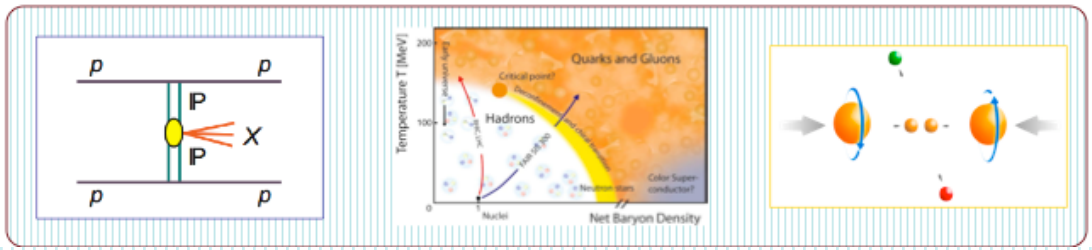
STAR Experiment at RHIC

Nu Xu
for the STAR Collaboration

Nuclear Science Division
Lawrence Berkeley National Laboratory



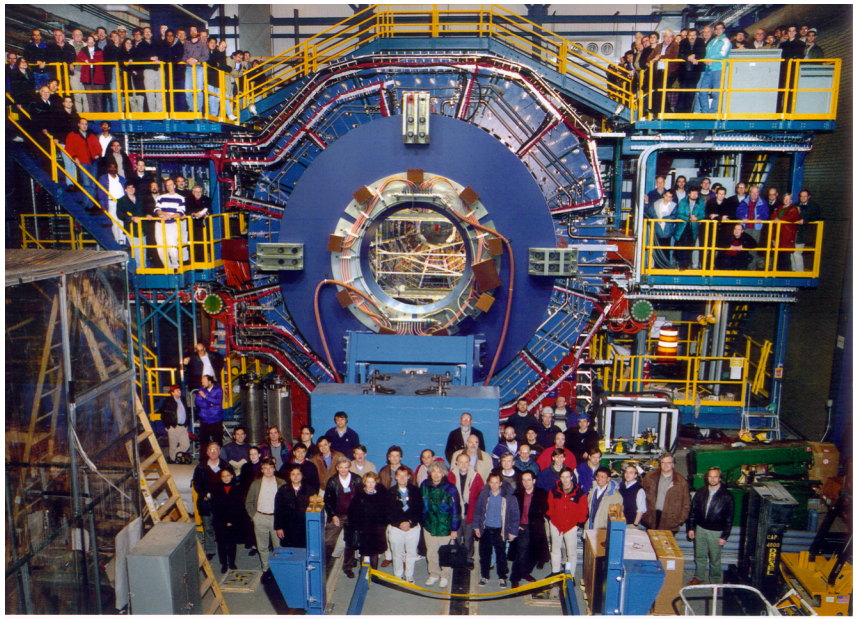
Outline

1) Introduction and the status of the experiment
2) Report on Run 8 and recent physics results
3) Upgrades and near future plans
4) Concerns
5) Summary

STAR Collaboration Membership

U.S. Labs: Argonne, Lawrence Berkeley, and Brookhaven
U.S. Universities: UC Berkeley, UC Davis, UCLA, Carnegie Mellon, Creighton, CCNY, Indiana, Kent State, MSU, Ohio State, Penn State, Purdue, Rice, Texas A&M, UT Austin, Washington, Wayne State, Valparaiso, Yale, MIT, Kentucky
Brazil: Universidade de Sao Paulo, Universidade Estadual de Campinas
China: IHEP, IOPP, USTC, Tsinghua U., SINAP, IMP
Croatia: Zagreb University
Czech Republic: Institute of Nuclear Physics
England: U. of Birmingham
France: Institut de Recherches Subatomiques Strasbourg, SUBATECH
Germany: Max Planck Institute
India: IOP, Bhubaneswar, Jammu U., IIT-Mumbai, Panjab U., Rajasthan U., VECC
Netherlands: NIKHEF
Poland: Warsaw University of Technology
Russia: MEPHI, LPP/LHE JINR – Dubna, IHEP – Protvino
South Korea: Pusan National University

Five institutes have applied for the membership:
- KISTI, South Korea: Super computing
- HIT, China: Two-particle correlations
- ShanDong U.: Spin
- ITEP, Moscow: pp2pp
- Old Dominion U.: pp2pp



12 countries
52 institutes
~ *600* scientists and engineers

Research topics at the QCD Lab:
- properties of strongly interacting matter
- proton spin structure
- gluonic matter

List of degree recipients: ***103 PhD (and 20 other) degrees awarded on STAR research to students at 34 institutions***

Max-Planck-Institut
2005 Frank Simon, PhD
2004 Joern Putschke, PhD
2003 Maierbeck Peter, Dipl.
2002 Markus Oldenburg, PhD
2000 Holm Huemmler, PhD
2000 Tobias Eggert, Dipl.
1998 Rainer Marstaller, Dipl.
1997 Michael Konrad, PhD
1997 Xaver Bittl, Dipl.

Michigan State University
2002 Ma

Ohio
2004
2004
2003
2002

Purd
2008
2007
2006
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Rice
2006
2001

UST
2007
2007
2005
2004
2004

IOP, B
2007 R. Sahoo, PhD
2003 D. Misra, PhD
2005 A. Dubey, PhD

MEPhI, Moscow
2007 Sergei Timoshenko, PhD

MIT
2008 Julie Milane, PhD

SUBATECH
2007 Jonathan Bouchet, PhD
2005 Magali Estienne, PhD
2004 Gael Renault, PhD
2003 Ludovic Gaudichet, PhD
2002 Javier Castillo, PhD
2000 Fabrice Retiere, PhD
2000 Walter Pinganaud, PhD

University of Texas - Austin
2004 Aya Ishihara, PhD
2004 Yiqun Wang, PhD

SINAP
2008 Jin-Hui Chen, PhD
2006 Guoliang Ma, PhD

VECC
2008 P. Netrakanti, PhD
2007 D. Das, PhD
2005 S. Das, PhD

University of Bern
2005 Mark Heinz, PhD

University of Birmingham
2008 Anthony Timmins, PhD
2008 Leon Gaillard, PhD
2005 John Adams, PhD
2002 Matthew Lamont, PhD

UC – Los Angeles
2008 Steve Guertin, PhD
2006 Jingguo Ma, PhD

Texas A&M
2006 Thomas Henry, PhD

NIKHEF/Utrecht
2008 Martijn Russcher, PhD
2007 Yuting Bai, PhD
2007 Oleksandr Grebenyuk, PhD

Wayne State University
2006 Ahmed Hamed, PhD
2005 Ying Guo, PhD
2005 Alexander Stolpovsky, PhD

Nucl. Physics Inst., Prague
2008 P. Jakl, BS
2006 Jan Kapitan, M.S.
2004 Michal Bystersky, M.S.
2002 Petr Chaloupka, M.S.

UC – Davis

g

2002 Aihong Tang, PhD

LBNL
2008 Xiangming Sun, PhD
2007 Sarah Blyth, PhD
2007 Mark Horner. PhD
2003 Vladimir Morozov, PhD

LPP, JINR
2006 Alexei Zubanov, B.S.

103 Ph.D degrees
21 other degrees
(Since last review: 25)

STAR continues to do an excellent job of educating the next generation of physicists!

Blue = awarded 2007 - 2008

Publications

Total # of refereed publications: 84 !

- *Phys. Rev. Lett*: 40, *Phys. Rev*: 33, *Phys. Lett. B*. 7, *J. Phys. G*: 3, *Nucl. Phys. A*: 1

Total # of citations: 6627 !

Number of Renowned (500+) 1 **8th most cited paper in all nucl-ex**
Number of Famous (250-499): 6
Number of Very Well Known (100-249): 11
Number of Well Known (50-99): 20

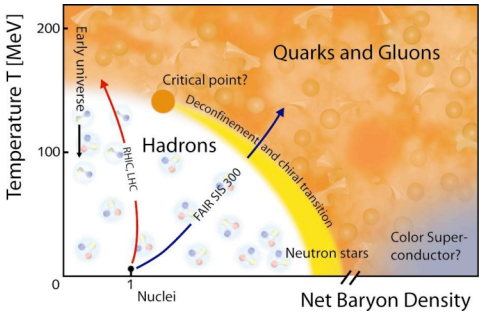
Total # of publications since last review: 12 !

- *Phys. Rev. Lett*: 4, *Phys. Rev*: 8 and 5 manuscripts are in referee process.

Total # of Quark Matter 2008 talks: 24 !

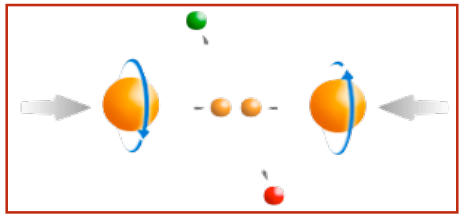
STAR is very productive!

STAR Physics Focus at the QCD Lab

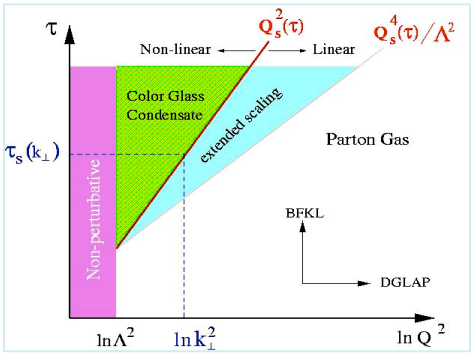


1) **Heavy-ion program**
   - Study ***medium properties, EoS***
   - pQCD in hot and dense medium

2) **RHIC beam energy scan**
   - Search for ***critical point***
   - Chiral symmetry restoration



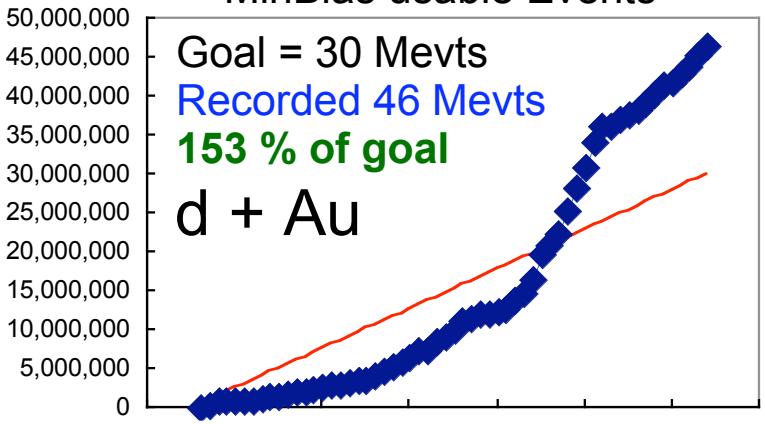
Polarized spin programs
   - Study ***proton intrinsic properties***



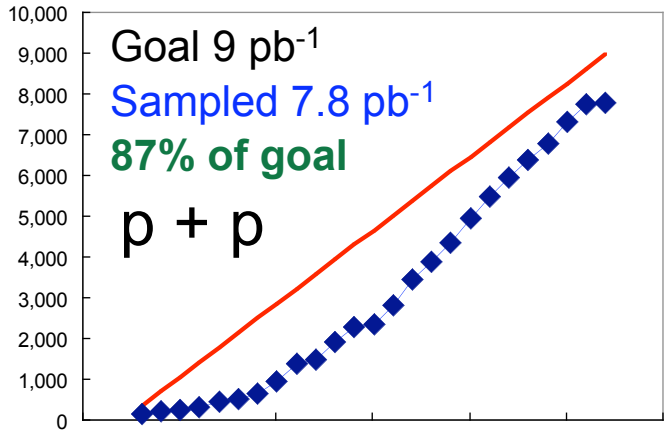
Forward programs
   - Study low-x properties and search for ***CGC***
   - Study elastic and inelastic processes (pp2pp)
   - Investigate ***gluonic exchanges*** and search for ***gluonic matter***

Run 8: d-Au and Polarized p+p

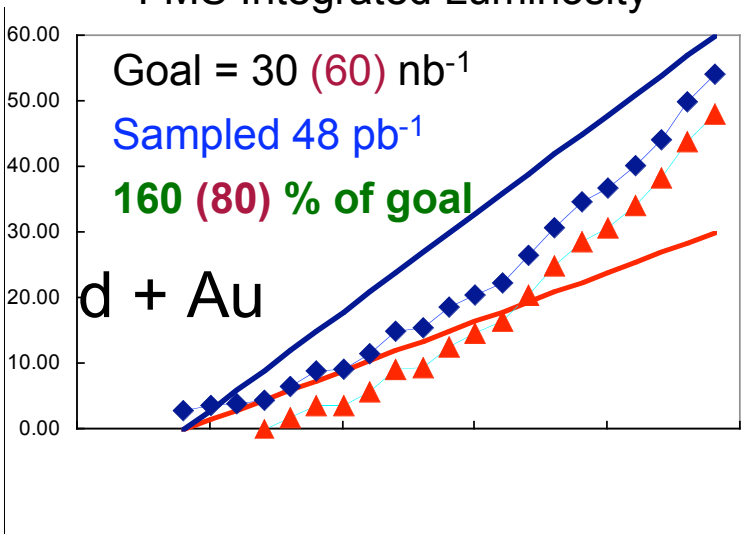
MinBias usable Events



Integrated FMS Luminosity (nb^{-1})



FMS Integrated Luminosity



See B. Christie talk

I. d+Au run: **Success!**

II. Polarized p+p run:

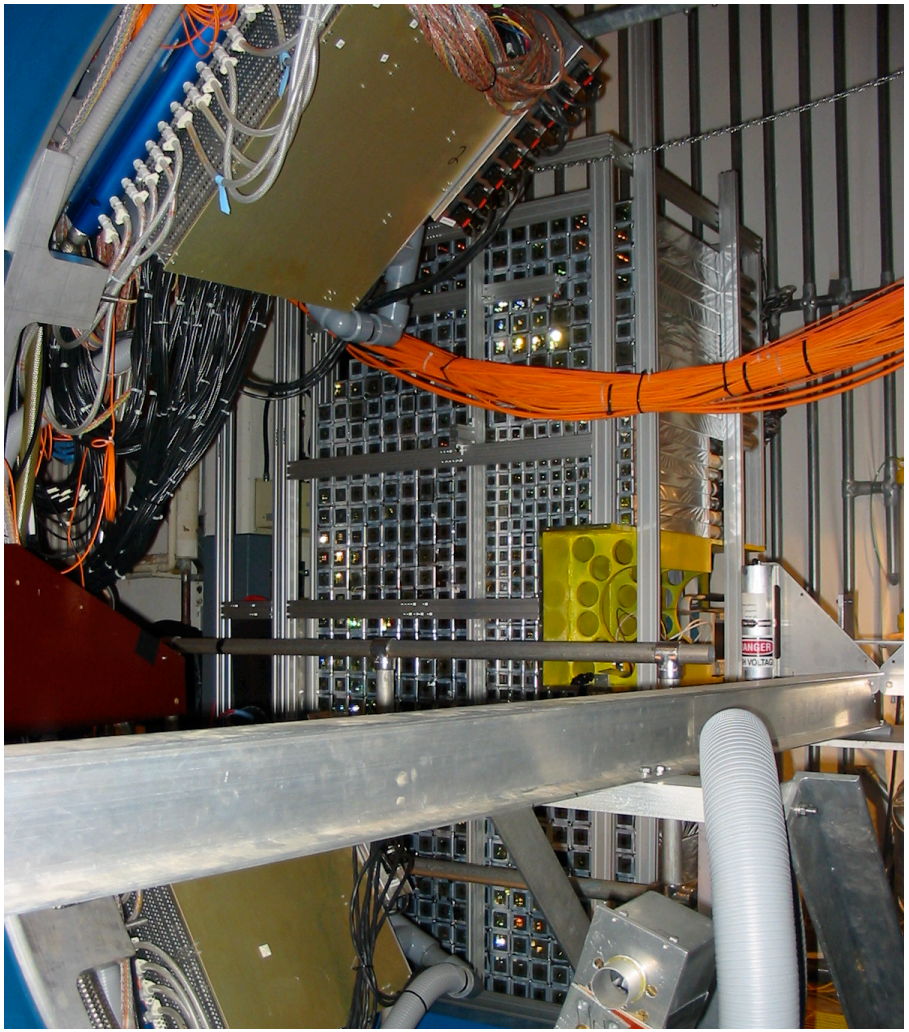
(1) FMS CGC reference data: **Good**

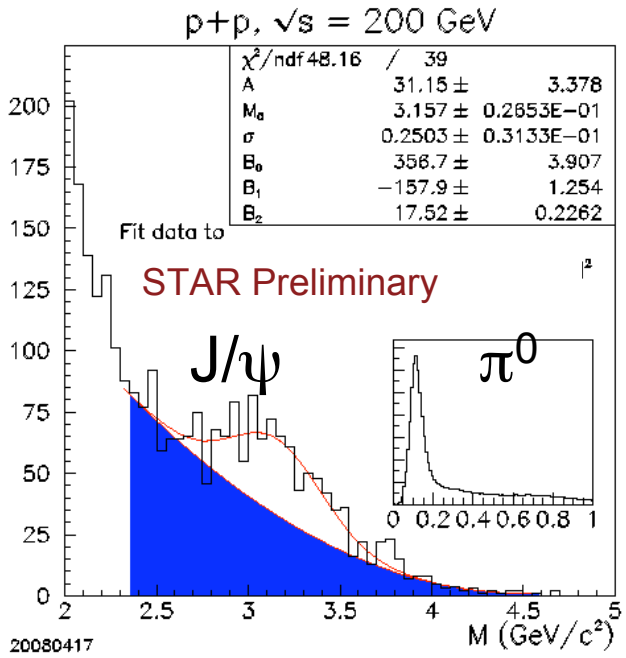
(2) Forward A_N (x_F, p_T): **Short of what we had intended to achieve**

(3) Forward direct photon asymmetries: **Not enough**

(4) Electrons from Charm and Bottom, with low material, to resolve STAR/PHENIX discrepancy: **Good**

Forward Meson Spectrometer (FMS)



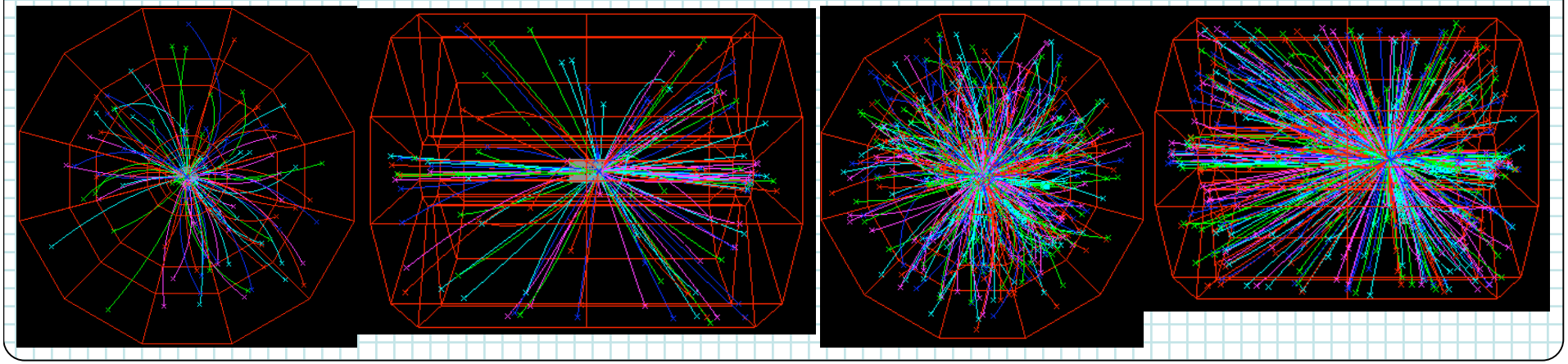


- **CGC, A_N, $\Delta G(x < 10^{-3})$**
- FMS important for all physics topics
- The ***1st of the suite of new upgrades*** in the BNL mid-term plan which was successfully completed from the BNL base budget and is now already taking important physics data.

See B. Christie talk

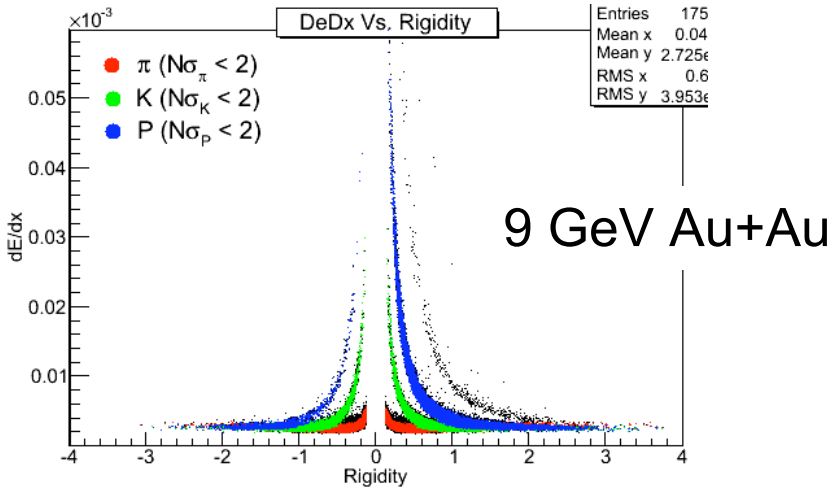
Low Energy Test Run (9 GeV)

Au + Au Collisions!



1) **~ 3500 collisions collected**
2) **Determine Luminosity**
3) **STAR has preliminary results on:**

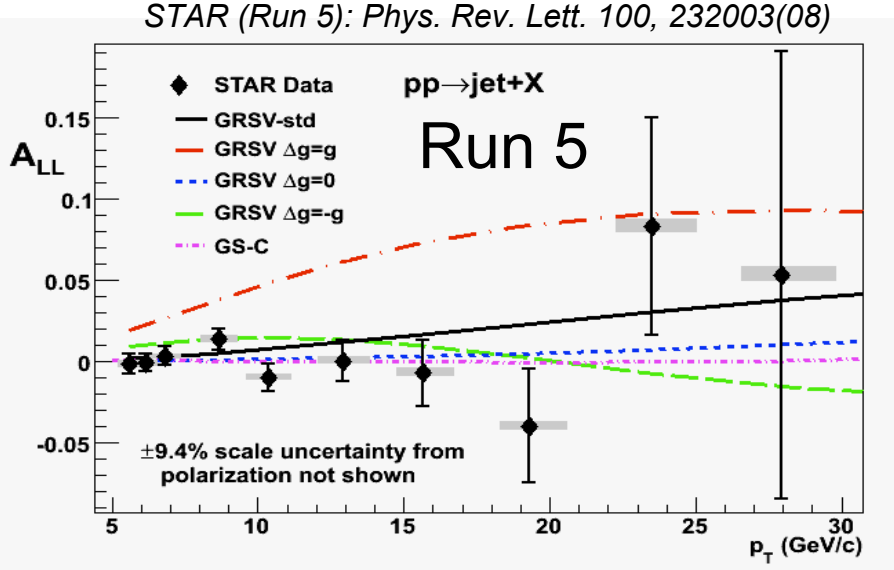
   Particle identification in TPC; charged multiplicity, π-π interferometry, particle ratios; v_1 and v_2



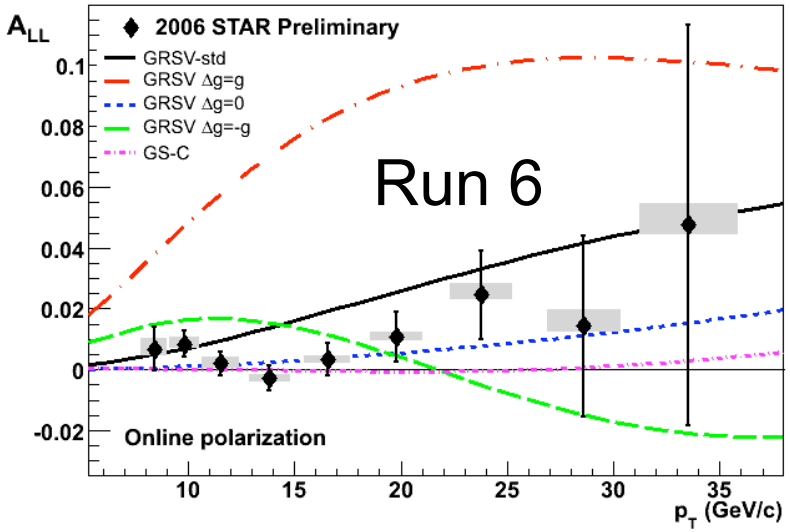
PID will be significantly extended using full TOF

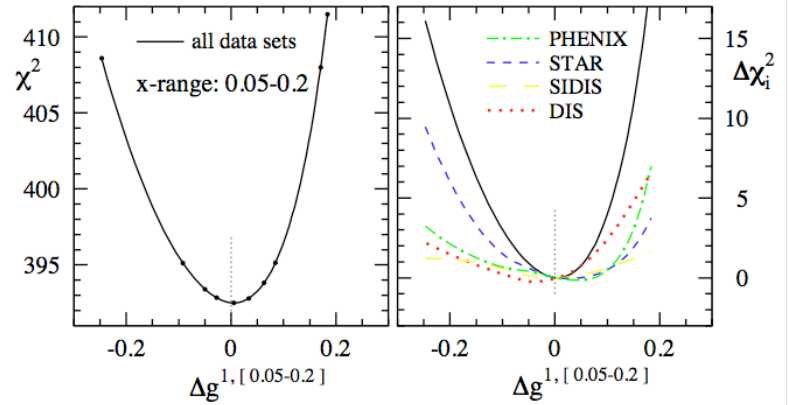
STAR Spin Results

STAR (Run 5): Phys. Rev. Lett. 100, 232003(08)



STAR (Run 6, 8.5pb^{-1}): Preliminary





de Florian et al, arXiv: 0804.0422

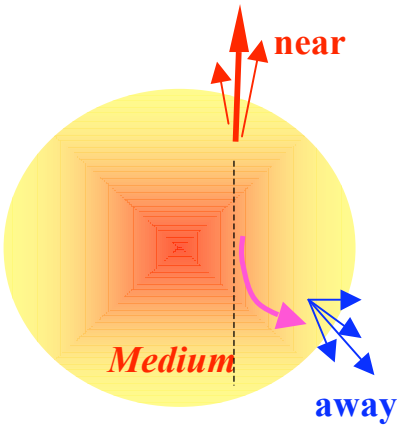
- The A_{LL} measurements for inclusive jets have gained significant precision and kinematic reach from Runs 3 & 4 to Run 5 (published) and, once more, to Run 6.

- **Placed significant new constraints on the magnitude of ΔG** for $0.02 < x < 0.3$. Our most precise data to date (Run 6) ***remain statistics limited***.

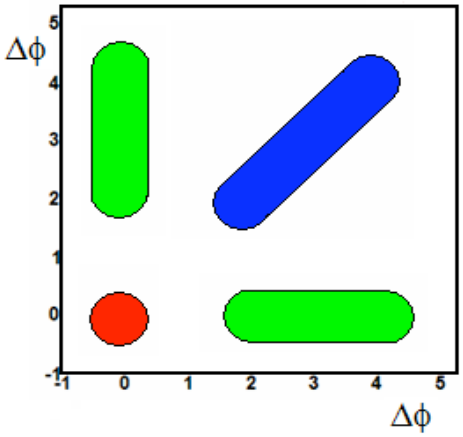
Search for Mach Cone

with Three Particle Correlations

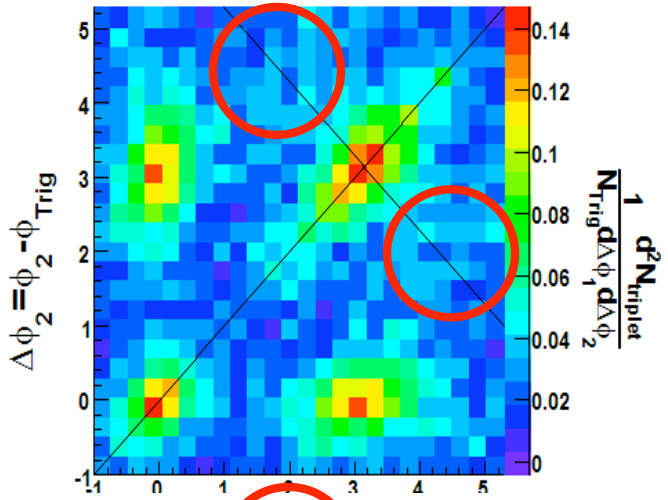
STAR: sub. to PRL, arXiv: 0805.0622

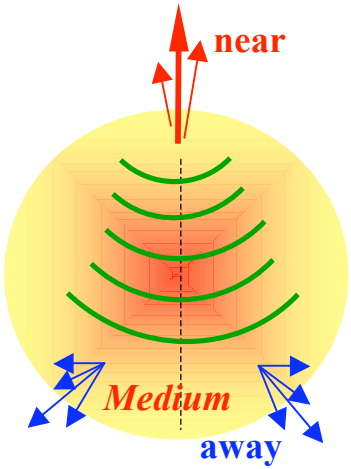


deflected jets

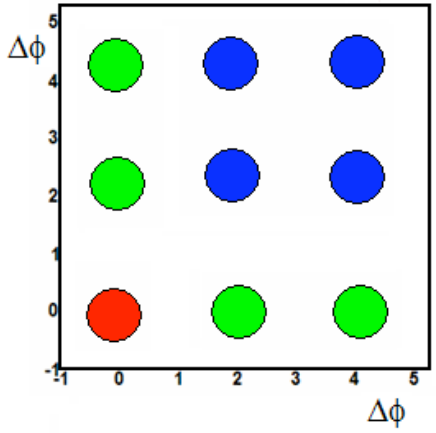


d+Au



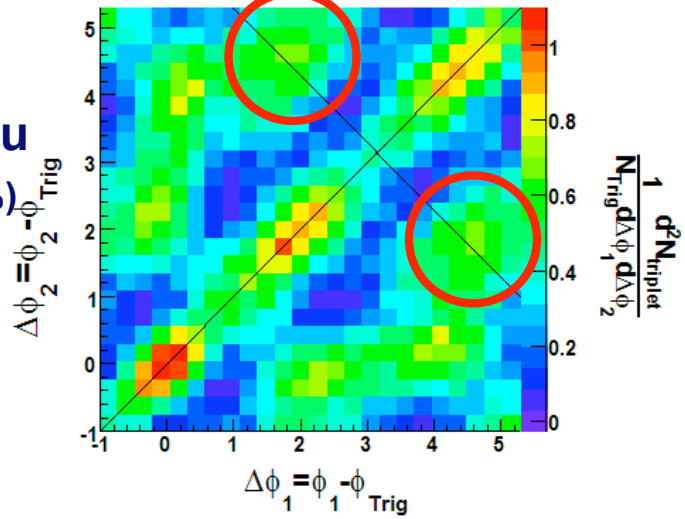


Conical Emission



Au+Au

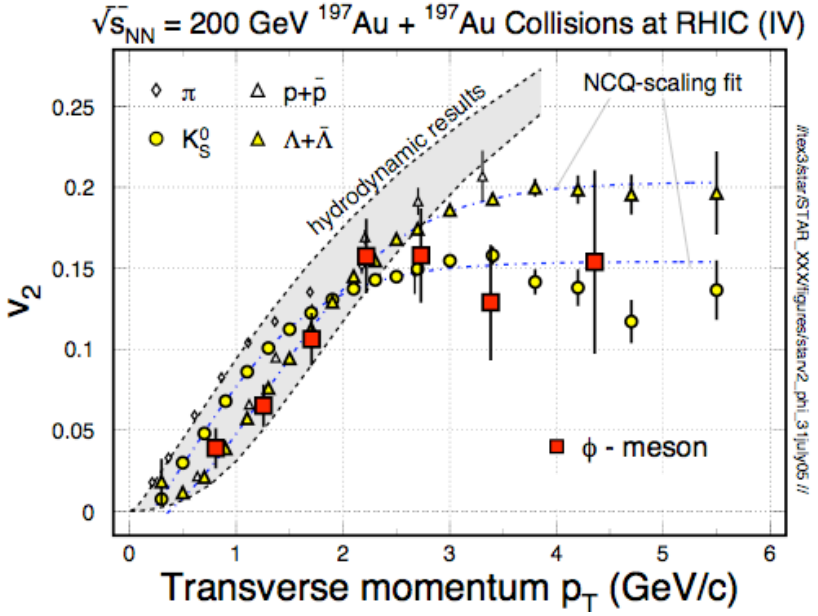
(0-12%)

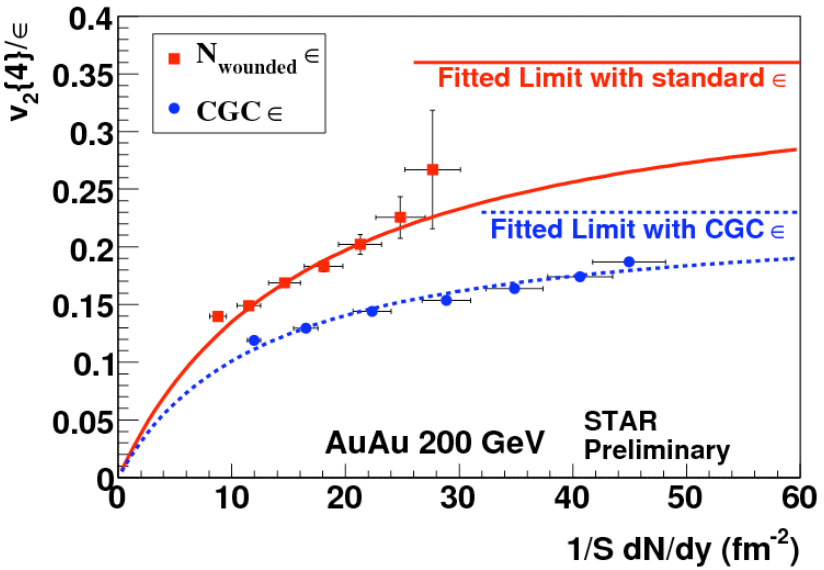


$$\cos\vartheta^{Mach} = \sqrt{p/\varepsilon}$$

"Evidence of conical emission …"

Recent Bulk Results at STAR





Phys. Rev. Lett. ***99*** (2007) 112301// * STAR, Duke, TAMU

$$\frac{v_2}{\varepsilon} = \frac{h(1/S,\varepsilon)}{1+1.4K}$$

K: Knudsen number
h: hydrodynamic limit

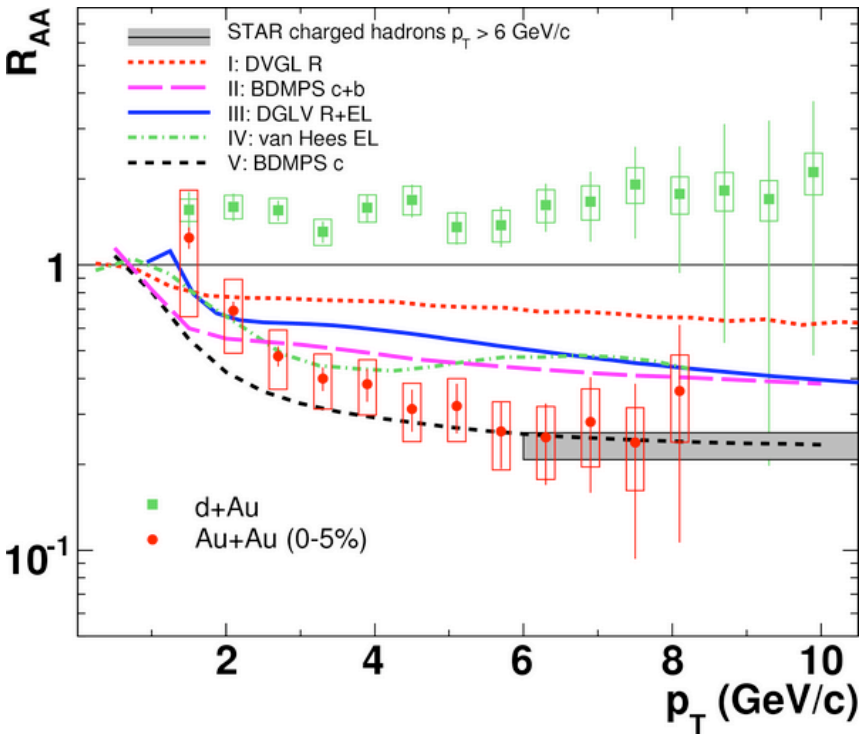
(i) Strong collectivity; (ii) Jet quenching; (iii) N_Q scaling
⇒ ***hot and dense matter with partonic collectivity*** **at RHIC!**

⇒ ***In order to understand energy loss and test early thermalization at RHIC, precision c- and b-hadrons data are needed!***

⇒ ***Using heavy quarks to probe medium properties!***

Heavy Quark Energy Loss at RHIC

STAR PRL, 98, 192301 (2007)



1) Non-photonic electrons decayed from - charm and beauty hadrons

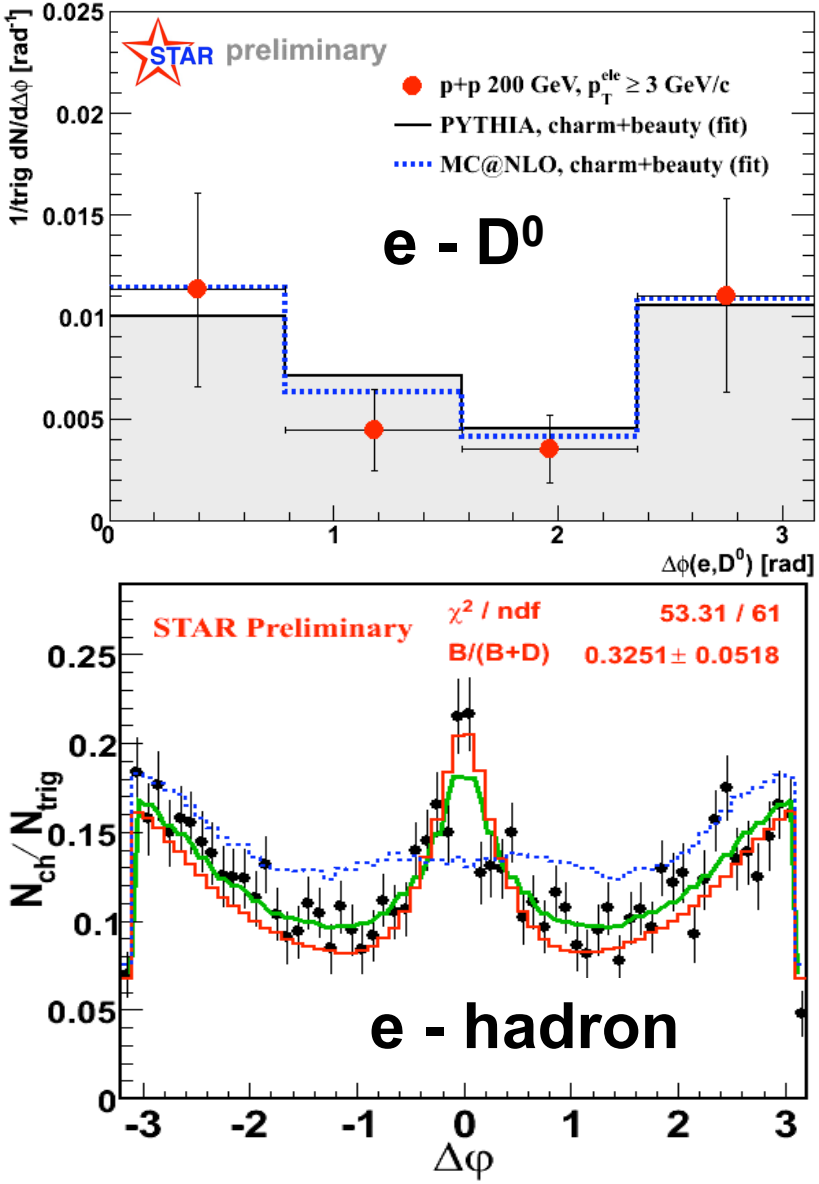
2) At $p_T \geq 6$ GeV/c,

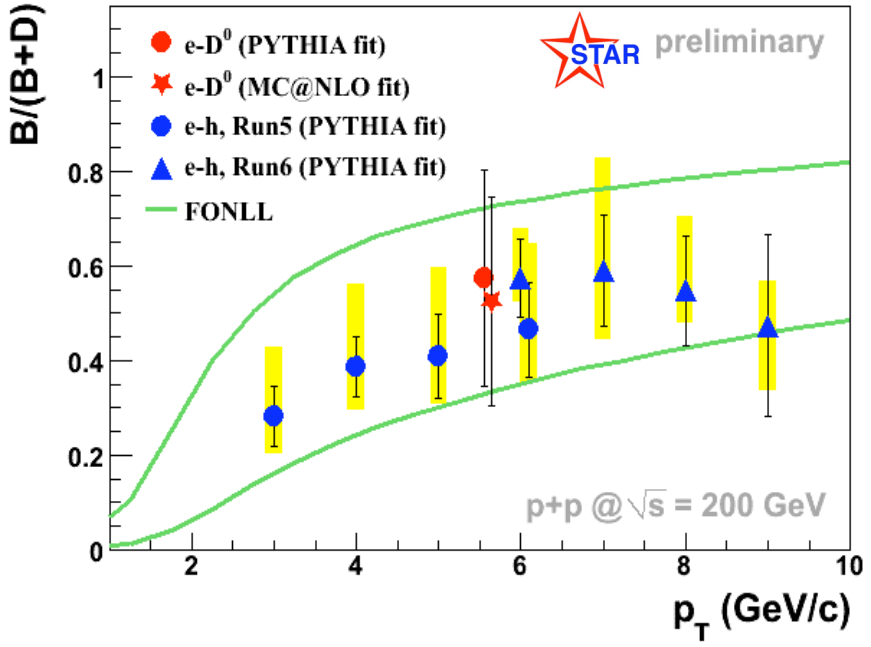
$R_{AA}(n.e.) \sim R_{AA}(h^{\pm})$!

contradicts to naïve pQCD predictions

Surprising results -
- challenge our understanding of the energy loss mechanism
- force us to RE-think about the collisional energy loss
- **Requires direct measurements of c- and b-hadrons.**

Identify *b* Contributions at RHIC



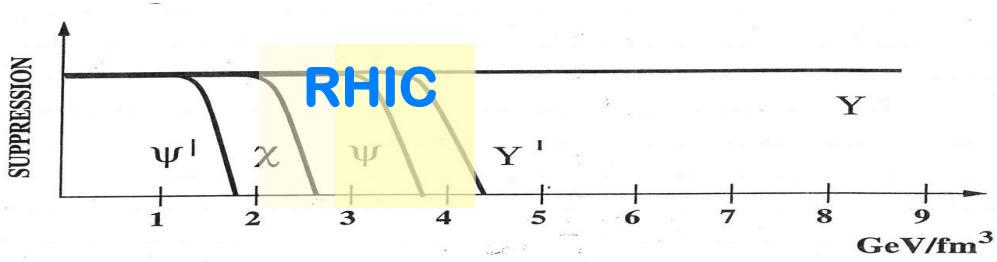


Both *e-hadron* and *e-D⁰* results are consistent

FONLL calculations are consistent with data

⇒ **Significant *b* contribution when p_T > 4 GeV/c!**

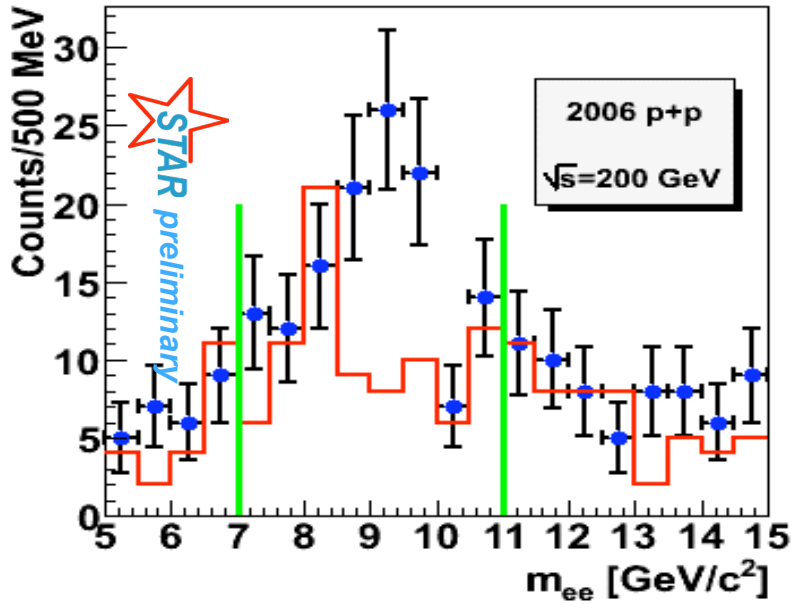
Extending to Higher Mass: Υ



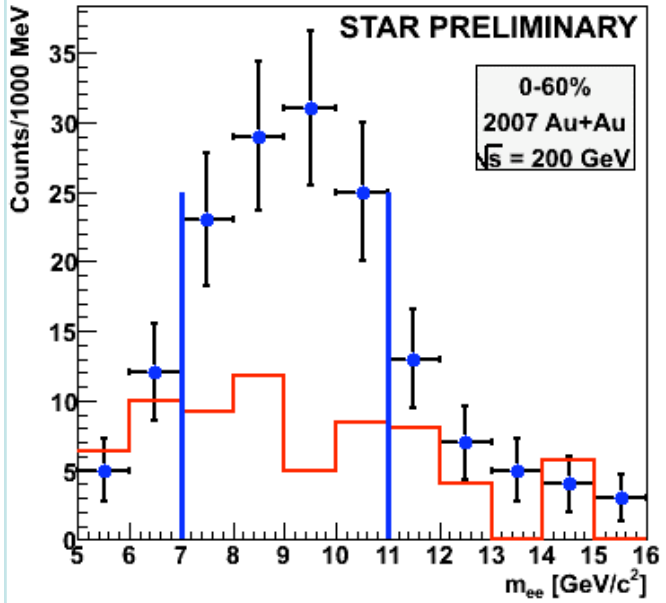
Sequential dissociation of quarkonia is sensitive to energy density of plasma

Υ (1S+2S+3S) $\longrightarrow$ e^+e^-

Run 6: 200 GeV p+p



Run 7: 200 GeV Au+Au

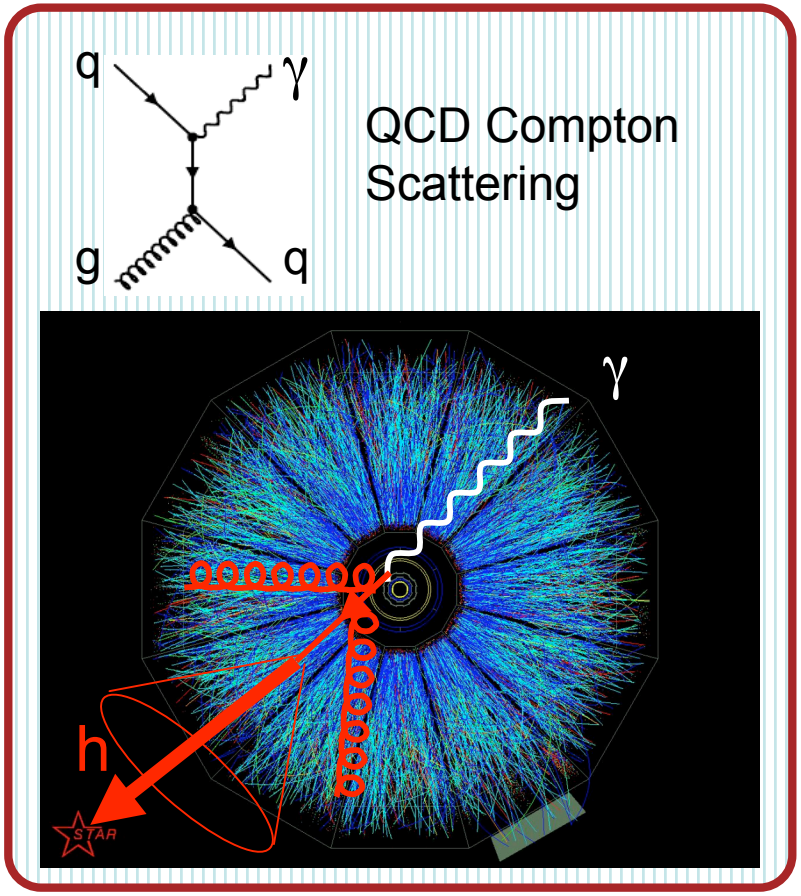


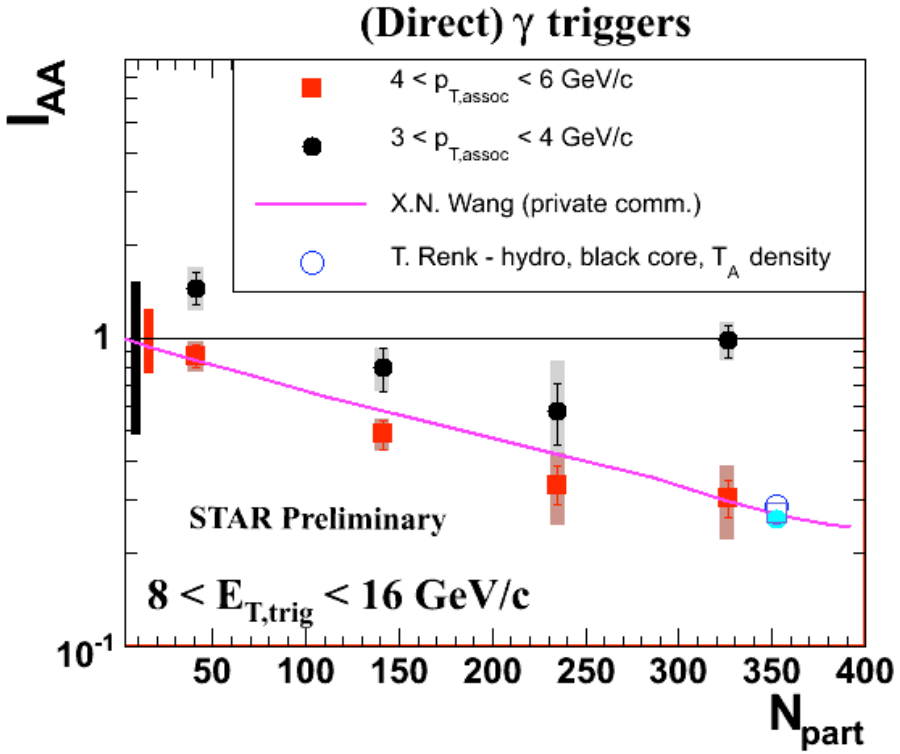
STAR high p_T topological electron trigger works!

pQCD calculations are consistent with data!

γ-Jet Measurement in STAR

"Golden Probe" of QCD Energy Loss

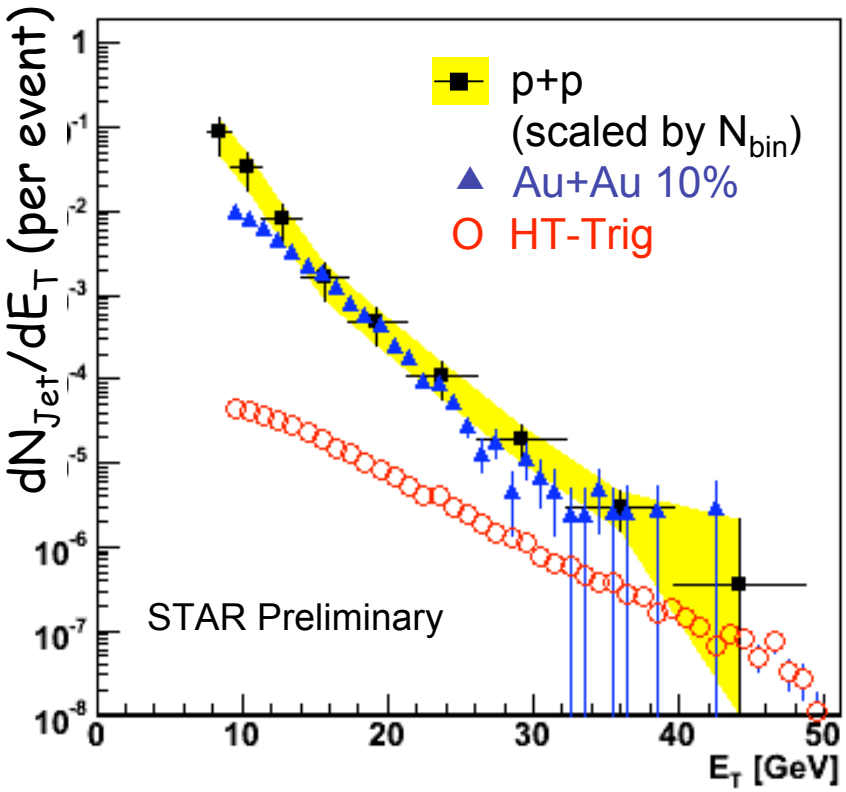




- This probe is valuable for comparison with di-hadron correlations
- Goal:Full reconstructed kinematics: real fragmentation function D(z)

Wang et al., Phys.Rev.Lett. 77, 231(1996)

Reconstructed Jet in Au+Au Collisions



Leading Order High Seed Cone(LOHSC)
R=0.4, p_T = 1 GeV/c, seed = 4.6 GeV/c
Statistical errors only.

MB-Trig: Good agreement with N_{bin} scaled p+p collisions

HT-Trig: Large trigger bias persists at least to 30 GeV.

Relative normalization systematic uncertainty: ~50%

Resolution effect corrected assuming Pythia fragmentation.

Further statistics of MB is needed to assess the bias in HT Trigger.

First step towards jet reconstruction in heavy ion collisions.

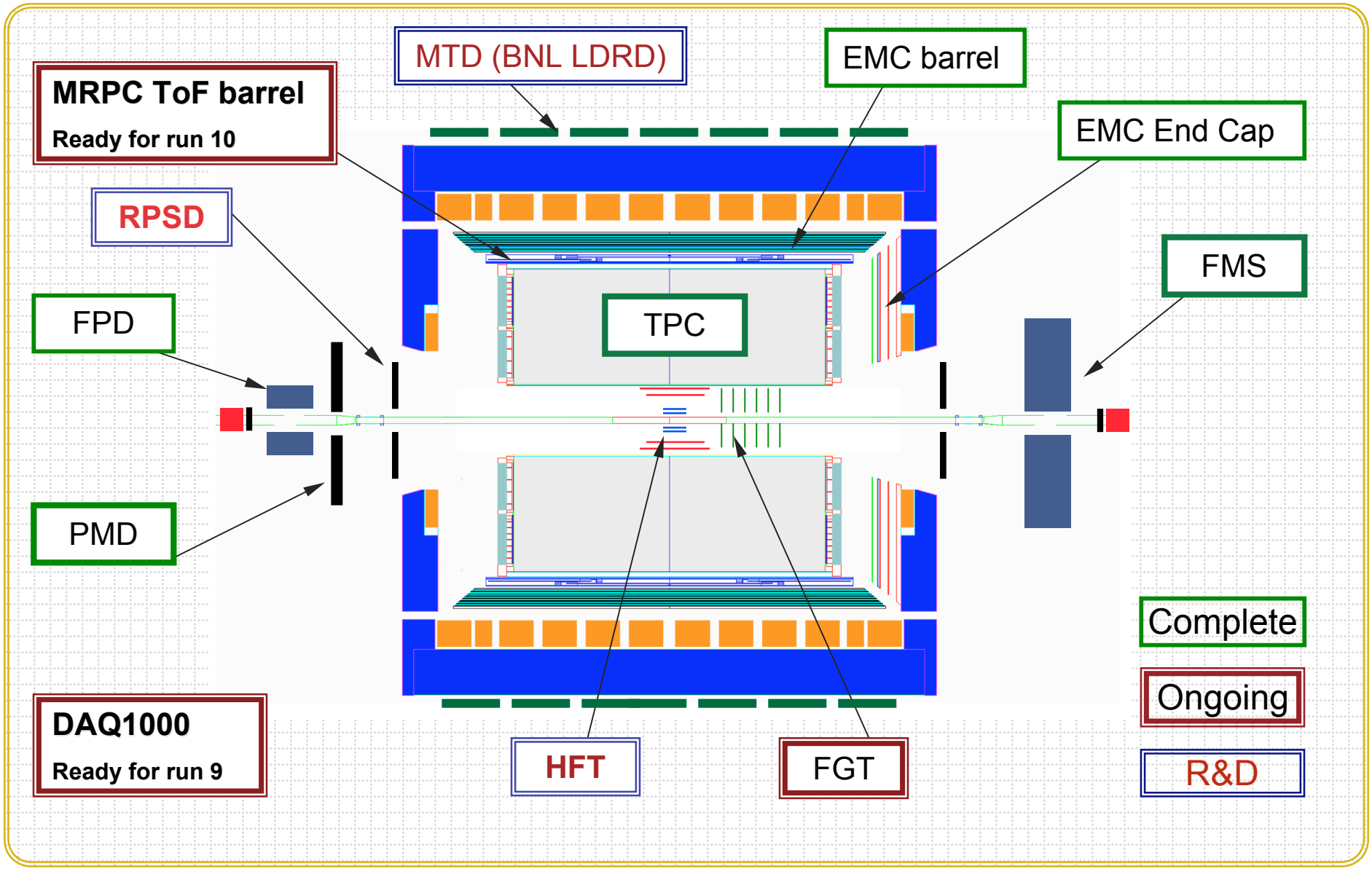
Computing Achievements at STAR

1) Homogenous framework for both offline and online (DAQ)
   - Full integration achieved by the end for Run 8
   - Allowing addressing advanced tasks seamlessly such as
     Quasi-online, offline high level trigger
     Automated calibration, automated quality assurance

2) Grid job stability outstanding
   - Efficiency > 97%
   - All Monte-Carlo have moved to a Grid-based operation

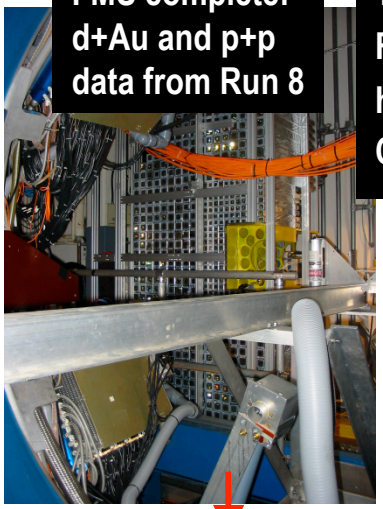
3) Actively pursing remote computing site for STAR's needs
   - KISTI: Network tuning (almost like NIP/Prague experience) underway; Data transfer in near real-time

STAR Detector and Upgrades

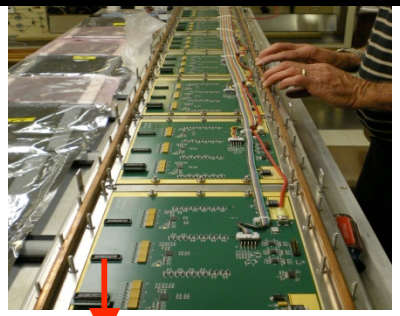


The STAR Upgrade Plan

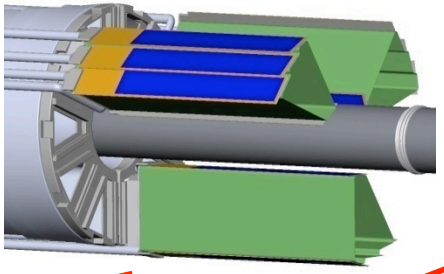
FMS complete:
d+Au and p+p
data from Run 8



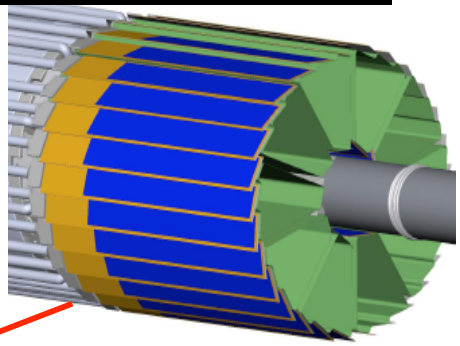
TOF complete:
Full azimuthal PID for charged hadrons in the STAR acceptance
Clean $e^{\pm}$ $\mu^{\pm}$ ID down to low p_T



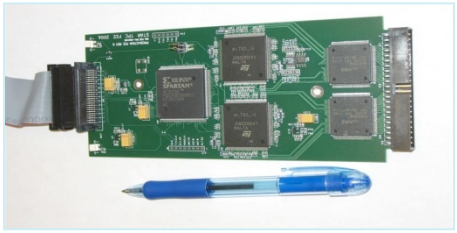
HFT partial implementation



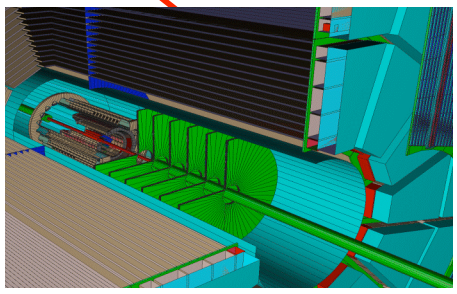
HFT complete:
Full azimuthal and topological PID for Charm-hadrons.



Run08 Run09 Run10 ***Run11*** ***Run12*** ***Run13*** ***Run14*** ***Run15***



DAQ1000 complete:
Immediate improvement of 300% in sampled luminosity for rare probes (e.g. jets in p+p)

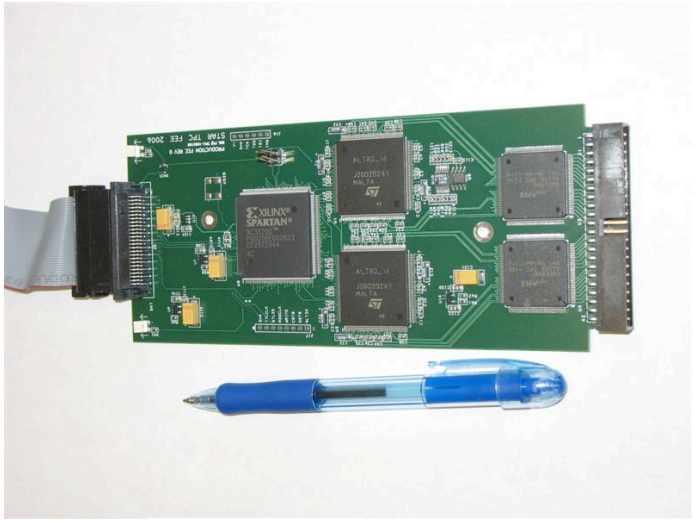


FGT complete:
Accurate charge sign Determination for W's.

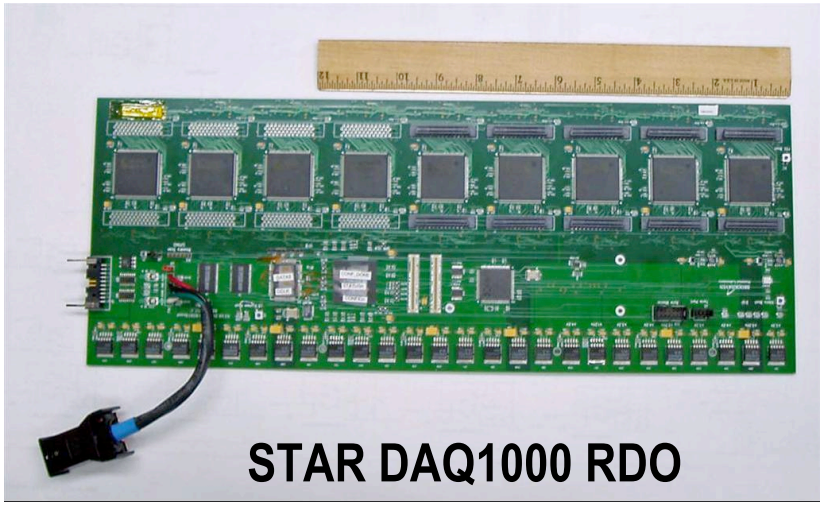
Upgrade goals:

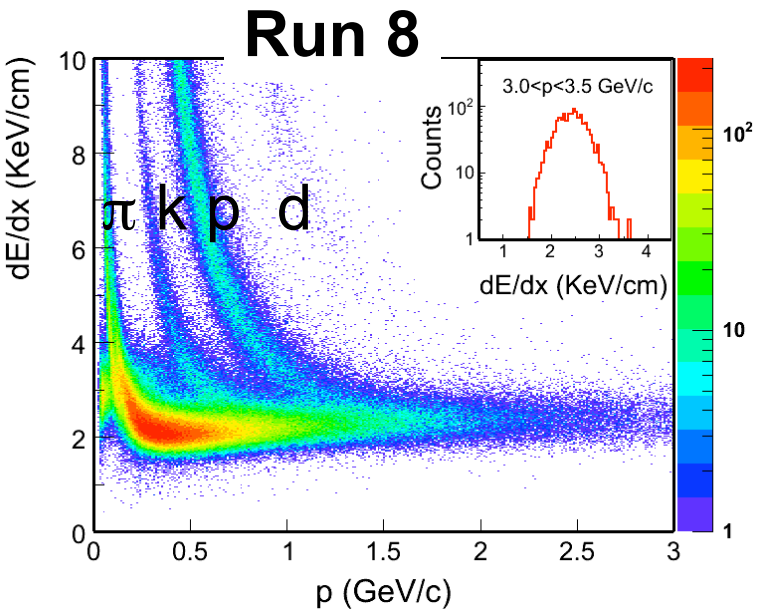
- Full azimuthal, high speed PID at the RHIC-II era
- Technically driven schedule

STAR DAQ1000



CERN/ALICE Altro chip development



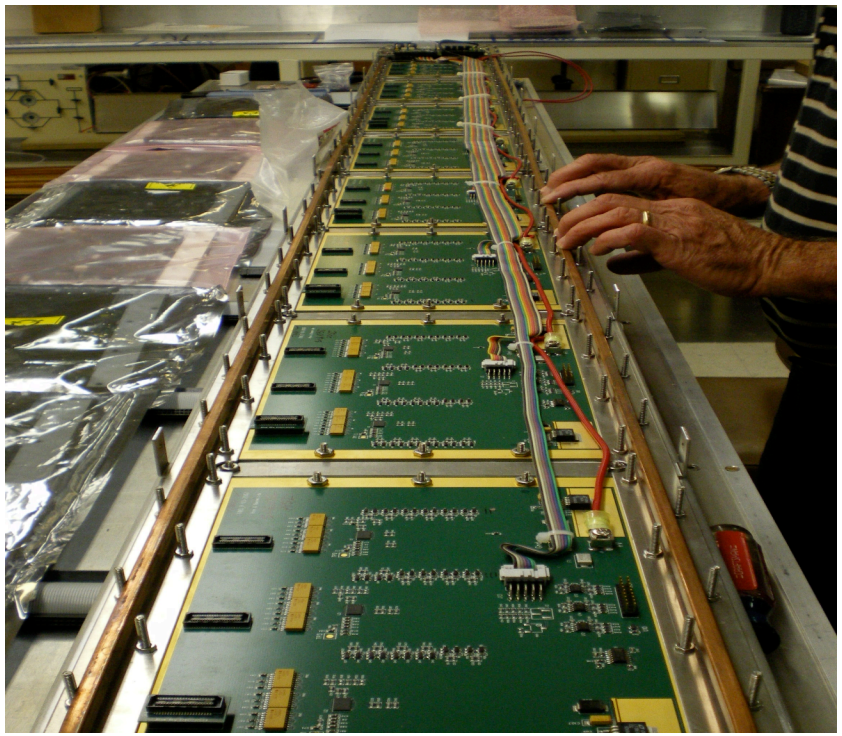


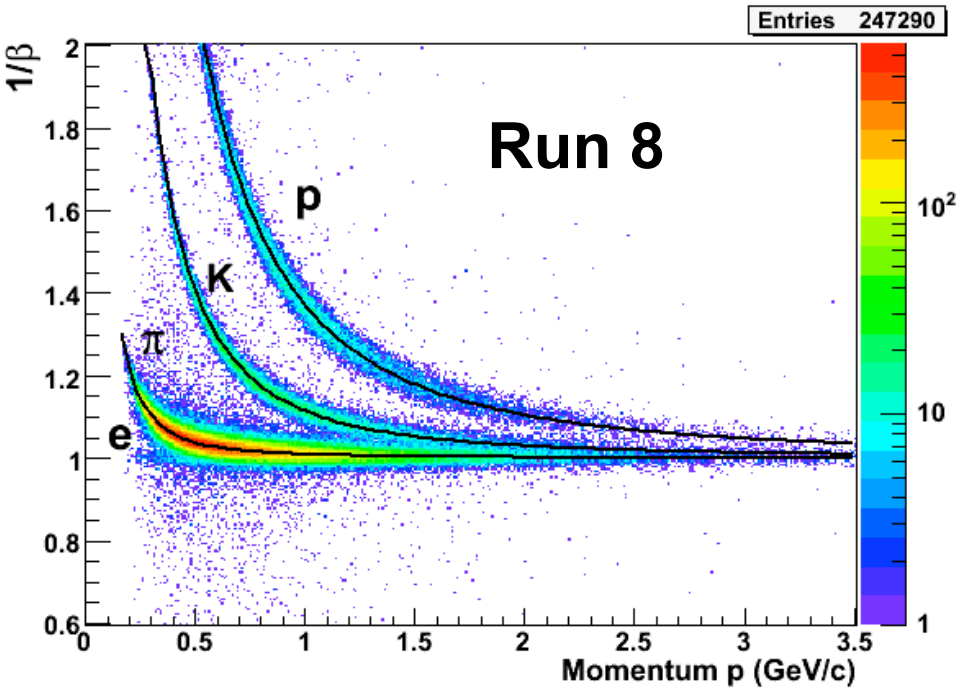
Run 8 tests:

- **One sector of the TPC (1/24) instrumented with DAQ1000 electronics**
- **Routine operation for physics.**
- **Speed test: operated at 1 kHz with only 5-7% dead time**
- **Full TPC will be instrumented before Run 9**

See B. Christie talk

STAR MRPC ToF





Run 8 test:

- Five trays of ToF system installed, commissioned, and used for physics
- Behind sector with DAQ1000 TPC electronics. Routine operation for physics.
- **90 (of 120) ToF trays to be installed for Run 9 and the full ToF (120) will be completed before Run 10**

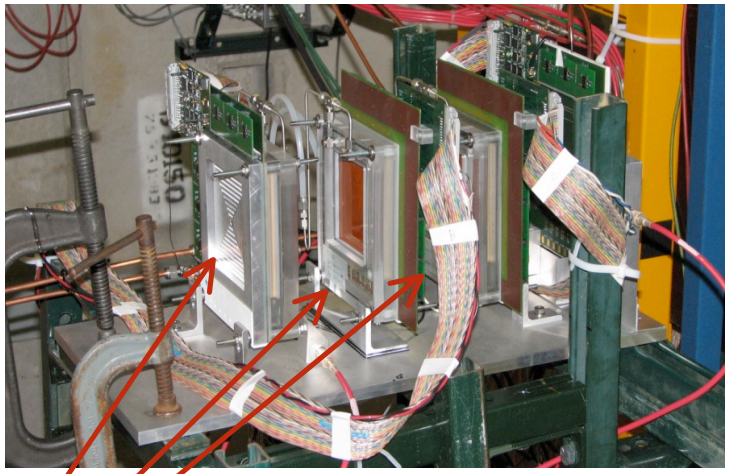
See Ed O'Brien talk

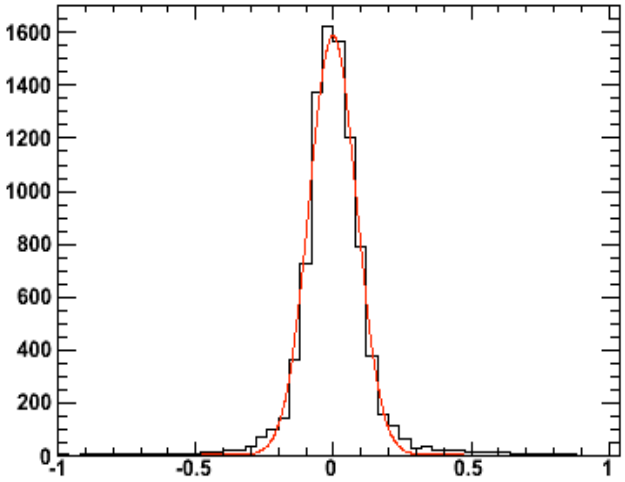
FGT Layout / GEM Technology

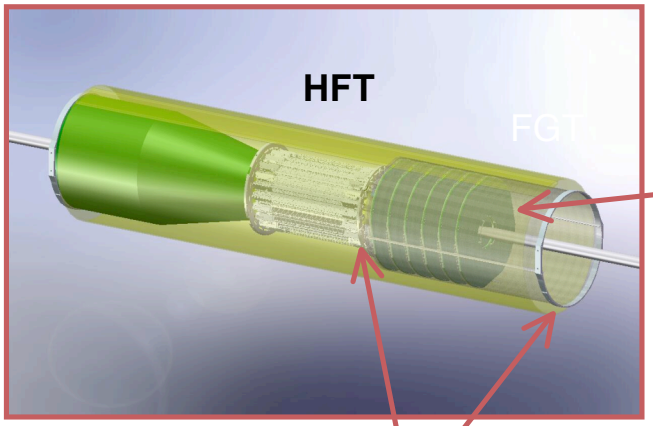
SBIR proposal (Phase I/II): Established commercial GEM foil source (Tech-Etch Inc.)

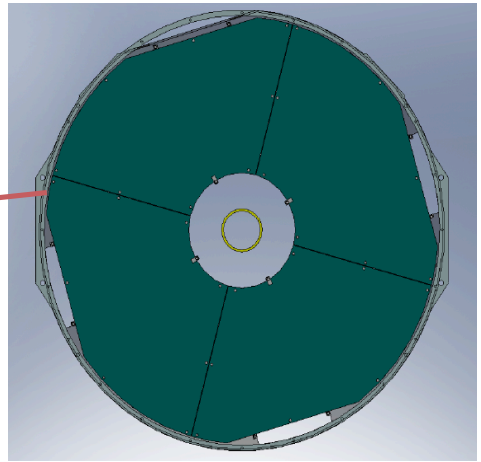
FNAL test beam of three prototype triple-GEM chambers including APV25 chip readout

Performance meets requirements!





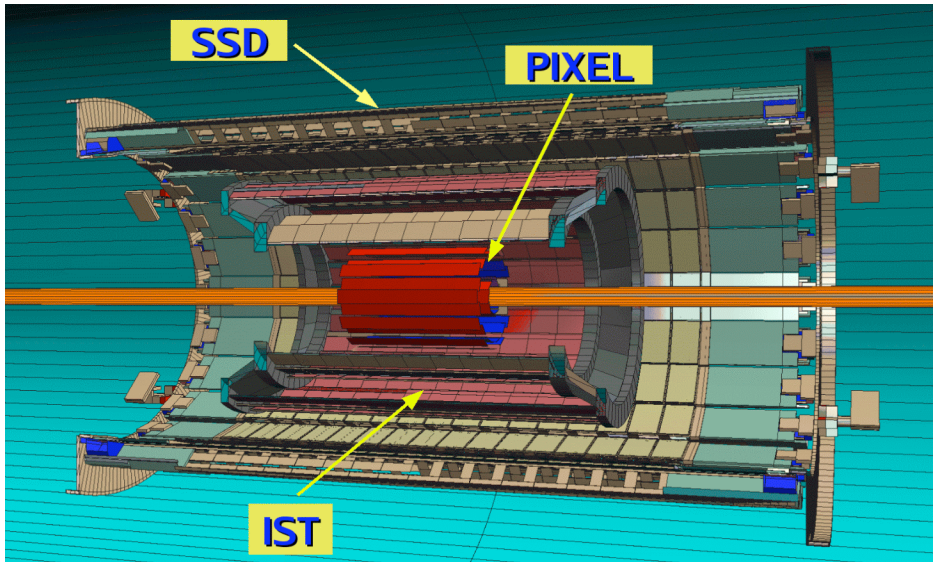




New WEST support structure

See Ed O'Brien talk

The Future of Heavy Quark Program



Direct reconstruction of charm hadrons:

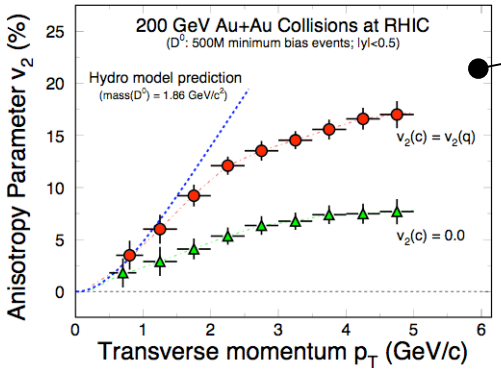
D^0, D^*, $D^{\pm}$, Λ_C

- σ_c, R_{AA} and v_2

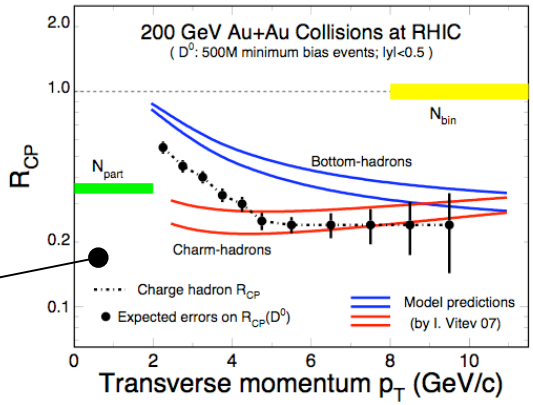
Essential for future RHIC heavy ion program!

Timely construction, to take advantage of the development of RHIC-II, is crucial for the STAR physics program.

v_2



R_{AA}



Technical Driven Schedule:

CD0 review: Feb. 08

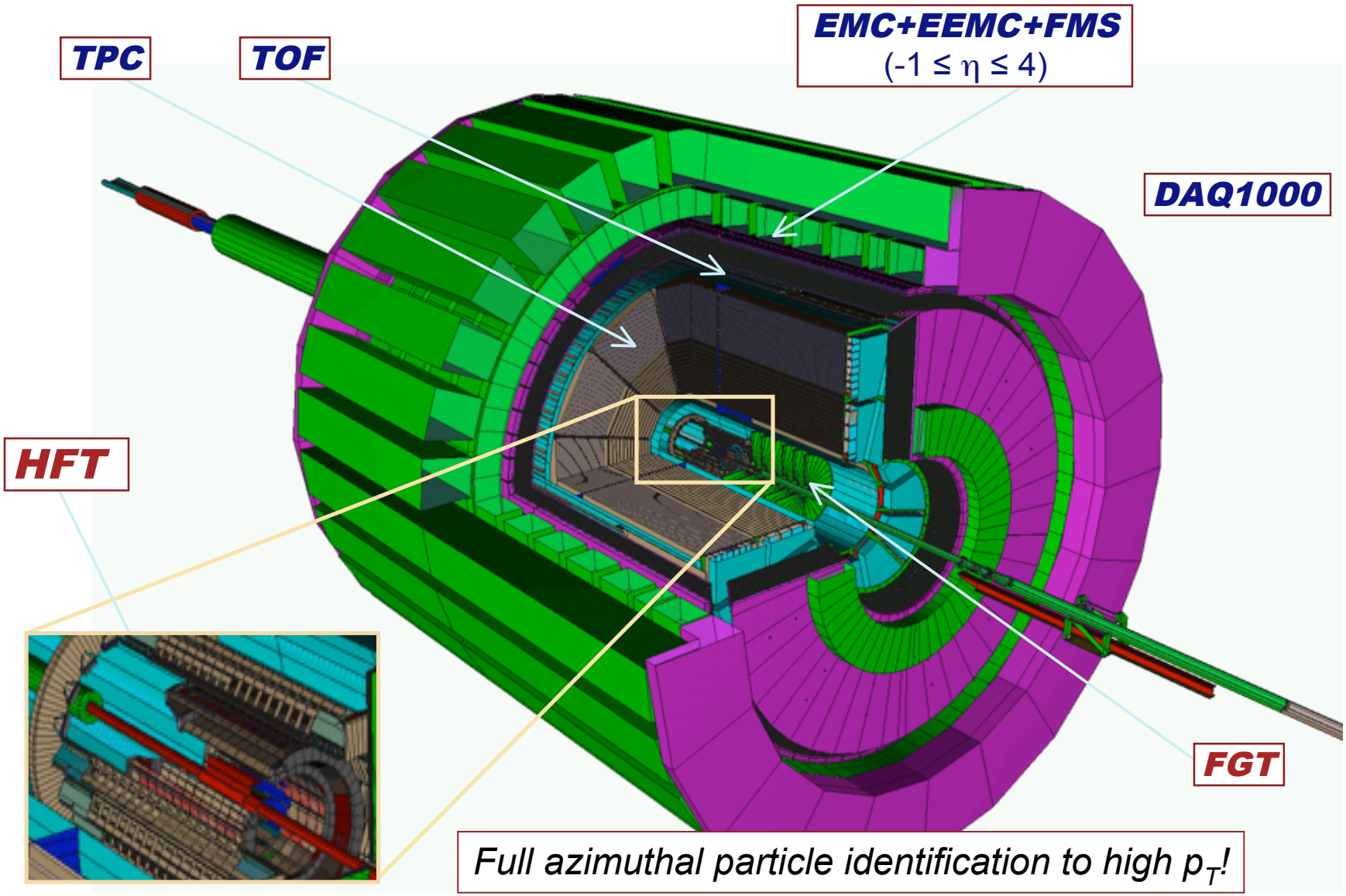
CD1 review: Oct. 08

CD2/3 review: Aug. 09

Completion: Sep. 13

See Ed O'Brien talk

STAR Detectors (*Full φ PID and fast!*)



3) Near Future Runs

STAR priorities for near future runs:

(1) 200 GeV longitudinally polarized p+p collisions
- $\Delta g(x)$, ***FOM = P^4L = 6.5 pb^{-1}***

(2) 500 GeV longitudinally polarized p+p collisions

FOM = P^4L ~ 1.5 pb^{-1}

First measurement of A_{LL} for inclusive jets

First measurement of A_L for mid-y W production (W^+)

(3) Beam energy scan down to $\sqrt{s_{NN}}$ ~ 5-6 GeV

- Search for the QCD phase boundary and tri-critical point

* Very high priority for STAR physics program
Closely working with C-AD to assure the low energy runs

(4) 200 GeV Au+Au collisions (low material run)

200M central events / 300M M.B. events / 2 nb^{-1} trigger events

High p_T J/ψ and v_2 of J/ψ

Jet trigger multi-hadron correlation, PIDed correlations

Starting the di-electron invariant mass program

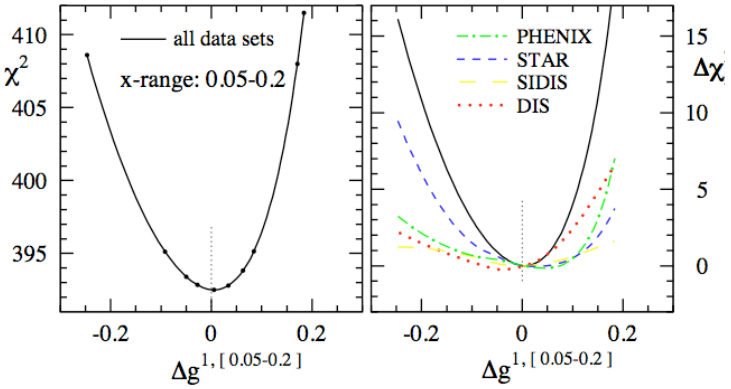
Global Fits with Inclusive RHIC Data

Goals for taking: Run 9 ~ 16* Run 6

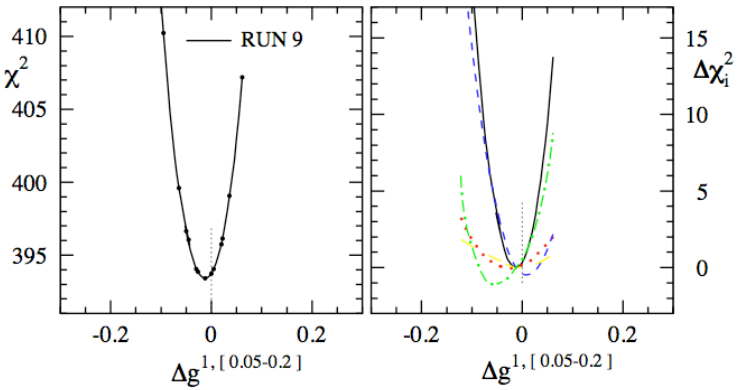
Run 9: STAR bottom line is to collect FoM: 6.5 pb^{-1}

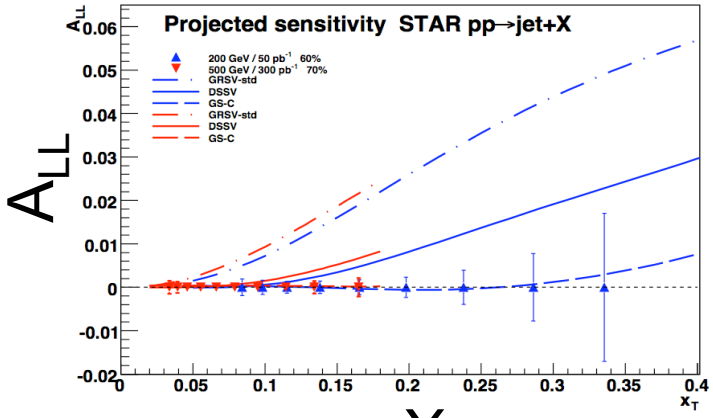
inclusive jet, di-jets, γ-jet… analysis

Run 6



Run 9



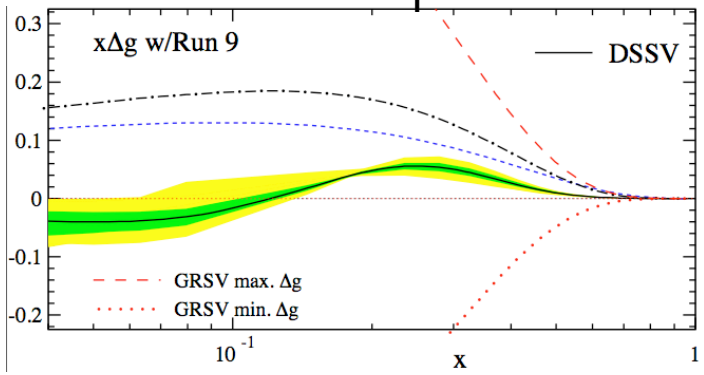


Run 9

200 GeV

500 GeV

X_T



de Florian et al, arXiv: 0804.0422

4) Concerns

R&D and CE Funds

1) R&D Funding far below the funding targets in last mid-term plan

	FY2006	FY2007	FY2008
Requested ($M)	0.5	1.2	1.3
Actual ($M)	0.35	0.4	0.7

2) Sufficient capital equipment funding is crucial:

(i) Intermediate upgrades

- ***e.g.*** DAQ1000 was very successful
- FGT upgrade

(ii) Maintain and improving existing systems

- Need funds for *trigger electronics/readout* and SSD upgrades

4) Concerns

Support to university groups for detector operations and computing efforts is important.

Computing:

- Funding issues to remote institutions have cascading effect on BNL S&C team.
- Challenge manpower to absorb and maintain healthy activities for data production and software development at BNL.
- **Distributed resources are import, *e.g.* PDSF, 'KISTI'**

Operation:

- Replacement of key people (left the collaboration) for upgrades and computing should happen soon.

TPC operation Tsar:

- Blair Stringfellow, Purdue University, retired. An additional burden falls to BNL operation group.

See B. Christie talk

5) Summary

1) STAR: a successful experiment for scientific discovery and an institution for training a new generation of physicists.
2) Upgrades have progressed well. Rapid physics outputs from upgrades (TOF and FMS).
3) We have plan for future success but there are serious challenges: (i) the adequate and timely funding for both upgrade and operation; (ii) sufficient running time.

Many thanks to C-AD!

Many thanks to BNL operation group!

Many thanks to BNL management!