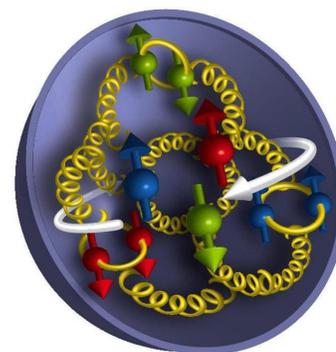


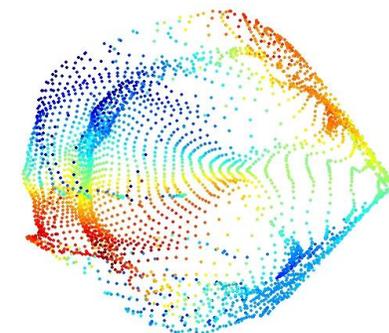
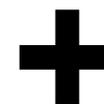
Dmitry Romanov



- **Software architect**
- **Artificial Intelligence**
- **High energy and Nuclear physics
Experimental analysis**

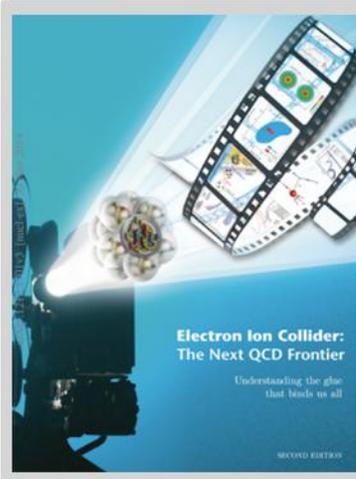


Nuclear Physics



Artificial Intelligence

Electron Ion Collider



Study **structure** and **dynamics** of **nuclear matter** in **ep** and **eA collisions** with high luminosity and versatile range of beam energies, beam polarizations, and beam species.

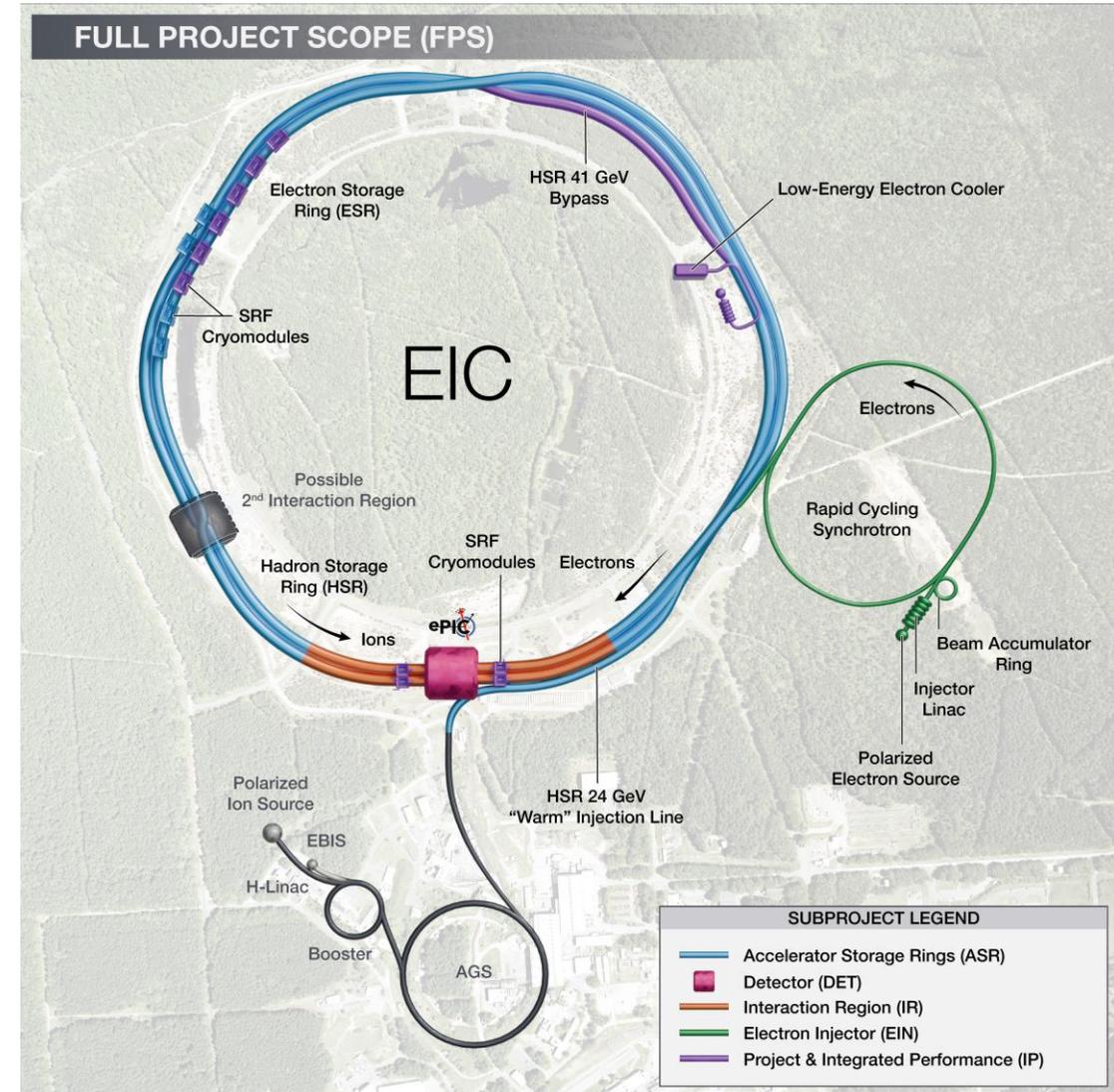
Where: BNL, Jlab is a partner

When: First physics in 2035

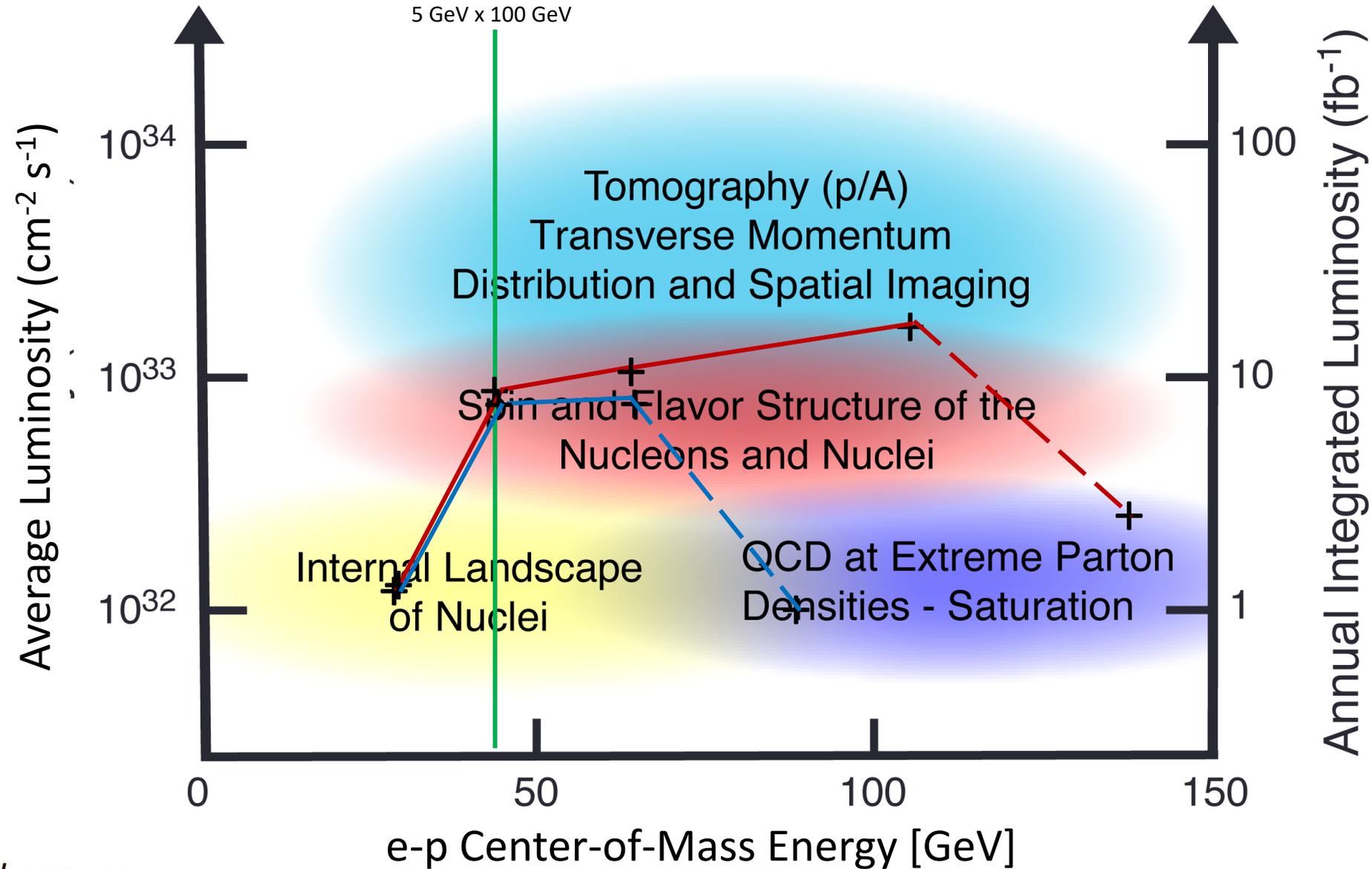
EIC has LARGE physics program

Fundamental questions EIC tries to answer include:

1. The Origin of Nucleon Spin
2. The Origin of Nucleon Mass
3. 3D Tomography of Nucleons and Nuclei
4. Gluon Saturation (High-Density QCD)



EIC Science Reach for **ep** and **eA**



High level overview

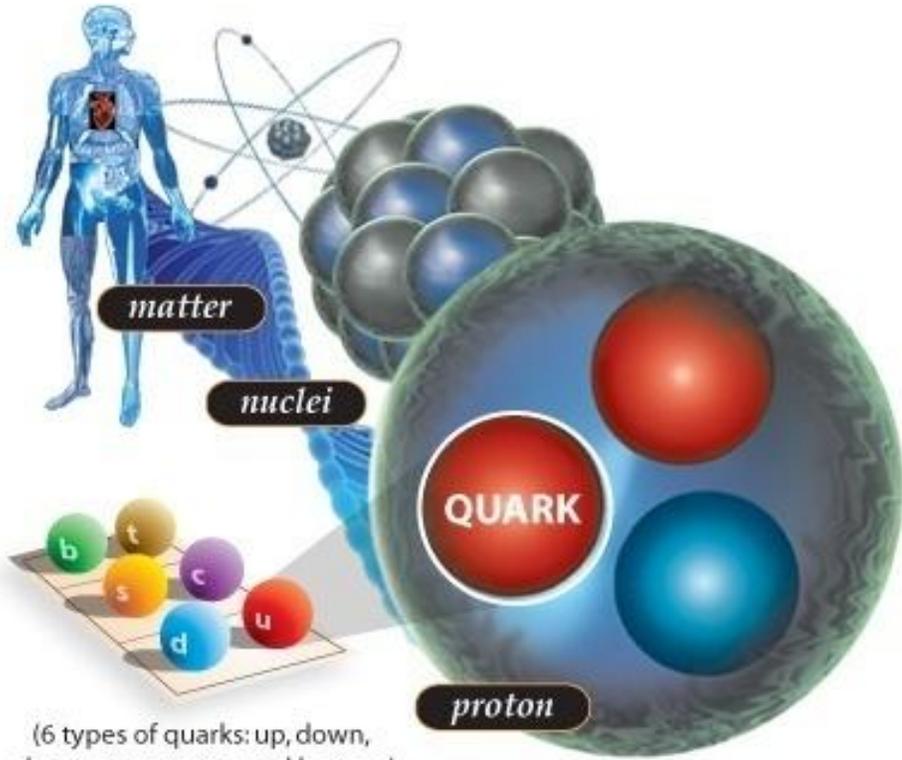


Scientific method

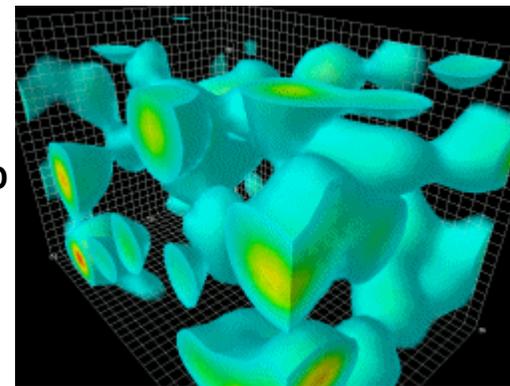
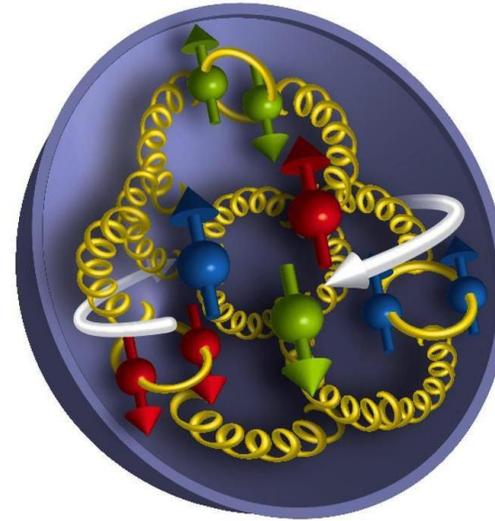
Observation → Theory → Prediction → Experiment → Compare → Refine

Physics scientific methods

Observation → Theory → Prediction → Experiment → Compare → Refine

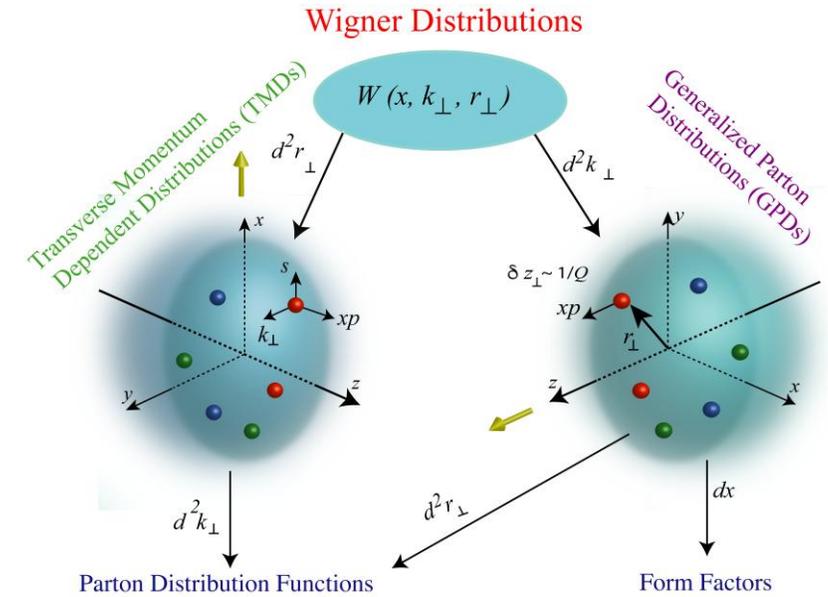


(6 types of quarks: up, down, charm, strange, top and bottom)

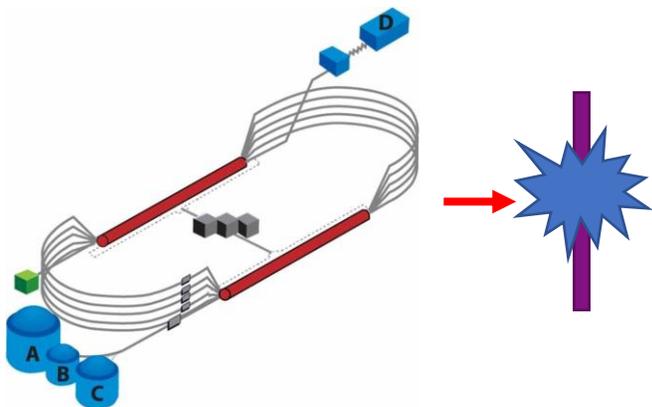
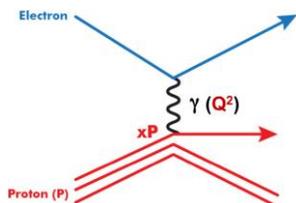
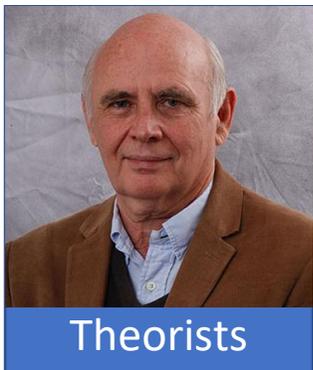


The QCD vacuum

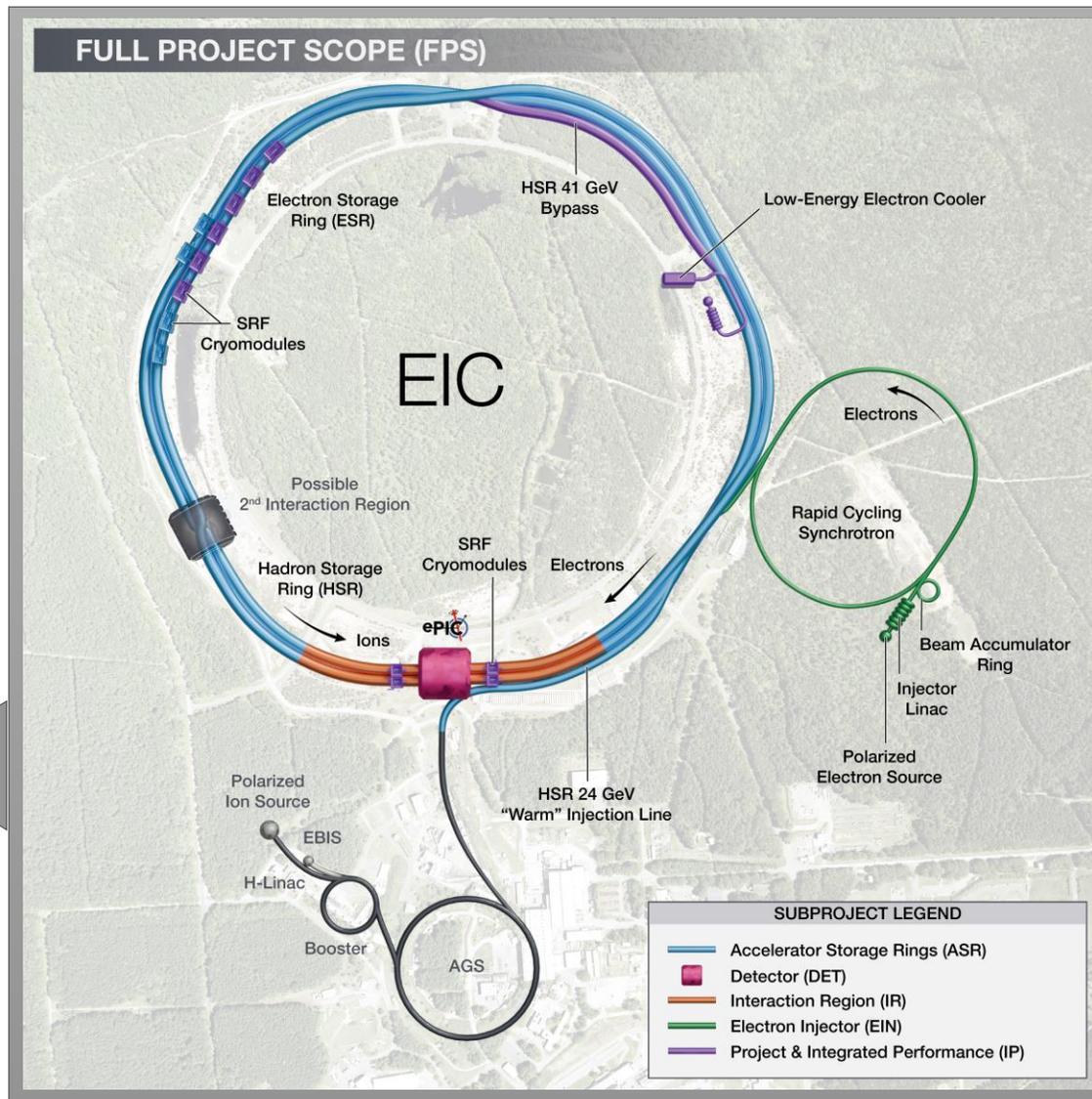
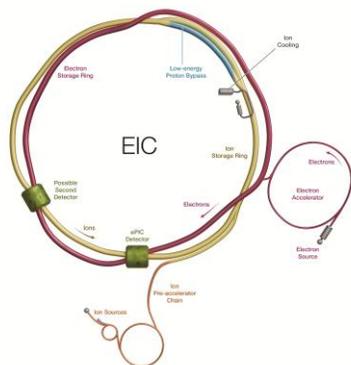
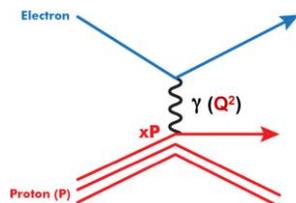
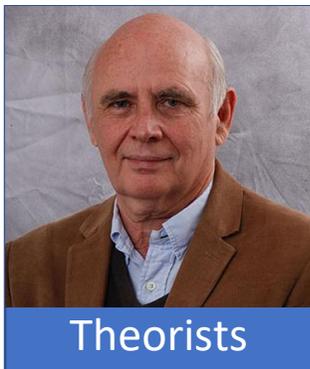
Long-distance gluonic fluctuations



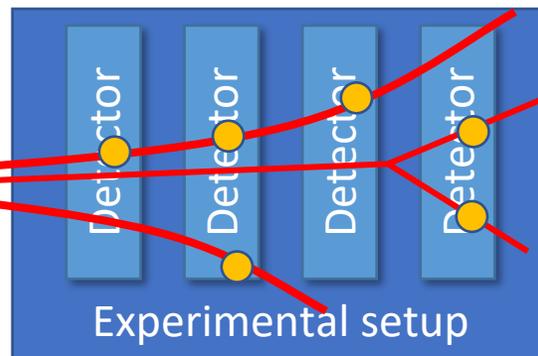
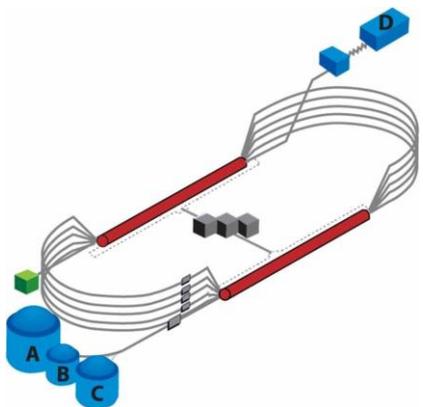
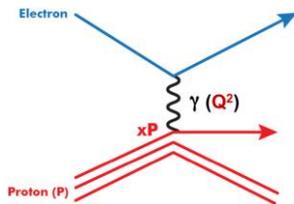
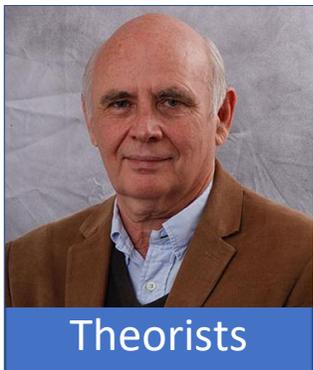
Experimental data workflow



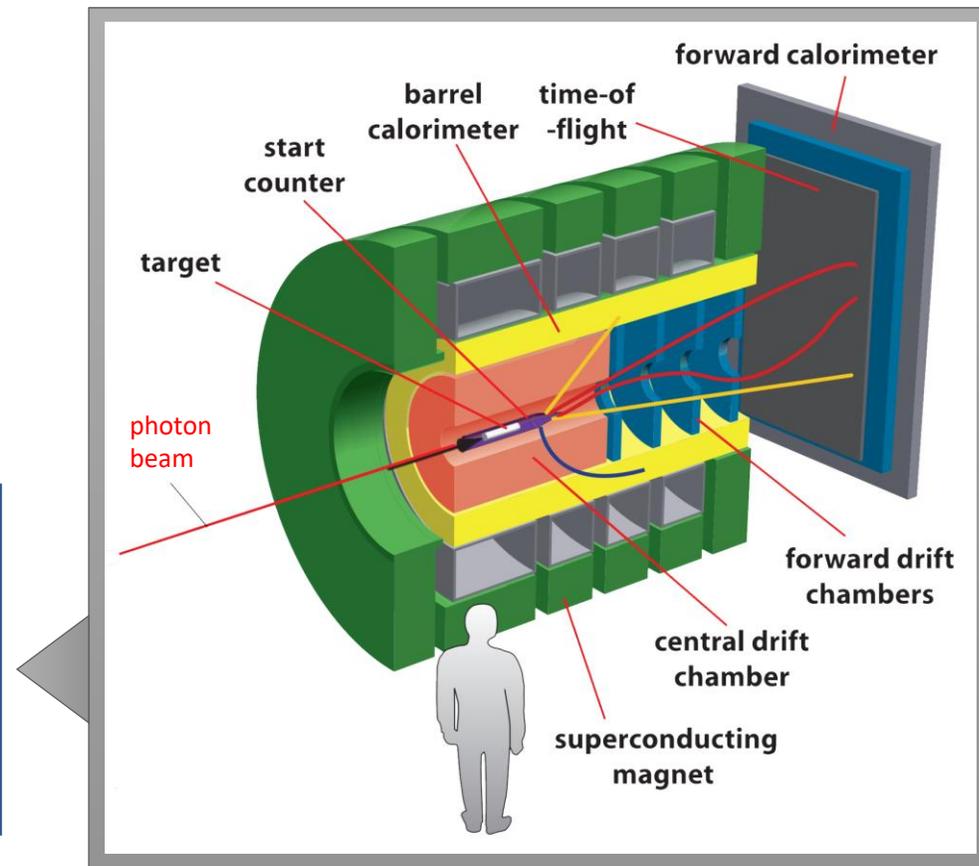
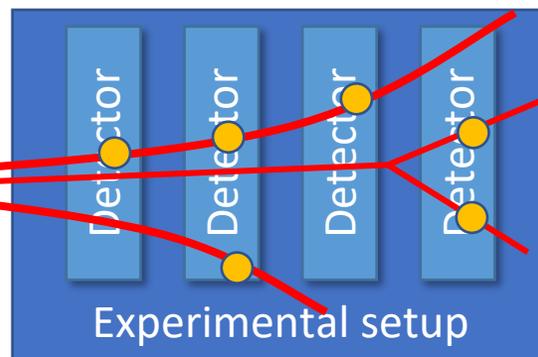
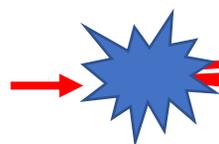
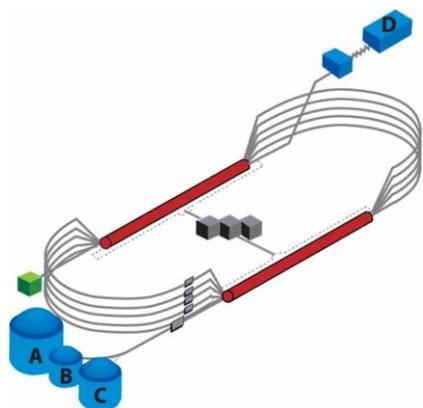
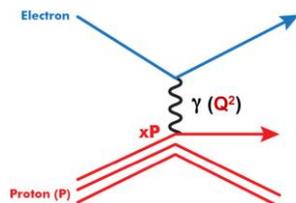
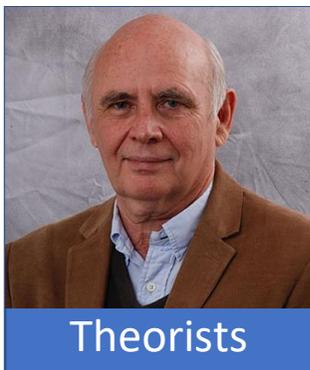
Experimental data workflow



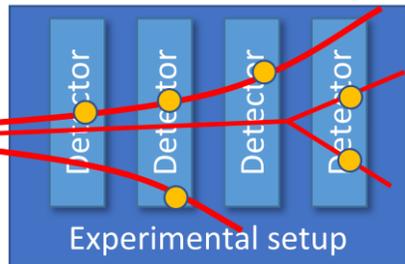
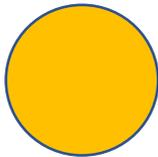
Experimental data workflow



Experimental data workflow



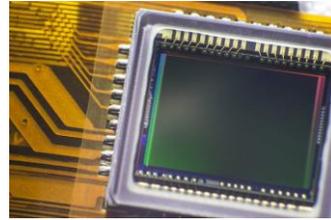
What is a hit



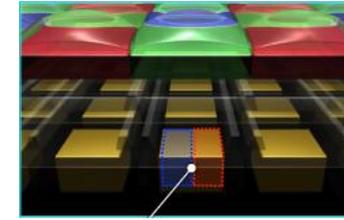
Collider as a monster photo camera



Camera



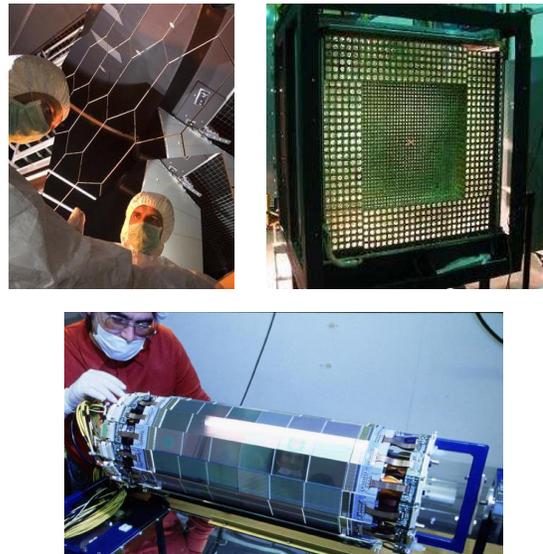
Matrix



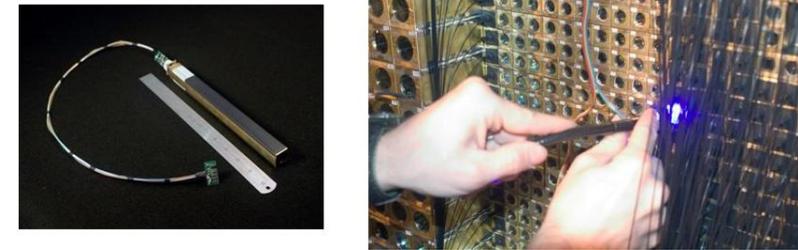
Individual pixels



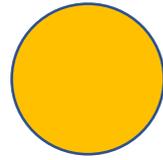
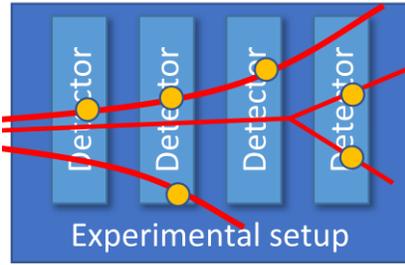
Experimental setup



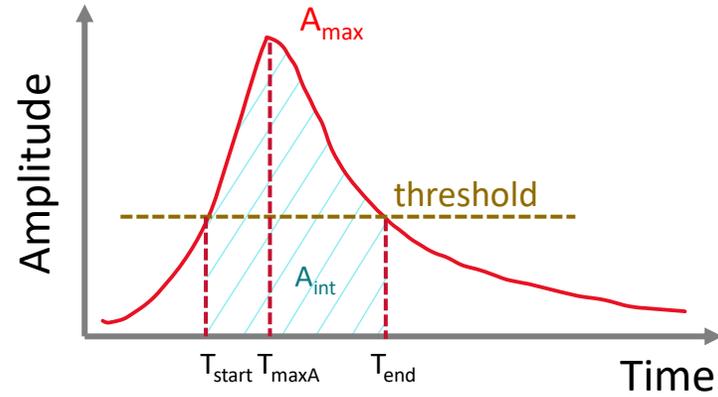
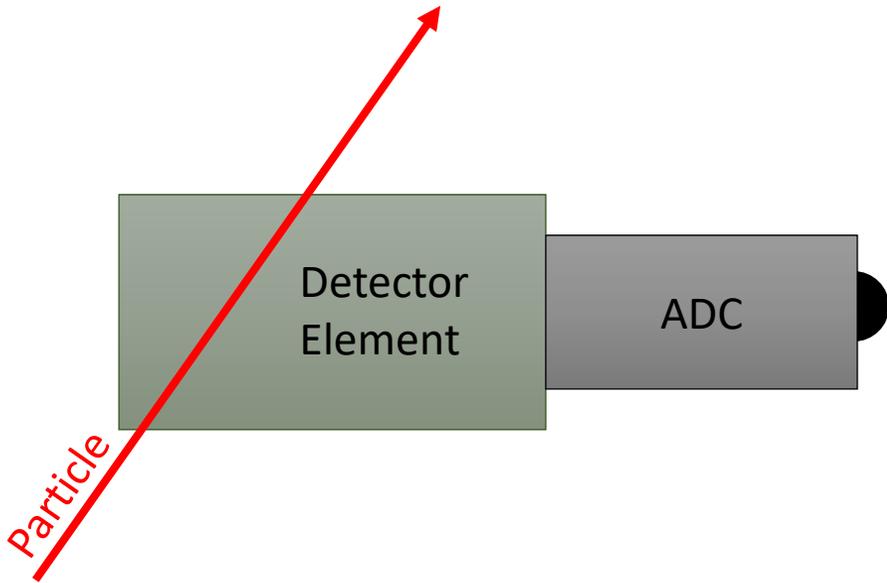
Detector



Detector ADC-s



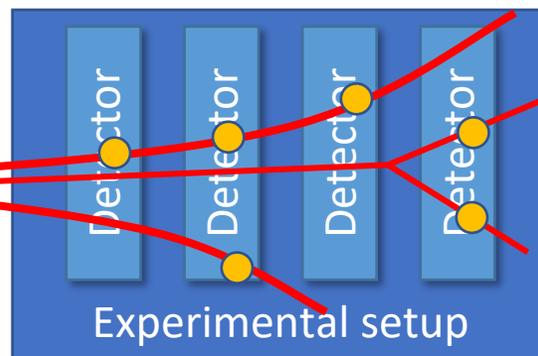
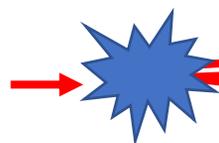
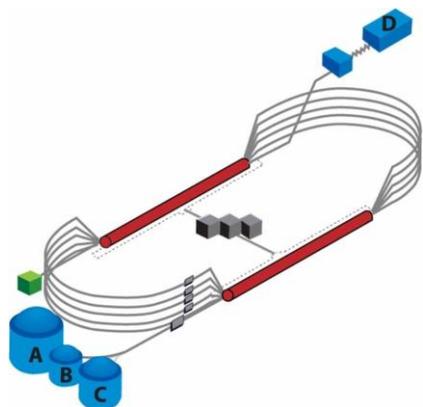
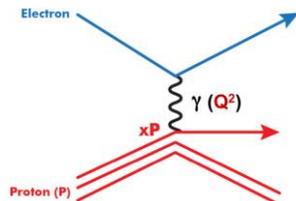
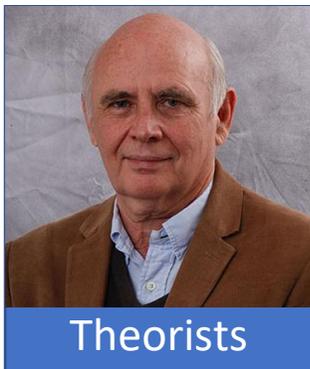
What is a hit



- T_{start}
- T_{maxA}
- T_{end}
- $A_{integral}$
- A_{max}

Some values to analyze / save

Experimental data workflow

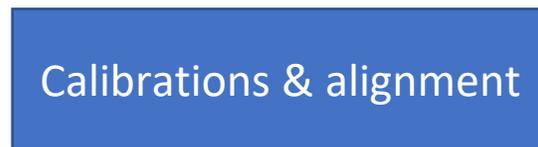
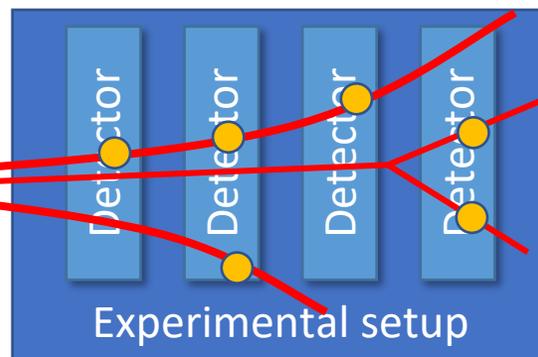
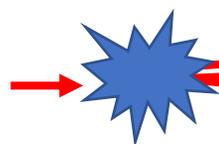
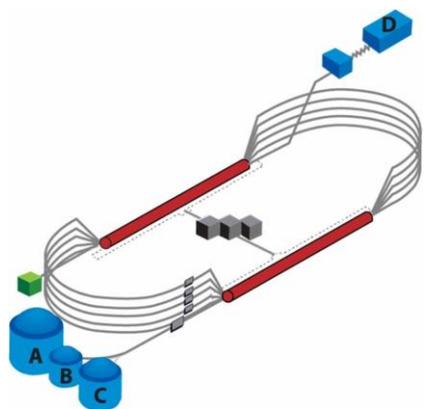
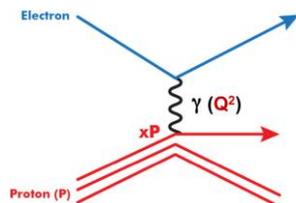


- Data - a stream of “raw values”
- Stream is cut into “**events**” (trigger)
- HallD spring 2018 run:
 - ~1.9PB of data
 - 150B of events

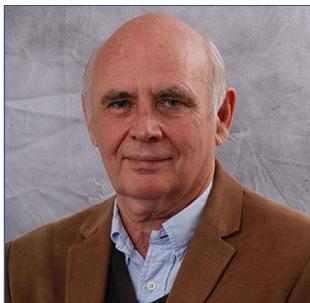
Experimental data workflow



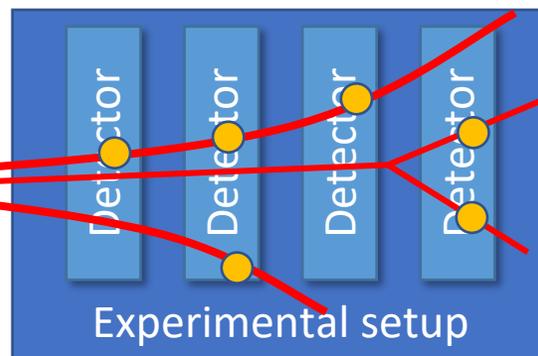
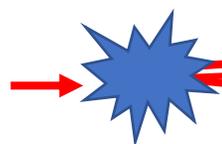
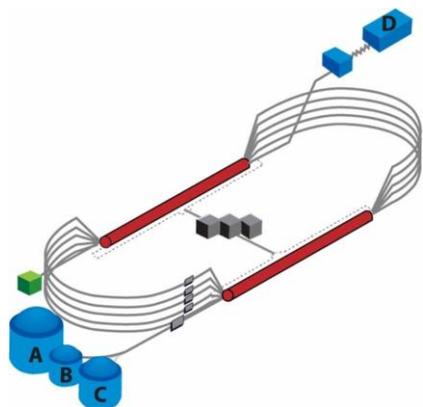
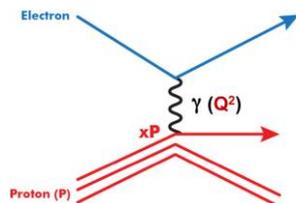
Theorists



Experimental data workflow



Theorists



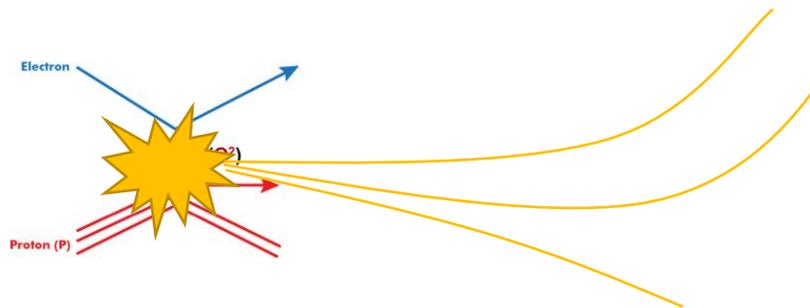
Calibrations & alignment

- **Calibration** – allow to get physical meaning from electronics' data
- **Alignment** – corrections due to non ideal positioning and assembly of detector elements
- **Everything changes in time!** – something constantly being replaced, repaired and upgraded!

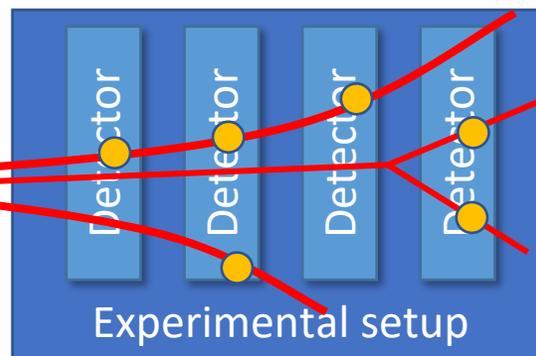
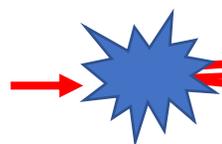
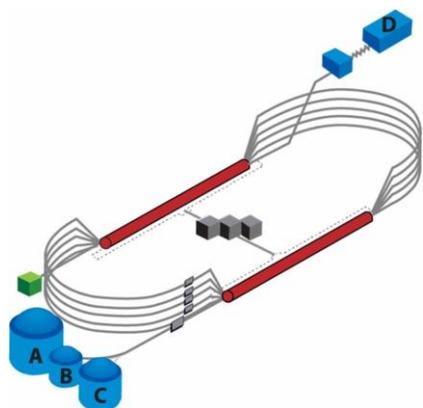
Experimental data workflow



Theorists

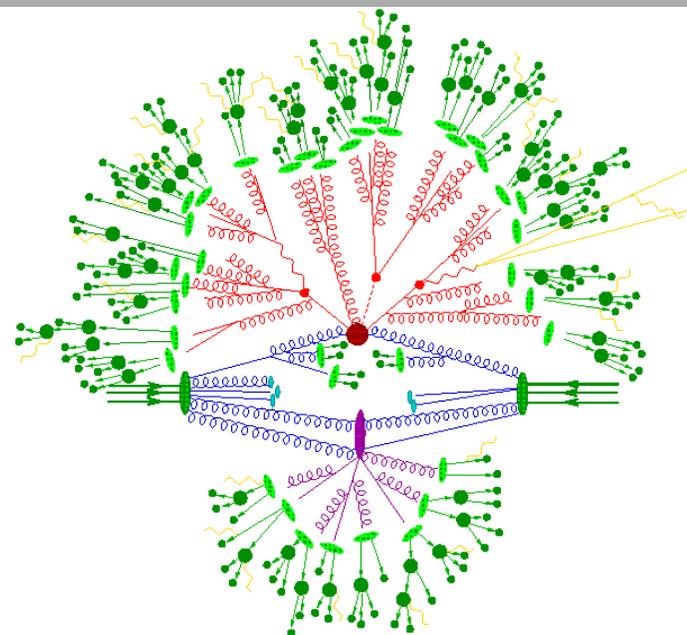


What is on theory side?



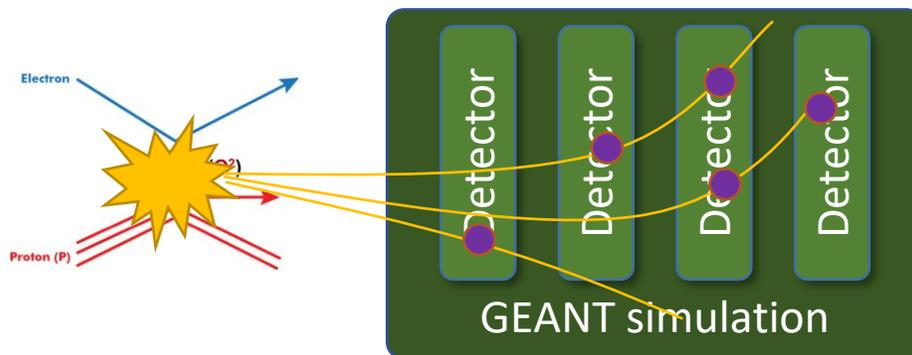
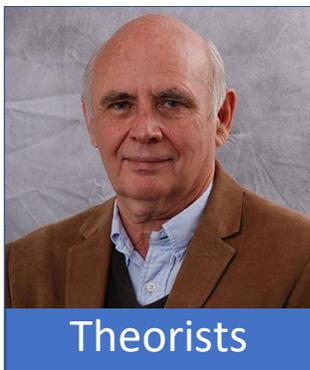
Calibrations & alignment

- MCEG – Monte Carlo Event Generators

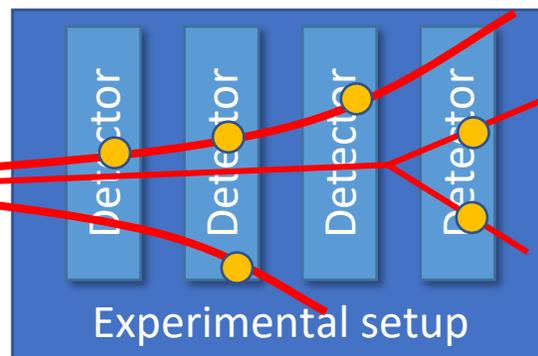
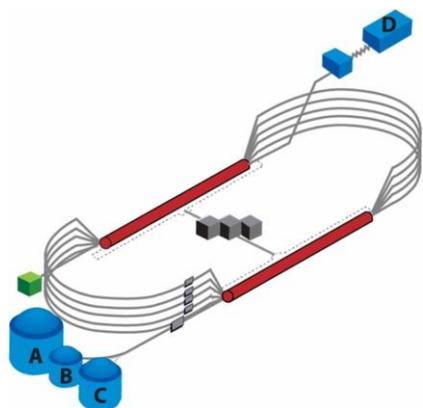


Simulation of a $t\bar{t}h$ event as produced by an event generator.

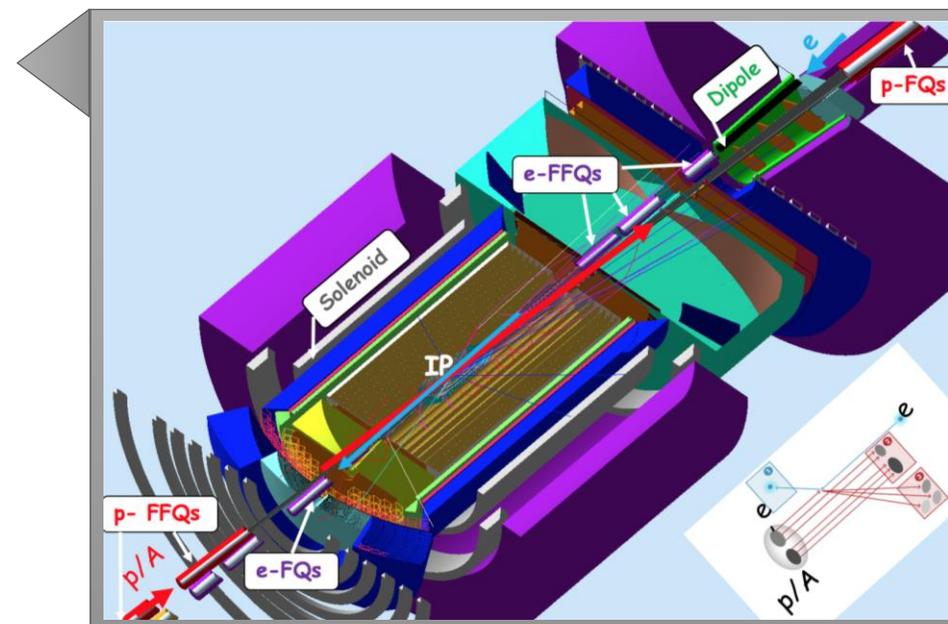
Experimental data workflow



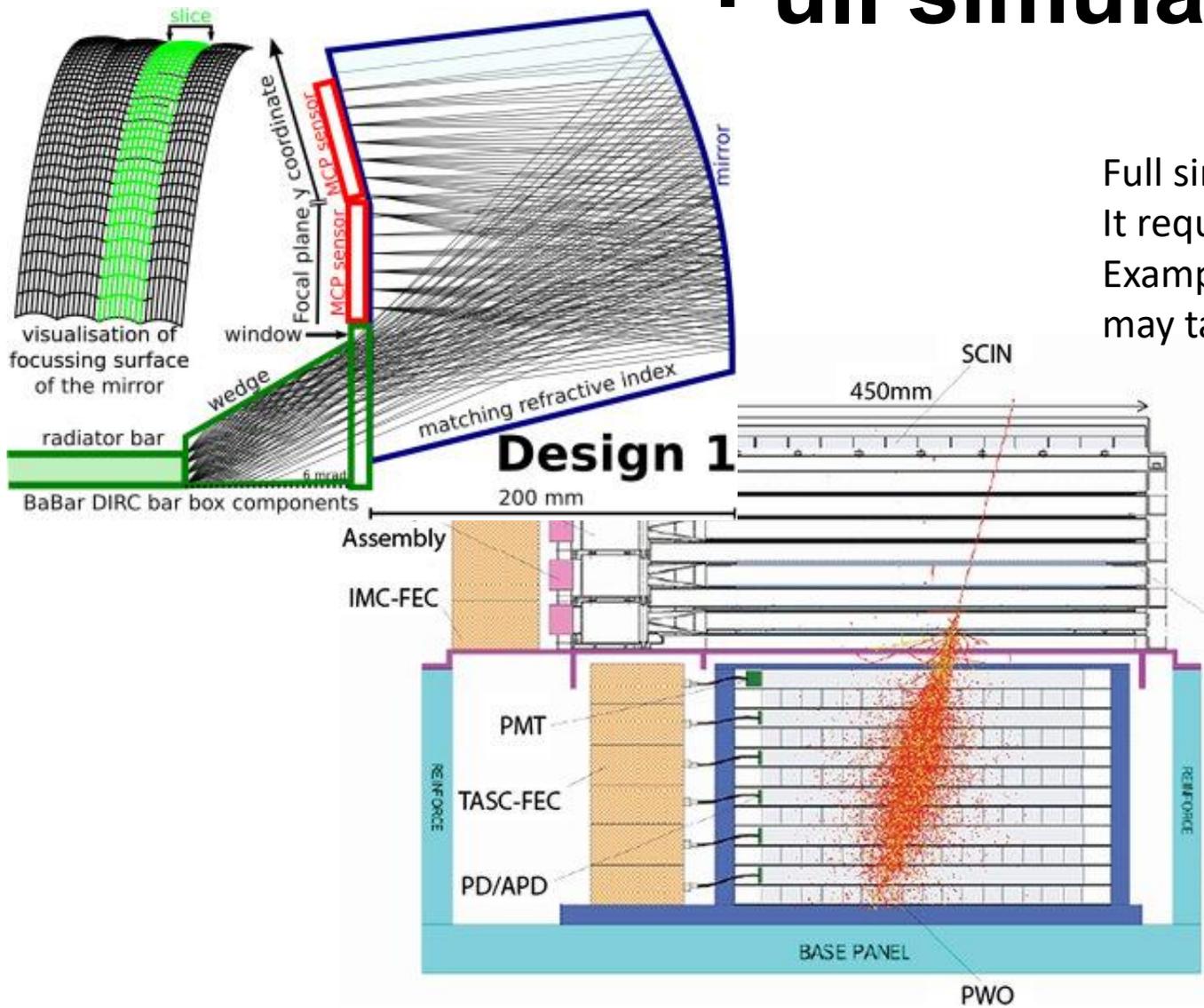
What is on theory side?



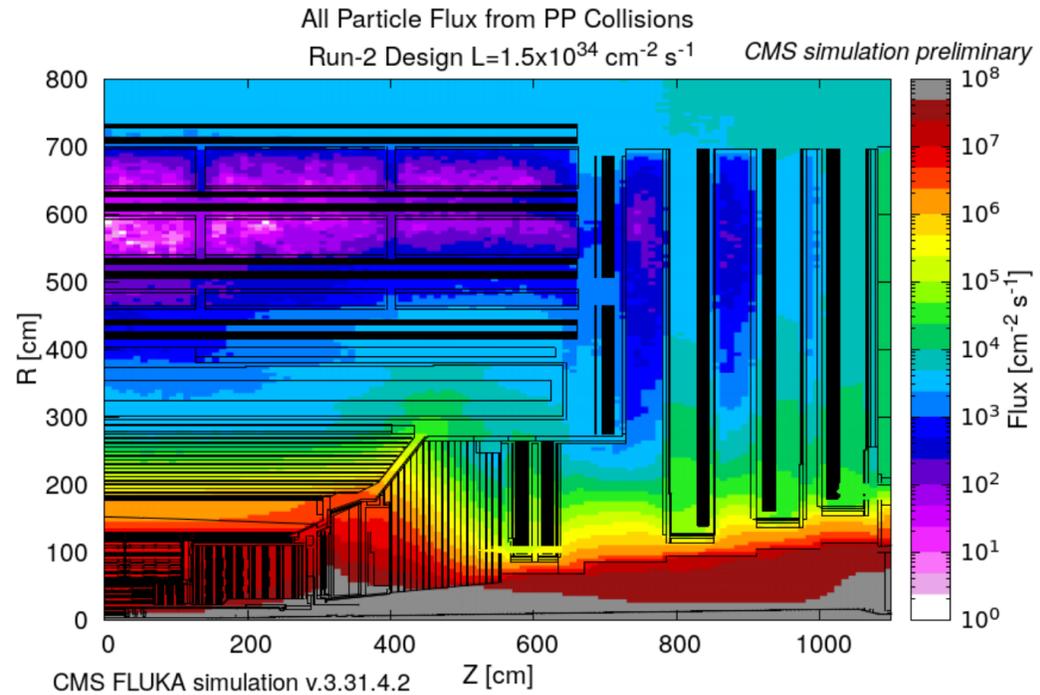
Calibrations & alignment



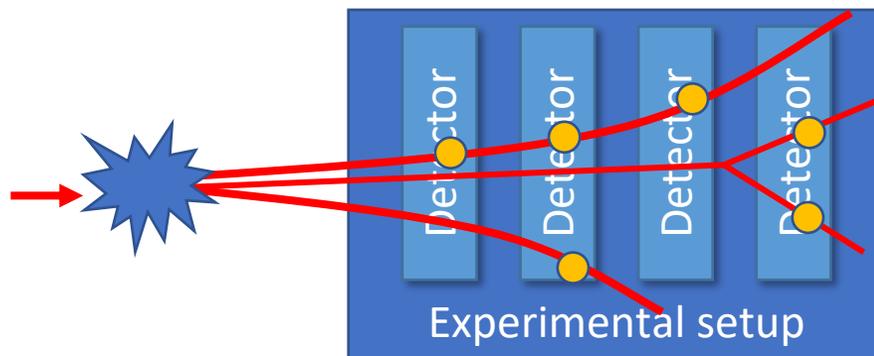
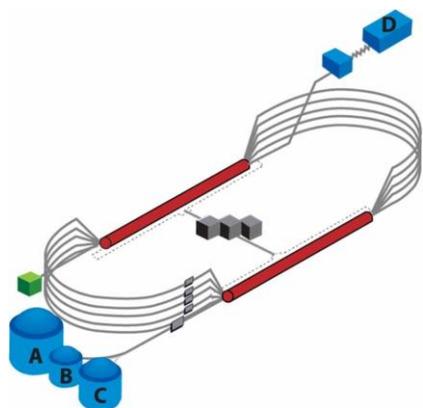
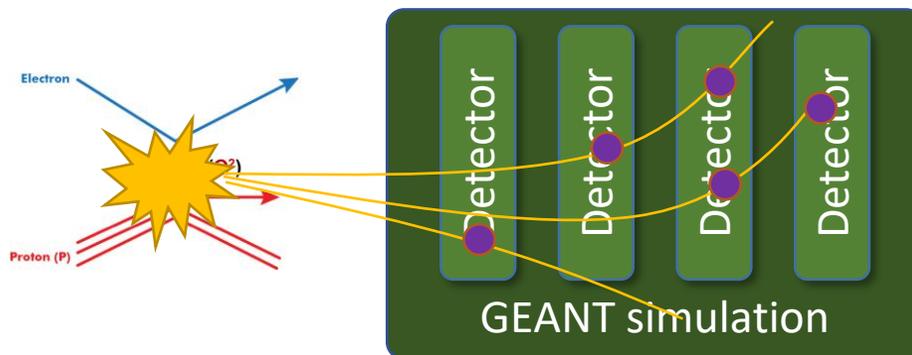
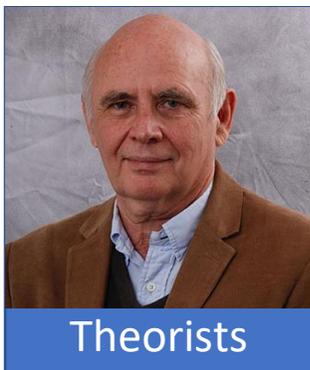
Full simulation



Full simulation goes into details
 It requires enormous amount of resources
 Example: Fun4All sPhenix simulation of 1 event
 may take up to 25 seconds © Chris P.

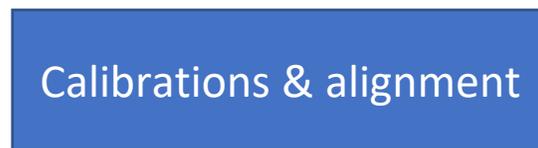
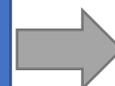
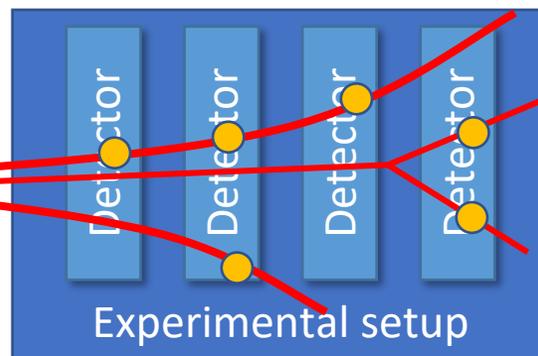
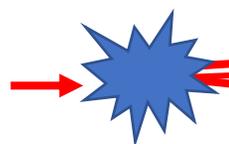
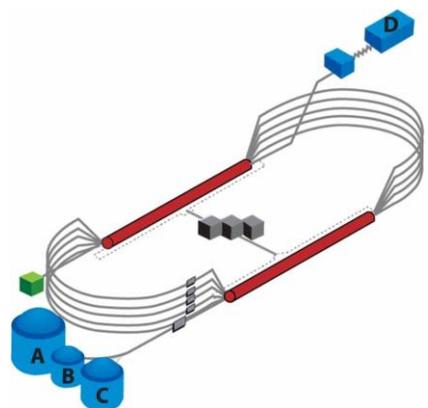
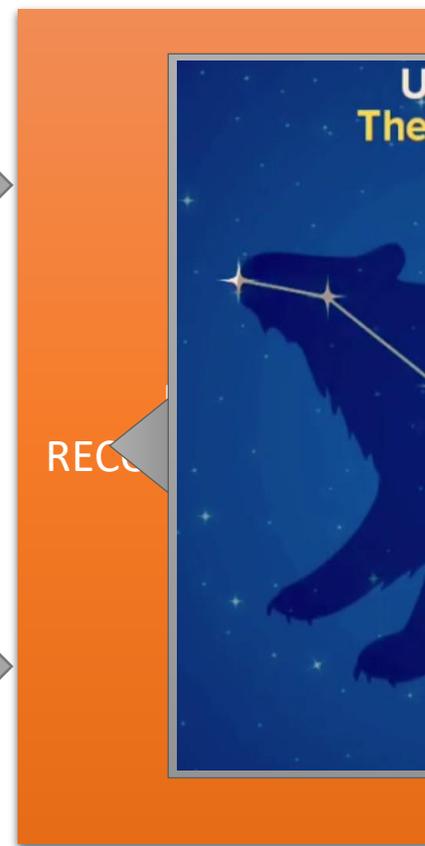
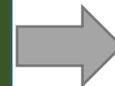
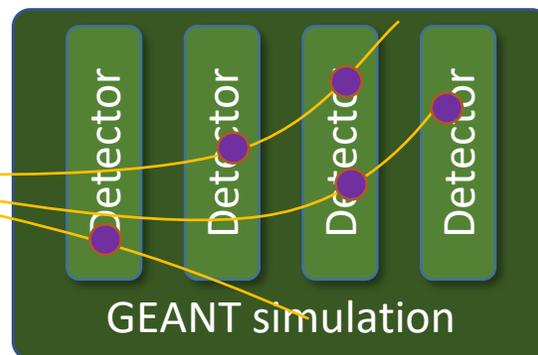
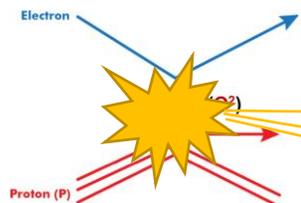
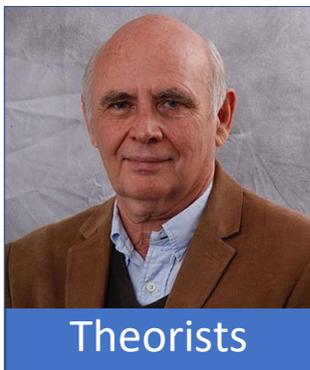


Experimental data workflow

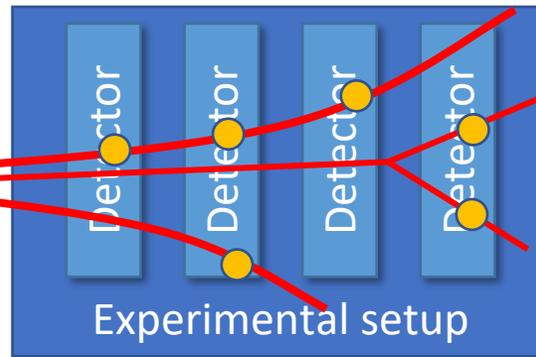
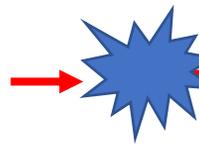
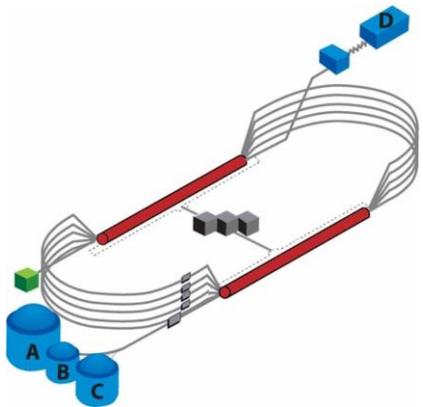
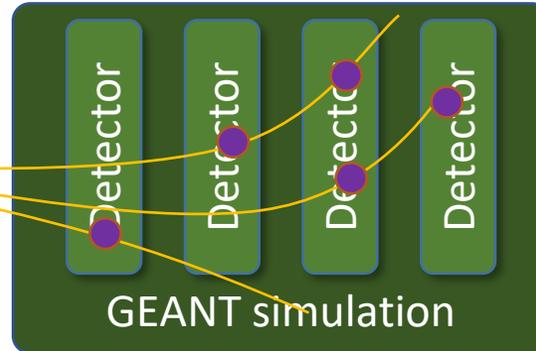
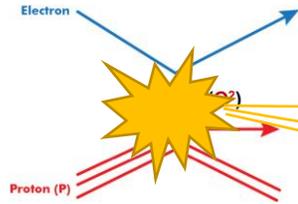
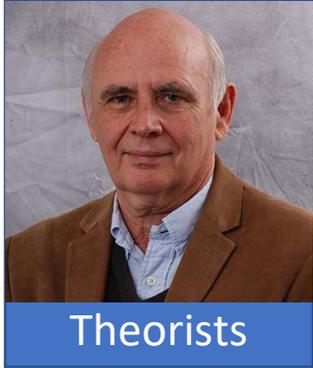


Calibrations & alignment

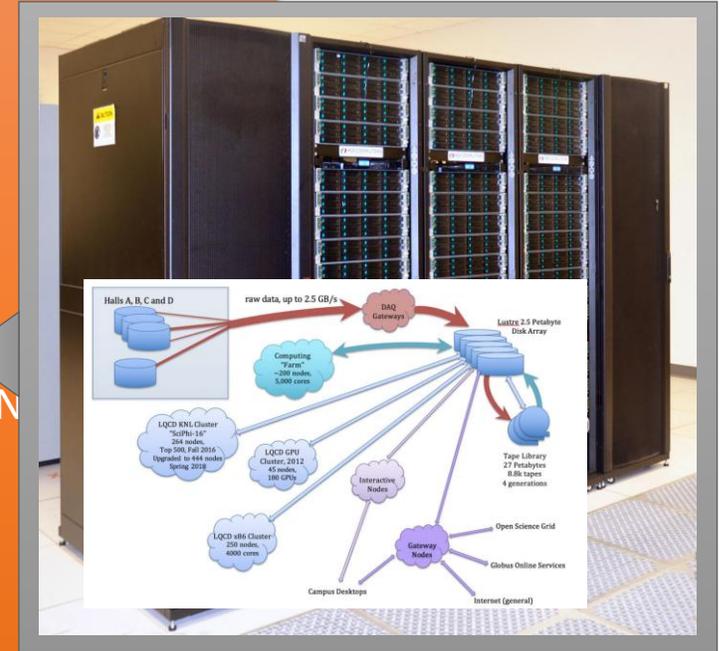
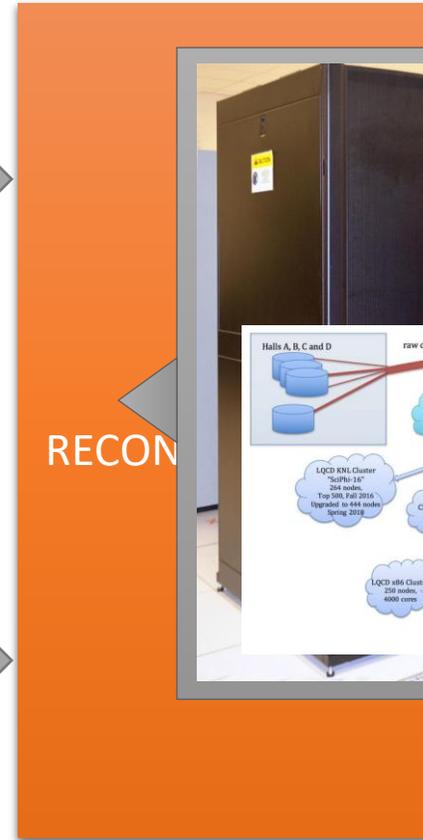
Experimental data workflow



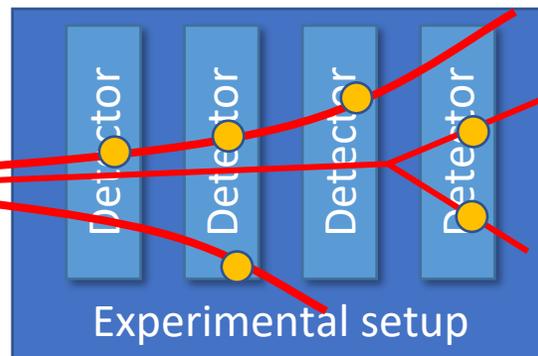
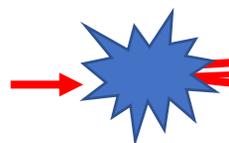
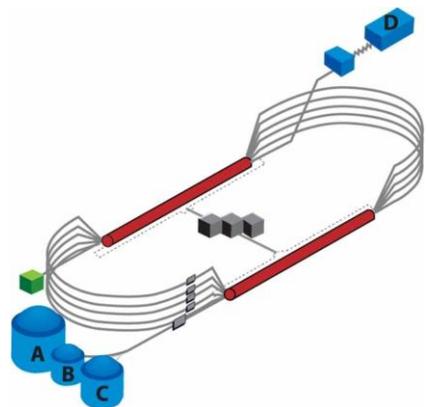
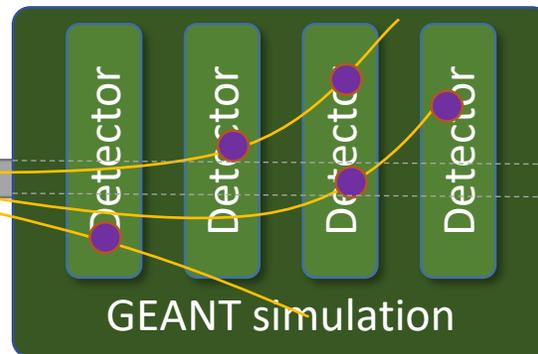
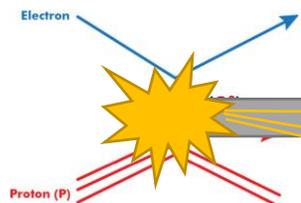
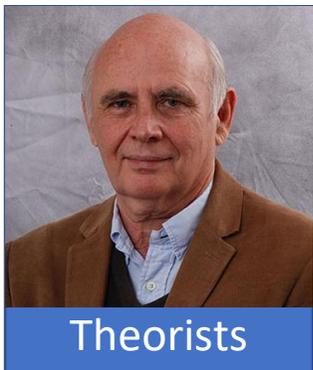
High performance computing for reconstruction



Calibrations & alignment

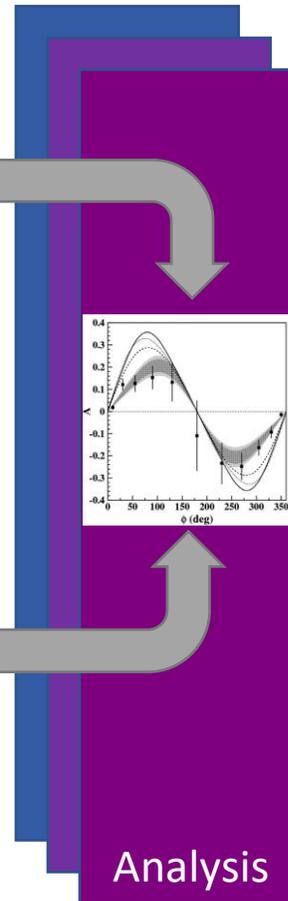


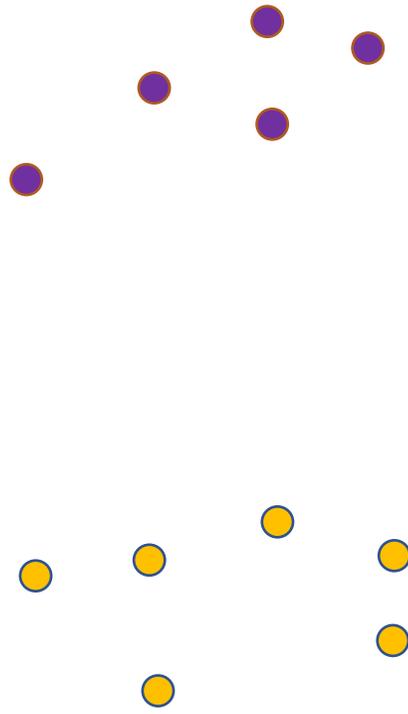
Experimental data workflow



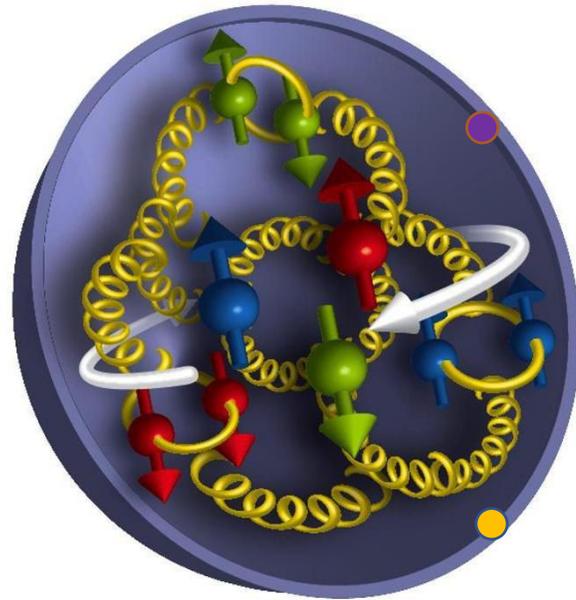
Calibrations & alignment

EVENT RECONSTRUCTION



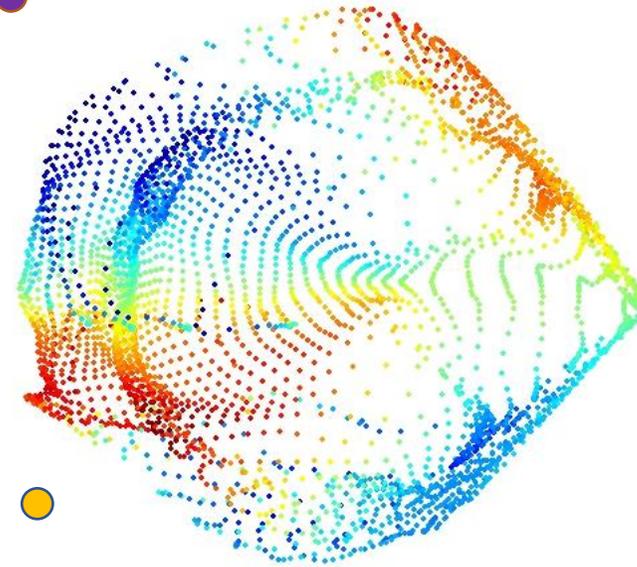


AI and Machine Learning for NP



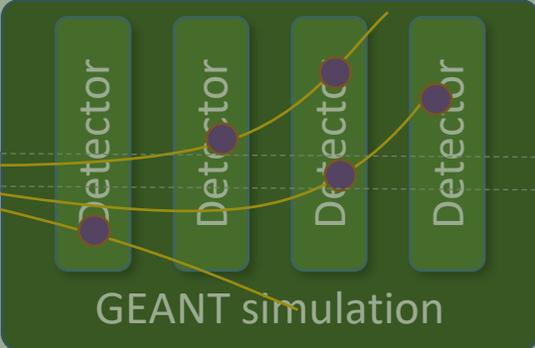
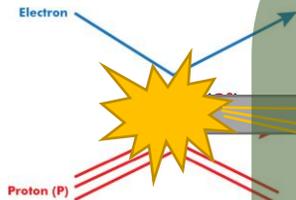
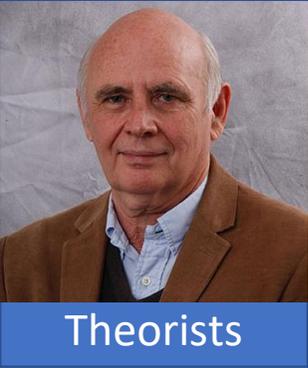
EIC

+

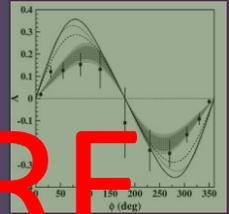


Machine Learning

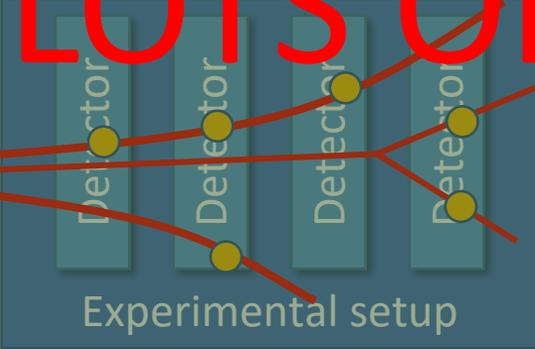
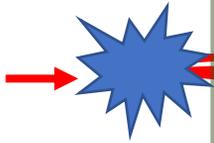
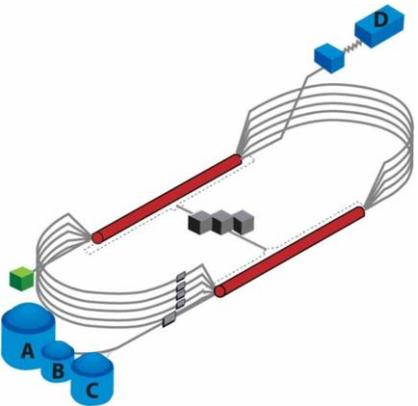
Full simulation flow



EVENT RECONSTRUCTION

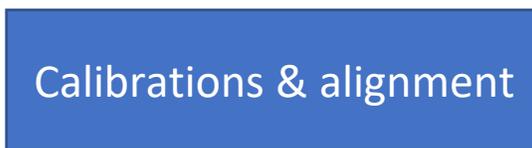
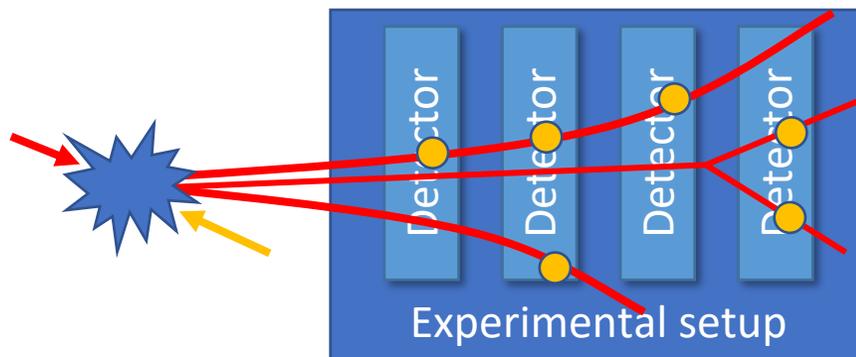
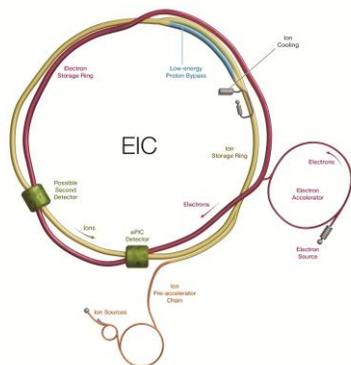
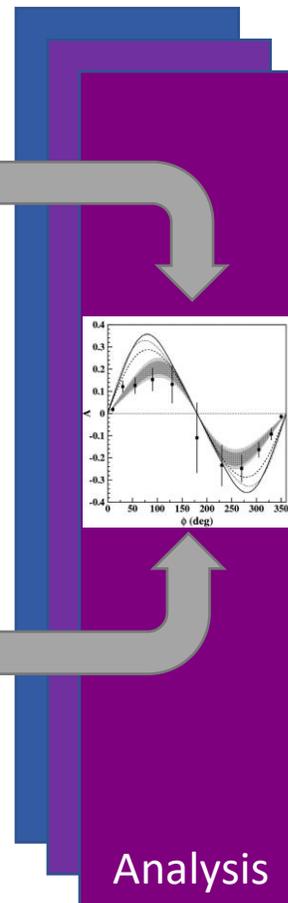
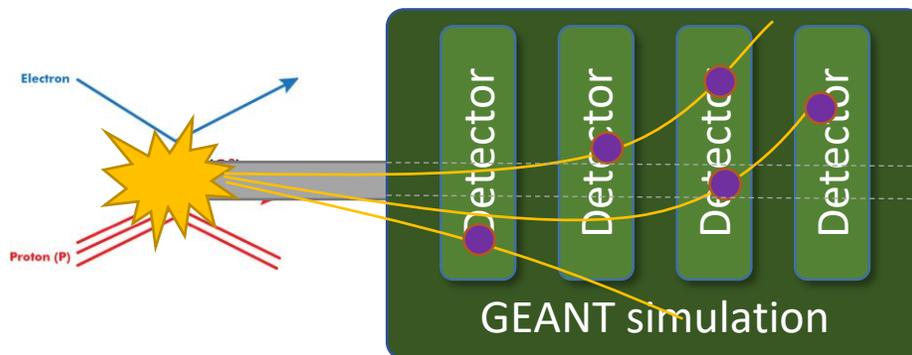
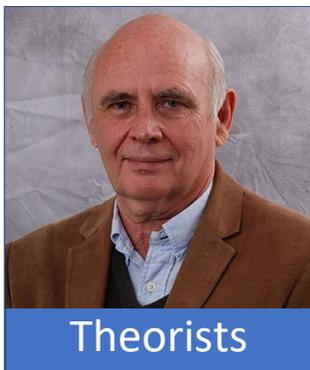


LOTS OF SOFTWARE

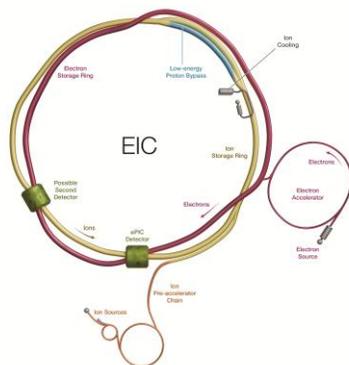
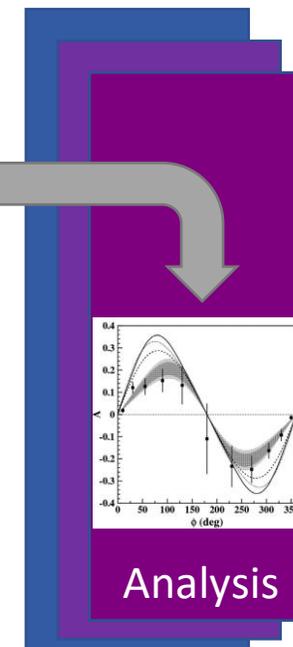
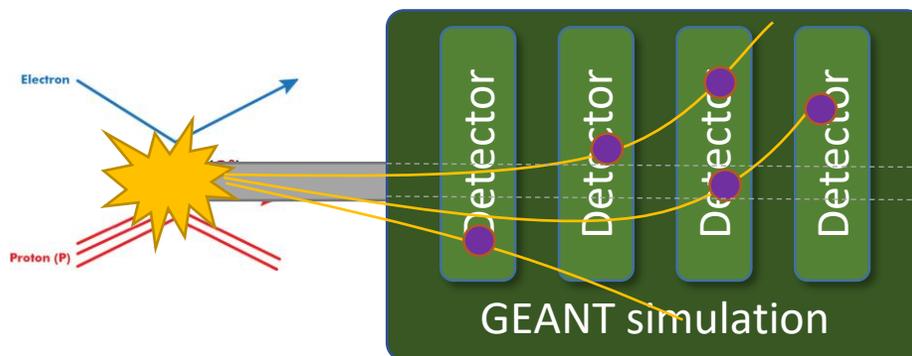
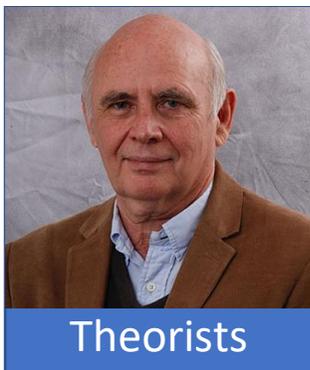


Calibrations & alignment

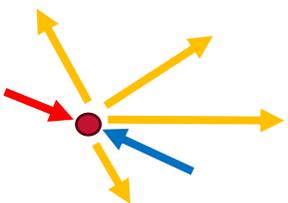
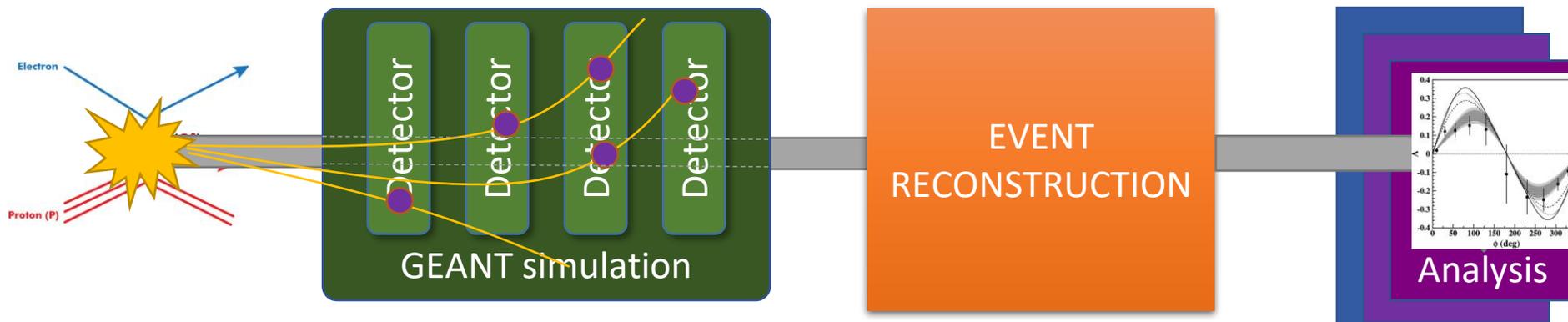
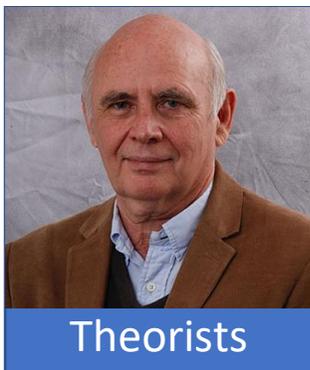
Experimental data workflow



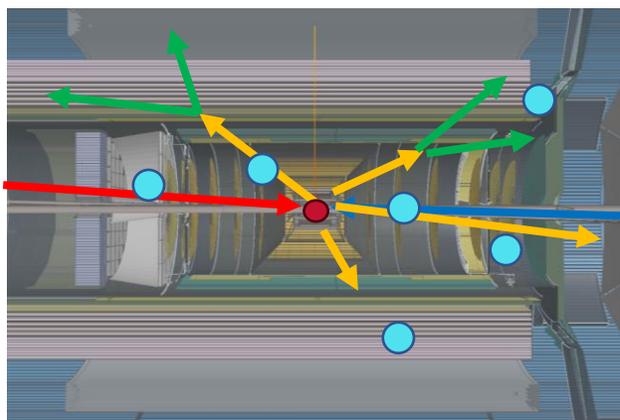
Experimental data workflow



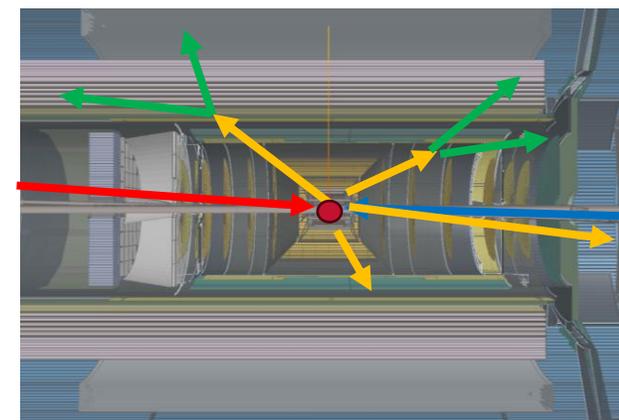
Experimental data workflow



-4 vectors
- Int. point

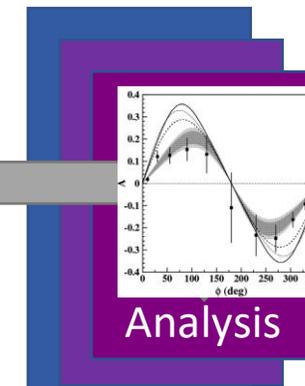
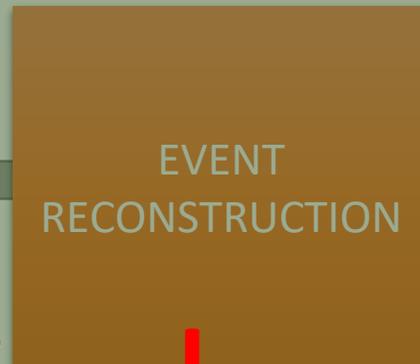
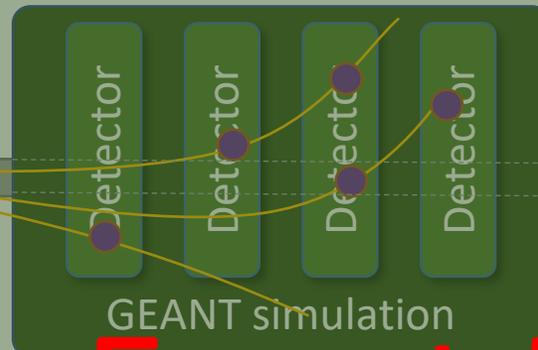
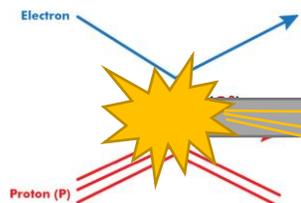
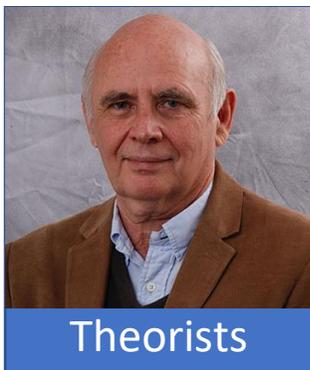


-Interaction with matter
-Detector responses

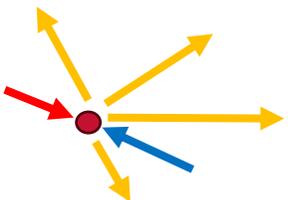


-Reconstruct detector responses
-Get Event kinematics

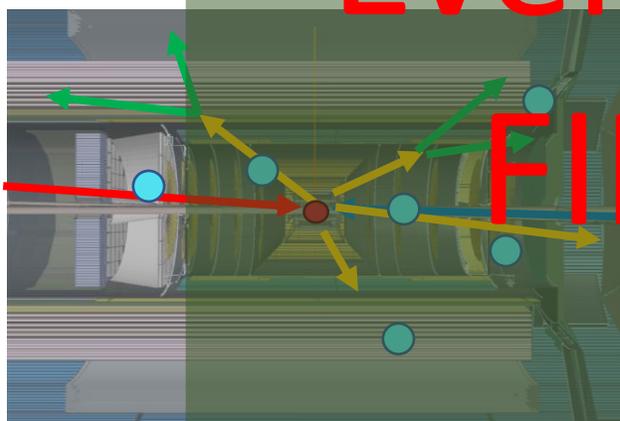
Experimental data workflow



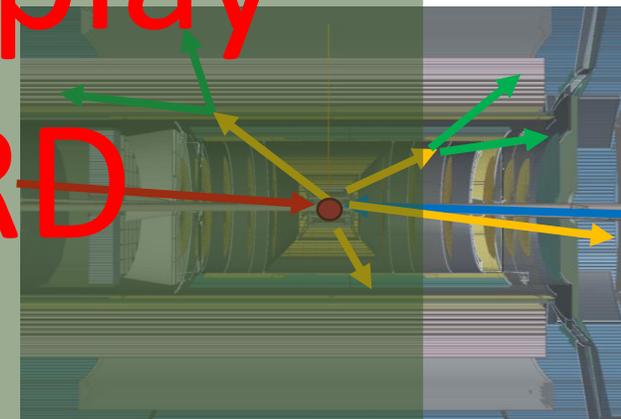
Event Display
FIREBIRD



Pythia8
-4 vectors
- Int. point



DD4Hep – Geant4
-Interaction with matter
-Detector responses

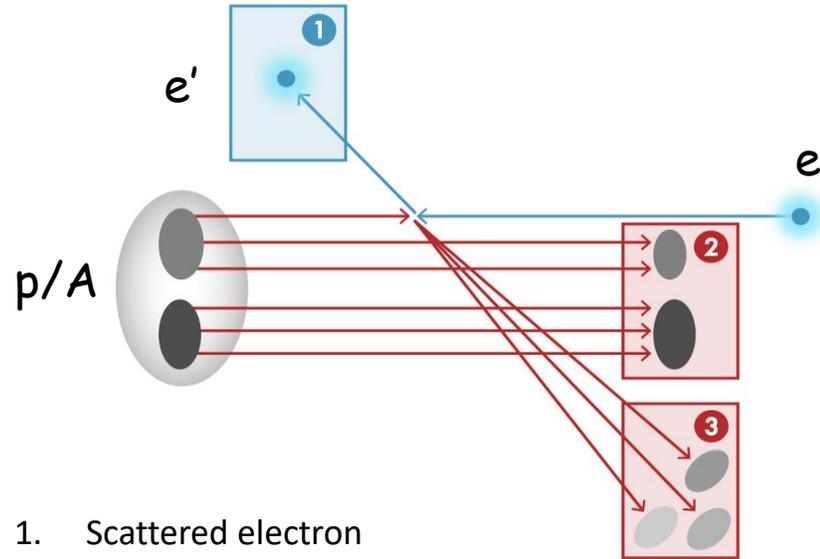


EICRecon
-Reconstruct detector responses
-Get Event kinematics

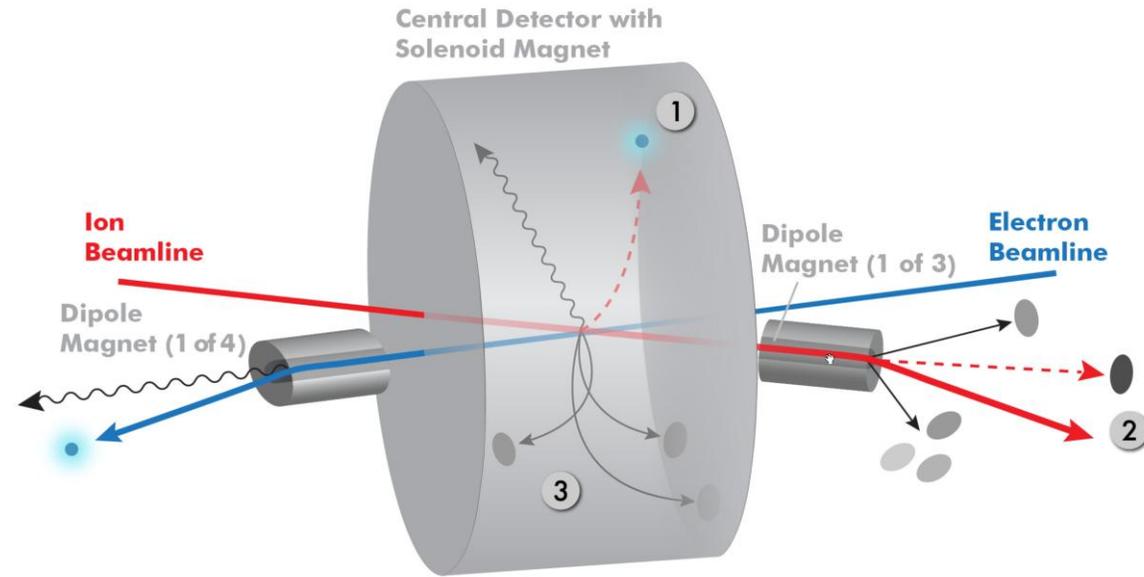
EIC even kinematics

Classification of the final-state particles of a DIS process at the EIC

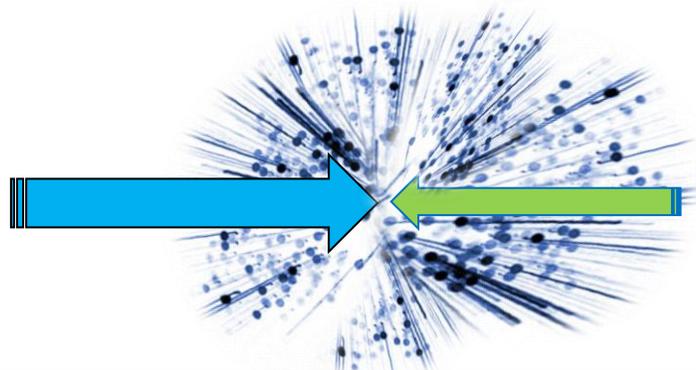
Neutral Current (NC) DIS $e + p \rightarrow e' + X$



1. Scattered electron
2. Particle associated with initial Ion
3. Particle associated with struck quark



4π total acceptance detector
with efficient PID, tracking, calorimetry.



For typical collider experiments, measurements are performed mainly in central region.

DIS Kinematic Variables

EIC @ Jefferson Lab

Deep Inelastic Scattering: $e + p \rightarrow e' + X$

Q^2

4-Momentum transfer squared

Resolution scale — how deep we probe

$$Q^2 = 4EE' \sin^2(\theta/2)$$

x

Bjorken x

Parton momentum fraction ($0 < x \leq 1$)

$$x = Q^2 / (s \cdot y)$$

y

Inelasticity

Fractional energy transfer to hadrons

$$y = 1 - (E'/E) \cos^2(\theta/2)$$

W^2

Hadronic Mass²

Invariant mass² of final state X

$$W^2 = M^2 + Q^2(1/x - 1)$$

ν

Energy Transfer

Energy lost by the scattered electron

$$\nu = E - E' = Q^2 / (2Mx)$$

s

CM Energy²

Center-of-mass energy squared (EIC: $\sim 45k \text{ GeV}^2$)

$$s \approx 4 E_e E_p$$

t

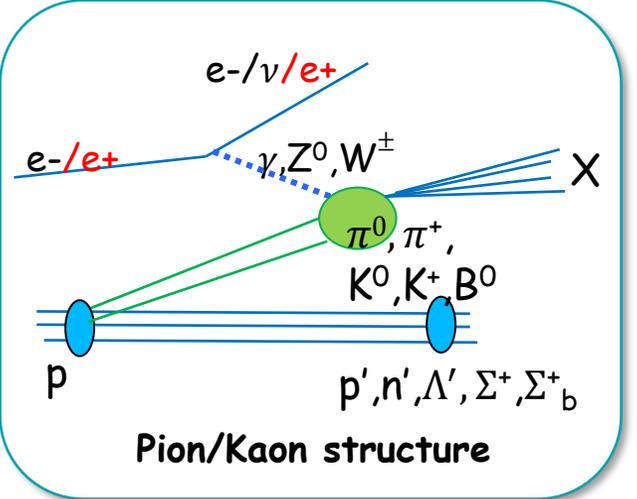
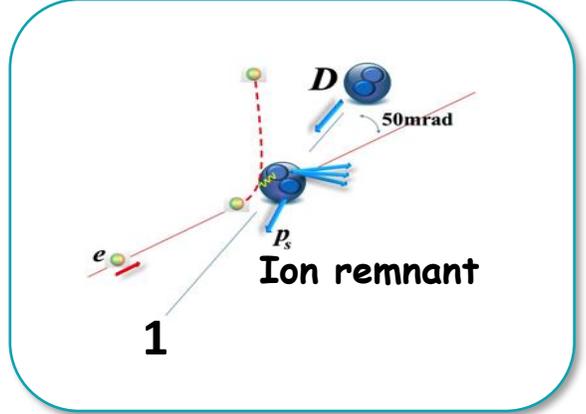
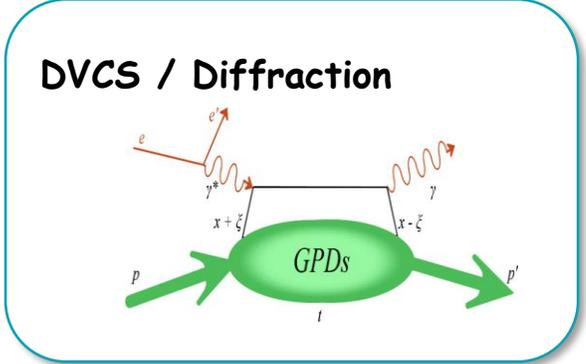
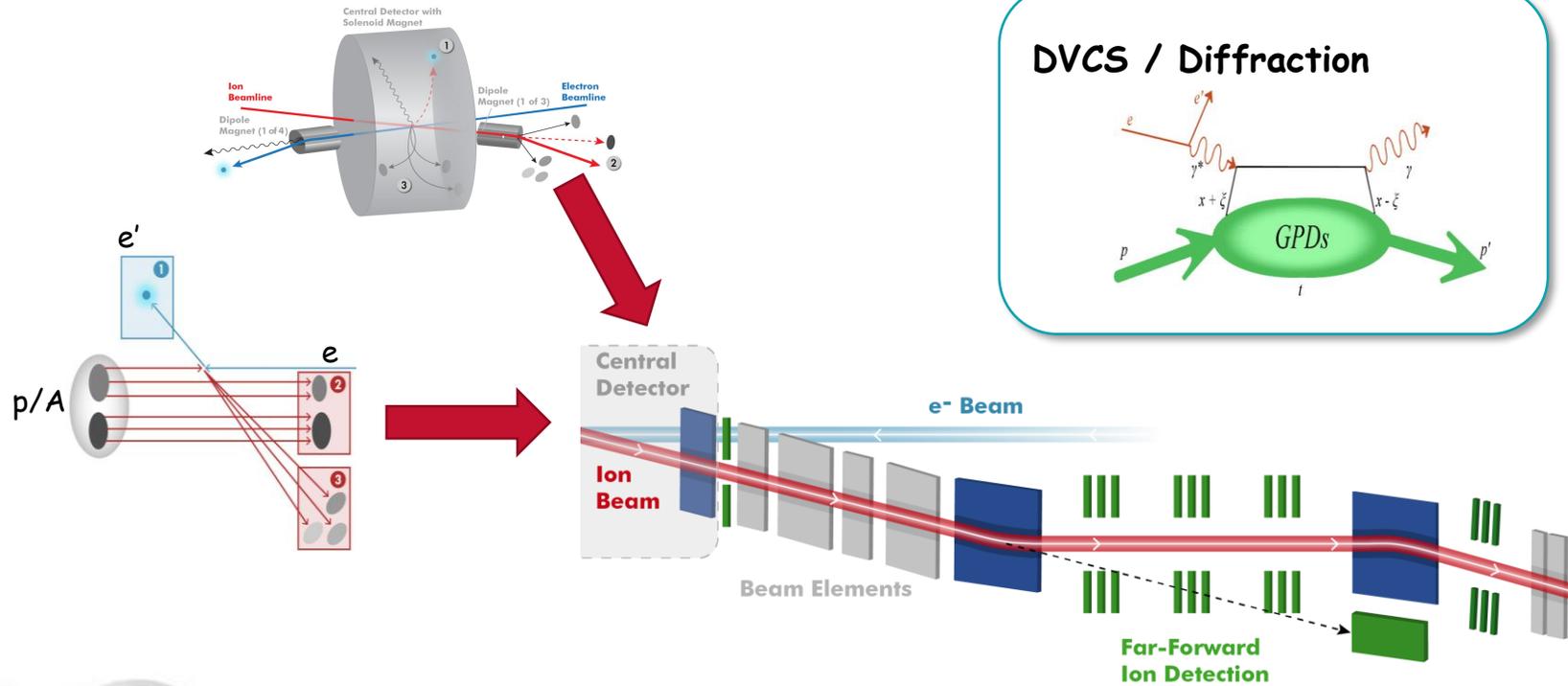
Mandelstam t

Momentum transfer to recoil proton (diffraction, DVCS, GPDs)

$$t = (p - p')^2 \approx -p_{\perp}^2$$

Fundamental Identity: $Q^2 = s \cdot x \cdot y$ | Electron method: x, Q^2, y from (E, E', θ) alone | $t \rightarrow$ proton imaging & GPDs (diffraction / DVCS)

Far forward region importance



Provide transport of the forward going particles along the beam line

Design should be done close together with detector & accelerator

seeEIC.org

QUESTIONS?