

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**

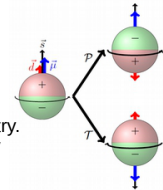
dedicated polarimeter for srEDM experiment

- **Summary**

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^0 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.



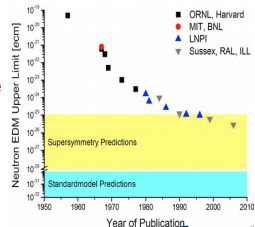
SM CP violation is enough to explain what has been observed in the K & B meson systems but orders of magnitude smaller than observed in the universe

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

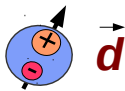
1967: Sacharov conditions for the Baryon Asymmetry of the Universe

- 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 \rightarrow physics beyond SM



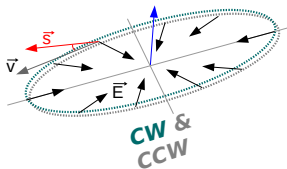
method differs strongly from nEDM



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

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

- Store longitudinally polarized **protons**
- Interact with a radial E-field
- Analyze Polarization Build-up (this talk)



**build-up of vertical
polarization**

$$\vec{s}_{\perp} \propto |d|$$

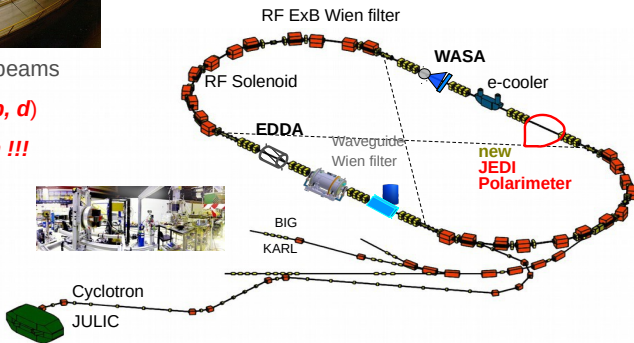
POLARIMETER & WIEN FILTER SETUP @ COSY



Internal and external beams

High polarization (*p*, *d*)

Spin manipulation !!!



Energy range (min.-- max.):

0.045 – 2.8 GeV (p)

0.023 – 2.3 GeV (d)

Max. momentum ~ 3.7 GeV/c

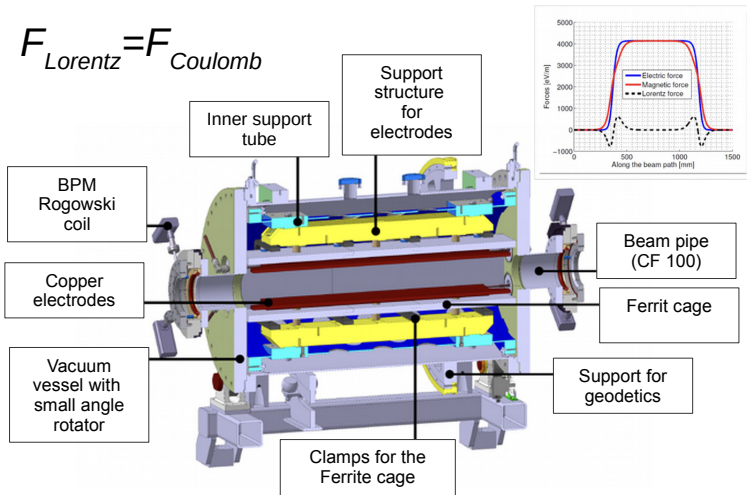
Electron & Stochastic cooling

Feed-forward machine

RF-WIEN-FILTER

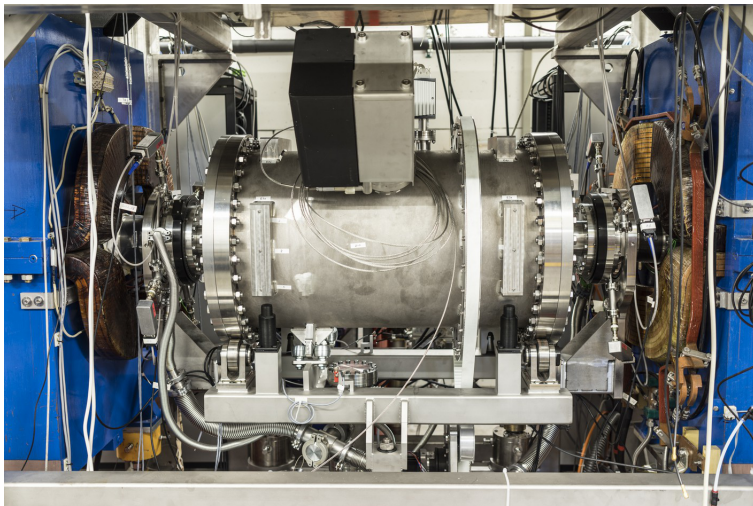
second generation at COSY

$$F_{\text{Lorentz}} = F_{\text{Coulomb}}$$



RF-WIEN-FILTER

commissioning beam time done



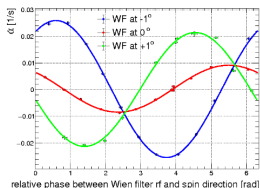
WF at nominal angle 0°

FIRST MEASUREMENT OF EDM-LIKE BUILDUP SIGNALS

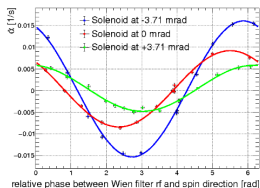
EDM induced vertical polarization oscillations

Rate of out-of-plane rotation angle $\dot{\alpha}(t)|_{t=0}$ as function of Wien filter RF phase ϕ_{RF}

- B field of RF Wien filter normal to the ring plane.
- Wien filter operated at $f_{\text{WF}} = 871$ kHz.
- Variations of $\phi_{\text{rot}}^{\text{WF}}$ and $\chi_{\text{rot}}^{\text{Sol}1}$ affect the pattern of observed initial slopes $\dot{\alpha}$.



$\dot{\alpha}$ for $\phi_{\text{rot}}^{\text{WF}} = -1^\circ, 0^\circ, +1^\circ$ and $\chi_{\text{rot}}^{\text{Sol}1} = 0$.

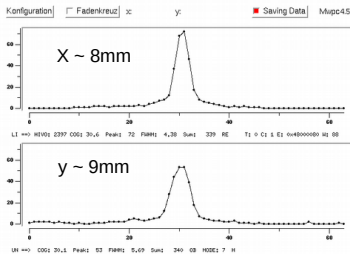


$\dot{\alpha}$ for $\chi_{\text{rot}}^{\text{Sol}1} = -1, 0, +1^\circ$ and $\phi_{\text{rot}}^{\text{WF}} = 0$.

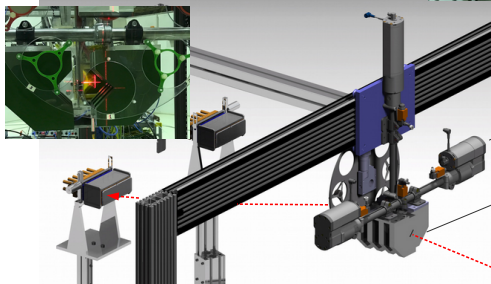
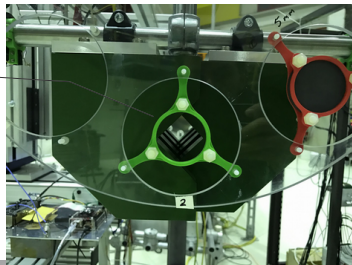
Planned measurements:

- 1st EDM measurement run Nov-Dec/2018 (6 wk).
- 2nd run planned for Fall/Winter 2019 (6 wk).

COSY BEAM MWPC PROFILE



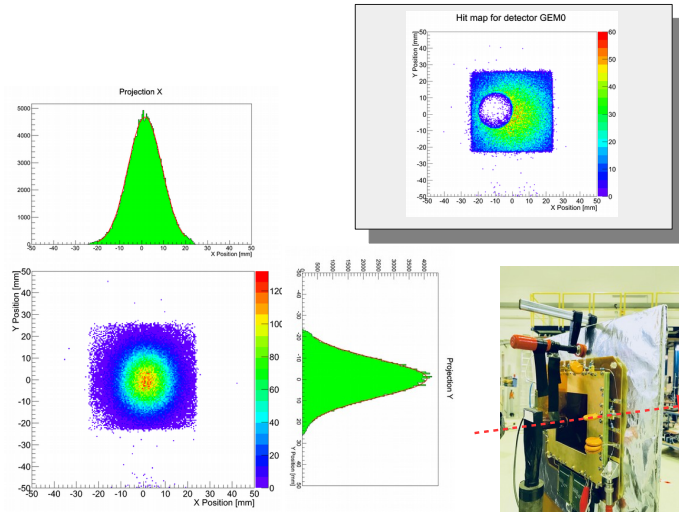
Empty target holder



2D movement
Spot diameter

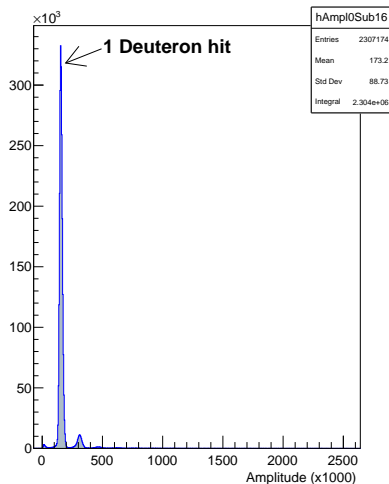
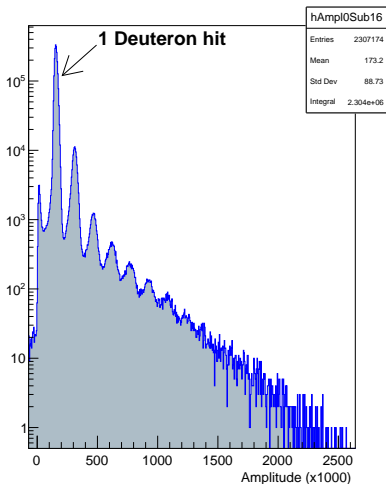
4x2.5cm Iron
collimator blades

COSY 2D PROFILE



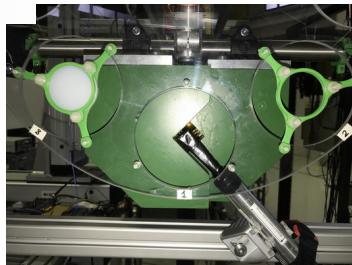
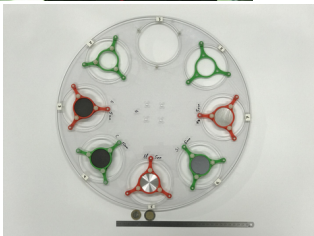
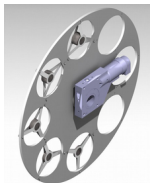
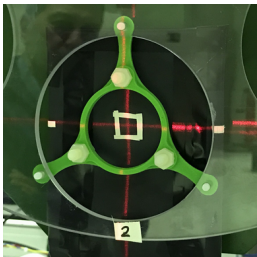
START COUNTER

Clearly seen deuteron pile-ups



TARGET WHEEL

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

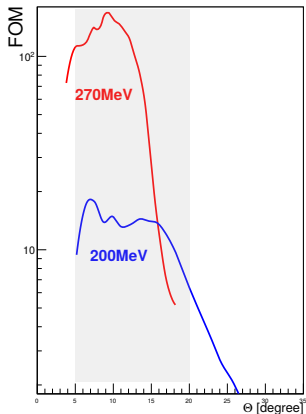
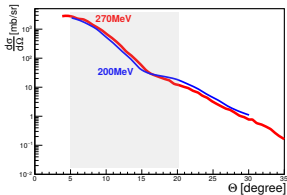
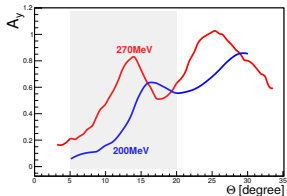


srEDM – Precision Experiment !

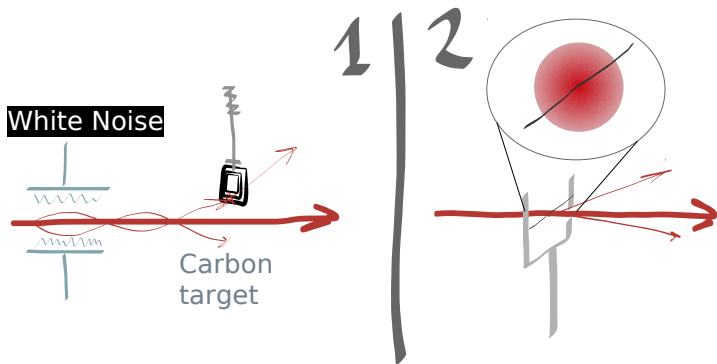
- Reaction with Large **FOM** (σA_y^2) & ($\sigma_{\text{ela}}/\sigma_{\text{tot}}$): Best $dC \rightarrow dC$
- **Maximum** Detection & Data Taking Efficiency
- **Full ϕ** in Reasonable **FOM**(θ) region
- **No** strong Magnetic / Electric Field
- **Stability** – Long / Short Term

deuteron carbon elastic scattering

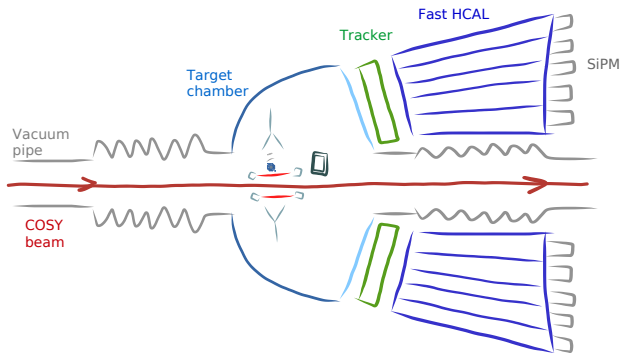
$$FOM = A_y^2 \cdot \sigma_{ela.}$$



Carbon block 18mm or fiber 25 μ m

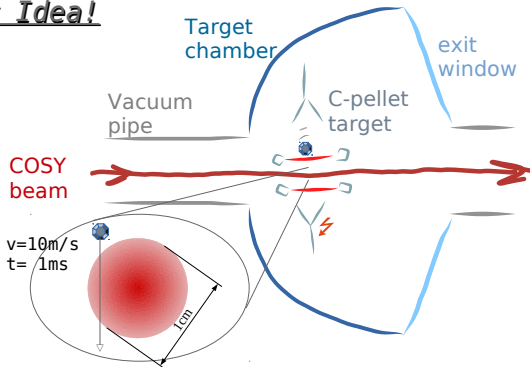


POLARIMETER SKETCH

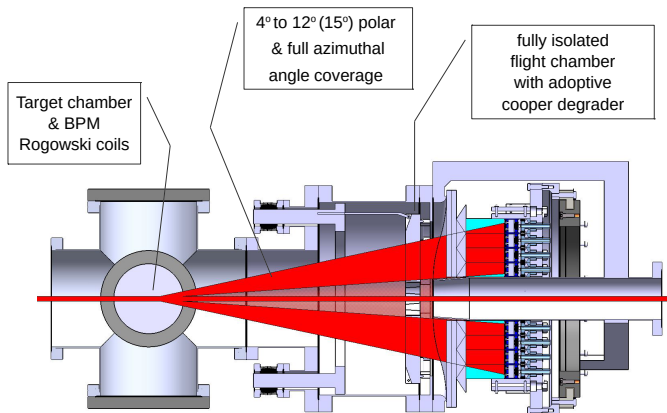


Juelich ballistic Diamond pellet Target

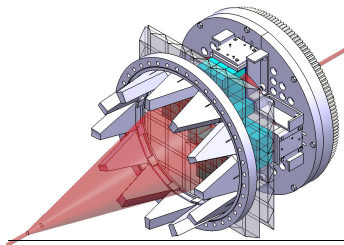
New Idea!



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*

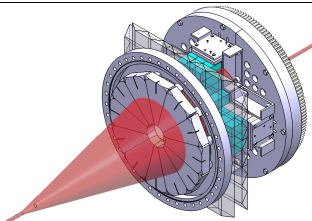
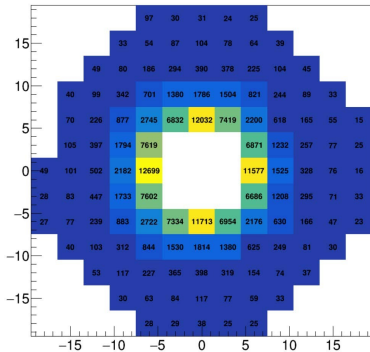
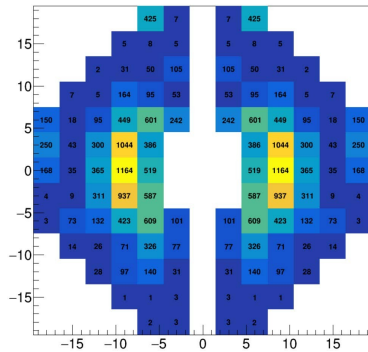


Figure of merit

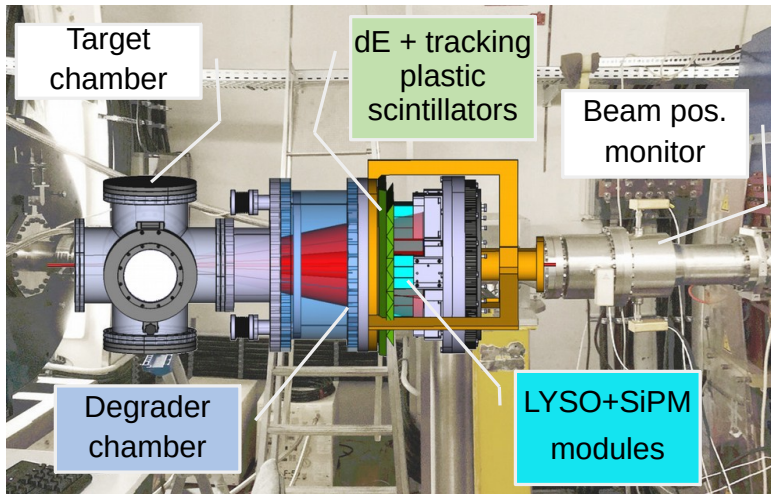
hHIT



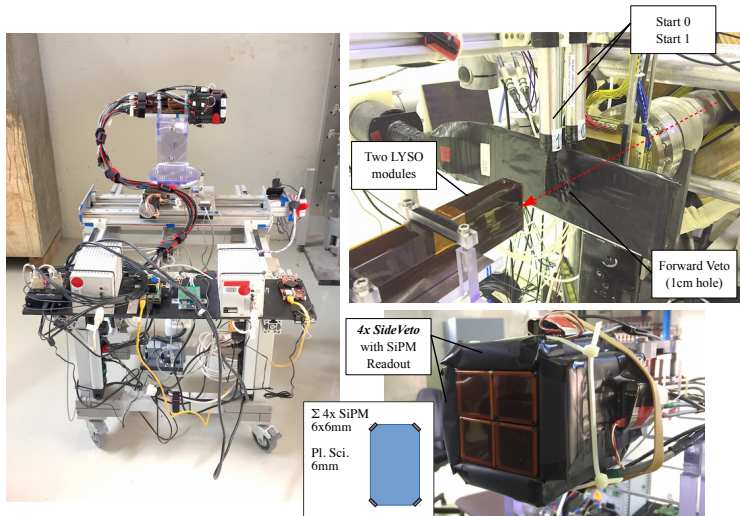
hFOM



INTERNAL POLARIMETER

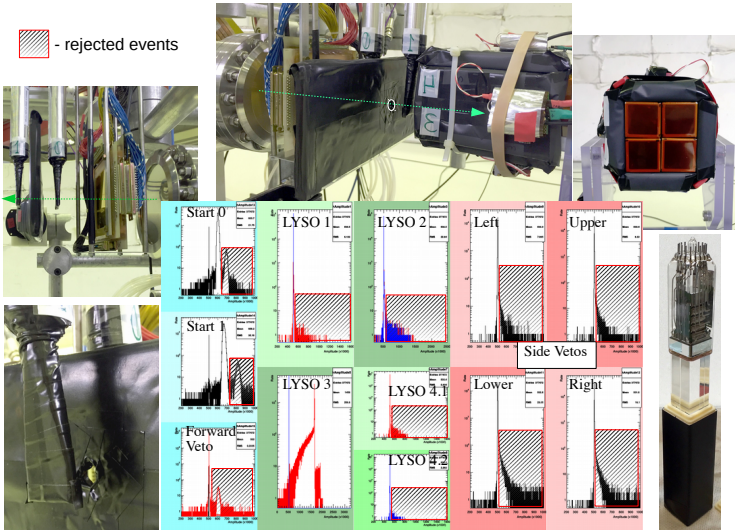


STEP 1

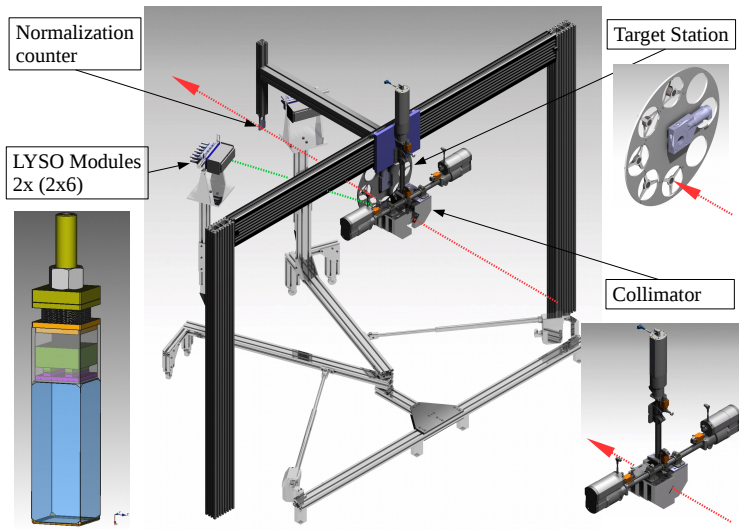


STEP 1

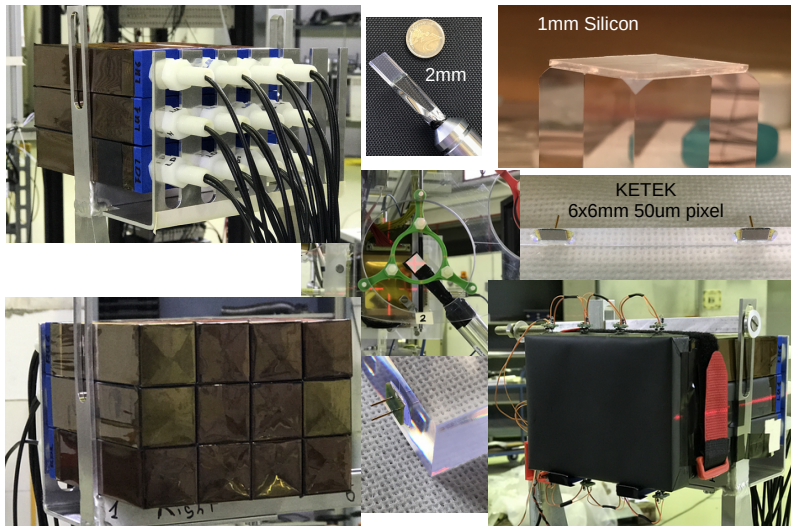
 - rejected events



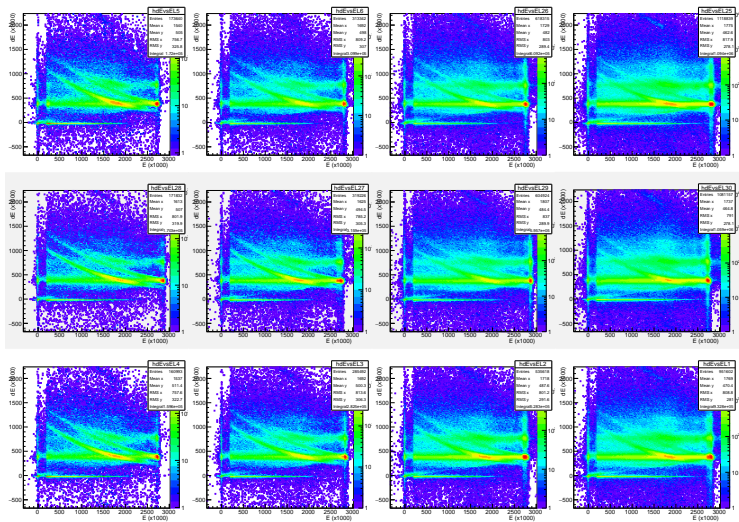
STEP 2



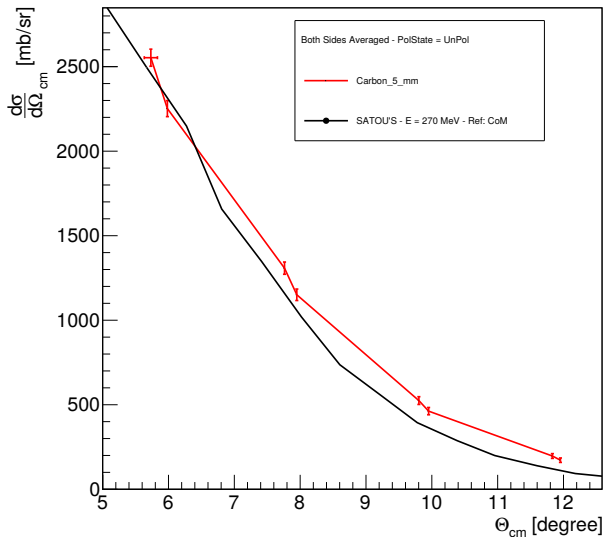
STEP 2



STEP 2

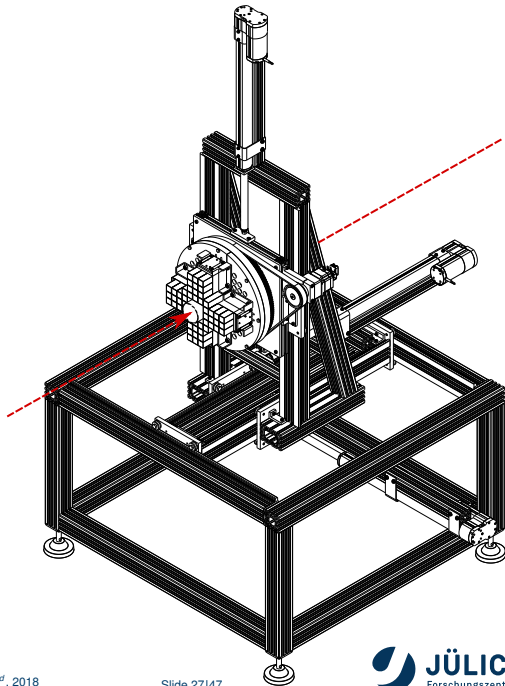
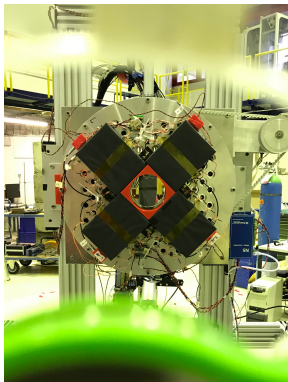


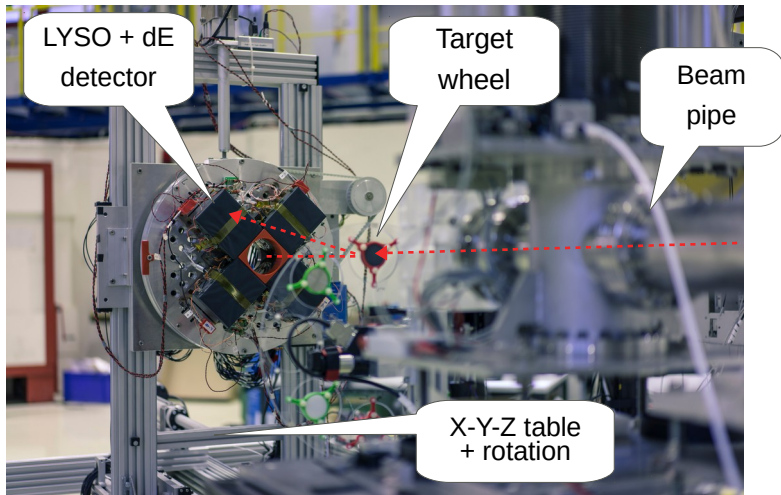
STEP 2



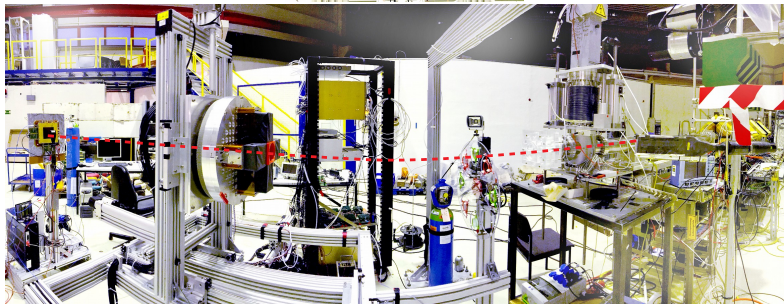
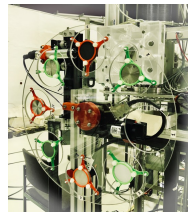
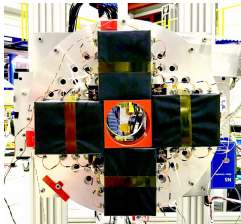
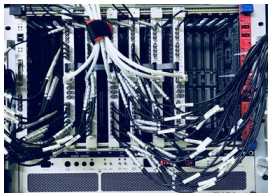
STEP 3

Test setup for polarimeter



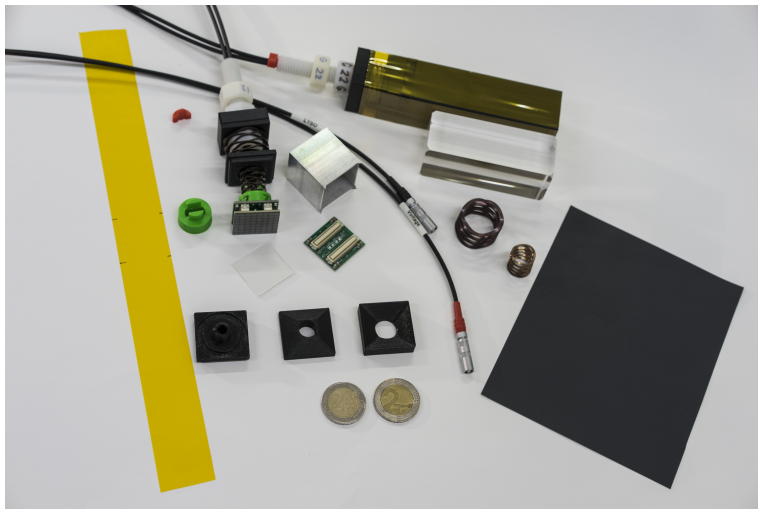


BIG KARL EXP. HALL

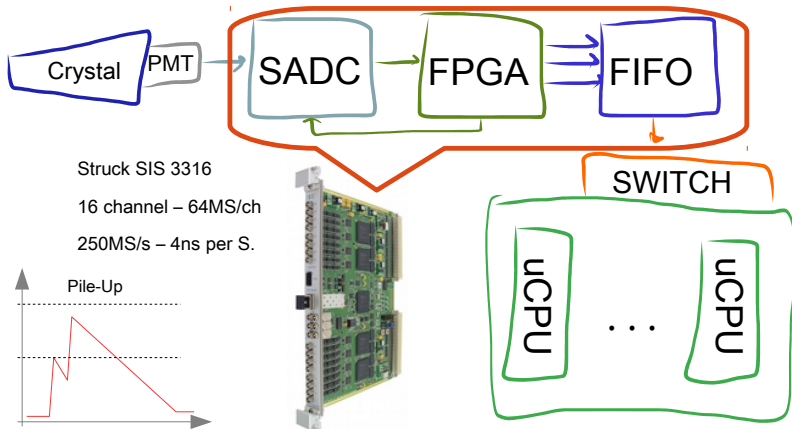


LYSO MODULE

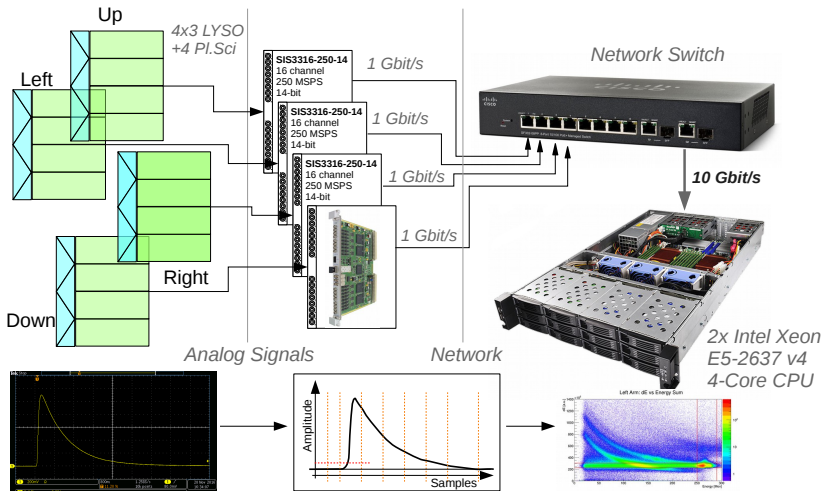
New improved mechanics and electronic components



SADC BASED DAQ SYSTEM

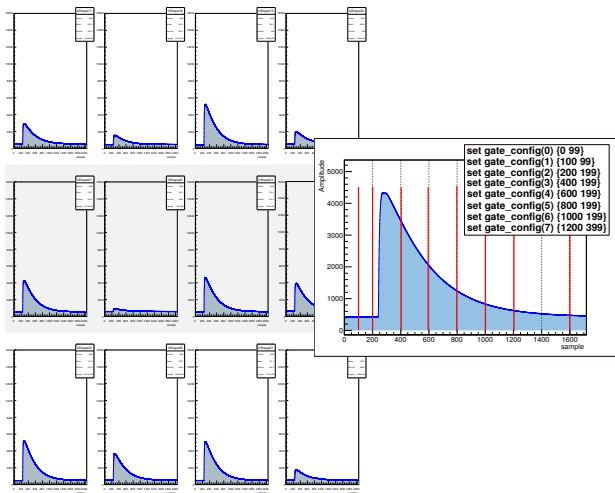


SADC BASED DAQ SYSTEM



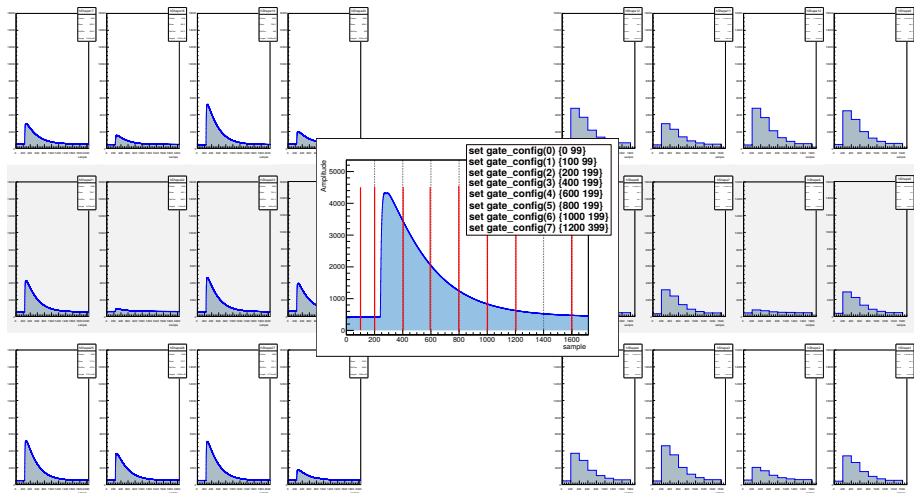
SIGNAL SHAPES

Full signal shape vs 8 accumulator/integral region



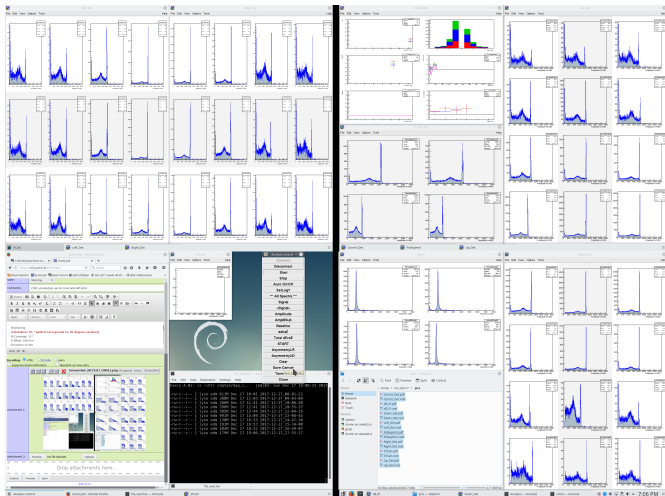
SIGNAL SHAPES

Full signal shape vs 8 accumulator/integral region

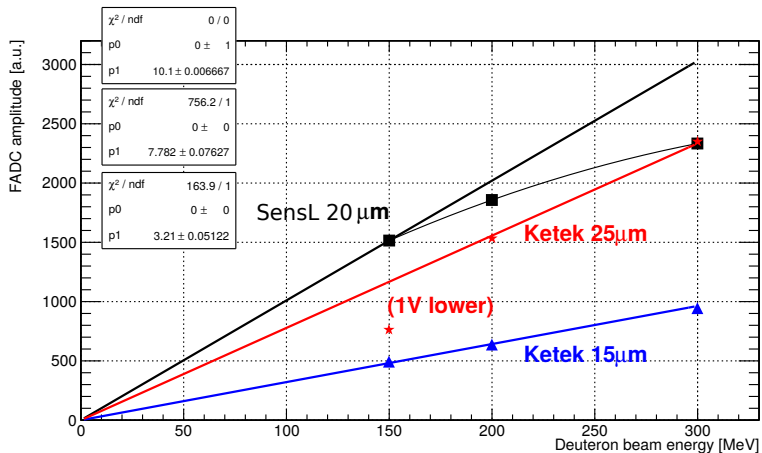


ONLINE MONITORING SYSTEM


Monitoring of all amplitudes



Comparison of different SiPM sensors



SAINT-GOBAIN PRELUDE™ 420 (LYSO)




**Next Generation
LYSO:Ce,Ca Single Crystals**

S. Bhatta¹, V. Ouspenski¹, P. Menge², K. Yang²

1. Saint-Gobain Crystals, 427-53, USA
2. Saint-Gobain Crystals, 427-53, USA

1. Saint-Gobain Crystals, 427-53, USA
2. Saint-Gobain Crystals, 427-53, USA

Context



LYSO-Ca for Position Sensitive Tomography (PST)

Crystal	Size	Length	Weight	Density	Length/Weight
LYSO	7.1	22.0 mm	400	3.700	20%
LYSO:Ca	8.3	22.0 mm	300	3.800	65 + 60%*
LYSO:Ca	7.4	22.0 mm	420	3.800	60%
LYSO:Ca	7.1	22.2 mm	420	3.800	60%*


LYSO:Ca combines interesting features:

- High density
- Stable crystal, for PSTs
- Good mechanical performance
- Good optical performance

Chosen by Catechological techniques

Possible improvements:

- Faster Delivery Time
- Lower Mitigation



Consequences of co-doping

Performance improvement:

- Higher light yield
- Higher energy resolution
- Higher temperature stability

Practical application:


- Same effort to produce same size crystal
- Higher mechanical resistance
- Charge compensation
- Temperature stability

Limits of standard co-doping

Fast crystal growth, leading to higher dislocation density and lower light yield

Possible explanation:

Proton surface defect due to too heavy dopants (Ca, Mg)



Performance improvement by increasing co-doping:

- Higher light yield
- Higher energy resolution
- Higher temperature stability

Solutions and Improvements (3rd Generation LYSO)

Optimized composition

Optimized doping and co-doping systems

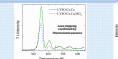
Optimizing agent (e.g. Mg) can be used during the growth

Development of a wettable salt

Compensation on the growth

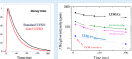
Temperature compensation

Water quality system




Performance improvement

Composition	Weighted LYSO	LYSO:Ca:Ca	LYSO:Ca:Ca
Light Yield (Photons/MeV)	20,000	20,000	20,000
Energy Resolution	10%	10%	10%
Temperature	20°C	20°C	20°C



Controlled Growth



Progressive optimization of the composition:

- High quality material with enhanced performance

Conclusions & Perspectives

Improvements and Limitations with standard co-doping:

- Improved light yield, Decay Time and Attenuation
- Reduction of Ca²⁺ on charge compensation
- Controlled co-doping leads to fast crystal growth
- A Growth Performance compromise is required

The wettable agent technique

- Reduction to growth issues with high co-doping
- Reduction of oxygen during the growth
- No significant pollution to impact crystallization
- NOV possibilities for scintillator preparation

3rd GENERATION LYSO

- Light Yield better than 20000 Ph/MeV (> 60% wt)
- Decay Time close to 30 ns (> 60% wt)
- Attenuation similar to the commercial GOS ceramics
- A NEW option for the market (PST or CT applications)


References

[1] S. Bhatta, V. Ouspenski, P. Menge, K. Yang, "Next Generation LYSO:Ce,Ca Single Crystals", 2014 IEEE NSS 427-53

Acknowledgments

© 2014 Saint-Gobain Crystals, Saint-Gobain

2014 IEEE Nuclear Science Symposium & Medical Imaging Conference
Nov. 02 - 11, 2014, Washington State Convention Center • Seattle, USA



SAINT-GOBAIN PRELUDE™ 420 (LYSO)

**Next Generation
LYSO:Ce,Ca Single Crystals**

S. Blahuta ^{1,2}, V. Ouspenski ¹, P. Menge ², K. Yang ²

¹ Saint-Gobain Research, Jülich AHEP, Jülich, Germany
² Saint-Gobain Crystals, North, CA, USA

Context

LYSO:Ce for Positron Emission Tomography (PET)

Locality	Type	Volume	Height/Width	Energy	Scatter Ratio
100	1.1	30.0 mm	400	0.025	10%
LYSO:Ce	0.7	30.0 mm	300	1.000	9%
LYSO:Ce	1.0	30.0 mm	400	0.000	9%
LYSO:Ce	1.1	30.0 mm	400	0.000	9%

LYSO:Ce combines interesting features:
 • High density
 • Suitable for PET
 • Good mechanical performance
 • Grown by Czochralski technique
 Possible improvements:
 • Faster Growth Time
 • Lower Filtration

Consequences of co-doping

Performance improvement:
 • Lower thermal expansion
 • Higher mechanical strength

Proposed explanation:
 • Lower thermal expansion due to charge compensation
 • Charge compensation
 • Lower thermal expansion

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 low density (LYSO:Ca Mg)
 • Reduced surface tension

Solutions and improvements (3rd Generation LYSO)

Optimized composition

Optimal doping and no doping systems:
 • Doping species in 3d shells need during the growth
 • Compensation in the lattice site
 • Charge compensation
 • Compensation for the growth
 • Higher quality crystals

Performance improvement

Composition	Volume [L]	LYSO:Ce [%]	LYSO:Ca [%]
LYSO:Ce	20.000	0.000	0.000
LYSO:Ca	27.000	0.000	0.000
LYSO:Ce	27.000	0.000	0.000
LYSO:Ca	27.000	0.000	0.000

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:

- Reduced light yield, decay time and afterglow
- Distribution of Ca²⁺ for charge compensation
- Uncontrolled on doping leads to fast crystal growth
- Inhomogeneous performance (compensation is required)

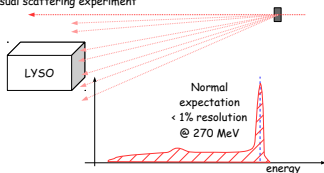
The stabilizing agent technique

- Addition to growth issues with high co-doping
- Source of oxygen during the growth
- No significant pollution to impact scintillation
- Better preparation for scintillator preparation

3rd GENERATION LYSO

- Light yield better than 40000 Ph (300% @ 400 keV)
- Decay time close to 30 ns @ 400 keV
- Behavior similar to the commercial GSO scintillator
- 3d shell option for the fastest PET or CT systems

a) Usual scattering experiment



**Next Generation
LYSO:Ce,Ca Single Crystals**

S. Blahuta¹, V. Ouspenski¹, P. Menge², K. Yang²

¹ Saint-Gobain Prelude, ² Jülich Forschungszentrum

Context

LYSO:Ca for Positron Emission Tomography (PET)

Property	Value	Unit	Value	Unit	Value	Unit
Length	7.1	35.8 mm	400	0.025	100%	300 mm
LuP:Ca	8.7	35.8 mm	300	1.000	9%	60 - 400 mm
LYSO:Ca	2.6	35.8 mm	400	0.000	9%	60 - 400 mm
LYSO:Ca	7.1	35.8 mm	400	0.000	9%	60 - 400 mm

LYSO:Ca combines interesting features:
 • High density
 • Suitable for PET, SPECT
 • Good scintillation performance
 • Grown by Controlled Growth technique

Possible Impurities:
 • Fluorine
 • Oxygen
 • Lead
 • Strontium

Consequences of co-doping

Performance improvement:
 • Increased light yield
 • Improved energy resolution
 • Improved timing resolution

Proposed explanation:
 • Increased light yield due to charge recombination
 • Improved energy resolution due to charge recombination
 • Improved timing resolution due to charge recombination

Limits of standard co-doping:
 • Uncontrolled co-doping content
 • Bad crystal growth leading to spiral shape
 • Checks more likely to occur

Possible explanation:
 • Reduced surface tension due to low density (Lu:Ca Mg)

Solutions and improvements (3rd Generation LYSO)

Optimized composition

Optimal doping and no-doping systems:
 • Optimizing doping in 3rd Gen LYSO to avoid being the growth agent
 • Optimizing the Lu:Ca ratio
 • Optimizing the Lu:Ca ratio
 • Optimizing the Lu:Ca ratio

Performance improvement

Composition	Yield (1000)	Energy Res. (%)	Timing Res. (ps)
LYSO:Ca	20.000	12.000	300.000
LYSO:Ca	27.000	10.000	270.000
LYSO:Ca	30.000	9.000	250.000
LYSO:Ca	35.000	8.000	230.000

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:

- Increased light yield, Energy Time and alignment
- Distribution of Ca for charge compensation
- Uncontrolled on doping leads to bad crystal growth
- A distribution performance compromise is required

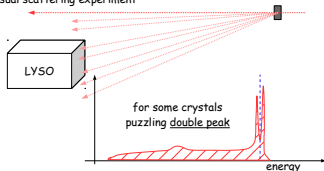
The stabilizing agent technique

- Addition to growth issues with high co-doping
- Source of oxygen during the growth
- No significant pollution to impact scintillation
- Better preparation for excellent preparation

3rd GENERATION LYSO

- Light yield better than 30000 Ph (3000 Ph)
- Energy Time Res. to 30 Ph (30 Ph)
- Alignment similar to the commercial LYSO crystals
- A better option for the market (PET or CT systems)

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!

**Next Generation
LYSO:Ce,Ca Single Crystals**

S. Blahuta^{1*}, V. Ouspenski¹, P. Menge², K. Yang²

¹ Saint-Gobain Prelude, ² Jülich Research Centre

Context

Locality	Type	Volume	Height/Width	Energy	Scatter Ratio
100	100 mm	400	800	120%	100%
LYSO:Ce	8.7	35.8 mm	300	1.000%	9%
LYSO:Ce	2.6	23.8 mm	420	1000%	9%
LYSO:Ce	1.1	12.2 mm	420	1000%	9%

LYSO:Ce for Positron Emission Tomography (PET)

LYSO:Ce combines interesting features:
 • High density
 • Suitable μ_{att} for PETs
 • Good scintillation performance
 • Grown by Controlled Growth technique

Possible Impairments:
 • Pulse Decay Time
 • Laser Filtration

Consequences of co-doping

Limits of standard co-doping

Optimized composition

Composition	Yielded Crystals	LYSO:Ce	LYSO:Ce:Ca
LYSO:Ce	20/200	100%	0%
LYSO:Ce:Ca	27/27	0%	100%
LYSO:Ce:Ca	0/30	0%	100%

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:

- Increased light yield, decay time and afterglow
- Introduction of Ca²⁺ for charge compensation
- Uncontrolled on-doping leads to laser crystal growth
- Ca²⁺ distribution performance a compromise to require

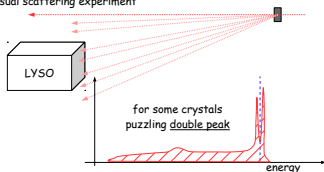
The stabilizing agent technique

- Addition to growth issues with high co-doping
- Source of oxygen during the growth
- No significant pollution to impact scintillation
- Better perspective for scintillation performance

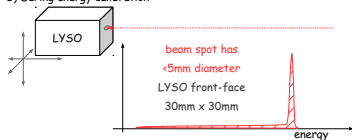
3rd GENERATION LYSO

- Light yield better than 40000 Ph (MPP) (400 keV)
- Decay time lower to 34 ns (400 keV)
- Afterglow similar to the commercial GSO scintillator
- 0.8 MPP option for the standard PET or CT systems

a) Usual scattering experiment



b) During energy calibration



**Next Generation
LYSO:Ce,Ca Single Crystals**

S. Blahuta¹, V. Ouspenski¹, P. Menge², K. Yang²

¹ Saint-Gobain Prelude, ² Jülich Research Centre

Context

Locality	Type	Volume	Height/Width	Energy	Scatter Ratio
LYSO	0.1	20.0 mm	400	0.025	10%
LYSO:Ce	0.1	20.0 mm	300	1.000	9%
LYSO:Ce,Ca	0.1	20.0 mm	400	0.025	9%
LYSO:Ce,Ca	0.1	20.0 mm	400	0.025	9%

LYSO:Ce conditions including features: High density, Outstanding Transparency for PMTs, Good mechanical performance, Grown by Controlled Growth technique.

Consequences of co-doping

Property	LYSO:Ce	LYSO:Ce,Ca
Light Yield	~20,000	~25,000
Decay Time	~40 ns	~45 ns
Scatter Ratio	~9%	~9%

Performance improvement: Higher light yield, shorter decay time, stable performance over time.

Solutions and improvements (3rd Generation LYSO)

Optimized composition

Optimized doping and no-doping systems, Optimizing optical and thermal properties, Minimizing impurities, Optimizing growth conditions.

Performance improvement

Property	Standard LYSO	LYSO:Ce	LYSO:Ce,Ca
Light Yield	~20,000	~25,000	~25,000
Decay Time	~40 ns	~45 ns	~45 ns
Scatter Ratio	~9%	~9%	~9%

Conclusions & Perspectives

Improvements and Limitations with standard co-doping:

- Highly dependent on growth conditions
- Unstable light yield, decay time and scatter ratio
- Unstable performance over time

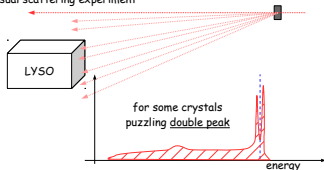
The stabilizing agent technique:

- Reduction to growth issues with high co-doping
- Stabilization of growth conditions
- No significant pollution to impact scintillation
- Highly reproducible for scintillator production

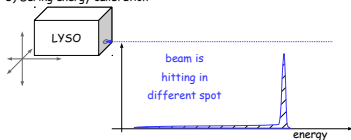
3rd GENERATION LYSO:

- Light yield better than standard PMT (LYSO:Ce)
- Stable time decay to 30 ns @ 400 MHz
- Stable performance over time
- Highly reproducible for scintillator production

a) Usual scattering experiment



b) During energy calibration



SAINT-GOBAIN CRYSTALS

Next Generation LYSO:Ce,Ca Single Crystals

S. Blahuta¹, V. Ouspenski¹, P. Menge², K. Yang²

¹ saib@stg.com

1 Saint-Gobain Recherche, 42050 PRELUDE, FRANCE
2 Saint-Gobain Crystals, 14010 St. Quentin, USA

Context

LYSO:Ce for Positron Emission Tomography (PET)

Locality	Type	Volume	Height/Width	Energy	Scatter Ratio
100	10	10.0 mm	400	0.025	10%
LYSO:Ce	8.7	10.0 mm	300	1.000	9%
LYSO:Ce	2.0	10.0 mm	400	0.000	9%
LYSO:Ce	1.1	10.0 mm	400	0.000	9%

LYSO:Ce combines interesting features:
 • High density
 • Suitable ρ_{refr} for PMTs
 • Good scintillation performance
 • Grown by Controlled Growth technique

Possible Improvements:
 • Faster Decay Time
 • Lower Afterglow

Consequences of co-doping

Performance improvement:
 • Higher light yield
 • Lower afterglow
 • Higher energy resolution

Proposed explanation:
 • Lower defect trapping sites
 • Higher recombination efficiency
 • Charge compensation
 • Lower self-absorption

Limits of standard co-doping:
 • Uncontrolled co-doping content
 • Bad crystal growth leading to spiral shape
 • Checks more likely to succeed

Possible explanations:
 • Reduced surface stresses due to low density (LYSO:Ce Mg)
 • Reduced surface stresses due to low density (LYSO:Ce Mg)

Solutions and improvements (3rd Generation LYSO)

Optimized composition

Optimized doping and no-doping systems:
 • Optimizing doping by ICP-MS
 • Optimizing doping by XRF
 • Optimizing doping by FTIR
 • Optimizing doping by Raman
 • Optimizing doping by EPR
 • Optimizing doping by UV-Vis
 • Optimizing doping by XPS

Performance improvement

Composition	Decay Time	Energy Res.	Light Yield
LYSO:Ce	40 ns	12%	30,000
LYSO:Ce,Ca	30 ns	10%	40,000
LYSO:Ce,Ca,Mg	25 ns	8%	50,000
LYSO:Ce,Ca,Mg	20 ns	6%	60,000

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:

- Reduced light yield, decay time and afterglow
- Distribution of Ca²⁺ for charge compensation
- Uncontrolled co-doping leads to bad crystal growth
- Inhomogeneous performance (composition is required)

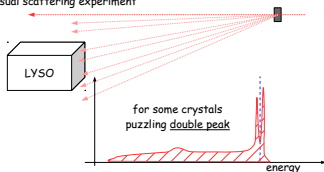
The stabilizing agent technique

- Addition to growth issues with high co-doping
- Source of oxygen during the growth
- No significant pollution to impact scintillation
- Better preparation for excellent preparation

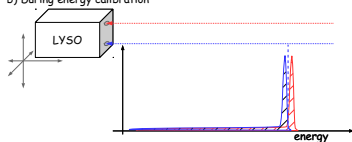
3rd GENERATION LYSO

- Light yield better than 40000 Ph (30 Ph (1) 400 Ph (1))
- Decay time lower than 40 ns (1) 400 Ph (1)
- Energy resolution better than 10% (1) 400 Ph (1)
- 4-8 MeV option for the medical PET or CT systems

a) Usual scattering experiment



b) During energy calibration



Peak is front face position dependent!
 Is it also energy dependent?
 not really...

SAINT-GOBAIN PRELUDETM 420 (LYSO)

**Next Generation
LYSO:Ce,Ca Single Crystals**

S. Blahuta¹, V. Ouspenski¹, P. Menge², K. Yang²

¹ stg@stg.com | ² yangk@slac.stanford.edu

Context

Locality	Type	Volume	Yield/Year	Energy	Scatter Ratio
USA	US	20.0 mm	400	0.025	10%
LuP:Ca	0.2	20.0 mm	300	1.000	9%
LYSO	2.0	20.0 mm	400	0.000	9%
LYSO:Ce	0.1	20.0 mm	400	0.000	9%

LYSO:Ce for Positron Emission Tomography (PET)

LYSO:Ce combines interesting features:
 • High density
 • Outstanding τ_{decay} for PETs
 • Good scintillation performance

Grown by Controlled Growth technique

Possible Improvements:
 • Faster Decay Time
 • Lower Afterglow

Consequences of co-doping

Limits of standard co-doping

Performance improvement

Controlled Growth

Optimized composition

Conclusions & Perspectives

Improvements and Limitations with standard co-doping:

- Reduced light yield, decay time and afterglow
- Introduction of Ca²⁺ for charge compensation
- Uncontrolled on-doping leads to fast crystal growth
- Ca²⁺ distribution performance compromise to require it

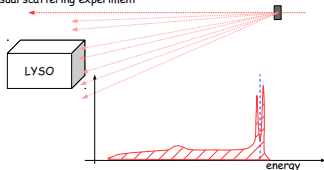
The stabilizing agent technique

- Addition to growth results with high co-doping
- Increase of oxygen during the growth
- No significant pollution to impact scintillation
- 100% possibilities for excellent preparation

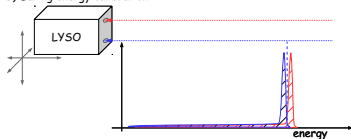
3rd GENERATION LYSO

- Light yield better than 20000 Ph (MPP) @ 662 keV
- Decay Time lower to 34 ns @ 662 keV
- Afterglow similar to the commercial GSO crystals
- 0.800 option for the standard PET or CT systems

a) Usual scattering experiment



b) During energy calibration



c) Different hypotheses

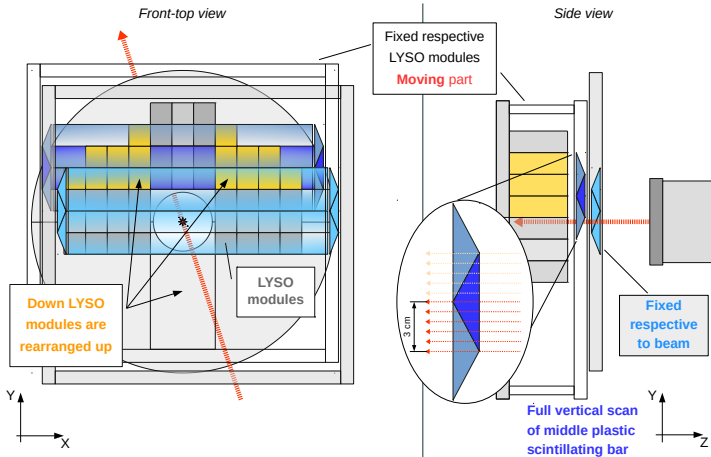


We spend <3 days of March beam time
to clarify this problem
very successfully!

We measured 2D maps for all crystals at
150, 200, 300 MeV

PLASTIC SCINTILLATOR TRACKER

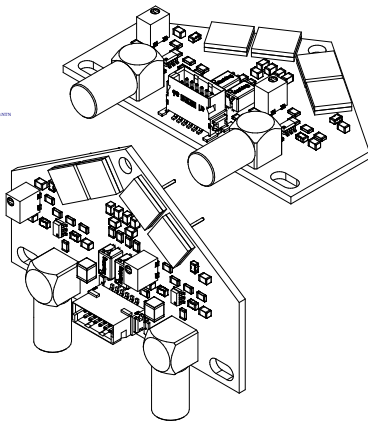
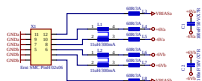
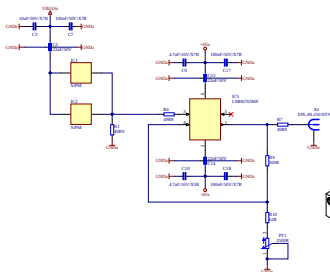
Consisting of the overlapping triangular scintillator bars. The upstream (forward) frame is installed to be fixed vertically relative to the beam while the downstream (backward) frame can scan the beam. All scintillators were scanned vertically and horizontally (along the bar).



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



PLASTIC SCINTILLATOR TRACKER

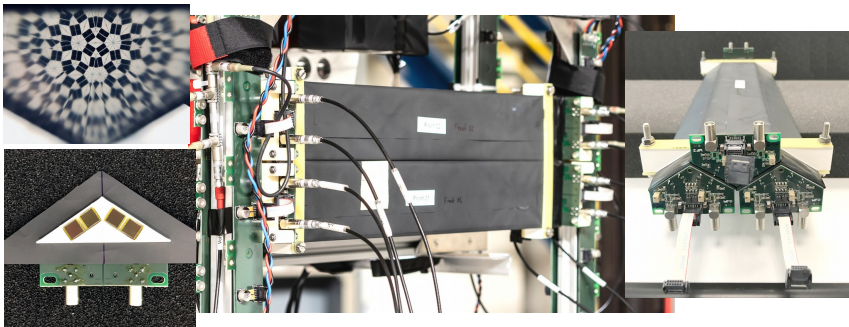
Left-up: the view through the wrapped triangular scintillator bar where the kaleidoscopic picture of the SiPM's is seen from another end.

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.

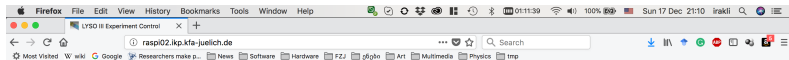
Right: one of the layers with three bars after assembly.

Each counter has 4 independent preamplifier output, 2 each end, and eight $6 \times 6 \text{ mm}$ SiPM's four each end.



SLOW CONTROL SYSTEM

Controls all movements



LYSO III Experiment Status

Actuators

α-Rotation: online
 Start Counter: online
 Target Driver: online
 X-Axis: online
 Y-Axis: online
 Z-Axis: online

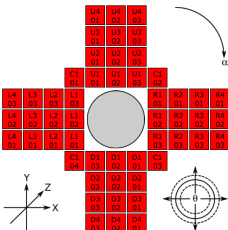
Positioning

α-Rotation: 55 °
 Θ-Coverage: 15 °
 X-Offset: 299 mm
 X-Position: 0 mm
 Y-Offset: 268 mm
 Y-Position: 0 mm
 Z-Offset: 0 mm
 Z-Position: 0 mm

Target

Active Target: Silicon
 Start Counter
 Status: out of the beam
 Voltage: 0 V

Position Control



Position Control

Θ-Coverage: [-] Set

X-Position: [-] Set

Y-Position: [-] Set

Z-Position: [-] Set

Target Control

Empty Target	Nickel
Carbon	Tin
Aluminum	Silicon
Magnesium	Polyethelene

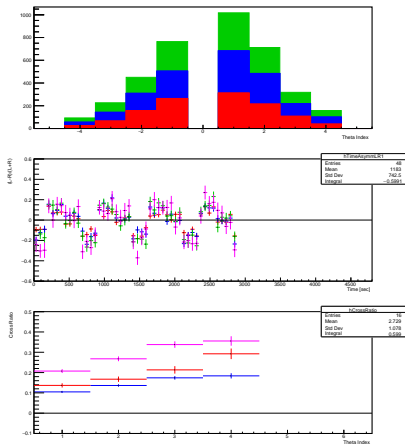
Start Counter

Position: Move Start Counter In

Voltage: [-] Set

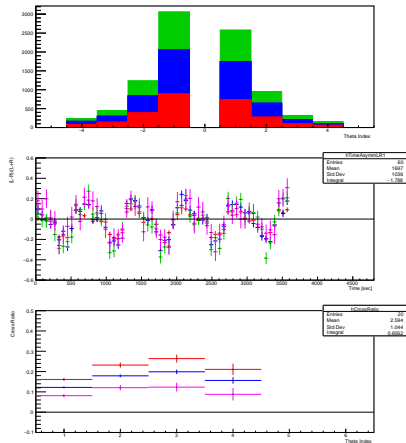
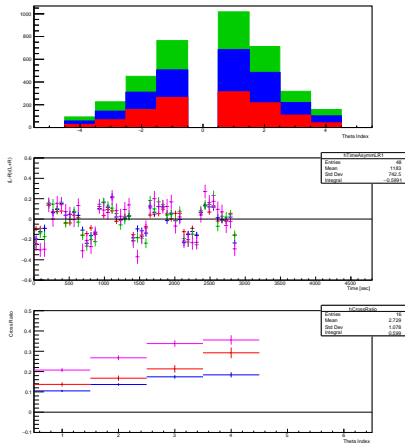
ASYMMETRY

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



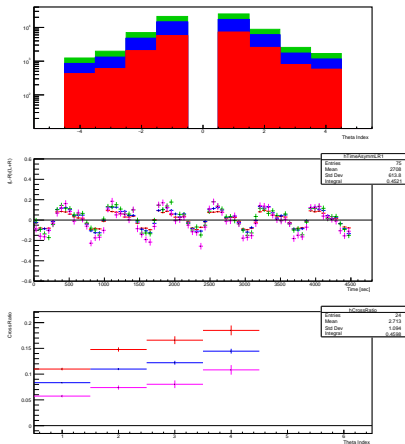
ASYMMETRY

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



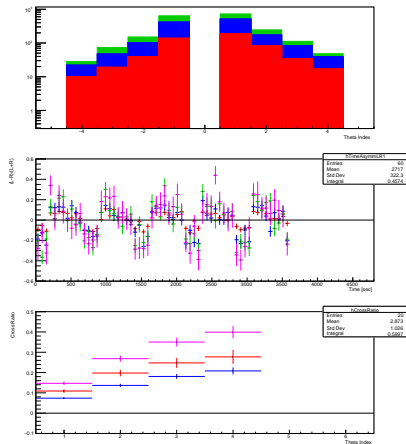
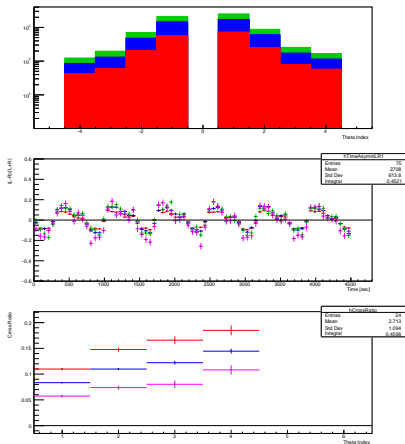
ASYMMETRY

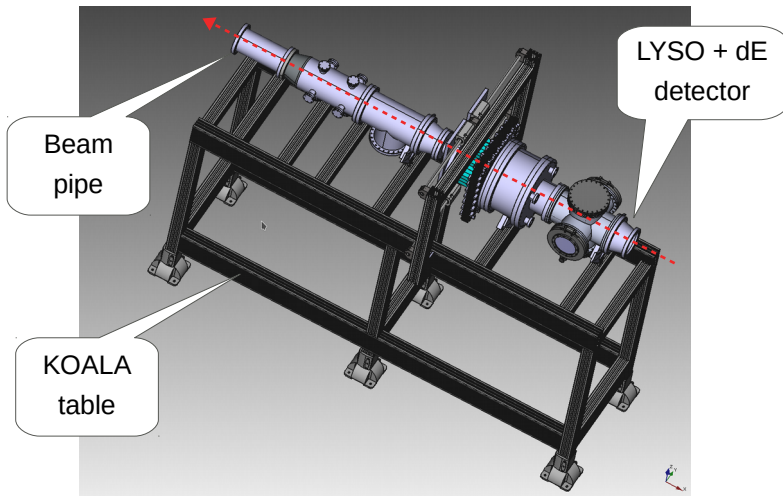
Different target materials (left Nickel; right Tin)

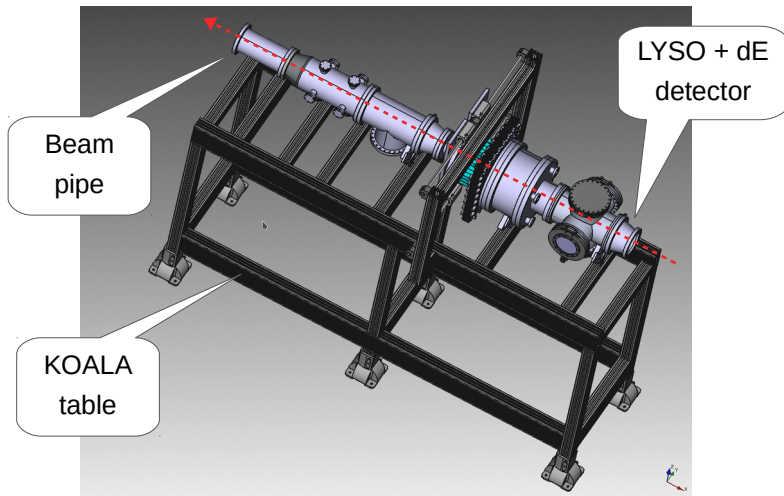


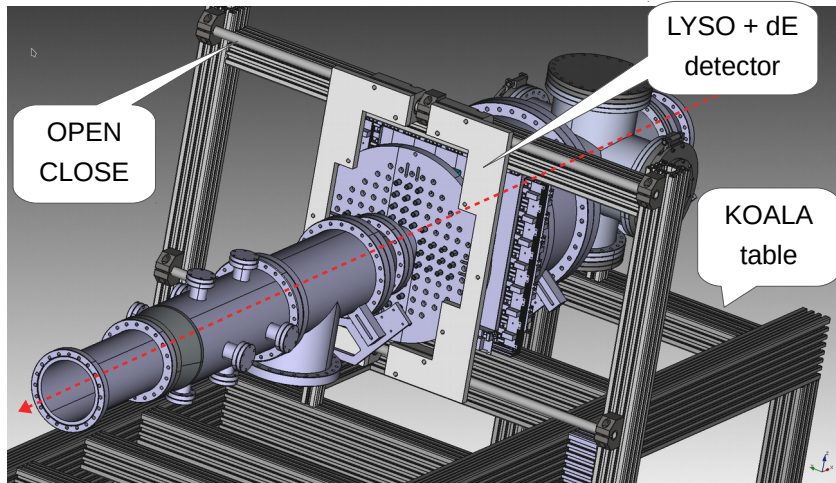
ASYMMETRY

Different target materials (left Nickel; right Tin)









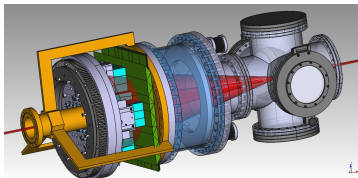
ACKNOWLEDGMENT

People contributing to the experiment

- Mechanics: N. DeMary, M. Maubach, G. D'Orsaneo & D. Spölgem
- Electronics: Tanja Hahnrahts-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**



Appendix

CONTACT

Contacting me via e-mail

Click here: i.keshelashvili@fz-juelich.de

GENERAL FORMALISM

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

$$\sigma^{\text{pol}}(\theta, \phi) = \sigma_0(\theta) \left[1 + \frac{3}{2} PA_y(\theta) \cos \phi + \left\{ \frac{1}{3} \sum P_{ij} A_{ij} \right\} \right]$$

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

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

