Homogeneous EM Calorimeter R&D for EIC

(part of eRD1)

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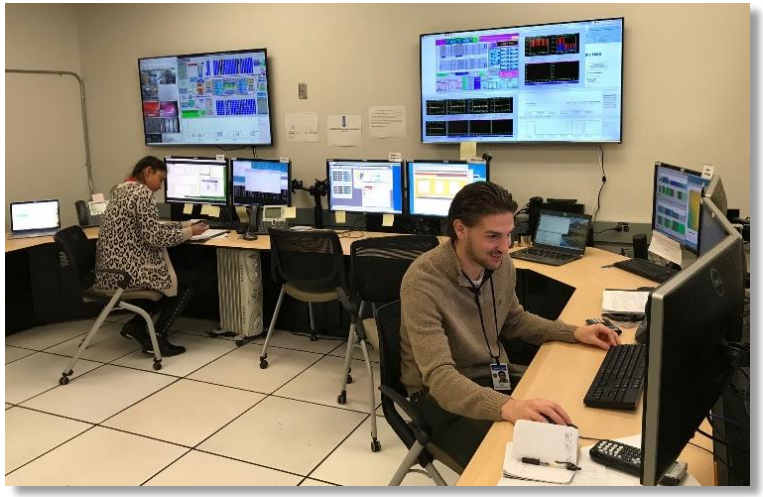
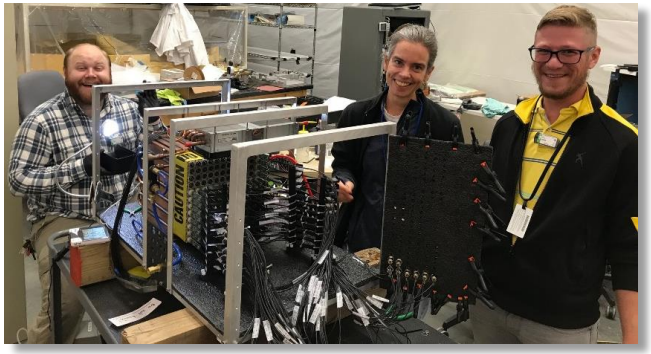
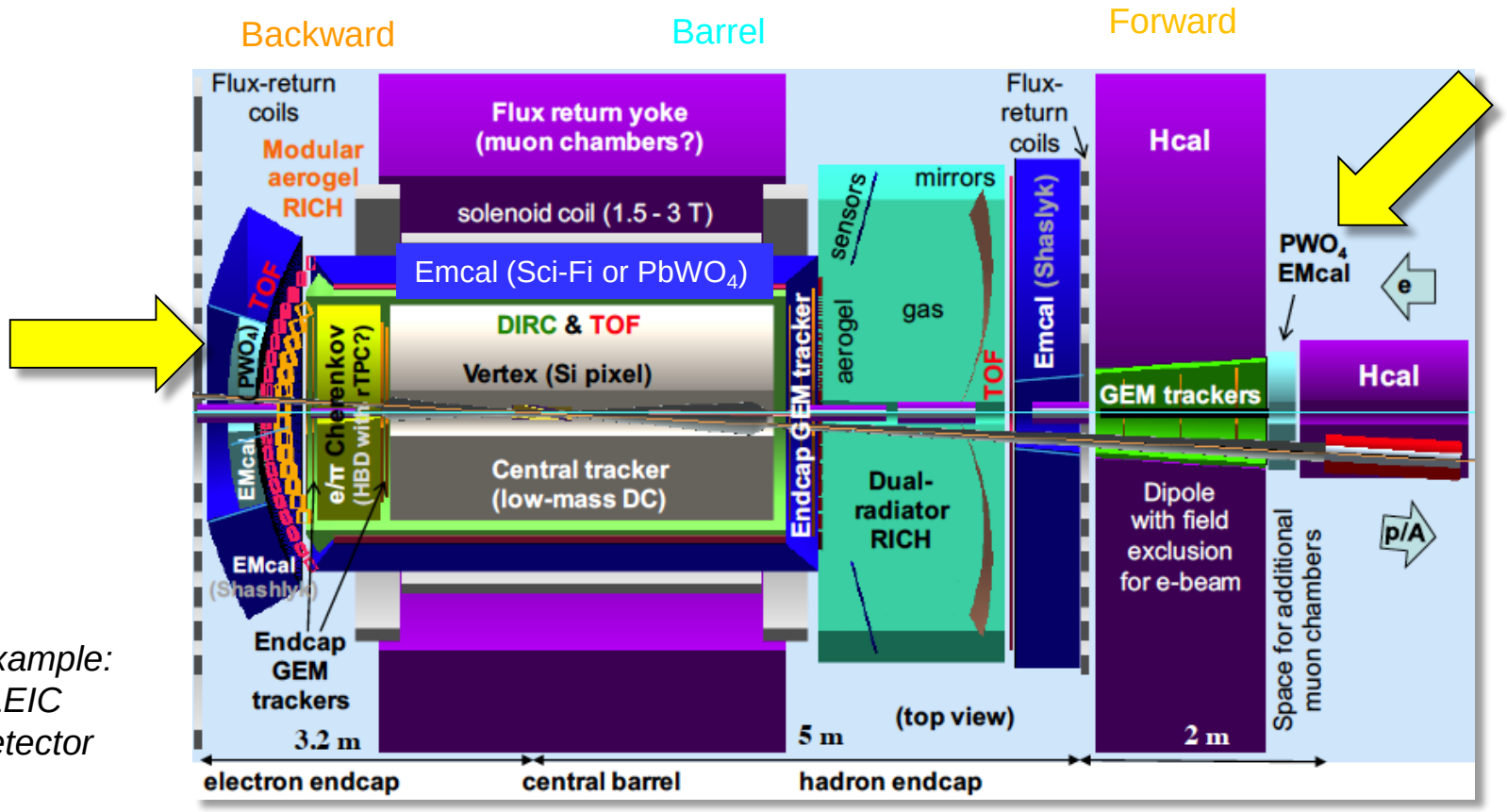




For/Backward and Very Forward Design

- **Lead Tungstate ($PbWO_4$) –** high resolution inner EM Cal
- **Glass ceramics (DSB:Ce) –** alternative active material, easier to manufacture than crystals and more cost effective



Example: JLEIC detector

What was planned for FY19

Work with vendors on cost-effective production of high-quality scintillator material

- Develop crystal and glass formulation and production processes and optimization of quality assurance/quality control procedures
- Purchase and setup of additional equipment needed for material evaluation and providing feedback to vendors

Start beam test program with EMCal prototype – establish real resolutions

- Design prototype including real readout system and temperature monitoring
- Develop analysis/calibration software for prototype beam test program

Start working on future activities – readout, matching materials, etc.

- Set up a test bench for testing different readout options
- Analysis of raw materials, investigation of reflective coating, array geometry

What was achieved in FY19 – 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 FY19 budgets

Work with vendors on cost-effective production of high-quality scintillator material

Progress

- Characterized 460 SICCAS and 100 CRYTUR $PbWO_4$ crystals, feedback to vendors
- Produced and characterized ~35 glass samples – worked on formulation to increase sensitivity and meet requirements of detector applications
- Identified methods for higher precision material evaluation
- STTR proposal submitted  **SCINTILEX**

Start beam test program with EMCal prototype – establish real resolutions

Progress

- Designed and constructed a 12 x 12 array including development of slow controls, calibration and analysis software
- Commissioning completed in December 2018 – very preliminary results

Start working on future activities – readout, matching materials, etc.

Progress

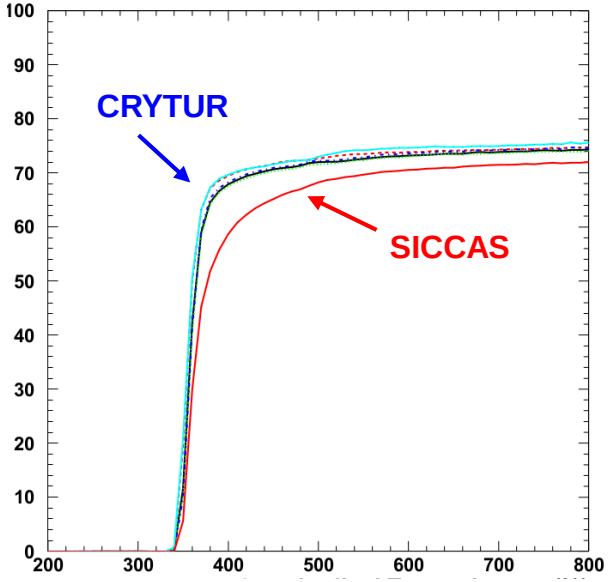
- Set up a test bench for testing different readout options

Crystal Activities – characterization and vendors

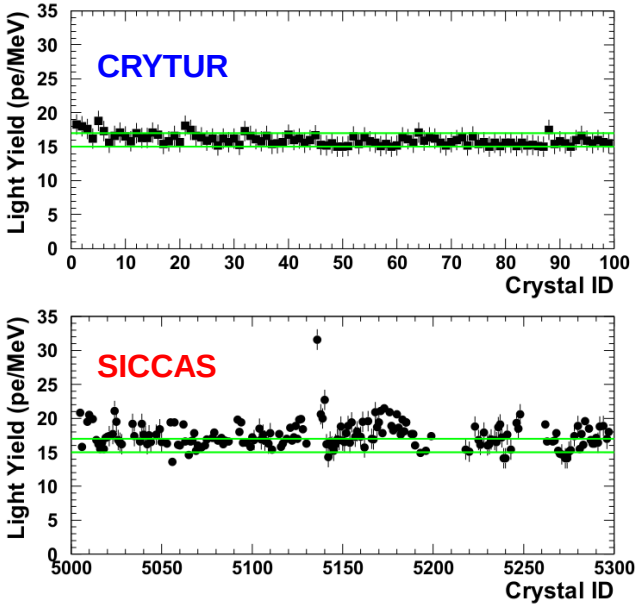
- **SICCAS**: 160/460 SICCAS 2017 crystals rejected due to major mechanical defects – an additional 52 pieces fail specifications

- **CRYTUR**: Strict quality control procedures – so far 100% of crystals accepted
  - Limited capacity, ~200 pc/year – 100 crystals in 2018, maxed out due to PANDA order

Transmittance



Light Yield



Radiation Hardness

CRYTUR crystal quality superior to SICCAS – measurements important for placement in detector, e.g. SICCAS away from high radiation zones

Crystal Activities – characterization and vendors

- **CRYTUR**: high-purity raw material, but limited supply – need ability to produce high quality raw material
  - Company aims to produce raw material as close as possible in quality to that available from BTCP
  - University groups provide crucial feedback through quality control measurements

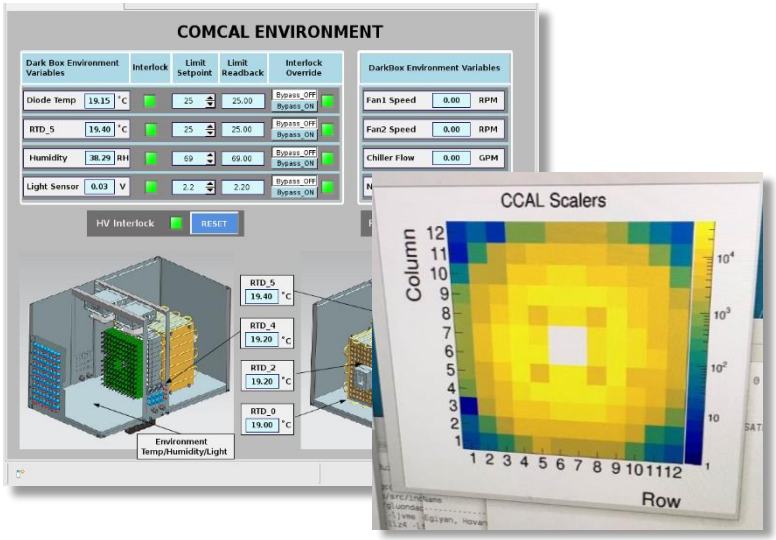
Element	Concentration [ppm wt]	Element	Concentration [ppm wt]
Li	0.15	Ag	3.5
Be	< 0.005	Cd	< 0.5
B	0.13	In	Binder
O	Matrix	Sn	< 0.05
F	< 0.02	Sb	0.55
Na	0.80	Te	< 0.05
Mg	0.03	I	< 0.05
Al	0.38	Cs	< 0.1
Si	1.8	Ba	< 0.005
P	0.06	La	< 0.01
S	5.0	Ce	< 0.01
Cl	1.1	Pr	< 0.01
K	0.80	Nd	< 0.01
Ca	0.61	Sm	< 0.01
Sc	< 0.05	Eu	< 0.05
Ti	0.02	Gd	< 0.005
V	< 0.005	Tb	< 0.005
Cr	0.75	Dy	< 0.005
Mn	< 0.01	Ho	< 0.005
Fe	0.29	Er	< 0.005
Co	0.04	Tm	< 0.01
Ni	0.09	Yb	< 0.005
Cu	2.0	Lu	< 0.005
Zn	< 0.01	Hf	< 0.01
Ga	< 0.05	Ta	< 1
Ge	< 0.1	W	Matrix
As	< 0.01	Re	< 0.5
Se	< 0.01	Os	< 0.05
Br	< 0.01	Ir	< 0.01
Rb	< 0.01	Pt	< 0.05
Sr	0.02	Au	< 0.5
Y	< 0.01	Hg	< 5
Zr	0.07	Tl	<= 1.8*
Nb	< 0.05	Pb	Matrix
Mo	0.17	Bi	< 0.5
Ru	< 0.005	Th	< 0.0005
Rh	< 0.05	U	< 0.001
Pd	< 0.05		

Purity specs:<10ppm for Mo and <40 (100) ppm for La, Y, Nb, Lu

Crystal Activities – Beam Test Program

- Designed and constructed a 12 x 12 prototype of geometry representative of NPS and EIC EMCal
  - 144 scintillator blocks of dimensions 2.05cm x 2.05 cm x 20cm with PMT readout and custom HV divider
  - Rectangular geometry most suitable
  - Developed analysis software and slow controls for monitoring temperature etc.

- Installed and commissioned in Hall D in fall 2018
  - Photon beam energies between 1 -10 GeV
    - Measured with Hall D tagging system – resolution ~0.1%
  - Preliminary results indicate prototype energy resolution ~2% (1.4-1.6%) for 4.2 (10) GeV photons – improvement anticipated

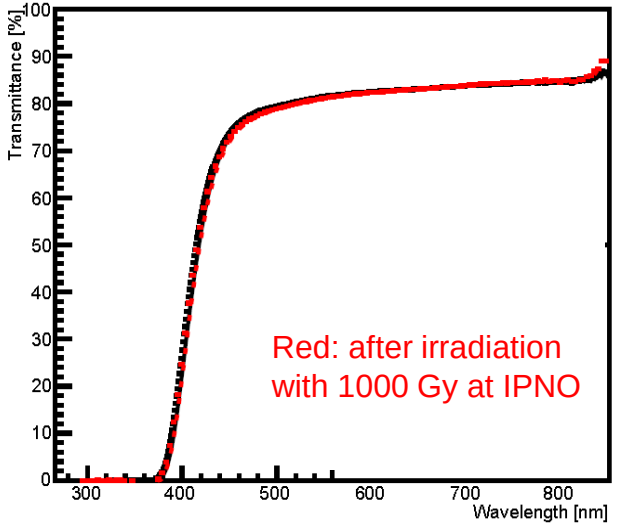


Status of New Glass/Ceramic Scintillator Material

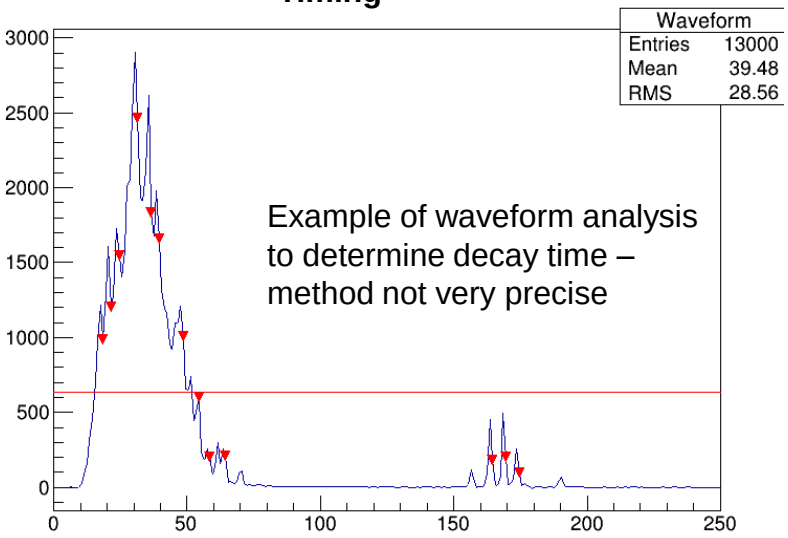
- Glass scintillators being developed at *VSL/CUA/Scintilex* – optical properties comparable or better than $PbWO_4$
  - Preliminary tests on radiation damage look promising
  - Ongoing optimization work

Scintilex samples

Radiation Hardness



Timing

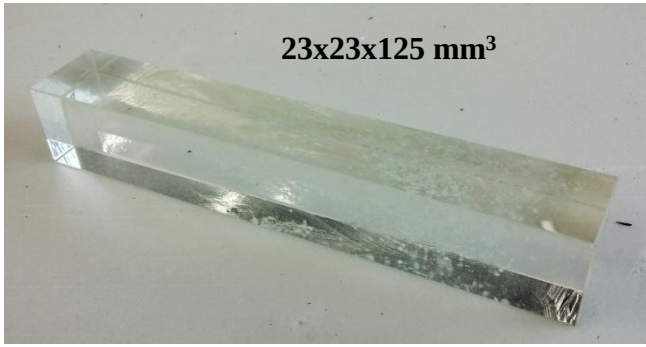


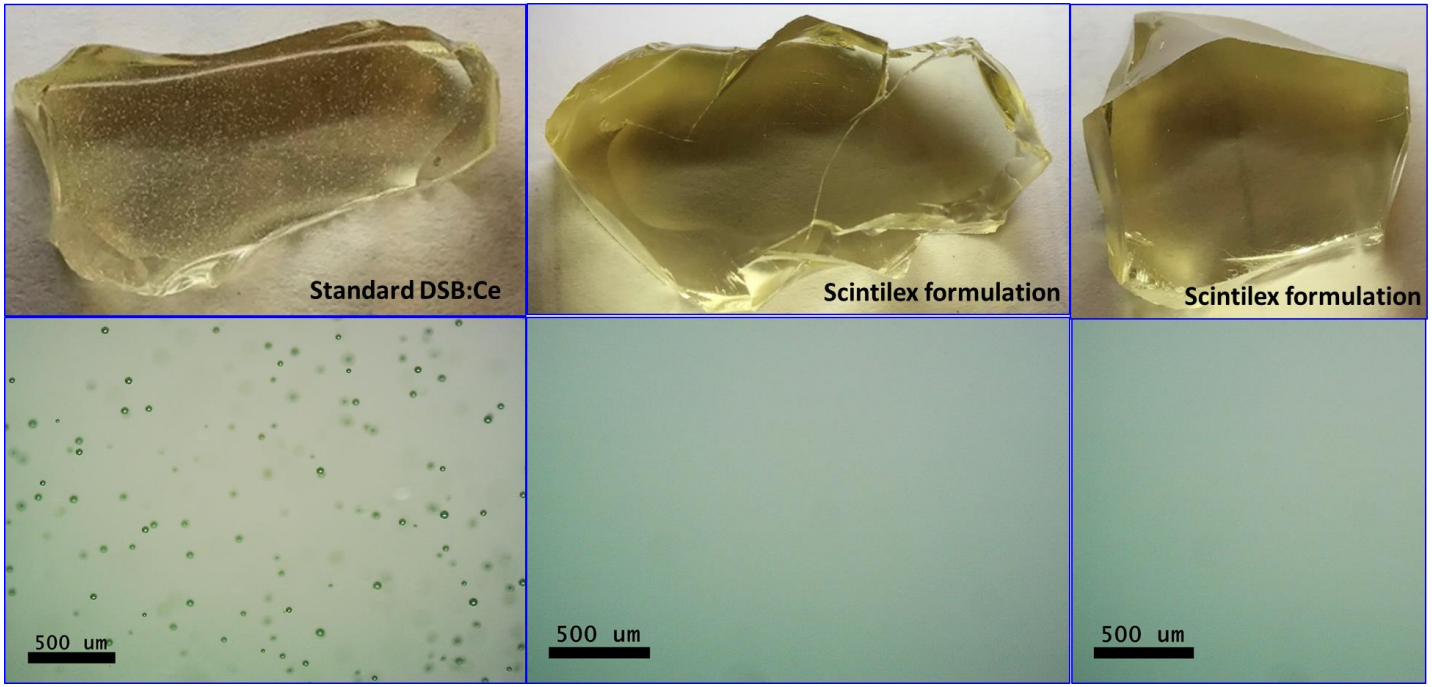
Light Yield

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/Scintilex



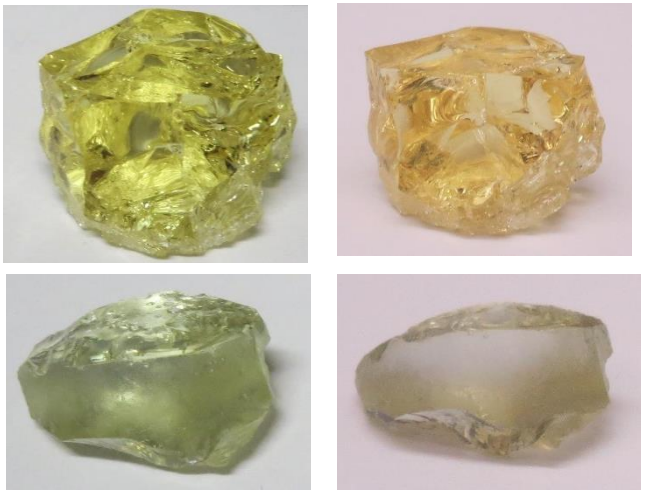


Sample made at CUA/VSL based on previous DSB:Ce work

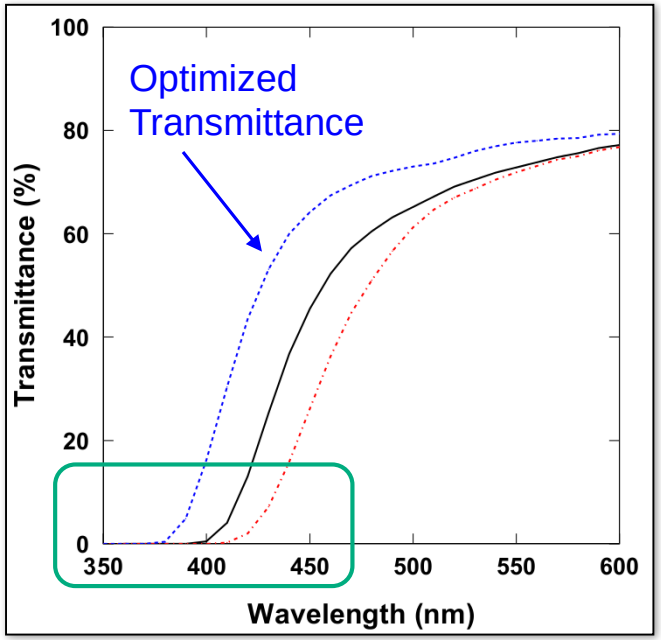
Samples made at CUA/VSL/Scintilex with our new method

Status of New Glass/Ceramic Scintillator Material

- Color optimization – progress with new method at CUA/VSL/Scintilex



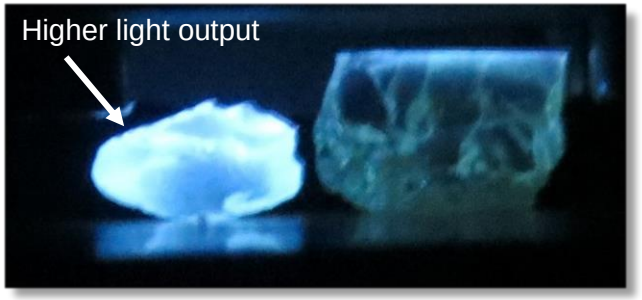
New glass has improved properties



New Scintilex formulations

More transparent

Higher light output



Excitation with 160 keV photons

What was not achieved

- **Procurement of CRYTUR large-volume crystals** due to delays in delivery of larger crucible and quality assurance methods – company hopes to test the new method soon. **Production of larger glass blocks due to delays in equipment delivery** – new equipment is expected to arrive early in the next six month period.

- **Procurement of additional SICCAS and CRYTUR crystals** due to equipment malfunction at SICCAS and capacity limit at CRYTUR – hope to have at least 100 additional CRYTUR and ~200 additional SICCAS crystals

- **Acquisition and analysis of prototype data to study performance -** expected over next six month period, also important for additional work on constant term characterization in resolution

- **Investigation of benefit of reflective coating –** initial results suggest not beneficial for crystals, benefit for glass not yet studied, wrapping remains an option for all cases as done for NPS and PANDA

Overview Future Plans

- **Continue working with vendors on crystal/glass production** and optimization, as well as continue characterization to provide feedback to vendors

- **Further develop and optimize glass property models and property measurement evaluation** – includes procurement of equipment and rapid production of small samples for evaluation of material properties. We also plan to produce larger samples for physical, luminescence and radiation studies

- **Continue prototype data taking and data analysis** to determine actual performance parameters

- **Explore response of $PbWO_4$ and glass to different photosensors** – continue effort at INFN-GE, synergistic with streaming readout consortium

- **Continue setting up Monte Carlo studies** for resolution studies and matching crystal and glass materials in EMCal