Forward Upgrade and Possible Use for Fixed Target

CBM-STAR Joint Workshop, TU Darmstadt, 3/18/2017

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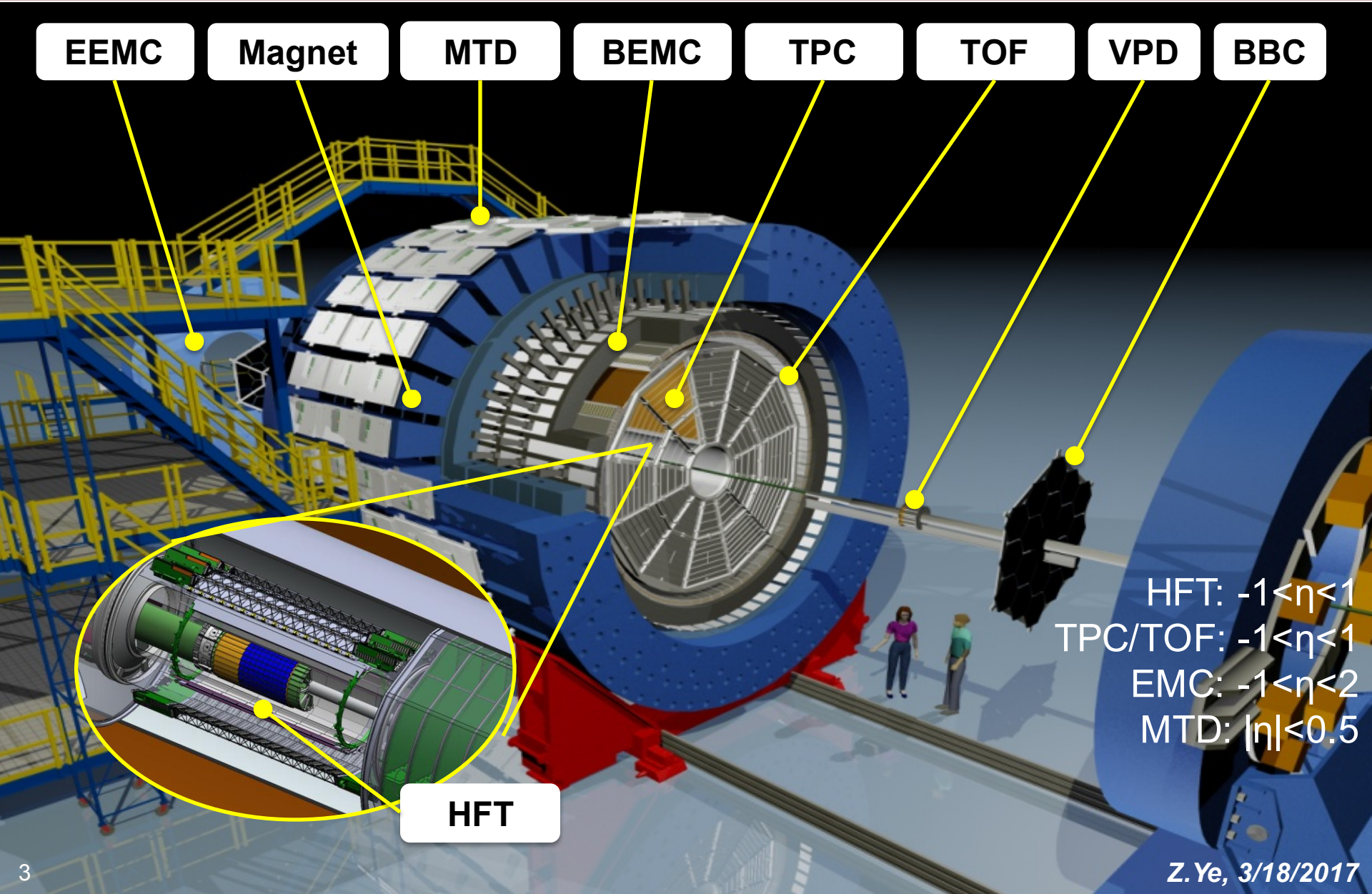
Outline

- STAR Forward Upgrade
  - STAR and RHIC run and upgrade plans
- Physics Perspective
  - p+p, p+A and Au+Au collisions
  - possible use for fixed target?
- Summary and Outlook

STAR Experiment in 2014-2016



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RHIC and STAR Run Plan

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2014-16	p+p, p+Au, p+Al, d+Au, He^3+Au, and Au+Au at 200 GeV 15 GeV Au+Au	Heavy quark energy loss, flow, thermalization Quarkonium studies Transverse spin physics Extract eta/s + initial quantum fluctuations Search for QCD critical point	STAR HFT STAR MTD STAR FMS pre-shower, PHENIX MPC-EX Electron lenses 56 MHz SRF
2017	p+p at 510 GeV Au+Au at 62 GeV	Transverse spin physics Energy dependence of parton energy loss	STAR FMS post-shower (PHENIX decomissioning)
2018	^{96}Ru+^{96}Ru and ^{96}Zr+^{96}Zr at 200 GeV	Chiral Magnetic Effects	**STAR EPD**
2019-20	Au+Au at 5-20 GeV (BES II)	Search for QCD critical point and onset of deconfinement	**STAR iTPC, eTOF** Low energy e-cooling
2021	p+p at 510 GeV (?)	Low-x gluon helicity, TMD	**fSTAR (?)**
2022-23	p+p, p+Au, Au+Au at 200 GeV	Transverse spin physics, gluon saturation, nuclear PDF, longitudinal flow decorrelation, initial conditions, eta/s, multiple haromoics Jet probe of parton transport and energy loss, Color-screening of Upsilon	**fSTAR (?)** sPHENIX (+fsPHENIX?)
2024-	No Runs		Transition to eRHIC

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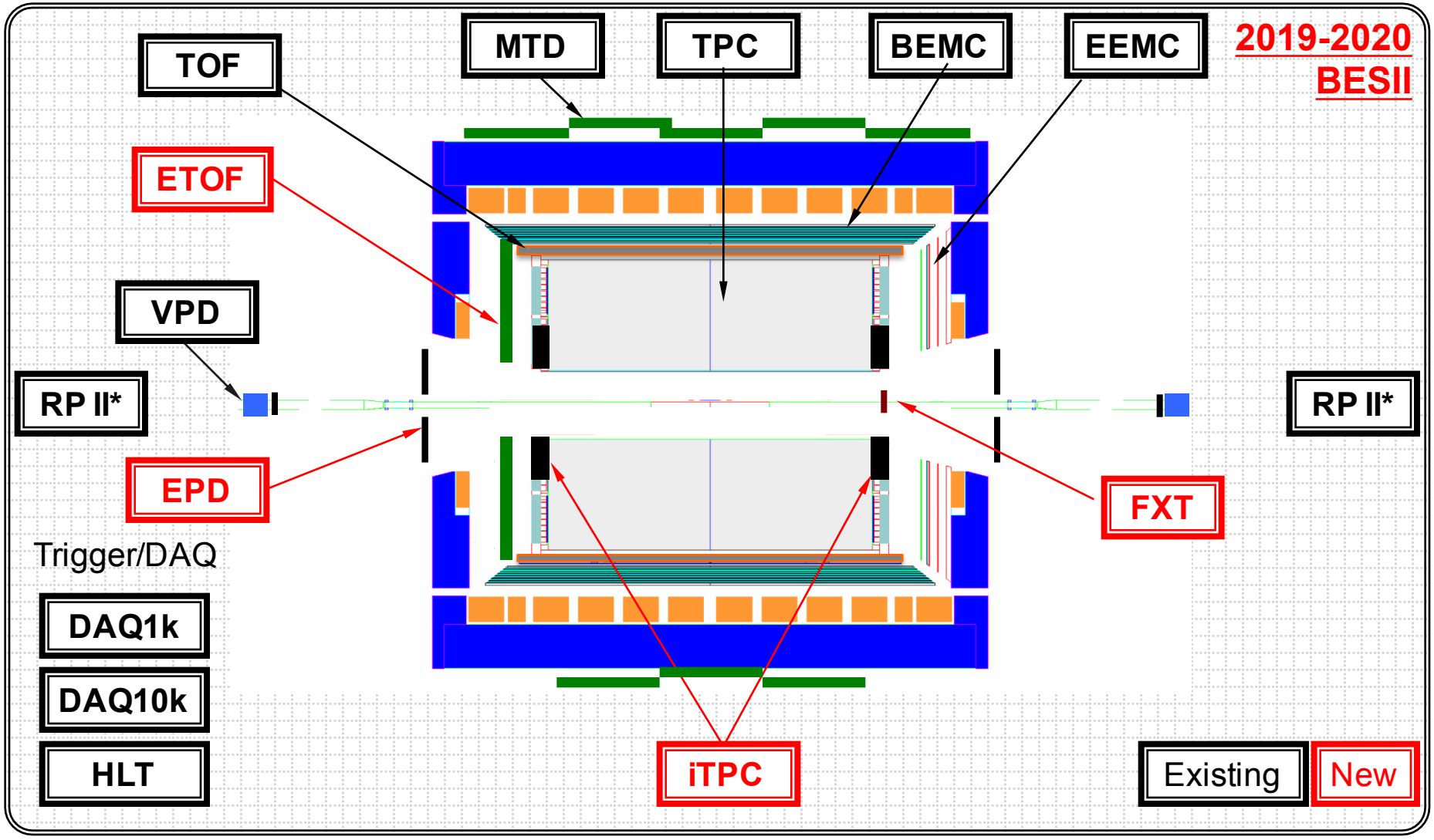
STAR Upgrade Plan



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

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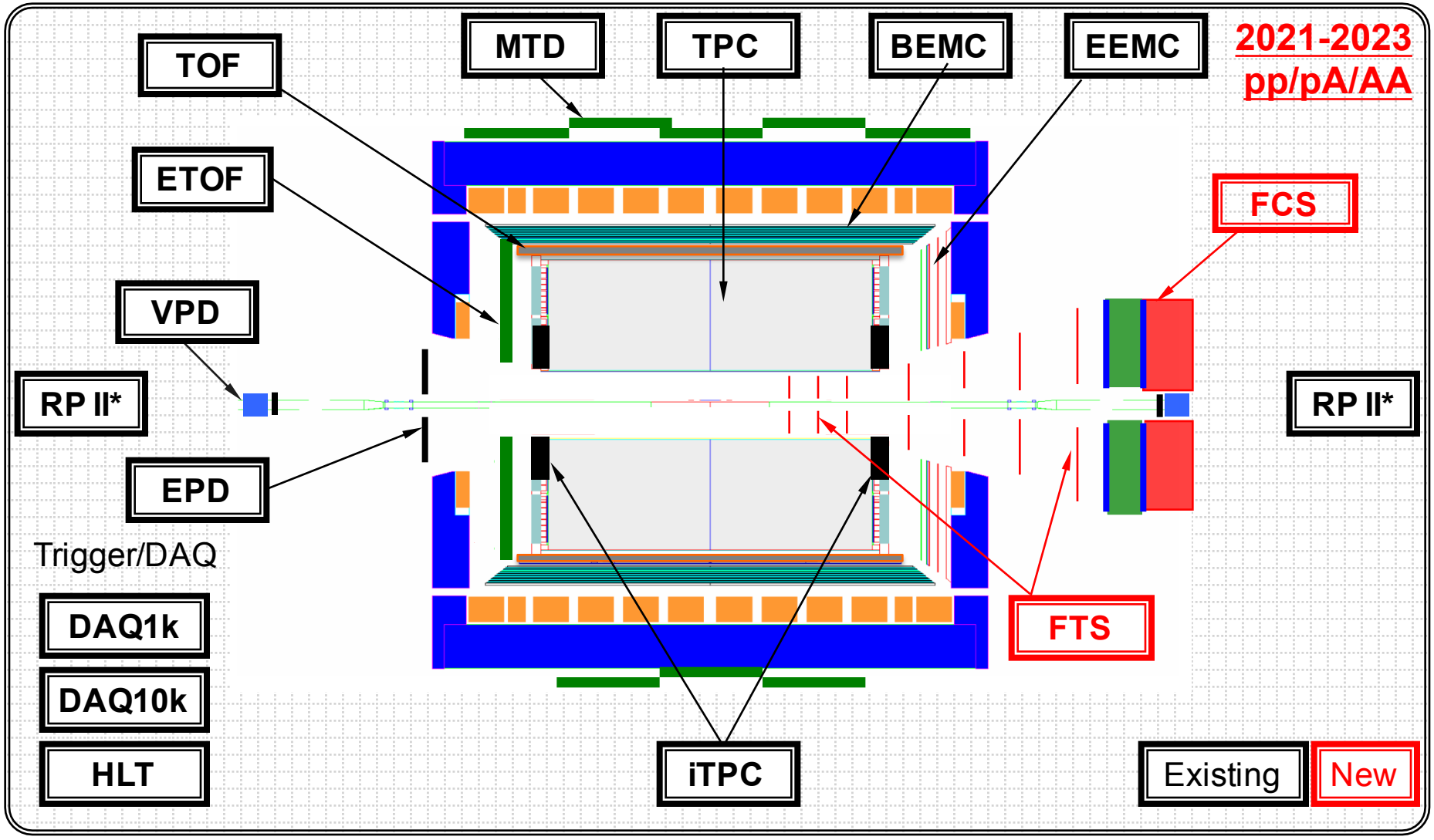
STAR Upgrade Plan



FCS: Forward Calorimeter System, **FTS:** Forward Tracking System

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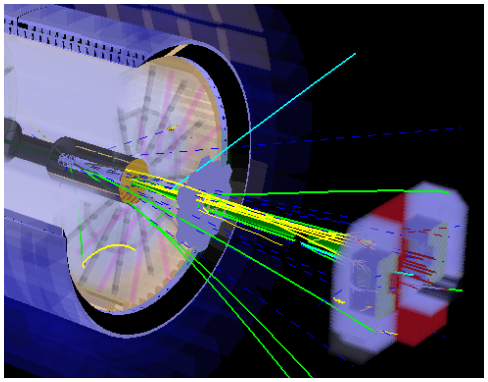
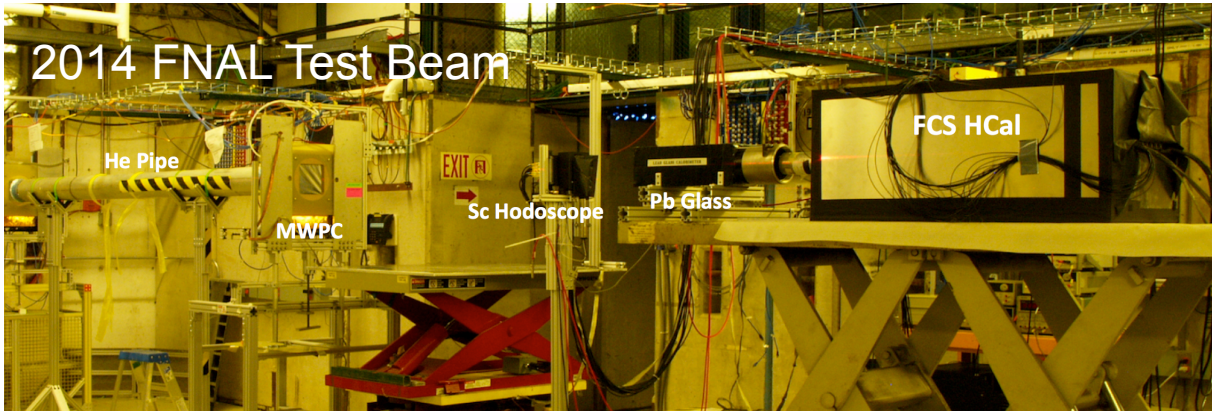
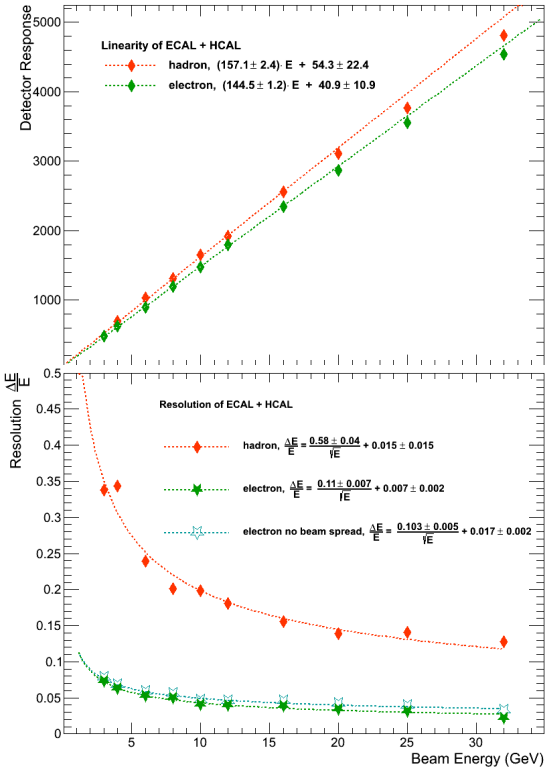
Forward Calorimeter Upgrade

- Requirement:
  - Full azimuthal in $2.5 < \eta < 4$
  - EM energy resolution ~ 10%/√ (E)
  - Hadronic energy resolution ~ 70%/√ (E)

- Current design (area 3x2 m^2, z=8-10 m):
  - EM section:
    - reuse PHENIX EMCal Pb-Sci towers
    - SiPM read out
  - Hadronic section:
    - Sandwich Fe-Sci
    - SiPM or APD read out







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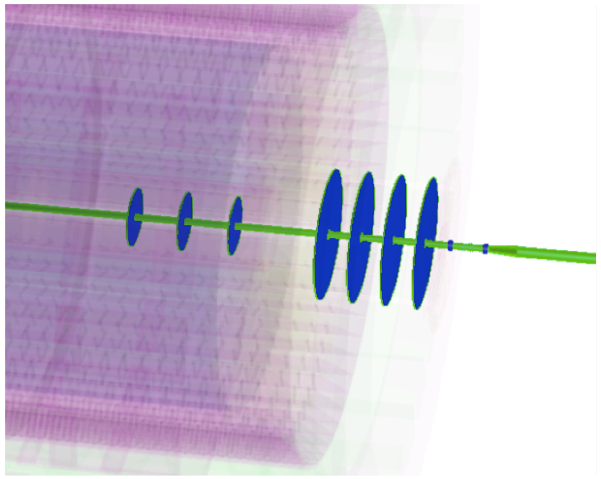
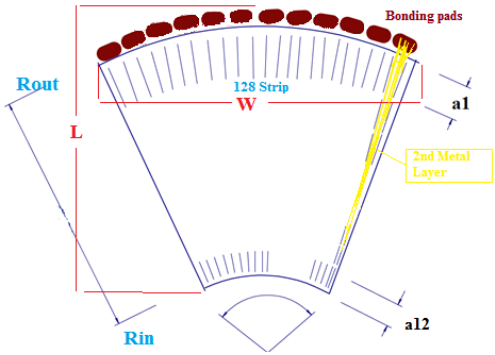
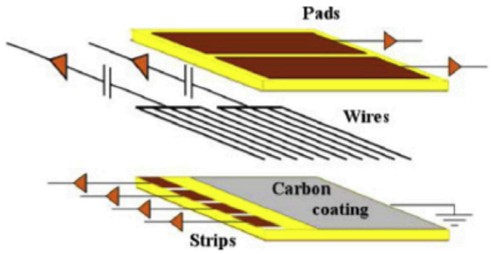
Forward Tracker Upgrade

- Requirement:
  - Full azimuthal in $2.5 < \eta < 4$
  - good resolution in ϕ for charge separation and momentum measurement
  - low material to reduce multiple scattering and conversional background

- Current design (**Si only or Si+sTGC**):
  - inside TPC: 3 (6) **Si** disks at z=70-140 cm
    - Single-sided double-metal pad sensor: pad size depends on (R, z) - minimum size is ~ 3 mm x 100 μm in R-ϕ
    - APV25 FEE, HFT-IST DAQ and cooling
    - 0.5-1.0% X_0 per plane
  - Outside TPC: 4 **sTGC** at z=2.4-7 m
    - Modified ATLAS orward design
    - Position resolution: <300 μm in x-y
    - 0.5% X_0 per plane







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Forward Upgrade for pp/pA Physics

	Year	$\sqrt{s}$ (GeV)	Delivered Luminosity	Scientific Goals	Observable	Required Upgrade
Scheduled RHIC running	2017	$p^{\uparrow}p$ @ 510	400 pb^{-1} 12 weeks	Sensitive to Sivers effect non-universality through TMDs and Twist-3 $T_{q,F}(x,x)$ Sensitive to sea quark Sivers or ETQS function Evolution in TMD and Twist-3 formalism	A_N for γ, $W^{\pm}$, Z^0, DY	A_N^{DY}: Postshower to FMS@STAR
				Transversity, Collins FF, linearly pol. Gluons, Gluon Sivers in Twist-3	$A_{UT}^{\sin(\phi_S-2\phi_h)}$ $A_{UT}^{\sin(\phi_S-\phi_h)}$ modulations of h^+ in jets, $A_{UT}^{\sin(\phi_S)}$ for jets	None
				First look at GPD Eg	A_{UT} for J/Ψ in UPC	None
	2023	$p^{\uparrow}p$ @ 200	300 pb^{-1} 8 weeks	subprocess driving the large A_N at high x_F and η	A_N for charged hadrons and flavor enhanced jets	Yes Forward instrum.
				evolution of ETQS fct. properties and nature of the diffractive exchange in p+p collisions.	A_N for γ A_N for diffractive events	None None
	2023	$p^{\uparrow}$Au @ 200	1.8 pb^{-1} 8 weeks	What is the nature of the initial state and hadronization in nuclear collisions	R_{pAu} direct photons and DY	R_{pAu}(DY):Yes Forward instrum.
				Nuclear dependence of TMDs and nFF	$A_{UT}^{\sin(\phi_S-\phi_h)}$ modulations of h^+ in jets, nuclear FF	None
				Clear signatures for Saturation	Dihadrons, γ-jet, h-jet, diffraction	Yes Forward instrum.
	2023	$p^{\uparrow}$Al @ 200	12.6 pb^{-1} 8 weeks	A-dependence of nPDF,	R_{pAl}: direct photons and DY	R_{pAl}(DY): Yes Forward instrum.
				A-dependence of TMDs and nFF	$A_{UT}^{\sin(\phi_S-\phi_h)}$ modulations of h^+ in jets, nuclear FF	None
				A-dependence for Saturation	Dihadrons, γ-jet, h-jet, diffraction	Yes Forward instrum.
Potential future running	202X	$p^{\uparrow}p$ @ 510	1.1 fb^{-1} 10 weeks	TMDs at low and high x	A_{UT} for Collins observables, i.e. hadron in jet modulations at $\eta > 1$ and	Yes Forward instrum.
				quantitative comparisons of the validity and the limits of factorization and universality in lepton-proton and proton-proton collisions	mid-rapidity observables as in 2017 run	None
	202X	$\vec{p}\vec{p}$@ 510	1.1 fb^{-1} 10 weeks	$\Delta g(x)$ at small x	A_{LL} for jets, di-jets, h/γ-jets at $\eta > 1$	Yes Forward instrum.

Table 1-2: Summary of the Cold QCD physics program propsed in the years 2017 and 2023 and if an additional 500 GeV run would become possible.

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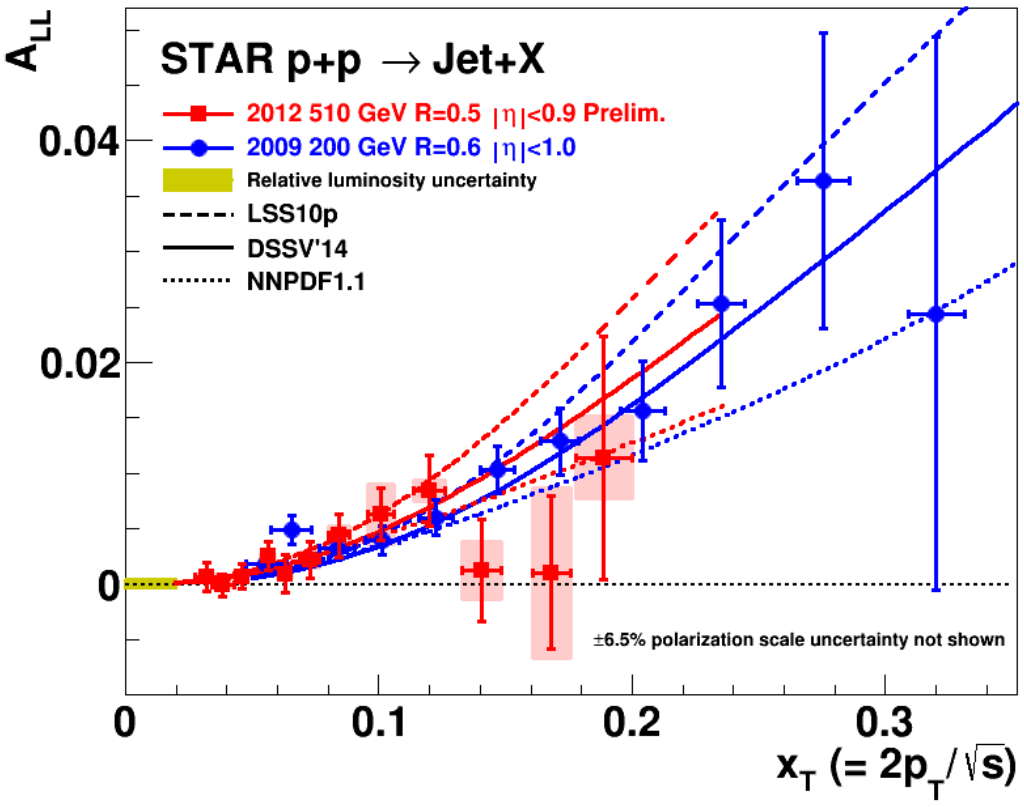
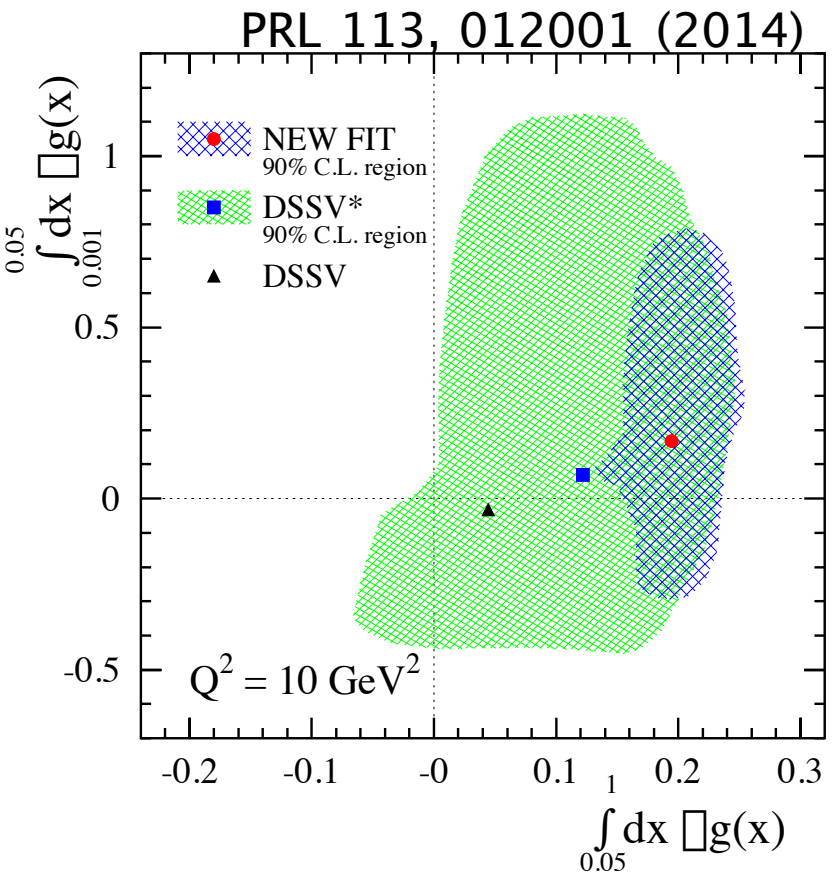
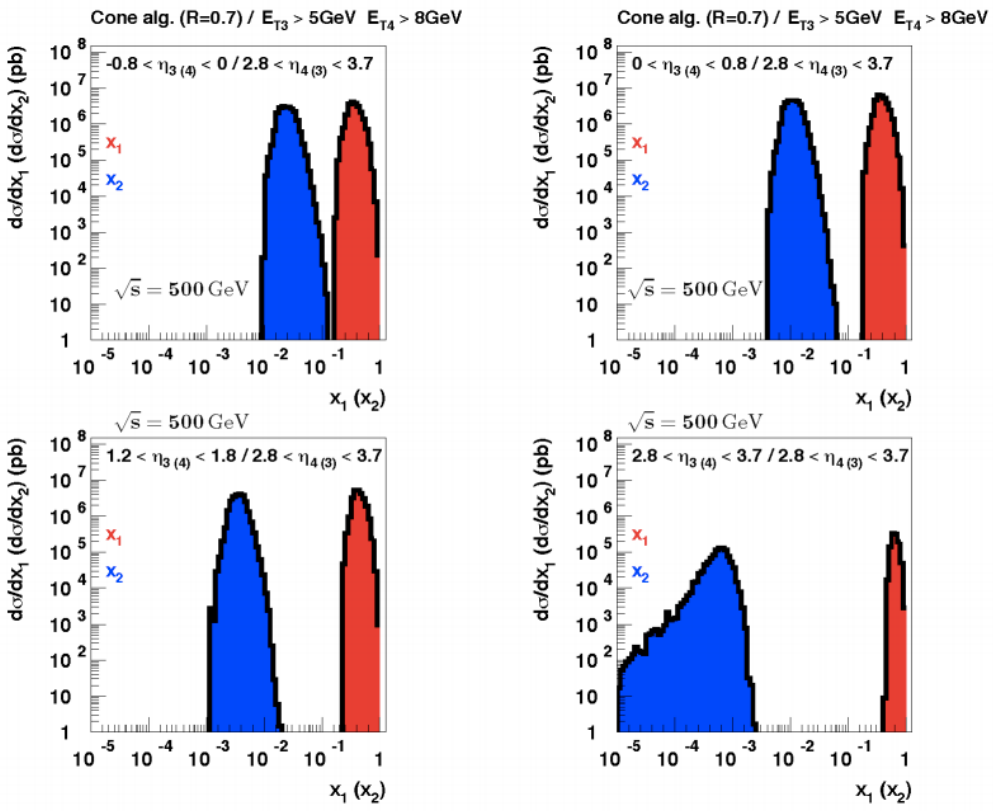
pp/pA Forward Physics - ΔG

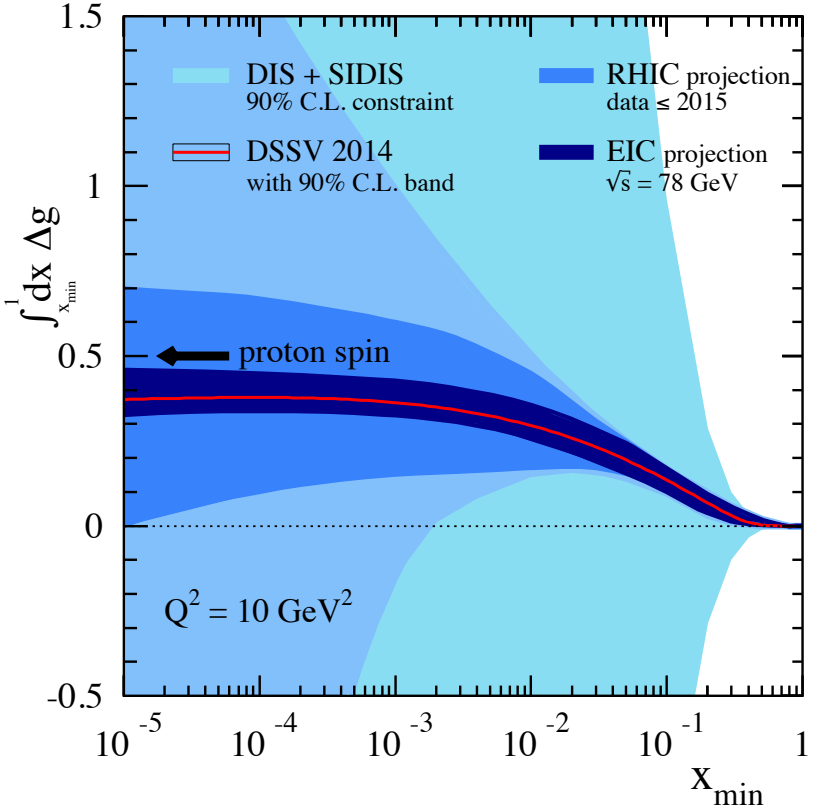




- Single pion and jet A_{LL} at RHIC have provided the first indication of positive contribution of the gluon polarization for x>0.05 to the proton spin.

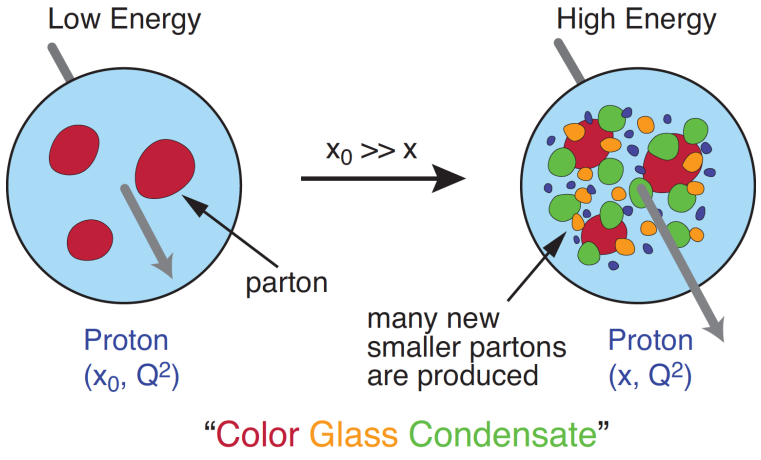
pp/pA Forward Physics - ΔG

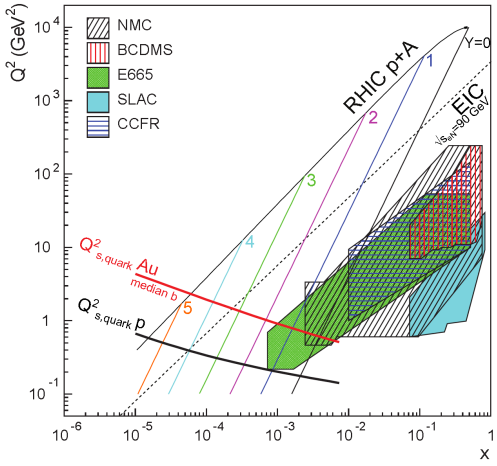


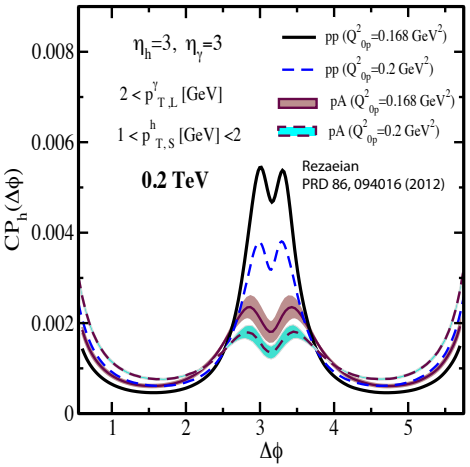


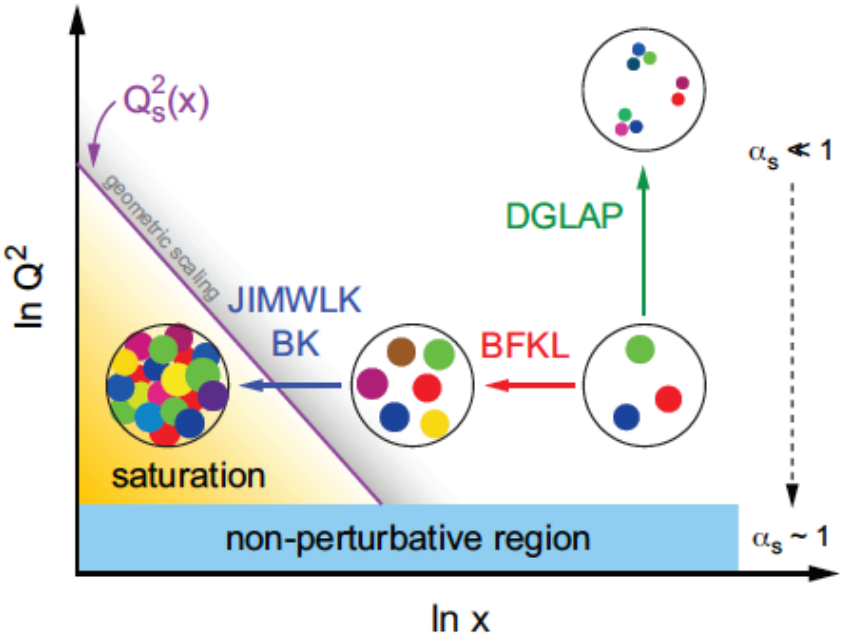
- Single pion and jet A_{LL} at RHIC have provided the first indication of positive contribution of the gluon polarization for x>0.05 to the proton spin.
- Di-jet A_{LL} at forward regions will provide access to lower x regime.

pp/pA Forward Physics - Saturation









gamma-hadron correlations

- gluon saturation at low x and Q^2 in p+p collisions
- A-dependence of gluon saturation in p+A collisions

Forward Upgrade for AA Physics

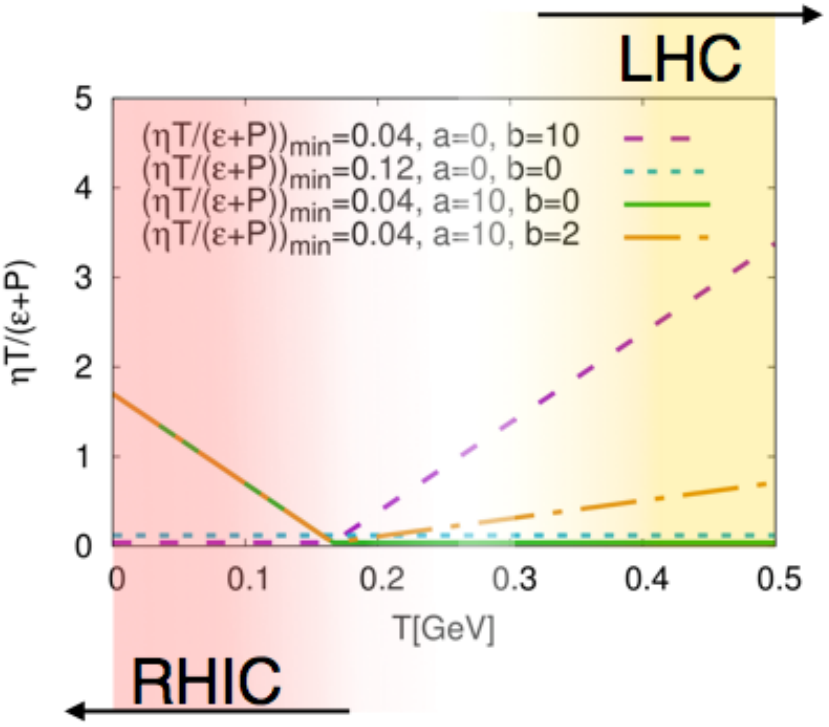
Physics Measurements		Longitudinal de-correlation $C_n(\Delta\eta)$ $r_n(\eta_a,\eta_b)$	η/s(T), ζ/s(T)	Mixed flow Harmonics $Cm,n,m+n$	Ridge	Event Shape and Jet-studies
Detectors	**Acceptance**					
Forward Calorimeter **(FCS)**	$2.5 < \eta < 4$ (photons, hadrons)	One of these detectors necessary		One of these detectors necessary	Good to have	One of these detectors needed
Forward Tracking System **(FTS)**	$2.5 < \eta < 4$ (charged particles)		Important		Important	

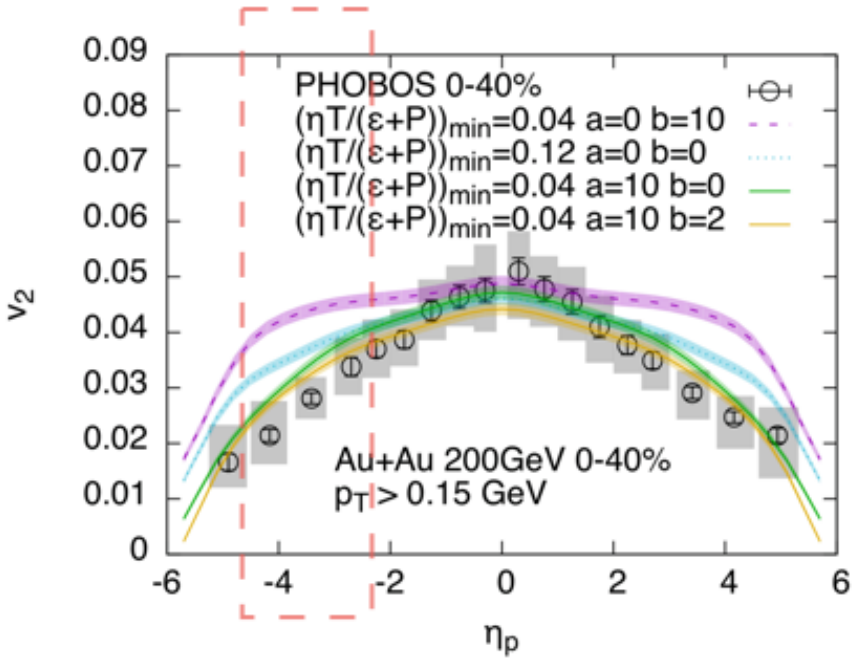
Table 2-1: Physics measurements in A+A collisions with the proposed forward upgrade and with other STAR upgrades that are relevant to those measurements.

STAR Public Note SN0648 : The STAR Forward Calorimeter System and Forward Tracking System beyond BES-II

https://drupal.star.bnl.gov/STAR/starnotes/public/sn0648

AA Forward Physics - $\eta/s(T)$

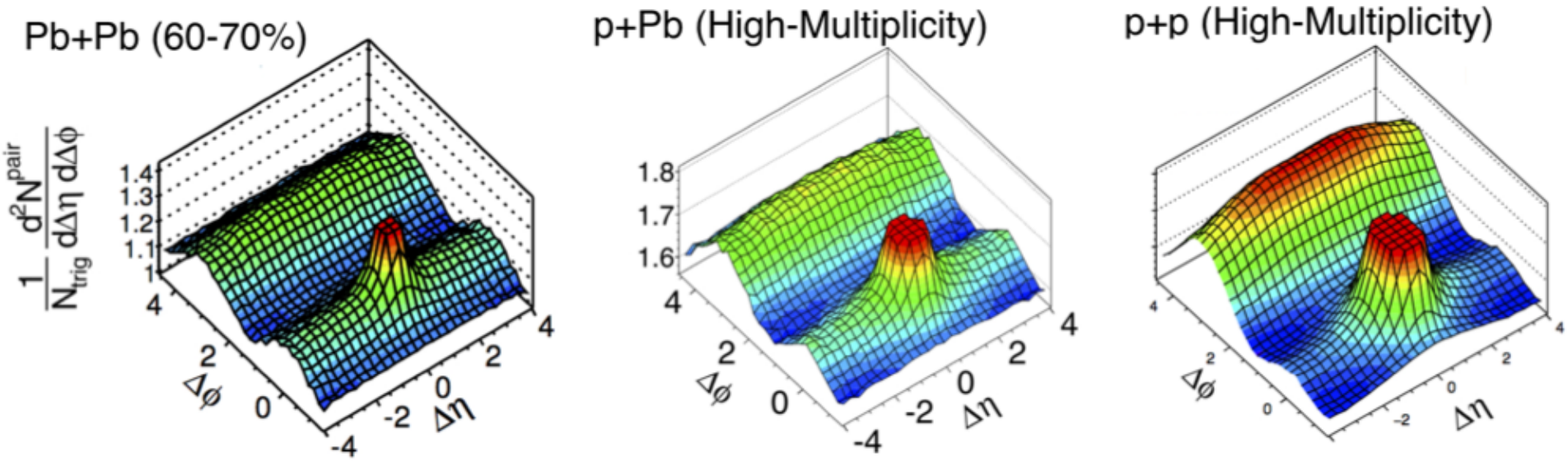




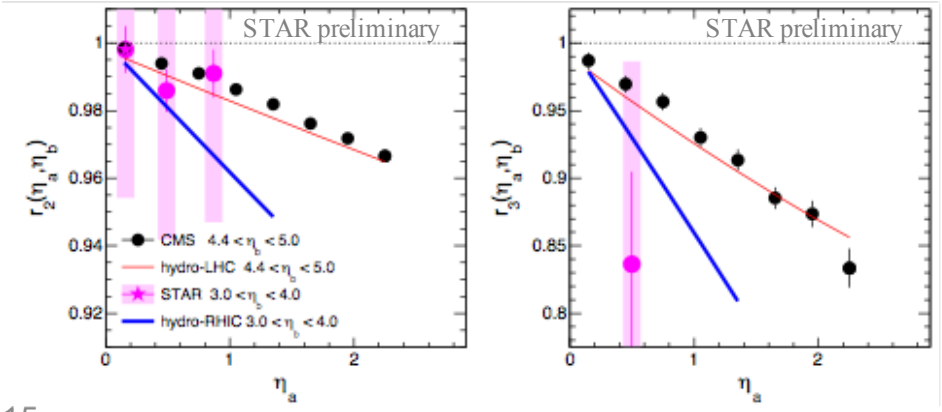
Denicol et al. PRL 116, 212301 (2016)

Effects on elliptic flow co-efficient v_2 due to different parameterization of viscosity parameter indicating a better constrain on $\eta/s(T)$ can only be performed by measurements at forward rapidity.

AA Forward Physics – Large y



Long-range ridge structure observed in the di-hadron correlation in peripheral Pb+Pb and high multiplicity p+Pb and p+p collisions at the LHC



Need precision measurements at RHIC on longitudinal invariance and full 3D fluid-dynamic modeling of heavy-ion collisions

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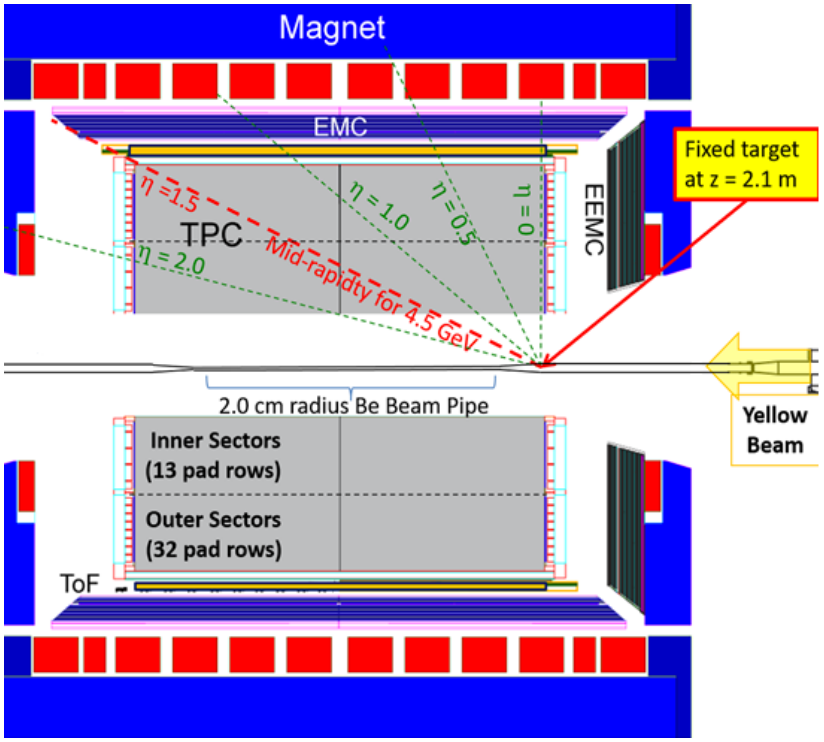
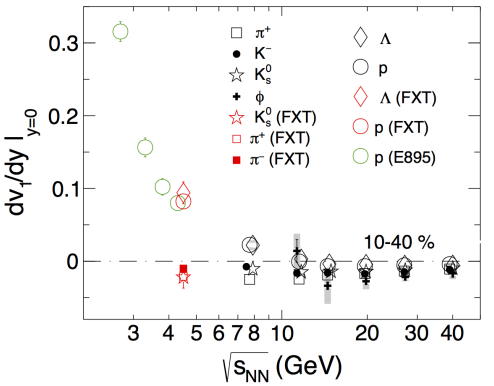
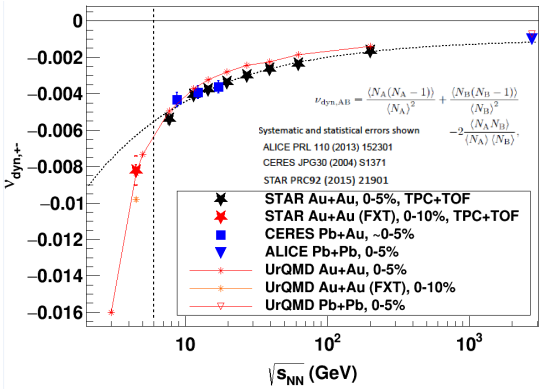
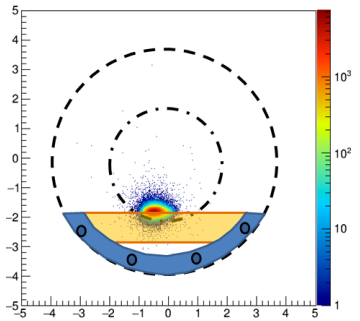
Fixed Target Program at STAR

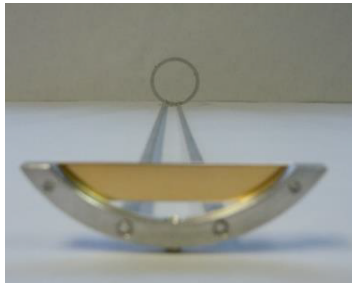






V_y vs. V_x Distribution





1 mm thick (4% interaction probability) gold foil target

First successful operation in FXT mode: 1.3 M top central 30% events in Au+Au collisions at $\sqrt{s_{NN}} = 4.5$ GeV

- Measurements of yield, directed and elliptic flow of pion, Kaon and Lambda.
- First measurement of dynamical charge number fluctuation for this energy range.

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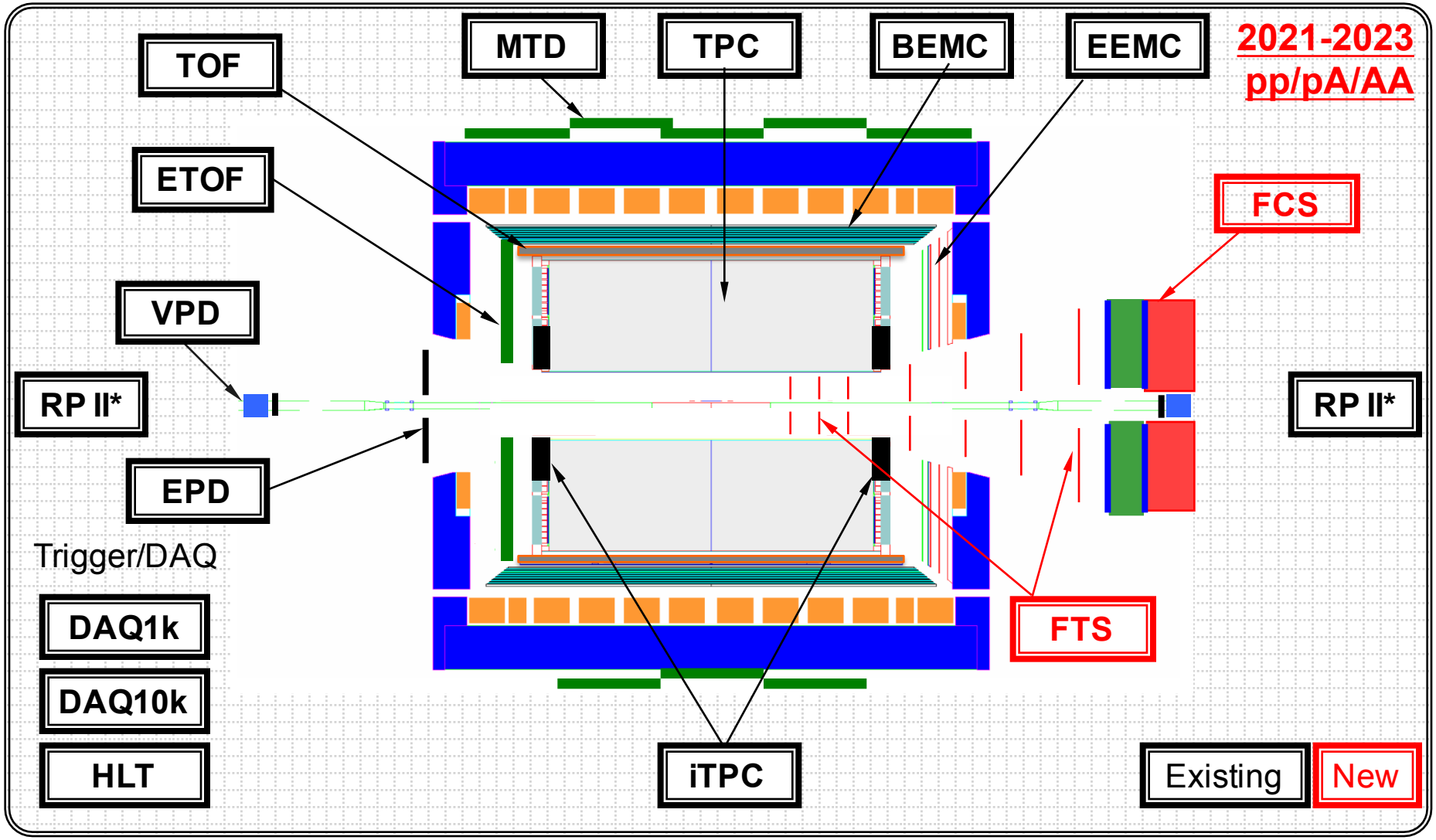
Using Forward Upgrade for FXT



FCS: Forward Calorimeter System, **FTS:** Forward Tracking System, **FXT**: Fixed Target

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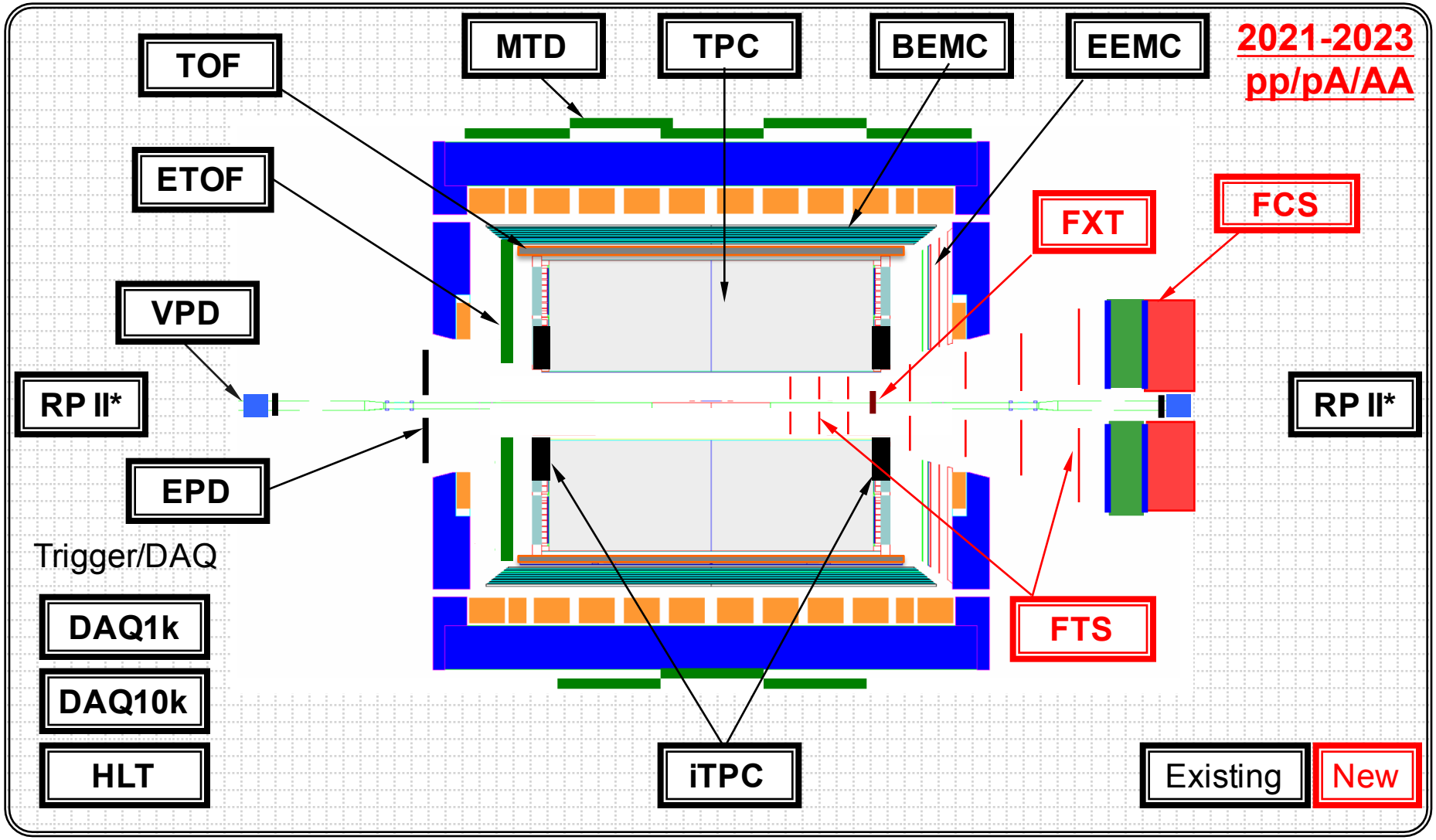
Using Forward Upgrade for FXT



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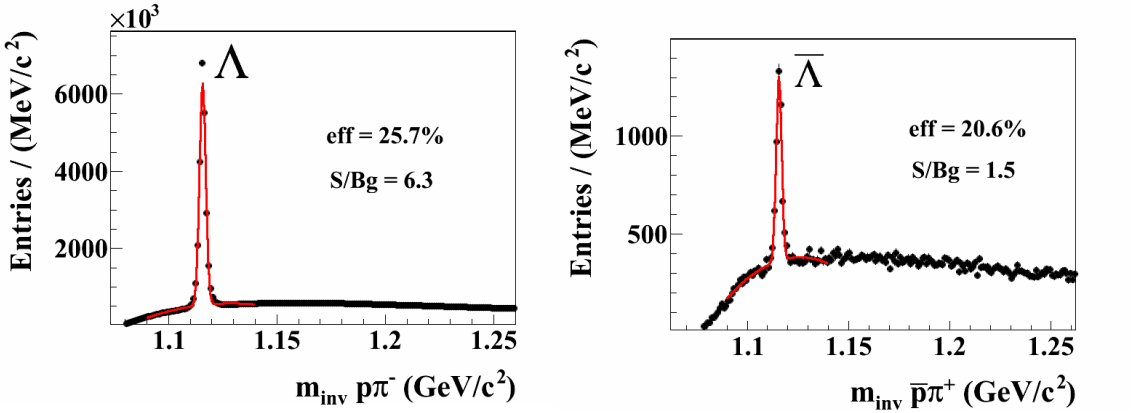
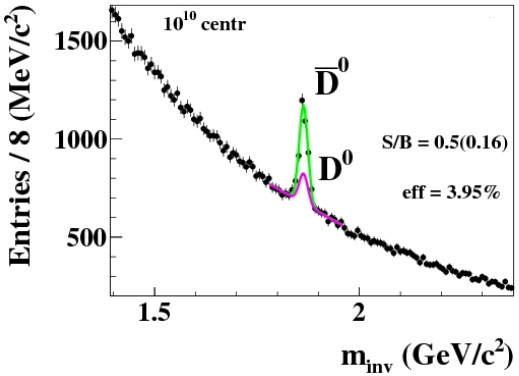
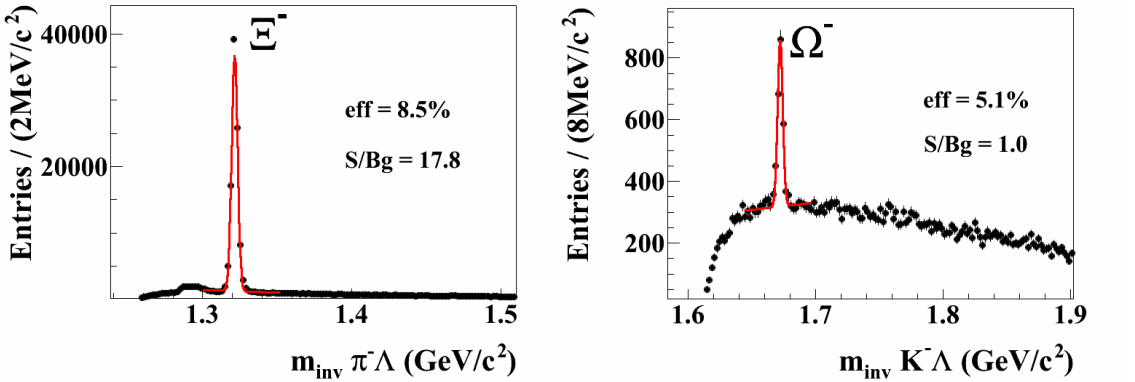
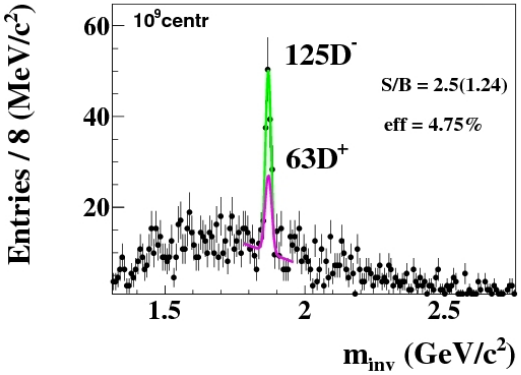








CBM-STS TDR Fig 2.20
Hyperon from 5x10^6 Au+Au collisions at 10 AGeV

CBM-STS TDR Fig 2.21
D from 10^{10} and 10^9 central Au+Au collisions at 25 AGeV.

What can the forward upgrade do for the FXT at STAR?

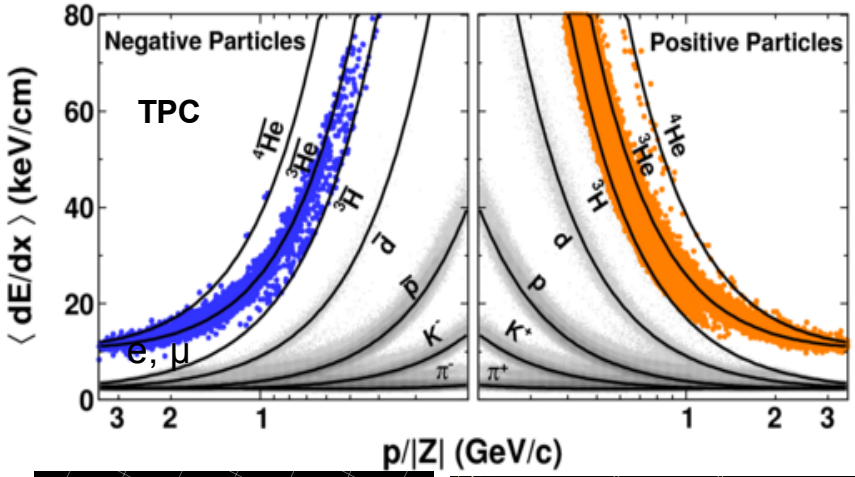
Summary and Outlook

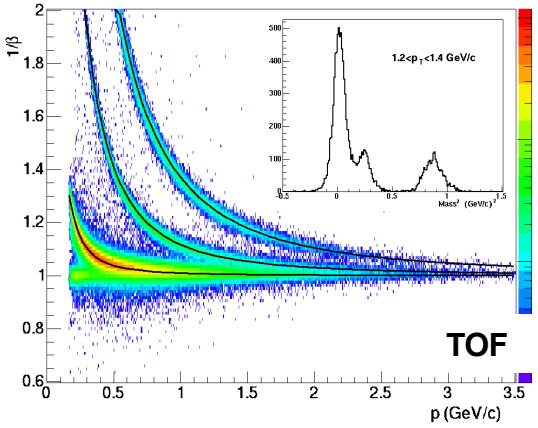
- Forward upgrade at STAR provide excellent opportunities to study spin, initial condition, and QGP in 2021-2023
  - p+p collisions: ΔG, transverse spin, A_N
  - p+A collisions: gluon saturation, nuclear PDF
  - A+A collisions: $\eta/s\ (T)$, longitudinal decorrelation, initial condition
  - Fixed target: to be explored - hyperon, hypernuclei, charm meson …

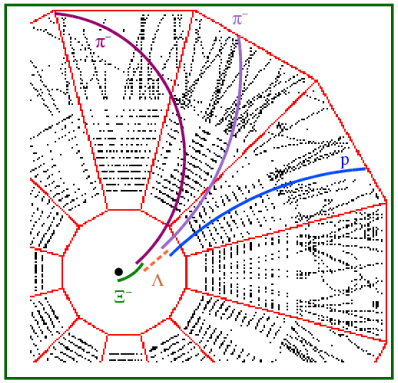
- Potential interest for some joint efforts?
  - Compelling and overlapping physics interests for CBM and STAR?
  - Construct extra CBM-STS stations for STAR forward?
  - Use CBM-STS stations for STAR forward?
  - …

Backup

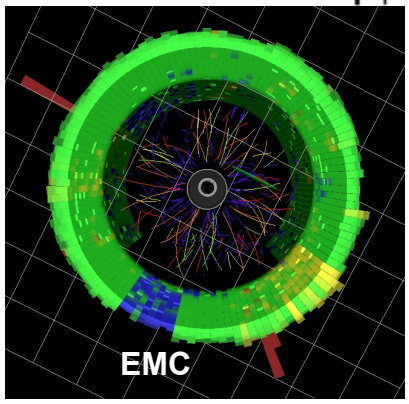
Particle Identifications at STAR



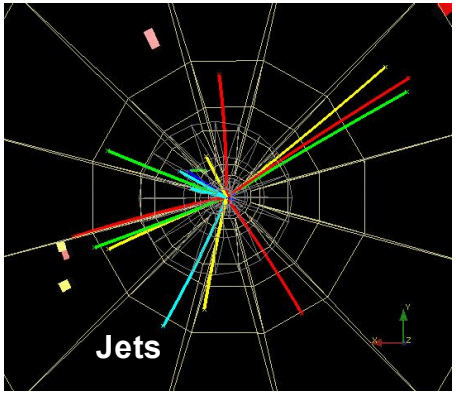




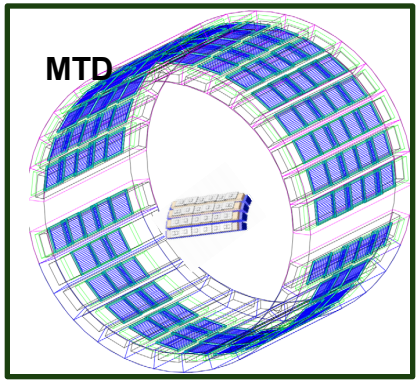
Hyperons & Hyper-nuclei



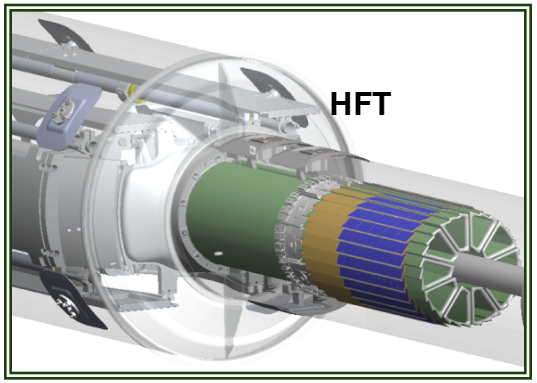
Neutral particles



Jets & Correlations



High p_T muons



Heavy-flavor hadrons

Multiple-fold correlations for identified particles at mid-rapidity!

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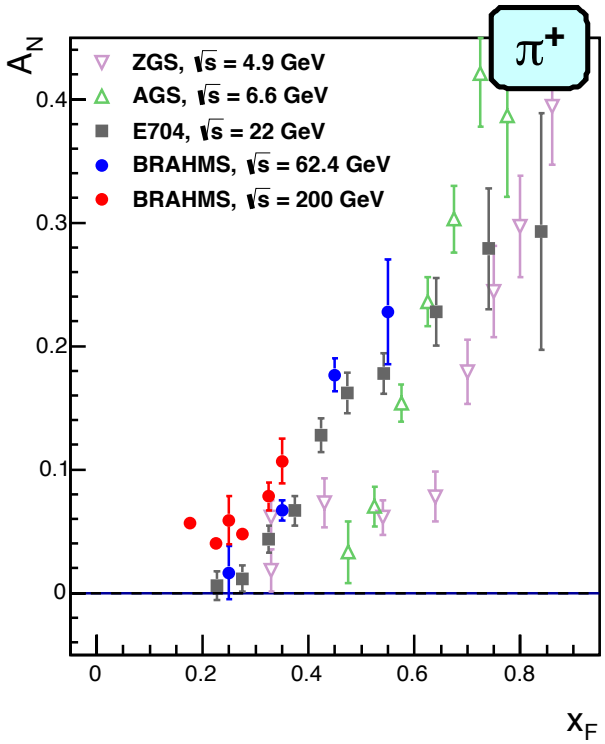
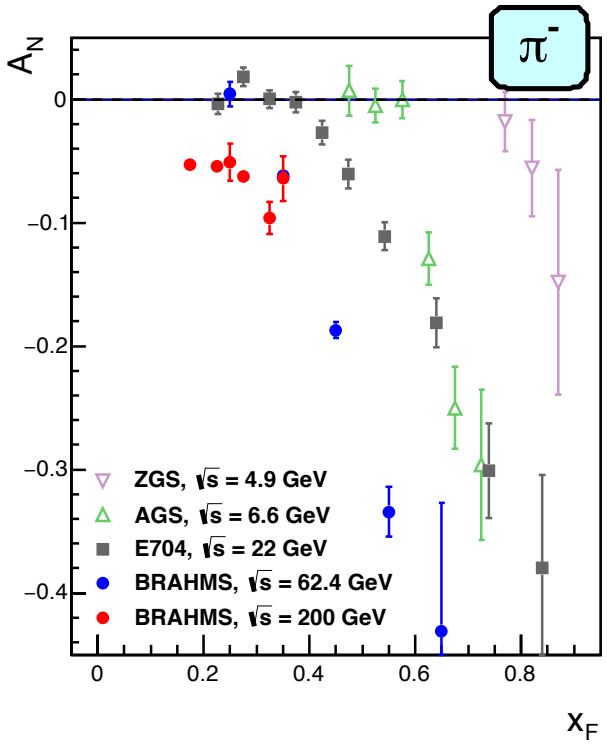
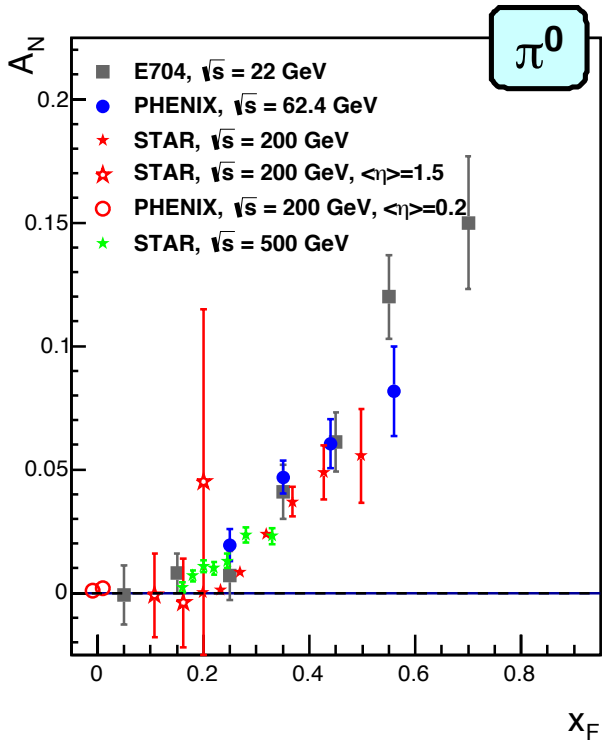
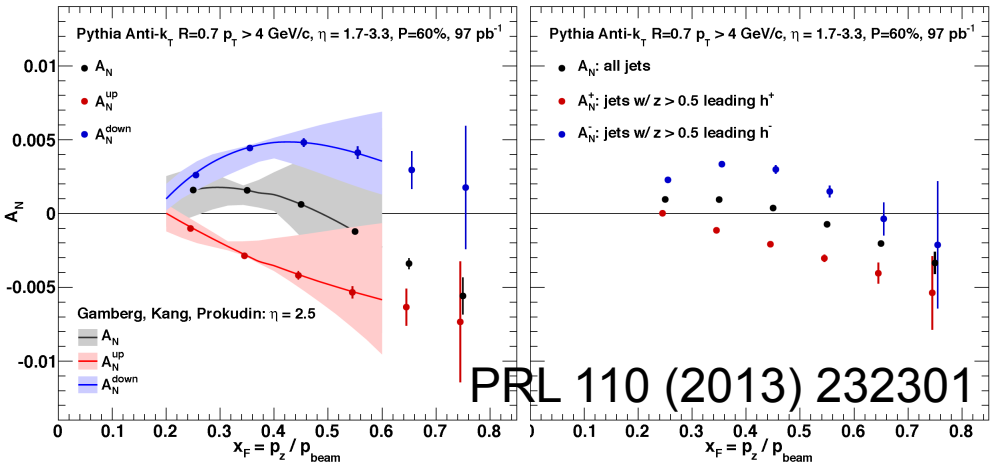
pp/pA Forward Physics - A_N









PRL 110 (2013) 232301

- New work suggests that twist-3 FF could explain large pion A_N and small jet A_N
- Measurements of charged pions and flavor-enhaced jets in the forward region would help confirm this approach.

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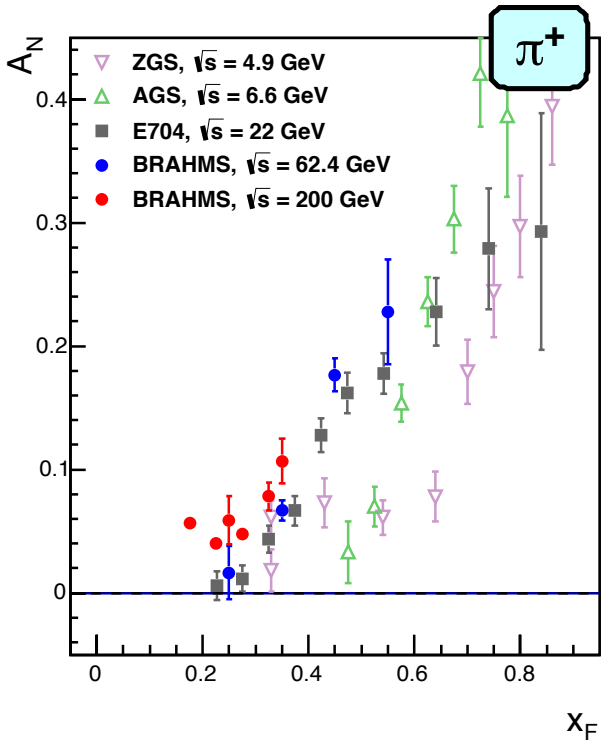
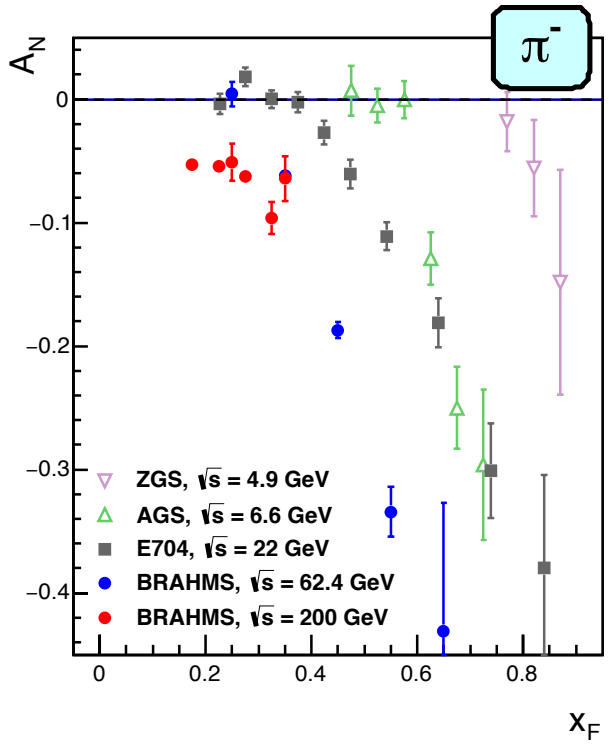
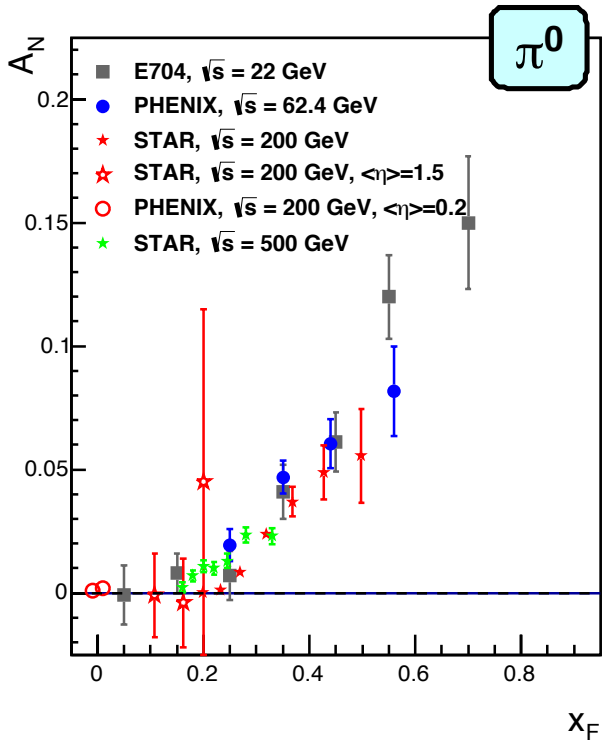
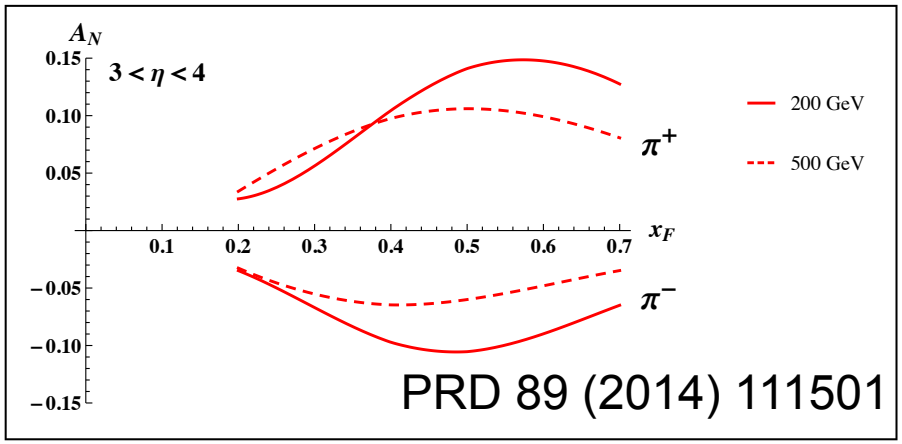
pp/pA Forward Physics - A_N









PRD 89 (2014) 111501

- New work suggests that twist-3 FF could explain large forward pion A_N
- Measurements of charged pions and flavor-enhanced jets in the forward region would help confirm this approach.

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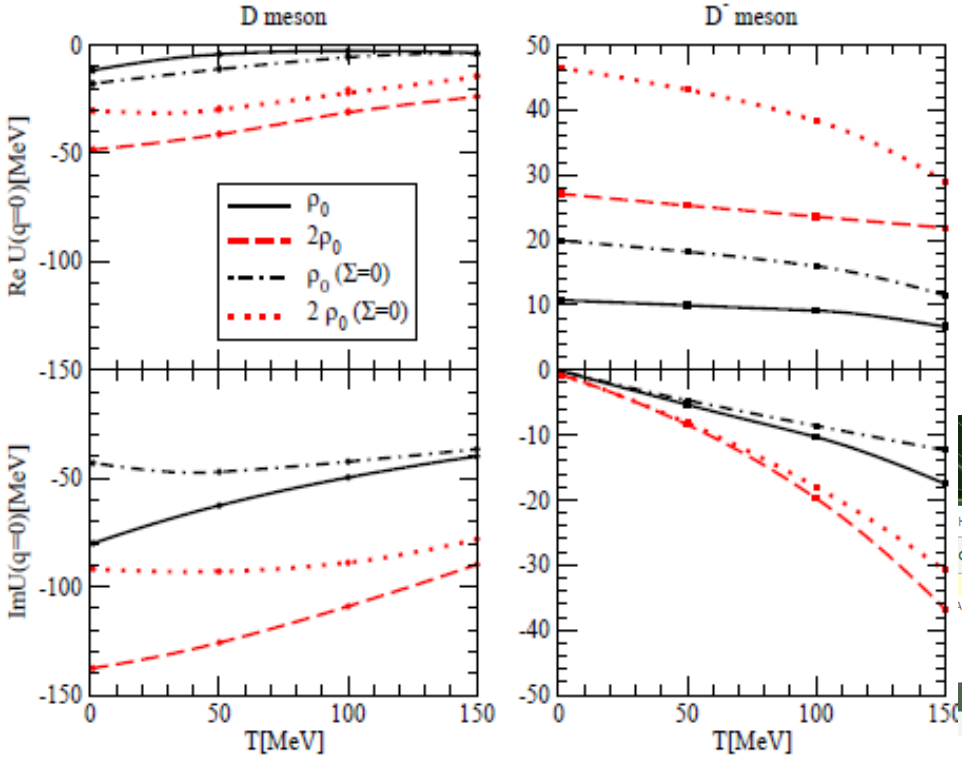
AA Forward Physics – HF Hypernuclei

- Heavy-flavor states

http://belle.kek.jp/belle/talks/moriondQCD10/p.pakhlov.ppt

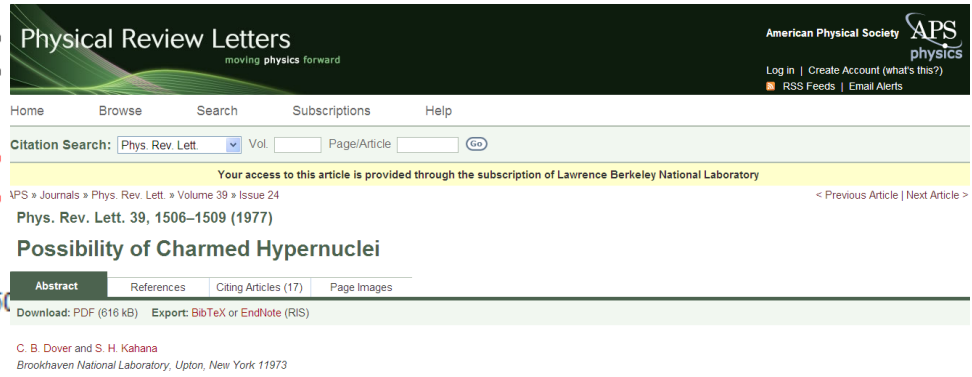


Tolos 0905.1850

How about baryon states?
$D^- + p \rightarrow n + D^0$
$D^- + {}^4He$ stable

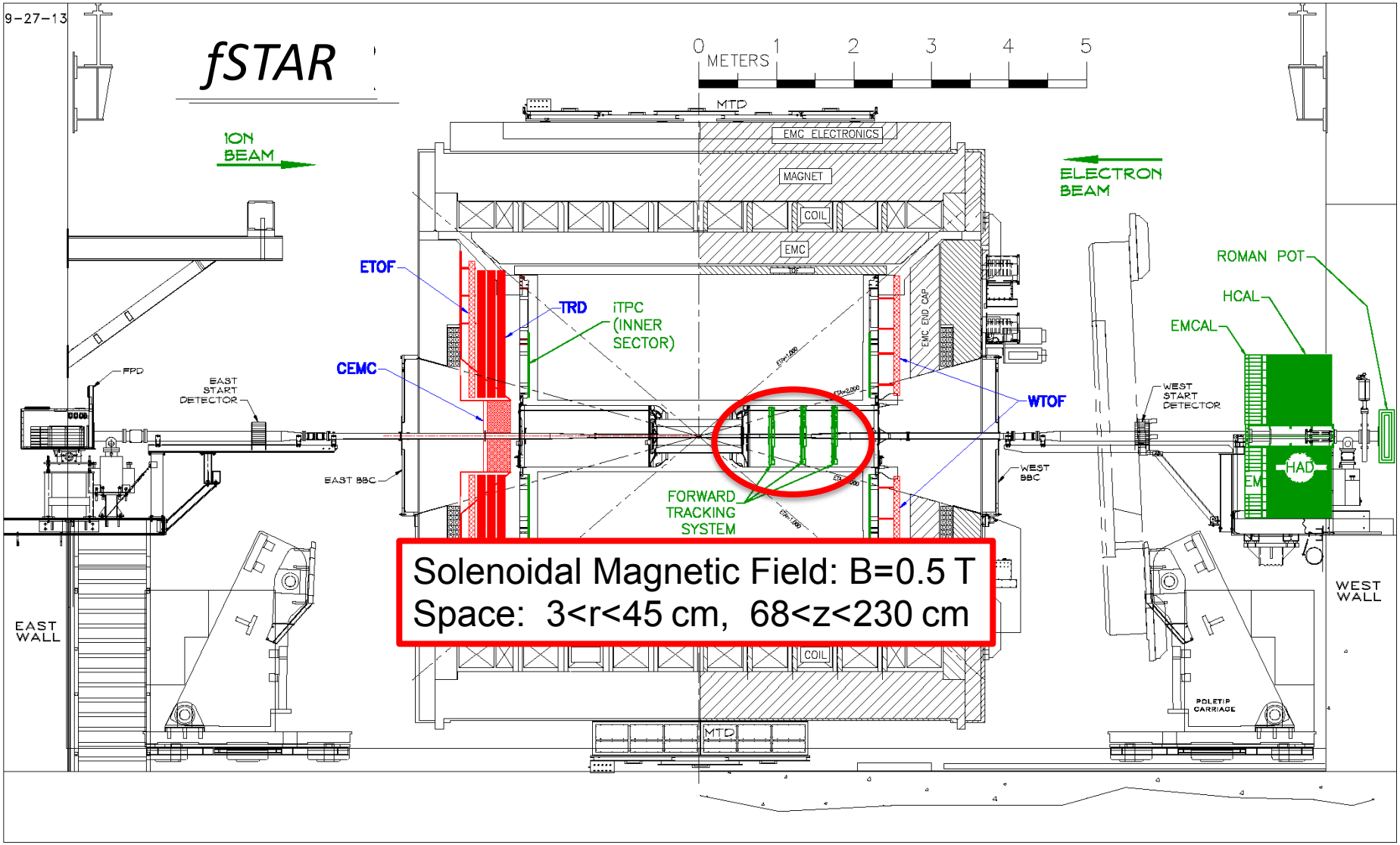
- Heavy-flavor hypernuclei

Predicted to exist (70's)
Cannot be produced in pp, ep
EIC enough energy for D/B hypernuclei
Forward p+A and peripheral A+A?
Vertex detector at Fragmentation region
Displace vertex: 3cm

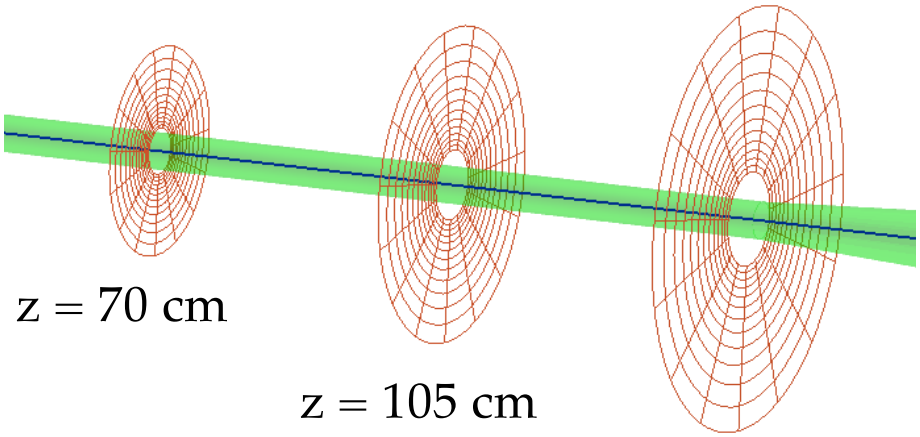


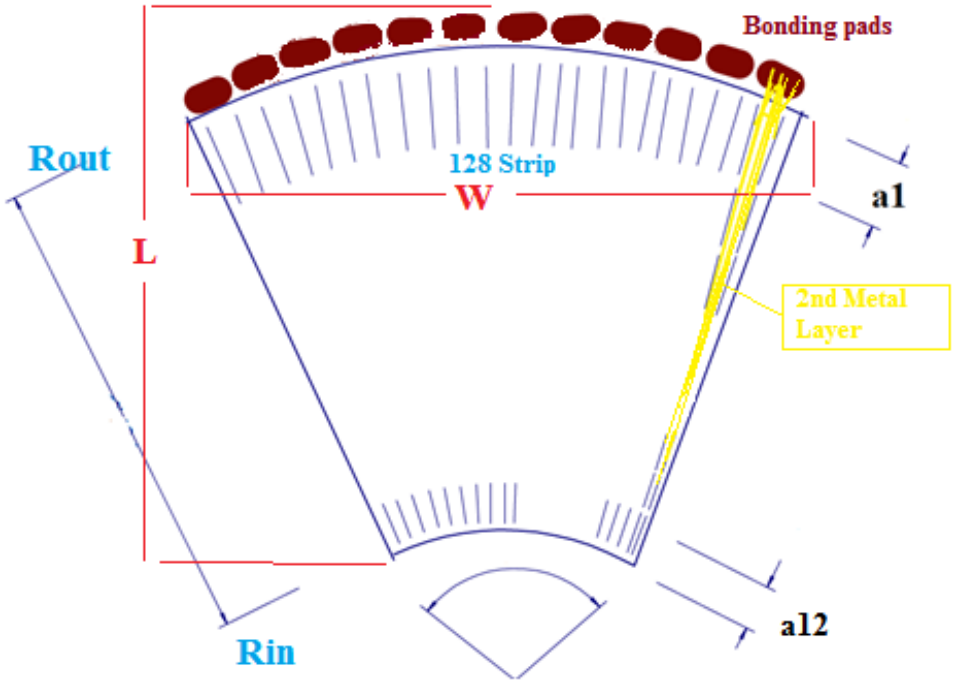
Discovery potential !

Location & Space Constraints



Layout with uniform width in η





Material budget: <0.5% X_0 per plane

in [mm]	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	r_{12}	r_{13}
plane 1	25.7	29.1	32.9	37.3	42.3	48.0	54.4	61.6	69.9	79.2	89.9	102.0	115.7
ϕ pitch	0.11	0.12	0.15	0.17	0.19	0.21	0.24	0.28	0.31	0.34	0.38	0.43	
plane 2	38.5	43.6	49.4	56.0	63.5	71.9	81.5	92.4	104.8	118.9	134.8	152.9	173.5
ϕ pitch	0.17	0.18	0.22	0.26	0.28	0.32	0.36	0.42	0.46	0.51	0.56	0.64	
plane 3	51.3	58.1	65.9	74.7	84.6	95.9	108.7	123.3	139.8	158.5	179.7	203.9	231.4
ϕ pitch	0.22	0.25	0.29	0.34	0.38	0.43	0.48	0.56	0.61	0.68	0.75	0.85	

CBM STS

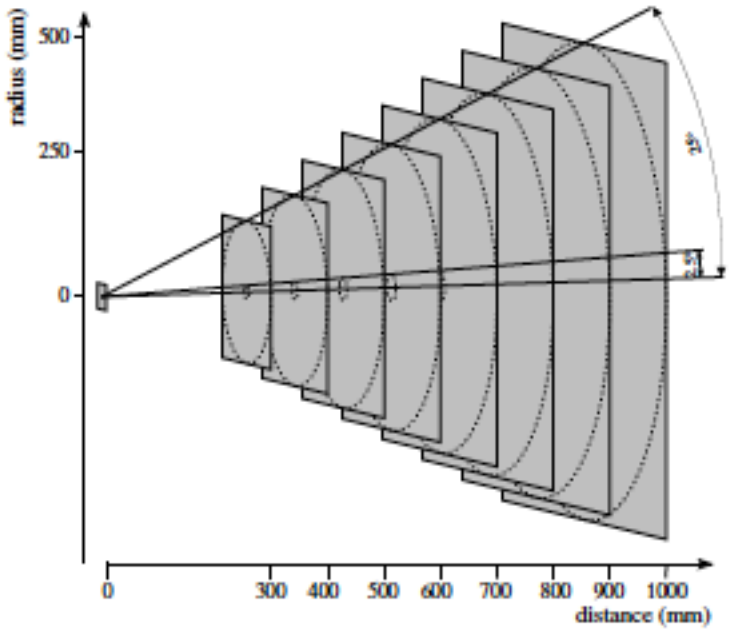
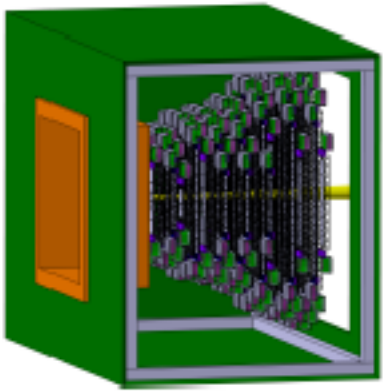


Figure 2.2: Concept of STS tracking stations covering the polar angles $2.5° < \Theta < 25°$.

station	1	2	3	4	5	6	7	8
z position [cm]	30	40	50	60	70	80	90	100
r_{inn} [cm]	1.31	1.75	2.18	2.62	3.06	3.49	3.93	4.34
acceptance $\Theta_{inn}^{hor.,vert.}$	2.5°	2.5°	2.5°	2.5°	2.5°	2.5°	2.5°	2.5°
vertical r_{out} [cm]	13.99	18.65	23.32	27.98	32.64	37.31	41.97	46.63
acceptance $\Theta_{out}^{vert.}$	25°	25°	25°	25°	25°	25°	25°	25°
horizontal increase	65%	65%	50%	40%	20%	10%	0%	0%
horizontal r_{out} [cm]	23.08	30.77	34.98	39.17	39.17	41.04	41.97	46.63
acceptance $\Theta_{out}^{hor.}$	38°	37°	35°	33°	29°	27°	25°	25°

Table 2.2: Dimensions and acceptance radii of the tracking stations. Several stations are horizontally enlarged to enhance the reconstruction of low-momentum particles. See also Fig. 2.6.



1400x2000x
1100 mm3

station	ladders	modules	sensors	r/o chips	channels
1	8	76	76	1216	156k
2	12	100	100	1600	205k
3	12	108	132	1728	222k
4	14	116	144	1856	238k
5	14	112	168	1792	230k
6	14	112	168	1792	230k
7	16	136	216	2176	279k
8	16	136	216	2176	279k
Total	106	896	1220	14336	1835k

Table 2.6: Breakdown of STS components.

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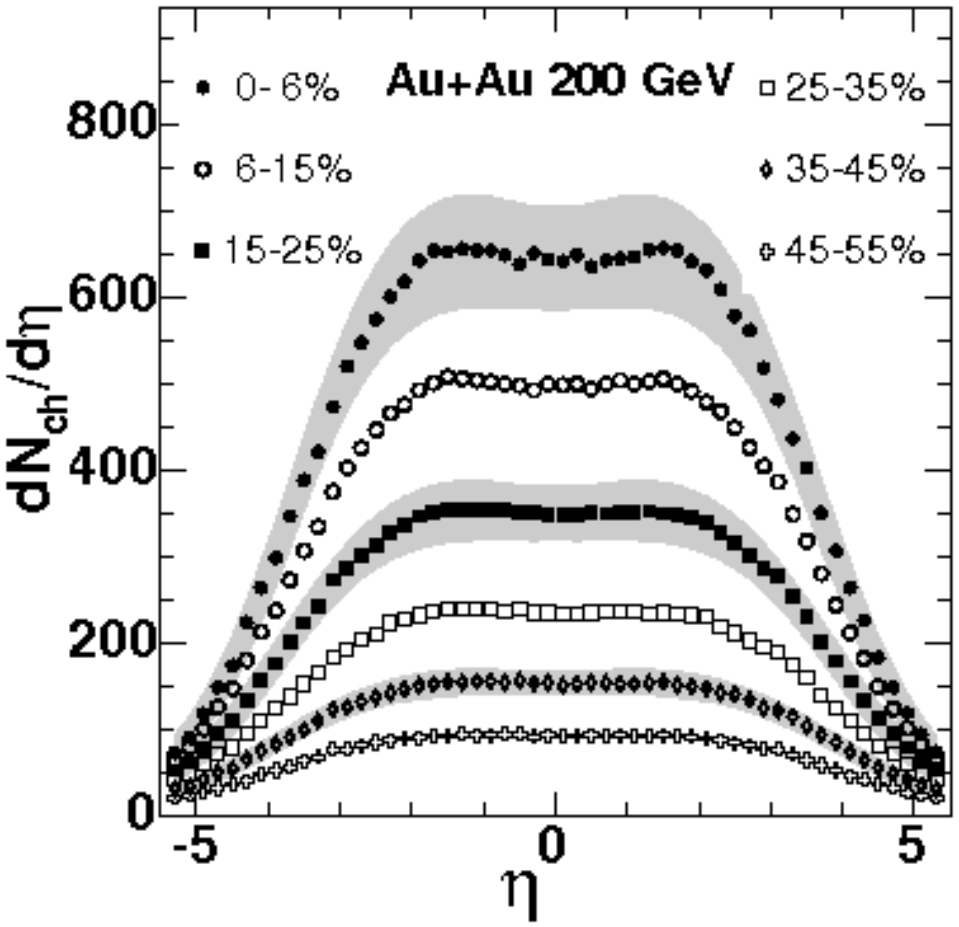
Occupancy



Assume total track=2*primary tracks:

Occupancy ≤ 5% (inner R)
10% (outer R)

in 0-3% Au+Au collisions at 200 GeV