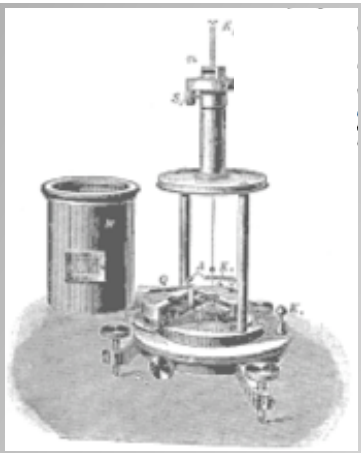
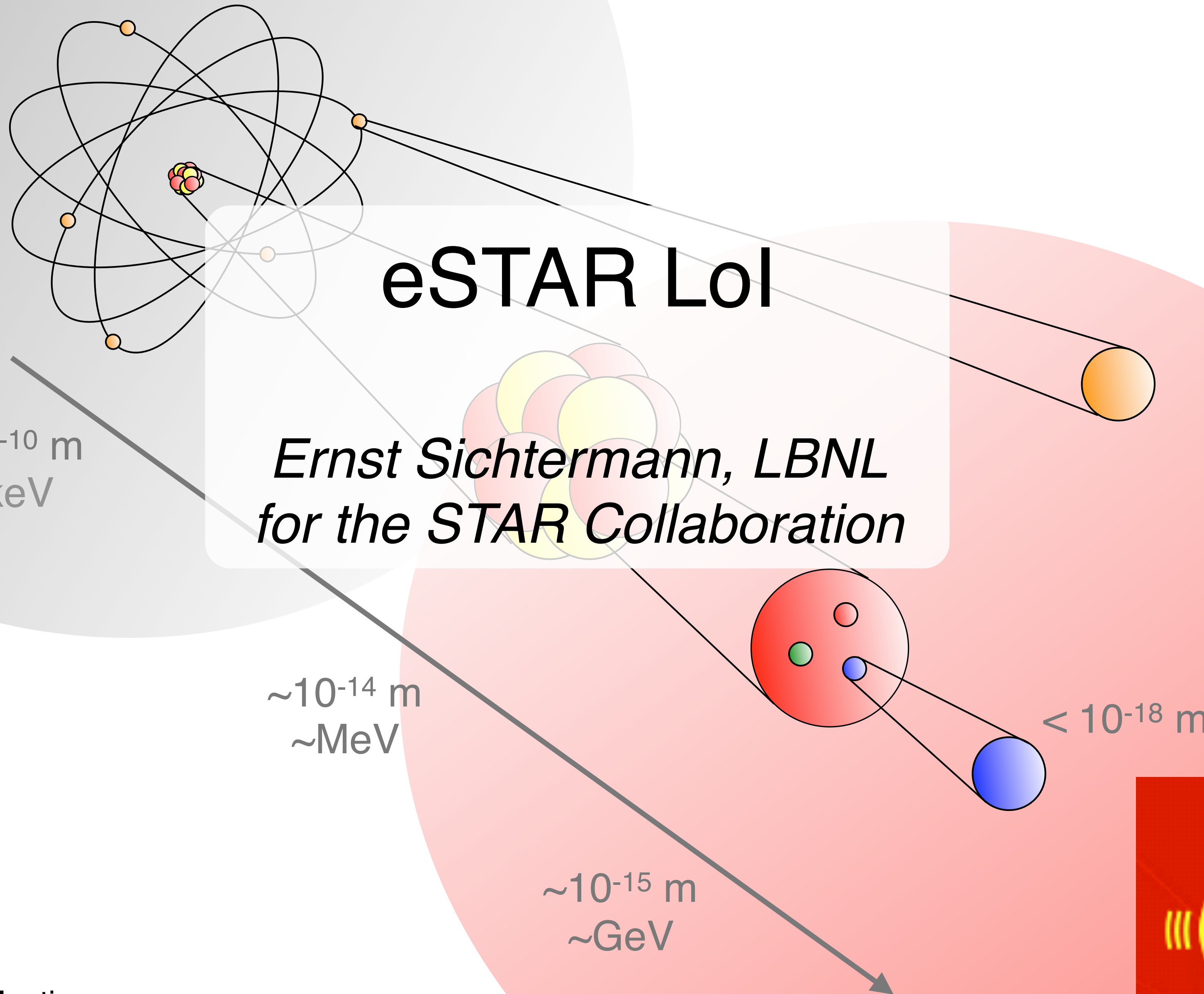


eSTAR LoI

Ernst Sichtermann, LBNL
for the STAR Collaboration



RHIC & AGS Users' Meeting
BNL, June 17, 2014

Electron Ion Colliders

Past

Possible Future

	HERA @ DESY	LHeC @ CERN	HIAF @ CAS	ENC @ GSI	MEIC/ELIC @ JLab	eRHIC @ BNL
$\sqrt{s}$ [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

Electron Ion Colliders

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

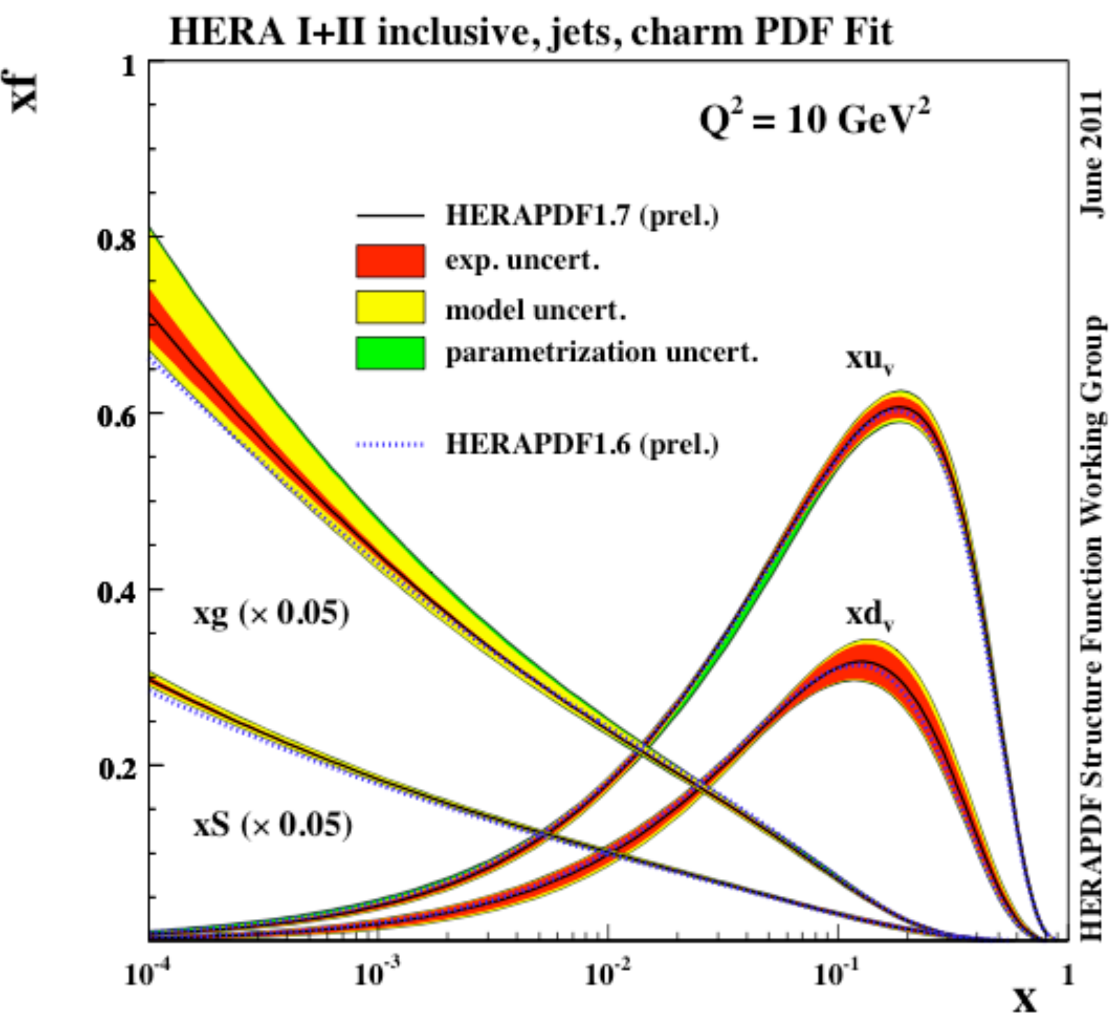
High-Energy Physics

Nuclear Physics

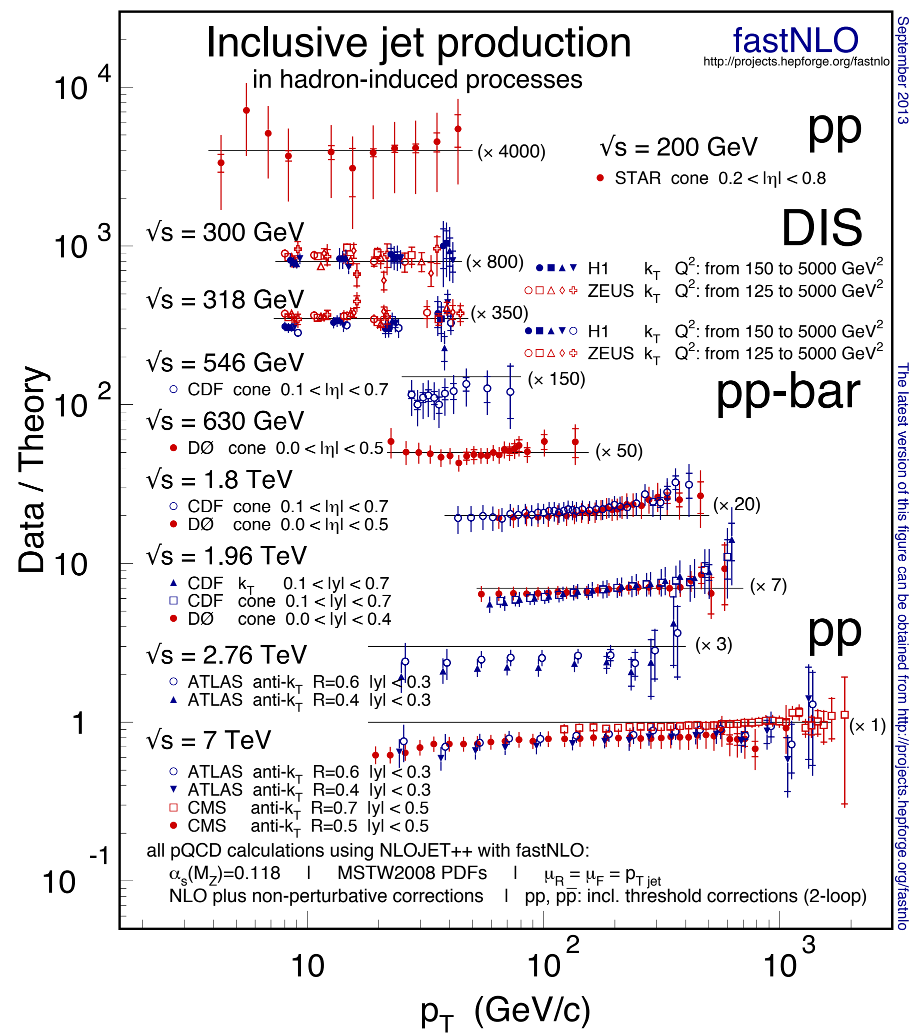
World Wide Interest

HERA's legacy

The proton in terms of gluons and quarks

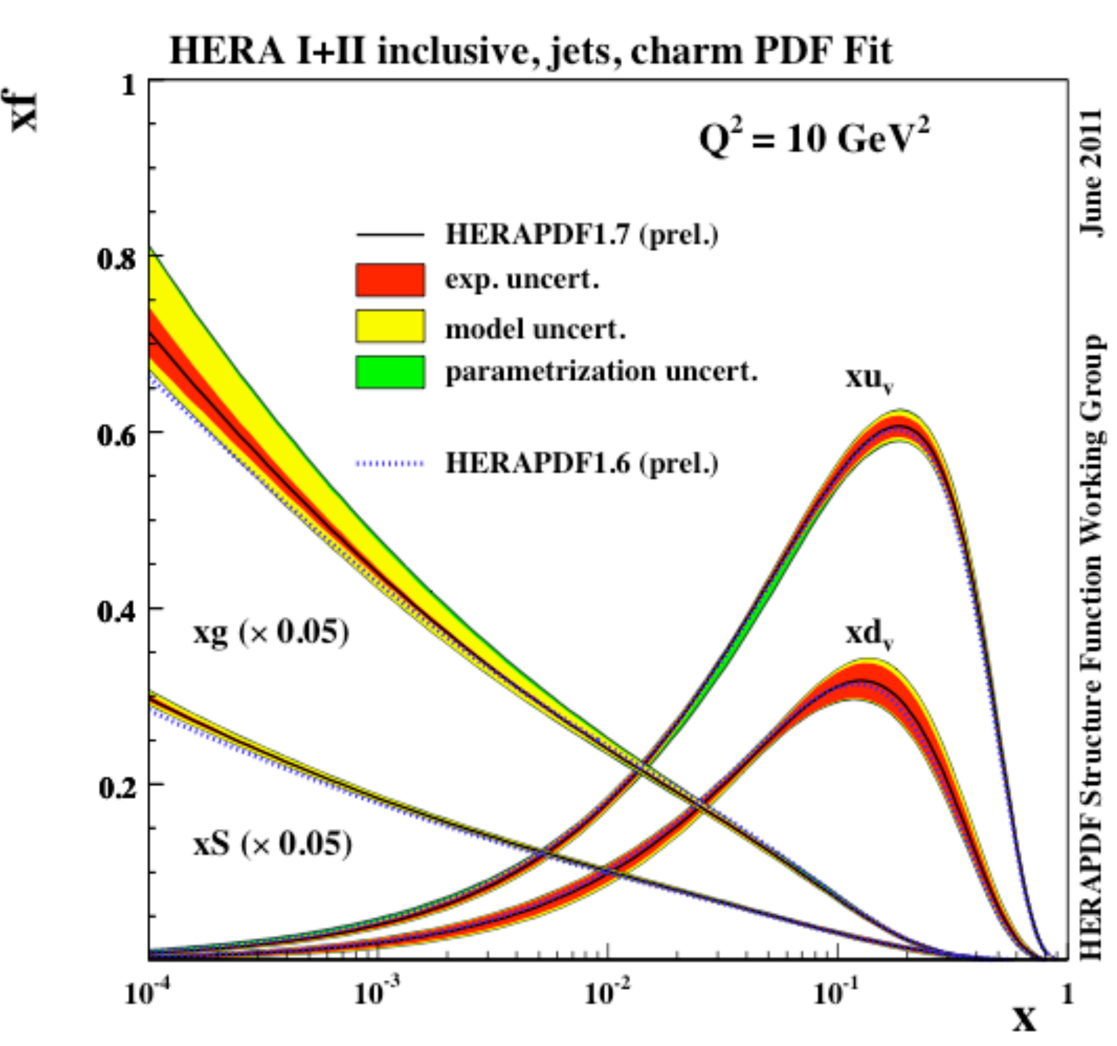


pQCD at work...



HERA's legacy

The proton in terms of gluons and quarks



... and quite remarkable voids:

Precision F_L - insufficient time,

Test isospin, u-d, - no deuterons,

d/u at large *x* - luminosity,

Strange quark distributions - luminosity,

Spin puzzle - no hadron beam polarization,

Quark-gluon dynamics in nuclei - no nuclei,

Saturation - insufficient √s / no nuclei,

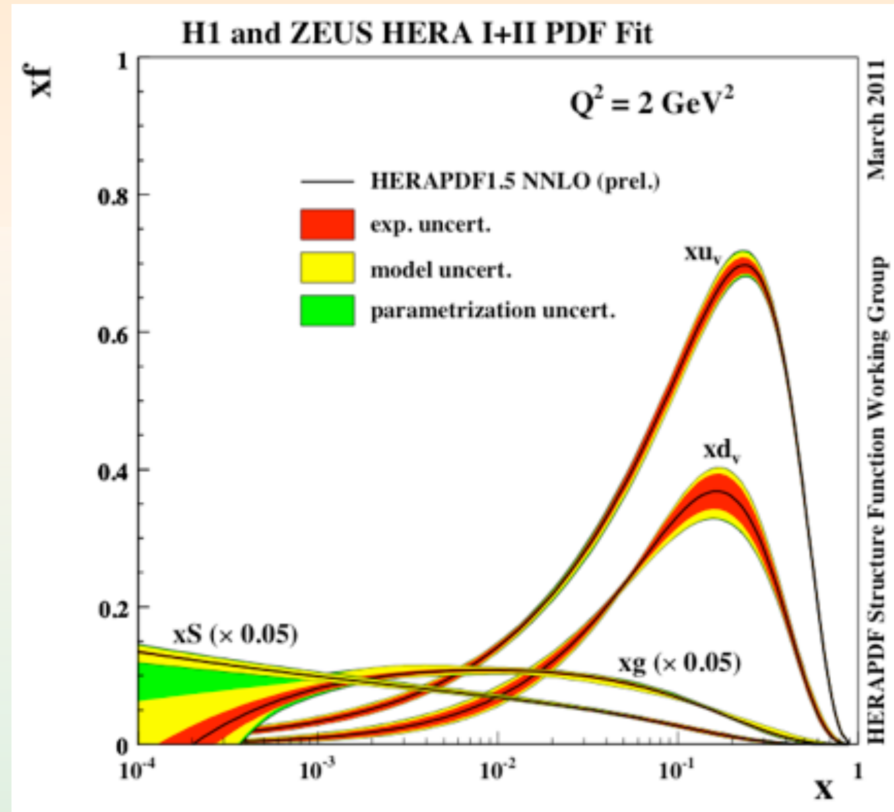
Fragmentation - limited particle-ID,

...

HERA - RHIC

Saturation:

- geometric scaling of the cross section,
- diffractive cross-section independent of W and Q^2,
- hints of a negative gluon number distribution (at NLO),
- forward multiplicities and correlations at RHIC,

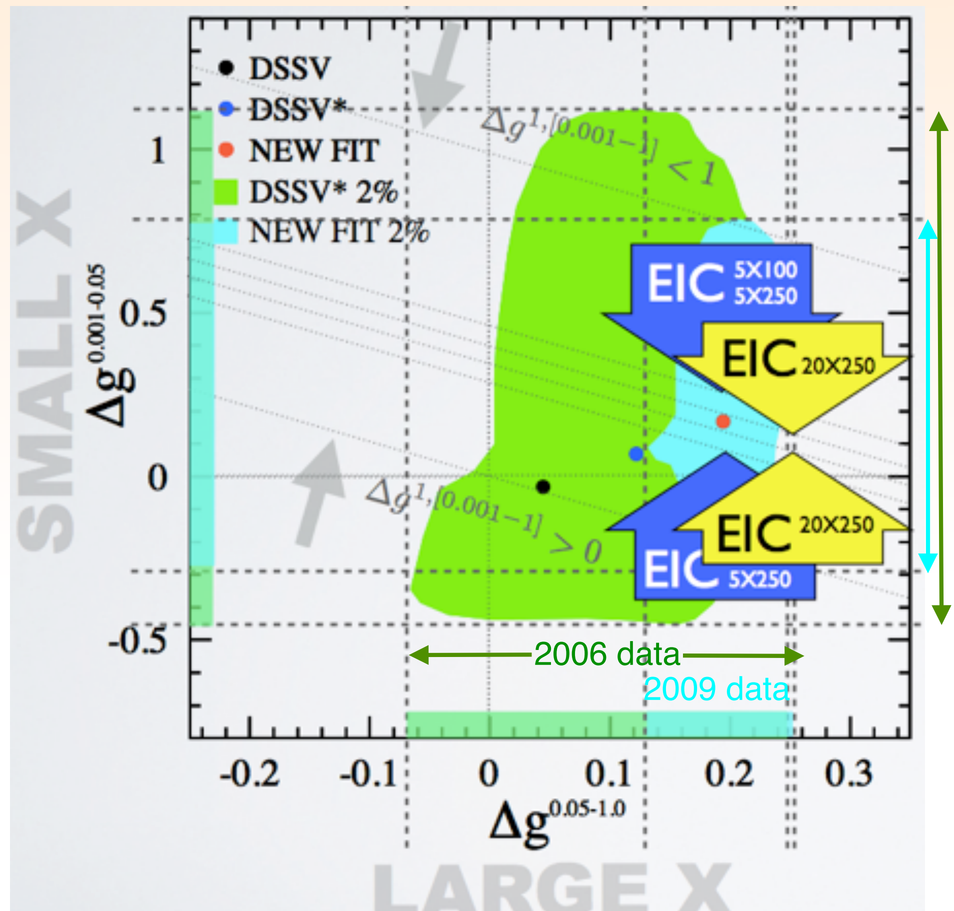


HERA - RHIC

Saturation:

- geometric scaling of the cross section,
- diffractive cross-section independent of W and Q2,
- hints of a negative gluon number distribution (at NLO),
- forward multiplicities and correlations at RHIC,

Rodolfo Sassot at 2013 Spin Summer Program



Spin puzzle:

- defining constraint on ΔG(x) for x > 0.05,
  smaller *x* is terra-icognita,
- fragmentation-free insight in Δu, Δd, Δū, Δd̄
  strange (anti-)quarks?
- large forward transverse-spin phenomena
  origin?

Mid-term: forward upgrade(s) at RHIC

Longer-term: EIC

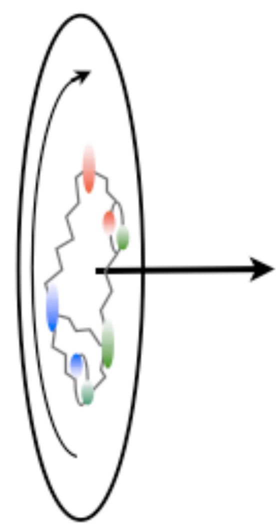
HERA - RHIC, JLab

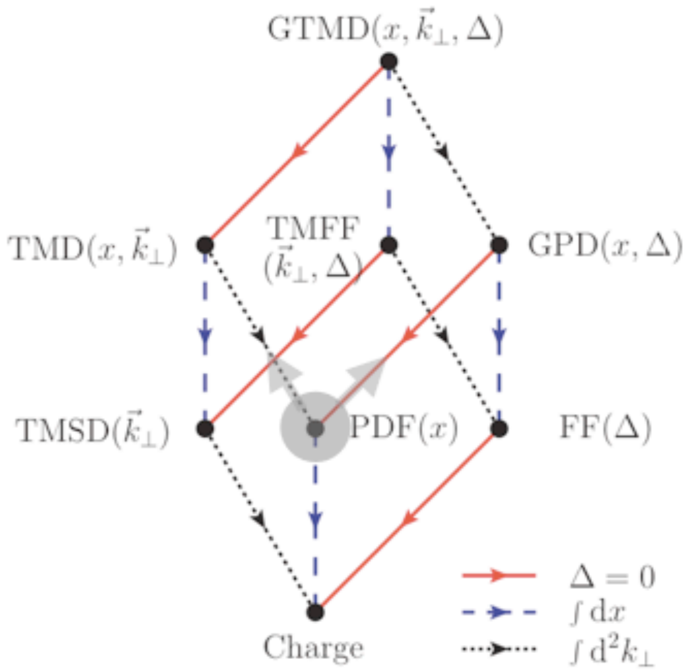
Saturation:

- geometric scaling of the cross section,
- diffractive cross-section independent of W and Q2,
- hints of a negative gluon number distribution (at NLO),
- forward multiplicities and correlations at RHIC,

Spin puzzle:

- defining constraint on $\Delta G(x)$ for $x > 0.05$,
  smaller *x* is terra-icognita,
- fragmentation-free insight in Δu, Δd, $\Delta \bar{u}$, $\Delta \bar{d}$
  strange (anti-)quarks?
- large forward transverse-spin phenomena
  origin?



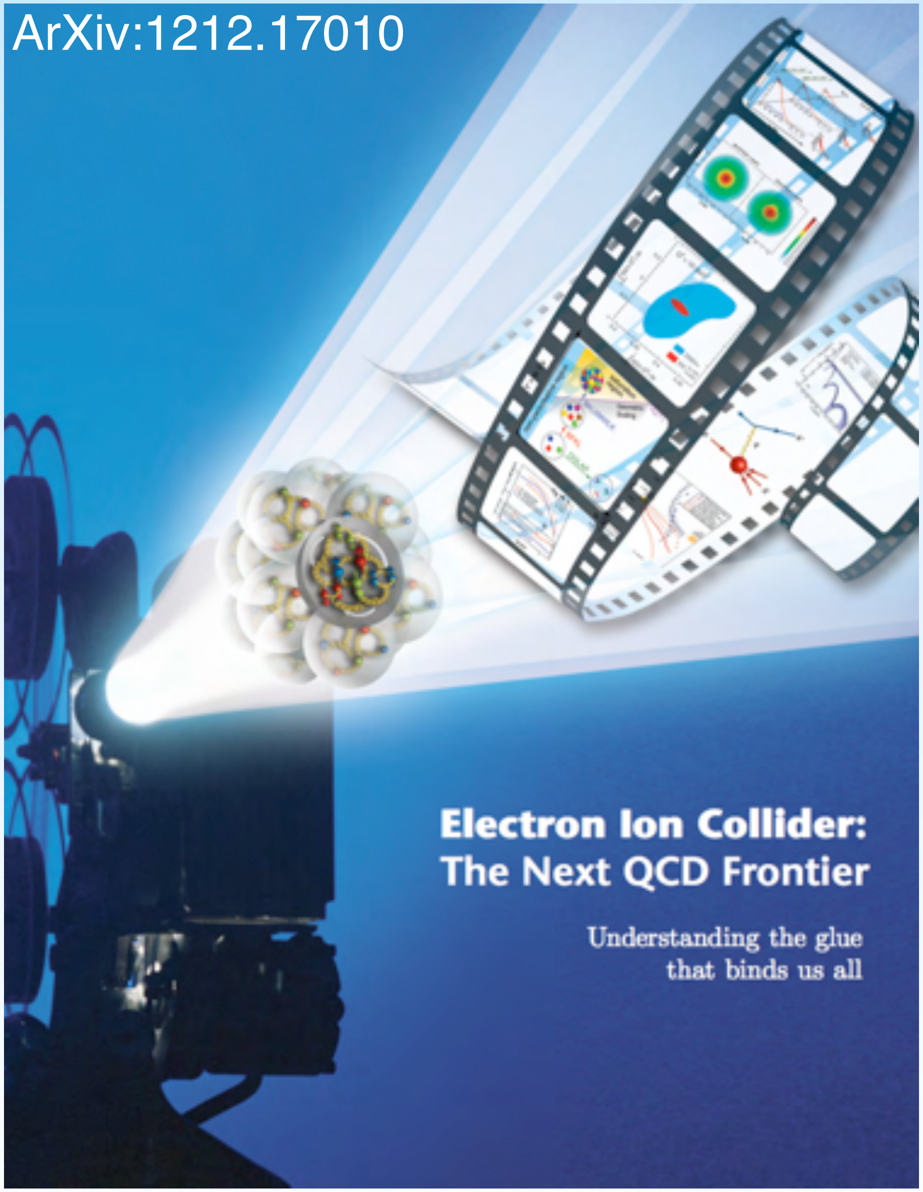


Lorce, Pasquini, Vanderhaeghen

Imaging / tomography:

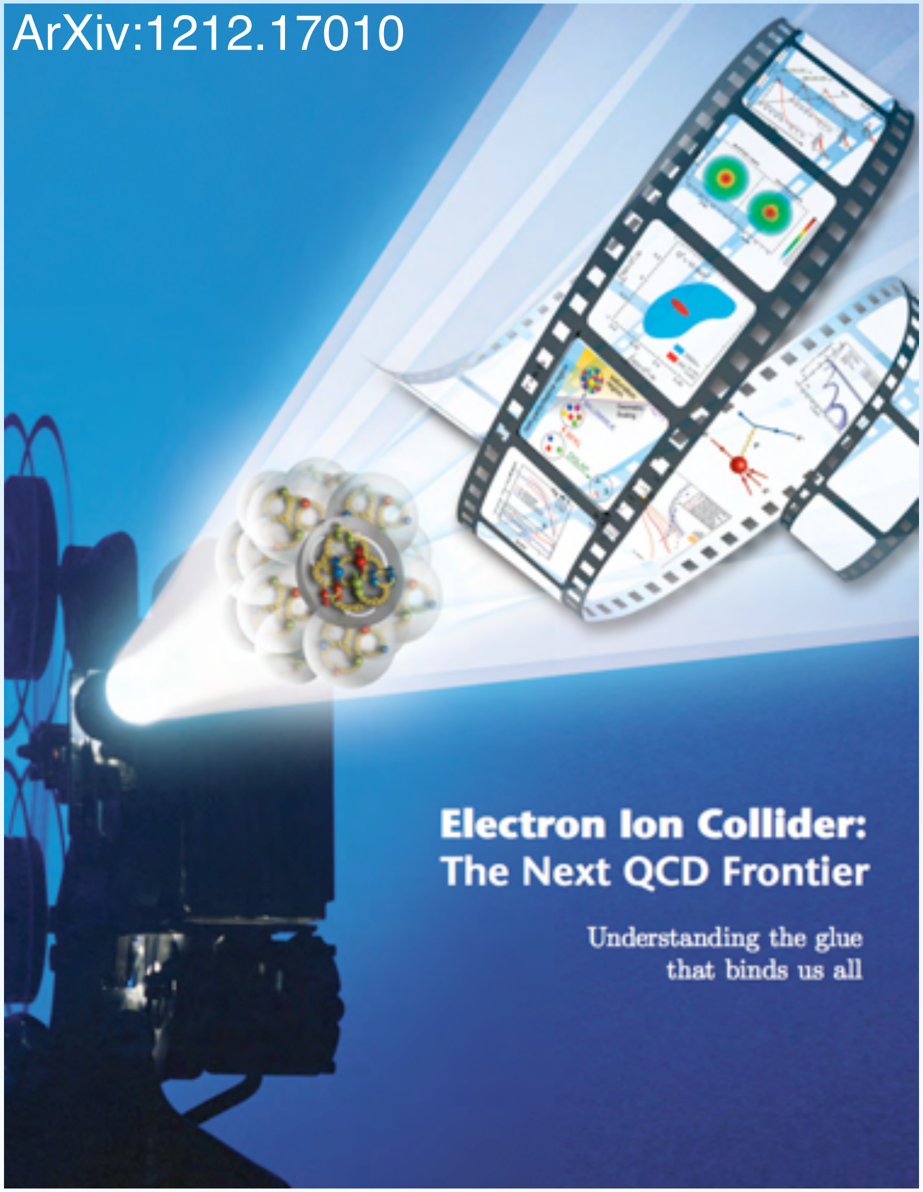
- valence quark region at JLab,
- precision insight in the gluon region *requires* EIC

U.S. EIC Key Science Questions



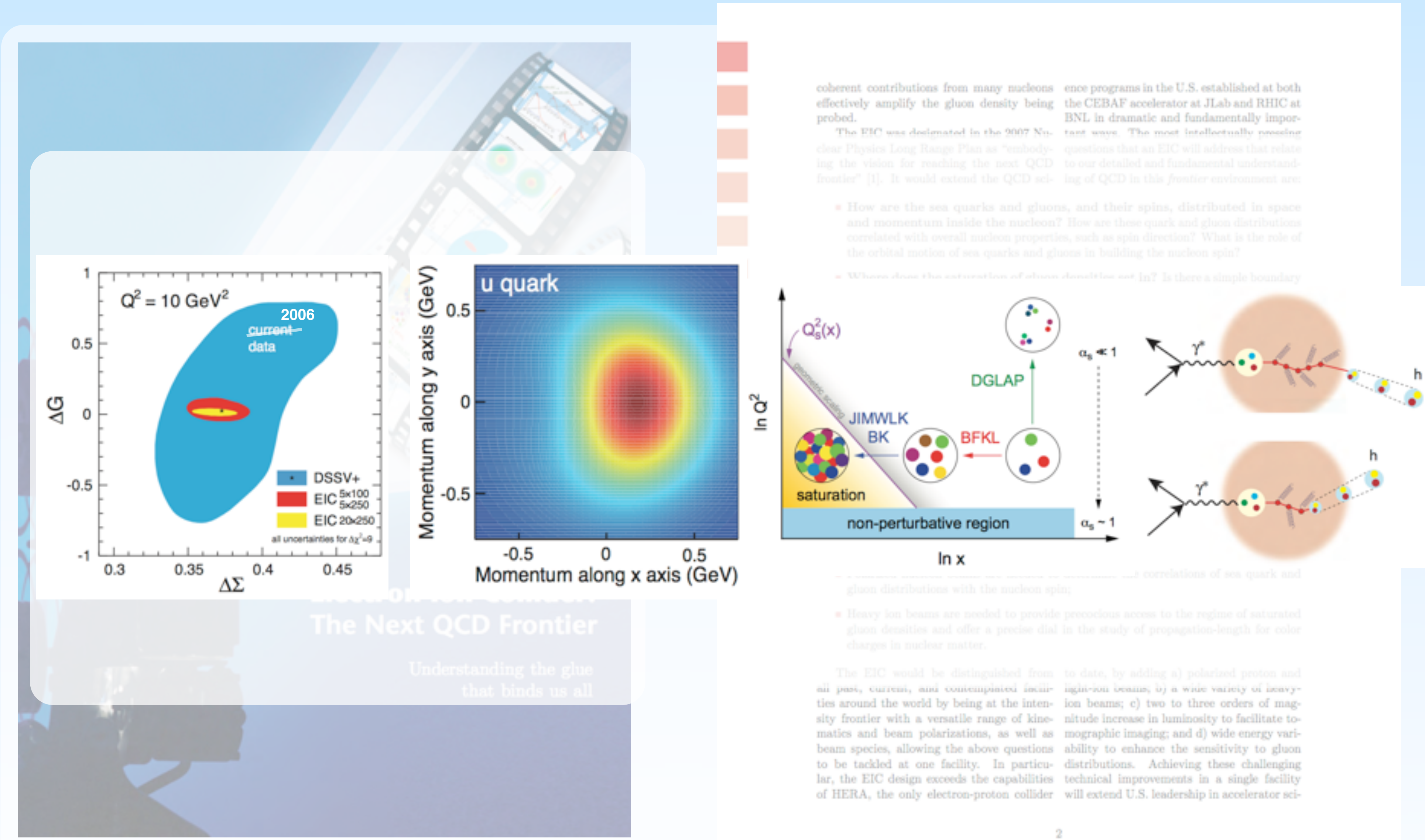
- *How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleus?*
- *Where does the saturation of gluon densities set in?*
- *How does the nuclear environment affect the distribution of quarks and gluons and their interactions in nuclei?*

U.S. EIC Necessary Capabilities



- *A collider to provide kinematic reach well into the gluon dominated regime,*
- *Electron beams provide the unmatched precision of the electromagnetic inter-action as a probe,*
- *Polarized nucleon beams to determine the correlations of sea quark and gluon distributions with the nucleon spin,*
- *Heavy Ion beams to access the gluon-saturated regime and as a precise dial to study propagation of color charges in nuclear matter.*

U.S. EIC Science Case and Measurements



ArXiv:1212.17010

U.S. EIC Science Case and Measurements

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. EIC Science Case and Measurements

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*

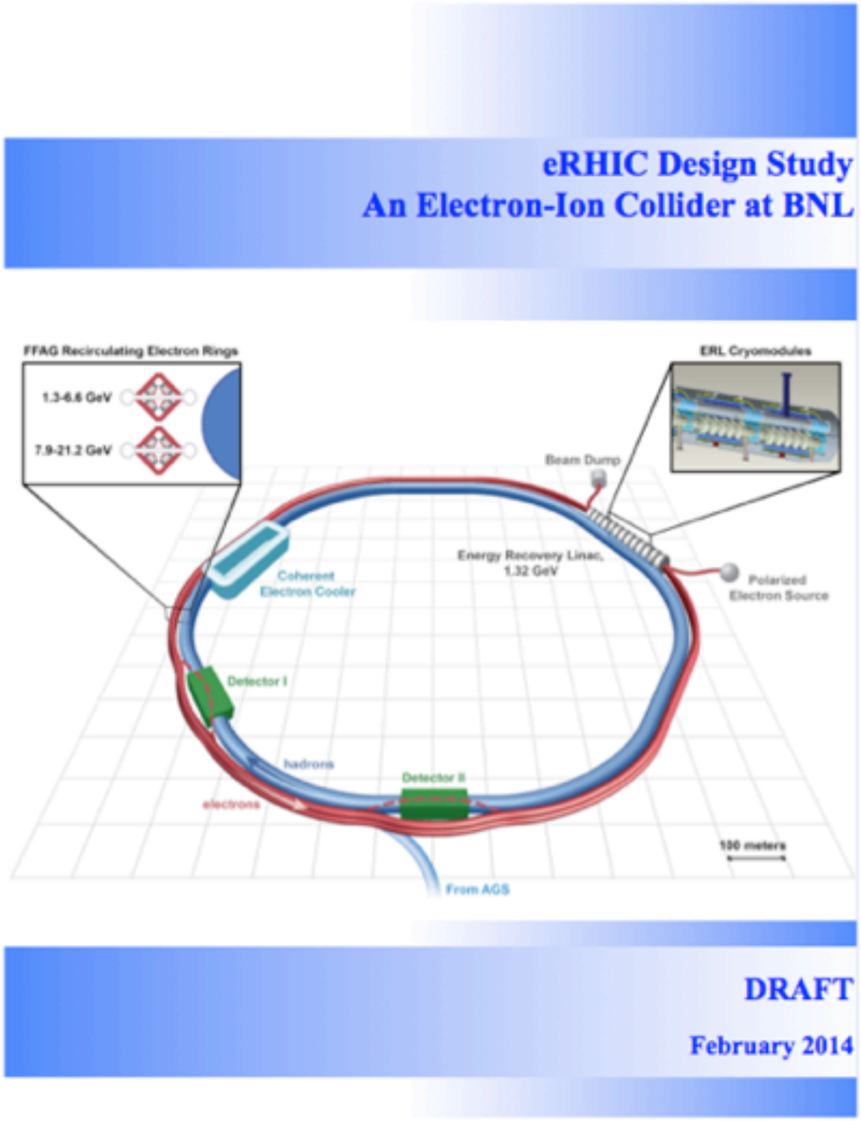
Key measurements:

- *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 National Laboratory

c.f. Talk by Vadim Ptytsin, Thursday's plenary III

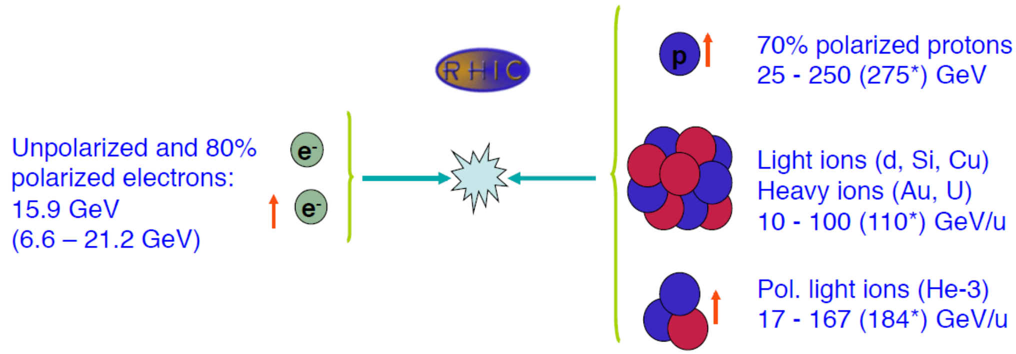


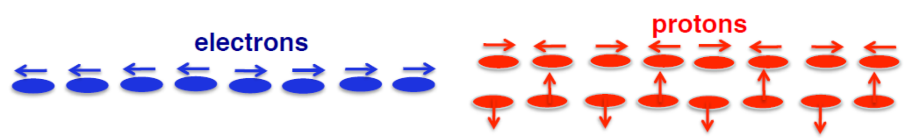
E.C. Aschenauer et al.

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:

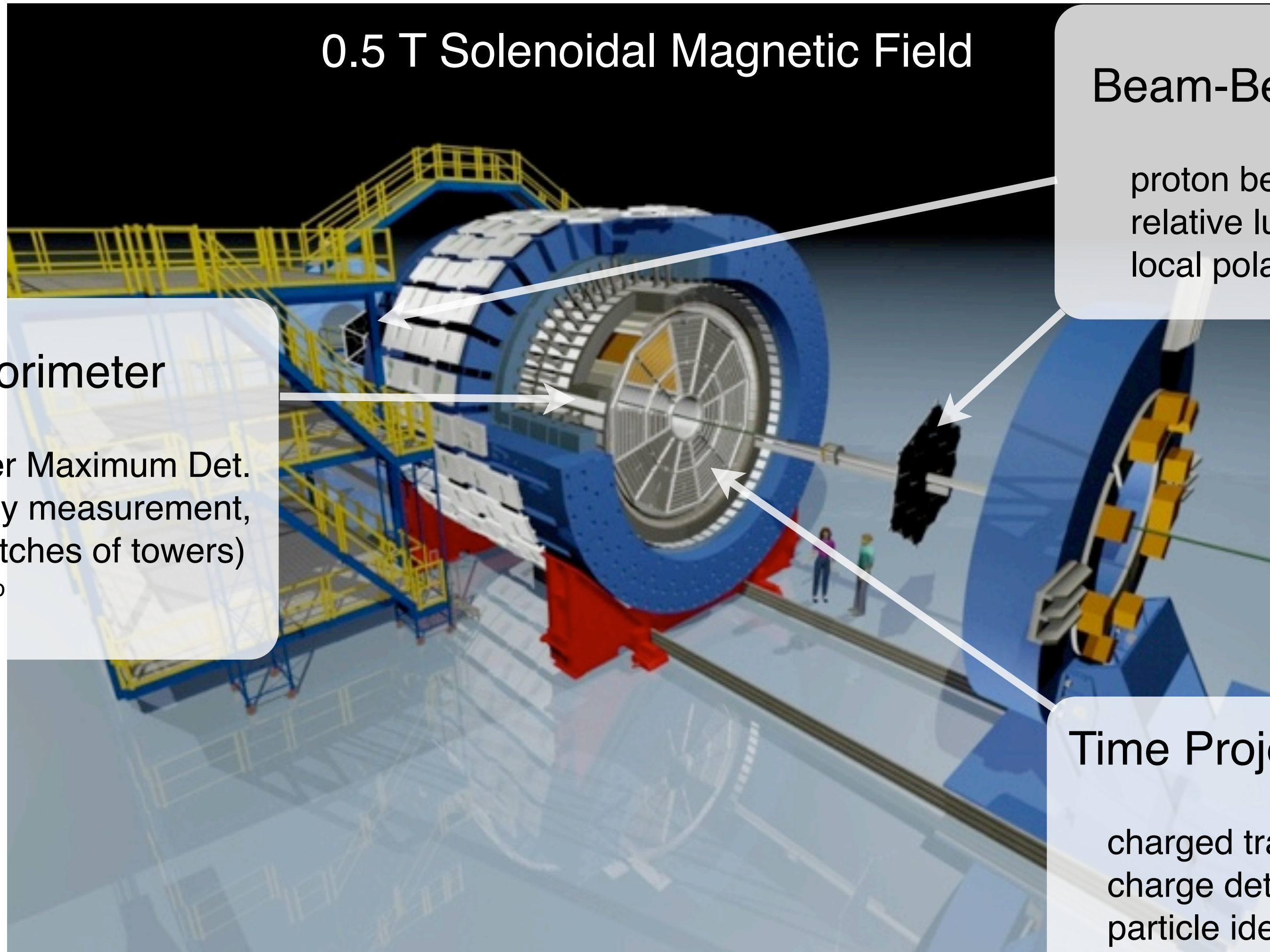




* It is possible to increase RHIC ring energy by 10%

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} $cm^{-2}sec^{-2}$.

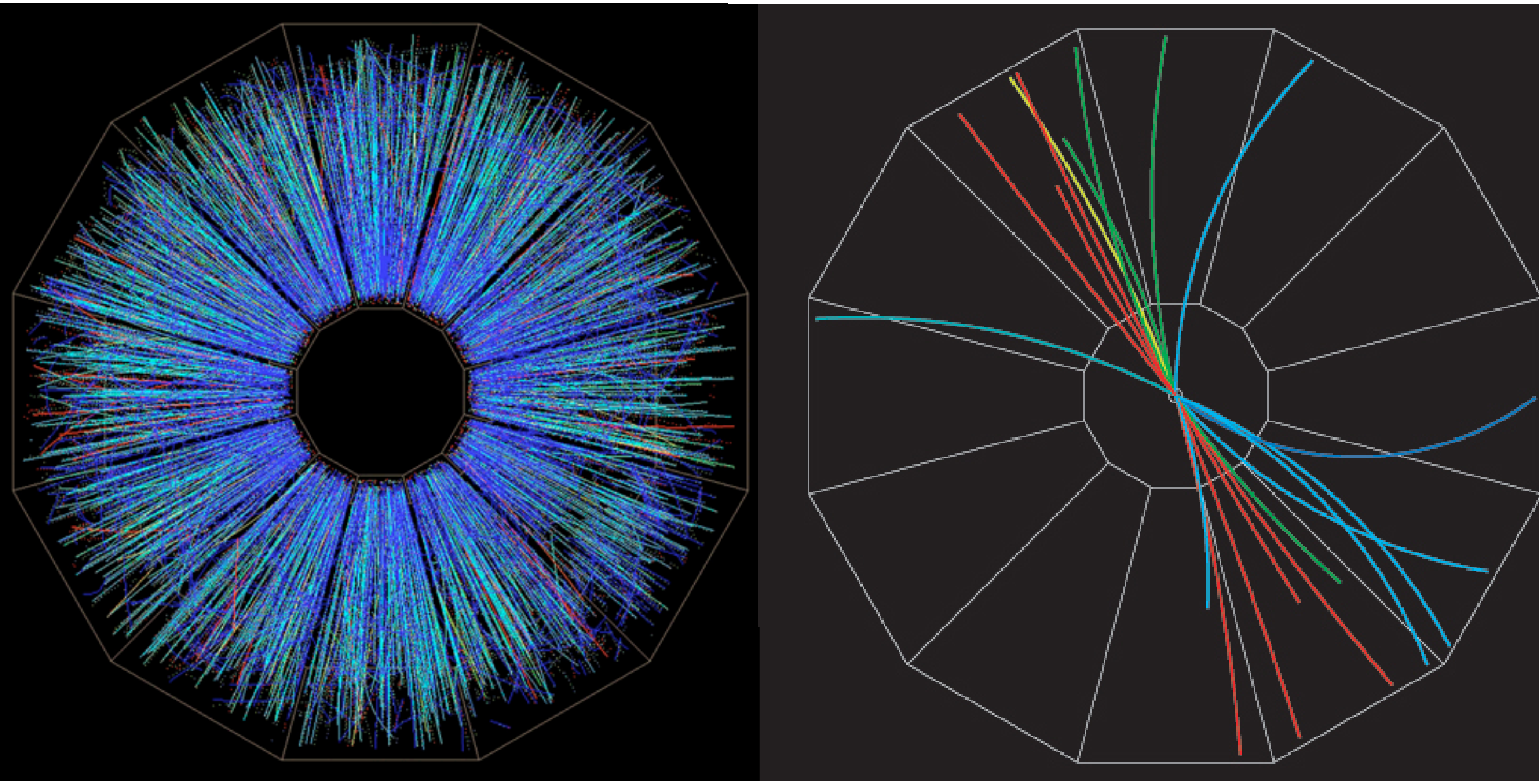
STAR - Solenoidal Tracker at RHIC



Nucl. Instrum. Meth. A499, 624, 2003

Additional subsystems, e.g. DAQ-1000, ZDC, Time-of-Flight, EEMC, FGT (complete),
Ongoing upgrades: Heavy Flavor Tracker, Muon-Telescope Detector
Upgrade plans: Roman Pot system (phase IIa), Forward Calorimeter System, ...

STAR - Solenoidal Tracker at RHIC

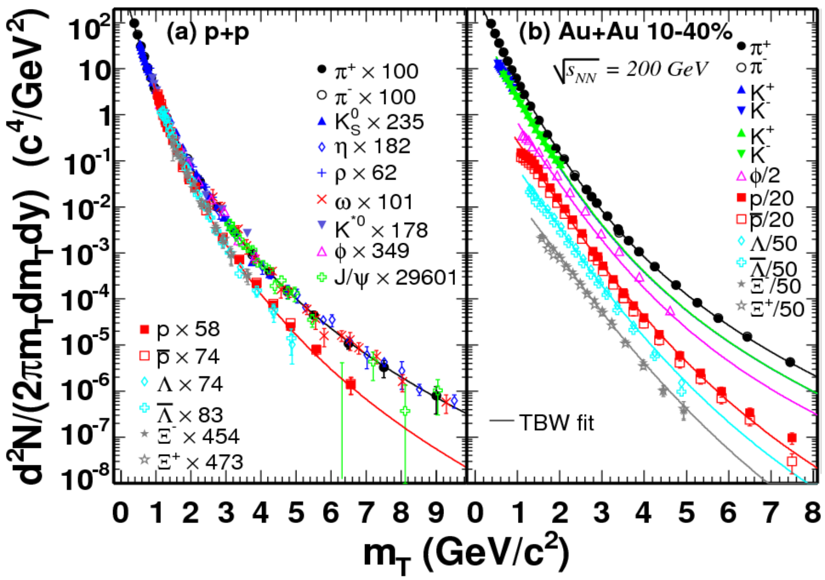


A versatile instrument to study QCD: Au+Au, d+Au, p+p, $\sqrt{s}$ = 7.7 - 500 GeV, polarization.
key strengths: Acceptance, low-mass, mid-rapidity Particle-Identification.

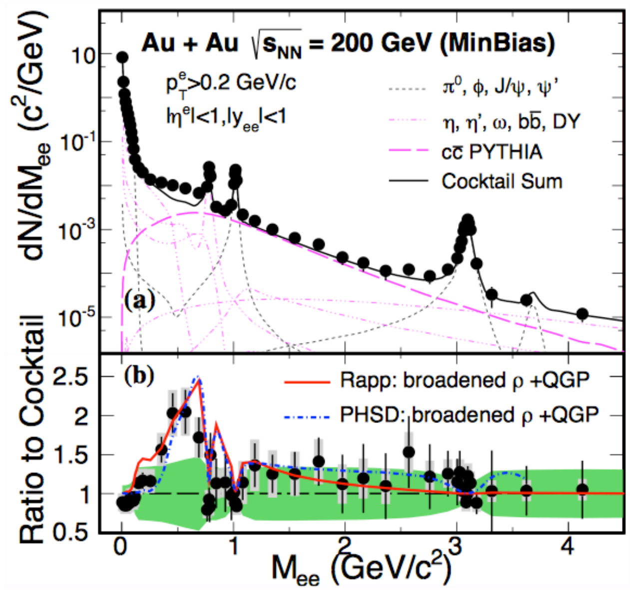
Can it be adapted to eRHIC? If so, how? - *STAR Decadal Plan 2010-2020, eSTAR LoI.*

The Future Evolves from the Present...

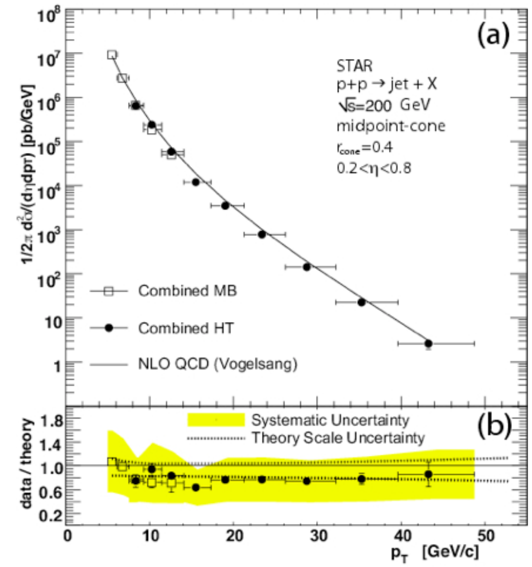
Z. Tang et al, ArXiv:1101.1912



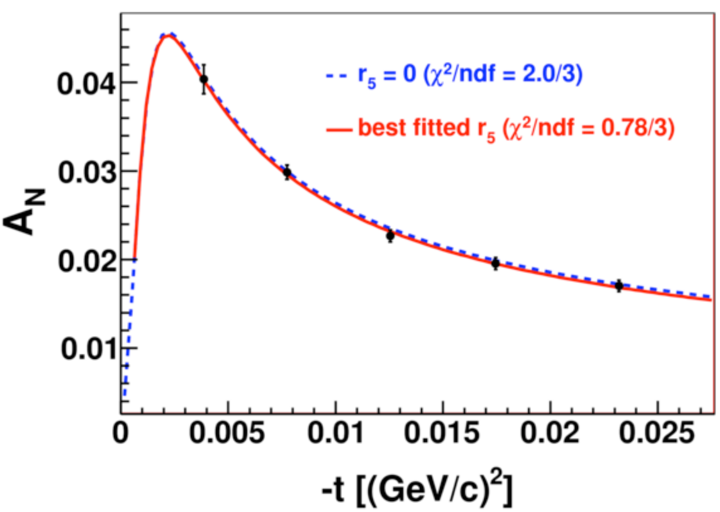
ArXiV: 1312.7379, accepted for publ. in PRL



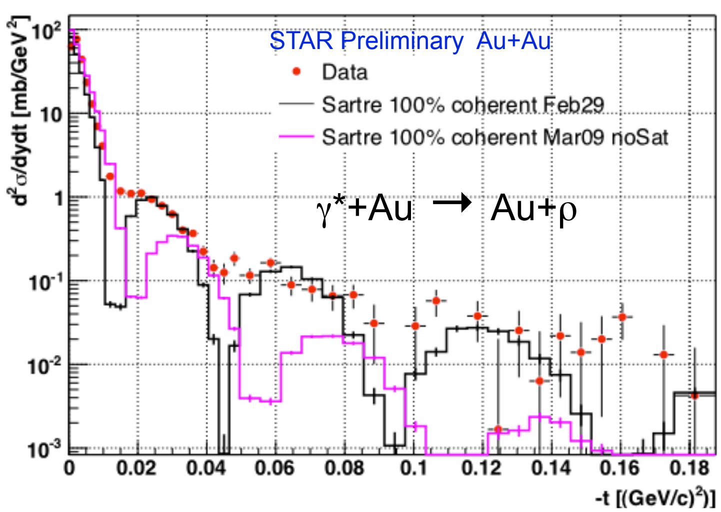
PRL 97 (2006) 252001



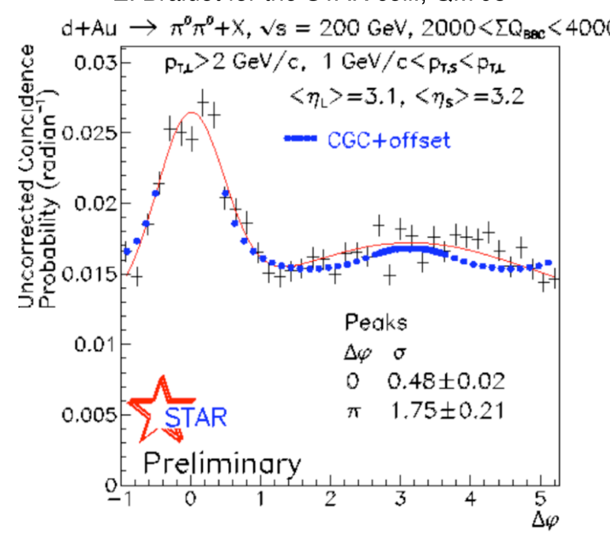
PLB 719 (2013) 62



R. Debbe for the STAR coll. WWND'12



E. Braidot for the STAR coll., QM'08



Berndt Müller's charge to Dave Morison, Jamie Nagle, Nu Xu, all (May 2013):

...

We now have an EIC White Paper with a comprehensive outline of the physics questions for an Electron Ion Collider, a rapidly maturing machine design for eRHIC, and a clearer view of a possible path to an early-stage eRHIC program leading to first measurements in the mid-2020s.

Therefore, the PHENIX and STAR Collaborations are now being asked to consider their role in a transition from RHIC to eRHIC on this time scale, and to provide specific plans (i.e. Letters of Intent) to upgrade/reconfigure the detectors from their present form to first-generation eRHIC detectors ...

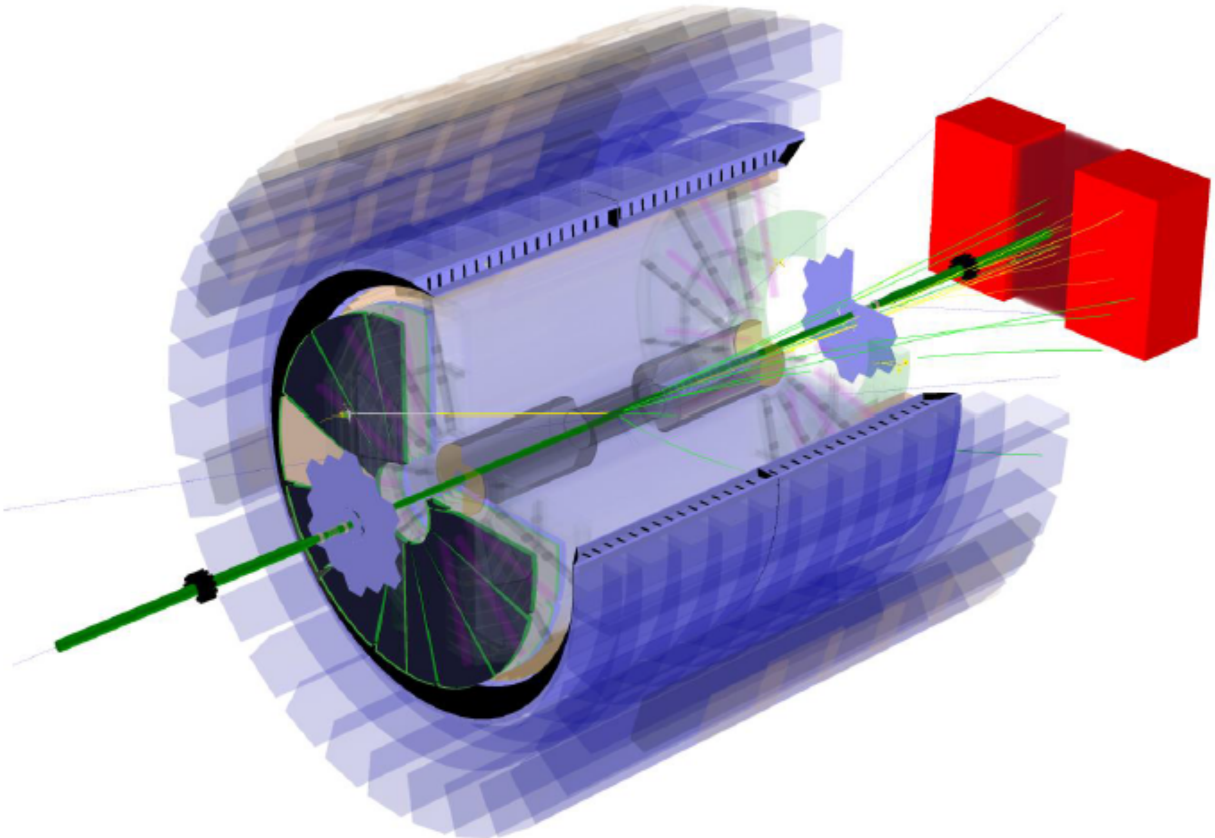
In preparing these LOI the collaborations should assume an eRHIC machine with:

- an electron beam energy up to 10 GeV,
- hadron beam energies as provided by the current RHIC machine,
- design luminosities of 10^{33} $cm^{-2}s^{-1}$ for 10 GeV on 255 GeV ep collisions and the equivalent of 6.10^{32} $cm^{-2}s^{-1}$ for 10 GeV on 100 GeV/nucleon eA collisions.

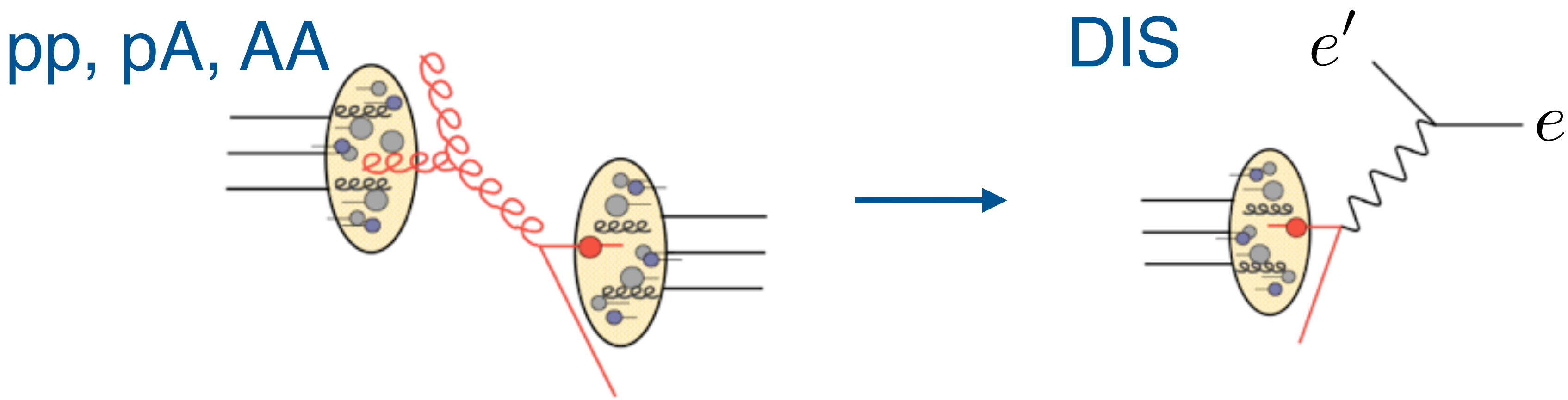
... submitted by September 30, 2013

eSTAR: A Letter of Intent

The STAR Collaboration



https://drupal.star.bnl.gov/STAR/starnotes/public/sn0592



Relevant invariants:

$$s = (e+p)^2$$
Square of total c.m. energy

$$q = e - e' \quad Q^2 = -(e-e')^2$$
Square of (4-)momentum transfer

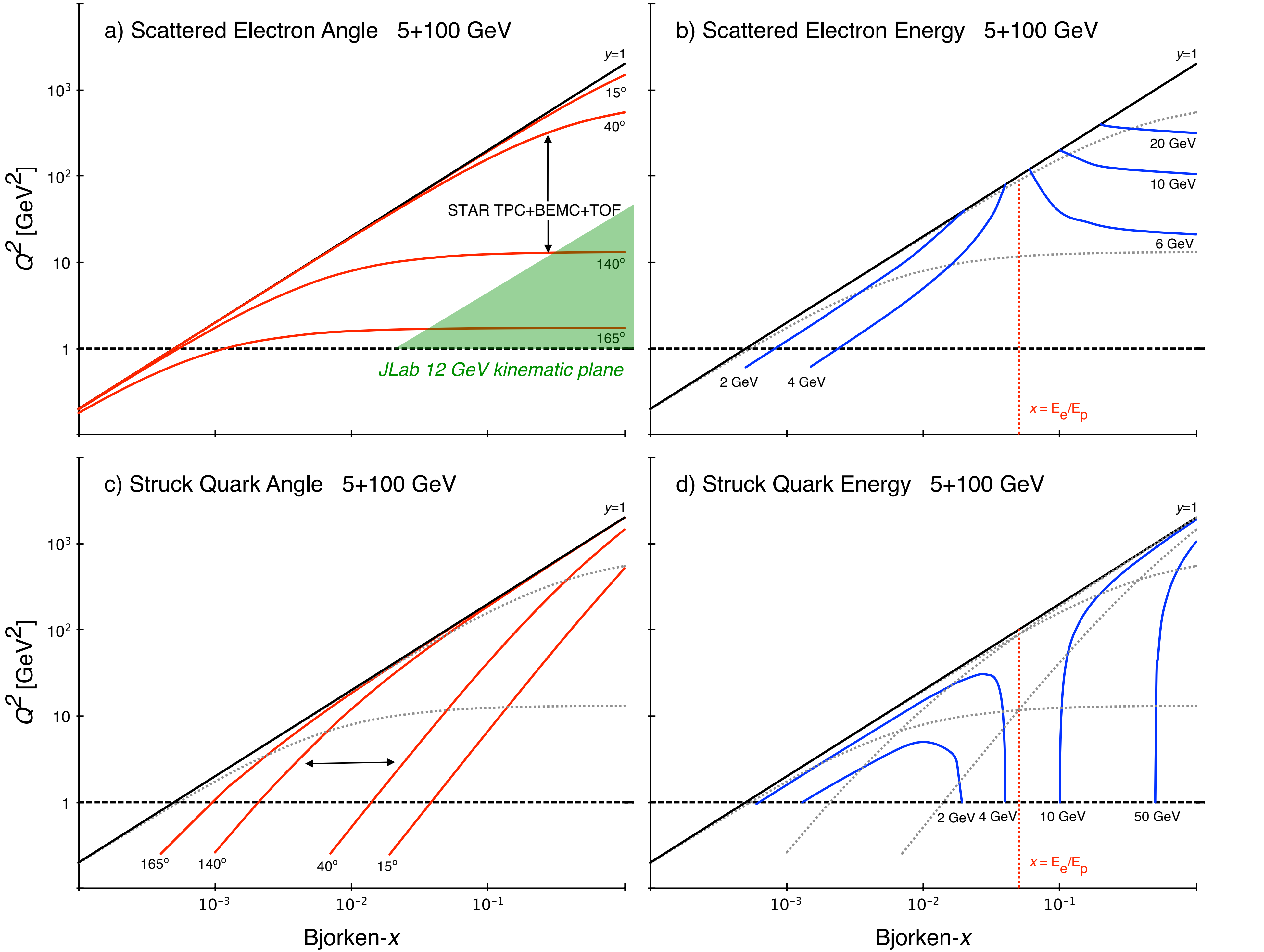
$$x = \frac{Q^2}{ys}$$
Bjorken-x, ~parton mom. fraction

$$y = (q.p)/(e.p)$$
Fractional energy transfer

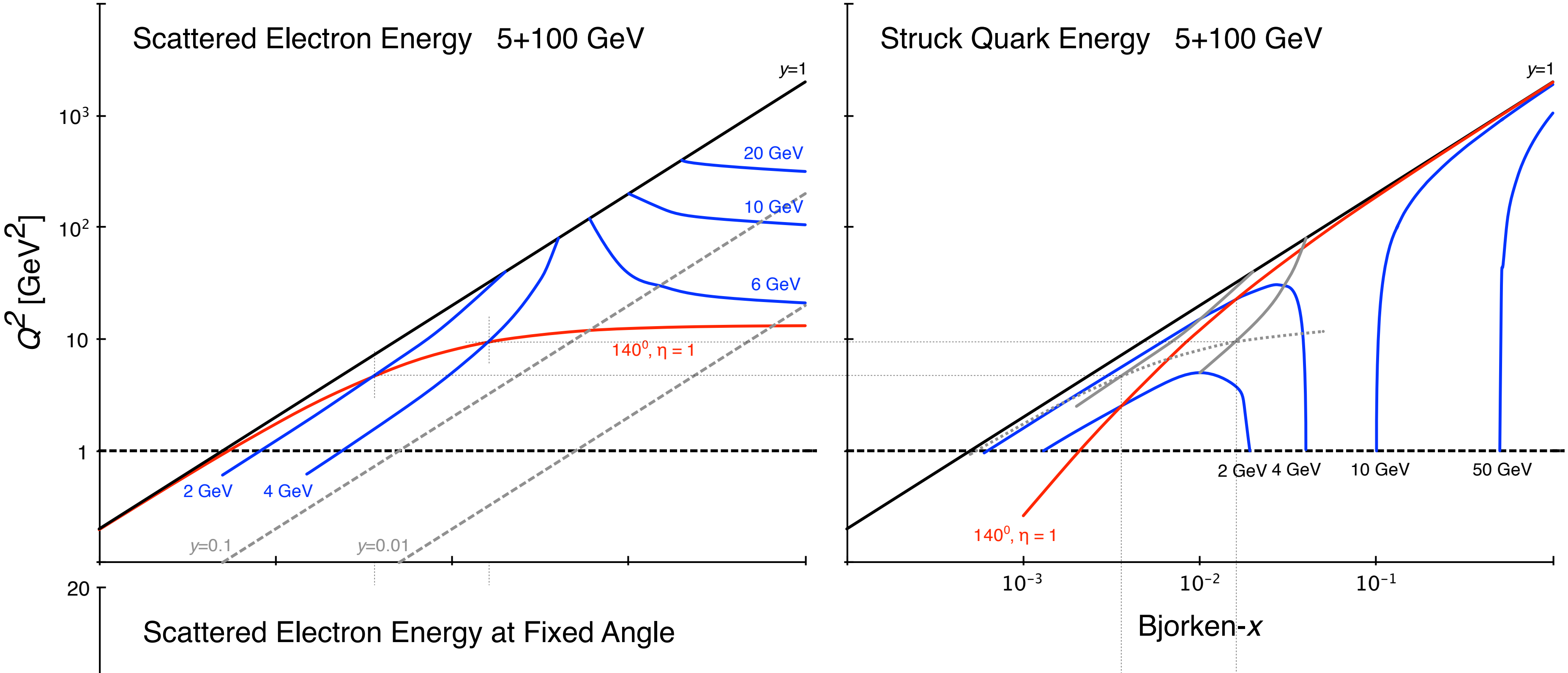
x, Q^2 can be reconstructed from the scattered electron, the “current jet”, or hybrids.

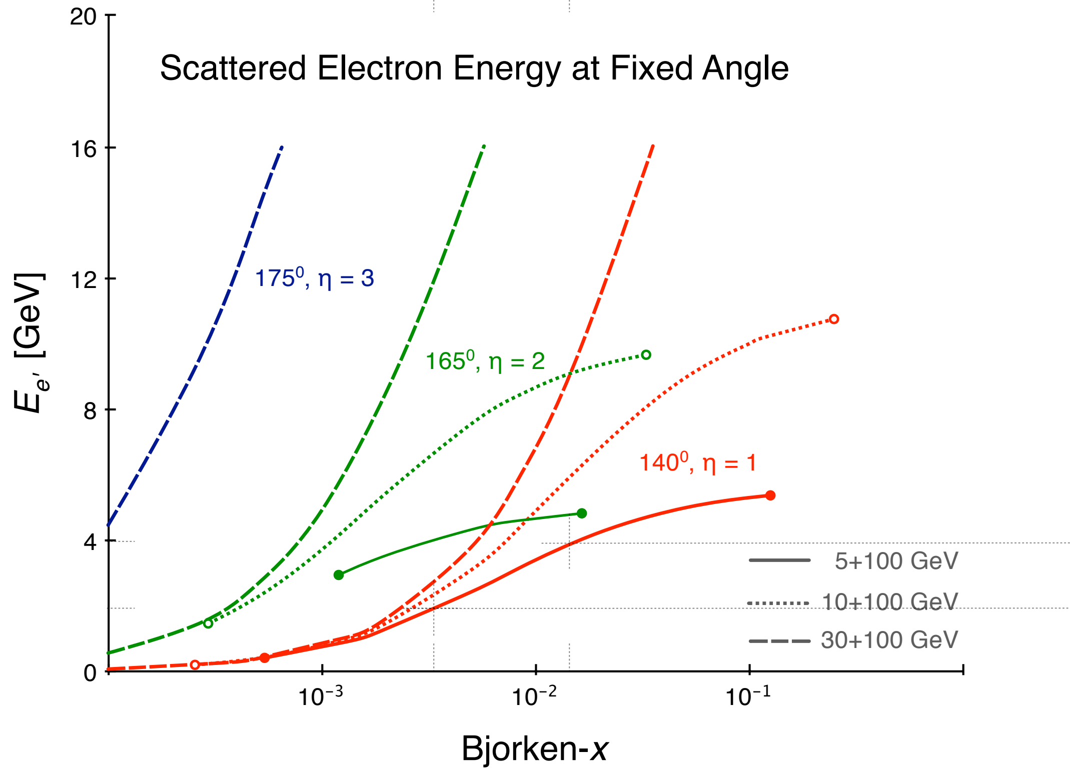
Adopt HERA-convention; angles w.r.t. hadron beam.

eSTAR - Initial Considerations



eSTAR - Initial Considerations





Bending radii ~m,

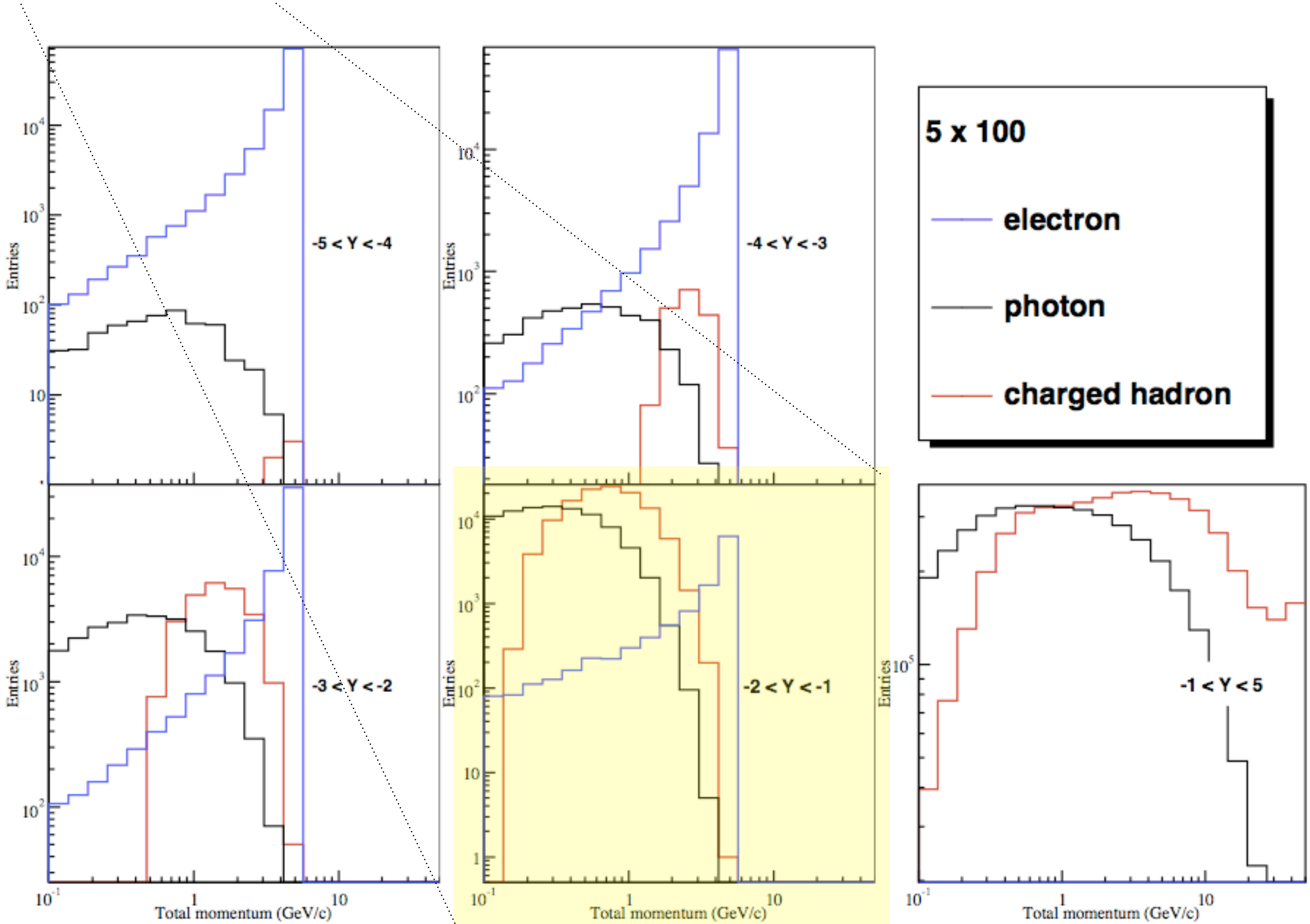
Sagitta ~mm (over 40cm),

At 140º, 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 165º, dx/x~2 implies dE/E~0.09 at 5.10^{-3}

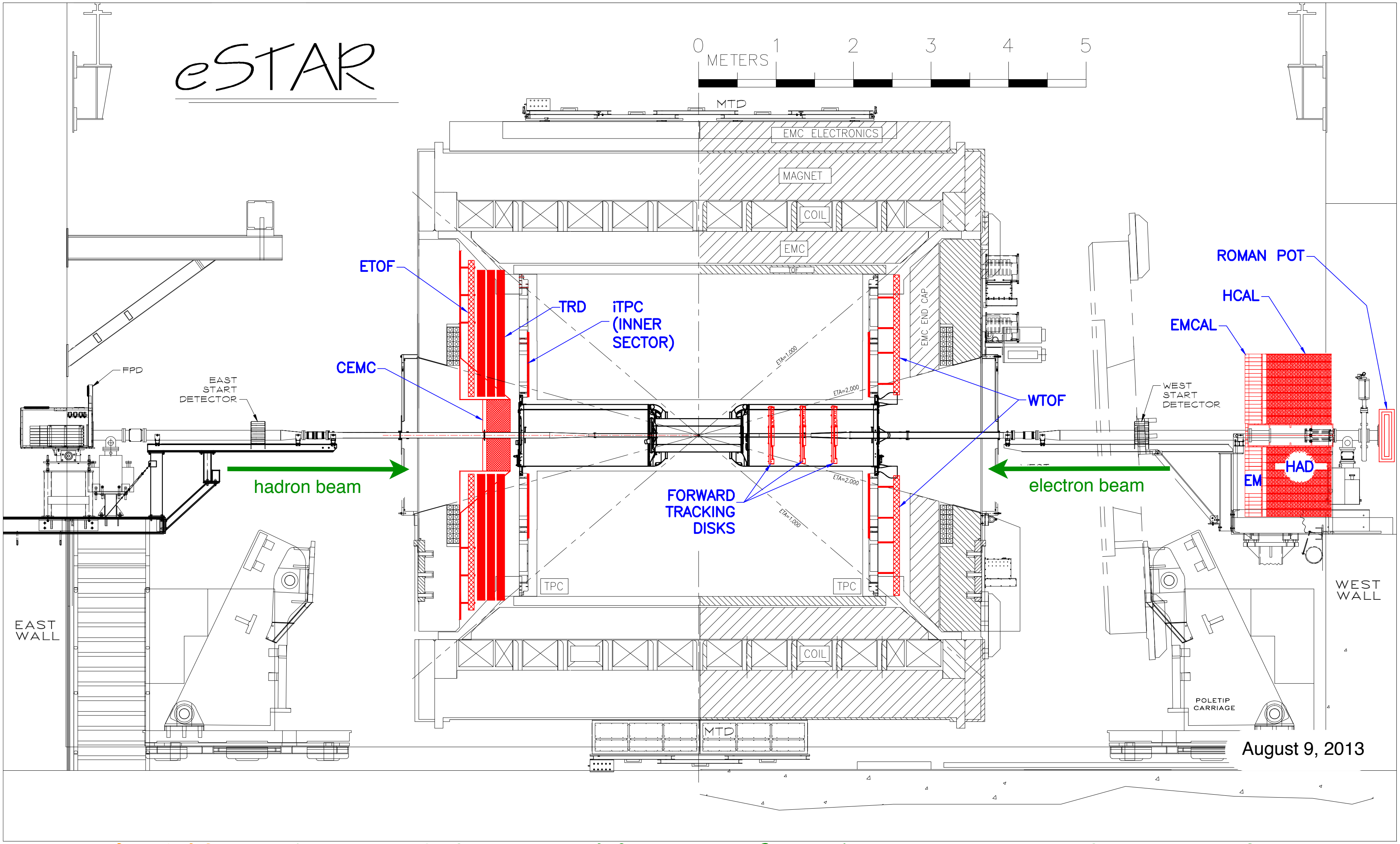
eSTAR - Initial Considerations

Electron identification, from ArXiV 1108.1713v2:



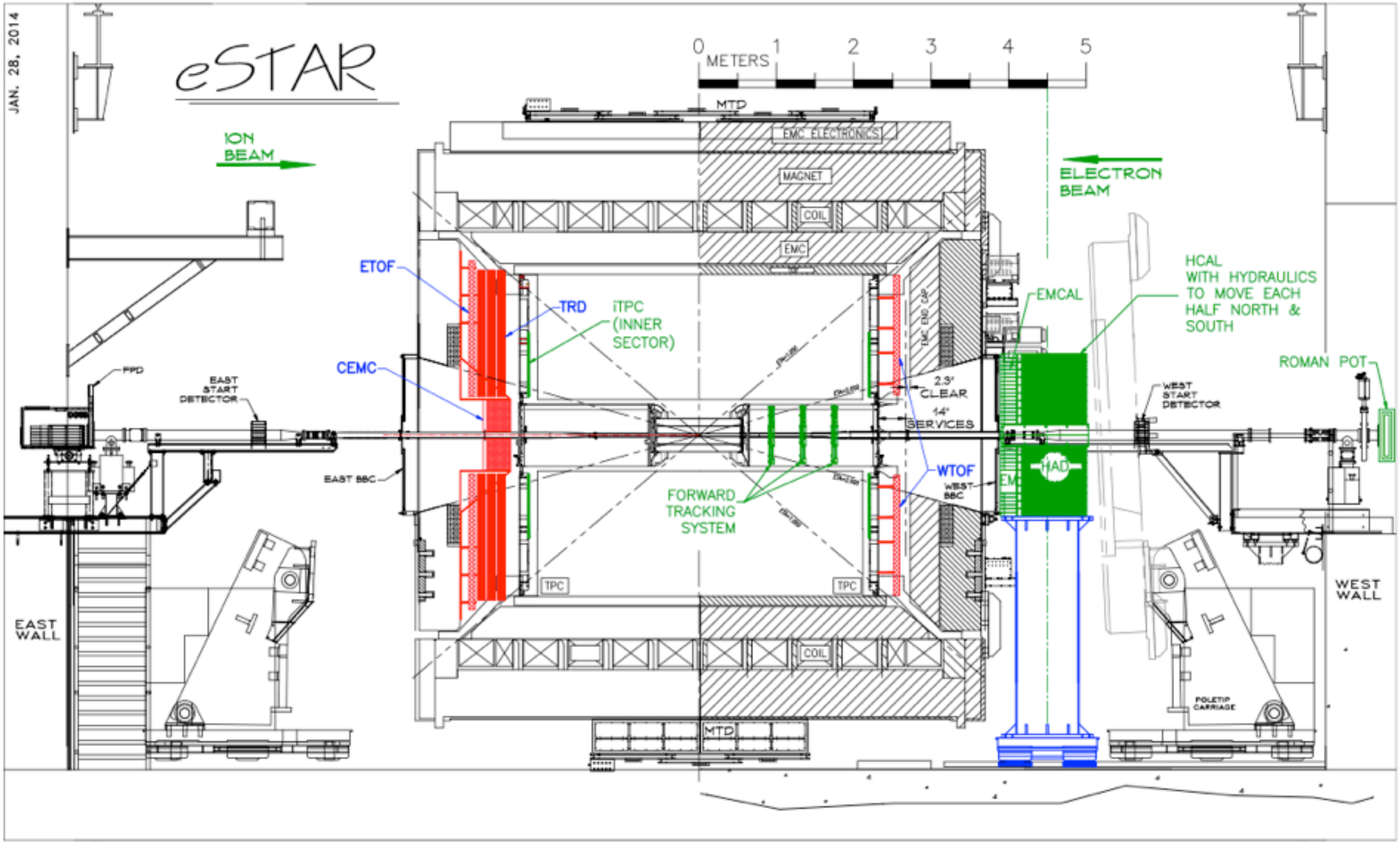
eSTAR - Concept

A modest evolution compared to the upgrade-plan outlined in the STAR Decadal Plan:



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

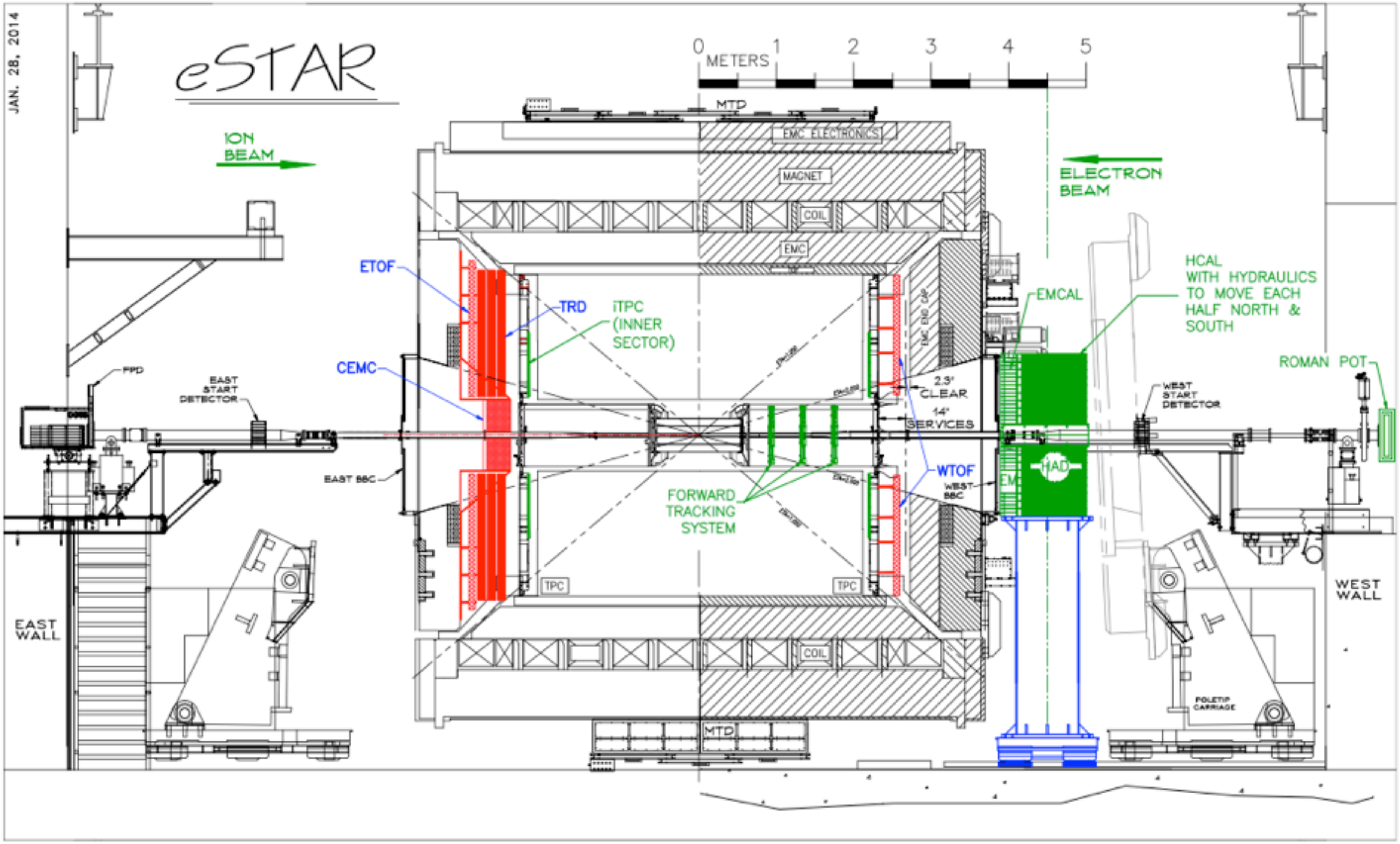


Rough "DNA": Forward Calorimeter(s), Roman Pots, Tracking essential to p+p, p+A,

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

Compactified.

eSTAR - Concept



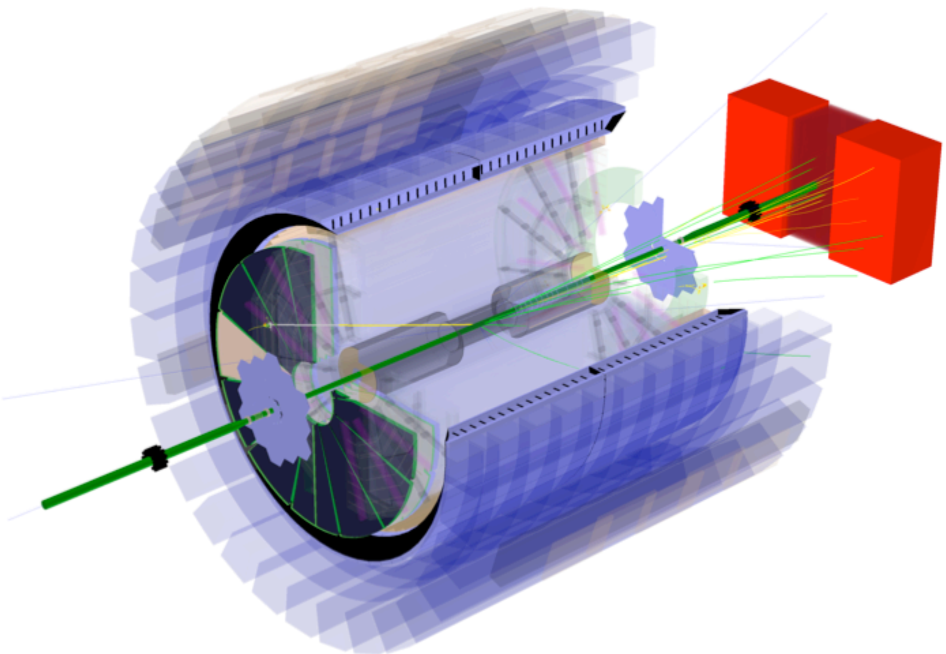
Simulations: a combination of GEANT3/4-based full response simulations and response parametrizations applied to event-generator outputs (Pythia, MILOU, Sartre, ...)

R&D: BNL-EIC R&D and STAR-specific R&D: CEMC, ETTIE, FCS, (FTS), iTPC

eSTAR - Concept and Intent

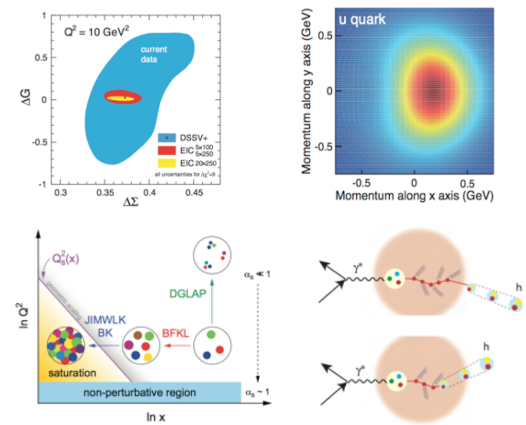
eSTAR: A Letter of Intent

The STAR Collaboration



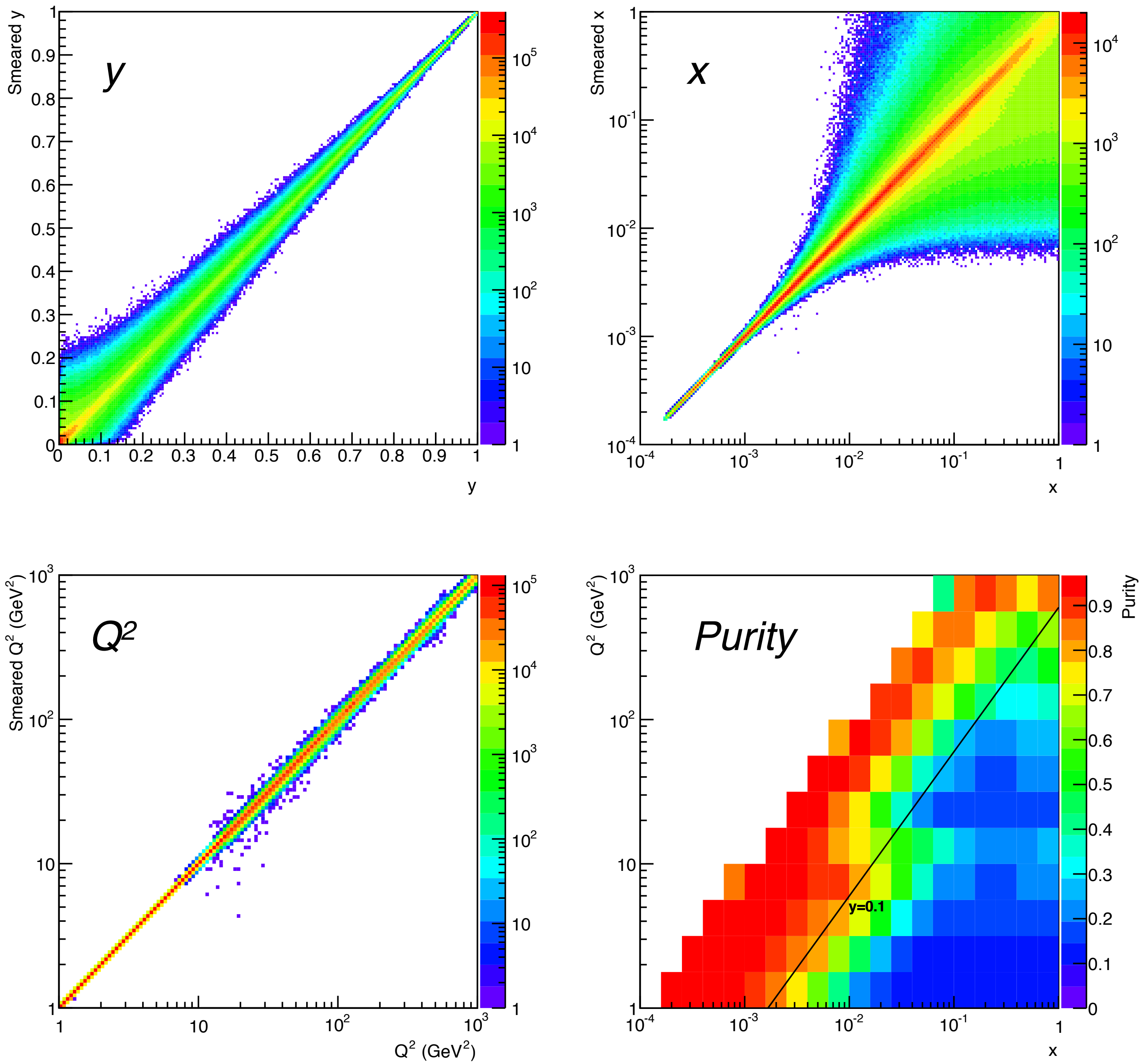
September 2013

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



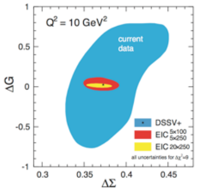
- *Initial quantitative assessment of capabilities,*
- *Backed by simulations and R&D*
- *Context: open collaboration with an instrument and a science-driven plan.*

eSTAR: A Letter of Intent - Scattered electron capability

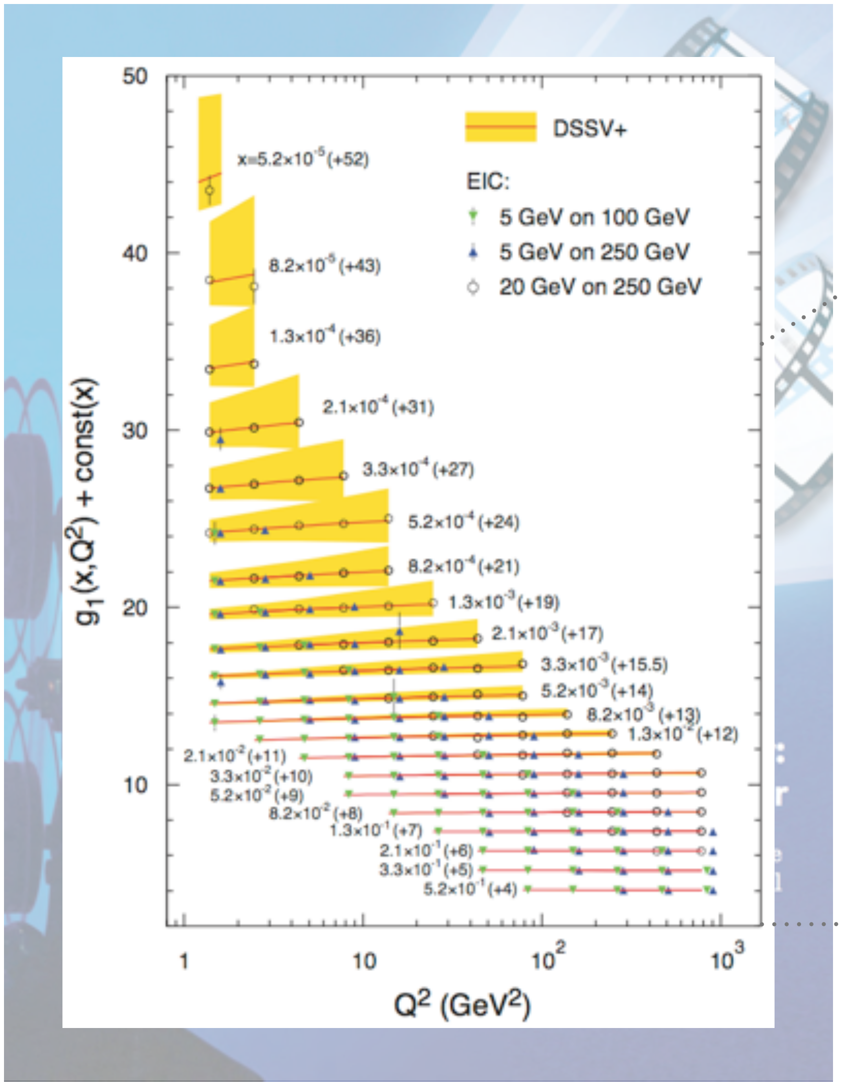


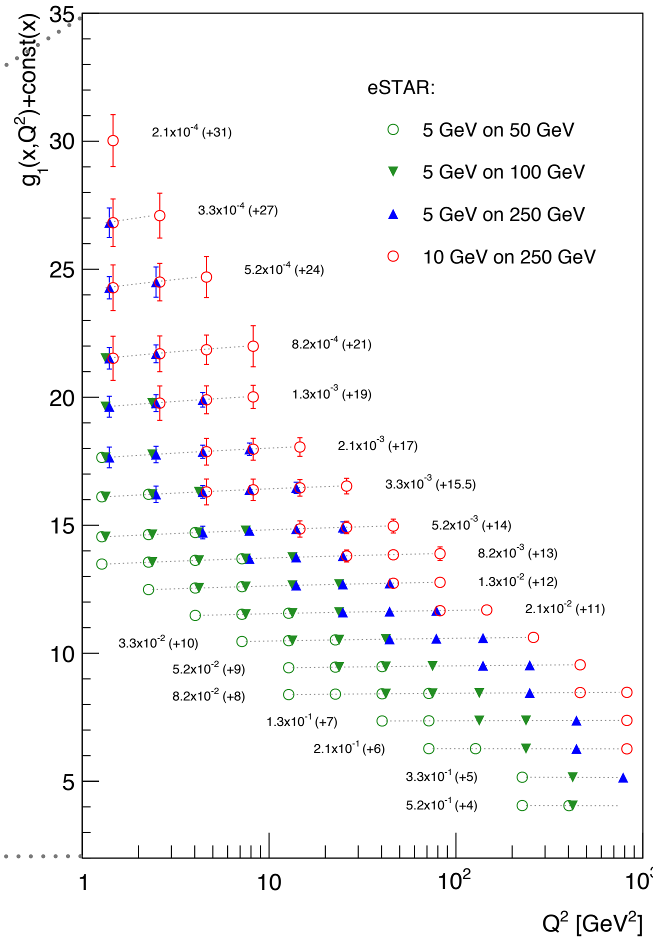
15 GeV electron beam energy + 100 GeV hadron beam energy

eSTAR: A Letter of Intent - Inclusive Measurements



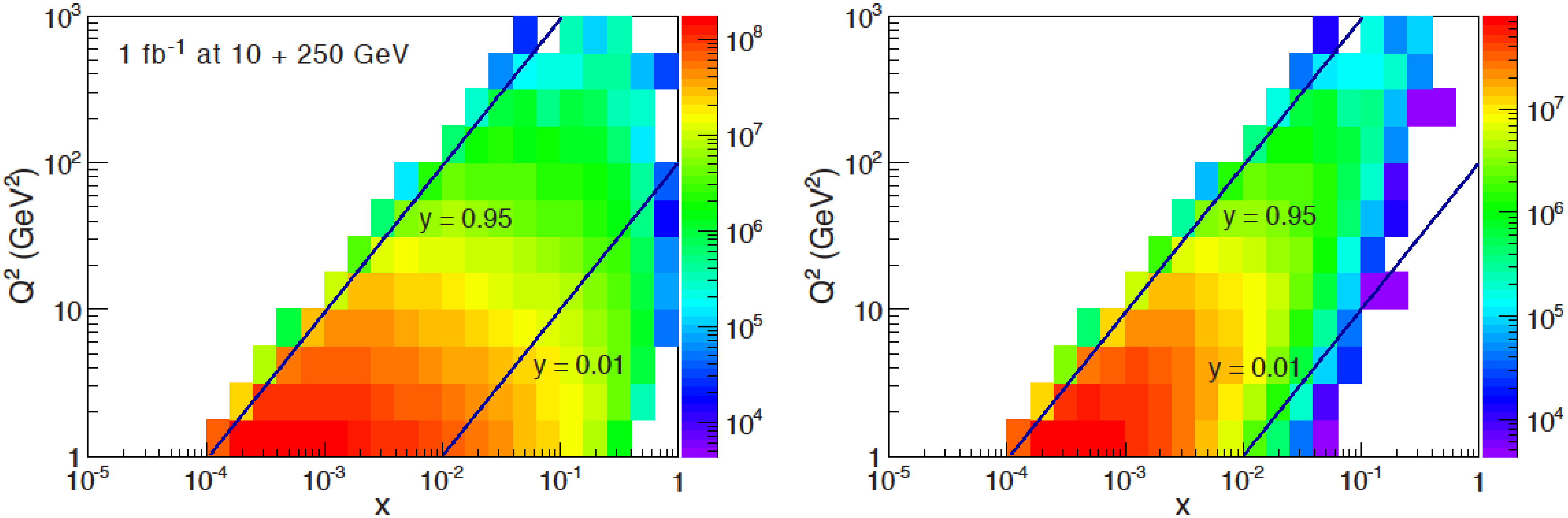
Full eRHIC, dedicated detector → Initial stage eRHIC, eSTAR





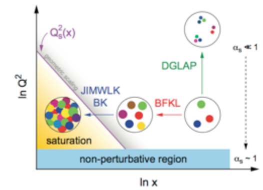
Significant measurement capability for the unpolarized and polarized inclusive structure functions.

eSTAR: A Letter of Intent - PID capability



generator level → eSTAR charged pion response

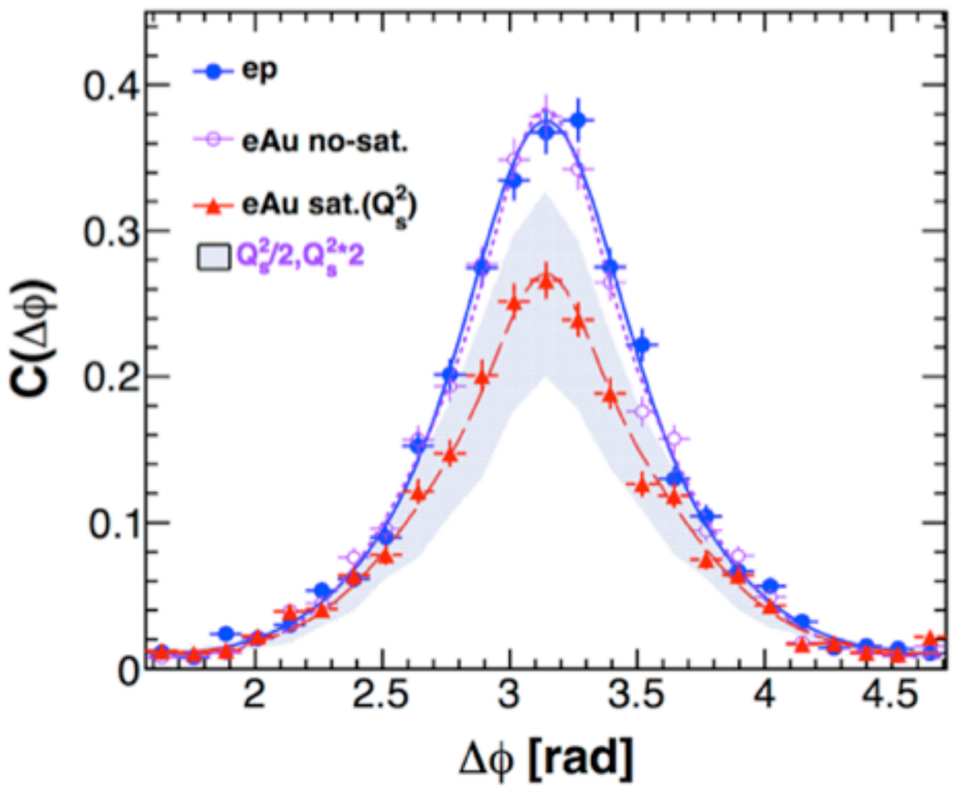
eSTAR: A Letter of Intent - SIDIS

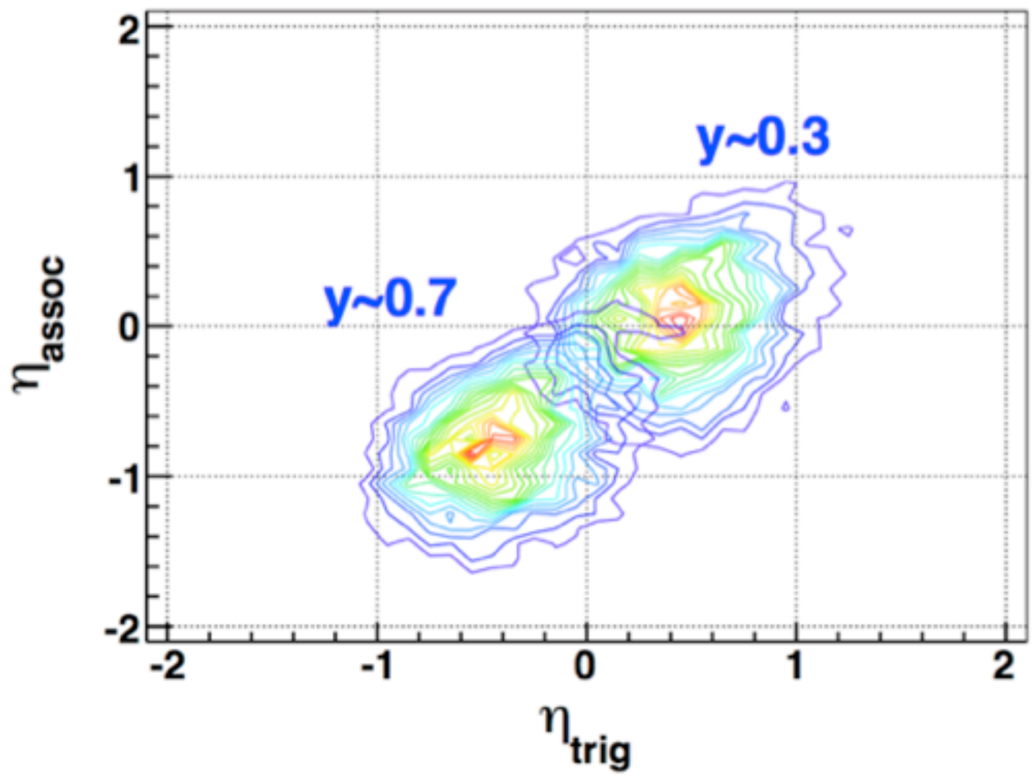


Azimuthal correlations in di-hadron (semi-inclusive deep-inelastic scattering) measurements,

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

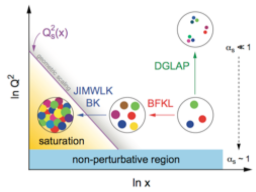
provide sensitivity to gluons and have been proposed as a robust probe of saturation:



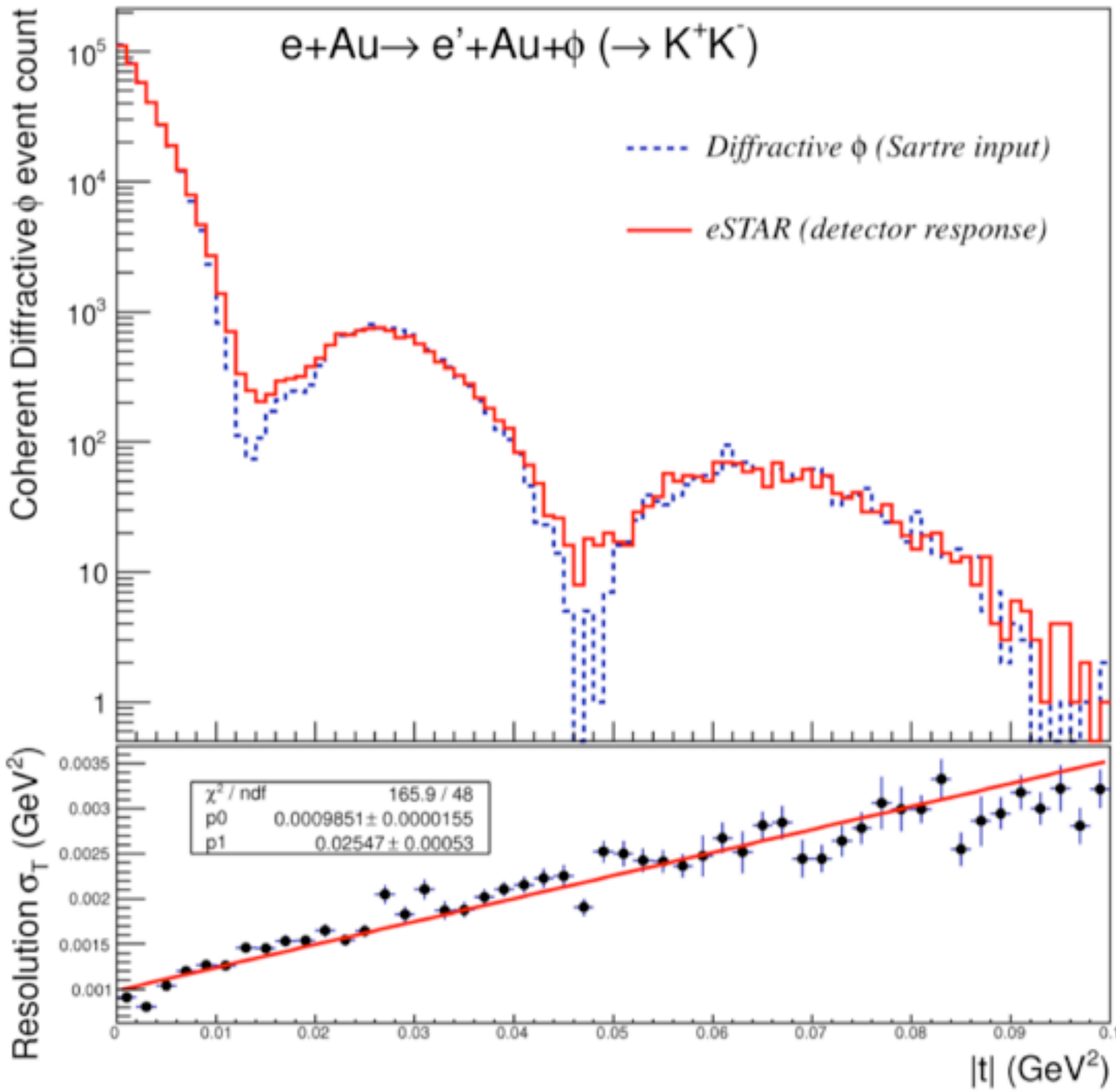


eSTAR projections for 10 GeV electrons scattering off 100 GeV/nucleon Au beams, 1 fb^{-1}.

eSTAR: A Letter of Intent - Exclusive VM

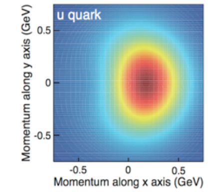


eSTAR projections for coherent diffractive production of phi-mesons

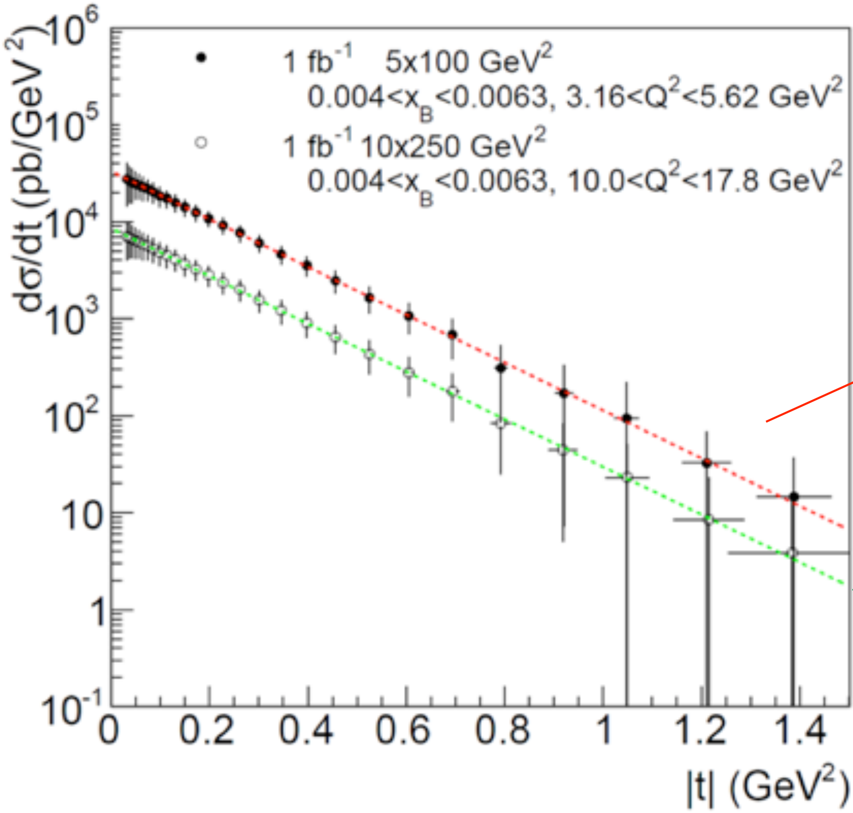


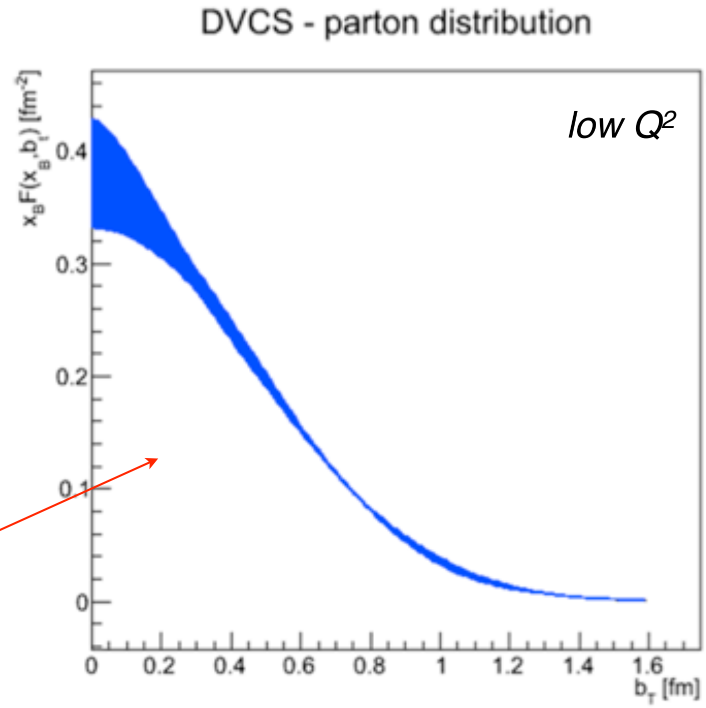
Plays well to STAR's mid-rapidity PID strengths, good resolution.

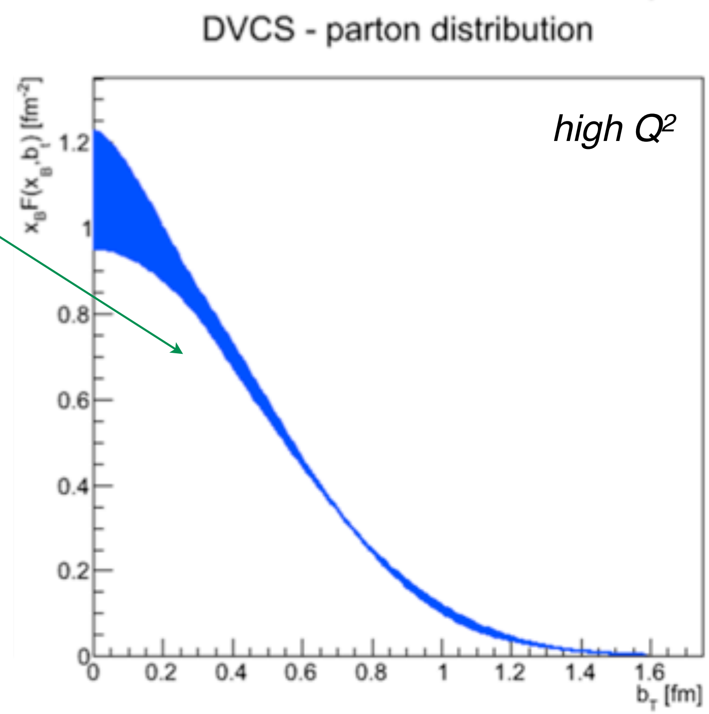
eSTAR: A Letter of Intent - DVCS



Imaging

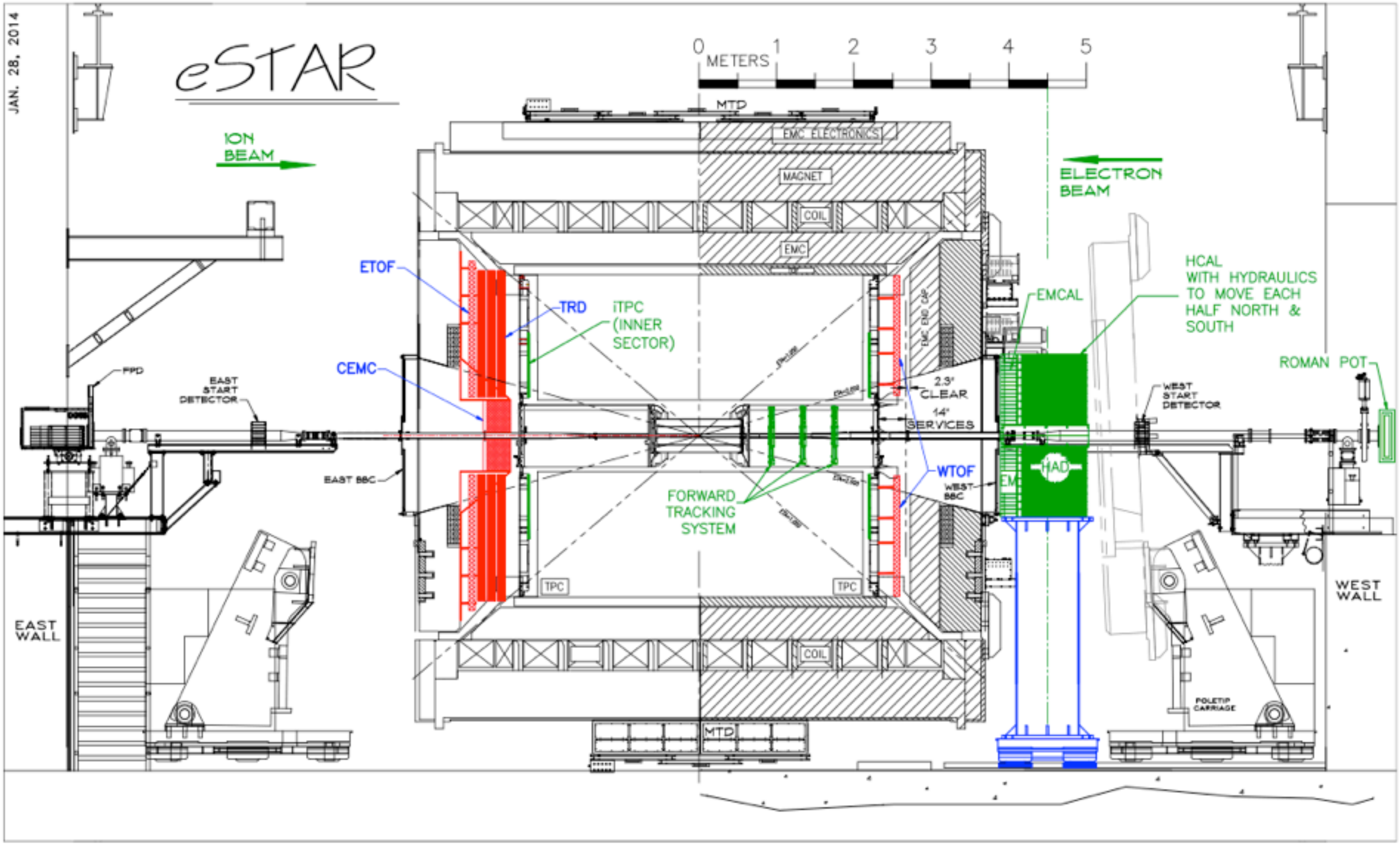






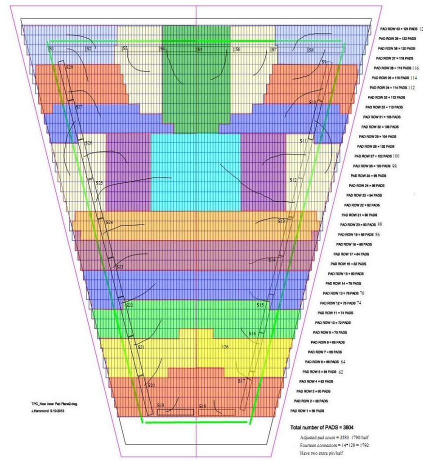
eSTAR projections for “DVCS”, Deeply-Virtual Compton Scattering / exclusive photon production, measurements

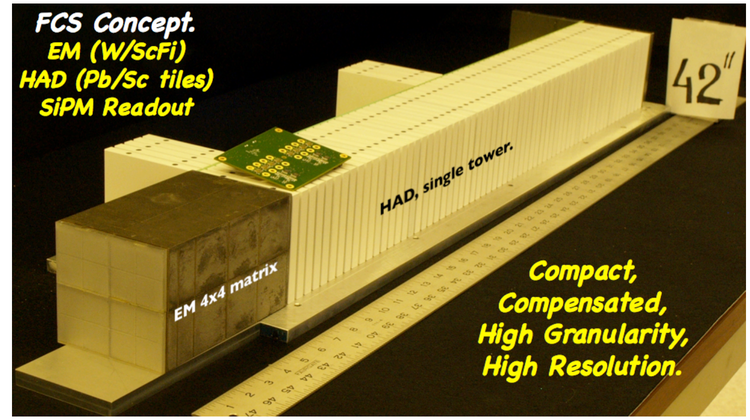
eSTAR - (selected) R&D



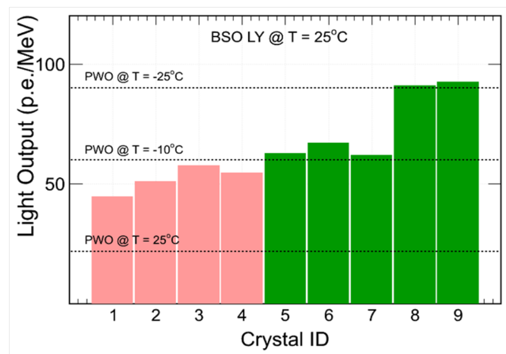
eSTAR - (selected) R&D

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

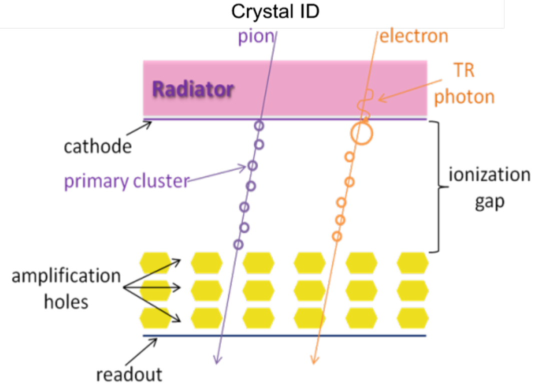


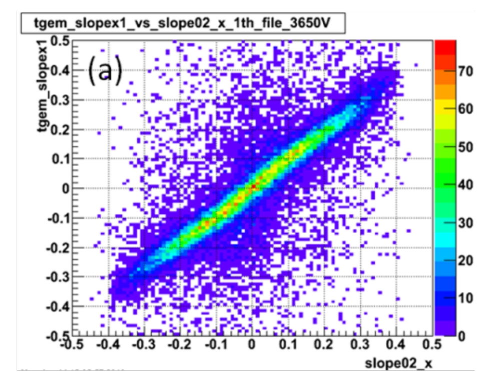


- *Forward Calorimeter System (FCS)*
  - *W-powder + Fiber*



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



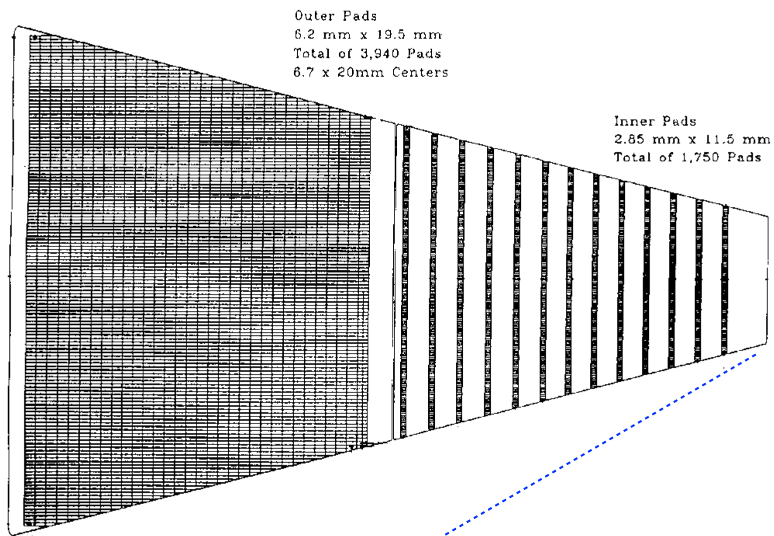


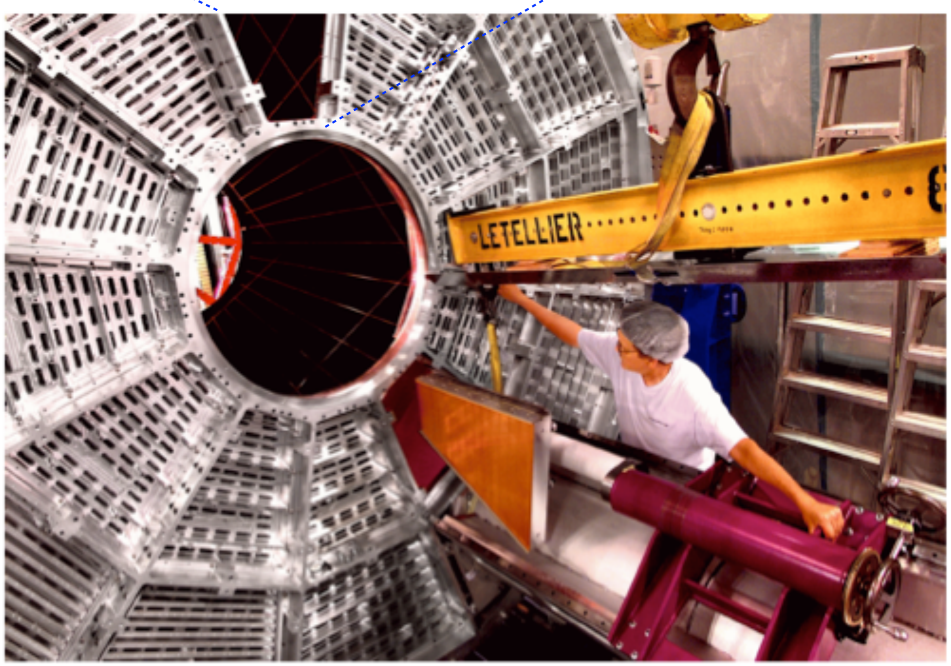
- *GEM based TRD.*

(e)STAR - iTPC Upgrade *c.f. talk by Jim Thomas*

Multi motivation, Beam-Energy Scan - physics case for phase II ⟶ iTPC

STAR





Increase inner pad channel density by a factor two or more,

Benefits most STAR physics:

- Eliminate the concern about issues related to wire aging,
- Increase pseudo-rapidity coverage by ~0.5 unit,
- Improve low-p_T acceptance,
- Improve dE/dx resolution for particle identification,

Bridges HI and spin goals,

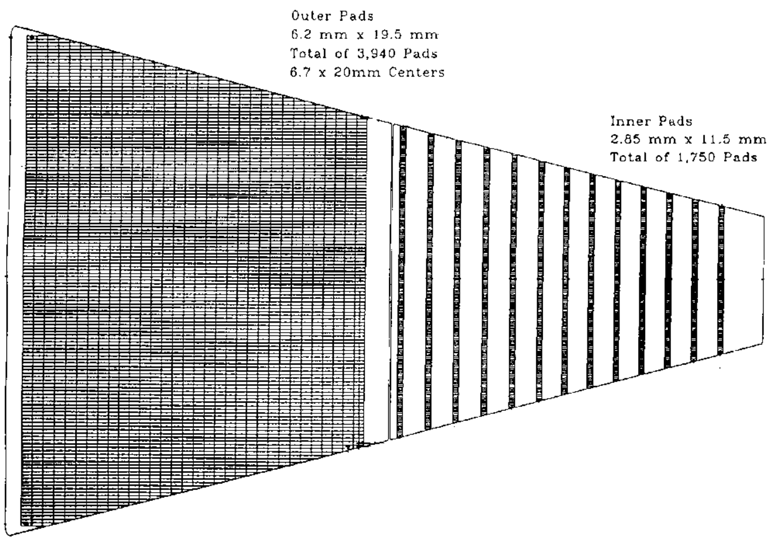
Status:

- many/most simulations in hand,
- MWPC (SDU/SINAP
- Mechanics (LBL/BNL)
- Electronics (BNL/ALICE)
- Timeline: 3 years, 2017, cost estimate: 5M$

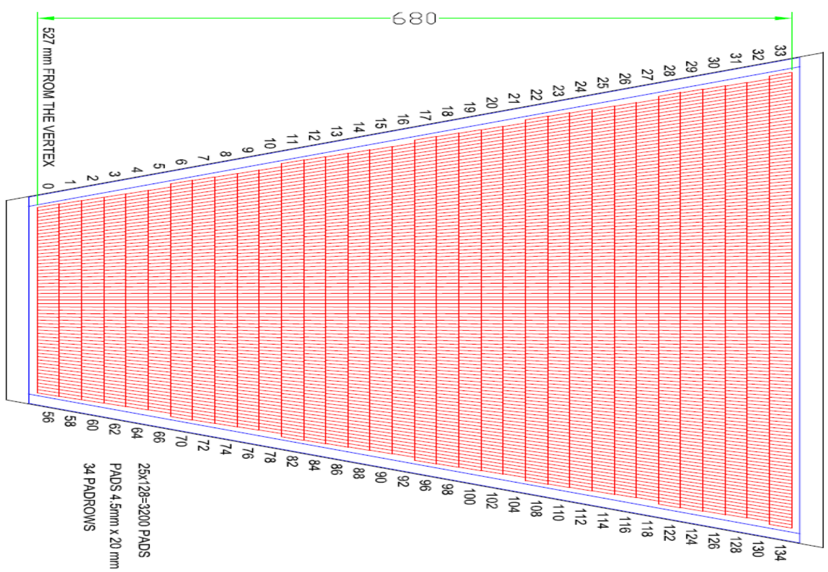
(e)STAR - iTPC Upgrade *c.f. talk by Jim Thomas*

Multi-motivation, Beam-Energy Scan - physics case for phase II ⟶ iTPC

STAR



ALICE



Increase inner pad channel density by a factor two or more,

Benefits most STAR physics:

- Eliminate the concern about issues related to wire aging,
- Increase pseudo-rapidity coverage by ~0.5 unit,
- Improve low-p_T acceptance,
- Improve dE/dx resolution for particle identification,

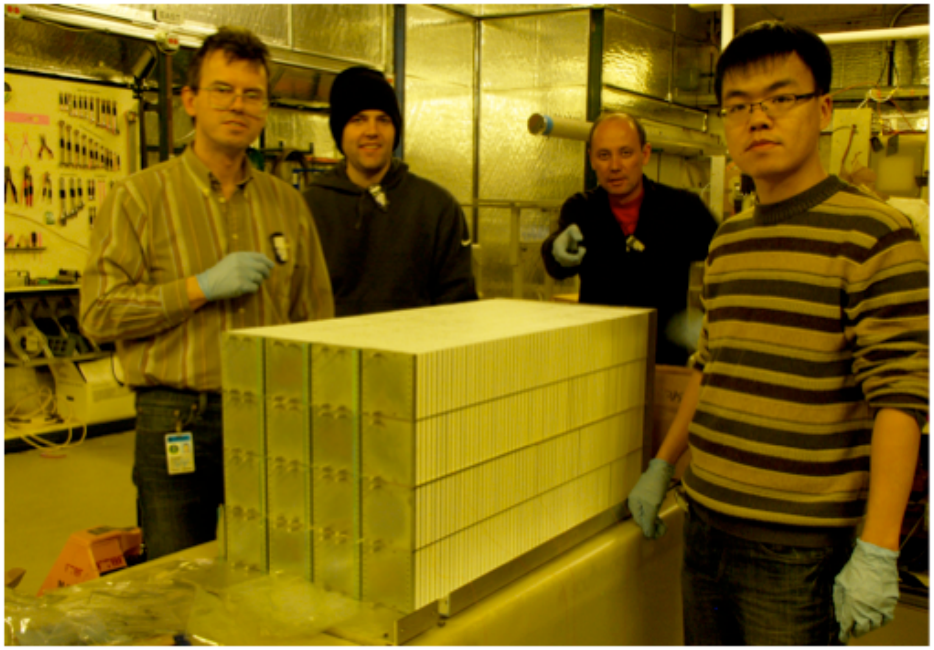
Bridges HI and spin goals,

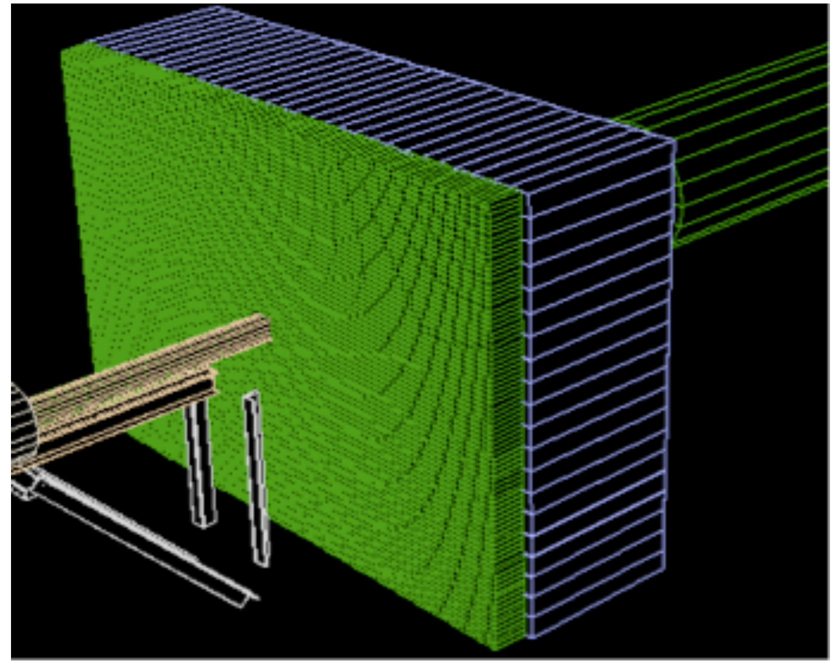
Status:

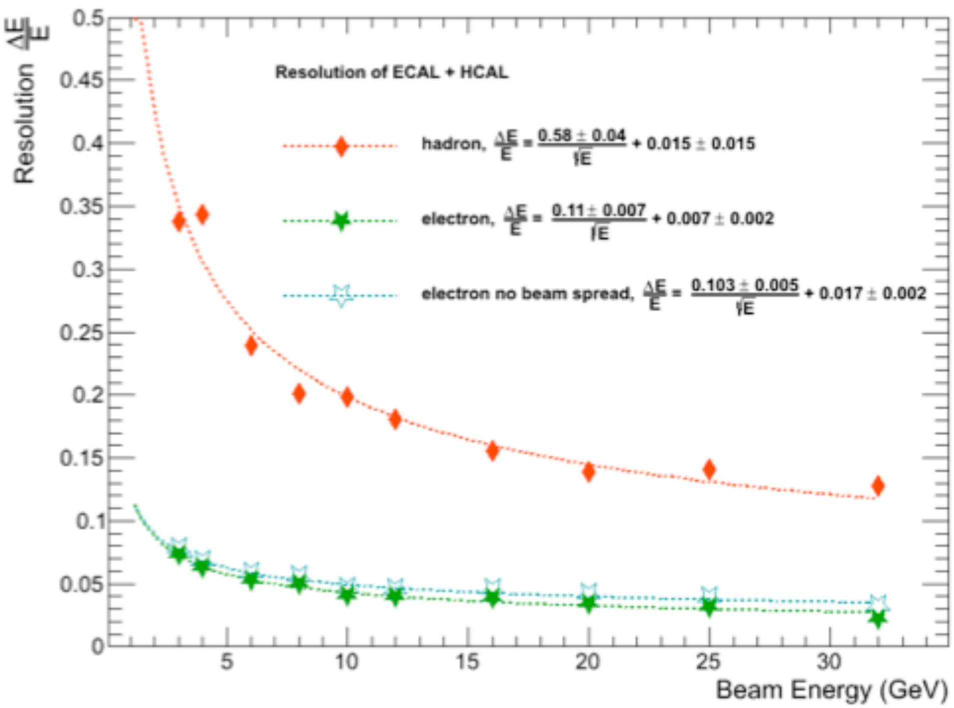
- many/most simulations in hand,
- MWPC (SDU/SINAP
- Mechanics (LBL/BNL)
- Electronics (BNL/ALICE)
- Timeline: 3 years, 2017, cost estimate: 5M$

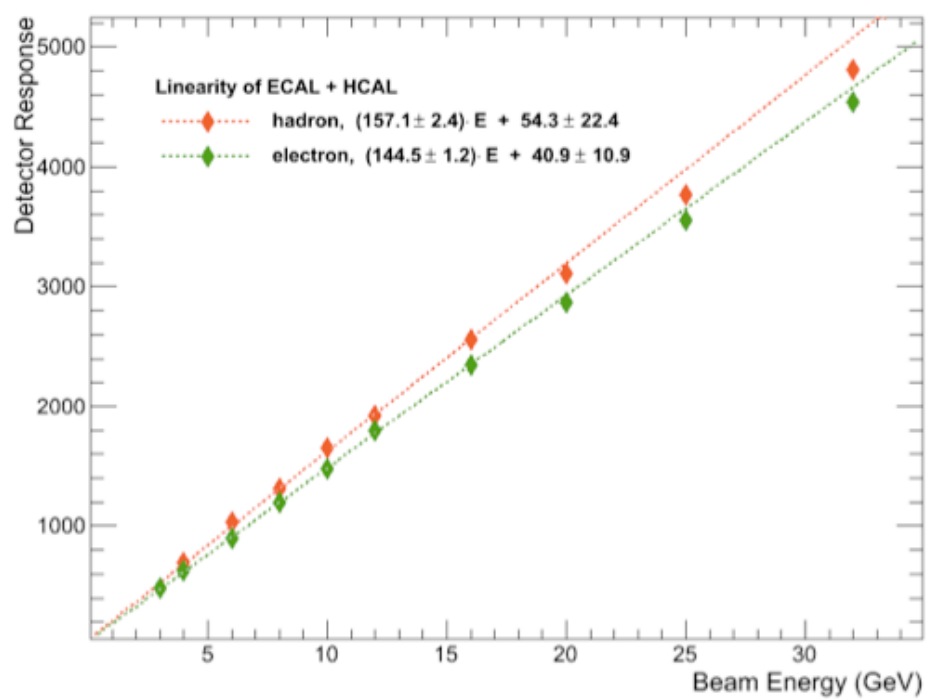
(e)STAR - FCS Upgrade

c.f. Oleg Tsai @ Calor 2014



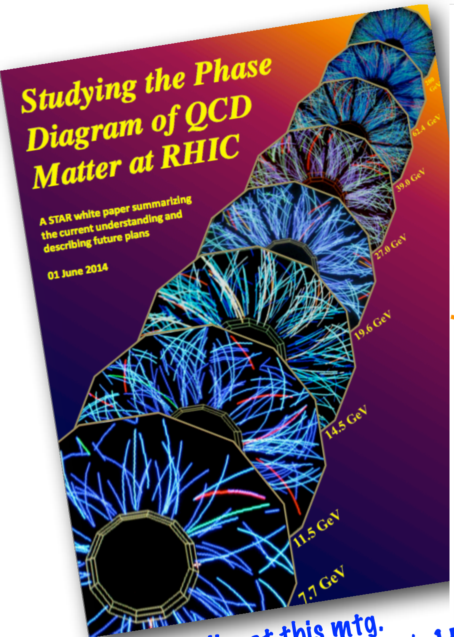


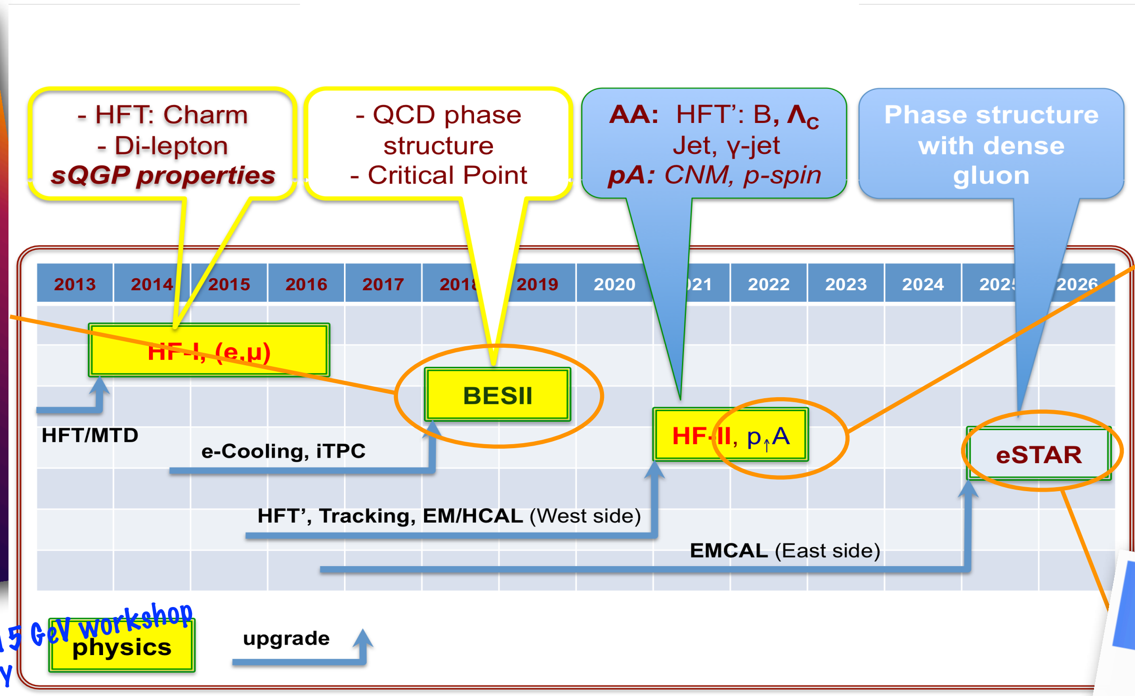


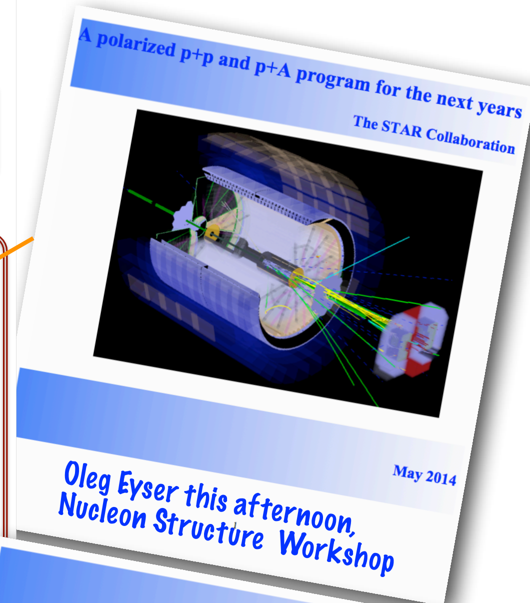


eSTAR - A Detector for eRHIC

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

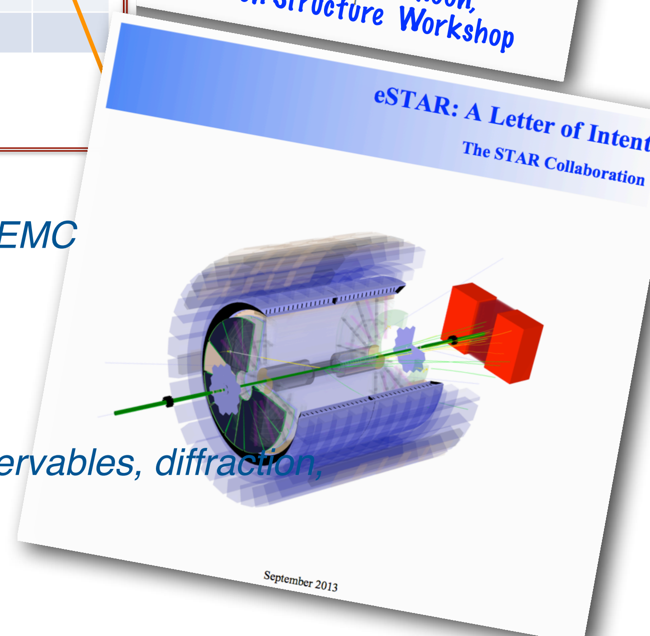






Oleg Eyser this afternoon, Nucleon Structure Workshop

Several talks at this mtg.
Evan Sangaline - tomorrow's 15 GeV workshop
Alex Schmah - Friday's plenary



- *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!*

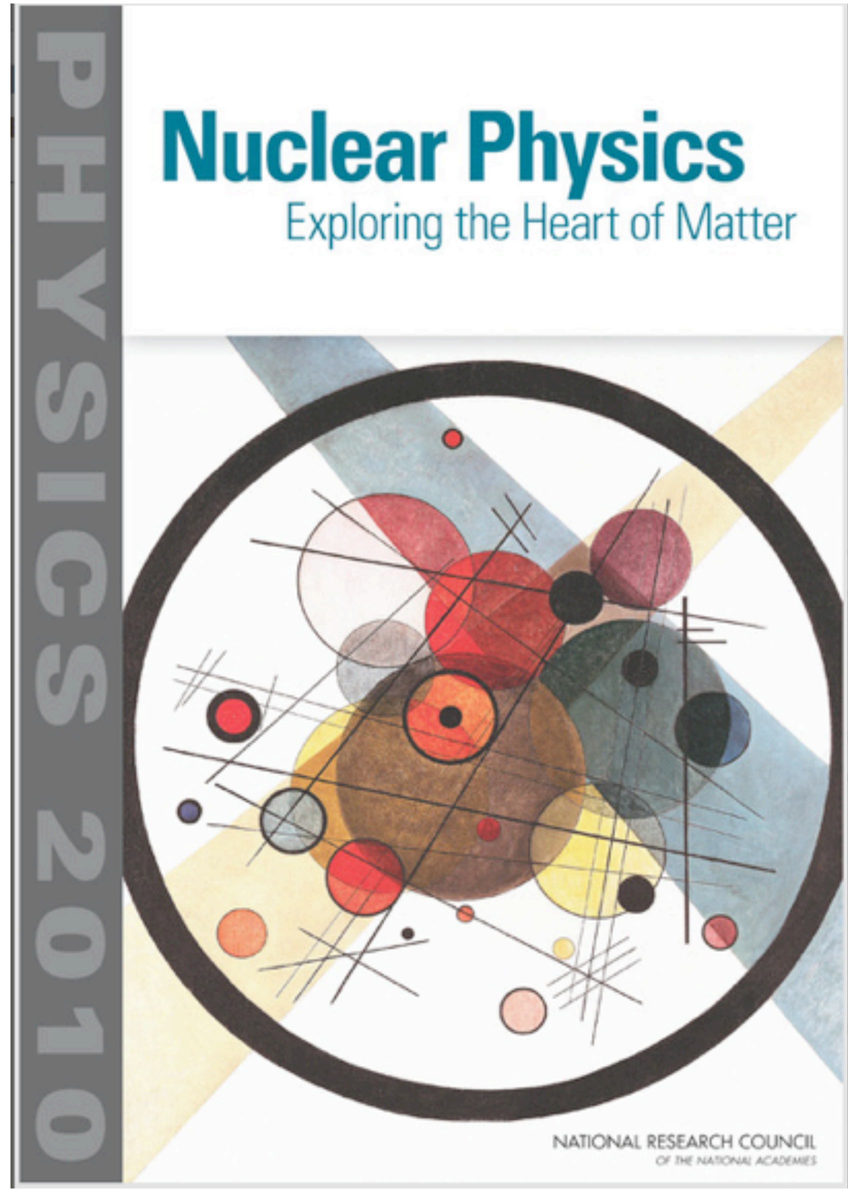
Page 236 - Recommendations,
Building a Foundation for the Future:

Without gluons, there would be no neutrons or protons and no atomic nuclei. Gluon properties in matter remain largely unexplored and mysterious.

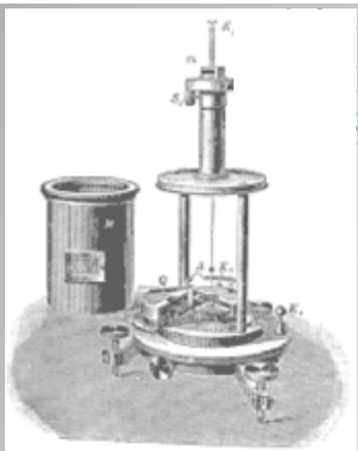
Finding: An upgrade to an existing accelerator facility that enables the colliding of nuclei and electrons at forefront energies would be unique for studying new aspects of quantum chromodynamics. In particular, such an upgrade would yield new information on the role of gluons in protons and nuclei. An electron-ion collider is currently under scrutiny as a possible future facility.

Recommendation: Investment in accelerator and detector research and development for an electron-ion collider should continue. The science opportunities and the requirements for such a facility should be carefully evaluated in the next Nuclear Science Long Range Plan.

No other facility finding or recommendation.



National Research Council. *Nuclear Physics: Exploring the Heart of Matter*. Washington, DC: The National Academies Press, 2013.



Concluding Remarks

QCD is, in many cases, still *far* from ab-initio calculations,

RHIC is a) a truly unique facility, b) online, and
c) a timely path to a polarized high-energy EIC,

STAR capabilities, with continued suitable upgrades:
- TPC inner-sectors,
- forward calorimetry,
- endcap TOF & TRD,
- crystal calorimeter,
- ...

match rather well to eRHIC with 5-15 GeV electron beams for inclusive, semi-inclusive, and exclusive / diffractive measurements - key measurements of the eRHIC science program,

Active groups, opportunities abound to take part, and lots of work ahead!