eSTAR?

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Many thanks to colleagues in STAR and outside
HERA

Truly impressive proton data:

H1 and ZEUS Combined PDF Fit

\[ \sigma(x, Q^2) \]

- H1 NC e^+p (prel.)
- HERAPDF0.2 (prel.)
  (exp. uncert.)

\[ x = 0.002 \]
\[ x = 0.02 \]
\[ x = 0.25 \]

\[ Q^2 / \text{GeV}^2 \]

H1 and ZEUS Combined PDF Fit

\[ Q^2 = 10 \text{ GeV}^2 \]

- HERAPDF0.2 (prel.)
- exp. uncert.
- model uncert.
- parametrization uncert.

\[ x_{u,v} \]
\[ x_{d,v} \]
\[ x_S (\times 0.05) \]
\[ x_g (\times 0.05) \]
HERA

Truly impressive proton data:

Much less so for nuclear or polarized data:

Very clear science opportunities for EIC, but also keep in mind that lots has been learned and is being learned (fixed target, RHIC, LHC, ...)

See talks by Marco Stratmann, Dieter Mueller this morning.
Steve Vigdor to Nu Xu, Barbara Jacak, 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 ...
Staging all-in tunnel eRHIC: energy of electron beam is increasing from 5 GeV to 30 GeV by building-up the linacs

2 SRF linac
1 → 5 GeV per pass
4 (6) passes
4 to 6 vertically separated recirculating passes. # of passes will be chosen to optimize eRHIC cost

Common vacuum chamber
20 GeV e-beam
16 GeV e-beam
12 GeV e-beam
8 GeV e-beam

The most cost effective design

RHIC: 325 GeV p or 130 GeV/u Au

See Nick Tsoupas’s talk this morning
STAR - Solenoid Tracker at RHIC

0.5 T Solenoidal Magnetic Field

Time Projection Chamber
charged track momentum msmt,
charge determination,
particle identification dE/dx,
collision vertex reconstruction
coverage ~40° to ~140°

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

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

Fwd. Meson Spectr.
coverage ~10°- ~15°

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


Several detectors not shown above, e.g. Zero-Degree-Calorimeters, (Barrel) Time-Of-Flight,
Active upgrade program, Low mass Heavy-Flavor Tracker, Fwd Gem Tracker,
STAR - Solenoid Tracker at RHIC

+ Particle identification at mid-rapidity, *which continues to improve (TOF,...)*
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- Jet reconstruction 5-50 GeV in p+p, *which is being extended to d+A, A+A,*

STAR - Solenoid Tracker at RHIC

+ Particle identification at mid-rapidity, which continues to improve (TOF,...)

+ Jet reconstruction 5-50 GeV in p+p, which is being extended to d+A, A+A,

+ Large electromagnetic coverage, covering pseudorapidity -1 to 4,

+ Zero-Degree Calorimeters,

+ Active upgrade plan,

STAR - Near-term Upgrades

+ Heavy Flavor Tracker,
  *low-mass*, mid-rapidity

+ Forward Gem Tracker,
  Endcap EMC region,
  optimized for charge-sign discrimination,

+ Roman Pots,
  Phase II will enable concurrent running,
STAR - Near-term Upgrades

+ Heavy Flavor Tracker, *low-mass*, mid-rapidity

+ Forward Gem Tracker,
  Endcap EMC region,
  optimized for charge-sign discrimination,

+ Roman Pots,
  Phase II will enable concurrent running,
  Tagging of spectator protons with $^3$He beams,
STAR - Upgrades

+ Heavy Flavor Tracker, 
  \textit{low-mass}, mid-rapidity

+ Forward Gem Tracker, 
  Endcap EMC region, 
  optimized for charge-sign discrimination,

+ Roman Pots, 
  Phase II will enable concurrent running, 
  Tagging of spectator protons with $^3\text{He}$,

+ Forward Hadron Calorimeter,

\textit{Capabilities + Collaboration} - investigate possibilities with an electron beam.
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 proton beam direction (HERA-like).

Relevant invariants:

\[ s = (e + p)^2 \]
\[ q = e - e' \quad Q^2 = - (e - e')^2 \]
\[ x = \frac{Q^2}{y s} \]
\[ y = \frac{(q.p)}{(e.p)} \]

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

4 on 100 GeV: \( s = 1600 \text{ GeV}^2 \)

400 GeV fixed target equivalent,
- reaches 2 times lower \( x \) (10^{-4})
- 2 times higher \( Q^2 \)
Trivia - 2

For those who prefer angles or pseudo-rapidities:
Medium (low) energy variants will not likely be able to address saturation or EW struct.fct.
MeRHIC and STAR - 4 on 100 GeV

STAR Angular acceptance for scattered electrons seems quite reasonable/sizable:

EEMC+FGT could fill in low-$Q^2$ (hadrons in RHIC-yellow), or high-$x$, high-$Q^2$, not both.
Forward region becomes increasingly important, in particular with higher electron energy.

Existing instrumentation faces the RHIC-blue beam, and would (thus) seem to favor hadrons in RHIC-yellow, electrons in “blue”.
MeRHIC and STAR - electron kinematics

Electron issues: low-x trigger, electron energy resolution at intermediate to high $x$, and low-$Q^2$, possibly high-x and high-$Q^2$ acceptance.

EEMC+FGT could fill in low-$Q^2$ (hadrons in RHIC-yellow), or high-x, high-$Q^2$, not both.

FGT optimized for charge-sign discrimination of electrons from $W$-decay; investigate momentum resolution, as well as jet capabilities - further upgrade (?). Investigate also particle identification capabilities in non-central region.
MeRHIC and STAR - electron resolution

Electron issues: low-$x$ trigger, electron energy resolution at intermediate to high $x$, and low-$Q^2$, possibly high-$x$ and high-$Q^2$ acceptance.

Resolution:

Effect of a 0.1 degree uncertainty in scattered electron angle on Bjorken-$x$

Effect of a 1% uncertainty in scattered electron energy on Bjorken-$x$

Effects of electron measurement on $Q^2$ generally (much) smaller in the DIS region.
MeRHIC and STAR - jet kinematics

The role of jets is principally at high-\(x\), and intermediate to high \(Q^2\)

\[
\begin{aligned}
\text{Struck quark angle} \\
\text{Struck quark energy}
\end{aligned}
\]

Assume that the EEMC+FGT will fill in the low-\(Q^2\) region (hadrons in RHIC-yellow), FGT optimized for charge-sign discrimination of electrons from \(W\)-decay;

\[x = \frac{E_e}{E_p}\]

\text{investigate momentum resolution, as well as jet capabilities - further upgrade (??)}

\text{Investigate also particle identification capabilities in non-central region.}
MeRHIC and STAR - jet resolution

The role of jets is principally at high-\(x\), and intermediate to high \(Q^2\)

The effects of resolution on Bjorken-\(x\):

Effect of a 1 degree uncertainty in scattered quark ("jet") angle on Bjorken-\(x\)

Effect of a 10% uncertainty in scattered quark ("jet") energy on Bjorken-\(x\)
The role of jets is principally at high-$x$, and intermediate to high $Q^2$.

The effects of resolution on $Q^2$: 

- Effect of a 1 degree uncertainty in scattered quark ("jet") angle on $Q^2$
- Effect of a 10% uncertainty in scattered quark ("jet") energy on $Q^2$

Figures are meant for scaling purposes, real resolutions require true simulation. $x$-$Q^2$ coverage is in general not a “given” - STAR seems in reasonable shape. Electron-jet hybrid reconstruction not addressed here.
Assume that the EEMC+FGT will fill in the low-$Q^2$ region (hadrons in RHIC-yellow),

*Investigate momentum resolution, as well as jet capabilities w. FGT (upgrade),
  particle identification capabilities in non-central region,*

Forward instrumentation becomes more important with higher energy, esp. electron E.
10^6 counts within reach, corresponding to ~10^{-3} precision in asymmetries (=> syst. req.), Binning would obviously need to be optimized.

Rates, and also occupancies, trigger-rates appear (well) within reach.
MeRHIC and STAR - $g_1$

The graph shows the behavior of $xg_1$ in the Bjorken-$x$ parameter space for different energy transfers ($1$ GeV$^2$, $10$ GeV$^2$, $100$ GeV$^2$). The curves are labeled for proton and neutron species, with the DSSV model indicated.
MeRHIC and STAR - $g_1, A_1$

Within reach at smallest Bjorken-$x$
Running with $Q^2$ likely within reach as well.
Baseline inclusive asymmetries seem well within reach; their kinematic coverage is only a modest factor beyond existing data, in view of the electron beam energy.
MeRHIC and STAR - Baseline Asymmetries

$A_1 \sim 2.10^{-3}$

$A_1 \sim 25.10^{-3}$

$A_1 \sim 21.10^{-3}$

$A_1 \sim \frac{g_1}{F_1}$

$A_1$ should be within reach at smallest Bjorken-\(x\),

Running with $Q^2$ likely observable for $x > \sim 10^{-2}$.
Small(er)-x

Neutron is most striking,

\[ g_1^n(x) \pm g_1^p(x) \propto x^{-\alpha_{\pm}}, \quad x \to 0, \]

\[ g_1(x) \approx 0.09 \left( 2 \ln \frac{1}{x} - 1 \right), \quad x \to 0, \]

\[ g_1(x, Q^2) \propto \exp \sqrt{\ln \frac{1}{x} \ln \ln \frac{Q^2}{\Lambda^2}}, \quad x \to 0, \; Q^2 \to \infty, \]

which, if any?

FIG. 3. Results for \( g_1^n \) versus \( x \) for the low \( x \) region from SLAC experiment E154 compared to the CERN SMC experiment. The data is evolved to \( Q^2 = 5 \) (GeV\(^2/c^2\)). Fits that impact the low \( x \) extrapolation (discussed in the text) are presented.

Small(er)-x

Today’s knowledge is better, but remains inconclusive.

E154 used a polarized $^3$He (neutron) target,

SMC and COMPASS are subtractions of measurements on targets with polarized D and H,

COMPASS aims for an additional H run.

FIG. 3. Results for $g_1^n$ versus $x$ for the low $x$ region from SLAC experiment E154 compared to the CERN SMC experiment. The data is evolved to $Q^2 = 5$ (GeV$^2$/c$^2$). Fits that impact the low $x$ extrapolation (discussed in the text) are presented.
Small(er)-x

Coarse estimate of uncertainty,

4 + 100 GeV beams at STAR,

1 fb\(^{-1}\), 70% polarizations,

idealized efficiency,

no radiative dilution or corrections,

statistical uncertainty only,

Expect significant impact;
tools exist to quantify impact.

FIG. 3. Results for \(g_1^n\) versus \(x\) for the low \(x\) region from SLAC experiment E154 compared to the CERN SMC experiment. The data is evolved to \(Q^2 = 5\) (GeV\(^2\)/c\(^2\)). Fits that impact the low \(x\) extrapolation (discussed in the text) are presented.
Summary

STAR would be in reasonable shape for a medium (low) energy MeRHIC,

I’ve sketched an inclusive example,

Inclusive physics is a start, not the end:

Essential upgrades: lumi, polarization,

Existing instrumentation would seem to favor hadrons in RHIC-yellow, electrons in “blue”: momentum resolution improvements are likely needed in FGT+EEMC region, sensible also to investigate additional particle-identification in this region, perhaps sensible also to consider a somewhat displaced IR, That is, relatively modest upgrades, initially (MeRHIC).

Quite obviously, there is lots to be done: Roman Pot optimization (tagging, DVCS), two-jet events, heavy flavor, ...

My bias: Think timely, eSTAR, and Think BIG, a dedicated high-energy eRHIC detector.