JÜLICH
FORSCHUNGSZENTRUM

Polarimetry - from basics to precision

*on behalf of the **JEDI** collaboration*

PSTP 2017 | Daejeon, Republic of Korea

October 19th, 2017 | Irakli Keshelashvili |

Outline

- Mission of ***Polarimetry***

  challenges for srEDM case

- **COSY** Accelerator Facility

  Spin gymnastic & operating polarimeters

- New Polarimeter Concept

  dedicated polarimeter for srEDM experiment

- Experimental Results

  3 beam time since PSTP 2015

- Summary

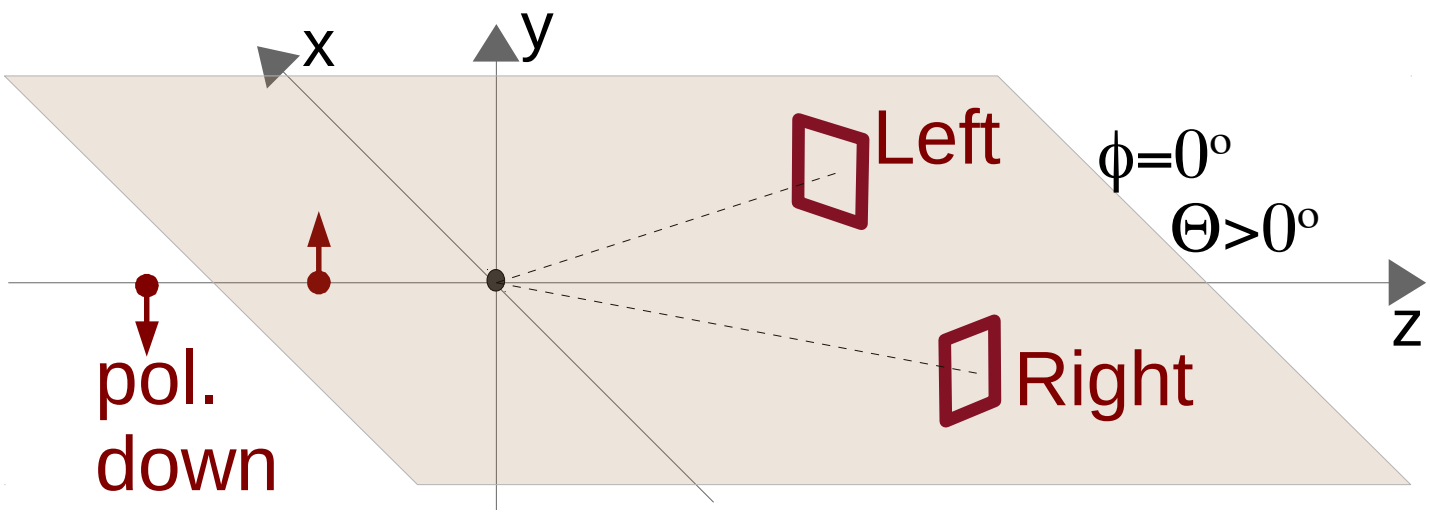
General Formalism

$$PA_y(\theta) = \frac{\sigma^L(\theta)-\sigma^R(\theta)}{\sigma^L(\theta)+\sigma^R(\theta)} \approx \frac{N^L(\theta)-N^R(\theta)}{N^L(\theta)+N^R(\theta)} - \text{between } -1:1$$

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

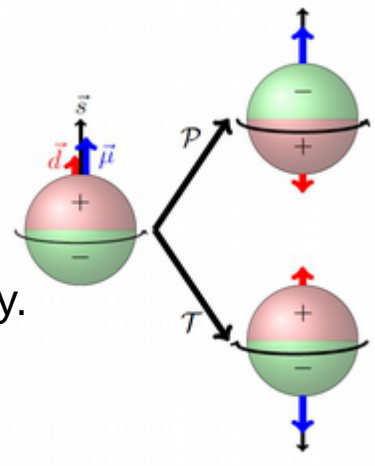
$$CR(\theta) = \frac{\sqrt{N^{L\uparrow}N^{R\downarrow}}-\sqrt{N^{R\uparrow}N^{L\downarrow}}}{\sqrt{N^{L\uparrow}N^{R\downarrow}}+\sqrt{N^{R\uparrow}N^{L\downarrow}}} \approx PA_y - \text{known } A_y : \text{calculate } P$$

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



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.



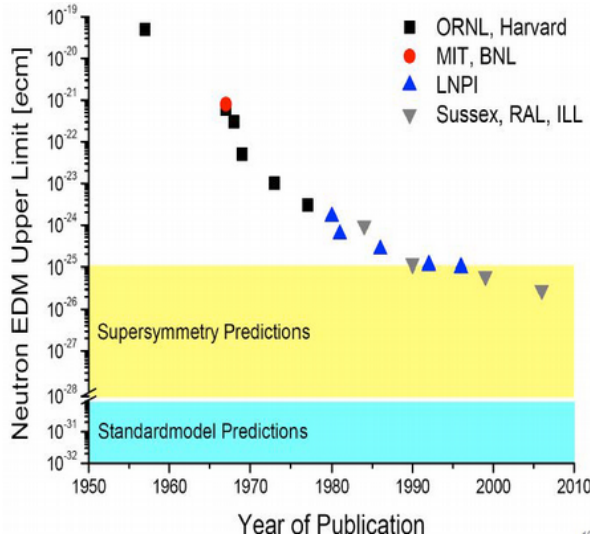
CP (K^o decays) violation means **T** is also violated assuming **CPT** symmetry.
The existence of a non-zero EDM is a violation of P and T simultaneously & the search for a EDM is a search for **CP** violation and a search for **direct T** symmetry violation.

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

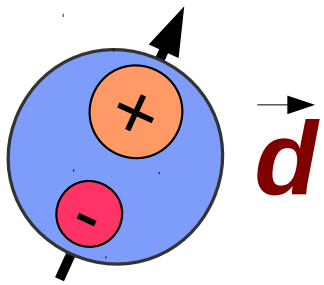
$$\eta = \frac{N_B - N_{\bar{B}}}{N_\gamma} = \sim 10^{-18}\,(SCM) \sim 6 \cdot 10^{-10}\,(BAU)$$

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***

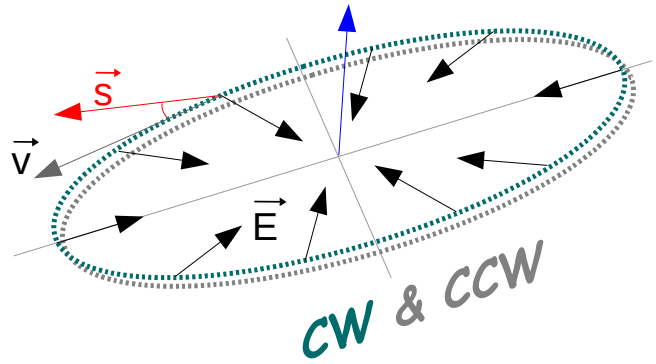


Storage Ring – srEDM
method differs strongly from nEDM



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 an radial E-field

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

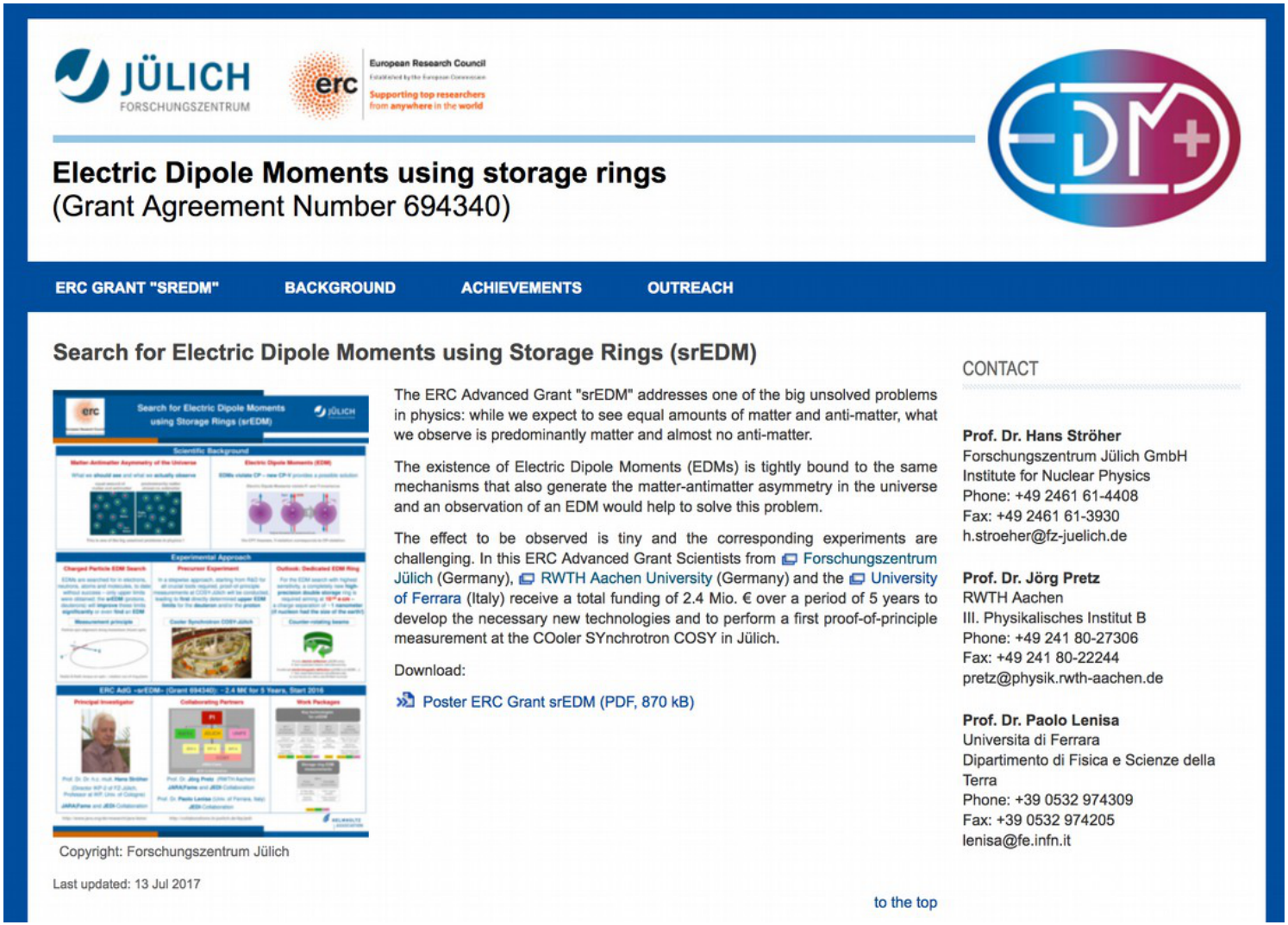
build-up of vertical polarization $\vec{s}_{\perp} \propto |d|$

Jülich Electric Dipole moment Investigation

http://collaborations.fz-juelich.de/ikp/jedi/

135 members & different Institutes from 7 country

Logo



JÜLICH FORSCHUNGSZENTRUM

European Research Council
Supporting top researchers from anywhere in the world

Electric Dipole Moments using storage rings
(Grant Agreement Number 694340)

ERC GRANT "SREDM" | BACKGROUND | ACHIEVEMENTS | OUTREACH

Search for Electric Dipole Moments using Storage Rings (srEDM)

The ERC Advanced Grant "srEDM" addresses one of the big unsolved problems in physics: while we expect to see equal amounts of matter and anti-matter, what we observe is predominantly matter and almost no anti-matter.

The existence of Electric Dipole Moments (EDMs) is tightly bound to the same mechanisms that also generate the matter-antimatter asymmetry in the universe and an observation of an EDM would help to solve this problem.

The effect to be observed is tiny and the corresponding experiments are challenging. In this ERC Advanced Grant Scientists from Forschungszentrum Jülich (Germany), RWTH Aachen University (Germany) and the University of Ferrara (Italy) receive a total funding of 2.4 Mio. € over a period of 5 years to develop the necessary new technologies and to perform a first proof-of-principle measurement at the COoler SYnchrotron COSY in Jülich.

Download:

Poster ERC Grant srEDM (PDF, 870 kB)

CONTACT

Prof. Dr. Hans Ströher
Forschungszentrum Jülich GmbH
Institute for Nuclear Physics
Phone: +49 2461 61-4408
Fax: +49 2461 61-3930
h.stroeher@fz-juelich.de

Prof. Dr. Jörg Pretz
RWTH Aachen
III. Physikalisches Institut B
Phone: +49 241 80-27306
Fax: +49 241 80-22244
pretz@physik.rwth-aachen.de

Prof. Dr. Paolo Lenisa
Universita di Ferrara
Dipartimento di Fisica e Scienze della Terra
Phone: +39 0532 974309
Fax: +39 0532 974205
lenisa@fe.infn.it

Copyright: Forschungszentrum Jülich

Last updated: 13 Jul 2017

to the top

COSY Accelerator Facility

Cooler Sychrotron

Energy range (min.-- max.):

0.045 – 2.8 GeV (p)

0.023 – 2.3 GeV (d)

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

Electron & ***Stochastic*** cooling

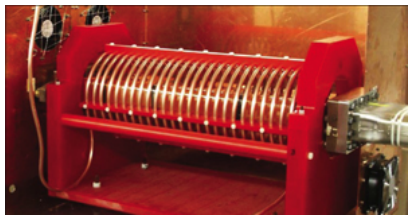
Feed-forward machine

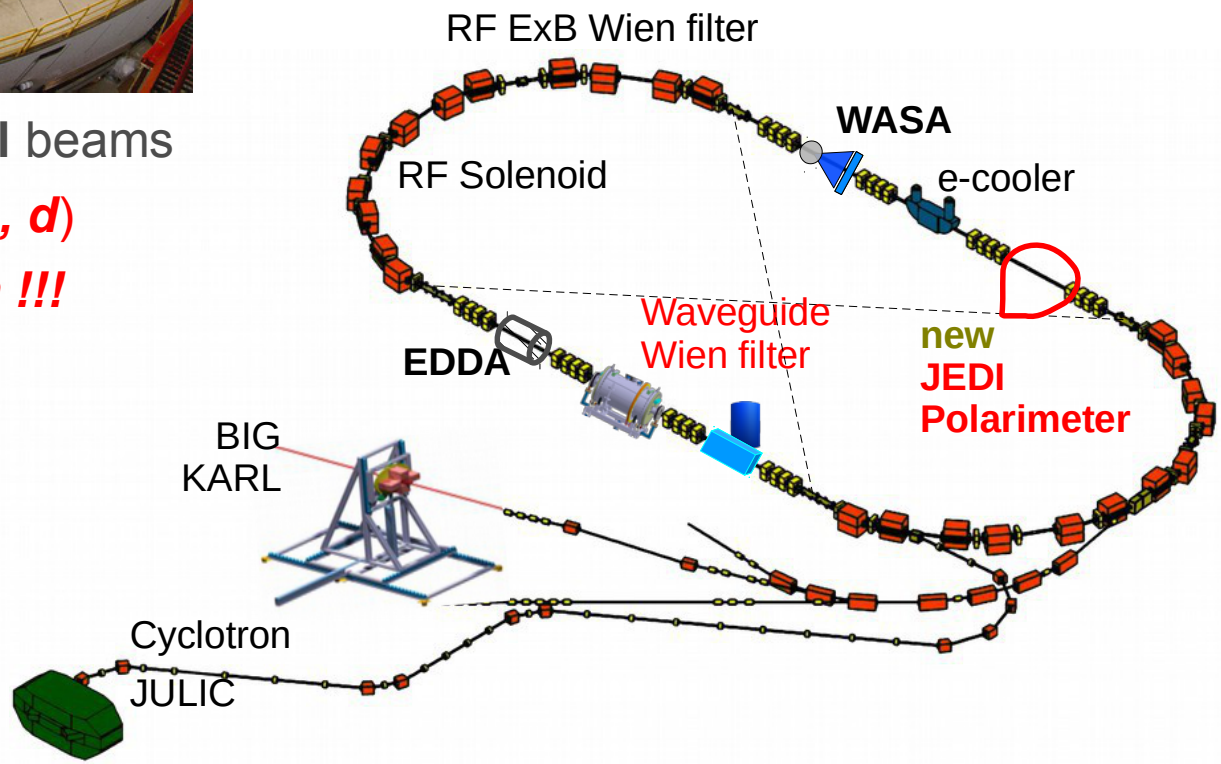
Internal and **external** beams

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

Spin manipulation !!!

RF Solenoid

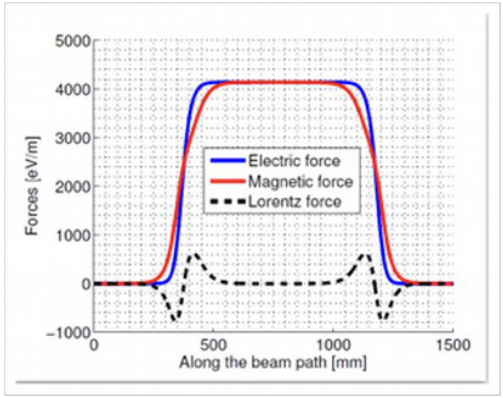




RF-Wien-Filter

second generation at COSY

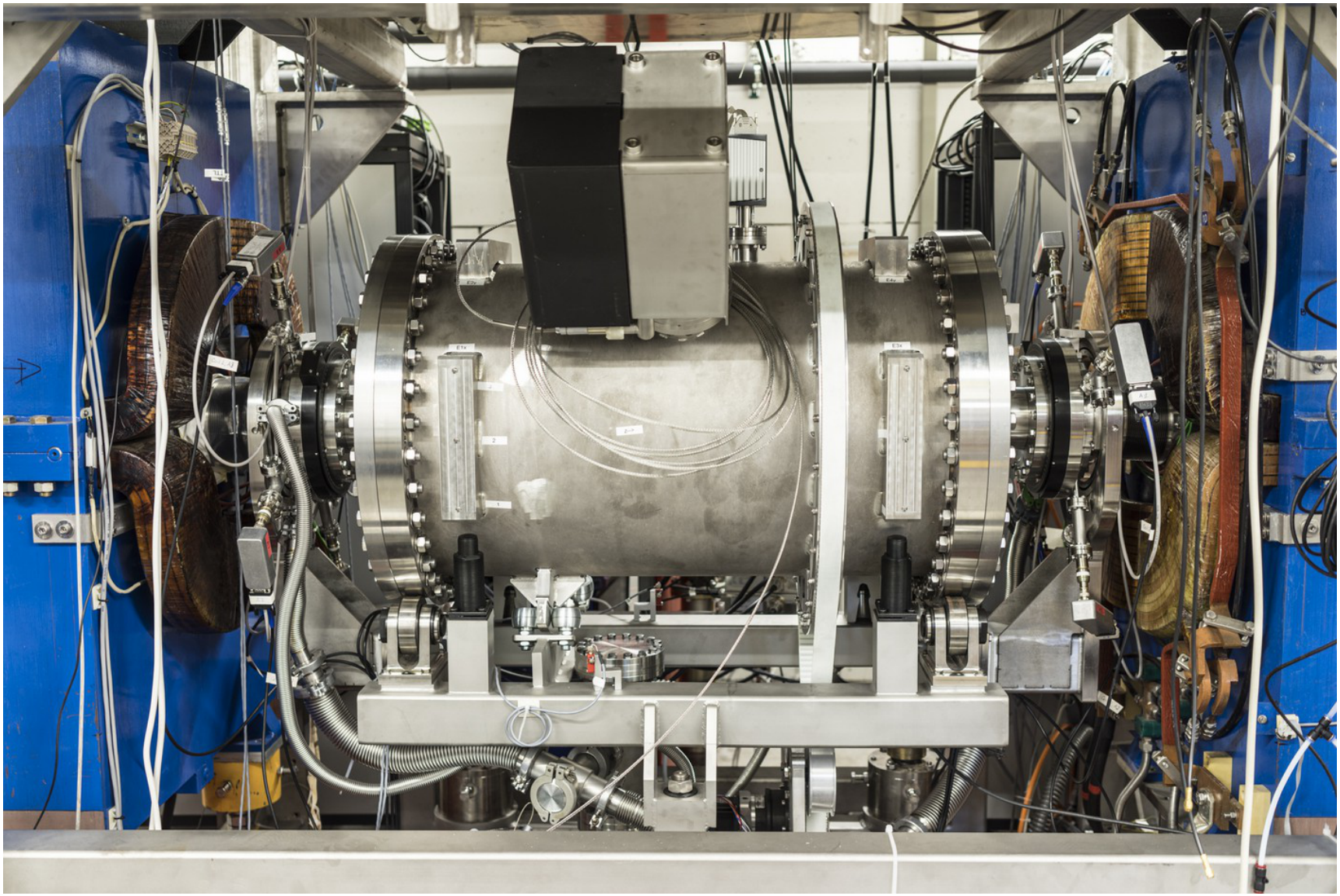
$$F_{Lorentz} = F_{Coulomb}$$



RF-Wien-Filter

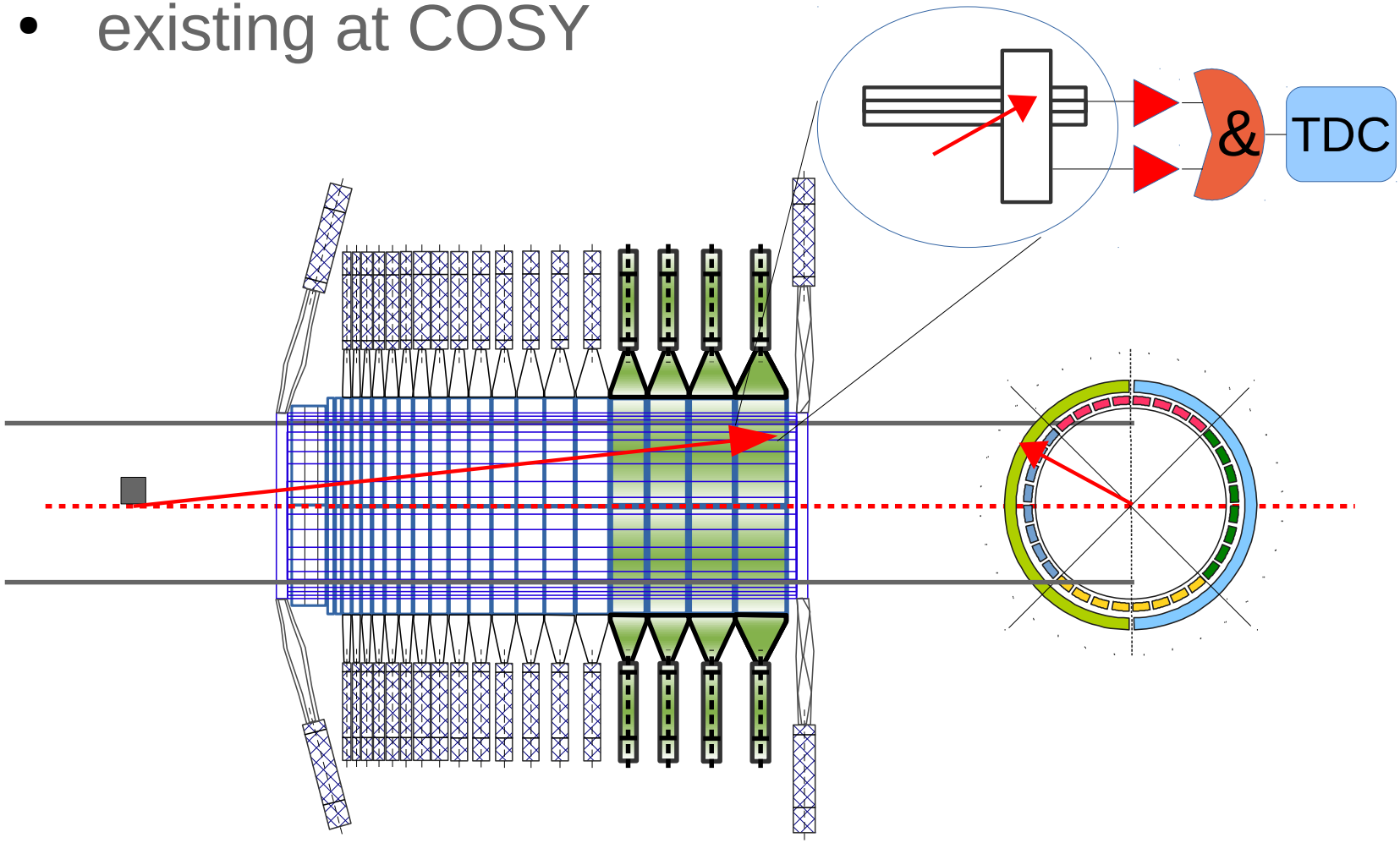
commissioning beam time done

November 2017 – first polarized $\vec{d}$ measurement with WASA



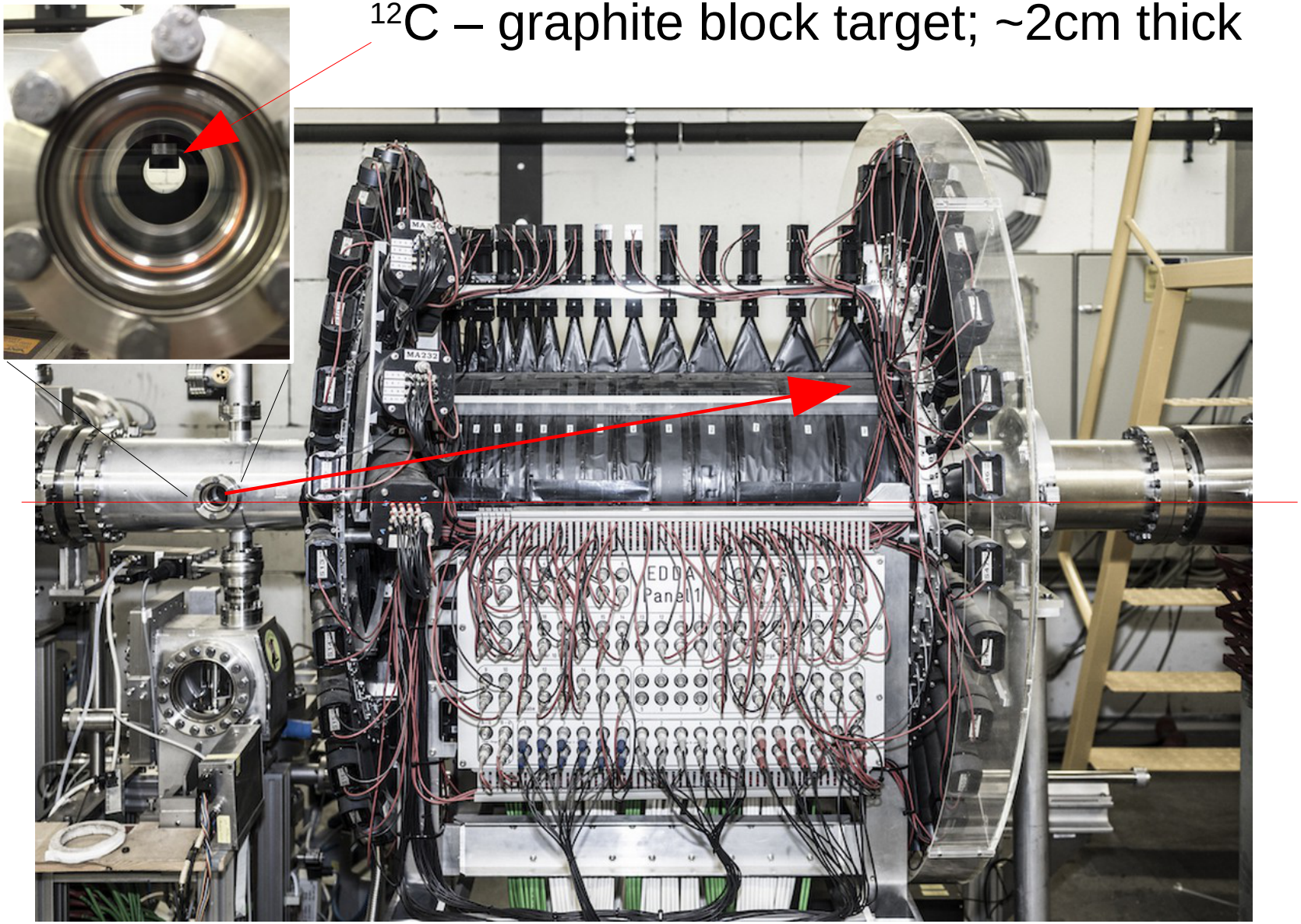
EDDA
Simple Polarimeter

- very simple and robust (pl.scintillator + PMT)
- ideal for beam pol. monitoring
- existing at COSY

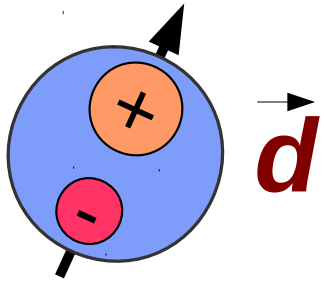


EDDA
Simple Polarimeter

^{12}C – graphite block target; ~2cm thick



Recent Results of JEDI

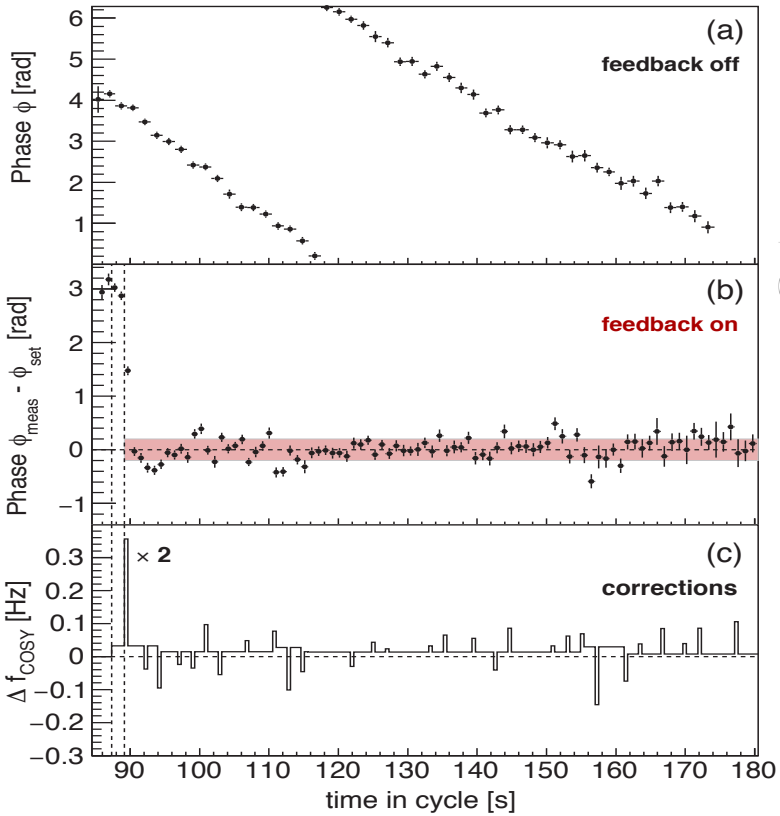


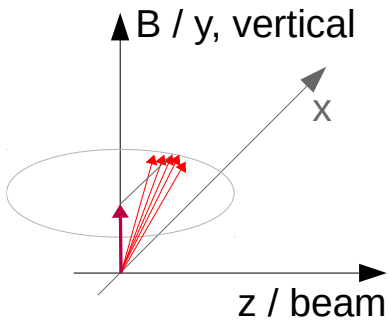
Store polarized deuterons (COSY)

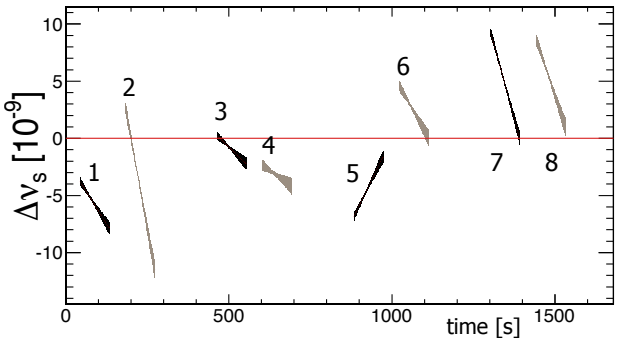
Phys. Rev. Lett. 119, 014801 (**2017**) Phase Locking

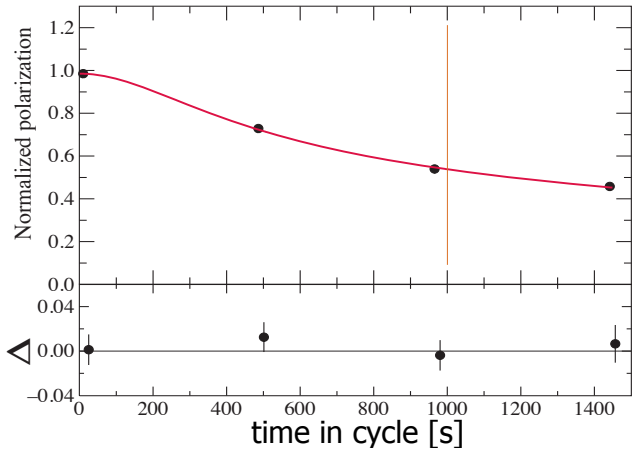
Phys. Rev. Lett. 117, 054801 (**2016**) 1000s in-plane

Phys. Rev. Lett. 115, 094801 (**2015**) New method







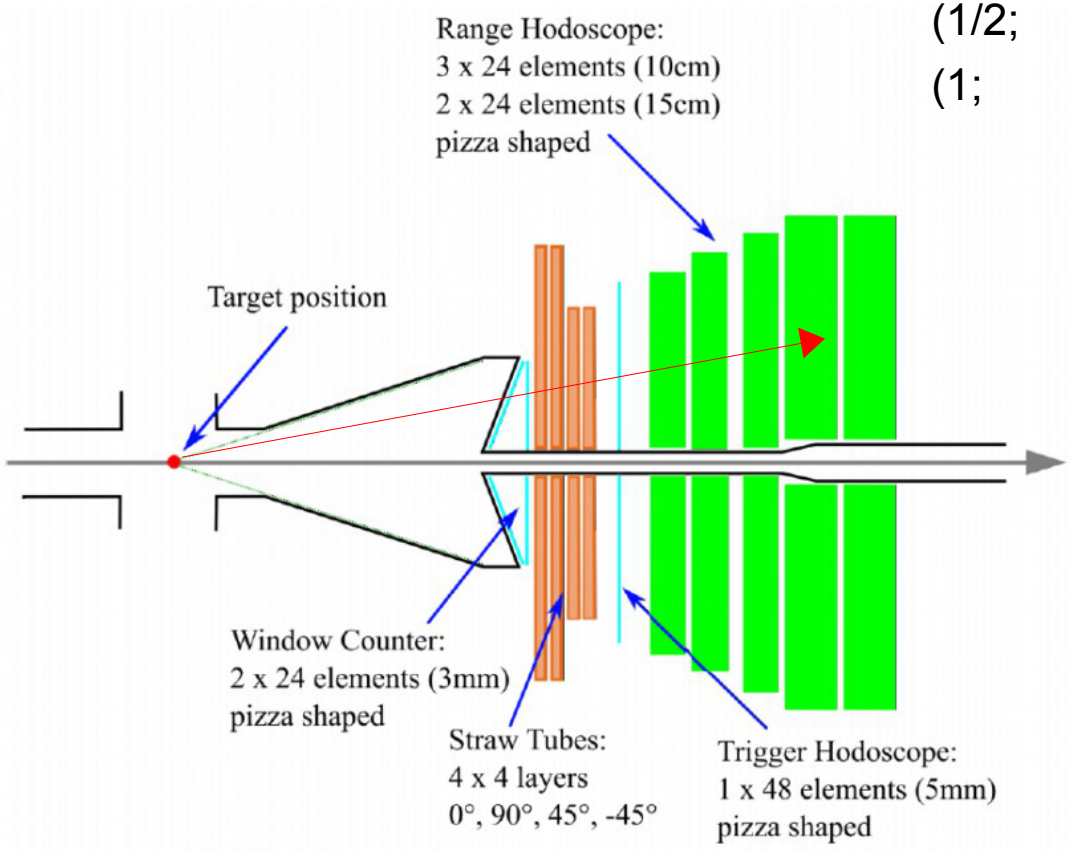


WASA Detector
Deuteron Data Base Exp.

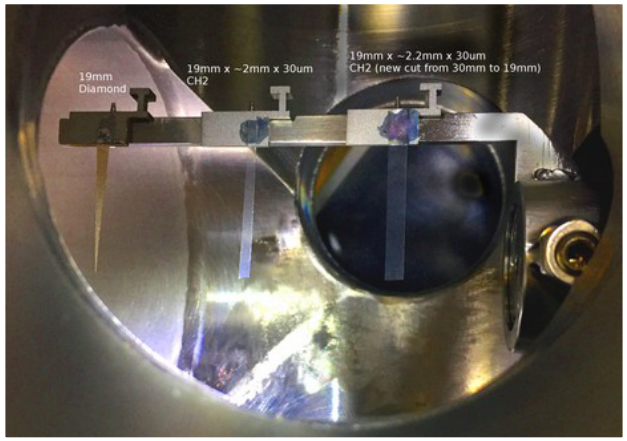
Deuteron beam:
170 MeV,
200 MeV,
235 MeV,
270 MeV, (Y. Satou at al.)
300 MeV,
340 MeV and
380 MeV

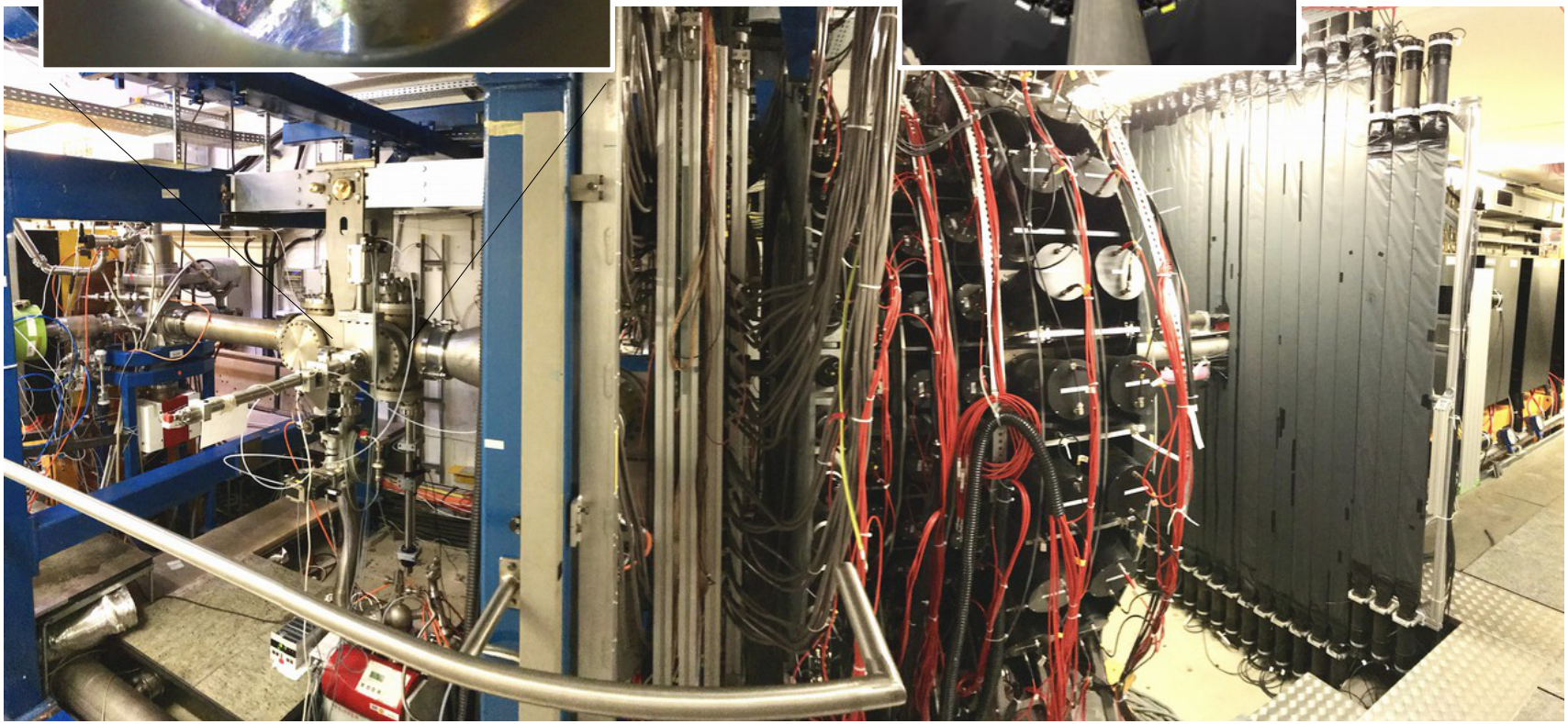
Two targets:
C (diamond) and
CH2 (Polyethylene)

polarization states:
(P_y ; P_{yy}) =
(0; 0);
(-2/3; 0);
(2/3; 0);
(1/2; 1/1);
(1; 1)



WASA
configuration for the data base experiments

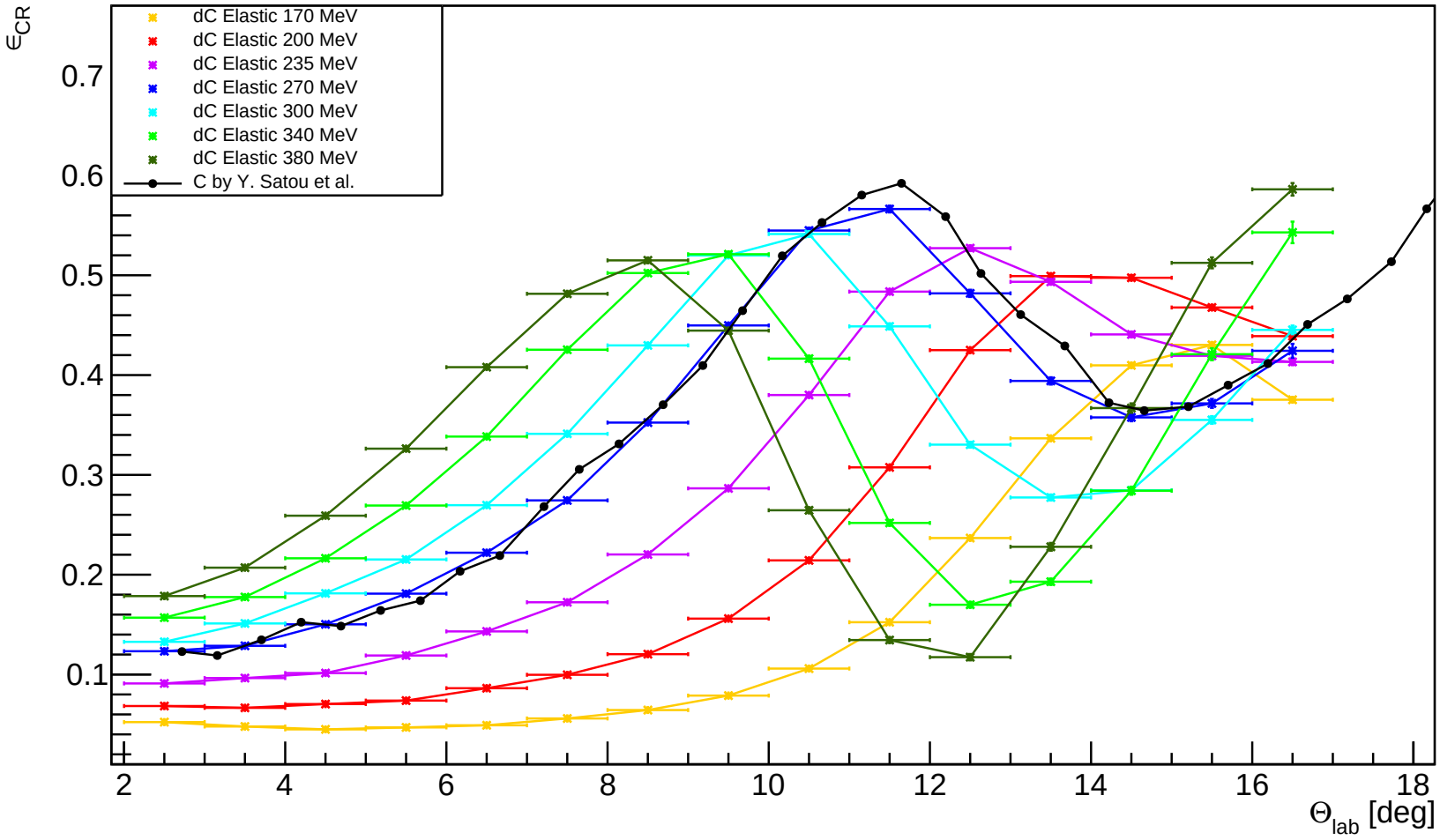




Preliminary Analyzing Powers

Ph.D. F. Müller

dC Cross Ratios



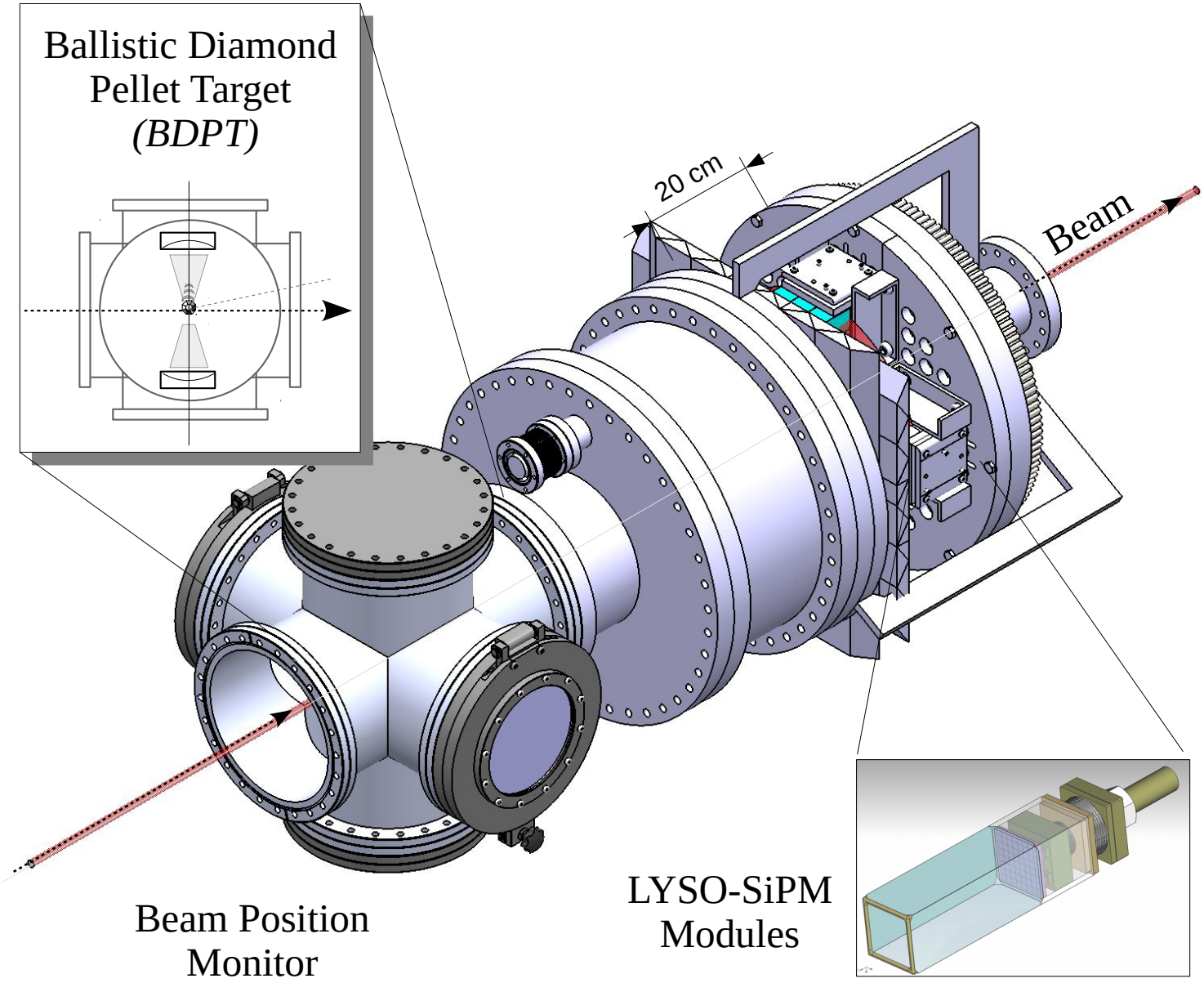
Talk by: Mr. Hoyong JEONG, Realization of Spin-dependent p-C Scattering in GEANT4 and Its Application...

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

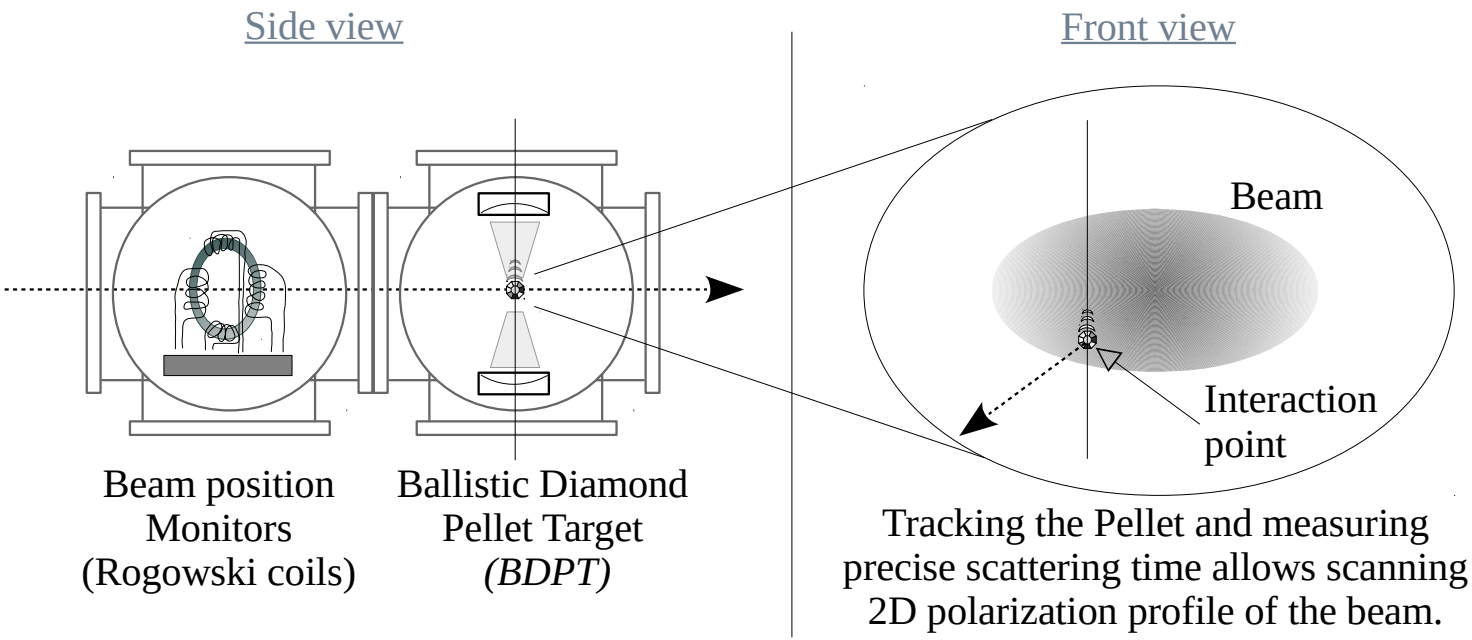
JEDI Polarimeter

High Precision Polarimeter Concept



JuDiT
Jülich ballistic Diamond pellet Target

- Target capable to measure **polarization profile**
- Huge dynamic range in effective target thickness (sampling)
- Non-invasive, no rest gas, point like
- Increased Θ & ϕ resolution



Experimental Setup

Asymmetry Measurements & Target Material Test

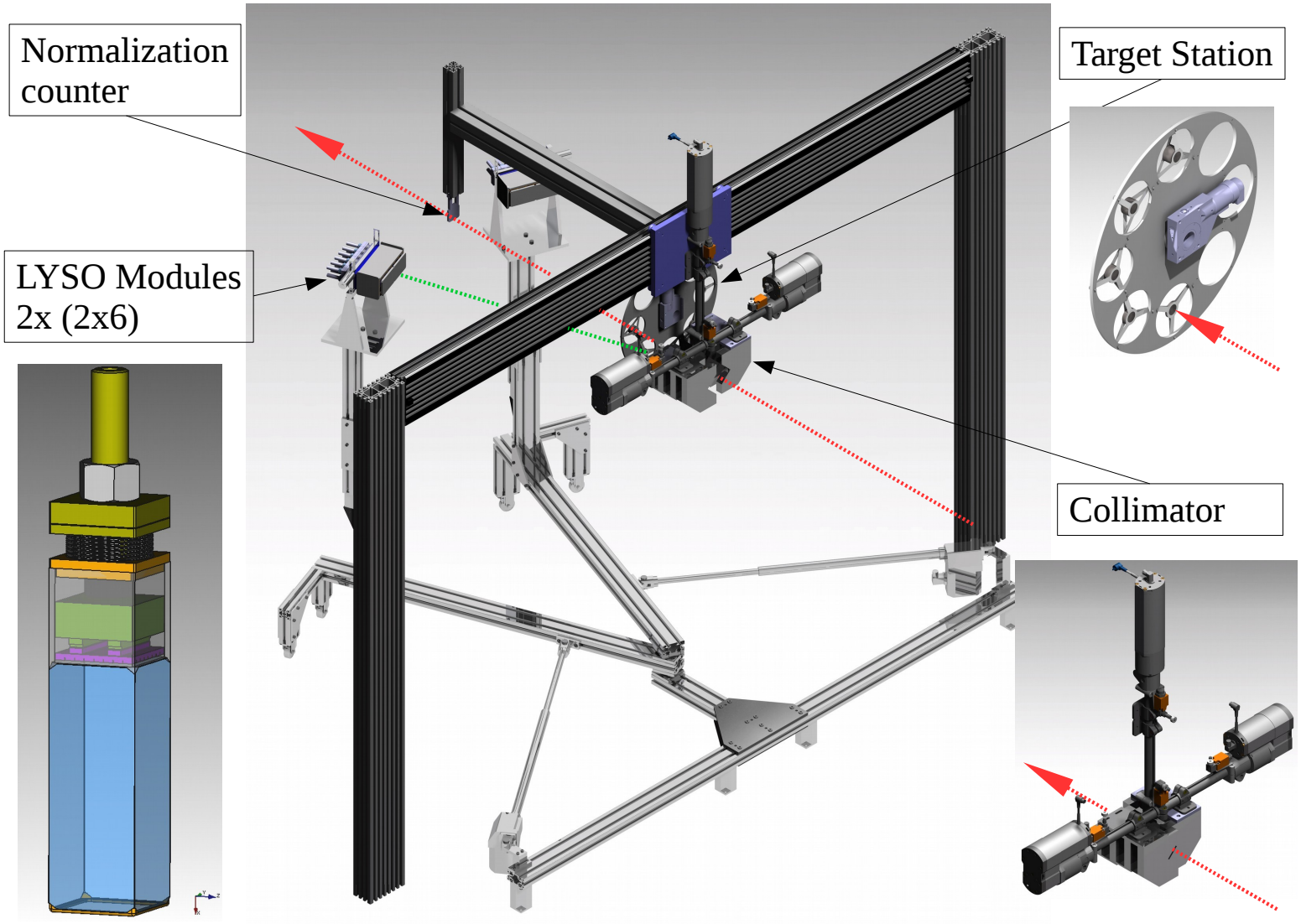
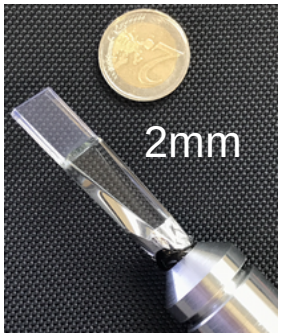
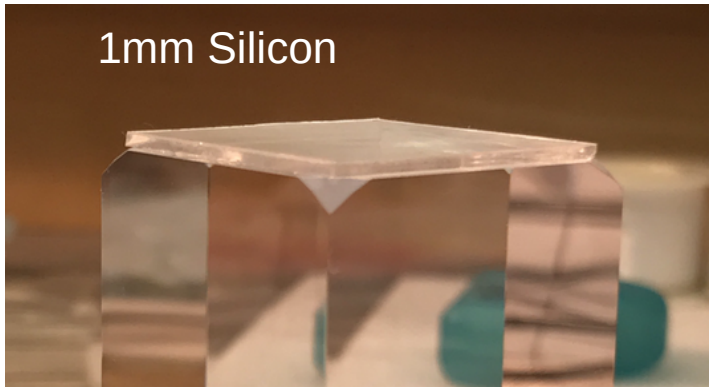
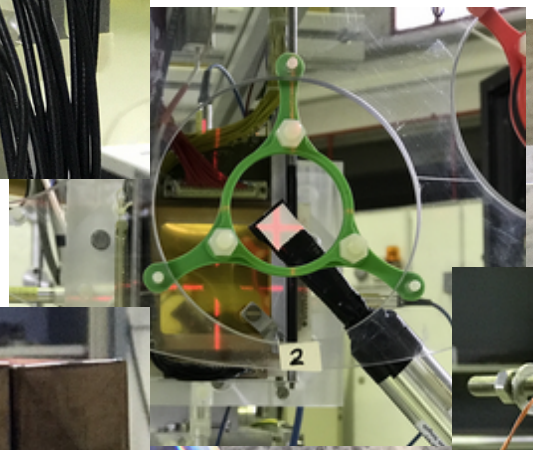
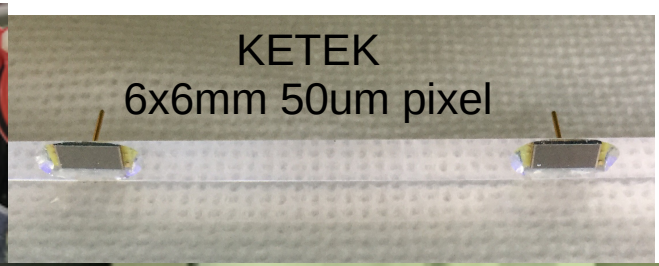


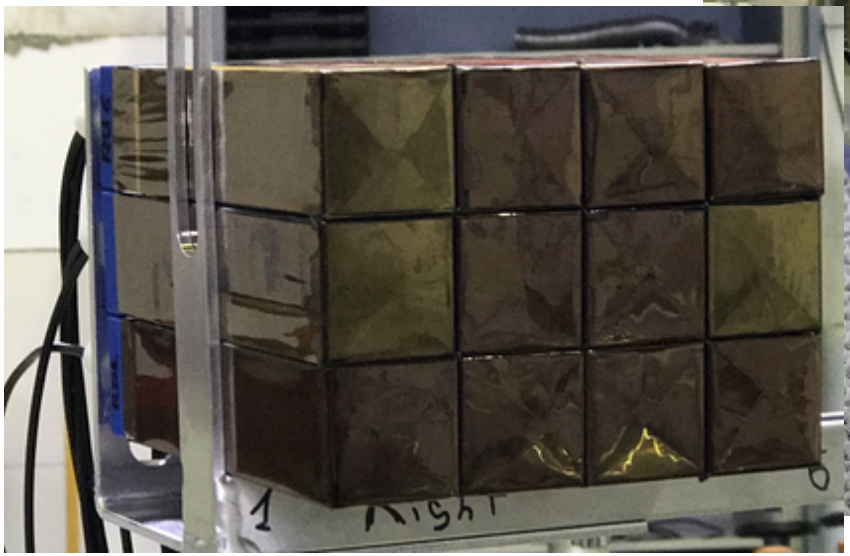
Photo Gallery

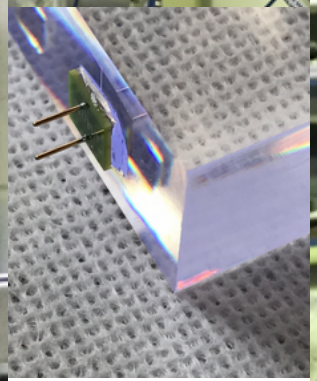


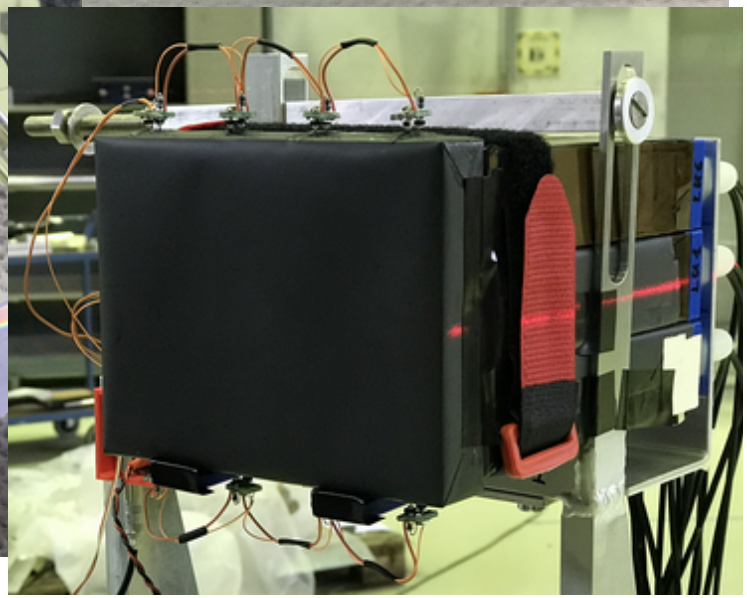




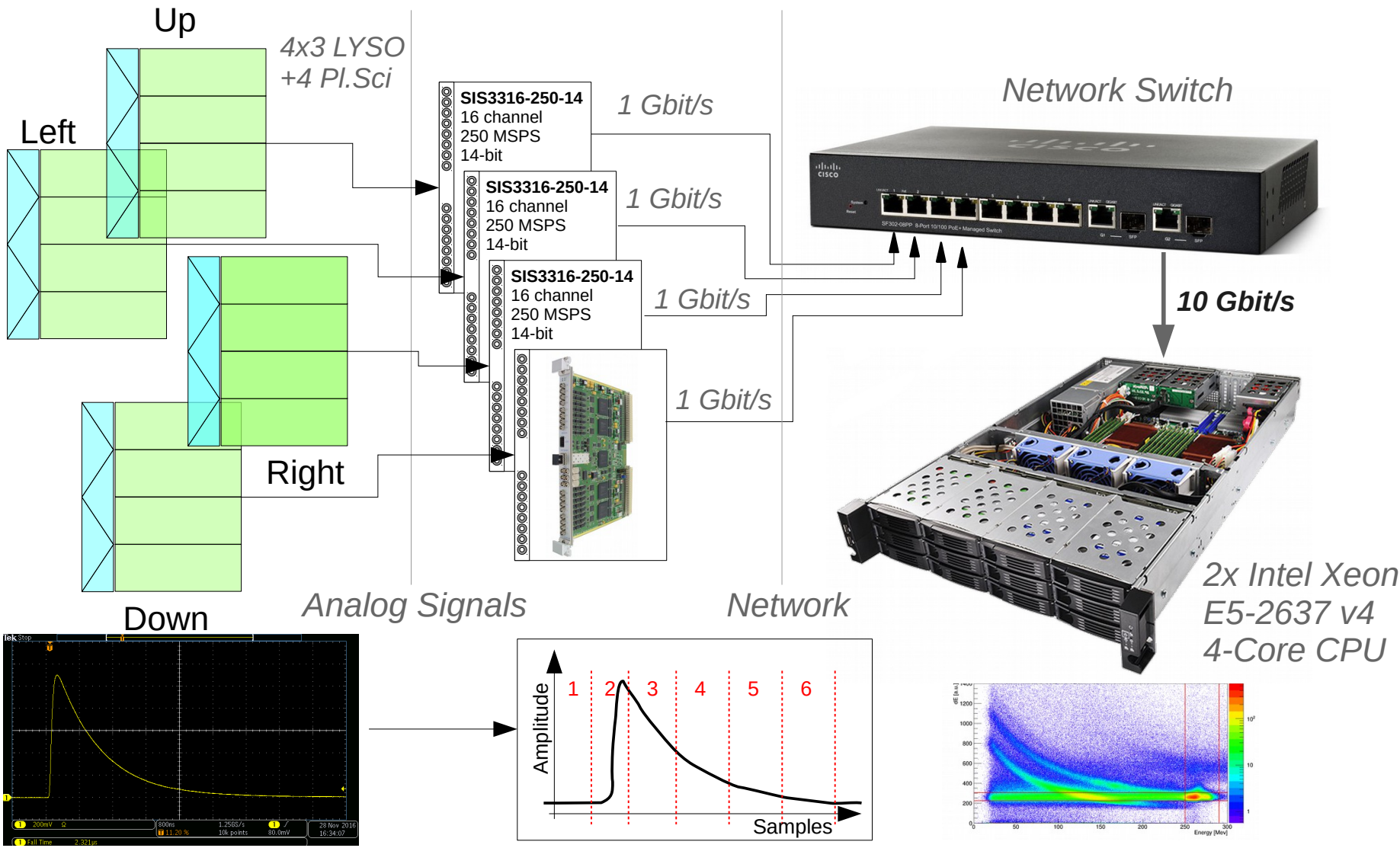




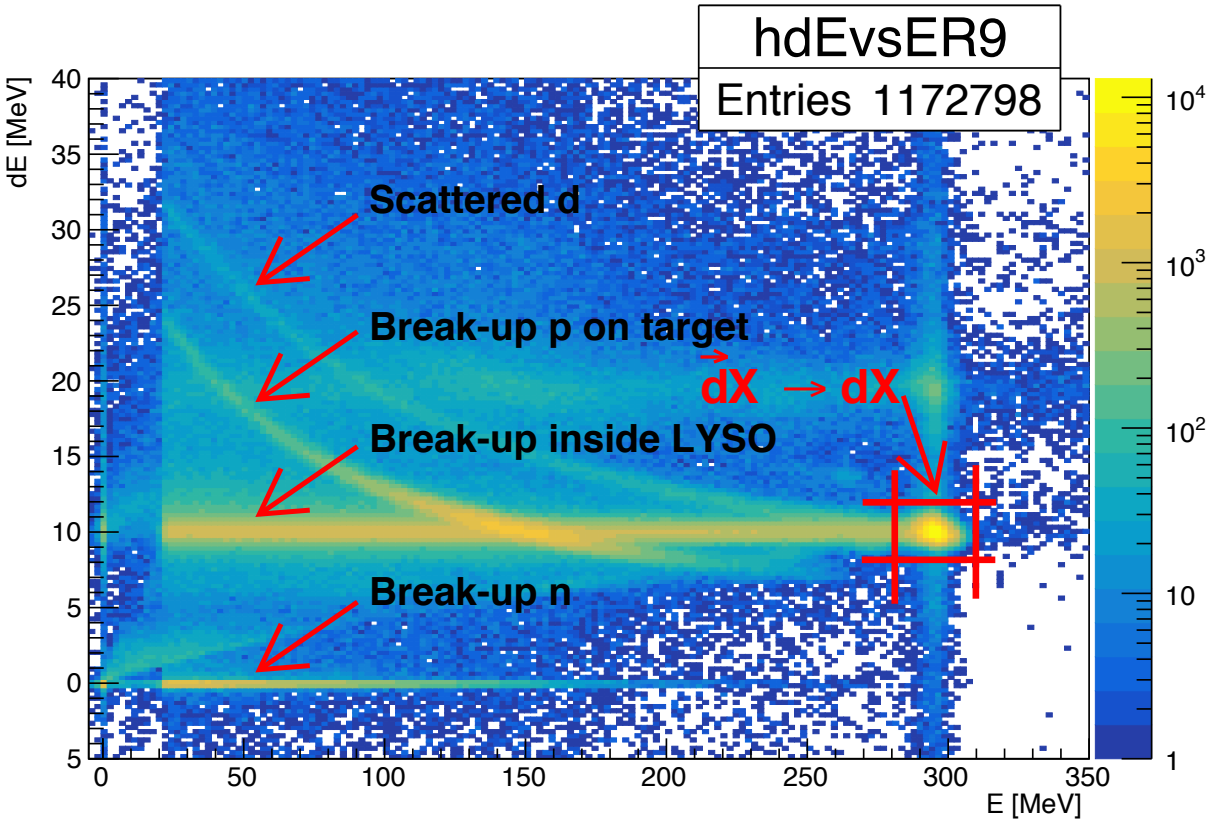




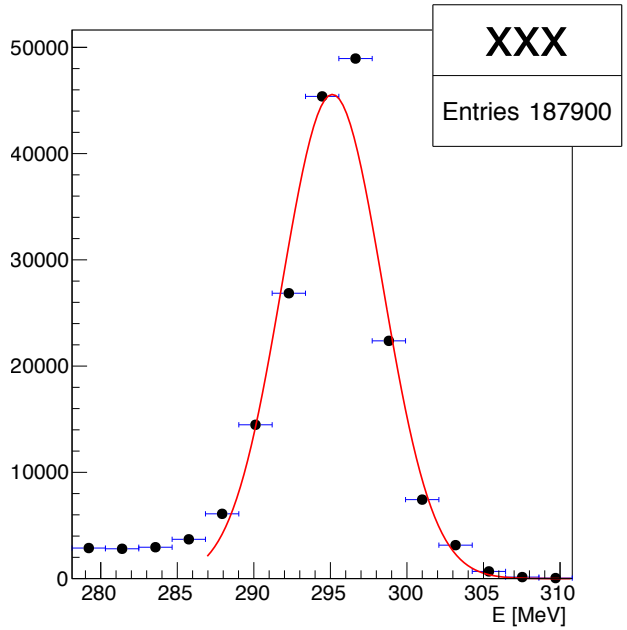
Data Acquisition System
Flash ADC Based System



Event Selection
Online cuts



Projection within the red cut

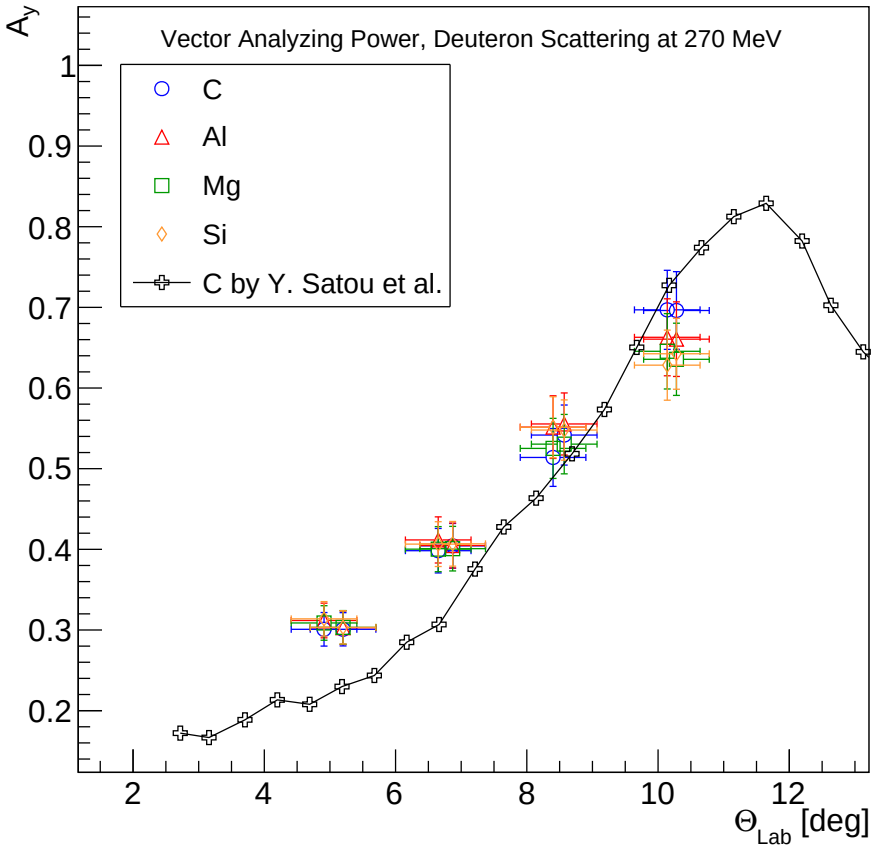


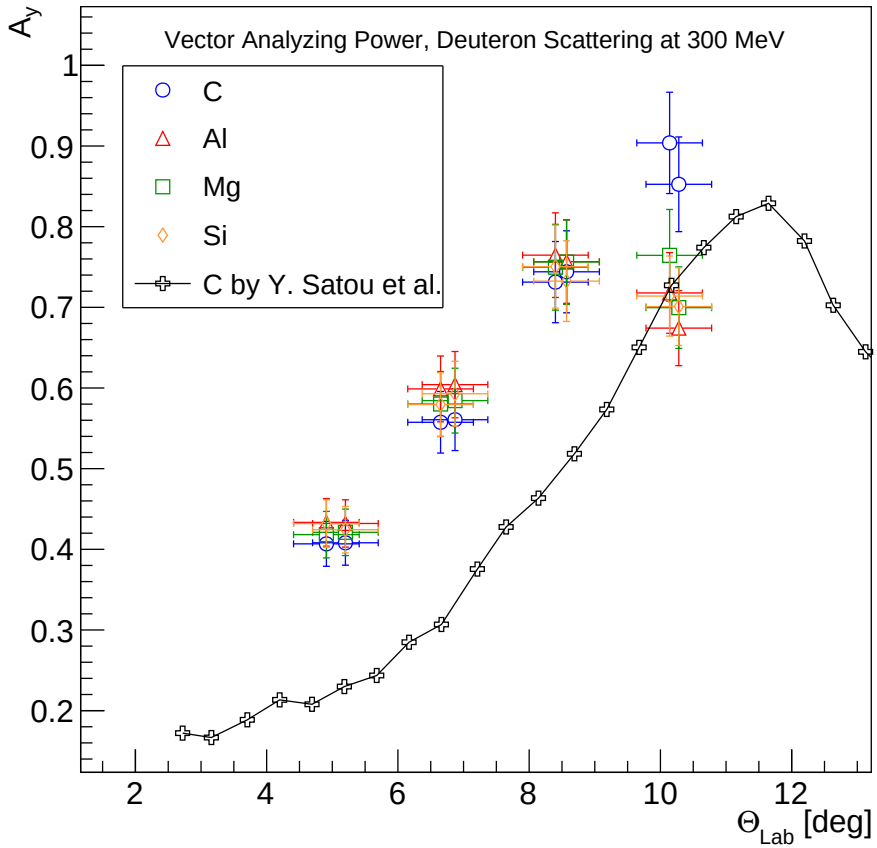
2D Hostogram is very effective for the reaction identification

Preliminary Results

PhD: Fabian Müller

$$A_y(\Theta)\ \ \vec{d}X \rightarrow dX$$

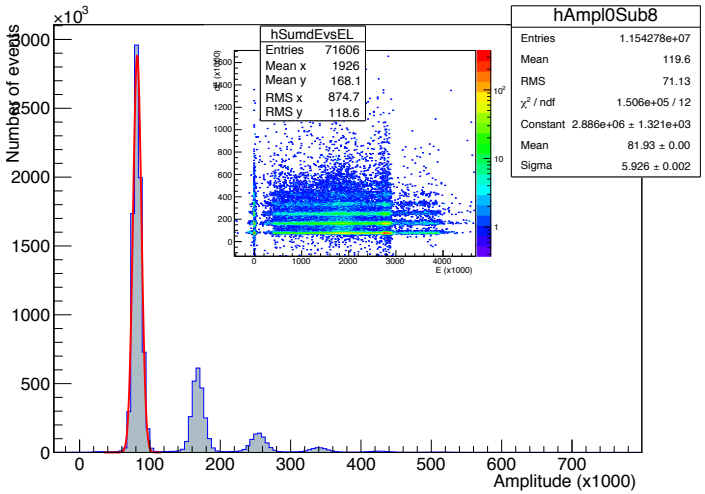


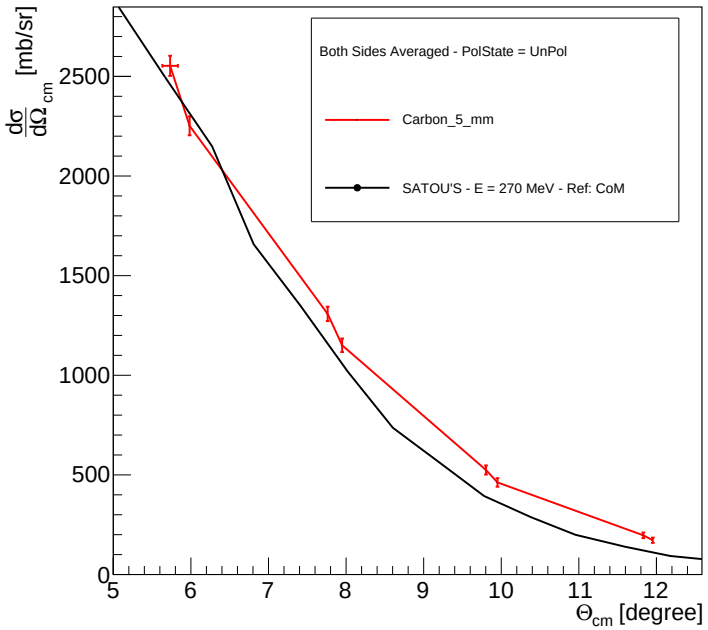


Next talk: Dito will show the analyzing power for the break-up reaction

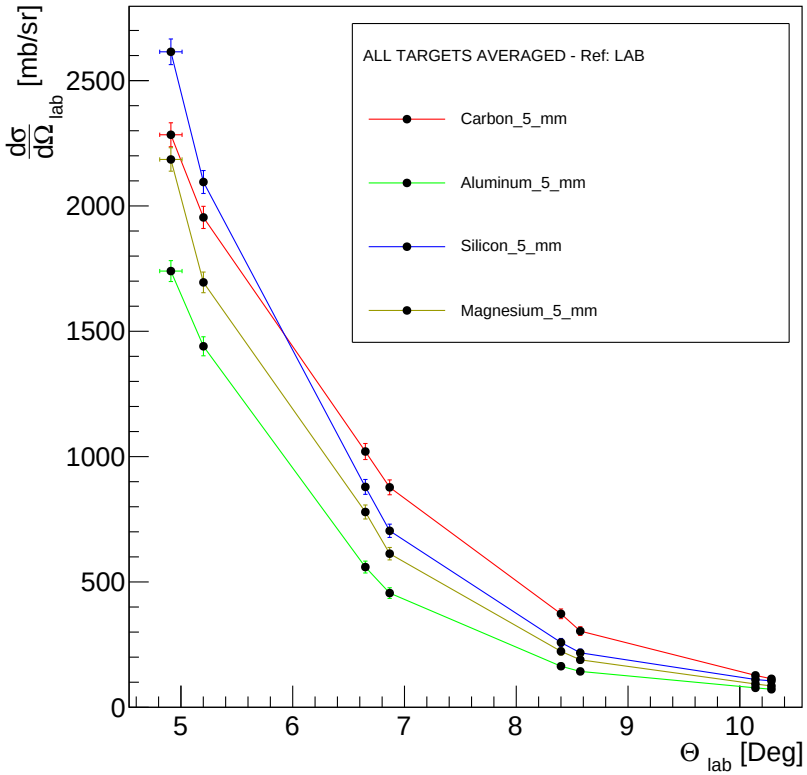
Preliminary Results

PhD: Simone Basile



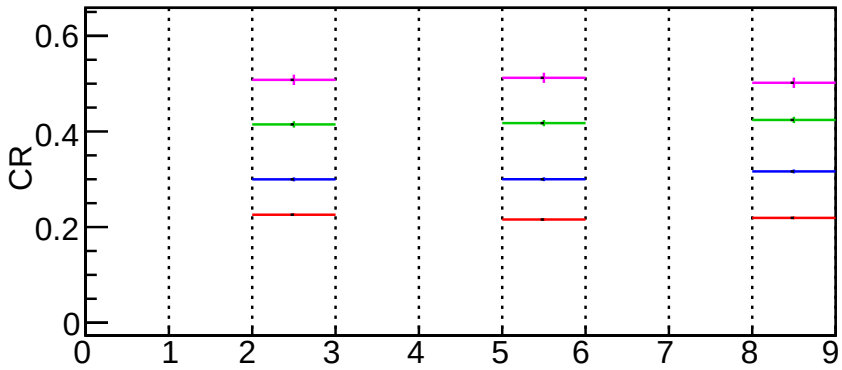


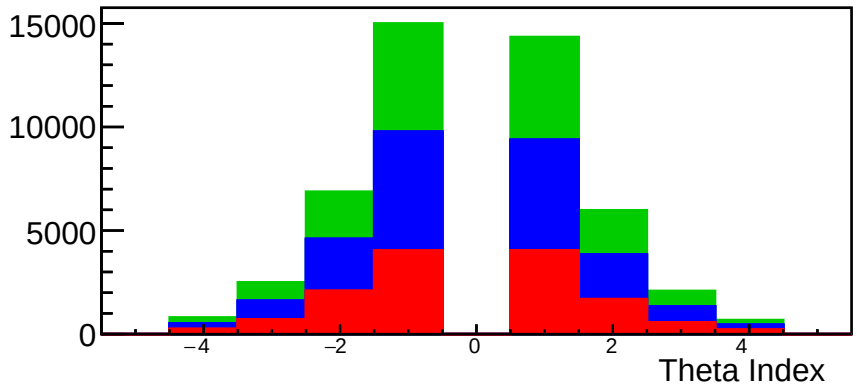
$$\vec{d}X \rightarrow dX \text{ at } T_d = 300\ MeV$$

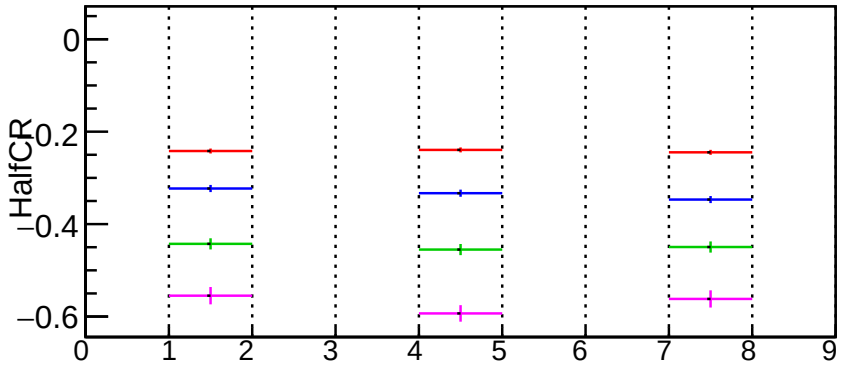


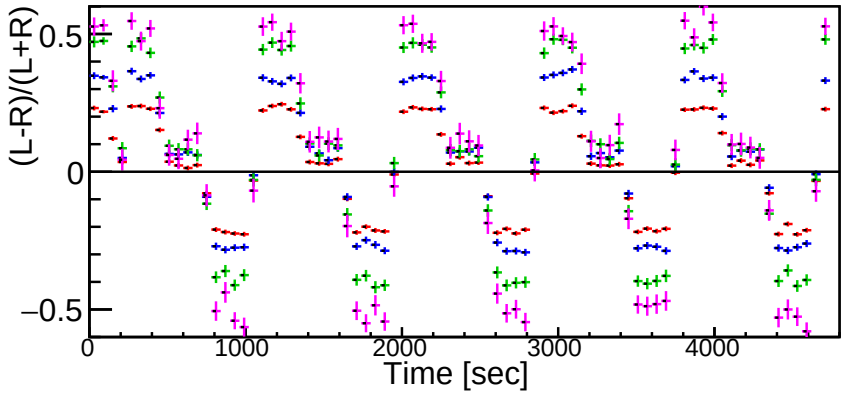
$$\frac{d\sigma_{ela}}{d\Omega} = \frac{N_{det}}{L\,\Omega} = \frac{N_{det}\eta_{LYSO}\eta_{acc}}{N_d N_{target}\Omega}$$

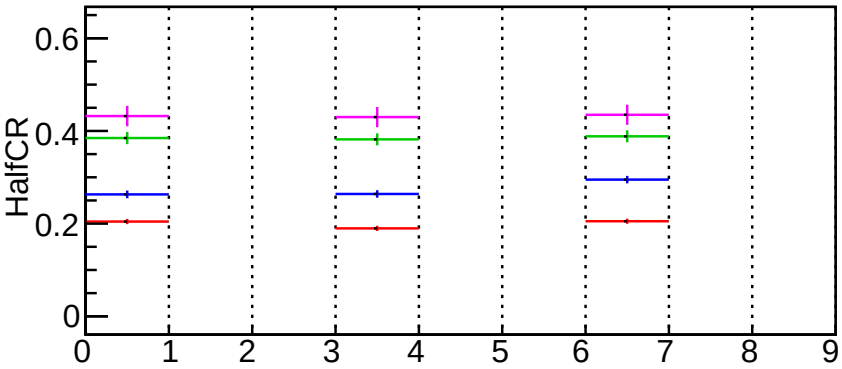
Online Monitoring

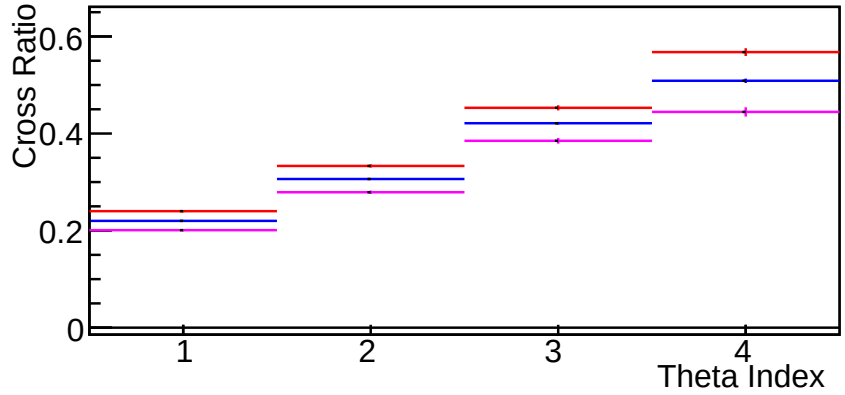




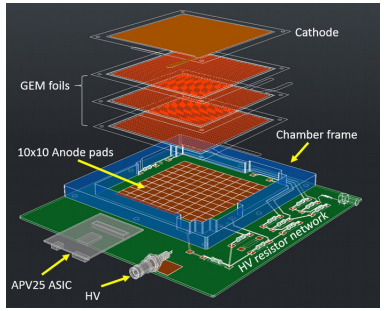






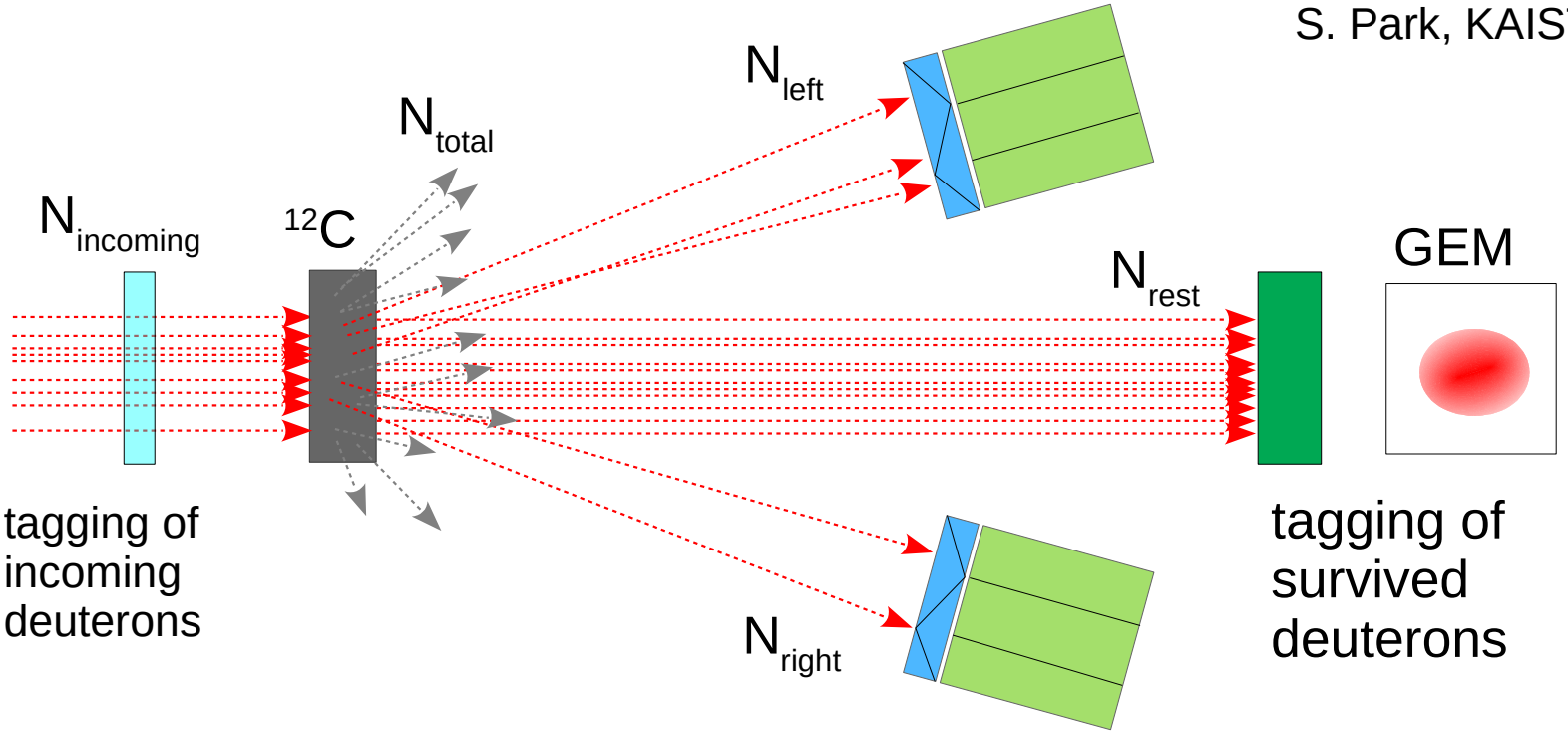


Next Measurement
searching of effective target



S. Park, KAIST

$$N_{lost} = N_{scattered} + N_{dE} + N_{acc}$$



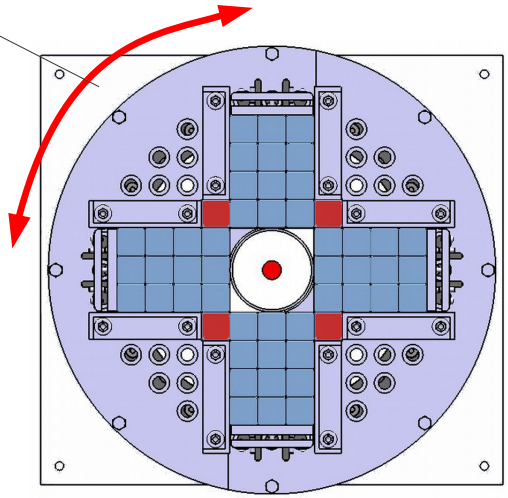
$$N_{scattered} = L \times \sigma_{tot} = N_{el} + N_{inel} = N_{incoming} - N_{rest}$$

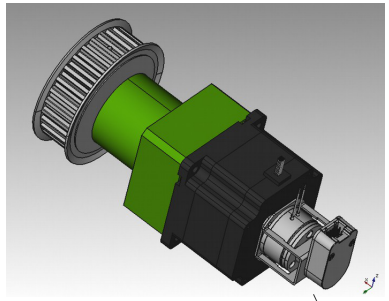
New Setup

beam time will be performed in December 2017

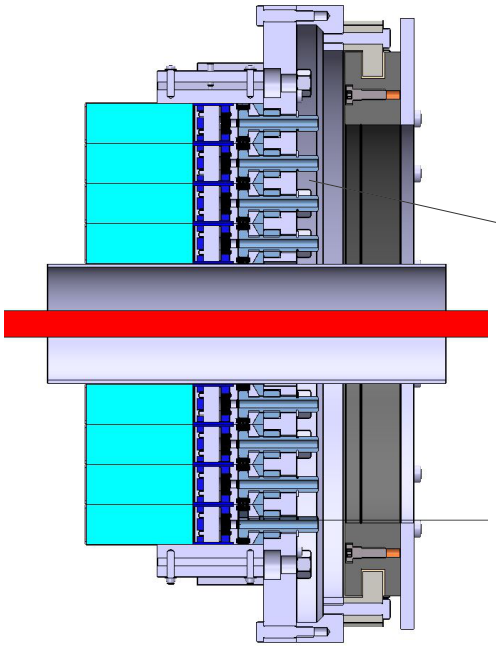
90° rotatable

52 LYSO

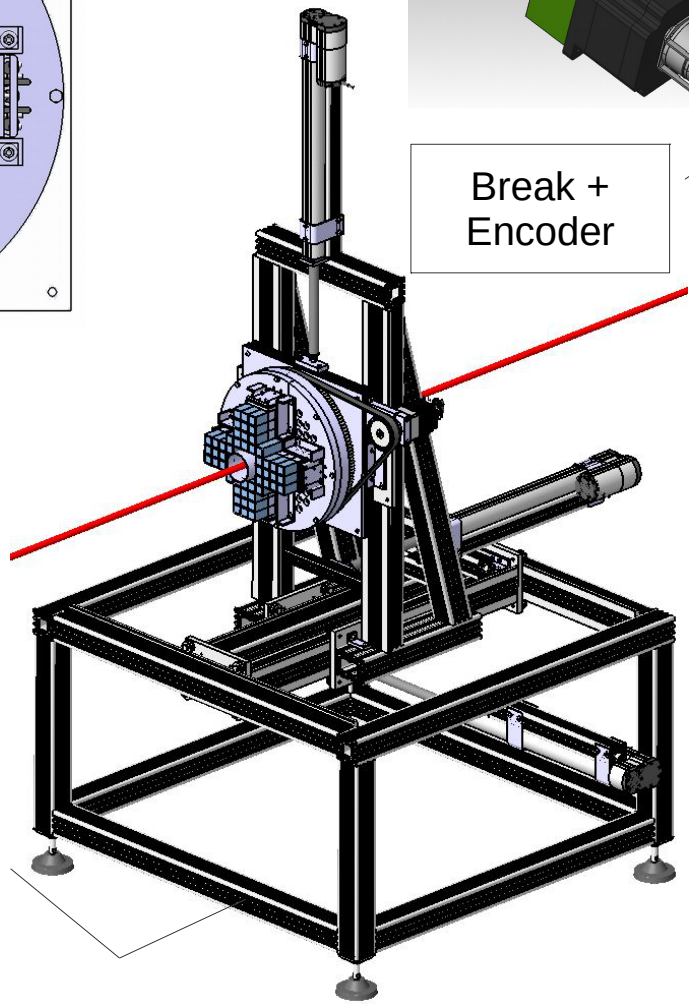




Break + Encoder

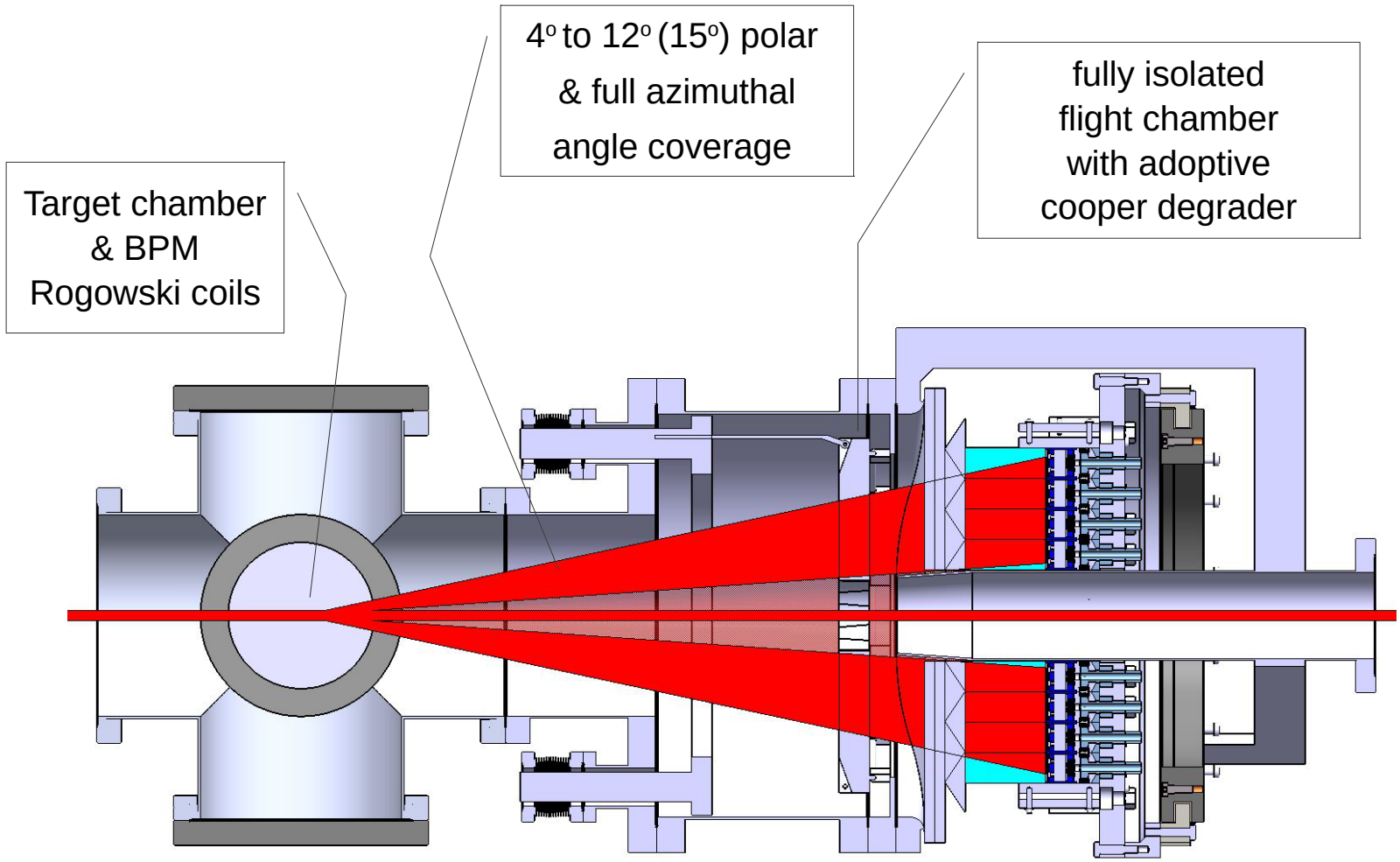


New mechanical holding

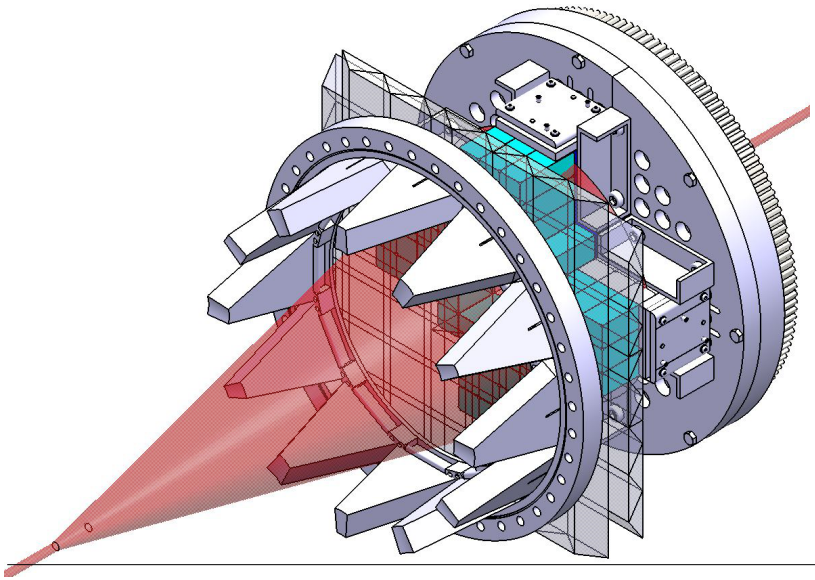


3D (X, Y, Z) Table

Detector Acceptance
adopted for elastic scattering

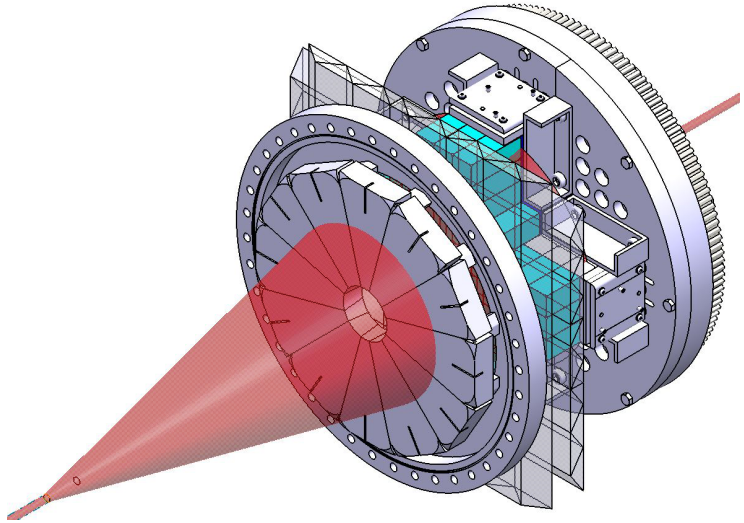


Detector with Degrader
adopted for deuterons and protons



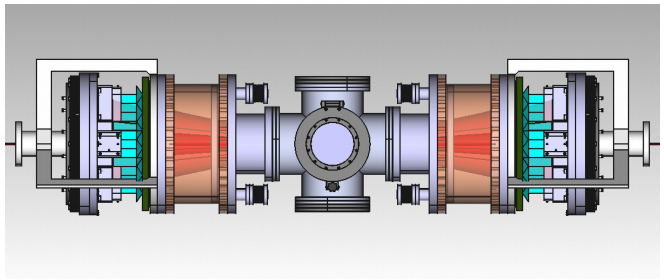
only LYSO + 4cm plastic can cover 320 MeV kinetic energy + cooper degrader can increase up to 350 MeV kinetic energy

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



Summary

- We had 3 very successful beam times.
  Preparing 4^{th}, end of 2017



- LYSO-SiPM - Excellent Performance
- $\Delta E(x)$ Plastic scintillator modules
  are under development...

- New 24 modules will be assembled and tested in 2017
  in total 48 (4x12) Modules

- **We have universal external beam experimental setup with various measurement possibilities.**

This work was supported by the Shota Rustaveli National Science Foundation (SRNSF)

Appendix

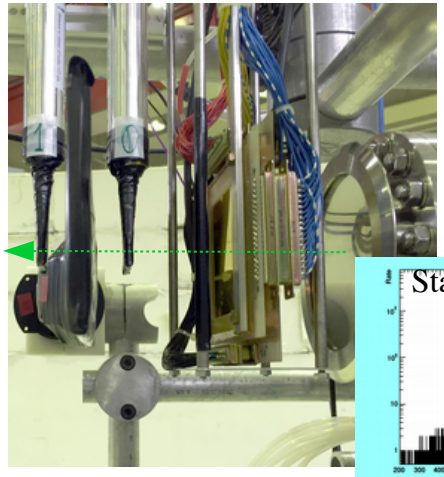
Acknowledgment
People contributing to the experiment

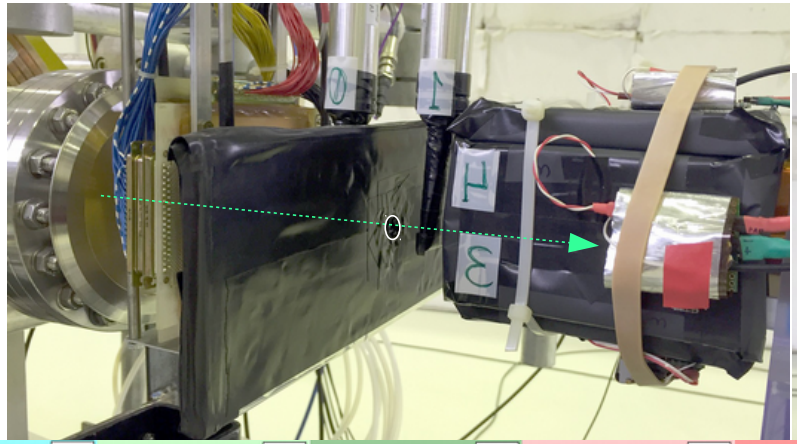
- **PhD: F. Müller, S. Basile, & D. Shergelashvili**
- Mechanics: N. Giese, M. Maubach, G. D'Orsaneo & D. Spölgen
- Electronics: Tanja Hahnraths-von der Gracht & T. Sefzick
- DAQ & FEE: D. Mchedlishvili, L. Barion & P. Wüstner
- G4: G. Macharashvili, P. Maanen & N. Lomidze
- **Ms & Bs: O. Javakhishvili, M. Gagoshidze**

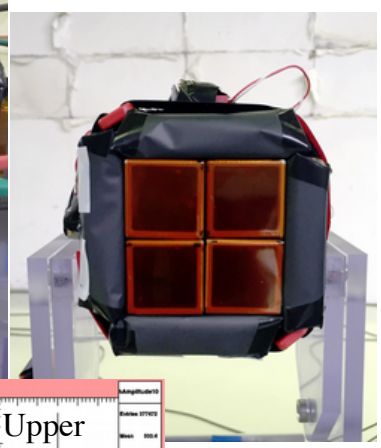
First Step: LYSO Crystal Test

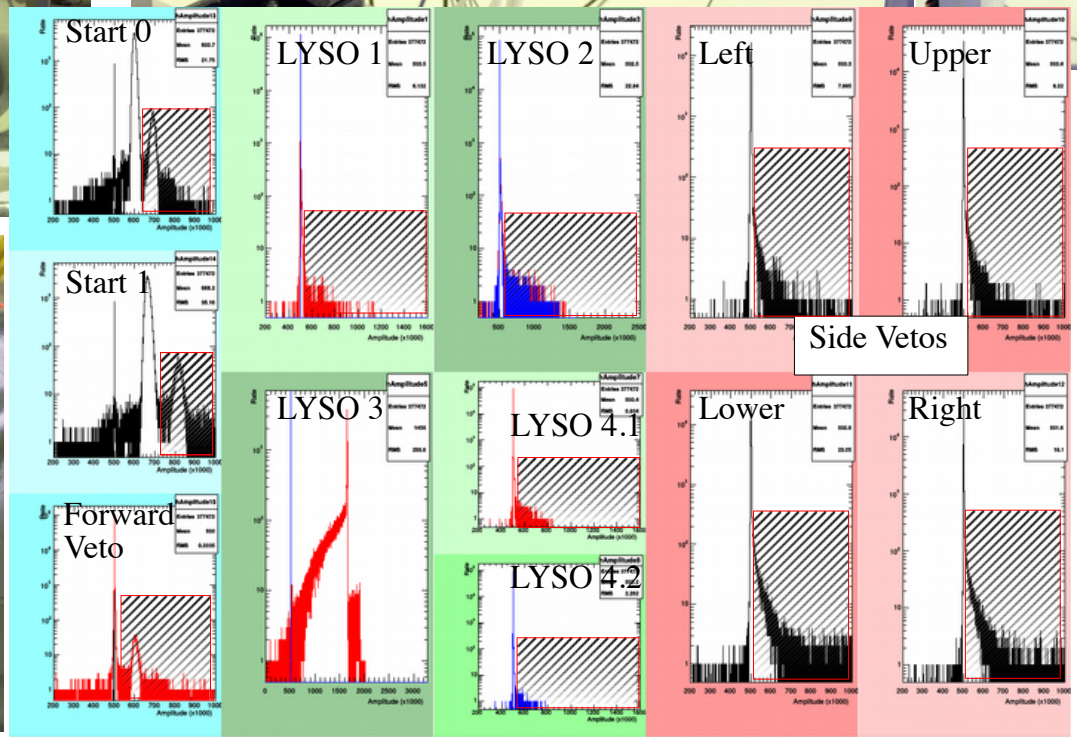
E-Linearity, E/T-Resolution, d-Efficiency, DAQ, Bragg Peak, Vendors,...

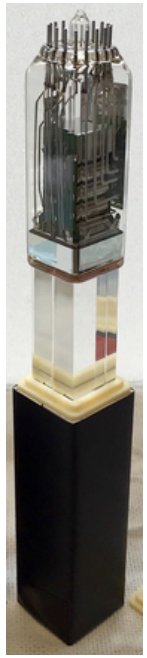
- rejected events





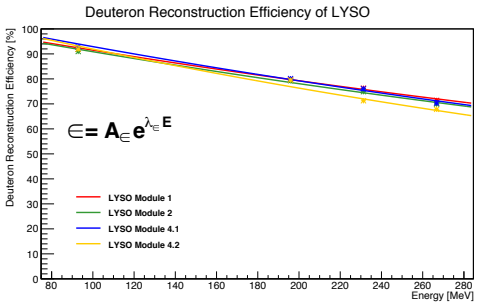


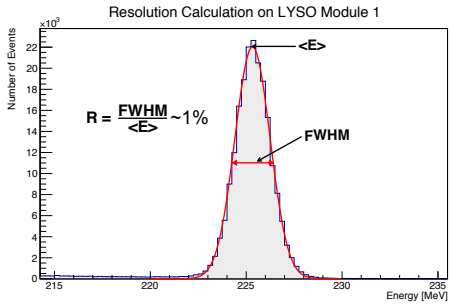


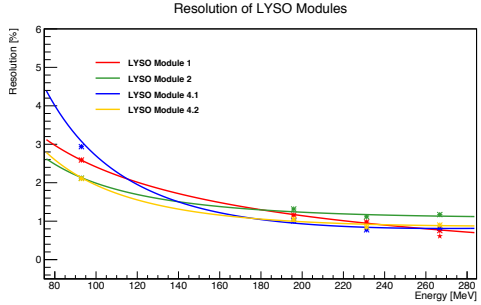


Results of LYSO Tests
Study of the LYSO Properties

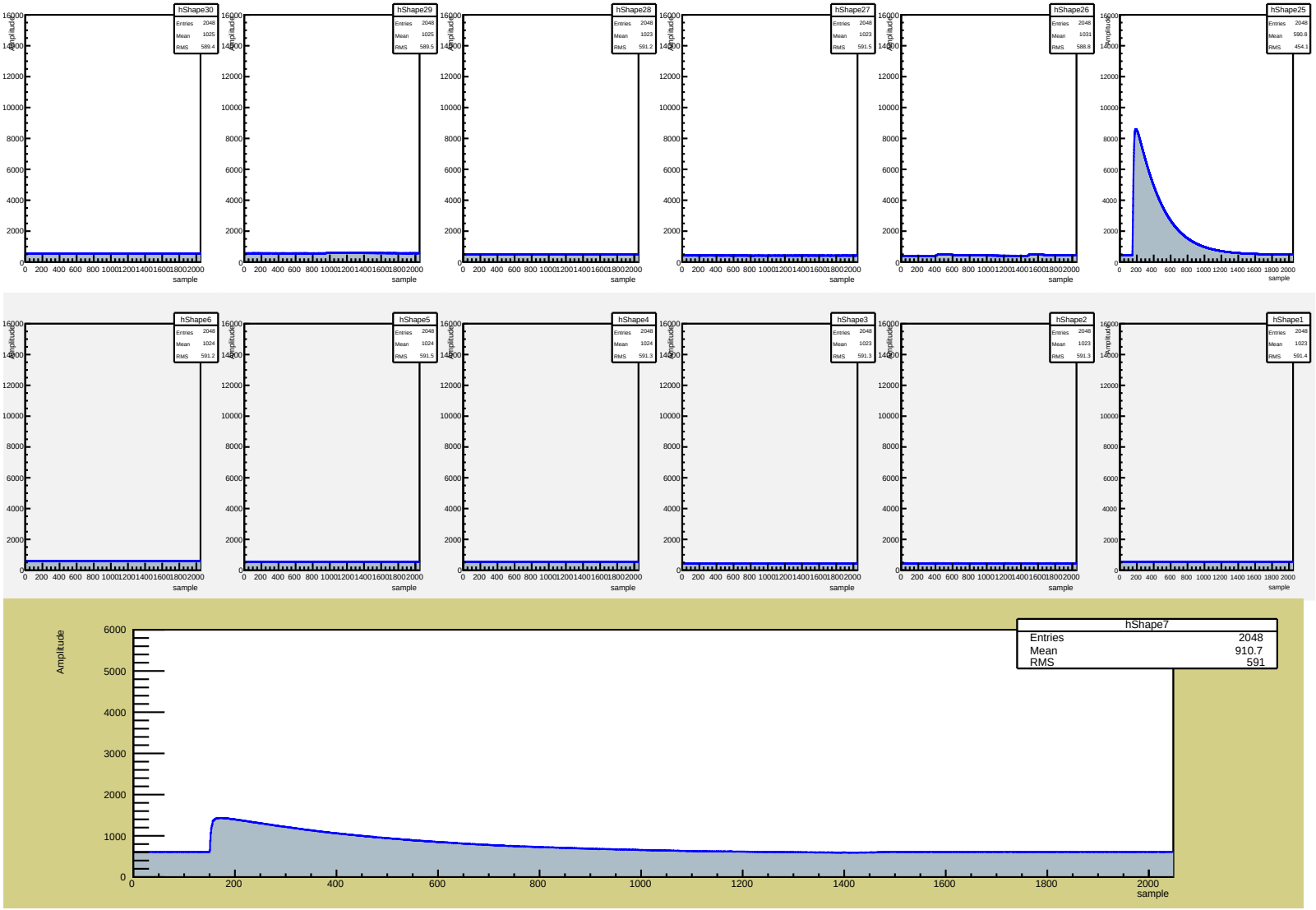
- Test of FADC (250 MS/s, 14-bit) 'dead-time less' **DAQ** system
  Full signal shape were recorded
- Linearity of **particle energy** *vs.* **light output** up to 270 *MeV*
- Energy Resolution ($\frac{FWHM}{Amp} \sim 1\%$), time resolution $\Delta t \sim 300ps$
- *d* detection/reconstruction eff. @ 270 *MeV* drops $\sim 70\%$
- Measuring Bragg-Peak by rotating split LYSO,
  peak @ 6 cm @ 270 *MeV* $\rightarrow$ crystal length 8 *cm* (can be flipped)
- Tests of Saint-Gobain and EPIC Crystals with **PMT & SiPM (C)**



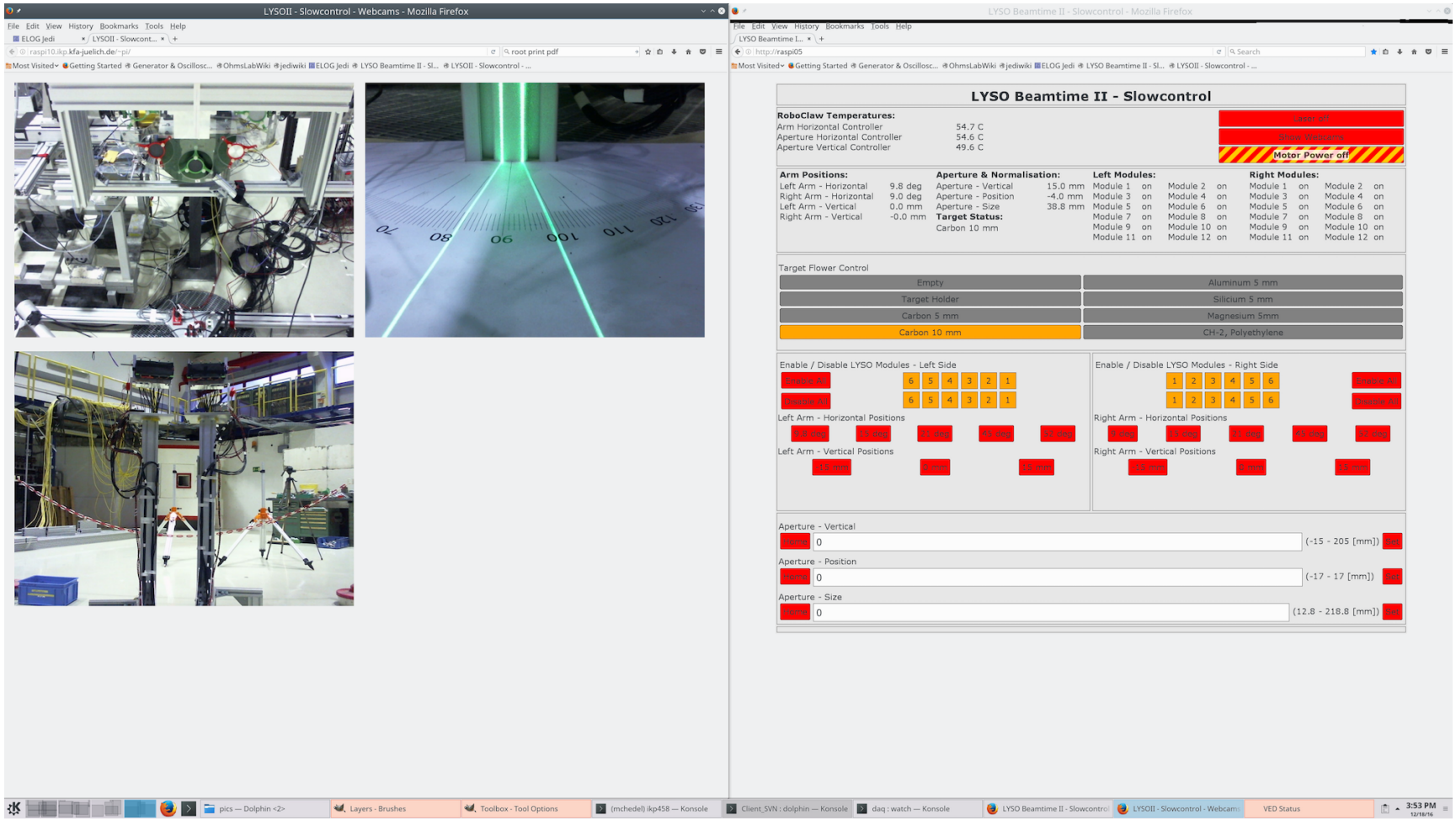




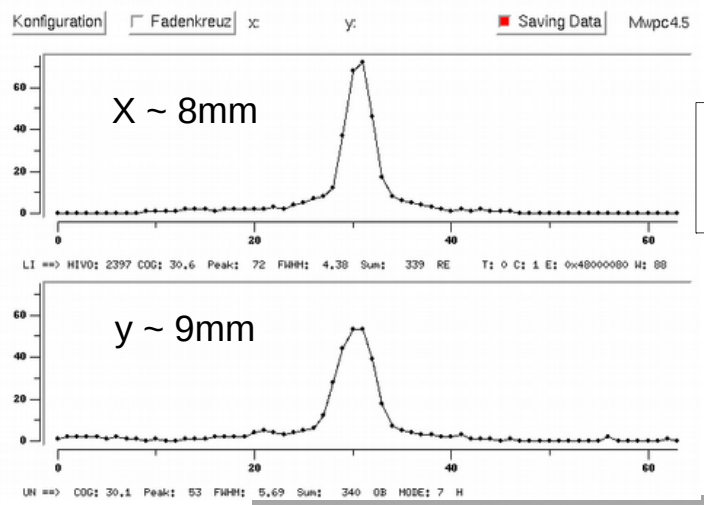
Online Monitoring
December 2016 Beam Time



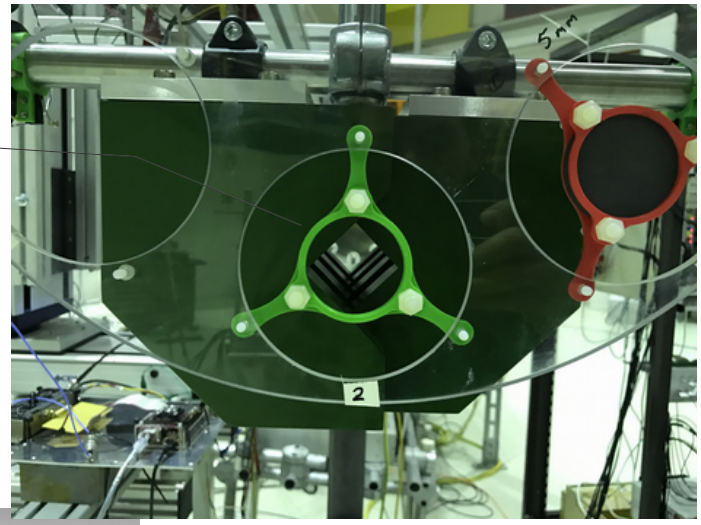
Slow Control System
December 2016 Beam Time

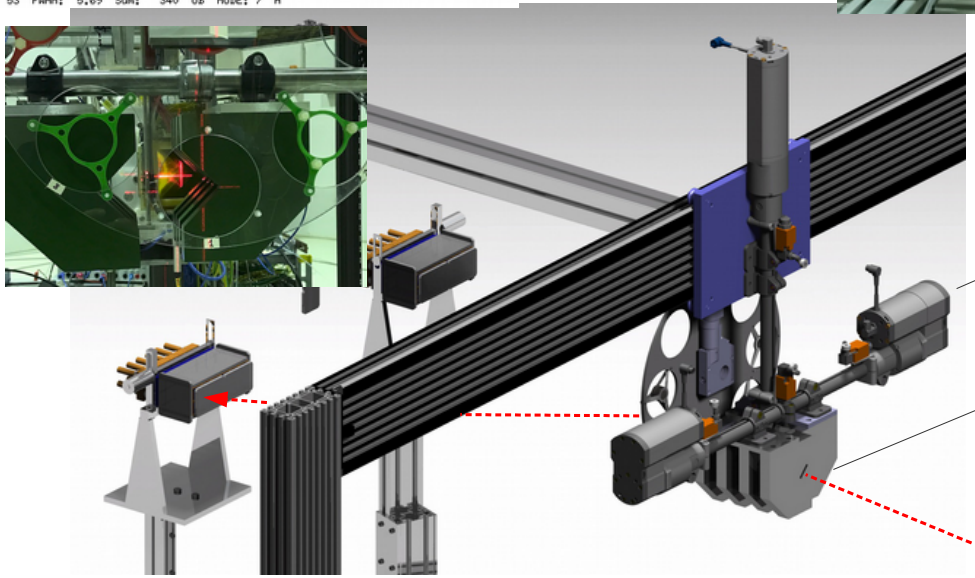


Collimator System
December 2016 Beam Time



Empty target holder





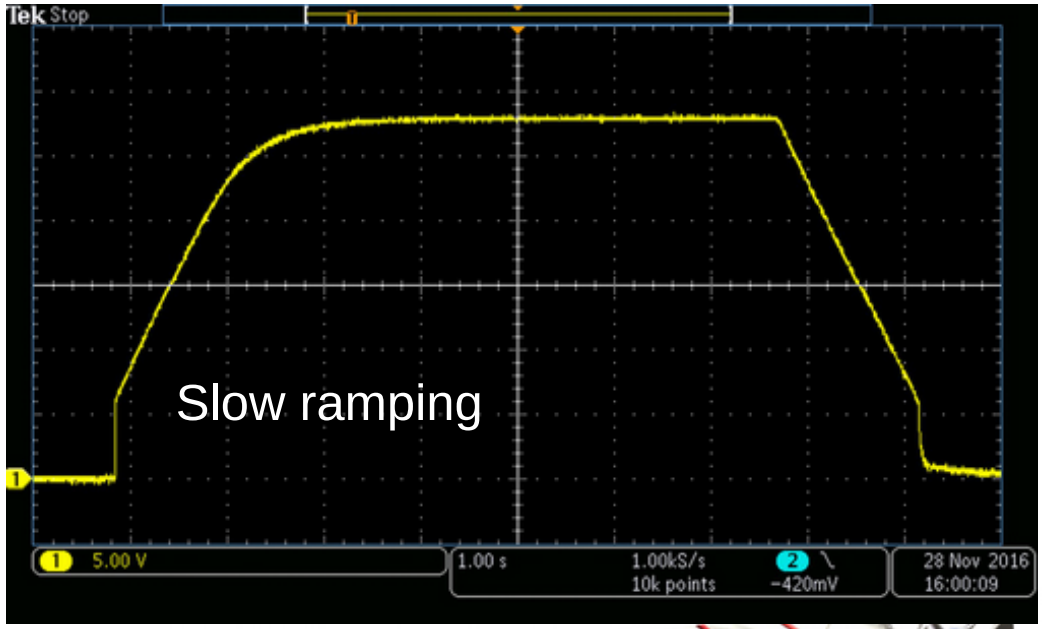
2D movement
Spot diameter

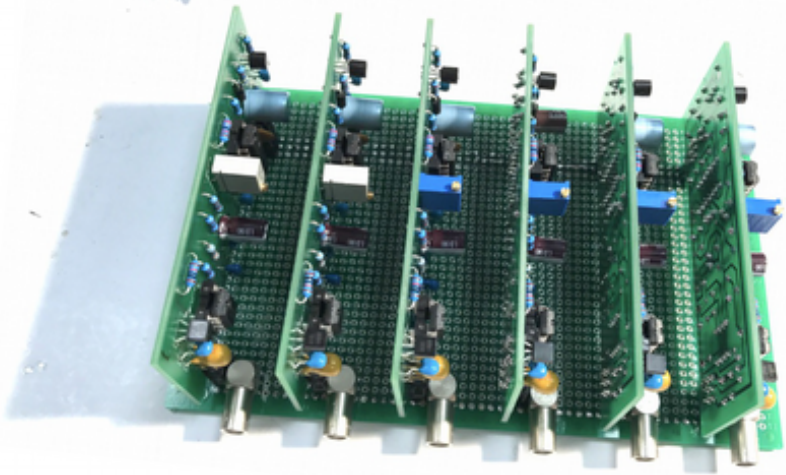
4x2.5cm Iron collimator blades

SiPM Voltage Supply

Very Good Long Term Stability $\sim 1 \mu V_{pp}$

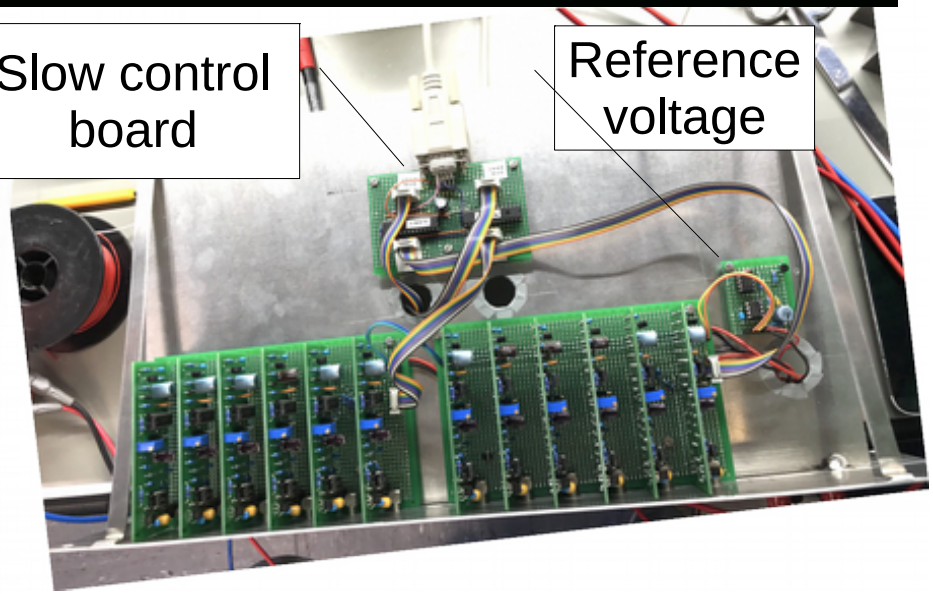
24 Channels



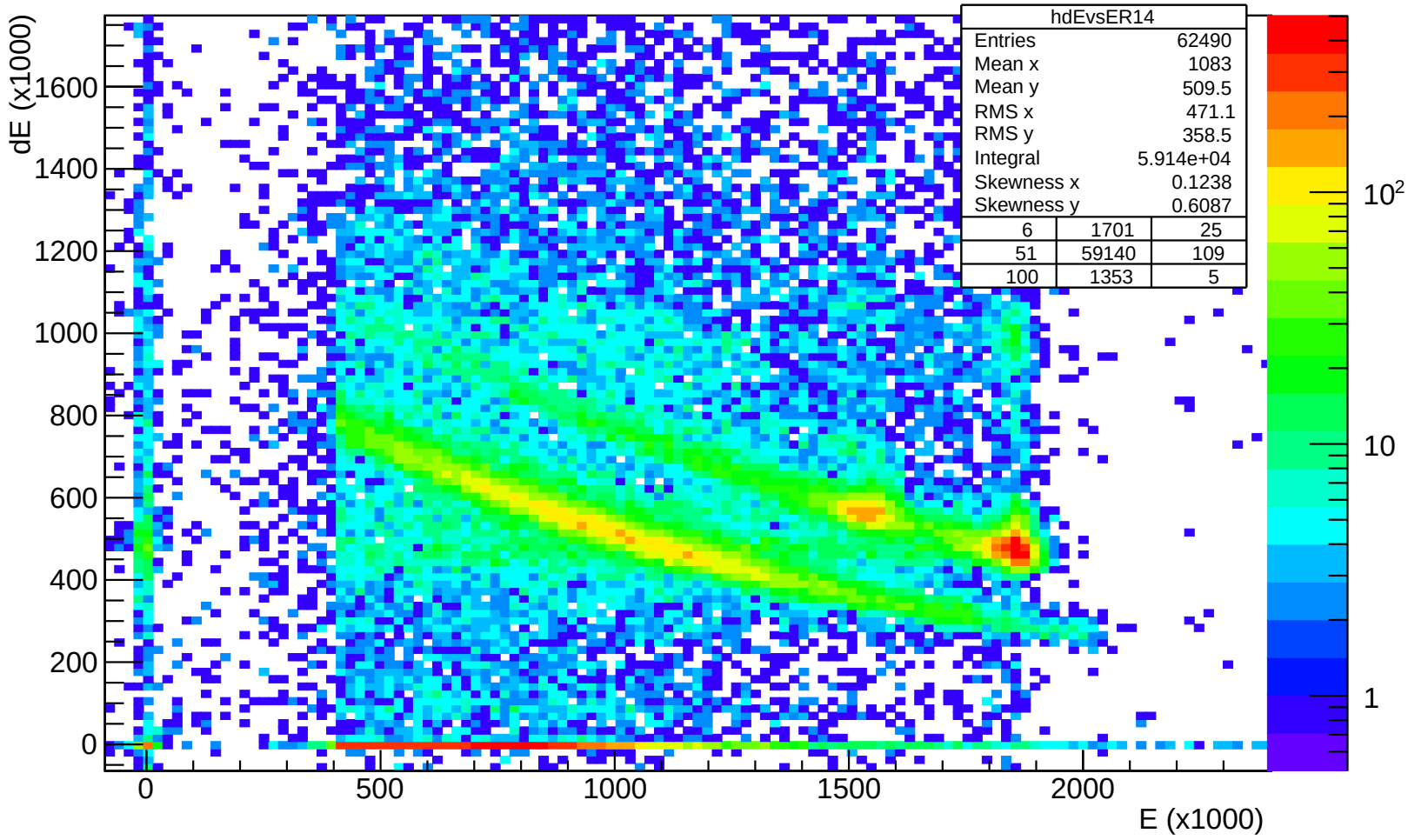


Slow control board

Reference voltage



Measurement on CH_2 Polyethylene target

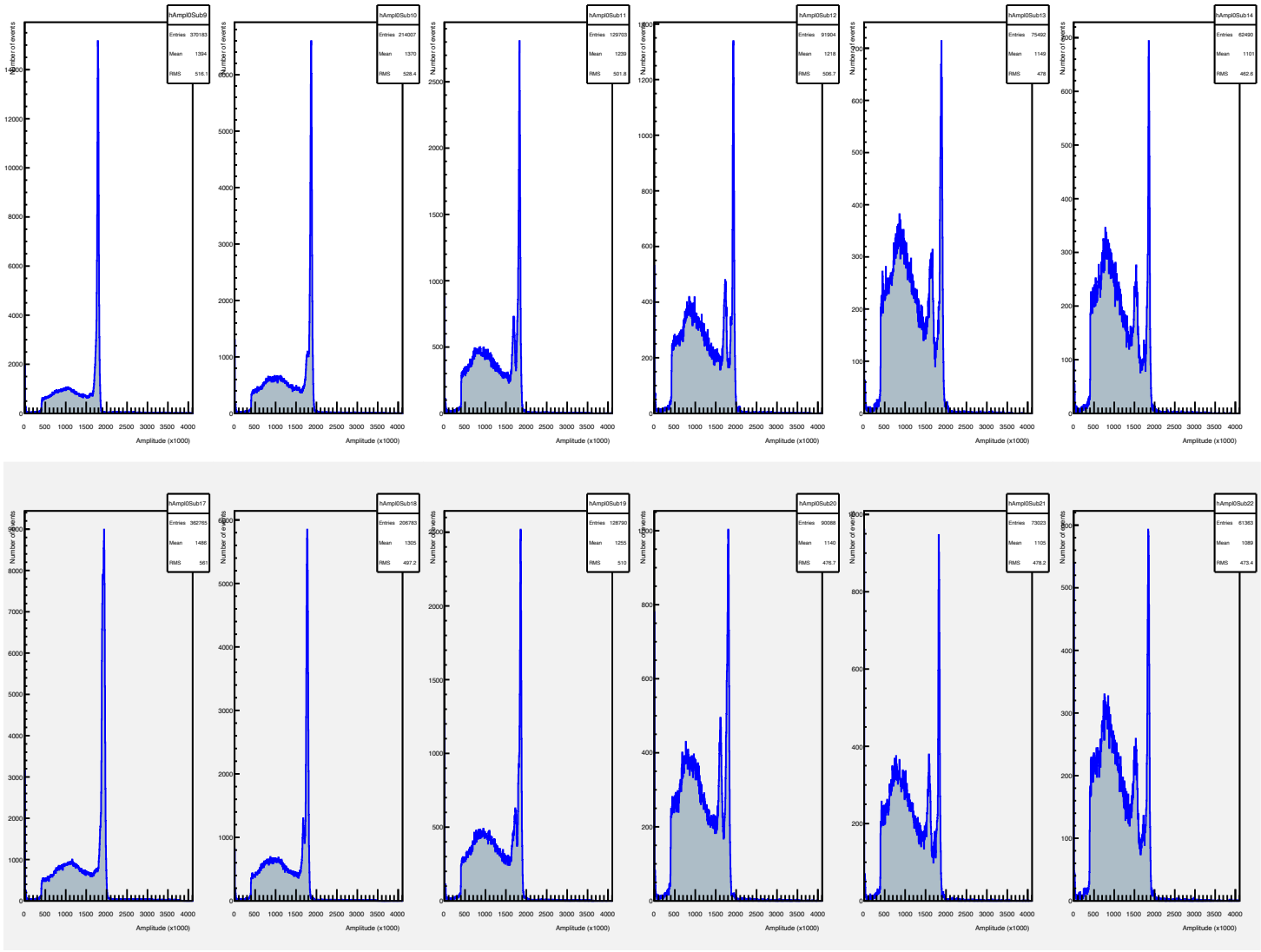


Preliminary results
December 2016 Beam Time

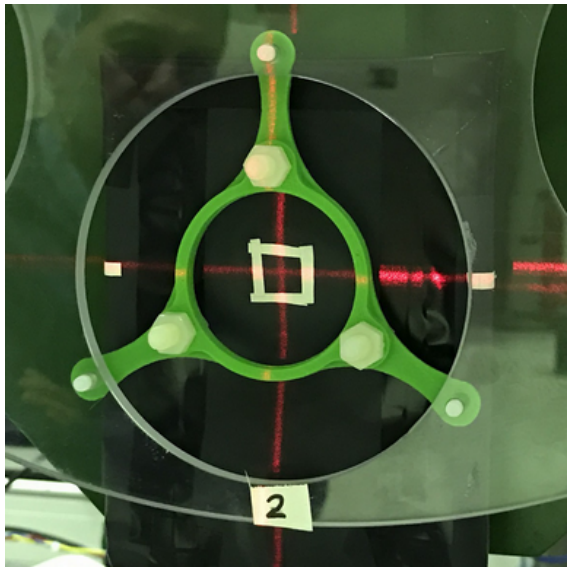
JEDI

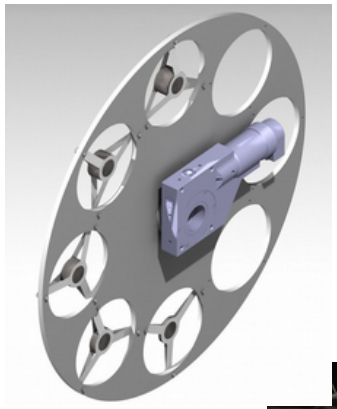
JÜLICH FORSCHUNGSZENTRUM

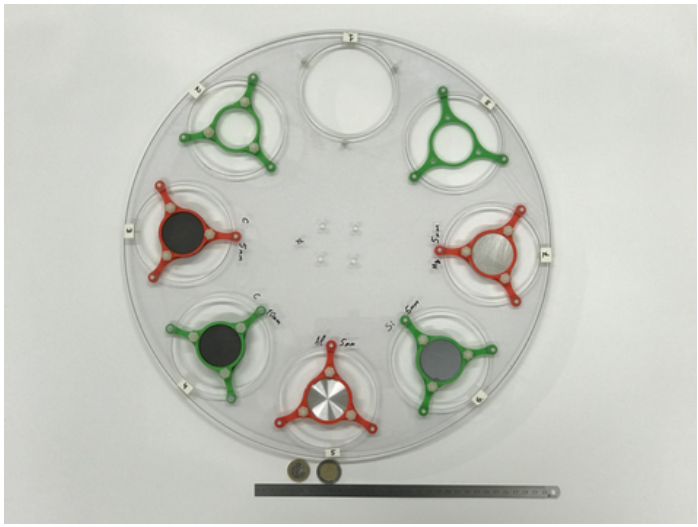
Measurement on CH_2 Polyethylene target

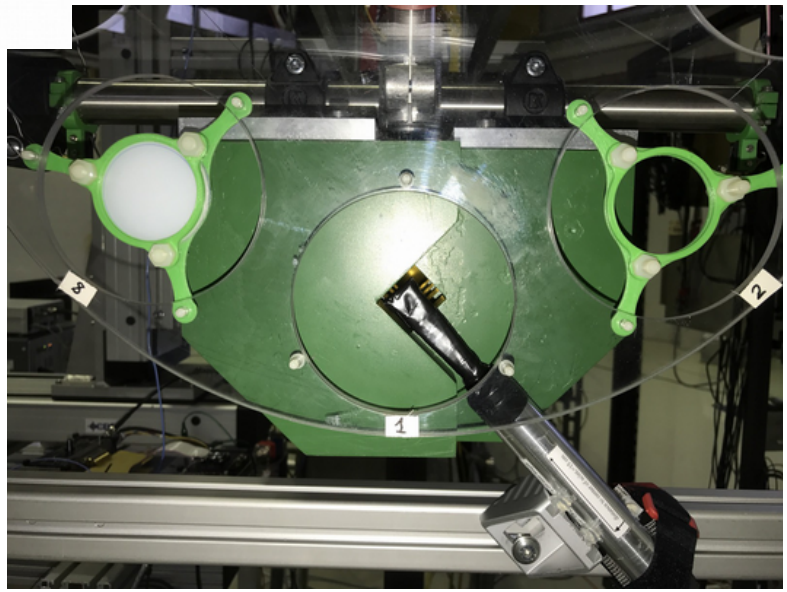


Target System + Start Counter
December 2016 Beam Time









Online Analysis Software
December 2016 Beam Time