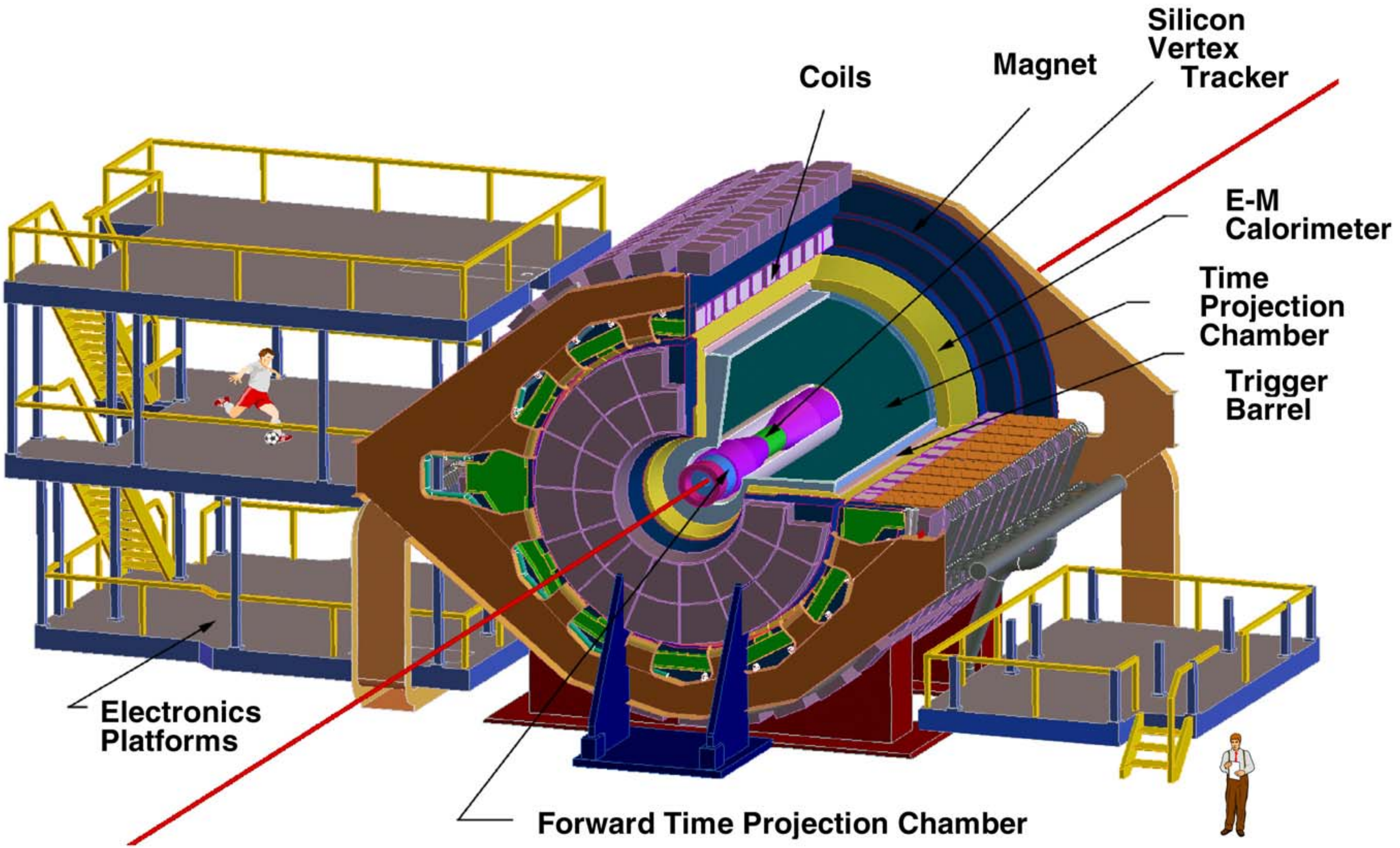
The STAR Detector at RHIC



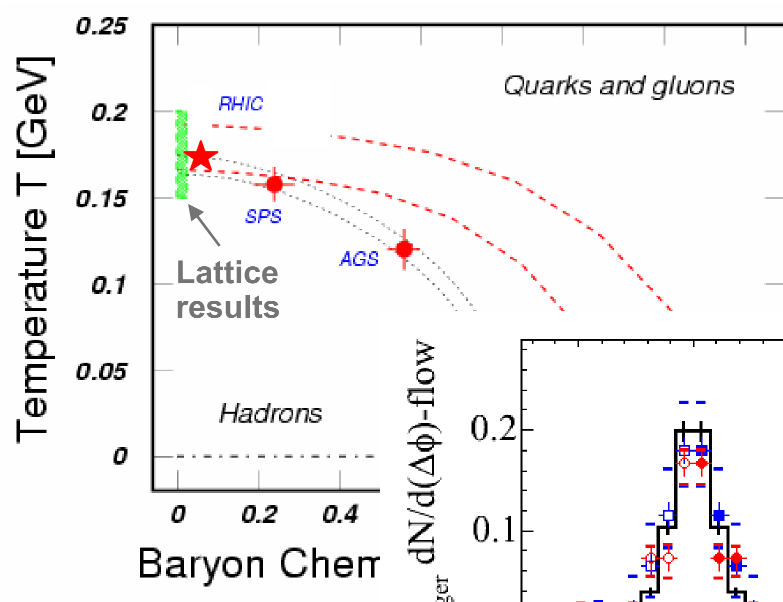
The STAR Upgrade Plan

looking to the future

Jim Thomas
Lawrence Berkeley National Laboratory

RHIC and AGS Users Meeting
June 22nd, 2007

Great Discoveries at RHIC ⇒ Precision Measurements

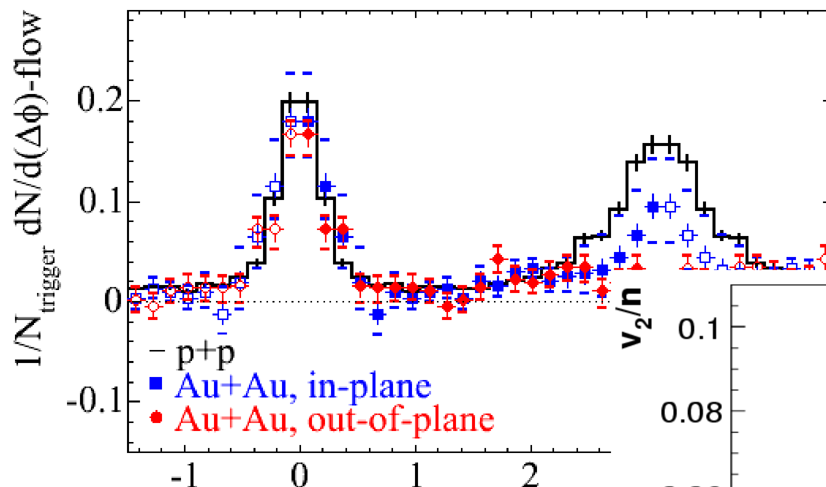


It's hot

Spectra

It's dense

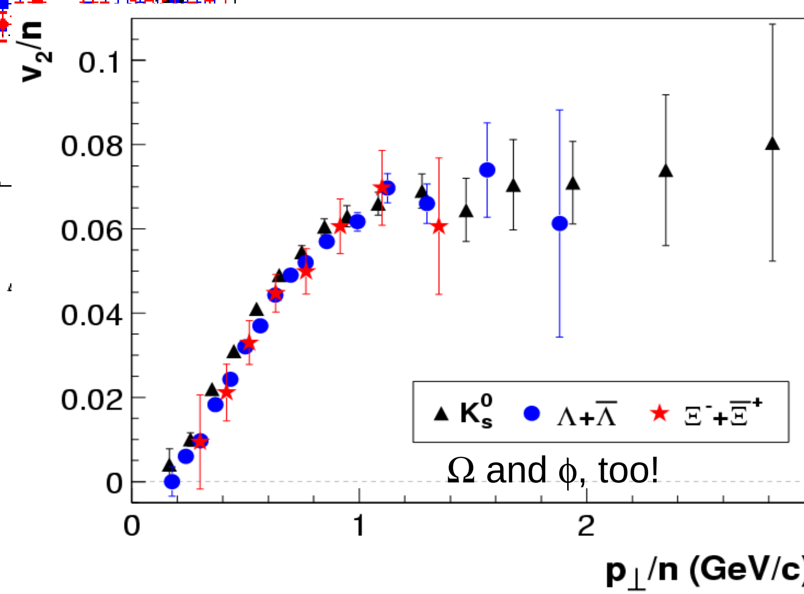
Jets & R_{cp}



and it flows

at the partonic scale

V_n



Yes, Virginia, there is a (s)Quark Gluon Plasma. It's *the* hypothesis that we are all testing.

STAR Upgrades to keep the discoveries rolling …

In the queue

- **Forward Meson Spectrometer**
  - Gluon density distributions, saturation effects, and transverse spin
- **DAQ Upgrade**
  - order of magnitude increase in rate
  - extra bandwidth opens the door to 'small' physics
- **Full Barrel MRPC TOF**
  - extended particle identification at intermediate p_T

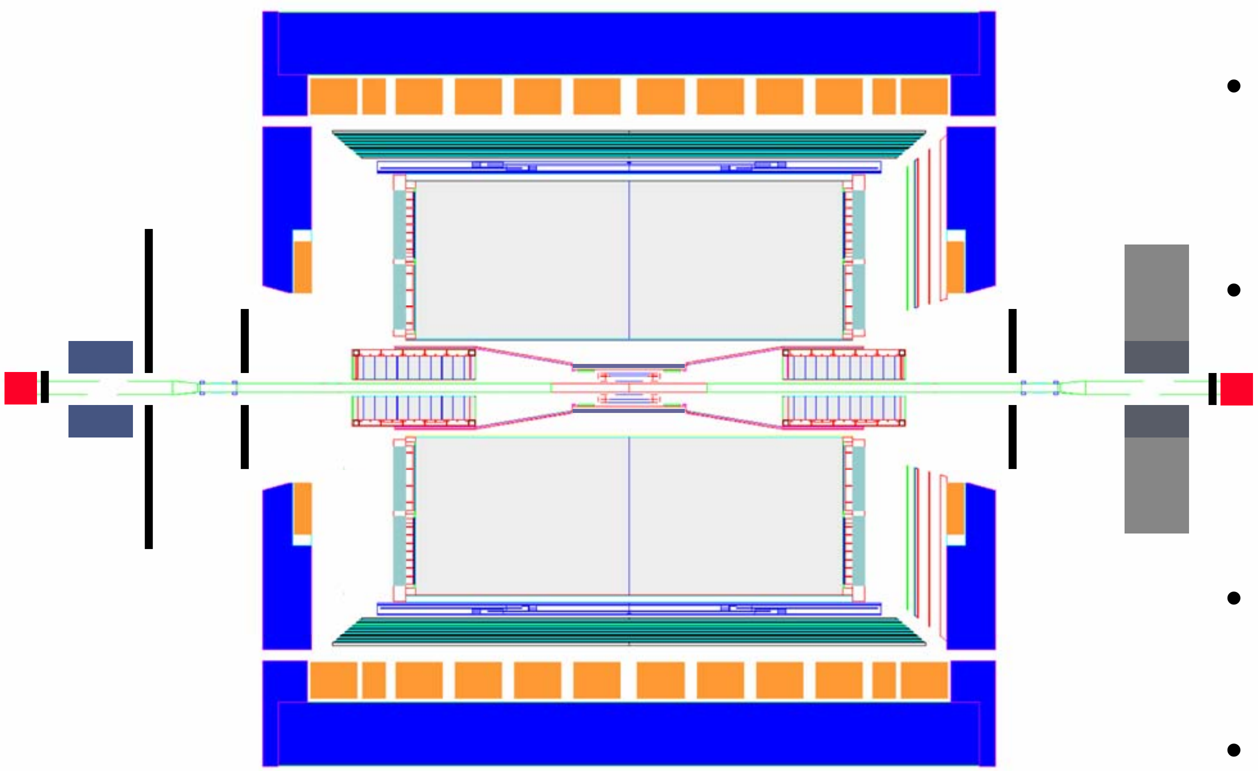
Engines running

- **Forward GEM Tracker**
  - end cap tracker for W sign determination
- **Heavy Flavor Tracker**
  - high precision Heavy Flavor Tracker near the vertex
  - opens the door to direct topological ID of Charm & Beauty

Warming Up

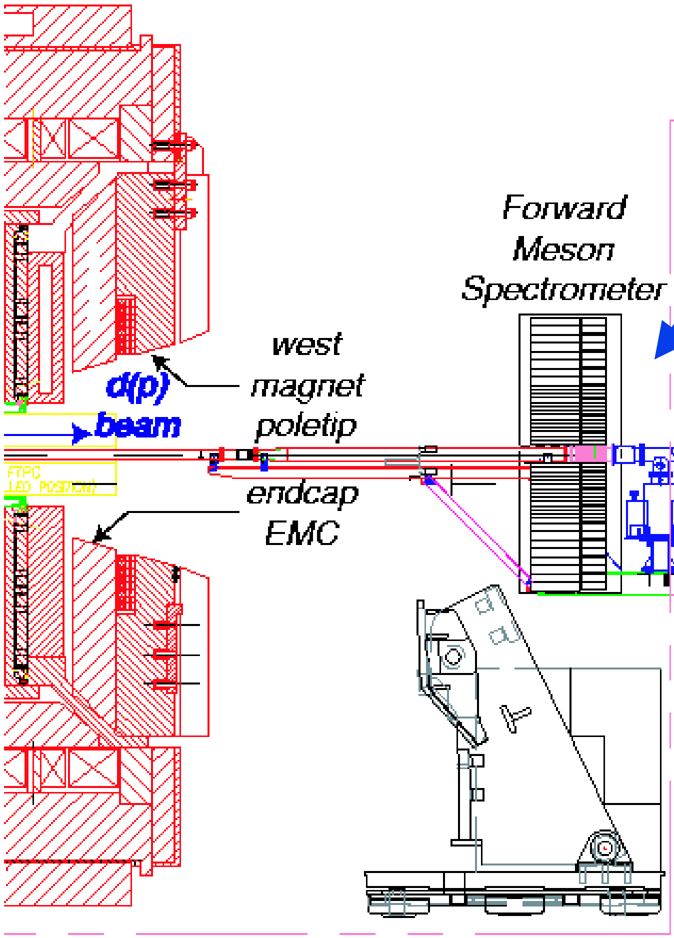
- Muon Telescope
- Forward Reaction Plane Detector
- A Crystal Calorimeter for low E photons
- γ-γ HBT

Forward Meson Spectrometer Upgrade



- Study forward π^0 production at RHIC ($2.4 < \eta < 4.0$)
- Expand the existing FPD array for forward physics
- The FPD originated as a test cell for the EEMC and has evolved into a 2 x 2 meter square array of PbGl EMCal
- Finer segmentation in the middle of the array
- Search for the onset of gluon saturation at high η
- Installation '7, run '8

The Forward Meson Spectrometer (detail)



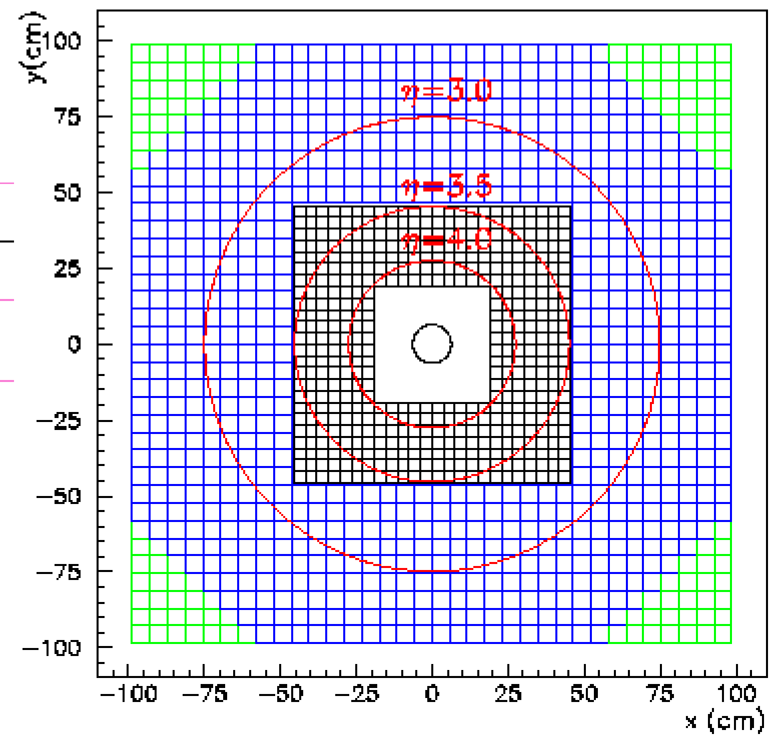
L.Bland

Side View of the East Pole Tip

End View of the PbGl Array

475 x 3.8 cm inner cells

788 x 5.8 cm outer cells

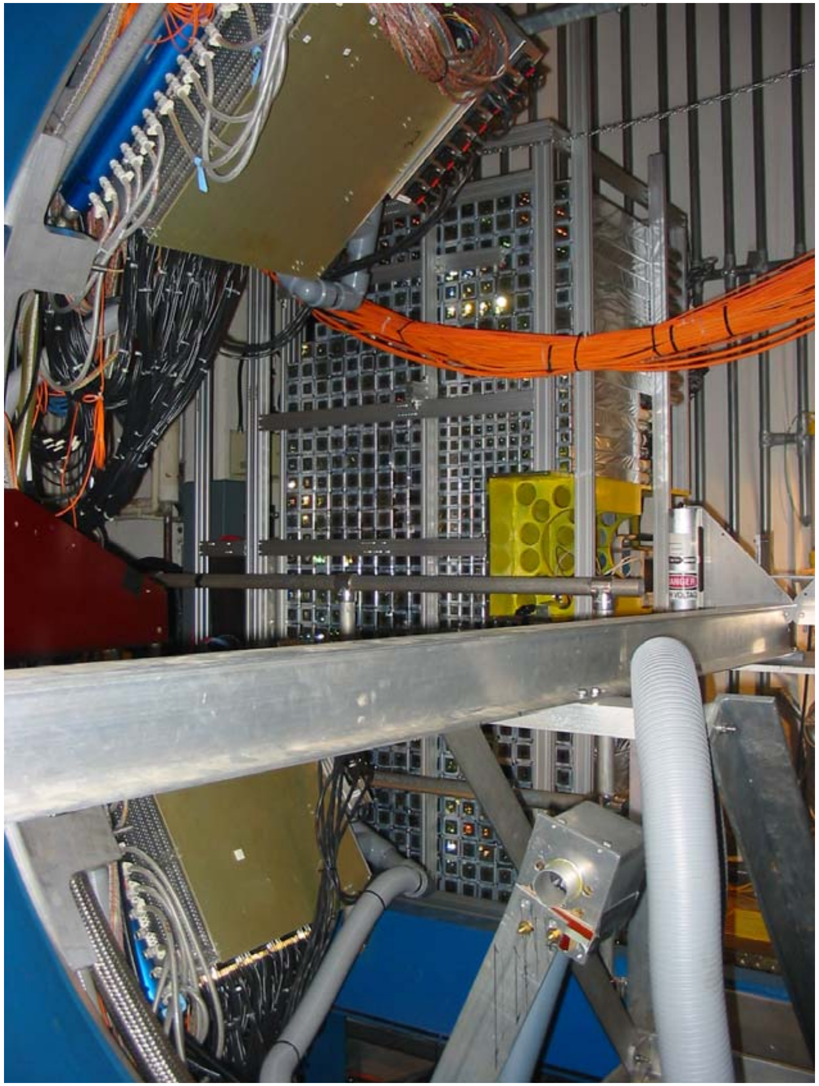


Physics Goals and Realization of the FMS

- A d(p) + Au $\rightarrow \pi^0\pi^0$+X measurement of the parton model gluon density distributions $x\,g(x)$ in gold nuclei for $0.001< x <0.1$. For $0.01< x <0.1$, this measurement tests the universality of the gluon distribution.

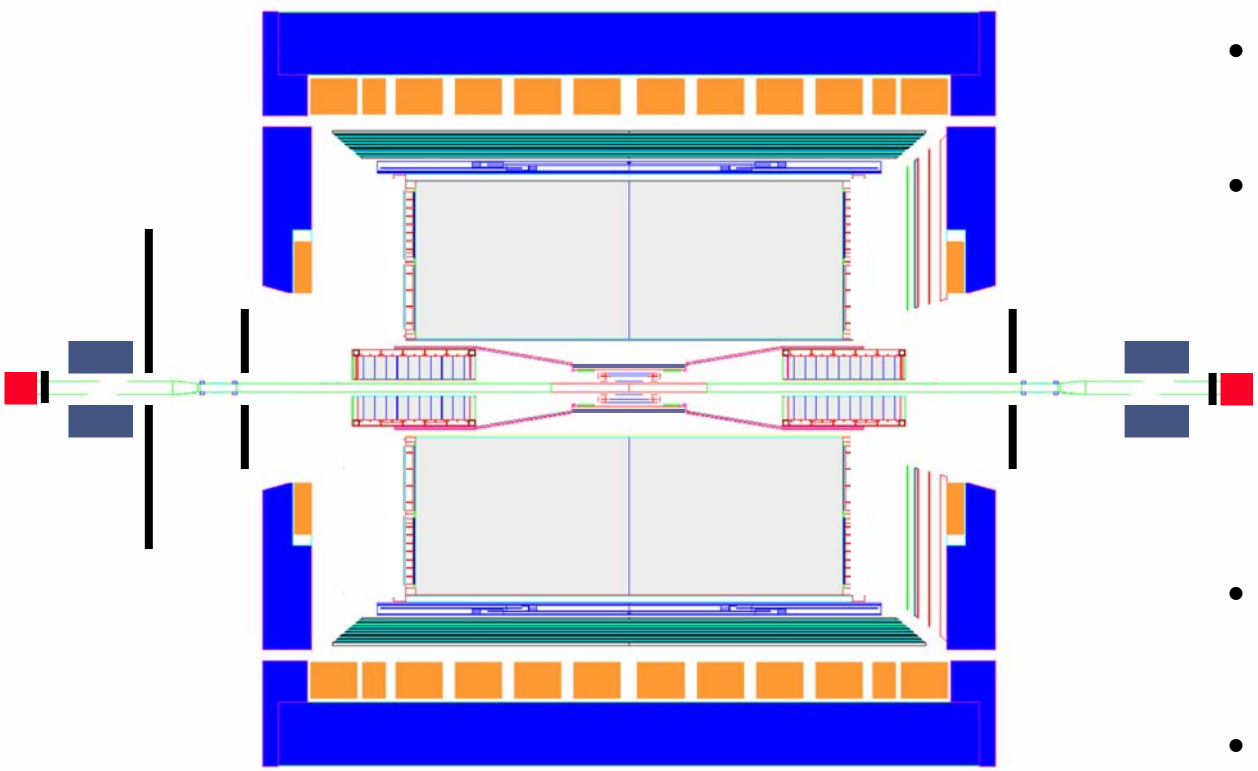
- Characterization of correlated pion cross sections as a function of Q^2 (p_T^2) to search for the onset of gluon saturation effects associated with macroscopic gluon fields.
(again d-Au)

- Measurements with transversely polarized protons that are expected to resolve the origin of the large transverse spin asymmetries in reactions for forward π^0 production.
(polarized pp)



Ready for Run 8

TPC FEE and DAQ Upgrade – DAQ 1000



- Faster, smaller, better … (10x)
- Current TPC FEE and DAQ limited to 100 Hz
- 1 kHz central
  3 kHz minBias
  5 kHz future
- Replace TPC FEE with next generation CERN ALTRO, PASA
- Make the FEE smaller and creates less heat
- No dead time (well, almost …)
- Opens the door for rare physics probes

DAQ1000 Concept

Existing TPC

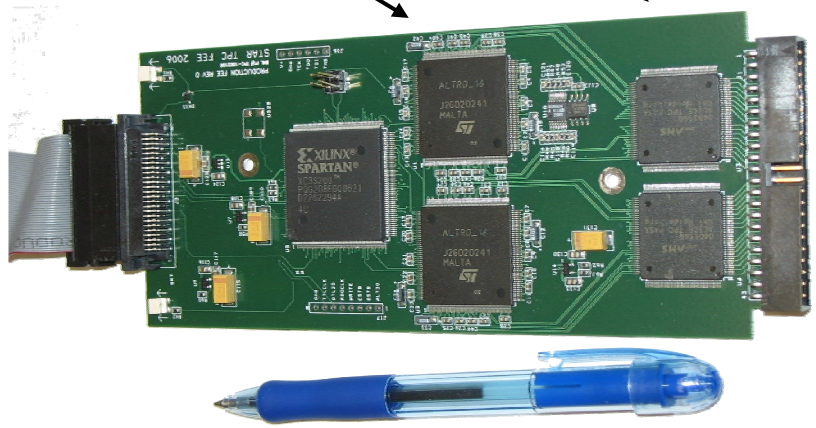
- Zero suppression done at RB in the DAQ room
  - ➔ Full ~460,000 10 bit words transferred over each fiber.
  - ➔ 10ms readout time every event. 100hz max rate.
- No event buffering on FEE
  - ➔ TPC dead during digitization & readout time.
  - ➔ 1% dead / hz readout.

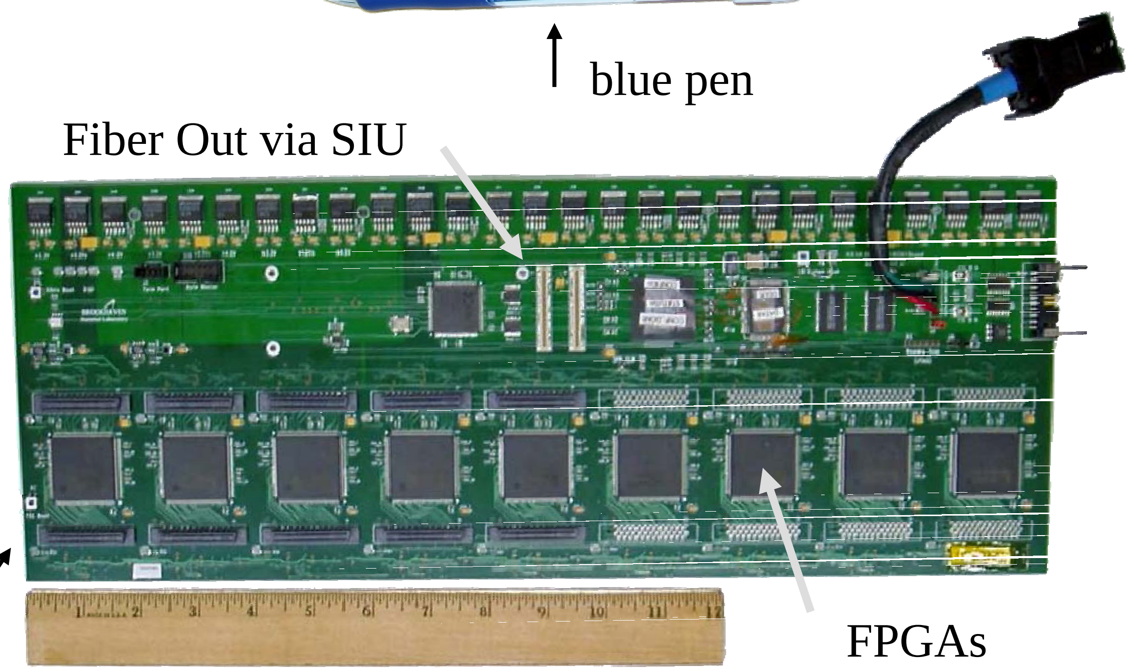
DAQ 1000

- Zero suppression done at FEE in the Altro
  - ➔ Event transfer 16-20 times smaller
  - ➔ Combined with slightly faster link, will allow rates ~1000-5000 hz
- Event Buffering on FEE
  - ➔ TPC stays alive as long as throughput is < max
  - ➔ Deadtime only caused by TPC Drift..
  - ➔ 0.004% dead / hz readout

One RDO+29 Fees are Already Working in STAR

- **Multiplex data from 36 FEEs onto 1 optical interconnect**
  - **2.5 G bps bi-directional link to DAQ**
- **Old TPC was 1% dead for every Hz triggered. New TPC effectively 100% live until data throughput is saturated.**
- **Studies demonstrate that pedestal subtraction, tail suppression & zero suppression is as good or better than the old TPC**
- **Gain as measured in ADC counts is slightly lower for DAQ 1000, however signal to noise is 50% better**
- **Readout is via dual RORCs in Linux Boxes. No VME crates.**



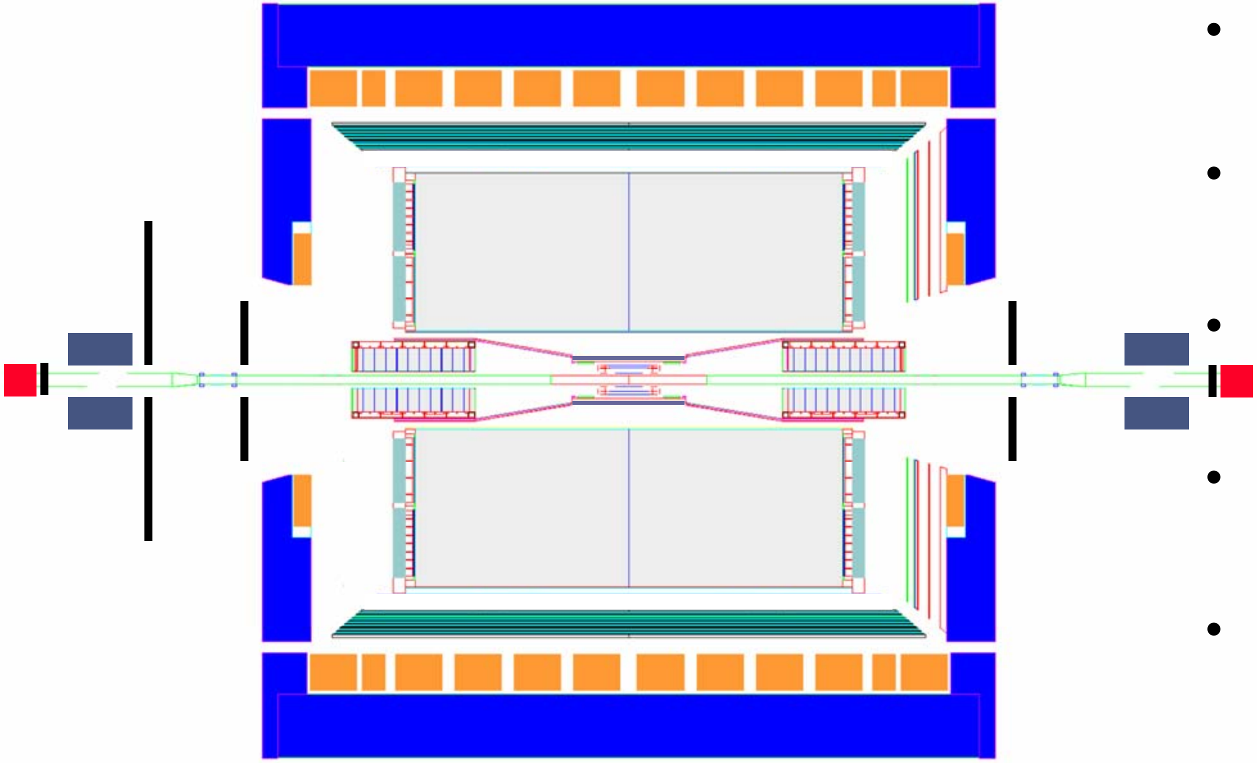


Technically Driven Schedule (means money is a problem :-)

2007			2008		
Q2	Q3	Q4	Q1	Q2	Q3
final FEE					
final RDO					
system test					
	RDO PCB				
electronics parts procurement					
		RDO assembly			
			RDO test		
	FEE PCB				
		FEE assembly			
			FEE test		
		DAQ procurement (fibers, RORCs, PCs)			
		LVPS procurement			
					Installation

We are optimistic that the full TPC can be instrumented with new electronics in time for Run 9

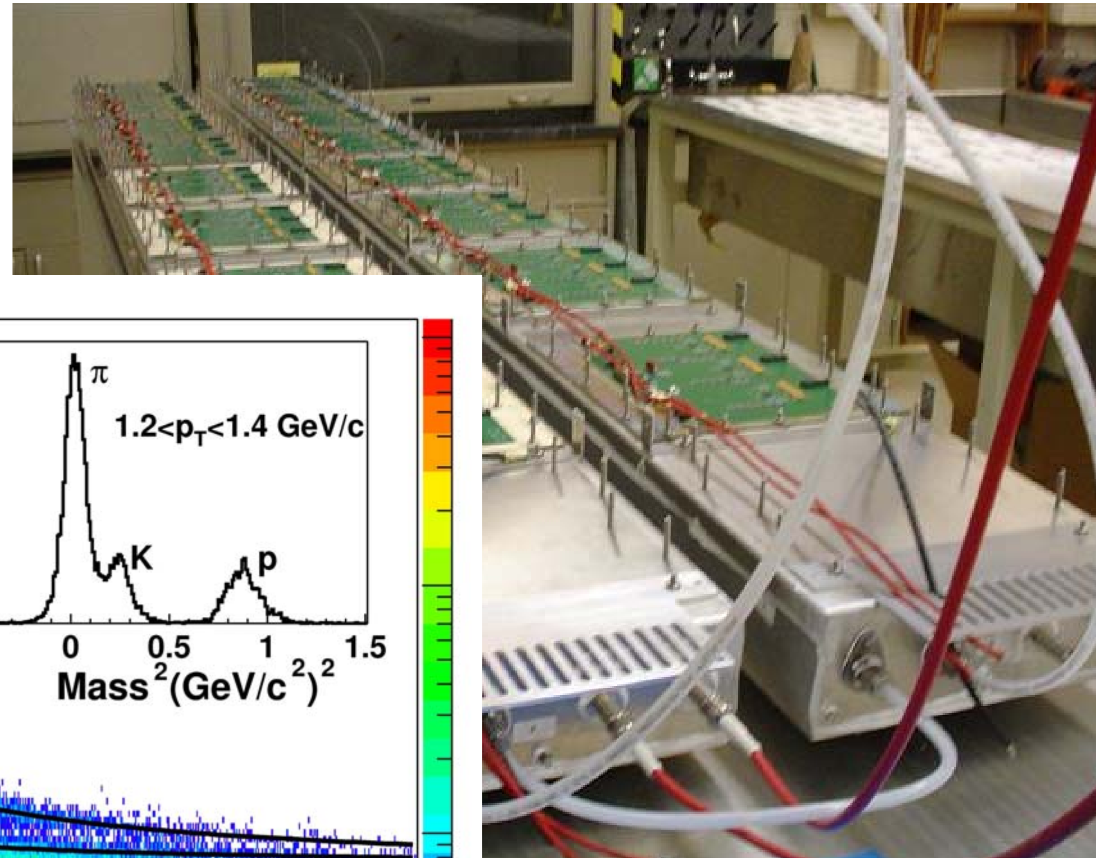
The TOF Upgrade

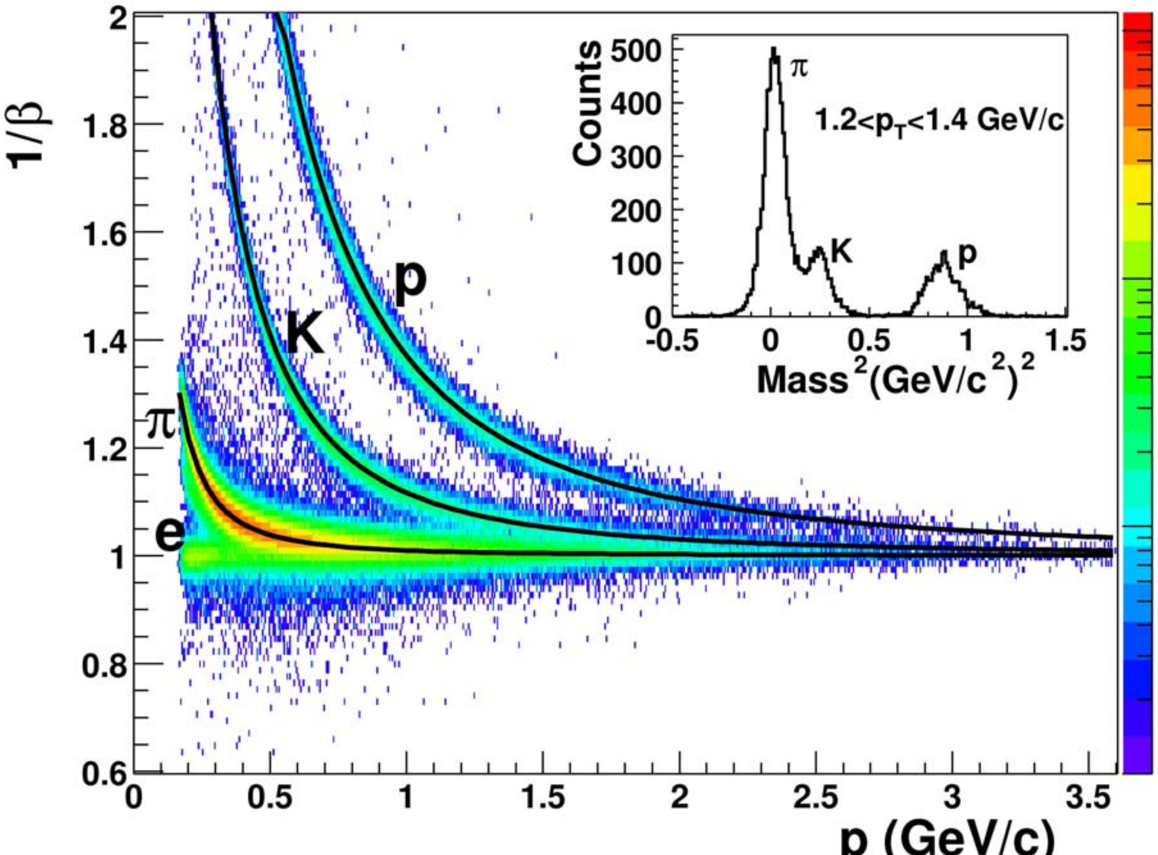


- Multiplate RPC technology
- Extended PID: 2π ± 1 η Beautiful electron ID
- 80 ps timing resolution after slewing corrections
- Each tray has 72 channels
- China-TOF has produced 1600/4000 MRPC modules
- Electronic design is complete
- 5 full trays next year
- Full installation (120 trays) in run 8, run 9, and run 10

Two "trays" at Rice (each 2π / 60 azimuth, $0<\eta<1$)

- PID information for > 95% of kaons and protons in the STAR acceptance
- Clean $e^{\pm}$ ID down to 0.2 GeV/c





- π/K separation to 1.6 GeV/c
  - 0.7 for TPC Alone
- $(\pi+K)/p$ to p = 3 GeV/c
  - 1.2 for TPC Alone

TOF is a Benefit to the Full STAR Program

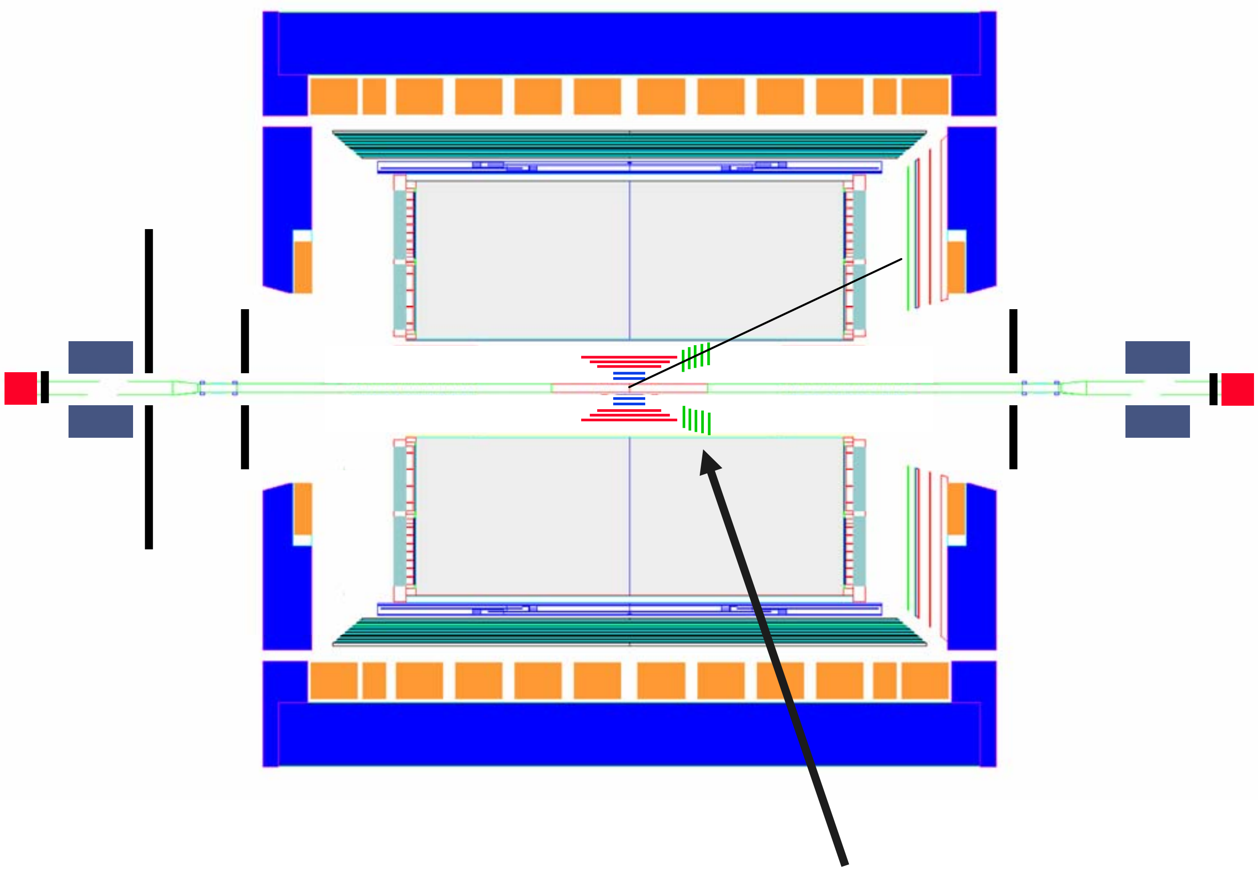
Open Charm and Resonances in central Au-Au collisions

	p_T (GeV/c)	FOM
D^o	All	4.6
D^o	2-4	2.6
D^o	4-6	2.0
D^o	>6	1.0
K^{*o}	0-1	2.0
K^{*o}	1-2	1.85
K^{*o}	2-3	1.74
K^{*o}	3-5	1.39
ϕ (1020)	0-2	5.0
ϕ (1020)	2-5	3.4
Λ (1520)	0-1.6	11.4

- **FOM (figure of merit) is the reduction in required data set by using TOF PID for a significance of 3σ**
- **TOF PID also reduces systematic errors from correlated back-ground due to misidentified particles**
- **Certain measurements are impossible without TOF – such as unlike-particle correlations, scale dependent correlation studies (velocity vs momentum correlations), exotic searches…**

5 Trays in Run 8, 65 Trays in run 9, 120 Trays in run 10

Forward GEM Tracking



Six layers of GEM Detectors at forward rapidity

- Flavor structure of the proton sea can be probed via W± production
- Experimental signature is a high p_T lepton from W decay

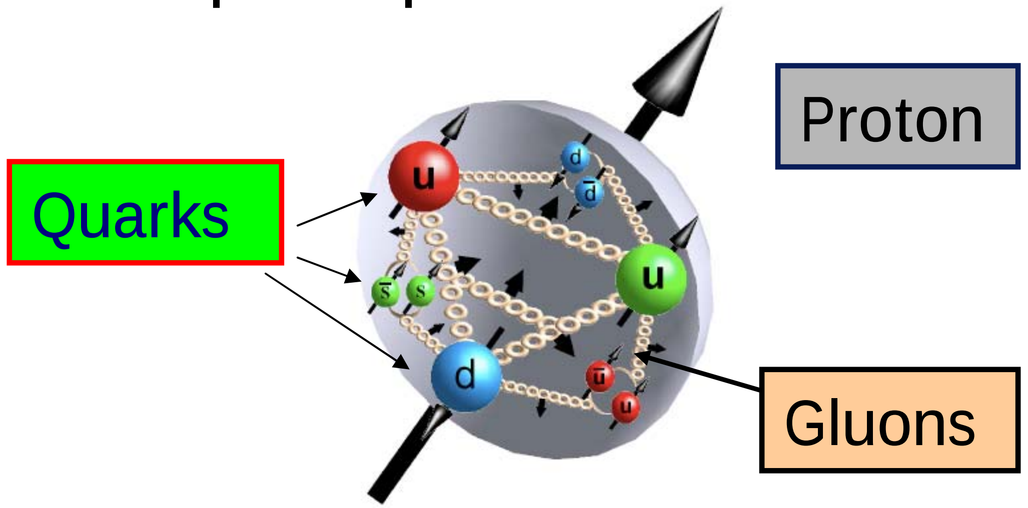
$$W^- \rightarrow e^- + \overline{\nu}_e$$

$$W^+ \rightarrow e^+ + \nu_e$$

- The FGT adds high quality space points at forward η
  - $1 < \eta < 2$
- 40 cm GEM Disks with 80 μm resolution

The Spin Puzzle

- **How do the quark and gluons combine to make up the exact 1/2 of the proton spin?**



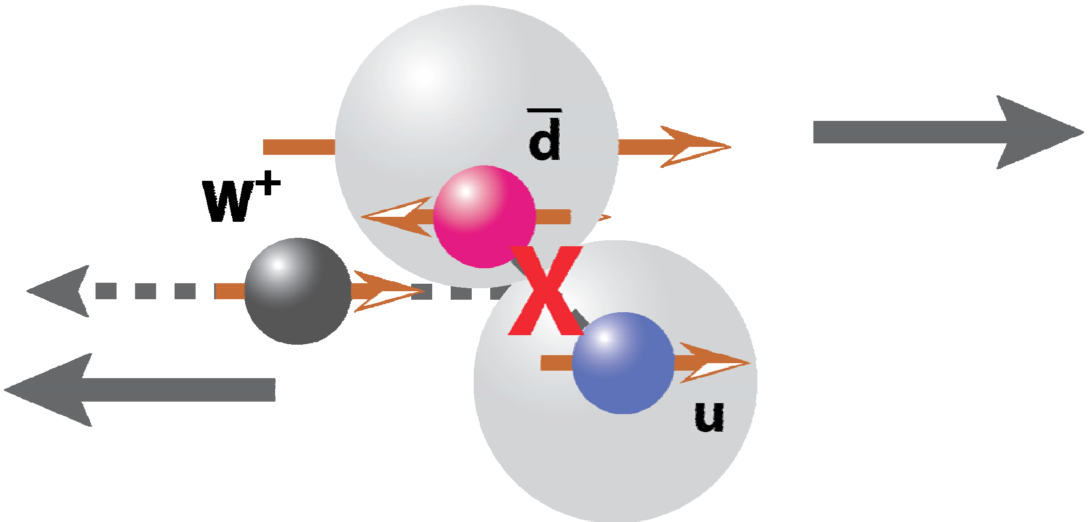
$$J_{PROTON} = \frac{1}{2} = \langle S_q \rangle + \langle S_G \rangle + \langle L_q \rangle + \langle L_g \rangle$$

Integral known, ~1/3 of total spin
how is this distributed among quark flavors?

Current focus of longitudinal
Spin program

Accessing Quark Helicities with W Bosons

- **Maximal Party-Violation in Weak Interaction: Inherent spin sensitivity of W production**

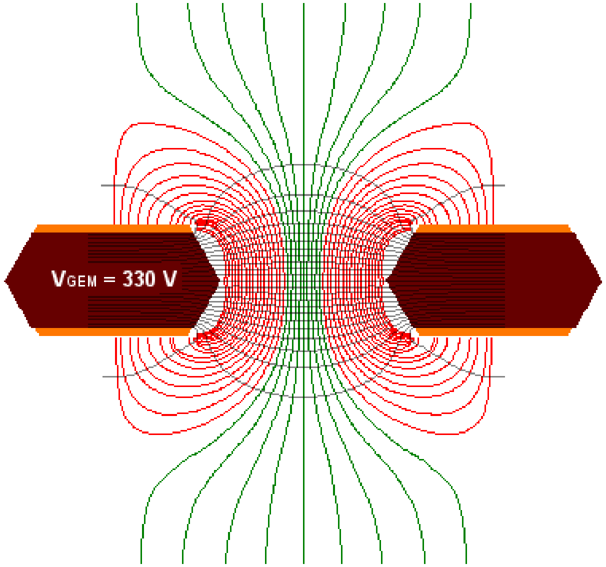


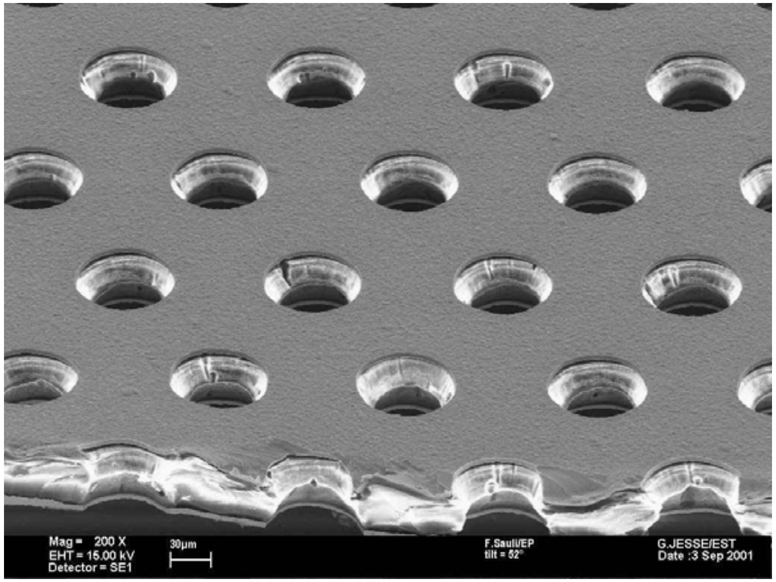
- **Charge of the Boson provides flavor tagging:**

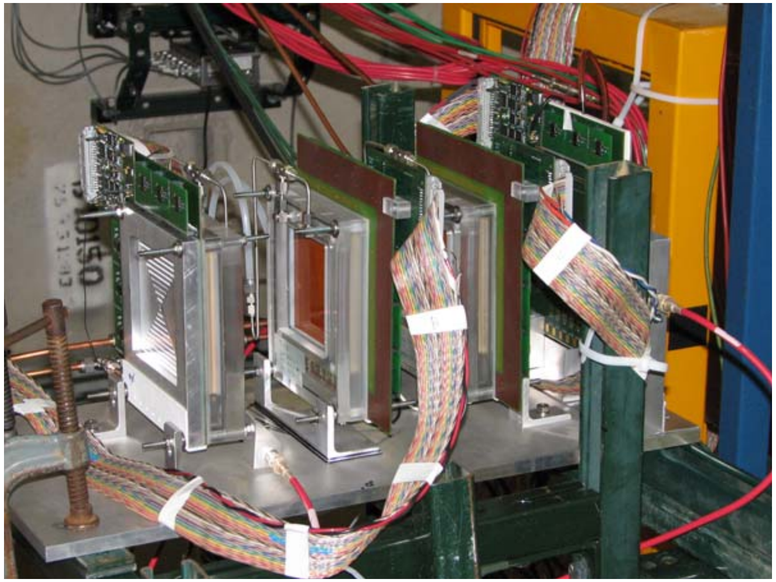
$$d + \overline{u} \rightarrow W^-$$
$$\overline{d} + u \rightarrow W^+$$

RHIC: 500 GeV CME in p+p collisions
⇨ the quark is usually a valence quark (large x)

FGT – Test and Construction Plans



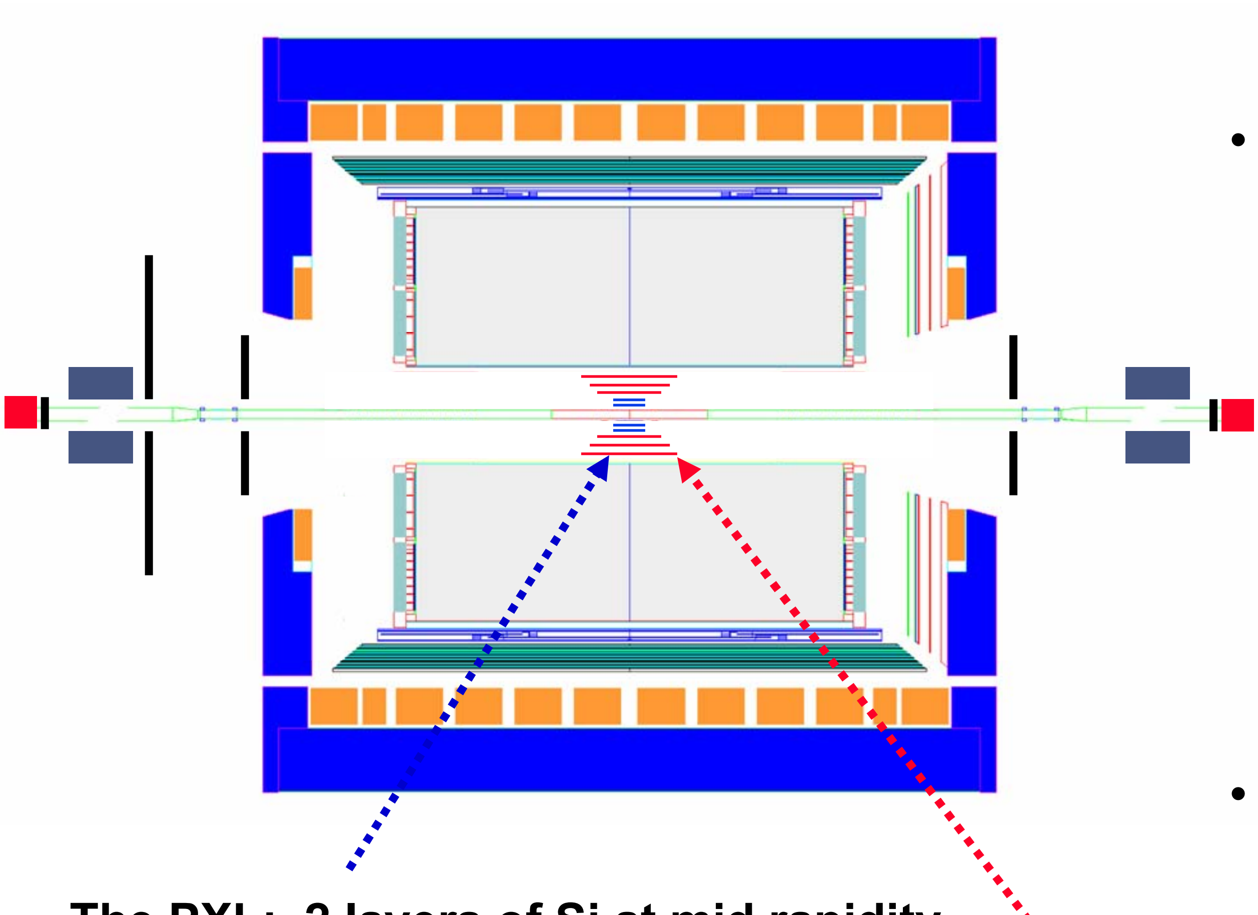




- Tech-Etch foils successfully tested in test beam at Fermilab
- total construction time: ~ 54 weeks

Installation possible for run 10
DOE project costs ~ $2M

The Heavy Flavor Tracker = PXL + IST + SSD

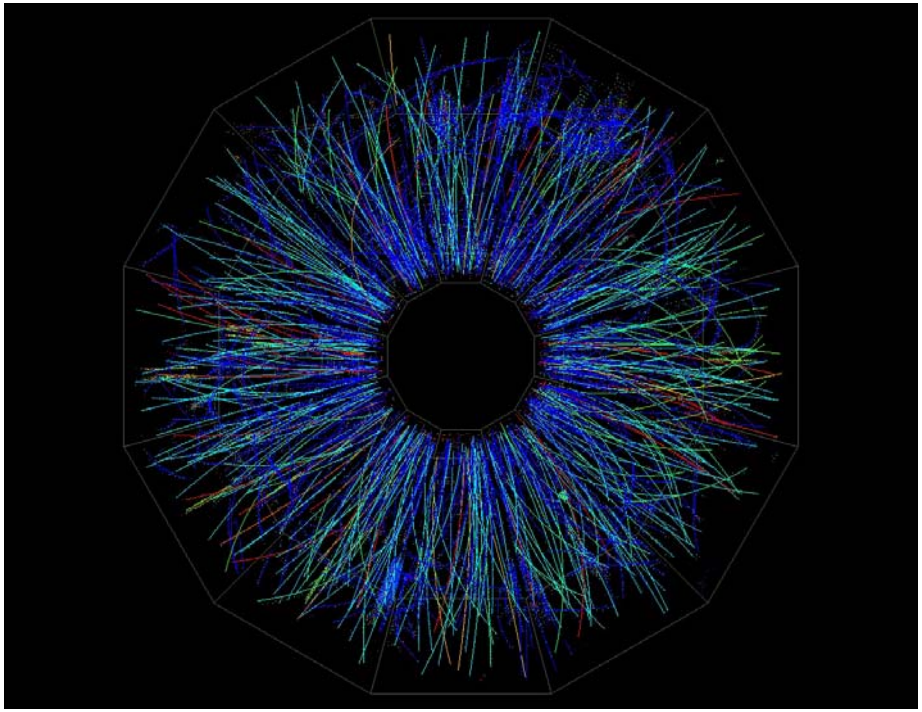


The PXL: 2 layers of Si at mid rapidity

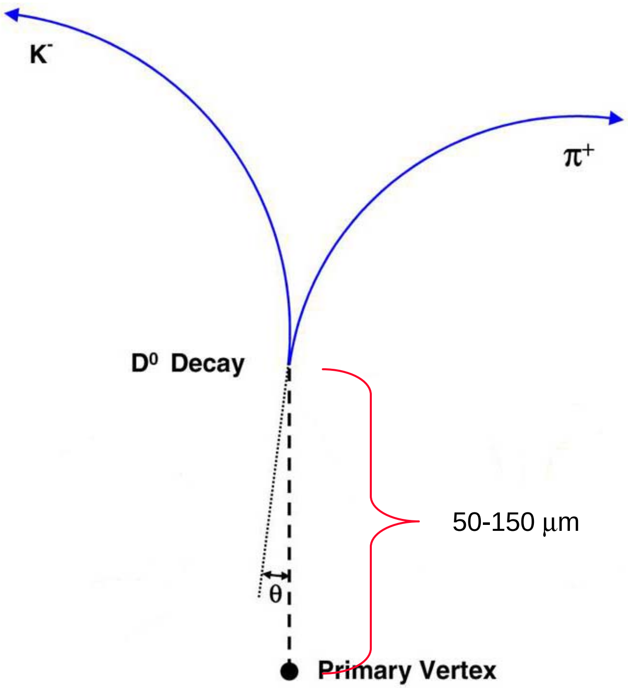
Mid-rapidity Pointing Devices: IST + SSD

- The PXL is a new detector
  - 30 μm silicon pixels to yield 10 μm space point resolution
- Direct Topological reconstruction of Charm
  - Detect charm decays with small cτ, including $D^0 \rightarrow K\,\pi$
- New physics
  - Charm collectivity and flow to test thermalization at RHIC
  - C & B Energy Loss to test pQCD in a hot and dense medium at RHIC
- The proposed Tracking Upgrades include
  - PXL (2 layers)
  - IST (2 layers)
  - SSD (existing layer)

Direct Topological Identification of Open Charm



Goal: Put a high precision detector near the IP to extend the TPC tracks to small radius

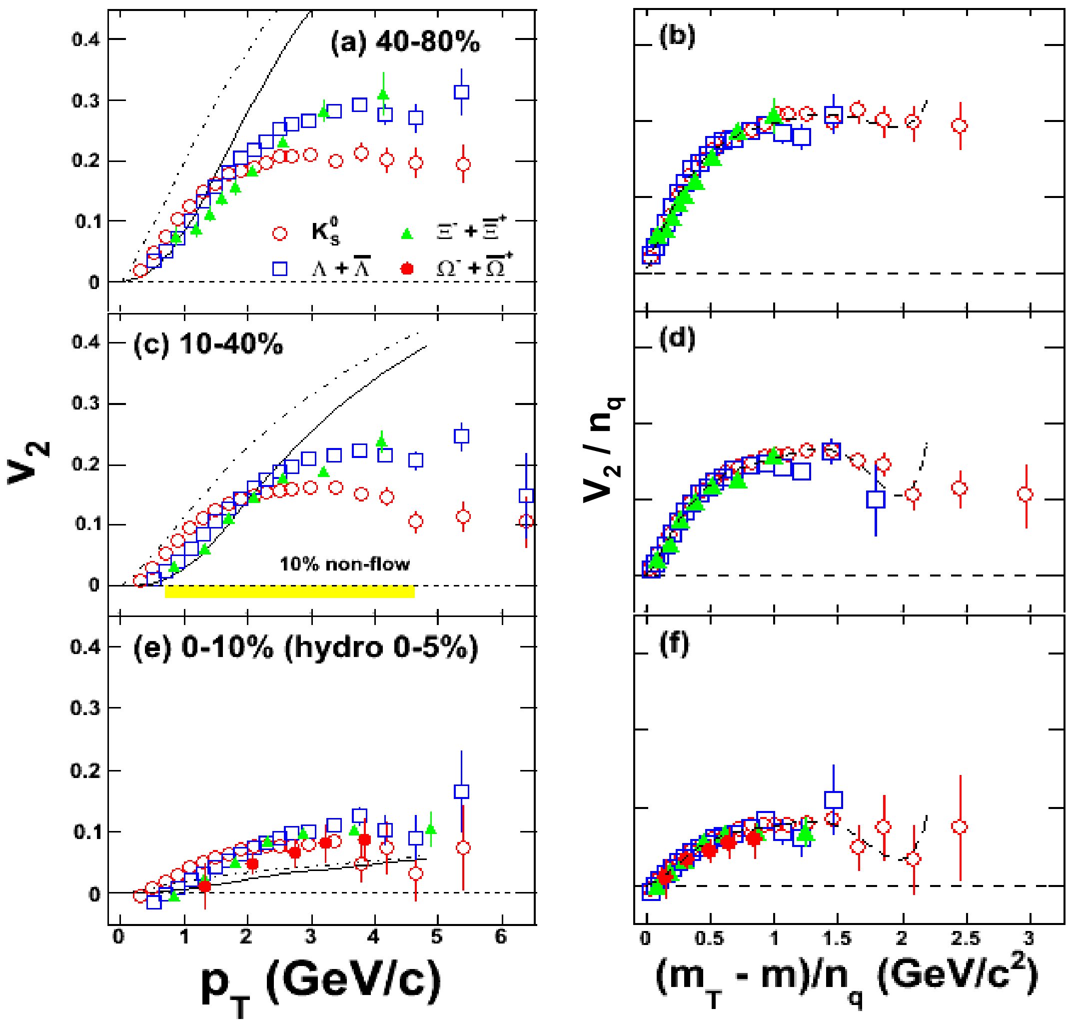


The STAR Inner Tracking Upgrade will identify daughters of the decay and do direct topological reconstruction of open charm hadrons.

No Mixed events, no random background subtraction.

Scaling as a Function of $(m_T - m_0)$

STAR Preliminary work by Yan Lu



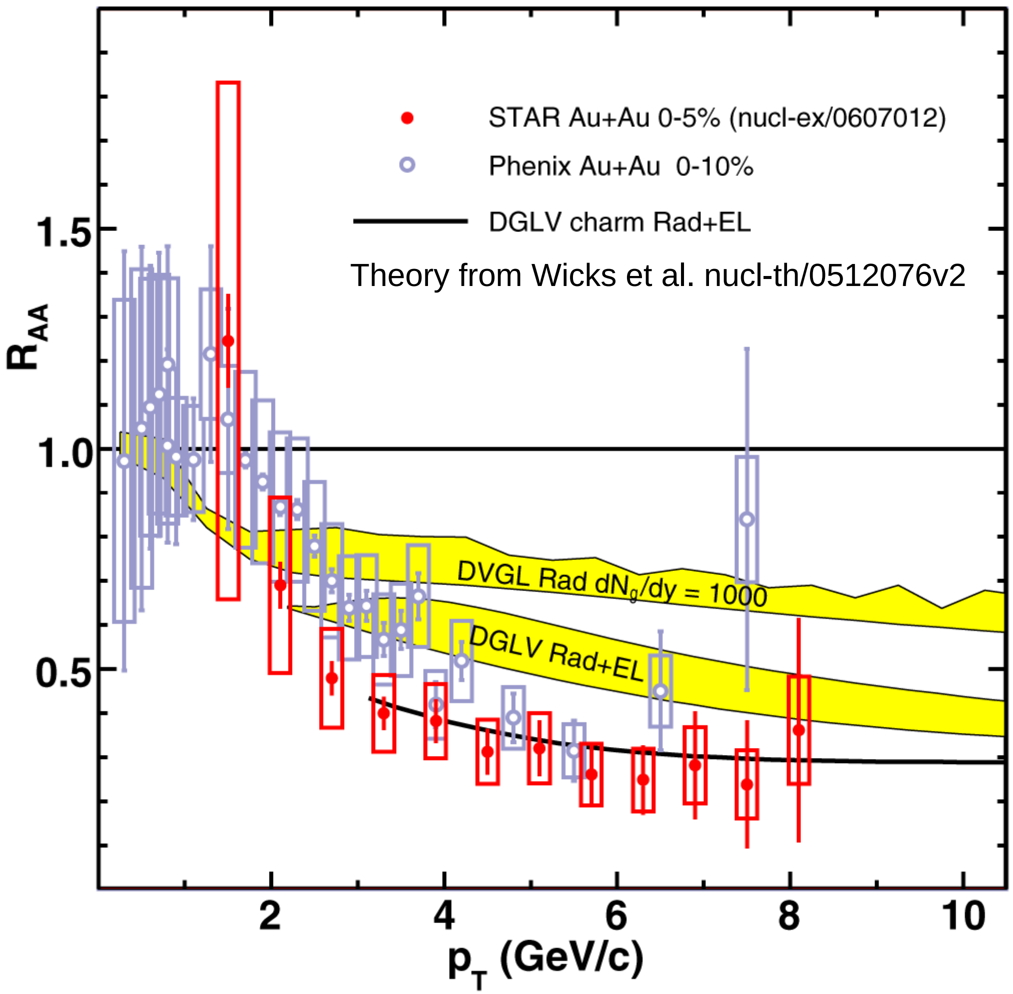
Yuting Bai, QM 2006 for the STAR Collaboration

- **The light quark sector scales beautifully with v_2/n_q .vs. $(m_T - m_0)/n_q$**
  - **Note that $p_T < 1$ GeV always did scale !**
- **The strange quark sector also scales with $<v^2>$ and the scaling holds at all centralities**
- **Even the ϕ meson**
  - **See S. Blythe QM2006**

Does it work in the Charm Sector?

A strong test of the theory

Heavy Flavor Energy Loss … R_{AA} for Charm

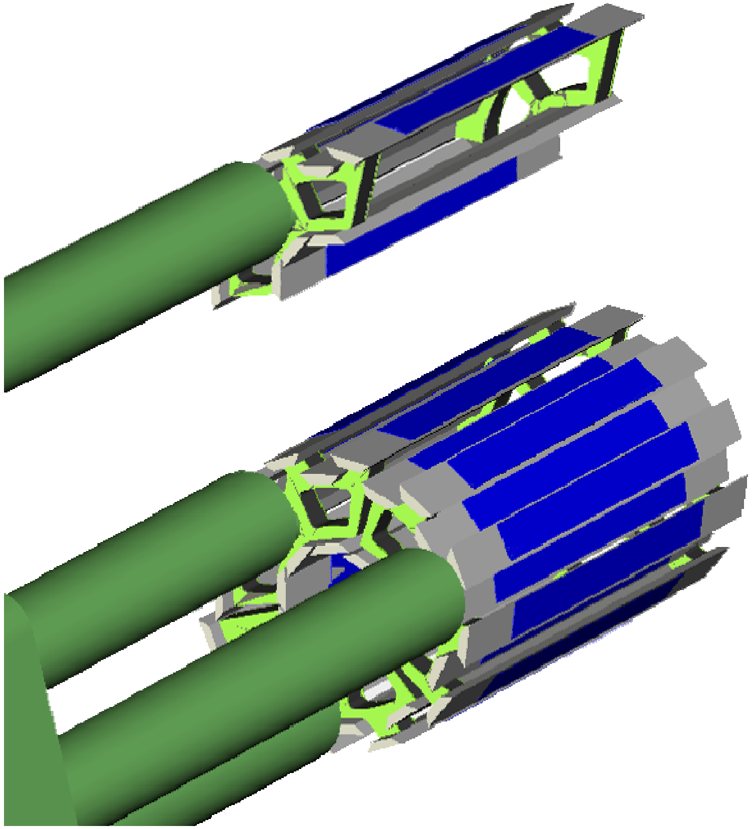


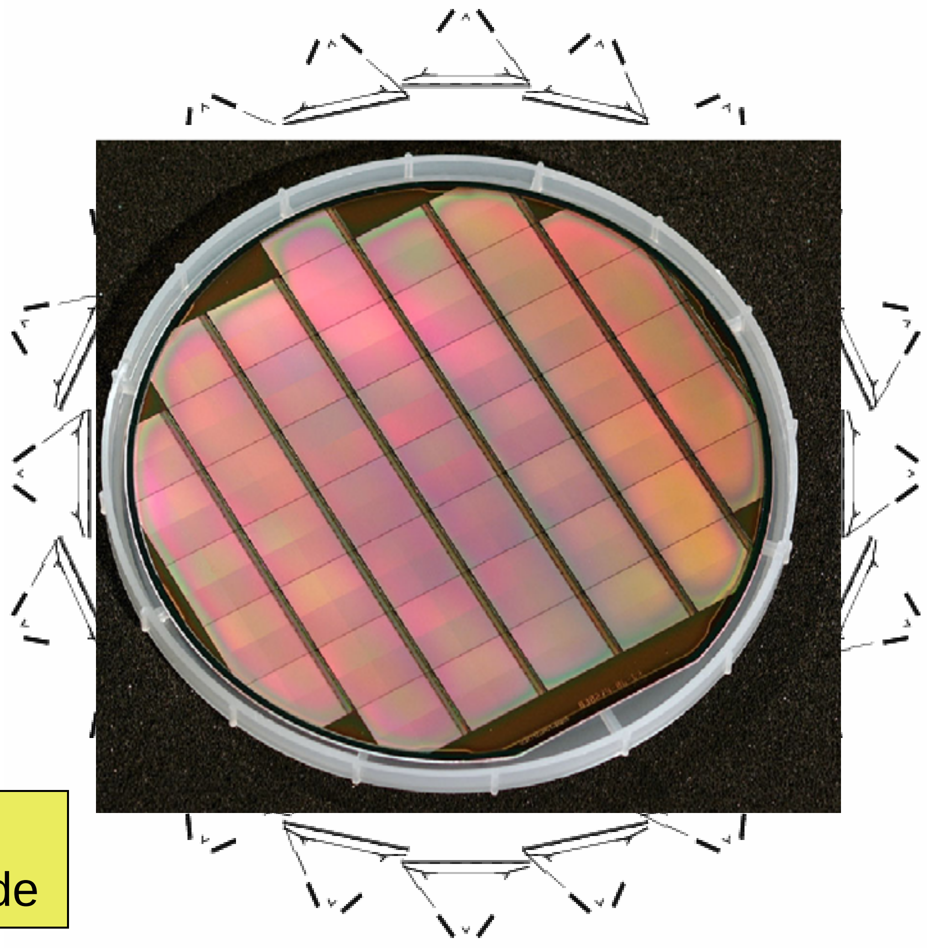
Where is the contribution from Beauty?

- **Heavy Flavor energy loss is an unsolved problem**
  - **Gluon density ~ 1000 expected from light quark data**
  - **Better agreement with the addition of inelastic E loss**
  - **Good agreement only if they ignore Beauty …**
- **Beauty dominates single electron spectra above 5 GeV**
- **We can separate the Charm and Beauty by the direct topological identification of Charm**

The Methodology: Surround the Vertex with Si

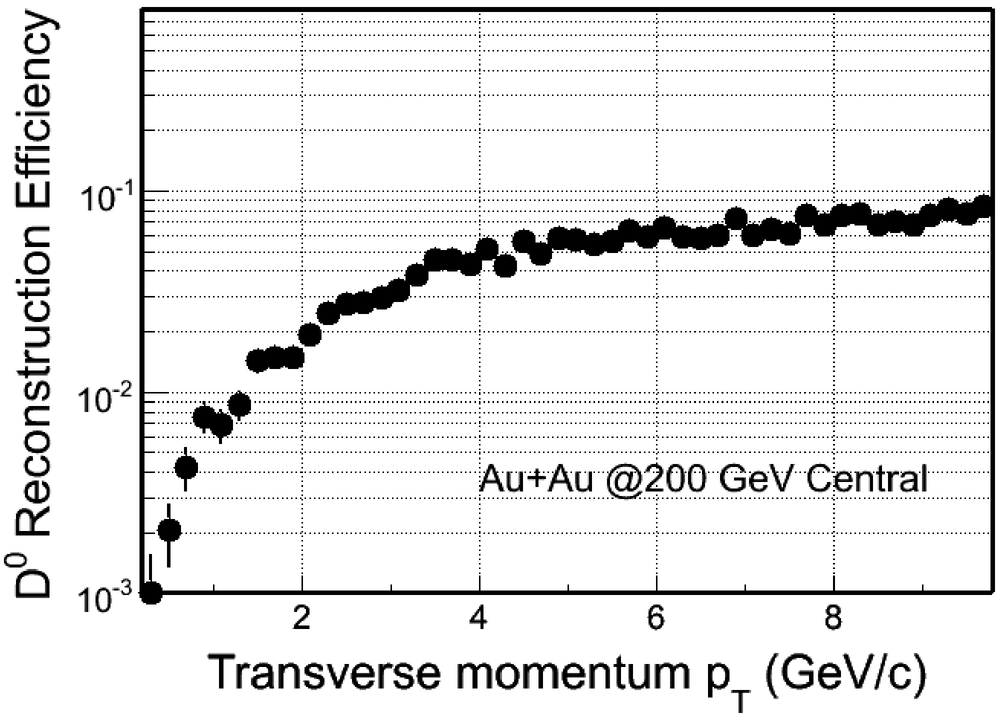
The PXL is a thin detector using 50 μm Si to finesse the limitations imposed by MCS





The PXL, IST and SSD form the ingredients of an Inner Tracking Upgrade

Charm-hadron Simulation Results

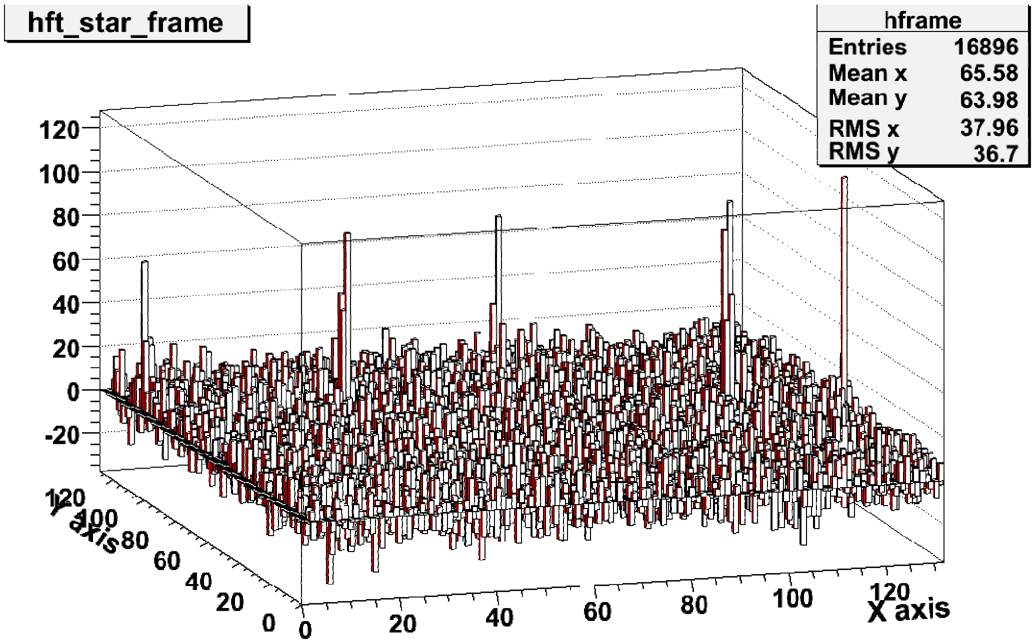


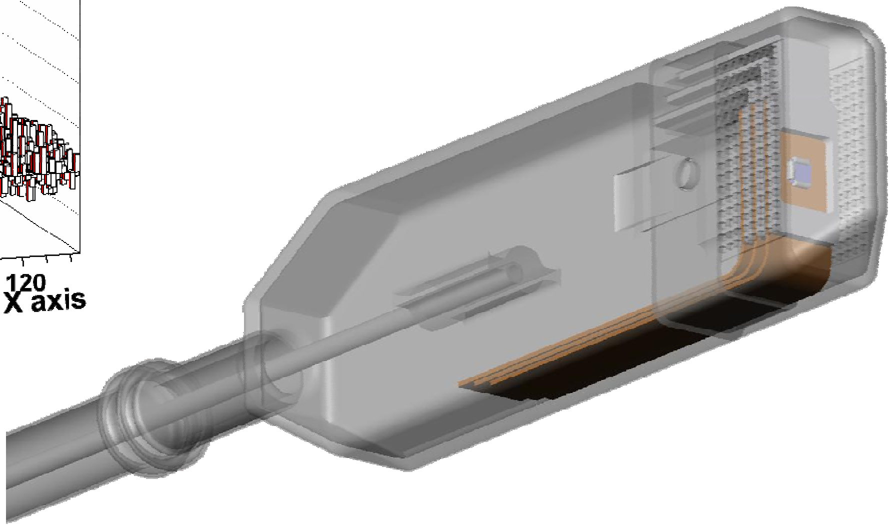
Detector radii:

TOF	
TPC	(60 cm)
SSD	(23 cm)
IST2	(17 cm)
IST1	(12 cm)
PXL2	(7.0 cm)
PXL1	(2.5 cm)

- **The Monte Carlo reconstructed yield of D^0 is very good**
  - **A complex p_T dependence … however efficiency vs p_T is the FOM**
  - **D^0 decay length is ~ 125 μm**
  - **IST helps reduce search radius on HFT and thus reduces ghost track inefficiencies as well as allows more relaxed kinematic cuts on the data**
  - **Kinematic cuts in the software are a significant contributor to the total efficiency**

R&D in Run 7 – real data with real Si pixels





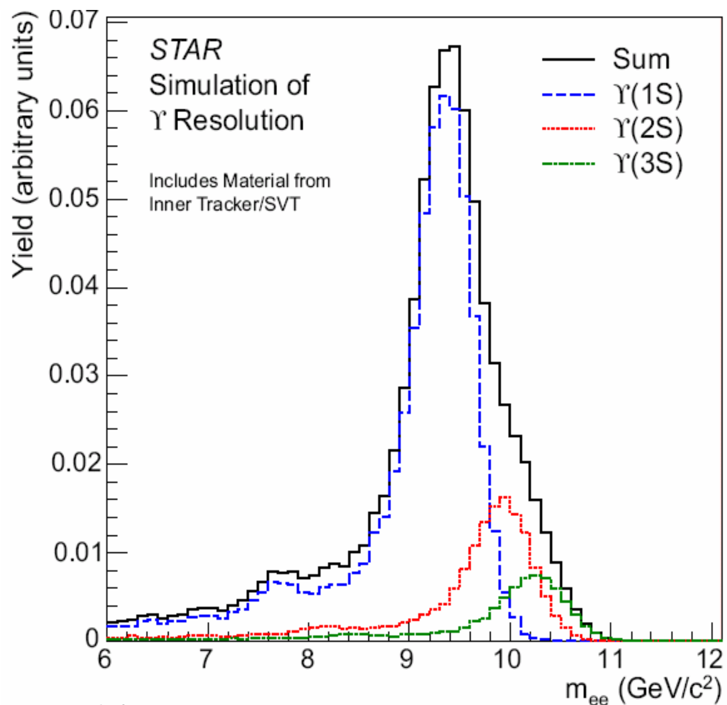
A Three Layer Telescope with MimoSTAR II Chips.

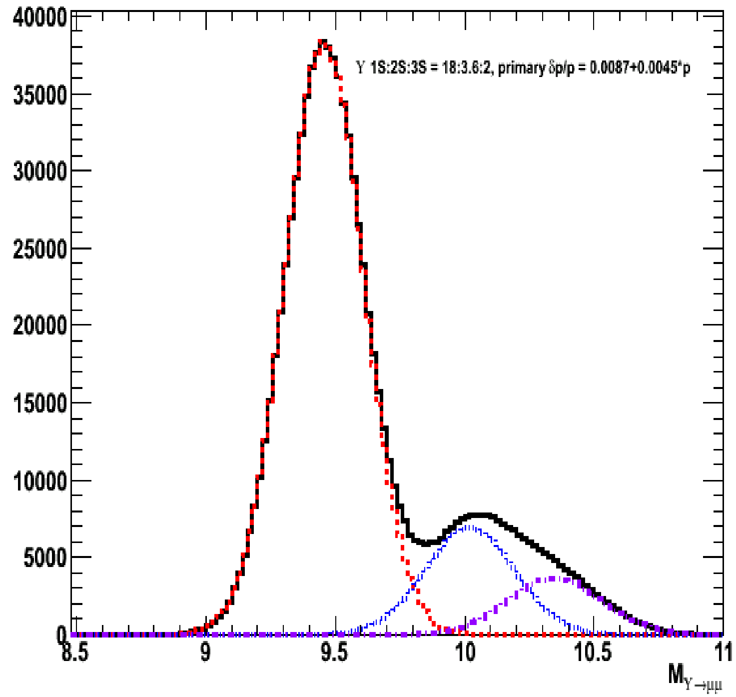
A full system test from PXL to DAQ at r = 10 cm, z = 1.5 m using a 128x128 array of pixels. A very clean environment.

The technically driven schedule would have an HFT ready for run 11

A Novel and Compact Muon Detector at mid rapidity

- **DiMuons at mid-rapidity to study DiMuon continuum, QGP thermal radiation, QGP Color Screening, and Quarkonia (J/Ψ, ϒ)**
- **But most especially the ϒ**

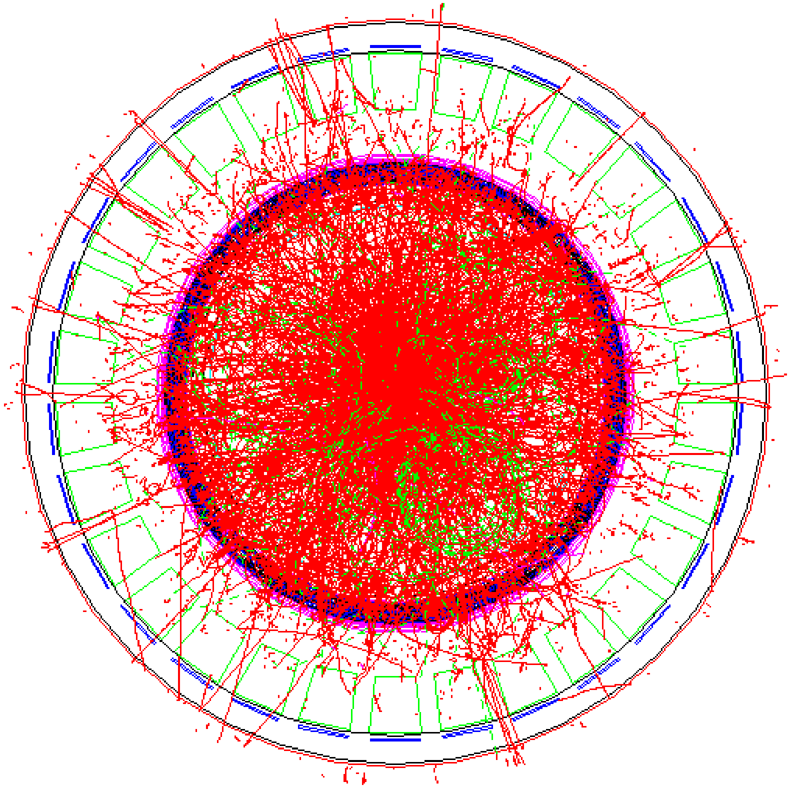




ϒ→e+e- ϒ→μ+μ-

Electron Bremsstrahlung Radiation muon better mass resolution

Muon Telescope: Simulations

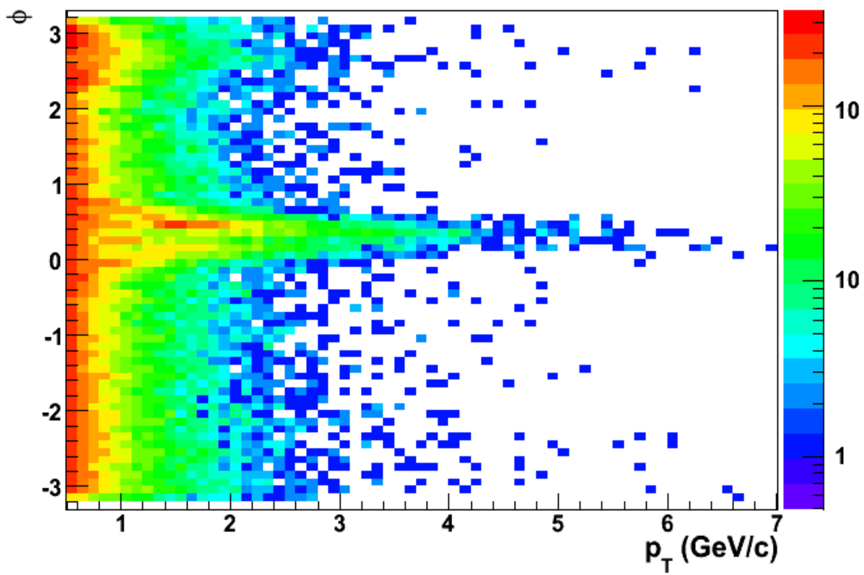


Cuts	Nhit/event
No cut	70
TOF	1.6
Eloss	7.6
TOF&Eloss	0.72
TOF (-400ps,100ps)	0.23

- Hijing event illustrates that the challenge is to identify muons amongst the hadrons
- Use the STAR Magnet steel as one of the tools to ID the muon
- Muon penetrates iron bars
- Other particles are stopped
- A tractable problem using the tracking and dE/dx capabilities of the TPC and high resolution TOF
- Good Timing Resolution (60ps) rejects background (>100)

Muon Telescope: Test at STAR

- Successful test with two layers of scintillator outside of the STAR magnet
- Muons easily identified
- Propose to use MRPCs which are identical to the STAR TOF
- Successful test in the Fermilab Test Beam in ’07
- Preliminary timing resolution of MRPC is about 60-80 ps.
- Preliminary spatial resolution of MRPC is about 0.6-1.0 cm.
- MRPC is ideal for MTD.
- Incremental construction possible on a small budget
- Financing and schedule still to be worked out



Direct Photon HBT : γ-γ HBT

- Direct photons are produced in all stages of a collision and are emitted without re-scattering
  - but measurement is swamped by π^0 decay background

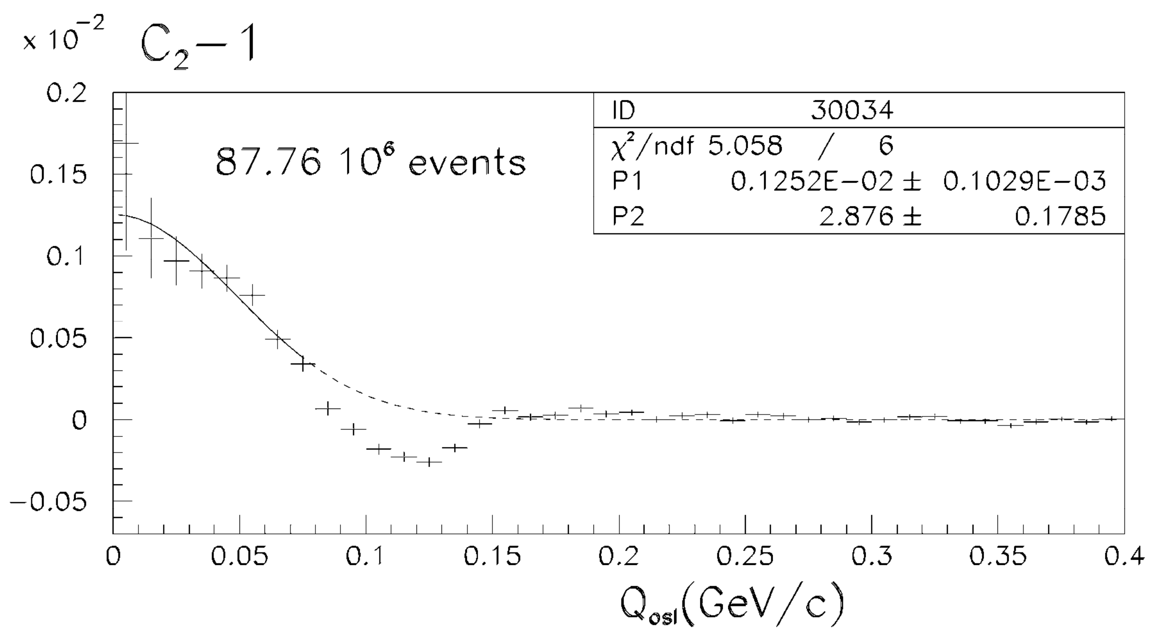
- HBT correlations only exist between direct photons and so can be used to measure direct photon spectrum down to low p_T

- Perhaps more importantly, measurement of HBT gives information on temperature vs. size development through all stages of collision!

Simulation:

90M central Au-Au events

10% converter



New Approach to Photon HBT

Proposal for R&D towards a measurement of direct photon HBT with STAR

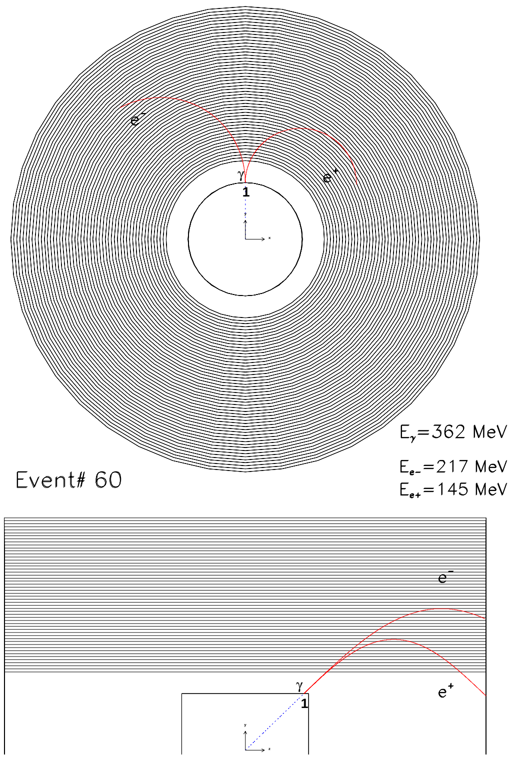
A.Chikanian, E. Finch, R. Majka, J. Sandweiss

Yale University

Two critical changes to the STAR detector:

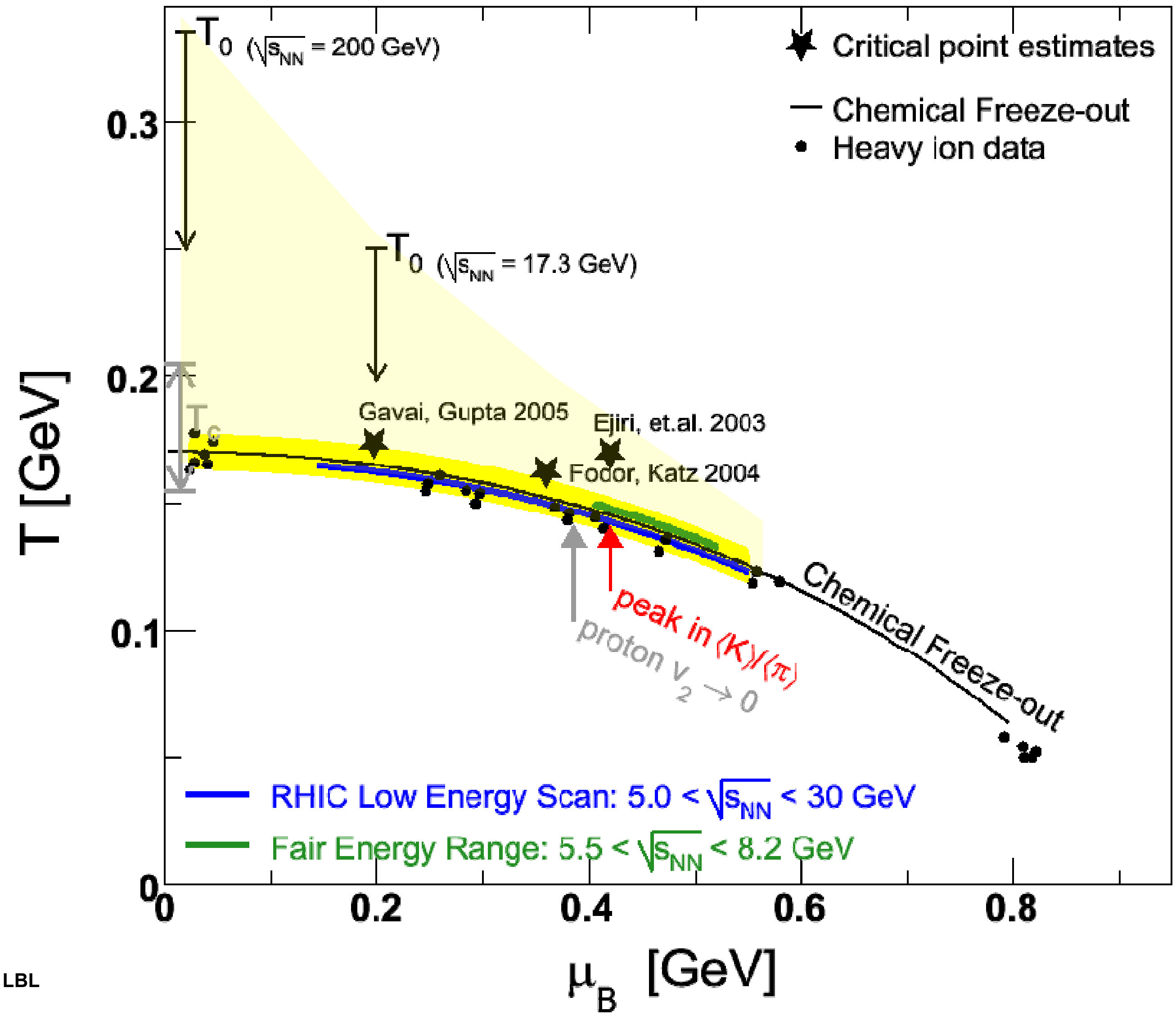
1. Install a photon converter of about 0.1 radiation length at r≈45 cm inside the inner field cage. The TPC detection efficiency is about 7%.
2. A "shashlyk" calorimeter with improved energy resolution (on the order of 5%/√E) and good efficiency for photons down to around 100 MeV of energy.

Use 1 γ in TPC, 1 γ in calorimeter.

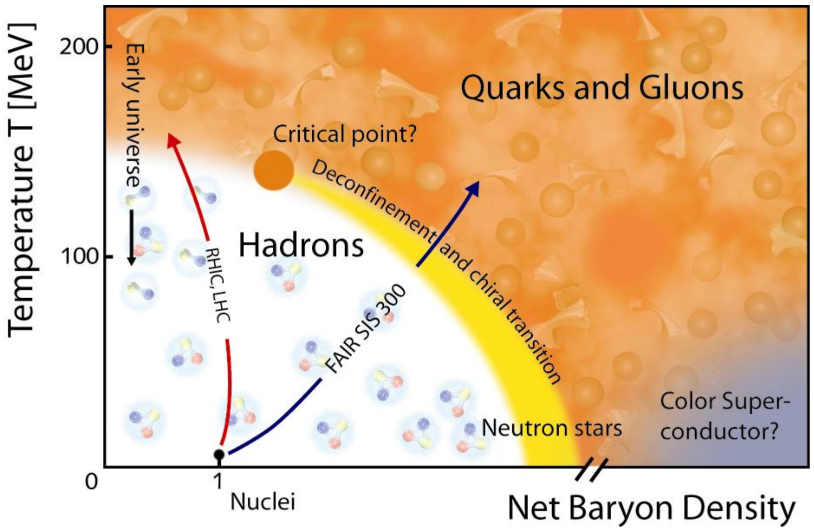


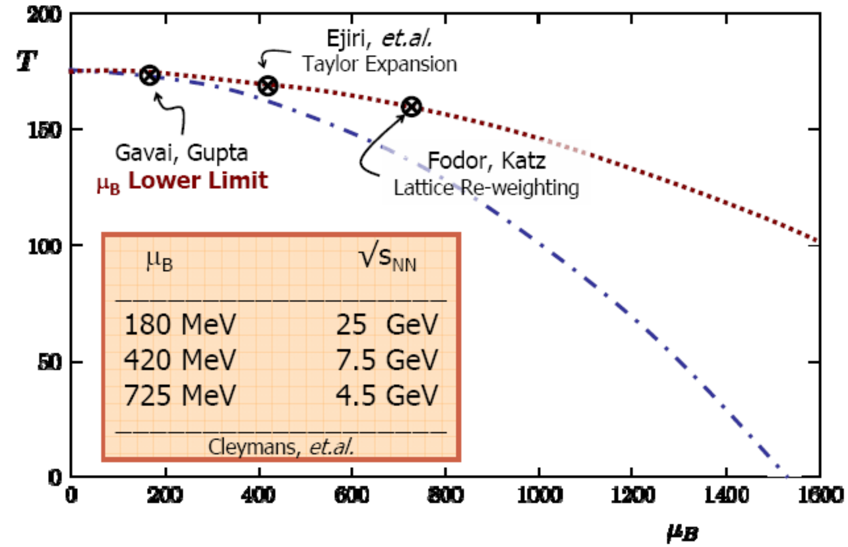
Upgrades for a low energy scan

RHIC collisions are possible over a broad range of Energies



Does a Critical Point Exist? If so, where?



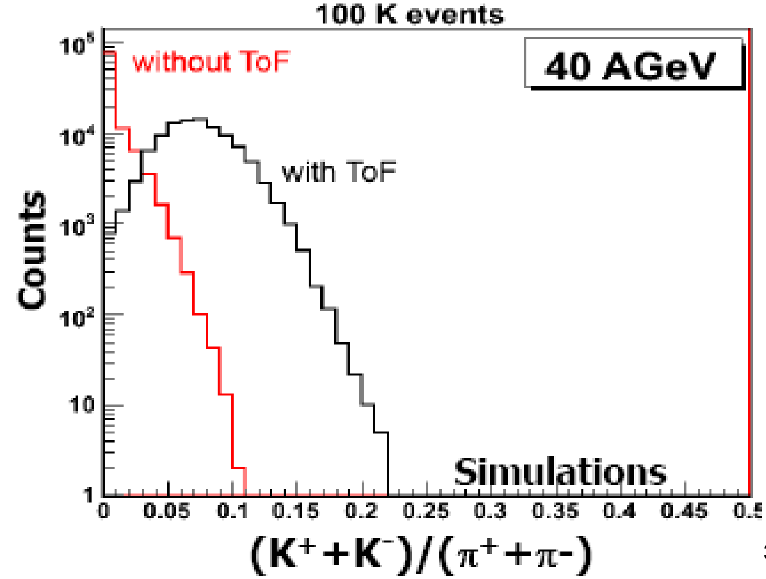


- LQCD results show that as the baryon chemical potential increases, fluctuations on the cross-over line increase suggesting a critical point in the QCD phase diagram.

The location of the QCD Critical Point, if it exists, remains a matter for experiment

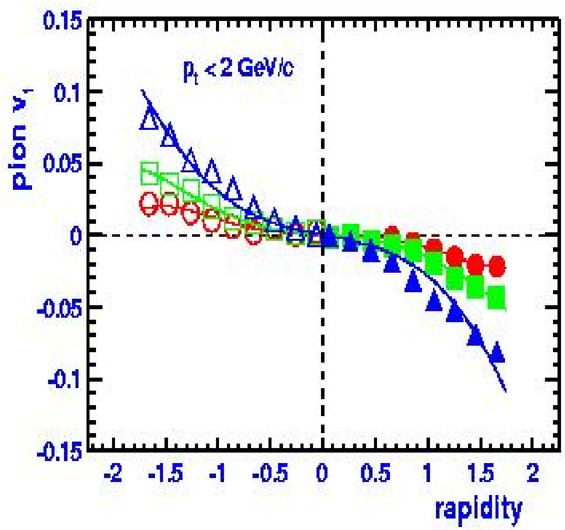
The search for critical fluctuations will be central for which full 2π TOF is crucial:

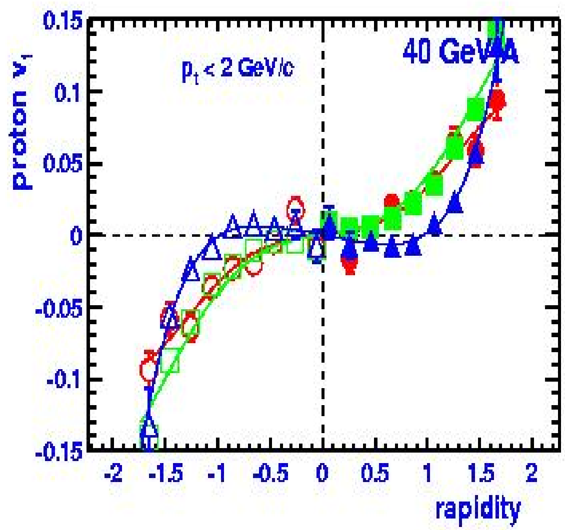
Misidentification of only 1% leading to a swapping of pions for kaons reduces the width of the observed k/pi fluctuation distribution by 10%. A misidentification of 2% leads to a reduction in width of 20%.



Measurements

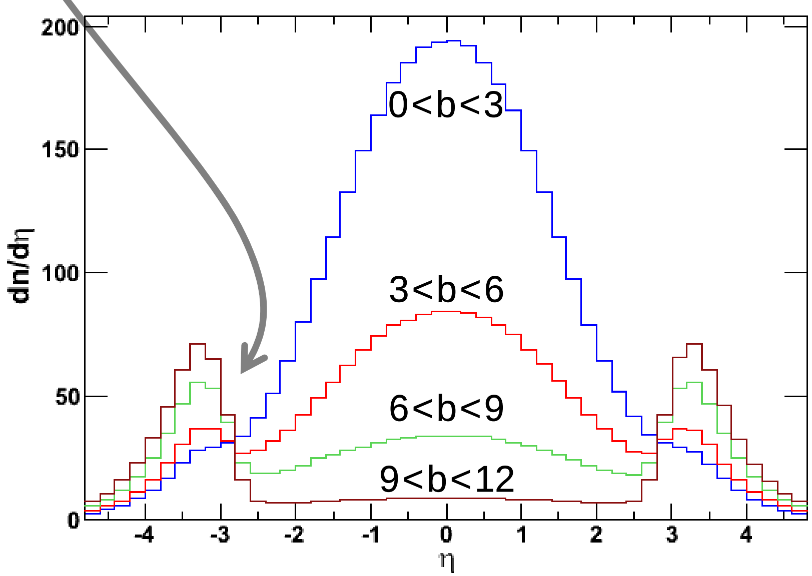
- elliptic flow v_2
  - → *φ and Ω v_2 (deconfinement?)*
  - → *quark number scaling (deconfinement?)*
  - → *collapse of proton flow? (phase trans?)*
  - → *v_2 fluctuations near critical point*
- directed flow v_1
  - → *multiple inflection points (wiggle)*
  - → *possible signature of 1st order phase transition*
- reaction plane dependent analyses

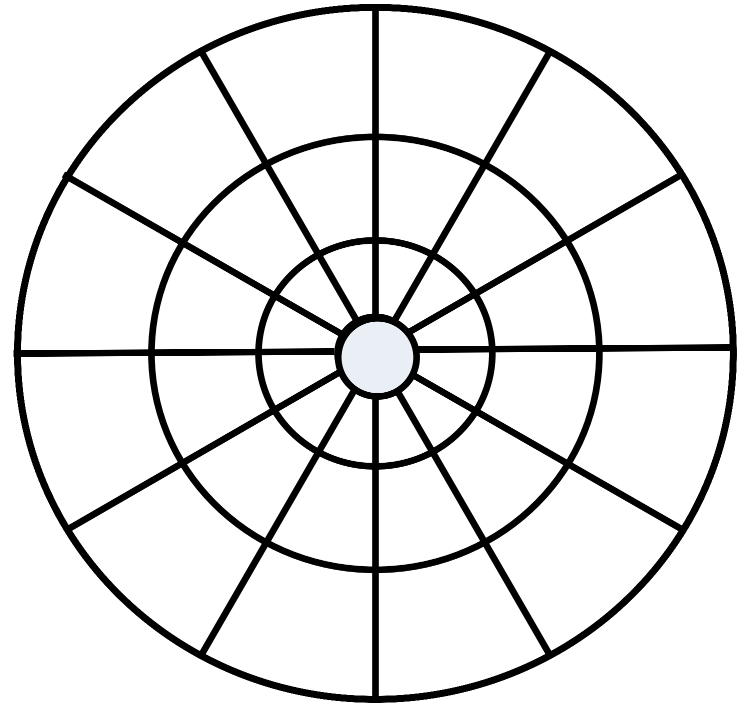




Method: Instrument the Spectator Region

- **Segmentation in η could help determine centrality during the low energy run: spectators vs produced particles**





- **Placed in the region where the beam pipe is narrowest for maximum η coverage**
- **Scintillator tiles with PMTs are one possibility**
- **Draw inspiration from similar detectors at PHOBOS**

Timeline for STAR Upgrades

Fiscal Year	2005	2006	2007	2008	2009	2010	2011	2012	2013
Forward Meson Spect.									
FEE & DAQ Upgrade									
MRPC TOF									
Forward GEM Tracker									
Heavy Flavor Tracker									
For. Reaction Plane Det.				?	?				
Muon Telescope						?	?	?	
Crystal Calorimeter						?	?	?	
γ-γ HBT						?	?	?	

Key	R&D	Construction	Phased Installation	First Physics	Full System Running

Summary

- The scientific program at STAR is rich and diverse
  - Rare probes and high p_T phenomena are a rich source of new discoveries
  - Strangeness, Charm, and Beauty are likely to yield even more new discoveries
  - We have promising spin program that is making critical and unique measurements
- The scientific program at RHIC will keep getting better
  - The performance of the accelerator is improving due to a carefully planned set of upgrades.
  - STAR will explore charm, beauty, and higher p_T spectra at ever increasing data acquisition rates.
- These upgrades will yield exciting new physics results

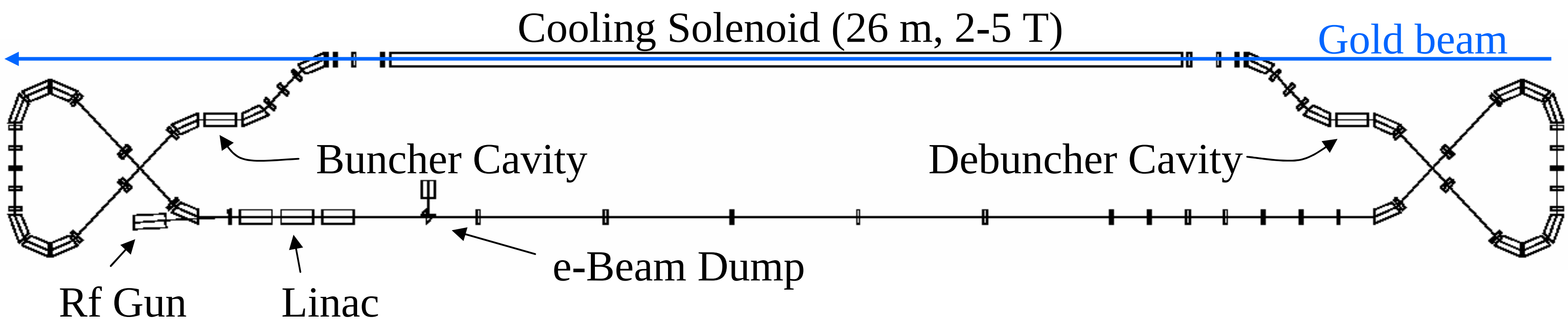
The Future is Very Bright

Backup Slides

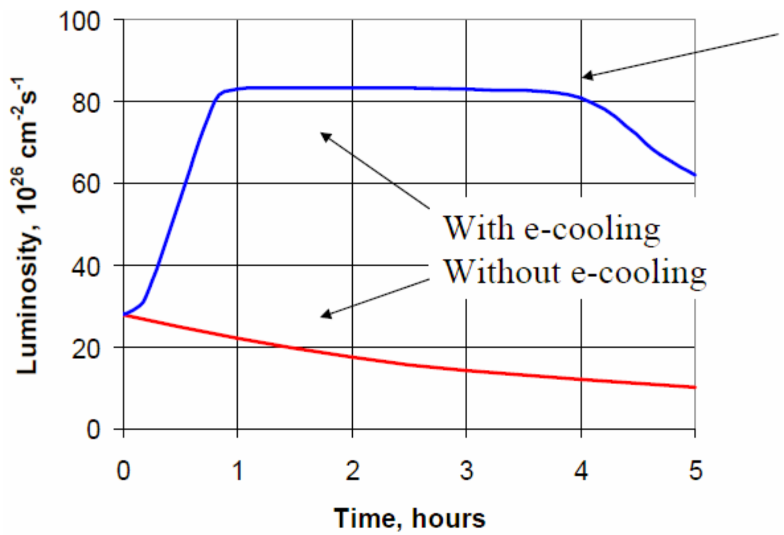
STAR Benefits Tremendously from RHIC II

- Everything we are doing today will make STAR a better detector when RHIC II arrives
- Figure of merit is bytes to tape … or better bytes to PRL
  - There are many ways to achieve this goal
  - DAQ upgrade
  - Larger acceptance
  - Larger Luminosity
  - STAR is anticipating being able to realize all of these opportunities
- RHIC II utilizes all of the beam
  - x10 increase in bytes to PRL
  - flattop luminosity is very efficient for detectors and triggers
  - eCooled beams actually burn up the beam due to collisions
  - absolutely the most efficient way to run the machine
- STAR benefits from increased $\mathcal{L}$ for rare probes (μ, γ, C+B)
  - HFT is for beauty and charm. Low cross-section needs the $\mathcal{L}$
  - Mu telescope. Low cross-sections and limited acceptance of telescope
  - Calorimeter upgrades (crystal and $\gamma\gamma$ HBT)
  - also helps p-p and d-Au programs (FMS, FGT)

Luminosity Upgrade with Electron Cooling



Gold collisions (100 GeV/n x 100 GeV/n):	w/o e-cooling	with e-cooling
Ave. store luminosity [10^{26} cm^{-2} s^{-1}]	8	70
Pol. Proton Collision (250 GeV x 250 GeV):		
Ave. store luminosity [10^{32} cm^{-2} s^{-1}]	1.5	5.0



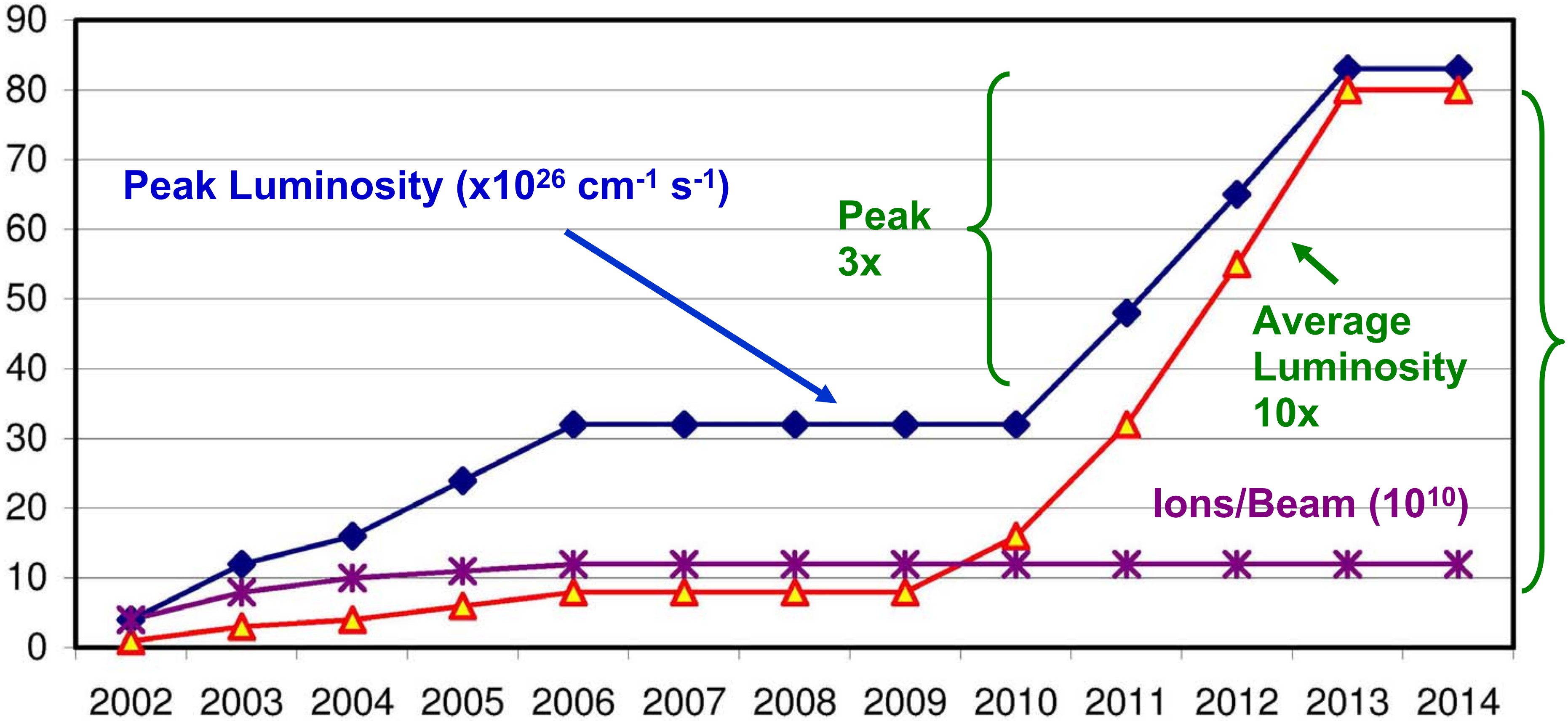
Electron cooling reduces the inter-beam Coulomb scattering and reduces the size of the beam at the IP

Luminosity leveling through continuously adjusted cooling

Store length limited to 4 hours by "burn-off"

First collider accelerator to be limited by beam losses due to interactions that are the subject of study by the experiments

Future Heavy Ion Luminosity at RHIC



Machine Short Term Upgrades include:
- Vacuum improvements ⇒ 112 bunches
- NEG pipe coating
- Stochastic cooling

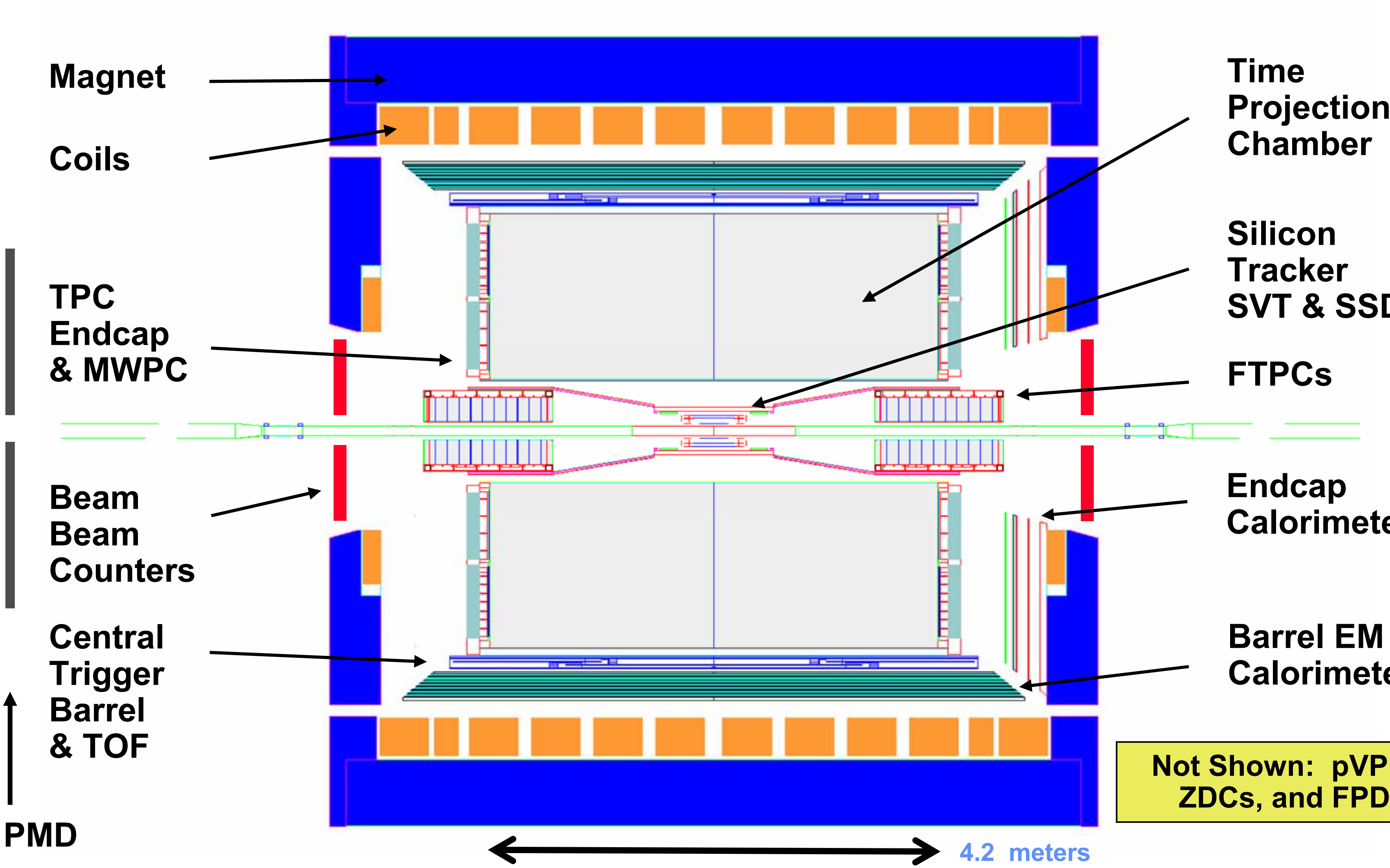
Machine Long Term Upgrades include:
- Electron Beam Cooling
- EBIS ion source

Goal:
- More events to tape per year

Theory and Experiment

Working Together to Build a Better Future

STAR is a Suite of Detectors



Not Shown: pVPDs, ZDCs, and FPDs

A TPC lies at the heart of STAR

STAR Beam Use Proposal for Run 8 – Run 10

A typical beam use request cycle

- **protons**
- **deuterons**
- **Au**

With a topical selection of alternative beam energies

- **'top' energy**
- **500 GeV**
- **low energy**

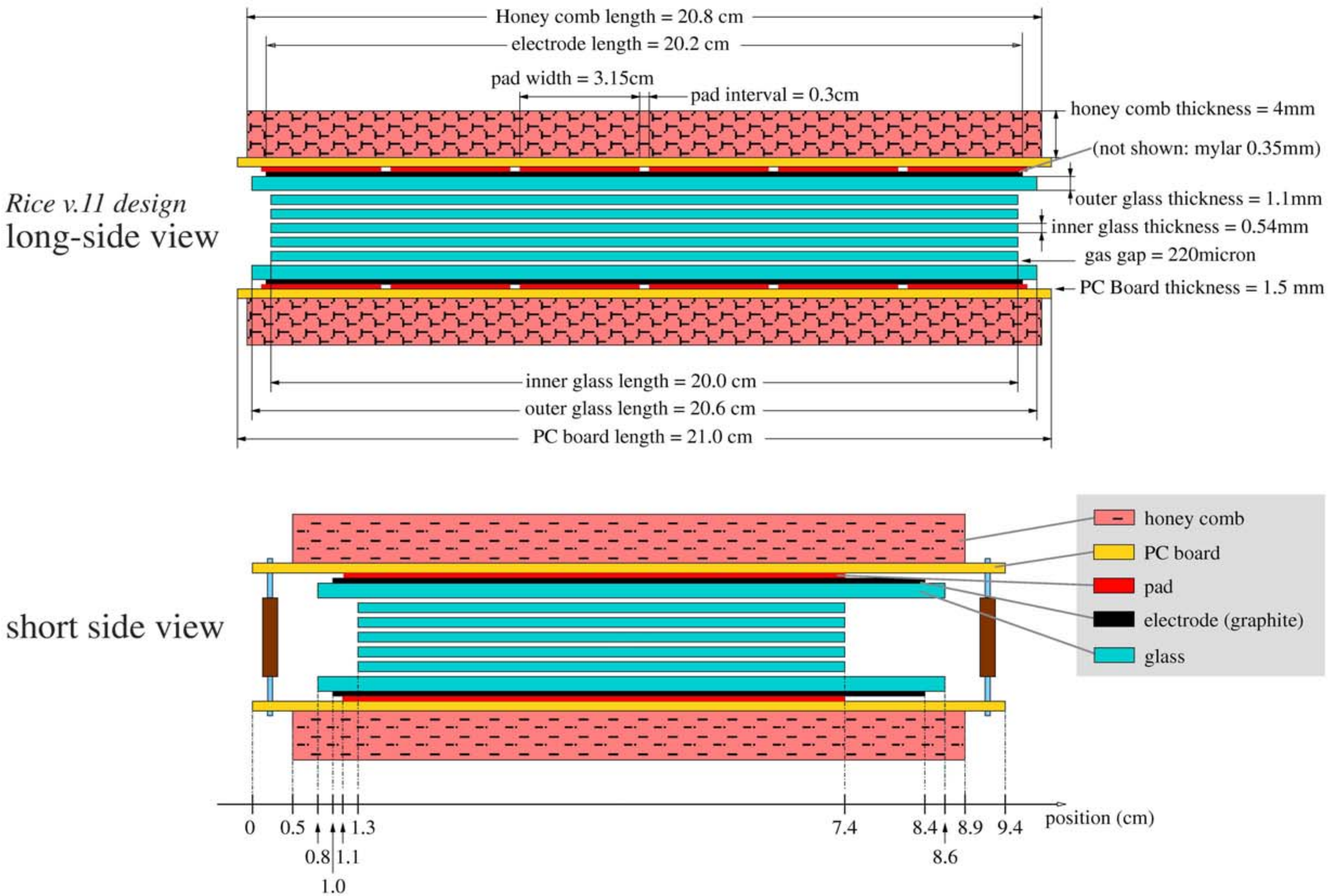
and occasionally alternative beams

Run	Energy	System	Goal
8	$\sqrt{s_{NN}}$ = 200 GeV	d + Au	(10 + 2 weeks) 30/60 nb^{-1} sampled*
	$\sqrt{s}$ = 200 GeV	$p_{\rightarrow} p_{\rightarrow}$, $p_{\uparrow} p_{\uparrow}$	(~12 + 2 weeks)
	$\sqrt{s}$ = 200 GeV	$p_{\uparrow} p_{\uparrow}$	~ 3 days pp2pp
	$\sqrt{s}$ = 500 GeV	pp	Commissioning**
9	$\sqrt{s_{NN}}$ = 200 GeV	Au + Au	(8 + 2 weeks)
	$\sqrt{s}$ = 200 GeV	$p_{\rightarrow} p_{\rightarrow}$, $p_{\uparrow} p_{\uparrow}$	(~14 + 2 weeks)
	$\sqrt{s}$ = 200 GeV	$p_{\rightarrow} p_{\rightarrow}$	~ 3 days pp2pp
	$\sqrt{s}$ = 500 GeV	pp	Commissioning**
10	Low $\sqrt{s_{NN}}$	Au + Au	12 + 3 weeks
	$\sqrt{s}$ = 500 GeV	$P_{\rightarrow} P_{\rightarrow}$	8 + 3 weeks

* First number with slow detectors, second number with fast detectors

** Contingent on achieving primary physics goals early

Chambers are multiple narrow gaps (6 *x* 220μm) separated by glass. Module sensitive area is ~6 *x* 20 cm

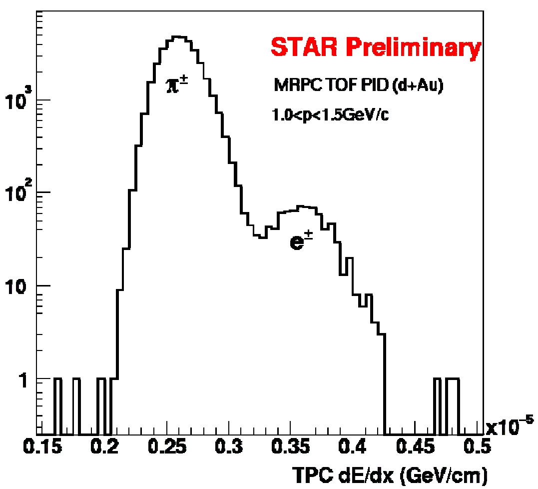


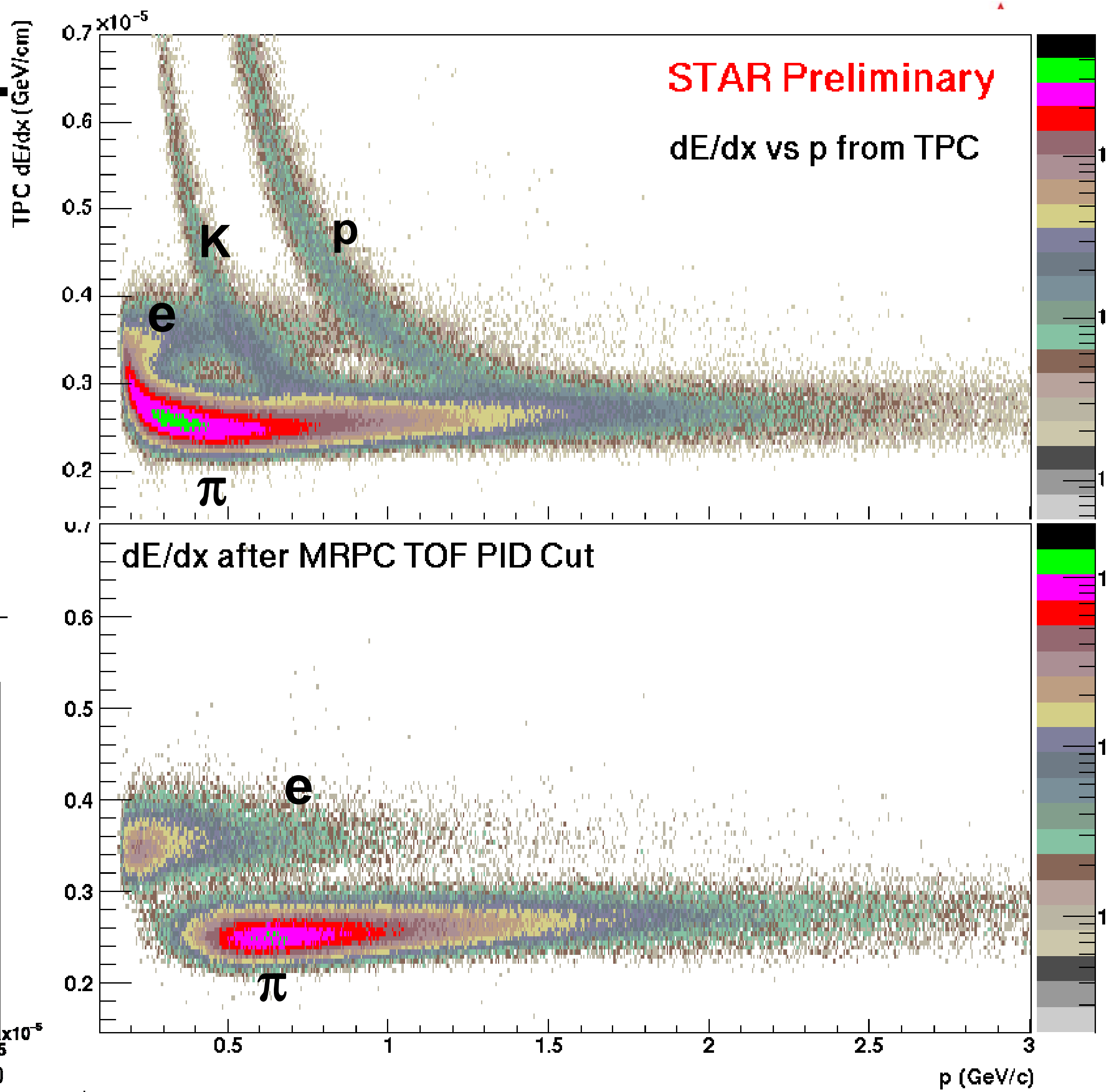
applied potential ±7-8kV

Gas will be 96% Freon R134a, 4% CO_2

Added benefit:

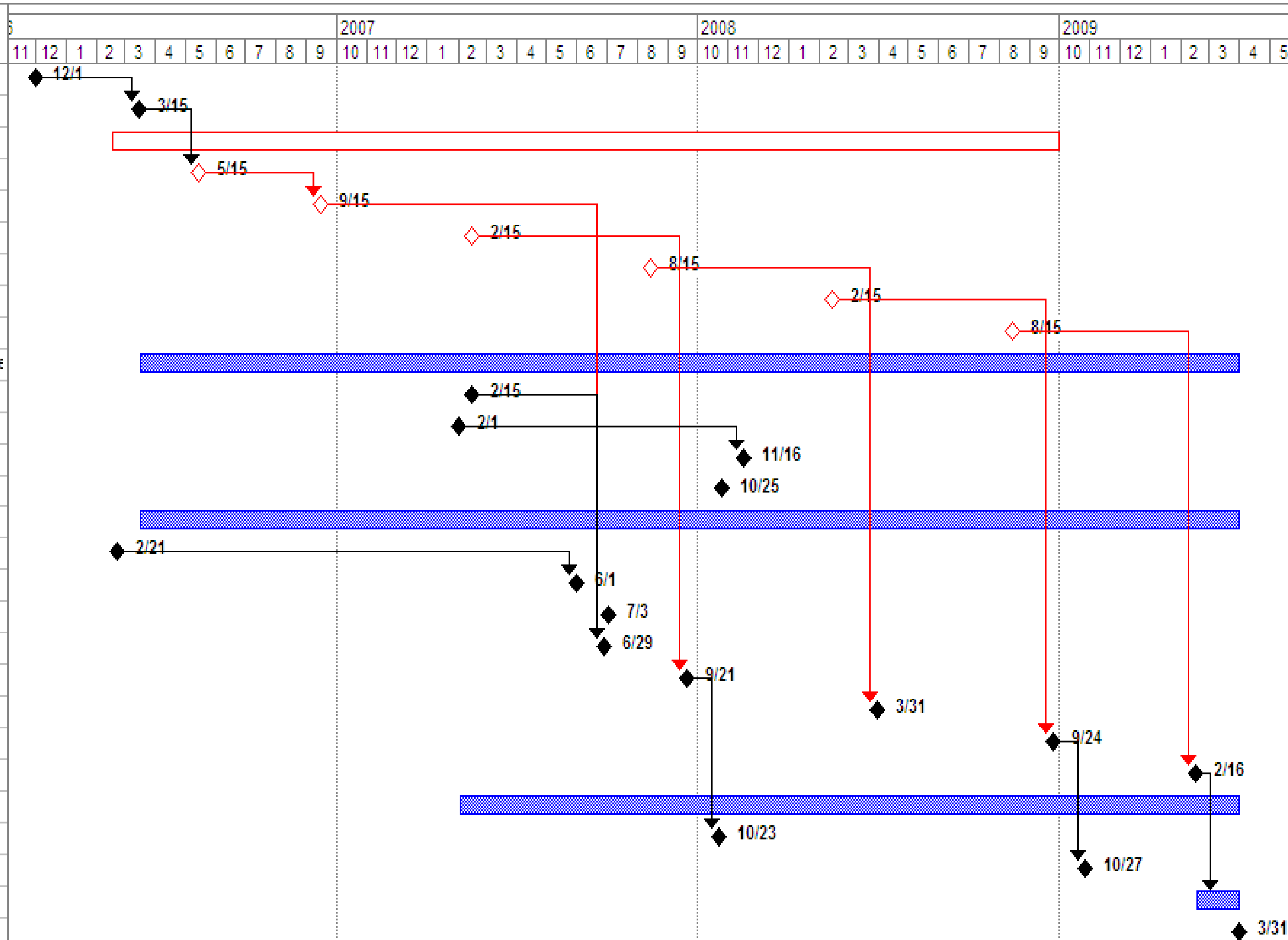
Combined TPC dE/dx and TOF gives *electron tag* at low to moderate momentum





TOF Project Schedule

ID	Task Name	Date
1	Project approved	12/1
2	Project accounts open	3/15
3	MRPC Modules - China	
4	MRPC construction begins	5/15
5	132 MRPCs received	9/15
6	768 MRPCs received	2/15
7	1856 MRPCs received	8/15
8	2944 MRPCs received	2/15
9	4032 MRPCs received	8/15
10	Detectors & Mechanical Syste	
11	Tray assembly begins	2/15
12	Gas system design complete	2/1
13	Gas system complete	11/16
14	Start Detector complete	10/25
15	Electronics	
16	TINO viability decision	2/21
17	TINO,TDIG R&D complete	6/1
18	TCPU, THUB R&D complete	7/3
19	1 Tray complete	6/29
20	5 Trays complete	9/21
21	40 Trays complete	3/31
22	86 Trays complete	9/24
23	120 Trays complete	2/16
24	System Installation	
25	5-tray system installed	10/23
26	87-tray system installed	10/27
27	Schedule contingency	
28	Project complete	3/31

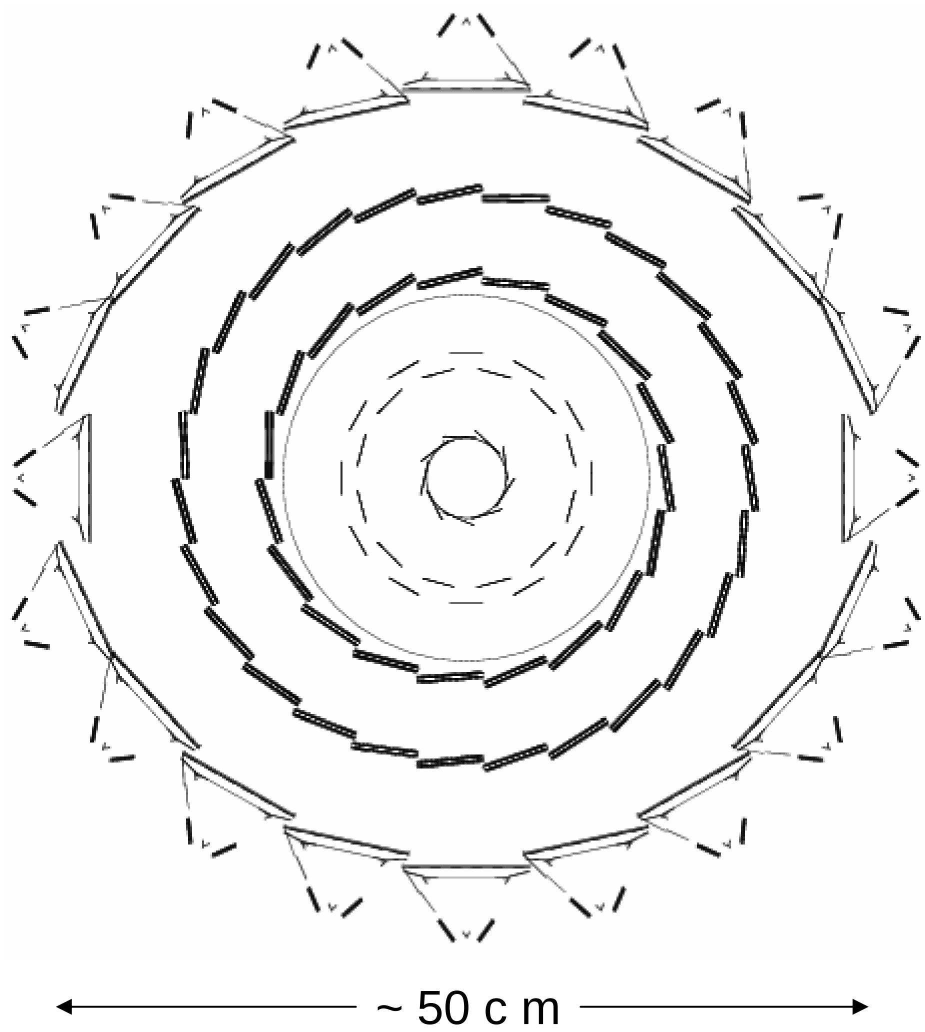


5 Trays in Run 8, 65 Trays in run 9, 120 Trays in run 10

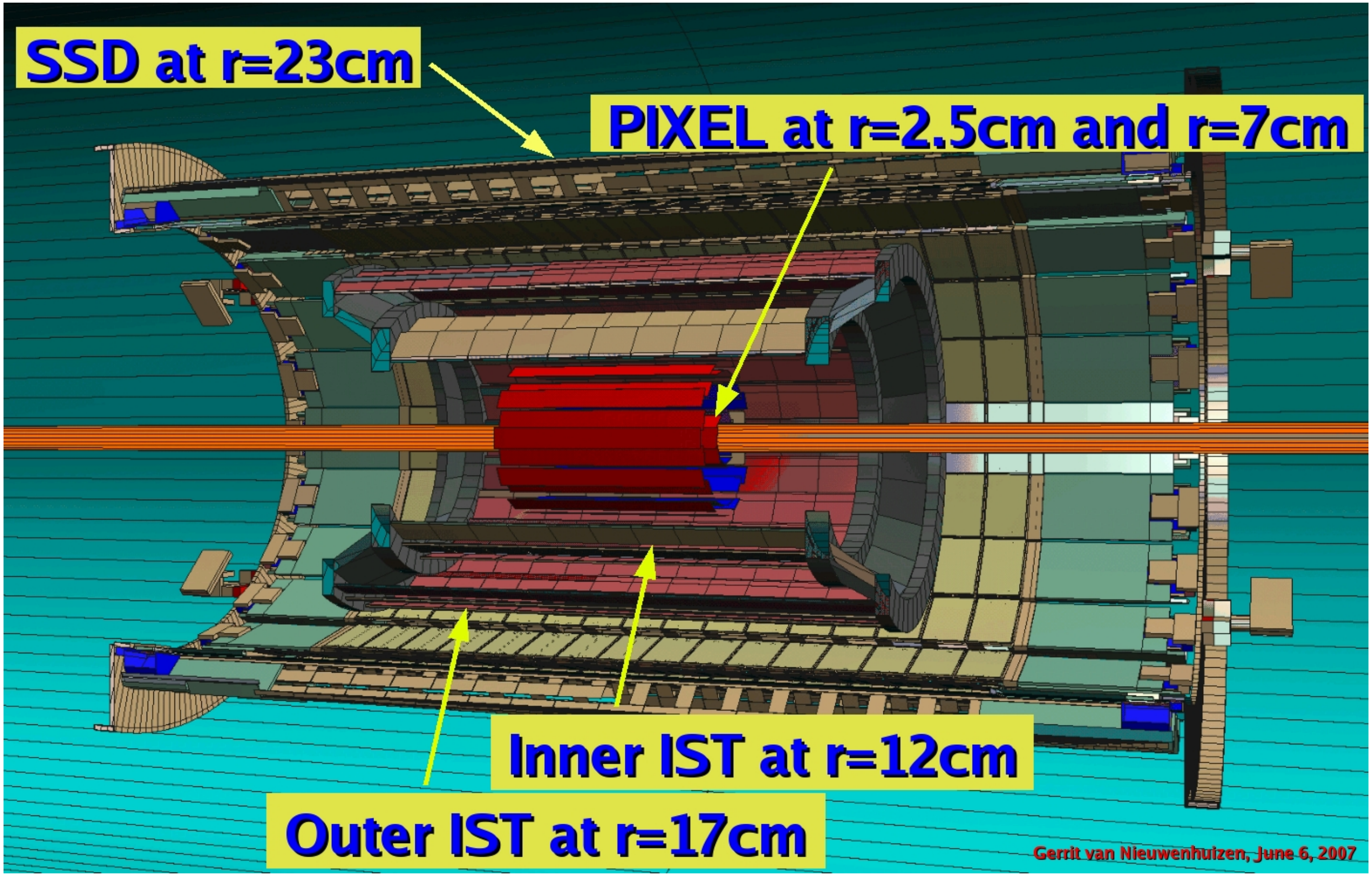
Summary of Si Detectors Inside the TPC

- Goal: graded resolution from the outside → in
- TPC – SSD – IST – PXL
  (single track pointing, without a vertex constraint)
- TPC pointing resolution at the SSD is ~ 1 mm
- SSD pointing at the IST is ~ 330 μm
- IST pointing at the HFT is ~ 200 μm
- PXL pointing at the VTX is ~ 40 μm

Inside the TPC



The Geant View of the Heavy Flavor Tracker



Rates Estimation - v_2

(a) dN/dp_T distributions for D-mesons.

Scaled by $\langle N_{bin} \rangle = 290$, corresponds to the minimum bias Au + Au collisions at RHIC.

(b) Assumed v_2 distributions for D-mesons.

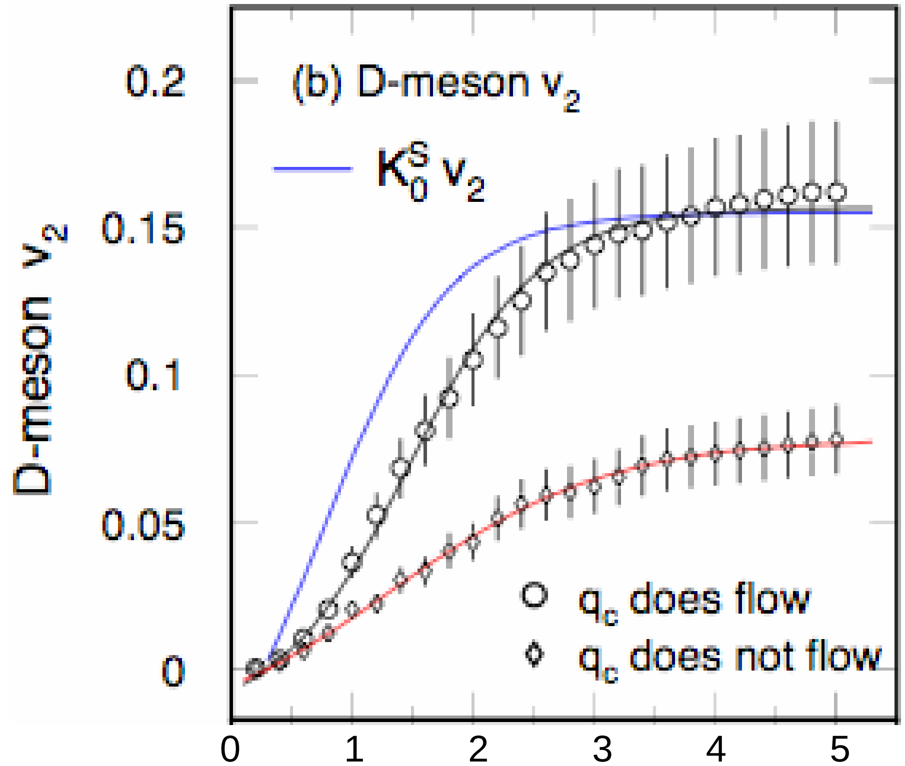
---- PLB 595, 202 (2004)

Error bars shown are from 15% systematic errors

(c) D^0 meson v_2 rates from minimum bias Au + Au collisions at 200 GeV.

The small and large error bars are for 15% and 30% systematic errors, respectively. For the v_2 analysis, 12 bins in φ are used.

500 M Events is achievable with DAQ1000



p_T(GeV/c)	Δp_T(GeV/c)	# events $q_C = q_{u,d,s}$	# events $q_C = 0$
0.6	0.2	260×10^6	525×10^6
1.0	0.5	70×10^6	140×10^6
2.0	0.5	53×10^6	125×10^6
3.0	1.0	390×10^6	270×10^6
5.0	1.0	520×10^6	880×10^6