ECal R&D for STAR Upgrade

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Acknowledgement:

EIC generic R&D program, DOE, US

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Hadron Physics Workshop@DKU, August 5th, 2015

Outline

- Physics introduction
- eRHIC and eSTAR
- EM Calorimeter R&D
  - W powder
  - BSO
- Summary

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- eRHIC and eSTAR
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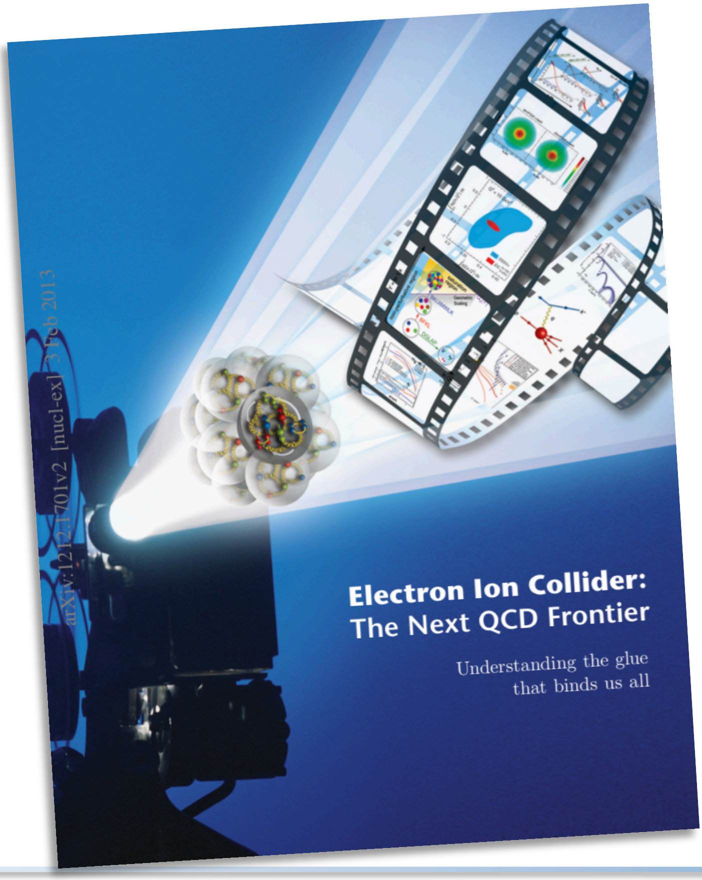
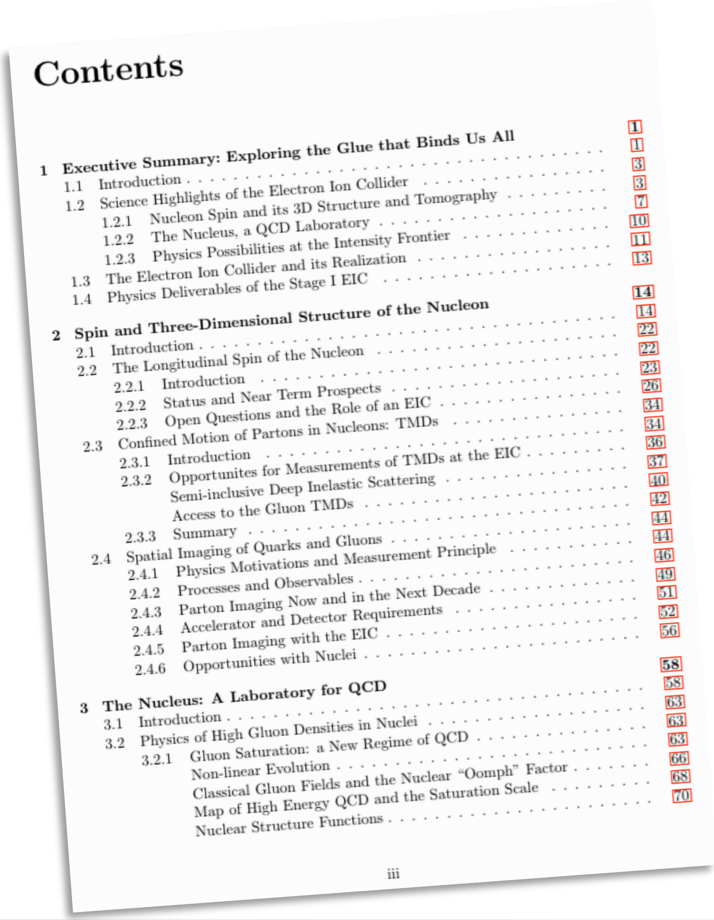
Introduction

Physics of electron–ion collision (EIC):

- Nucleon spin and its 3D structure and tomography.
- The nucleus, a QCD laboratory.
- Physics possibilities at the intensity frontier.
- …



arXiv: 1212.1701



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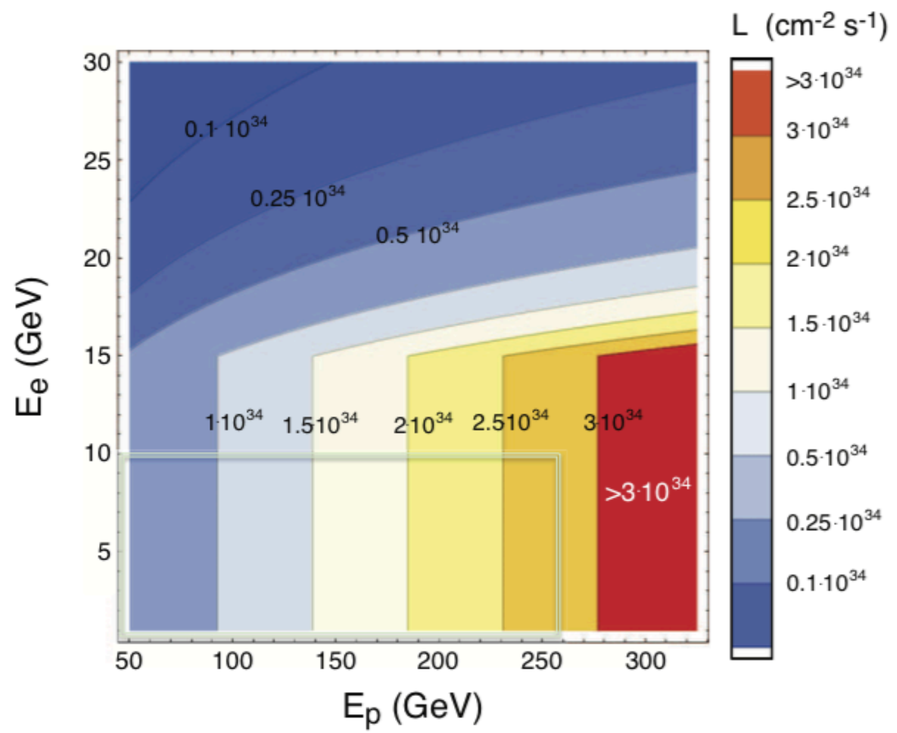
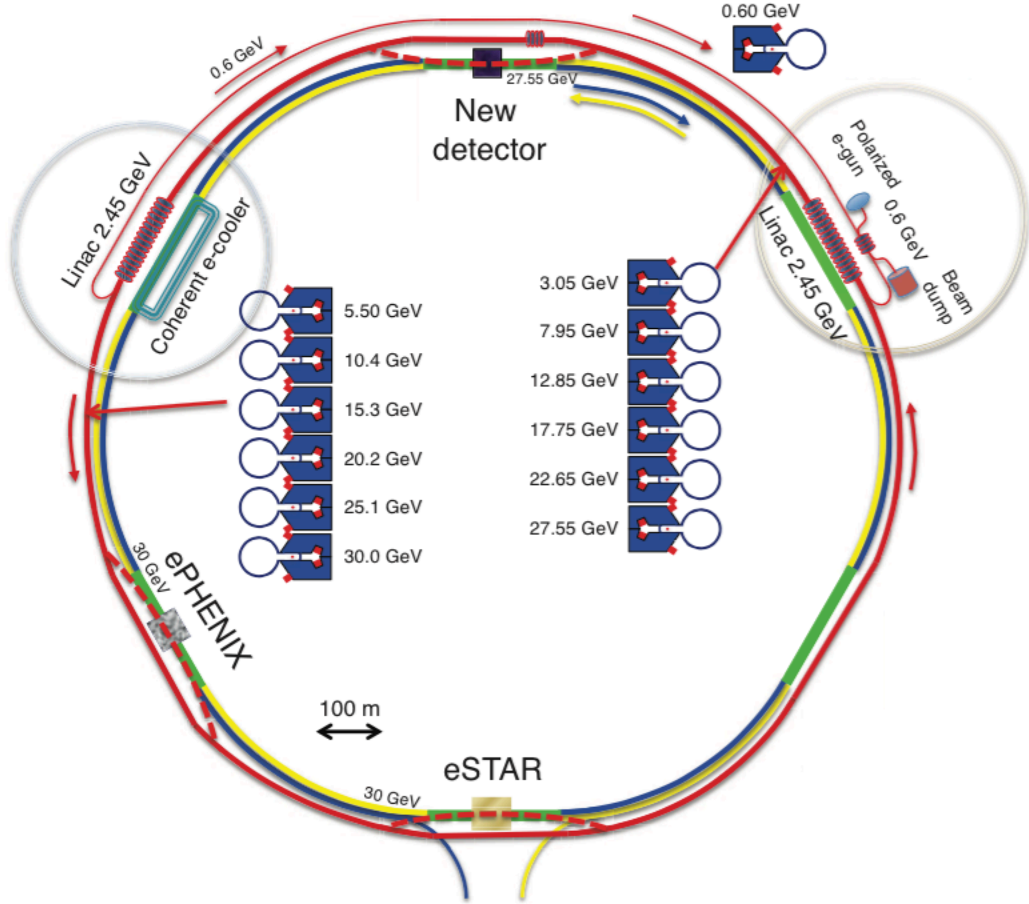
eRHIC

eRHIC is a future EIC based on existing RHIC.

- Add a polarized electron beam (ERL) up to 30 GeV.
- Existing polarized proton beam up to 250 GeV.
- Au/U up to 200 GeV/u.
- Luminosity ~ 10^{34} $cm^{-2}s^{-1}$.





eSTAR

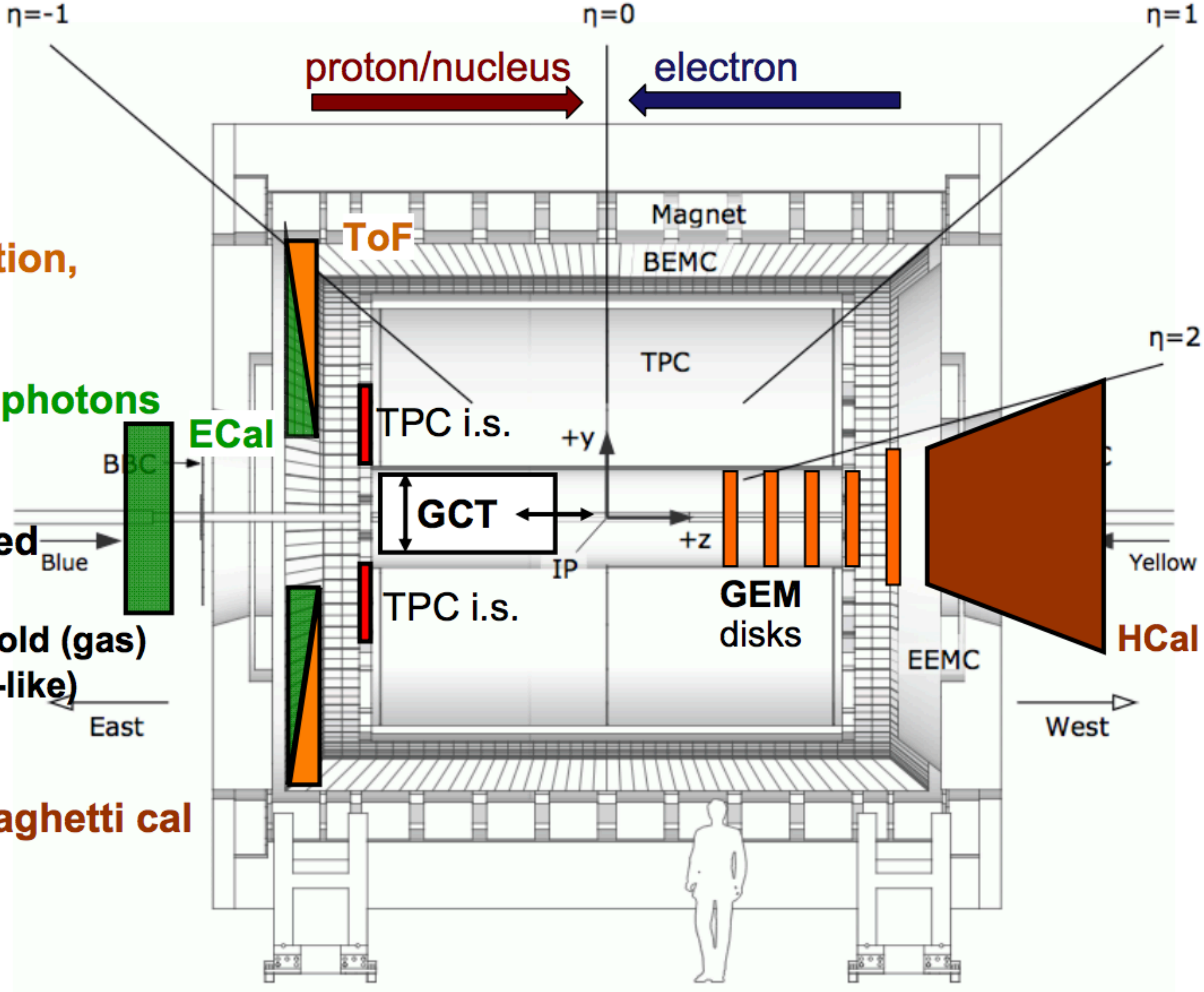
eSTAR is an upgrade for EIC based on existing STAR detector.

ToF: π , *K* identification, t_0, electron

ECal: electrons and photons

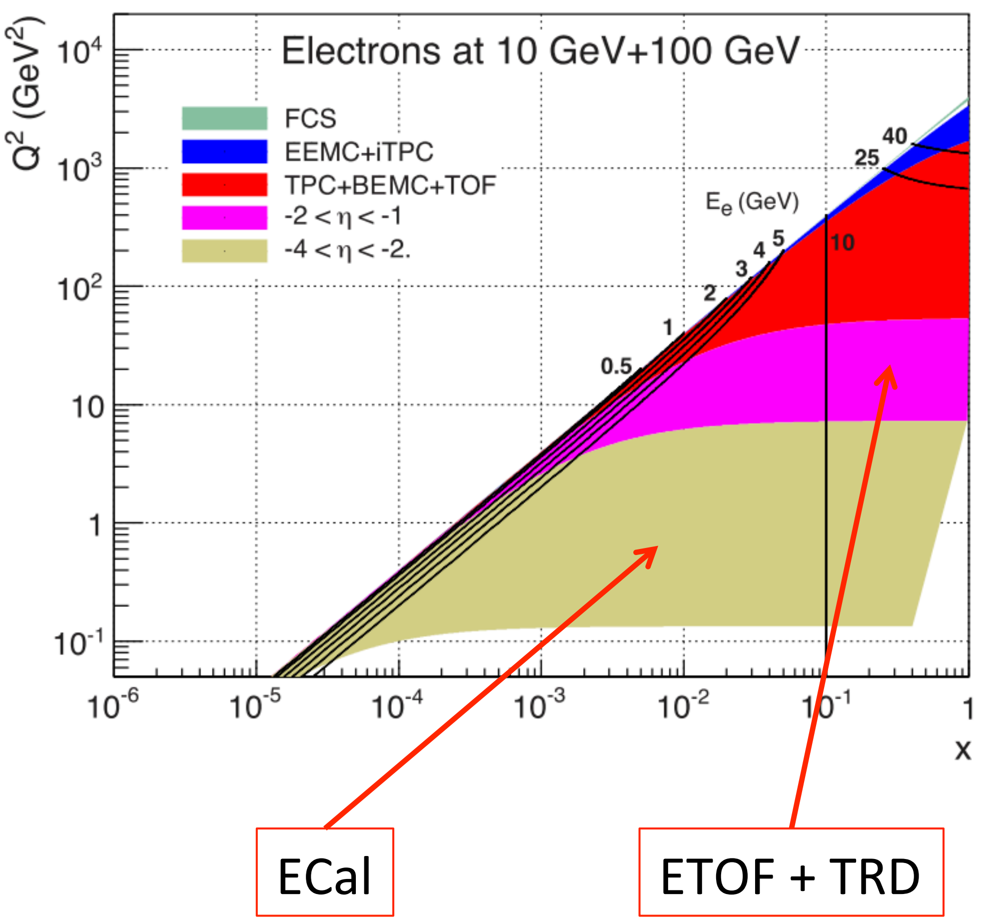
GCT: a compact tracker with enhanced electron capability
- **Combine high-threshold (gas) Cherenkov with TPC(-like) tracking**

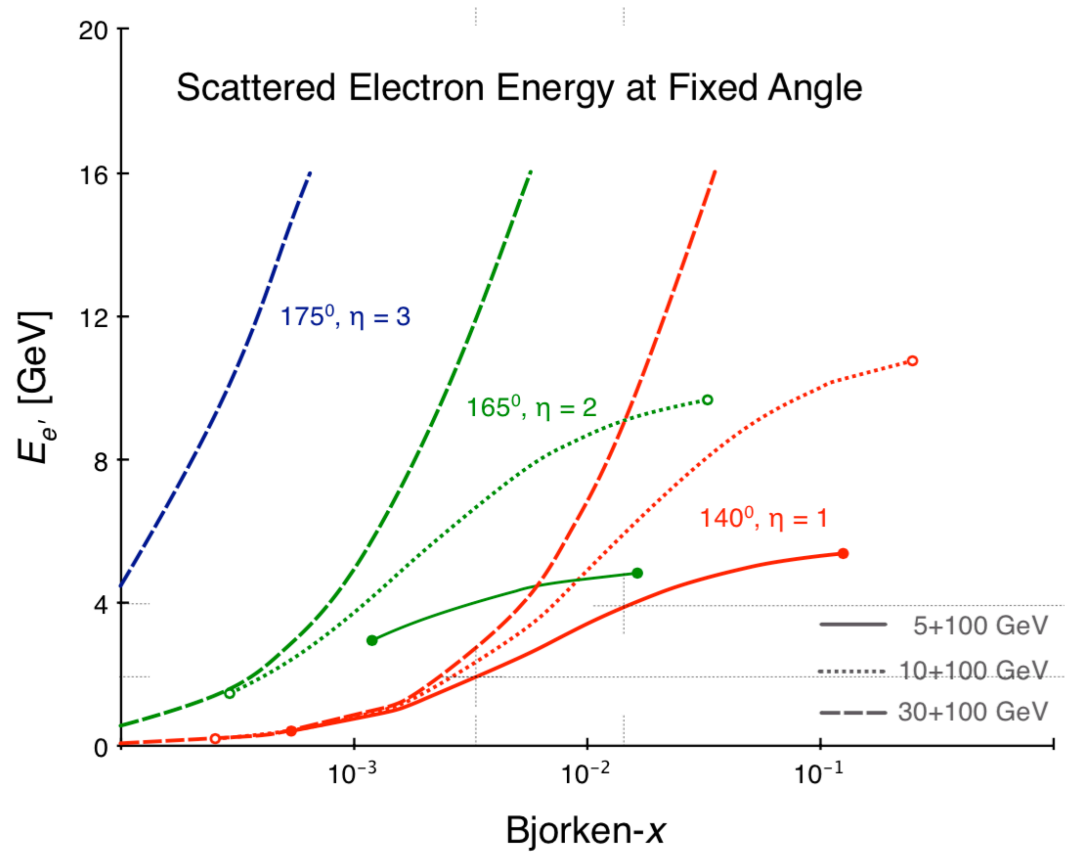
HCal: W powder, spaghetti cal



eSTAR acceptance

- Forward ECal is crucial to extend the acceptance towards low x region.
- Very good energy resolution is required.





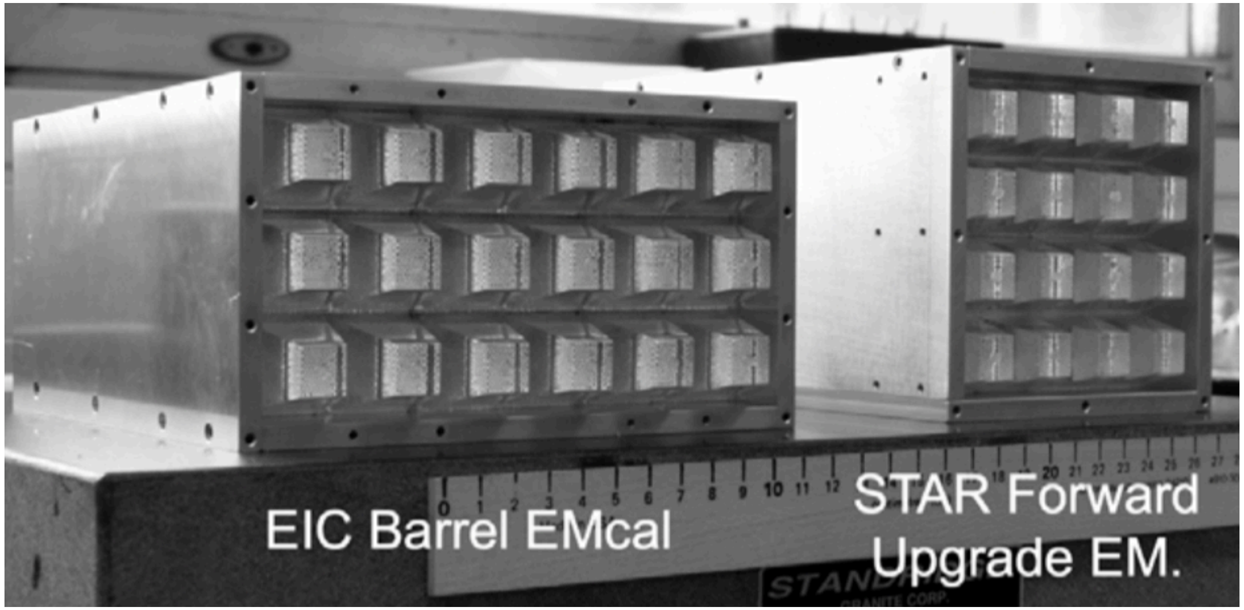
$$\sigma_E / E = 2\% / \sqrt{E} \oplus 0.75\%$$

Tungsten Powder Calorimeter

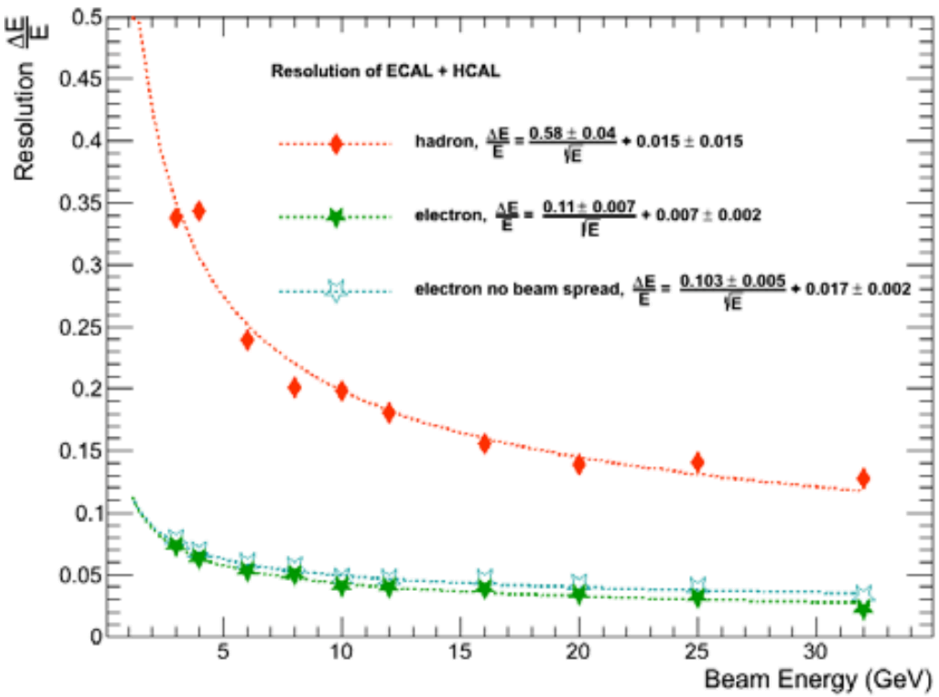
Test the limit of the technology of W powder SPACAL type detector.

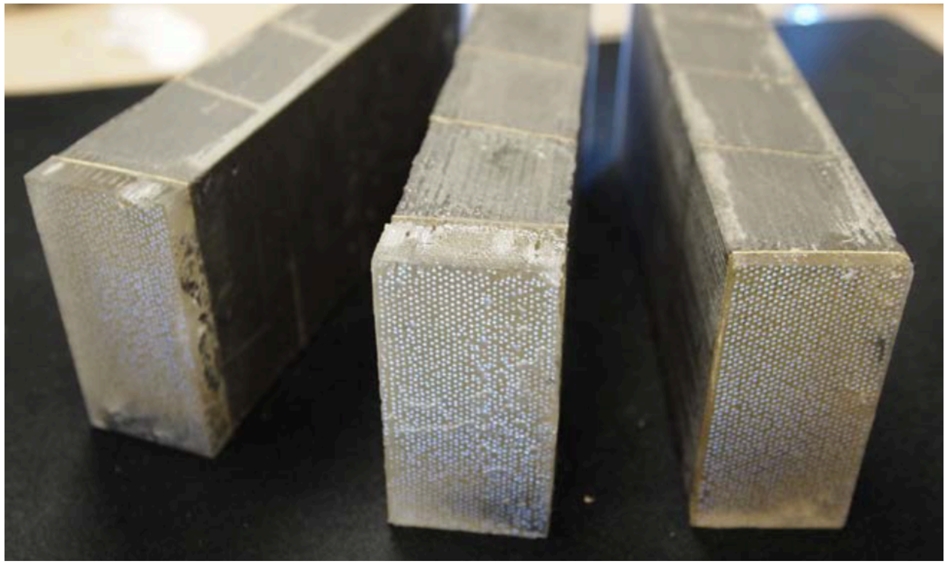
Application of SiPM/MPPC readout.

Achieve good energy resolution.



W powder SPACAL at UCLA by H. Huang and O. Tsai



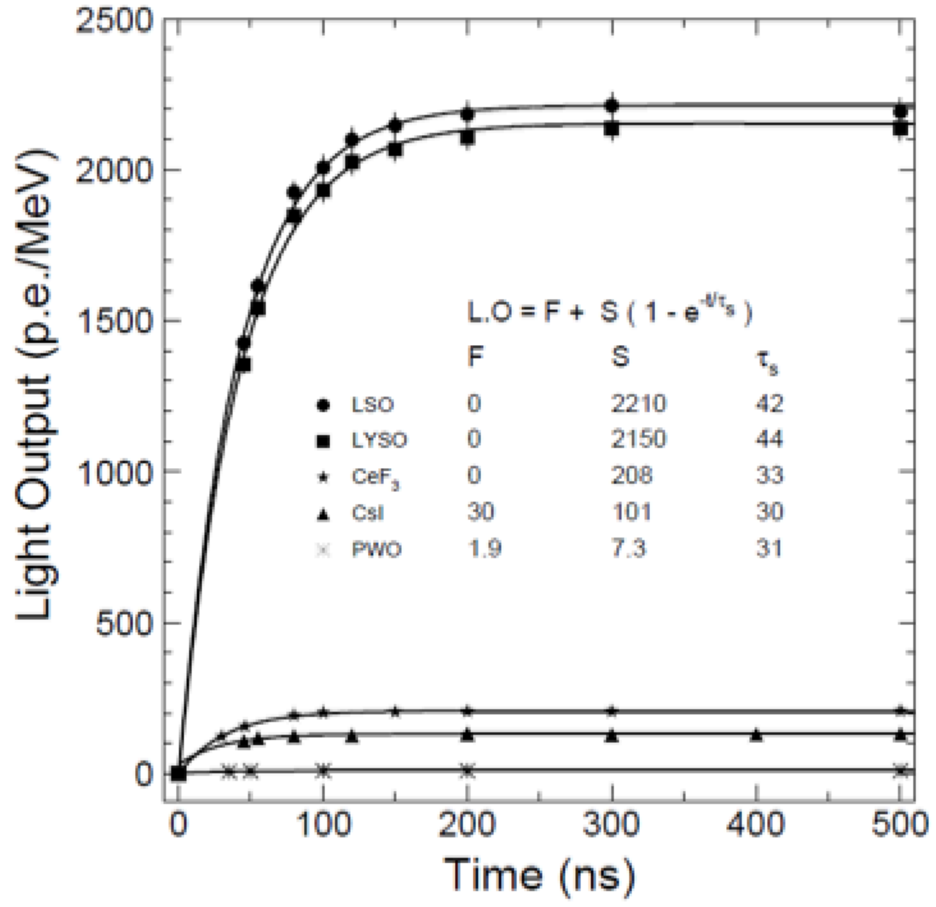


W powder SPACAL module at BNL by C. Woody

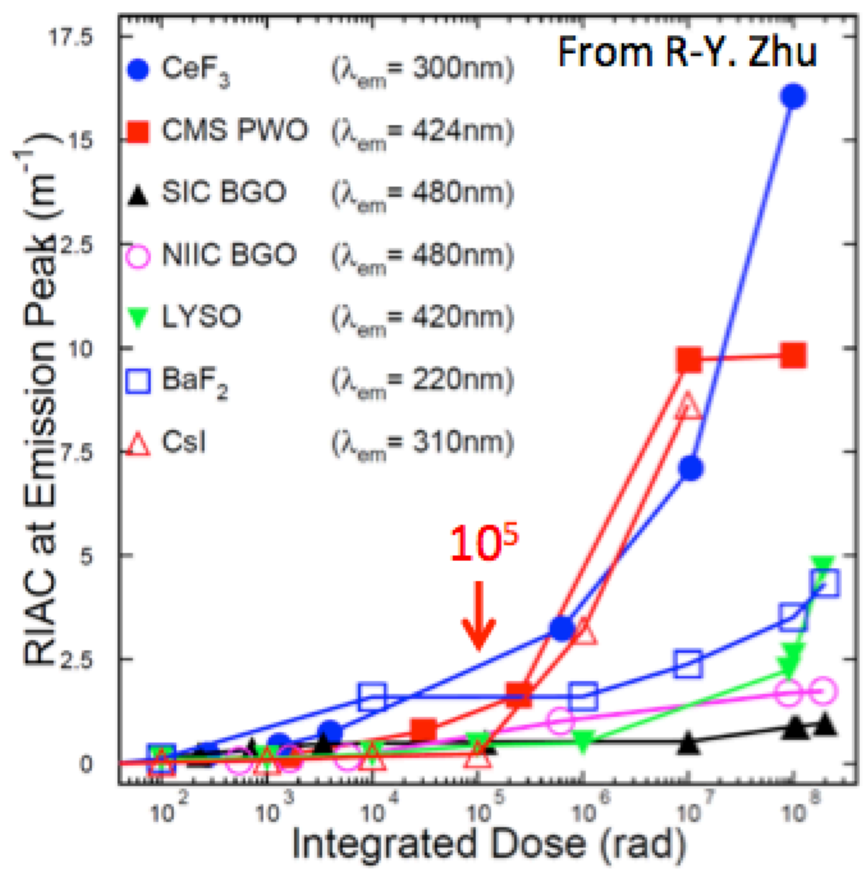
Crystal options

Crystal	CsI(Tl)	CsI	BaF_2	CeF_3	BGO	BSO	$PbWO_4$	LYSO(Ce)
Density (g/cm^3)	4.51	4.51	4.89	6.16	7.13	6.8	8.3	7.40
Melting Point (°C)	621	621	1280	1460	1050	1030	1123	2050
Radiation Length (cm)	1.86	1.86	2.06	1.70	1.12	1.15	0.89	1.14
Molière Radius (cm)	3.57	3.57	3.10	2.41	2.23	2.2	2.0	2.07
Interaction Len. (cm)	39.3	39.3	30.7	23.2	22.7	23.1	20.7	20.9
Refractive Index [a]	1.79	1.95	1.50	1.62	2.15	2.06	2.2	1.82
Hygroscopicity	Slight	Slight	No	No	No	No	No	No
Luminescence [b] (nm) (at peak)	550	420 310	300 220	340 300	480	480	425 420	420
Decay Time [b] (ns)	1220	30 6	650 0.9	30	300	100 26,2.4	30 10	40
Light Yield [b,c] (%)	165	3.6 1.1	36 4.1	7.3	21	3.4 0.5/0.25	0.30 0.077	85
d(LY)/dT [b] (%/ °C)	0.4	-1.4	-1.9 0.1	0.05	-0.9	-2.0	-2.5	-0.2
Radiation hardness (rad)	10^3	10^{4-5}	10^{6-7}	10^{6-7}	10^{5-6}	10^{6-7}	10^{6-7}	10^8
Experiment	CLEO BABAR Belle BES III	KTeV, E787	TAPS		L3 BELLE		CMS ALICE PANDA	

Crystal options



L. O for fast crystals.

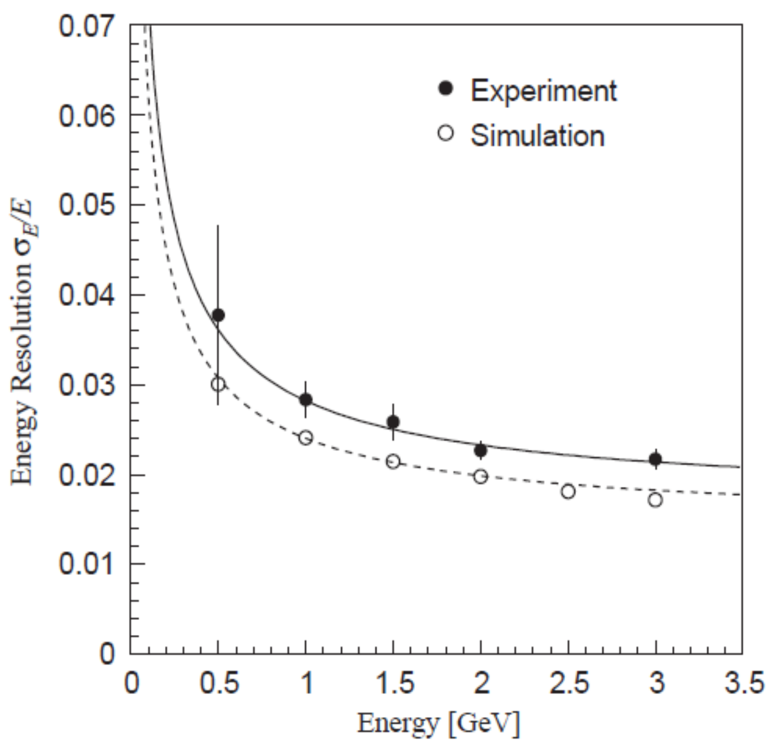


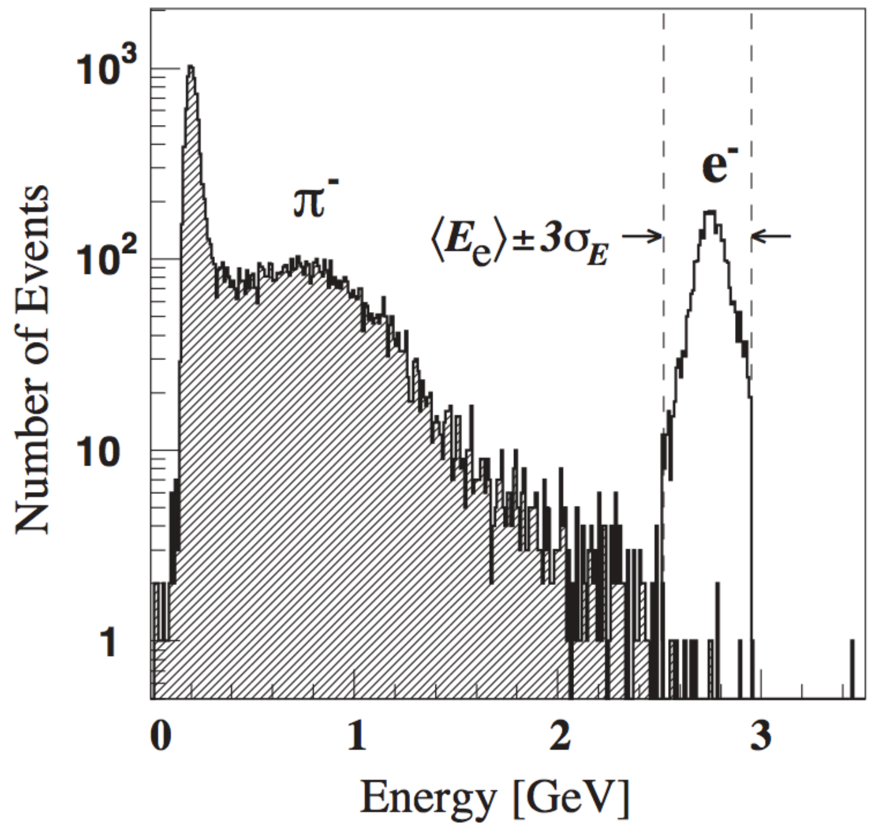
Radiation Induced Absorption Coefficient

- LYSO is the best choice except the price (~40$/cc).
- BGO is good but slow, PWO is fast but radiation hardness is poor.
- BSO is in between, need further development.

BSO crystal

- Si to replace Ge in the BGO. Potential to reduce cost.
- x5 light yield output of PWO-II.
- Radiation hardness needs more study.



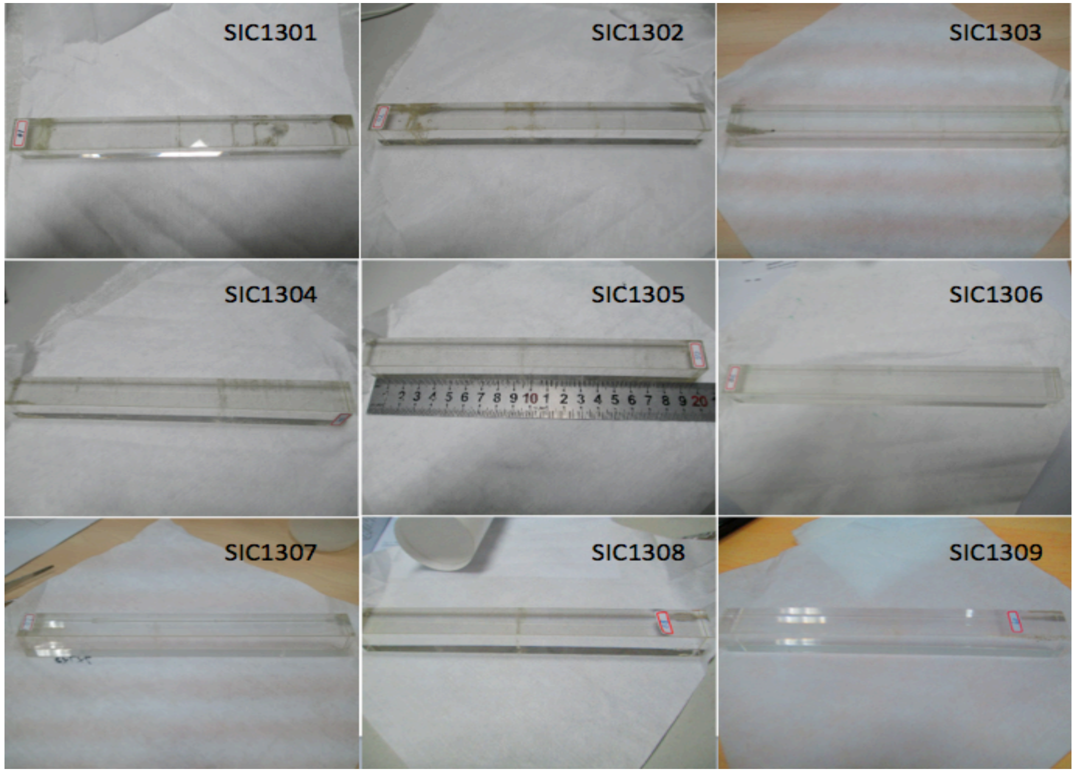


2-3 GeV electron -> 2-3% energy resolution. Nice pi/e separation at a few GeV.

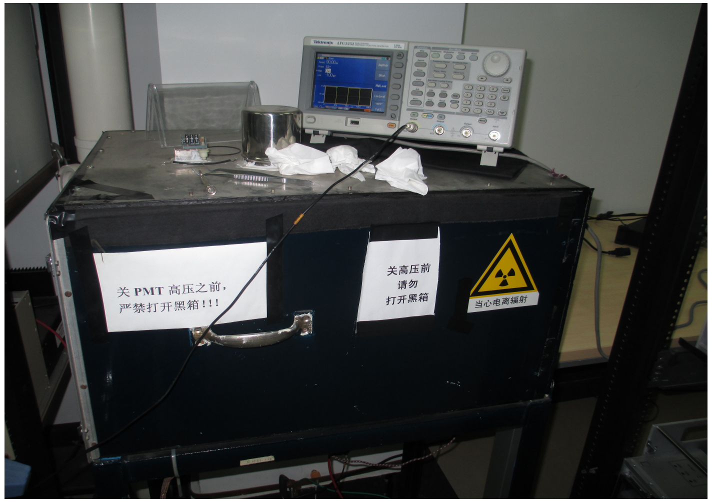
H. Shimizu, et al., NIM A**550** (2005) 258.

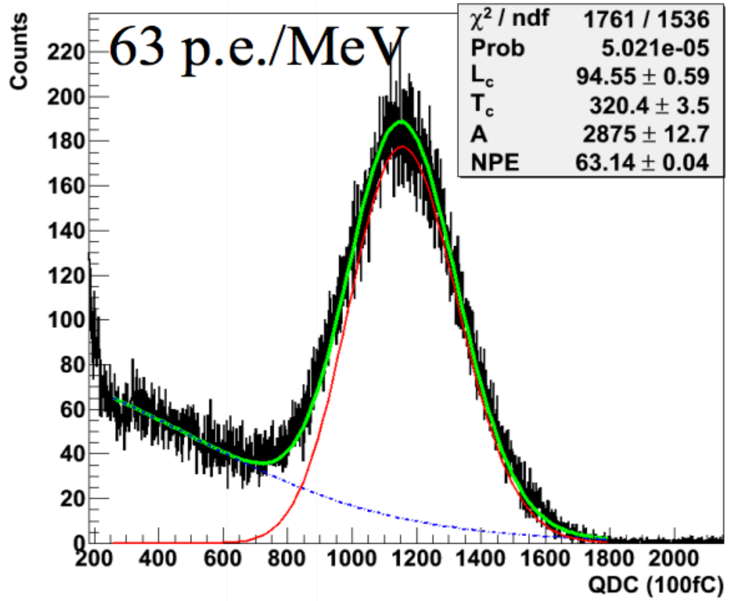
BSO-ECal R&D at USTC

- BSO technology is far from mature.
- Has never been used in large physics experiment facility.
- Relative low cost (similar as PWO).
- Nice cooperation with SICCAS.
- Involved in some projects, e.g. Generic EIC program from US, HIEPA ECal R&D …



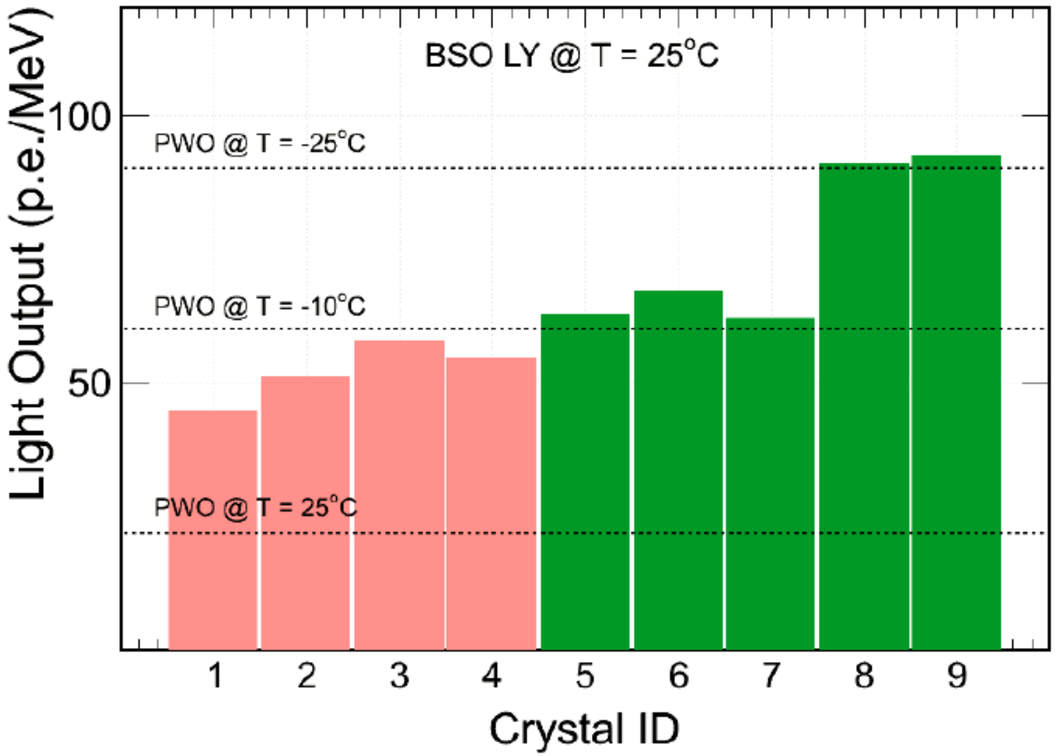
Crystal test system

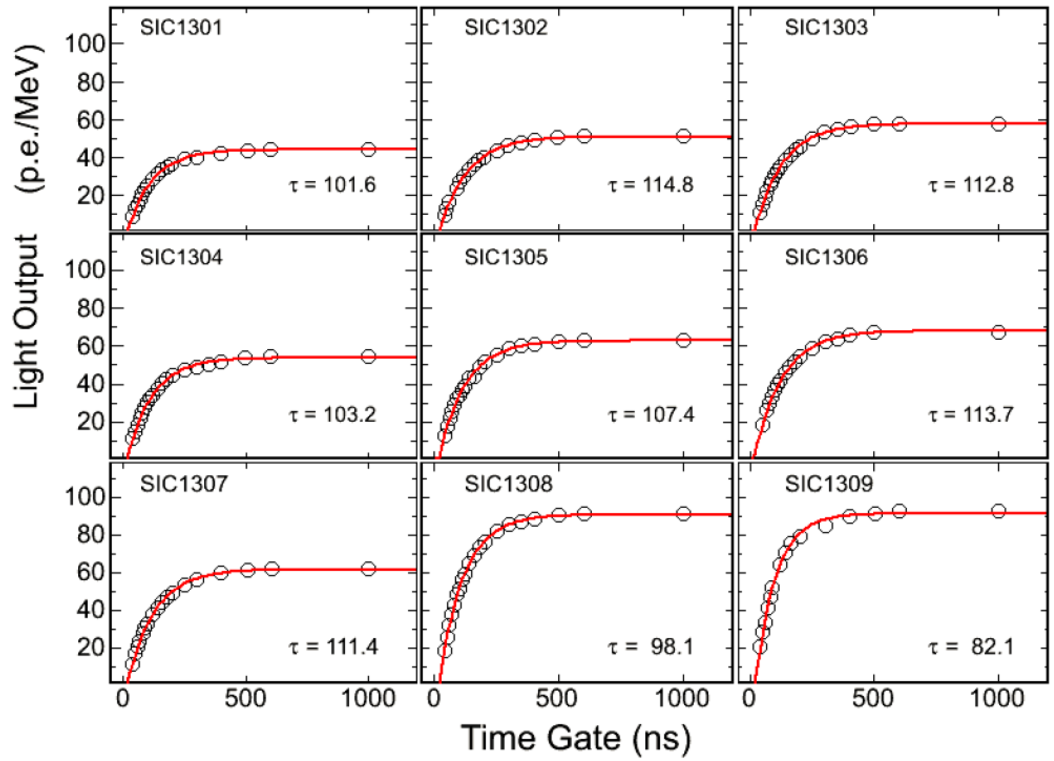




oscilloscope

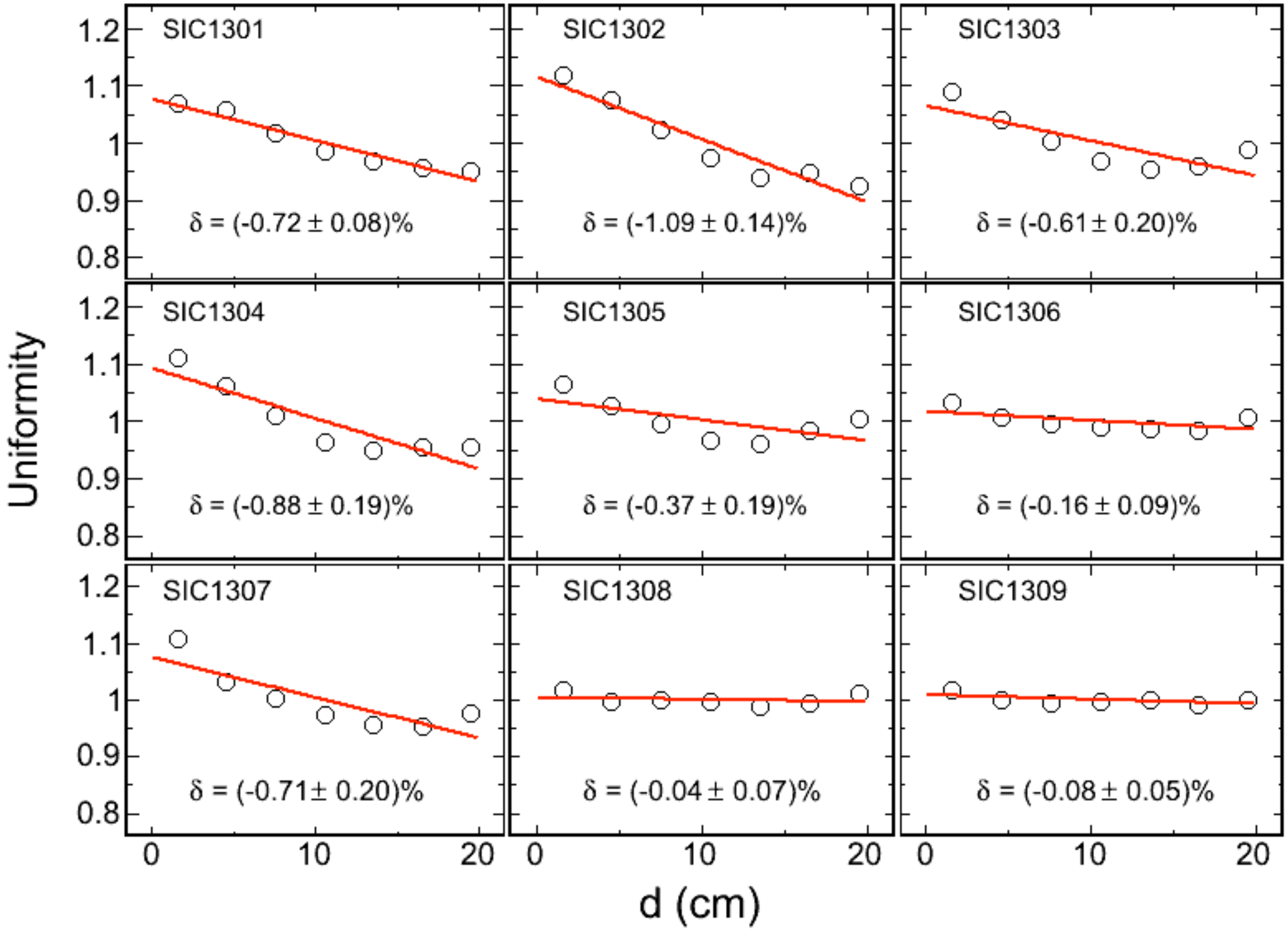
Progress on the growth



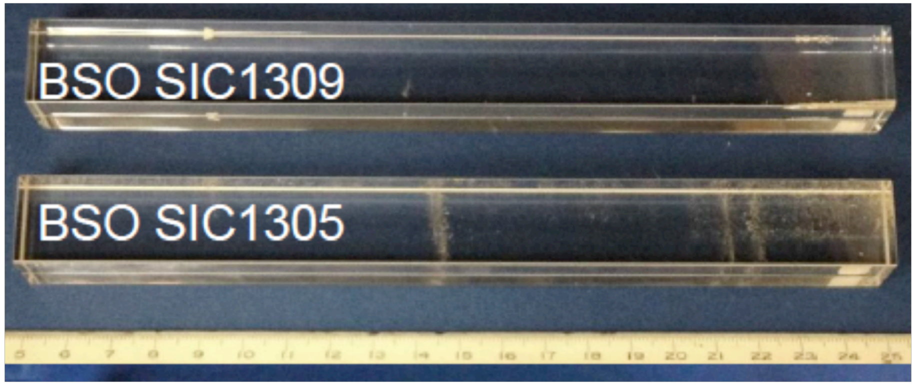


- ~100ns decay time, relative fast.
- LY improved and achieve the level of PWO at -25°C.
- An increase trend can be seen from the development.

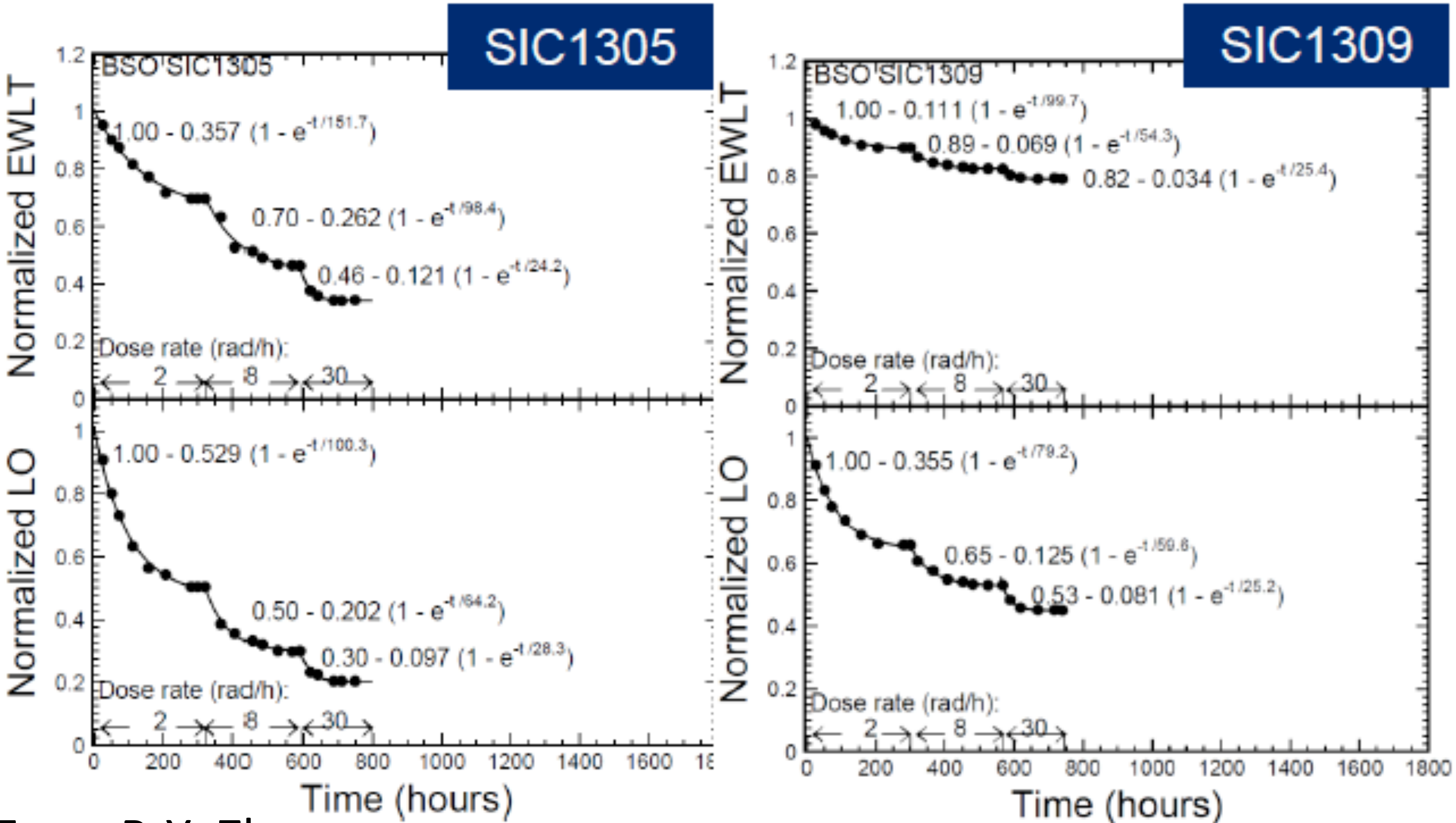
Uniformity


SIC1301
δ = (-0.72 ± 0.08)%
SIC1302
δ = (-1.09 ± 0.14)%
SIC1303
δ = (-0.61 ± 0.20)%
SIC1304
δ = (-0.88 ± 0.19)%
SIC1305
δ = (-0.37 ± 0.19)%
SIC1306
δ = (-0.16 ± 0.09)%
SIC1307
δ = (-0.71± 0.20)%
SIC1308
δ = (-0.04 ± 0.07)%
SIC1309
δ = (-0.08 ± 0.05)%
Uniformity
1.2
1.1
1
0.9
0.8
0
10
20
d (cm)

Radiation test at CalTech



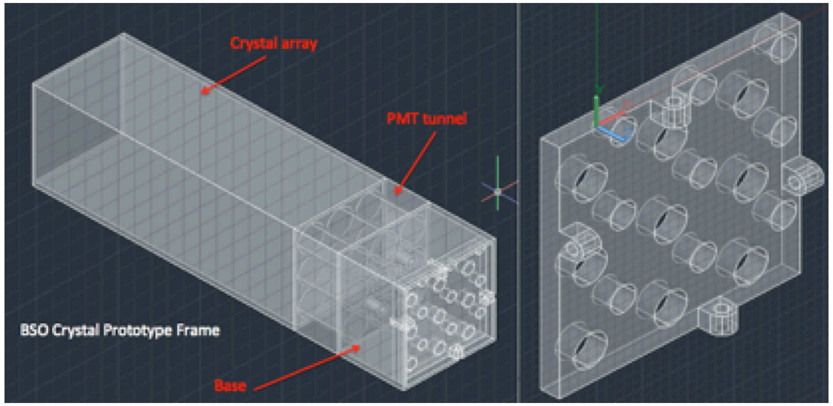
$$EWLT = \frac{\int LT(\lambda)Em(\lambda)d\lambda}{\int Em(\lambda)d\lambda}$$

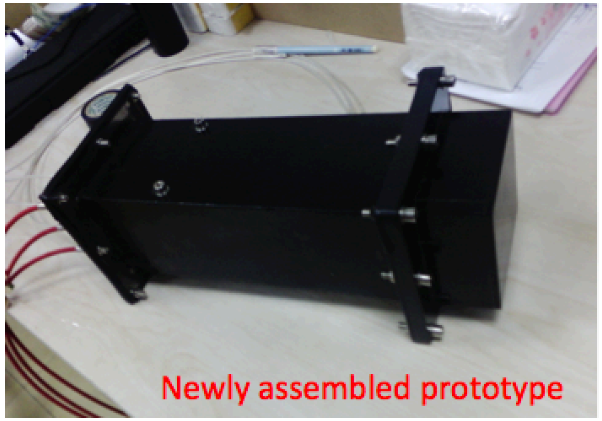


- ❑ Does rate dependence
- ❑ Both EWLT and LO saturate after long time exposure.
- ❑ SIC 1309 has smaller degradation.

From R-Y. Zhu

Very preliminary prototype

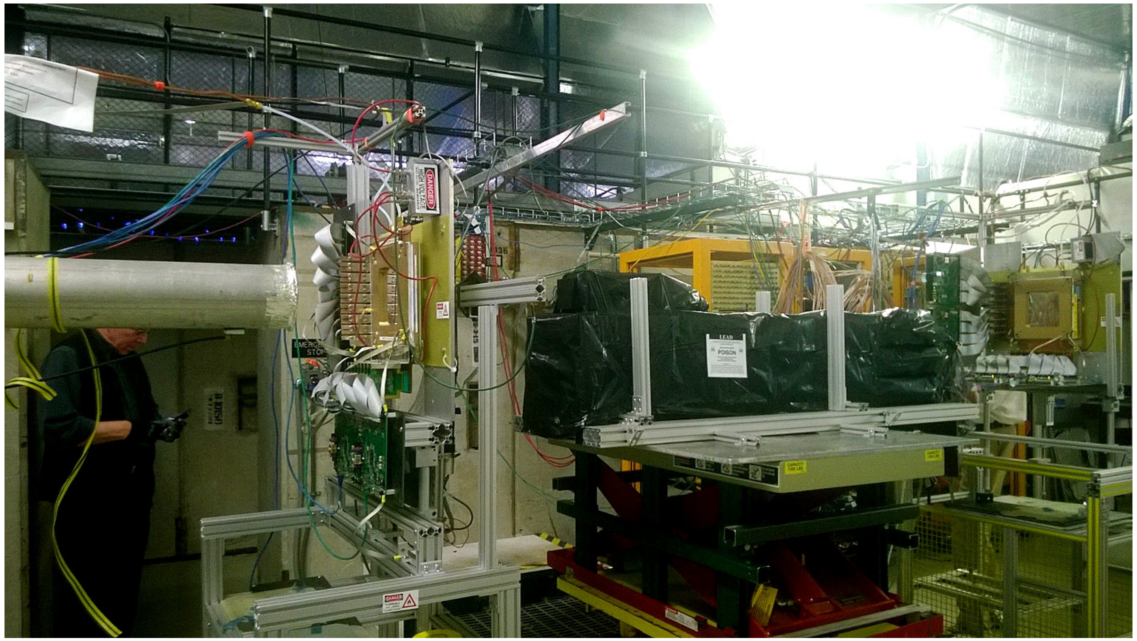




Shipped to BNL in Nov. 2014.

Pre–test with cosmic ray at BNL in Jan. 2015.

Beam test at FermiLab in June 2015.

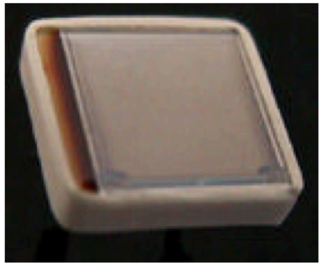


Readout choice

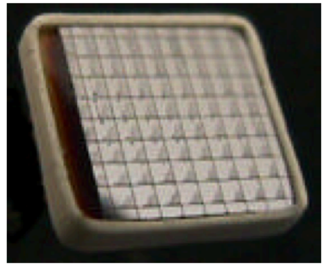
Multi-Pixel Photon Counter (MPPC/SiPM)

New, available on market

High gain, low ENE, simple electronics

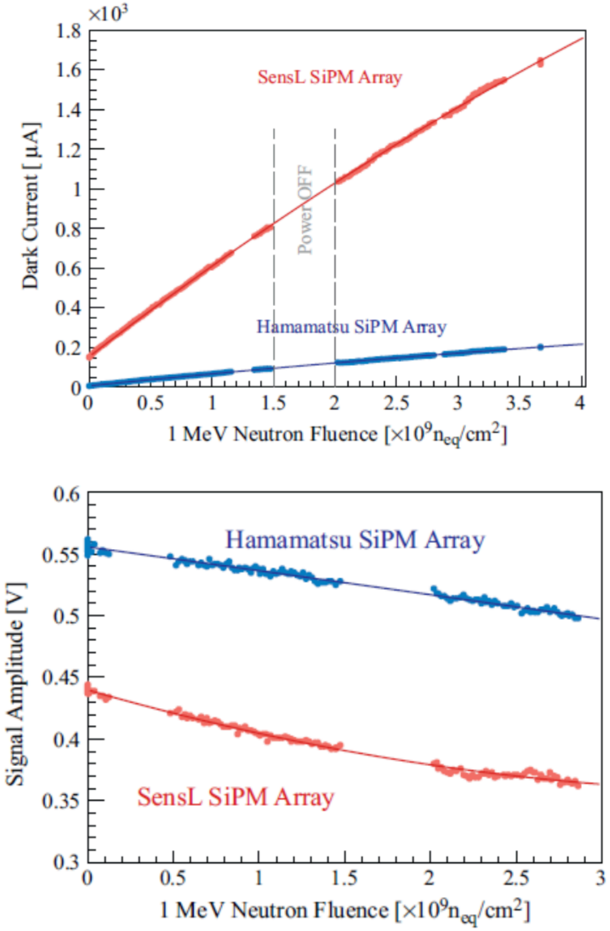


64 mm² active area of **S0814**



Array with 64 pixels. **A6403**

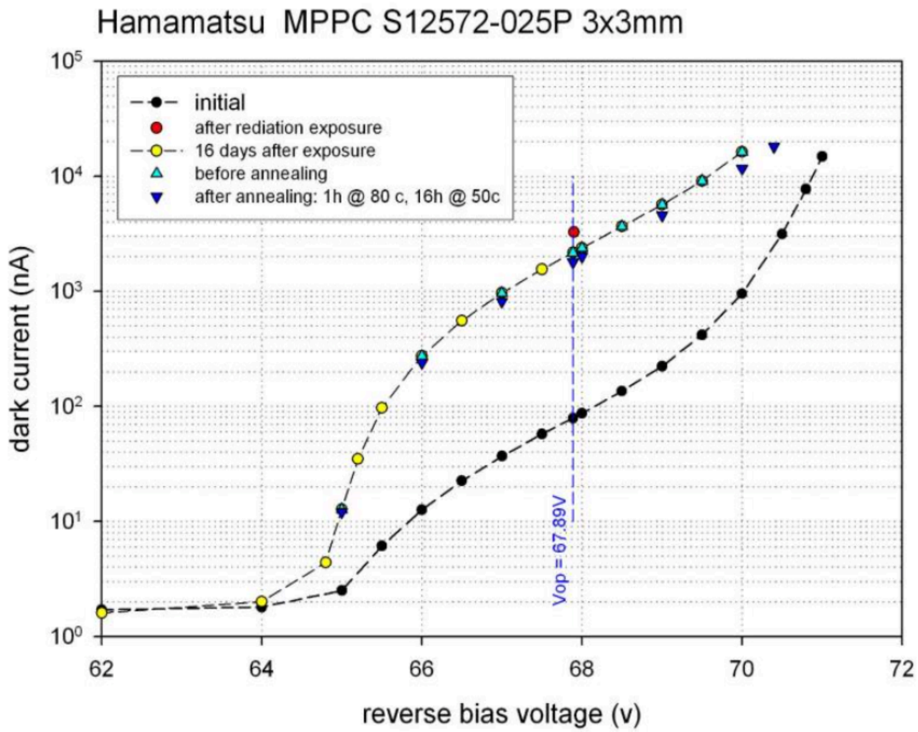
GlueX



Y.Qiang et.al., NIM A698 (2013) 234-241

PHENIX

12 days Au+Au running
Total dose ~ 10^9 n/cm^2

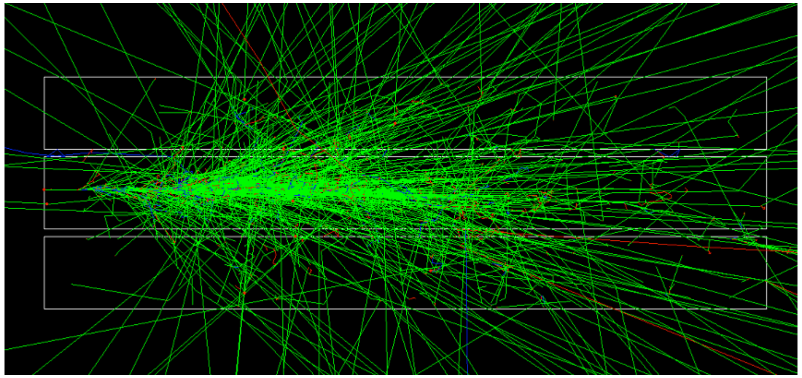


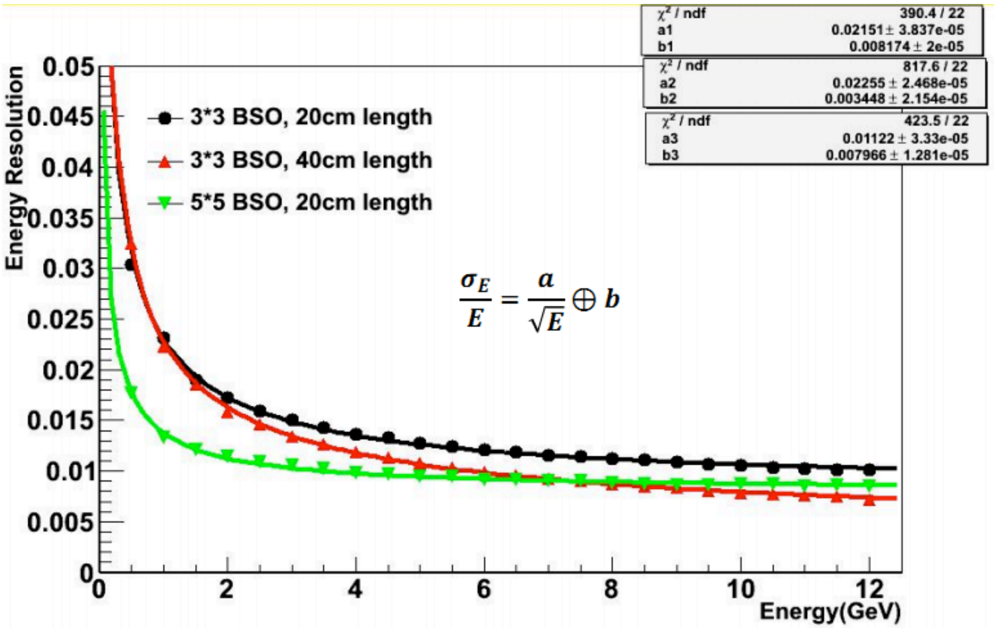
Summary

- EIC is of great interest for future nuclear physics.
- Forward ECal with high energy resolution is crucial for small−x region.
- W powder SPACAL is designed with moderate cost but good resolution.
- BSO performance is in between BGO and PWO, it has the potential to be used in ECal design. USTC and SICCAS are working together for the BSO development.
- Sorry for not covering all options: PWO+SiPM、Shashlyk …

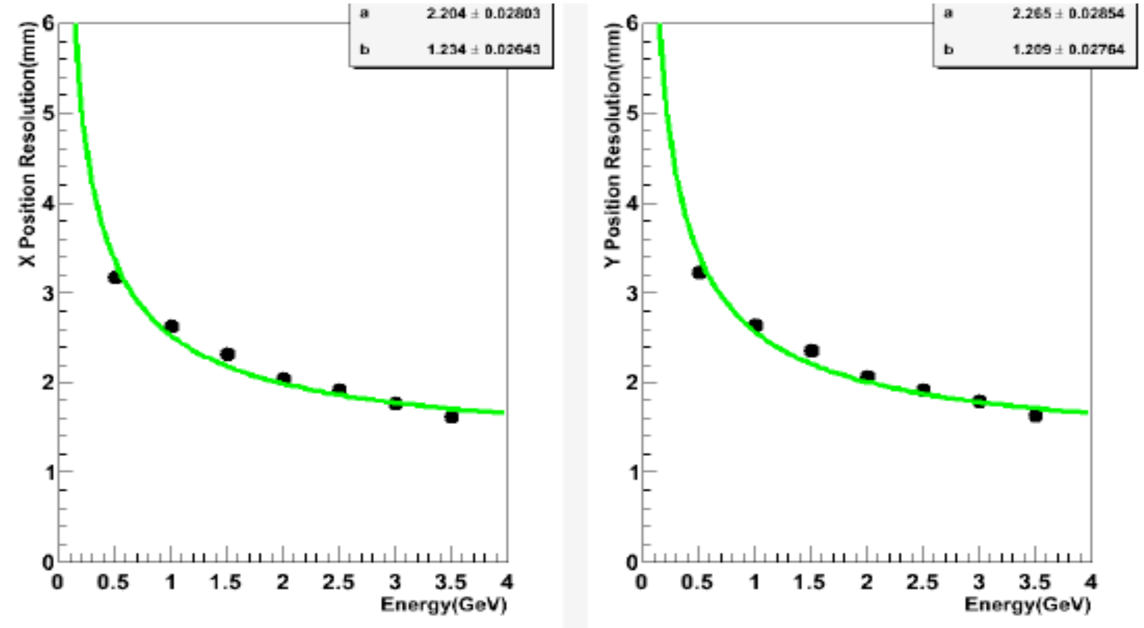
Backup slides

Simulation

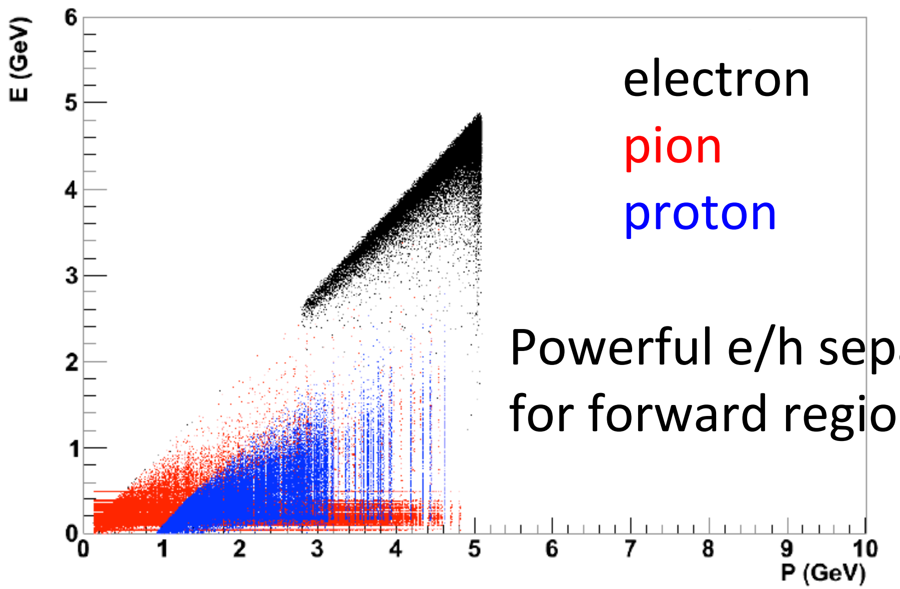




Intrinsic energy resolution is promising < 2% at E > 2 GeV.



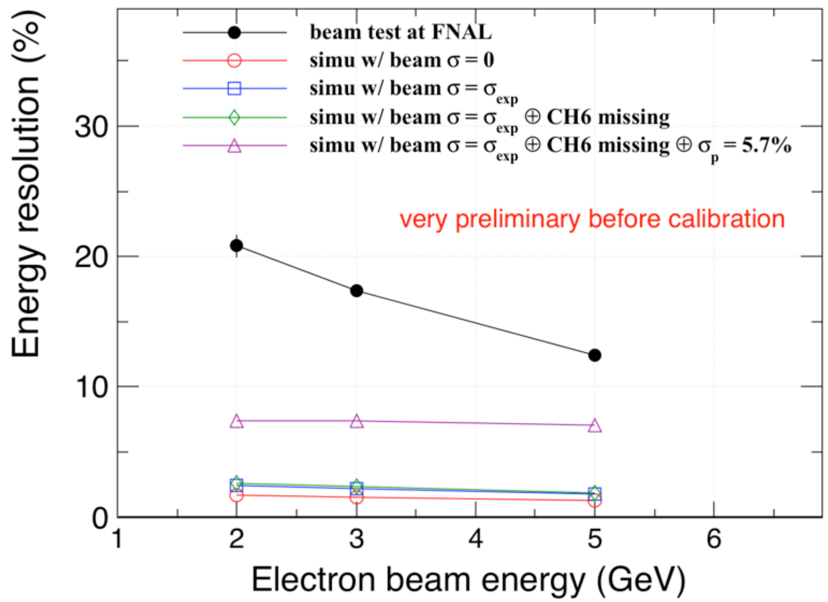
Position resolution < 2 mm at E > 2 GeV.

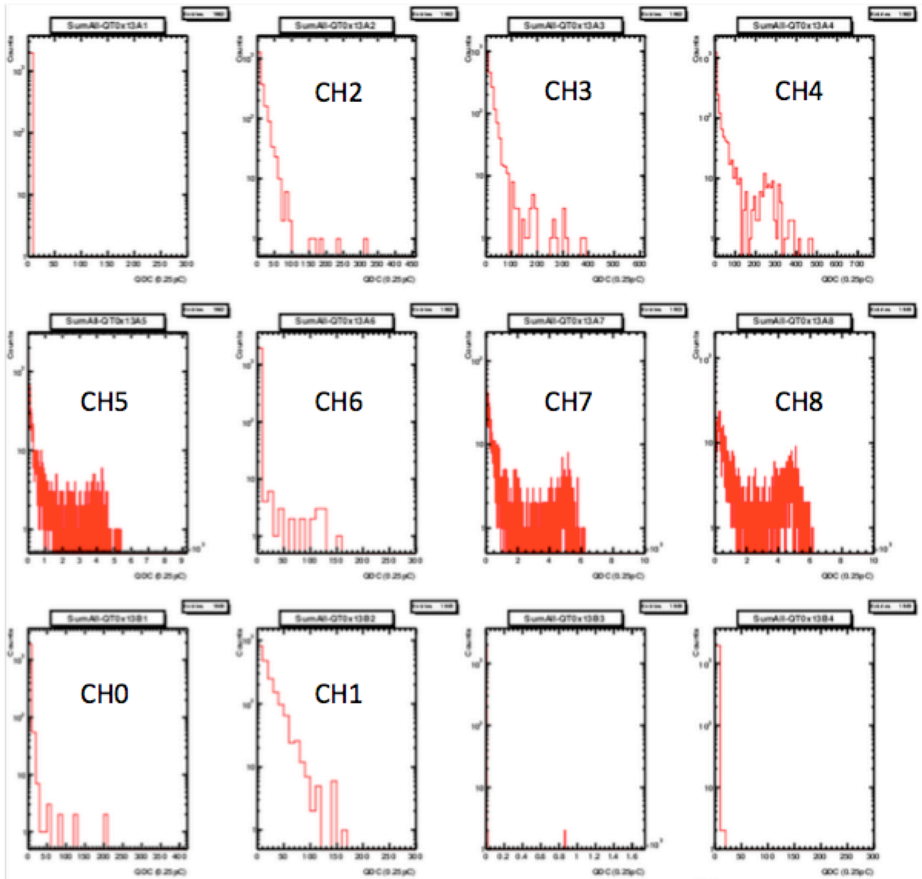


Powerful e/h separation for forward region.

Channel	CH0	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8
BSO #	03	11	01	07	08	10	02	06	04

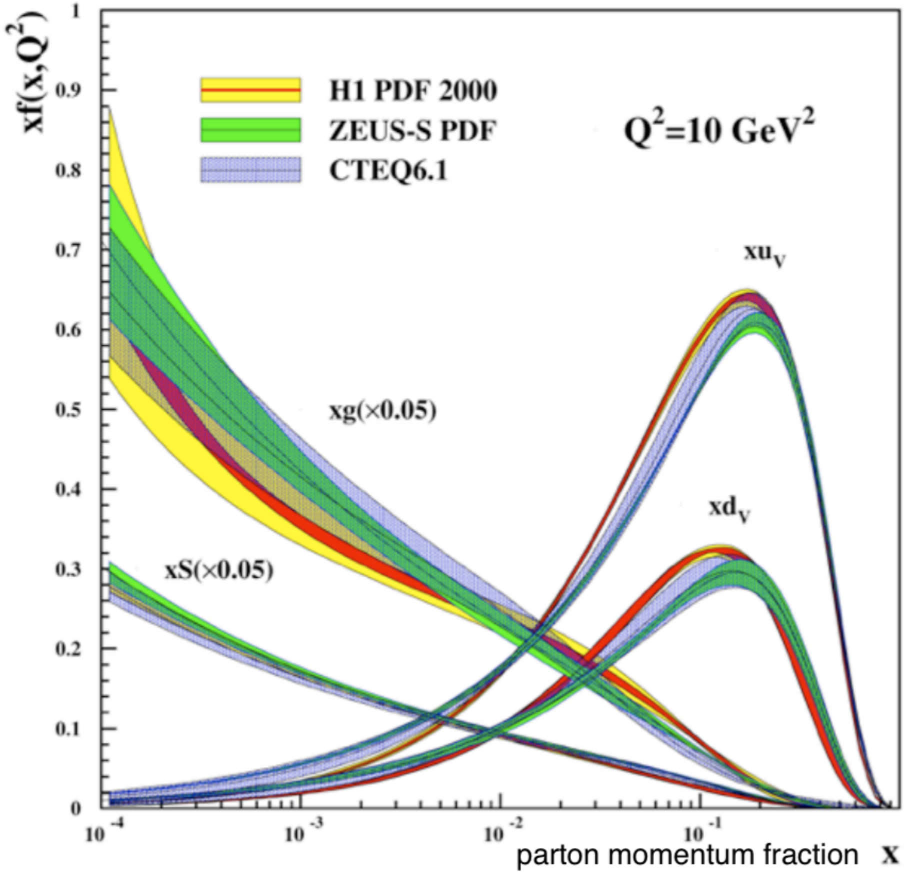
B1/ch0	B2/ch1	A2/ch2
A3/ch3	A4/ch4	A5/ch5
A6/ch6	A7/ch7	A8/ch8

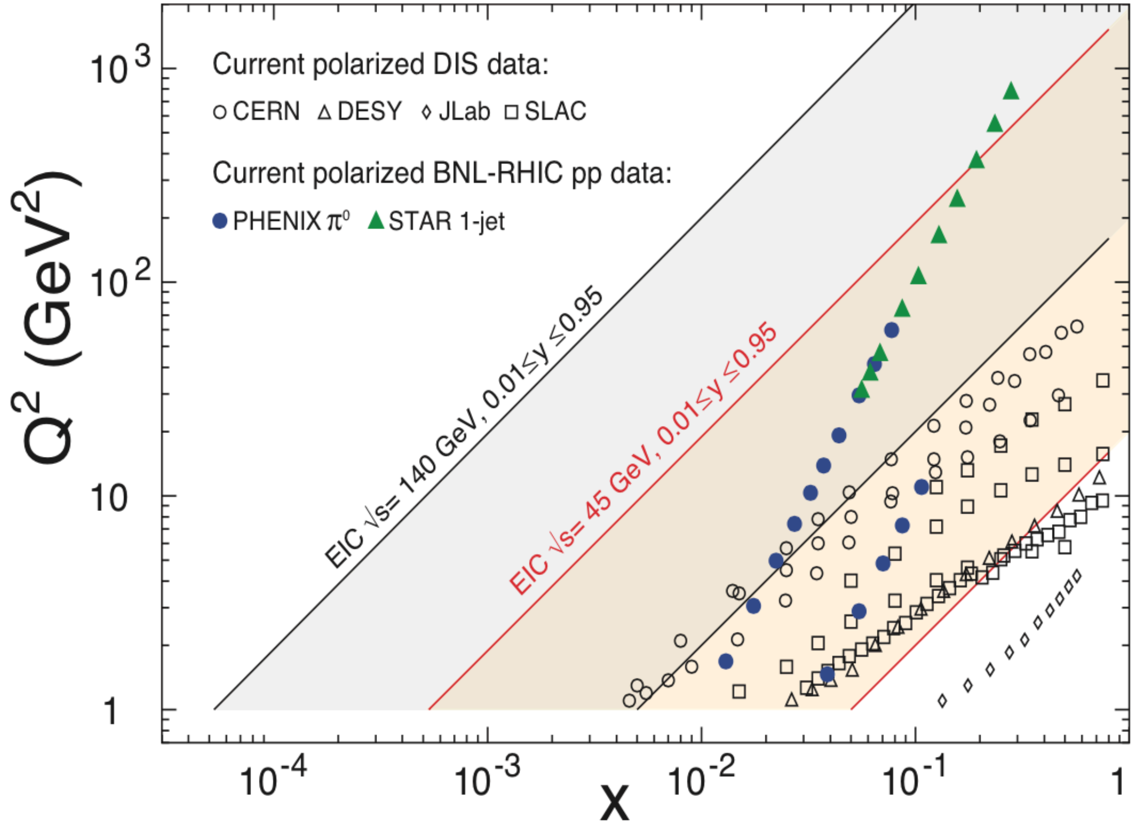




Introduction: Proton spin puzzle

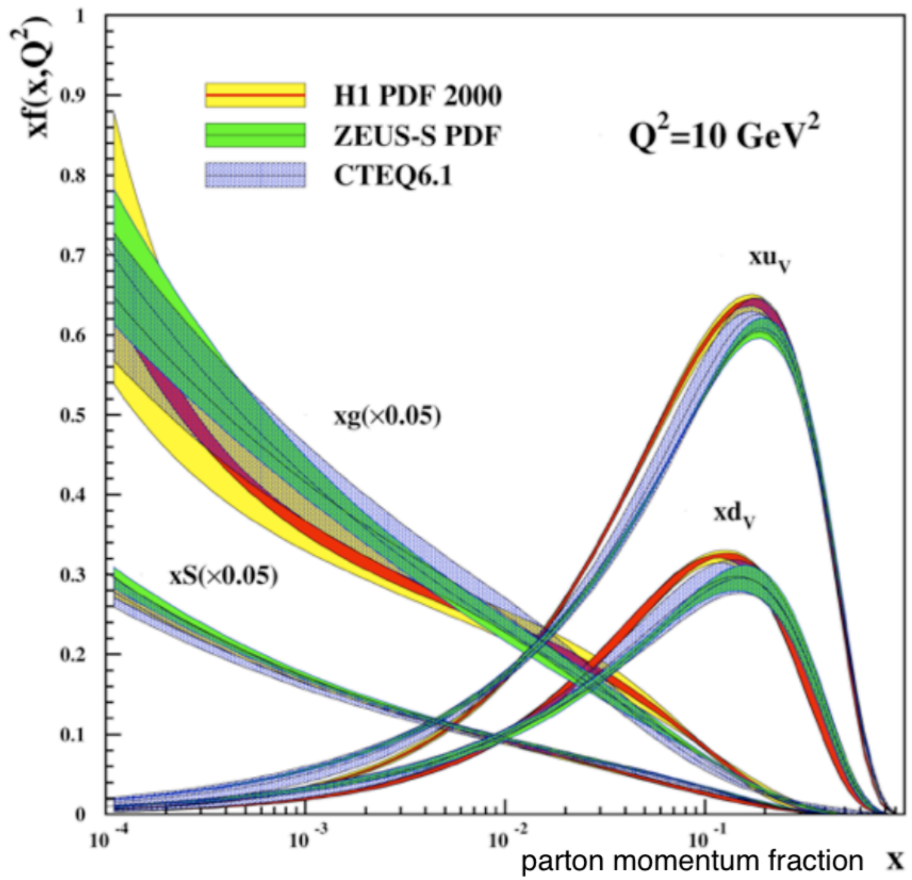
- Where the proton spin come from?
- How does gluon contribute to the proton spin?

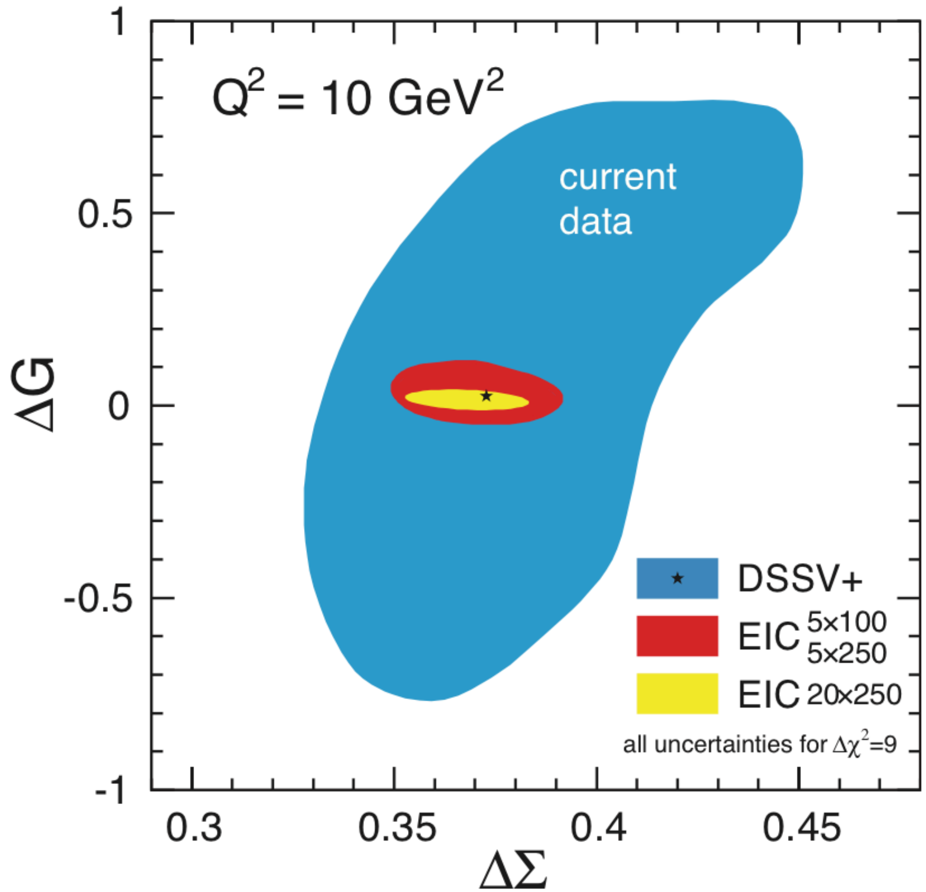




Introduction: Proton spin puzzle

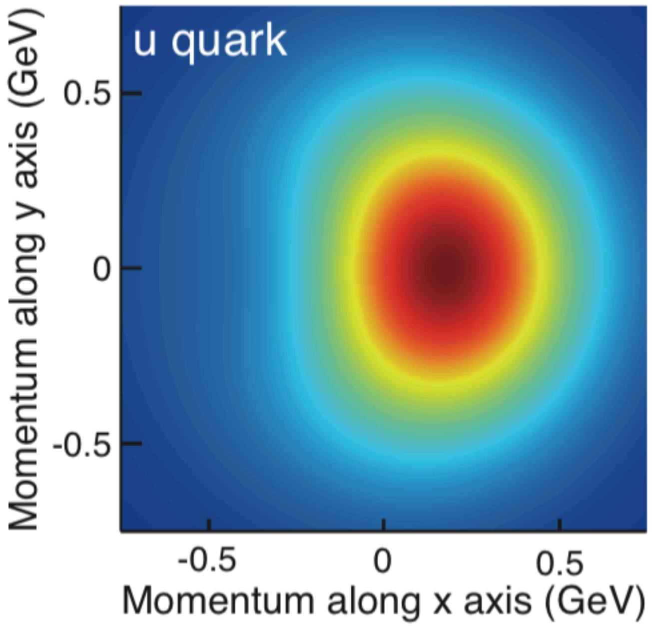
- Where the proton spin come from?
- How does gluon contribute to the proton spin?
- What the precision can EIC achieve?

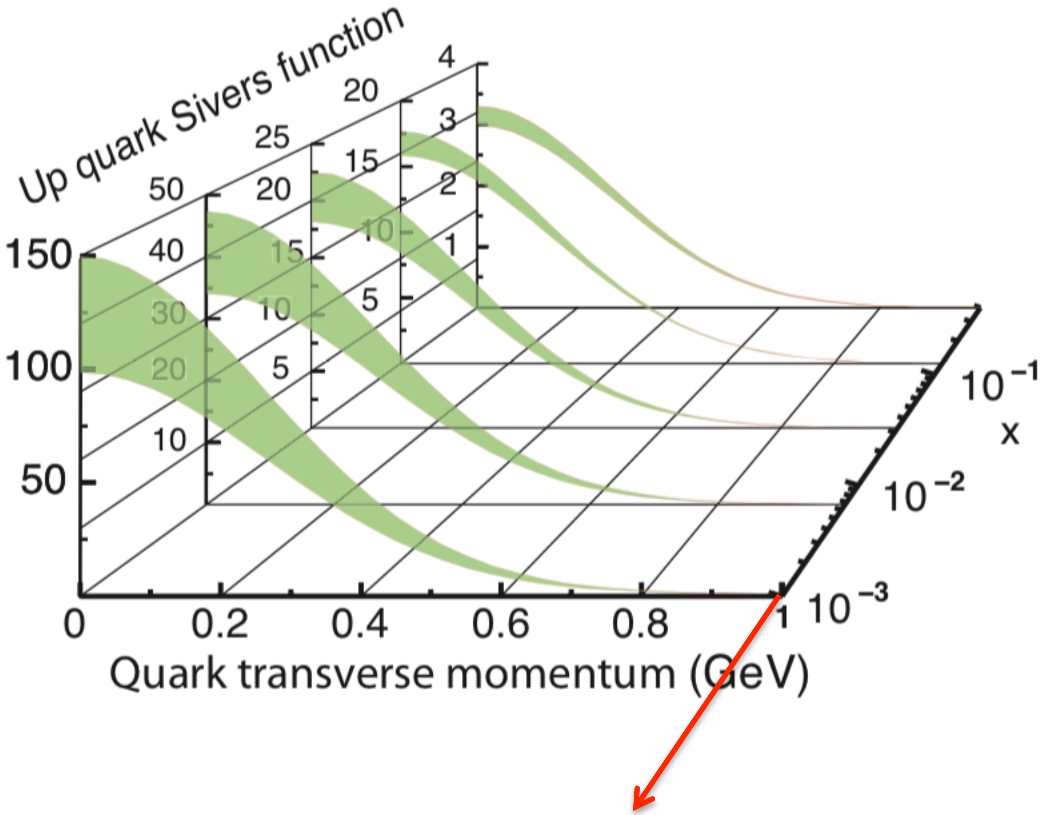




Introduction: Parton motion in the nucleon

- How do partons move inside the nucleon?
- EIC will broaden our knowledge about the PDFs, TMD, GPD, etc…





Requirements for crystals

Scintillating crystal detectors have been widely used in particle physics experiments.

- Identify electron and photon
- Measure energy/position(angle)
- Electron/photon trigger

Requirements:

- High light yield output for high energy resolution (~ few percent).
- Relatively fast, short integration/shaping time.
- Good resistance to radiation damage.
- Cost saving.