STAR Upgrades & Physics Plans

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Thanks to D.Cebra, J.Thomas, E.Aschenauer, A.Schmah, J.Thomas
T.Lubijic and for slide content

BROOKHAVEN NATIONAL LABORATORY

Office of Science U.S. DEPARTMENT OF ENERGY

Overview

- RHIC future running
- BES-II
  - iTPC
  - Event Plane Detector (EPD)
- Farther Future
  - Forward Calorimetry System
  - Forward Tracking System

From Berndt Mullers presentation at Users meeting in June 2014:

Proposed run schedule for RHIC

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2014	15 GeV Au+Au 200 GeV Au+Au ^{3}He+Au at 200 GeV	Heavy flavor flow, energy loss, thermalization, etc. Quarkonium studies QCD critical point search	Electron lenses 56 MHz SRF STAR HFT STAR MTD
2015-16	Pol. p+p at 200 GeV p+Au, p+Si at 200 GeV High statistics Au+Au Pol. p+p at 510 GeV? Au+Au at 62 GeV?	Extract η/s(T) + constrain initial quantum fluctuations More heavy flavor studies Sphaleron tests Transverse spin physics	PHENIX MPC-EX Coherent e-cooling test
2017	No Run		Low energy e-cooling upgrade
2018-19	5-20 GeV Au+Au (BES-2)	Search for QCD critical point and onset of deconfinement	STAR ITPC upgrade Partial commissioning of sPHENIX (in 2019)
2020	No Run		Complete sPHENIX installation STAR forward upgrades
2021-22	200 GeV Au+Au with upgraded detectors Pol. p+p, p+Au at 200 GeV	Jet, di-jet, γ-jet probes of parton transport and energy loss mechanism Color screening for different quarkonia	sPHENIX
2023-24	No Runs		Transition to eRHIC

No run in 2017

No run in 2020

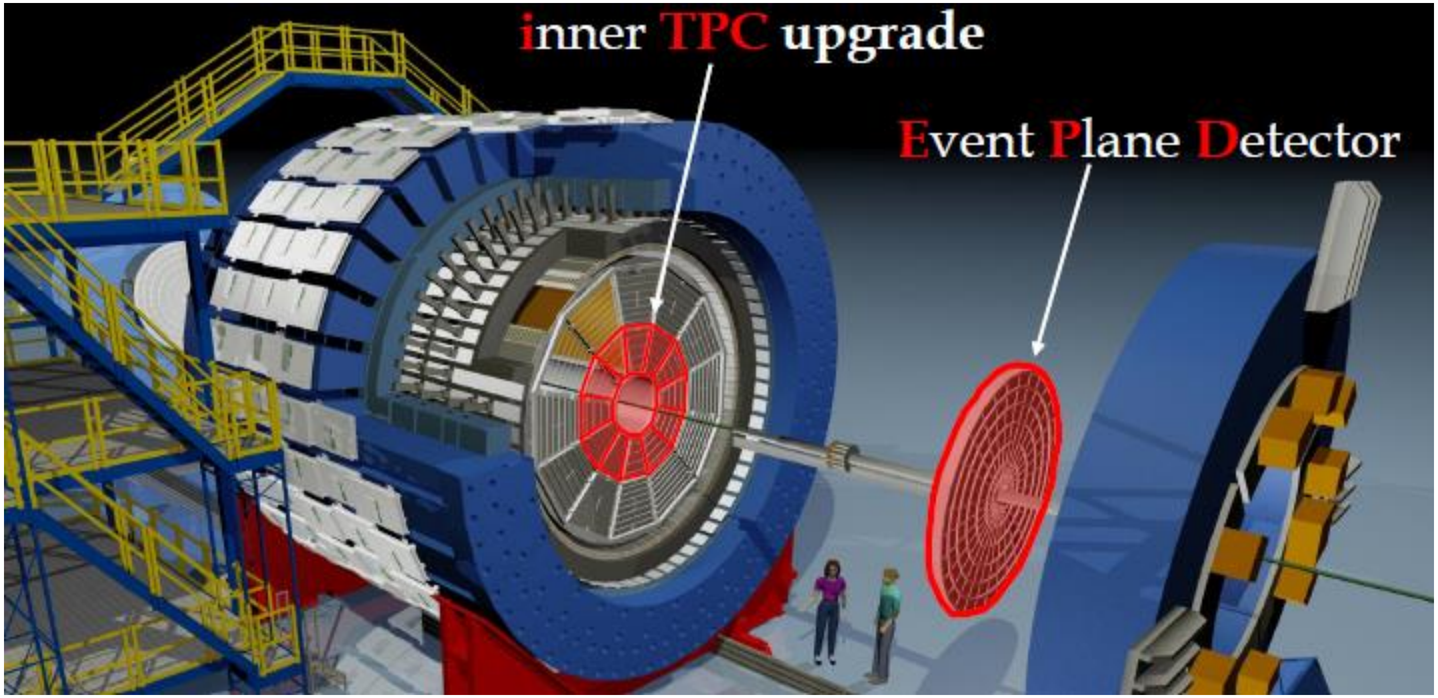
STAR upgrade time scale

15	16	17	18	19	20	21	22
Pp,pA	AuAu,	-	BES-II	BES-II	-	AA,pp,pA	AA,pp,pA
HFT,MTD,-FMS-PS							
	Buildl iTPC,						
			iTPC,EVD				
			Build FCS,FT,RP-II,HFT+				
						FCS,FT,RP-II	

HFT/MTD

- STAR completed two major upgrades for Run-14 – HFT and MTD
- H.Wieman will address performance of the PXL subsystem in this workshop
- Both systems are crucial to the STAR physics program for run 14,15, and 16 focusing on Heavy flavor – open charm, charmonium and quarkonium

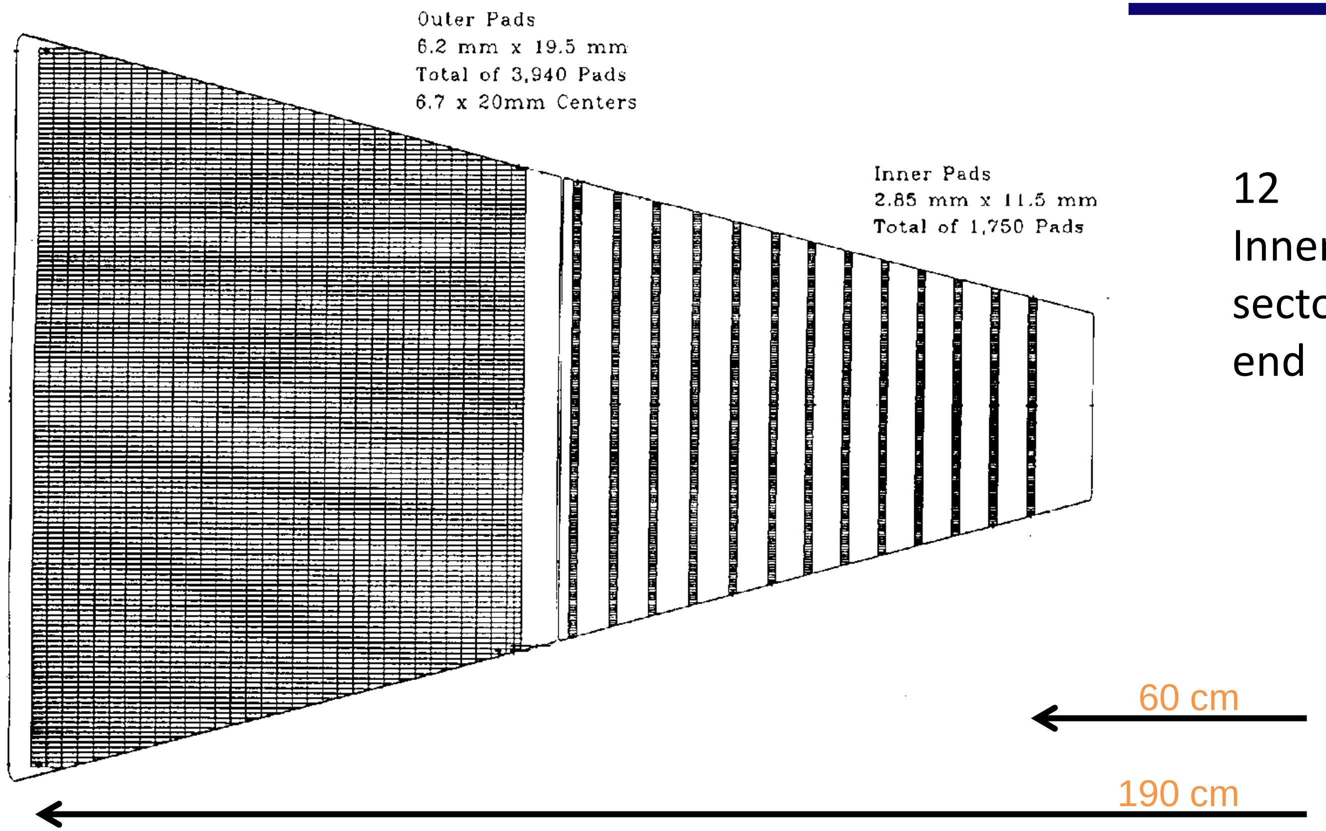
The STAR Upgrades -- iTPC



Several key physics analyses are improved by the additional capabilities of the iTPC:

- The directed flow measurements greatly improved with the extended η coverage
- The kurtosis studies are strongly dependent of acceptance and improved by more η coverage, the lower p_T cut, and the improved dE/dx
- The R_{CP} and ϕ meson studies benefit from the improved dE/dx
- Additional η dependent analysis (longitudinal studies are made possible)

Why upgrade the Inner Sectors?



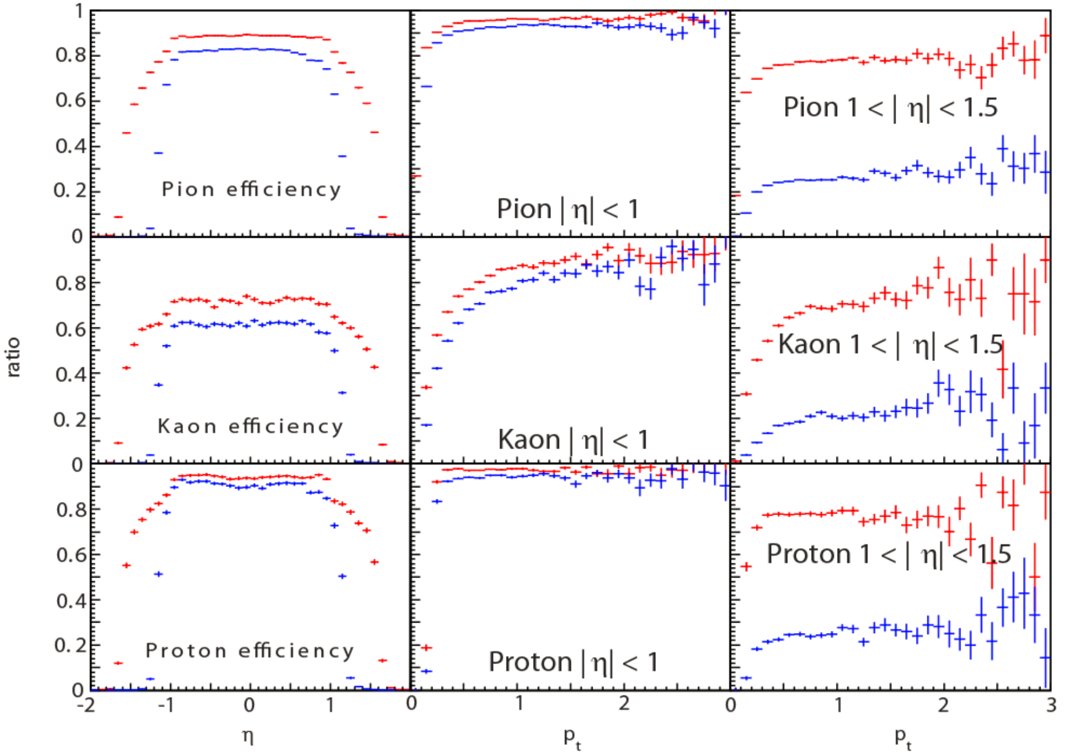
12 Inner/outer sector per end

- **The outer pad plane is hermetic … while the inner pad plane is not**
  - **Increase the segmentation on the inner pad plane!**
  - **Renew the inner sector wires which are showing signs of aging**

The upgrade will provide better momentum resolution, better dE/dx resolution, and improved acceptance at high η

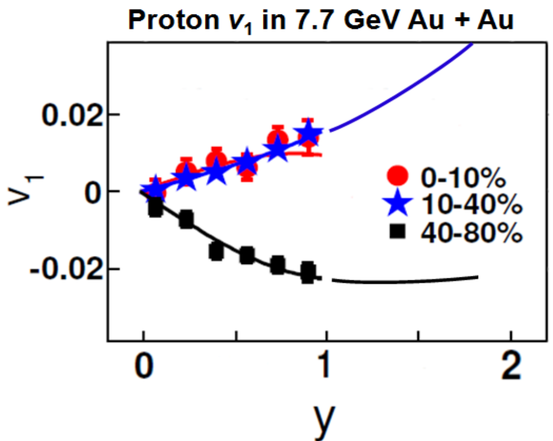
Coverage- improvements

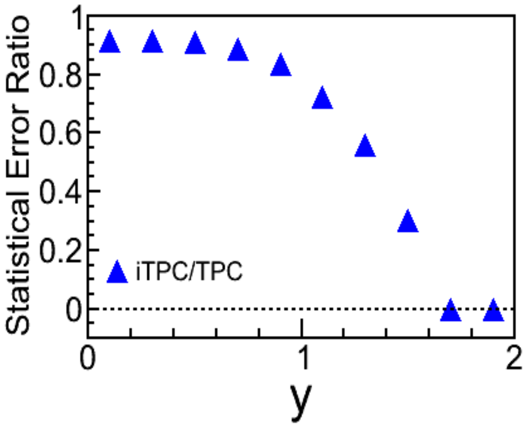
- The coverage will extend the eta range over which the TPC will have good acceptance.
- This is also important due to the extended vertex range expected in the BES-II era.



Directed flow

Phys. Rev. Lett. **112** (2014) 162301



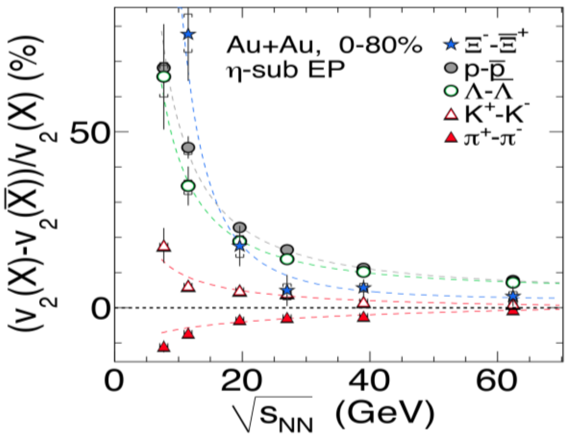


- Plotted points show measured directed flow $v_1(y)$ for protons in three centrality bins for Au + Au collisions at $\sqrt{s_{NN}}$ = 7.7 GeV.
- The solid curves are a cubic fit to the measured data points, and for intermediate and peripheral centralities, these curves are extrapolated into the rapidity region that will become accessible after the iTPC upgrade.

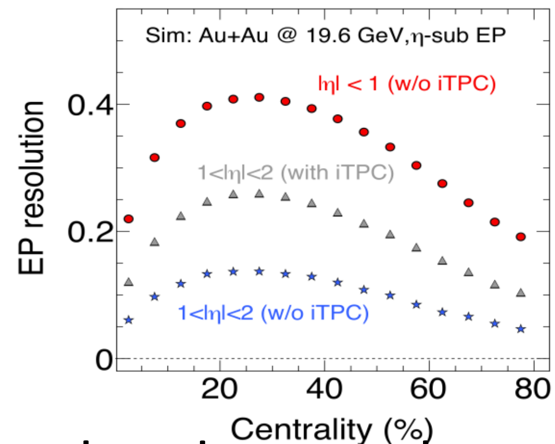
The improvement in statistical errors that would be achieved with the iTPC upgrade, for directed flow measurements at low RHIC energies as a function of rapidity, for any fixed number of events, based on simulations using the UrQMD model. Positive and negative rapidities give the same result, and are averaged in this plot. The two high rapidity points where a zero ratio is plotted correspond to acceptance regions where the present TPC provides no data whatsoever.

Flow and resolution

] L. Adamczyk *et al.*, (STAR Collaboration), Phys. Rev. Lett. **110**, 142301 (2013); Phys. Rev. C **88**, 014902 (2013).



The difference in v_2 between particles and their antiparticles as a function of $\sqrt{s_{NN}}$ for 0-80% central Au+Au collisions. The error bars depict the combined statistical and systematic errors.

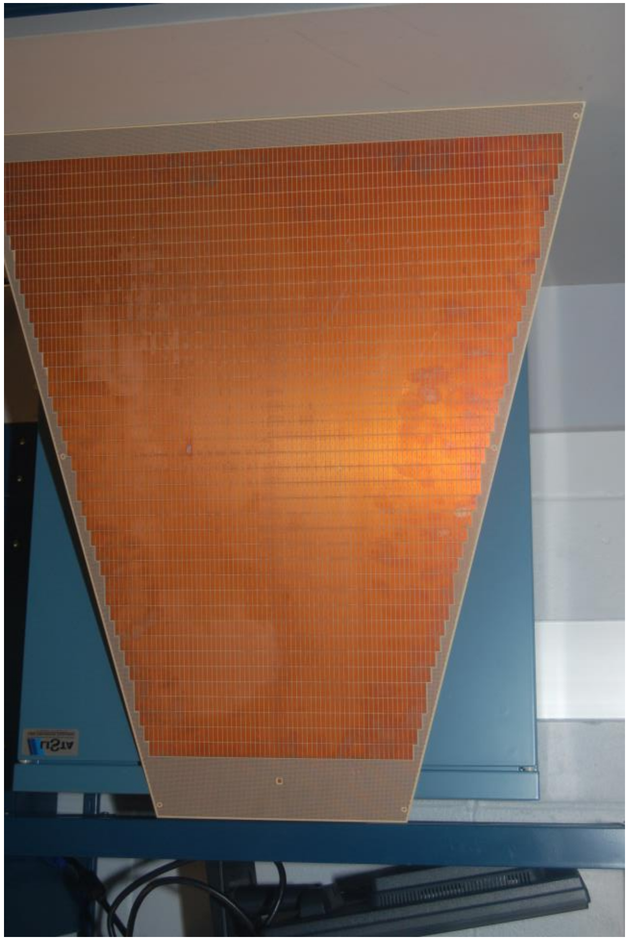


Simulated event plane resolutions as a function of centrality for Au+Au collisions at 19.6 GeV (η-sub method). A factor of ~2 improvement is observed in $1 < |\eta| < 2$ by using the iTPC.

Key ingredients for Upgrade

- 24 Inner sectors
  - Strong backs
  - MWPC
  - Pad plane
- Readout Electronics (since we double #channels)
  - iFEE with SAMPA chip
  - iRDO
- One examples on ingredients

Padplane and wire planes



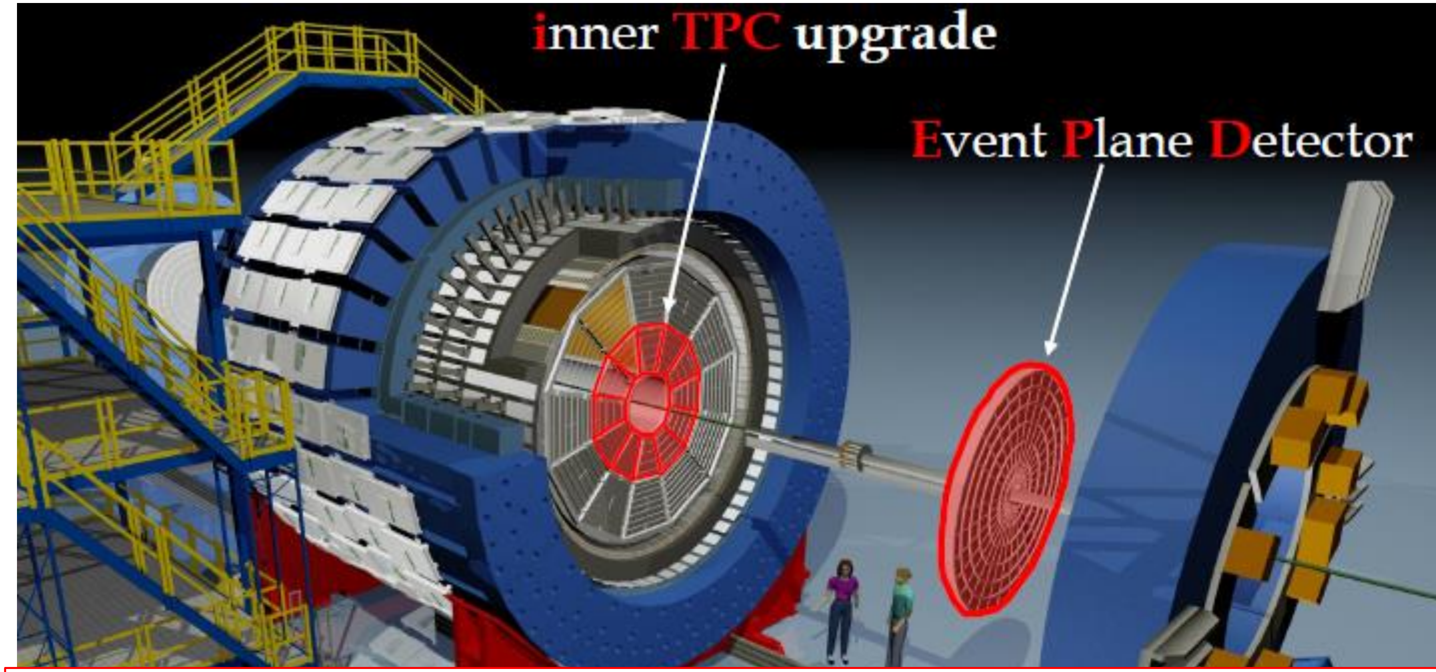
- The full area of the inner sectors are covered
- # pads ~ 2* current design.
- Electronics much more dense.
- Several planes needed
  - Anode, ground, gating grid
  - Precisely positioned wire relative to pads
- Precision work and tooling required

High Density Electronics

1. Front End Electronics (iFFE)
2. Readout Board (iRDO)
3. Miscellaneous electronics cards and smaller modules

- Completely new FEE design
  - 128 channels per iFEE (32 for current TPX)
  - New "SAMPA" ASIC
    - 32 channel preamplifier & shaper with ADC & digital pedestal subtraction, zero-suppression & storage (4 per iFEE)
    - analog front end has programmable input signal polarity, gain and shaping time (for both wire chambers & GEM-like detectors)
  - Designed for ALICE@CERN by Sao Paolo team (TPC upgrade)
  - R&D at BNL is moving well along

The STAR Upgrades – Event Plane Detector



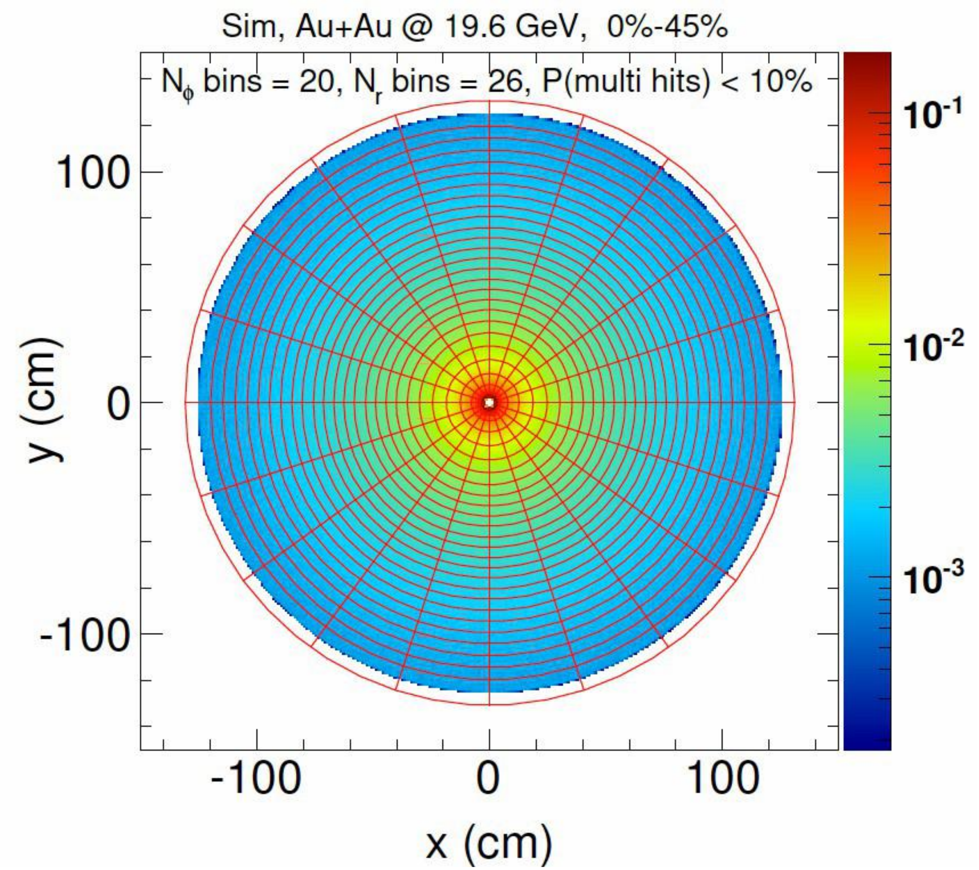
Several key physics analyses are improved by the additional capabilities of the EPD:

- The directed flow, elliptic flow, and CME studies are improved using a quality reaction definition using detectors well separated in η from the region of interest (analysis)
- Provides a better centrality definition for the Kurtosis measurement

EPD specifications

- Large rapidity gap relative to the TPC to minimize non-flow effects and physics correlations
- Significant azimuthal segmentation for good Event Plane (EP) resolution (v_1, v_2, v_3, v_n)
- Significant radial (η) segmentation to reduce (EP) biases
- Large acceptance to maximize the EP resolution
- Symmetric in pseudo rapidity (east and west side) to determine an unbiased EP resolution and to measure as many particles as possible
- Fine granularity (single) hit determination for goodEP and centrality resolution

EPD details



Pie shape detector setup is optimal

→ symmetry, η segmentation

● Large area to be covered

→ plastic scintillator (fast, efficient,

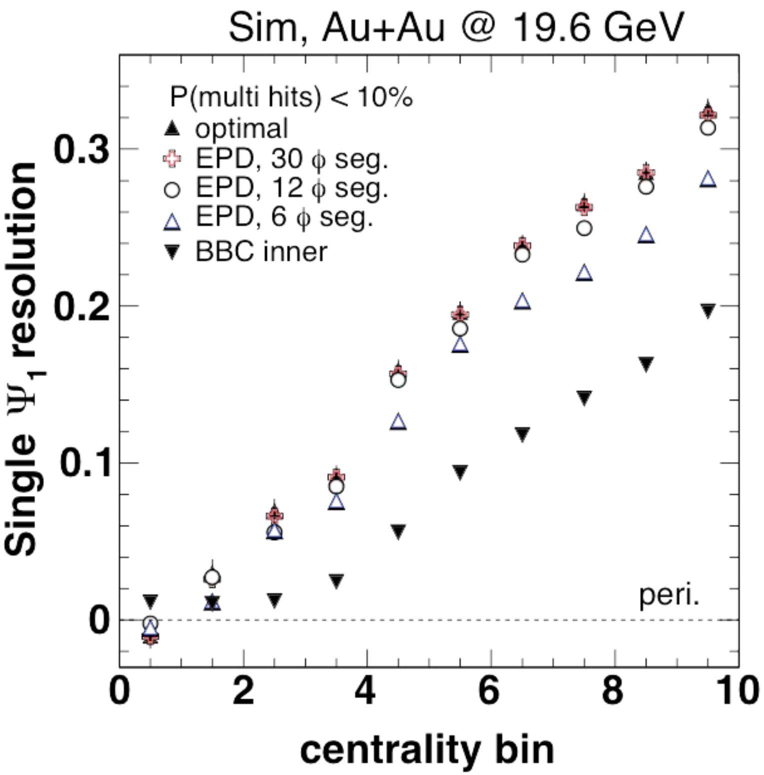
cheap)

● Silicon PhotoMultiplier (SiPM) for readout

→ cheap, equivalent to standard photomultiplier

● Detector will be optimized for a limited amount of different tile shapes for cost efficiency

Expected Performance and Status



- Event plane resolution studied as a function of centrality and for different EPD setups
- Optimum reached for >= 12 azimuthal segments
- Factor 2-4 difference for first harmonic EP resolution compared to BBC

R&D currently on-going
Proposal by end FY15
Built and ready for run-18

2020+ FCS & HFT+

- Physics program
  - pp, pA (Spin & Gluon Saturation)
  - AA (long range correlations)
- Components
  - Forward Calorimetry System (FCS)
  - Forward tracking (pp)

Physics at end of decade

Critical Questions:

- *What are the dynamics of partons at very small and very large momentum fraction (x) in nuclei, and at high gluon-density.*
  What are the nonlinear evolution effects (i.e. saturation)?
- *What are the pQCD mechanisms that cause energy loss of partons in CNM, and is this intimately related to transverse momentum broadening?*
- *What are the detailed hadronization mechanisms and time scales and how are they modified in the nuclear environment?*

- measure tensor charge $\int_0^1 (\delta q^f(x) - \delta \bar{q}^f(x))dx$ → connection to lattice
- difference between $\delta q(x)$ and $\Delta q(x)$ allows to study orbital angular momentum in wave functions.

- Rapid rise in gluons described naturally by linear pQCD evolution equations
- This rise cannot increase forever - limits on the cross-section
  → non-linear pQCD evolution equations provide a natural way to tame this growth and lead to a saturation of gluons, characterized by the saturation scale $Q^2_s(x)$

Forward AA program

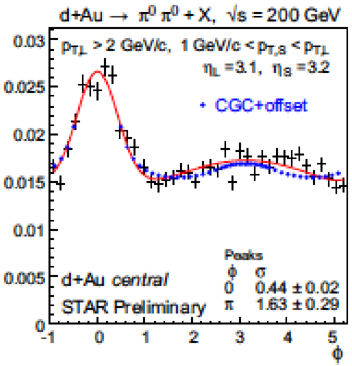
Long range energy flow correlation with forward measurements

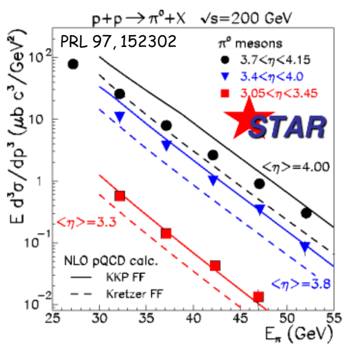
Fourier expansion of FCal ET distribution:

(ATLAS, CMS method)

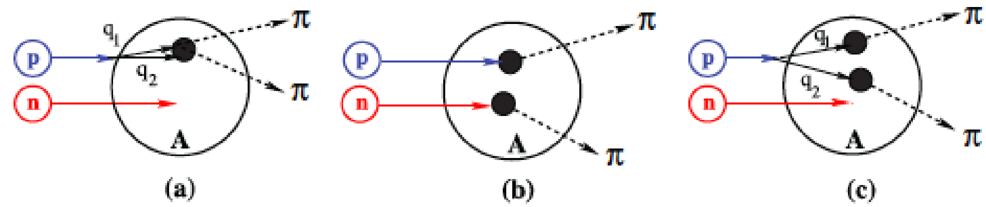
Event shape selection
0th order event-shape selection: Centrality by ΣE_T (system size)
2nd order event-shape selection: ellipticity by q2 (system shape)
3rd order event-shape selection: triangularity by q3 (system shape)

Correlations: Di-Hadron and γ-Jet



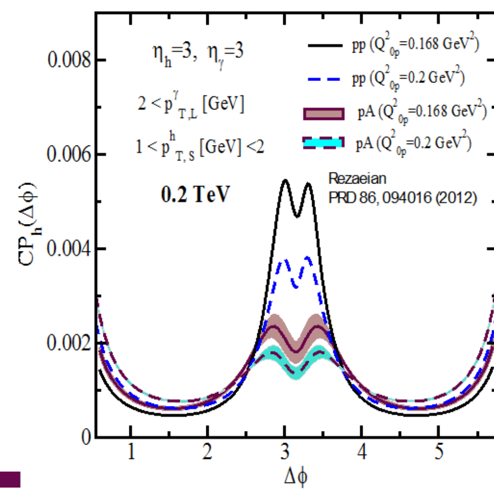


Phys.Rev.D83 (2011)034029
two-pion production in d+A collisions through the double-interaction mechanism



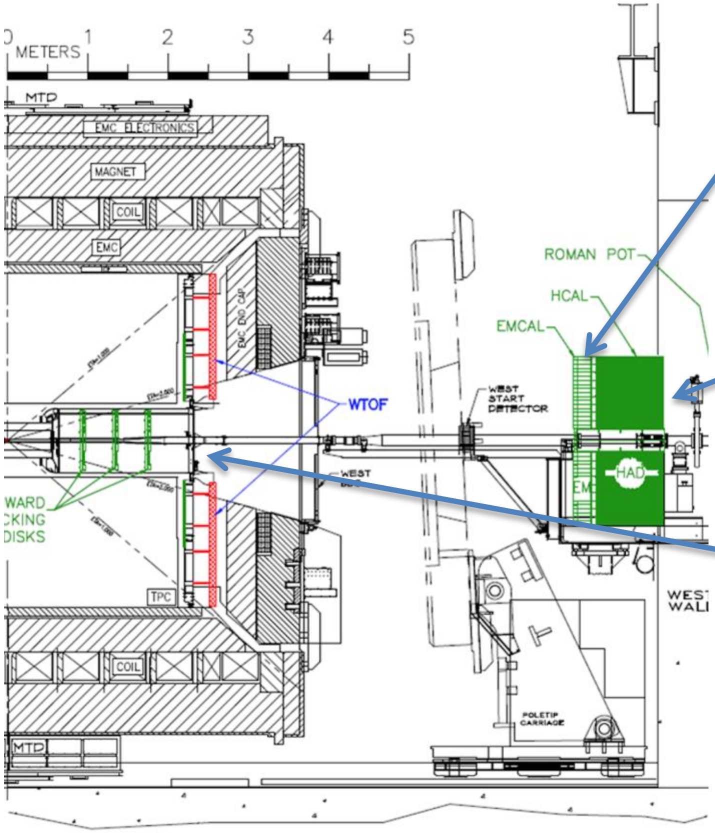
2020+ pA runs:

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



0.001<x<0.005

STAR Forward Upgrades for 2020+



ECal:

Tungsten-Powder-Scintillating-fiber
2.3 cm Moliere Radius, Tower-size:
$2.5\times2.5\times17$ cm^3
23 X_o

HCal:

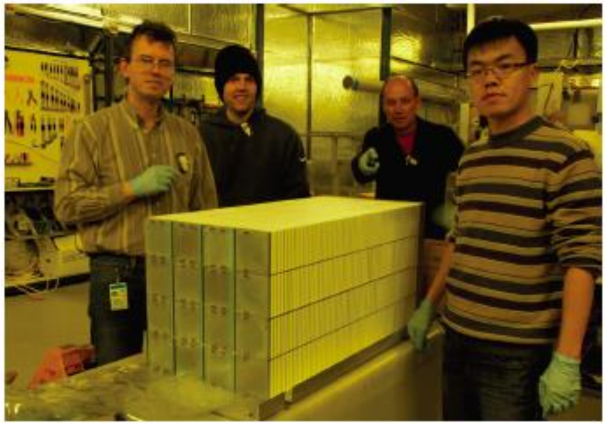
Lead and Scintillator tiles, Tower size of
$10\times10\times81$ cm^3
4 interaction length

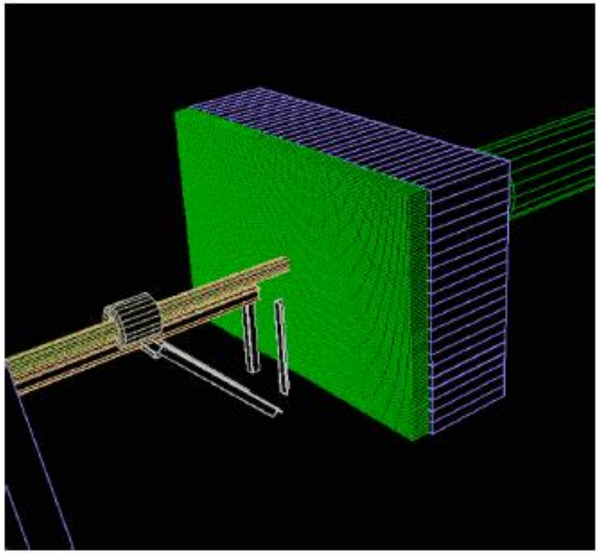
Tracking:

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

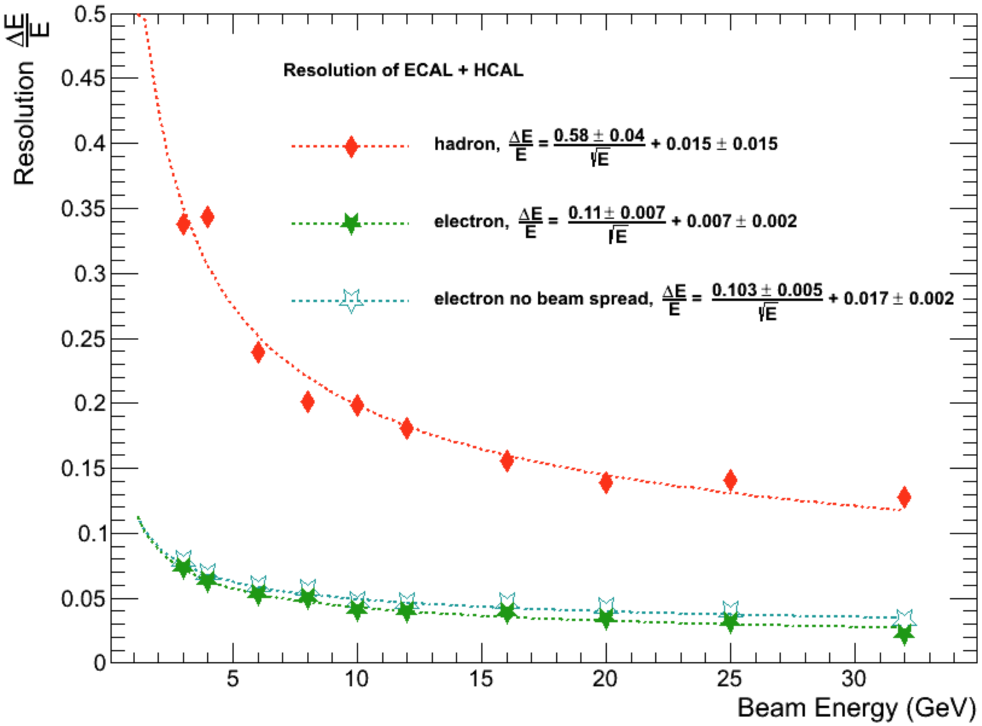
STAR LOI on pp and pA was written in 2014 as part of RHIC planning process
https://drupal.star.bnl.gov/STAR/starnotes/public/sn0605

Calorimetry



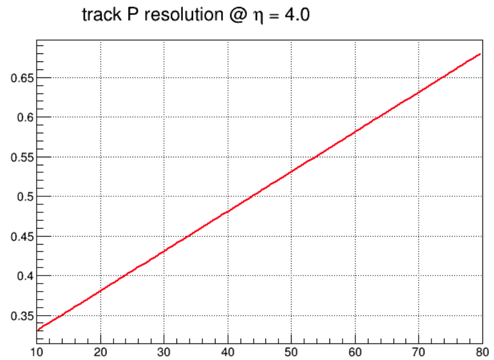


Ecal SpaCal design developed by UCLA and also leading candidate for sPHENIX
Future use in EIC detectors
Excellent Energy resolution.



Tracking

Forwards Tracking:
Silicon mini-strip detector
3-4 disks at z ~70 to 140 cm
Each disk has wedges covering full 2π range in ϕ and 2.5-4 in η
→ other options still under study e.g GEM



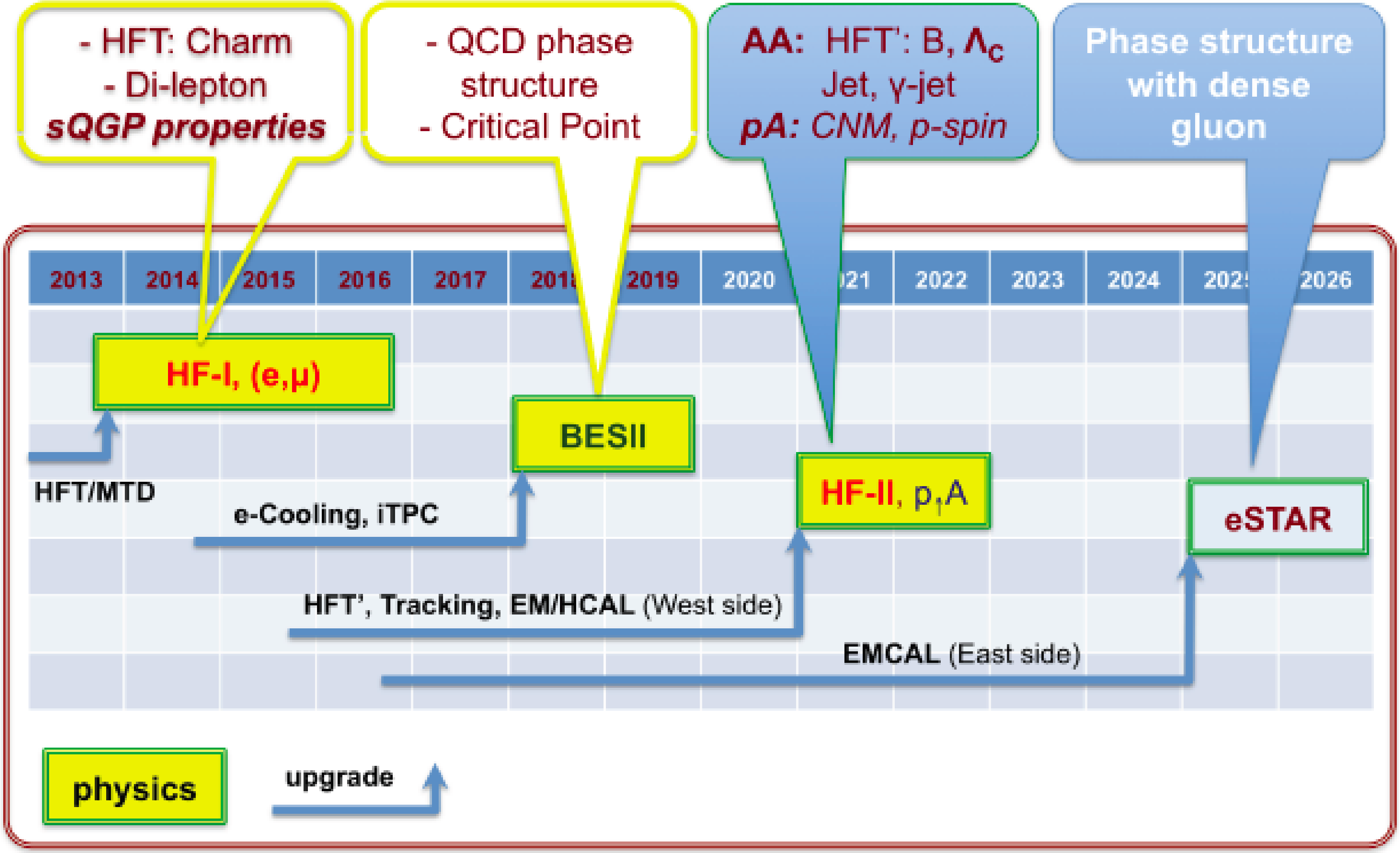
HFT+

Mid-rapidity upgrade: Λ_C and bottom production at RHIC, complimentary with LHC HF-jets and sPHENIX jets programs

Consider a faster Maps detector with readout < TPC.

If triggerable could lead to significant measurements of bottom quarks at RHIC.

STAR: Upgrade Plan



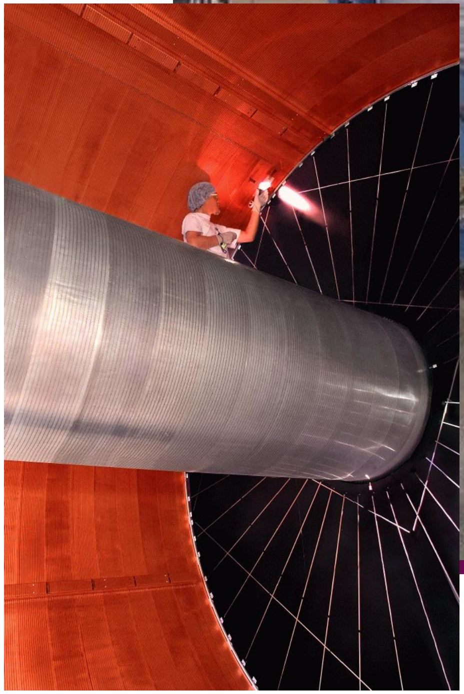
BACKUP

Physics Motivation

- **Study of the QCD phase diagram (Beam Energy Scan Phase II)**
  - Increase η coverage for hadron acceptance and correlation studies
  - Improve low-p_T coverage for hyperon reconstruction
  - Increase dE/dx resolution for particle identification
  - High eta coverage for fixed-target datasets
- **Study of the QGP Properties**
  - A tool to systematically map chiral symmetry restorations
  - Improve low-p_T coverage for weak-decay reconstruction
  - Heavy-Flavor physics by increasing η coverage
  - Heavy-Flavor physics by increasing dE/dx resolution
  - Identified high-p_T hadron spectra and correlation for understanding jets
- **Spin structure in polarized p+p collisions (2020+)**
  - Improved forward tracking
  - Interference Fragmentation Functions at high x
  - Rapidity dependence of Lambda hyperon polarization

The STAR TPC Under Construction at LBL

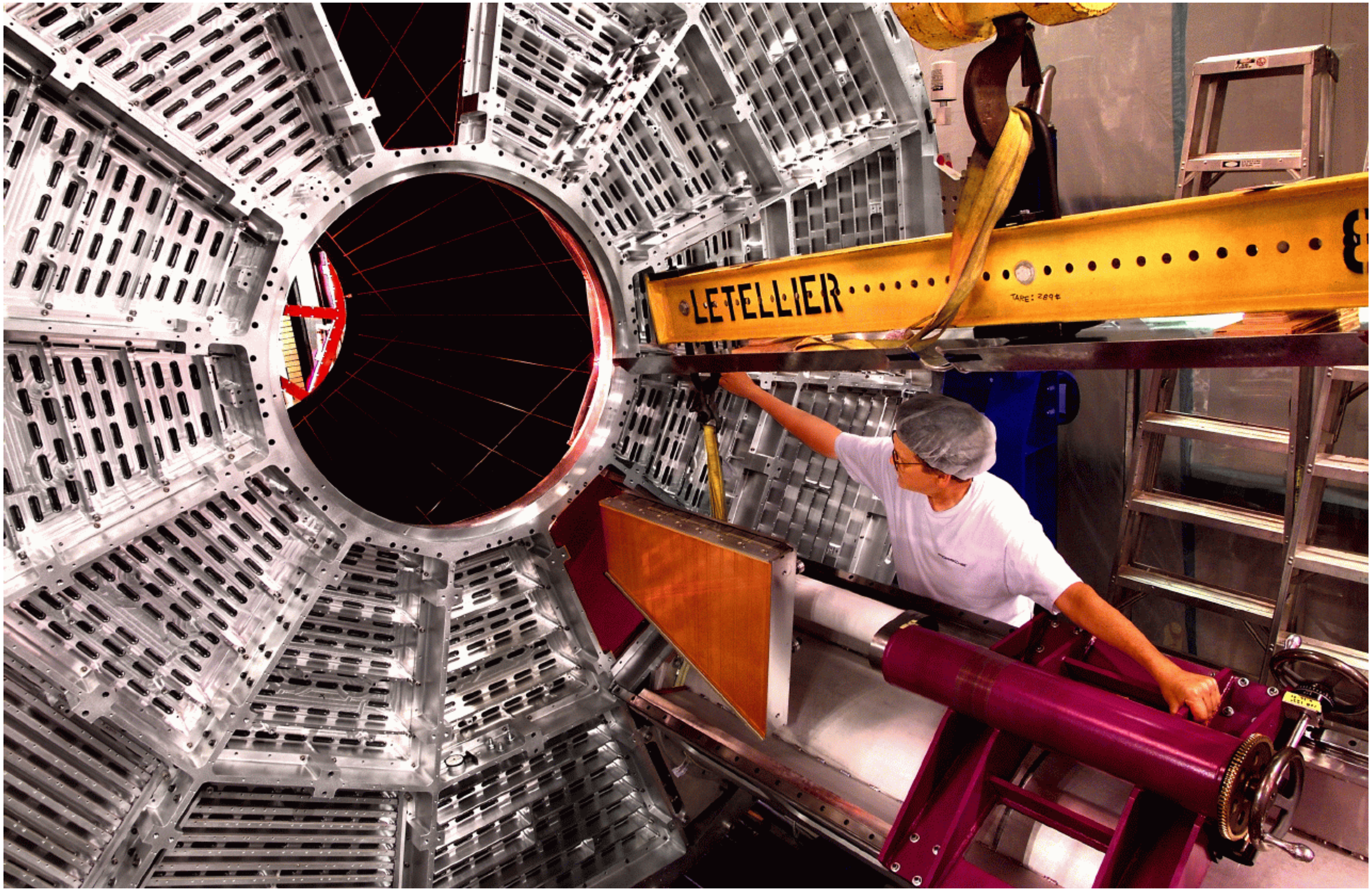
Anno 1996



First Successful Mating of:

- **Gas Vessel**
- **Outer Field Cage**
- **Sector Wheels**
- **Central membrane**

Sector Insertion



Strongbacks

- Pad Plane Support
- Initially considered radically different design to reduce mass dramatically.
- Constructed two copies of existing design.
- Will only make minor modifications to this design as needed (wire spacing, -gridleak)

Transverse Spin Physics at the end of the Decade

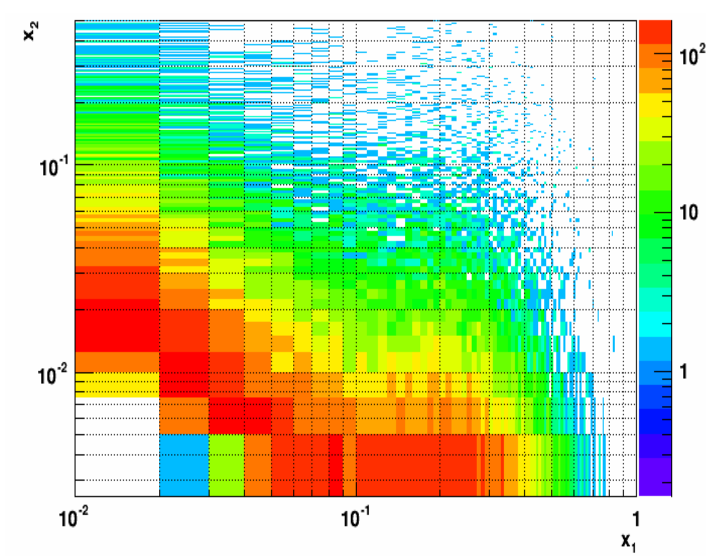
Bring mid rapidity observables (jets, IFF, ..) to high rapidities → high x

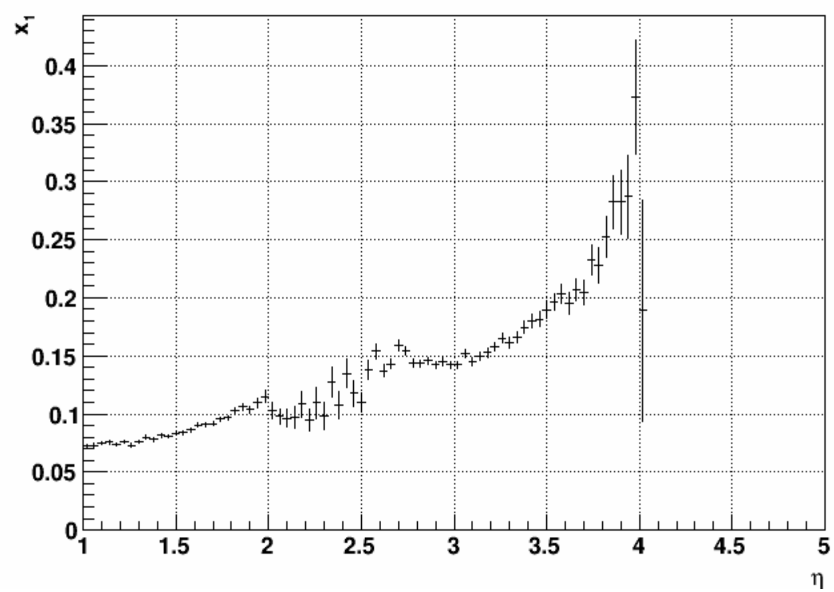
Needs:

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

Address the following questions:

- measure tensor charge $\int_0^1 (\delta q^f(x) - \delta \bar{q}^f(x))dx$ → 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 $\delta q^f(x,Q^2) < \left| q^f(x,Q^2) - \Delta q^f(x,Q^2) \right| / 2$





Cuts: 2.8 <| < 3.5 and jet p_t > 3 GeV

The beauty of RHIC

mix and match beams as one likes

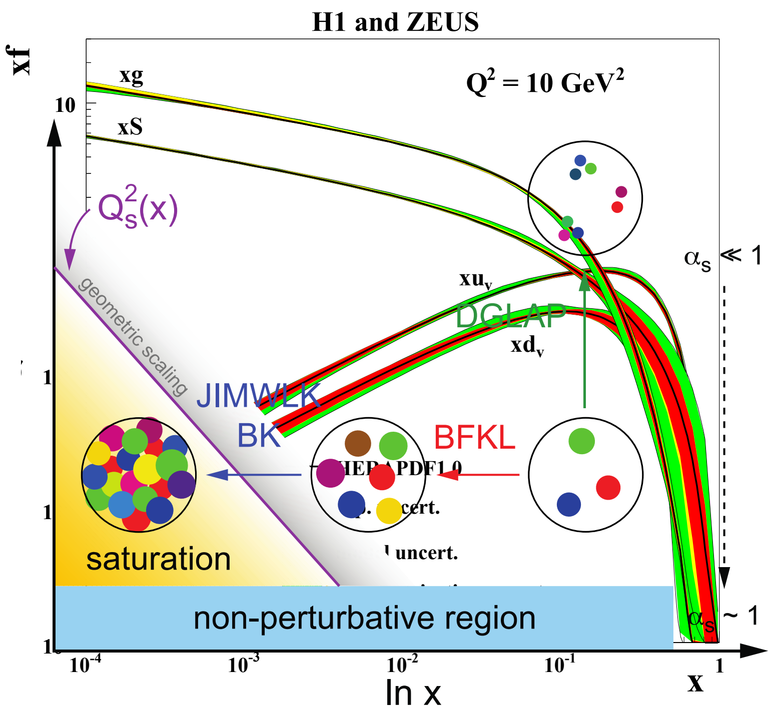
→ **polarised p↑(d,He)A** (Au, C, Cu, …)

→ A-scan unique to RHIC

Critical Questions:

- *What are the dynamics of partons at very small and very large momentum fraction (x) in nuclei, and at high gluon-density.*
  What are the nonlinear evolution effects (i.e. saturation)?
- *What are the pQCD mechanisms that cause energy loss of partons in CNM, and is this intimately related to transverse momentum broadening?*
- *What are the detailed hadronization mechanisms and time scales and how are they modified in the nuclear environment?*

Do Gluons Saturate



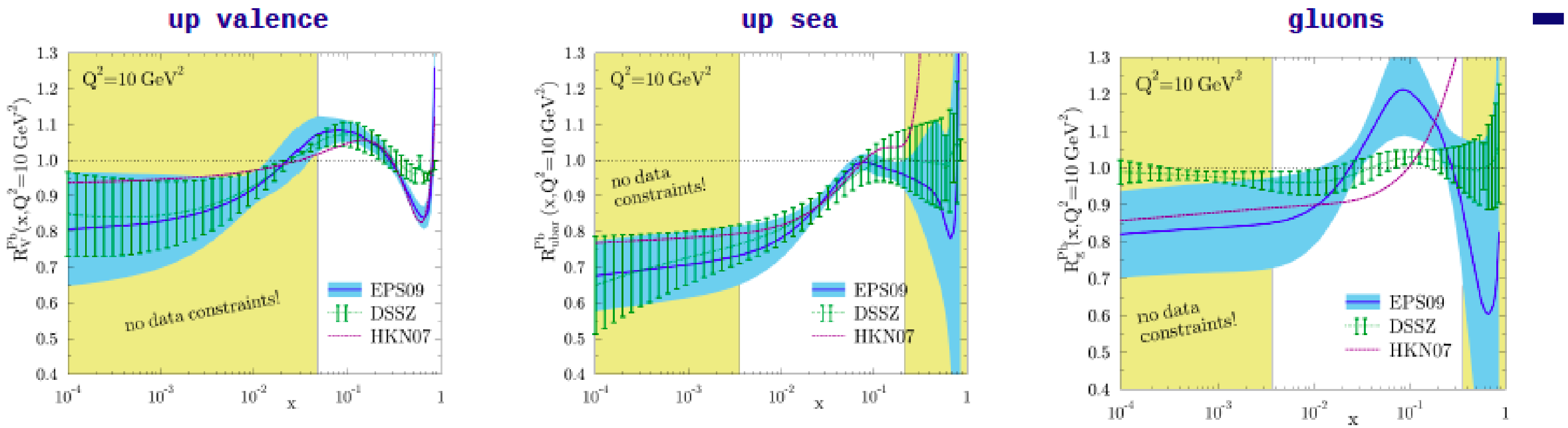
Gluon density dominates at x<0.1

- Rapid rise in gluons described naturally by linear pQCD evolution equations
- This rise cannot increase forever - limits on the cross-section

  → non-linear pQCD evolution equations provide a natural way to tame this growth and lead to a saturation of gluons, characterised by the saturation scale $Q^2_s(x)$

Current situation: before LHC-data are included

nuclear PDFs



DGLAP: predicts Q^2 but no A-dependence and x-dependence

Saturation models: predicts A-dependence and x-dependence but not Q^2

H. Paukkunen, DIS-2014

Need: Q^2 lever-arm → LHC-RHIC   A-scan: RHIC

Observables addressed :

- ❑ UPC pA: $g(x,Q^2,b)$
- ❑ direct photon: R_{pA}
- ❑ Di-hadron correlation measurements
- ❑ A_N^{pA}/A_N^{pp}
- ❑ Direct-photon Jet correlations
- ❑ R_{pA} for DY

} FCS + FTS → 2020+

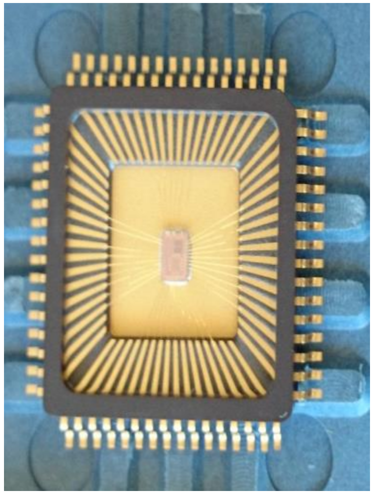
SAMPA

- 3 different prototypes were submitted as part of the MWP1 step
  - "chip 1" → just the analog preamplifier+shaper
  - "chip 2" → just the ADC
  - "chip 3" → only 3 channels of the semi-complete chain: shaper, ADC, some digital manipulation logic

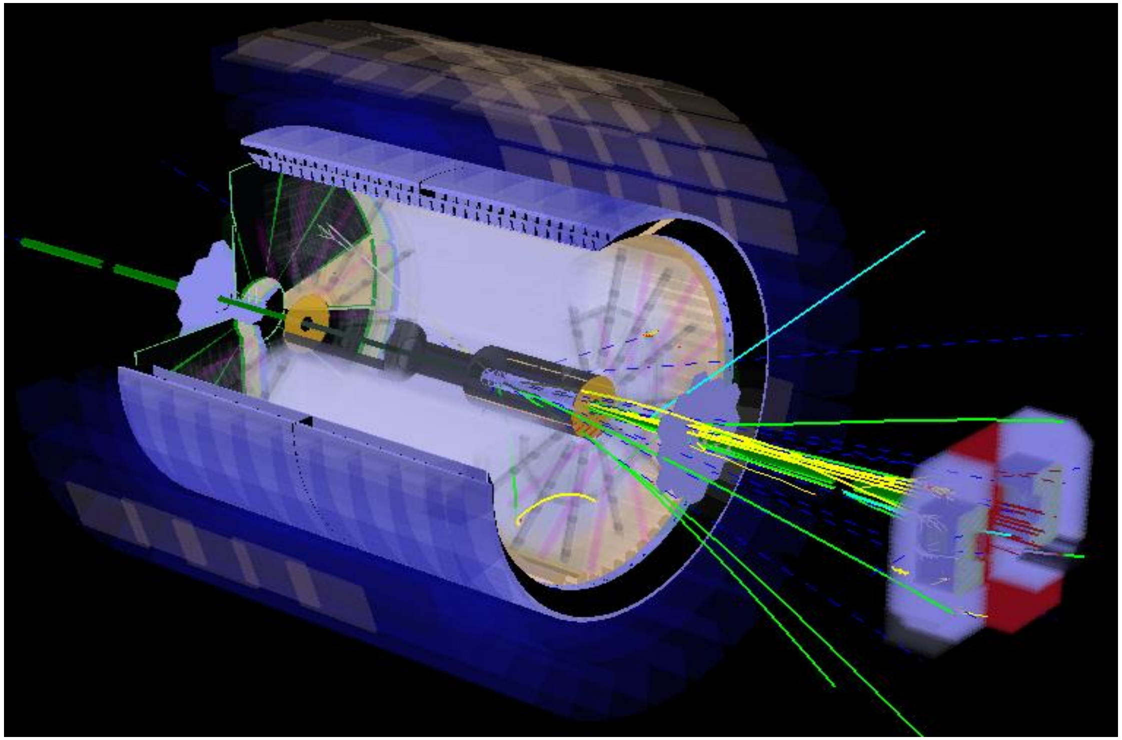
- prototypes are back from the foundry (packaged already)

MWP1 "chip 3"
(3channel version)

MWP1 "chip 1"
(preamp/shaper)



Schematic outline of FCS



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