The DVCS Experiment in Hall C at Jefferson Lab with the new NPS

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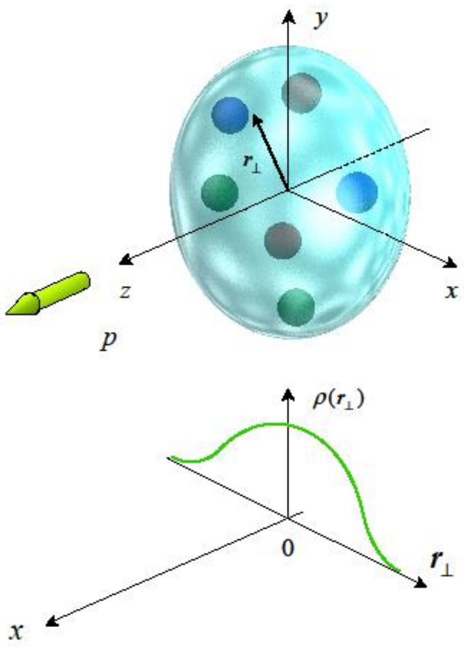
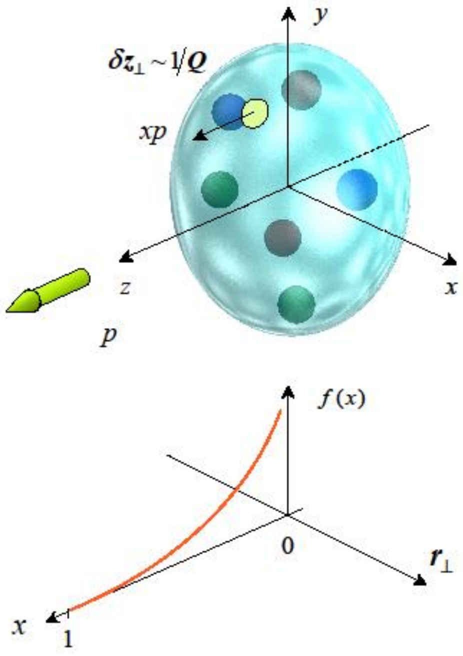
Future Facilities
14:00 Rangos 2
Presented by Dave Mack,
TJNAF

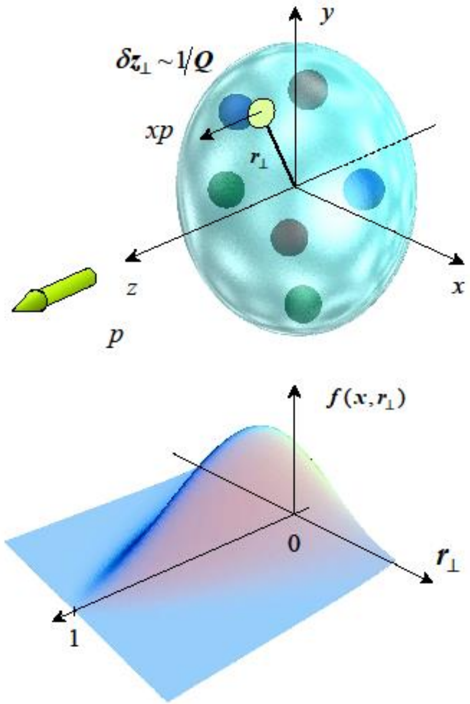
Outline

- Deeply Virtual Compton Scattering(DVCS) for GPDs
- Neutral Particle Spectrometer(NPS) for DVCS experiments in Hall C
- NPS simulations and crystal optical properties

Generalized Parton Distributions







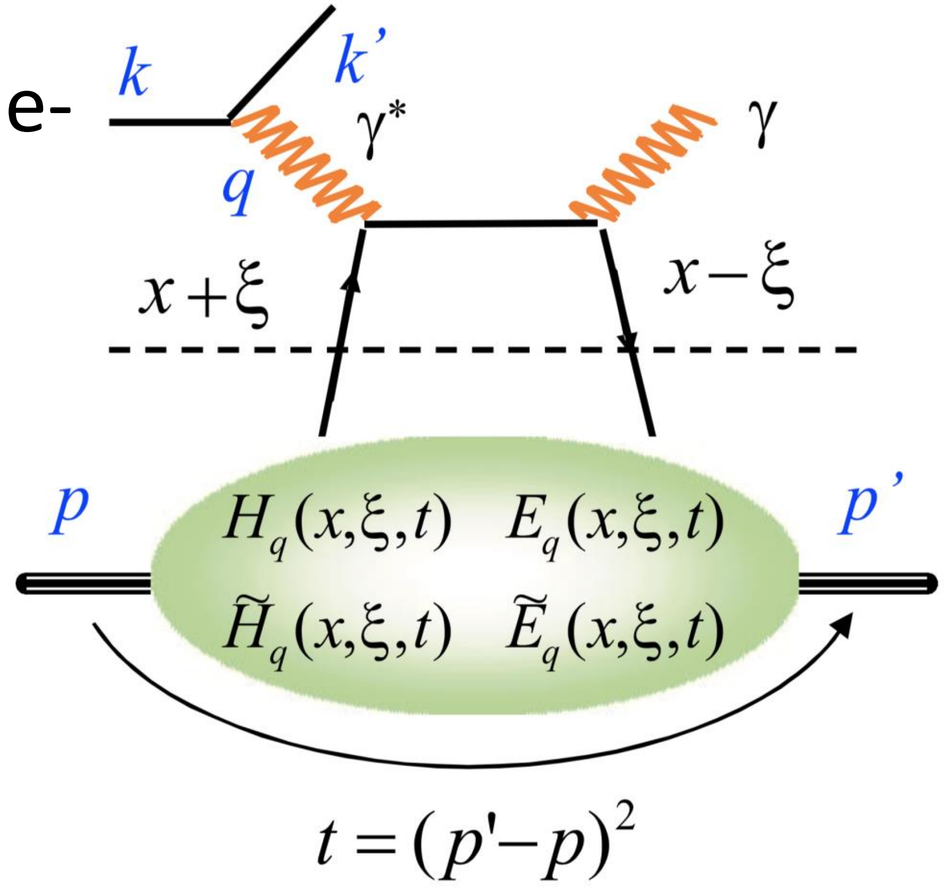
Form Factors:
<u>via elastic scattering</u>
-charge & magnetization spatial distribution

Parton distribution:
<u>via deep inelastic scattering</u>
-Longitudinal momentum & helicity distribution of partons

Generalized Parton Distributions:
<u>via deep exclusive reactions</u>
-Transverse position distribution of partons to longitudinal momentum

Deeply Virtual Compton Scattering

$$\gamma^* p \rightarrow p' \gamma$$



Hard Part

Soft Part

Bjorken limit

$$Q^2 \rightarrow \infty$$

$$\nu \rightarrow \infty$$

$$x_B = \frac{Q^2}{2M\nu}$$

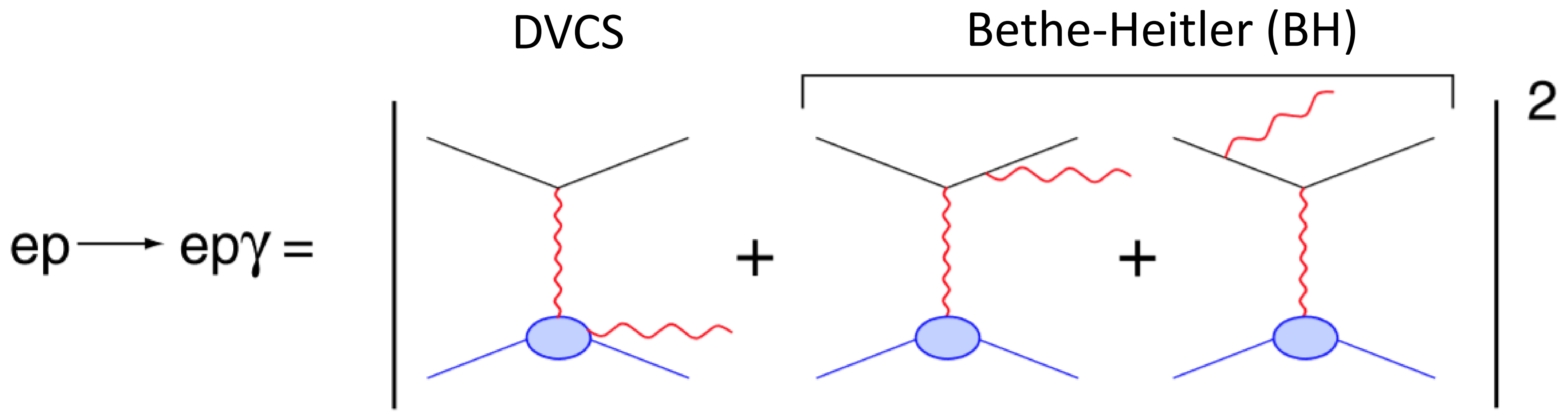
$$Q^2 = -q^2$$

$$\nu = \frac{p \cdot q}{M}$$

$$\xi \sim \frac{x_B}{2 - x_B}$$

At high Q^2, DVCS amplitudes can be factorized into 2 parts
«Hard Part» : Perturbatively calculable
«Soft Part» : Nucleon structure → Parameterized by GPDs

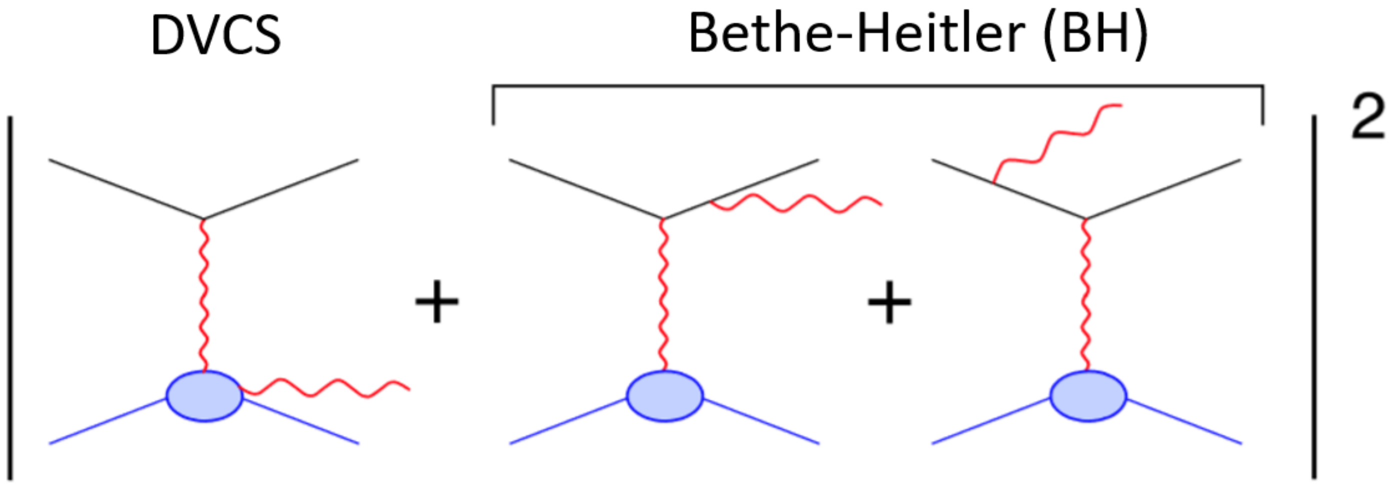
Deeply Virtual Compton Scattering

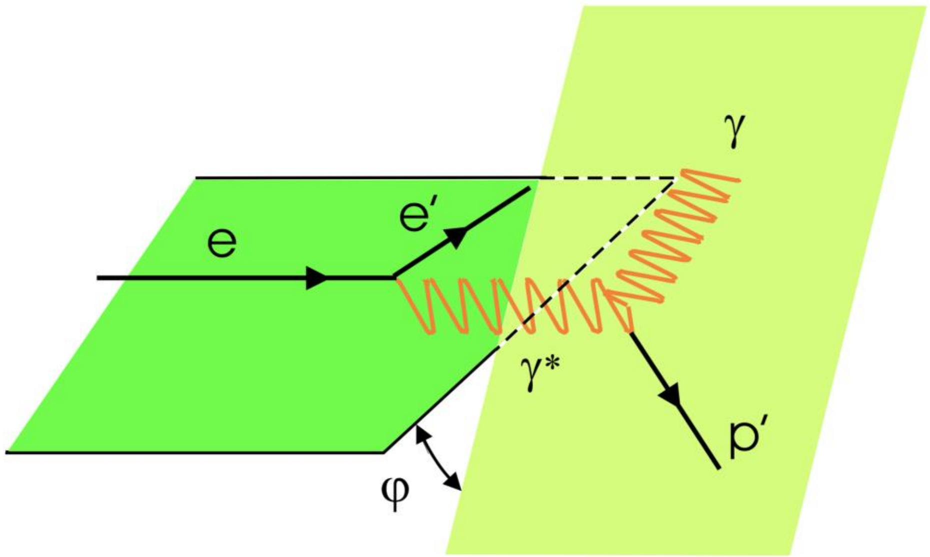


$$\sigma \propto |\mathrm{BH}|^2 + |\mathrm{DVCS}|^2 + Interference$$

DVCS process and BH process entangle → Need to separate each term to extract the GPDs

Deeply Virtual Compton Scattering





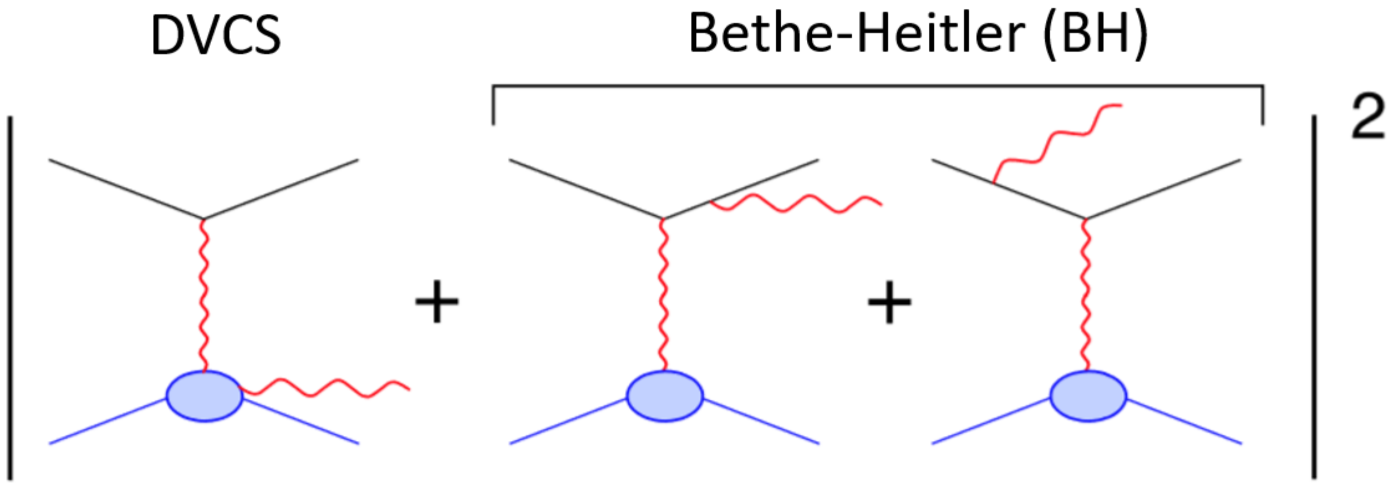
$$\sigma \propto \left|\mathrm{BH}\right|^2 + \left|\mathrm{DVCS}\right|^2 + \mathit{Interference}$$

Calculable from QED

~ 1

$$\sim \frac{1+\cos\varphi}{P_1(\varphi)P_2(\varphi)}$$

Deeply Virtual Compton Scattering



$$I \propto (E_b/\nu)^3$$

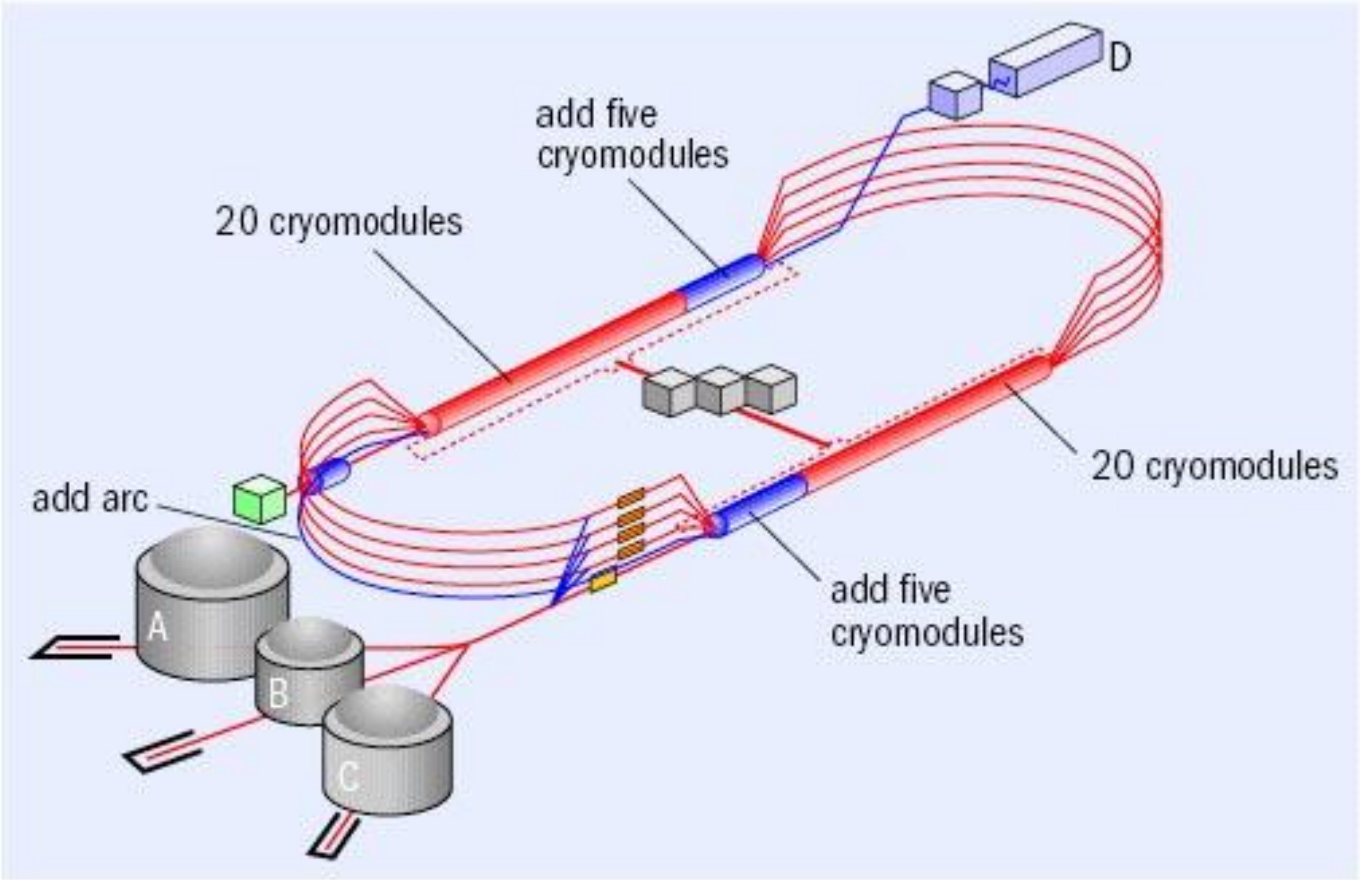
$$|\mathrm{DVCS}|^2 \propto (E_b/\nu)^2$$

At fixed Q^2 and $\nu = Q^2/(2Mx_B)$

$$\sigma \propto |\mathrm{BH}|^2 + |\mathrm{DVCS}|^2 + \mathit{Interference}$$

Calculable from QED

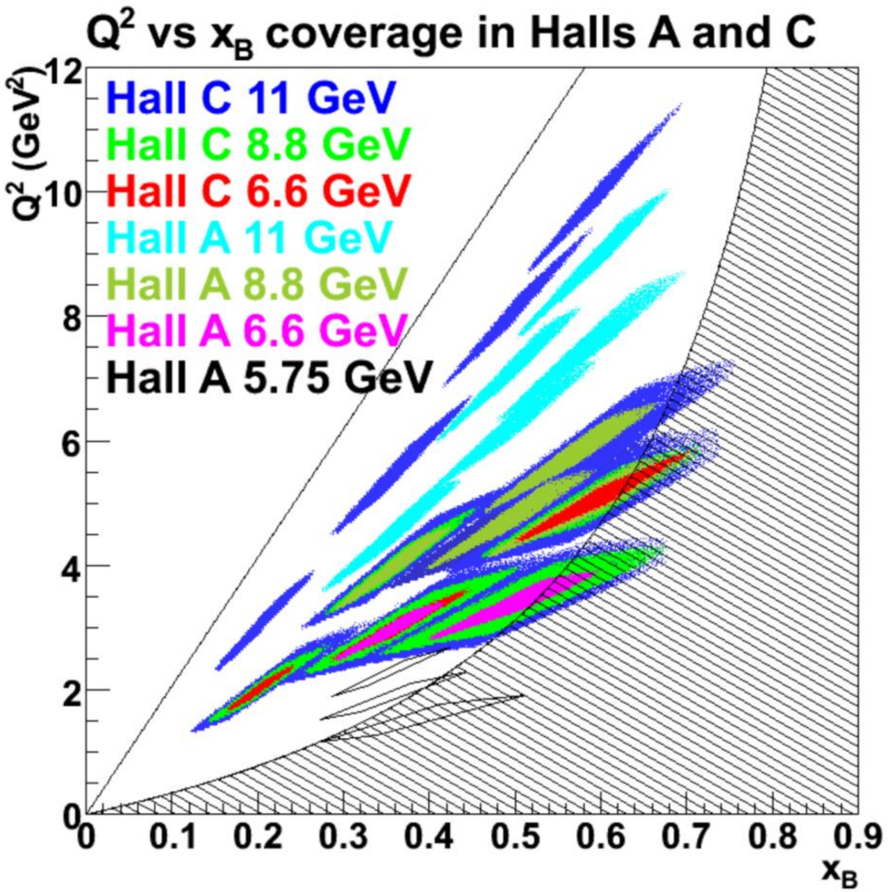
Jefferson Lab.



<<Thomas Jefferson National Accelerator Facility>>

- Newport News, Virginia, USA
- 12 GeV continuous electron beam
- Hall A, B, C and D
  - Each hall has different setups
  - A : High momentum resolution
  - B : High acceptance
  - C : High momentum reach
  - D : 12 GeV Photon beam

DVCS experiments in Hall C



<<Kinematic region accessible by JLab 11GeV beam>>

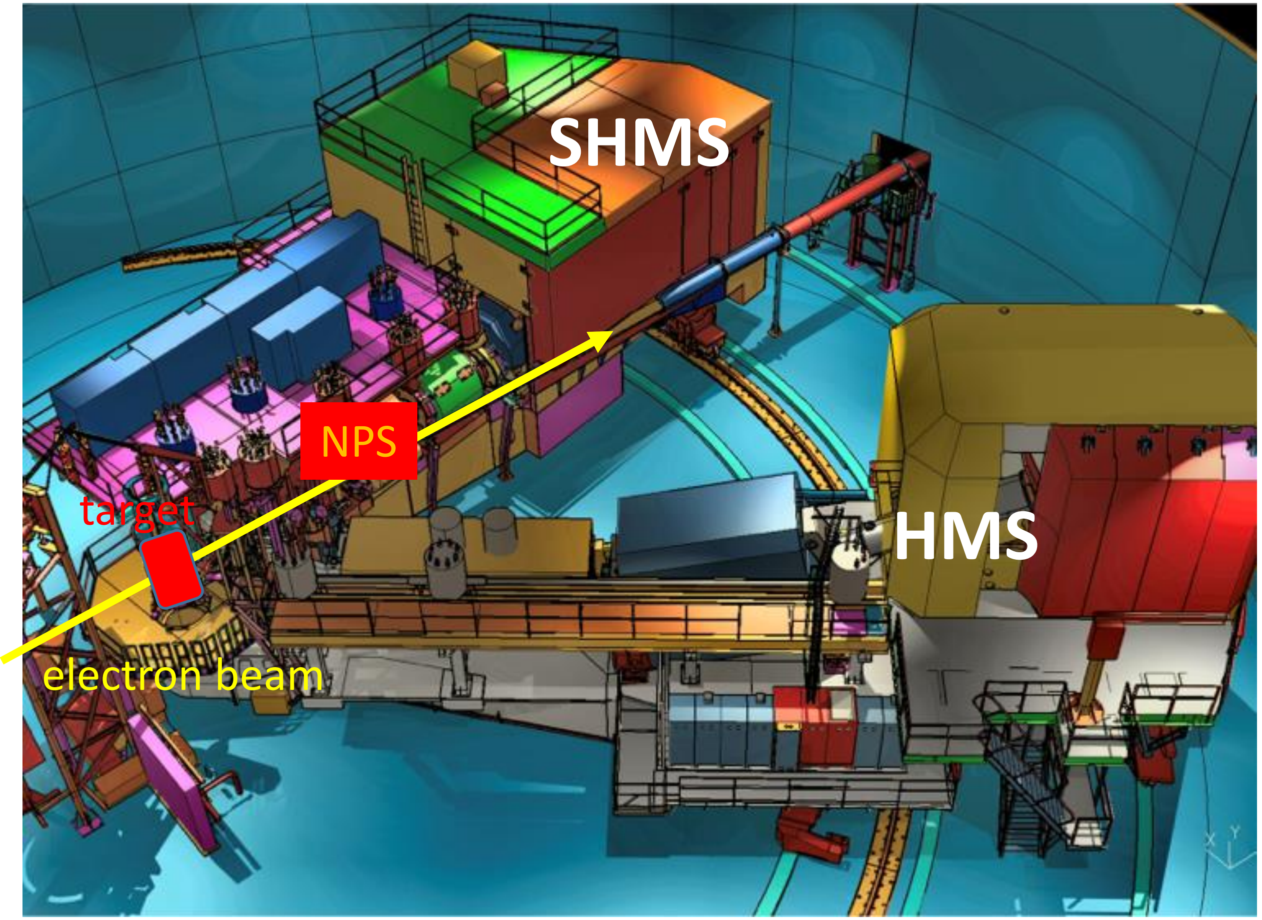
Need a full kinematic region to better understand the GPDs

- Reach higher Q^2
  : further test the Q^2 dependence of the observables
- Different beam energies
  : separate $|\mathrm{DVCS}|^2$ and *Interference* term
- Reach lower value of x_B
  : Cross-check with CLAS, CLAS12 and COMPASS

→Highest precision data in the kinematic domain accessible with a 11GeV beam

Neutral Particle Spectrometer(NPS) in Hall C

Hall C focusing spectrometers

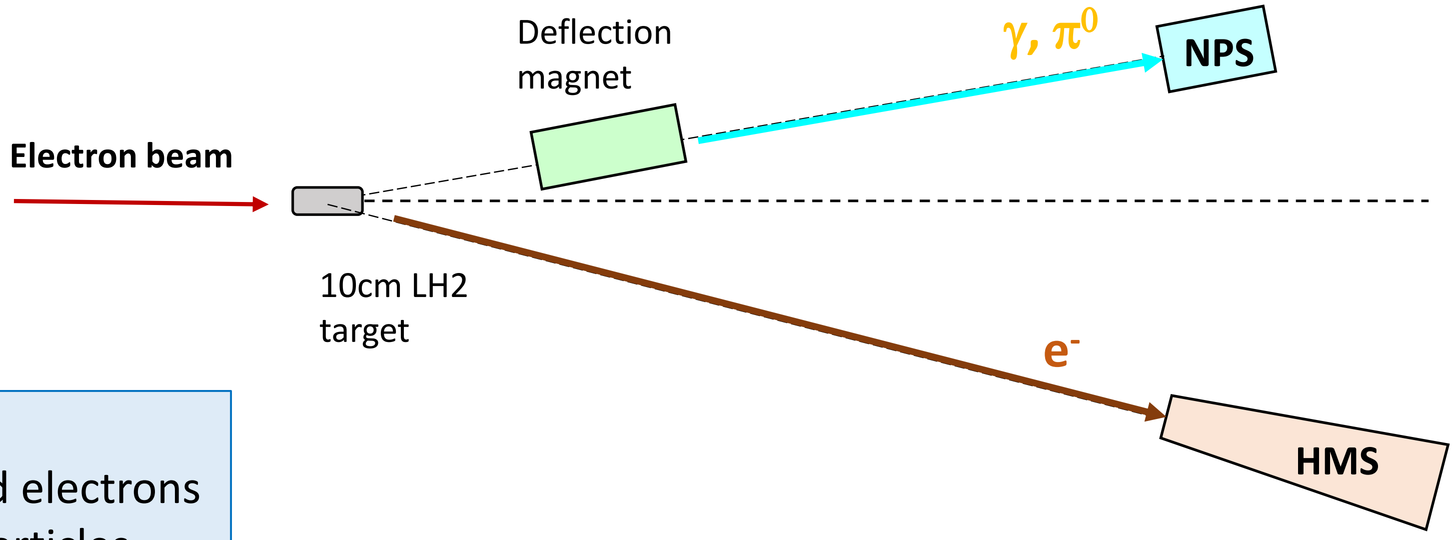


- Neutral Particle Spectrometer replaces one of the Hall C focusing spectrometers in the experiments

- HMS (existing 6 GeV era)
  - Has been recommissioned for 12 GeV

HMS : High Momentum Spectrometer
SHMS : Super High Momentum Spectrometer

Experimental Technique



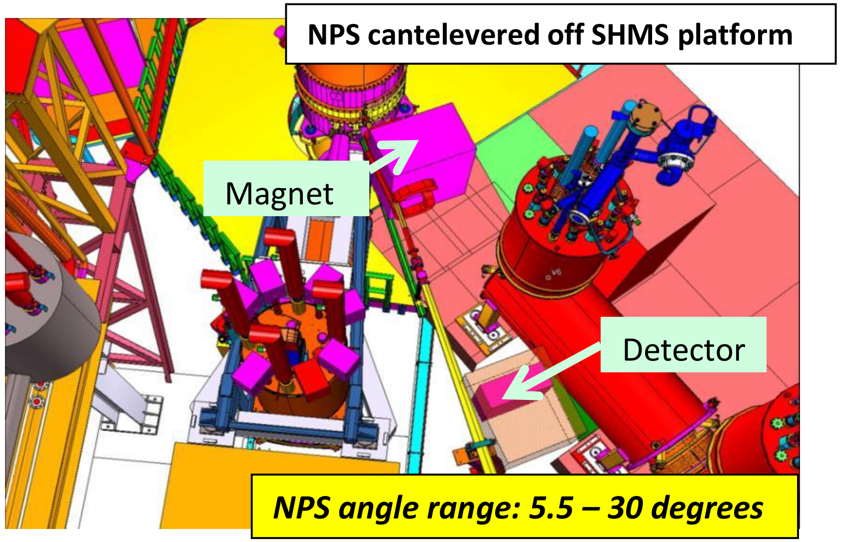
Trigger: HMS, HMS+NPS

HMS: 1 MHz (max)

NPS: 86 MHz (max)

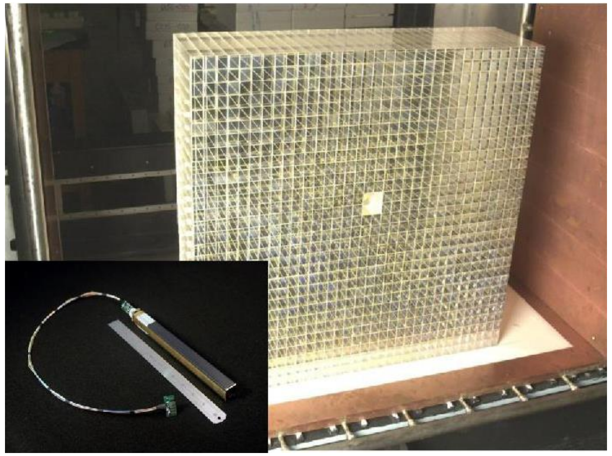
In DVCS:
HMS detects scattered electrons
NPS detects neutral particles

- ❑ NPS angle reach between 5.5 and 30 degrees
- ❑ NPS allows for precision (coincidence) cross section measurements of neutral particles (γ and π^0).

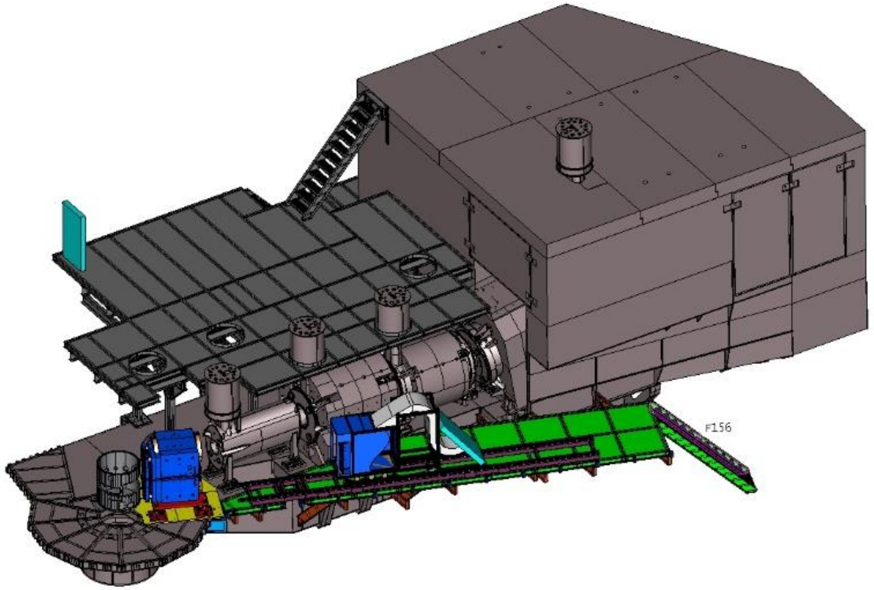


Neutral Particle Spectrometer(NPS)

- ~25 msr neutral particle detector consisting of ~1080 **$PbWO_4$ crystals** in a temperature-controlled frame including gain monitoring and curing systems – outer layers of 30x36 crystal matrix only to catch showers

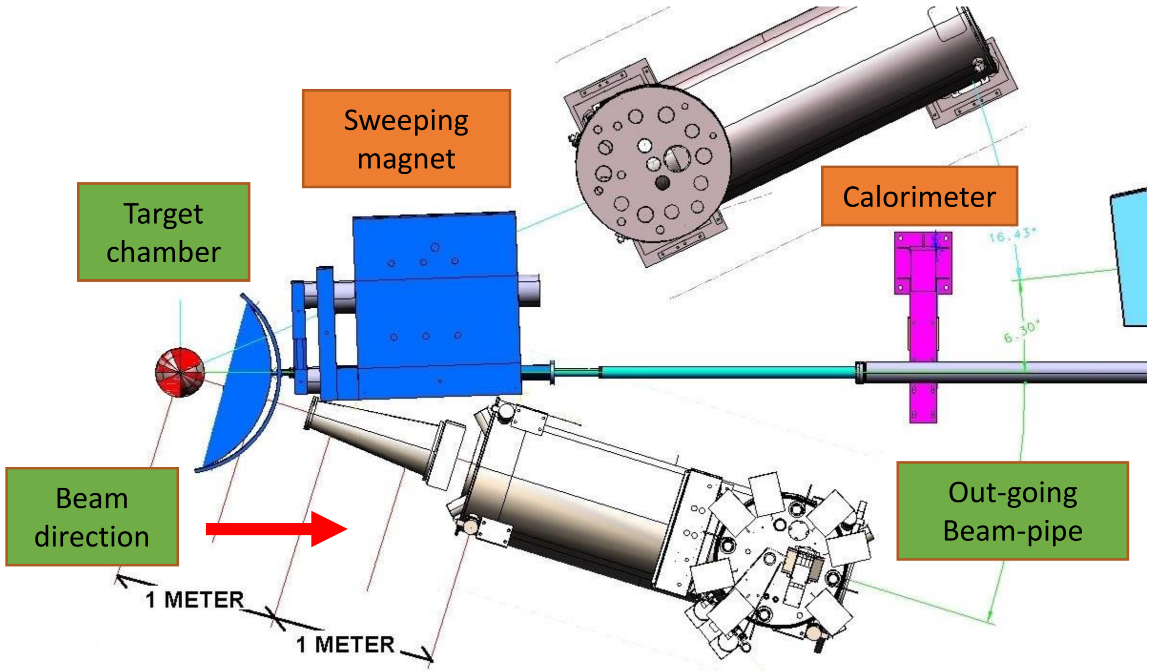


- HV distribution bases with built-in amplifiers for operation in a high-rate environment
- Essentially deadtime-less digitizing electronics to independently sample the entire pulse form for each crystal – JLab-developed Flash ADCs
- 0.3Tm sweeping magnet allowing for small-angle and large angle operation at 0.6 Tm. The magnet is compatible with existing JLab power supplies.



- Cantilevered platforms off the SHMS carriage to allow for remote rotation (in the small angle range), and platforms to be on the SHMS carriage (in the large angle range)
- A beam pipe with as large critical angle as possible to reduce beamline-associated backgrounds – only a small section needs modification

Sweeping Magnet

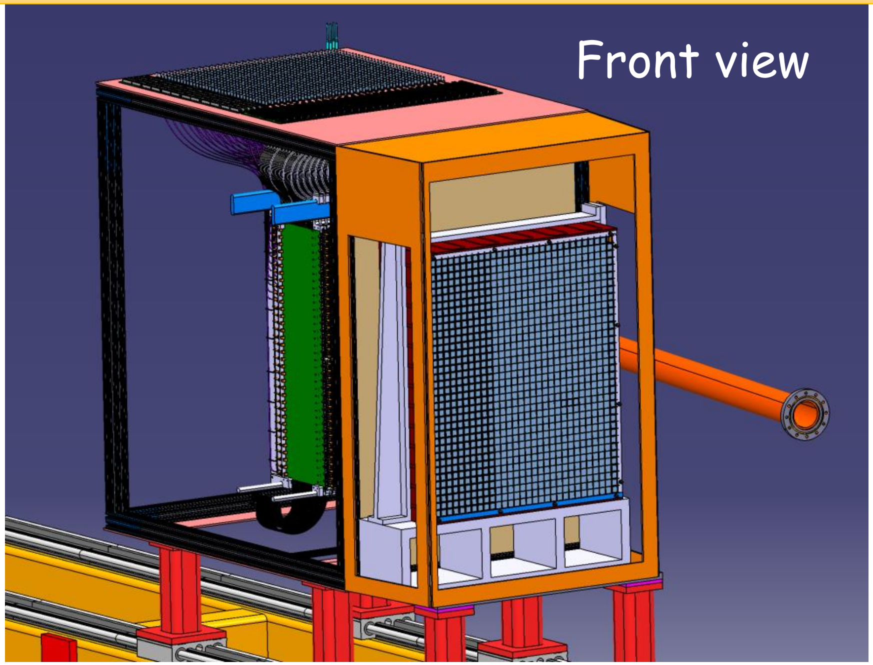


Highest luminosity($\sim 10^{38} cm^{-2} sec^{-1}$) of DVCS ever before with smallest angle(for the high Q^2 data) possible

- Creates big amount of background to the calorimeter
  → Introduce sweeping magnet to reduce the background

Supported by NSF MRI 1530874: <u>CUA (lead)</u>, OU, ODU

Calorimeter



- 30x36 (1080) $PbWO_4$ crystals (2x2x20 cm^3)
- Hamamatsu R4125 PMTs
- Custom-made active bases

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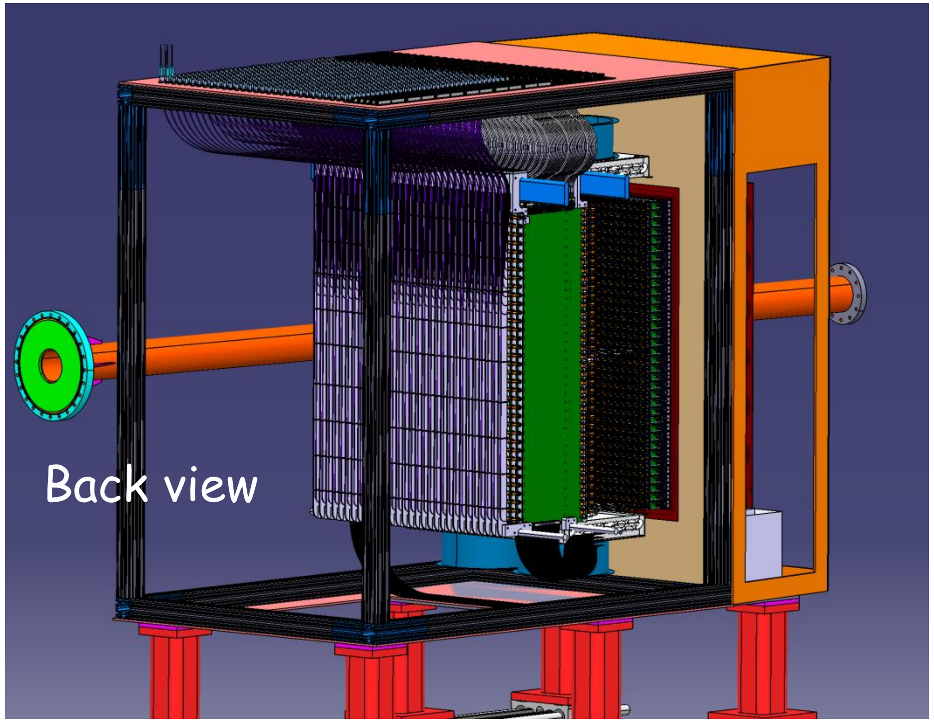
+ NSF MRI 1530874:
<u>CUA (lead)</u>, OU, ODU

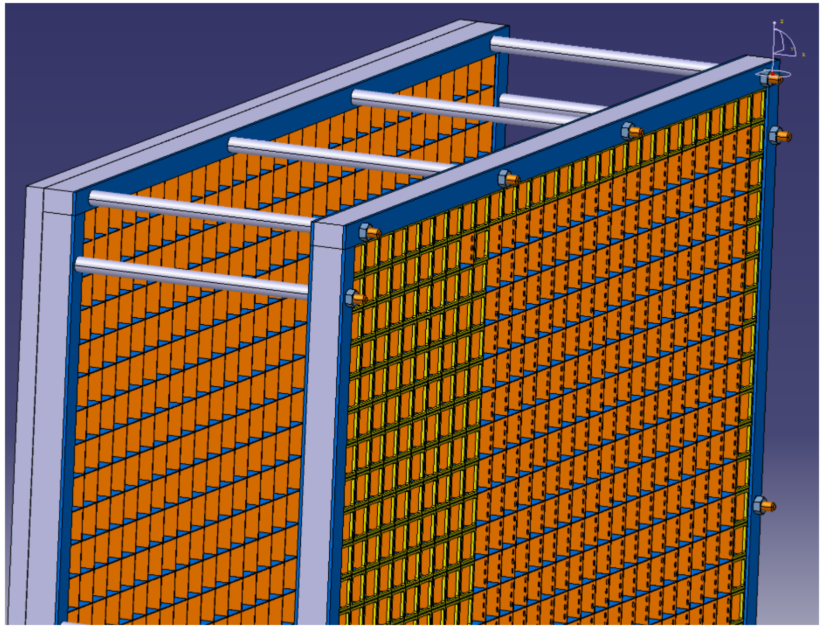
Survey & alignment requirements: ~1mm



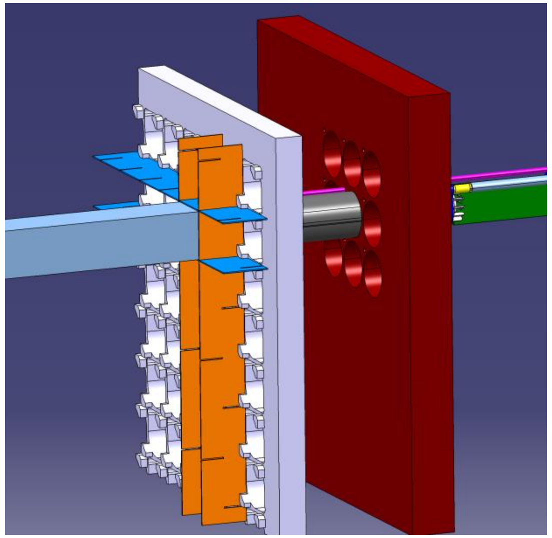
Calorimeter frame:

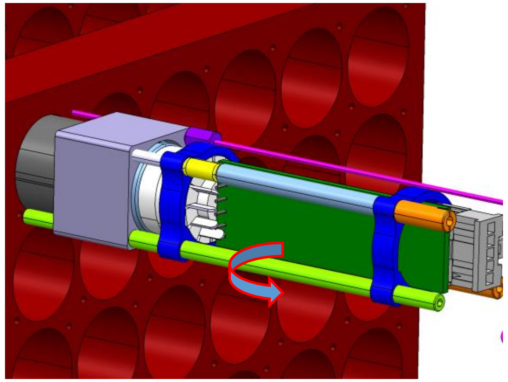
- Crystals placed in a 0.5 mm-thick carbon frame to ensure good positioning
- PMTs accessible from the back side to allow maintenance
- Calibration and radiation curing with blue LED light though quartz optical fiber

Calorimeter carbon frame

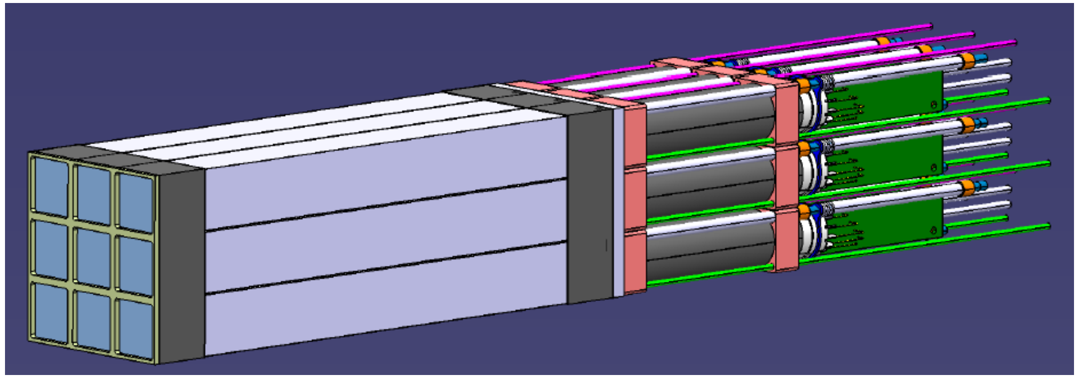


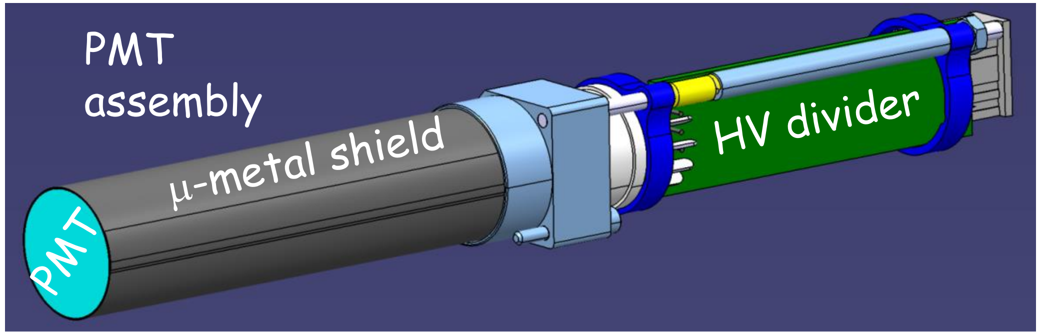
2-cm of C (0.5 mm thick) at the front and back of the crystals





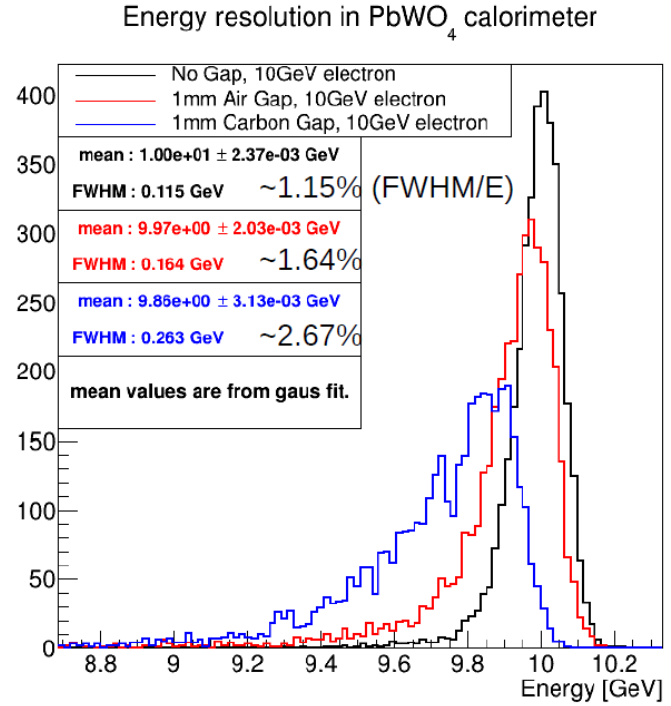
Easy disassembly of PMT block with one long single captive screw

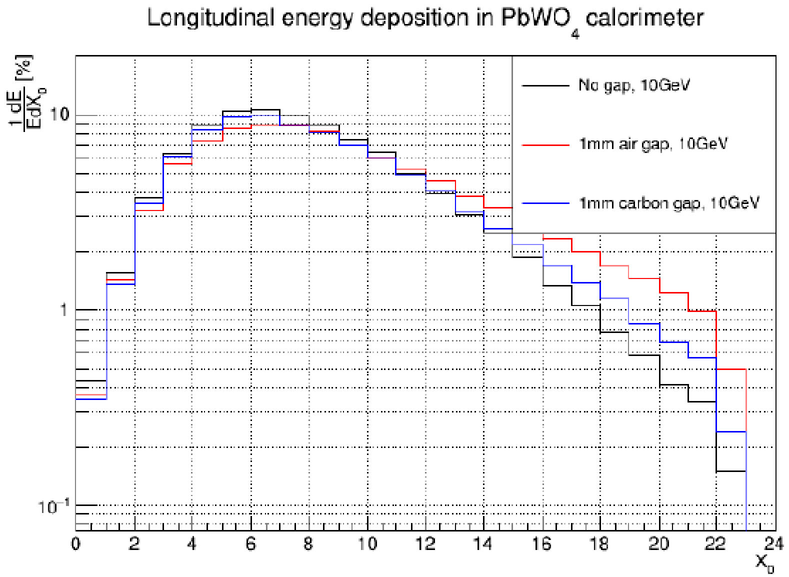


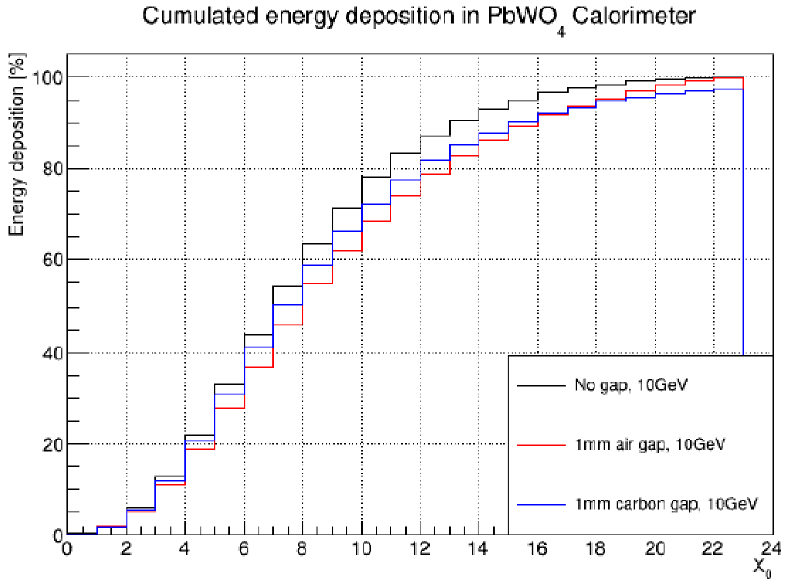


Carbon frame: impact on energy resolution and efficiency

- 1.2% (ideal case) to 1.6% at 10 GeV with 1mm of air between crystals
- More than 97% of energy collected after 22 X_0



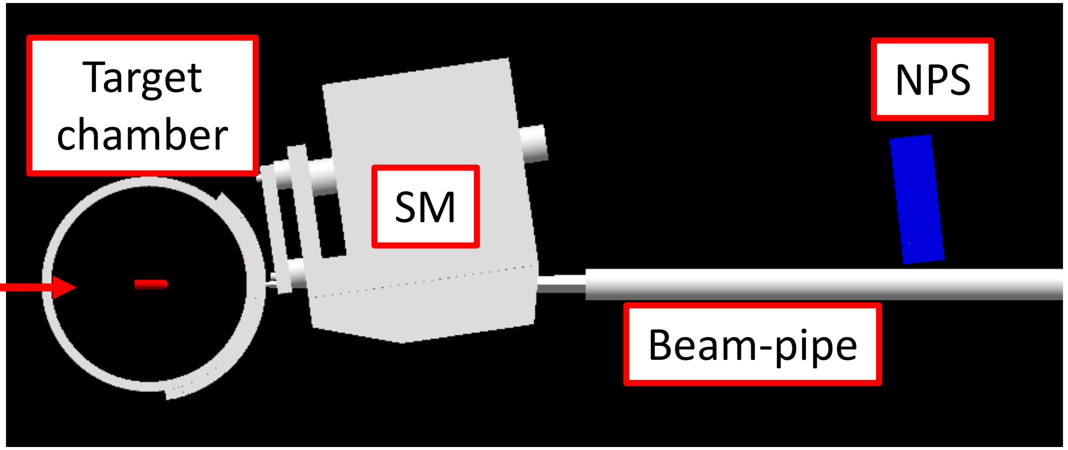


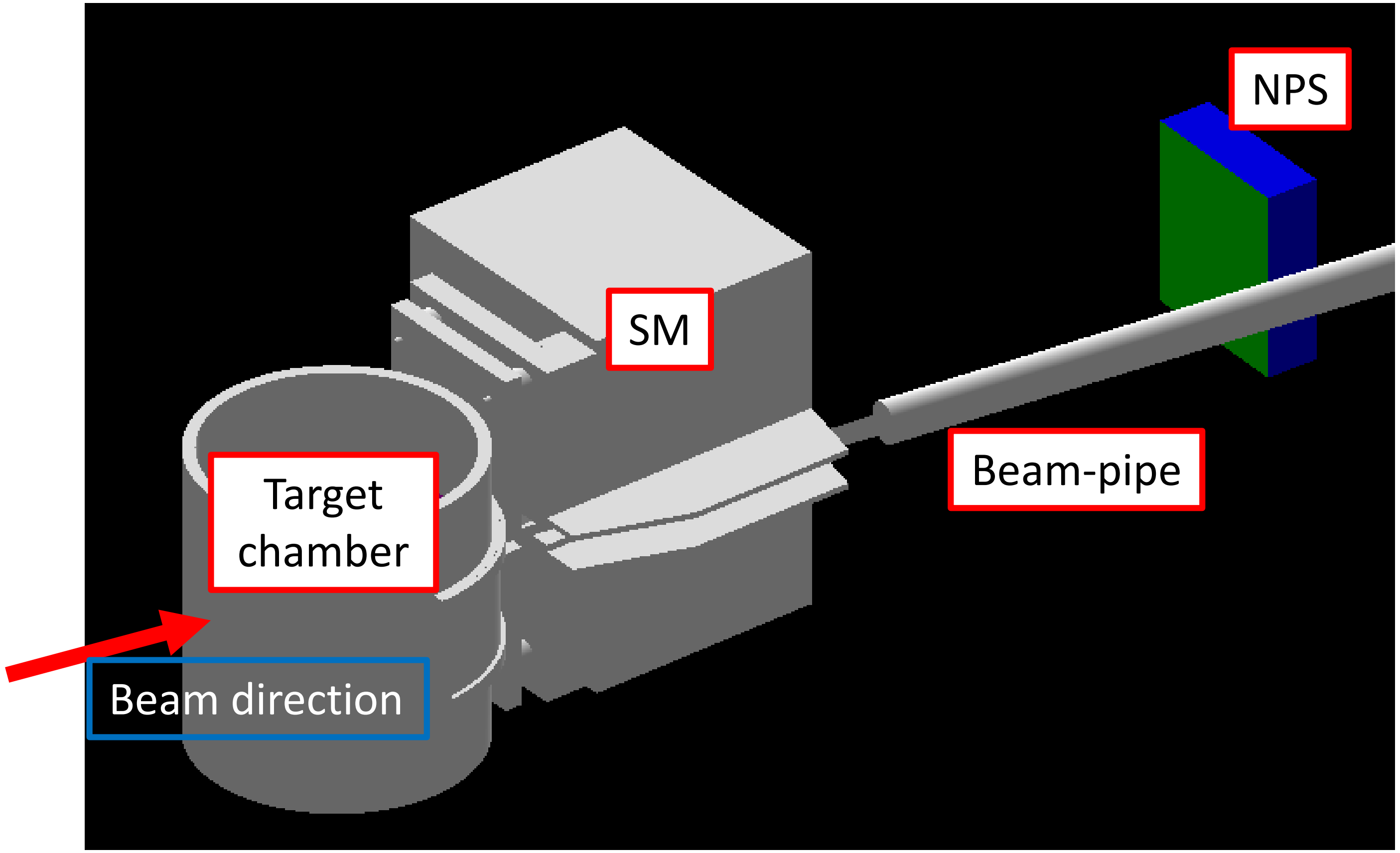


Radiation Environment

<<picture : Geant4 simulation>>

Beam direction





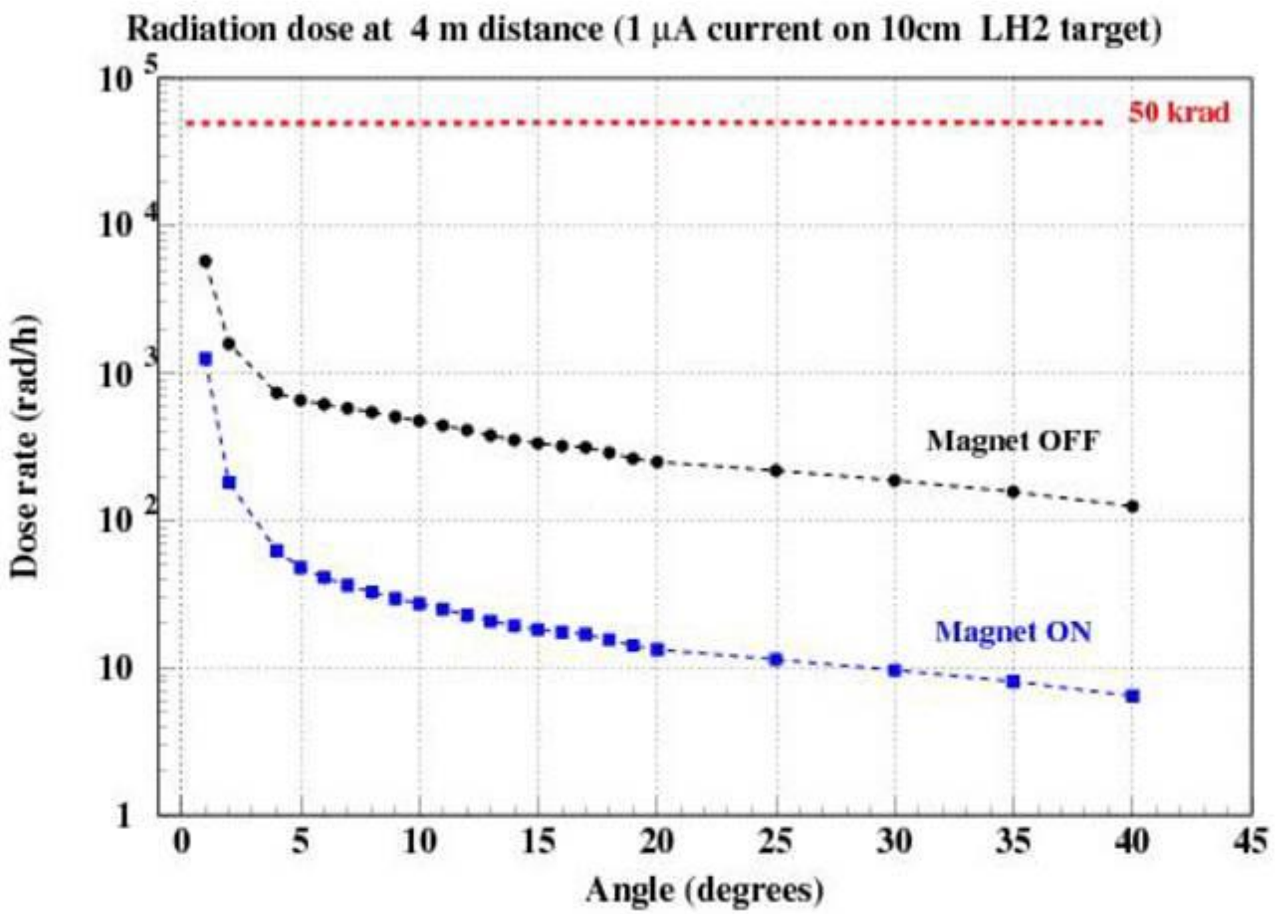
Simulation geometry contains:
- Liquid hydrogen target(red), and its chamber
- NPS(blue & green)
- Beam-pipe
- Sweeping Magnet(SM)(0.3T·m)

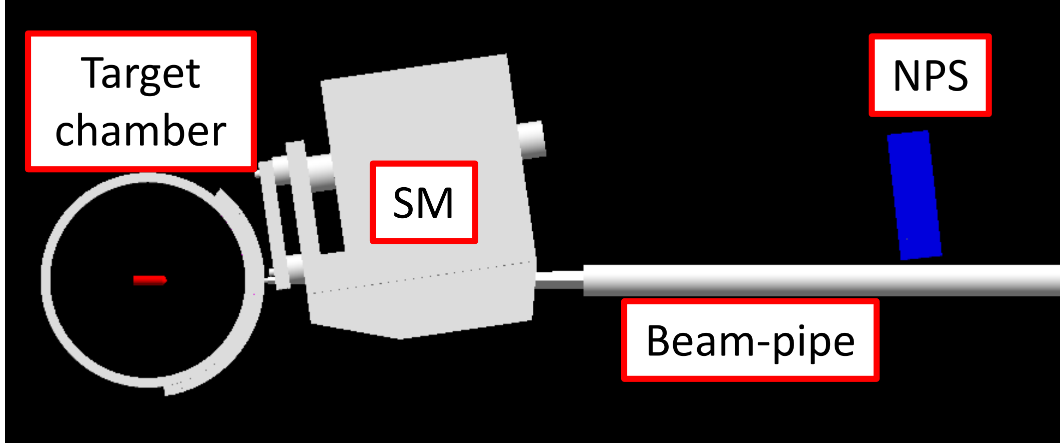
Sweeping magnet :
- Reduces the electromagnetic backgrounds

→ Reach smaller angle

→ Tolerate higher luminosity

Radiation environment





1μA beam in 15cm Liquid hydrogen target
(approximate luminosity : ~2× $10^{36} cm^{-2} s^{-1}$)
NPS placed 4m away from the target

After about 50kRad, crystals are expected to be in need of curing

Sweeping magnet :

- Reduces the dose rate about an order or more of magnitude

→ Reach smaller angle

→ Tolerate higher luminosity

$PbWO_4$ Crystal Specification Categories

- Visual

  - Defects such as chips, scratches, discoloration, chemical films, chamfers
- Geometry

  - Tolerances, planarity, perpendicularity, chamfers, surface
- Optical Properties

  - Transmittance (L, T), Light Yield, decay time
- Radiation hardness

  - Induced absorption, recovery

$PbWO_4$ Crystal Testing Facilities

$PbWO_4$ Crystal Testing Facilities

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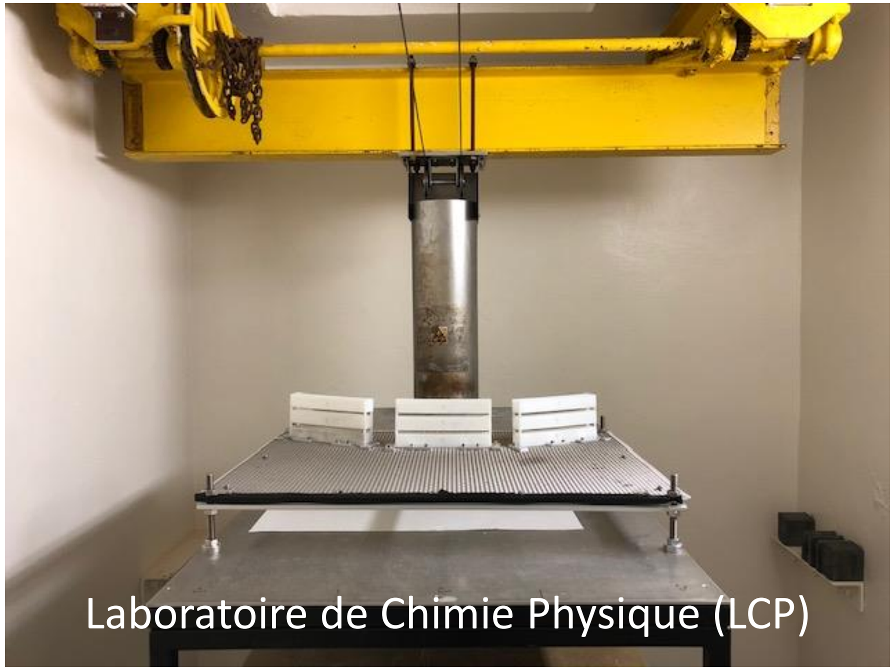
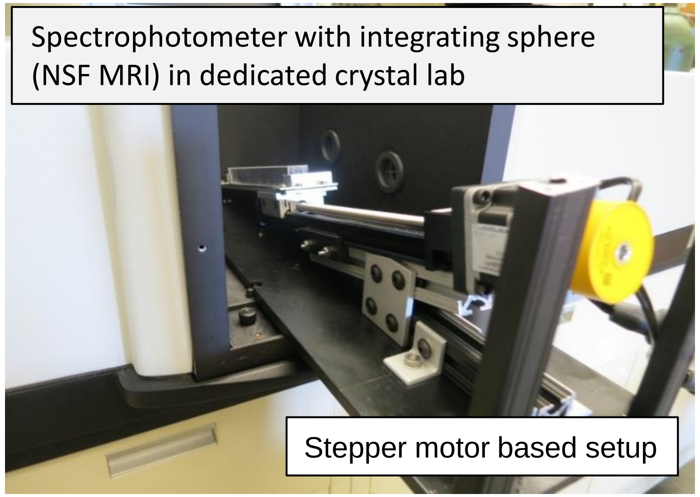
- ❑ Optical Transmittance (L/T)
- ❑ Radiation Hardness

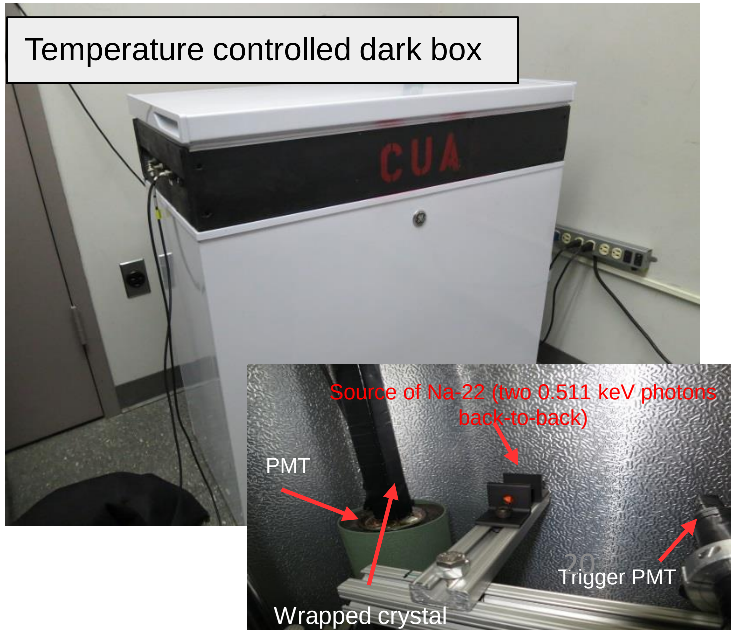


- 222TBq Co_{60} source
- Vary the distance from the source to change the dose rate
- Can simultaneously irradiate 9 crystals

CUA

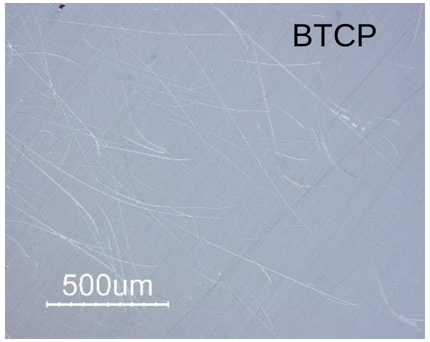
- ❑ Visual inspection
- ❑ Mechanical dimensions
- ❑ Optical Transmittance (L/T)
- ❑ Light yield and timing
- ❑ Chemical and surface analysis
- ❑ Irradiation, Xray

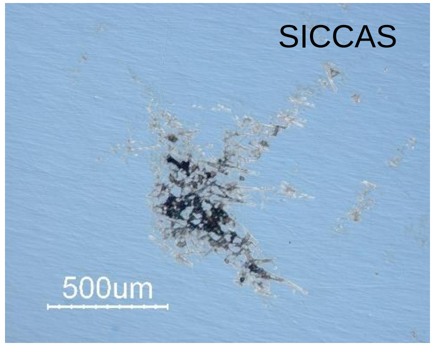


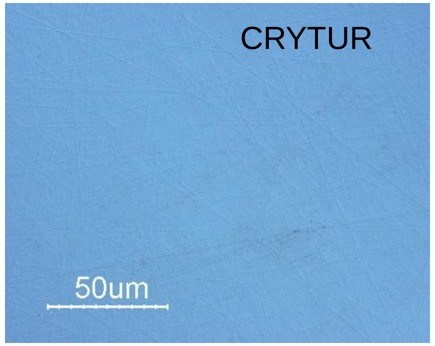


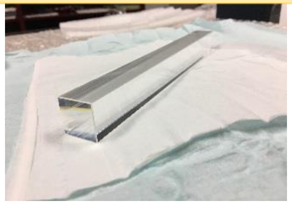
$PbWO_4$ - Example Surface Quality

- Typical crystal surface quality





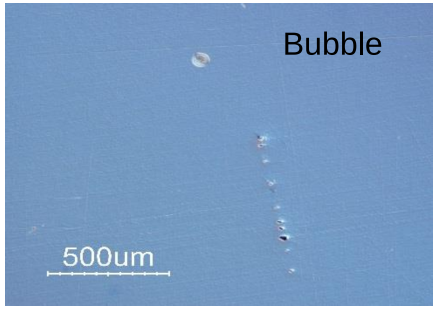


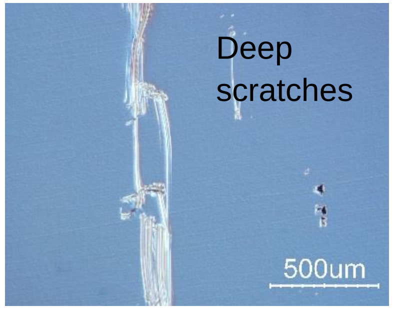


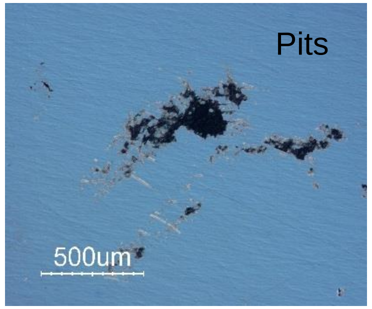
Measurements: scanning microscope in collaboration with VSL

  - Scratches applied in a well-defined manner may benefit crystal properties

- Looking deeper into defects: SICCAS 2017 crystals



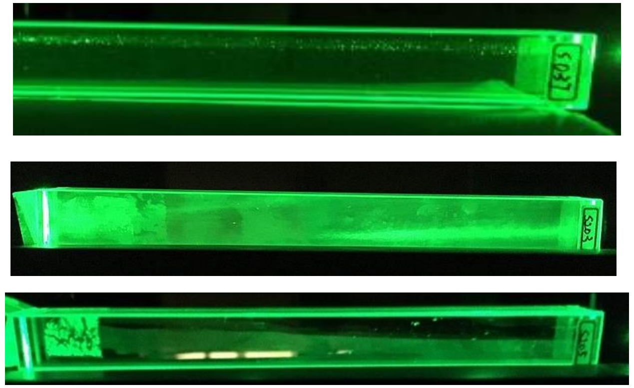




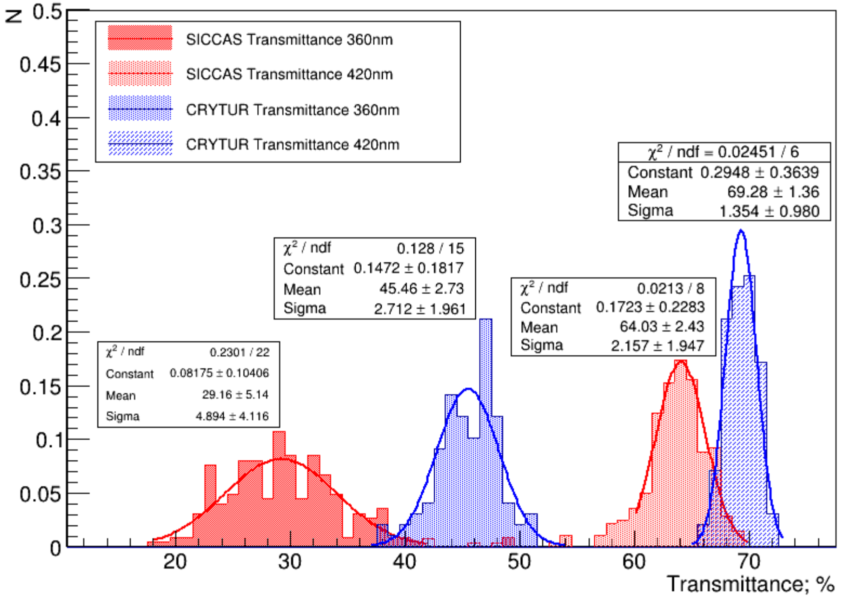
  - Defects result in high, but non-uniform light yield

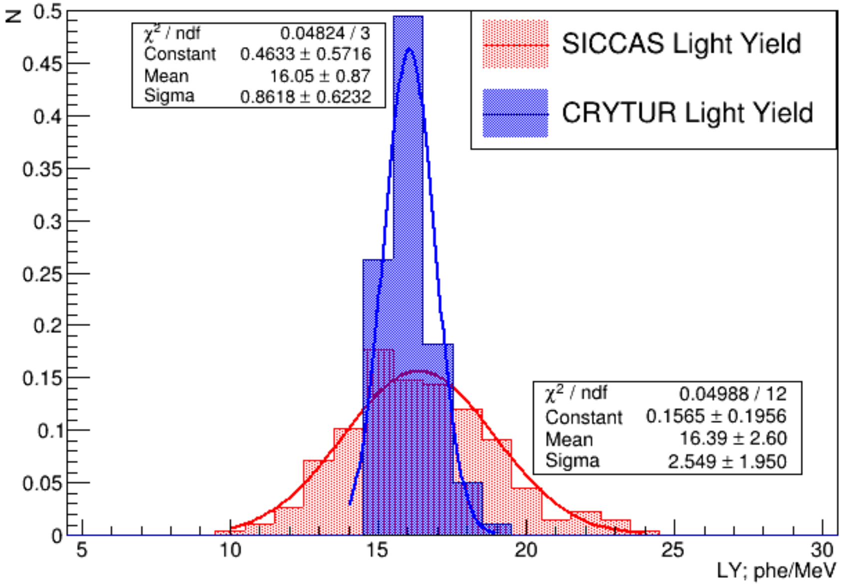
$PbWO_4$ - Example Optical Quality

- **<u>Two Vendors</u>**: SICCAS (China) and Crytur (Czech Republic)
- In general, distribution of SICCAS crystal properties are broader than those of Crytur crystals – not as uniform



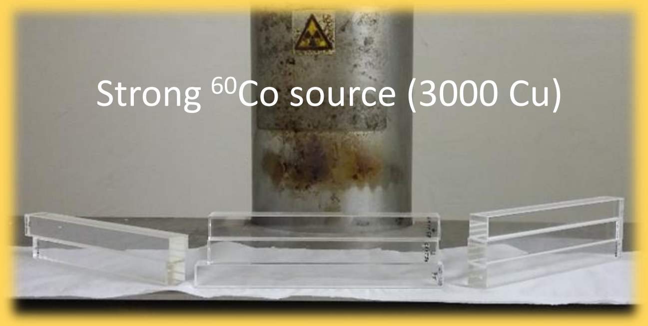
Visual properties of crystals correlated with optical ones

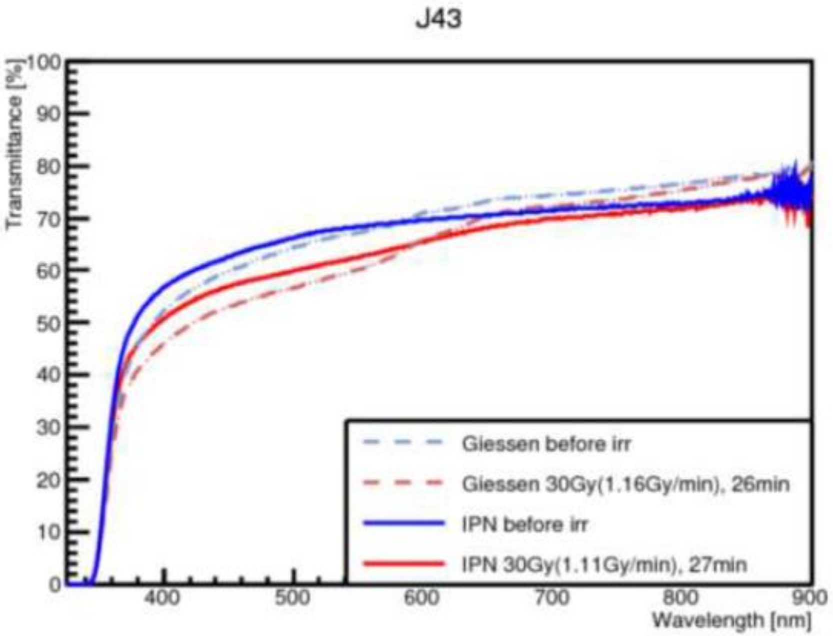


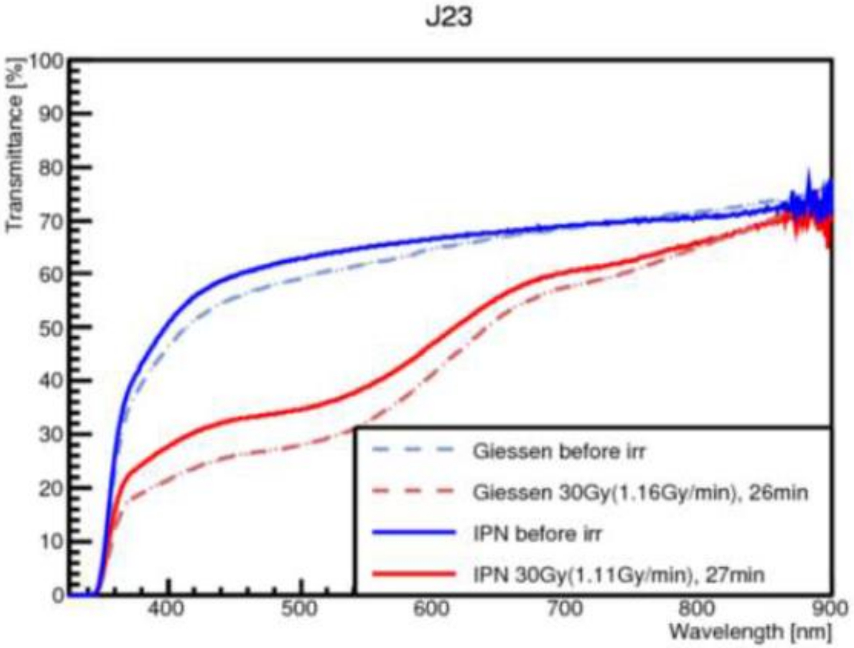


Irradiation and Curing Tests

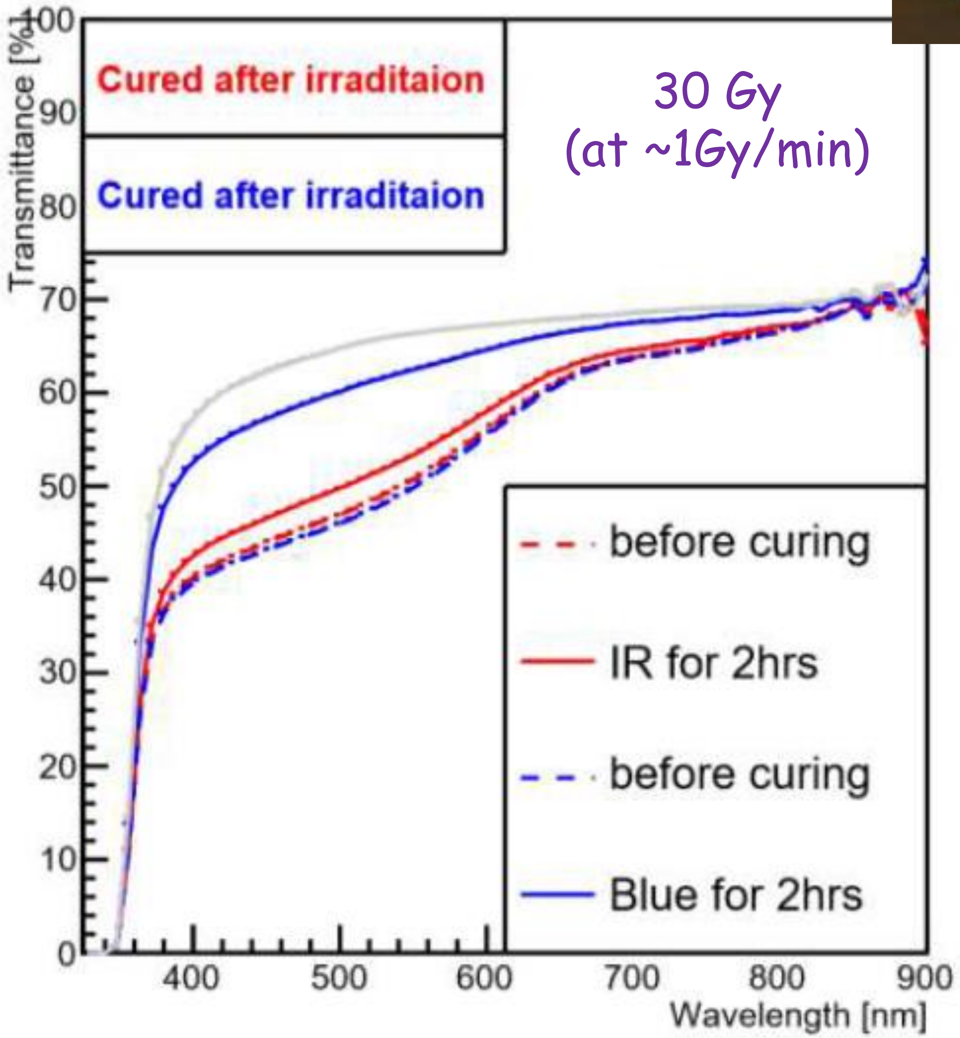
Radiation hardness measurements





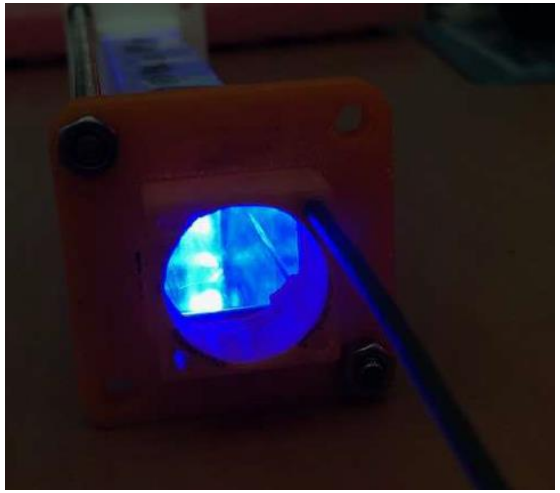


Irradiation and Curing Tests



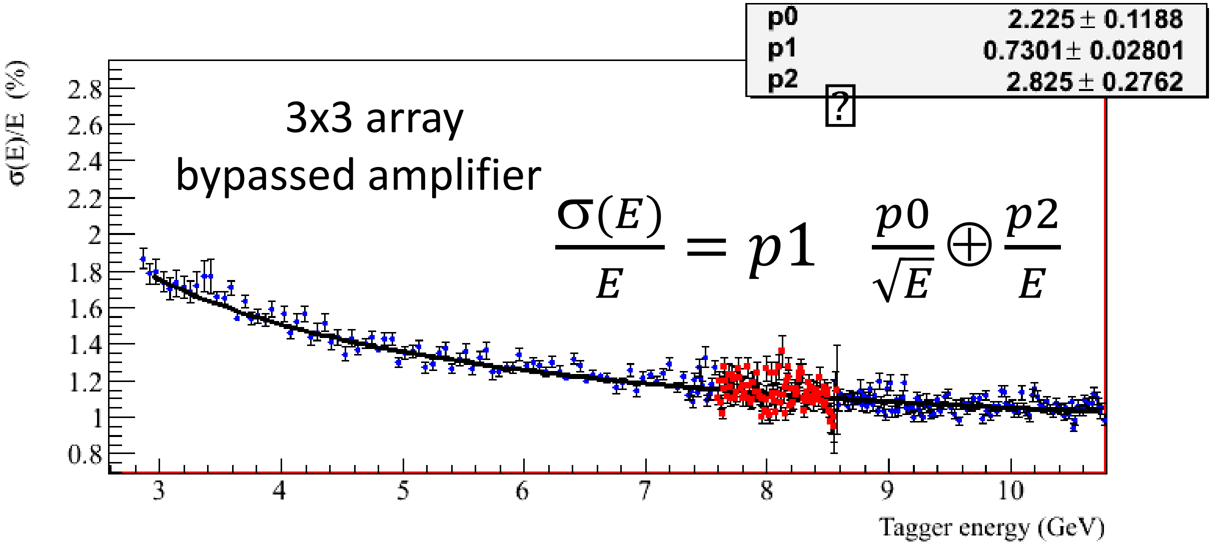
Radiation damage recovered with a few hours of blue light curing

Blue LED optical bleaching

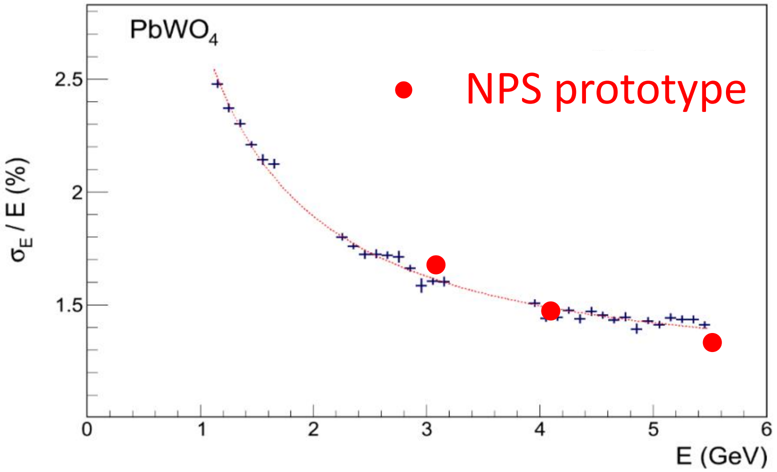


Energy resolution of prototype

NPS Prototype



HyCal



- Relatively good energy resolution.
- Consistent with Hall B HyCal, constructed with SICCAS crystals

More details can be found in GlueX-doc-3590, GlueX-doc-3998, V. Berdnikov, A.Somov, J. Crafts

Summary

- DVCS access to the GPDs
- DVCS experiments in Hall C will exploit vast kinematic region and cross check Hall A, CLAS, HERMES and COMPASS data
- NPS is needed in Hall C in order to perform the DVCS experiment
- NPS construction is in progress
- Assembly and tests at Jlab can start from September 2020

Spin – off: NPS prospects Glass Scintillators

- 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