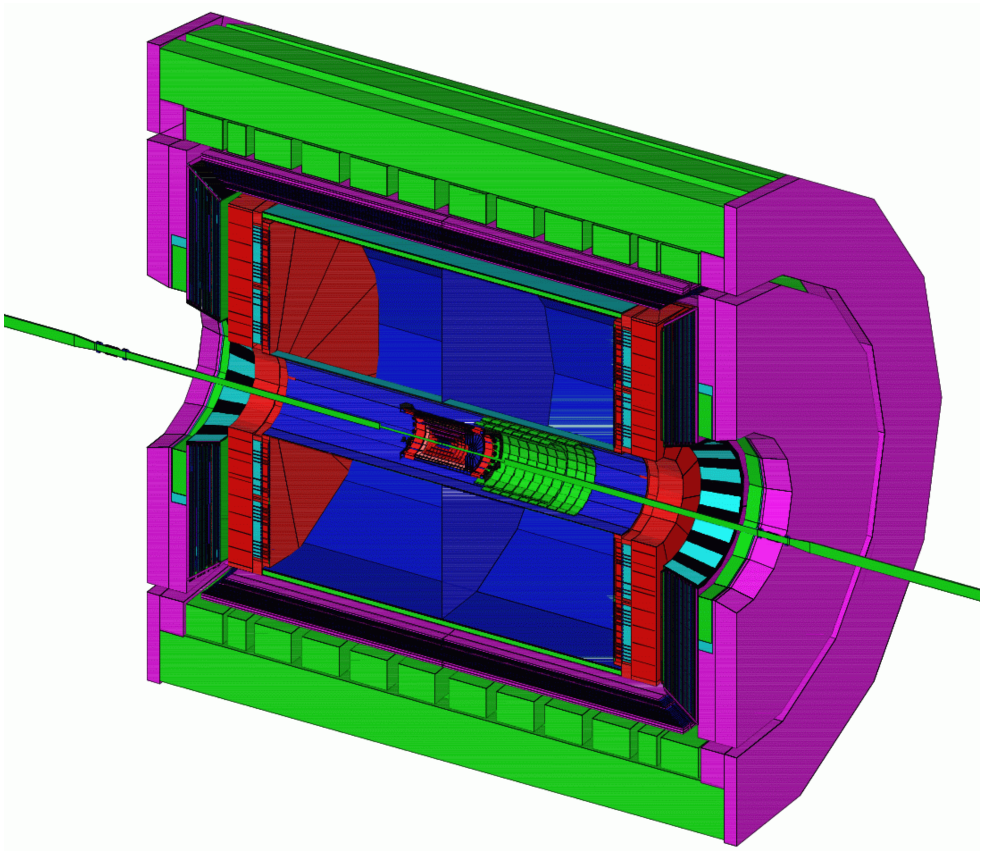
What should/can we do STAR Upgrades?

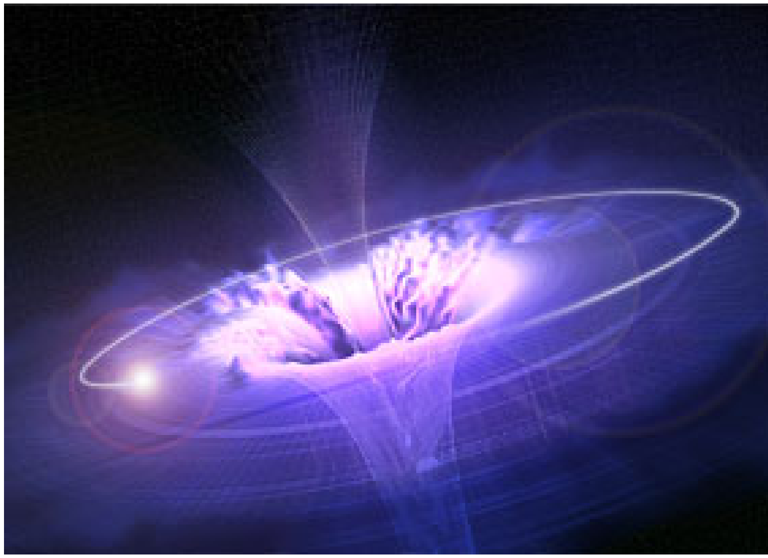
Zhangbu Xu (BNL)

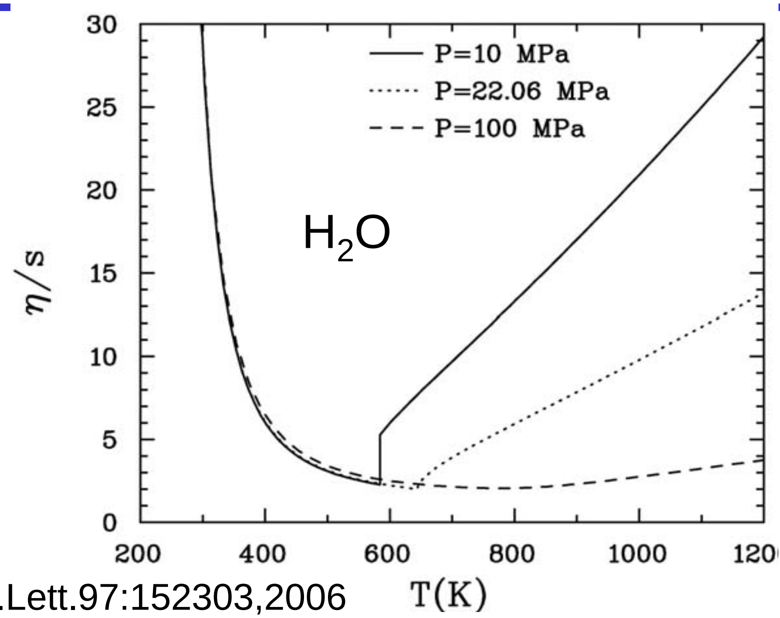
- Near/long term Physics Goals
- Mid-term upgrades
- Outlooks for future upgrades
- "Small upgrades"




STAR

Connections to other fields

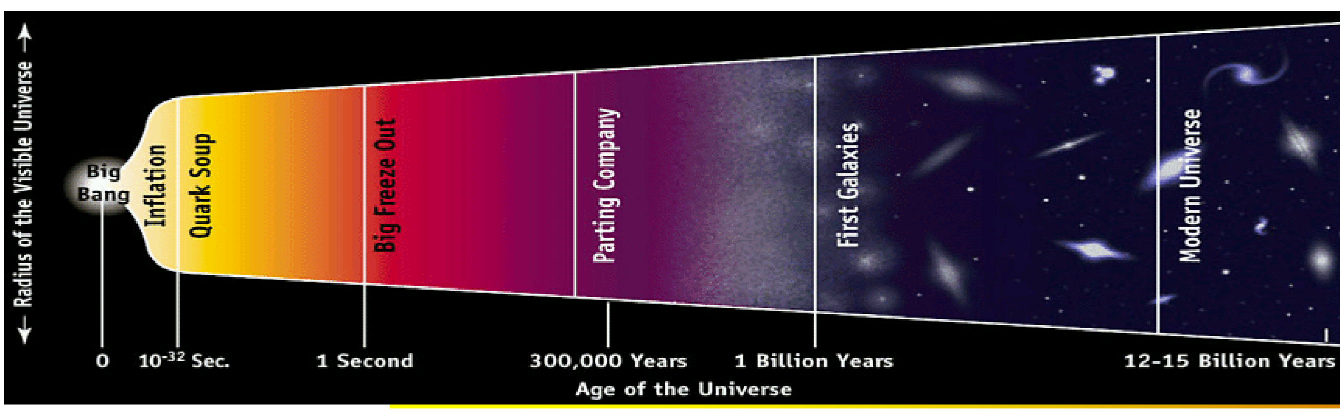




Phys.Rev.Lett.94:111601,2005; Phys.Rev.Lett.97:152303,2006

Black Hole, String Theory

universal low viscosity limit 1/4π?



Big Bang

- Low-temperature Atomic Physics
- EOS of Neutron stars
- Strong field condensed matter physics of QCD

STAR Upgrade Concepts

Summary of the RHIC II Science Working Groups

The RHIC facility – Evolution and future

Equation of state and the QCD phase diagram

1. Dynamical considerations
   - A. Evidence for Thermalization
   - B. Thermalization Timescale
   - C. Thermalization Mechanisms
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   - A. Measurements of Energy Density
   - B. Initial Temperature: How to measure it?
3. Exploring the QCD Phase Diagram
   - A. Search for the QCD critical point
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Gluon Saturation

Exploring the spin structure of the nucleon at RHIC-II

STAR upgrade concepts

1. Preserve large acceptance
2. Extend forward coverage
3. Particle Identification
4. Precise Secondary Vertex
5. Leptons/photons
6. Faster DAQ
7. Cost-effective, do it best

Upgrade overview – Jim Thomas (plenary)

Critical needs from future experiments

Near Term

- v2 scaling **for coalescence**
- jet quenching as **parton energy loss**
- energy dependence **testing model prediction**
- **Heavy flavor yields and flow: color screening and partonic ollectivity.**
- forward jet correlation: **CGC**

STAR Mid-term upgrades

Time of Flight

Forward Meson Spectrometer

DAQ1000

Mid-rapidity Tracker

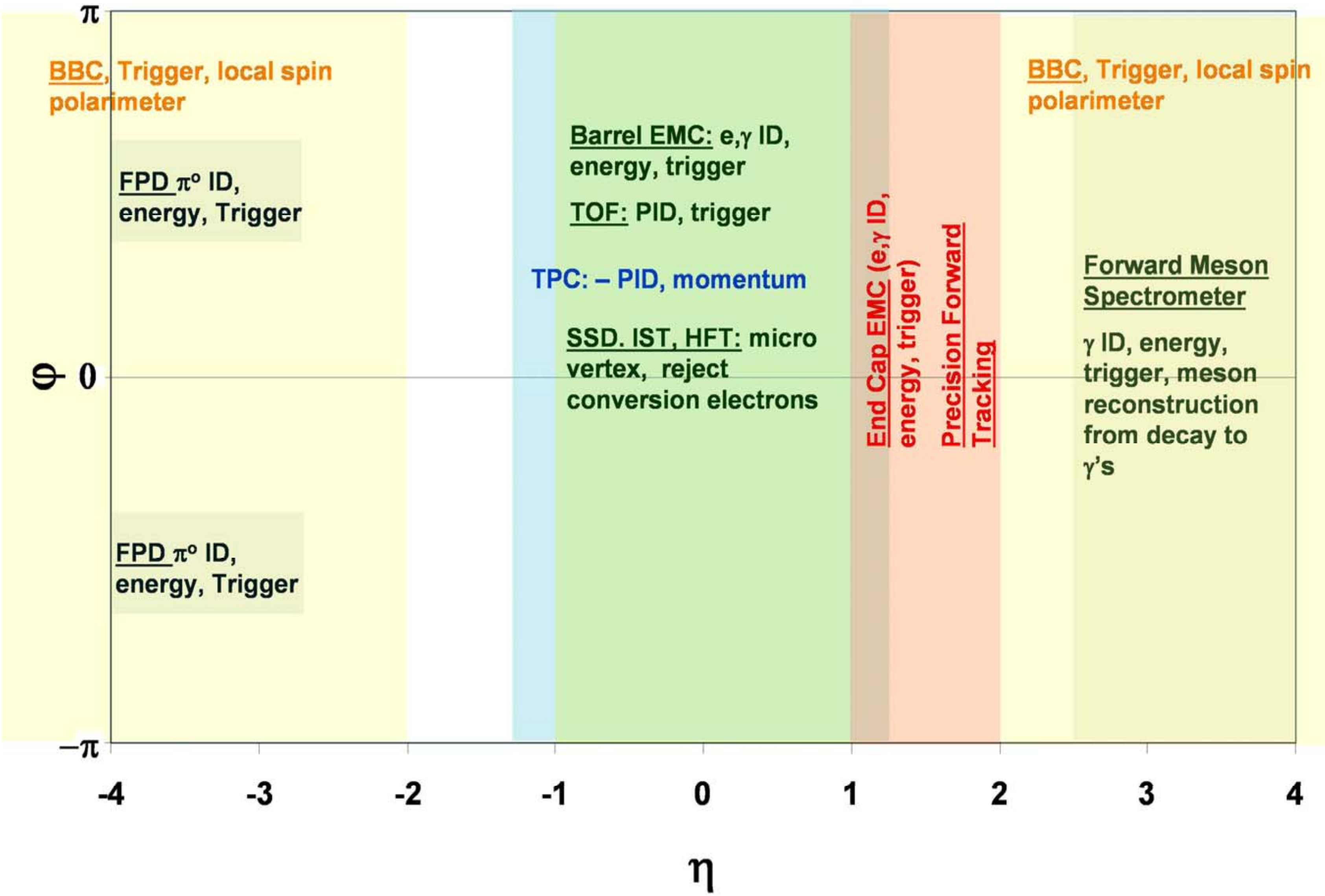
Forward Tracking

Long Term

- **Thermometers**: **dilepton, photon**
- **heavy quarkonium species**.
- **jet fragments tagged** by a hard direct photon, a heavy flavor
- **elliptic flow in U+U collisions**.
- LHC and GSI energies
- **fundamental QCD symmetries**

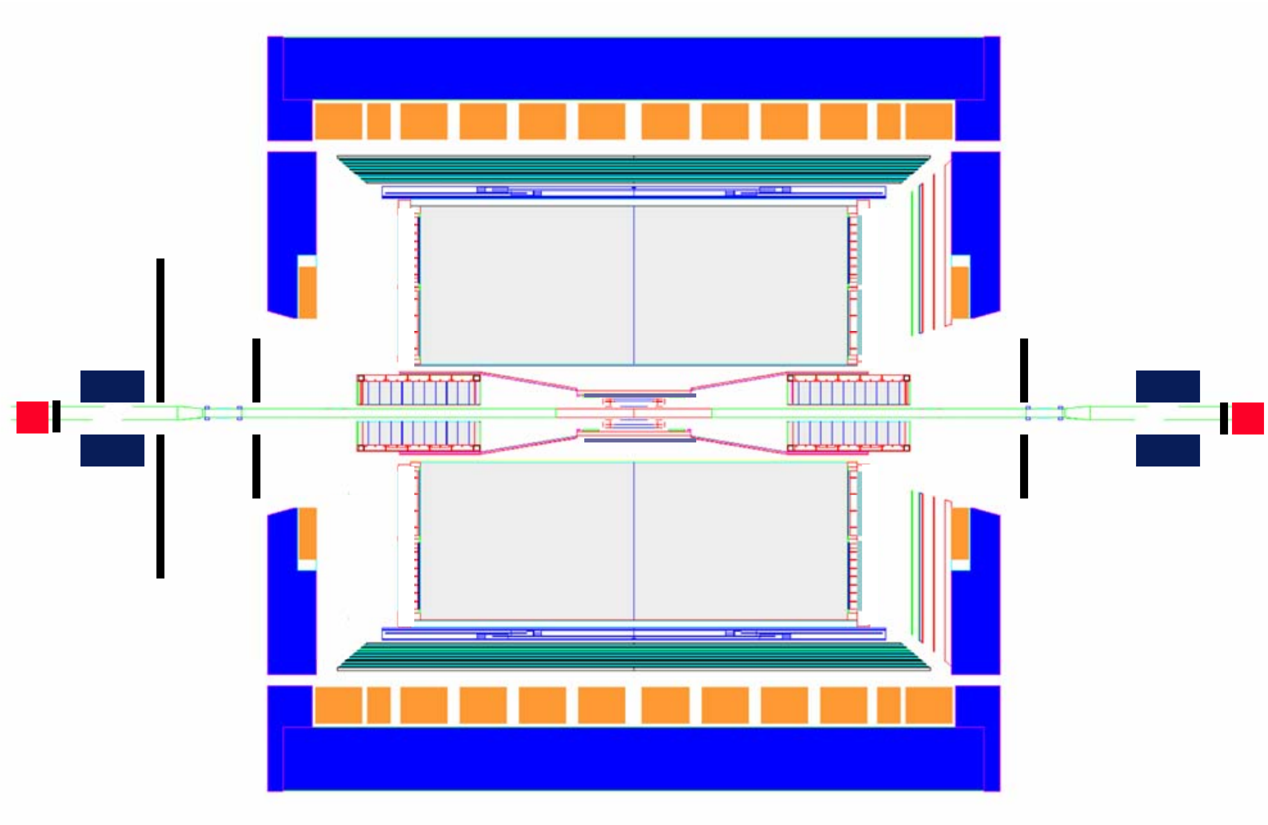
Near/Long Term: STAR white paper Nucl. Phys. A 757 (2005) 102

Coverage


π
φ 0
−π
-4
-3
-2
-1
0
1
2
3
4
η
BBC, Trigger, local spin polarimeter
FPD π° ID, energy, Trigger
FPD π° ID, energy, Trigger
Barrel EMC: e,γ ID, energy, trigger
TOF: PID, trigger
TPC: – PID, momentum
SSD. IST, HFT: micro vertex, reject conversion electrons
End Cap EMC (e,γ ID, energy, trigger)
Precision Forward Tracking
BBC, Trigger, local spin polarimeter
Forward Meson Spectrometer
γ ID, energy, trigger, meson reconstruction from decay to γ's

TPC FEE and DAQ Upgrade – DAQ 1000

DAQ1000 workshop – August 16-17



TPC is now a fast detector!!!
Prototype in run 7 – Jeff Landgraf (plenary)

- Faster, smaller, better … (10x)
- Current TPC FEE and DAQ limited to 100 Hz
- Replace TPC FEE with next generation CERN based chips … 1 kHz readout
- Make the FEE smaller to provide space for a forward tracking upgrade
- Further improvements by only archiving “associated” clusters – build on L3 algorithms … 5 kHz !

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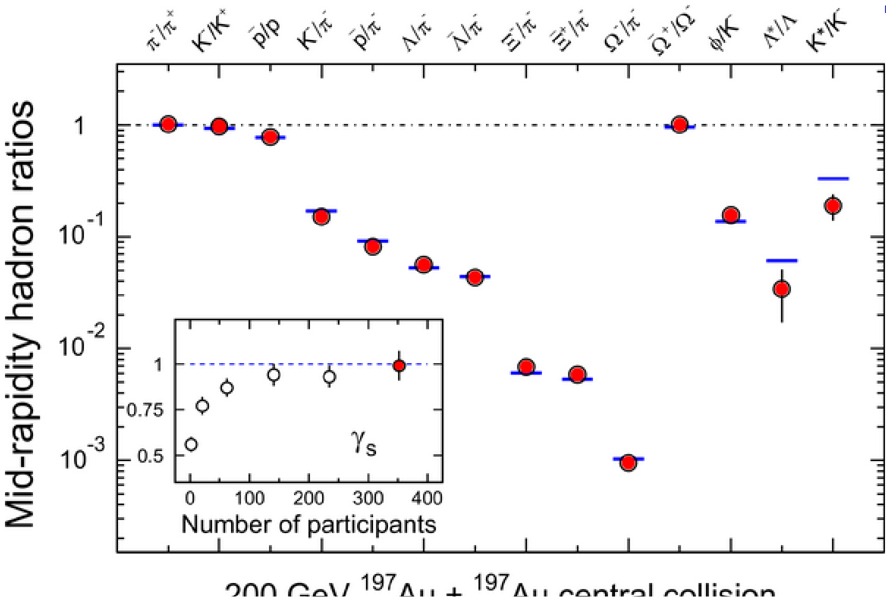
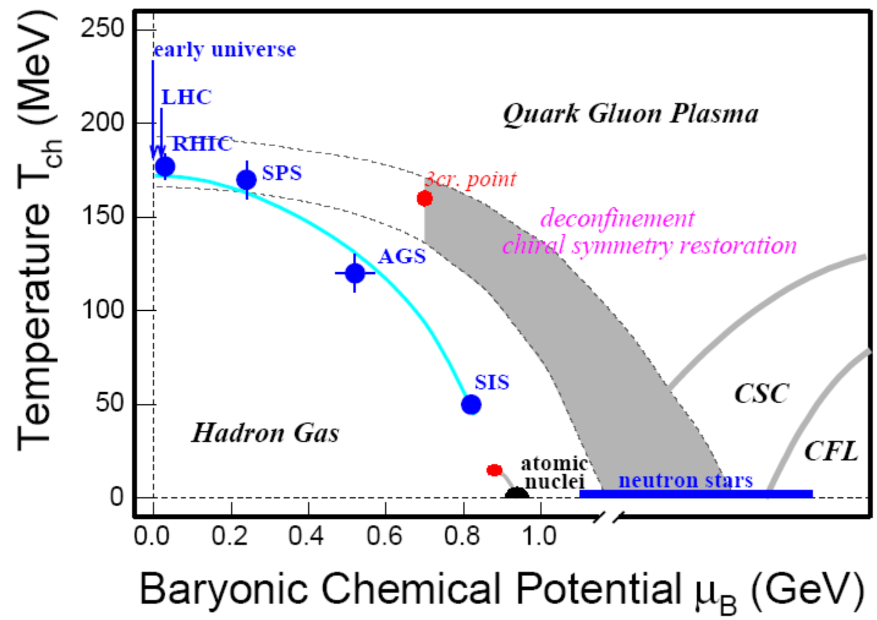
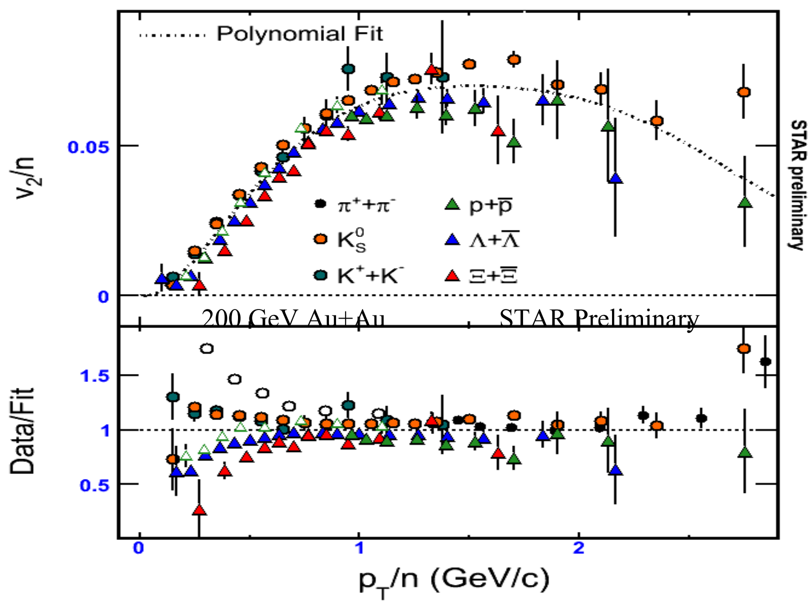
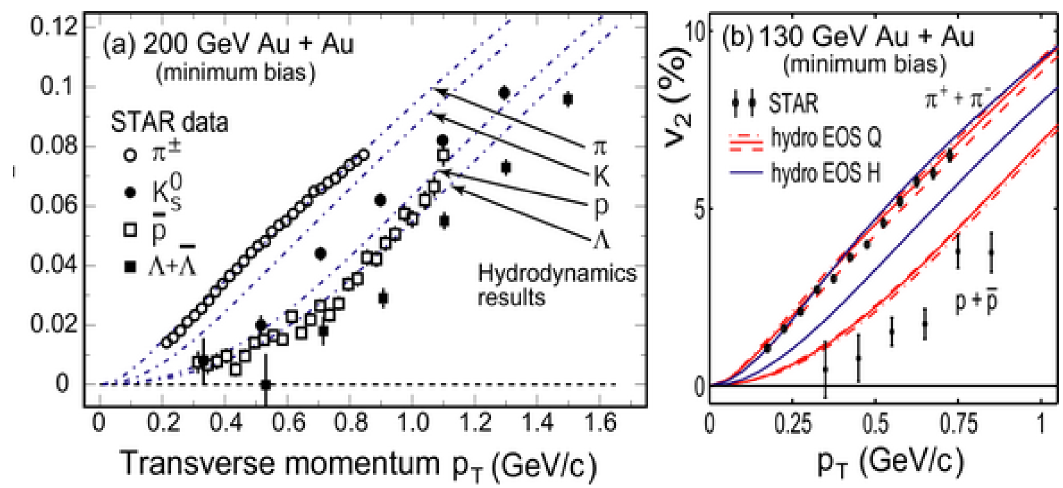
Hadron PID play crucial roles in RHIC discoveries









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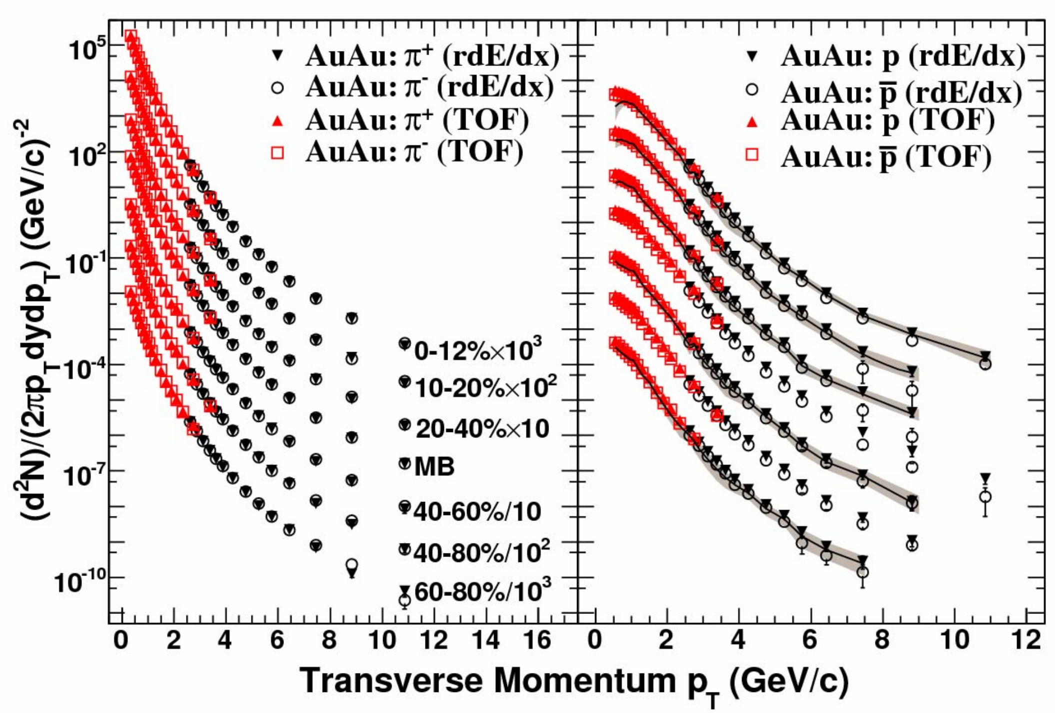
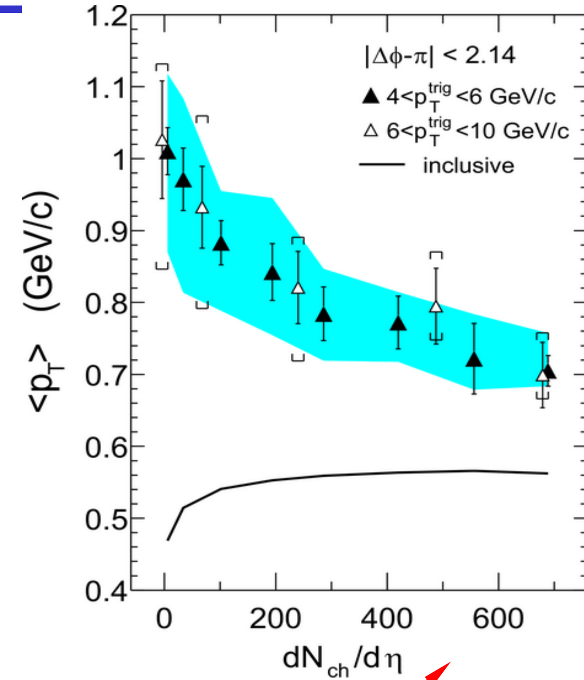
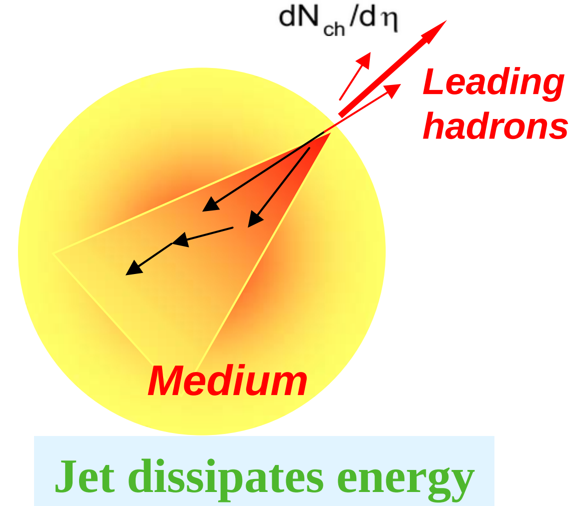
PID Jet Quenching, Associated Spectra/Correlations

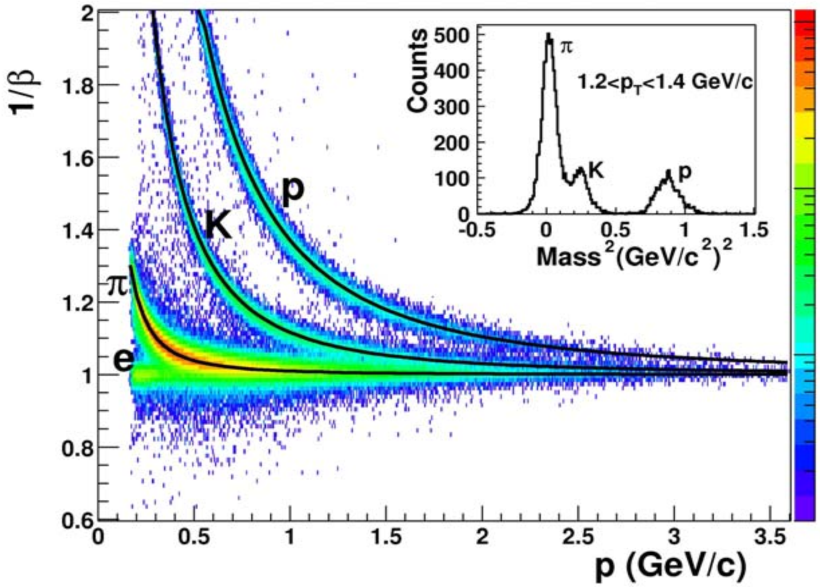


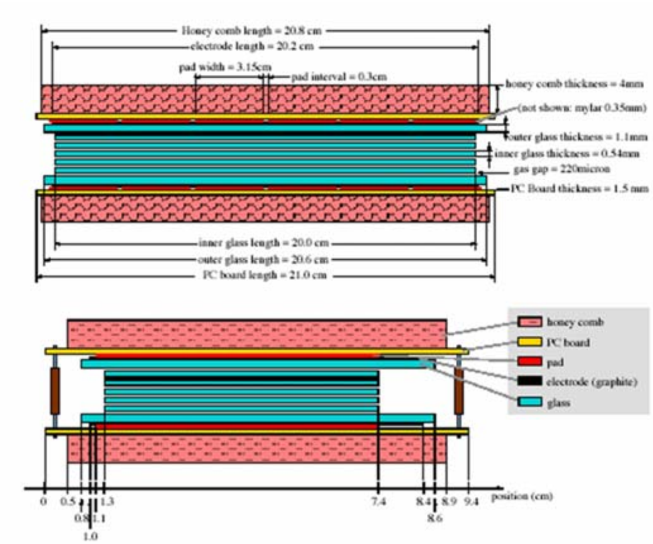


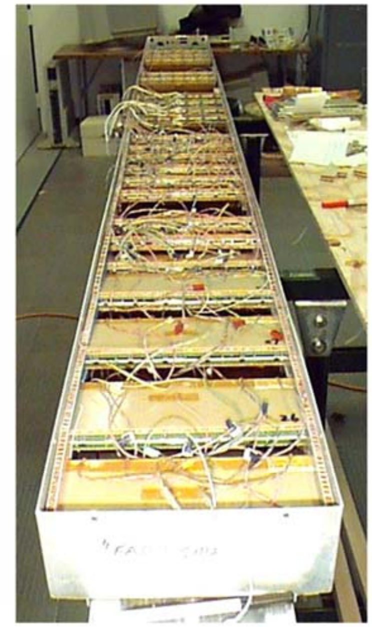


- Identified proton/pion at very high pT
- Away-side spectra approaching the bulk
- Chemically and thermally?
- Need PID $1<p_T<4$ GeV/c
- Fluctuation K/π, p/π (Critical point)?

Time-of-Flight Identifies Particles







Particle	pT range (GeV/c)	TPC+TOF/TPC
K*0	0-1	2.0
K*0	1-2	1.85
K*0	2-3	1.74
K*0	3-5	1.39
ϕ	0-2	5.0
ϕ	2-5	3.42
Λ*	0-1.6	11.4
D0	0-5	4.6

State-of-art Multi-gap Resistive Plate Chamber:
6 gap, 3x6cm^2 pad
23,000 channels, $-0.9<\eta<0.9$, $0<\phi<2p$

the most significant collaboration
to date between the United States and China
in high-energy particle physics detector research

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Near Term

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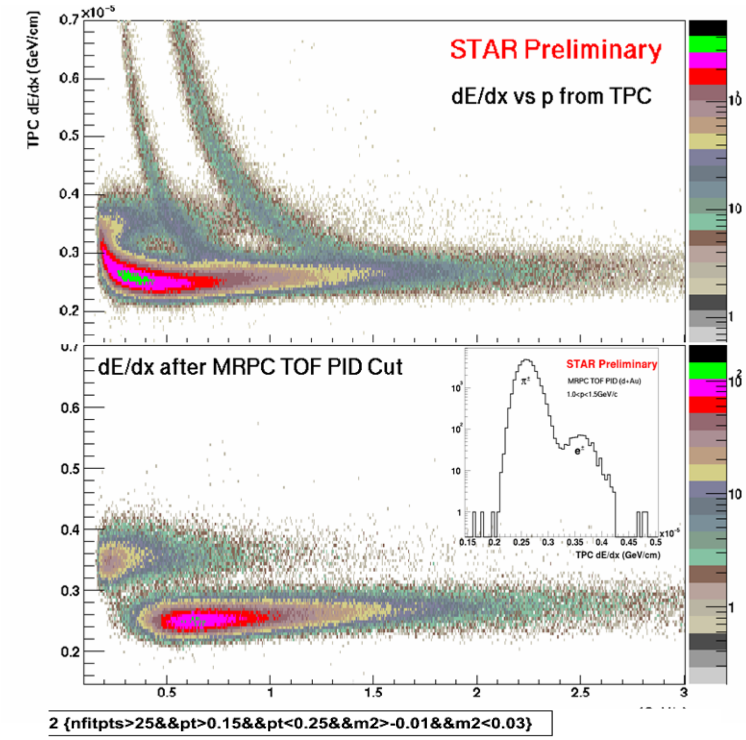
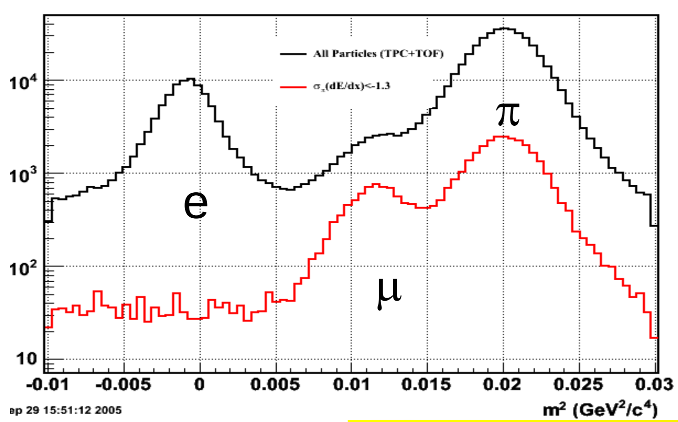
Near/Long Term: STAR white paper Nucl. Phys. A 757 (2005) 102

poor man's open heavy flavor measurements



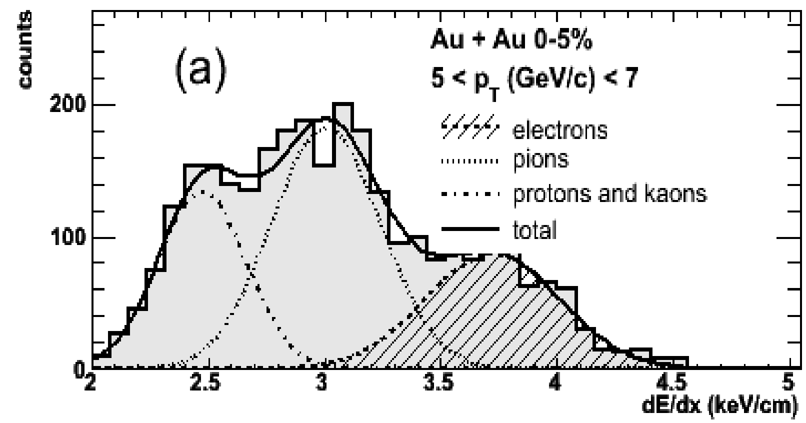


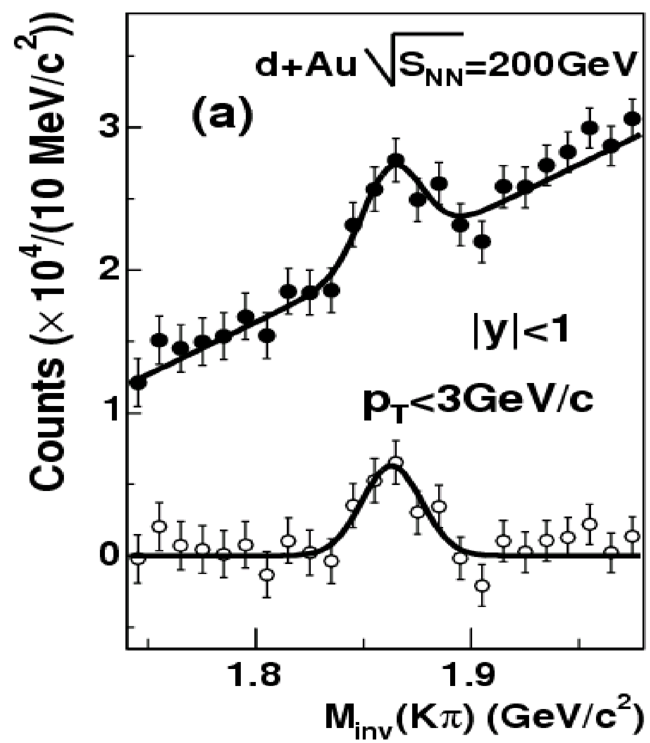
Electrons:
EMC:
pT>2 GeV/c

TOF+TPC:
0.2<pT<4

Muon:
TOF+TPC:
pT~=0.2

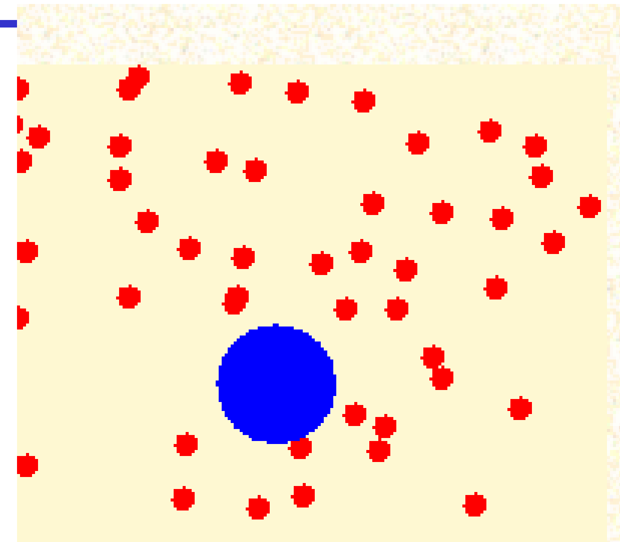
Kπ:
Combinatoric Kπ reconstruction

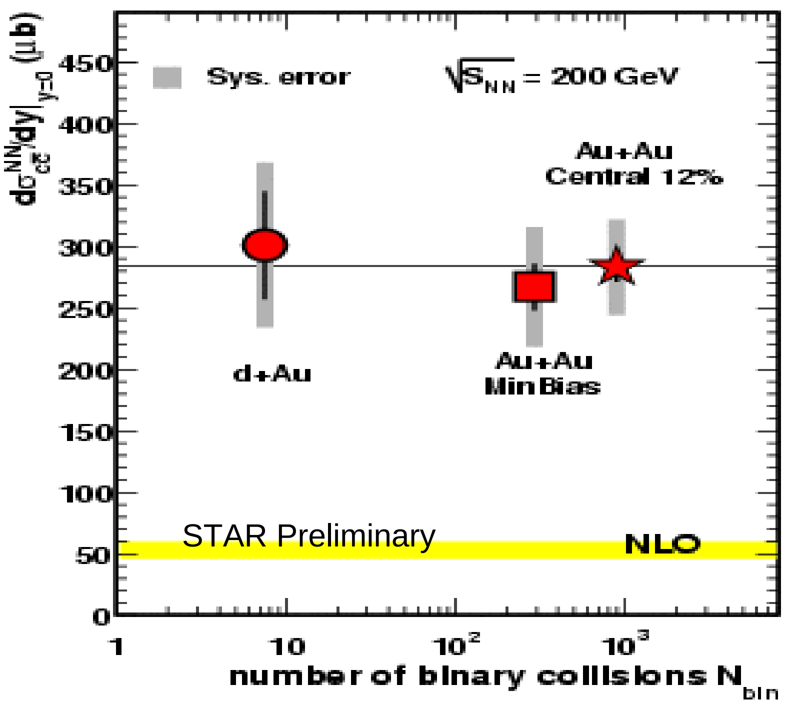




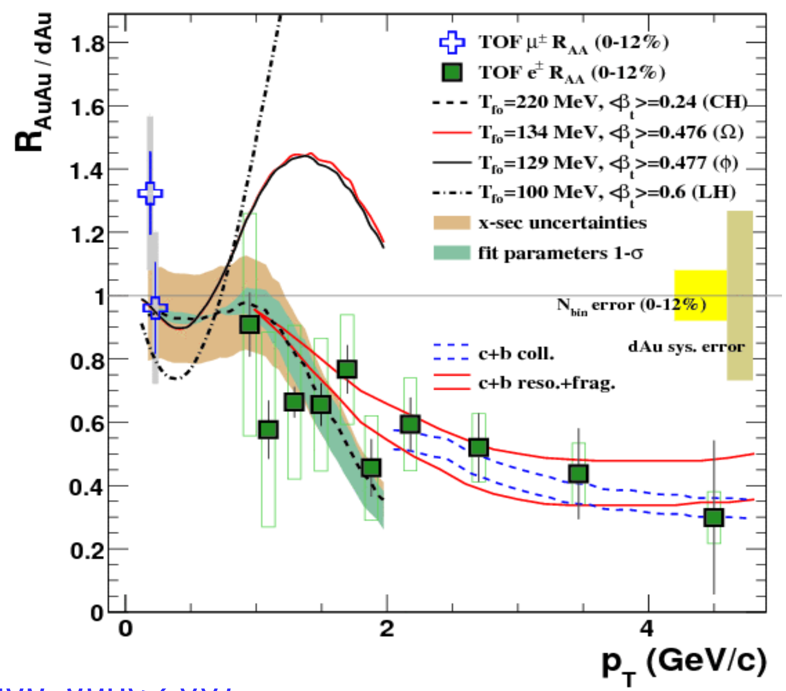
Brownian motion of heavy quarks

- Charm quarks
  m ~ 1200 MeV
  T ~ 165 MeV
- "drag" and diffusion of "solid" object
- Direct Reconstruction, v2



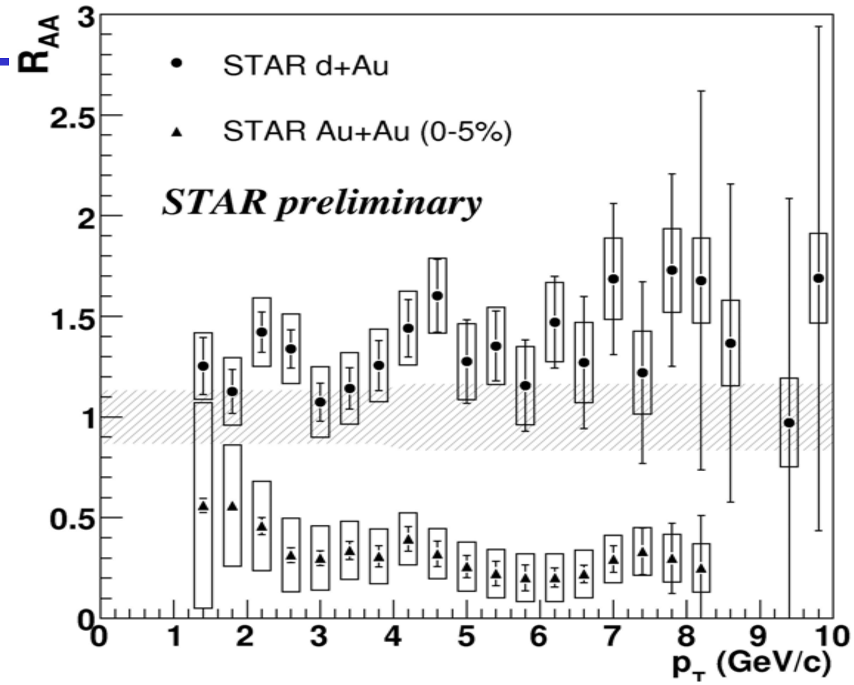


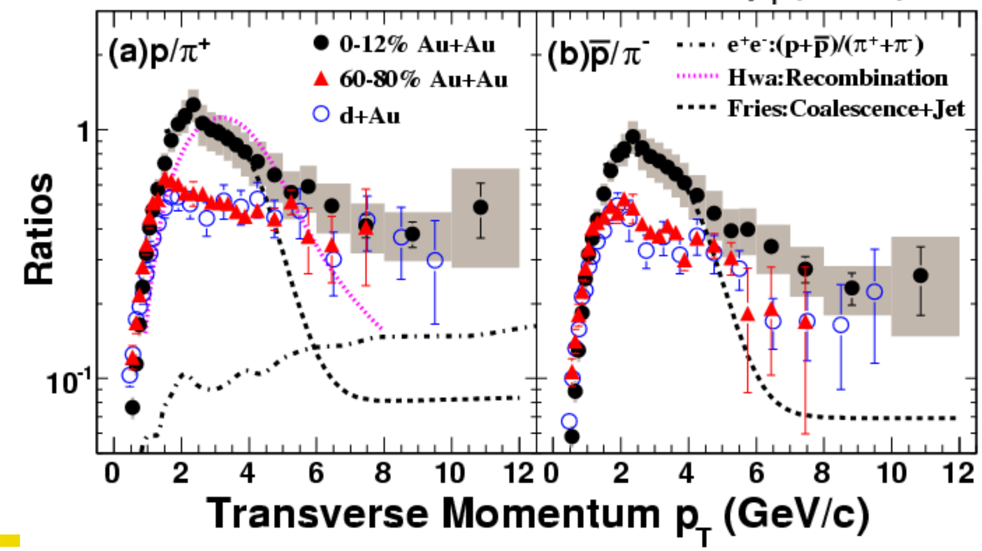
H.B. Zhang, Y.F. Zhang, C. Zhong QM06



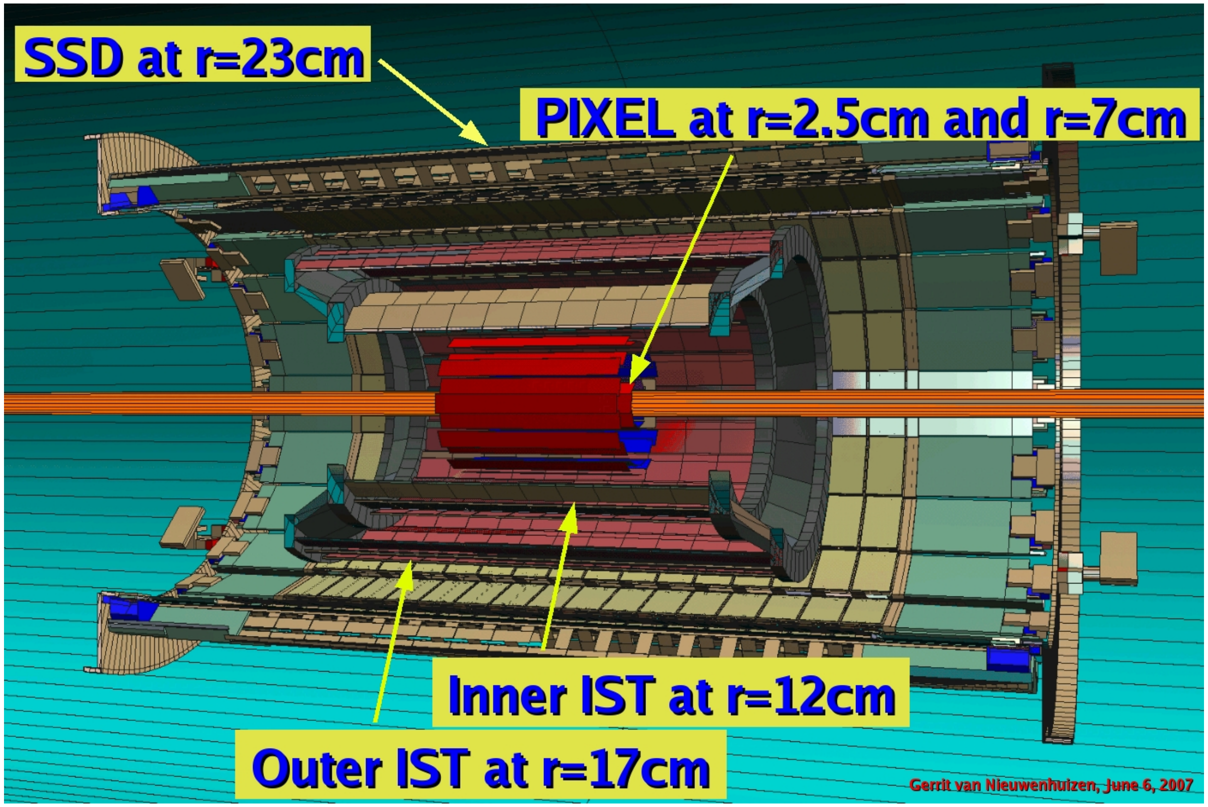
Are we sensitive to Color/Flavor?

- QCD: gluon, light quark and heavy quark lose different amount of energy (9/4,1,0.5)
- Experimental results so far do not g$\rightarrow$pbar, u/d $\rightarrow$ p, c/b $\rightarrow$ e
- Jet Quenching picture is solid, in general
- Something interesting besides the general framework
- RHIC and II:
  Directly Reconstructed charm





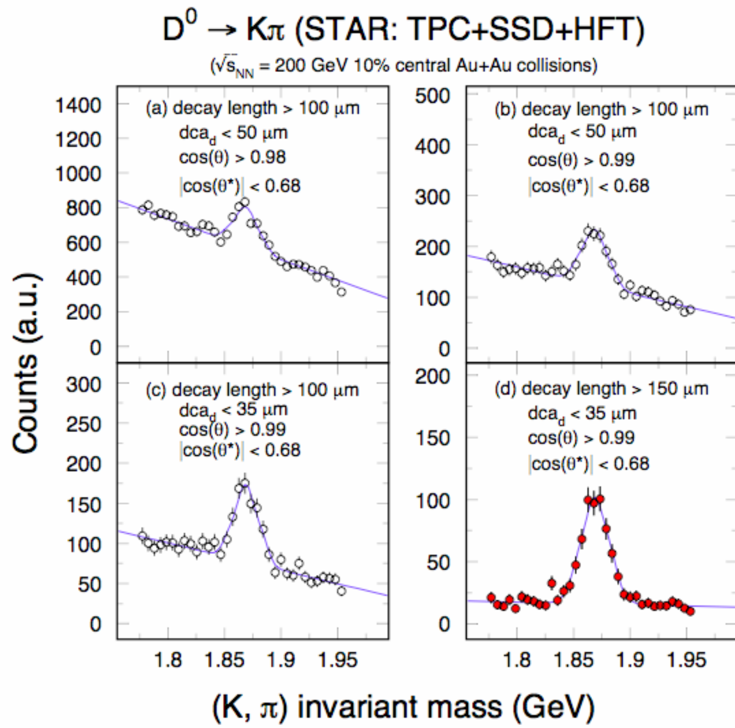
The Silicon Pixel Tracker



A thin detector using 50 μm Si
to finesse the limitations imposed by MCS

- A new detector
  - 30 μm silicon pixels to yield 10 μm space point resolution
  - 100 M pixels
- Direct Topological reconstruction of Charm
  - Detect charm decays with small $c\tau$, including $D^0 \rightarrow K\,\pi$
- New physics
  - Charm collectivity and flow to test thermalization at RHIC
  - Charm Energy Loss to test pQCD in a hot and dense medium at RHIC
- Desirable to have it in time for the next long Au-Au run

HFT Direct Charm Measurements



Spectra vs pT at 10% error

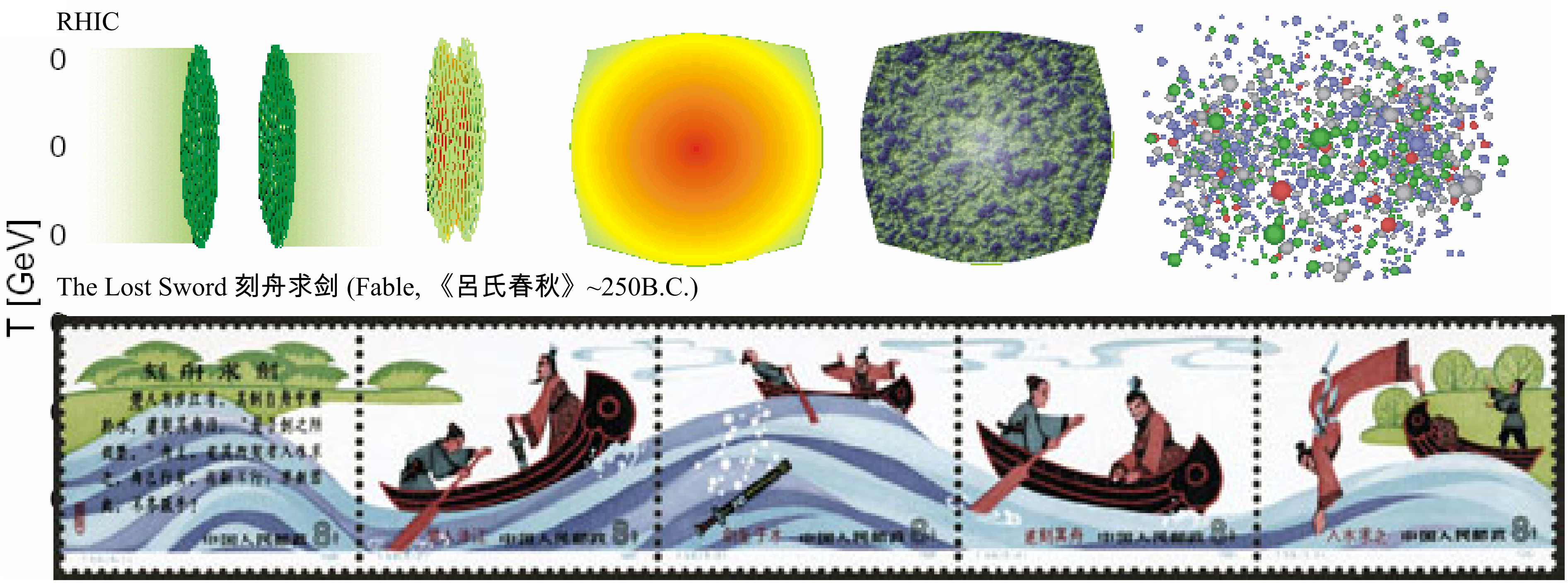
p_T (GeV/c)	Δp_T (GeV/c)	# of Events (p + p)	# of Events 0-10% Au + Au (N_{bin} = 950)	# of Events 0-80% Au + Au (N_{bin} = 290)
1.0	0.5	44×10^6	0.45×10^6	1.75×10^6
2.0	0.5	70×10^6	0.45×10^6	1.75×10^6
3.5	1.0	70×10^6	0.45×10^6	1.75×10^6
5.5	1.0	350×10^6	0.75×10^6	3×10^6
7.5	1.0	1200×10^6	3.5×10^6	11×10^6
10.5	1.5	7500×10^6	9×10^6	30×10^6

Elliptic flow v2 vs pT at 10% error

p_T (GeV/c)	Δp_T (GeV/c)	# of Events q_c does flow	# of Events q_c does not flow
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	105×10^6	175×10^6
5.0	1.0	210×10^6	440×10^6

Jan Kapitan (Prague)
Xin Dong (LBL)
Willie Leight (MIT)

Electromagnatic probes



R. Rapp, hep-ph/0010101

- Vector Meson Properties
- Thermal Dileptons/photons
- Quarkonia

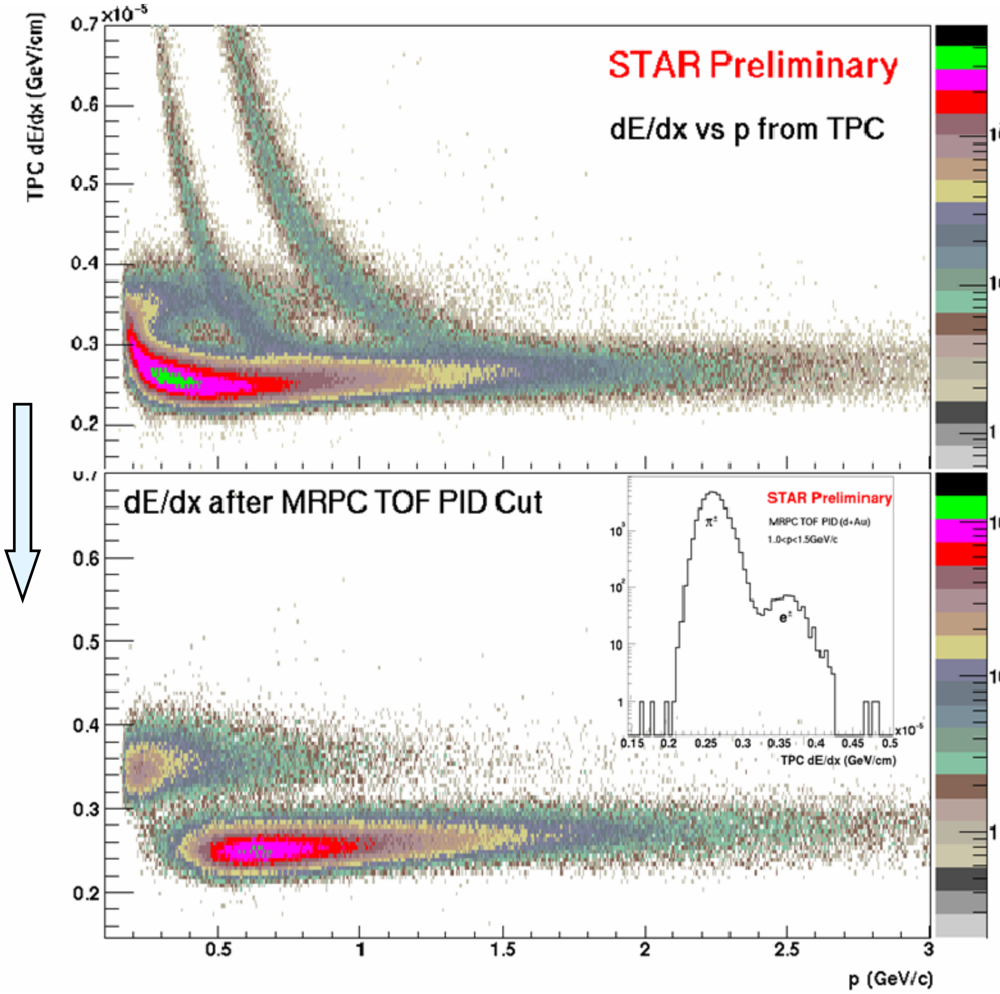
Electron Identification

TPC dE/dx: large hadron background

EMC: p_T>~2.0 GeV/c

A prototype TOF tray (TOFr)

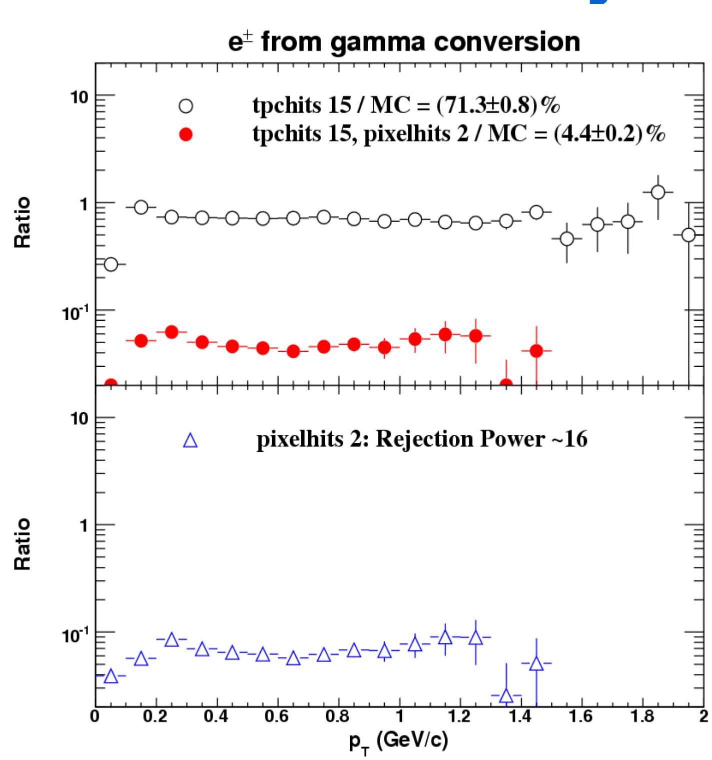
|1/β-1|<0.03

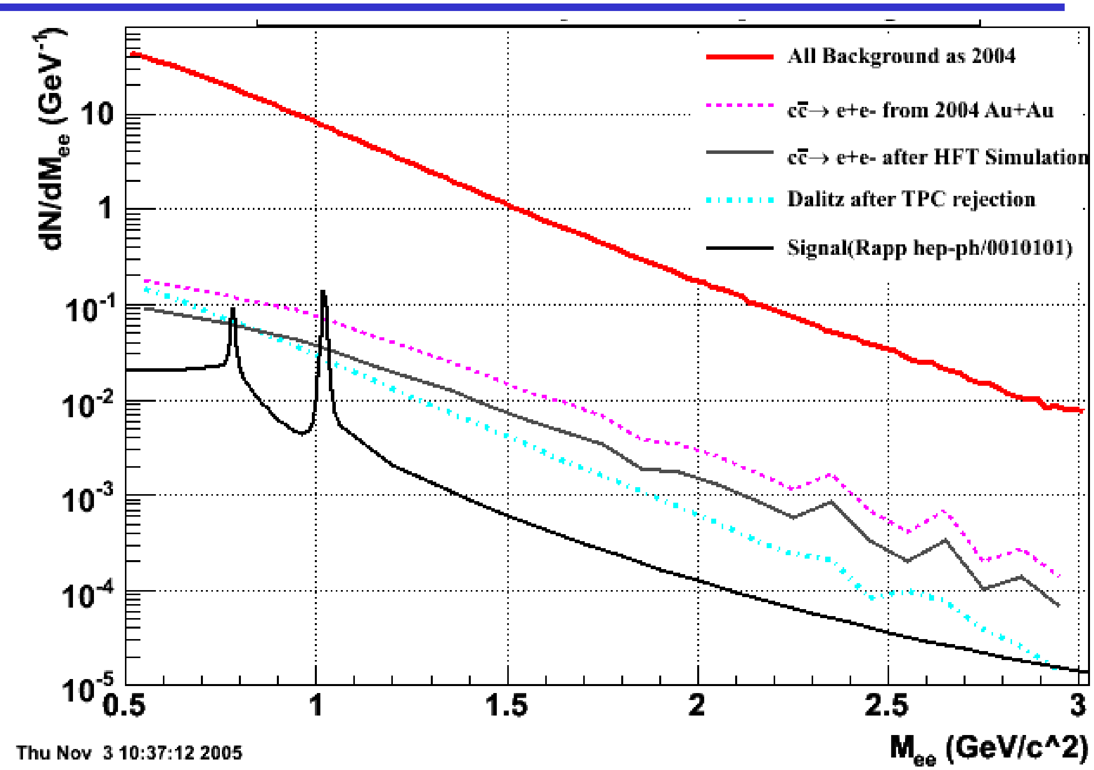


Not able to do without TOF!

Nucl-ex/0505026, M. Shao et al.
X. Dong PHD Thesis (USTC 2005)

HFT rejects gamma conversion

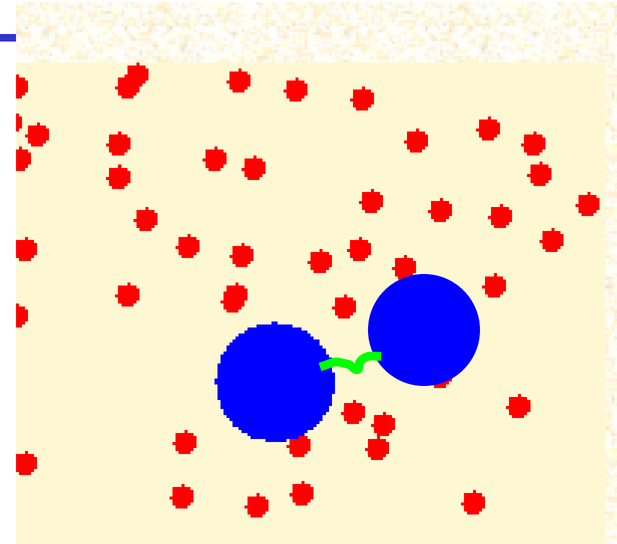




- Background: $\gamma \rightarrow e^+e^-$
- HFT discriminates background
- Need low mass detector
- Statistics comparable to NA60
- Charm background

Detectors	ω	φ
TPC+TOF+HFT	20K	6K

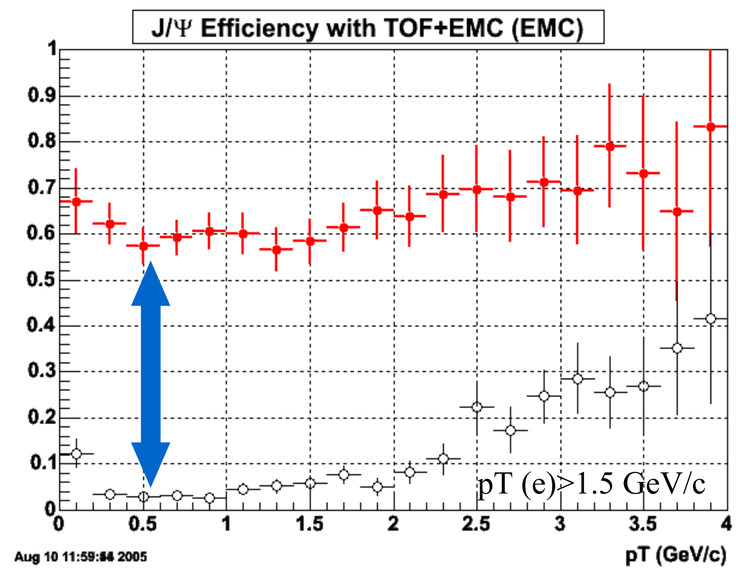
Color Screening of heavy quarks



EMC+TOF+HFT (large acceptance):

- J /Ψ production

- Different states predicted to melt at different T in color medium
- Charmonia(J/Ψ), bottonia (ϒ)



Quarkonium dissociation temperatures – Digal, Karsch, Satz

state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	> 4.0	1.76	1.60	1.19	1.17

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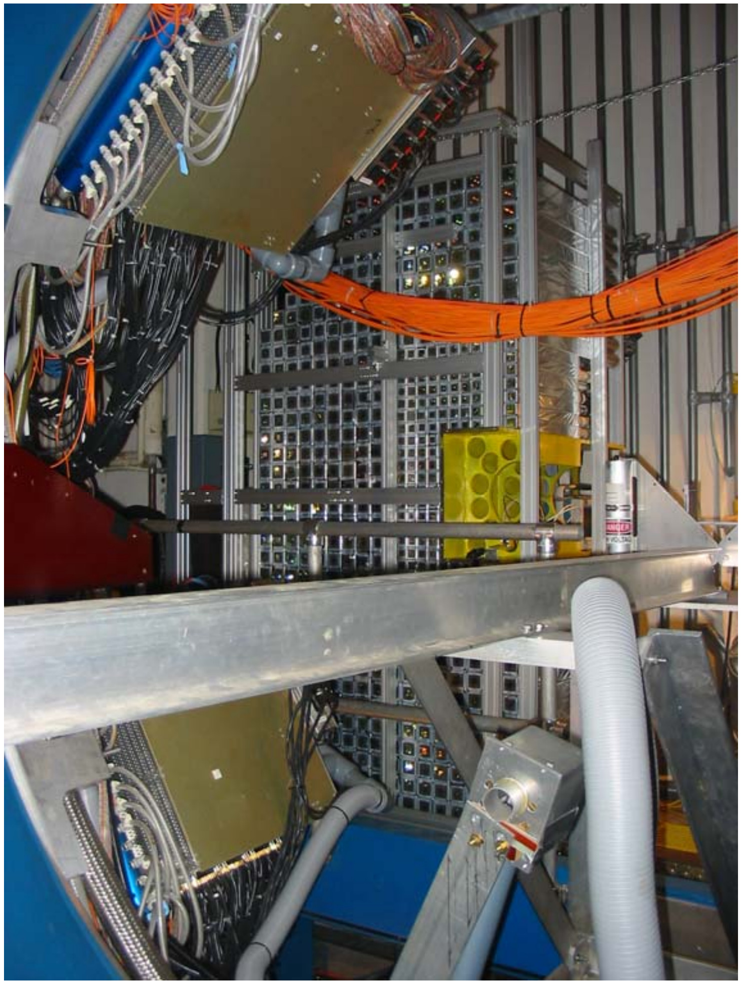
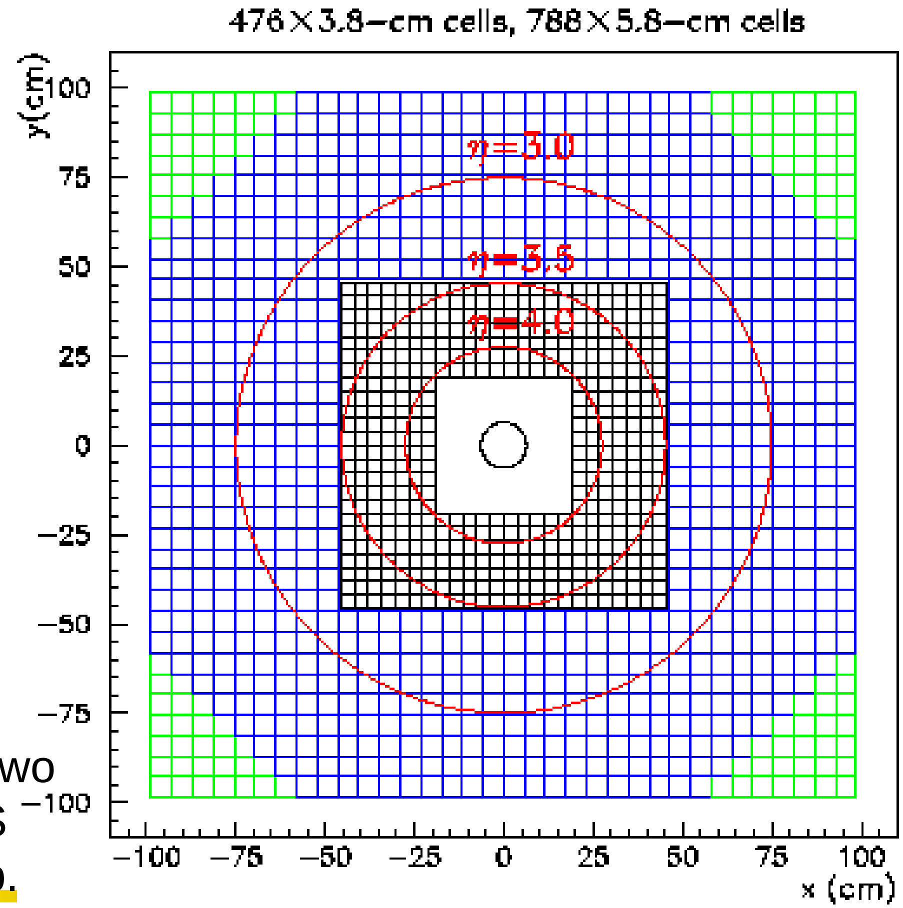
The Forward Meson Spectrometer

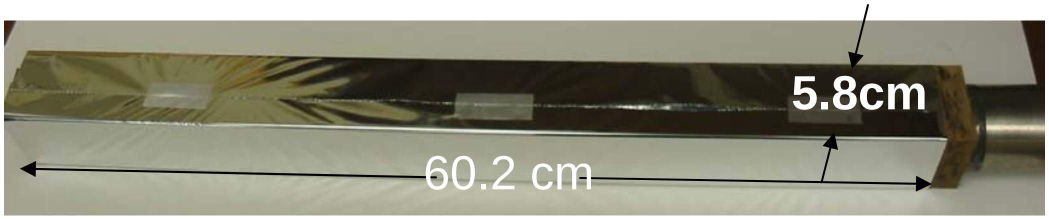


Schematic of the FMS as seen from the interaction point. The small-cell inner calorimeter has 476 detectors and the large cell outer calorimeter has 788 detectors.



Detectors are stacked on the west platform in two movable halves. This view is of the south FMS half, as seen through the retracted west poletip.

Cell details



Large Cells / 788 in total

$(5.8\text{cm})^2$ x 60.2 cm lead glass

18.75 radiation lengths

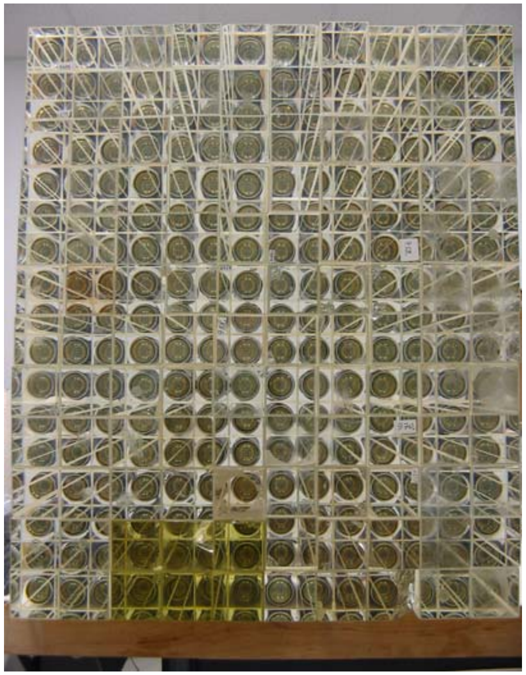
XP2202 photomultiplier

Small Cells / 476 in total

$(3.8\text{cm})^2$ x 45 cm lead glass

18 radiation lengths

FEU84 + XP2972 photomultipliers



170 small cells prior to wrapping

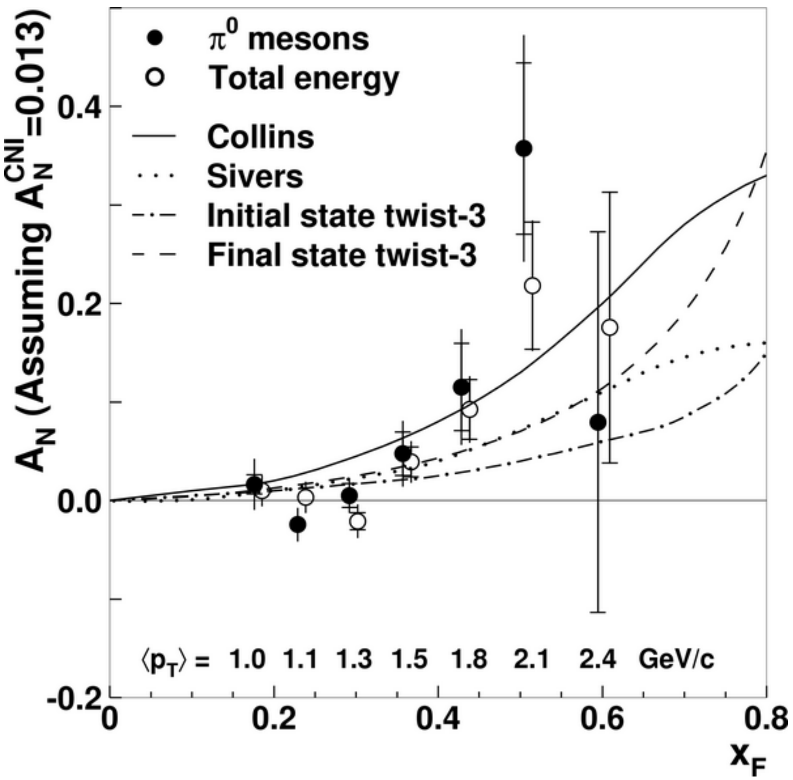
Three Highlighted Objectives and Plans

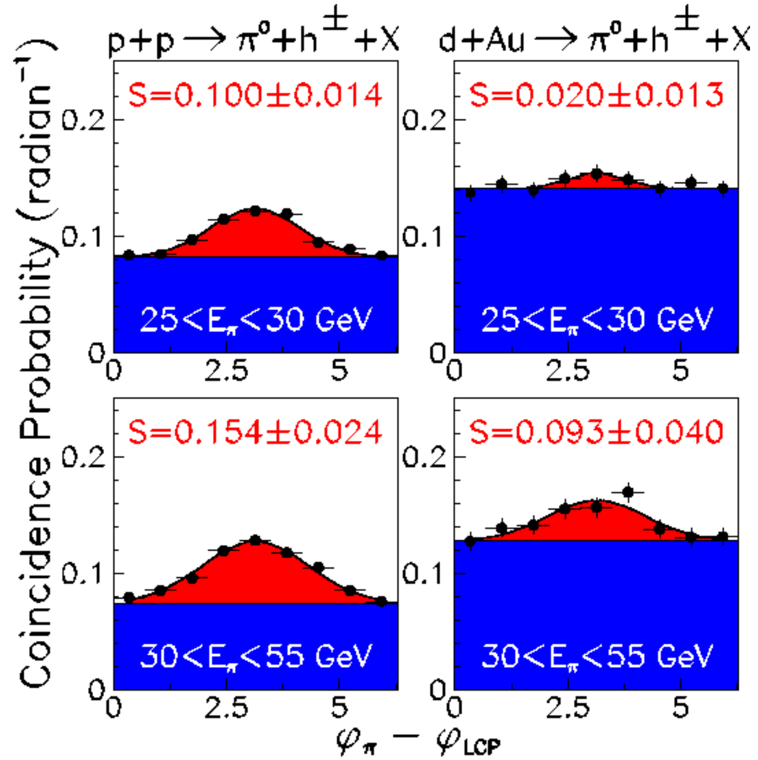
DOE performance Milestone (2012)

- Prototype FPD proposal Dec 2000
  - Approved March 2001
  - Run 2 polarized proton data (published 2004 spin asymmetry and cross section)
- FPD proposal June 2002
  - Review July 2002
  - Run 3 data pp dAu (Preliminary A_n Results)
- FPD++
  - Engineering test of FMS staged for Run 6
- FMS Proposal: Complete Forward EM Coverage in run7 [**hep-ex/0502040**].

1. A **d(p)+Au→$\pi^0\pi^0$+X** measurement of the **parton model gluon density distributions *xg*(*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.
2. 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)**
3. 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)**

Physics publications before the full detector





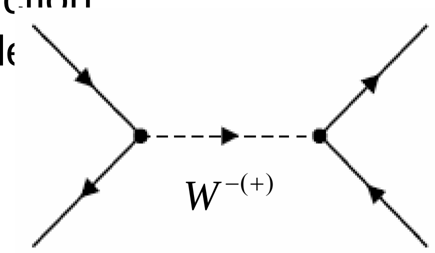
- **Spin:**
  Single spin asymmetry
  Phys. Rev. Lett. **92** (2004) 171801
  Collins/Sivers effects

- **Gluon Saturation:**
  Production and correlation
  in d+Au forward rapidity
  PRL 97 (2006) 152302

Forward Tracking

- Flavor structure of the proton sea can be probed via W± production: flavor separation possible

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

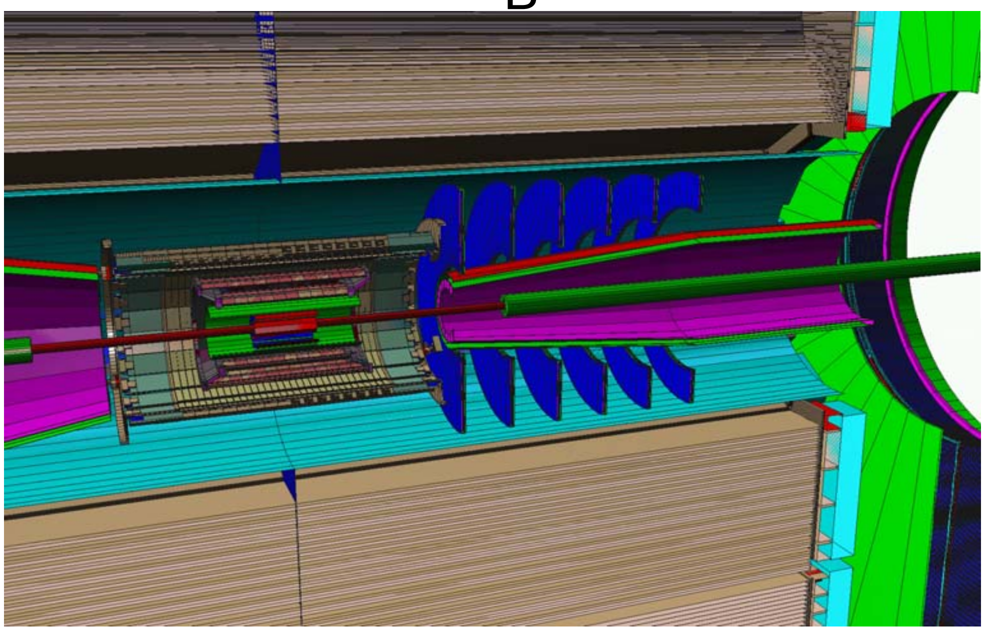


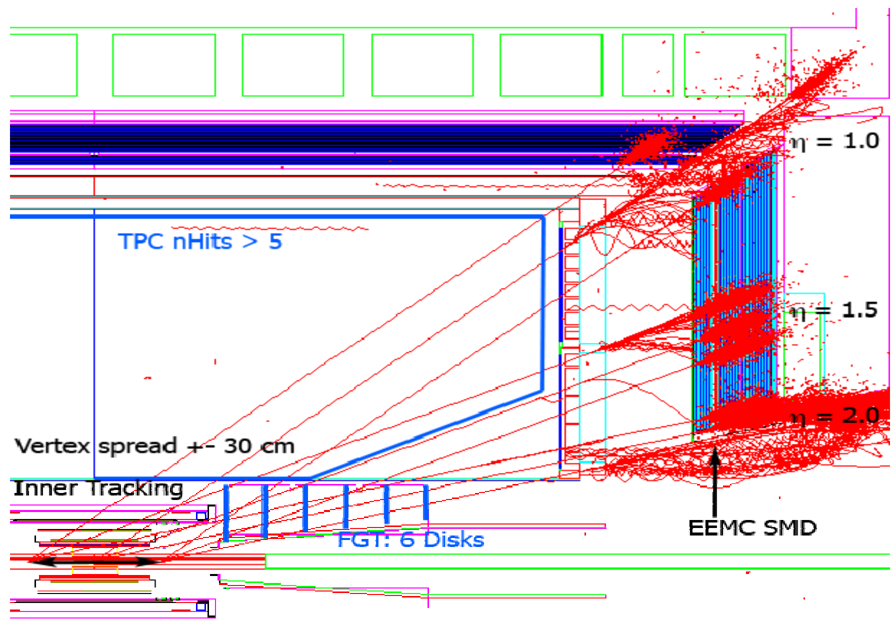
Forward GEM Tracker (FGT)

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

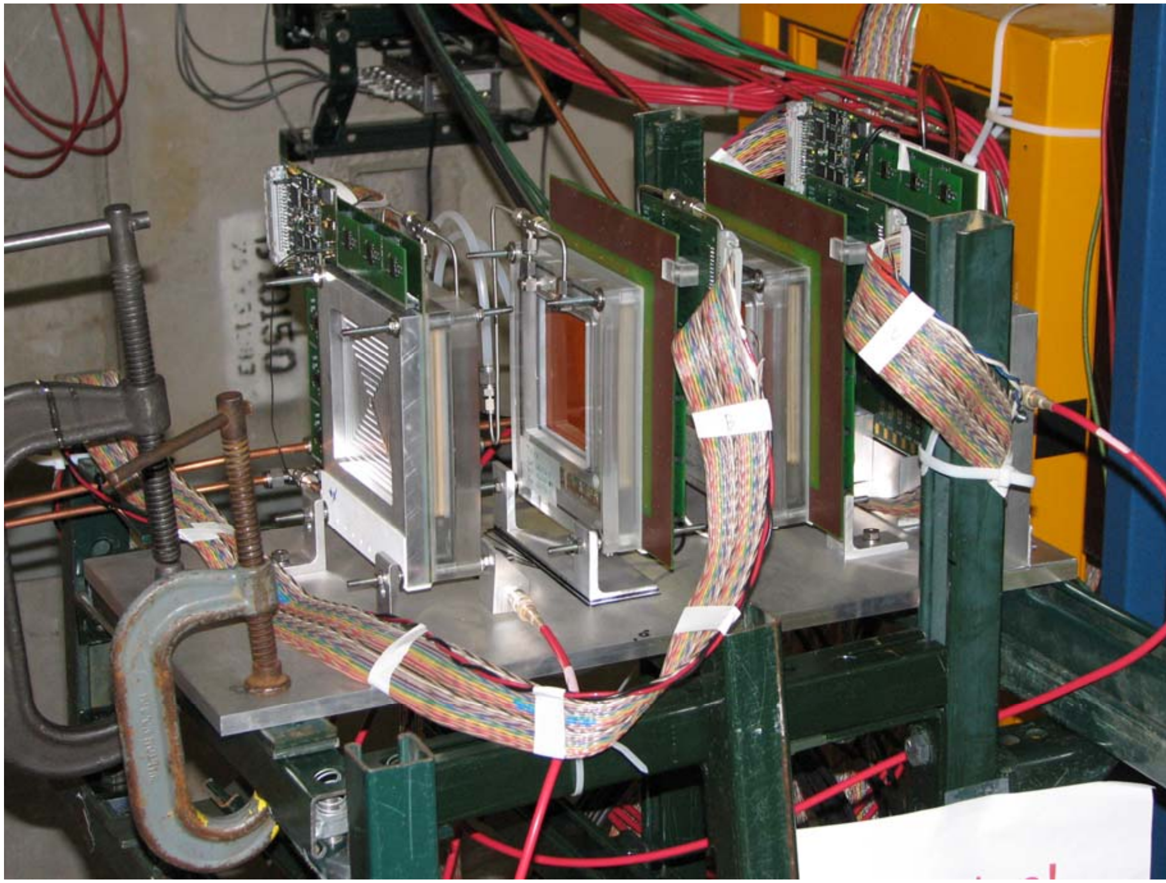
experimental signature: high p_T lepton from W decay

B

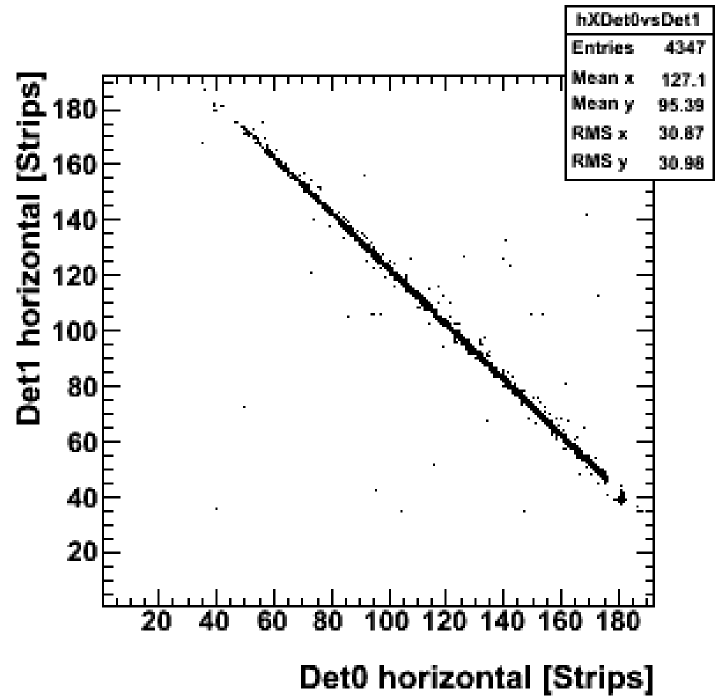




Test beam at FNAL (T963, May 2—15, 2007)



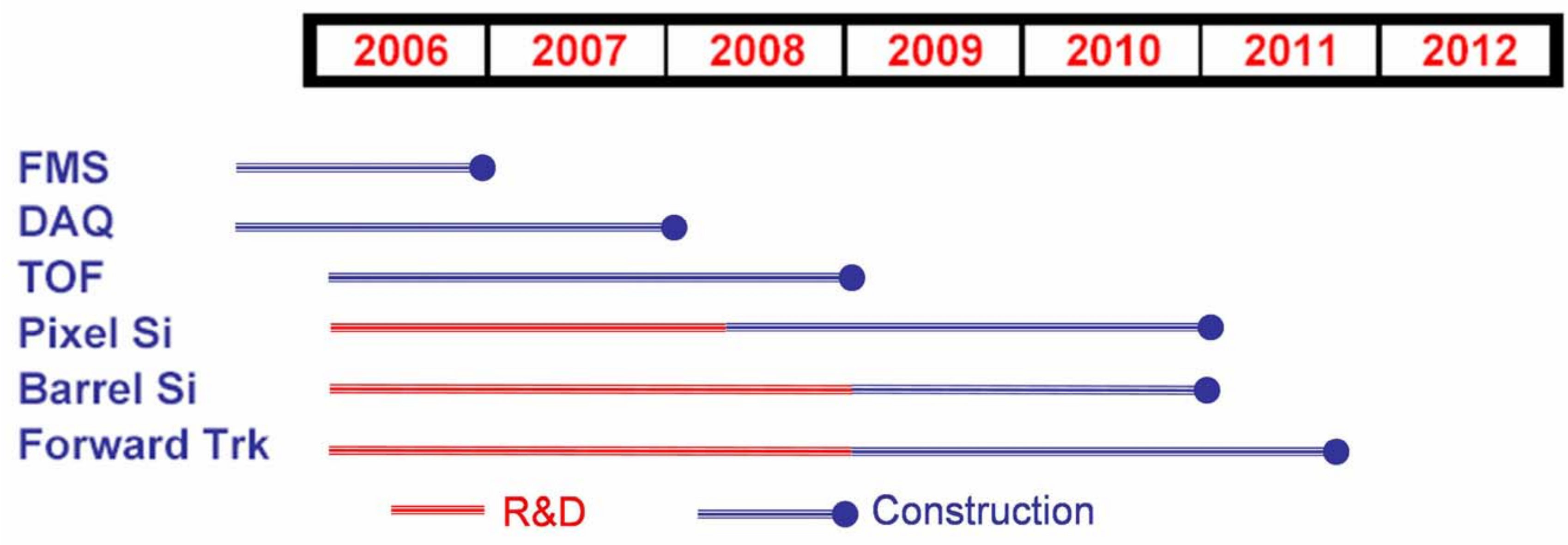
Resolution:
<80µm as expected



Prototype Gas Electron Multiplier
3 layers: 10x10cm^2

120 GeV beam resolution x ~ 51 µm, y ~ 63 µm

32 GeV beam resolution x ~ 66 µm, y ~ 78 µm



Beam Use Request strongly coupled with detector upgrades to optimize the maximum physics output

It is never too early

- $\gamma\gamma$ HBT for direct photons (Yale group)

  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.

- Crystal calorimeter for soft photons (UCLA)

  CsI(Tl) crystals for photons 20MeV<E<1GeV

- Moun Telescope Detector (BNL)
- Roman Pot (move pp2pp to STAR)

Novel & Compact Muon Detector for QCDLab

- **Novel and Compact -------- Convention**
  Timing, Position ↔ Track Segments+FastHits

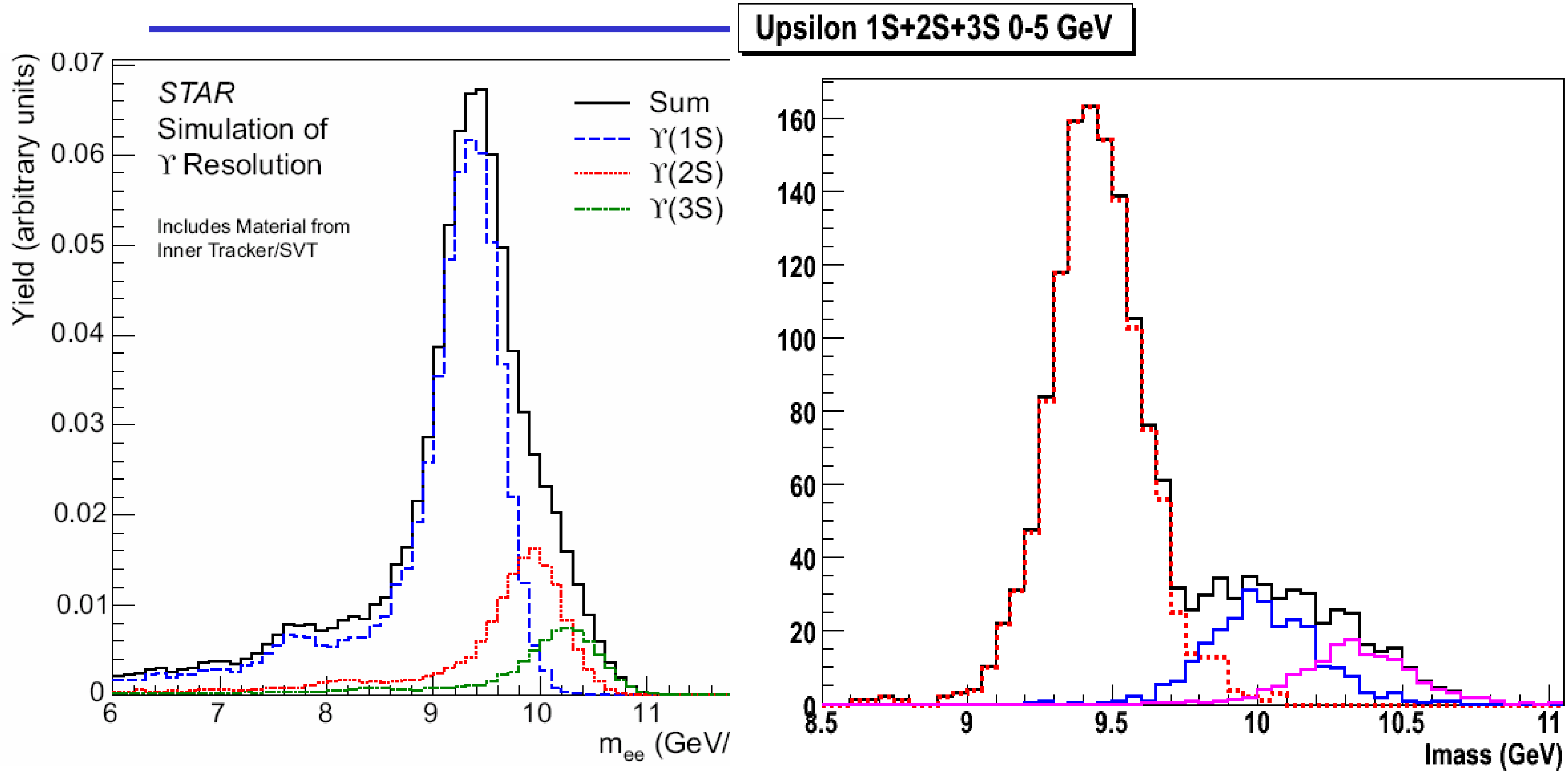
- **Muon** is penetrating probe
  J/ψ trigger, separate $\Upsilon \rightarrow \mu^+\mu^-$ states

- **QCDLab (RHIC II, eRHIC)**

- Works with Accelerator **High Luminosity** upgrades

A BNL 2007 LDRD project

Separate Upsilon States



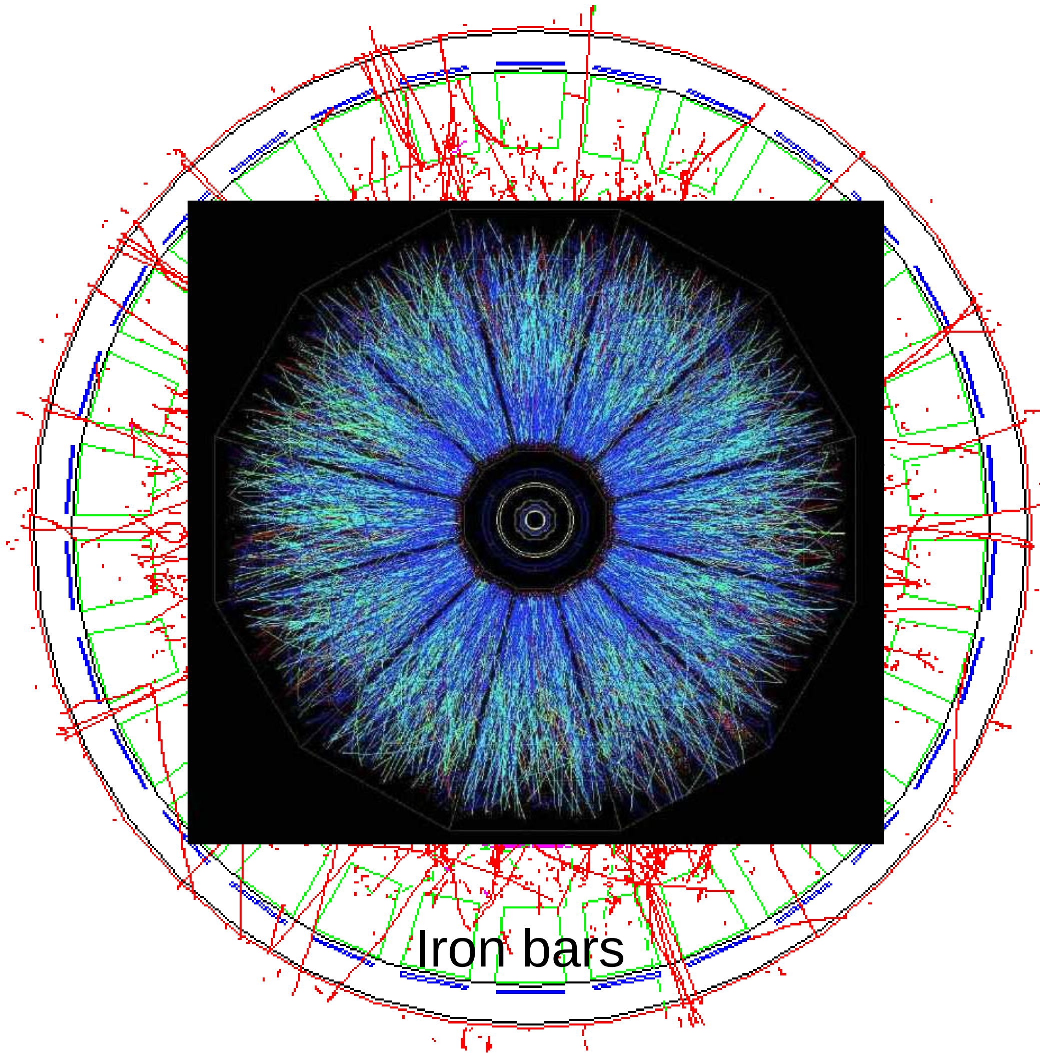
ϒ→e+e-

Electron Bremsstraglung Radiation

ϒ→μ+μ-

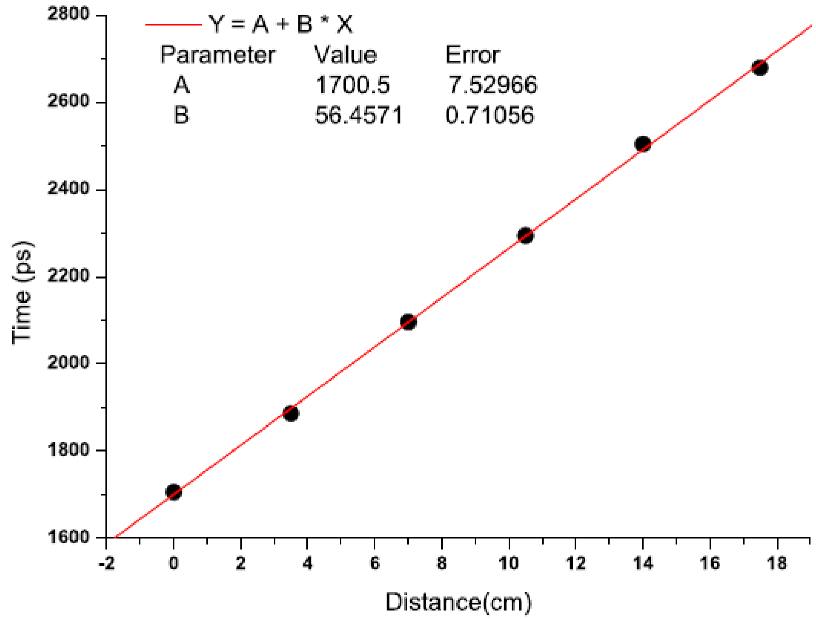
muon better mass resolution

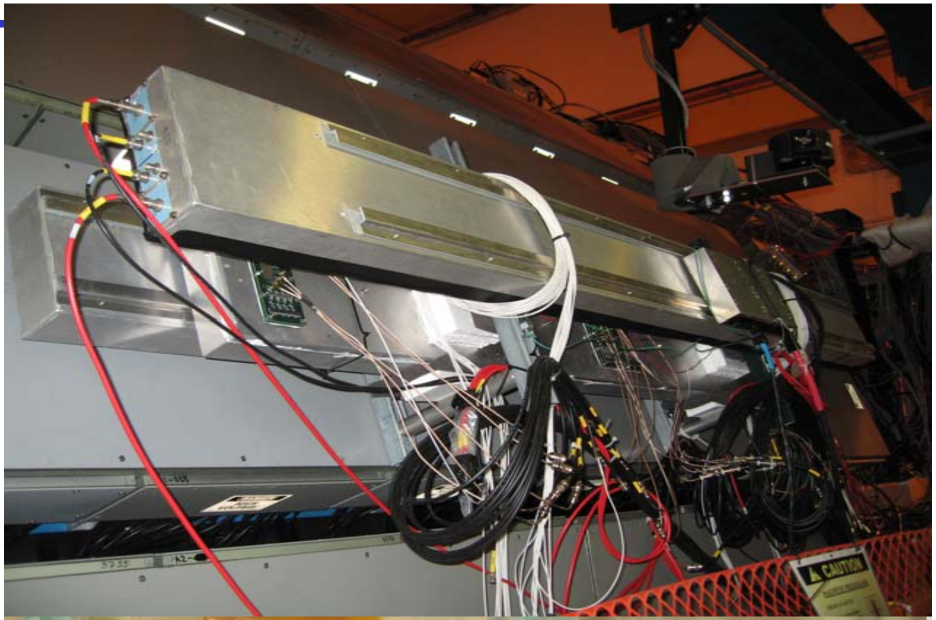
Hadron Rejection and Muon Trigger at STAR

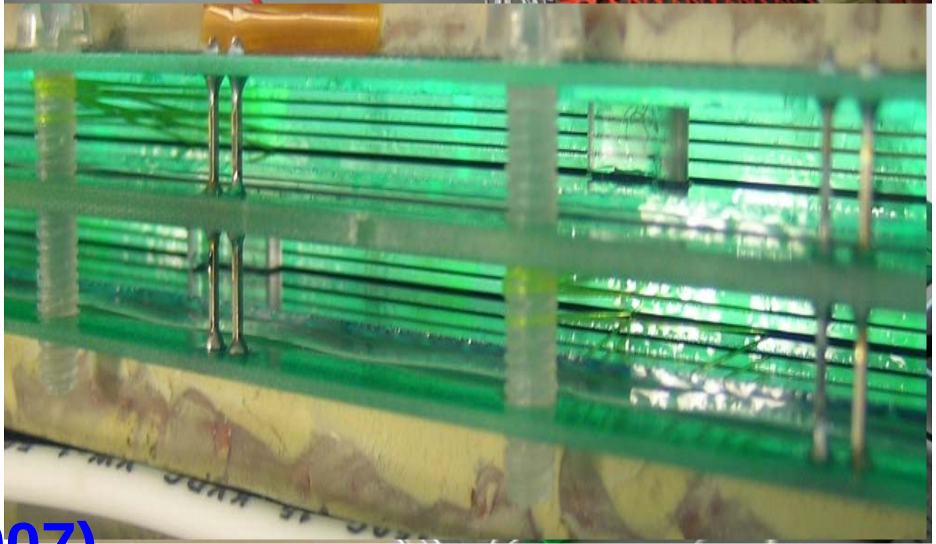


- Muon penetrates iron bars
  Other particles are stopped
- Good Time Resolution (60ps) rejects background (>100)
- 1 hit per 5 head-on Au+Au
  Dimuon trigger (>25)
- Large coverage:
  diameter of 7 meters

A prototype in the making







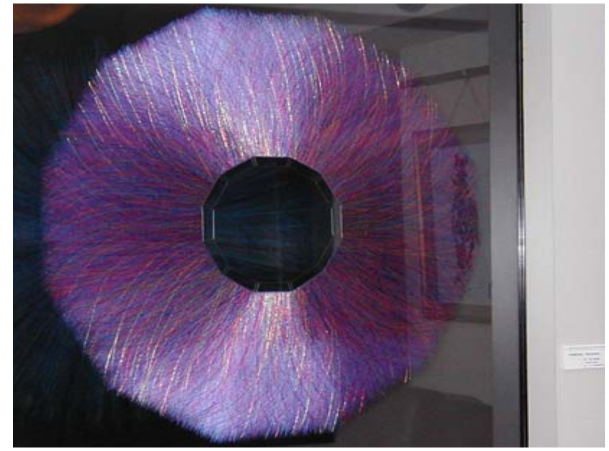
Resolution: ~60ps (6x10^{-11}second)
Signal propagation velocity: ~60ps/cm
Spatial resolution: ~1cm
20x larger than the TOF modules

Install in RUN 7 (March-June, 2007)

Conclusions (a colorful journey)

- Strongly Interacting Liquid

- Continue to explore its:
  - Flavor, **color**, sound, temperature
  - Viscosity, in-medium mass, critical point, correlation length
  - Multi-discipline: string, condensed matter, DIS, atomic, astrophysics



- Detector and accelerator upgrades necessary (RHIC II)

The Holy Grail is not in the finding. It is in the journey!
Saul Zaentz, 1997

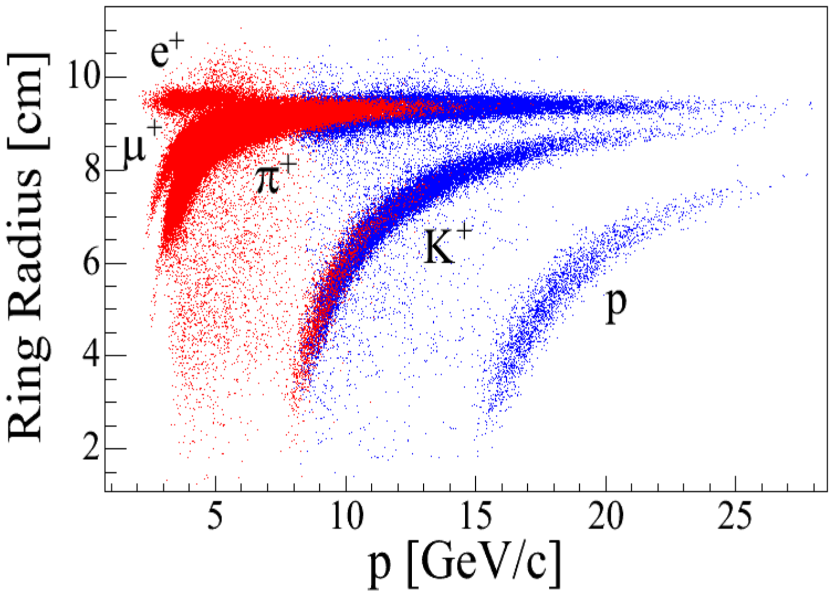
Backup Slides

"Concerns"

- Can we analyze all the data from DAQ1000 effectively?
- Can we understand the distortion at high luminosity and keep the momentum resolution?
- Do we understand our rdE/dx (TPC) at high momentum?
- Can we improve our vertex position detector efficiency?
- Can we improve our reaction plane?

“Small” upgrades

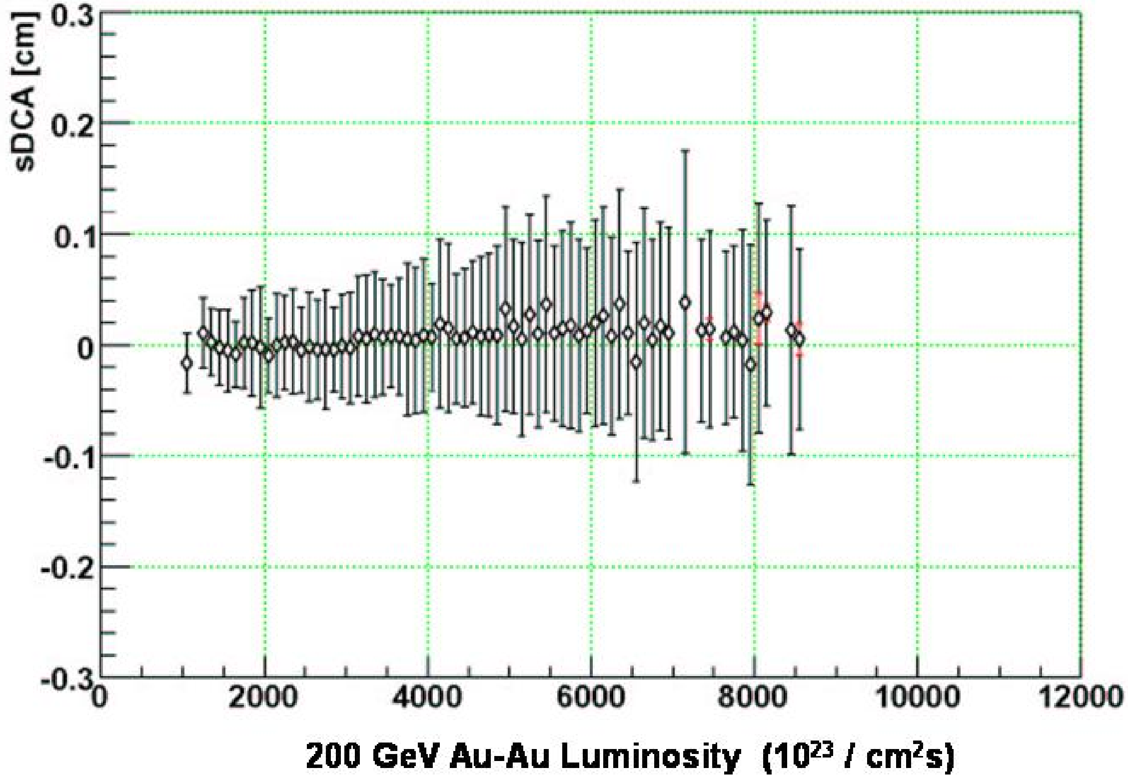
- L3 tracking (revised):
  - High momentum track
  - Dilepton PID and Mass Selection
  - Rare decay topology (D0, Ω)
- Hadron PID (Cherenkov)
  - BRAHMS PID range
  - Small acceptance
  - Calibrate rdE/dx
  - Leading particle physics



“Small” upgrades

- **GEM trays (replace 2 TOF trays)**
  - Fixed point at outer radius
  - Calibrate space-charge and other distortion
  - Tracking calibration for high-momentum particles
- **Vertex-Beam-ReactionPlane Detector (VBRP)**
  - BBC, upVPD, and future Reaction Plane Detector
  - Combine 3 in 1
  - High-rate MRPC (~100KHZ/cm2, CBM R&D)
- **GEM for ZDC SMD and forward charged spectators**

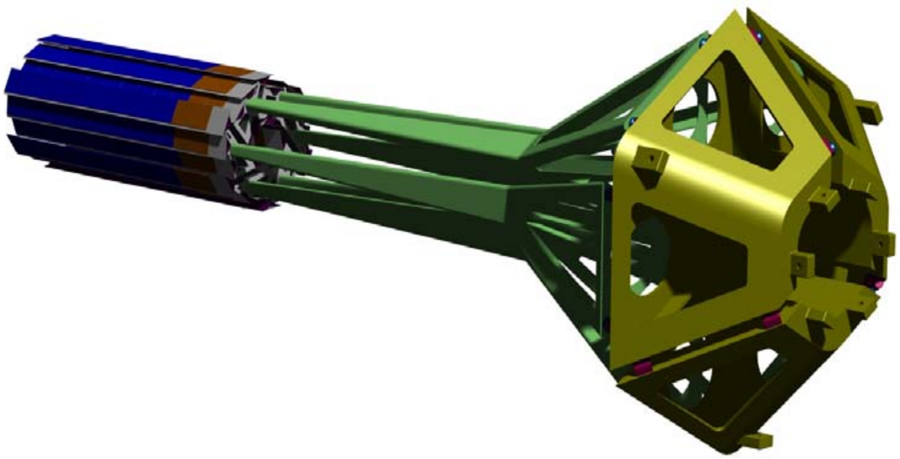
Can TPC survive RHIC II Luminosity



FY09: peak luminosity $30x10^{26}$
We will know!
Inner Trackers: HFT+IST

HFT parameters

Number of pixels	98,304,000
Pixel dimension	30 μm × 30 μm
Detector Chip active area	19.2 mm × 19.2 mm
Detector Chip pixel array	640 × 640
Number of ladders	24
Ladder active area	192 mm × 19.2 mm
Number of barrels	2
Inner barrel (6 ladders)	r = 1.5 cm
Outer barrel (18 ladders)	r = 5.0 cm
Frame read time	4 ms
Pixel read rate, after zero suppression	63 MHz
Ladder (w/Al cable) % X_0	0.28% (0.38%)
Beam Pipe Thickness	0.5 mm or 0.14% X_0



HFT schedule

7 Preliminary Cost and Schedule Estimates

7.1 Cost and Schedule

The HFT is a very demanding technical project and it requires a substantial amount of R&D in order to ensure that it will be ready to take data when RHIC is running. The enclosed cost and schedule estimates reflects the need to develop and test the pixel sensors over a period of several years. We envision at least four generations of chips before we have a full sized, production quality, chip design. The cost and schedule also reflects the need for replacement parts so that the detector can be easily repaired during a run.

Synchronizing with the RHIC run schedule is beyond the scope of this document, but it is an important topic none-the-less because a successful HFT program requires several years of running, including (as a minimal set) a high statistics top energy Au-Au run, a p-p run, and a d-Au run. Since the RHIC schedule is hard to predict, it is very important that the HFT be ready on time, and be reliable during each run. The number of opportunities to run top energy Au-Au beams are very limited. Therefore, we have designed the HFT to be easily repaired during a run and even replaced, if necessary.

A schematic overview of the proposed R&D and construction schedule is shown in Figure 64 with particular emphasis on the installation dates. Note, for example, that the figure includes a milestone for the installation of a detector telescope based on MimoSTAR II chips in the summer of '06. The detector telescope will take data in FY07 with the goal of testing the APS chip technology under working conditions at the STAR experiment. Additional installation activities are shown in each year. A more detailed roll-up of the projects activities is shown in Figure 65.

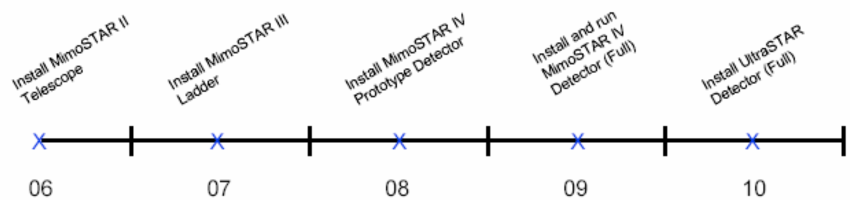
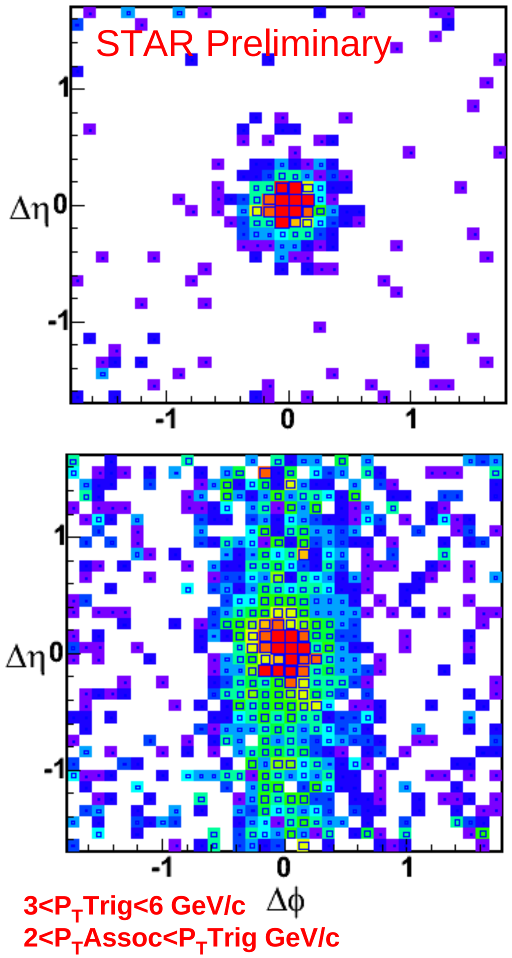


Figure 64: A Schematic view of the installation activities in each year. Installation is typically done in the summer of each year.

Correlation & Fluctuation

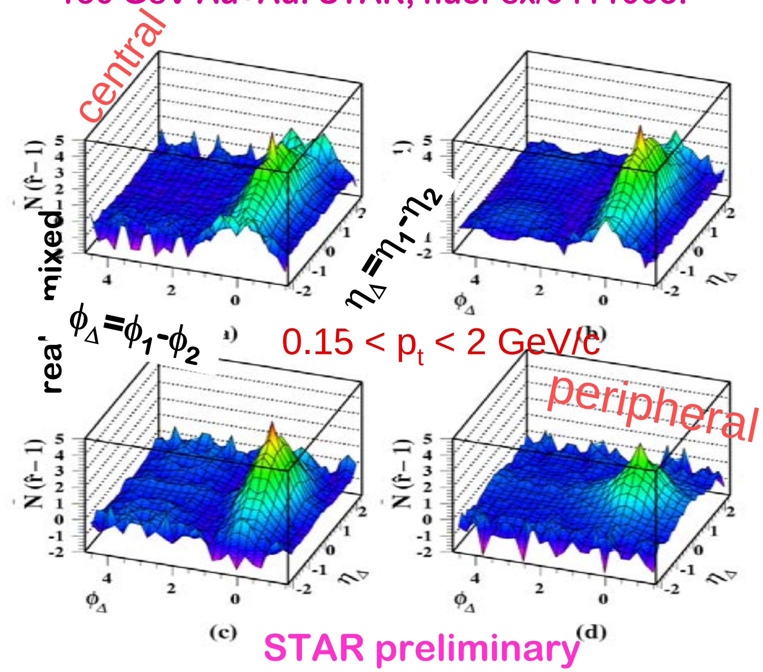
dAu

AuAu



decrease p_T

130 GeV Au+Au: STAR, nucl-ex/0411003.



- Jet modified by medium
- Strong coupling to medium
- Strong correlations among bulk particles
- **Depends on particle type, velocity, momentum?**

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

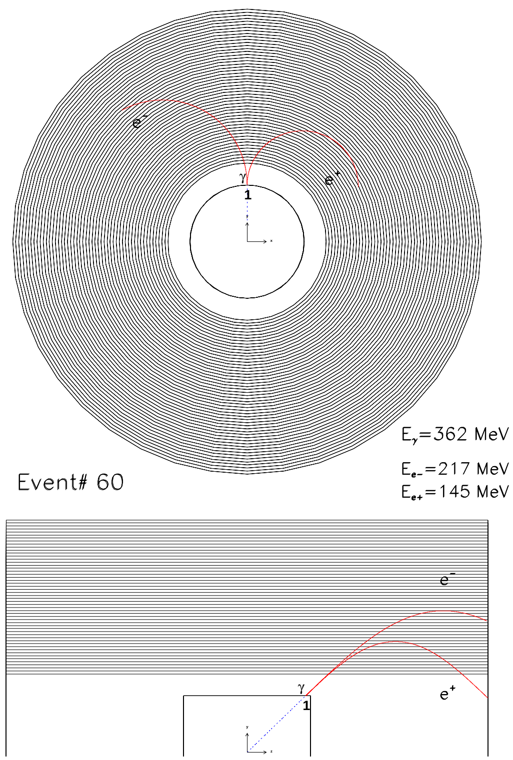
Yale University

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.



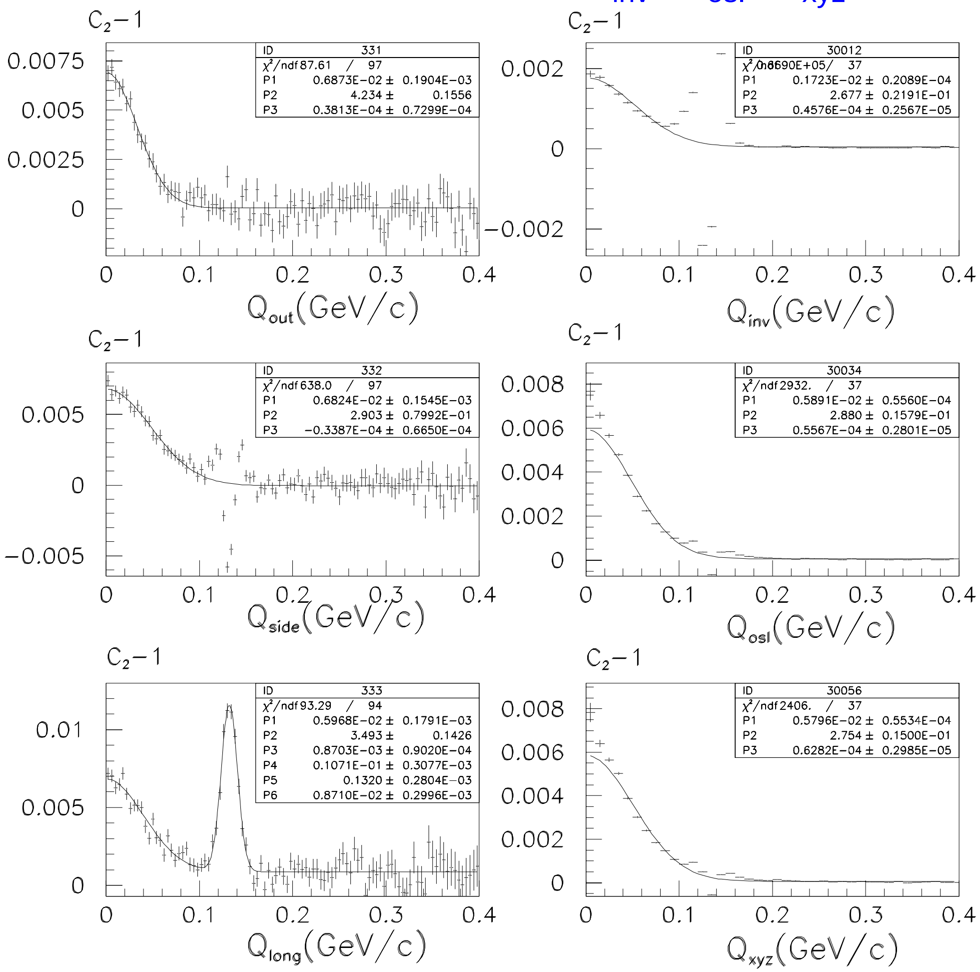
Results from 'Complete' Simulation

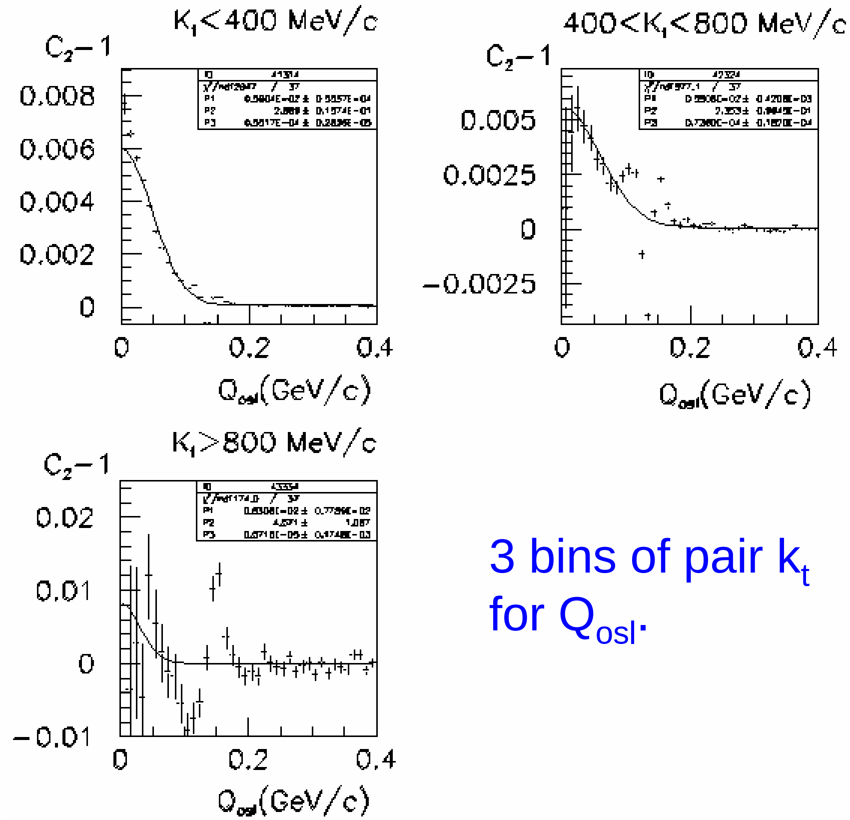
Q_{out}, Q_{side}, Q_{long}

3d−slices (±10 MeV/c)

1-D observables:

Q_{inv}, Q_{osl}, Q_{xyz}.

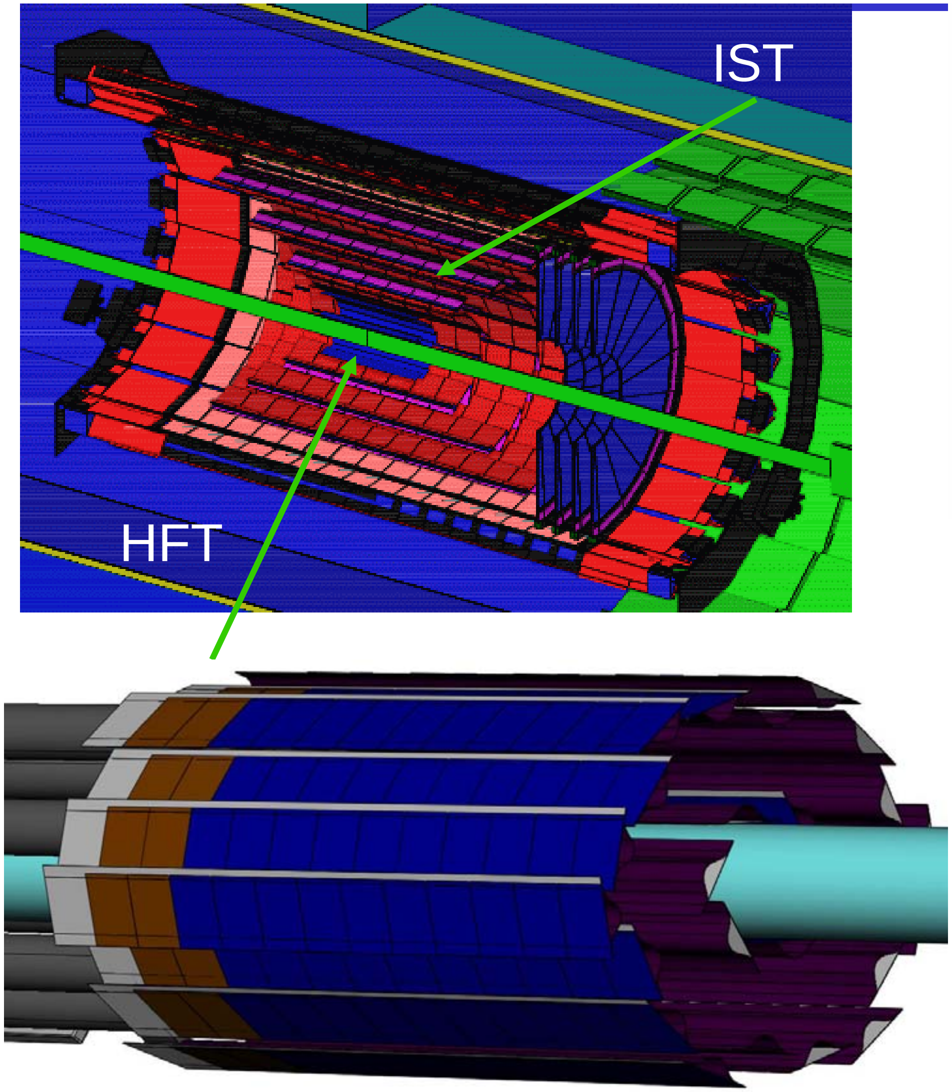


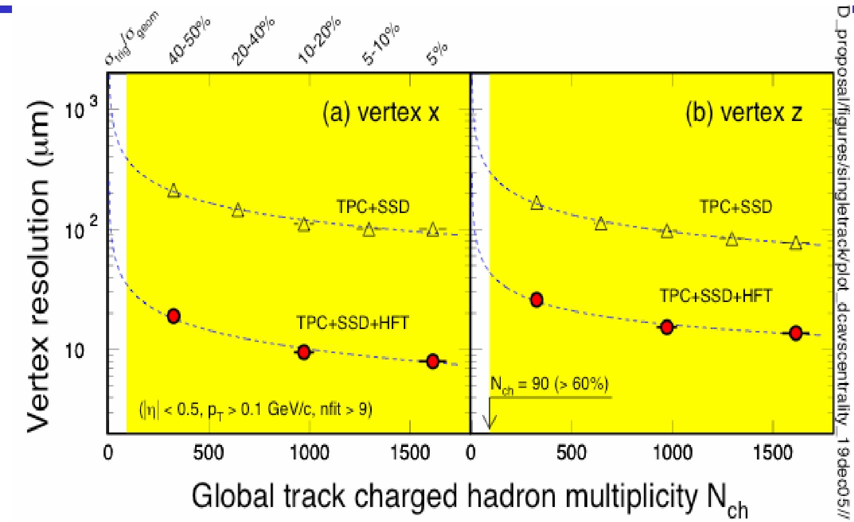


3 bins of pair k_t for Q_{osl}.

80M equivalent central STAR events.

HFT needs Intermediate Tracker





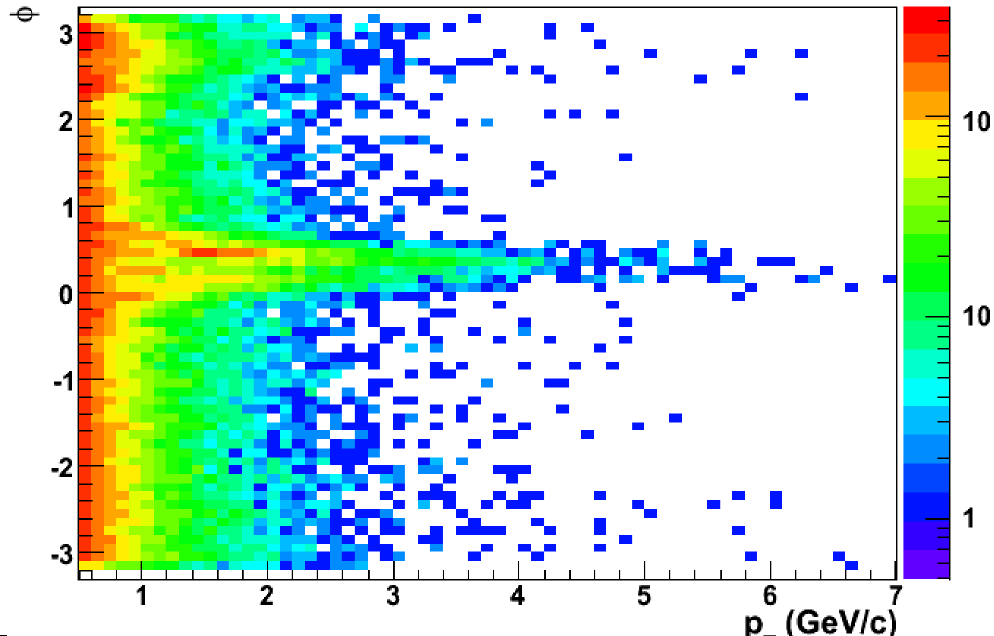
- Associate HFT hits to track with vertex constraints
  break down at 60-100% Au+Au, p+p
- HFT:
  Good spatial resolution,
  Slow readout
- IST:
  between TPC+SSD and HFT
  Fast readout, low occupancy

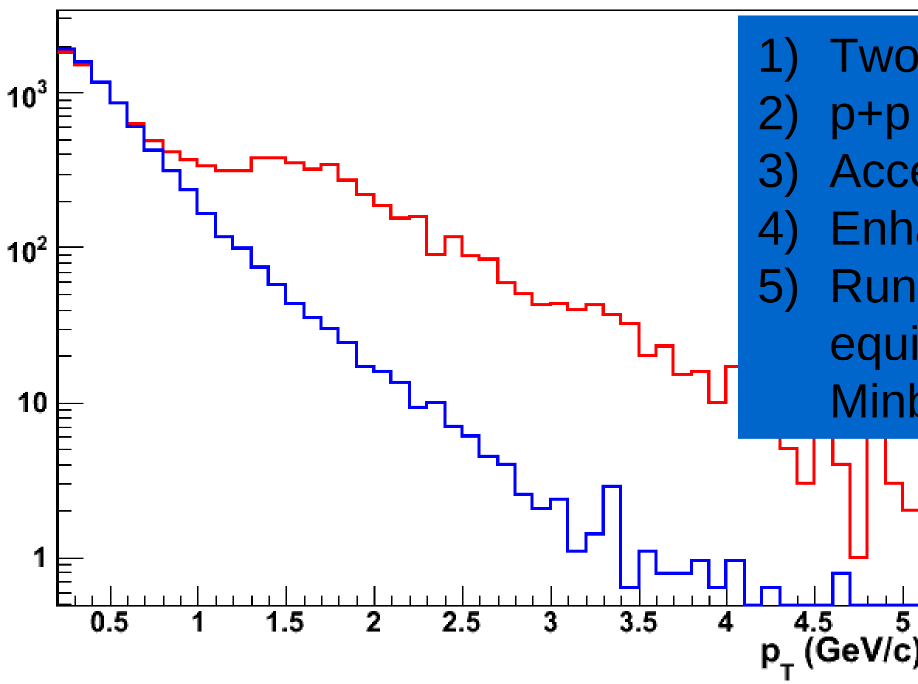
a Novel and Compact Muon Detector for QCDLab

- Novel and Compact:
  Timing, Position ↔ Track Segments+FastHits
  One Layer/Detector ↔ Many Detector Systems
  MRPC ↔ RPC+MWPC
- Muon:
  Dimuon continuum, J/Ψ, DY, ϕ, e-μ correlation
- QCDLab:
  Momentum: few GeV/c ↔ 10—1000 GeV/c
  Background tracks: 1000 ↔ 10
- One-Layer charged hadron trigger
- R&D:
  Simulation, MRPC Detector, Online Trigger, Background

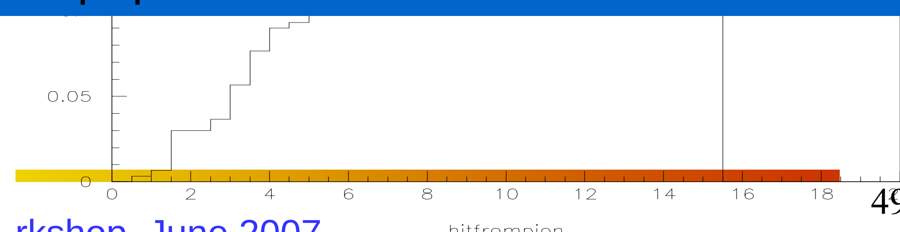
Hadron Rejection Benchmark:
Usual Muon Detectors: 100 – 200

Test Scintillator Trays

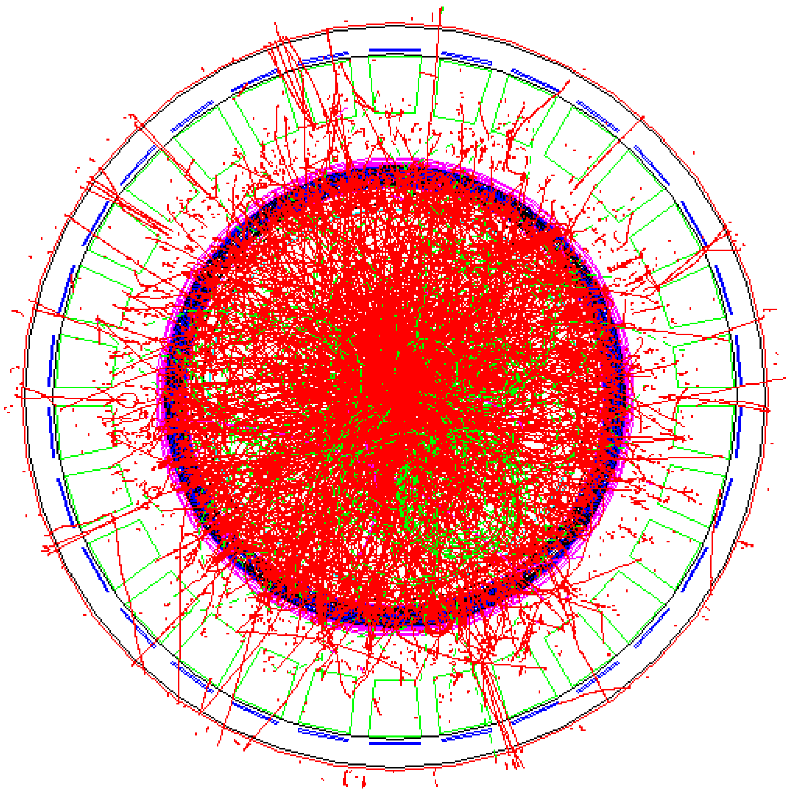


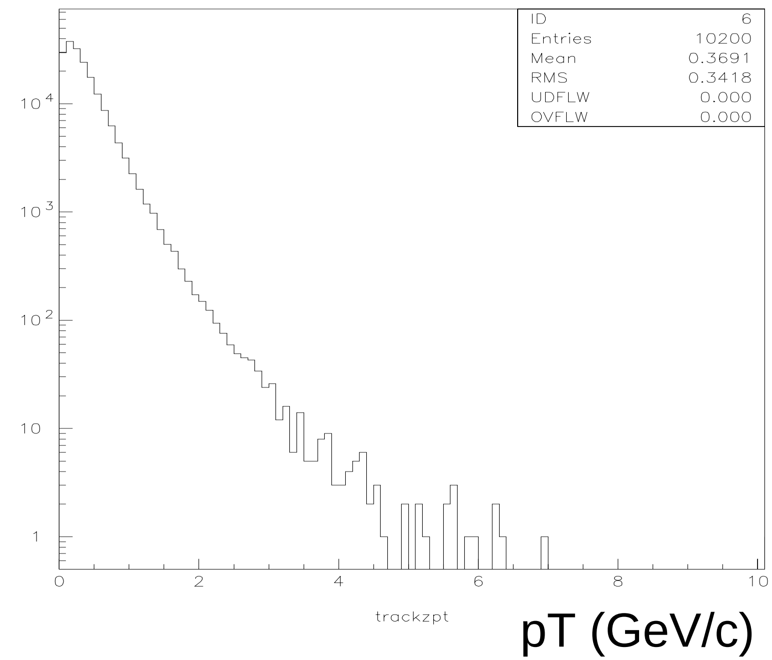


1) Two spare scintillator trays outside the magnet
2) p+p trigger rate: 1 per 100K events
3) Acceptancexeff: 1/200*0.2 = 1/1000
4) Enhancement for leading **charged hadron**: 100
5) Run6 p+p 2.5M events
   equivalent to 250M p+p TPC events
   Minbias p+p events in STAR so far: ~10M



Hadron Rejection and Trigger at RHIC



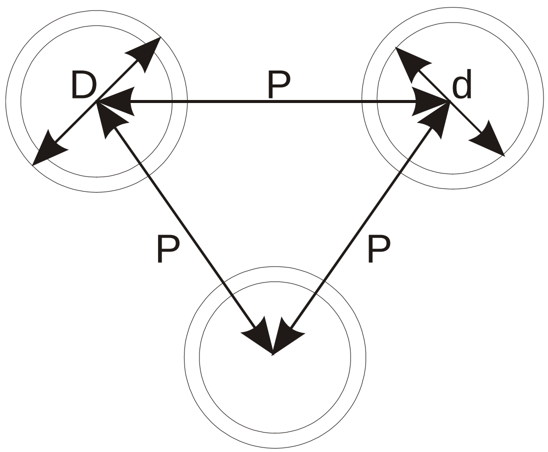


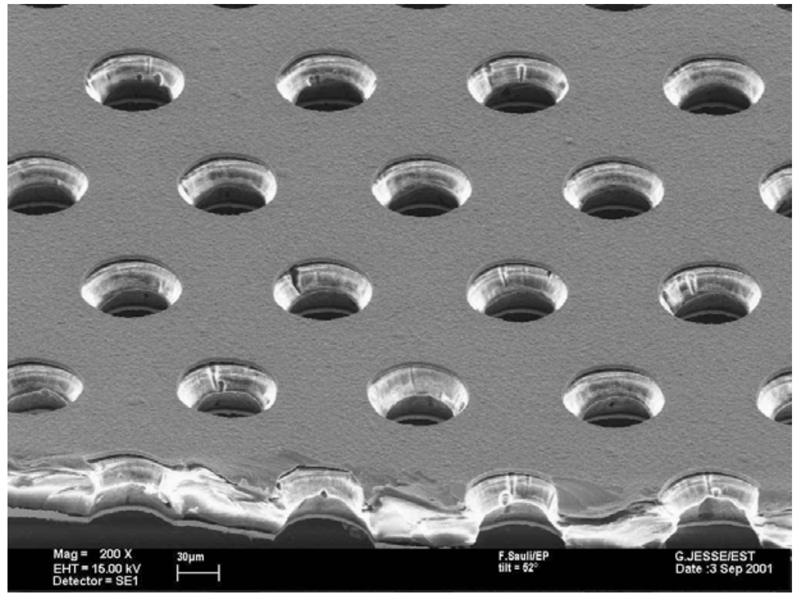
100 HIJING central events:
18 Events with >=2 hits (dt<20ns)
2 Events with >=2 hits (-400ps<dt<100ps)
3 out of 840 tracks matched (pT>2 GeV/c)

TPC rdE/dx+TOF reject >3 hadrons

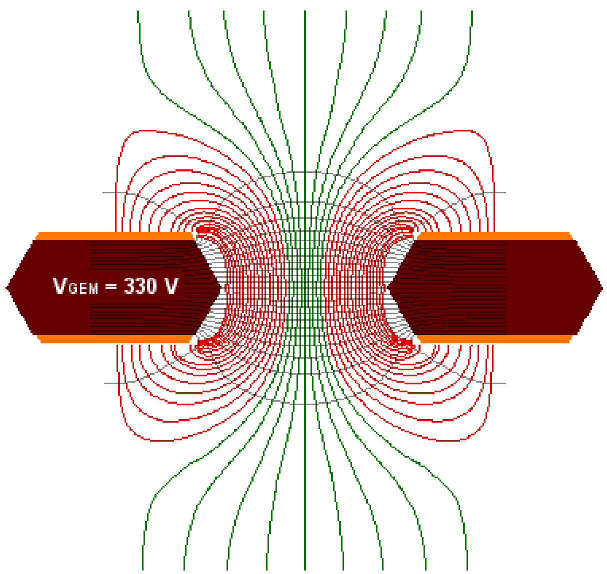
Cuts	Nhit/event
No cut	70
TOF	1.6
Eloss	7.6
TOF&Eloss	0.72
TOF (-400ps,100ps)	0.23

GEM: Gas Electron Multiplier





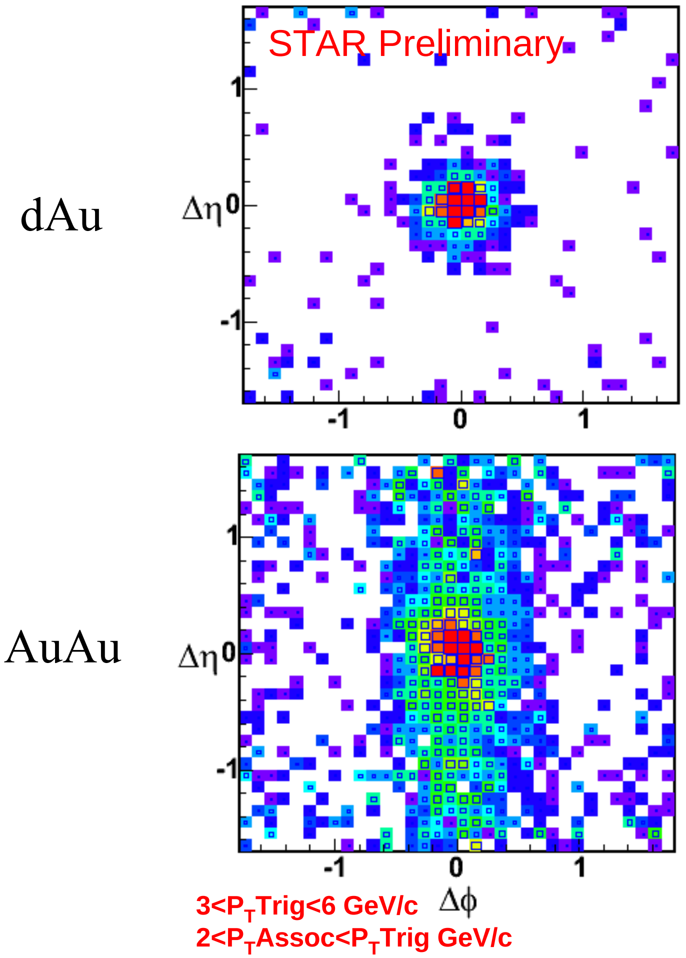
F.Sauli, 1997



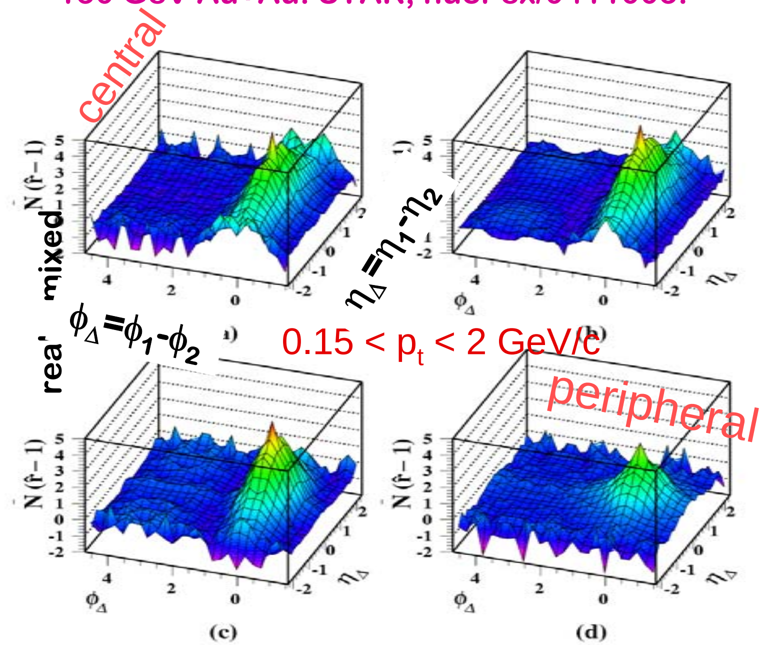
Metal-clad insulator foil with regular hole pattern

- Hole Pitch 140 µm
- Outer diameter ~70 µm, Inner diameter ~60 µm

Correlation & Fluctuation



130 GeV Au+Au: STAR, nucl-ex/0411003.



decrease p_T

- **Jet modified by medium**
- **Strong coupling to medium**
- **Strong correlations among bulk particles**
- **Depends on particle type, velocity, momentum?**

Publications from STAR MRPC TOF Prototype

- Charm Cross section and spectra in p+p, d+Au;
  Published **Phys. Rev. Lett. 94 (2005) 062301**
- Color-factor dependence of energy loss
  Published **Phys. Rev. Lett. 97 (2006) 152301; nucl-ex/0703040**
- Charm flow and Energy loss in Au+Au
  SQM06, QM04, QM05, QM06 talks, 2 PHD theses
- PID Cronin Effect in d+Au,
  published in **Phys. Lett. B 616 (2005) 8;637(2006)161**
- π K p spectra for bulk/coalescence study in Au+Au and Cu+Cu
  SQM04, QM05, QM06 talks, two PHD theses
- 8 **NIMA** publications:
  Nucl.Instrum.Meth.A538:243-248,2005
  Nucl.Instrum.Meth.A533:60-64,2004
  Nucl.Instrum.Meth.A492:344-350,2002
  Nucl.Instrum.Meth.A508:181-184,2003
  Nucl.Instrum.Meth.A478:176-179,2002
  Nucl.Instrum.Meth.A538:425-430,2005
  Nucl.Instrum.Meth.A537:698-702,2005
  Nucl.Instrum.Meth.A558:419-429,2006
  1 PHD Thesis
- More to come from prototype TOFr
- **Imagine what we can accomplish with Full TOF**