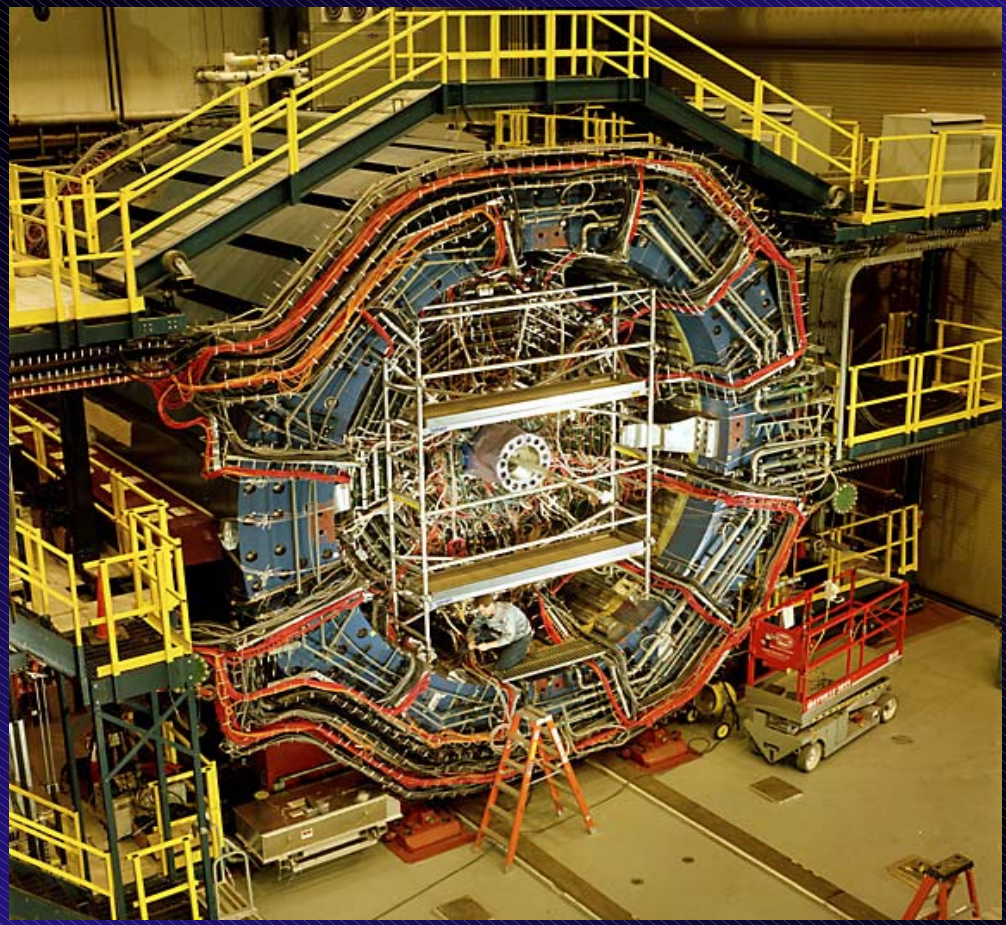
STAR Future Physics and Planned Upgrades



Tim Hallman

Detector Advisory Committee Meeting
December 19-20, 2002

STAR Future Physics and Planned Upgrades

This talk:

- *addresses the period now to 2010 +*
- *Provides a projection of the future STAR/RHIC physics program during this period (a picture being developed)*
  - *high pt (triggered) probes* $\Rightarrow$ *high luminosity, good tracking and vertexing*
  - *studies of bulk (untriggered) phenomena* $\Rightarrow$ *fast DAQ, FEE*
- *Identifies important technology and R&D directions that need to begin <u>now</u> based on what is already visible in the foreground*

STAR Future Physics and Planned Upgrades

This work has moved forward since the LRP

- **through workshop at Bar Harbor, June 17-20, 2002**
- **through periodic phone conferences of the STAR Upgrade Steering Committee**
- **through work of STAR TPC Evaluation and Study Group**

STAR Future Physics and Planned Upgrades

Present Status of the Heavy Ion Program:

We appear to be producing matter which exhibits features qualitatively different than previously observed!

- **The evolution is clearly that of highly dynamic, strongly interacting matter**
  - **(high radial flow ($\beta \sim 0.6$) and v2, HBT $\rightarrow \tau$ for emission ~ 1 fm/c)**
- **The produced matter appears to be opaque**
  - **(Suppression of high p_T inclusives, suppression of back-to-back correlations)**

The future program must (still) answer <u>definitively</u>:

Is there a phase with bulk- matter properties which are partonic ?

What are those properties in detail?

STAR Future Physics and Planned Upgrades

In STAR these questions will be attacked

– **using hard 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**

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

– **with very large samples of "soft physics" events to unfold the bulk properties of the produced matter, studying e.g.**
  - **heavy quark thermalization**
  - **heavy baryon / meson elliptic flow**
  - **spectrum of extended hadronic matter (resonances)**
  - **broken / restored symmetries (e.g., cp violation, chiral restoration)**

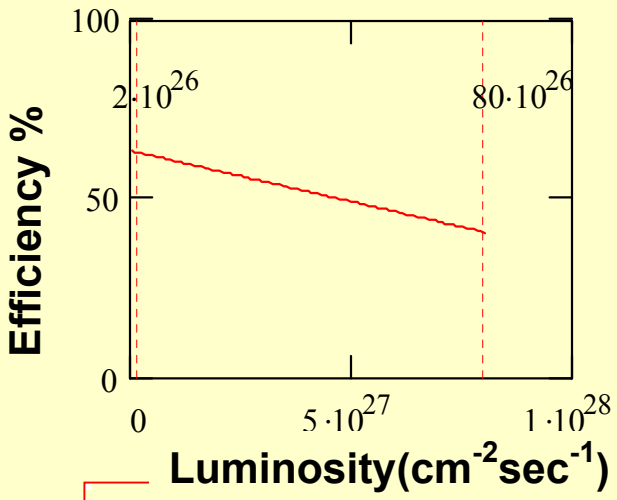
The STAR Experimental Program

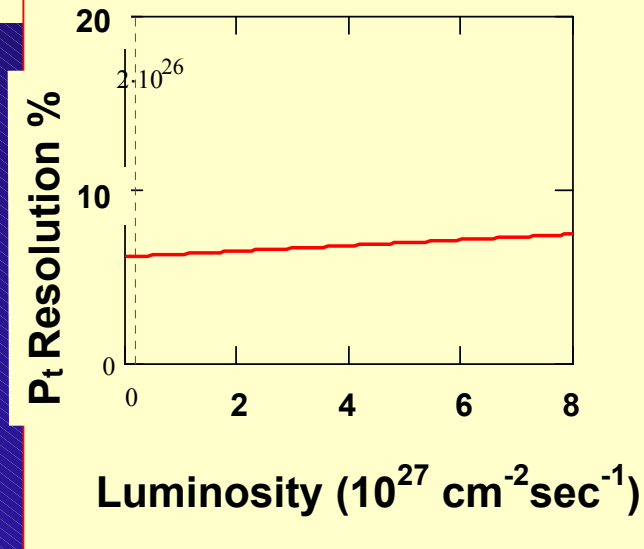
To carry out this program STAR needs:

- **A micro-vertex detector** — **precise (3 μm) hit position close to the primary vtx → D's ,flavor- tagged jets**
- **A DAQ/ TPC FEE Upgrade** — **new architecture / FEE → 1 khz of events sampled at L3; effective integration of 10 x more data**
- **A Barrel MRPC TOF** — **4 vector information for an additional 60% of the hadrons in final state; extended scientific reach for key observables**
- **Development of GEM tech.** — **Preparation for a compact, fast, next generation TPC needed for 40 x L**
- **High Luminosity** — **10 - 50 times the luminosity (10 nb^{-1}) integrated up to 2010 (Thomas Roser will provide)**

STAR Future Physics and Planned Upgrades

What about existing TPC operation at High Luminosity ?





Initial Study by TPC Evaluation & Study Group

	now	4 x	40 x
Track Eff (Central)	60%	58%	41%
Pt Resolution*	6.1%	6.2%	7.4%

(* half field for pt = 3 GeV/c; full field 3 x less)

DCA Distortion (SC)	0.7mm	2.7mm	2.7cm

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

Questions Under Study

- Full understanding of space charge effects
- 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?

This continues to be an active ongoing study; measurements with beam are also planned

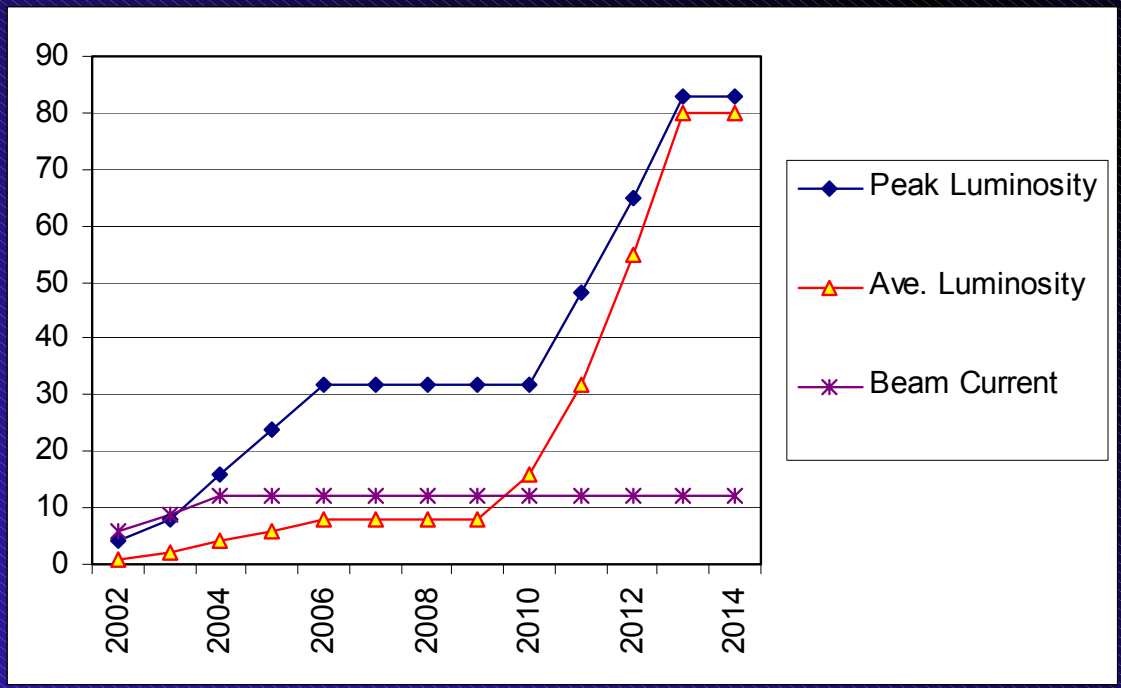
STAR Future Physics and Planned Upgrades

This projection for the TPC assumes the following RHIC Luminosity Upgrade Plan

Enhancements possible with existing machine:
Double the number of bunches to 112
Decrease b^* from 2 m to 1m

4x increase in ave. L;
Still limited by I.B.S.

Electron beam cooling at full RHIC energy will eliminate intra-beam scattering effects and reduce beam emittance: 10x increase in average luminosity

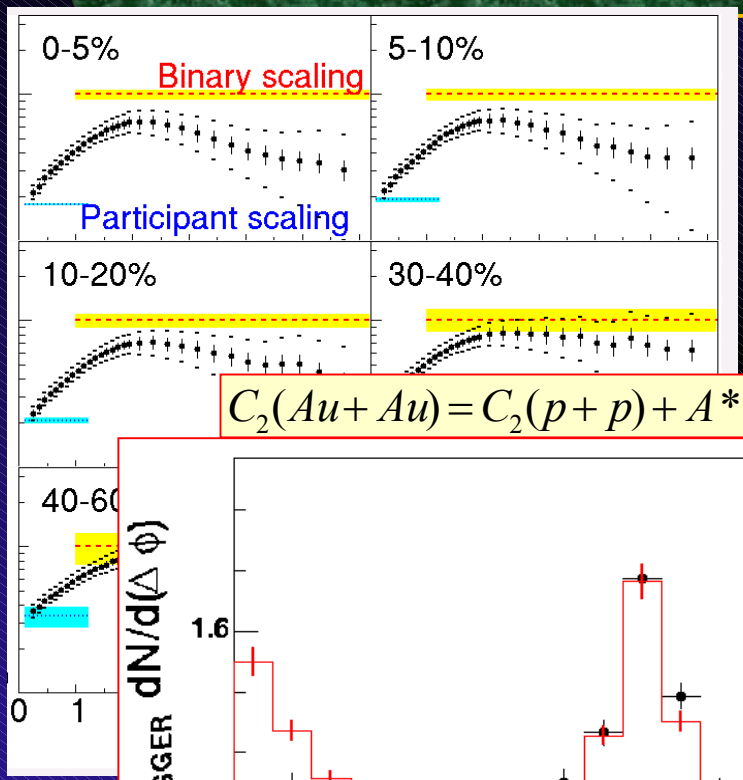


Evolution of Au Au parameters:

Luminosity in units of 10^{26} $cm^{-2}sec^{-1}$

Current in units of 10^{10} ions/beam

STAR Future Physics and Planned Upgrades

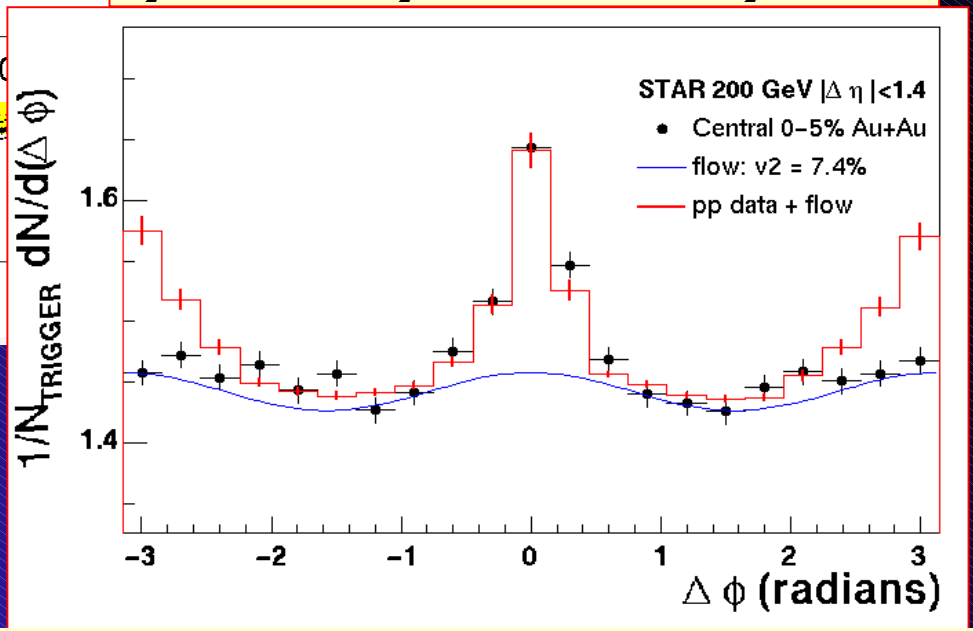


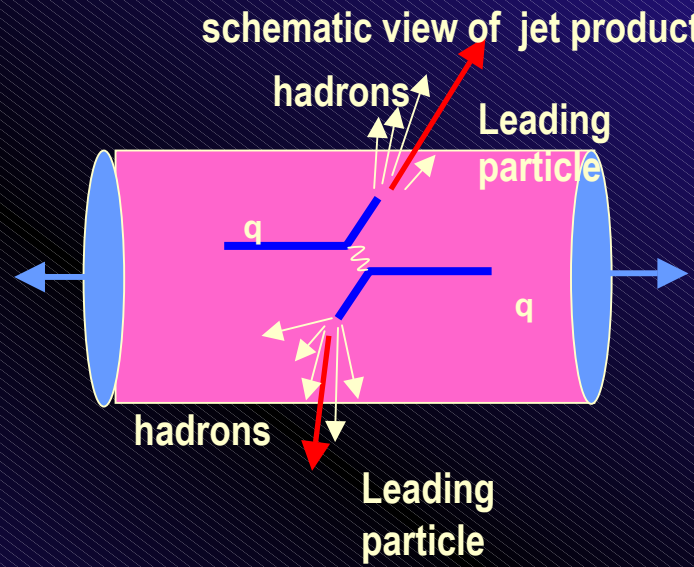
From an initial study of High P_T -

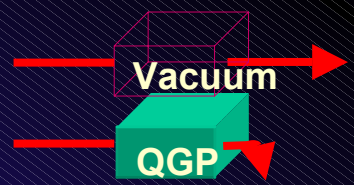
A major find from the last RHIC run:

- Suppression of high p_t particles
- Suppression of angular correlations

$$C_2(Au+Au) = C_2(p+p) + A*(1+2v_2^2\cos(2\Delta\phi))$$

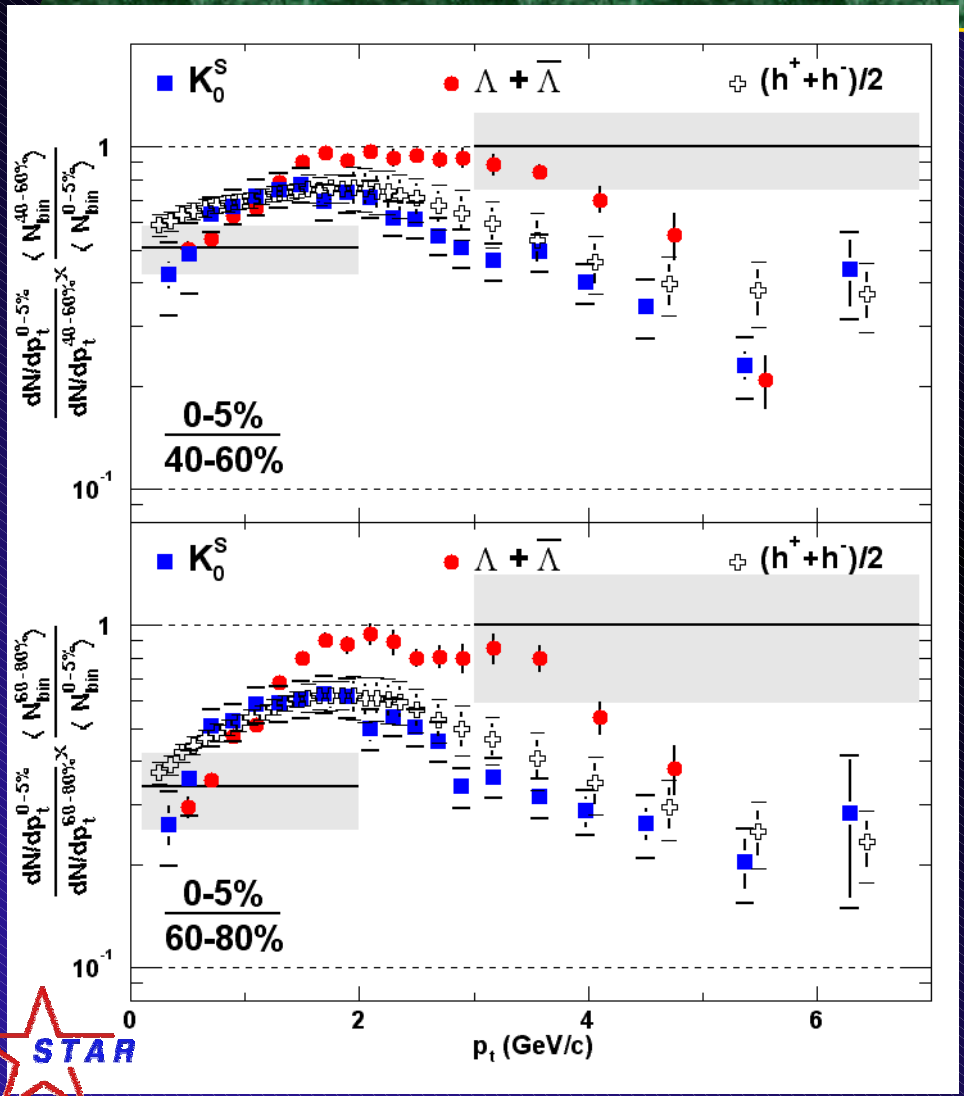






RHIC and STAR are robust "laboratories" for studying high pt probes !

STAR Future Physics and Planned Upgrades



Nuclear modification factor :

$$R_{AA} = \frac{d^2N^{AA}/dp_T dy}{T_{AA}\, d^2\sigma^{NN}/dp_T dy}$$

Geometric modification factor :

$$R_{AA}^{geo} = \frac{d^2N^{Central}/dp_T dy}{d^2N^{Peripheral}/dp_T dy} \frac{\left\langle N_{bin}^{Peripheral} \right\rangle}{\left\langle N_{bin}^{Central} \right\rangle}$$

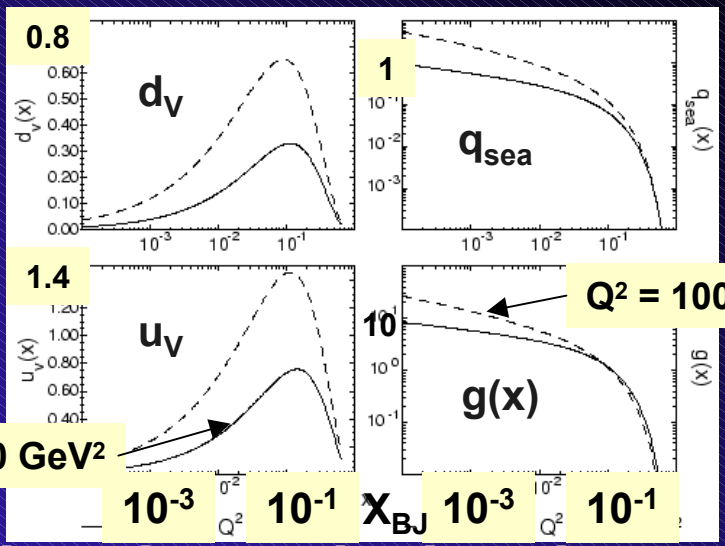
STAR Future Physics and Planned Upgrades

The next step? -- Trying to be quantitative. The question -- Is the suppression due to <u>partonic</u> energy loss?

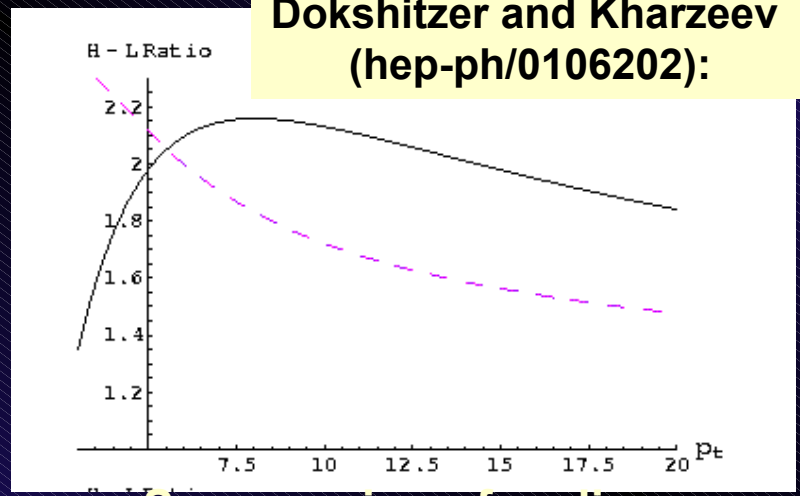
A possible approach:

differential energy loss of gluon, light quark, and heavy quark jets

- **Statistical, kinematic separation of gluon and light quark jets based on underlying PDF's and "reconstructed" parton- parton cms**
- **flavor tagging of heavy quark jets**
- **D/ π, B / π ratio versus p_T**



Dokshitzer and Kharzeev (hep-ph/0106202):



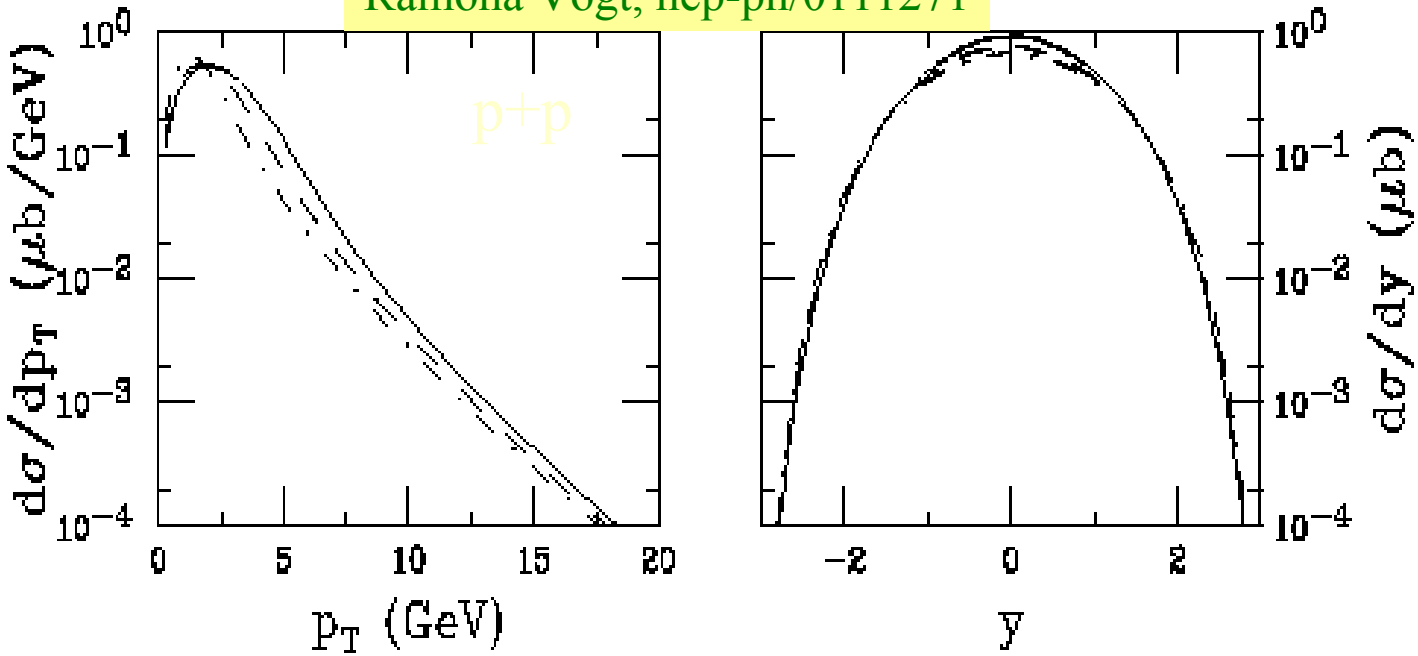
Suppression of co-linear gluon radiation

Further theoretical and experimental development needed !

STAR Future Physics and Planned Upgrades

With regard to flavor tagging, e.g.

Ramona Vogt, hep-ph/0111271



↗ p_T ~ 15 GeV/c: σ (p+p)~5x10^{-4} μb/Gev ⇒ σ (Au+Au) ~ 20μb/Gev

↗ centrally produced

↗ 5 years of Au+Au =10 nb^{-1} ⇒ 200K b-bar pairs

The yield is there! Can they be pulled out?

STAR Future Physics and Planned Upgrades

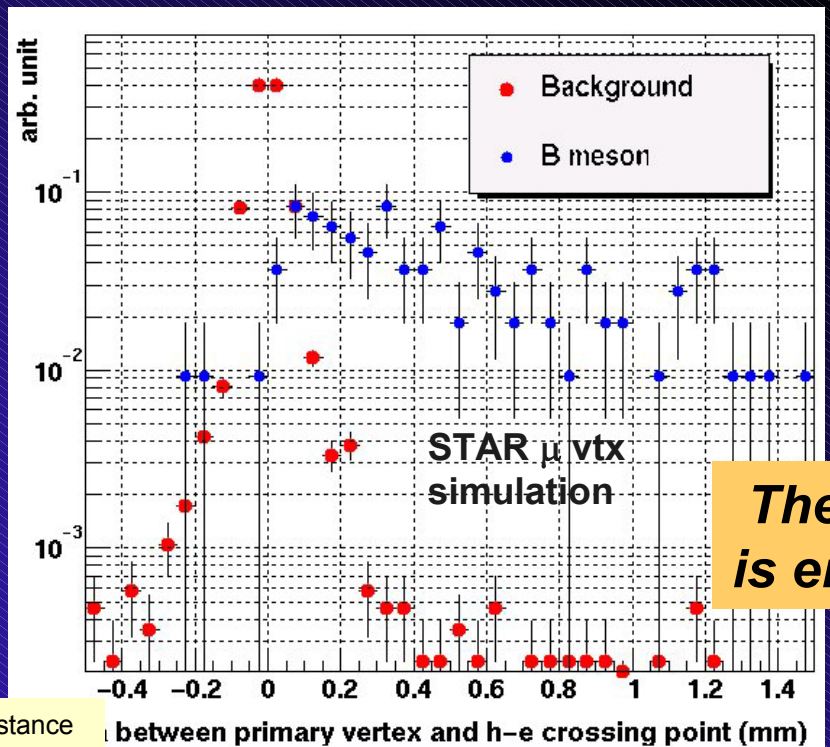
A First look - Using a proposed STAR μVTX Detector

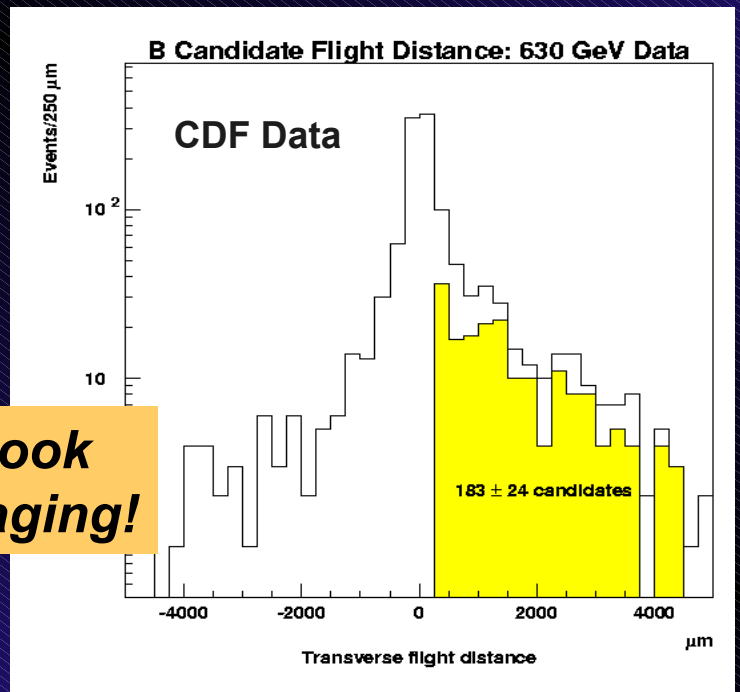
B - Jet Tagging - Heavy Quark Energy Loss: B → $e^{+/-}$ + hadron + X

EMC triggers $e^{+/-}$ from B, μVertex cleans the sample

- P_e > 4 GeV/c, P_h > 0.7 GeV/c
- DCA between e and h < 150 μm
- Assume 50% e+/- misidentification

- High pt $e^{+/-}$ triggered by EMC
  - Enhance yield; some h $^{+/-}$ mis-id'd as $e^{+/-}$
  - Remove hadronic background
- Associate e+/- with h +/- at a displaced vtx
  - DCA sign positive if displaced vertex and P_e point in the same direction



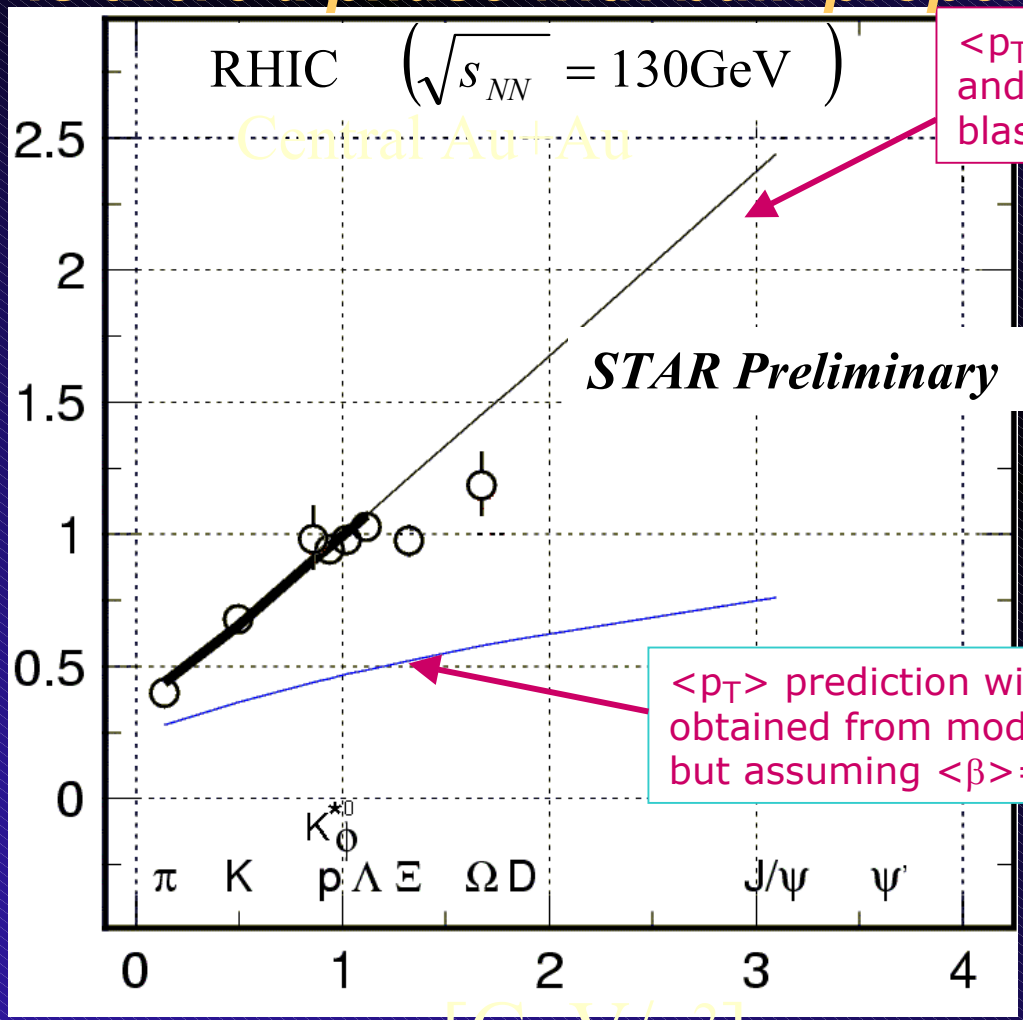


The first look is encouraging!

distance

STAR Future Physics and Planned Upgrades

Soft Physics Measures:
Is there a phase with bulk properties which are Partonic ?



- Ξ and Ω show deviation
- Possible interpretation:
  Early decoupling?

⇒ V2 of heavy baryons and mesons may reflect pressure in partonic phase

Without TOF need 200M min- bias events ! for v2 study; ~ 20M with MRPC TOF Barrel

Publications:
PRL 87, 242301 (2001)
PRC 65, 041901(R) (2002)

STAR Future Physics and Planned Upgrades

A possible probe: Charm hadron chemistry; D_s^+ reconstruction

- **Do c quarks thermalize?**
  - If yes, ratio of charm hadrons yield changes from p-p to Au-Au
    (D_s^+ most sensitive)

	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	0.013

System	N events for 3 σ
TPC+SVT ($K^0_s + K^+$)	500 M
TPC+SVT+μVertex ($\phi+\pi^+$)	80M
TPC+SVT+μVertex+TOF ($\phi+\pi^+$)	5M

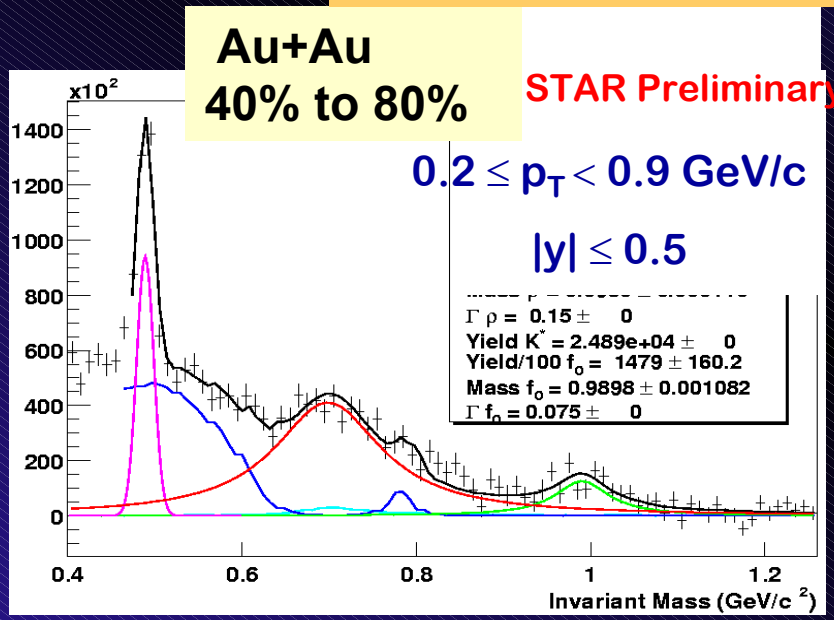
* A.Andronic, P.Braun-Munzinger, K.Redlich, J.Stachel

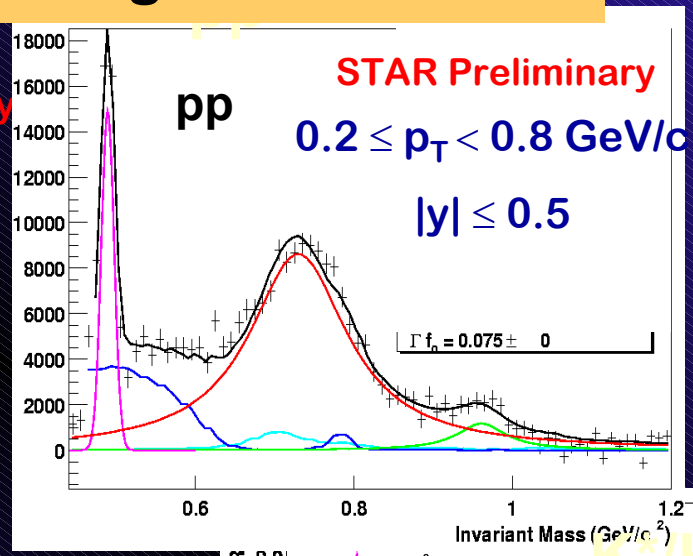
nucl-th/0209035 (QM02 proceedings)

No Trigger Possible -
Need large event sample, precision vtx, additional PID

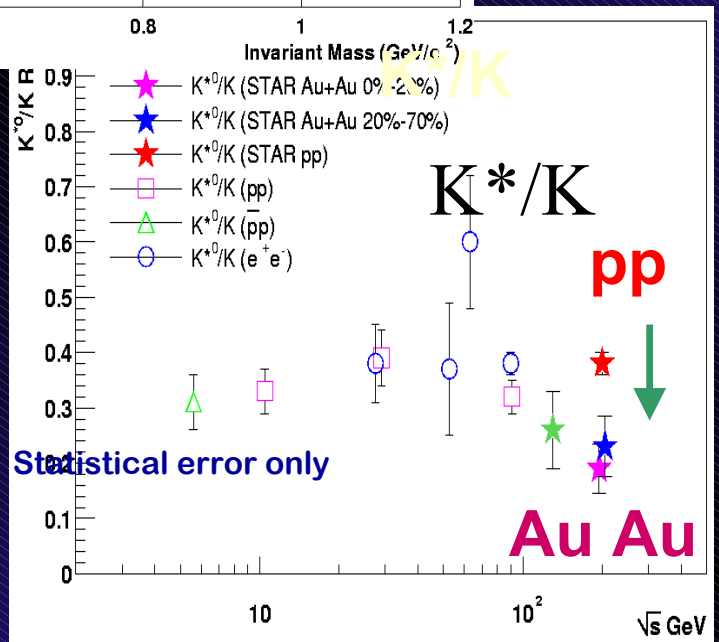
The STAR Experimental Program

Probing Rescattering: Resonances





ρ⁰
f₀
K⁰S
ω
K*0



- Short-lived resonances probe the medium and map the history wrt rescattering after chemical freezeout
  - Destruction of signal in hadronic channel
  - Regeneration in "elastic" scattering stage
- No trigger possible
- Large data samples necessary
- PID from TOF essential to extend p_T reach

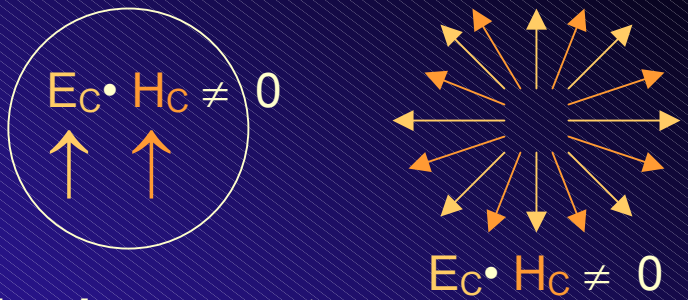
STAR Future Physics and Planned Upgrades

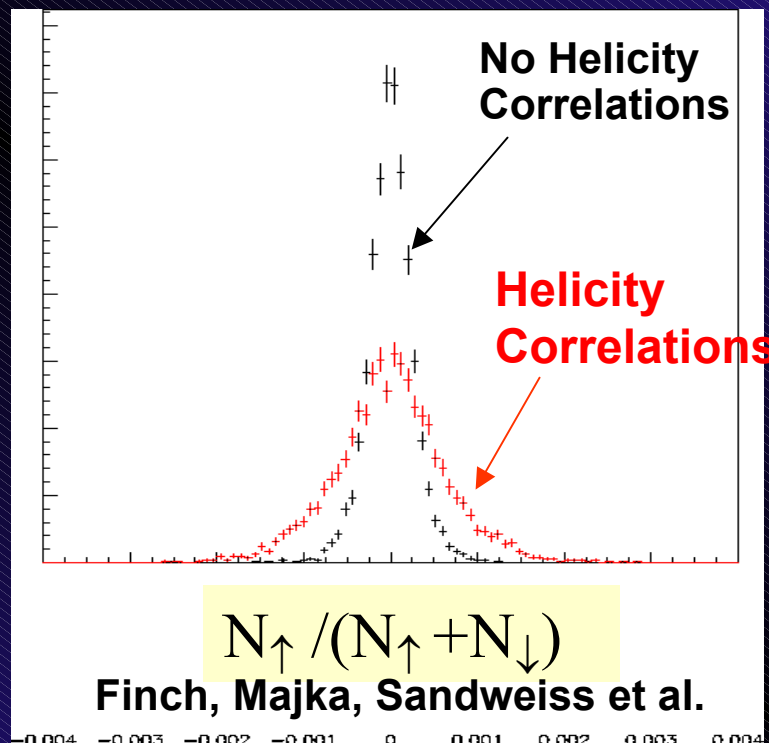
Studying the fundamental nature of QCD: Strong CP Violation

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

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)

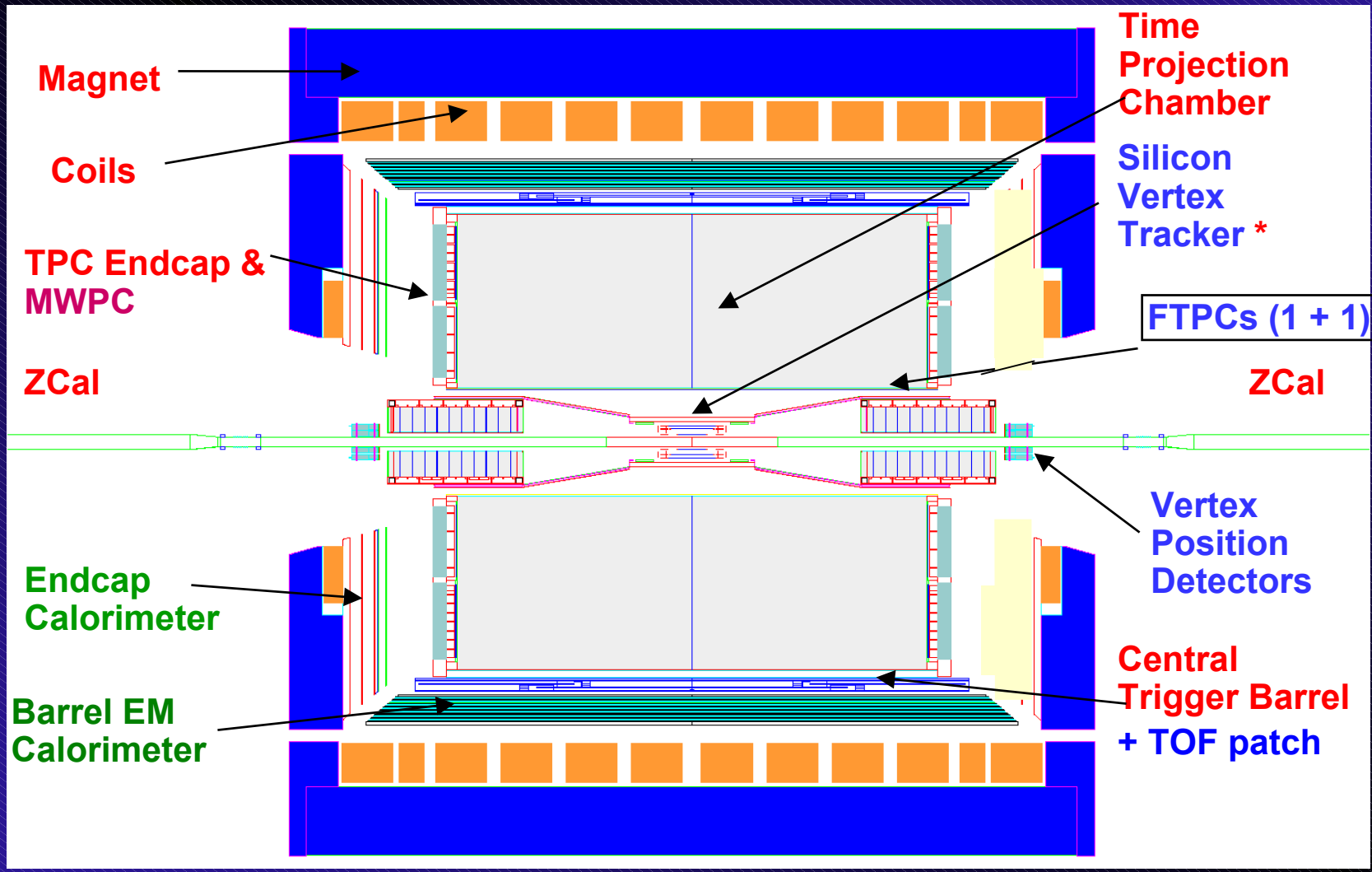




⇒ Simple momentum space asymmetry probably not good enough → look at e-by-e helicity balance of fermions (Λ°) and search for fluctuation (too many positive helicity Λ°)

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

STAR Future Physics and Planned Upgrades



Baseline STAR Detector System

STAR Future Physics and Planned Upgrades

Ongoing improvements of STAR Capability

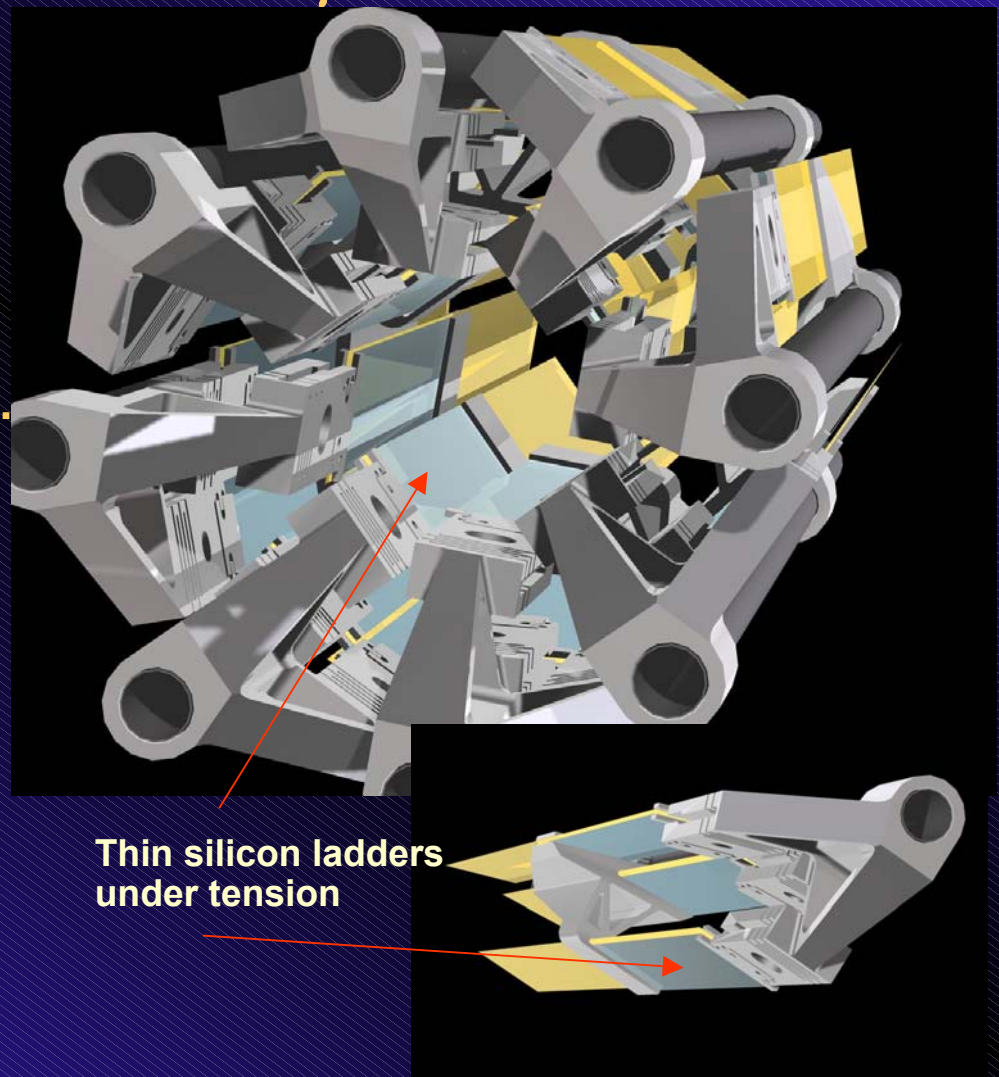
Summary

Detector / Interest	Status by 11/02	Completion
Barrel Electromagnetic Calorimeter (high pt, photons, π^0, jets)	60 modules of 120 installed	2004
Endcap Electromagnetic Calorimeter (reach in x_BJ, high pt, photons, π^0, jets)	1/2 mech / struct, installed; 30% instr.	2004
Photon Multiplicity Detector $<m_\gamma>$ (π^0) fluctuations, Chiral Condensate	Material arriving at BNL	2003
TOFr (< 100 ps TOF PID with MRPC Modules)	Tray installed	2002
DAQ 100 (Event Rates ~ 50mb,30ctrl,50pp Hz)	Hardware/Code Ready	2002
Forward Pi Zero Detector (A_N for leading π^0, G(x) in d + Au)	Acquisition / Initial Constr. in progress	2002-2003
Level I, II Trigger Aborts (Rare Trigger Selection e.g. J/Ψ)	Commissioning	Ongoing Dev.

STAR Future Physics and Planned Upgrades

Physics provided by the STAR μVertex detector

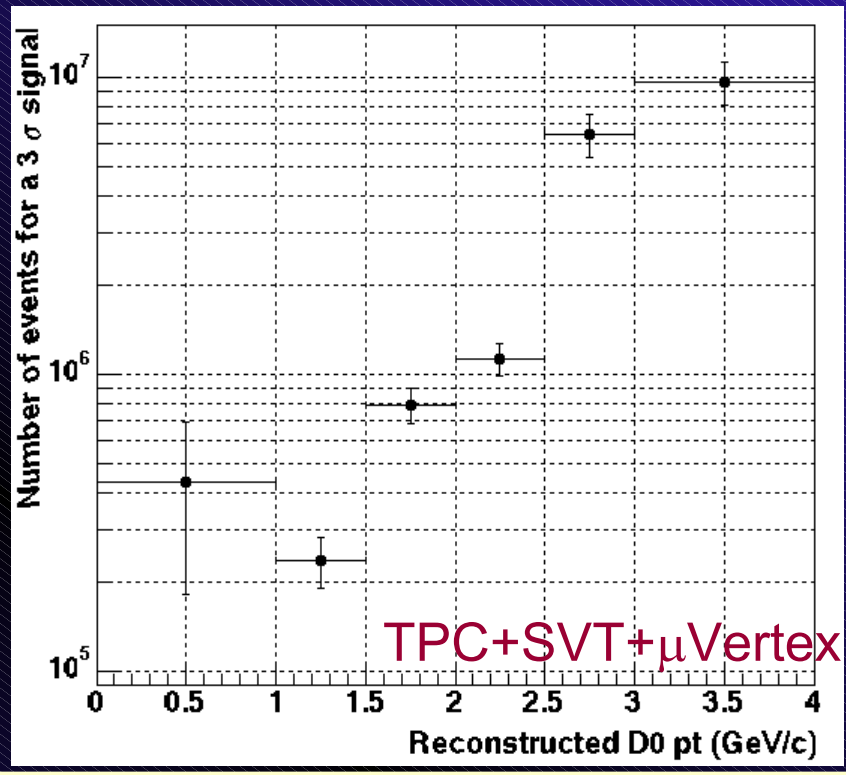
- **Open charm**
  - **Charm quark yield**
    - **Reconstructing D^0**
  - **Charm hadron chemistry**
    - **Reconstructing D^+, D_s^+, ..**
  - **Charm hadron flow**
    - **Constructing D^0 spectra**
- **Open beauty**
  - **Identifying B mesons**
- **Identifying heavy quark jets**



STAR Future Physics and Planned Upgrades

Charm hadron flow; D^0 spectra

System	N events for 3 σ
TPC+SVT	12.6 M
TPC+SVT+TOF	2.6 M
TPC+SVT+μVertex	0.1 M
TPC+SVT+μVertex+TOF	0.01 M



- Do D^0 flow?
  - Need pt spectra
    - <pt> ~ 1.6 GeV/c if D0 flow as proton
    - <pt> ~ 1 GeV/c in p-p (Pythia)
- 10M events enough to construct D^0 spectra

System	N events for 3 σ (pt > 2 GeV/c)
TPC+SVT	59 M
TPC+SVT+TOF	23 M
TPC+SVT+μVertex	0.6M

STAR Future Physics and Planned Upgrades

Key features of the proposed STAR μvtx detector:

- ***ultra-thin 50 μm silicon (APS) chips***
- ***excellent position resolution (3 μm), 20 μm x 20 μm pixels***
- ***minimal coulomb scattering, beam pipe wall < 600 μm***
- ***state of the art mechanical support allowing easy insertion/removal and eventual replacement with faster APS chips***
- ***10-20 ms readout initially; storage of all events in 20 ms "bucket"; per pixel probability of hit 0.5% at 4 x L; per pixel probability of pile up in 20 ms, ~ 10^{-5}***
- ***data matching offline***
- ***upgrade to 5 ms readout for 40 x luminosity upgrade***

STAR Future Physics and Planned Upgrades

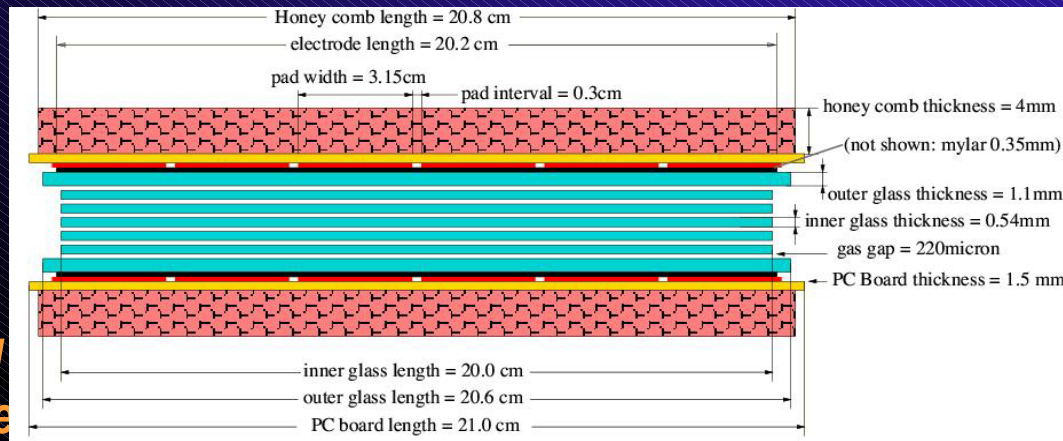
What about readout speed of inner tracking system?

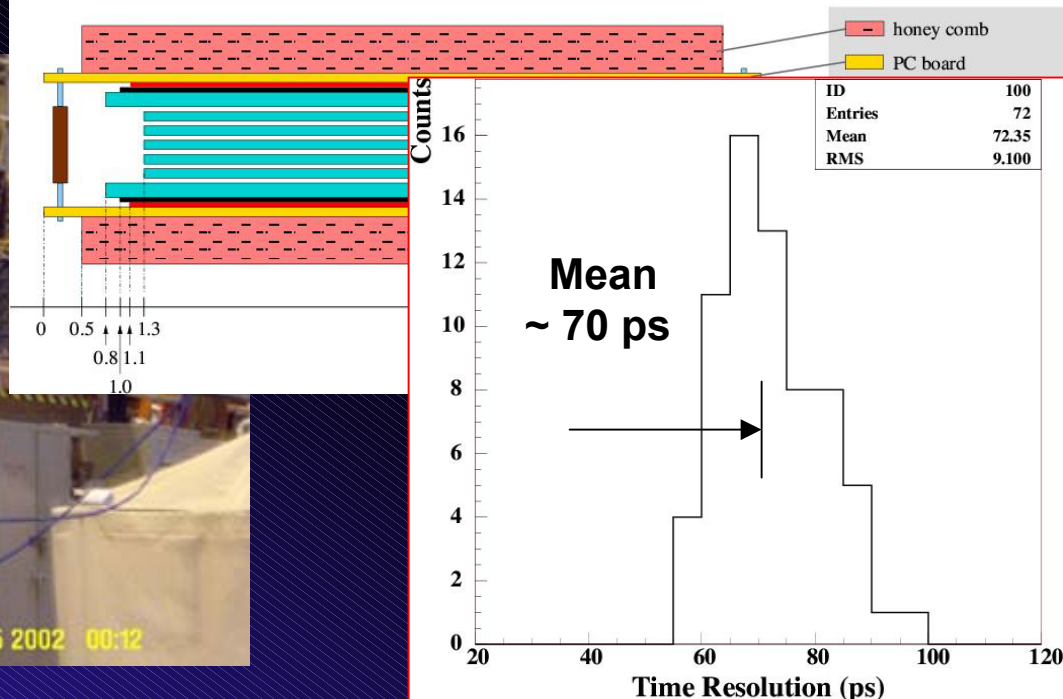
- ***First version of APS will be able to readout in 10-20 msec (50 - 100 Hz); second generation APS will readout in 5 msec***
- ***Each read will contain all hit information from a 20 msec window (50 → 100 min bias events at 4 x L).***
- ***Sparse data population and precision pointing of projected tracks in 100 μm search window will eliminate non-trigger hits***
- ***SSD layers capable of being readout at ~ 1 Khz (present estimate, ~ 800 Hz)***
- ***SVT readout limited to 100 Hz (200 ?); information from "in-between" events lost. SVT projected for use until 2006-2007; possible ALICE hybrid pixel layer(s) replacement at that time***

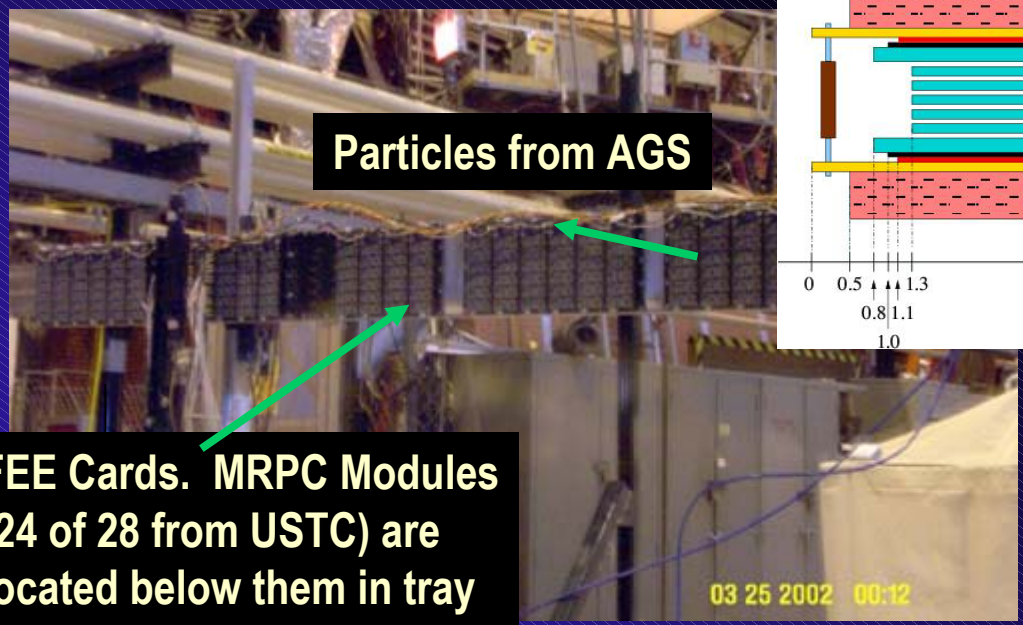
STAR Future Physics and Planned Upgrades

MRPC TOF Barrel

- *Extensive testing / development in collaboration with lead group from Bologna ⇒ MRPC technology is mature and not in question*
- *R&D needed to demonstrate on-board electronics feasibility taking advantage of ALICE HPTDC chip development*







STAR Future Physics and Planned Upgrades

The STAR MRPC TOF Barrel will:

- ***allow STAR to measure 4 vectors for an additional 60% of the particle in the hadronic final state, saturating the information content available from soft physics measures***
- ***Cut the time (events) needed to measure the open charm yield by a factor of 5 (12.6M → 2.6M) (TPC + SVT versus TPC + SVT + TOF)***
- ***Cut the time (events) needed for bulk measures (e.g. heavy baryon elliptic flow) which may distinguish between hadronic/ partonic degrees of freedom by a factor of 10 (200M → 20M)***
- ***allow the detailed unfolding of large and small scale correlations & fluctuations to map the dynamics/evolution of the produced matter***
- ***extend the pt reach to for measuring resonances to 1-2 GeV/c affording a precision tool for model comparison and a definitive determination of the importance of re-scattering versus regeneration (calibration of an important set of standard candles)***

STAR Future Physics and Planned Upgrades

The DAQ and Front End Electronics Upgrades

- **The DAQ and FEE upgrades will allow STAR to acquire large data samples, increasing the luminosity effectively integrated by STAR by a factor of 10**

- **This upgrade will increase the number of events sampled to 1000/sec minimum bias, ~ 200 Hz central. The baseline plan is to present these to level III and write out 100/sec.**

- **The upgrade will address the present bottlenecks throughout the DAQ/FEE chain:**

DAQ	FEE
DAQ CPU	Chip Speed
VME Bandwidth	Analog Processing
Event Builder	Zero Suppression
LIII CPU	Noise

STAR Future Physics and Planned Upgrades

The GEM Development: essential for STAR tracking in the High Luminosity Era at RHIC

In 2010:

- **the STAR TPC will be ~ 15 years old**
- **large space charge distortions and pile-up may be problematic for the high luminosity, high pt program STAR intends to carry out**

The proposed GEM development will:

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

STAR Future Physics and Planned Upgrades

To be ready, the R&D must start now

Proposal for FY2003 - FY2005

Project	Principal Investigator	Collaborating Institutions	Requested Funds (K$) FY 2003	FY 2004	FY 2005
TPC FEE Upgrade	J. Marx	LBNL	79.8	166.5	0.0
DAQ Upgrade	T. Ljubicic	BNL	207.0	716.0	850.0
MRPC Time-of-Flight Development	G. Eppley	Rice, Texas	128.0	134.0	0.0
High Resolution Vertex Detector Development	H. Wieman	LBNL, BNL	133.3	336.5	495.0
Micropattern Readout Development for Gas Detetectors	N. Smirnov	Yale, BNL, LBNL	210.0	347.0	347.0
		Totals	758.1	1700.0	1692.0

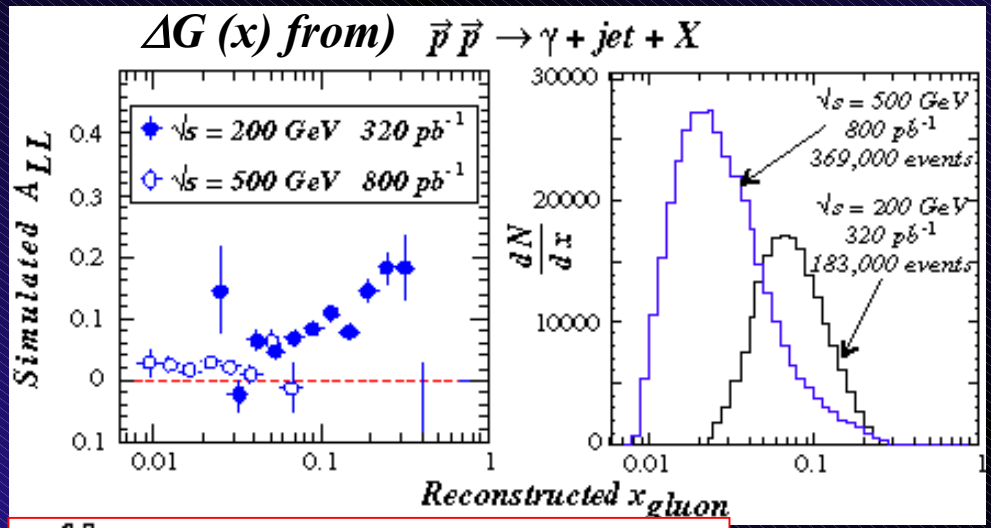
STAR Future Physics and Planned Upgrades

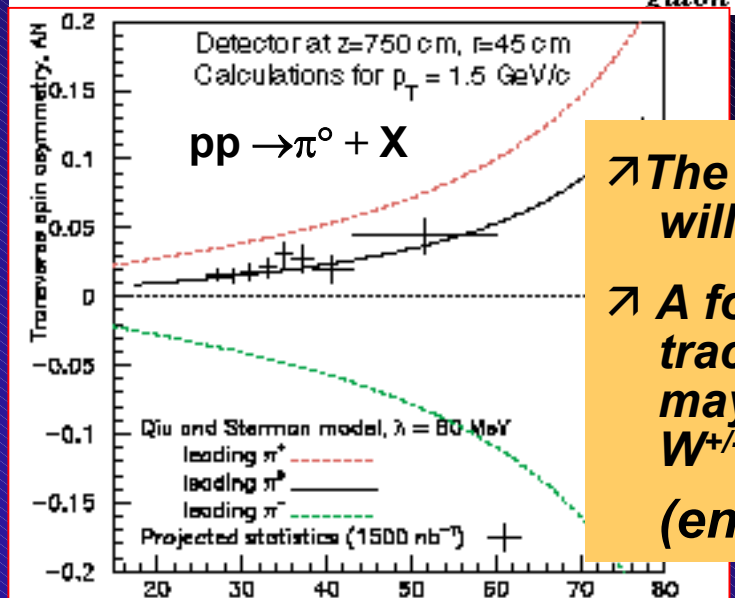
The Scope & Scientific Merit of Proposed R&D / Upgrade Plan

System	*R&D*	*Constr/Cost*	*Benefit to STAR*
Inner μvtx	'03 → '05 $ 965K	' 06 → '07 $4M	D's , flavor- tagged jets
DAQ Upgrade	'03 → '05 $1.77M	' 06 → '08 $5M	1 kz → L3; D's; Ω & D, v2, cp, D thermalization
FEE Upgrade	'03 → '04 $250k	' 04 → '06 $2.5M	1 kz → L3; D's; Ω, D, v2, cp, D thermalization
Barrel MRPC TOF	' 03 → '04 $260k	' 04 → '05 $4.5M + $2.5M in- kind	4 vector information for all charged hadrons; extended p_T for resonances Ω v2; D's; ebe correlations; anti-nuclei
GEM DeV	' 03 → '05 $900k	'08 - '10 ?	Compact, fast TPC;robust tracking for high Q^2 physics at 40 x L

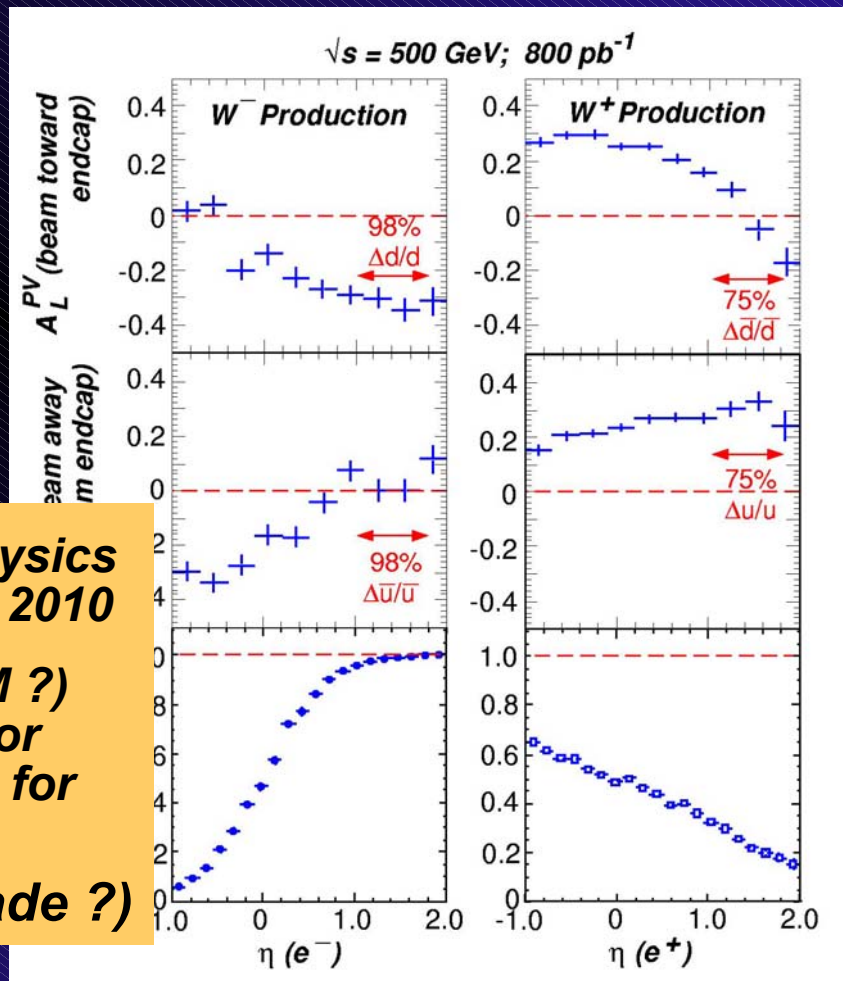
STAR Future Physics and Planned Upgrades

What about the STAR Spin Program





Δu , Δd determination via A_L^{PV} in $p + p \rightarrow W^{\pm} + X$ @ $\sqrt{s} = 500$ GeV



- ↗ *The baseline physics will take until ~ 2010*
- ↗ *A forward (GEM ?) tracking detector may be needed for $W^{+/-}$ sign*

  (energy upgrade ?)

STAR Future Physics & Planned Upgrades: Conclusions

- To fully characterize and understand the properties of the new matter being produced at RHIC, STAR needs upgraded capability to extend its scientific reach for hard and soft physics observables. The "picture" is still developing but main features are visible now.
- In addition to high luminosity, the success of STAR's future physics program requires:
  - 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 Barrel MRPC TOF detector to extend STAR's scientific reach
  - Development of GEM technology to insure robust tracking for the 40 x L era

  Other important issues such as full tracking at Level III, future RCF capability, and forward tracking in front of the EEMC also need to be investigated
- R&D needs to begin now, to be able to effectively use the 4 x luminosity increase in 2006-2010 and to allow STAR to be ready for high luminosity running in 2010