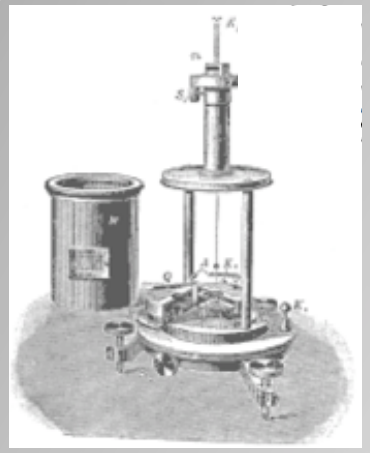
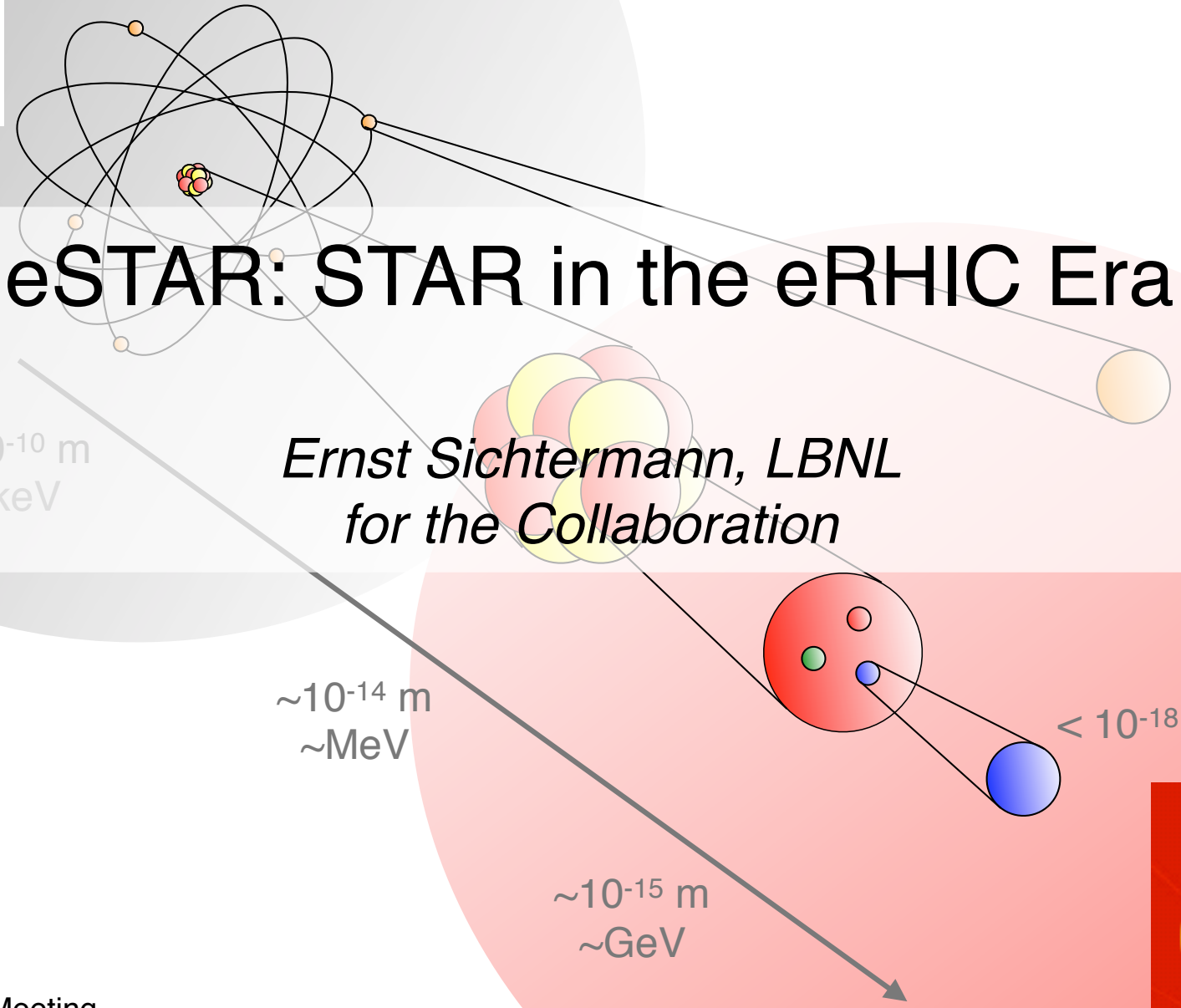


eSTAR: STAR in the eRHIC Era

Ernst Sichtermann, LBNL
for the Collaboration



RHIC & AGS Users' Meeting
BNL, June 25, 2013

Why eRHIC?

What is the role of gluons and of gluon self-interactions in nucleons and nuclei?

Measurements: inclusive DIS structure functions,
semi-inclusive DIS,
diffraction

What is the internal landscape of the nucleon?
- its combined spatial and momentum structure?
- its spin structure?

Measurements: polarized DIS,
transverse-momentum dependent distributions
exclusive reactions, vector-meson production, DVCS

What governs the transition of from quarks and gluons to hadrons? Propagation through matter?

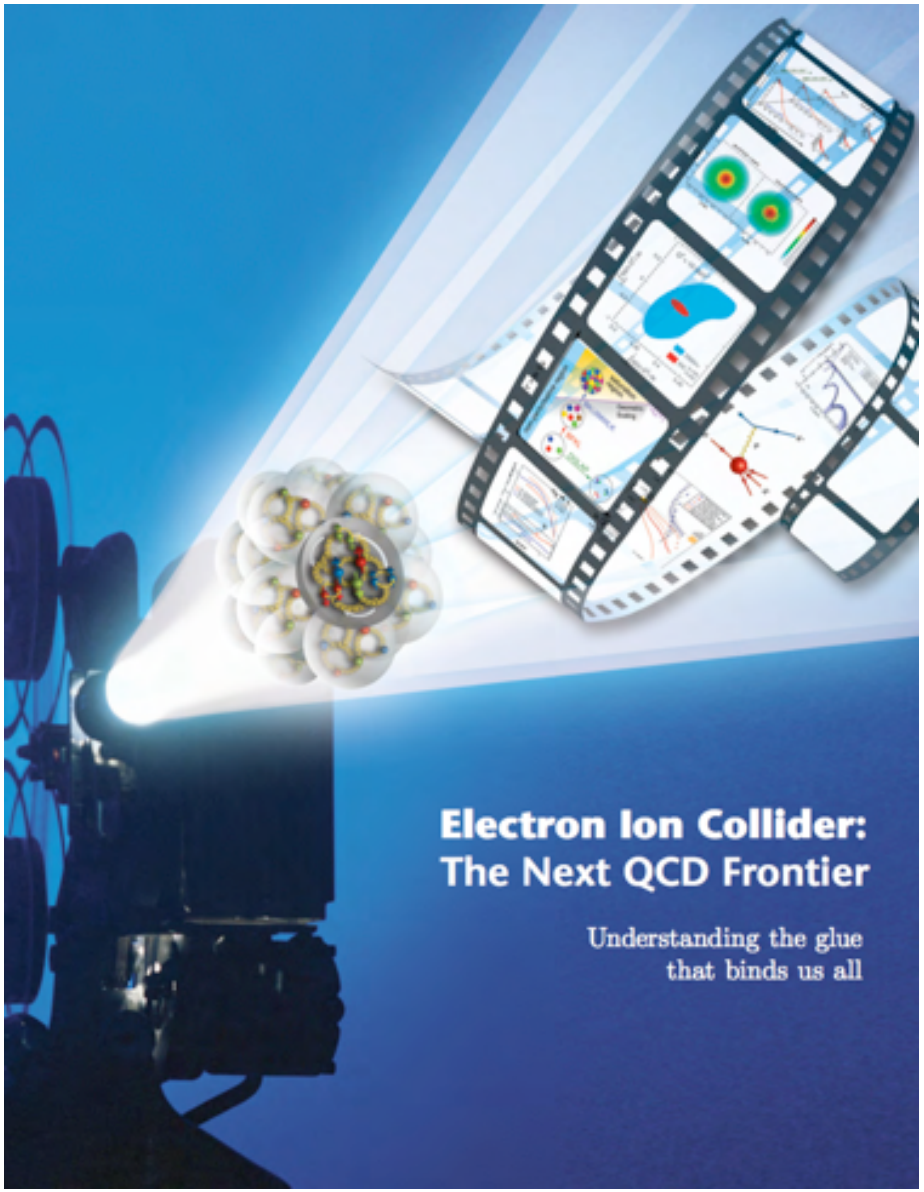
Measurements: (ratios of) semi-inclusive DIS cross sections, jets

Well-developed Science Case, most recently via EIC community White-paper

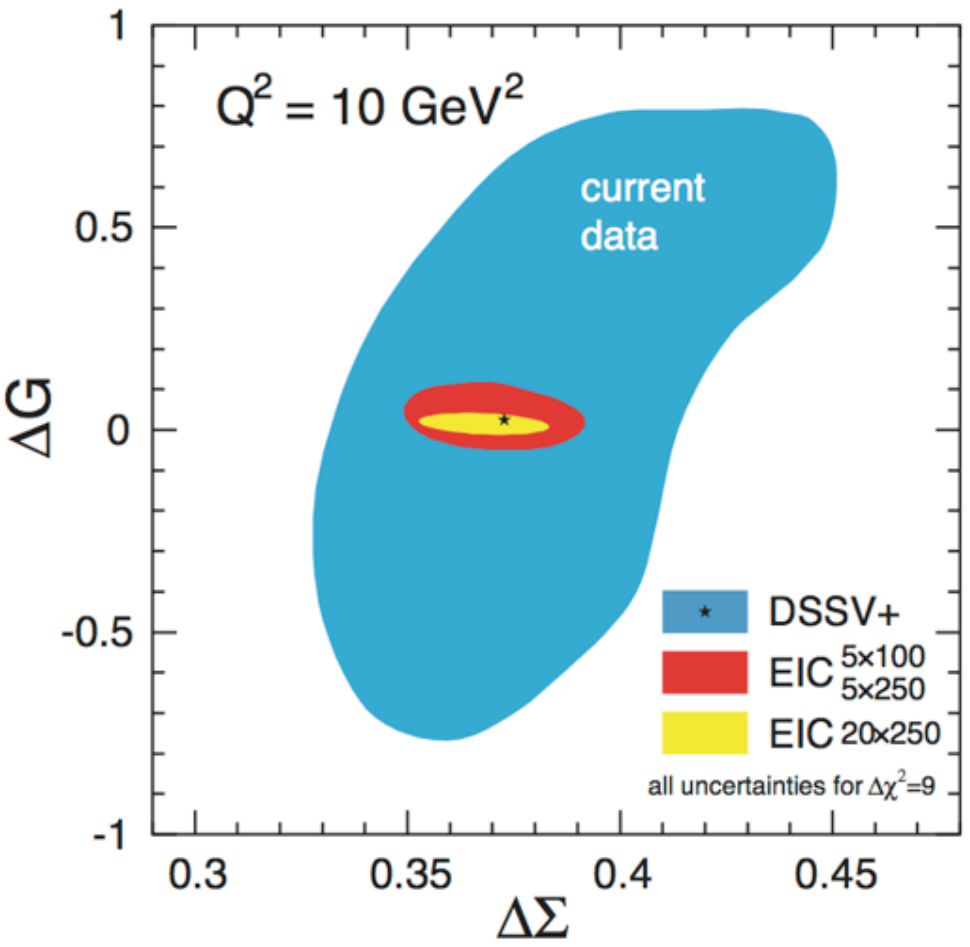
New measurements: e.g. di-hadron correlations, electroweak structure functions.

EIC - Science Case

ArXiv:1212.17010



One of the science highlights:



definitive insight in nucleon spin.

Separate talk(s), e.g. Matt Lamont's in this session, just before the break.

Needs for eRHIC

Viable e + (p,A) beam collisions, polarized and unpolarized,

See e.g. the preceding talk by Vadim Ptitsyn.

Viable collaborations and instruments to observe, analyze, and publish.

Staging? Investigate (im-)possibilities.

STAR - Decadal Plan

Steve Vigdor's charge to Barbara Jacak, Nu Xu, all (December 2009):

1) ... summary of ongoing upgrades

2) ... compelling science ... RHIC A+A, p+p, d+Au ... requiring upgrades

3) ... prioritized list of major upgrades ...

4) Any plans or interest your Collaboration has in adapting your detector or detector subsystems (or detector R&D) to study electron-nucleon and electron-ion collisions with an eventual eRHIC upgrade. This is relevant only near the end of the decade addressed here, but will be important for planning purposes. (We may well be forced by financial or environmental considerations, even for a first MeRHIC stage, to consider options in which acceleration of the electron beam is carried out around the RHIC tunnel, requiring some scheme for getting an electron beamline through or around PHENIX and STAR. So it's worth considering if there is some way you could make use of the e-p and e-A collisions if we provided them.)

5) ... future of collaboration ...

eSTAR - LoI

Berndt Mueller'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.

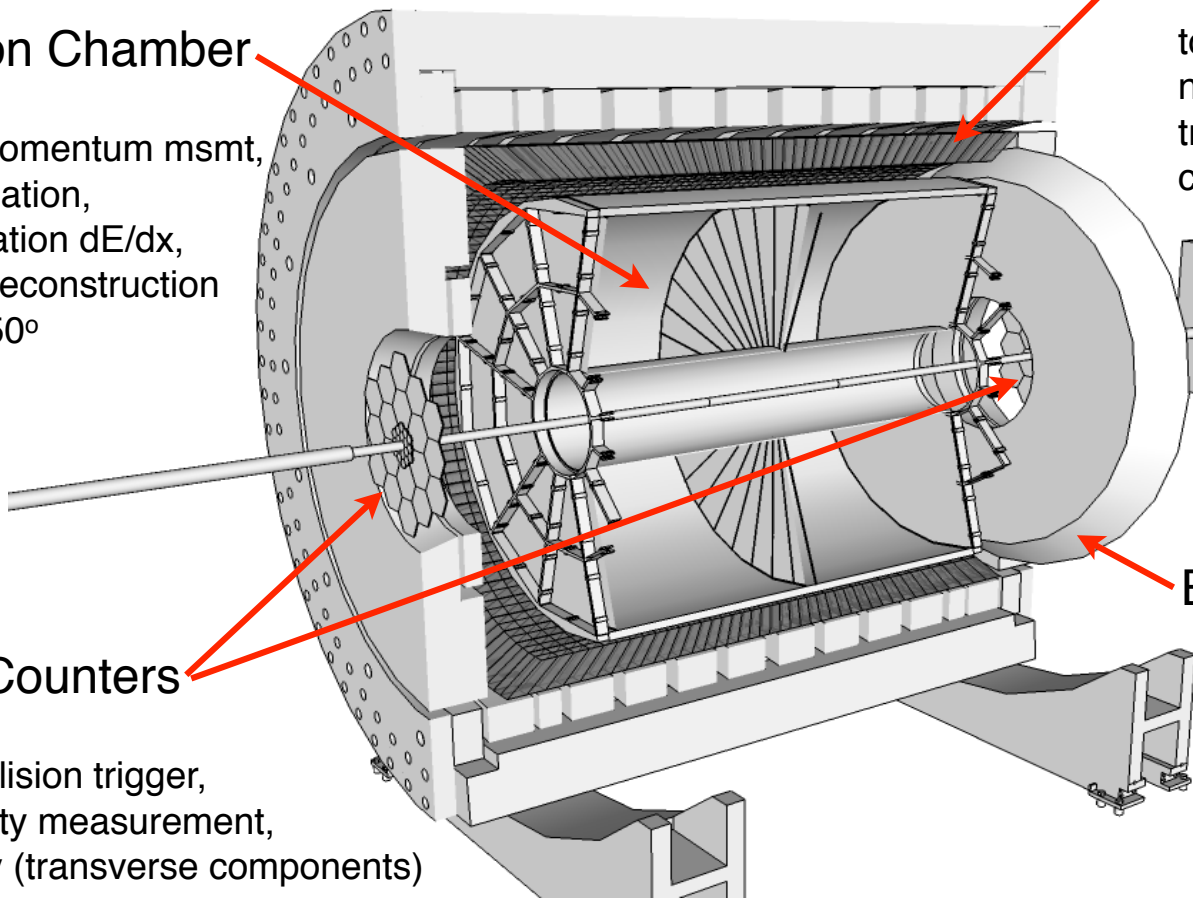
Therefore, the PHENIX and STAR Collaborations are now being asked to consider their role in a transition from RHIC to eRHIC on this time scale, and to provide specific plans (i.e. Letters of Intent) to upgrade/reconfigure the detectors from their present form to first-generation eRHIC detectors. These Letters of Intent (LoI) will be an important part of BNL's strategic planning as we move forwards towards the next Nuclear Physics Long Range Plan. These ...

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 (255 GeV for p and 100 GeV/nucleon for Au), and 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.

... should be submitted by September 30, 2013 (!)

STAR - Solenoidal Tracker at RHIC

Nucl. Instrum. Meth. A499, 624, 2003



Barrel E.M. Calorimeter

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

Time Projection Chamber

charged track momentum msmt,
charge determination,
particle identification dE/dx,
collision vertex reconstruction
coverage 30^{o}-150^{o}

Forward Meson Spectr.

Endcap E.M. Calorimeter

towers and SMD.
neutral e.m. energy measurement,
trigger (towers, patches of towers)
coverage 15^{o}-40^{o}

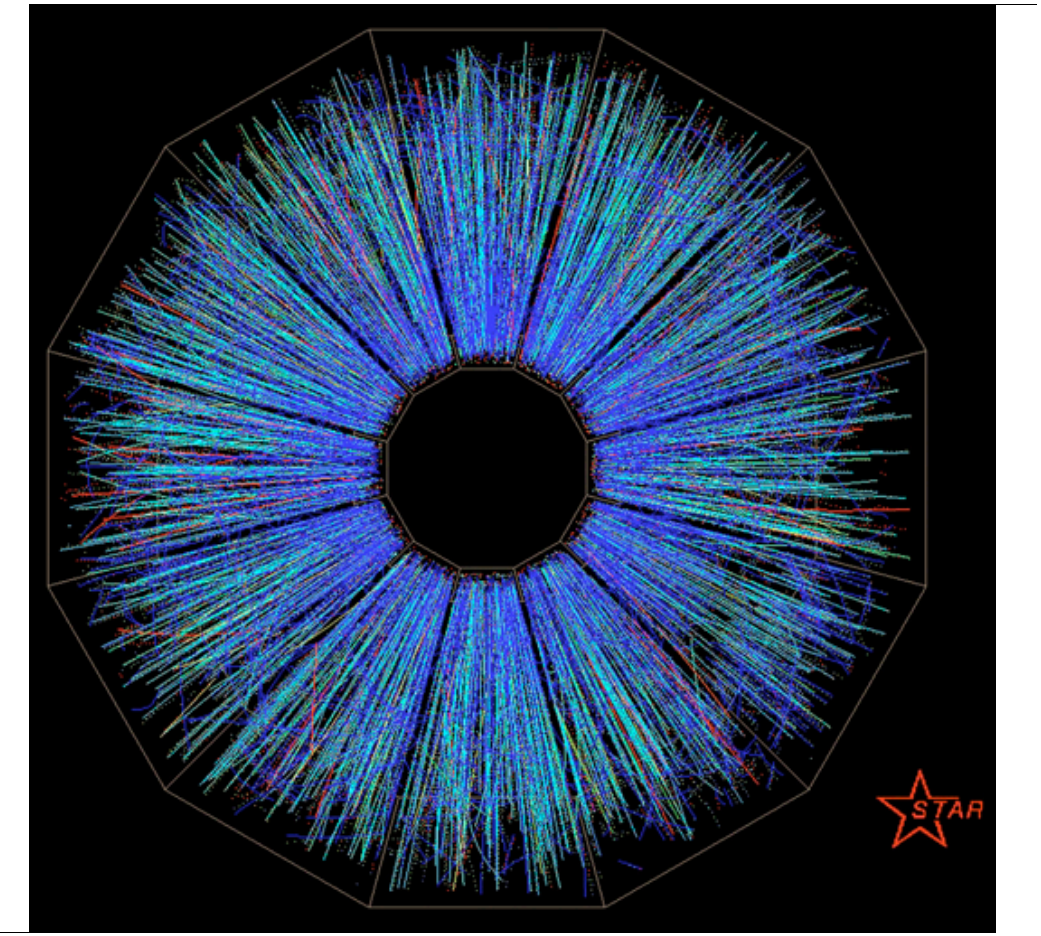
Beam-Beam Counters

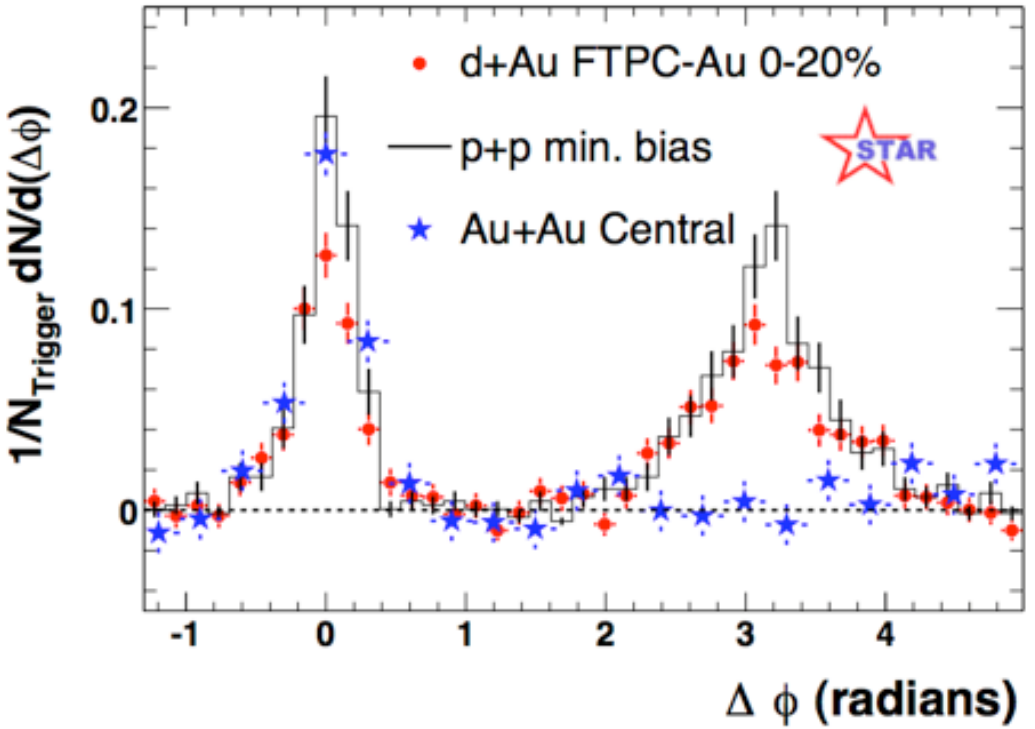
proton beam collision trigger,
relative luminosity measurement,
local polarimetry (transverse components)

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 (ongoing),
Roman Pot system, Forward Calorimeter System, ...

STAR - Today



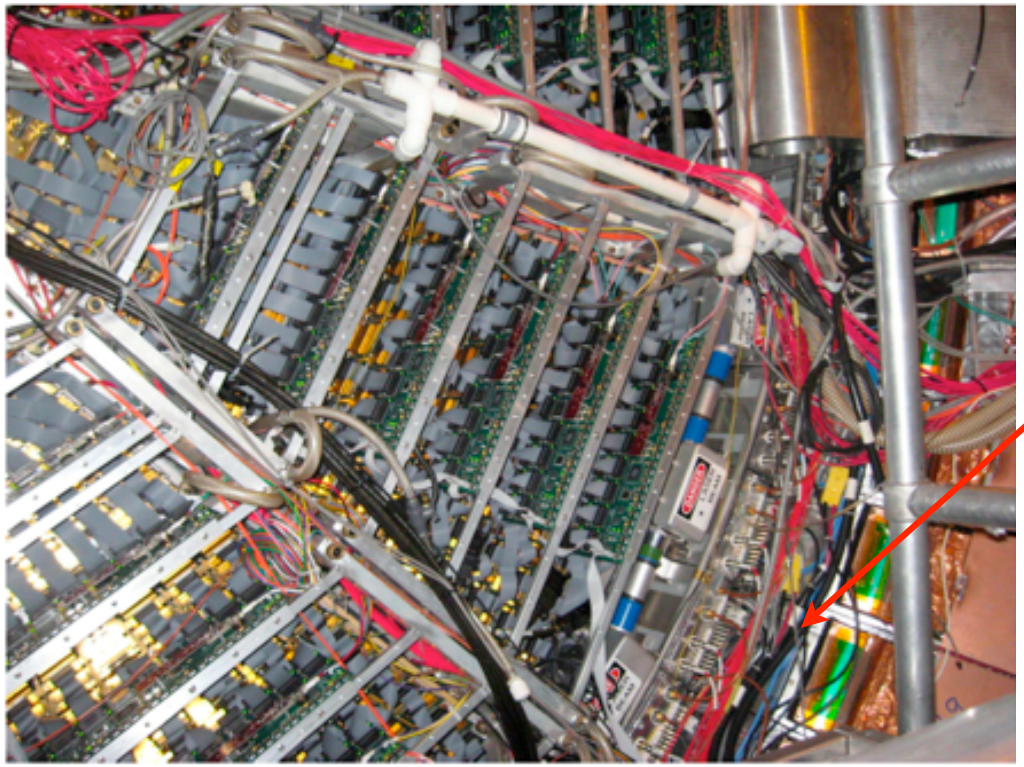


J. Adams et al., Phys.Rev.Lett.92:052302,2004,
J. Adams et al., Nucl.Phys.A757:102,2005.

Capability to measure correlations,

Versatility in *symmetric* p+p, d+Au, Au+Au collisions spanning $\sqrt{s}$ = 7.7 - 500 GeV.

STAR - Today



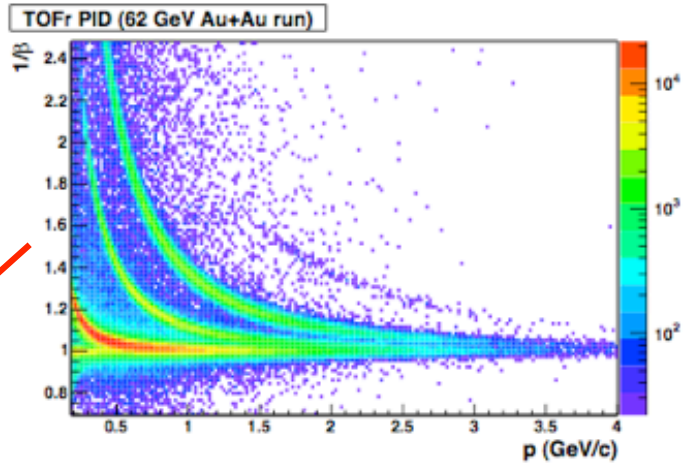


Fig. 1. $1/\beta$ vs. momentum for pions, kaons and (anti-)protons from TOFr at 62.4 GeV Au+Au collisions. The separation between pions and kaons ((anti-)protons) is achieved to $p_T \sim 1.6$ (3.0) GeV/c..

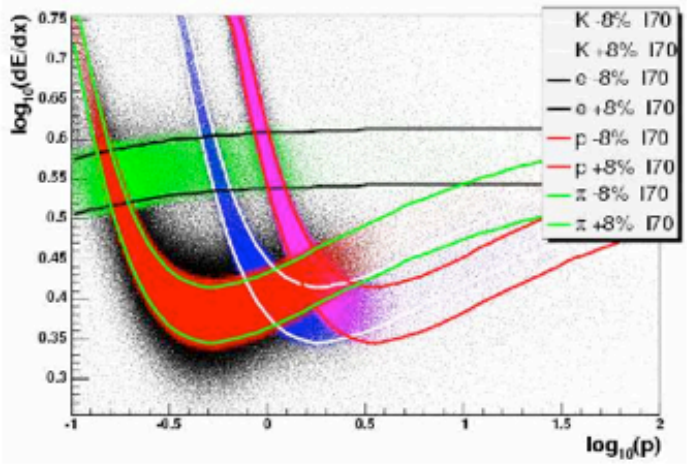


Fig. 2. Distribution of $log_{10}(dE/dx)$ as a function of $log_{10}(p)$ for electrons, pions, Kaons and (anti-)protons. The units of dE/dx and momentum (p) are keV/cm and GeV/c, respectively. The color bands denote within $\pm 1\sigma$ the dE/dx resolution. *I70* means Bichsel's prediction for 30% truncated dE/dx mean.

Mid-rapidity Particle Identification capability:

dE/dx in TPC and flight-time with ToF,

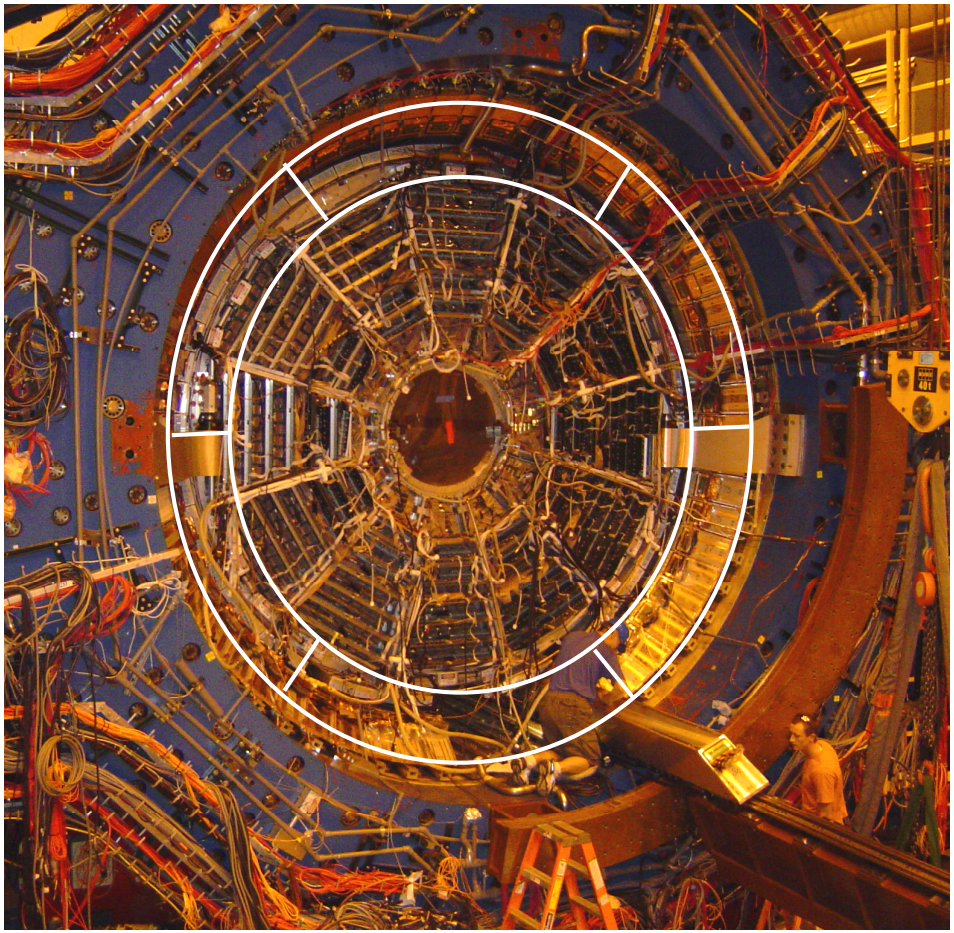
And soon:

displaced vertices - Heavy Flavor Tracker

muons - Muon Telescope Detector

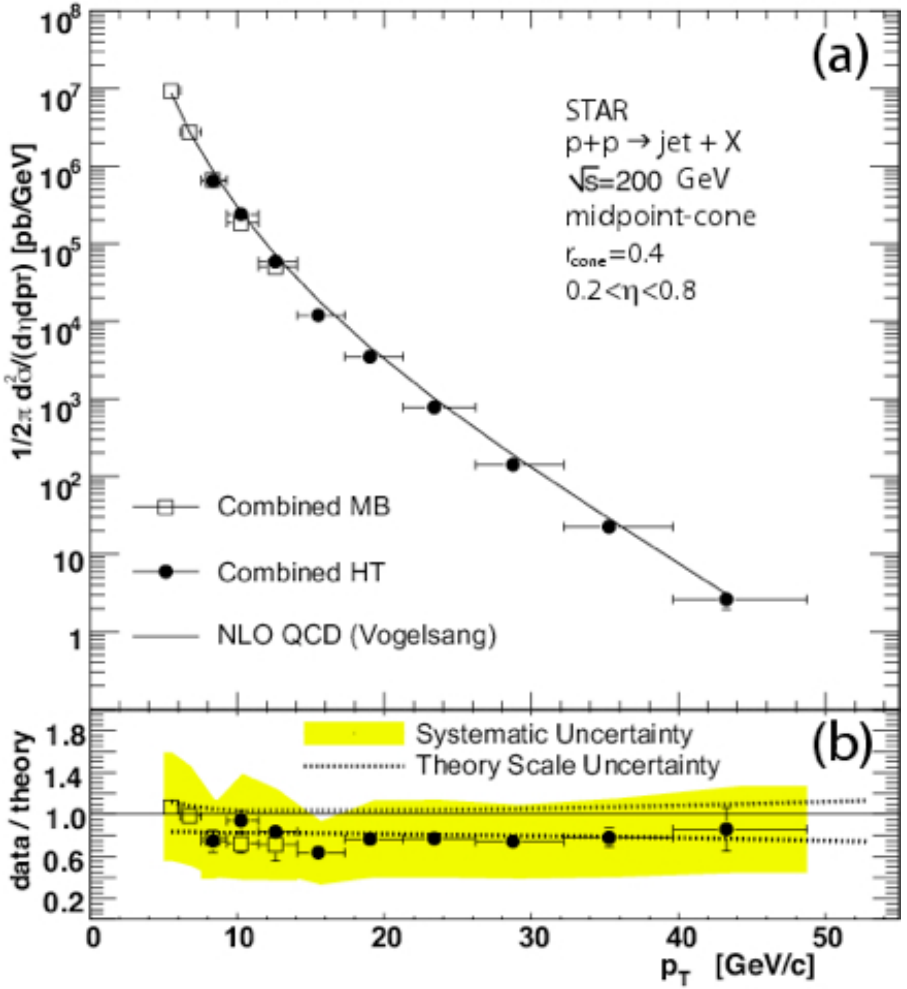
STAR: M. Shao et al, Nucl.Instrum.Meth.A558:419-429,2006.

STAR - Today



TPC: - charged track measurement
over 2+ units in pseudo-rapidity

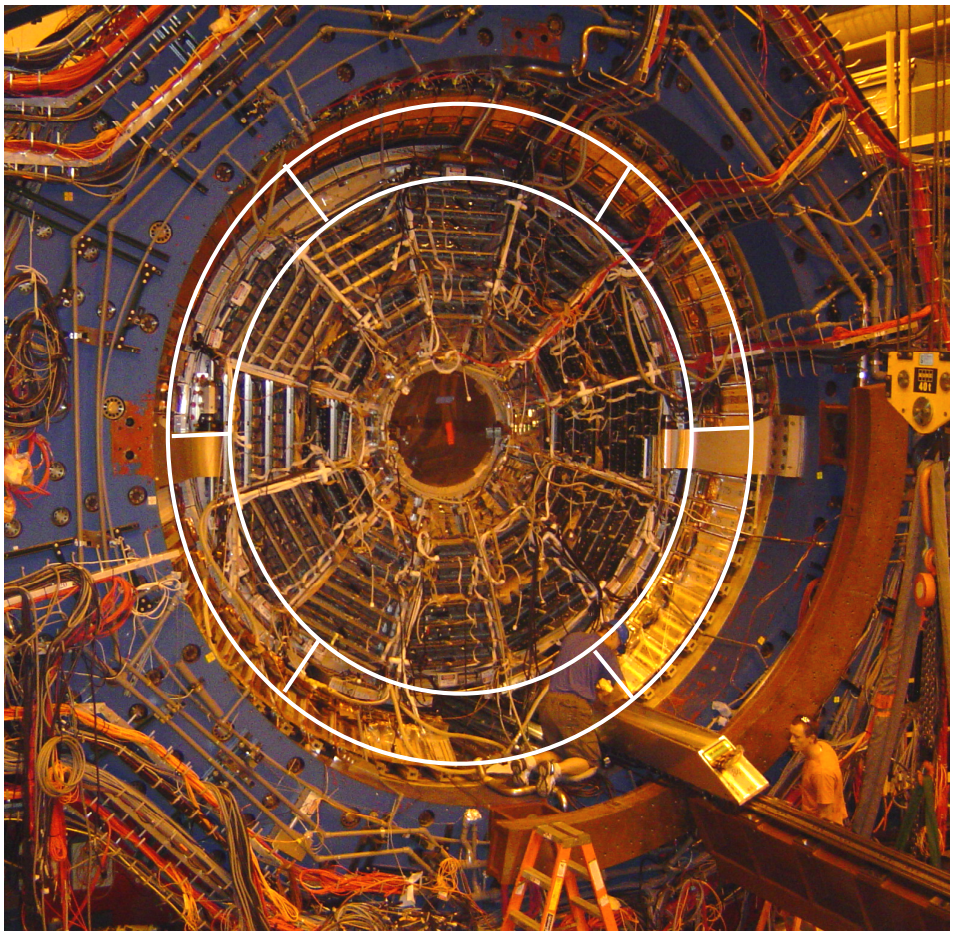
EMCs: - neutral energy measurement
over an even wider range,
- triggering



Phys. Rev. Lett. 97, 252001 (2006)

Jet capability.

STAR - Today



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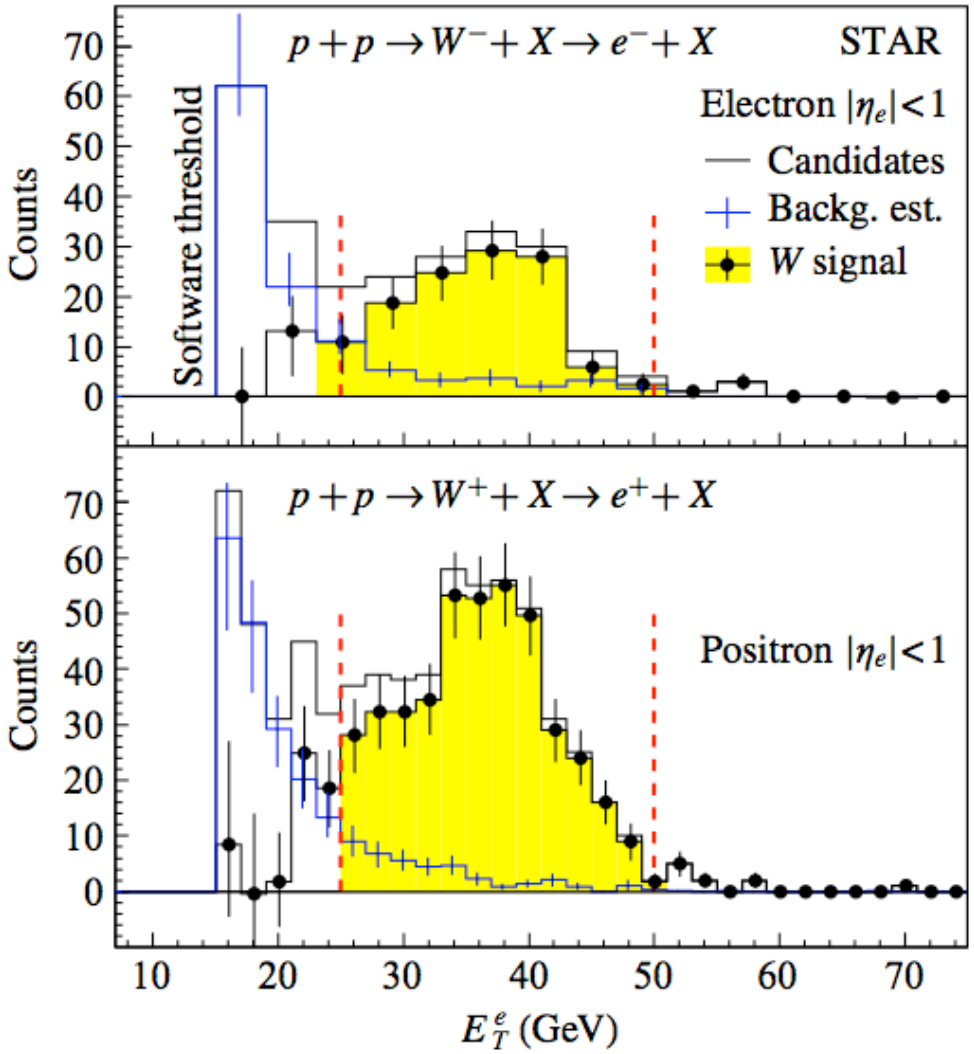
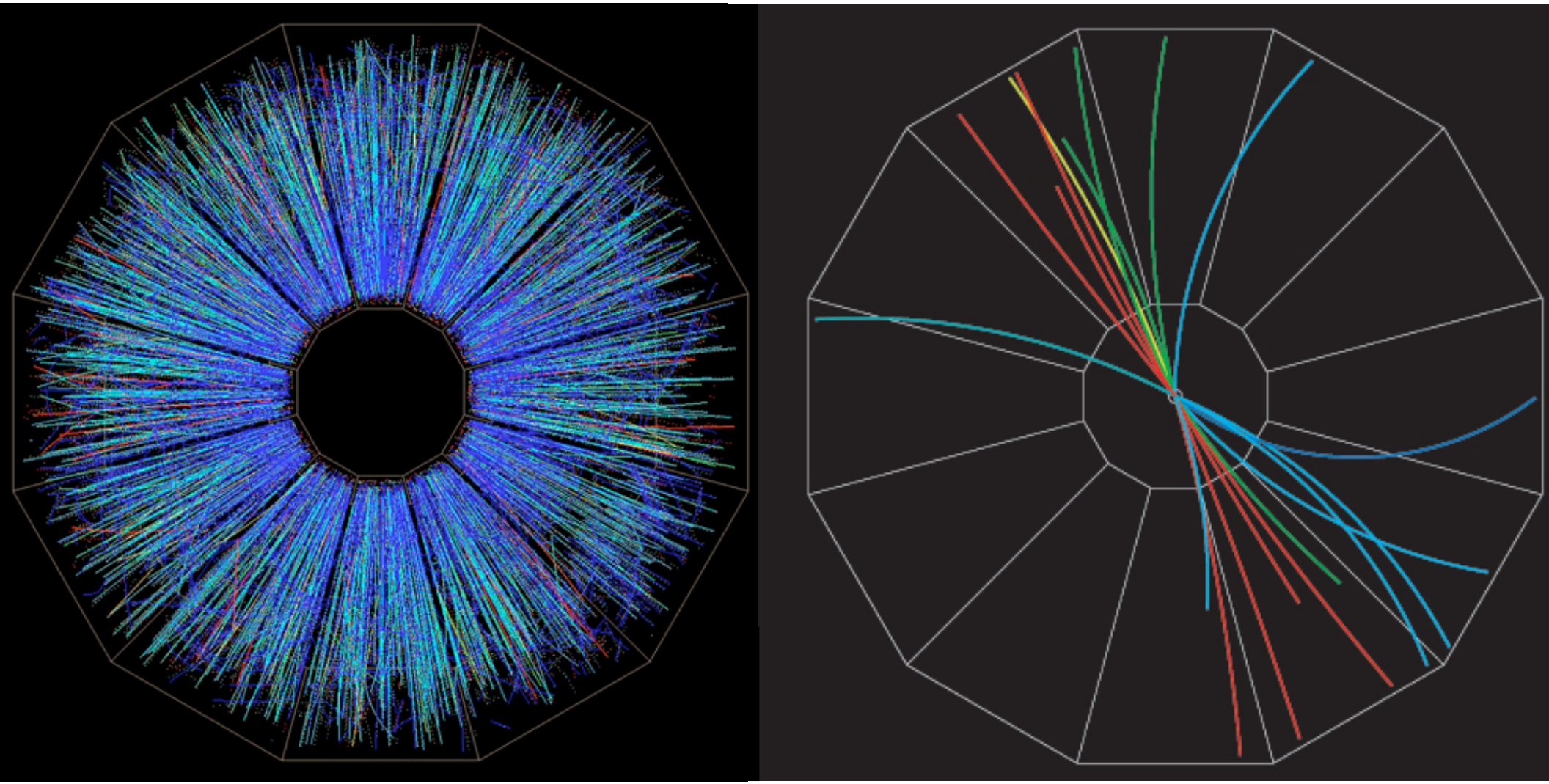


Phys. Rev. Lett. 106, 062002 (2011)

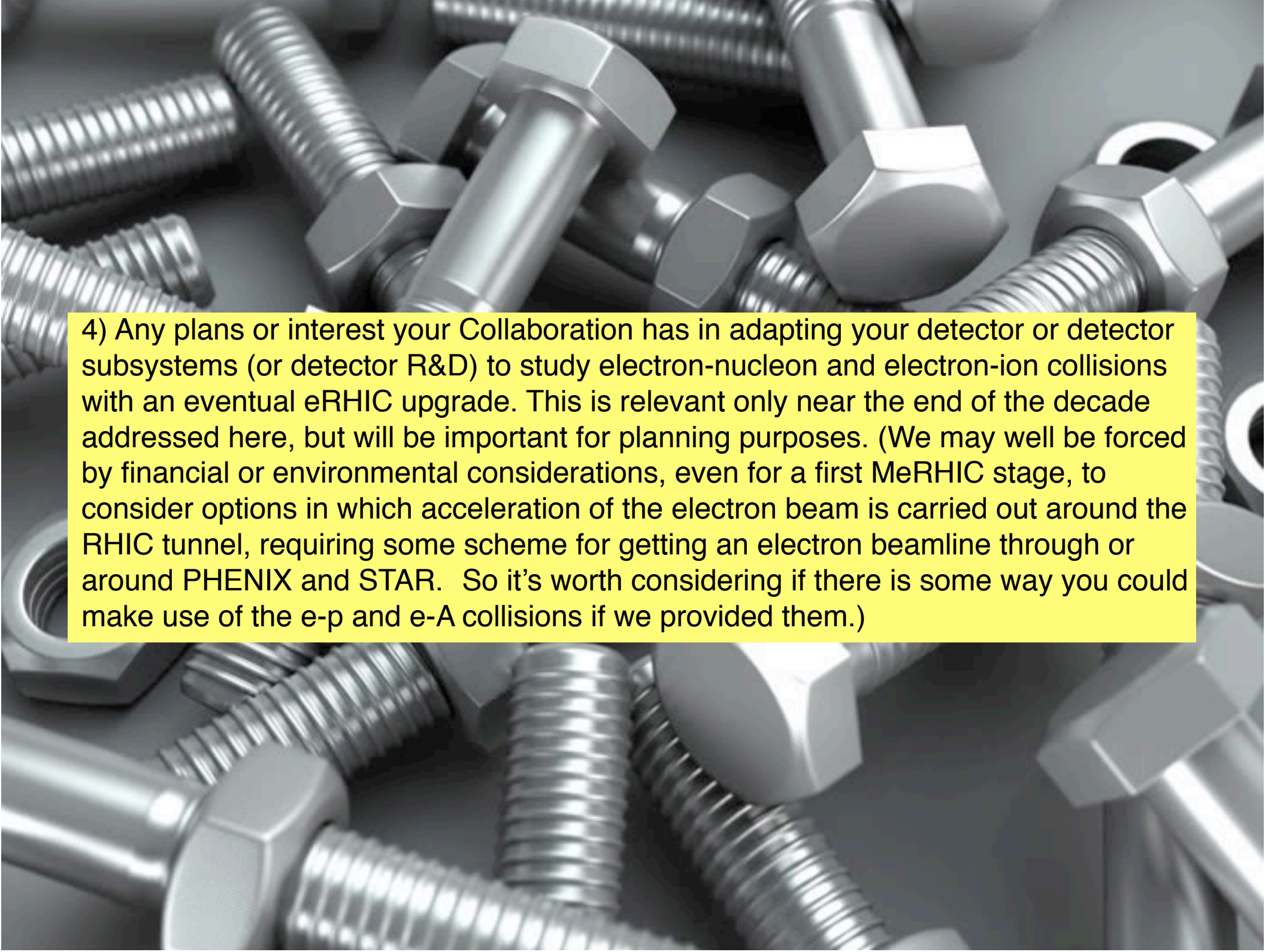
Electrons to very high momentum.

STAR - Solenoidal Tracker at RHIC



A versatile instrument to study QCD: Au+Au, d+Au, p+p, √s = 7.7 - 500 GeV, polarization.
key strengths: Acceptance, mid-rapidity Particle-Identification.

Can it be adapted to the asymmetric collisions systems eRHIC? If so, how?



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STAR Science leading into eRHIC

From the STAR Decadal Plan 2010-2020:

	Near term (Runs 11–13)	Mid-decade (Runs 14–16)	Long term (Runs 17–)
Colliding systems	p+p, A+A	p+p, A+A	p+p, p+A, A+A, e+p, e+A
Upgrades	FGT, FHC, RP, DAQ10K, Trigger	HFT, MTD, Trigger	Forward Instrum, eSTAR, Trigger
(1) Properties of sQGP	Υ, $J/\psi \to ee$, m_{ee}, v_2	Υ, $J/\psi \to \mu\mu$, Charm v_2, R_{CP}, Charm corr, Λ_c/D ratio, μ-atoms	p+A comparison
(2) Mechanism of energy loss	Jets, γ-jet, NPE	Charm, Bottom	Jets in CNM, SIDIS, c/b in CNM
(3) QCD critical point	Fluctuations, correlations, particle ratios	Focused study of critical point region	
(4) Novel symmetries	Azimuthal corr, spectral function	$e-\mu$ corr, $\mu-\mu$ corr	
(5) Exotic particles	Heavy anti-matter, glueballs		
(6) Proton spin structure	W A_L, jet and di-jet A_{LL}, intra-jet corr, $(\Lambda+\bar{\Lambda})$ D_{LL}/D_{TT}		$\bar{\Lambda}$ D_{LL}/D_{TT}, polarized DIS, polarized SIDIS
(7) QCD beyond collinear factorization	Forward A_N		Drell-Yan, F-F corr, polarized SIDIS
(8) Properties of initial state			Charm corr, Drell-Yan, J/ψ, F-F corr, Λ, DIS, SIDIS

Note: measurements are listed when they first become feasible. Many continue in future periods.

Themes for 2015+:

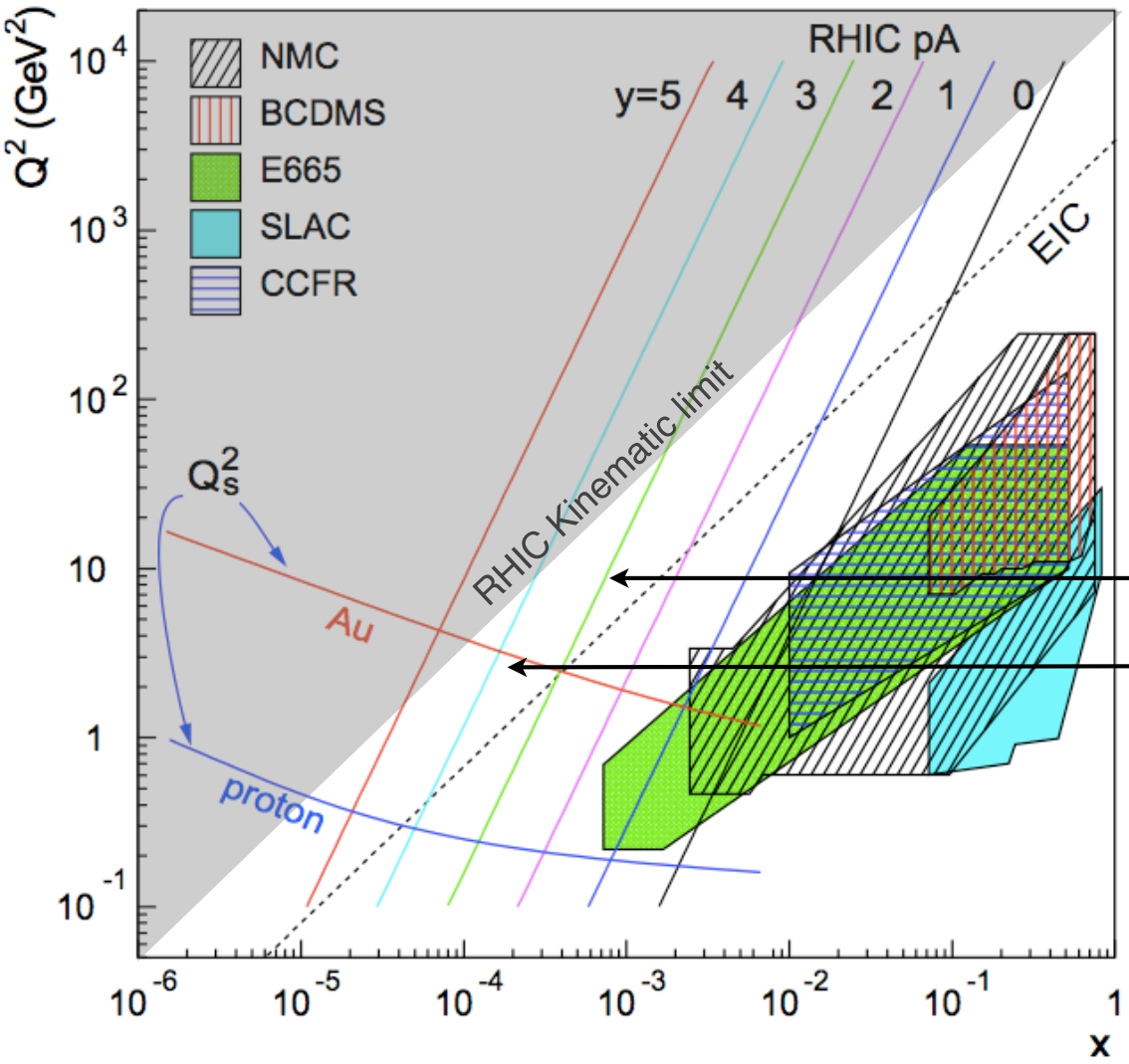
Heavy Flavor,

Beam-Energy-Scan,

polarized pp, pA

Polarized pA - *What* are we *colliding*?

STAR Decadal Plan, fig 3.21



External measurements thus far provide poor constraints; nuclear gluon distributions are uncertain.

Windows of opportunity:

DY - sea quark distributions,

forward collisions (jets, ...),

Natural next steps:

upgrade instrument, y ~ 3 - 4

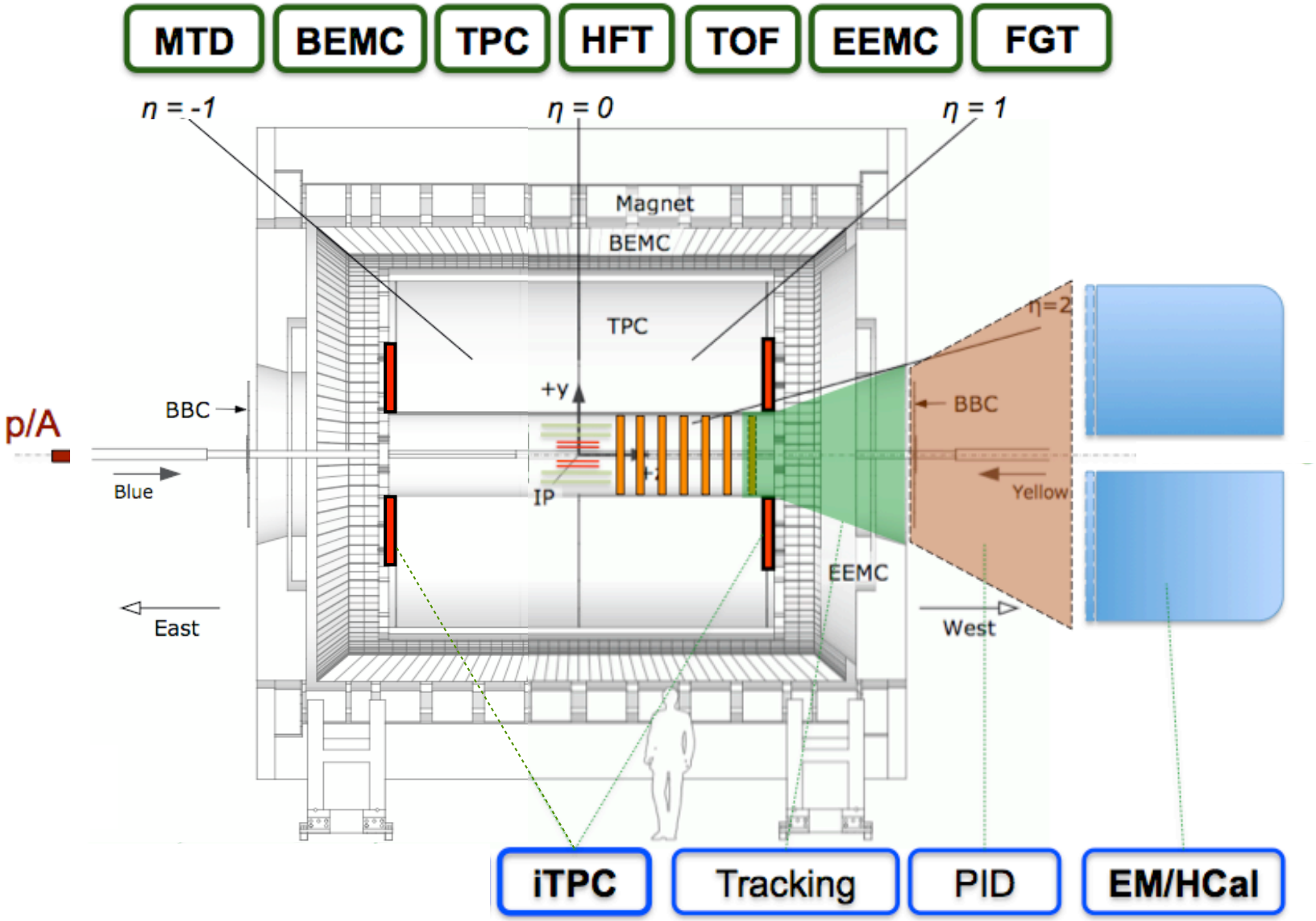
scan beam nucleus A,*

*explore proton-probe polarization**

** unique at RHIC*

<u>and</u> eRHIC

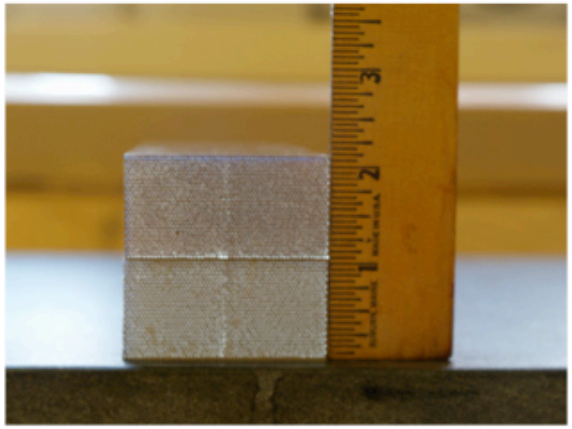
STAR Upgrade Plan for Second Half of the Decade



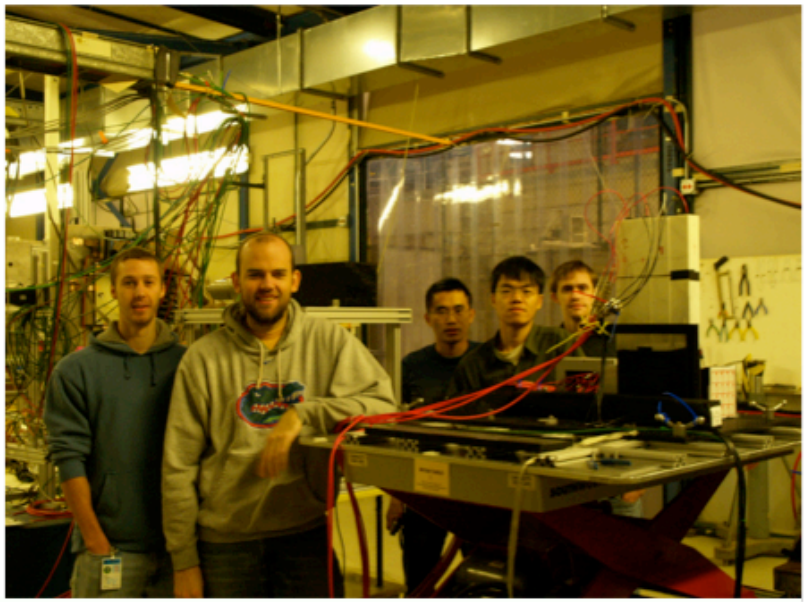
Science: Beam-Energy-Scan, Cold-Nuclear-Matter, Proton Spin,

Separate talk(s), e.g. Len Eun's this morning in the spin workshop.

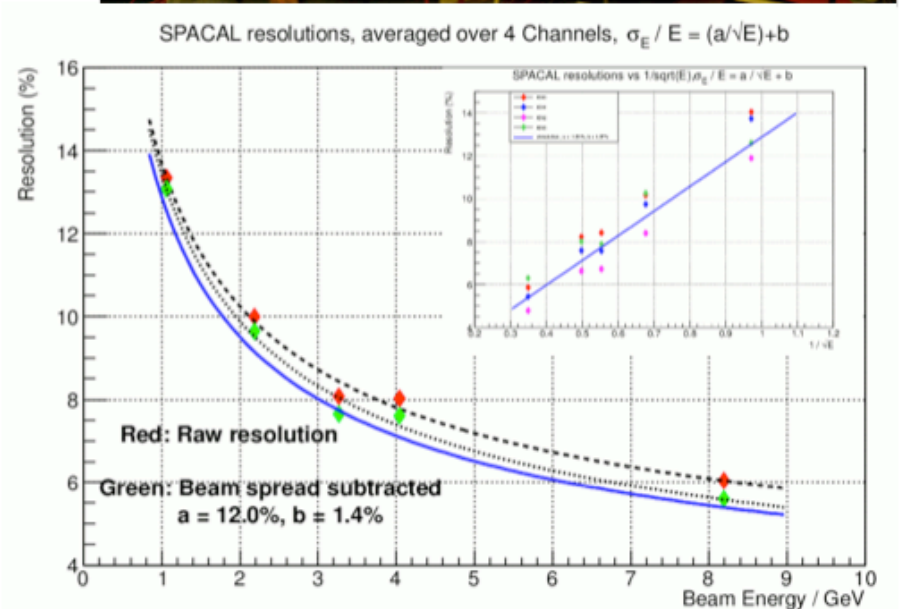
STAR Upgrade Plan for Second Half of the Decade



- UCLA, PSU, TAMU
- advanced simulations on photons, jets, hyperons
- EIC R&D as of May 2011



Hadronic calorimeter prototype for STAR



Potential in eSTAR: hadron/jet-detection in semi-inclusive DIS; proton spin, energy-loss.

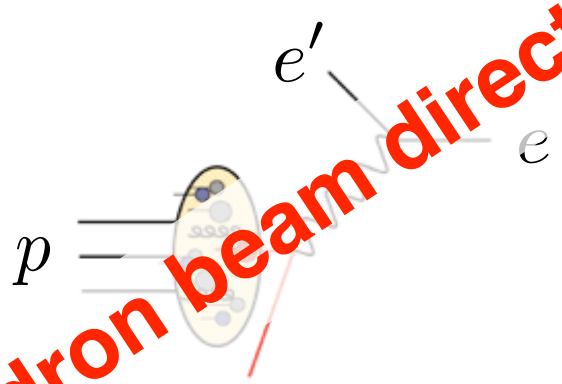
ep, eA at STAR - DIS 101

To get the angles deconfused:

$$e = (0, 0, -E_e, E_e)$$

$$e' = (E'_e \sin\theta'_e, 0, E'_e \cos\theta'_e, E_e)$$

$$p = (0, 0, E_p, E_p)$$



i.e. angles are defined *w.r.t. the hadron beam direction* (HERA-like).

HERA convention: angles are w.r.t. hadron beam direction

Relevant invariants:

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

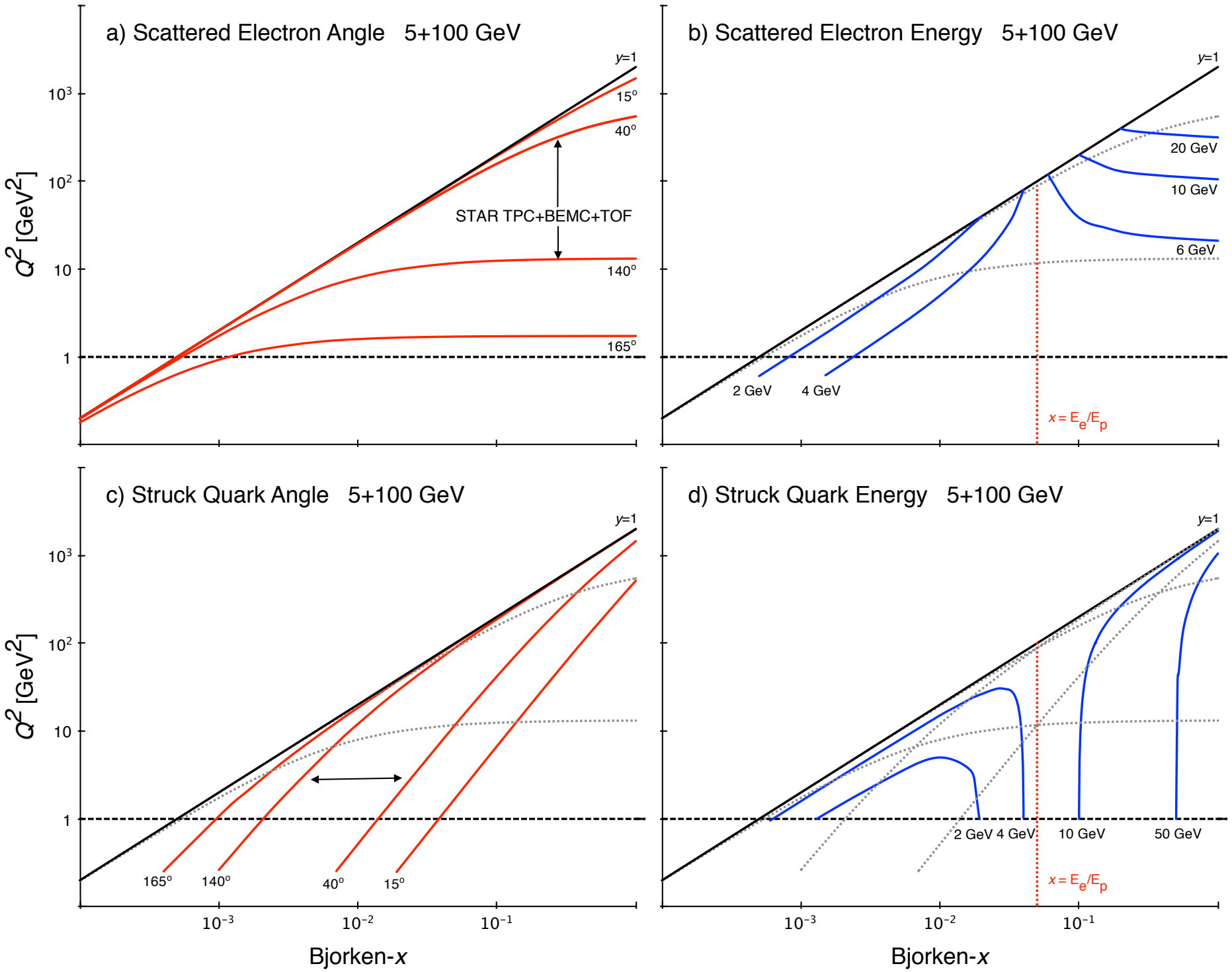
$q = e - e'$ $\quad Q^2 = -(e - e')^2$ — Square of (4-)momentum transfer

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

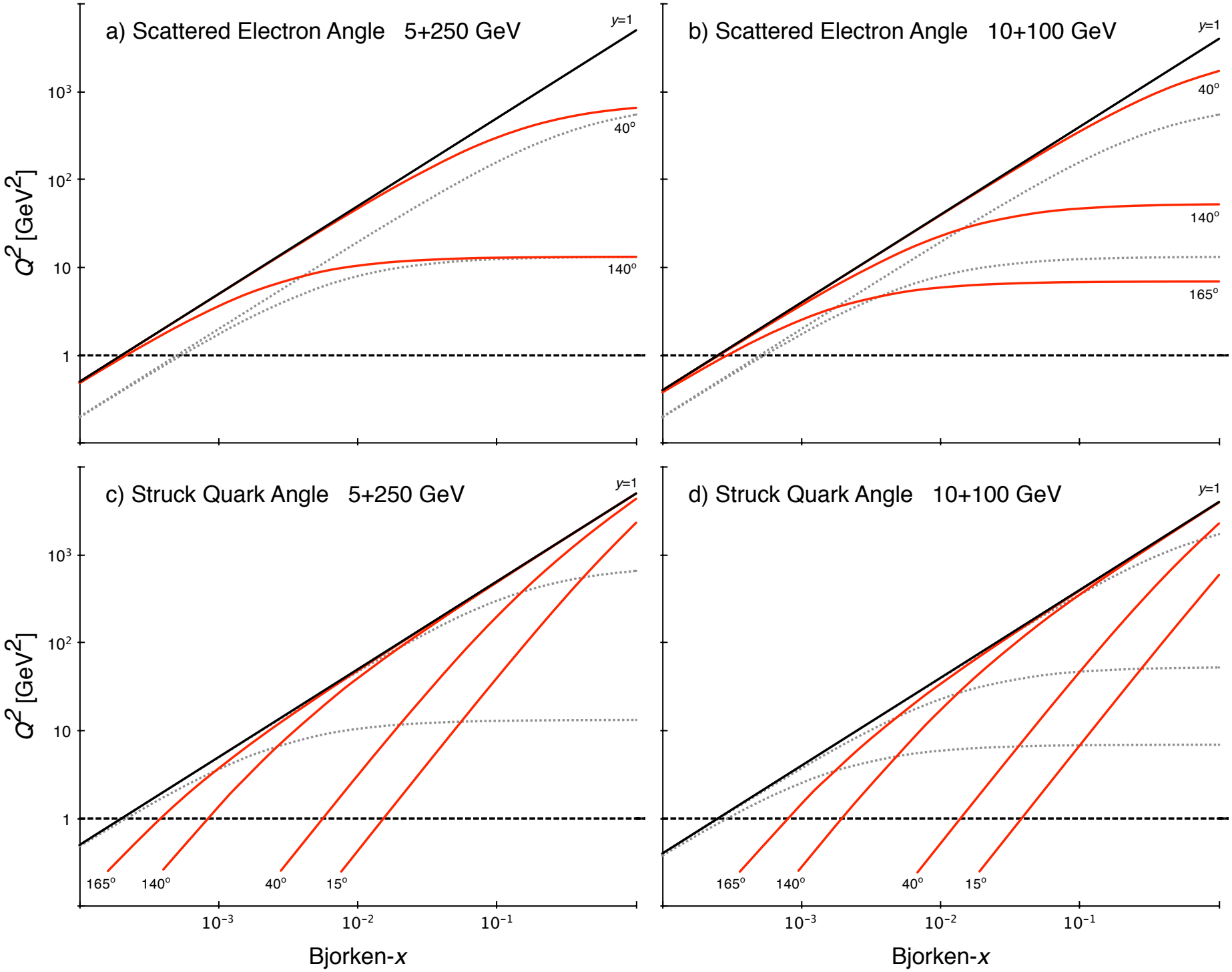
$y = (q.p)/(e.p)$ — Fractional energy transfer

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

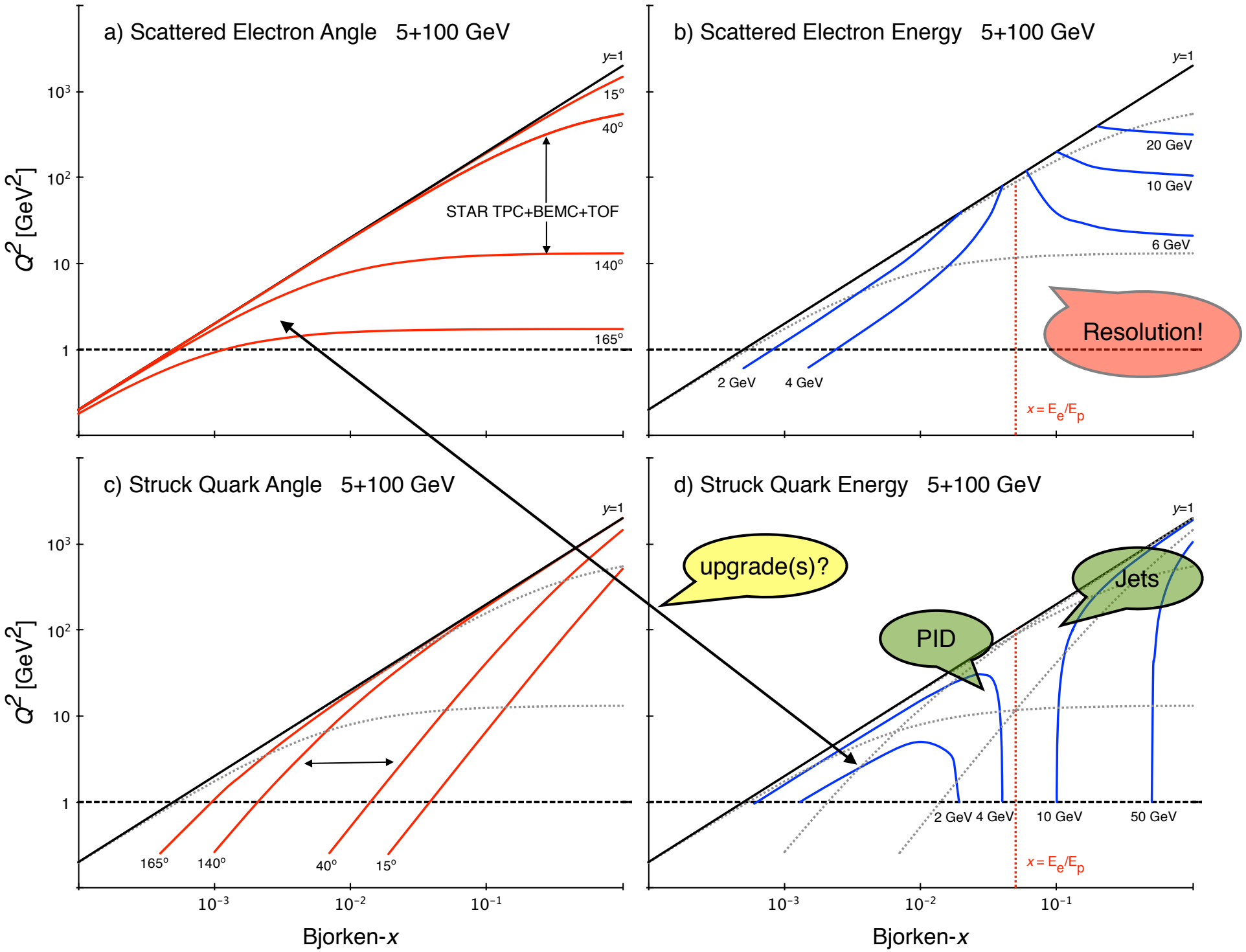
DIS with eSTAR



DIS with eSTAR - Scaling with Beam Energy



eSTAR - Towards a Concept



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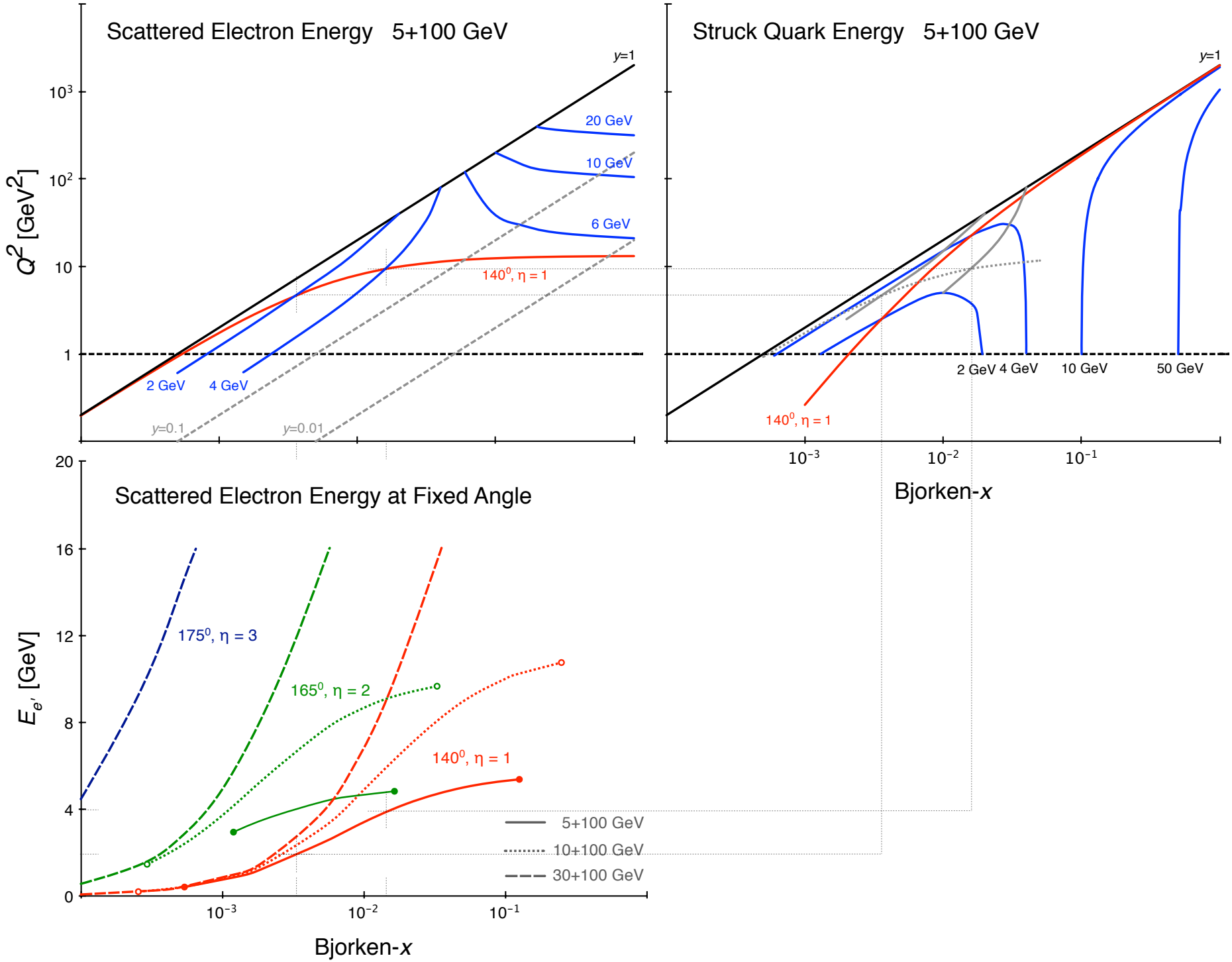

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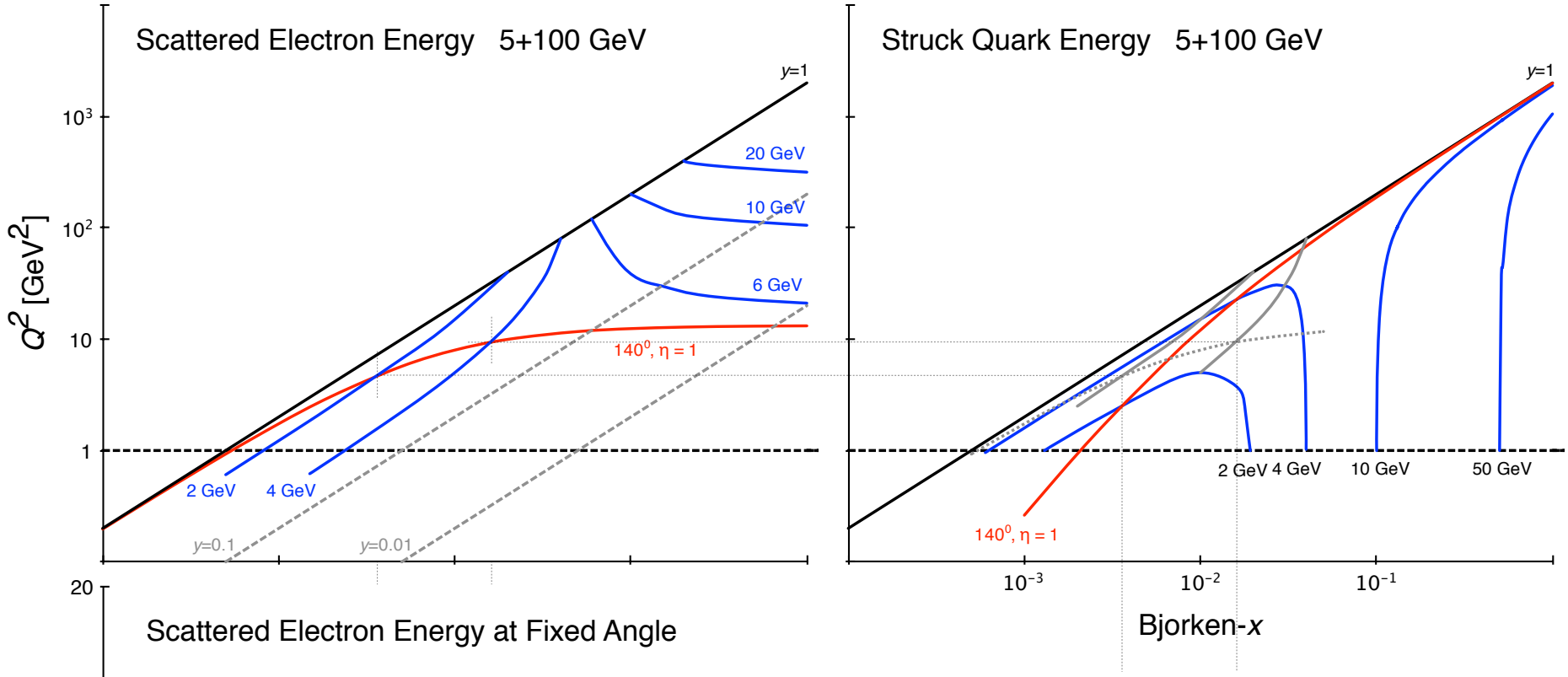
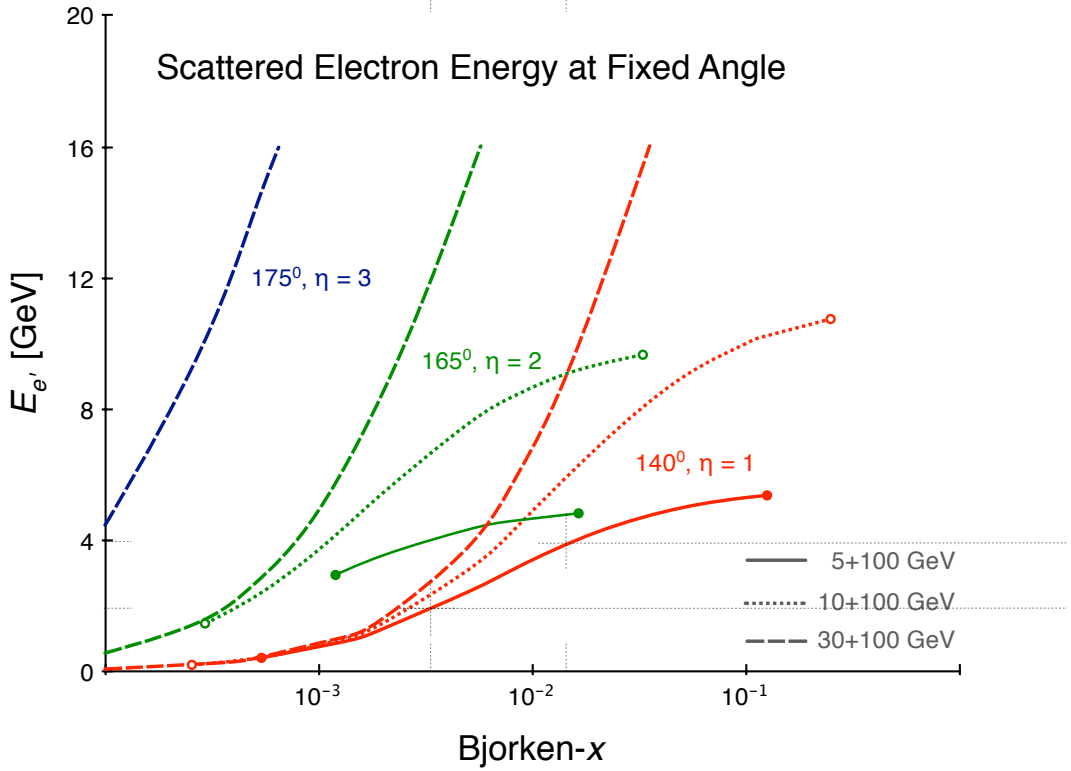




Bending radii ~m,

Sagitta ~mm (over 40cm),

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

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

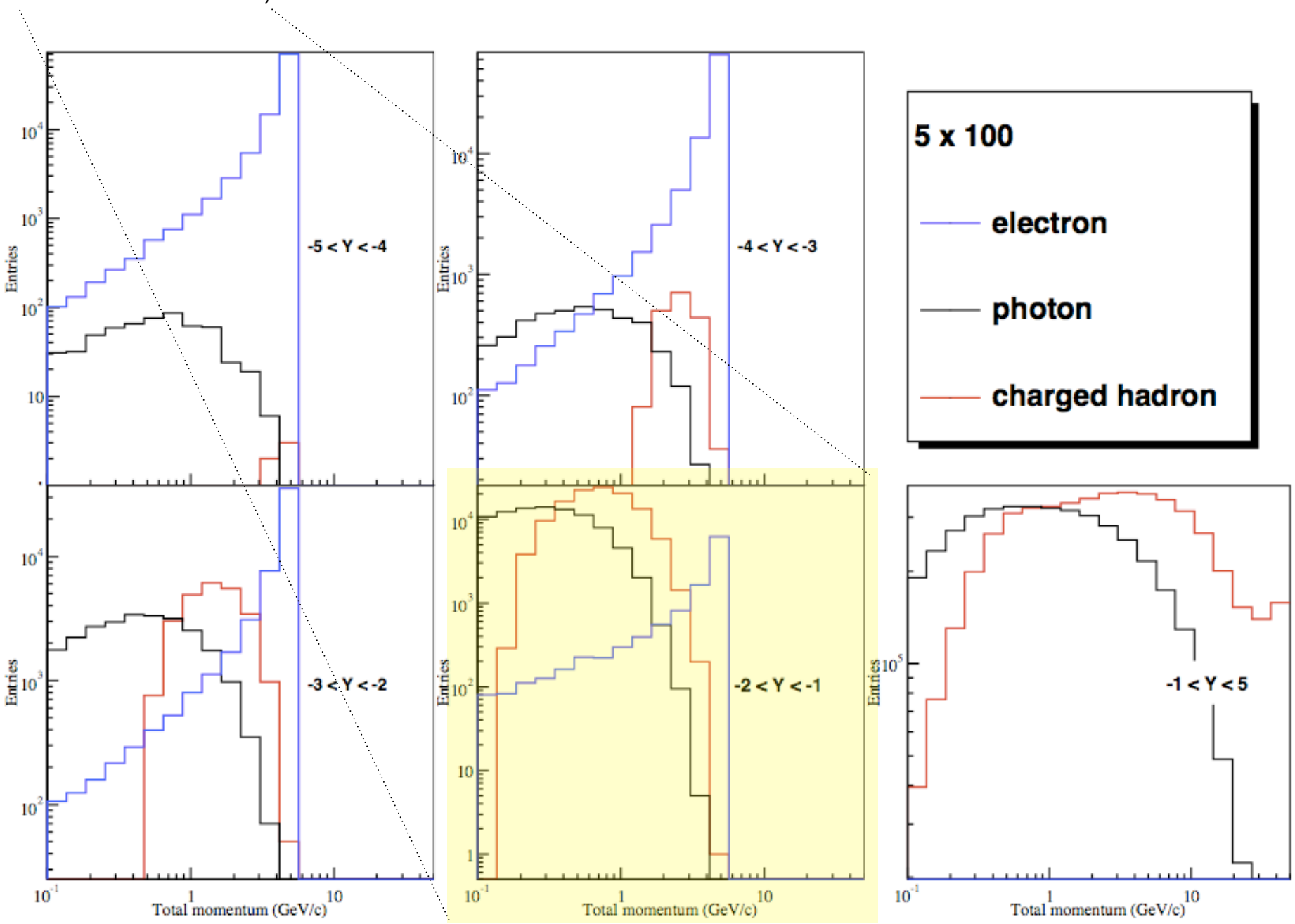
dE/E~0.3 at x ~ 10^{-2}

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

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

eSTAR - Towards a Concept

Electron identification, from ArXiV 1108.1713v2:



Towards an eSTAR Concept - Electron Side

Quite possibly suited for 5-10 GeV electron beams,

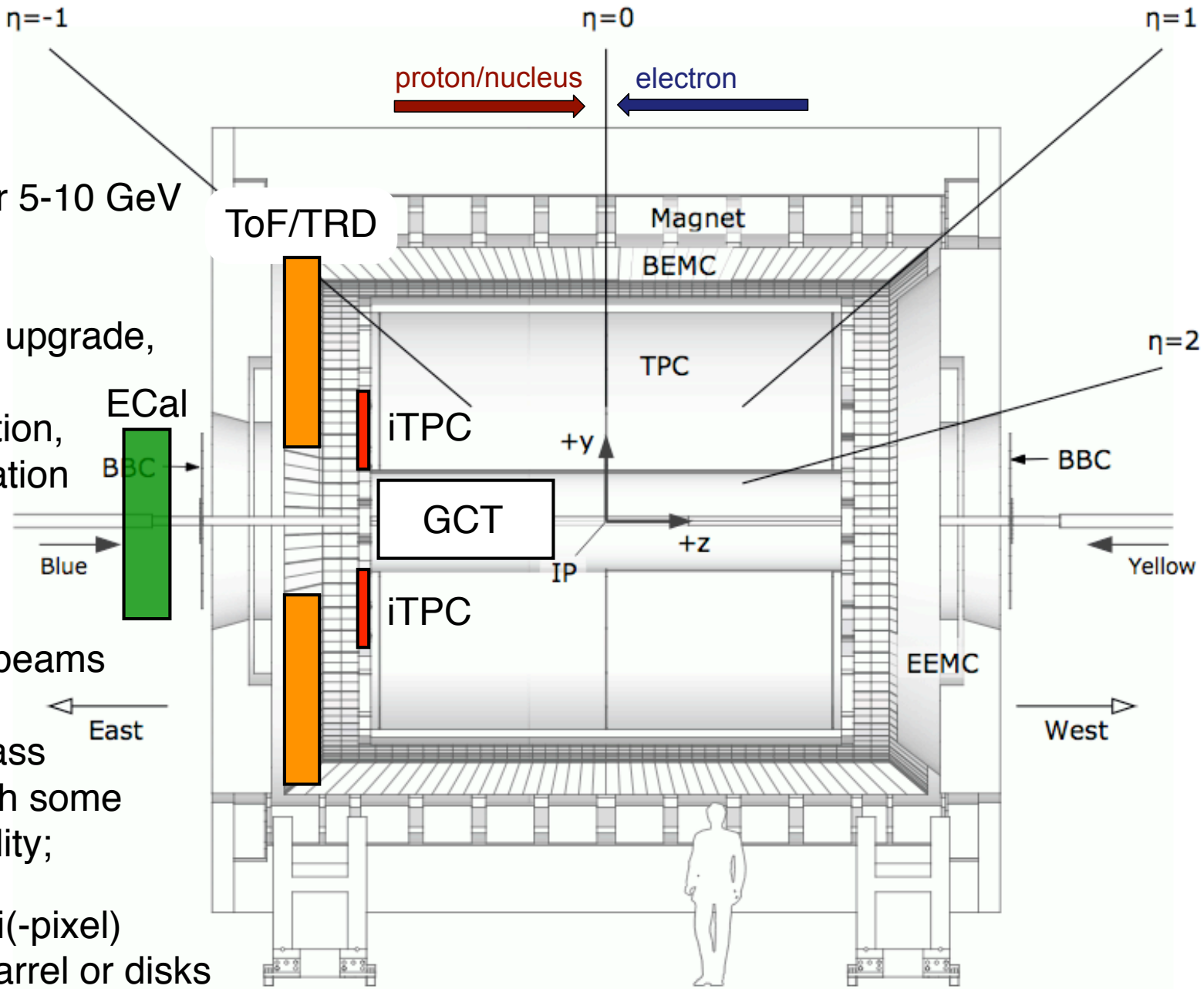
iTPC: inner-sector TPC upgrade,

ToF/ t_0, π, K identification,
TRD: electron identification

ECal: 10 GeV electron beams

GCT: a compact low-mass tracker, ideally with some electron id capability;

GCT alternatives e.g. Si(-pixel) barrel or disks

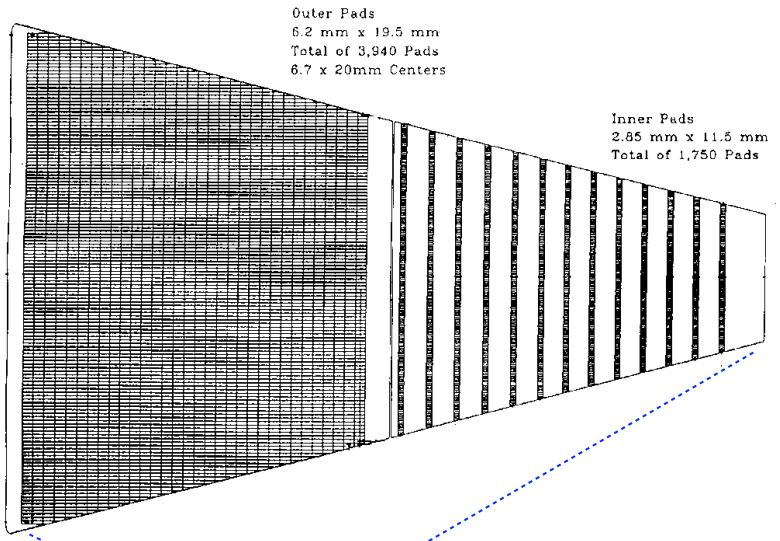


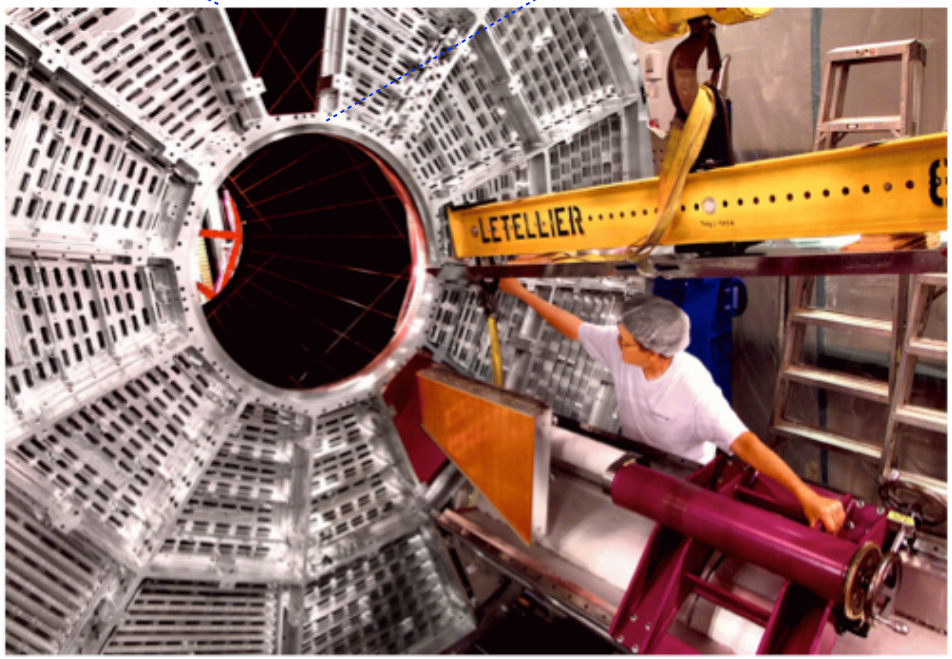
Note: Hadron Side not shown here.

eSTAR Concept - inner TPC sector upgrade

Dual 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,

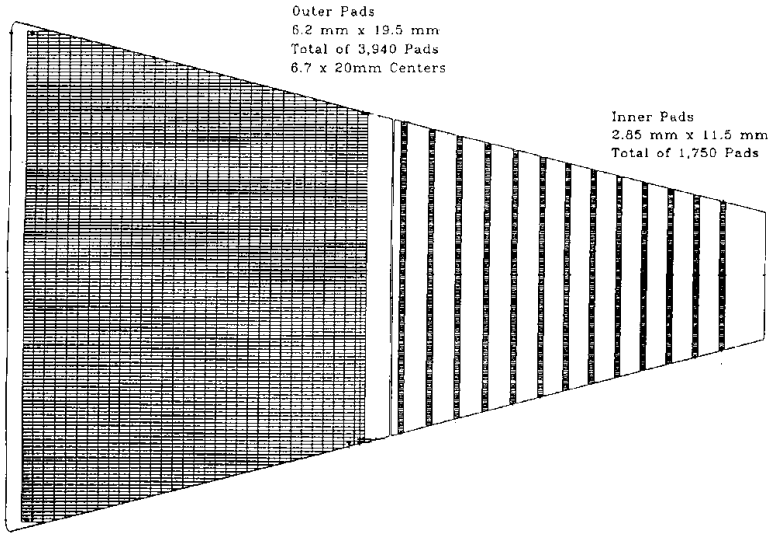
Status:

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

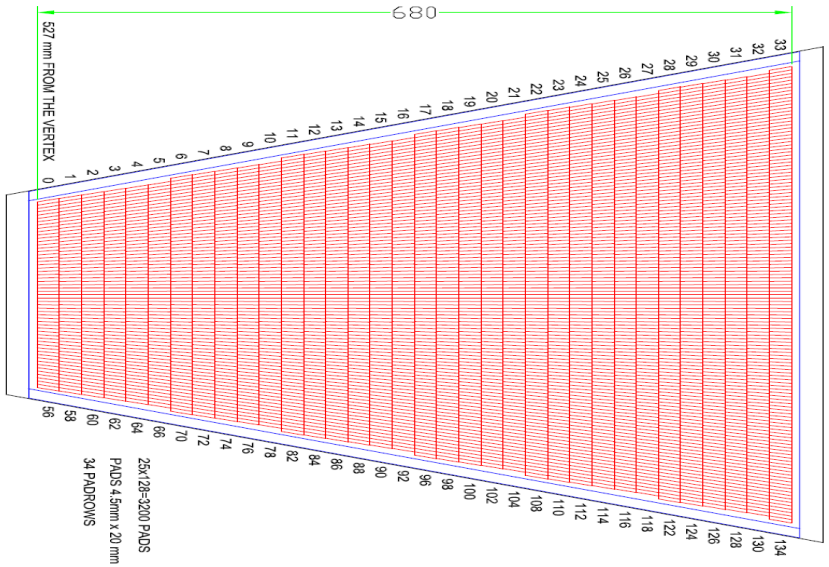
eSTAR Concept - inner TPC sector upgrade

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

STAR



ALICE



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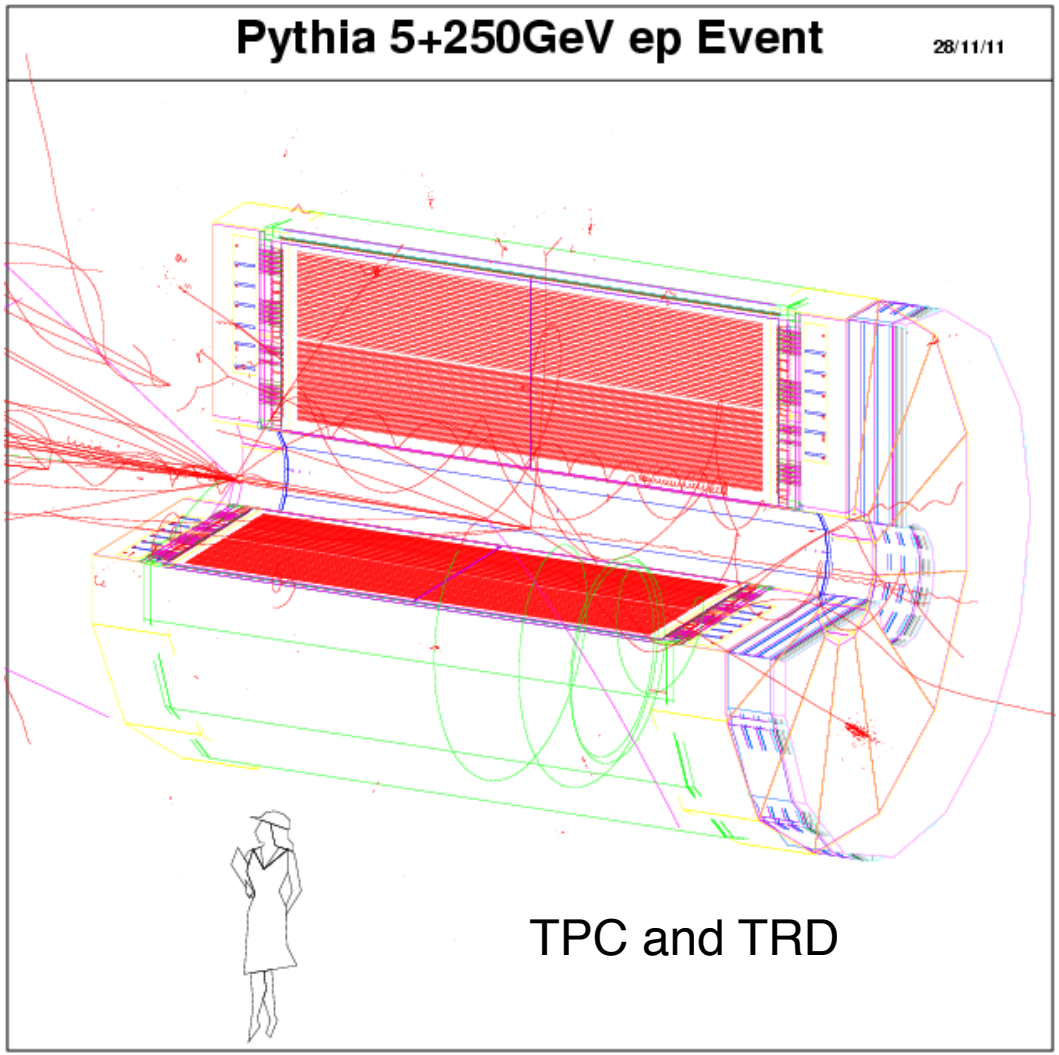
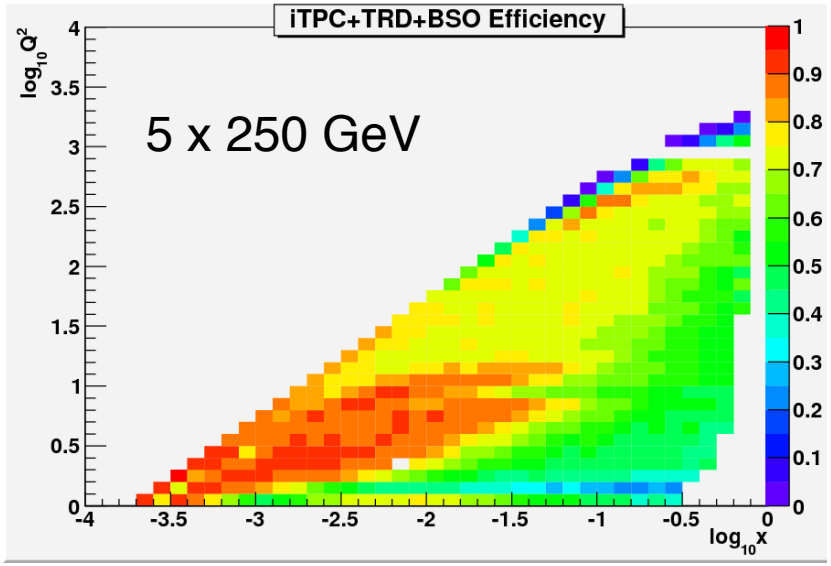
- Electronics (BNL/ALICE)
- Timeline: 3 years, 2017, cost estimate: 5M$

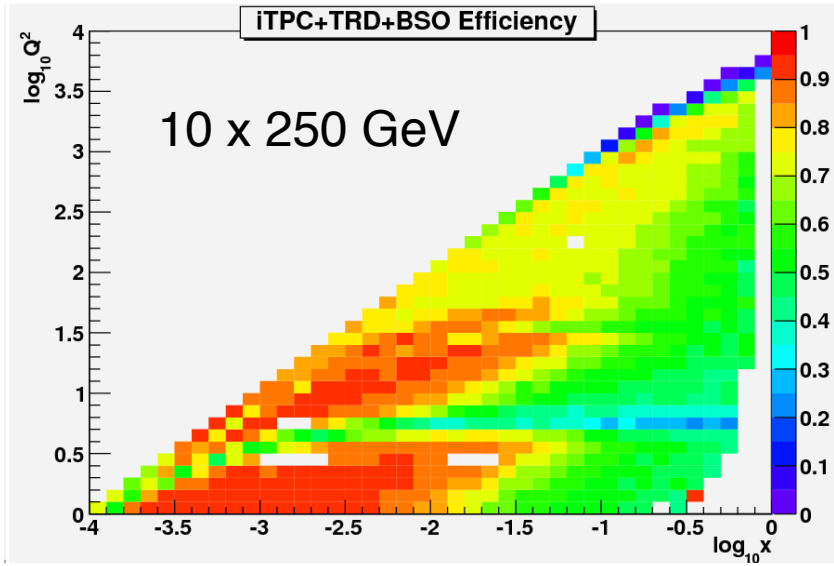
eSTAR Concept - Electron Side

Simulations are a work in progress:



Inclusive electron acceptance:





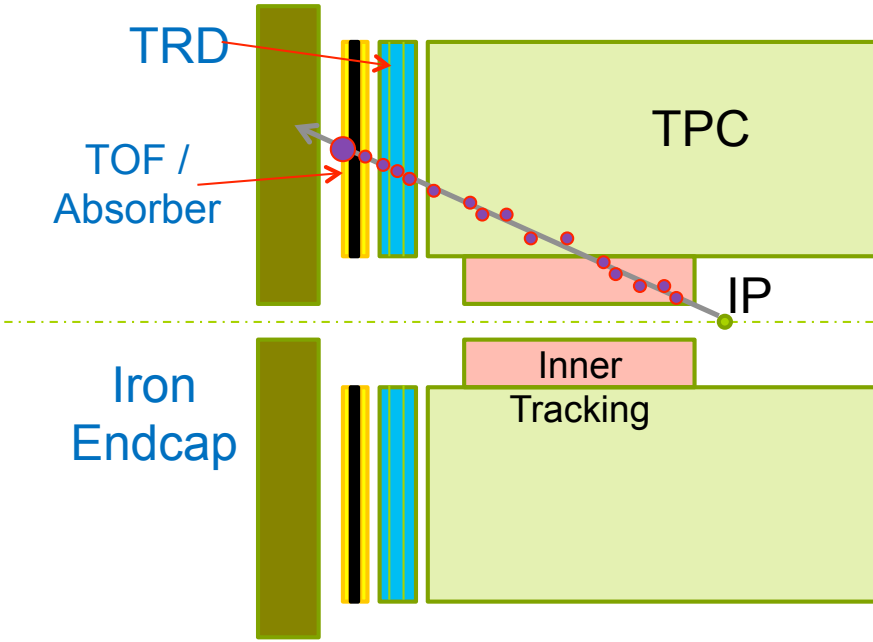
eSTAR Concept - ETTIE

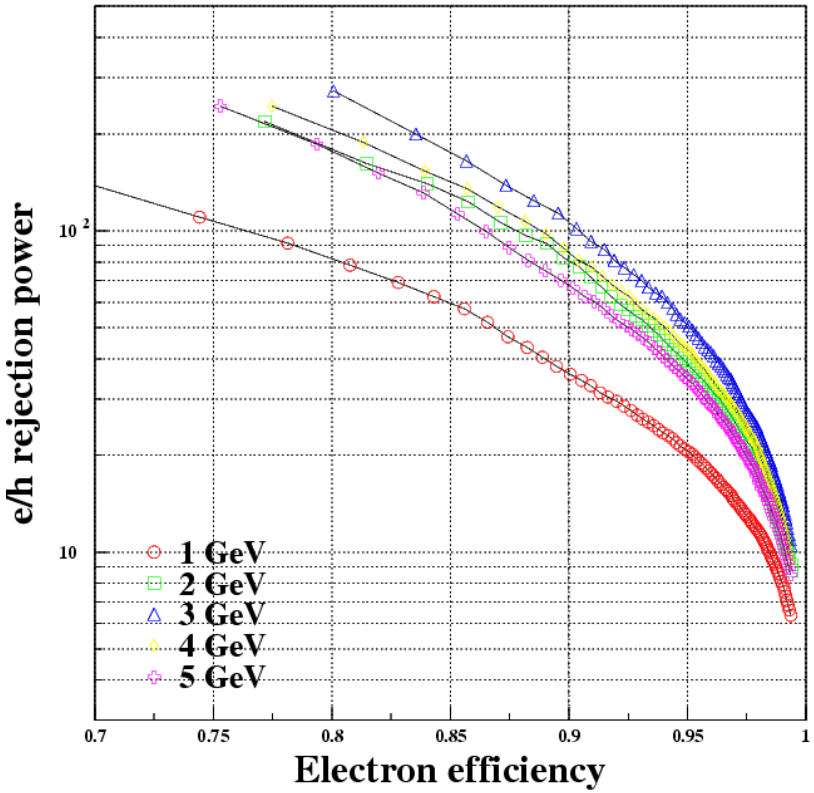
ETTIE: Endcap ToF and TRD for Identifying Electrons

- complement tracking with iTPC with precision points from GEM-based TRD and ToF / absorber sandwich,

- ToF as start-time, hadron PID

- dE/dx from (Xe/CO2) TRD + ToF for electron PID





< 70 cm constraint between TPC and Endcap,

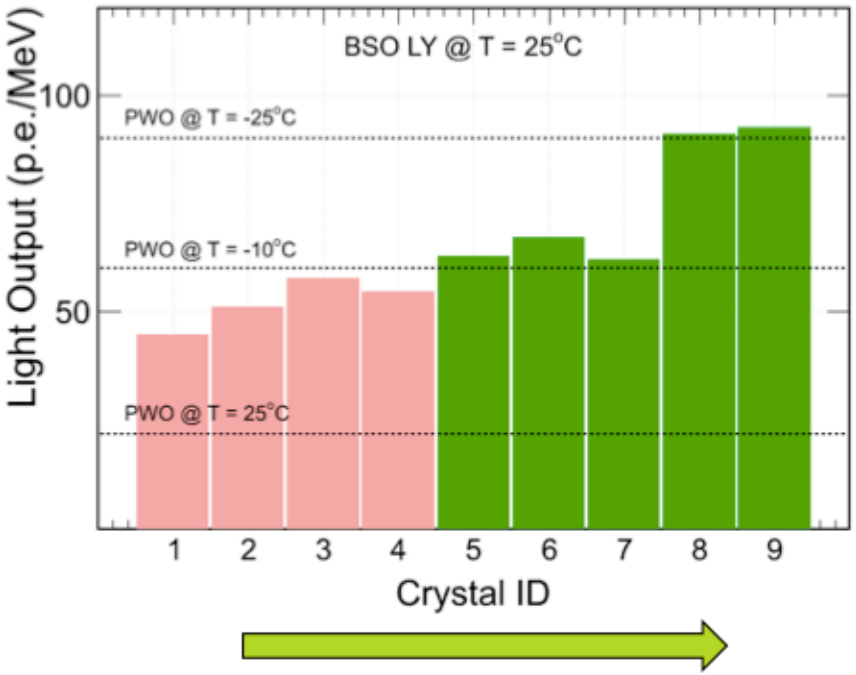
Simulations: e.g. e/h rejection,

Ongoing R&D on GEM-based TRD read-out.

Inner Tracking still largely open.

eSTAR Concept - Crystal R&D for Forward Electron

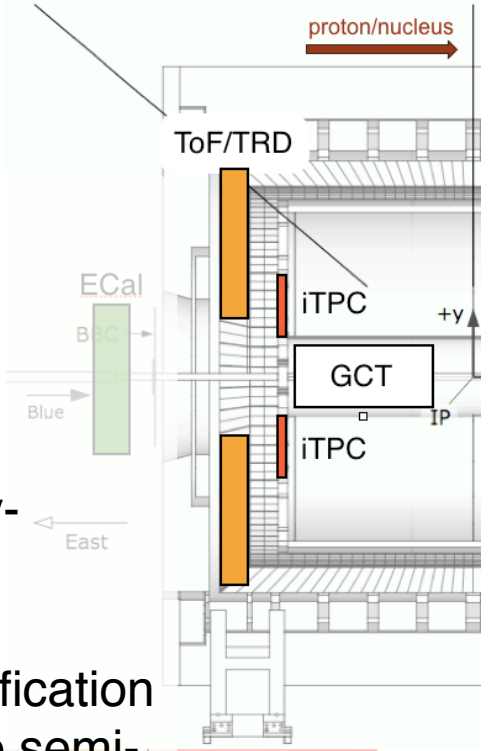
Crystal	Long_BSO	Short_BSO	Long_PWO	Short_PWO
ID	BSO_L	BSO_S	PWO-B	PWO-A
Size	20*20*200mm	Φ=25mm,L=30mm	25*25*220mm	30*30*45mm



Production Getting better over time

- **Very Forward Electron Detection (eta<-2.0)**
- BSO is produced by replacing Ge in BGO with Si, the material cost for BSO reduced by x3-4.
- Collaborators: USTC,SINAP,THU,UCLA
- Vendor: Shanghai SICCAS High Technology Coorporation (USTC/UCLA/SICCAS)
- **R&D proposal partially funded by BNL/DOE**

Closing Comments



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

Next frontier: a polarized Electron-Ion Collider,

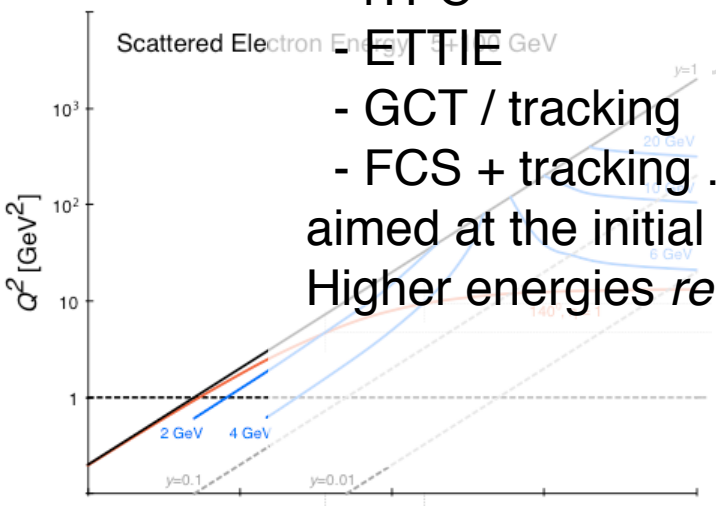
eSTAR is an attractive entry-option towards a timely, energy-staged EIC at RHIC, eRHIC,

STAR's key strengths include, in particular, its particle identification capabilities at mid-central rapidities that are well-matched to semi-inclusive DIS with 5-10 GeV electron beams,

STAR collaboration is pursuing evolutionary upgrades towards more forward electron+hadron identification and measurement:

- iTPC
- ETTIE
- GCT / tracking
- FCS + tracking ...

aimed at the initial 5-10 GeV eRHIC electron beam energies. Higher energies *require* a dedicated design.



Thank you!