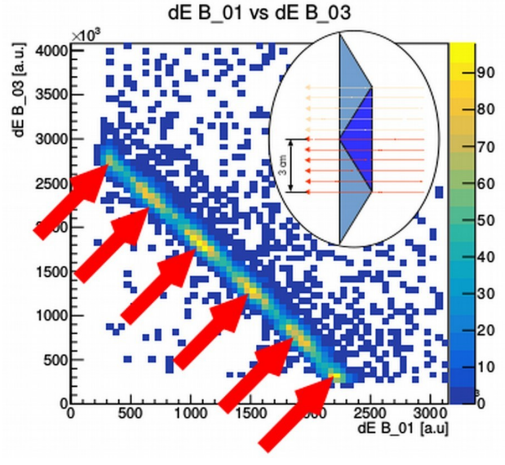
Tested and 1 mm space resolution achieved

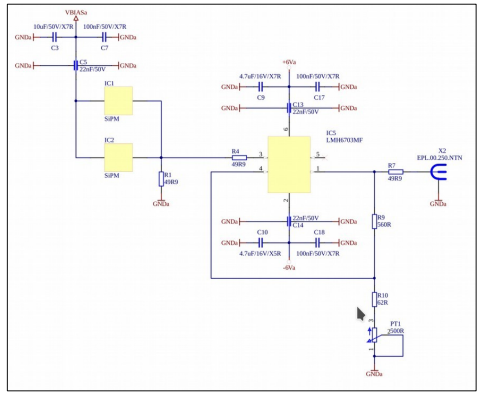












SUMMARY

- We have fully functional online polarimeter
  –needs further software development!
- Mechanical support & slow control
  shows excellent performance
- New DAQ system reached its
  max. designed data transfer of 600 MB/s
- We have assembled and tested new LYSO and SiPM vendors
  in total 52 (48+4) Modules
- **Next major step is to install a tracking system made with the triangular scintillator bar**

ACKNOWLEDGMENT

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”High-precision polarimetry for charged-particle Electric Dipole Moment (EDM) searches in storage rings”

Appendix

CONTACT

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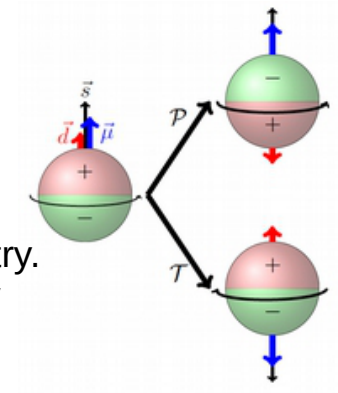
ELECTRIC DIPOLE MOMENT

of the elementary particles

In the **SM**, the **CP** violation originates from the complex phase in the Cabibbo-Kobayashi-Maskawa (***CKM***) matrix,
which couples the quarks' weak and the mass eigenstates, and the θ term in the QCD Lagrangian.



CP (K^o decays) violation means **T** is also violated assuming **CPT** symmetry.
The existence of a non-zero EDM is a violation of P and T simultaneously & the search for a EDM is a search for **CP** violation and a search for **direct T** symmetry violation.

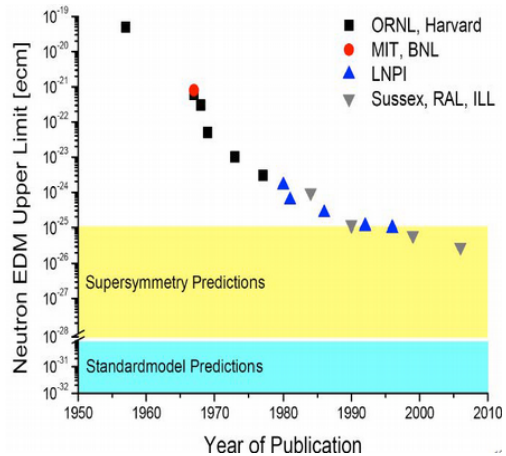
SM CP violation is enough to explain what has been observed in the *K & B* meson systems but orders of magnitude smaller than observed in the universe

$$\eta = \frac{N_B - N_{\bar{B}}}{N_\gamma} = \sim 10^{-18}\,(SCM) \sim 6 \cdot 10^{-10}\,(BAU)$$

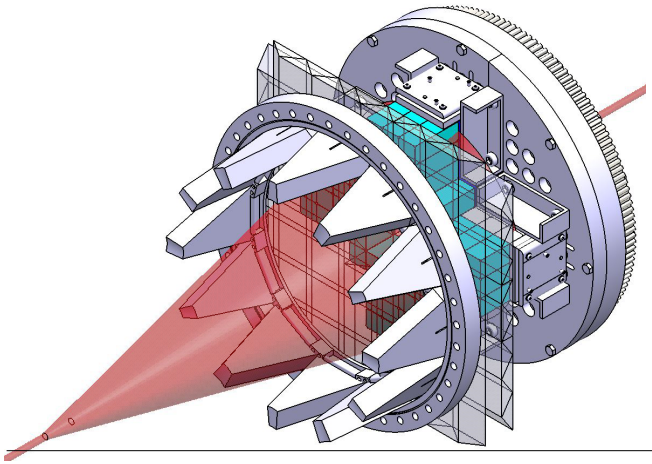
1967: Sacharov conditions for the Baryon Asymmetry of the Universe

1) At least one N_B violating process.
2) **C** and **CP** violation
3) Interactions outside of thermal equilibrium.

*Measurement of the non zero **EDM** → physics beyond **SM***

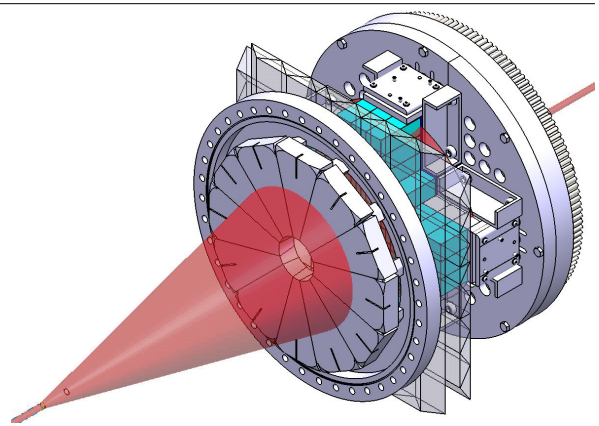


DEGRADER



only LYSO + 4cm plastic can cover 320 MeV kinetic energy + cooper degrader can increase up to 350 MeV kinetic energy

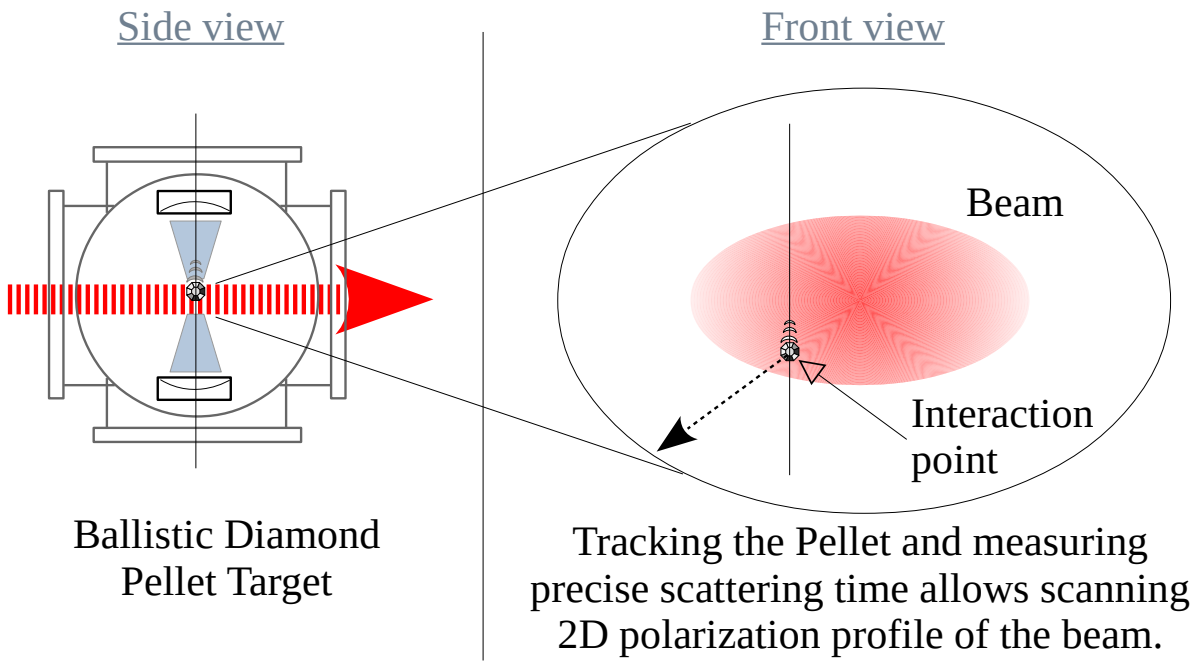
degrader will be adjusted for the proton magic momentum and used for the deuteron energy calibration too



JUDIT

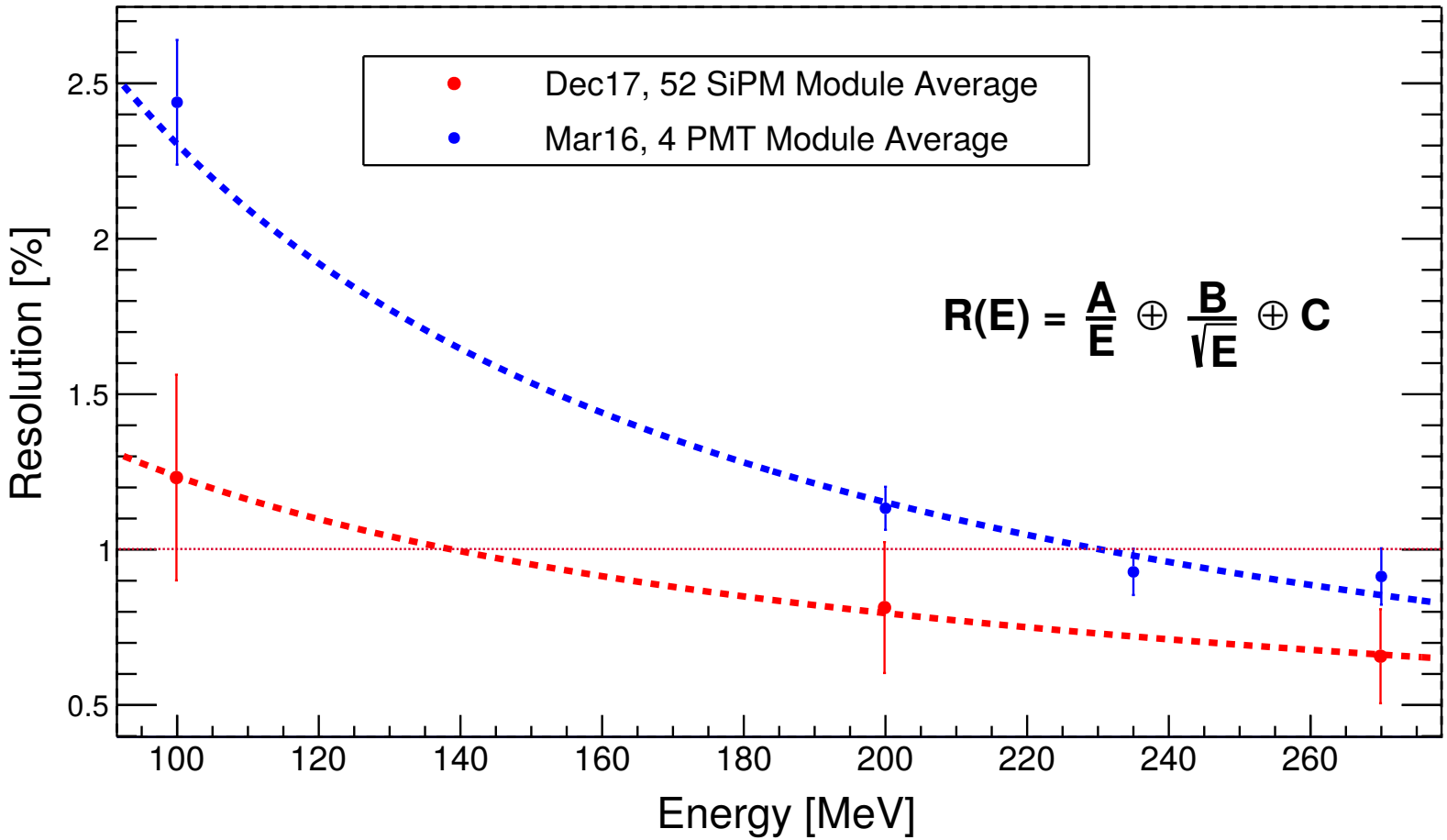
Jülich ballistic Diamond pellet Target

- Target capable to measure polarization profile
- Huge dynamic range in effective target thickness
- Non-invasive, no rest gas



LYSO-SIPM ENERGY RESOLUTION

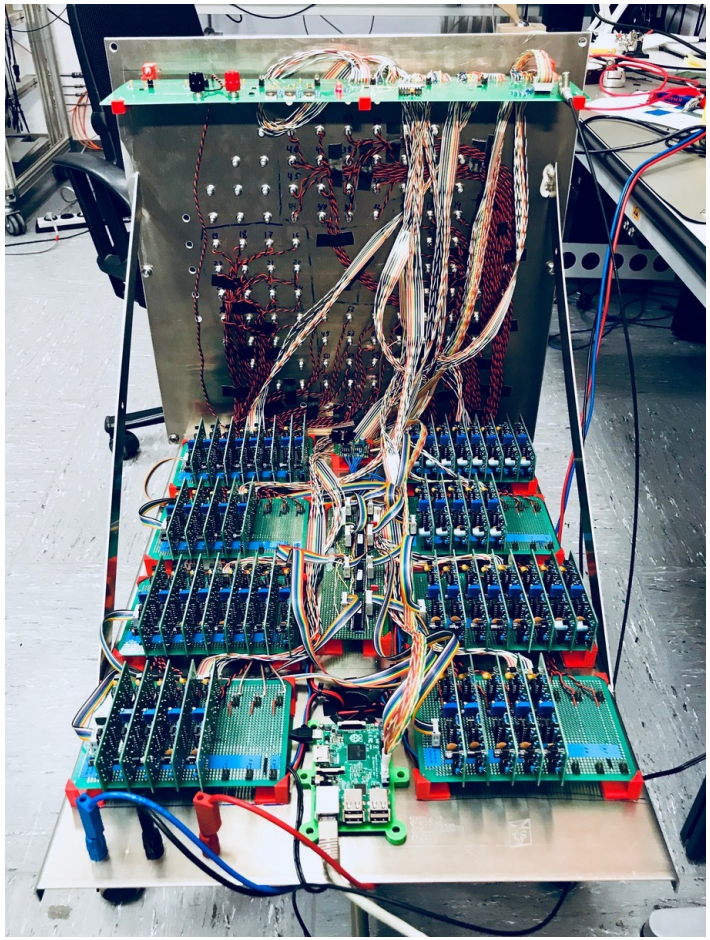
FWHM / Mean

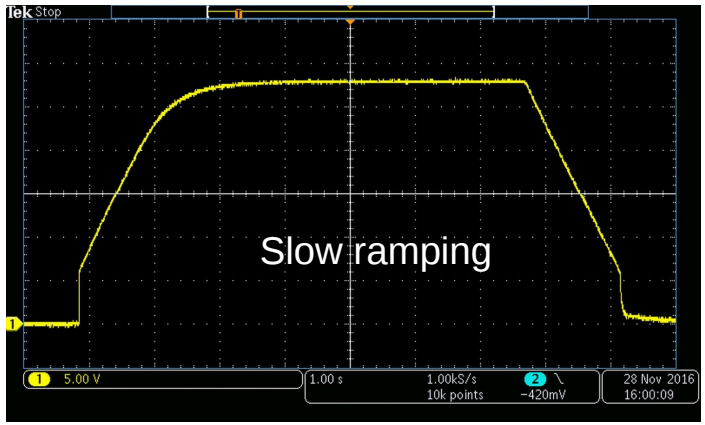


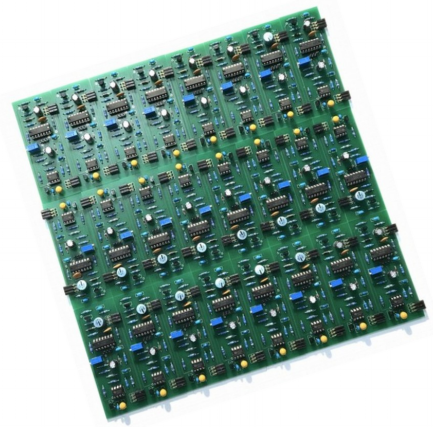
SIPM VOLTAGE SUPPLY

Very Good Long Term Stability $\sim 50\mu V_{pp}$

Entirely SmartLab and Agruni contribution







DEUTERON KINETIC ENERGY 150 *MeV*

Measurement on CH_2 Polyethylene target