Homogeneous EM Calorimeter R&D for EIC

(part of eRD1)

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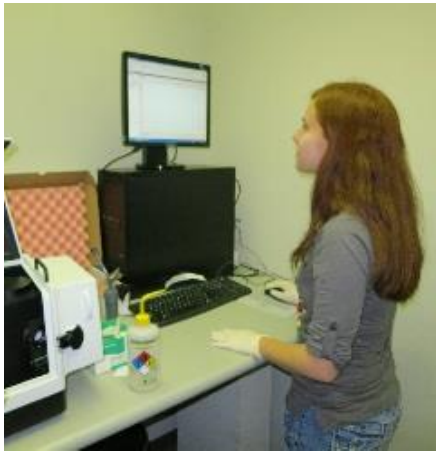
EIC R&D Committee Meeting

CUA, July 26-27, 2018

Students

- Diana Damenova (Marshall High School)
- Juan Jose Paez Chavez (Marshall High School)
- Salim Roustom (VTech)
- Dannie Griggs (U. Chicago)

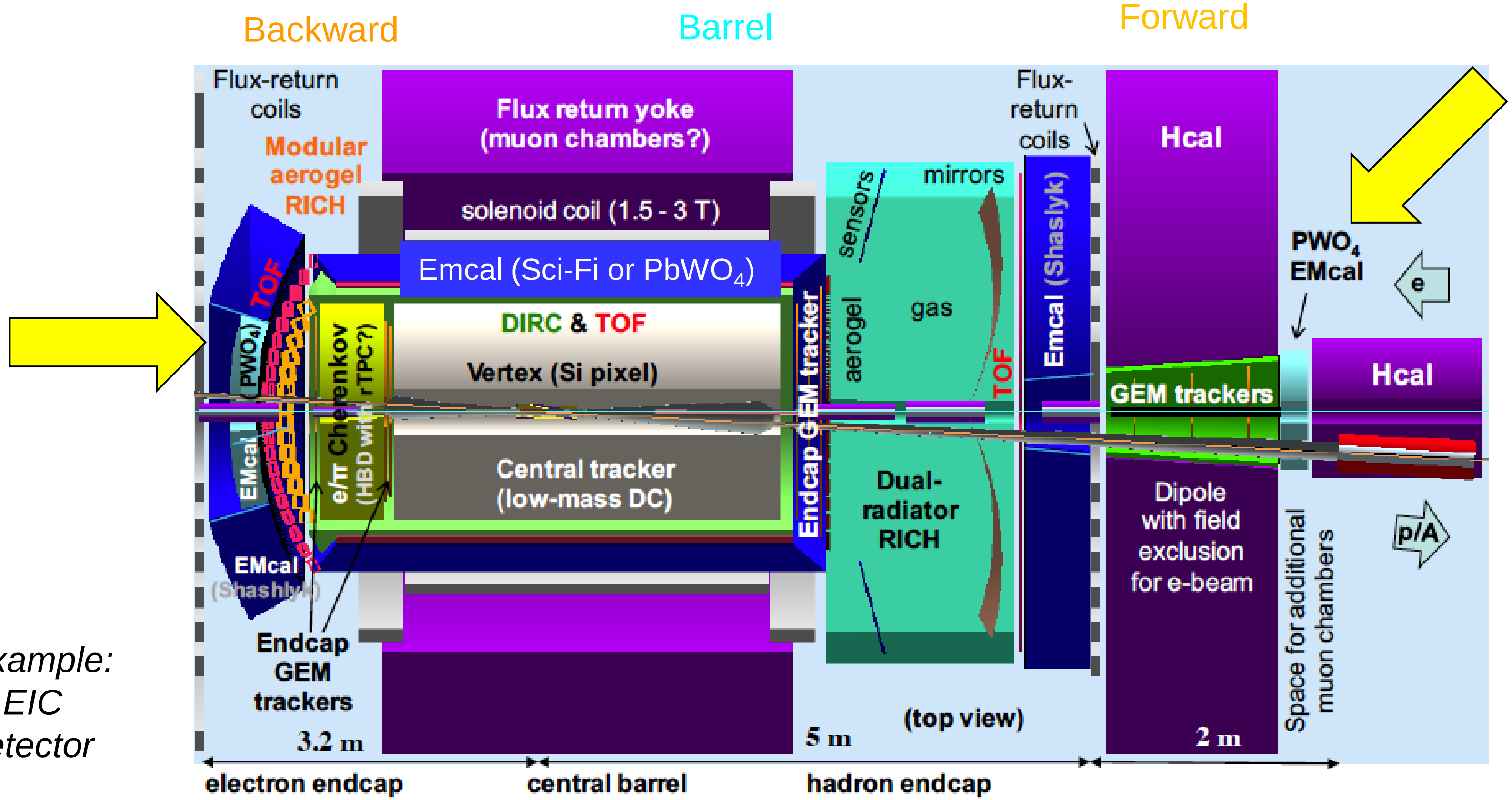


- Callum Walton (CUA)
- Blessed Ngwenya (U. Capetown)
- Salina Ali (CUA)
- Richard Trotta (CUA)
- Ho San (IPN-Orsay)

High resolution calorimetry for endcaps

- **PID requirements in the electron endcap** primarily driven by nearly real photo-production and semi-inclusive and exclusive processes
- **PID requirements in the ion endcap** primarily driven by exclusive processes, e.g., DVCS (γ vs. photons from π^0 decay) and to detect excitation in recoil baryons

Detection at very small angle is needed



Example: JLEIC detector

What was planned for FY18

Crystal characterization for specifications and iteration with vendors

- Characterize, including chemical analysis, 460 SICCAS crystals produced in 2017 in collaboration with NPS project
- Evaluate influence of crystal surface properties
- Procure 450 crystals from Crytur in collaboration with NPS project

Analysis of constant term and establish limiting energy resolution and uniformity

- Model energy resolution, e.g. simulate the impact of miscalibrations and dead zones between crystals

Design a beam test program to establish limiting energy resolution and uniformity

- Design prototype including real readout system and temperature monitoring
- Develop analysis/calibration software for prototype beam test program
- Investigate different readout options to be tested with prototype

What was achieved in FY18 – to date

With commitment of internal university and laboratory funds and through synergy with the NPS project at JLab we made progress even within constrained FY18 budgets

Progress

Crystal characterization for specifications and iteration with vendors

- Tested optical properties of 200 crystals produced at SICCAS in 2017 including systematic uncertainty studies
- Provided feedback to vendors and iterating on reaching required crystal properties and quality – collaboration meeting at SICCAS on 23 July 2018
- Submitted procurement for 400 SICCAS and 100 CRYTUR crystals through synergy with NPS project

Progress

Analysis of constant term and establish limiting energy resolution and uniformity

- Performed simulations to analyse impact of reflector, miscalibrations, dead zones

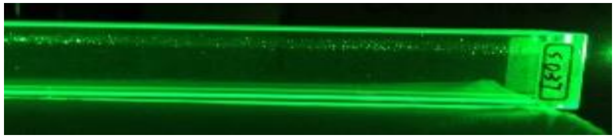
Progress

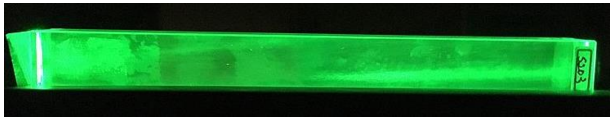
Design a beam test program to establish limiting energy resolution and uniformity

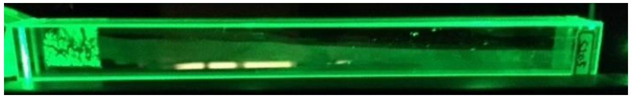
- Worked towards beam test program, but no EIC prototype constructed
- Worked towards evaluation of different readout options

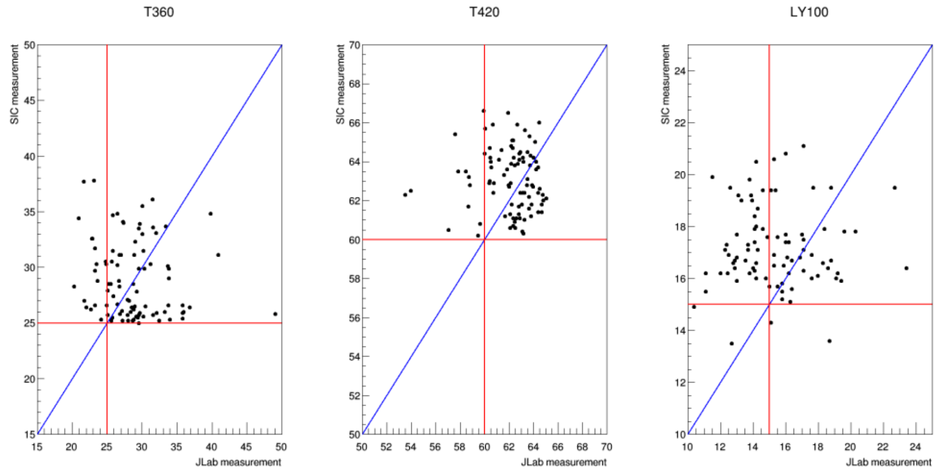
Crystal Activities – characterization and vendors

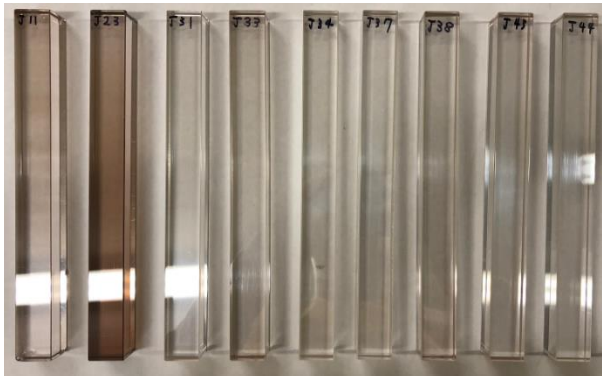
- **SICCAS**: ~40% of SICCAS 2017 crystals fail specs
  - Major categories for failure: LT@420nm or light yield (10%), bubbles and other defects (13%), chips/scratches (8%)
  - Meeting at SICCAS 23 July (https://halldweb.jlab.org/wiki/index.php/Meeting_with_SICCAS)







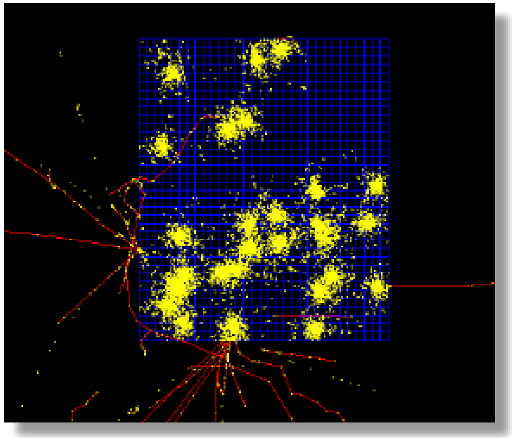


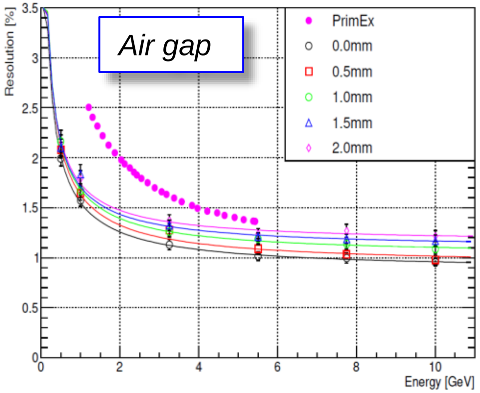


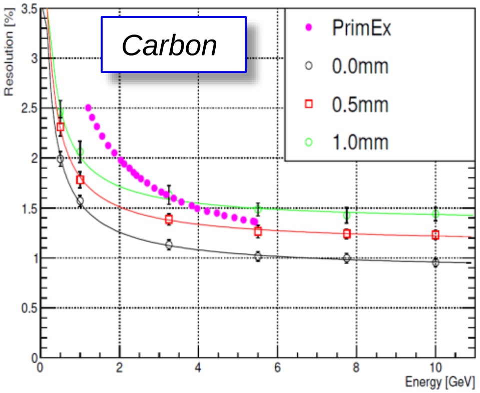
- **CRYTUR**: Considerable limitation in mass production
  - Limited to ~400 crystals/year – maxed out in 2018 due to PANDA order

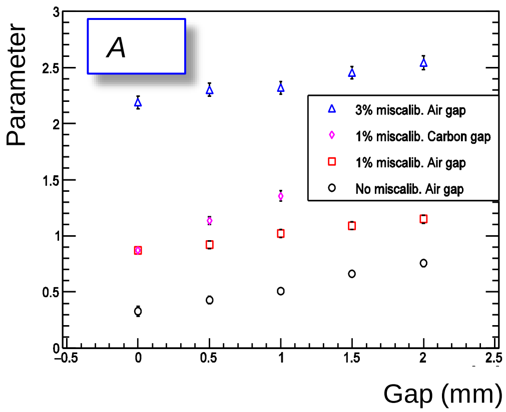
Crystal Activities - Impact on constant term

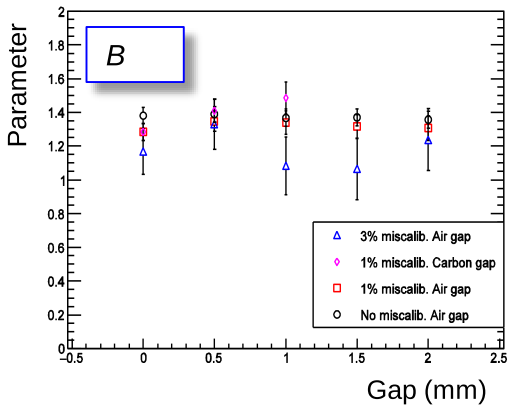
- Impact of calibration and dead zones on constant term – GEANT4 simulation
  - 1 mm gap increases energy resolution by 1-1.5% - impact is mainly on constant term
  - 3% miscalibration doable, 1% challenging







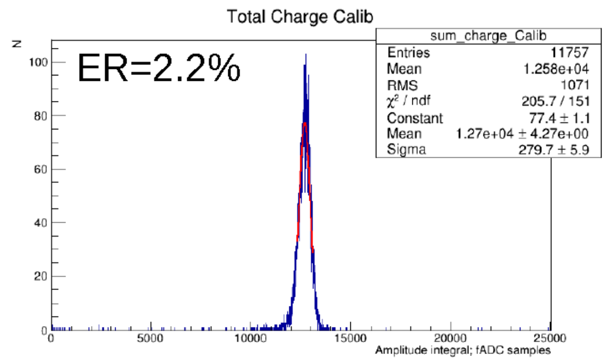




$$\frac{\sigma}{E} = A \oplus \frac{B}{\sqrt{E}} \oplus \frac{C}{E}$$

Crystal Activities – beam test program

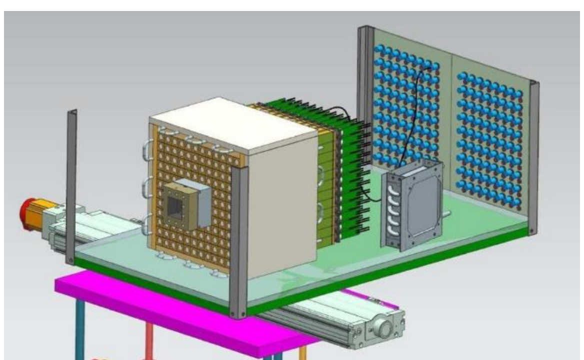
- Initial prototype work with NPS and design test beam program
  - Proof of principle established – completed measurement with NPS 3x3 prototype in Hall D in spring 2018

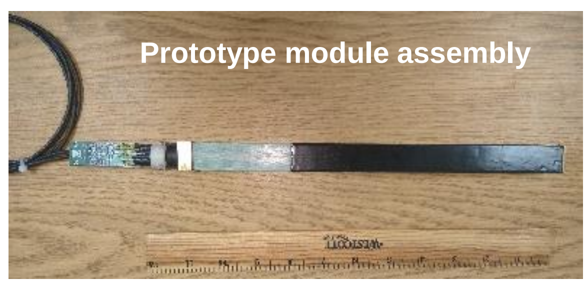


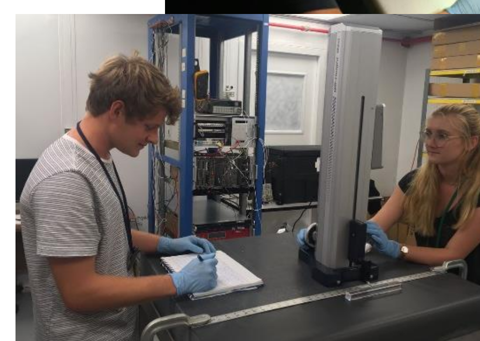
Before optimization. Final result: 2%

- Identified possible improvements including gain calibration, trigger, prototype size, module assembly

- NPS 12x12 prototype run in fall 2018 – assembly ongoing







Glass-based Scintillators for Detector Applications

An alternative active calorimeter material that is more cost effective and easier to manufacture than, e.g. crystals

Material/ Parameter	Density (g/cm^3)	Rad. Length (cm)	Moliere Radius (cm)	Interact Length (cm)	Refr. Index	Emission peak	Decay time (ns)	Light Yield (γ/MeV)	Rad. Hard. (krad)	Radiation type	Z_{Eff}
(PWO)$PbWO_4$	8.30	0.89 0.92	2.00	20.7 18.0	2.20	560 420	50 10	40 240	>1000	.90 scint. .10 Č	75.6
($BaO*2SiO_2$):Ce glass	3.7	3.6	2-3	~20		440, 460	22 72 450	>100	10 *(no tests >10krad yet)*	Scint.	51
($BaO*2SiO_2$):Ce glass loaded with Gd	4.7-5.4	2.2		~20		440, 460	50 86-120 330-400	>100	10 *(no tests >10krad yet)*	Scint.	58

Also: ($BaO*2SiO_2$):Ce shows no temperature dependence

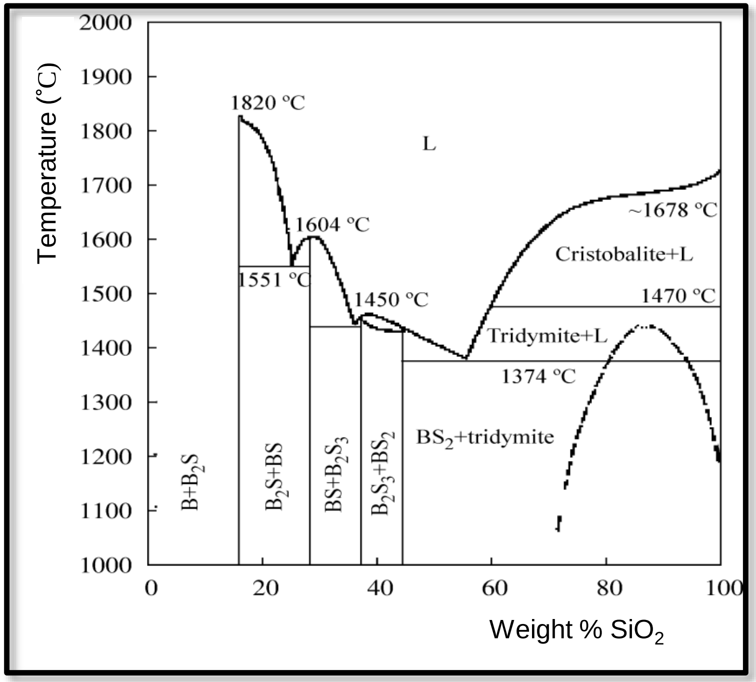
Shortcomings of earlier work:

- Macro defects, which can become increasingly acute on scale-up
- Sensitivity to electromagnetic probes

Material Overview

Technology: Glass production combined with successive thermal annealing (800 – 900ºC)

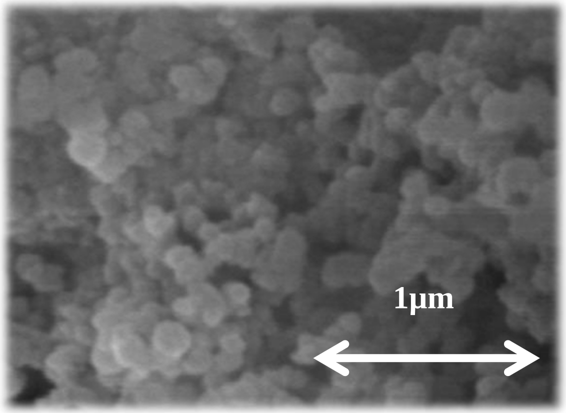
Phase diagram of the $BaO*SiO_2$ system



Material	Density (g/cm³)	X_0 (cm)	Emission peak (nm)	Cutoff (nm)	Zeff
($BaO*2SiO_2$):Ce glass	3.7	3.6	440, 460	310	51
DSB:Ce	3.8	3.5	440, 460	310	51
($BaO*2SiO_2$):Ce glass loaded with Gd	4.7-5.4	2.2	440, 460	318	58

Study of New Glass and Glass Ceramics Scintillation Material (Novotny et al., 2016+)

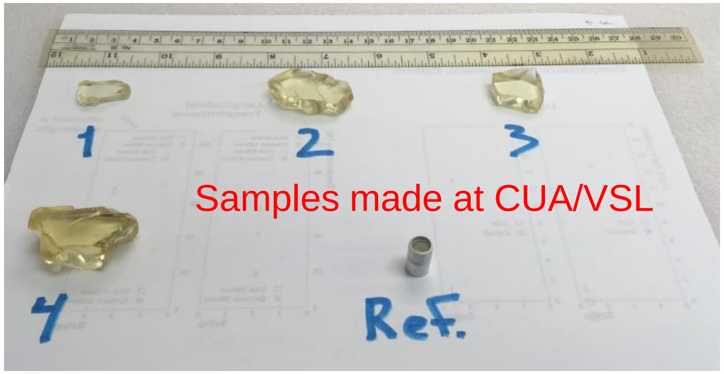
- ❑ Nano-sized particles of **$BaSi_2O_5$**
  - ➢ improve scintillation!
- ❑ Ba-Si system allows to incorporate trivalent ions: **Lu, Dy, Gd, Tb, Yb, Ce**

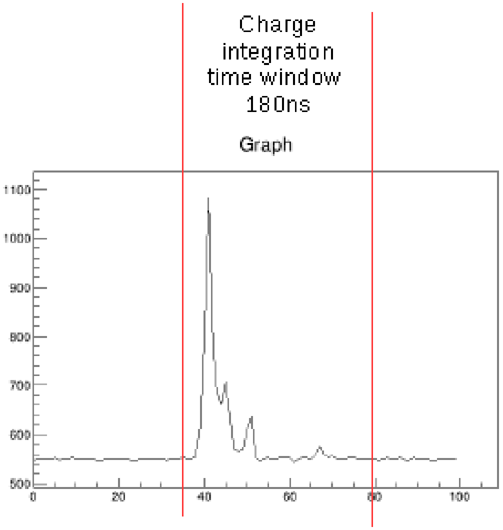


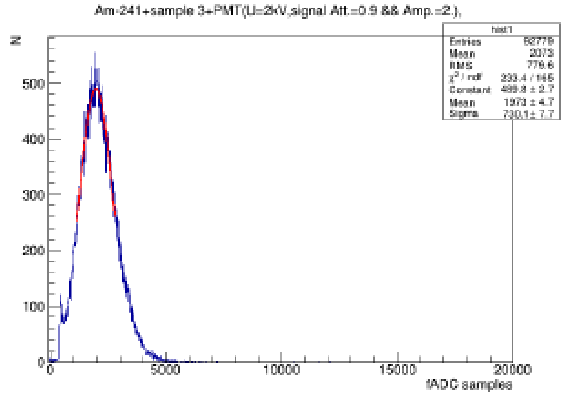
SEM image of recrystallized $BaO*2SiO_2$ at 950ºC

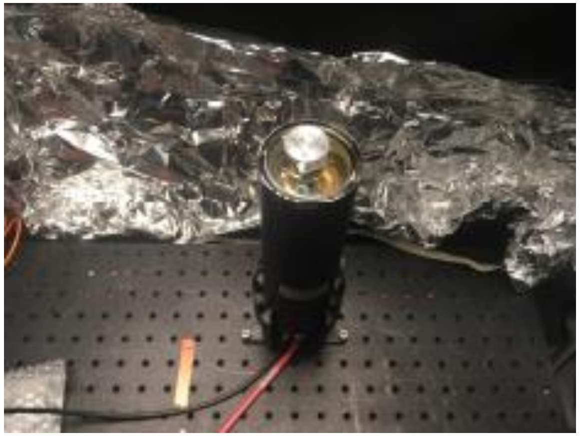
Status of New Glass/Ceramic Scintillator Material

- Optical properties, radiation resistance, light yield and temperature stability seem competitive, sometimes better than $PbWO_4$



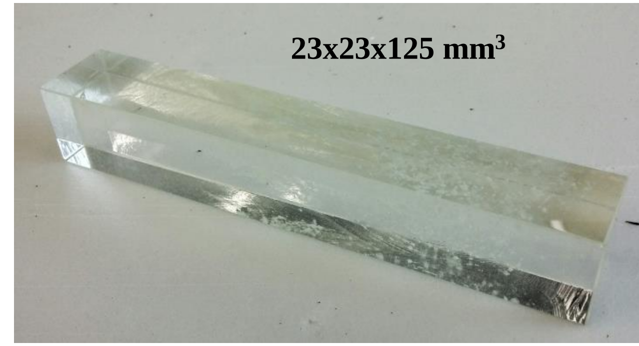




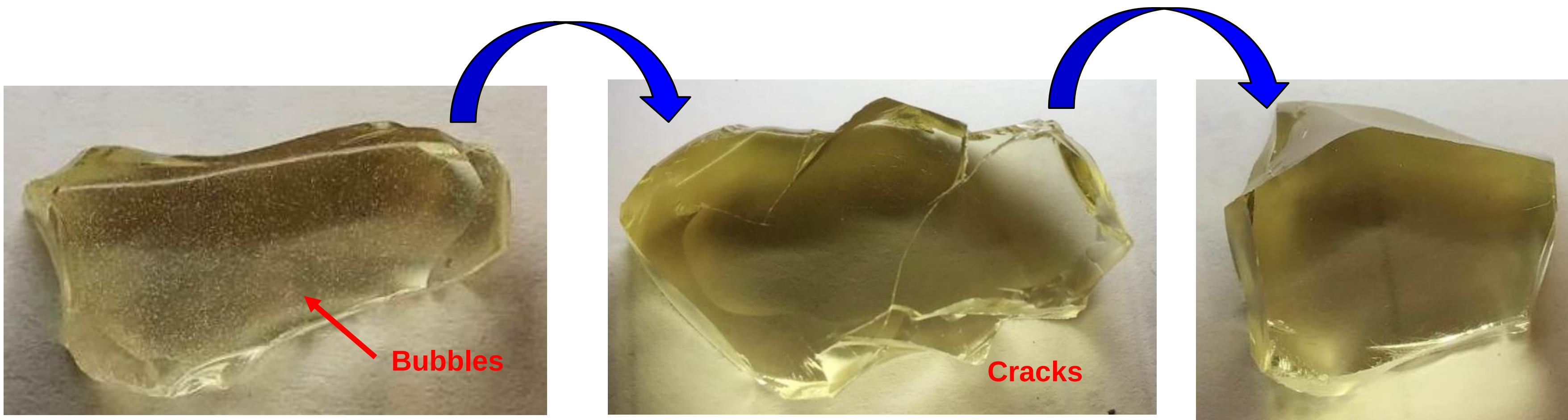


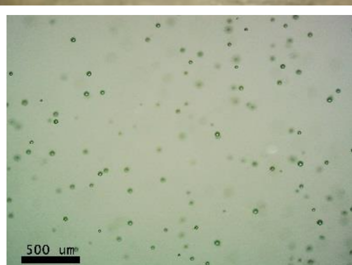
Material/ Parameter	$PbWO_4$	Sample 1	Sample 2	Sample 3	Sample 4
Luminescence (nm)	420	440	440	440	440
Relative light output (compared to $PbWO_4$)	1	35	16	23	11

Status of New Glass/Ceramic Scintillator Material

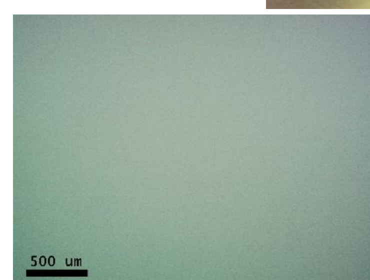


- ❑ Uniformity remains a concern – manufacturing process requires optimization – progress with new method at CUA/VSL





Sample made at CUA/VSL based on previous DSB:Ce work



Samples made at CUA/VSL with our new method

Overview Plans for FY19

- **Construct a $PbWO_4$ crystal prototype** and carry out test beam program to establish actual crystal performance, limiting resolution and uniformity with available SICCAS or CRYTUR crystals

- **Continue crystal characterization** and iterate with vendors on requirements and manufacturing process optimization
  - Procure in collaboration with NPS project 400 crystals from SICCAS and 100 crystals from CRYTUR

- **Produce and evaluate cost-effective alternative glass-ceramic material**
  - Determine origin and develop a method to eliminate macro defects
  - Optimize composition for sensitivity to EM probes
  - Scale up connection with glass manufacturers, SBIR funding possibility

SCINTILEX

- **Explore readout options** in collaboration with Streaming Readout Consortium

Budget Request FY2019 - Crystals

Item	FY18 ($)	FY19 ($)
Materials for glass production	**5k**	5k
Technical Support	**15k**	20k
Parts for prototype and construction		10k
Travel	**10k**	15k
TOTAL	**30k**	50k

- ❑ **20% cut:** we would be able to produce additional simulations of the impact of crystal properties on detector resolution, and in particular the constant term. However, we would have to delay the construction and test program with a prototype, which would impact our ability to determine the real limits of position and energy resolution of the material for application in EIC calorimeters.

- ❑ **40% cut:** we would not be able to construct and test a prototype to determine the real limits of resolution of the material for EIC. Our focus would mainly shift towards the NPS project, which would be the funding source for our activities, and we may only provide information relevant specifically for EIC, as possible.

Budget Request FY2019 – Glass Ceramics

Item	FY18 ($)	FY19 ($)
Materials for glass production	**5k**	5k
Technical Support	**15k**	20k
Parts for prototype and construction		10k
Travel	**10k**	15k
TOTAL	**30k**	50k

- ❑ **20% cut:** we would be able to produce and test small glass-ceramic samples and perform investigation and optimization of the manufacturing process. However, we would have to delay the construction and testing with a prototype, which would impact our ability to determine the real limits of position and energy resolution of the glass-ceramic material for application in EIC calorimeters

- ❑ **40% cut:** we would not be able to construct and test a prototype to determine the real limits of resolution of the glass-ceramic material for EIC. Our focus would mainly shift towards the NPS project, which would be the funding source for our activities, and we may only provide information relevant specifically for EIC, as possible.

Publications and Talks

- C. Munoz-Camacho et al.. “R&D for high resolution calorimetry at the future Electron-Ion Collider”, Presentation at the XVIIth International Conference on Calorimetry in Particle Physics, 15-20 May 2016, Daegu, South Korea

- R. Trotta et al. “*Exclusive reactions and the PbWO4-based Inner Calorimeter for the Electron-Ion Collider*” presentation at the APS April 2017 meeting, Washington, DC

- T. Horn, C. Munoz-Camacho, C. Keppel, I. Strakovsky et al., arXiv:1704:00816 (2017) “*Workshop on High-Intensity Photon Sources (HIPS2017) Mini-Proceedings*”

- T. Horn et al., J.Phys. Conf. Ser. **587** (2015) 1, 012048 “*A PbWO4-based Neutral Particle Spectrometer in Hall C at 12 GeV JLab*”

- T. Horn et al. “*Physics Opportunities with the Neutral Particle Spectrometer in Hall C*”, presentation at the APS DNP 2015 Fall meeting, Santa Fe, NM