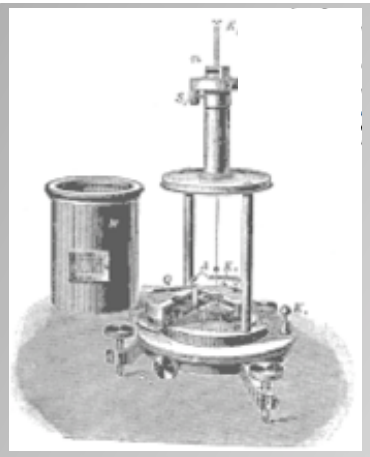
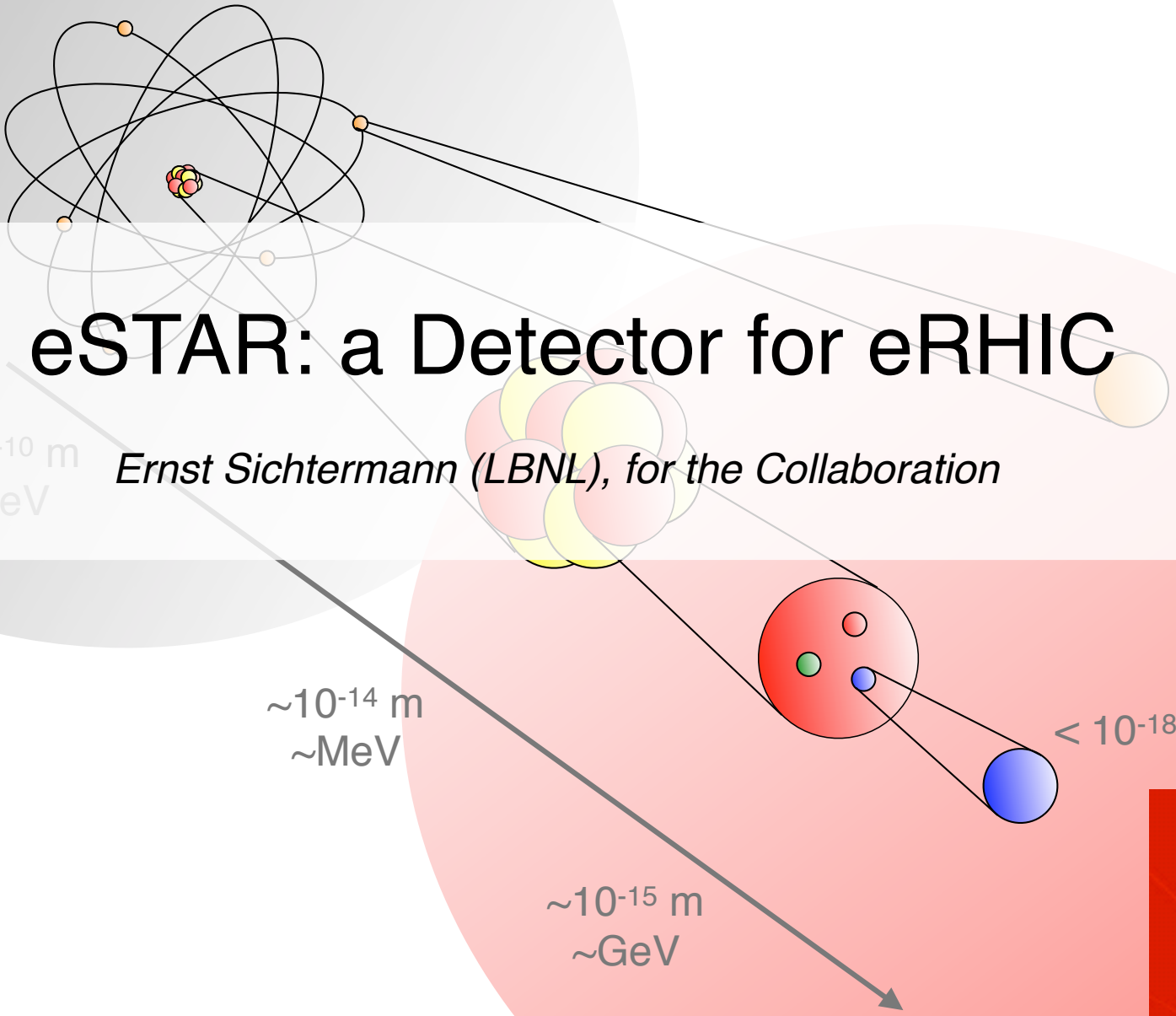




eSTAR: a Detector for eRHIC

Ernst Sichtermann (LBNL), for the Collaboration

Electron Ion Colliders

c.f. R. Ent's talk past Monday

Past

Possible Future

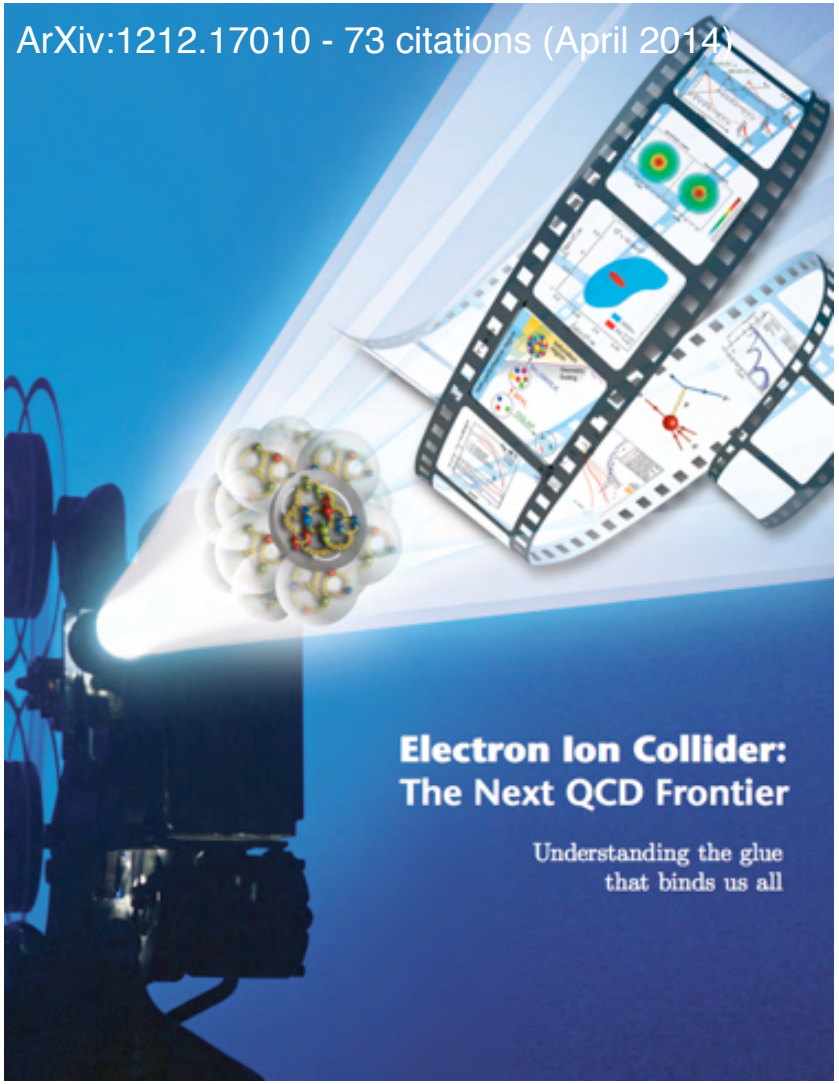
	HERA @ DESY	LHeC @ CERN	HIAF @ CAS	ENC @ GSI	MEIC/ELIC @ JLab	eRHIC @ BNL
√s [GeV]	320	800 - 1300	12 - 65	14	20 - 140	78 - 145
proton x_{min}	1×10^{-5}	5×10^{-7}	7×10^{-3} - 3×10^{-4}	5×10^{-3}	1×10^{-4}	5×10^{-5}
ion	p	p to Pb	p to U	p to ~^{40}Ca	p to Pb	p to U
polarization	-	-	p, d, ^{3}He	p, d	p, d, ^{3}He (^{6}Li)	p, ^{3}He
L [$cm^{-2}s^{-1}$]	2×10^{31}	10^{34}	10^{32-33} - 10^{35}	10^{32}	10^{33-34}	10^{33}
Interaction Points	2	1 (?)	1	1	2+	1-2
Year	1992 - 2007	post ALICE	2019 - 2030	upgrade to FAIR	post 12 GeV	2025

High-Energy Physics

Nuclear Physics

World Wide Interest

U.S.-based Electron Ion Collider(s)



Overall Editors:
A. Deshpande (Stony Brook), Z-E. Meziani (Temple), J. Qiu (BNL)

Gluon Saturation in e+A:
T. Ullrich (BNL) and Y. Kovchegov (Ohio State)

Nucleon spin structure (inclusive e+N):
E. Sichtermann (LBNL) and W. Vogelsang (Tübingen)

GPD's and exclusive reactions:
M. Diehl (DESY) and F. Sabatie (Saclay)

TMD's and hadronization and SIDIS:
H. Gao (Duke) and F. Yuan (LBNL)

Parton Propagation in Nuclear Medium:
W. Brooks (TSFM) and J. Qiu(BNL)

Electroweak physics:
K. Kumar (U Mass) and M. Ramsey-Musolf (Wisconsin)

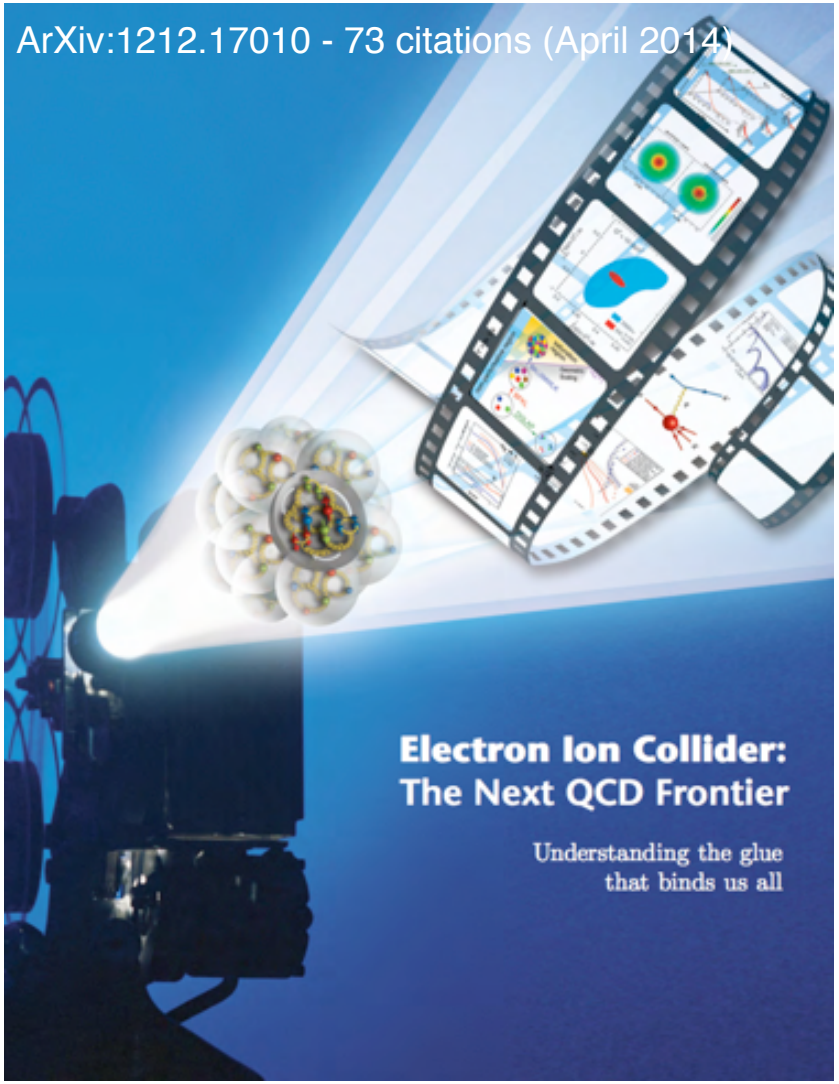
Accelerator design and challenges:
A. Hutton (JLab) and T. Roser (BNL)

Detector design and challenges:
E. Aschenauer (BNL) and T. Horn (CUA)

Senior Advisors:
A. Mueller (Columbia) and R. Holt (ANL)

Successful thanks to many other co-authors and contributions

U.S.-based Electron Ion Collider(s)



coherent contributions from many nucleons effectively amplify the gluon density being probed.

The EIC was designated in the 2007 Nuclear Physics Long Range Plan as "embodying the vision for reaching the next QCD frontier" [1]. It would extend the QCD science programs in the U.S. established at both the CEBAF accelerator at JLab and RHIC at BNL in dramatic and fundamentally important ways. The most intellectually pressing questions that an EIC will address that relate to our detailed and fundamental understanding of QCD in this *frontier* environment are:

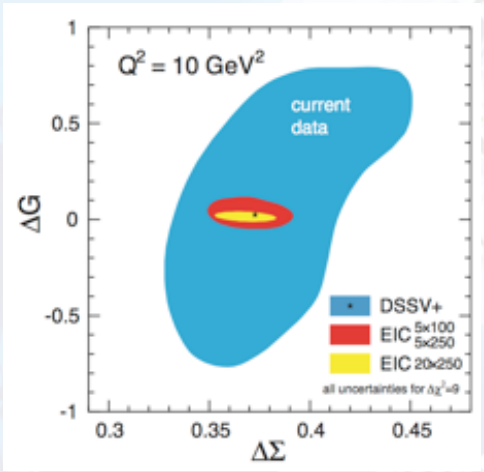
- **How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?** How are these quark and gluon distributions correlated with overall nucleon properties, such as spin direction? What is the role of the orbital motion of sea quarks and gluons in building the nucleon spin?
- **Where does the saturation of gluon densities set in?** Is there a simple boundary that separates this region from that of more dilute quark-gluon matter? If so, how do the distributions of quarks and gluons change as one crosses the boundary? Does this saturation produce matter of universal properties in the nucleon and all nuclei viewed at nearly the speed of light?
- **How does the nuclear environment affect the distribution of quarks and gluons and their interactions in nuclei?** How does the transverse spatial distribution of gluons compare to that in the nucleon? How does nuclear matter respond to a fast moving color charge passing through it? Is this response different for light and heavy quarks?

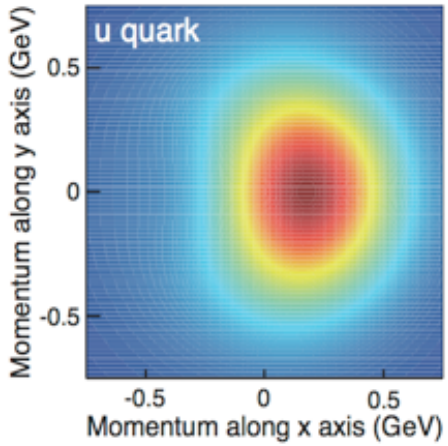
Answers to these questions are essential for understanding the nature of visible matter. An EIC is the ultimate machine to provide answers to these questions for the following reasons:

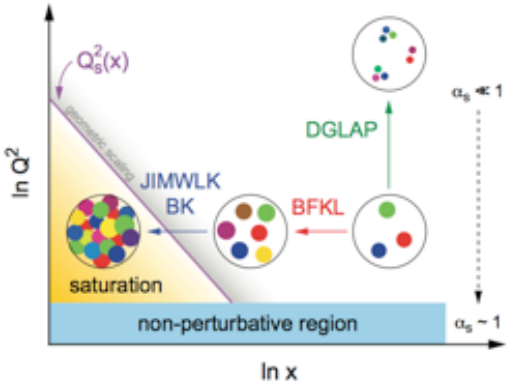
- A collider is needed to provide kinematic reach well into the gluon-dominated regime;
- Electron beams are needed to bring to bear the unmatched precision of the electromagnetic interaction as a probe;
- Polarized nucleon beams are needed to determine the correlations of sea quark and gluon distributions with the nucleon spin;
- Heavy ion beams are needed to provide precocious access to the regime of saturated gluon densities and offer a precise dial in the study of propagation-length for color charges in nuclear matter.

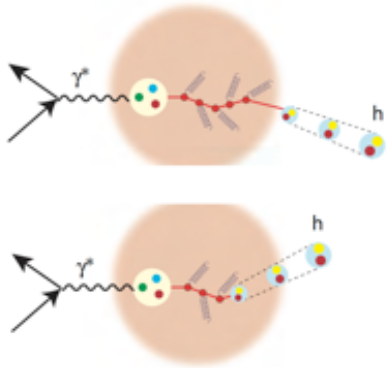
The EIC would be distinguished from all past, current, and contemplated facilities around the world by being at the intensity frontier with a versatile range of kinematics and beam polarizations, as well as beam species, allowing the above questions to be tackled at one facility. In particular, the EIC design exceeds the capabilities of HERA, the only electron-proton collider to date, by adding a) polarized proton and light-ion beams; b) a wide variety of heavy-ion beams; c) two to three orders of magnitude increase in luminosity to facilitate tomographic imaging; and d) wide energy variability to enhance the sensitivity to gluon distributions. Achieving these challenging technical improvements in a single facility will extend U.S. leadership in accelerator sci-

U.S.-based Electron Ion Collider(s)









ArXiv:1212.17010

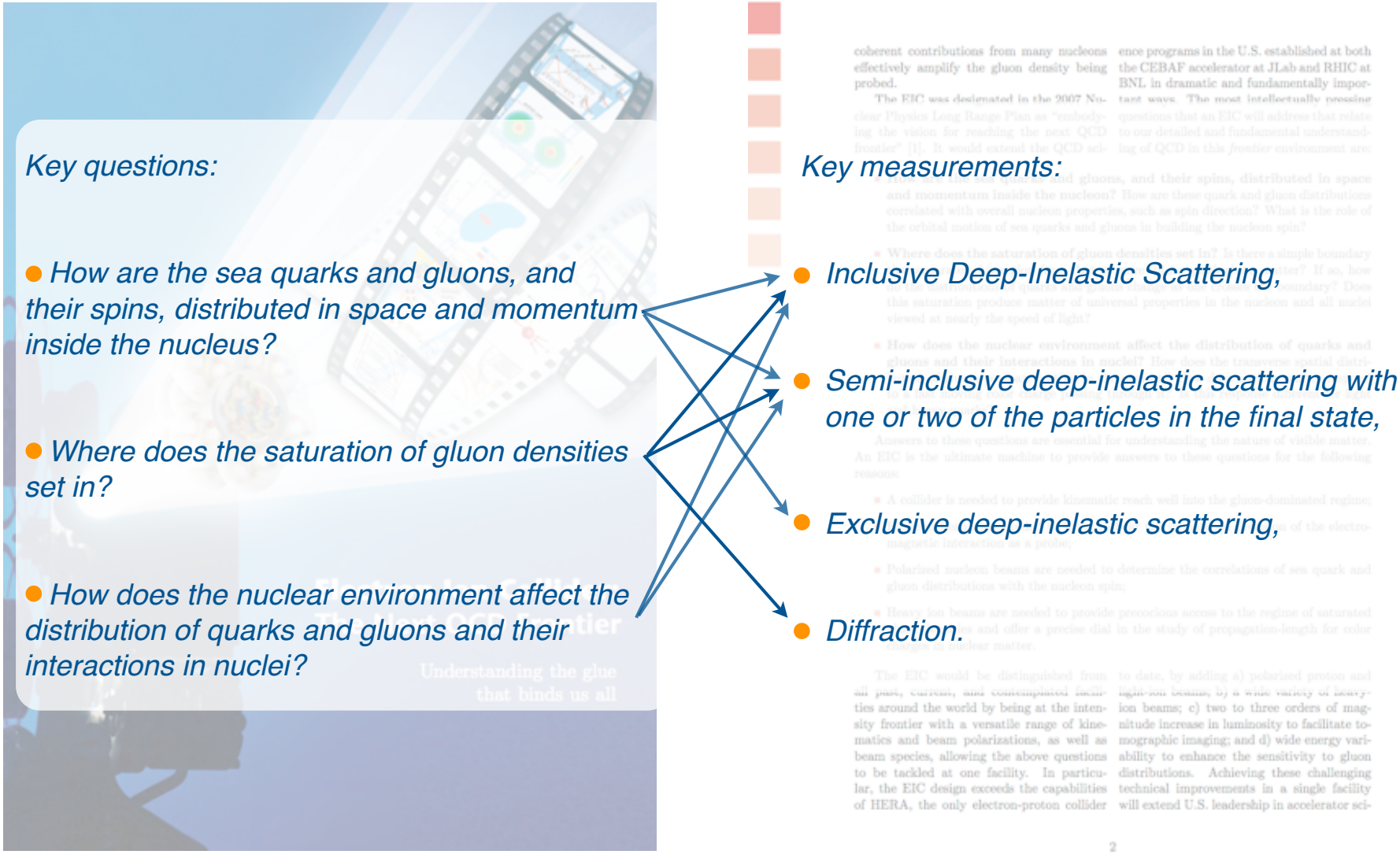
U.S.-based Electron Ion Collider(s)

Key questions:

- *How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleus?*
- *Where does the saturation of gluon densities set in?*
- *How does the nuclear environment affect the distribution of quarks and gluons and their interactions in nuclei?*

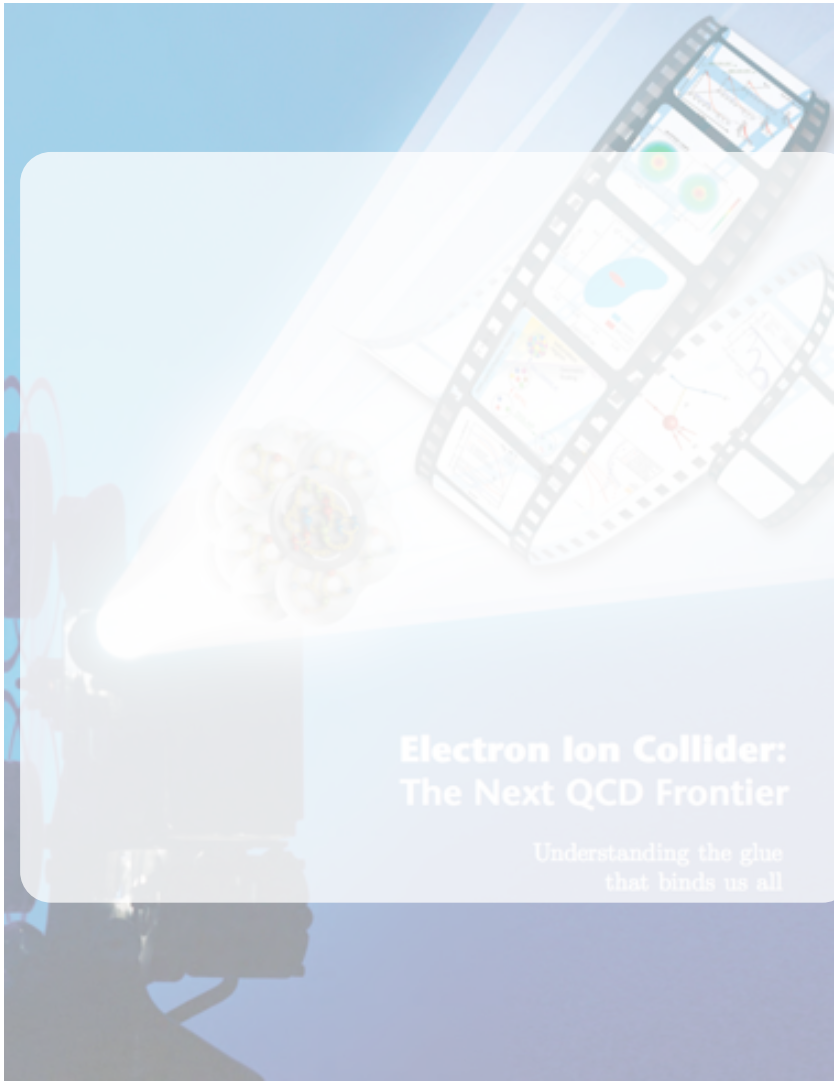
Key measurements:

- *Inclusive Deep-Inelastic Scattering,*
- *Semi-inclusive deep-inelastic scattering with one or two of the particles in the final state,*
- *Exclusive deep-inelastic scattering,*
- *Diffraction.*



ArXiv:1212.17010

U.S.-based Electron Ion Collider(s)



Key measurements:

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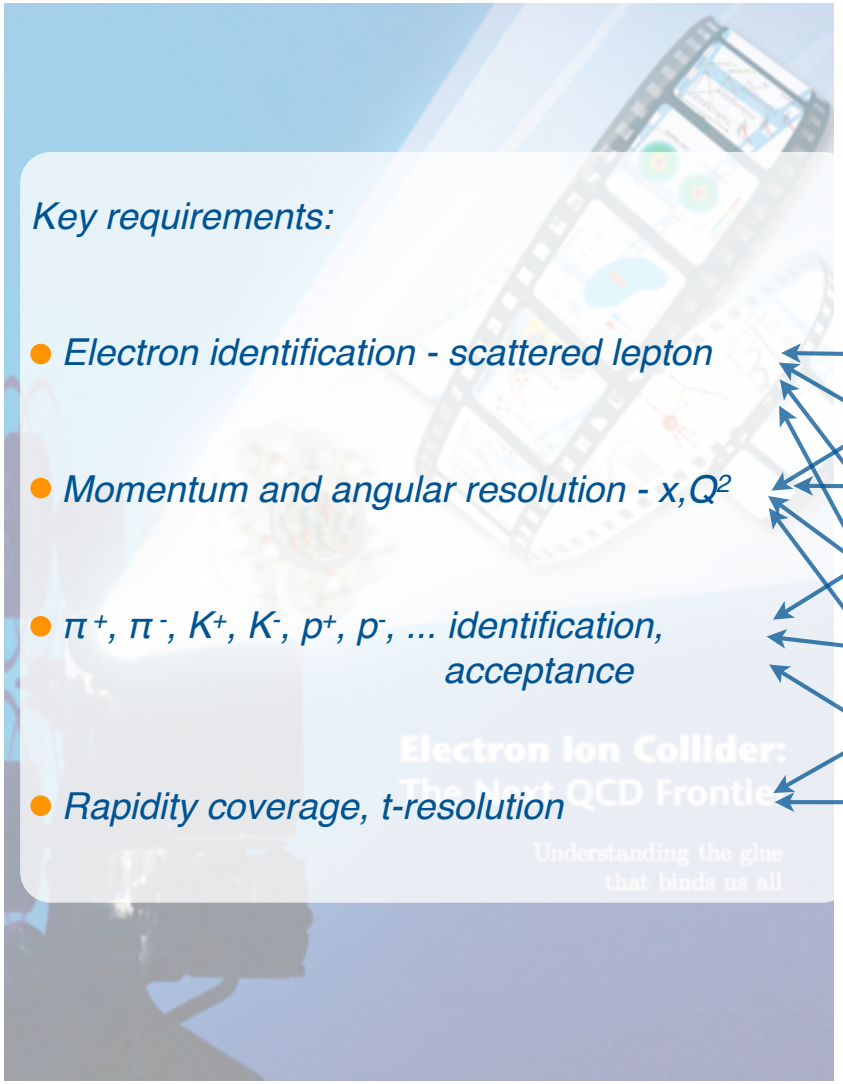
ArXiv:1212.17010

U.S.-based Electron Ion Collider(s)

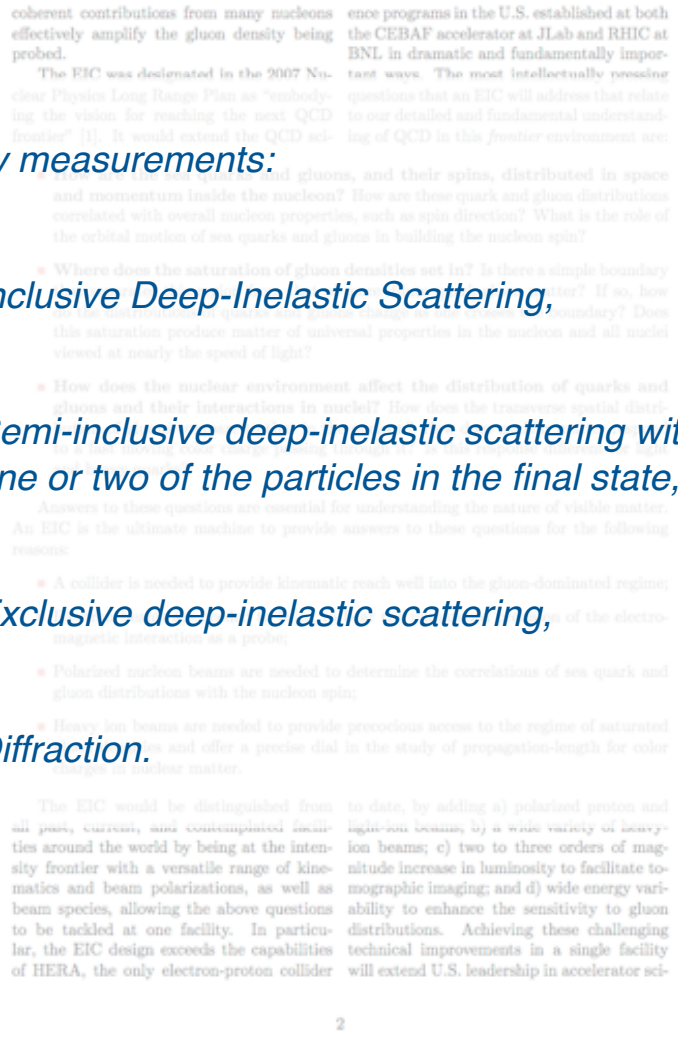


Key requirements:

- *Electron identification - scattered lepton*
- *Momentum and angular resolution - x,Q^2*
- *π^+, π^-, K^+, K^-, p^+, p^-, ... identification, acceptance*
- *Rapidity coverage, t-resolution*

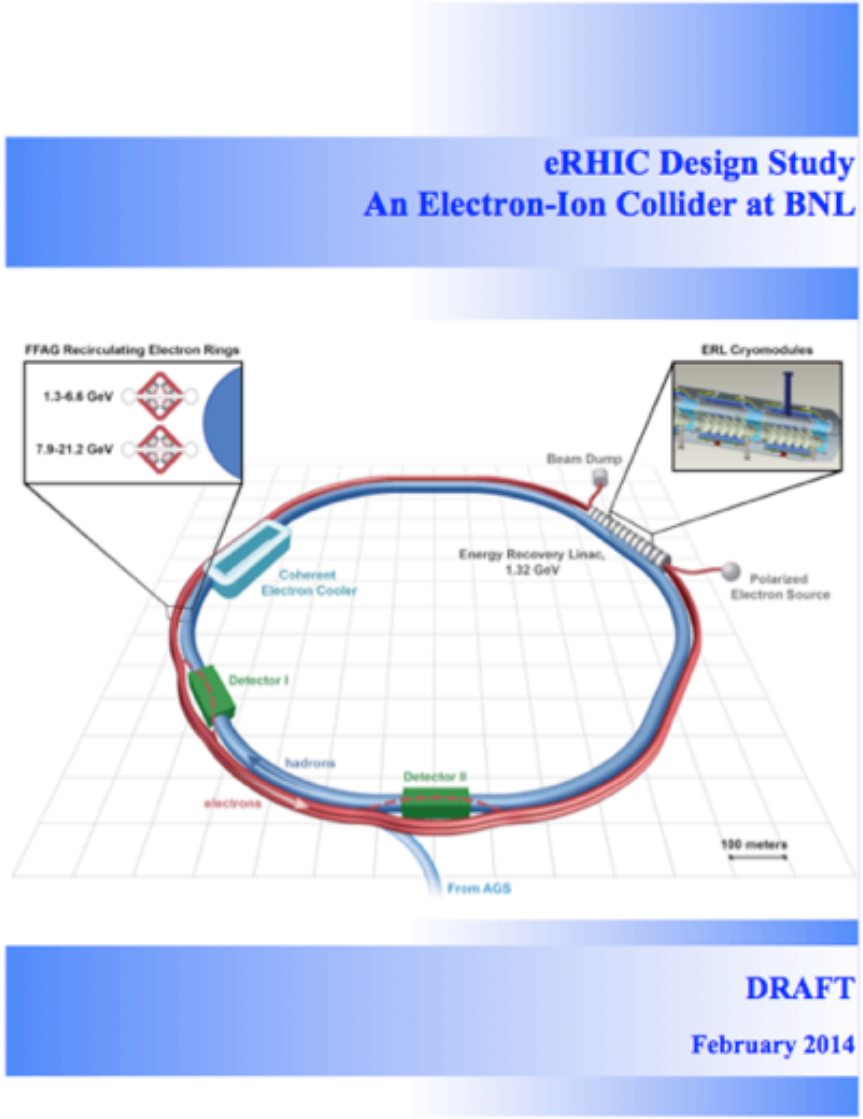
Key measurements:

- *Inclusive Deep-Inelastic Scattering,*
- *Semi-inclusive deep-inelastic scattering with one or two of the particles in the final state,*
- *Exclusive deep-inelastic scattering,*
- *Diffraction.*



ArXiv:1212.17010

eRHIC: EIC at Brookhaven Natl. Laboratory

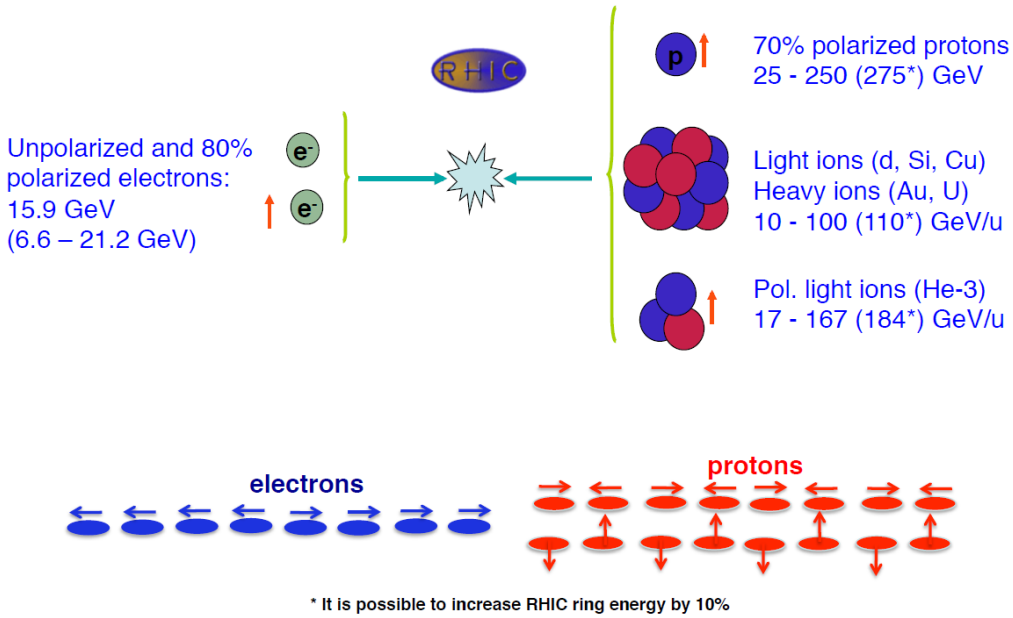


E.C. Aschenauer et al.

Numerous external contributions,

See talk by T. Roser at EIC-IAC meeting past February 28, 2014

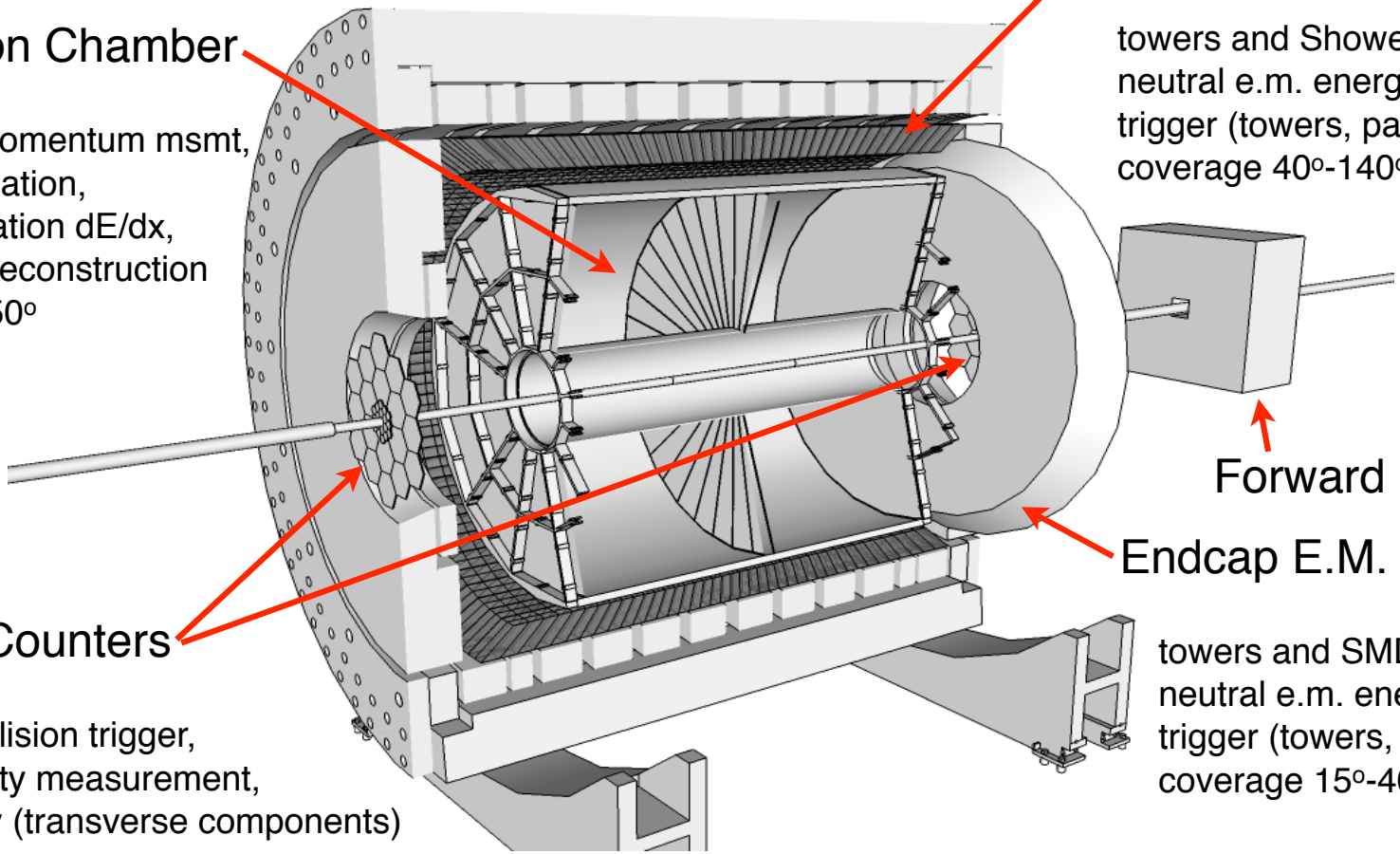
The eRHIC accelerator ... design adds a high-current, multi-pass Energy Recovery Linac (ERL) and electron recirculation rings to the existing RHIC hadron facility:



to provide a polarized electron beam with energy 15.9 GeV colliding with ion species ranging from polarized protons with a top energy of 250 GeV to fully stripped Uranium ions with energies up to 100 GeV/u, and e-nucleon luminosity of 10^{33} $cm^{-2}sec^{-2}$.

STAR - Solenoidal Tracker at RHIC

Nucl. Instrum. Meth. A499, 624, 2003



Time Projection Chamber

charged track momentum msmt,
charge determination,
particle identification dE/dx,
collision vertex reconstruction
coverage 30°-150°

Barrel E.M. Calorimeter

towers and Shower Maximum Det.
neutral e.m. energy measurement,
trigger (towers, patches of towers)
coverage 40°-140°

Forward Meson Spectr.

Endcap E.M. Calorimeter

towers and SMD.
neutral e.m. energy measurement,
trigger (towers, patches of towers)
coverage 15°-40°

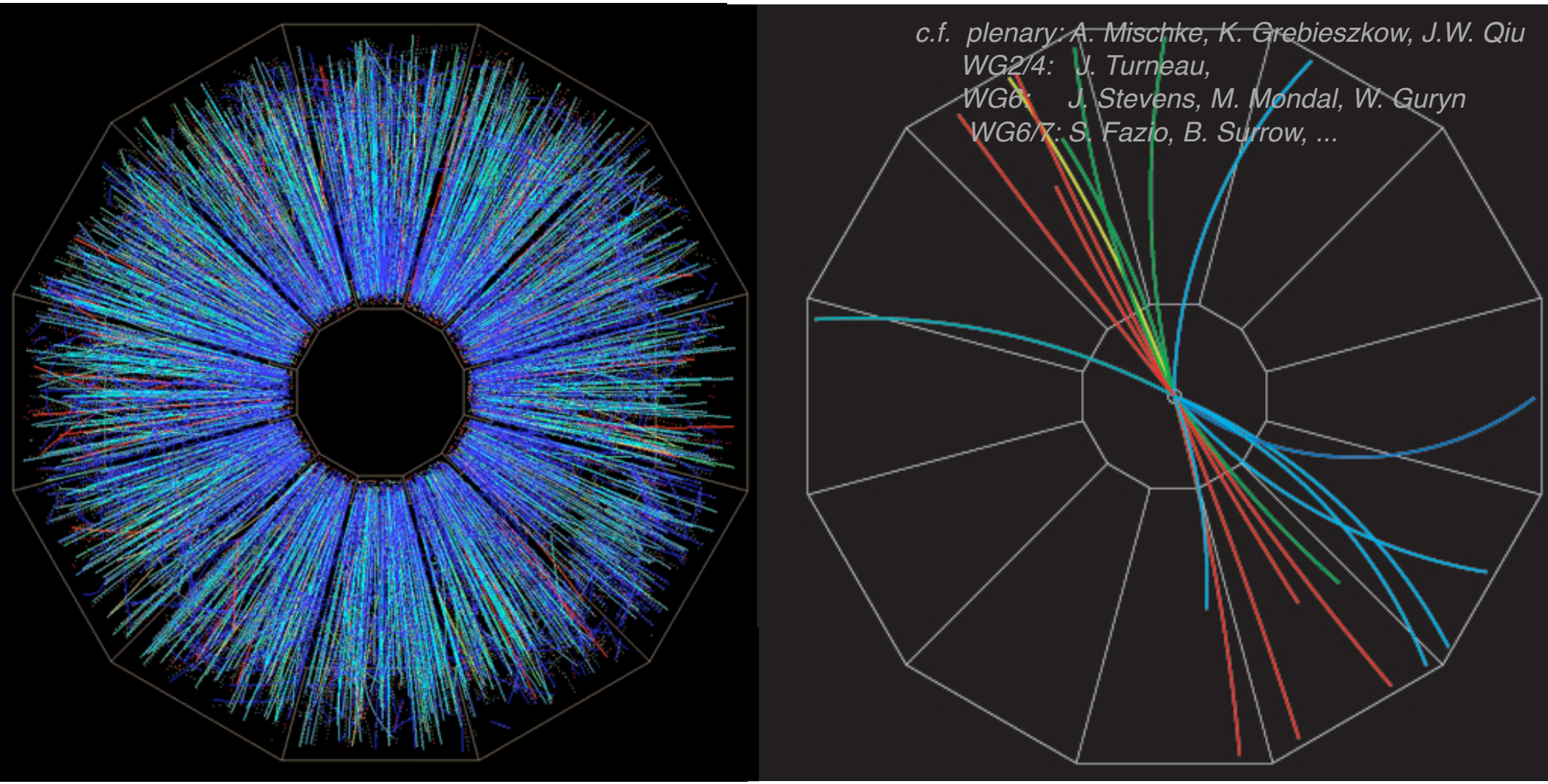
Beam-Beam Counters

proton beam collision trigger,
relative luminosity measurement,
local polarimetry (transverse components)

0.5 T Solenoidal Magnetic Field

Subsystems not shown above, e.g. DAQ, ZDC, Time-of-Flight, FGT (complete),
Heavy Flavor Tracker, Muon-Telescope Detector (taking data now!),
Roman Pot system, ...

STAR - Solenoidal Tracker at RHIC



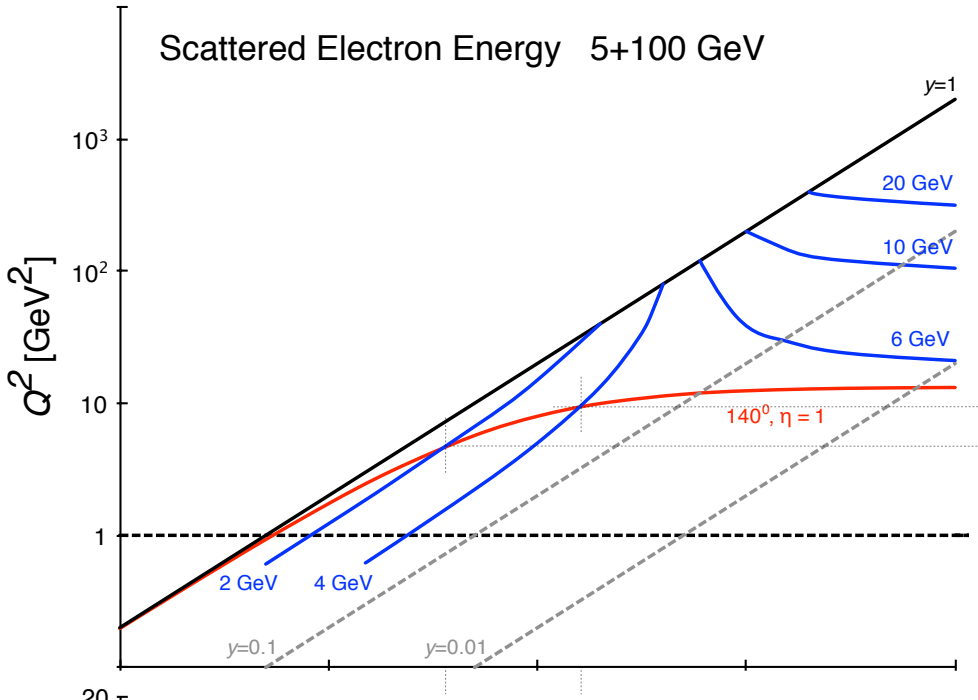
c.f. plenary: A. Mischke, K. Grebieszkow, J.W. Qiu
WG2/4: J. Turneau,
WG6: J. Stevens, M. Mondal, W. Guryn
WG6/7: S. Fazio, B. Surrow, ...

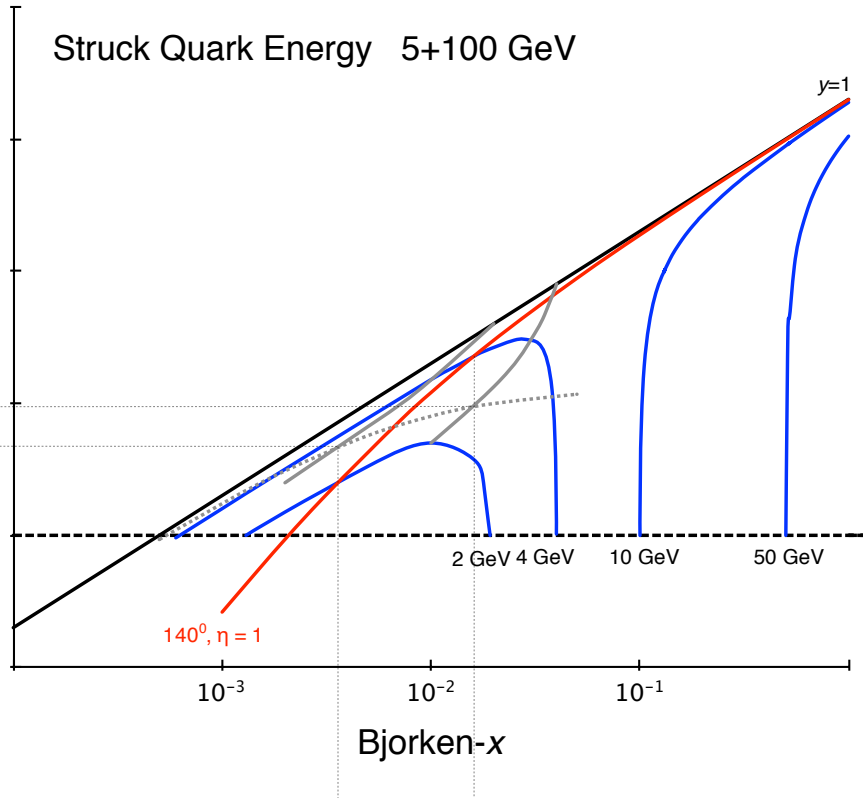
An existing versatile large-acceptance instrument to study QCD:
- Au+Au, d+Au, p+p,
- $\sqrt{s}$ = 7.7 - 500 GeV,
- polarization,

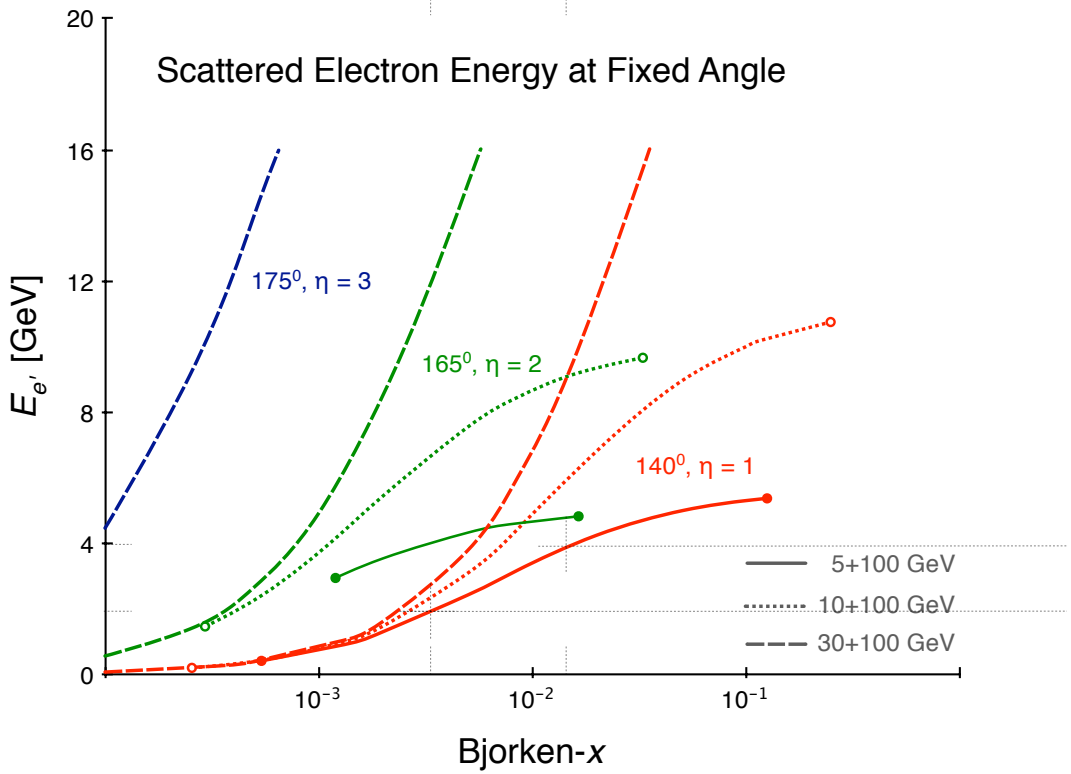
key strengths:
- acceptance, PID

Upgrade path into electron-ion collisions at eRHIC? - studied within eSTAR task force.

eSTAR - Initial Considerations







Bending radii ~m, sagittas ~mm (over 40cm),

At 140^o, dx/x~2 implies:

dE/E~0.5 at x ~ 10^{-3}

dE/E~0.3 at x ~ 10^{-2}

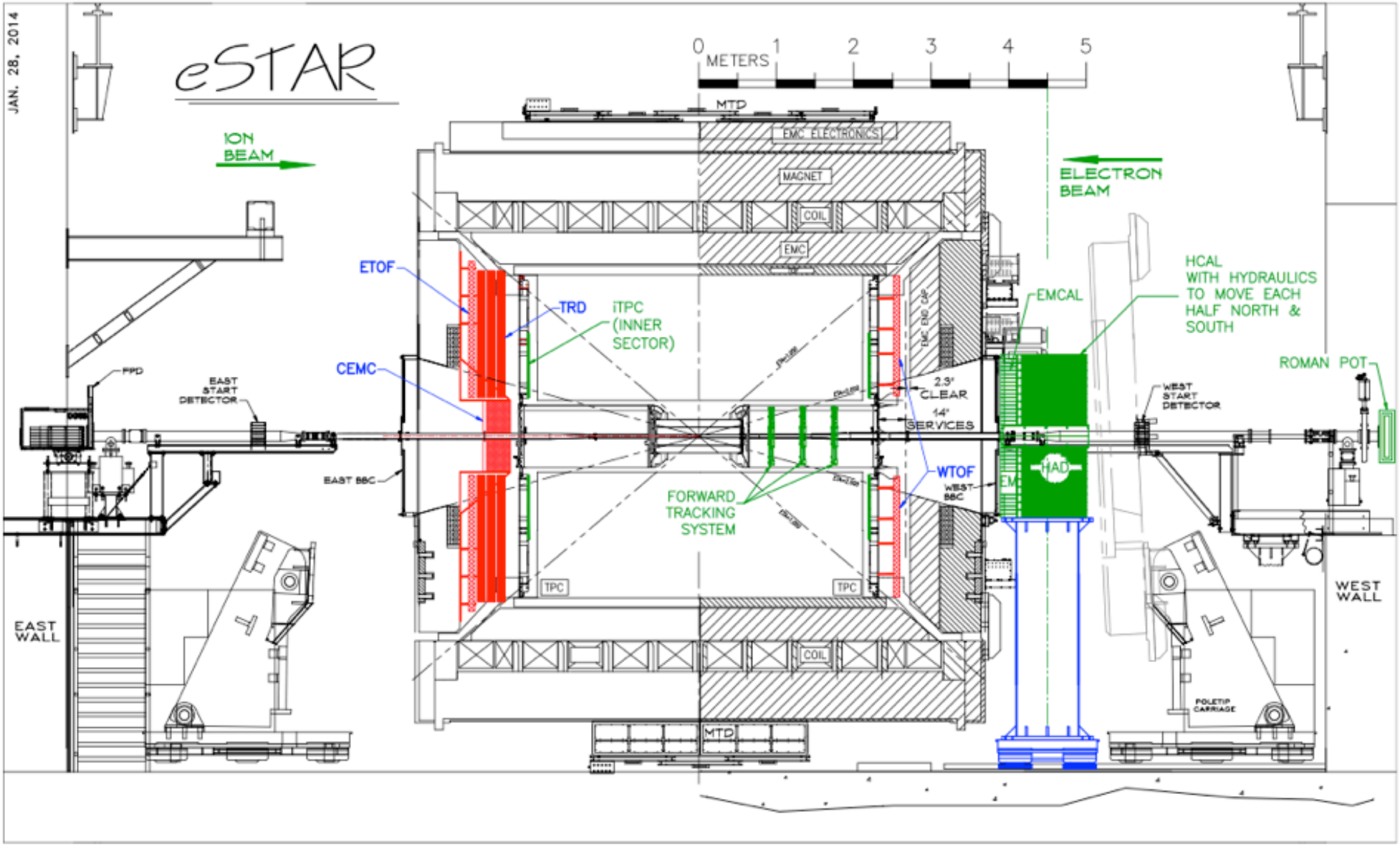
dE/E~0.04 at x ~ 10^{-1}

At 165^o, dx/x~2 implies dE/E~0.09 at 5.10^{-3}

Electron/hadron separation ~10^2

c.f. STAR Decadal Plan for 2010-2020

eSTAR - Concept



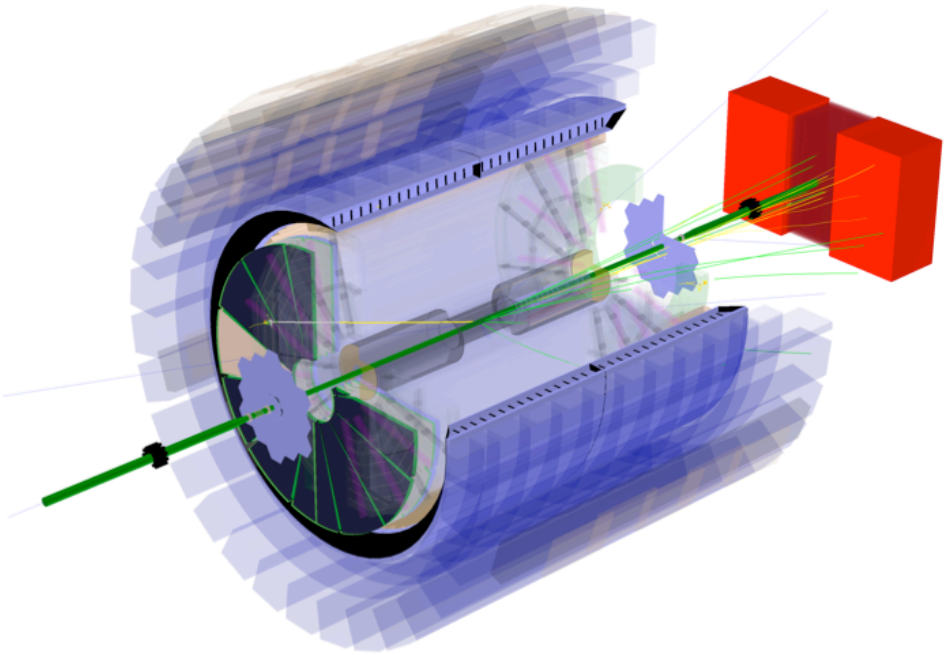
Rough "DNA": Forward Calorimeter(s), Roman Pots, Tracking essential to p+p, p+A,

Complement with iTPC, TRD, ETOF and CEMC form the baseline of eSTAR.

eSTAR - Concept and Intent

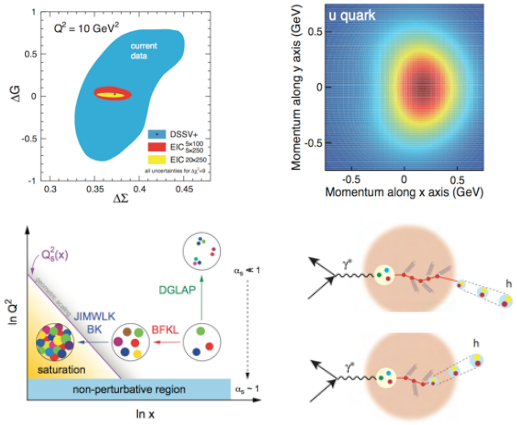
eSTAR: A Letter of Intent

The STAR Collaboration



September 2013

- *Adopts the U.S. EIC Science Case,*

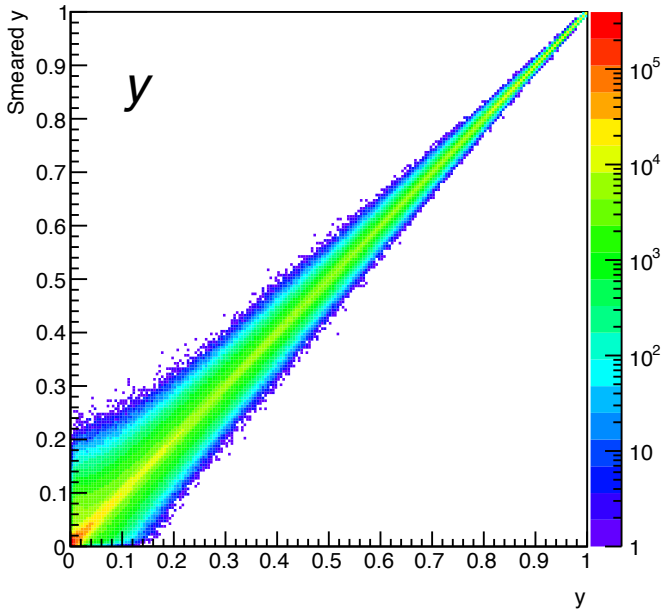


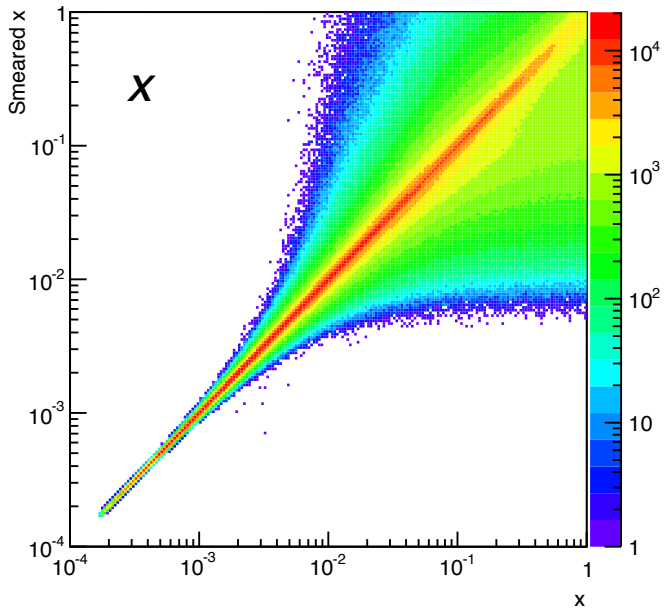
- *Initial quantitative assessment of capabilities,*

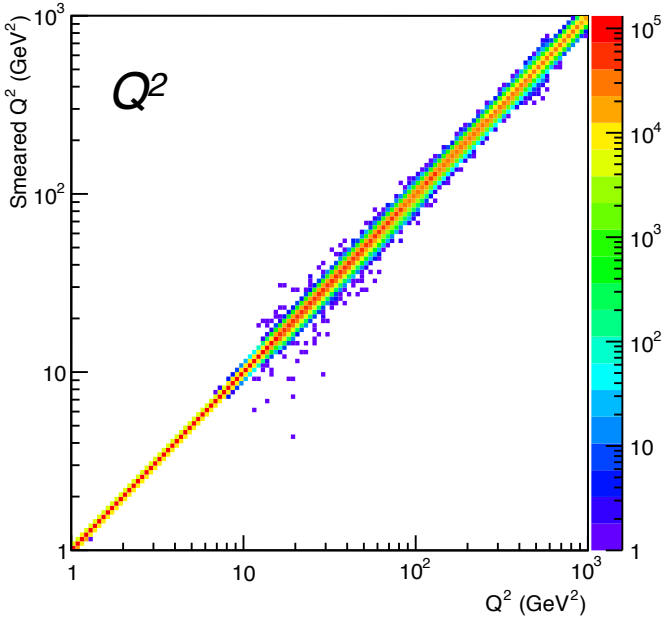
- *Backed by simulations and R&D*

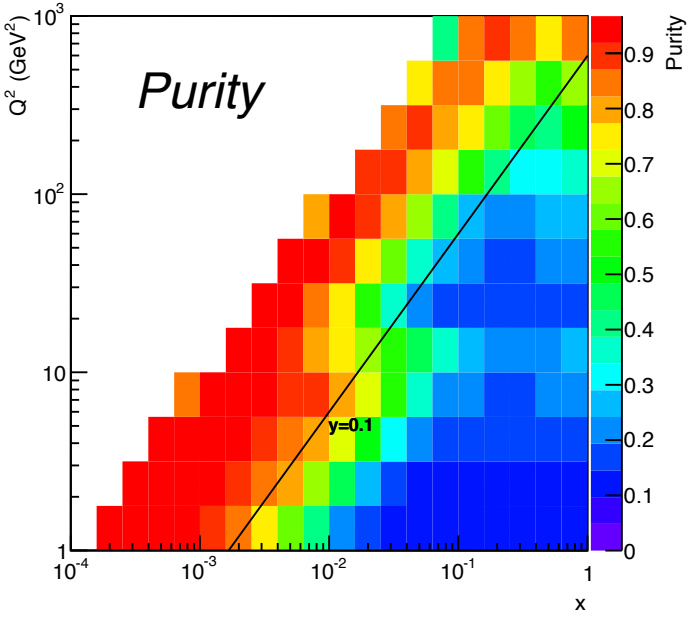
- *Context: open collaboration with an instrument and a science-driven plan.*

eSTAR: A Letter of Intent - Scattered electron capability



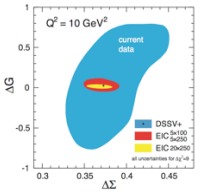




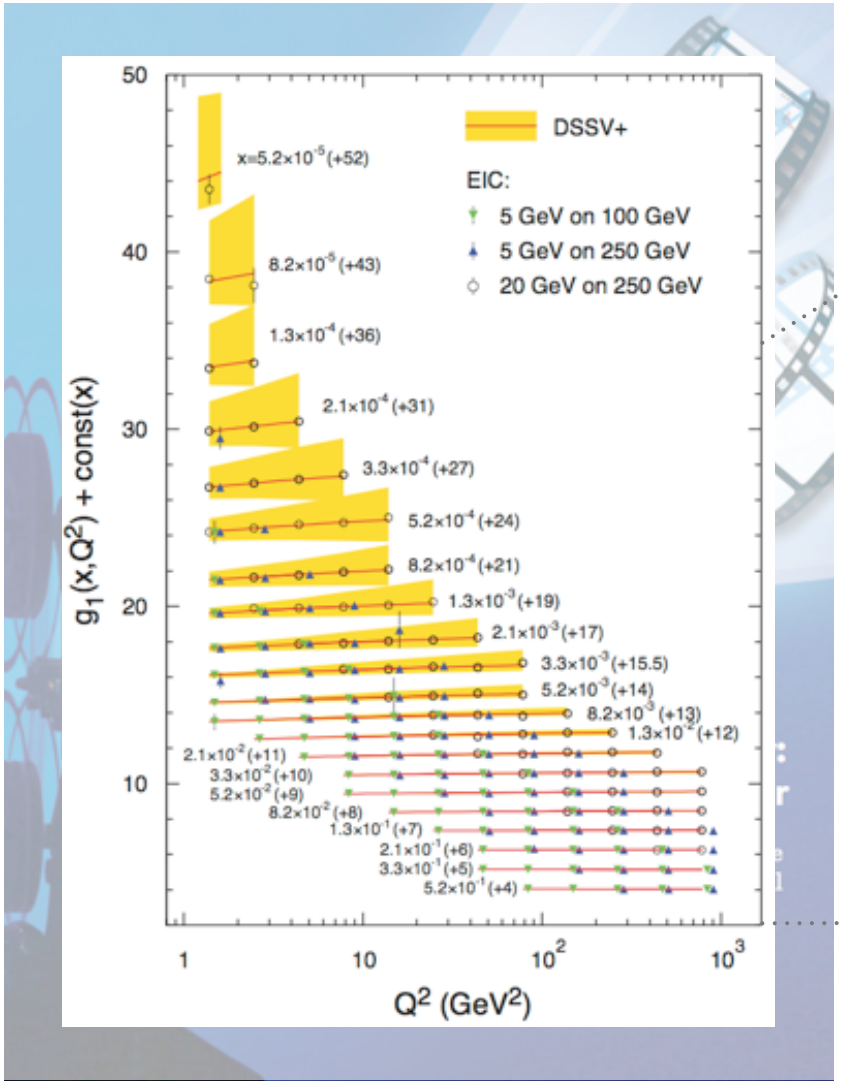


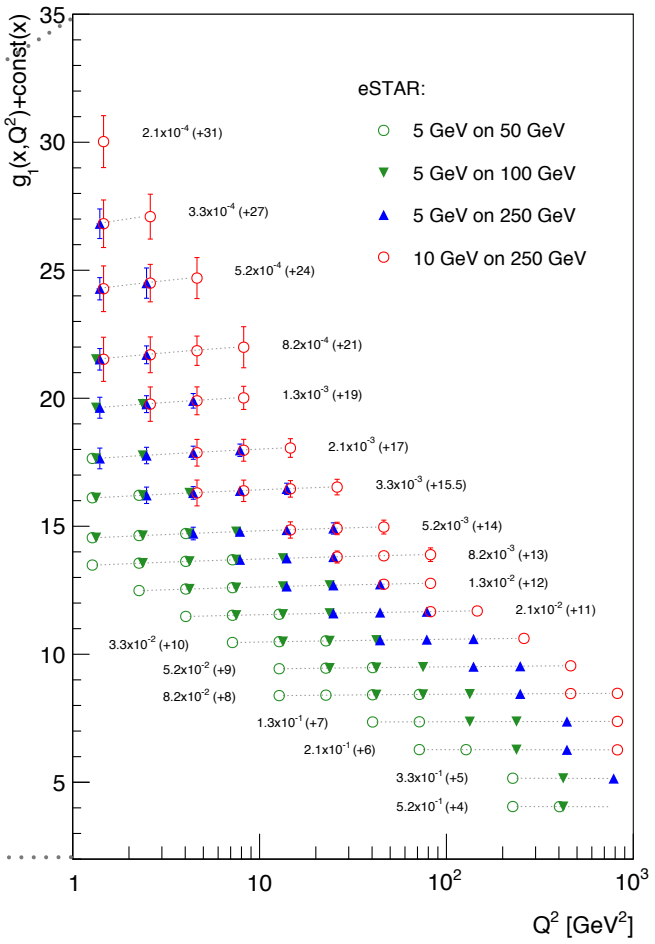
15 GeV electron beam energy + 100 GeV hadron beam energy

eSTAR: A Letter of Intent - Inclusive Measurements



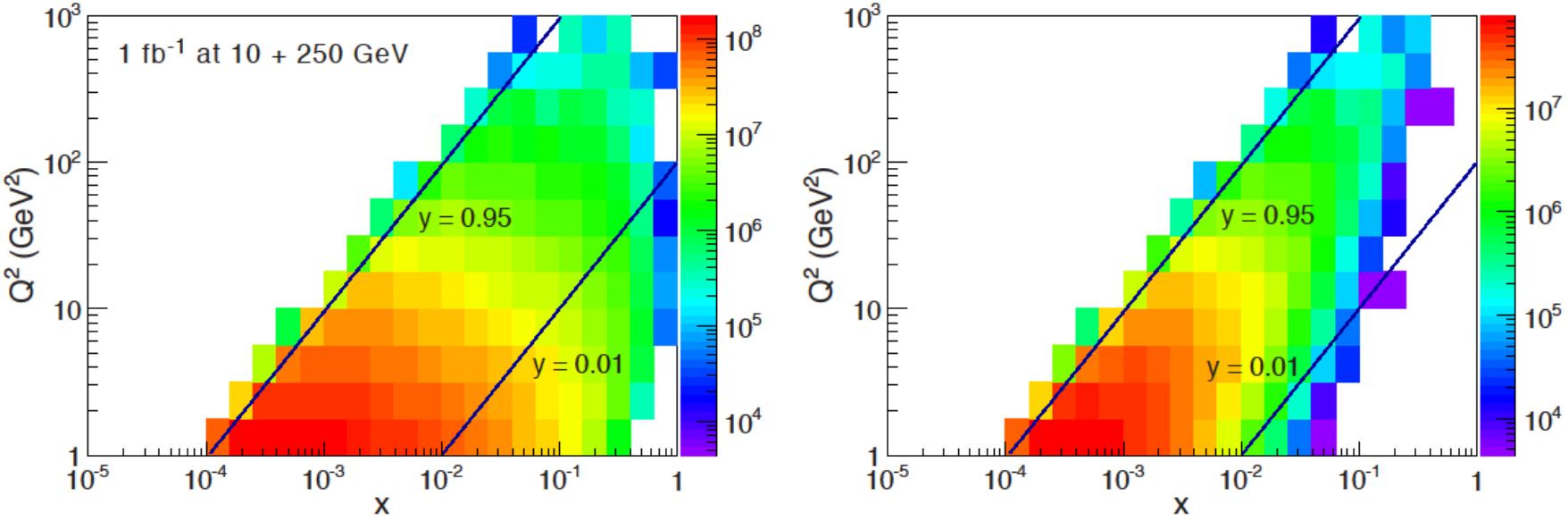
Full eRHIC, dedicated detector → Initial stage eRHIC, eSTAR





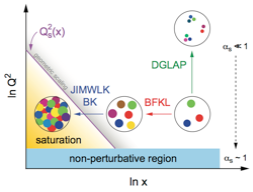
Significant measurement capability for the unpolarized and polarized inclusive structure functions.

eSTAR: A Letter of Intent - PID capability



generator level ⟶ eSTAR charged pion response

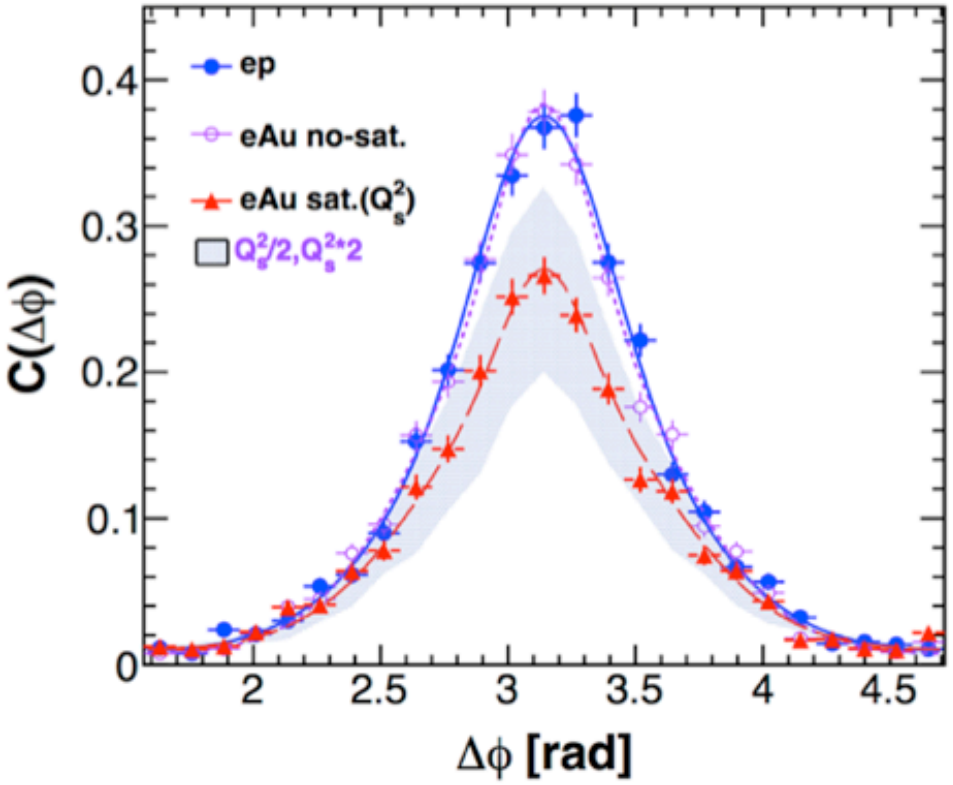
eSTAR: A Letter of Intent - SIDIS

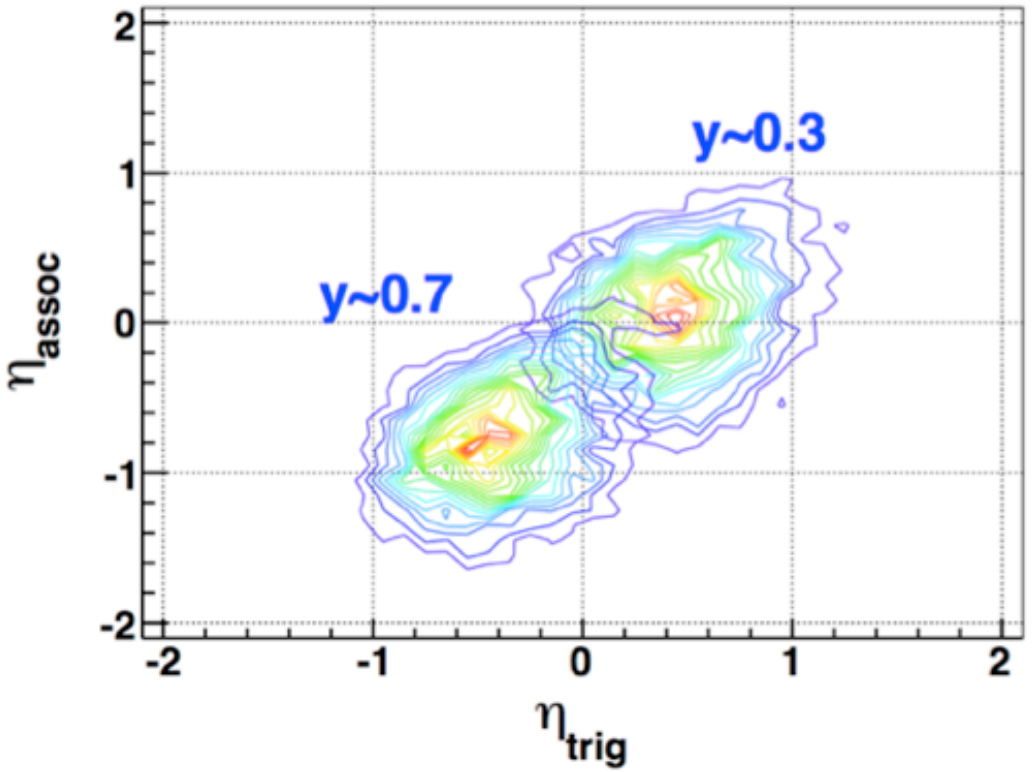


Azimuthal correlations in di-hadron (semi-inclusive deep-inelastic scattering) measurements,

$$e + \text{Au} \longrightarrow e' + \text{Au} + h_1 + h_2 + X$$

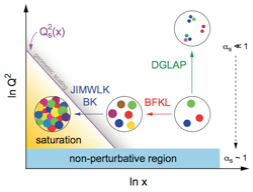
provide sensitivity to gluons and have been proposed as a robust probe of saturation:



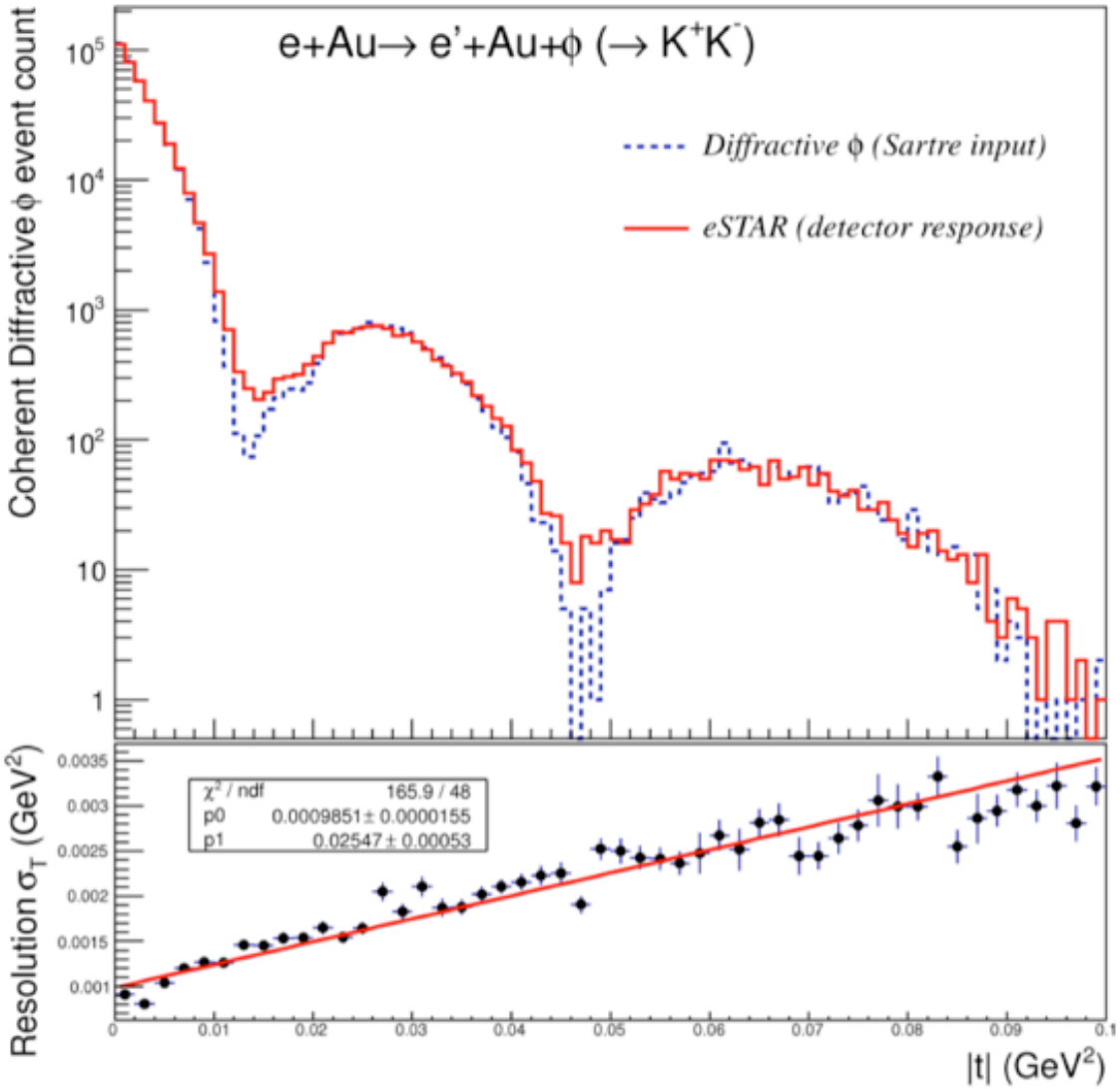


eSTAR projections for 10 GeV electrons scattering off 100 GeV/nucleon Au beams, 1 fb^{-1}.

eSTAR: A Letter of Intent - Exclusive VM

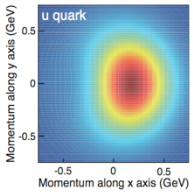


eSTAR projections for coherent diffractive production of phi-mesons

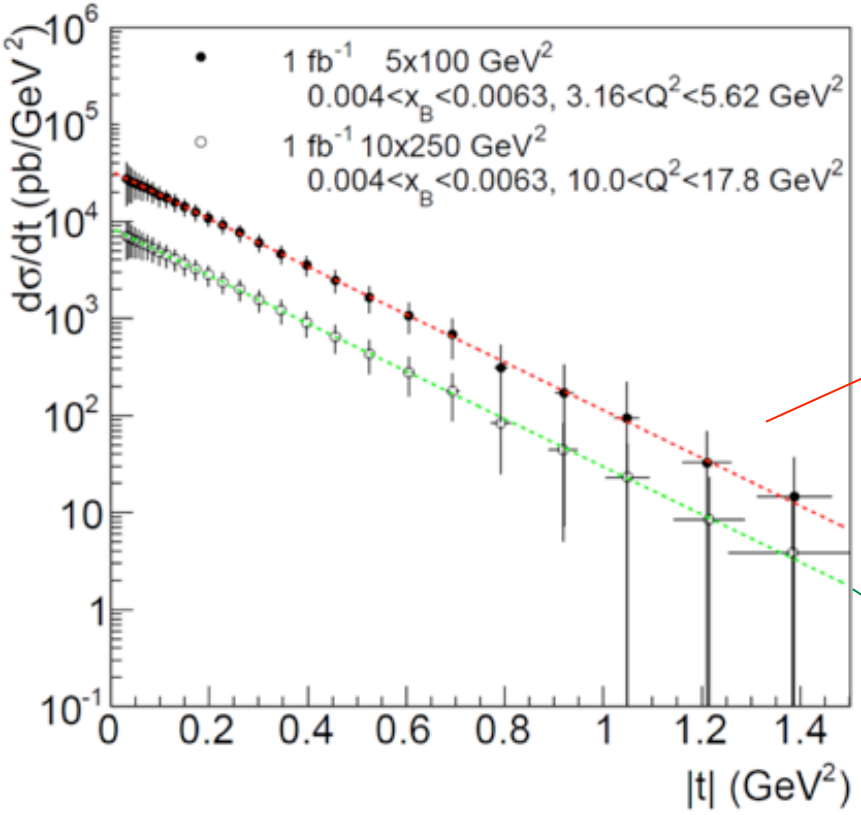


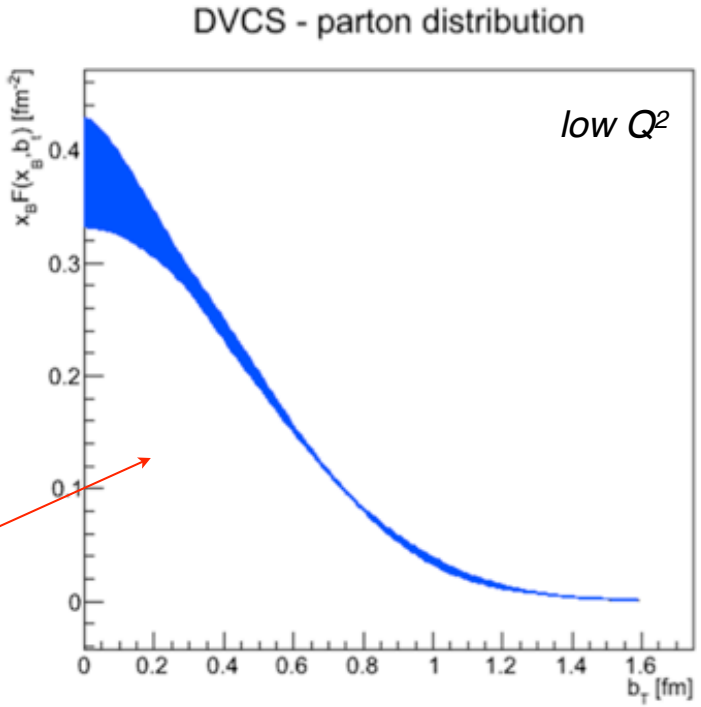
Plays well to STAR's mid-rapidity PID strengths, good resolution.

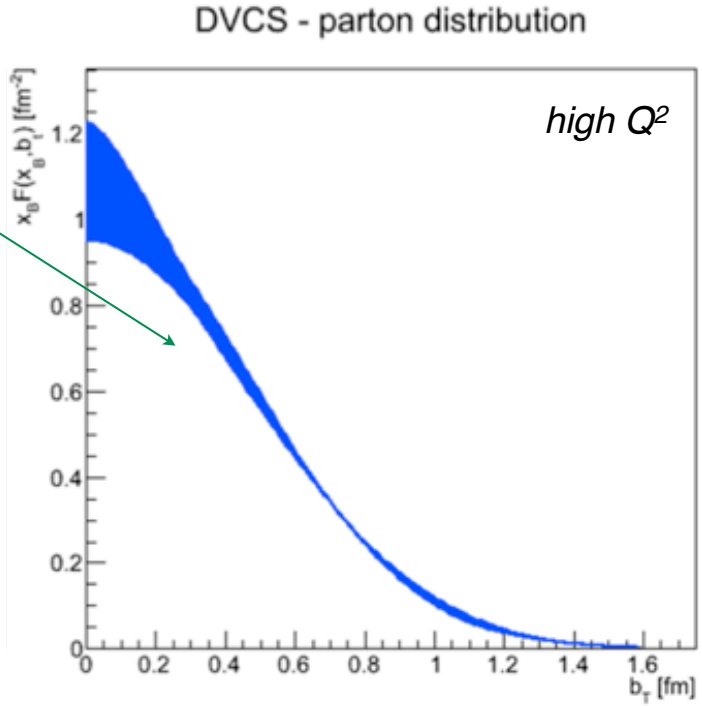
eSTAR: A Letter of Intent - DVCS



Imaging

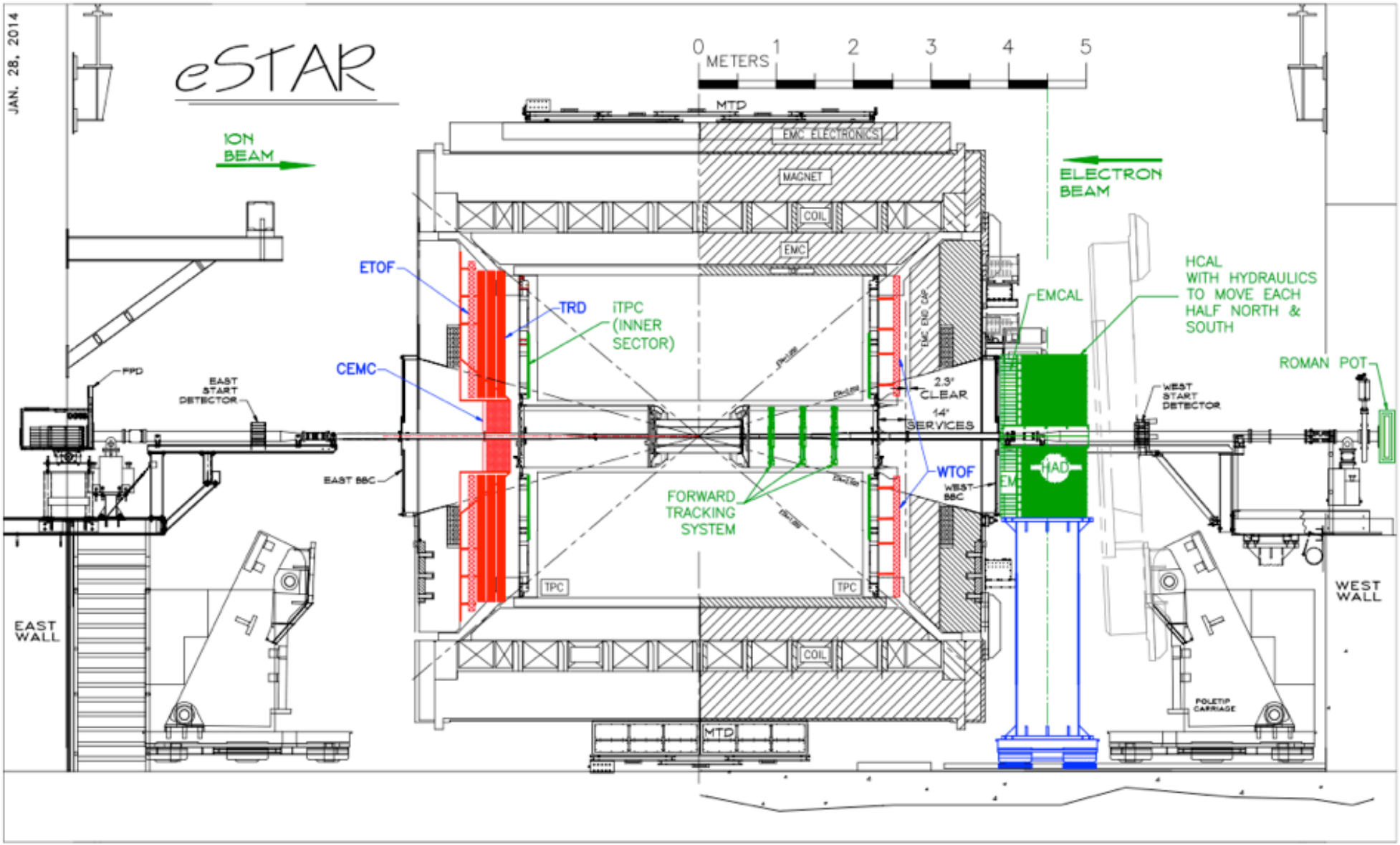






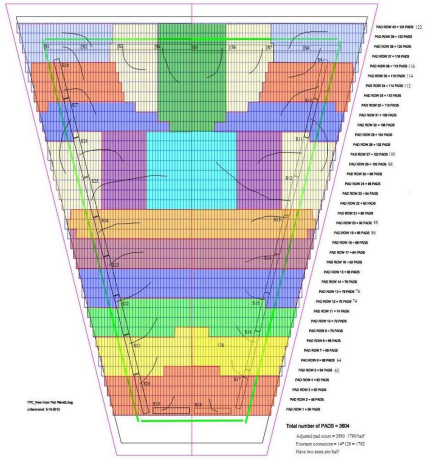
eSTAR projections for “DVCS”, Deeply-Virtual Compton Scattering / exclusive photon production, measurements

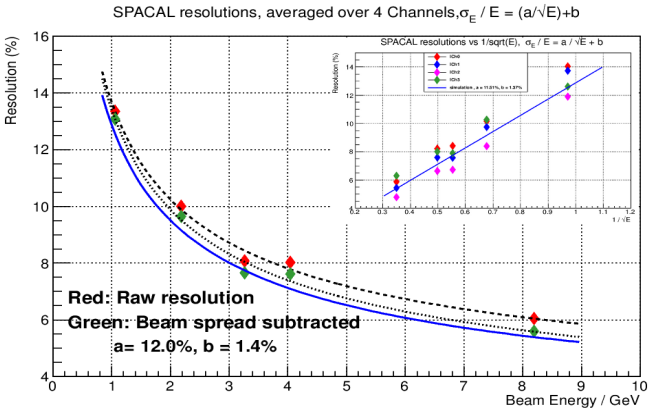
eSTAR - (selected) R&D



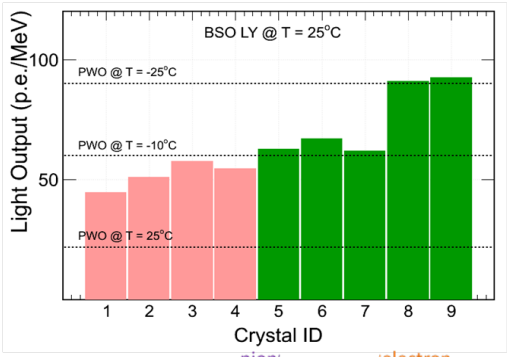
eSTAR - (selected) R&D

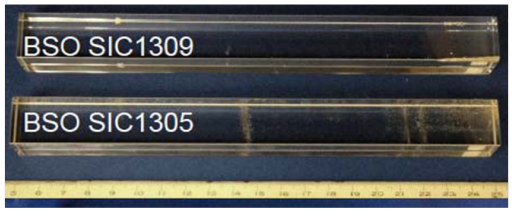
- *inner TPC (iTPC) sector upgrade*
  - *pad-row arrangement*
  - *material reduction*





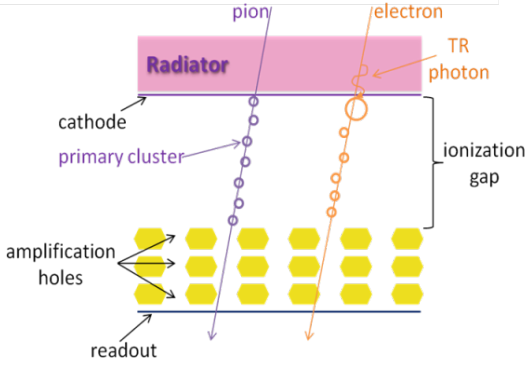
- *Forward Calorimeter System (FCS)*
  - *W-powder + Fiber*

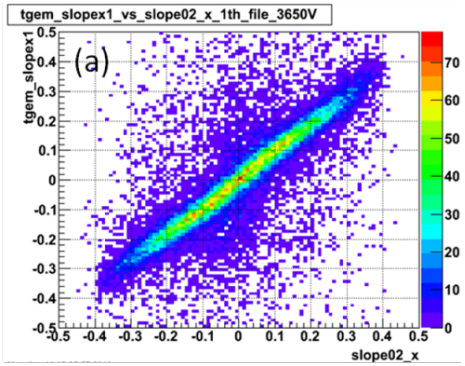




- *Crystal EM Calorimeter (CEMC)*
  - *new type of crystal*

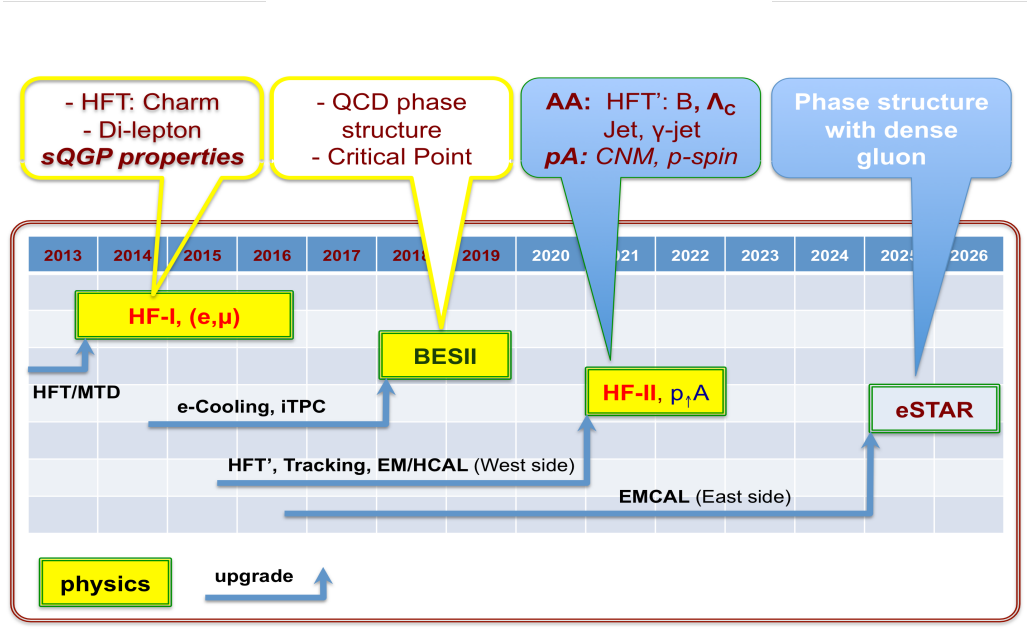
- *GEM based TRD.*





eSTAR - A Detector for eRHIC

- *Letter of Intent outlines a science-driven path to evolve STAR into a detector for of eRHIC (initial stage):*



- *Baseline eSTAR plan has three components: Endcap TOF, GTRD, and CEMC*

  relies on: iTPC, FCS, FTS

- *Significant measurement capabilities: inclusive DIS, SIDIS, exclusive observables, diffraction, key parts of EIC white-paper.*

- *Opportunity and lots of work ahead!*