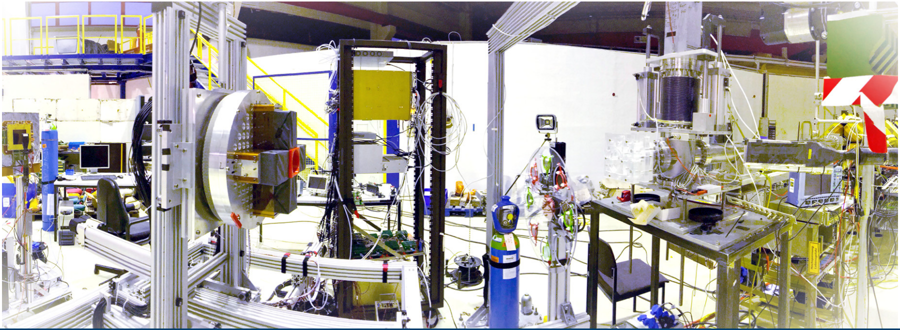


A NEW APPROACH: LYSO BASED POLARIMETRY FOR THE EDM MEASUREMENTS

Speaker: I. Keshelashvili

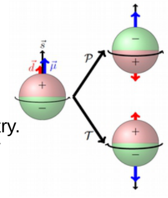
GGSWBS'18 — Tbilisi State University

OUTLINE

- ***Introduction***
  challenges for srEDM case
- **COSY** Accelerator Facility
  Spin gymnastic & operating polarimeters
- New Polarimeter Concept
  dedicated polarimeter for srEDM experiment
- Summary

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.



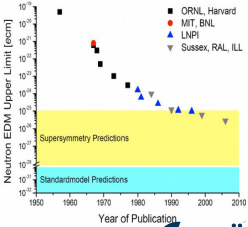
CP (K^o decays) violation means **T** is also violated assuming **CPT** symmetry.
The existence of a non-zero EDM is a violation of P and T simultaneously & the search for a EDM is a search for **CP** violation and a search for **direct T** symmetry violation.

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

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

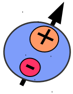
1967: Sacharov conditions for the Baryon Asymmetry of the Universe

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***

method differs strongly from nEDM



$\vec{d}$

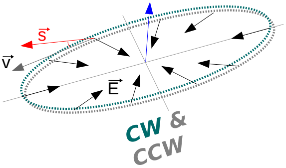
For all ***EDM*** experiments
Interaction of ***d*** with ***E***
is necessary!

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

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

b) Interact with a radial E-field

c) Analyze Polarization Build-up (this talk)



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

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**

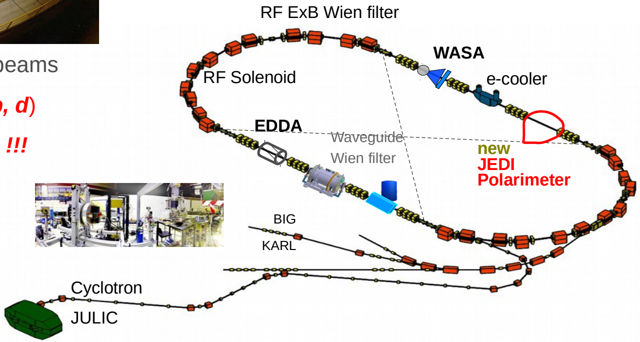
Electron & ***Stochastic*** cooling

Feed-forward machine

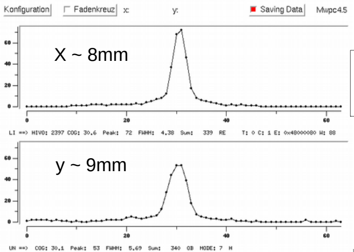
Internal and **external** beams

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

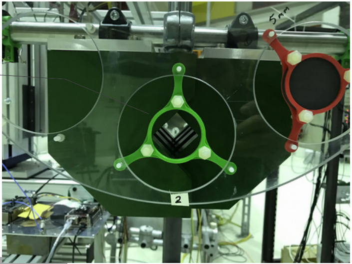
Spin manipulation !!!

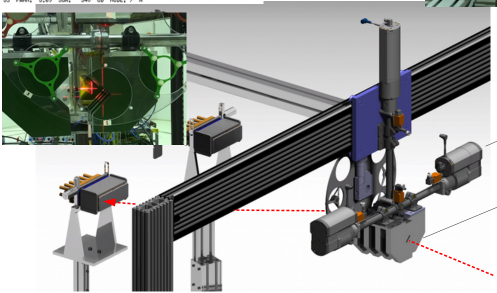


COSY BEAM MWPC PROFILE



Empty target holder

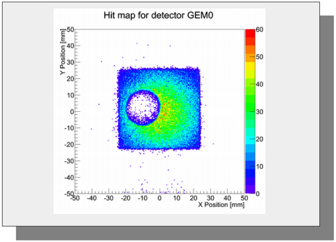


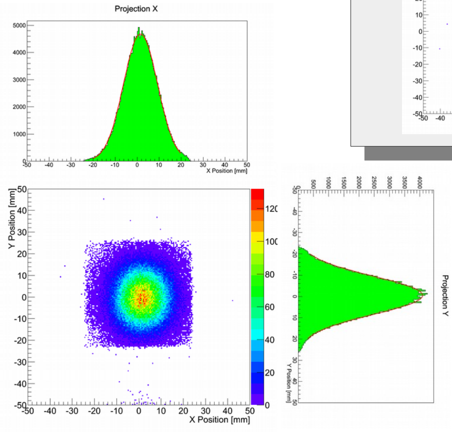


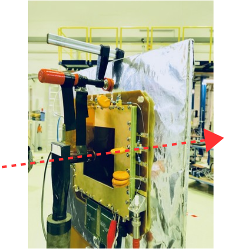
2D movement Spot diameter

4x2.5cm Iron collimator blades

COSY 2D PROFILE

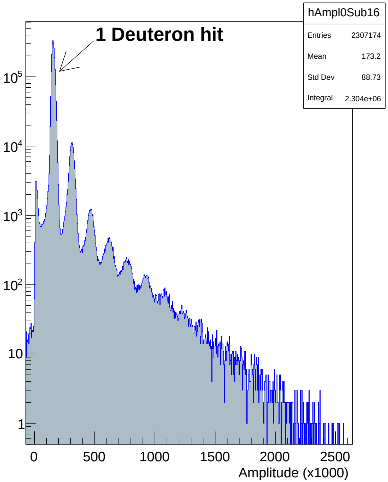


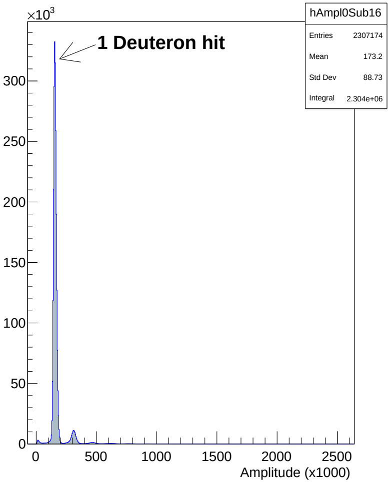




START COUNTER

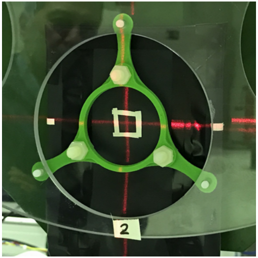
Clearly seen deuteron pile-ups

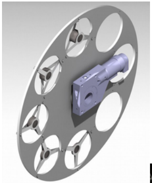


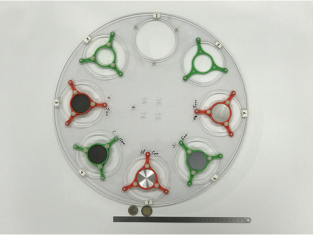


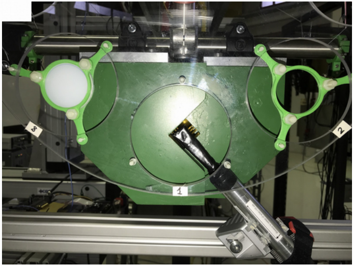
TARGET WHEEL

Materials: D=50mm and 5mm [C, Mg, Al, Si], 2mm [Ni, Sn] thickness







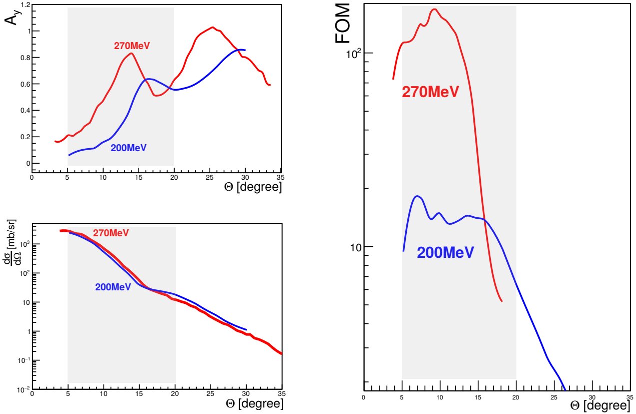


srEDM – *Precision Experiment !*

- 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

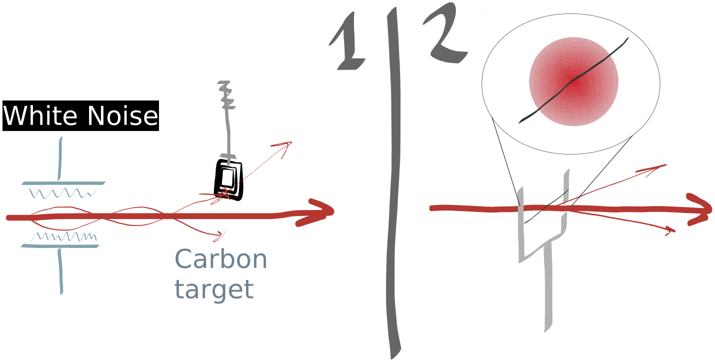
deuteron carbon ellastic scattering

$$FOM = A_y^2 \cdot \sigma_{ela}.$$

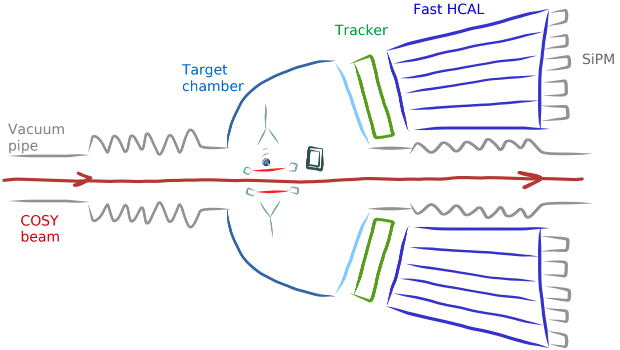


EDDA & WASA

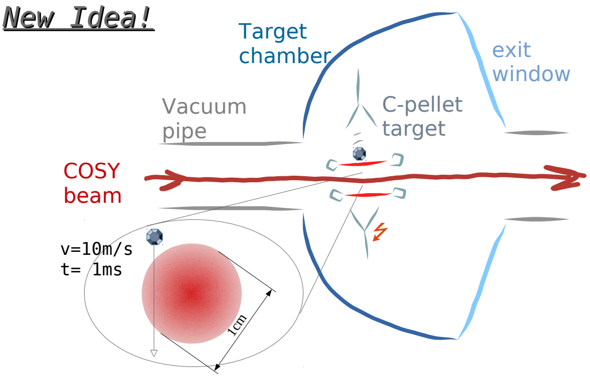
Carbon block 18mm or fiber 25μm



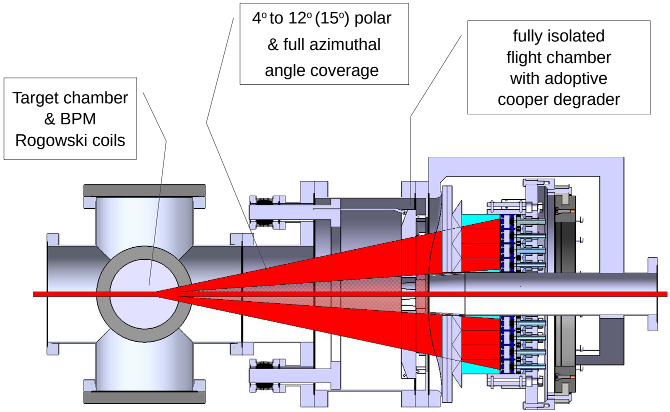
POLARIMETER SKETCH



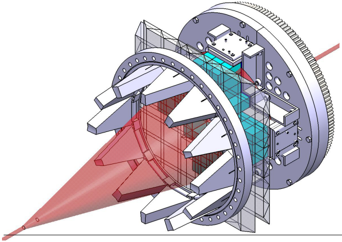
Juelich ballistic Diamond pellet Target



POLARIMETER



POLARIMETER



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

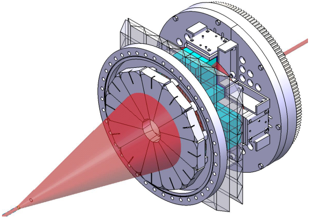
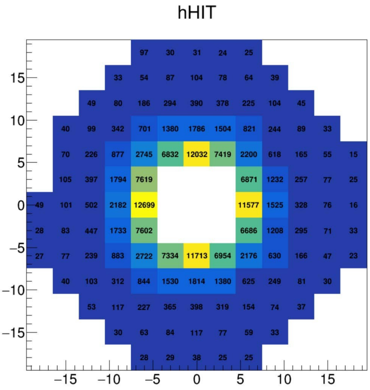
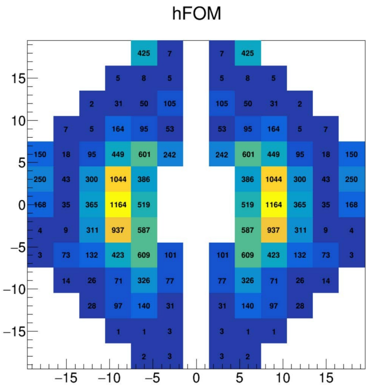


Figure of merit





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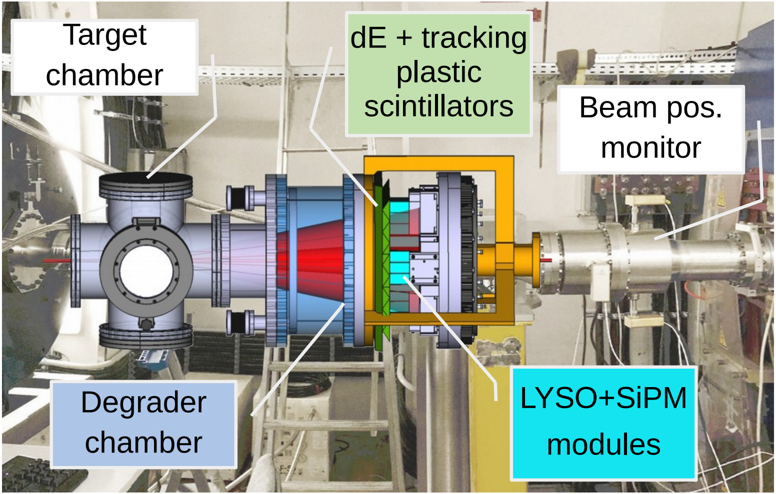
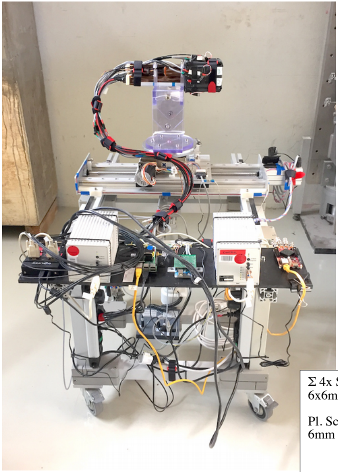
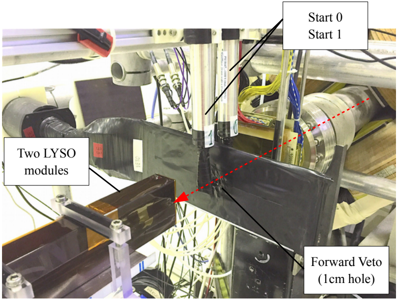
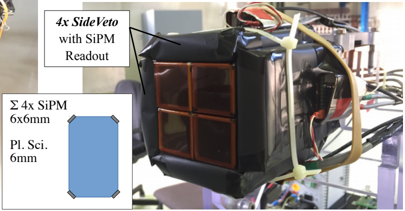
INTERNAL POLARIMETER



STEP 1







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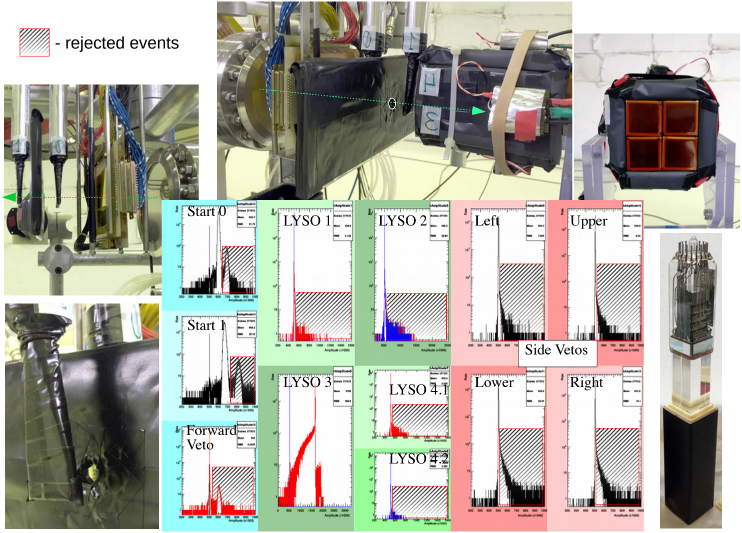
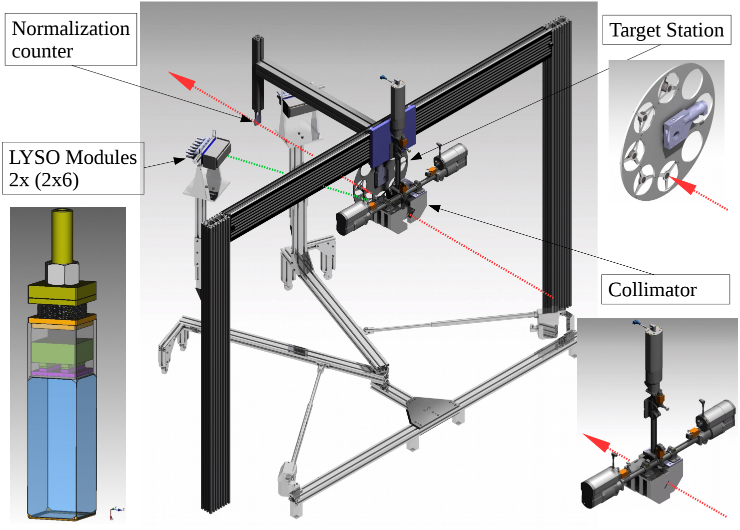
STEP 1

- rejected events

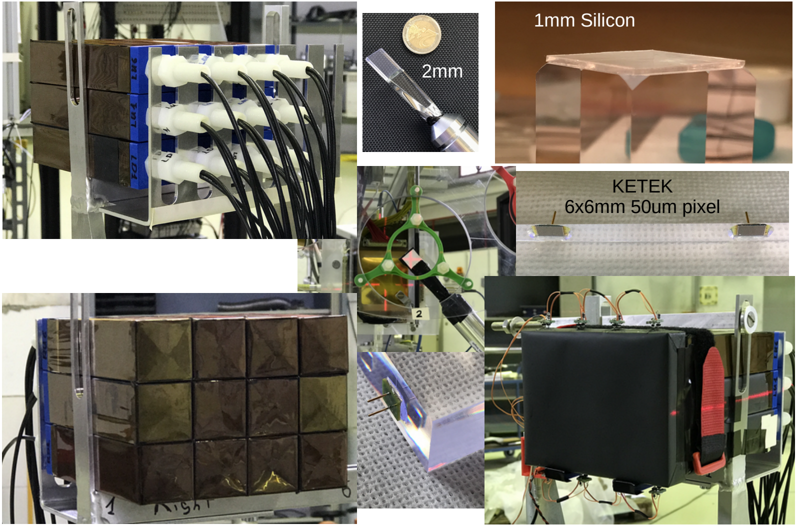


STEP 2

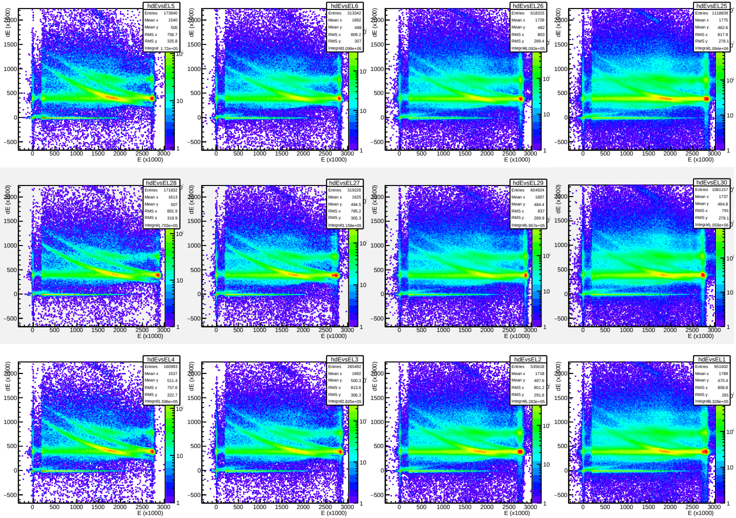


Normalization counter
LYSO Modules 2x (2x6)
Target Station
Collimator

STEP 2



STEP 2



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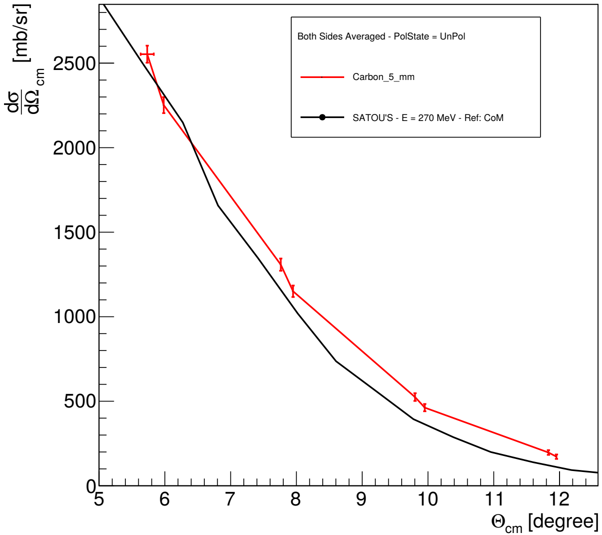
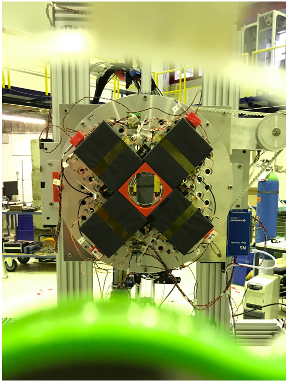
STEP 2

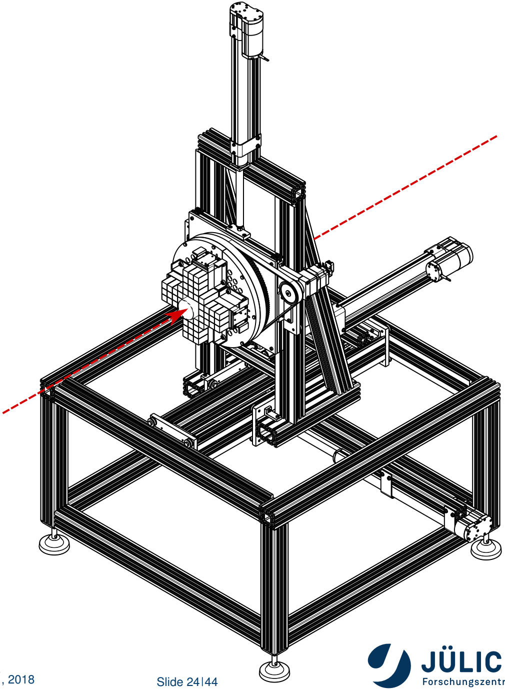


$\frac{d\sigma}{d\Omega_{cm}}$ [mb/sr]
2500
2000
1500
1000
500
0
5
6
7
8
9
10
11
12
Θ_{cm} [degree]
Both Sides Averaged - PolState = UnPol
Carbon_5_mm
SATOU'S - E = 270 MeV - Ref: CoM

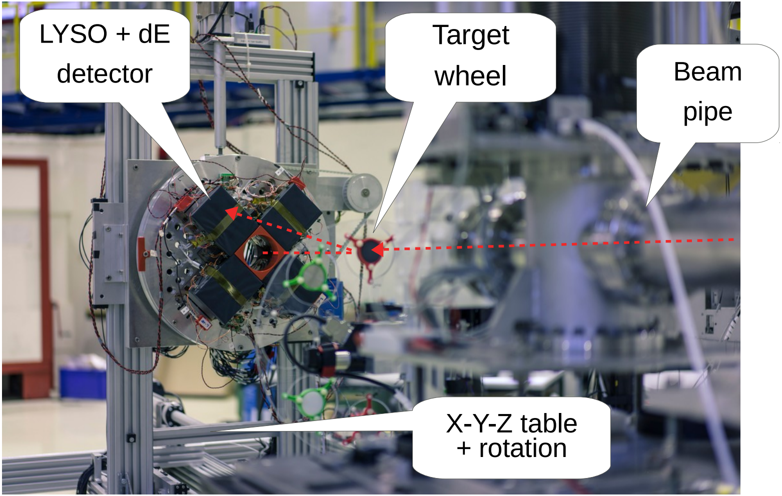
STEP 3

Test setup for polarimeter

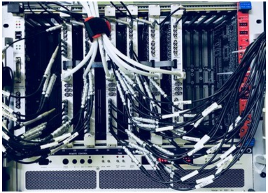


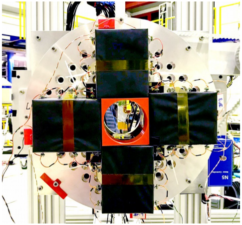


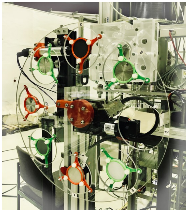
BIG KARL EXP. HALL

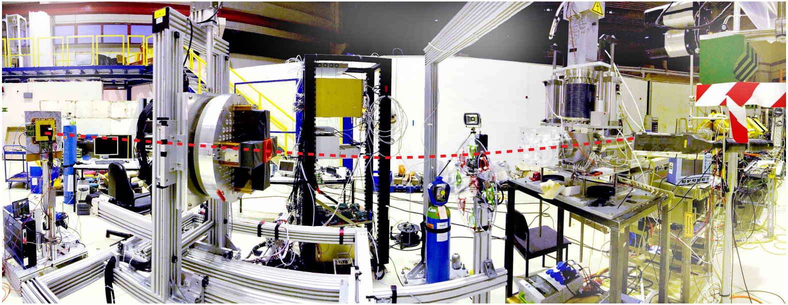


BIG KARL EXP. HALL









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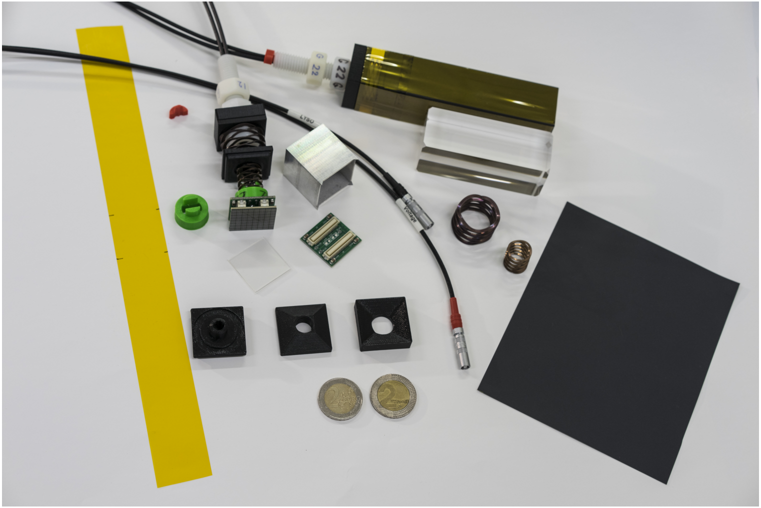
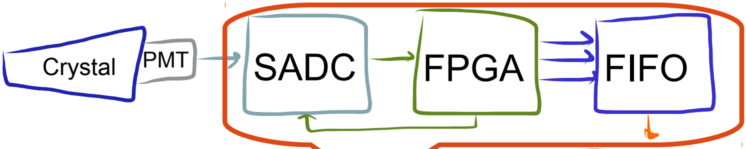
New improved mechanics and electronic components



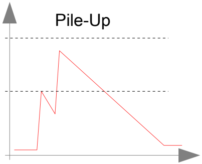
SADC BASED DAQ SYSTEM

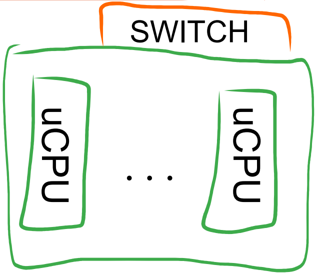


Struck SIS 3316

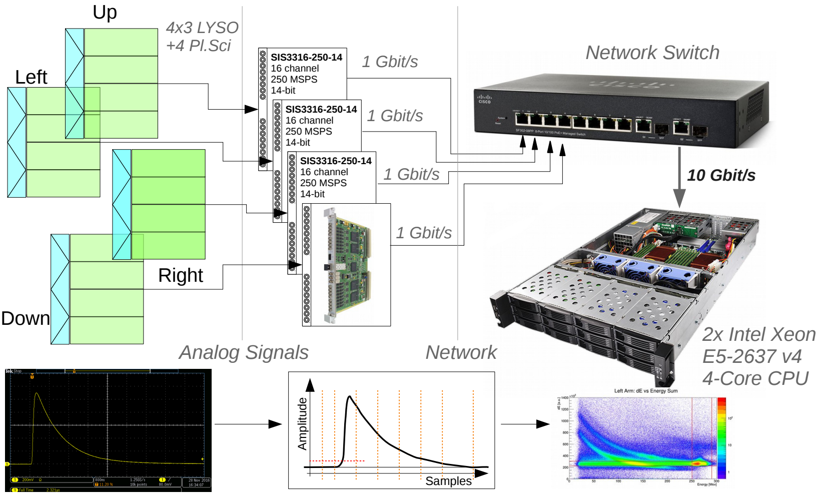
16 channel – 64MS/ch

250MS/s – 4ns per S.

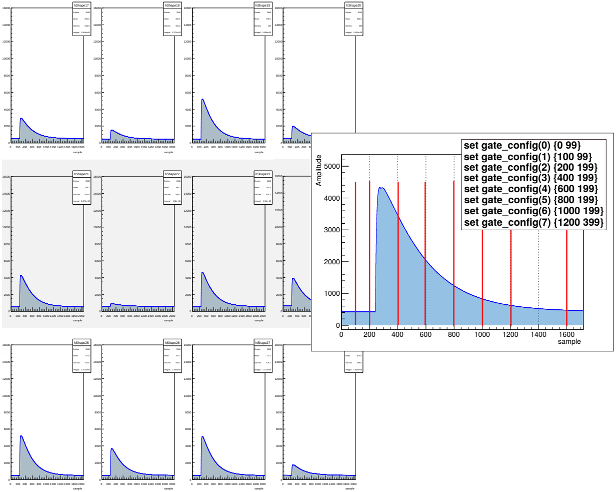




SADC BASED DAQ SYSTEM

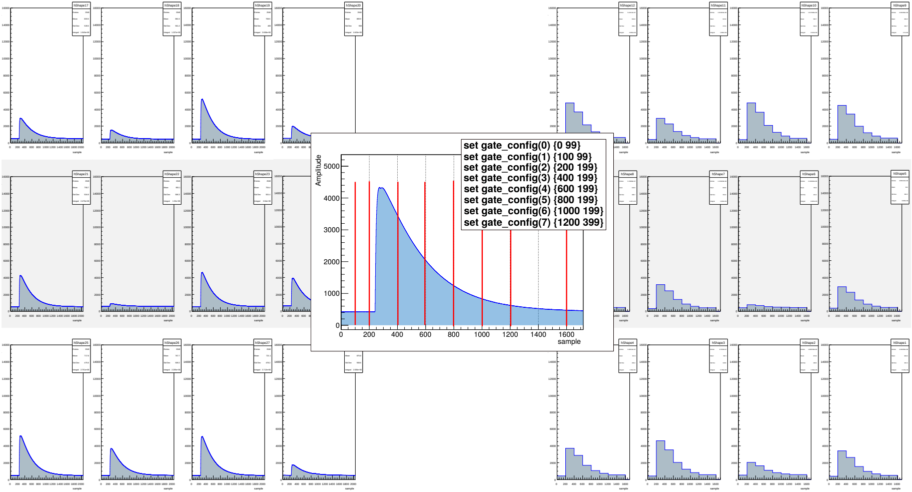


Full signal shape vs 8 accumulator/integral region



SIGNAL SHAPES

Full signal shape vs 8 accumulator/integral region



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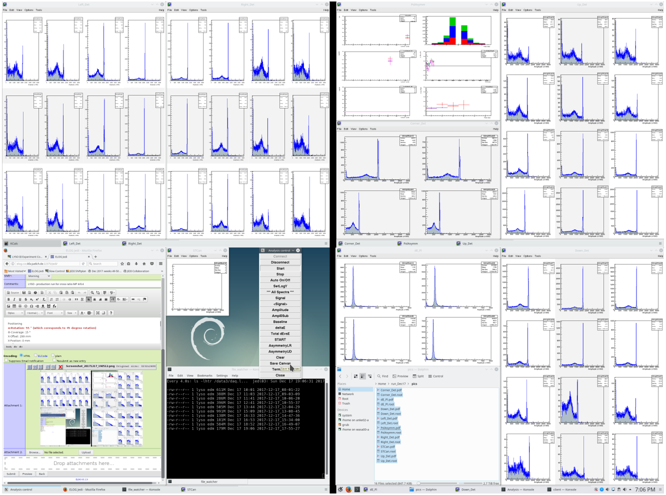
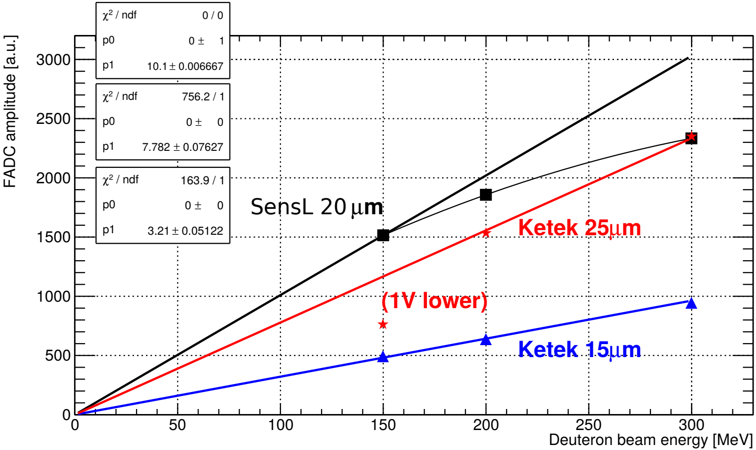
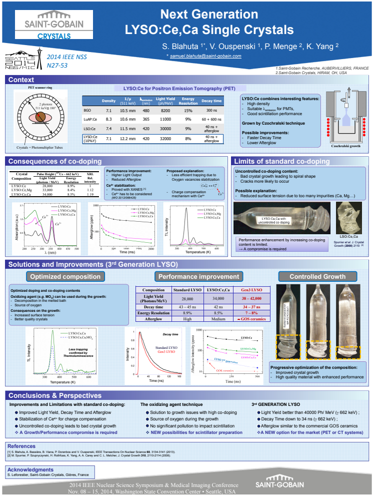
Monitoring of all amplitudes



Comparison of different SiPM sensors



SAINT-GOBAIN PRELUDE^{TM} 420 (LYSO)



SAINT-GOBAIN CRYSTALS

Next Generation LYSO:Ce,Ca Single Crystals

S. Blahuta [1*], V. Ouspenski [1], P. Menge [2], K. Yang [2]

* samuel.blahuta@saint-gobain.com

2014 IEEE NSS
N27-53

1.Saint-Gobain Recherche, AUBERVILLIERS, FRANCE
2.Saint-Gobain Crystals, HIRAM, OH, USA

Context

PET scanner ring

Crystals + Photomultiplier Tubes

LYSO:Ce for Positron Emission Tomography (PET)

	Density	1/μ (511 keV)	$\lambda_{emission}$ (nm)	Light Yield (ph/MeV)	Energy Resolution	Decay time
BGO	7.1	10.5 mm	480	8200	15%	300 ns
LuAP:Ce	8.3	10.6 mm	365	11000	9%	60 + 600 ns
LSO:Ce	7.4	11.5 mm	420	30000	9%	40 ns + afterglow
LYSO:Ce (10%Y)	7.1	12.2 mm	420	32000	8%	40 ns + afterglow

LYSO:Ce combines interesting features:
- High density
- Suitable $\lambda_{emission}$ for PMTs,
- Good scintillation performance

Grown by Czochralski technique

Possible improvements:
- Faster Decay Time
- Lower Afterglow

Czochralski growth

Consequences of co-doping

Crystal Composition	Pulse Height (^{137}Cs – 662 keV) Light Yield (photons / MeV)	Energy Resolution	XRL Rel. intensity
LYSO:Ce	28,000	8.9%	1
LYSO:Ce,Mg	33,000	8.4%	1.12
LYSO:Ce,Ca	34,000	8.5%	1.19

Performance improvement:
- Higher Light Output
- Reduced Afterglow

Ce⁴⁺ stabilization:
- Proved with XANES [1]
- Ce⁴⁺ has to be considered (WO 2012/066425)

Proposed explanation:
- Less efficient trapping due to Oxygen vacancies stabilization
- Charge compensation mechanism with Ce⁴⁺

Limits of standard co-doping

Uncontrolled co-doping content:
- Bad crystal growth leading to spiral shape
- Cracks more likely to occur

Possible explanation:
- Reduced surface tension due to too many impurities (Ca, Mg…)

LYSO:Ce,Ca with uncontrolled co-doping

LSO:Ce,Ca

Spurrier et al. J. Crystal Growth (2008) 2110 [2]

Performance enhancement by increasing co-doping content is limited.
→ A compromise is required

Solutions and Improvements (3rd Generation LYSO)

Optimized composition

Optimized doping and co-doping contents

Oxidizing agent (e.g. MO_x) can be used during the growth:
- Decomposition in the melted bath
- Source of oxygen

Consequences on the growth:
- Increased surface tension
- Better quality crystals

Less trapping confirmed by Thermoluminescence

Performance improvement

Composition	Standard LYSO	LYSO:Ce,Ca	Gen3 LYSO
Light Yield (Photons/MeV)	28,000	34,000	38 – 42,000
Decay time	43 – 45 ns	42 ns	34 – 37 ns
Energy Resolution	8.9%	8.5%	7 – 8%
Afterglow	High	Medium	~ GOS ceramics

Controlled Growth

Progressive optimization of the composition:
- Improved crystal growth
- High quality material with enhanced performance

Conclusions & Perspectives

Improvements and Limitations with standard co-doping:
- Improved Light Yield, Decay Time and Afterglow
- Stabilization of Ce⁴⁺ for charge compensation
- Uncontrolled co-doping leads to bad crystal growth
- ❖ A Growth/Performance compromise is required

The oxidizing agent technique
- Solution to growth issues with high co-doping
- Source of oxygen during the growth
- No significant pollution to impact scintillation
- ❖ NEW possibilities for scintillator preparation

3rd GENERATION LYSO
- Light Yield better than 40000 Ph/ MeV (γ 662 keV) ;
- Decay Time down to 34 ns (γ 662 keV) ;
- Afterglow similar to the commercial GOS ceramics
- ❖ A NEW option for the market (PET or CT systems)

References

[1] S. Blahuta, A. Bessière, B. Viana, P. Dorenbos and V. Ouspenski, IEEE Transactions On Nuclear Science **60**, 3134-3141 (2013).
[2] M. Spurrier, P. Szupryczynski, H. Rothfuss, K. Yang, A. A. Carey and C. L. Melcher, J. Crystal Growth **310**, 2110-2114 (2008).

Acknowledgments
S. Leforestier, Saint-Gobain Crystals, Gières, France

2014 IEEE Nuclear Science Symposium & Medical Imaging Conference
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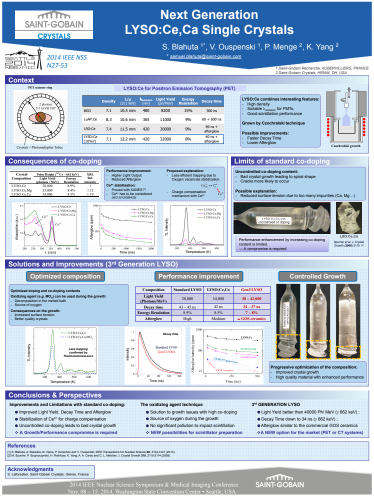
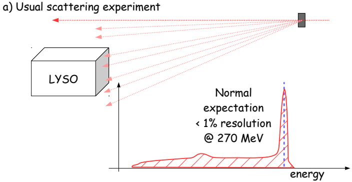
SAINT-GOBAIN

SAINT-GOBAIN PRELUDE^{TM} 420 (LYSO)





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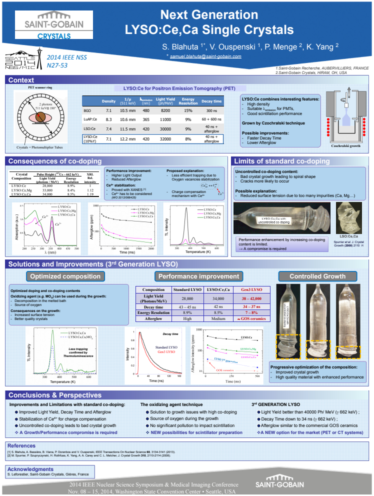
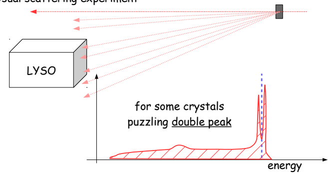


a) Usual scattering experiment



It was actually appearing
almost randomly…

The same crystal time to time had
absolutely **clean signal**
but in some situations manifesting
double peak!

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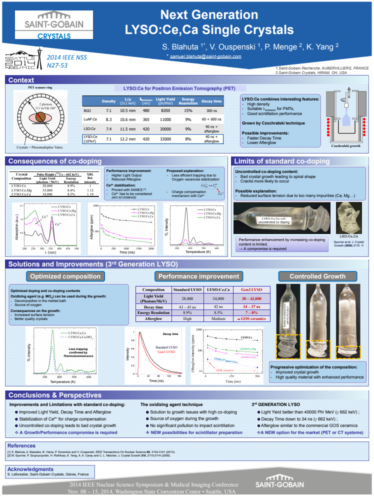

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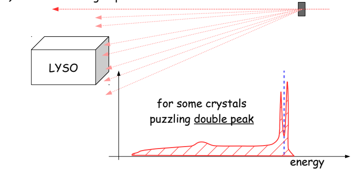
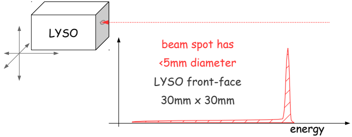


b) During energy calibration



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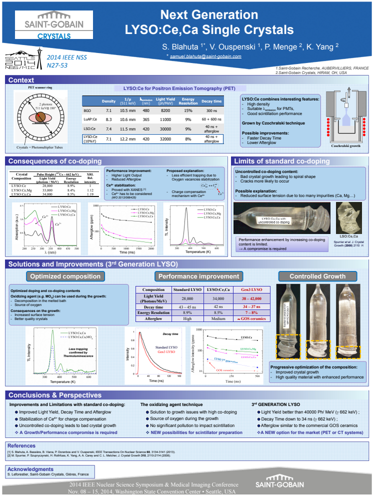

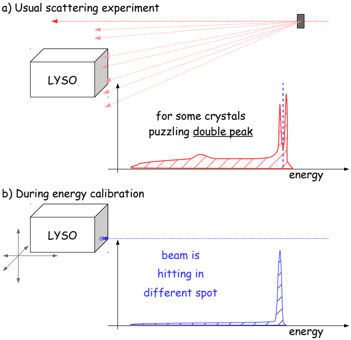

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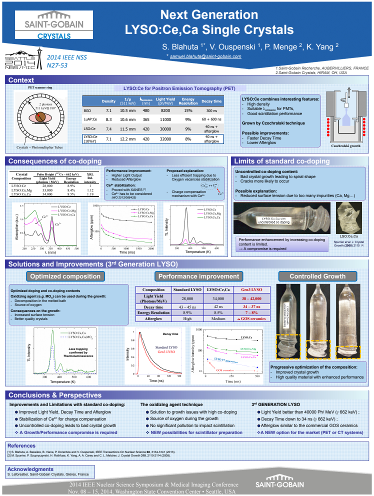

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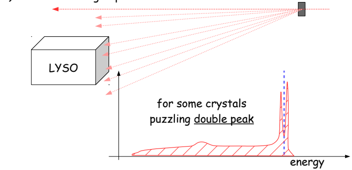

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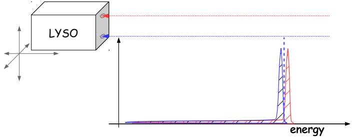

Peak is front face position dependent!

Is it also energy dependent? not really...

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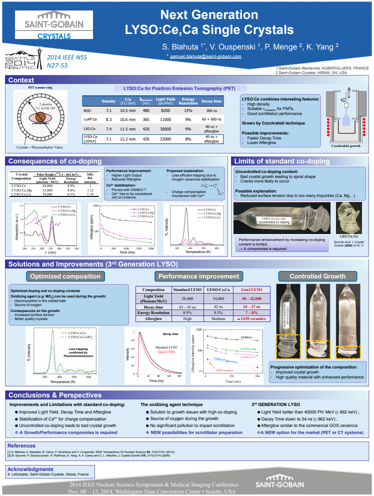

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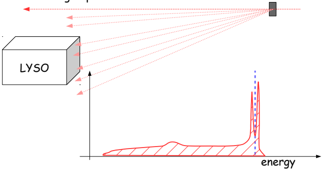

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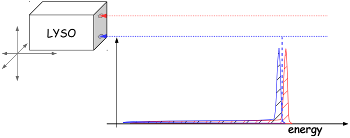


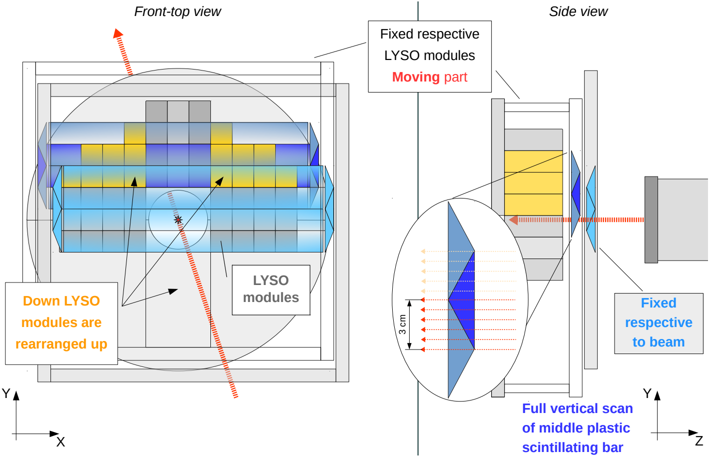
c) Different hypotheses

We spend <3 days of March beam time
to clarify this problem
very successfully !
We measured 2D maps for all crystals at
150, 200, 300 MeV

PLASTIC SCINTILLATOR TRACKER

Consisting of the overlapping triangular scintillator bars. The upstream (forward) frame is installed to be fixed vertically relative to the beam while the downstream (backward) frame can scan the beam.

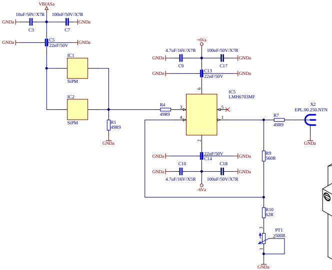
All scintillators were scanned vertically and horizontally (along the bar).

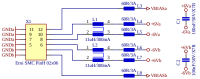


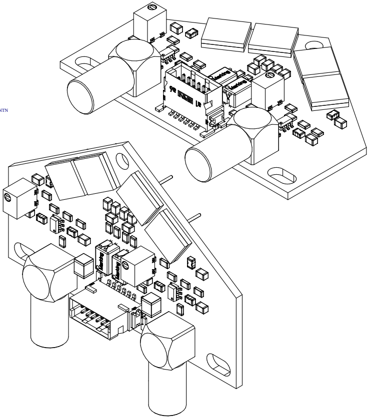
PLASTIC SCINTILLATOR TRACKER READOUT PCB

Dual channel operational amplifier based SiPM signal preamplifier PCB

The supply voltage $\pm 6V$ and reverse bias voltages $+29V$ is shared for each PCB







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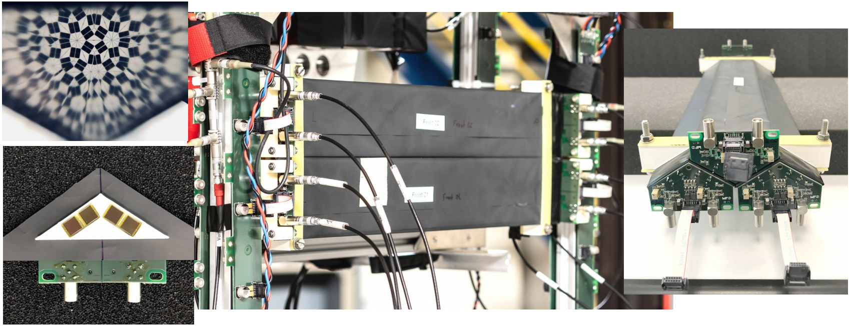
PLASTIC SCINTILLATOR TRACKER

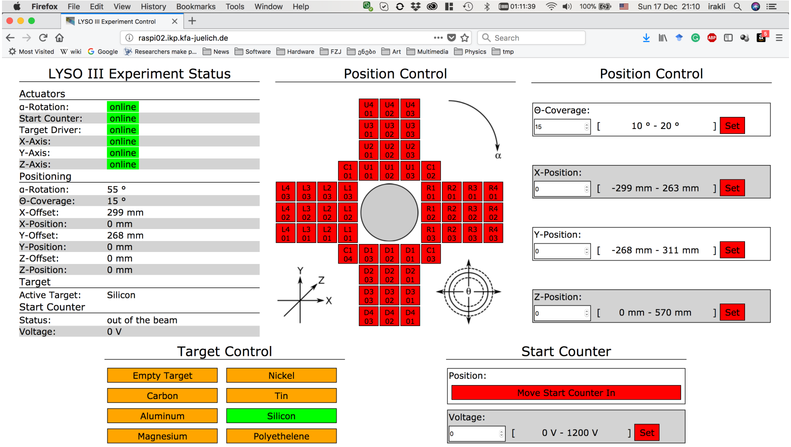
Left-up: the view through the wrapped triangular scintillator bar where the kaleidoscopic picture of the SiPM's is seen from another end.
Left-down: the end cup of the bar is shown with four SiPM's split into two independent preamplifier channels.
Middle: already attached tracker in front of LYSO modules.
Right: one of the layers with three bars after assembly.

Each counter has 4 independent preamplifier output, 2 each end, and eight 6×6 *mm* SiPM's four each end.



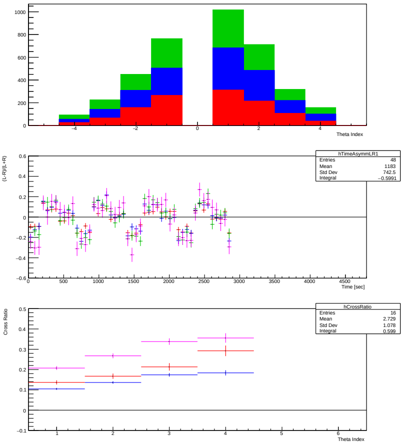
SLOW CONTROL SYSTEM

Controls all movements



ASYMMETRY

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



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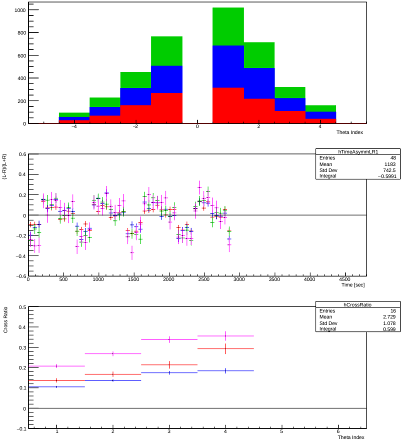

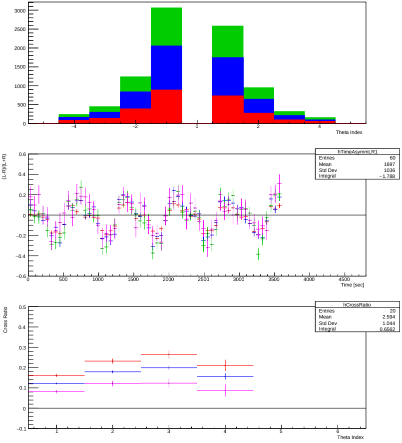

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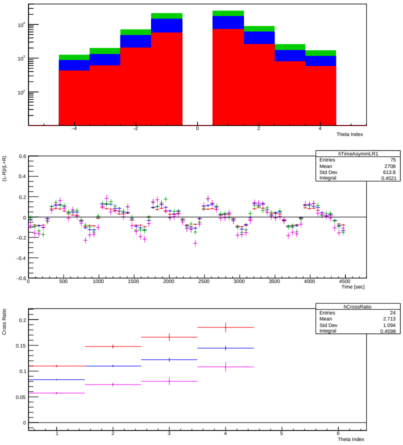
Different target materials (left Nickel; right Tin)



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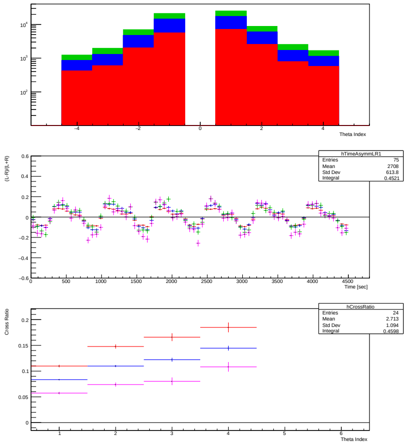

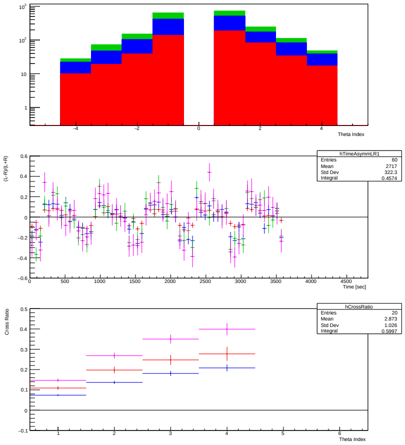

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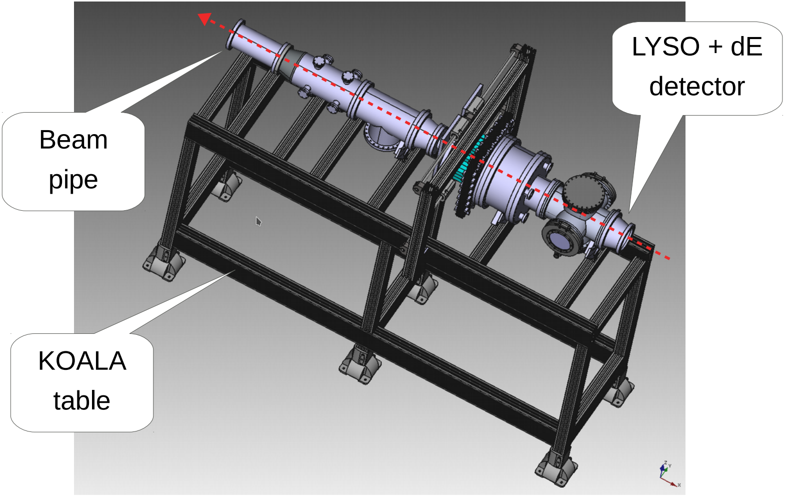
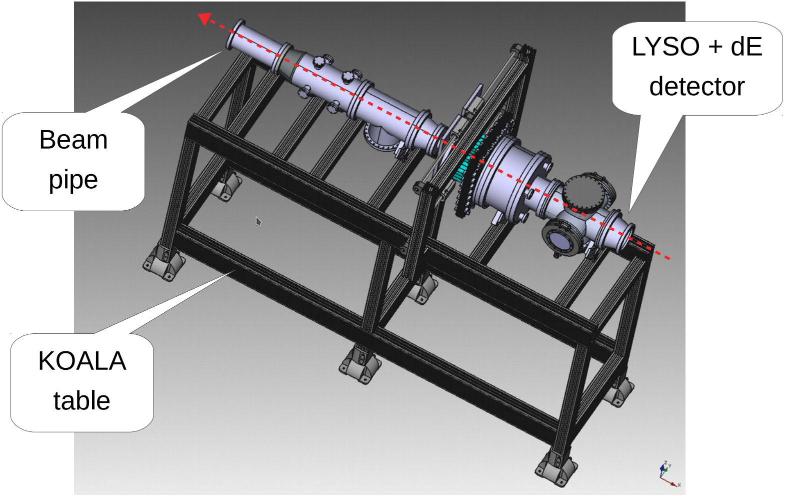


Beam pipe
KOALA table
LYSO + dE detector

JEPO AT ANKE



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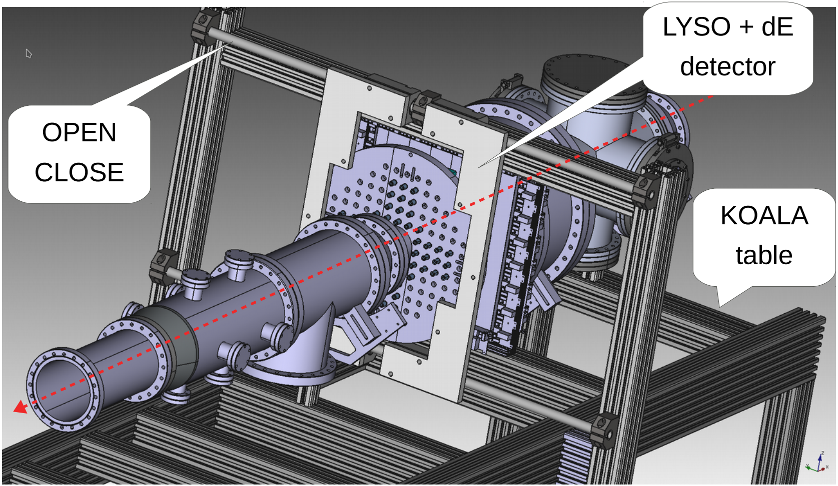


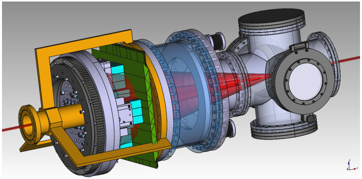
ACKNOWLEDGMENT

People contributing to the experiment

- Mechanics: N. DeMary, M. Maubach, G. D'Orsaneo & D. Spölgen
- Electronics: Tanja Hahnraths-von der Gracht & T. Sefzick
- DAQ & FEE: D. Mchedlishvili, & P. Wüstner
- G4: **H. Jeong (PhD)** , G. Macharashvili, & N. Lomidze
- **Ms.: O. Javakhishvili, G. Kvantrishvili, M. Gagoshidze, & D. Kordzaia**
- **PhD: F. Müller, D. Shergelashvili, & S. Basile**

SUMMARY

- We have functional online polarimeter
  –needs further software development!
- Mechanical support & slow control
  shows excellent performance
- New DAQ system reached its
  max. designed data transfer of 400 MB/s
- We have assembled and tested new LYSO and SiPM vendors
  in total 48+4 Modules
- **Next step: installation at ANKE**



A p p e n d i x

CONTACT

Contacting me via e-mail

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GENERAL FORMALISM

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

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

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

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