Global Properties of p+p Collisions at RHIC at 200 GeV

Helen Caines - Yale University

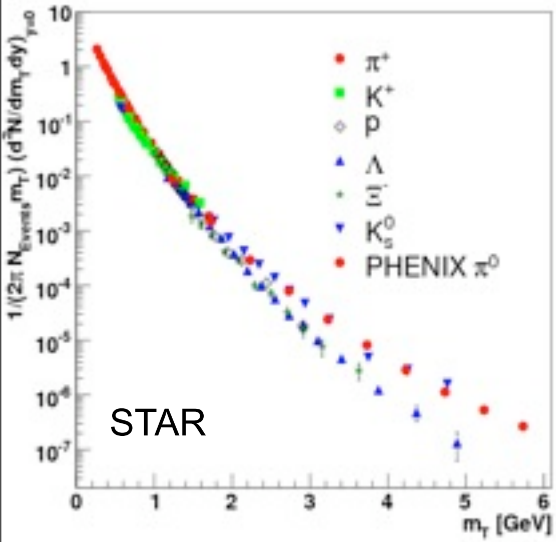
Quantifying the Properties
of Hot QCD Matter
INT - Seattle
Friday May 28th 2010

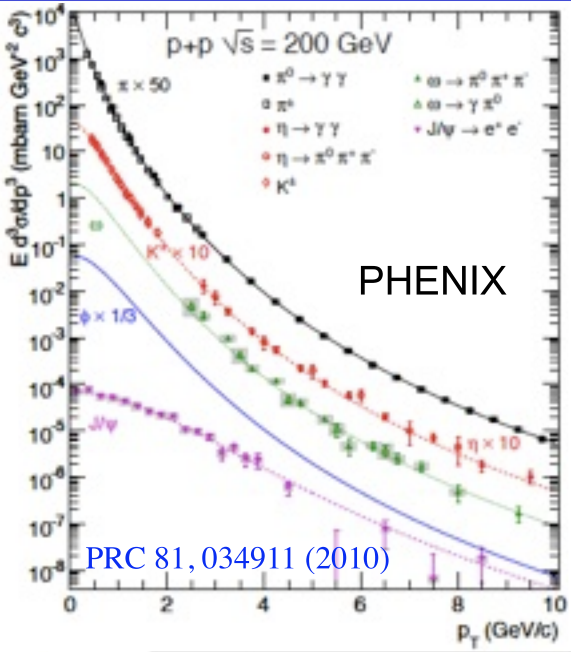
Outline

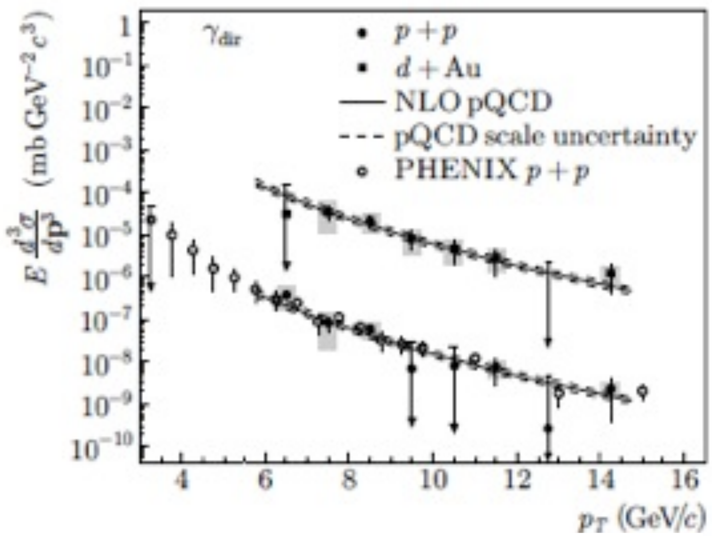
- Data comparison
- Hard vs Soft
- Jet properties
- Constraining fragmentation functions
- Summary

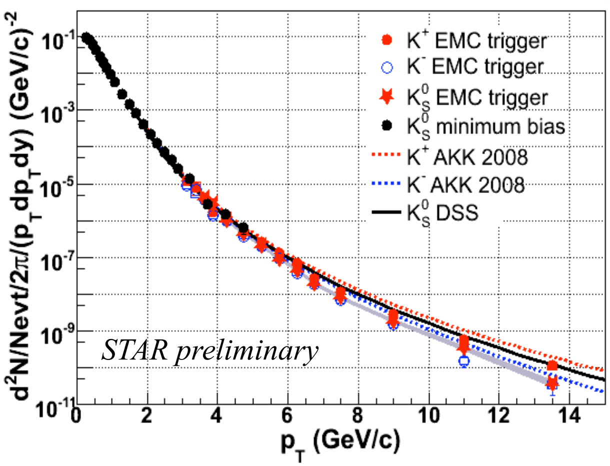
Some samples from the p-p data at √s=200 GeV

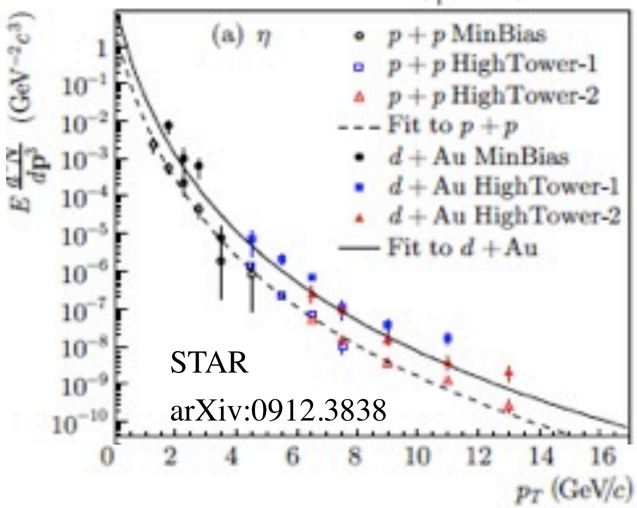
PHENIX PRL 98, (2007) 012002
STAR arXiv:0912.3838

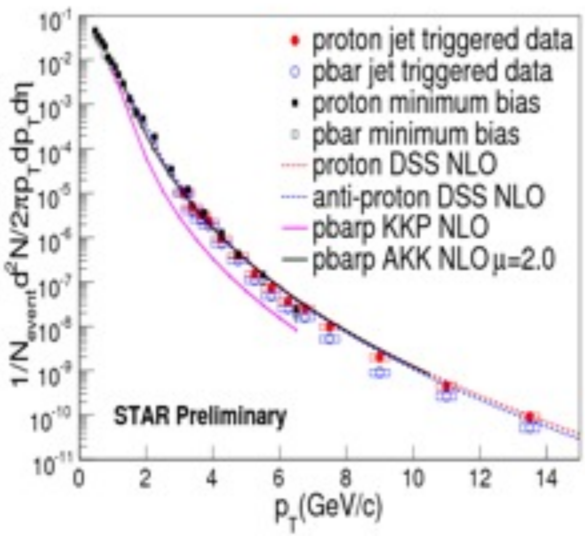






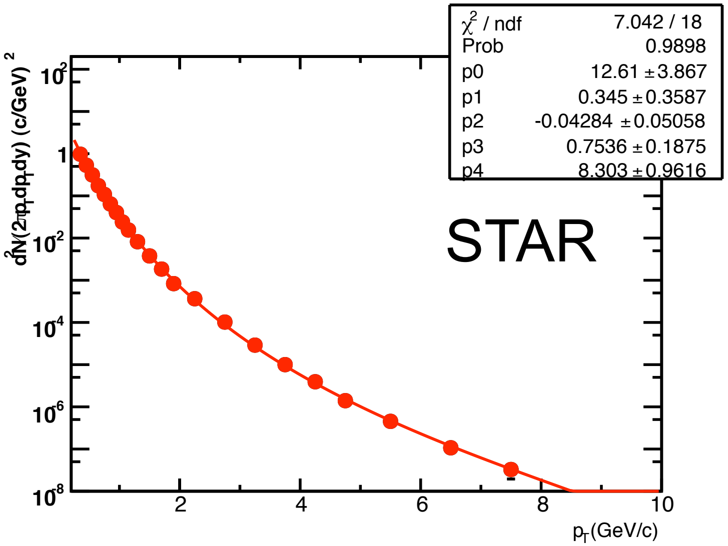


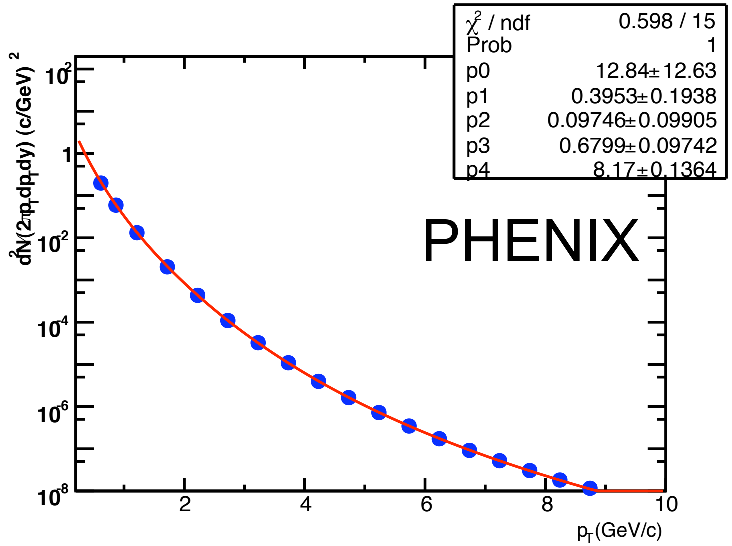




Wednesday, June 9, 2010

π in p-p - Comparison

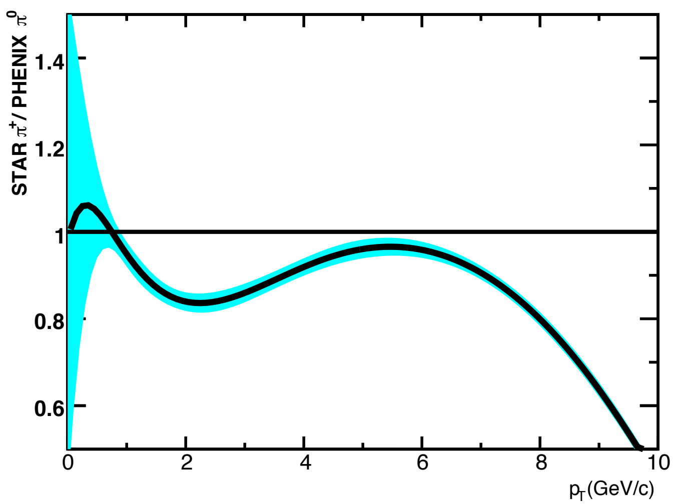




- Data fit to:

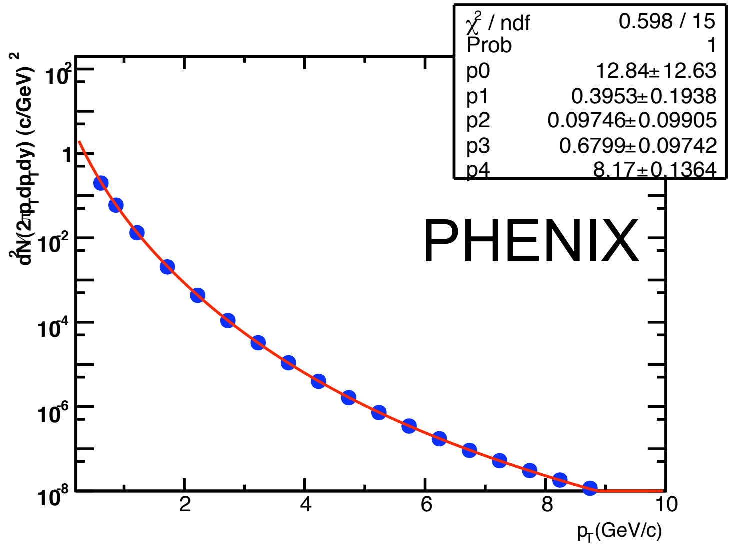
$$\frac{A}{\left(e^{(-ap_T - bp_T^2)} + p_T/p_0\right)^n}$$

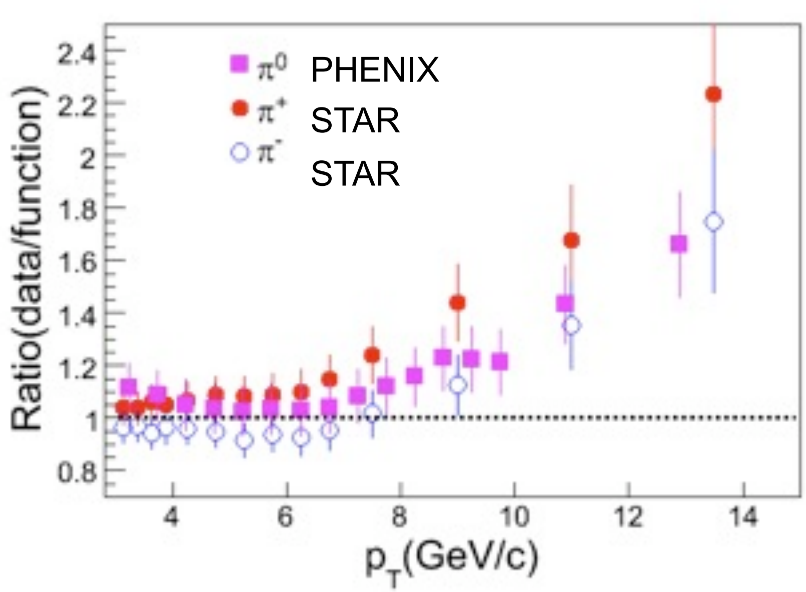
- Not interested in parameters just want good fit to data

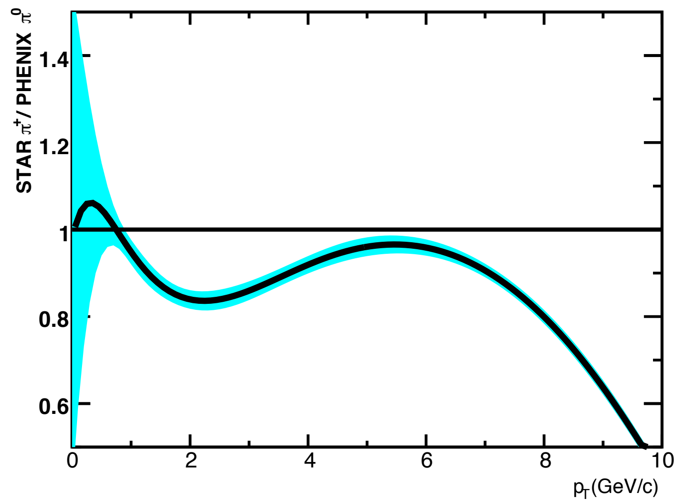


π in p-p - Comparison

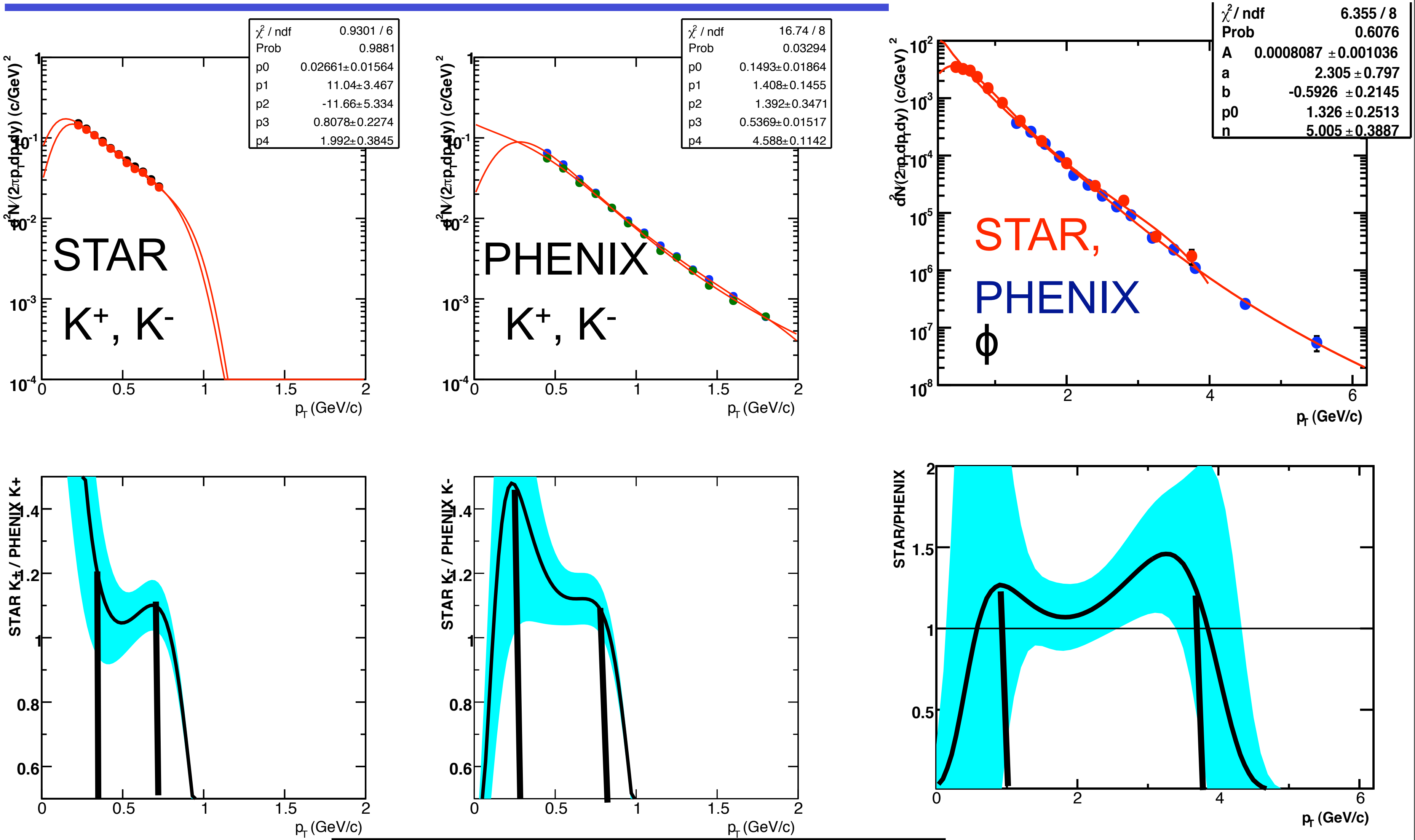
- STAR π$^{\pm}$, PHENIX π^{0} compared to a Tsalis fit
- New STAR data from run without SVT not published - presented at QM09





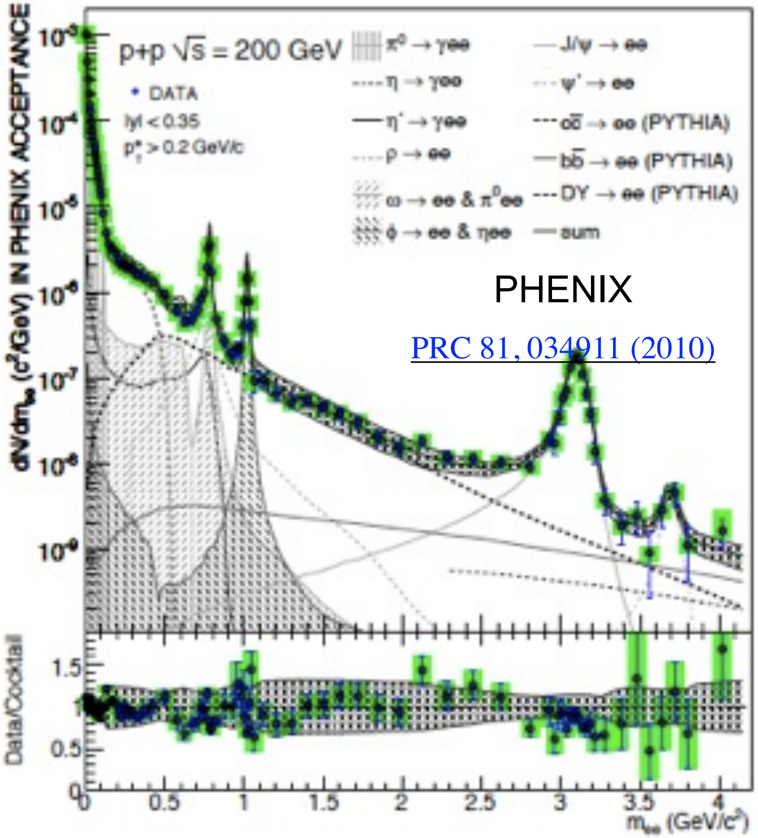


K and ϕ in p-p - Comparison



Data in agreement within ~20%

c/b in p-p - Comparison



e^+e^- invariant mass cocktail gives a good description of the PHENIX data - including charm and bottom predictions from PYTHIA

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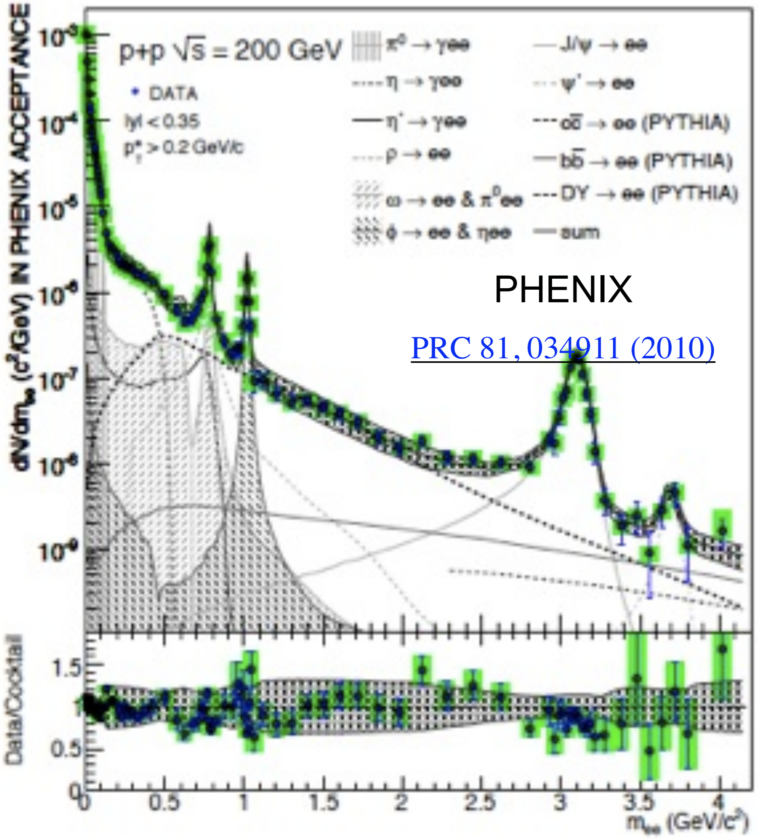

PHENIX

PRC 81, 034911 (2010)

Long standing disagreement over NPE yield between STAR and PHENIX

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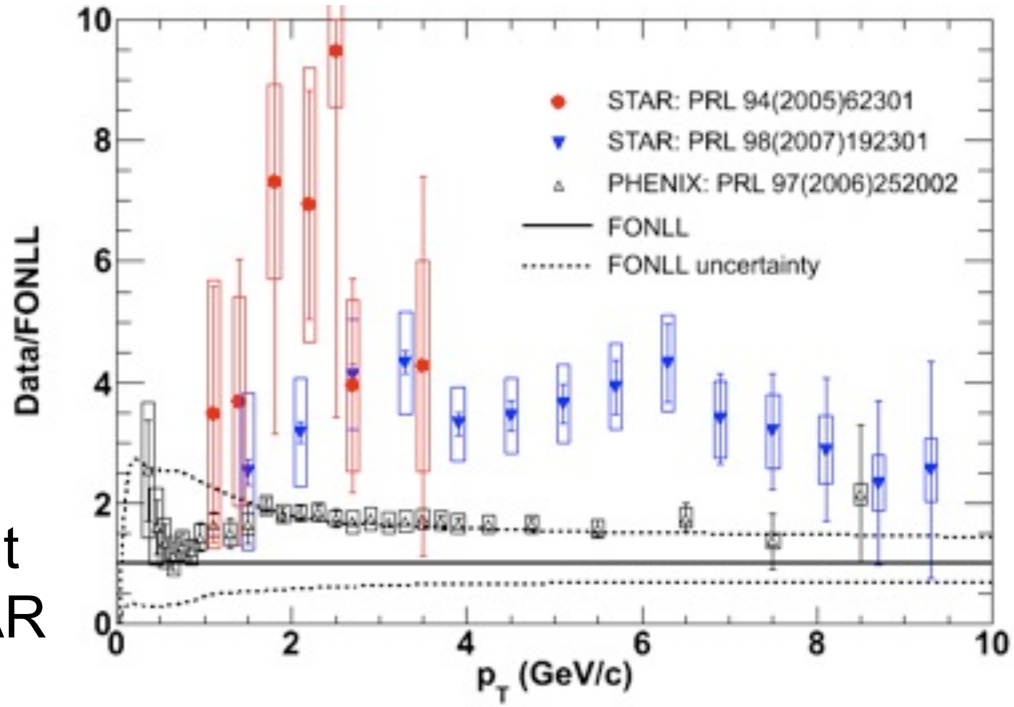

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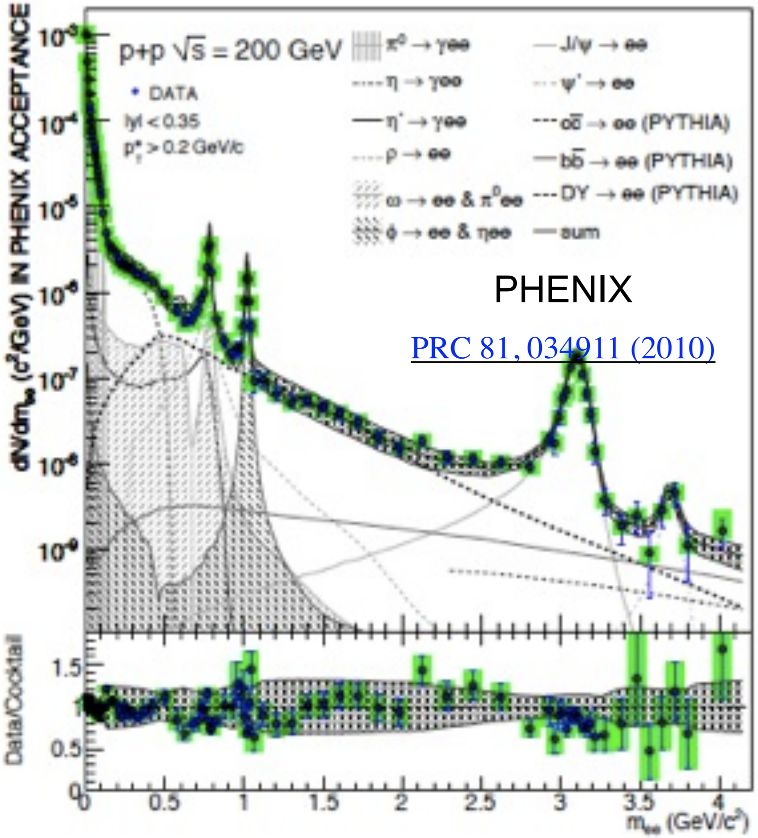

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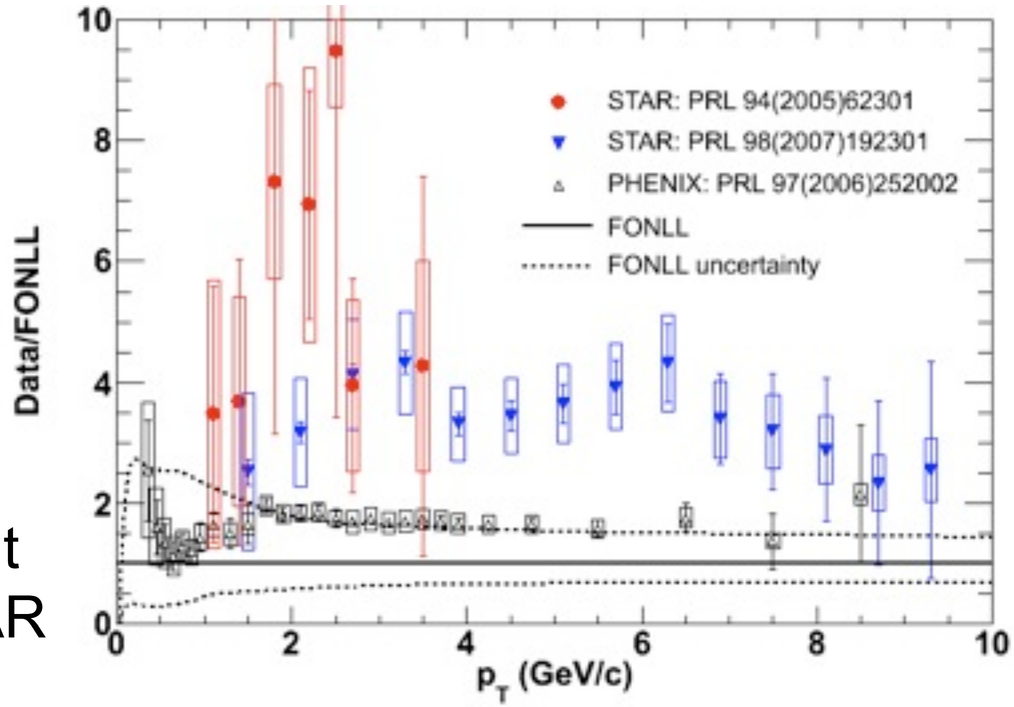
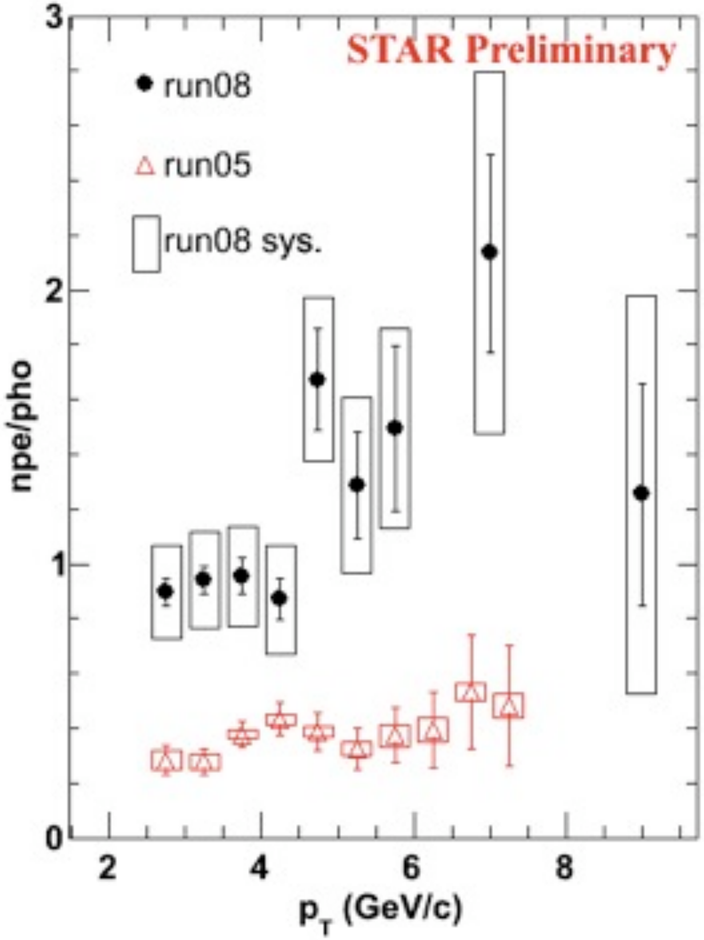
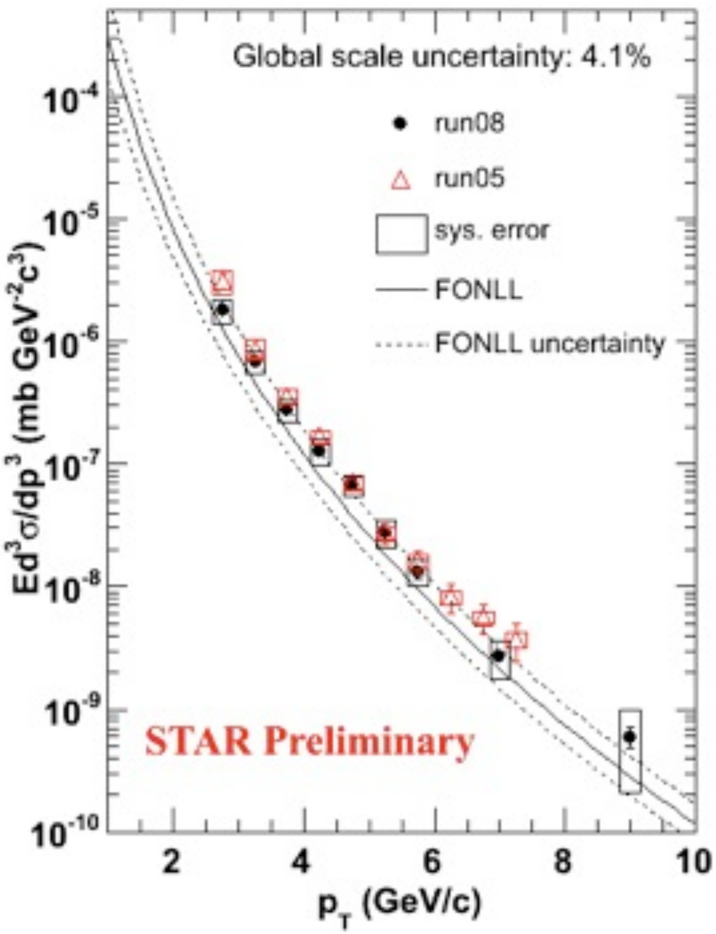


Long standing disagreement over NPE yield between STAR and PHENIX

STAR removed inner silicon - less conversion contamination

NPE STAR p-p - new analysis





W. Xie DIS2010

Despite dramatically different background Run 8 low mass data and new analysis of Run 5 give consistent results

NPE STAR p-p - new analysis

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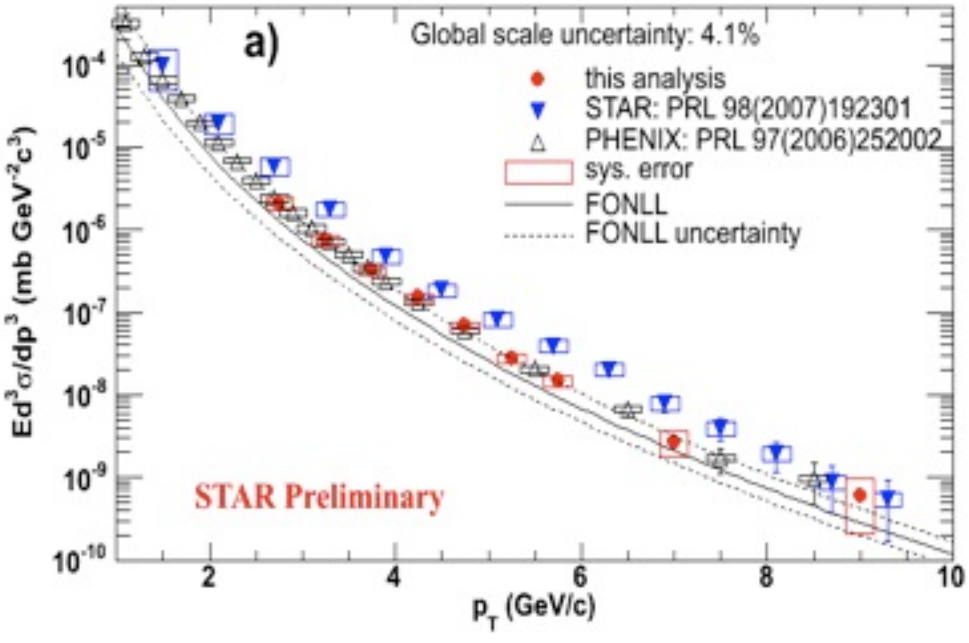

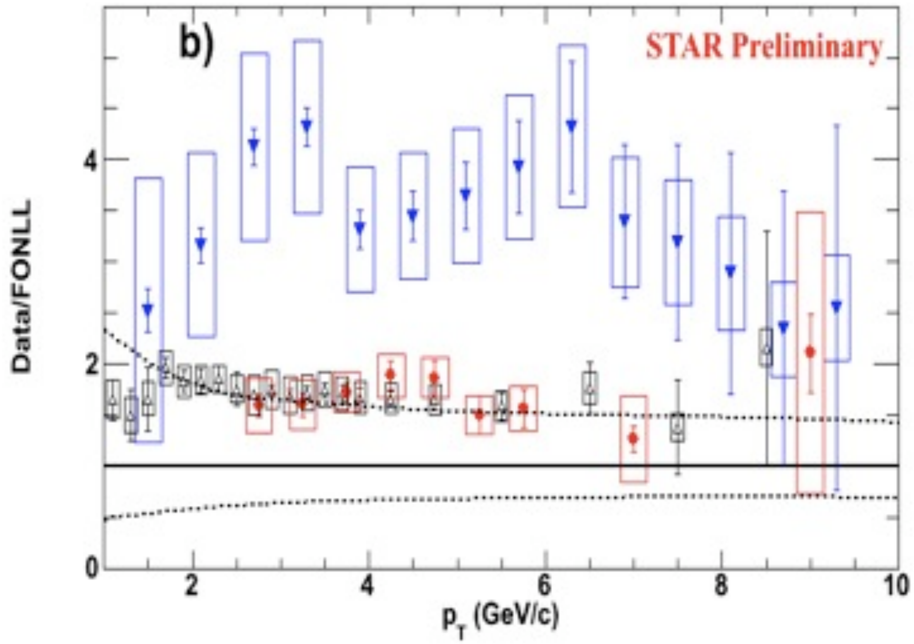

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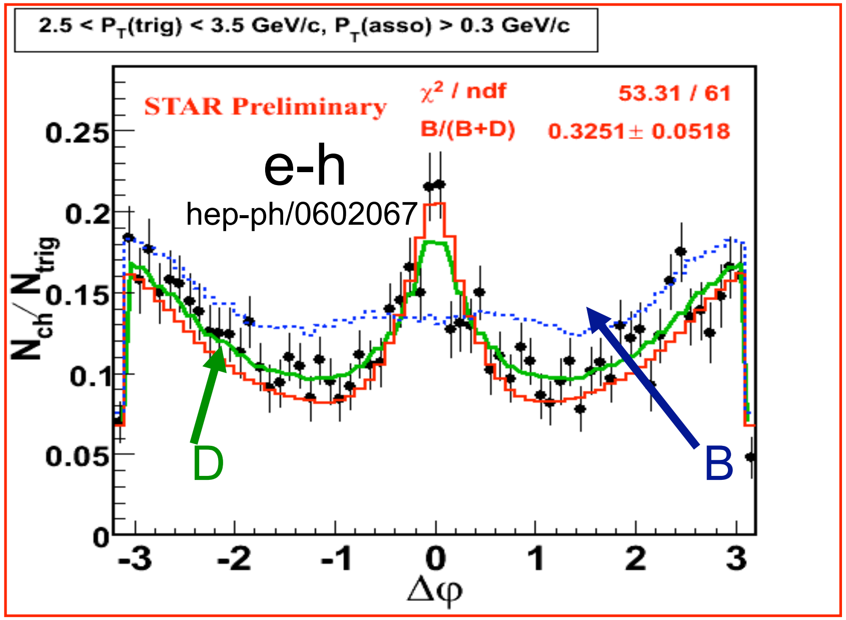
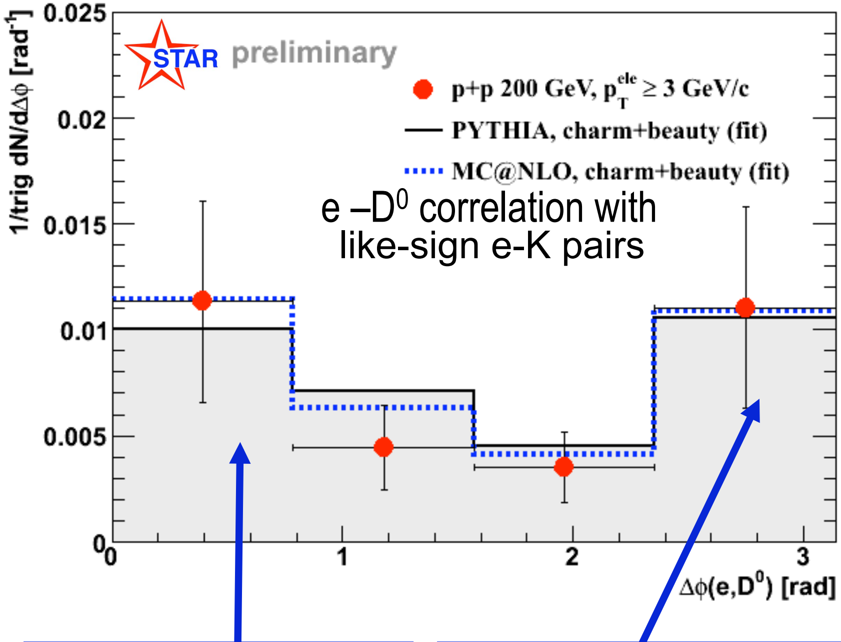
STAR and PHENIX p-p NPE consistent within errors

Disentangling bottom and charm in NPE





B wider than D due to decay kinematics and mass.

essentially from B decays only

≈75% from charm
≈25% from beauty

Combined fit to data reveals the B meson contribution to NPE

$$\Delta\phi_{e-h} = r_B \Delta\phi^{B}_{e-h} + (1 - r_B)\Delta\phi^{D}_{e-h} \qquad r_B = e_B / (e_D + e_B)$$

At p_T= 5 GeV/c Bottom contribution is ~50%

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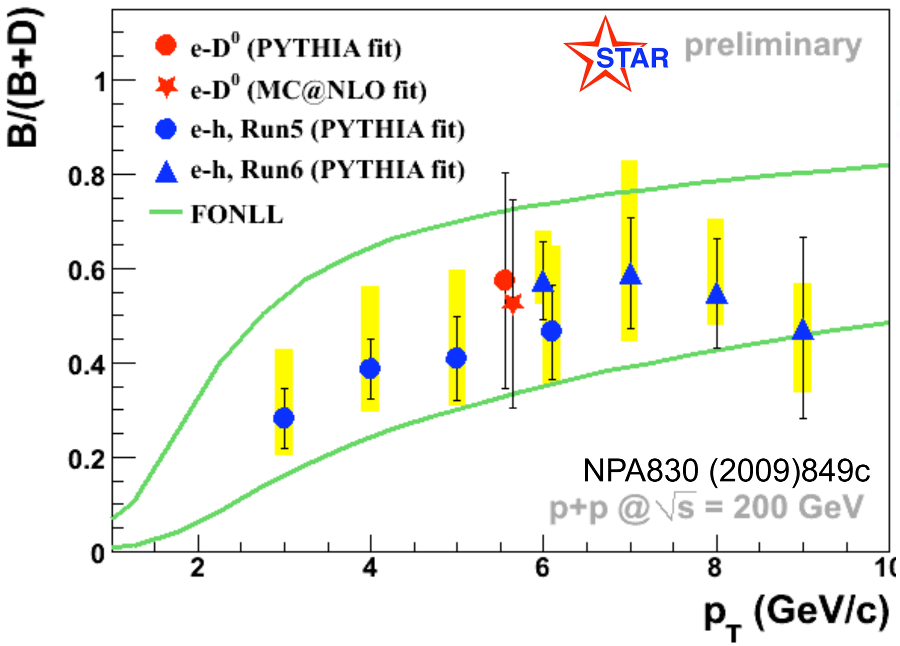

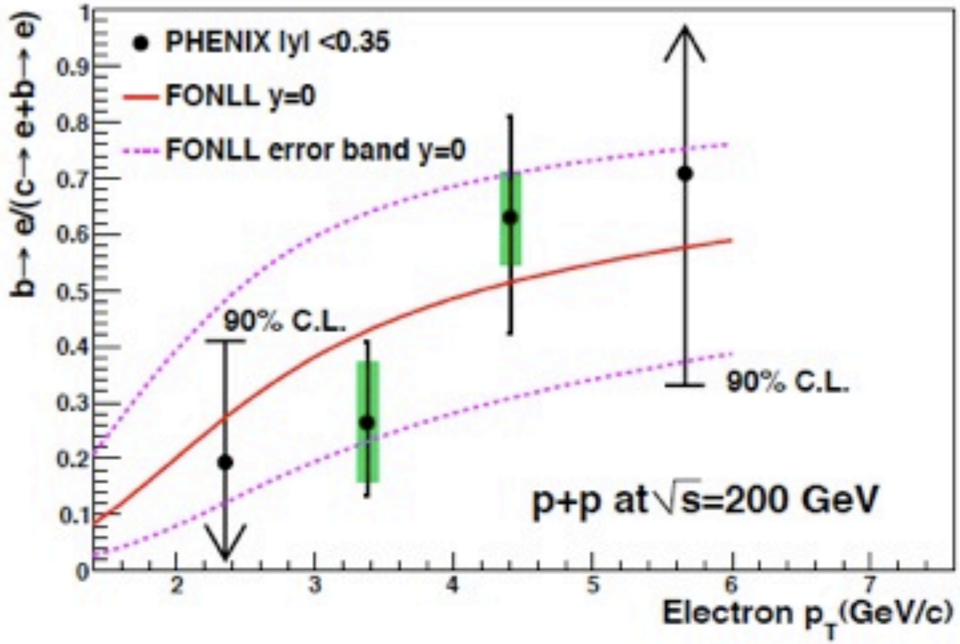

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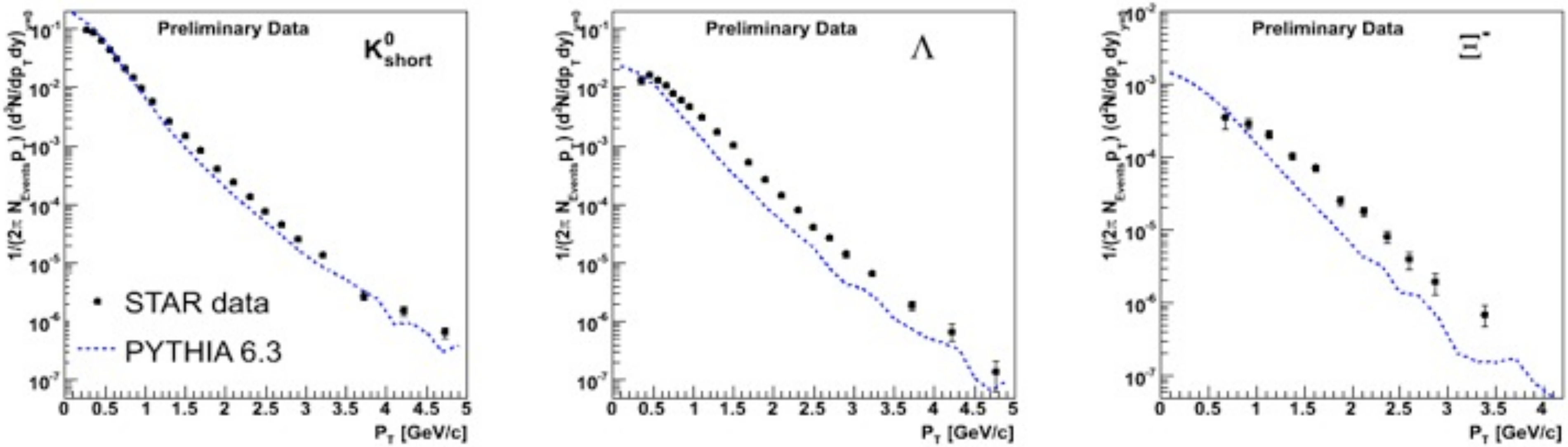
Strange and multi-strange p_T spectra

- 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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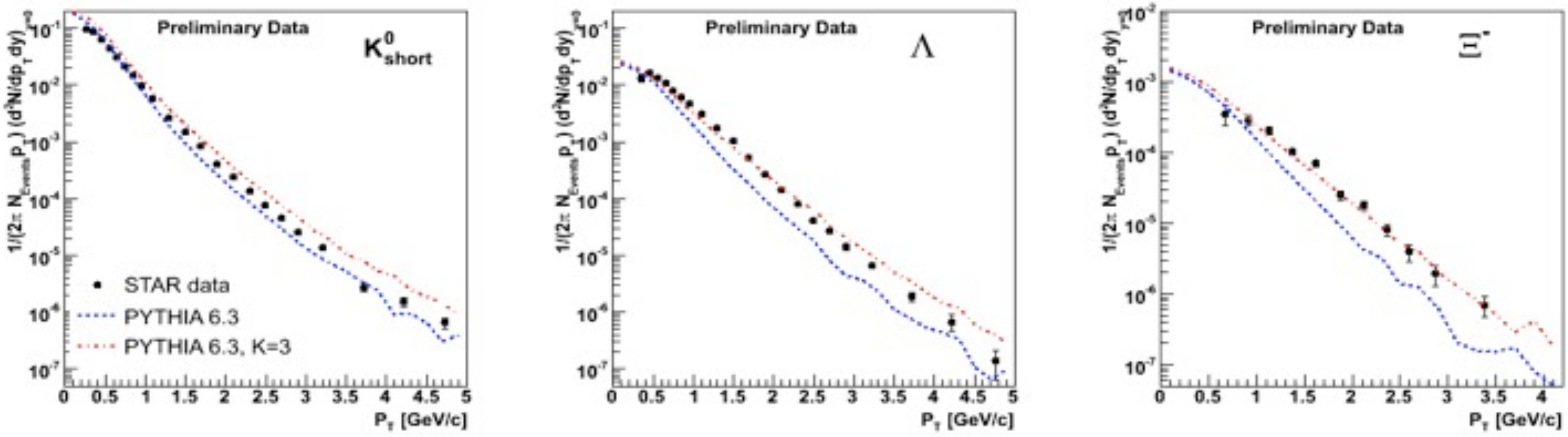
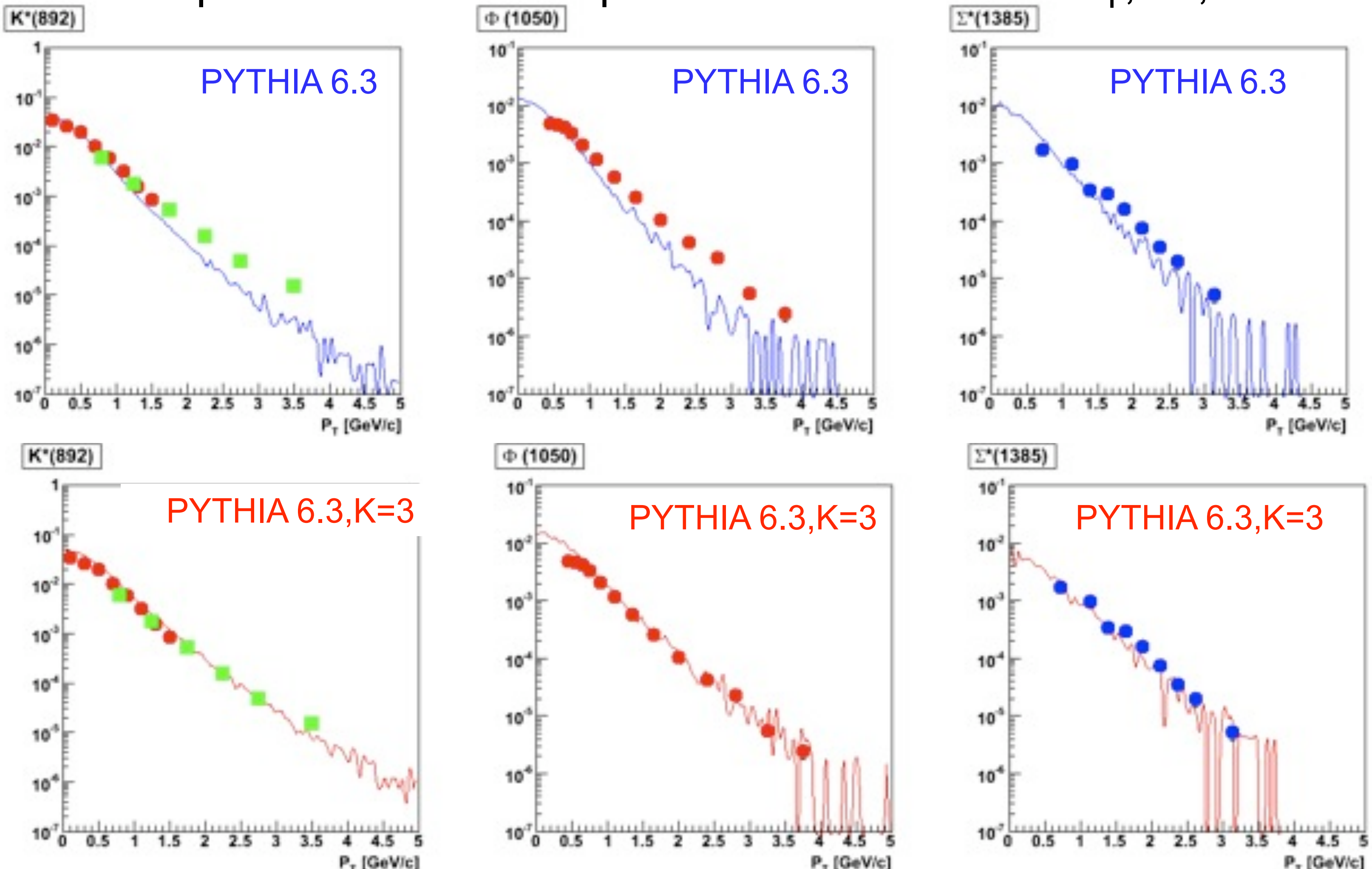


Necessary to tune: K-Factor (accounts for NLO contribution)

There are also resonance measurements

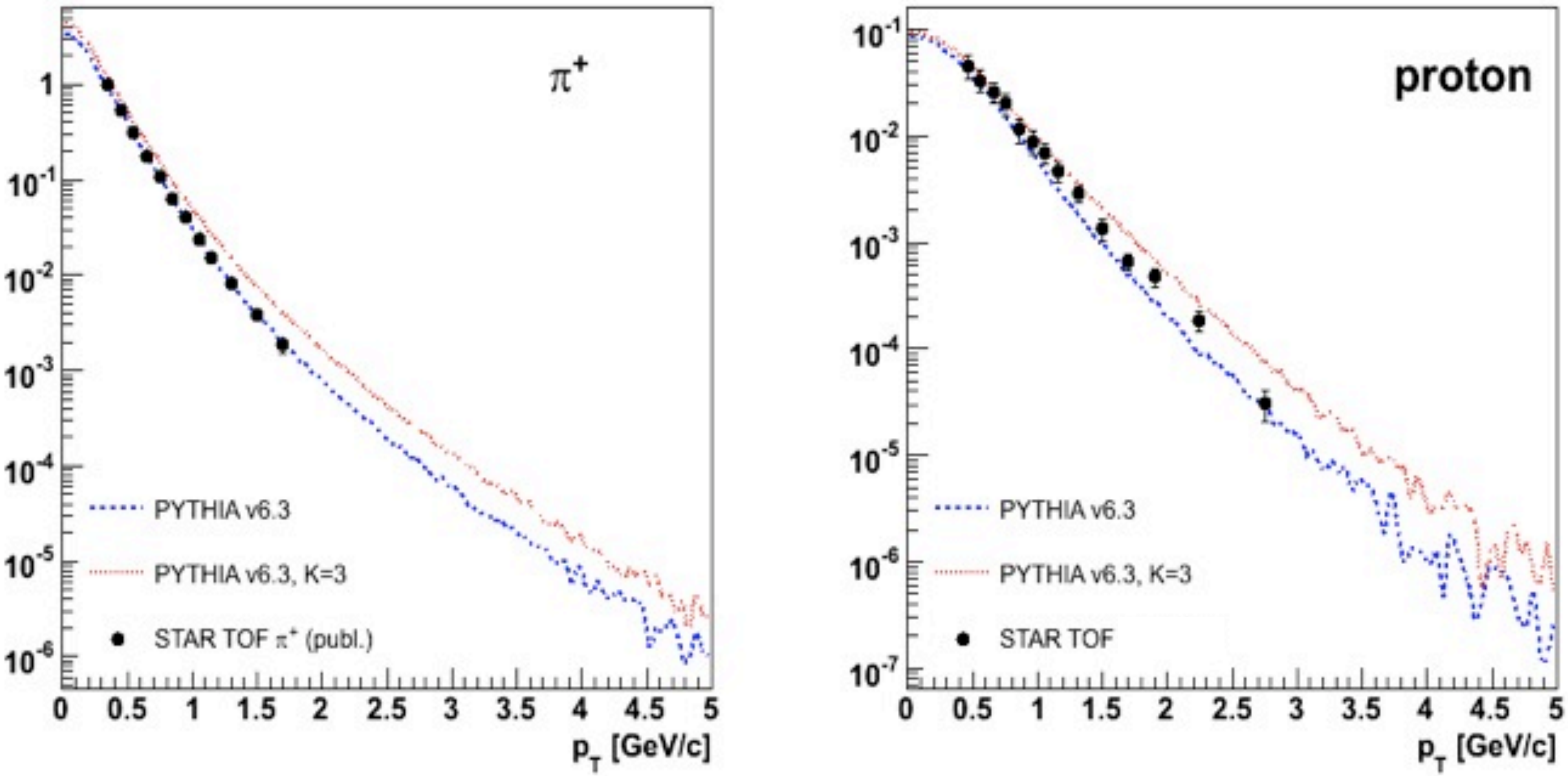
- Compare PYTHIA 6.3 to published STAR data on ϕ, K*, Σ^*



Resonance data also need K=3 for good description

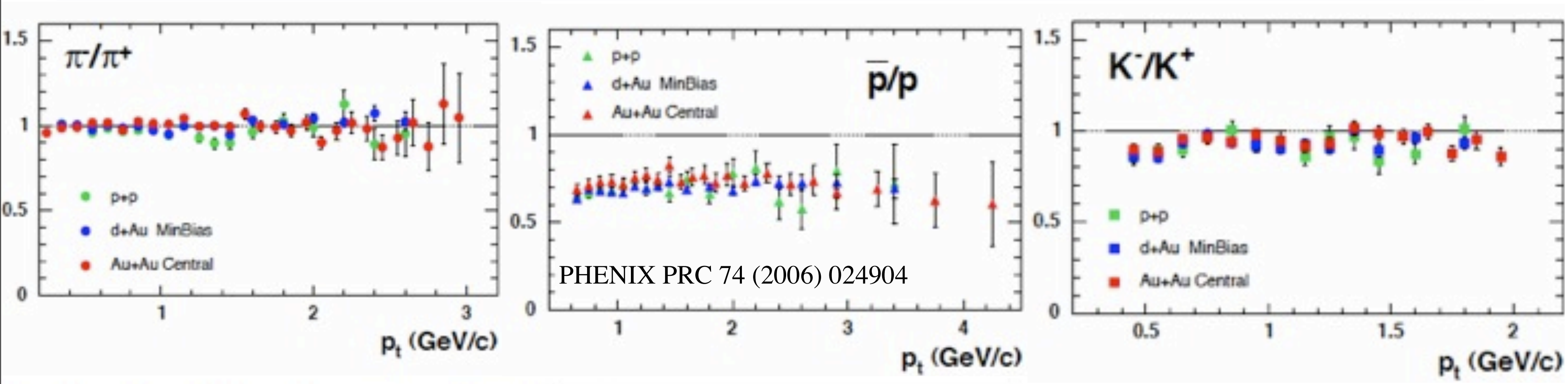
Non-strange particles

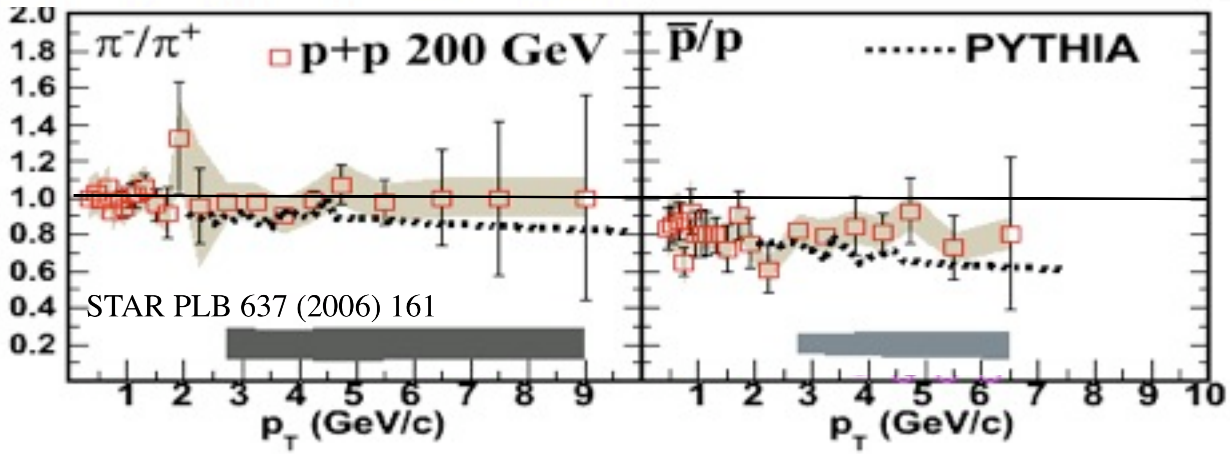
- Good agreement for π with K=1 but not for K=3
- proton with 1< K <3

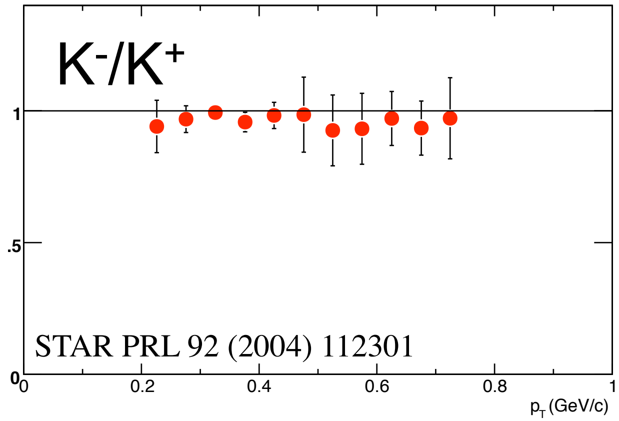


Need different K factors for different particles!

Anti-particle/particle ratios







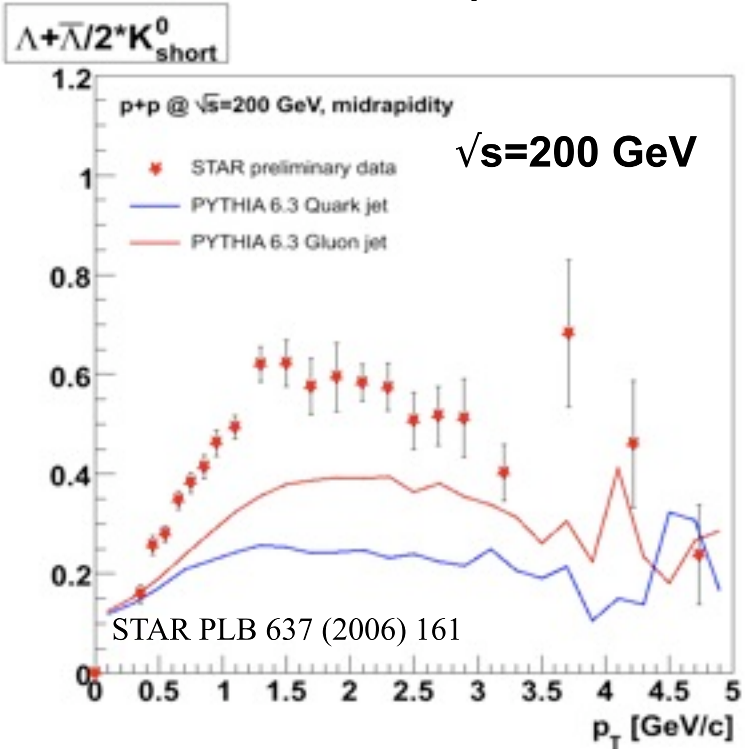
At low p_T ratios are: ~ flat

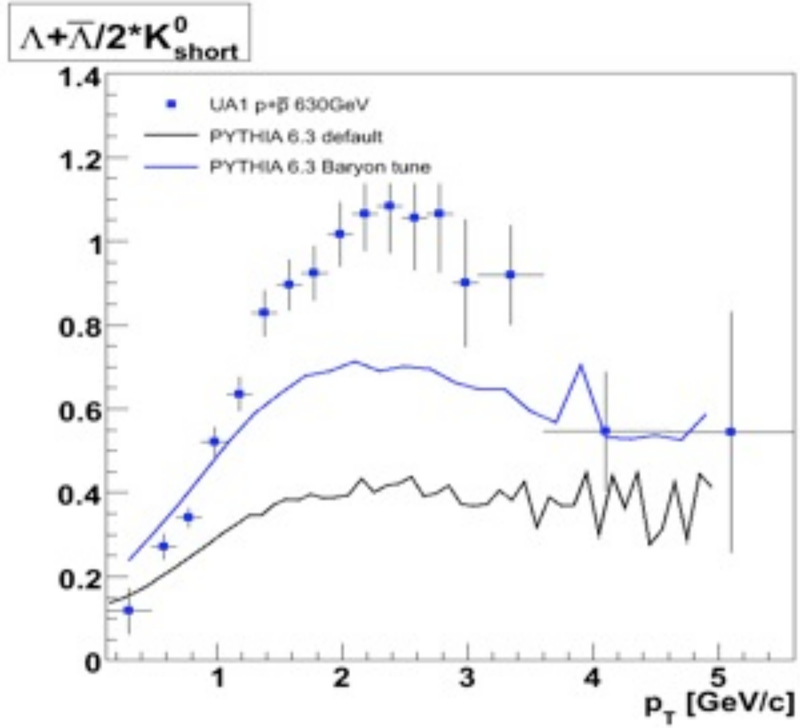
~ reasonably represented by PYTHIA

similar to Au-Au and d-Au

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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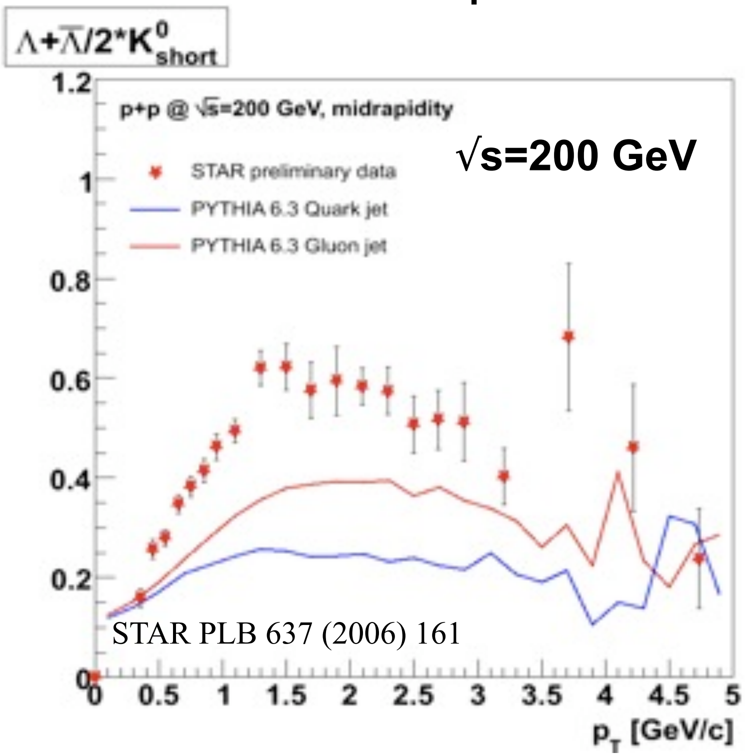

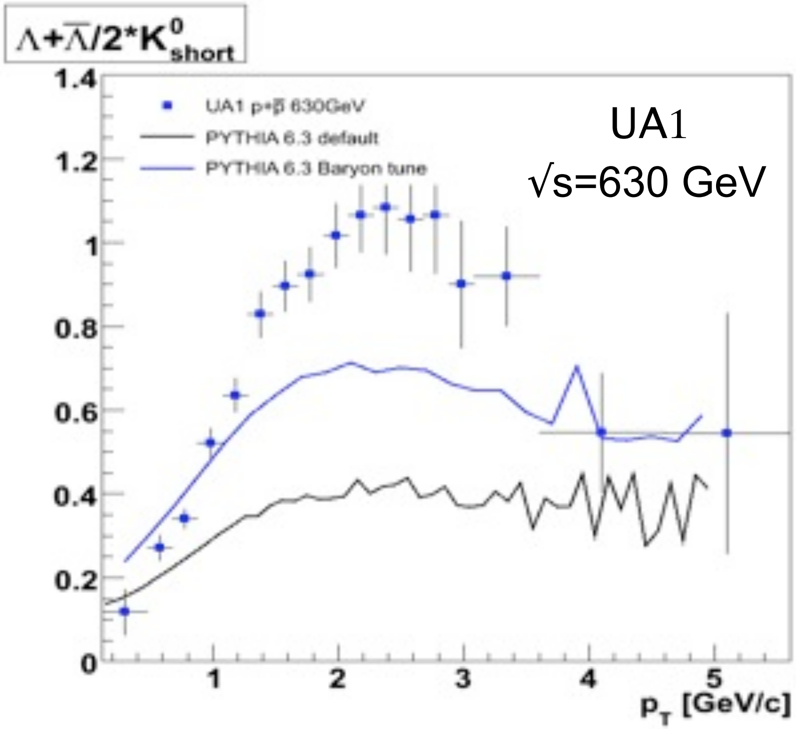

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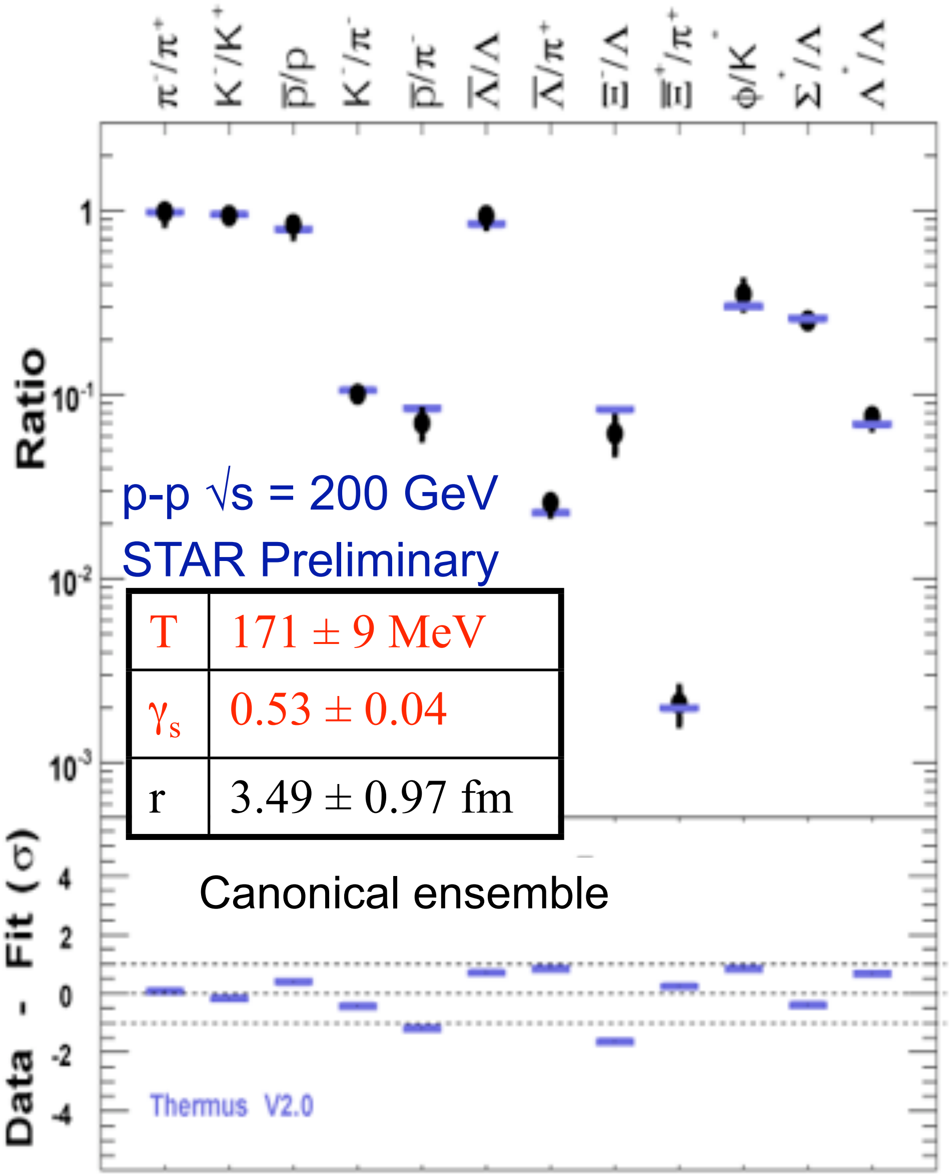
Hadro-chemistry in p+p events



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

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

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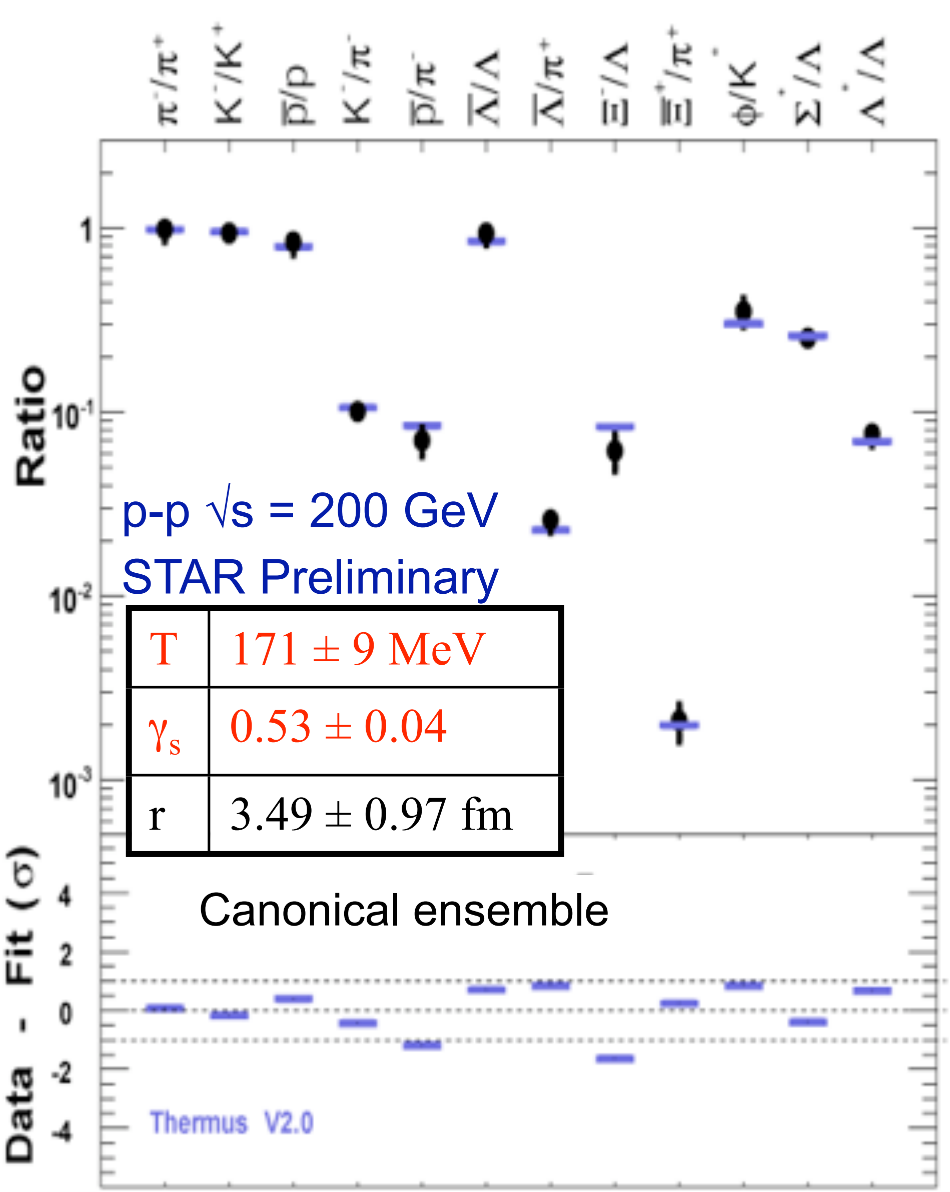

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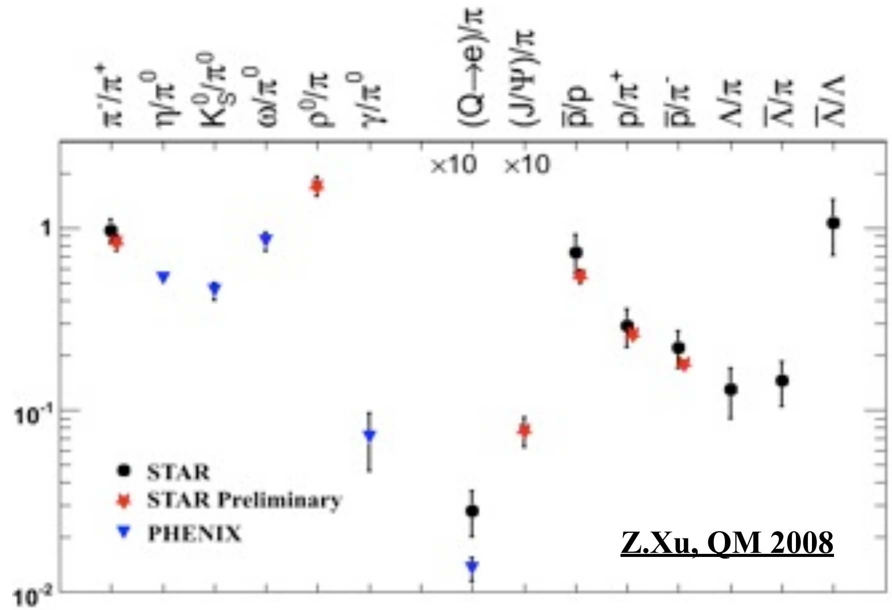

p_T>**5** GeV/c

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

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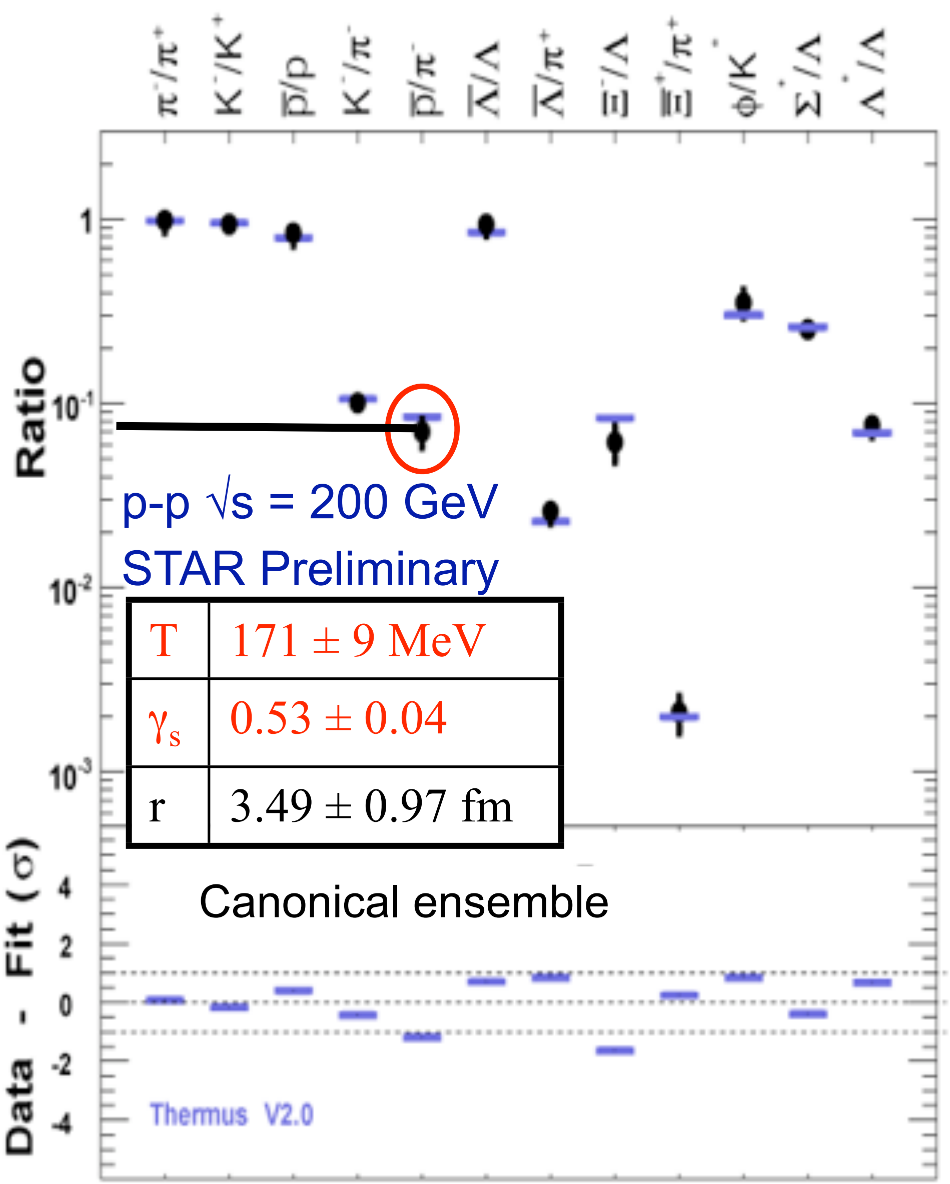

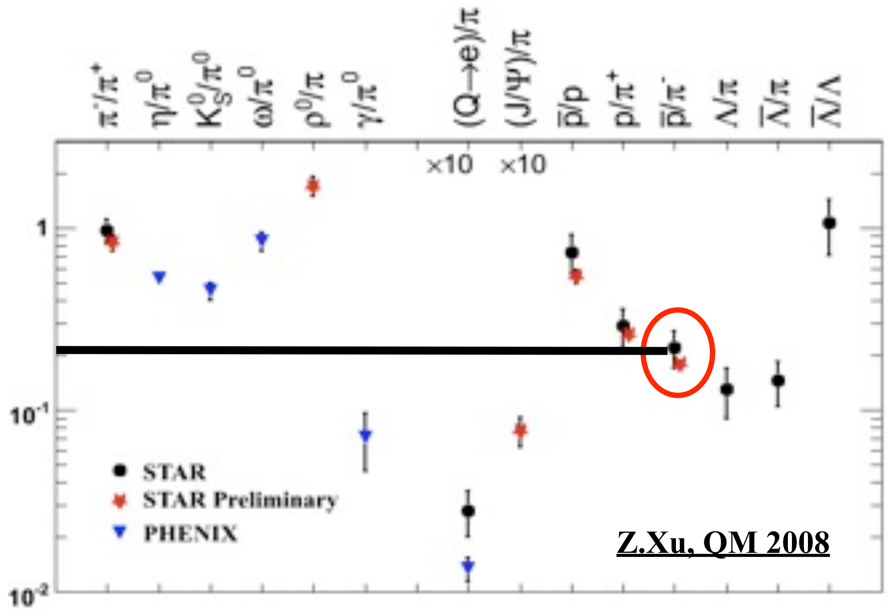

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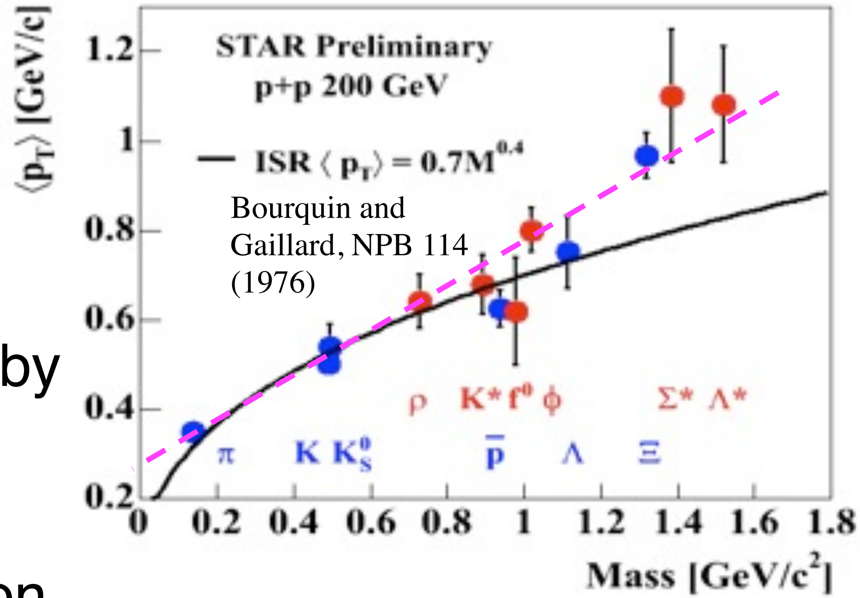
Some ratios change significantly

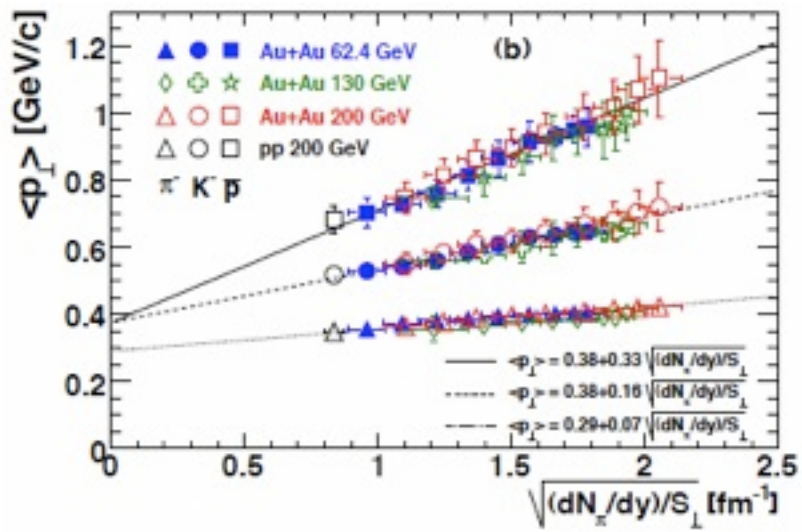
$\langle p_T \rangle$ vs particle mass

Measured particle spectra over large mass range

- Nice agreement with phenomenological curve established by ISR (23 GeV) for lower masses
- Linear dependence better description of data when all masses included
- p-p data fits into A-A systematics

Mass dependence but don't expect flow in p-p





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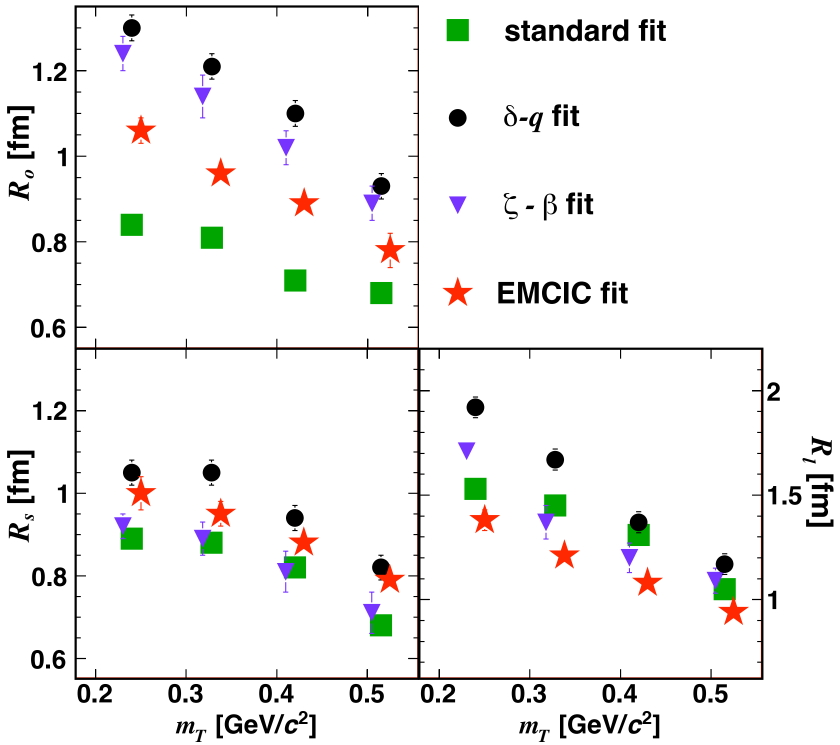
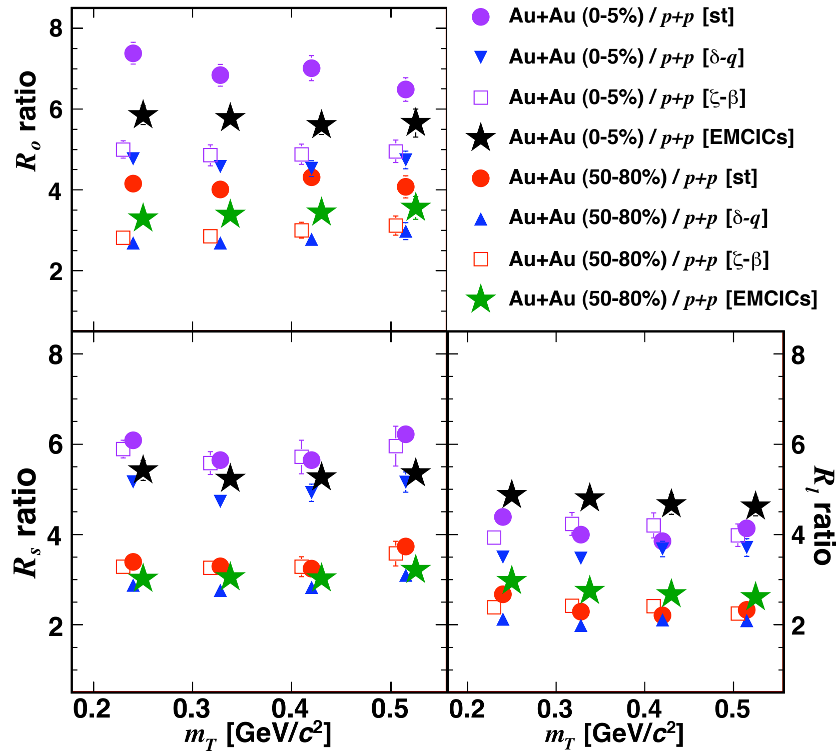
HBT in p-p

STAR arXiv: 1004.0925





Radii:

- ~1 fm (the size of a proton)
- all drop as a function of m_T

- Slope of radii as function of m_T same as in Au-Au

m_T trend used as evidence of flow in Au-Au

Taking a closer look at the events

- Minimum-bias events: Hard + Soft
- Hard Scattering : Back-to-back jet
- Underlying Event: soft or semi-hard multiple parton interactions (MPI), initial & final state radiation, beam-beam remnants

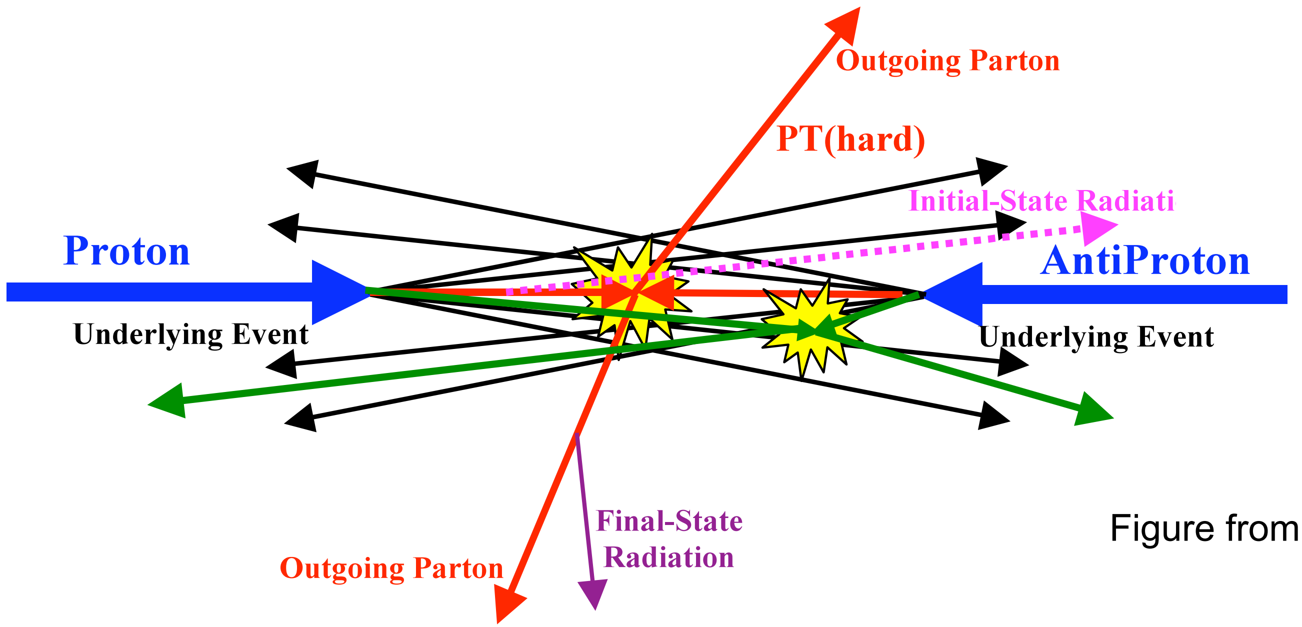
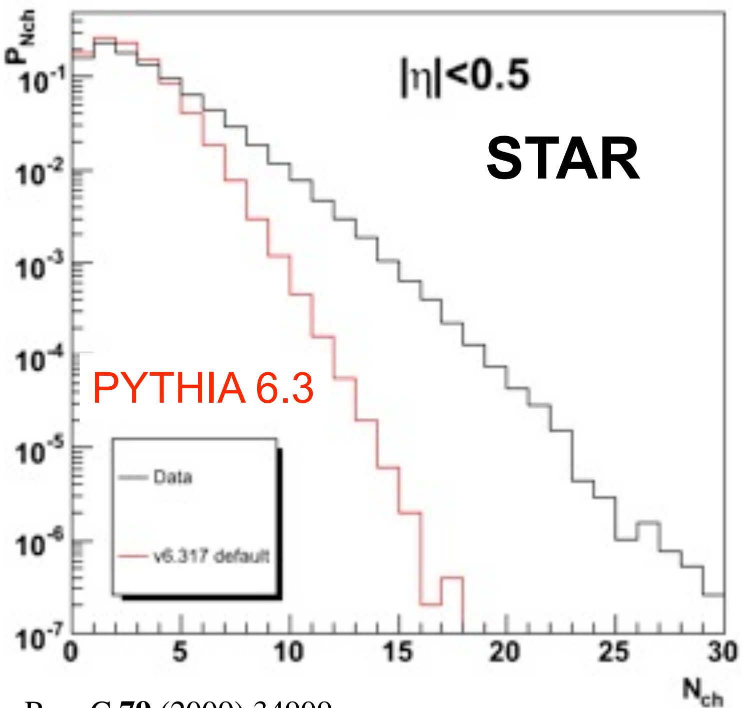


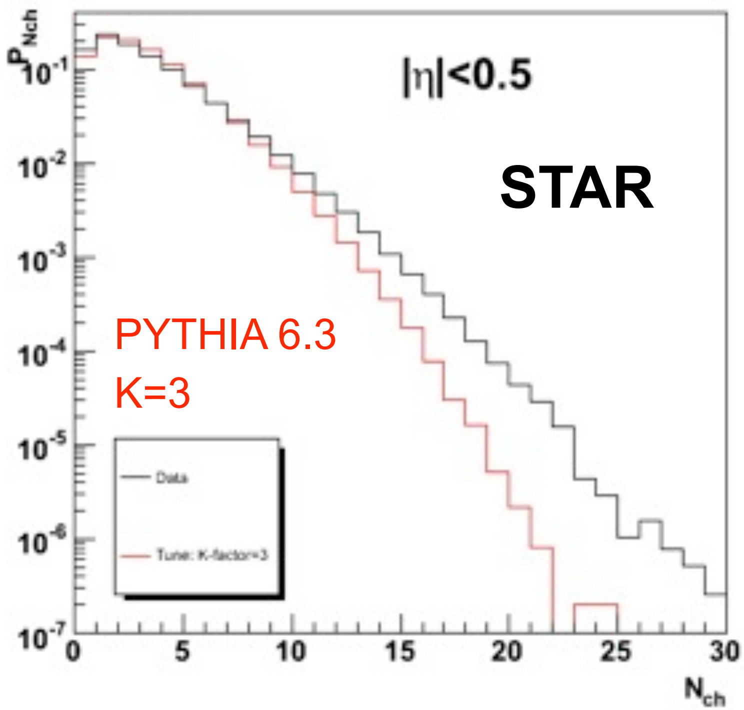
Figure from Rick Field

What does each component contribute to an event?

Charged particle multiplicity distribution

PYTHIA + simulated trigger and detector acceptance





Phys. Rev. C **79** (2009) 34909

- Minimum-bias distribution dominated by low multiplicity events

Probability of high multiplicity events occurring very sensitive to NLO corrections

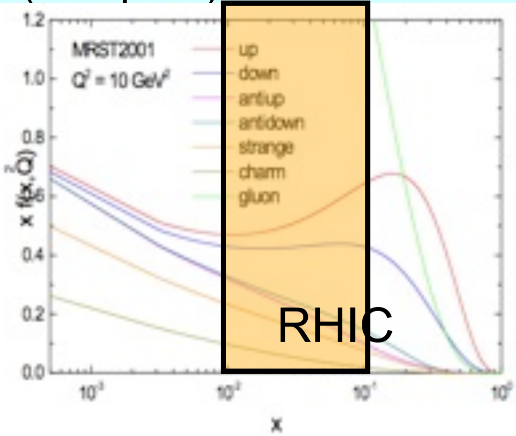
Modeling the collision - pQCD ansatz

$$\frac{d\sigma_{pp}^{h}}{dy d^{2} p_{T}} = K \sum_{abcd} \int dx_a dx_b f_a(x_a, Q^2) f_b(x_b, Q^2) \frac{d\sigma}{d\hat{t}}(ab \circledR\ cd) \frac{D_{h/c}^{0}}{\pi z_c}$$

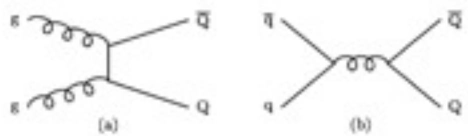
Assume that the calculation is factorizable

K factor

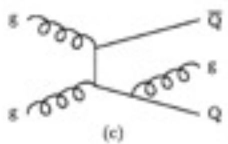
Parton Distribution Function (non-pert.)



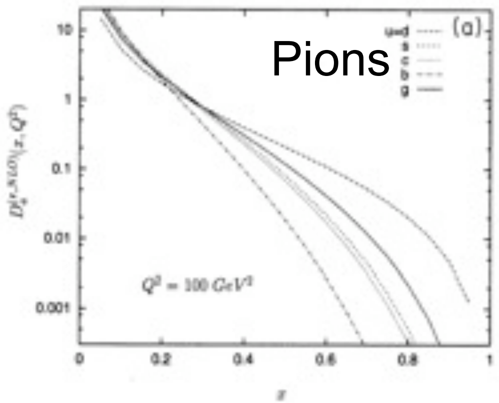
LO parton processes



NLO parton processes



Fragmentation Function (non-pert.)



BKK, Phys Rev D (1995)

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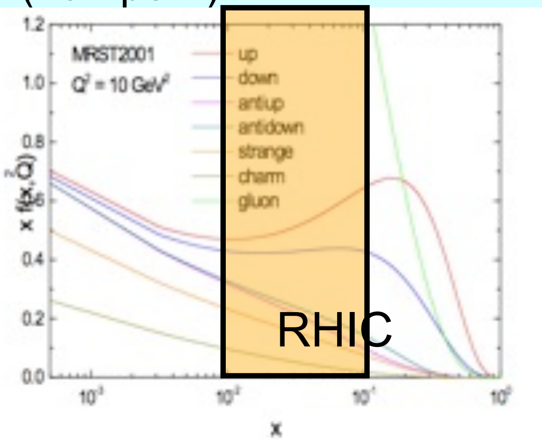

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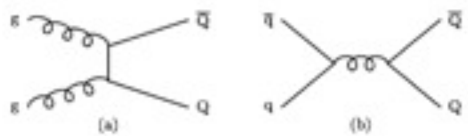

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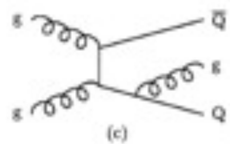

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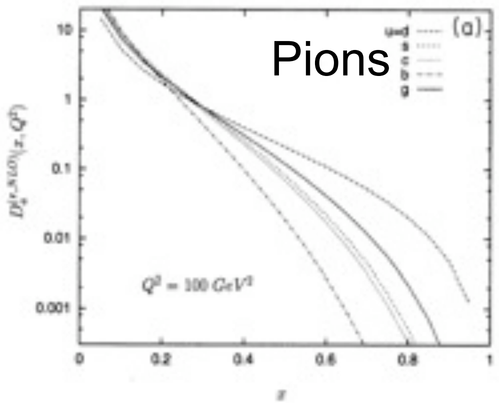
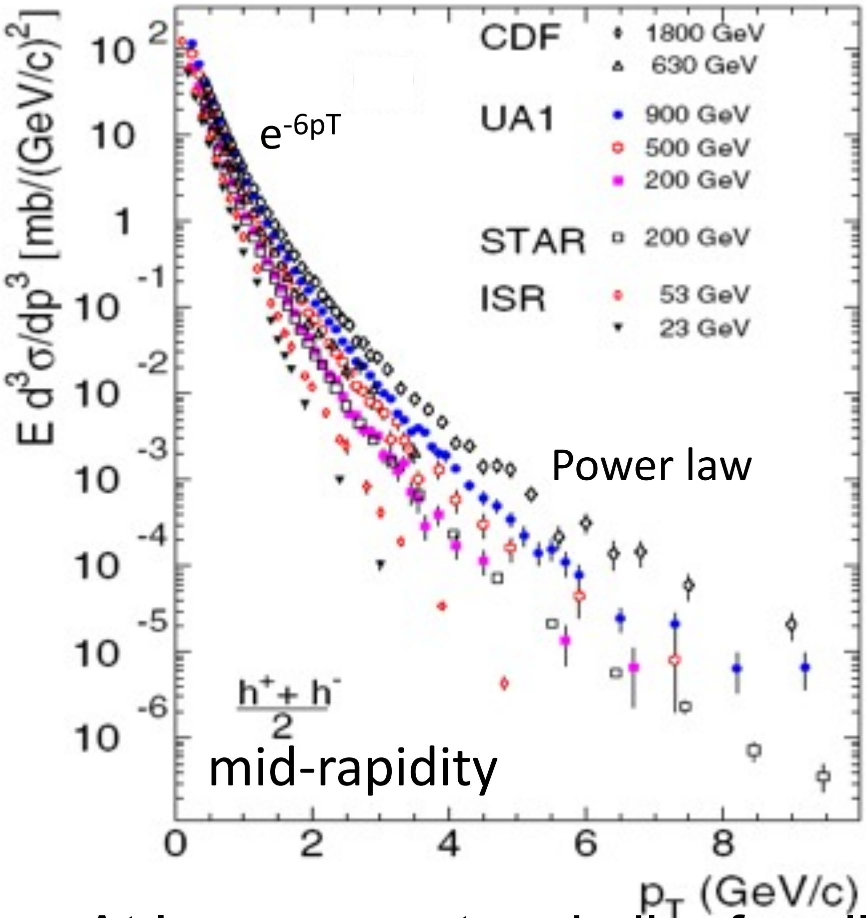


BKK, Phys Rev D (1995)

p-p collisions “messy”

Not all energy involved in the collision

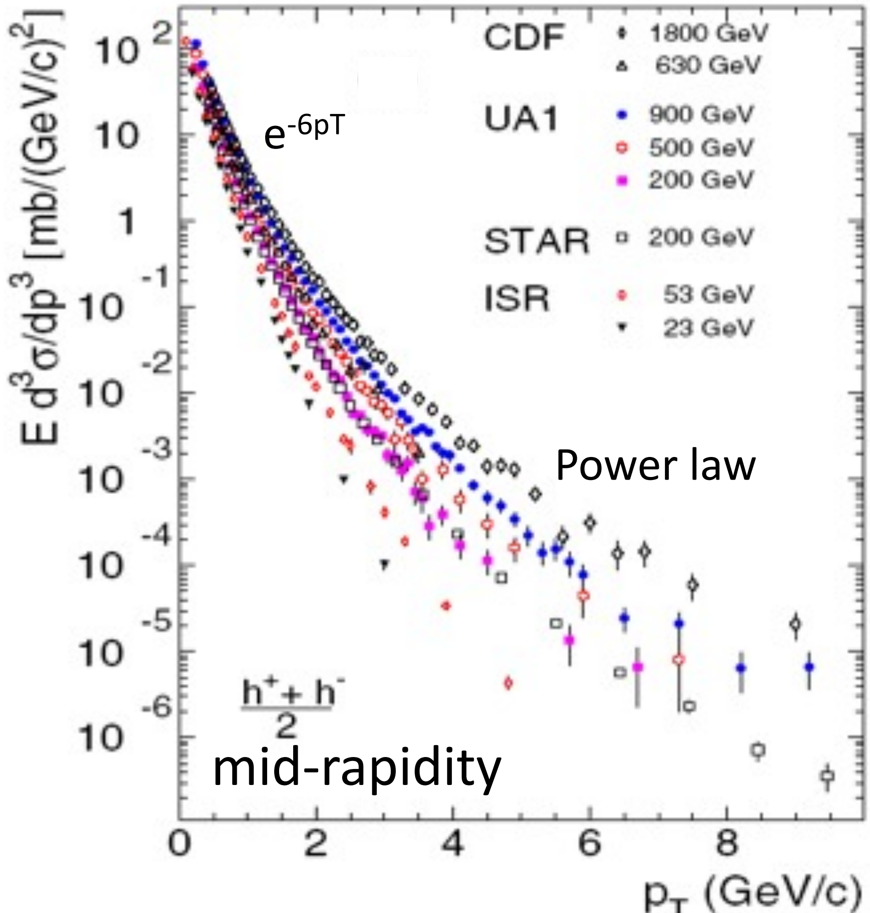
Charged particle p_T distribution

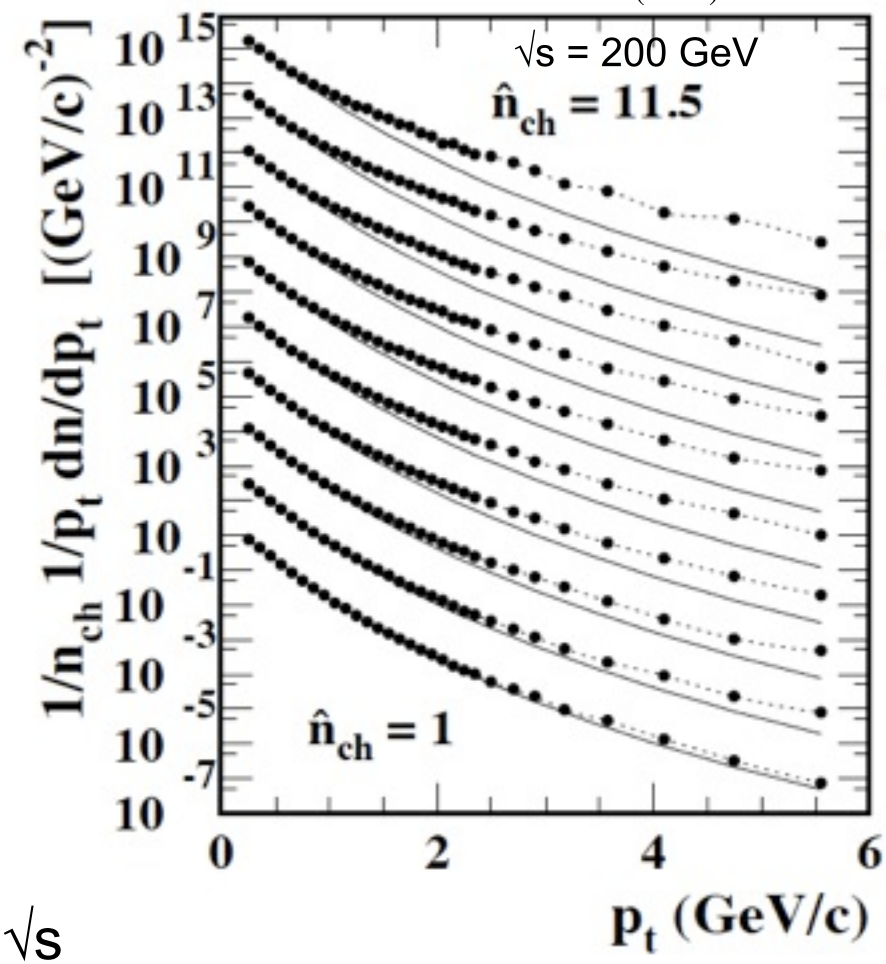


- At low p_T spectra similar for all $\sqrt{s}$
- Power-law tails dependent on $\sqrt{s}$

Charged particle p_T distribution

STAR: PRD 74 (2006) 32006





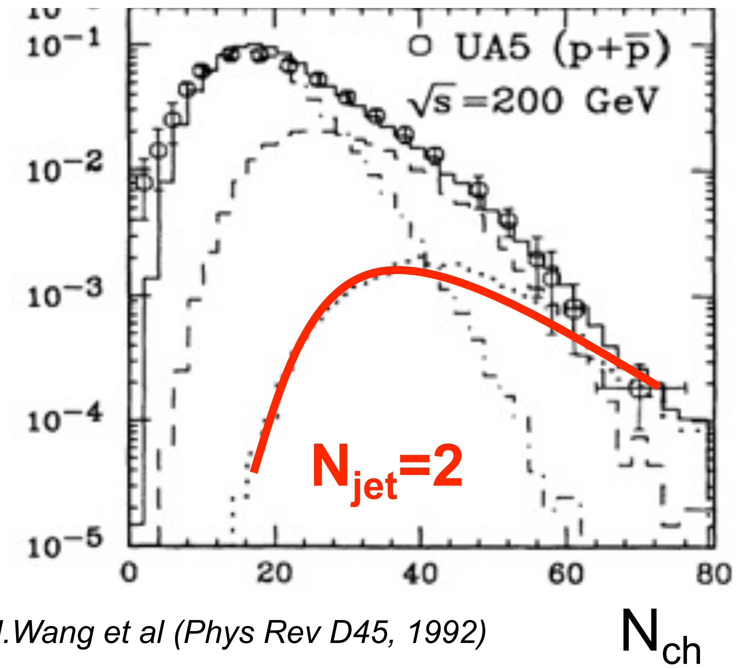
- At low p_T spectra similar for all $\sqrt{s}$
- Power-law tails dependent on $\sqrt{s}$
- Shape dependent on multiplicity

"Hard" and "soft" contributions varying

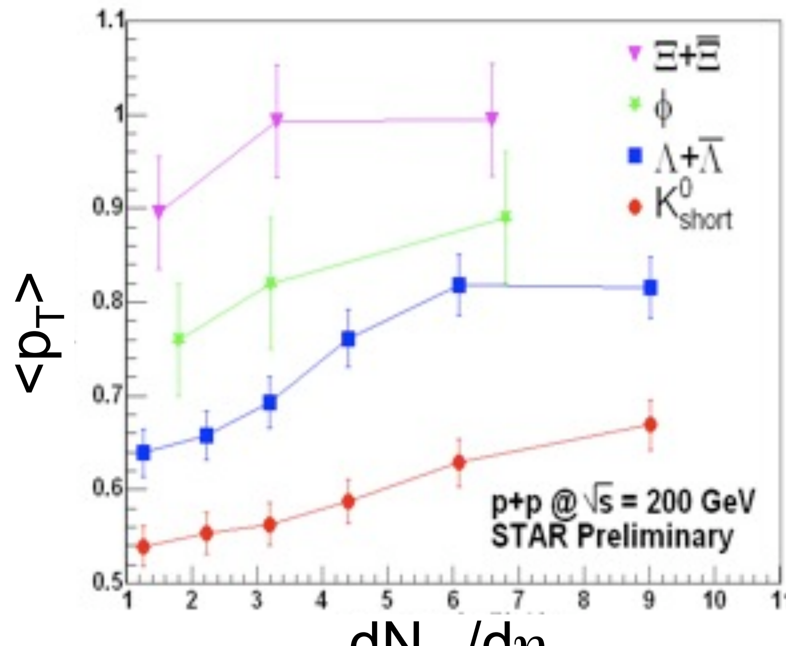
Mini-jet production in p+p

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

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



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



Evidence of jet production in high mult. events

Mini-jet production in p+p

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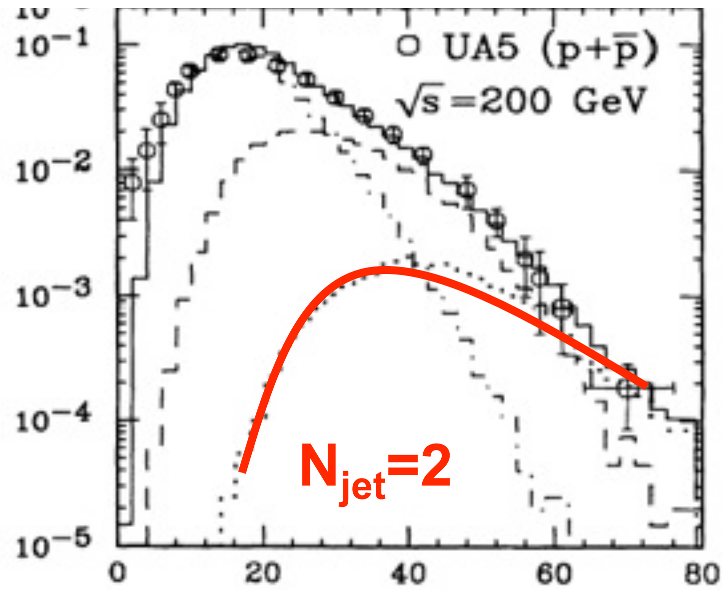

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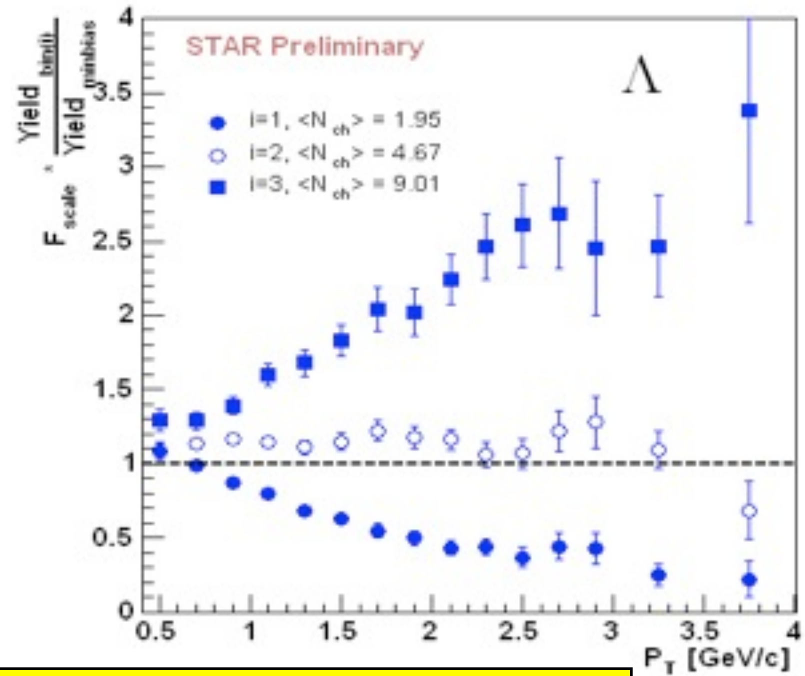


Evidence of jet production in high mult. events

Where do hard scattering processes dominate?

High-p_T particles are produced via hard scattering processes.

Rates calculable via pQCD:

$$E\frac{d^3\sigma}{dp^3} = \frac{1}{\sqrt{s}^n} g(x_T)$$, $x_T = 2p_T/\sqrt{s}$

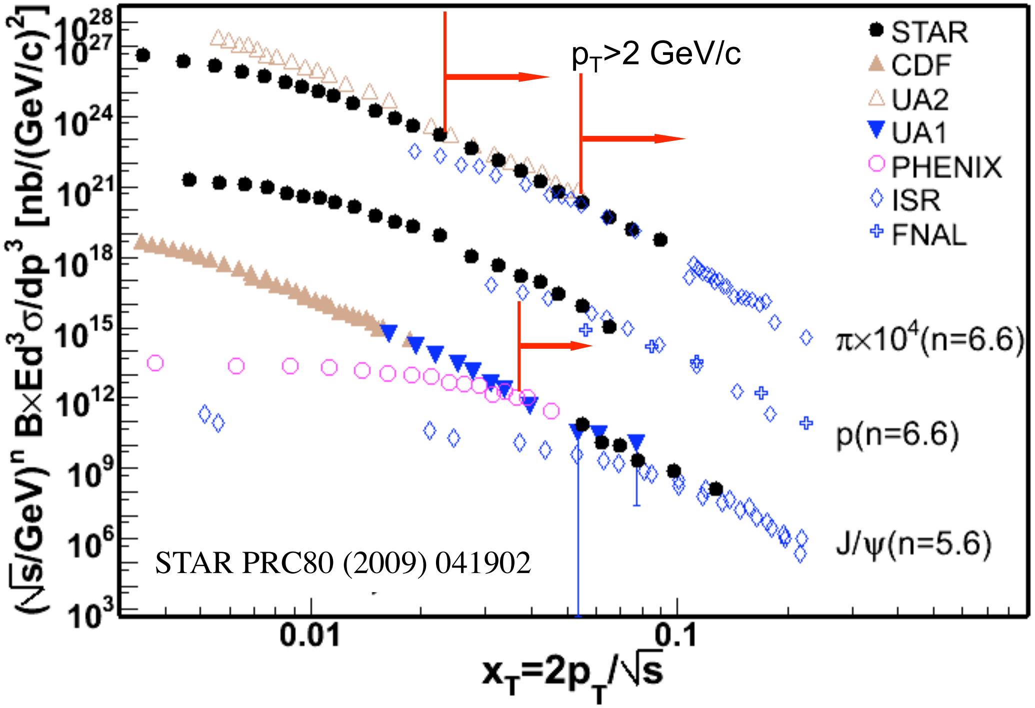
n ~ 4 for basic (vector-gluon) scattering processes

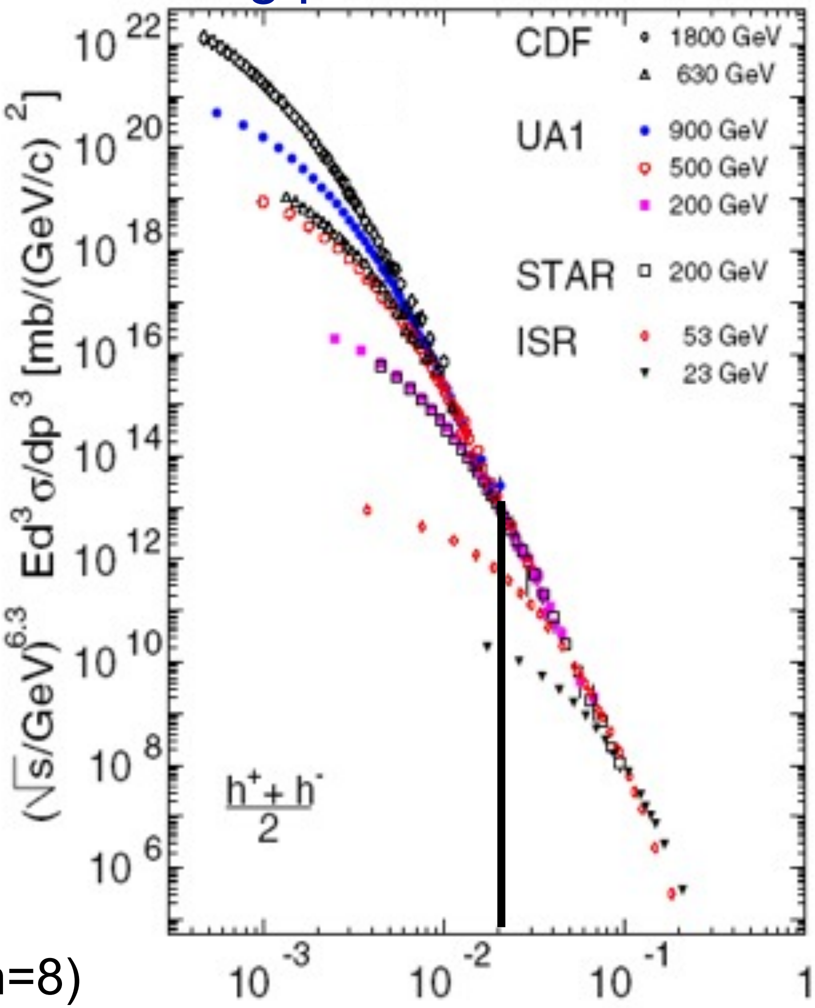
In QCD:

$n \rightarrow n(x_T, \sqrt{s})$ ~ 5-8 depending on evolution of structure functions and fragmentation functions

Where do hard scattering processes dominate?

High-p_T particles are produced via hard scattering processes.





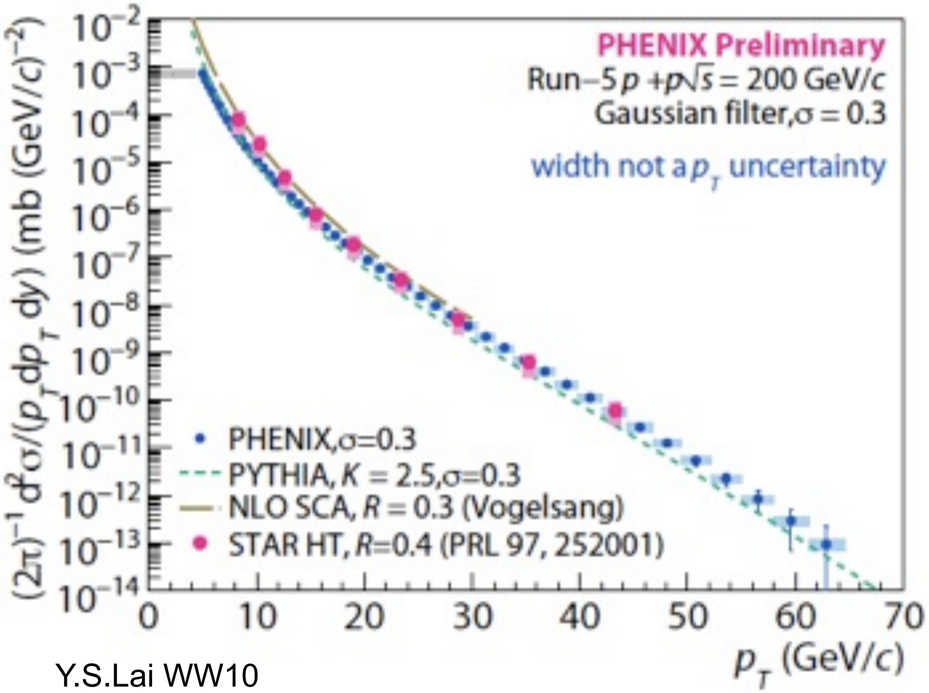
n = 6.3 - 6.5 for $h^{\pm}$, π, K and p

n = 5.6± 0.2 for J/ψ at high p_T

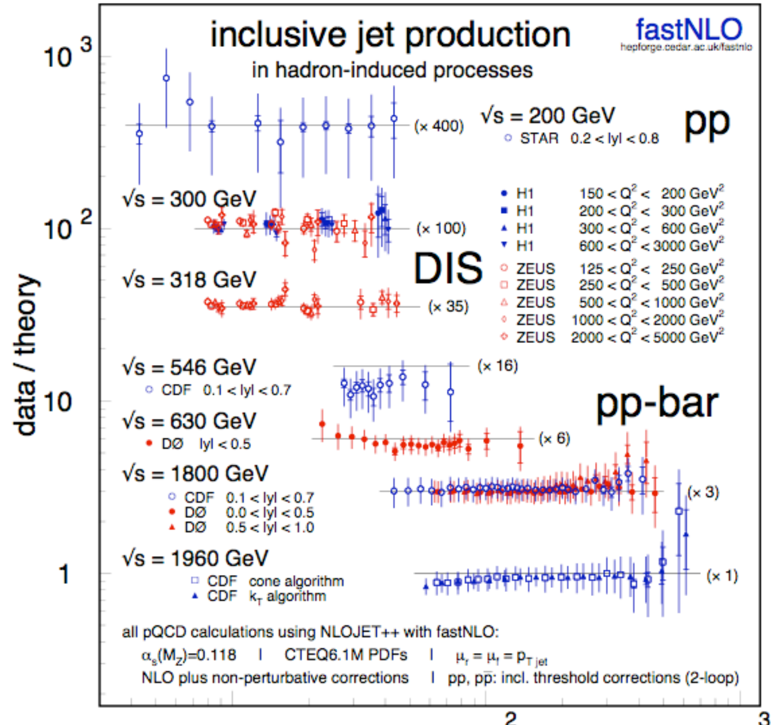
color octet & evaporation (n=6), color singlet (n=8)

Transition from soft to hard processes p_T~2 GeV/c (x_T~ 0.02)

Jets in p-p at RHIC



Y.S.Lai WW10



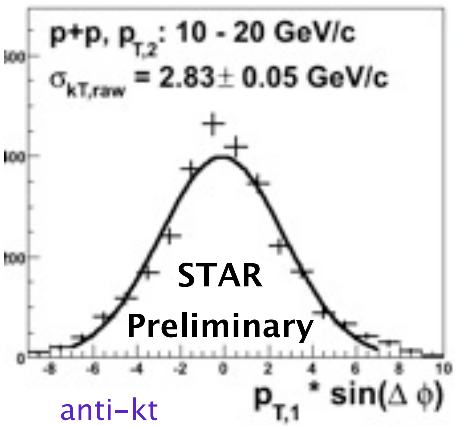
T. Kluge,
K.Rabbertz, M.Wobish

- 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

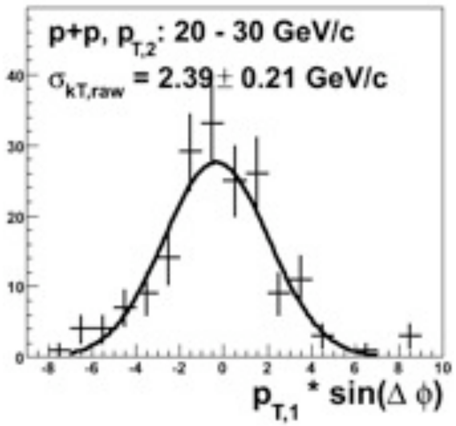
All algorithms used give same result when same R used

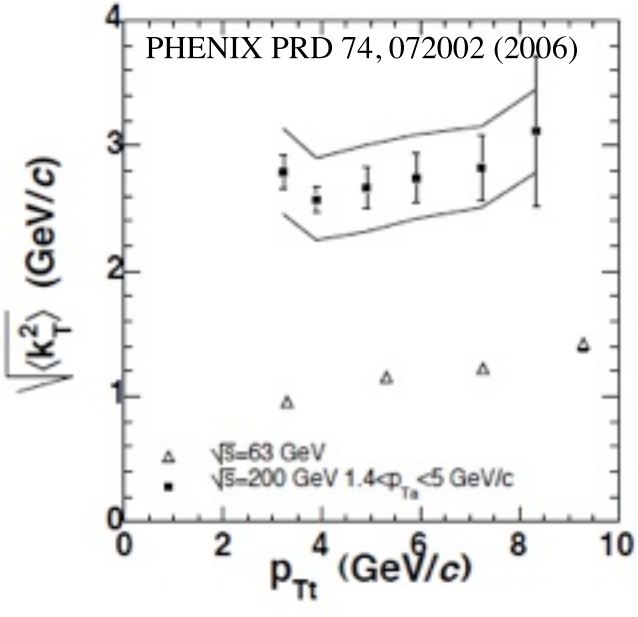
Intrinsic properties - k_T and j_T

J. Kapitán, EPS HEP 2009



anti-kt





k_T = p_T(Jet) sin(ΔΦ)

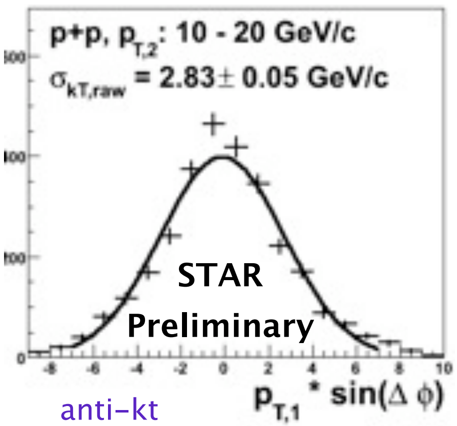
$k_{T,di\text{-}had}$(p-p) = 2.68 ± 0.07 ± 0.34 GeV/c

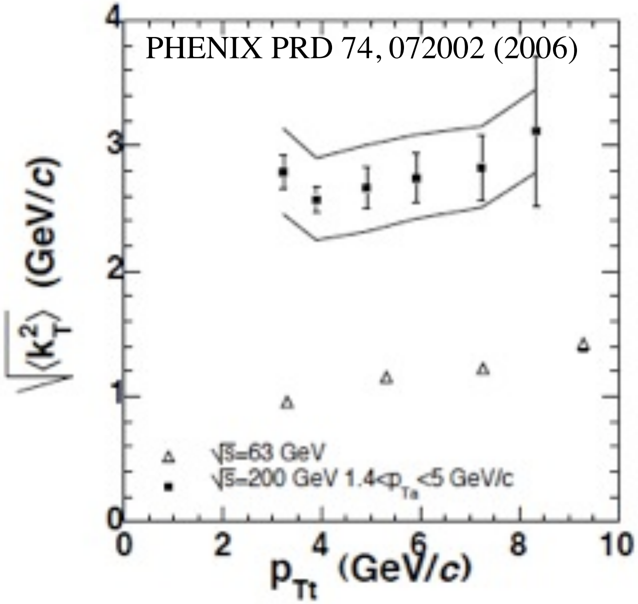
$\sigma_{kT,raw}$ (p-p) = 2.8 ± 0.1 (stat) GeV/c

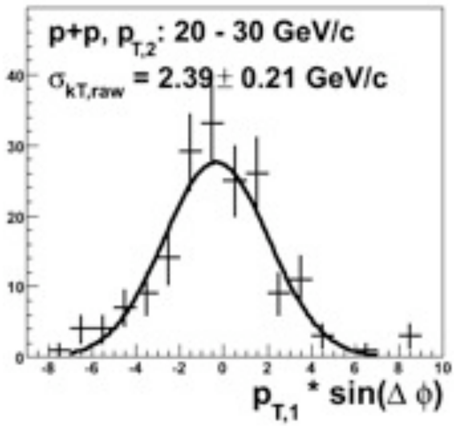
$k_T(\sqrt{s}=200) > k_T(\sqrt{s}=63)$

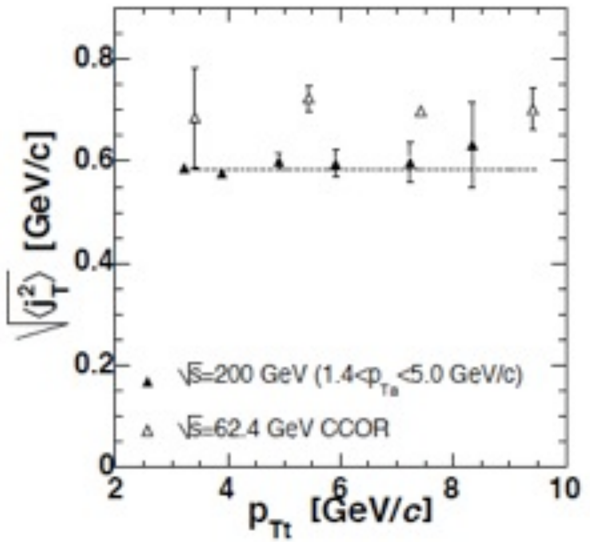
Intrinsic properties - k_T and j_T

J. Kapitán, EPS HEP 2009









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$\sigma_{kT,raw}$ (p-p) = 2.8 ± 0.1 (stat) GeV/c

$k_T(\sqrt{s}=200) > k_T(\sqrt{s}=63)$

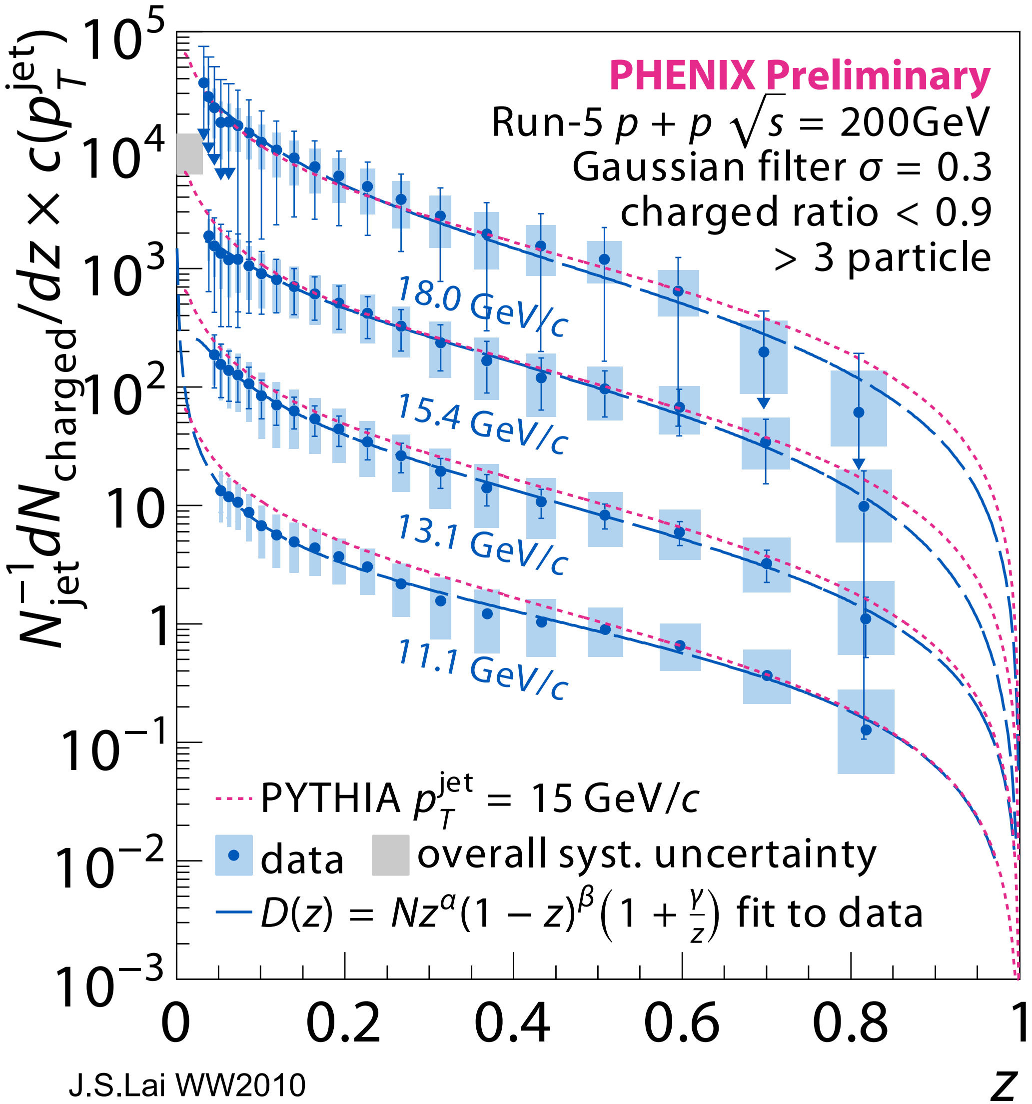
$j_T = p_T(\text{particle}) \sin(\Delta\Phi_2)$

$j_{T,\text{di-had}}$(p-p) = 585 ± 6 ± 15 MeV/c

$j_T(\sqrt{s}=200) = j_T(\sqrt{s}=63)$

k_T and j_T independent of p_T over measured range

Fragmentation functions for charged hadrons



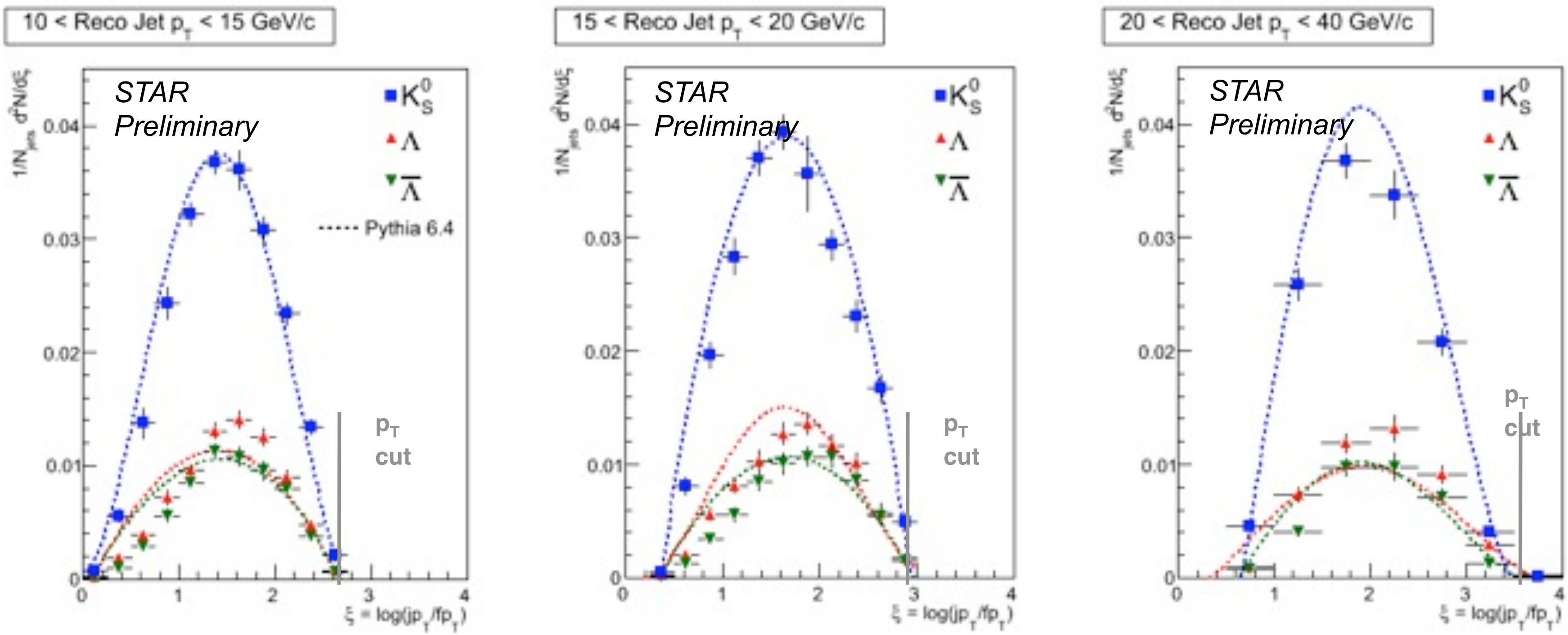
J.S.Lai WW2010

- Analysis details:
  - Z_{max} ~ 0.81
  - Electrons are rejected
  - FF scaled by successive factors of 10
- Reasonable agreement between data and PYTHIA
- Similar good agreement has been shown by STAR using R=0.4 and 0.7

NLO corrections small or accounted for in PYTHIA

Strange hadron FF

PYTHIA = PYTHIA+GEANT

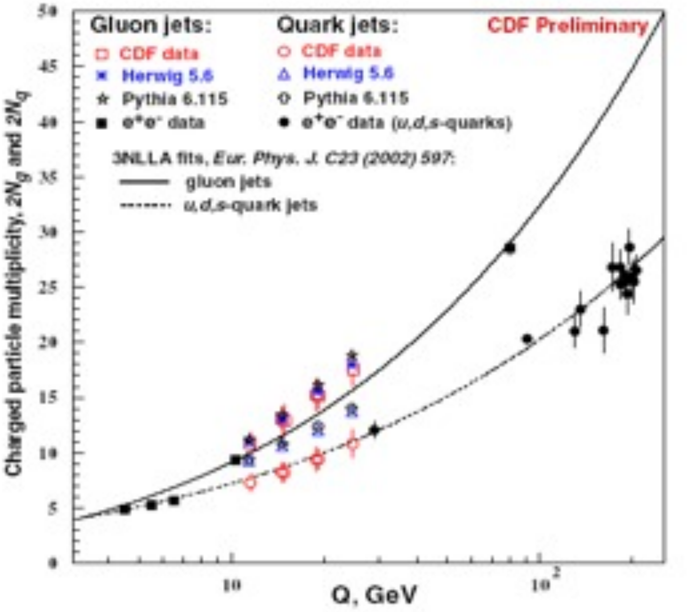


A. Timmins SQM2009

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

Description of K^0_S seems better than for Λ

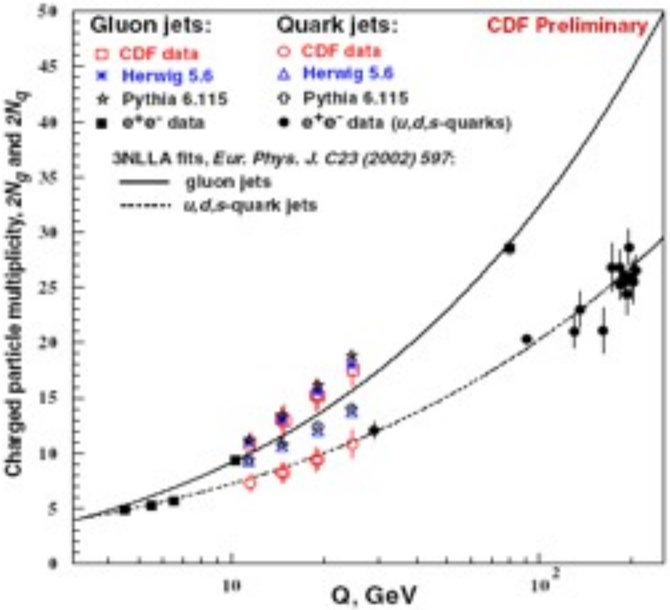
Quark and gluon jets

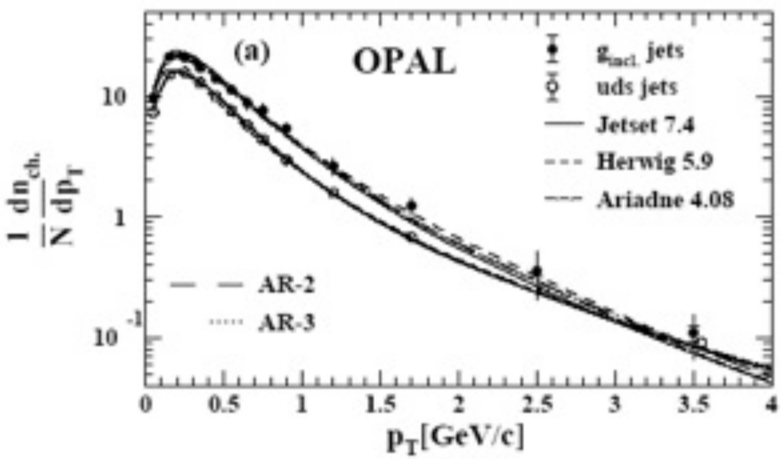


Extensive studies into jet properties have been done with e^+e^- data

- Gluon jet fragmentation:
  - produces higher multiplicities

Quark and gluon jets





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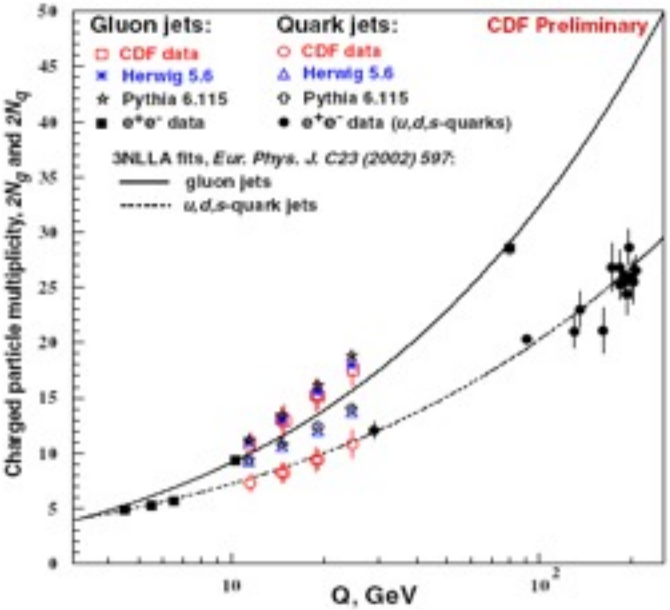

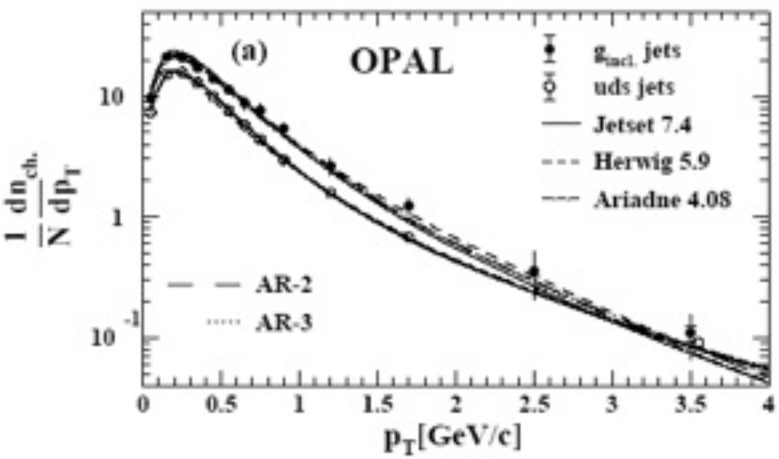

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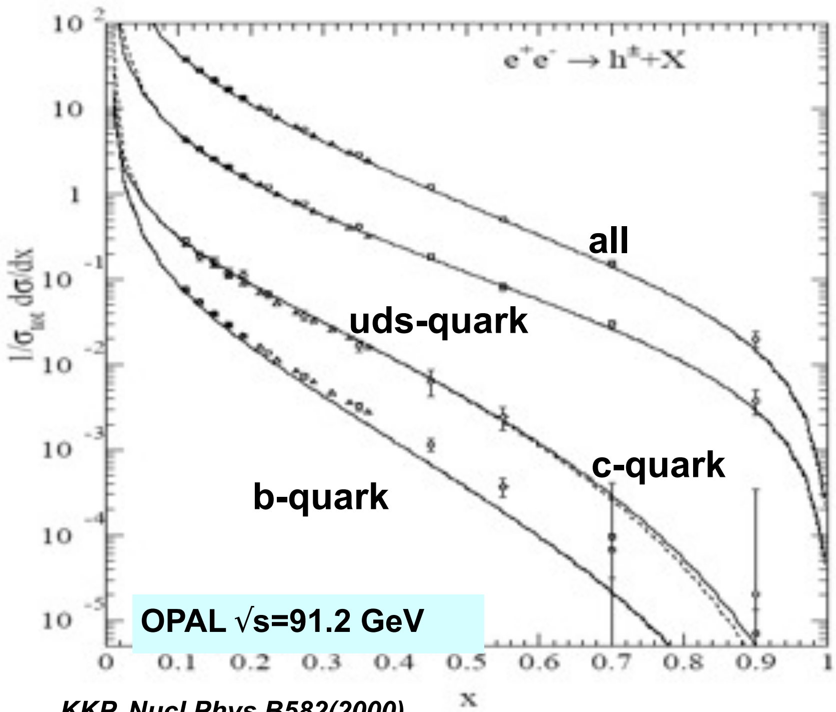
- In p-p study:
  - particle vs anti-particle
  - different species

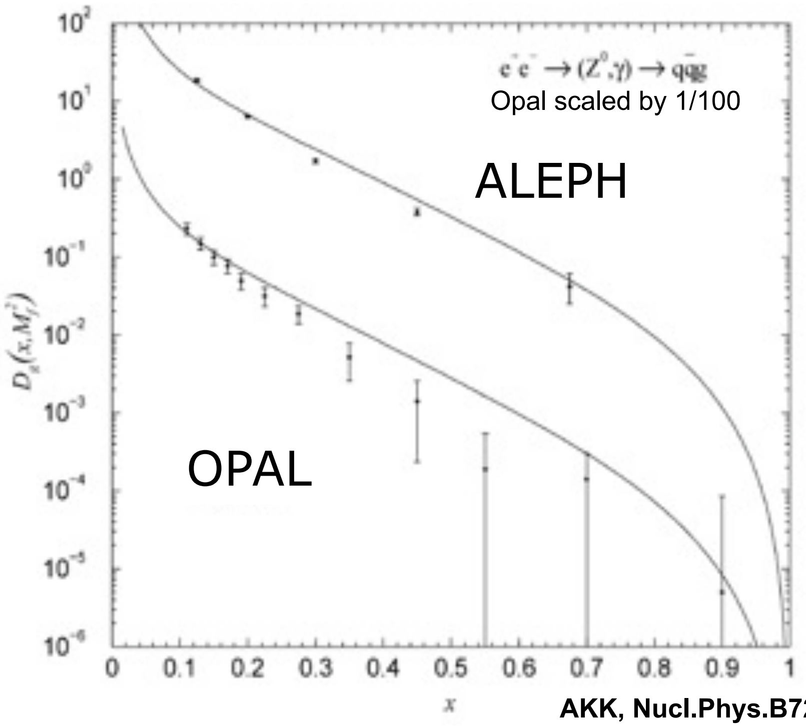
Vary gluon vs quark sensitivities: constrain theory further

Quark and gluon FF and PDFs

- Experimental data from different collisions systems have been fit with the same fragmentation function (FF)
- Constraints on Gluon FF and PDF were poor



KKP, Nucl.Phys.B582(2000)



AKK, Nucl.Phys.B725(2005)

3-jet events

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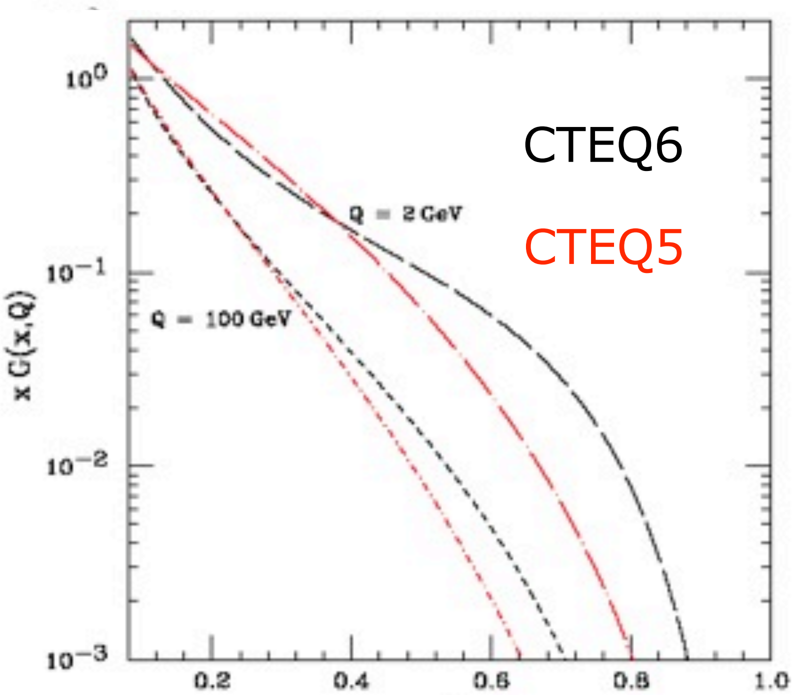
Parton Distribution function for Gluons



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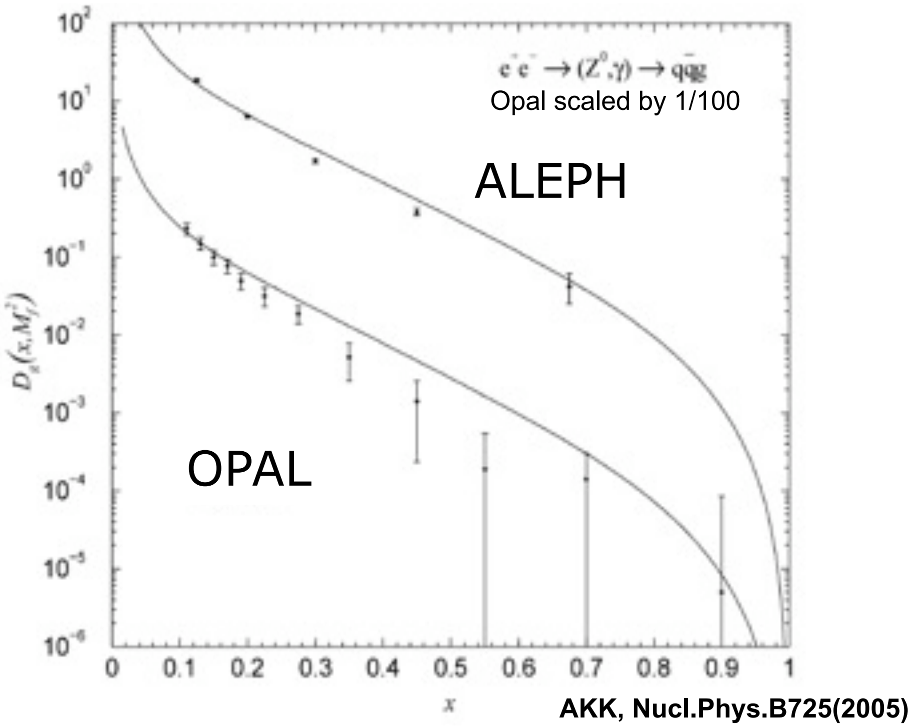
Fragmentation function for Gluons



AKK, Nucl.Phys.B725(2005)

3-jet events

Partonic hard scatterings in p+p at RHIC

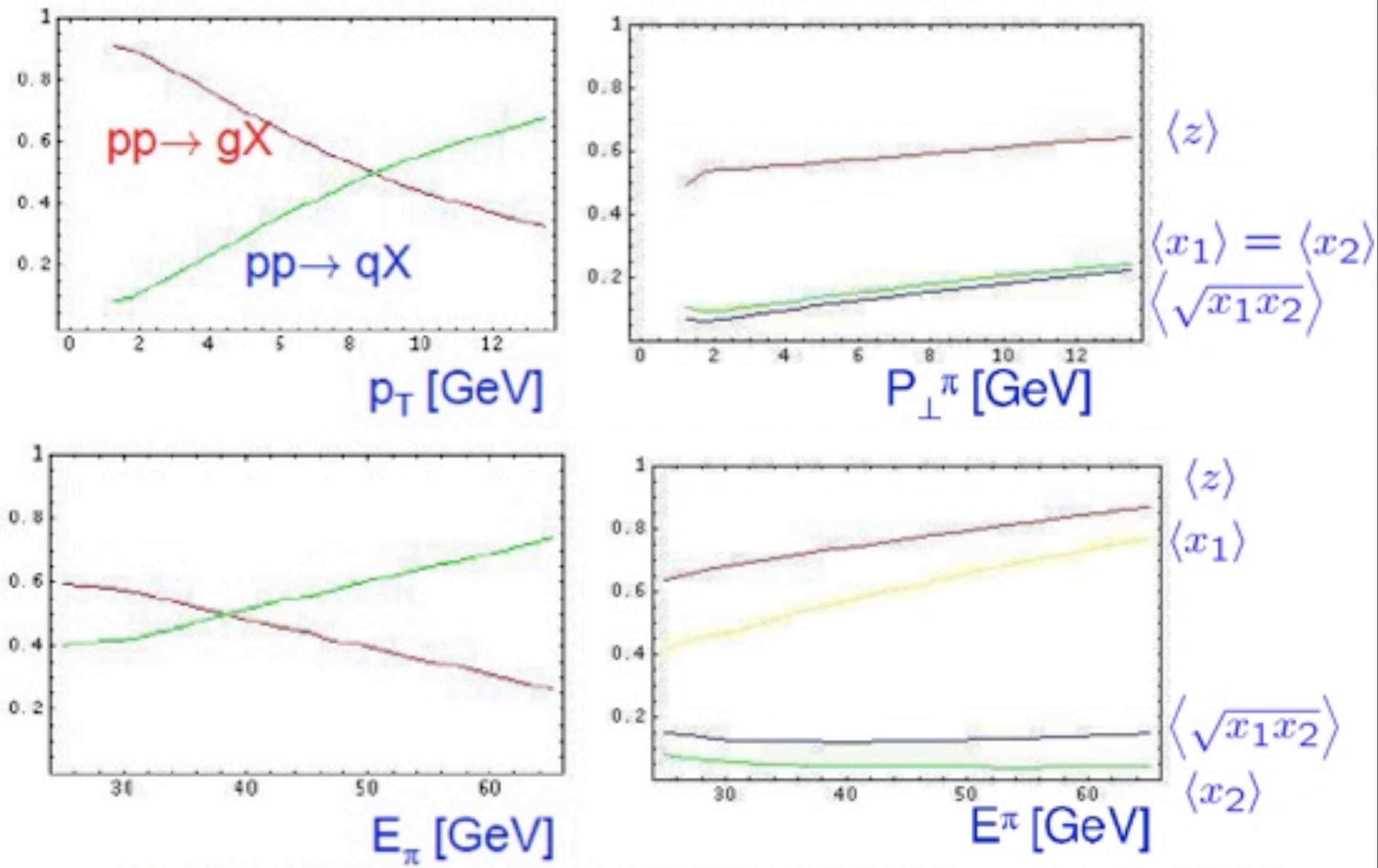
S. Kretzer APP 36 (2005) 179

At mid y:

Low p_T particles come from gluon fragmentation

At forward y:

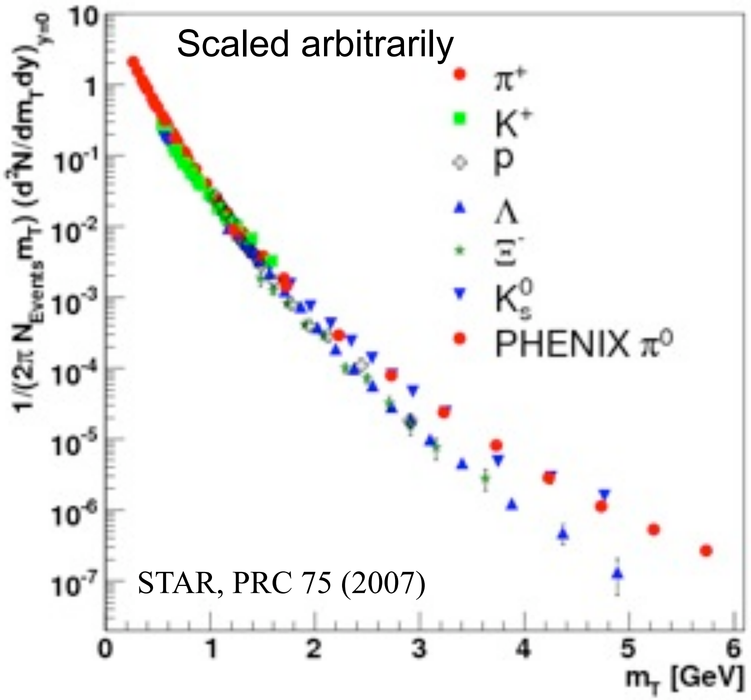
Add-mixture of quark and gluon but at high z



Significant information available about gluon FF from RHIC

m_T scaling of identified particles

- First studied at ISR - In 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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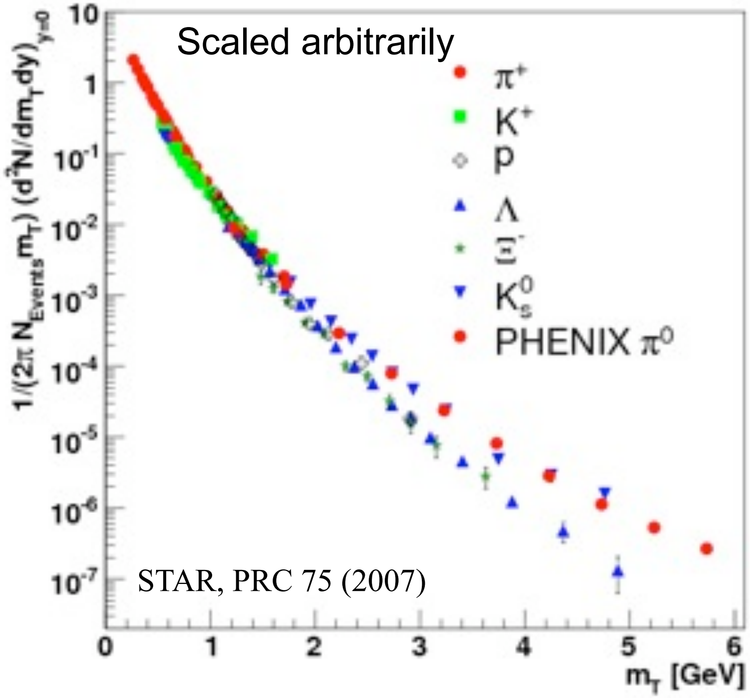

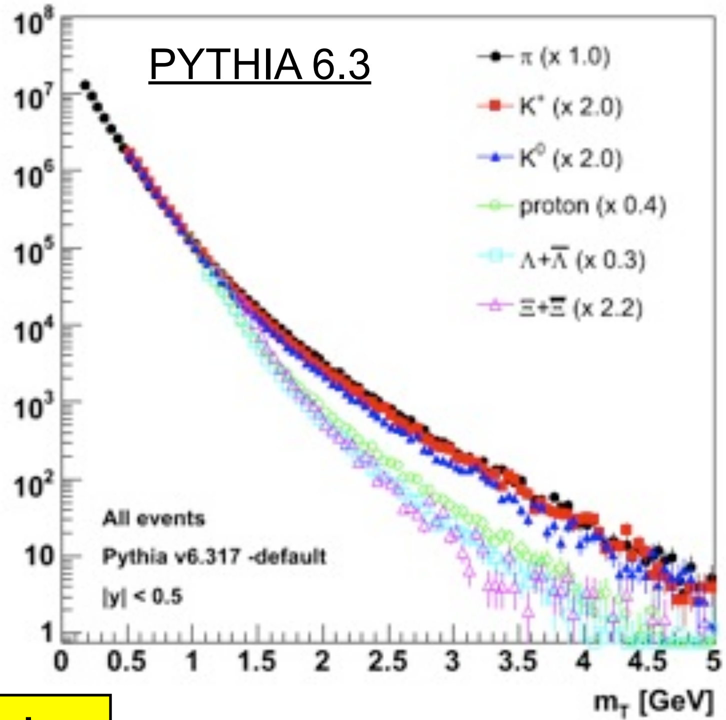

PYTHIA and data show similar trends

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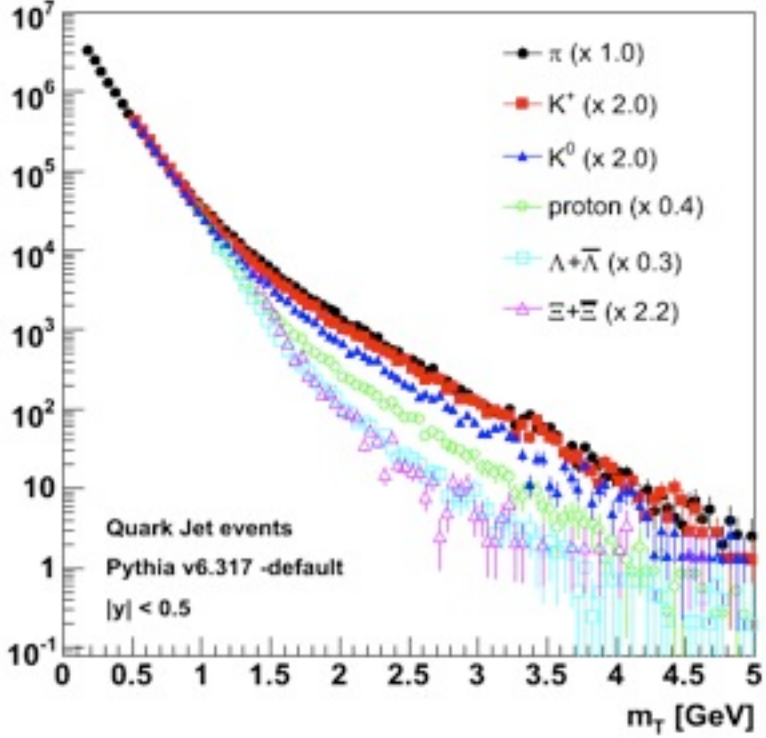
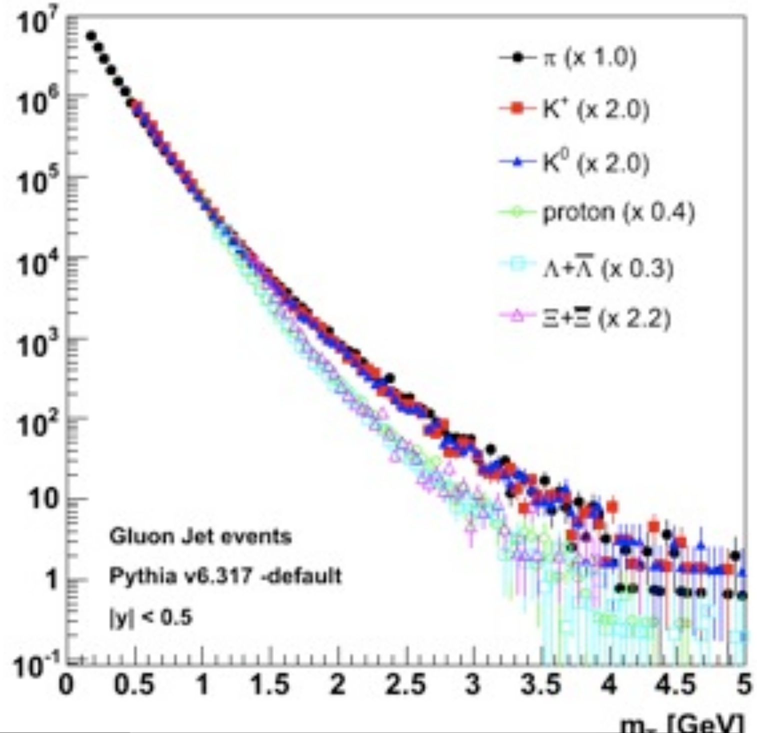
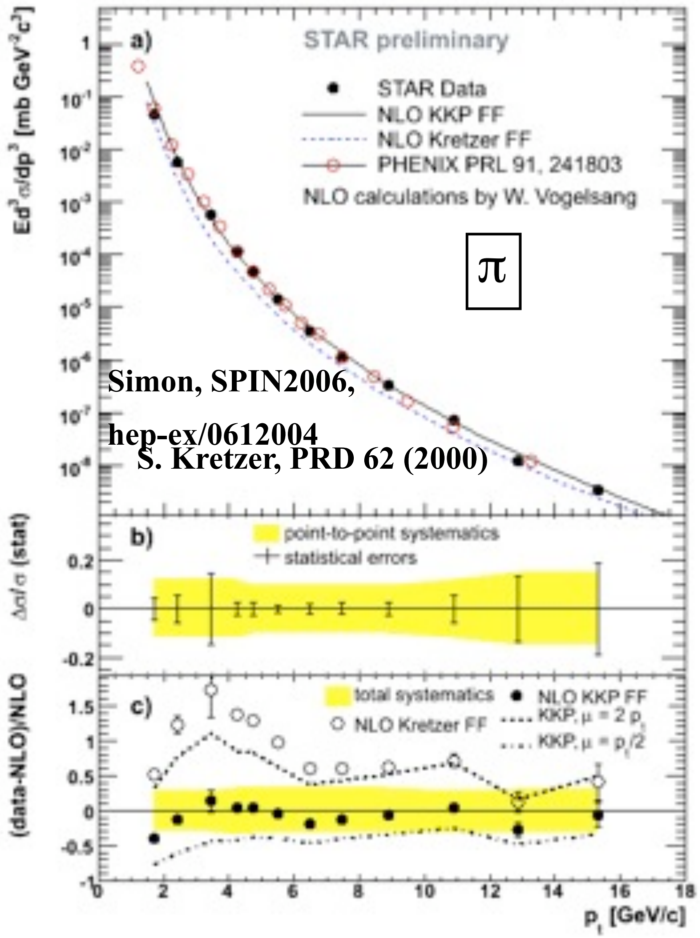


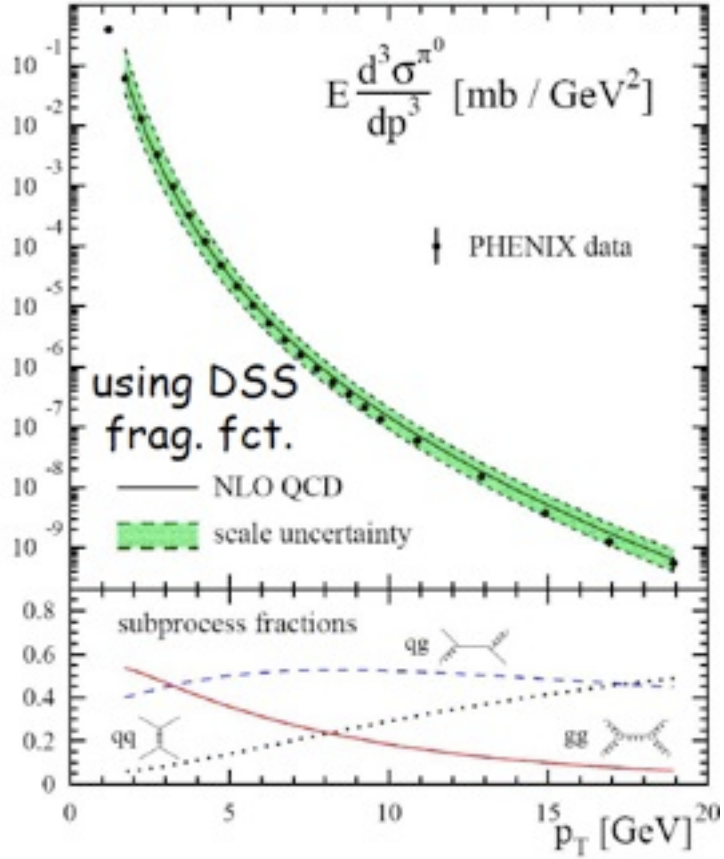


PYTHIA and data show similar trends - comes from gluon jets

π cross-section - sensitivity to FF

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



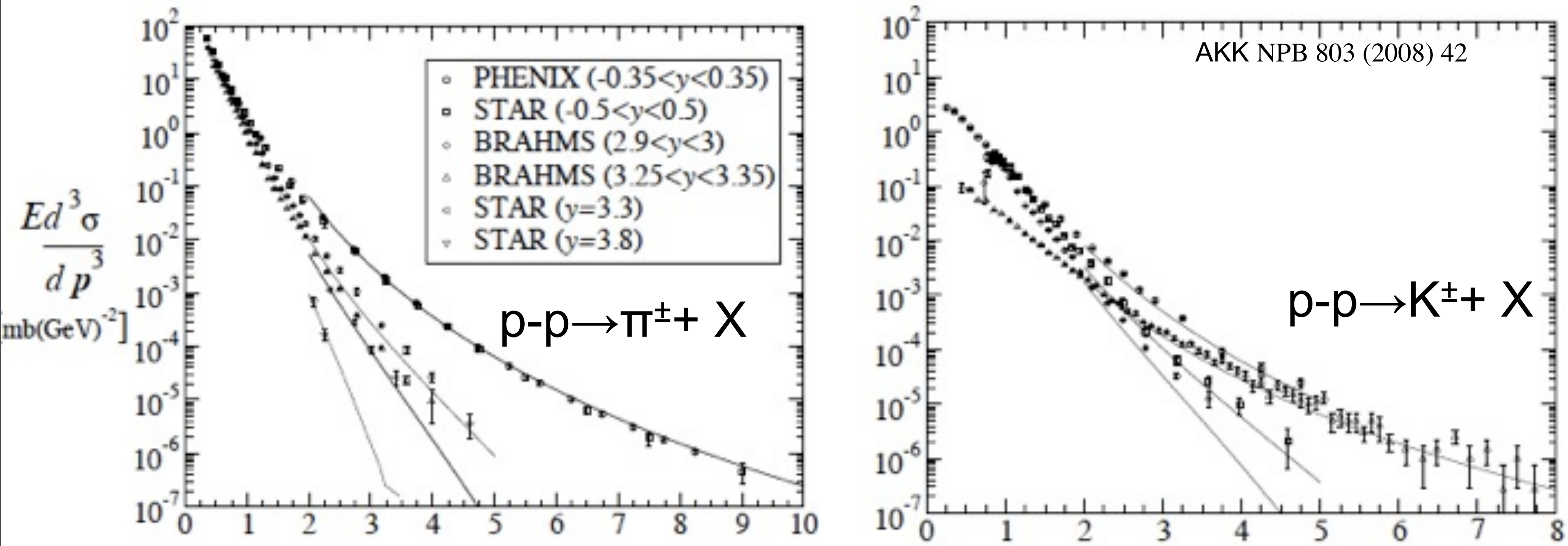


- Brahms forward π and K also used

RHIC data now sufficiently precise to be sensitive to different FF

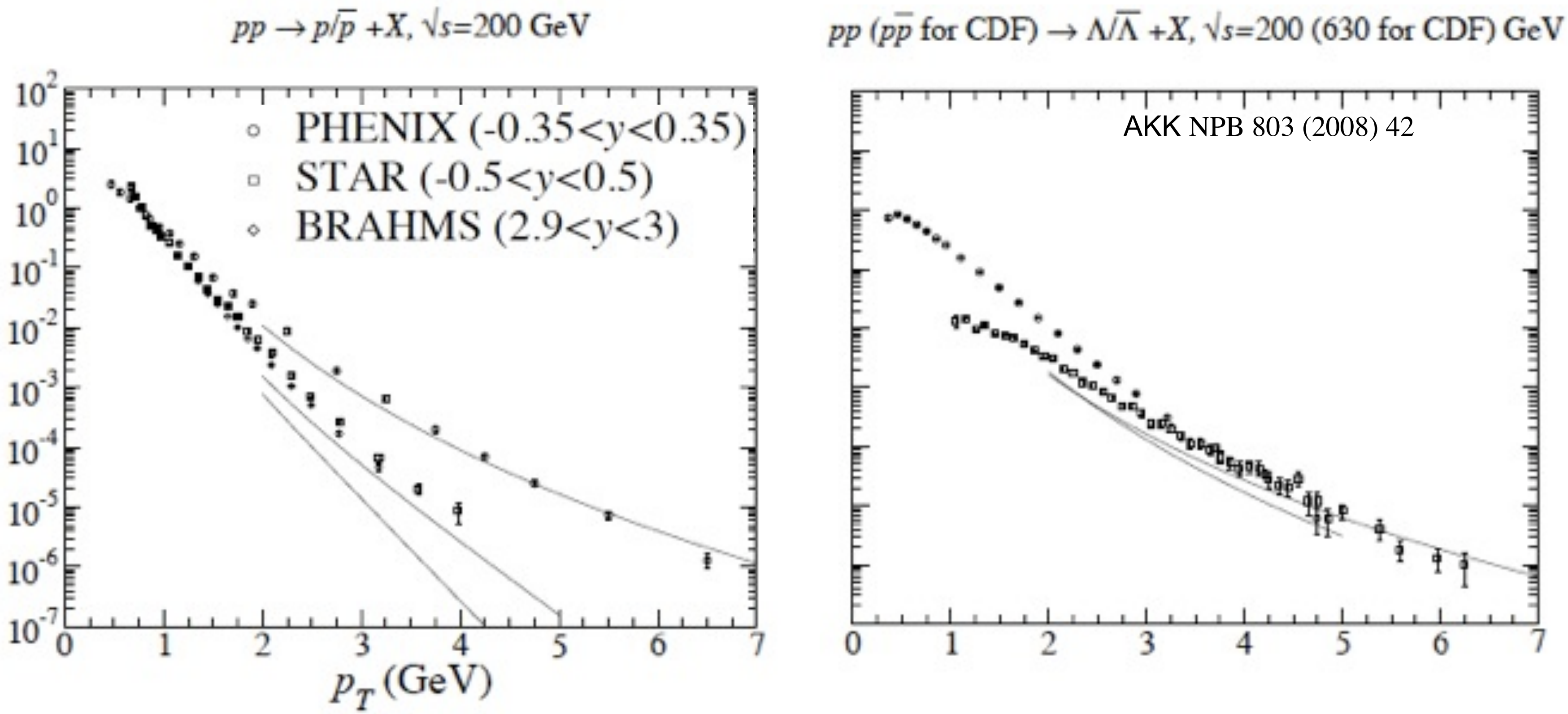
Constraining the valence and sea parton FF

- New RHIC and Tevatron, as well as e^+e^-, data used
- Global fits to all data
- RHIC charged separated data used to constrain valence partons
- Calculations now include hadron mass effects since p, K, Λ included
- AKK Shown but similar calculations/results from DSS



Mesons at mid-y well represented, undershoot at forward-y

FF into baryons are also calculated



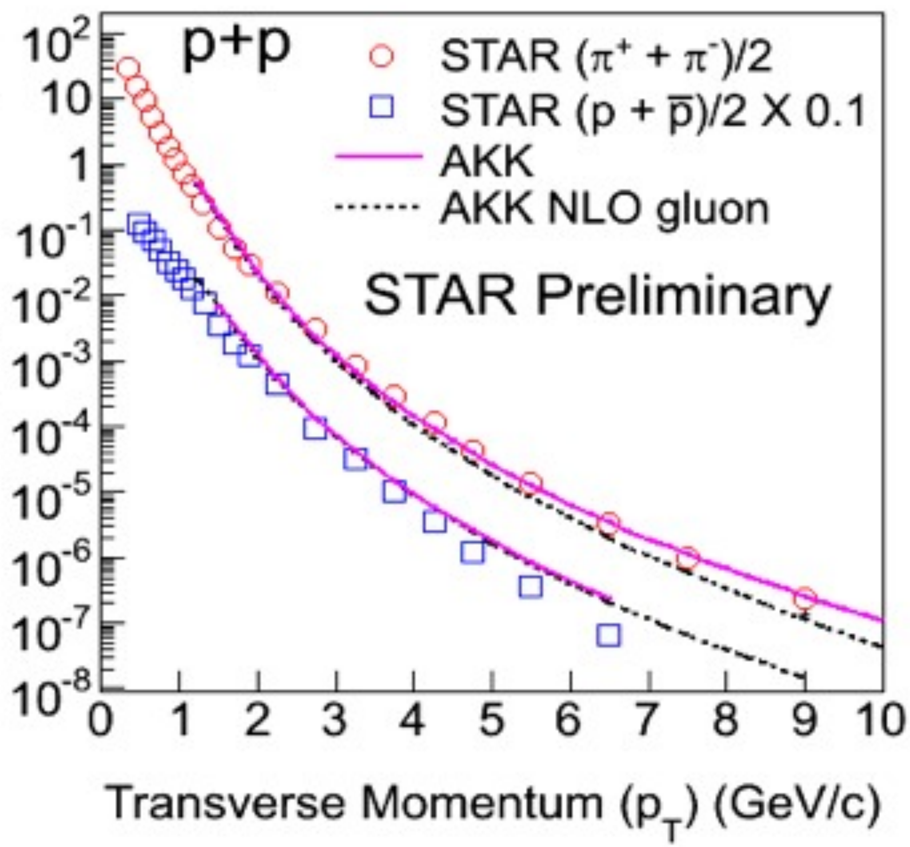
- (anti)p mid-rapidity described OK, undershoots as go forward
- (anti)Λ OK at high p_T for CDF but miss at RHIC energies

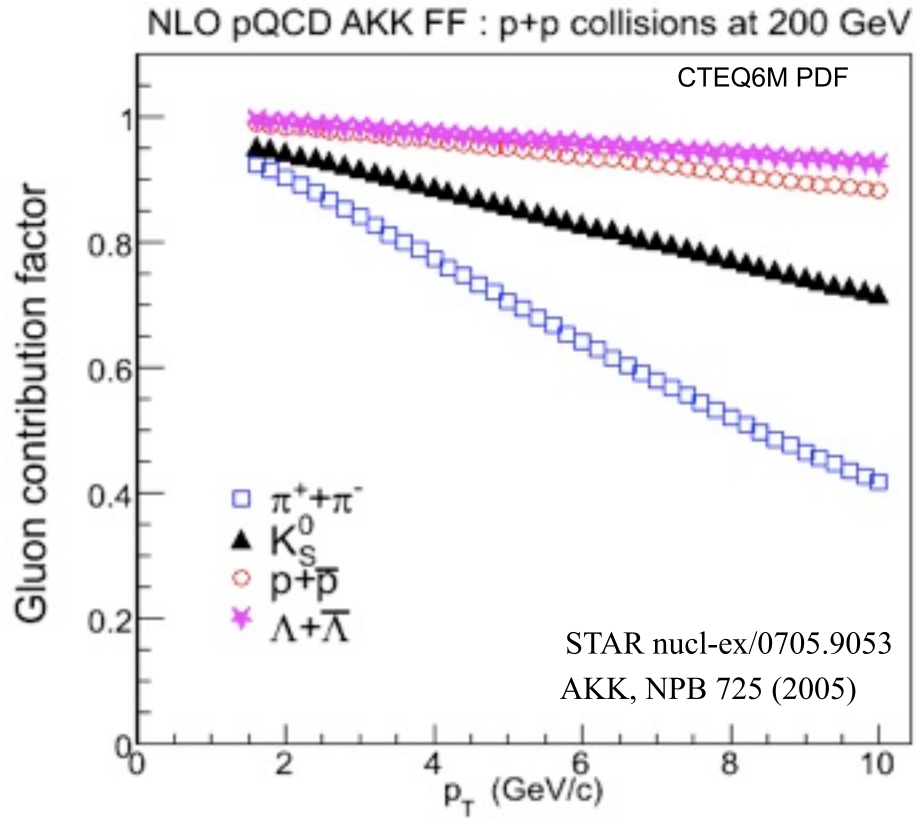
Baryons continue to be hard to describe collectively

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



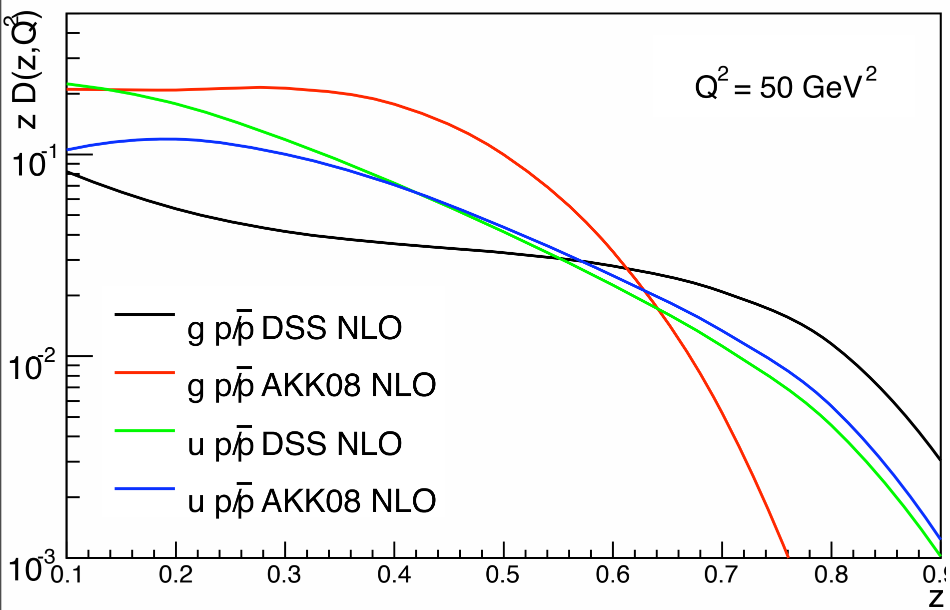


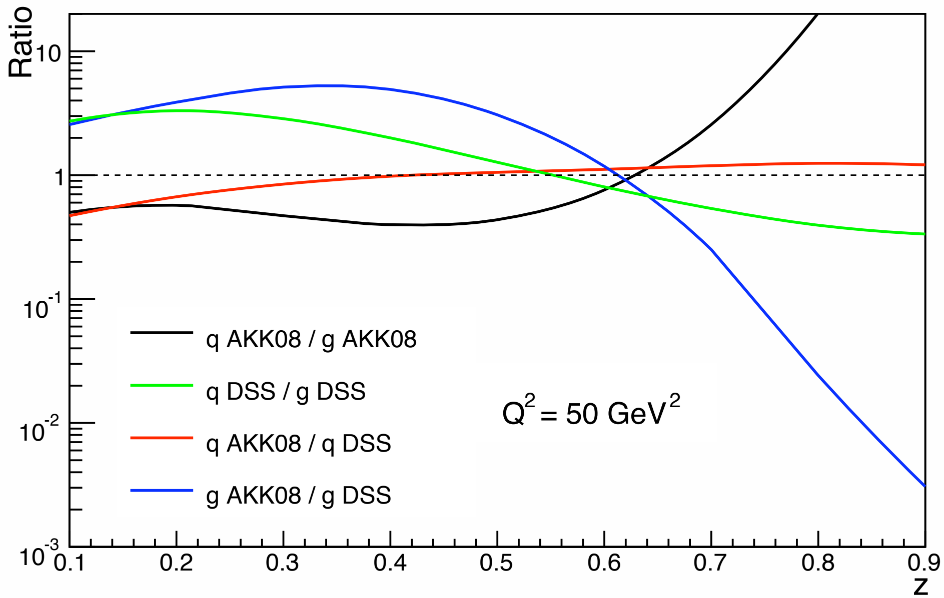
At RHIC: baryons from glue, π both quark and glue contribution

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

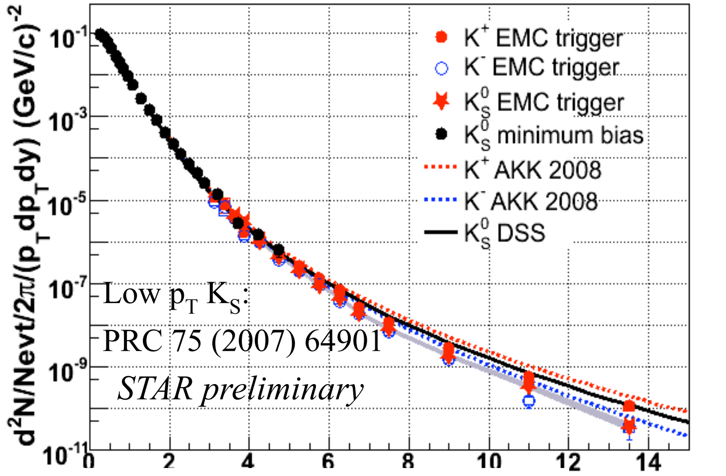
Need more precise data at high p_T to finally resolve

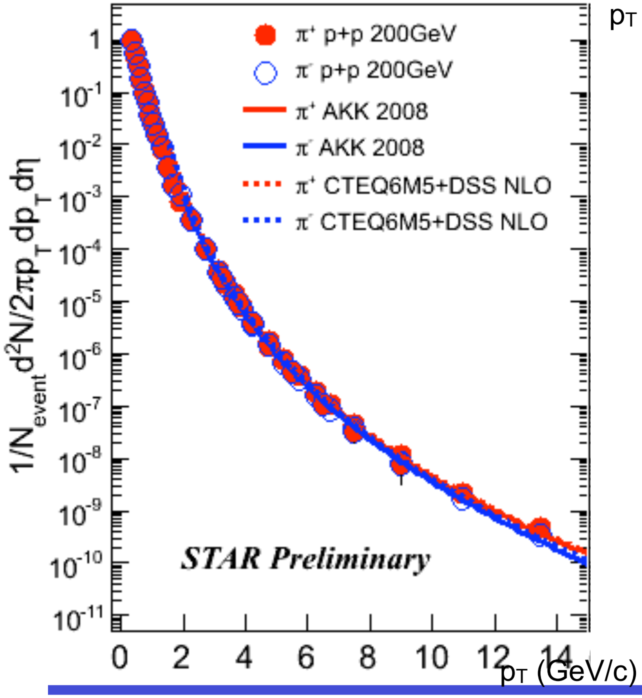




http://lappweb.in2p3.fr/lapth/ffgenerator/, AKK08: NPB (2008) 803 DSS: PRD75 (2007) 114010, PRD76 (2007) 074033

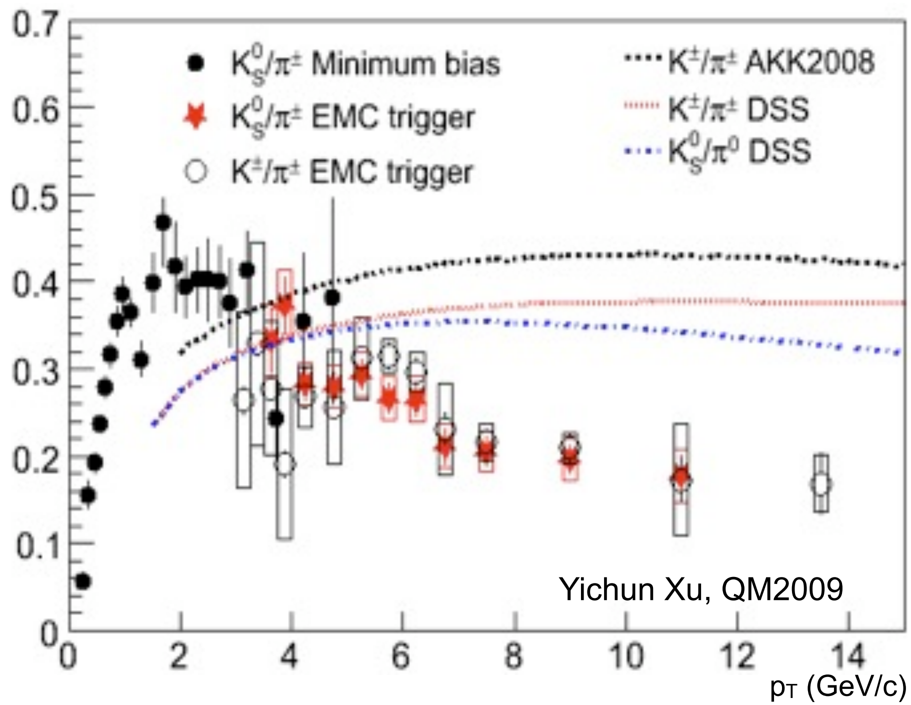
K/π ratio at high p_T





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

Ratio indicates how off the fits really are



Summary

- RHIC p+p data are extensive and can be used to constrain models
- There is good agreement between experiments on 20% level
- The STAR/PHENIX NPE difference has been resolved in p-p
- $m_T(x_T)$-scaling show that hard processes (related to PDF and FF) dominate over soft process for min-bias collisions for $p_T \sim 2$ GeV/c
- OPAL and RHIC light-flavor separated measurements in e^+e^- collisions provided significant improvement of FF for valence partons
- RHIC data provides a unique tool for understanding gluon vs. quark jet contributions
- FF have been improved but the details are still not correct (B/M ratios) and the add-mixture of quark and gluon still uncertain