RHIC&AGS Annual Users Meeting 2014, BNL

Upgrade and New Physics STAR

Zhenyu Ye for the STAR Collaboration

(1) University of Illinois at Chicago
(2) Central China Normal University

Outline

Introduction

Upgrade and Physics

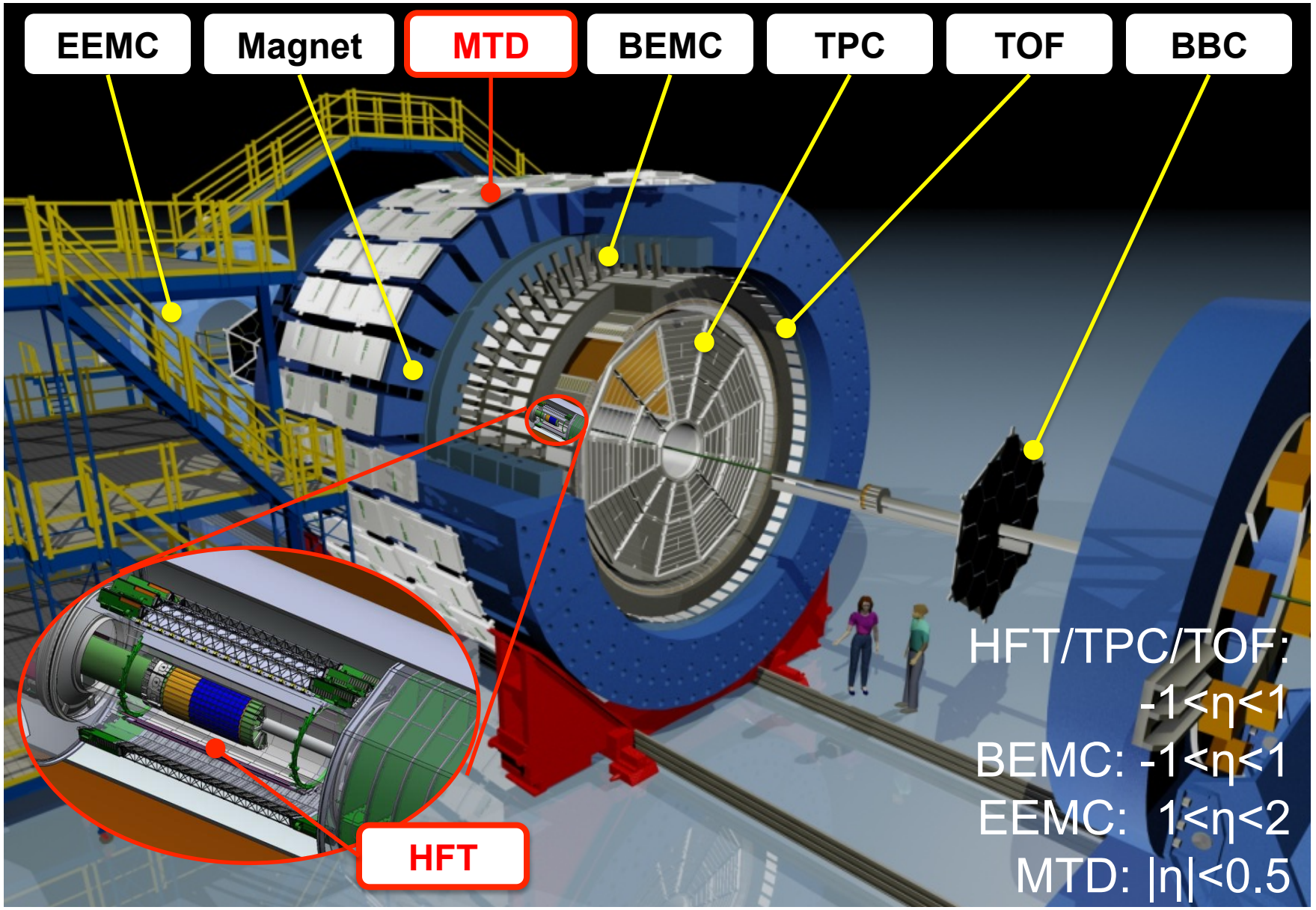
Summary

STAR

UIC The University of Illinois at Chicago

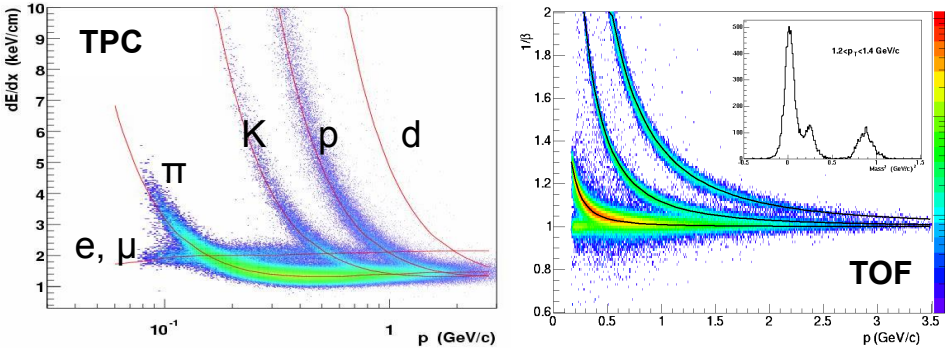
Office of Science U.S. DEPARTMENT OF ENERGY

STAR Detector (2014)

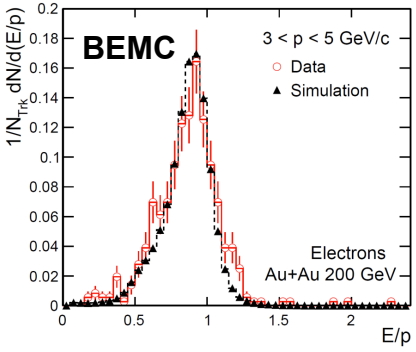


Excellent mid-rapidity detector with full azimuthal Tracking+PID+Calorimetry

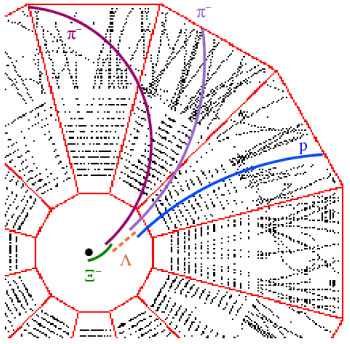
STAR Detector (2014)



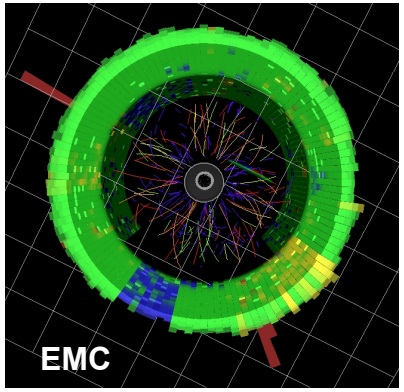
Identified charged hadrons



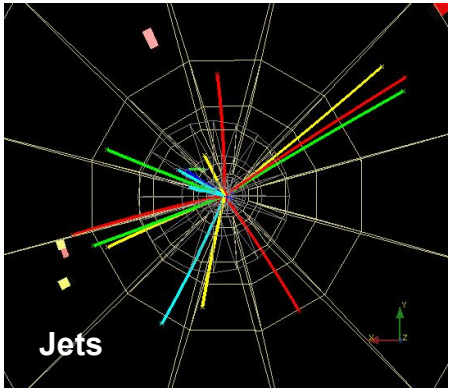
High p_T electrons



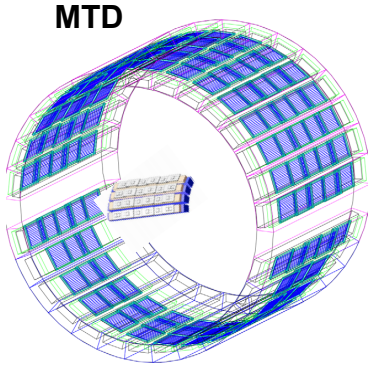
Hyperons & Hyper-nuclei



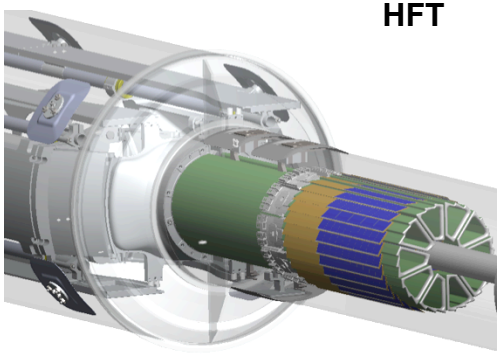
Neutral particles



Jets & Correlations



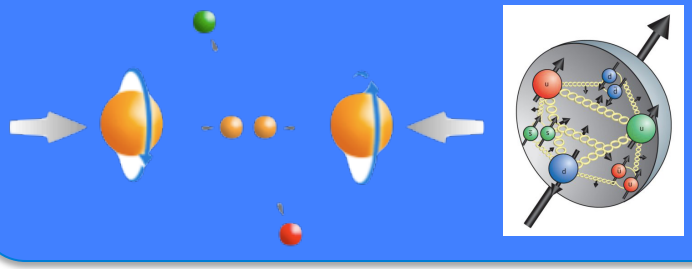
High p_T muons



Heavy-flavor hadrons

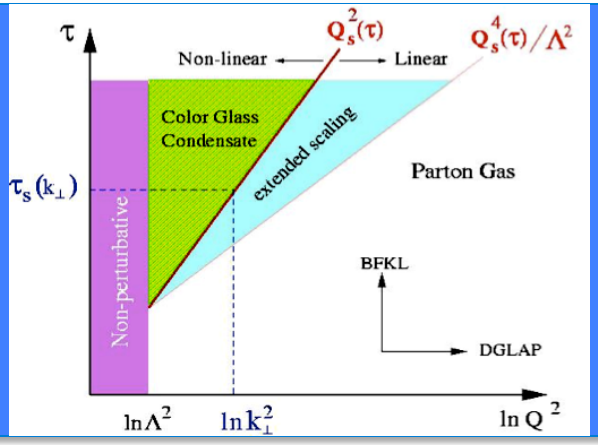
Identifying and measuring almost all kinds of particles produced from collisions

STAR Physics



Polarized p+p Program

- proton spin structure
- perturbative QCD



p(d)+A Program

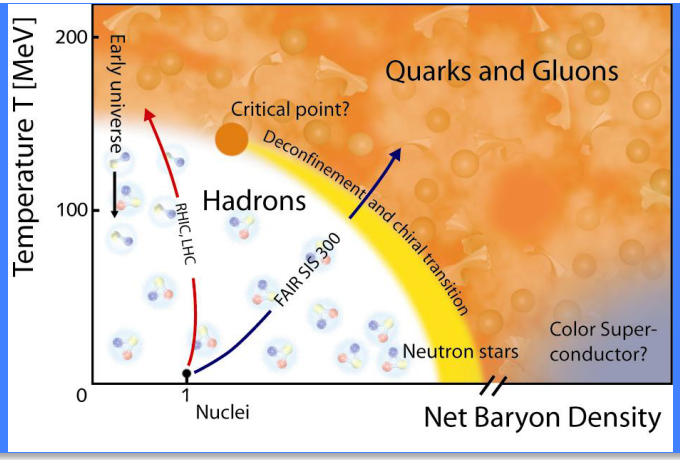
- gluon saturation, CGC
- initial conditions, CNM
- diffractive interactions

eSTAR:

Polarized

e+p / e+A

Program



A+A Top Energy

- QGP medium properties, EoS
- QCD in hot and dense medium

A+A Beam Energy Scan

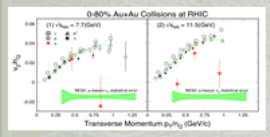
- search for the critical point
- chiral symmetry restoration

Interaction, property, and dynamics of confined and deconfined QCD matter

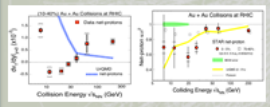
STAR HIGHLIGHTS at QM2014

May 18 - 24, 2014, Darmstadt

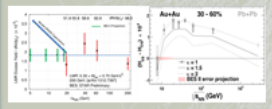
QCD Phase Structure and Beam Energy Scan at RHIC



- **Recently released:**
  - (1) May 19, 15:00-15:20, Europium [Collective dynamics] Md. Rihan Haque *"Elliptic flow of light nuclei and identified hadrons, their centrality and energy dependence in STAR"*
  - (2) May 21, 10:20-10:40, Helium [Thermodynamics and hadron chemistry] Lokesh Kumar *"Systematics of the kinetic freeze-out properties in high-energy nuclear collisions from STAR"*
  - (3) May 21, 11:10-11:30, Helium [QCD phase diagram] Amal Sarkar *"Energy dependence of higher moments of net-kaon, net-proton and net-charge multiplicity distribution at STAR"*

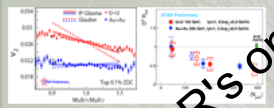


- **New at QM2014:**
  - (1) May 19, 11:00-11:20, Helium [Electromagnetic probes] Patrick Huck *"Beam energy dependence of dielectron production in Au+Au collisions from STAR at RHIC"*
  - (2) May 20, 9:20-9:40, Helium [QCD phase diagram] Ling Zhao *"$\Lambda(K_s^0)$-h± azimuthal correlations with respect to event plane and searches for chiral magnetic and vortical effects at STAR"*
  - (3) May 20, 10:00-10:20, Helium [QCD phase diagram] Qi-Ye Shou *"Charge asymmetry dependency of π/K anisotropic flow in U+U and Au+Au collisions at STAR"*
  - (4) May 21, 9:20-9:40, Helium [Thermodynamics and hadron chemistry] Xianglei Zhu *"Ω and φ production in p+p, Au+Au and U+U collisions at STAR"*

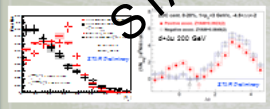


References: PRL 110,142301(2013); PRL 112,032302(2014); PRL 112,162301(2014); arXiv: 1404.4693

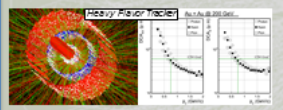
Initial State Physics, Penetrating Probes, sQGP Properties



- **Recently released:**
  - (1) May 19, 12:00-12:20, Titanium [Initial state physics] Hui Wang *"Flow measurements and selection of body-body and tip-tip enhanced samples in U+U collisions at STAR"*
  - (2) May 19, 12:00-12:20, Platinum [Heavy flavor] Zhenyu Ye *"Open charmed hadron production in p+p, Au+Au and U+U collisions at STAR"*
  - (3) May 20, 9:40-10:00, Platinum [Heavy flavor] Wangmei Zha *"Recent STAR measurements of J/ψ production from Beam Energy Scan and U+U collisions"*

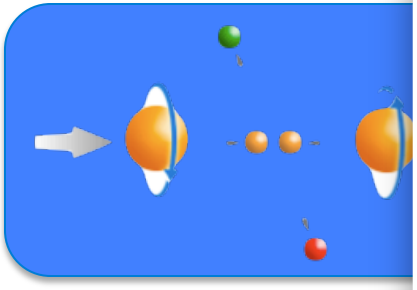


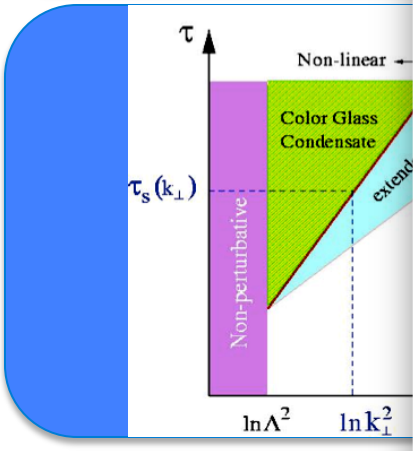
- **New at QM2014:**
  - (1) May 19, 14:40-15:00, Helium [Electromagnetic probes] Chi Yang *"Direct virtual photon and dielectron production in Au+Au collisions at 200 GeV at STAR"*
  - (2) May 19, 16:30-16:50, Helium [Electromagnetic probes] Ahmed M. Hamed *"Measurements of direct-photon-hadron correlations and direct-photon azimuthal anisotropy by STAR"*
  - (3) May 19, 17:30-17:50, Titanium [Initial state physics] LiYi *"Searching for the "Ridge" in d+Au collisions at RHIC by STAR"*
  - (4) May 21, 9:40-10:00, Titanium [Jets] Joern Putschke *"Semi-inclusive recoil jet distribution and di-jets imbalance measurements in central Au+Au collisions in STAR"*
  - (5) May 21, 11:50-12:10, Platinum [Future experimental facilities, upgrades, and instrumentation] Hao Qiu *"STAR Heavy Flavor Tracker"*

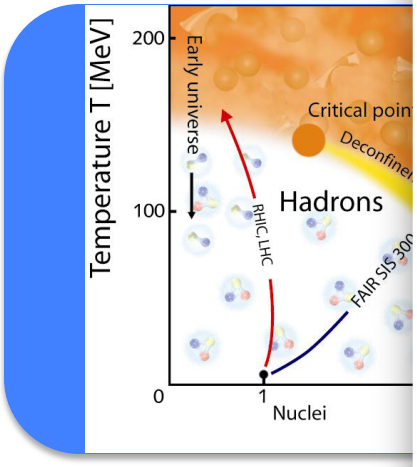


References: PRL 111,052301(2013); PRL 112,122301(2014); arXiv: 1312.7397; arXiv: 1404.6185

STAR's one-page handout to QM14 participants







eSTAR:

Polarized

e+p / e+A

Program

s, EoS

medium

n

oint

ation

Interaction, proper http://www.star.bnl.gov/central/publications/ **ed QCD matter**

RHIC/eRHIC Schedule

BNL document on transition to eRHIC, submitted to DOE in 10/2013

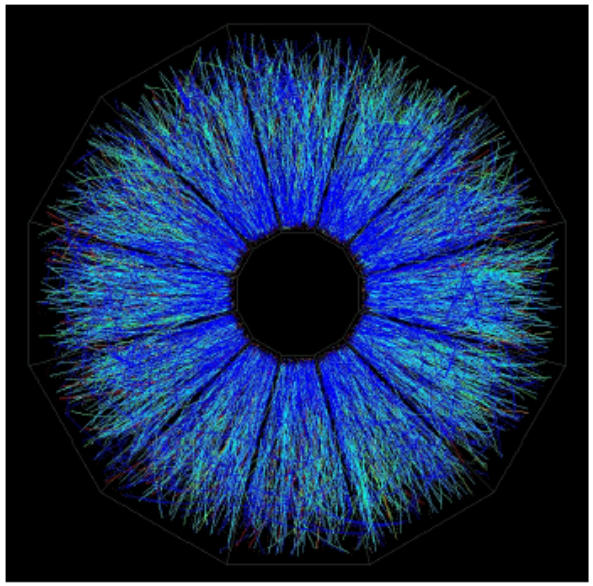
Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2014	15 GeV Au+Au 200 GeV Au+Au	Heavy flavor flow, energy loss, thermalization, etc. Quarkonium studies QCD critical point search	Electron lenses 56 MHz SRF STAR HFT STAR MTD
2015-16	p+p at 200 GeV p+Au, d+Au, ^{3}He+Au at 200 GeV High statistics Au+Au	Extract η/s(T) + constrain initial quantum fluctuations More heavy flavor studies Sphaleron tests Transverse spin physics	PHENIX MPC-EX Coherent e-cooling test
2017	No Run		Low energy e-cooling upgrade
2018-19	5-20 GeV Au+Au (BES-2)	Search for QCD critical point and onset of deconfinement	STAR ITPC upgrade Partial commissioning of sPHENIX (in 2019)
2020	No Run		Complete sPHENIX installation STAR forward upgrades
2021-22	Long 200 GeV Au+Au with upgraded detectors p+p, p/d+Au at 200 GeV	Jet, di-jet, γ-jet probes of parton transport and energy loss mechanism Color screening for different quarkonia	sPHENIX
2023-24	No Runs		Transition to eRHIC

Upgrade and Physics

- pp+pA+AA 2014-2016
  - heavy flavor, dilepton
  - transverse spin …
- BES II 2018-2019
- pp+pA+AA 2021-2022
- eRHIC 2025+

RHIC Beam Use Request
For Runs 15 and 16

The STAR Collaboration



June 2, 2014

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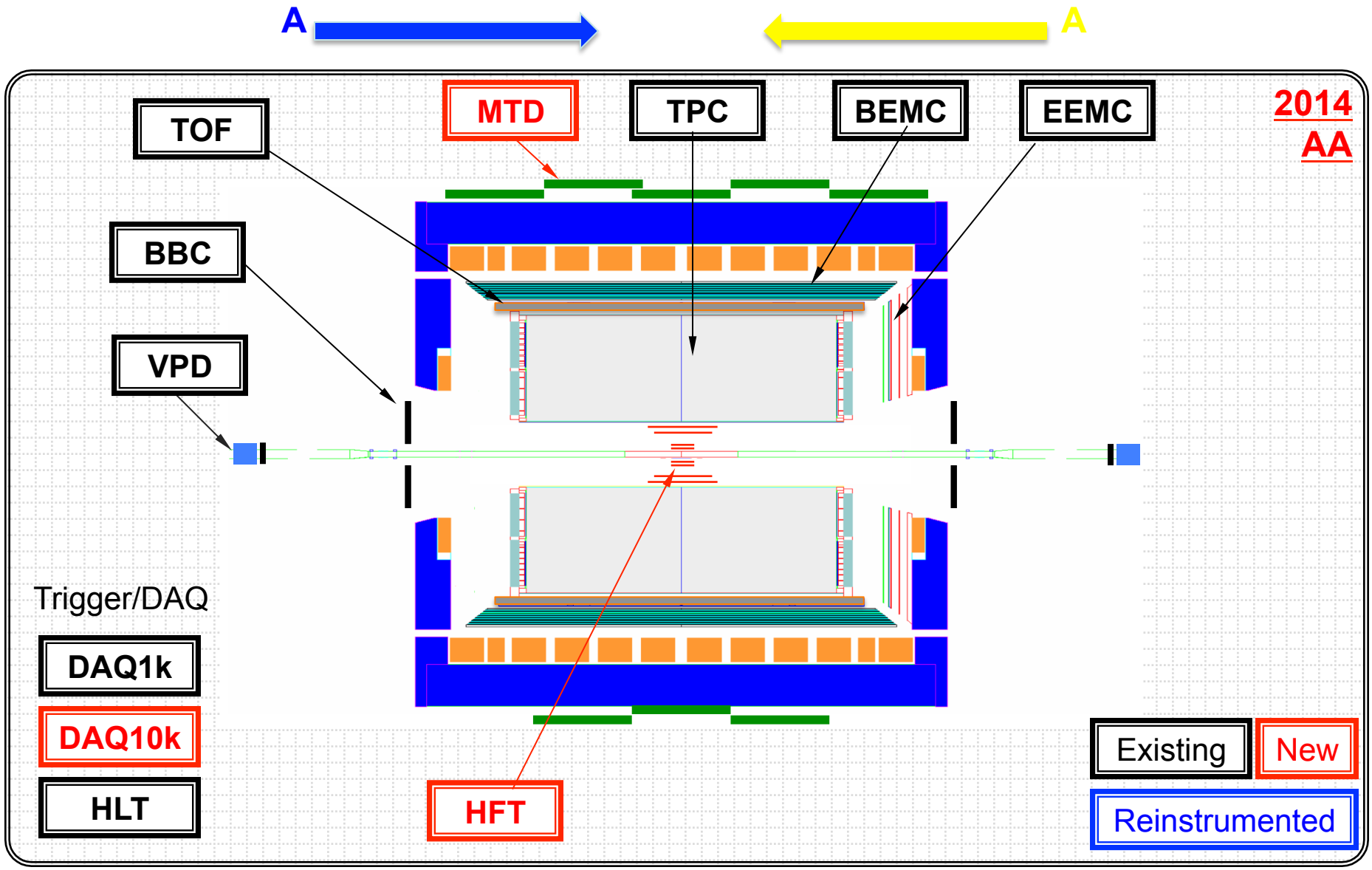
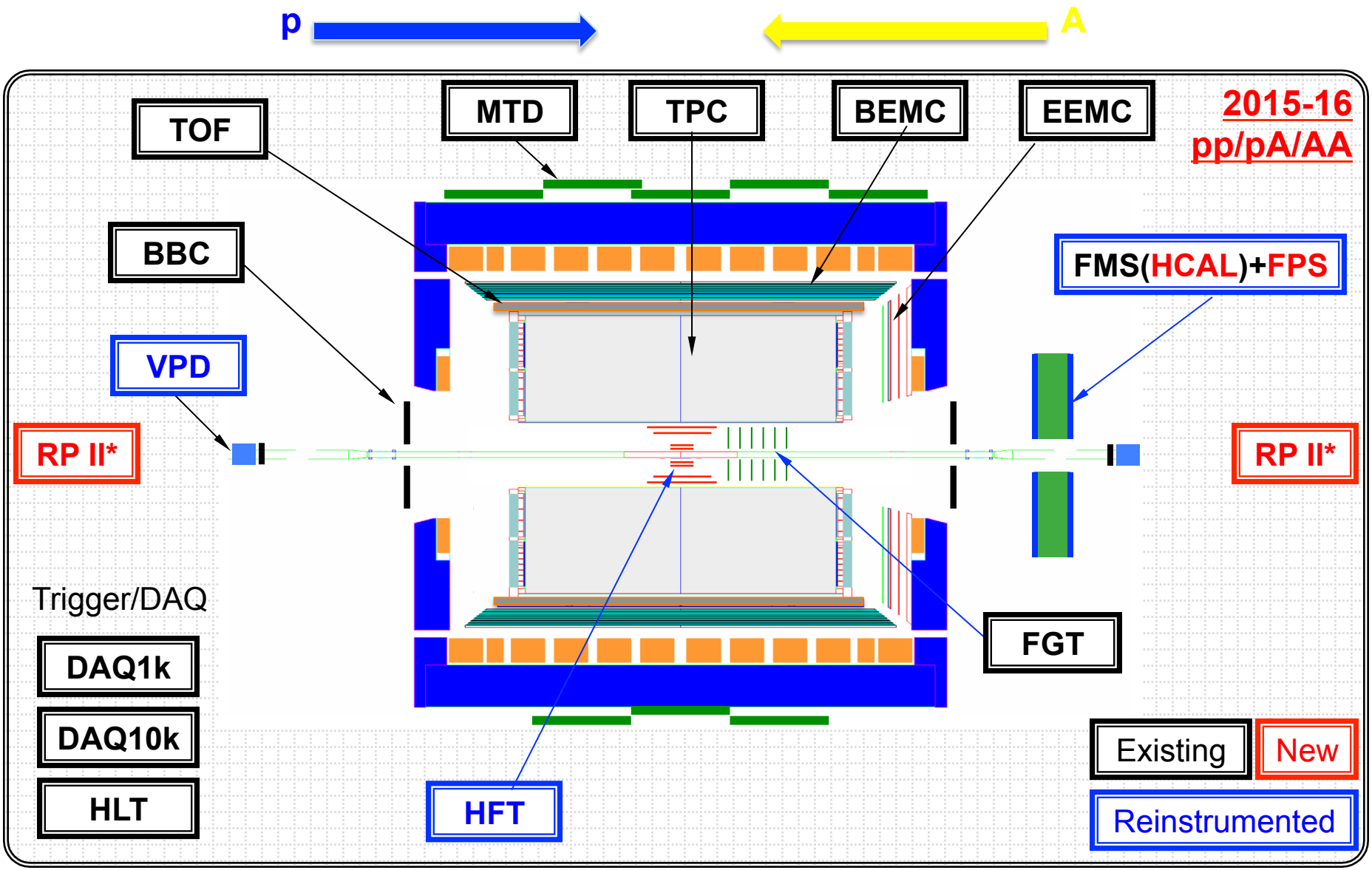
https://drupal.star.bnl.gov/STAR/starnotes/public/sn0606

STAR Detector in 2014



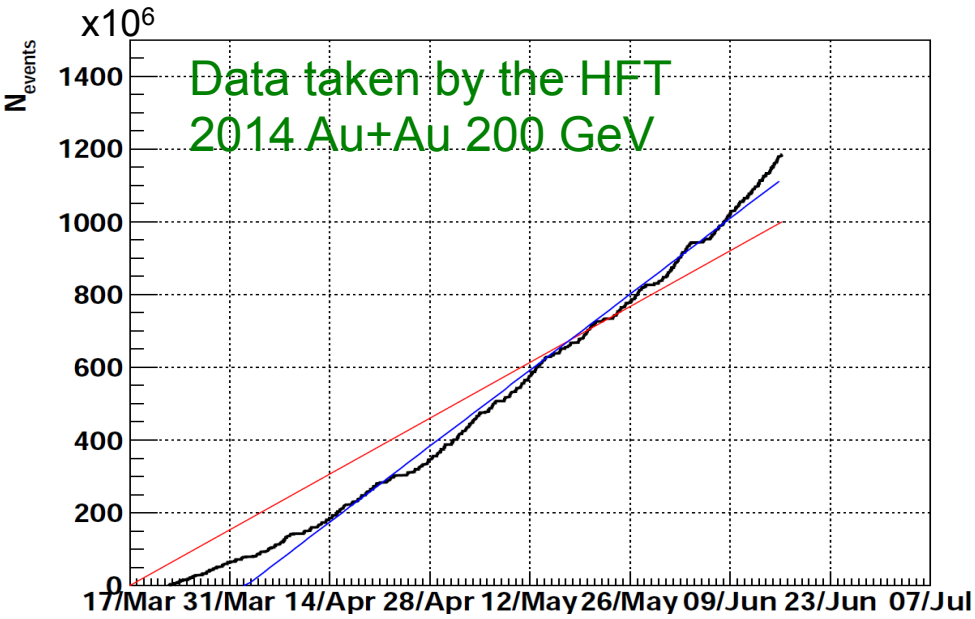
See Flemming Videbaek's talk on Thursday

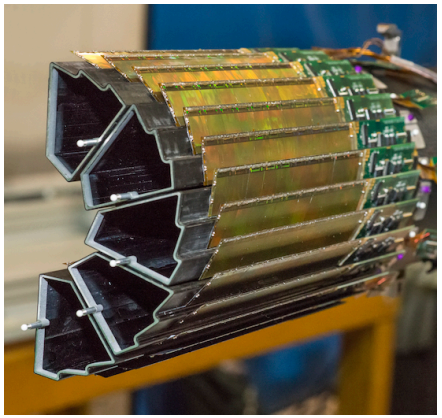
STAR Detector in 2015-2016

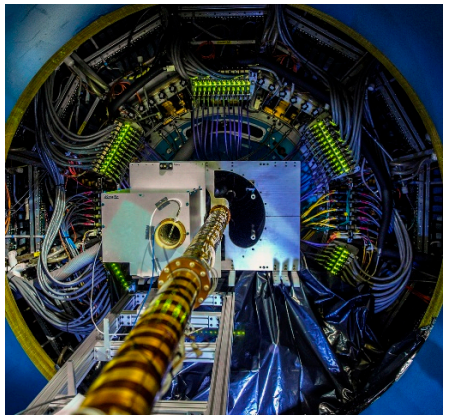


FMS: Forward Meson Spectrometer, **FPS**: Forward Preshower, **RP II***: Roman Pot Phase II*

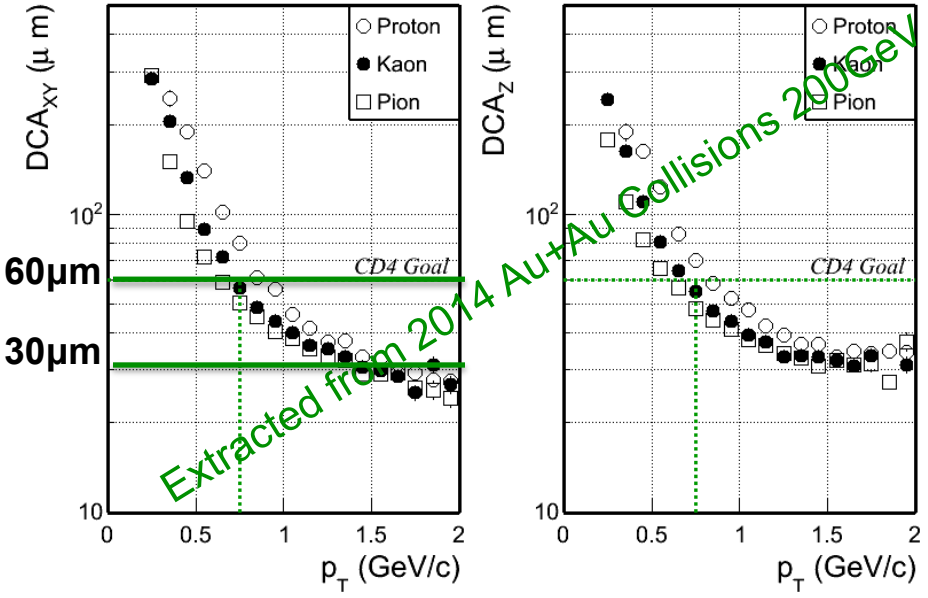
Heavy Flavor in 2014-2016

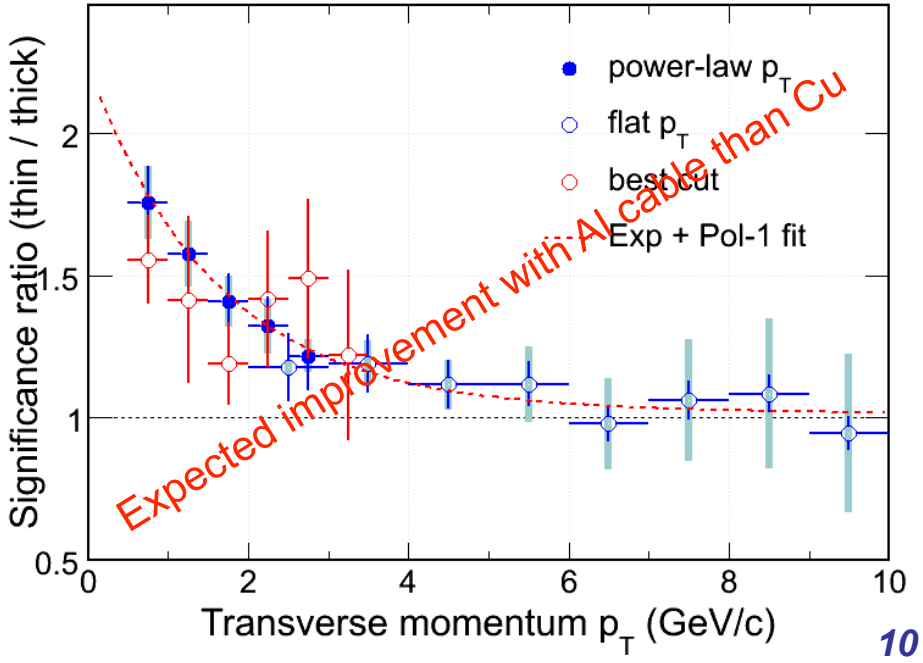




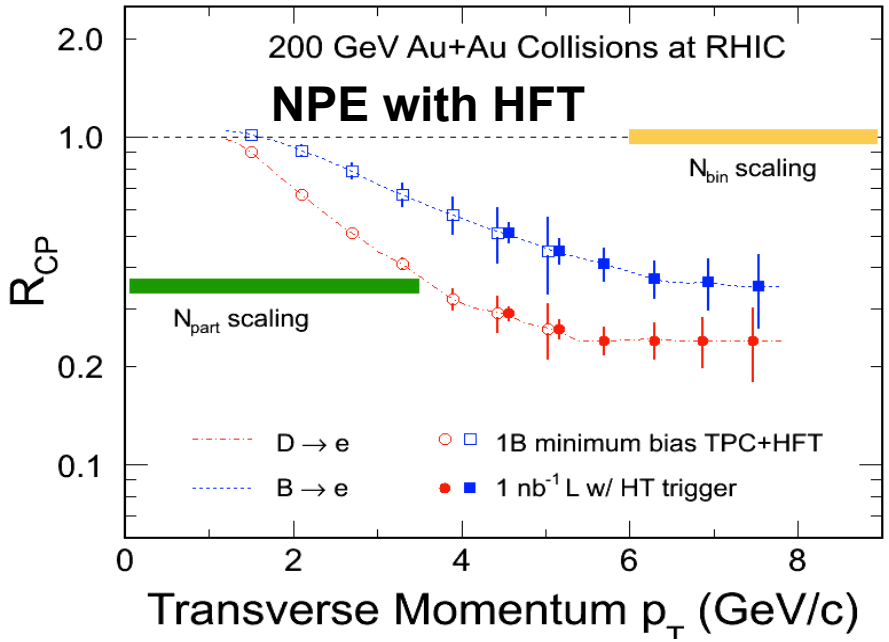


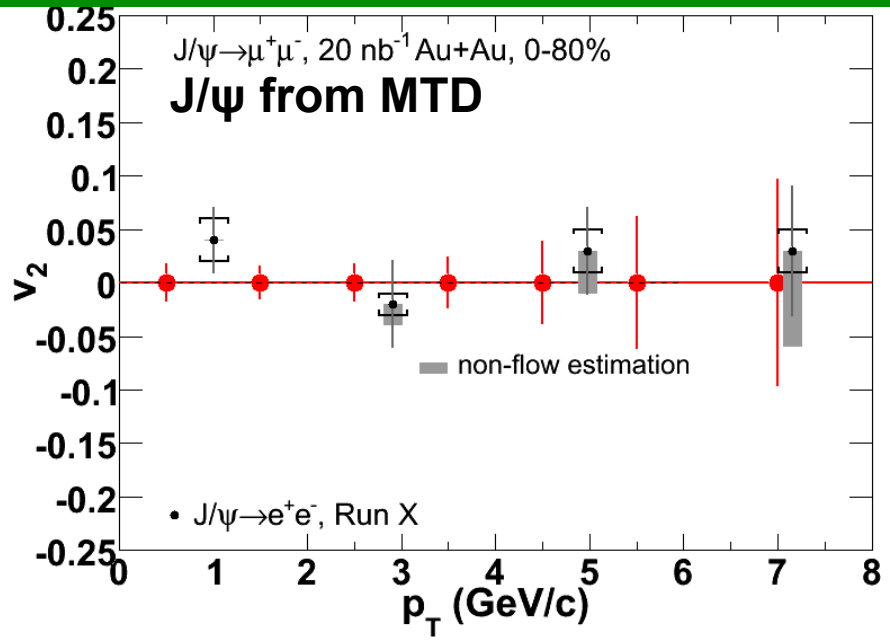
PXL with Al cable and VPD with new QT electronics in 15/16 -> F.O.M. x6 over 14

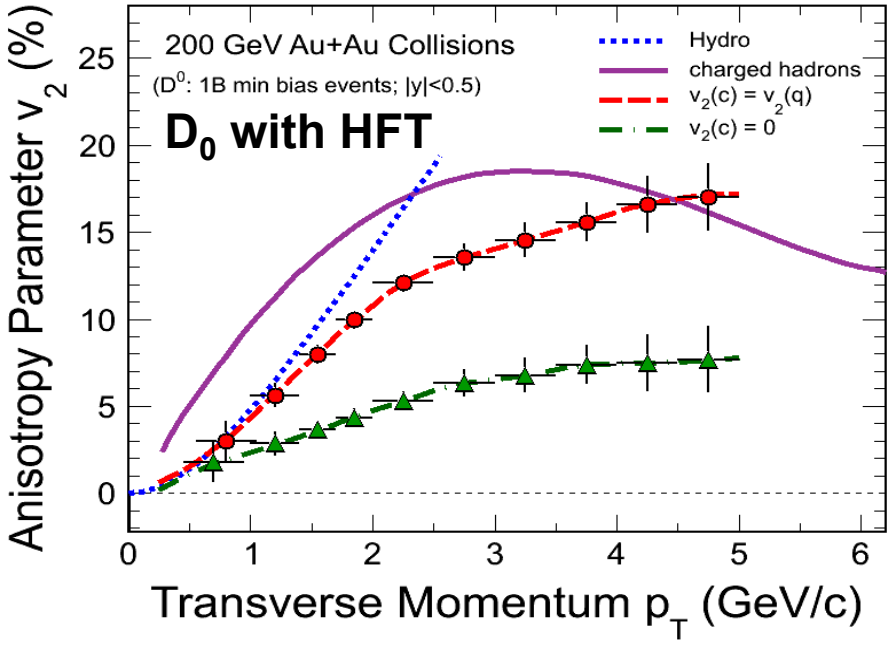


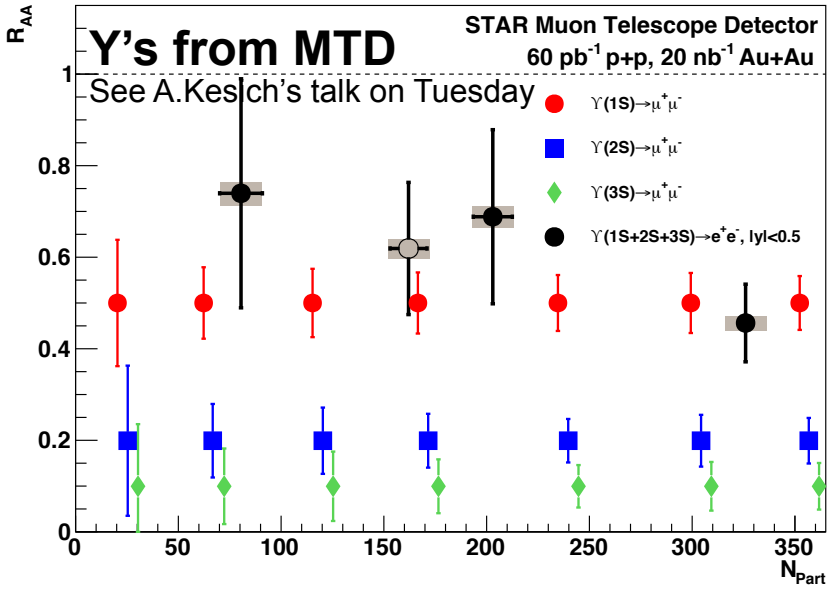


Heavy Flavor in 2014-2016



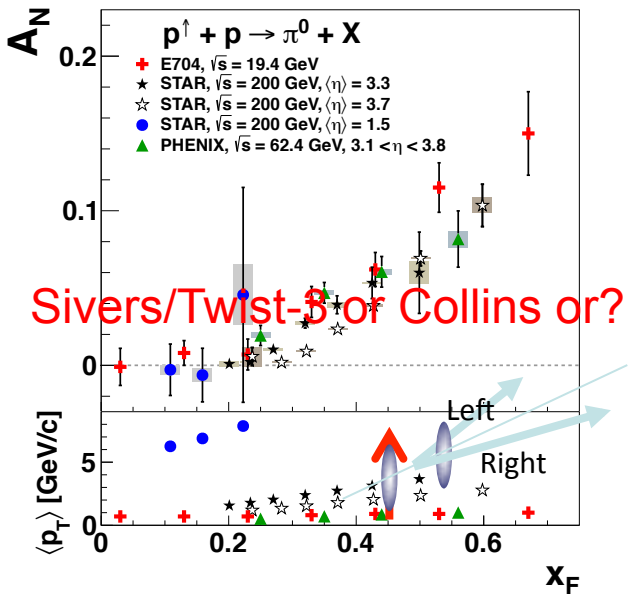






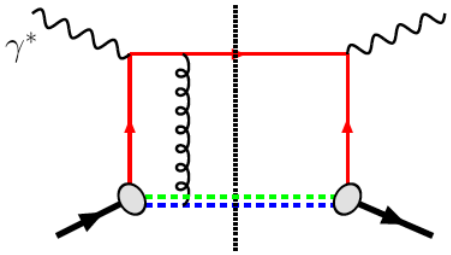
Transverse Spin in 2015-2016

Year	#	NSAC LRP Milestone
2013	HP8	Measure flavor-identified q and $\bar{q}$ contributions to the spin of the proton via the longitudinal-spin asymmetry of W production.
2013	HP12 (update of HP1, met in 2008)	Utilize polarized proton collisions at center of mass energies of 200 and 500 GeV, in combination with global QCD analyses, to determine if gluons have appreciable polarization over any range of momentum fraction between 1 and 30% of the momentum of a polarized proton.
2015	HP13 (new)	Test unique QCD predictions for relations between single-transverse spin phenomena in p-p scattering and those observed in deep-inelastic lepton scattering.

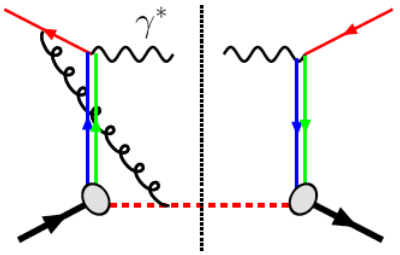


Sivers/Twist-3 or Collins or?

DIS:
gq-scattering
attractive FSI

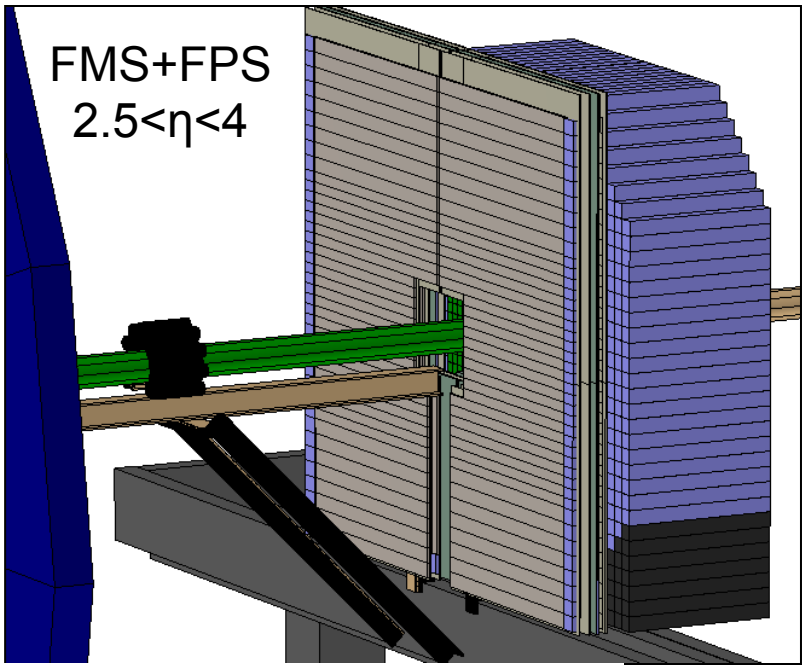


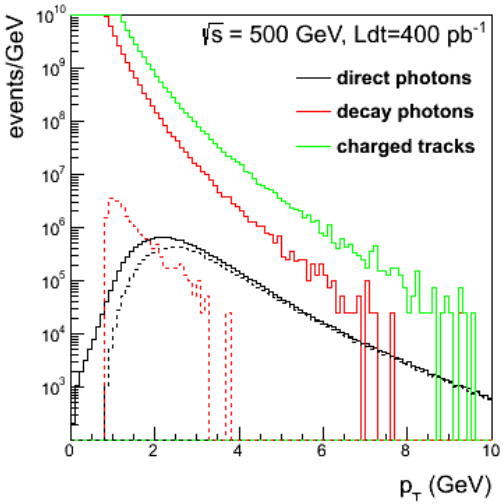
p+p:
qqbar-anhilation
repulsive ISI

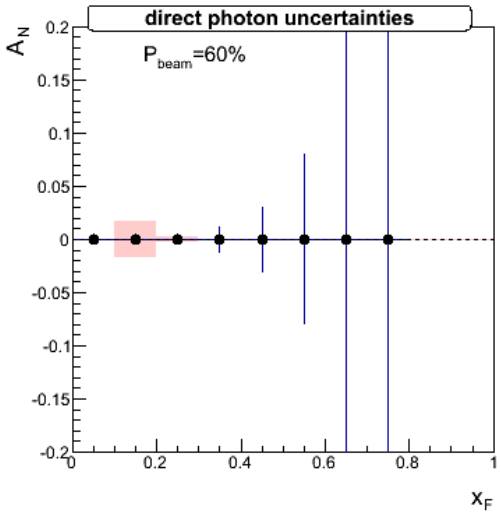


A_N of γ, $W^\pm$, DY are sensitive to the sign-change $W^\pm$/DY also to TMD evolution. STAR can access to all these three world-class measurements

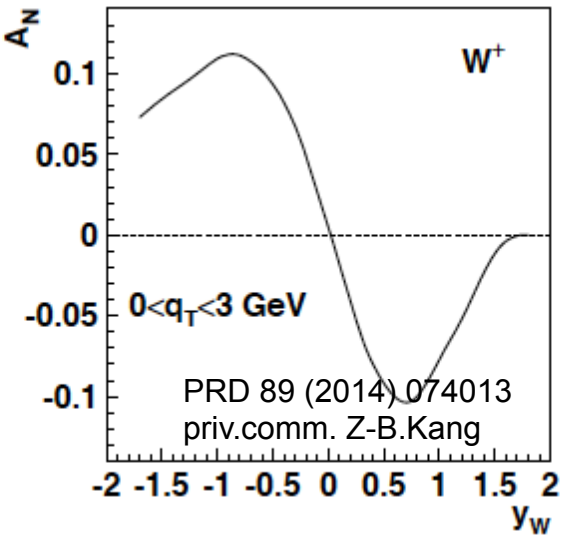
FMS+FPS in 2015-2016

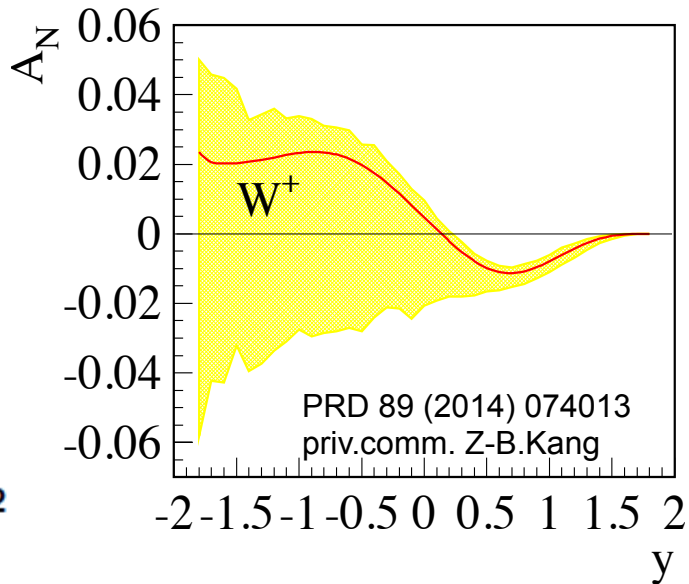


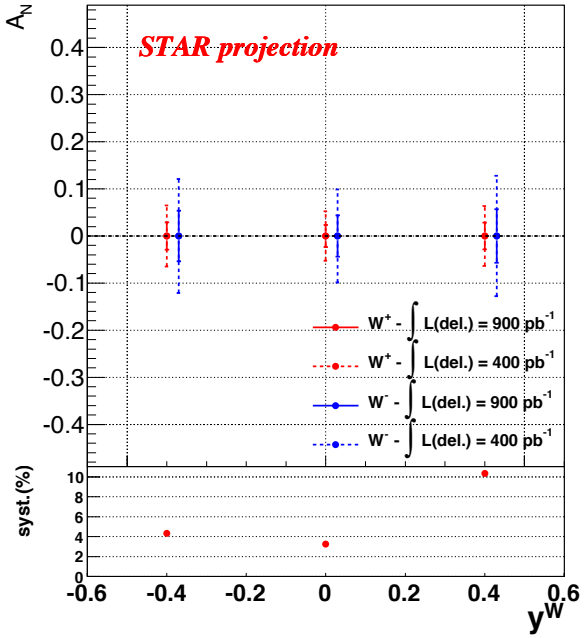




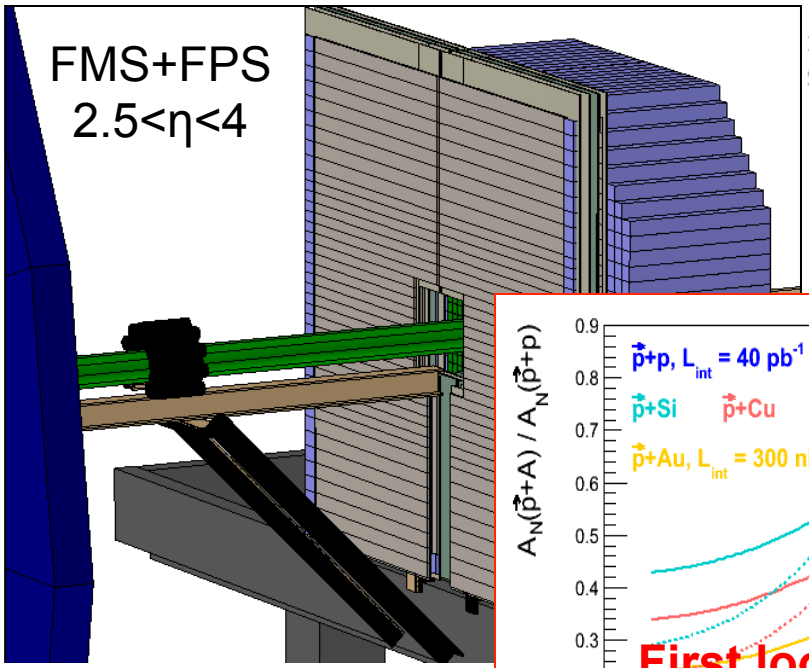
Solid: generated distributions
Dashed: reco. with FMS+FPS

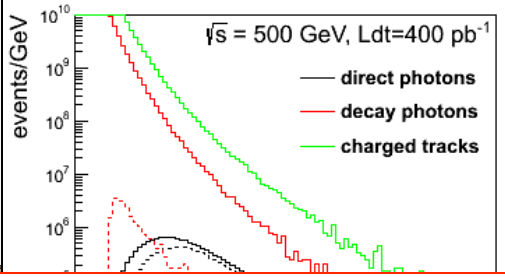


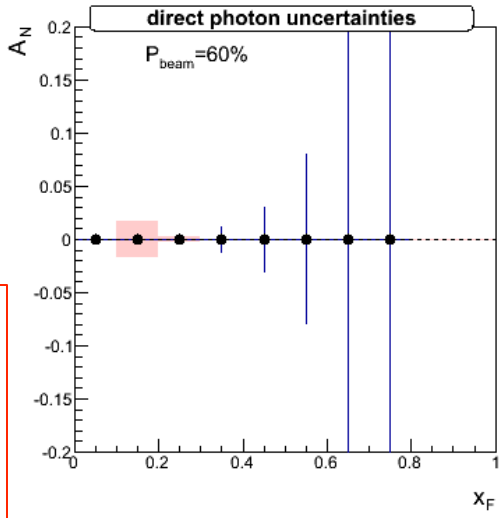


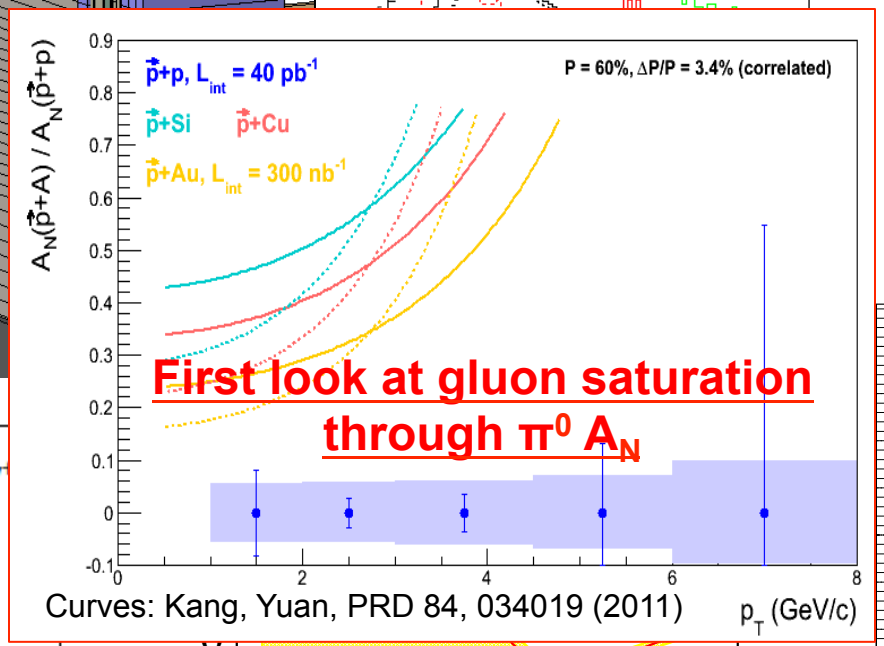


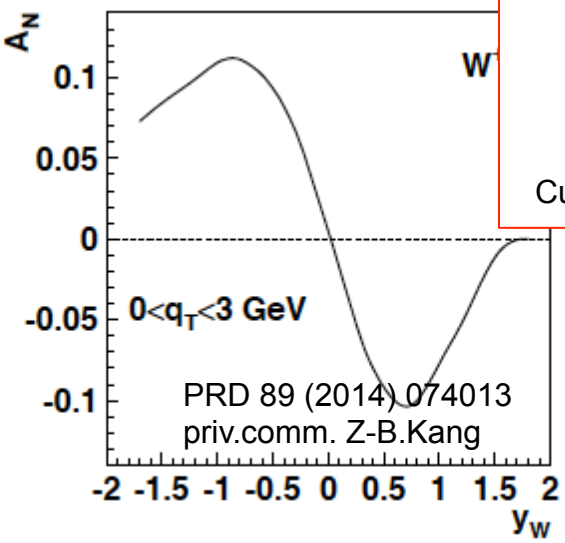
FMS+FPS in 2015-2016

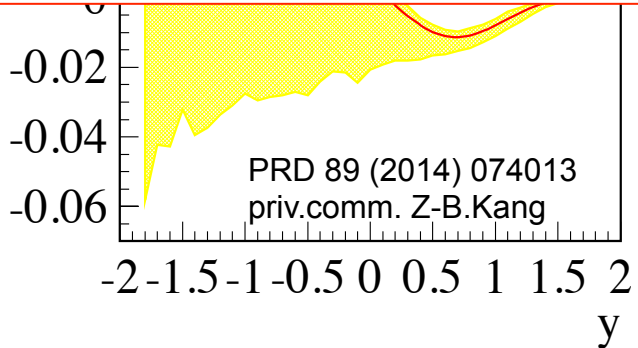


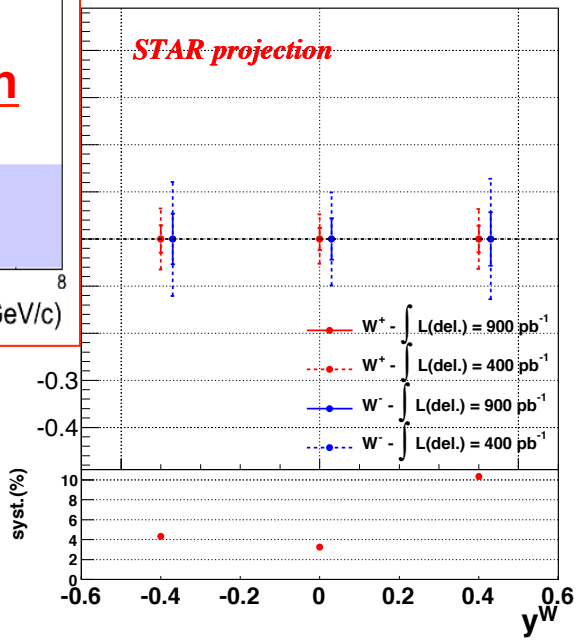




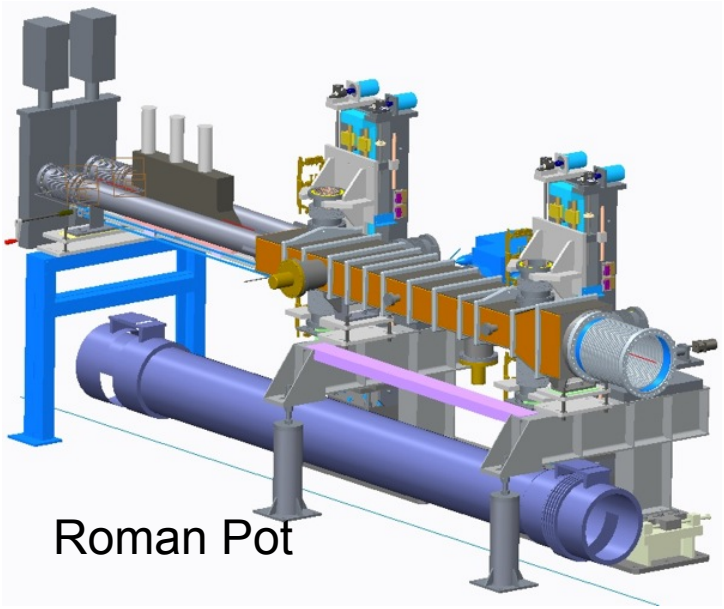


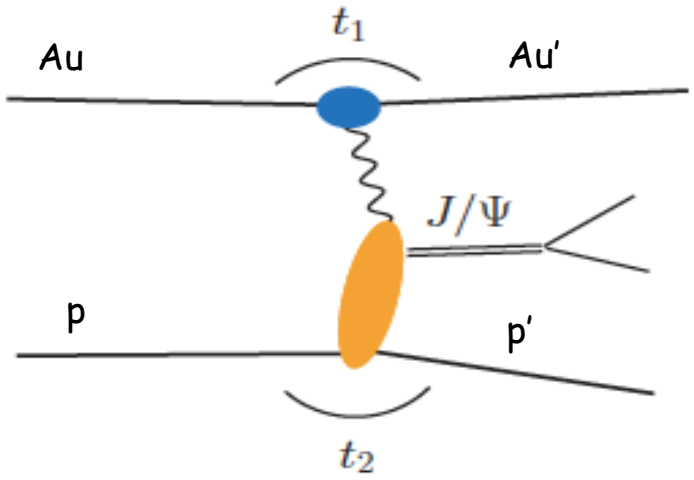




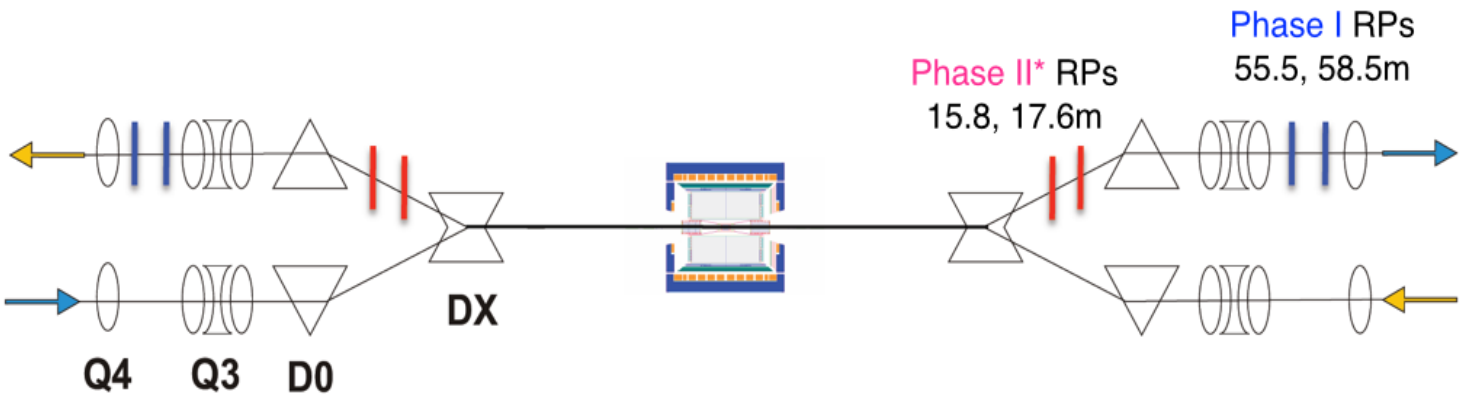


Roman Pot II* in 2015-2016



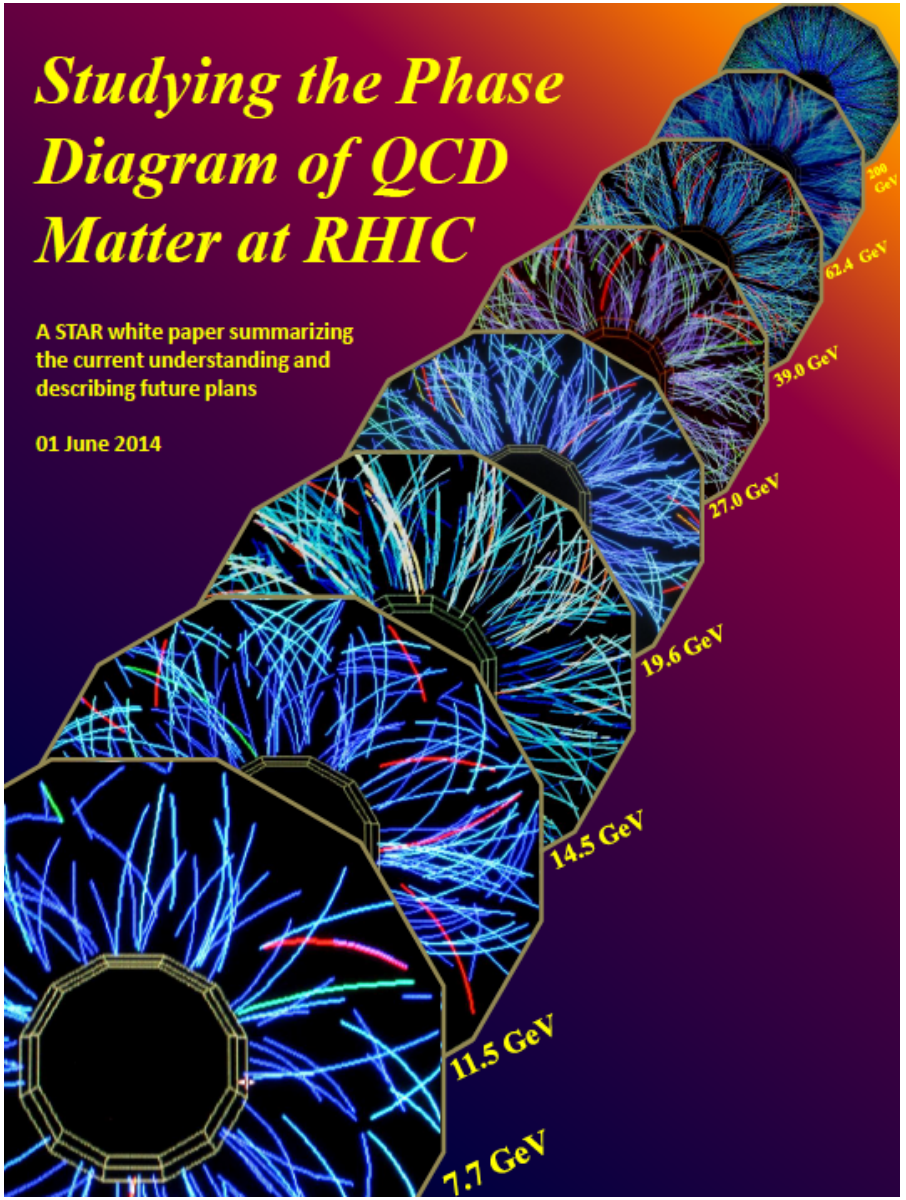


First access to gluon Generalized Parton Distributions (GPDs)



Upgrade and Physics

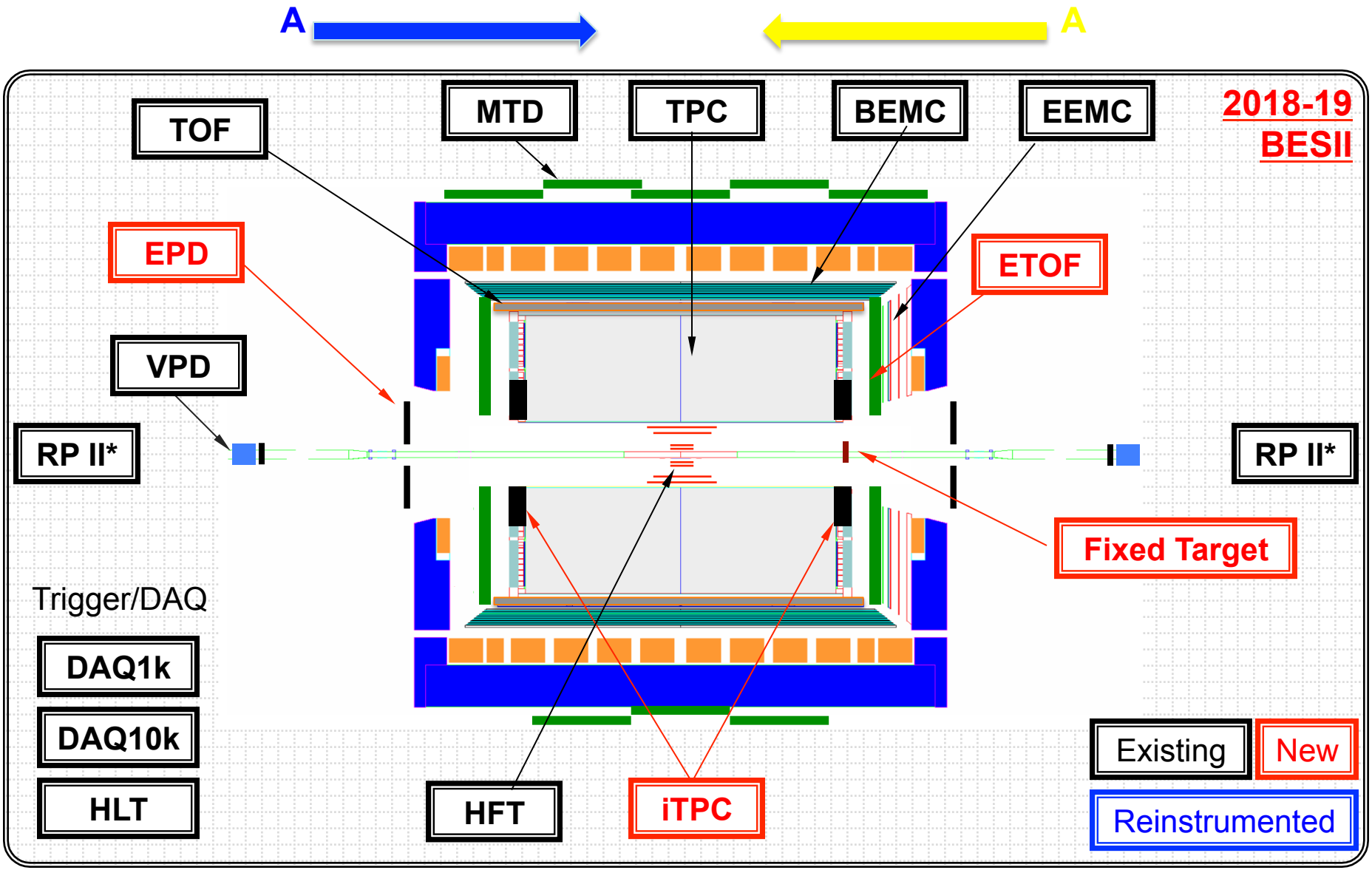
- pp+pA+AA 2014-2016
- BES II 2018-2019
  - QCD phase diagram
  - search for Critical Point
- pp+pA+AA 2021-2022
- eRHIC 2025+



See A. Schmah's talk this morning

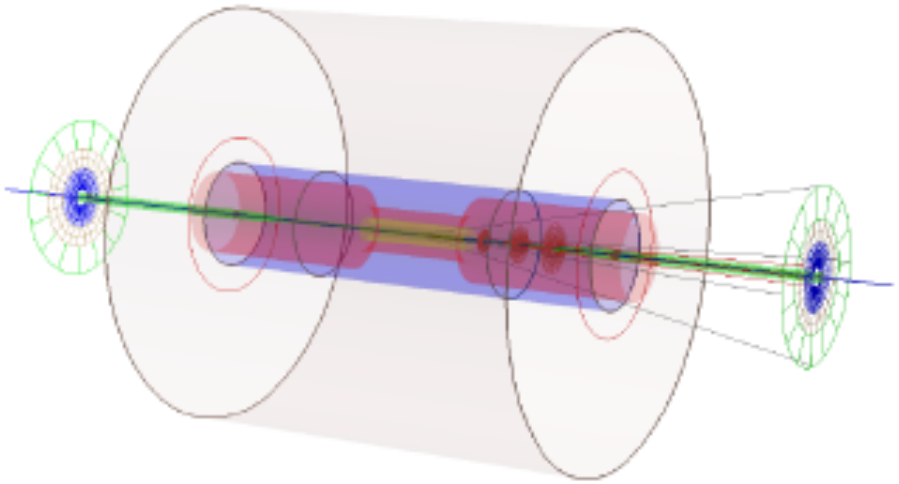
https://drupal.star.bnl.gov/STAR/starnotes/public/sn0598

STAR Detector in 2018-2019



iTPC: inner TPC, **EPD**: Event Plane and Centrality Detector, **ETOF**: End-cap TOF, **Fixed Target**

Proposed Upgrade for BES II



iTPC Upgrade:

- Rebuilds the inner sectors of the TPC
- Continuous Coverage
- Improves dE/dx
- Extends η coverage from 1.0 to 1.7
- Lowers p_T cut-in from 125 MeV/c to 60 MeV/c

EndCap TOF Upgrade:

Rapidity coverage is critical for several BES Phase II measurements

Particle Identification at forward rapidity is only possible with an end-cap TOF

Prototype modules will be available

EPS Upgrade:

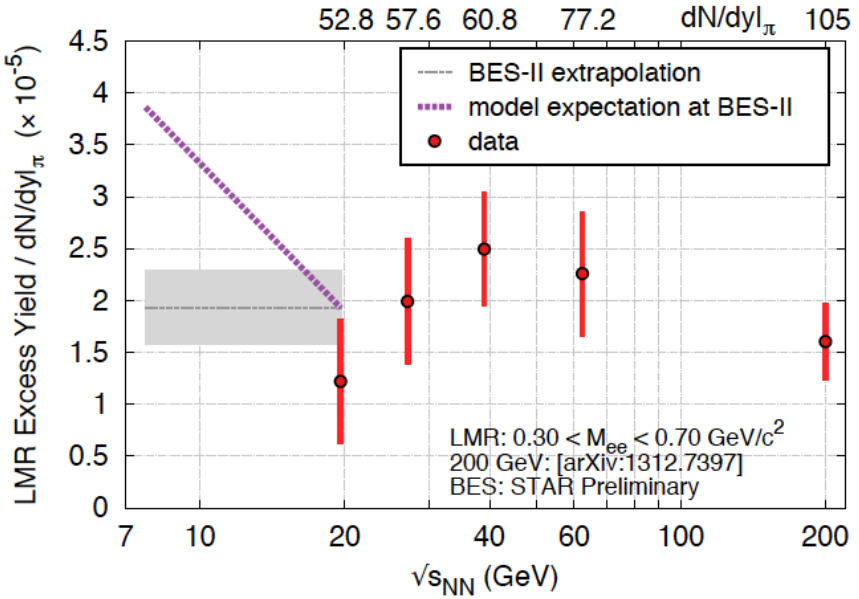
- For the 7.7 GeV system, in BES-I, 95% of STARs triggers were bad.

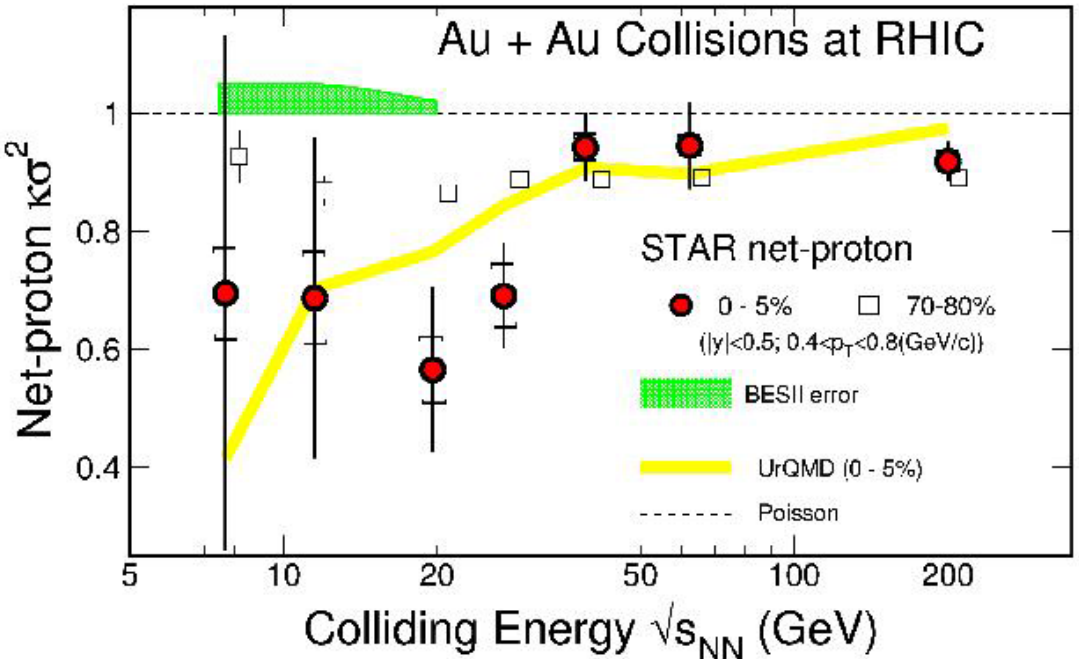
- Flow studies have been some of the most conclusive BES results. A better/independent reaction plane is critical to BES physics

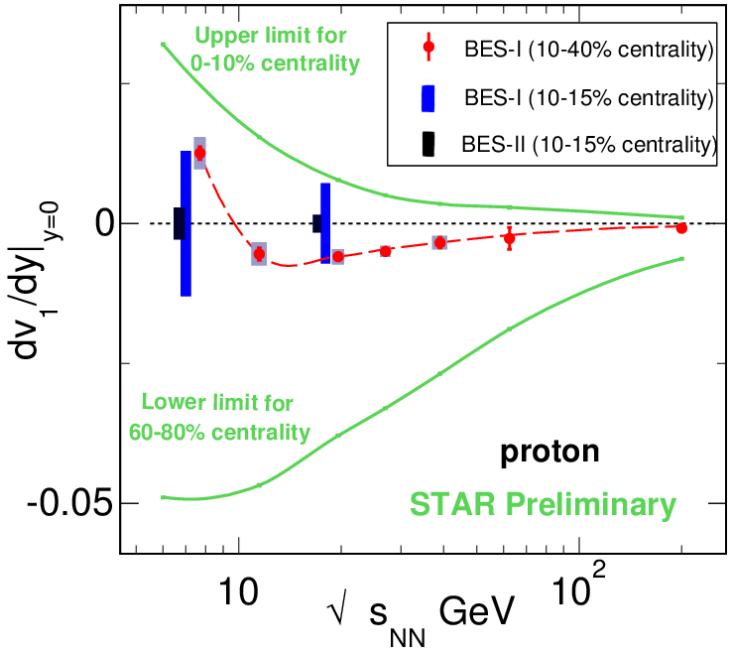
QCD Phase Diagram and BES II

BES Phase II is planned for two 22 cryo-week runs in 2018 and 2019

$\sqrt{s_{NN}}$ (GeV)	7.7	9.1	11.5	14.5	19.6
μ_B (MeV)	420	370	315	250	205
BES I (MEvts)	4.3	---	11.7	24	36
Rate(MEvts/day)	0.25*	0.6%	1.7*	2.4%	4.5*
BES I $\mathcal{L}$ (1×10^{25}/cm^{2}sec)	0.13	0.5%	1.5	2.1%	4.0
BES II (MEvts)	100	160	230	300	400
eCooling (Factor)	4	4	4	8	15(4)
Required Beam (weeks)	**14**	**9.5**	**5.0**	**2.5**	**3.0+**





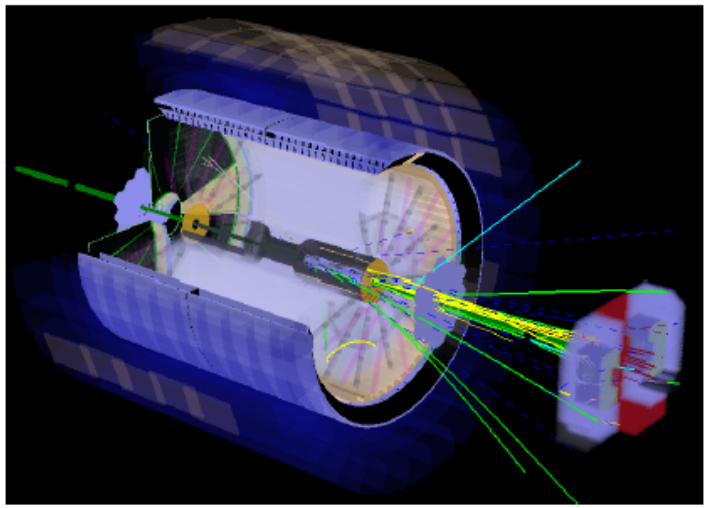


Upgrade and Physics

- pp+pA+AA 2014-2016
- BES II 2018-2019
- pp+pA+AA 2021-2022
  - proton structure
  - gluon saturation
  - QGP, CNM
  - HF, γ, DY, jets, $W^{\pm}$, …
- eRHIC 2025+

A polarized p+p and p+A program for the next years

The STAR Collaboration

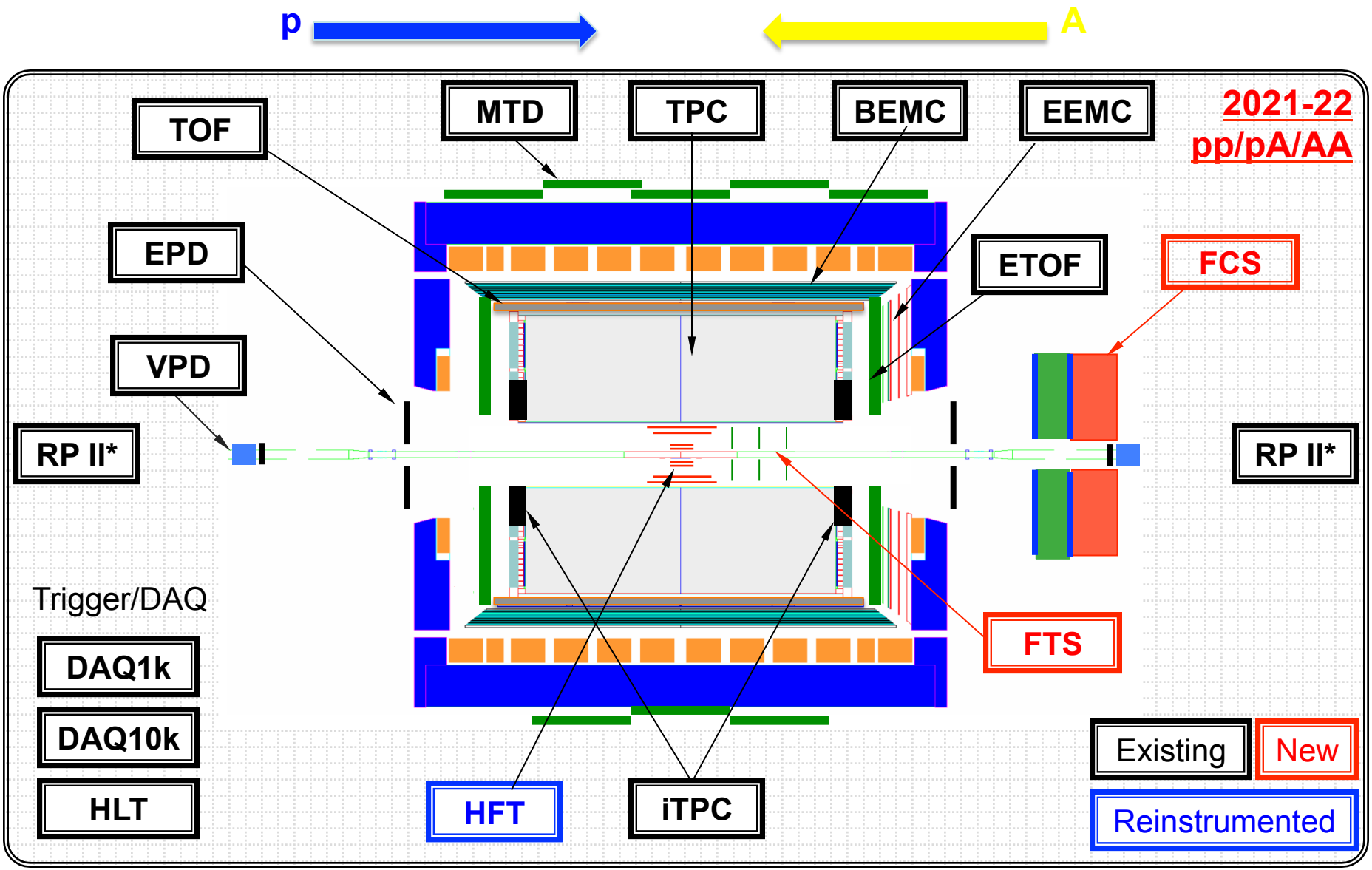


May 2014

1

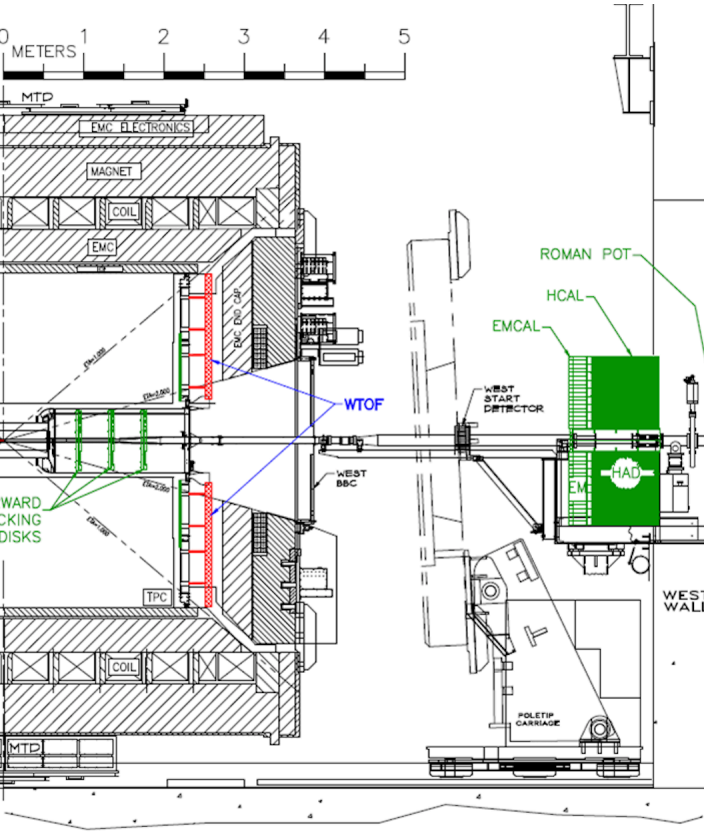
https://drupal.star.bnl.gov/STAR/starnotes/public/sn0605

STAR Detector in 2021-2022



FCS/FTS: Forward Calrimeter/Tracking System, **RP II**: Full Roman Pot Phase II

Forward Upgrade in 2019-2020



ECal:

Tungsten-Powder-Scintillating-fiber

2.3 cm Moliere Radius, Tower-size: 2.5x2.5x17 cm^3

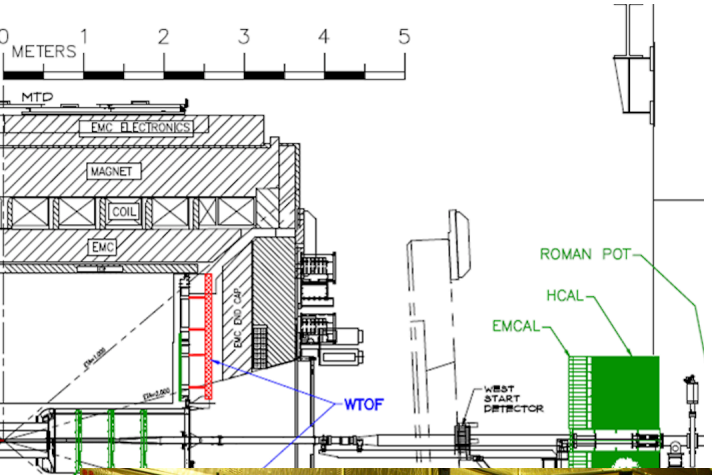
23 X_0

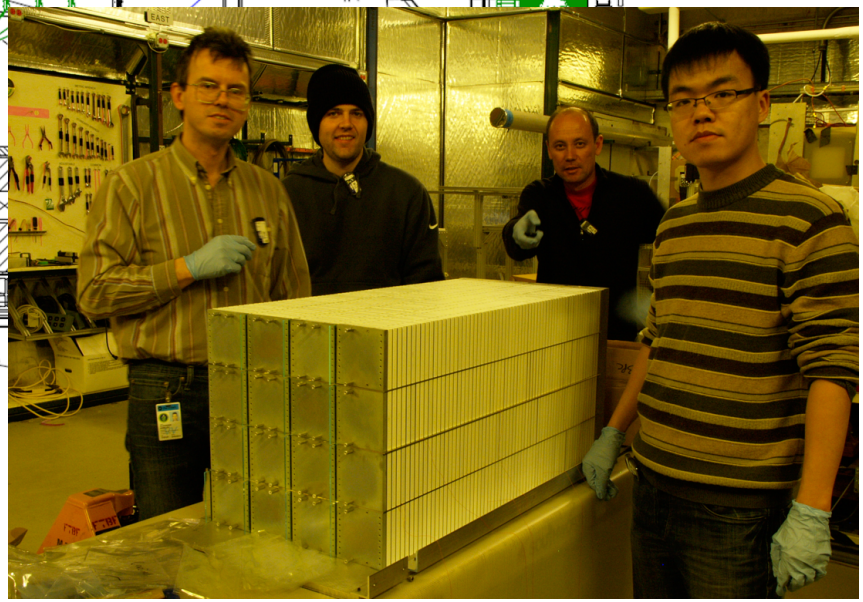
HCal:

Lead and Scintillator tiles, Tower size of 10x10x81 cm^3

4 interaction length

Forward Upgrade in 2019-2020





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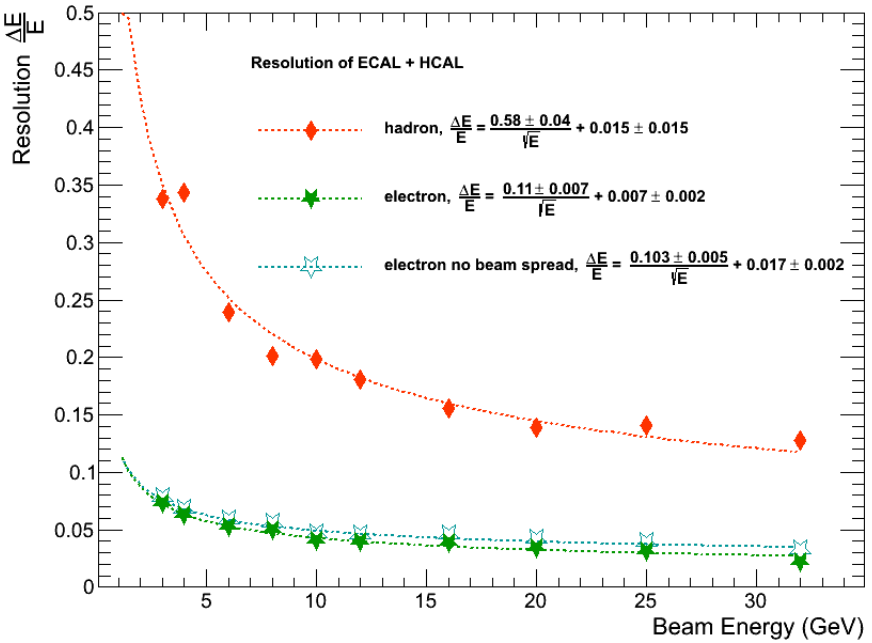
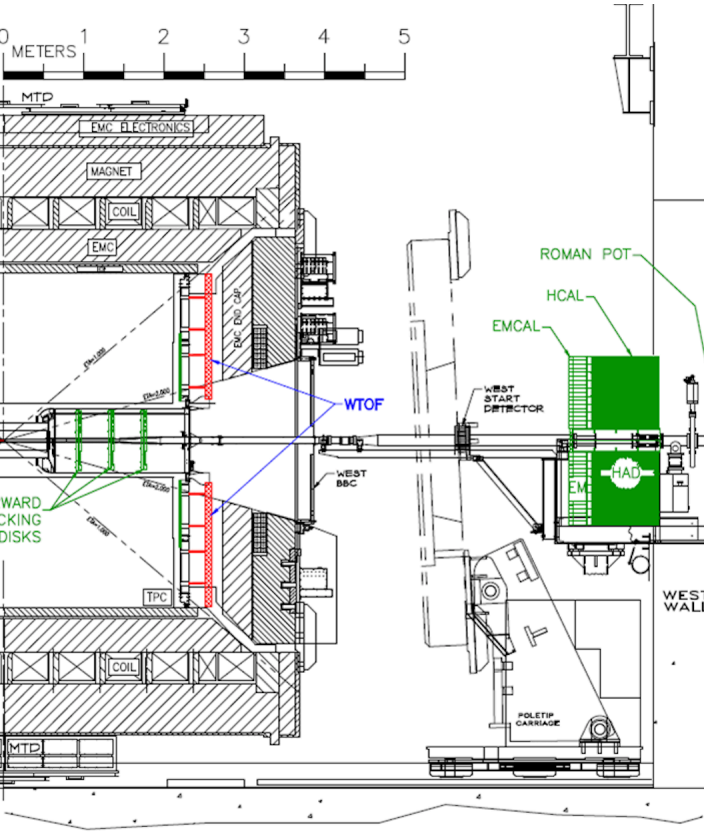
Latest Test-Beam results:



Forward Upgrade in 2019-2020



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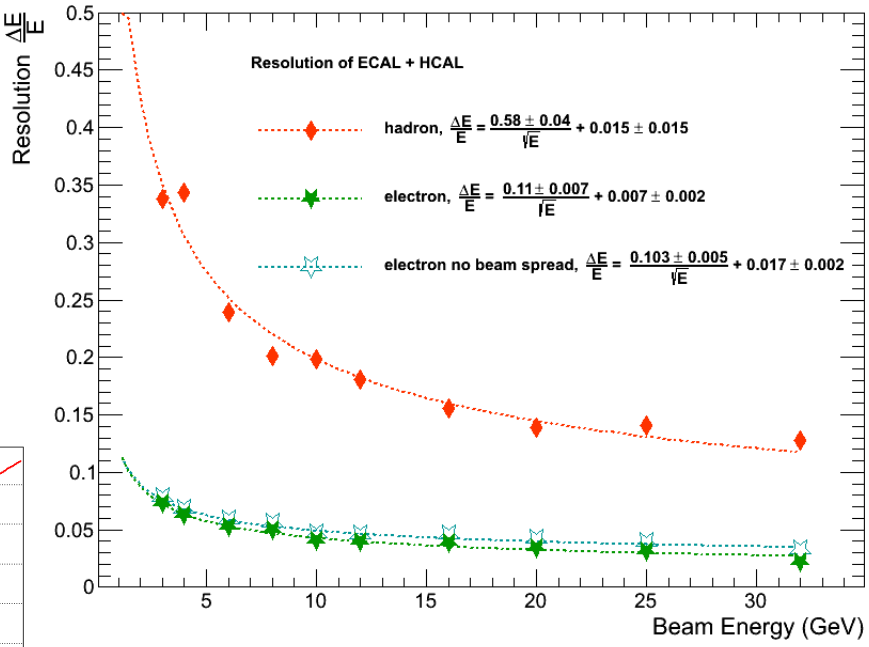
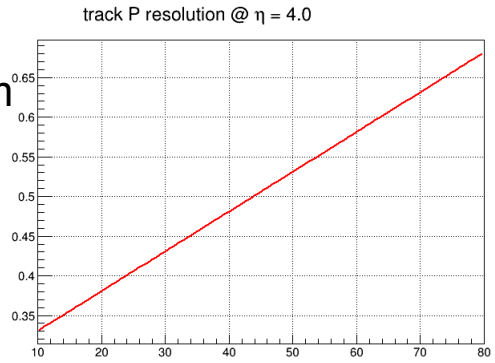


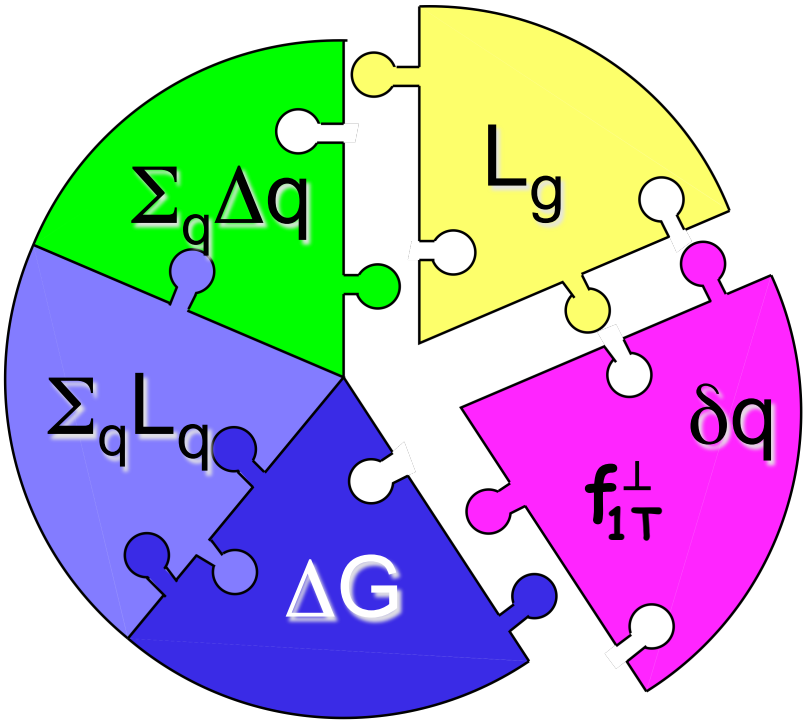
Forward Tracking:

→ Silicon mini-strip detector
3-4 disks at z ~70 to 140 cm
Each disk has wedges covering full 2π range in ϕ and 2.5-4 in η

→ GEM-based option/FGT also in consideration



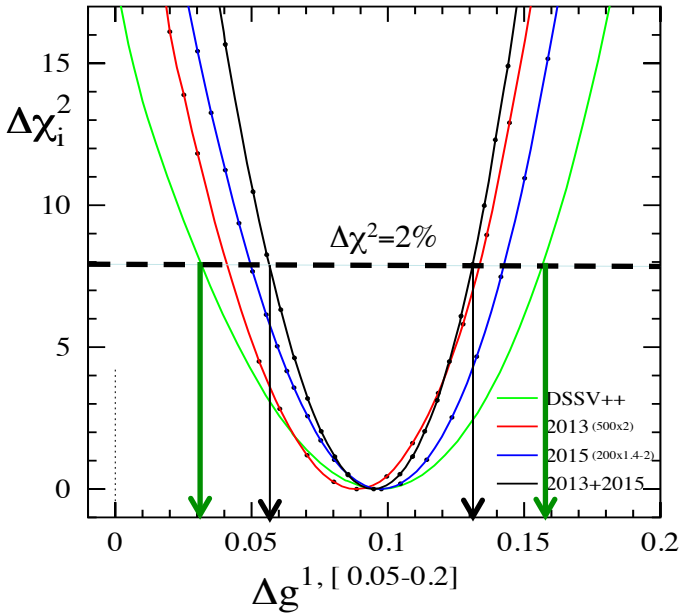
Proton Helicity Structure

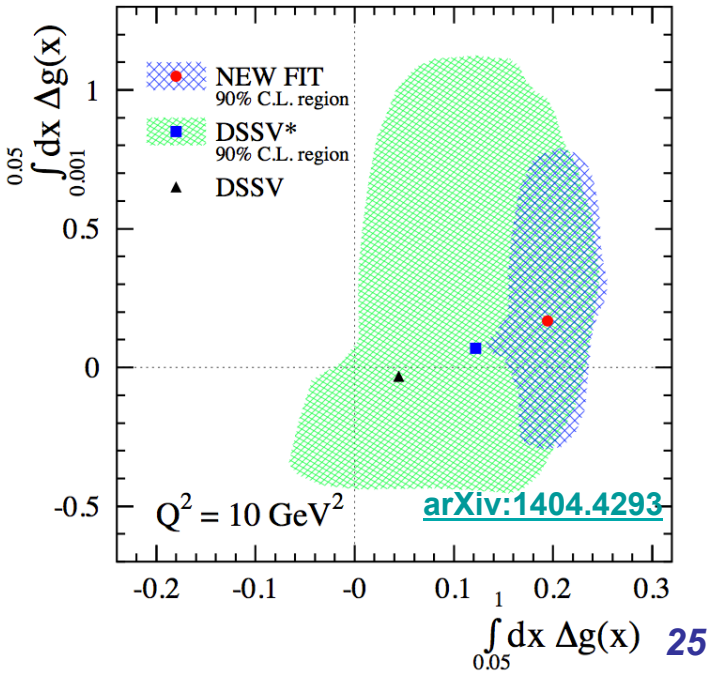


$$\frac{1}{2}\hbar = \left\langle P,\frac{1}{2}\left| J^z_{QCD} \right| P,\frac{1}{2}\right\rangle = \sum_q \frac{1}{2}S^z_q + S^z_g + \sum_q L^z_q + L^z_g$$

Contribution to proton spin to date: MISS at least 50%

Can quarks and gluons explain it all ?





Proton Helicity Structure

510 GeV Di-Jets, gamma-jet: constrain the shape of $\Delta g(x,Q^2)$ and go to lower x:

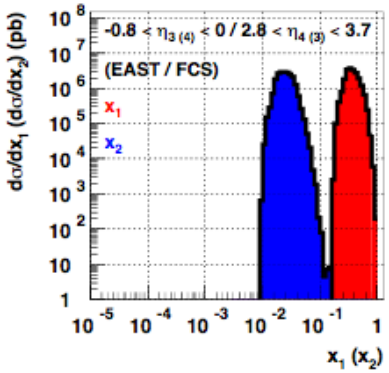
$\sqrt{s}=500\ GeV$

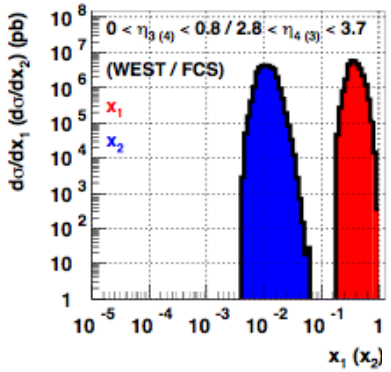
$-1<\eta<2$

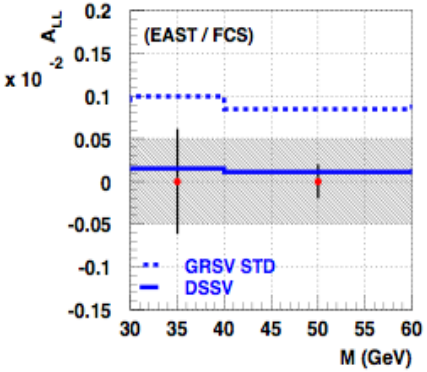
$2.8<\eta<3.7$

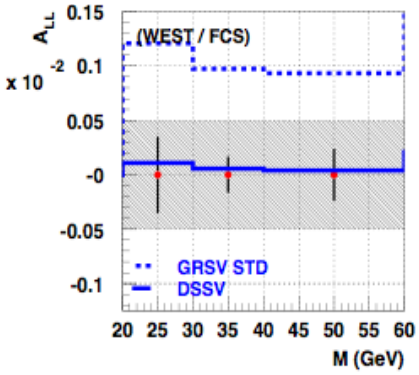
R_{cone}=0.7
E_{T1}>8 GeV
E_{T2}>5 GeV

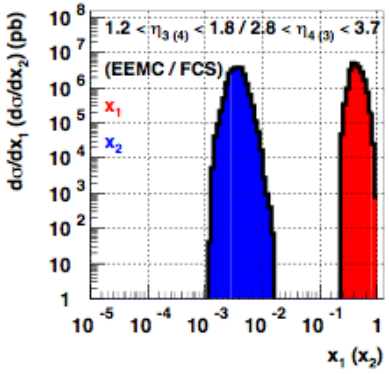
L=1fb^{-1}
P=60%

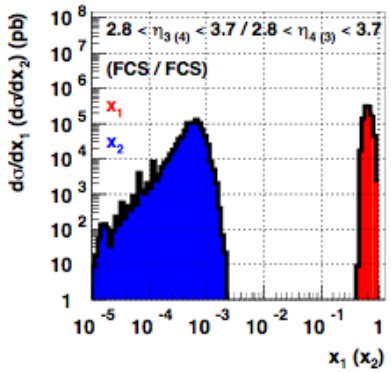


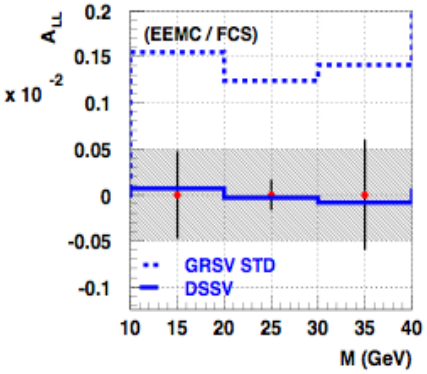


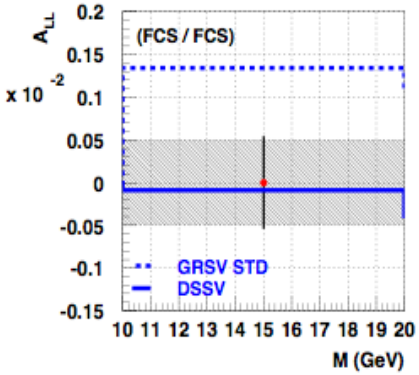






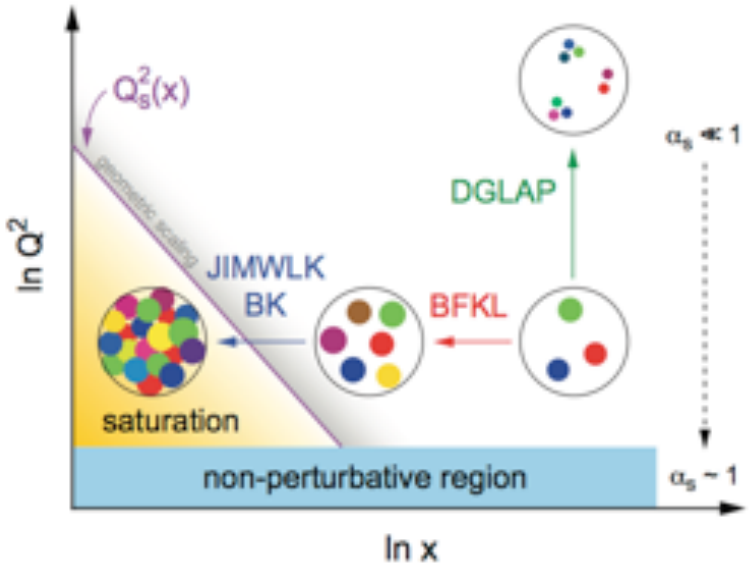


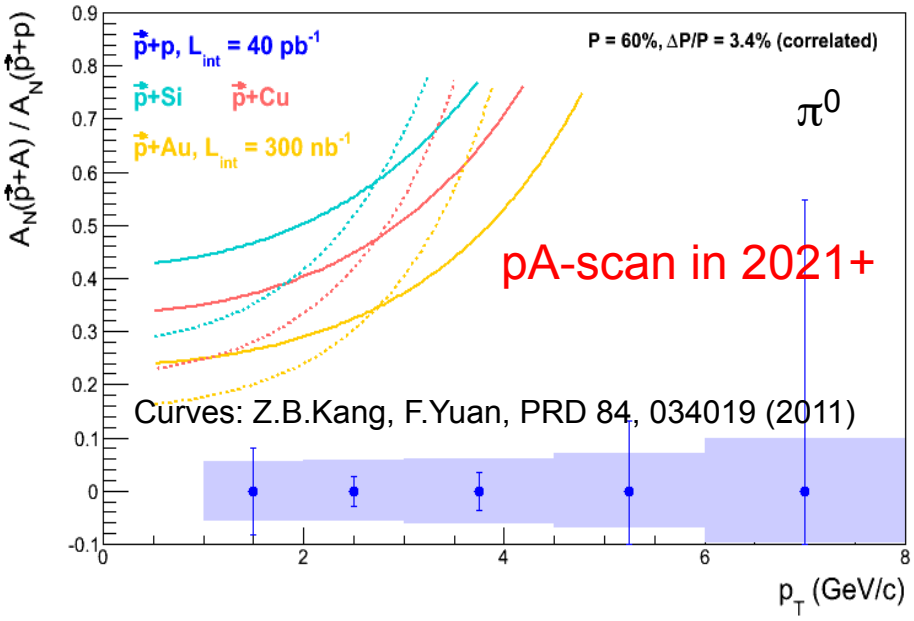




Utilize FCS + FTS: x: → 0.001

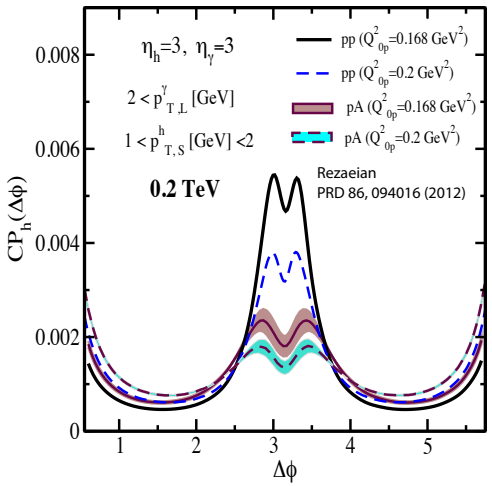
Gluon Saturation at Small-x

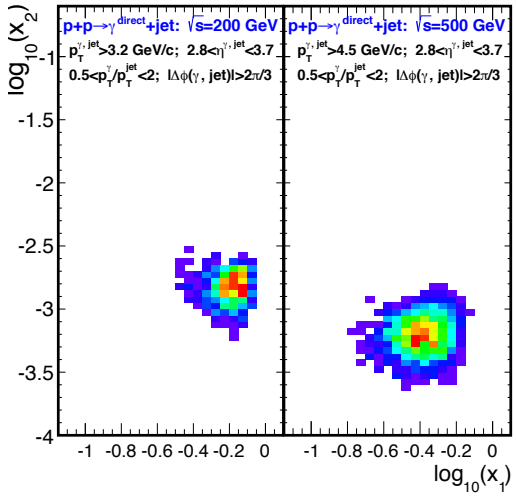




2021-2022 pA runs:

- A-scan to scan saturation scale and new channel: γ-jet correlation





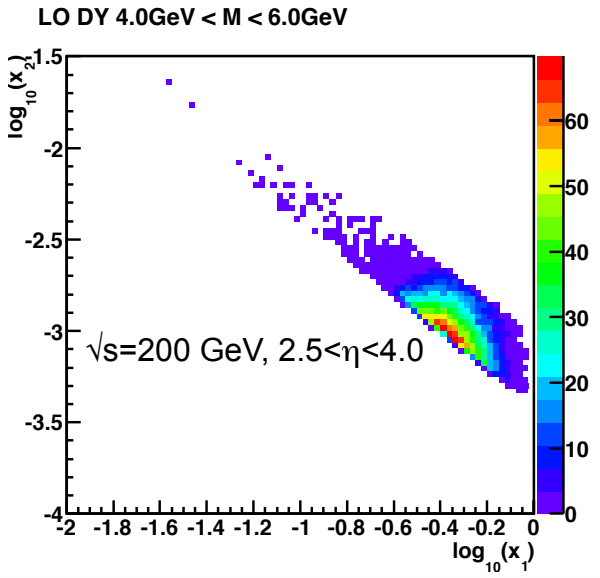
Cuts:
$|\phi_\gamma - \phi_{jet}| > 2\pi/3$
$0.5 < p_T^\gamma / p_T^{jet} < 2$. $2.8 < \eta < 3.7$
p_T>4.5 (3.2) GeV/c in 500 (200) GeV
photon isolation
→ signal-to-background 3:1

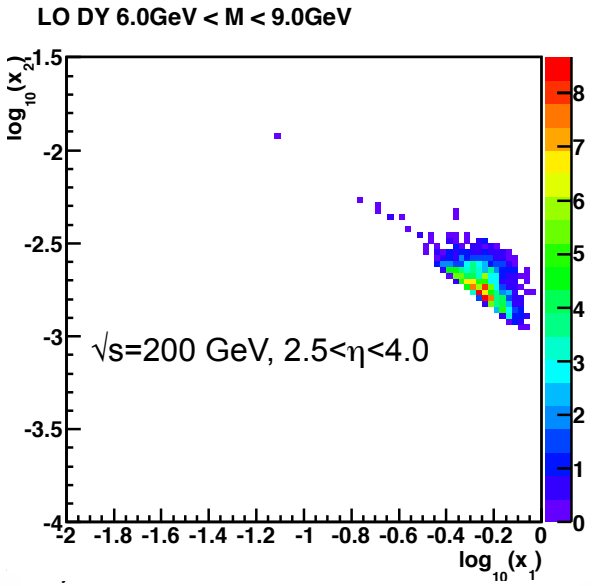
Statistics:
1.2 million with 500 pb^{-1} at √s=500 GeV.
100k with 500 pb^{-1} (2.5pb^{-1}) p+p (p+Au) at $\sqrt{s_{NN}}$=200 GeV..

Gluon Saturation at Small-x

Physics

DY-h correlations → saturation Stasto et al. PRD 86, 014009 (2012)



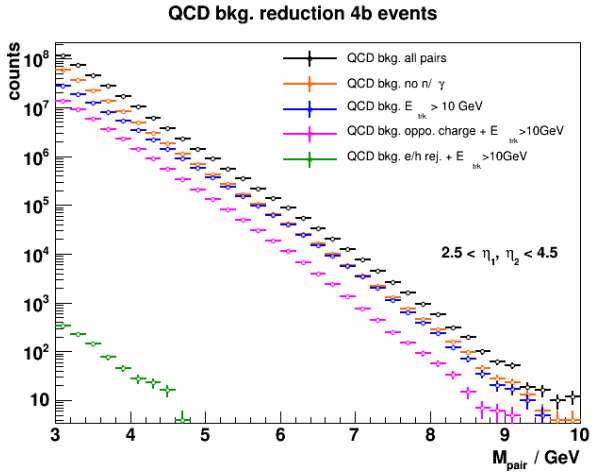


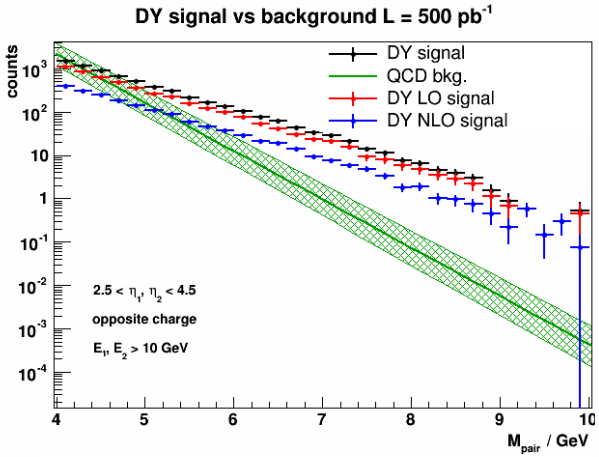
very challenging

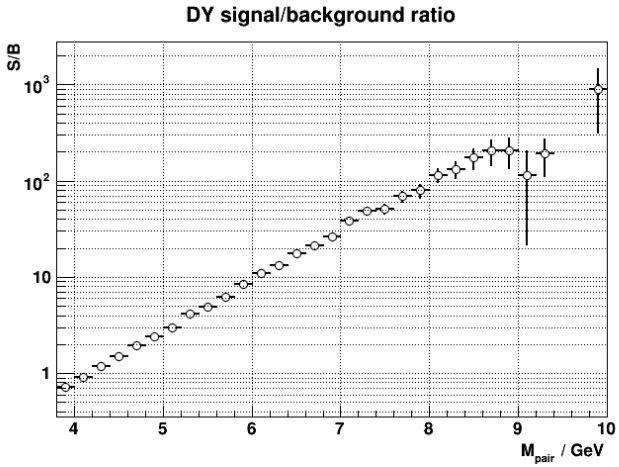
need big bkg. suppression

→ FCS + FTS

→ 2.5 pb^{-1} p+Au

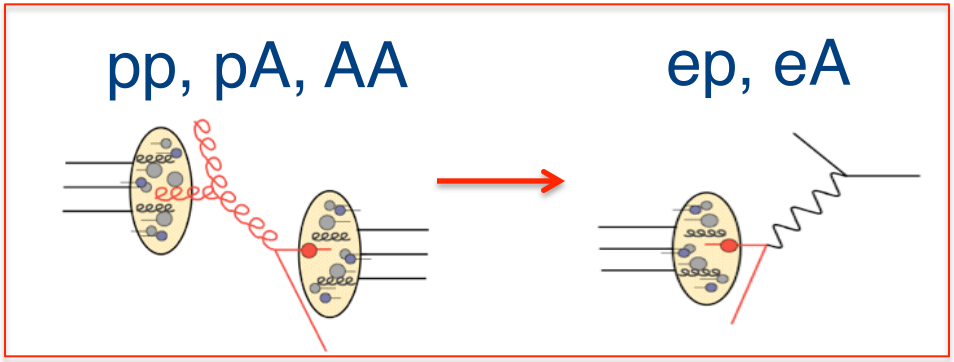






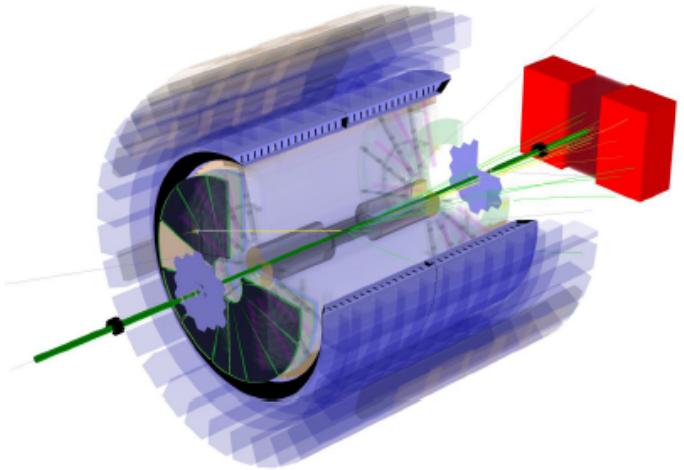
Upgrade and Physics

- pp+pA+AA 2014-2016
- BES II 2018-2019
- pp+pA+AA 2021-2022
- eRHIC 2025+



eSTAR: A Letter of Intent

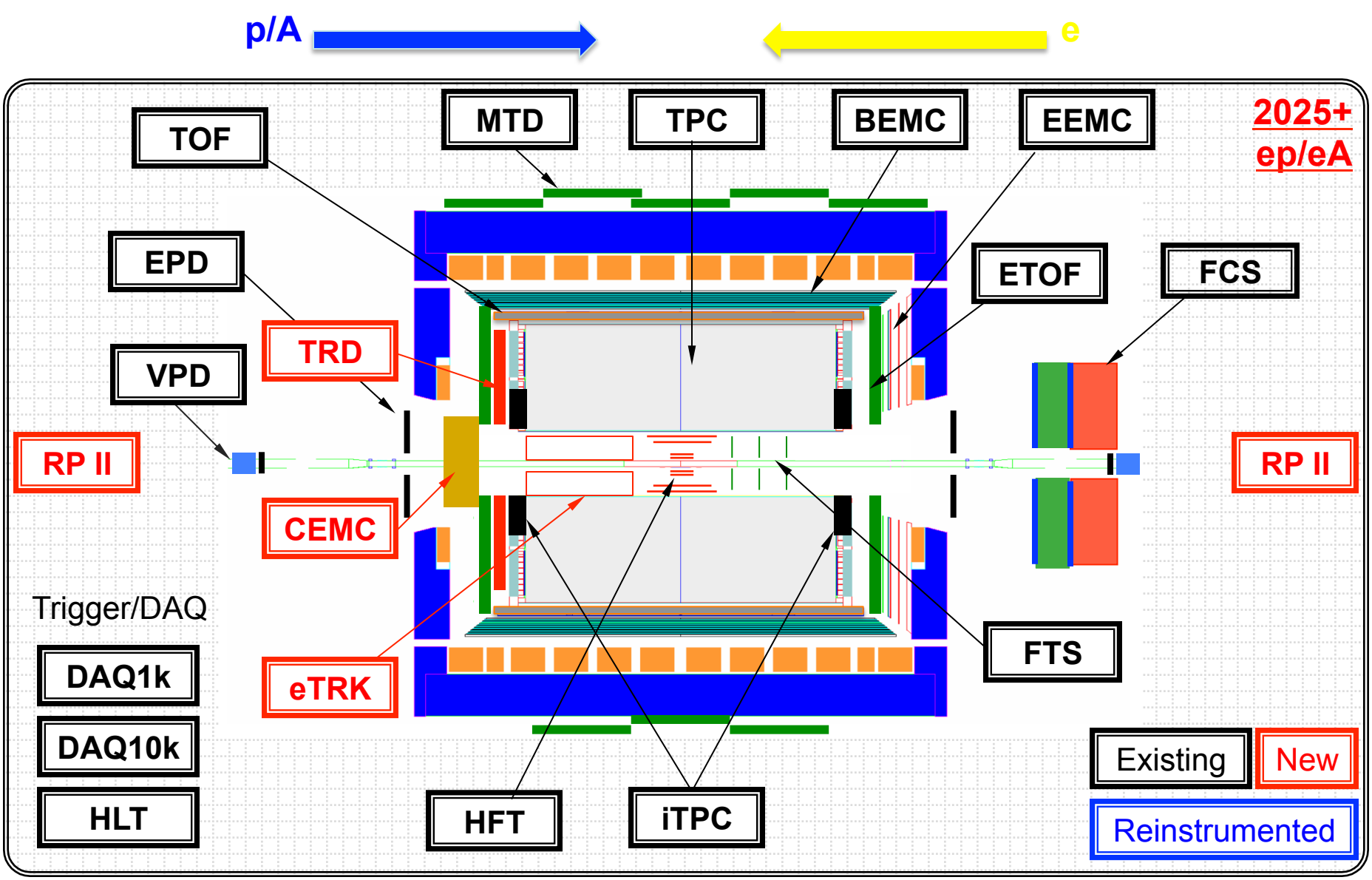
The STAR Collaboration



September 2013

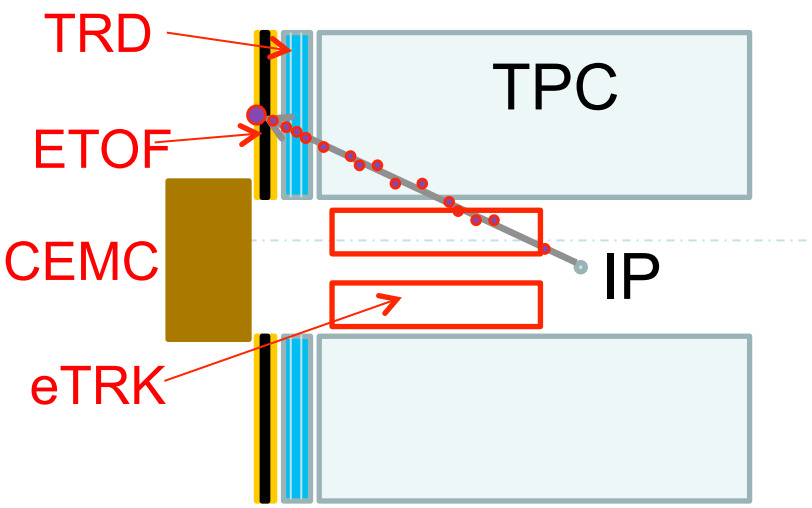
https://drupal.star.bnl.gov/STAR/starnotes/public/sn0592

STAR Detector in 2025+

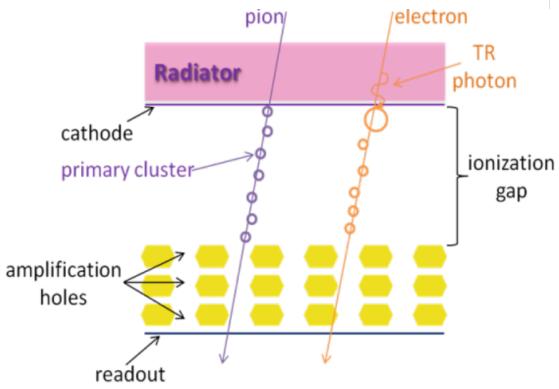


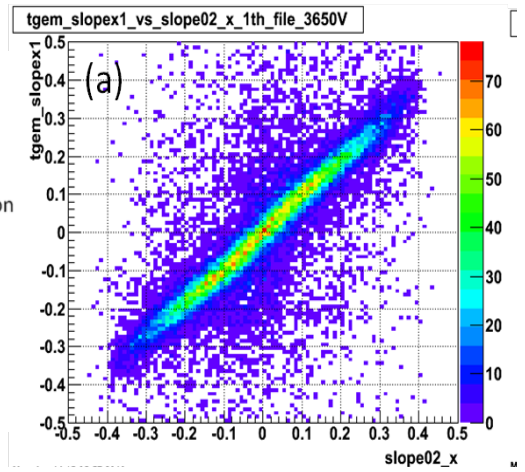
CEMC: Central EM Calorimeter, **eTRK:** electron Tracker, **TRD:** Transition Radiation Detector

Upgrade for Electron Detection

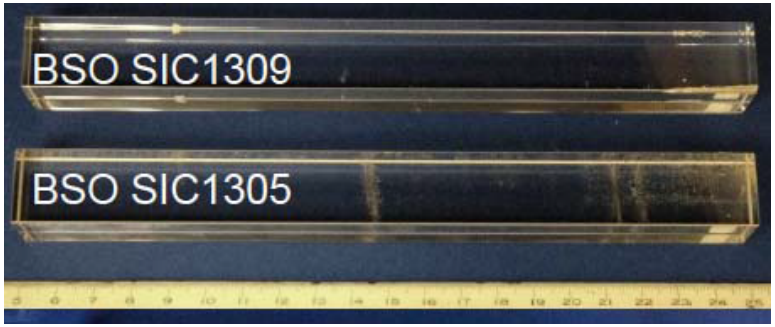


Electron Detectors

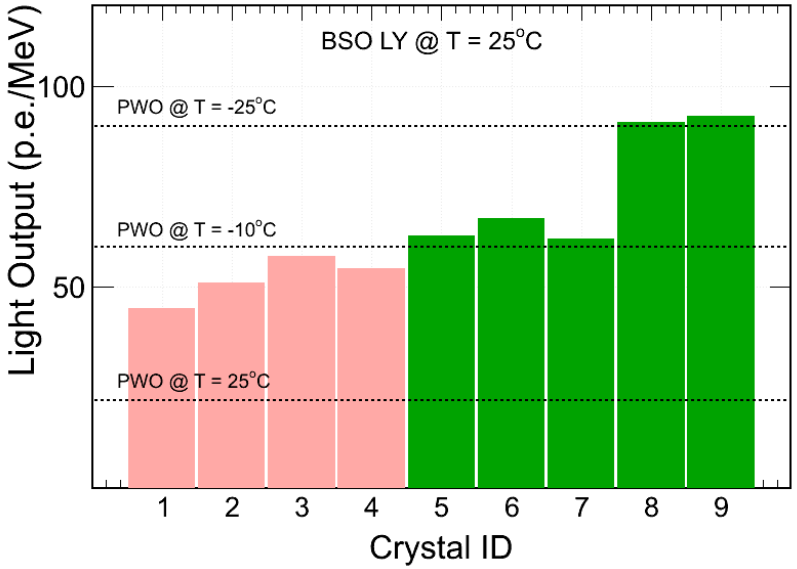




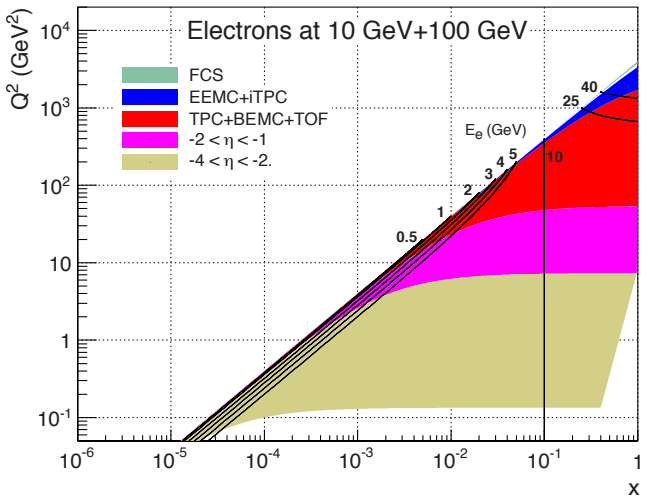
TRD with GEM-readout

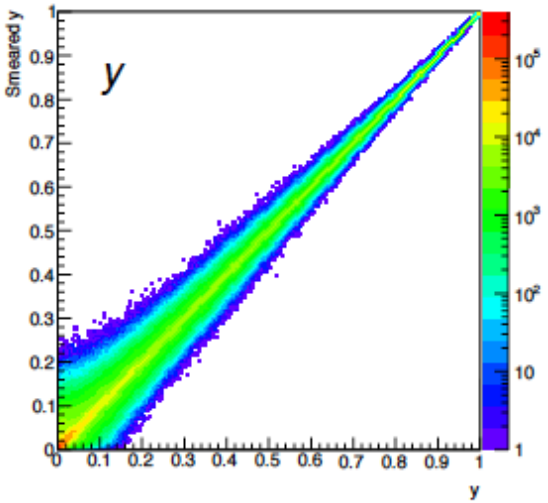


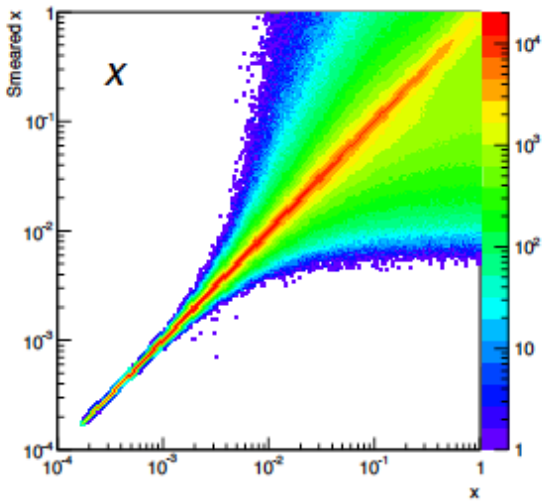
BSO Crystals for CEMC

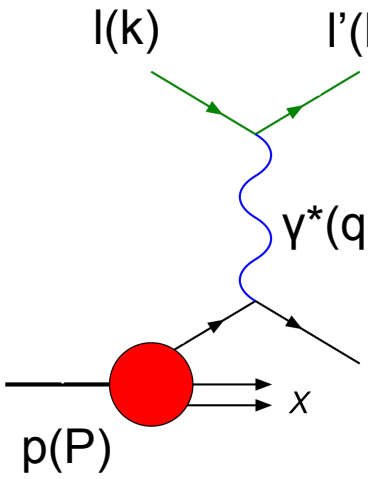


Electron Detection Performance





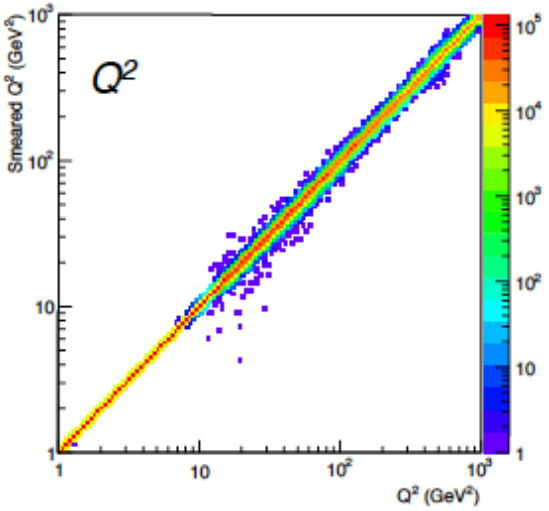


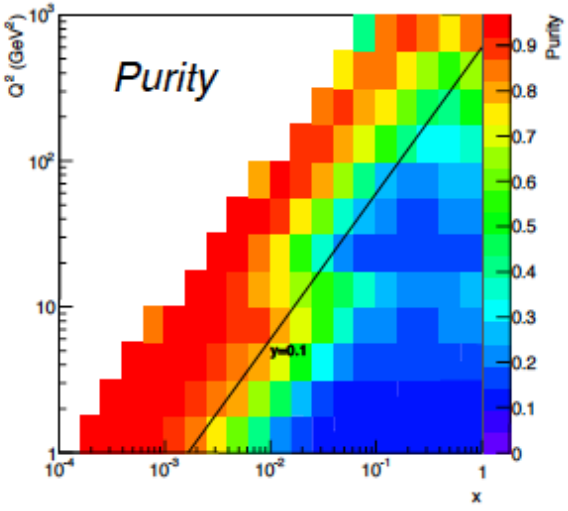


$$Q^2 = -q^2$$

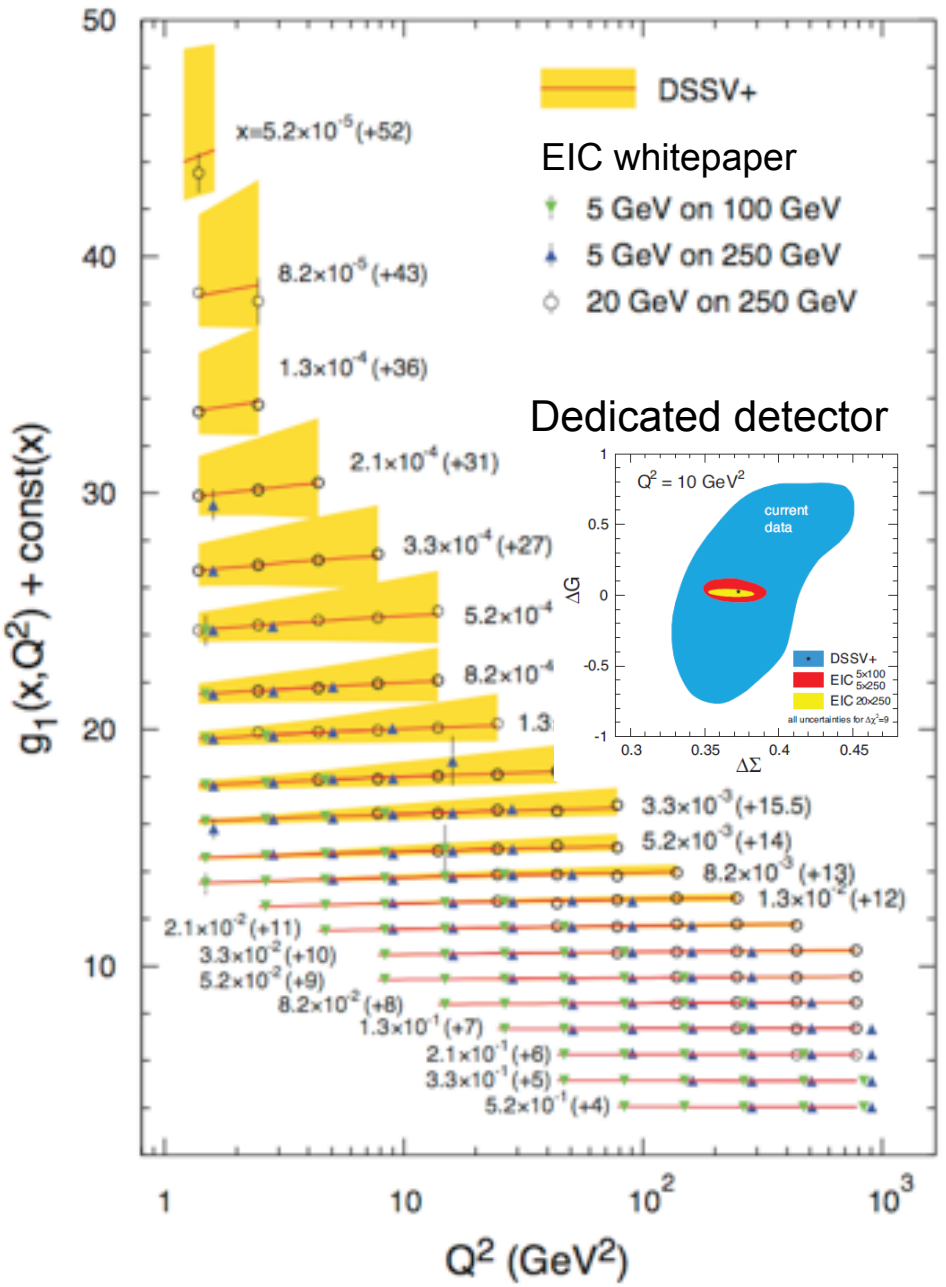
$$x = Q^2 / (2q \cdot P)$$

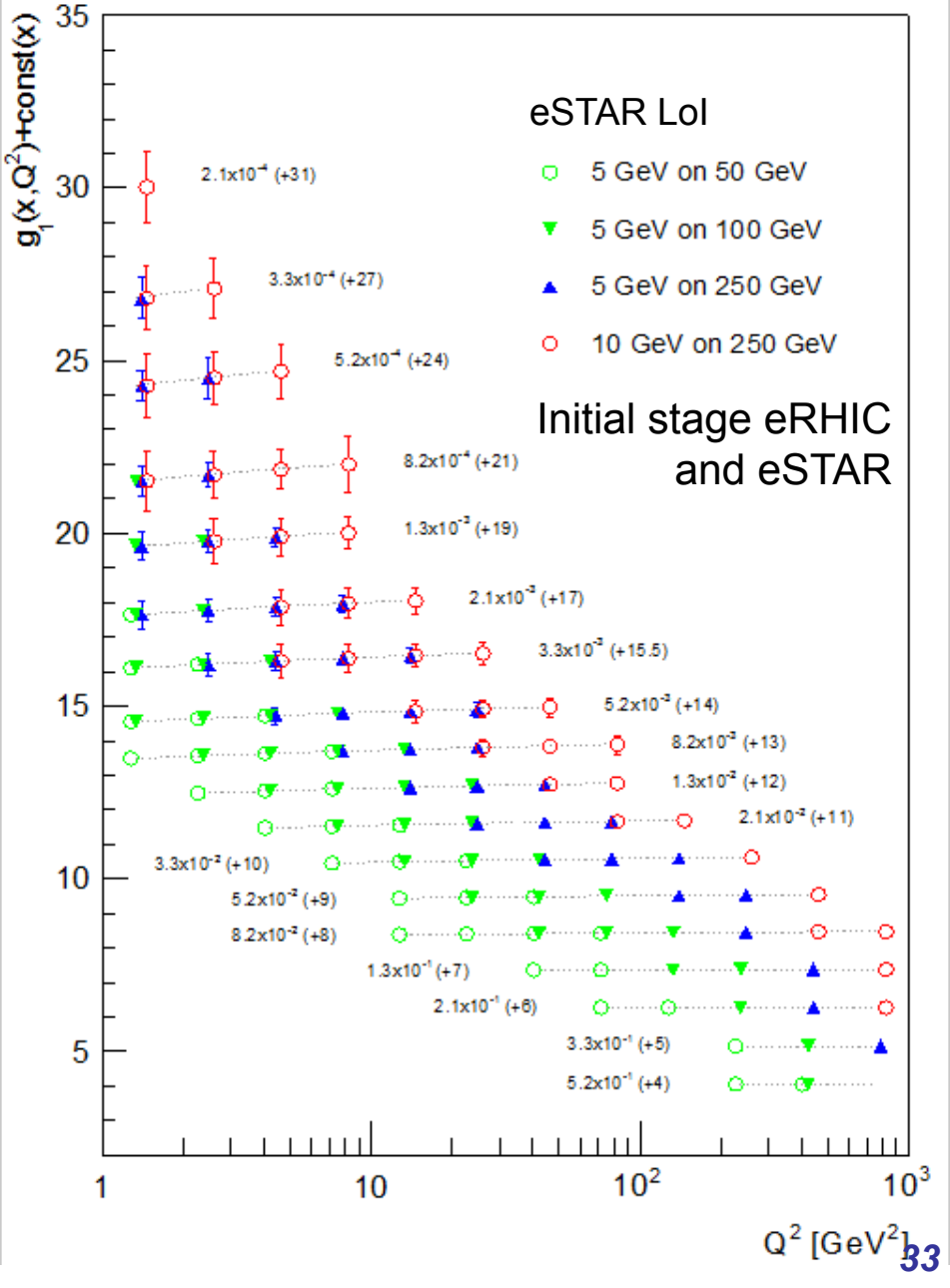
$$y = (q \cdot P) / (k \cdot P)$$



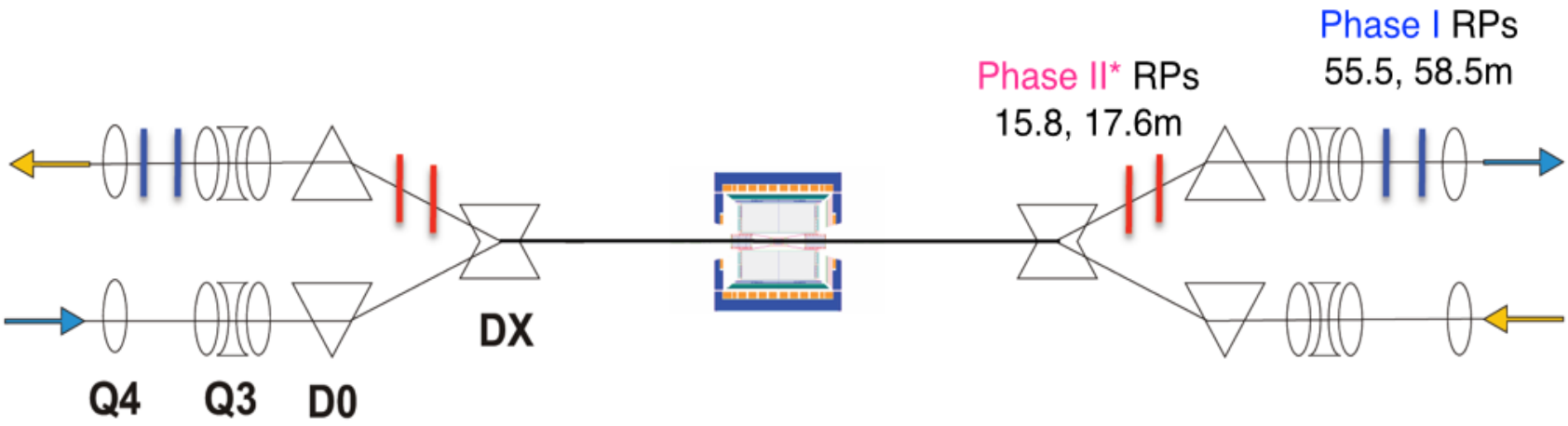


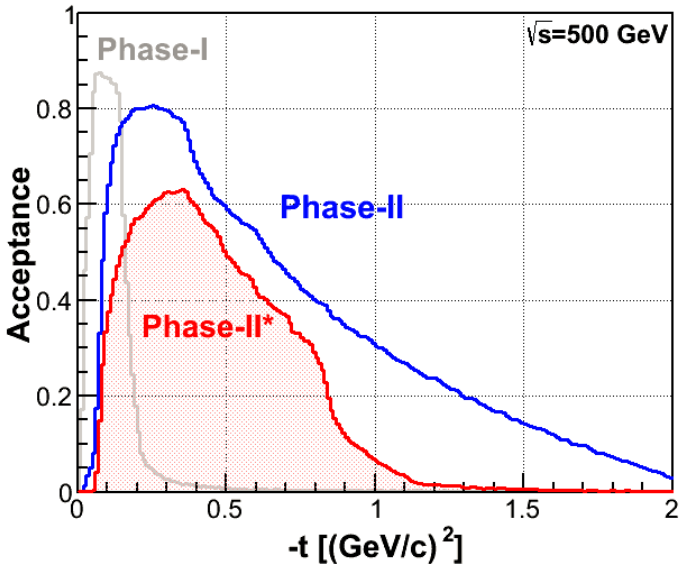
Proton Helicity Structure

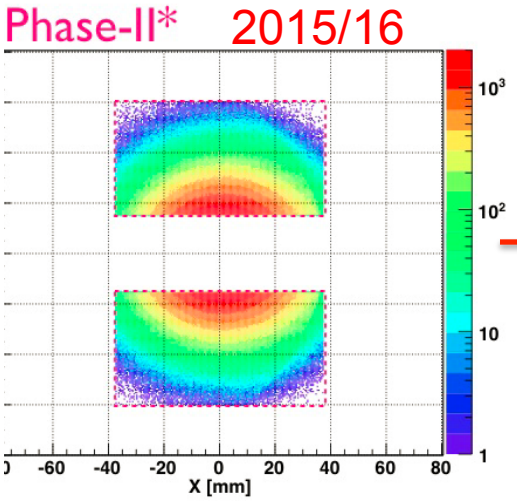


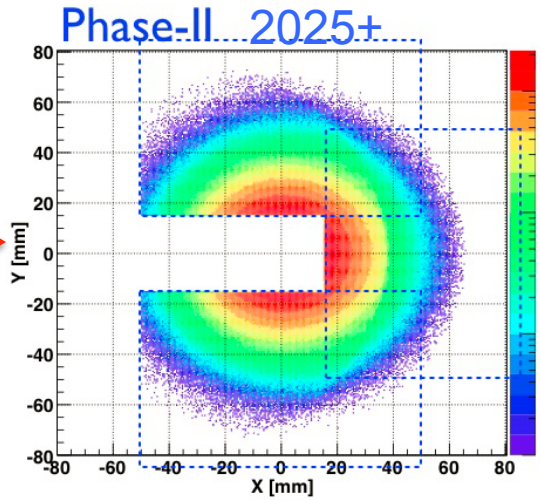


Roman Pot II for eSTAR

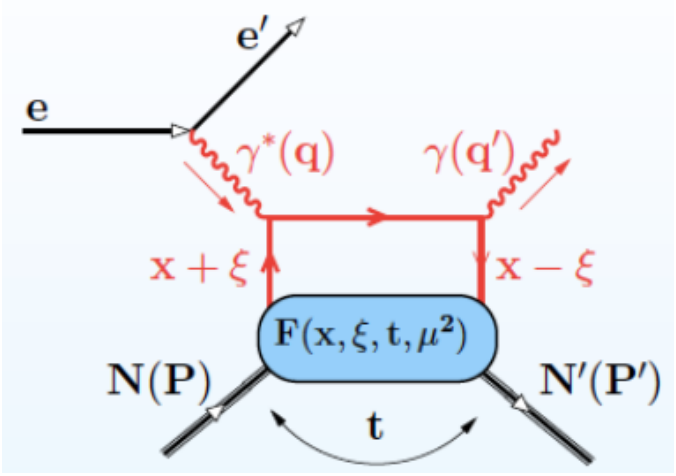


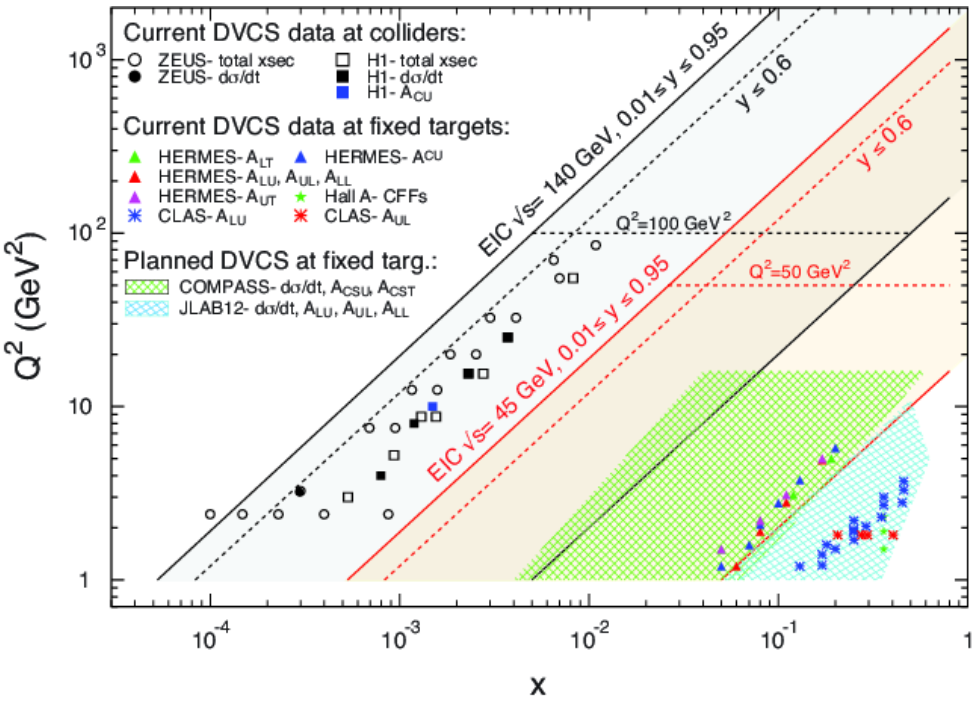


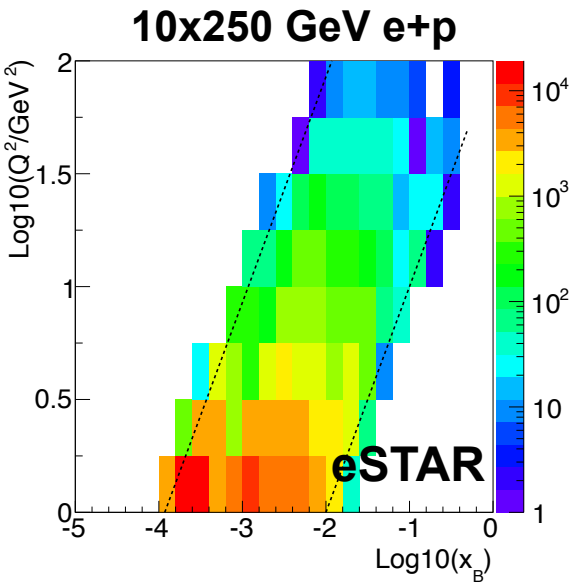


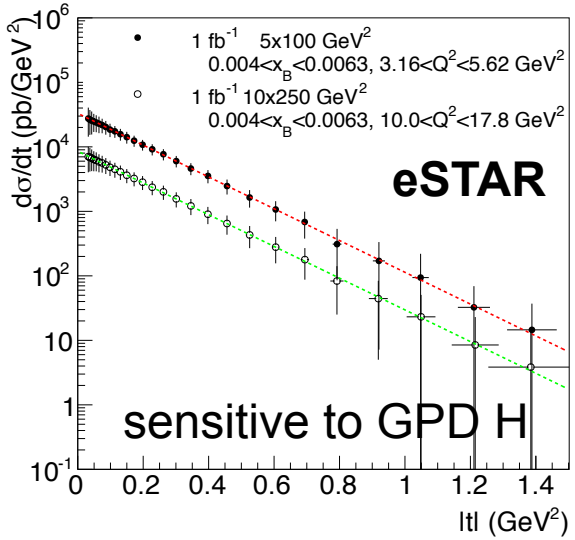


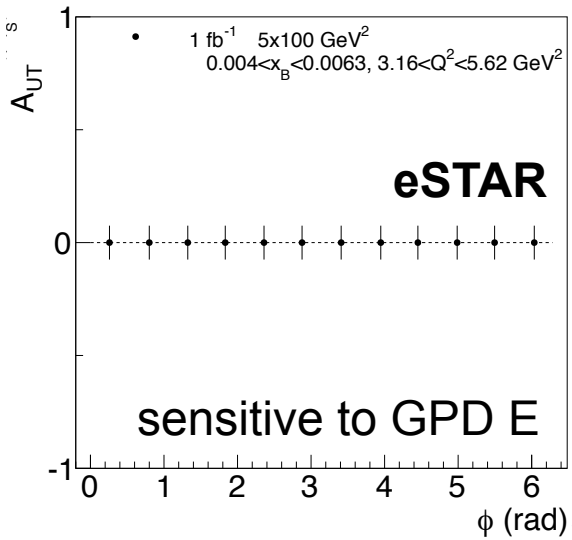
Deeply Virtual Compton Scattering



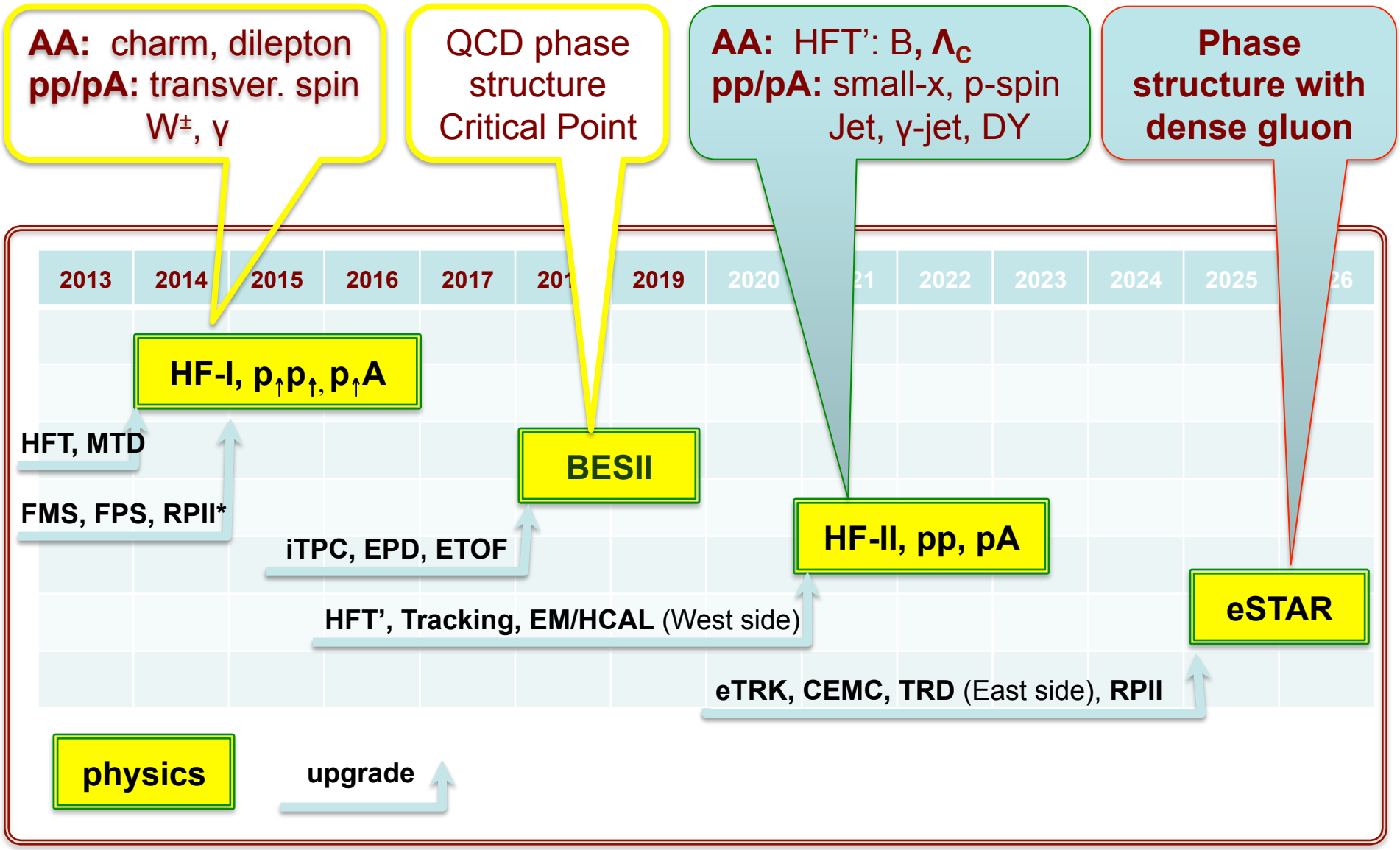






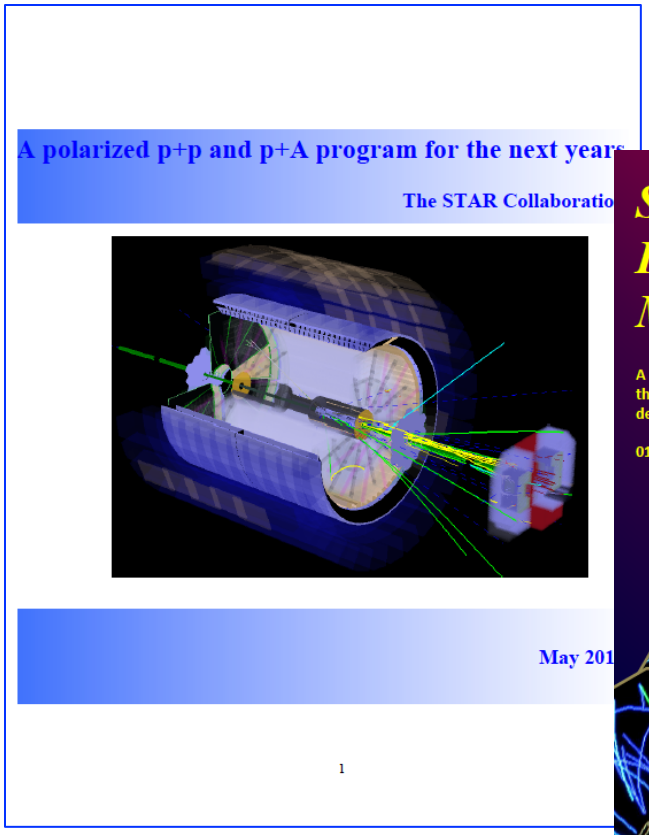


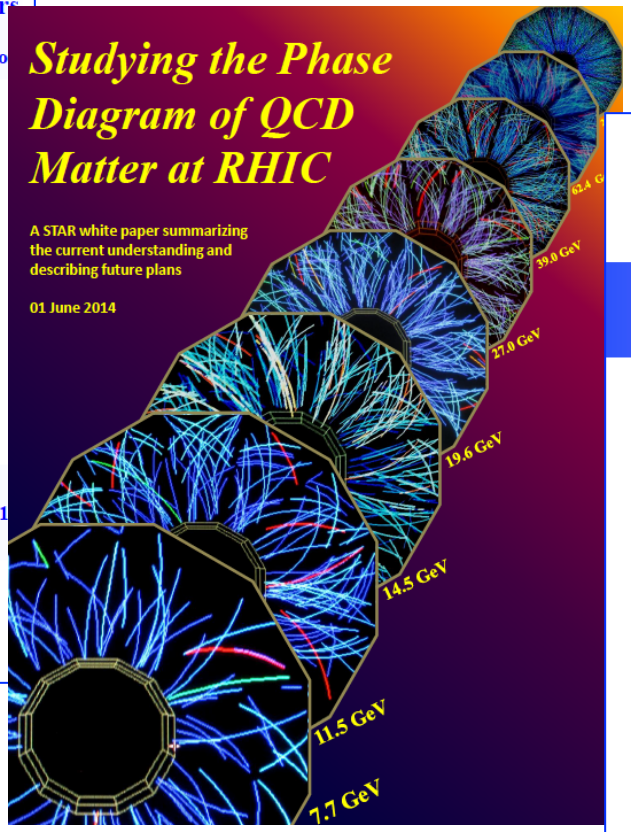
Summary

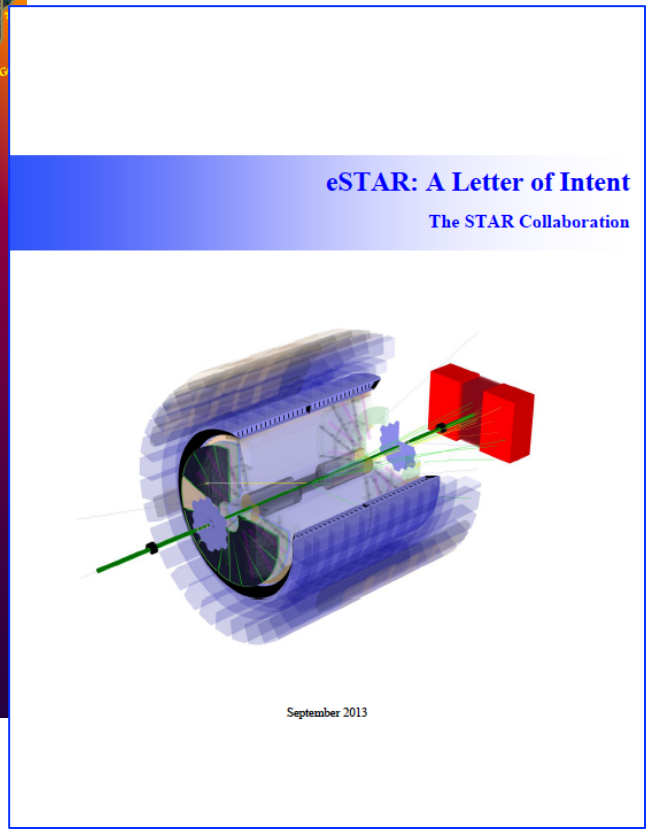


Very exciting physics and detector development programs in the coming years

Summary







Great new ideas, proposals and collaboration are very welcome!

Relevant STAR Talks in Parallel Session

Upgrades for the Future Program

- eSTAR LoI - Ernst Sichtermann
- STAR plans for BES II - Jim Thomas

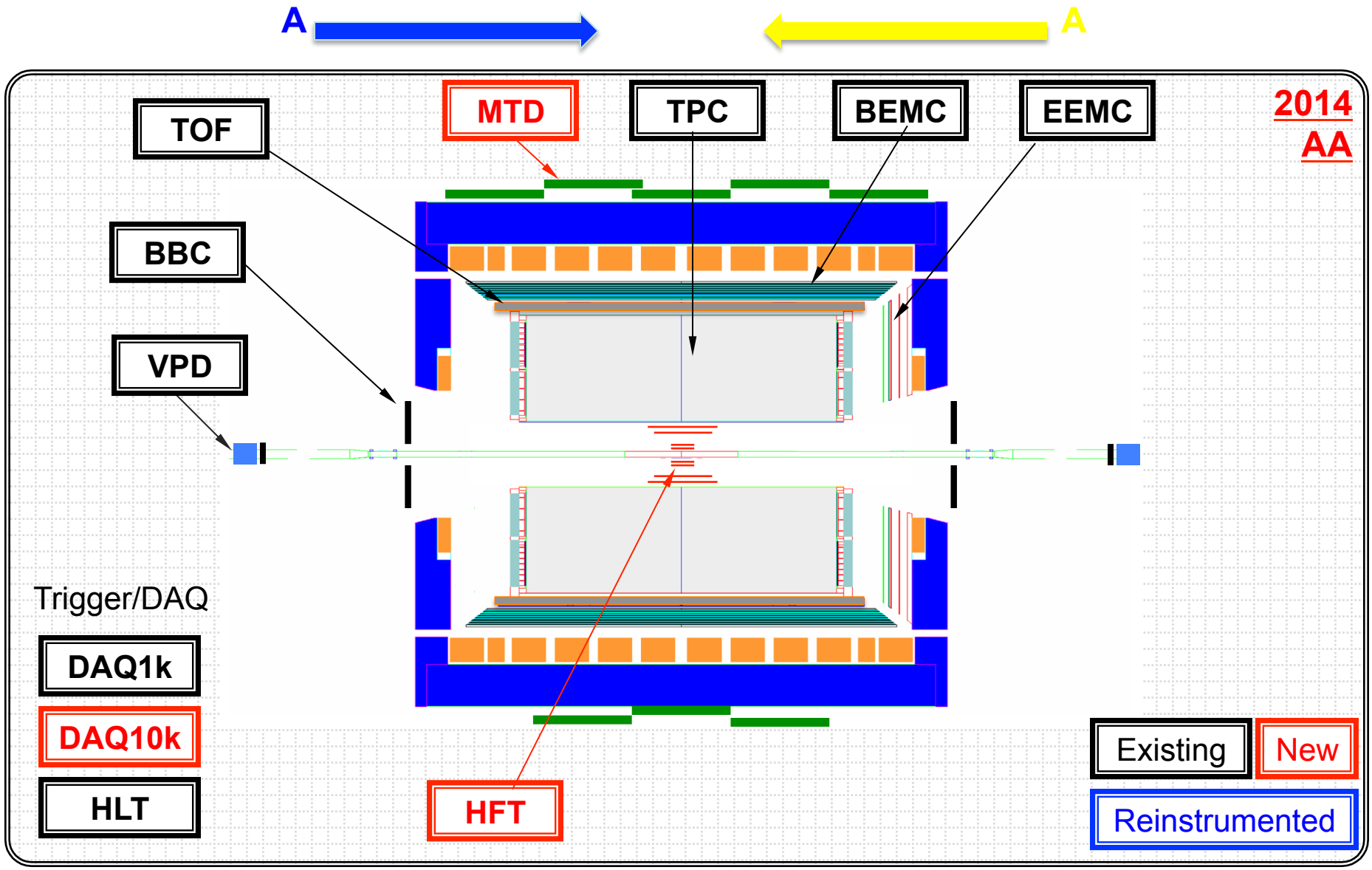
Nucleon Structure

- Plans and Prospects for STAR and eSTAR - Oleg Eyser

Thanks to Elke Aschenauer, Daniel Cebra, Xu Nu, Alex Schmah, Ernst Sichtermann, Zhangbu Xu and many other STAR collaborators for material used in talk

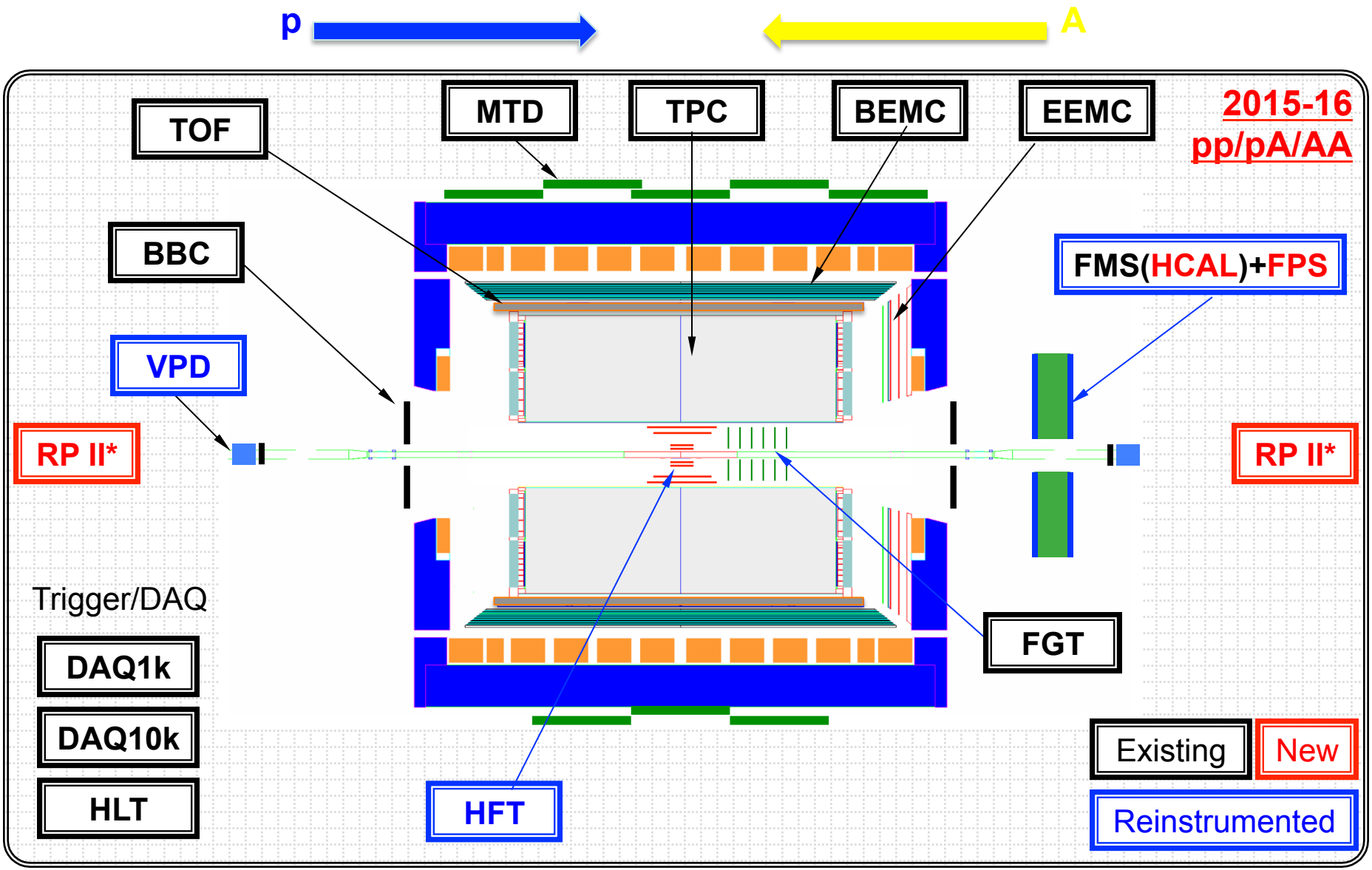
Backup

STAR Detector in 2014



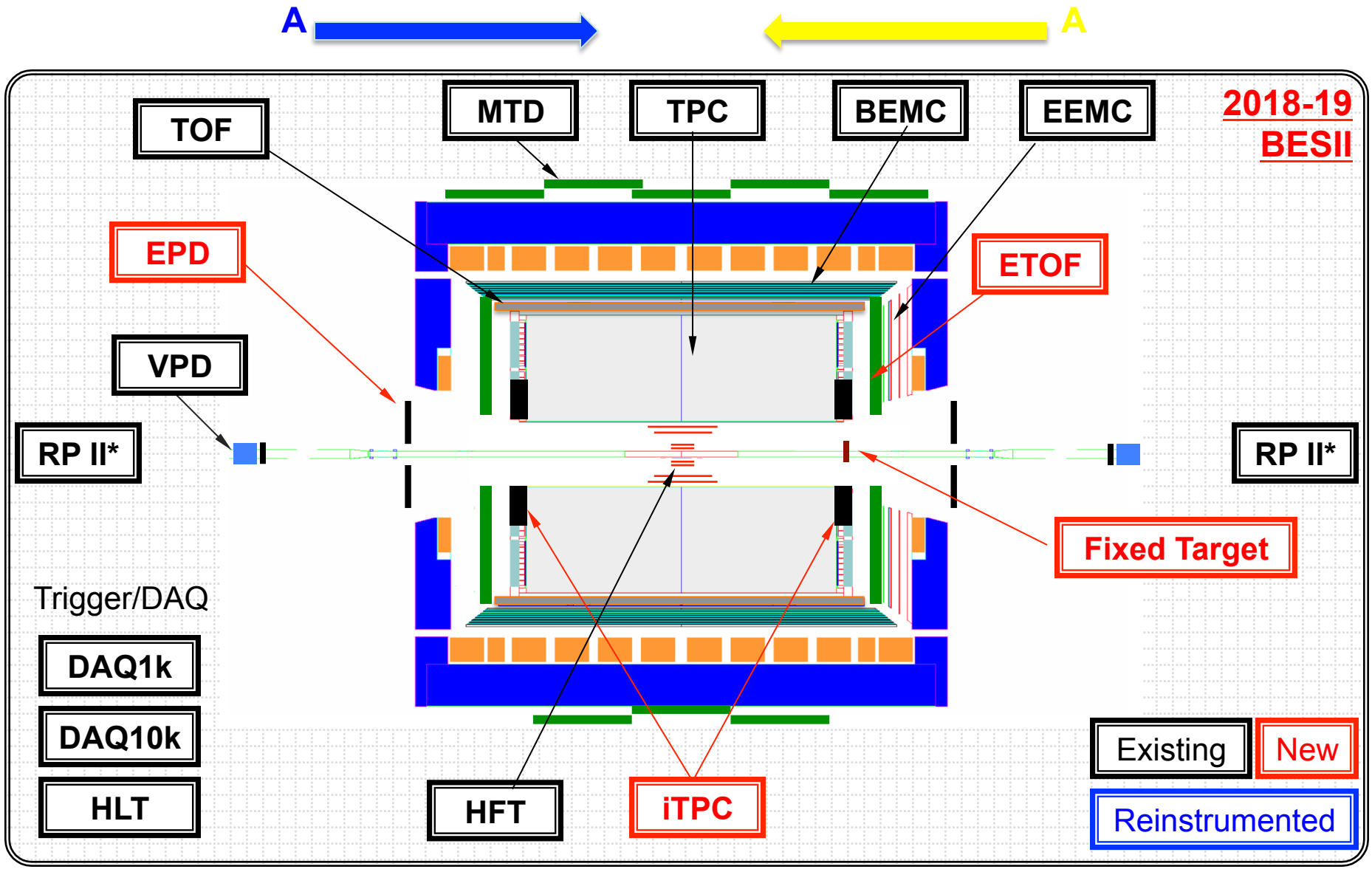
HFT: Heavy Flavor Tracker, **MTD**: Muon Telescope Detector

STAR Detector in 2015-2016



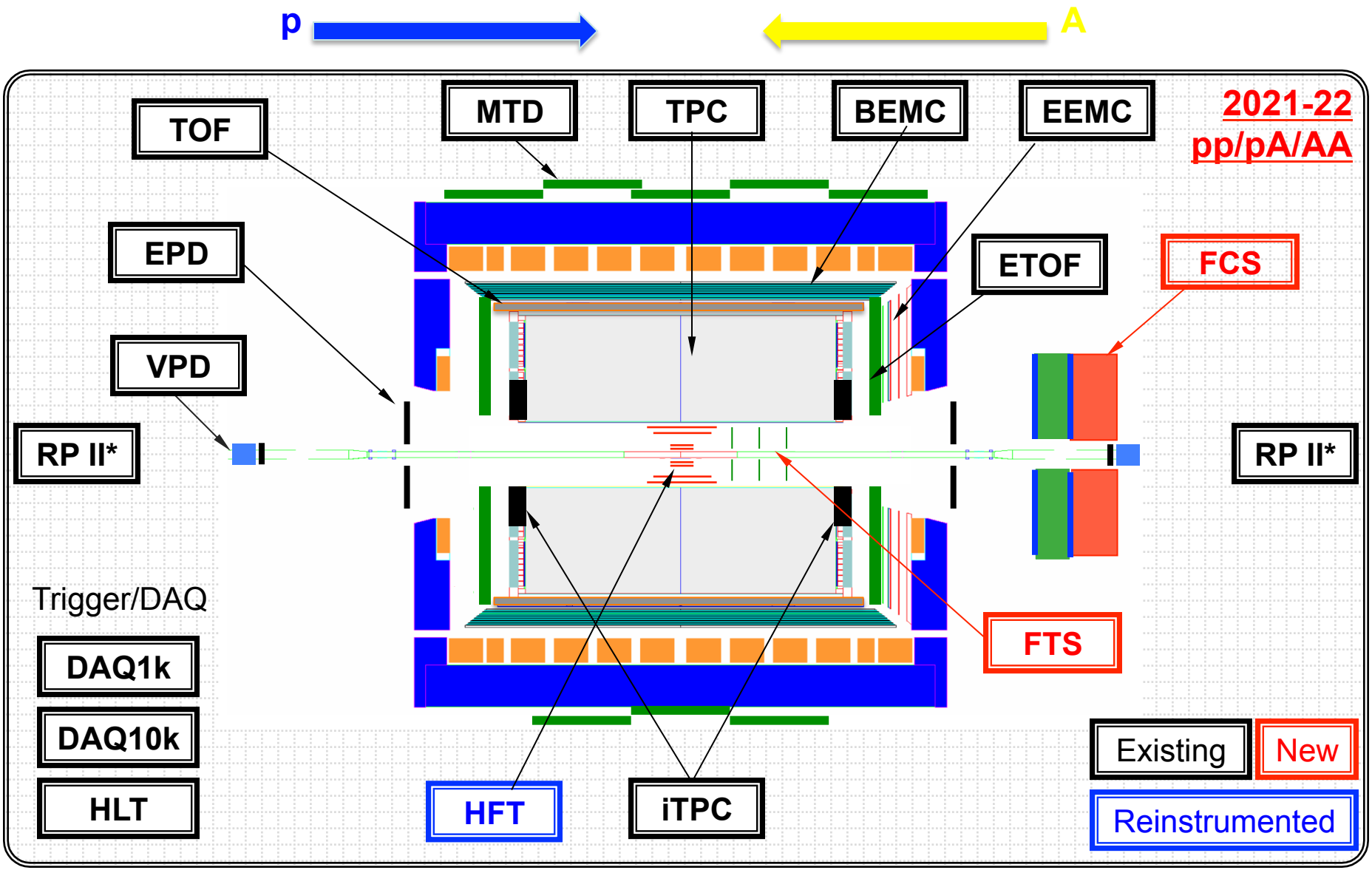
FMS: Forward Meson Spectrometer, **FPS**: Forward Preshower, **RP II***: Roman Pot Phase II*

STAR Detector in 2018-2019



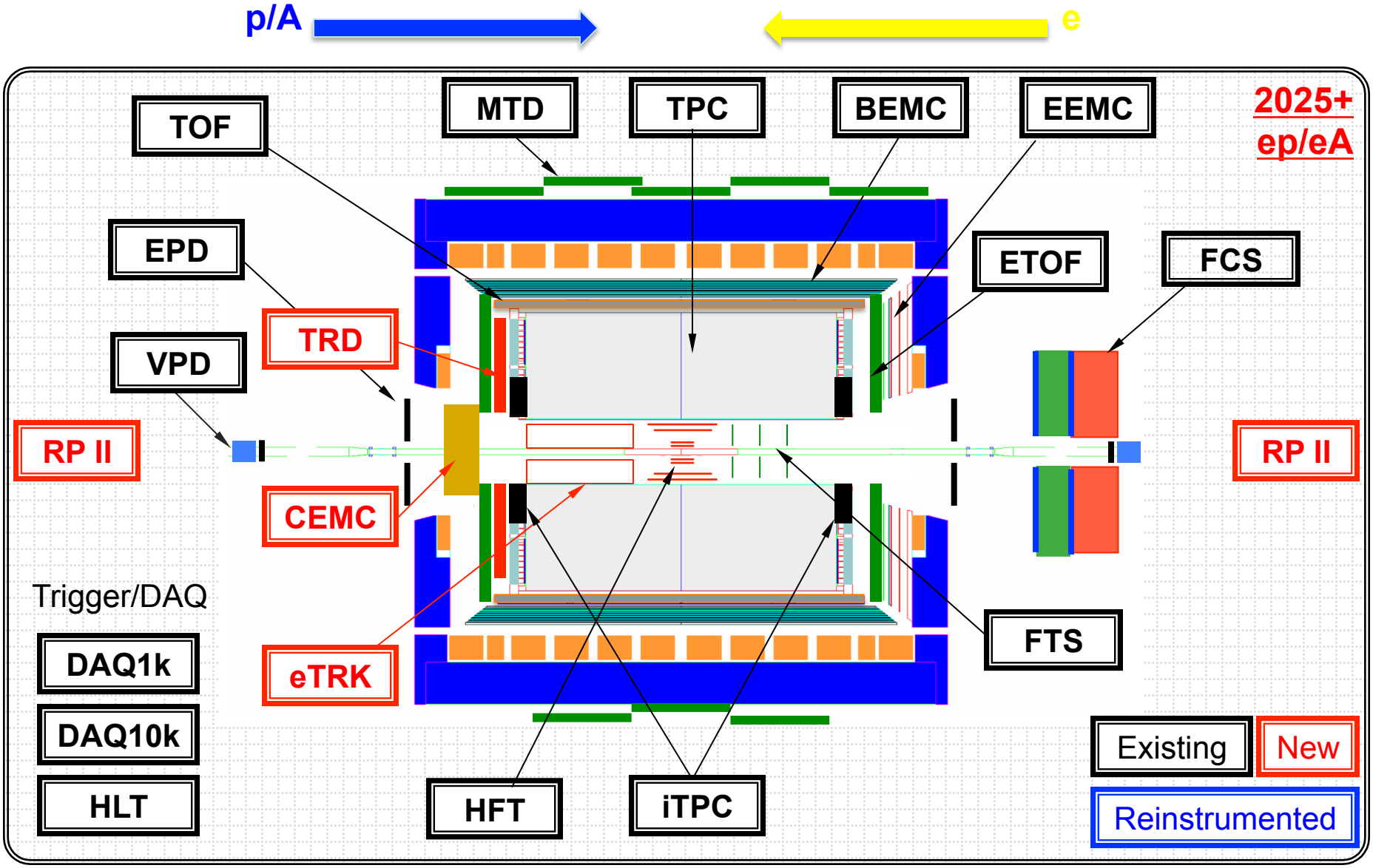
iTPC: inner TPC, **EPD**: Event Plane and Centrality Detector, **ETOF**: End-cap TOF, **Fixed Target**

STAR Detector in 2021-2022



FCS/FTS: Forward Calrimeter/Tracking System, **RP II**: Full Roman Pot Phase II

STAR Detector in 2025+



CEMC: Central EM Calorimeter, **eTRK:** electron Tracker, **TRD:** Transition Radiation Detector

STAR Highlights for QM14

Initial State Physics, Penetrating Probes, sQGP Properties

(1) [Initial state physics] *"Flow measurements and selection of body-body and tip-tip enhanced samples in U+U collisions at STAR"*
(2) [Initial state physics] *"Searching for the "Ridge" in d+Au collisions at RHIC by STAR"*
(3) [Electromagnetic probes] *"Direct virtual photon and dielectron production in Au+Au collisions at 200 GeV at STAR"*
(4) [Electromagnetic probes] *"Measurements of direct-photon-hadron correlations and direct-photon azimuthal anisotropy by STAR"*
(5) [Heavy flavor] *"Open charmed hadron production in p+p, Au+Au and U+U collisions at STAR"*
(6) [Heavy flavor] *"Recent STAR measurements of J/y production from Beam Energy Scan and U+U collisions"*
(7) [Jets] *"Semi-inclusive recoil jet distribution and di-jets imbalance measurements in central Au+Au collisions in STAR"*
(8) [Future experimental facilities, upgrades, and instrumentation] *"STAR Heavy Flavor Tracker"*

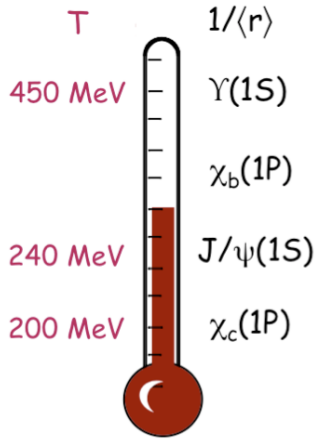
QCD Phase Structure and Beam Energy Scan at RHIC

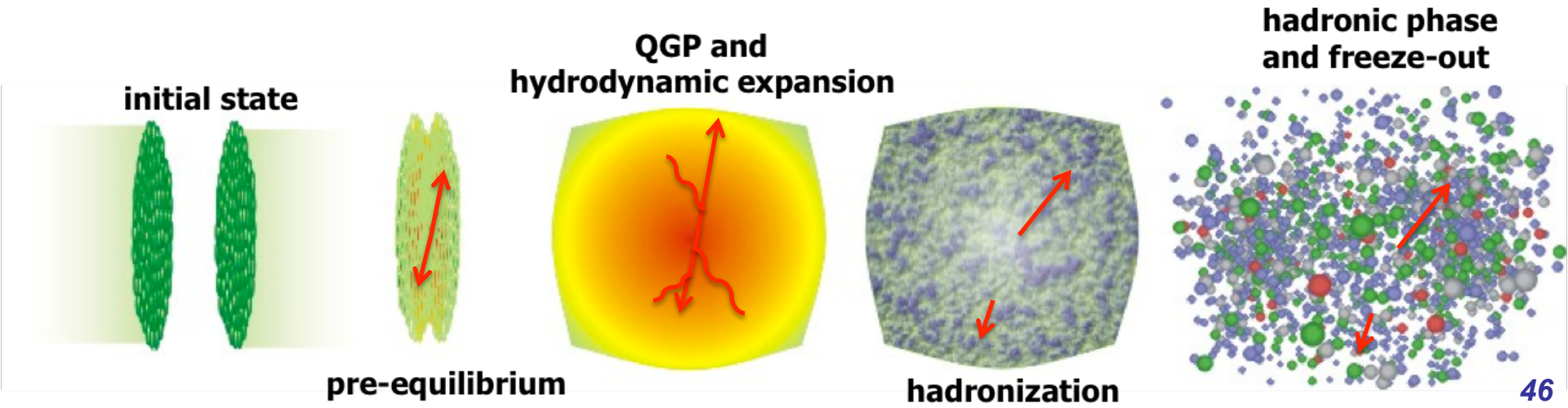
(1) [Collective dynamics] *"Elliptic flow of light nuclei and identified hadrons, their centrality and energy dependence in STAR"*
(2) [Electromagnetic probes] *"Beam energy dependence of dielectron production in Au+Au collisions from STAR at RHIC"*
(3) [QCD phase diagram] *"Energy dependence of higher moments of net-kaon, net-proton and net-charge multiplicity distribution at STAR"*
(4) [QCD phase diagram] *"$L(K_s^0)$-$h^{\pm}$ azimuthal correlations with respect to event plane and searches for chiral magnetic and vortical effects at STAR"*
(5) [QCD phase diagram] *"Charge asymmetry dependency of p/K anisotropic flow in U+U and Au+Au collisions at STAR"*
(6) [Thermodynamics and hadron chemistry] *"Systematics of the kinetic freeze-out properties in high-energy nuclear collisions from STAR"*
(7) [Thermodynamics and hadron chemistry] *"Ω and ϕ production in p+p, Au+Au and U+U collisions at STAR"*

Heavy Flavor Physics

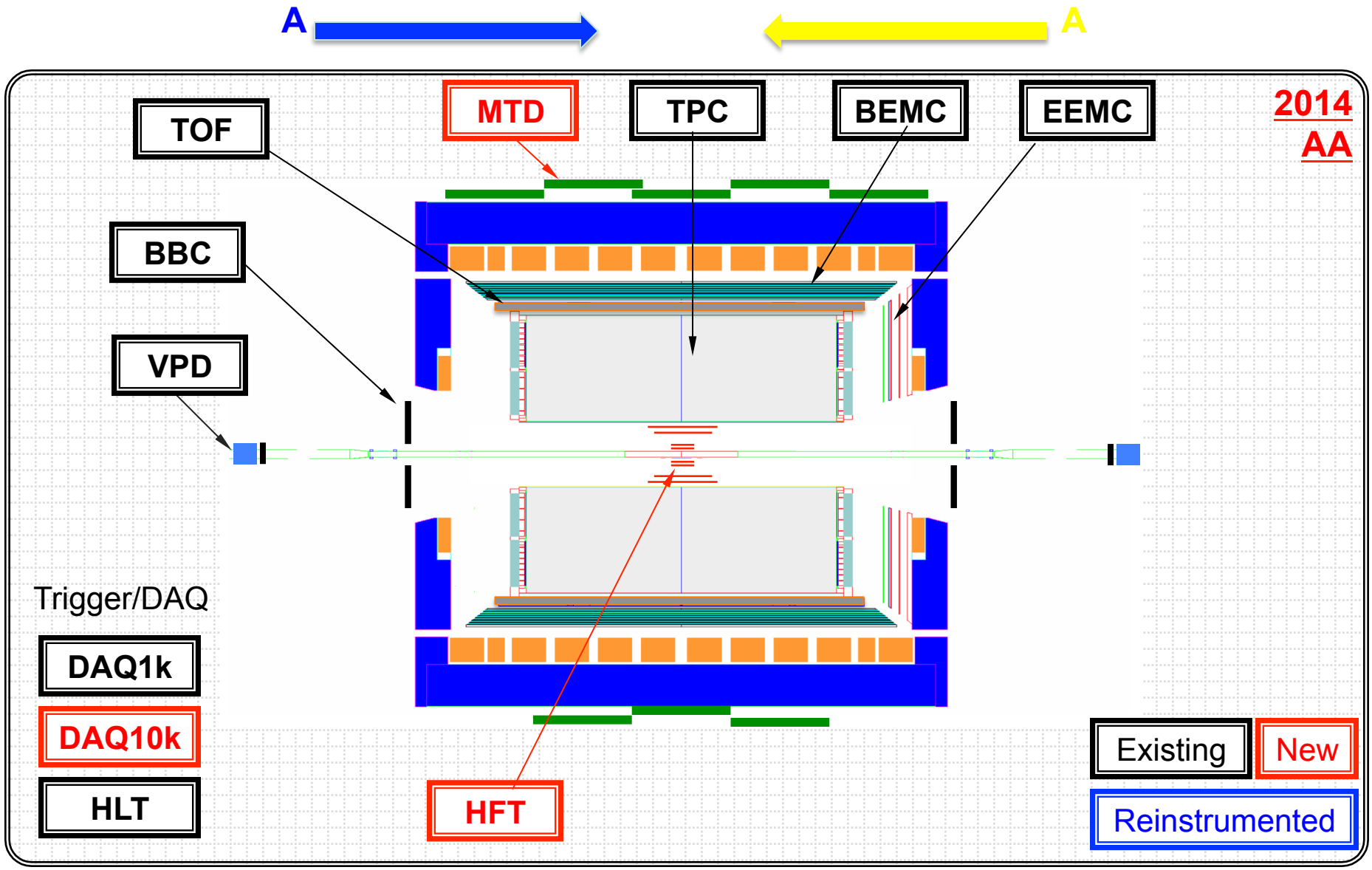
Heavy quarks primarily produced in initial hard scatterings, and exposed to the entire evolution of the hot nuclear matter created at RHIC.

- **A+A**
  - How does a parton lose its energy in the QGP?
    $\Delta E_g > \Delta E_{u/d/s} > \Delta E_c > \Delta E_b$?
  - HF as a probe to study properties of the QGP
- **p+p**
  - Test of pQCD and reference for studies of the QGP
- **p+A**
  - Cold Nuclear Matter effects (shadowing, CGC, Cronin effect, …)





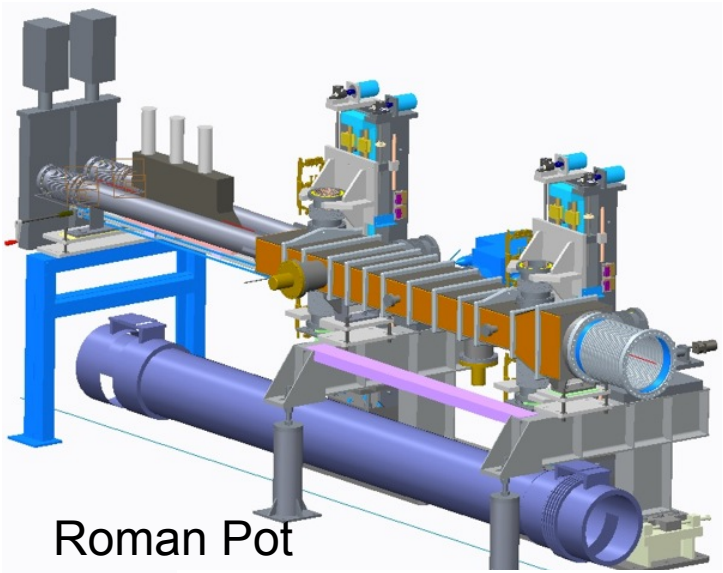
STAR Detector in 2014

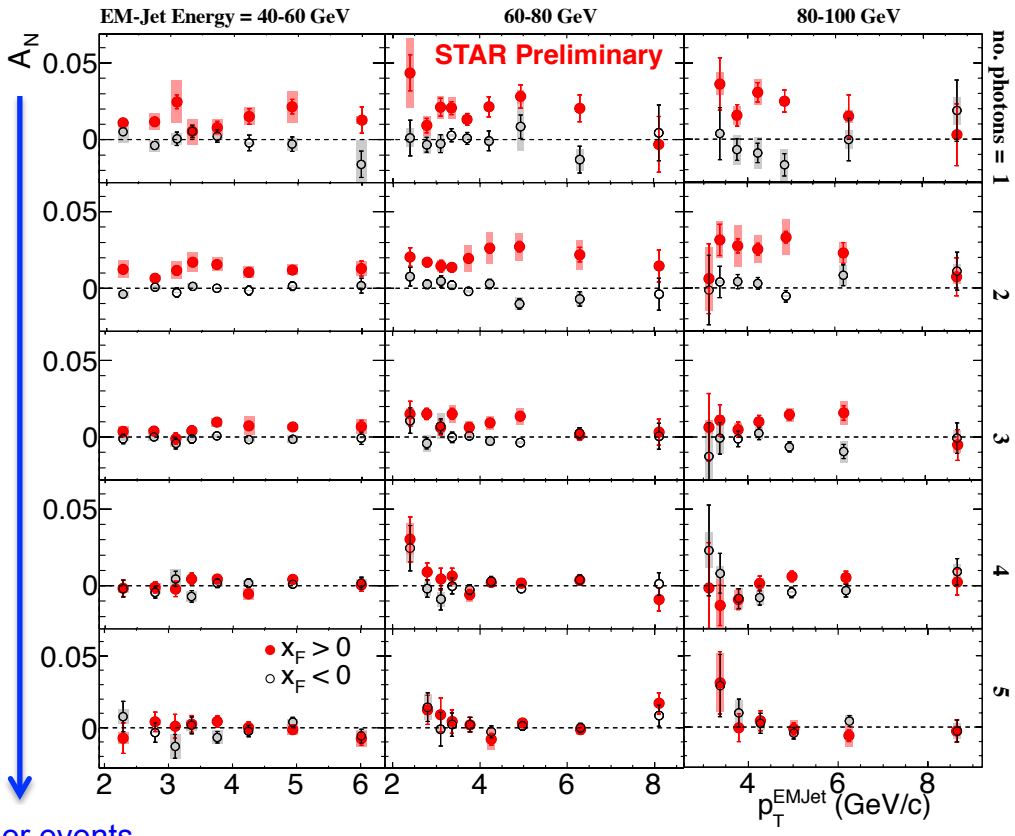


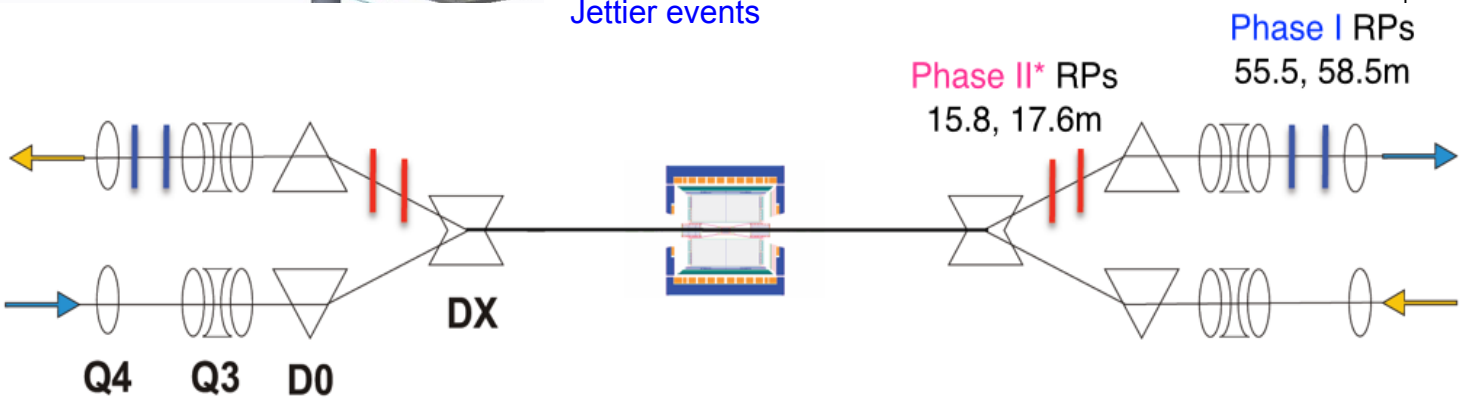
See F. Videbaek's talk on Thursday

Roman Pot II* in 2015-2016

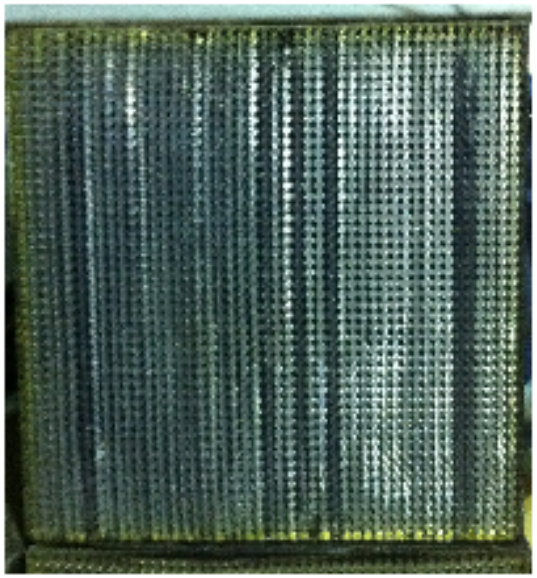
A_N decreases with increased jettiness of the event; Possible diffractive nature. Roman Pot Upgrade critical

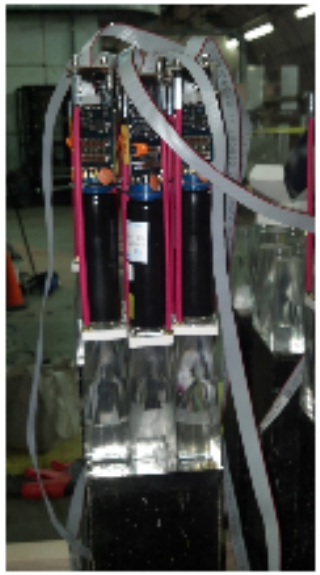


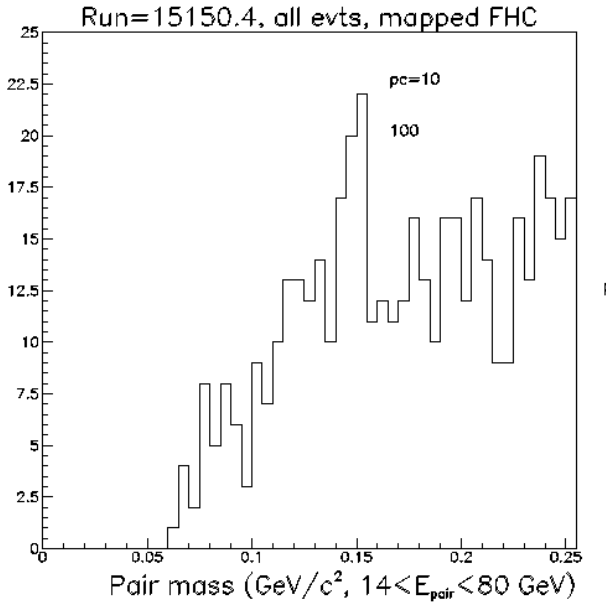


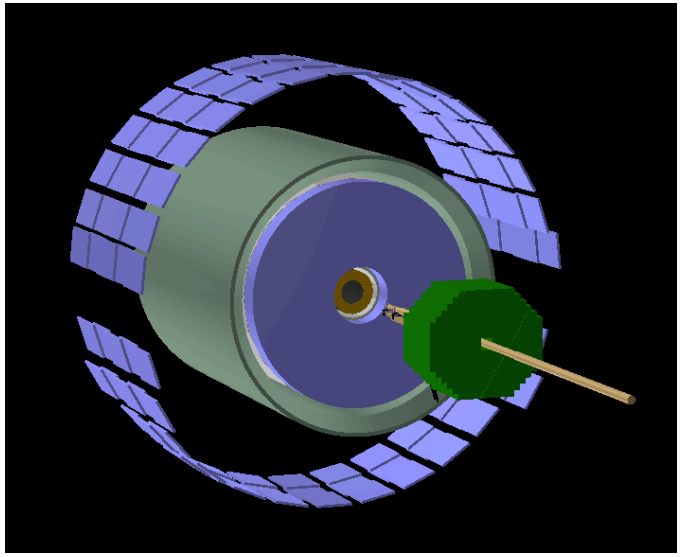


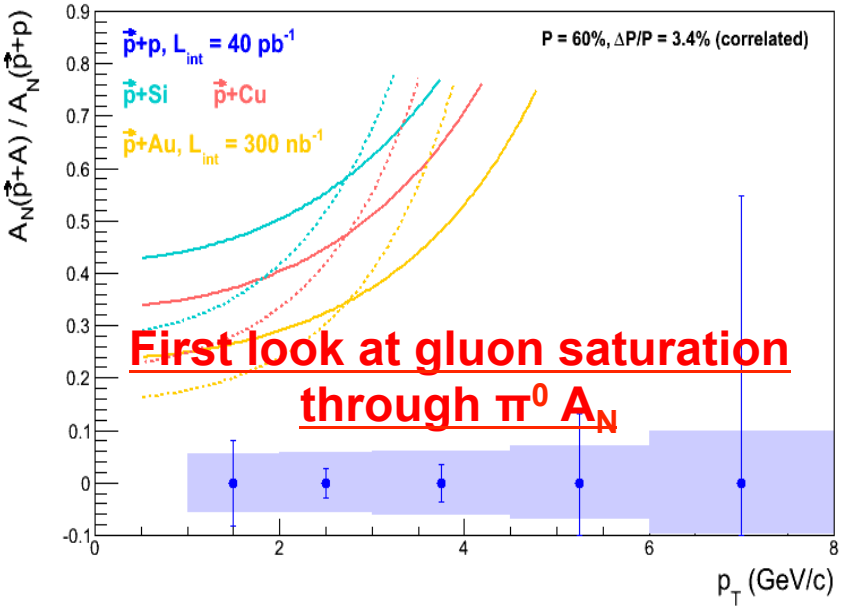
Pixelized E864 HCAL in 2016 (?)



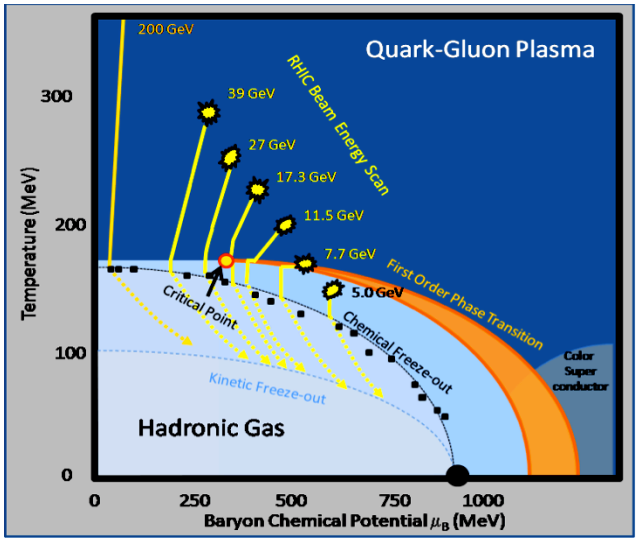


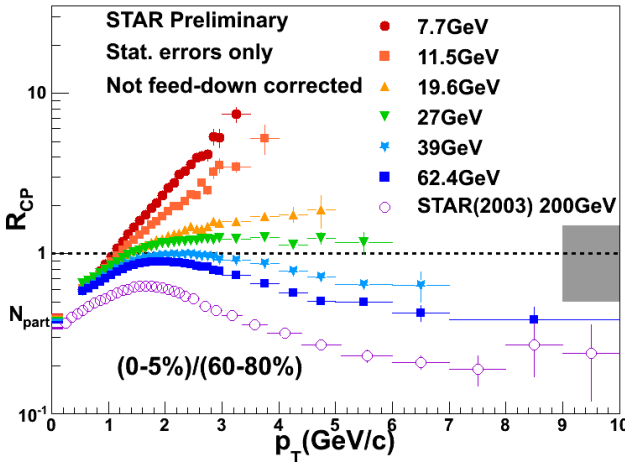


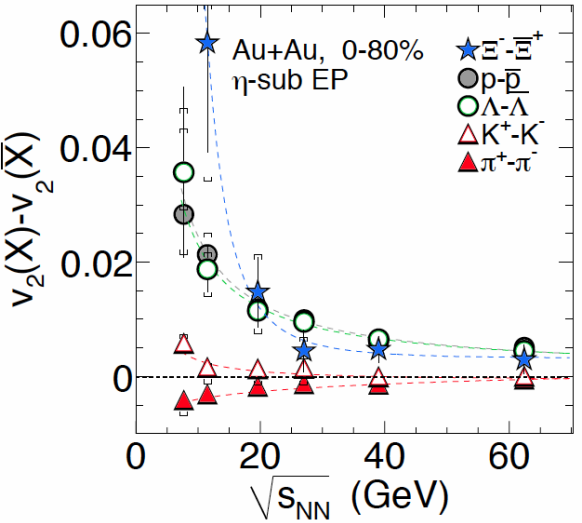


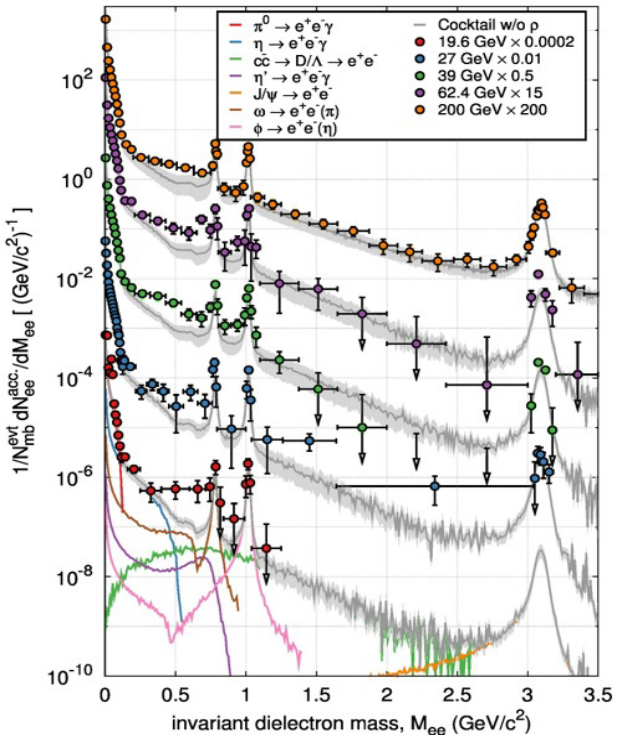


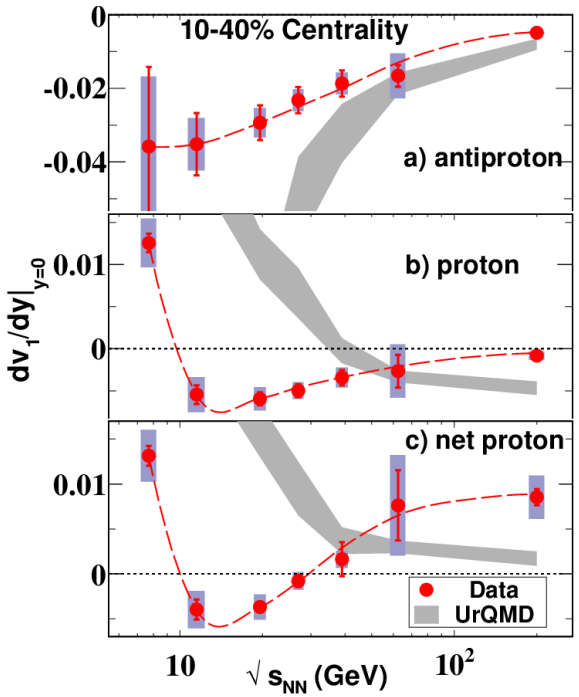
QCD Phase Diagram and BES I

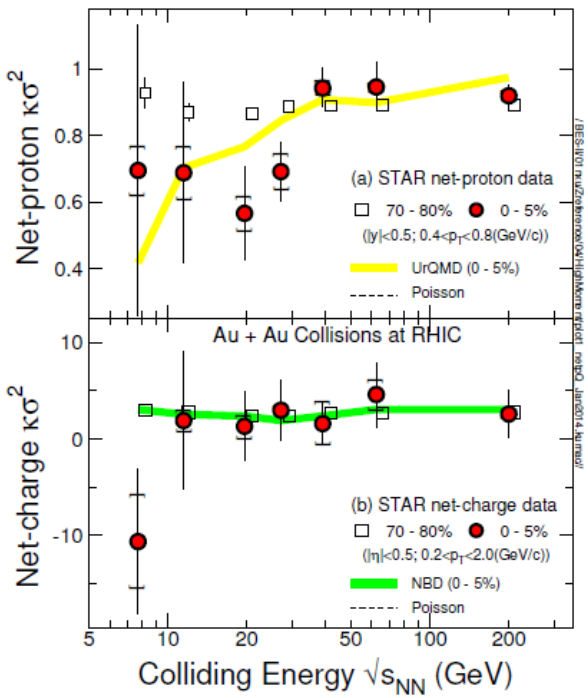








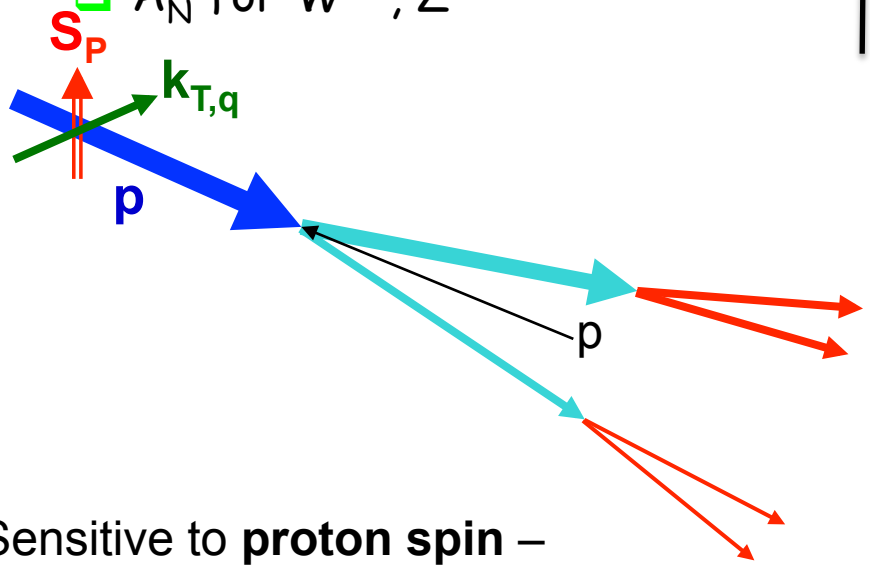




Transverse Asymmetry with Jets

SIVERS/Twist-3

- A_N for jets, direct photons
- A_N for heavy flavour → gluon
- A_N for $W^{+/-}$, Z^0



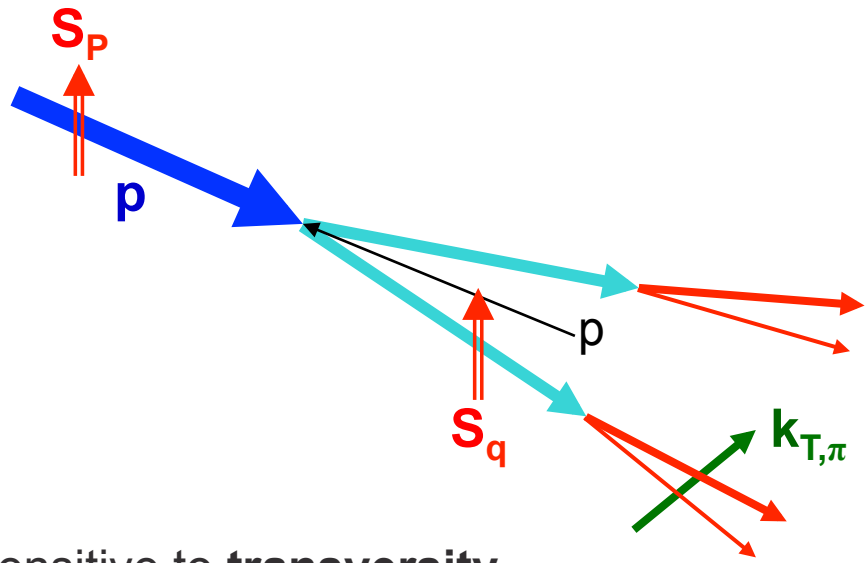
Sensitive to **proton spin** – parton **transverse motion** correlations not universal between SIDIS & pp

Collins Mechanism

Rapidity dependence of

- **A_N for π^0 and eta with increased p_t coverage**

- asymmetry in jet fragmentation
  - **$\pi^{+/-}\pi^0$ azimuthal distribution in jets**
  - **Interference fragmentation function**



Sensitive to **transversity** universal between SIDIS & pp & e+e-

Transverse Spin Asymmetry with Jets

Bring mid rapidity observables to high rapidities → high x

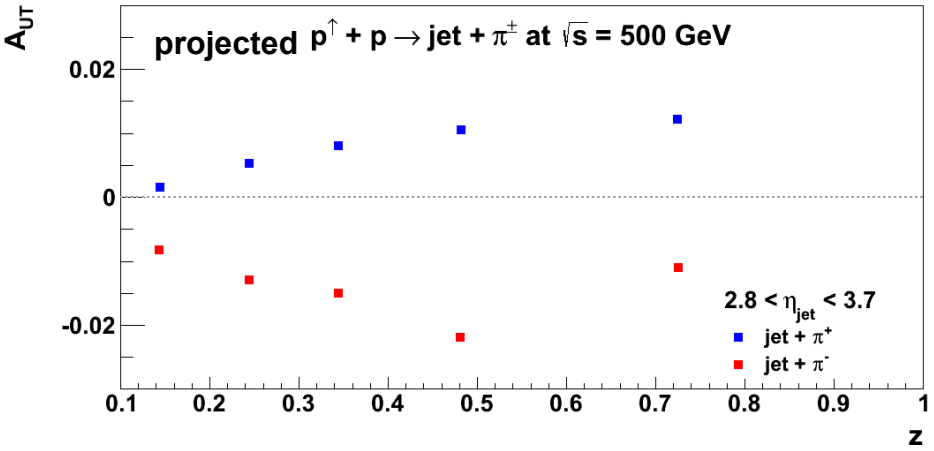
Needs:

forward upgrade (FCS + FTS) & 500 GeV & delivered luminosity: $1fb^{-1}$

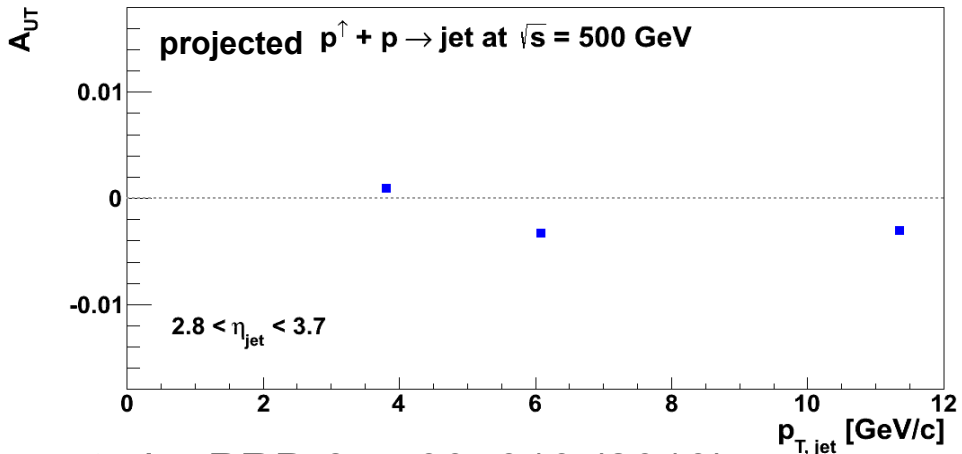
Address the following questions:

- ❑ measure tensor charge → connection to lattice
- ❑ difference between $\delta q(x)$ and $\Delta q(x)$ allows to study orbital angular momentum in wave fct.
- ❑ is the Soffer bound violated

Transversity PDF x Collins FF:



Sivers/Twist-3

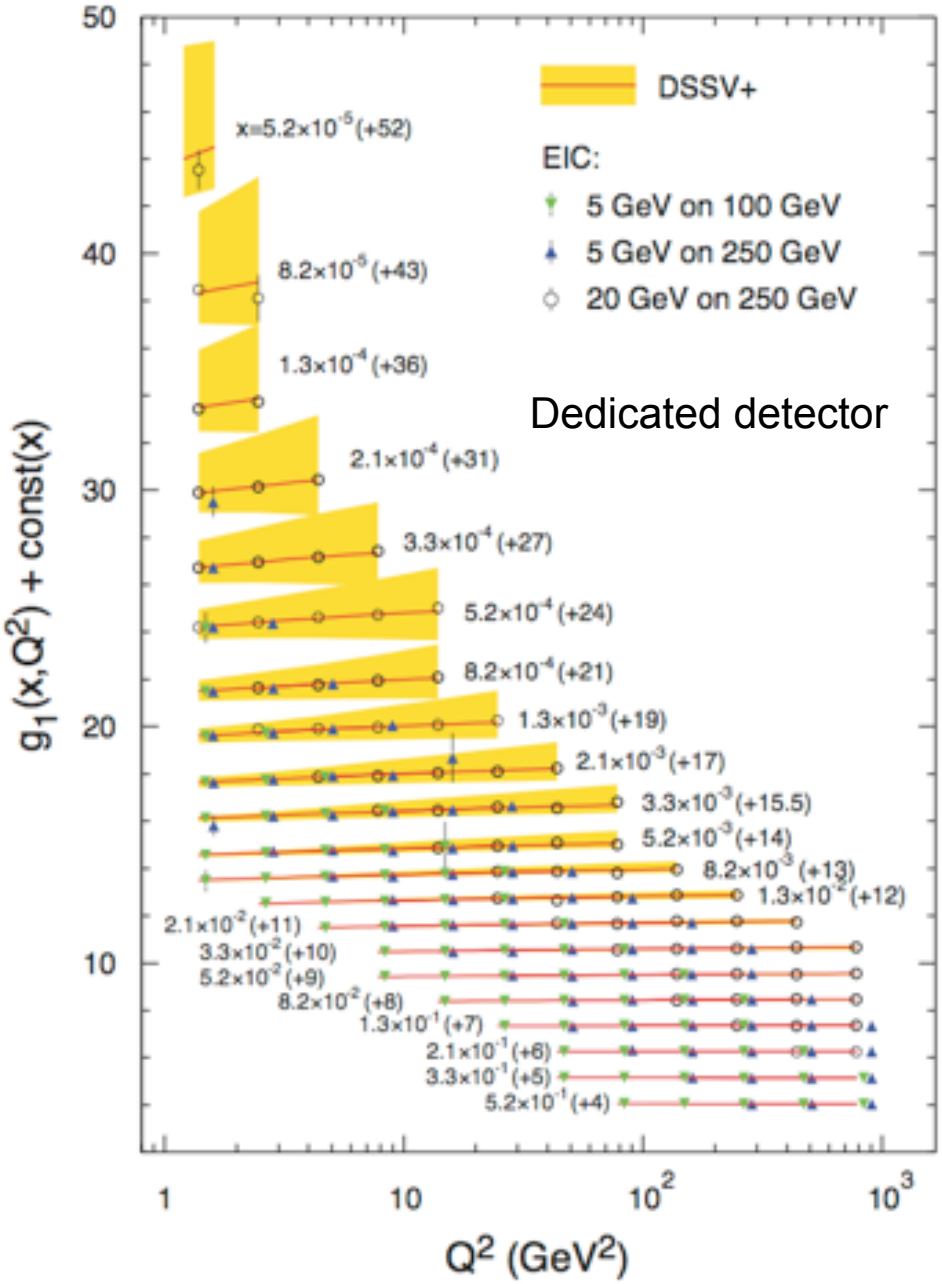


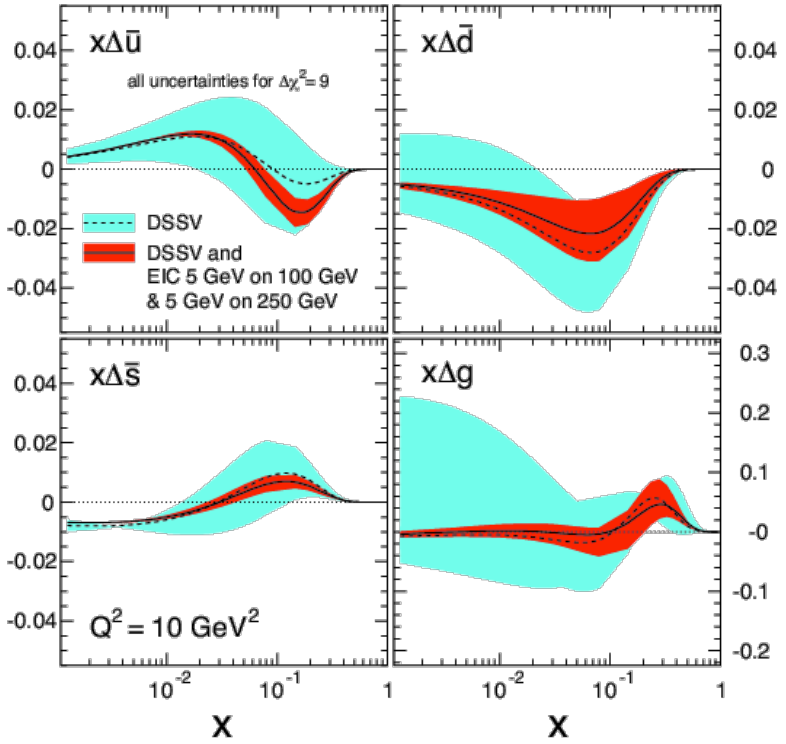
Projection based on M. Anselmino et al., PRD 87 , 094019 (2013)

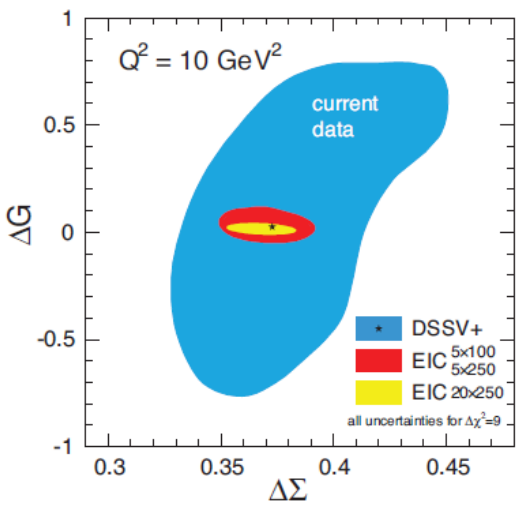
Sensitive to **transversity** universal between SIDIS & pp & e^+e^-

Sensitive to **proton spin** – parton **transverse motion** correlations non-universal between SIDIS&pp

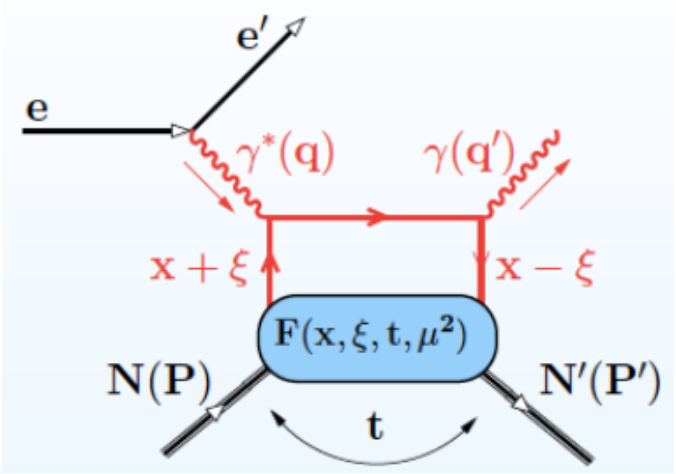
Proton Helicity Structure

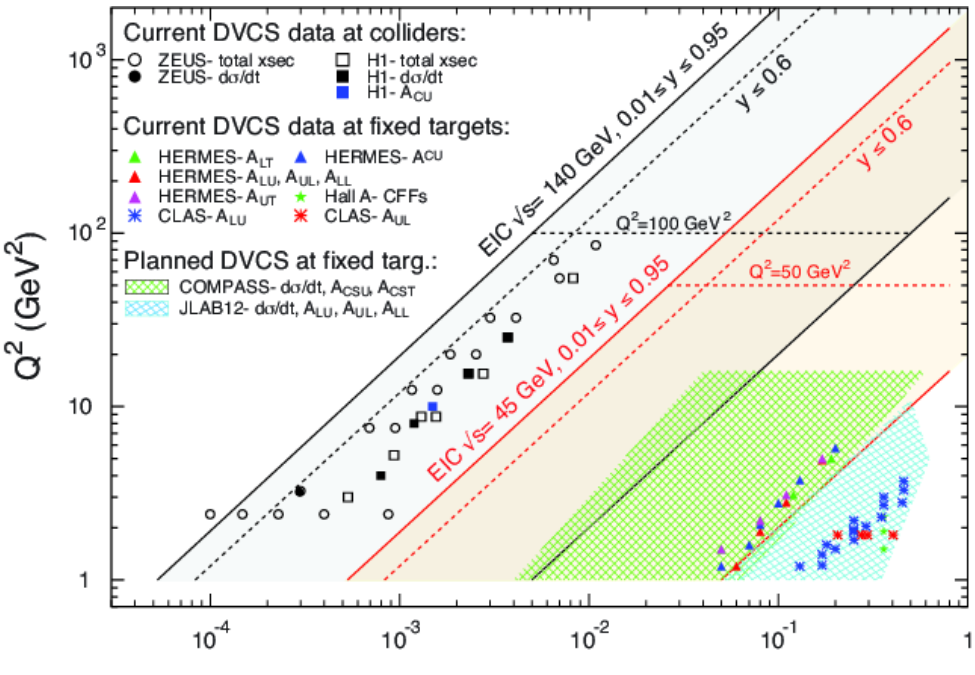




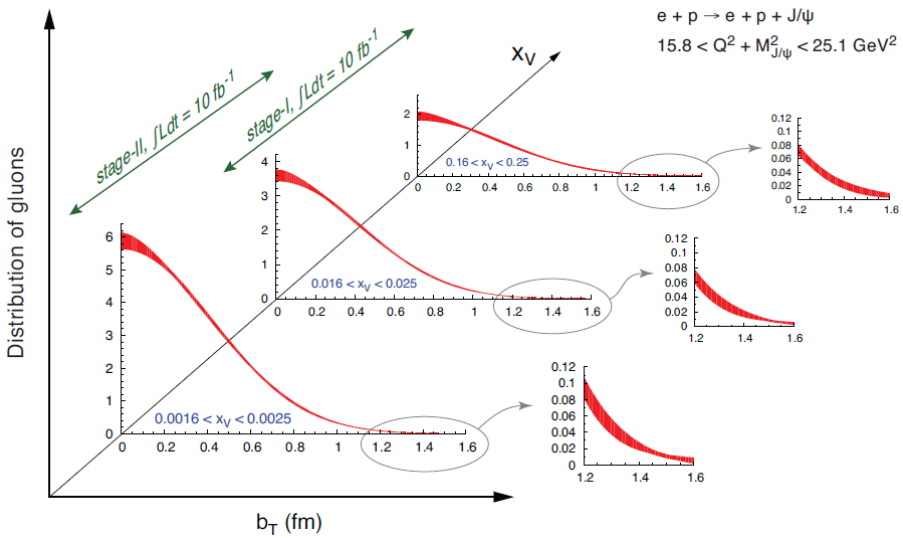


Deeply Virtual Compton Scattering



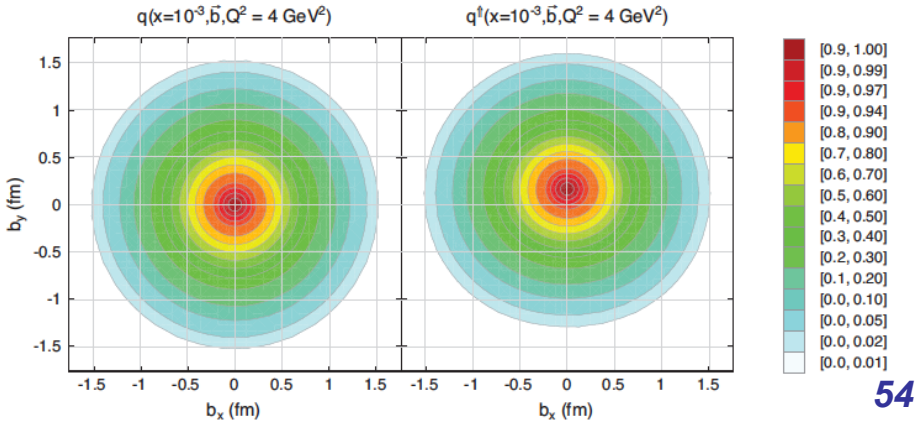


3D Imaging of the Proton

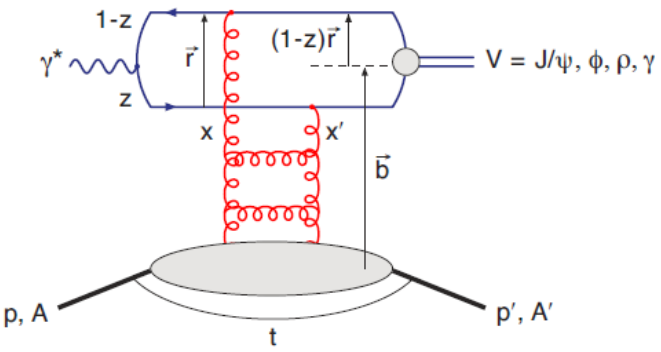


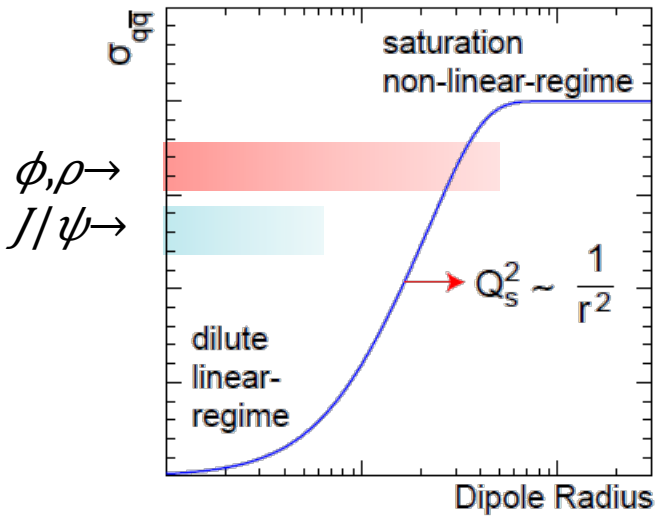
Access to orbital angular momentum

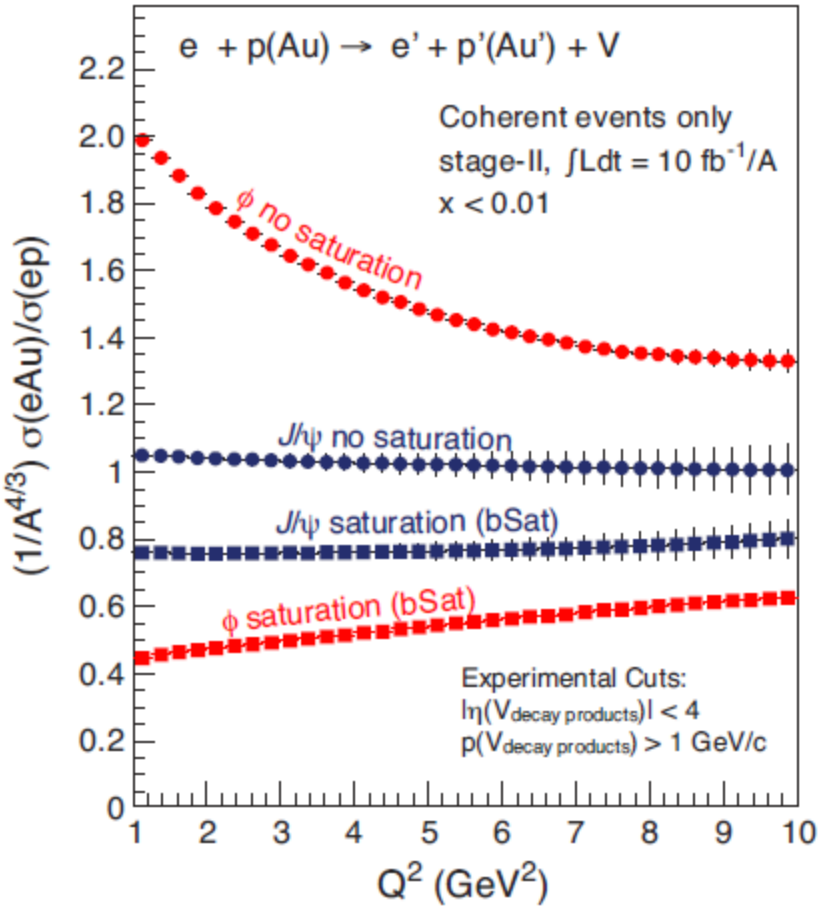
$$J_{q,g} = \int_{t\to 0} dx \cdot x \cdot \left[H_{q,g}(x,\xi,t) + E_{q,g}(x,\xi,t) \right]$$



Gluon Saturation from Exclusive VM

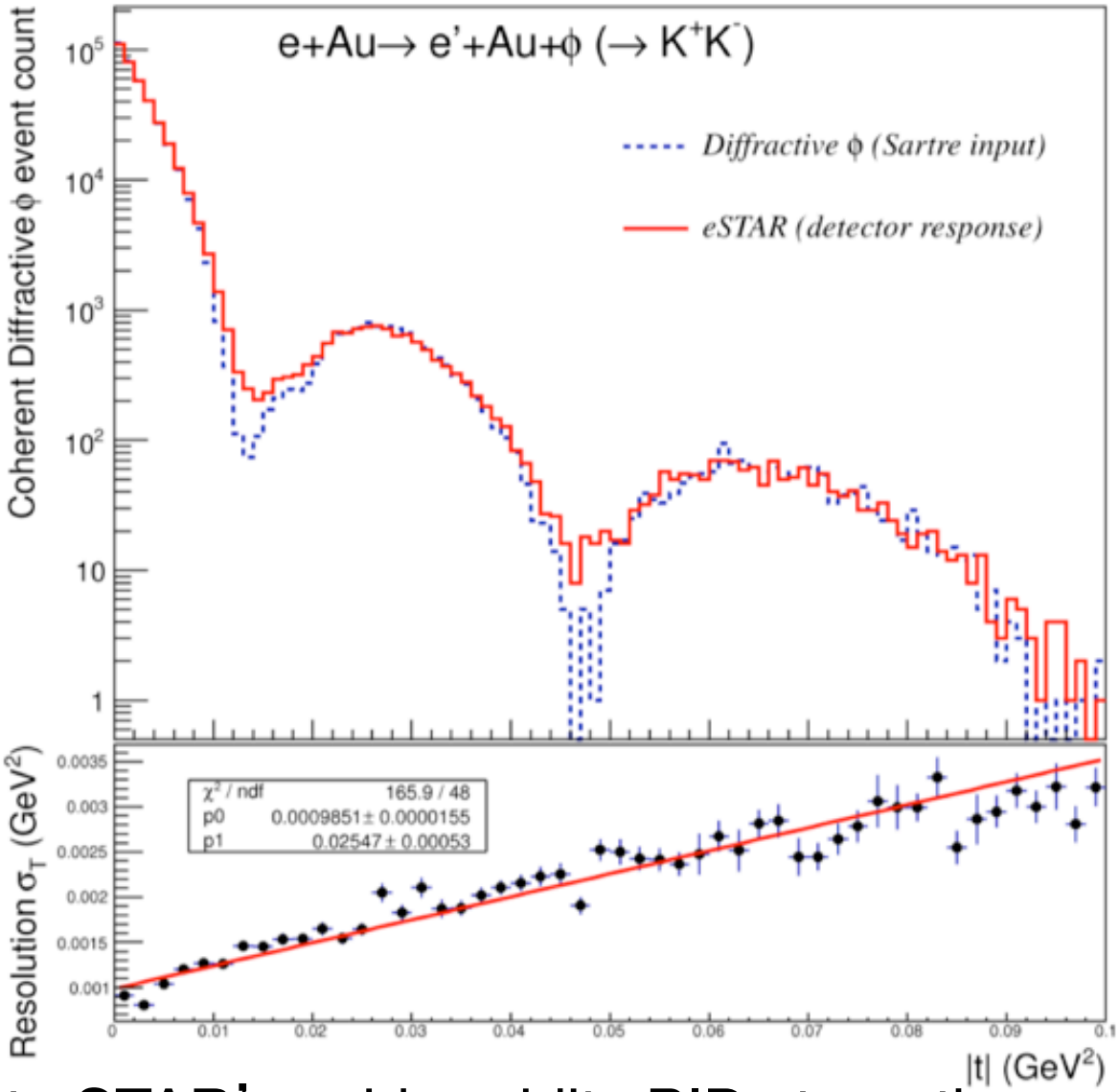






Gluon Saturation from Exclusive VM

eSTAR projections for diffractive production of phi-mesons



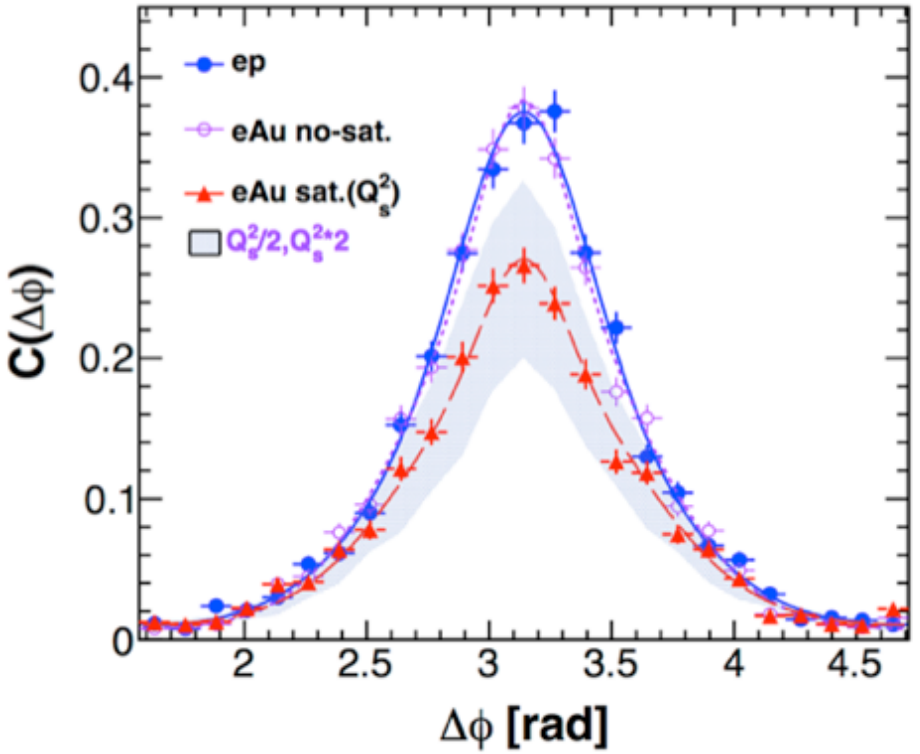
Plays well to STAR's mid-rapidity PID strengths, good resolution

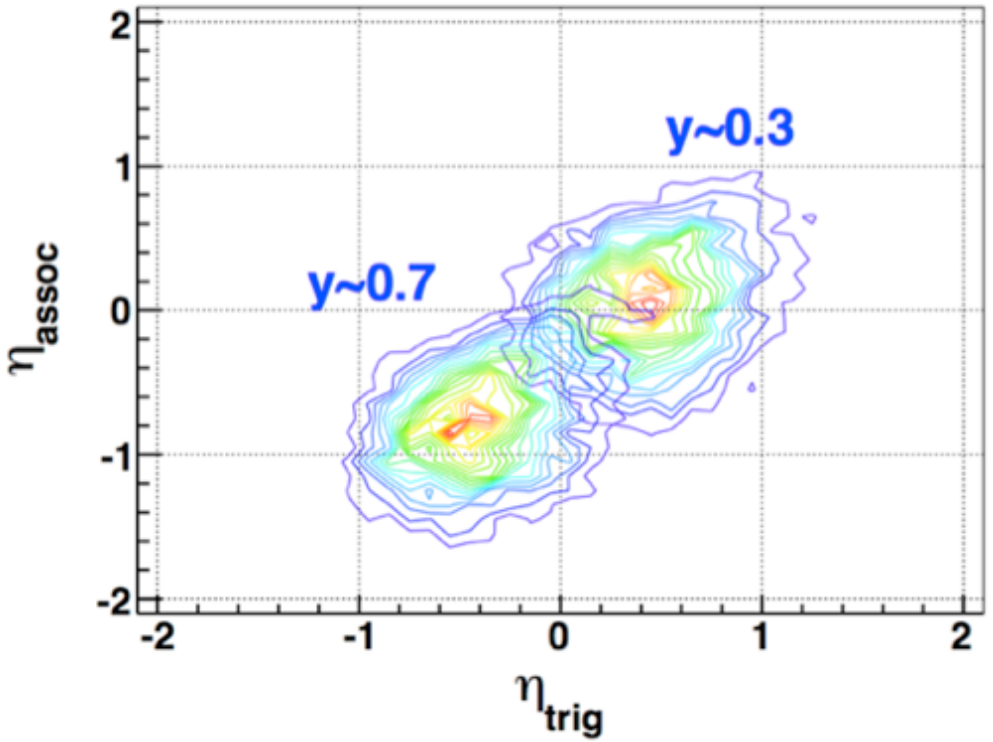
Gluon Saturation from Di-Hadron

Azimuthal correlations in di-hadron (semi-inclusive DIS) measurements,

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

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

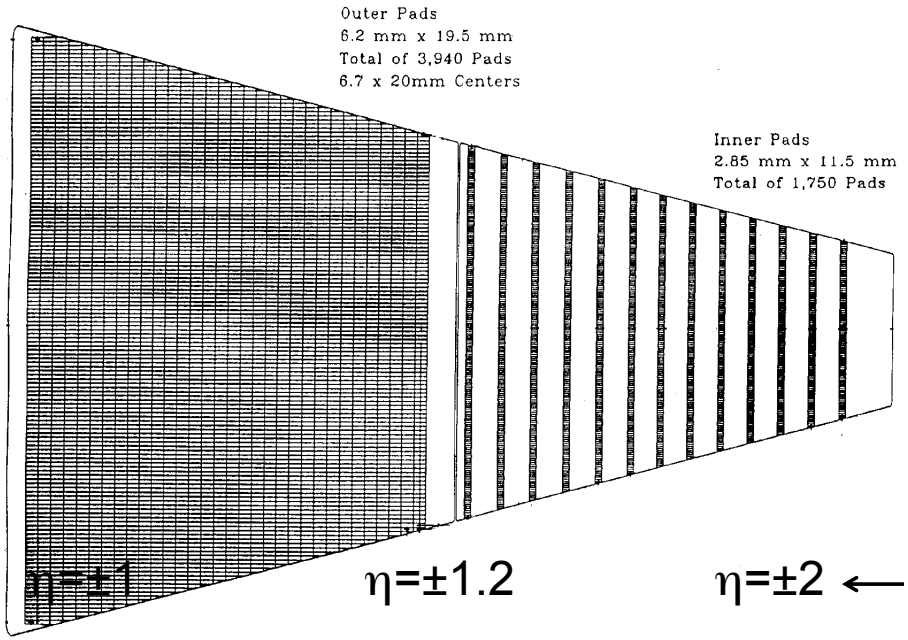


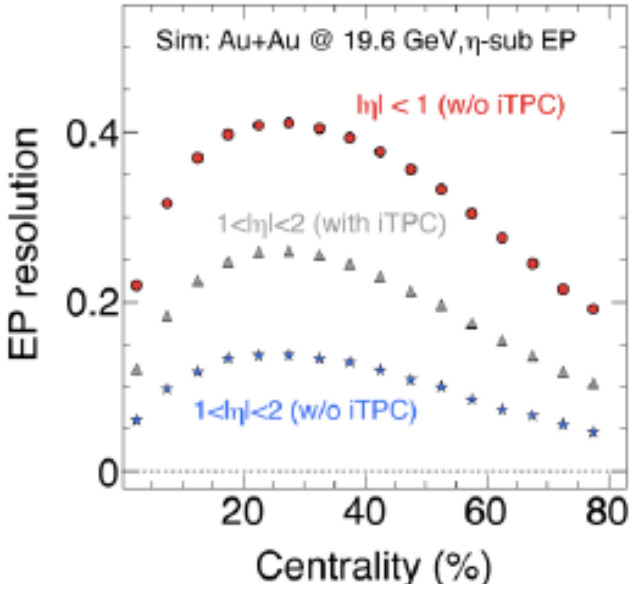


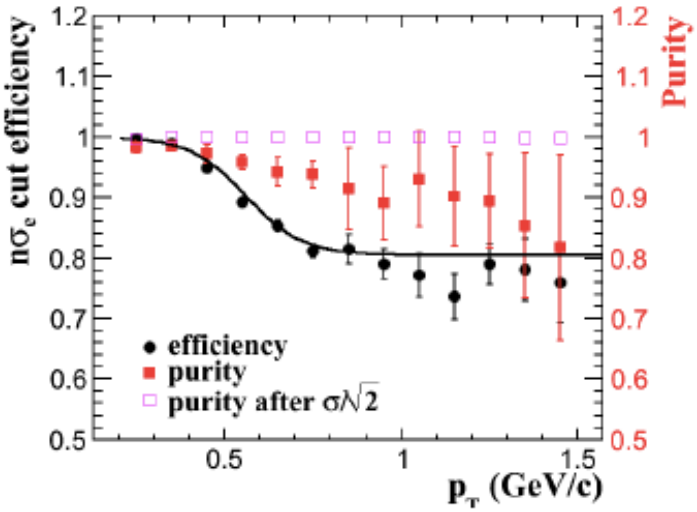
eSTAR projections for 10 GeV electrons scattering off 100 GeV/nucleon Au beams, 1 fb^{-1}.

Upgrades for BES II

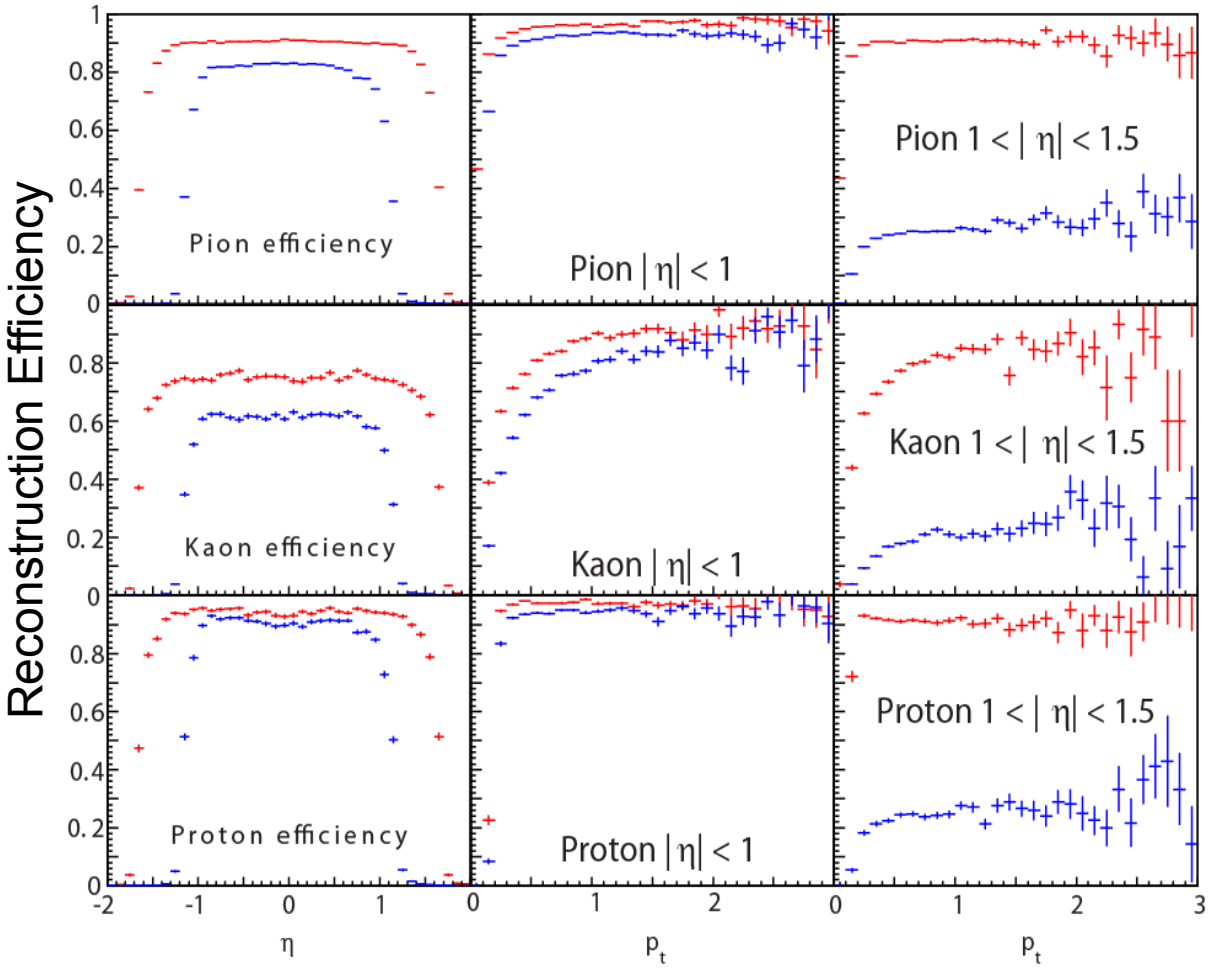
- Current pad plane with 13 rows and gaps
  - only 13 maximum possible points
  - only reads ~20% of possible gas path length
    - Inner sectors essentially not used in dE/dx
- Limits effective acceptance to |η|<1





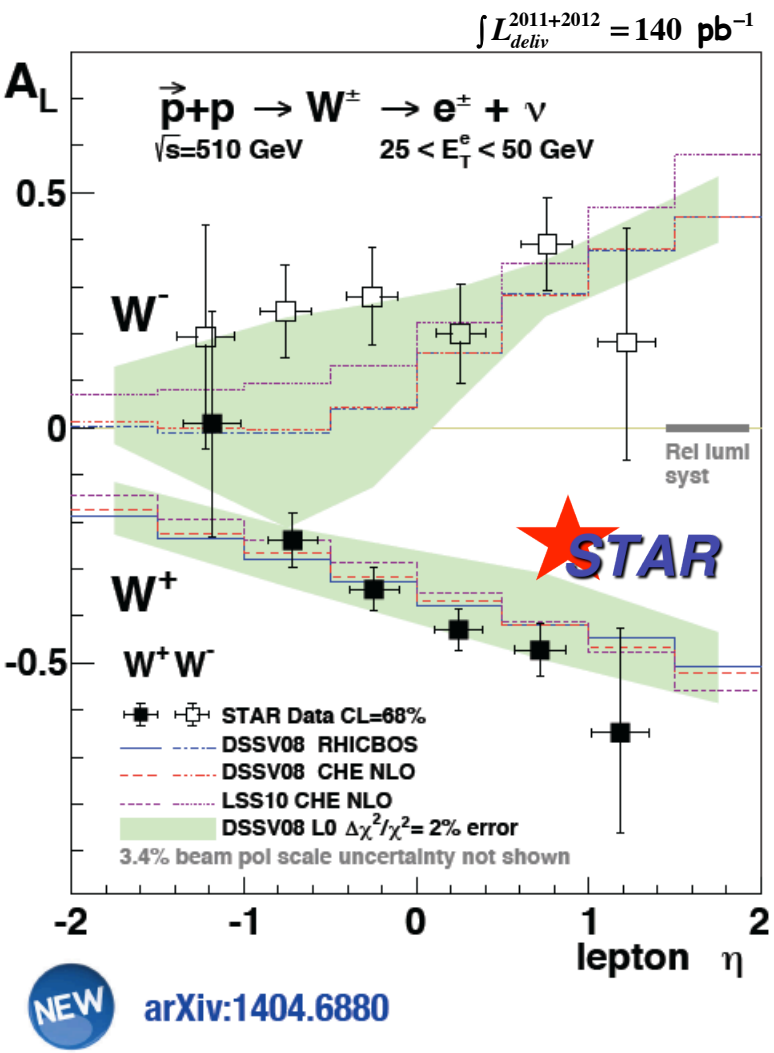


Upgrades for BES II

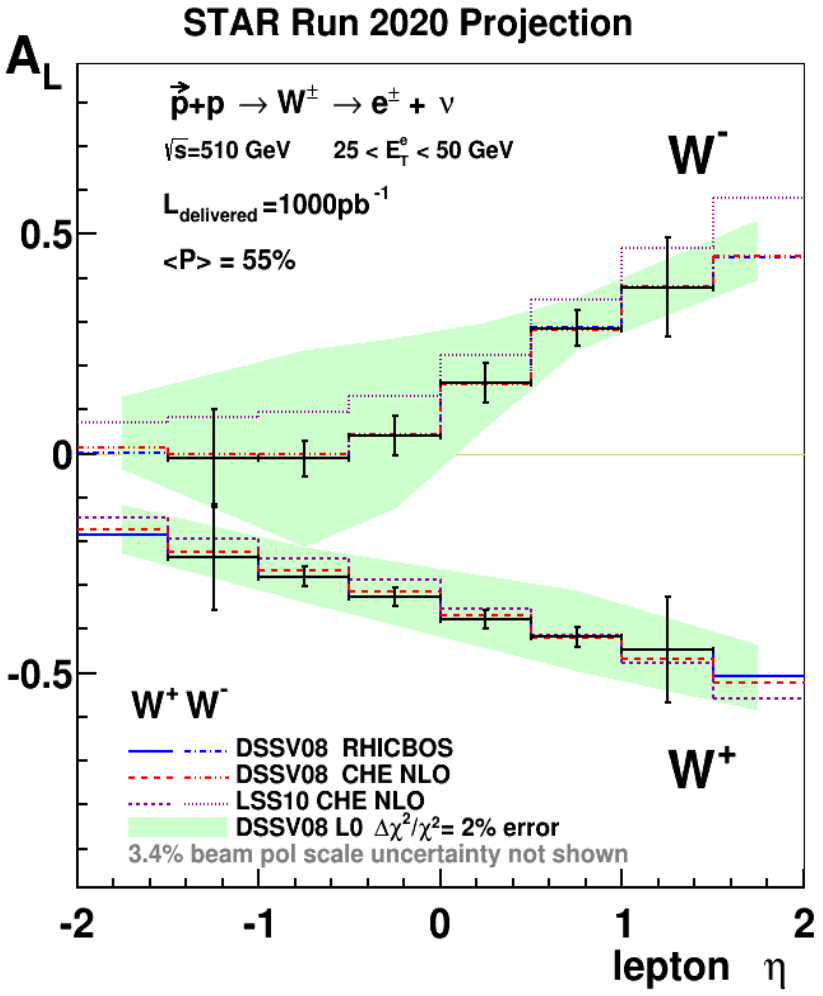


Essential for both BESII and eSTAR physics

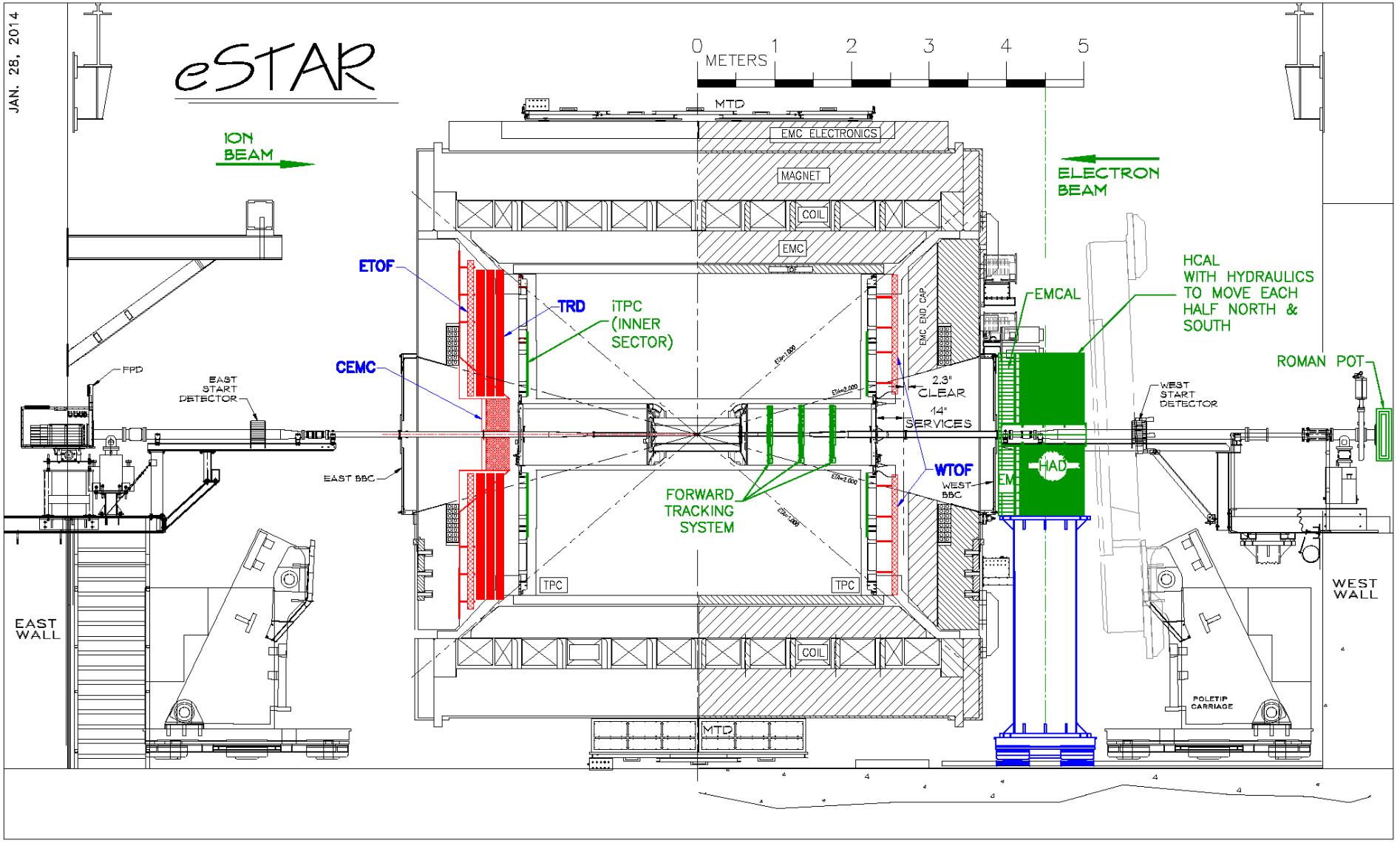
Proton Helicity Structure



arXiv:1404.6880



eSTAR Detector in 2025+



The very successful STAR detector will **evolve into an EIC detector**