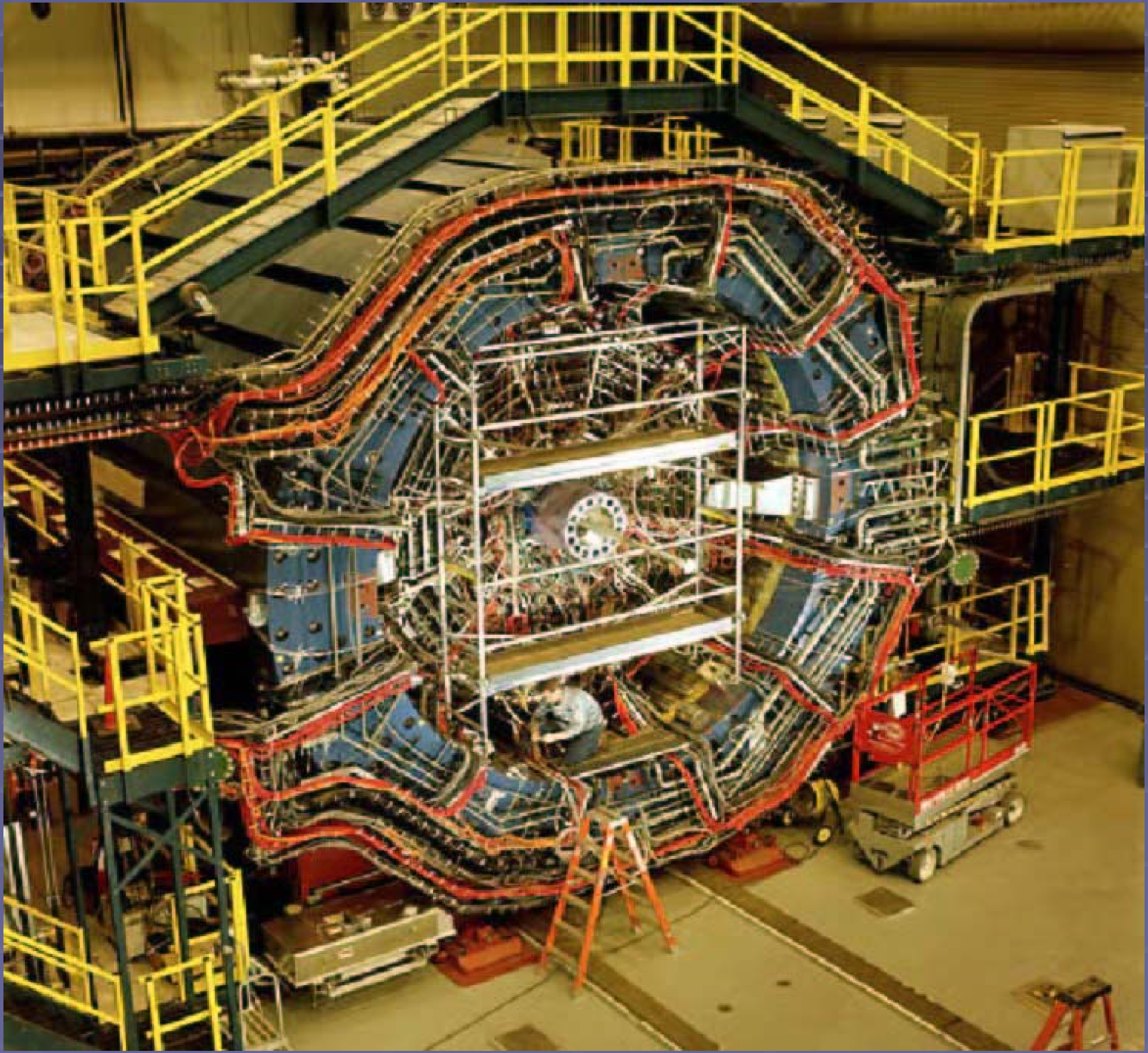
STAR Upgrade Plans



MIT Tracking Upgrade Meeting, November 7, 2003 *Richard Majka*

STAR

Outline:

I. Broad Physics Questions

II. Types of Measurements

III. Detector Requirements

IV. Baseline STAR Detector

V. Ongoing Improvements/Upgrades

VI. Sample of a Few Specific Measurements

VII. Details of Upgrades

VIII. Summary

Physics Questions

✓ Gyulassy
Pratt …

1. **Is partonic matter dominant in the early stages of A+A collisions?**

2. **What are the gross properties of the partonic matter?**
   - *Is it equilibrated?*
   - *Does it behave collectively?*
   - *What are its early temperature and pressure?*
   - *What is its gluon density?*

3. **Are symmetries restored/broken in the partonic matter?**
   - *Spontaneous CP violation*
   - *Chiral symmetry and $U_A(1)$ restoration*

4. What are the properties of the hadronic medium after hadronization

5. What are the gluon densities in normal nuclear matter

6. What are the contributions to the proton spin?

Types of Measurements

1. "Hard" probes: tagged jets - γ-tagged, flavor tagged (esp. heavy flavor)
2. Study of properties of "away" side, behavior vs centrality, energy, colliding species
3. Collective behavior of partonic matter – heavy baryon, heavy meson flow
4. Charm, Beauty, J/psi and Upsilon yields and spectra
5. Symmetry violations (Λ spin correlation) and indications of chiral restoration ("away" side di-leptons, particle ratios, η, η')

Types of Measurements

6. Direct photons – $\gamma\gamma$-HBT could access low to moderate p_t regions to allow the most direct temperature measurement.
7. Correlations over a large range of scales as a probe of EOS and probe of parton energy loss
8. HBT, Unlike particle correlations, Resonance yield as tools to probe late stage (hadronic) medium
9. p(d)-A to probe initial state – jets vs. impact parameter - nuclear gluon density profile.
10. $W^{\pm}$ production in longitudinally polarized p-p to probe sea anti-quark contribution to nucleon spin

Requirements

Keep (expand) STAR's large coverage

1. Enhanced (higher momentum) PID – barrel TOF

2. Micro vertex detector and inner tracking for enhanced heavy quark ID

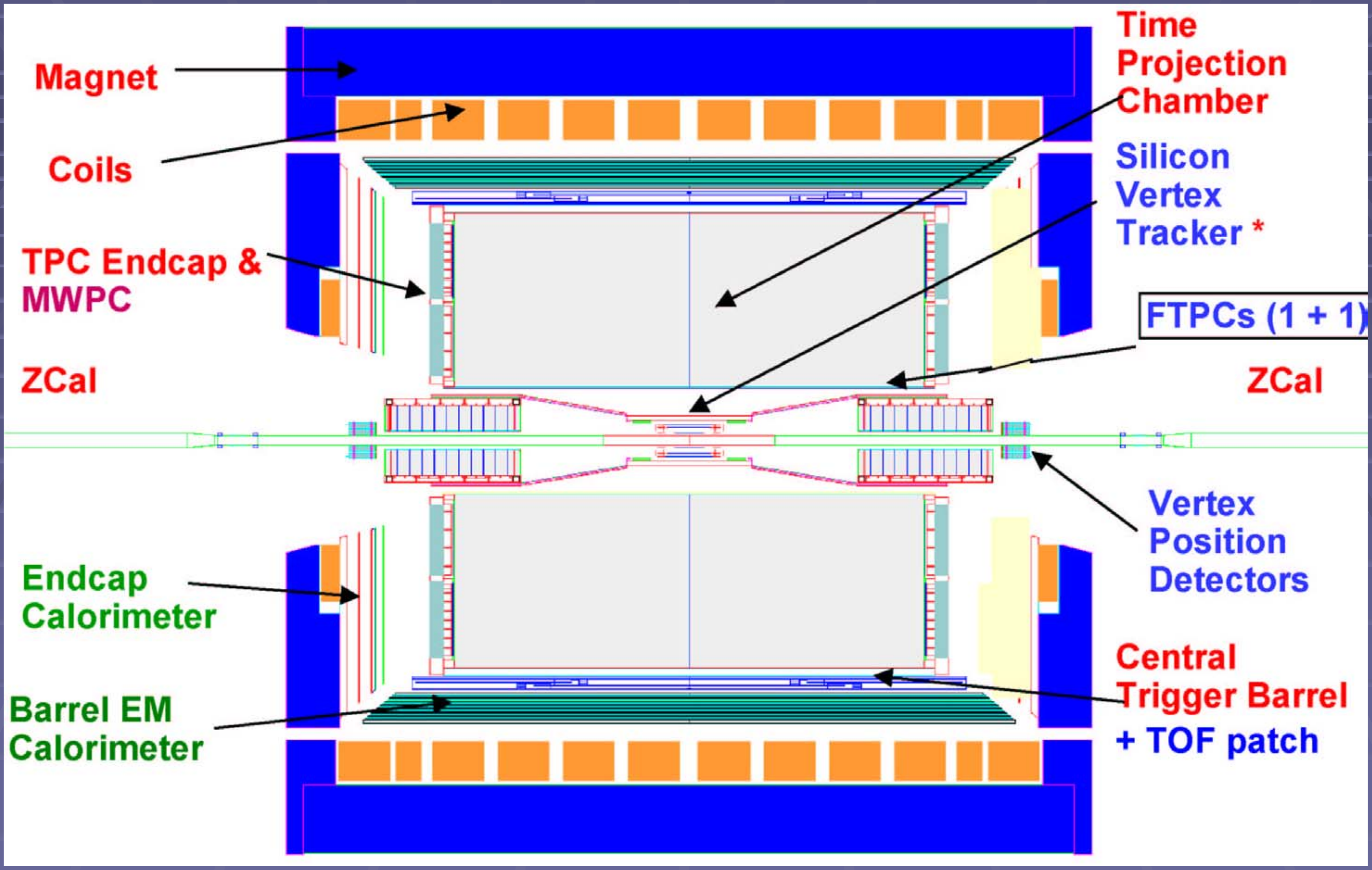
3. Improved momentum resolution for forward ($1<|\eta|<2$) region - intermediate and end cap tracking,

4. High rate readout and DAQ – present large samples to high level trigger, also record very large samples

5. High rate tracking capability

6. High Luminosity, Large pp polarization – RHIC development and upgrades

“Baseline” STAR Detector



Ongoing Improvements of STAR Capability

Detector / Interest	Status	Completion
Barrel Electromagnetic Calorimeter (high pt, photons, $\pi°$, jets)	90 modules of 120 installed	2004
Endcap Electromagnetic Calorimeter (reach in x_{BJ}, high pt, photons, $\pi°$, jets)	mech structure installed; 40% instr.	2004
Silicon Strip Detector (x 1.5 efficiency for hyperon reconstr.)	11 ladders installed	2004
Photon Multiplicity Detector $<N\gamma>$ ($\pi°$) fluctuations, Chiral Condensate	Installed	2003
TOFr (< 100 ps TOF PID with MRPC Modules)	New prototype Tray	2003
DAQ 100 ($\rightarrow$ Event Rates ~ 100 Hz)	Completed	2003
Forward Pi Zero Detector (A_N for leading $\pi°$, G(x) in d + Au)	Complete	2003
New Triggers and increased capability (Rare Trigger Selection e.g. J/Ψ)	Ongoing Dev.	

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

- **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

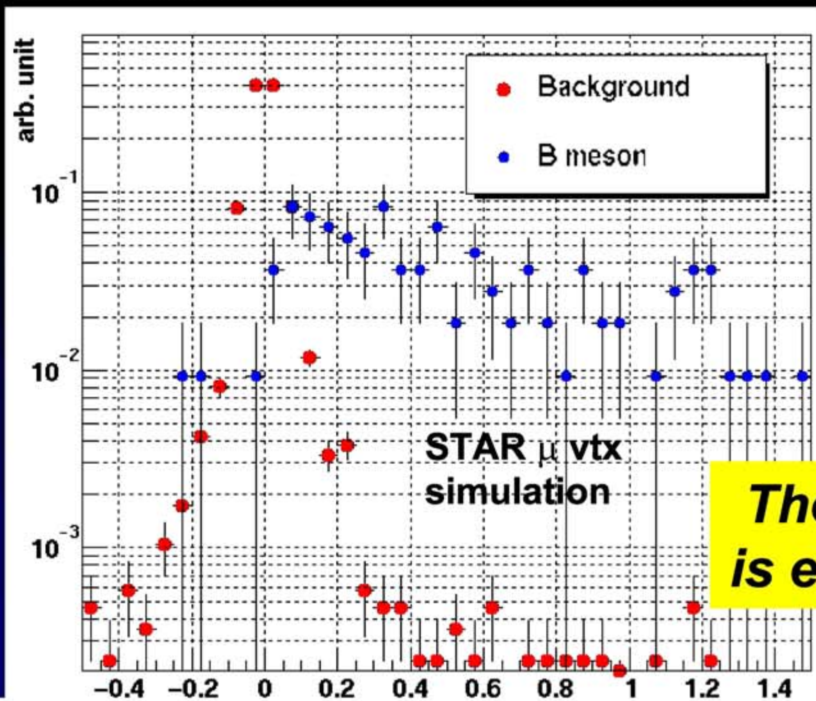
1

A First look - Using a proposed STAR μVTX Detector

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

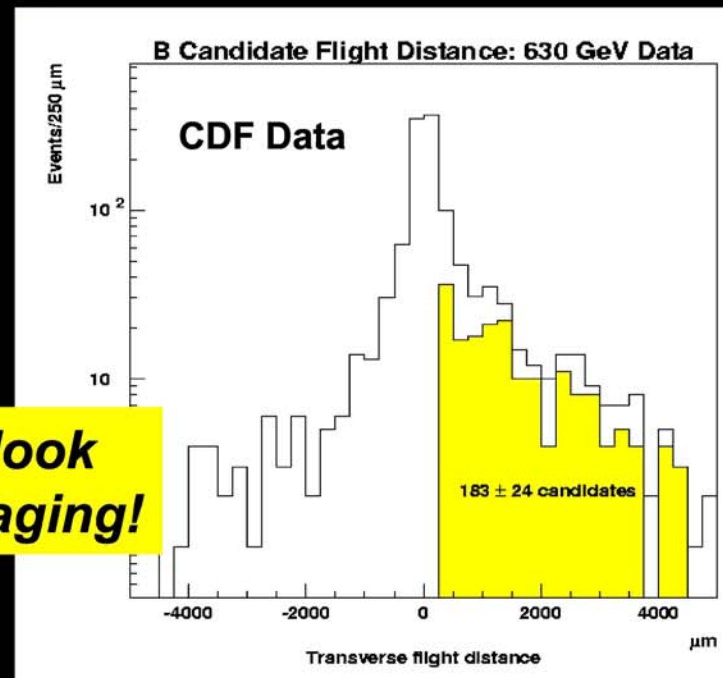
EMC triggers $e^{+/-}$ from B, μVertex cleans the sample

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



Distance from primary vertex To candidate vertex (mm)

- 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



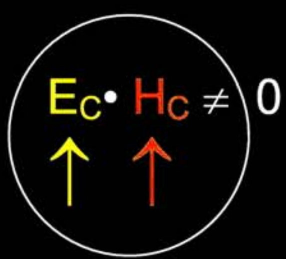
The first look is encouraging!

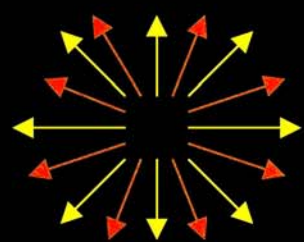
Studying the fundamental nature of QCD: Strong CP Violation

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

QCD "should " include CP violation, but experimentally, θ = 0

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

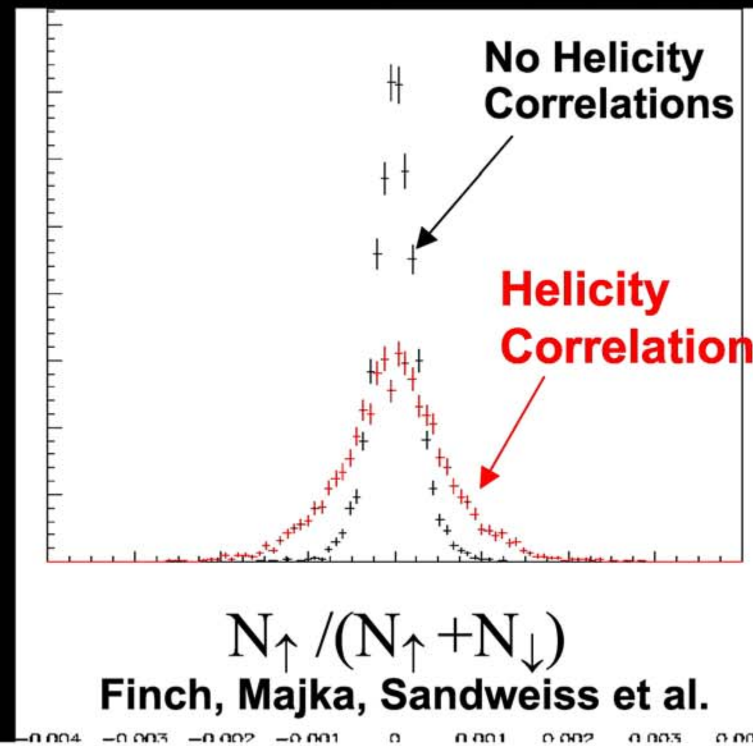




Ec• Hc ≠ 0

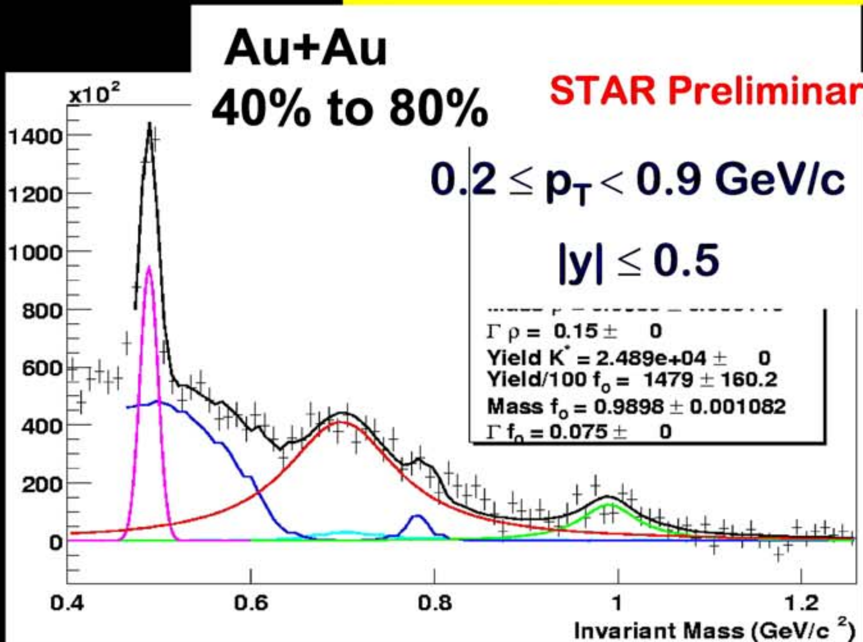
⇒ Simple momentum space asymmetry probably not good enough → look at e-by-e helicity balance of fermions (Λ°) and search for fluctuation (too many positive helicity Λ°)

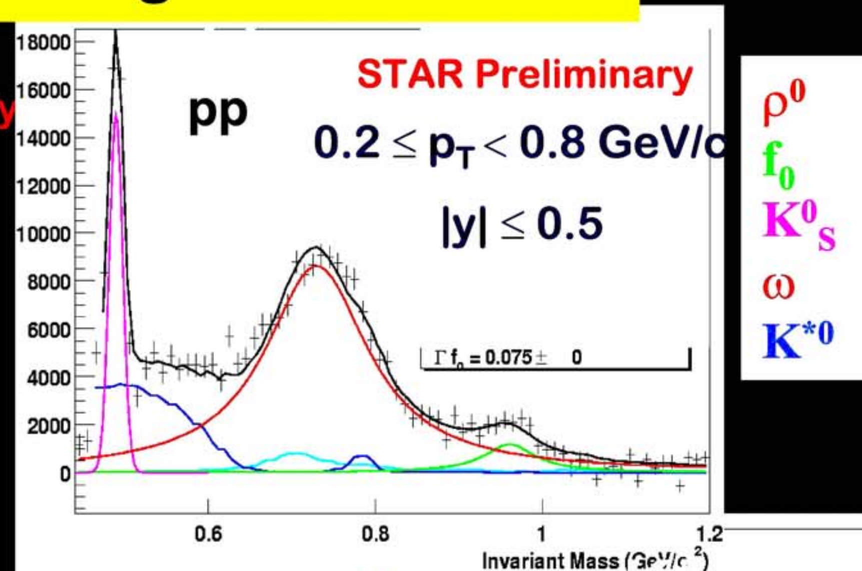
Estimated need: several hundred million events! (efficiency dependent)

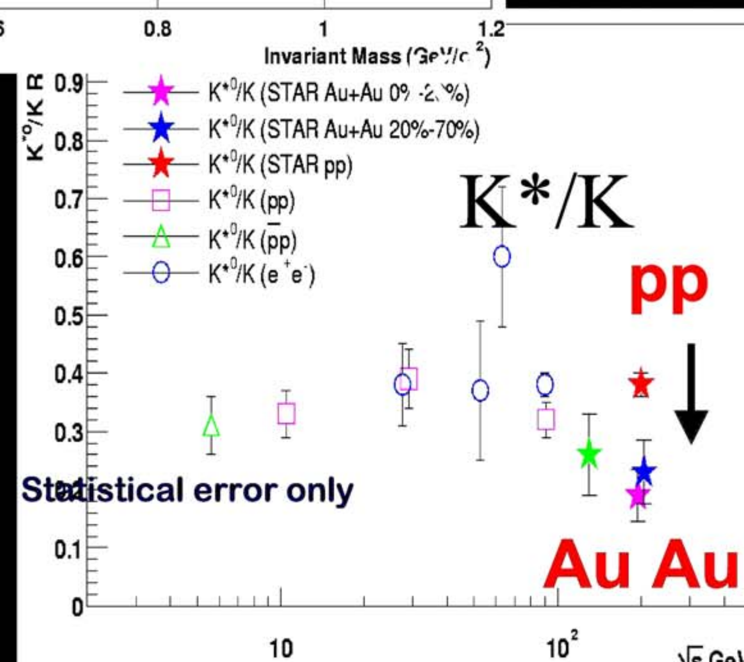


Finch, Majka, Sandweiss et al.

Probing Rescattering: Resonances





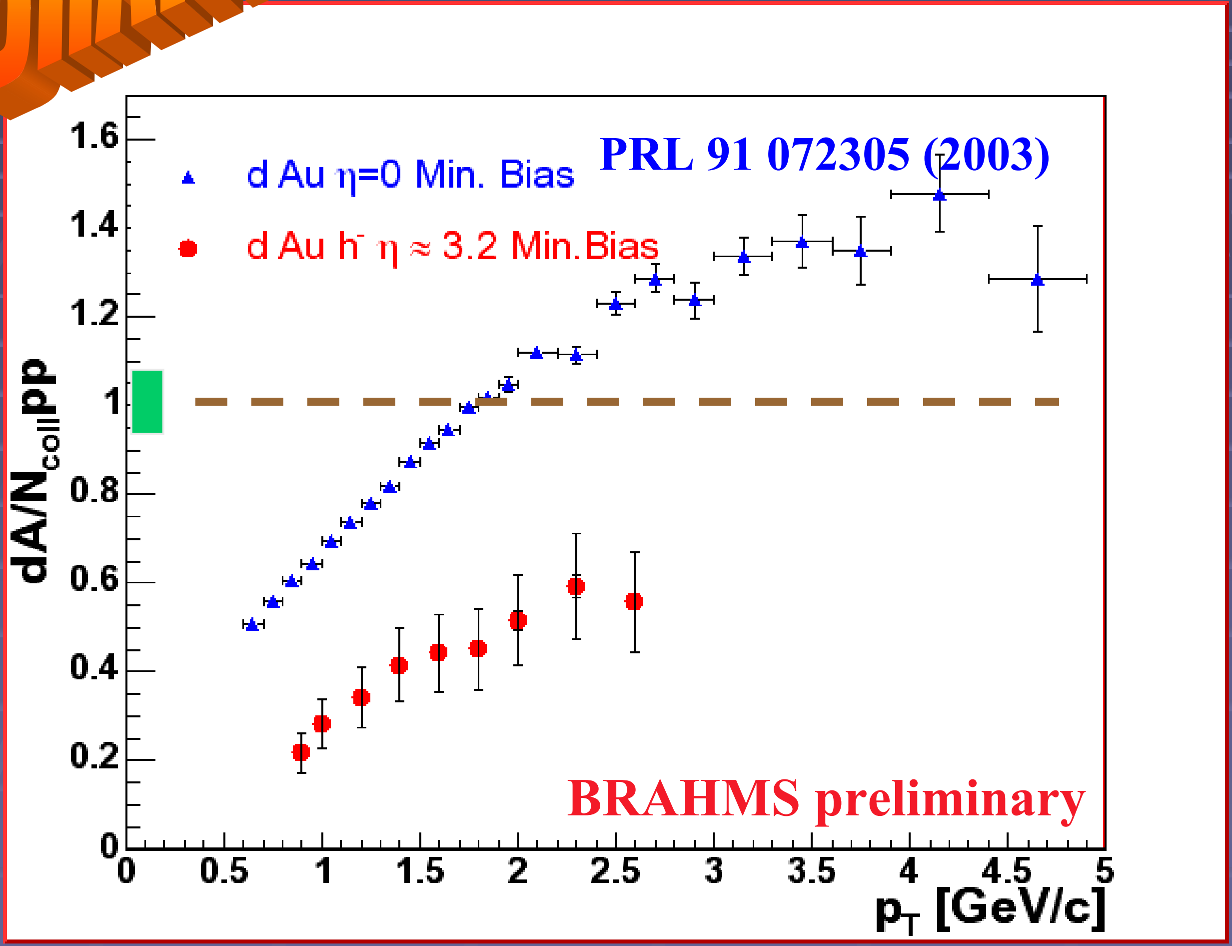


- **Short-lived resonances probe the medium and map the history wrt rescattering after chemical freezeout**
  - Destruction of signal in hadronic channel
  - Regeneration in "elastic" scattering stage

- No trigger possible
- Large data samples necessary
- PID from TOF essential to extend p_T reach

•Modification to Resonance mass or width – possible medium effects

d-Au Nuclear Modification factor at η ~3.2



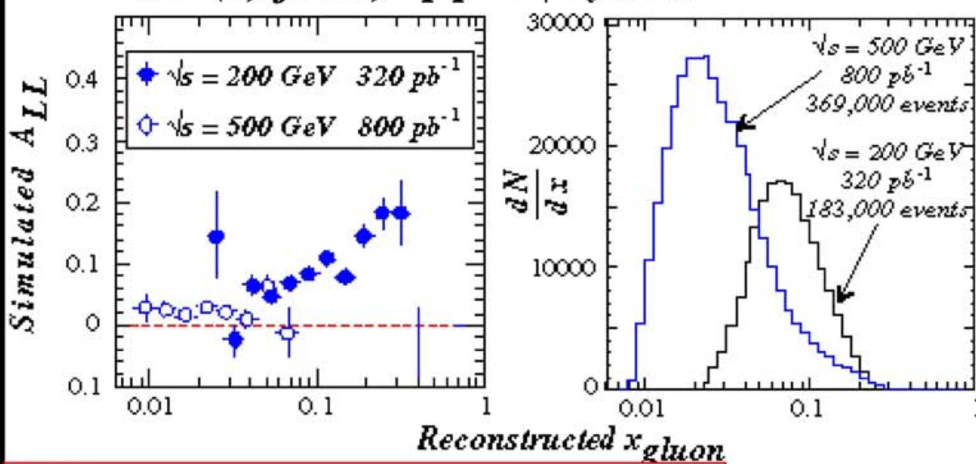
RdAu compares the yield of **negative particles** produced in dAu to the scaled number of particles with same sign in p-p

The scale is the number of binary collisions:

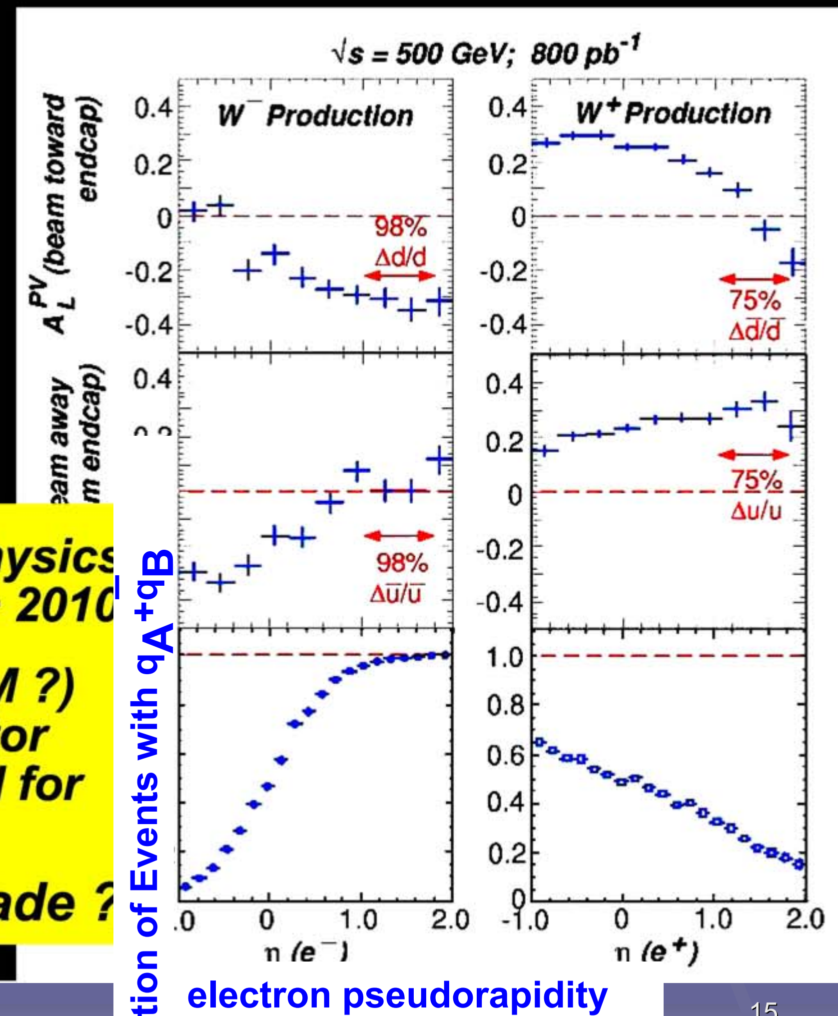
$N_{coll}=7.2$
(minimum biased)

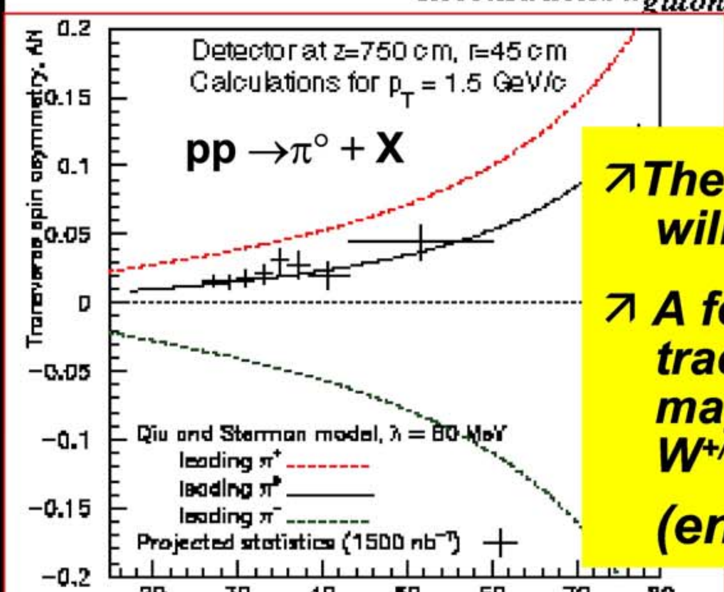
What about the STAR Spin Program

$\Delta G(x)$ from) $\vec{p}\,\vec{p} \rightarrow \gamma + jet + X$



$\Delta\bar{u}$, $\Delta\bar{d}$ determination via A_L^{PV} in $p + p \rightarrow W^{\pm} + X$ @ $\sqrt{s}$ = 500 GeV

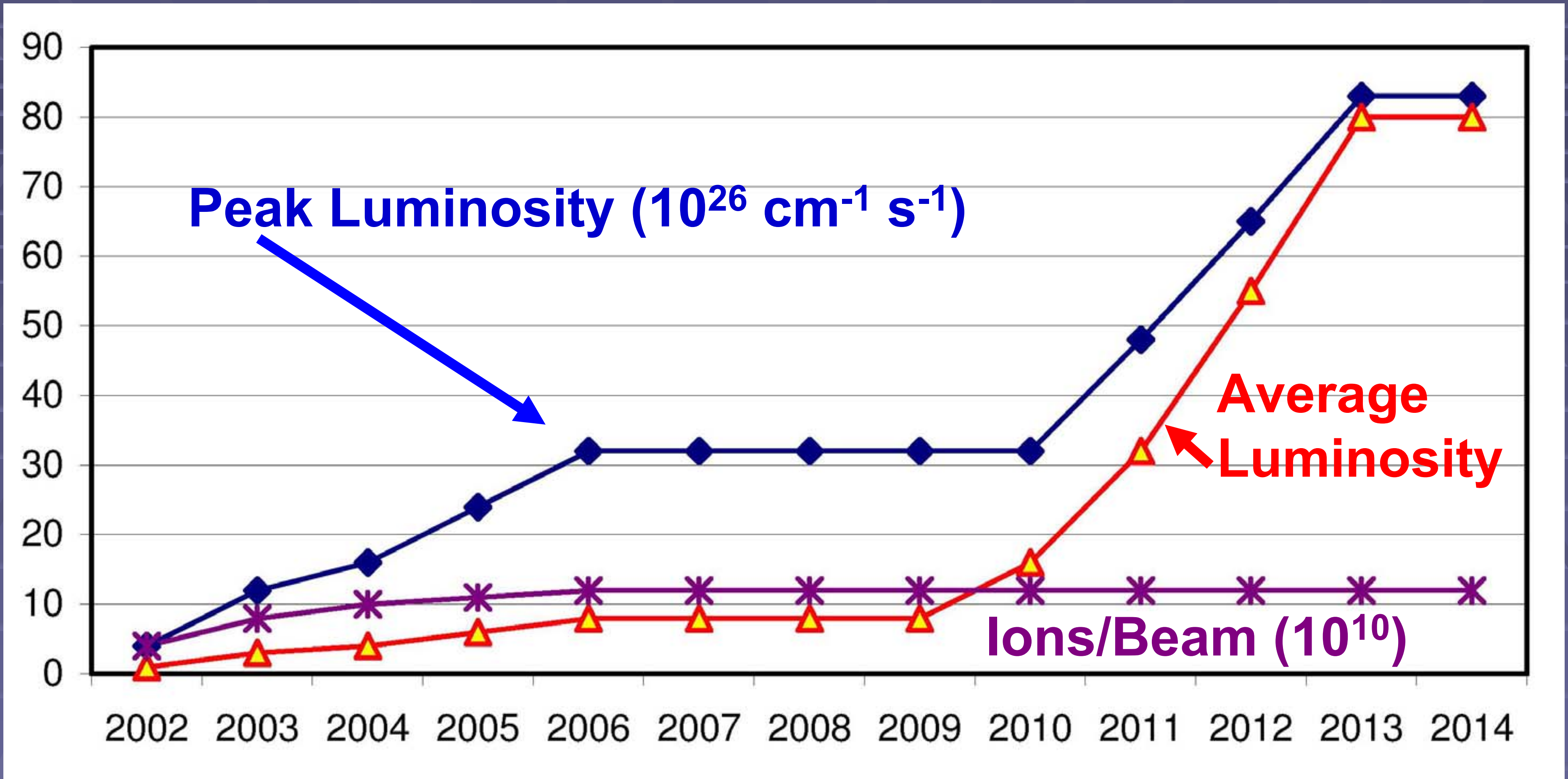




- ↗ The baseline physics will take until ~ 2010
- ↗ A forward (GEM ?) tracking detector may be needed for $W^{+/-}$ sign

(energy upgrade ?

RHIC Heavy Ion Luminosity Upgrades



STAR Upgrades Required for Physics Program

- Full Barrel MRPC TOF
- Tracking upgrade:
  - High precision APS pixel vertex detector
  - Inner tracker
  - End cap tracker
- DAQ Upgrade (order of magnitude increase in rate)
- Compact, Fast TPC for high luminosity tracking.

Barrel Time of Flight using Multi-gap Resistive Plate Chambers

Goal: Cover entire outer barrel of TPC with affordable, high resolution TOF ($0<\Phi<2\pi$, $-1<\eta<1$, $\Delta t<100$ps)

Limits For PID:

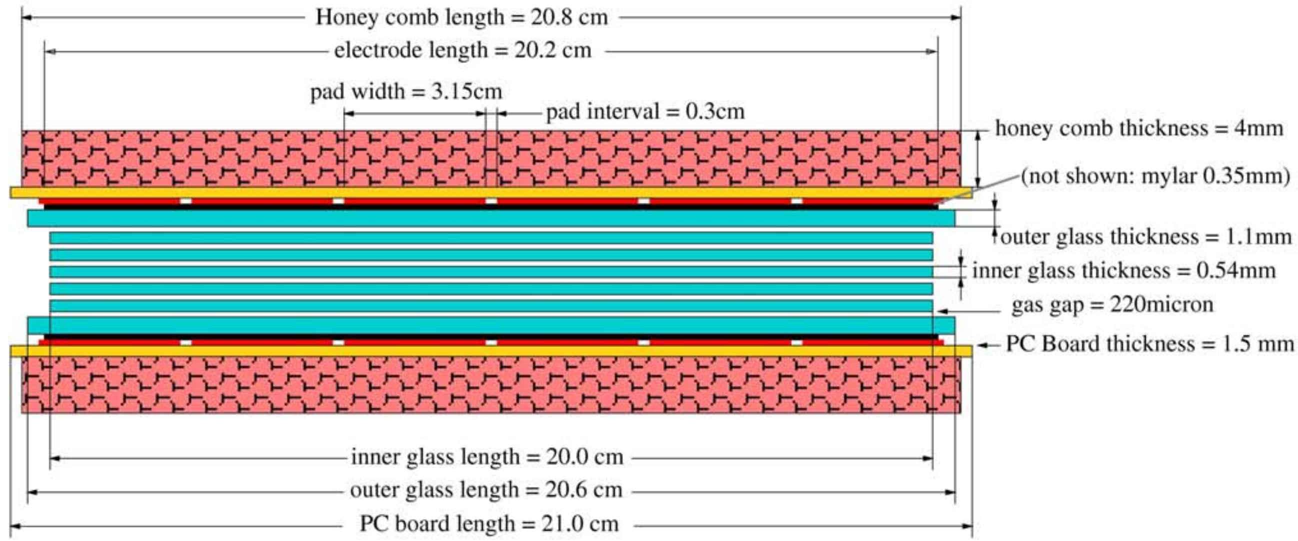
2σ PID	TPC dE/dx	TOF (η~0)	TOF (η~1)
π/K/P	~0.7 GeV/c	~1.6 GeV/c	~2.0 GeV/c
(π+K)/p	~1.0 GeV/c	~2.6 GeV/c	~3.2 GeV/c
d	~1.0 GeV/c	~4.0 GeV/c	~4.7 GeV/c

With TOF, over 95% of the particles in the TPC acceptance will be ID'ed

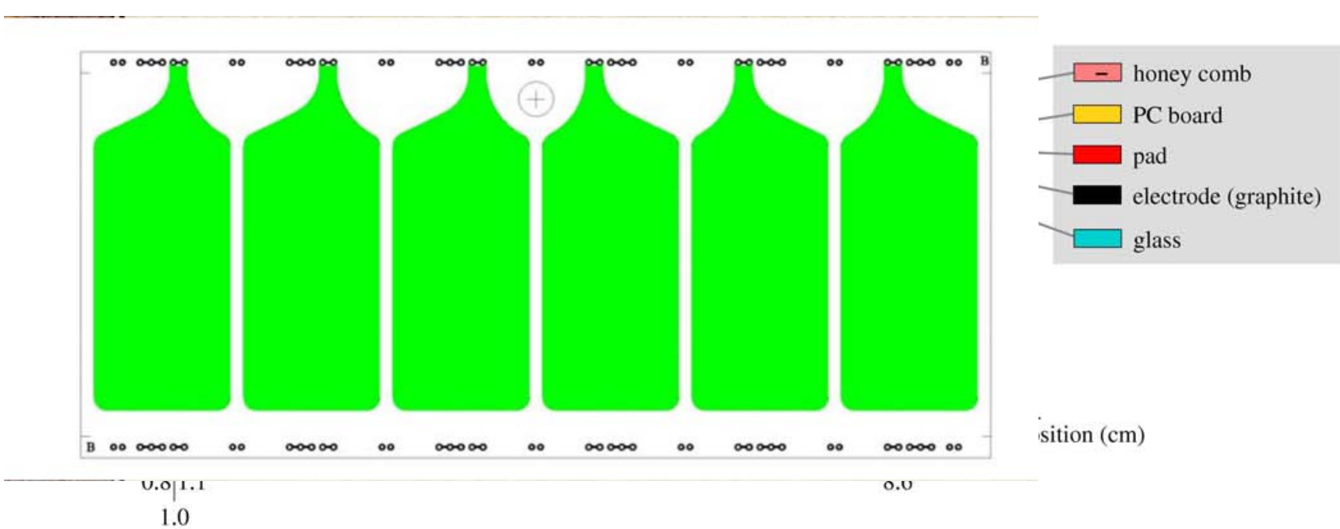
Technology is demonstrated, and has produced physics results in *STAR*

Chambers are multiple narrow gaps (6 *x* 220μm) separated by glass.
HV and readout on pc boards on either side.
Module sensitive area is ~6 *x* 20 cm

Rice v.11 design
long-side view

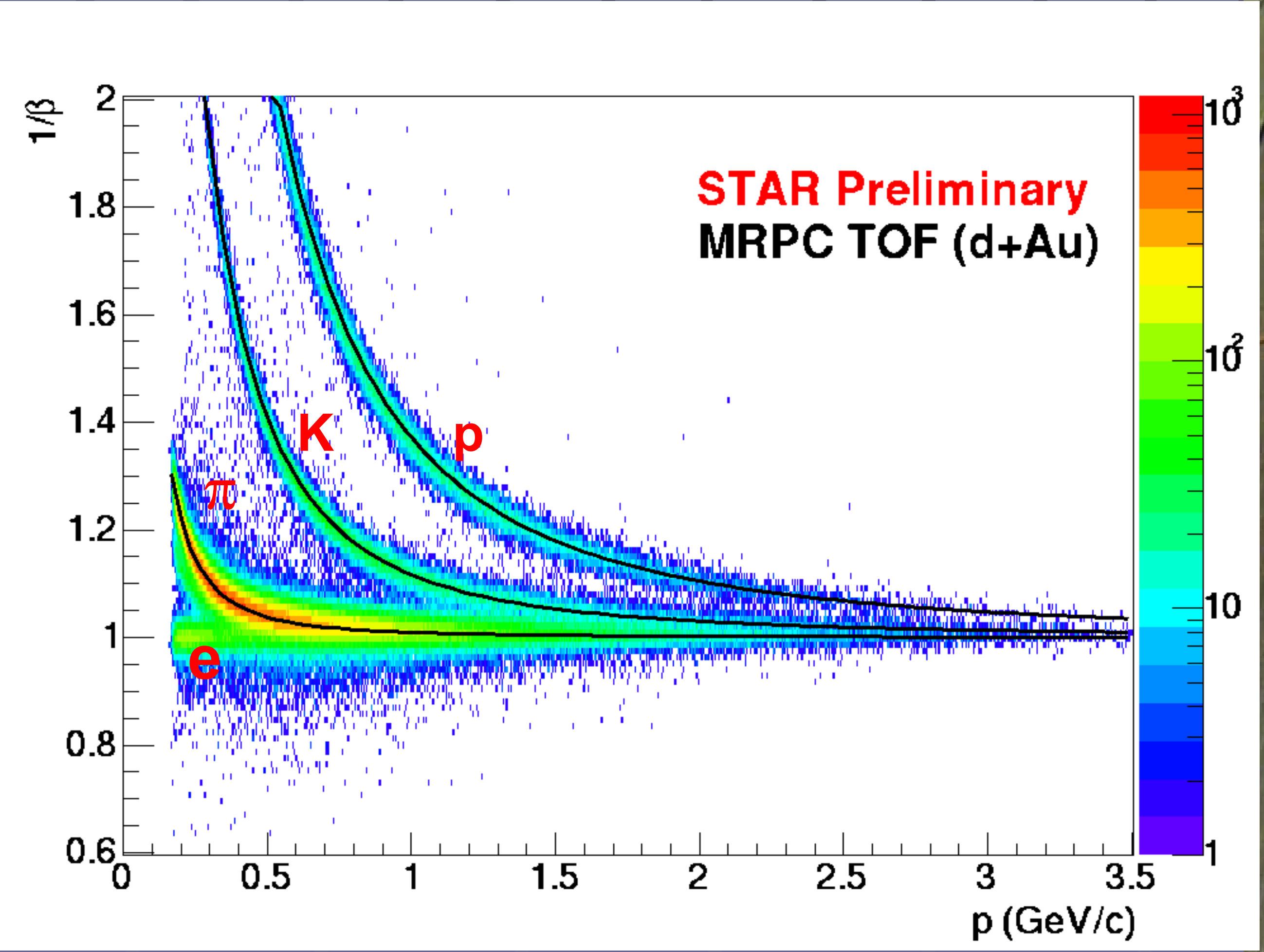


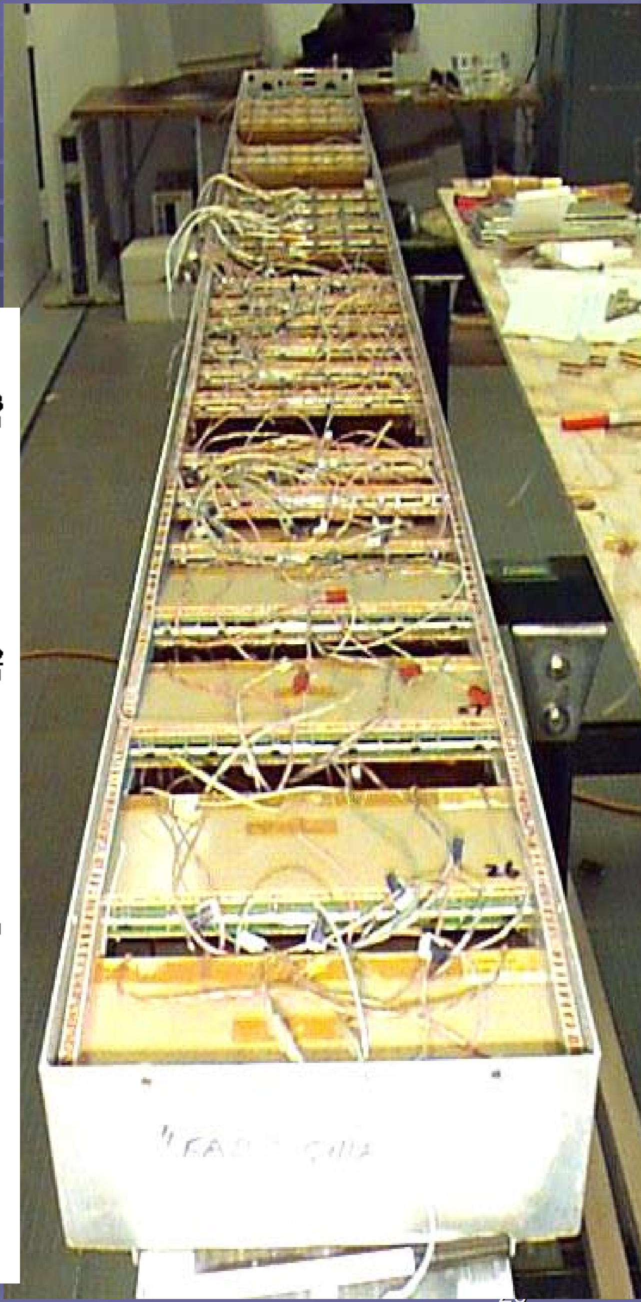
Readout Pads



applied potential ±7-8kV gas typically 90% Freon R134A, 5% isobutane, 5% SF6

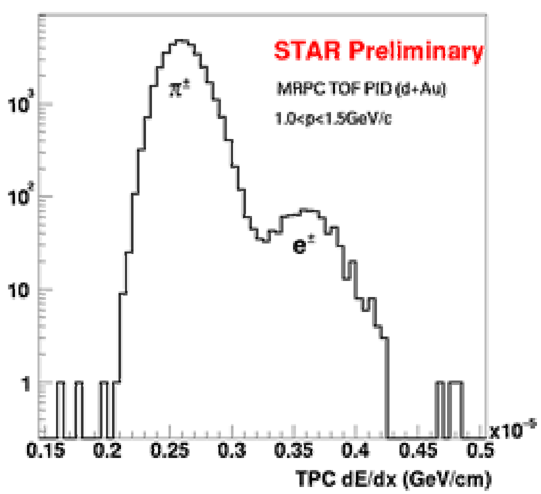
One "tray" ($2\pi/60$ azimuth, $0<\eta<1$) ~30 modules installed in STAR for the 2003 run.

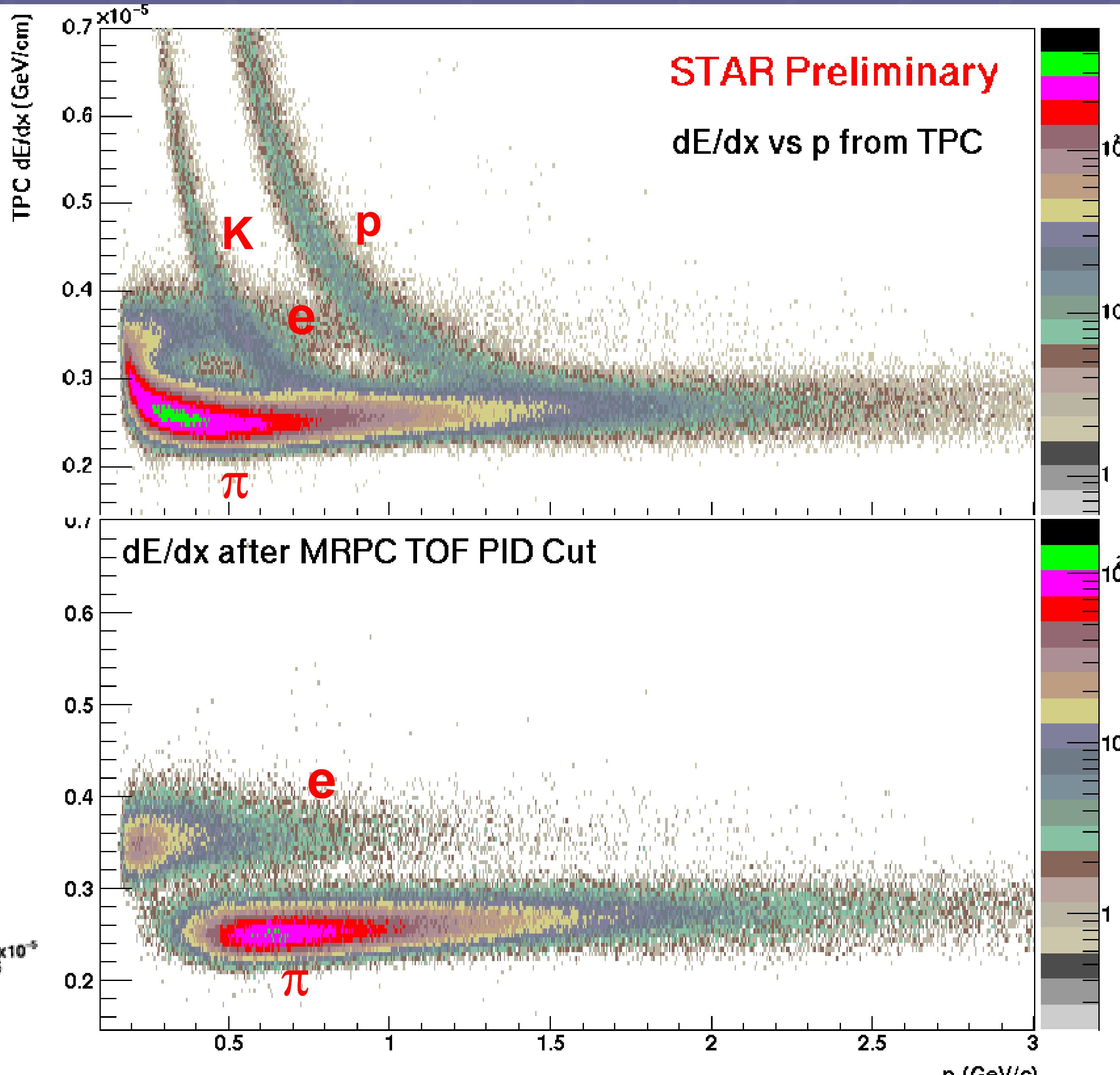




Added benefit:

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





Micro-Vertex Detector

High resolution inner vertex detector, better than 10 μm resolution, with better than 20 μm point-back accuracy at the primary vertex.

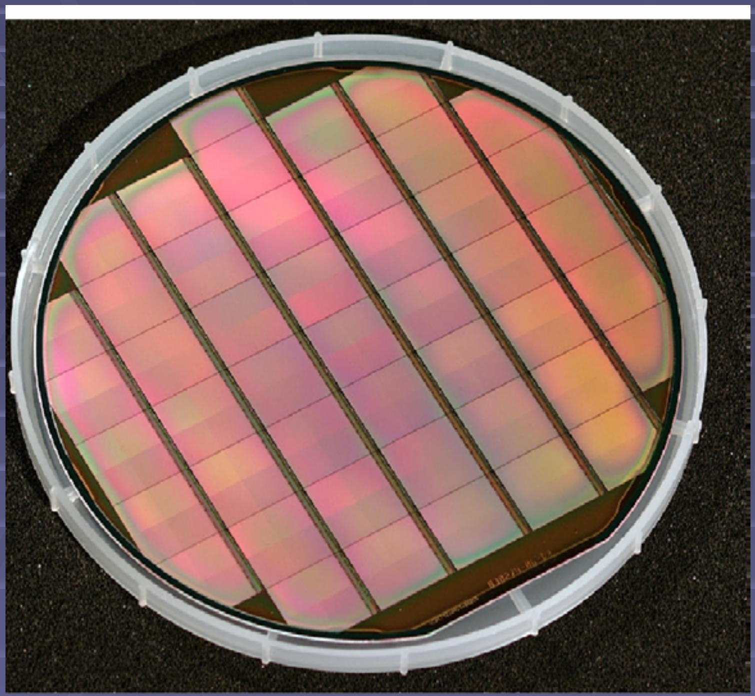
CMOS Active Pixel Sensor (APS) technology – can be very thin, allows readout to be on same chip as detector.

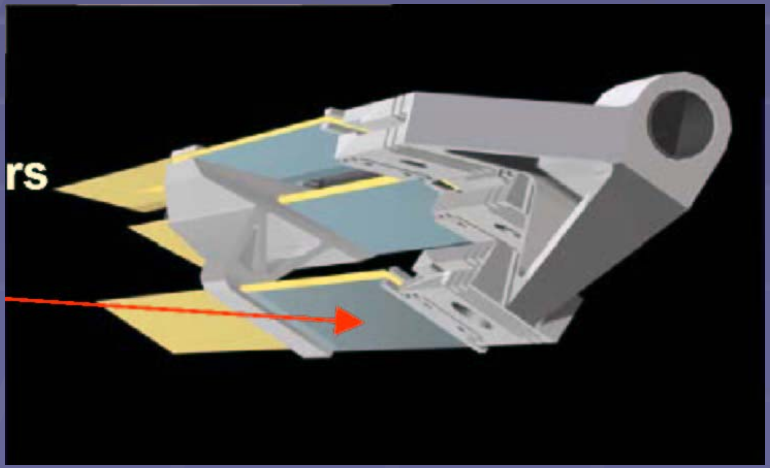
Develop high speed APS technology for second generation silicon replacement (LEPSI/IReS, and LBNL+UC Irvine)

Required Areas of development:

- APS detector technology
- Mechanical support and cabling for thinned silicon
- Thin beam pipe development
- Calibration and position determination
- Data stream interfacing

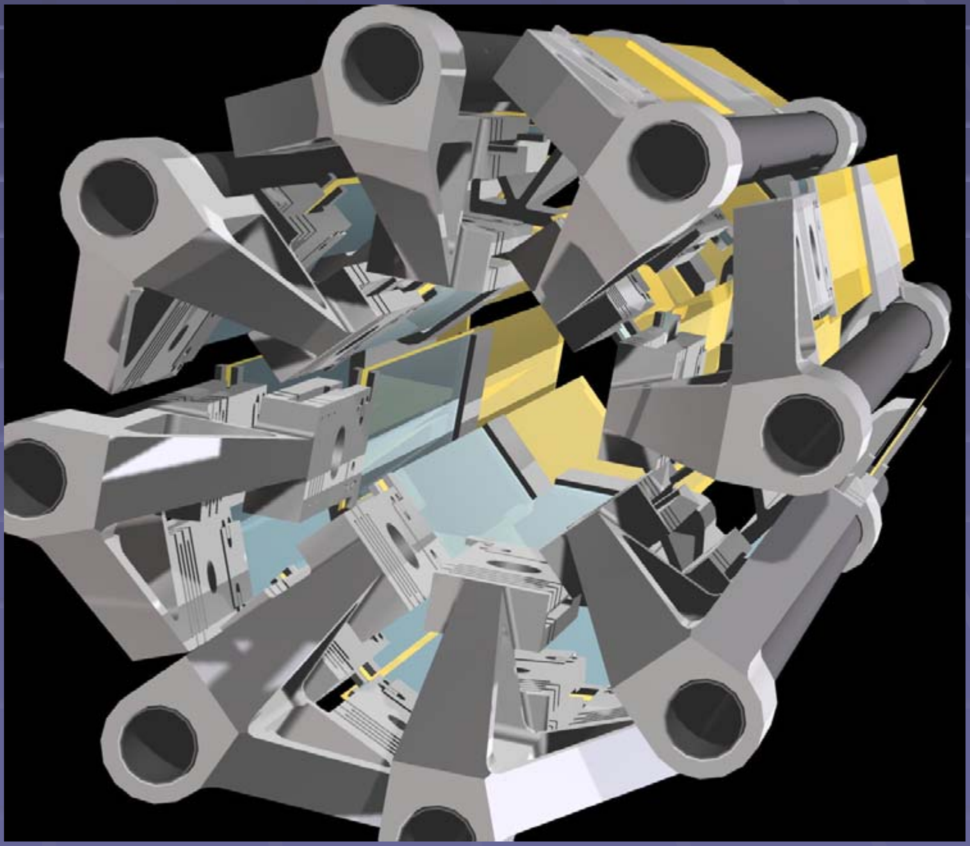
LEPSI – Ladders on a Wafer



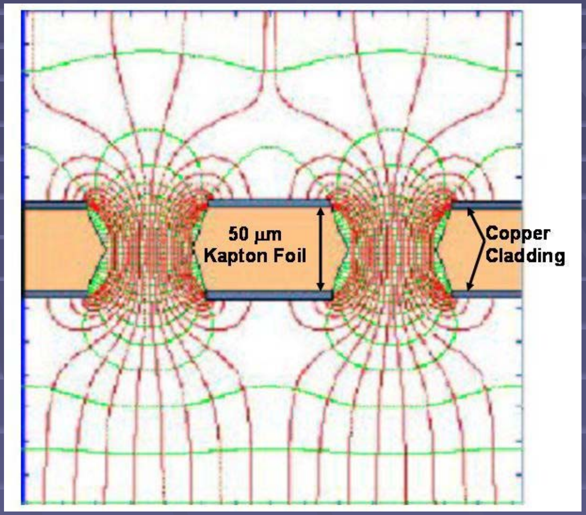


Conceptual Design for "infrastructure"

Supports are outside active area



GEM =*Gas Electron Multiplier*

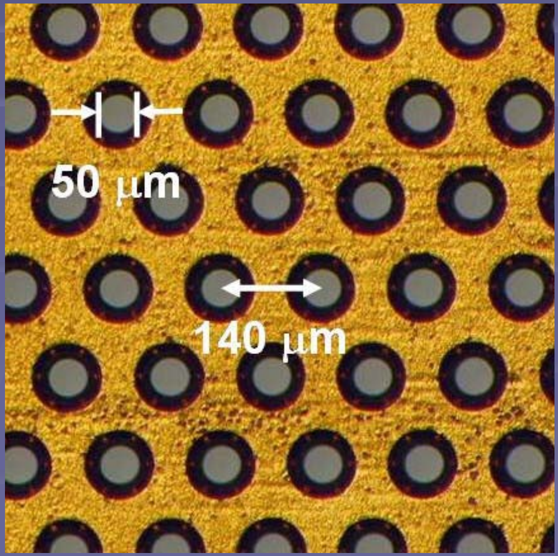


A micropattern structure produced in 50μm thick copper clad kapton using lithographic techniques.

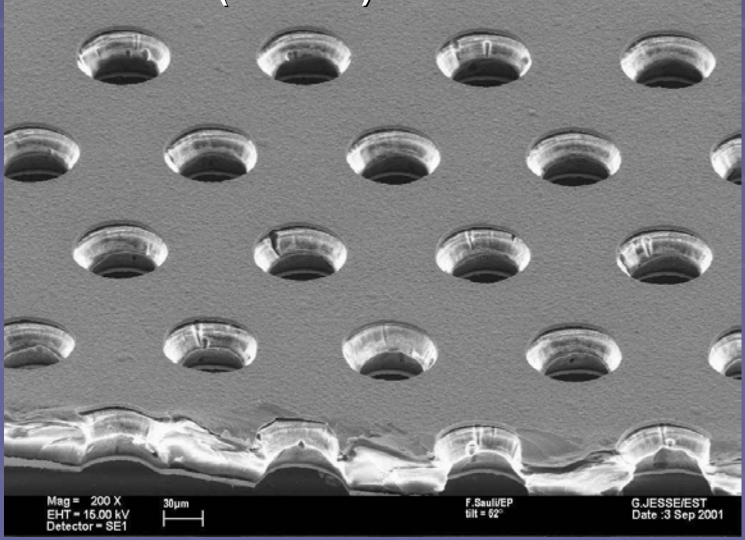
55μm holes on ~140μm centers

Gain up to ~10^3 for single foil

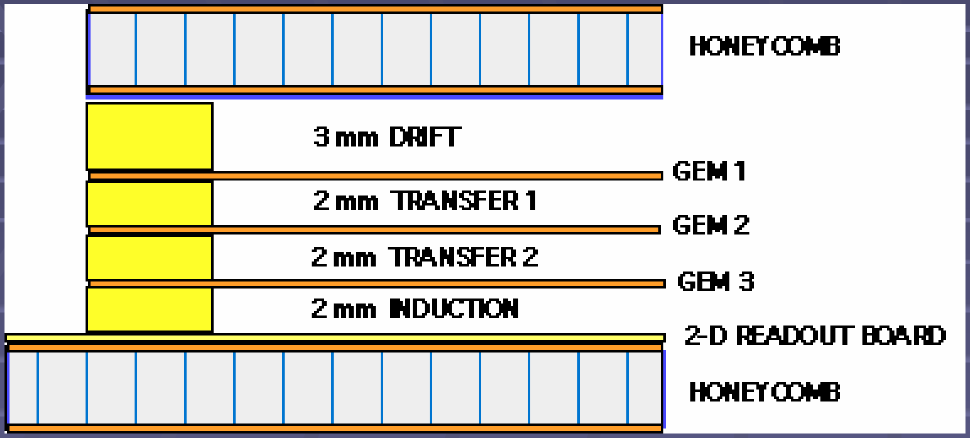
3M Foil (J. Collar) Photo – Bo Yu, BNL



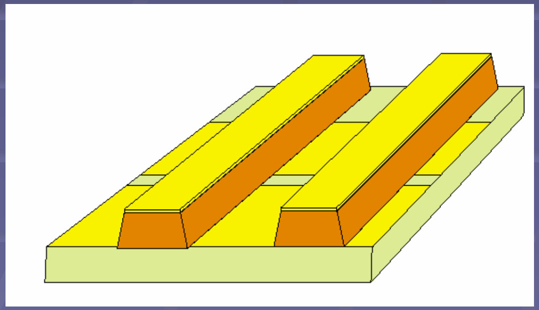
CERN Foil (F. Sauli) Photo – G. Jesse

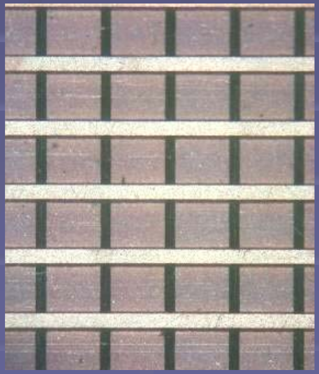


GEM technology used successfully in high intensity fixed target environment at CERN (COMPASS)



Triple GEM used with 0.4 mm pitch crossed strip readout to achieve ***46 μm resolution in both coordinates.***





This is an excellent candidate for improving STAR momentum resolution with chambers covering the endcap and at large radius with compact TPC

PLAN: Joint R&D with PHENIX to understand GEM technology – Goal: build and test prototype TPC module

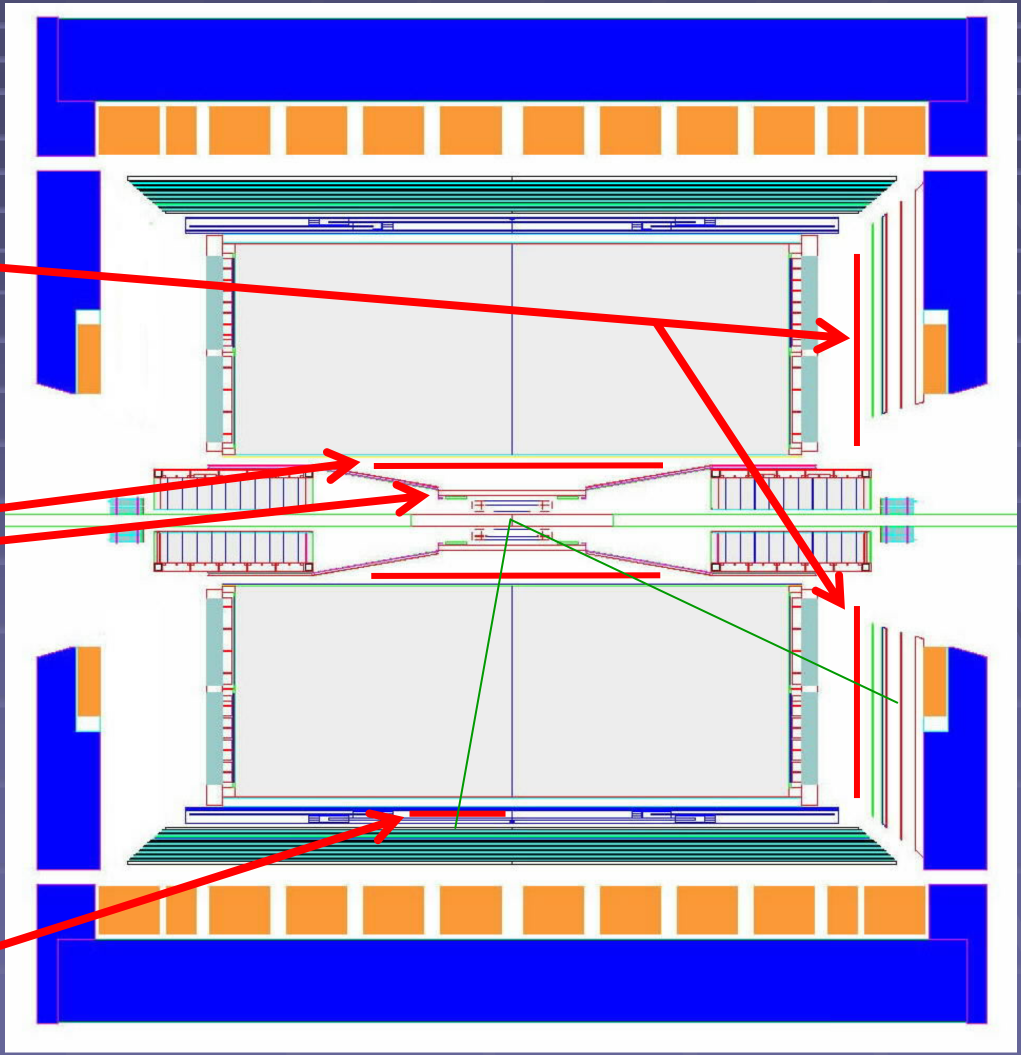
Intermediate Tracking + Forward Tracking

GEM pad or strip chambers:

Endcap – GEM pad or strip chambers to help resolve sign of $e^{\pm}$ from $W^{\pm}$ decay – polarization of sea anti- u,d.

Intermediate tracker (GEM plus Si to help match TPC tracks to pixel detector and, give intermediate point for forward tracking

Patch of GEM pads at outer radius to help TPC calib.



Cross section through STAR detector

High Rate Data Acquisition and Front End Electronics

Since initial operation, the STAR DAQ has been upgraded from a rate of 1 to ~30 Hz Hz central Au-Au events (DAQ100)

The system is now at hard limits throughout.

Propose an order of magnitude increase in throughput (DAQ1000)

- Replace TPC front end electronics
- Replace SVT (silicon drift tracker – slow readout)
- Implement DAQ100 cluster finding code in hardware
- New interconnect and event builder hardware

Moving *Forward*

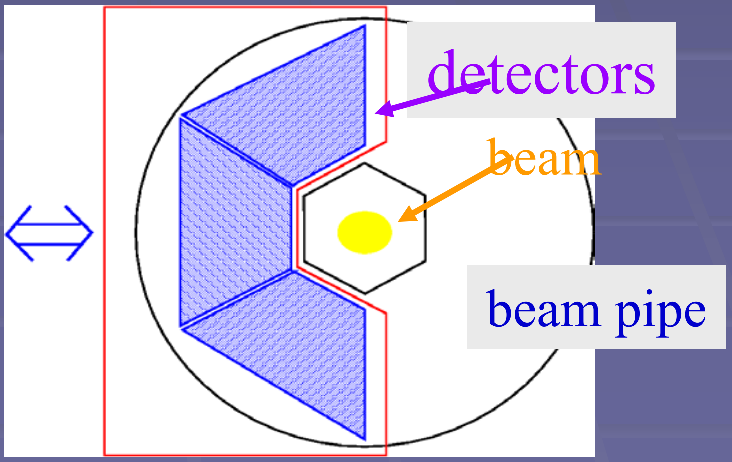
Forward Hadron Calorimetry (~$2.4<\eta<4.0$, $0<\phi<2\pi$)

- **Is the asymmetry for pions produced in transversely polarized proton scattering due to spin dependent fragmentation (Collins)?**

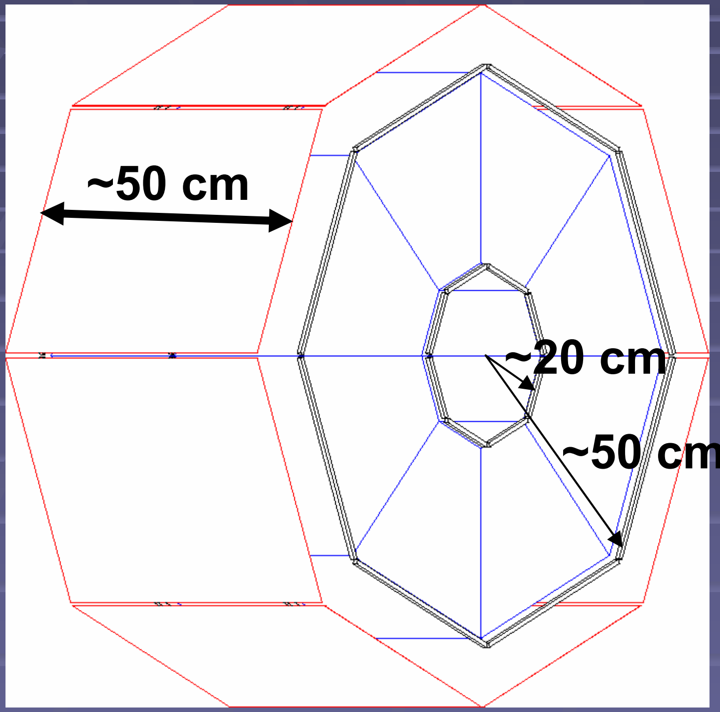
➔ **Forward jets – probing gluon saturation**

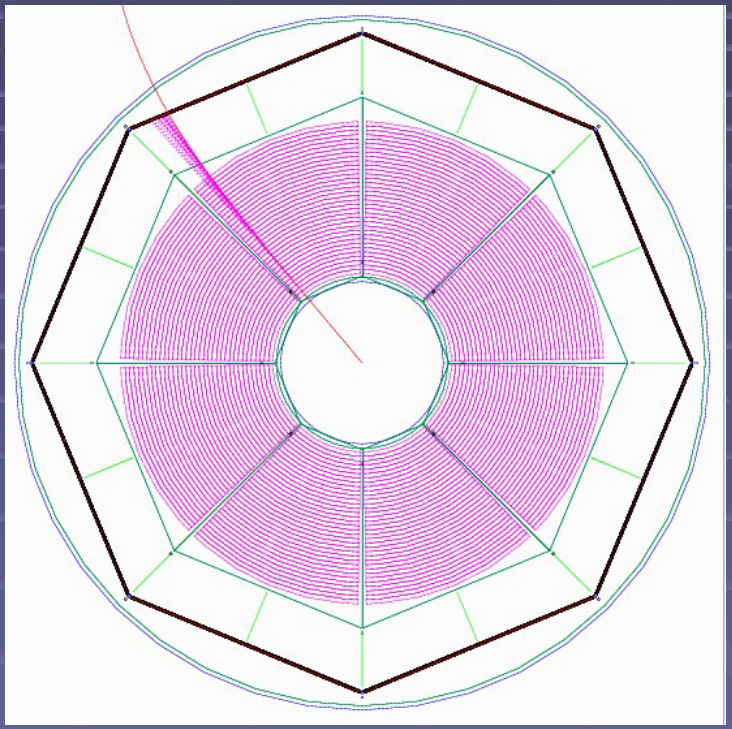
Roman Pots (η~6.5)

Access to a variety of diffractive phenomena in p-p scattering



Goal: Develop fast compact TPC which will overcome the rate limitations of the current TPC using GEM for the gas gain element.



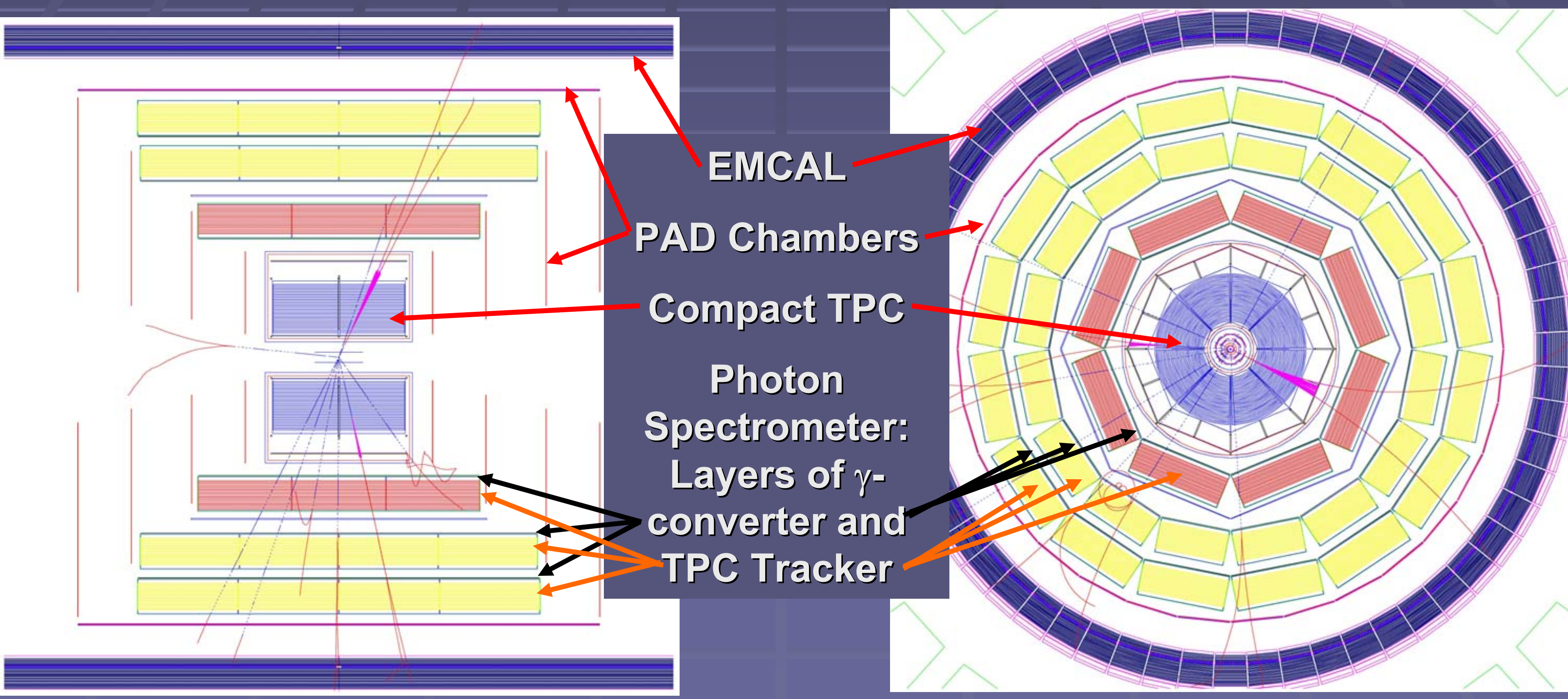


16 identical modules with 35 pad-rows, double (triple) GEM readout with pad size: 0.2x1. cm². Maximum drift: 40-45 cm. "Working" gas: fast, low diffusion.
GEM structure: very small positive ion feedback

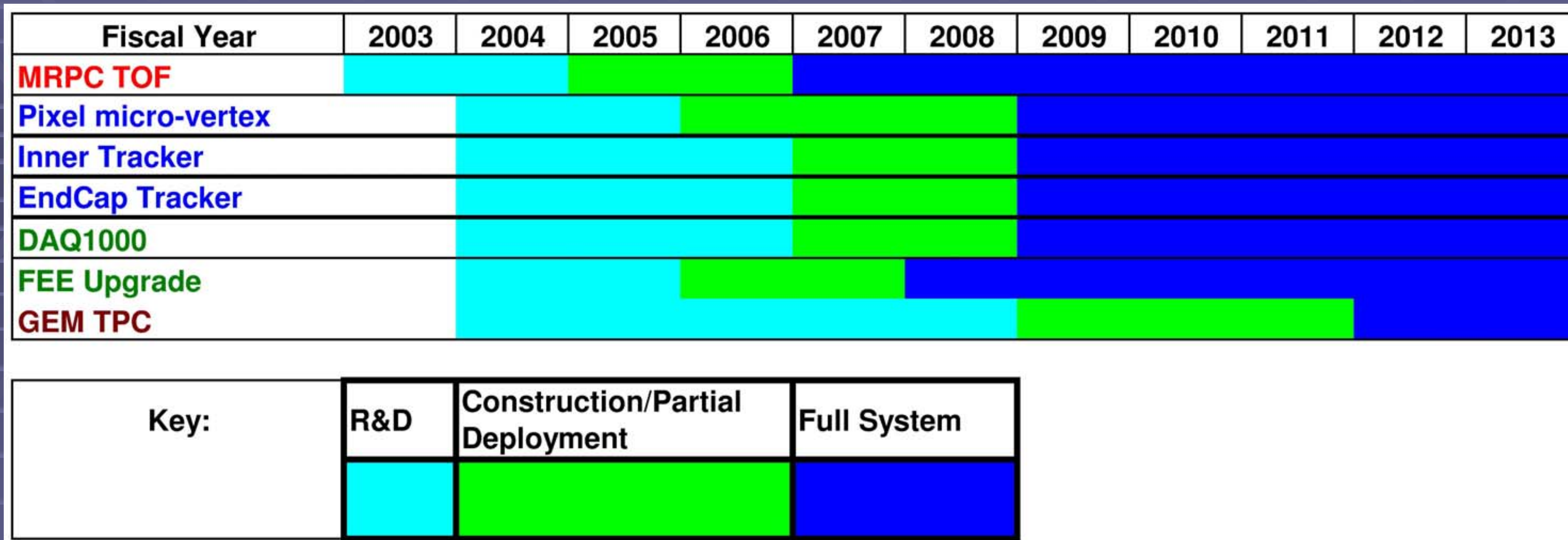
Main goal of Compact TPC is high rate tracking – but it also leaves a lot of room for other detectors!

Conceptual design for γγ-HBT

Three layers of converter and tracker form a photon spectrometer outside the “normal” tracker.



Proposed Timeline for STAR Upgrades



MRPC TOF – US proposal submitted, Detector R&D *Spectacular* success

Pixel μVertex – Draft proposal by end of year

Inner Tracker / EndCap Tracker (+μVtx) Design Coordination Meeting, MIT, Nov. 7-8, 2003

DAQ1000+FEE – DAQ R&D to start next spring

GEM Compact Fast TPC - Full R&D in FY04, Prototype module in one year

Summary

STAR plans a broad program of measurements in the next 10 years aimed at characterizing

- Partonic matter created in RHI collisions
- RHI initial state (cold nuclear matter)
- Hadronic medium after freeze out
- Contributions to nucleon spin

Meeting the technological challenges requires significant R&D and upgrades to the STAR detector and upgrades and development of the collider luminosity and pp polarization