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

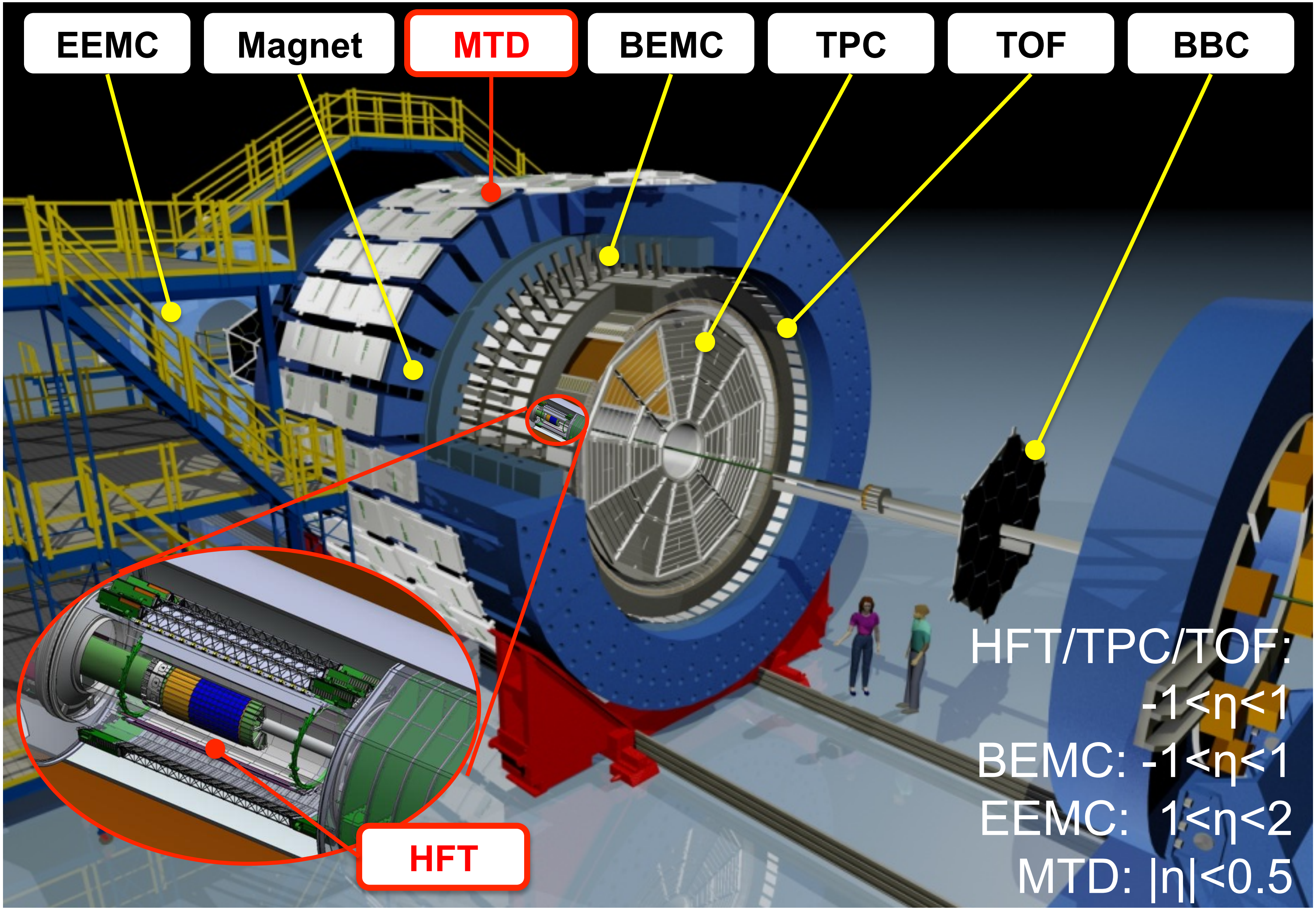

**Outline**

Introduction

Upgrade and Physics

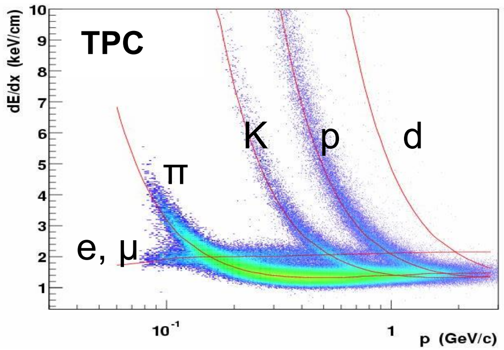
Summary

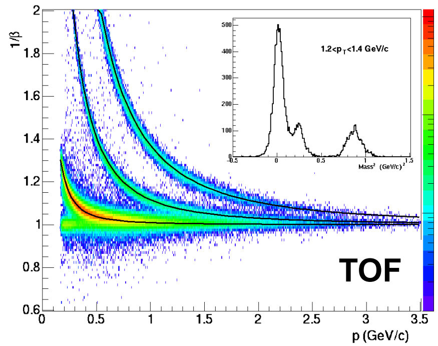
# STAR Detector (2014)



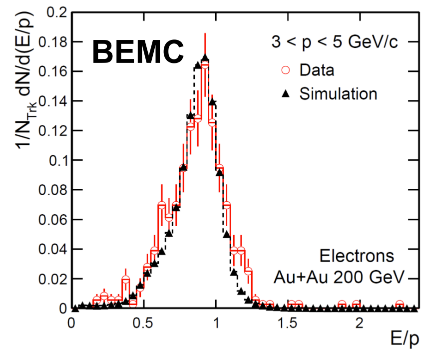

**Excellent mid-rapidity detector with full azimuthal Tracking+PID+Calorimetry**

# STAR Detector (2014)

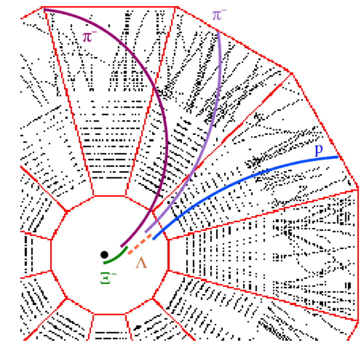


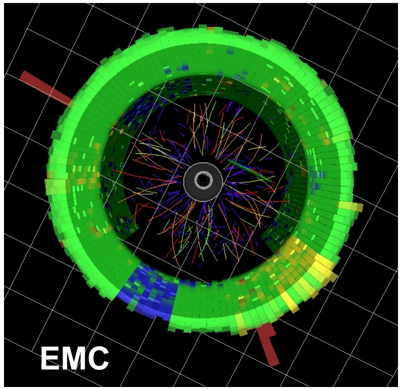

*Identified charged hadrons*



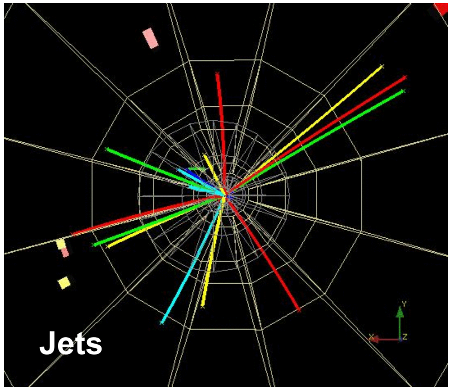

*High $p_T$ electrons*



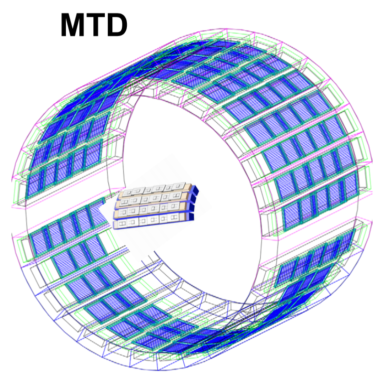

*Hyperons & Hyper-nuclei*



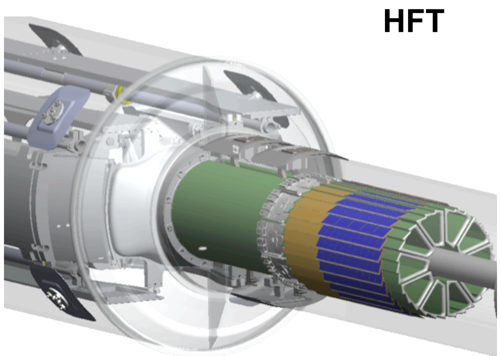

*Neutral particles*




*Jets & Correlations*



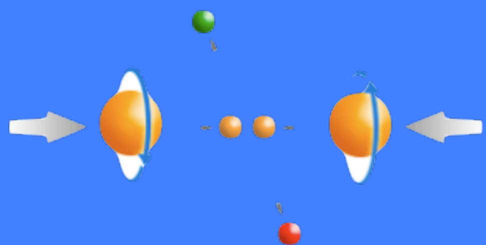

*High $p_T$ muons*

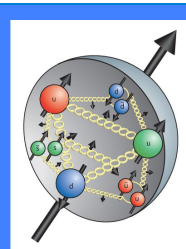



*Heavy-flavor hadrons*

**Identifying and measuring almost all kinds of particles produced from collisions**

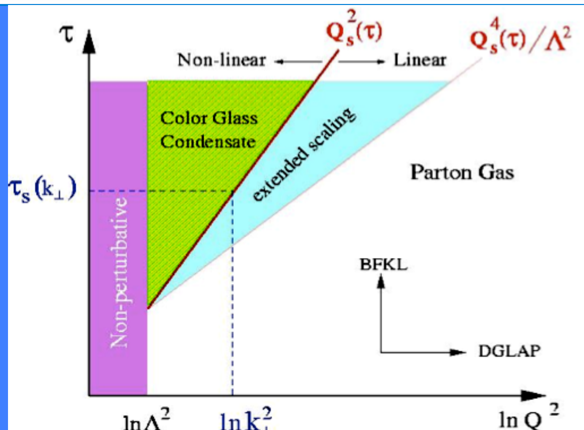
# STAR Physics





## Polarized p+p Program

- proton spin structure
- perturbative QCD




## p(d)+A Program

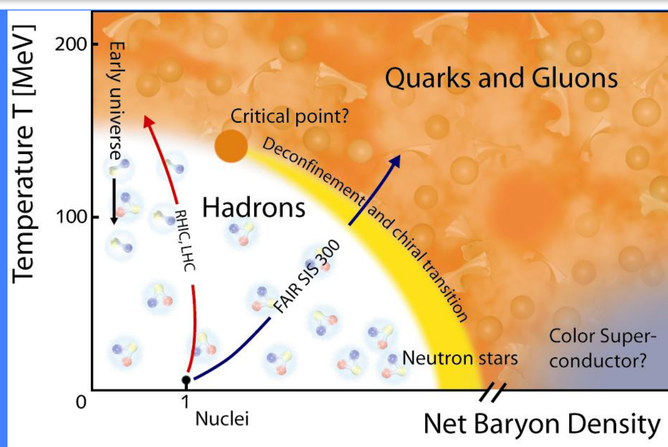
- gluon saturation, CGC
- initial conditions, CNM
- diffractive interactions

## eSTAR:

Polarized

e+p / e+A

Program



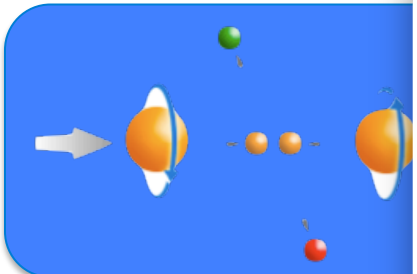

## A+A Top Energy

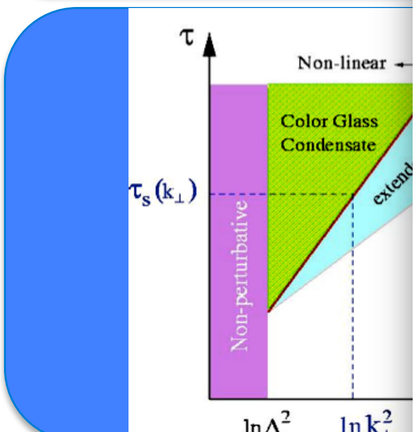
- QGP medium properties, EoS
- QCD in hot and dense medium

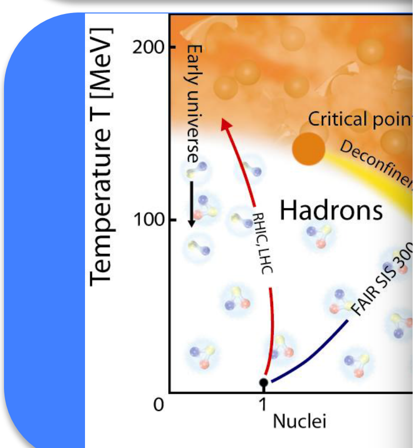
## A+A Beam Energy Scan

- search for the critical point
- chiral symmetry restoration

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



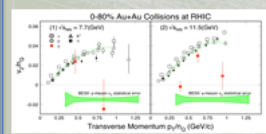


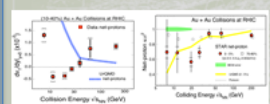



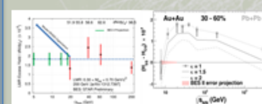

# STAR HIGHLIGHTS at QM2014

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"***

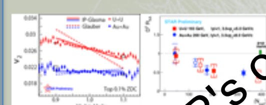
(2) May 20, 9:20-9:40, Helium [QCD phase diagram] Feng Zhao ***"$\Lambda(K_s^0)$-$h^\pm$ azimuthal correlations with respect to event plane and searches for chiral magnetic and vortical effects at STAR"***

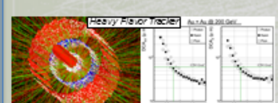
(3) May 20, 10:00-10:20, Helium [QCD phase diagram] Qi-Ye Shou ***"Charge asymmetry dependency of π/K anisotropic flow in U+U and Au+Au collisions at STAR"***

(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: 1404.1433

## 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"***

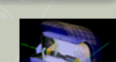
(2) May 19, 16:30-16:50, Helium [Electromagnetic probes] Ahmed M. Hamed ***"Measurements of direct-photon-hadron correlations and direct-photon azimuthal anisotropy by STAR"***

(3) May 19, 17:30-17:50, Titanium [Initial state physics] Li Yi ***"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<br>200 GeV Au+Au | Heavy flavor flow, energy loss, thermalization, etc.<br>Quarkonium studies<br>QCD critical point search | Electron lenses<br>56 MHz SRF<br>STAR HFT<br>STAR MTD |
| 2015-16 | p+p at 200 GeV<br>p+Au, d+Au, $^{3}$He+Au at 200 GeV<br>High statistics Au+Au | Extract $\eta/s(T)$ + constrain initial quantum fluctuations<br>More heavy flavor studies<br>Sphaleron tests<br>Transverse spin physics | PHENIX MPC-EX<br>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<br>Partial commissioning of sPHENIX (in 2019) |
| 2020 | No Run | | Complete sPHENIX installation<br>STAR forward upgrades |
| 2021-22 | Long 200 GeV Au+Au with upgraded detectors<br>p+p, p/d+Au at 200 GeV | Jet, di-jet, $\gamma$-jet probes of parton transport and energy loss mechanism<br>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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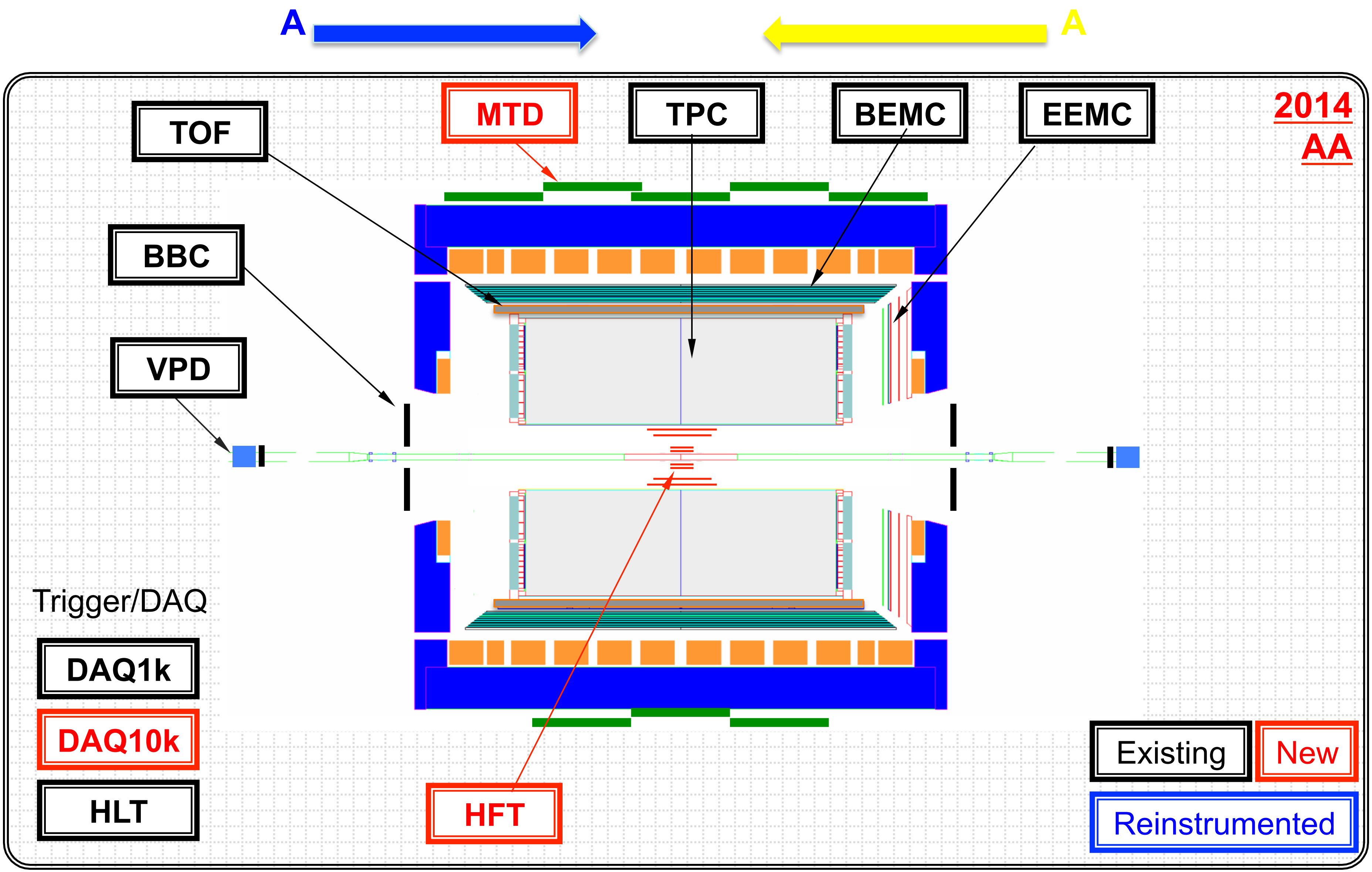
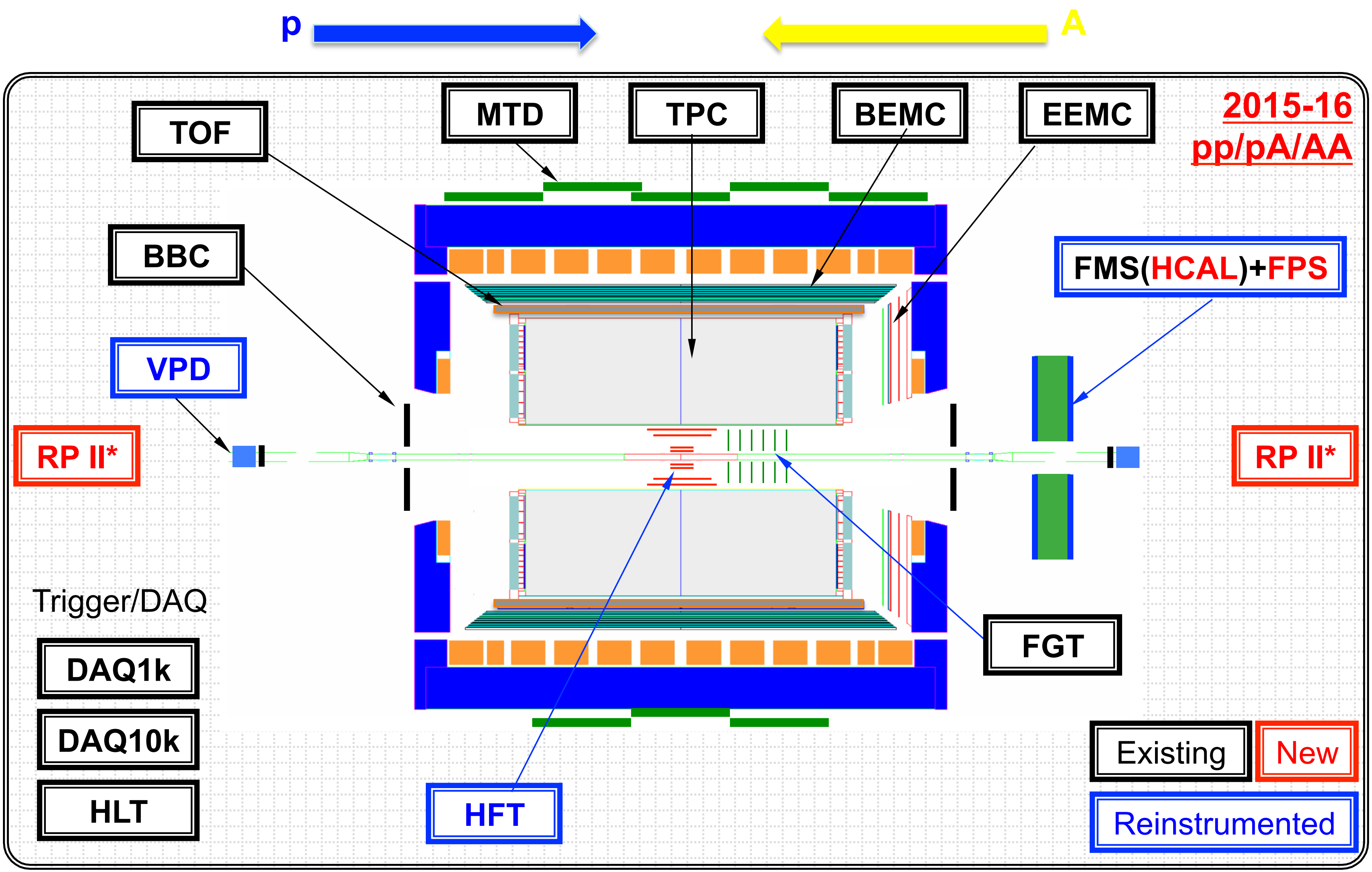
https://drupal.star.bnl.gov/STAR/starnotes/public/sn0606

# STAR Detector in 2014



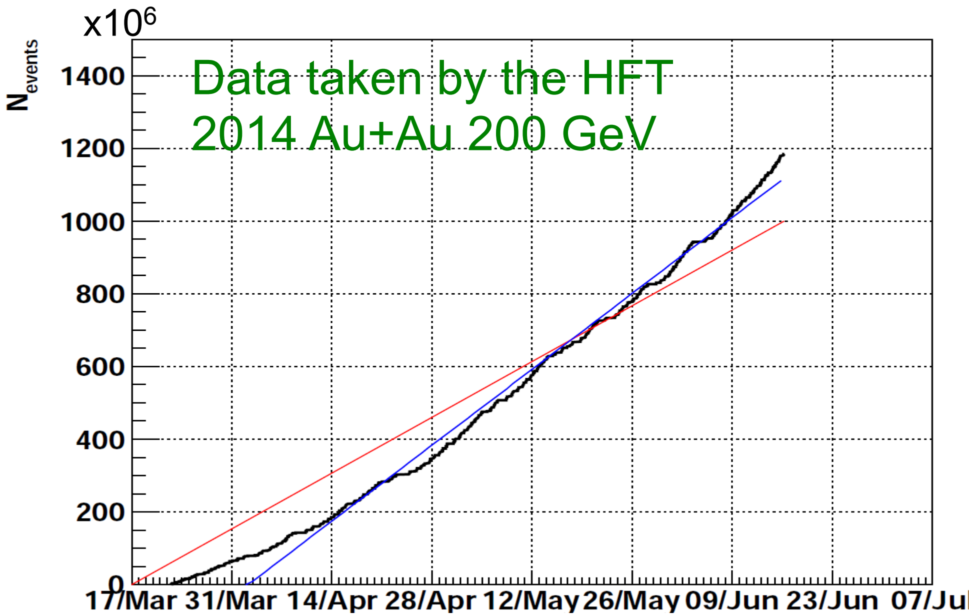

See Flemming Videbaek's talk on Thursday

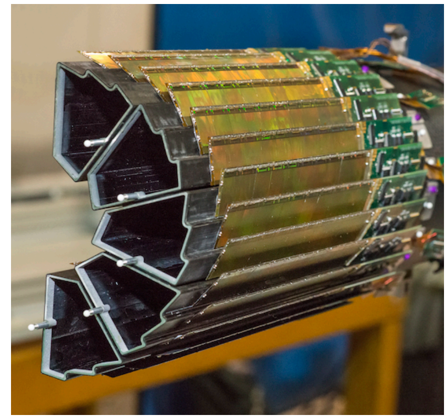
# STAR Detector in 2015-2016

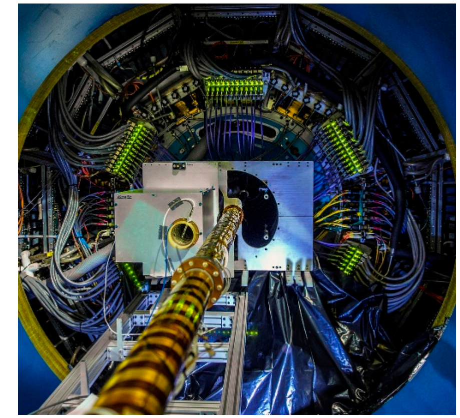



**FMS**: Forward Meson Spectrometer, **FPS**: Forward Preshower, **RP II***: Roman Pot Phase II*

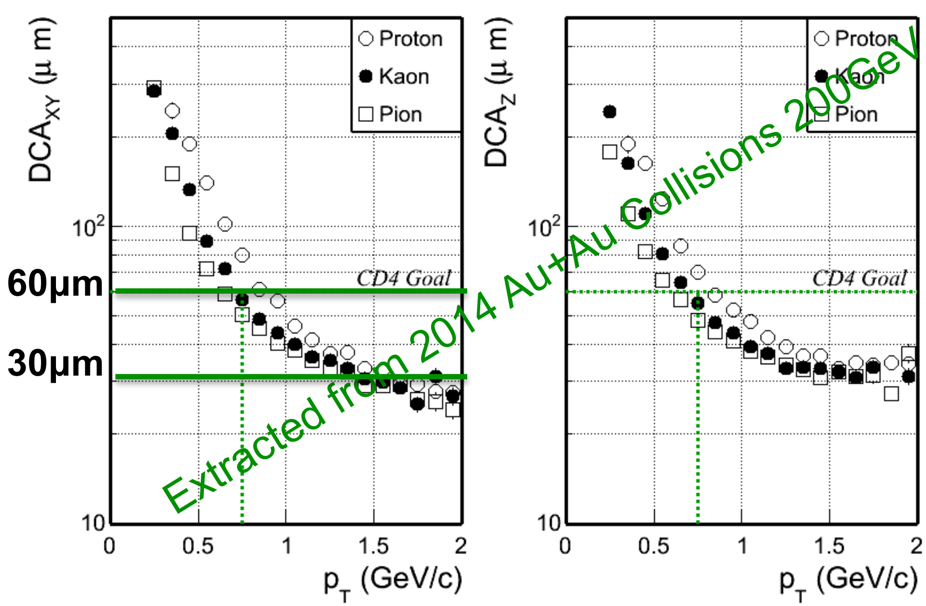
# Heavy Flavor in 2014-2016

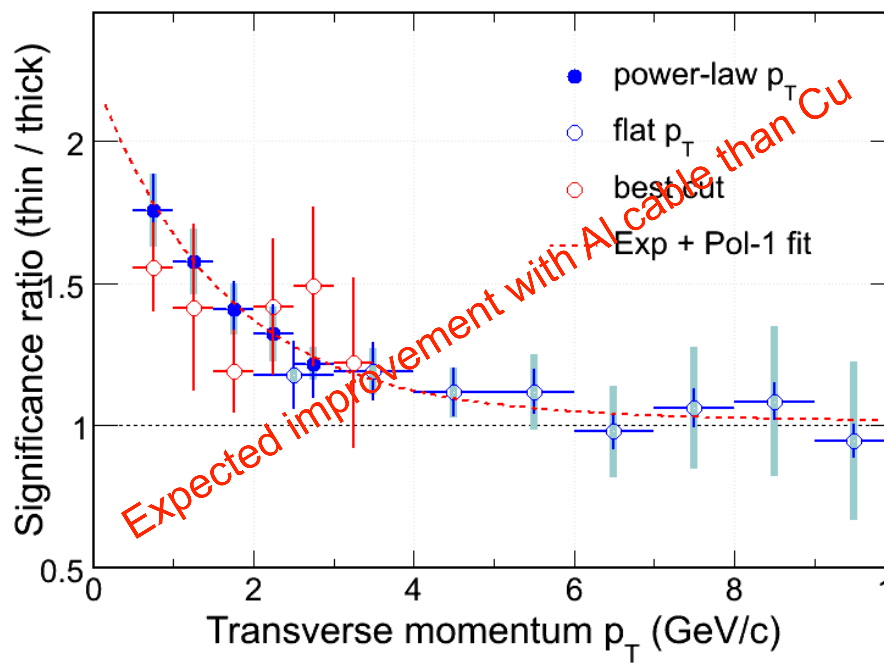


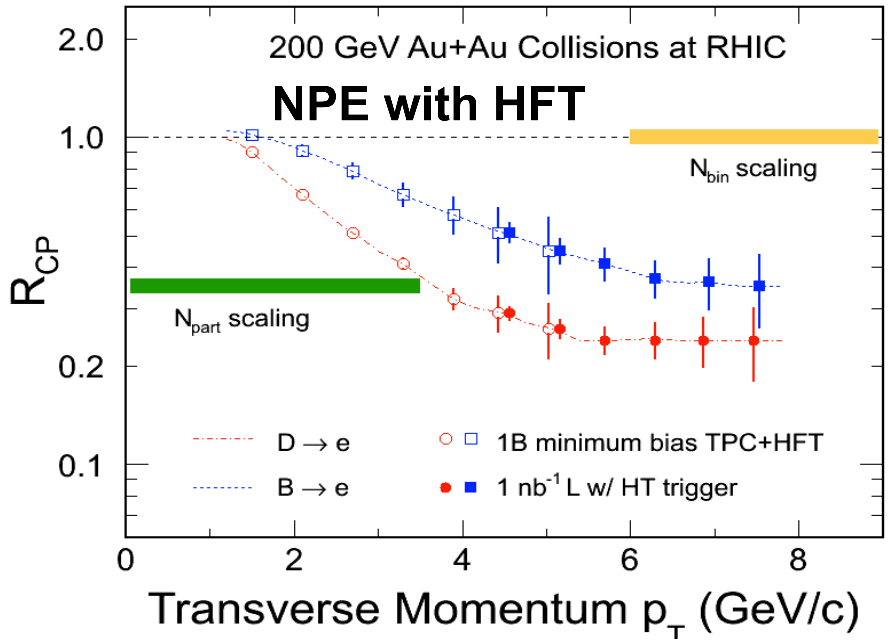


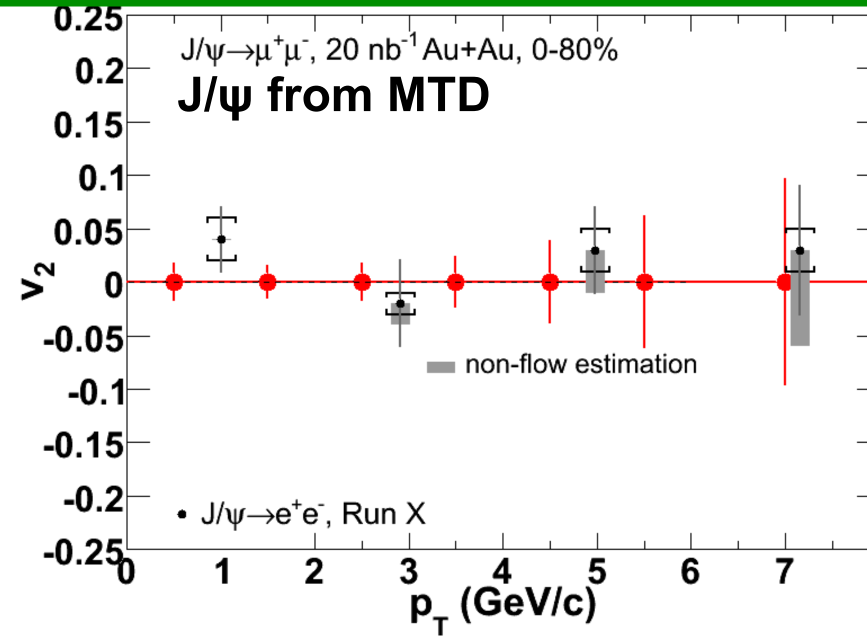
PXL with Al cable and VPD with new QT electronics in 15/16 -> F.O.M. x6 over 14

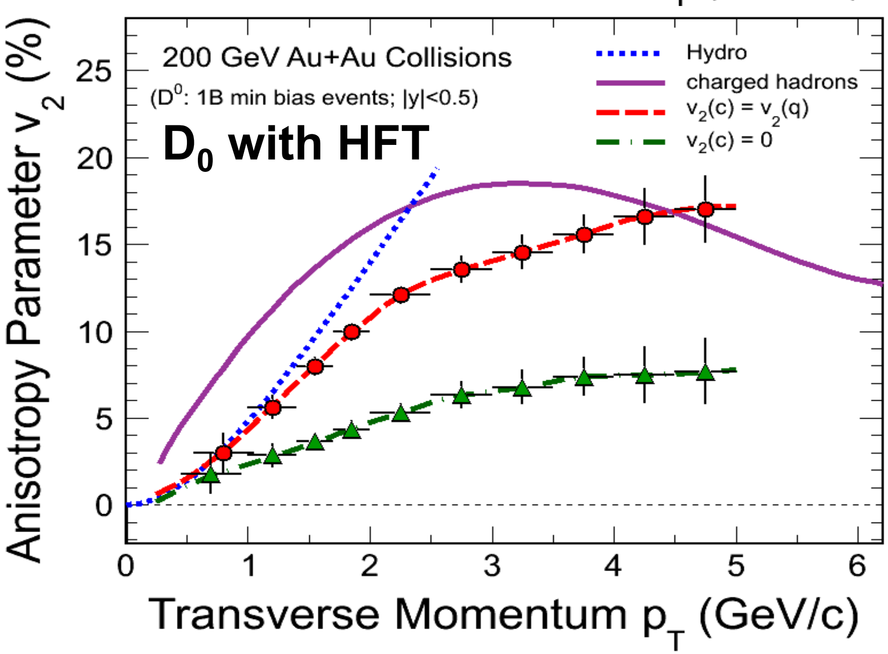


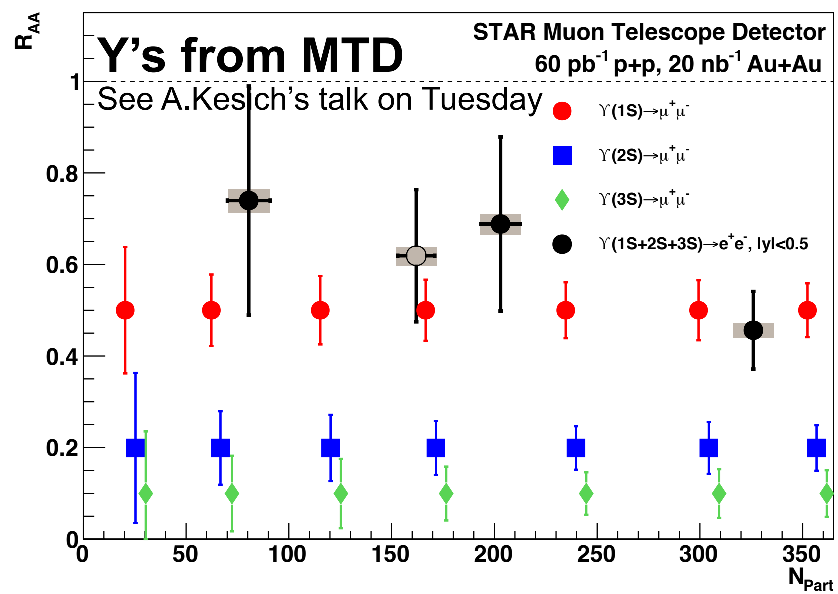



# Heavy Flavor in 2014-2016



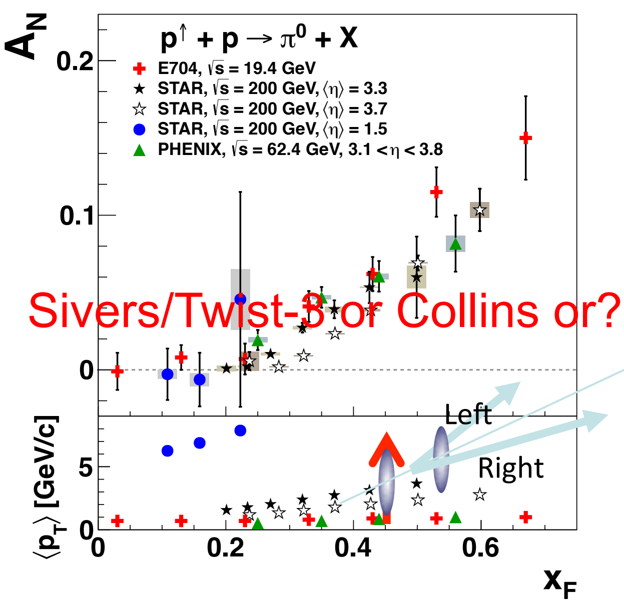



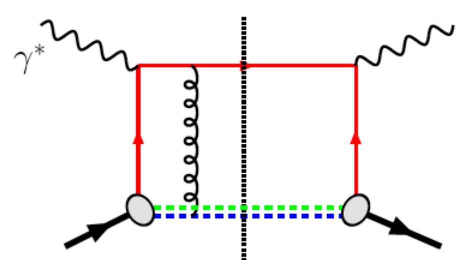



# Transverse Spin in 2015-2016

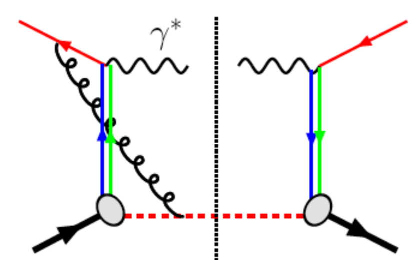
| Year | # | NSAC LRP Milestone |
|---|---|---|
| 2013 | HP8 | Measure flavor-identified $q$ and $\bar{q}$ contributions to the spin of the proton via the longitudinal-spin asymmetry of W production. |
| 2013 | HP12 (update of HP1, met in 2008) | Utilize polarized proton collisions at center of mass 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. |




**DIS:**
gq-scattering
**attractive FSI**

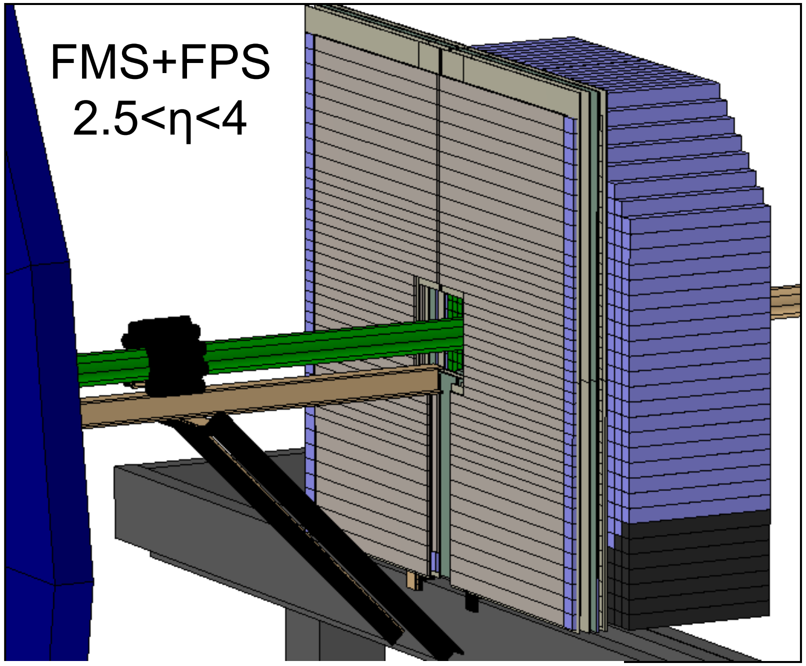


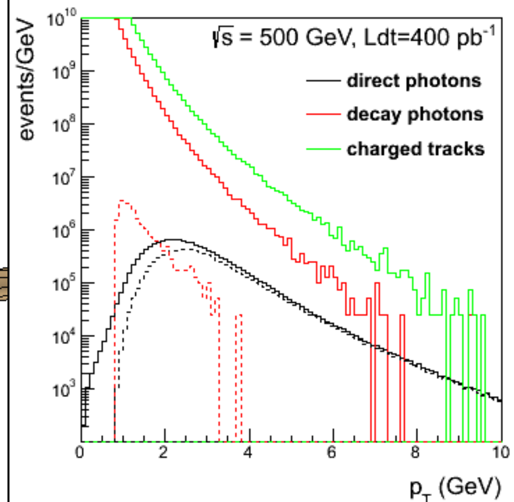

**p+p:**
qqbar-anhilation
**repulsive ISI**

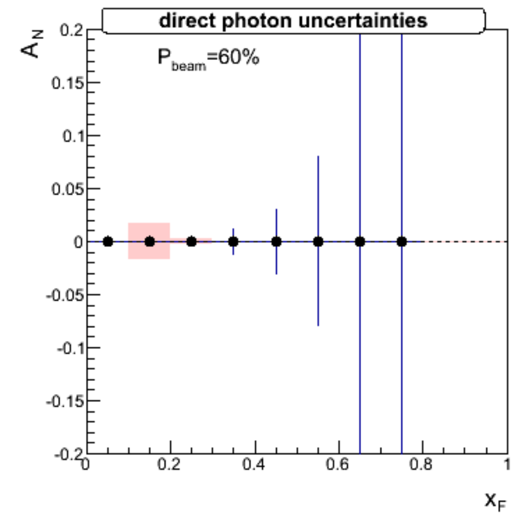



$A_N$ of $\gamma$, $W^{\pm}$, DY are sensitive to the sign-change $W^{\pm}$/DY also to TMD evolution. STAR can access to all these three world-class measurements

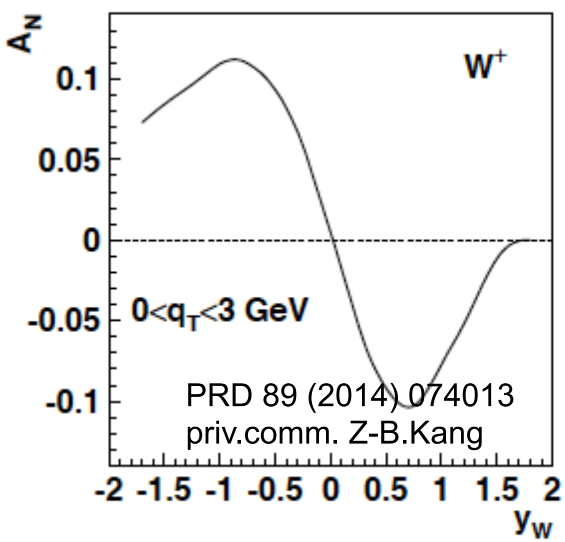
# FMS+FPS in 2015-2016

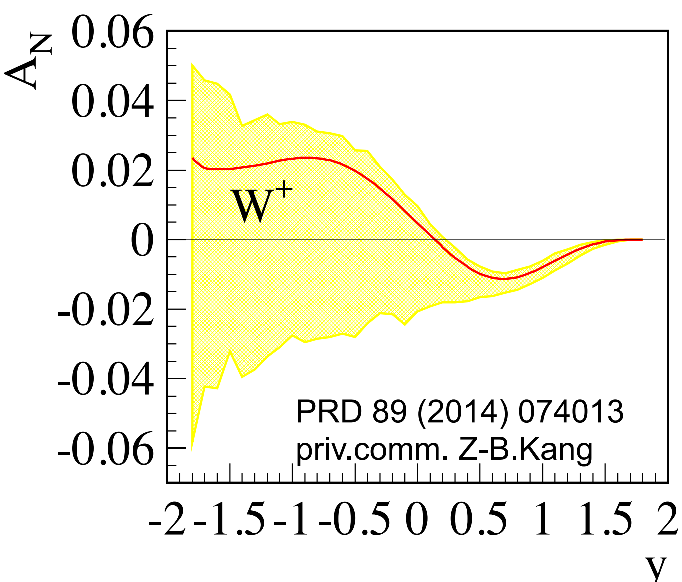


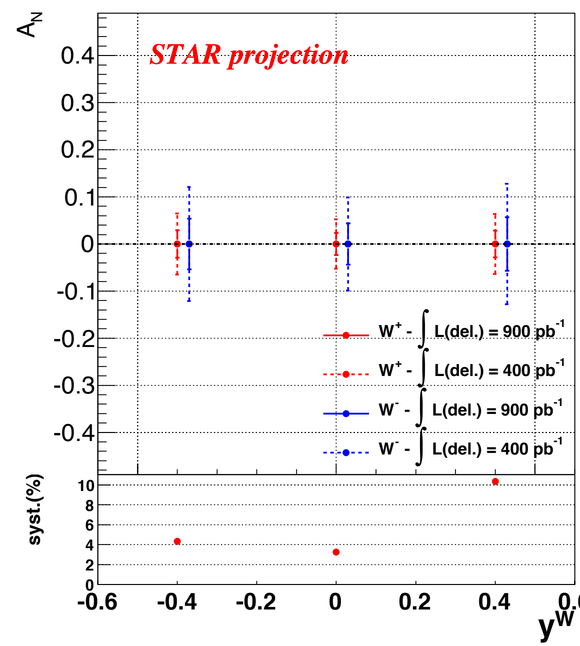



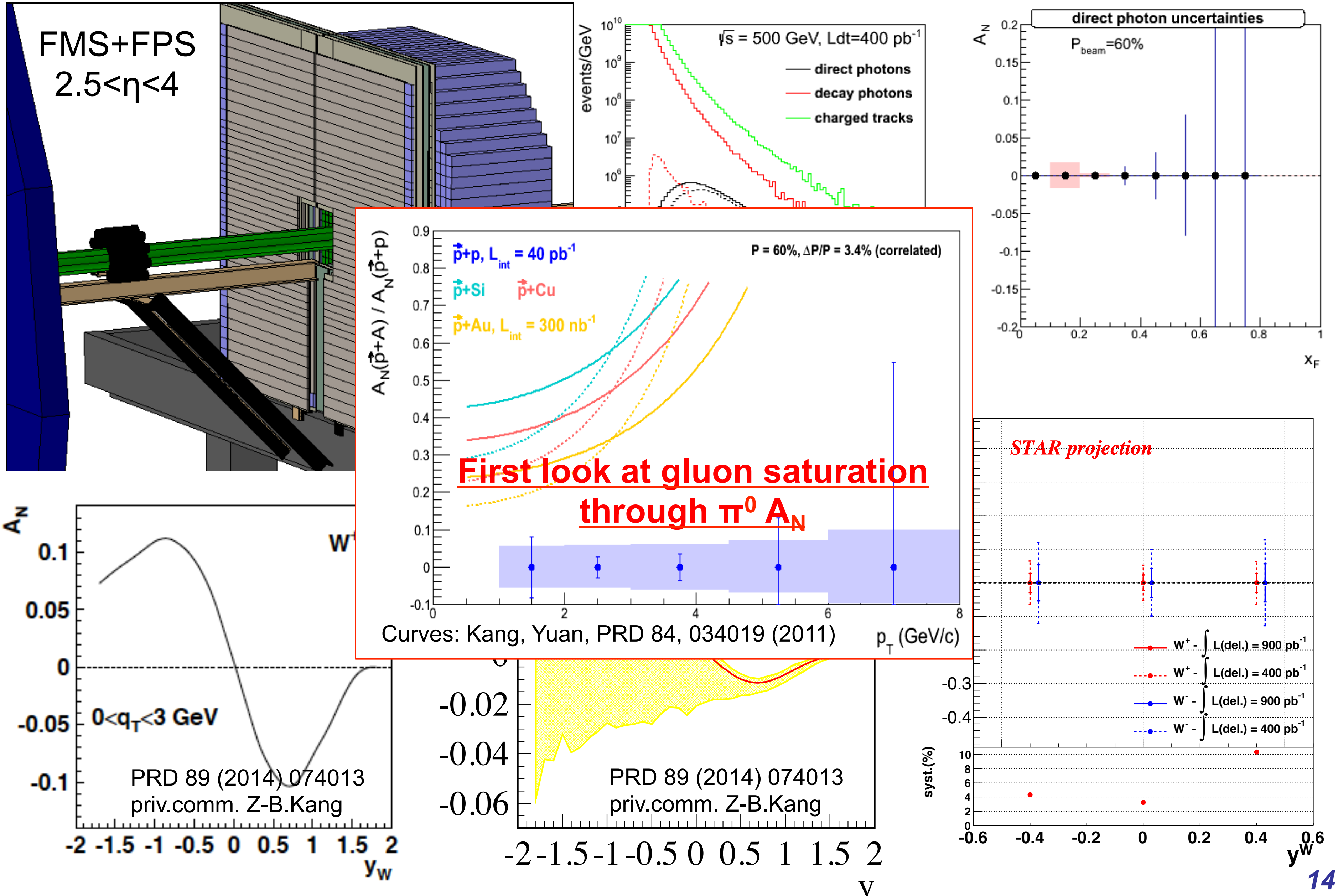

Solid: generated distributions
Dashed: reco. with FMS+FPS



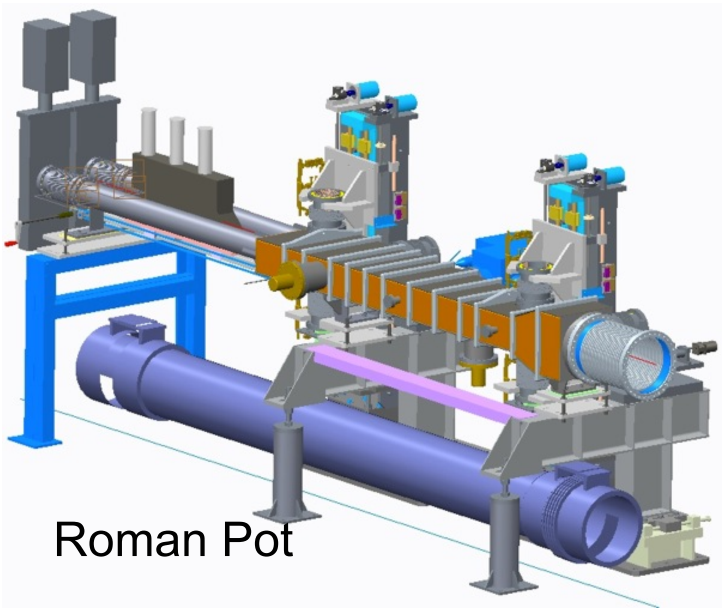



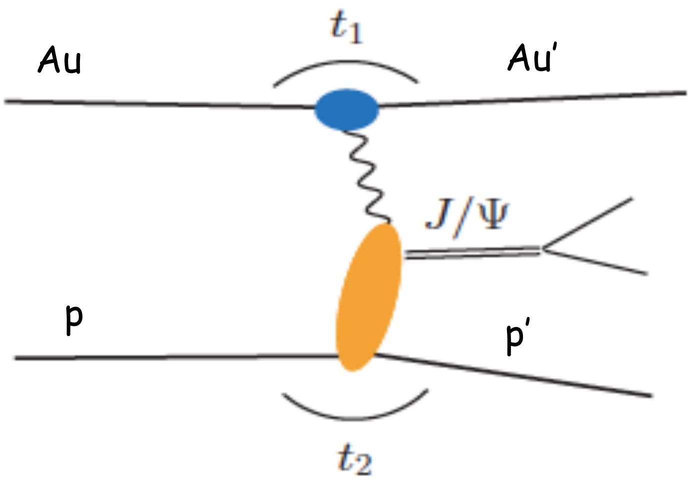



# FMS+FPS in 2015-2016

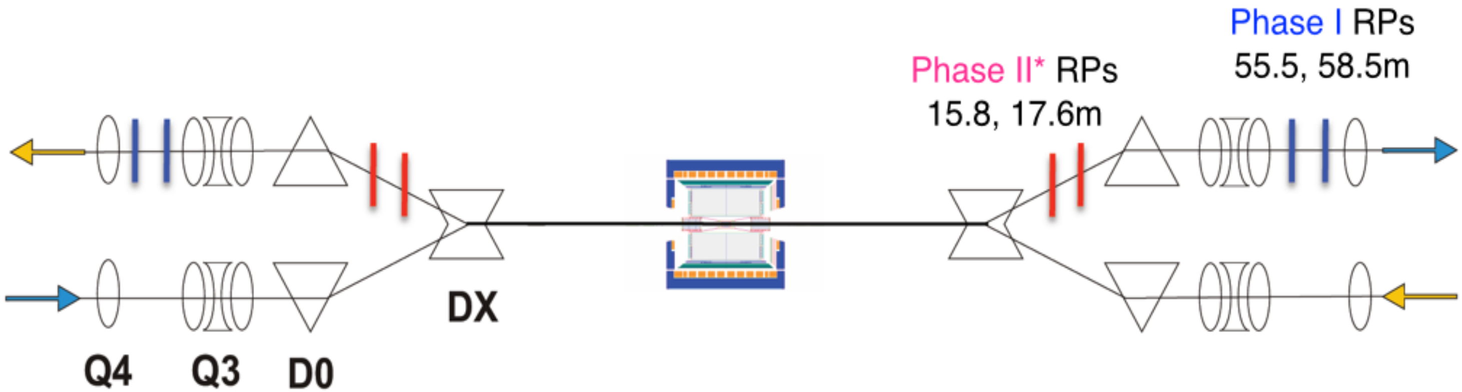


# Roman Pot II* in 2015-2016



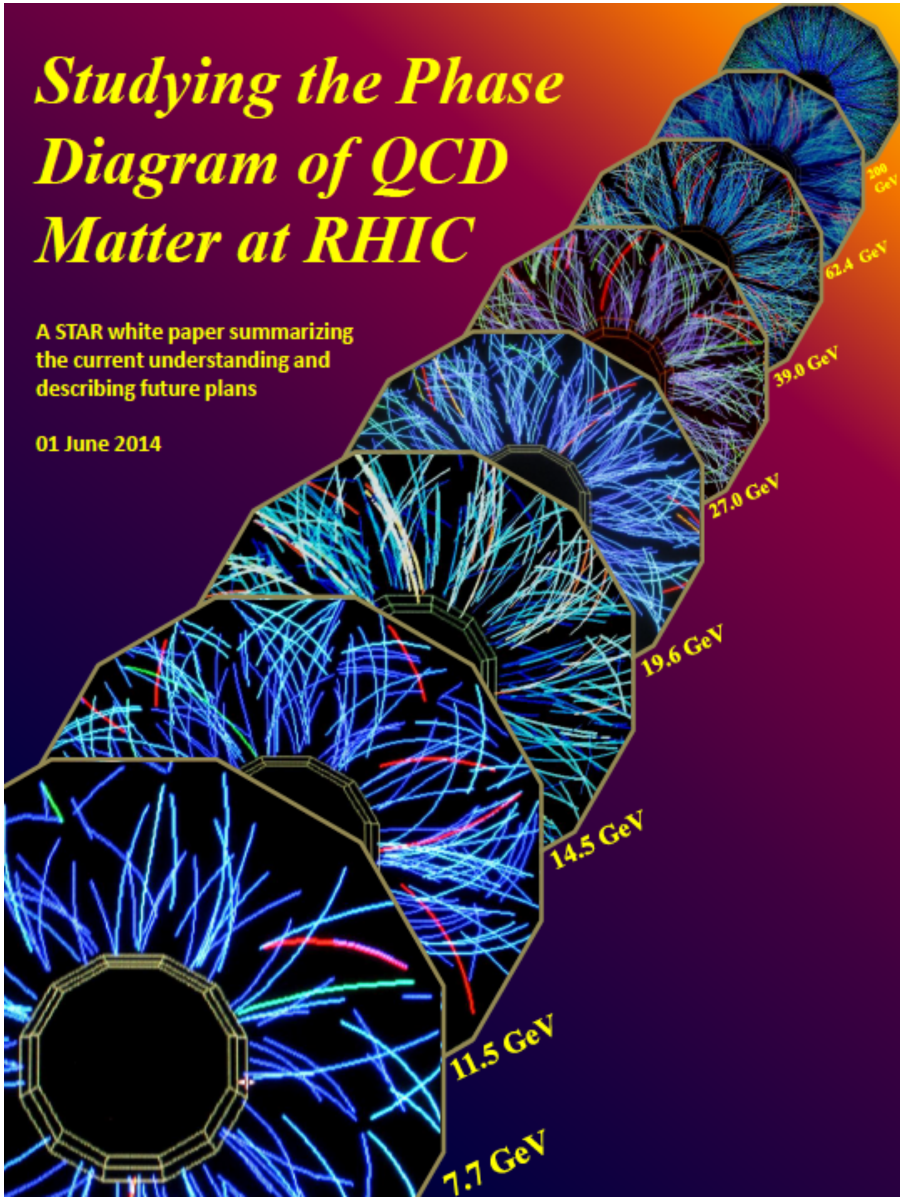




**First access to gluon Generalized Parton Distributions (GPDs)**



# Upgrade and Physics

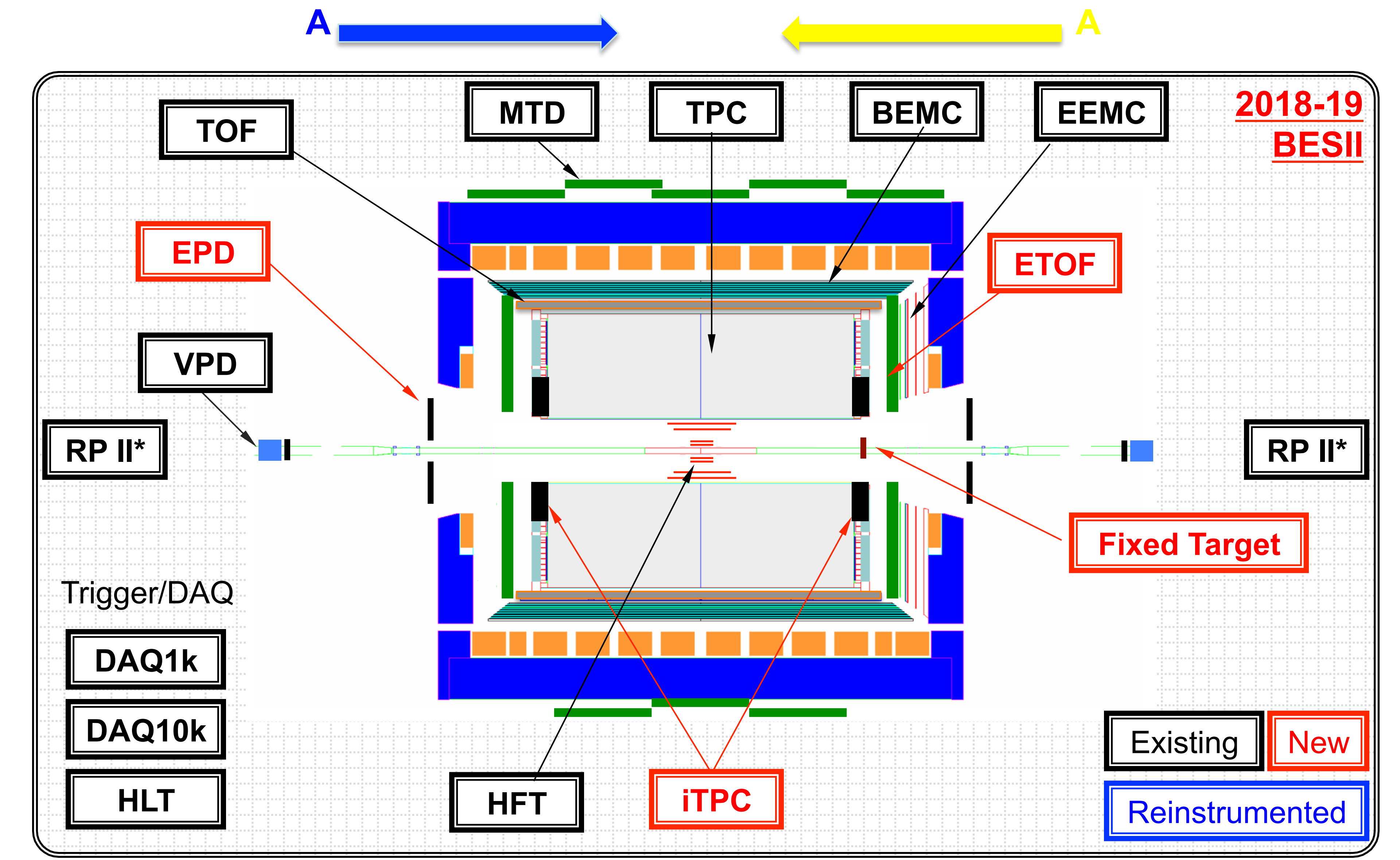
- pp+pA+AA 2014-2016
- BES II 2018-2019
  - QCD phase diagram
  - search for Critical Point
- pp+pA+AA 2021-2022
- eRHIC 2025+




See A. Schmah's talk this morning

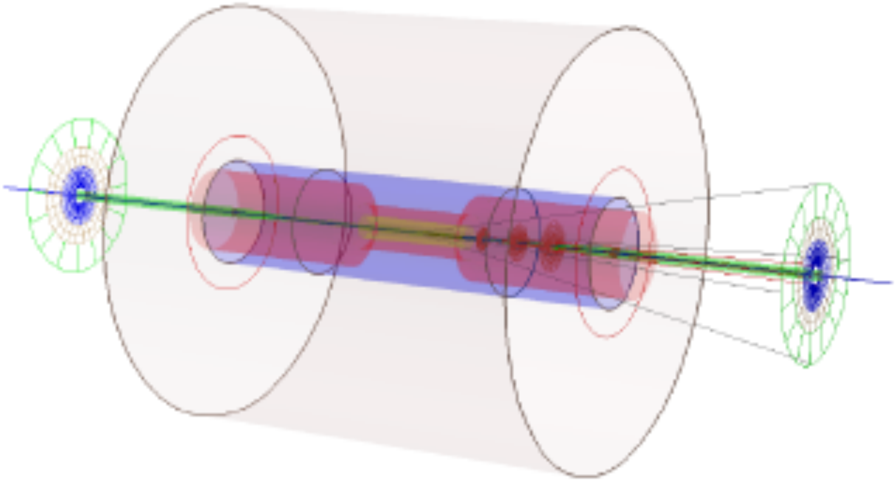
https://drupal.star.bnl.gov/STAR/starnotes/public/sn0598

# 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 $\eta$ 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:**

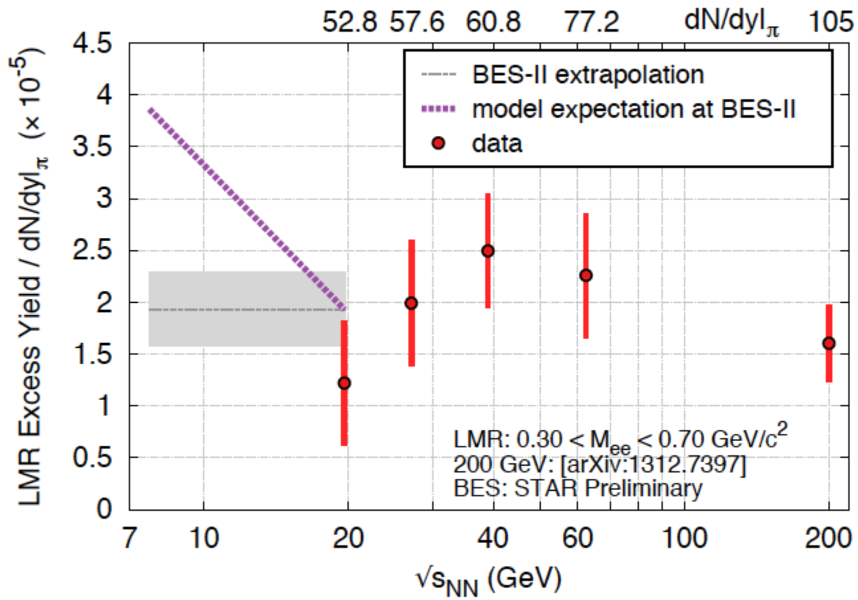
- For the 7.7 GeV system, in BES-I, 95% of STARs triggers were bad.

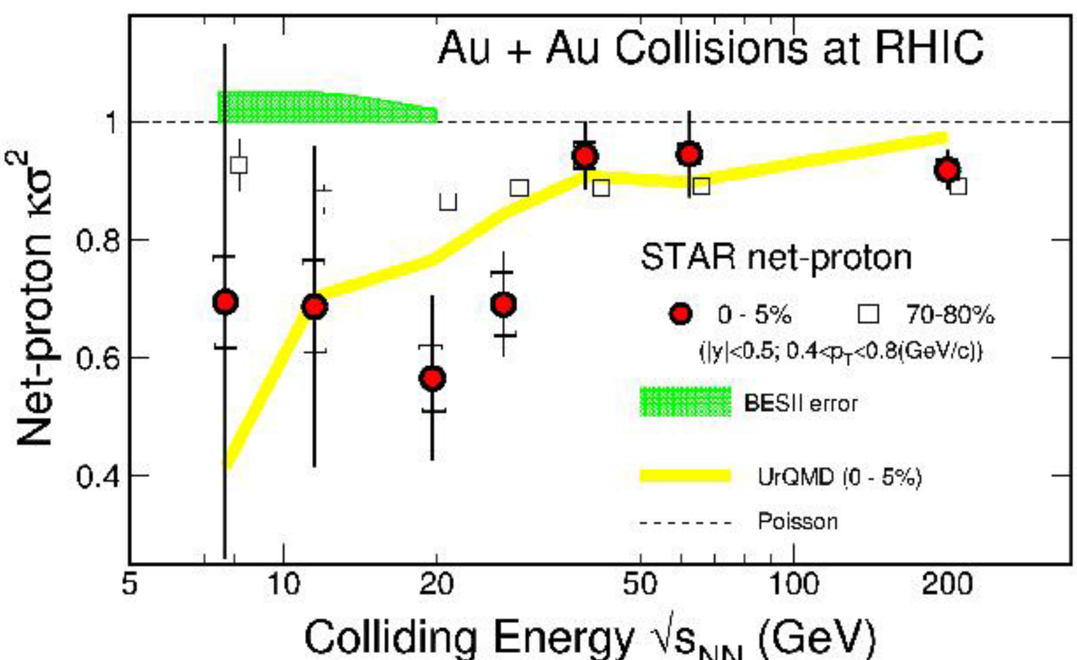
- Flow studies have been some of the most conclusive BES results. A better/independent reaction plane is critical to BES physics

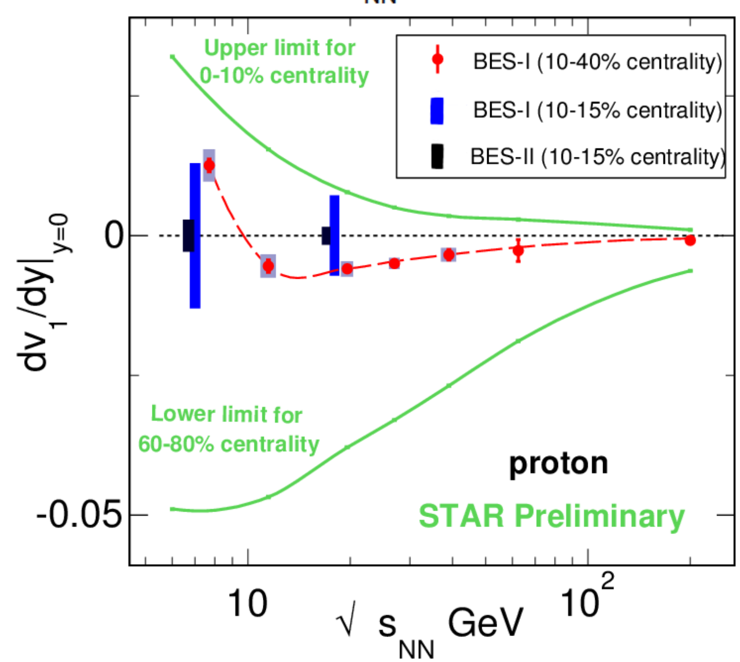
# QCD Phase Diagram and BES II

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 |
|---|---|---|---|---|---|
| $\mu_B$ (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 $\mathcal{L}$ ($1\times10^{25}/cm^2sec$) | 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** | **$3.0^{+}$** |



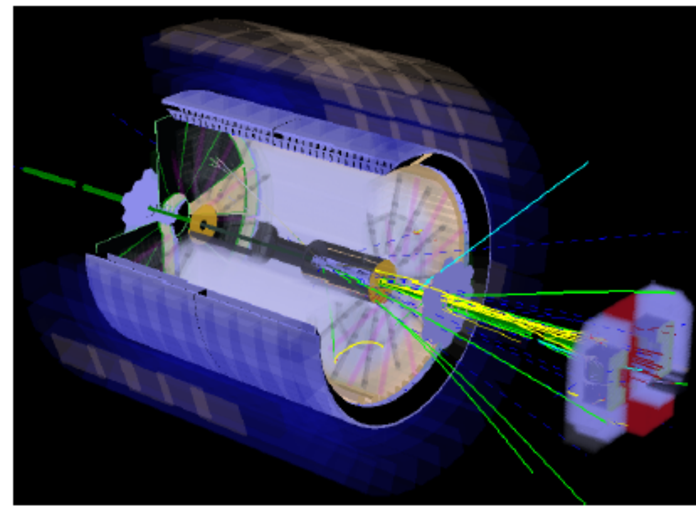



# Upgrade and Physics

- 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

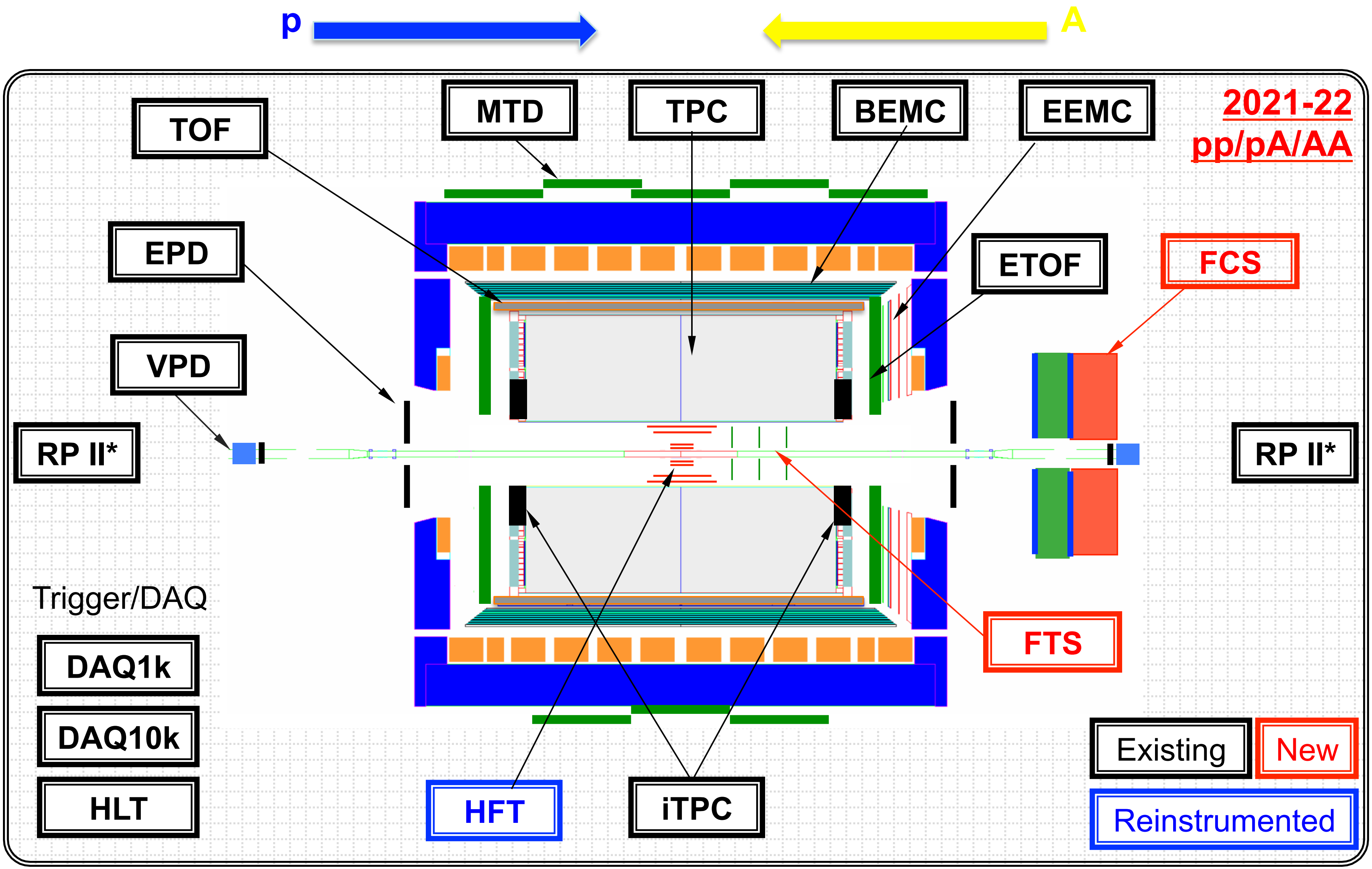


May 2014

1

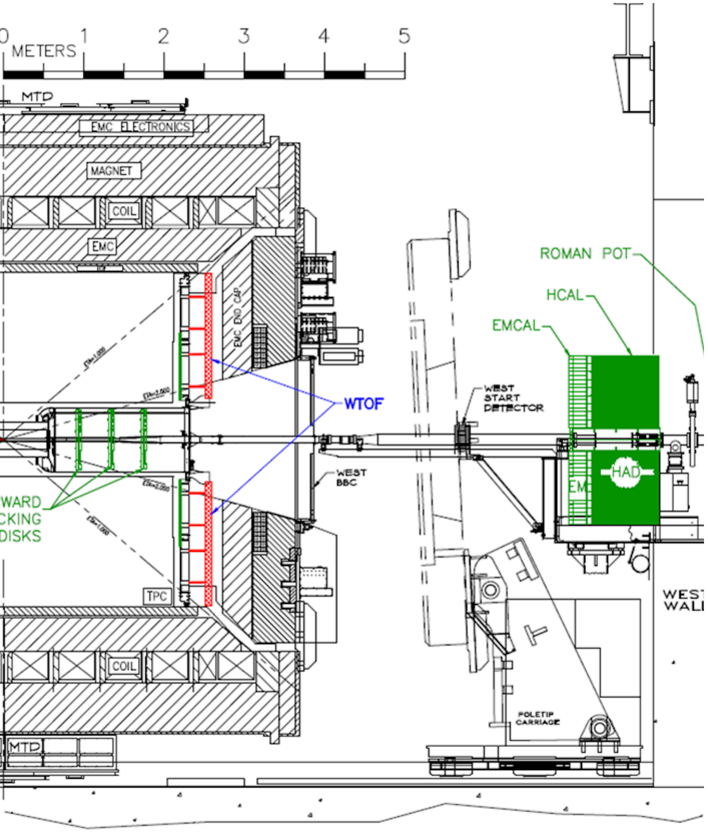
https://drupal.star.bnl.gov/STAR/starnotes/public/sn0605

# 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 $cm^3$

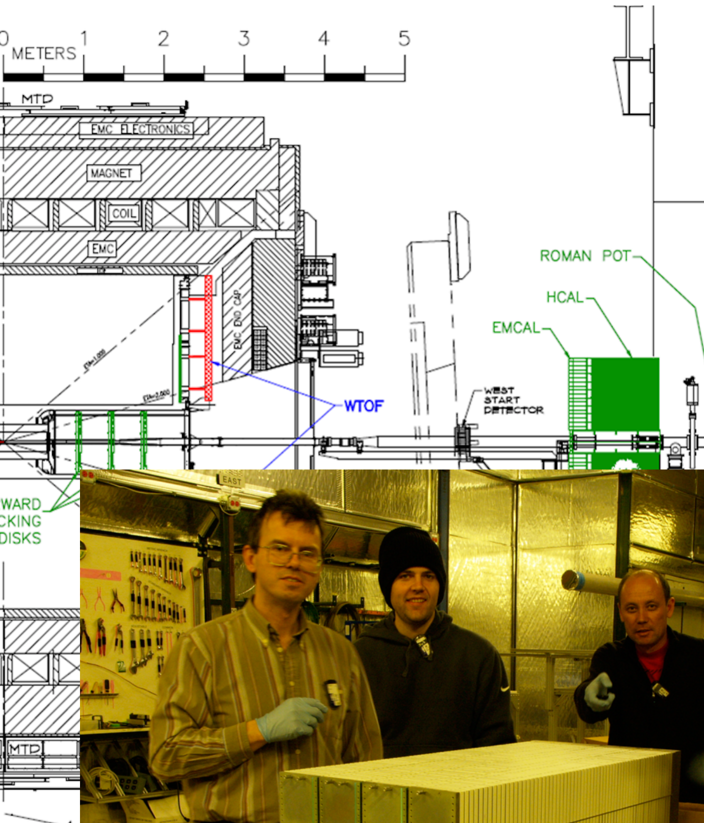
23 $X_o$

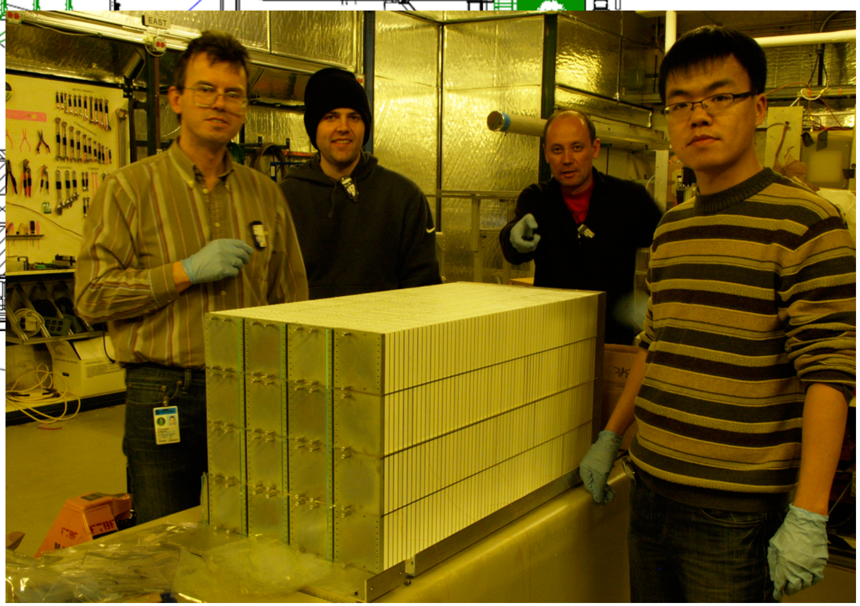
HCal:

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

4 interaction length

# Forward Upgrade in 2019-2020



## ECal:

Tungsten-Powder-Scintillating-fiber

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23 $X_o$

## HCal:

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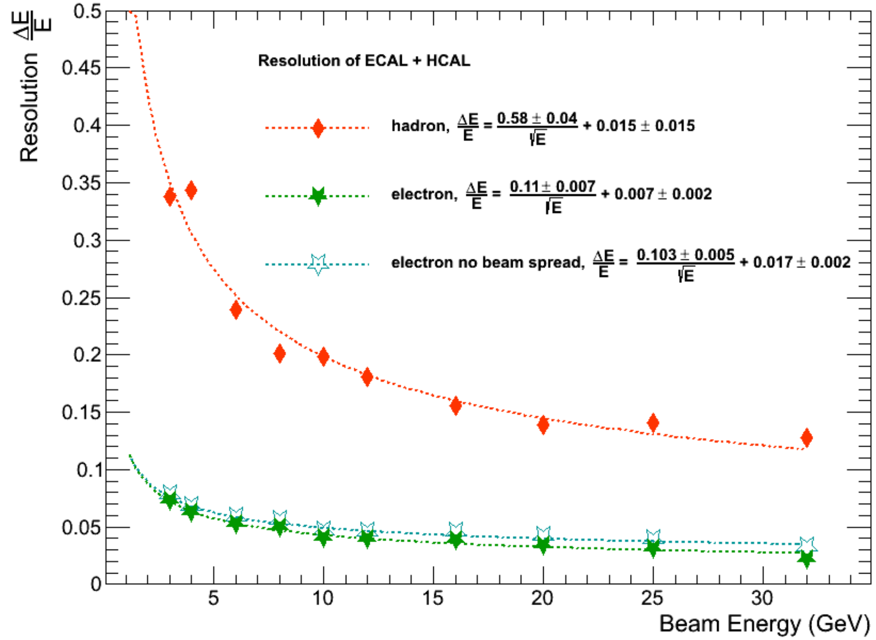
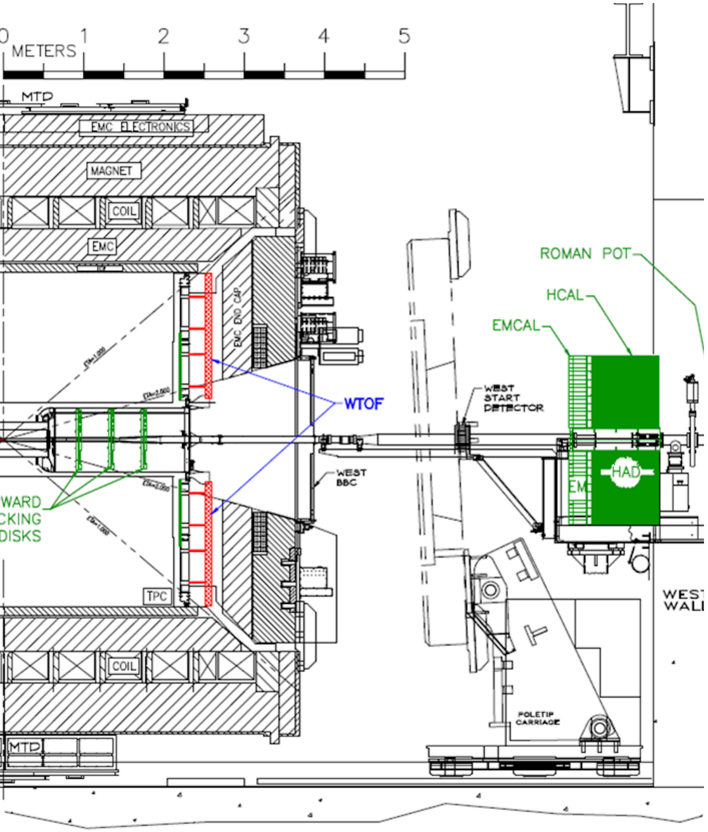
4 interaction length

## Latest Test-Beam results:



# Forward Upgrade in 2019-2020

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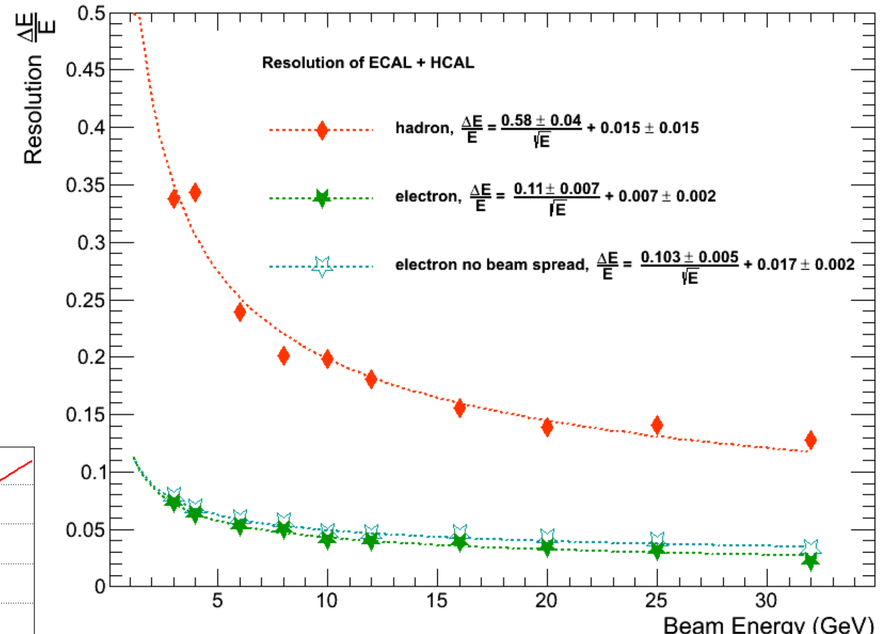
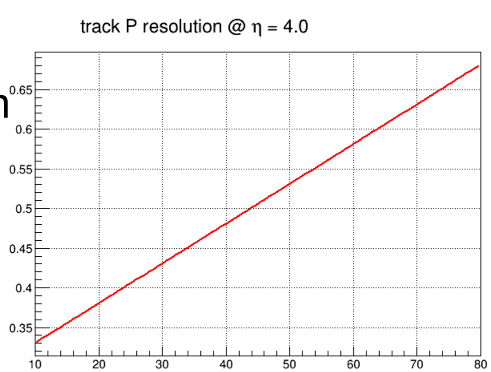


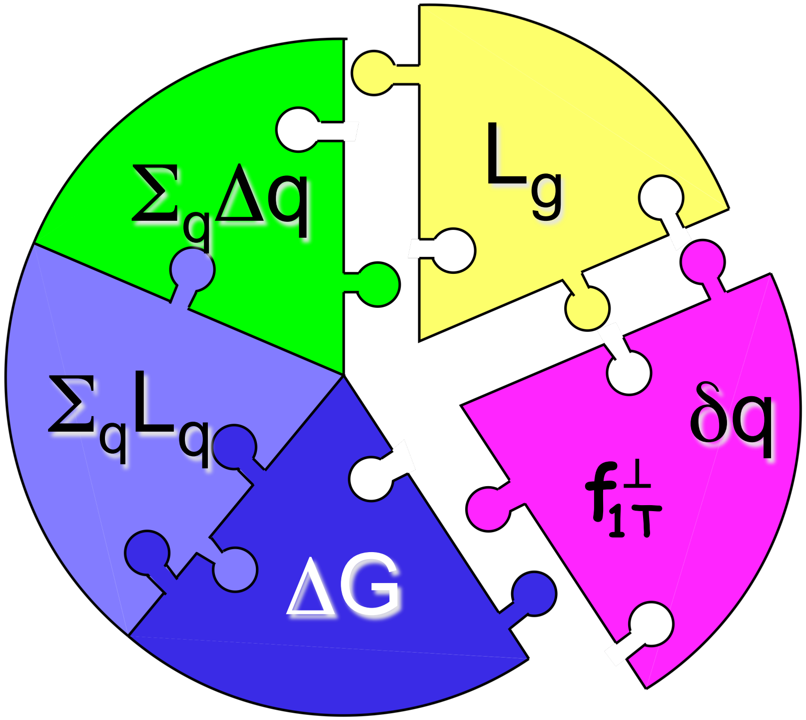

## Forward Tracking:

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

→ GEM-based option/FGT also in consideration



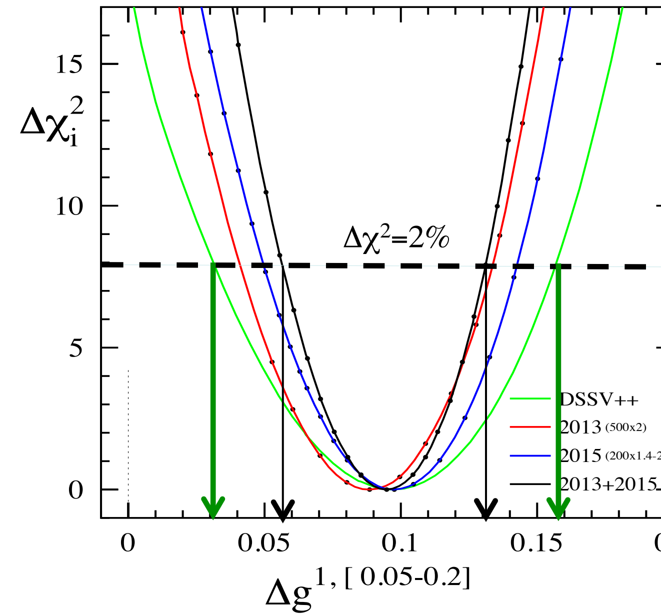
# Proton Helicity Structure

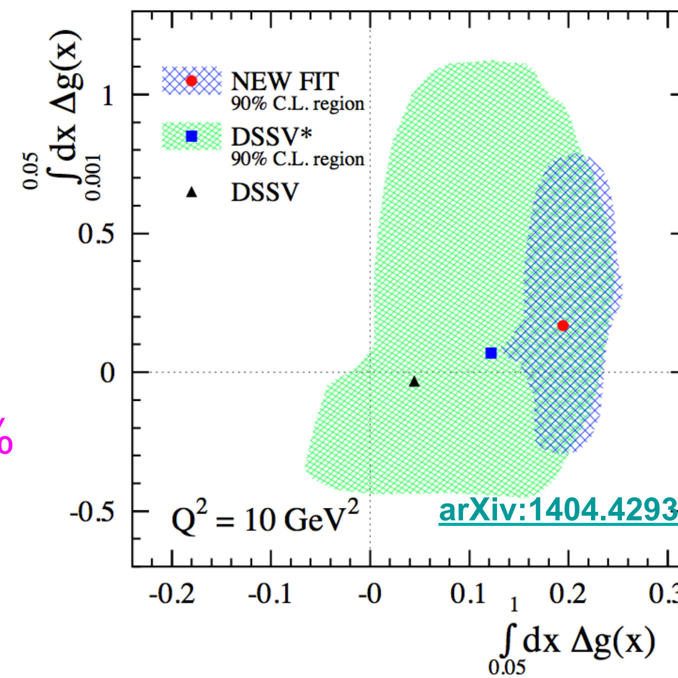



$$\frac{1}{2}\hbar = \left\langle P,\frac{1}{2} \,|\, J^z_{QCD} \,|\, P,\frac{1}{2} \right\rangle = \sum_q \frac{1}{2} S^z_q + S^z_g + \sum_q L^z_q + L^z_g$$

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:

$\sqrt{s} = 500\ GeV$

$-1 < \eta < 2$

$2.8 < \eta < 3.7$

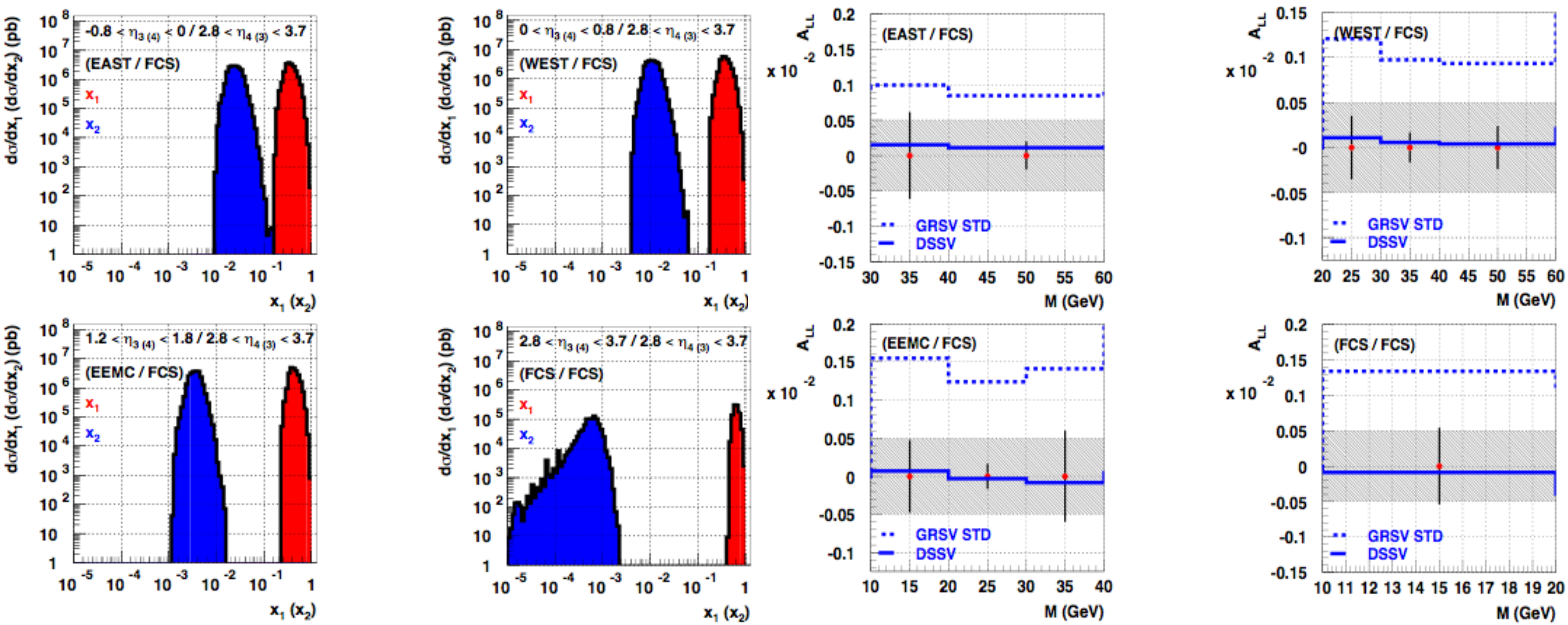
$R_{cone}=0.7$

$E_{T1}>8$ GeV

$E_{T2}>5$ GeV

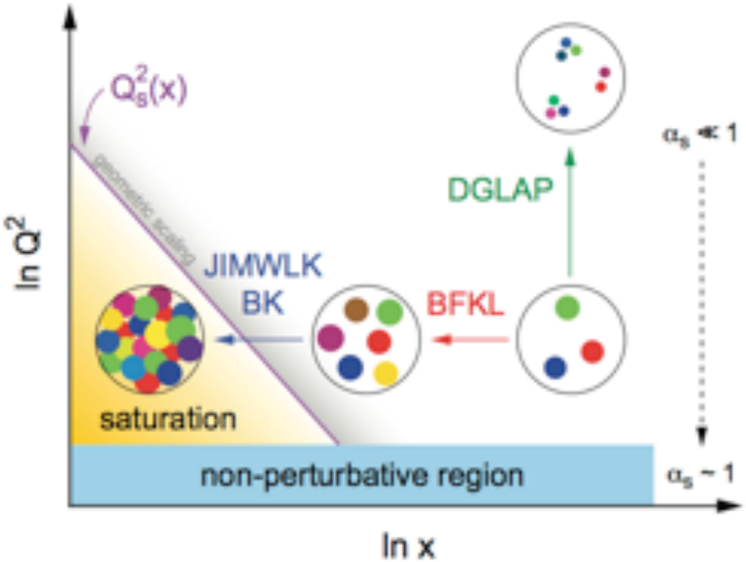
$L=1fb^{-1}$

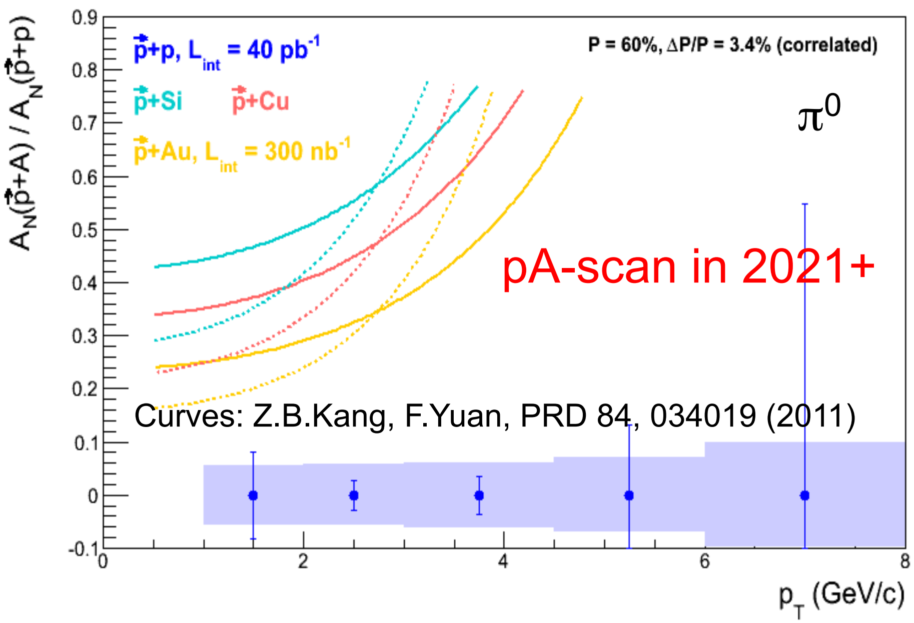
P=60%




Utilize FCS + FTS:  x: → 0.001

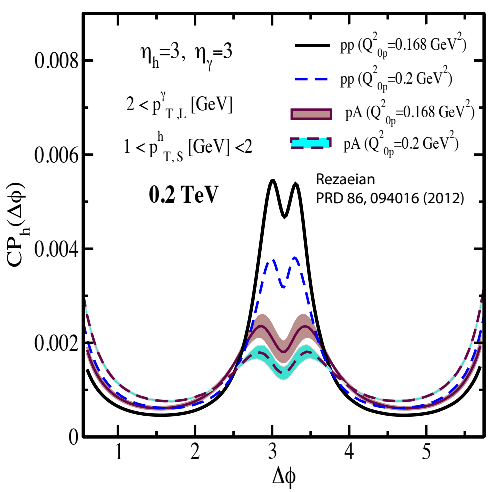
# Gluon Saturation at Small-x

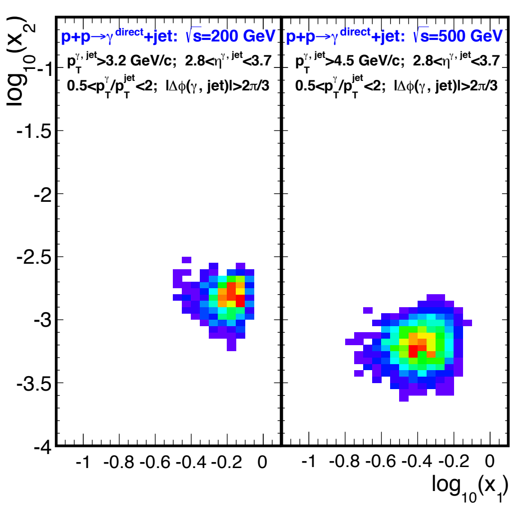



2021-2022 pA runs:

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



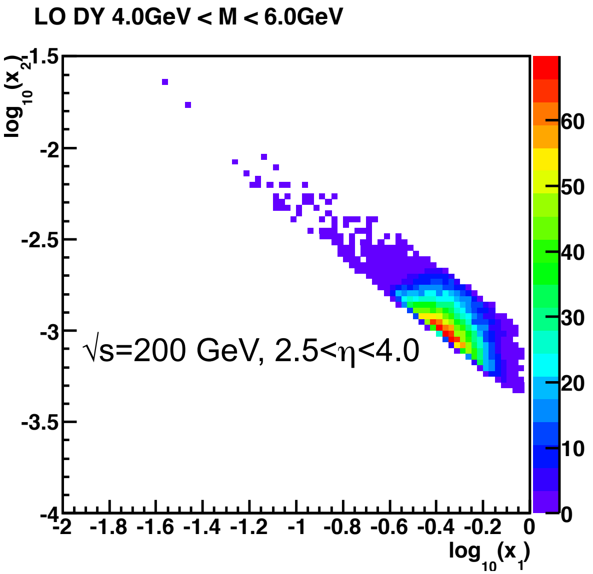



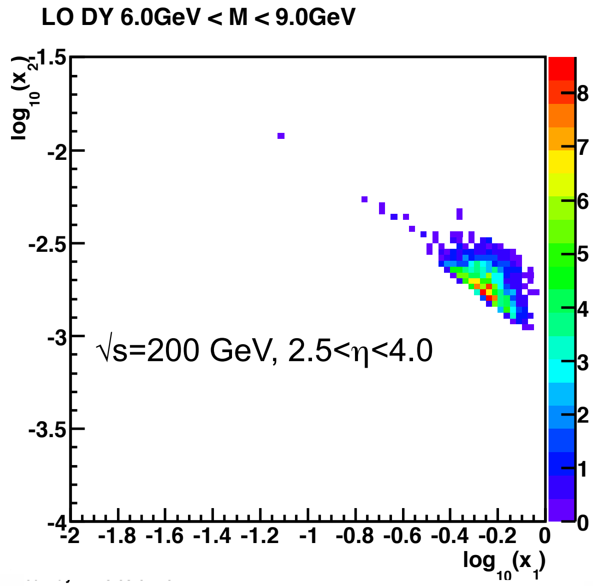

Cuts:
$|\phi_\gamma - \phi_{jet}| > 2\pi/3$
$0.5 < p_T^\gamma < p_T^{jet} < 2$. $2.8 < \eta < 3.7$
$p_T > 4.5$ (3.2) GeV/c in 500 (200) GeV
photon isolation
→ signal-to-background 3:1

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

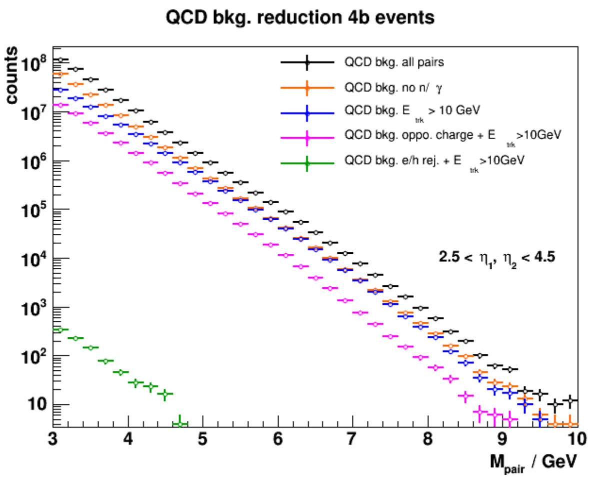
# Gluon Saturation at Small-x

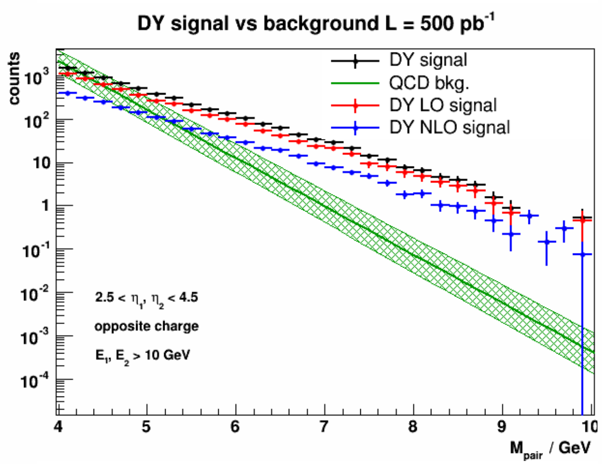
Physics
DY-h correlations → saturation Stasto et al. PRD 86, 014009 (2012)

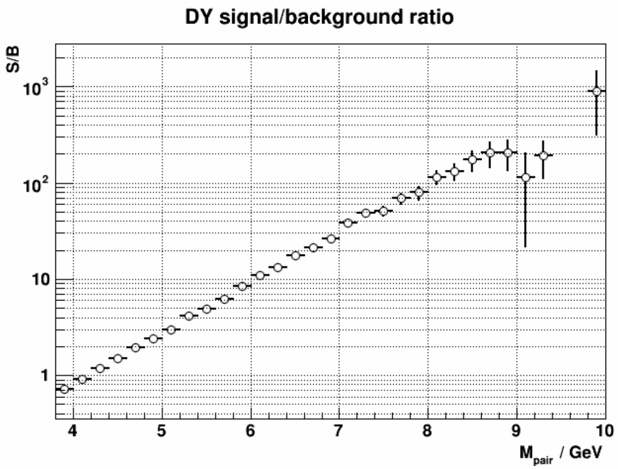



very challenging
need big bkg. suppression
→ FCS + FTS
→ 2.5 $pb^{-1}$ p+Au

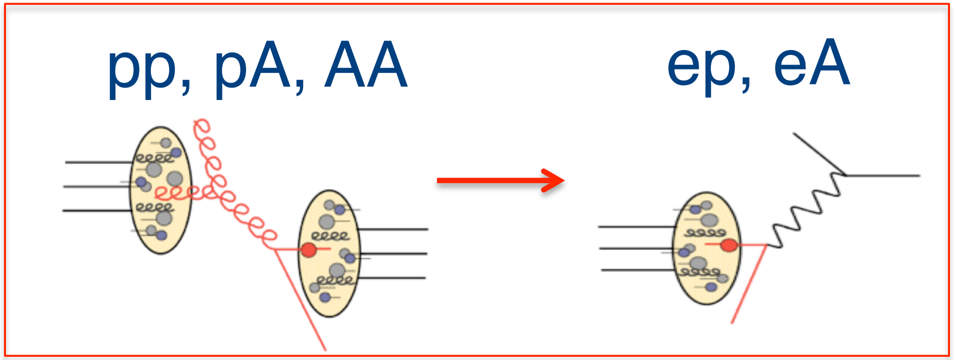


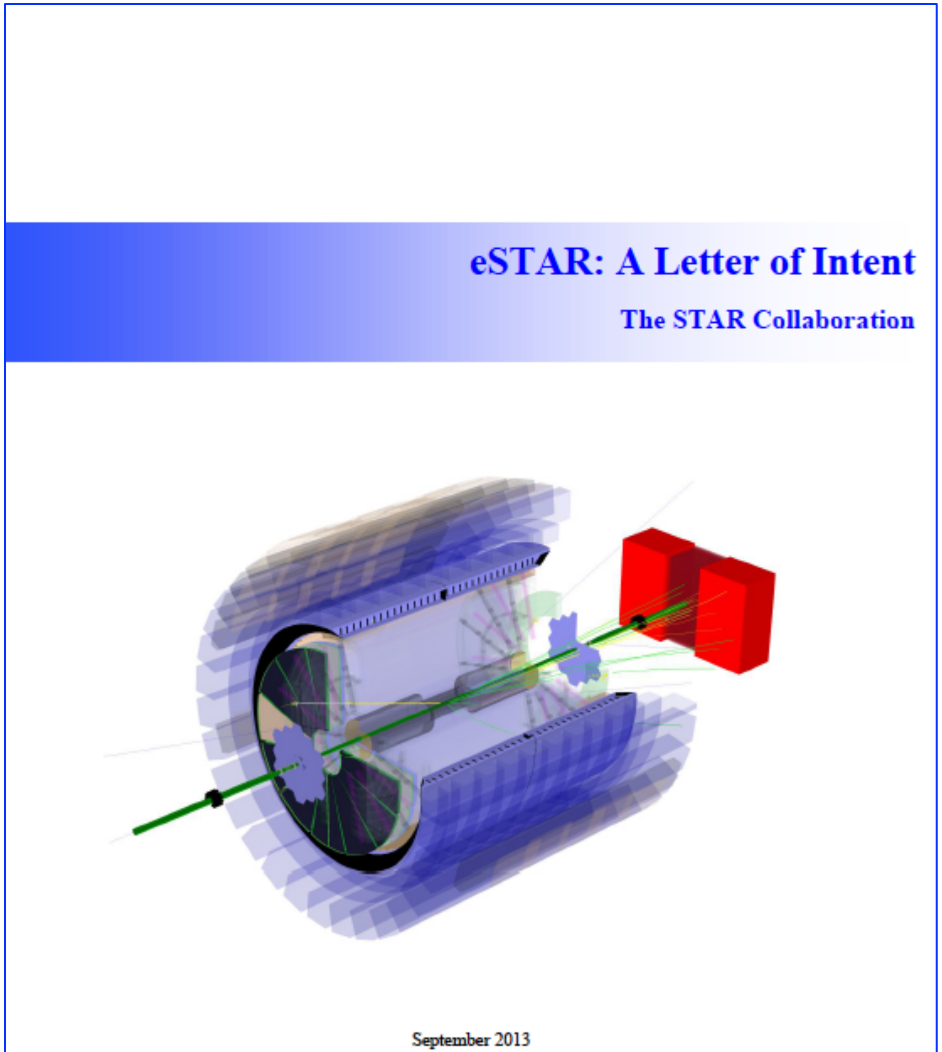



# Upgrade and Physics

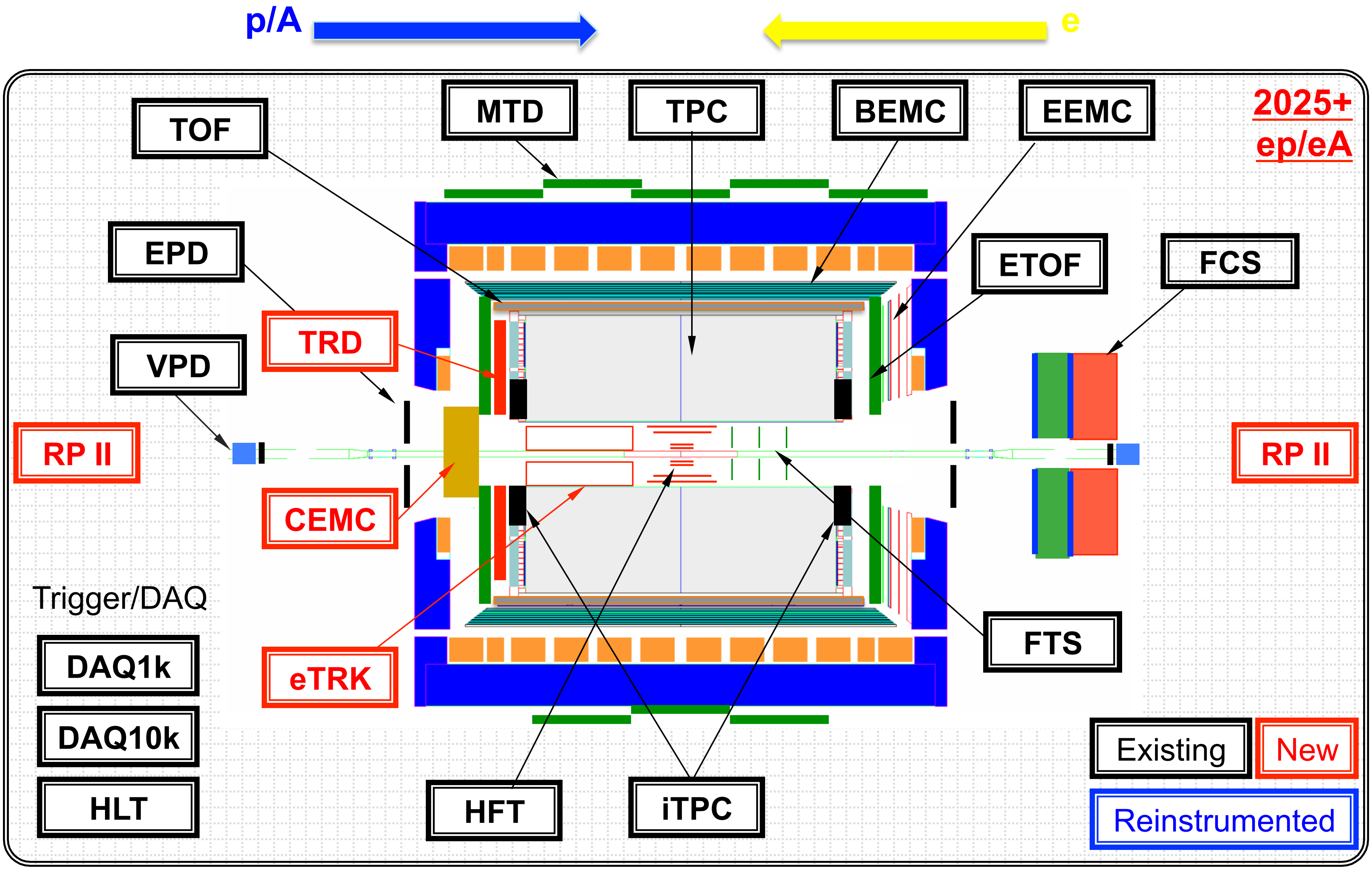
- pp+pA+AA 2014-2016
- BES II 2018-2019
- pp+pA+AA 2021-2022
- eRHIC 2025+



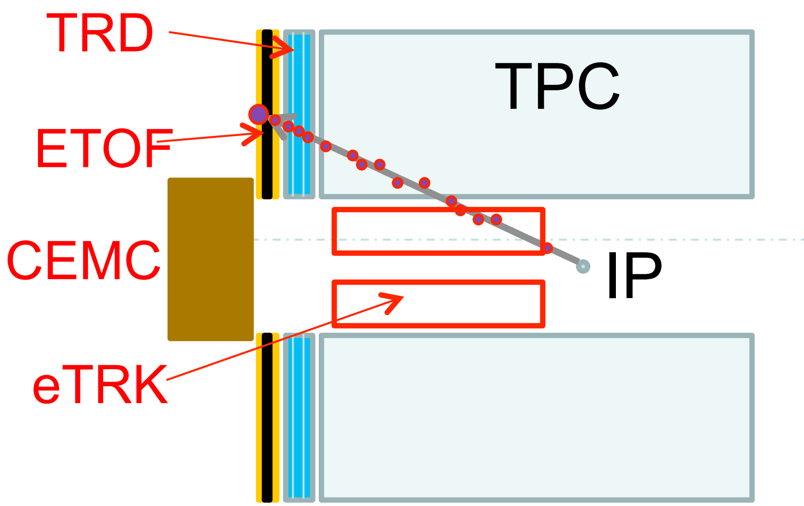

https://drupal.star.bnl.gov/STAR/starnotes/public/sn0592

# STAR Detector in 2025+

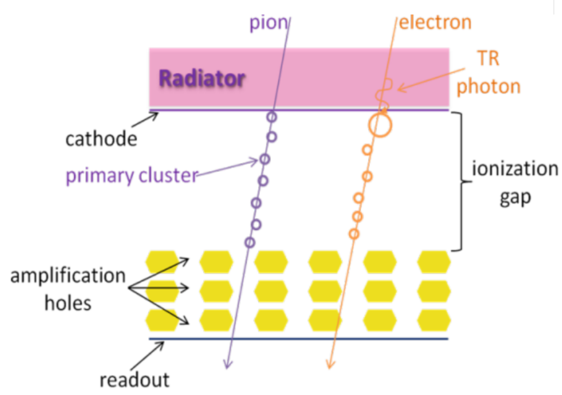


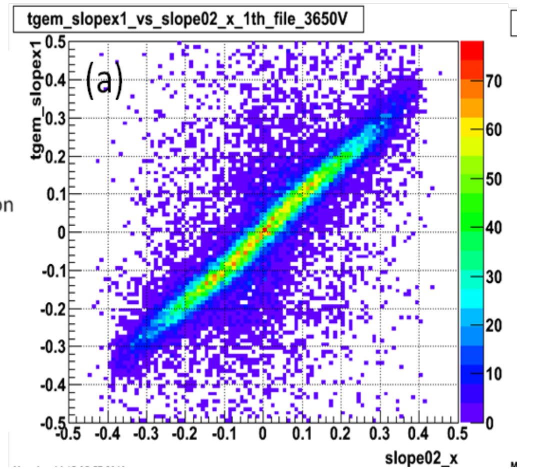

**CEMC:** Central EM Calorimeter**, eTRK:** electron Tracker, **TRD:** Transition Radiation Detector

# Upgrade for Electron Detection

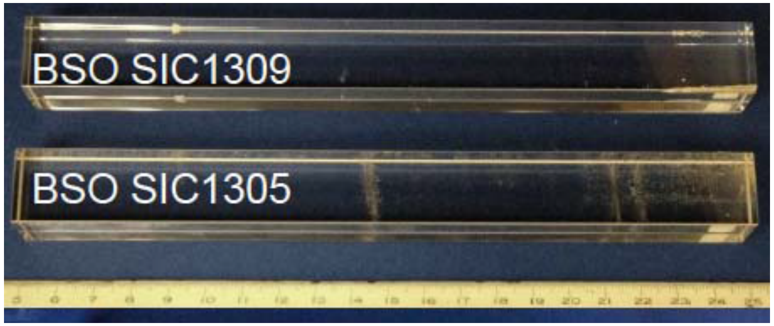



Electron Detectors

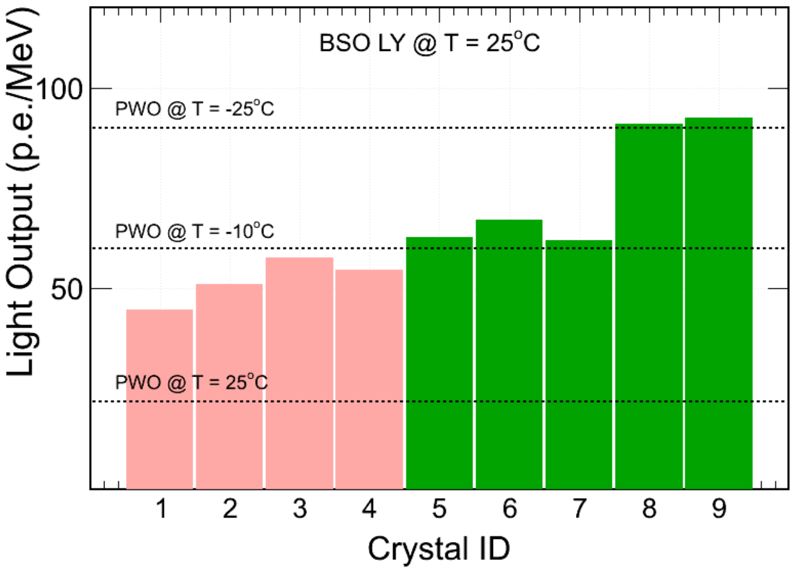


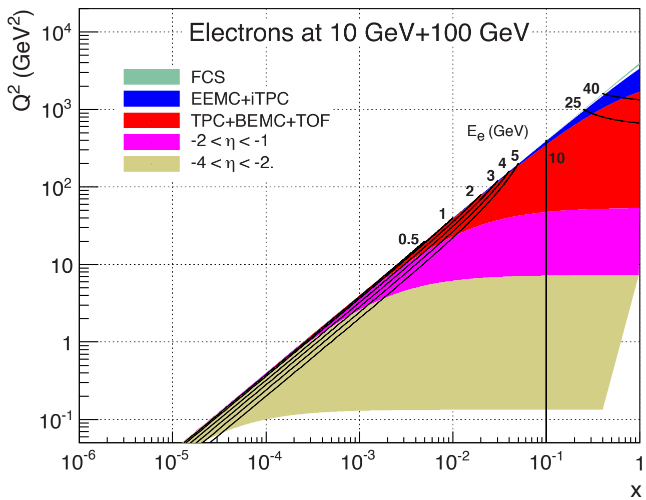

TRD with GEM-readout

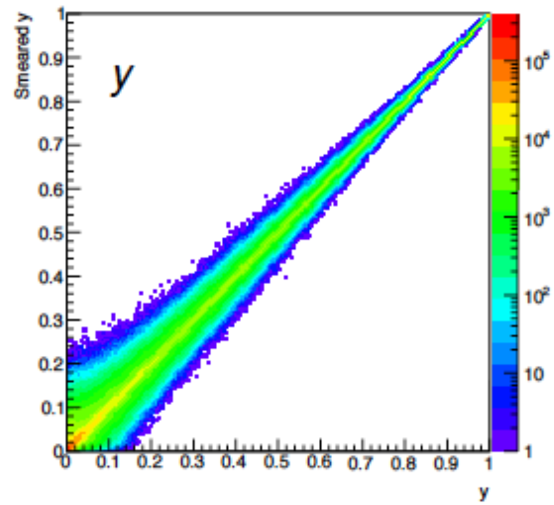


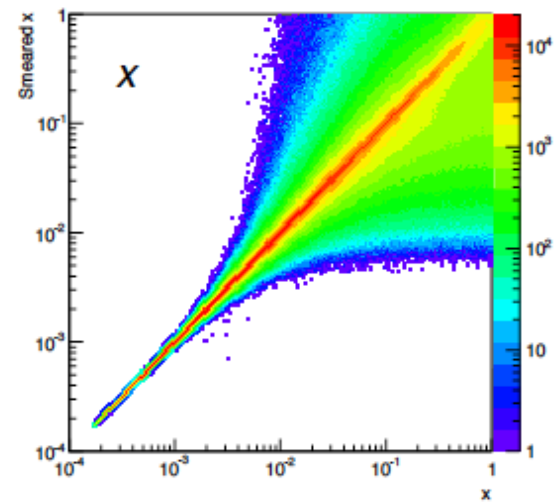

BSO Crystals for CEMC

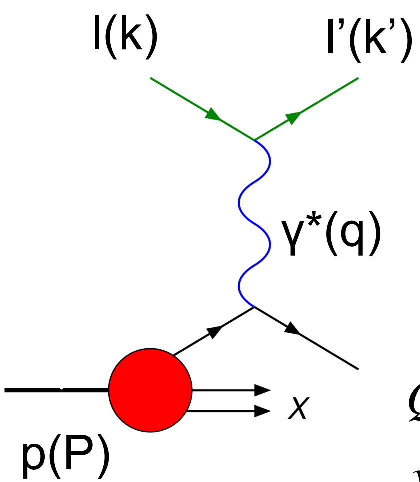


# Electron Detection Performance



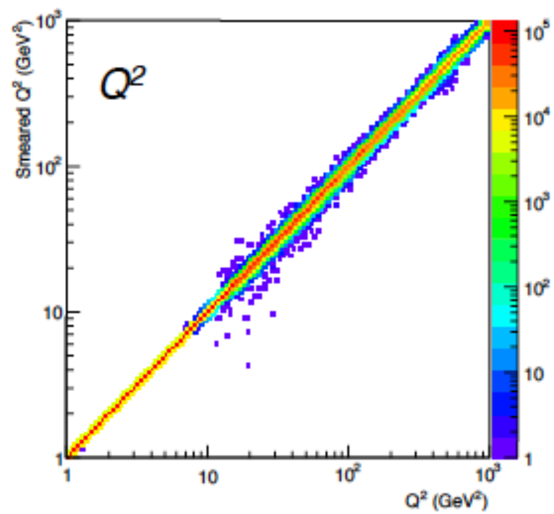



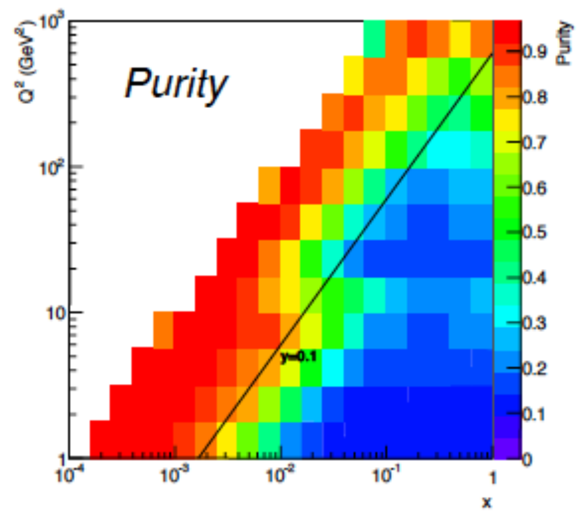




$$Q^2 = -q^2$$

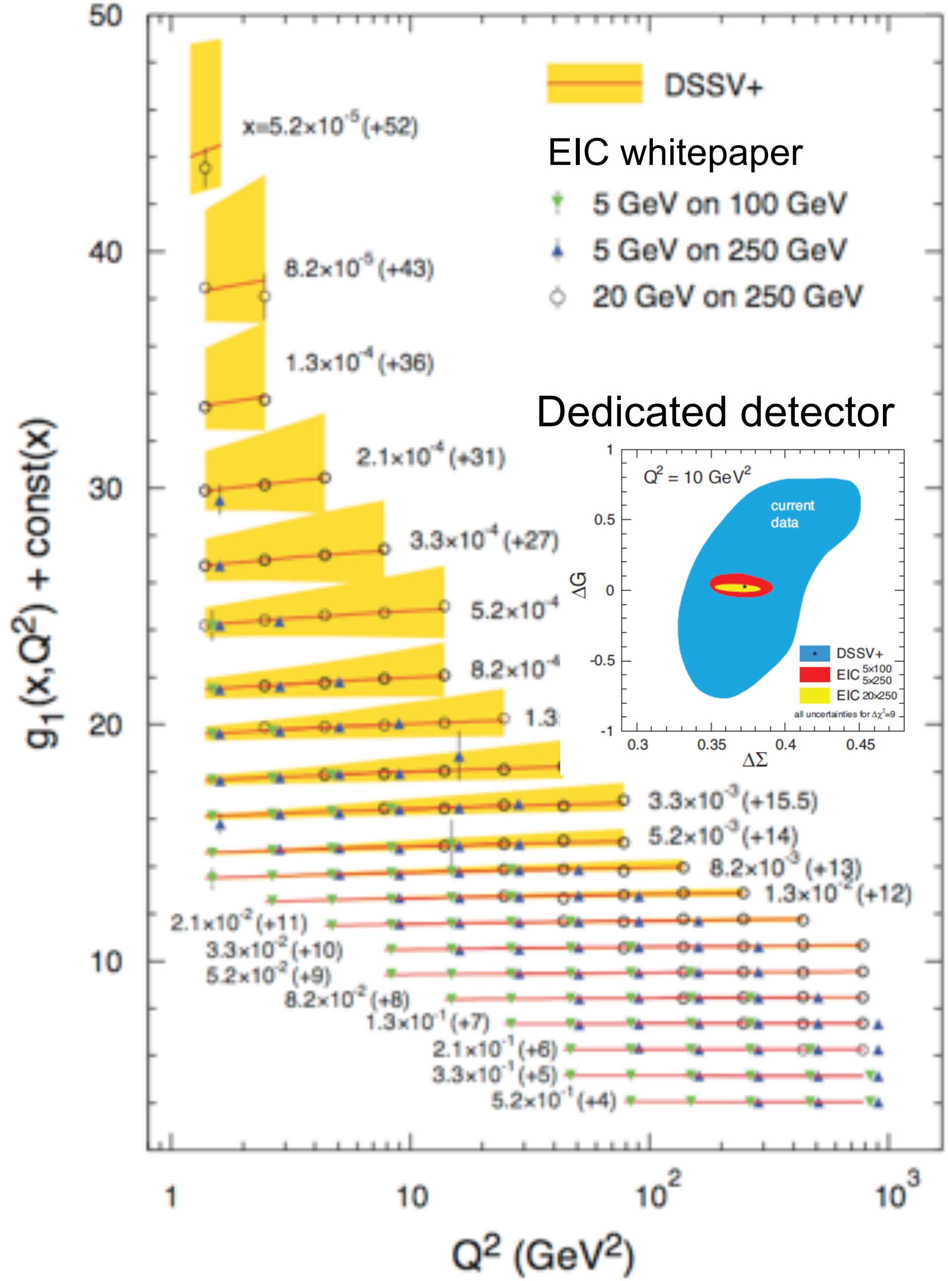
$$x = Q^2/(2q \cdot P)$$

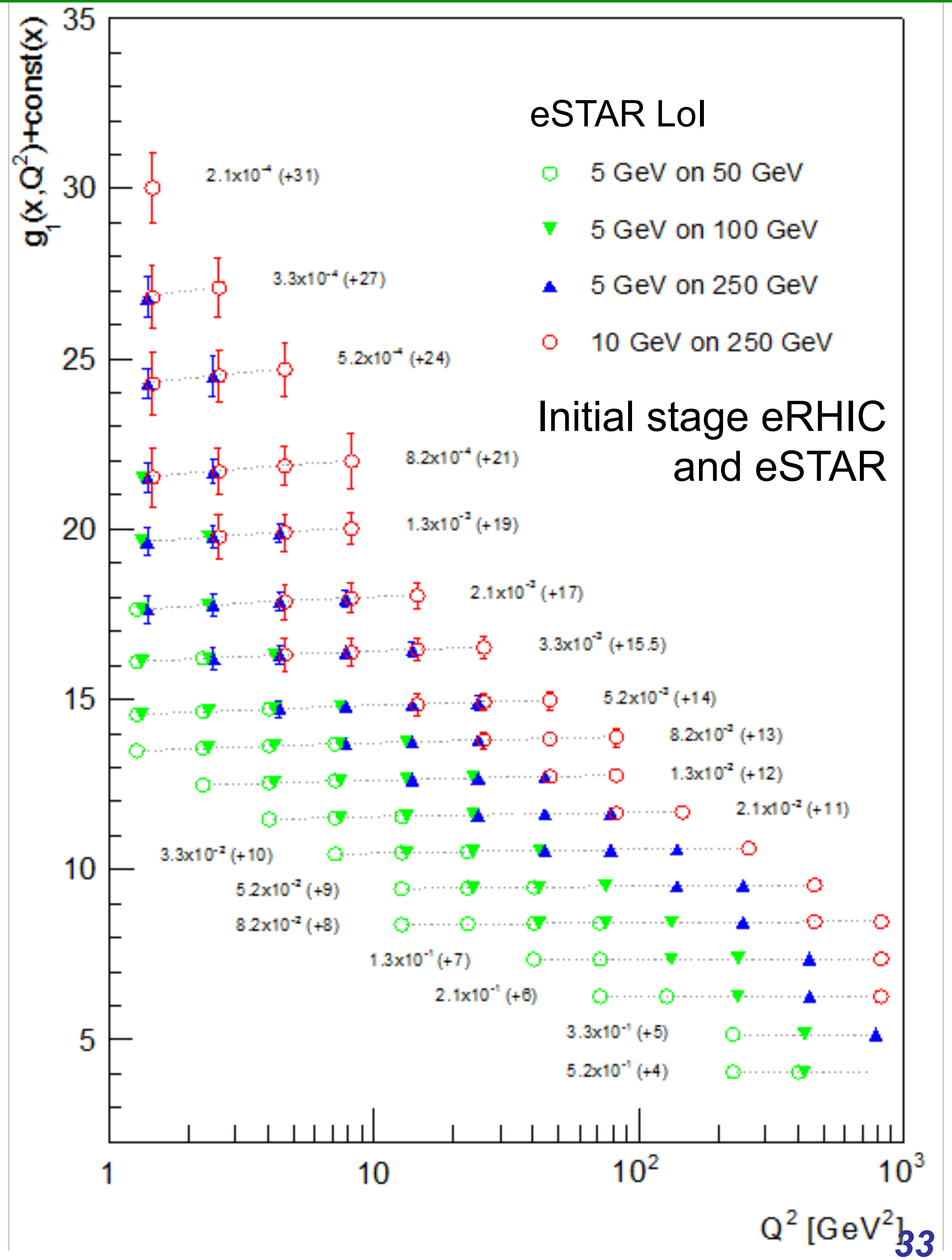
$$y = (q \cdot P)/(k \cdot P)$$



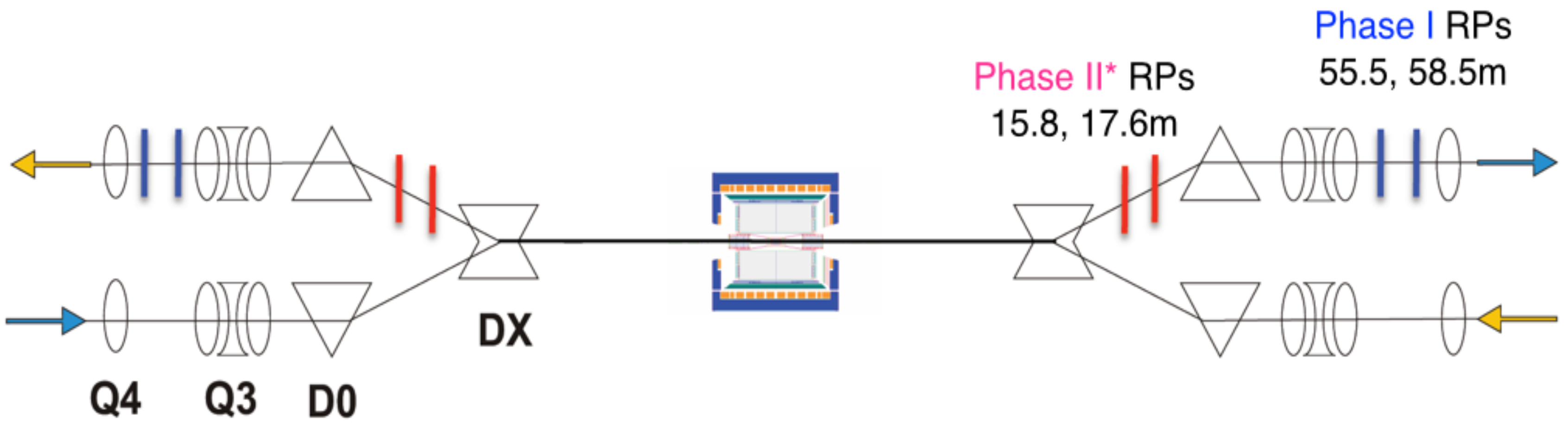



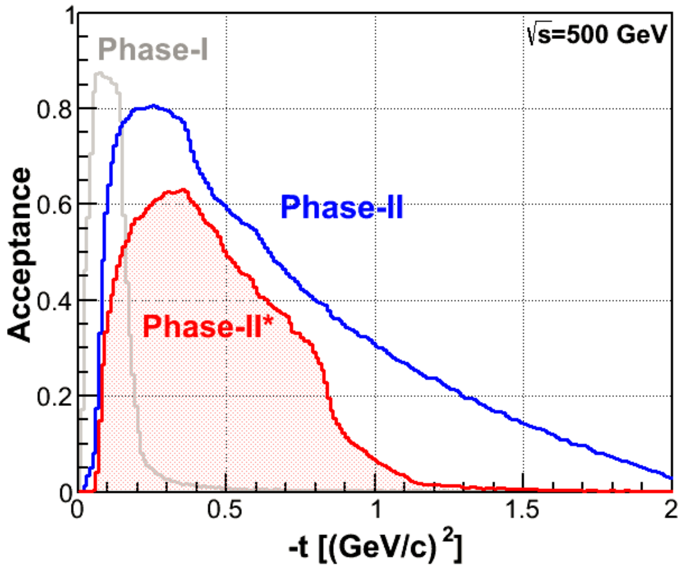
# Proton Helicity Structure

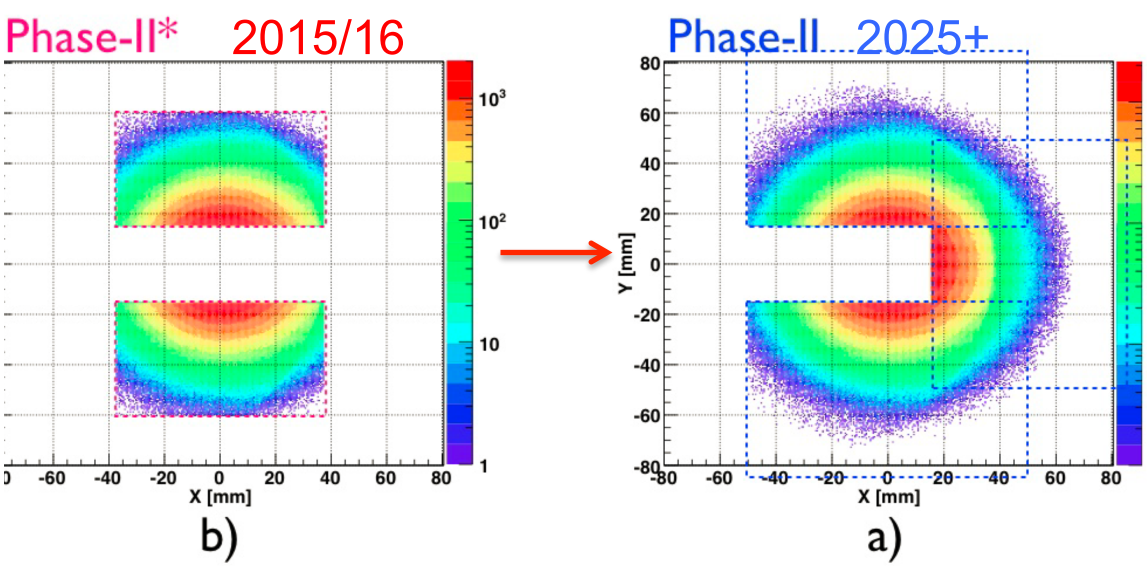


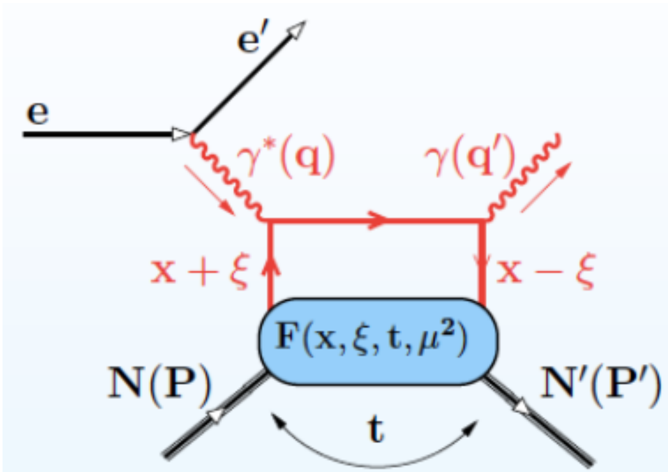
# Roman Pot II for eSTAR

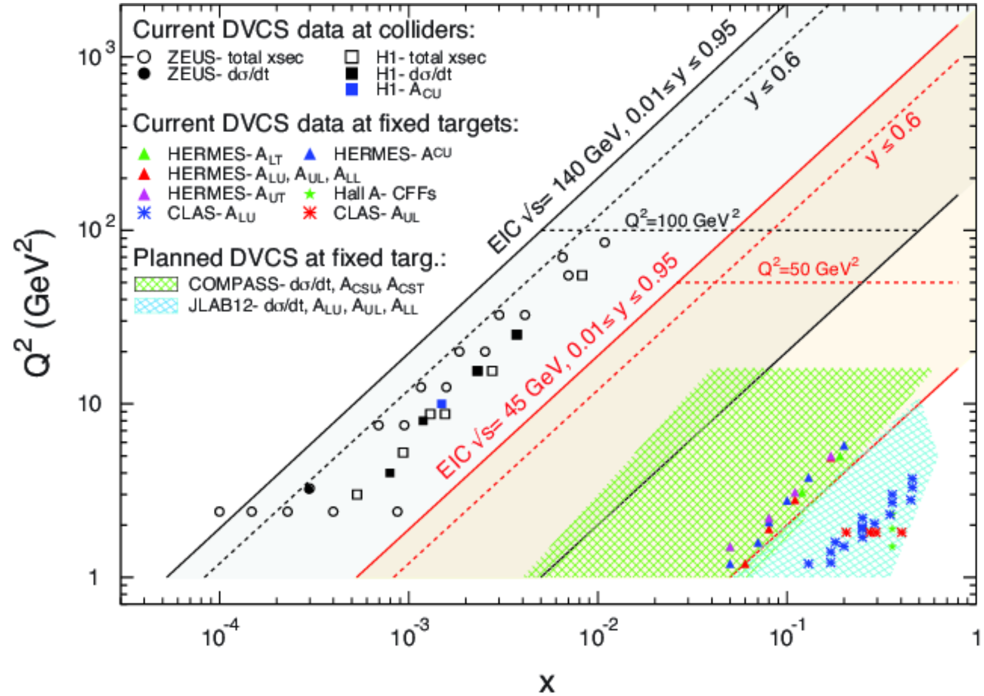


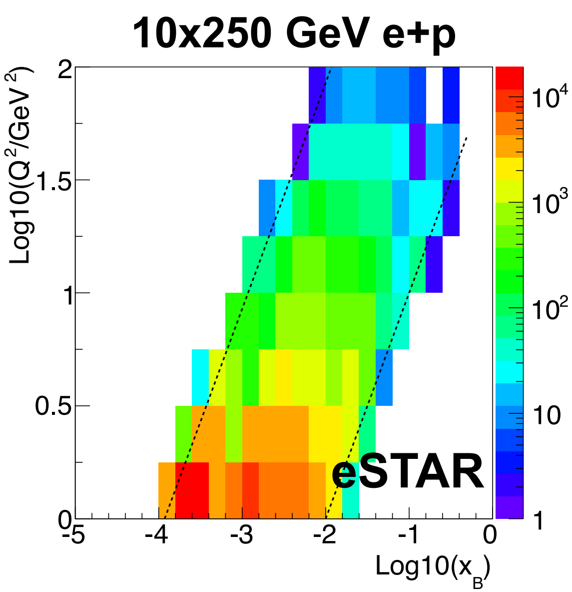



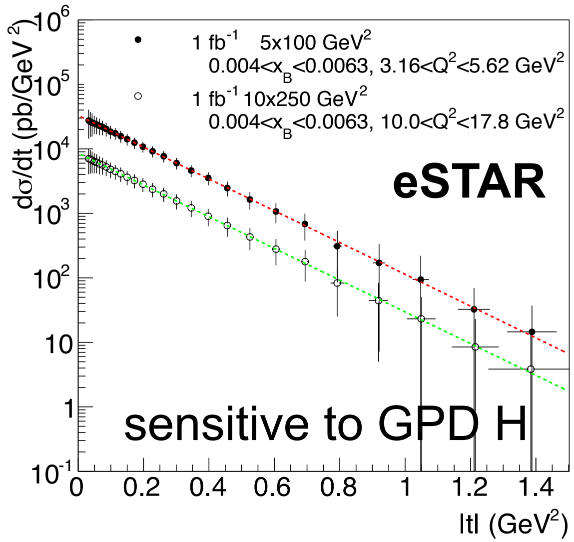



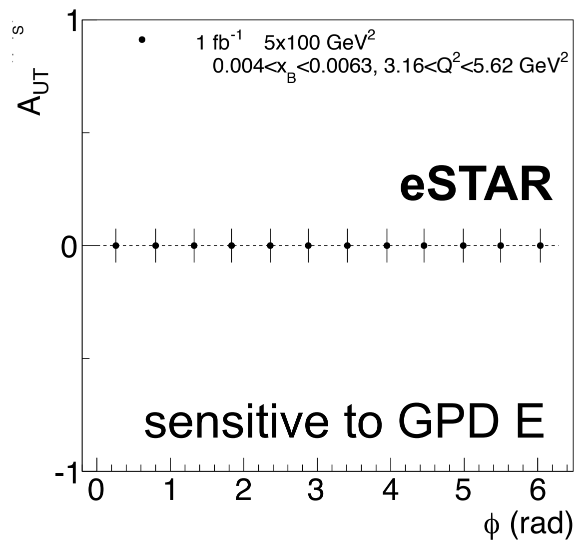
# Deeply Virtual Compton Scattering



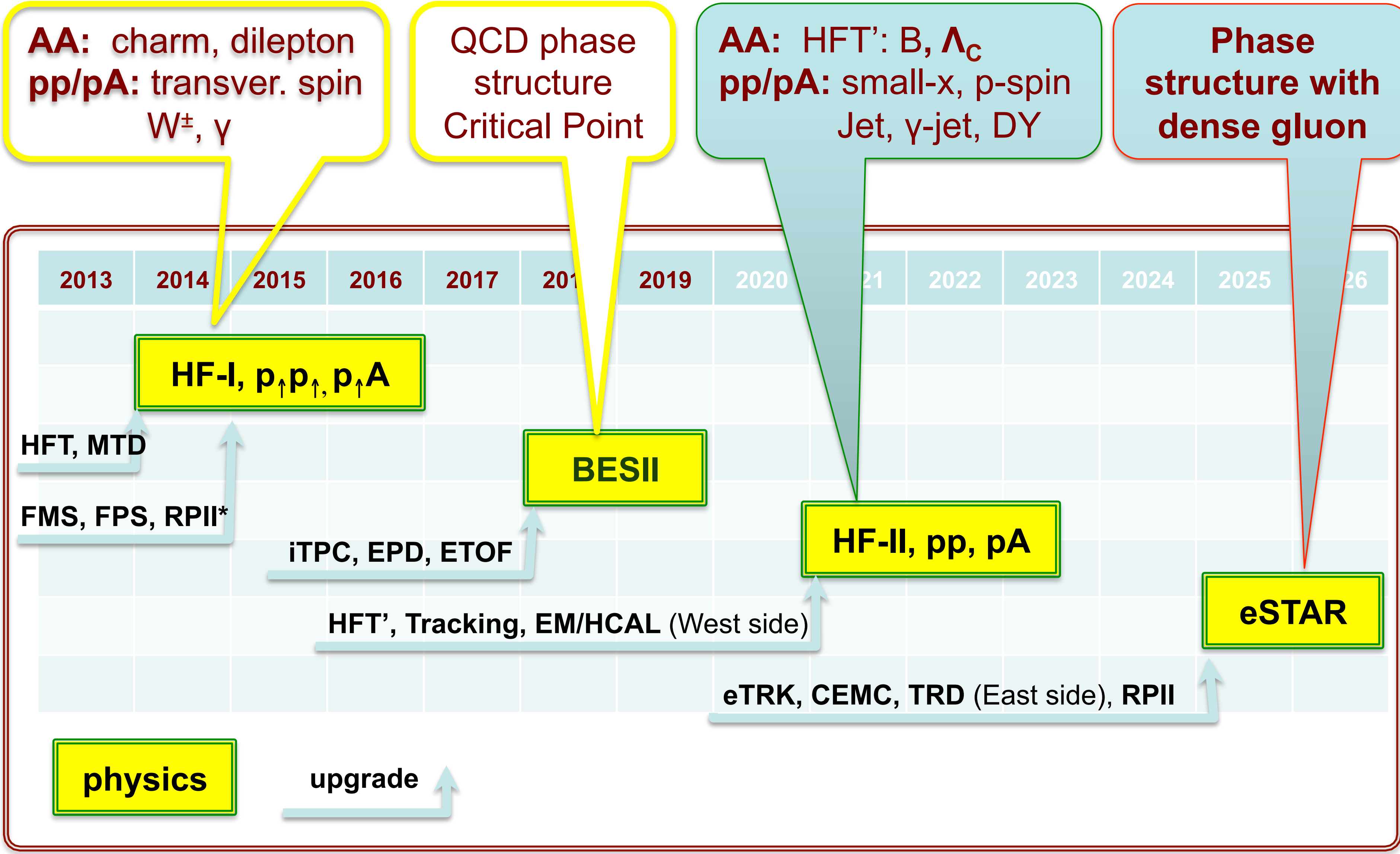



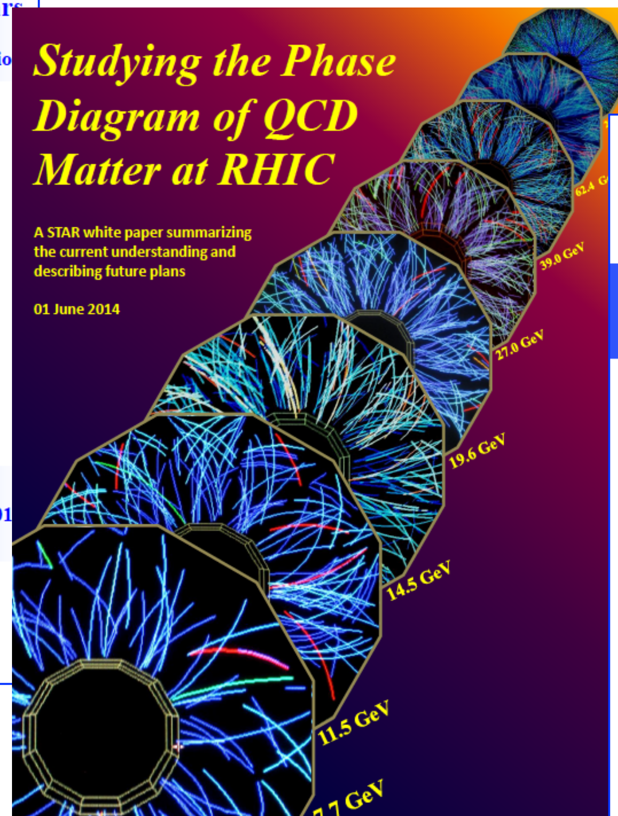



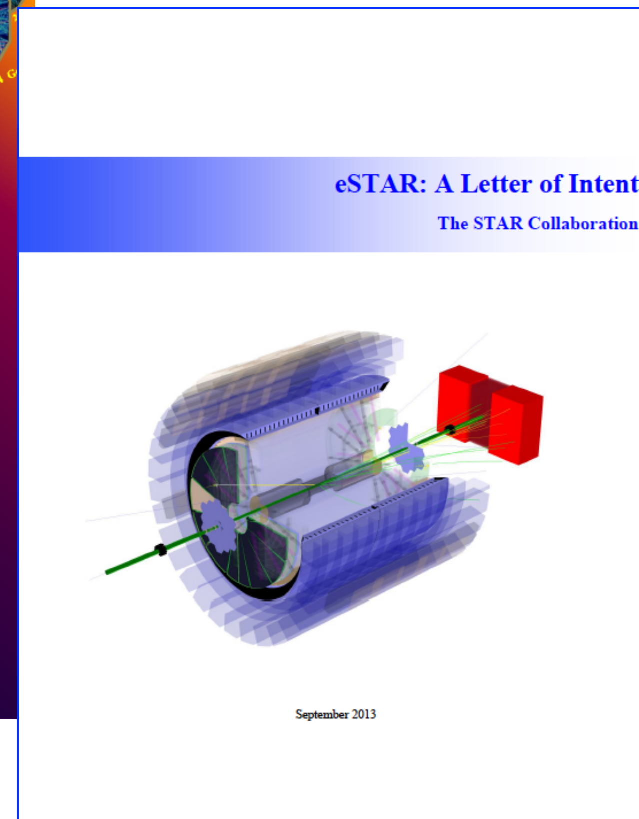
# Summary




**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

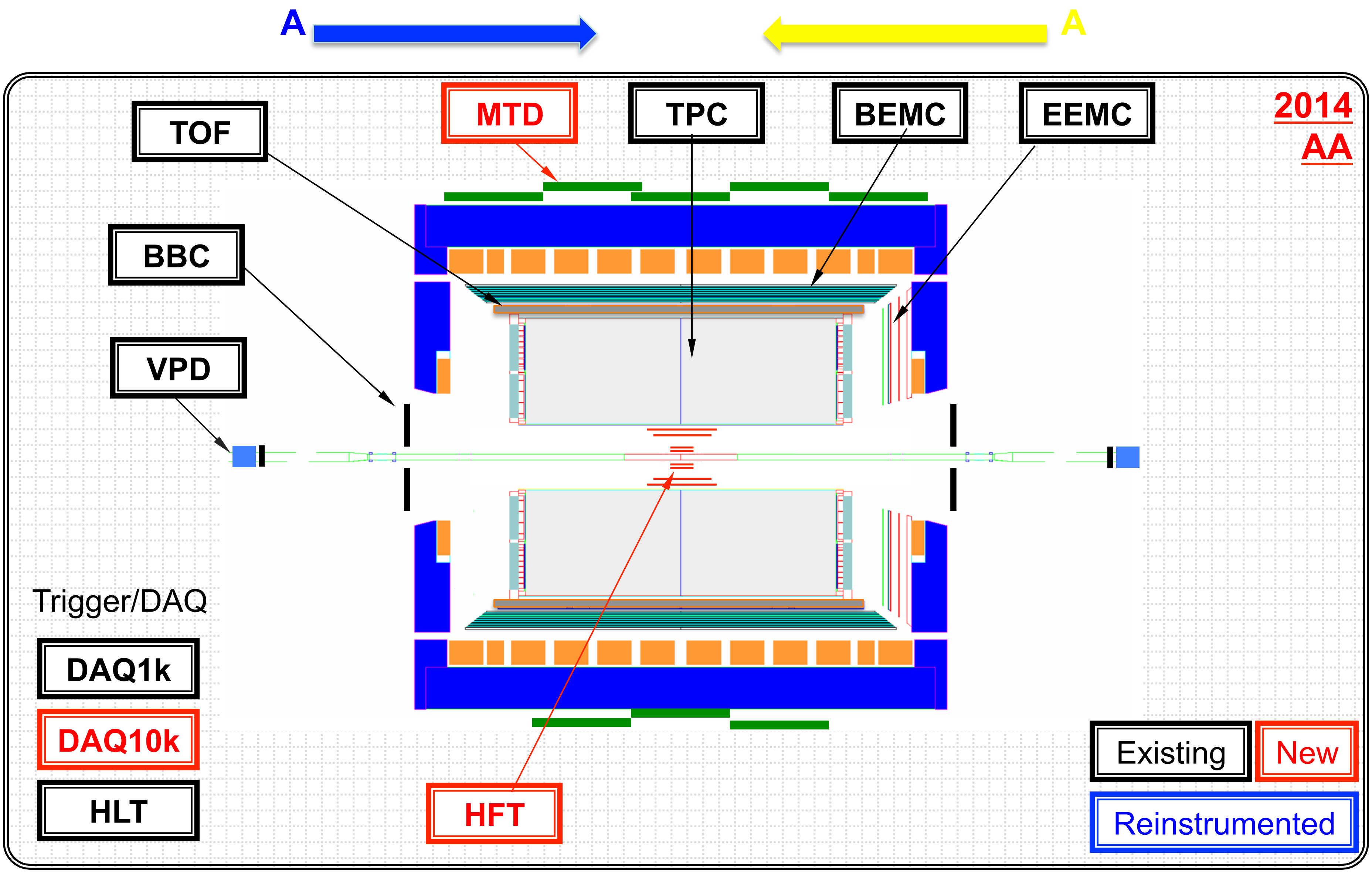
## Nucleon Structure

- 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

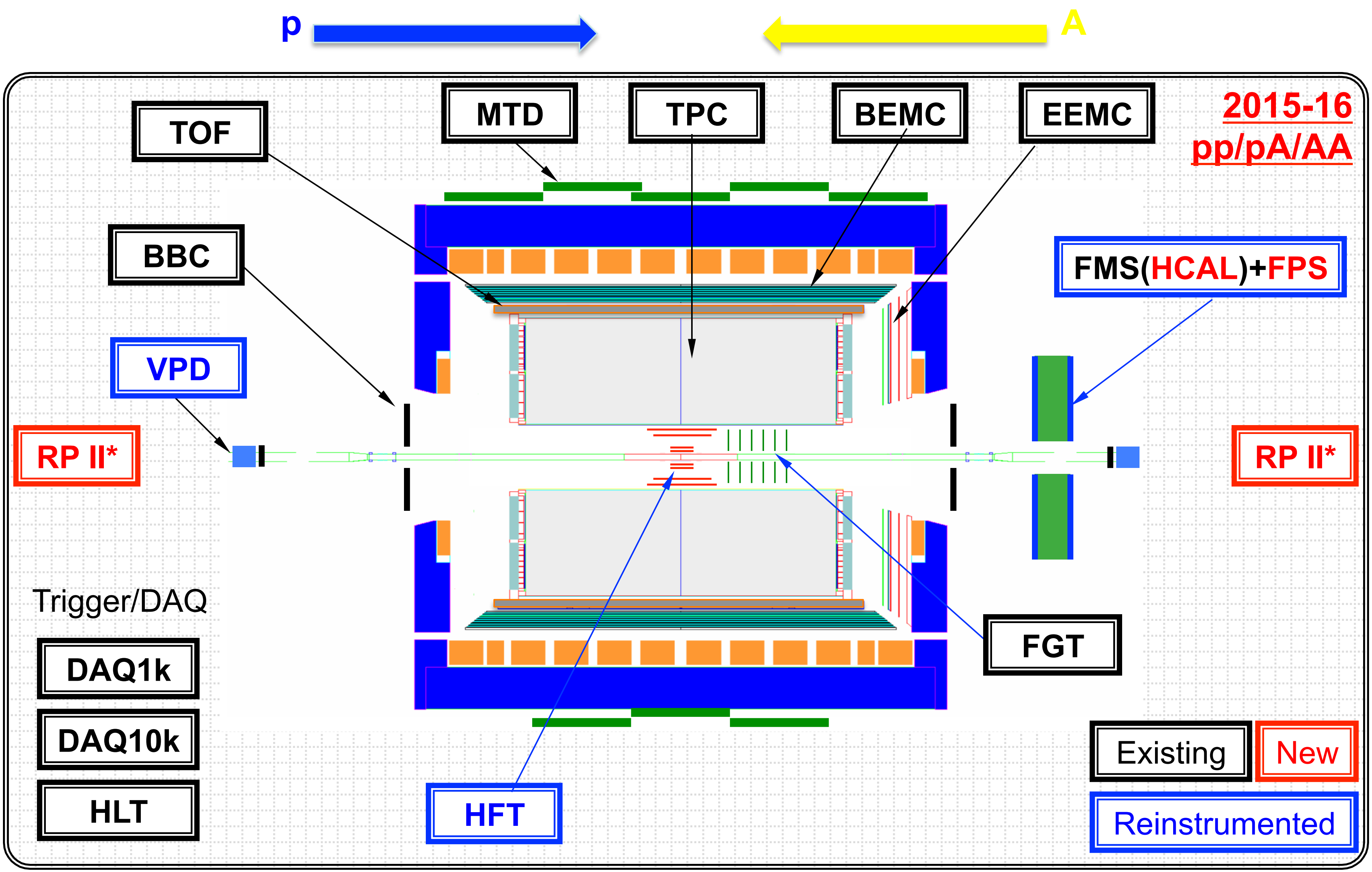
# Backup

# STAR Detector in 2014



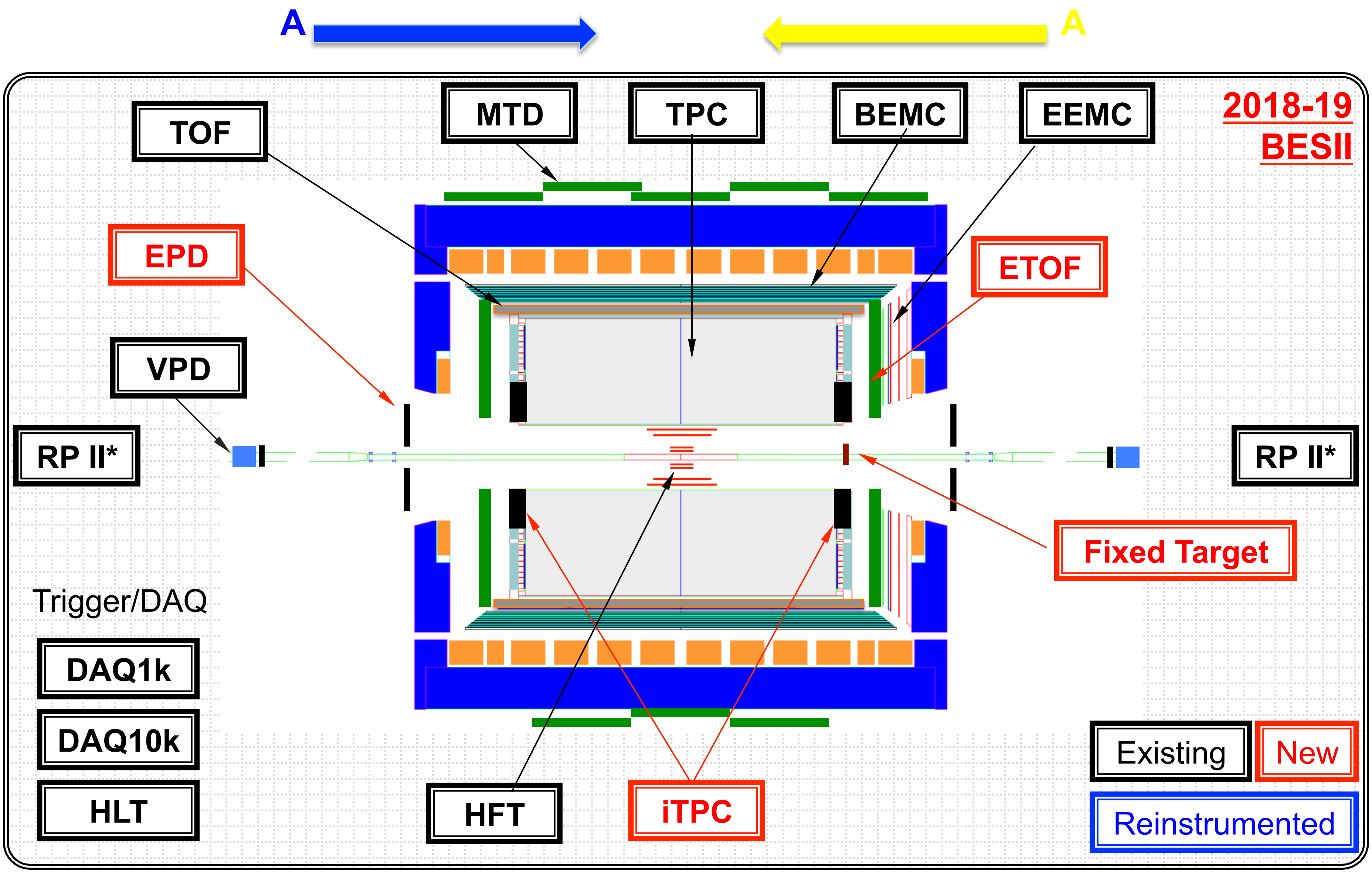

**HFT**: Heavy Flavor Tracker, **MTD**: Muon Telescope Detector

# STAR Detector in 2015-2016



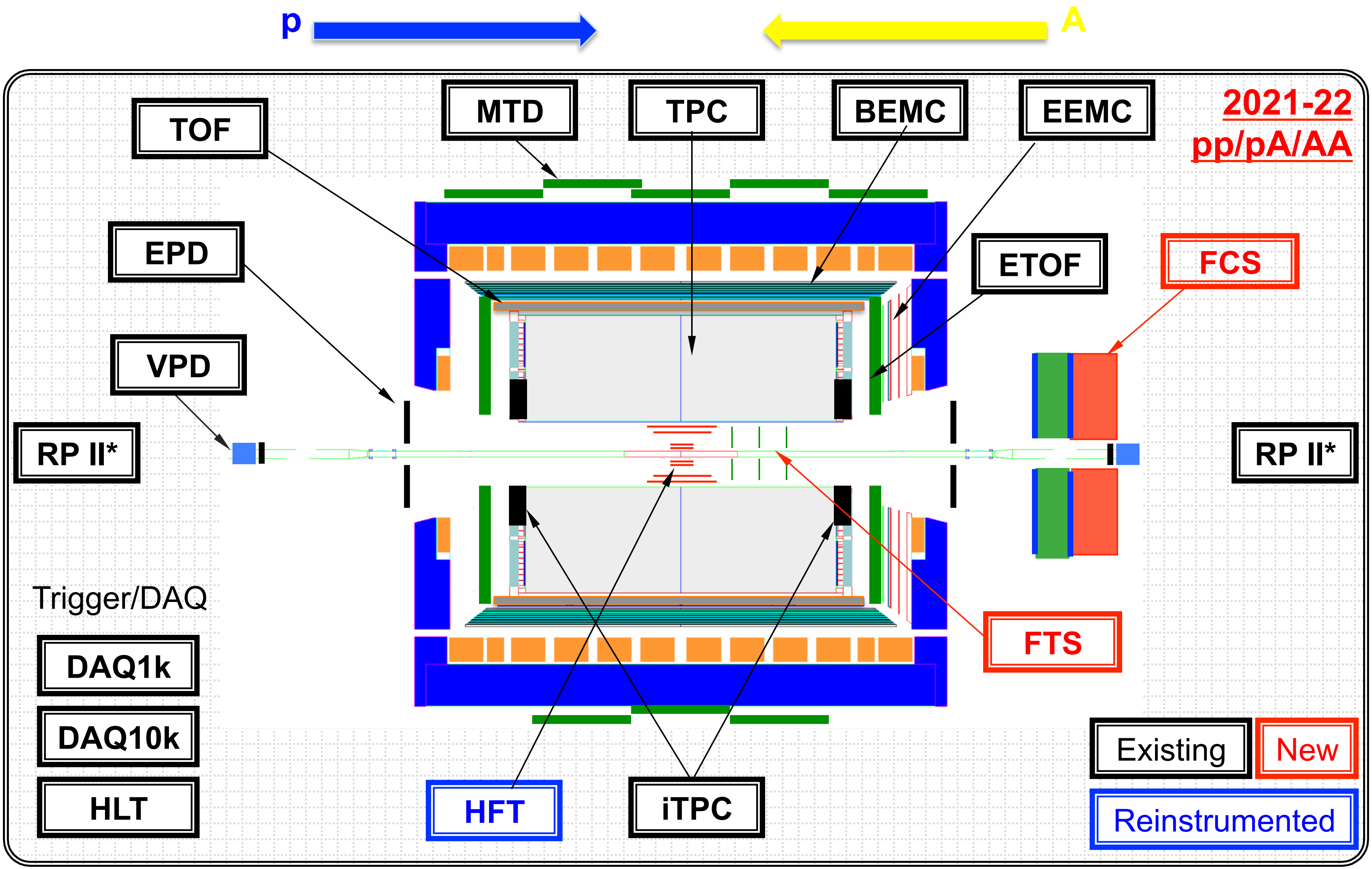

**FMS**: Forward Meson Spectrometer, **FPS**: Forward Preshower, **RP II***: Roman Pot Phase II*

# STAR Detector in 2018-2019



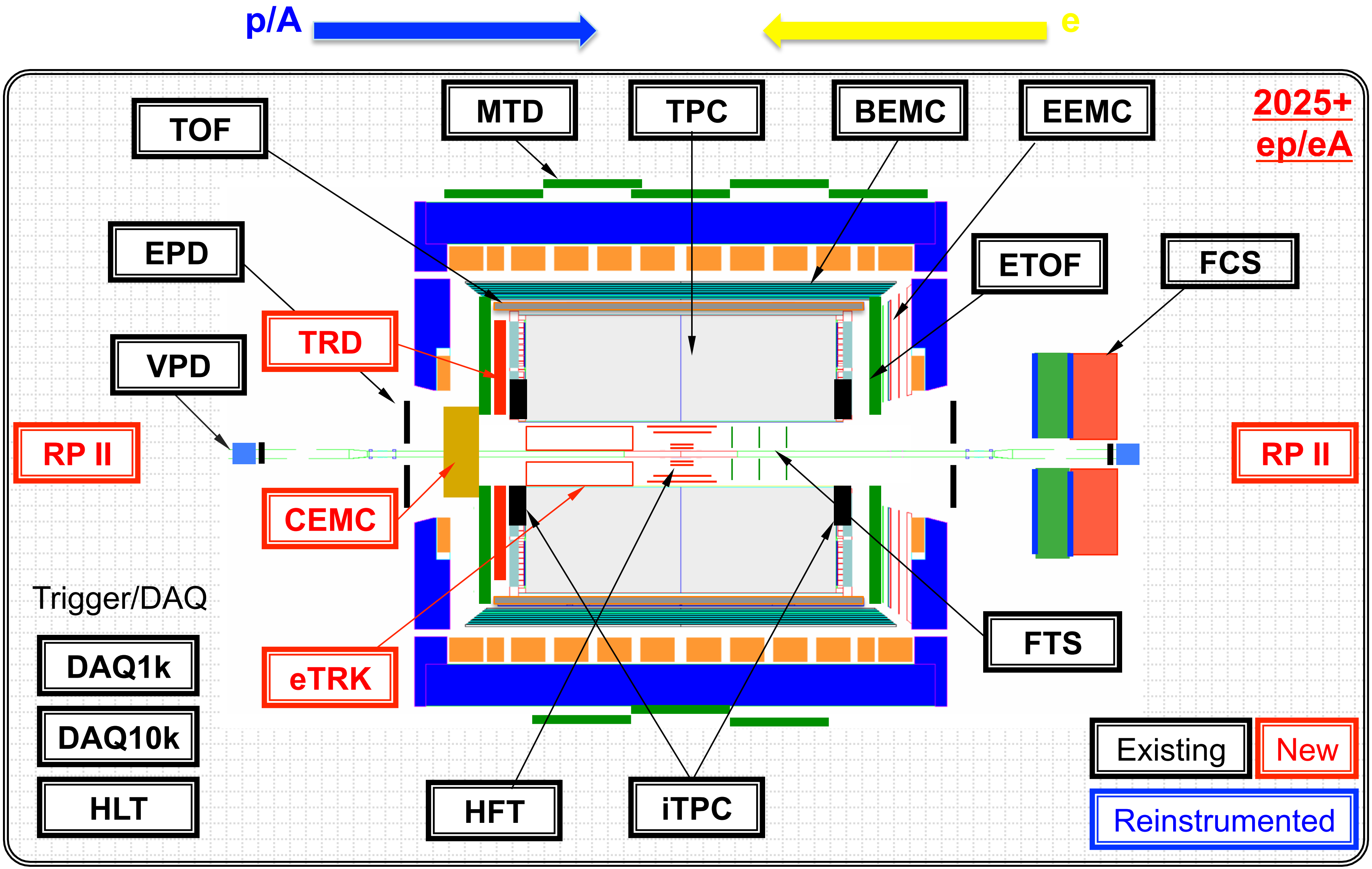

**iTPC**: inner TPC, **EPD**: Event Plane and Centrality Detector, **ETOF**: End-cap TOF, **Fixed Target**

# 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"*

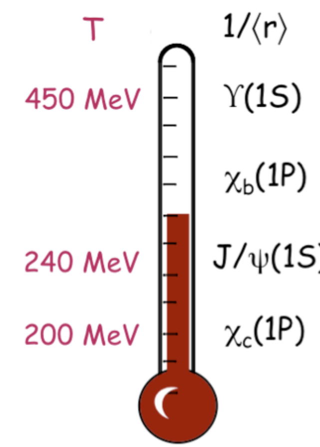
## ***QCD Phase Structure and Beam Energy Scan at RHIC***

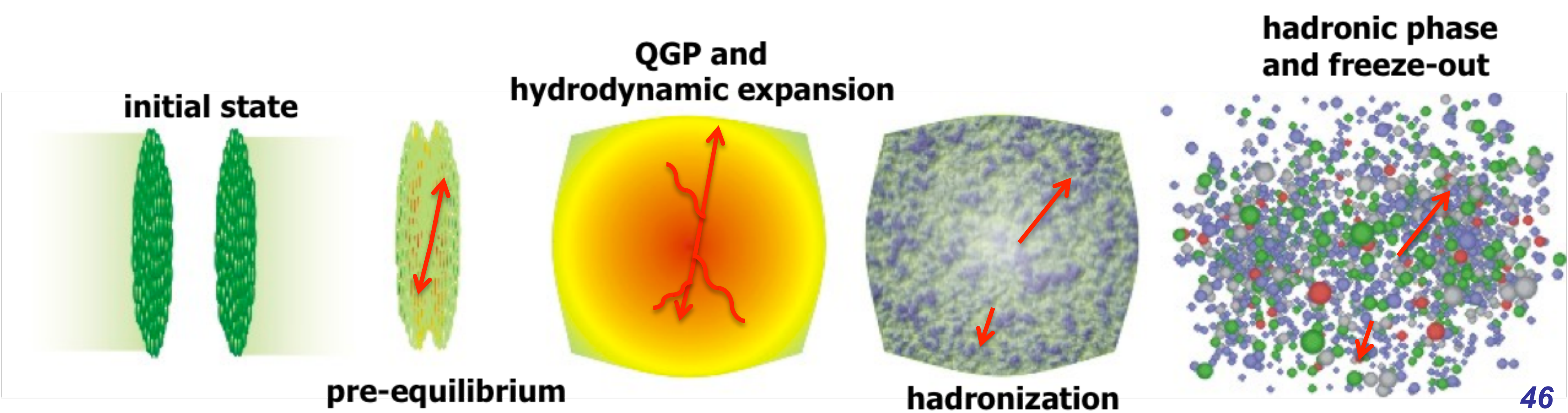
(1) [Collective dynamics] *"Elliptic flow of light nuclei and identified hadrons, their centrality and energy dependence in STAR"*
(2) [Electromagnetic probes] *"Beam energy dependence of dielectron production in Au+Au collisions from STAR at RHIC"*
(3) [QCD phase diagram] *"Energy dependence of higher 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] *"$\Omega$ and $\phi$ production in p+p, Au+Au and U+U collisions at STAR"*

# Heavy Flavor Physics

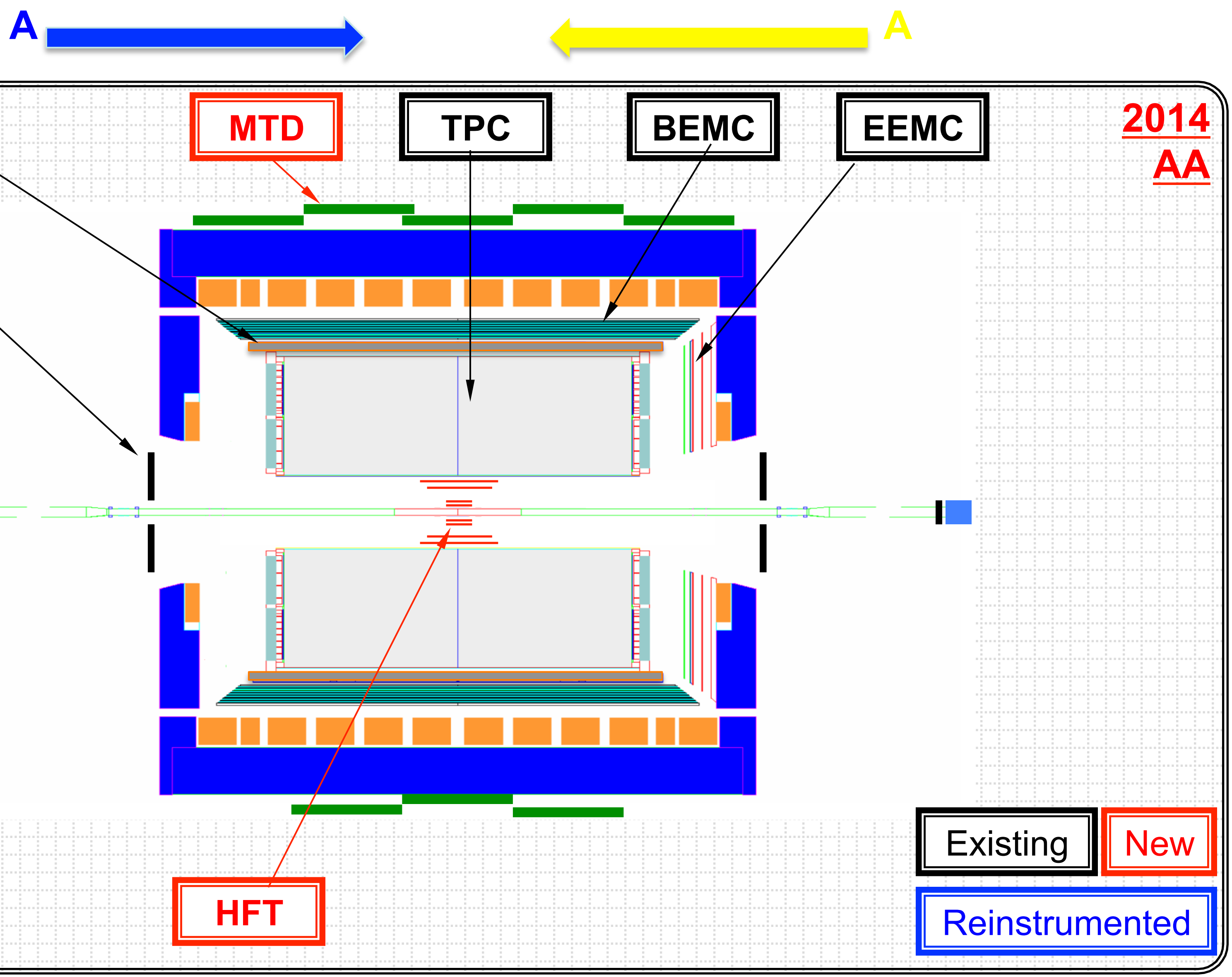
Heavy quarks primarily produced in initial hard scatterings, and exposed to the entire evolution of the hot nuclear matter created at RHIC.

- **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, …)



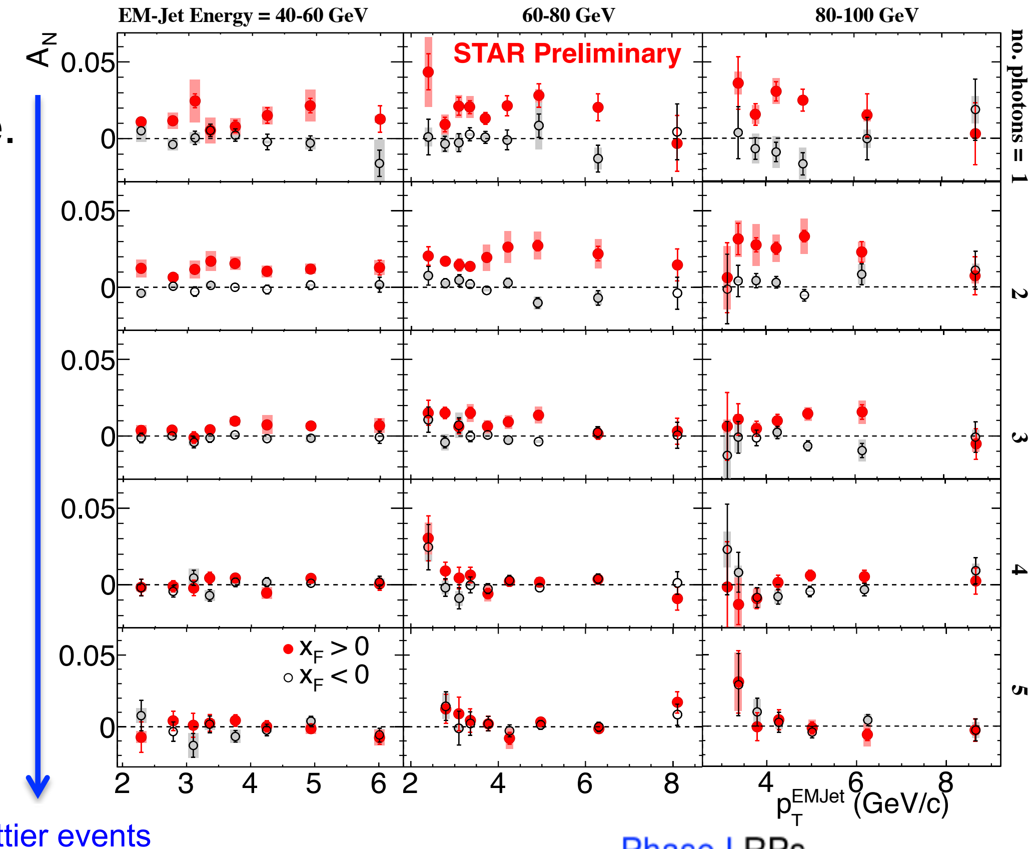
# STAR Detector in 2014

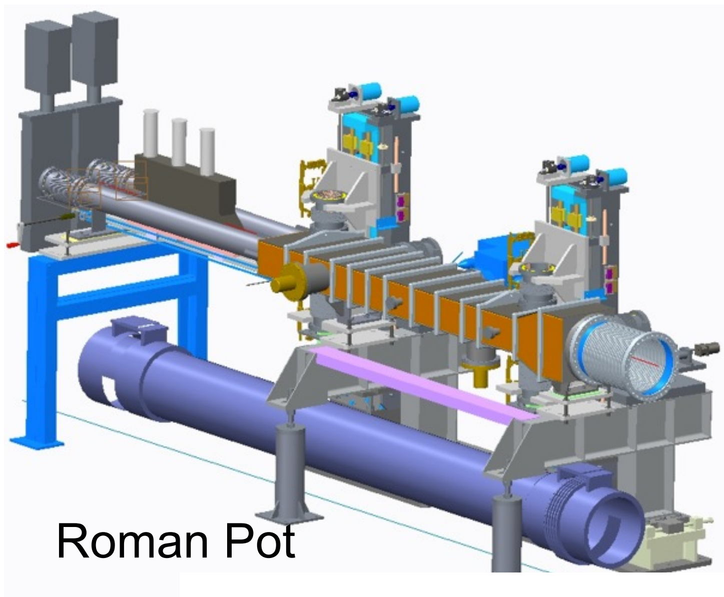


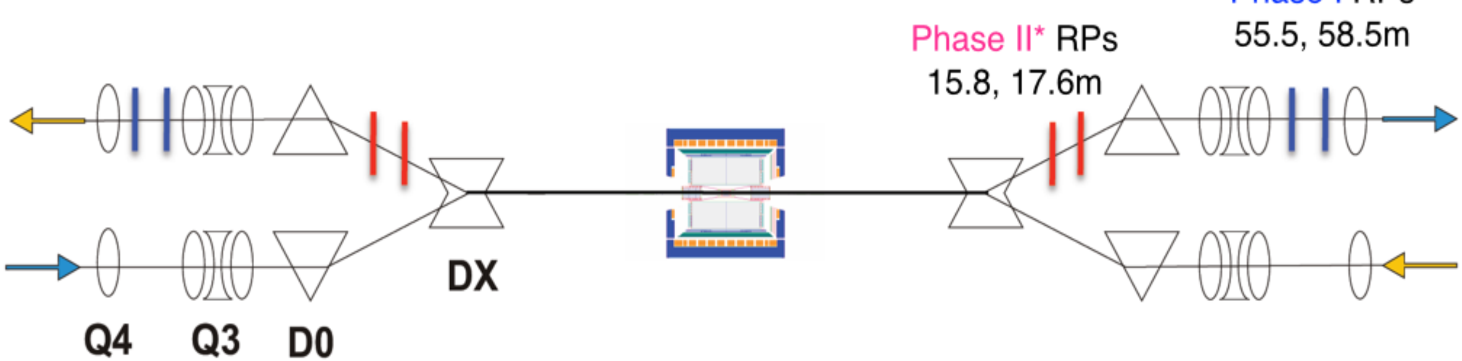

See F. Videbaek's talk on Thursday

# Roman Pot II* in 2015-2016

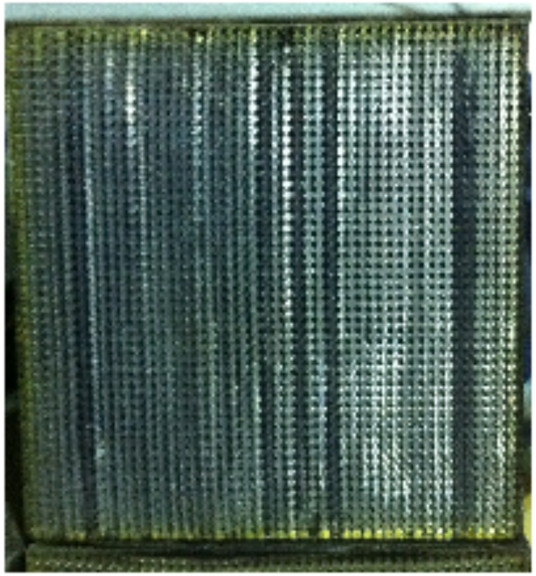
$A_N$ decreases with increased jettiness of the event; Possible diffractive nature. Roman Pot Upgrade critical

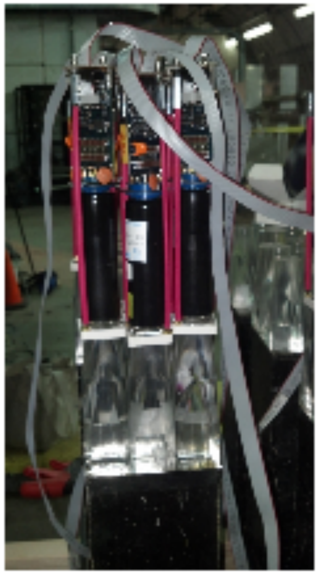


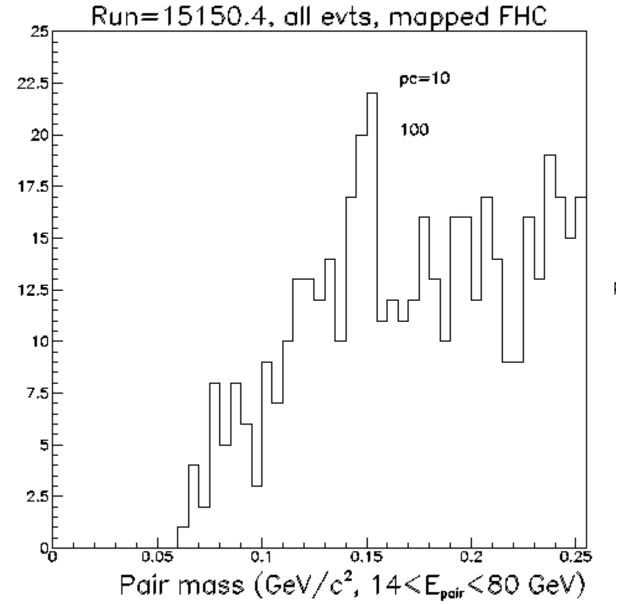



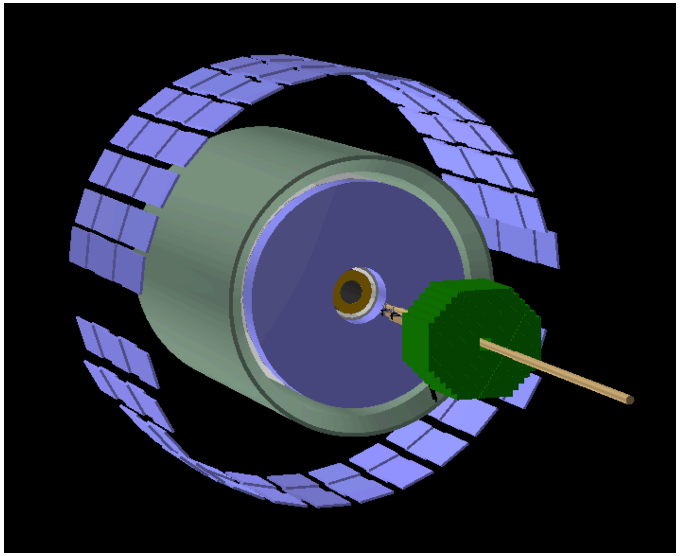



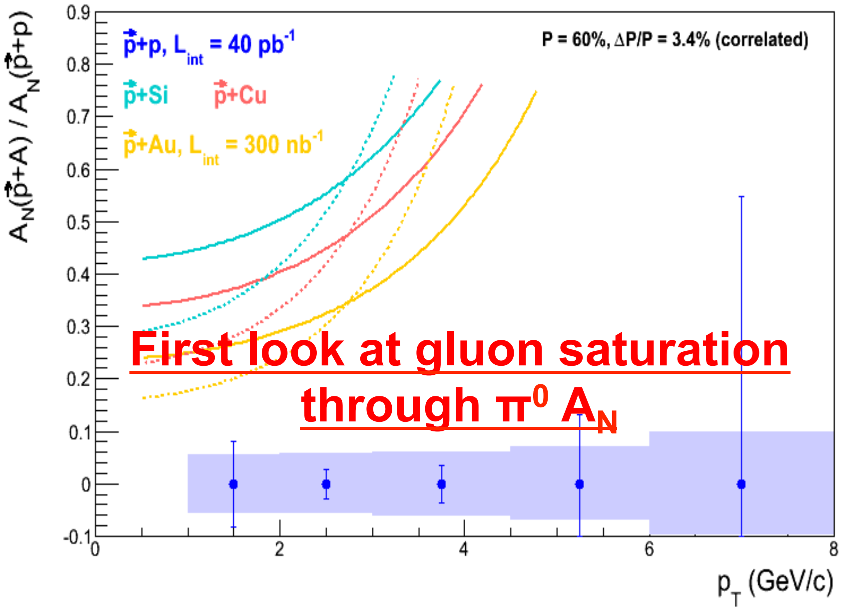
# Pixelized E864 HCAL in 2016 (?)





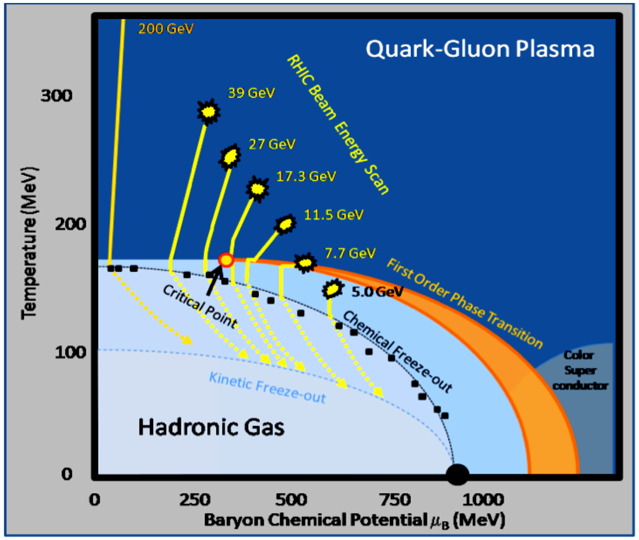


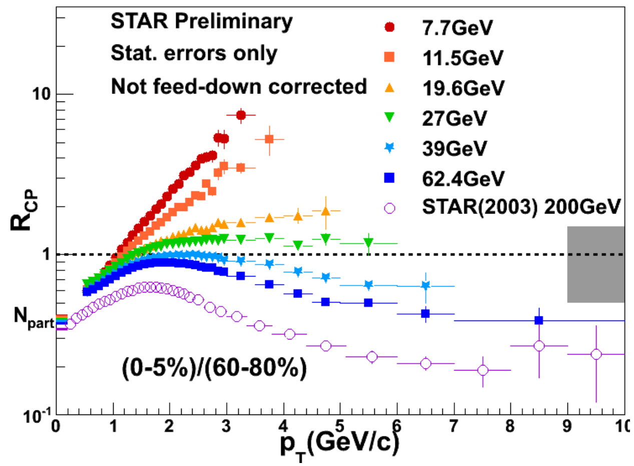



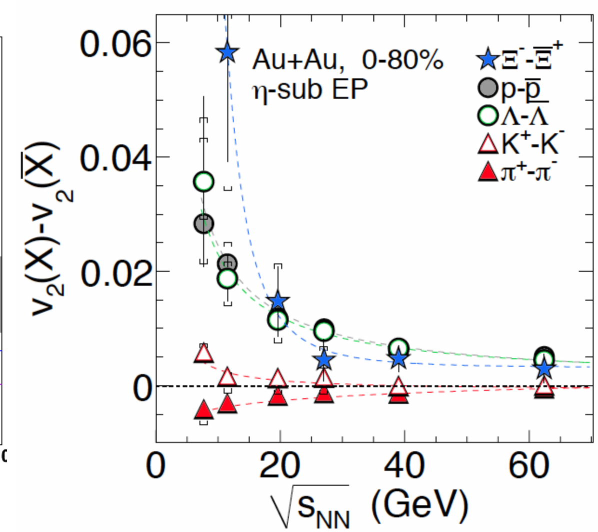


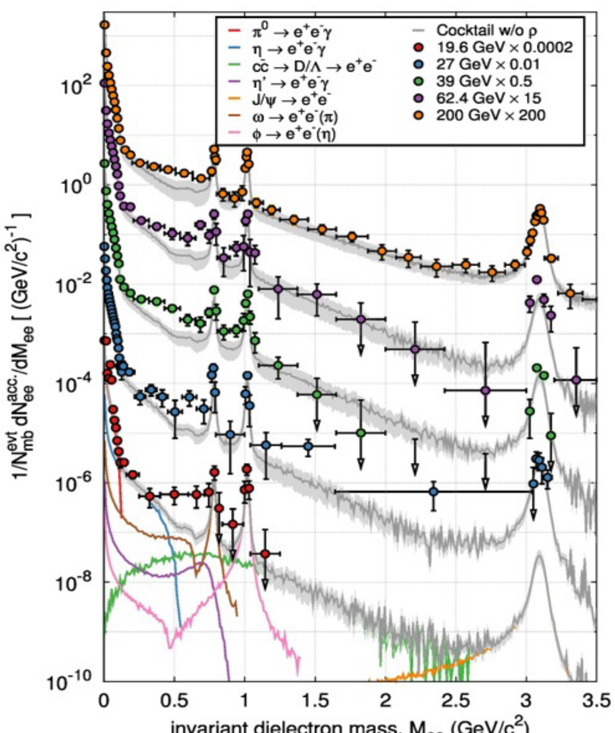

**First look at gluon saturation through $\pi^0$ $A_N$**

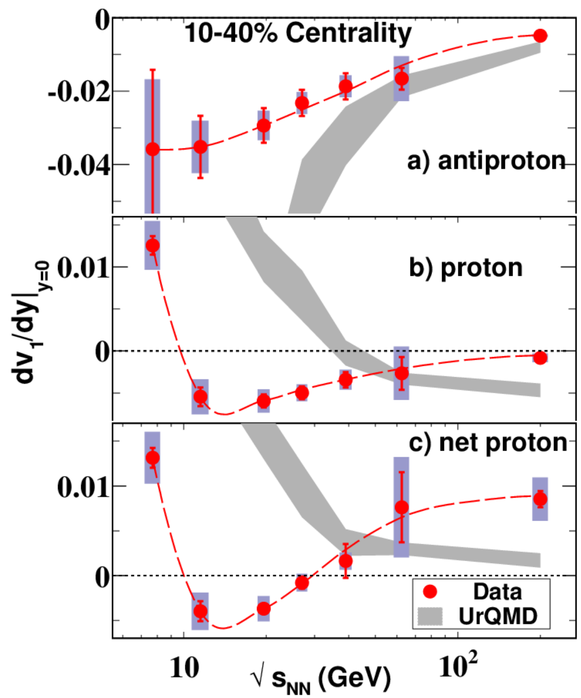
# QCD Phase Diagram and BES I

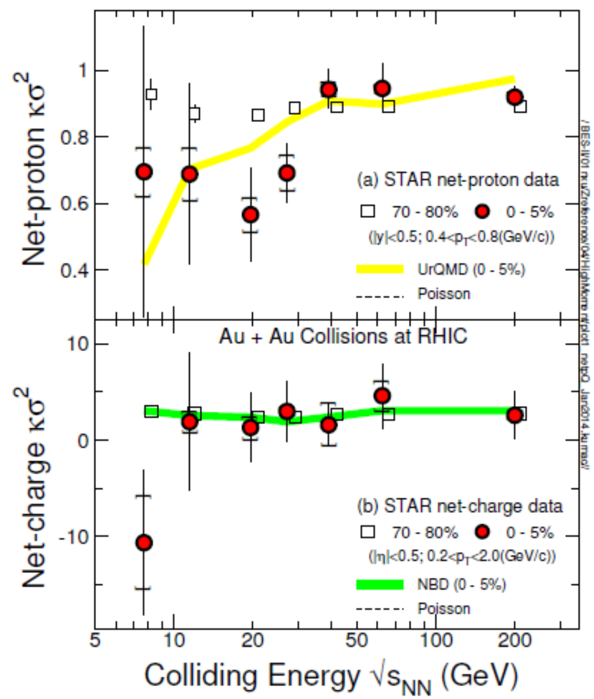


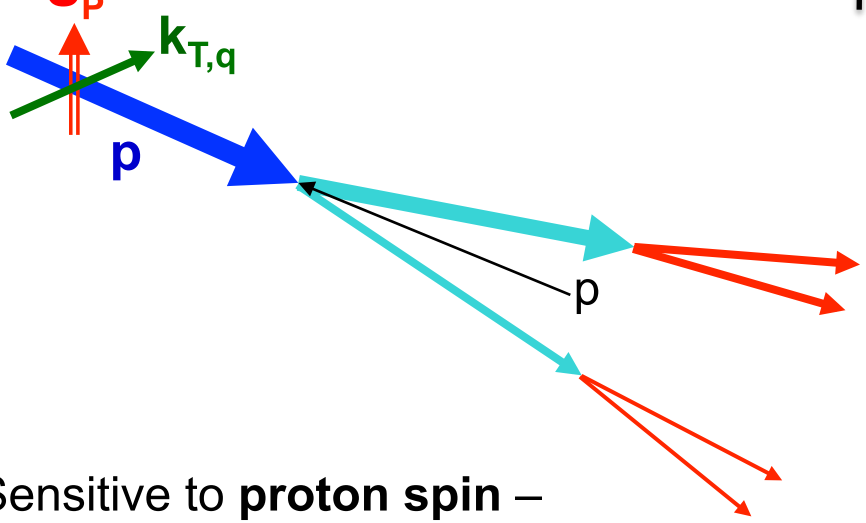
# Transverse Asymmetry with Jets

| SIVERS/Twist-3 | Collins Mechanism |
| --- | --- |

Rapidity dependence of

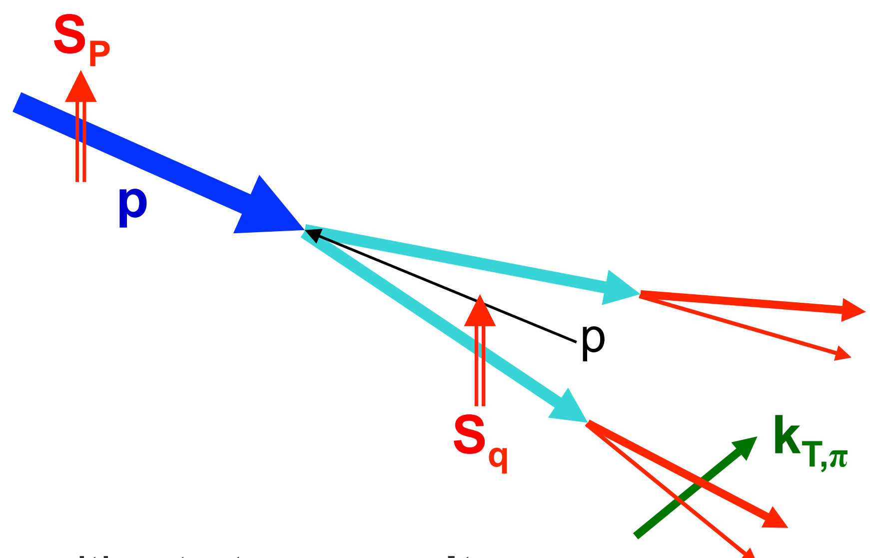
- $A_N$ for $\pi^0$ and eta with increased $p_t$ coverage

- $A_N$ 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

- 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

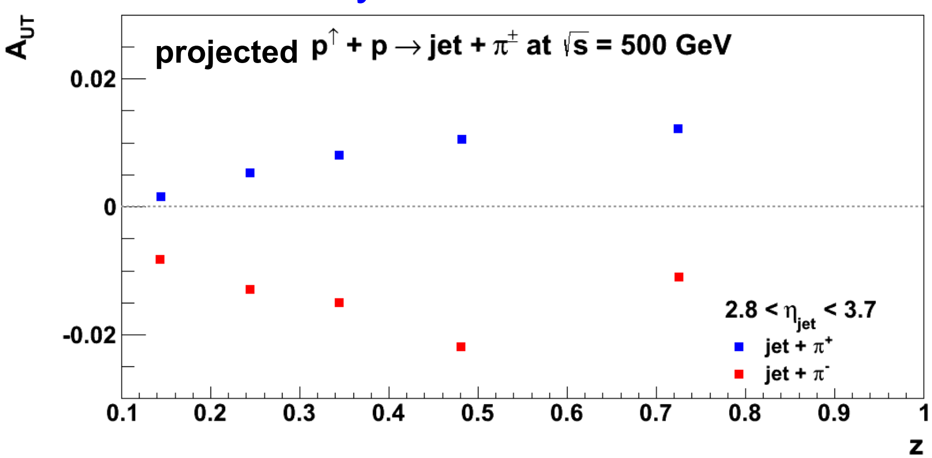
Needs:

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

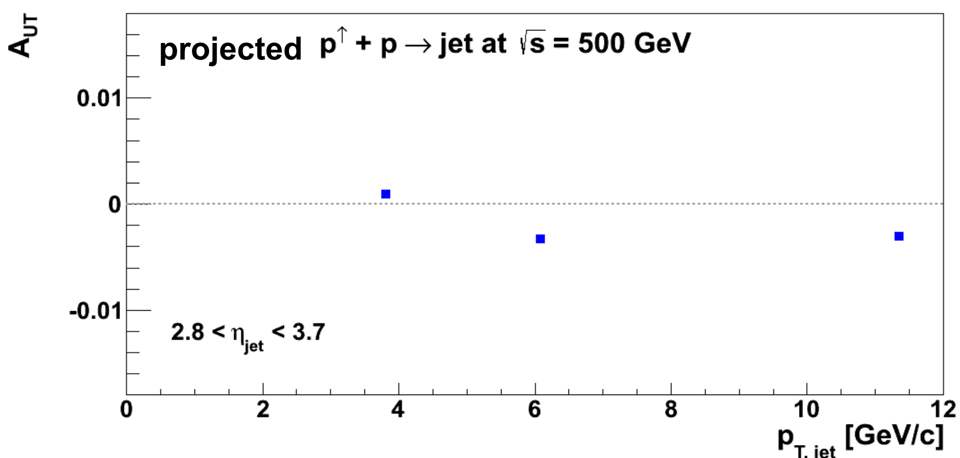
Address the following questions:

- ❑ 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

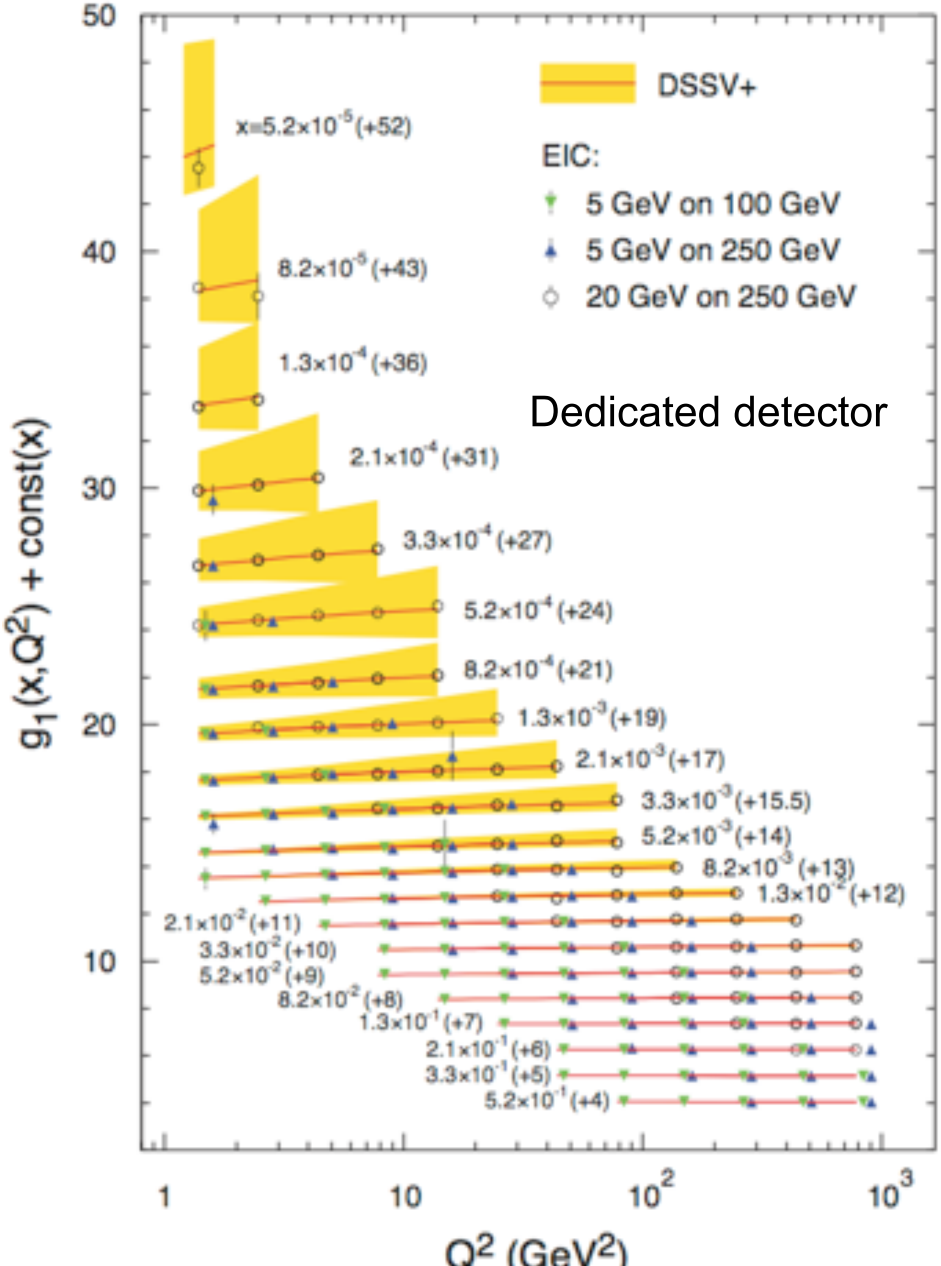



Projection based on M. Anselmino et al., PRD 87 , 094019 (2013)

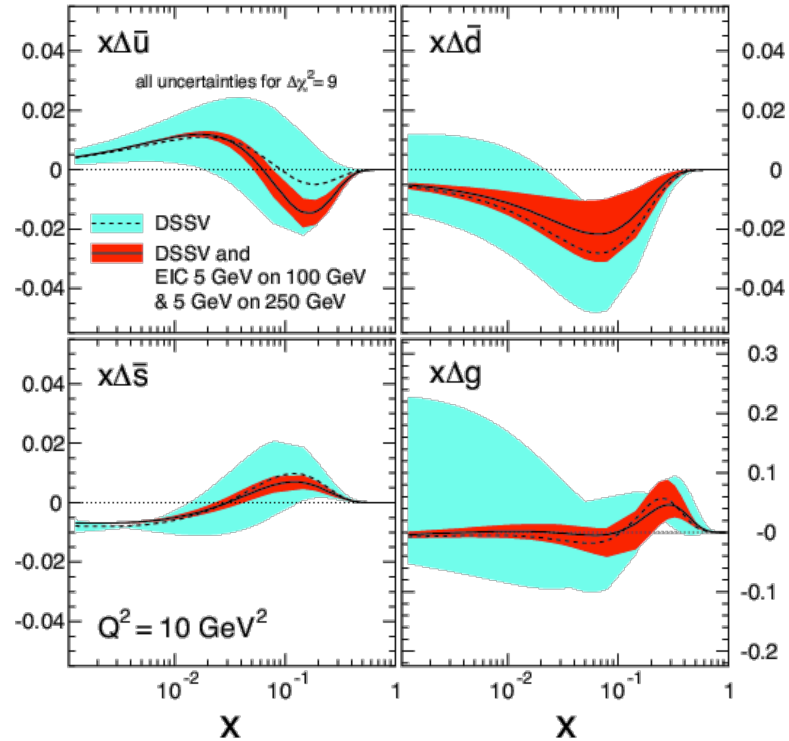
Sensitive to **transversity**
universal between SIDIS & pp & $e^+e^-$

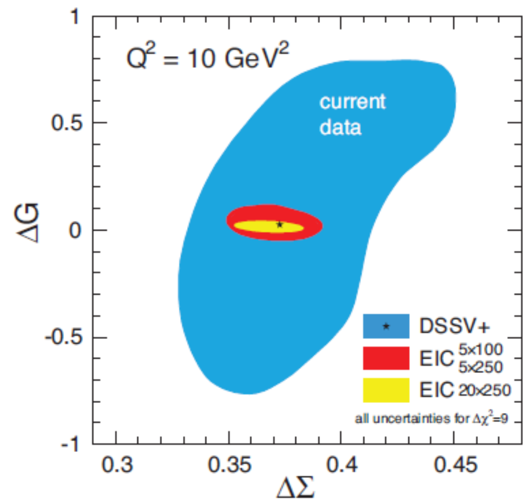
Sensitive to **proton spin** – parton **transverse motion** correlations
non-universal between SIDIS&pp

# Proton Helicity Structure

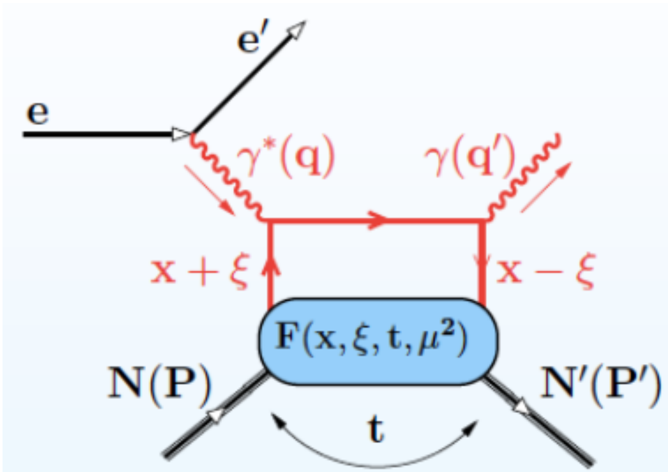


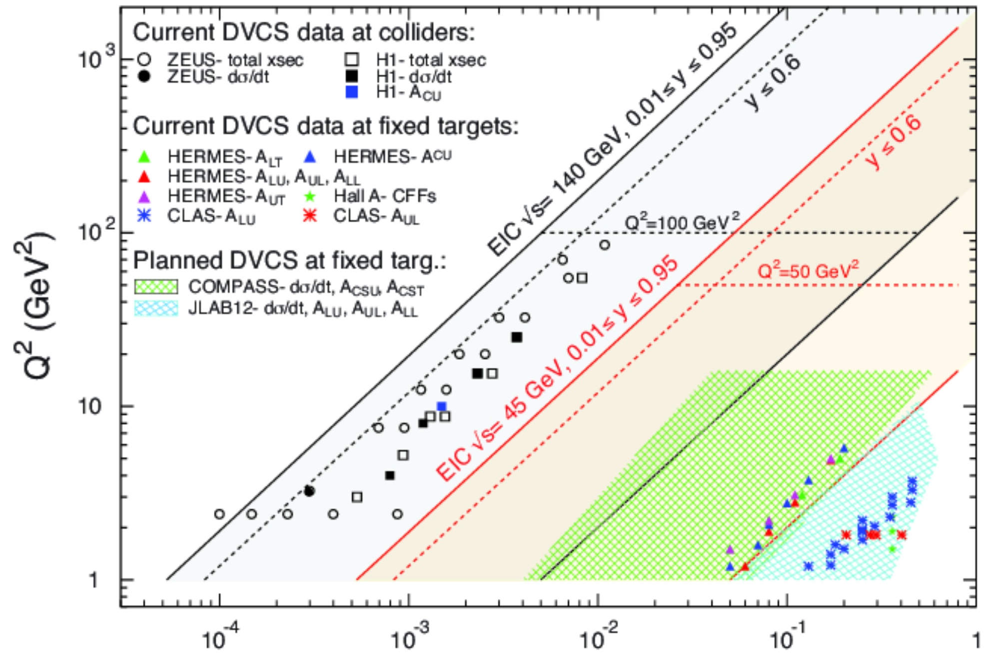

Dedicated detector



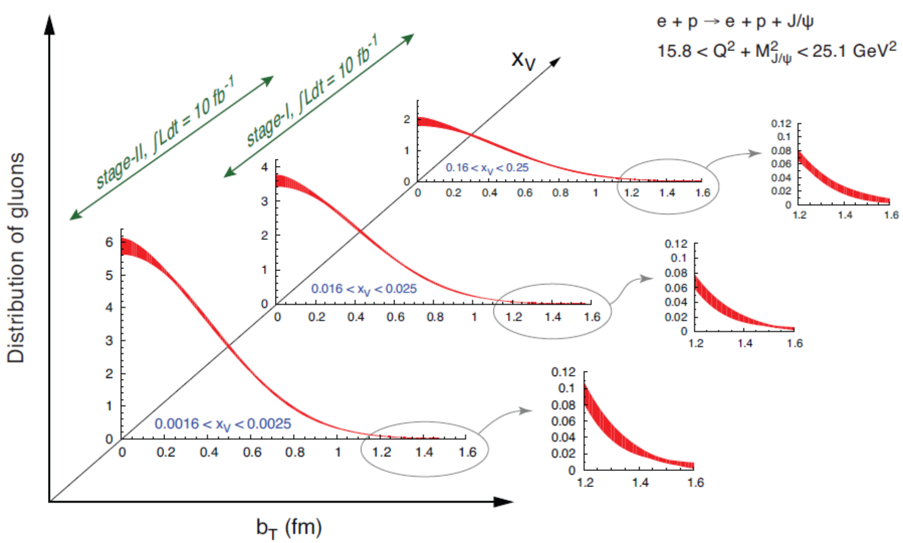



# Deeply Virtual Compton Scattering



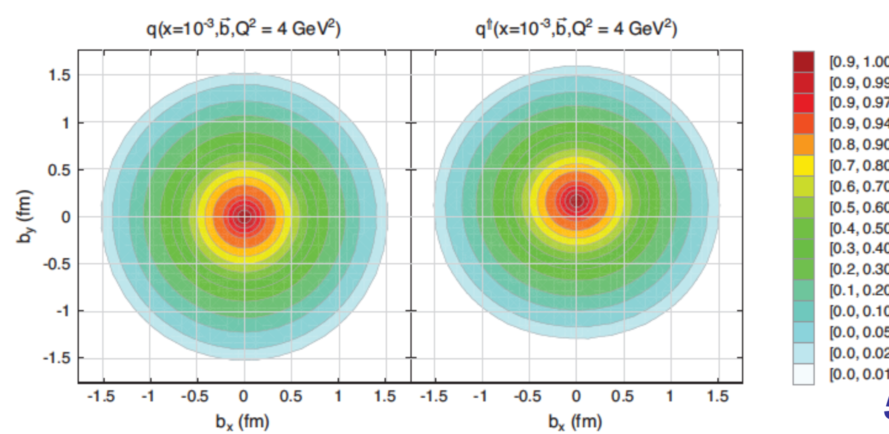




## 3D Imaging of the Proton

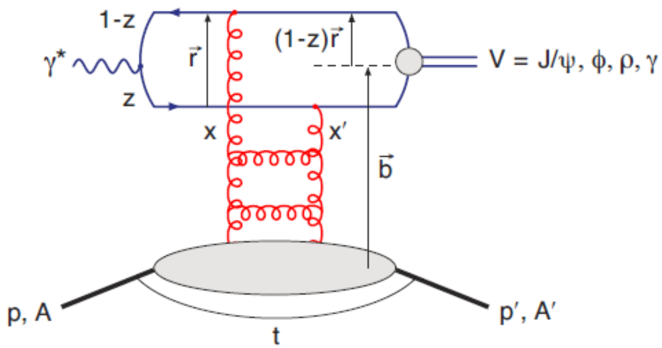


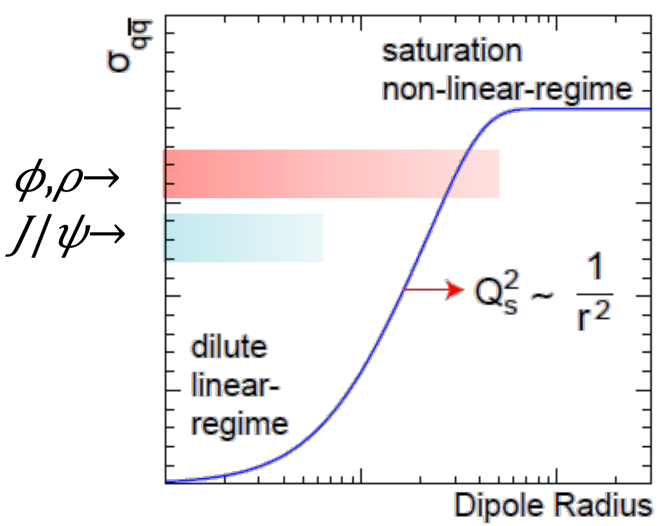

## Access to orbital angular momentum

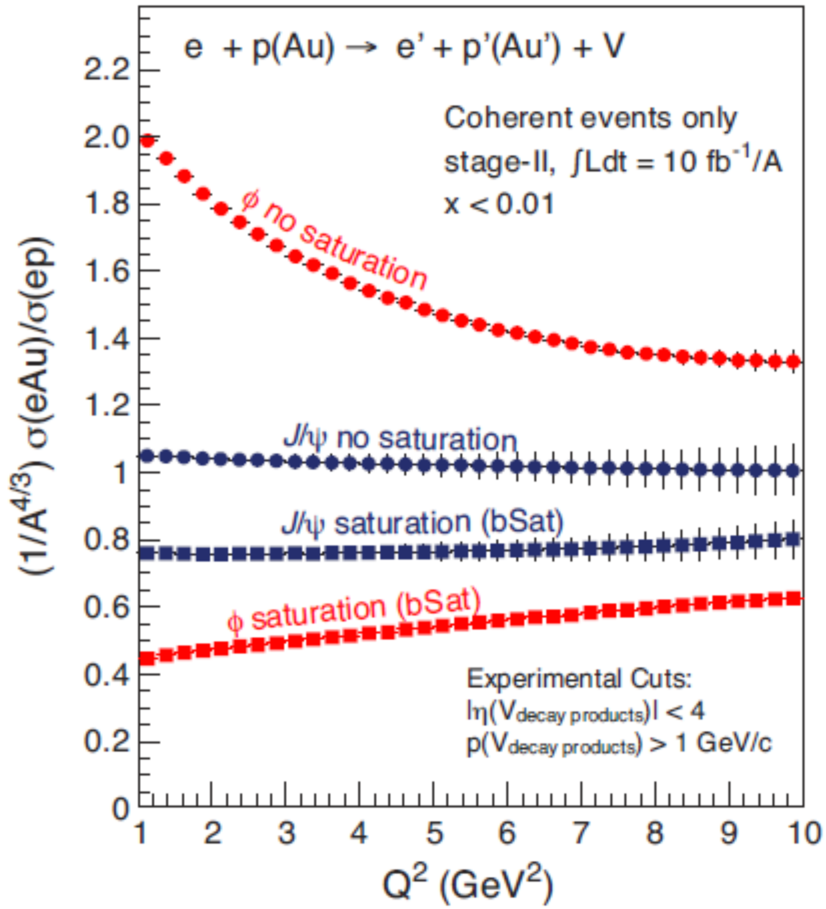
$$J_{q,g} = \int\limits_{t\to 0} dx \cdot x \cdot \left[ H_{q,g}(x,\xi,t) + E_{q,g}(x,\xi,t) \right]$$



# Gluon Saturation from Exclusive VM

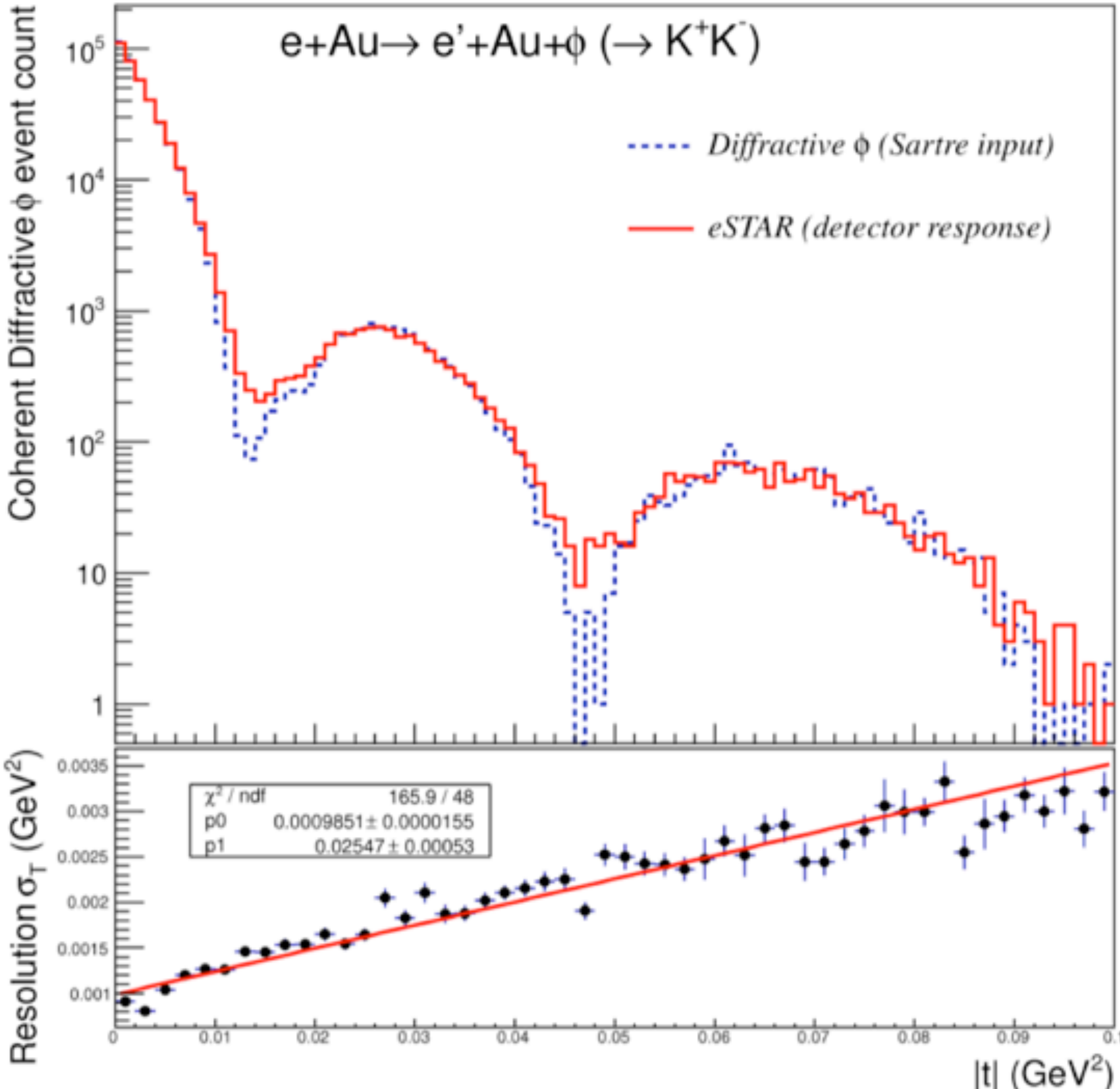


# Gluon Saturation from Exclusive VM

eSTAR projections for diffractive production of phi-mesons



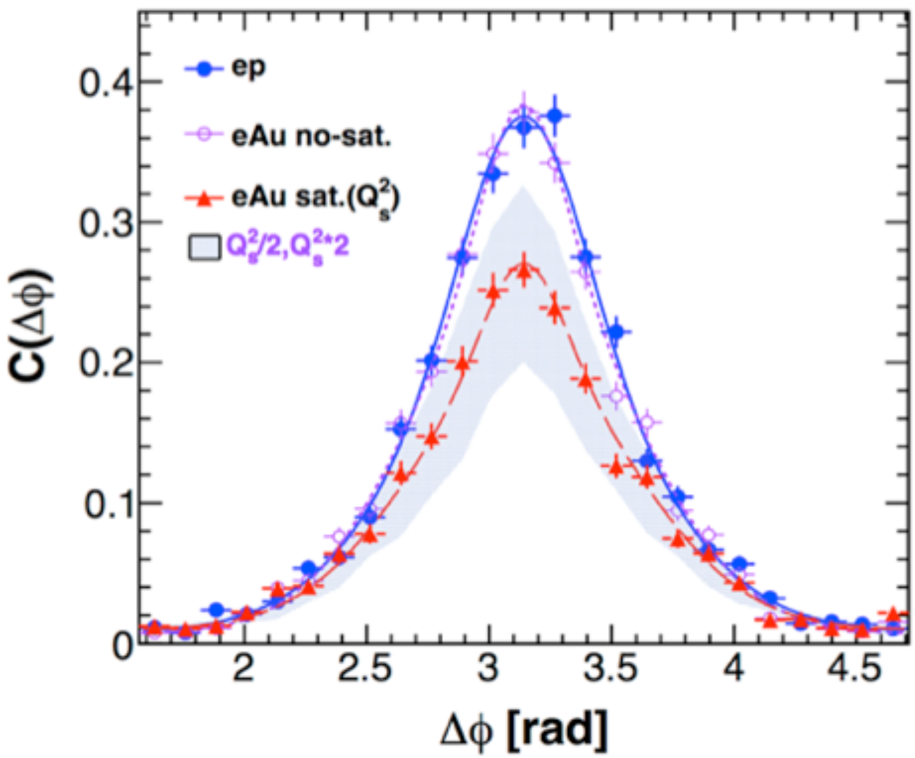

Plays well to STAR's mid-rapidity PID strengths, good resolution

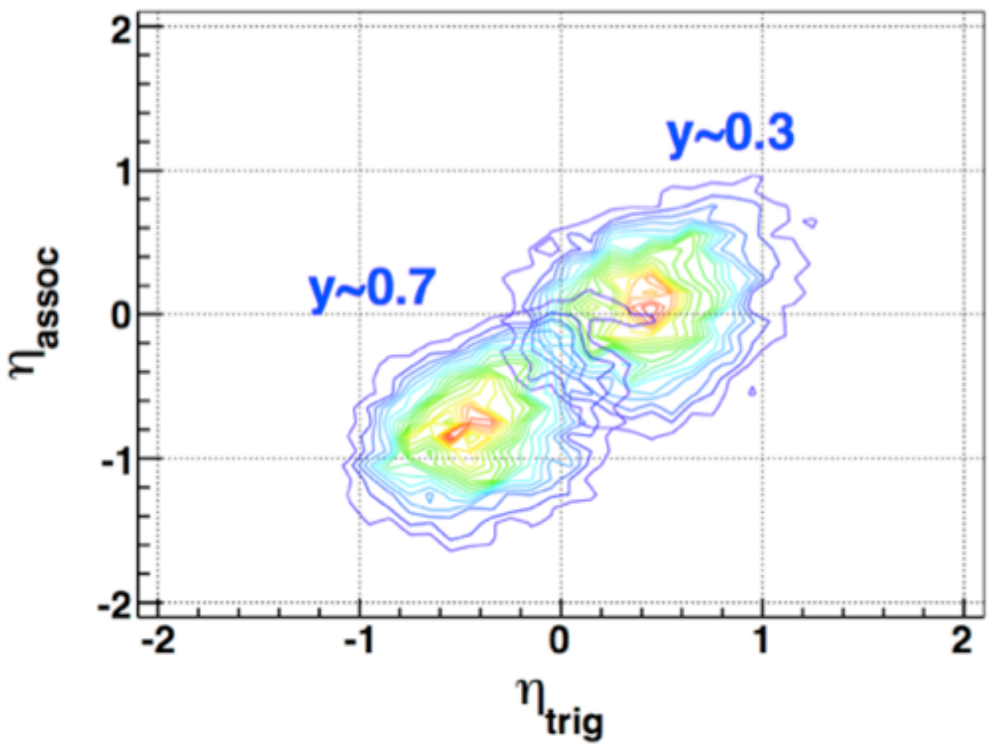
# Gluon Saturation from Di-Hadron

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:*

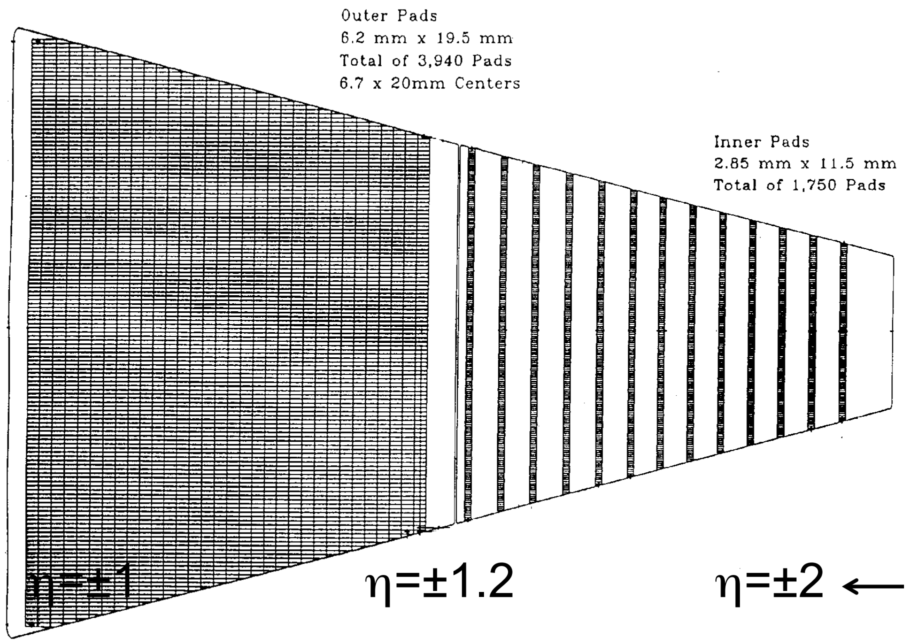


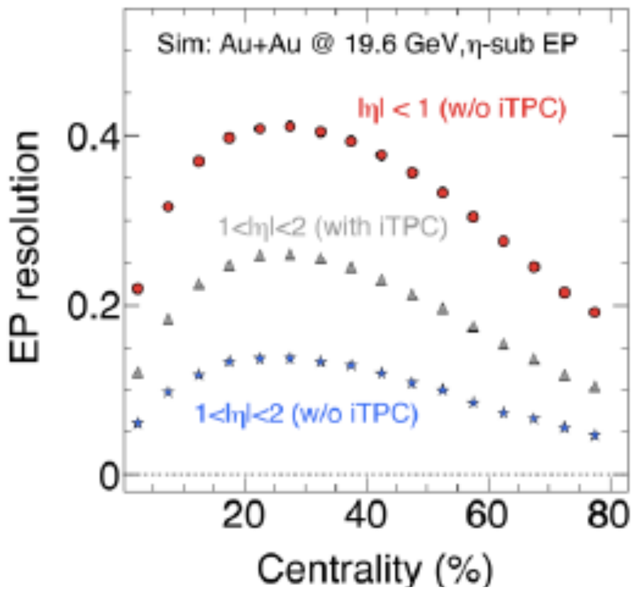



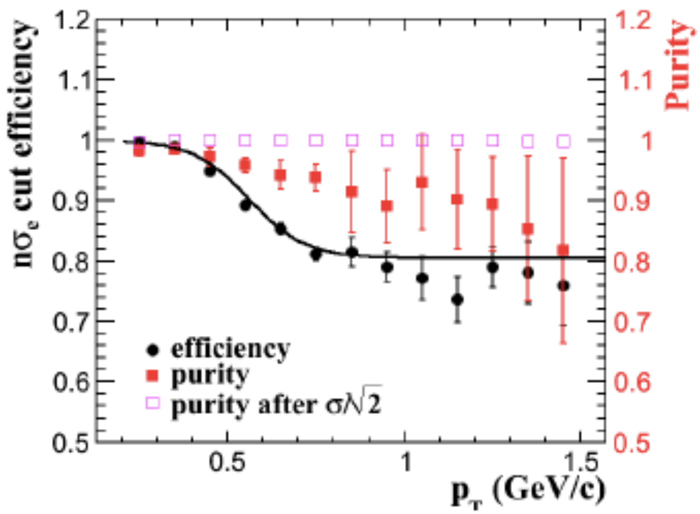

eSTAR projections for 10 GeV electrons scattering off 100 GeV/nucleon Au beams, 1 $fb^{-1}$.

# Upgrades for BES II

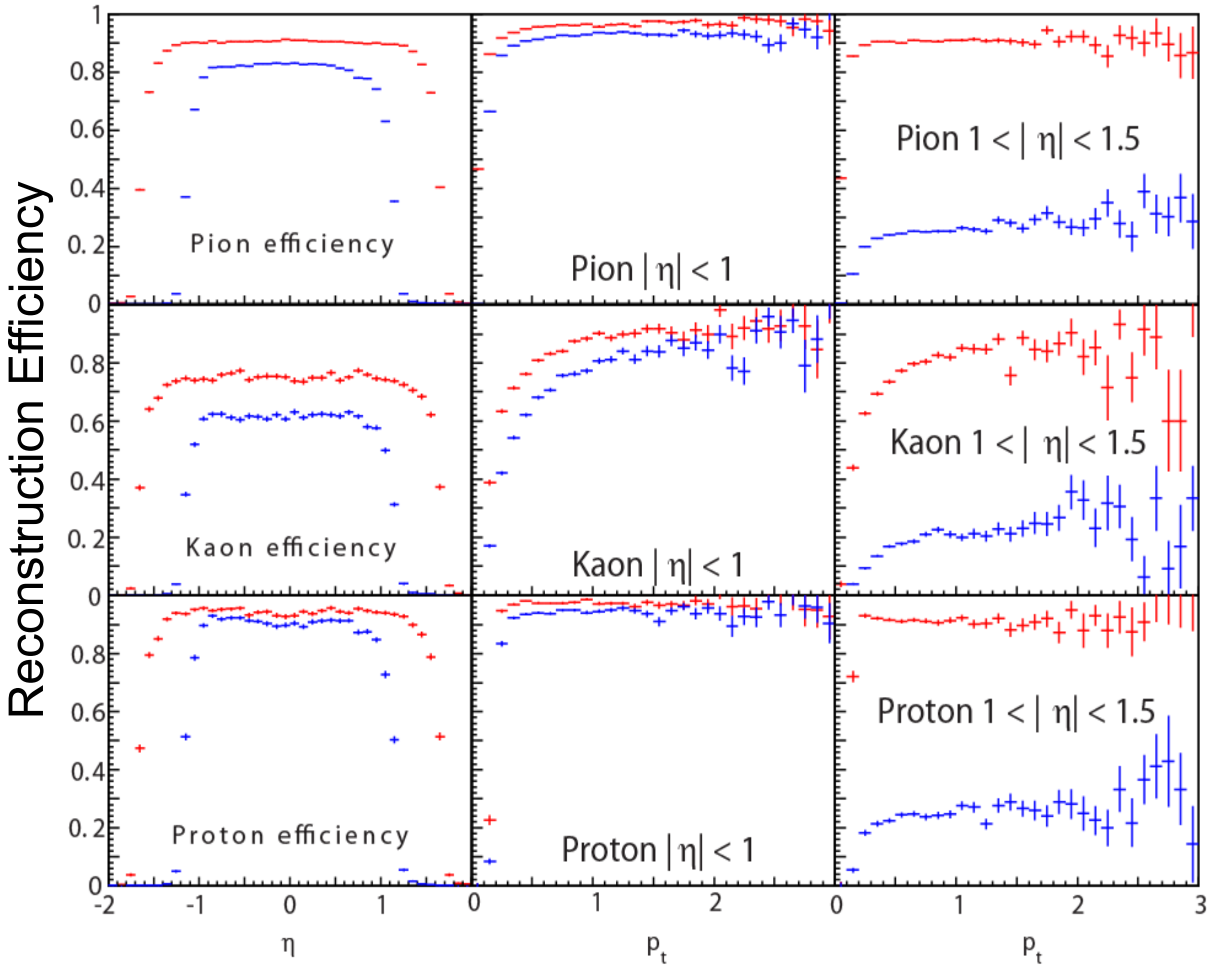
- Current pad plane with 13 rows and gaps
  - only 13 maximum possible points
  - only reads ~20% of possible gas path length
    - Inner sectors essentially not used in dE/dx
- Limits effective acceptance to |η|<1



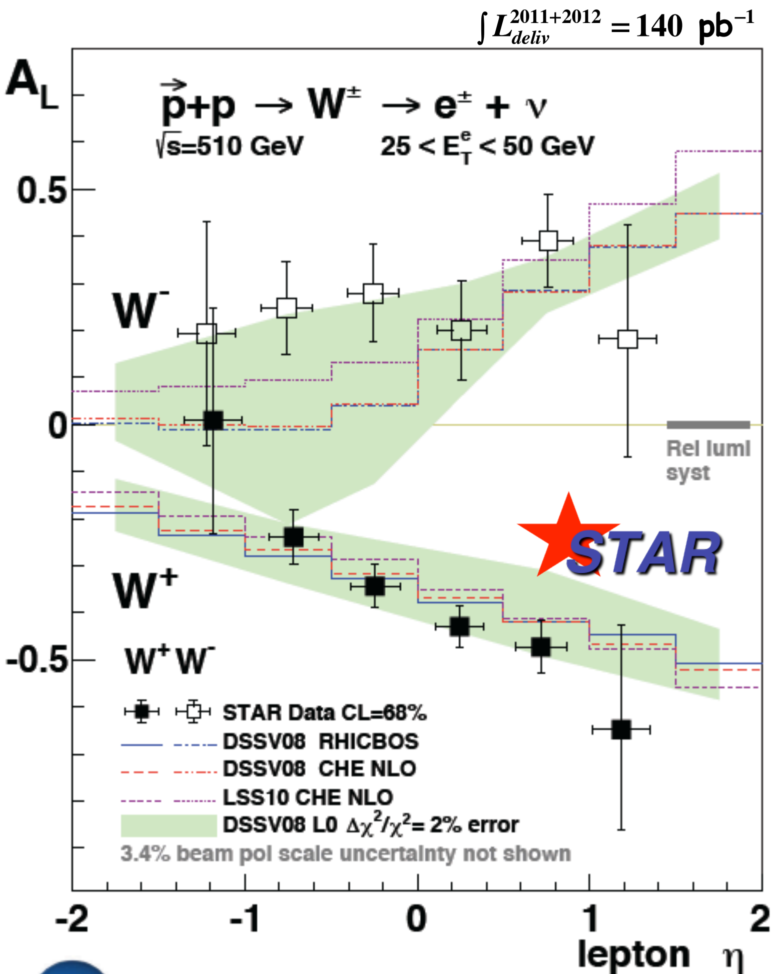
# Upgrades for BES II



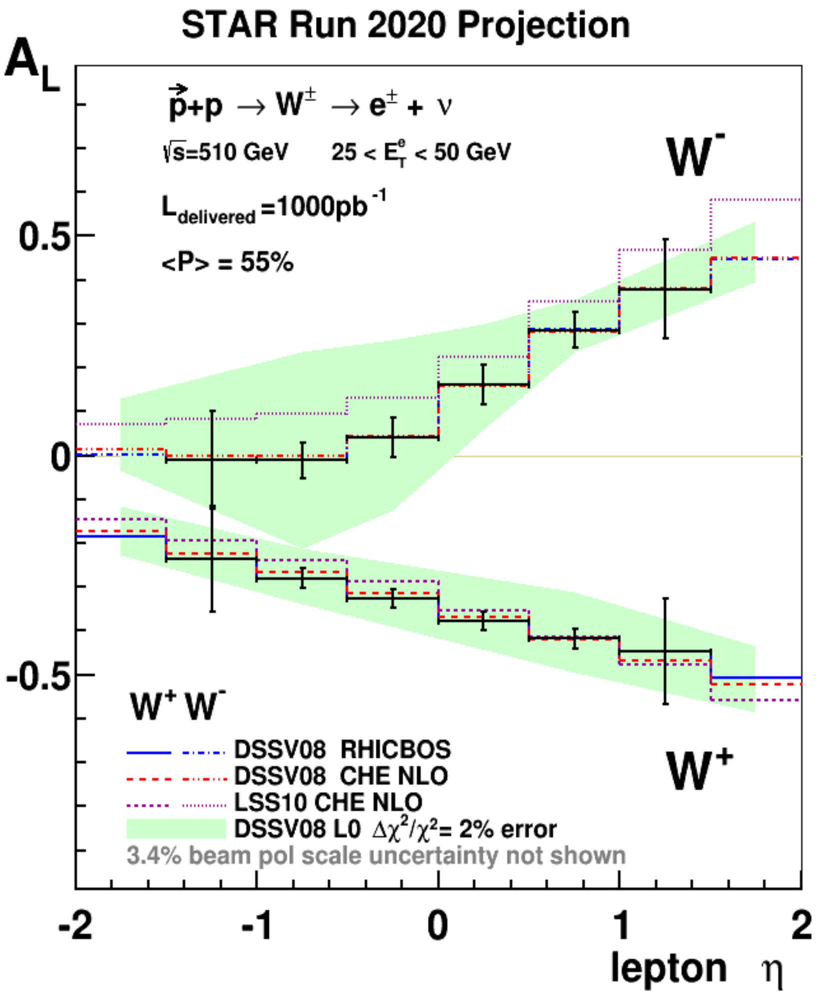

Red/Blue points: with/without iTPC

**Essential for both BESII and eSTAR physics**

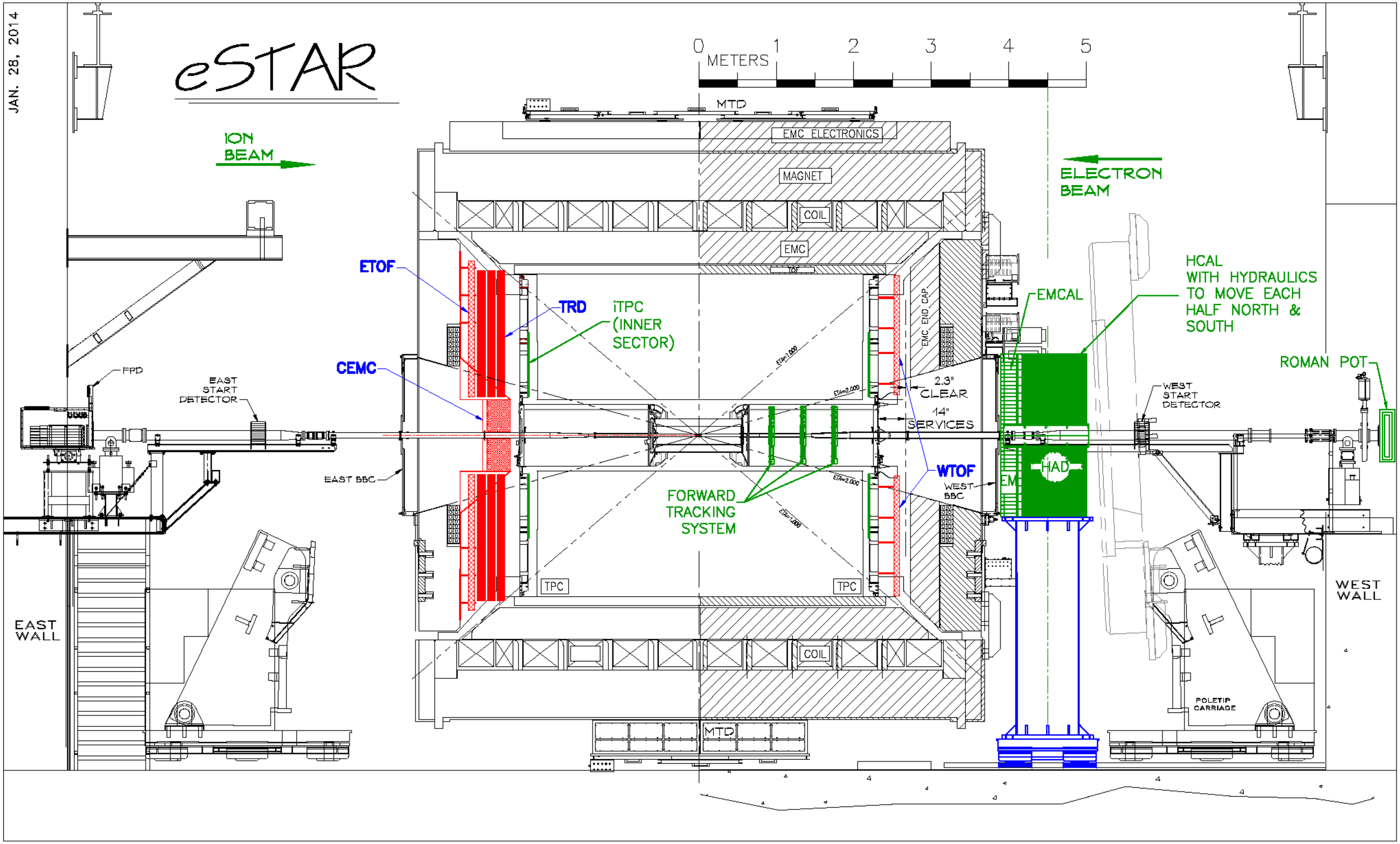
# Proton Helicity Structure




arXiv:1404.6880



# eSTAR Detector in 2025+




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