Generalized Parton Distributions

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Collaborating institutions

France:

- Institut de Physique Nucléaire d'Orsay
- Departement de Physique Nucléaire (CEA-Saclay)

Korea:

- Seoul National University
- Kyungpook National University

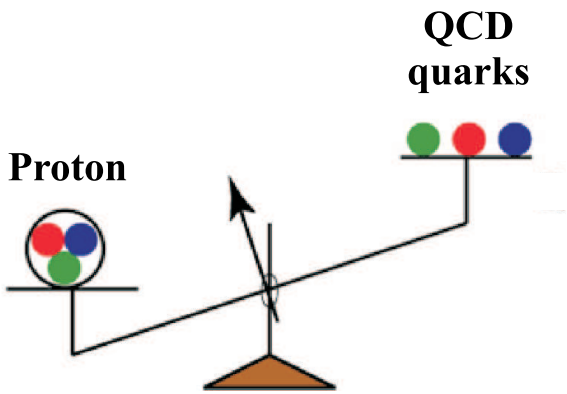
The proton: QCD at work!

What we know...

- 2 up quarks ($q_u = 2/3\ e$) + 1 down quark ($q_d = -1/3\ e$)
- any number of quark-antiquark pairs & any number of gluons

$$|p\rangle = |uud\rangle + |uudq\bar{q}\rangle + |uudg\rangle + \ldots$$

Fundamental questions

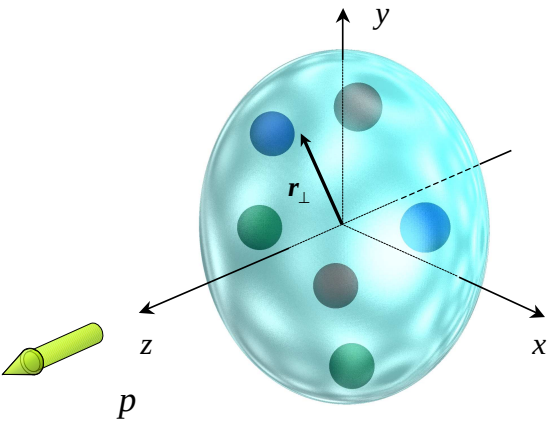


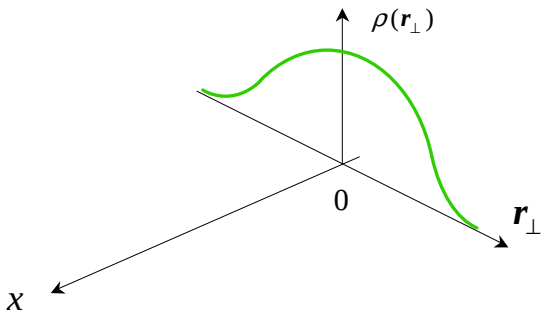
- Origin of proton mass?
  - Most of it comes from the motion of quarks & gluons
  - Only a small fraction comes from *quark masses*
- Origin of proton spin?

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

Studying the structure of the nucleon experimentally

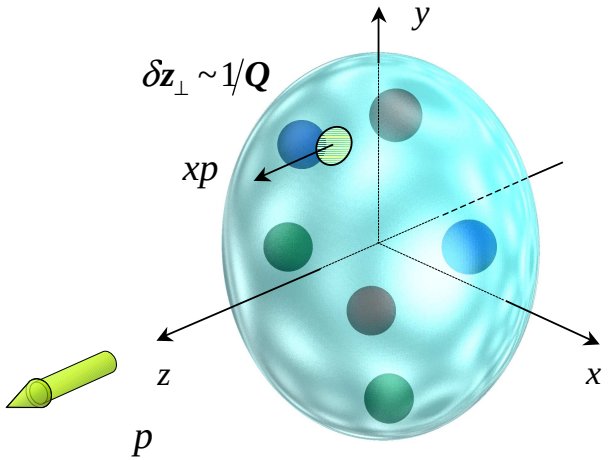
Elastic scattering

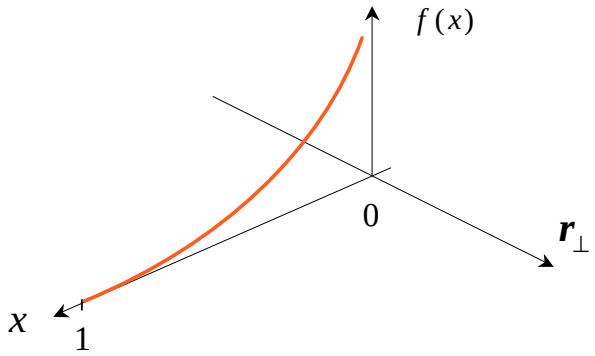




Form factors

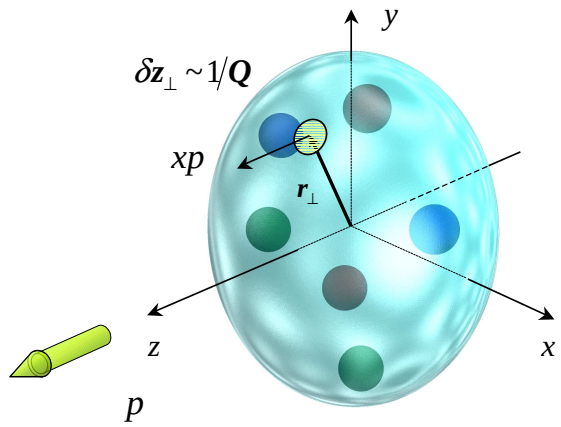
Deeply Inelastic Scattering

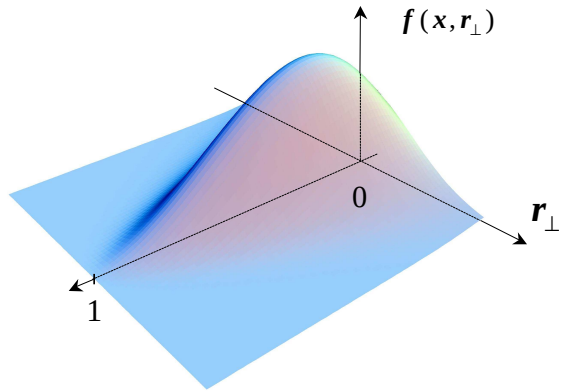




Parton distributions

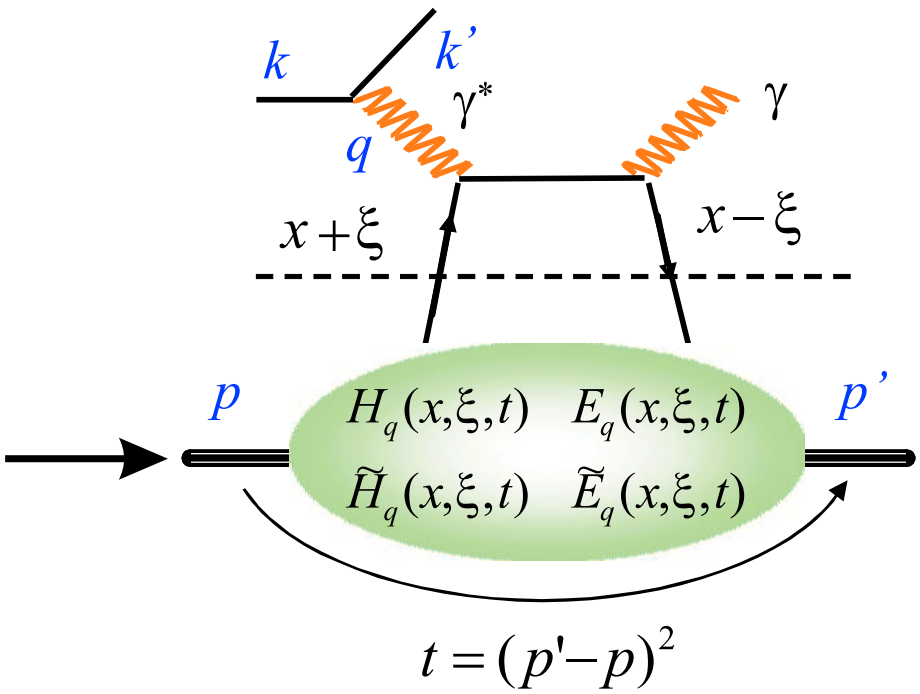
Hard exclusive processes





Generalized Parton Distributions (GPDs)

Deeply Virtual Compton Scattering (DVCS): $\gamma^* \; p \to \gamma \; p$



Handbag diagram

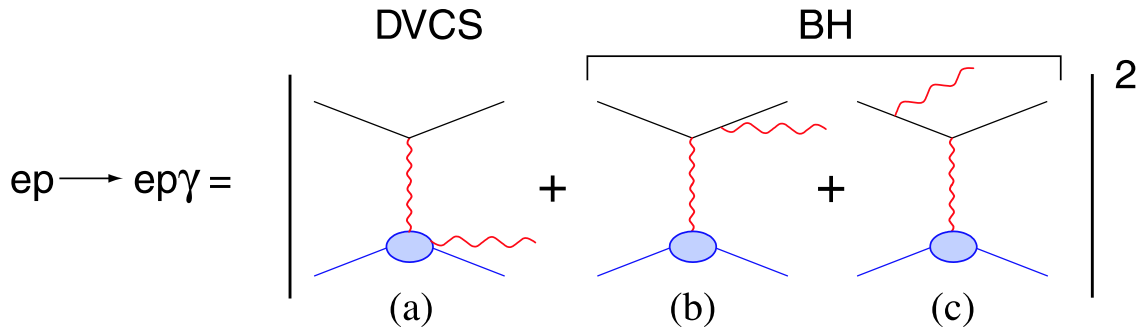
High Q^2
Perturbative QCD

Non-perturbative
GPDs

Bjorken limit :

$$\left.\begin{array}{rcl} Q^2 = & -q^2 \to & \infty \\ & \nu \to & \infty \end{array}\right\} \quad x_B = \frac{Q^2}{2M\nu} \text{ fixed}$$

DVCS experimentally: interference with Bethe-Heitler



At leading order in $1/Q$ (leading twist) :

$$d^5\overrightarrow{\sigma} - d^5\overleftarrow{\sigma} = \Im m\left(T^{BH}\cdot T^{DVCS}\right)$$

$$d^5\overrightarrow{\sigma} + d^5\overleftarrow{\sigma} = |BH|^2 + \Re e\left(T^{BH}\cdot T^{DVCS}\right) + |DVCS|^2$$

$$\mathcal{T}^{DVCS} = \int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\epsilon} + \cdots =$$

$$\underbrace{\mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}}_{\text{Access in helicity-independent cross section}} - \underbrace{i\pi\, H(x=\xi,\xi,t)}_{\text{Access in helicity-dependent cross-section}} + \ldots$$

Accessing different GDPs

Polarized beam, unpolarized target (BSA)

$$d\sigma_{LU} = \sin\phi \cdot \mathcal{I}m\{F_1\mathcal{H} + x_B(F_1 + F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E}\}d\phi$$

Unpolarized beam, longitudinal target (ITSA)

$$d\sigma_{UL} = \sin\phi \cdot \mathcal{I}m\{F_1\tilde{\mathcal{H}} + x_B(F_1 + F_2)(\tilde{\mathcal{H}} + x_B/2\mathcal{E}) - x_B kF_2\tilde{\mathcal{E}} \ldots\}d\phi$$

Polarized beam, longitudinal target (BITSA)

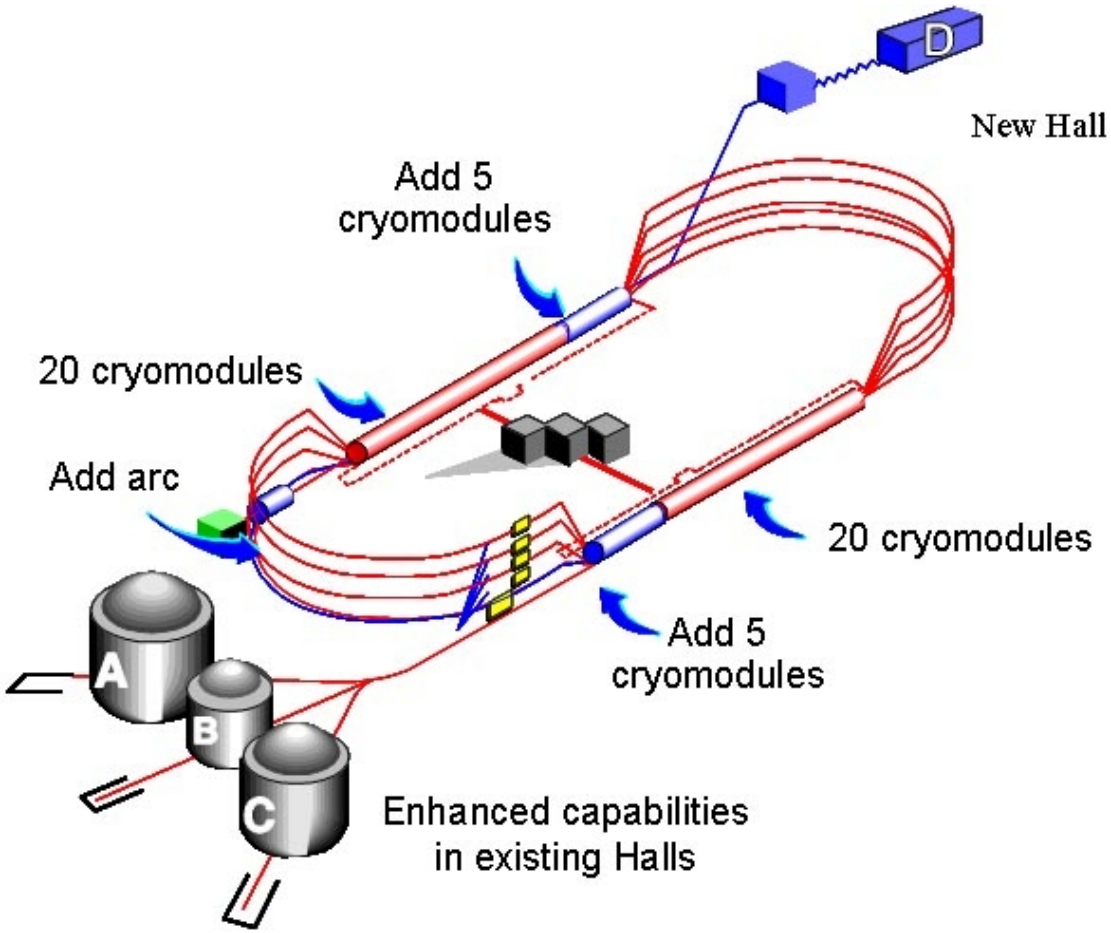
$$d\sigma_{LL} = (A + B\cos\phi) \cdot \mathcal{R}e\{F_1\tilde{\mathcal{H}} + x_B(F_1 + F_2)(\tilde{\mathcal{H}} + x_B/2\mathcal{E})\ldots\}d\phi$$

Unpolarized beam, transverse target (tTSA)

$$d\sigma_{UT} = \cos\phi \cdot \mathcal{I}m\{k(F_2\mathcal{H} - F_1\mathcal{E}) + \ldots\}d\phi$$

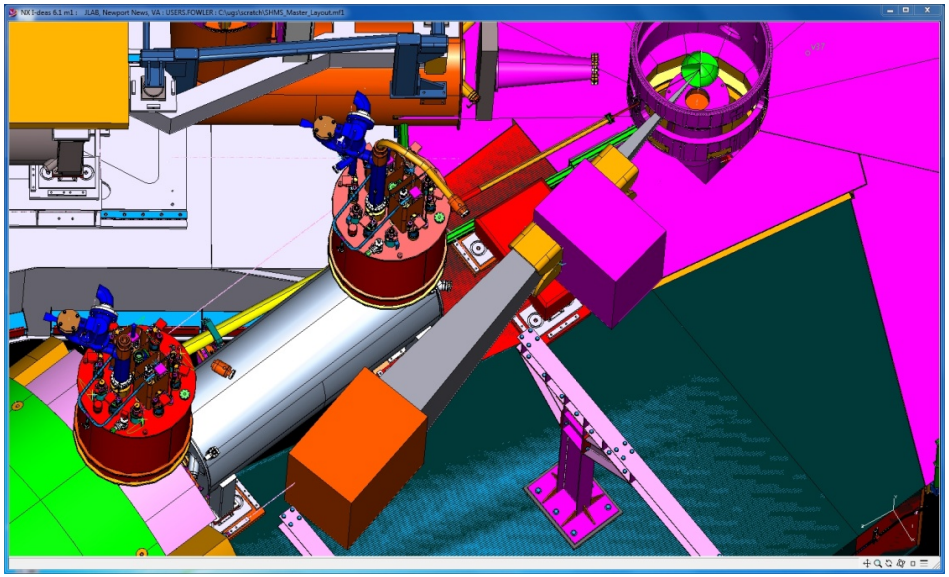
Jefferson Lab: upgraded to 12 GeV

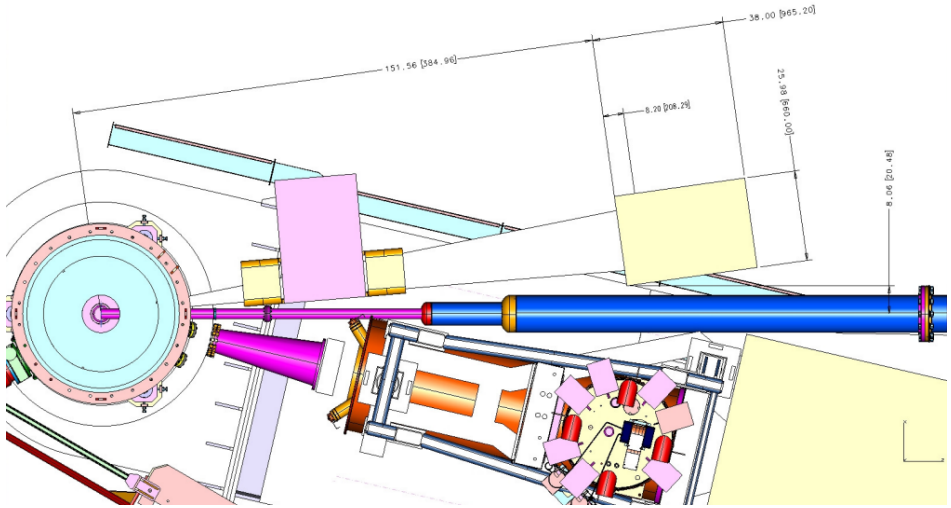
- 6-12 GeV longitudinally polarized (>85%) continuous electron beam
- High intensity (>100 μA): luminosities $> 10^{38}\,\mathrm{s}^{-1}\,\mathrm{cm}^{-2}$
- 3 experimental Halls (A, B, C) w/ fixed target and dedicated detectors



Recent collaboration activity: DVCS experiment in Hall C

- Experiment E12-13-010 approved in 2013 with highest scientific rating
- Running planned in ~ 2021
- Requires the construction of a new calorimeter and sweeping magnet



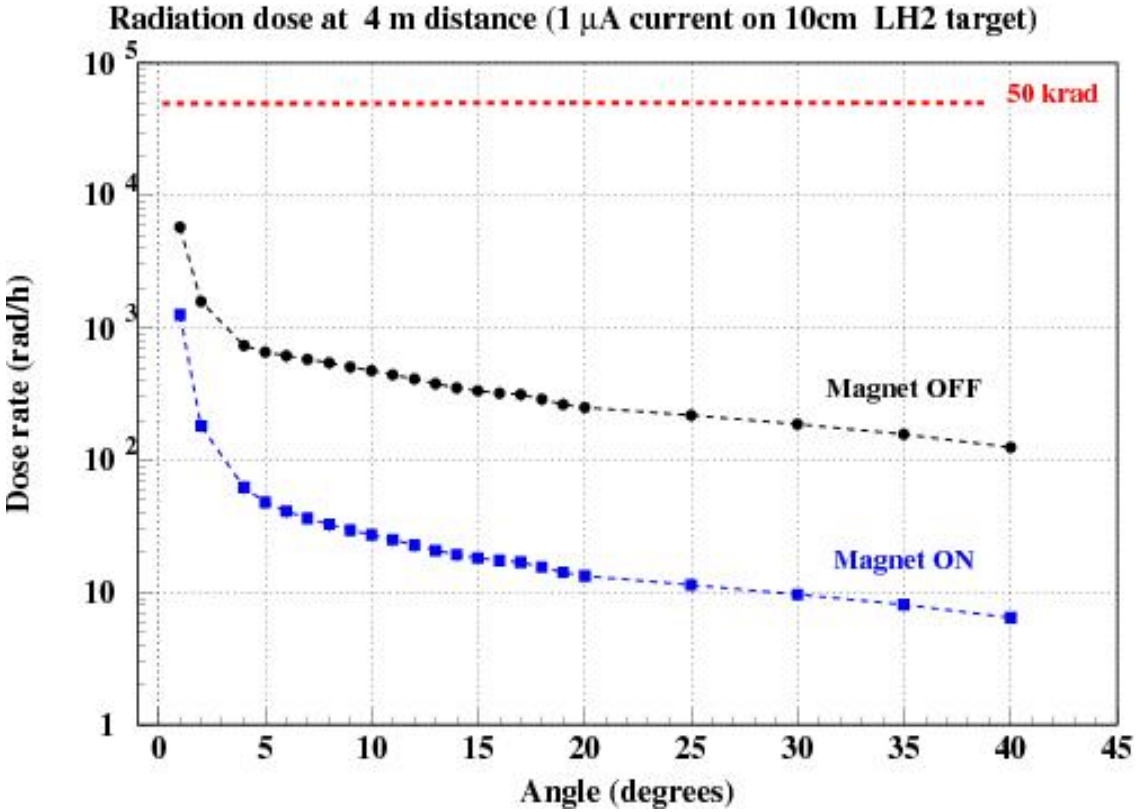


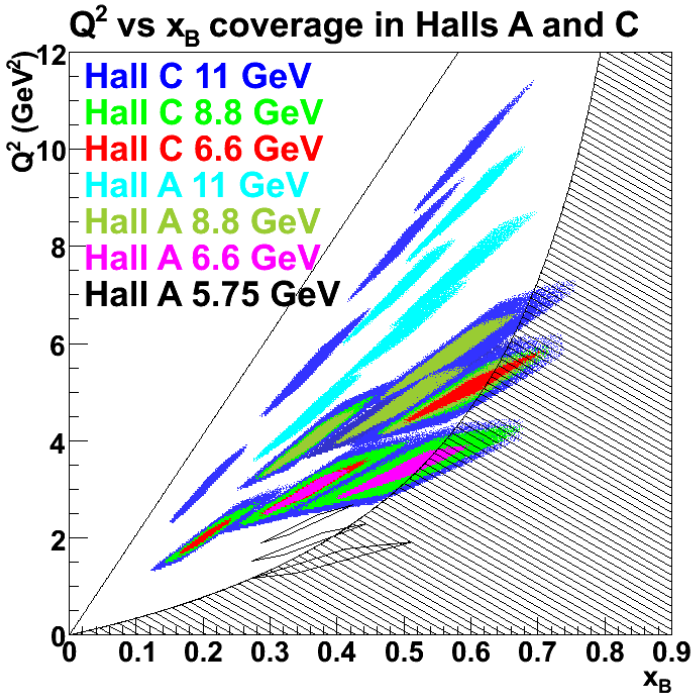
Neutral Particle Spectrometer (NPS) facility

Physics highlights and experimental challenges

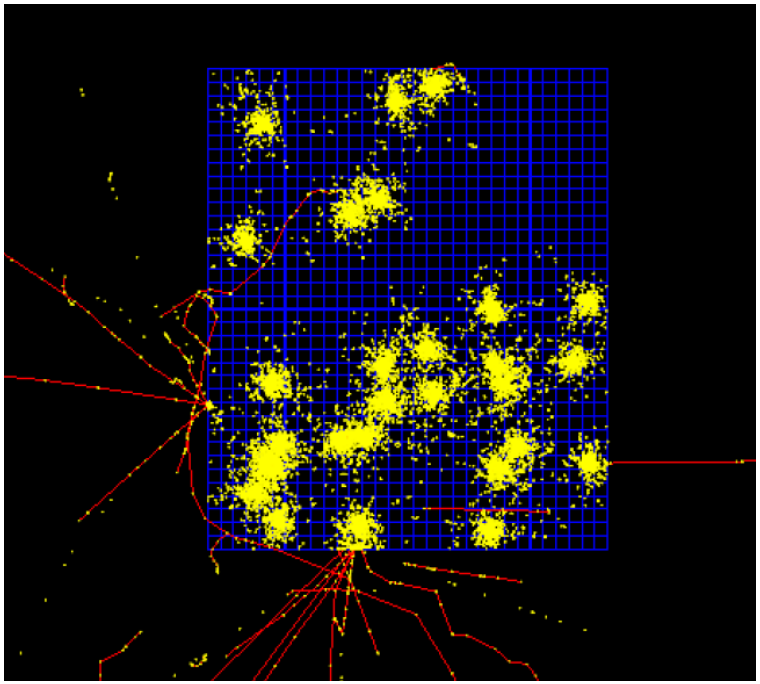
- Energy separation of the DVCS cross section
- Higher Q^2: measurement of higher twist contributions
- Low x_B extension (thanks to sweeping magnet)

Experimental challenge – radiation damage:

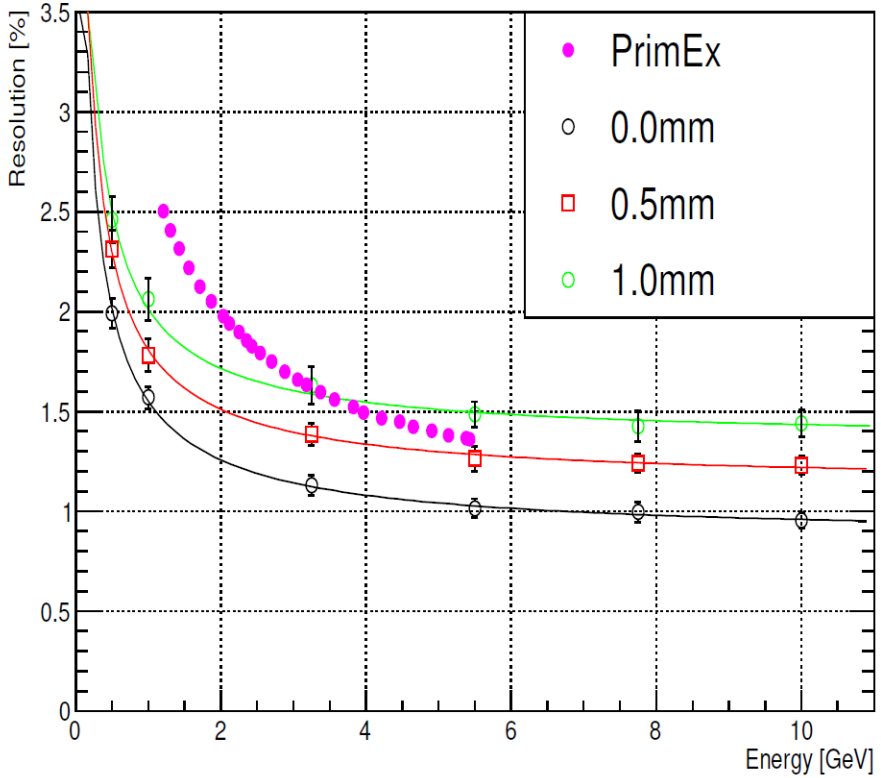




Simulations



- GEANT4 simulation of setup (1116 $PbWO_4$ crystals)
- Study of energy resolution
- Estimate of backgrounds
- Calculation of radiation damage

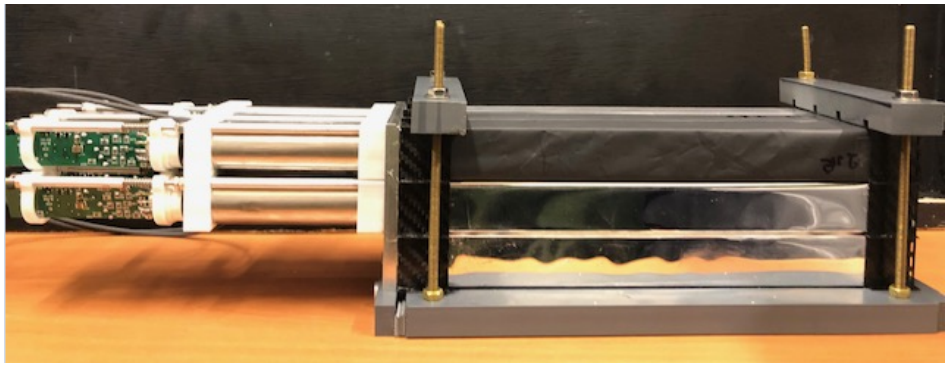


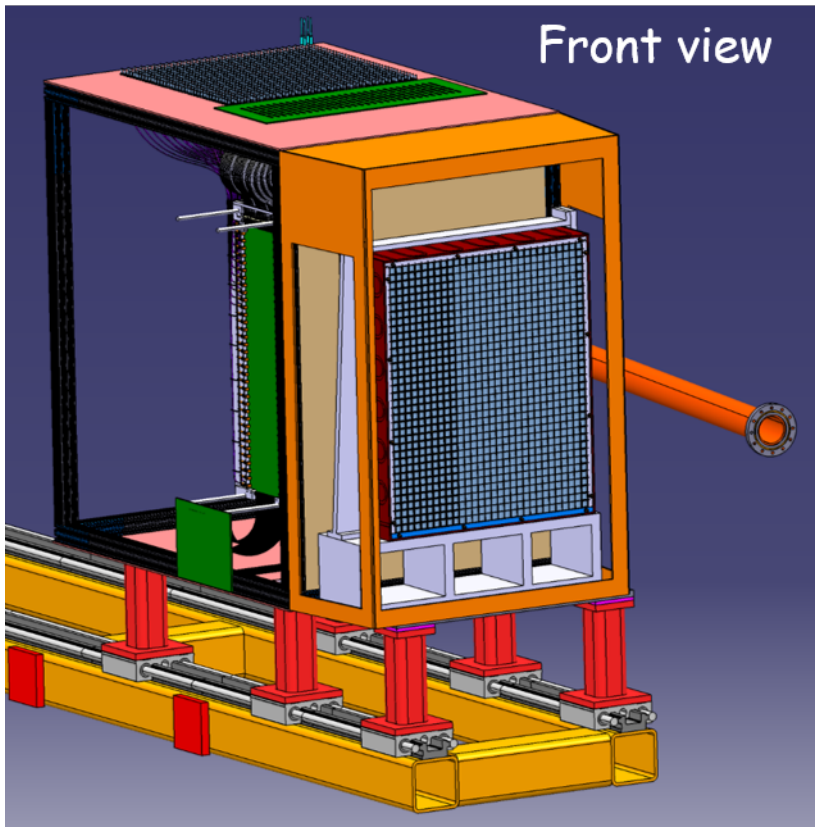
- Energy resolution as a function of space between crystals
- Key parameter for the mechanical design of the calorimeter

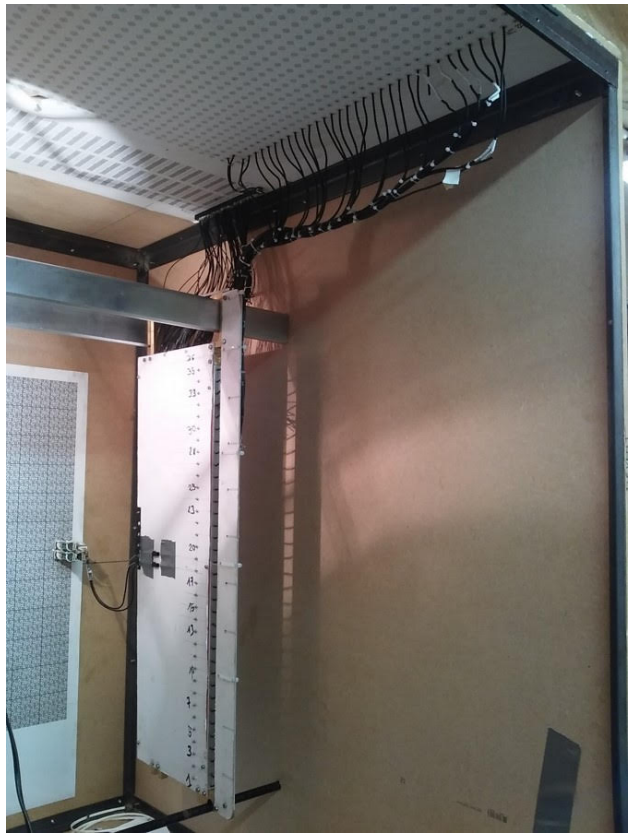
Calorimeter prototype

Goal:

- Test the mechanical assembly,
- calibration system &
- radiation damage recovery

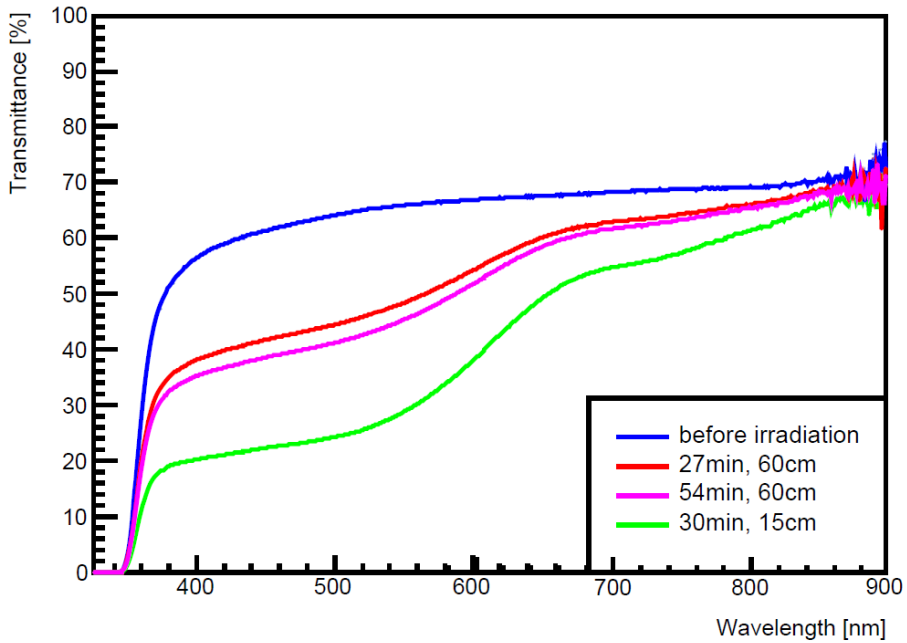




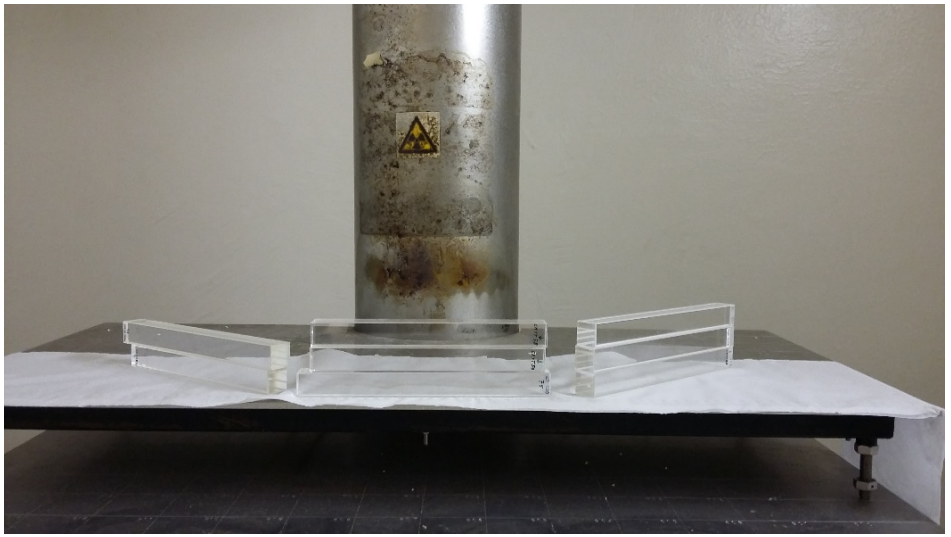


$PbWO_4$ crystal characterization: radiation hardness

- Crystal transparency/absorption measured using a double-beam optical spectrometer

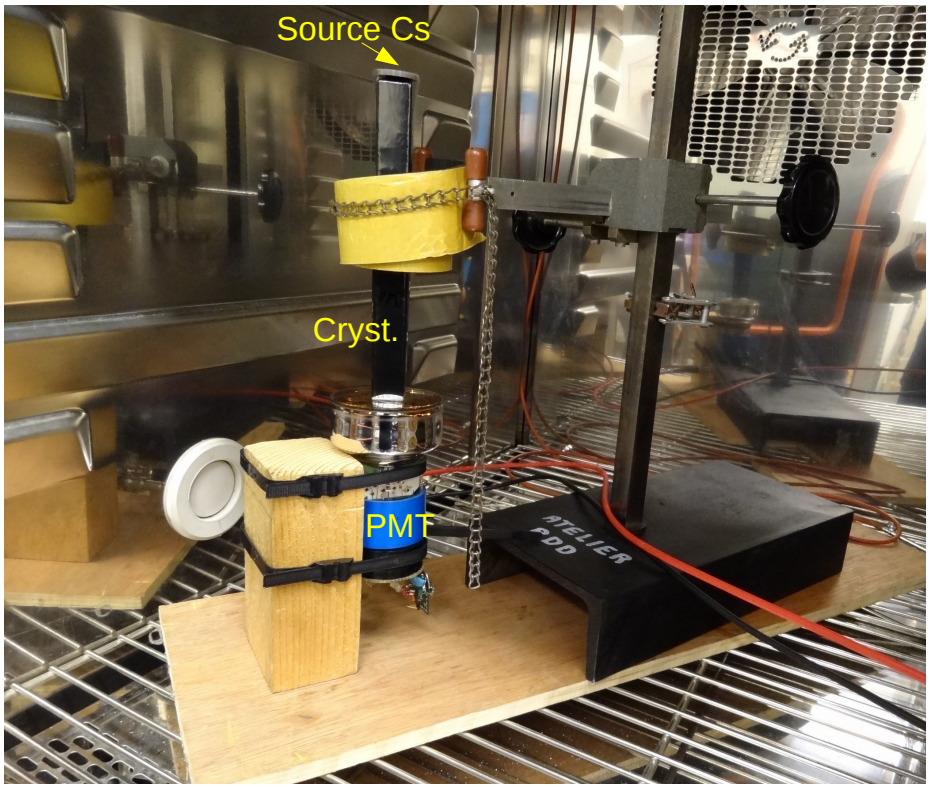


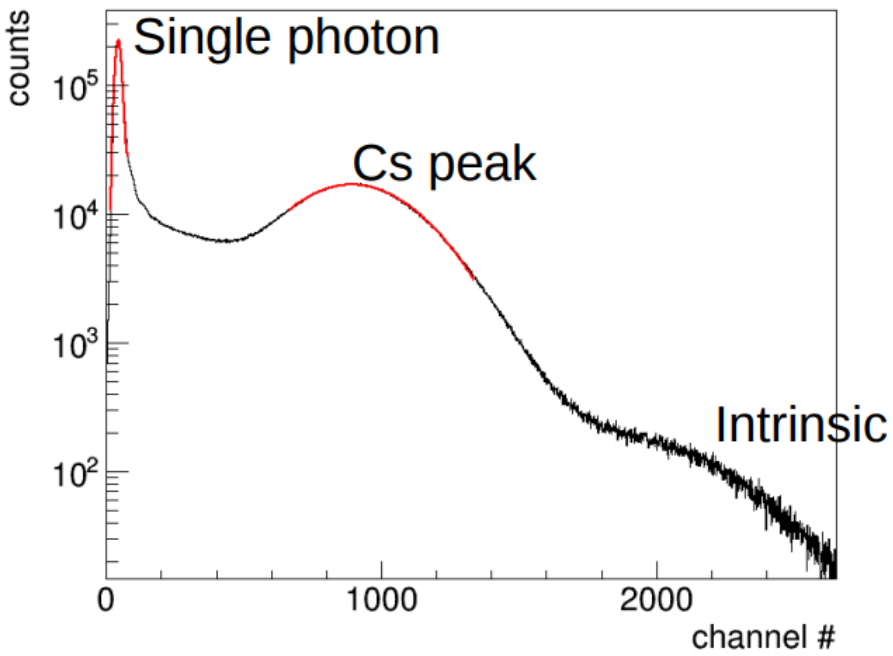
- Longitudinal and transverse transmittance measured as a function of position and radiation dose



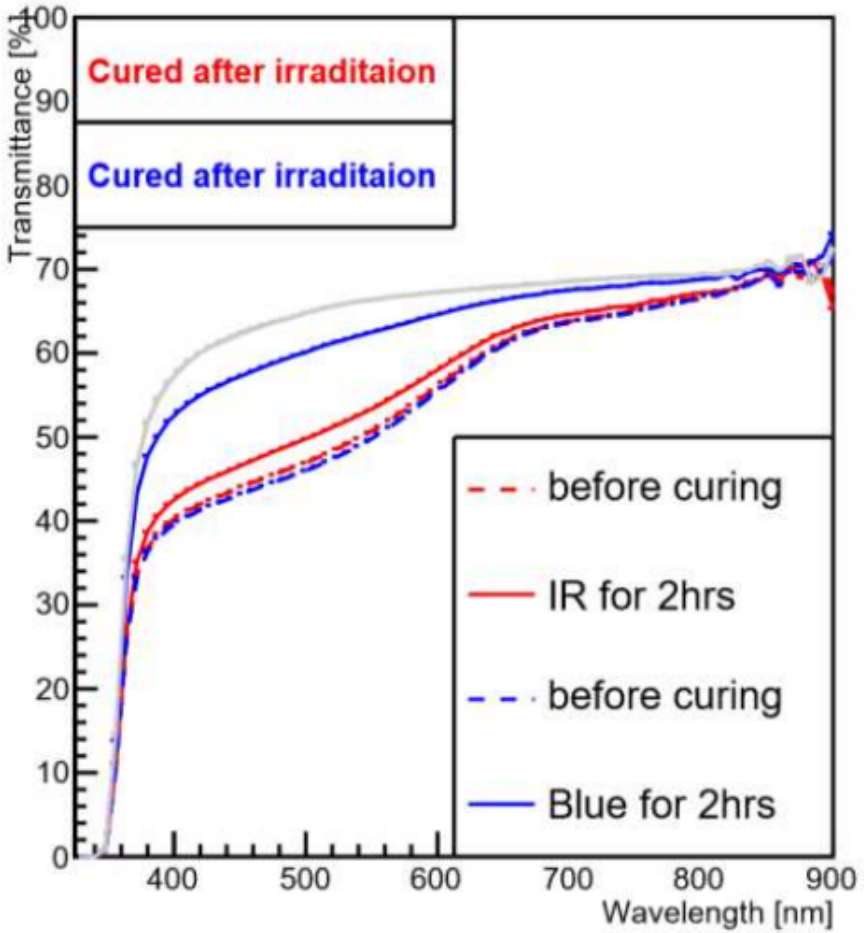
$PbWO_4$ crystal characterization: light yield

- Using a ^{137}Cs source in a temperature controlled chamber
- Light yield studied as a function of position (and temperature)





Optical bleaching of crystals



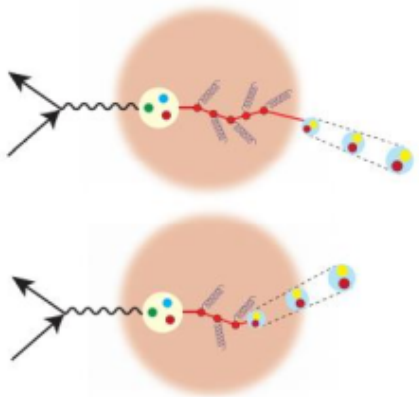
30 Gy dose (at ∼1 Gy/min):

- Infrared curing:
  less effective but PMTs insensitive
- Blue curing:
  more efficient but invasive

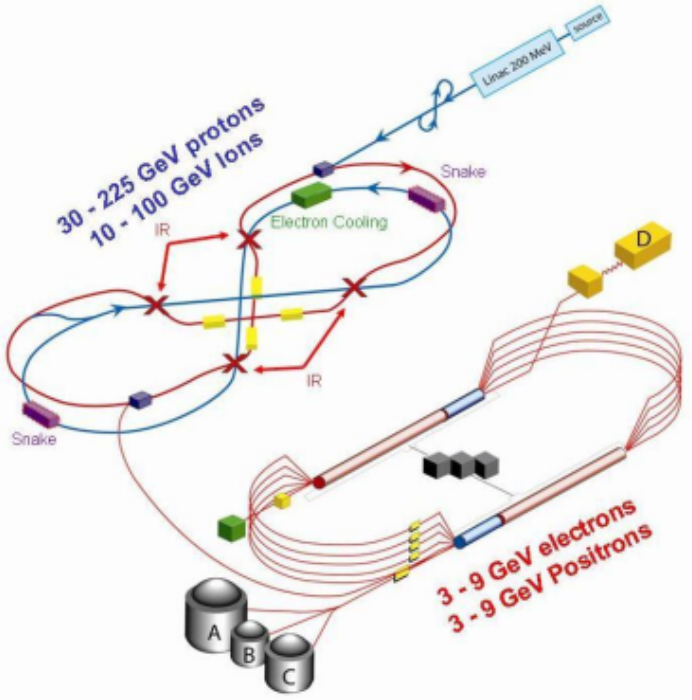
New project: the Electron-Ion collider

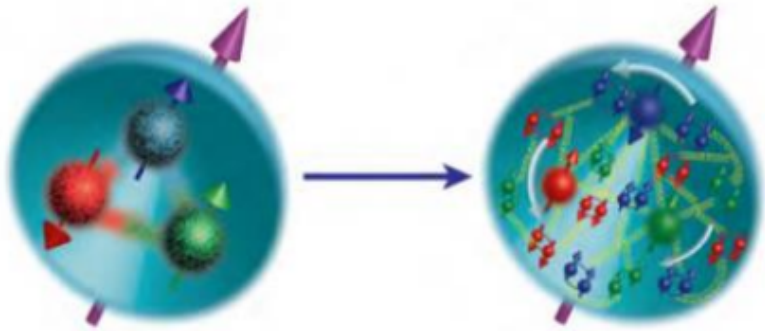
Outstanding questions in QCD:

- Saturation: new state of hadronic matter
- Distributions of position, momentum, angular momentum...
- Role of gluons in the nuclear medium



Golden future facility to study QCD at high *E*/small *x*: role of gluons in nuclear matter



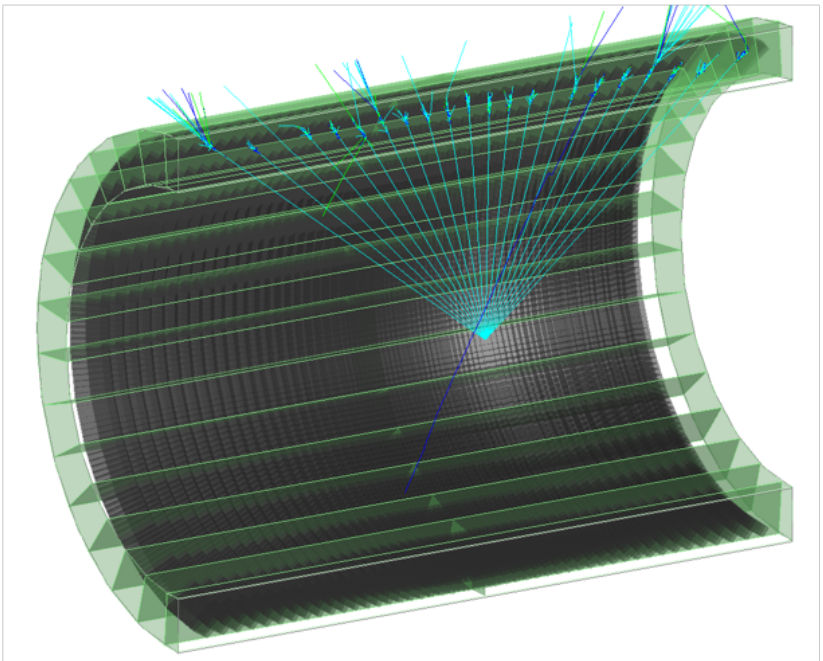


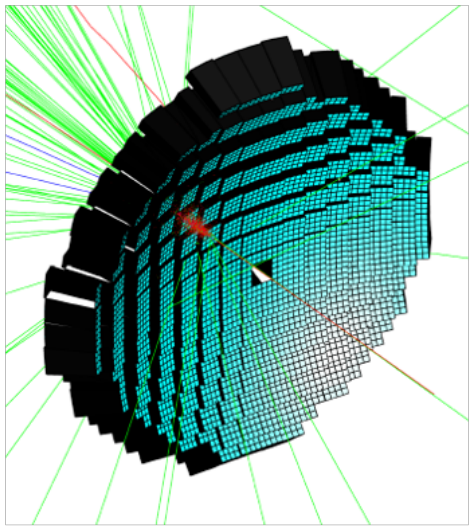
- e-p/A collisions with EIC:
  - ✓ Polarized beams: e, p, d/^{3}He
  - ✓ Electron beam: 3-10(20) GeV
  - ✓ Luminosity L_{ep}~$10^{33\text{-}34}$ $cm^{-2}s^{-1}$ (100-1000 x HERA)
  - ✓ E_{cdm}=20-100 (140) GeV
  - ✓ Large choice of nuclei

Future location in United States:
Jefferson Lab (VA) or Brookhaven National Lab (NY)

French/Korean collaboration funded by the STAR program

- So far only primary interactions simulated
- Radiation damage from secondary particles produced in the beam and surrounding material is probably the largest contribution.
- Need to evaluate damage from synchrotron radiation



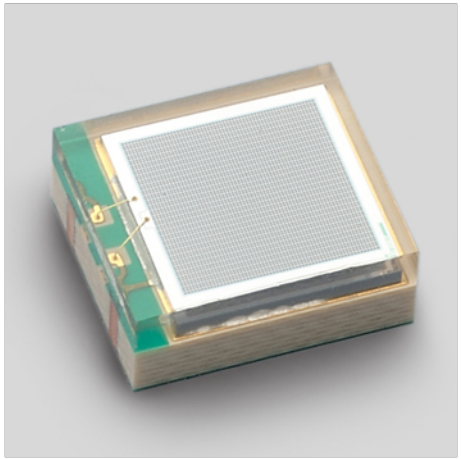


French/Korean collaboration funded by the STAR program

APD readout:
- Limited time resolution
- Small gain

SiPM:
- Single photon time resolution (<50ps)
- Linearity and dynamic range (1:50)

Challenges:
- Currently small sizes (little light collection)
- Radiation hardness under investigation



Tasks:

1. Extend sensitivity to the UV region
(in order to collect more light and increase energy resolution)

2. Understand microscopic effects of ionizing radiation
(for example, lattice defects with levels in the middle of the band-gap act as recombination/generation centers responsible for the increase in leakage current or as trapping centers reducing the charge collection efficiency)

3. Study damage recovery
and its dependence on temperature, source of irradiation and on the SiPM operating conditions

High quality PWO crystals with radiation-hard UV-enhanced SiPM would revolutionize state-of-the-art energy and time resolutions for calorimetry applications

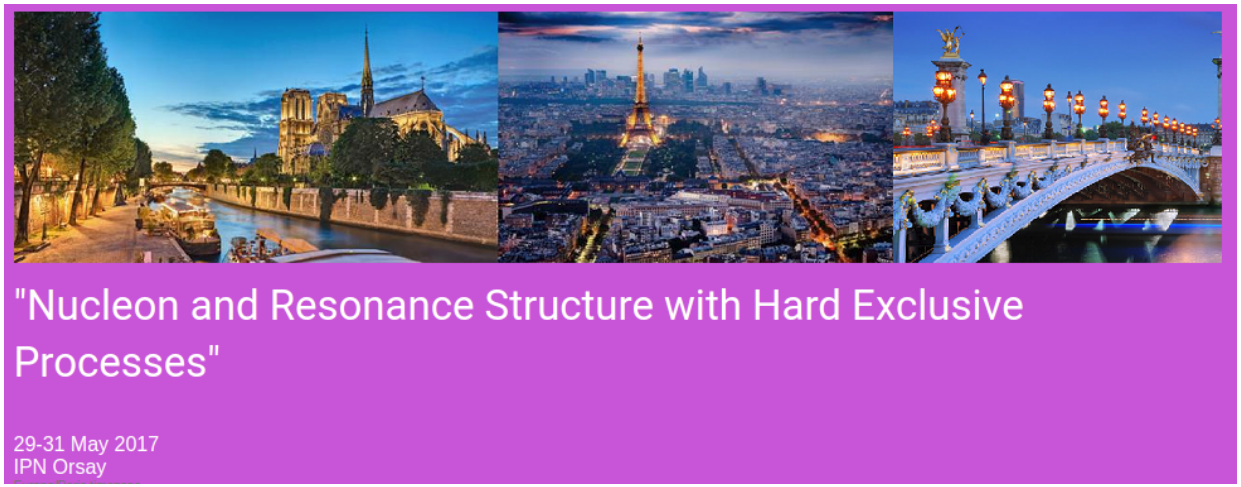
Joint PhD supervision

- Co-supervision between IPN-Orsay and SNU
- Awardee of "France Excellence" program funded by the Embassy of France in Korea
- 3-year stay in France (Sep 2017 – Sep 2020)

Ho San KO (SNU & Paris-Saclay)

Other activities:
France-Korea-USA workshops on hadron physics

- 2017: https://indico.in2p3.fr/event/14398



- 2018: https://www.apctp.org/plan.php/Jlab-12GeV

- 2019: Strong QCD from Hadron Structure Exp's, Nov 6-9 at JLab

Summary

- France–Korea collaboration on hadron physics at JLab (USA)
- Physics goal: 3D structure of the nucleon through GPDs
- Latest efforts focussed on the preparation of an upcoming DVCS experiment in Hall C (to run in 2021)
- Extension of the R&D program to EIC through the STAR program
- Joint PhD supervision
- Annual workshop organized among France/Korea/USA