# *EIC*

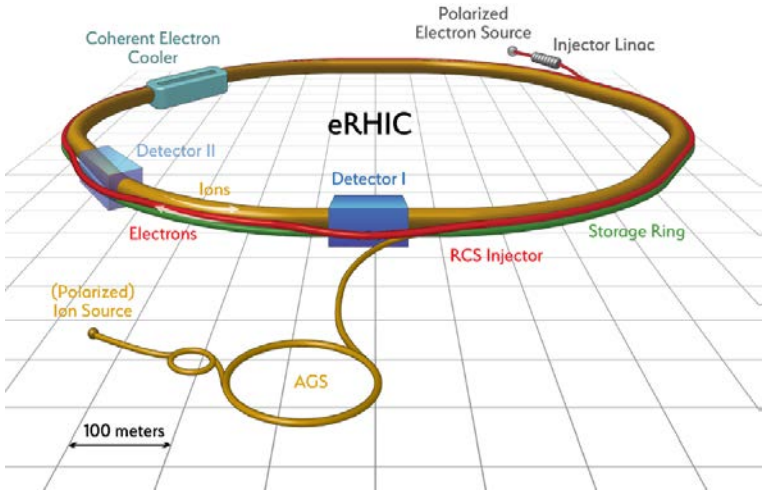
5th Kore-Japan
PHENIX/sPHENIX/EIC Collaboration Meeting
at Sejong University in Seoul, Korea
October 12th, 2019

Yuji Goto (RIKEN/RBRC)

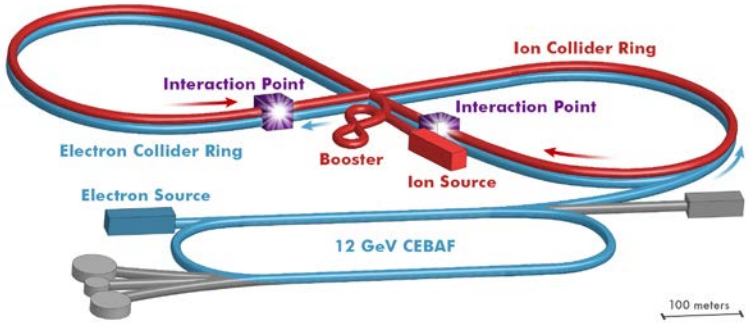
# EIC - Electron Ion Collider

- High-energy QCD frontier to study nucleon (hadron) and nucleus (cold nuclear matter) from quarks and gluons
- World's first polarized electron + proton / light-ion / heavy-ion collider
  - Wide ($Q^2$, $x$) region
- Electron + proton / light-ion collision
  - Polarized beam
    - e, p, d/$^3$He
  - High luminosity
    - $L_{ep} \sim 10^{33\text{-}34}\ cm^{-2}s^{-1}$
    - 100-1000 times HERA
  - Collision energy
    - $\sqrt{s}$ = 20 – 100 (140) GeV
- Electron + heavy-ion collision
  - Wide range in nuclei

eRHIC at BNL

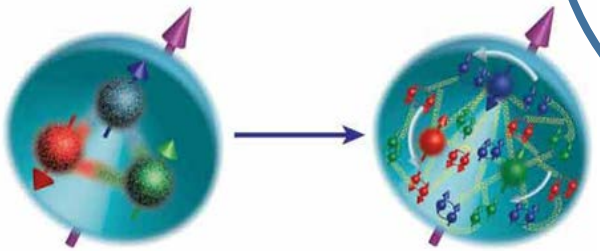



JLEIC at Jefferson Lab



# Physics at EIC

Understanding how the nucleon structure and properties emerge from quarks and gluons and their interactions from QCD

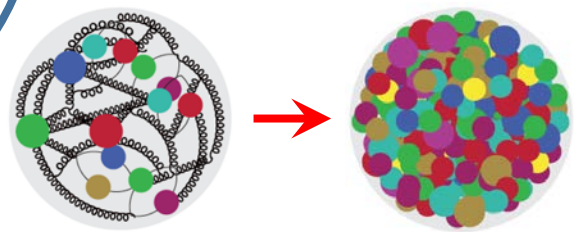


How does the mass of the nucleon arise?

3D Picture of the Nucleons and Nuclei

- *Transverse -Momentum Distribution and Spatial Imaging*
- *Orbital Motion of Quarks and Gluons Inside*

Systematic understanding of the structure of nucleons and nuclei covering the wide kinematic range



## New Picture

## Precision Measurement

How does the spin of the nucleon arise?

Spin and Flavor Structure of the Nucleons and Nuclei

- *Gluon Polarization*
- *Quarks and Gluons Inside the Nuclei*
- *Hadronization*

Luminosity

Collision Energy

## Discovery

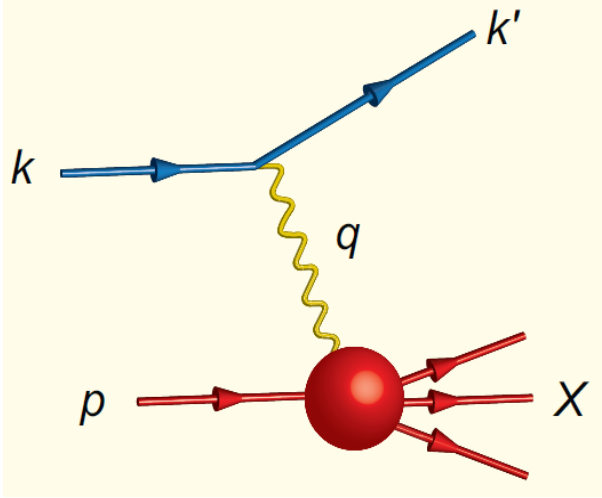
What are the emergent properties of dense systems of gluons?

Gluon Saturation at Extreme Density

- *Initial State of the QGP (Quark-Gluon Plasma)*

# Precision measurement of PDFs

- Inclusive DIS
  - $Q^2 = -q^2$: large $Q^2$ provides a hard scale to resolve partons (quarks and gluons) in the proton
  - Bjorken-*x*: 1D longitudinal motion of partons in the proton
- Spin puzzle
  - Gluon polarization measurement with polarized DIS
    - Small Bjorken-*x* region with QCD evolution (DGLAP equation)



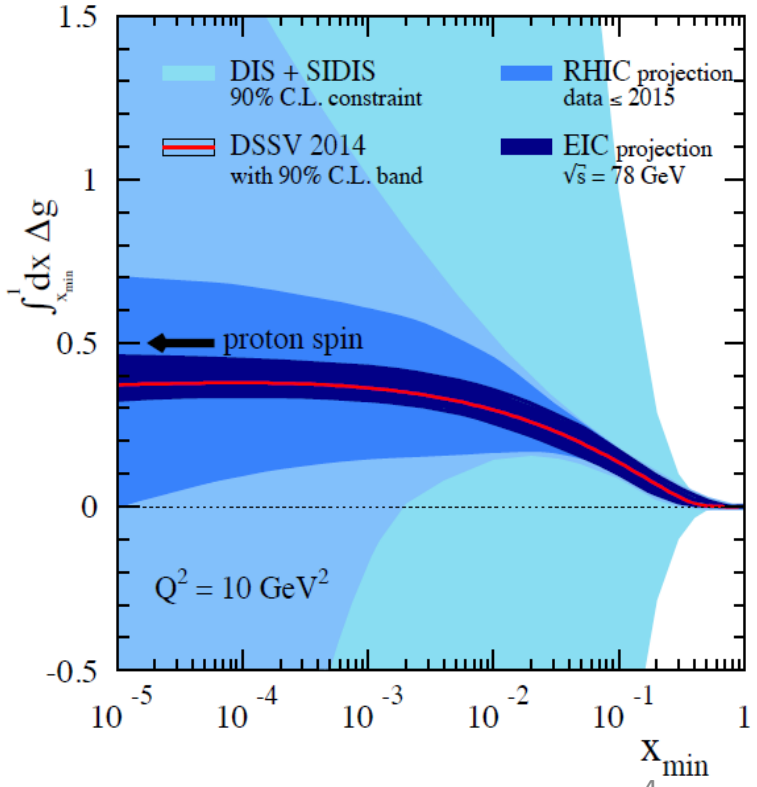

$$\frac{1}{2} = \left[\frac{1}{2}\Delta\Sigma + L_Q\right] + \left[\Delta g + L_G\right]$$

$\Delta\Sigma/2$ = Quark contribution to Proton Spin

$L_Q$ = Quark Orbital Ang. Mom

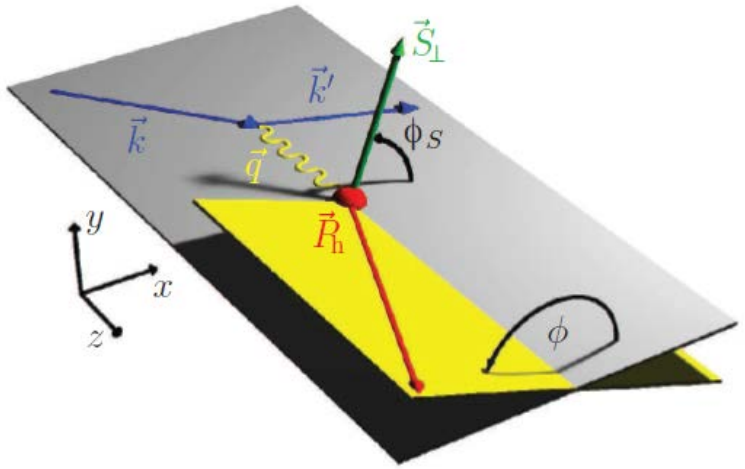
$\Delta g$ = Gluon contribution to Proton Spin

$L_G$ = Gluon Orbital Ang. Mom



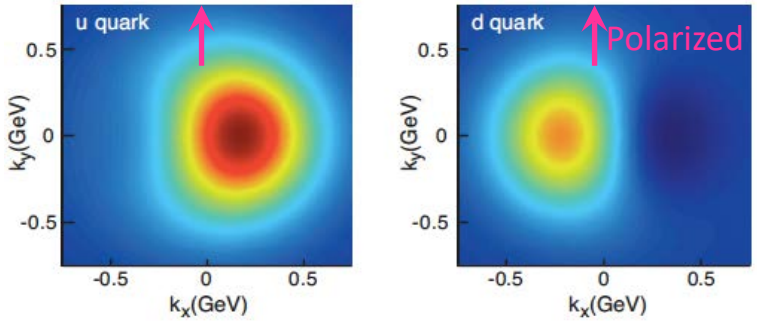
# Precision measurement of PDFs

- Semi-Inclusive DIS (SIDIS)
  - Flavor dependence of the quark polarization
  - Transverse-momentum dependence (TMD): orbital motion of partons in the proton
- TMD distribution function
  - 3D distribution: longitudinal & transverse momentum dependence
  - Correlation of spin and parton's orbital motion

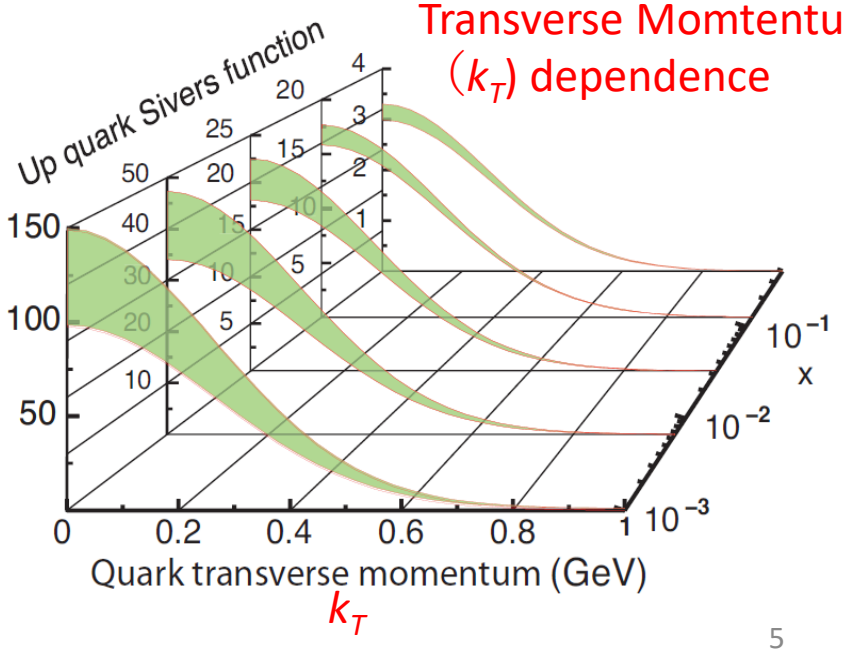



Sivers function:
Correlation of the nucleon spin and the parton transverse momentum

Sivers function at $x$ = 0.1

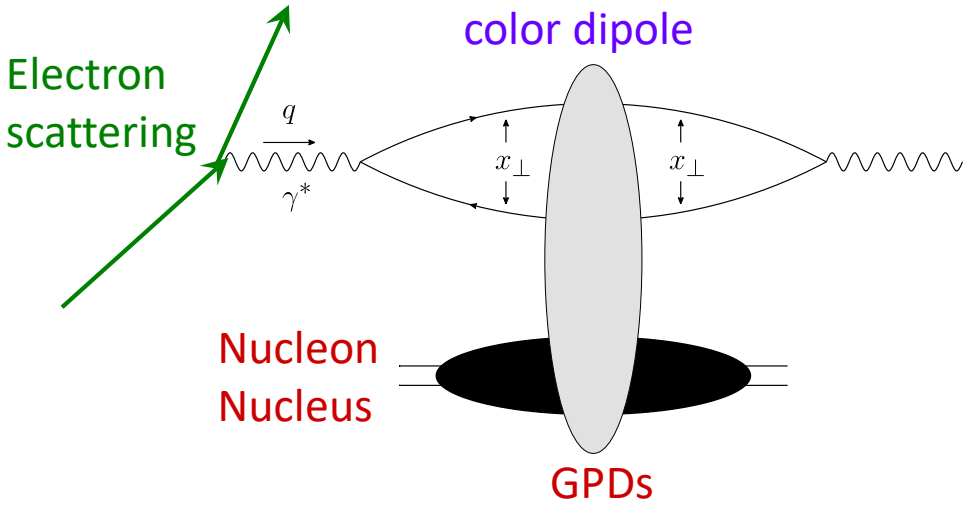



Transverse Momtentum ($k_T$) dependence

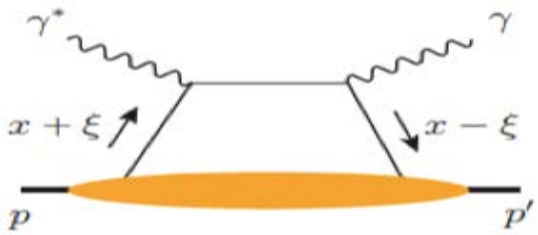


# Tomography of the nucleon / nucleus

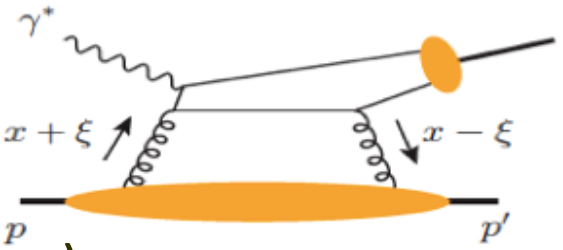
- EIC = color dipole microscope
  - Exclusive process and diffractive process
  - 3D distribution: transverse spatial distribution




DVCS (Deeply Virtual Compton Scattering)




Meson Production




J/ψ, ϕ, ρ, etc.

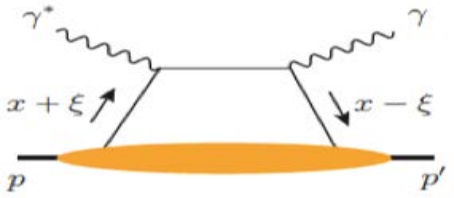
- GPD (Generalized Parton Distribution)
  - Spatial imaging of gluons and quarks = tomography
    - HERA: 1st generation
    - EIC: 2nd generation (high luminosity, heavy ion, polarization)
  - Orbital angular momentum
    - Ji's sum rule

$$J_q^z = \frac{1}{2}\sum_q \Delta q + \sum_q L_q = \frac{1}{2}\left(\int_{-1}^{1} x dx (H^q + E^q)\right)_{t\to 0}$$

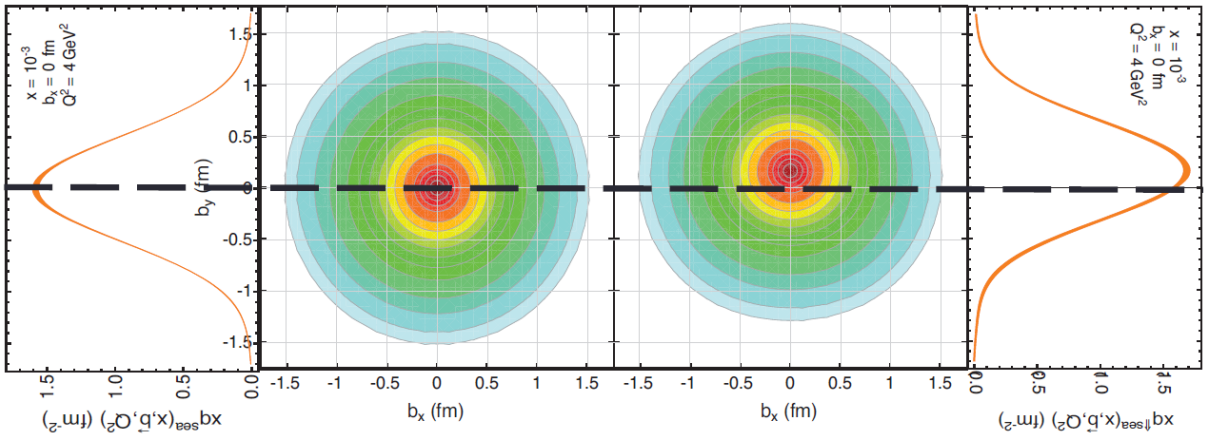
# Tomography of the nucleon / nucleus

- DVCS
  - Deeply virtual Compton scattering

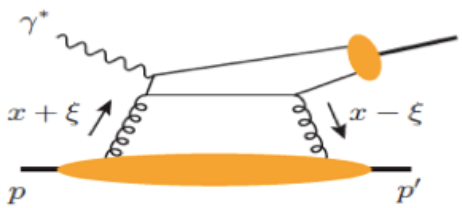
Spatial distribution of sea quarks at EIC 100 $fb^{-1}$ and corresponding density of partons in the transverse plane



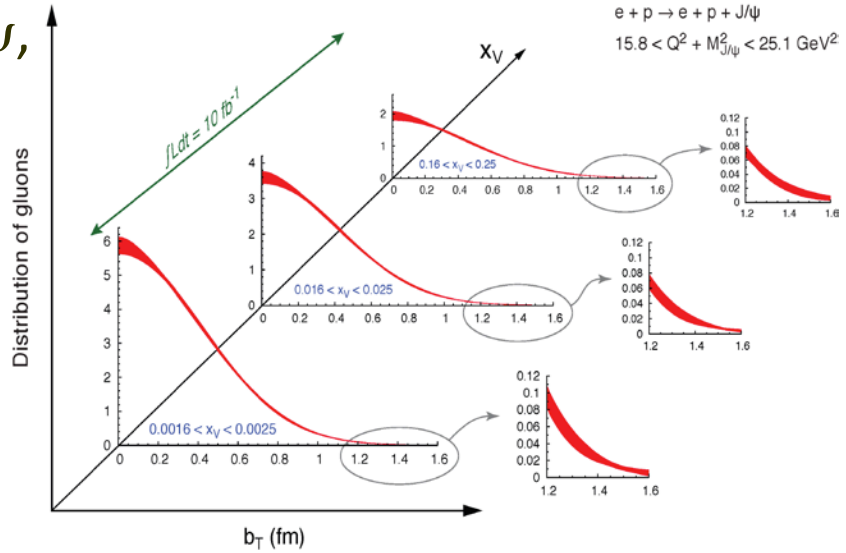

Unpolarized Polarized




- Meson production
  - Gluon tomography by measuring J/ψ, ϕ, ρ, etc.
  - Precision measurement at large radius with high luminosity

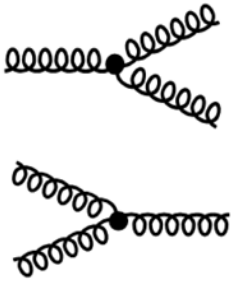


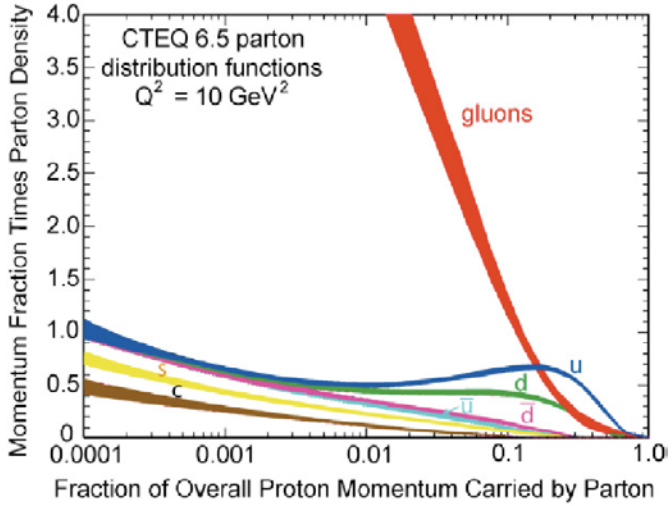

J/ψ, ϕ, ρ, etc.

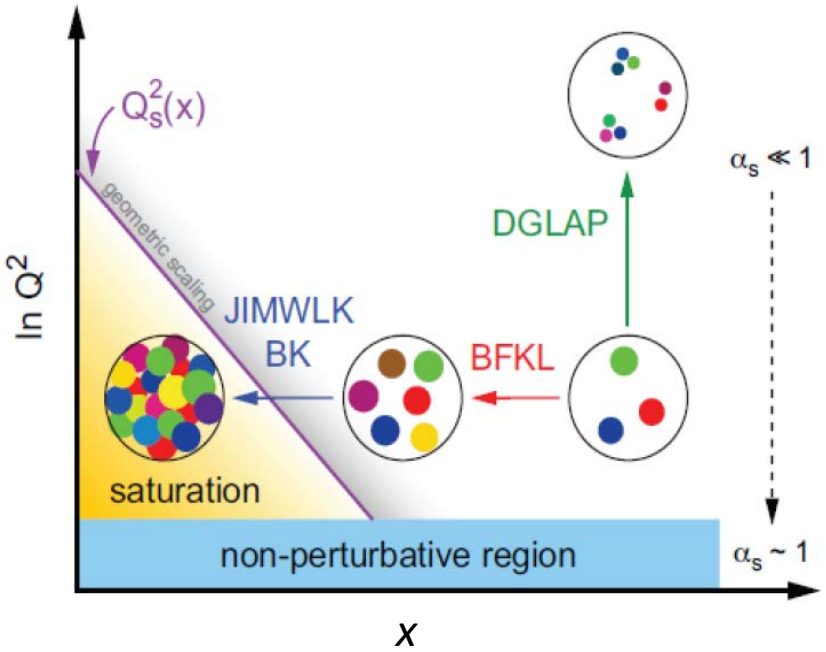


# Gluon saturation in e+A collisions

- Gluon emission
  - Divergence at small x
- Gluon recombination
  - Restriction of divergence
- Gluon saturation in balanced
  - Based on classical idea of the saturation
- First observation of a quantum collective gluonic system
  - Precision comparison of experiment and Chiral Glass Condensate (CGC) as a theoretical model of the gluon saturation
- Precision understanding of nucleus with the quark-gluon picture necessary as the initial state of the QGP for understanding its production mechanism



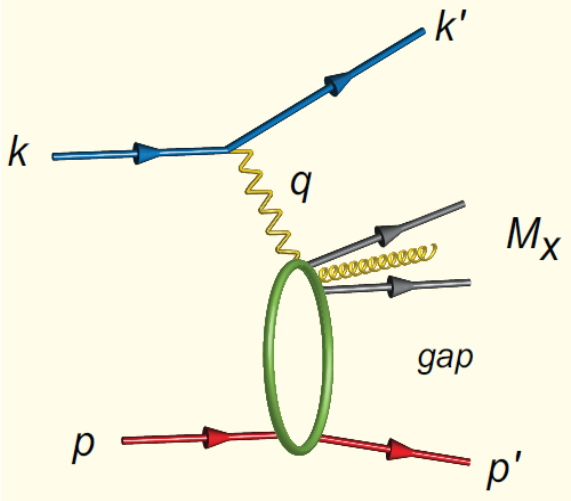


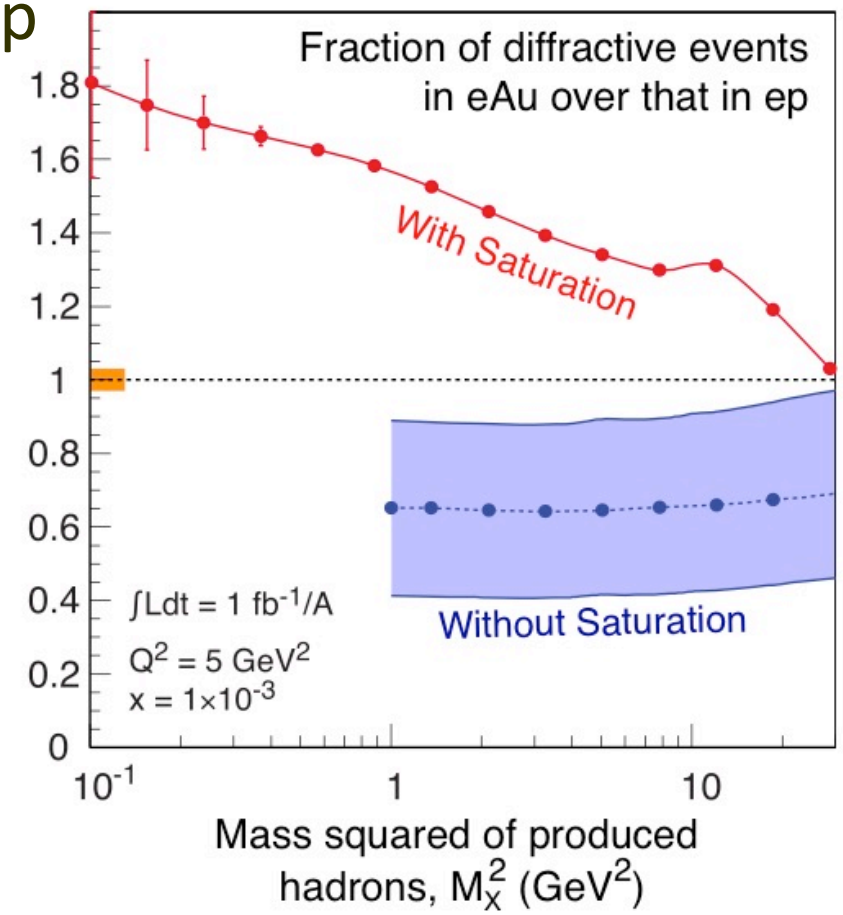



# Gluon saturation in e+A collisions

- Diffractive cross section
  - Most sensitive way to study the gluon saturation
- 10-15% diffractive at HERA e+p
- 25-30% diffractive predicted by CGC at EIC e+A

$$\sigma_{\mathrm{diff}} \propto [g(x, Q^2)]^2$$

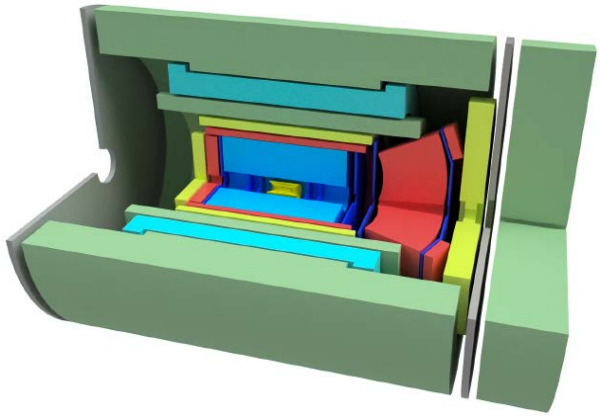


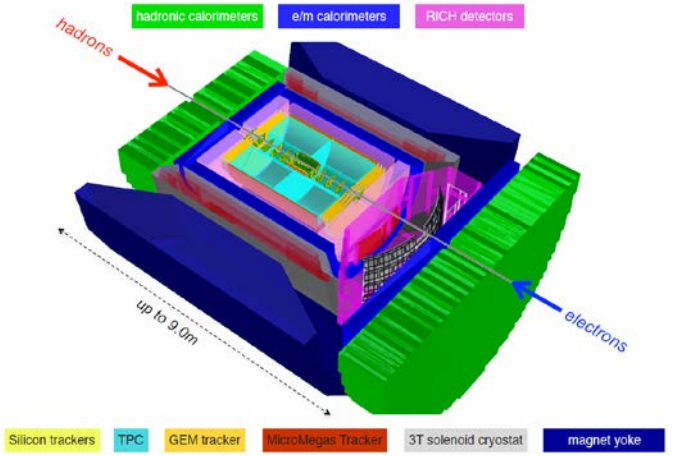
# EIC detector

- Many opportunity and need for additional contributions and collaborators

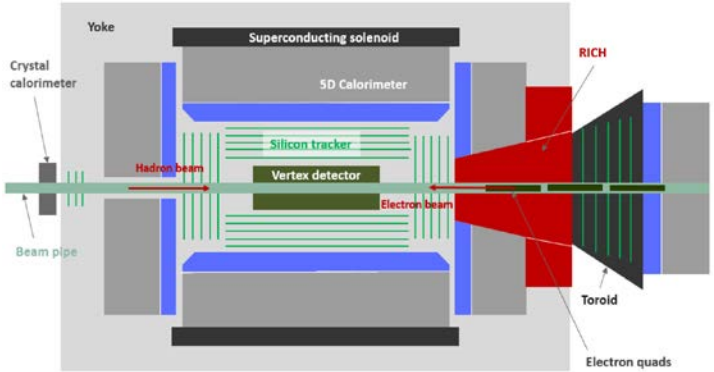
EIC Day-1 detector with BaBar Solenoid
(aka EIC-sPHENIX)



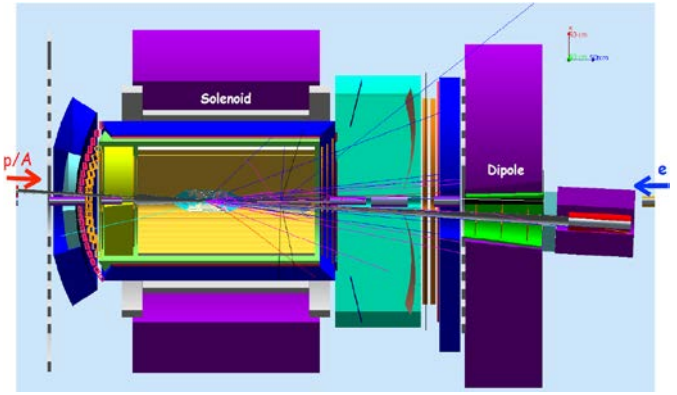
BeAST at BNL




TOPSiDE
(Time Optimized PID Silicon Detector for EIC)

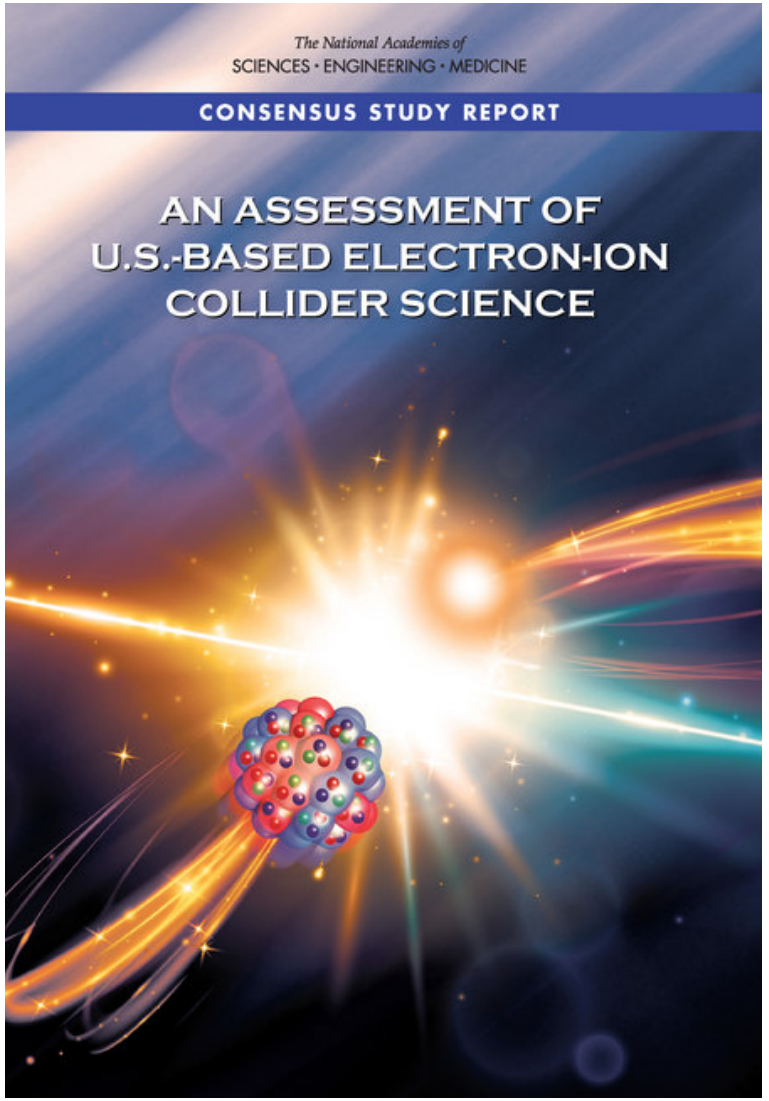



JLEIC Detector Concept with CLEO Solenoid



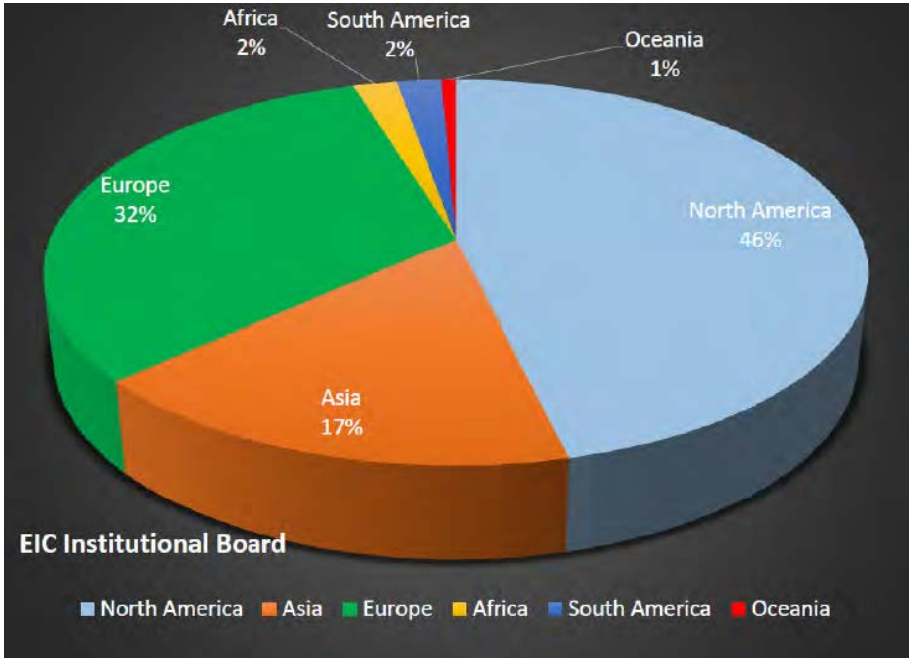
# *Status of the EIC project*

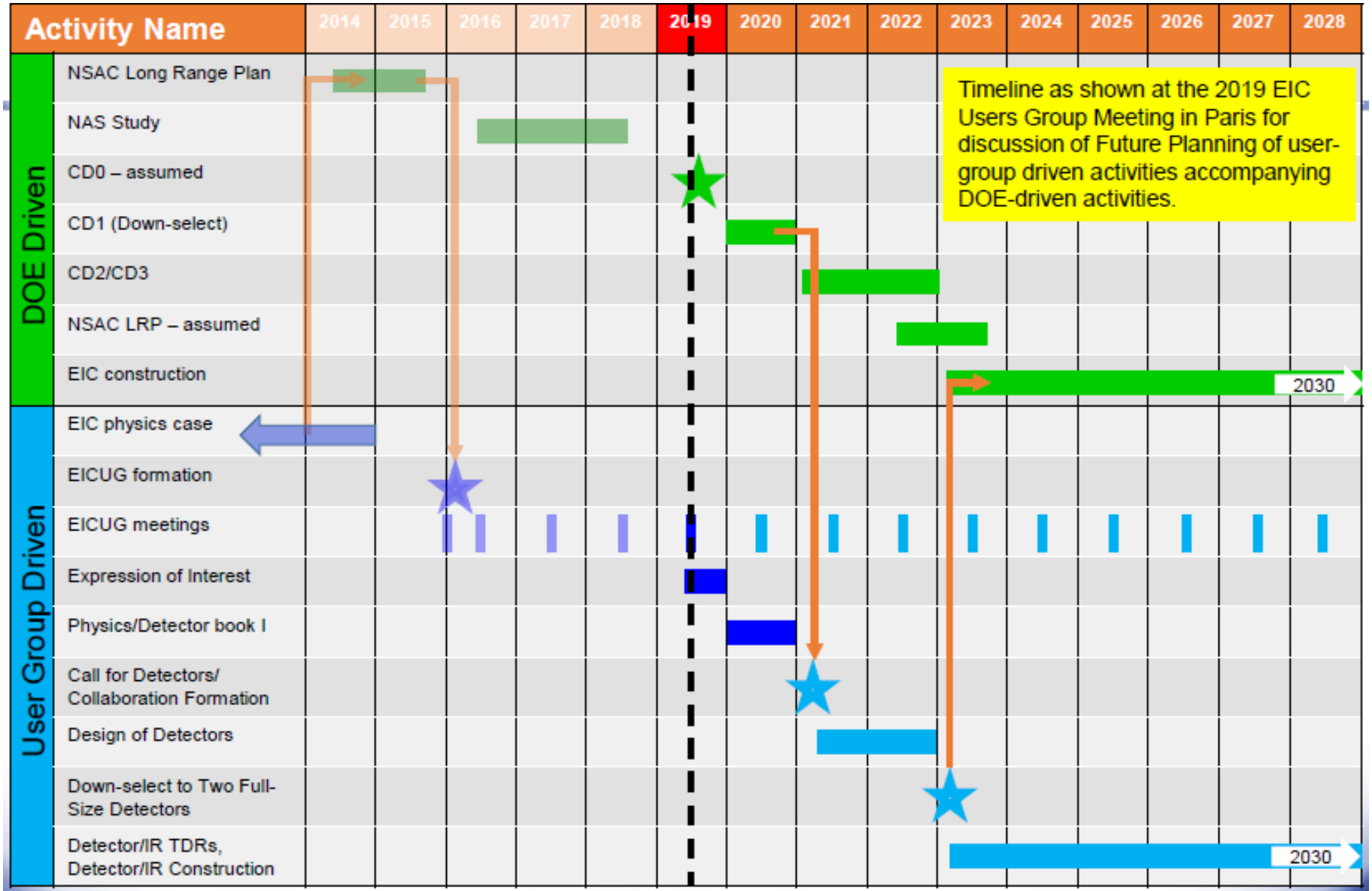
- NSAC 2015 Long Range Plan
  - We recommend a high-energy high luminosity polarized Electron Ion Collider as the highest priority for new facility construction after the completion of FRIB.
- NAS (National Academies of Sciences, Engineering, and Medicine) assessment of a U.S.-Based Electron-Ion Collider Science release in 2018
  - EIC can uniquely address three profound questions
  - How does the mass of the nucleon arise?
  - How does the spin of the nucleon arise?
  - What are the emergent properties of dense systems of gluons?
- EIC detector R&D program operated by BNL with ~$1.3M / year since 2011
  - Increase anticipated soon after project officially begins
- EIC accelerator R&D already assigned ~$7M / year since FY2017



# EIC Users Group (EICUG)

- EIC Users Group
  - Established in summer 2016
  - 945 members
  - 190 institutes
  - 30 countries
- EICUG structures in place and active
  - Steering Committee
  - Institutional Board
  - Conference & Talks Committee
  - Working groups
    - software
    - polarimetry
    - IR & luminosity
  - Annual meetings
    - SBU (2014), Berkeley (2015), ANL (2016), Trieste (2017), CAU (2018), Paris (2019)




**CD0** = DOE "Mission Need" statement; **CD1** = design choice and site selection
**CD2/CD3** = establish project baseline cost and schedule

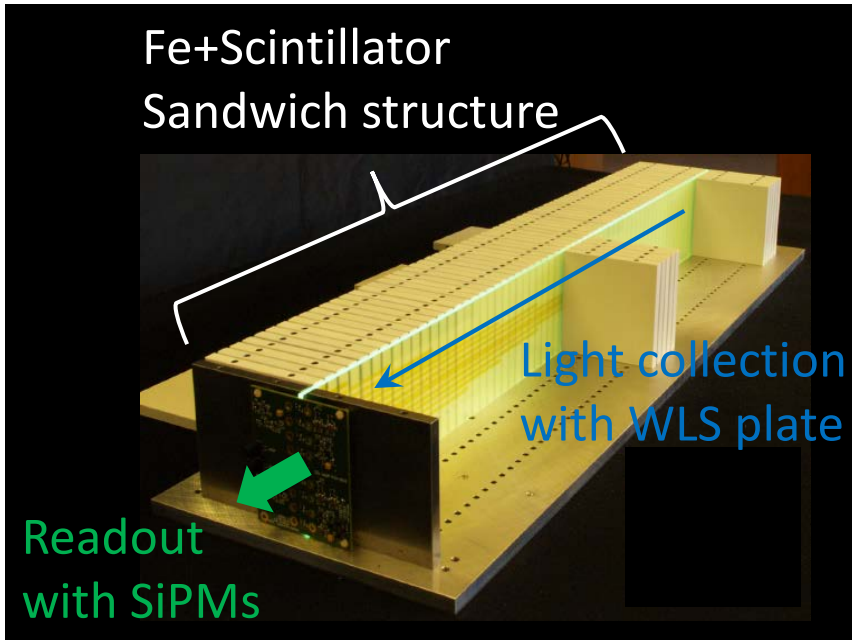
Slide shown by Rolf Ent in the EICUG IB meeting on Oct. 10th, 2019

# *Yellow Report for EIC physics and detector*

- Discussion in the EICUG IB meeting this week, Oct. 10th (Thu)
- EICUG Steering Committee plans for the Yellow Report to prepare for design of detectors
  - Quantify physics measurements
  - Study detector concepts
- Form physics/detector, detector/physics and accelerator physics working groups
- Timeline
  - Kick-off meeting in mid-December 2019
  - 4 workshops in 2020
  - (optional) final meeting in January 2021
  - Release in April 2021 (or January, 2021)

# *Forward hadron calorimeter R&D*

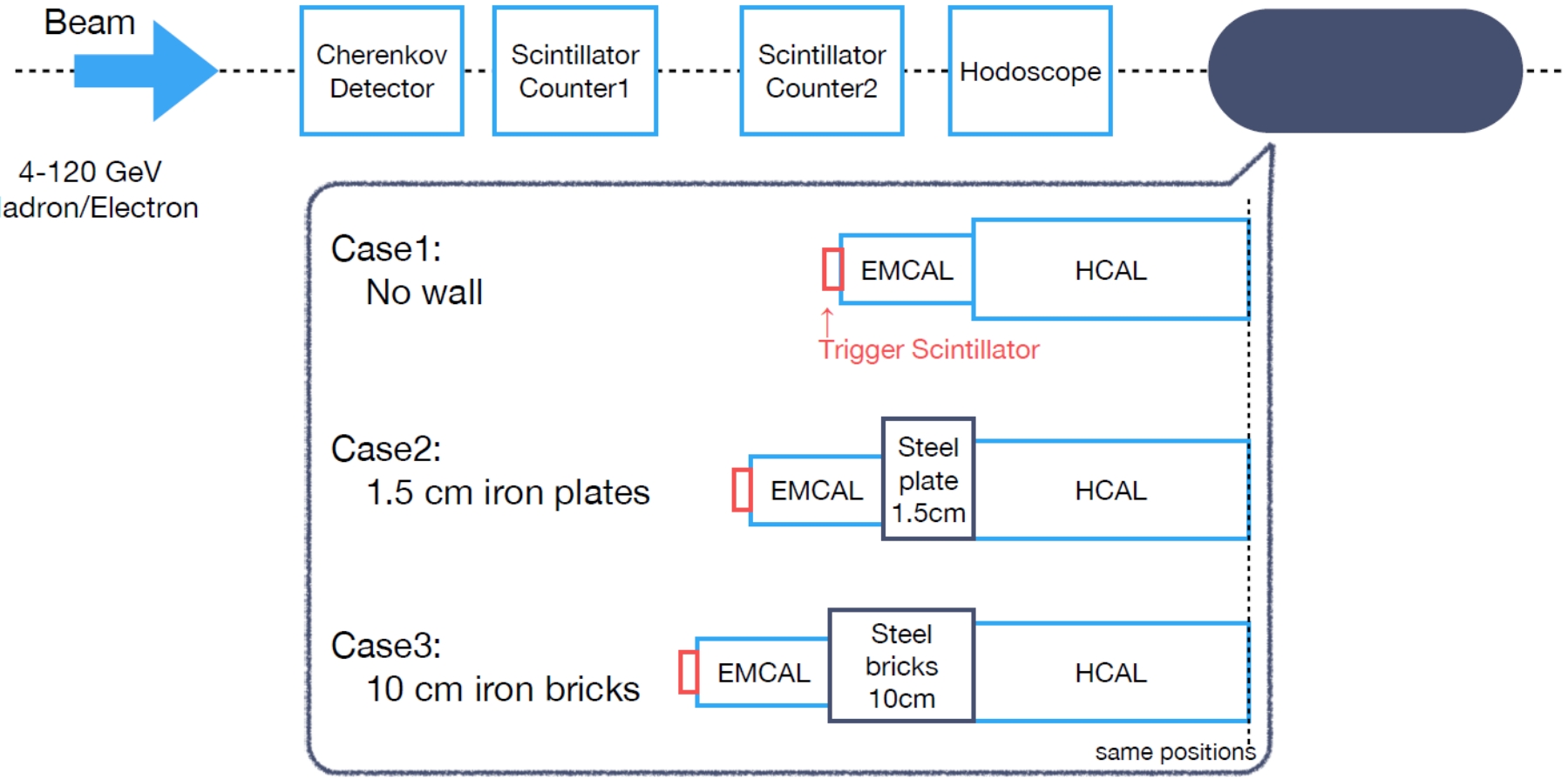
- Essential for forward jet reconstruction, hadron energy measurement, and triggering
- Collaboration with UCLA group for STAR upgrade and EIC detector R&D eRD1
- Scalable and re-configurable with a minimal number of mechanical components
  - Minimal resources required for construction and operation
- Fe + scintillator sandwich, 38 layers for STAR FCS
- 10cm x 10cm x 90cm tower
- 4.5 interaction length
- WLS light collection
- SiPM readout
- Expected energy resolution
  - $\sigma_E/E = 70\%/\sqrt{E}$ (GeV)
  - Constant/noise terms?



# *Fermilab FTBF test beam, April 2019*

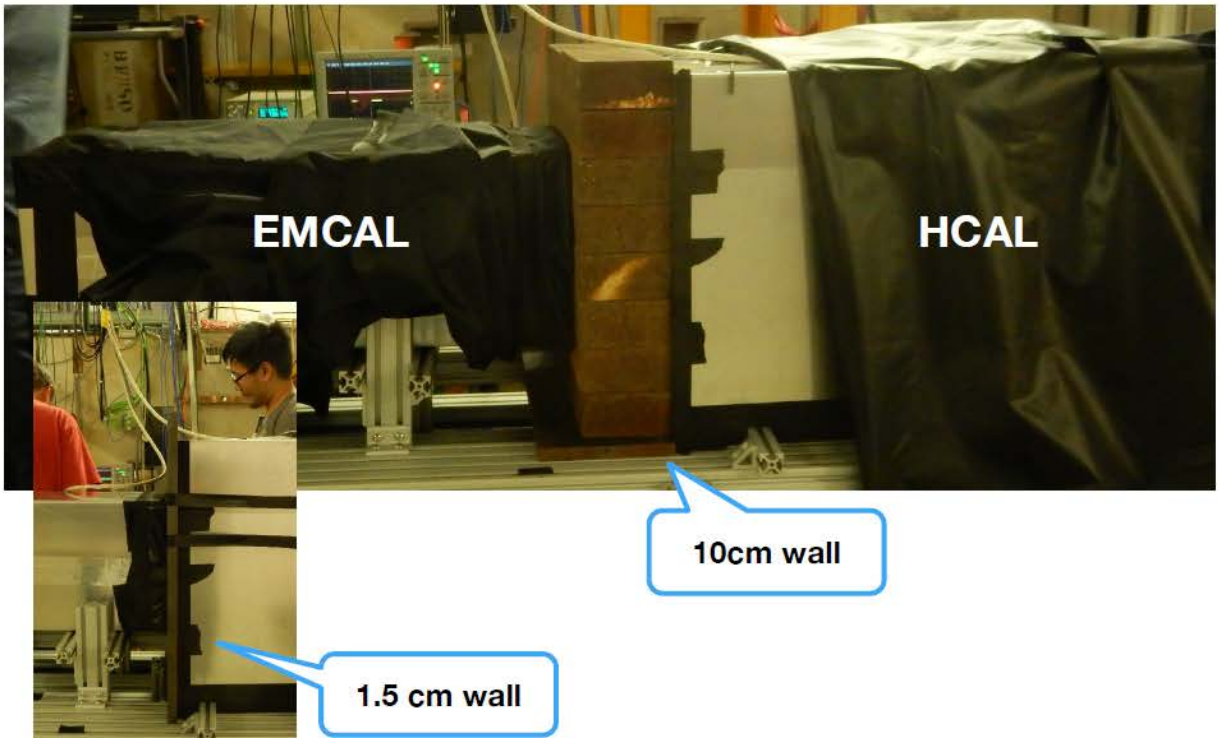
- T1018 test beam for STAR and EIC R&D
  - April 3rd – 23rd
- Test with sPHENIX-like configuration
  - April 14th – 15th
  - With steel plates between EMCal & HCal
    - 10 cm thick (keeping the return yoke + HCal)
    - 1.5 cm thick (replacing the return yoke with HCal)
  - Performance comparison with & without the steel plates

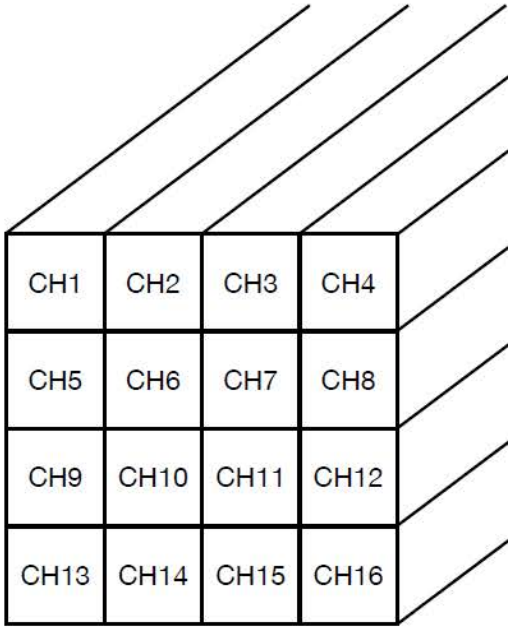
# Setup at Test of Test Beam Facility, FNAL




Slide by G. Nukazuka
(Yamagata Univ.)

# Setup: Pictures

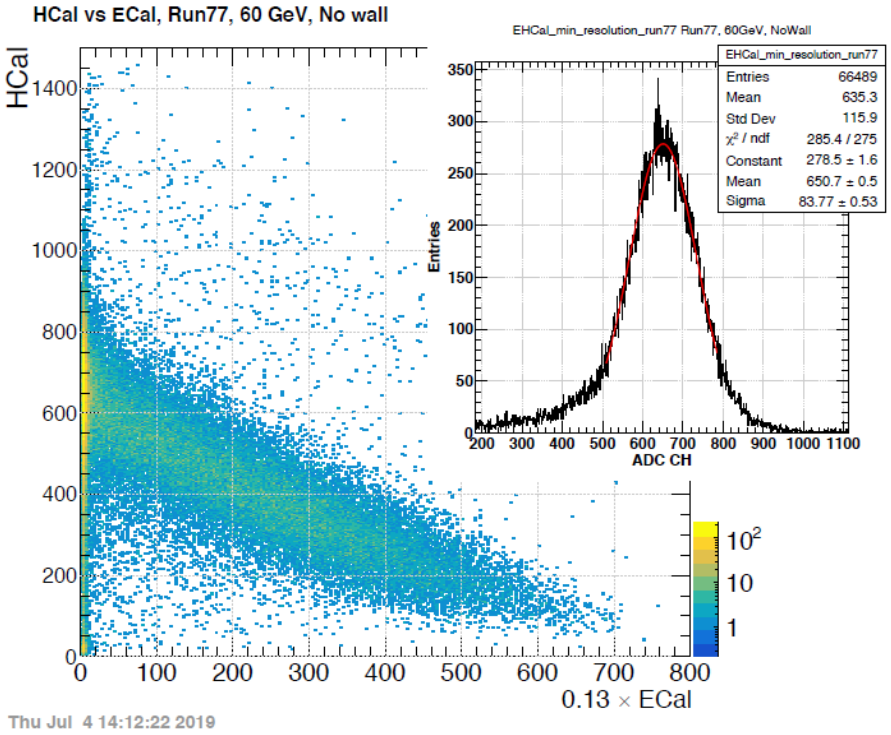




Calorimeters consist of 4×4 towers.

3

Slide by G. Nukazuka (Yamagata Univ.)

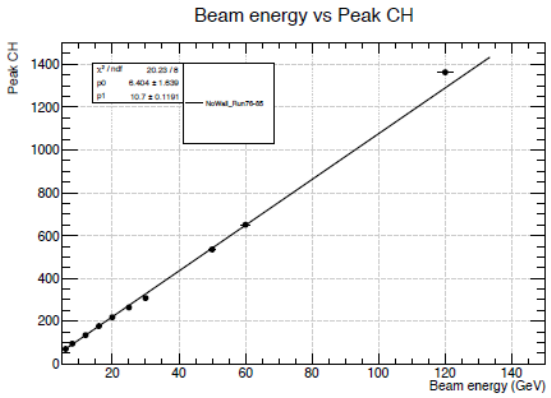
# Data Analysis





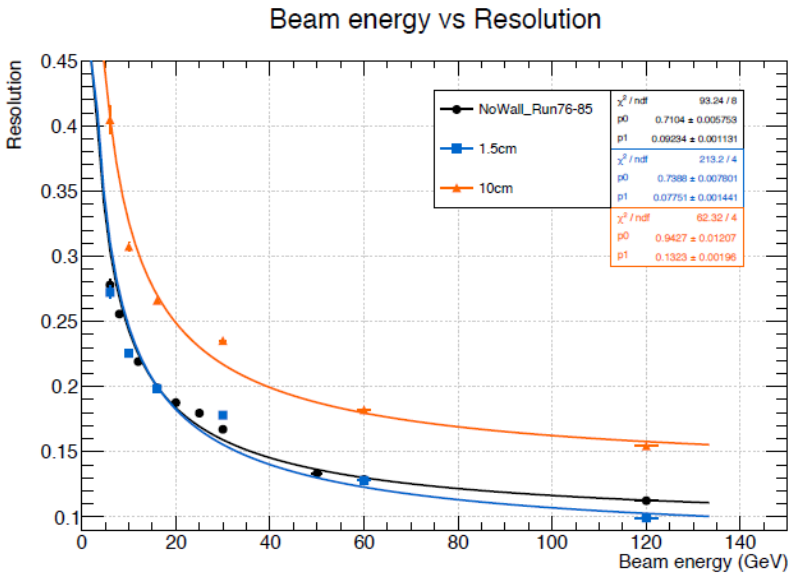


After summing signal of calorimeters, energy resolution was estimated by gaussian fit to the signal.




←Good linearity to beam energy.

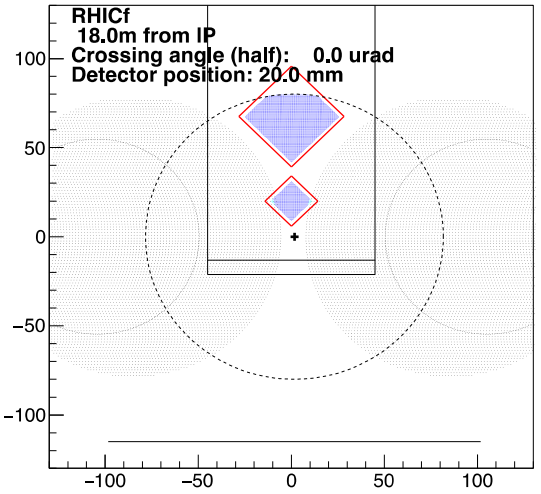
Clear deterioration of resolution with ↓10cm wall found.

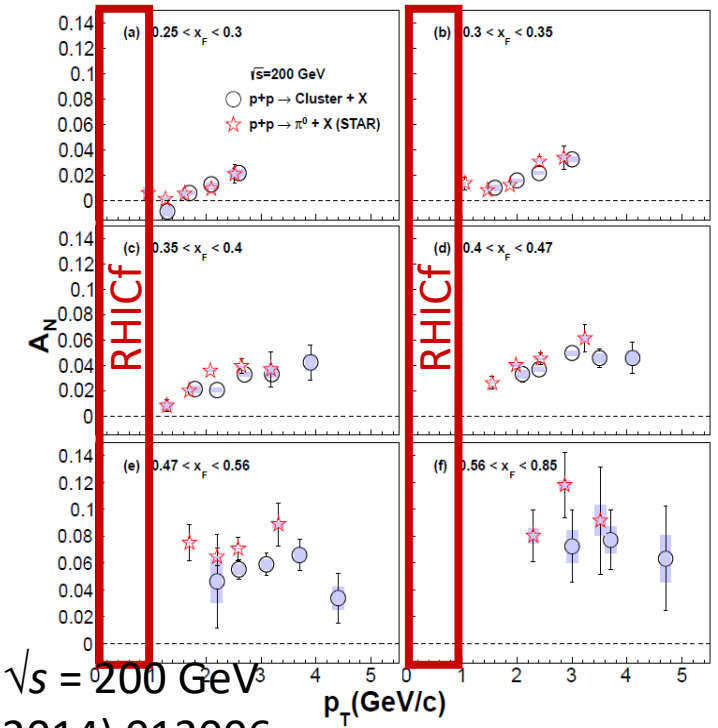



Slide by G. Nukazuka (Yamagata Univ.)

# Position-sensitive calorimeter

- RHICf @ z=18m from STAR IP
  - Downstream of the DX magnet
  - Acceptance limited by the DX magnet aperture
- For wide $\eta$ & $p_T$ coverage
  - To fill the gap
  - Large zero-degree detector
  - Azimuthal detector around the beam pipe @ sPHENIX?
    - Upstream of the DX magnet




PHENIX & STAR $\sqrt{s}$ = 200 GeV
Phys. Rev. D90 (2014) 012006.

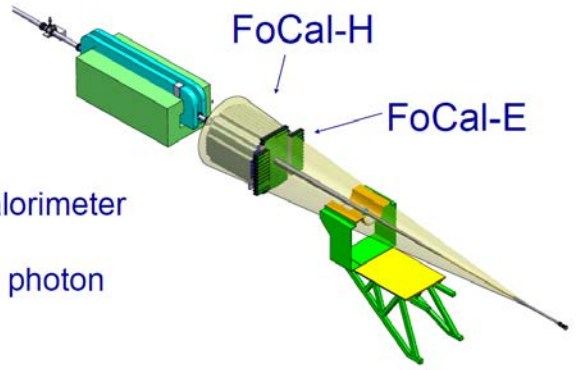
# *Position-sensitive calorimeter*

- Collaboration with people having common interest in position-sensitive calorimeter
- Tsukuba Univ.
  - ALICE FoCal
- Nagoya Univ.
  - RHICf / LHCf
  - Cosmic-ray group
  - Interest in $\eta$ & $K^0_S$ measurement
  - Interest in p+O / O+O collisions
- Kobe Univ.
  - EIC / LHeC
  - Radiation tolerance study
- EIC R&D for very forward measurements to be proposed
  - Calorimeter
  - Proton spectrometer (Roman Pot)

The FOCAL proposal

Under discussion within ALICE

$3.2 < \eta < 5.3$




**FoCal-E**: high-granularity Si-W calorimeter for photons and $\pi^0$

**FoCal-H**: hadronic calorimeter for photon isolation and jets

by M. van Leeuwen (Nikhef)

# *Summary*

- Physics at EIC
  - 3D picture of nucleons and nuclei
    - Understanding how the nucleon structure and properties emerge from quarks and gluons and their interactions from QCD
  - Gluon saturation at extreme density
    - Systematic understanding of the structure of nucleons and nuclei covering the wide kinematic range
  - Many other topics
    - Spin and flavor structure of nucleons and nuclei
    - Hadronization
- Status of the EIC project
  - NAS assessment release in 2018
  - EIC Users Group (EICUG) and R&D activities ongoing
  - Yellow Report will be produced by EICUG
- Forward hadron calorimeter R&D
  - Fermilab test beam in April 2019
- Position sensitive calorimeter R&D to be developed
  - CFNS & RBRC workshop held in September 2019