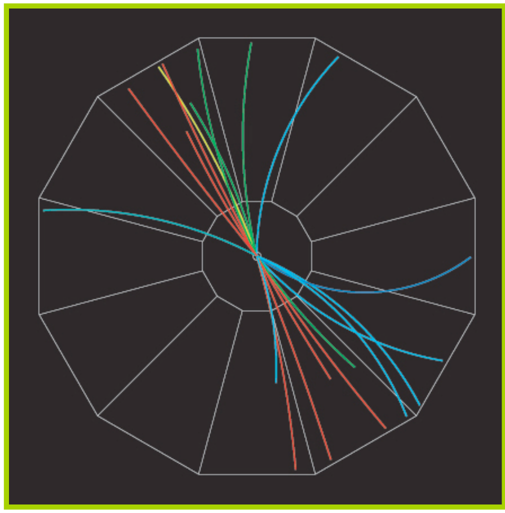
RHIC's View of Hadron Collisions

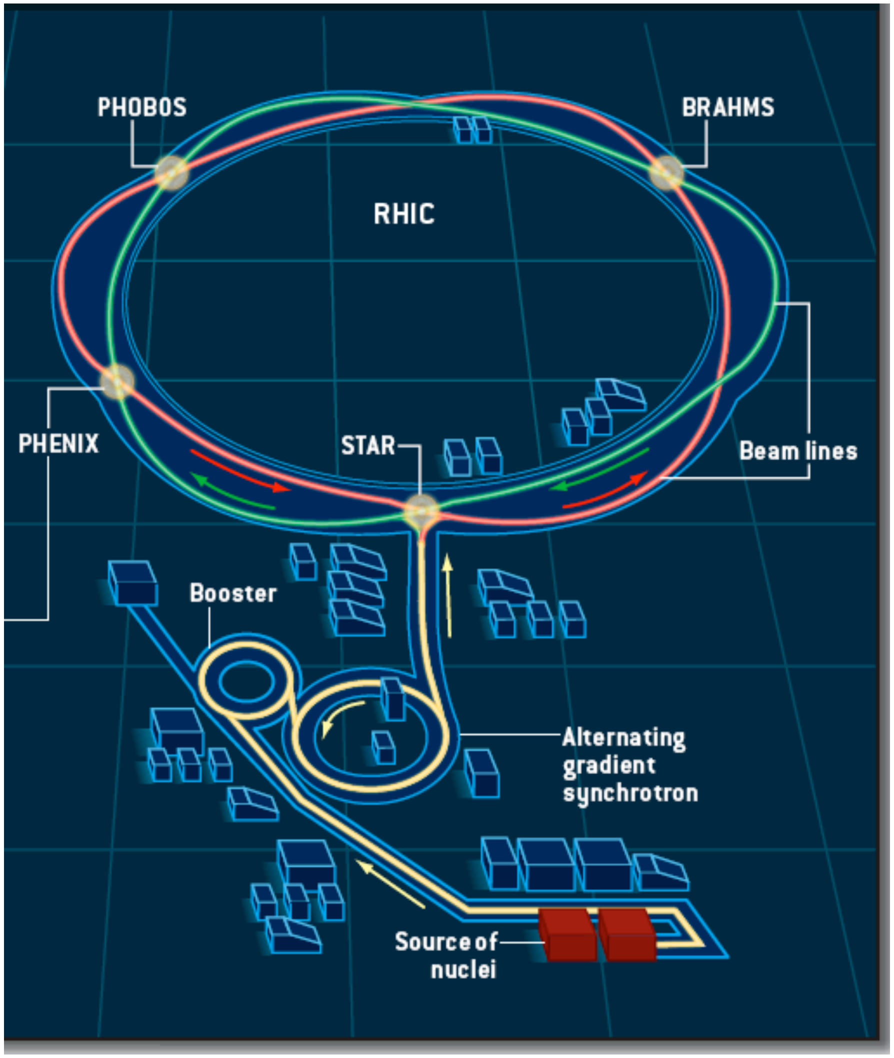


- P-P Collisions at RHIC
- STAR Detector and Triggers
- Hard Scattering at RHIC kinematics
- The STAR Jet-Finders
- Underlying Event at STAR

Renee Fatemi
For the STAR Collaboration

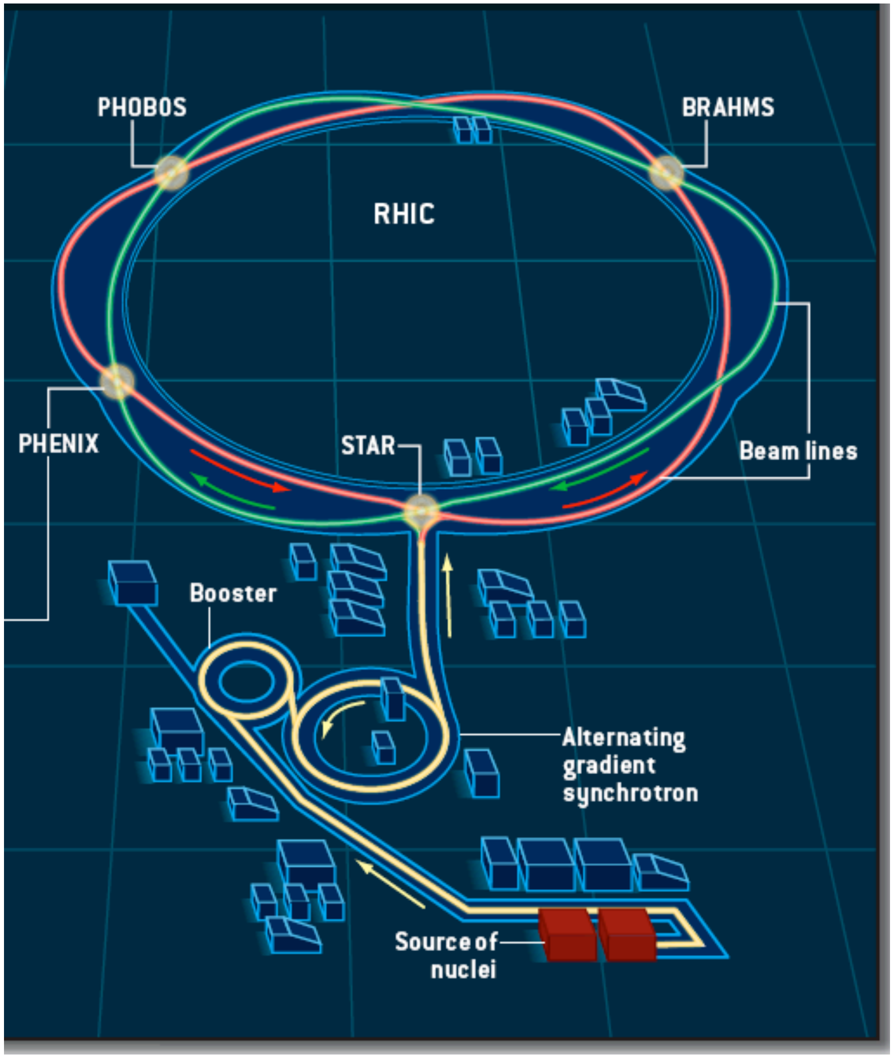
1st Joint Workshop on Energy Scaling of Hadron Collisions
April 27, 2009

Recipe for Proton Collisions @ RHIC



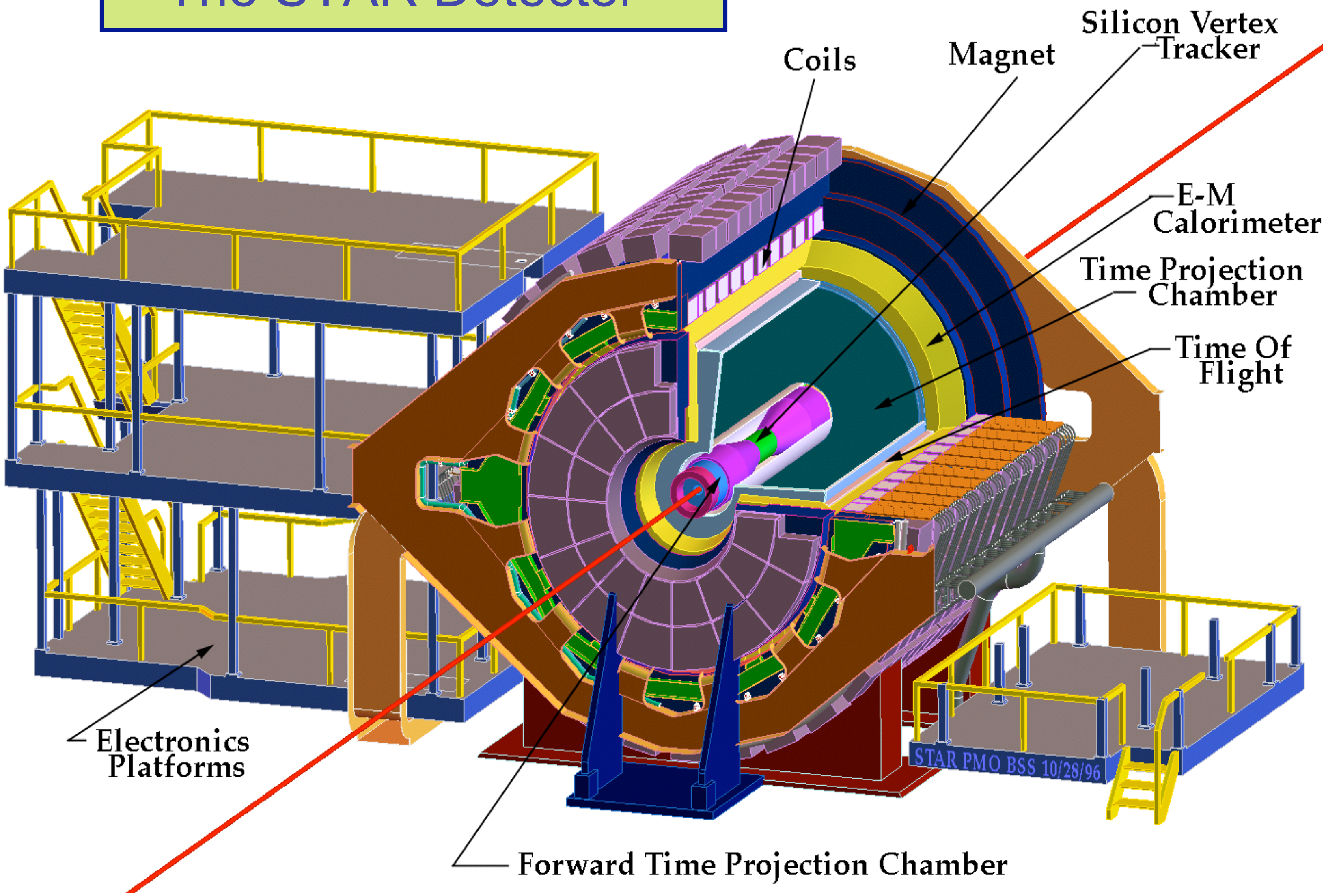
1. Take one optically pumped polarized H^- source
2. Accelerate ions in the linac
3. Strip ions and inject protons into fast cycling synchroton (Booster)
4. Accelerate protons to 2.35 GeV.
5. Inject protons into AGS and accelerate to 24.3 GeV.
6. Inject two protons into RHIC, filling BLUE and YELLOW beams
7. Accelerate to at least 100 GeV. (Just finished 250 GeV run!)
8. Steer for collisions at 2-4 IR
9. Serve immediately to hungry experimentalists.

Recipe for Proton Collisions @ RHIC

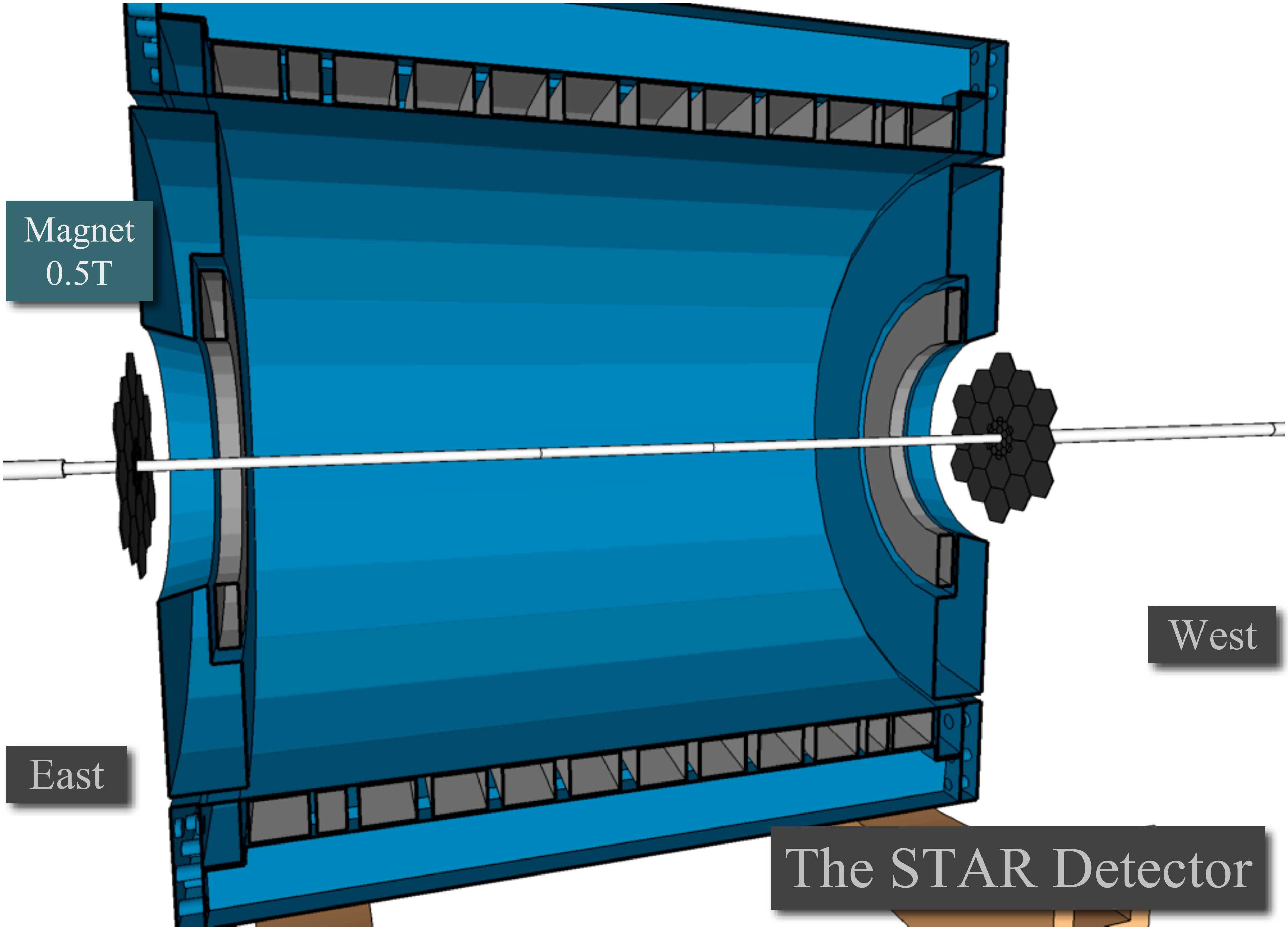


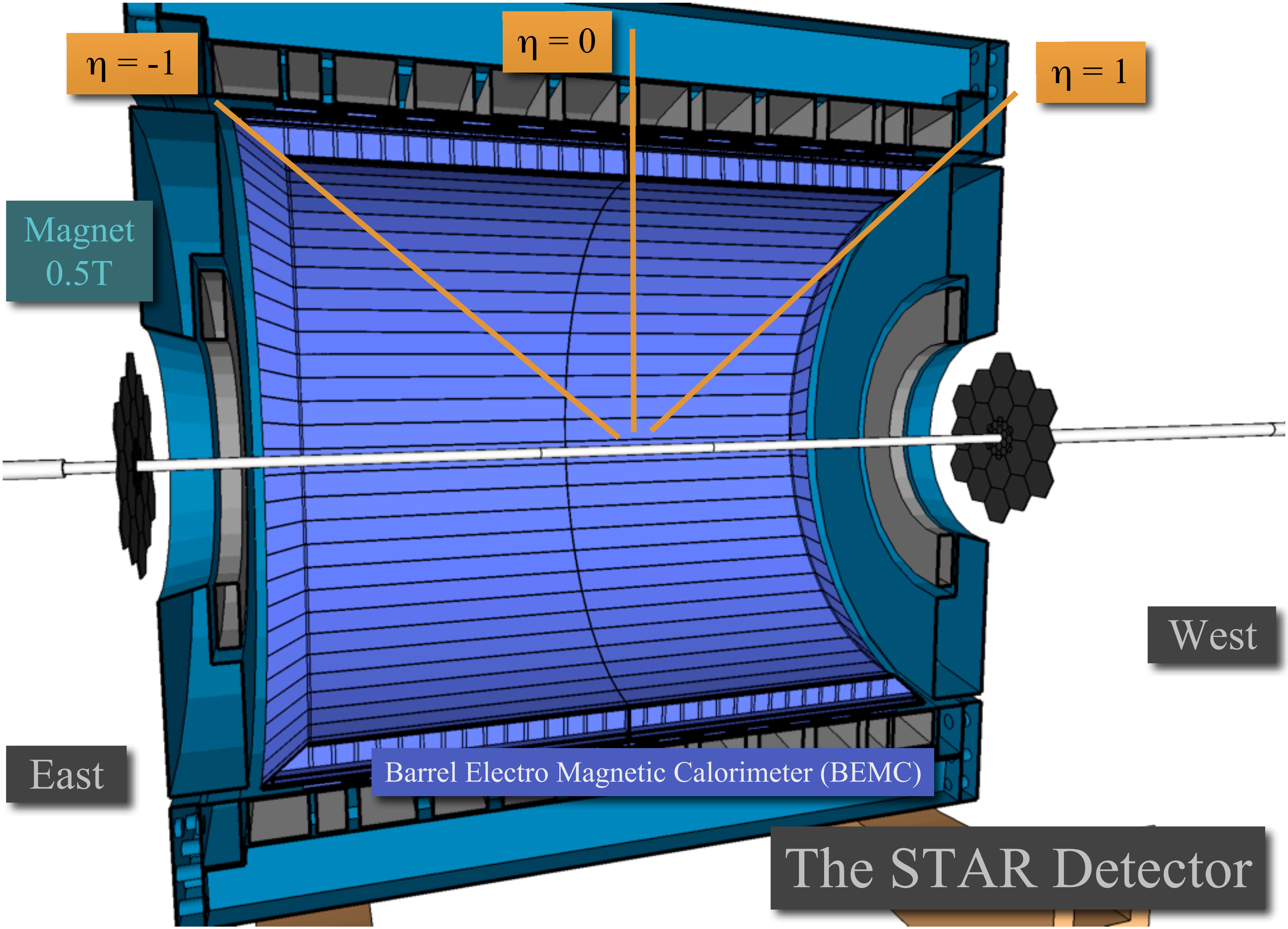
YEAR	L_{max} ($10^{30}s^{-1}cm^{-2}$)	L_{int} (pb^{-1})
2002	2	0.3
2003	6	0.55
2004	6	0.4
2005	16	3.5
2006	30	19

The STAR Detector

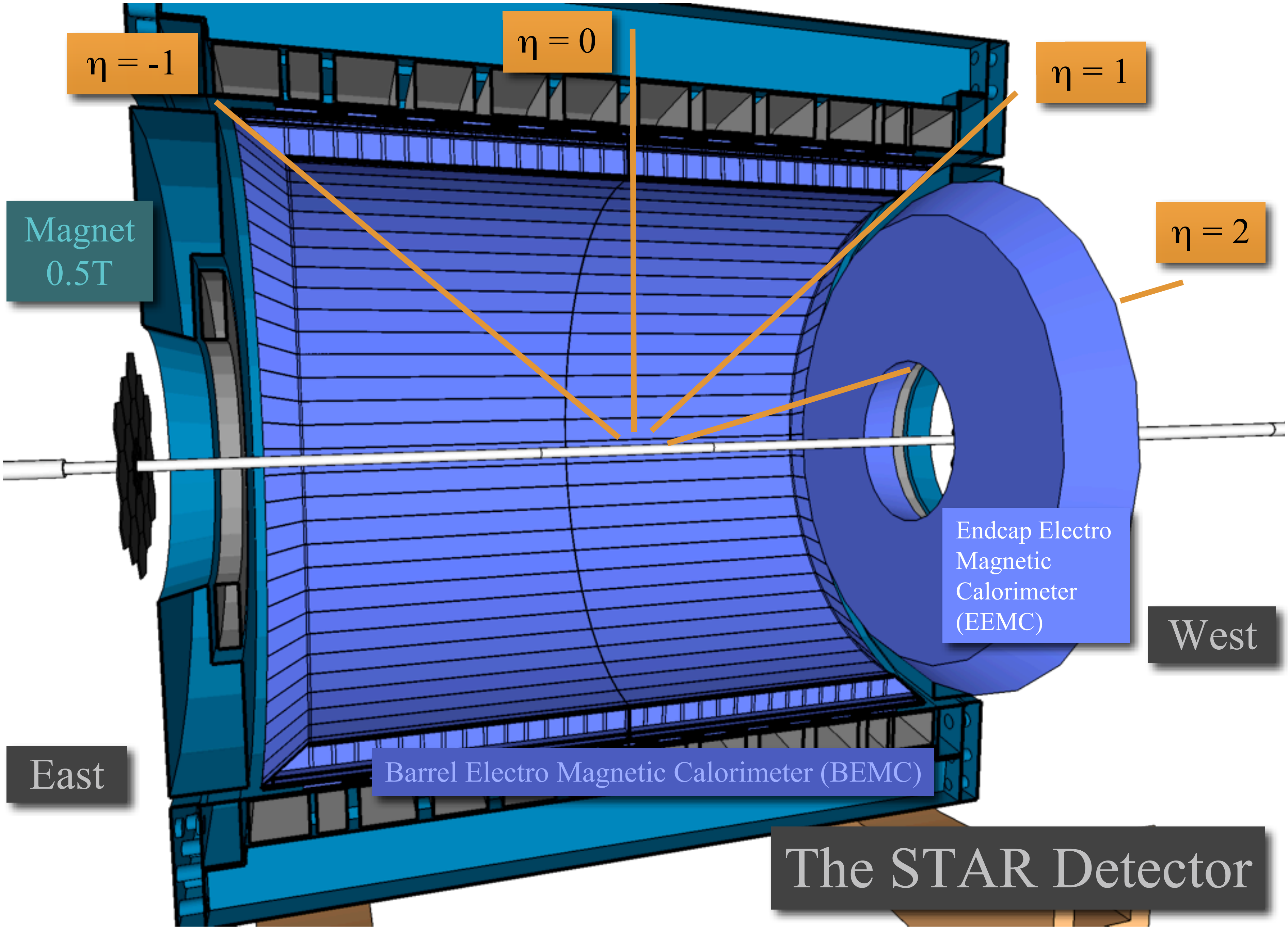


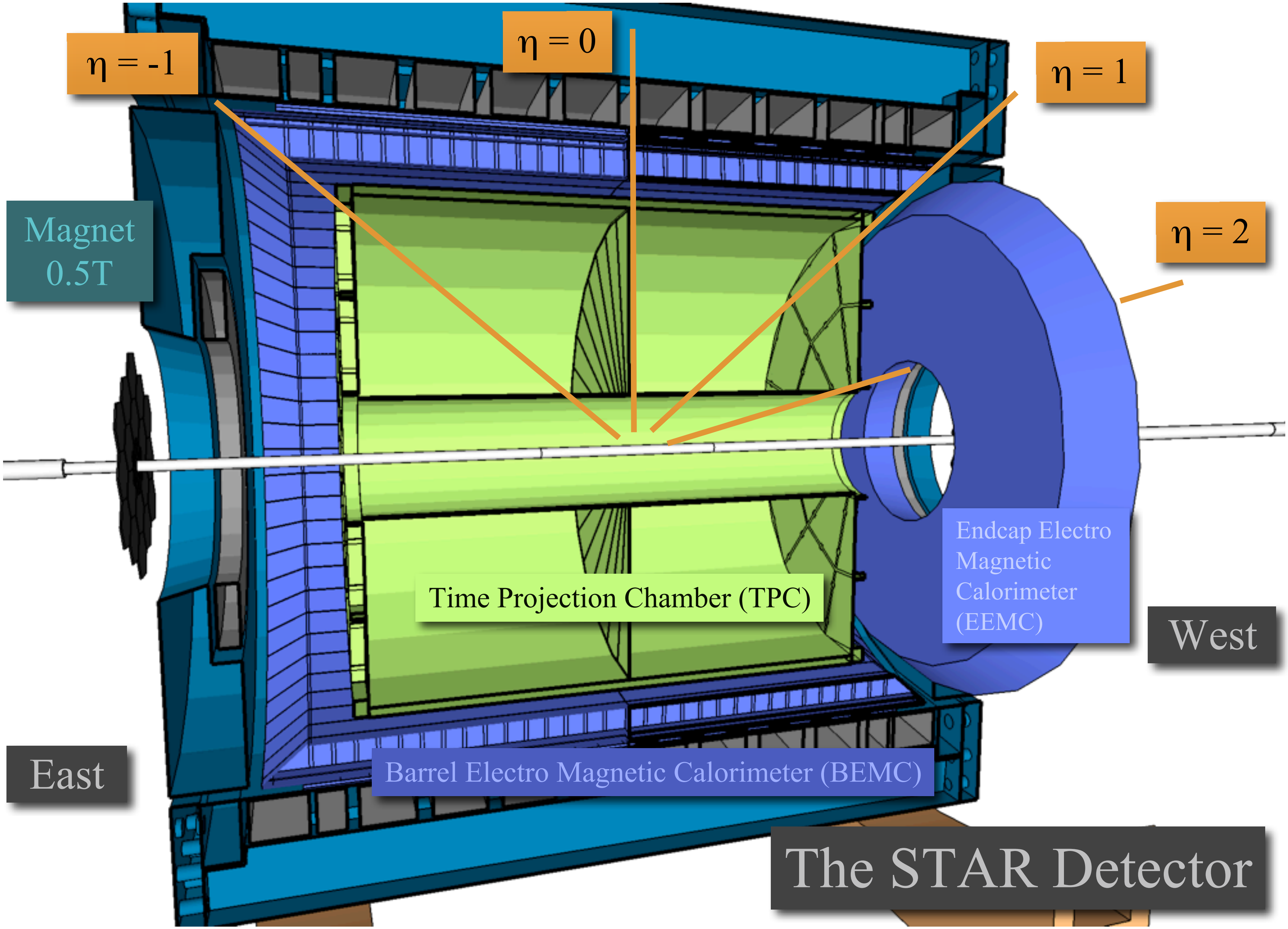
Like all high energy detectors, STAR is composed of many sub-detector systems. This talk will review only those currently used in jet triggering and reconstruction.


Magnet
0.5T
East
West
The STAR Detector



η = -1
η = 0
η = 1
Magnet
0.5T
West
East
Barrel Electro Magnetic Calorimeter (BEMC)
The STAR Detector


η = -1
η = 0
η = 1
η = 2
Magnet
0.5T
Endcap Electro
Magnetic
Calorimeter
(EEMC)
West
East
Barrel Electro Magnetic Calorimeter (BEMC)
The STAR Detector



η = -1
η = 0
η = 1
η = 2
Magnet 0.5T
Endcap Electro Magnetic Calorimeter (EEMC)
Time Projection Chamber (TPC)
West
East
Barrel Electro Magnetic Calorimeter (BEMC)
The STAR Detector

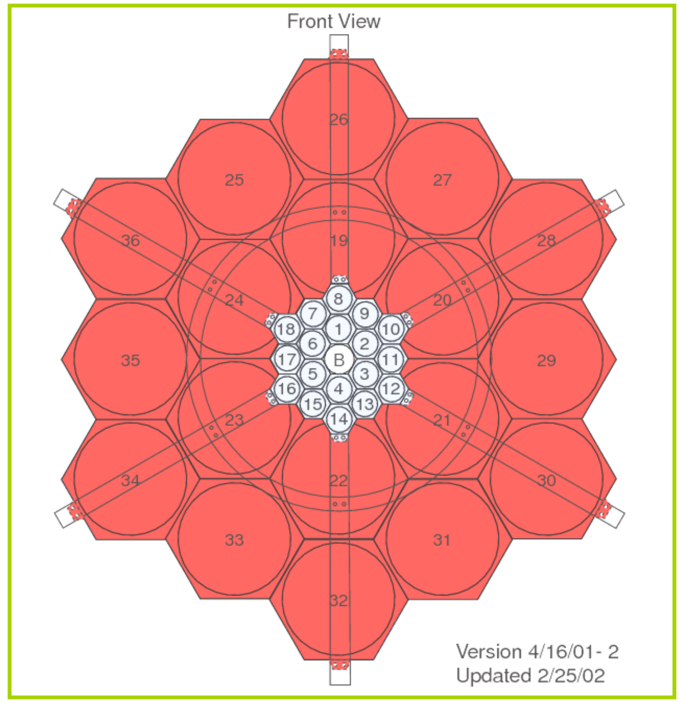
Minimum Bias Trigger for $\sqrt{s}$ = 200 GeV

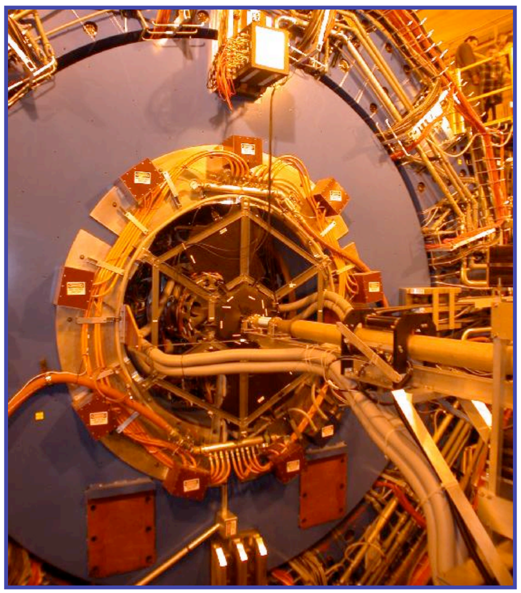
i. MINB events are defined by at least one coincident hit in the small tiles of the E+W BBC.

ii. Luminosities of 10^{30}-10^{32} $cm^{-2}s^{-1}$ produce BBC rates of 0.1-1 MHz.

iii. Total Acceptance samples 53% of the total pp Cross-Section

iv. 87% of the singly non-diffractive pp Xsec





Small tiles $3.9 < |\eta| < 5.0$

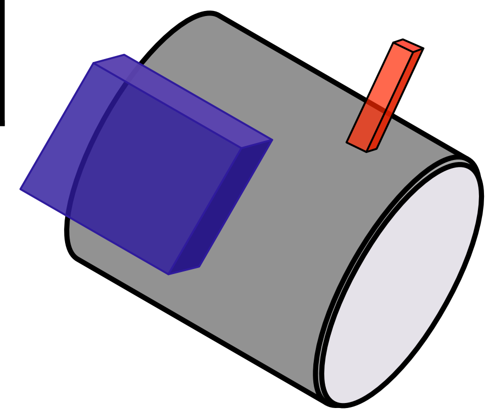
Large tiles $3.4 < |\eta| < 3.9$

$|z| = 375cm$ $\Delta\phi = 2\pi$

ArXiv:hep-ex/0501072v1

STAR High p_T Triggers

High Tower	1 tower $(\Delta\eta = \Delta\phi = 0.05)$ above threshold Requires hard neutral fragmentation



2003 HT THR > 2.2 GeV

2004 HT THR > 3.5 GeV

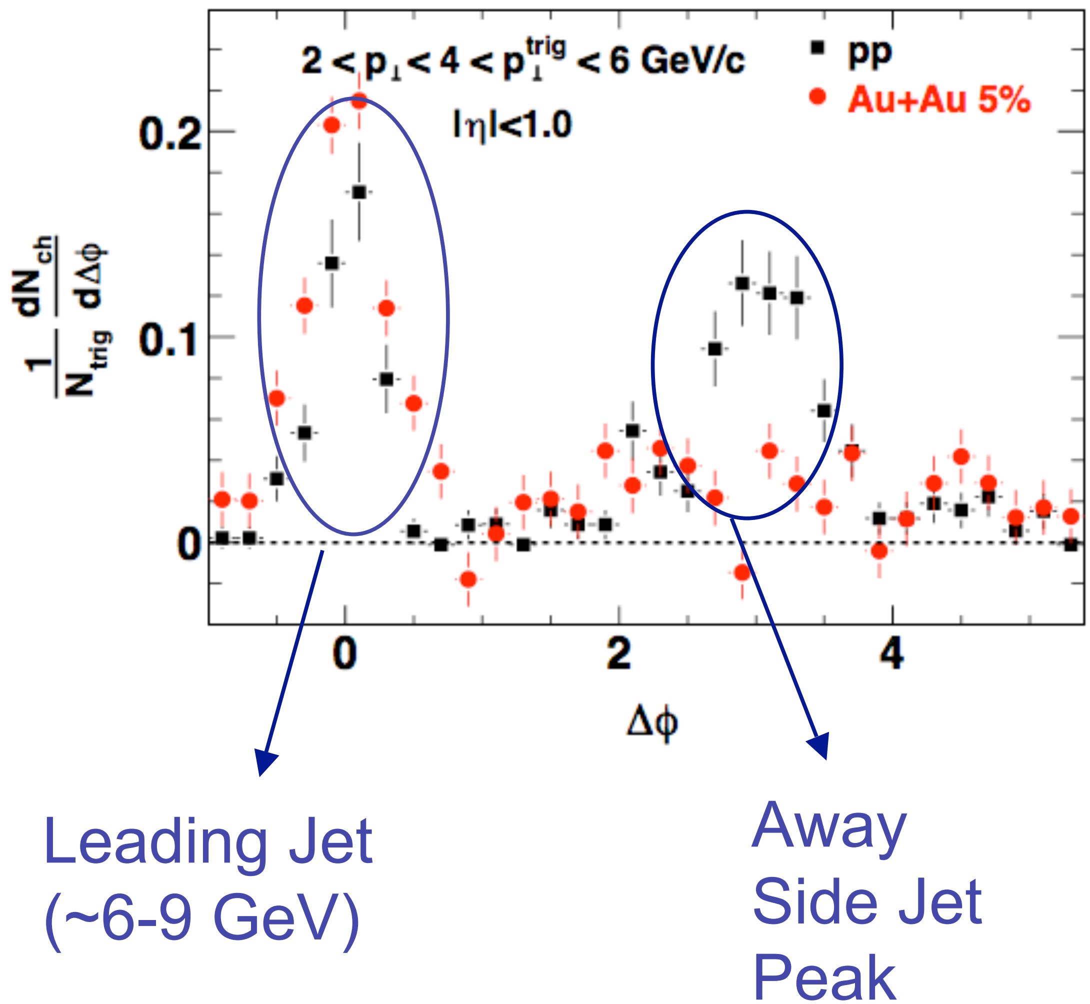
Jet Patch	400 localized towers $(\Delta\eta = \Delta\phi = 1)$ above threshold. Allows for cluster of softer fragmentation

2006 JPtrigI -> JP thr = 5.7 GeV + ETOT thr = 14 GeV

2006 JPtrigII -> JP thr = 8.3 GeV

Note: JP trigger doubles the jet reconstruction efficiency of the HT trigger and therefore 2006 jet sample is dominated by JP triggers.

Hard Scattering at RHIC
Just how low can you go?

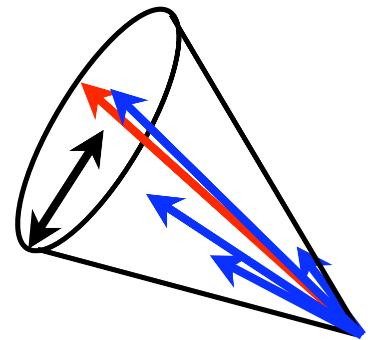


Phys. Rev. Lett. 95 (2005) 152301

1. Find all charged "trigger" particles with pT = 4 - 6 GeV.
2. Find $\Delta\Phi$ for all remaining charged particles of pT = 2-4 GeV.
3. Remove combinatorial background using mixed event subtraction for both p+p and Au+Au
4. Additional elliptic flow subtraction for Au+Au

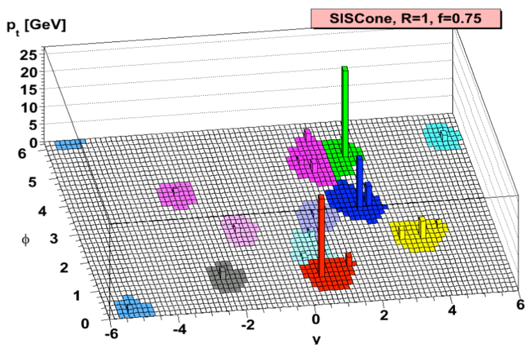
Clear peaks in correlated particles indicate we can "see" hard scattering even at low jet pT.

STAR Jet Algorithms



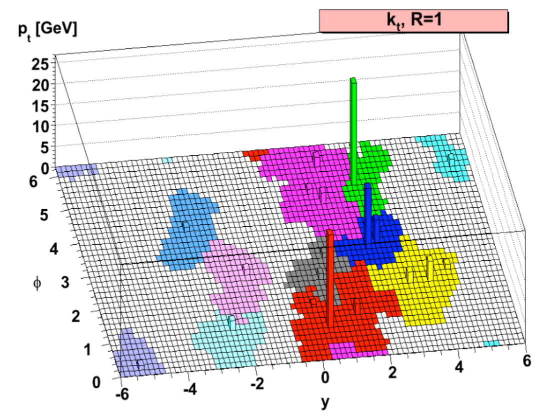
Midpoint cone algorithm

- Adapted from Tevatron II (hep-ex/0005012)
- P^{μ} of TPC track, EMC tower used as seed
- Jet Cone Radius = 0.4 (2003-2005) or 0.7 (2006)
- Look for additional stable clusters at "midpoint" between two clusters
- Split/Merge = 50%



Seedless Cone - SISCone

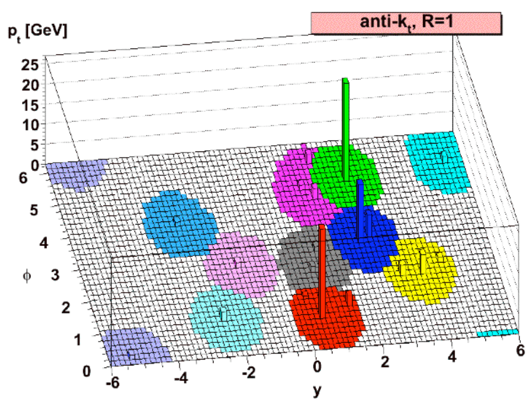
- Fastjet package - [Cacciari, Soyez, arXiv:0704.0292]
- Jet Cone Radius = 0.7
- Split/Merge = 0.75.



Recombination k_T

- starts from lowest p_T.
- merges weighted by $1/p_T$ i.e.

high p_T is dis-favored.

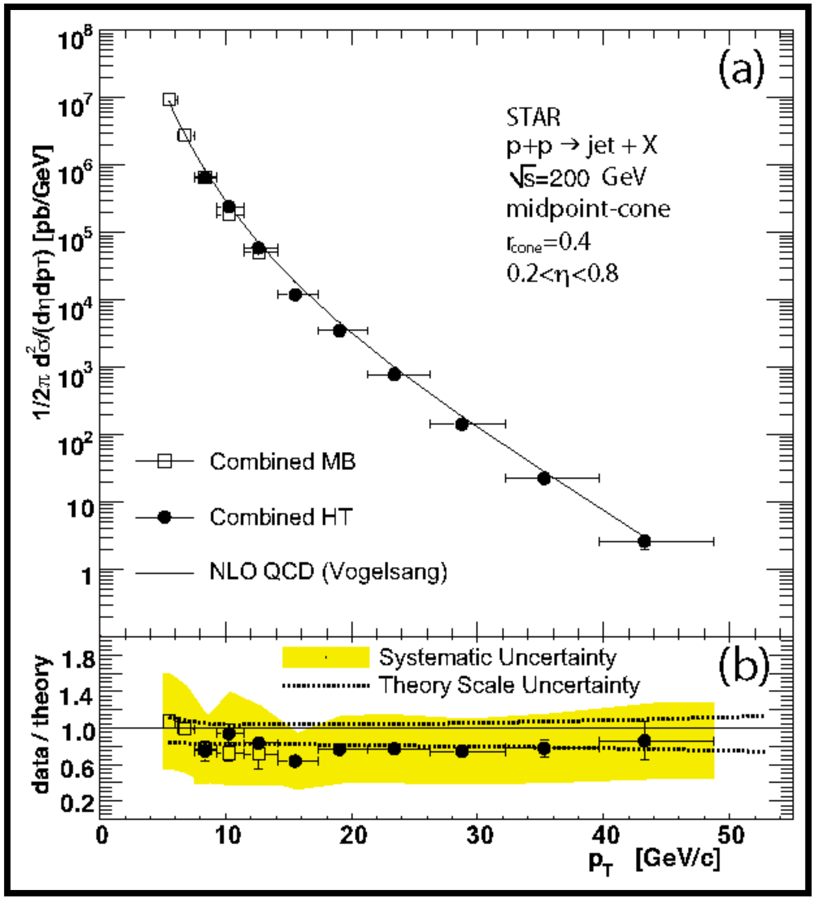


Anti-k_T

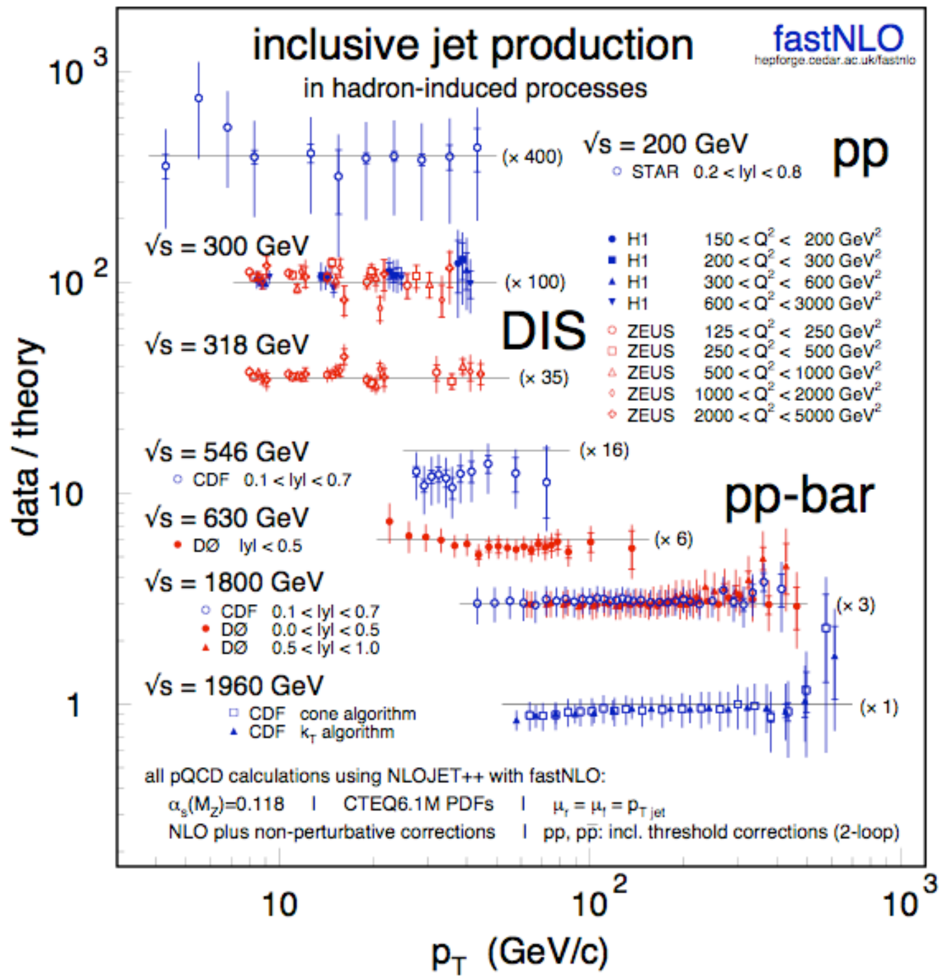
- [Cacciari, Salam, Soyez, arXiv:0802.1189]
- starts from high p_T - advantage in high HI environment
- merges weighted by p_T i.e. low p_T is dis-favored.

Mid-point Cone Inclusive Jet Cross-section

2003+2004 Inclusive Jet Production
Phys. Rev. Lett. 97 252001 (2006)



Thomas Kluge, Klaus Rabbertz, Markus Wobisch

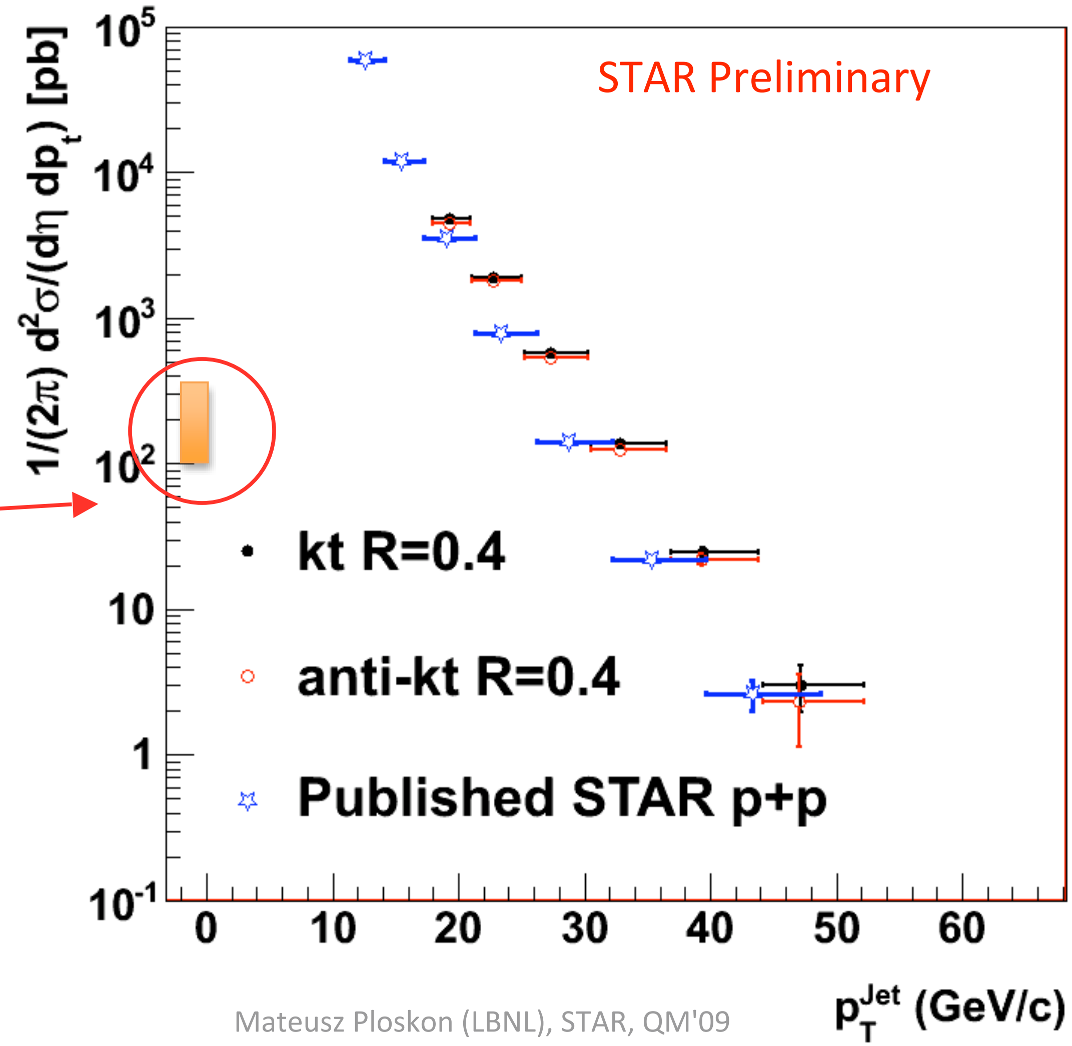


Experimental cross section agrees with NLO pQCD *over 7 orders of magnitude*

Excellent Agreement with World Data!

kT and anti-kT Inclusive Jet Cross-section

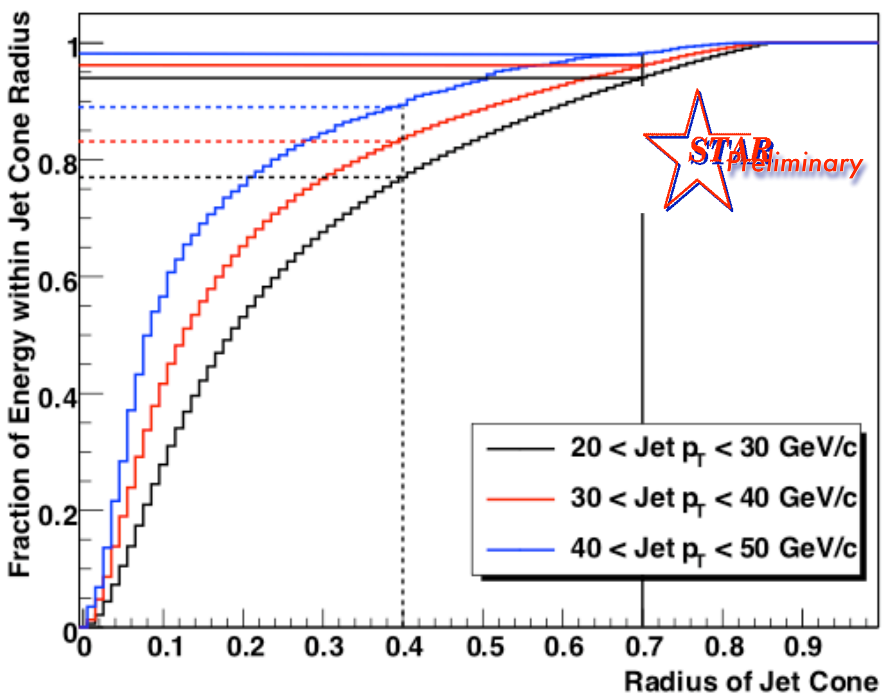
- Preliminary result on inclusive jet cross-section from kT and anti-kT finders shown at Quark Matter 2009.
- Reasonable agreement with published results - considering the calorimeter calibration systematic.
- Calorimeter gain was changed between 2003/2004 to 2006 dataset.



Mateusz Ploskon (LBNL), STAR, QM'09

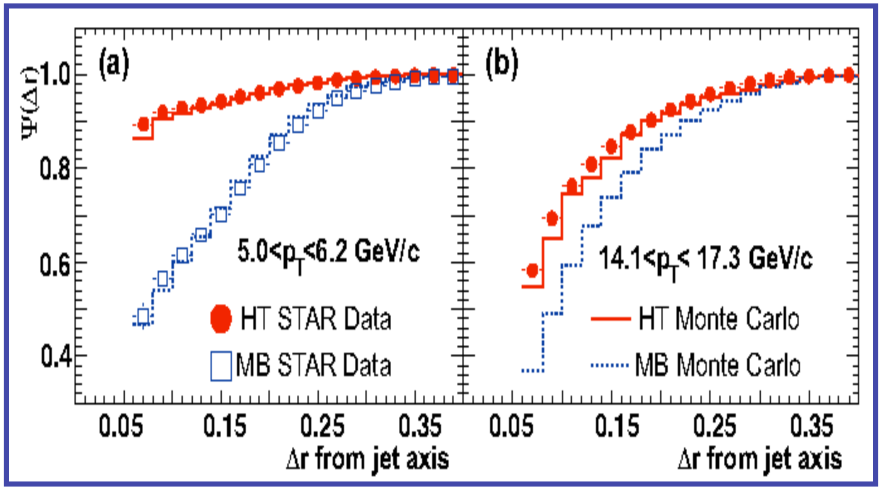
Jet Shapes

Jet Patch Triggered Jets
(SISCone Algorithm 2006)

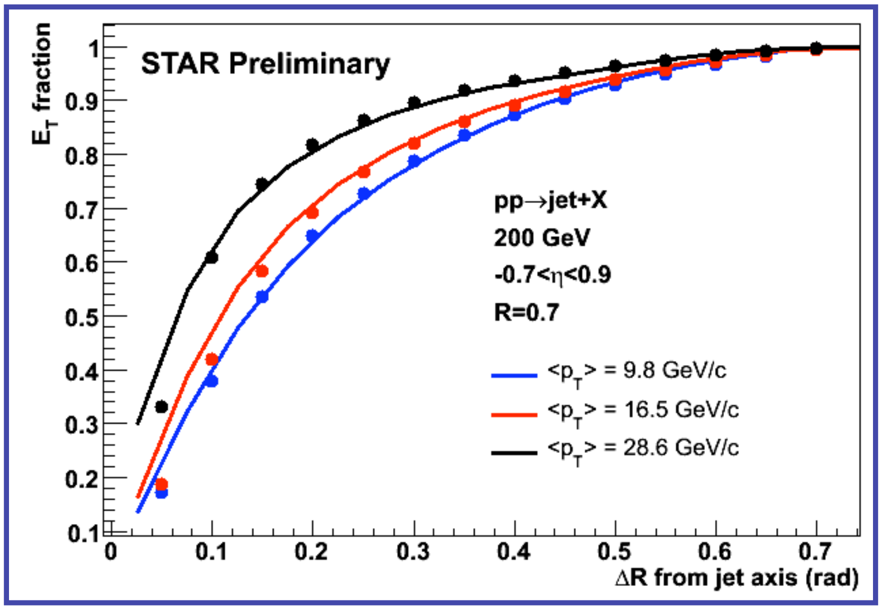


- Larger energy → more focussed jet
- Excellent agreement between mid-point and SISCone
- Consistent with CDF > 80% within R~0.3.

High Tower Triggered Jets
(Mid-point Cone 2004)



Jet Patch Triggered Jets
(Mid-point Cone 2006)



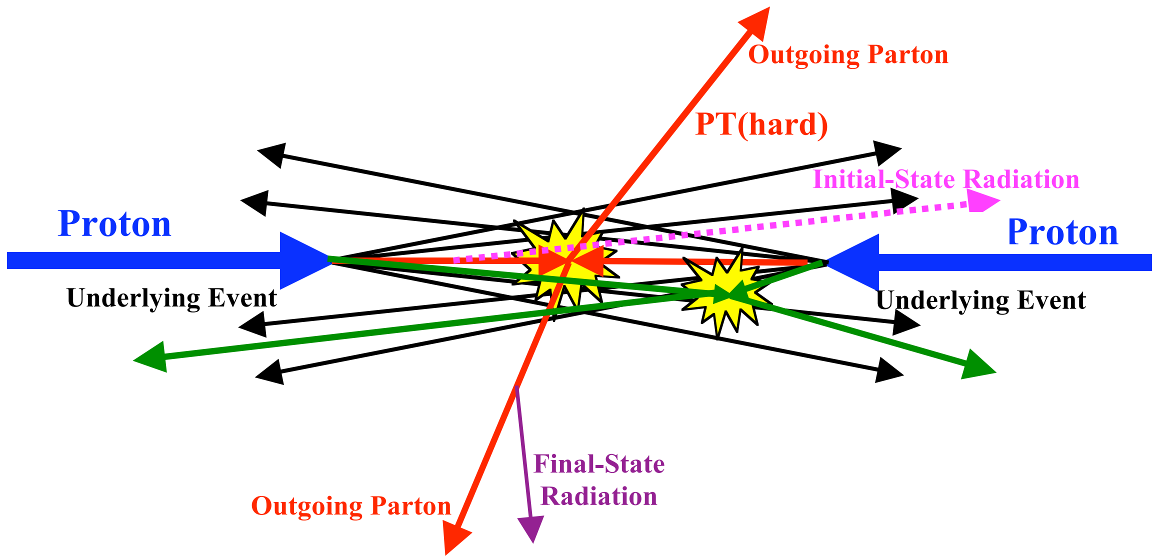
The Underlying Event at RHIC

Interest in the UE at RHIC comes from many directions:

1) Jet Energy Scale (JES) Corrections in PP which are needed for spin and medium modification analyses.

2) Optimization of photon isolation cuts

3) Physics of the UE itself!

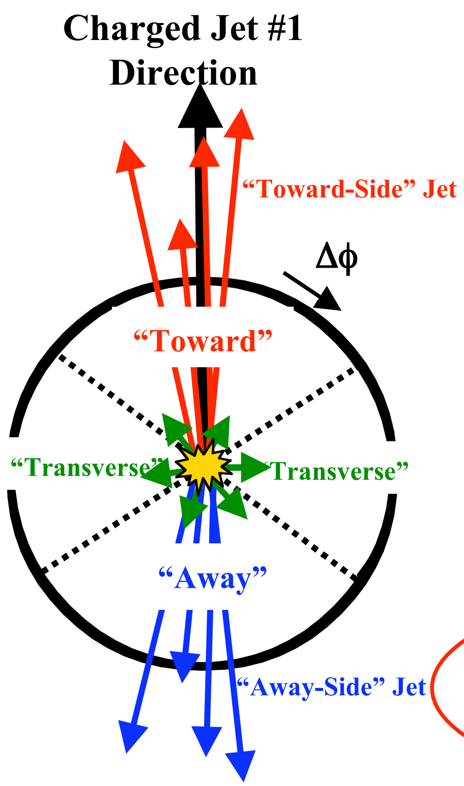


Definition of the Underlying Event

- The UE includes initial and final state radiation (ISR/FSR)
- The UE includes beam remnant interactions
- The UE includes Multiple Partonic Interactions *(nearly negligible for 2006 RHIC luminosities)*
- Results presented here follow closely the framework developed by Rick Field at CDF.
- This talk discusses two separate analyses using different jetfinders.

How can we measure the UE? Lets do what RICK did!

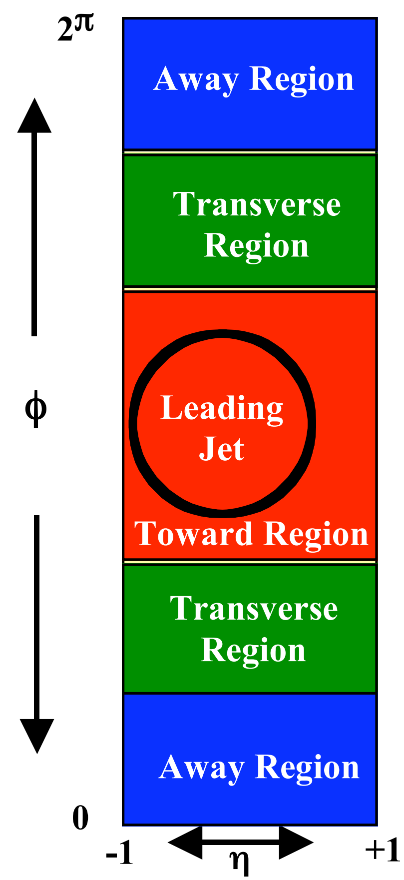
1st look at Back-to-Back Di-Jet Events in which the jet energies are relatively close so as to minimize radiation in transverse region.



Toward Region:
$|\Delta\varphi| \le 60$, $|\eta| \le 1$
Around highest pT jet

Away Region:
$|\Delta\varphi| > 120$, $|\eta| \le 1$
From leading jet

Transverse Region:
$120 < |\Delta\varphi| < 60$, $|\eta| \le 1$



Access Underlying Event Distributions HERE!

Jetfinder Parameters and Back-to-Back Data Cuts

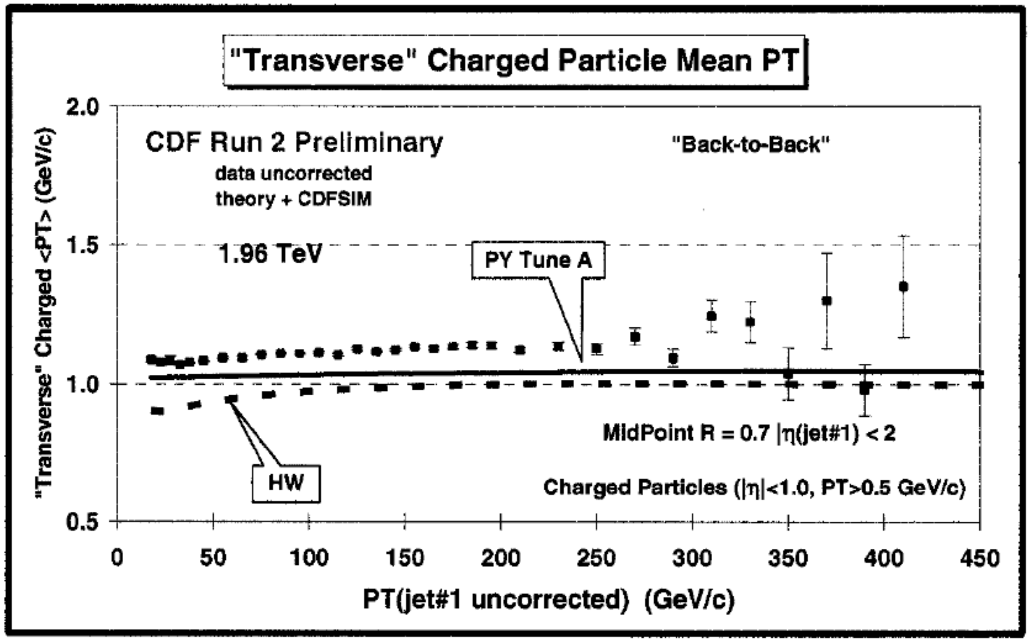
Analysis I	Analysis II
Mid-Point Cone R=0.7	SISCone R=0.7, kT + anti-kT
Number of jets = 2	Number of Jets = 2
$\lvert$Detector $\eta\rvert \leq 0.5$	$\lvert\eta\rvert \leq 0.3$
Vertex Z ≤ 30 cm	Vertex Z ≤ 30 cm
NE ratio ≤ 0.85	NE ratio ≤ 0.85
Away Jet pT/ Toward Jet pT ≥ 0.7	Away Jet pT/ Toward Jet pT ≥ 0.7
Track pT > 0.2 GeV	Track pT > 0.2 GeV
Tower Et ≥ 0.2 GeV (MIP corrected)	Tower Et ≥ 0.2 GeV (MIP + e corrected)
Normalized to Transverse/Toward/Away $\Delta\eta\times\Delta\varphi$	Normalized to inside Jet Cone for toward/away $\Delta\eta\times\Delta\varphi$
Uncorrected Jet Energy Scale	Uncorrected Jet Energy Scale
2006 JPtrigI	2006 JPtrigII

For CDF >0.5 GeV!

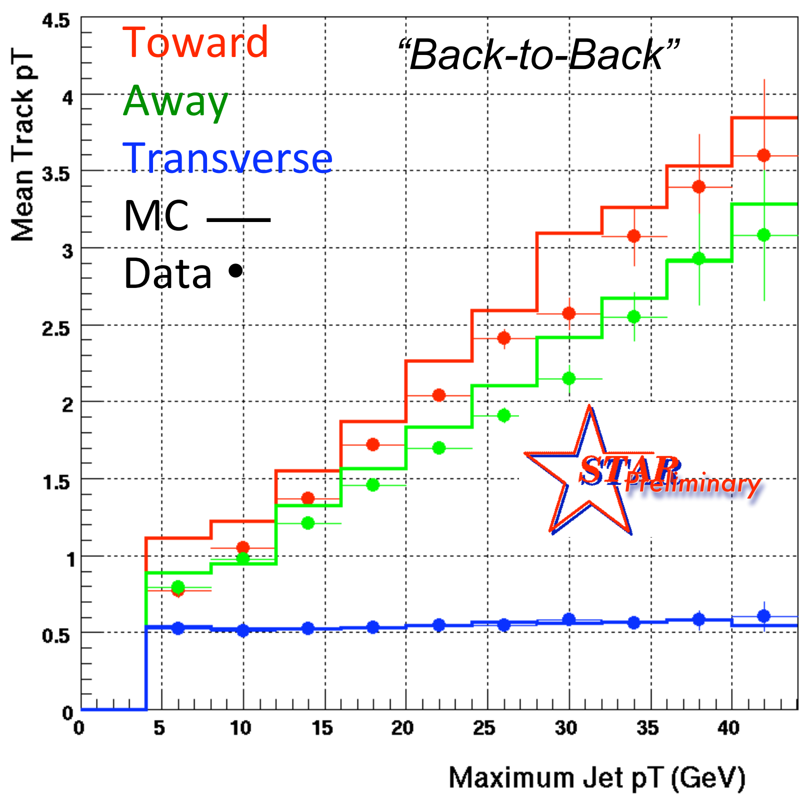
All Simulations are PYTHIA CDF Tune A + STAR GEANT Package

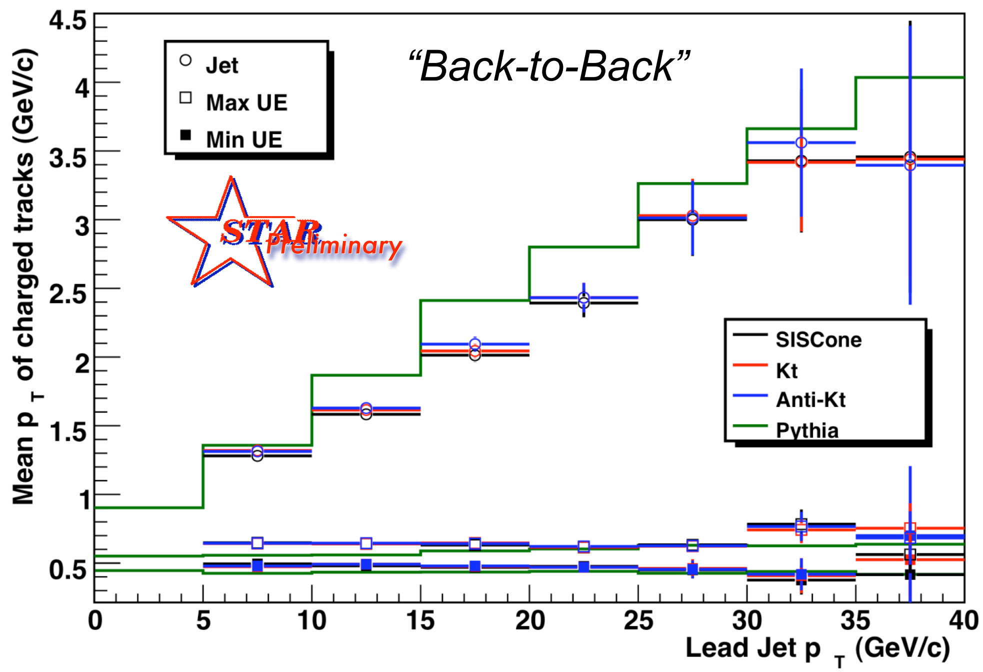
Mean Charged Track p_T

UE	<Data>	<Pythia>
CDF	1.1	1.0
STAR	0.55	0.55



L.A. Cruz, "Using MAX/MIN transverse regions to study the underlying event in run 2at the Tevatron" UMI-31-88071, 2005.





Charged Track Multiplicity Density

	<Data>	<Pythia>
CDF	0.5	0.5
STAR	0.7	0.6

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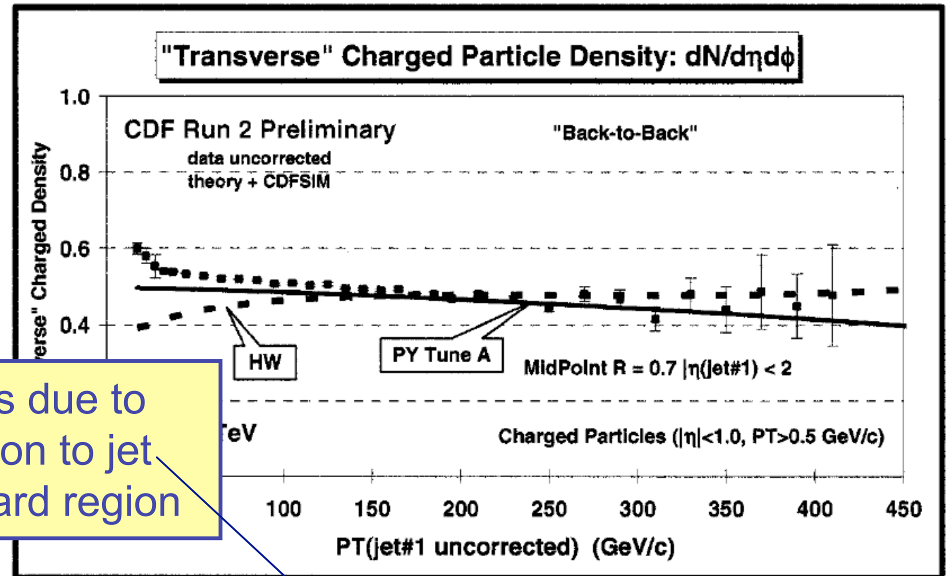
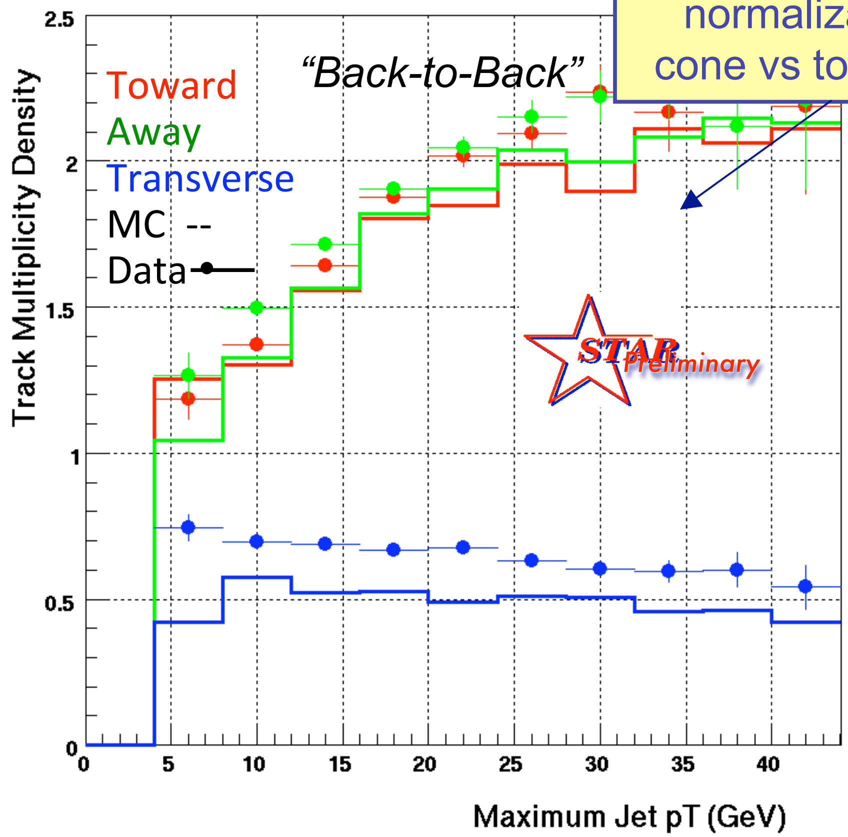
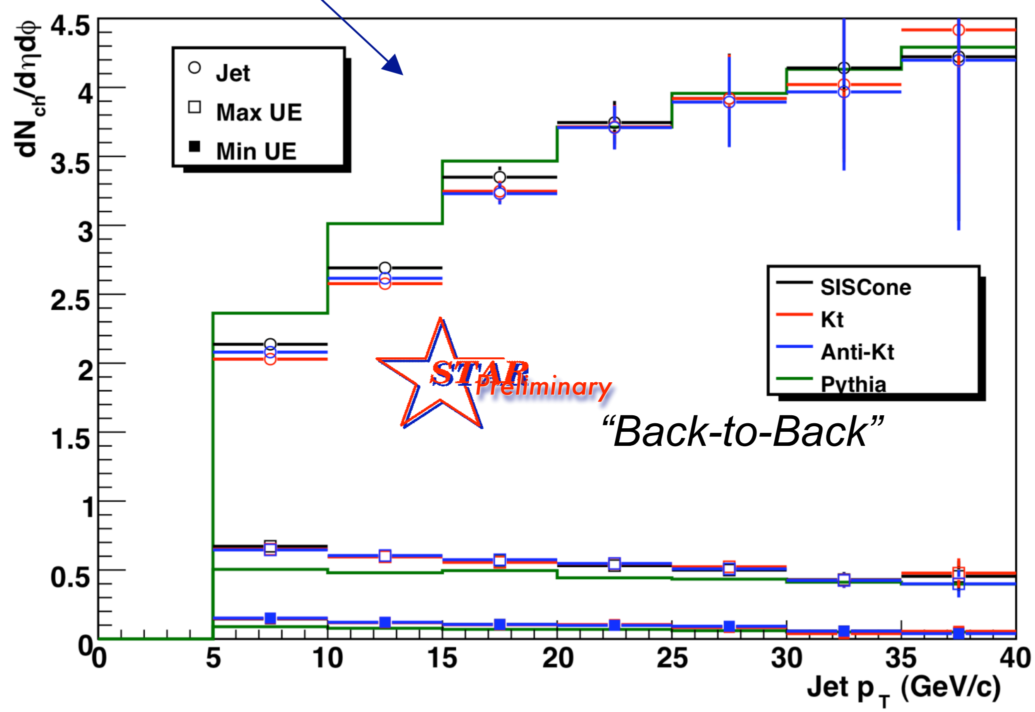
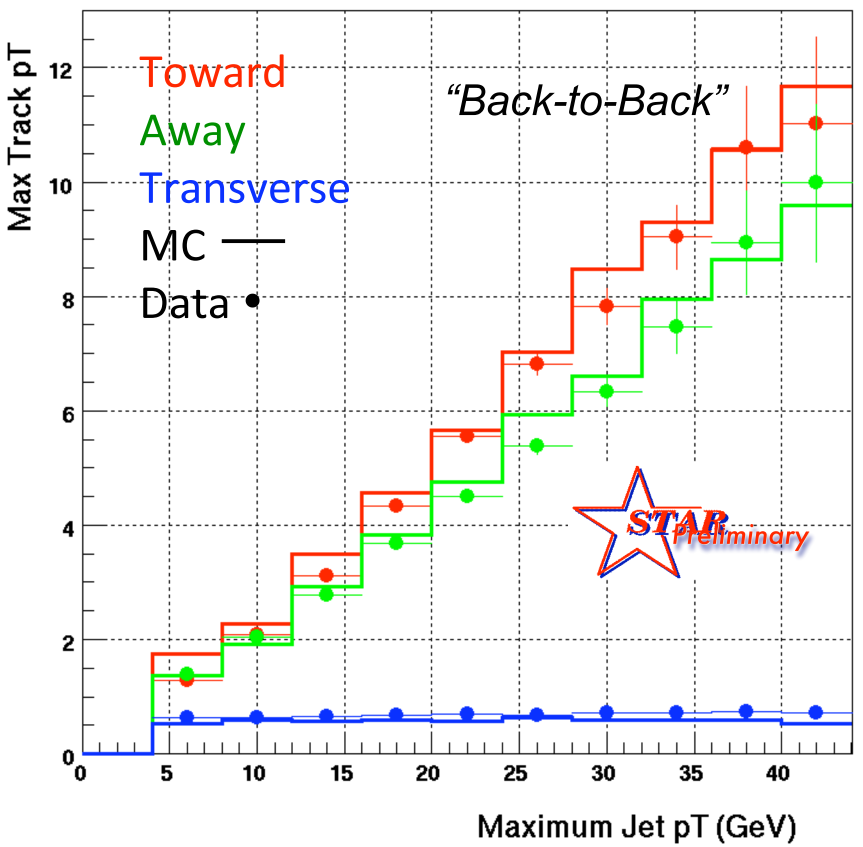


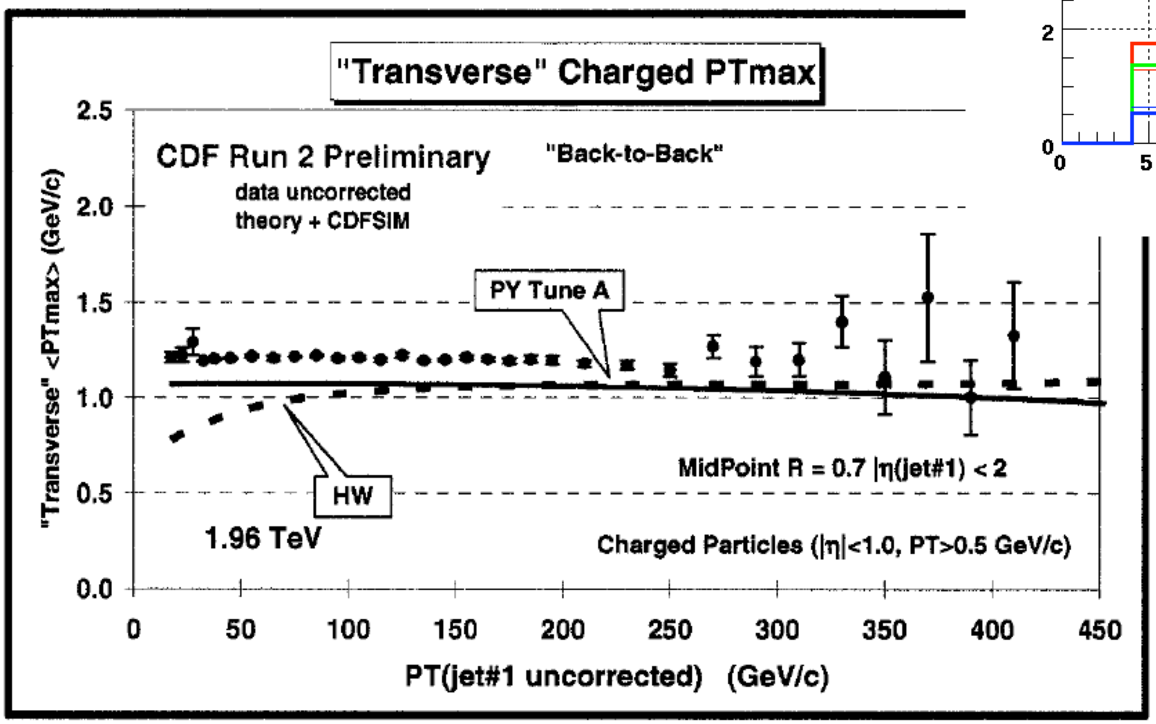
Differences due to normalization to jet cone vs toward region





Max Charged Track p_T		
UE	<Data>	<Pythia>
CDF	1.2	1.0
STAR	0.65	0.6

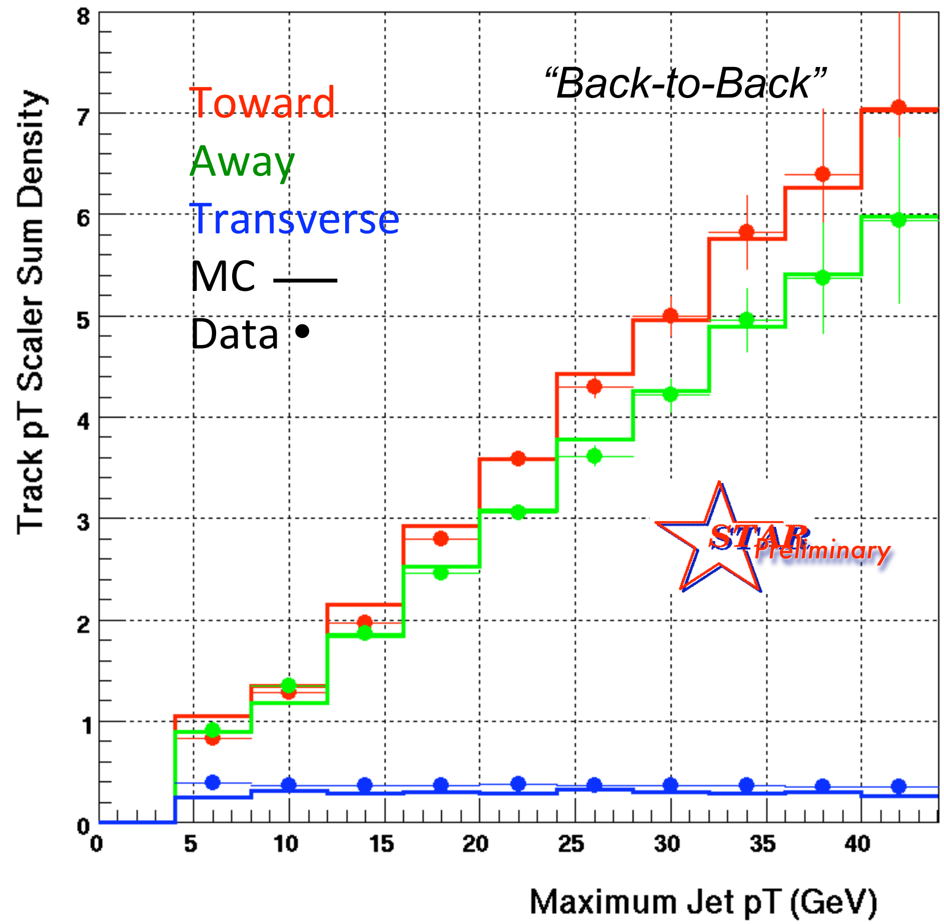


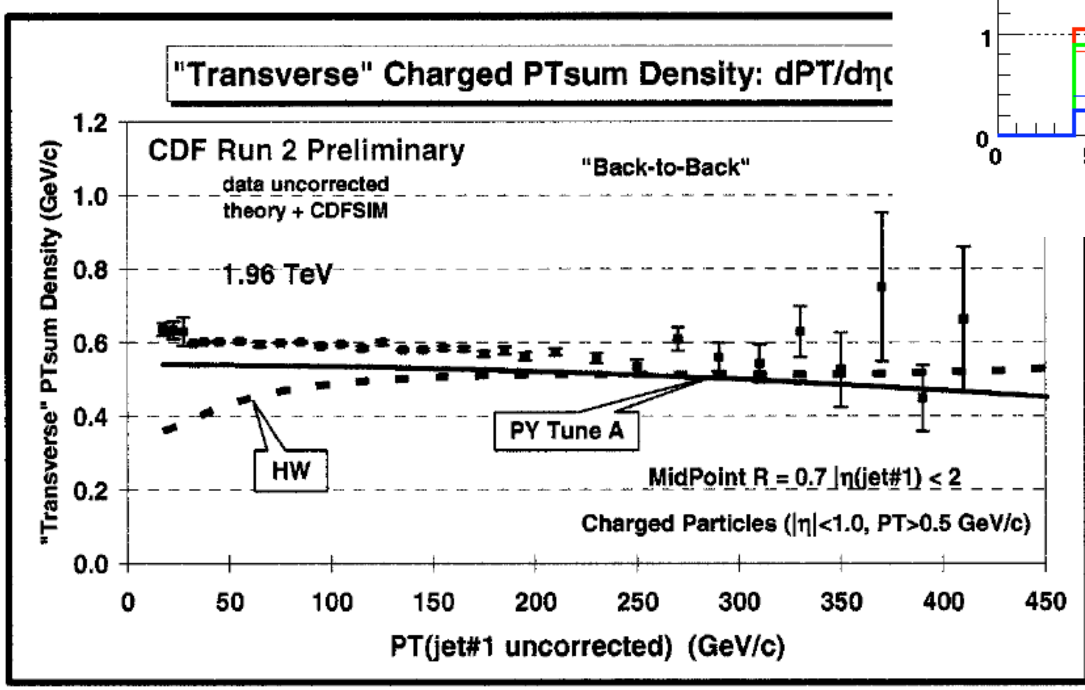


L.A. Cruz, "Using MAX/MIN transverse regions to study the underlying event in run 2at the Tevatron" UMI-31-88071, 2005.

Charged Track P_TSum Density

UE	<Data>	<Pythia>
CDF	0.6	0.55
STAR	0.37	0.30





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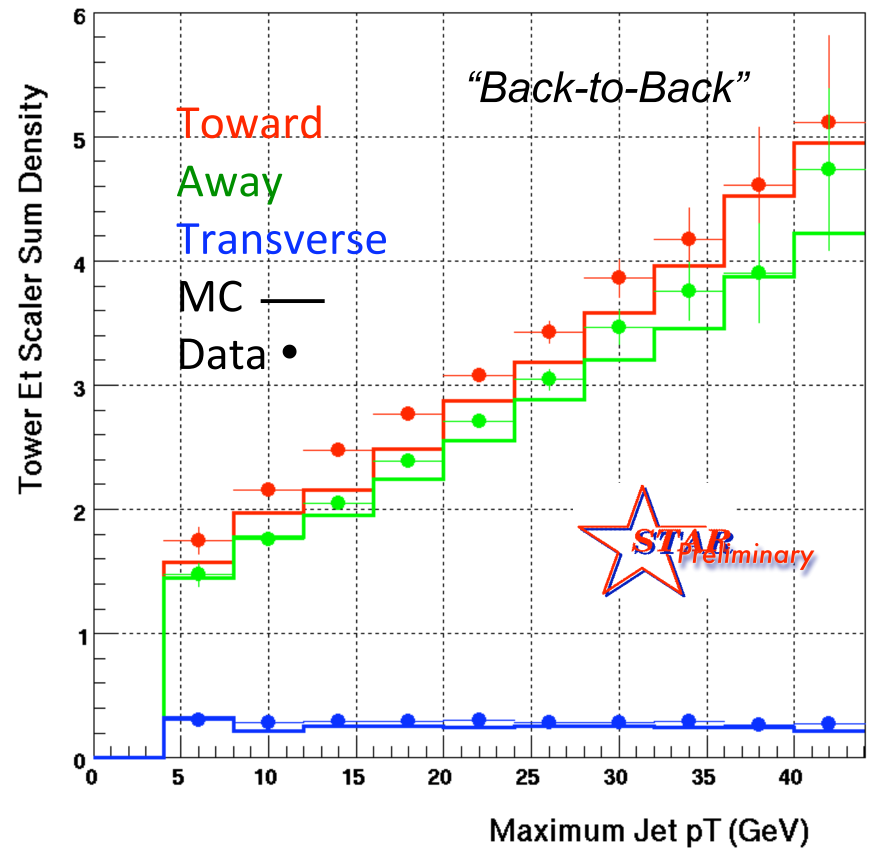
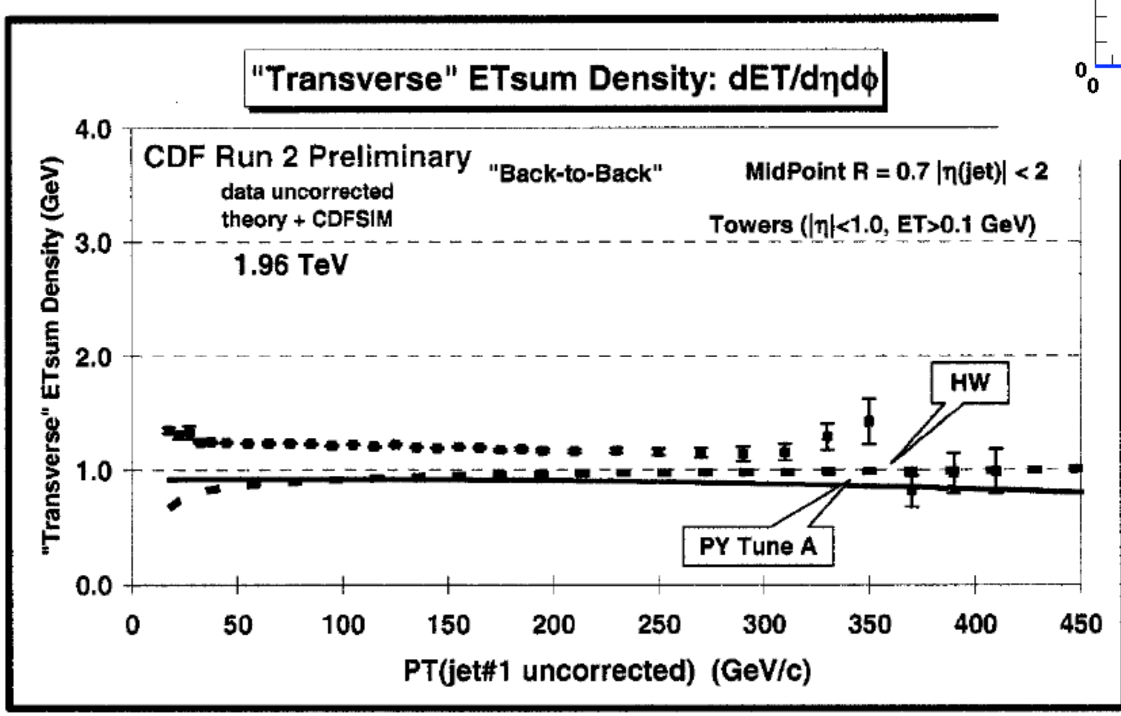
Tower E_T Scaler Sum Density

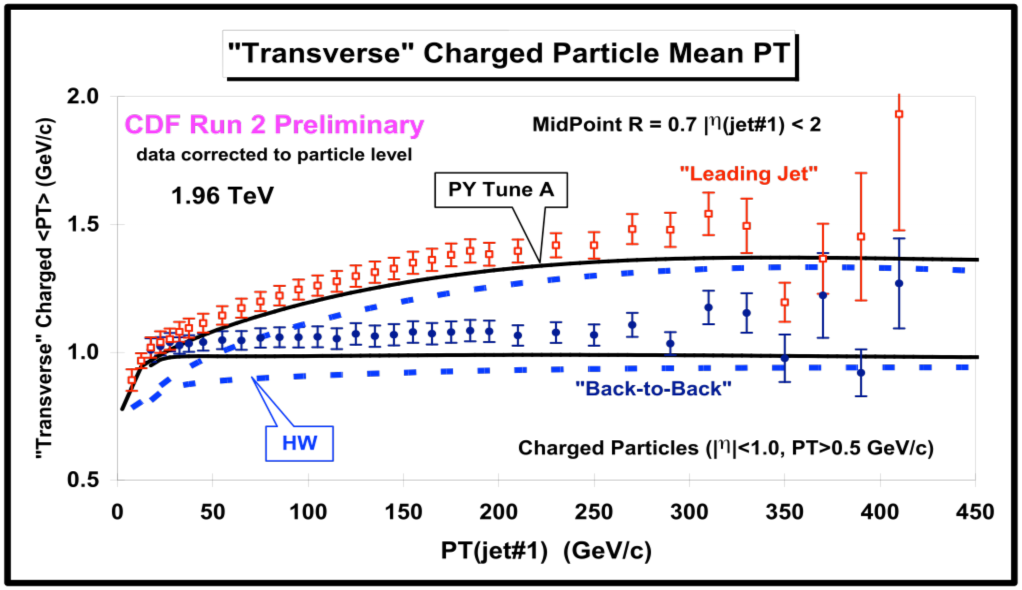
	Data	Pythia
CDF	1.3	0.9
STAR	0.30	0.25



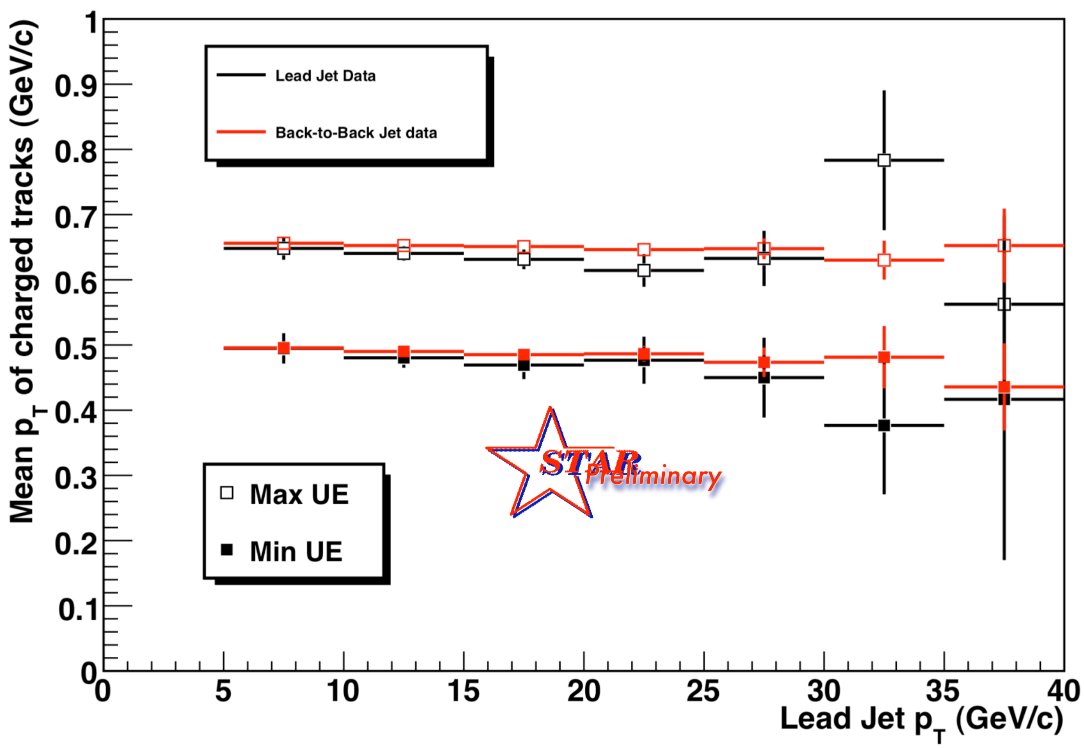


L.A. Cruz, "Using MAX/MIN transverse regions to study the underlying event in run 2at the Tevatron" UMI-31-88071, 2005.

Transverse MAX/MIN regions: Sensitivity to Initial and Final State Radiation



Back-to-Back dijet events minimize contributions from initial and final radiation in the transverse region.



- Study these effects by relaxing the dijet requirement and taking all Leading jet events

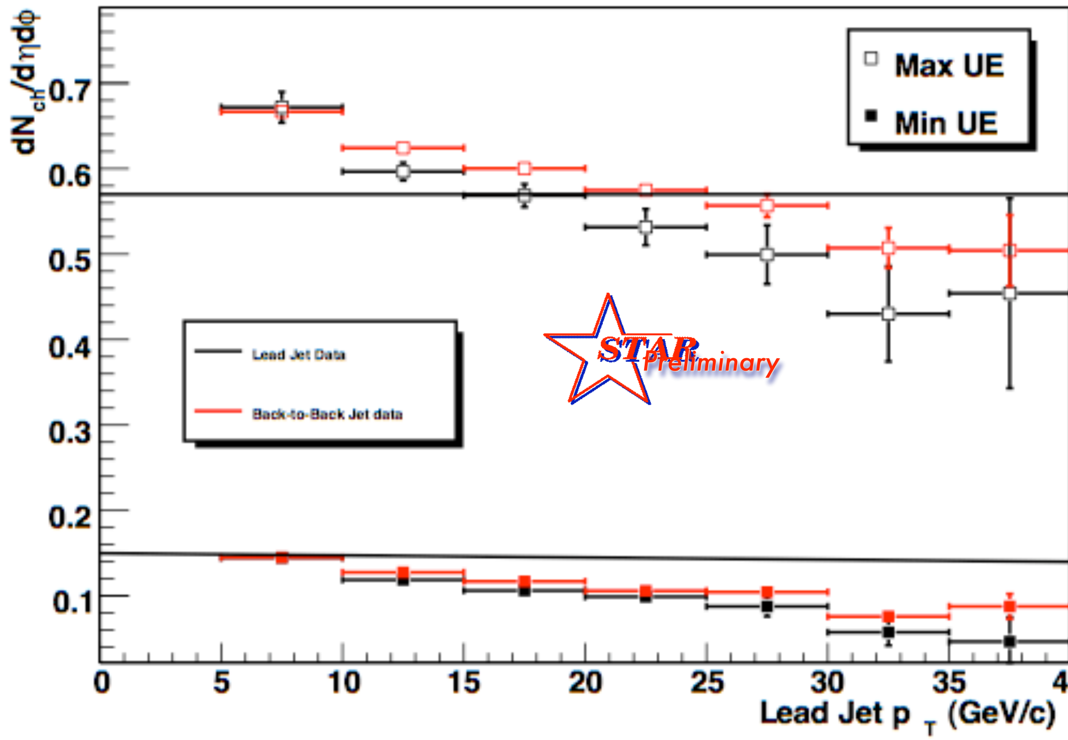
- Compare particle distributions for MAX/MIN transverse regions in Leading and Back-to-Back samples.

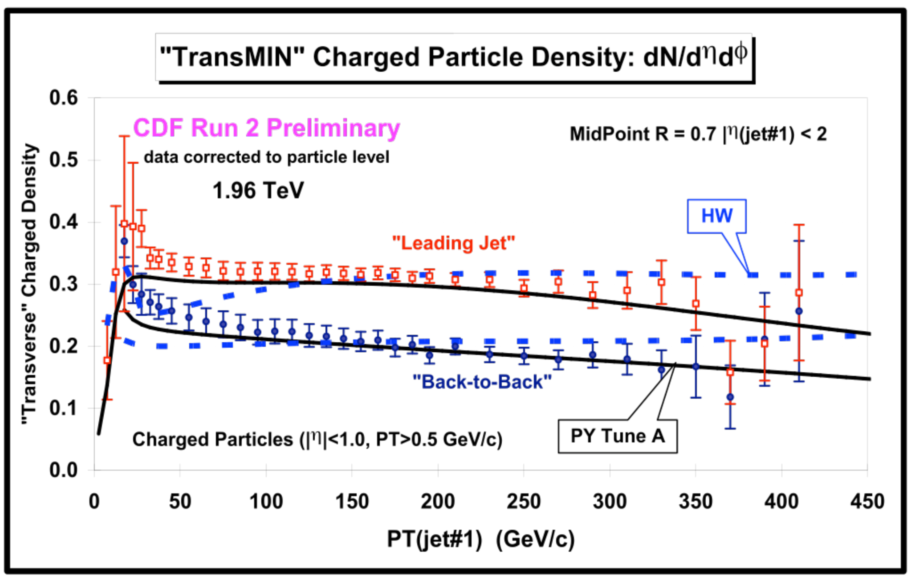
- The difference between leading and back-to-back events for Mean Charged Track pT is negligible at RHIC.

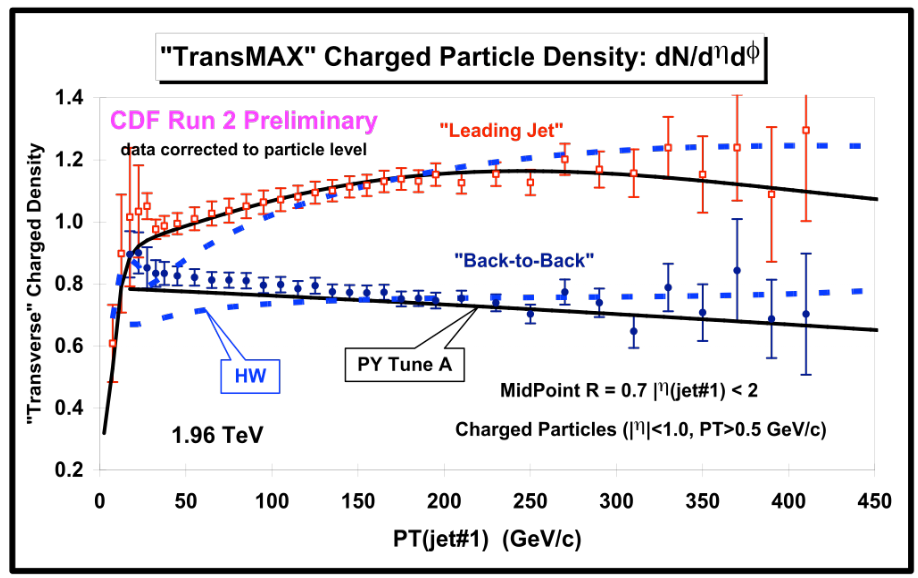
Charged Track Multiplicity Max/Min Distributions

-At RHIC the absolute values for MAX/MIN are lower than at the Tevatron, but Trans MAX - MIN is comparable.

- In current dataset the difference between Leading and Back-to-Back charged track <pT> distribution is statistically marginal.







Conclusions

I. Hadron Collisions at RHIC take place at an order of magnitude smaller $\sqrt{s}$ than the Tevatron. Nevertheless, jets are observed and reconstructed down to pT=5 GeV and are well described by pQCD

II. Comparisons between several jetfinders reveal consistent results

III. Interest in the Underlying Event at RHIC Kinematics is driven by the need for jet energy scale corrections as well as pure physics interests (see talks by M. Lisa and H. Caines)

IV. UE at RHIC appears to be independent of jet pT and decoupled from hard interaction

V. CDF Tune A provides an excellent description of the UE at $\sqrt{s}$ =200 GeV (thanks Rick!)

VI. Underlying Event distributions in general smaller than those at CDF. Tower & Track Multiplicities are the exception, but this may be due to the 0.2 (STAR) versus 0.5 GeV (CDF) pT/Et cut-off.

VII. For a cone jet with R=0.7 UE contributes 0.5-0.9 GeV.

VIII. Comparison of Leading Jet and Back-to-Back distributions indicate that large angle radiation contributions are small at RHIC energies.

Backup