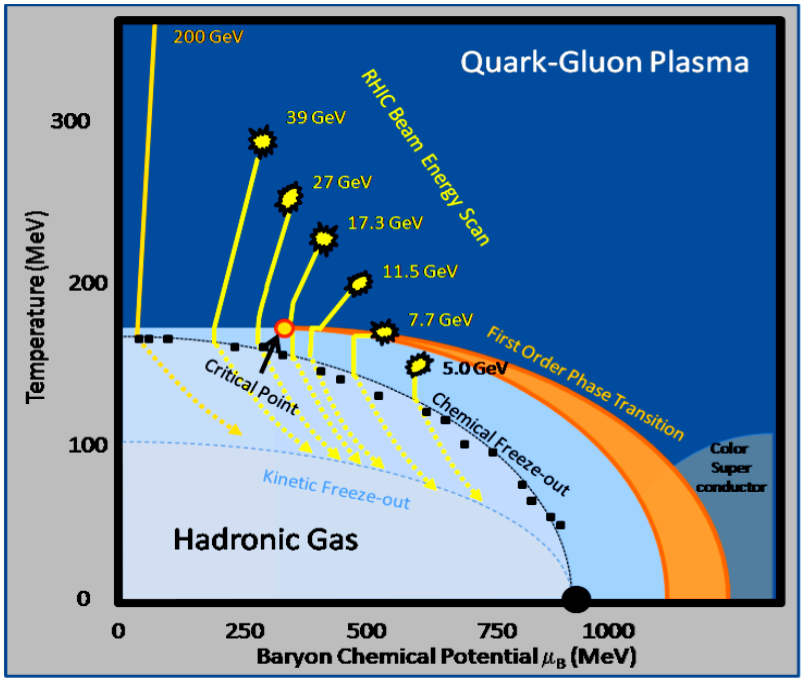
Prepare (e)STAR as an EIC detector

Zhangbu Xu (BNL)

- Introduction (eSTAR)
  - Physics Cases
  - STAR (status)→eSTAR
- R&D Projects
  - FCS/BSO/iTPC/TRD
  - On-going simulations
- Summary

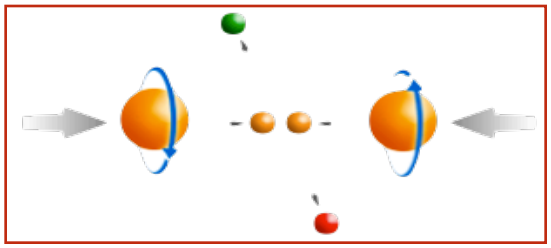
RHIC: eight key unanswered questions

Hot QCD Matter

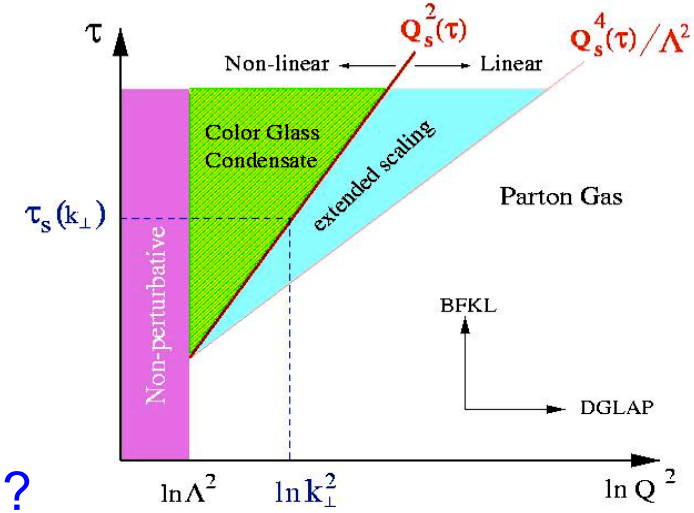


1: Properties of the sQGP
2: Mechanism of energy loss:
weak or strong coupling?
3: Is there a critical point, and if so, where?
4: Novel symmetry properties
5: Exotic particles

Partonic structure

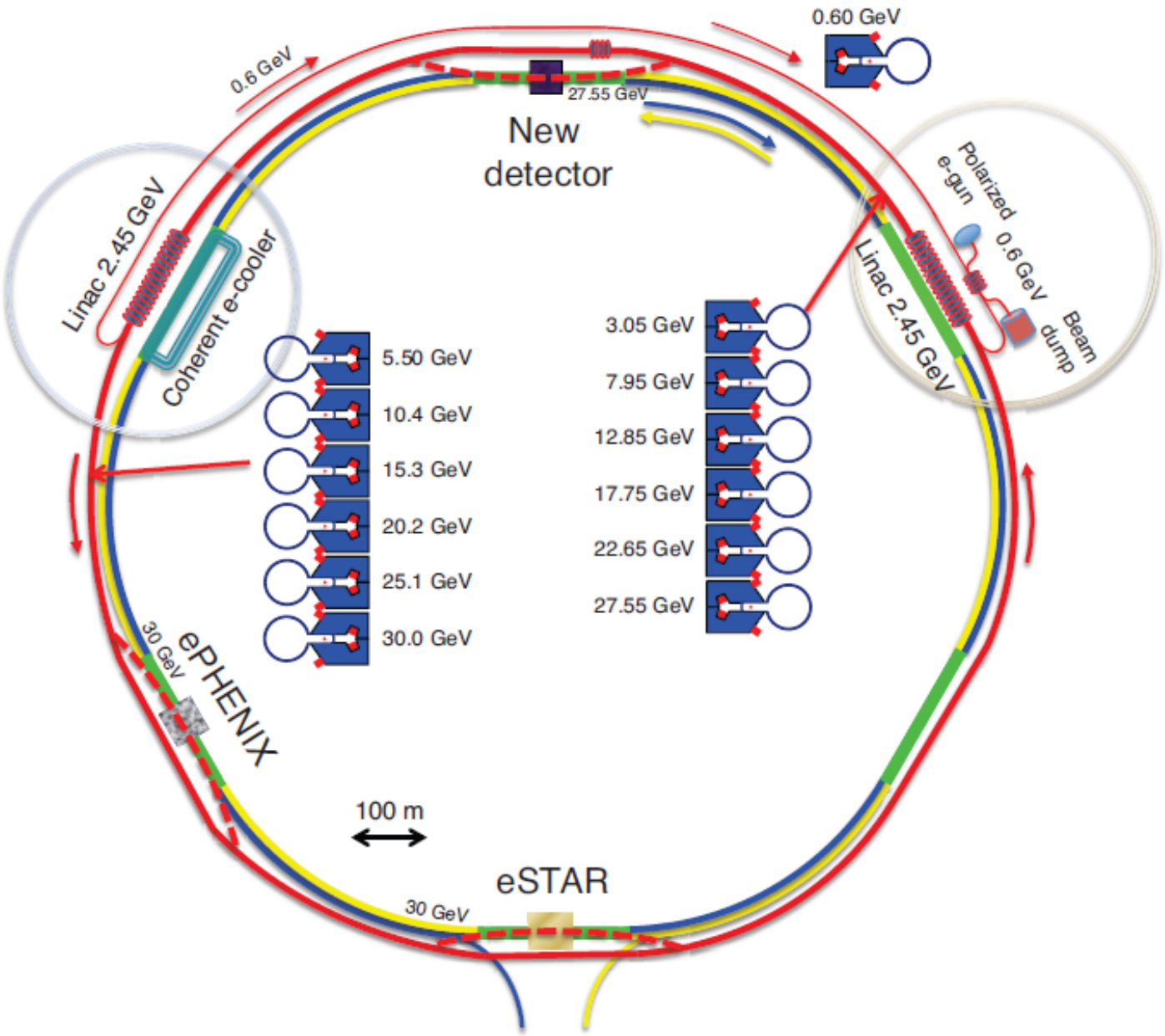


6: Spin structure of the nucleon
7: How to go beyond leading twist and collinear factorization?



8: What are the properties of cold nuclear matter?

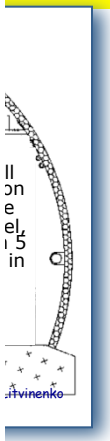
A Long Term (Evolving) Strategic View for RHIC



S. Vigdor

RHIC-I physics

EIC = Electron-Ion Collider; eRHIC = BNL realization by adding e beam to RHIC



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or this period.

nother option.

Golden Probes in eA

Physics eSTAR	Measurements	requirements
Structure functions of heavy nuclei (F2,FL)	Scattered electron (Q^2,x)	Precise electron p and PID
Semi-inclusive final-state correlation	Scattered electron (Q^2,x) and hadrons	Electron ID and hadron spectra
Exclusive Vector Meson	J/Ψ and other vector meson	Electron/muon ID and full coverage detector
Cold Nuclear Energy Loss	Jets and leading hadrons	Electron and Hadron PID
Heavy-Flavor Energy Loss	Charm PID	Secondly vertex detector
Exotics	Heavy-flavor hypernuclei	Forward Secondly vertex detector

Imaging nuclei

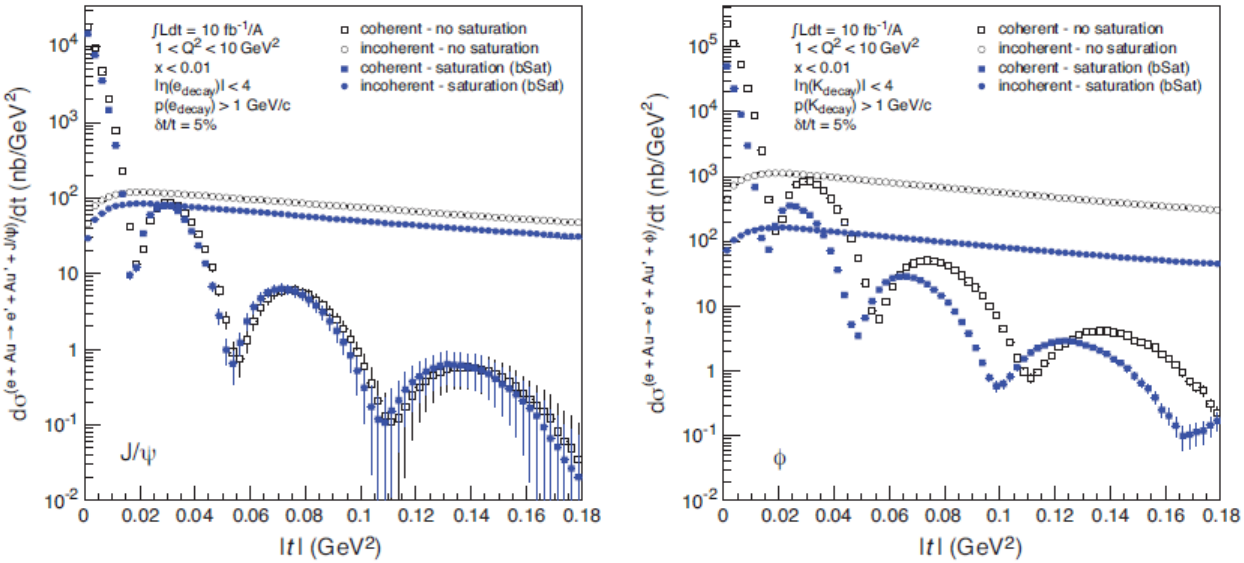
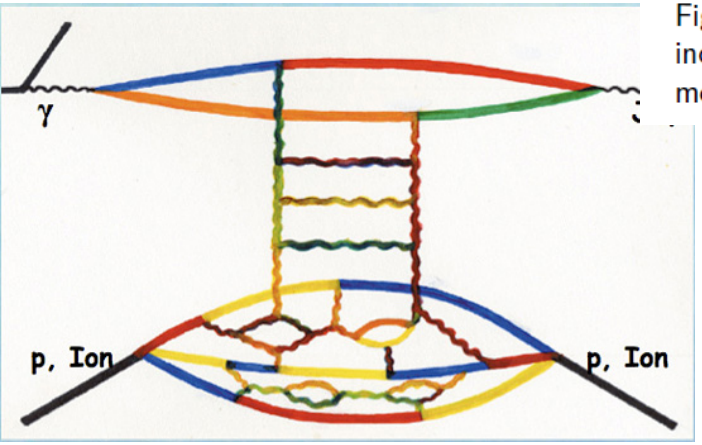
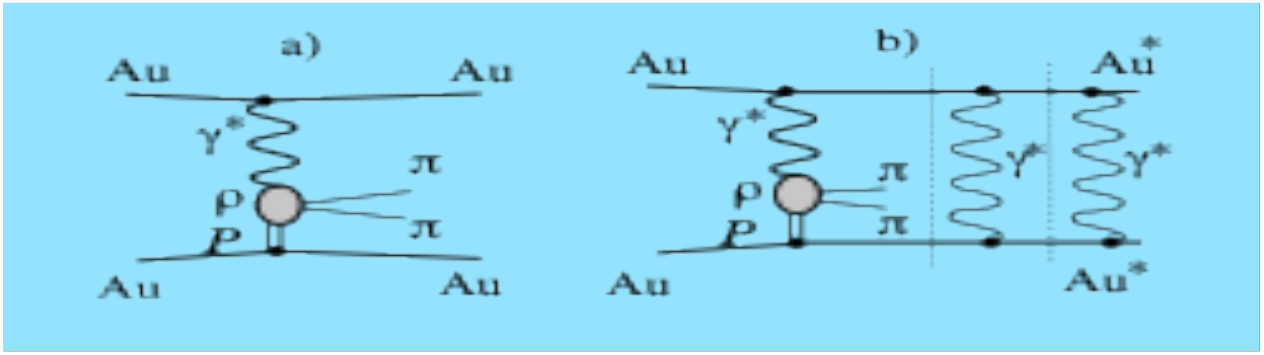


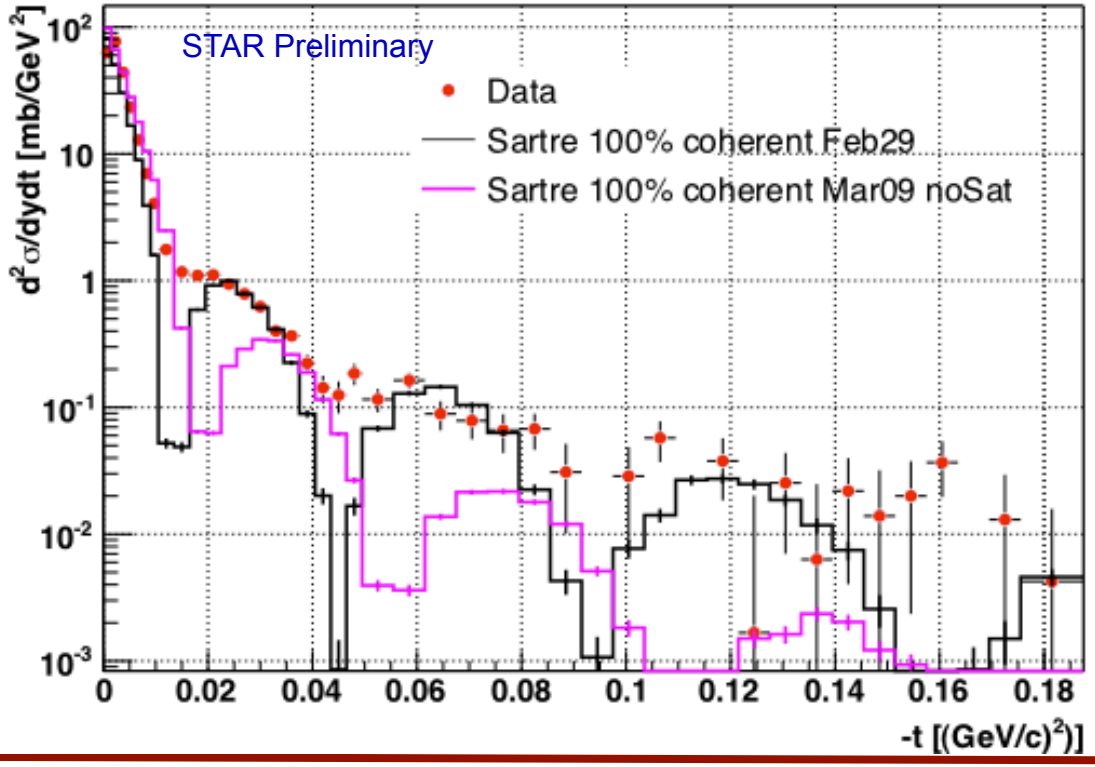
Figure 3.20: $d\sigma/dt$ distributions for exclusive J/ψ (left) and ϕ (right) production in coherent and incoherent events in diffractive eAu collisions. Predictions from saturation and non-saturation models are shown.



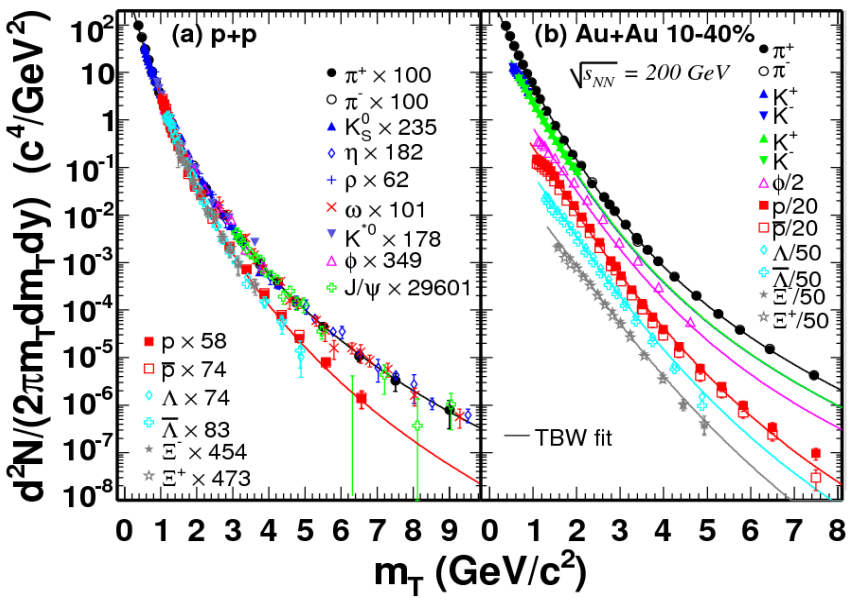
Colored dipole directly images gluon distribution

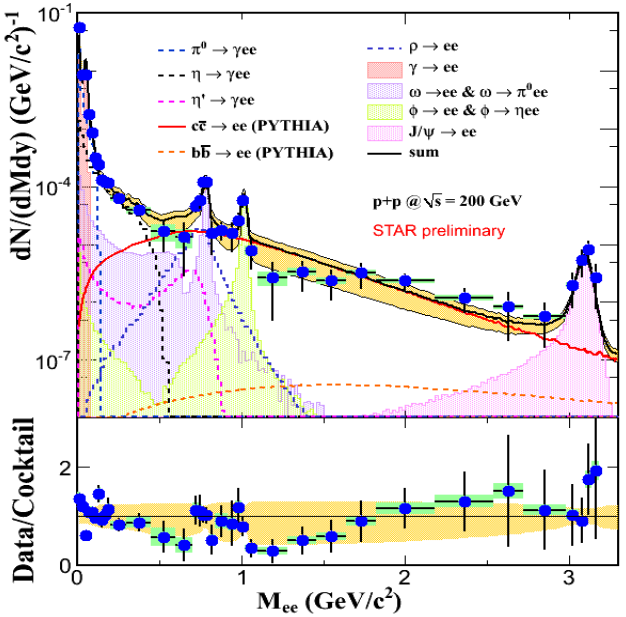
Proof of Principle of exclusive Diffractive in Au+Au

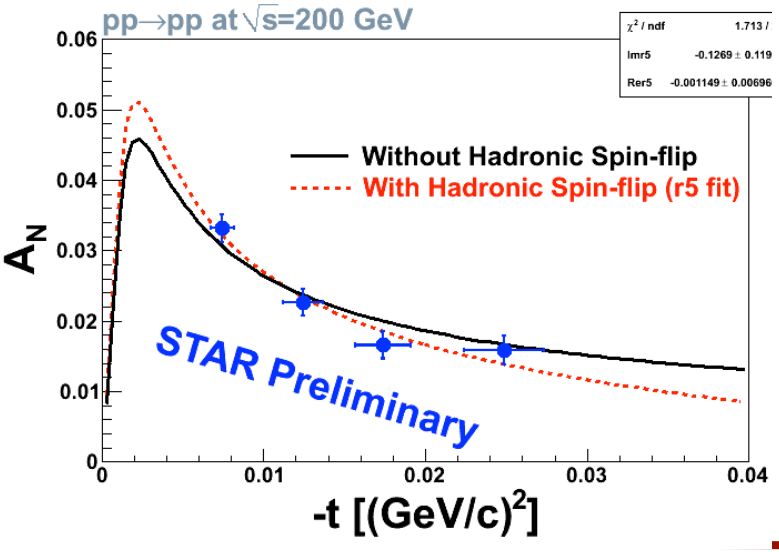


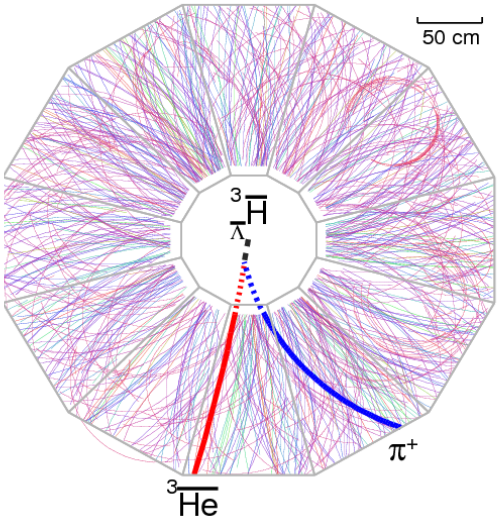


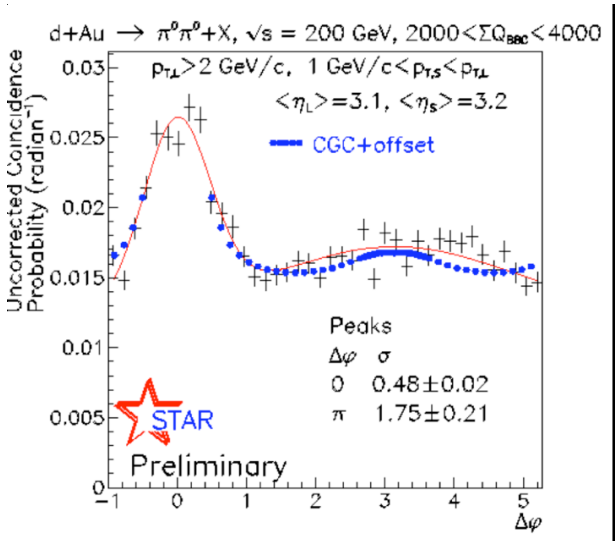
Proven STAR Capabilities







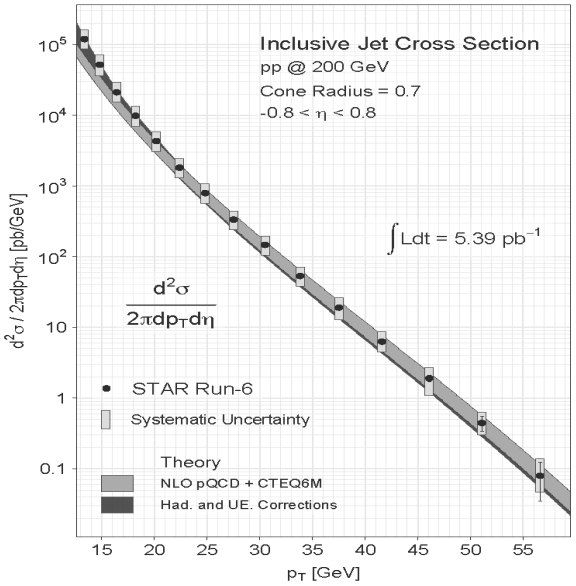


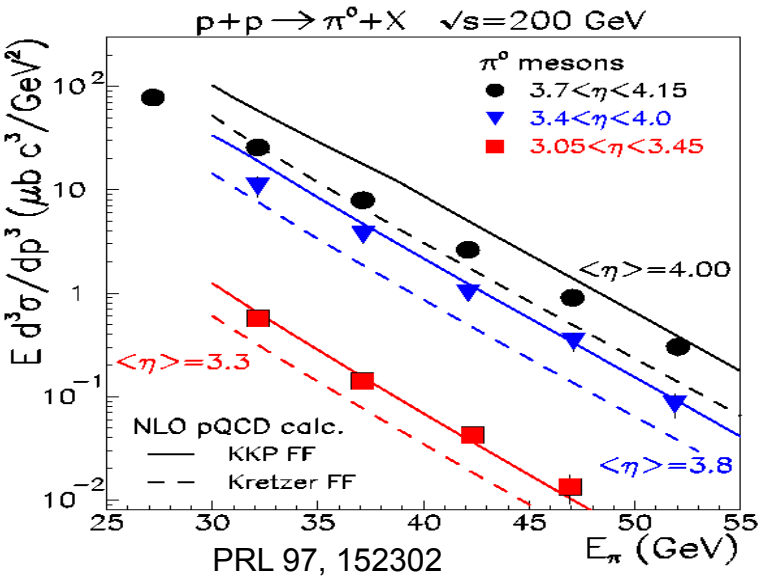


Deliverables with polarized e+p collider

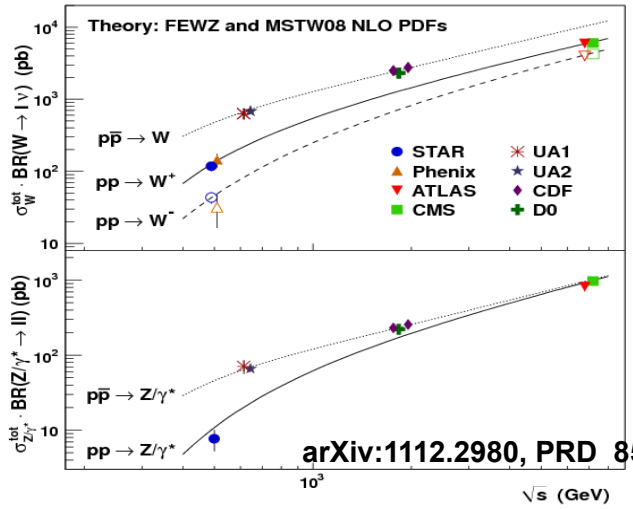
Science Deliverable	Basic Measurement	Uniqueness Feasibility Relevance	M. Stratmann: eRHIC workshop Requirements
spin structure at small x contribution of Δg, $\Delta\Sigma$ to spin sum rule	inclusive DIS	eSTAR ✔	minimal large x,Q^2 coverage about $10fb^{-1}$
full flavor separation in large x,Q^2 range strangeness, $s(x)-\bar{s}(x)$ polarized sea	semi-inclusive DIS	eSTAR ✔	very similar to DIS excellent particle ID improved FFs (Belle,LHC, …)
spatial structure down to small x through TMDs and GPDs	SIDIS azim. asym. & exclusive processes	eSTAR ✔ some results in valence region	p_T^H binning, t resolution, exclusivity, Roman pots, large (x,Q^2) range

Cross Sections in pp compared to pQCD

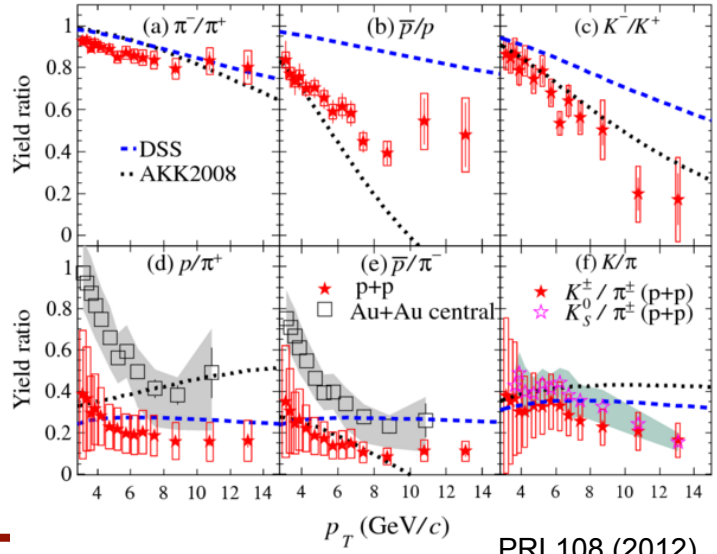




PRL 97, 152302

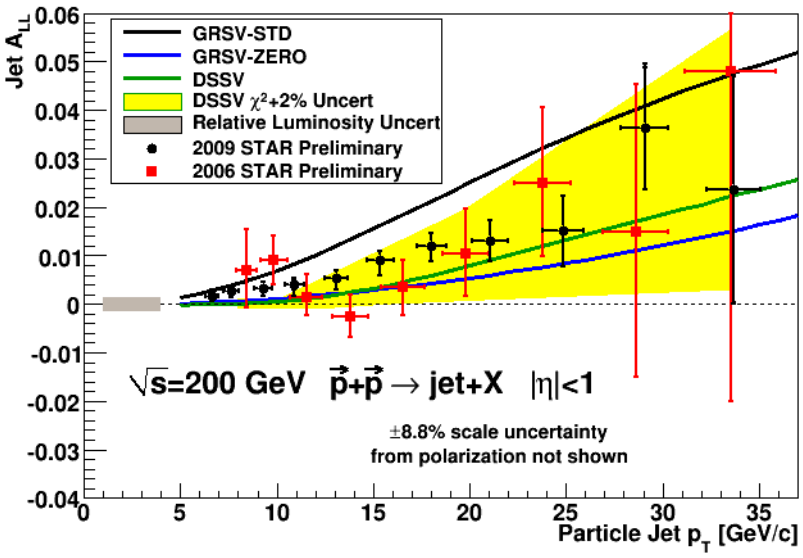


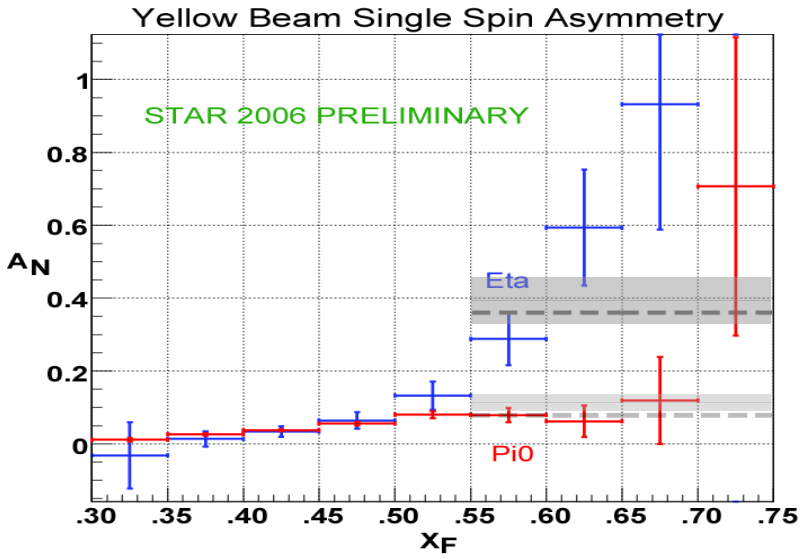
arXiv:1112.2980, PRD 85 (2012)

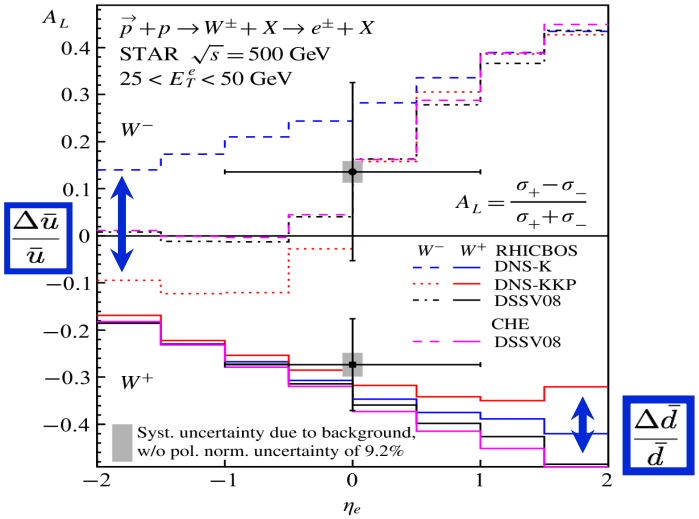


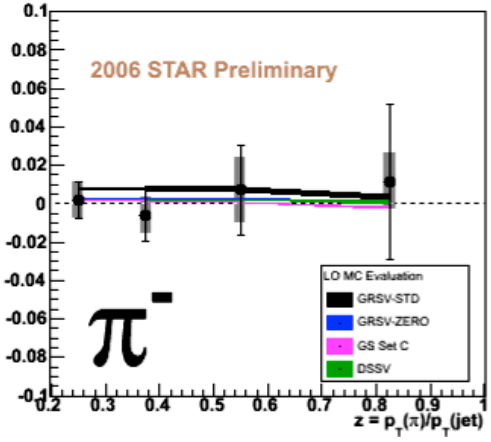
PRL108 (2012)

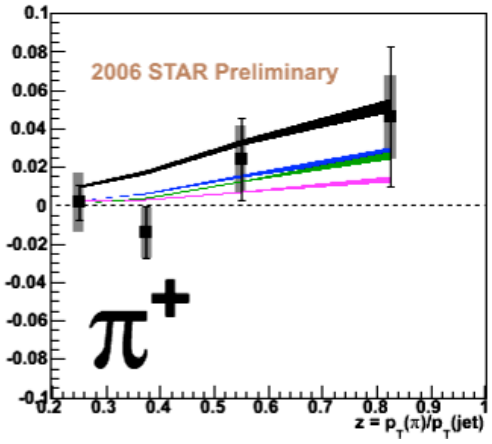
RHIC: the only polarized proton collider!



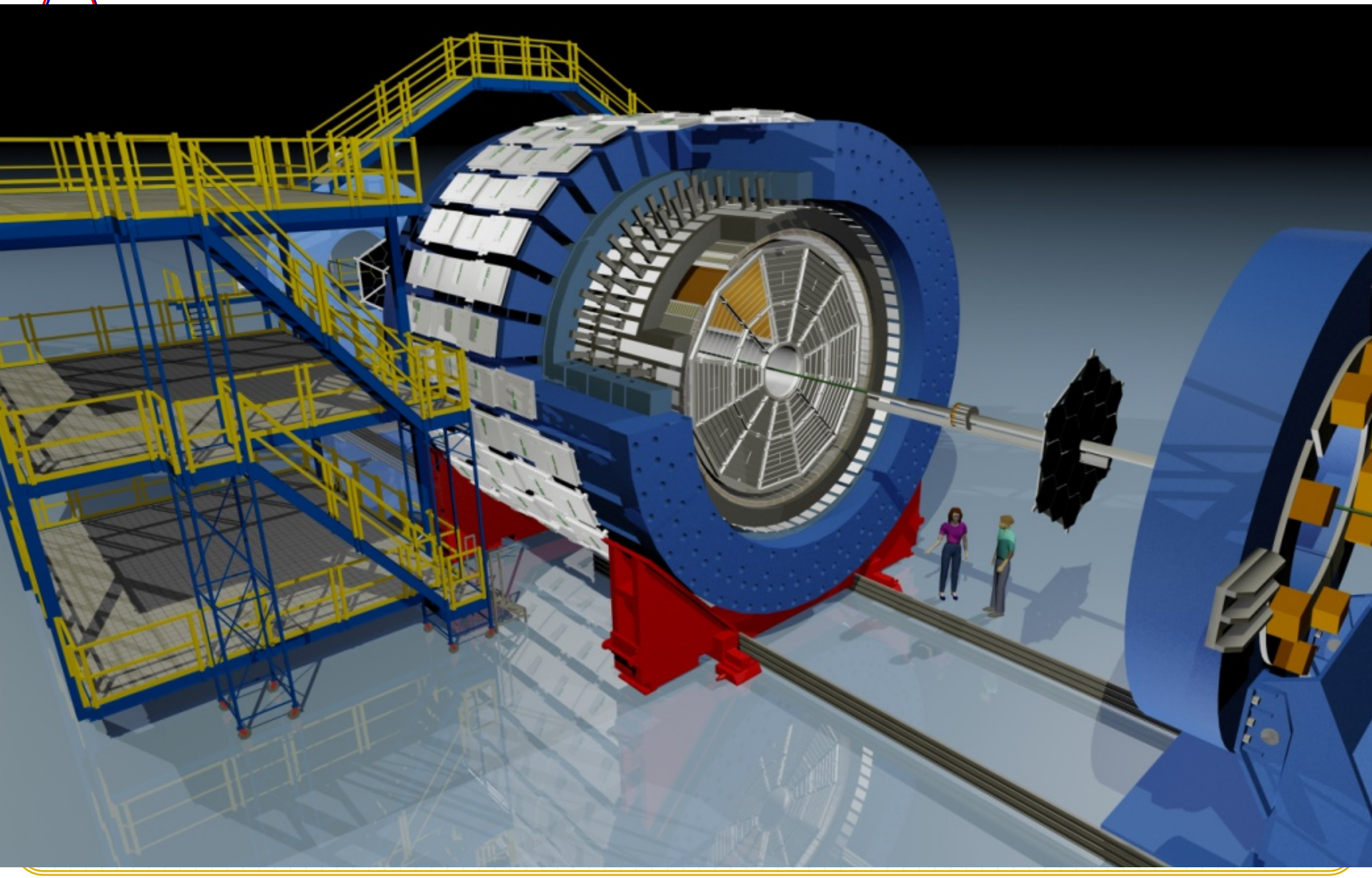








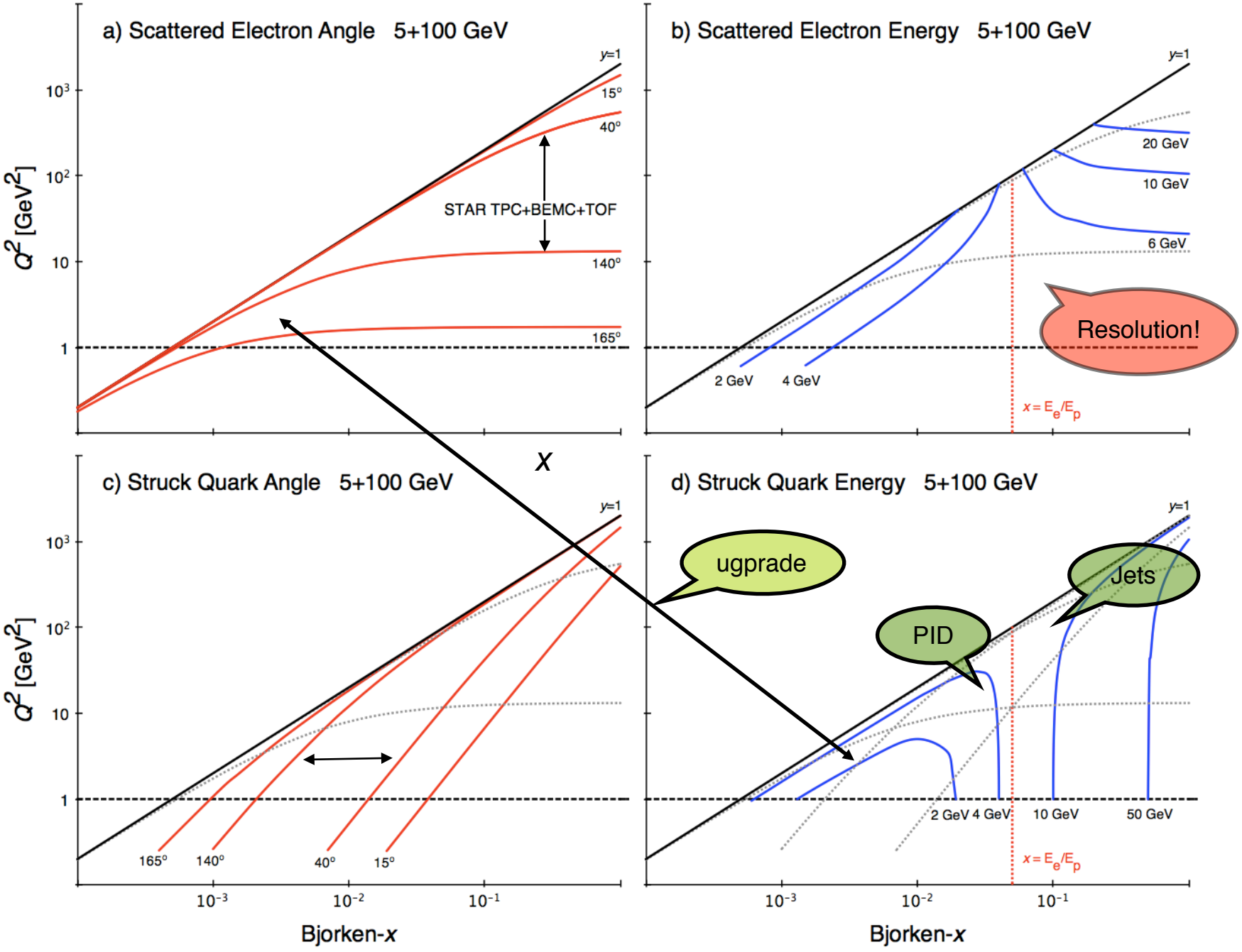
Current STAR Experiment



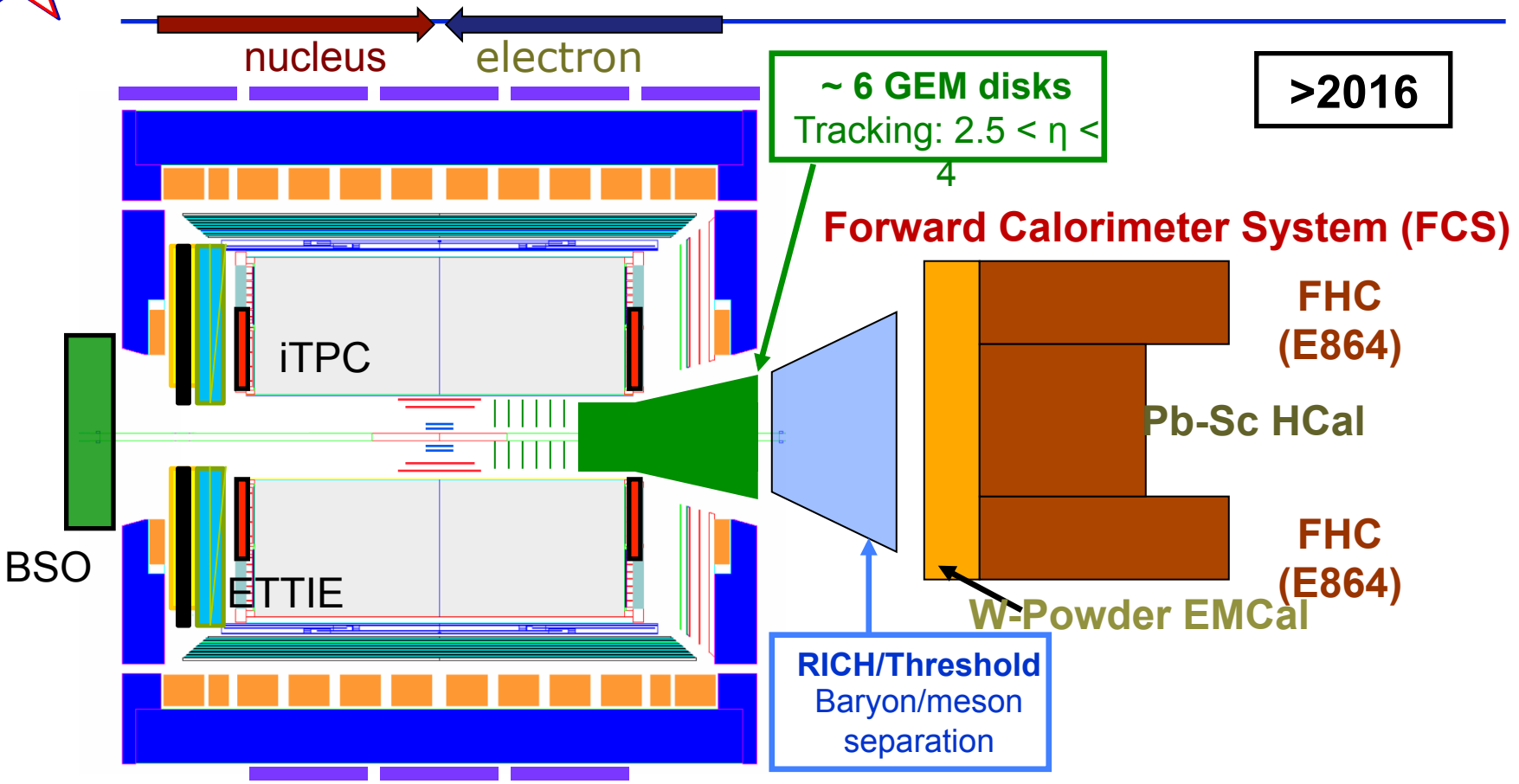
STAR Concept

- Large Coverage
- Low Material
- Electron and hadron ID with gas detector and TOF, EMC
- Extend this concept to hadron direction
  - GEM tracker (VFGT)
  - Hadron PID?
  - Forward Calorimetry
- Extend this concept to electron direction
  - Reinstrument inner TPC
  - TRD+TOF

DIS – eSTAR Kinematics



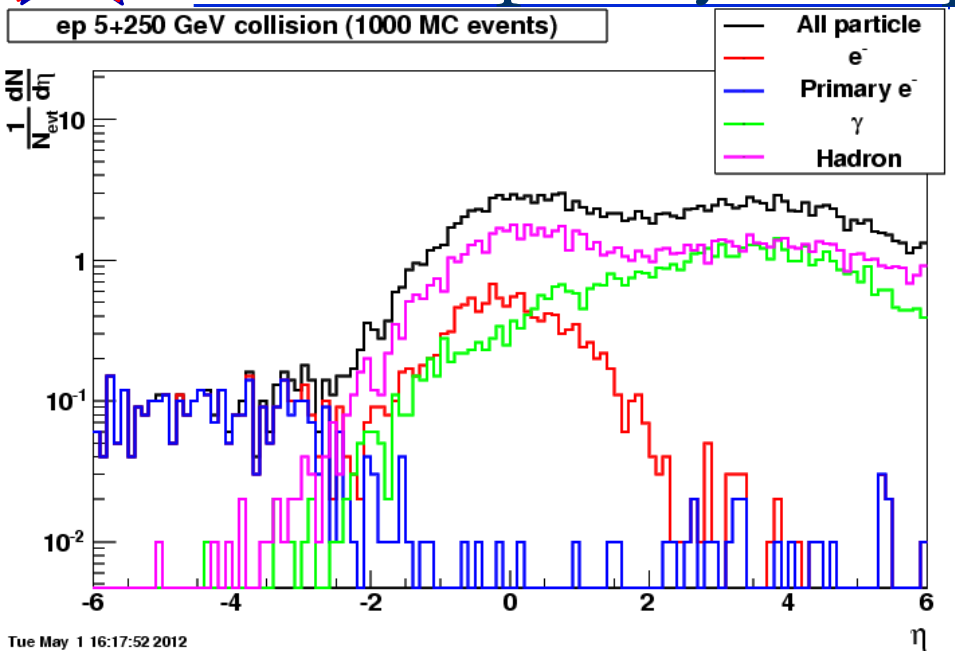
STAR forward instrumentation upgrade

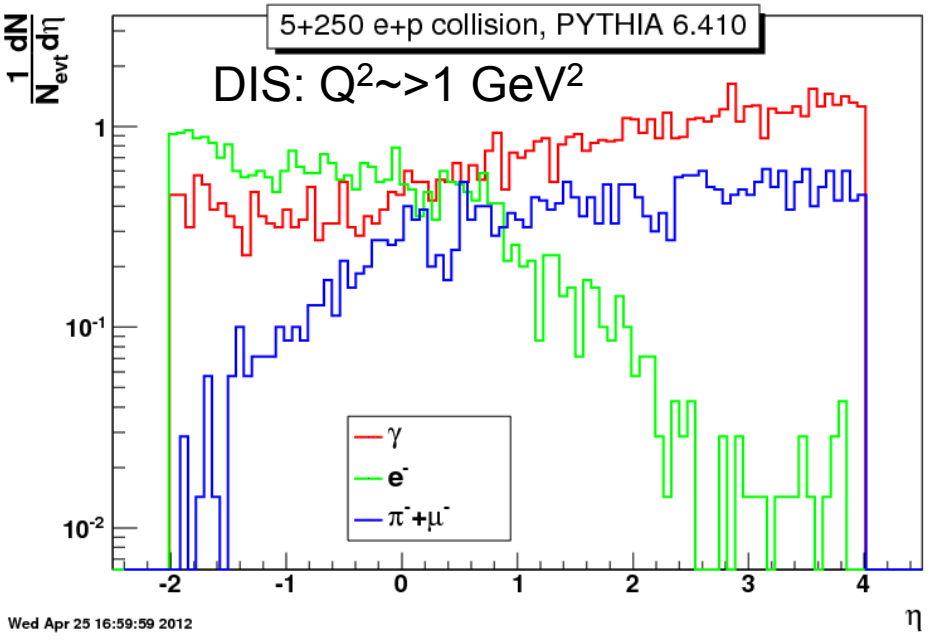


eSTAR specific upgrades:
ETOF: e, π, K identification,
ETRD: electron ID and hadron tracking
BSO: 5 GeV, 10 GeV, ...
electron beams
Re-instrument HFT

- **Forward instrumentation optimized for p+A and transverse spin physics**
  - **Charged-particle tracking**
  - ***e/h* and γ/π⁰ discrimination**
  - **Baryon/meson separation**

Occupancy and pile-up ii)

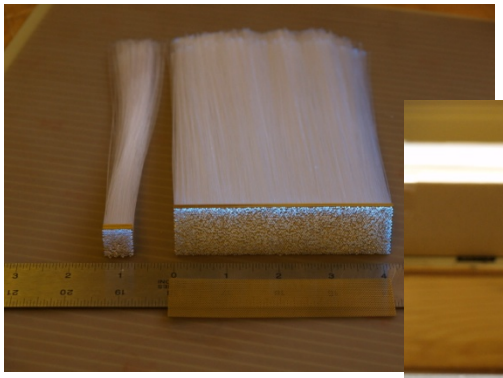


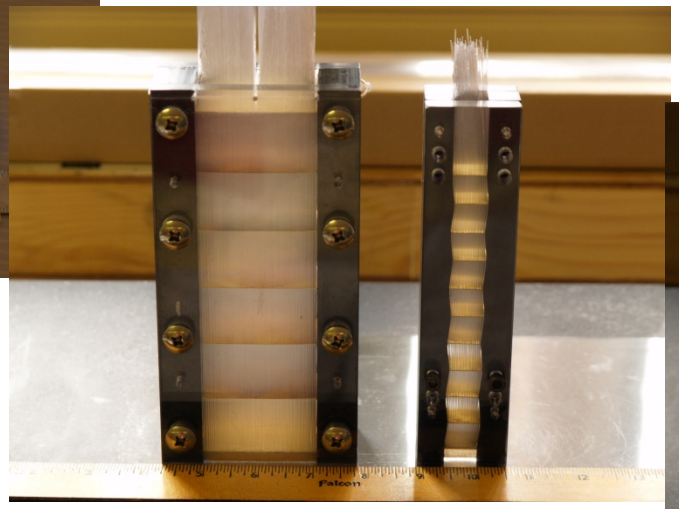


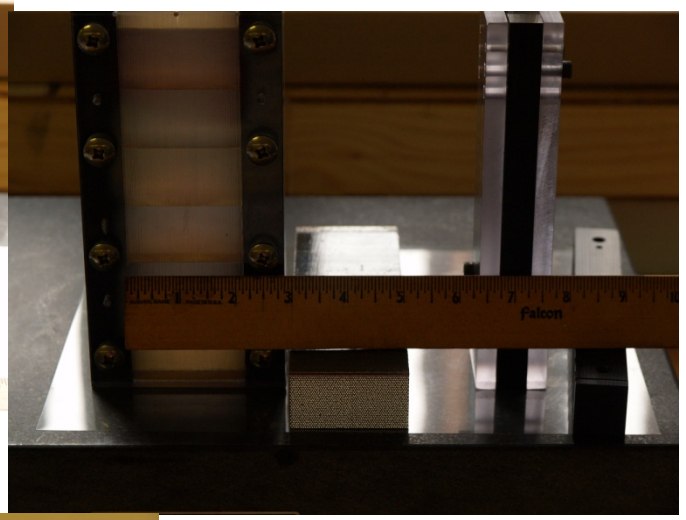
QED α=1/137 and low multiplicity ➔ an order of magnitude lower pile-up than RHIC

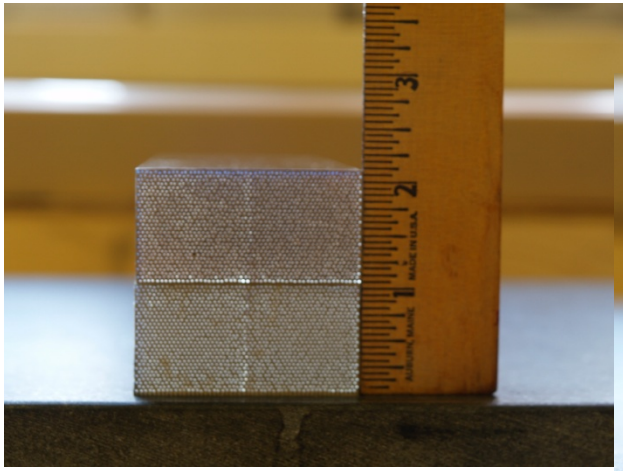
Beam species	Sqrt(s)	Peak Luminosity ($cm^{-2}s^{-1}$)	Cross section (cm^2)	Nch/dη	**Track density (dNch/dη MHz)**	Hit density impact hit finding	Space charge impact tracking
e+p	5x250	10^{34}	10^{-28}	0.7	**0.7**		
Au+Au	100x100	$5x10^{27}$	$7x10^{-24}$	161	**6**	Minor	Corrected to good precision
p+p	100x100	$5x10^{31}$	$3x10^{-26}$	2	**3**	Minor	Corrected to good precision
p+p	250x250	$1.5x10^{32}$	$4x10^{-26}$	3	**18**	Significant for inner	Corrected to acceptable

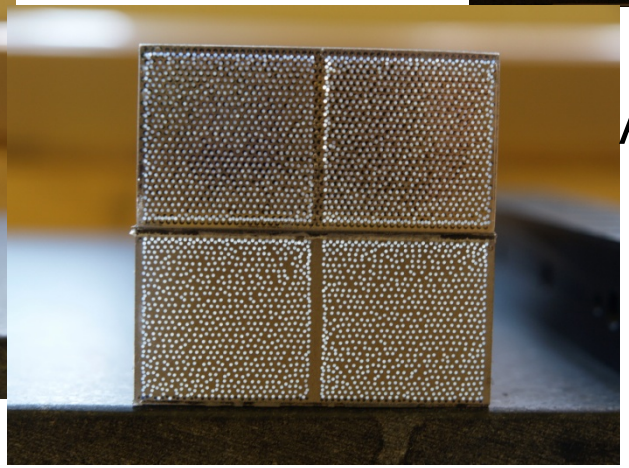
Spaghetti Tungsten powder with fibers











Approved EIC R&D project
from May 2011,
UCLA, TAMU, PSU

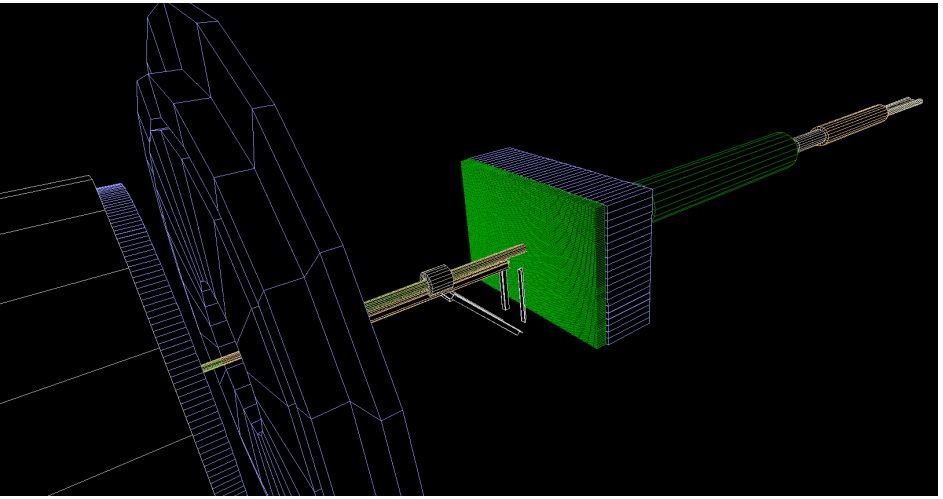
Calorimeter Test Beam and Simulations

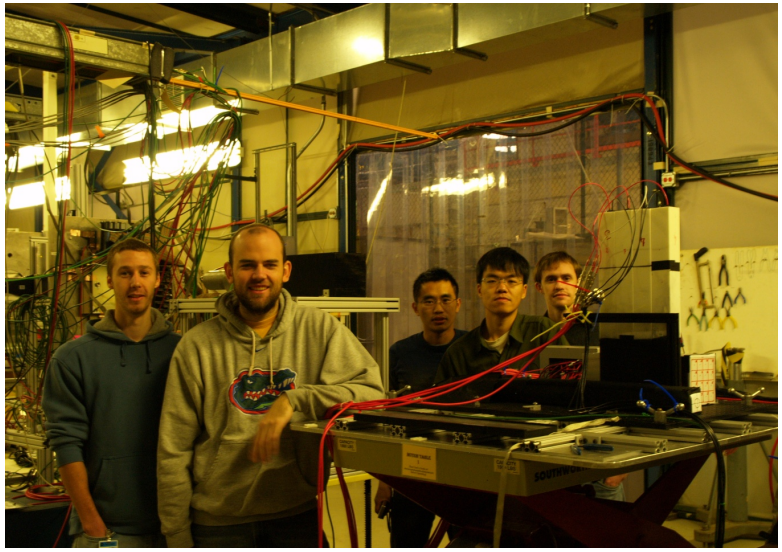
T1018

Jan.30, 2012

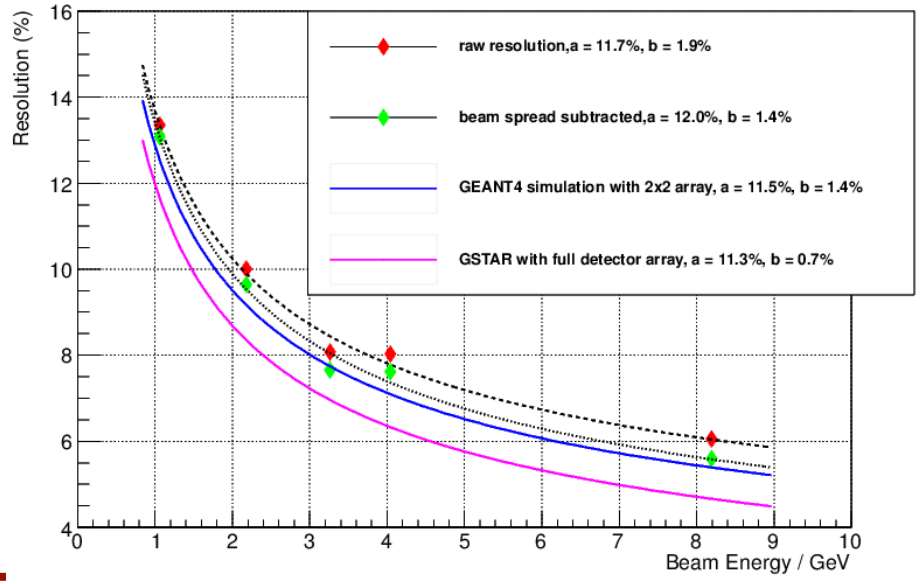
Very successful Run

Got "proof-of-principle"





SPACAL resolutions, averaged over 4 Channels, $\sigma_E / E = (a/\sqrt{E})+b$

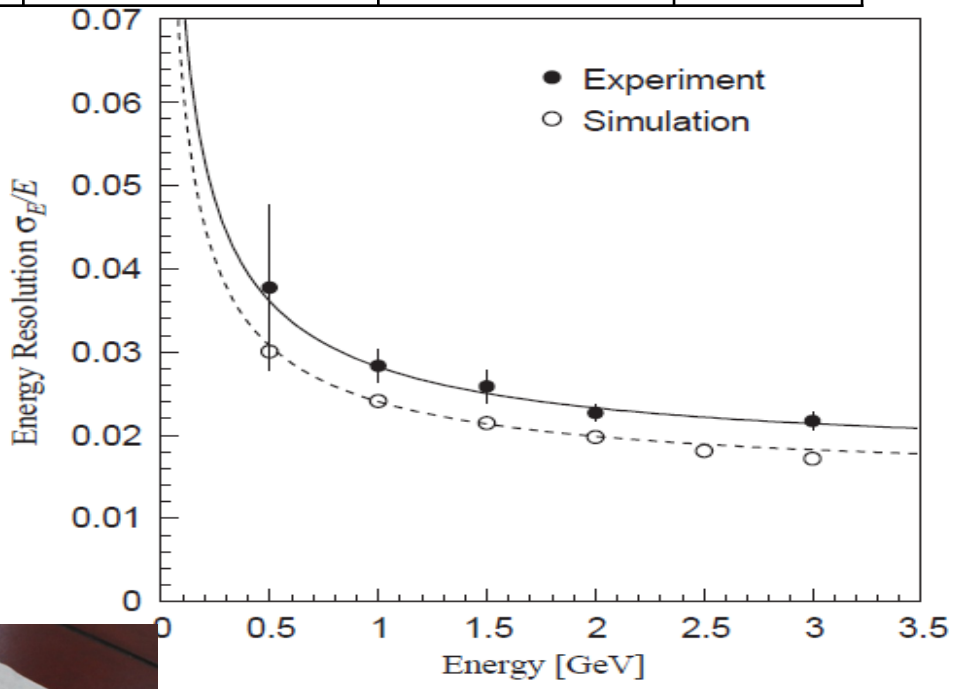


L. Dunkelberger, H.Z. Huang, G. Igo, K. Landry, Y.Pan, S.Trentalange, O.Tsai, W. Xu
Q.Zhang (UCLA)
C. Gagliarddi (Texas A&M)
C.Dilks, S.Heppelman (Penn State)

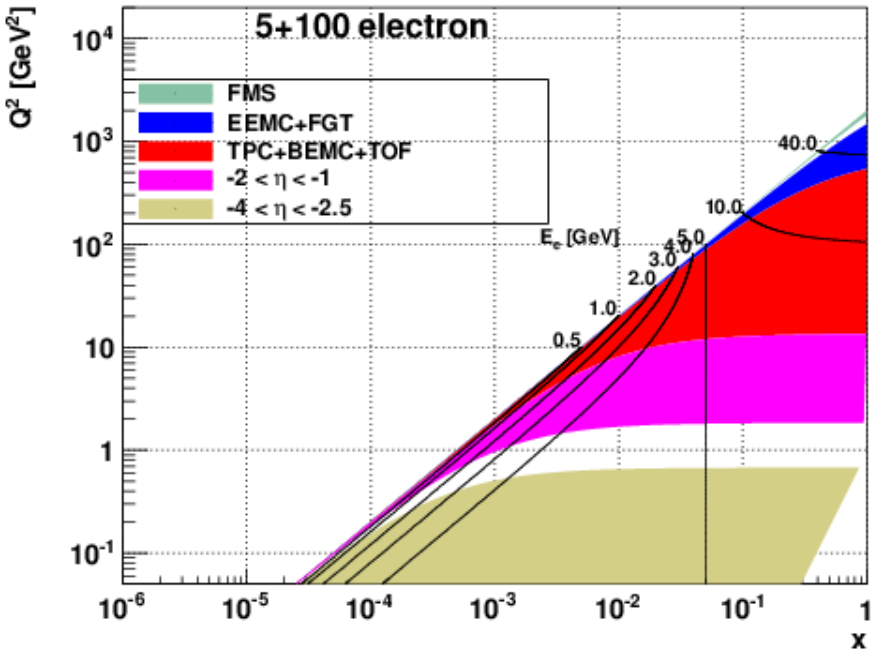
Crystal Calorimeter (BSO)

Crystal	Density (g cm^{-3})	Rad. length (mm)	Decay time (ns)	Peak emission (nm)	Relative light output	Price ($/ cc)
BSO	6.80	11.5	~ 100	480	0.04	13-18
BGO	7.13	11.2	~ 300	480	0.10 – 0.21	> 40
PWO	8.28	8.9	~ 10-30	410 - 450	0.003	10-13

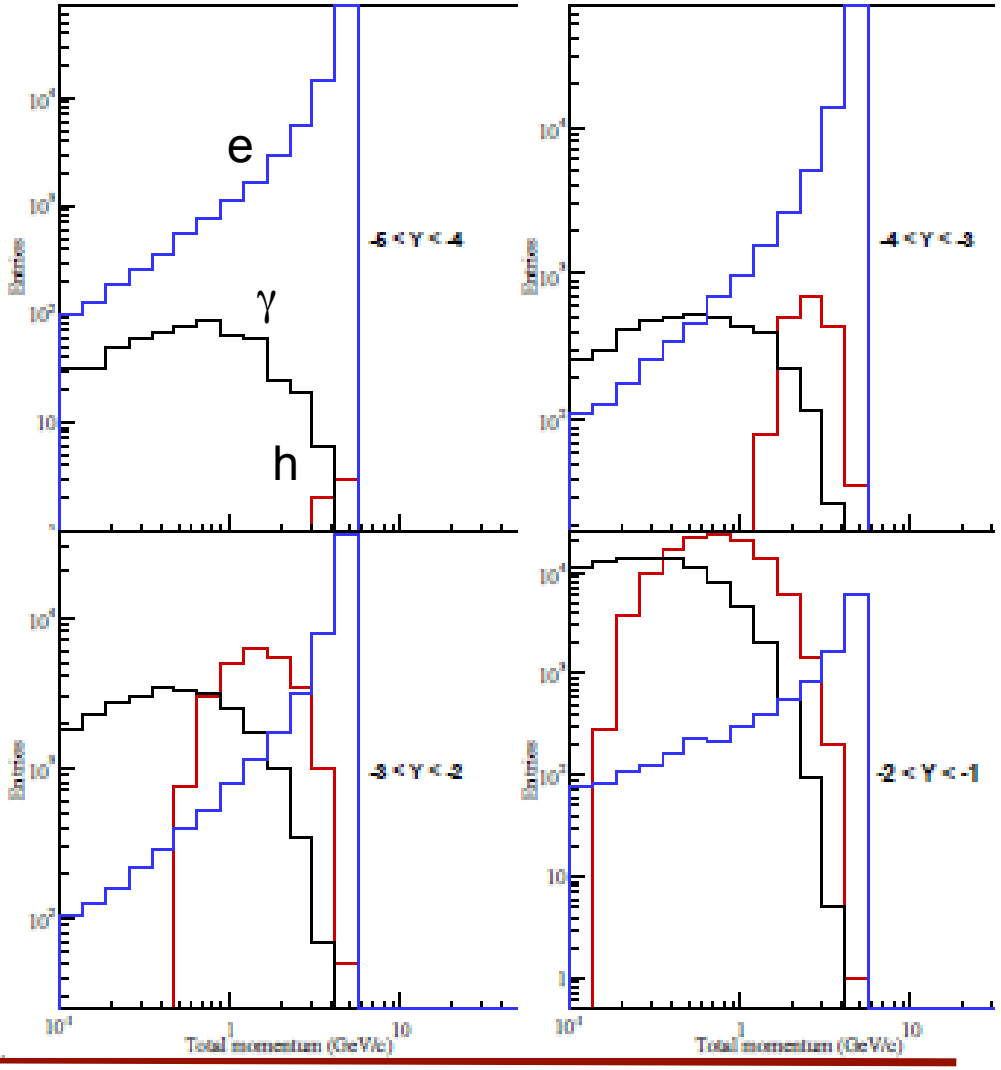
- **Very Forward Electron Detection (eta<-2.5)**
- BSO is produced by replacing Ge in BGO with Si, the material cost for BSO reduced by x3-4.
- Collaborators: USTC,SINAP,THU
- Vendor: Shanghai SICCAS High Technology Coorporation
- **R&D proposal partially funded by BNL/ DOE**



First Stage eRHIC electron/hadron PID

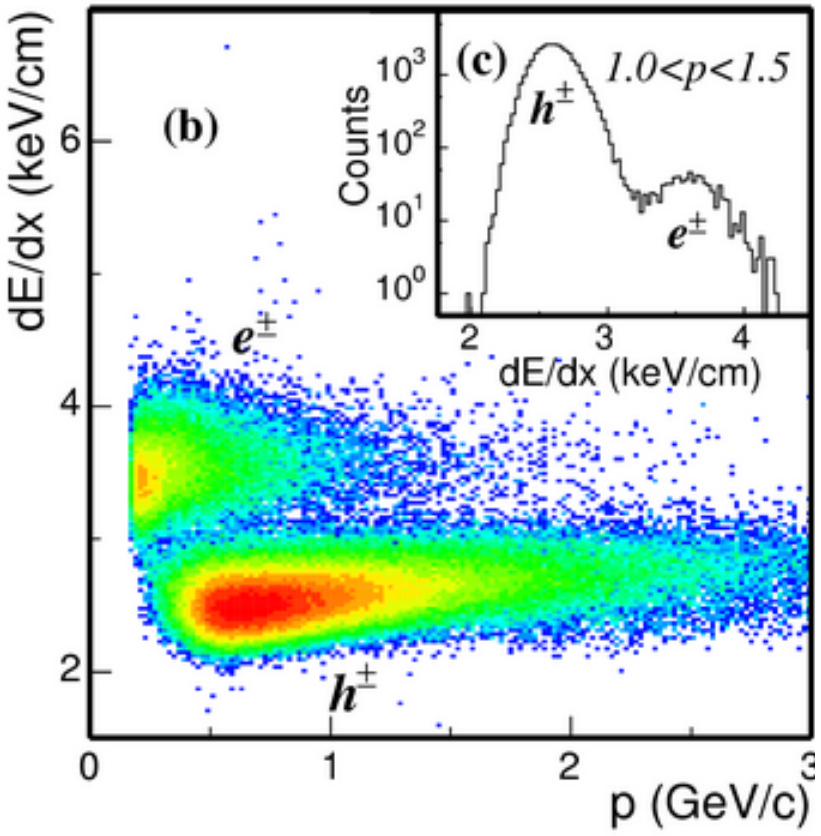


INT report (arXiv:1108.1713) Fig.7.18.



Electron coverage: 1>eta>-2.5
PID e/h: 1000
Low material: photon conversion

Midrapidity electron PID (TOF)



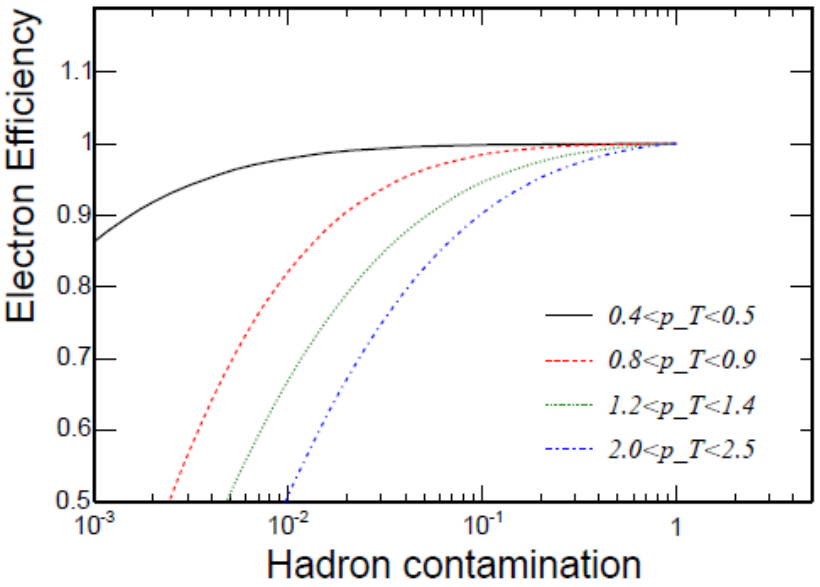
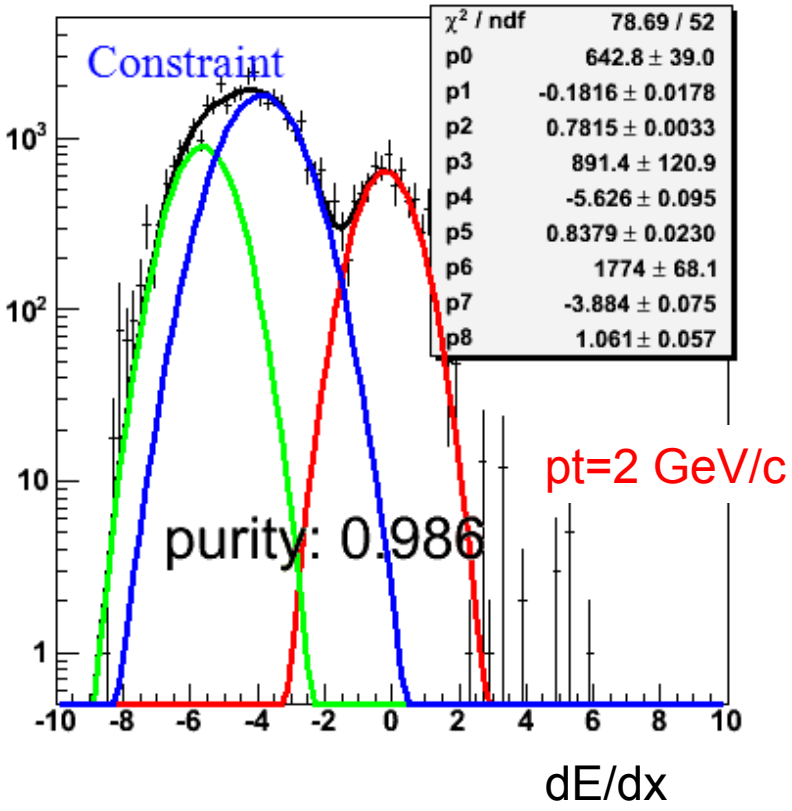


Figure 3.5: Electron efficiency vs. hadron contamination fraction by varying the dE/dx cut to selection electrons for 4 p_T bins.

Midrapidity electron PID (EMC)



Higher pT: BEMC increase the hadron rejection 10—100

All together: 10^3—10^4 hadron rejection

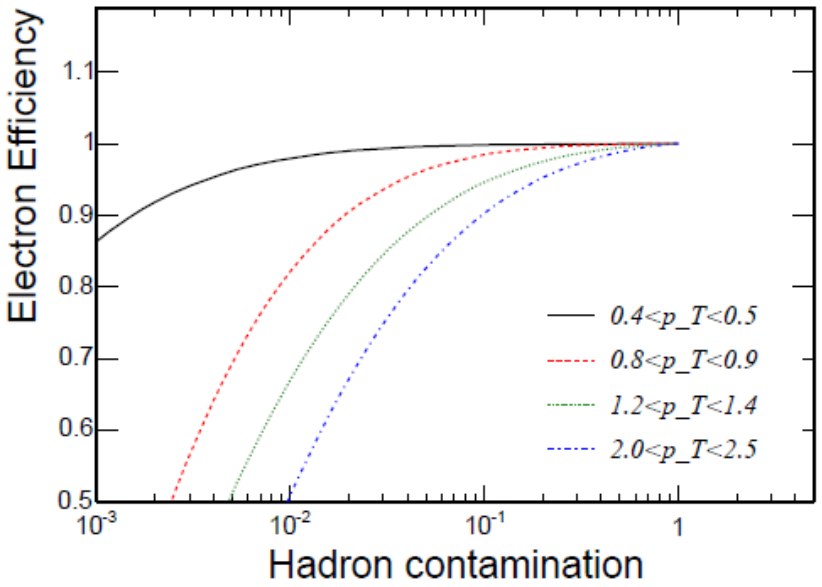
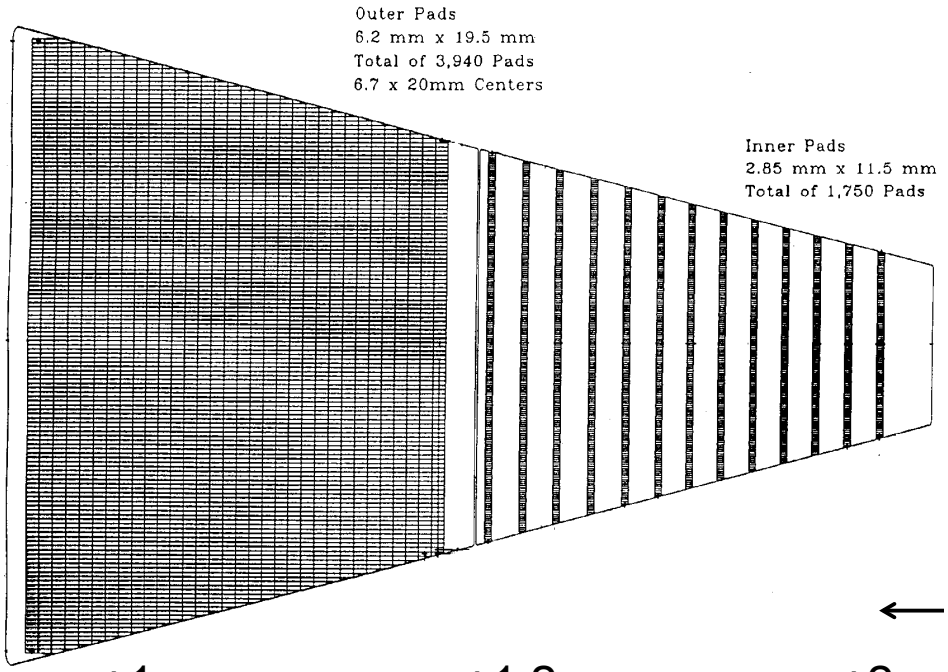
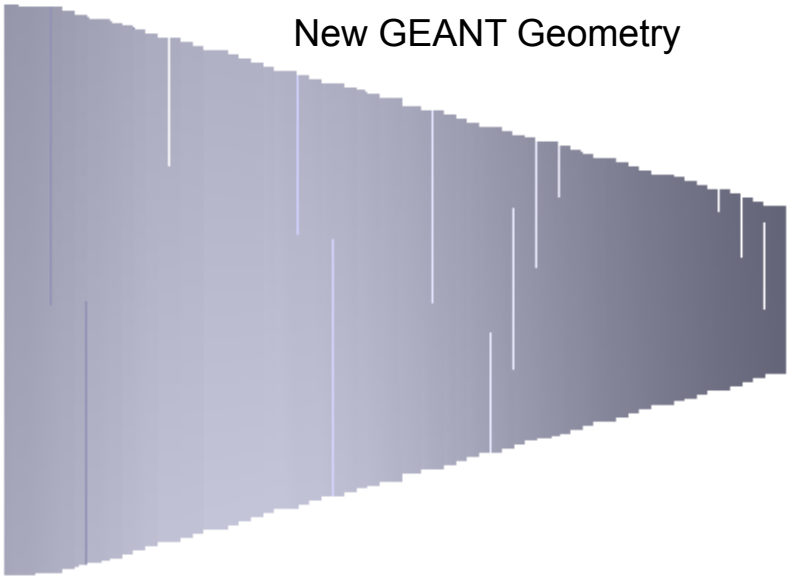


Figure 3.5: Electron efficiency vs. hadron contamination fraction by varying the dE/dx cut to selection electrons for 4 p_T bins.

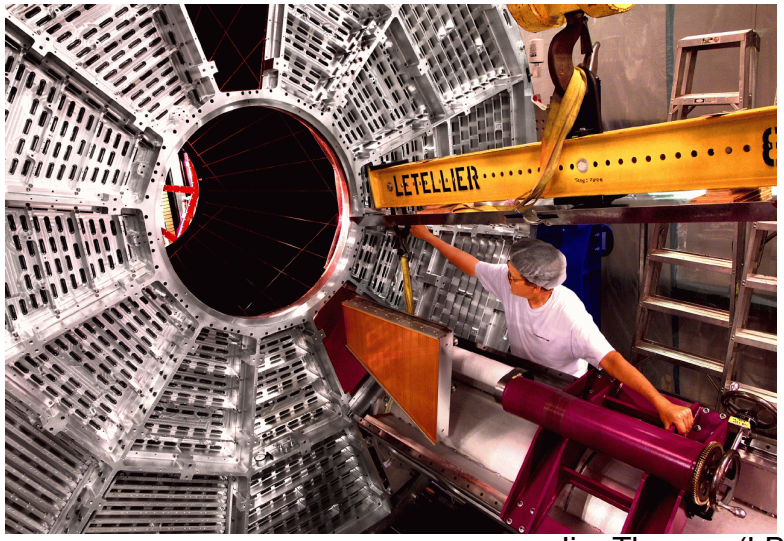
Current Inner Sector Limitations

- Staggered readout
  - Only 13 maximum possible points
    - Issues in Tracking: recognition and resolution
  - Only reads ~20% of possible gas path length
    - Inner sectors essentially not used in dE/dx
- Essentially limits TPC effective acceptance to |η|<1





Sector Replacement is possible but not Trivial



Jim Thomas (LBL)

Physics and Instrumentation R&D

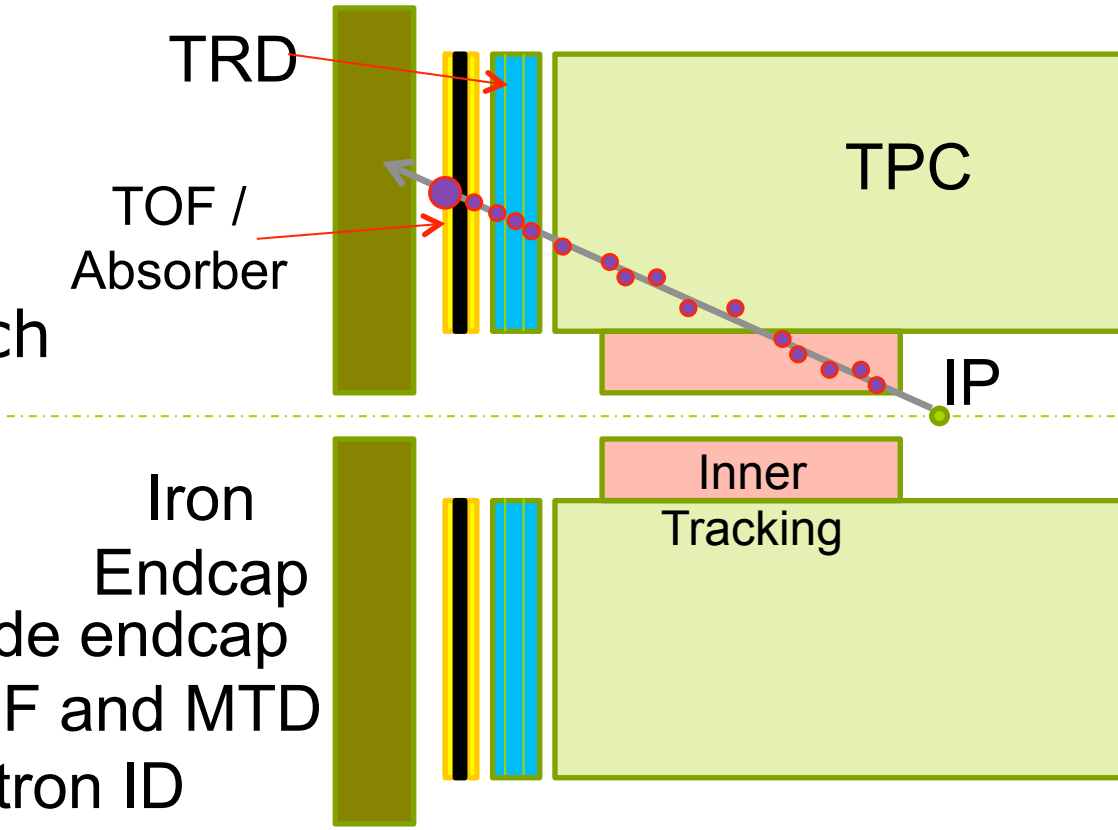
- Optimize number of rows to match available funds & Eng. factors
- Optimize pad size for greatest physics return
- Join existing R&D efforts for PASA and Altro chips

Technical Challenges (R&D by another name)

- Pad plane design – traces & connector technology, alignment
- Winding large wire planes … an art rather than a science
- Factory – assembly line, QA and efficiency

TRD+TOF at Endcap (-2<η<-1)

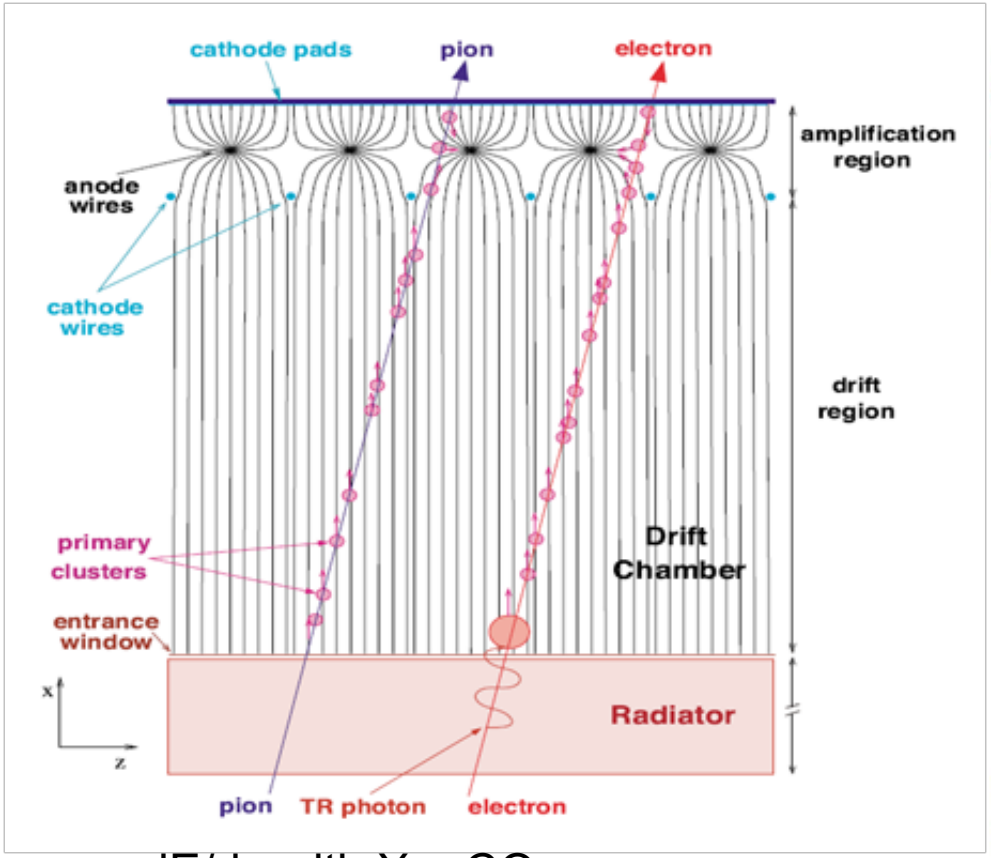
- Inner tracking
- TPC (endcap region): TRD + TOF/Absorber sandwich

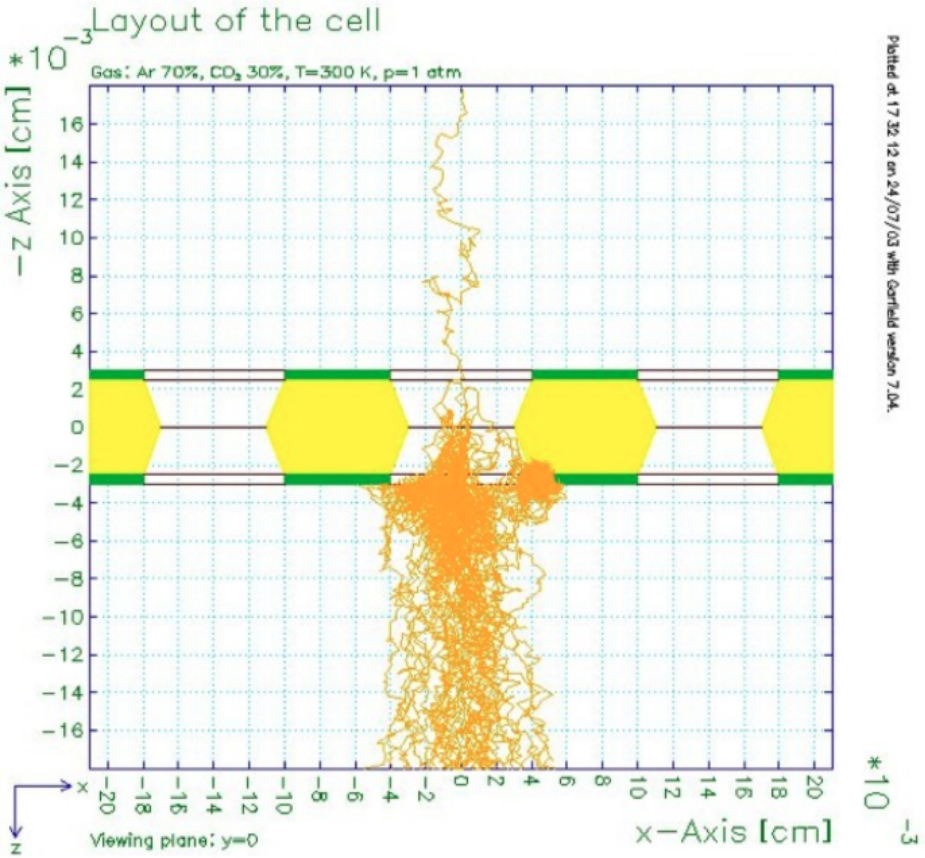


- Within <70cm space inside endcap
- TOF as start-time for BTOF and MTD
- TOF + dE/dx for electron ID
- TOF for hadron PID
- Extend track pathlength with precise points
- High-precision dE/dx (Xe+CO2) TRD

Ming Shao (USTC)

R&D on GEM based TRD



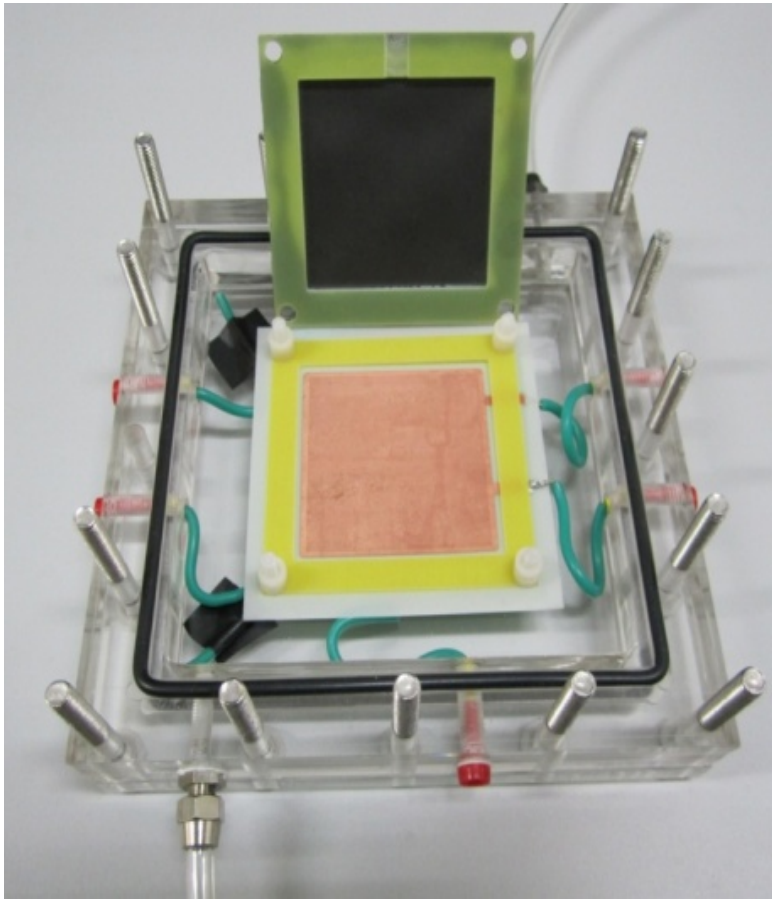


dE/dx with $Xe+CO_2$
position resolution
TRD gain

Collaboration: VECC/India, USTC/China, BNL, Yale et al.
Proposal funded by EIC R&D committee

R&D proposals: http://drupal.star.bnl.gov/STAR/future/estar-task-force

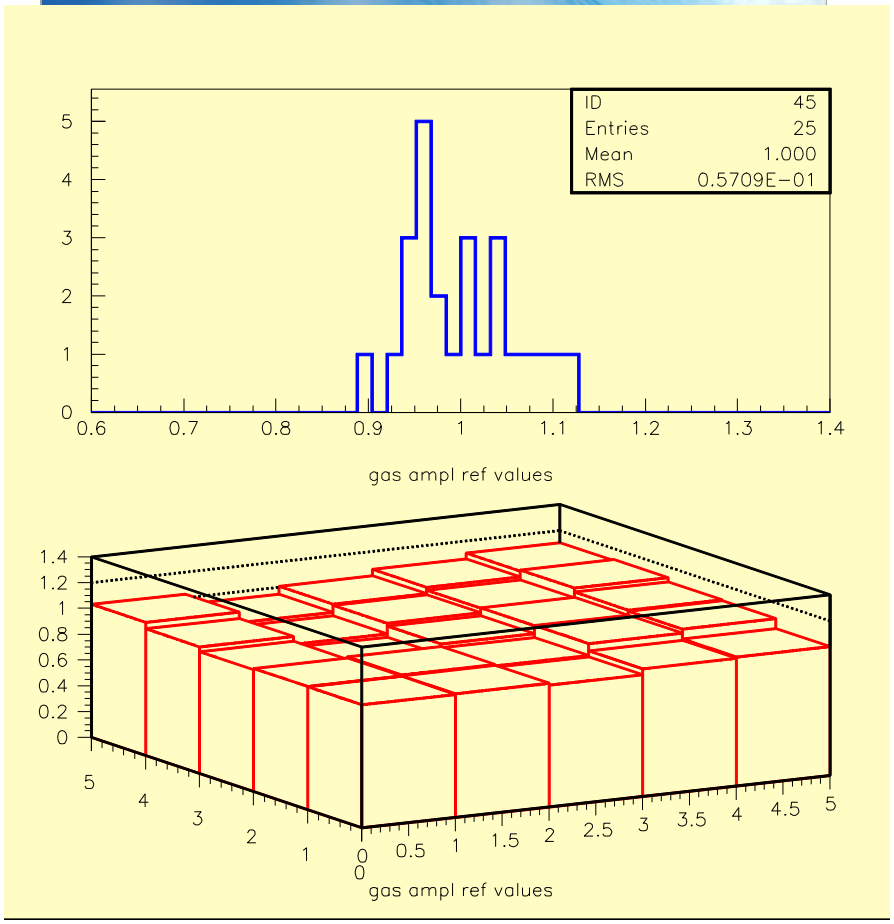
Prototype TGEM Products at IHEP/China



1. Ionization chamber: 6mm
2. Energy Resolution: 16% for ^{55}Fe @ Gain = 3700 Ar/iC_4H_{10}(97/3%)
3. Spatial resolution: 0.25mm

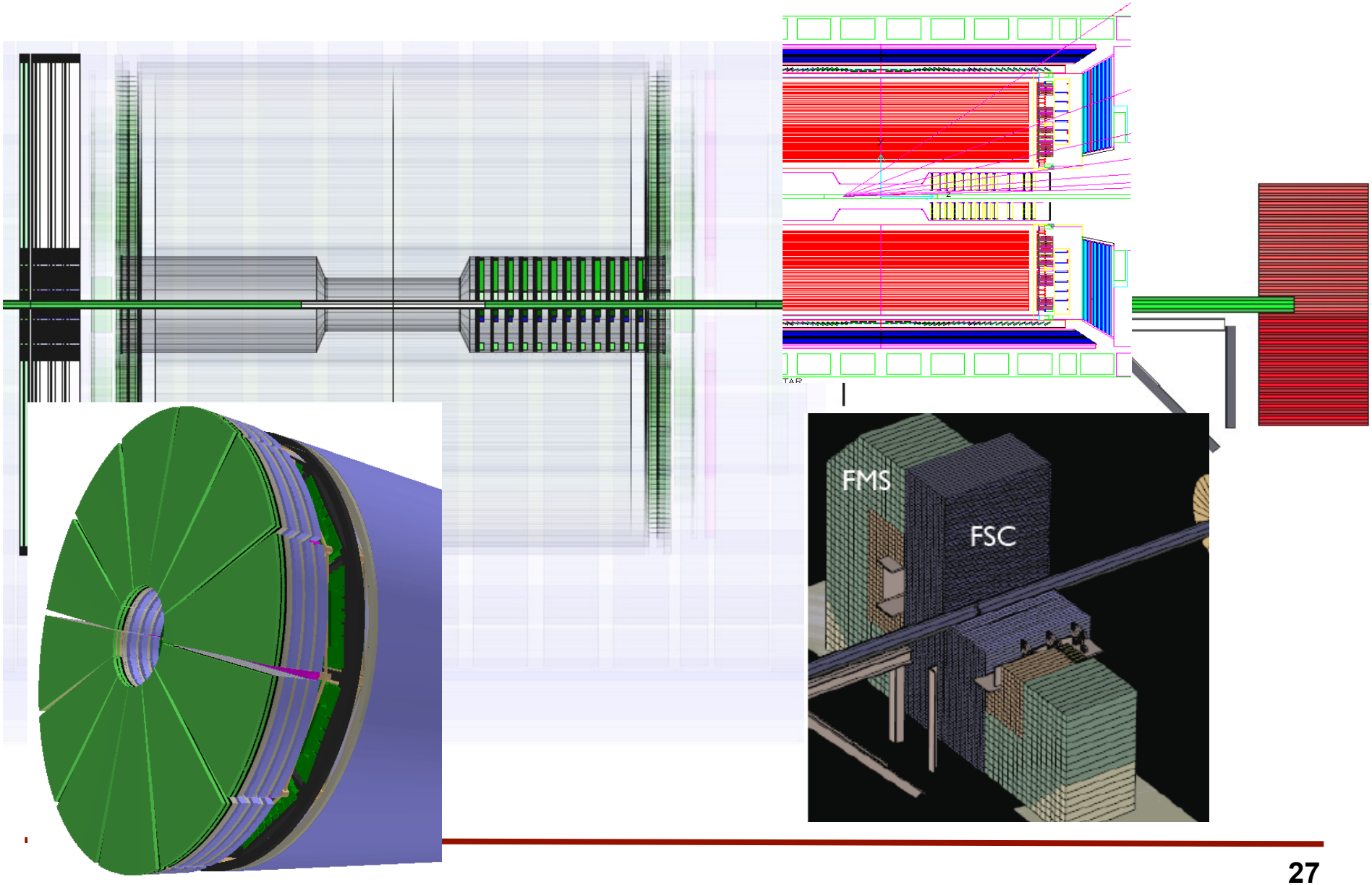
核探测与核电子学国家重点实验室

State Key Laboratory of Particle Detection and Electronics



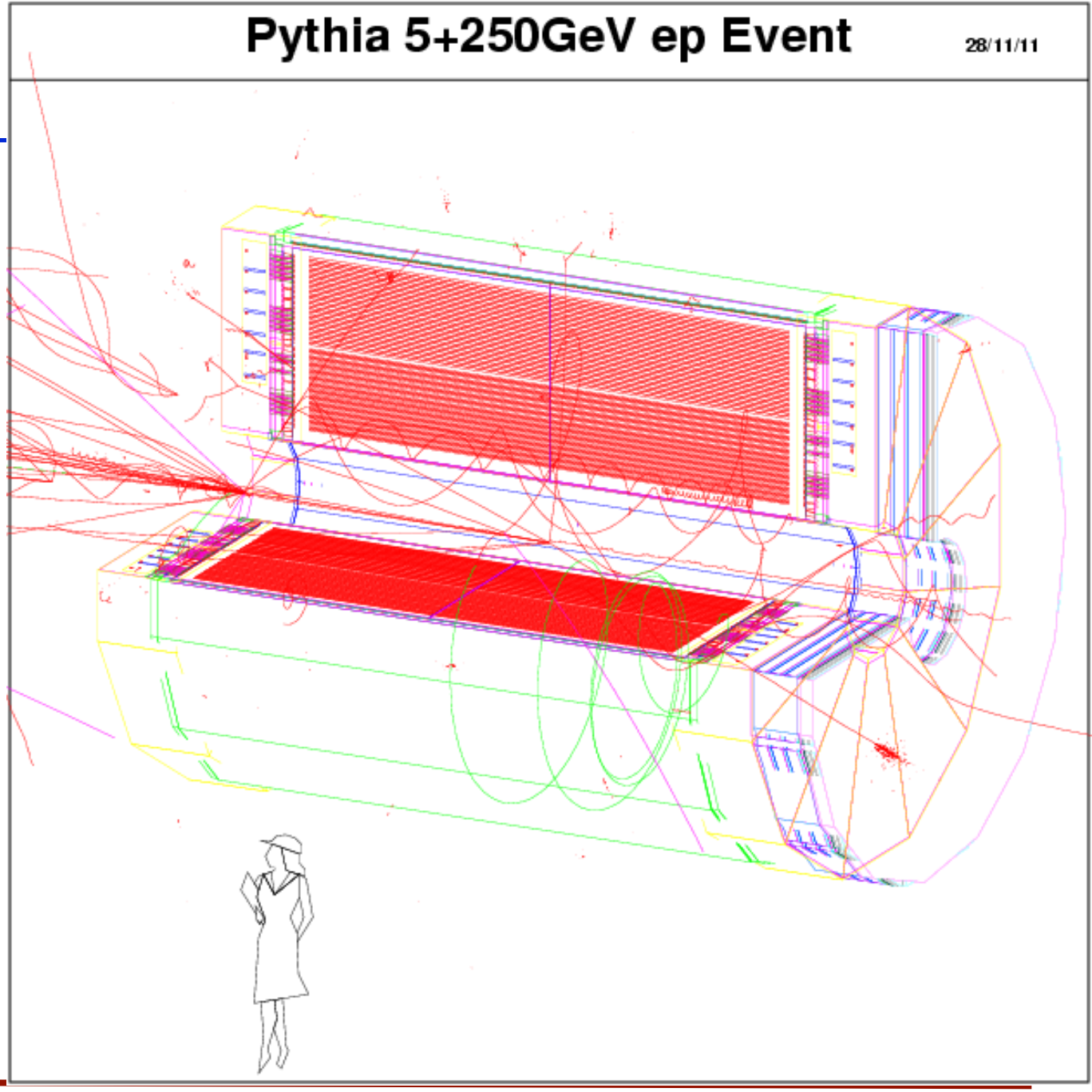
Test performed at Yale

Simulation Geometry

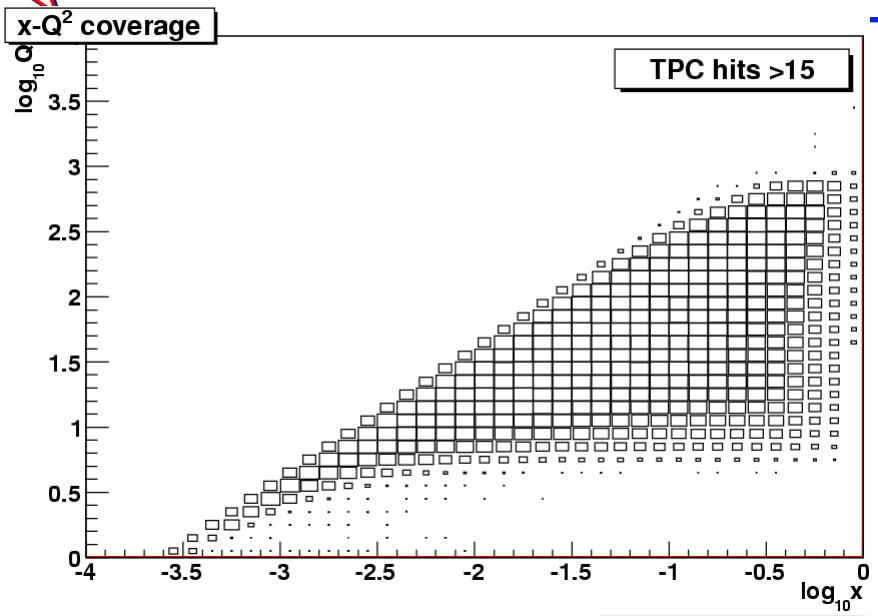


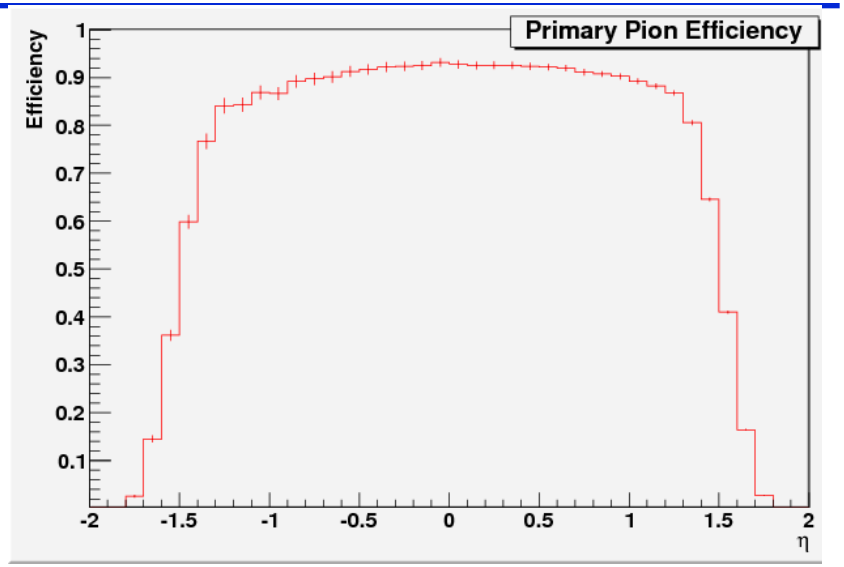
A Pythia Simulation Event

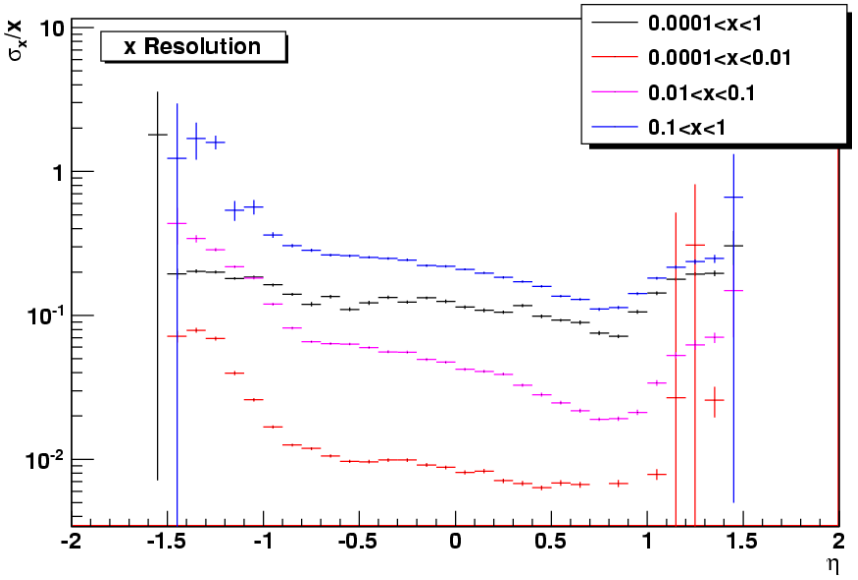
Only TPC and ETTIE are shown

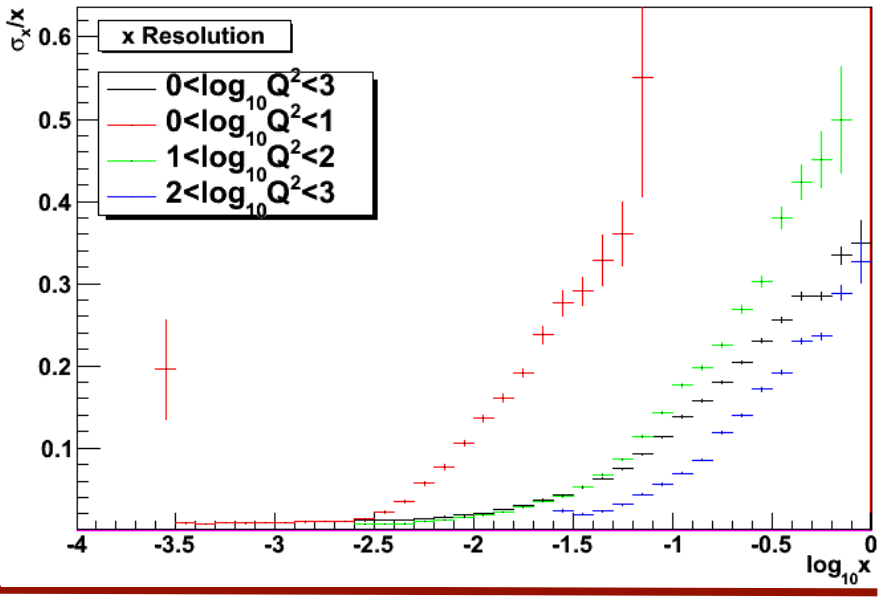


Acceptance and Resolution (first simulation)









Haven't optimized vertex finder (some events without vertex constraint)

Physics Simulations in Progress

5x250 ep collisions:

1. g_1 vs (x,Q^2), generator PEPSI
2. Semi-inclusive with PID: ΔG vs (x, Q^2)

eA (electron+Pb):

1. F_2, F_L 5x50, 5x75, 5x100 (DJANGOH)
2. $d\phi$ of di-hadron for given (x, Q^2) relative to virtual photon direction (as z): PYTHIA
3. Semi-inclusive $R(eA/ep)$ (ν, Q^2, z, p_t) PID (PYTHIA6.x)
4. J/Ψ exclusive (SARTRE)

For event generators, see EIC-TF webpage:
https://wiki.bnl.gov/eic/index.php/Simulations#Event_Generators

Plans

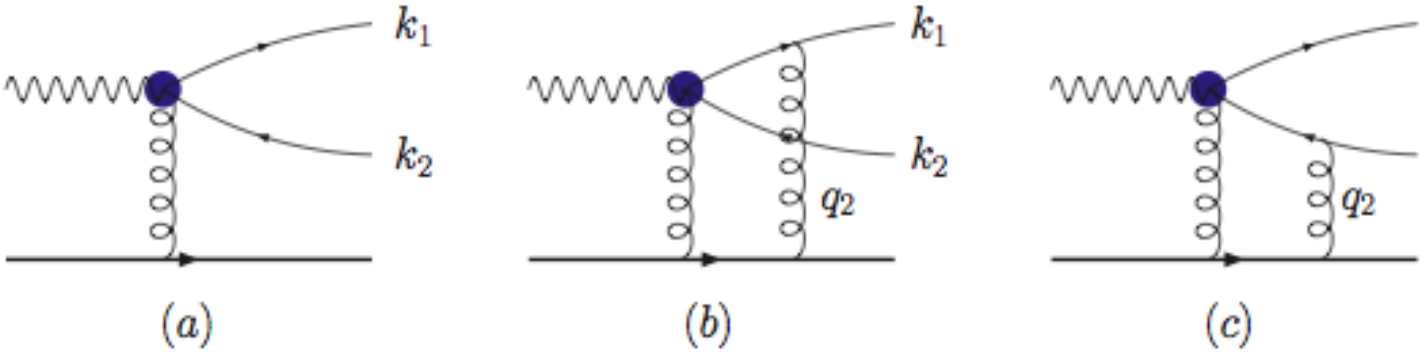
- Continue to sharpen the physics cases
- Possible R&D projects:
  1. Tracking and PID (hadron side)
  2. Calorimetry (hadron side)
  3. Tracking+eID (electron side)
  4. End-Cap TOF (electron side)
  5. Very forward electron ID
  6. Roman Pots (not really R&D, but necessary)
- Simulation of feasibilities
- Update Decadal Plan
- Discuss with CAD and EIC TF on IR design and detector R&D

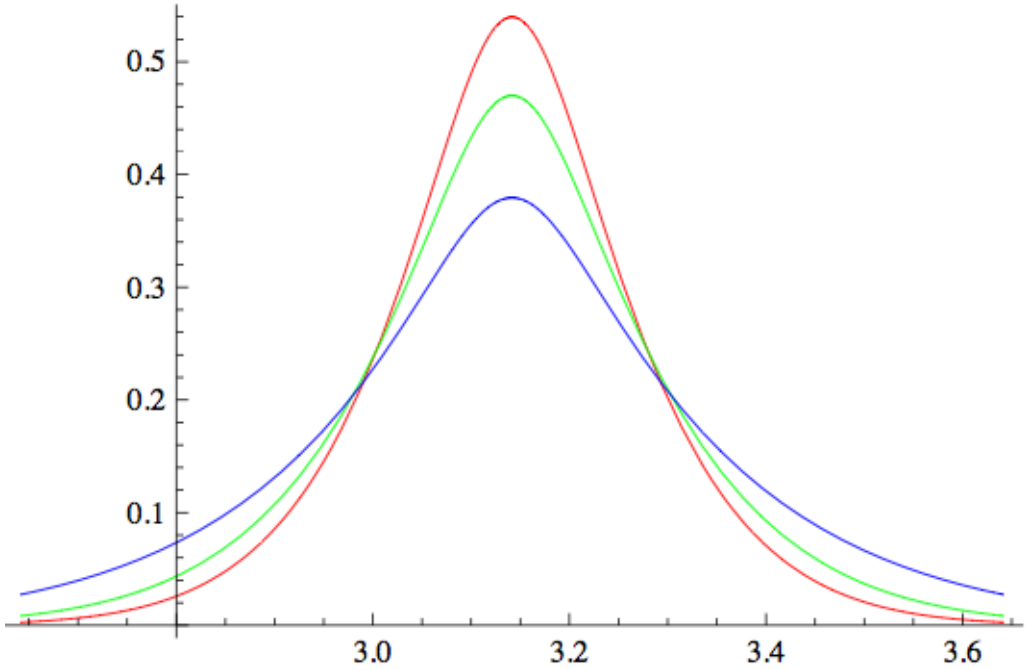
Summary

- eSTAR a possible option for first-stage EIC detector
- Near-term upgrades for RHIC have optimized for eSTAR option as well
- R&D projects and EIC simulation in progress
- STAR Collaboration is committed to the eSTAR path
- Inputs/helps from groups (theorists and experimental colleagues)

Semi-inclusive final state correlation

Dominguez,Xiao,Yuan (2010)



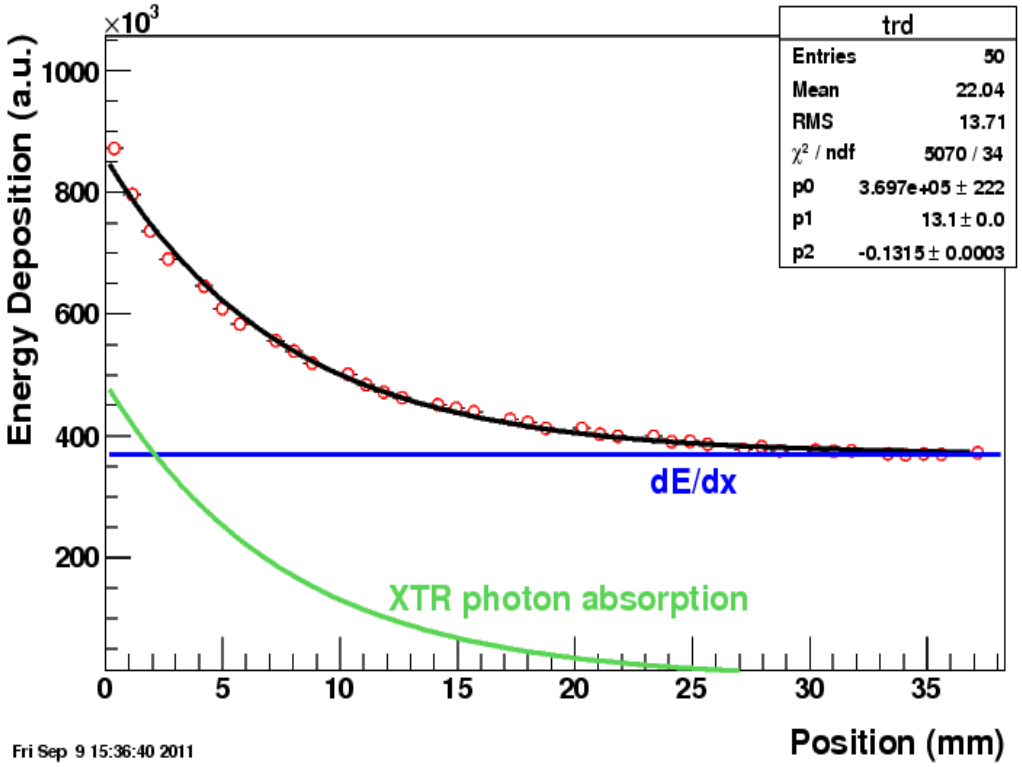


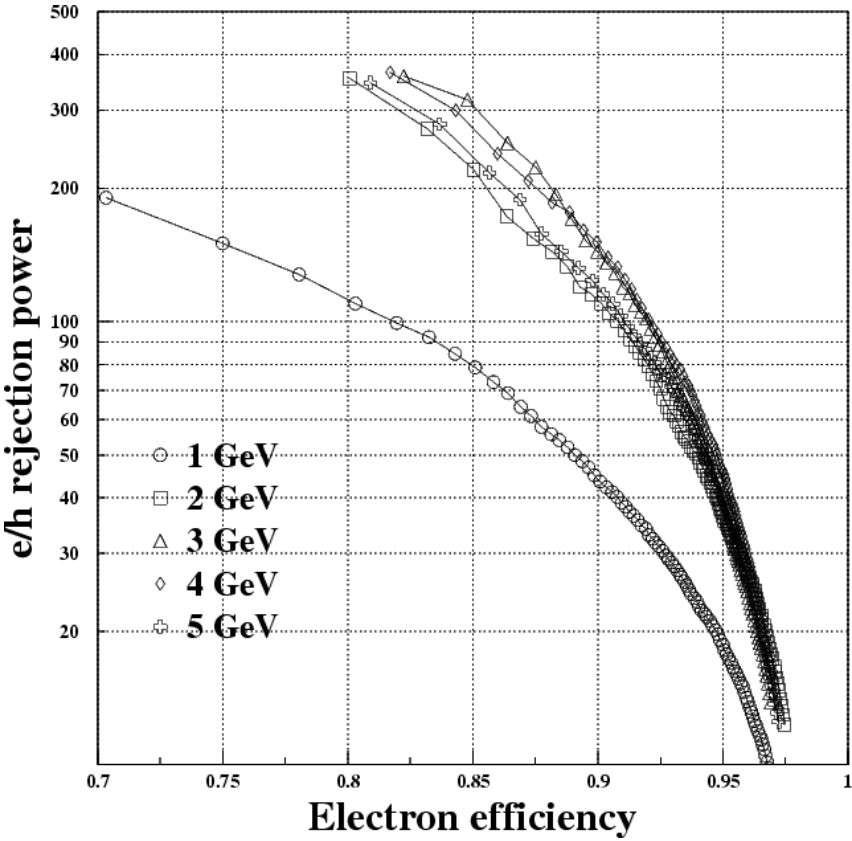
Raju Venugopalan, eRHIC workshop

Systematic depletion of away-side peak seen with increasing nuclear size/energy

No pedestal effect here!

Additional dE/dx and tracklet





dE/dx and TR signals for electron and hadron discrimination
High-position tracklet for hadron momentum reconstruction