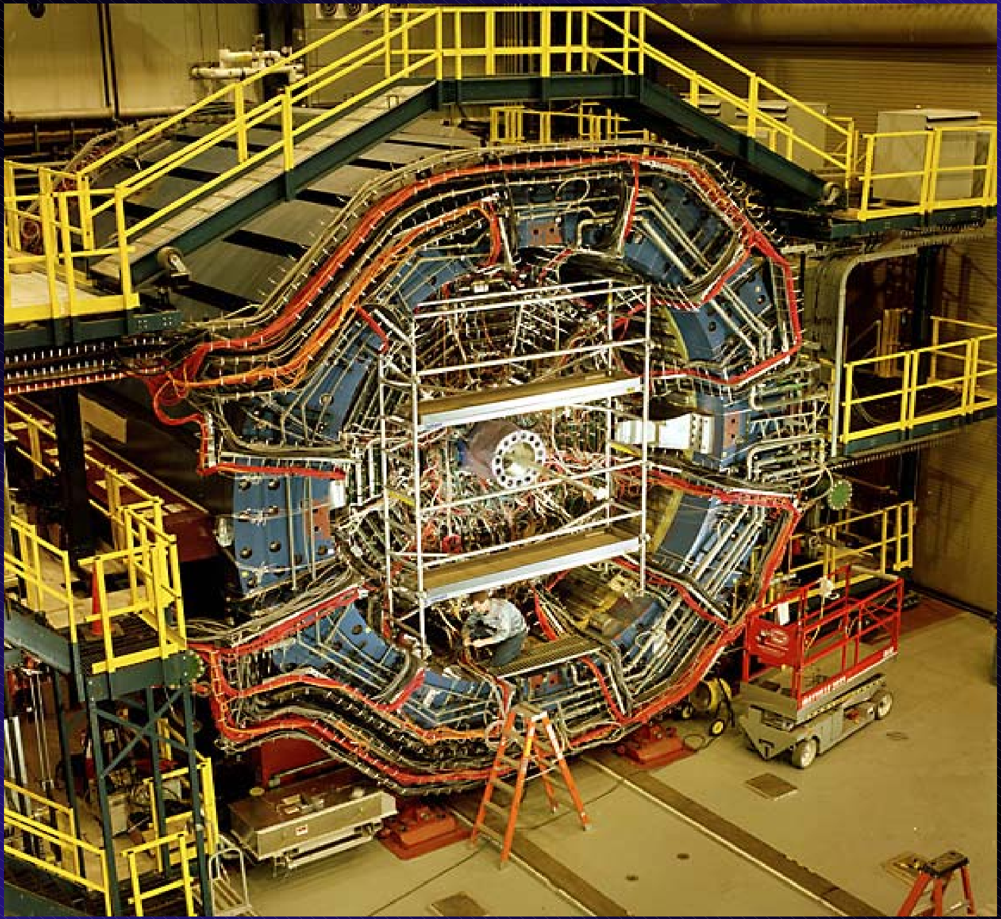
The STAR Future Program



Tim Hallman

NSAC Relativistic Heavy Ion Review
June 2-6, 2004

BROOKHAVEN NATIONAL LABORATORY

Office of Science
U.S. DEPARTMENT OF ENERGY

The Plan of the Talk

- Brief Status of the search for the QGP
- "Must do" physics in the next 5+ years
- The STAR scientific strategy for the future
- Compelling science at the RHIC II QCD Laboratory
- Implications for upgraded detector capability
- STAR Detector in the era of RHIC II
- Conclusions

Main topic: provide a vision of the compelling science STAR proposes to accomplish (a picture being developed)

- high Q^2 (triggered) probes $\Rightarrow$ high luminosity, good tracking, and vertexing
- studies of bulk phenomena $\Rightarrow$ fast DAQ, FEE

The Ongoing Scientific Journey at RHIC

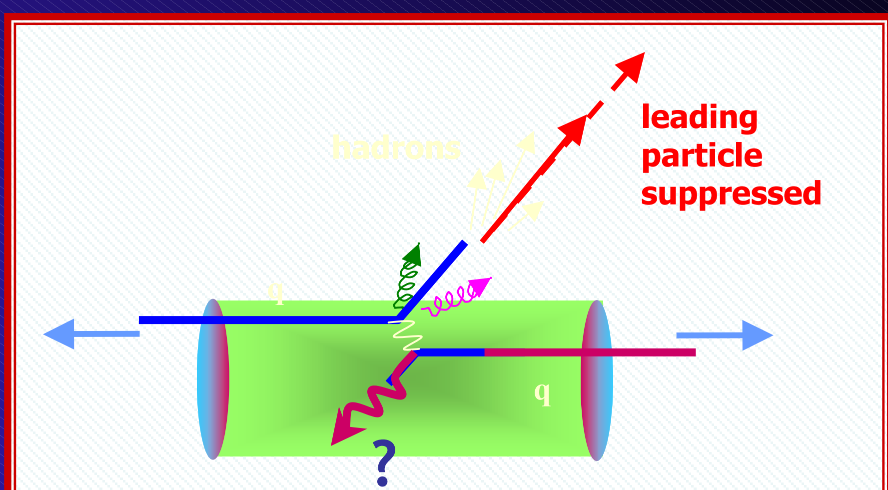
Search and discovery ⟶ Exploring new states of matter

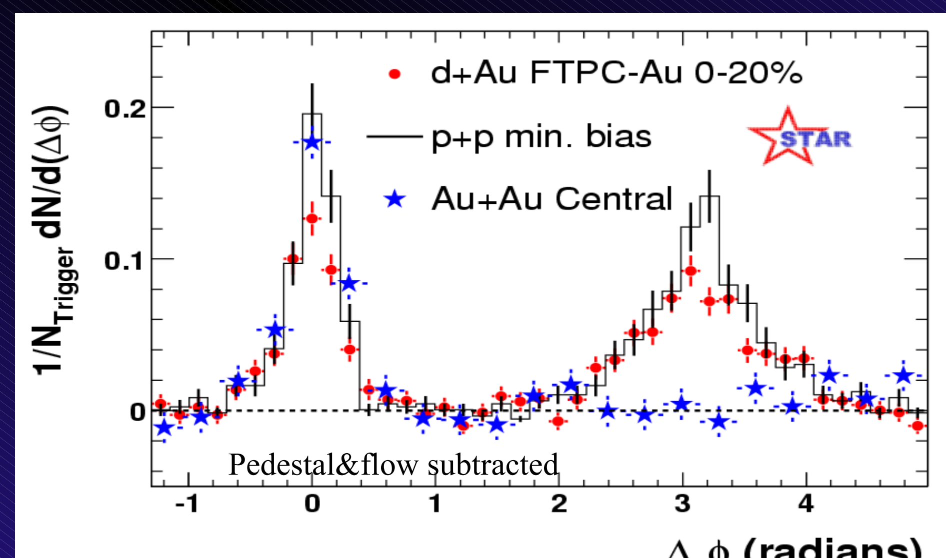
Do we have "Matter" at high energy density?

- Strong collective interaction; local kinetic equilibrium…
  Large volume compared with mean free path?
  ………………… **Yes**

Is it quarks and gluons?

- Temperature and energy density well above critical values? ……………… **Yes**
- Strong collective interaction at very early times? …………………… **Very likely yes**
- Color screening in dense phase? ……………………………… **First results coming soon**
- Opaque to jets? ………………………………………………………………………………… **Yes**

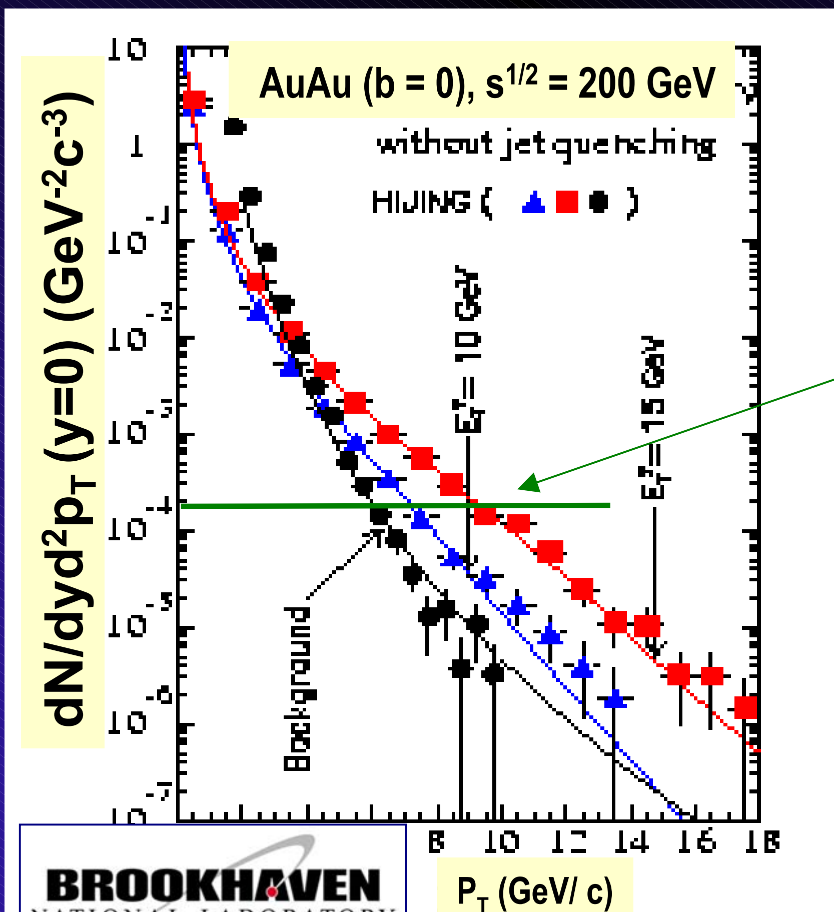




One thing apparent right away: rare probes need higher luminosity

Quantitative measurements of partonic energy loss

High p_T hadrons in coincidence with γ



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Measurement of the gluon density via direct γ + jet and flavor-tagged jets to study the quark mass dependence of energy loss

- **Leading hadrons are very rare: only ~0.1% of jets fragment hard enough that hadrons are above incoherent background**
- **cross section for γ + jet coincidences (central Au+Au):**
  - **E_γ=10 GeV: 6 nb/GeV**
  - **E_γ=15 GeV: 0.6 nb/GeV**
- **50 weeks of Au+Au @ RHIC I design: 10 nb^{-1} !! $\rightarrow$ luminosity upgrade needed to access this physics!**

Table 1. Prominent aspects of the STAR 10-year physics program, and their needs.

Proposed Measurement	Physics Goal	STAR Upgrades Needed	RHIC L Needed	Open Issues	Proposed Timeline
Heavy Ion Program					
Elliptic flow for hadrons with no light valence quarks	Evidence of partonic collectivity & thermaliz'n	Partial Barrel TOF	2 × present Au+Au	Mean free path of ϕ, J/ψ and Ω in hadronic matter.	2004-7
Upsilon yields and spectra	Temperature and gluon density of partonic matter	EMC completion with preshower	2 × present Au+Au	Is open *b* production needed in addition to interpret Ψ yields?	2004-10
Away-side jet suppression vs. E_T and $\Delta\eta$	Quark vs. gluon energy loss in partonic matter	EMC completion	2 × present Au+Au	Measurement of $\Delta\eta$ in the presence of jet quenching.	2004-10
Coherent J/ψ, open charm photoproduction in UPC	Search for strong gluon shadowing in heavy nuclei	EMC completion, μ-vertex	1—2 × present Au+Au	Hadron absorption in nucleus. Cleanliness of open charm signal.	2004-10
Fluctuation/ correlation studies with PID	Distinguish QCD dynamical effects on temp. and velocity distrib'ns	Complete Barrel TOF	Present Au+Au	Can different non-statistical effects be unraveled?	2007-2009
Away-side jet fragmentation yields, spectra	Search for effects of chiral and $U_A(1)$ symmetry restoration	Barrel TOF, fast DAQ	2 × present Au+Au	Selectivity for "early" hadrons formed in bulk partonic matter.	2007-9

"Present" = 4×10^{26} cm^{-2}sec^{-1} (Run IV AuAu Performance)

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Proposed Measurement	Physics Goal	STAR Upgrades Needed	RHIC L Needed	Open Issues	Proposed Timeline
Heavy Ion Program					
Yields, spectra of high-mass resonances	Duration and properties of the late-stage hadronic medium	Barrel TOF, fast DAQ	2 × present Au+Au		2007-9
Charmed hadron flow and yield ratios	Partonic collect-ivity & charmed quark thermaliz'n	Barrel TOF, μ-vertex, fast DAQ	2 × present Au+Au	D mean free path. Robustness of subtle thermaliz'n effects.	2007-10
Heavy quark jets; D,B-meson spectra at high p_T	Energy loss of heavy vs. light quarks in partonic matter	Barrel TOF, μ-vertex, fast DAQ	2× present Au+Au	Backgrounds for displaced lepton-hadron vertex tag.	2007-10
$\Lambda, \bar{\Lambda}$ longitudinal pol'n correl'ns	CP violation search	New inner tracker, barrel TOF, fast DAQ	2 × present Au+Au	Hyperon ID efficiency. Backgrounds and false signals.	2008-10
Direct photon spectrum via γγ HBT	Temperature of partonic matter	Replace TPC, pair spectrometer, fast DAQ	2-20 × present Au+Au	EMC upgrade needed for full 3-D. Un- folding early vs. late collision stage effects.	2013-15
γ-Tagged jets	Direct measure of parton energy loss	EMC completion; TPC replacement	20 × present Au+Au	Discrimination against background π^0, fragmentation γ.	2013-15

"Present" = 4×10^{26} cm^{-2}sec^{-1} (Run IV AuAu Performance)

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Proposed Measurement	Physics Goal	STAR Upgrades Needed	RHIC L Needed	Open Issues	Proposed Timeline
Spin Program					
A_{LL} for photon-jet coincidences	Determine gluon polarization in polarized proton	Full EMC (with preshower @ 500 GeV)	Design L, P=0.7 @ 200 + 500 GeV	Will design beam properties be attained?	2005-9
Parity-violating asymmetries for $W^{\pm}$ prod'n	Flavor dependence of sea anti-quark pol'ns	Full EMC + pre/postshower; fwd tracker; new TPC FEE (fast DAQ)	Design L, P=0.7 @ 500 GeV	Will design beam properties be attained?	2008-10
Transverse spin + jet fragment'n asymmetries	Quark transversity in polarized proton	Forward hadron calorimeter; barrel TOF	0.3-0.5 $\times$ design L, P>0.5 @ 200 GeV	Magnitude of jet fragmentation asymmetries.	2005-9
Transverse spin asymmetries for b-quark and very high p_T jets	Effects of quark mass-dependent terms in QCD; quark transversity	μVertex; forward tracker	2-4 $\times$ design L, P=0.7 @ 200 GeV	Is transversity still an issue on relevant time scale?	2010-12
Parity-violating asymmetries for very hard jets	Search for new ultra-short-range interactions	TPC replacement to handle luminosity	10 $\times$ design L, P=0.7 @ 650 GeV	Is jet energy recon-structable without hadron calorimeter?	2013 & beyond
Parity-violating asymmetries for W^{+}-n coincidence	Chiral structure of proton: purity of $n\pi^{+}$ configuration	TPC replacement to handle luminosity	10 $\times$ design L, P=0.7 @ 650 GeV	Is coincidence with other forward baryons feasible?	2013 & beyond

The STAR Future Scientific Program

Table 1. Prominent aspects of the STAR 10-year physics program, and their needs.

Proposed Measurement	Physics Goal	STAR Upgrades Needed	RHIC L Needed	Open Issues	Proposed Timeline
		Proton-Nucleus Program			
Direct photon production in p+A	Map gluon densities in heavy nucleus @ x < 0.1	EMC completion	4 × present d+Au	Background	2006-8

Proposed measurements, scientific motivations, needed upgrades and luminosities, open physics and technical issues and possible (optimistic!) timeline given in full STAR Decadal Plan!

General Observations

There is a continuum of compelling physics to address as detector capability and machine performance develop

Plans & priorities continue to evolve with new discoveries – e.g., BRAHMS/PHENIX high-η d+Au moderate-p_T hadron suppression & STAR mid-rapidity correlations with forward leading particles results have already resulted in more emphasis on forward physics!

Three "Must do" STAR Physics Goals in the next 5+ years that drive the planned use of RHIC:

- ***Probing the new matter at RHIC***
  - Extended range for p_T dependence of hadron suppression studies (> 15 GeV/c)
  - Tagged "away-side" fragmentation studies versus p_T and particle type
  - Yields and spectra of open charm and bottom and -onium
  - Full flow systematics (mesons, baryons, multiply strange baryons, open charm)
  - PID'd fluctuations and correlations
  - energy/species dependence
- ***Understanding the nucleon's spin***
  - A_{LL} for mid-rapidity jet production
  - A_{LL} for direct photon + jet
  - A_N in transverse spin and jet fragmentation studies
  - Sea quark and sea anti-quark polarization (origin of the proton sea) using parity violating W decay
- ***Gluon density saturation in cold nuclei at very low Bjorken x***
  - Inclusive leading hadrons/jets in d+Au collisions
  - Search for mono-jets in d+Au collisions

Good progress can be made on this program in the next 5 years with a 32 week program

Projected 5 year Beam Use Outlook

(STAR Input to BNL Planning Exercise)

Fiscal Year	27 weeks/year BUP (submitted 8/03)		"Optimized Constant Effort" Scenario		32 weeks each year run scenario	
2004	5+14 Au+Au 200	5+0 pp 200	5+14 Au+Au 200	5+0 pp 200	5+14 Au+Au 200	5+0 pp 200
2005	5+9 Au+Au Escan	5+5 pp 200	6+11 Au+Au Escan	5+12 pp 200	6+8 Au+Au Escan	5+10 pp 200
2006	5+9 d+Au 200	5+5 pp 200	5+9 d+Au 200	5+13 pp 200	5+8 d+Au 200	5+11 pp 200
2007	5+5 Au+Au 200	5+9 pp 200	5+15 Au+Au 200	5+8 Cu+Cu 200	5+10 Au+Au 200	5+9 Cu+Cu 200
2008	5+10 Au+Au 200	5+5 pp 500			5+10 Au+Au 200	5+9 pp 200
$\int \mathcal{L}_{max}$ dt pp 200	76 pb^{-1}		88 pb^{-1}		156 pb^{-1}	
$\int \mathcal{L}_{max}$ dt post-TOF Au+Au	1.4 nb^{-1}		1.6 nb^{-1}		2.1 nb^{-1}	
What's missing?	Any Cu+Cu 200; 2nd+3rd long pp		3rd long pp; 2 pp devel. chances		1 pp devel. chance	

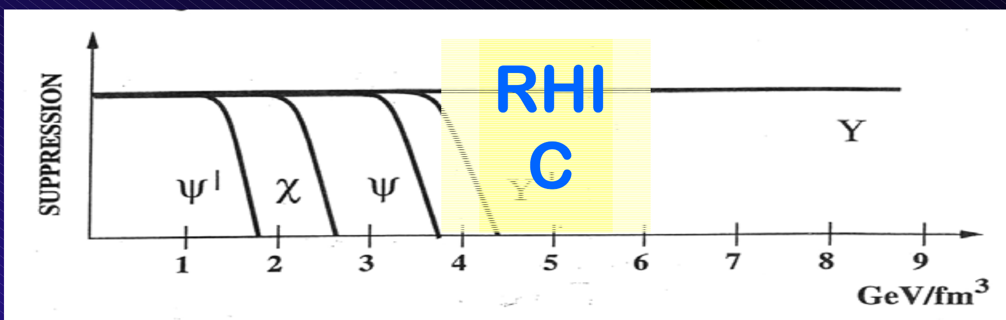
- 32 weeks (vs 27) gives a significant increase in integrated luminosity(!) and allows for timely progress on both the heavy ion and spin physics programs
- Up to 2010, the integrated L for AuAu is ~ 10nb^{-1}

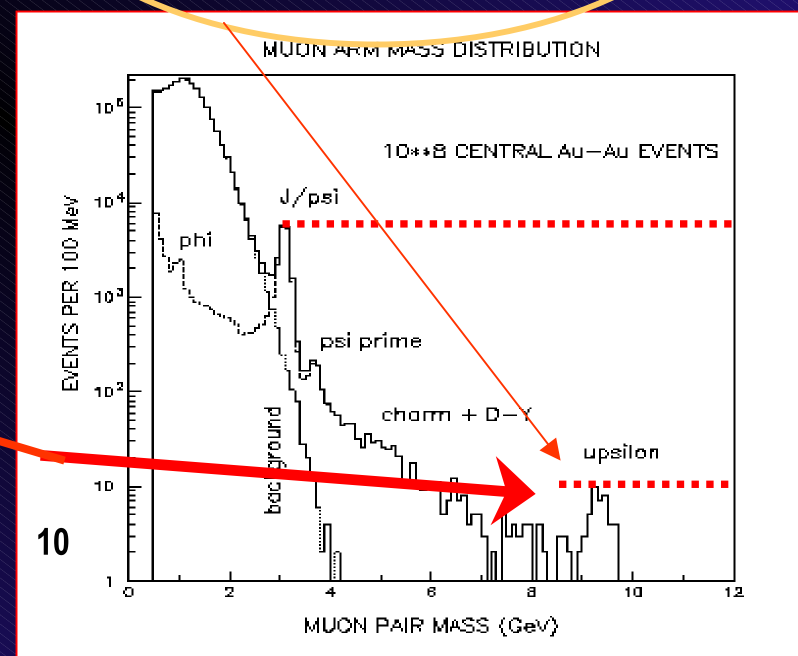
High Luminosity Physics Goals

Yields and Spectra of the onium states (J/ψ, Upsilon, and excited states) to measure the thermodynamics of deconfinement through varying dissociation temperatures

To deeply probe the plasma through studies of (Debye) screening length $\lambda \sim 1/gT$ and map in-medium QCD potential

Study vs. p_T
Study vs. centrality
Study in lighter systems
Study vs. a *control* (the Upsilon)



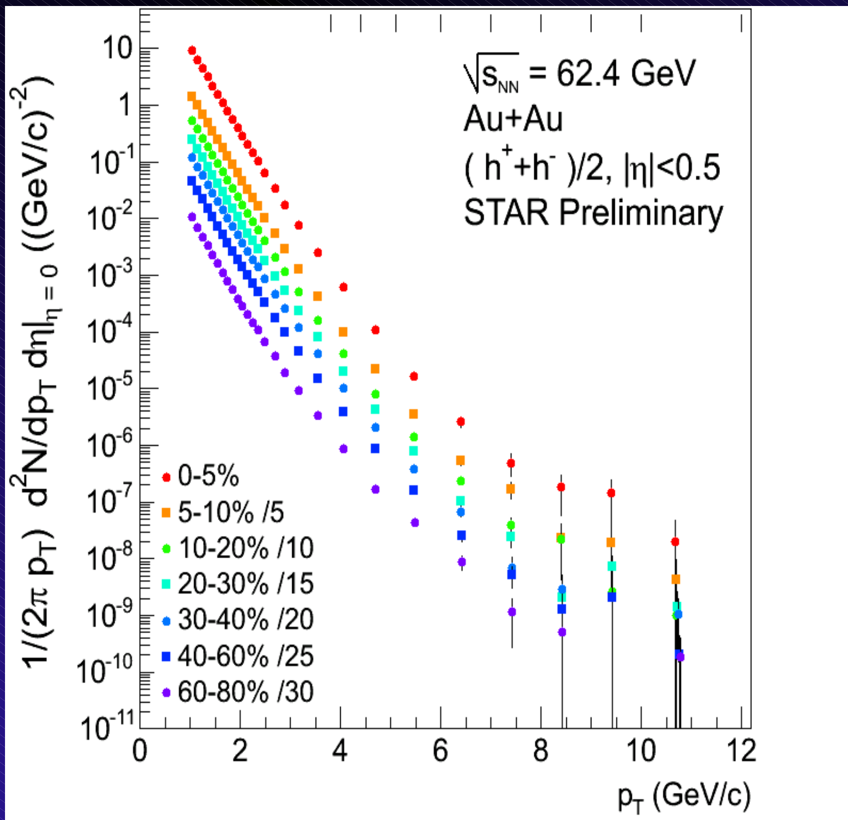


- **Upsilon rate ~ $10^{-3} \times J/\Psi$**

Yield in 10 weeks of AuAu running at design luminosity

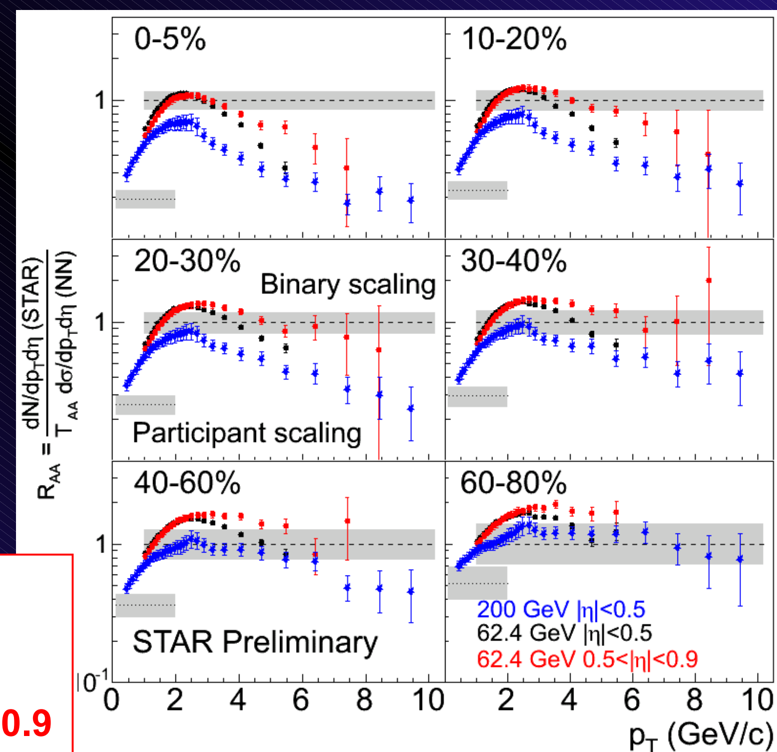
This physics requires 10x luminosity upgrade

Shorter runs are also productive: Inclusive hadron suppression from 1 week of data taking



- 2 η bins, driven by p+p
  - η = 0: p_T <~6 GeV
  - η = 0.7: p_T <~10 GeV
- Significant suppression seen at 62 and 200 GeV

1/3 of dataset



200 GeV |η| < 0.5

62 GeV |η| < 0.5

62 GeV 0.5 < |η| < 0.9

STAR Scientific Strategy:

STAR has tremendous capability and flexibility due to its large acceptance and efficient, complimentary suite of detectors. The future strategy for the Detector is to build on this strong core capability with upgrades that extend the Scientific reach of STAR

A robust program of measuring rare probes, as well as soft physics observables to study the bulk matter properties is possible

STAR believes the way to achieve maximum scientific impact and full utilization of the machine is to have a ***diverse, balanced portfolio***:

- soft physics studies of the properties of the bulk matter/ search for broken/restored symmetries
- triggered rare probes measurements
- change of energy
- change of system size

This will provide the most leverage in understanding the new matter produced at RHIC.

RHIC II Physics in STAR

- **Detailed studies of the fundamental properties of the new high temperature, high density (QGP) matter at RHIC**
  - *Is it equilibrated?*
  - *Does it behave collectively?*
  - *What are its early temperature and pressure?*
  - *What is its gluon density?*
  - *What is the quark mass dependence of partonic energy loss?*
  - *Does it exhibit the properties of a classical plasma?*

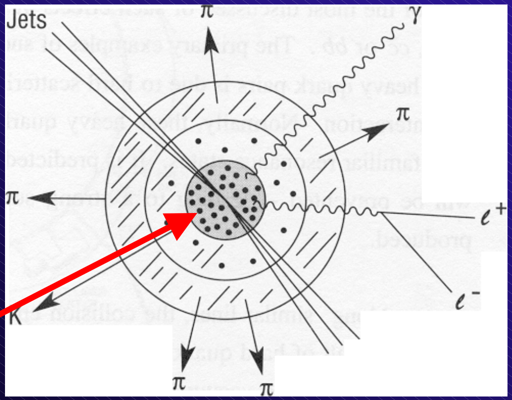
- **Studying the deconfinement and chiral transitions, and the hot, superdense states preceding the formation of a plasma of quarks and gluons to:**
  - *Test lattice predictions of the properties and behavior of bulk QCD matter*
  - *Study the nature of chiral symmetry breaking and how it is related to the masses of the hadrons*
  - *Study the nature of a possible saturated gluon state in cold nuclei at low momentum fraction (Bjorken x)*
  - *Search for broken/restored symmetries the QGP may provide access to (e.g. strong CP, parity)*

- **Understanding the contributions to the nucleon spin**
  - *The helicity preference of gluons inside a proton*
  - *The origin of the proton sea*
  - *The transversity distribution for quarks in a proton*

RHIC II STAR Physics: What's Needed

Sensitivity to rare probes and improved background rejection for plasma radiation; also characterization of the bulk matter

QGP is NOT rare in these collisions, but signals of early-time phenomena ARE!



To test and extend QCD theory and its predictions STAR will:

- use hard (short wavelength) probes such as
  - Inclusive jets and direct photons
  - back to back jets (correlation of leading particles)
  - direct gamma + leading hadron from jet
  - flavor tagged jets
  - measurement of spectra and yields for the Upsilon family of states

  to measure the differential energy loss for gluon, light quark and heavy quark probes which couple differently to the medium

- measure very large samples of "soft physics" events to study
  - heavy quark thermalization
  - heavy baryon / meson (open charm) elliptic flow
  - spectrum of extended hadronic matter (resonances)
  - broken / restored symmetries (e.g., cp violation, chiral restoration)

The STAR Future Plan: Short Form

Physics Bullets:

- Determine degree of thermalization and collectivity in partonic matter formed in RHIC collisions
- Test QCD (for variety of parton types) and determine the fate of its fundamental symmetries in bulk partonic matter
- Map the contributions of gluons and sea antiquarks of different flavor to the spin of the proton
- Probe the large gluon densities at low momentum fraction in heavy nuclei

RHIC-II

Inner/ endcap tracking

TOF Barrel

Pixel μVertex

DAQ/FEE upgrade

Forward calorimeter upgrade

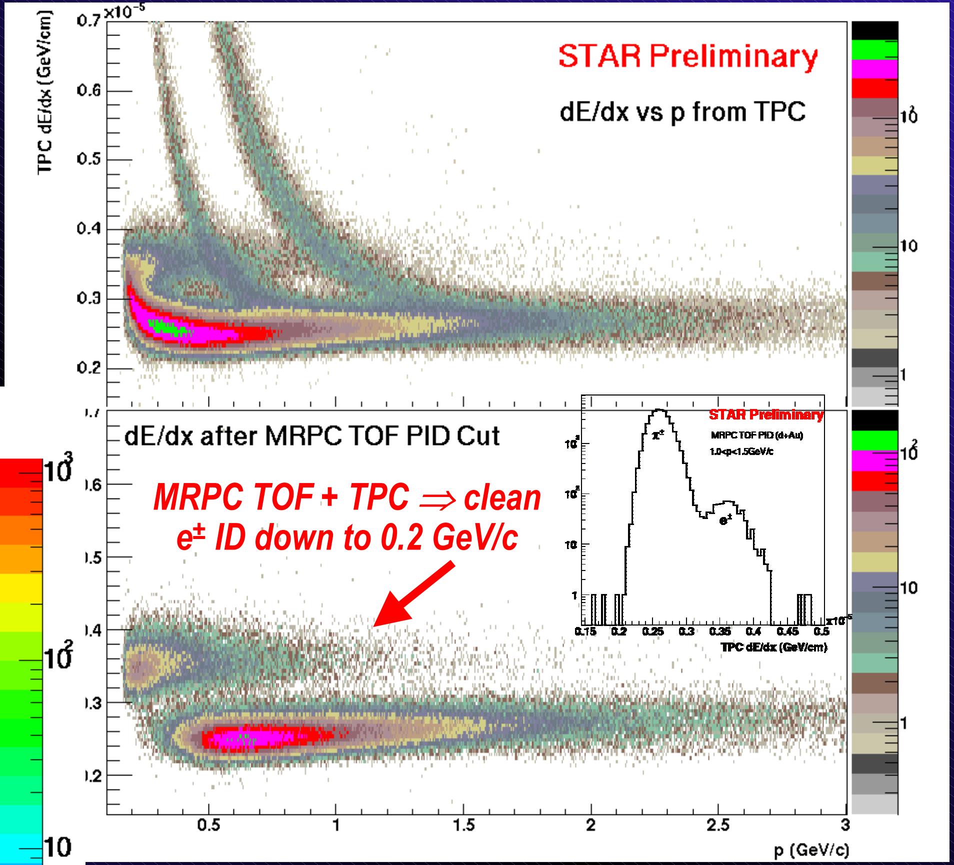
GEM R&D development for possible next Generation TPC Tracker is ongoing

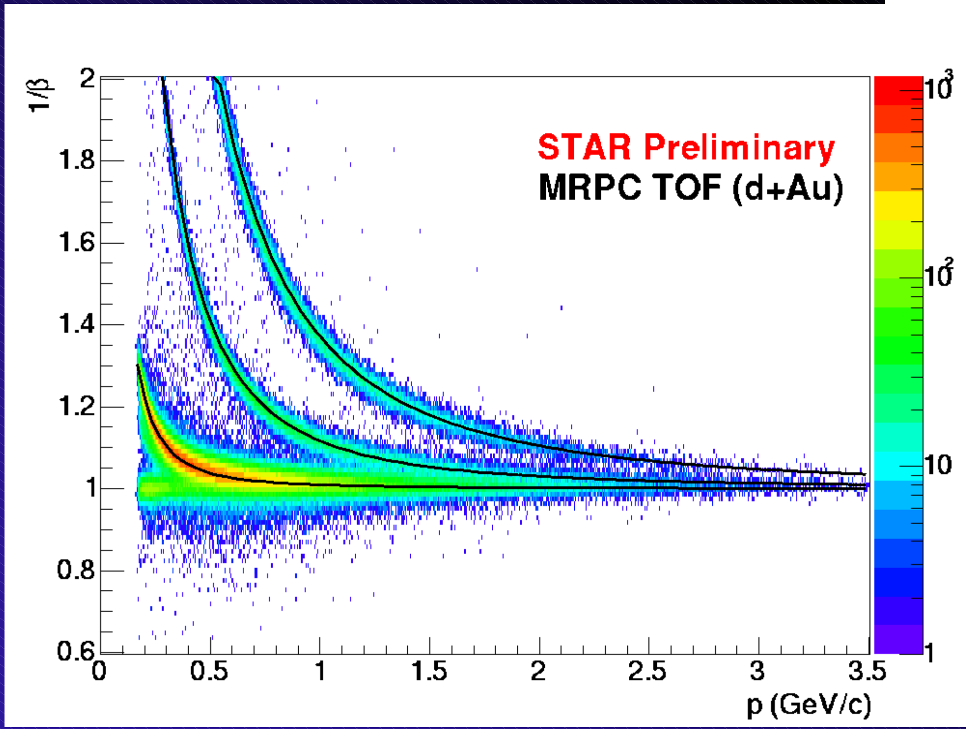
Upgrades planned to carry out the future STAR program

- **A Barrel MRPC TOF** — **PID information for > 95% of kaons and protons in the STAR acceptance; clean $e^{\pm}$ ID down to 0.2 GeV/c extended scientific reach for key observables**
- **A micro-vertex detector** — **precise (~5 μm) hit position close to the primary vtx $\rightarrow$ D's ,flavor- tagged jets**
- **A DAQ/ TPC FEE Upgrade** — **new architecture / FEE $\rightarrow$ > 1 khz of events available at L3; effective integration of 10 x more data**
- **Development of GEM tech.** — **Preparation for a compact, fast, next generation TPC needed for 40 x L**
- **Forward Tracking Upgrade** — **W charge sign identification**
- **Forward Calorimeter Upgrade:** — **Jet reconstruction at high pseudorapidity: CGC monojet search in d(p) + A; isolation of fragmentation effects in large pp $\rightarrow \pi^0$ production single-spin transverse asymmetries**
- **High Luminosity** — **10 - 50 times the luminosity (10 nb^{-1}) integrated at RHIC up to 2010**

The STAR Barrel TOF MRPC Prototype

Prototype modules met all performance specs in the STAR environment and produced important physics on PID'd Cronin Effect





Proposal reviewed and approved by STAR and BNL Management
Ready for submission to DOE

STAR Vertex Tracking, Now and in the Future

Track Residual: AuAu Prod 62 GeV: "Local" SVT Spatial Resolution

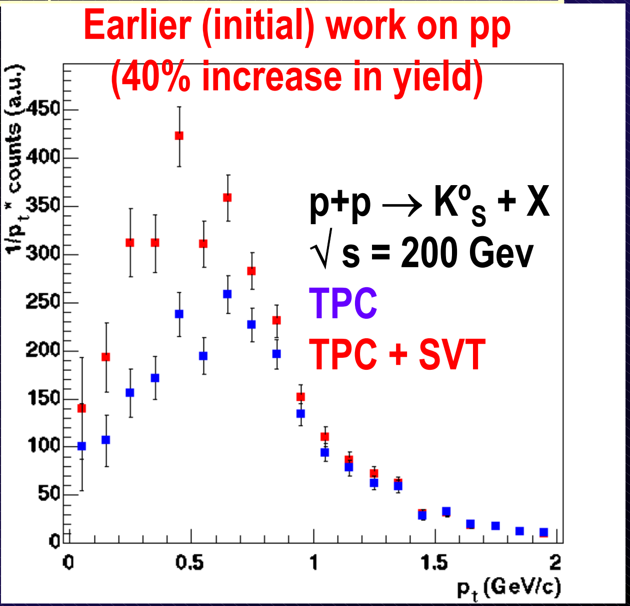
	Anode Direction	Drift Direction	Solution
Average over all Barrel 2	180 µm	300 µm	
Ladder 03	84 µm	140 µm	Ladder Alignment
L03/wafer 48	60 µm	140 µm	Wafer Alignment
L03/wafer 48/hybrid-02	60 µm	60 µm	T0 and drift velocity

- Dedicated effort for next several months to achieve approx.design spatial resolution globally on the detector

→ Significant higher yield for low momentum particles

→ Significantly higher yield for multiply strange baryons (e.g. a factor of ~ 2 for the Ω)

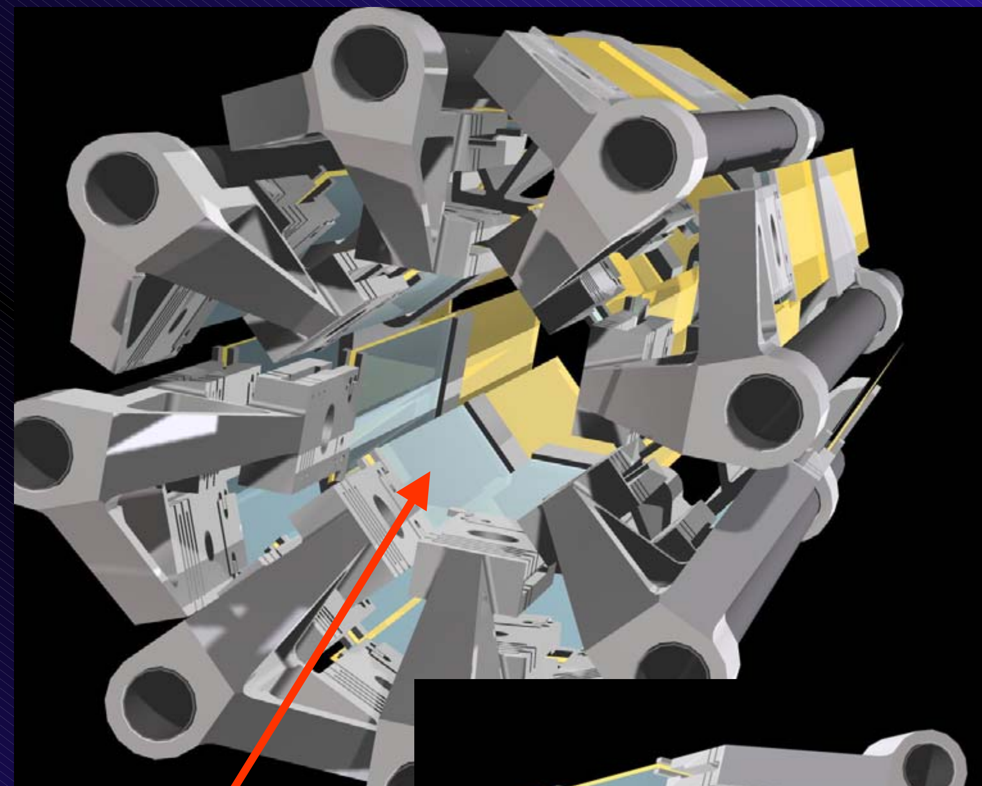
- Event-by-event charm & bottom requires an order of magnitude smaller (5 µm) resolution than SVT design

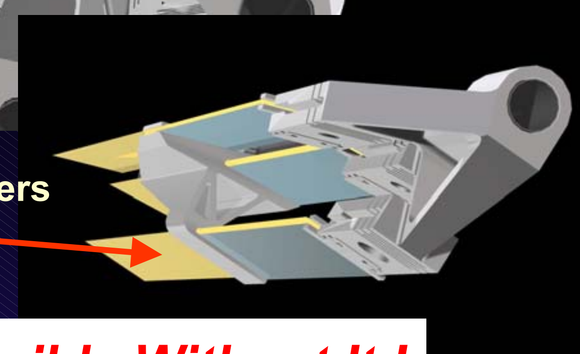


STAR Future Physics and Planned Upgrades

Physics provided by the STAR μVertex detector

- **Open charm**
  - Charm quark yield
    - Reconstructing D^0
  - Charm hadron chemistry
    - Reconstructing D^+, D_s^+, …
  - Charm hadron flow
    - Constructing D^0 spectra
- **Open beauty**
  - Identifying B mesons
- **Identifying heavy quark jets**





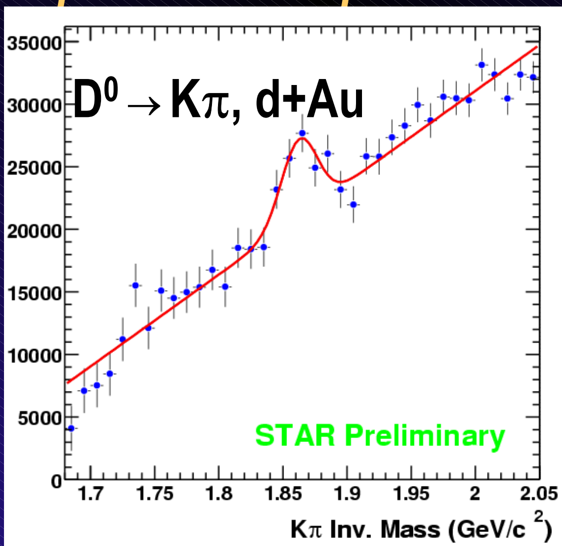
Thin silicon ladders under tension

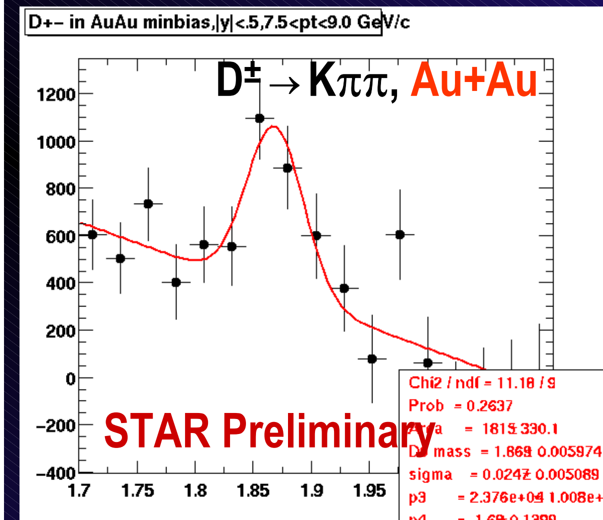
Number of events required for inclusive charm studies reduced by a factor of ~ 100

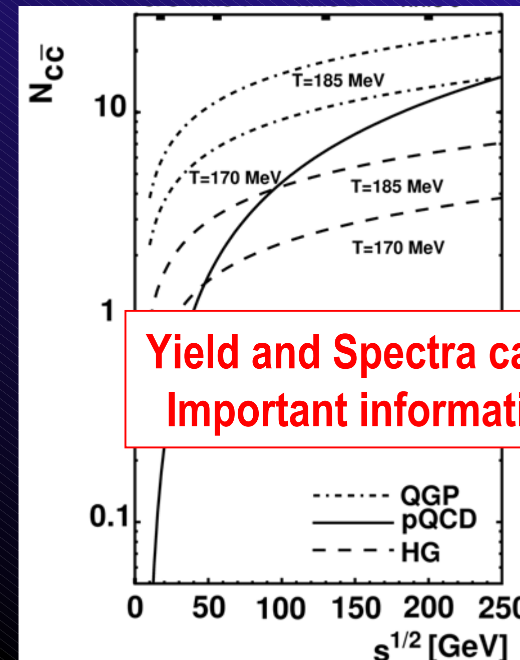
Event by Event Charm/Bottom Not Possible Without It !

An additional Requirement: Upgraded Detector Capability for Open Charm

Open charm: a probe of initial conditions, and possible equilibration at early times







Yield and Spectra carry Important information

Chemistry carries important information

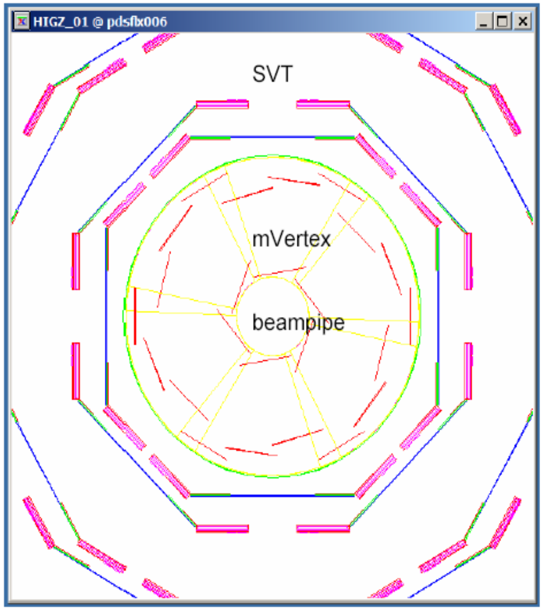
Do c quarks thermalize?

	Pythia p-p 200 GeV	Au-Au Thermal*
D^+/D^0	0.33	0.455
D_s^+/D^0	0.20	0.393
Λ_c^+/D^0	0.14	0.173
$J/\Psi/D^0$	0.0003	0.0004

Detector Complement (Decay Mode)	Au-Au Central Events for 3σ D_s^+signal
TPC+SVT ($K_s^o + K^+$)	500 x 10^6
TPC+SVT+μVertex	80 x 10^6
TPC+SVT+μVertex+TOF	5 x 10^6

For high statistics inclusive, MRPC TOF and silicon μvtx buy a factor of ~ 100 reduction (!)

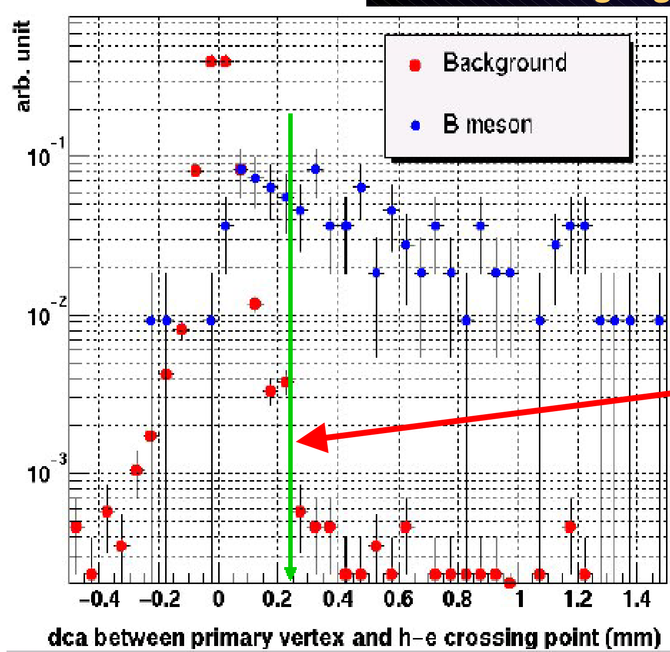
Recent Simulation Progress



- Two layers
- 24 ladders
- total length: 16cm
- inner radius: 1.4cm
- outer radius: 5.65cm
- new beampipe, 760μm Be
- position resolution: 3-10μm
- Δx~100μm Si-equivalent

- ***Microvertex detector makes b-quark jet tagging possible!***
- ***Trigger B decay event on $p_T > 4$ GeV/c $e^{\pm}$ detected in EMC***
- ***Search for hadron-electron vertex with DCA(e-h) < 150 μm from $B \rightarrow e^{\pm} + h + X$ decay***
- ***First look at background looks very encouraging!***

- ***Simulations assume: $p_e > 4$ GeV/c, $p_h > 0.7$ GeV/c***
- ***Allow for 50% of EMC-Identified $e^{\pm}$ to be mis-identified $h^{\pm}$***
- ***Extract signed DCA of e-h vertex from event vertex, where DCA > 0 for displacement along p_e →***



- $B \rightarrow e^{+/-}$ + hadron + X
  - High pt $e^{+/-}$ triggered by EMC

→ ***Background-free at dca>200μm !***

p_T ~ 15 GeV/c: σ (Au+Au) ~ 20μb/Gev →10 nb^{-1} yields 200K b-bar pairs

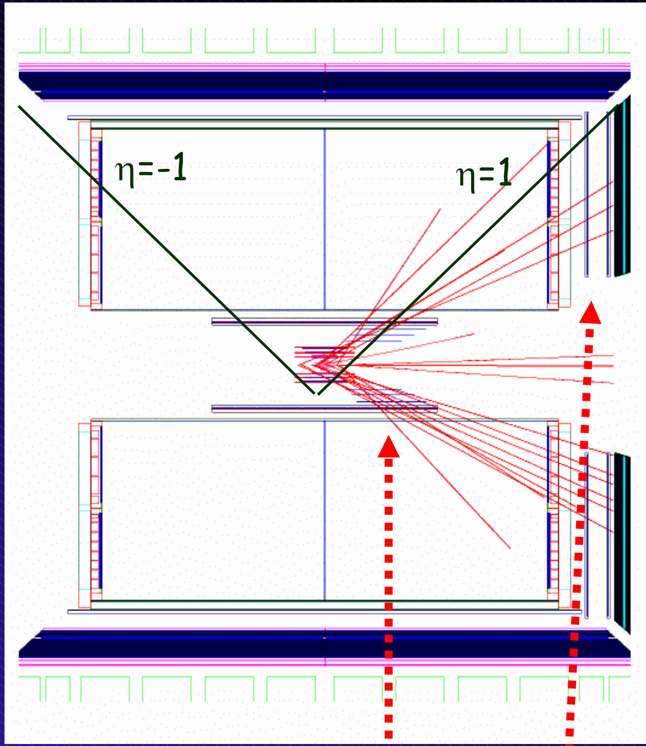
STAR Integrated Tracking Upgrade

- The study of heavy flavor and W production will require an upgrade of the STAR inner/forward tracking system
- Integrated tracking design for a new inner and forward STAR tracking system is mandatory
- Simulation and R&D work on silicon and triple-GEM technology started
- Staging of tracking upgrade in accordance with readiness of detector technology and beam development is under discussion:
- Possible scenario:
  - Stage 1: Installation of STAR Micro-Vertex Detector together with a minimal new barrel tracking detector based on silicon technology ($-1 < \eta < 1$) (Heavy Flavor Physics)
  - Stage 2: Upgrade of the forward tracking system ($1 < \eta < 2$) (W physics)
  - Aim for a proposal by summer 2005

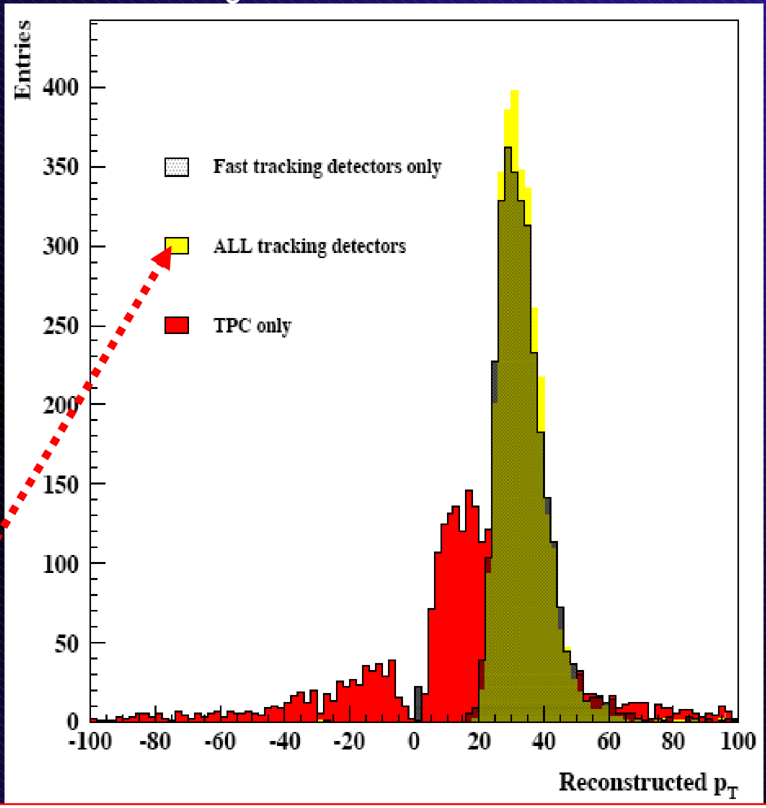
Recent Progress: Simulated Forward p_T Resolution

Forward p_T reconstruction: π^-

- True p_T = 30 GeV
- Range in η: $1 < \eta < 2$



Reconstructed p_T for various detector configurations:

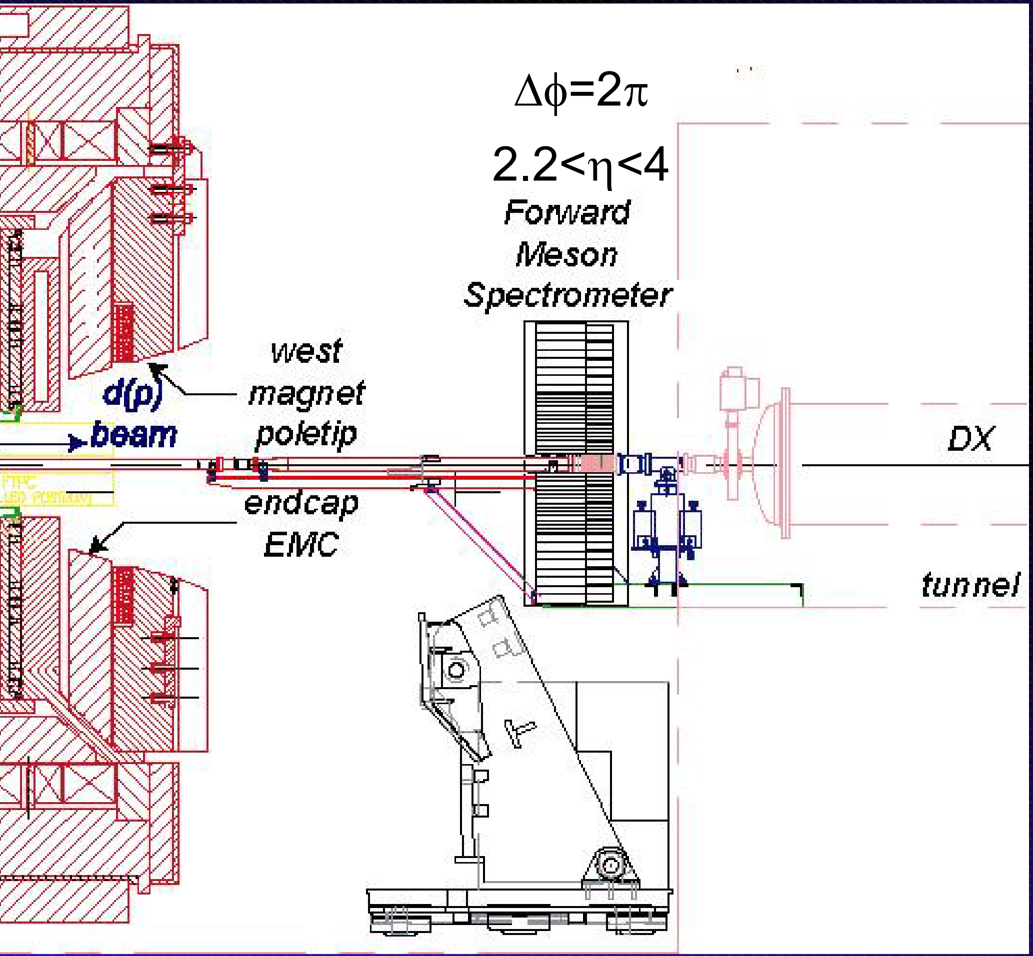


Simulated configuration:

- Inner configuration: 3 silicon layers (50 μm spatial resolution)
- Outer configuration: 2 triple GEM layers (100 μm spatial resolution)

➢ ***Inner (Si strip) + forward (GEM) tracking detector concept should eliminate incorrect sign reconstructions for W daughters in endcap region***

Forward Meson Spectrometer Conceptual Design



Physics Motivation:

- probing gluon saturation in p(d)+A collisions via…
  - large rapidity particle production ($\pi^0,\eta,\omega,\eta',\gamma,K^0,D^0$) detected through all γ decays.
  - di-jets with large rapidity interval (Mueller-Navelet jets)
- disentangling dynamical origins of large x_F analyzing power in $p_\uparrow$+p collisions.

STAR DAQ/FEE upgrade – *DAQ1000*

GOAL: *increase STAR's rate capability to equivalent of 1 kHz min-bias Au+Au ⇔ ~820 MB/s instantaneous (~300 MB/s time-averaged?)*

IMPLEMENTATION: *(1) replace TPC FEE with version based on ALICE ALTRO chip; (2) replace TPC DAQ system with one based on storage of only cluster information extracted in fast hardware; (3) upgrade EMC Level 2 Receiver Boards and use for other new subsystems as well.*

MILESTONES:

- *FY04 Run: deploy Fast Cluster Finder algorithm (≡DAQ100) and cluster storage only in software as proof-of-principle; handle clustered event building with 4 Linux-based EVB work stations*
- *FY04 R&D: implement a Row Computing Slice (RCS) incorporating FCF in hardware (FPGA, DSP, ...); design generic new DAQ Receiver Board; prototype ALTRO-based FEE*
- *FY05 Run: implement new Receiver Board for BEMC/EEMC Level 2 triggering*
- *FY05 R&D: design ALTRO ↔ DAQ interconnect; prototype DAQ fiber interconnect & network system*

TPC Tracking in the STAR Future Plan

What about existing TPC operation at High Luminosity ?

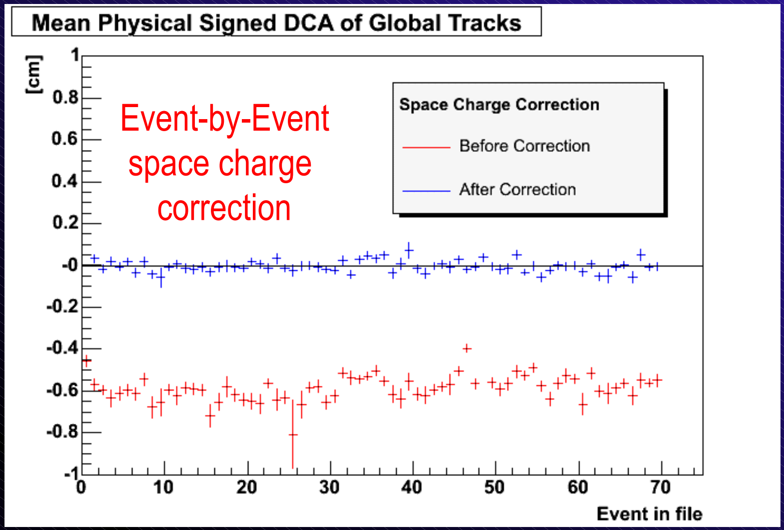
Initial Study by TPC Evaluation & Study Group

	40 x
Track Eff (Central)	✓
Pt Resolution	✓
DCA Distortion (SC)	ongoing study

- Gated Grid Operation at > 1 Khz ✓
- Laser calibration stabilized ✓

Questions Under Study

- Full understanding of space charge effects (event-by-event)
- Wire aging with increase gated grid rate?
- Sources/fluctuations of space charge



⇒ First indications are pretty good that TPC should work well at 4 x present luminosity

⇒ Space charge will likely require a TPC replacement for 40x era; also aging?

The ongoing GEM development will:

- *lay the foundation for a possible future high rate, compact TPC with shorter drift /trigger capability*
- *develop important technology which may needed elsewhere in STAR (e.g. forward tracking)*

Comment on STAR Upgrades Plan

Within STAR we are exactly at the stage of turning our beginning roadmap into a blueprint. This is the subject of a 3 day workshop organized by Dick Majka and Steve Vigdor at Yale, June 15-17

What we can provide at the moment is our best projection

Questions to be addressed at Yale:

- Physics goals versus time and money
- Technical feasibility
- Cost and schedule versus money
- Optimal phasing of upgrades (some thinking has/is evolved(ing))

STAR Future Physics and Planned Upgrades

The Scope & Scientific Merit of Proposed R&D / Upgrade Plan

System	R&D	Constr/Cost	Benefit to STAR
Barrel MRPC TOF TOF	' 04 → '06 $260k	' 06 → '08 $4.7M + $2.5M in- kind	E x E PID information for ~ 95% of kaons and protons in acc; extended p_T for resonances Ω v_2; D's; E x E PID'd correlations; $e^{\pm}$ ID
Inner μvtx	'04 → '06 $965k	'07 (?) → $5-10M	exclusive charm/bottom , enrichment factor of 100 100 for inclusuive open charm, flavor- tagged jets
Forward/Inner Tracker	TBD	~ $5 – 8M	Charge sign for $W^{\pm}$ (presently 500 GeV run ~ 200)
DAQ Upgrade (Plus Level III)	'05 $200k	'06 – '08 (?) → $1M ($2M)	1 kz → L3; D's; Ω & D v_2, cp, parity, Direct γ HBT
FEE Upgrade	'05 → '06 $250k	''06 –'08?) → $1-2 M	1 kz → L3; D's; Ω, D, cp, parity, Direct γ HBT
Forward HCAL	TBD	'06 (?)→ $1-2M	(Mono) jets at high η; transverse spin studies (A_N)
GEM TPC	' 05 → '09 $900k	'10 → ~ 20M(?)	Compact, fast TPC;robust tracking for high Q^2 physics at 40 x L

R&D on these projects has begun

STAR Detector RHIC II Compatibility

- Components in STAR that will continue to be operational & providing compelling physics in the high luminosity era (2010 and beyond)

Magnet
EEMC
BEMC
SSD
Conv. Systems
DAQ/Trigger/Software& Computing
Baseline $~ 60M

TOF
Micro-Vertex +
DAQ/FEE Upgrade
Planned upgrades $ ~ 20M

Under Study:

New TPC	?	
Forward Tracking Upgrade	?	$ ~ 30M (Direct)
Forward HCAL	?	

The Feasibility of the Future STAR program

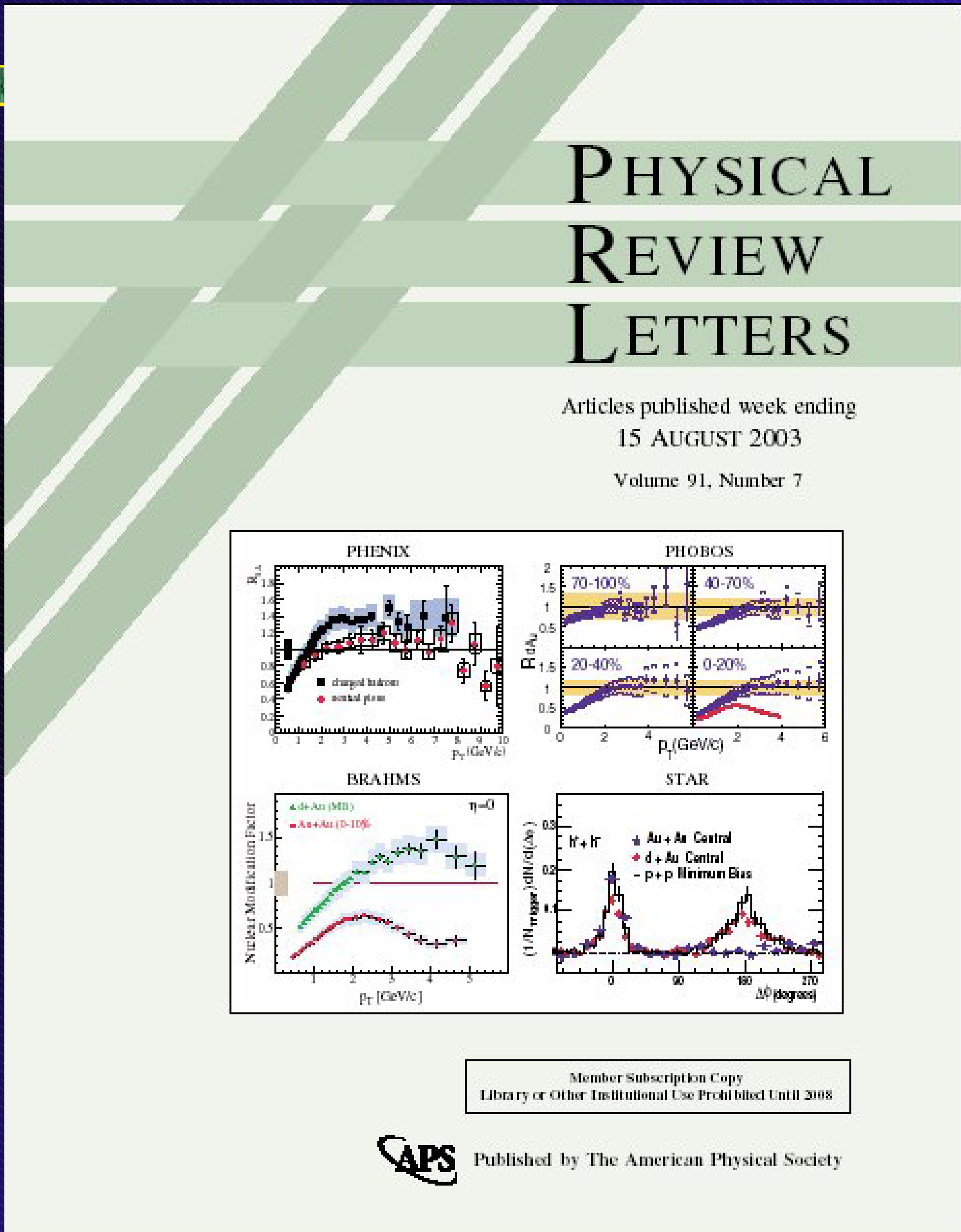
30 scientific papers published (25 PRL, 4 PRC, 1 PLB), and 9 submitted (5 PRL, 3 PRC, 1 PLB)

18 technical papers published

1544 Citations

32 Ph.D's granted

STAR is a vibrant, strong collaboration with a proven track record which can successfully carry out the proposed program



The STAR Collaboration: 50 Institutions, ~ 500 People

U.S. Labs:

Argonne, Lawrence Berkeley, and Brookhaven National Labs

U.S. Universities:

UC Berkeley, UC Davis, UCLA, **Caltech**, Carnegie Mellon, Creighton, Indiana, Kent State, **MIT**, MSU, CCNY, Ohio State, Penn State, Purdue, Rice, Texas A&M, UT Austin, Washington, Wayne State, Valparaiso, Yale

Brazil:

Universidade de Sao Paolo

China:

IHEP - Beijing, IPP - Wuhan, USTC, Tsinghua, SINR, IMP Lanzhou

Croatia:

Zagreb University

Czech Republic:

Nuclear Physics Institute

England:

University of Birmingham

France:

Institut de Recherches Subatomiques Strasbourg, SUBATECH - Nantes

Germany:

Max Planck Institute – Munich University of Frankfurt

India:

Bhubaneswar, Jammu, IIT-Mumbai, Panjab, Rajasthan, VECC

Netherlands:

NIKHEF

Poland:

Warsaw University of Technology

Russia:

MEPHI – Moscow, LPP/LHE JINR – Dubna, IHEP – Protvino

Switzerland:

University of BERN

Conclusions

STAR proposes a future program of QCD studies of unprecedented breadth and depth to study

- *the quark mass dependence of partonic energy loss*
- *collective behavior in partonic systems*
- *the nature of chiral symmetry breaking and how is it related to the masses of the hadrons*
- *the nature of a possible saturated gluon state in cold nuclei at low Bjorken x*
- *the helicity preference of gluons inside a proton; the origin of the proton sea; the transversity distribution for quarks in a proton*

This physics program requires:

a Barrel MRPC TOF detector to extend STAR's PID
a micro vertex detector to enable measurement of D's and flavor-tagged jets
a DAQ / FEE upgrade to allow 1 khz to L3 to integrate needed event samples
a tracking upgrade to afford good forward charge sign determination
a forward hadron calorimeter
Development of GEM technology to insure the possibility of robust tracking for the 40 x L era

STAR has embarked on this plan; work is in progress

Answers to Questions

1) Please provide some figure of merit to compare the physics achievable with the detector upgrades to that accessible without them

(answers embedded in the slides). Things not possible at all without upgraded RHIC/STAR: – exclusive charm, direct photon + jet, flavor tagged jets; investigation of possible CGC; symmetry studies (cp, parity), direct photon, HBT; event--by event charge sign for W's …;

•2) What R&D is required to make the upgrades possible? when is it needed, compared to construction start for the upgrades? (shown on slide 34)

3) Please compare the physics reach of the baseline experiments with and without the luminosity upgrade. Which detector upgrades are required to utilize the higher luminosity? How long does it makes sense to run without a luminosity upgrade?

All of the upgrades will begin contributing important physics as soon as they come on line; some physics is not accessible without the luminosity upgrade; the detector potentially driven by the luminosity upgrade is the TPC, but all the existing and upgraded detectors will provide increased reach or precision with increased luminosity

4) If the luminosity upgrade were advanced by two years, would that give RHIC more physics impact?

Likely, this would come before the capability to fully utilize it would be in place.

Answers to Questions

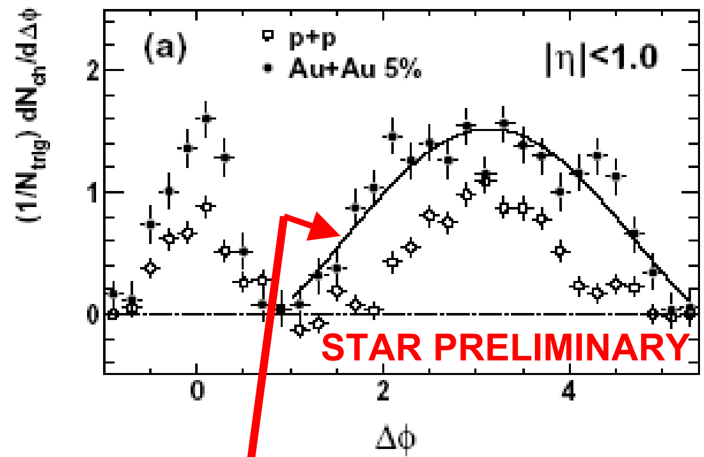
5) for STAR specifically: What are the envisioned DAQ and FEE upgrades? What is the scope of the changes and how much will they cost? Are any of these critical before higher luminosity is available? How are these upgrades optimized for Au+Au or p+p?

Implementation/cost addressed in talk. The DAQ and FEE upgrade will contribute as soon as available. The architecture is transparent to type of system being studied. The sustained rate for given system scales with the amount of data/event for a given event type.

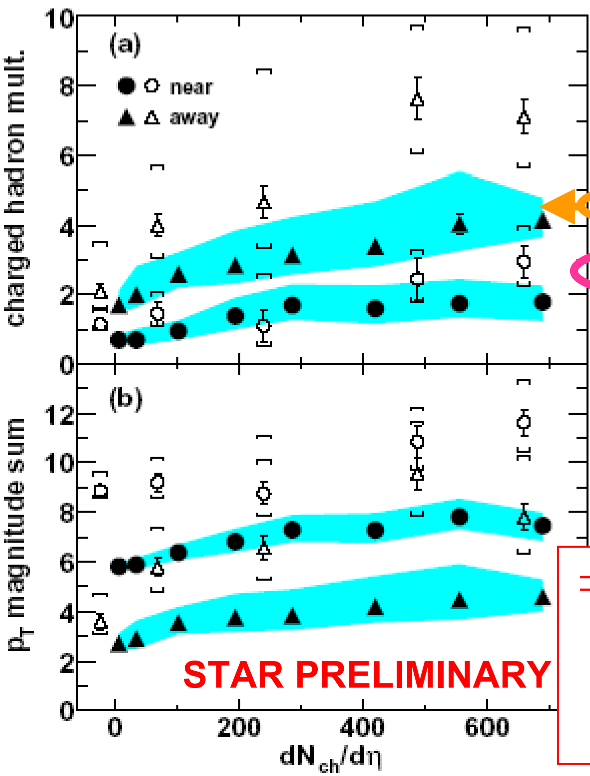
6) What kinds of solutions are under investigation for TPC operations or modifications to handle the luminosity increase?

(Discussed on slide 32: main effort at the moment is GEM R&D and space charge studies. Serious design study will need to be commissioned if the studies show it is needed)

Angular correlations of hard and soft hadrons in STAR explore transverse momentum balance opposite a high-p_T particle, in the light of jet quenching (F. Wang):



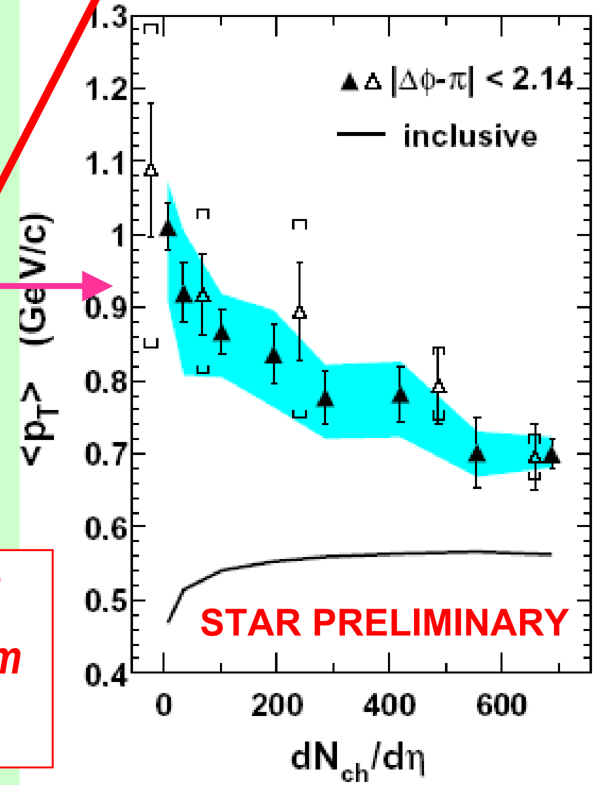
$\sqrt{s_{NN}}$ = 200 GeV Au+Au results: { Closed symbols ⇔ 4 < p_T^{trig} < 6 GeV/c; Open symbols ⇔ 6 < p_T^{trig} < 10 GeV/c } Assoc. particles: 0.15 < p_T < 4 GeV/c



Away side not jet-like!

In central Au+Au, the balancing hadrons are greater in number, softer in p_T, and distributed ~statistic-ally [~ cos(Δφ)] in angle, relative to pp or peripheral Au+Au.

⇒away-side products approach equilibration with bulk medium traversed !

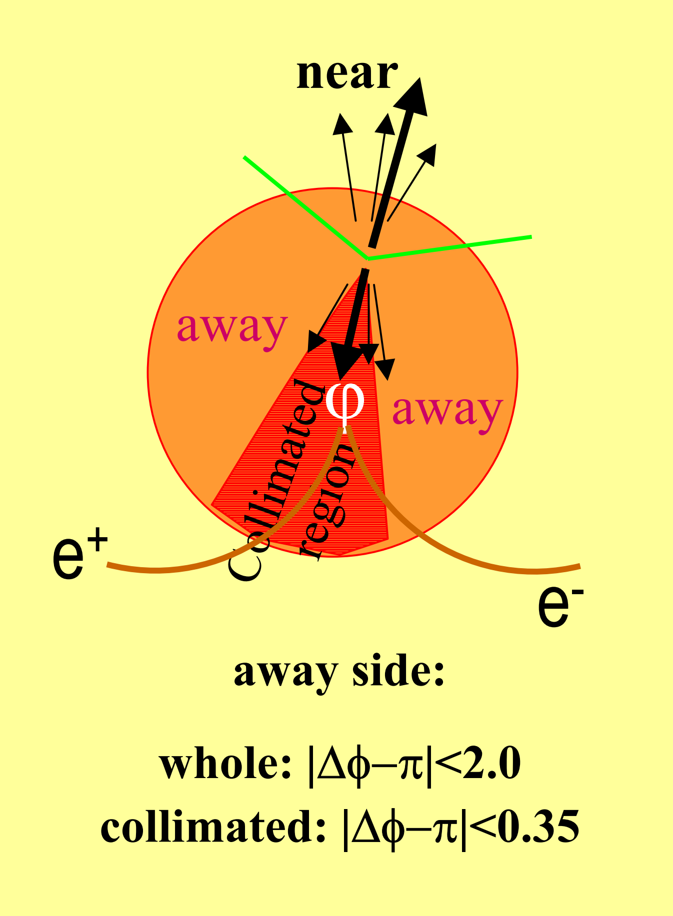


Scientific Conjecture:

The data suggest the away side products approach equilibrium with the bulk medium traversed

Suggests a means to study particles (e.g. leptonic decays of vector mesons such as the Φ) that have an increased probability of having been produced in a bulk medium which may be deconfined, and/or in which chiral symmetry is restored.

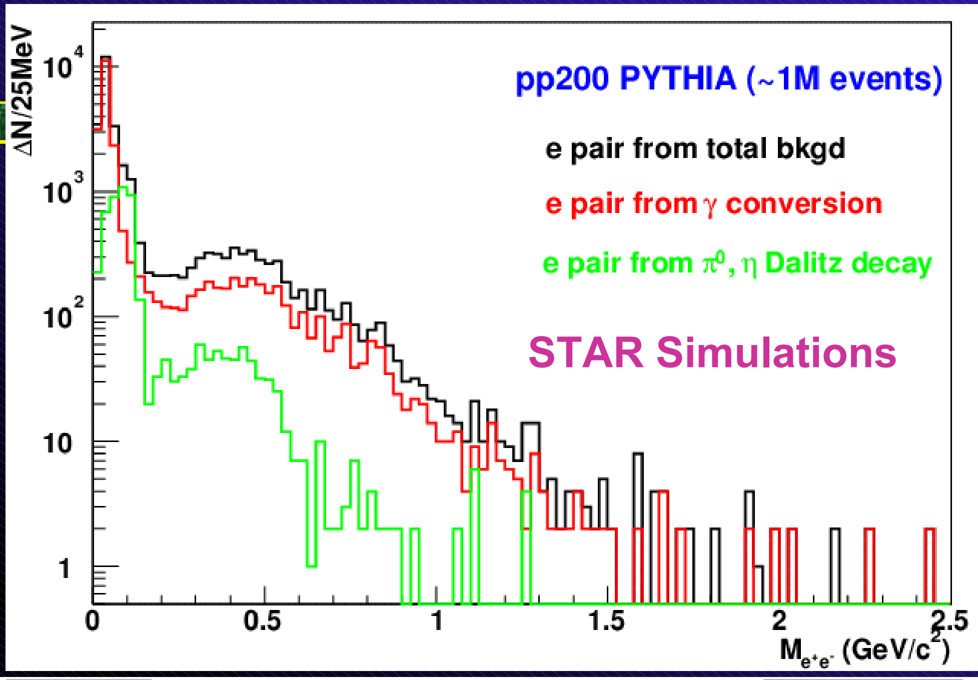
Differences between yields and spectra, branching ratios, flavor composition… for products 180° versus 90° from the tagged high pt particle may provide access e.g. to the study of chiral symmetry

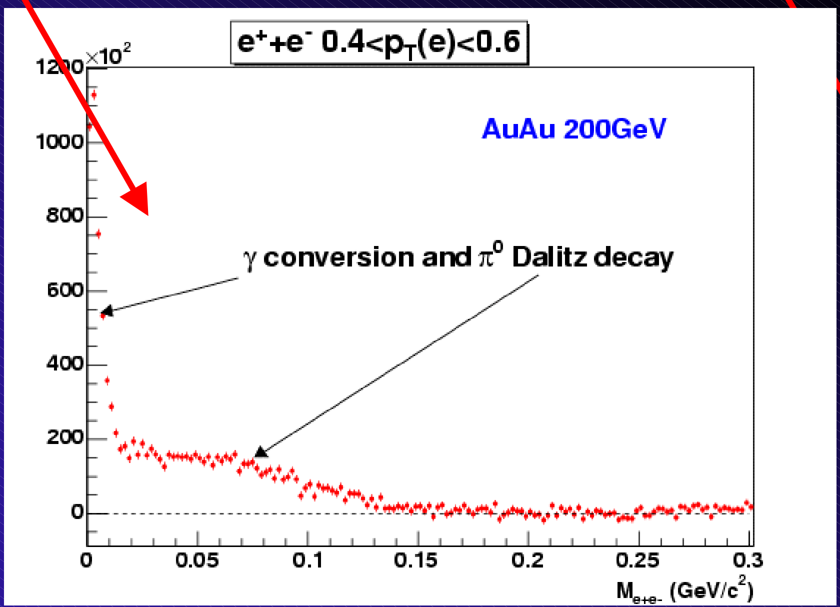


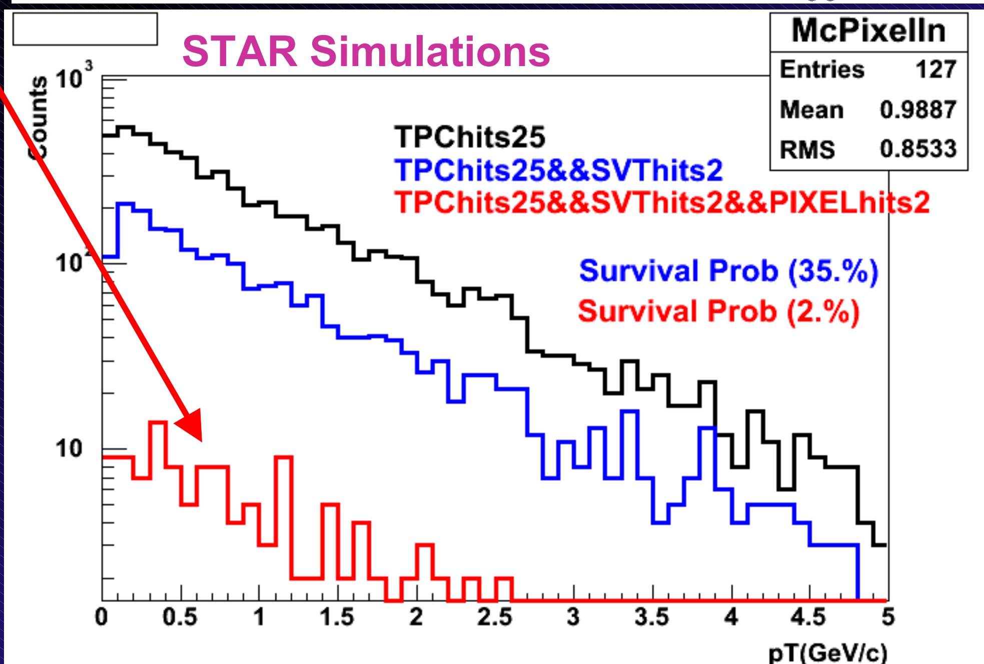
Spectroscopy of the away-side soft fragmentation may be as interesting as the high p_T tag

Example of Recent and Projected Progress

- *Combination of TOF + μVertex permits STAR to study low-mass dilepton pair spectrum: access to leptonic decays of vector mesons (chiral symmetry)*
- *MRPC TOF + TPC $\Rightarrow$ clean $e^{\pm}$ ID down to 0.2 GeV/c (from run 4 data!)*
- *Addition of μVertex suppress dominant γ conversion bkgd. by large factor!*







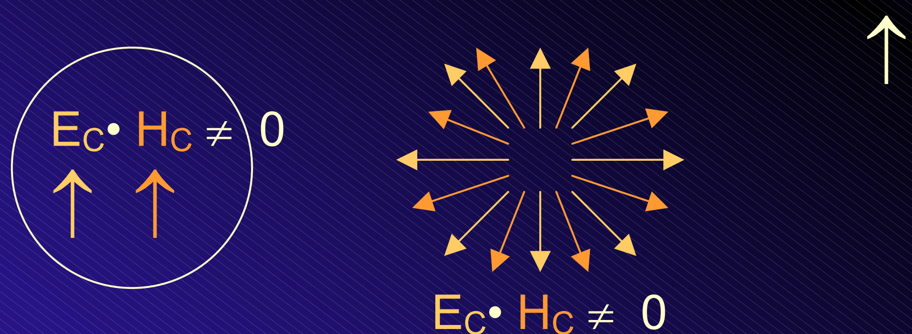
STAR Future Physics and Planned Upgrades

Studying the fundamental nature of QCD: Strong CP Violation

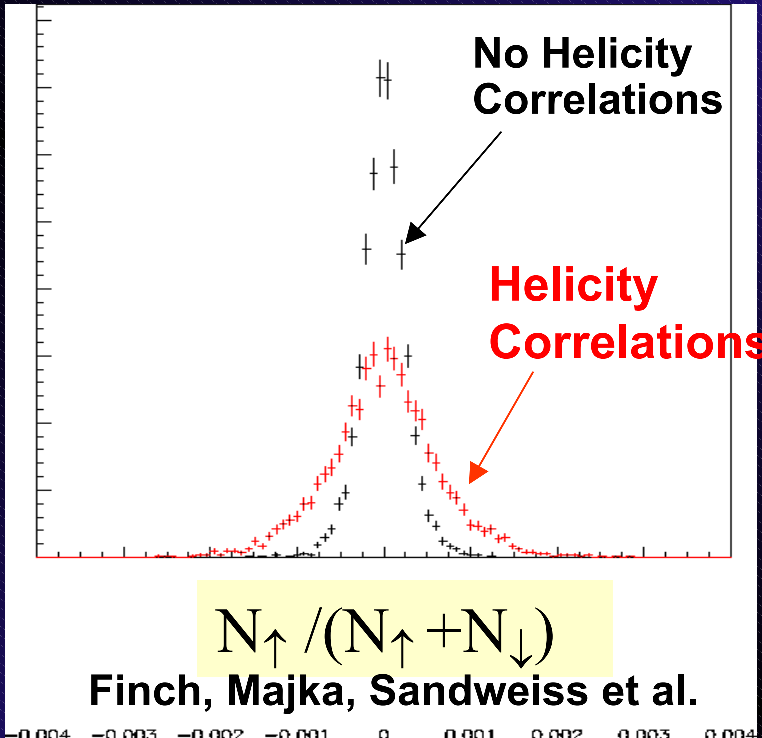
$$L_{QCD} \xrightarrow{axial\_anamoly, vacuum\_effects} L_{QCD} + \theta G_{\mu\nu}\tilde{G}^{\mu\nu} \left(\propto \theta \vec{E}_c \bullet \vec{B}_c\right)$$

QCD "should " include CP violation, but experimentally, $\theta = 0$

Under certain conditions around a de-confining phase transition, regions of space may be formed which behave as if $\theta \neq 0$ - spontaneous CP violation. (Kharzeev et al)



⇒ Simple momentum space asymmetry probably not good enough → look at e-by-e helicity balance of fermions (Λ°) and search for fluctuation (too many positive helicity Λ°)



Estimated need: several hundred million events! (efficiency dependent)

High Luminosity RHIC Physics

What about RHIC in the era of the LHC ?

- The center of mass energy at LHC will exceed that at RHIC by a factor of ~ 30 ⇒
  - *longer lifetime of QGP state*
  - *larger dynamic range for hard probes*
  - *higher Q^2 for study of jets, heavy flavor*
  - *higher multiplicity, more complex final state*

- RHIC is a dedicated facility ~ 30 weeks of physics running per year ⇒ Studies pp, pA, AA, e-A as a function of √s, A, B, →,↑
  - *unprecedented QCD studies*
  - *detailed understanding of "initial conditions" at RHIC*
  - *complete mapping of the spin dependent parton structure of the proton*

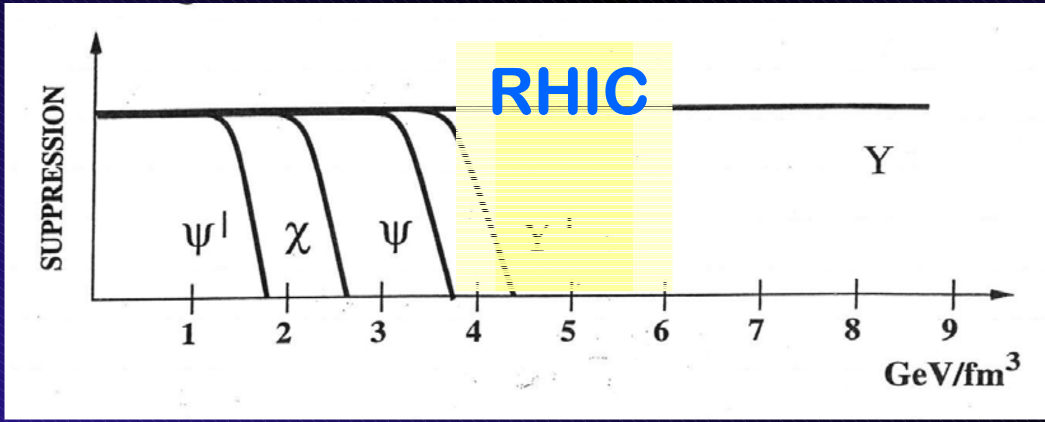
Complete understanding of the matter at RHIC is essential!

The LHC survey phase will begin near the end of the decade

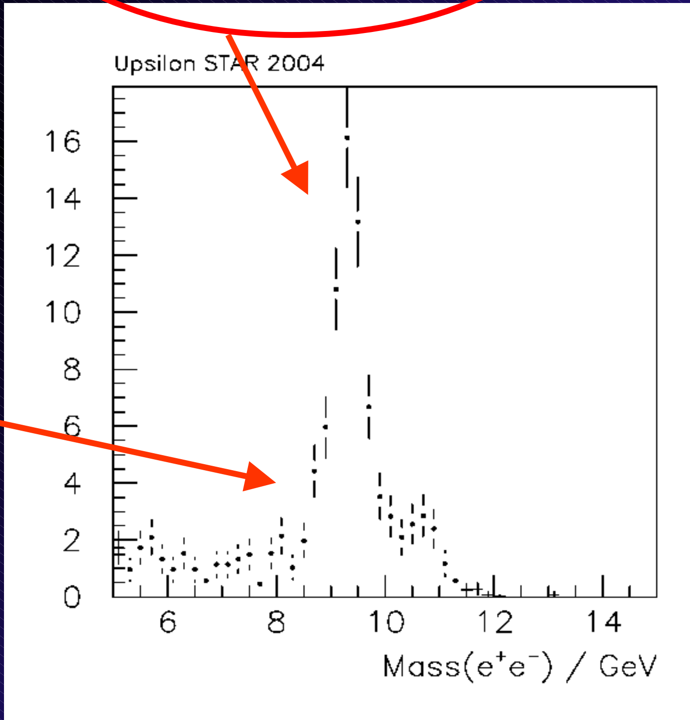
Opening a Window in STAR on Onium

First look in STAR at the onium states (J/ψ, Upsilon, and excited states) to measure the thermodynamics of deconfinement through varying dissociation temperatures

To deeply probe the plasma through studies of (Debye) screening length $\lambda \sim 1/gT$



- Study vs. p_T
- Study vs. centrality
- Study in lighter systems
- Study vs a control (the ϒ)

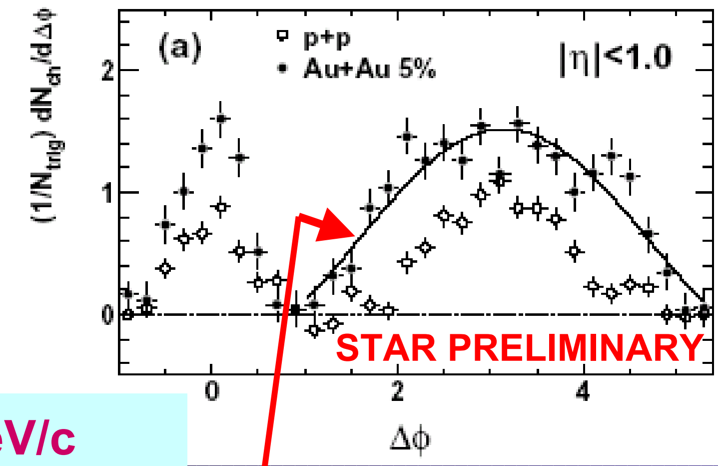


- Upsilon rate ~ 10^{-3} J/Ψ

Yield in 10 weeks of AuAu running at 32 μb^{-1} /week

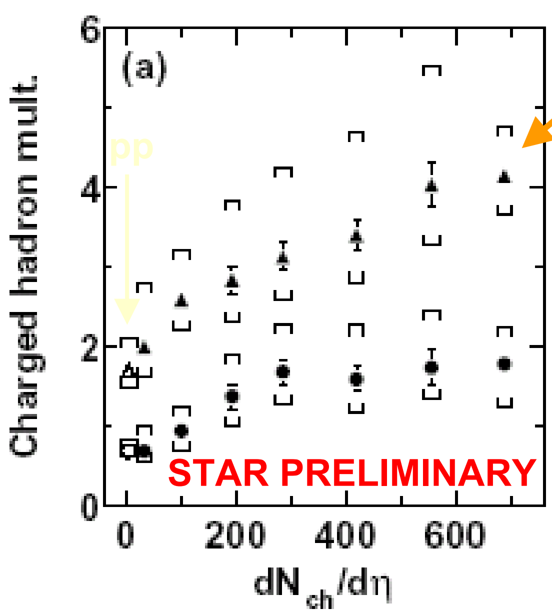
STAR will get started: But, to fully utilize this probe requires high luminosity RHIC running

Angular correlations of hard and soft hadrons in STAR explore transverse momentum balance opposite a high-p_T particle, in the light of jet quenching (F. Wang):



$\sqrt{s_{NN}}$ = 200 GeV
Au+Au results:
$4 < p_T^{trig} < 6$ GeV/c
$0.15 < p_T^{assoc} < 4$ GeV/c

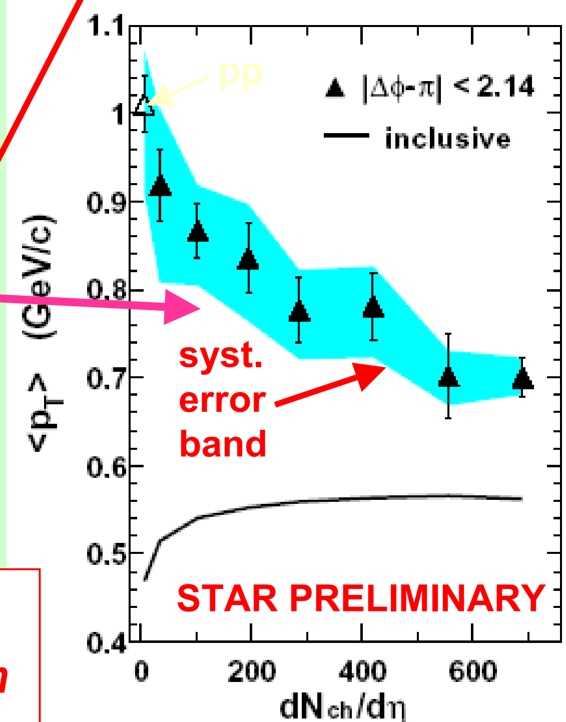
● Near (|Δφ| < 1.0, |Δη| < 1.4)
▲ Away (|Δφ| > 1.0, |η| < 1.0)



Away side not jet-like!

In central Au+Au, the balancing hadrons are greater in number, softer in p_T, and distributed ~statistic-ally [~ cos(Δφ)] in angle, relative to pp or peripheral Au+Au.

⇒away-side products approach equilibration with bulk medium traversed !



DCA vs ZDC

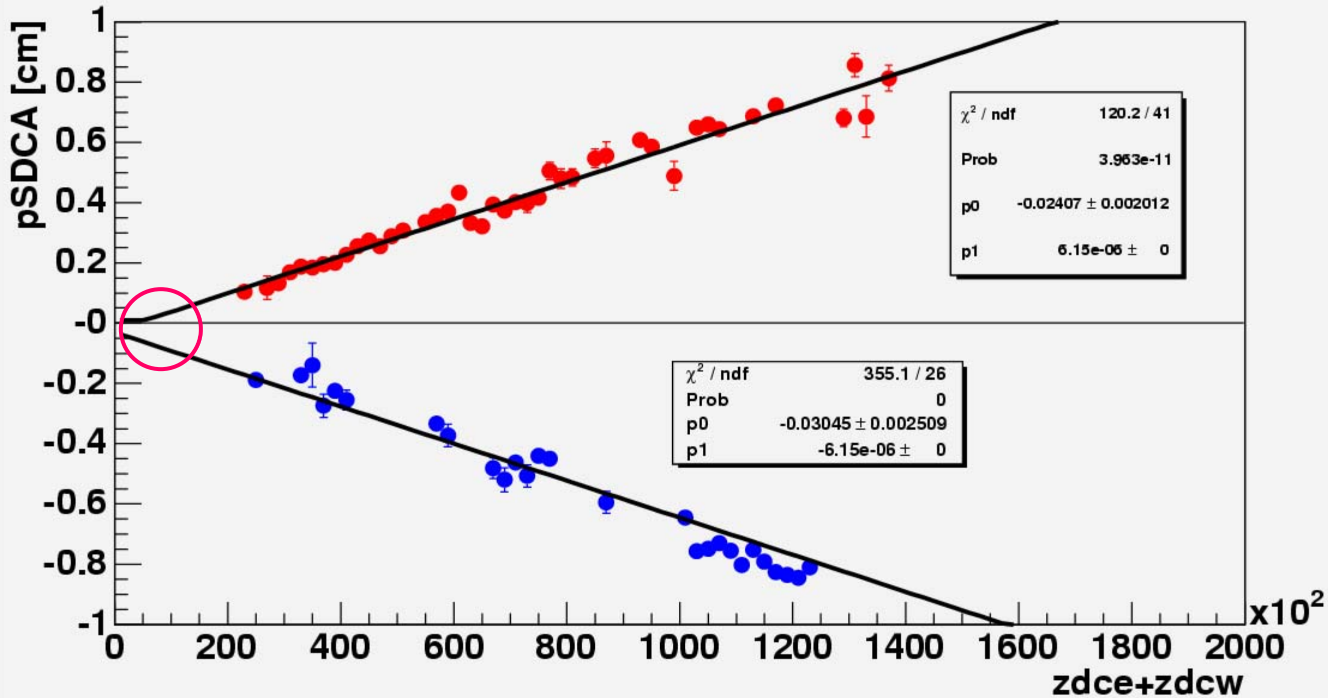


Figure 1: The physical signed DCA (pSDCA) versus the ZDC East + West scaler count rate. The red and blue data points show the DCAs for Au+Au at 200 GeV for positive and negative full field magnet settings. The purple circle shows the expected range for Au+Au at 62 GeV. The purple circle also illustrates that the DCAs extrapolate to small values indicating that the static (non-space charge) distortions are small.

Event by Event Space Charge Corr

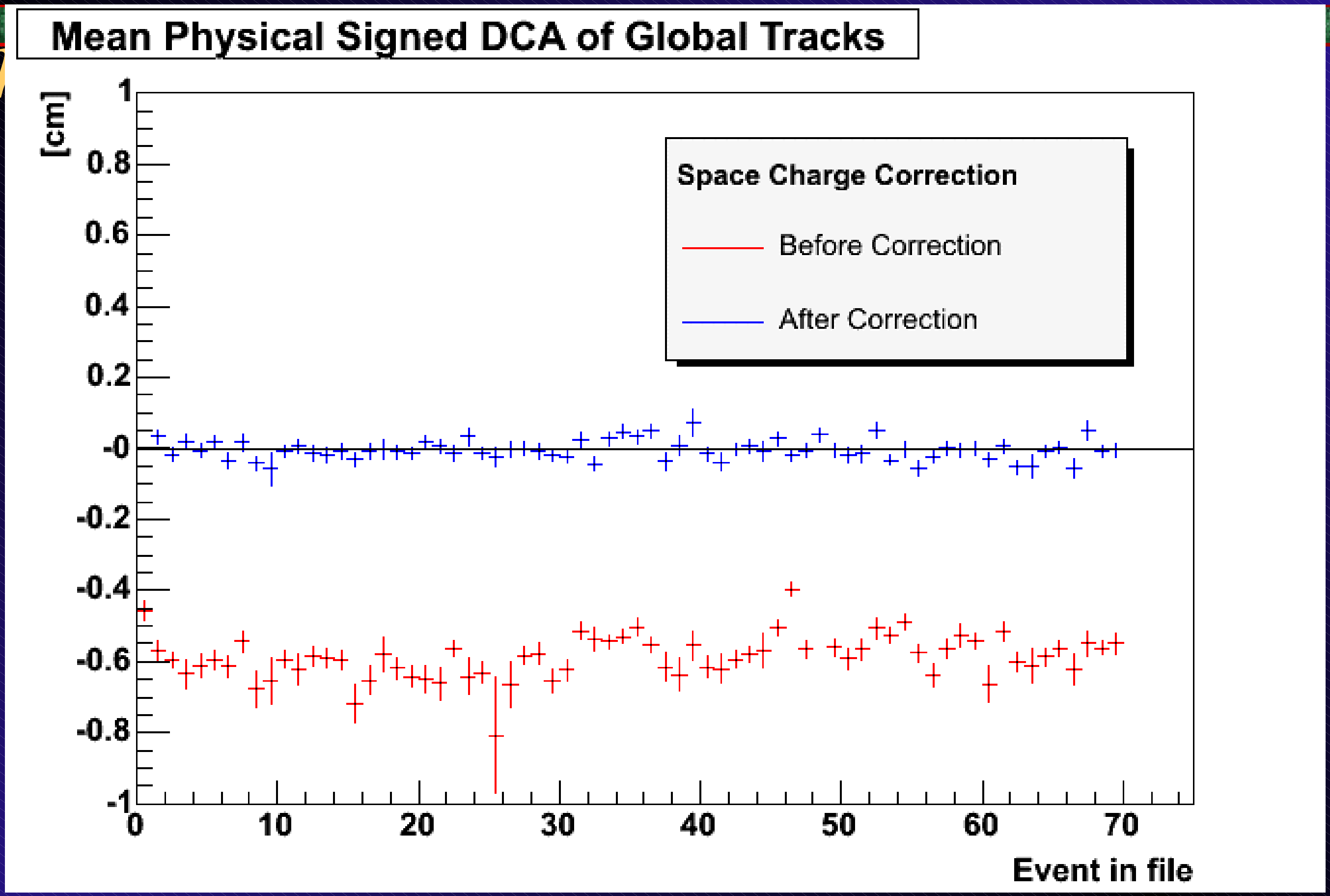


Figure 2: Event by Event space charge corrections are calculated using the average DCA from 1000 tracks in the TPC prior to the current event. The red data points show the raw data. The blue data points show the corrected data. Note that the red events show a small time dependent periodicity that is the result of fluctuating luminosity with a period of a few seconds. It is superimposed upon the mean luminosity of the beams.

Laser Track Test: insert extra

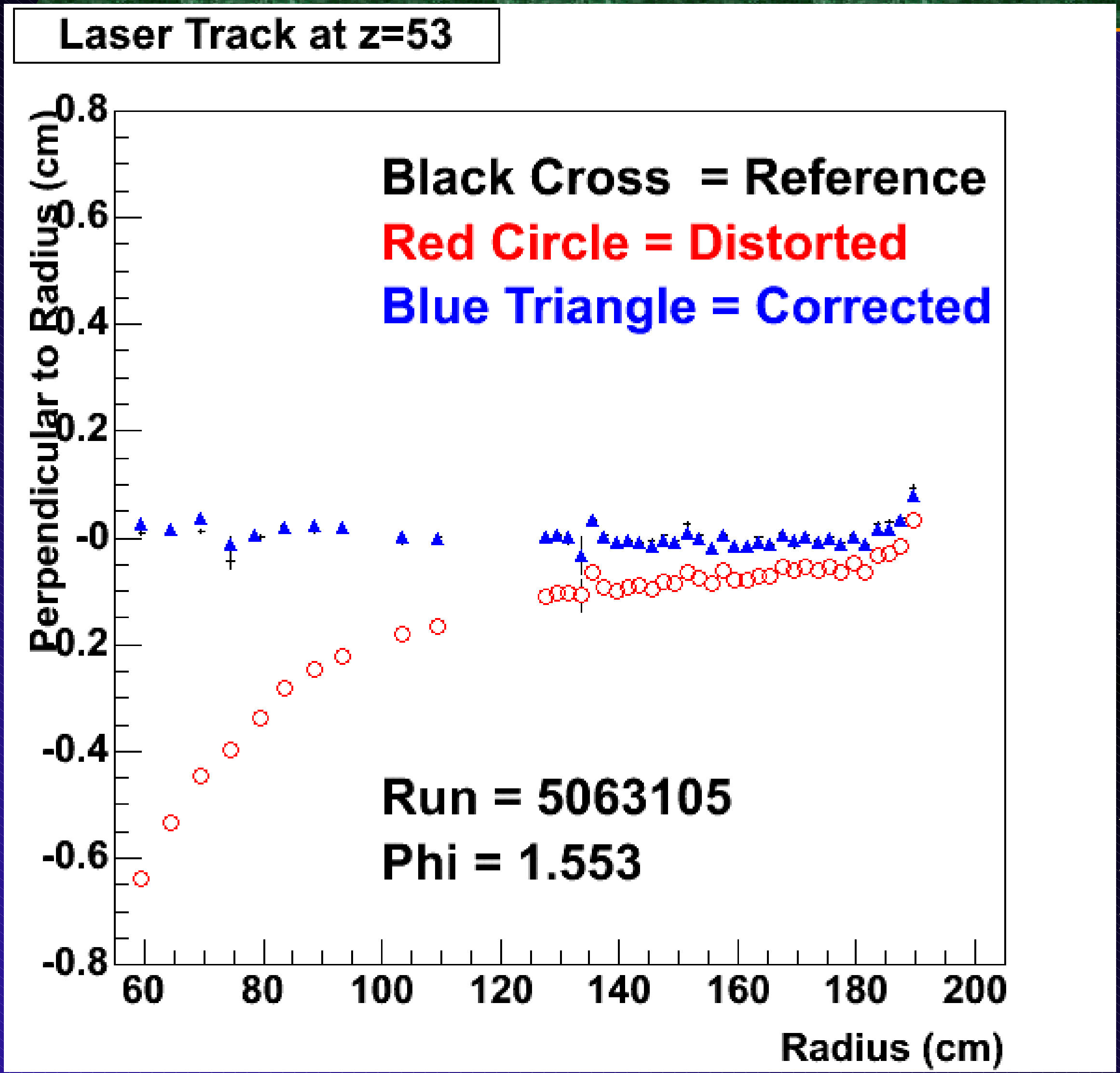


Figure 3: An electrostatic distortion was imposed upon the TPC as a test of our calibration procedures. In this test, we inserted one extra resistor in the chain of resistors that determine the electric field gradient in the TPC. This test is similar to the effects of shorting out a ring in the TPC field gradient structure (which, in fact, has happened on the other end of the TPC). The red points are the data that were measured after the resistor was inserted in the chain. The blue points are the corrected data, and the black crosses (which are difficult to see under the blue triangles) are the reference points that were recorded before the extra resistor was inserted in the chain.

Shape of the Charge Distribution

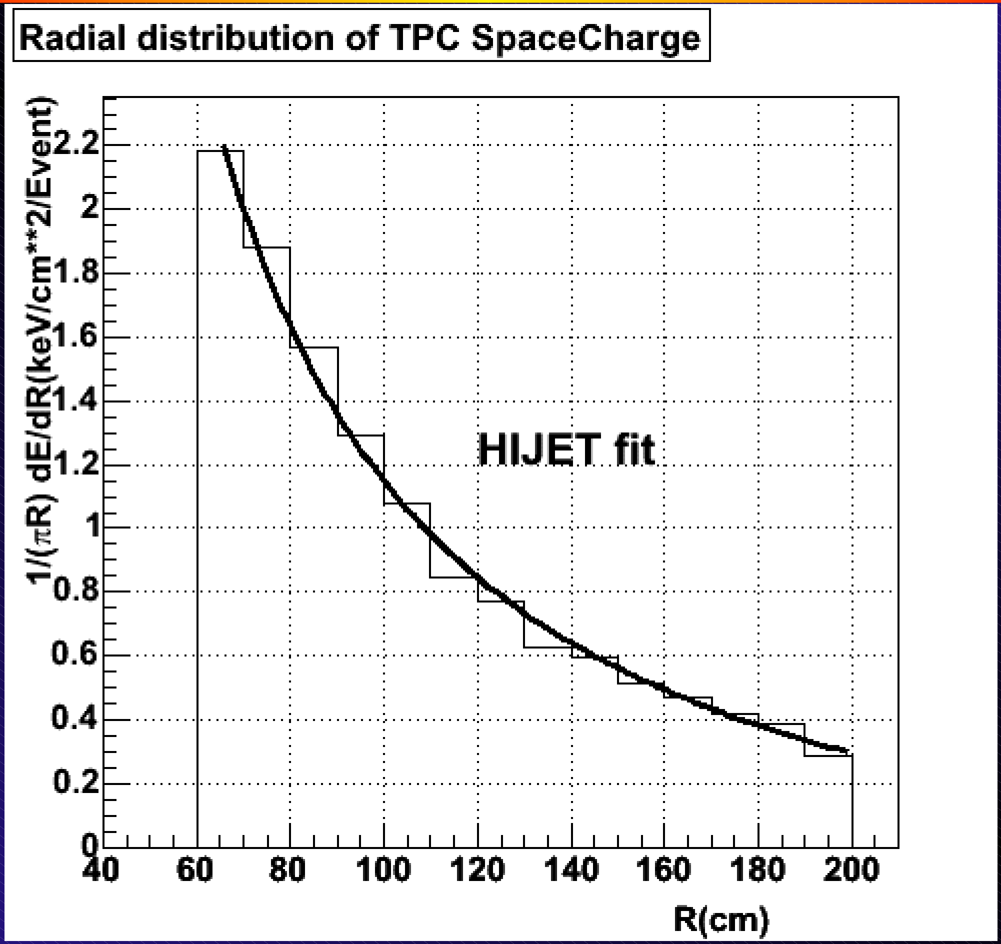
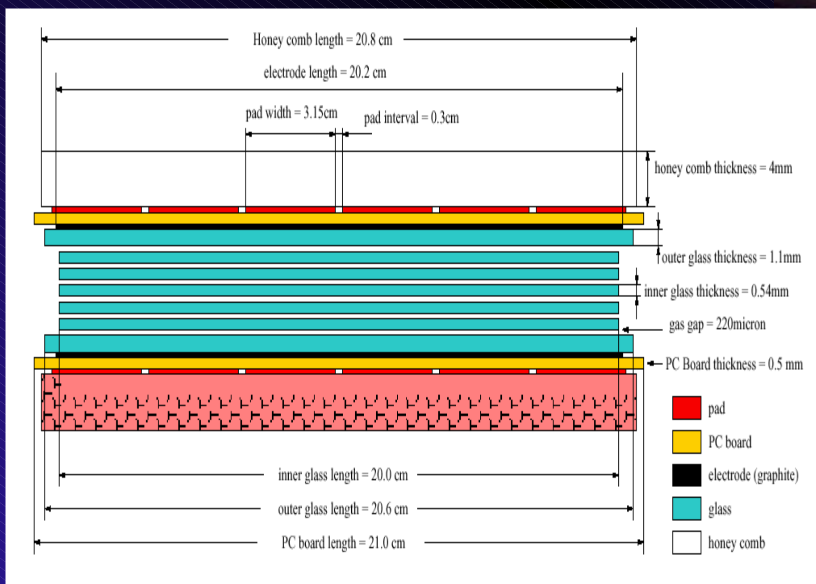
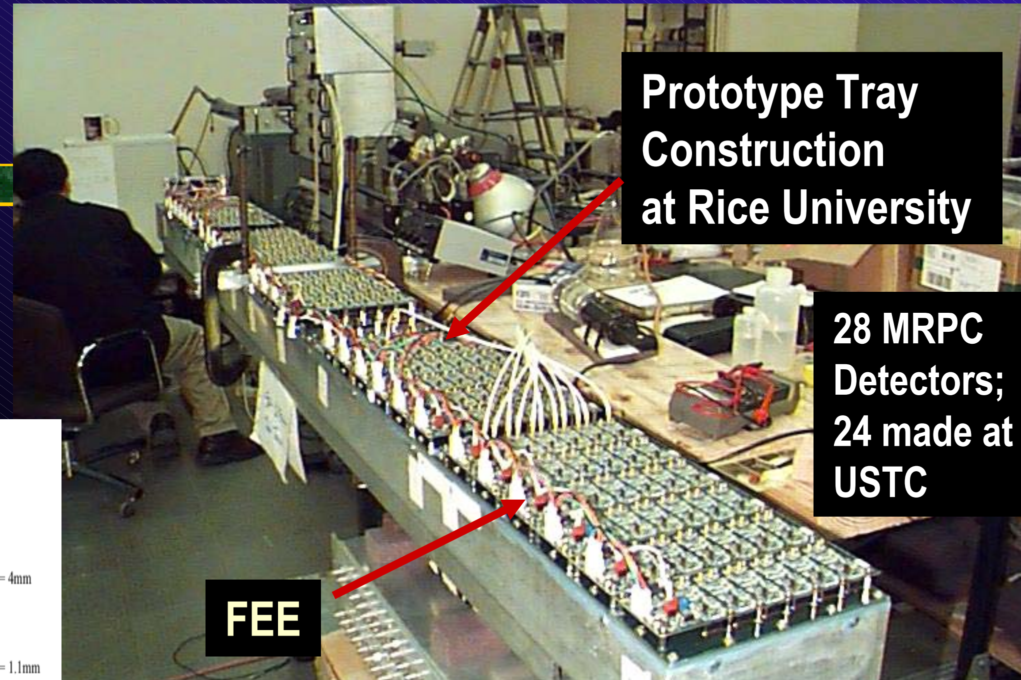


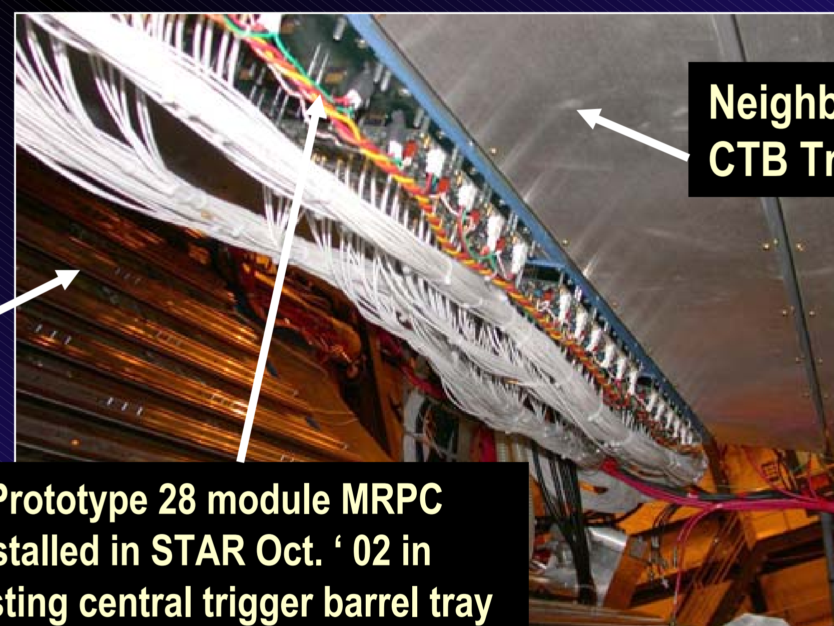
Figure 4: The radial distribution of space charge in the TPC is described very well by the charge distribution in a Hijet event.

The STAR Barrel TOF MRPC Prototype

MRPC design developed at CERN, built in China







Completed Prototype 28 module MRPC TOF Tray installed in STAR Oct. ' 02 in place of existing central trigger barrel tray

$\sigma \sim$ 70 ps, 2 meter path

Strong team including 6 Chinese Institutions in place

STAR

Forward Meson Spectrometer Status

- **Timing**
  - STAR Forward Workshop (6/9/04) to establish scope
  - STAR Upgrades Workshop (6/15-17/04) for development of overall upgrades plan
  - Completion of Proposal (Fall, 2004)
  - Commissioning (Fall, 2006)
- **Cost**
  - Depends critically on availability of existing calorimetry (Pb glass).
  - If existing calorimetry can be employed, costs are dominantly readout/triggering electronics, high-voltage distribution, and mechanical design.
    Rough estimate ~ $1.5M