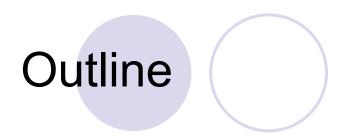
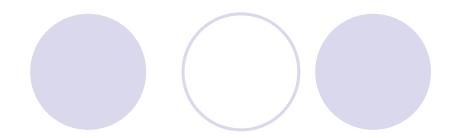
Experimental constraints on fragmentation functions for strange hadrons at RHIC

Mark Heinz Yale University

Workshop on Parton Fragmentation ECT Trento, Feb 25-29, 2008





- Introduction
- Current RHIC results on strange particle and baryon production
- Gluon vs Quark FF (Color Factors)
- Exciting new topics at RHIC

FF authors referred to in this talk

- BS: Bourelly, Soffer
- BKK: Binnewies, Kniehl, Kramer
- KKP: Kniehl, Kramer, Poetter
- AKK: <u>Albino</u>, Kniehl, Kramer
- DSV: DeFlorian, <u>Stratmann</u>, Vogelsang
- DSS: DeFlorian, <u>Stratmann</u>, Sassot
- SK: Kretzer
- HKNS: Hirai, <u>Kumano</u>, Nagai, Sudoh

<u>Underlined</u>: participants at this workshop

Recent developments in FF

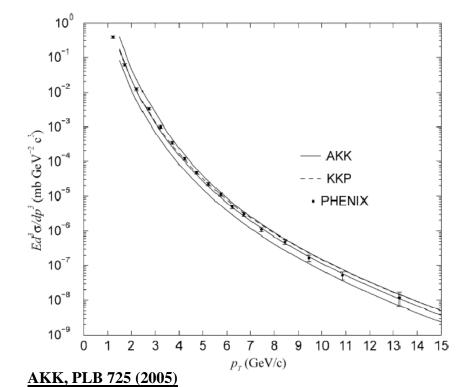
- A non-exhaustive list of (for this talk) relevant developments in the field of pQCD and FF:
 - 1995: LO/NLO kaon & pion FF (BKK)
 - 1998: FF for Lambda (DSV)
 - 2001: Universality of FF (KKP)
 - 2003: Statistical FF for Octet Baryons (BS)
 - 2005: Light-quark flavor separation (AKK)
 - 2007: Study of uncertainties in FF (HKNS)
 - 2007: Separate study of quark/antiquark FF (DSS)
- This is a <u>very</u> active field of study and there are significant exchanges between theory and experiment

Experimental hadron collider data

- e⁺e⁻ experiments (too many to mention seperately):
 - Inclusive hadrons
 - Tagged jets (gluons,quarks)
- UA1/2: 630 GeV
 - inclusive hadrons
- CDF: 630 & 1800 GeV
 - inclusive hadrons
- RHIC: p+p 200 GeV
 - Inclusive hadrons
 - O Identified π/π^0
 - baryons and strange particles (2007):
 - Measurement of Lambda
 - Measurement of K⁰_s
 - Measurement of protons & anti-protons

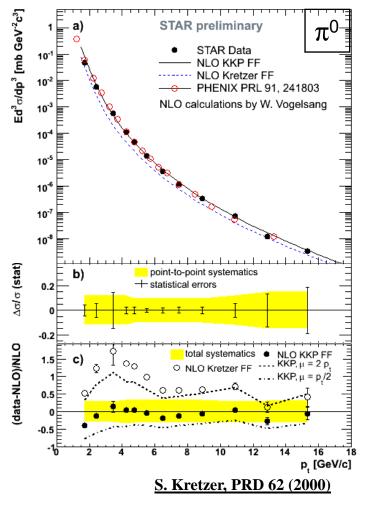
Pion Fragmentation Function (FF)





RHIC data sufficiently precise to be sensitive to different FF

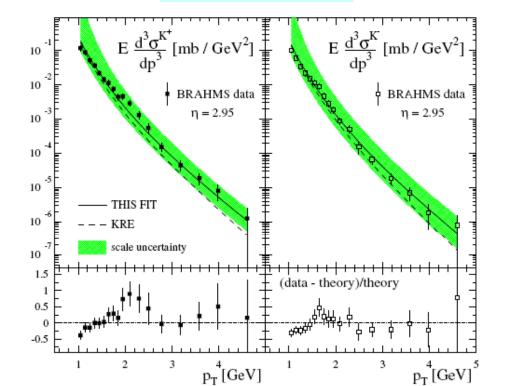
 π^0 : Kretzer vs KKP



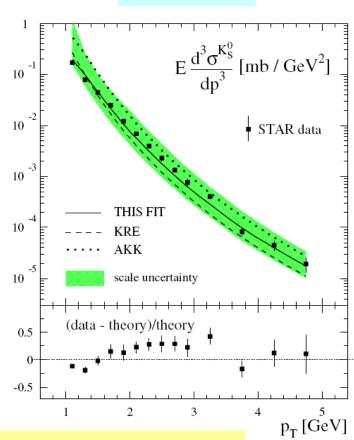
Simon, SPIN2006,hep-ex/0612004

Kaon FF (1)

BRAHMS: K+/-



STAR: K⁰

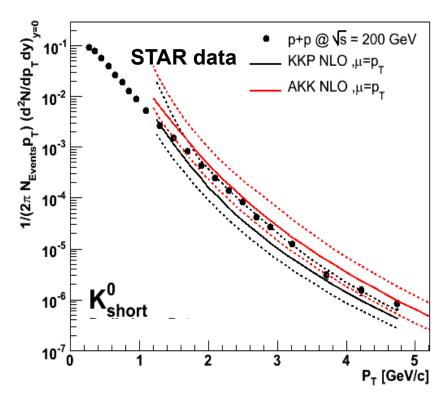


Same conclusion! Even for Kaons, the experimental errors are small enough to distinguish between FF

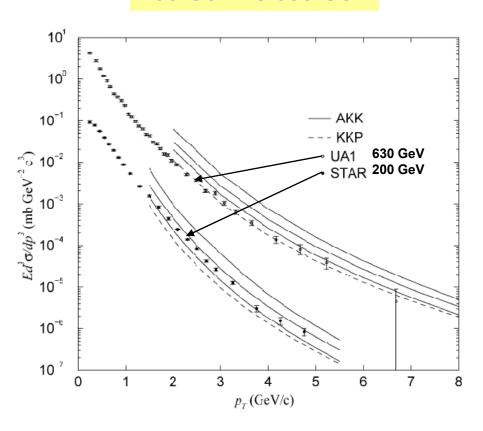
DSV, PRD76 (2007)

Kaon FF (2)

KKP (2003) vs AKK (2006)



200 GeV vs 630 GeV



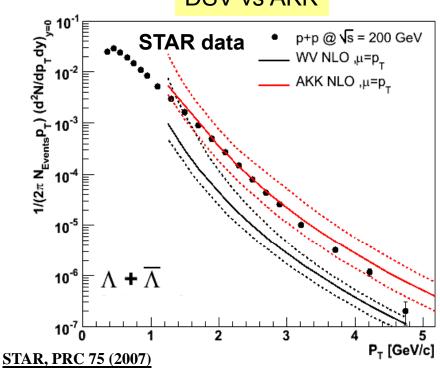
STAR, PRC 75 (2007)

AKK better describes RHIC better, KKP better for SPS. Consistency check is maybe needed.

AKK, PLB 725 (2005)

Lambda FF

DSV vs AKK

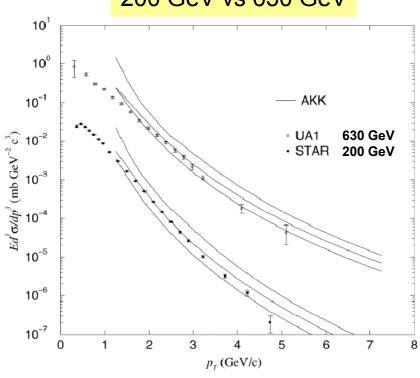


Sensitivity to gluon FF!

AKK used STAR data to constrain

Gluon FF to $D_q^{\Lambda} = D_q^{P}/3$!

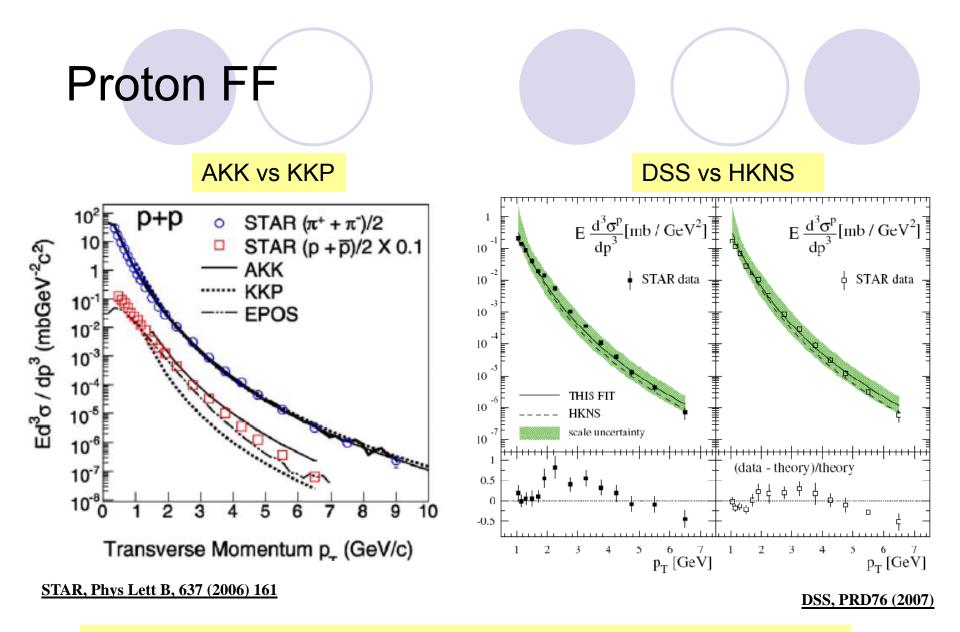
200 GeV vs 630 GeV



Constrained Gluon FF gives good agreement at both \sqrt{s}

AKK, PLB 734 (2006)

DSV, PRD57 (1998)

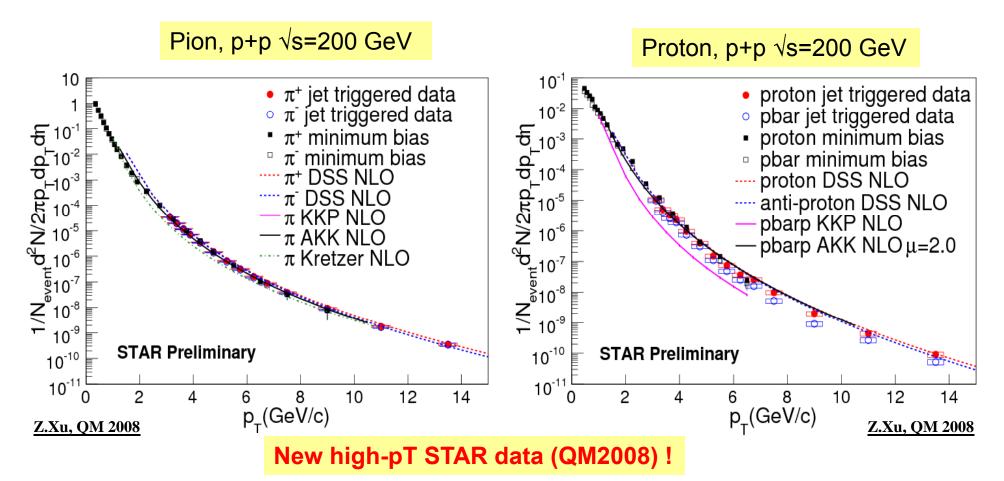


DSS: First separate calculation of FF for protons and anti-protons

Proton FF (2)



Extending the high-p_⊤ reach with QM 2008 data



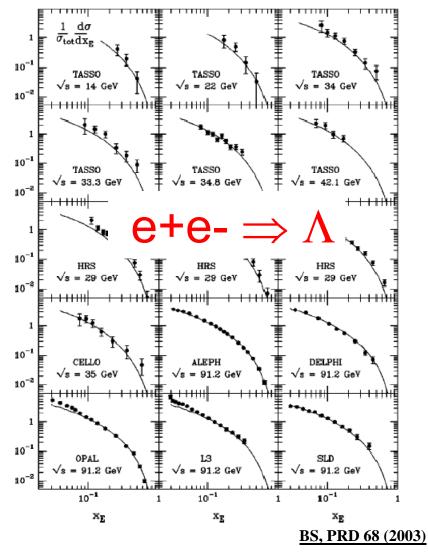
Statistical FF: a different approach

- In 2003 Bourrely and Soffer presented NLO FF for octet baryons (p,Λ,Ξ,Σ)
- Their goal was to obtain FF with fewer, physically motivated parameters

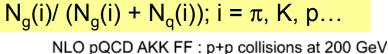
$$D_{q}^{B}(x,Q_{0}^{2}) = \frac{A_{q}^{B}X_{q}^{B}x^{b}}{\exp[(x-X_{q}^{B})/\overline{x}]+1},$$

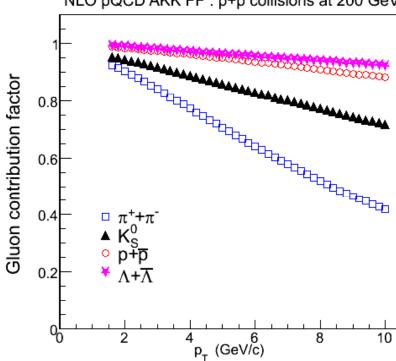
Fermi-Dirac type FF

- (SI)DIS data was used for the parameterization
- No determination of gluon FF
- Unfortunately no comparison with RHIC data available.

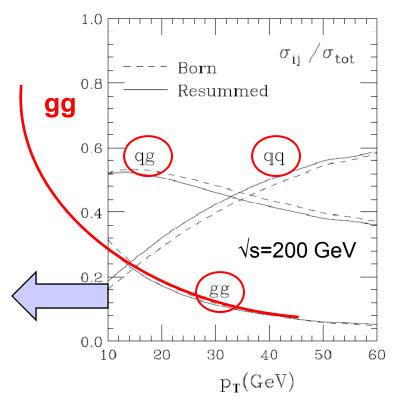


Why are baryons more sensitive to the gluon FF?





Why study gluon FF at RHIC?

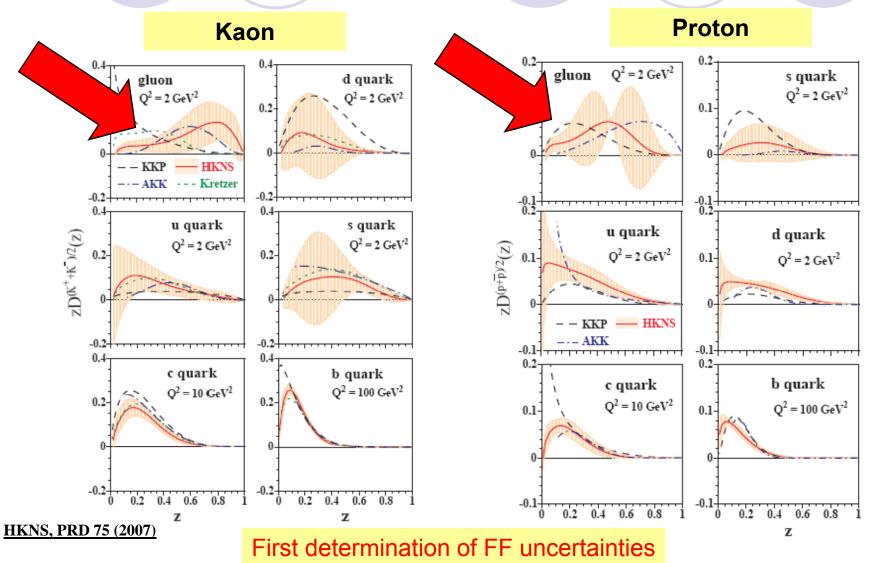


AKK, NPB 725 (2005)

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

De Florian, Vogelsang, hep-ph 0704.1677

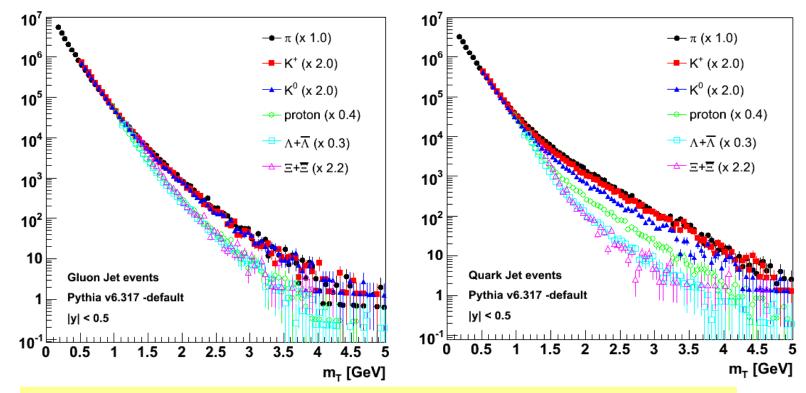
How large are the uncertainties from the FF parameterization?



m_T scaling of identified particles

- Gluon jets produce meson vs baryon "splitting", Quark jets produce mass splitting in m_T
- The overall shapes of the m_T spectra confirm that at RHIC particle production is gluon jet dominated.

STAR, PRC 75 (2007)



Arbitrarily scaled m_T-spectra data and PYTHIA simulation agree well

x_T scaling of identified particles

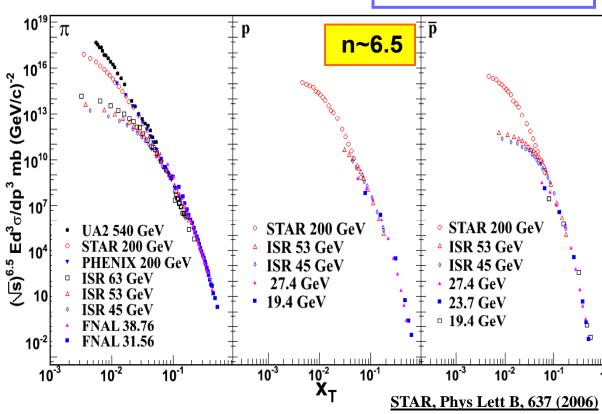
Shown to work well in e⁺e⁻

p+p / p+p collisions

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

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

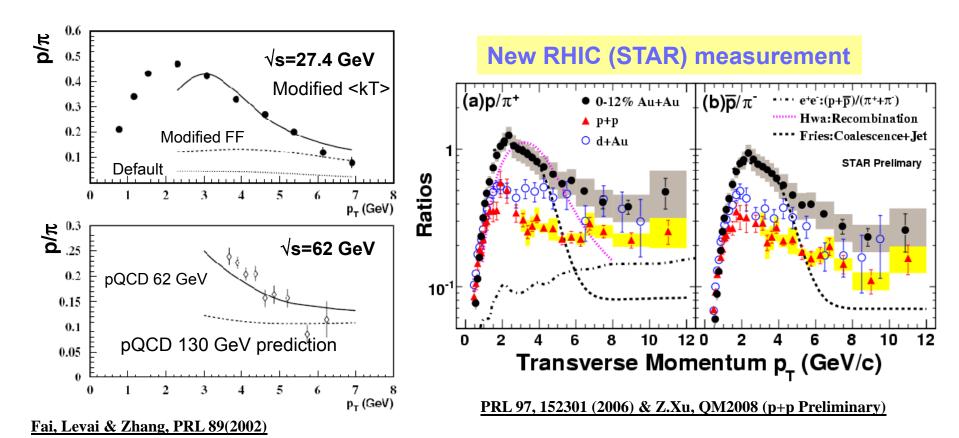
n ~ 4 for basic scattering process
 n ~ 5-8 depending on evolution of structure function and fragmentation function



 \Rightarrow Suggests transition from soft/hard processes $\sim p_T = 2 \text{GeV}$

Baryon-Meson ratios 1: p/π

- Levai et al (Phys Rev 89 (2002)) discuss the importance of RHIC pp data for the large-z part of the FF
- They argue that k_T smearing maybe a cause for the poor agreement and assign a larger <k_T> to the proton than the pion

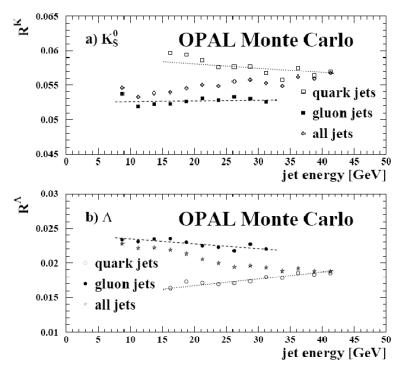


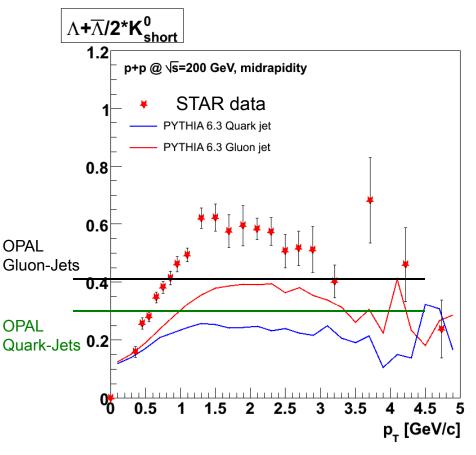
Baryon-Meson ratios 2 : Λ/K

These ratios are sensitive to the gluon jet contribution in the event

Default PYTHIA clearly underpredicts the ratio (need Baryon

production tune)

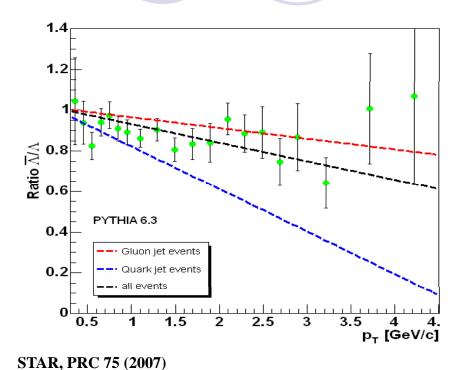


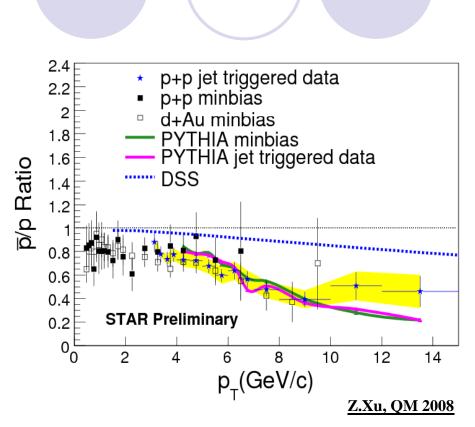


OPAL, EPJ, C8 (1999)

STAR, PRC 75 (2007)

B/B Ratios





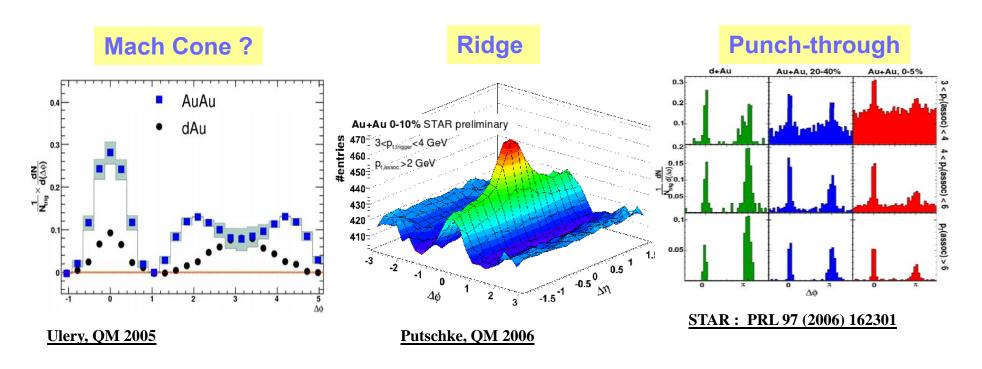
- pQCD predicts a drop of \overline{B}/B ratio at high p_T due to the increasing value quark contributions.
- The gluon contribution will counter that effect.
- New DSS NLO does <u>not</u> reproduce p/p ratio from data.

Next step... Medium modified FF

- How can we address the issue of medium modified fragmentation?
- Here is a wish-list of topics that <u>have recently</u> or <u>will be</u> "attacked" with RHIC data:
 - Identified di-hadron correlations (using strange/charmed particles)
 - 3-particle correlations
 - FF in HI collisions
 - Full jet reconstruction
 - "Hadrochemistry" in jets
 - Jets in heavy ions
 - Jet-tagging (gluon, light quark, heavy quark)
 - Heavy Flavor tagging
- For which observables can theory offer solid <u>predictions</u> to compare to?

Di-Hadron Correlations at RHIC

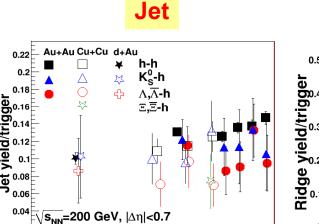
- Many "unexplained" phenomena:
 - Near-side phenomena: Ridge, modified fragmentation etc.
 - Away-side phenomena: mach-cone, punch-through etc.
- The data seem to produce more questions than answers!



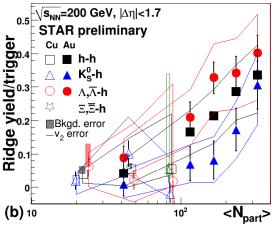
Identified Di-Hadron Correlations

- Probing the hadro-composition in the presence of a jet
- Near-side: Analysis separates correlation into jet+ridge
- Away-side: response of the medium

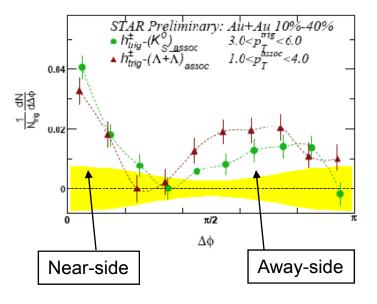
Identified trigger particle



Ridge



Identified associated particle

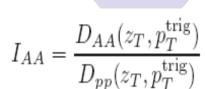


J.XU, SQM 2007

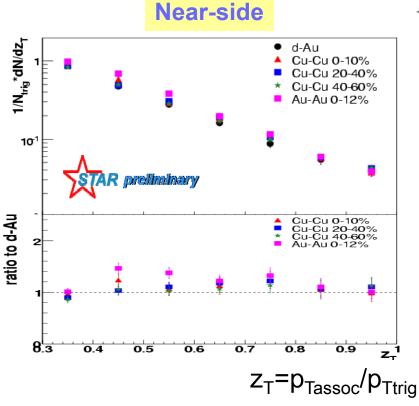
STAR preliminary

Nattrass, QM2008

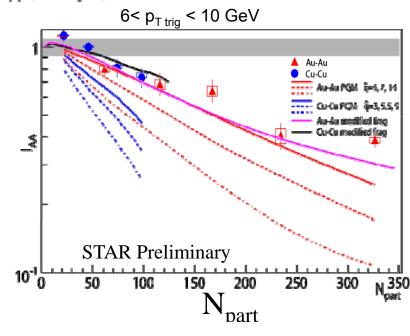
Medium modified FF







FF in Au+Au and Cu+Cu consistent with vacuum fragmentation

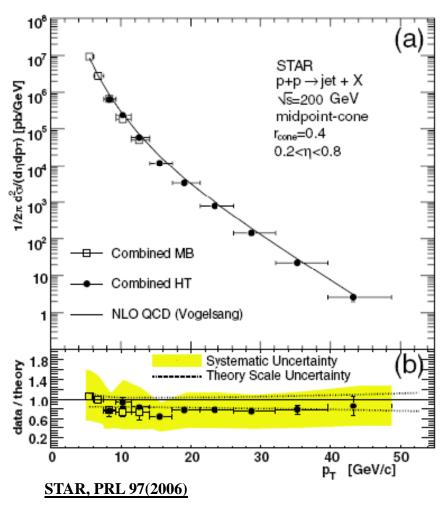


STAR data, O.Catu, QM2008 C. Loizides, EPJ. C 49 (2007) J.F. Owens et al, PRL98 (2007)

- -Inconsistent with PQM calculations
- -Modified fragmentation model better

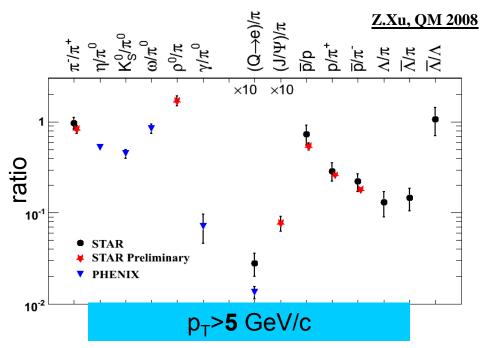
Full jet reconstruction at RHIC

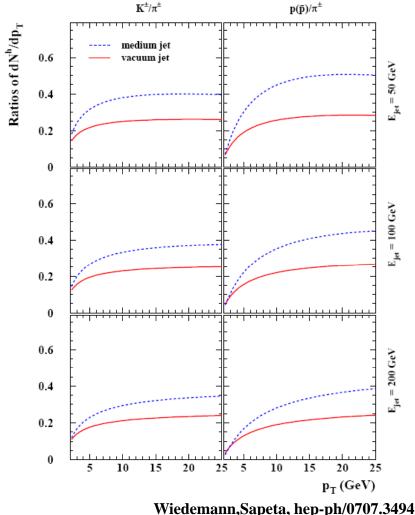
- In proton-proton: STAR published jet x-section in conjunction with A_{LL} measurement
- Efforts ongoing to measure jets in heavy ions



Hadro-chemistry in jets

- Wiedemann et al have recently (hep-ph 0707.3494) made predictions for particle ratios in jets at LHC
- Jet quenching will leave signatures in hadro-chemical composition
- High-p_T ratios were shown at QM 2008 and are a first step.

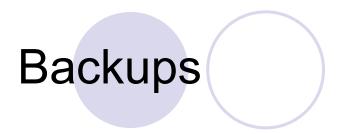


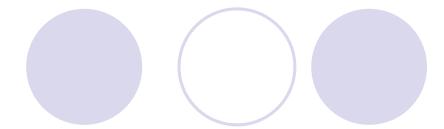


Mark Heinz, Yale

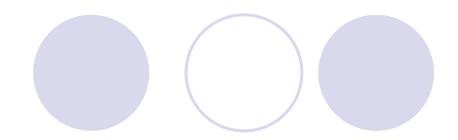
Summary

- Recent RHIC data from p+p collisions has been used to compare to NLO FF.
- RHIC (strange) baryon spectra (p,Λ) have allowed to better constrain the gluon FF.
- Baryon to meson ratios are powerful observables in determining the quark vs. gluon jet contribution.
- m_T/x_T scaling are interesting observables which can distinguish between quark and gluon jet fragmentation.
- Full jet reconstruction at RHIC & LHC will allow more detailed studies of jet characteristics and medium modified fragmentation.



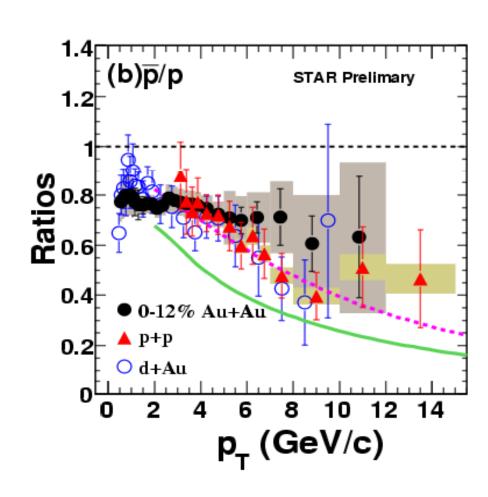


B/B Ratios



STAR, Phys Lett B, 637 (2006) & QM 2008 (Preliminary p+p)

Curves: X-N. Wang et al PRC70(2004) 031901



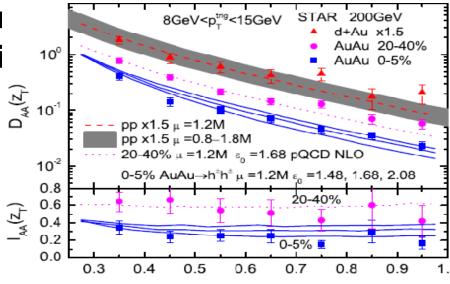
MOTIVATION

- Study medium-induced modification of fragmentation function due to energy loss
- Without full jet reconstruction, jet/parton energy not measurable
 - \rightarrow z not measured (z=p_{hadron}/p_{parton})
- Di-hadron fragmentation fur

$$D^{h_1 h_2}(z_T, p_T^{\text{trig}}) = p_T^{\text{trig}} \frac{d\sigma_{AA}^{h_1 h_2} / dp_T^{\text{trig}} dp_T}{d\sigma_{AA}^{h_1} / dp_T^{\text{trig}}} \underbrace{\frac{10^{\circ}}{5}}_{\text{3 so}^{-1}}$$

$$I_{AA} = \frac{D_{AA}(z_T, p_T^{\mathrm{trig}})}{D_{pp}(z_T, p_T^{\mathrm{trig}})} \quad \begin{array}{l} \text{(for experimental data} \\ \text{d-Au data used as} \\ \text{substitute of p-p)} \end{array}$$

$$z_T = p_{Tassoc}/p_{Ttrig}$$



H.Zhang, J.F. Owens, E. Wang, X.N. Wang - Phys. Rev. Lett. 98: 212301 (2007)