Development of NPS for the DVCS experiments in Hall C at Jefferson Lab

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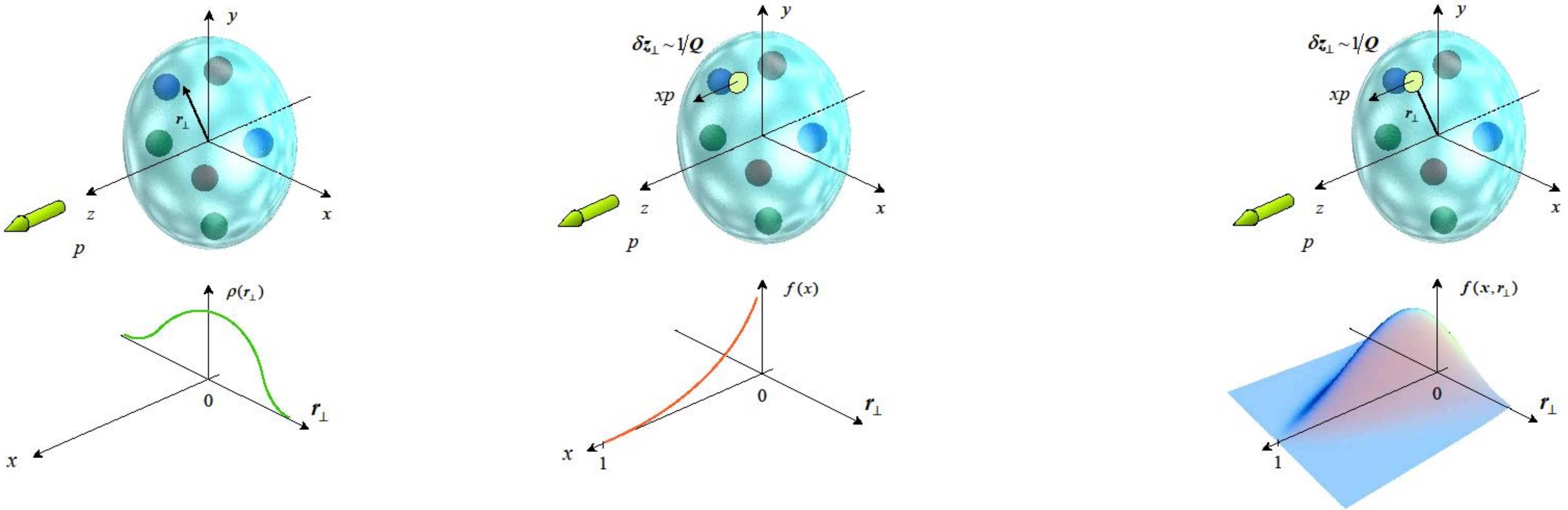
HADRON2019

Session 6: QCD and hadron structure

Outline

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

Generalized Parton Distributions



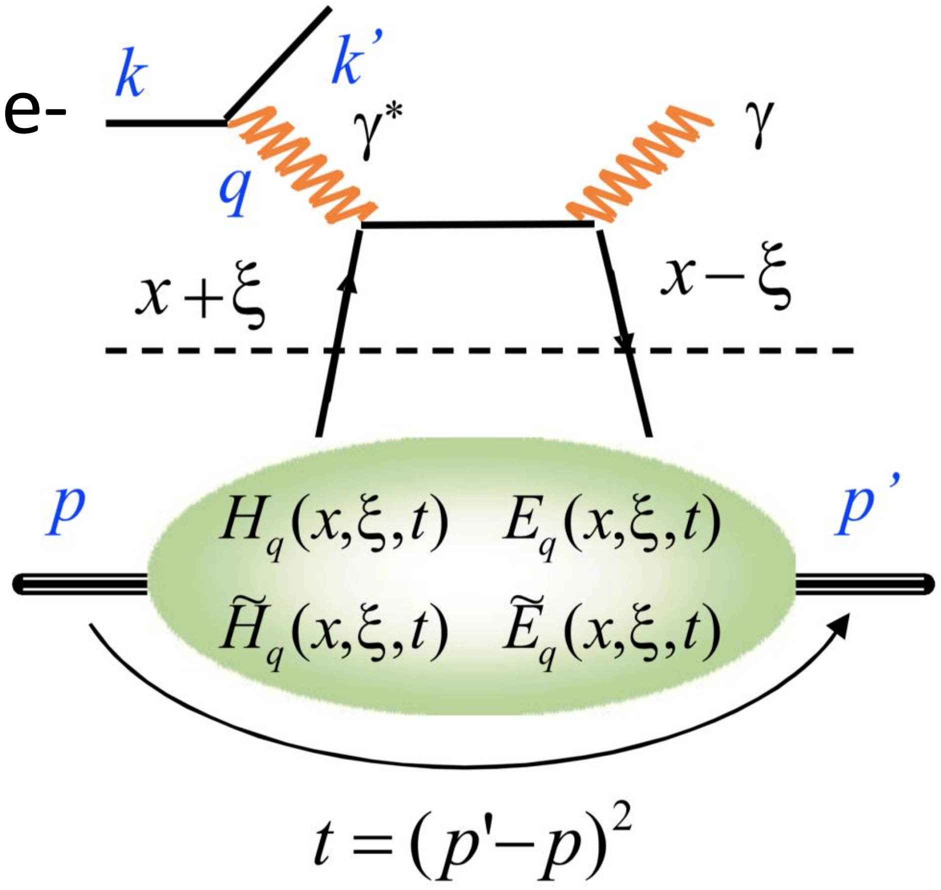
Form Factors:
<u>via elastic scattering</u>
-charge & magnetization spatial distribution

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

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

Deeply Virtual Compton Scattering

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



Hard Part

Soft Part

Bjorken limit

$$Q^2 \rightarrow \infty$$

$$\nu \rightarrow \infty$$

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

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

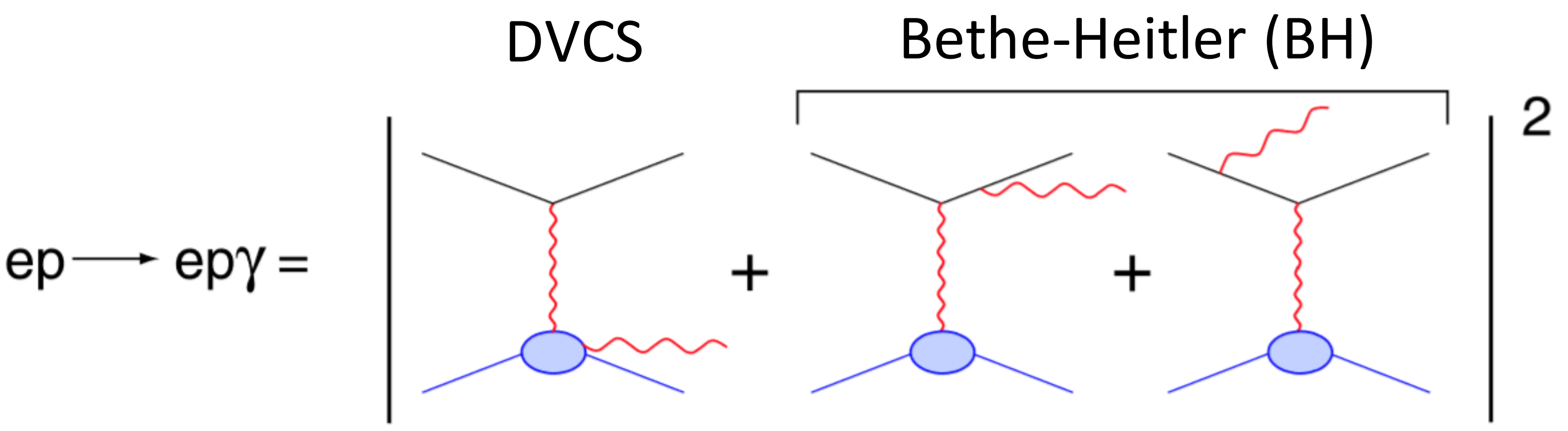
$$\nu = \frac{p \cdot q}{M}$$

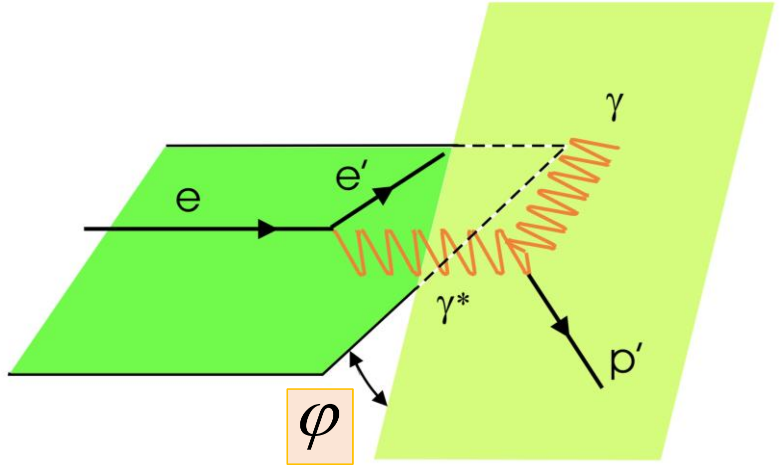
$$\xi \sim \frac{x_B}{2 - x_B}$$

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

<<pictures from thesis of C.Munoz Camacho>>





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

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

- $|\mathrm{BH}|^2$: Calculable from QED
- $|\mathrm{DVCS}|^2$: ~ 1
- Interference: $\sim \dfrac{1+\cos\varphi}{P_1(\varphi)P_2(\varphi)}$

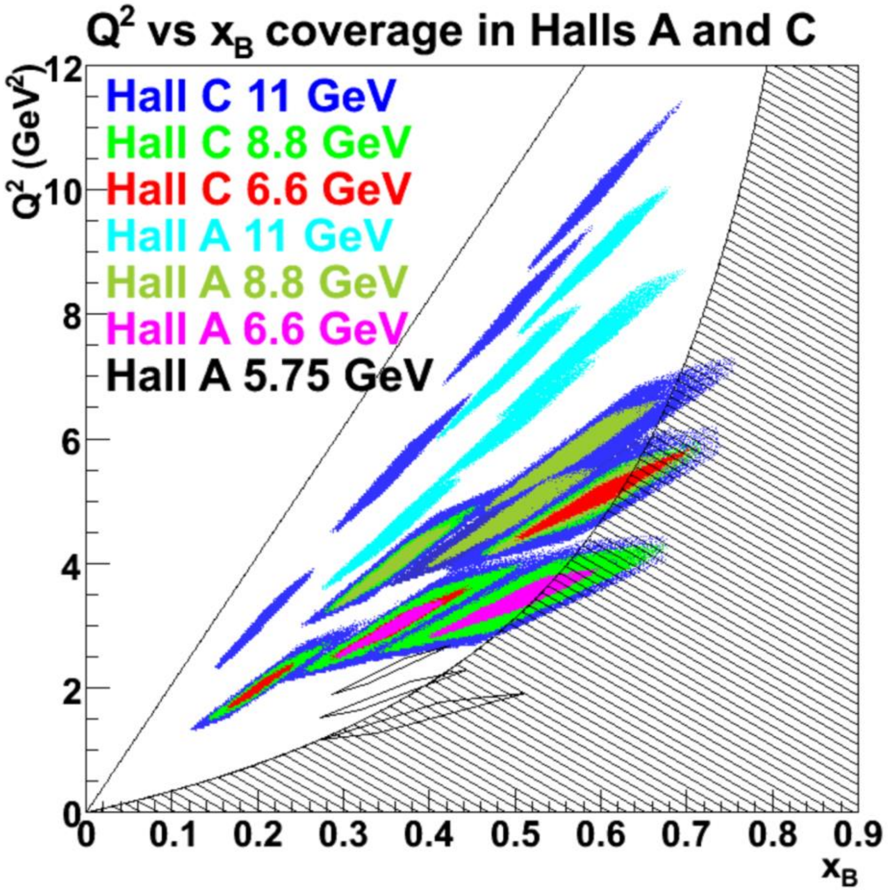
$$I \propto (E_b/\nu)^3$$

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

At fixed Q^2 and ν $= Q^2/(2Mx_B)$

DVCS experiments in Hall C

Thomas Jefferson National Accelerator Facility(Jefferson Lab), Virginia, USA.
12 GeV continuous electron beam. 4 experimental halls with different setups



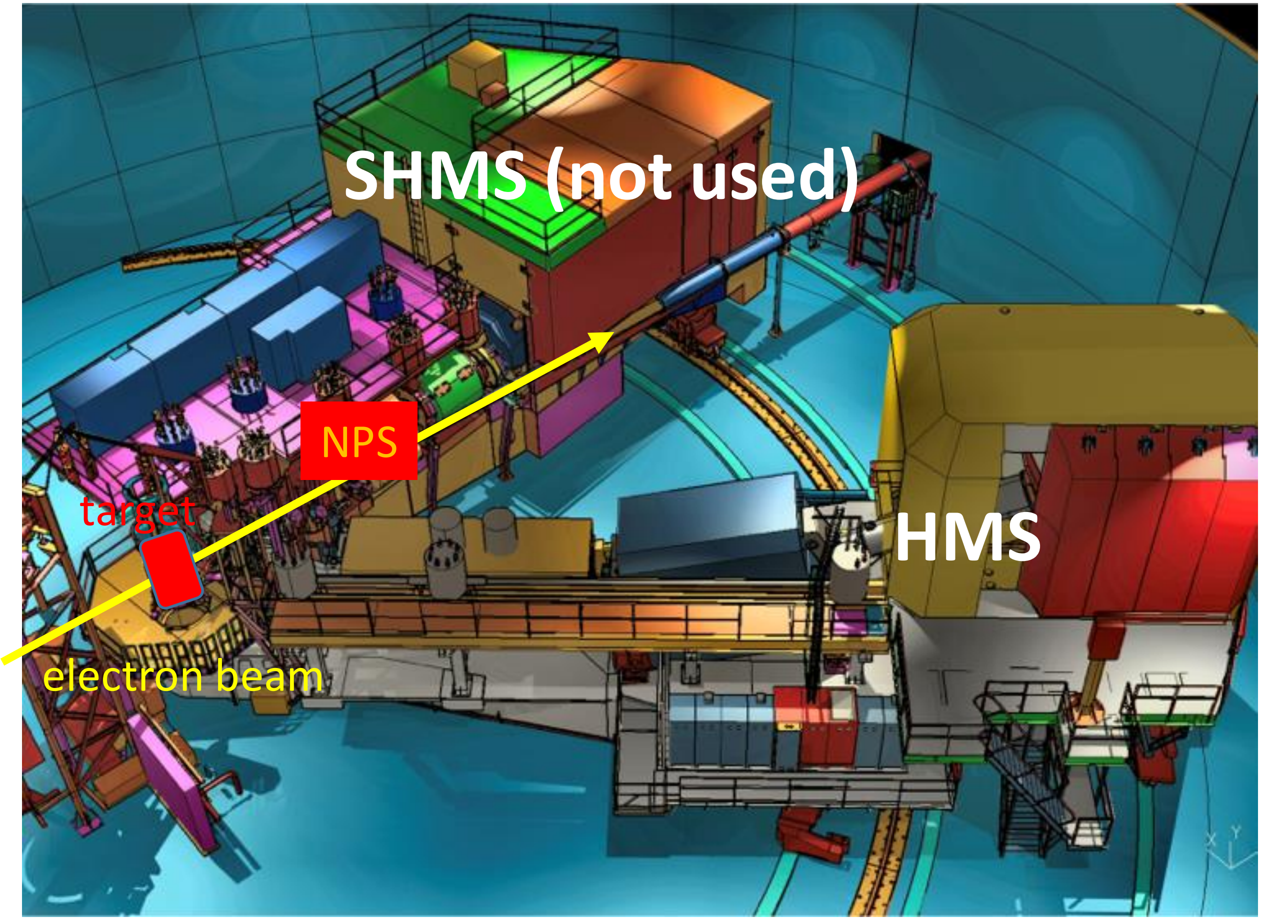
<<Kinematic region accessible by JLab 11GeV beam>>

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 an 11GeV beam

Neutron Particle Spectrometer(NPS) in Hall C



$$e\ p \rightarrow e'p'\gamma$$

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

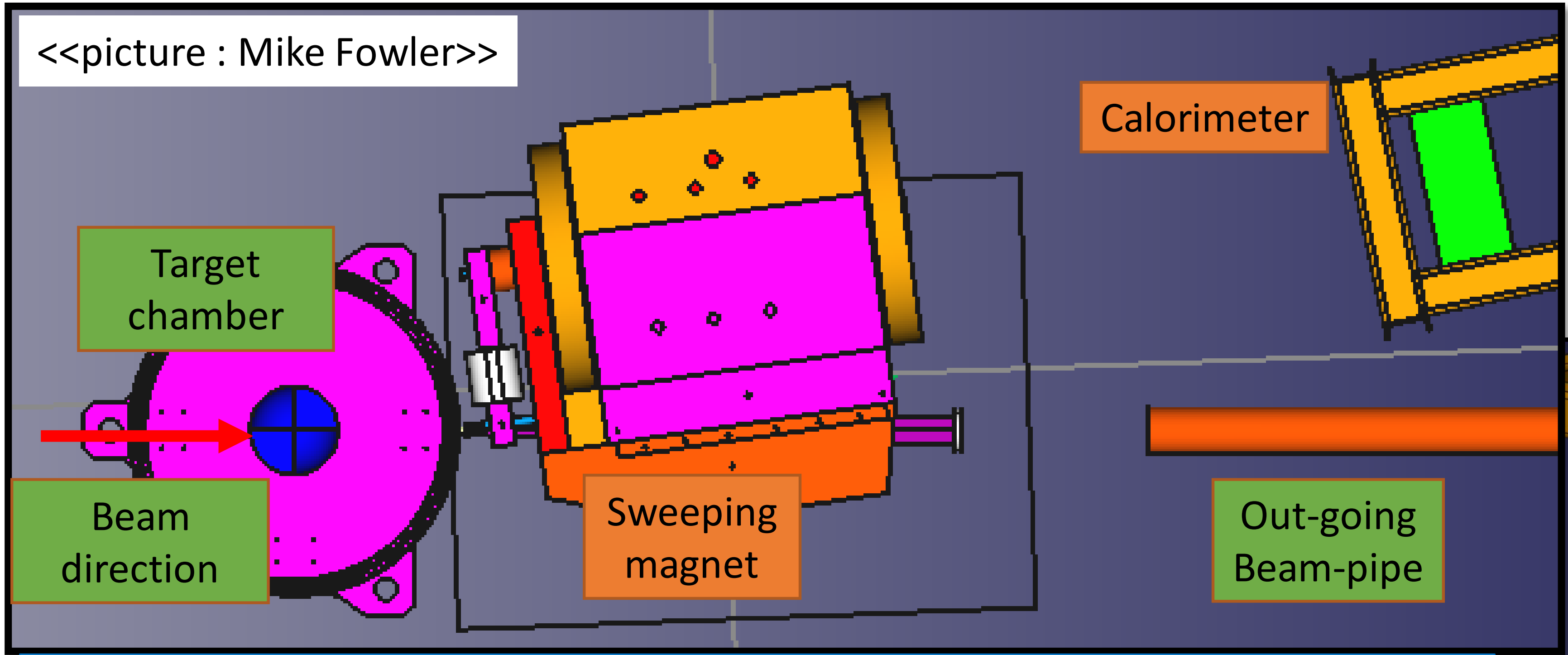
(Exclusive process)

To detect neutral particles (γ , π_0),
NPS will be installed on to the SHMS
SHMS will be used as a cantilever

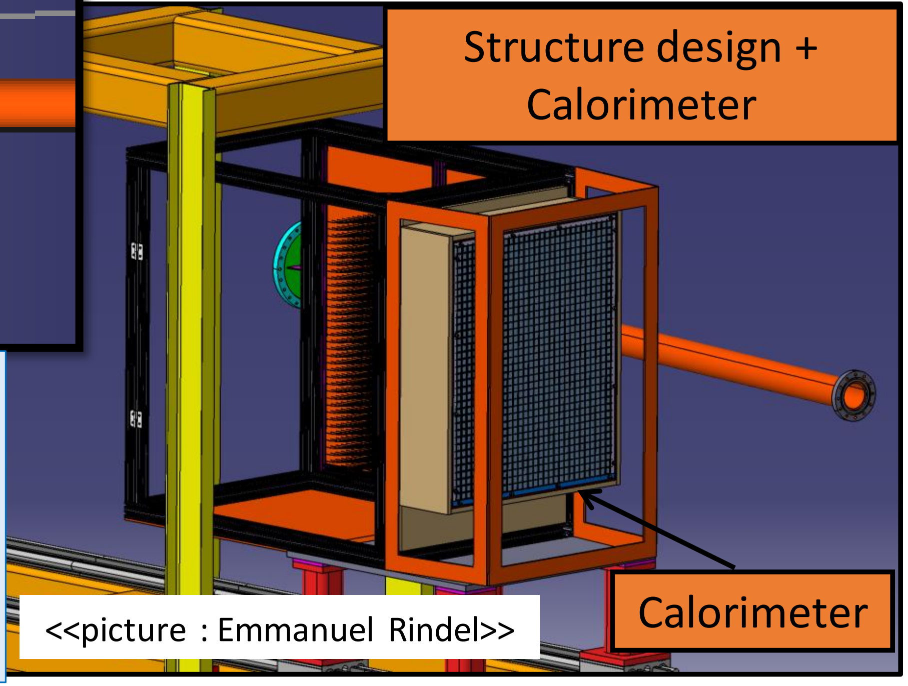
HMS detects scattered electrons
NPS detects neutral particles

HMS : High Momentum Spectrometer
SHMS : Super High Momentum Spectrometer

Neutron Particle Spectrometer(NPS) in Hall C



Calorimeter :
1080 (30X36) $\mathrm{PbWO_4}$ blocks
each crystals : 2X2X20 cm3, ~670 gram



Highest luminosity($\sim 10^{38} cm^{-2} s^{-1}$) 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

Contributions for the NPS

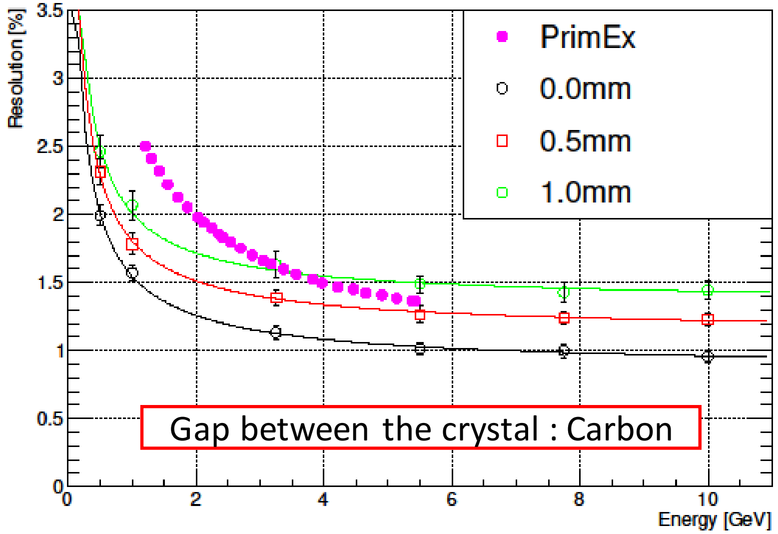
- Geant4 simulation
  - Energy resolution simulation
  - Dose rate calculation
  - Acceptance calculation

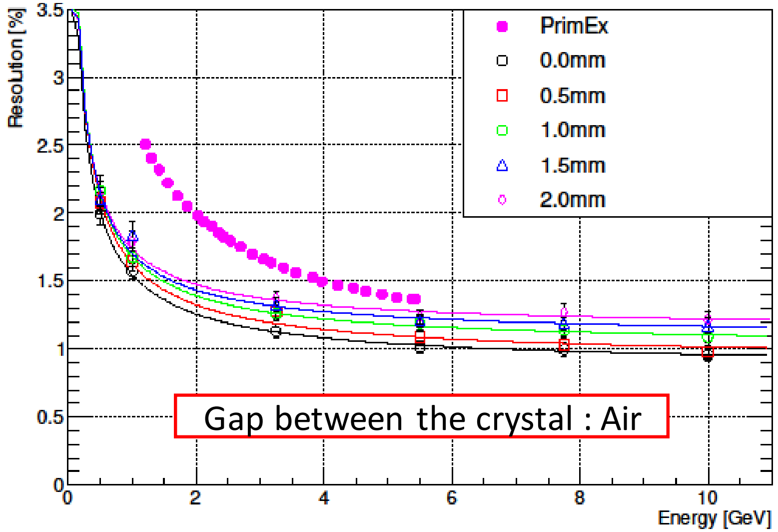
- Optical properties measurement of $PbWO_4$ crystals
  - Radiation hardness measurement
  - Optical bleaching

Geant4 NPS Simulation

- Energy resolution simulation
  - Decision of the design of the NPS
- Radiation dose rate calculation
  - Estimate dose rate on the NPS to take the radiation damage into account
    - How often we need to cure the crystals
    - What is the maximum luminosity we can tolerate
    - Effect of background on detector resolution
- Precise calculation of the detector acceptance
  - Work in progress

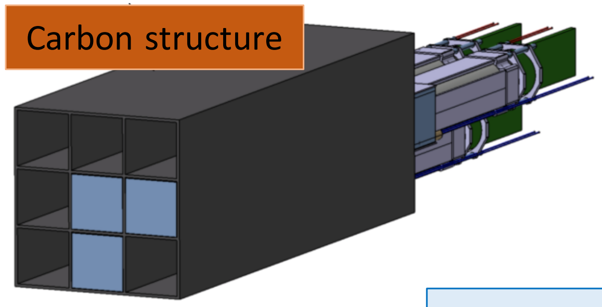
NPS Energy Resolution Simulation





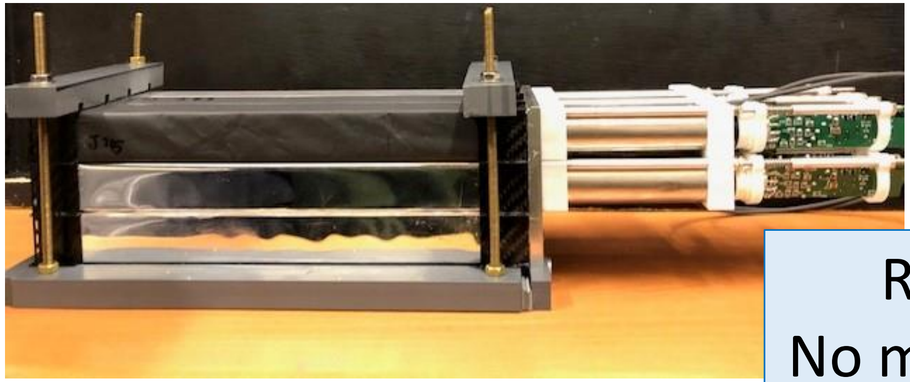
<<PrimEx also used $PbWO_4$ crystals for the calorimeter>>

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



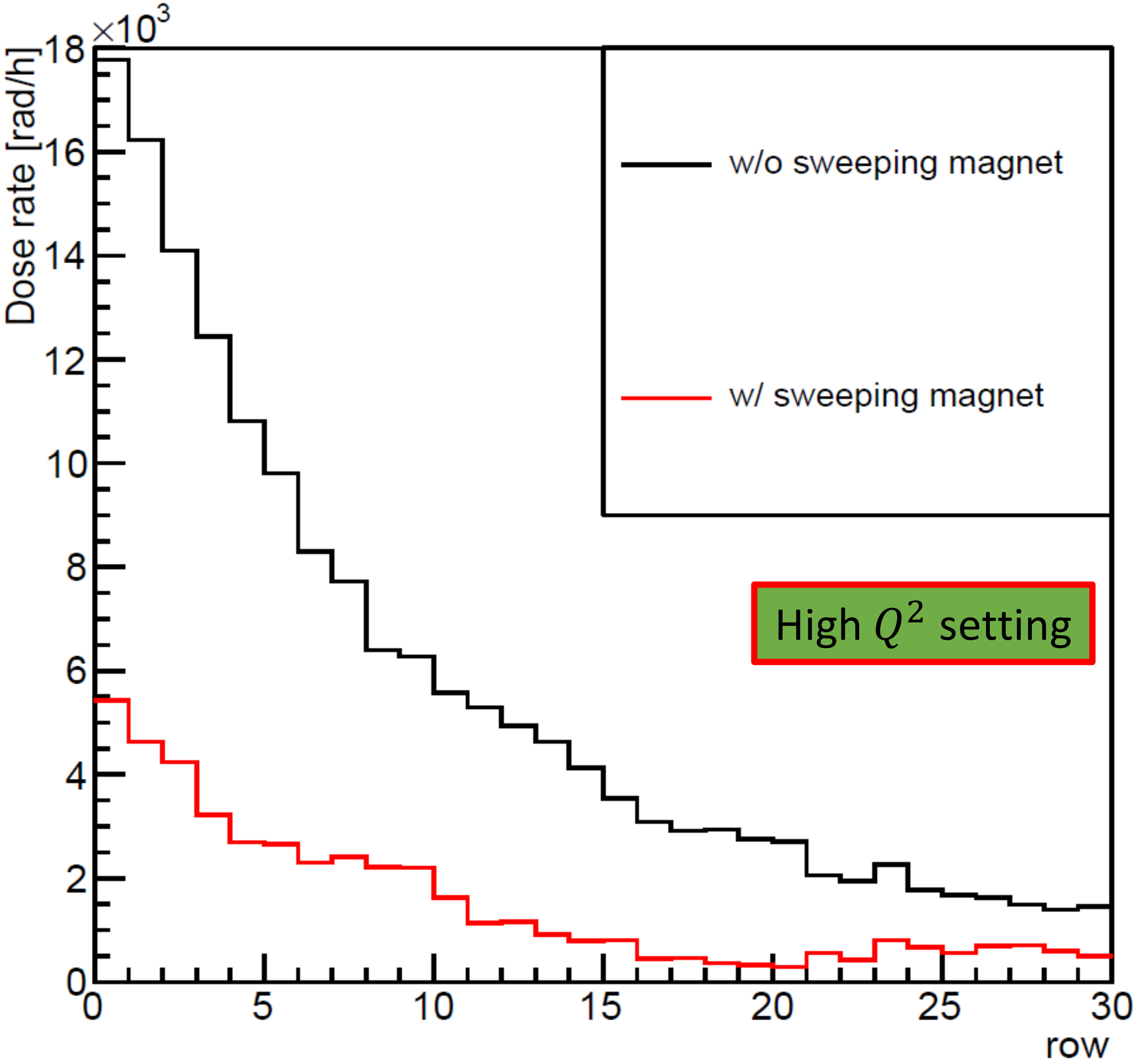
- **Purpose** :
  - -NPS is made of 1080 crystals (30X36, stacked)
  - -Need structures for uniform arrays → Better energy resolution
  - -More structure between crystals → Worse energy resolution

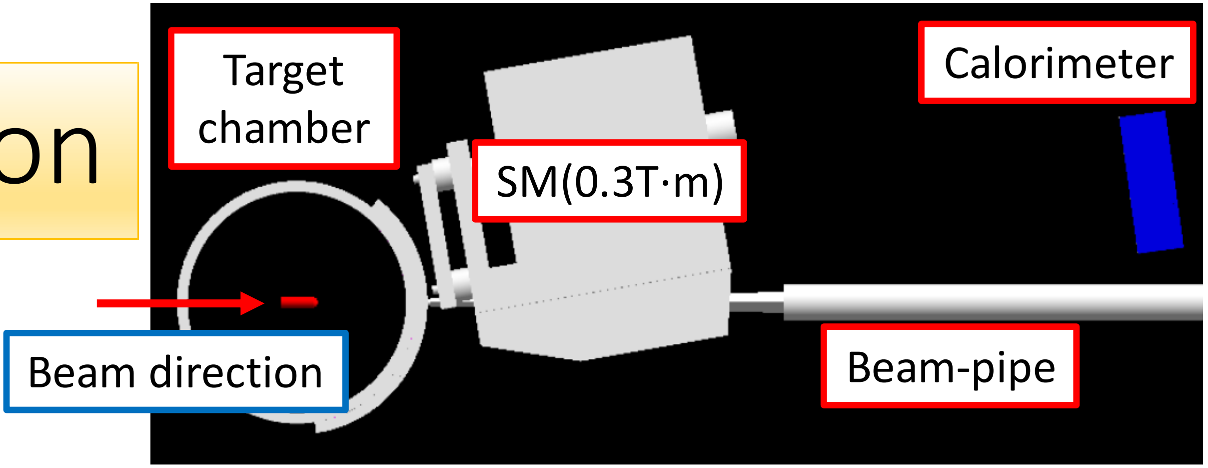
➔Check the dependency of the energy resolution of the NPS on the distance between the crystals(gap)



Recent NPS prototype : No material in the middle part

NPS Dose Rate Calculation





<<picture : Geant4 simulation>>

50μA beam in 15cm Liquid hydrogen target
(approximate luminosity : $\sim 10^{38} cm^{-2} s^{-1}$)
NPS placed 4m away from the target, 7.9°

Sweeping Magnet (SM) :

- Reduces the dose rate a factor of 3 or more
→ Reach smaller angle
→ Tolerate higher luminosity

Geant4 NPS Simulation Conclusions

- Energy resolution simulation

  - Detector structure : 0.5mm carbon material only in the front and the back side, 2cm each of the crystals

- Radiation dose rate calculation

  - Sweeping magnet : reach smaller angle for the high Q^2 and tolerate higher luminosity

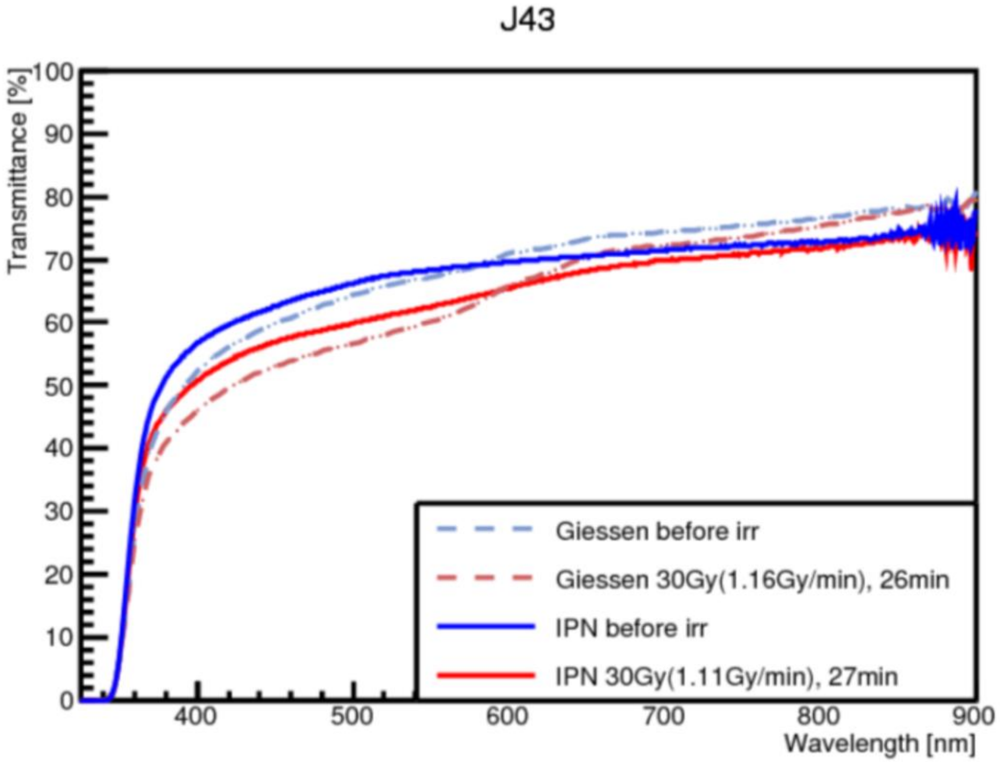
- Full package of experimental setup is ready for the NPS acceptance calculation

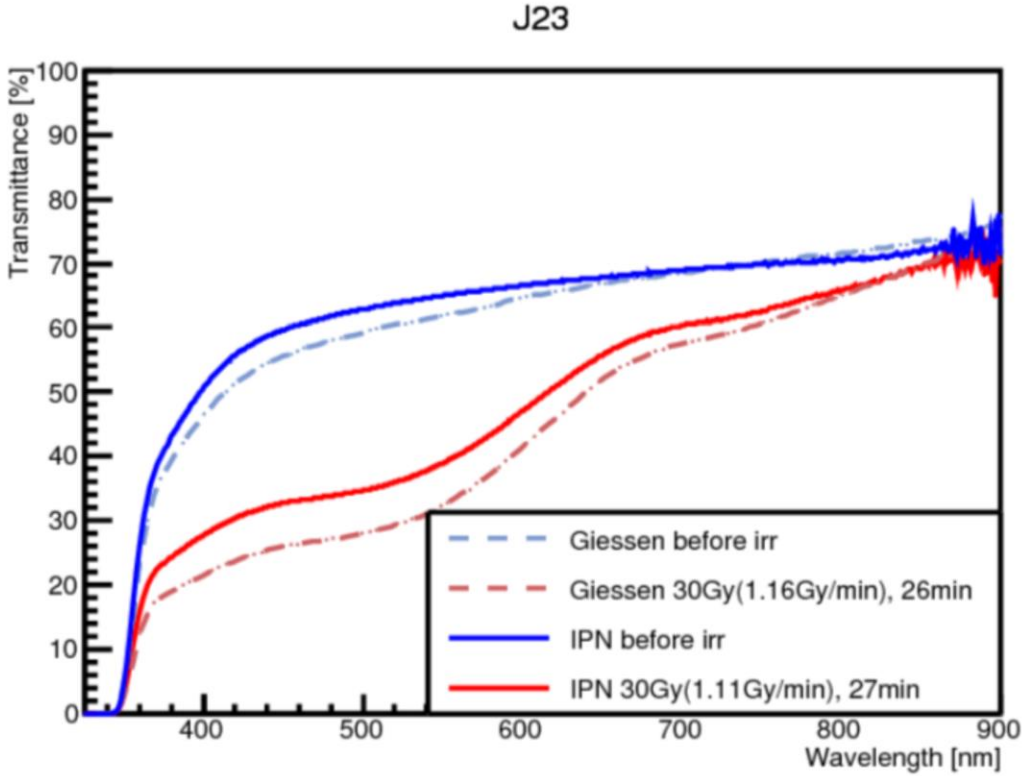
$PbWO_4$ Optical Properties Measurements

- Radiation hardness measurement
  - Check crystal performance in high radiation environment
  - Impact of radiation on crystal resolution
  - Study the needs for curing
- Optical bleaching
  - Method to recover the optical properties of the crystals after the irradiation damage

$PbWO_4$ Irradiation Test

Light transmittance measurement





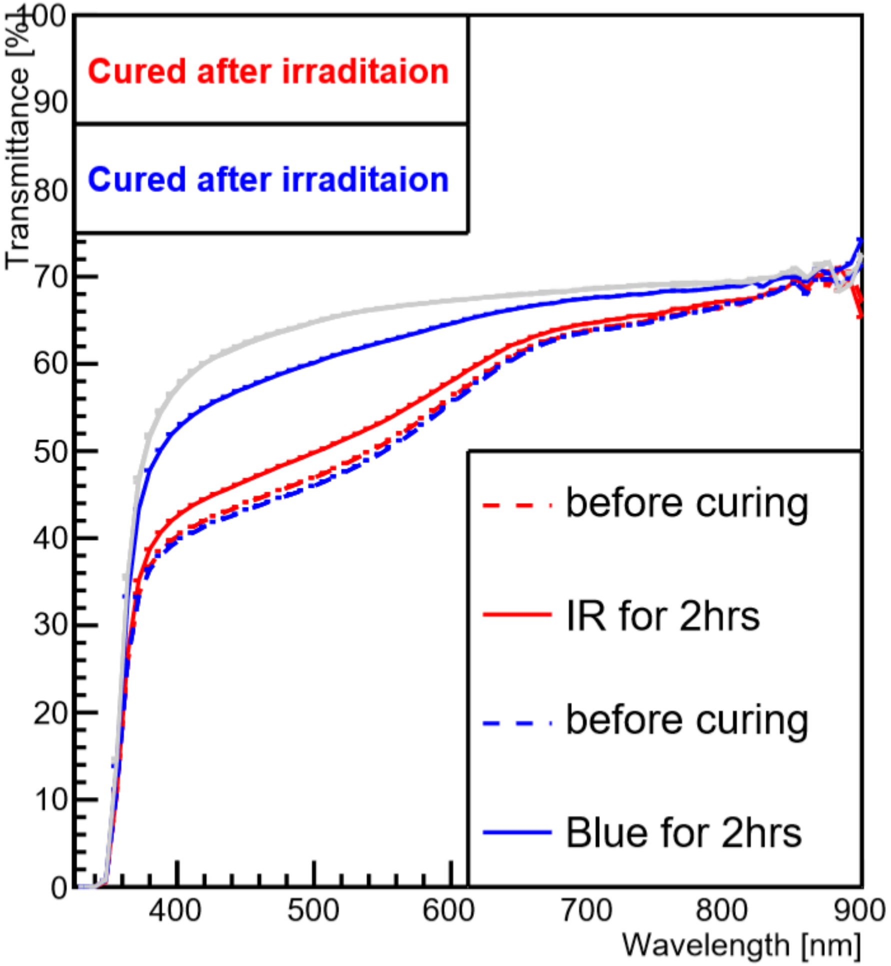
Picture : ~20Gy/min ~4hrs with ^{60}Co at Laboratoire de Chimie Physique

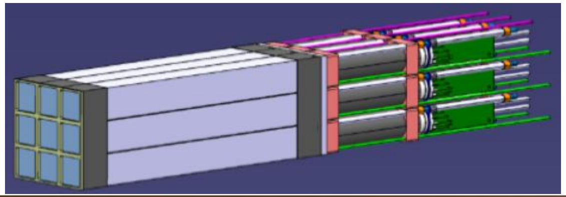
The radiation damage differs for every crystal

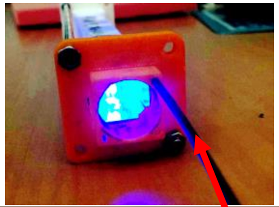
$PbWO_4$ Radiation Damage Recovery

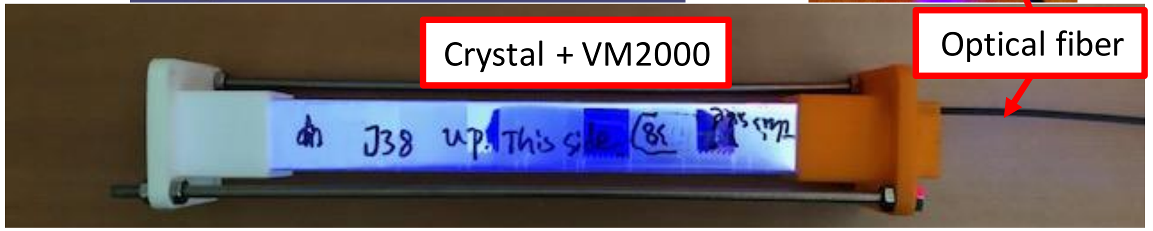
- Ionizing radiation creates color centers
  - By electron traps or point structure defects
- Relaxation of color centers
  - Thermo-activation
  - Injection of specific energy
    - -Blue light : PMT sensitive
    - -Infrared light : PMT insensitive → possibility of curing during data taking

$PbWO_4$ Optical Bleaching









-The crystal was irradiated with 30Gy of dose
-Applied two types of light illumination recovery

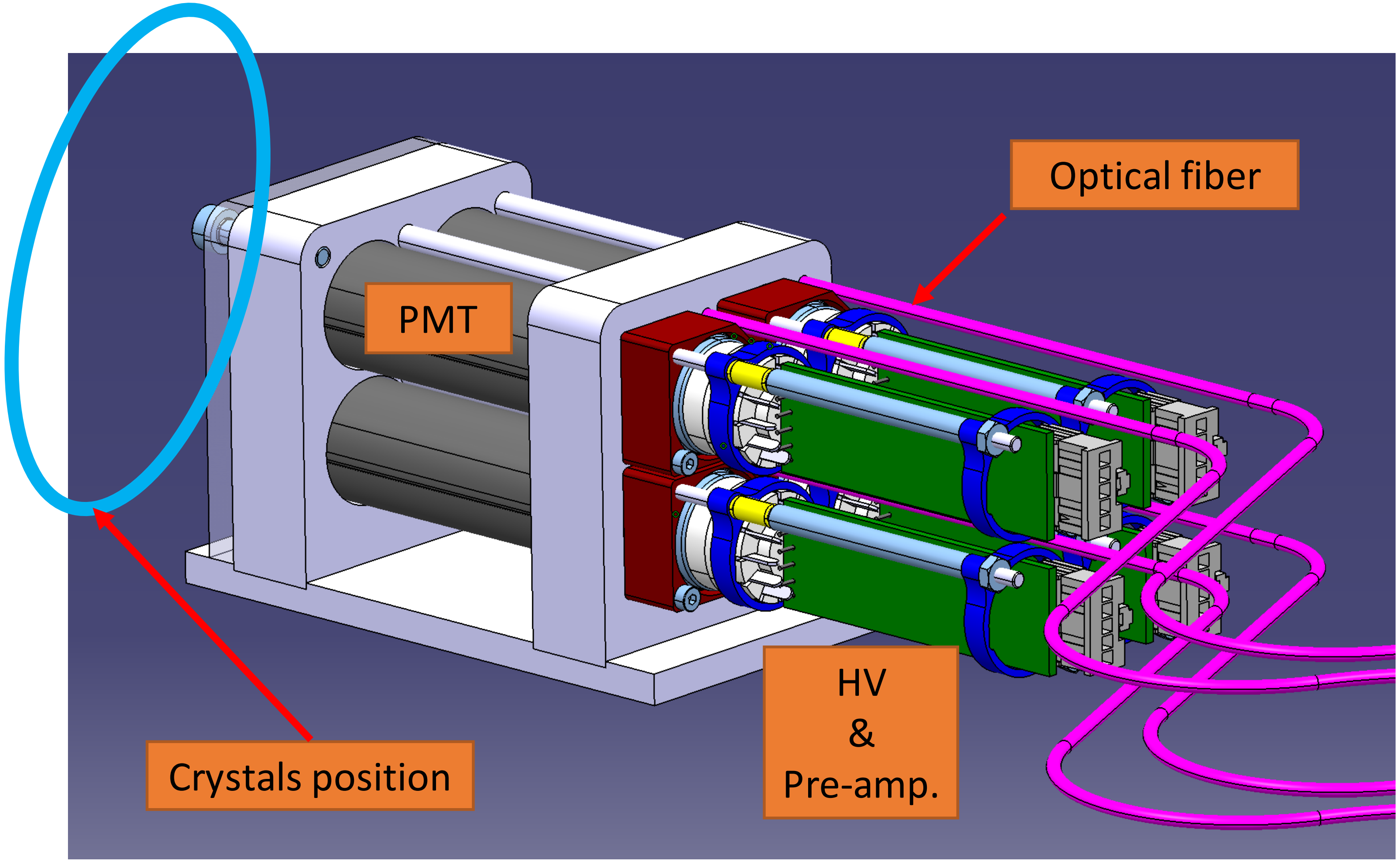
-Infrared(IR) light with optical fiber for 2hrs
-Blue light with optical fiber for 2hrs

→Blue light works better in recovering the transmittance

➔Blue light for the crystal optical property damage recovery system of NPS

Optical Bleaching

$PbWO_4$ Optical Properties Measurements Conclusion



- Radiation damage exists and varies with crystals
- Crystals radiation damage can be cured

  - Blue light curing (optical bleaching) via optical fiber to be used for the NPS

<<picture : Emmanuel Rindel>>

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 energy resolution and dose rate calculation with Geant4
- Optical bleaching method for maintaining calorimeter's energy and position resolution

Time Line of the NPS

- Detector construction in the 2nd half of 2019
- Delivery of NPS to Jefferson Lab at the beginning of 2020
- NPS tests at Jefferson Lab in 2020
- DVCS experiment expected in 2021