Using Identified Particles to study p+p Collisions at 200 GeV

Helen Caines - Yale University

Joint Workshop on Energy Scaling of Hadron Collisions
Fermi Lab
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Outline

- Why study p+p
- How PID is done
- Min-bias distributions
- Jets
- Summary

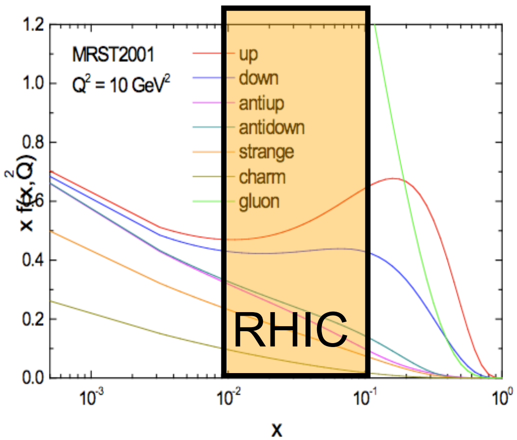
Modeling a collision - pQCD ansatz

$$\frac{d\sigma^{h}_{pp}}{dy\,d^2p_T} = K\sum_{abcd}\int dx_a dx_b\, f_a(x_a,Q^2)\, f_b(x_b,Q^2)\,\frac{d\sigma}{d\hat{t}}(ab \text{®}\ cd)\,\frac{D^0_{h/c}}{\pi z_c}$$

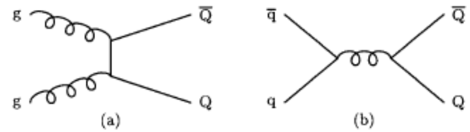
Assume that the calculation is factorizable

K factor

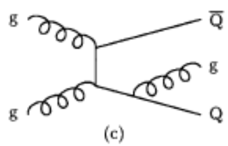
Parton Distribution Function (non-pert.)



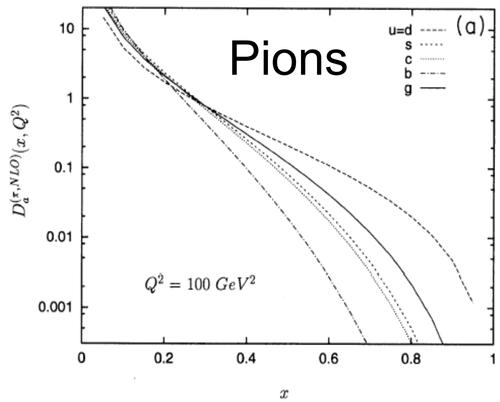
LO parton processes



NLO parton processes



Fragmentation Function (non-pert.)



BKK, Phys Rev D (1995)

Modeling a collision - pQCD ansatz

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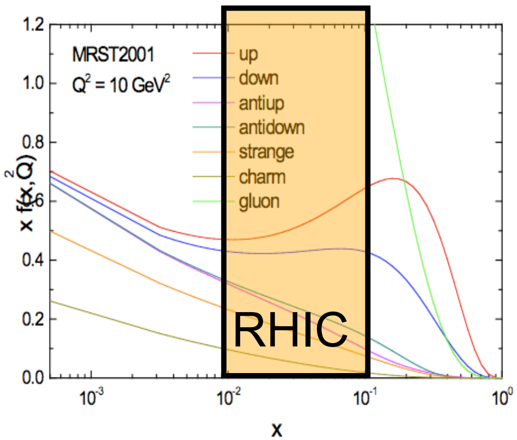

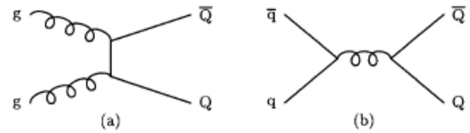

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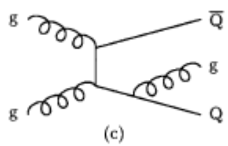
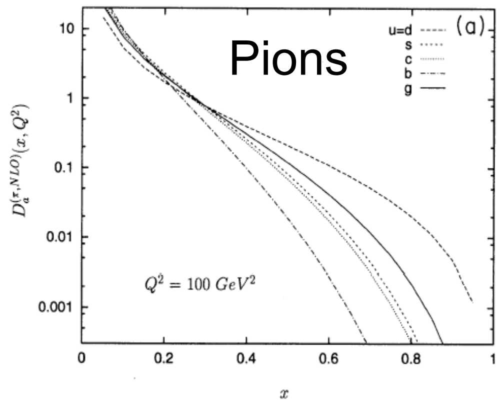




BKK, Phys Rev D (1995)

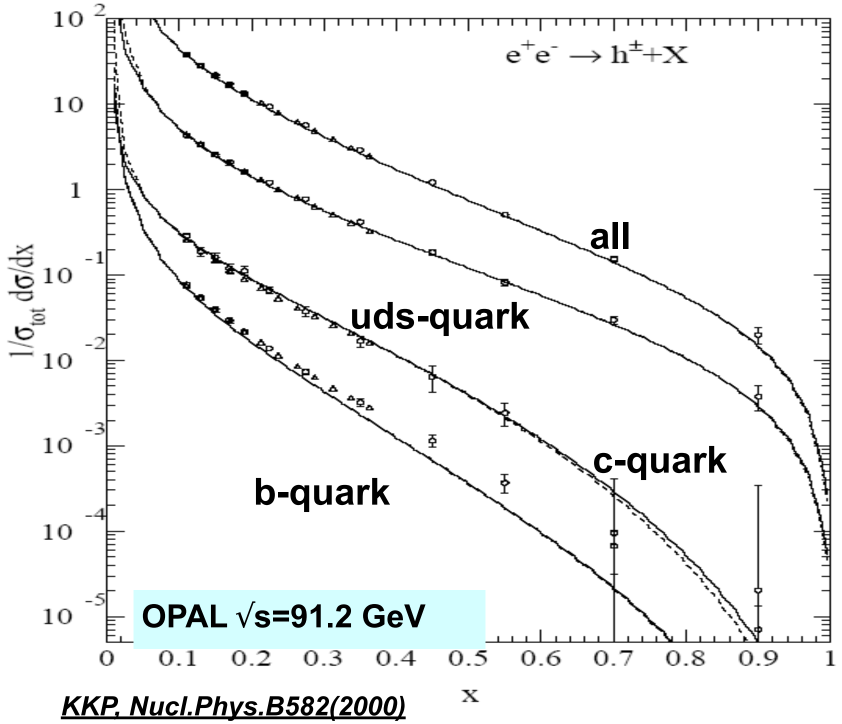
p+p collisions "messy"

Not all energy involved in the collision

Quark and gluon FF and PDFs

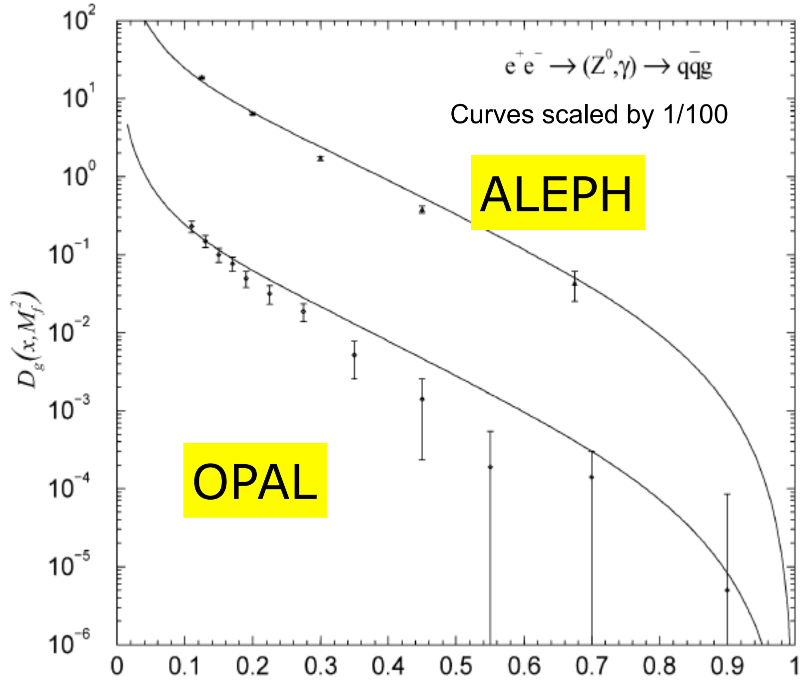
- Experimental data from different collisions systems have been fit with the same fragmentation function (FF)
- The constraints on Gluon FF and PDF are much worse

Fragmentation function for Quarks



KKP, Nucl.Phys.B582(2000)

Fragmentation function for Gluons



AKK, Nucl.Phys.B725(2005)

3-jet events

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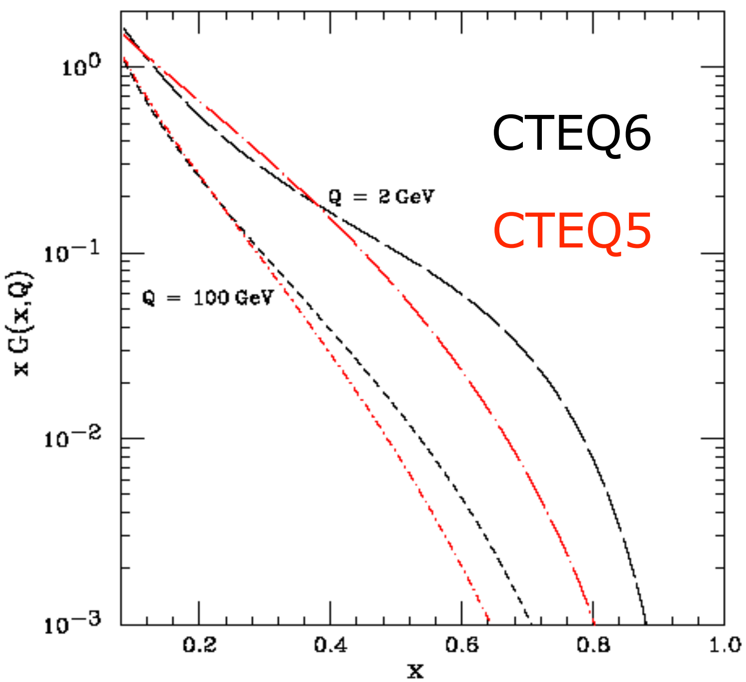
Parton Dist function for Gluons



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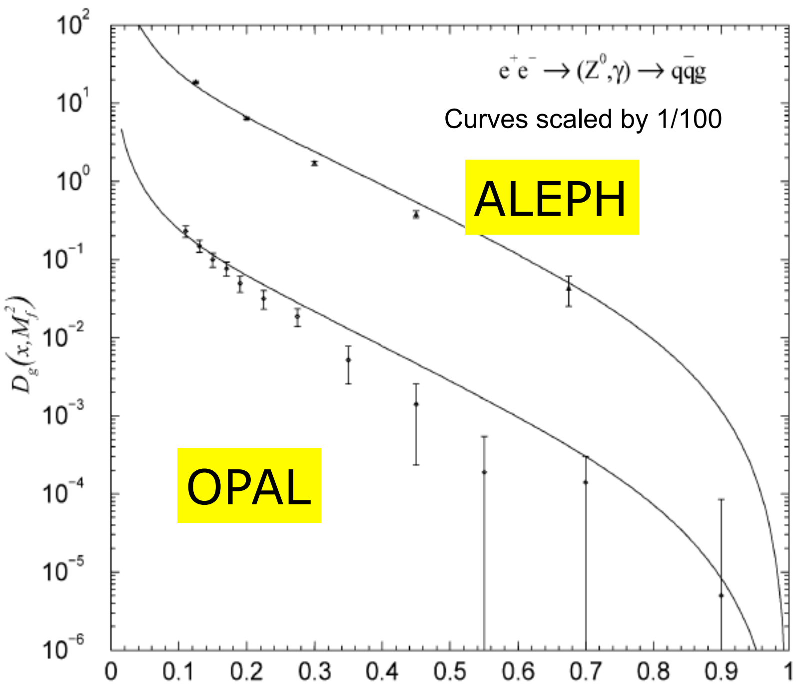
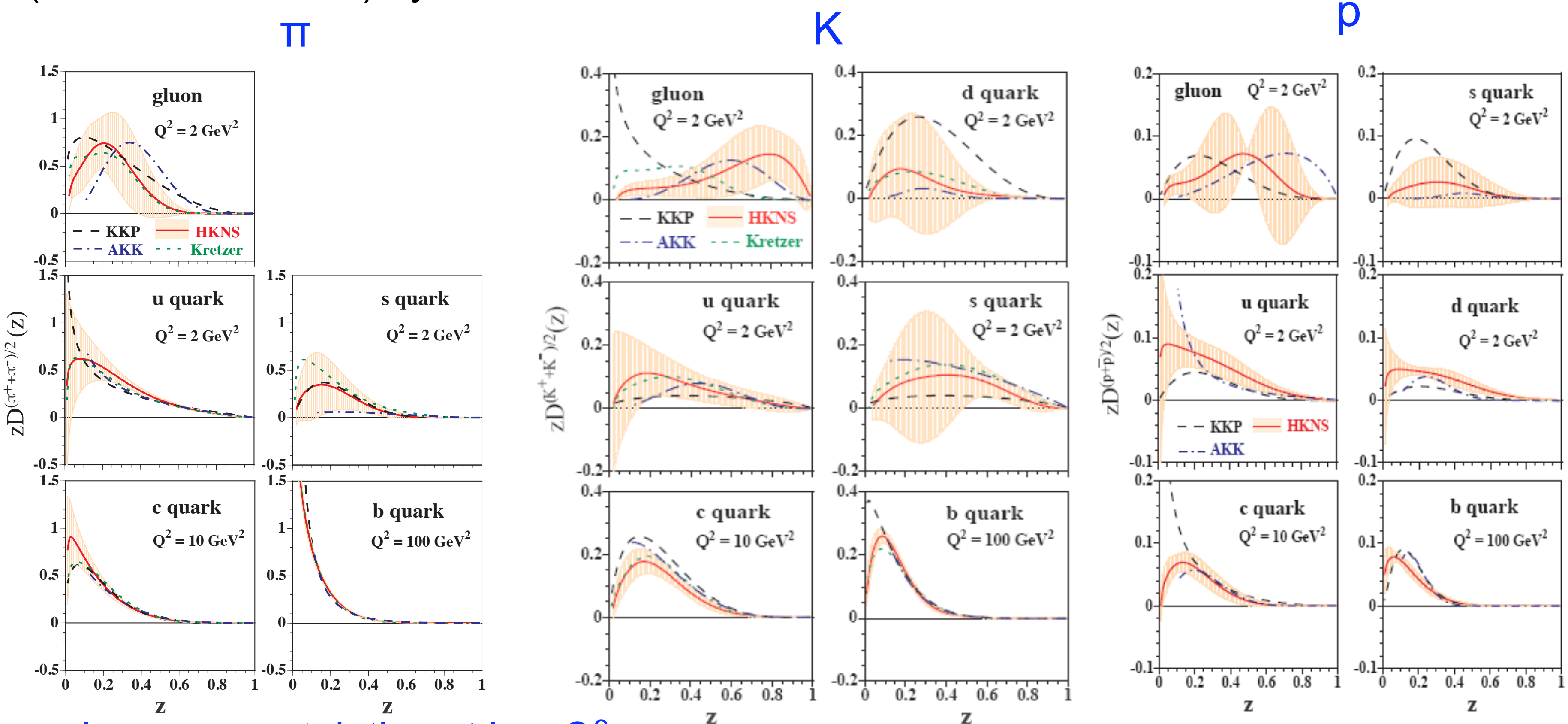


AKK, Nucl.Phys.B725(2005)

3-jet events

Uncertainties on the FF parameterization

- Recent compilation and error analysis of available fragmentation functions by (KKP,Kretzer, AKK) by Hirai et al. from e^+e^- data



HKNS, PRD 75 (2007)

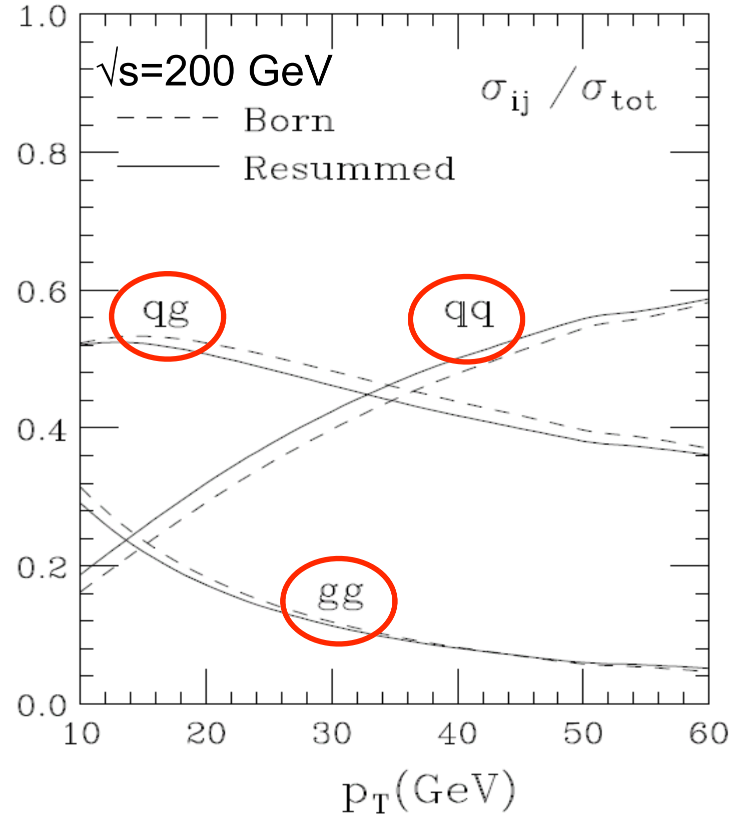
- Large uncertainties at low Q^2
- Different parameterizations give different fits

Need better constraints

RHIC: √s=200 GeV p+p

- Polarized p+p collisions at RHIC are used to investigate the spin structure of the proton
- 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

Significant contribution from gluons in the RHIC regime



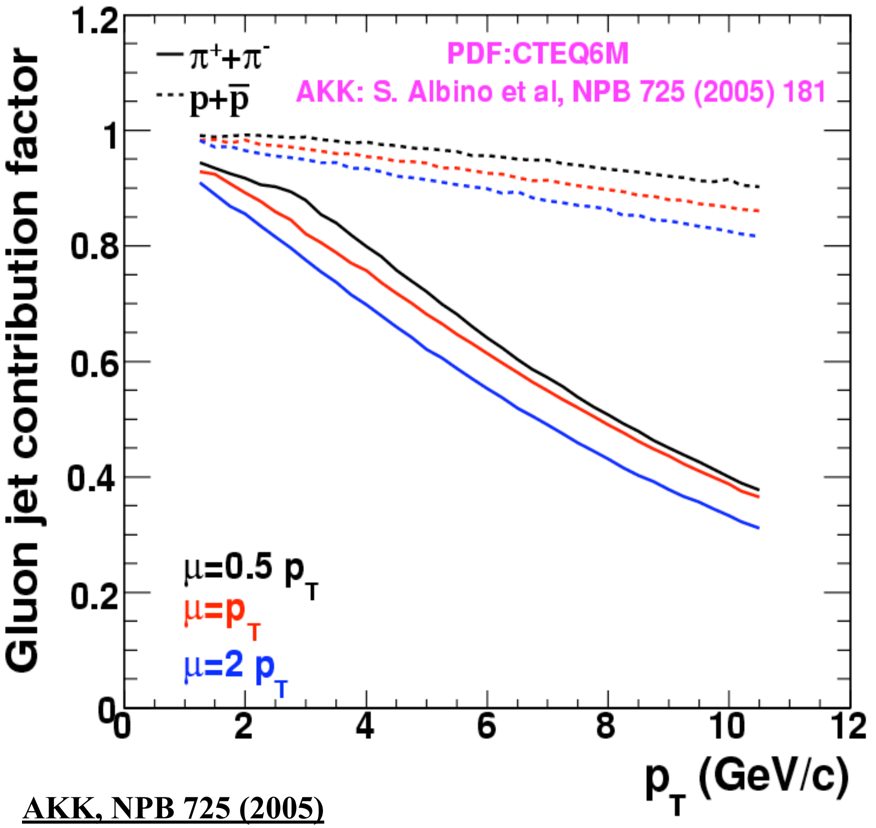
De Florian,Vogelsang, hep-ph 0704.1677

Baryons and mesons at RHIC

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

At p_T = 8 GeV/c: 50% for π

90% for p



AKK, NPB 725 (2005)

B. Mohanty(STAR), nucl-ex/0705.9053

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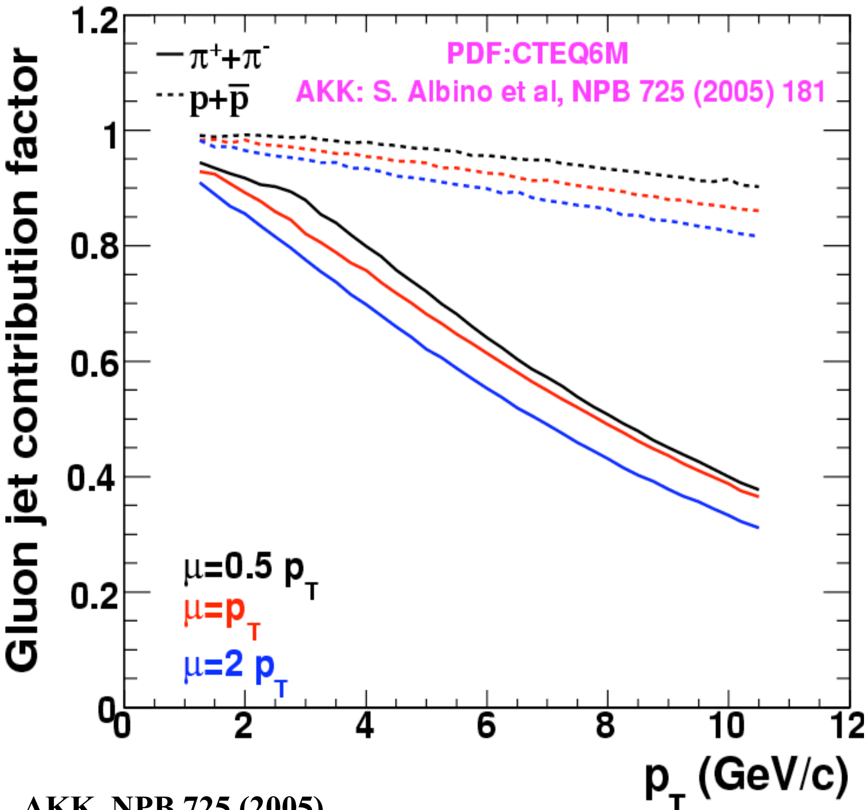

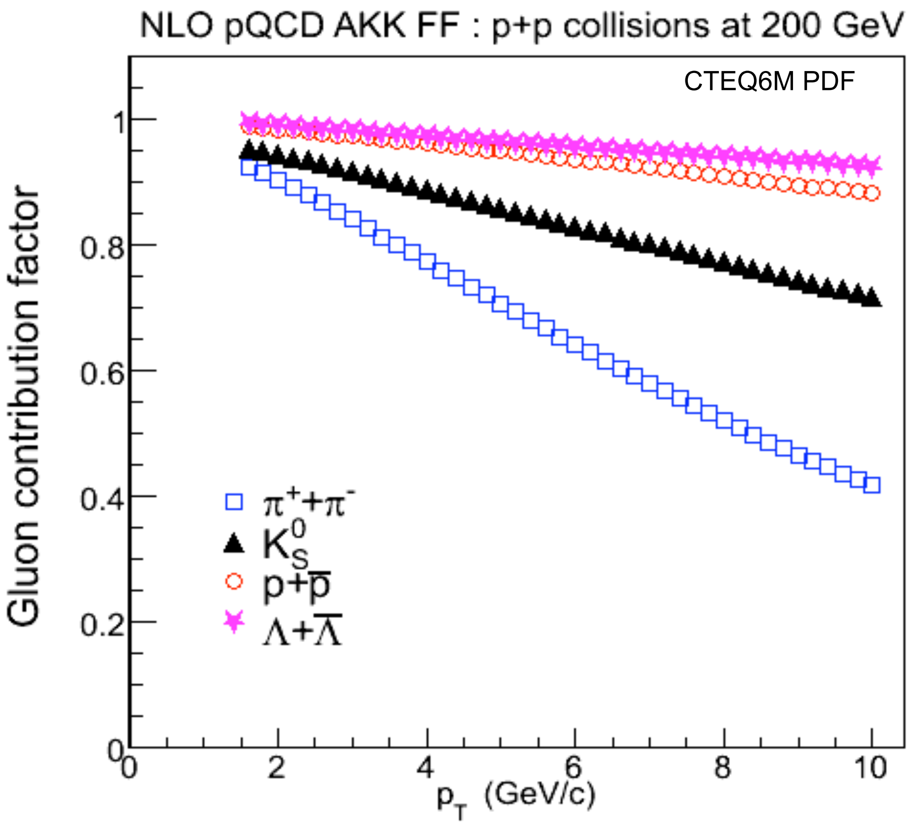

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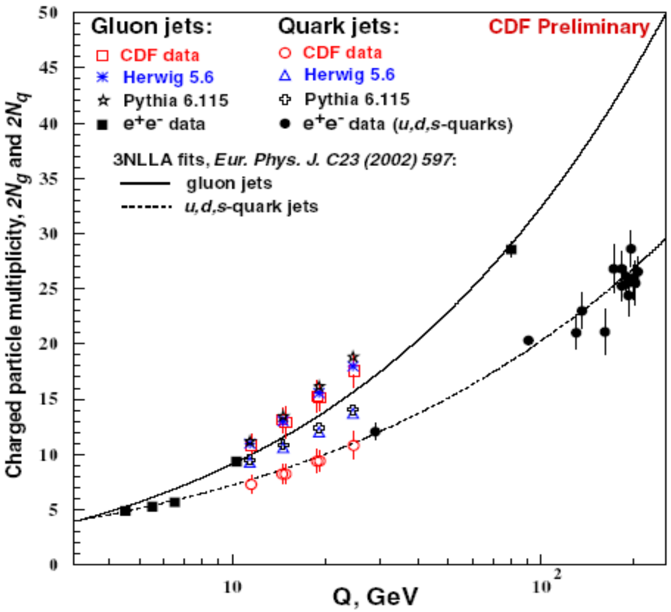
Gluon jet contribution to baryon >> meson at high p_T

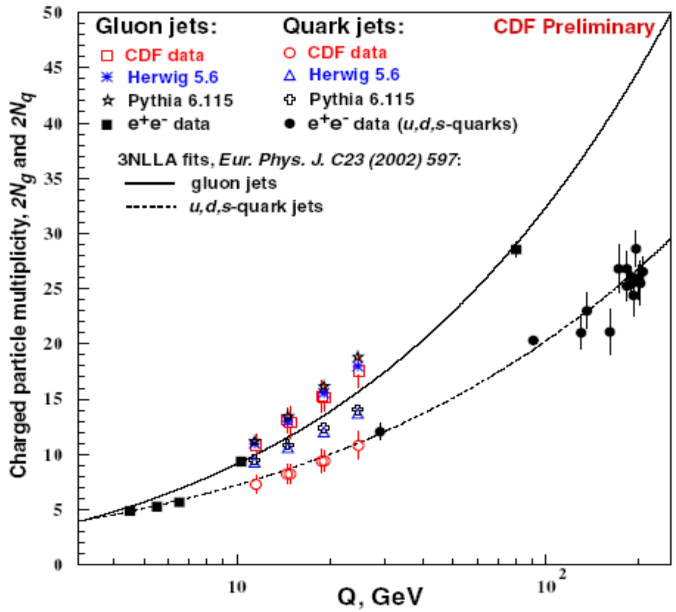
Quark and gluon jets

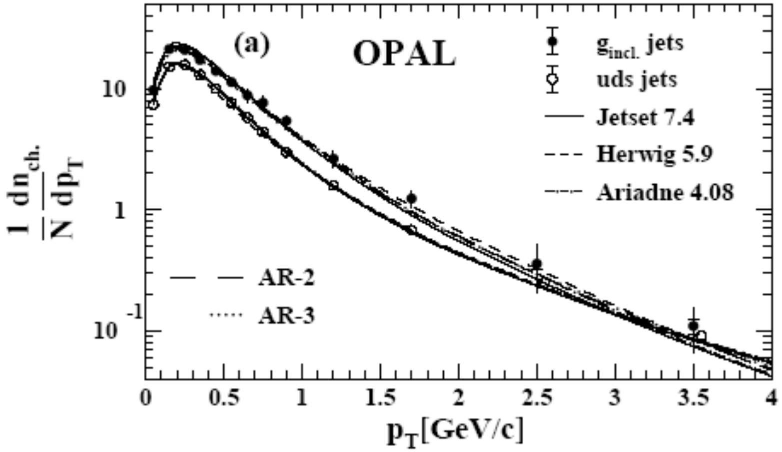


Extensive studies into jet properties have been done with e^+e^- data

- Gluon jets fragmentation:
  - produces higher multiplicities

Quark and gluon jets





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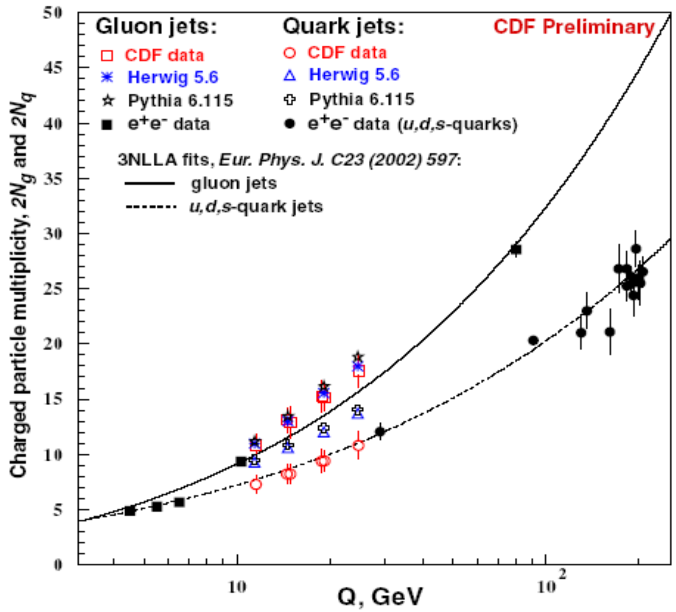

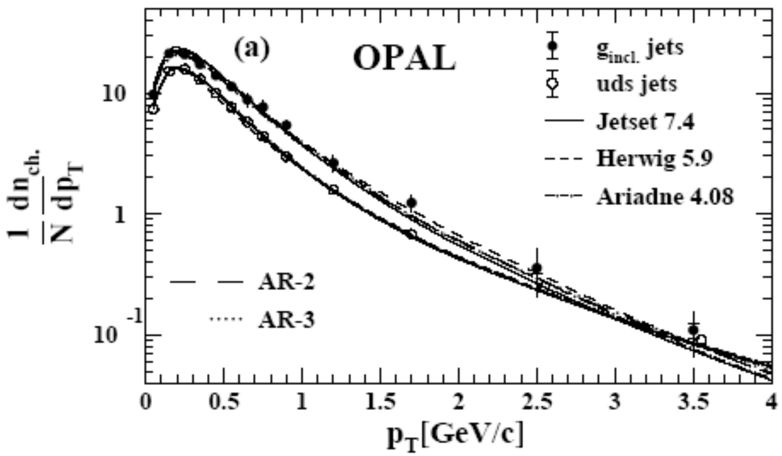

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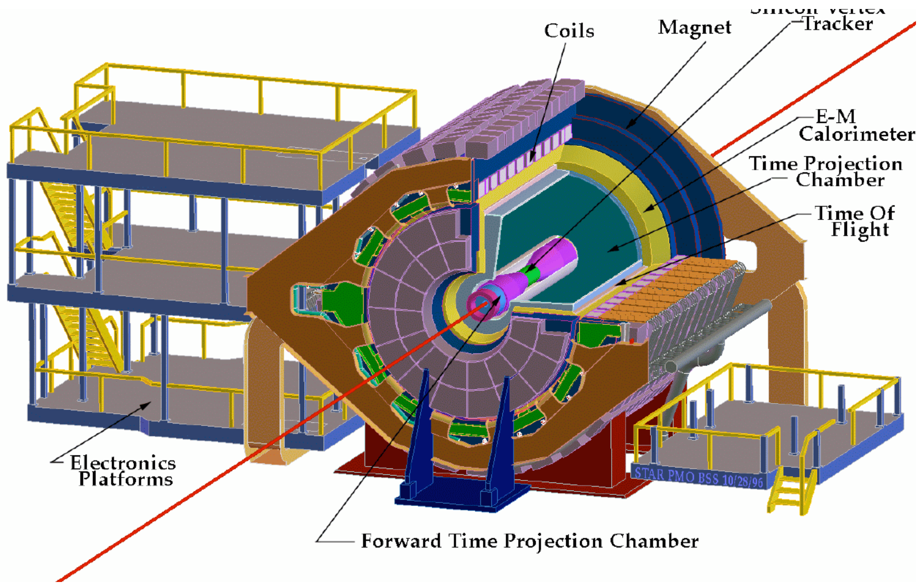
- In p+p study:
  - particle vs anti-particle
  - different species

Vary gluon vs quark sensitivities: constrain theory further

The STAR experiment at RHIC

- TPC and ToF: charged particle contribution
- EMCal: neutral energy contribution



Minbias:
Beam-Beam-Counter (BBC) coincidence

High Tower:
BBC coincidence + one tower (η x ϕ =0.05x0.05) above threshold: E_T >5.4 GeV

Jet-Patch:
BBC coincidence + EMCal Jet-Patch ($\Delta\eta$ x $\Delta\phi$ = 1x1 above threshold E_T > 8 GeV)

The STAR experiment at RHIC

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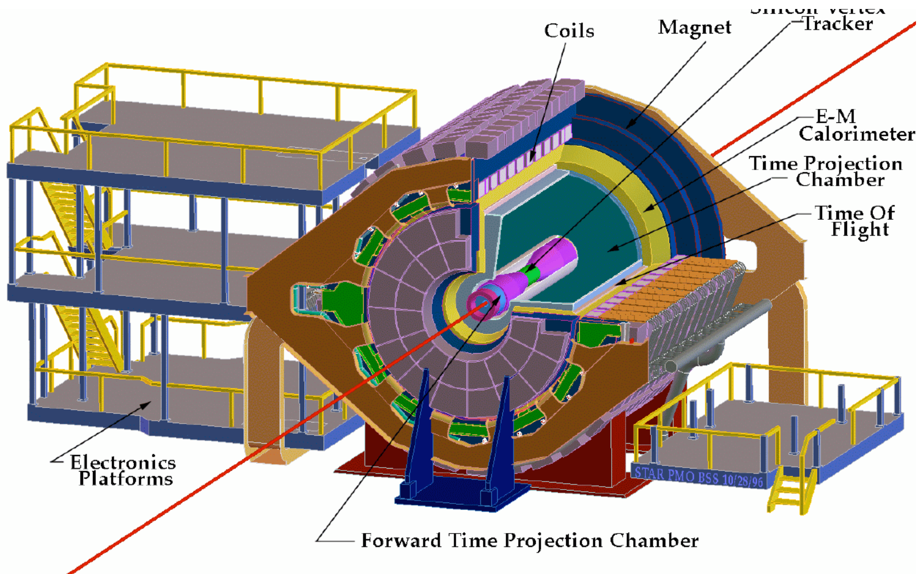


High tower and Jet-Patch triggers → NEF FF bias → for jet studies use non-triggered side

Minbias:
Beam-Beam-Counter (BBC) coincidence

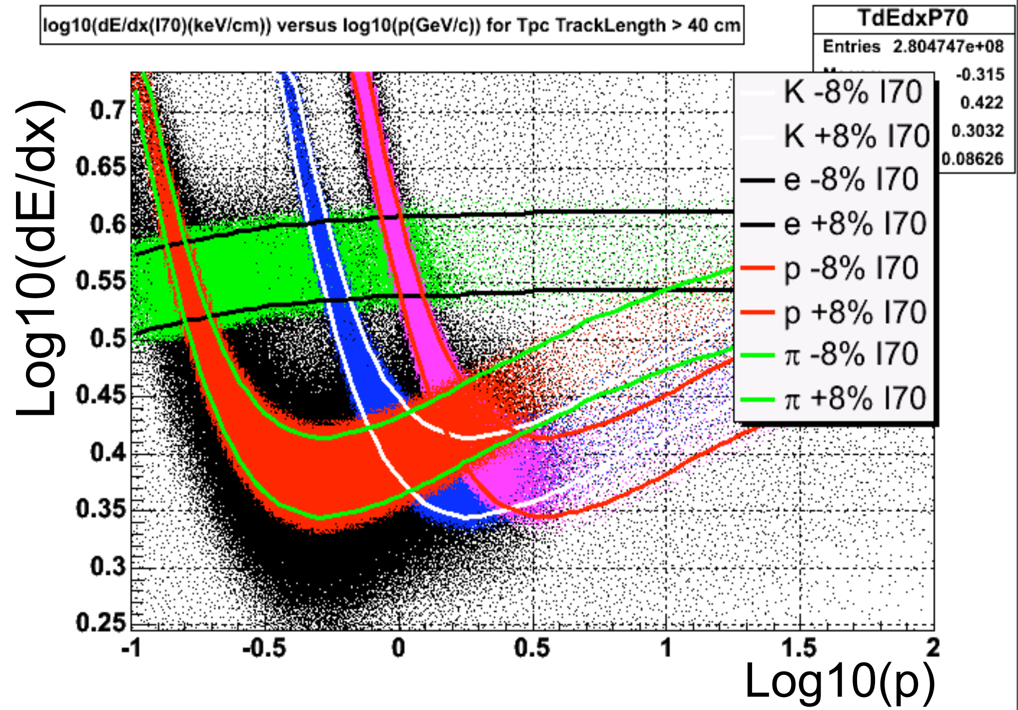
High Tower:
BBC coincidence + one tower (η x ϕ =0.05x0.05) above threshold: E_T >5.4 GeV

Jet-Patch:
BBC coincidence + EMCal Jet-Patch ($\Delta\eta$ x $\Delta\phi$ = 1x1 above threshold E_T > 8 GeV)

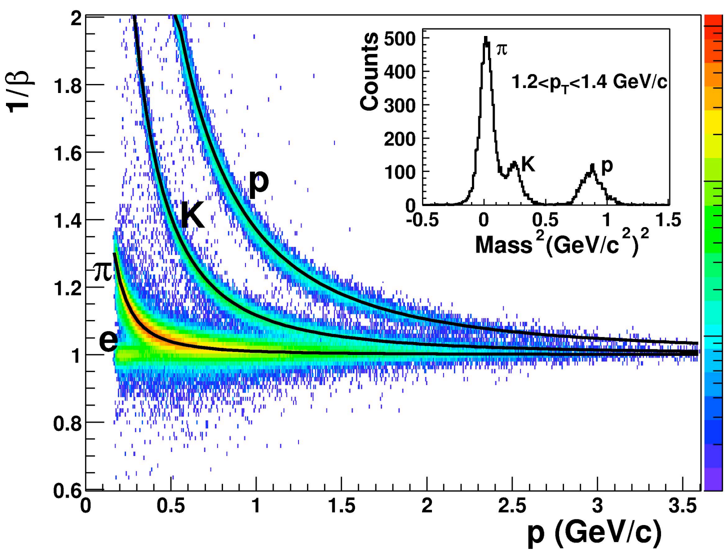
Particle identification: stable particles

Detectors used :
Time projection Chamber
($|\eta|<1.8$, full ϕ and 4.2 m long)
Time-Of-Flight ($-1.0 < \eta < 0$
and $\pi/30$ in ϕ)

Efficiency high and ~const at hight p_T



Low p_T : Particle identification by dE/dx and ToF (p_T < 2.5 GeV/c)



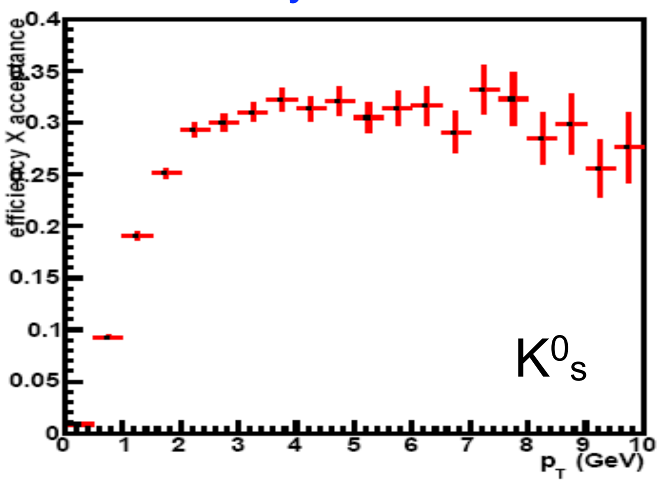
High p_T : Extend particle identification in TPC by exploiting the relativistic rise in ionization energy loss.

π, p separation up to p~10GeV/c

Particle Identification - weak decays

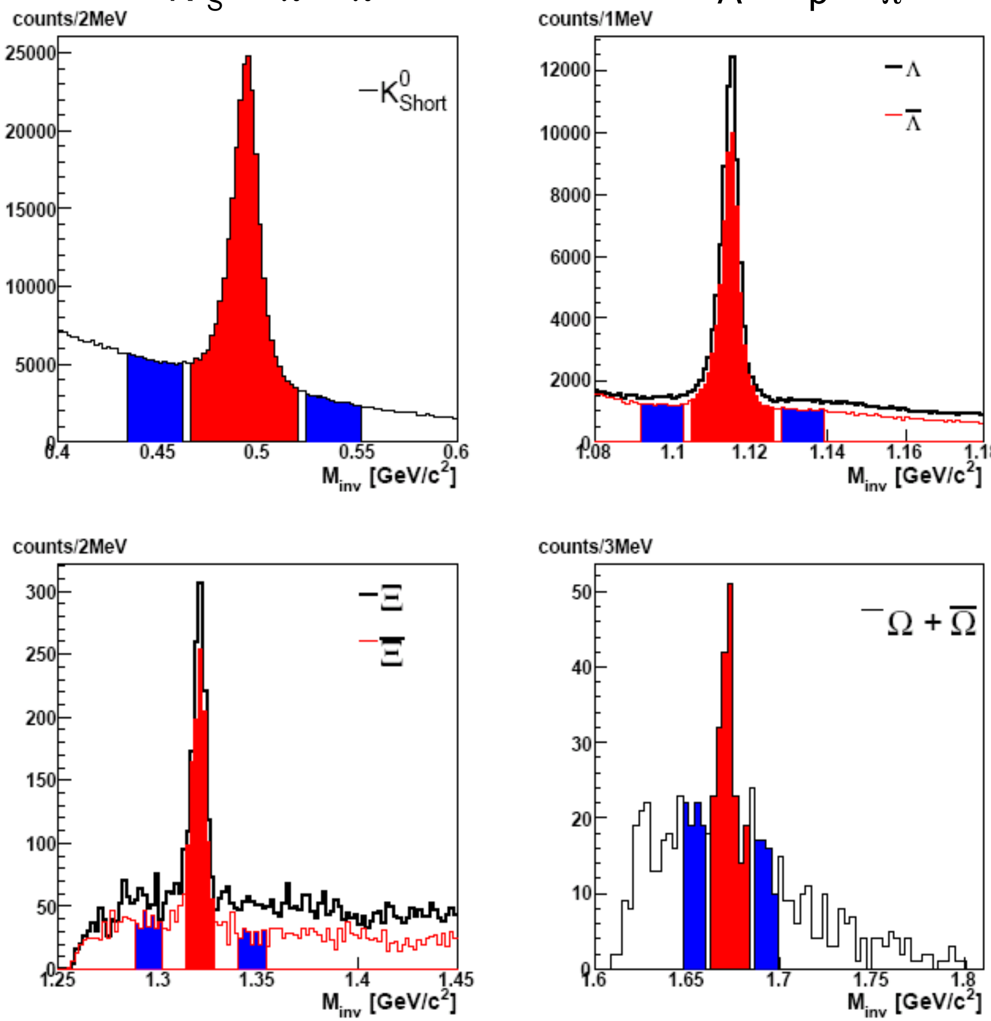
- Use charged decay channels to identify secondary vertex
- Invariant mass to identify parent
- Clean signals over large kinematical range,

  $0.5 < p_T < 10$ GeV/c - limit statistics
- Low efficiency



$K^0_S \rightarrow \pi^- + \pi^+$

$\Lambda \rightarrow p + \pi^-$

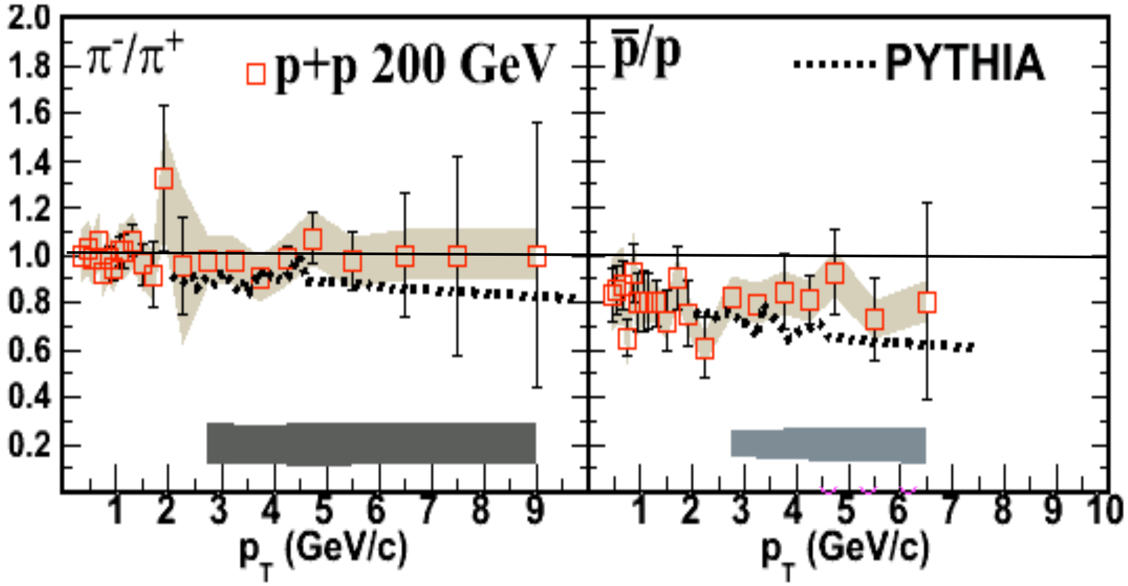


$\Xi^- \rightarrow \pi^- + \Lambda$

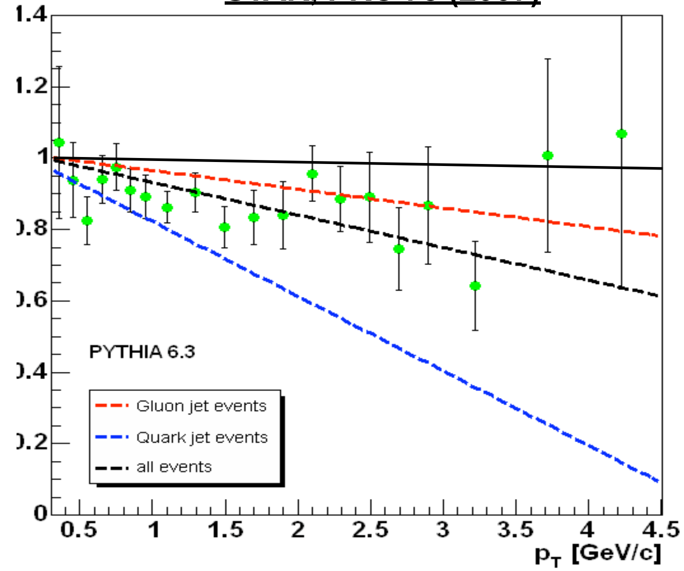
$\Omega^- \rightarrow K^- + \Lambda$

Particle/Anti-particle ratios

STAR, Phys Lett B, 637 (2006) 161



STAR, PRC 75 (2007)



PYTHIA predicts:

- flat p_T dependence for π^-/π^+
- slightly more prominent p_T dependence for $\bar{p}/p$
- even stronger dependence for $\bar{\Lambda}/\Lambda$

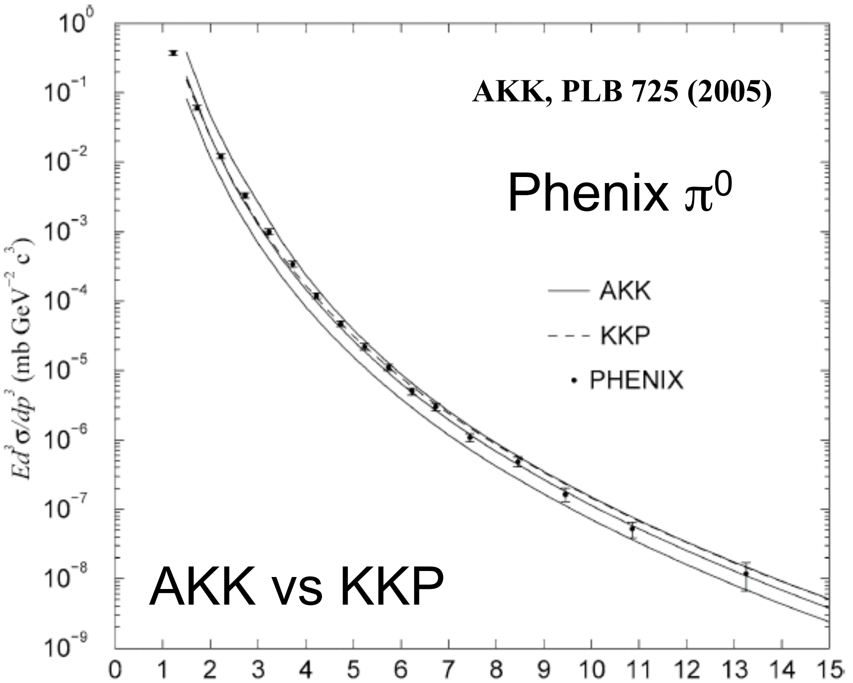
Good agreement with current data

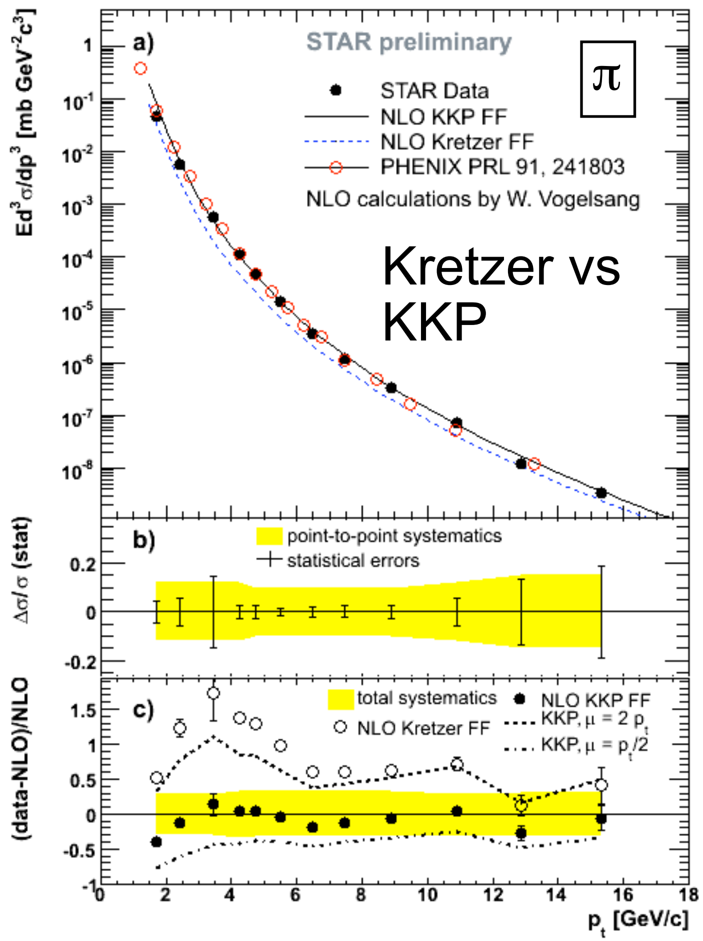
Data is consistent with gluon jet dominated production - but does not allow strong conclusion

π cross-section - sensitivity to FF

- p_T reach to 15 GeV/c

- NLO pQCD calculations (factorization scale $\mu = p_t$) with different fragmentation functions



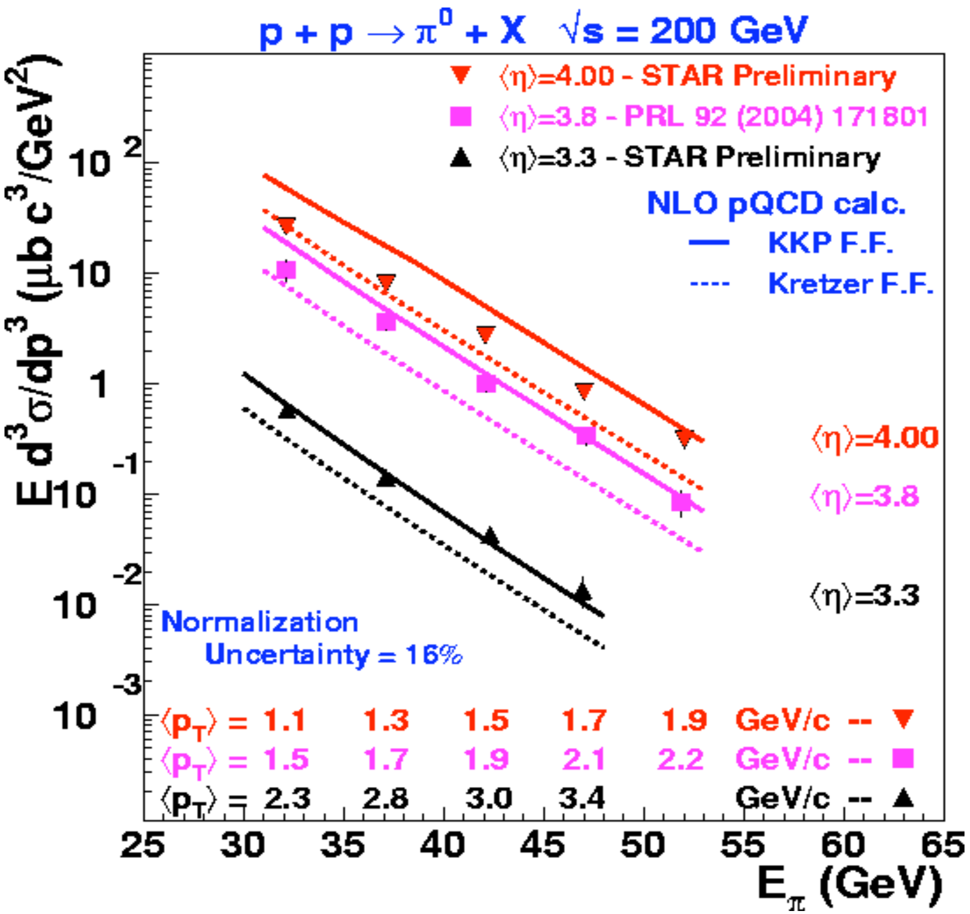


RHIC data now sufficiently precise to be sensitive to different FF

Simon, SPIN2006,hep-ex/0612004

S. Kretzer, PRD 62 (2000)

π^0 production at forward rapidity



STAR, Phys.Rev.Lett.97,152302 (2006)

Looking forward to probe the initial gluon densities

- Inclusive forward π^0 production in p+p collisions at 200 GeV also consistent with NLO pQCD calculations
- Small η:
  - data consistent with KKP
- Increasing η:
  - data approaches cal. with Kretzer set of FF

No one FF describes all data

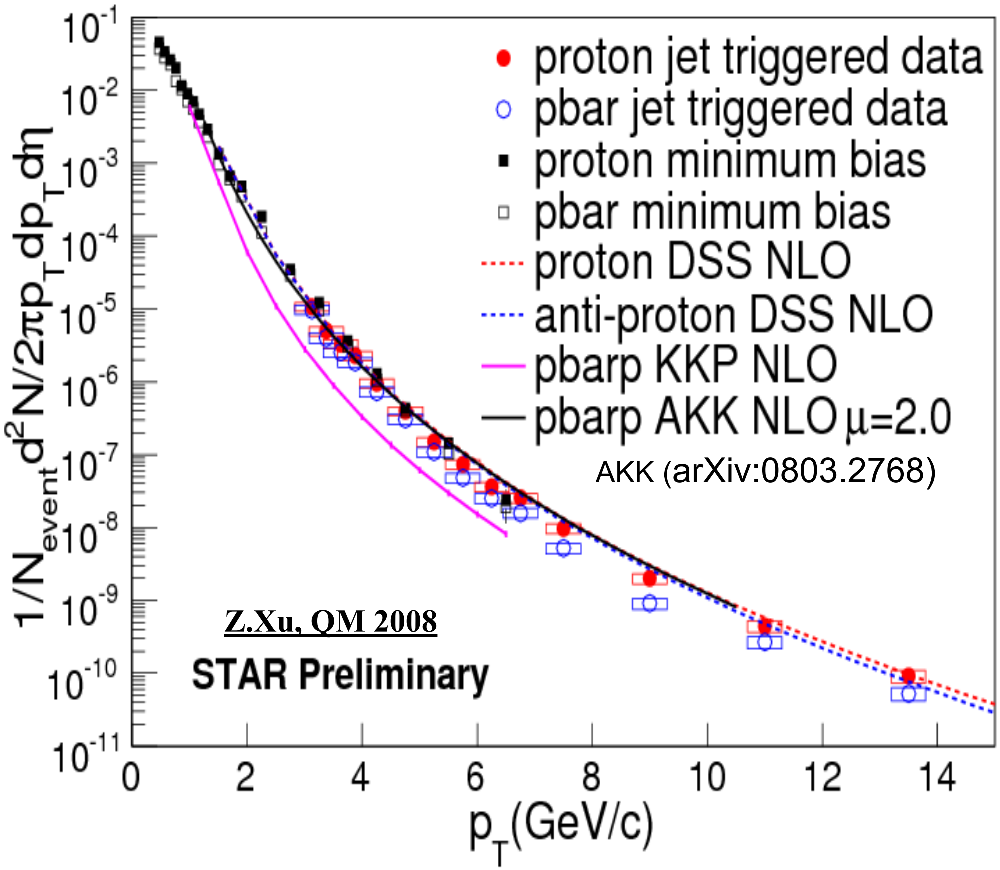
(anti)proton cross-section

Baryons notoriously difficult to fit: limited knowledge of FF

Albino, Kramer, Kniehl (AKK):

- use latest OPAL data to calculate light flavor (u,d,s) separated fragmentation functions for the firs time
- use BRAHMS p/$\bar{p}$ ratio as constrai (y=2.95, p_T<5GeV/c)

(Phys. Rev. Lett. 98, 252001 (2007))

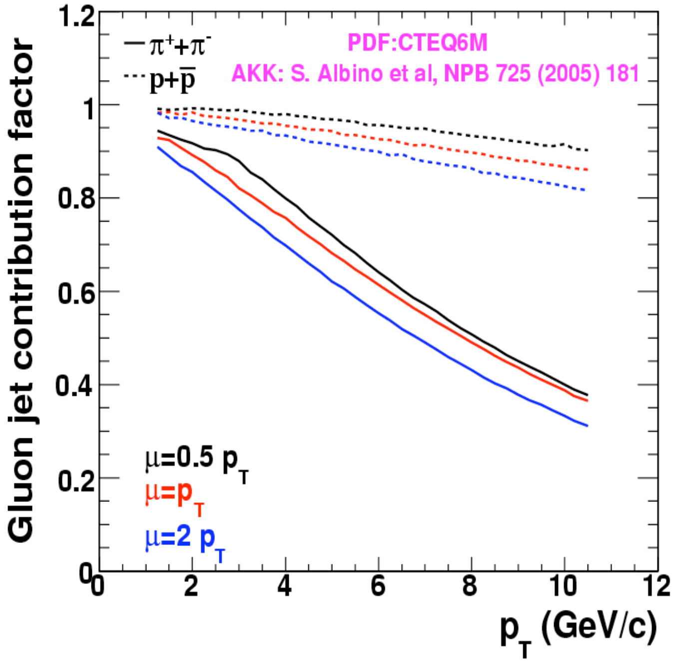


With improved FF baryon - data and theory in good agreement

Contributions from gluon vs. quark jet

Look closer at AKK calculation

- Compare:
  Gluon contribution to cross-section
  Total cross-section



- Should see affect for π

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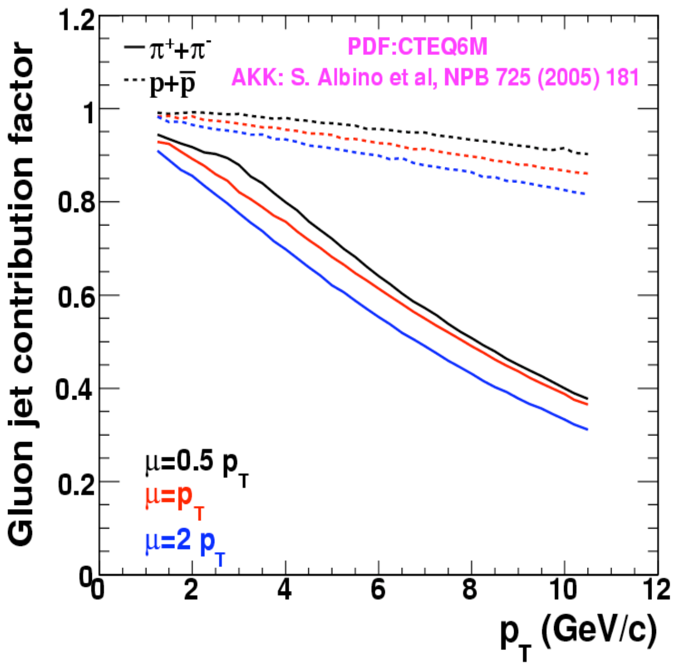

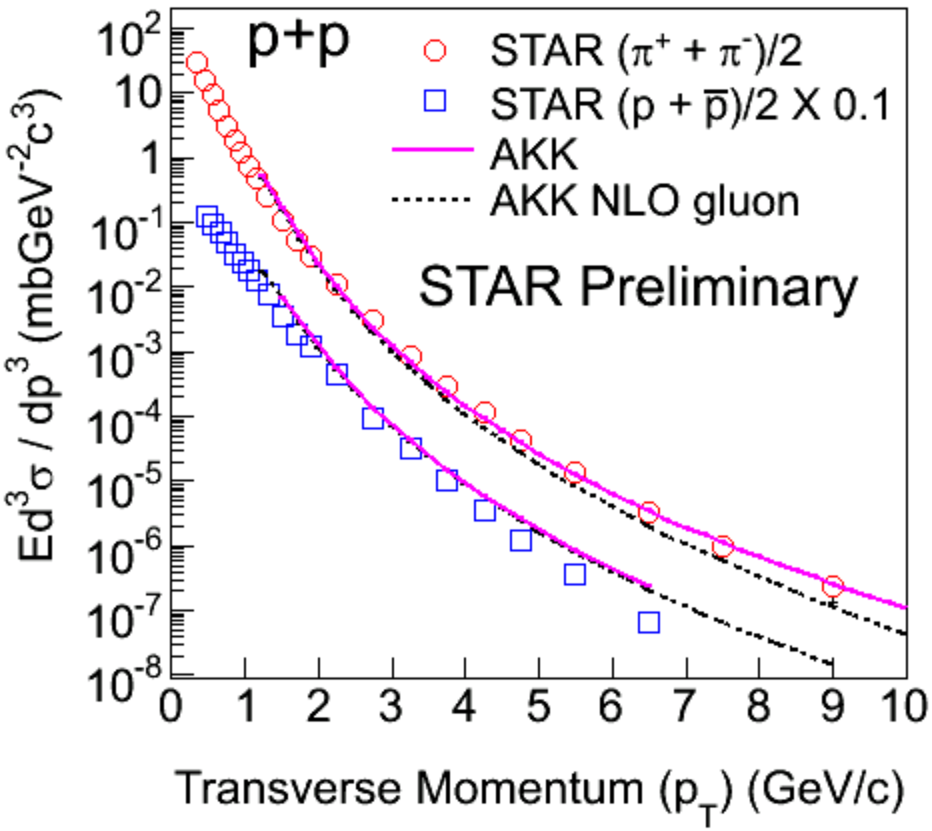

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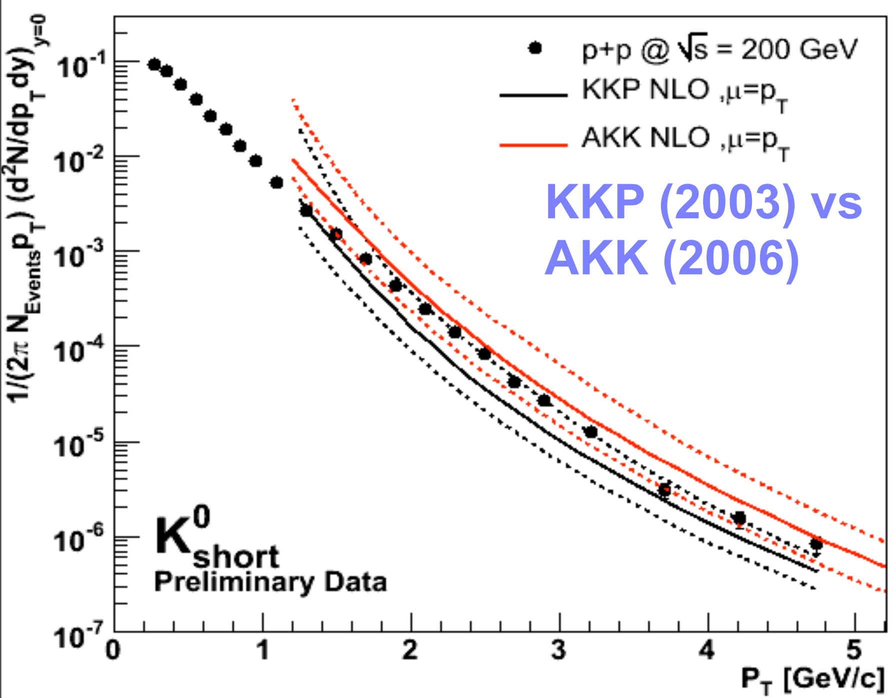
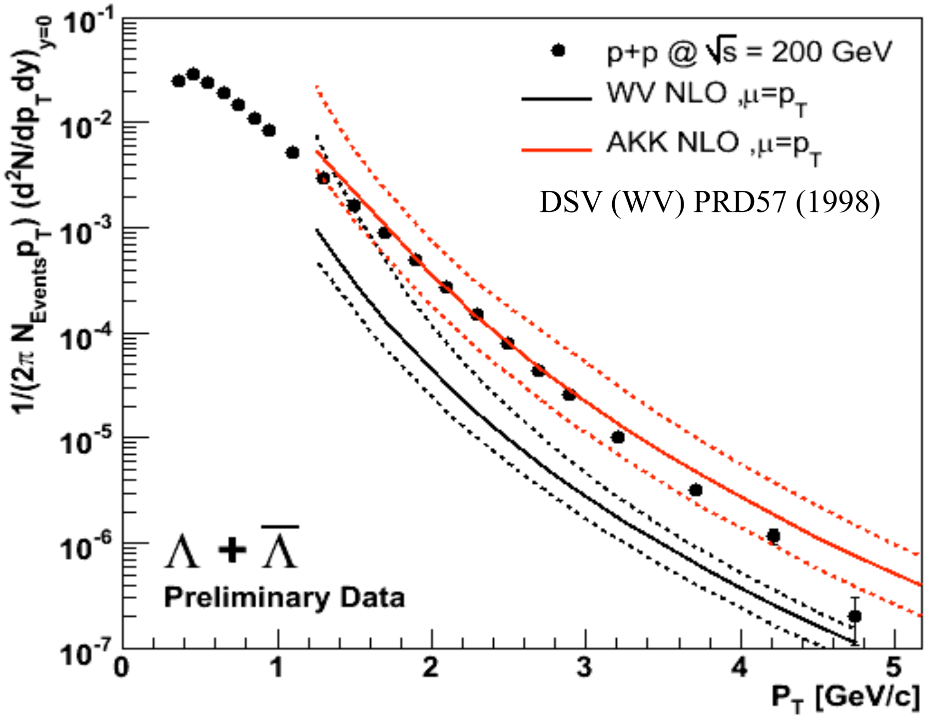
At RHIC:
Protons dominated by gluon FF
π need both quark contribution

NLO calculations for strange particles

- First NLO predictions for RHIC energies K^0_s and Λ by W.Vogelsang (RIKEN)
  - K^0_s OK but Λ poor
- AKK (2005) NLO for K^0_s and Λ - better agreement:
  - constrained shape of Gluon FF to $D_g^{\Lambda} = D_g^{P/3}$
  - constrained magnitude using by STAR data

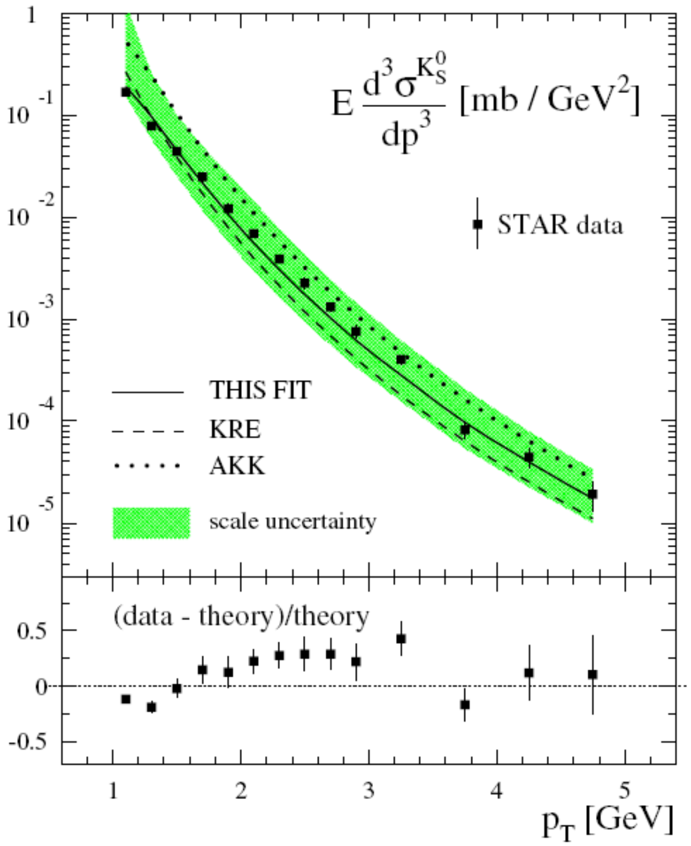


STAR, PRC 75 (2007)

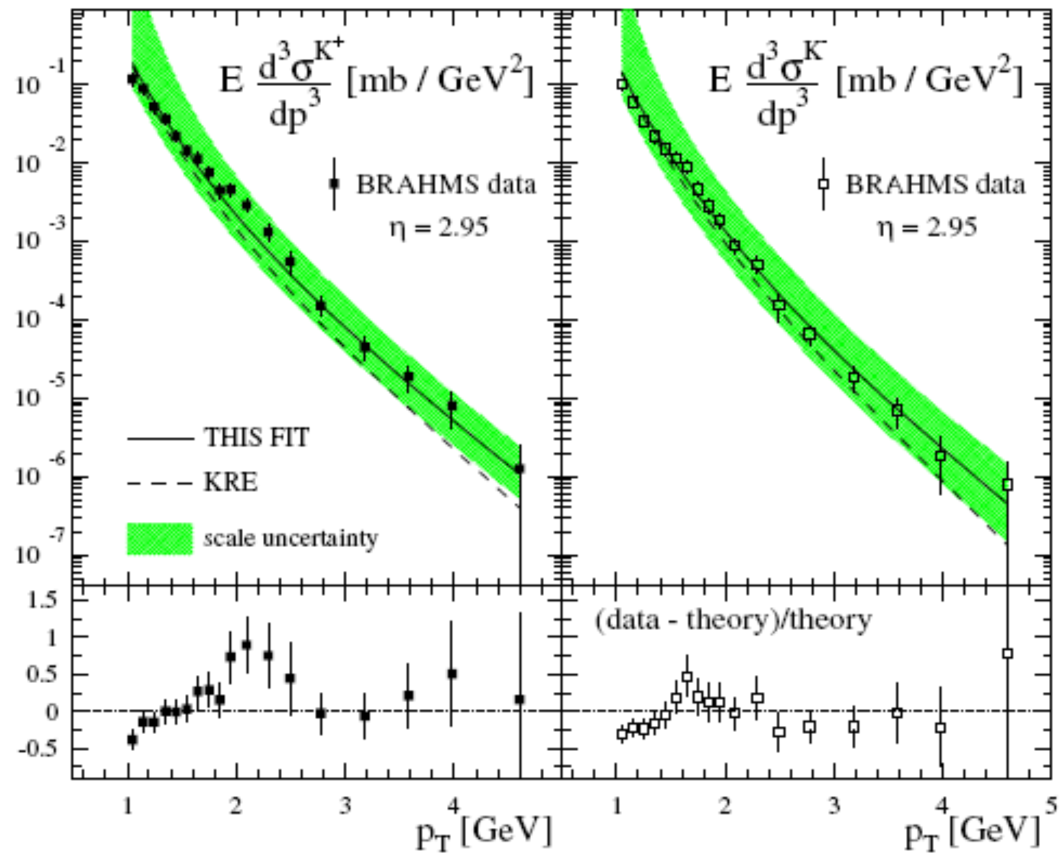


Kaon FF at forward rapidities

STAR: K^0_s - mid rapidity



BRAHMS: $K^{+/-}$ - forward rapidity



DSS, PRD76 (2007)

Good description of kaons over large rapidity range

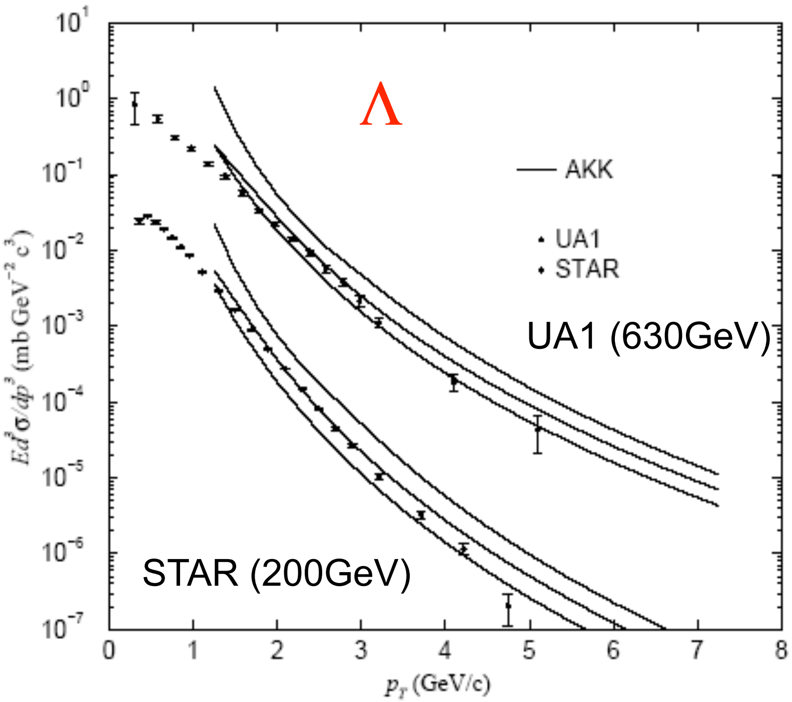
Extrapolating FF at higher energies

Fit to 200 GeV (STAR RHIC) and extrapolate to 630 GeV (UA1 SPS)

AKK Lines are for $\mu=2*p_T$, p_T, $p_T/2$

PLB 725 (2005), PLB 734 (2006)

- Gluon constrained fit for Λ gives good extrapolation



- AKK better fit to Λ
- KKP better fit to K

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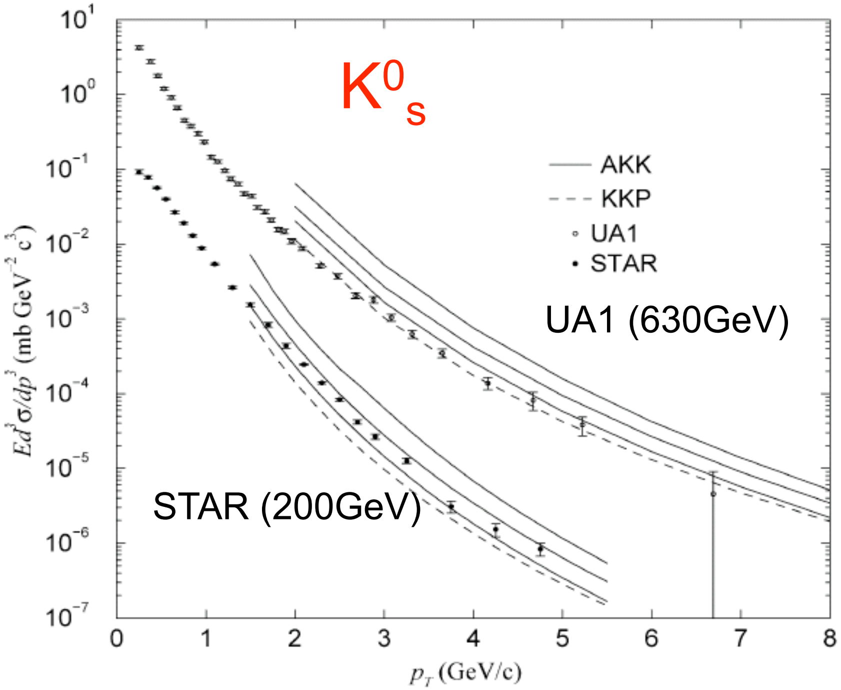

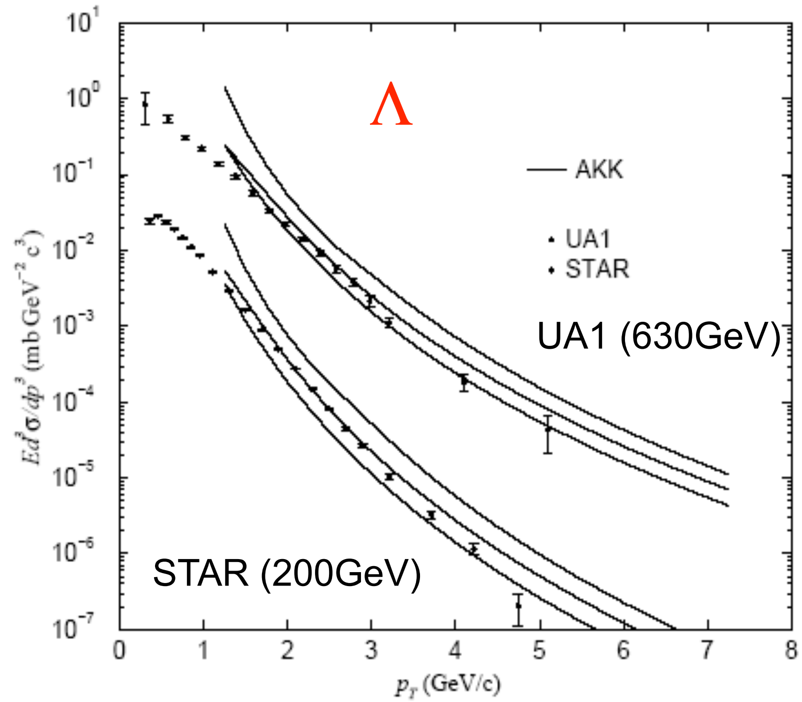

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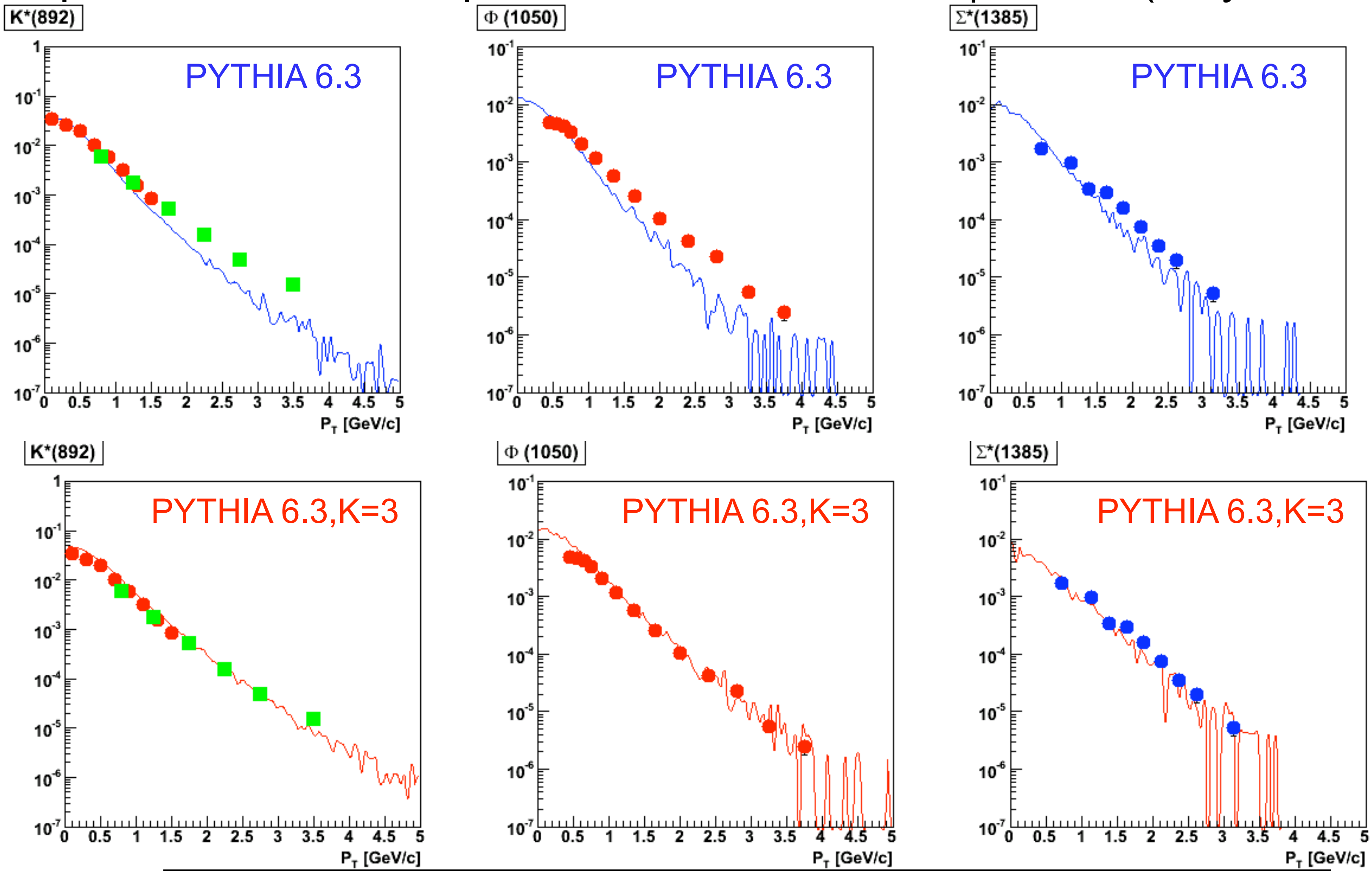
Something still missing in strange hadron description

What about strange resonances ?

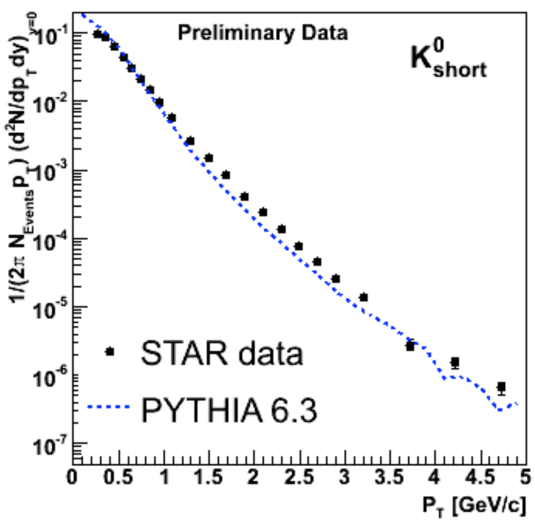
- Compare PYTHIA 6.3 to published STAR data on ϕ, K*, Σ* (baryon resonance)

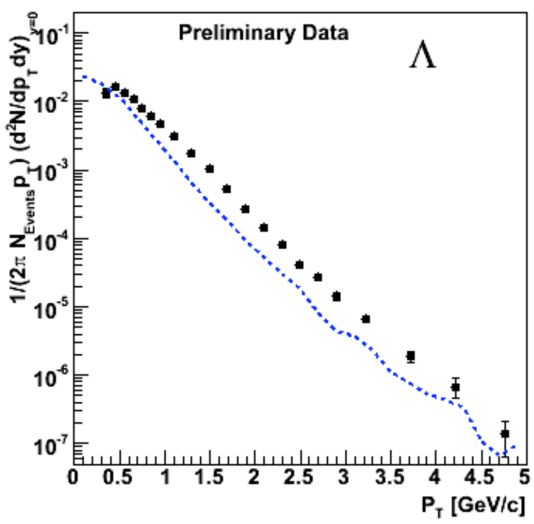


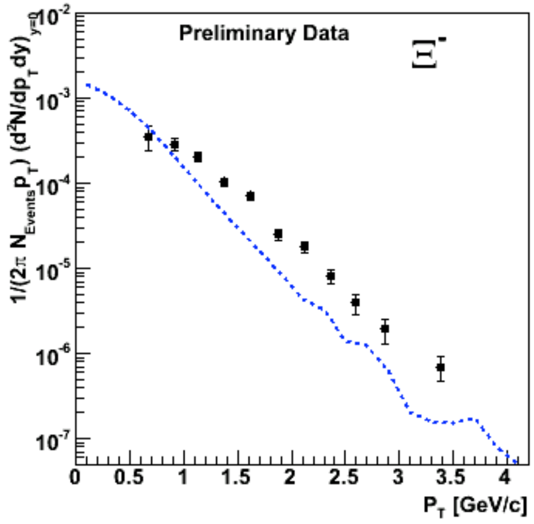
Resonance data also need K=3 for good description

PYTHIA description of strange p_T-spectra

- PYTHIA Version 6.3
  - Incorporated parameter tunes from CDF
  - New multiple scattering and shower algorithms
- Fails to describe baryons with default parameters







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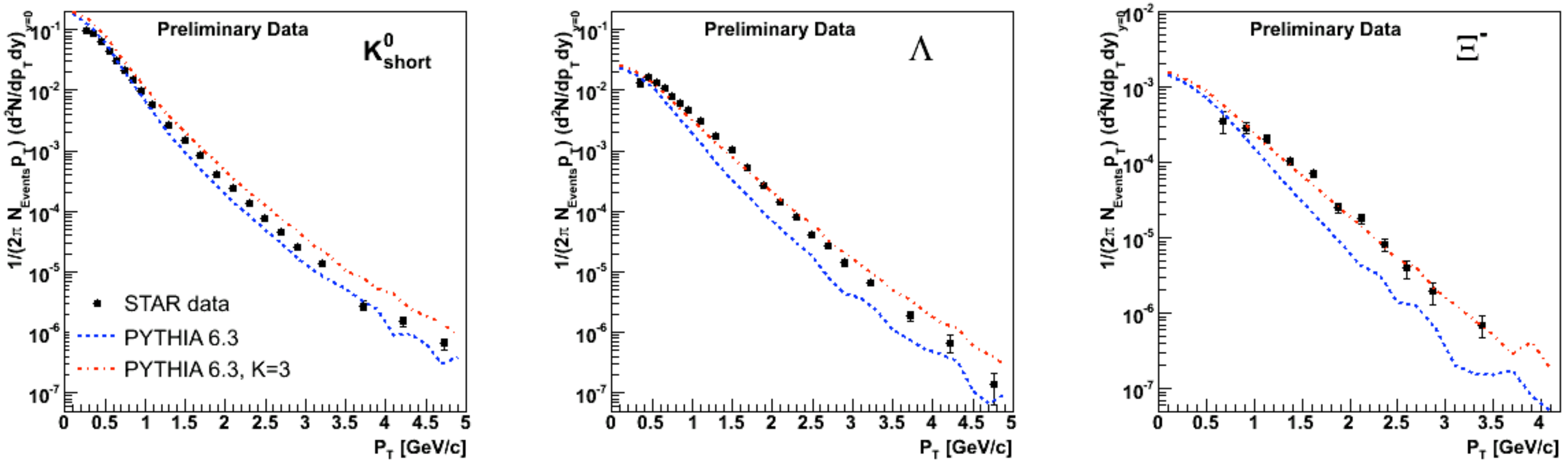


Necessary to tune: K-Factor (accounts for NLO contribution)

K-factor in LO pQCD

How is the K-factor defined?

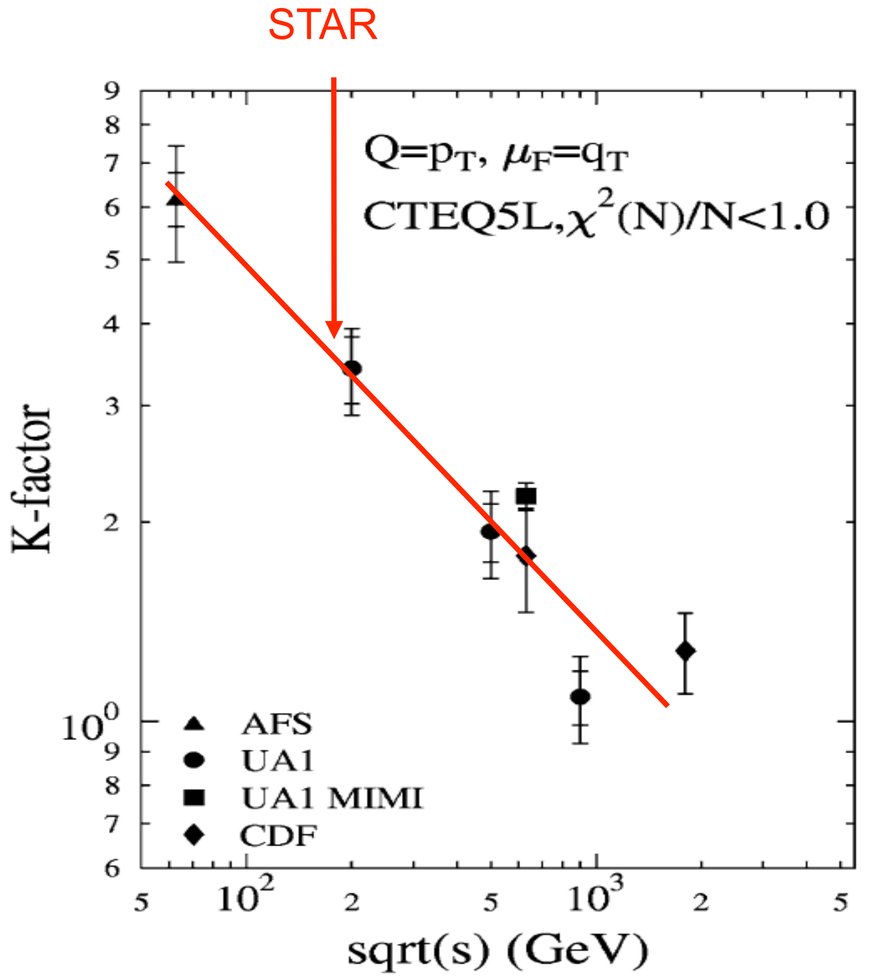
- Two definitions:

  $K_{obs} = \sigma_{exp} / \sigma_{LO}$

  $K_{th} = \sigma_{NLO} / \sigma_{LO}$

- Flavor dependence of K-factor, differing NLO contributions ?

- For h^- it decreases for collision energy
  - contribution of NLO processes smaller at higher energies

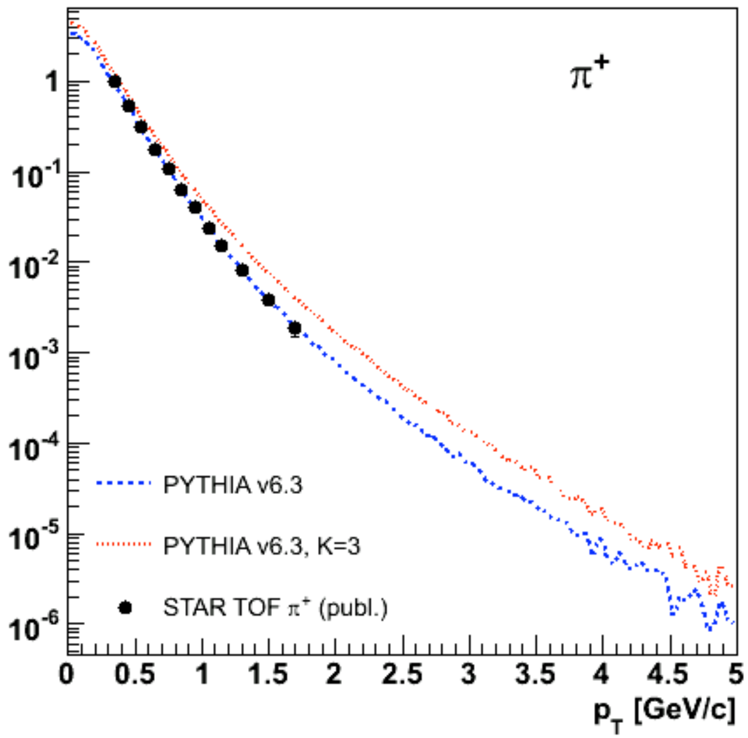


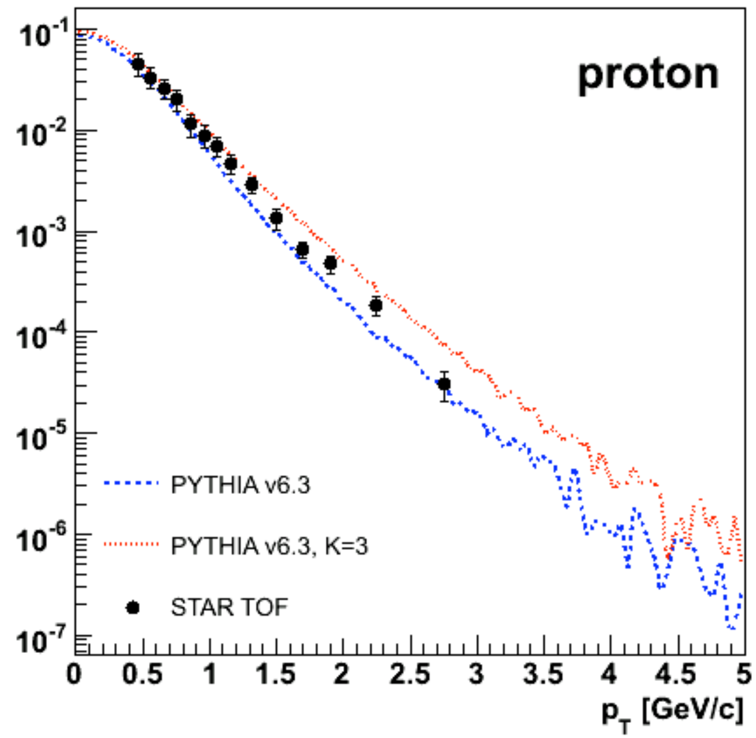
Eskola et al Nucl. Phys A 713 (2003)

K factor of 3 not unreasonable

What about non-strange particles ?

- Good agreement for π with K=1 but not for K=3
- proton with 1< K <3
  - However only lower p_T region measured

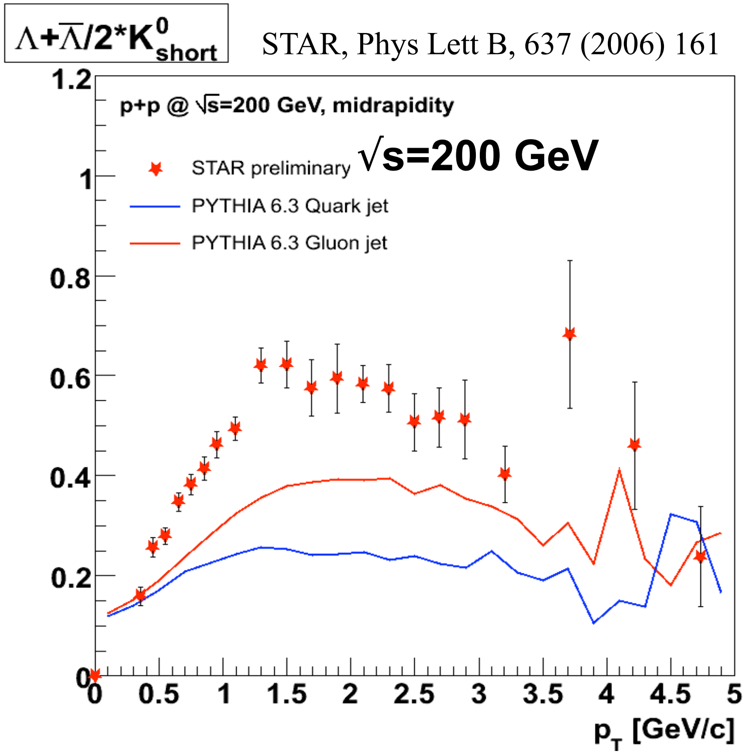




Need different K factors for different particles!

Baryon-meson ratios

- Gluon jets produce a larger Baryon/Meson ratio than quark-jets
- Cannot describe Baryon-Meson ratio at intermediate p_T even with tuned K-factors and/or di-quarks



Our "tuned" PYTHIA 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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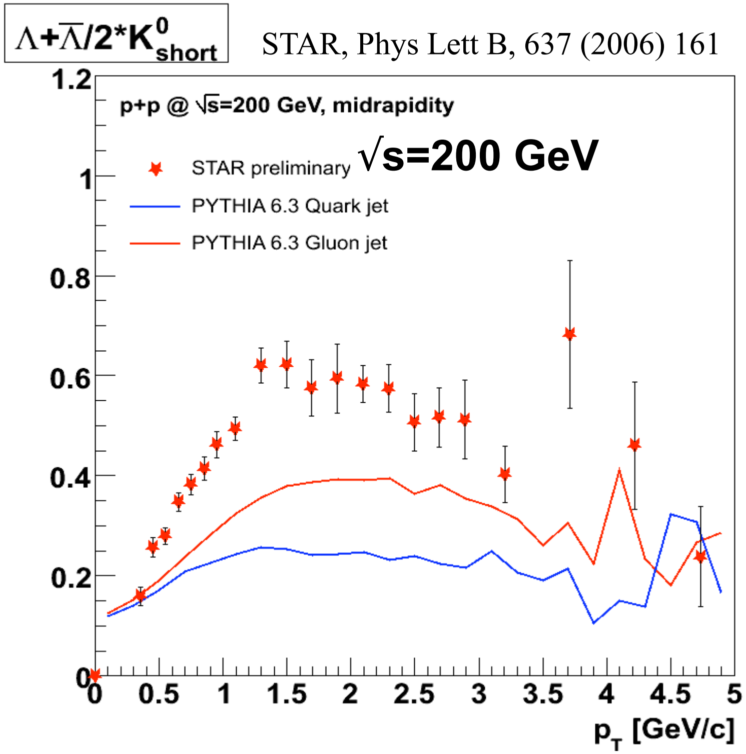

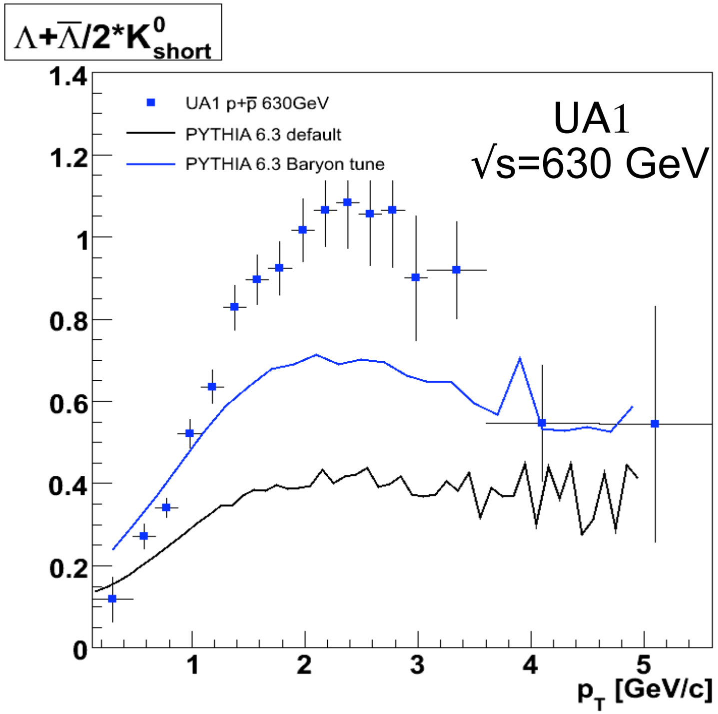

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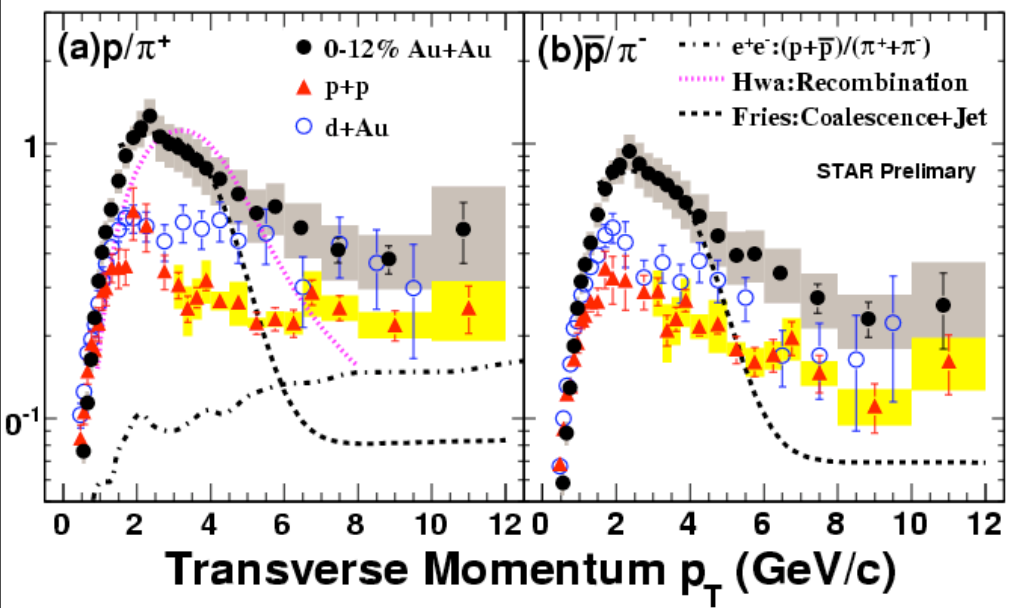
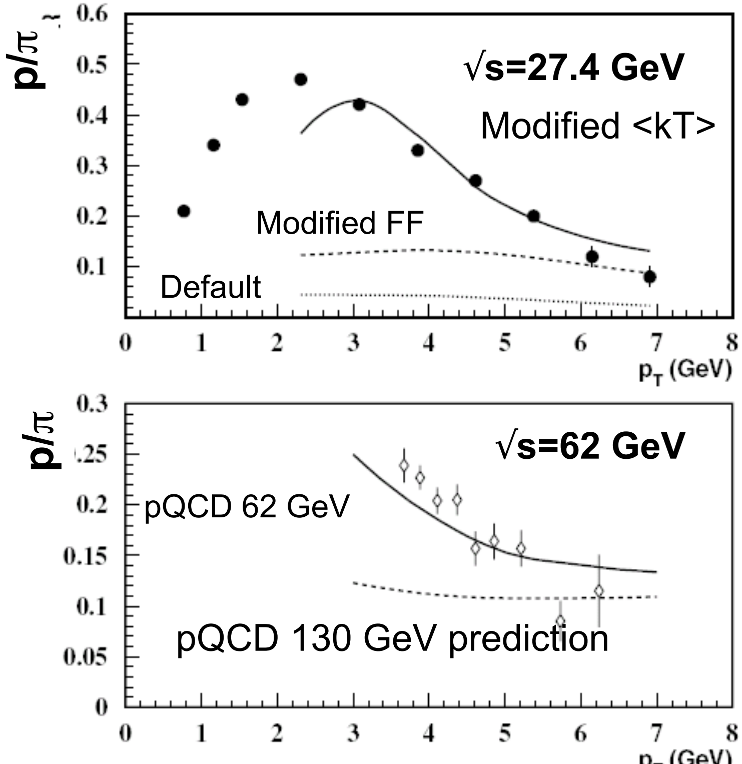
Baryon-meson ratios

- Levai et al. discuss importance of RHIC p+p data for large-z part of FF
- Argue that k_T smearing maybe a cause of poor agreement

  → assign a larger $\langle k_T \rangle$ to proton than π



PRL 97, 152301 (2006) & Z.Xu, QM2008 (p+p Preliminary)

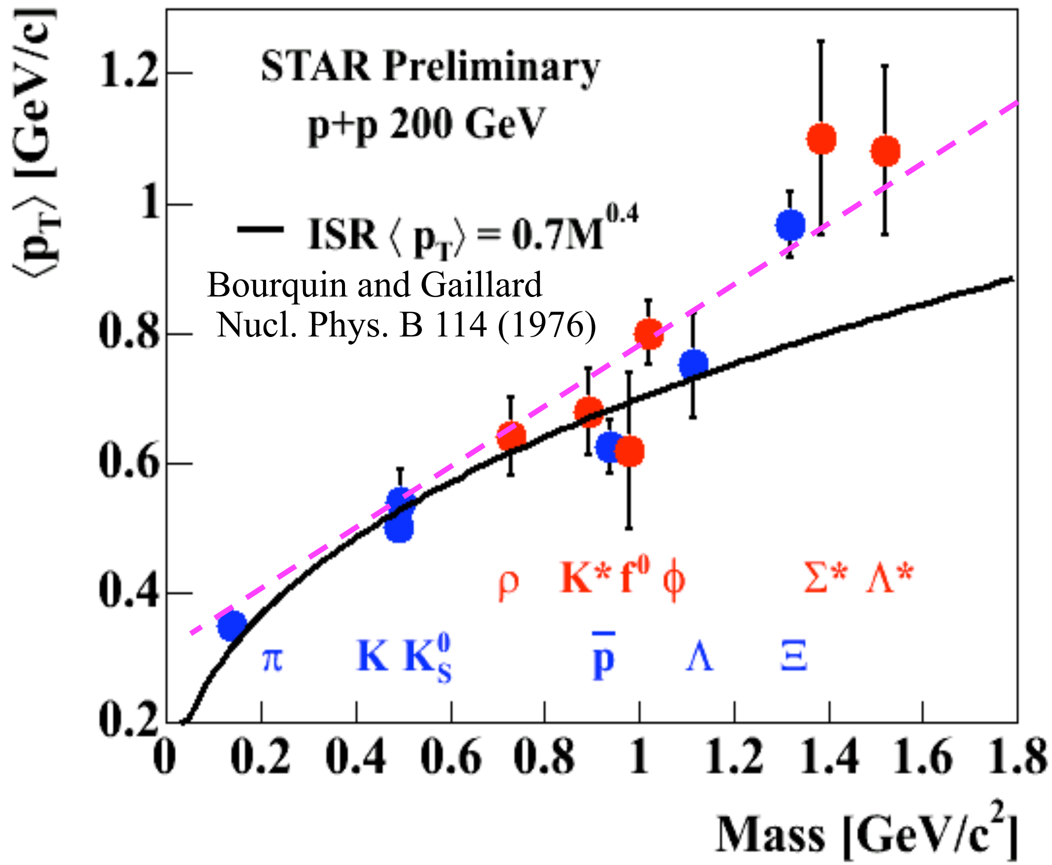


Fai, Levai & Zhang, PRL 89(2002)

$\langle p_T \rangle$ vs particle mass

Measured particle spectra over large mass range

- Mass dependence, but don't expect flow in p+p (see Mike on Wed)
- Nice agreement with phenomenological curve established by ISR (23 GeV) for lower masses
- Strange baryons and resonances are above the curve



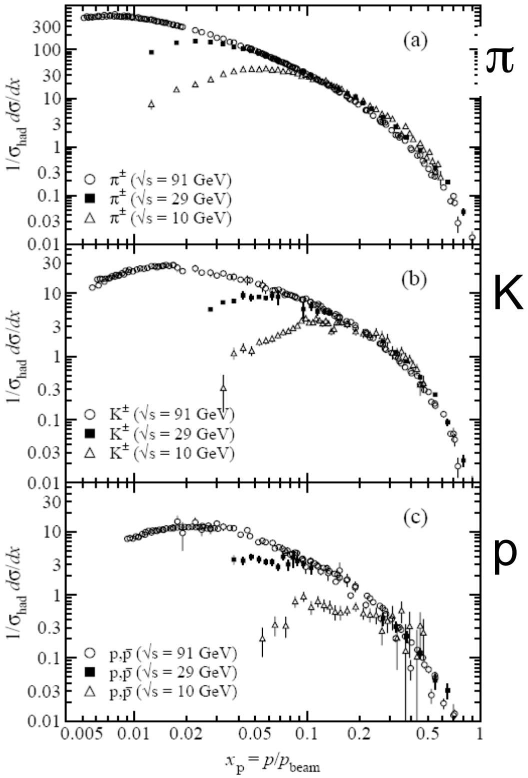
Linear dependence seems a better description at mid-rapidity

x_T-scaling

Works well in e+e- at higher x_T

$x_T = 2p_T/\sqrt{s}$

$$E\frac{d^3\sigma}{dp^3} = \frac{1}{\sqrt{s}^n} g(x_T)$$



Cross-section are multiplied by $(\sqrt{s_{NN}})^2$ factor

TPC, PRL 61(1988)
ALEPH,ZPC66(1995)
ARGUS,ZPC44(1989)

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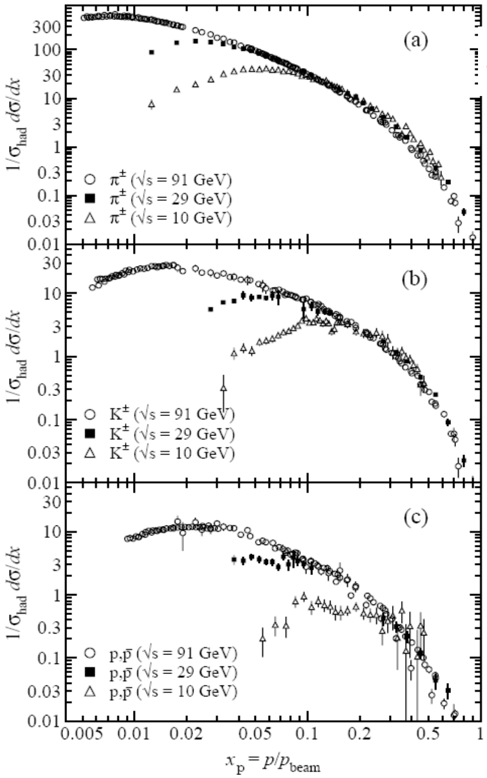
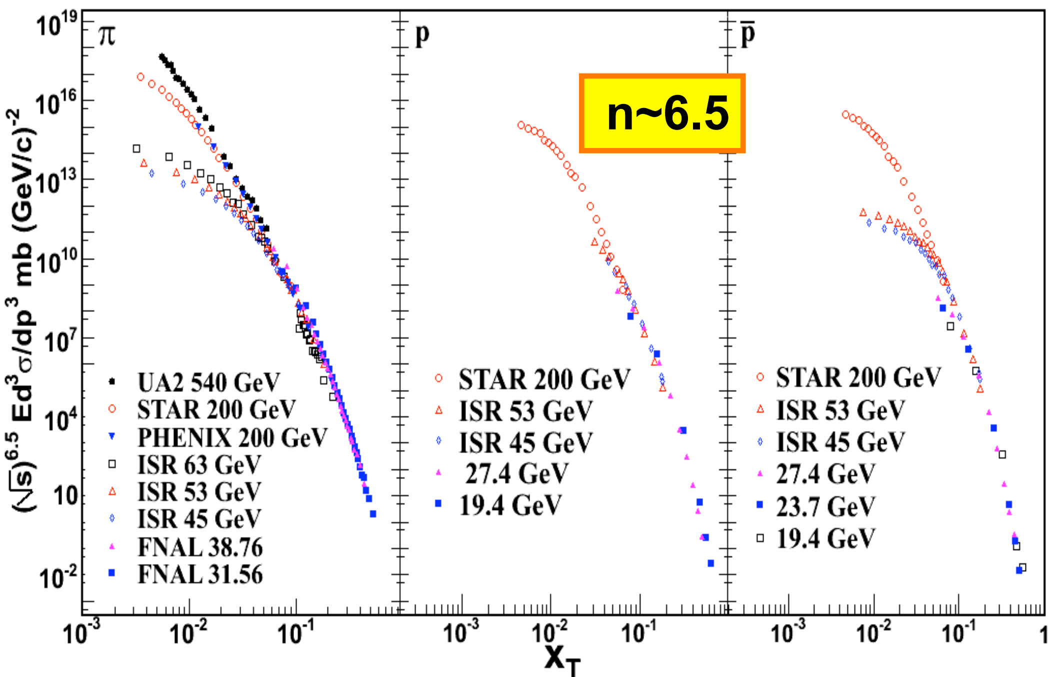
p+p or $\bar{p}$+p collisions





STAR, Phys Lett B, 637 (2006) 161

n ~ 4 for basic scattering process
n ~ 5-8 depending on evolution of structure function and fragmentation function (as seen in data)

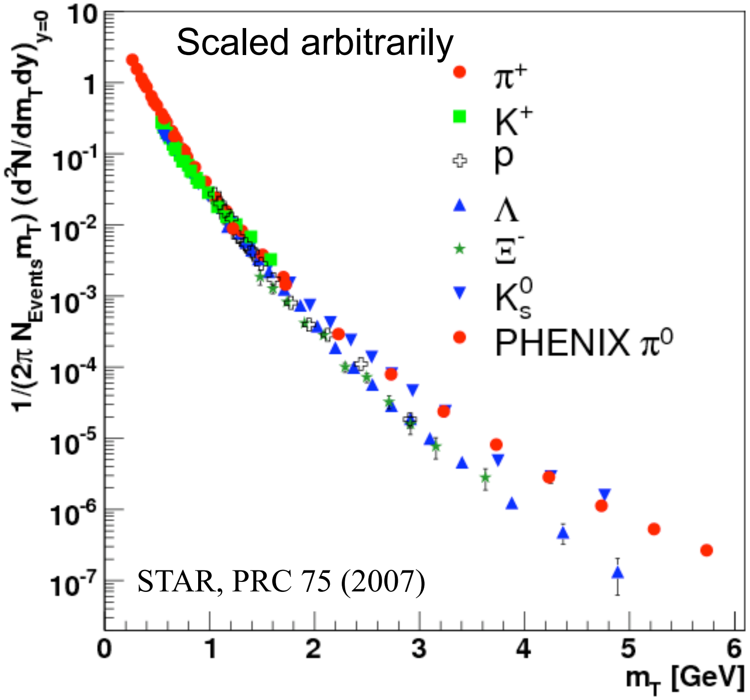
Cross-section are multiplied by $(\sqrt{s_{NN}})^2$ factor

TPC, PRL 61(1988)
ALEPH,ZPC66(1995)
ARGUS,ZPC44(1989)

Suggests transition from soft/hard processes ~p_T=2 GeV/c

m_T scaling of identified particles

- First studied at ISR - In Color Glass Condensate (CGC) picture m_T-scaling would be indicative of evidence of gluon saturation
- No absolute scaling (data shown are arbitrarily normalized)
- Baryon meson splitting above m_T ~2 GeV/c



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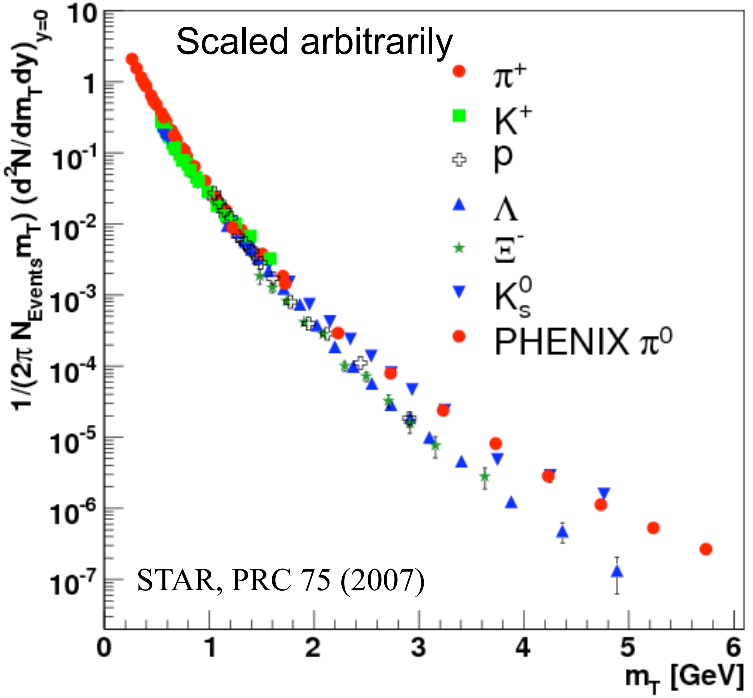

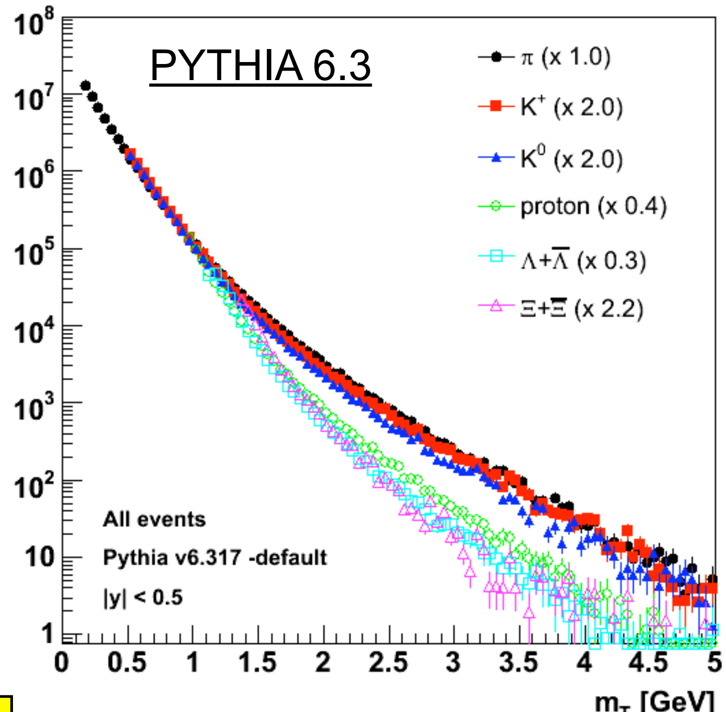

PYTHIA and data show similar trends

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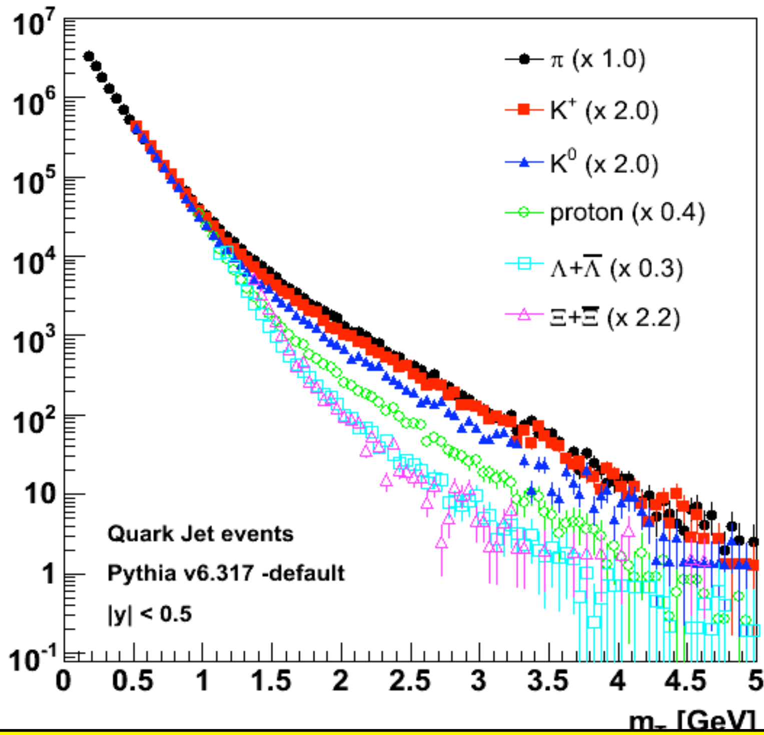
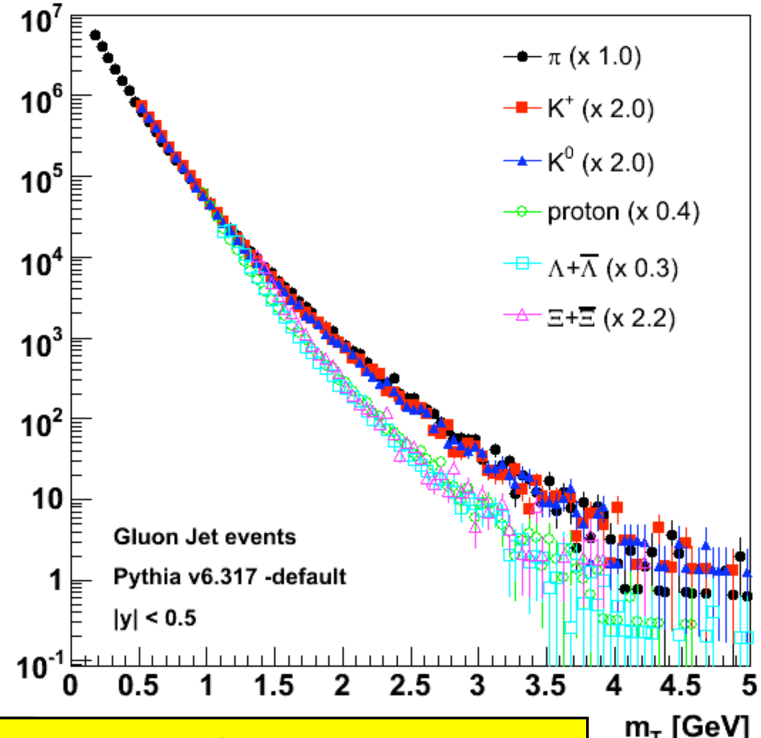
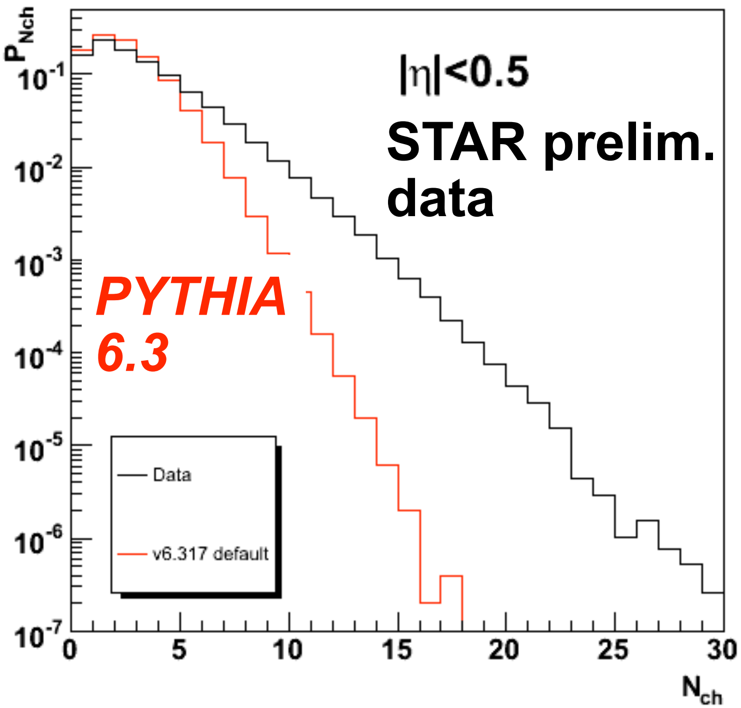
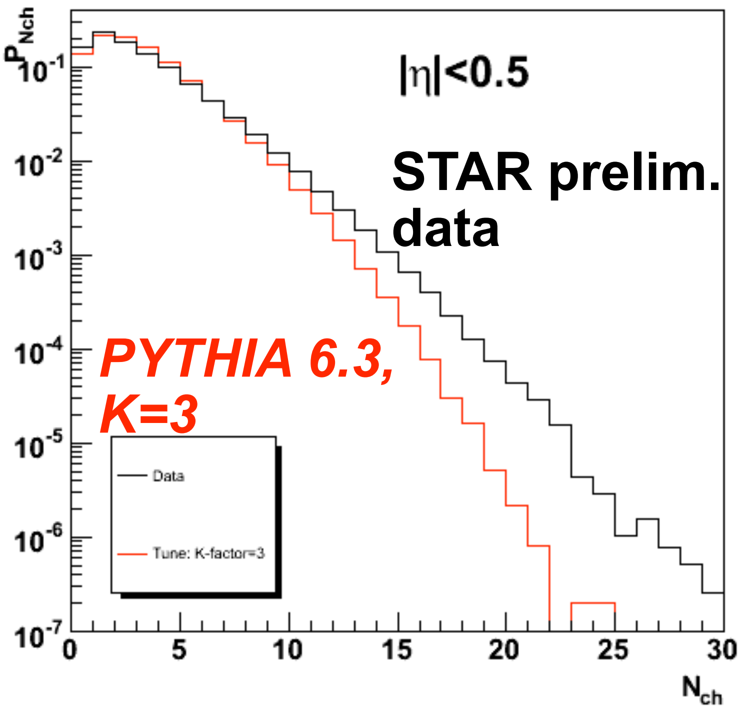




PYTHIA and data show similar trends - comes from gluon jets

K factor - charged multiplicity distribution



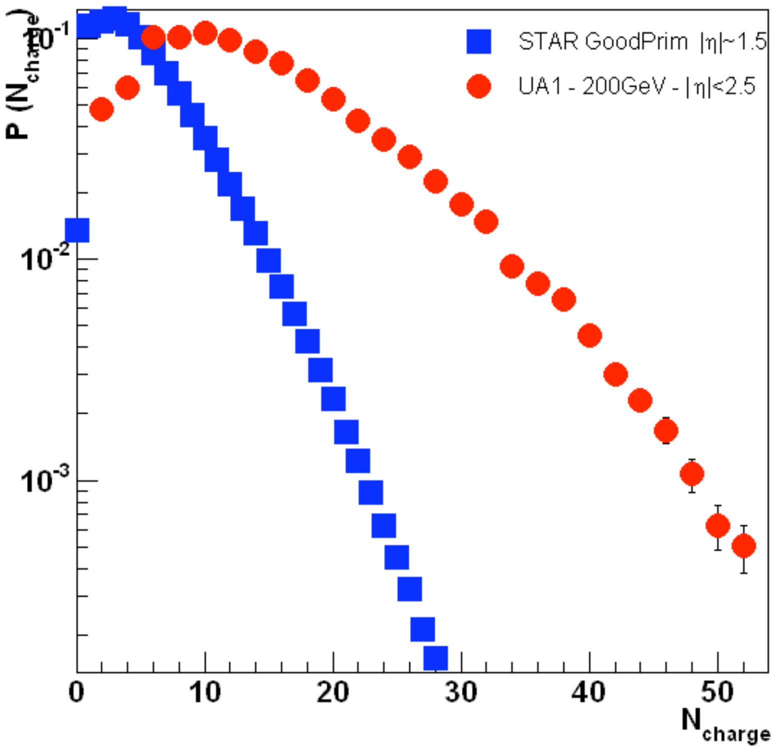


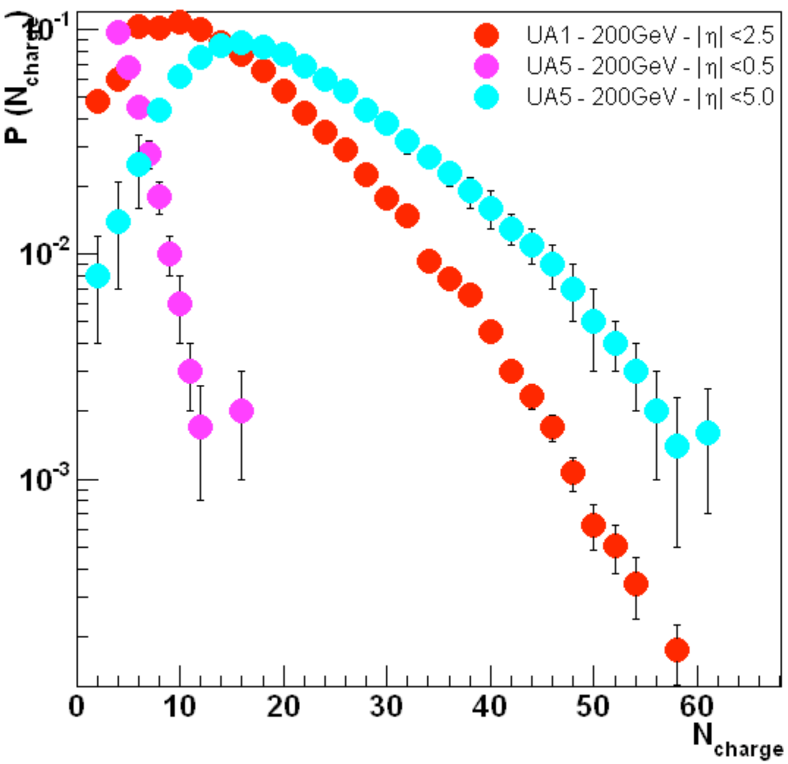
- PYTHIA + simulated trigger and detector acceptance.

Probability of high multiplicity events very sensitive to NLO corrections

Quick aside about N_{ch} measurements

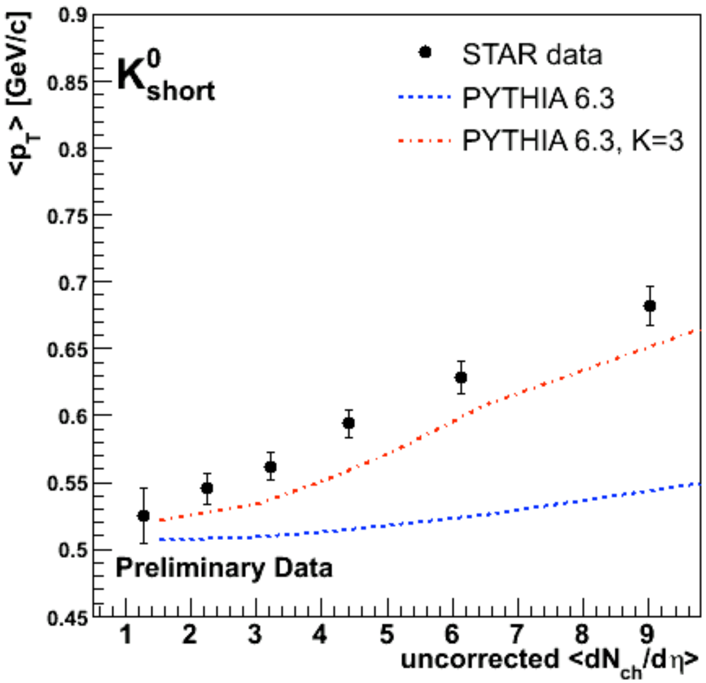
- How to define Multiplicity ?
  Definition of N_{ch} experiment dependent
  (pseudo-rapidity acceptance coverage, correction factors)

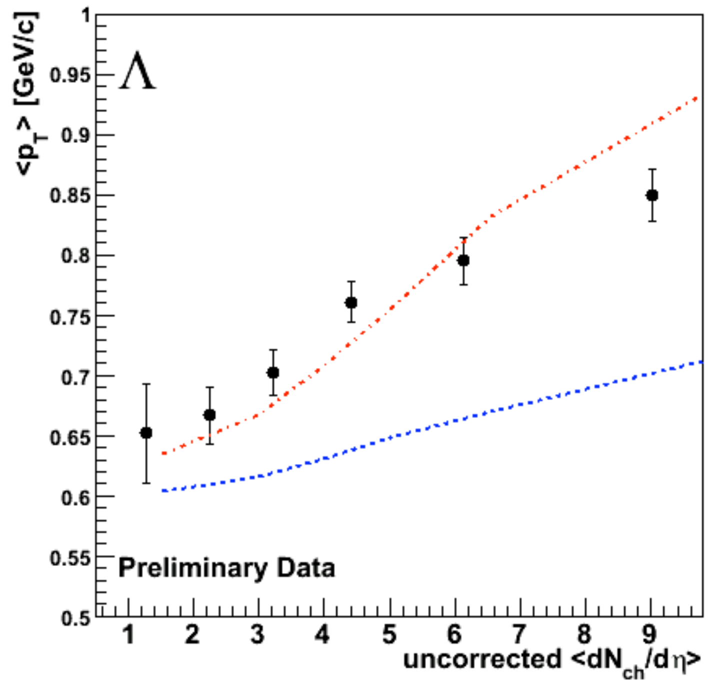




PYTHIA $<p_T>$ vs N_{ch}

- More sensitive observable to compare models to (mini-jet and/or multiple interaction implementations in models)

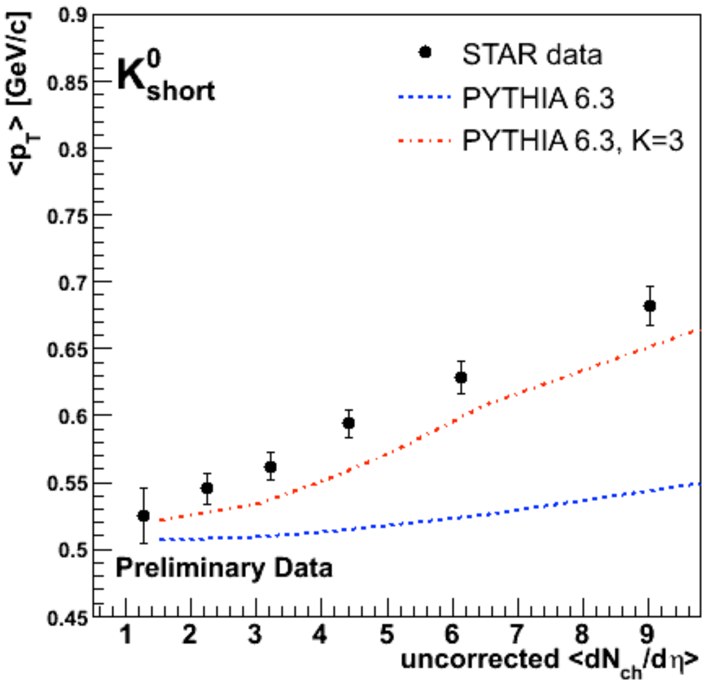


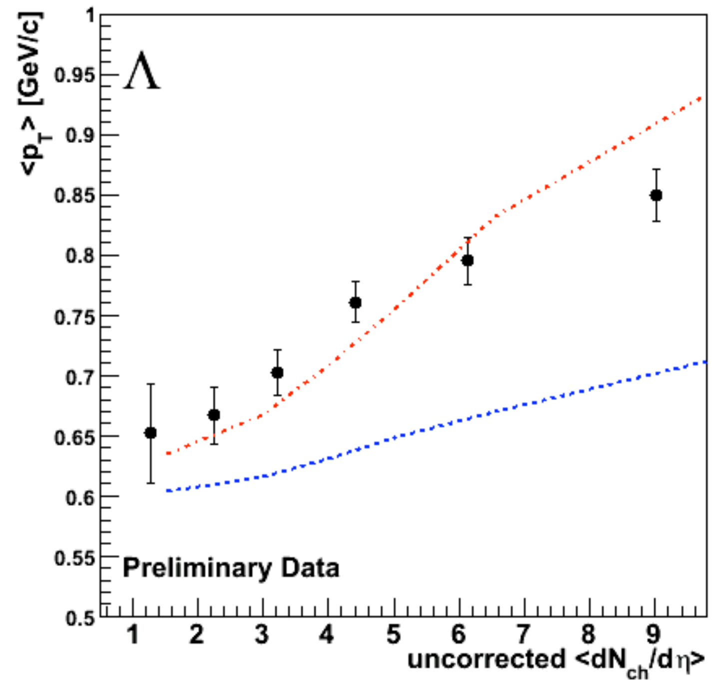


K factor tuned PYTHIA seems to do reasonable job for strange hadrons

PYTHIA $\langle p_T \rangle$ vs N_{ch}

- More sensitive observable to compare models to (mini-jet and/or multiple interaction implementations in models)
- K-factor accounts for increase of $\langle p_T \rangle$ with charged multiplicity





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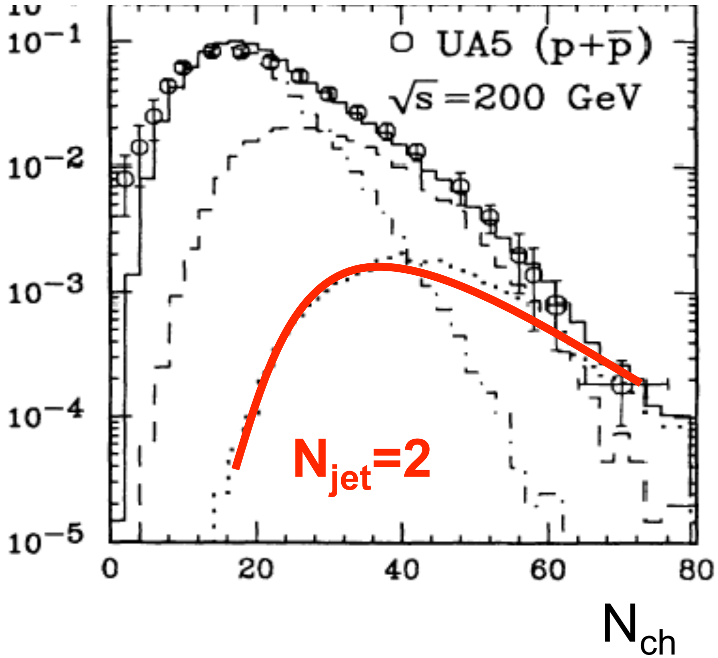
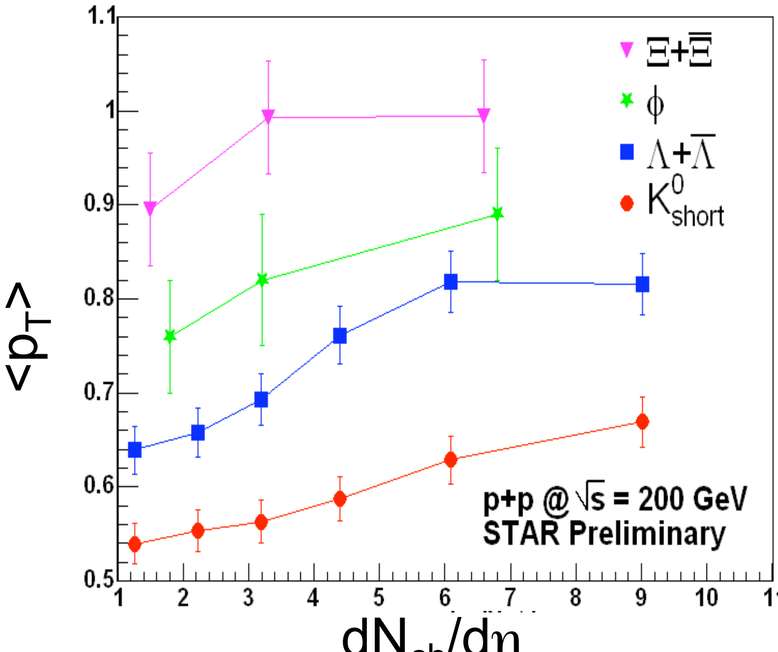
Mini-jet production in p+p

- Mini-jet - “Hardish” parton interaction (included in PYTHIA and HIJING)
  - jets occur in higher multiplicity events
  - produce higher p_T final states
  - measure higher $<p_T>$

$$R_{pp}(p_T) = \frac{< N_{ch}(minbias) > dN/dpt(mult, p_T)}{< N_{ch}(mult) > dN/dpt(minbias, p_T)}$$





XN.Wang et al (Phys Rev D45, 1992)

Evidence of jet production in high mult. events

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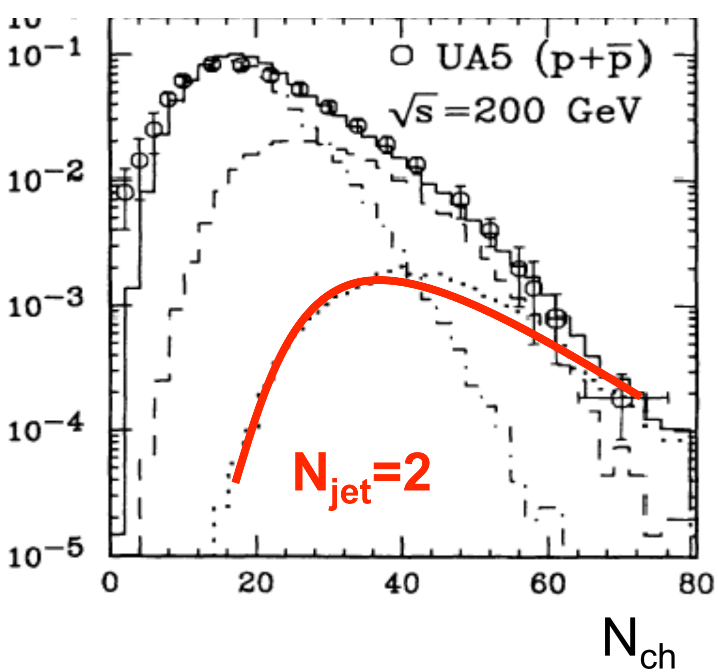

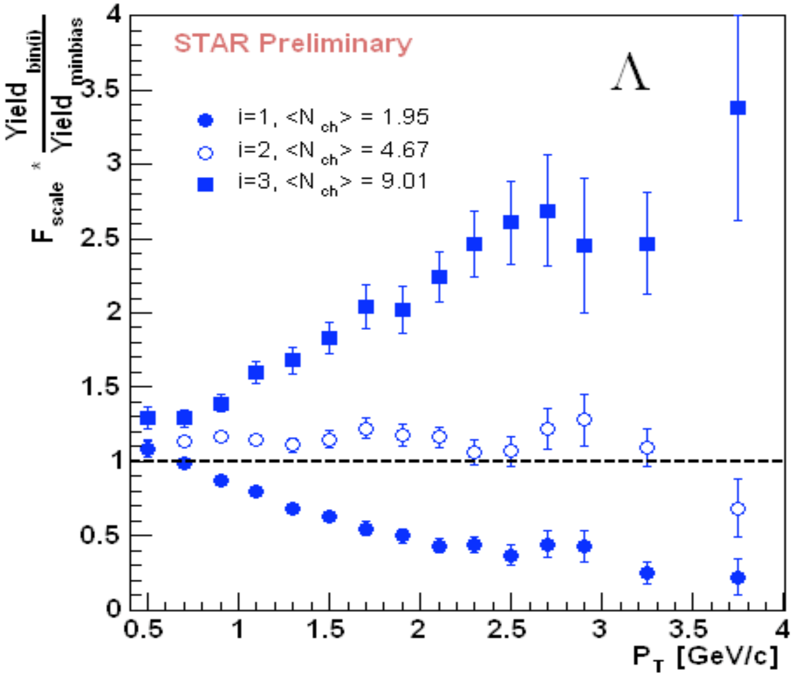

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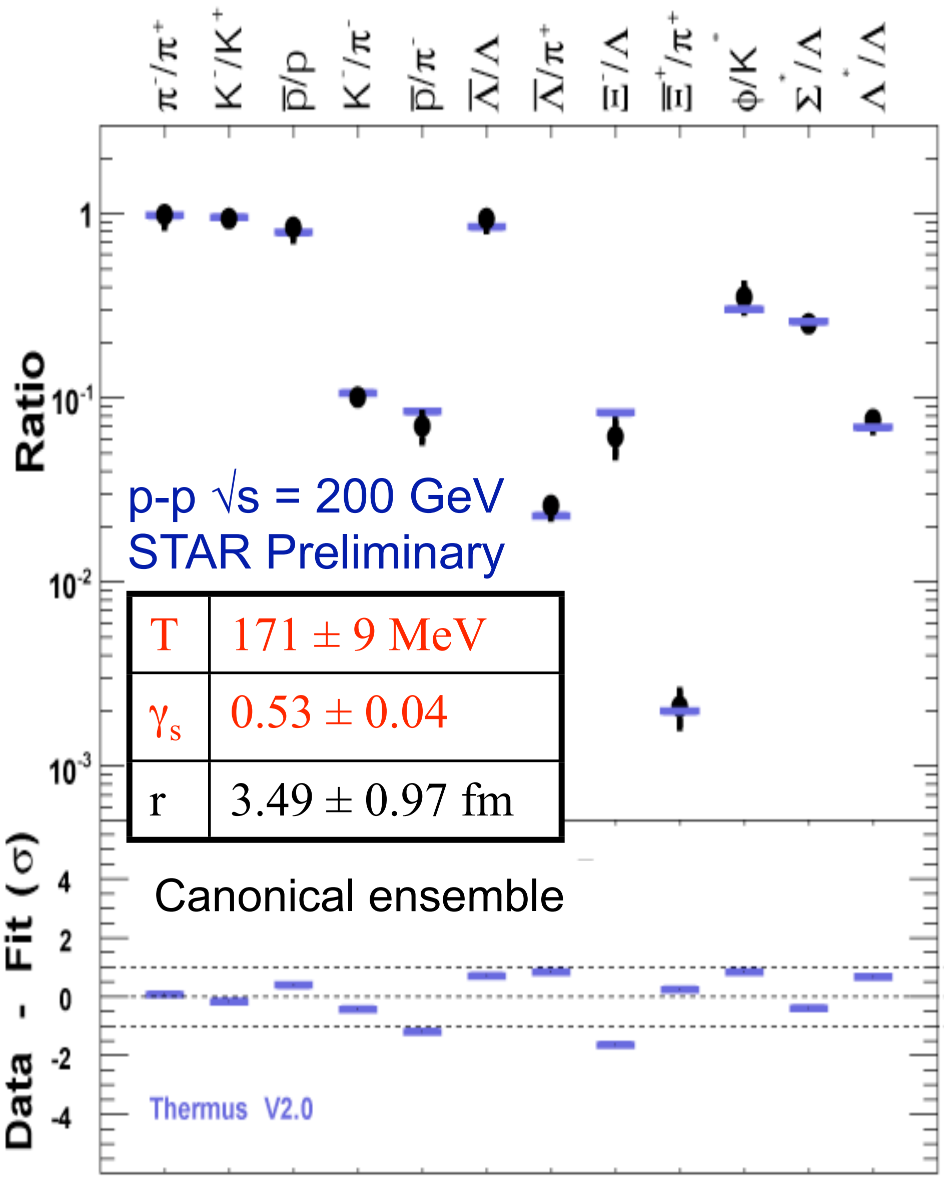
Hadro-chemistry in p+p events



- Statistical model fit OK but not as good as in A+A

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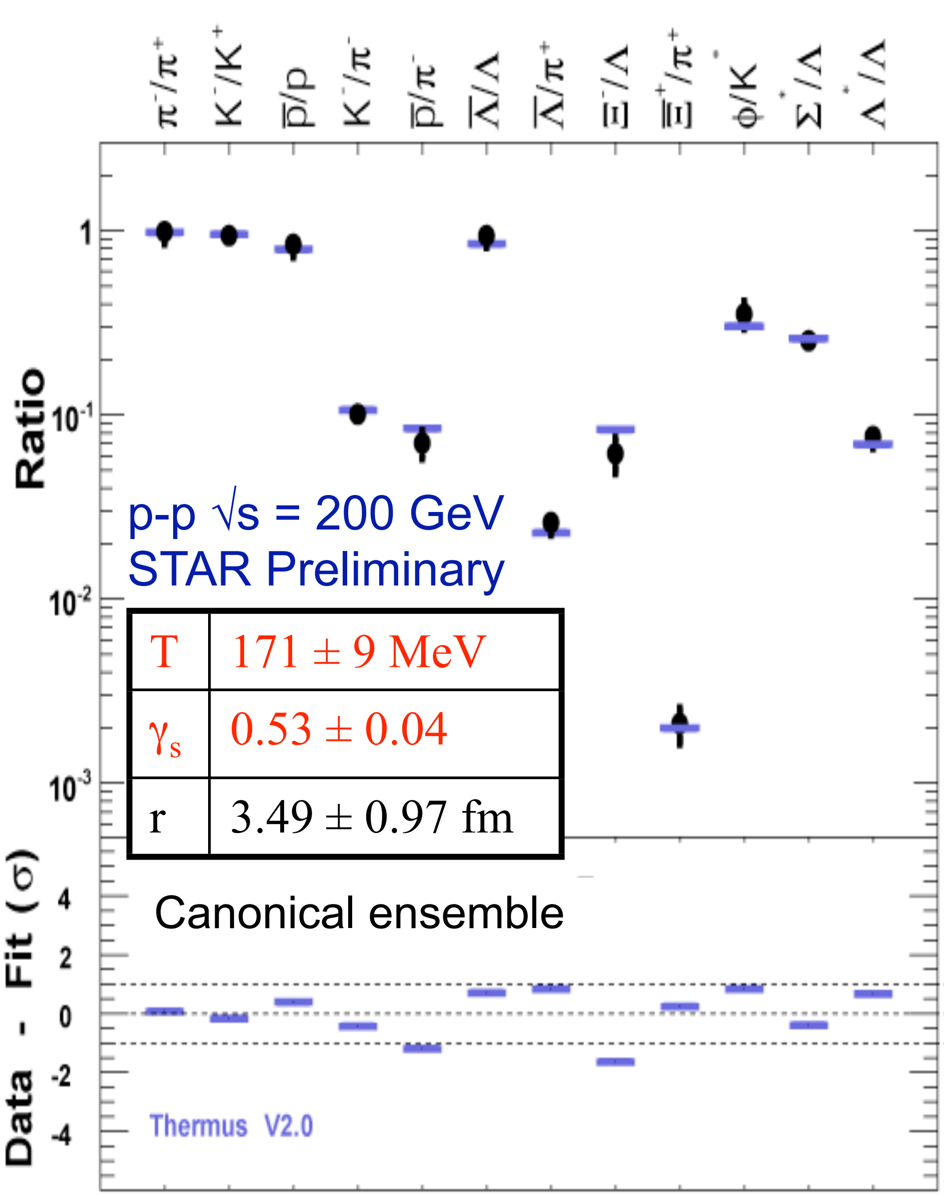
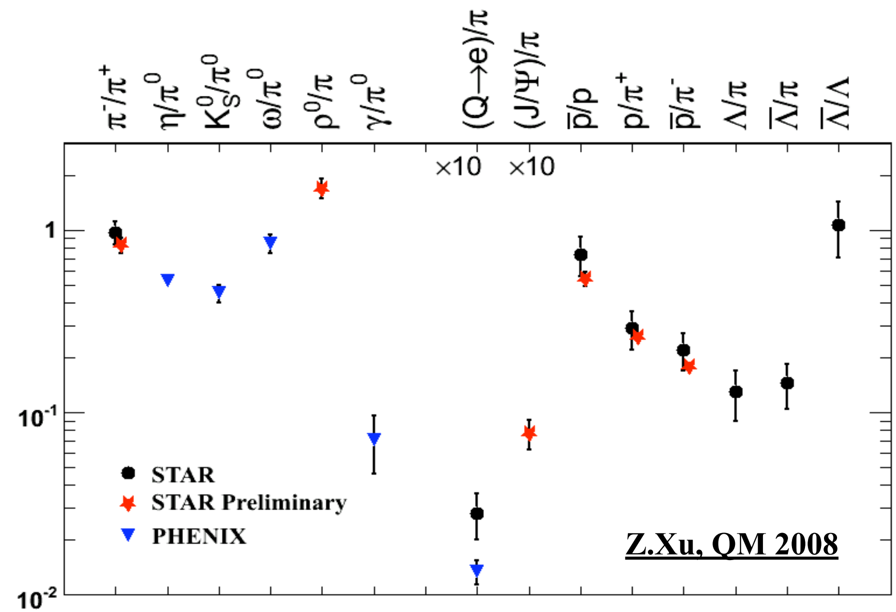


T	171 ± 9 MeV
γ_s	0.53 ± 0.04
r	3.49 ± 0.97 fm



p_T>**5** GeV/c

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- High-p_T ratios first step to looking at hadro-chemistry of jet FF

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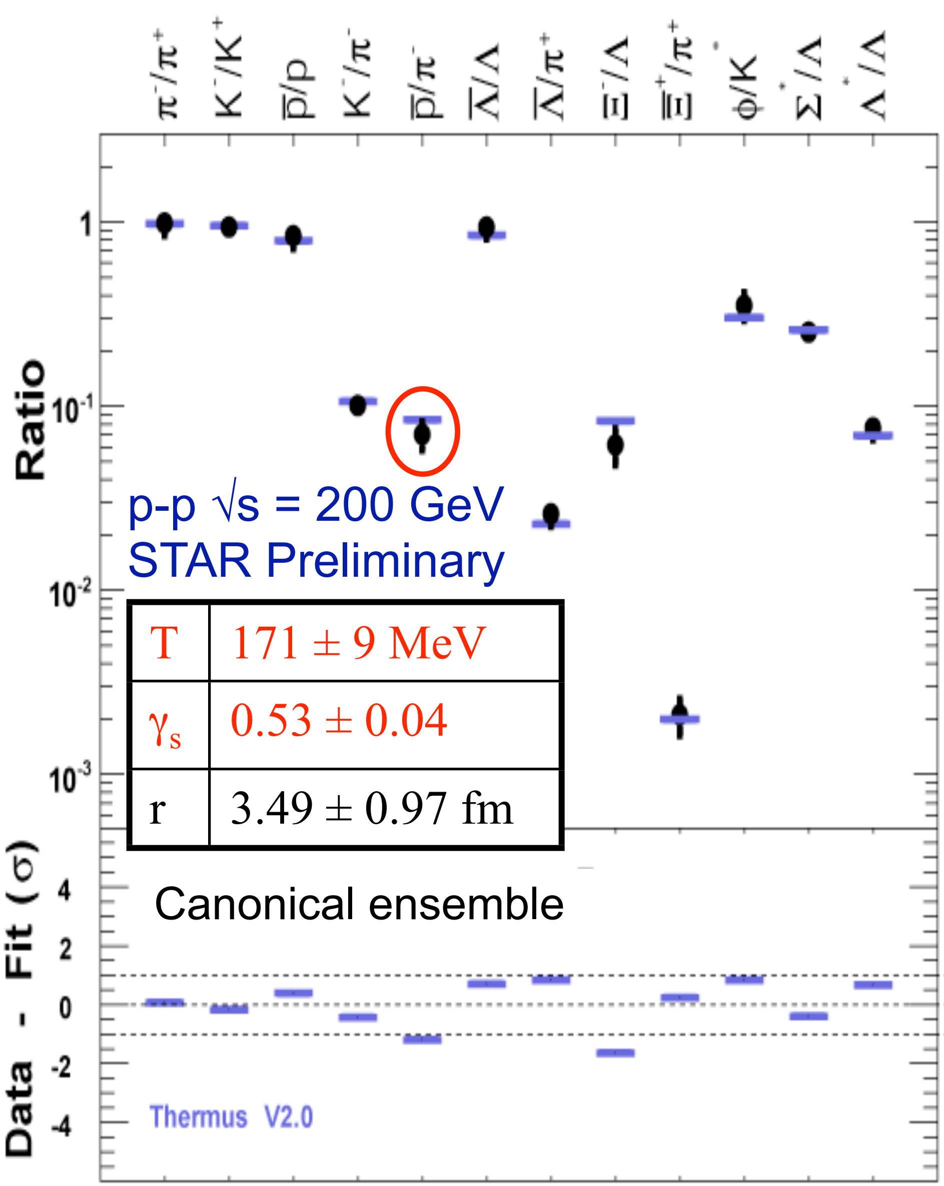

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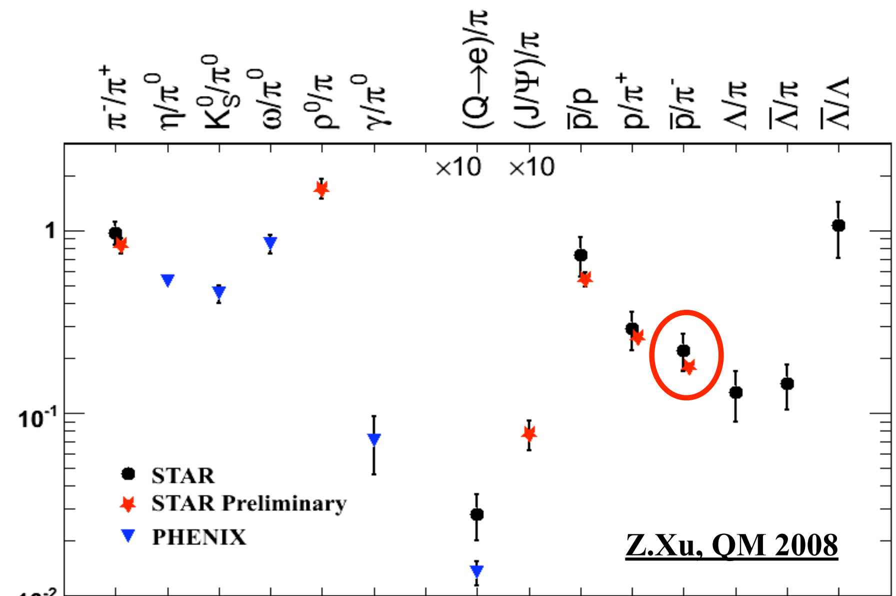

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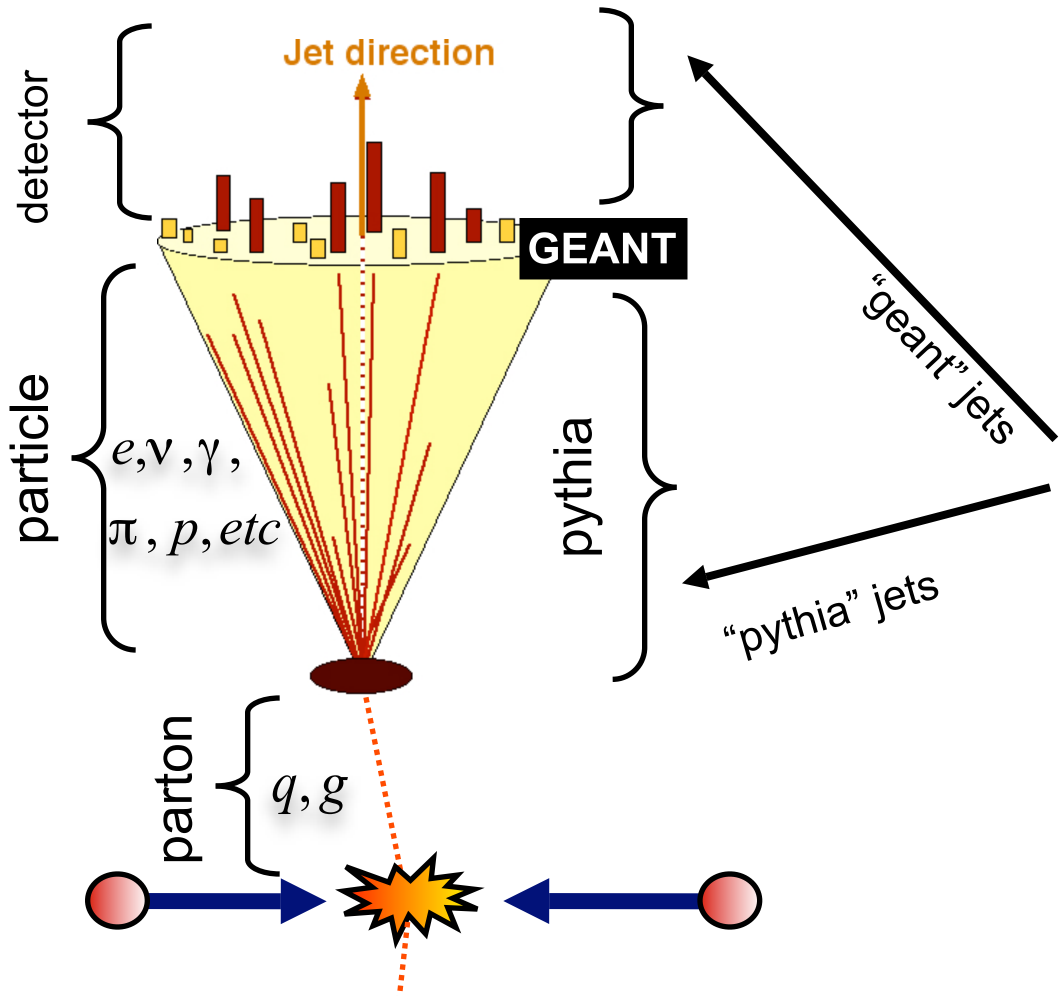
Some ratios change significantly

Jet-Finding Algorithm



Use 4 algorithms

- Midpoint-cone
- SISCone
- K_T
- Anti-K_T

Currently Pythia+GEANT+reco compared to reconstructed real data so data at "detector" level

Jet-Finder Algorithm cuts:

p_T (track/tower) > 0.2 GeV

|vertex-z|<50 cm

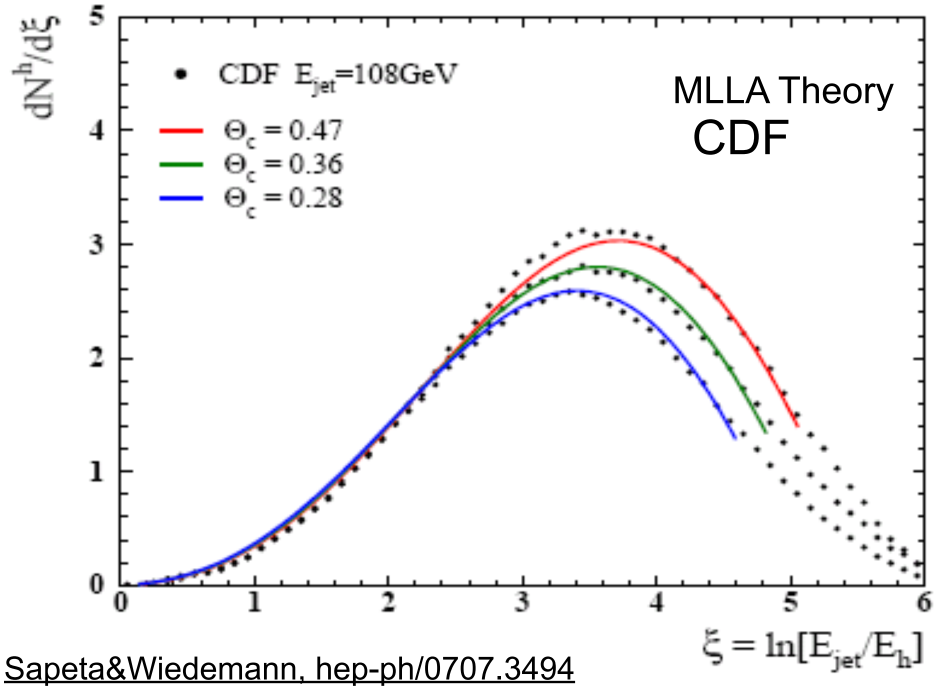
$|\eta_{jet}| < (1 - R_{jet})$

$0.05 < E_{neutral}/E_{jet}$ (NEF) < 0.85

Seed-Cut: 0.5 GeV/c (for midpoint only)

Compare results from different algorithms - estimate of systematics

Fragmentation functions

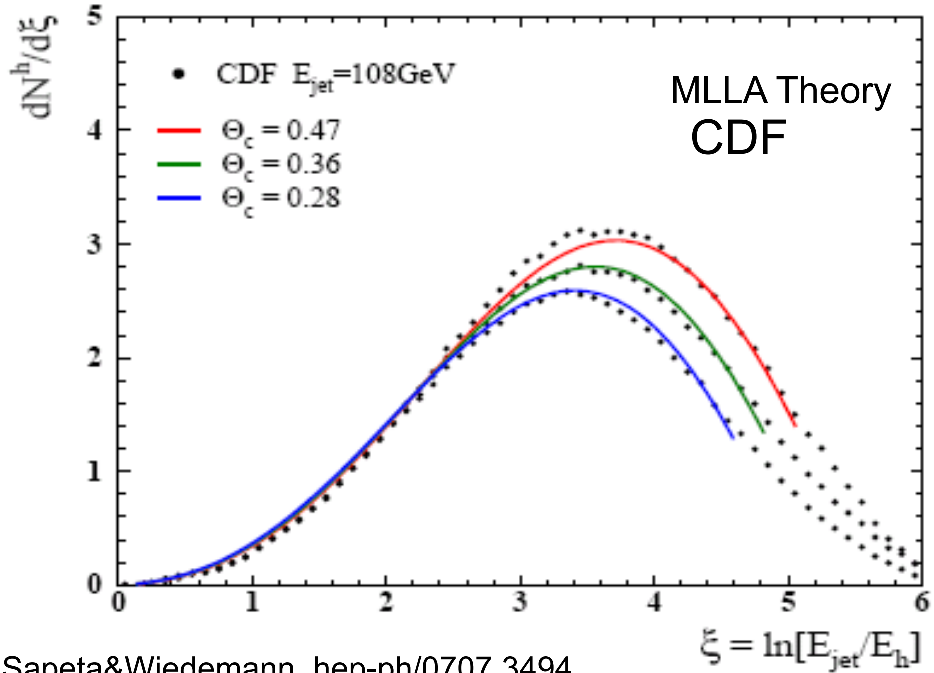


Sapeta&Wiedemann, hep-ph/0707.3494

- No previous comparisons at RHIC energies available.
- Measurements at higher $\sqrt{s}$ agree well with theory.

Test energy scaling of fragmentation functions.

Fragmentation functions



Sapeta&Wiedemann, hep-ph/0707.3494

- No previous comparisons at RHIC energies available.
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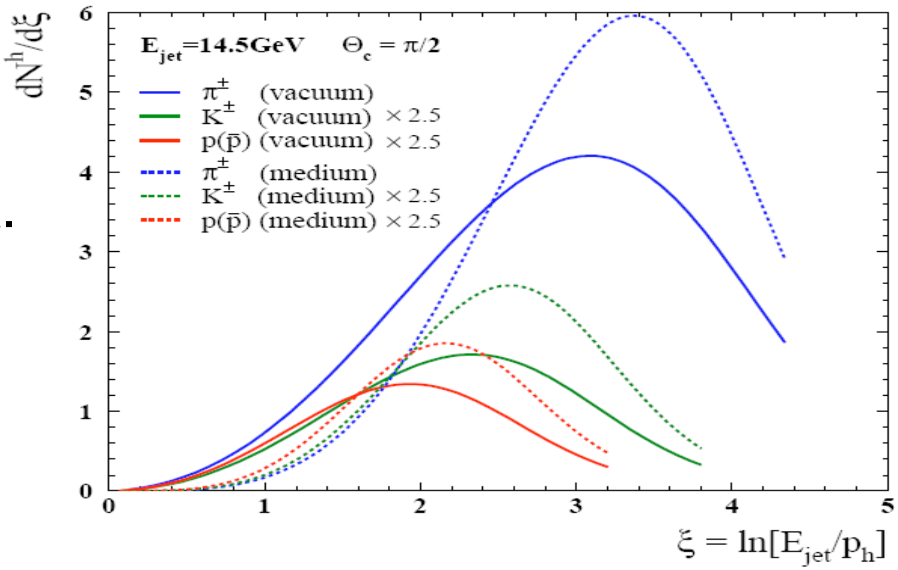
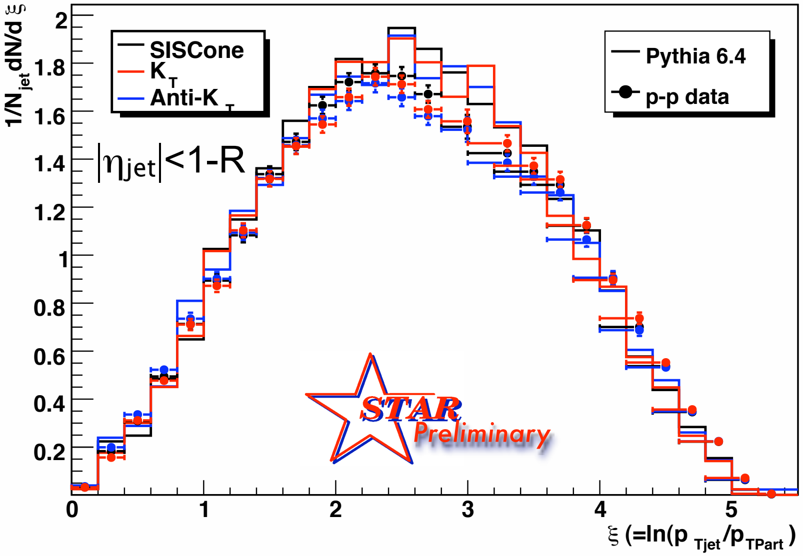
Test energy scaling of fragmentation functions.

- FF are particle species dependent.

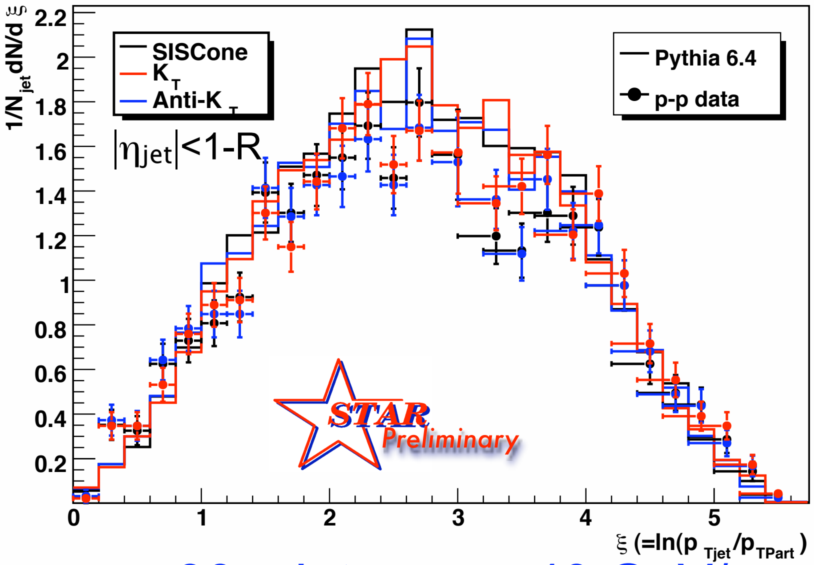
Need to study composition of jets and complete event.



ξ and z distributions for charged hadrons



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

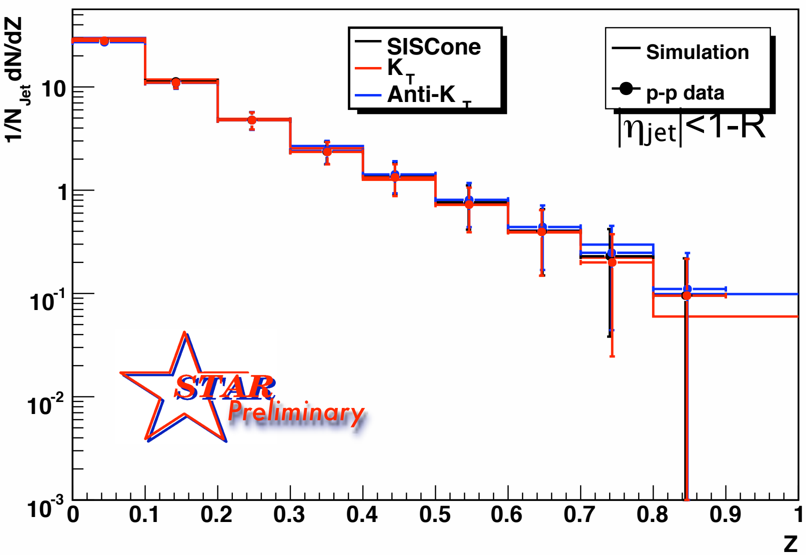


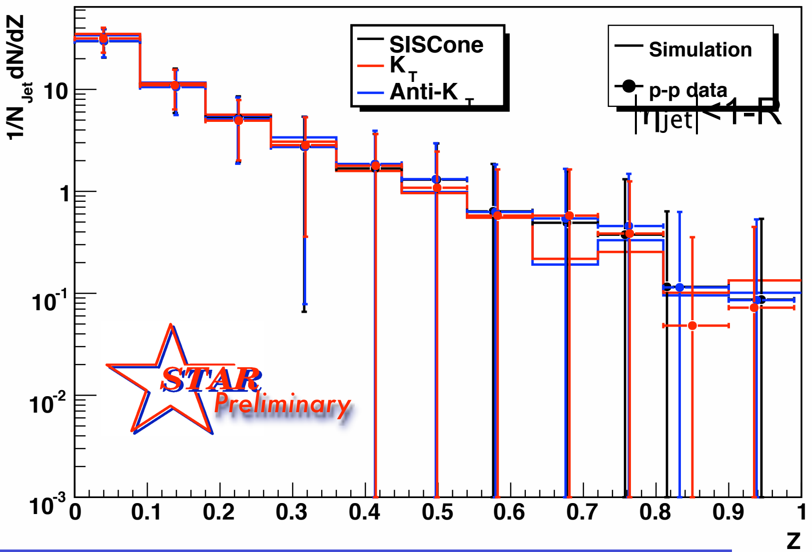
30 <Jet p_{Treco}< 40 GeV/c

Data not corrected to particle level.

R=0.4

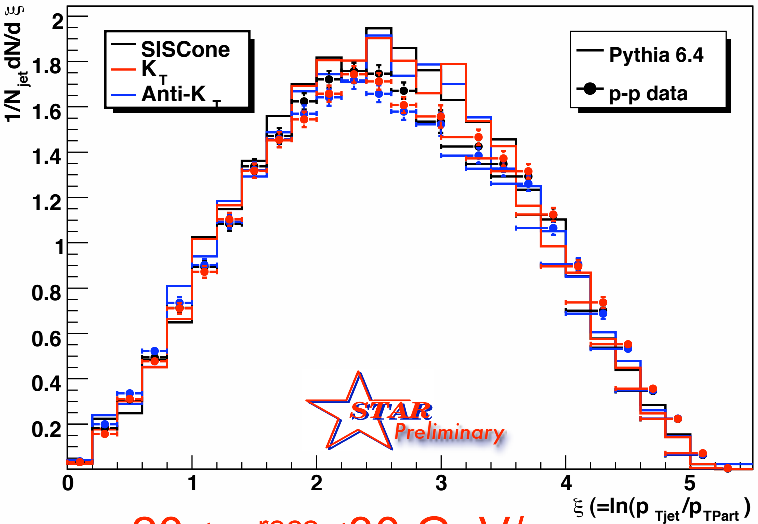
“PYTHIA” = PYTHIA +GEANT



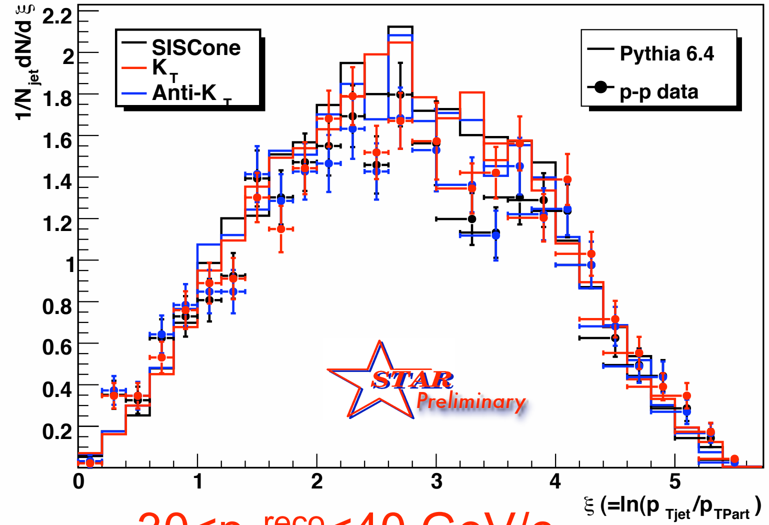


Reasonable agreement between data and PYTHIA+GEANT.

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

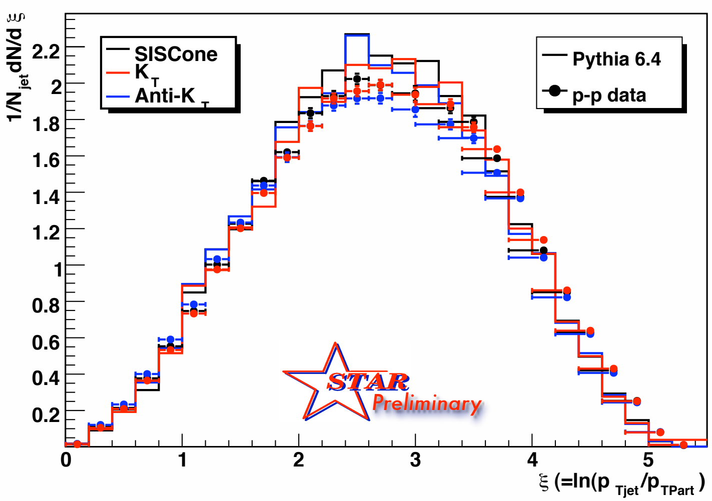
$|\eta_{jet}|$<1-R

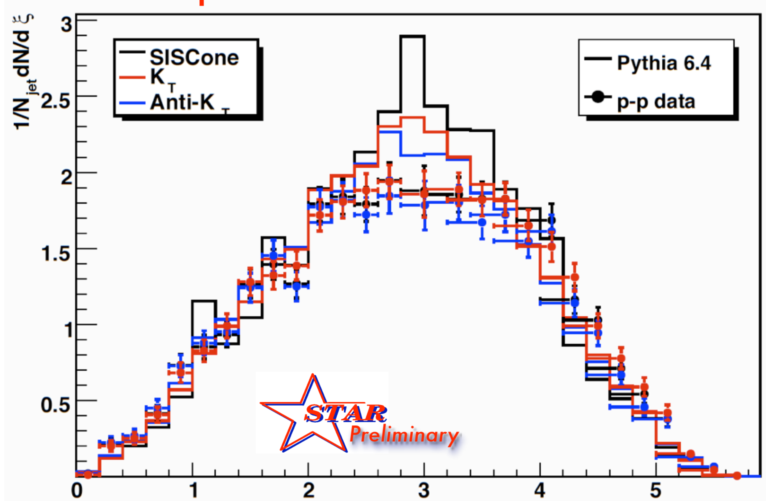
p_{Ttrack} > 0.2

Data not corrected to particle level.

"PYTHIA" = PYTHIA +GEANT

R<0.7

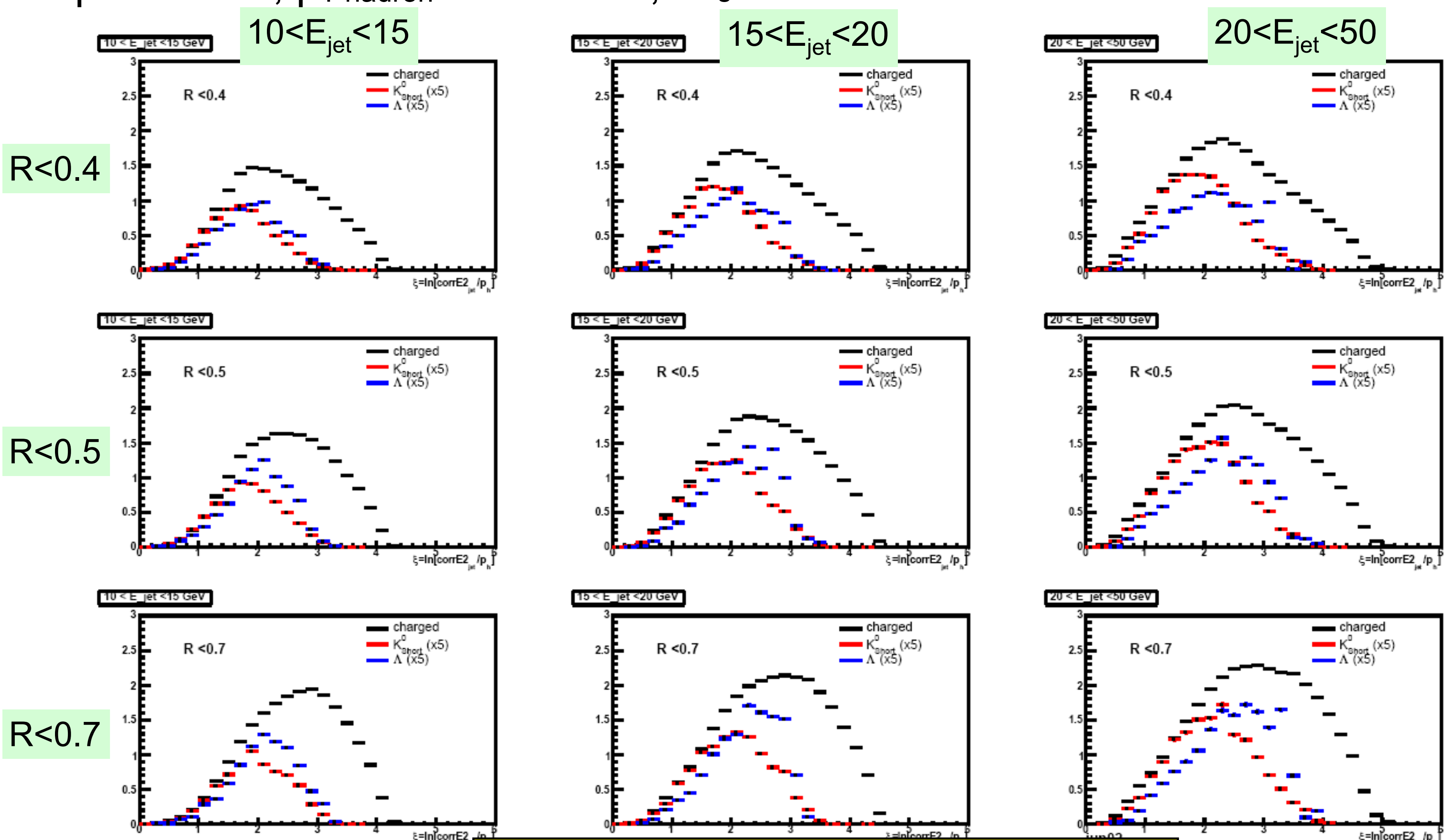




Agreement similar between PYTHIA and data for both radii.

ξ for K^0_s and Λ

Midpoint cone, $p_{T\ hadron}$>0.5 GeV/c, K^0_s and Λ effic. corrected

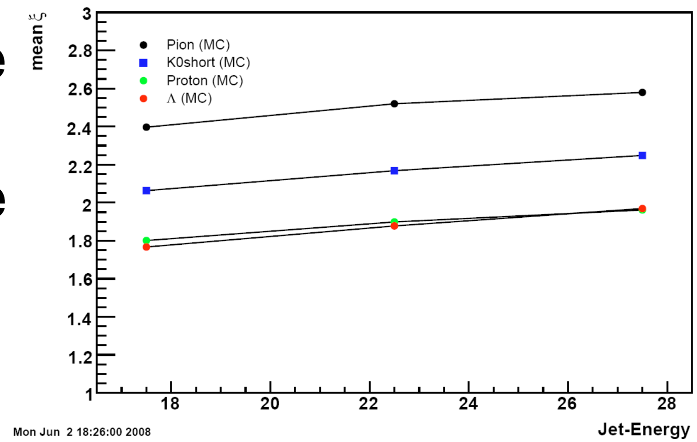


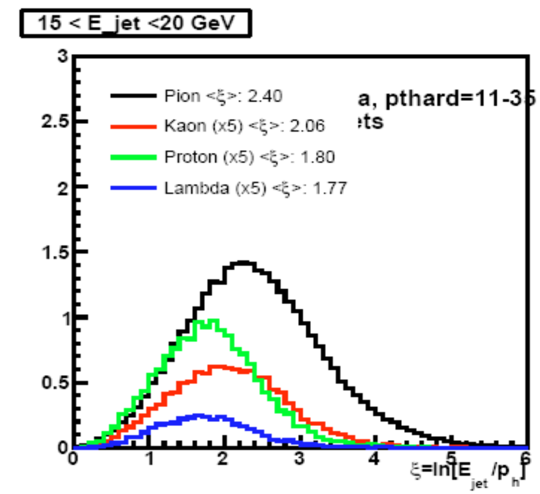
FF shapes different for $h^{\pm}$, K^0_s and Λ

Mean of ξ distributions

- PYTHIA predicts particle mass ordering of mean ξ value

$h^{\pm} > K^0_s > \Lambda / p$





Mean of ξ distributions

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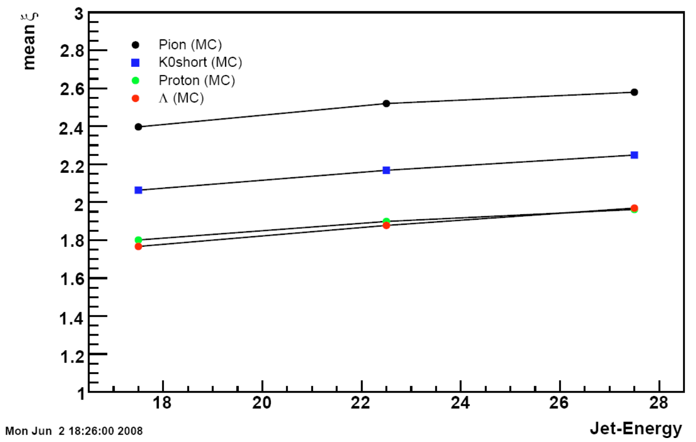
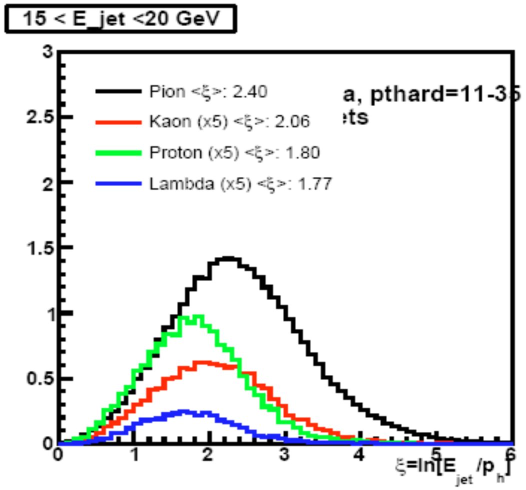
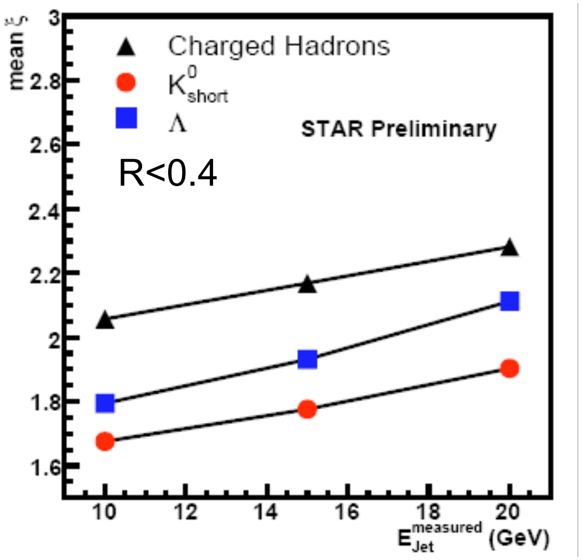
- Not observed in STAR data

  $h^{\pm} > \Lambda > K^0_s$

  (need to check contamination)







[M. Heinz, Hard Probes 2008]

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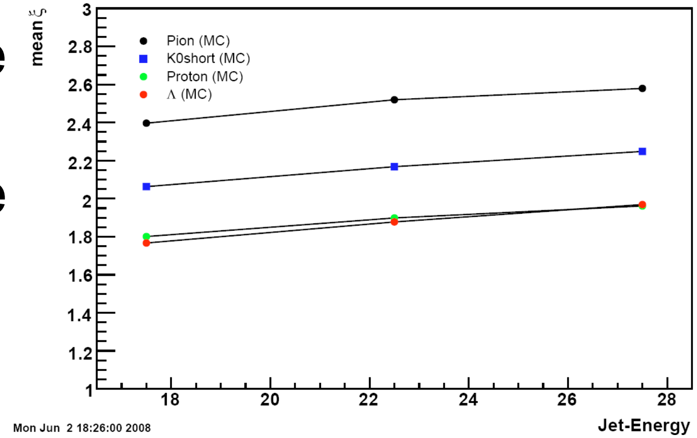

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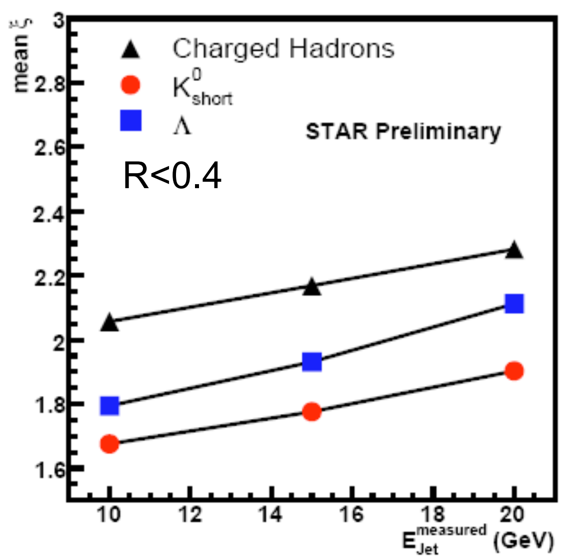
$h^{\pm} > \Lambda > K^0_s$

(need to check contamination)



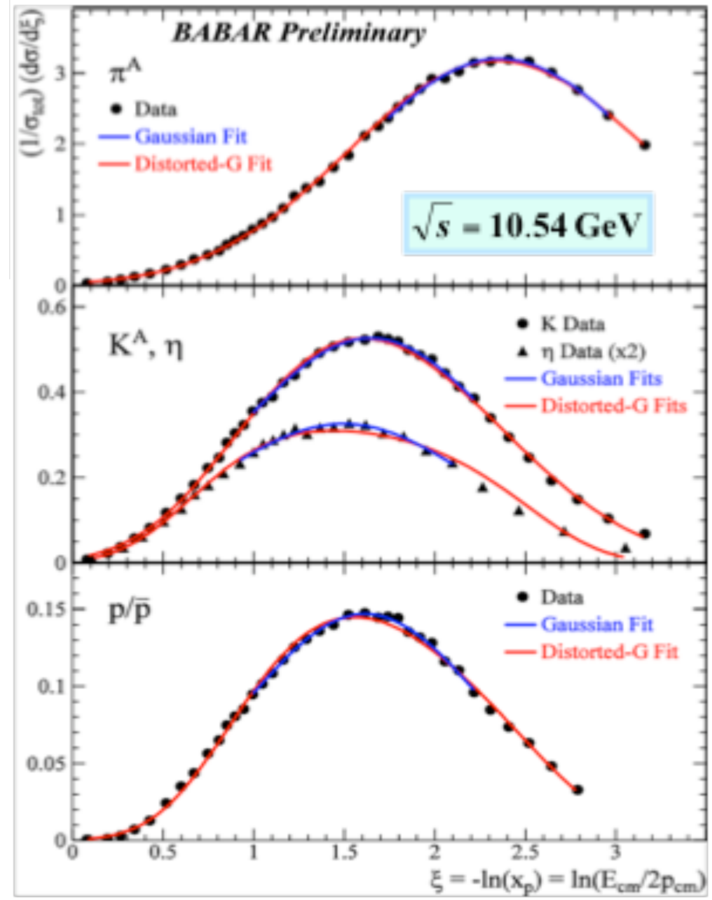
[M. Heinz, Hard Probes 2008]

- Nor BABAR

e^+e^- $\sqrt{s}$=10.54 GeV

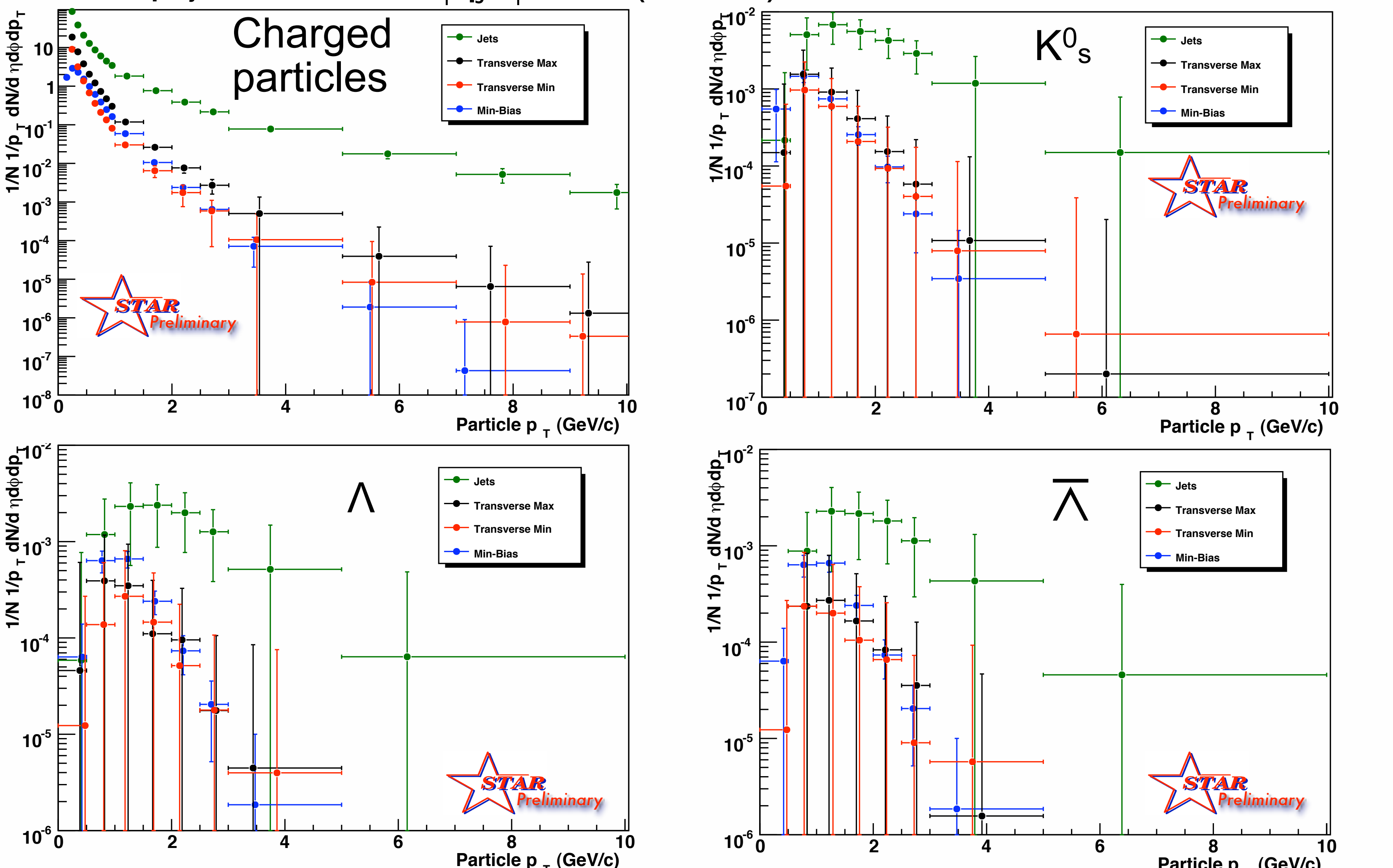
(F. Anulli, Trento 2008 [arXiv:0804.2021v1])

$h^{\pm} > K = p$



p_T spectra in jet, UE, Min-Bias event

$15<p_{Tjet}<20$ GeV/c, $|\eta_{jet}|<1$-R (R=0.7)   All data raw



Summary

- RHIC p+p data are extensive and can be used to constrain models
- Although the (OPAL) light-flavor separated measurements in e^+e^- collisions provided significant improvement of FF for baryons and strange particles there is still more detail required
- p+p data provides a unique tool for understanding gluon vs. quark jet contributions
  - Baryon to meson ratios
  - Splitting of high baryon-meson m_T
- $m_T(x_T)$-scaling in show that hard processes (related to PDF and FF) dominate over soft process for minbias collisions starts at p_T ~ 2 GeV/c
- PYTHIA
  - Reproduces the rise in $\langle p_T \rangle$ of strange hadrons with N_{ch}
  - Describes the charged hadron ξ and z distributions at $\sqrt{s}$=200 GeV
  - Cannot describe all the p+p data with a common K-factor
- Particle p_T spectra are significantly softer out of jet cone compared to in jet cone, those of UE are close to that of Min-Bias triggered events.