Underlying Event Studies at RHIC

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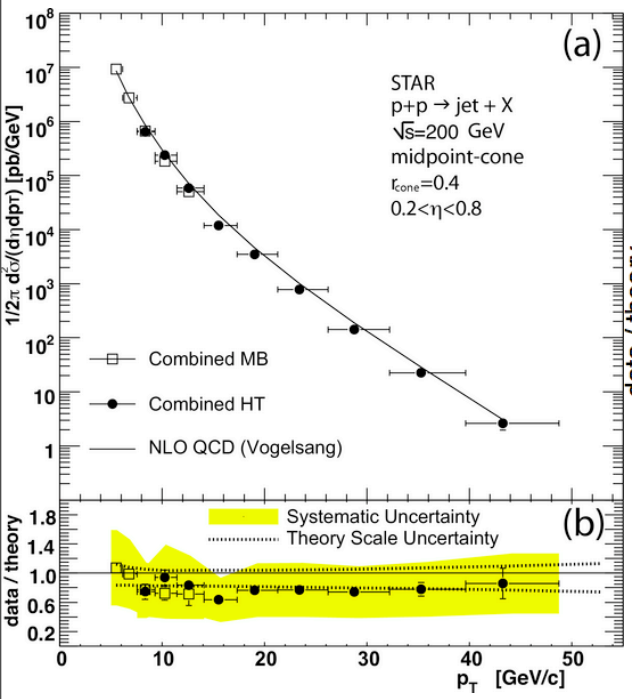
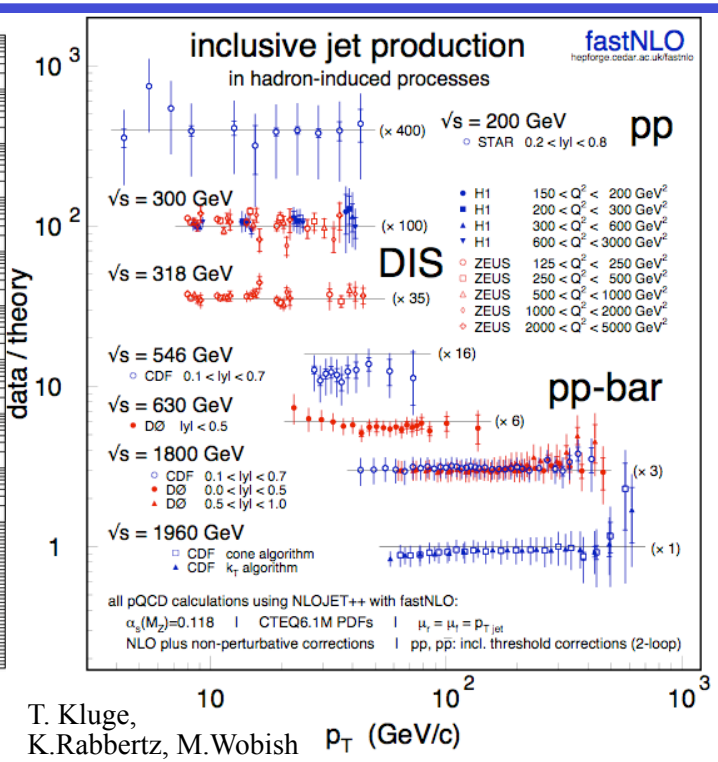
Outline

- Jets and our data set
- z and ξ distributions
- The underlying event
- Summary and outlook

Jets at RHIC – a calibrated probe?



STAR : PRL 97 (2006) 252001



T. Kluge,
K.Rabbertz, M.Wobish

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- Excellent description when included in world data

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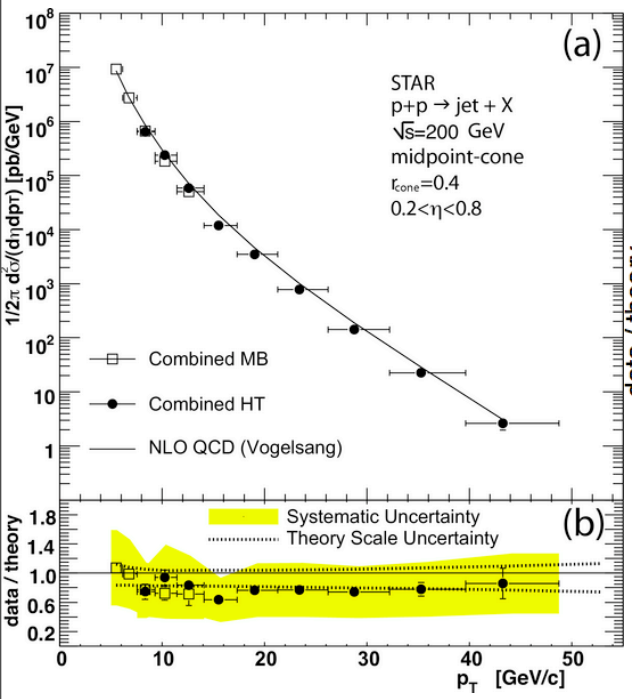

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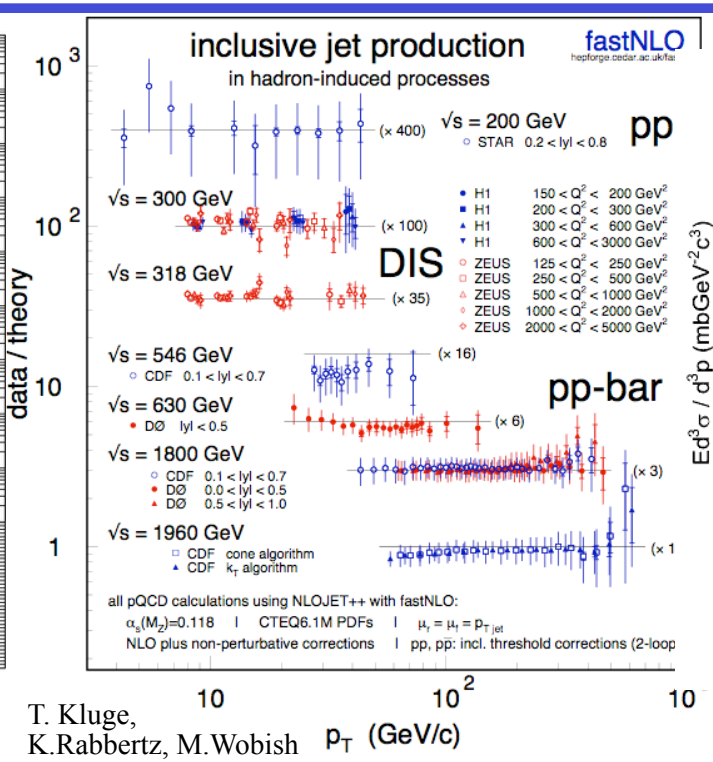

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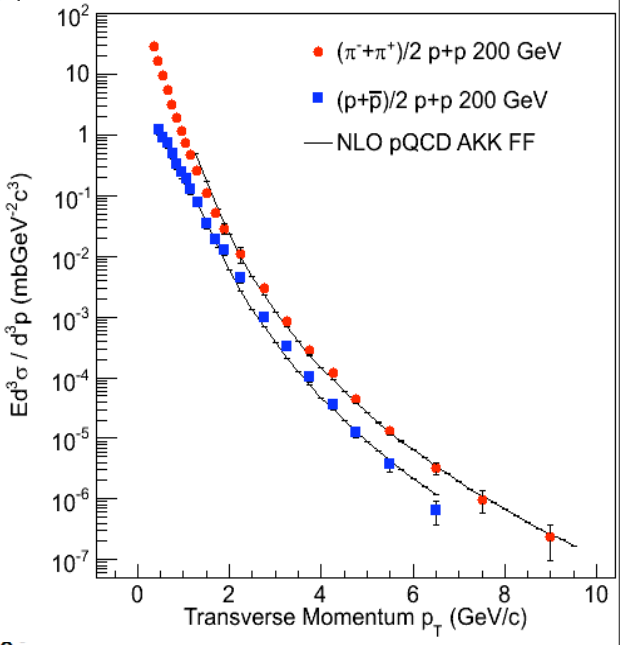

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S. Albino et al. NPB 725 (2005) 181

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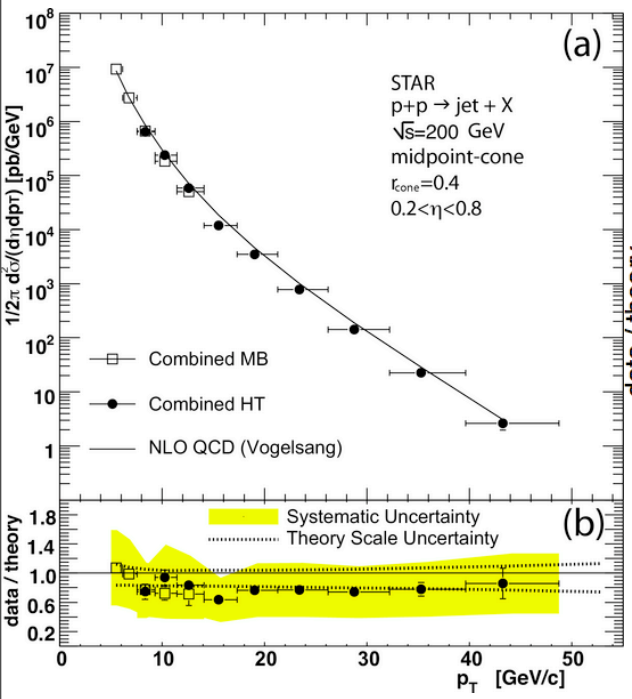

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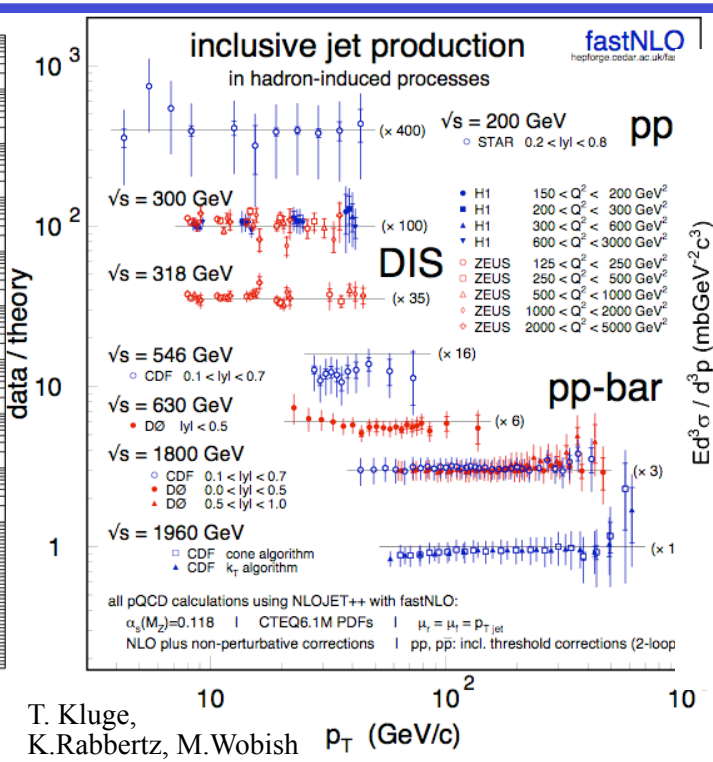

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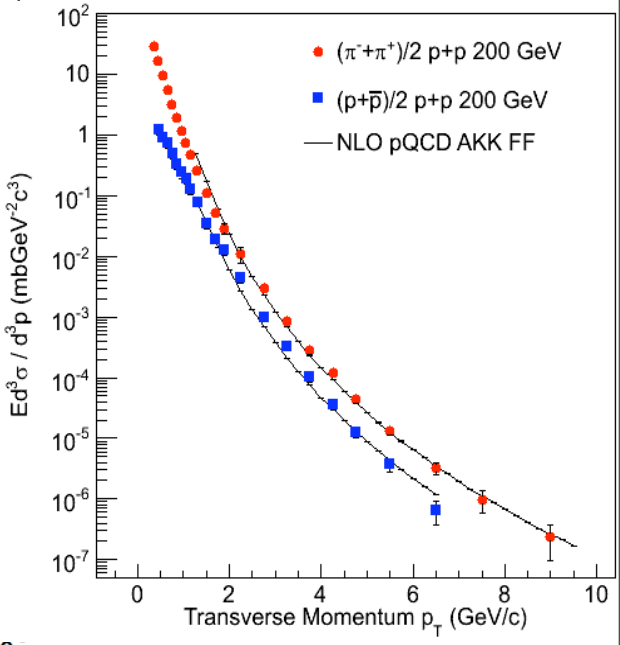

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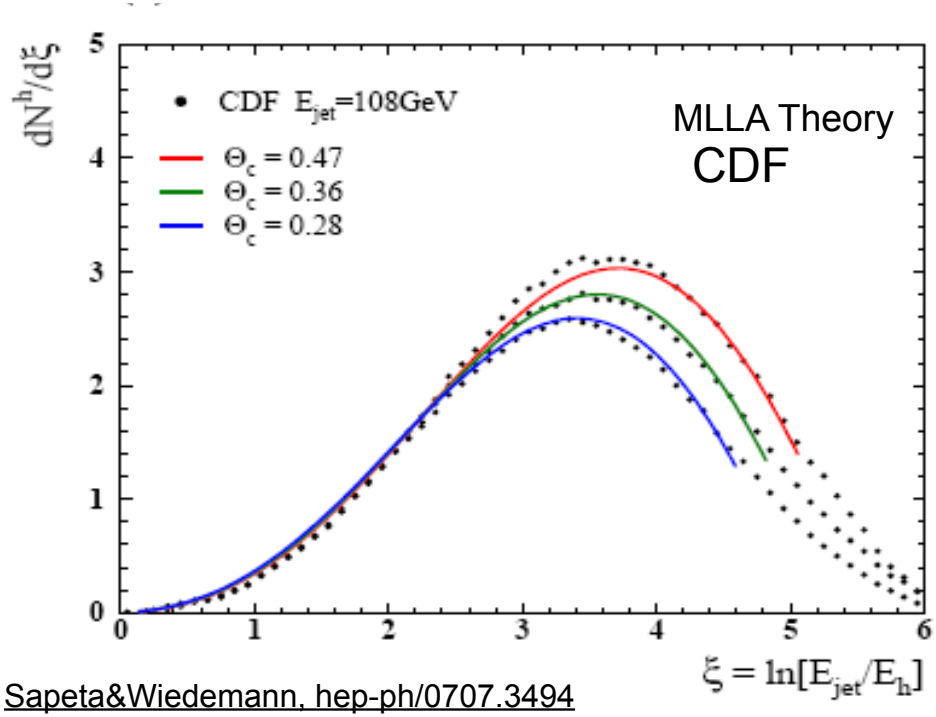
What about fragmentation?

Fragmentation functions (FF)



Sapeta&Wiedemann, hep-ph/0707.3494

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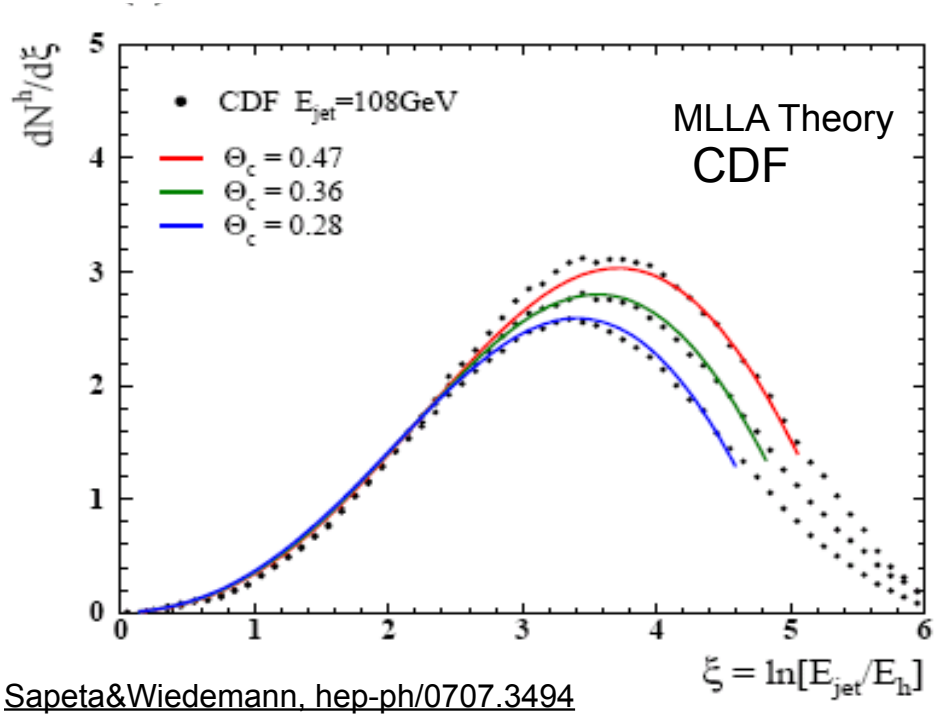
- Measurements at higher √s agree well with theory.

Test energy scaling of fragmentation functions.

Fragmentation functions (FF)



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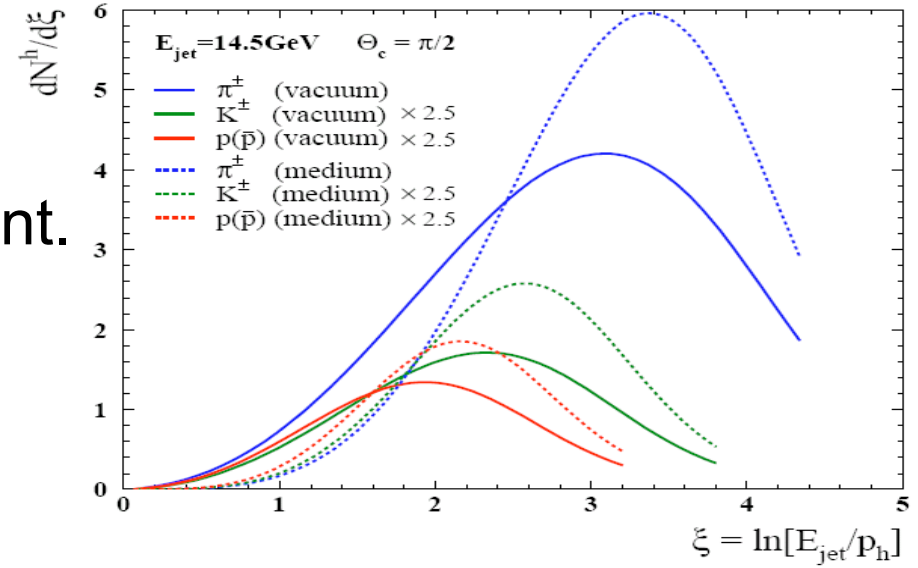
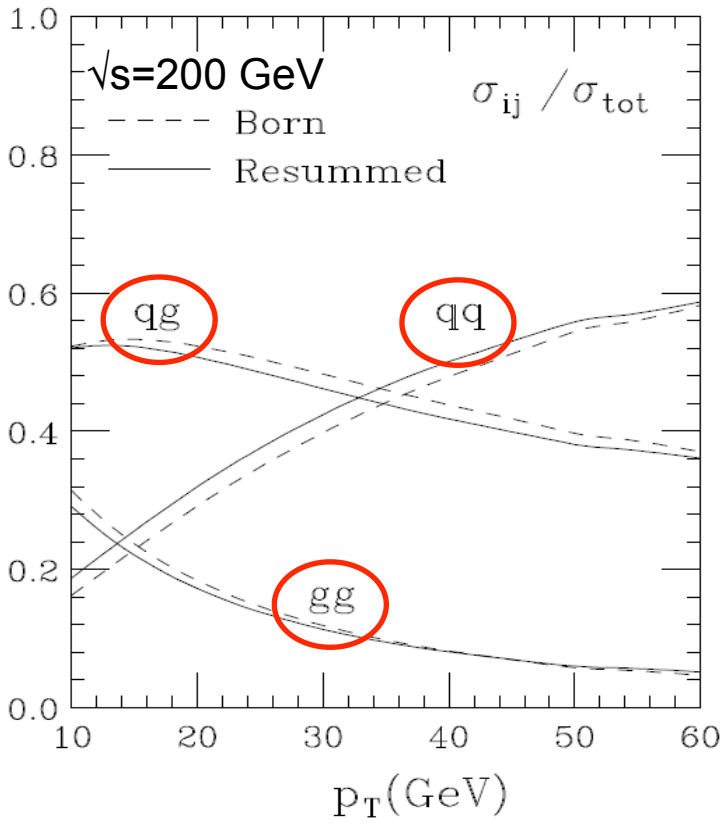
- FF are particle species dependent.

Need to study composition of jets and complete event.



Jets at RHIC: √s=200 GeV p+p

- Unpolarized measurements are a crucial part of the RHIC program
- Inclusive hadron and jet cross section measurements at RHIC add new results to existing data from other accelerators at different energies
- Constrain fragmentation functions:
  - Fits currently dominated by e^+e^- data
  - Still large uncertainties, especially in the gluon fragmentation functions



De Florian, Vogelsang, hep-ph 0704.1677

Significant contribution from gluons in the RHIC regime

There is also the Underlying Event

- p-p events are complicated. More than just hard scattering.

- Underlying Event: soft or semi-hard multiple parton interactions (MPI), initial & final state radiation, beam-beam remnants

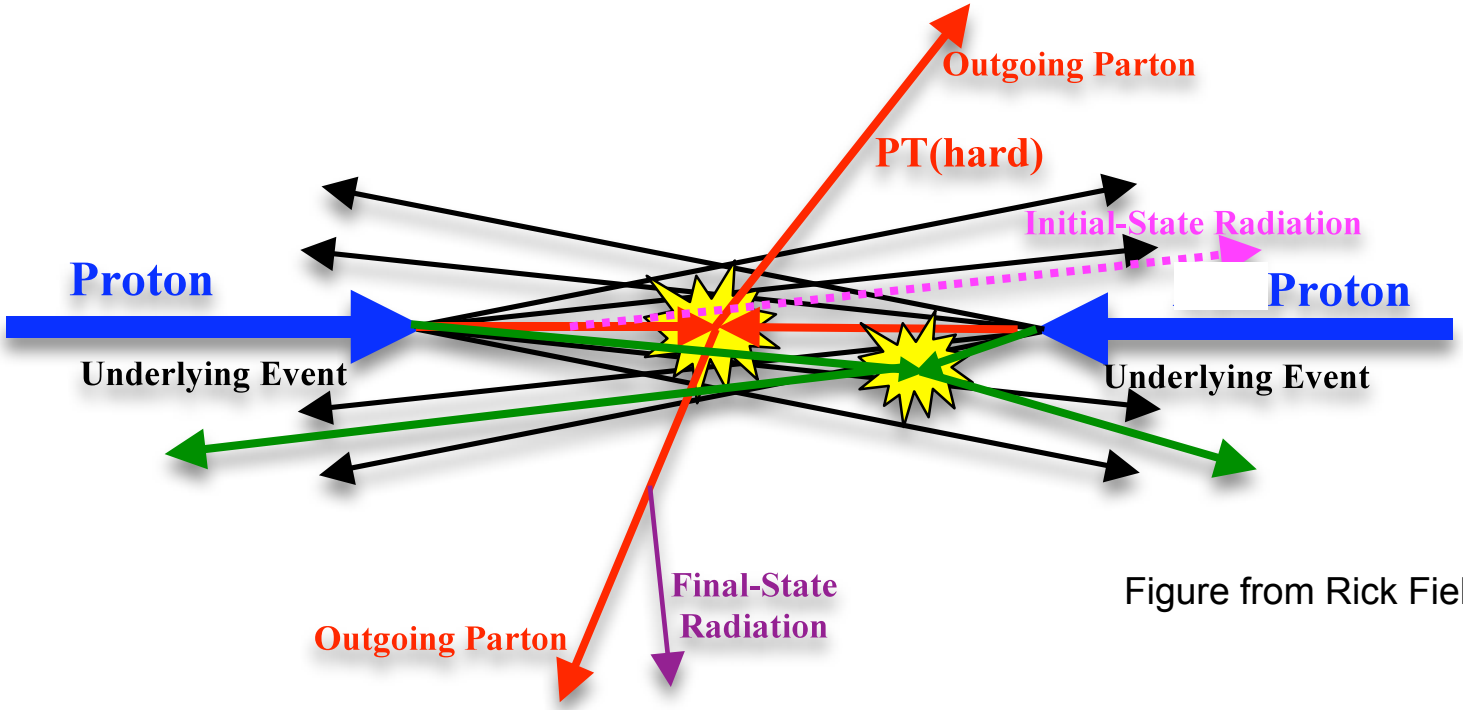


Figure from Rick Field

The Underlying Event is everything BUT the hard scattering

Energy Scaling of the Underlying event

- PYTHIA is tuned to 1.8 TeV - does the tune scale to another collision energy.

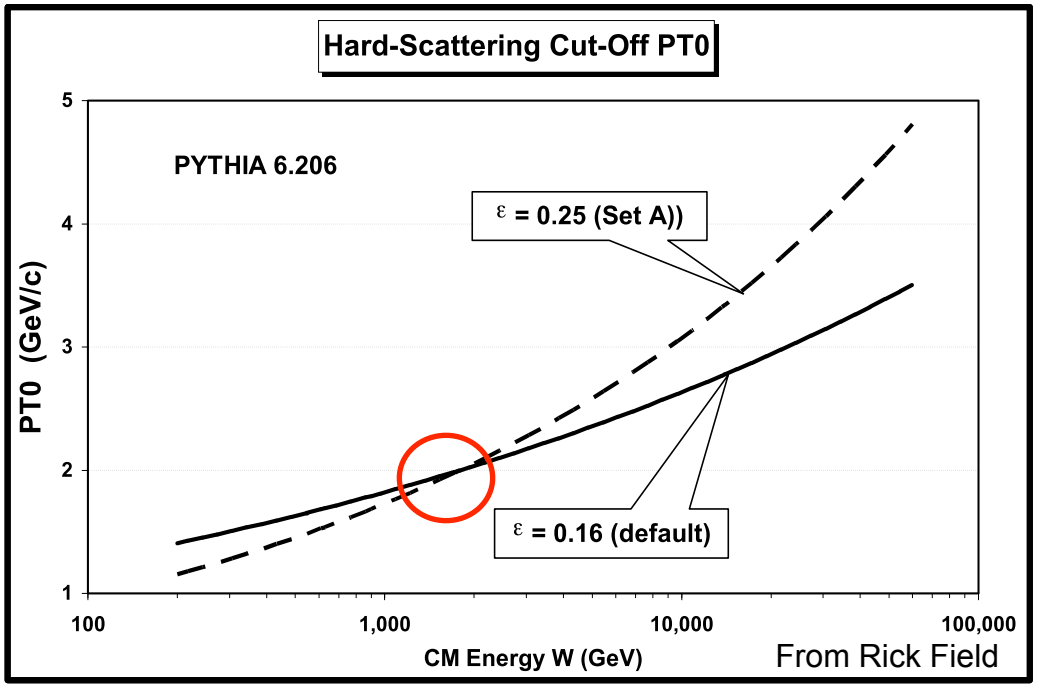
- An important scaling factor is the hard scattering cut-off for the MPI in UE:

$$P_{T0}(E_{cm}) = P_{T0}(E_{cm}/E_o)^{\varepsilon}$$

- Pivots around the tuning energy

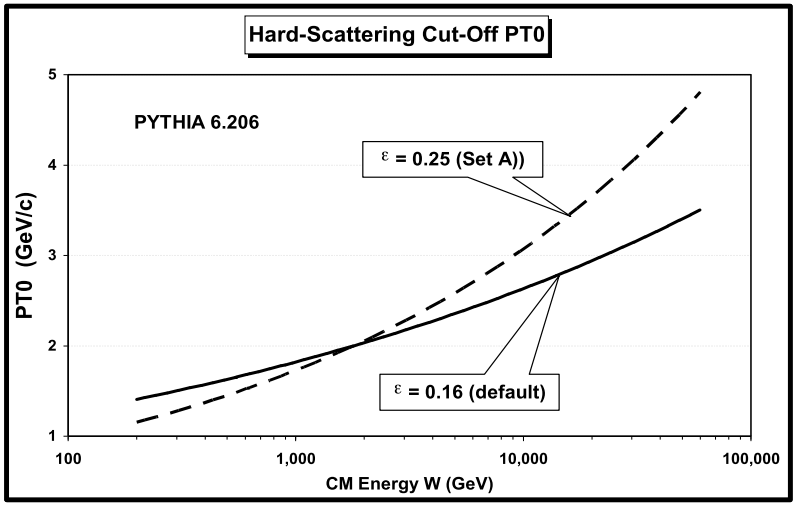
- ε = 0.16 - initial estimate

  = 0.25 (suggested by 630 GeV Tevatron)



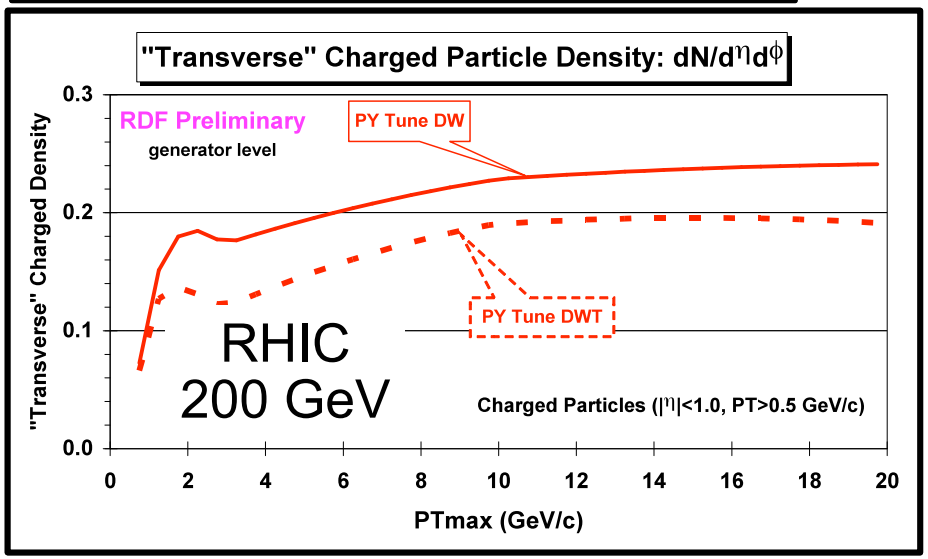
Correct scaling could improve LHC predictions prior to turn-on

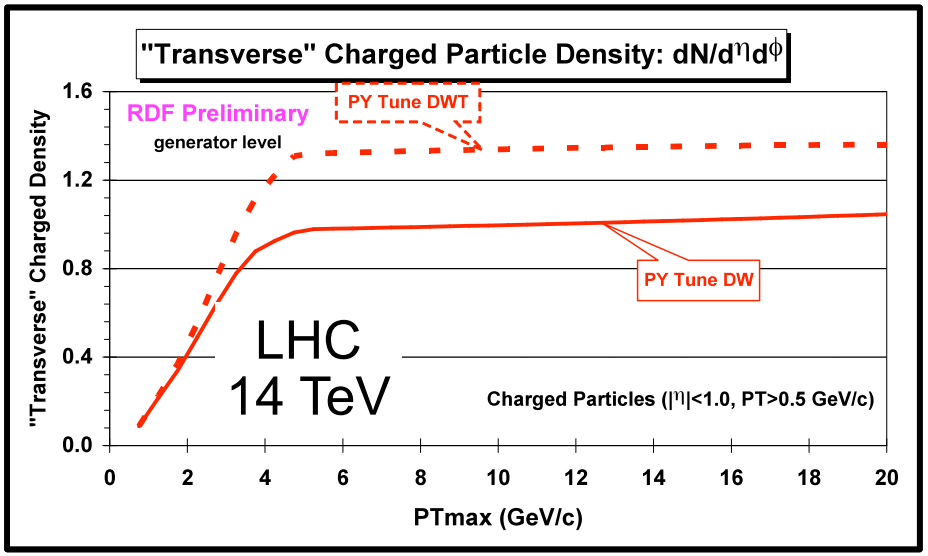
Effect of hard scattering cut-off scaling



- ε = 0.16 (DWT) → 0.25 (DW)
- Increasing ε creates smaller energy dependence for UE

→ 35% more RHIC
→ 26% less LHC



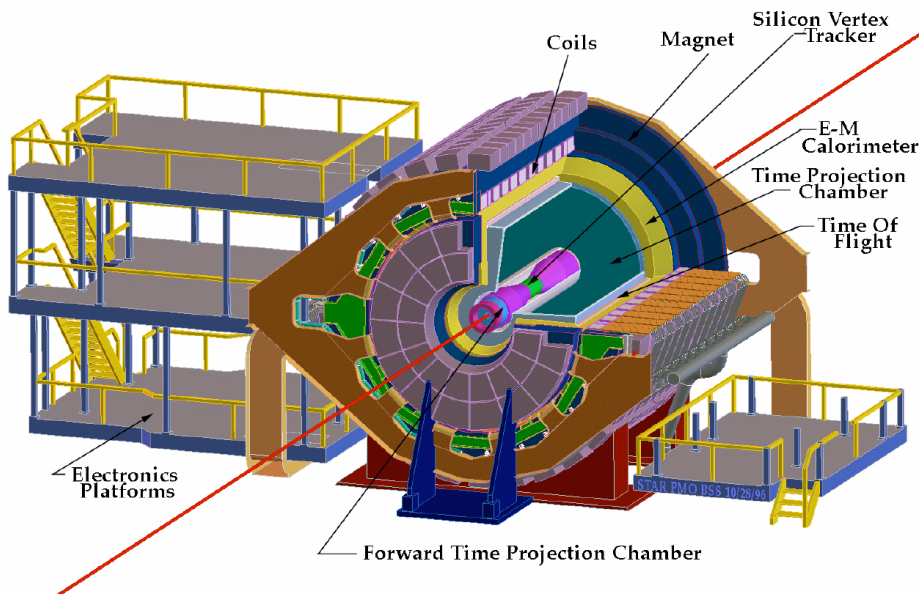


Measurable effect at RHIC

From Rick Field

The p+p data set - $\sqrt{s}$ = 200 GeV

- TPC tracks to identify charged particles contribution.
- Barrel EMCal for neutral energy contribution.



2006 Run

Sampled luminosity for Jet-Patch triggers:

~8.7 pb^{-1}

(~8 M events)

Jet-Patch Trigger:

BBC coincidence + EMCal Jet-Patch

Jet-Patch:

E_T > 8 GeV in

$\Delta\eta \times \Delta\phi = 1 \times 1$

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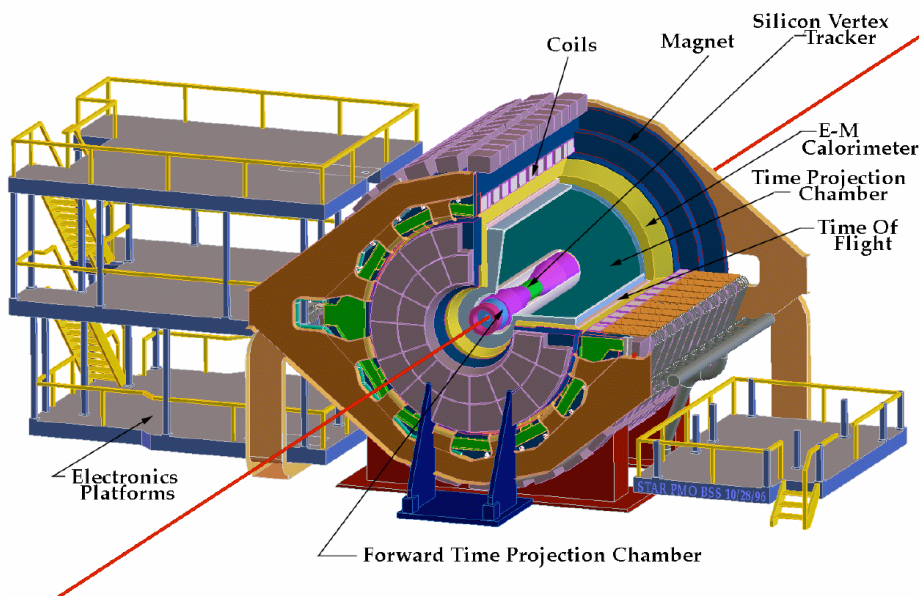

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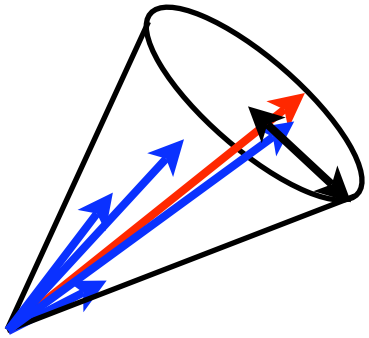
Jet-Patch - NEF FF bias - use non-triggered jet for studies.

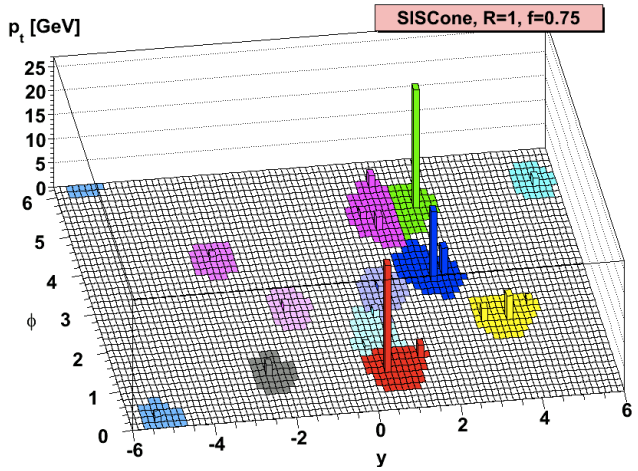
Jet reconstruction - algorithms

Seedless Cone - SISCone

Fastjet package - [Cacciari, Soyez, arXiv:0704.0292]



- $R_{cone}=\sqrt{(\Delta\varphi^2+\Delta\eta^2)}$
- all particles used.
- Splitting/Merging destroys cone shape.



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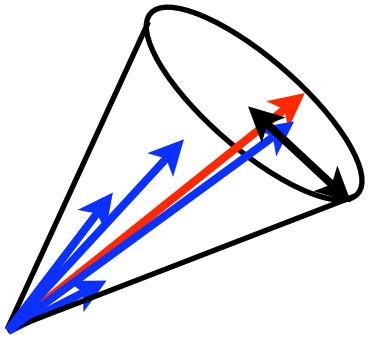

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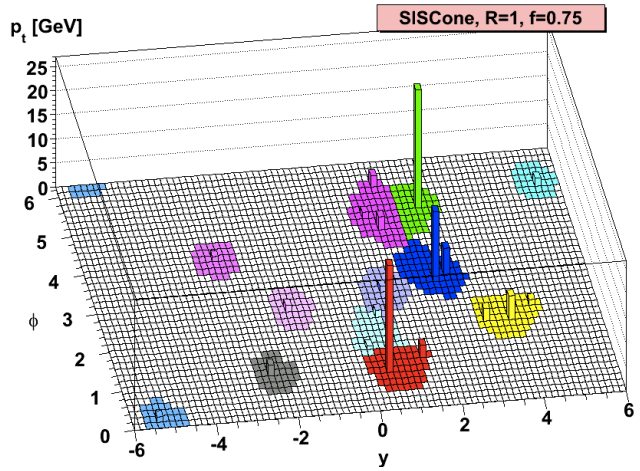

Recombination k_T

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

i.e. high p_T is dis-favored.

Anti-k_T

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- merges weighted by p_T

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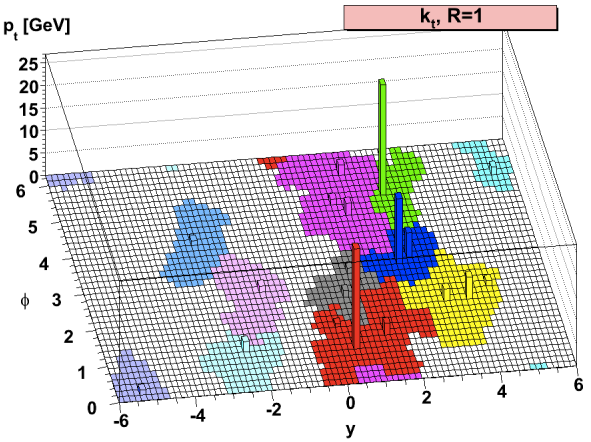

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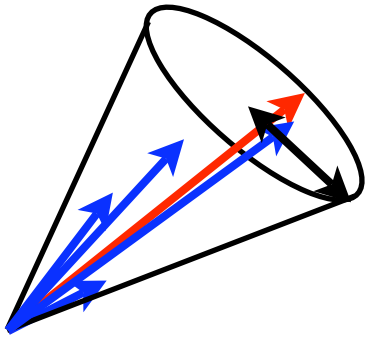

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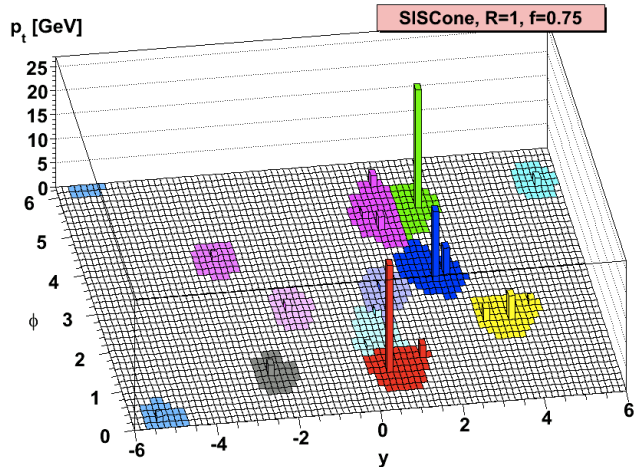

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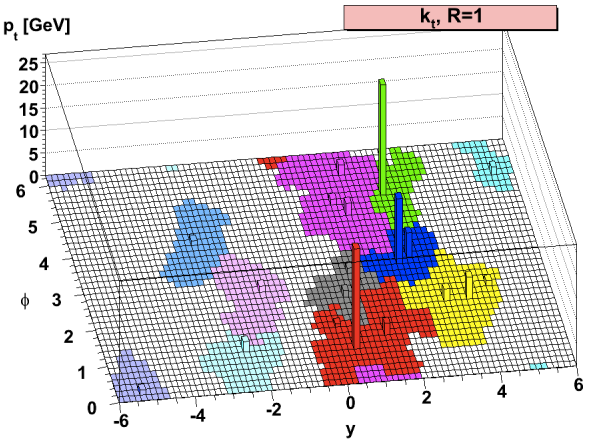

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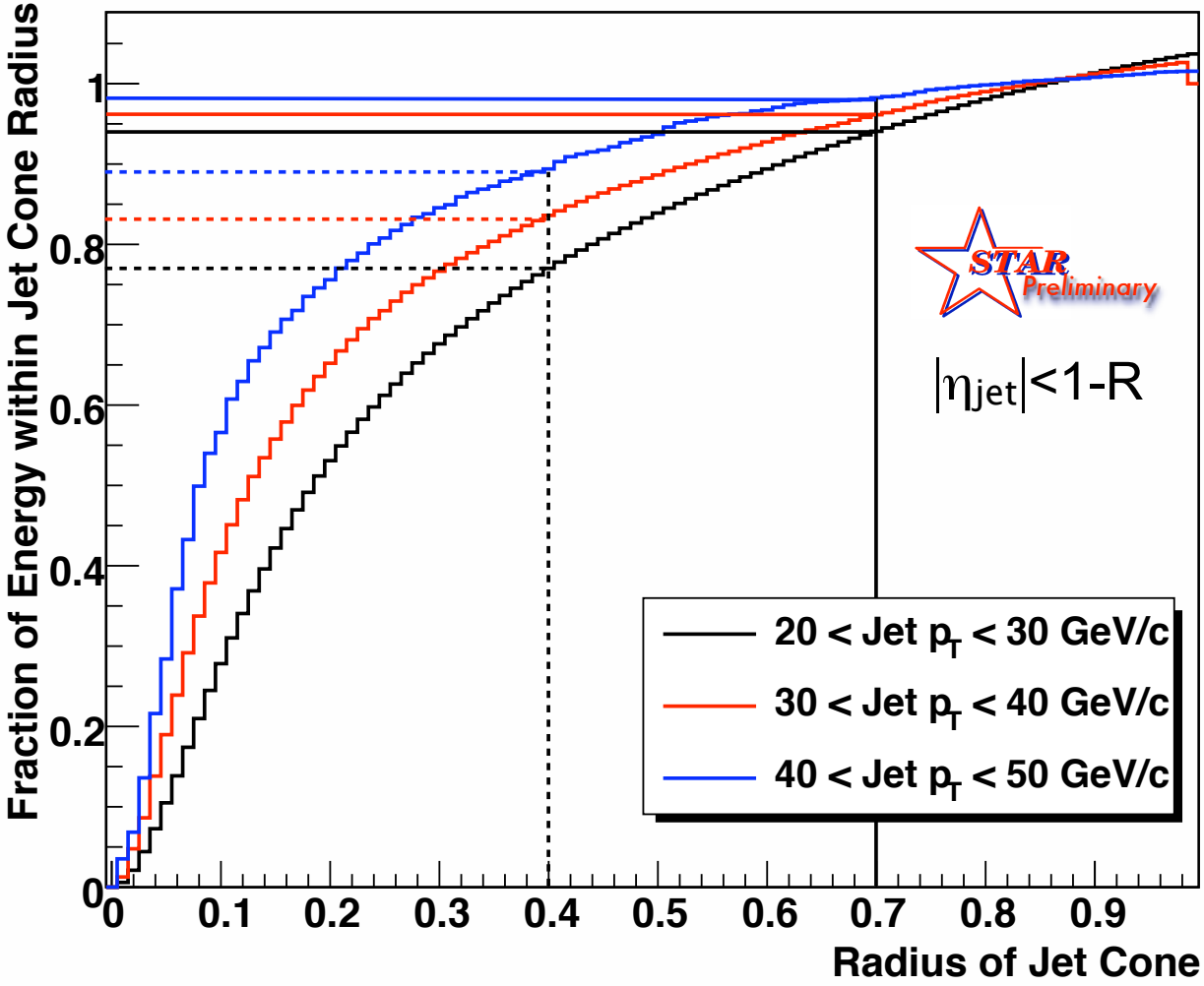
Compare results to explore effects in data

Jet reconstruction - the resolution parameter



Compare FF using different radii.

% Energy within resolution parameter R

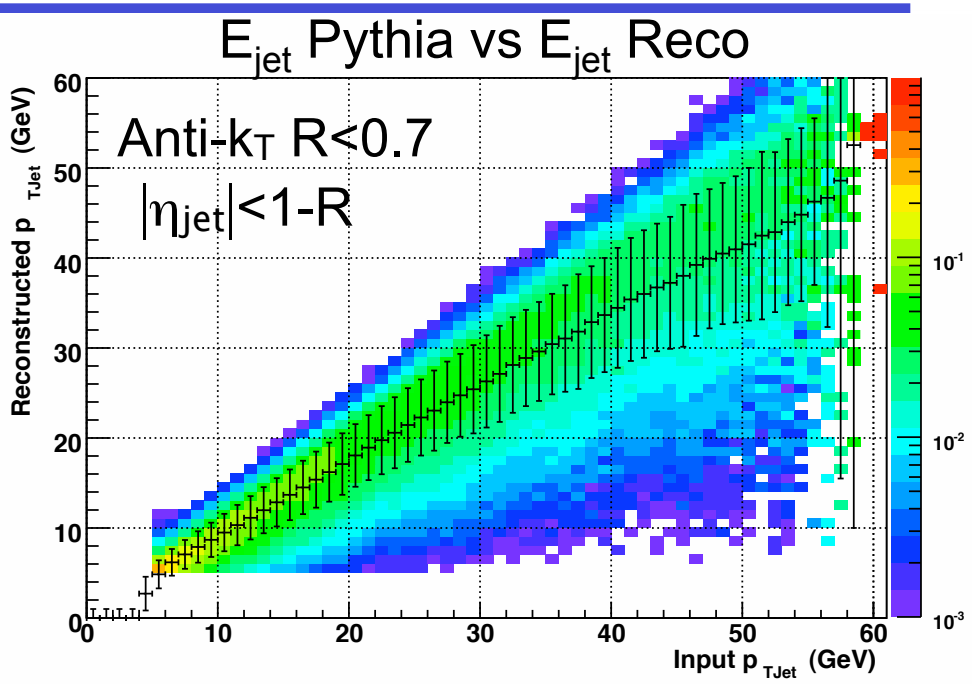
p_T (GeV/c)	R 0.4	R 0.7
20-30	77%	94%
30-40	83%	96%
40-50	89%	98%

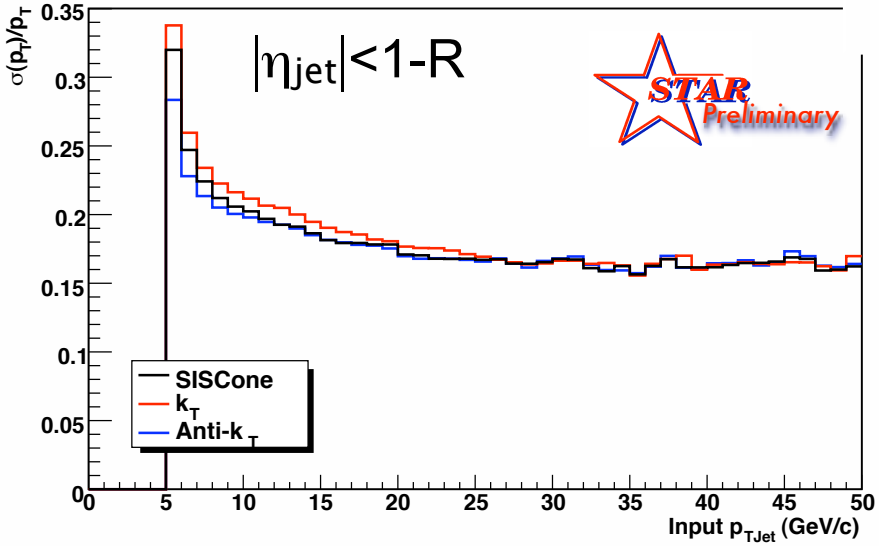
- Larger energy → more focussed jet.
- CDF > 80% R=0.3. (Jet p_T~ 50 GeV)

Energy resolution - the jet energy scale

Calculated in two way:

- Simulation
  - MC input compared to reconstructed output.



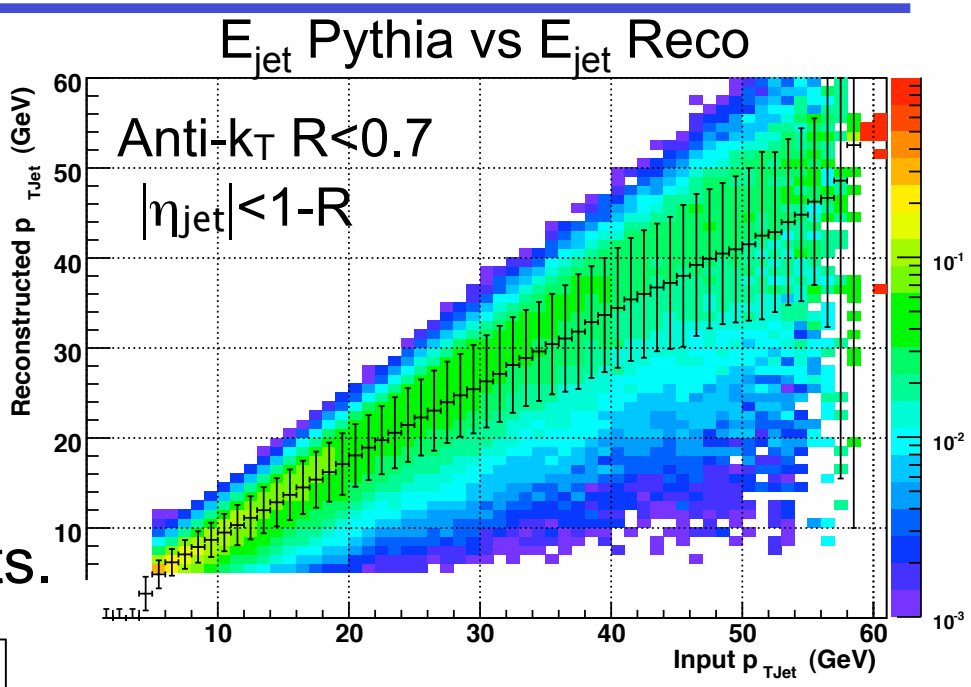


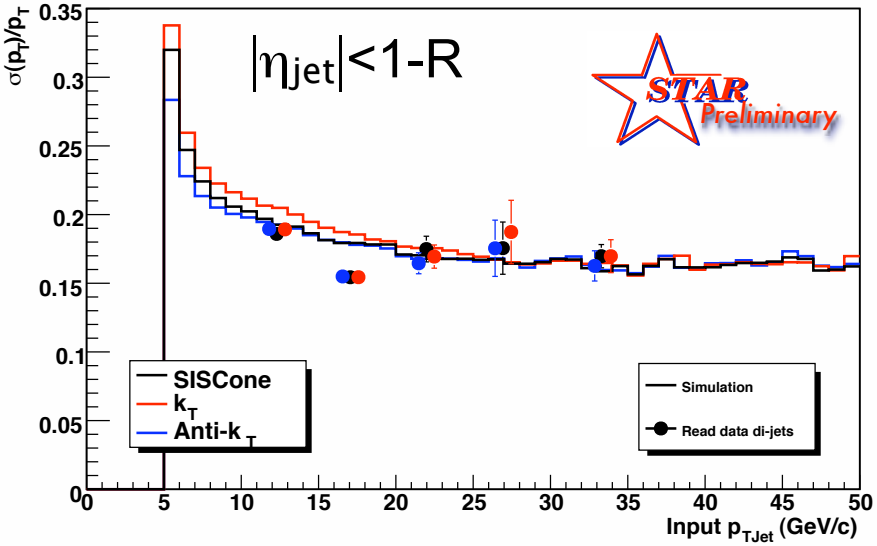
- Offset due to missing energy:
  - Detector efficiencies.
  - Undetected particles (n, K^0_L).
  - Resolution ~15-20% for p_{TJet}>15GeV/c.

Energy resolution - the jet energy scale

Calculated in two way:

- Simulation
  - MC input compared to reconstructed output.
- Real data
  - Energy balance of di-jets.





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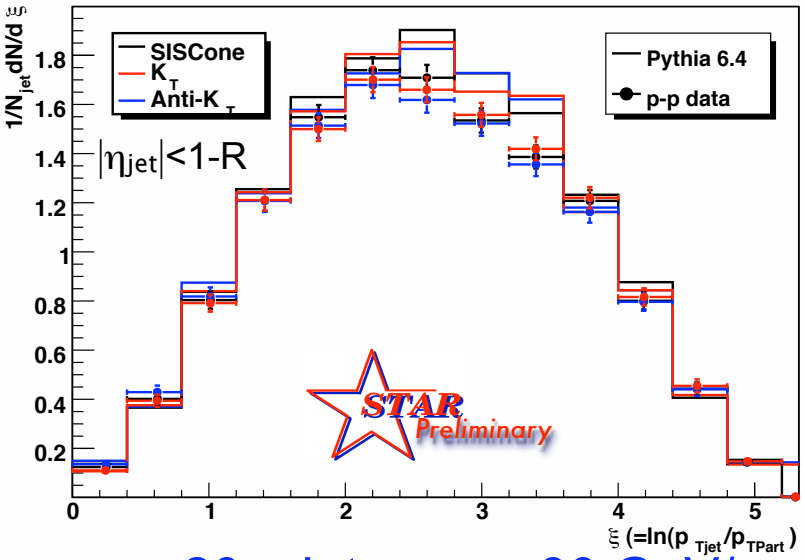
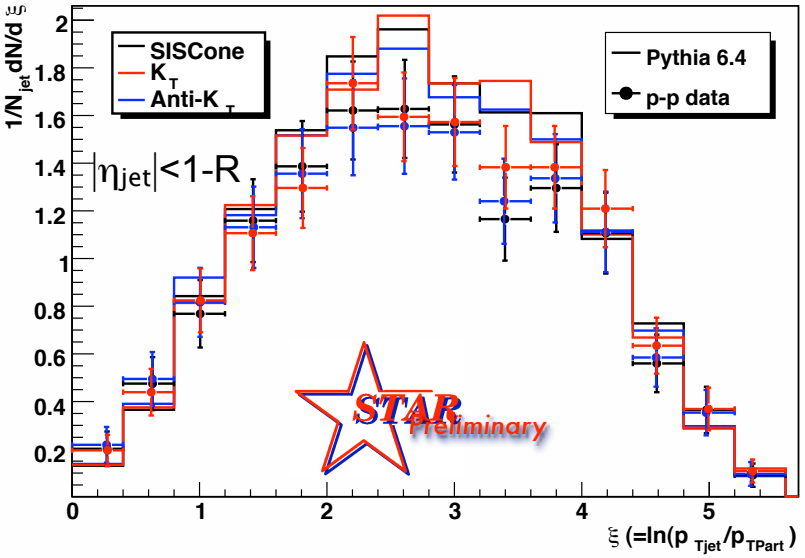
ξ and z distributions for charged hadrons



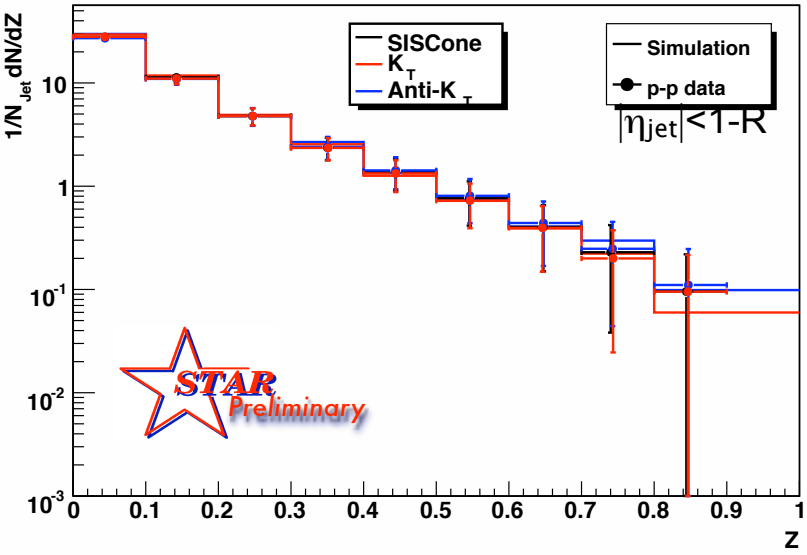
20 <Jet p_{Treco}< 30 GeV/c

Data not corrected to particle level.

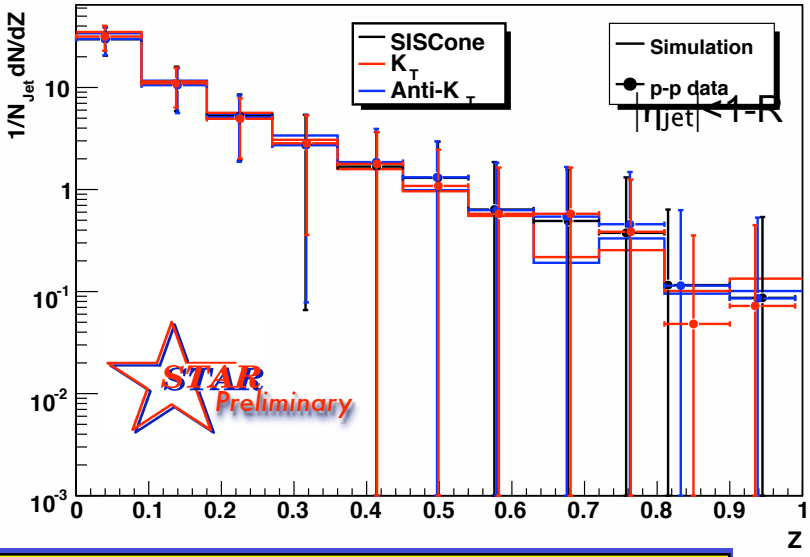
R=0.4



30 <Jet p_{Treco}< 40 GeV/c

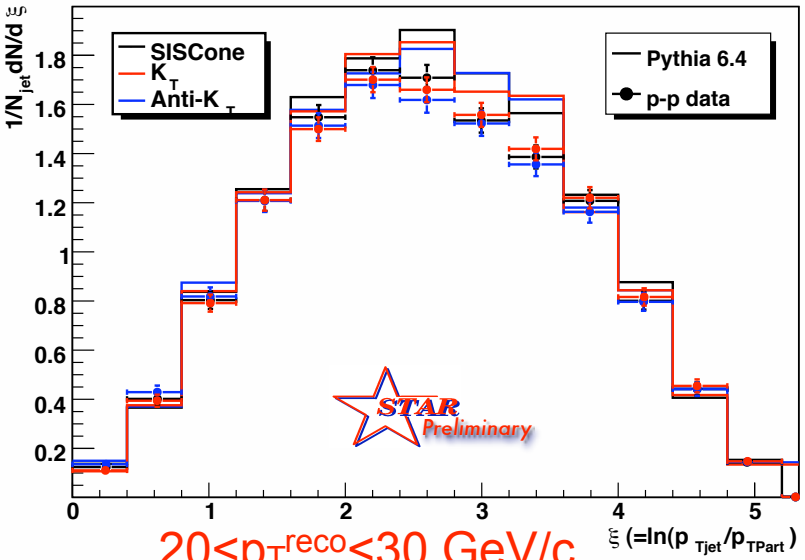


"PYTHIA" = PYTHIA +GEANT



Reasonable agreement between data and PYTHIA+GEANT.

Charged hadrons ξ for different R and jet p_T



$20<p_T^{reco}<30$ GeV/c

R=0.4

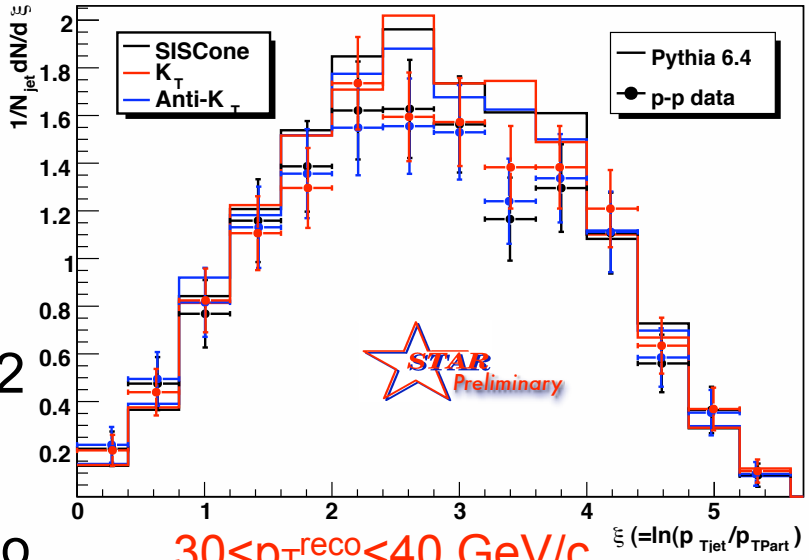
$|\eta_{jet}|<1-R$

$p_{Ttrack} > 0.2$

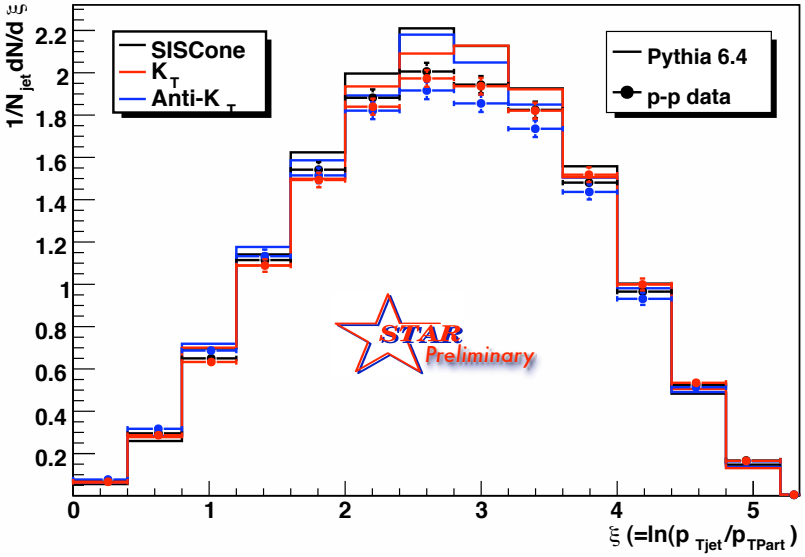
Data not corrected to particle level.

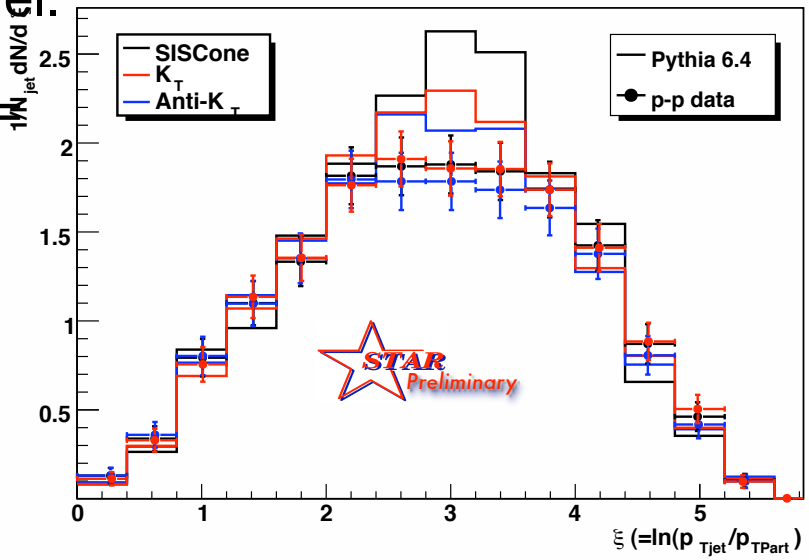
"PYTHIA" = PYTHIA +GEANT

R=0.7



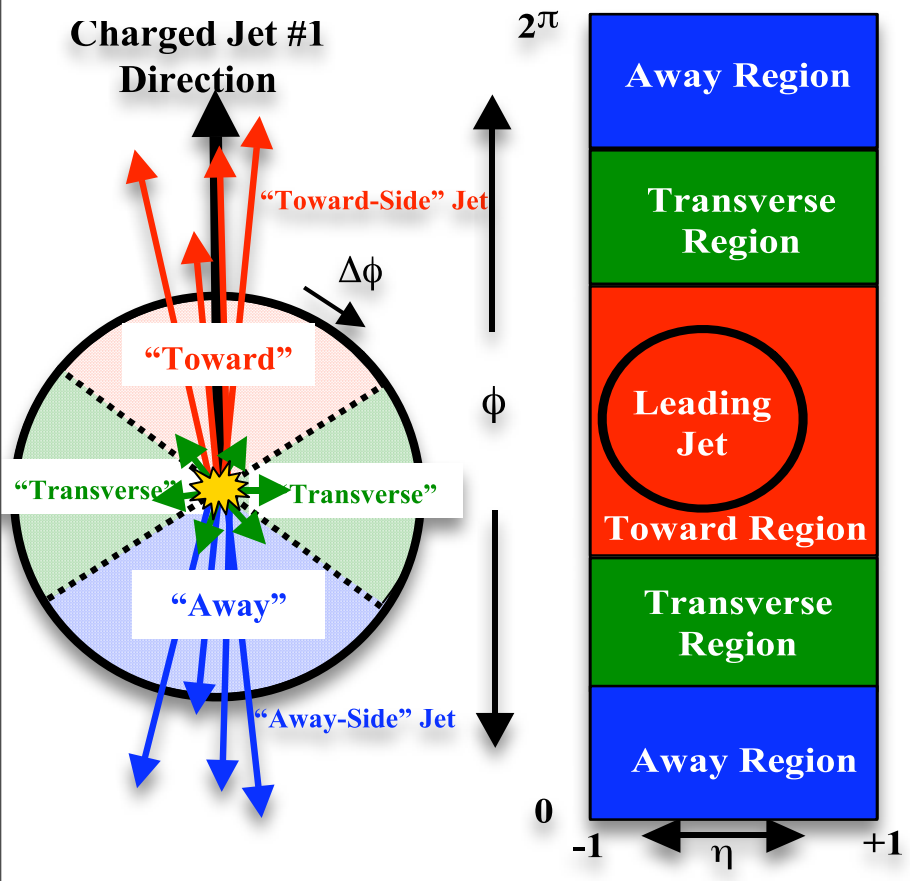
$30<p_T^{reco}<40$ GeV/c





Agreement similar between PYTHIA and data for both radii.

Measuring the Underlying Event



Define:

- $|\Delta\phi|$ – Angle relative to leading jet
- **"Toward" $|\Delta\phi| < 60°$**
- **"Away" $|\Delta\phi| > 120°$.**
- **"Transverse" $60° < |\Delta\phi| < 120°$**
  - **TransMax** - Trans. region with highest Σp_T or ΣN_{track}
  - **TransMin** Trans. region with least Σp_T or ΣN_{track}

Underlying Event is the data in the Transverse regions.

Sensitivities of the variables

leading : Most basic jet cut, one jet in our acceptance.

back-to-back : Sub-set of leading jet collection.
Require $|\Delta\phi| > 150$, $p_{TAway}/p_{TLead} > 0.7$
Suppresses hard initial and final state radiation.

TransMin : Sensitive to beam-beam remnants and soft multiple parton interactions.

TransMax : Enhanced probability of containing hard initial and/or final state radiation component.

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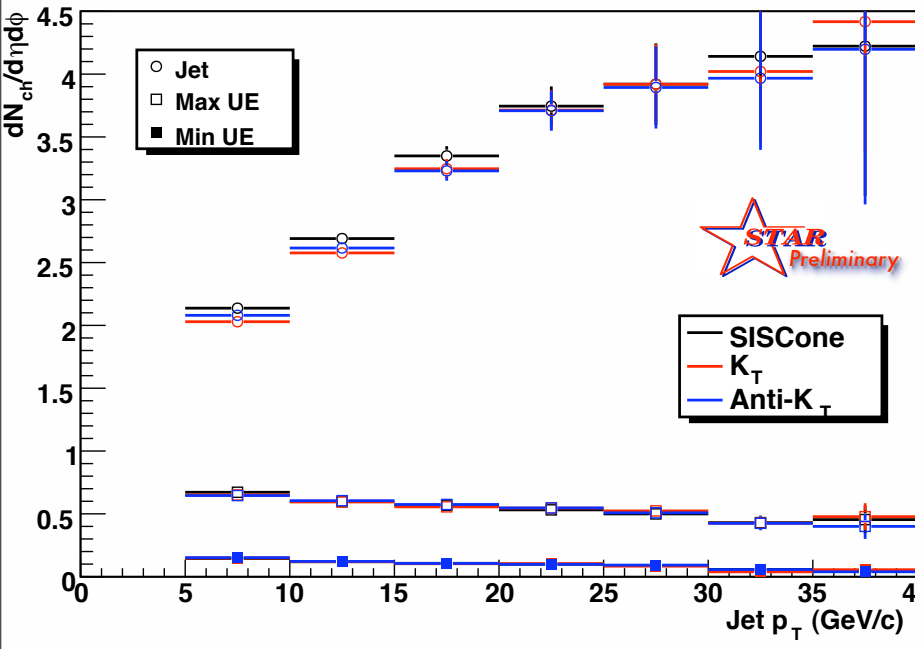
Compare TransMin and TransMax data from leading and back-to-back jet samples →

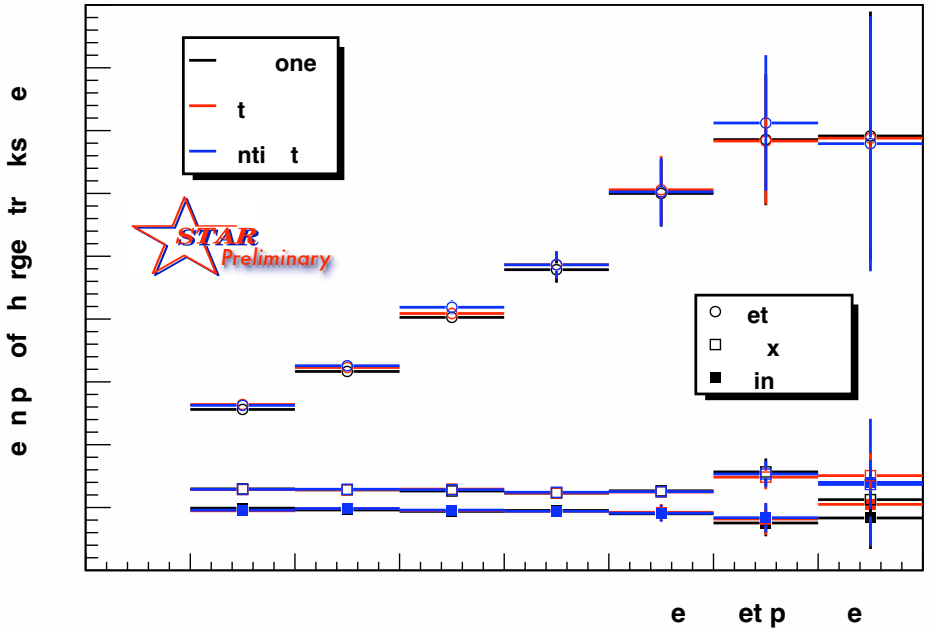
Information about large angle initial/final state radiation.

Underlying event vs jets properties

Back-to-Back, R=0.7, $|\eta_{jet}| < 1-R$, $p_{Ttrack} > 0.2$ GeV/c

Data not corrected to particle level.





- Jet charged track density and $\langle p_T \rangle$ rise with jet p_T as expected

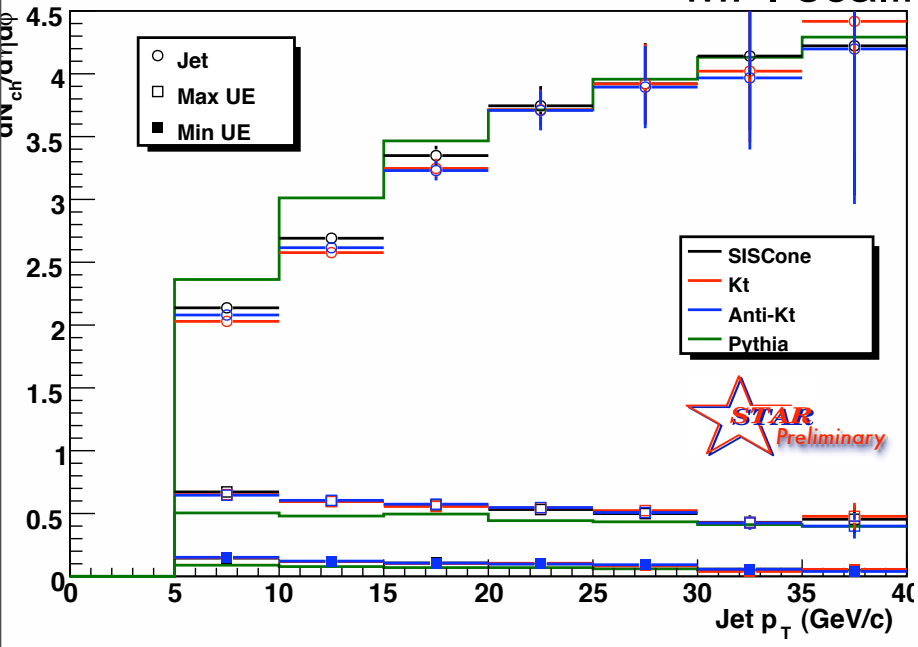
UE largely independent of jet p_T

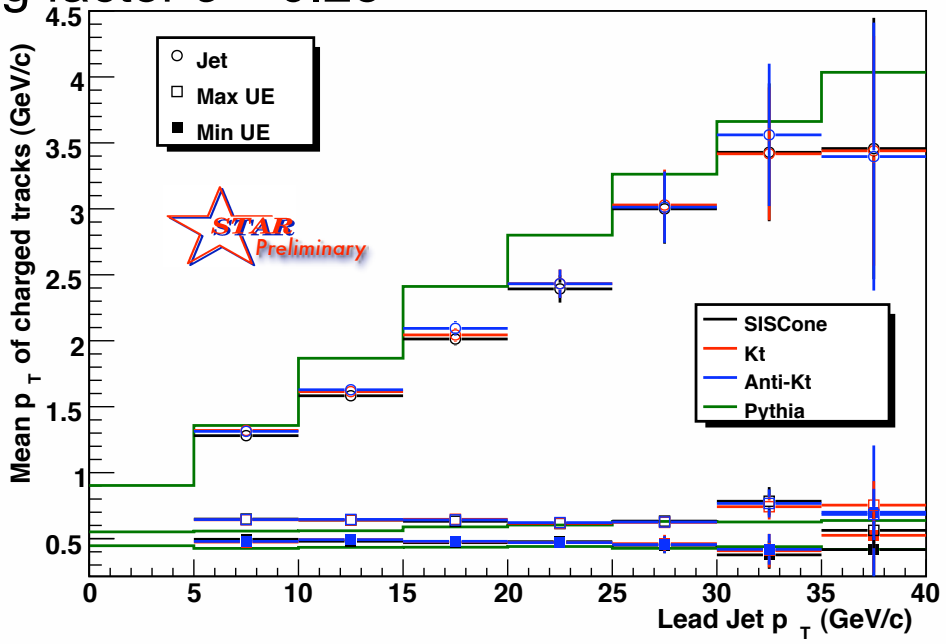
Checking energy scaling at RHIC

Back-to-Back, R=0.7, $|\eta_{jet}| < 1-R$, $p_{Ttrack} > 0.2$ GeV/c

Data not corrected to particle level, "PYTHIA" = PYTHIA +GEANT

MPI scaling factor ε = 0.25

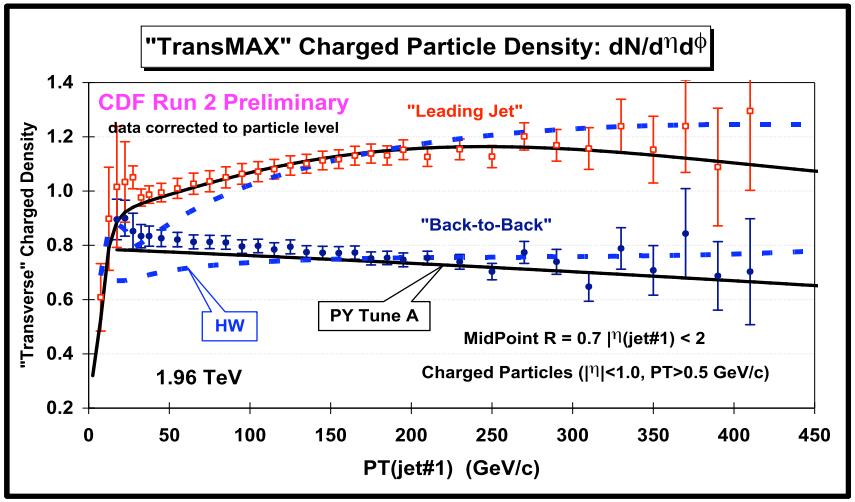




RHIC data support ε = 0.25

- Many standard PYTHIA tunes (including those labeled "ATLAS" in PYTHIA) tunes have ε = 0.16 this is INCORRECT activity in min-bias events wrong

TransMin vs TransMax regions of UE



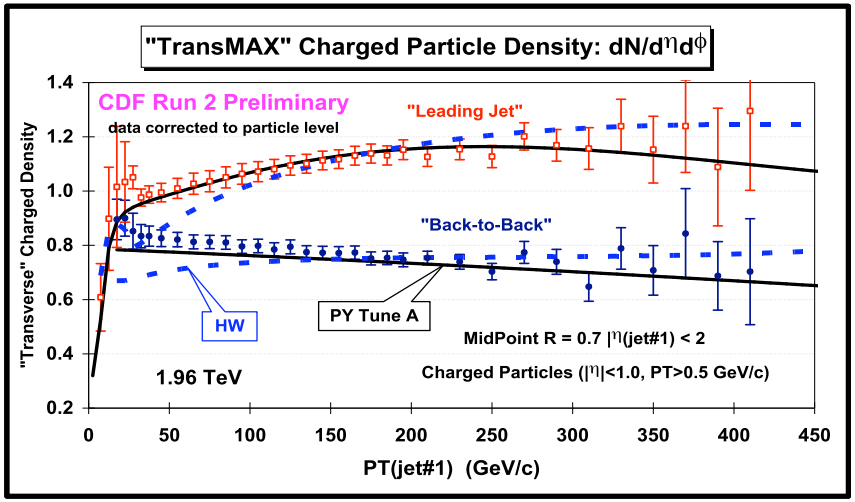
Data not corrected to particle level.

CDF $\sqrt{s}$=1.96 TeV

- leading TransMax > back-to-back TransMax

Significant initial/final state radiation at large angles.

TransMin vs TransMax regions of UE



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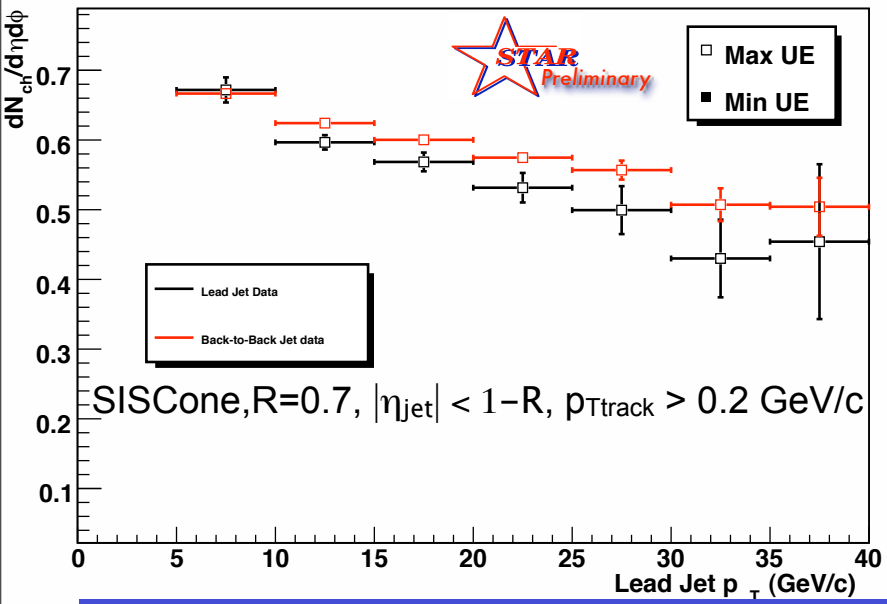


CDF √s=1.96 TeV

- leading TransMax > back-to-back TransMax

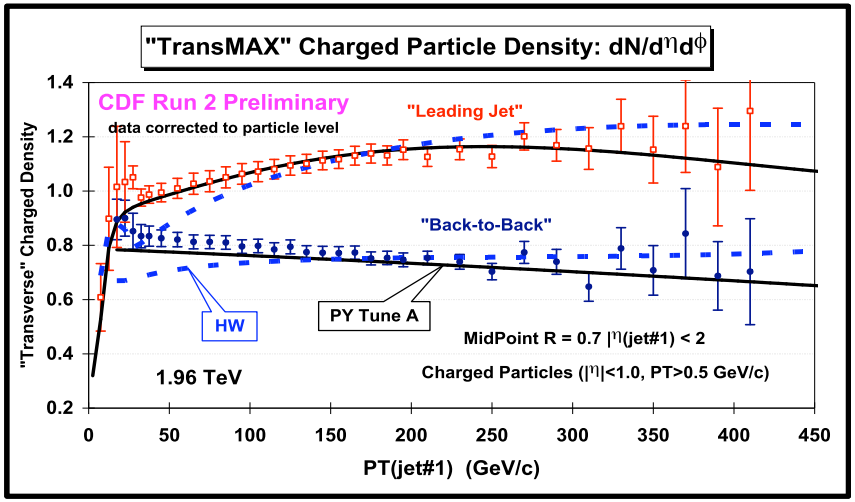
Significant initial/final state radiation at large angles.

STAR √s=200 GeV

- leading TransMax ~ back-to-back TransMax

Small initial/final state radiation at large angles.

TransMin vs TransMax regions of UE



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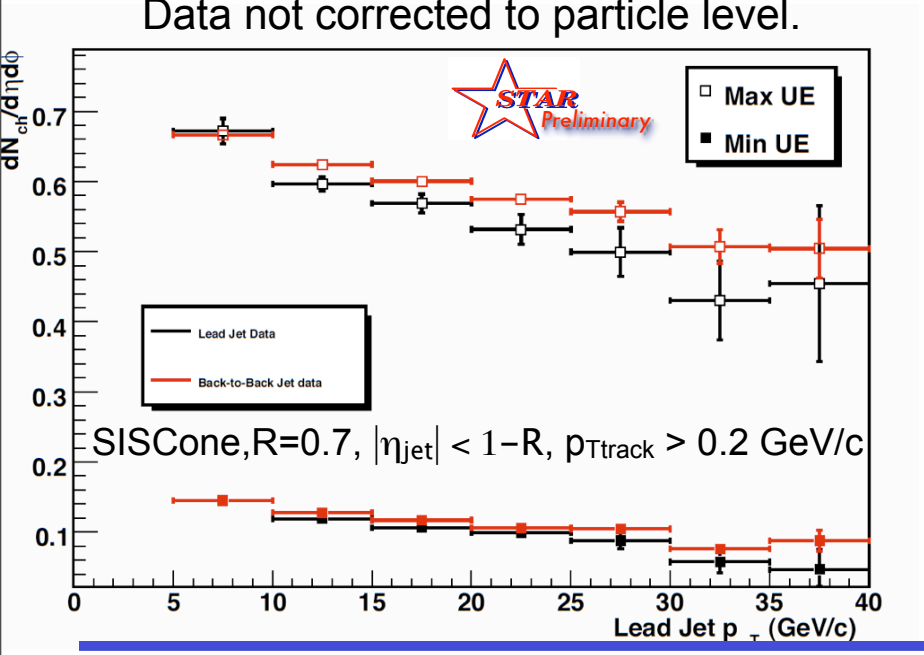

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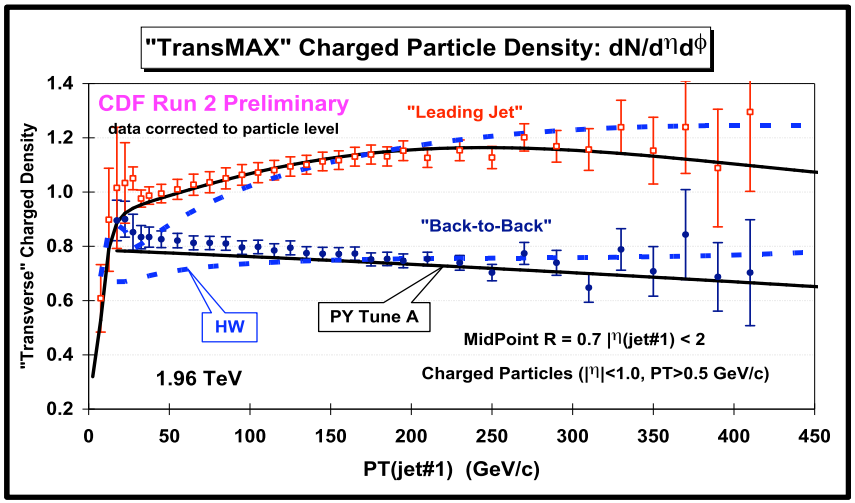
TransMin vs TransMax regions of UE



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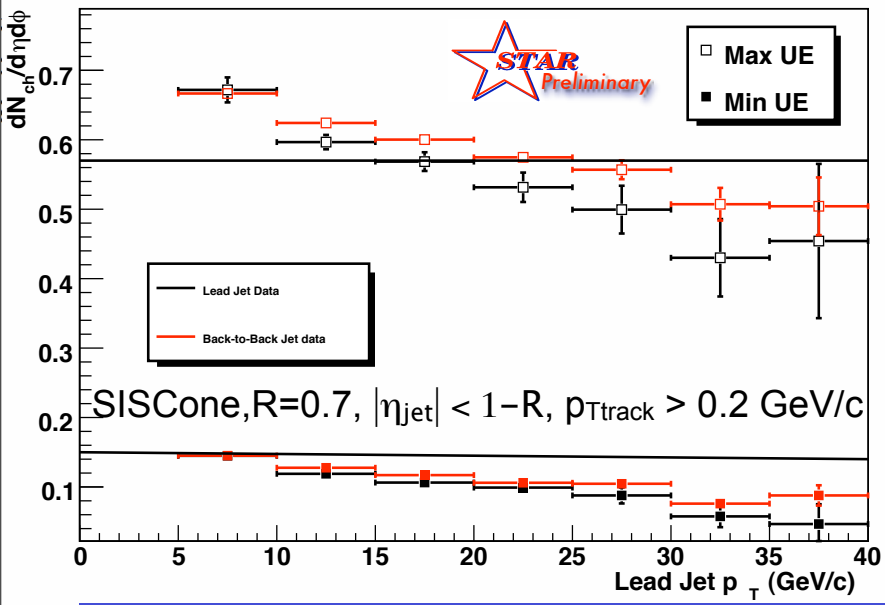

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- leading TransMax > back-to-back TransMax

Significant initial/final state radiation at large angles.

STAR √s=200 GeV

- leading TransMax ~ back-to-back TransMax

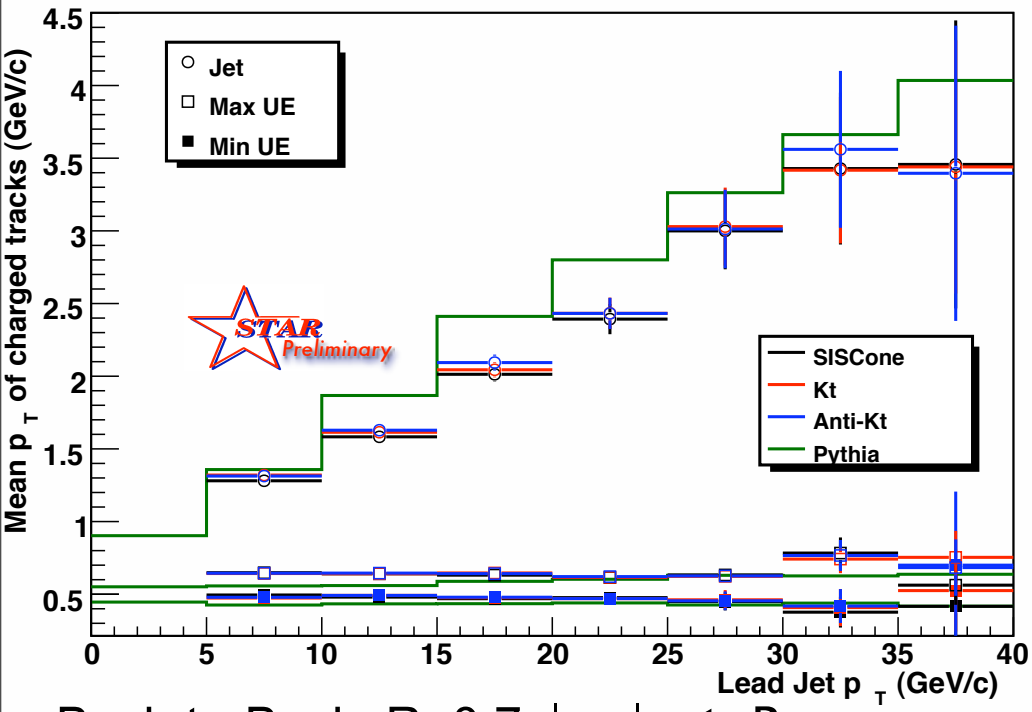
Small initial/final state radiation at large angles.

- TransMax > TransMin

Poisson distribution with average $dN_{ch}/d\eta d\phi = 0.36$

- UE ~independent of jet p_T.

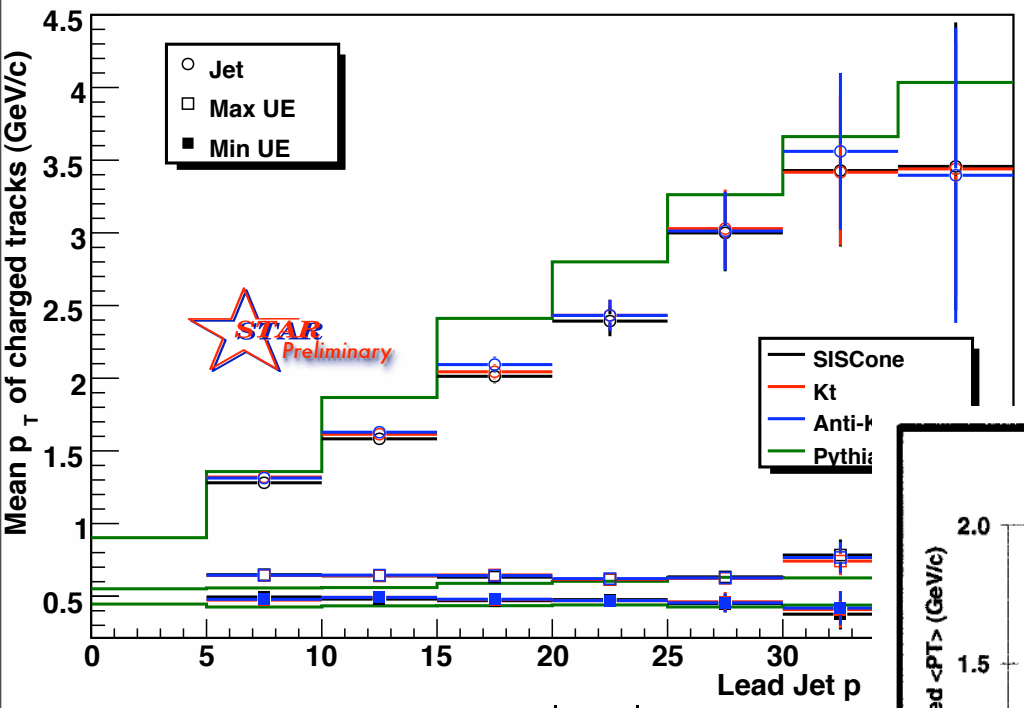
Mean p_T charged tracks



- Agreement between PYTHIA and data OK

, Back-to-Back, R=0.7, $|\eta_{jet}| < 1-R$,
p_{Ttrack} > 0.2 GeV/c
Data not corrected to particle level.
"PYTHIA" = PYTHIA +GEANT

Mean p_T charged tracks



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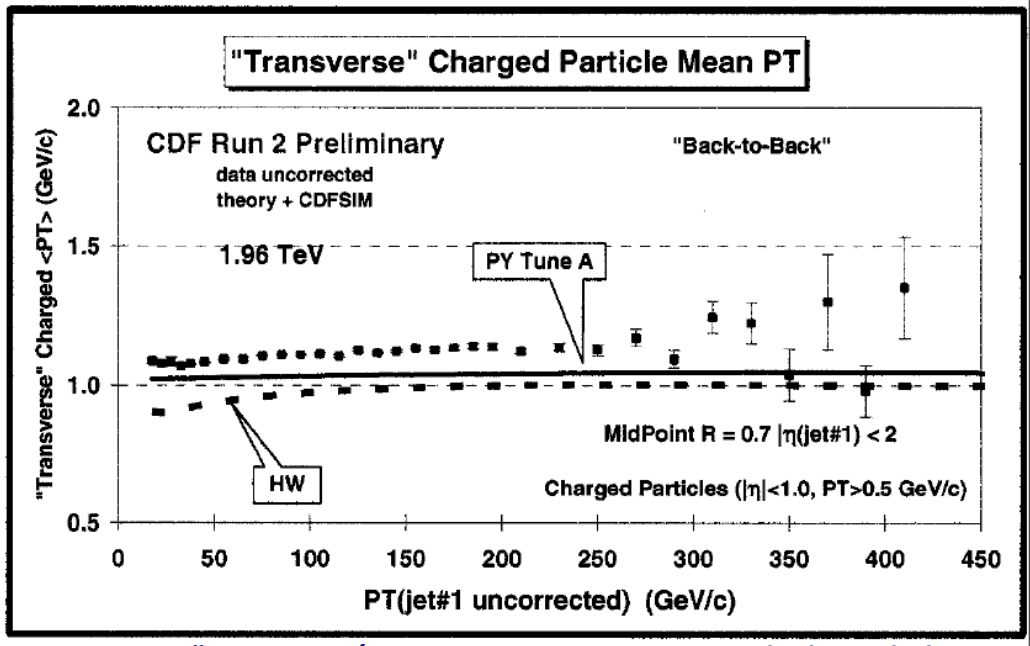
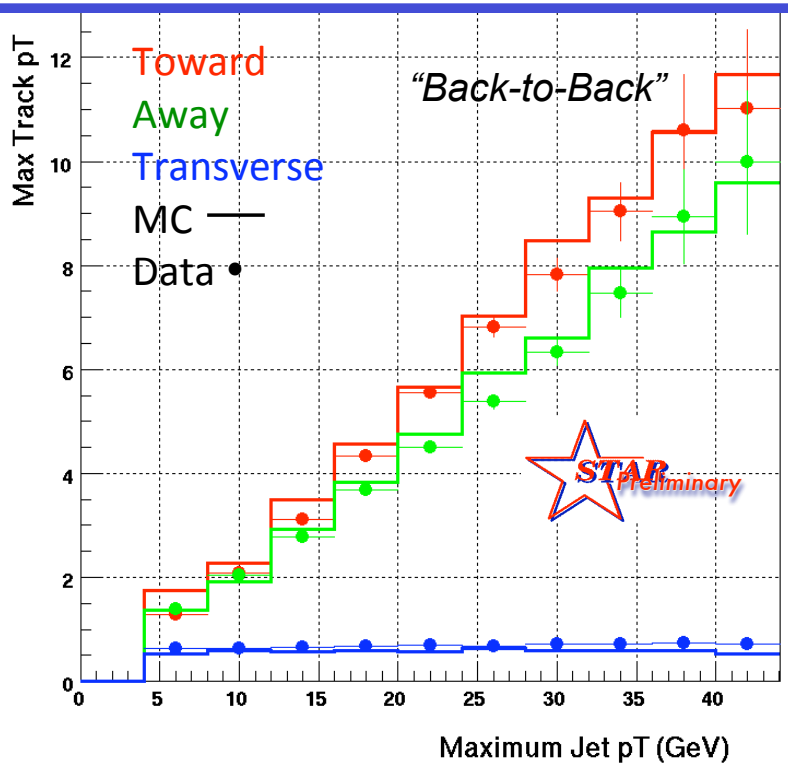


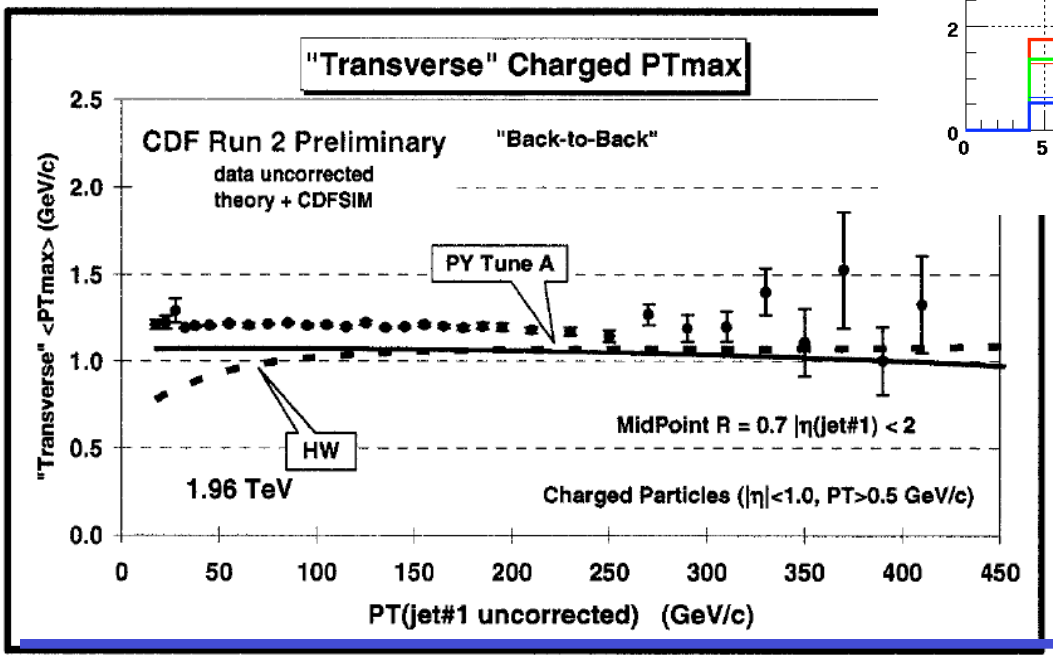
L.A. Cruz, "Using MAX/MIN transverse regions to study the underlying event in run 2at the Tevatron" UMI-31-88071, 2005.

CDF higher than STAR merely due to lower p_T cut?

Max p_T charged track

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





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RHIC UE is a little softer

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

Summary & outlook

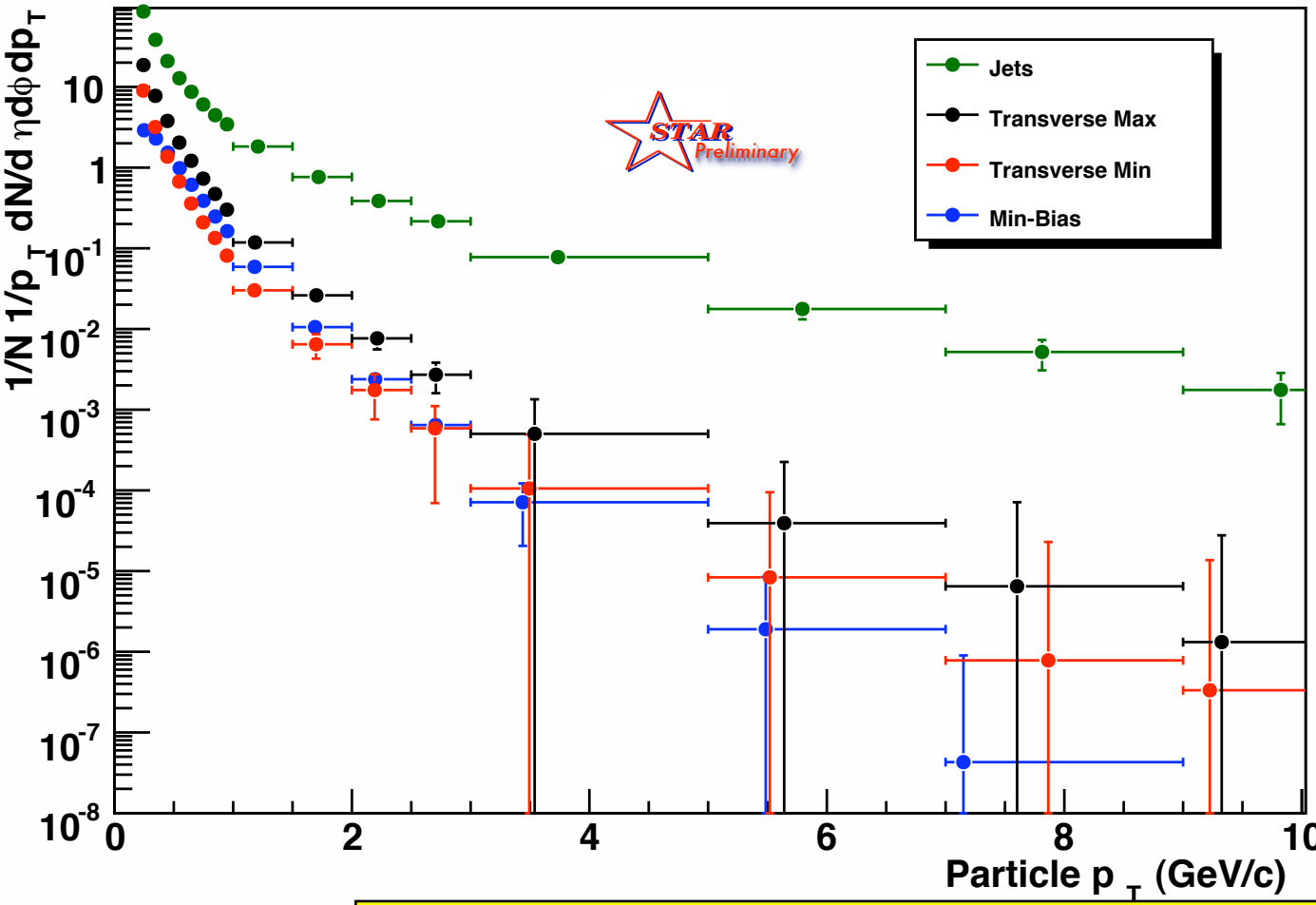
- Different jet algorithms produce consistent results
- Charged hadron ξ and z distributions at $\sqrt{s}$=200 GeV similar to PYTHIA 6.4.
- Underlying Event largely decoupled from hard scattering.
- The energy scaling suggested by PYTHIA for the MPI more accurate in the newer tunes - better predictions for LHC
- Large angle initial/final state radiation is small.
- Particle p_T spectra are significantly softer out of the jet cone compared to in the jet.

<u>Outlook</u>

- Compare more jet-variables (k_T, j_T, etc) to pQCD models.
- Look at particle composition in and out of jets
- Repeat measurements at $\sqrt{s}$=500 GeV.
- Measure PID FF in heavy ion collisions.

p_T spectra in jet, UE, Min-Bias event

•$15<p_{Tjet}<20$ GeV/c, $|\eta_{jet}|<1-R$, R=0.7



Uncorrected Spectra

	$\langle p_T \rangle$ GeV/c
Jet	1.2
Max UE	0.5
Min UE	0.4
Min-Bias	0.6

Minbias close to but ***not*** equal to UE

p_T spectra in jet, UE, Min-Bias event

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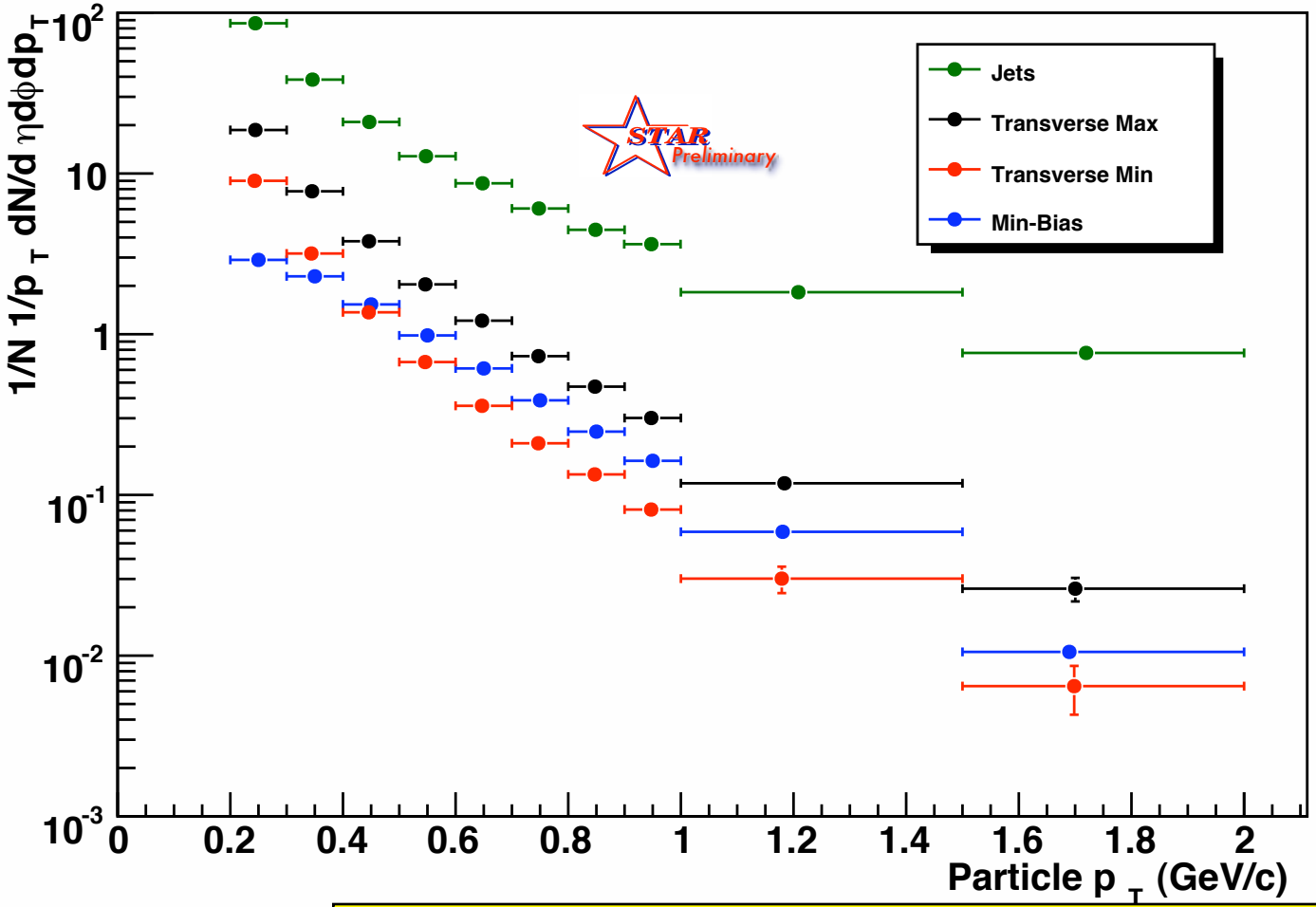

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