Jet and Underlying Event Measurements in p+p collisions at RHIC

Helen Caines - Yale University

for the STAR Collaboration

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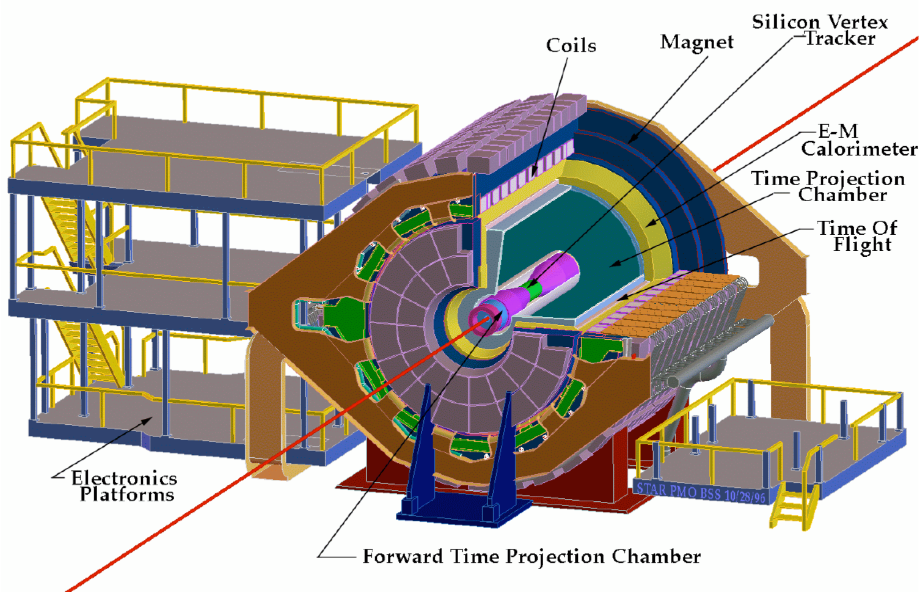
Jets at $\sqrt{s}$ = 200 GeV - the p+p data set

- 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 $\Delta\eta$ x $\Delta\phi$ = 1x1

Use k_T, Anti-k_T and SISCone, jet energy scale resolution ~15-20%

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

k_T and jet energy resolution

See J.Kapitan IVA for more details on k_T

Study k_T, di-jet balance, and jet energy resolution

k_T and jet energy resolution interplay

- k_T measure involves the jet p_T

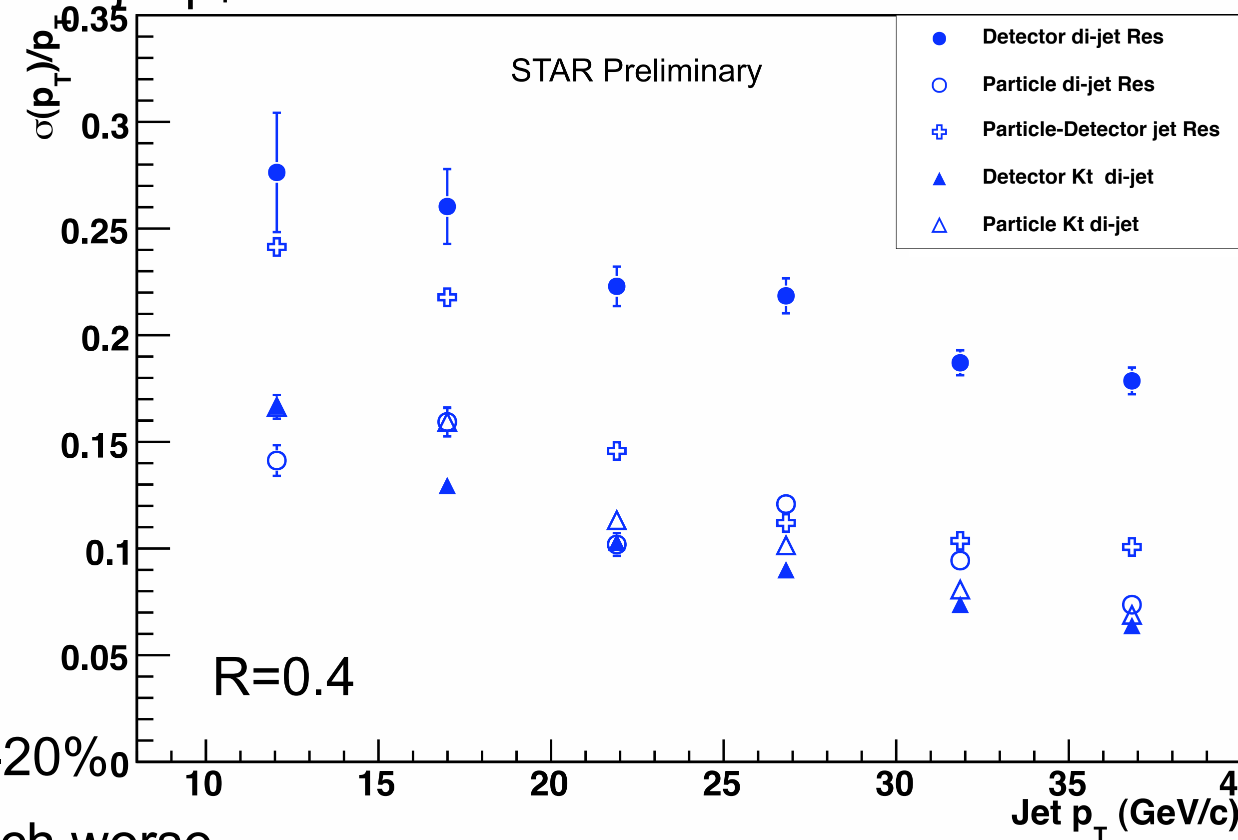
Study using PYTHIA

particle - pure PYTHIA

detector - PYTHIA +reconstruction

Allows to resolve detector effects from "physics"

- k_T - same at both levels
- di-jet particle ~ k_T
- Jet energy resolution 15-20%
- di-jet energy balance much worse



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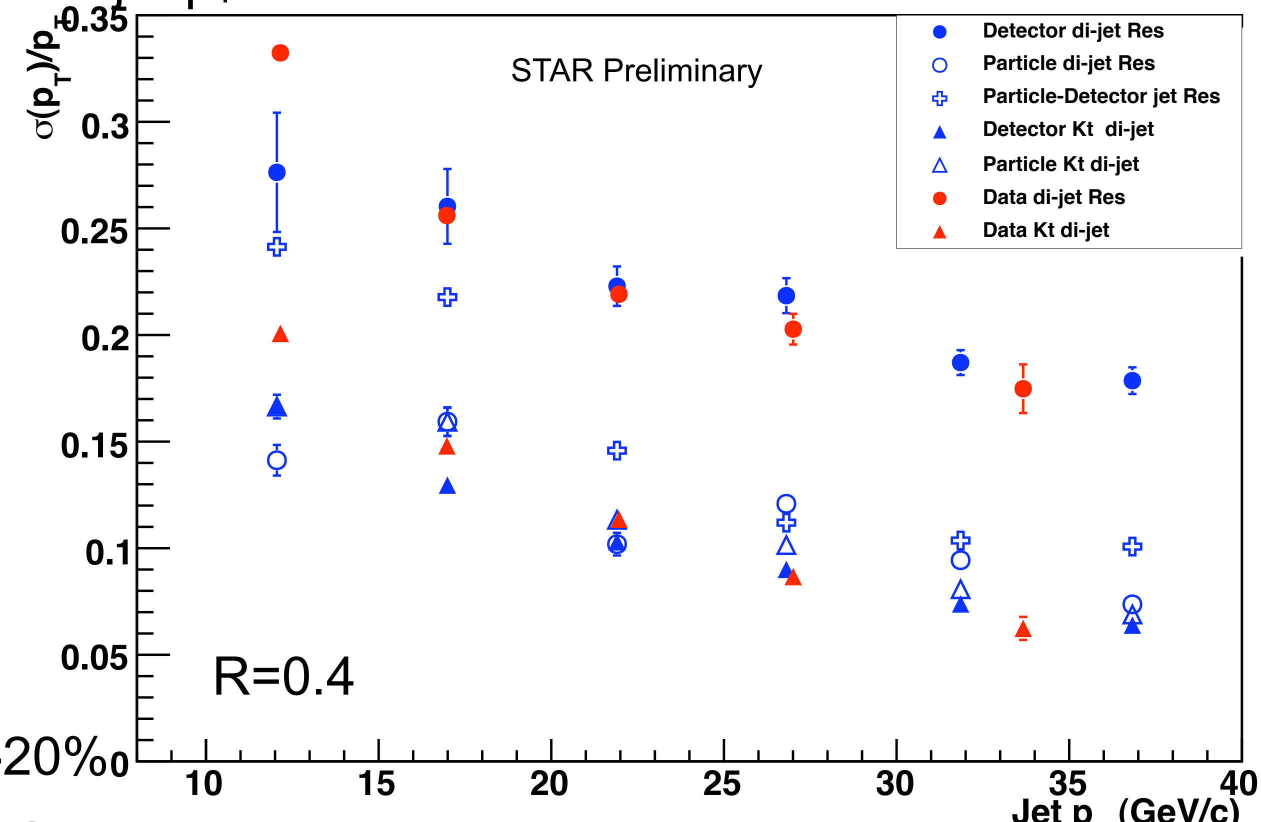
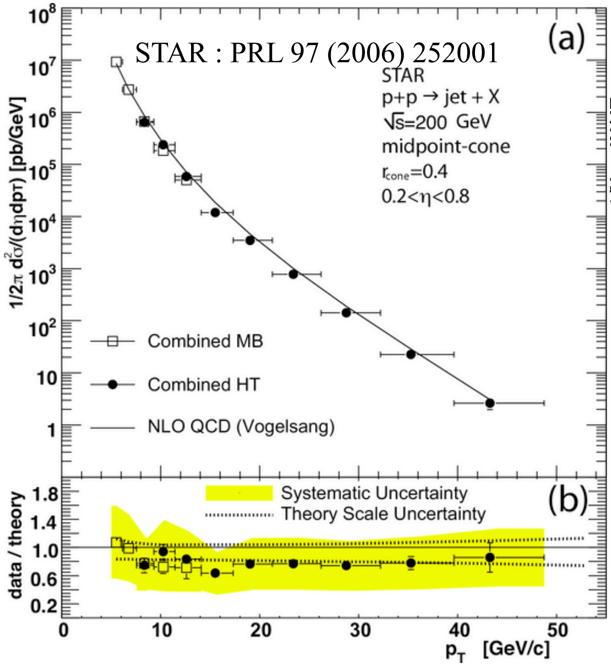
- Real data agrees with PYTHIA

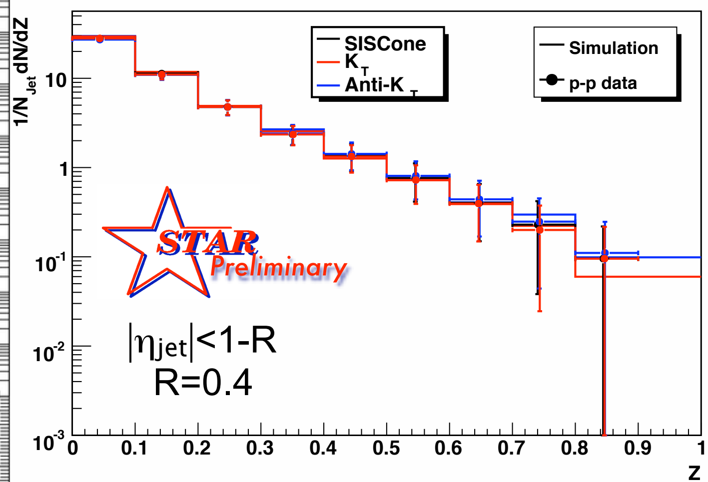


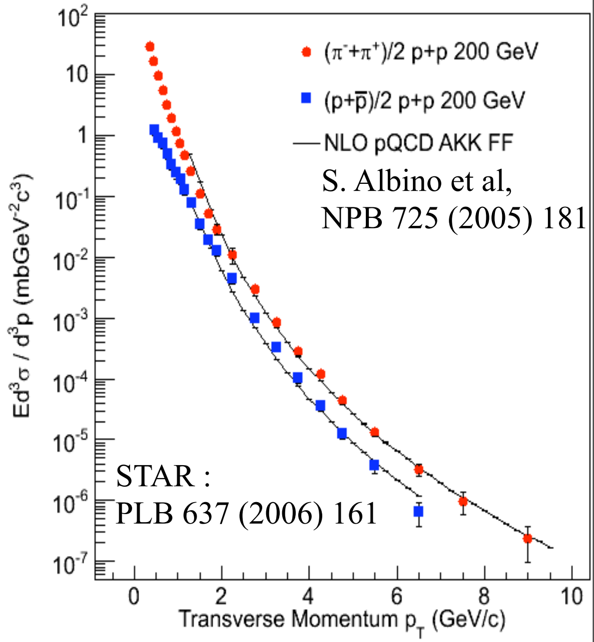
Use PYTHIA to determine jet energy resolution

Jets at RHIC



20 <Jet p_{Treco}< 30 GeV/c
Data and PYTHIA at detector level



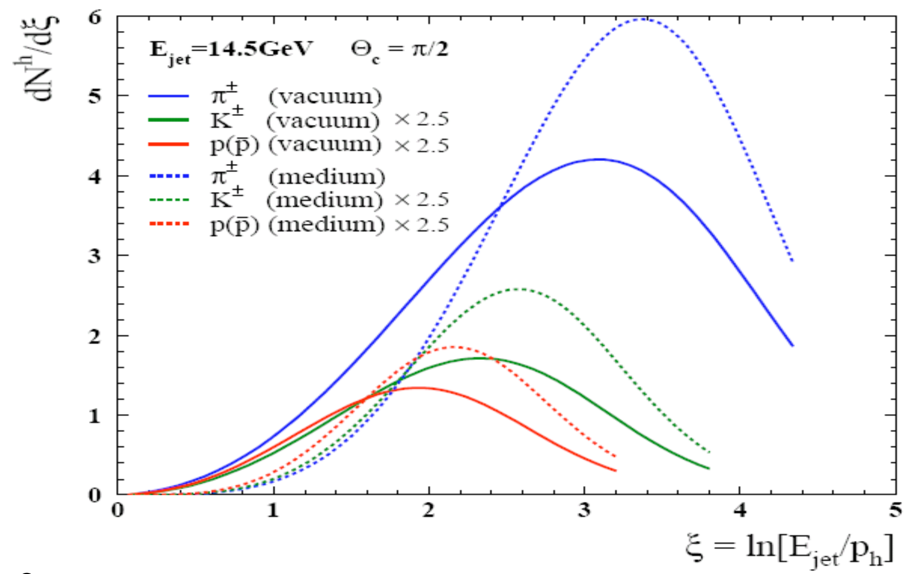


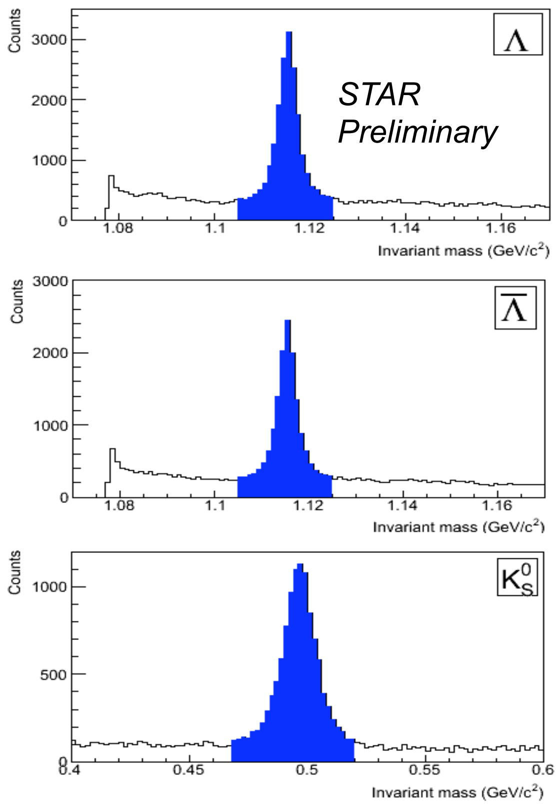
- Jet cross-section in p+p is well described by NLO pQCD calculations over 7 orders of magnitude.
- PYTHIA gives good description of charged particle FF
- Minimum bias particle production also well modeled

Results in agreement pQCD

Strange hadrons in jets

FF are particle species dependent but not well constrained

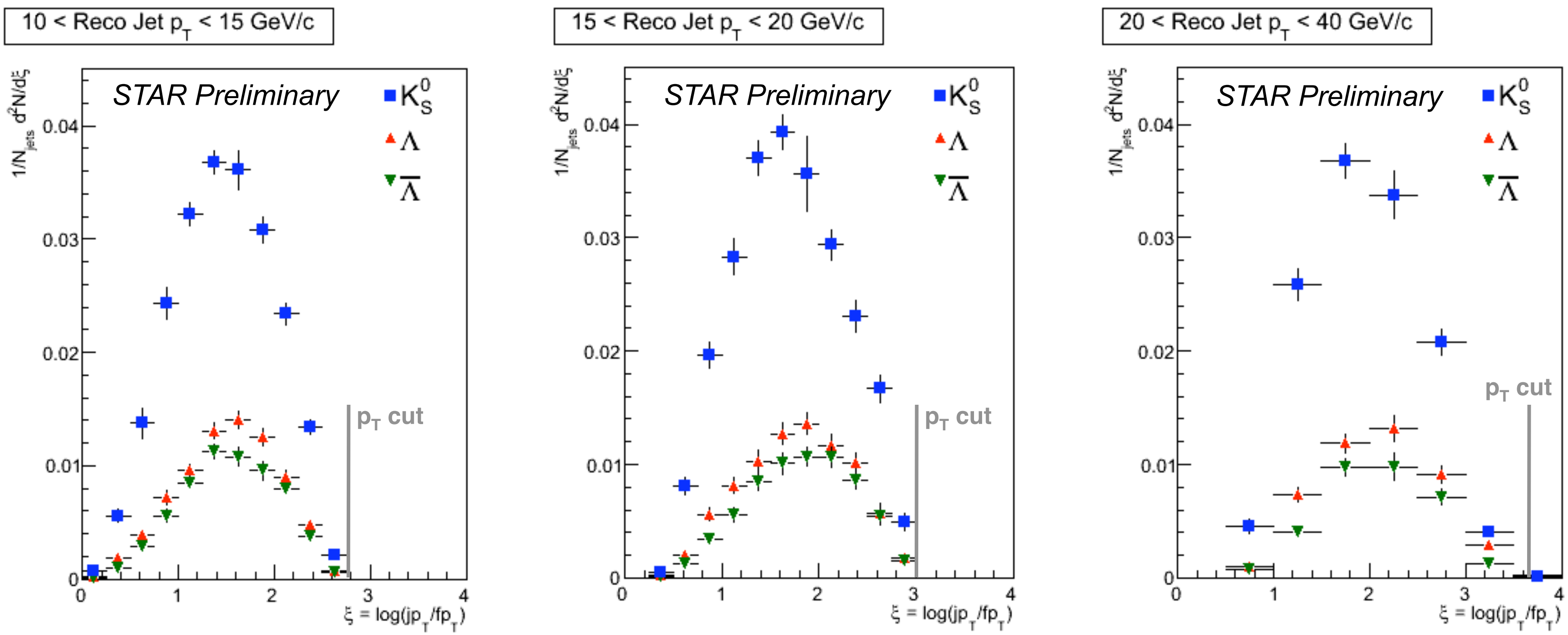




p_T > 1 GeV/c

- Λ, $\bar{\Lambda}$ and $K^0{}_S$ identified via decay products
- Reduce combinatoric background
  - Place topological cuts
  - Look at higher p_T
- For now ignore remaining background under mass peaks
- Identify jets containing strange particle

Strange hadron fragmentation functions



A. Timmins SQM2009

- Data presented at detector level
- Errors estimated - average from k_T, anti-k_T and SISCone
- V0 $p_T > 1$ GeV/c - artificial cut in distribution

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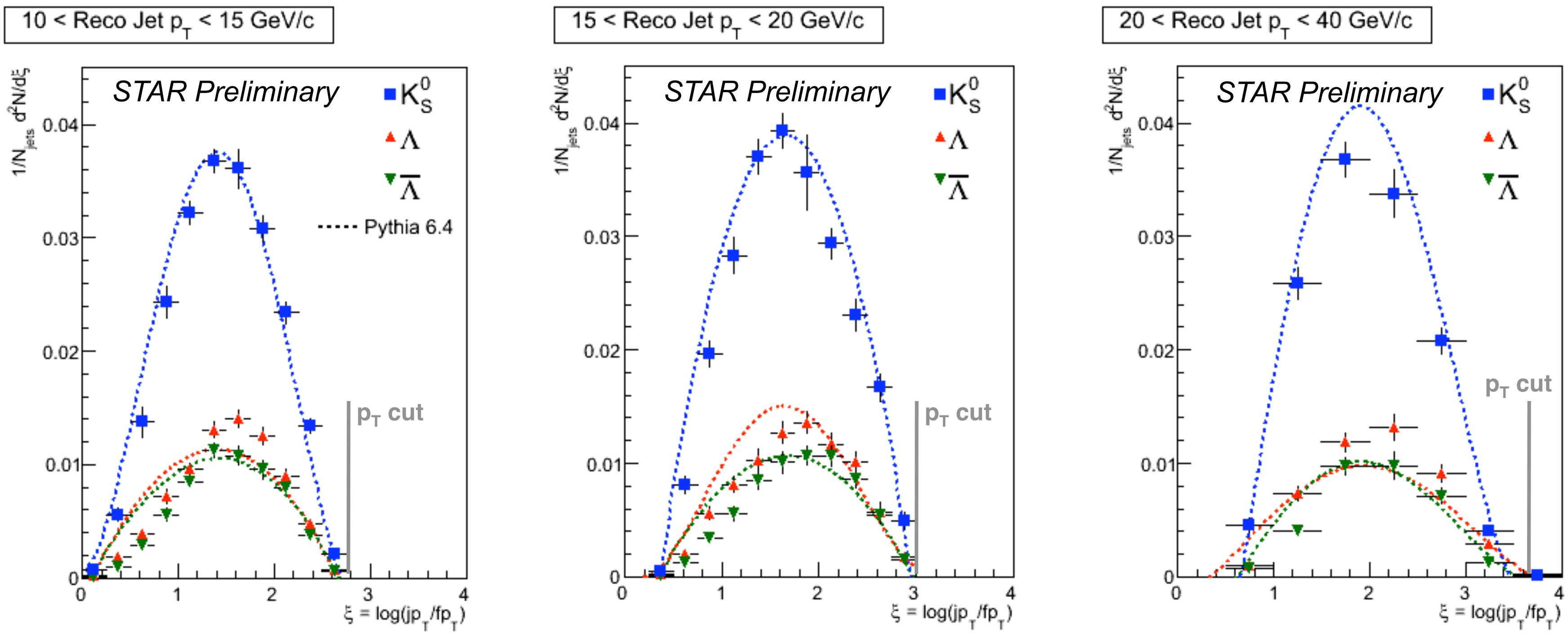

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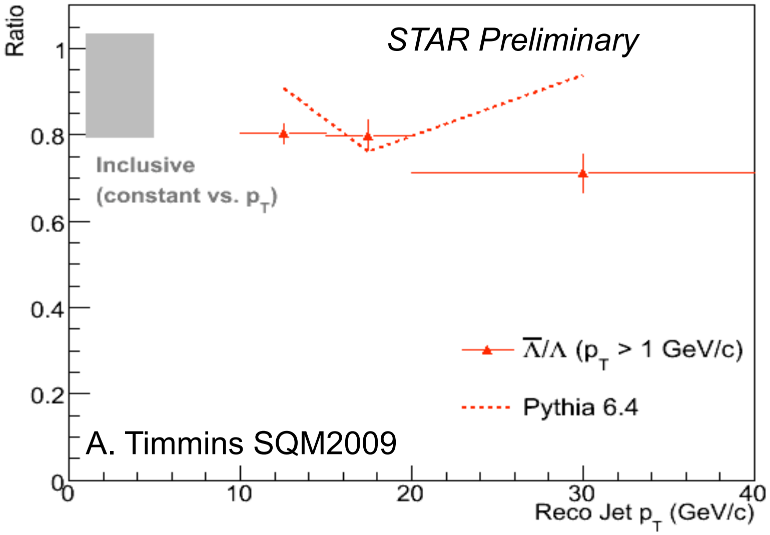
- PYTHIA = PYTHIA+GEANT

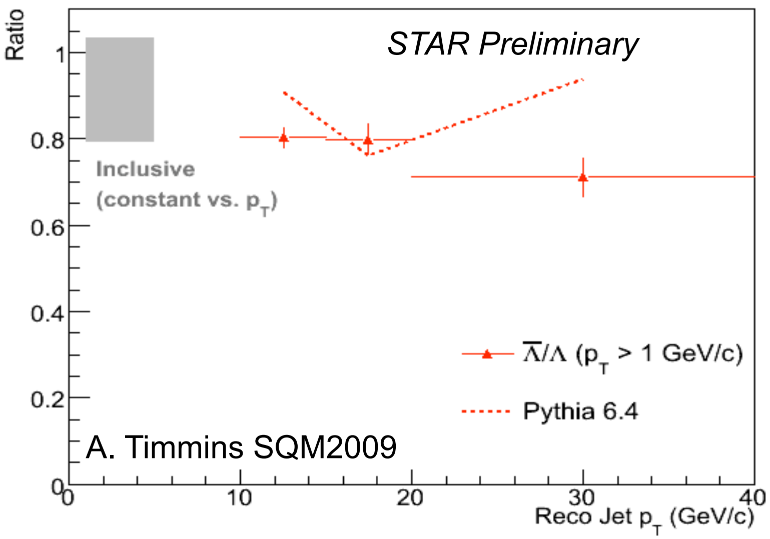
Description of K^0_s better than for Λ - as for min-bias p_T distributions

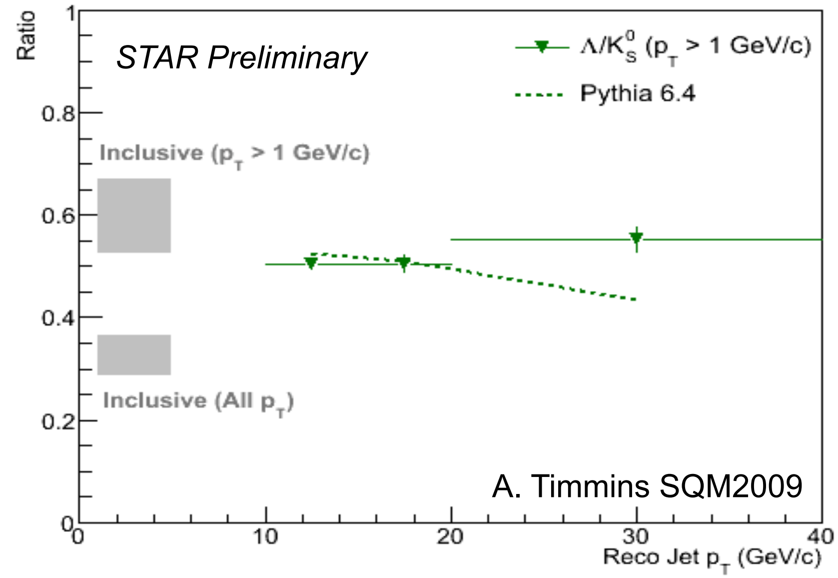
Strange ratios in jets



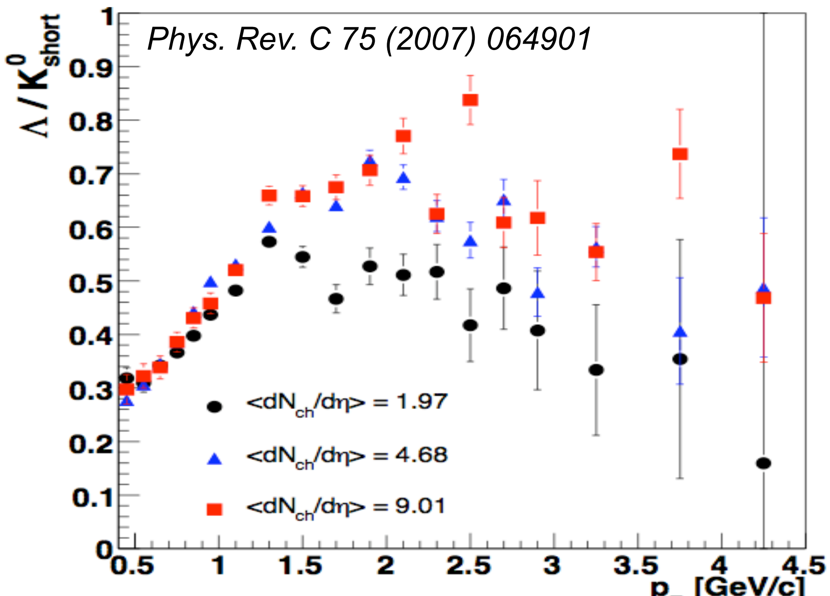
- $\bar{B}$/B ratio similar to inclusive

Strange ratios in jets





- $\bar{B}$/B ratio similar to inclusive
- Baryon/meson ratio similar to inclusive when measured p_T range considered
- Baryon/meson ratio ~ constant as function of jet p_T



Strange particle production predominantly from jets?

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

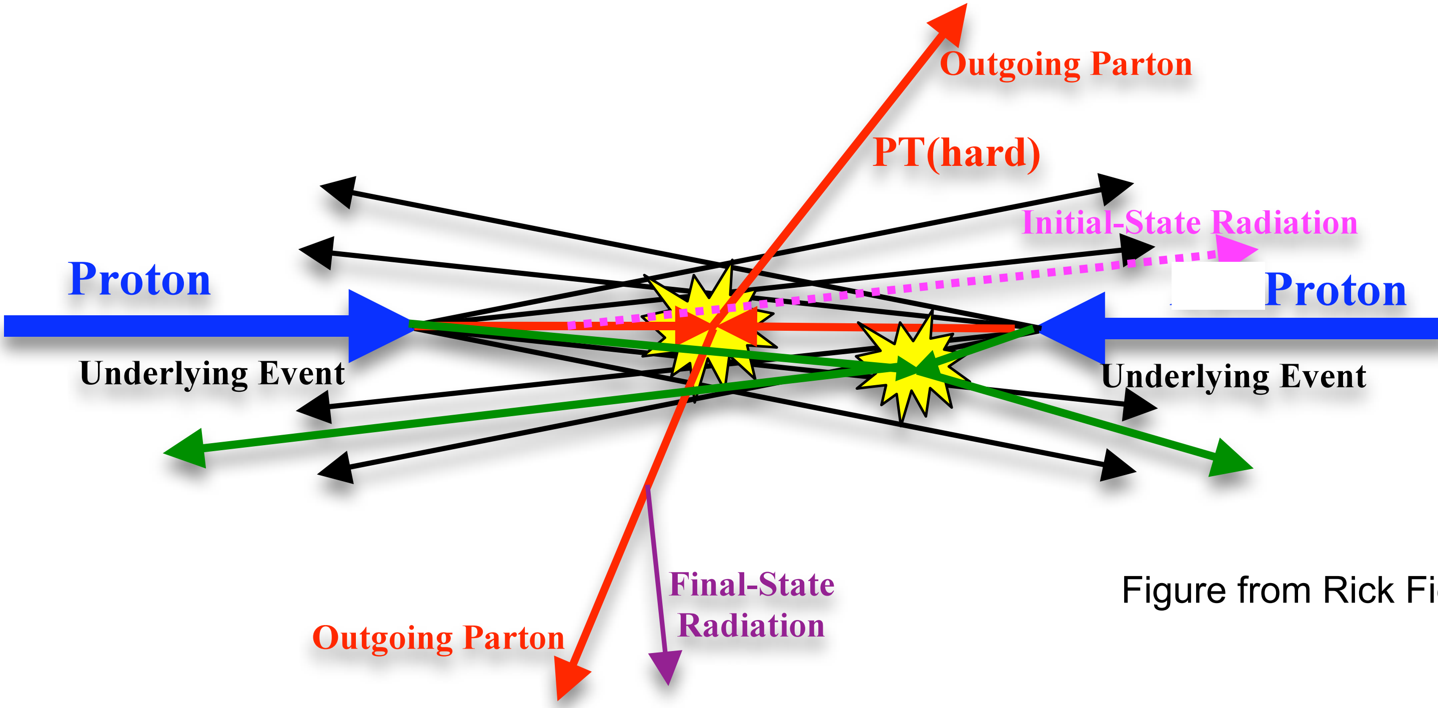
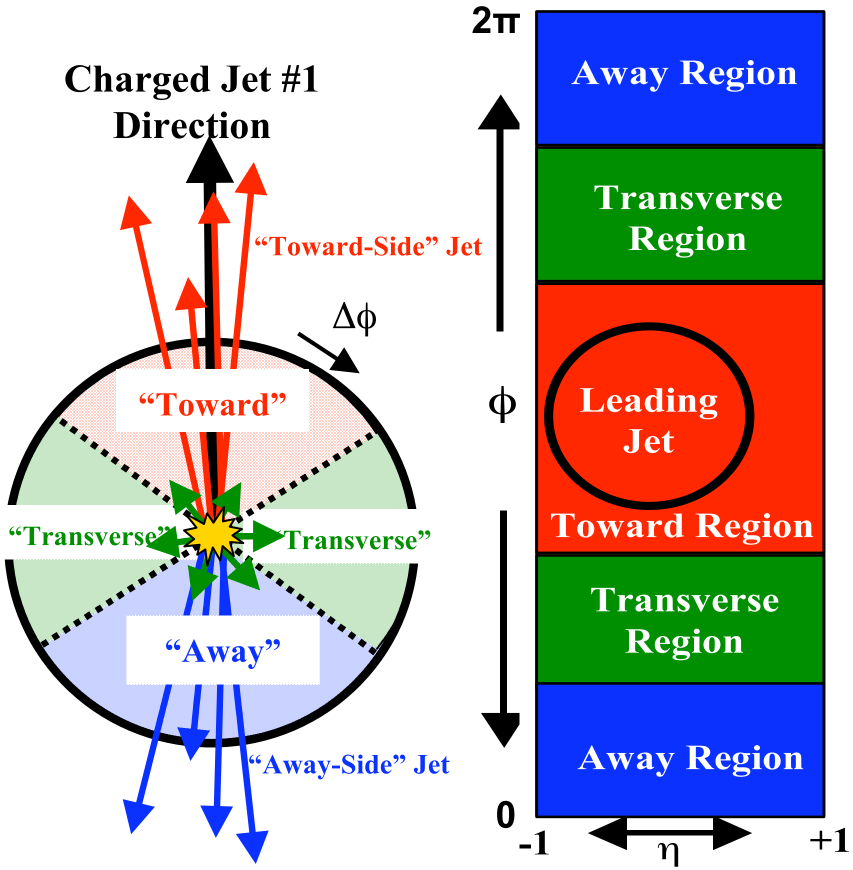


Figure from Rick Field

The Underlying Event is everything BUT the hard scattering

The underlying event



- Leading : One jet in acceptance.
- Back-to-back : Sub-set of leading jets

  $|\Delta\phi| > 150$, $p_{TAway}/p_{TLead} > 0.7$

  Hard ISR and FSR suppressed
- **TransMax** - highest Σp_T or ΣN_{track}

  Enhanced probability of containing hard ISR and/or FSR
- **TransMin** - least Σp_T or ΣN_{track}

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

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

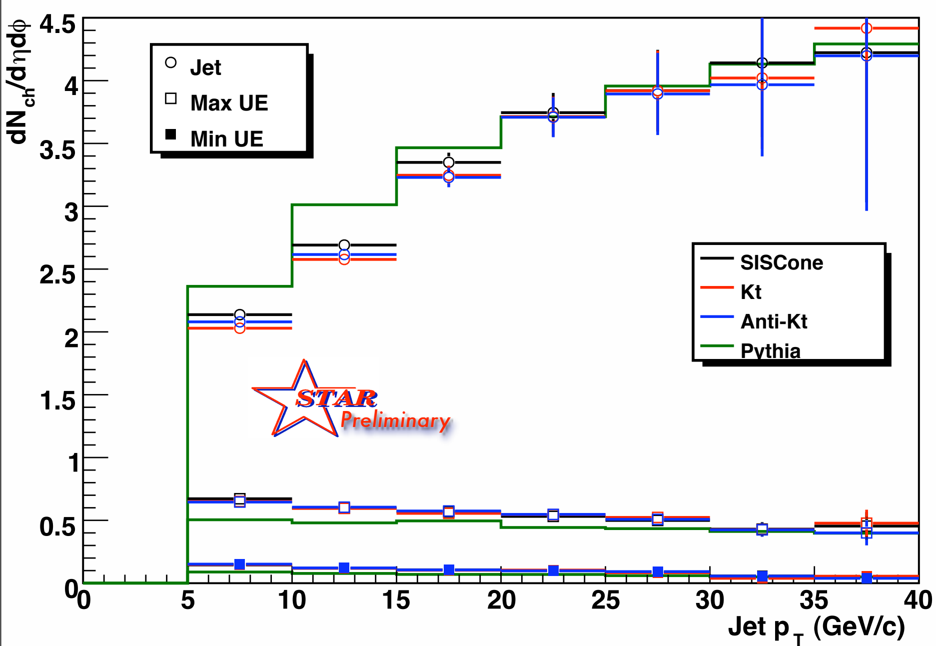
Information about large angle initial/final state radiation

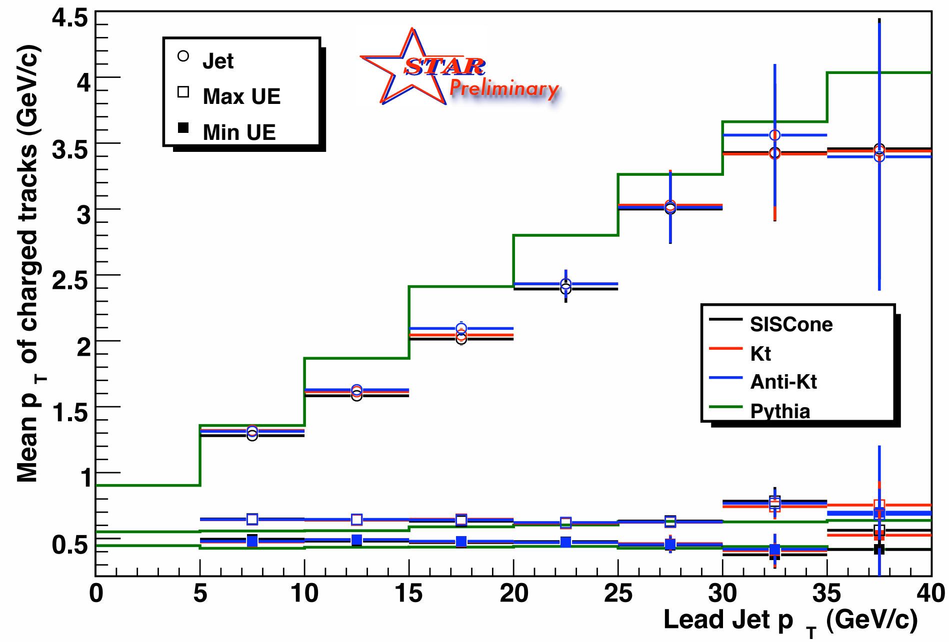
Multi-parton interaction energy scaling

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

Data not corrected to particle level

"PYTHIA" = PYTHIA +GEANT+full reconstruction





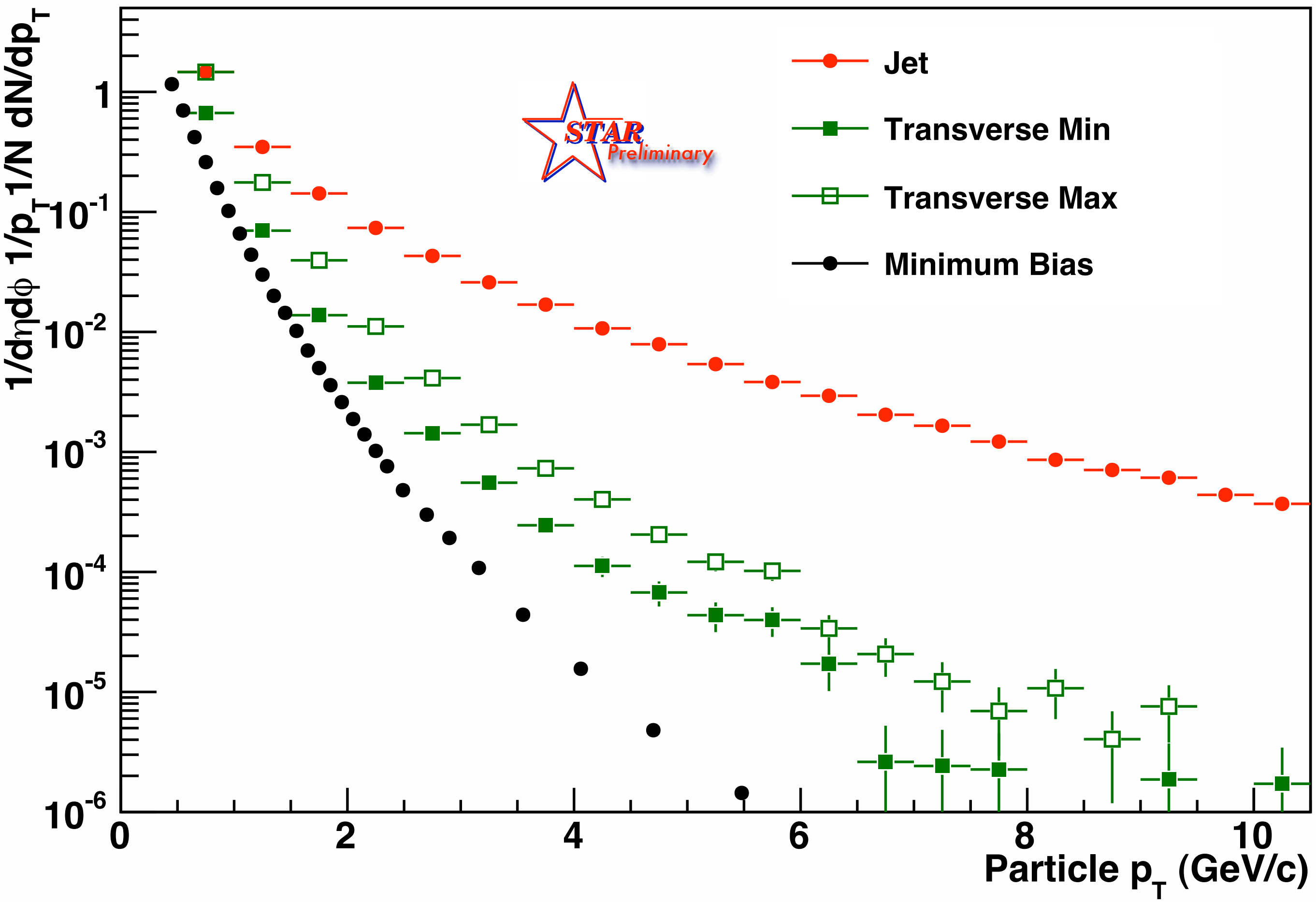
- Underlying event tuned to 1.8 TeV
- Hard scattering cut-off for the MPI - $P_{T0}(E_{cm}) = P_{T0}(E_{cm}/E_o)^{\varepsilon}$
- Other tunes, ε=0.16, predict 35% less (26% more) for RHIC (LHC)

RHIC, Tevatron and CMS [a] data support ε = 0.25

a) arXiv:1006.2083v1

Underlying event is not the same as minbias

Corrected charged particle p_T distributions



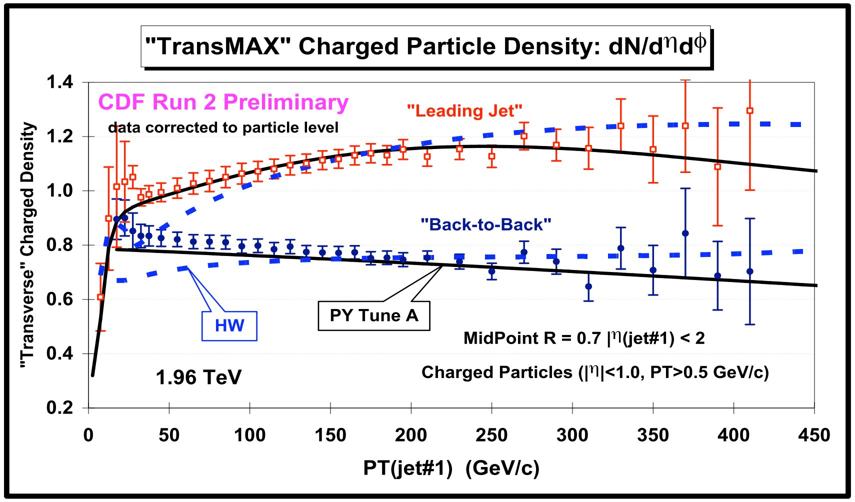
$15 < p_{Tjet} < 30$ GeV/c
$|\eta_{jet}| < 1-R$
Anti-k_T

Errors statistical only for Jet and UE

NSD spectrum from PRL 91 (2003) 172302

NSD Minbias p_T spectrum != Average UE p_T spectrum

TransMin vs TransMax regions of UE



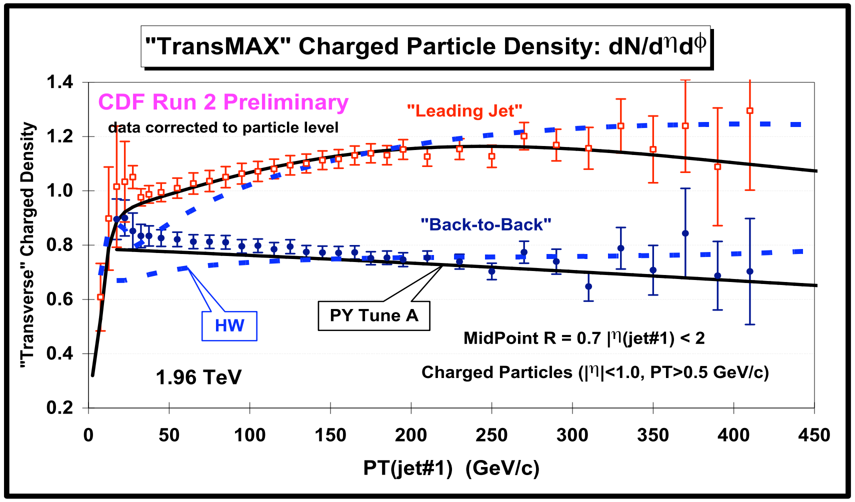
Data not corrected to particle level.

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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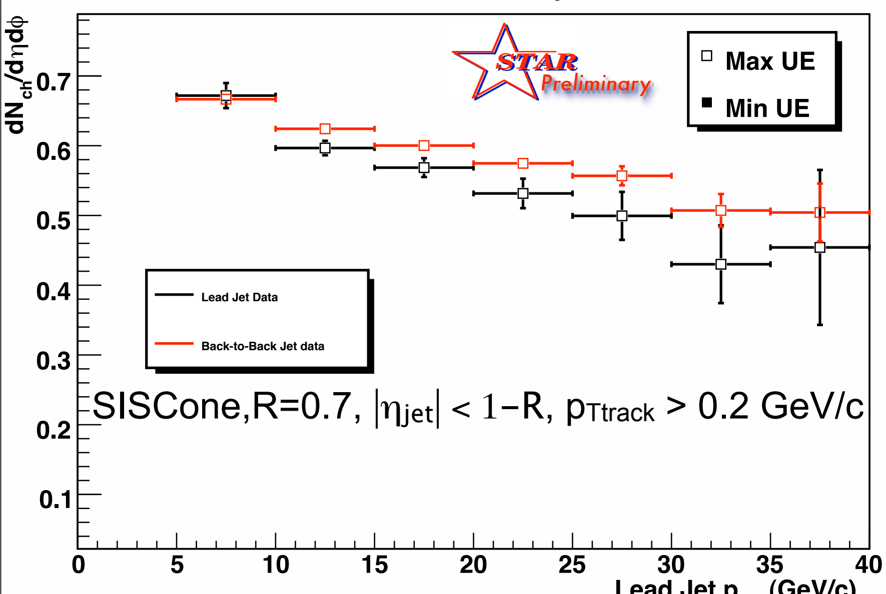


CDF √s=1.96 TeV

- leading TransMax > back-to-back TransMax

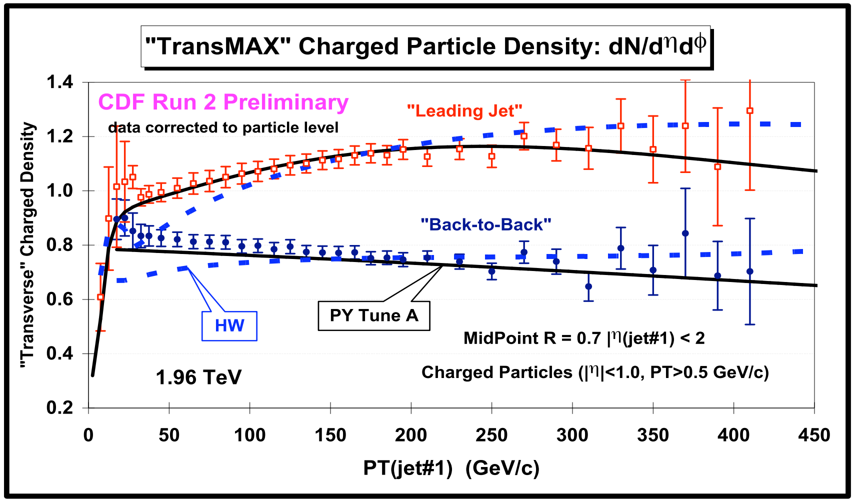
 Significant initial/final state radiation at large angles.

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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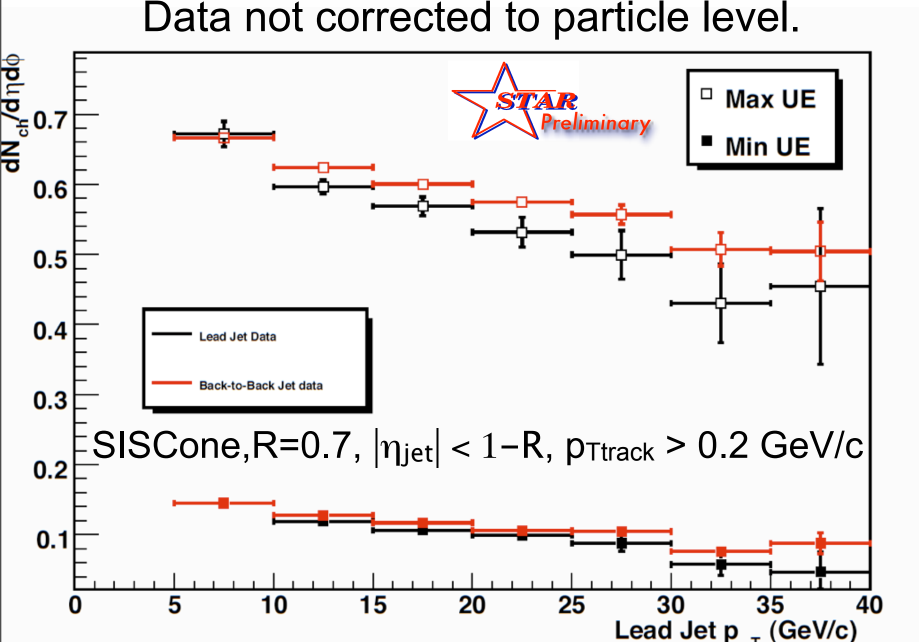

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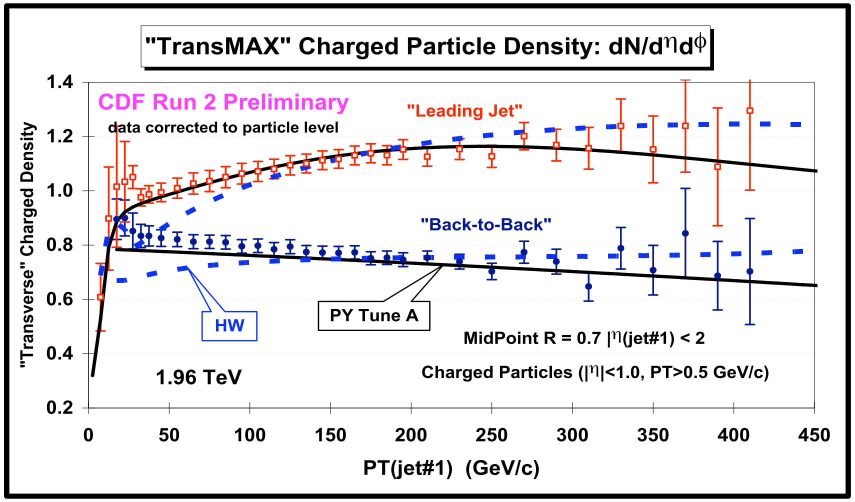

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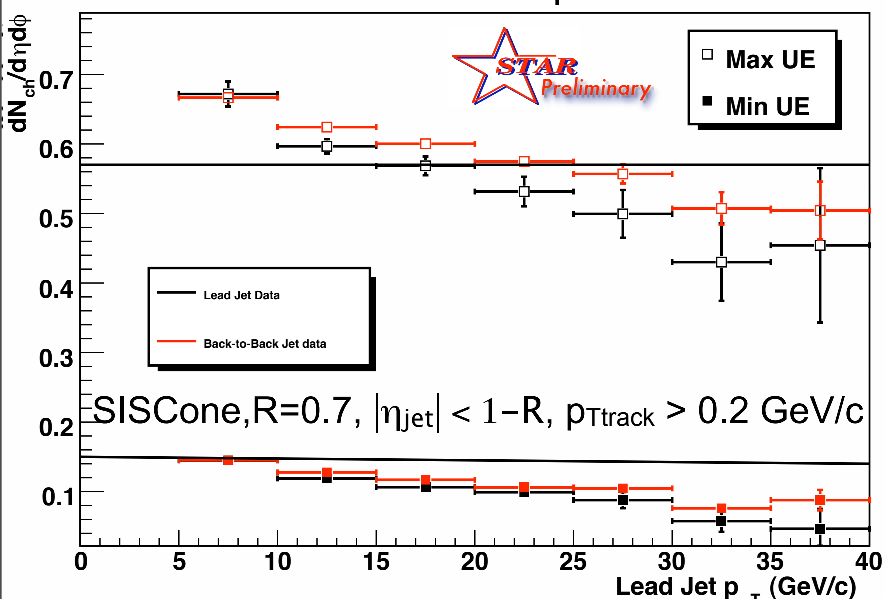

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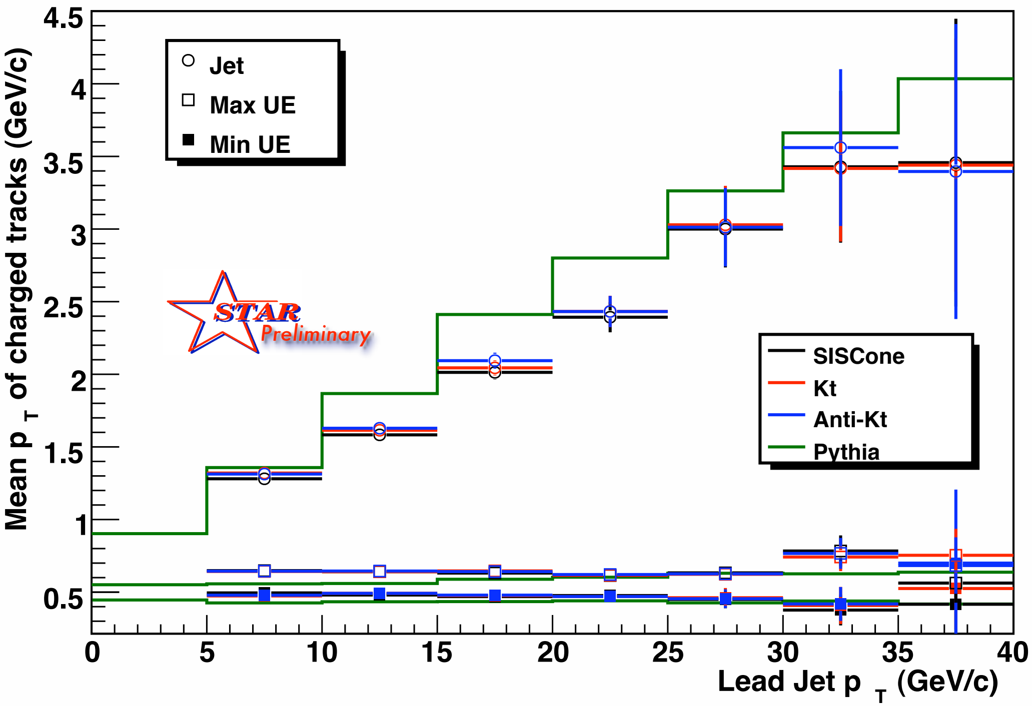
Small initial/final state radiation at large angles.

- 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

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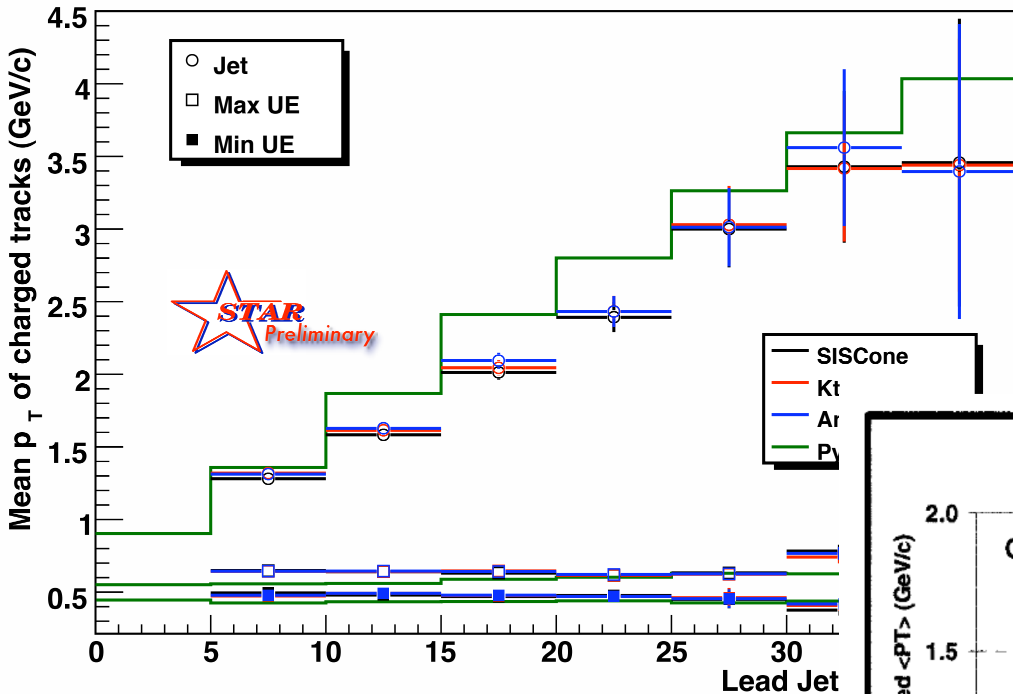

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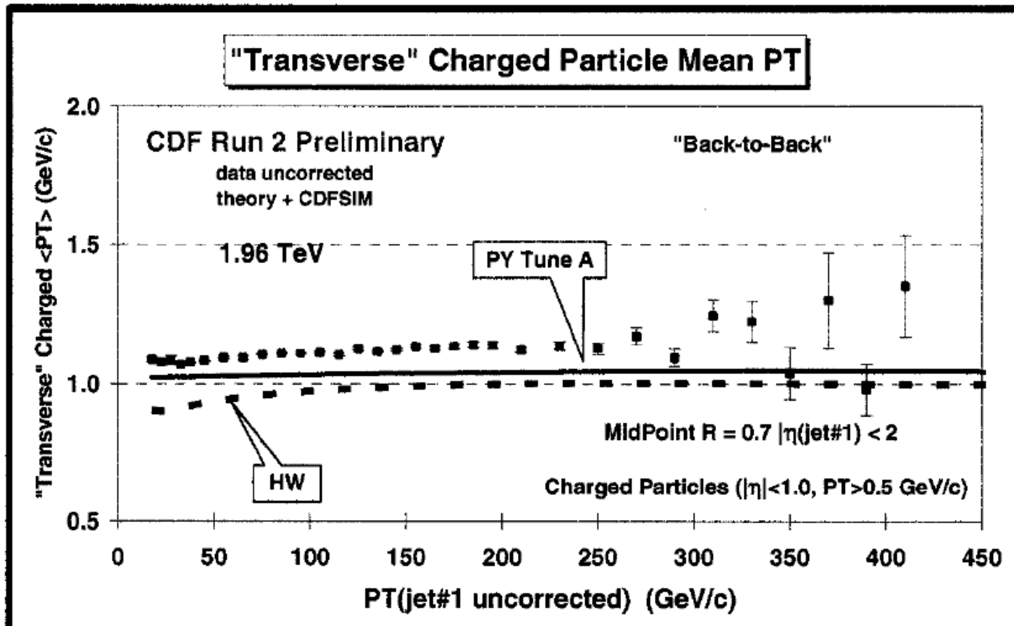

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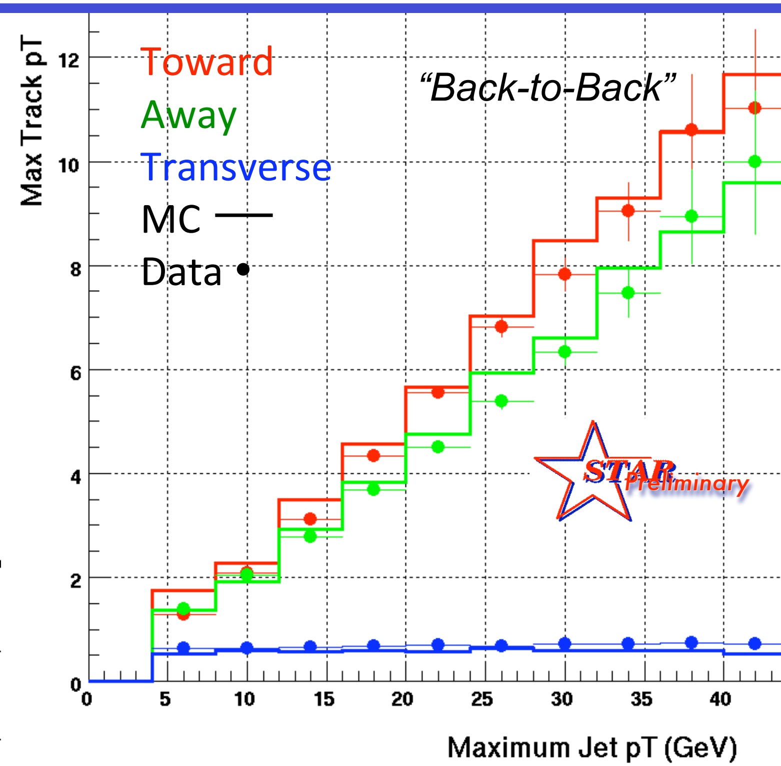
L.A. Cruz, "Using MAX/MIN transverse regions to study the underlying event in run 2at the Tevatron" UMI-31-88071, 2005.

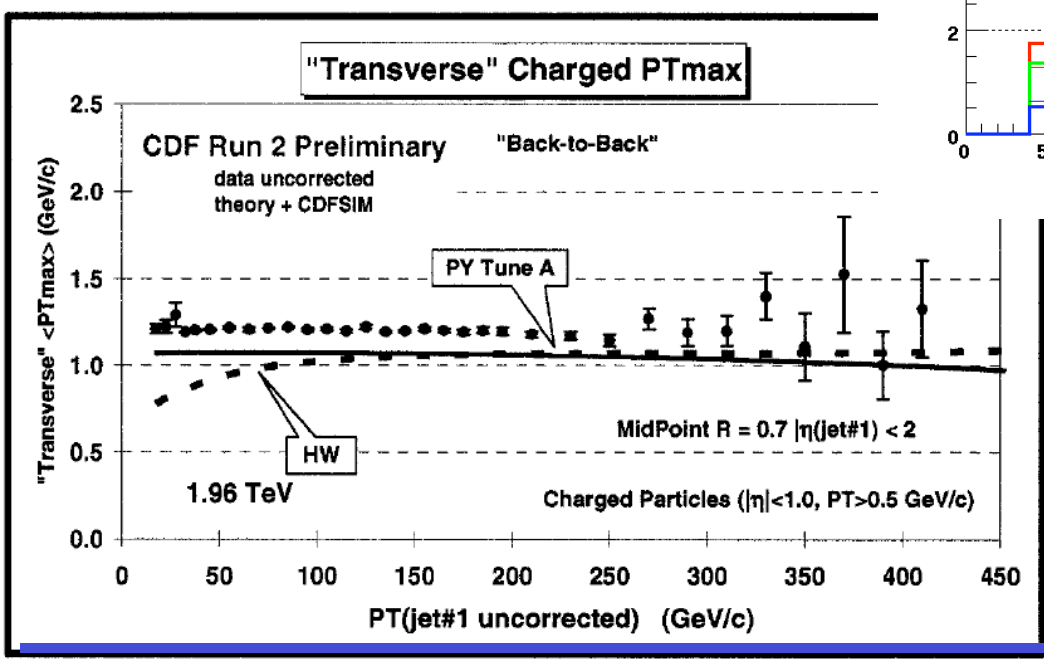
CDF higher than STAR merely due to lower p_T cut?

Max p_T charged track

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

G.Webb DNP 2008





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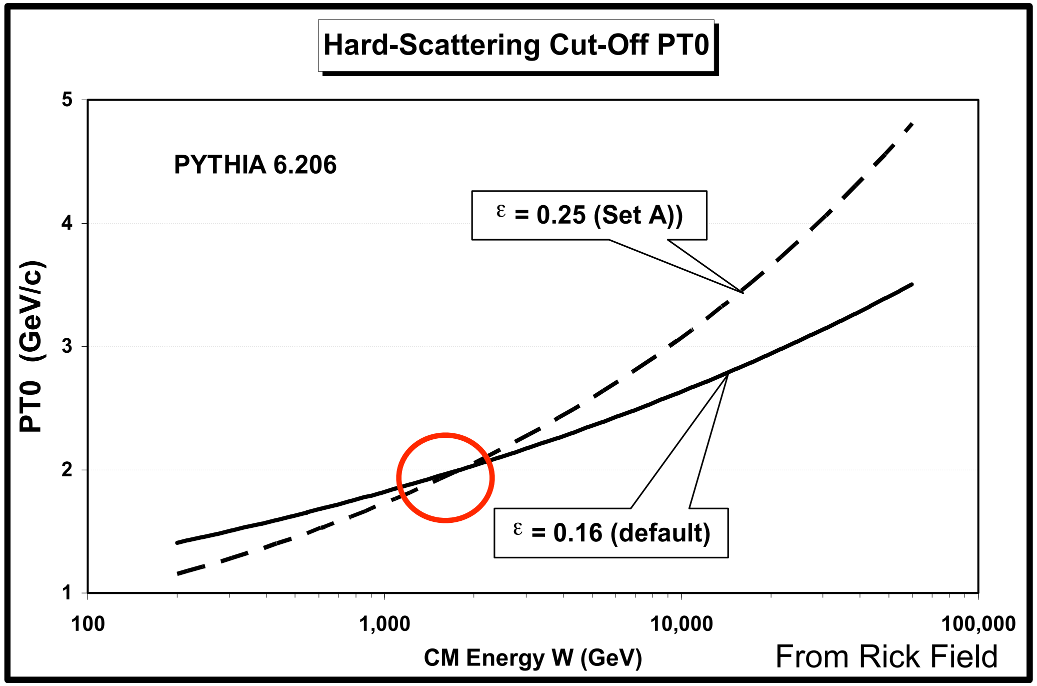
RHIC UE is softer

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

Summary of 200 GeV data analysis

- Different jet algorithms produce consistent results
- Charged particle and jet distributions well produced by pQCD
- Details of fragmentation into strange particles are being explored - poorly described by PYTHIA
- Underlying Event largely decoupled from hard scattering
- p_T spectra are significantly softer out of the jet cone than in the jet
- Particle p_T spectra are different in MB than in UE
- PYTHIA's energy scaling for the MPI works for RHIC and the LHC
- Large angle initial/final state radiation is small at RHIC

Energy scaling of the underlying event



- Pivots around the tuning energy
- ε = 0.16 - initial estimate

  = 0.25 (suggested by 630 GeV Tevatron)

Correct scaling important to know

Underlying event vs jets properties

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

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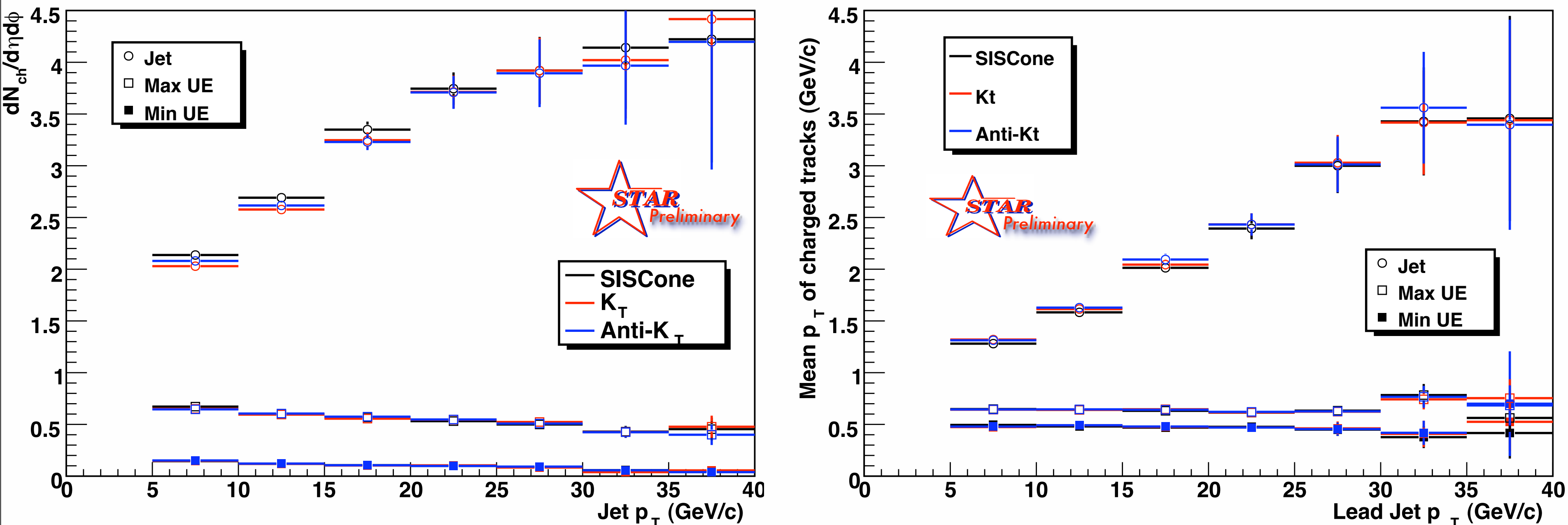
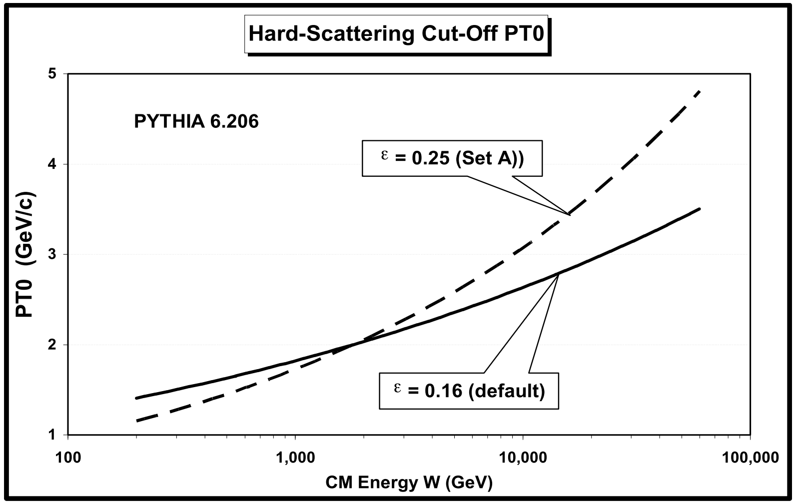


- Jet charged track density and $<p_T>$ rise with jet p_T as expected

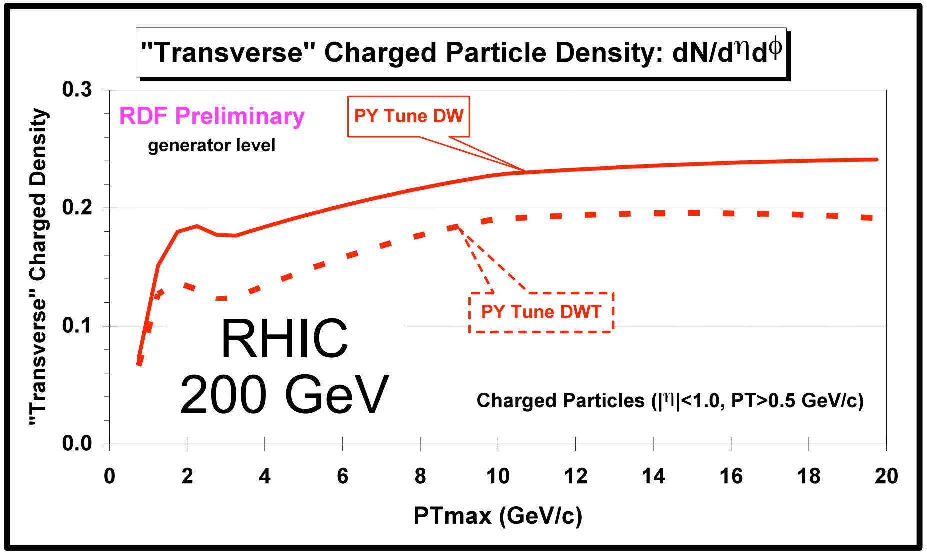
UE largely independent of jet p_T

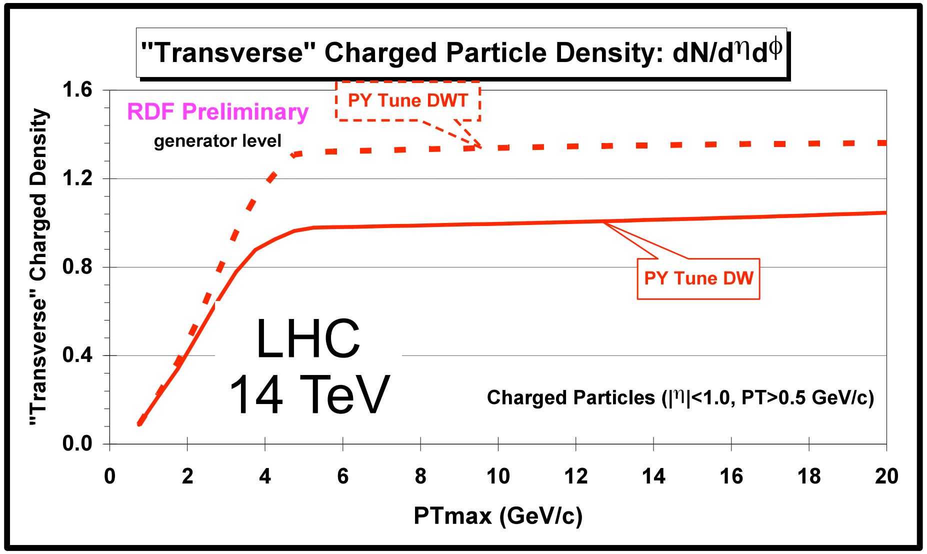
Effect of hard scattering cut-off scaling



- 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