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

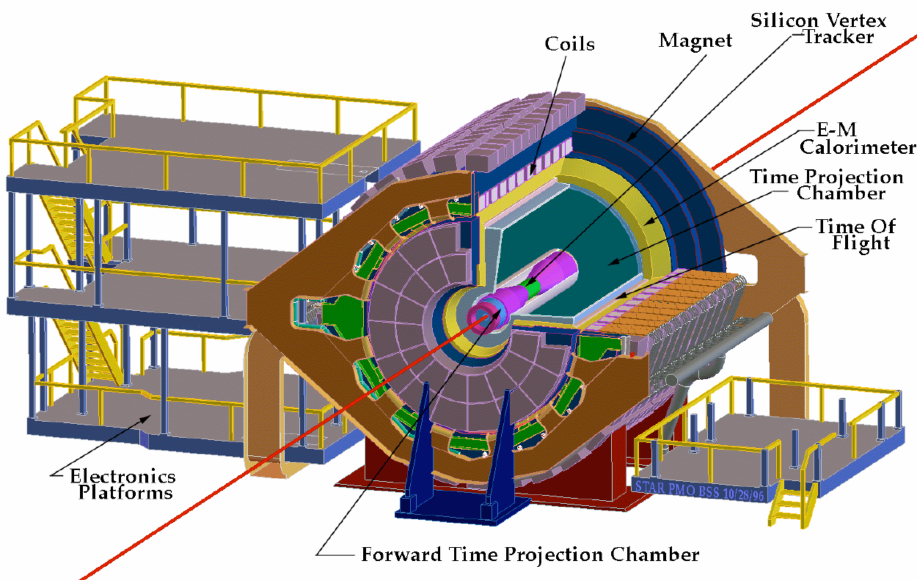
Helen Caines - Yale University

for the STAR Collaboration

Jets in pp and Heavy Ions
Prague
April 12-14 2010

Jets at √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 $\Delta\eta \times \Delta\phi = 1\text{x}1$

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

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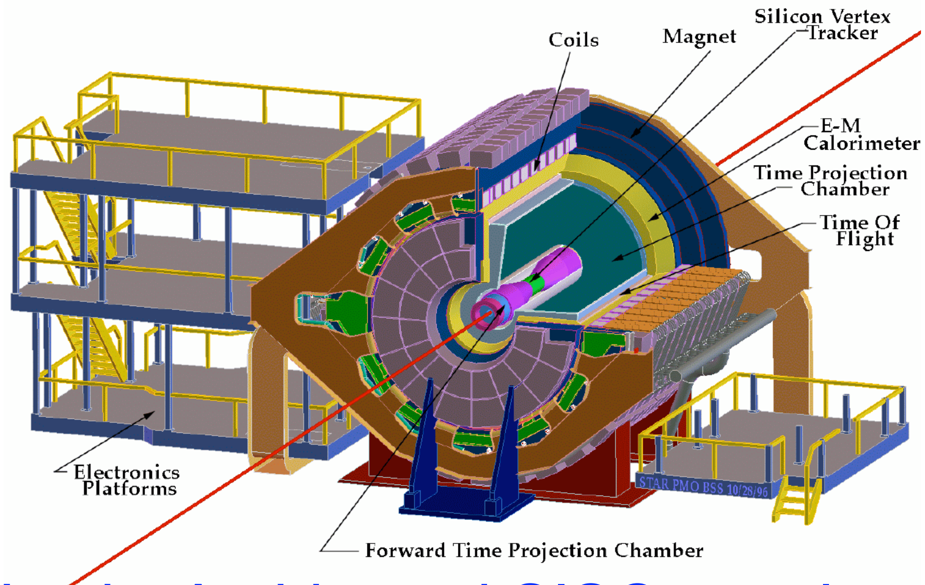

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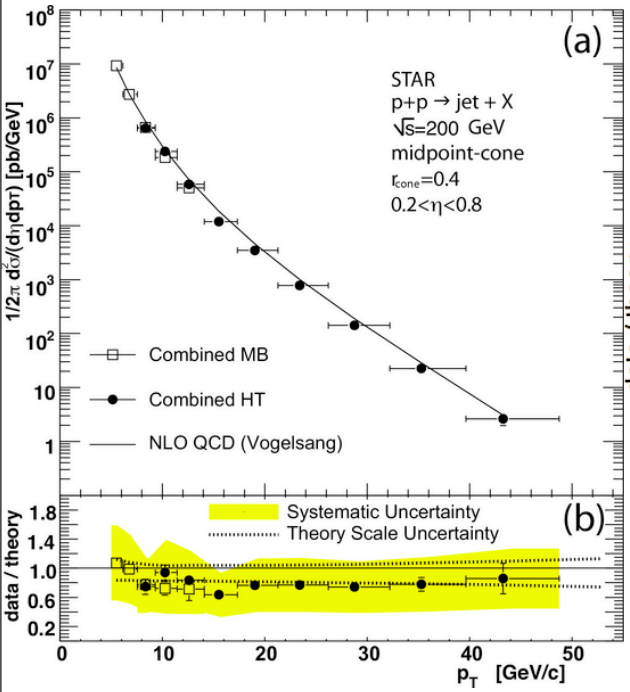
Jet-Patch:
E_T > 8 GeV in $\Delta\eta \times \Delta\phi$ = 1x1

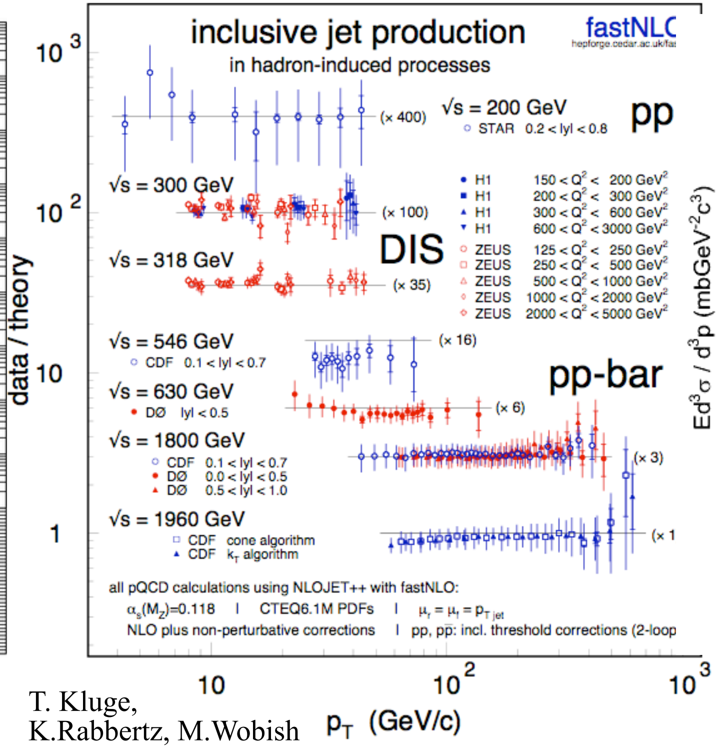
Use k_T, Anti-k_T and SISCone algorithms, jet energy scale ~15%

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

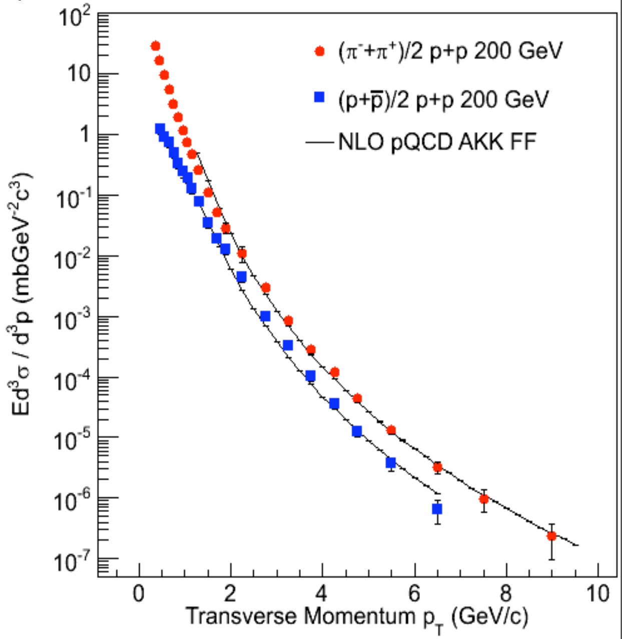
Jets at RHIC



STAR : PRL 97 (2006) 252001



T. Kluge, K.Rabbertz, M.Wobish

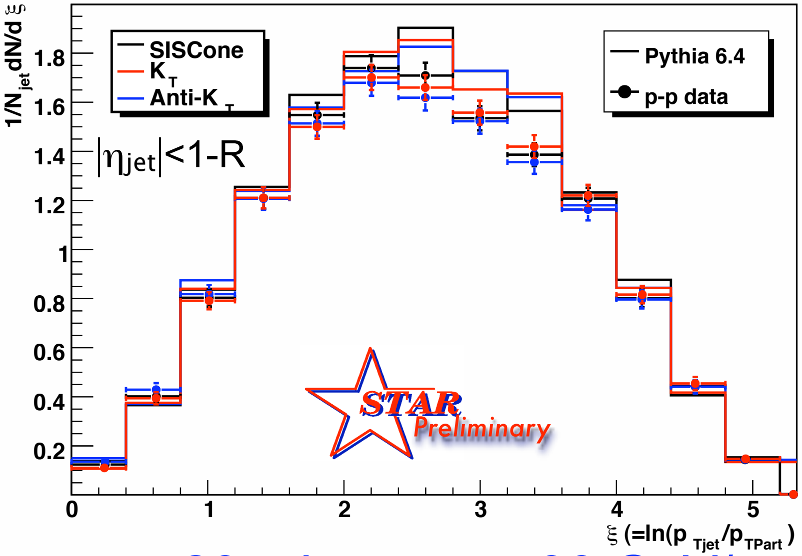


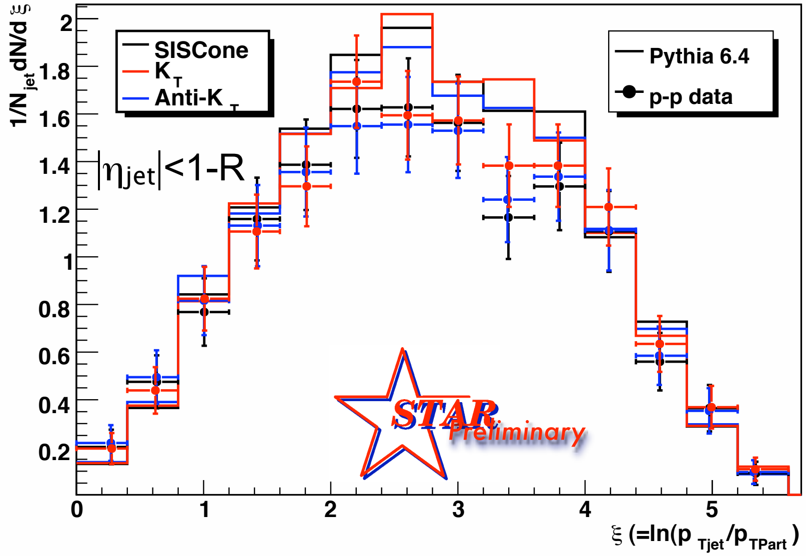
STAR : PLB 637 (2006) 161
S. Albino et al, NPB 725 (2005) 181

- Jet cross-section in p+p is well described by NLO pQCD calculations over 7 orders of magnitude.
- Excellent description when included in world data
- Minimum bias particle production in p+p also well modeled.

Results in agreement pQCD

ξ and z distributions for charged hadrons



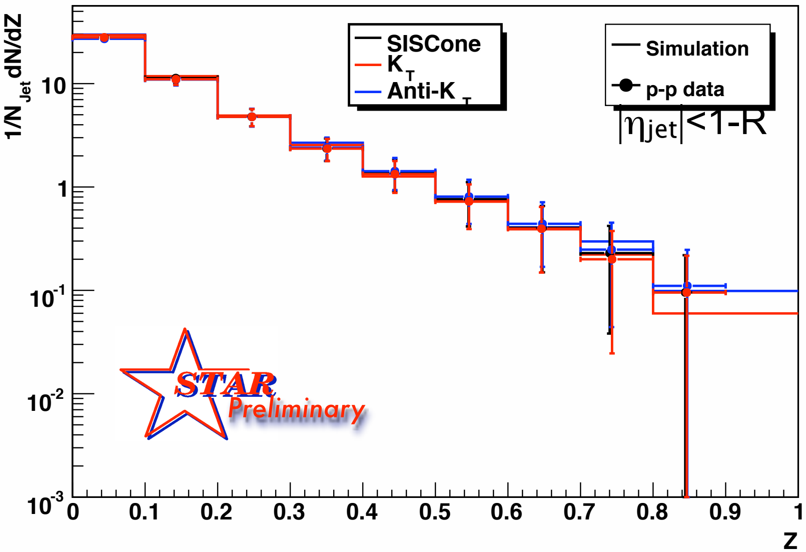


Data not corrected to particle level.

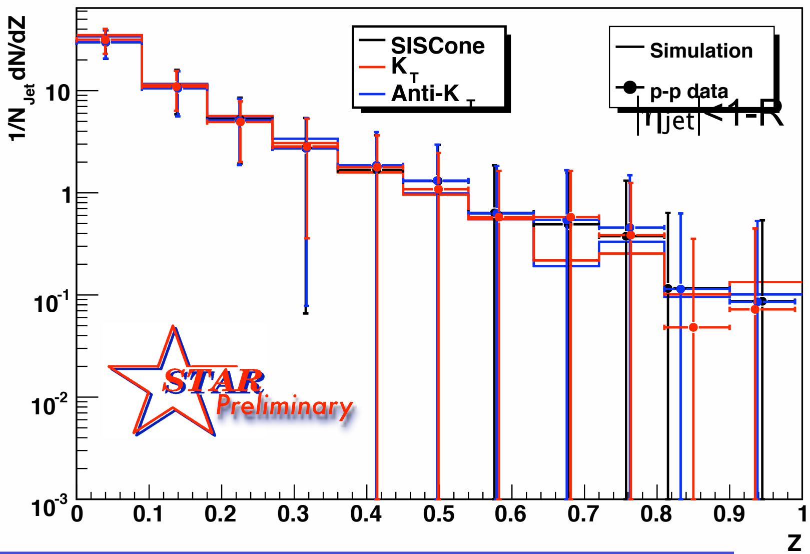
$20 <$ Jet $p_{Treco} < 30$ GeV/c

R=0.4

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

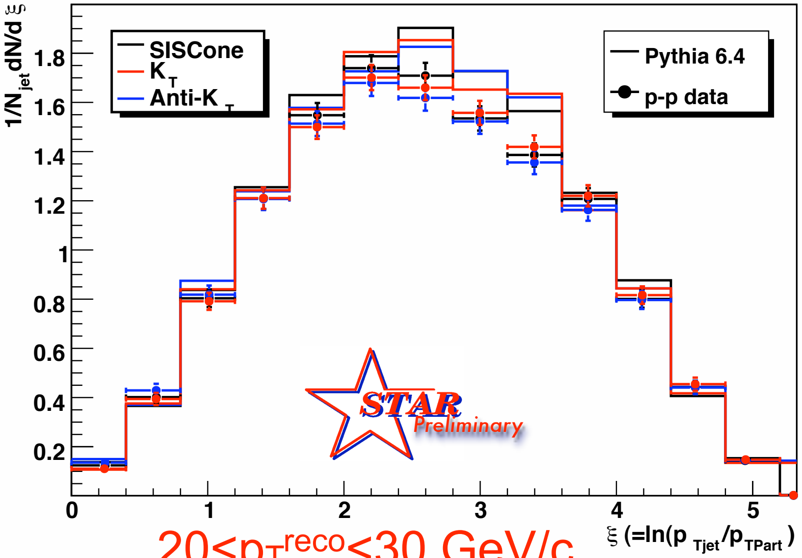


"PYTHIA" = PYTHIA +GEANT

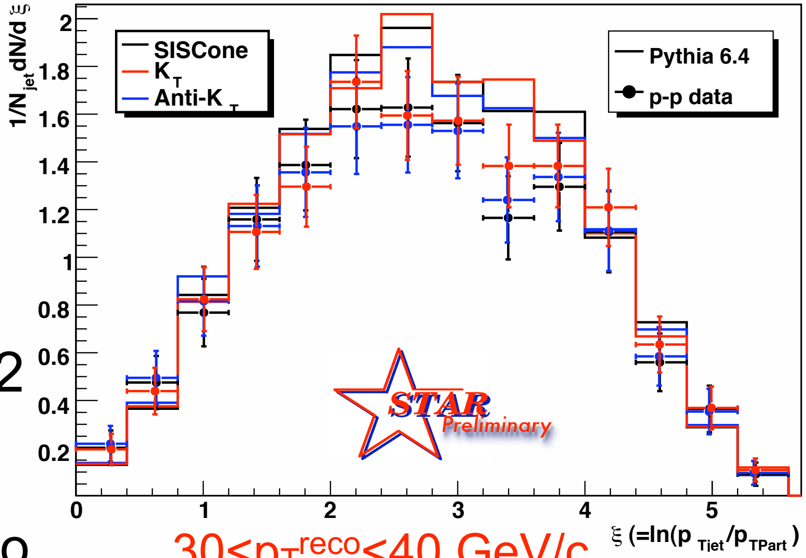


Reasonable agreement between data and PYTHIA+GEANT.

Charged hadrons ξ for different R and jet p_T



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



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

R=0.4

$|\eta_{jet}|<1-R$
$p_{Ttrack} > 0.2$

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"PYTHIA" = PYTHIA +GEANT

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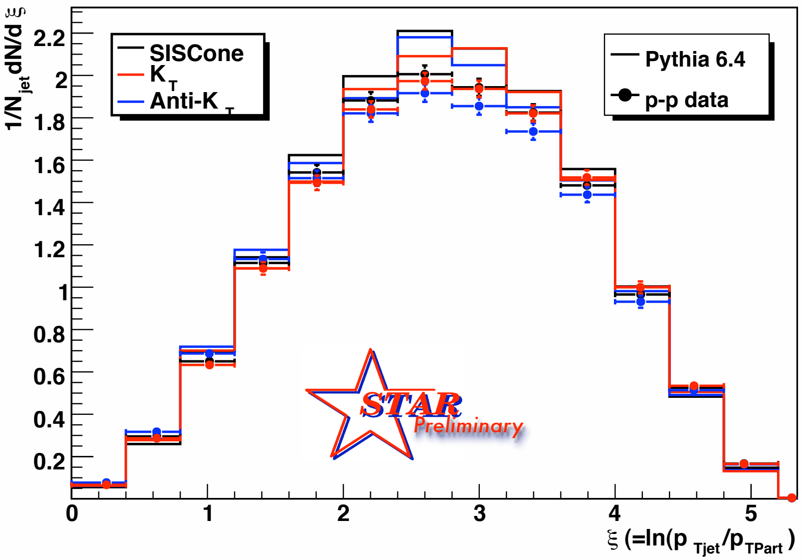
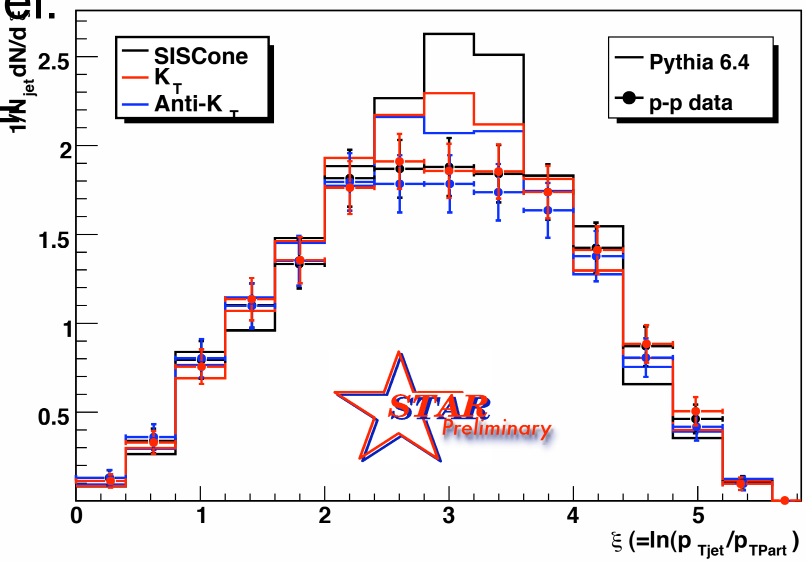
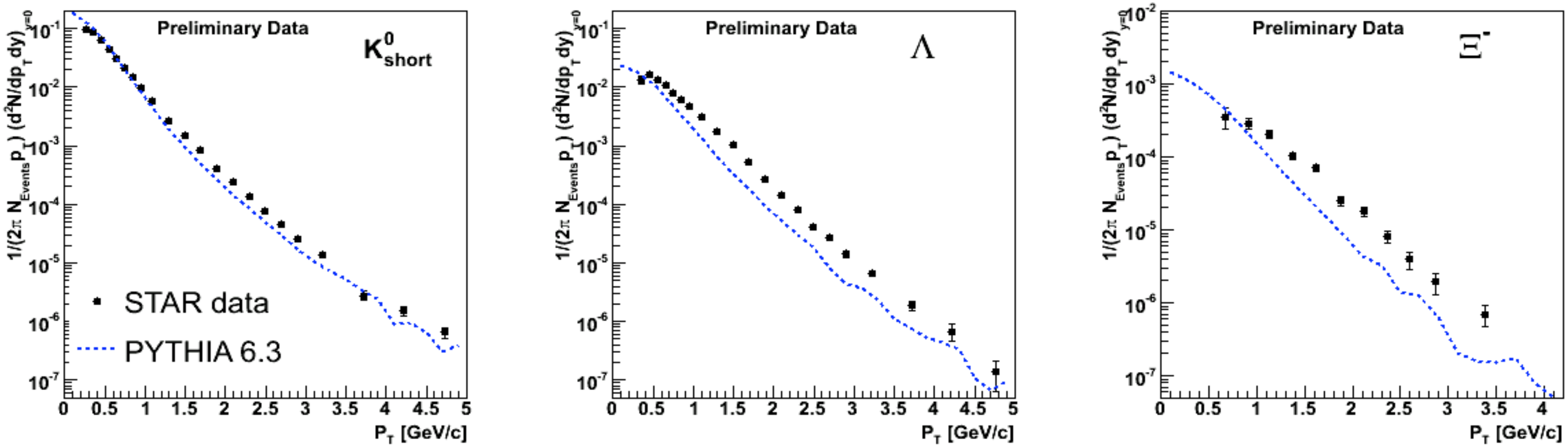




NLO corrections small or accounted for in PYTHIA

Strange and multi-strange p_T spectra

- PYTHIA Version 6.3 (TuneA)
  - Incorporated parameter tunes from CDF
  - Multiple parton interactions and and shower algorithms
- Fails to describe baryons with default parameters



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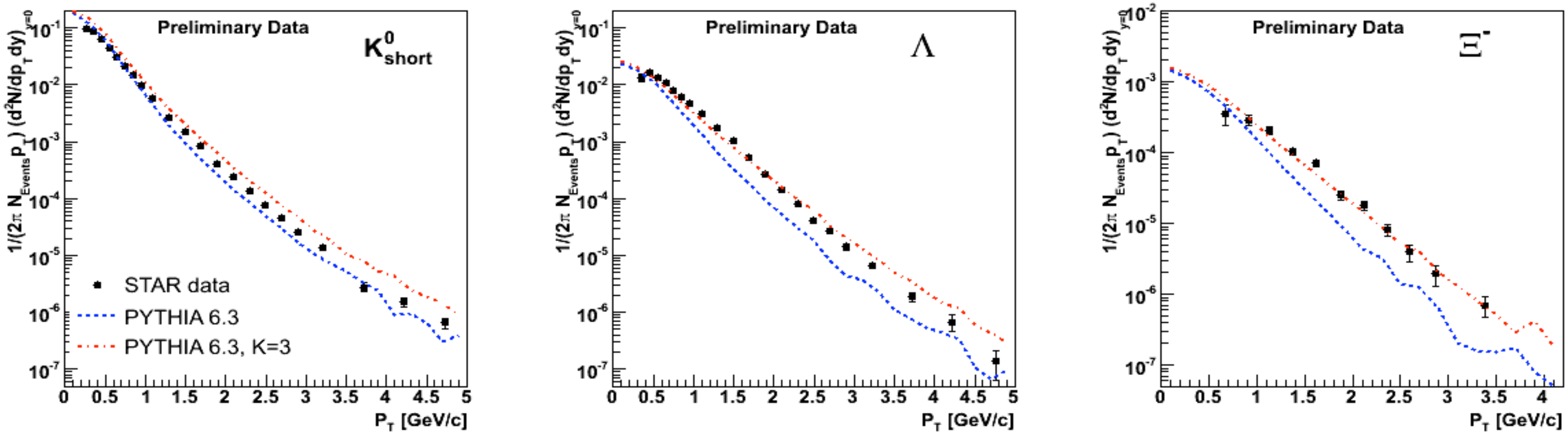
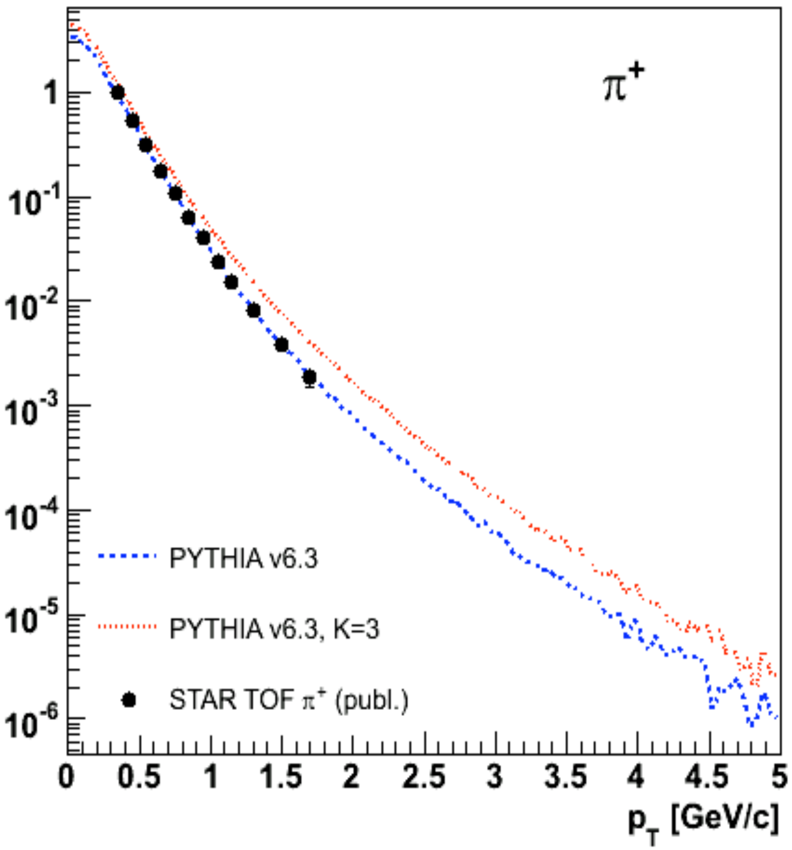
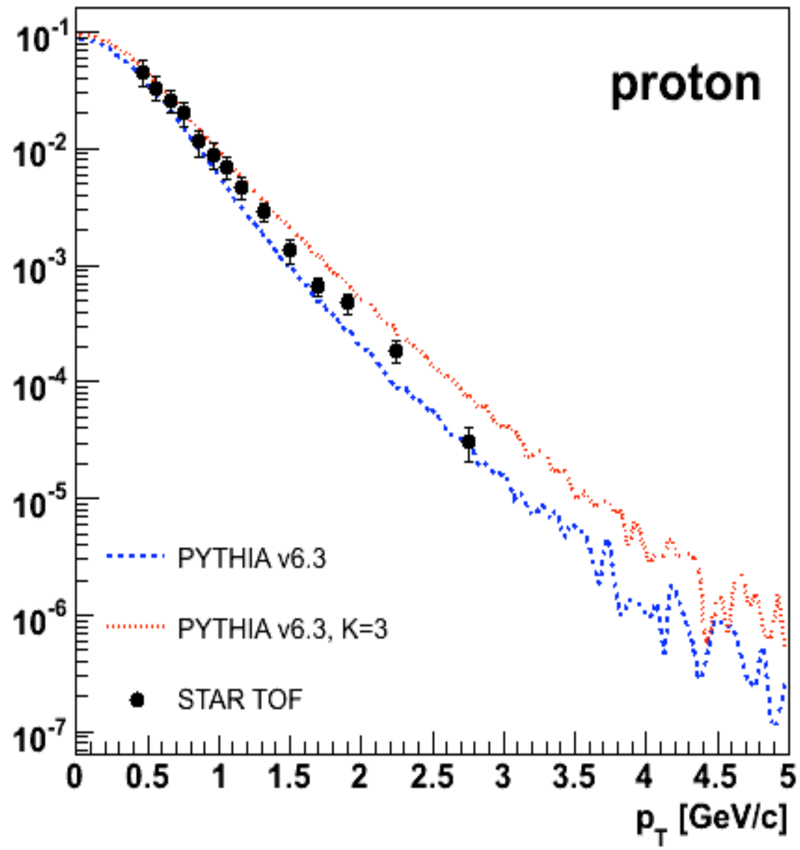


Necessary to tune: K-Factor (accounts for NLO contribution)

Non-strange particles

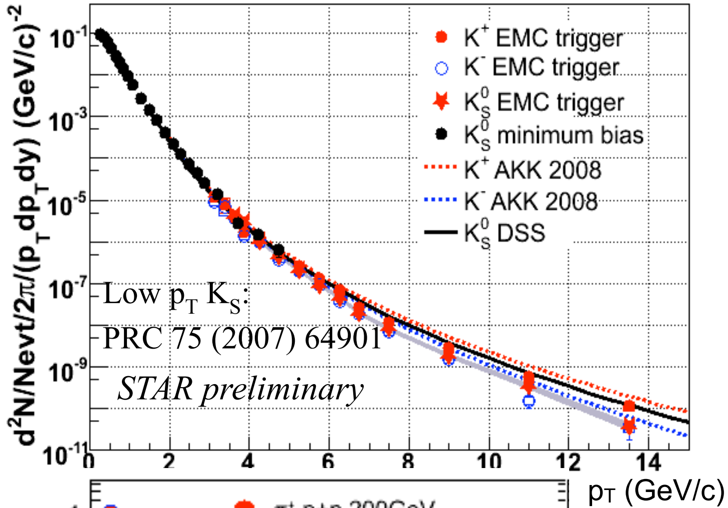
- Good agreement for π with K=1 but not for K=3
- proton with 1< K <3

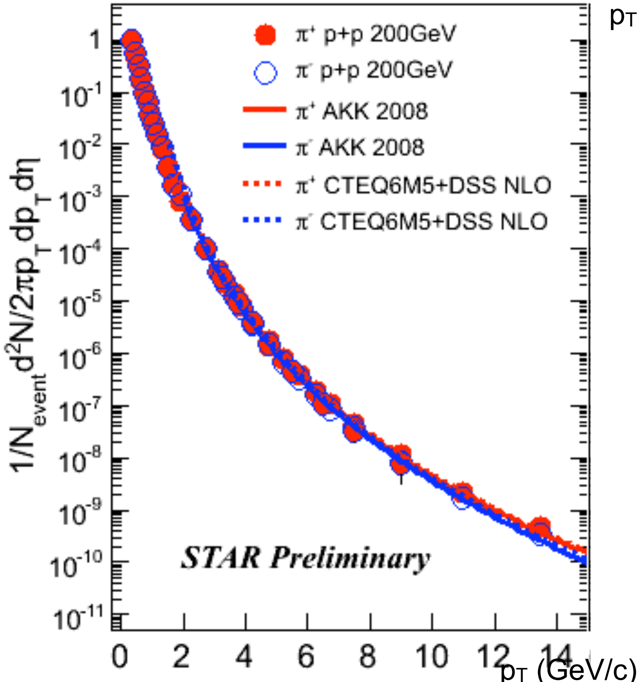




Need different K factors for different particles!

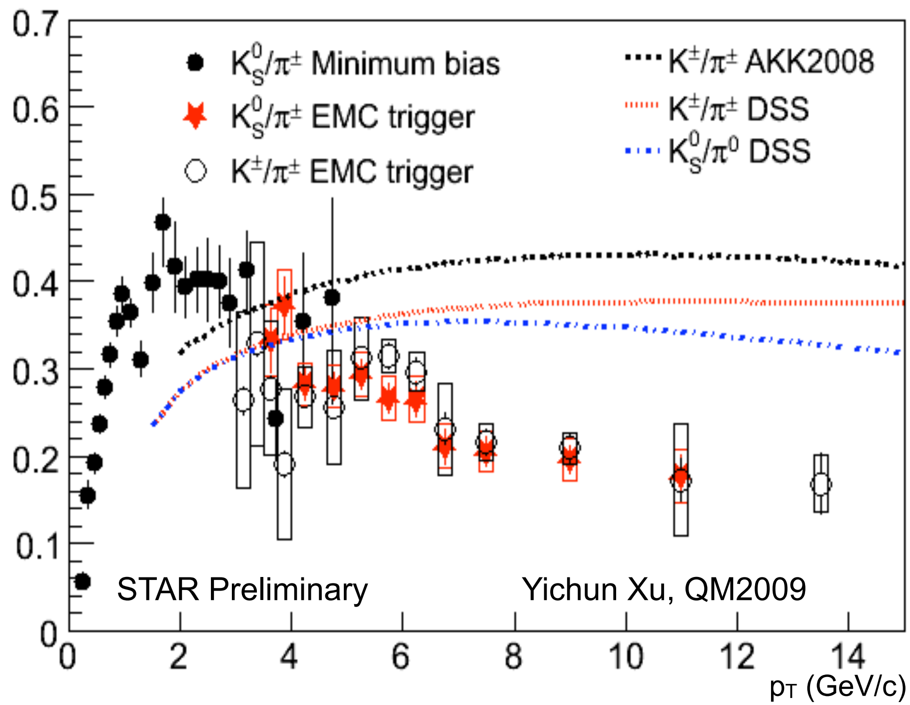
K/π ratio at high p_T





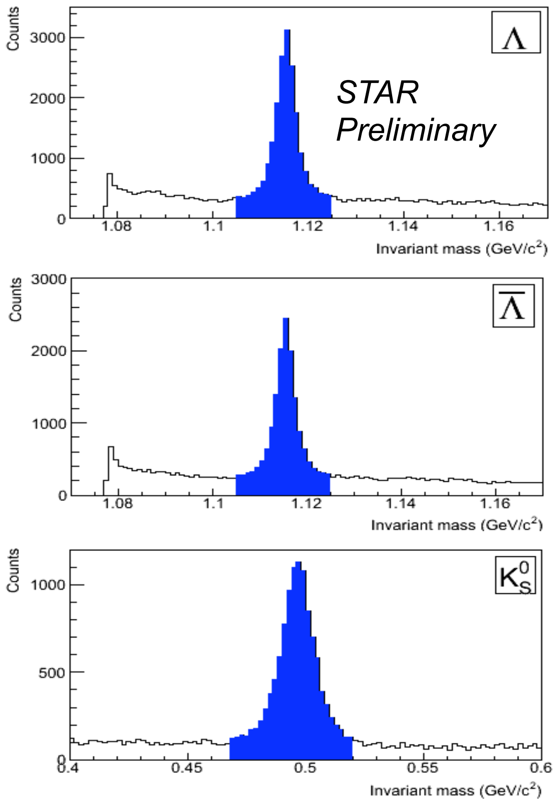
- Charged and neutral K and π now extend up to 15 GeV/c
- Charged and neutral results consistent
- Appears to be good fit to data

Ratio indicates the fits not so good

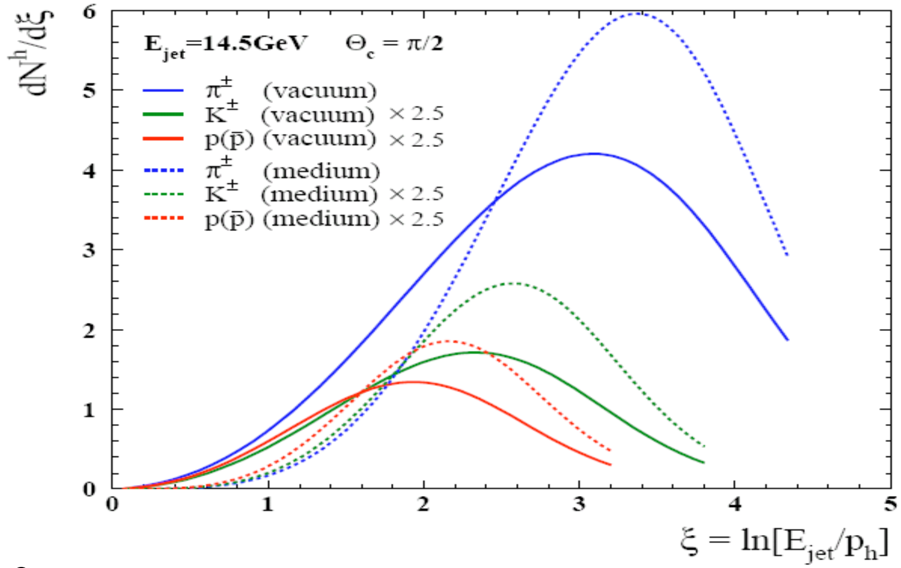


Strange hadrons in jets

FF are particle species dependent but not well constrained

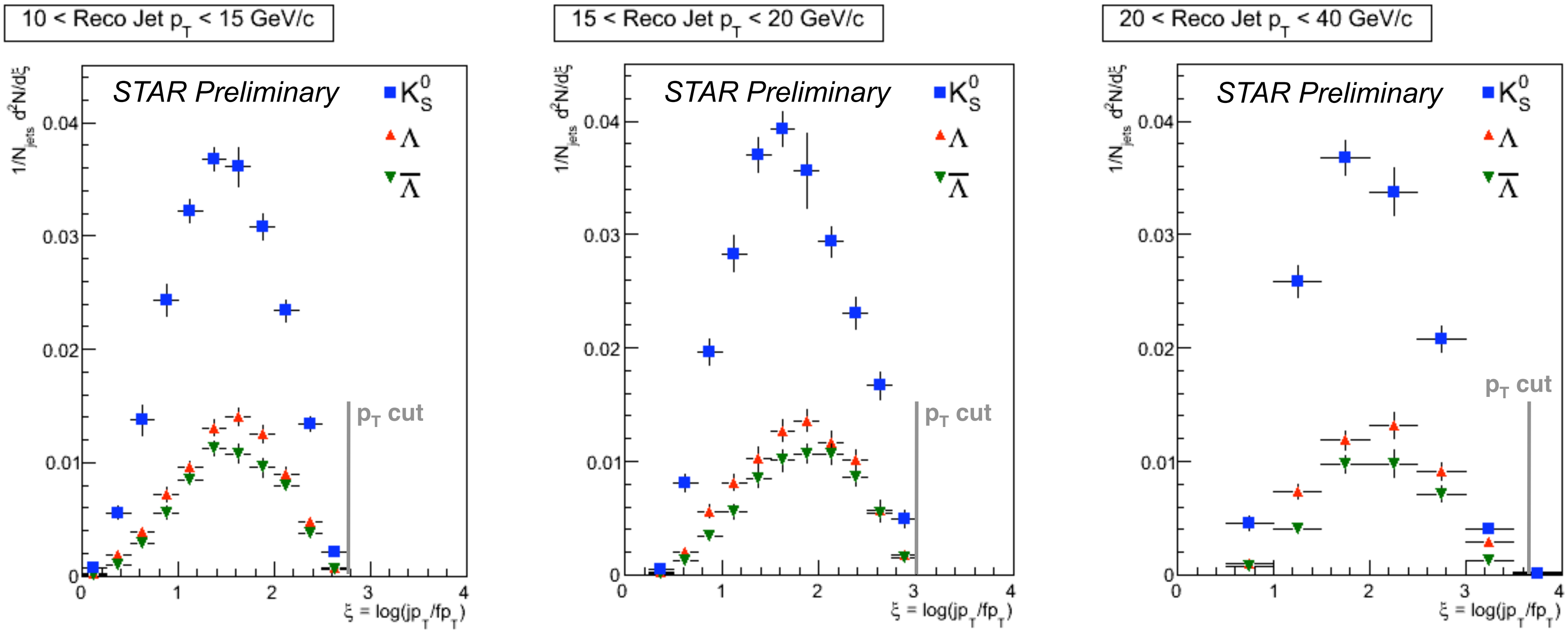


p_T > 1 GeV/c



- 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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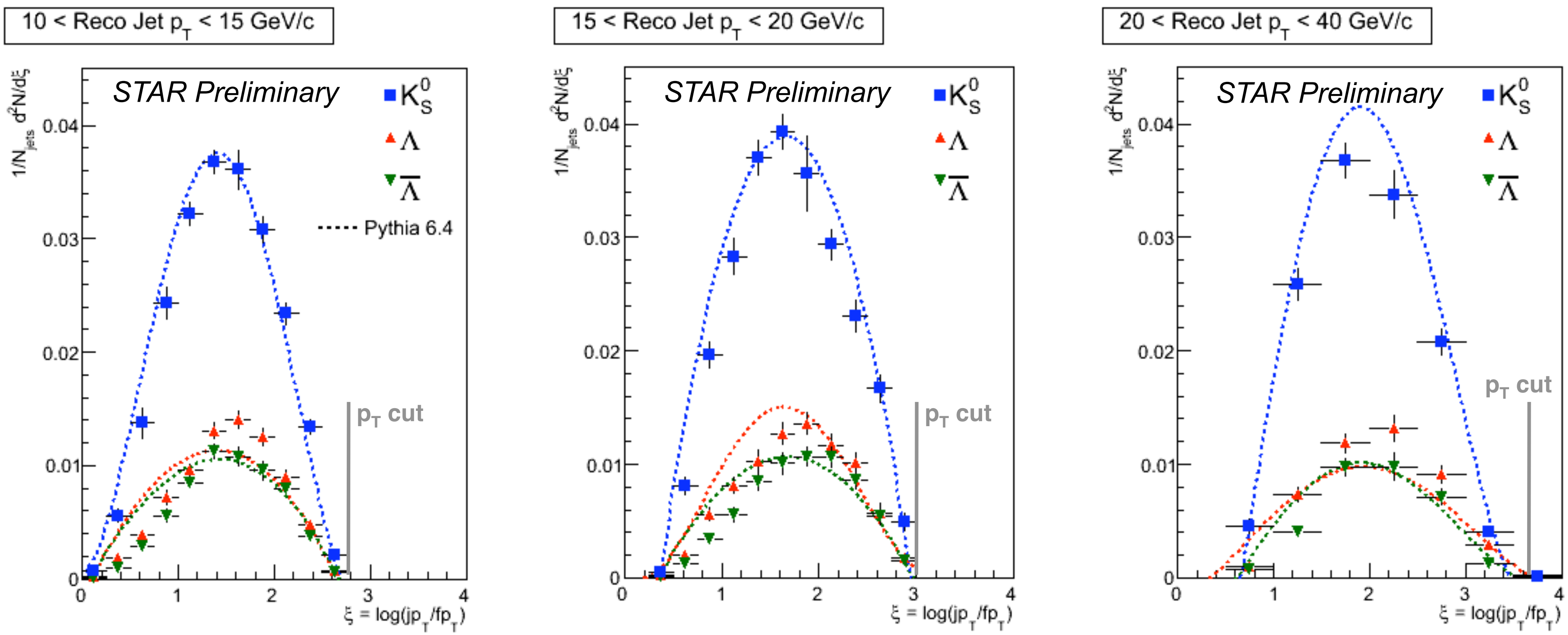

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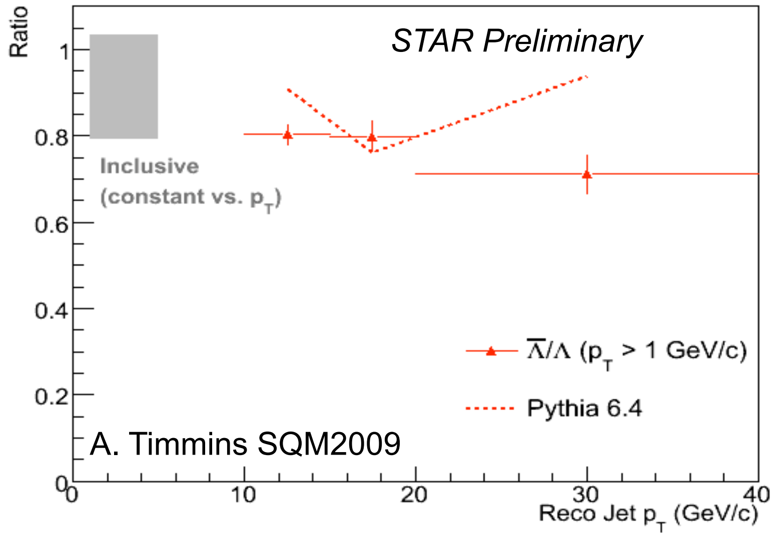
- PYTHIA = PYTHIA+GEANT

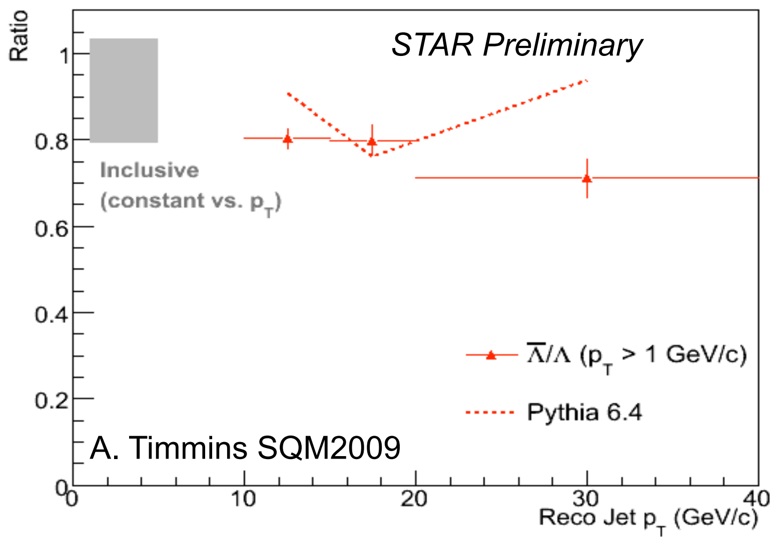
Description of K^0_s better than for Λ - as for min-bias p_T distributions

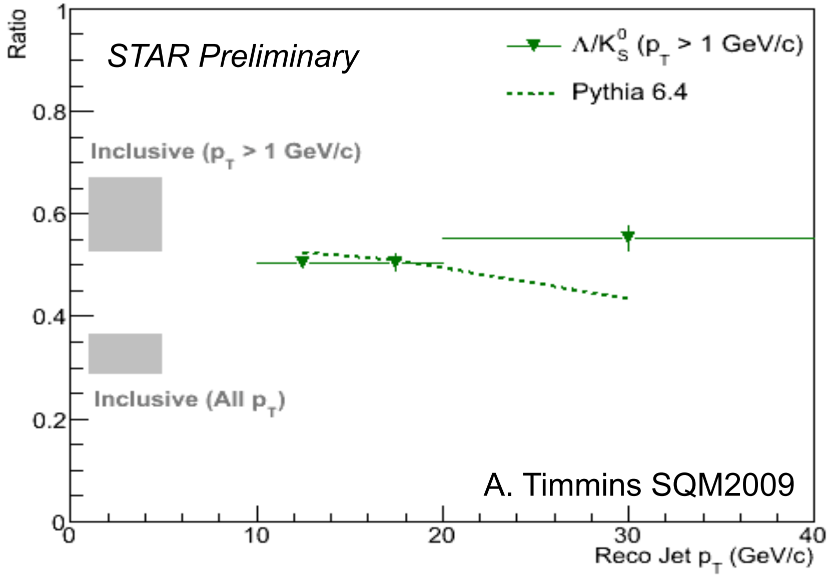
Strange ratios in jets



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

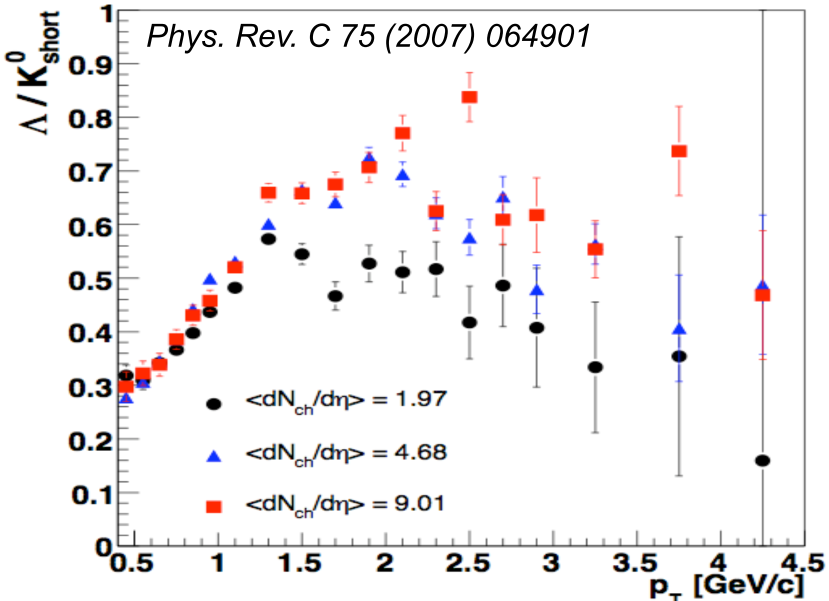
Strange ratios in jets



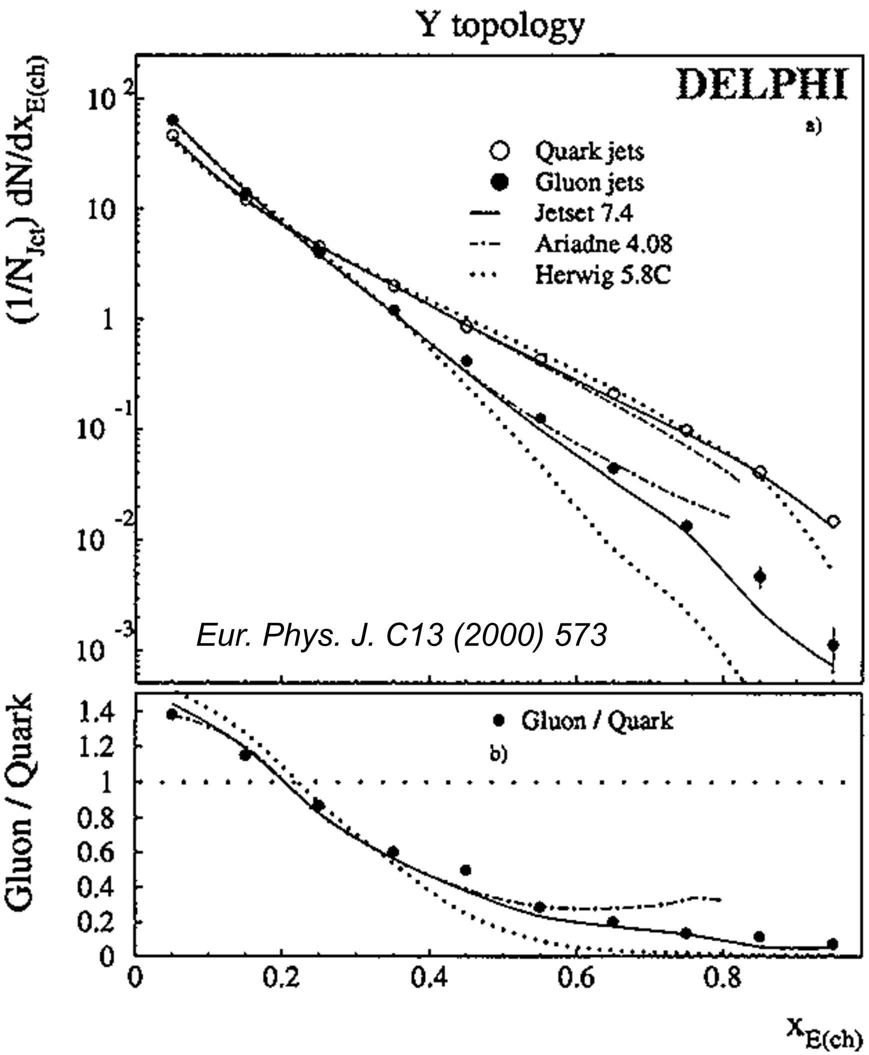


- $\overline{B}/B$ ratio similar to inclusive
- Baryon/meson ratio similar to inclusive when measured p_T range considered
- Baryon/meson ratio ~ constant as function of jet p_T

Strange particle production predominantly from jets?



Future measurements: quark vs gluon jets



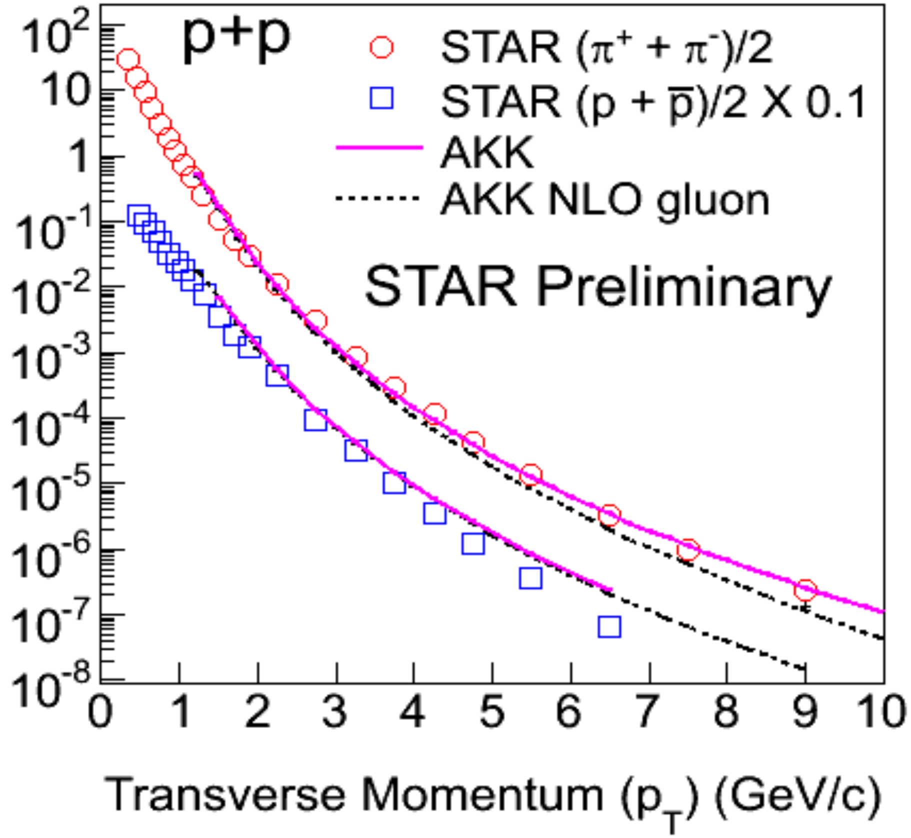
- Typically done using "Y" or "Mercedes" topology events in e^+e^- collisions - i.e. $Z \rightarrow b\bar{b}$
- Identify 2 jets with b decays, 3rd is the gluon
- FF of quark harder than gluon
- Can't use this technique at RHIC
- Can we tag jets via species identification of leading particle?
  Λ vs K^0_s vs charged hadron
- For jet energy <~ 30 GeV expect qg scatterings to dominate

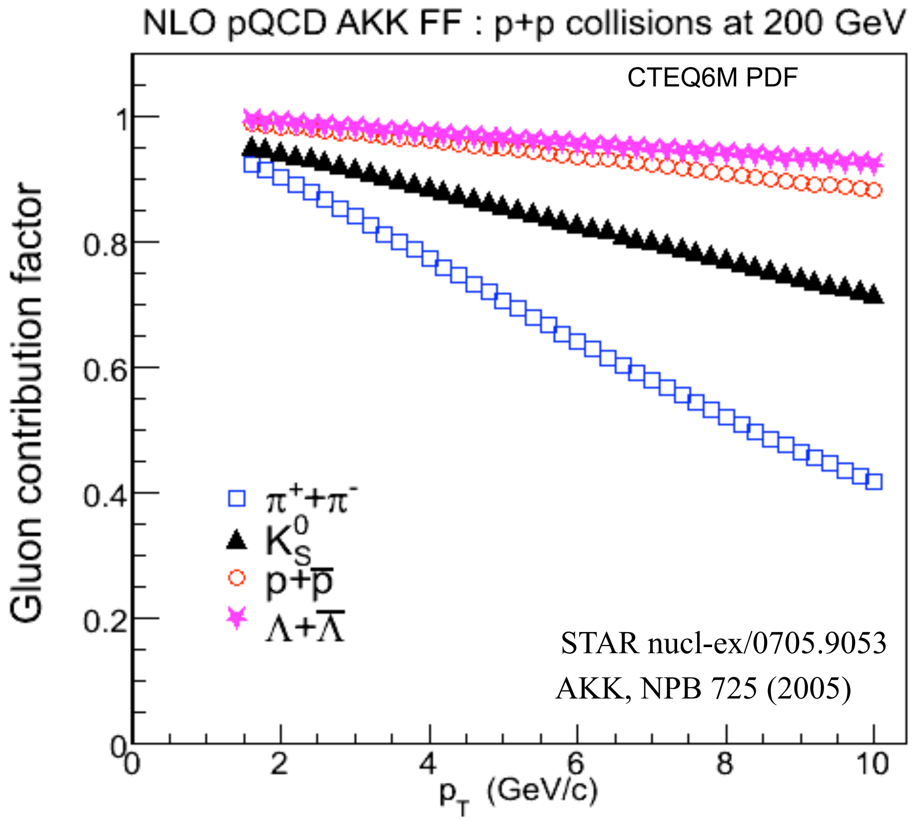
Examine charged hadron FF for jet tagged via various leading particles

Contributions from gluon vs. quark jet

Contribution factor: $N_g(i)/(N_g(i) + N_q(i))$; $i = \pi$, K, p…

At p_T = 8 GeV/c: 50% for π, 90% for p

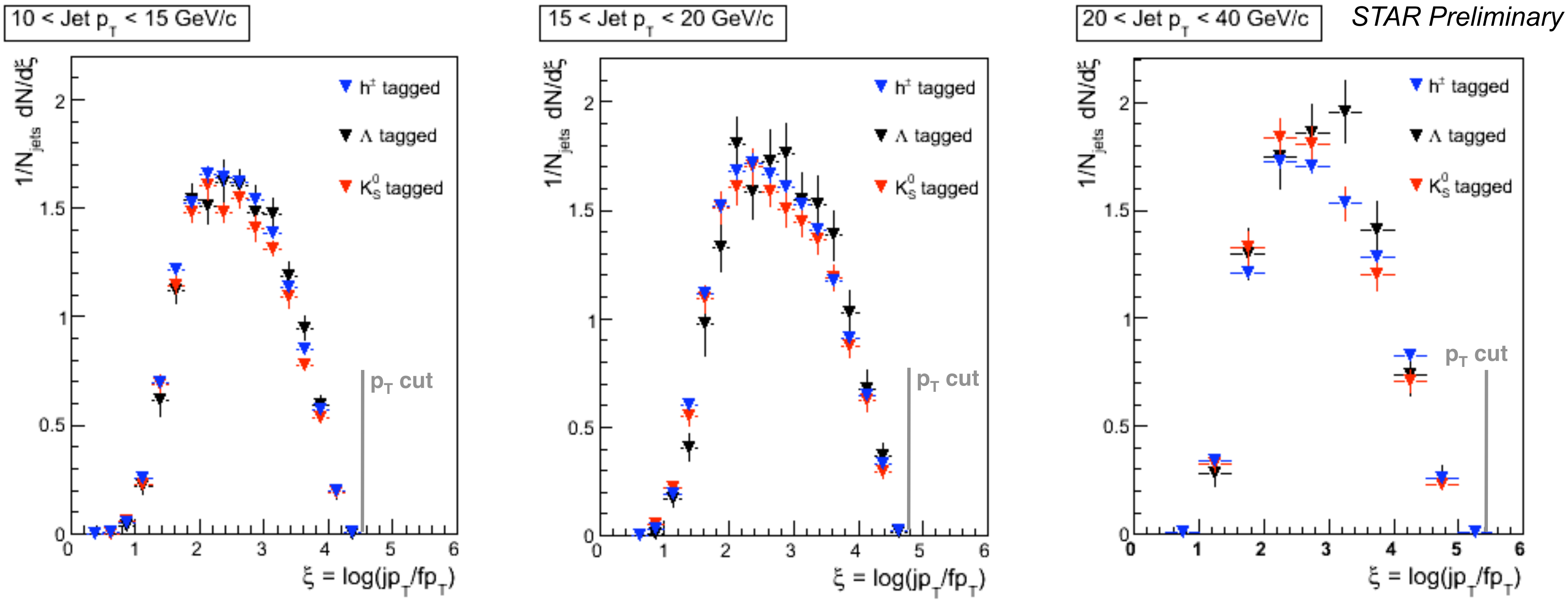




At RHIC: baryons from glue, π both quark and glue contribution

Leading particle tagged jets

"FF" of non-leading charged particle



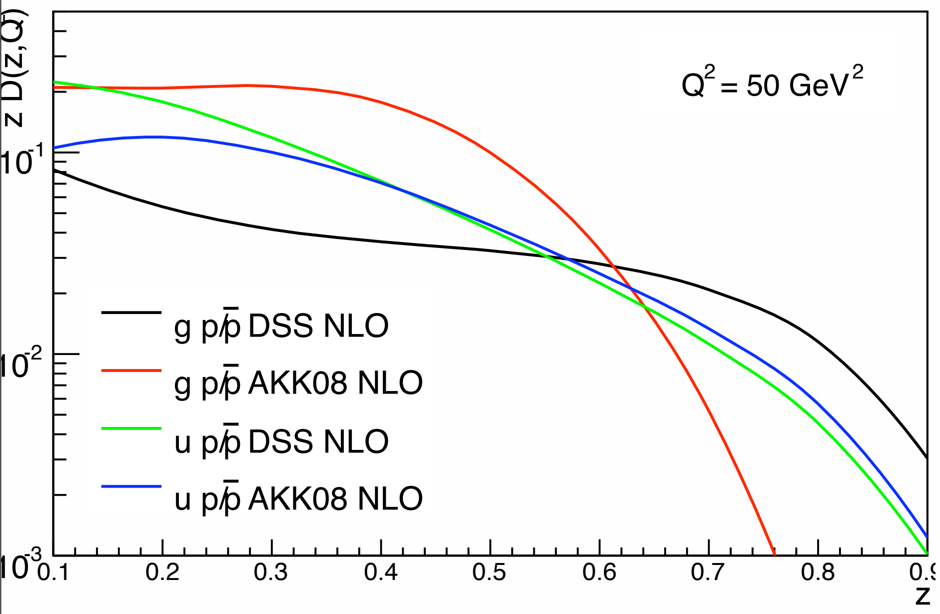
A. Timmins SQM2009

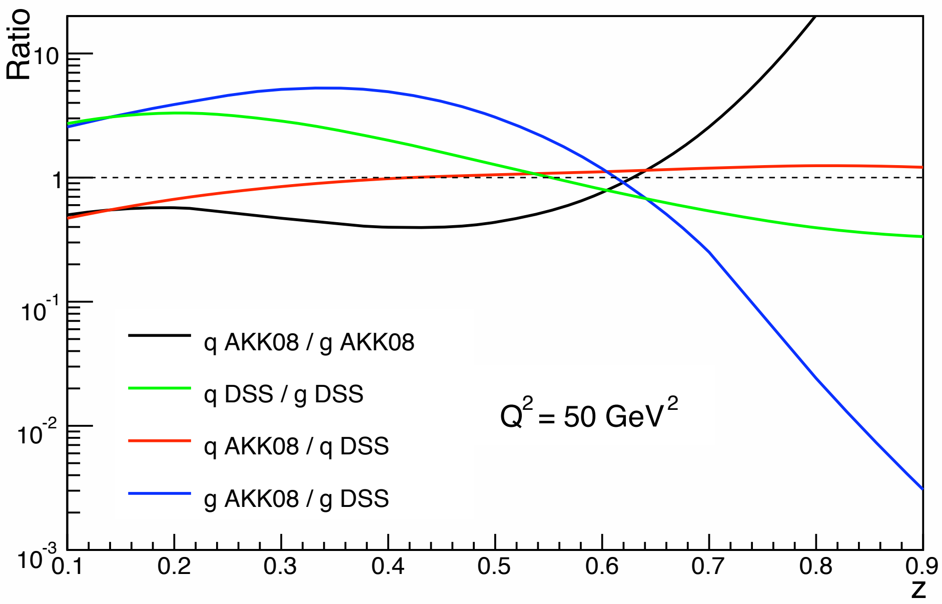
- No evidence seen of differing "FF" for different hadron tags
- Naive quark/gluon tagging does not seem to work

Is there some subtler tagging we can use?
- could be important in A+A studies

Protons predominantly from glue?

- Both AKK08 and DSS give satisfactory descriptions of data
- FF calculations for light quarks similar
- FF of glue still poorly constrained - even after using RHIC data
  >factor 3 differences between AKK and DSS for glue





http://lappweb.in2p3.fr/lapth/ffgenerator/, AKK08: NPB (2008) 803 DSS: PRD75 (2007) 114010, PRD76 (2007) 074033

Need more precise data at high p_T to finally resolve

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

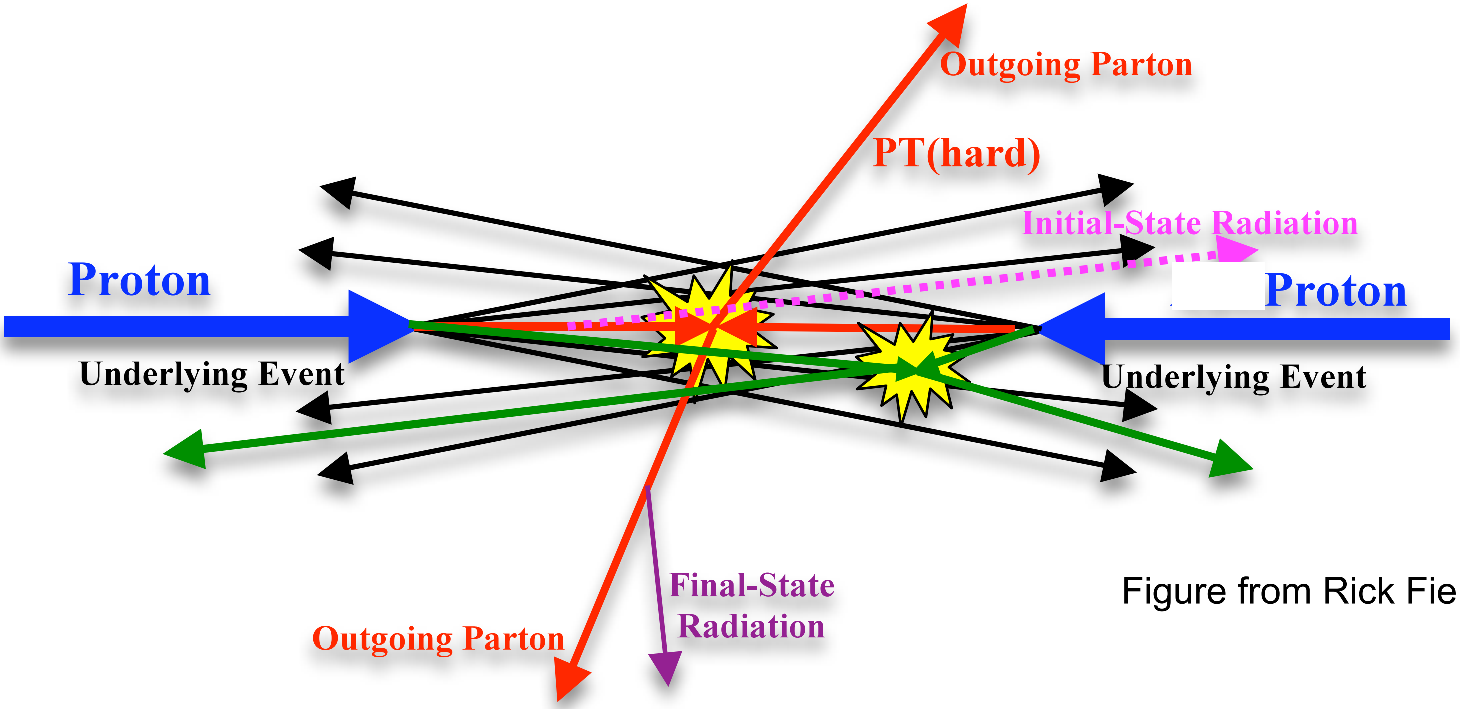
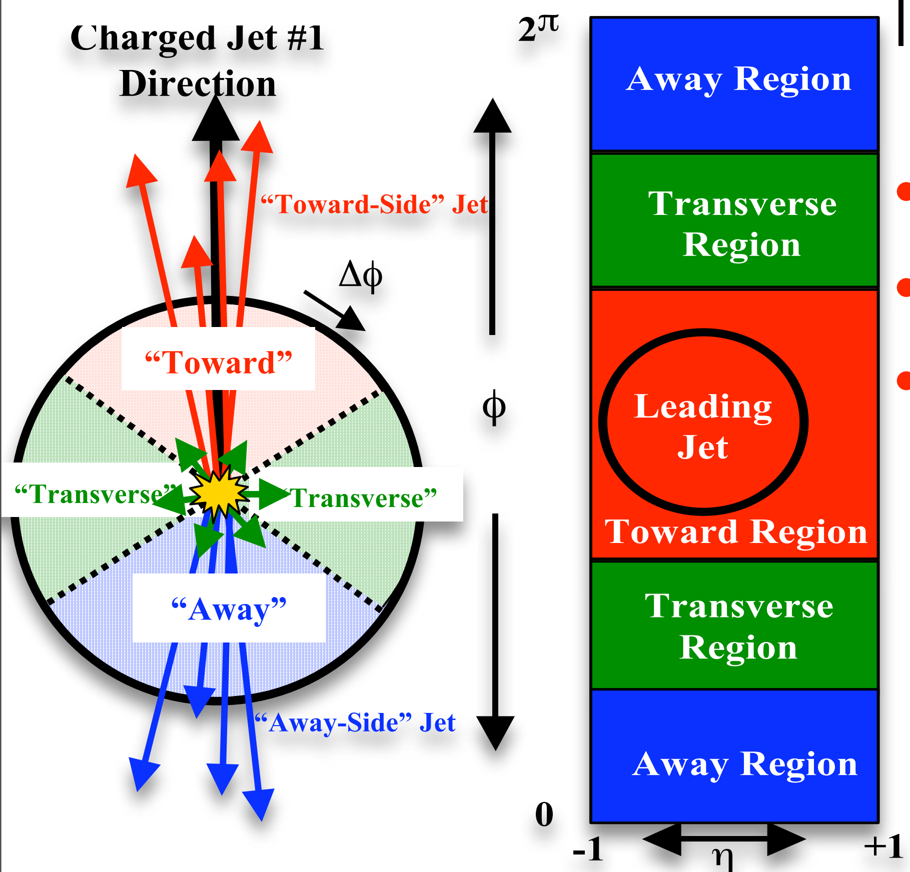


Figure from Rick Field

The Underlying Event is everything BUT the hard scattering

The underlying event



|Δϕ| – Angle relative to leading jet

- **"Toward"** |Δφ| < 60°
- **"Away"** |Δφ| > 120°
- **"Transverse"** 60° < |Δφ| < 120°
  - **TransMax** - Trans. region with highest Σp_T or ΣN_{track}
  - **TransMin** Trans. region with least Σp_T or ΣN_{track}

Underlying event contained in the Transverse region - everything BUT the hard scattering

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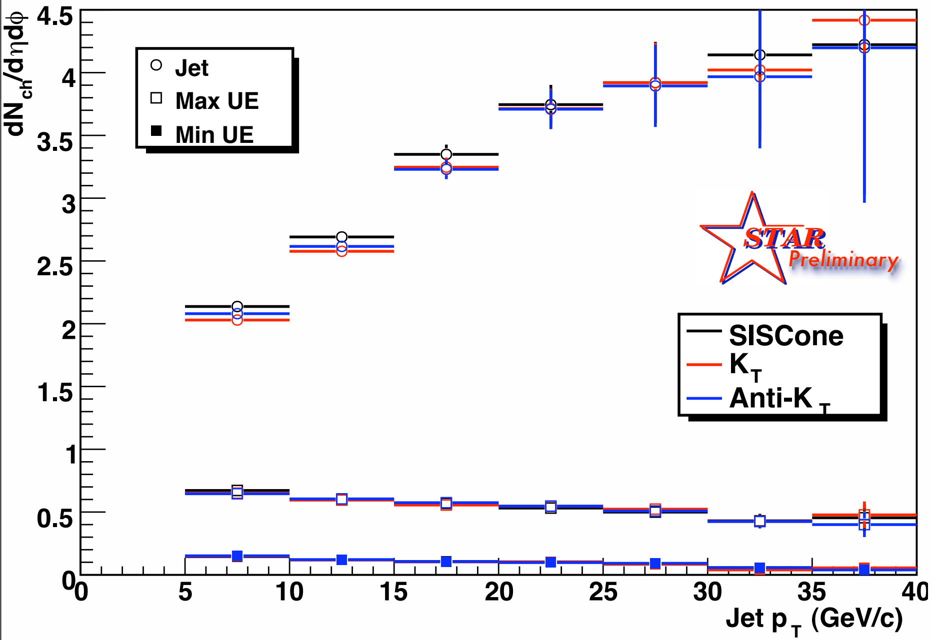
Compare TransMin and TransMax data from leading and back-to-back jet samples →

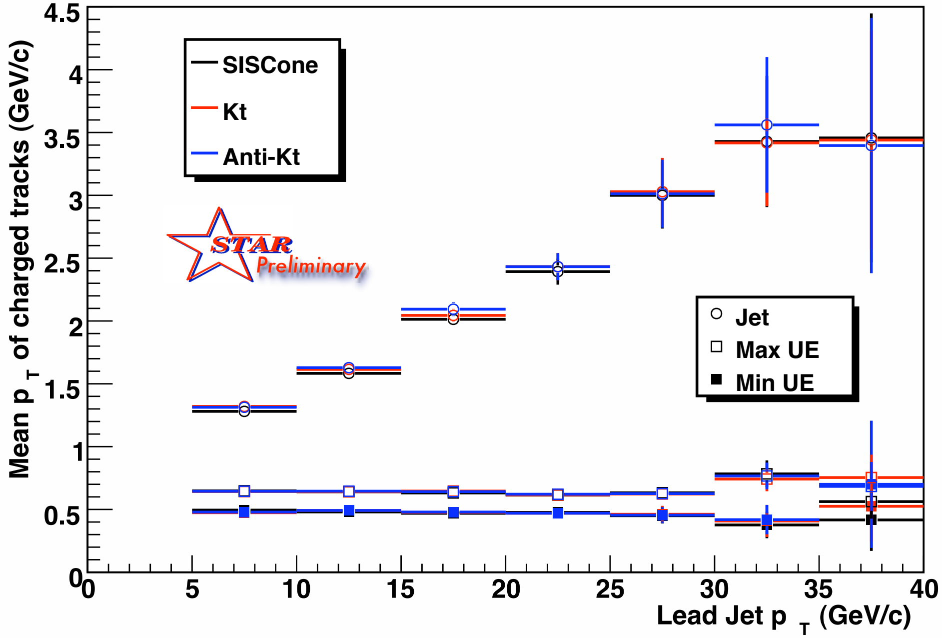
Information about large angle initial/final state radiation.

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.



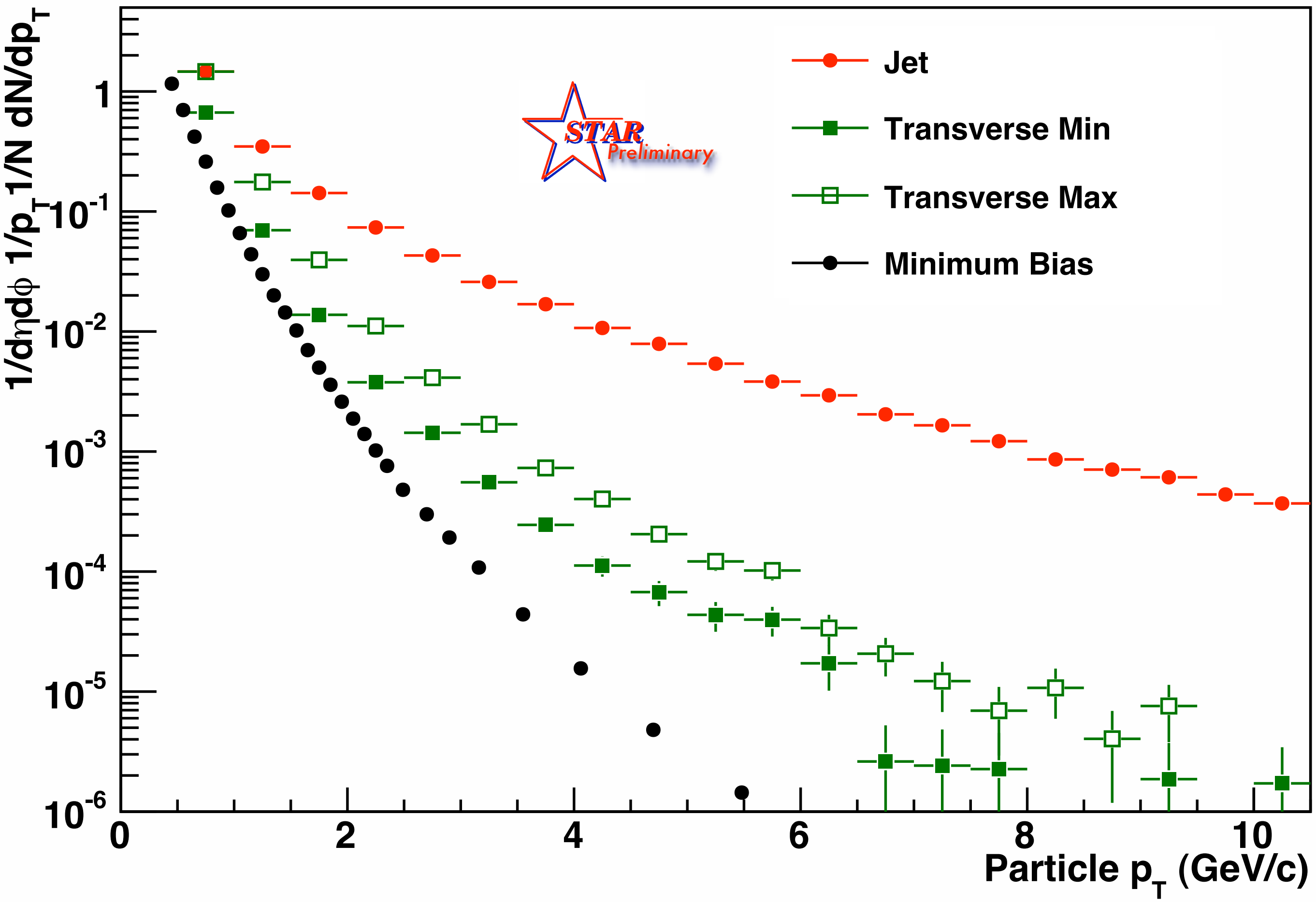


- Jet charged track density and $<p_T>$ rise with jet p_T as expected

UE largely independent of jet p_T

Underlying event is not the same as minbias

Corrected charged particle p_T distributions



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

Energy scaling of the underlying event

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

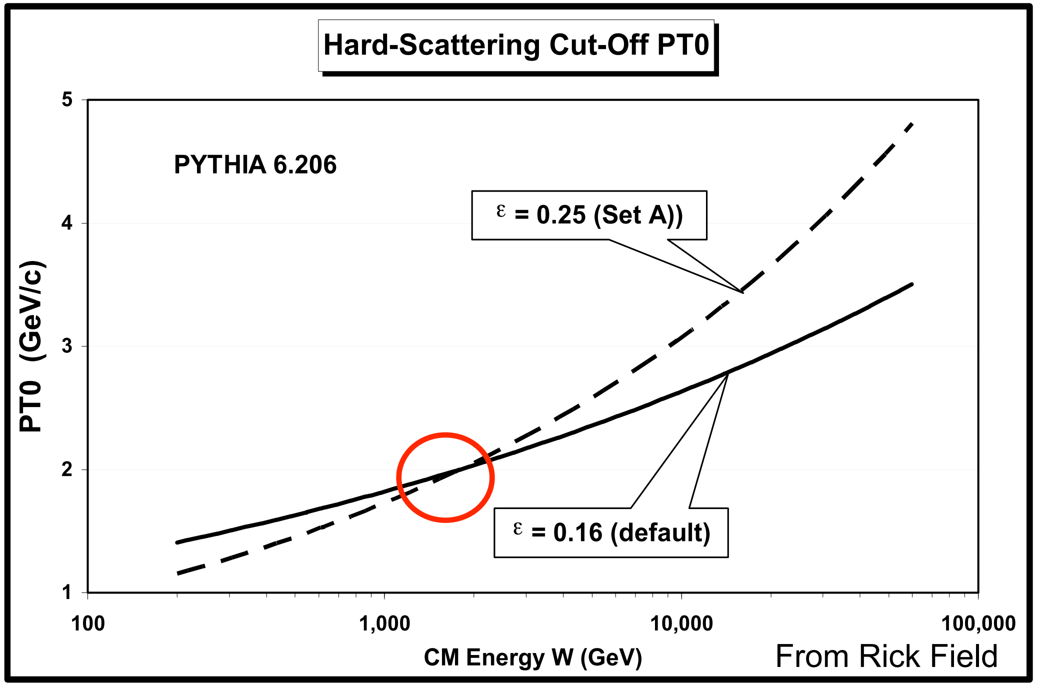
- An important scaling factor is the hard scattering cut-off for the MPI in UE:

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

- Pivots around the tuning energy

- ε = 0.16 - initial estimate

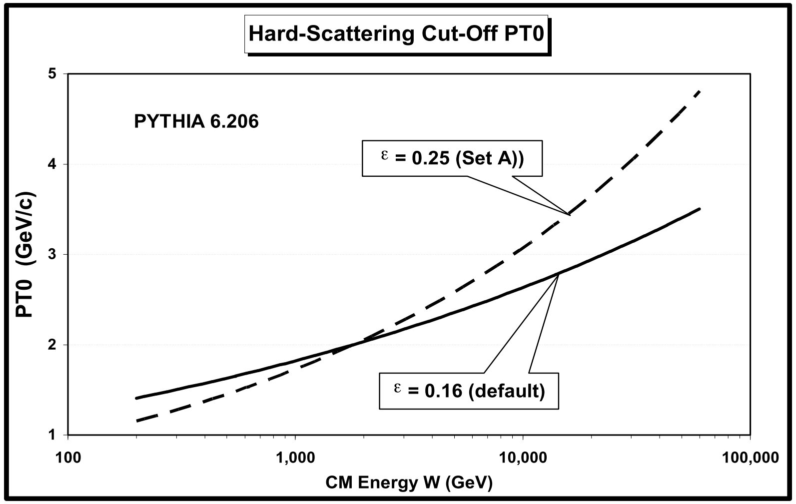
  = 0.25 (suggested by 630 GeV Tevatron)



From Rick Field

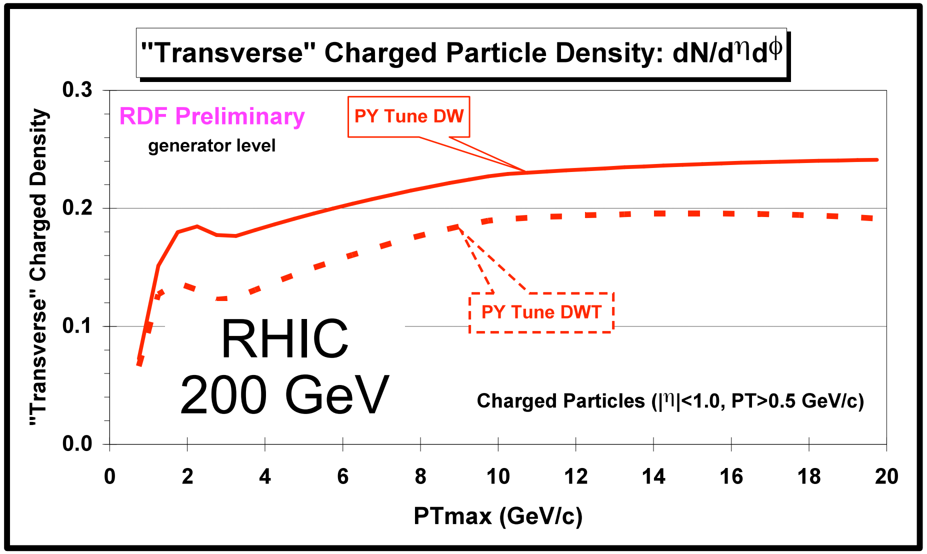
Correct scaling important to know

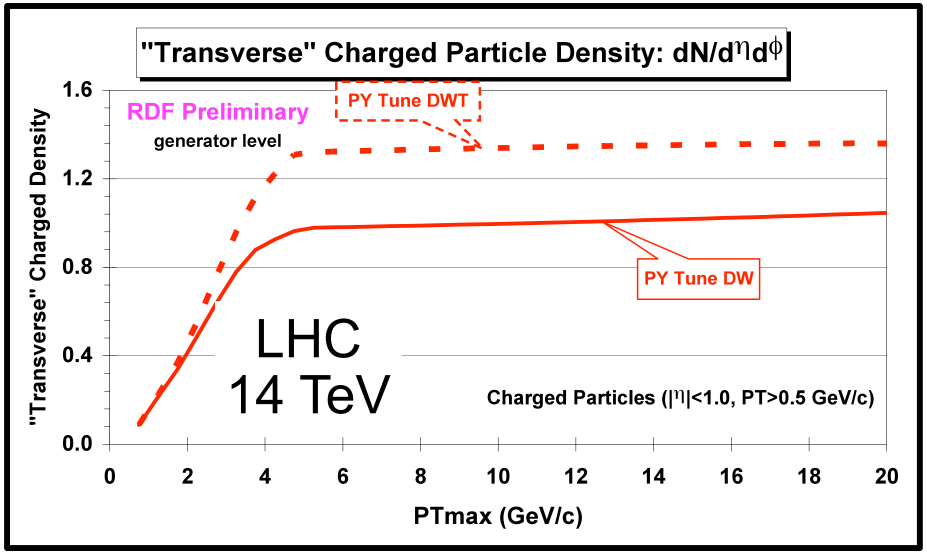
Effect of hard scattering cut-off scaling



- 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

Checking energy scaling at RHIC

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

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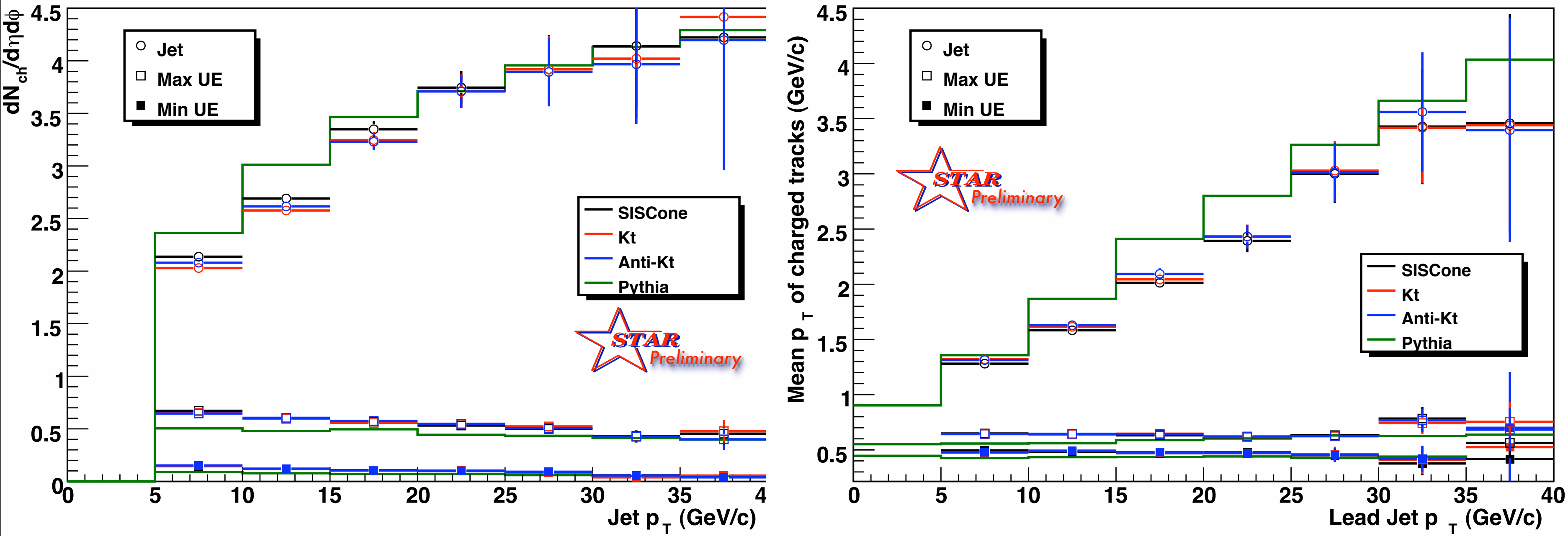
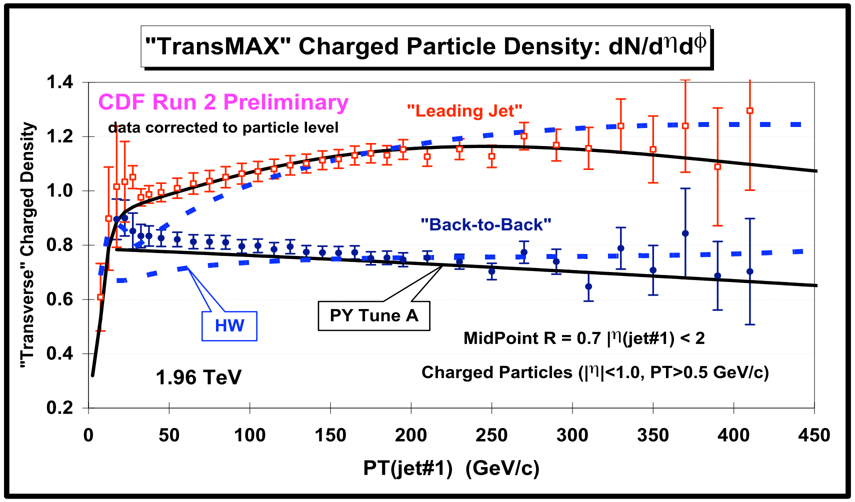
"PYTHIA" = PYTHIA +GEANT   MPI scaling factor ε = 0.25



RHIC data support ε = 0.25

TransMin vs TransMax regions of UE



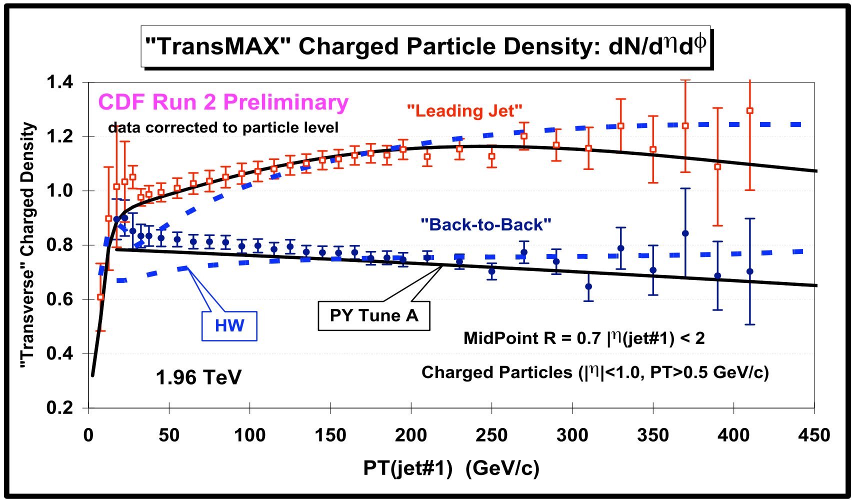
Data not corrected to particle level.

CDF √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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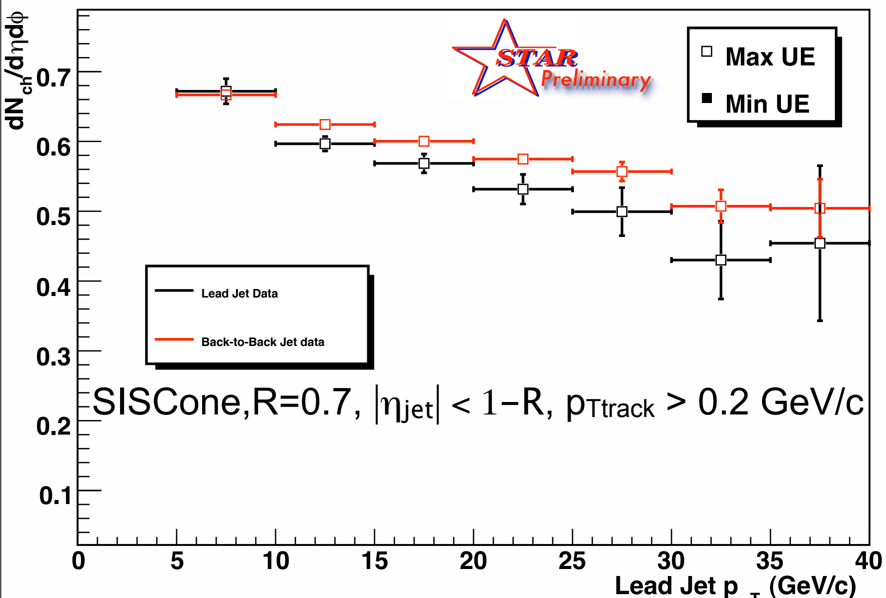

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STAR √s=200 GeV

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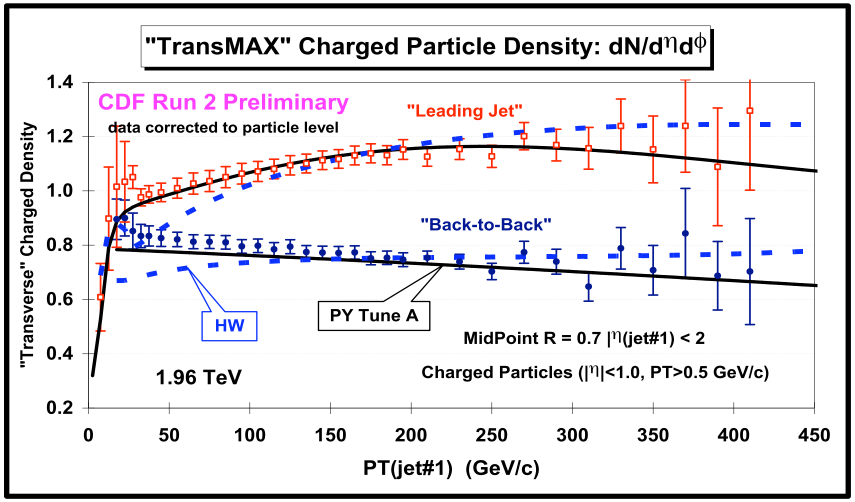
Small initial/final state radiation at large angles.

TransMin vs TransMax regions of UE



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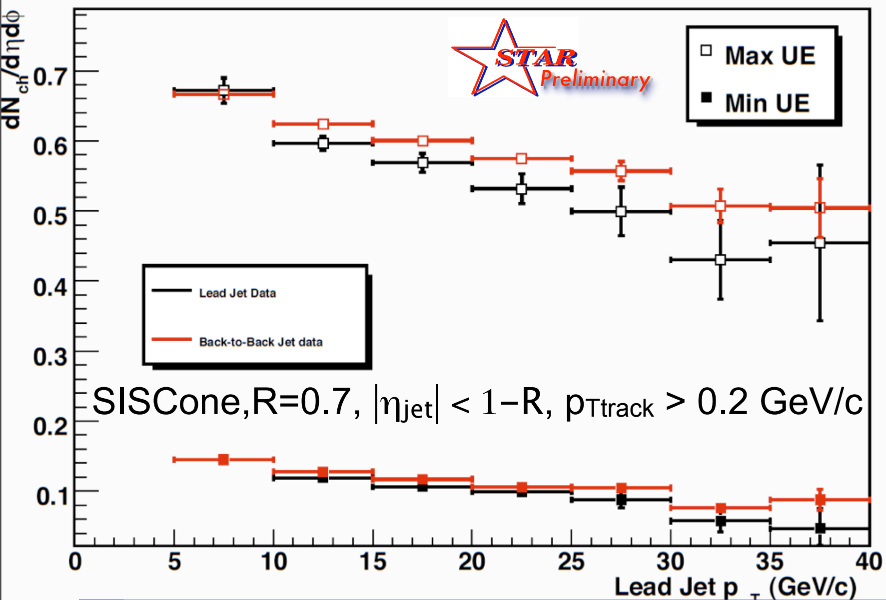

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- TransMax > TransMin

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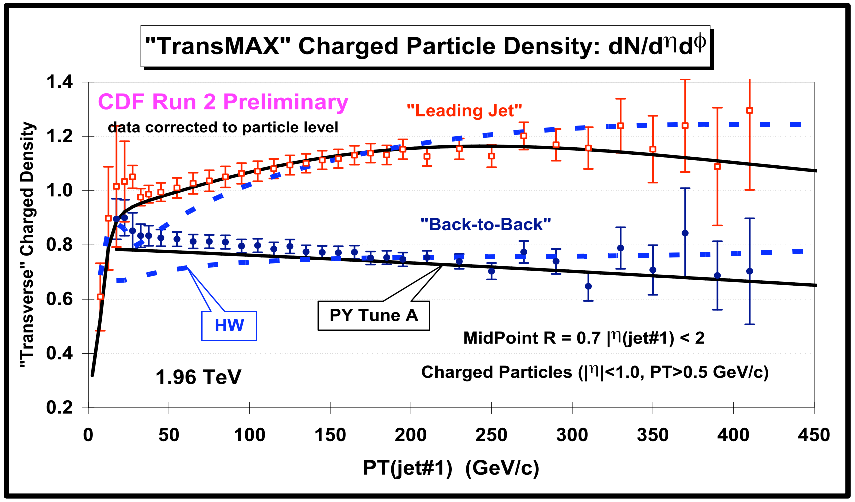
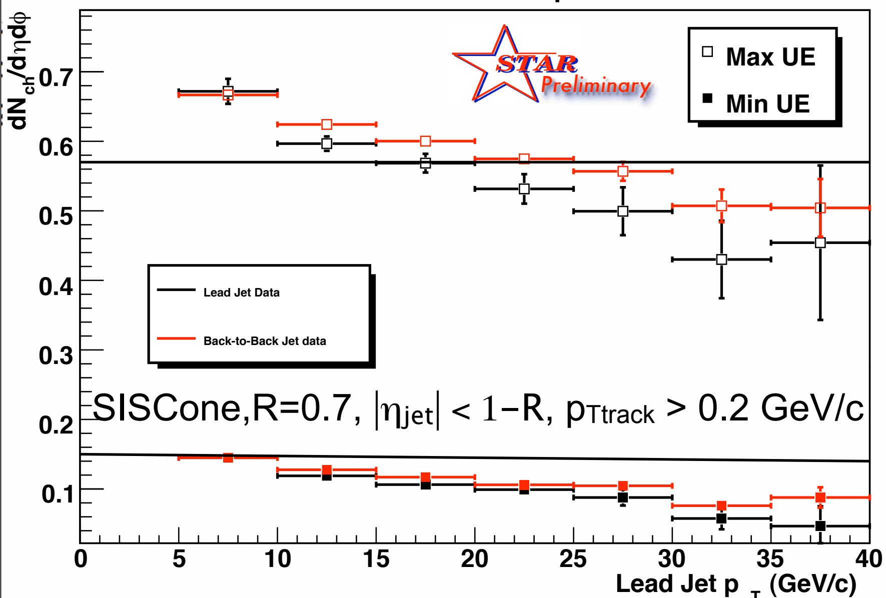


Data not corrected to particle level.



CDF $\sqrt{s}$=1.96 TeV

- leading TransMax > back-to-back TransMax

Significant initial/final state radiation at large angles.

STAR $\sqrt{s}$=200 GeV

- leading TransMax ~ back-to-back TransMax

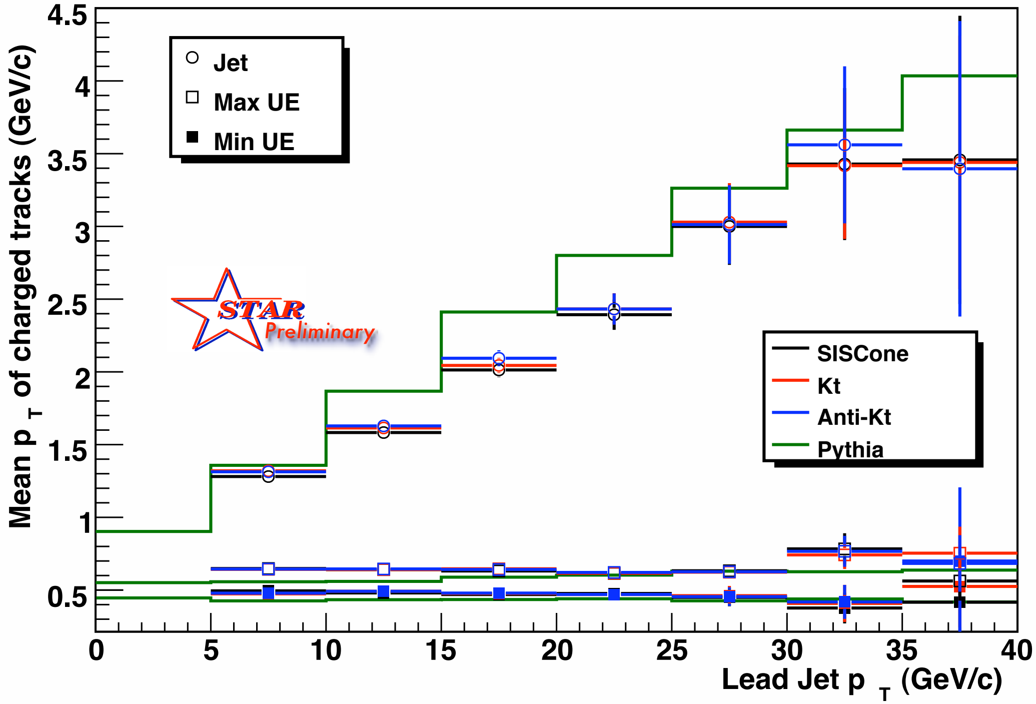
Small initial/final state radiation at large angles.

- TransMax > TransMin

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

- UE ~independent of jet p_T.

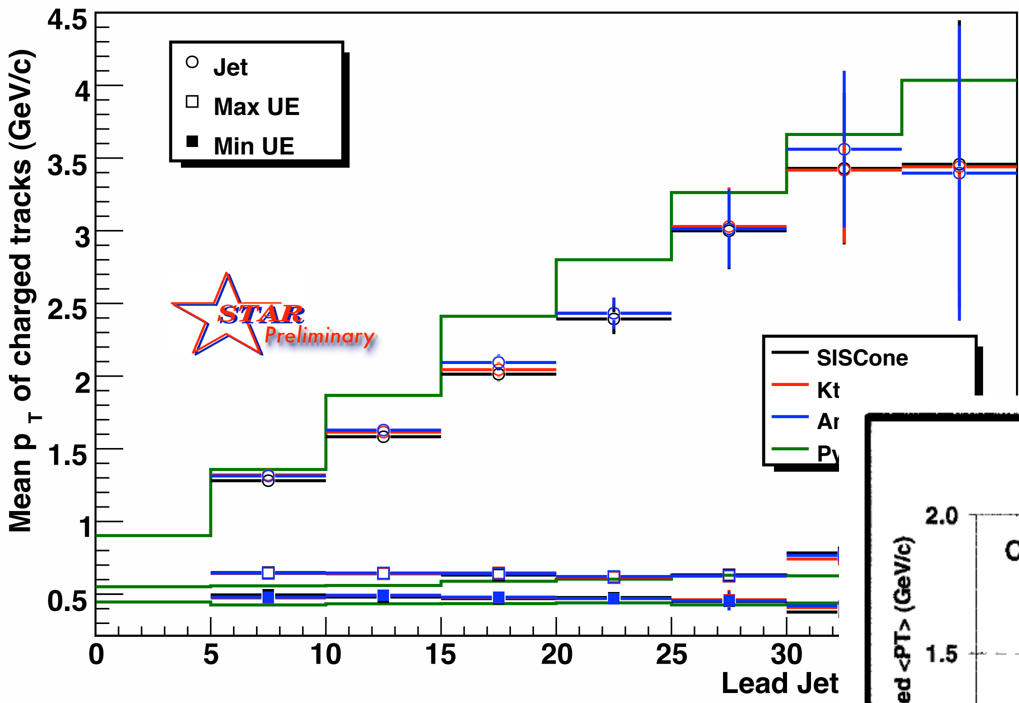
Mean p_T charged tracks



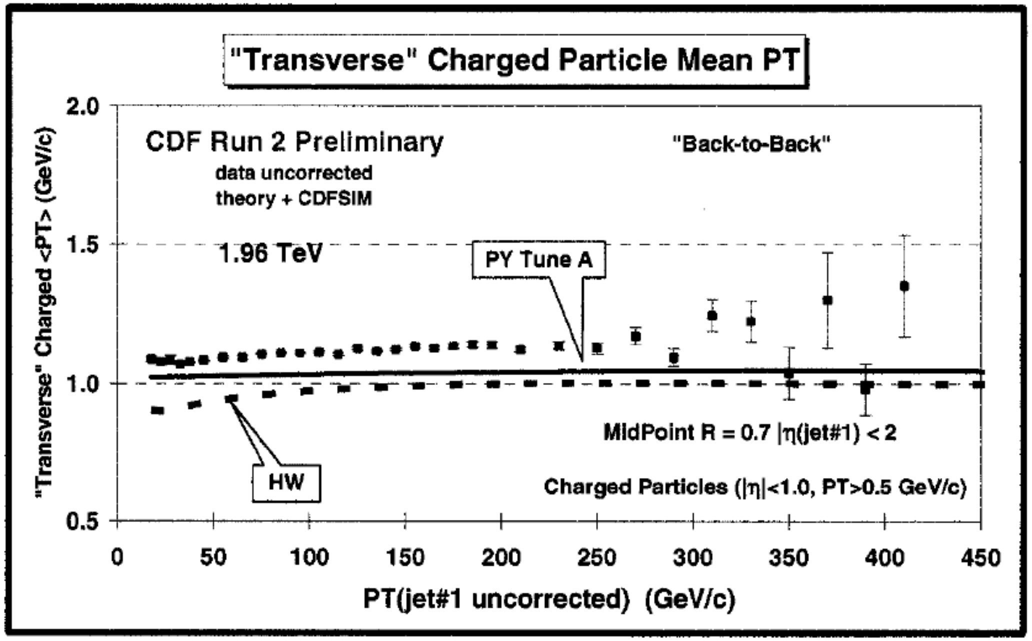
, Back-to-Back, R=0.7, $|\eta_{jet}| < 1-R$,
p_{Ttrack} > 0.2 GeV/c
Data not corrected to particle level.
"PYTHIA" = PYTHIA +GEANT

- Agreement between PYTHIA and data OK

Mean p_T charged tracks



- Agreement between PYTHIA and data OK



, 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

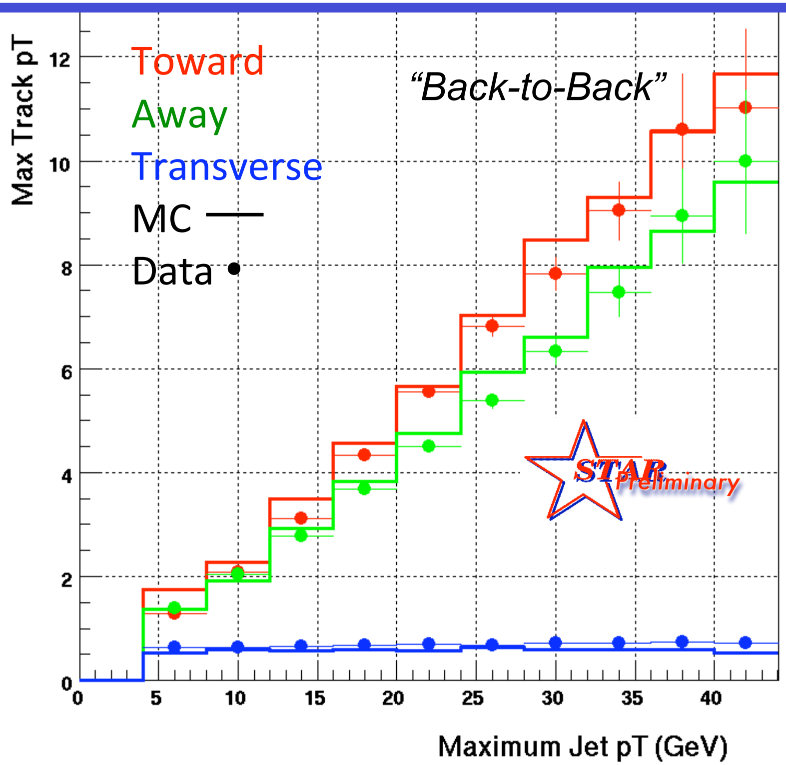
L.A. Cruz, "Using MAX/MIN transverse regions to study the underlying event in run 2at the Tevatron" UMI-31-88071, 2005.

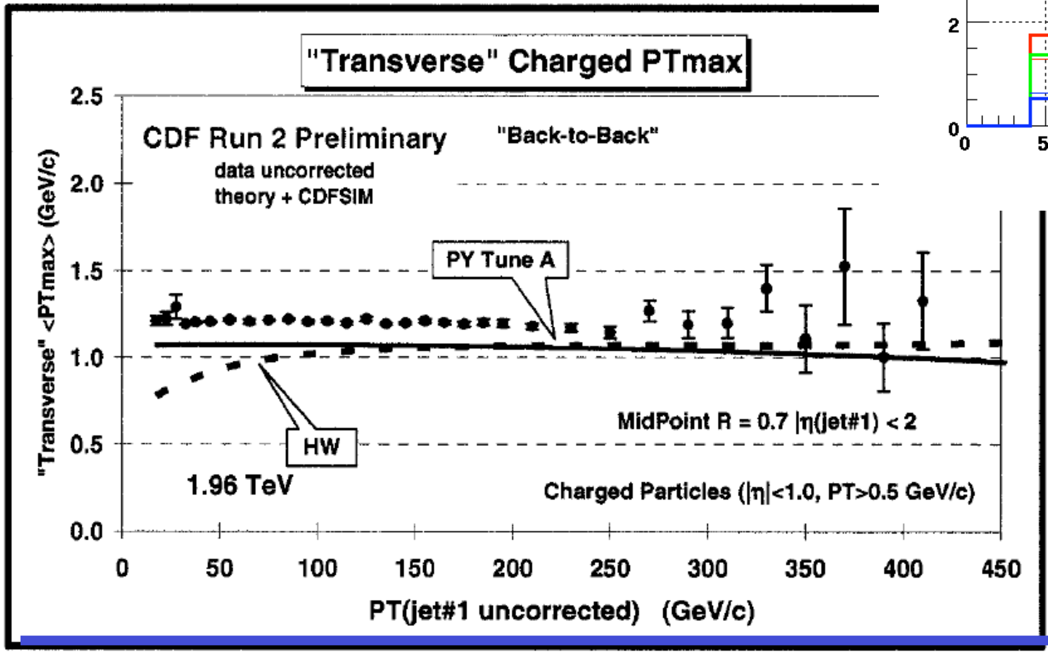
CDF higher than STAR merely due to lower p_T cut?

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





Data not corrected to particle level

"PYTHIA" = PYTHIA +GEANT

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.

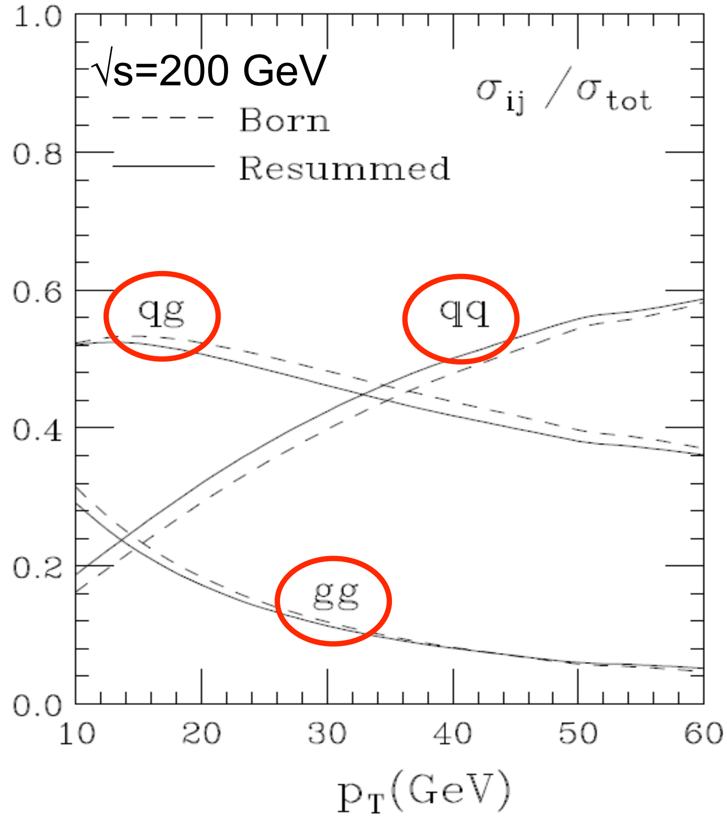
Summary

- 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
- 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.
- Particle p_T spectra are different in MB than in UE
- Strange particles appear to predominantly come from jets
- Charged particle and jet distributions well produced by pQCD
- Species dependence of fragmentation poorly described

Jets at RHIC: √s=200 GeV p+p

- Unpolarized measurements 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



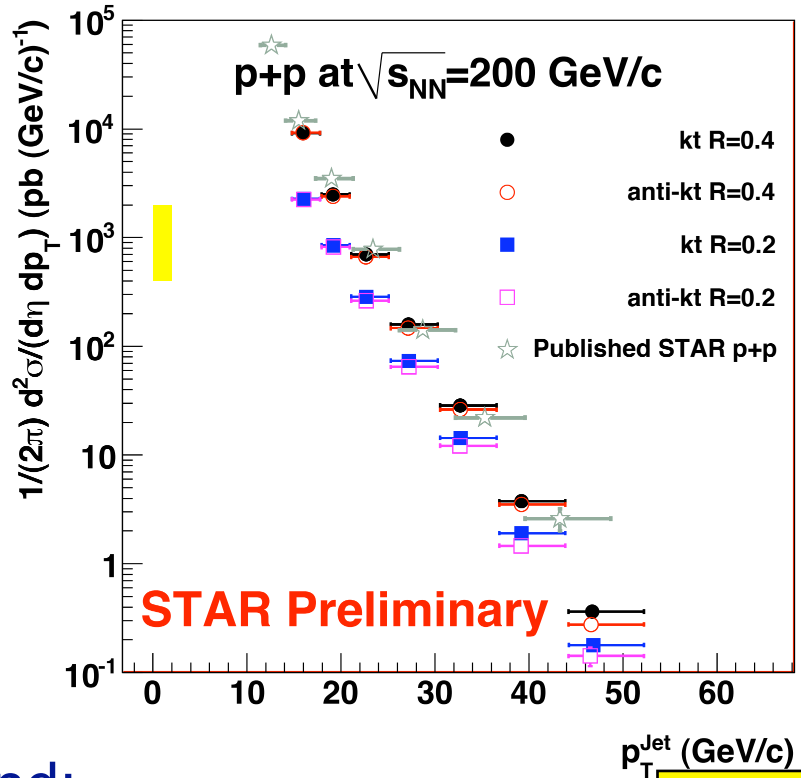
De Florian,Vogelsang, hep-ph 0704.1677

- Constrain fragmentation functions:
  - Fits currently dominated by e^+e^- data
  - Still large uncertainties, especially in the gluon fragmentation functions

Significant contribution from gluons in the RHIC regime

Result depends on "question" asked

"Jet" is not a rigorous term

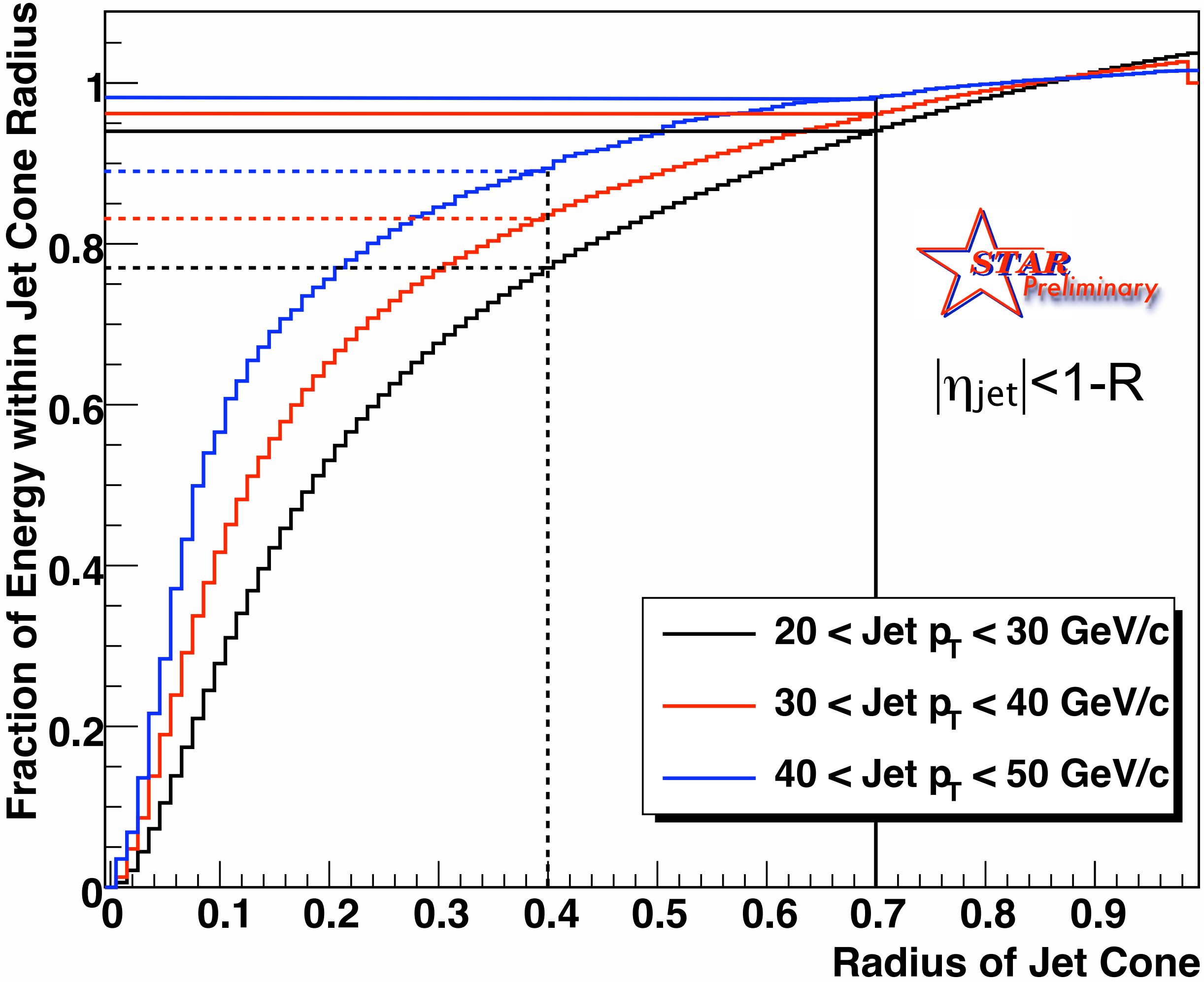


Results depend:

Strongly on resolution parameter, R
Weakly on algorithm choice

Need to be clear when discussing results exactly what was run

Jet reconstruction - the resolution parameter



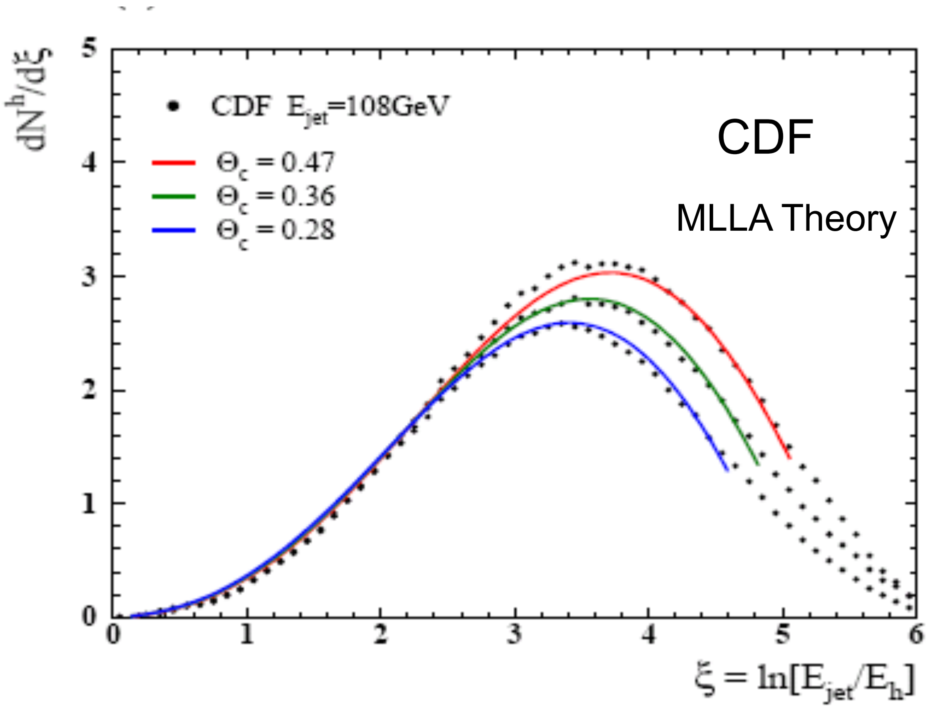
% Energy within resolution parameter R

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)

Compare FF using different radii.

Fragmentation functions (FF)



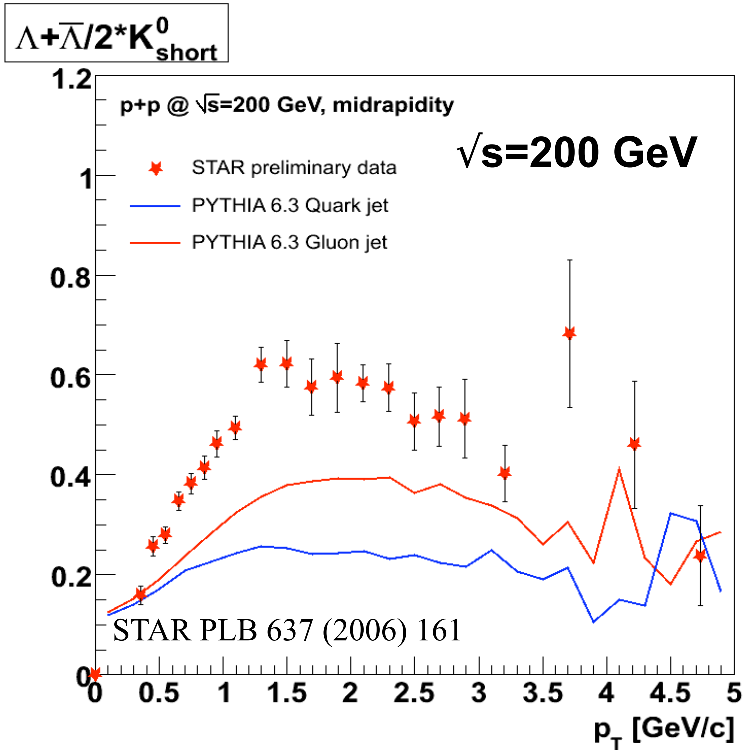
Sapeta&Wiedemann, hep-ph/0707.3494

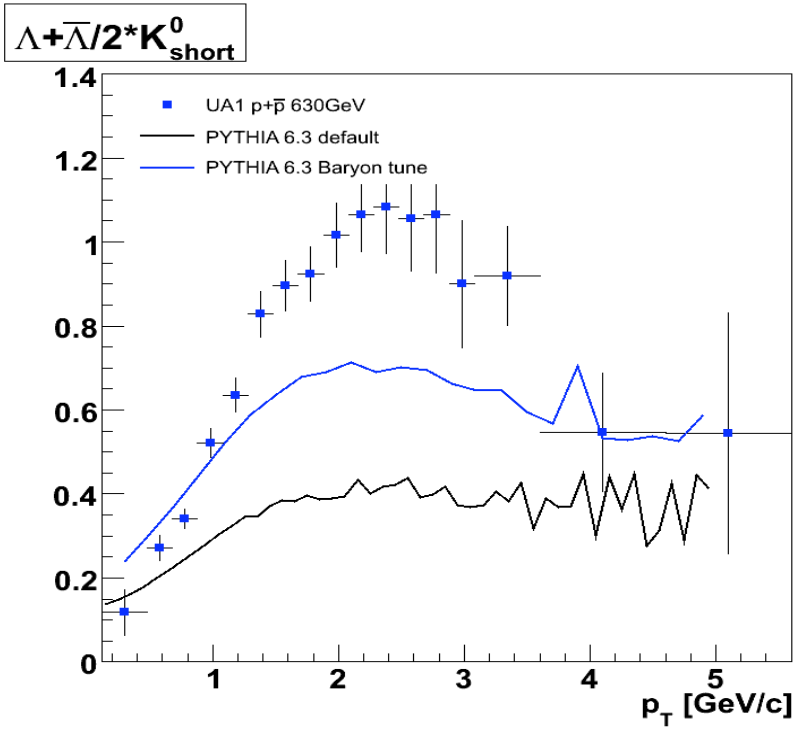
- No previous comparisons at RHIC energies available.
- Measurements at higher √s agree well with theory.

Test energy scaling of fragmentation functions

Baryon-meson ratios

- Gluon jet B/M > quark jet B/M
- Cannot describe B/M ratio at intermediate p_T even with tuned K-factors and/or di-quarks





"K-tuned" PYTHIA still under-predicts B/M ratio at 200 and 630 GeV

also fails for p/π at ISR and FNAL: 19-53 GeV (not shown)

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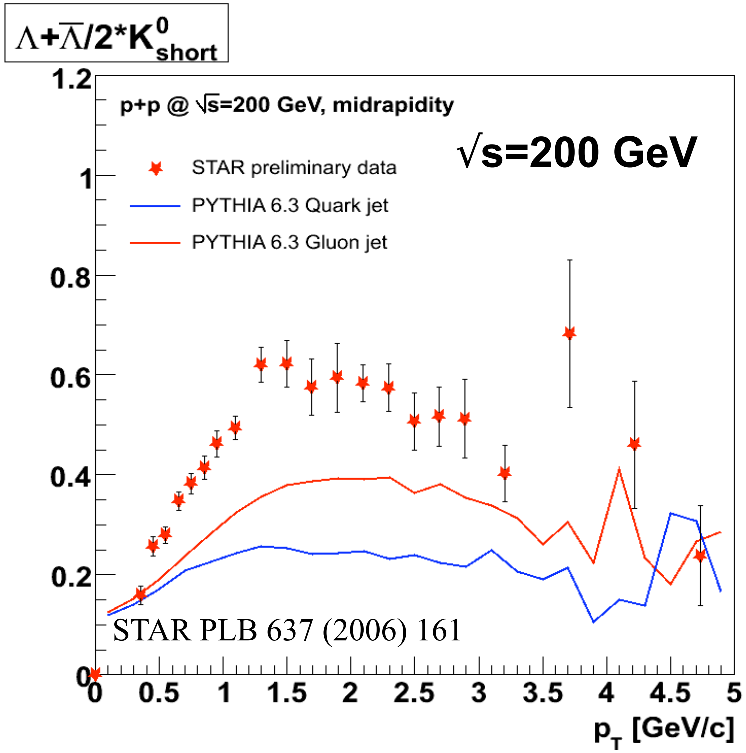

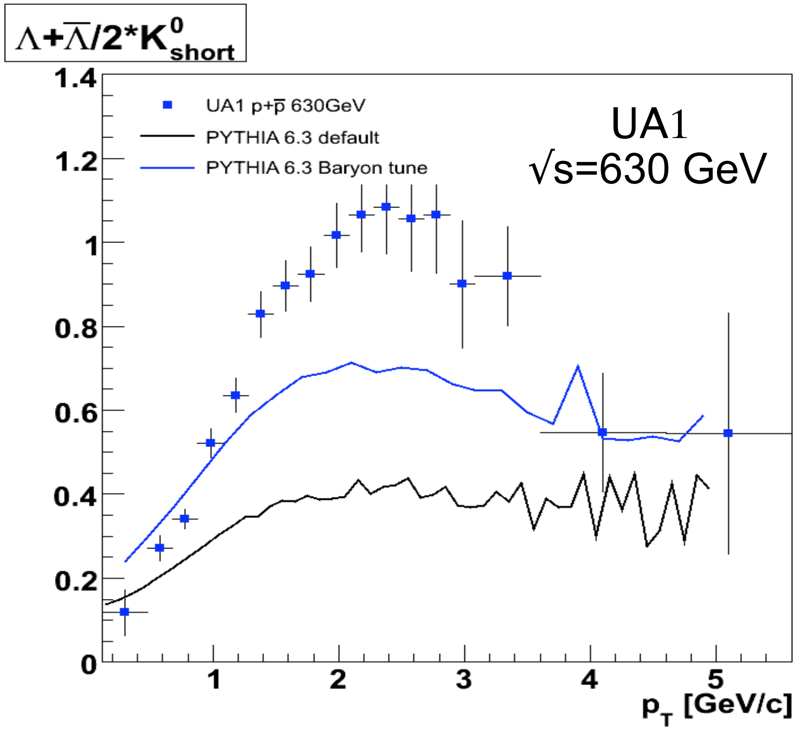

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