Relevance of baseline hard p+p spectra for A+A and p+A physics at high p_T

HOT QUARKS'04

Taos, NM - July 24th, 2004

David d'Enterria
Nevis Labs, Columbia University, NY

High p_T p+p baseline spectra: Overview

- Case I: p+p → π+*X* at √s ≈ 20 GeV

  Is high p_T A+A hadroproduction at SPS enhanced or suppressed ?

  [or ... how to bring (part of) the RHIC high p_T excitement to SPS energies]

- Case II: p+p → π,$h^{\pm}$+*X* at √s = 62.4 GeV

  How accurate are our current ISR-averaged p+p references ?

  [or ... how to make M.J.Tannenbaum happy]

- Case III: p+p → $h^{\pm}$+*X* at √s = 200 GeV at forward y vs pQCD:

  Is there truly suppresssion in d+Au collisions at η=3.2 ?

  [or ... how **not** to make friends in BRAHMS (or CGC "community") :-)]

- Case IV: p+p → γ+*X* at √s = 200 GeV

  Is there a way to disentangle suppressed prompt photons (from quenched jet fragmentation) from enhanced (thermal) photons in Au+Au at RHIC ?

  [or ... how to make life difficult to PHENIX "photoners"]

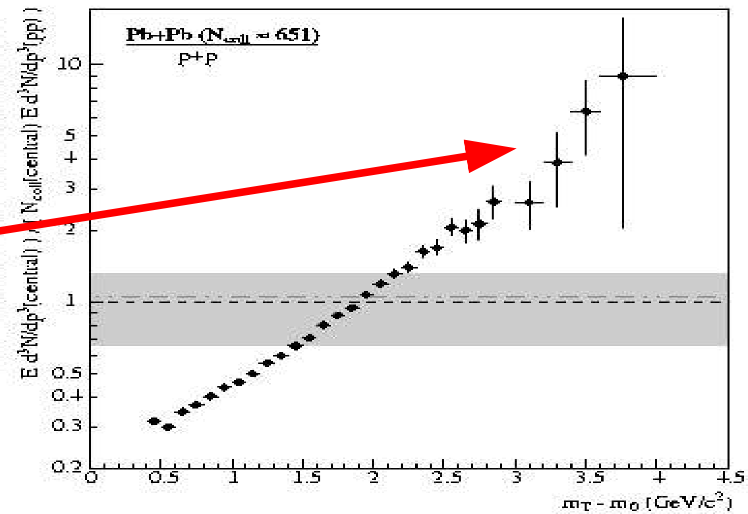
Case I:
p+p high p_T reference at $\sqrt{s} \approx 20$ GeV

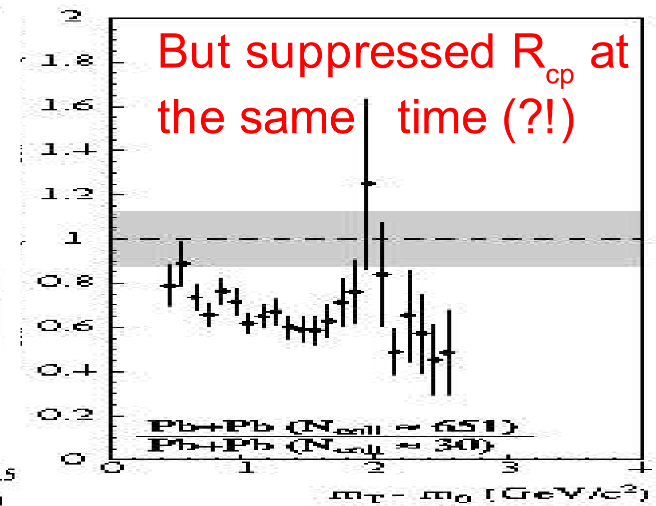
Enhanced high p_T production in Pb+Pb @ CERN-SPS ?

- NO $p+p \rightarrow \pi^0 X$ baseline measurement at SPS Pb+Pb energy ($\sqrt{s}$ = 17.3 GeV)
- R_{AA} for central Pb+Pb constructed with 2 different parametrizations:

WA98 Collab.
EPJ C23 (93)225

Huge Cronin enhancement

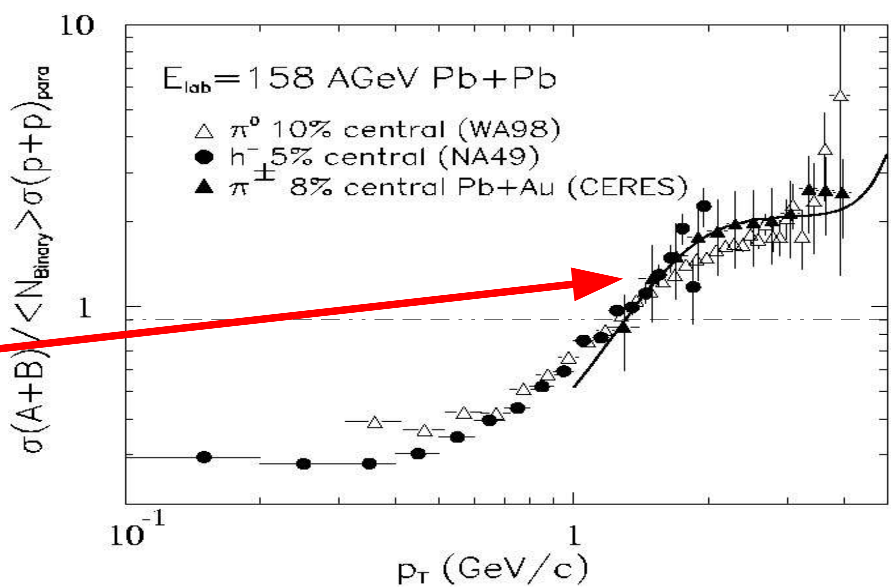




But suppressed R_{cp} at the same time (?!)

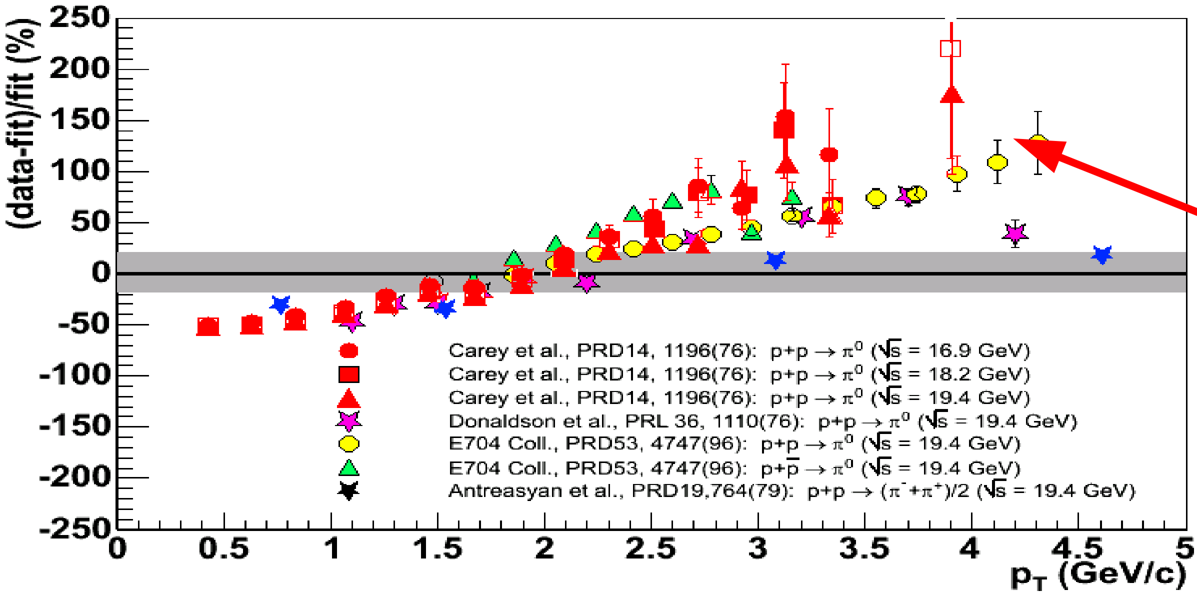
Wang&Wang
PRC 64 (01) 034901

Cronin enhancement



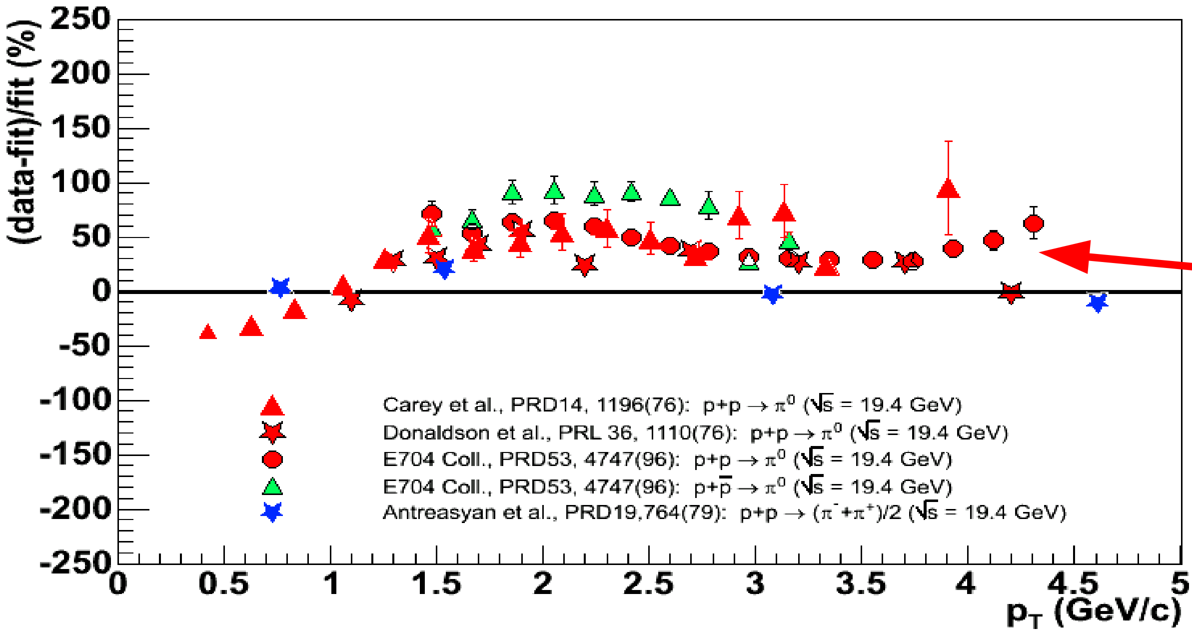
p+p → π+X references @ √s ≈ 20 GeV

- p+p → $\pi^0 X$ parametrizations confronted to data @ √s = 16 – 20 GeV:



WA98 parametrization undershoots the data by up to a factor of ~3

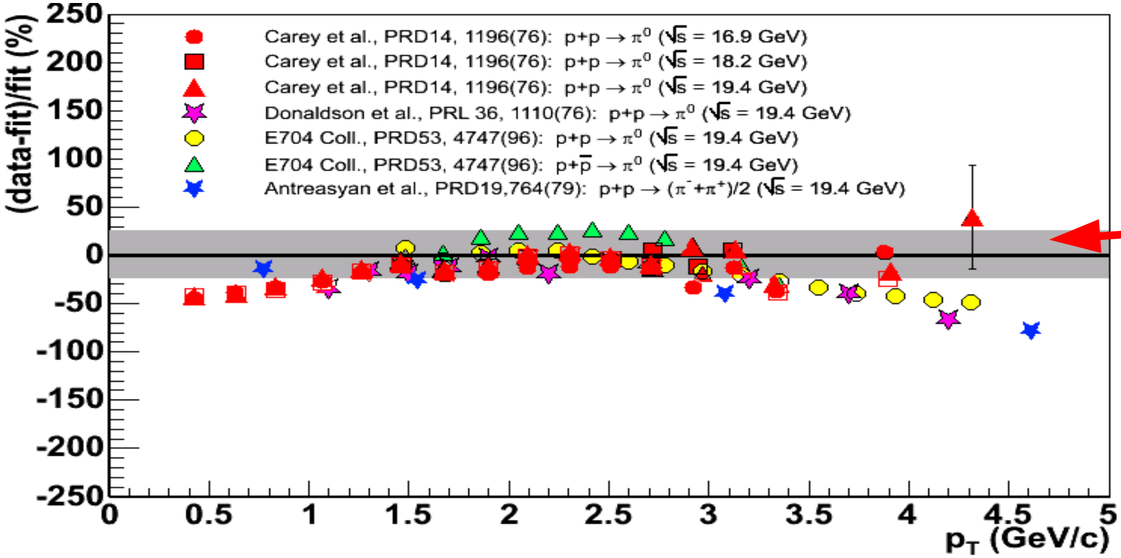
D.d'E. nucl-ex/0403055
PLB 596 (2004) 32



X.N.Wang parametriz. undershoots the data by up to a factor of ~2

New p+p → π+X reference @ √s ≈ 20 GeV

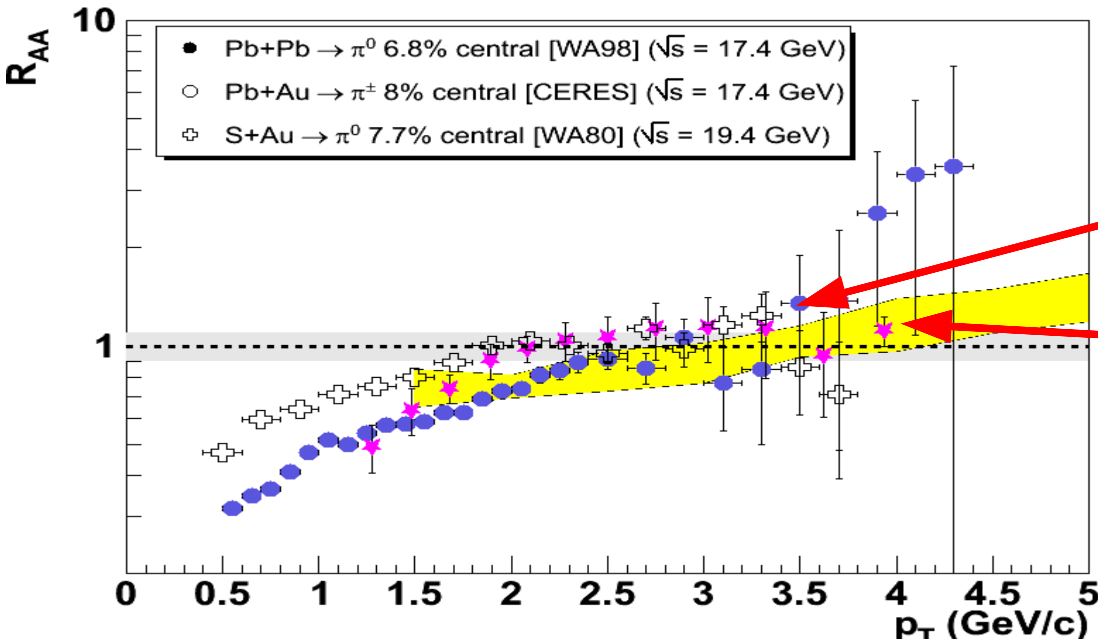
- New parametrization [Blattnig00] versus p+p data √s = 16 – 20 GeV:



Much better agreement in shape and magnitude (within exp. uncertainties)

D.d'E. nucl-ex/0403055
PLB 596 (2004) 32

- New WA98, WA80 & CERES nuclear modification factors:

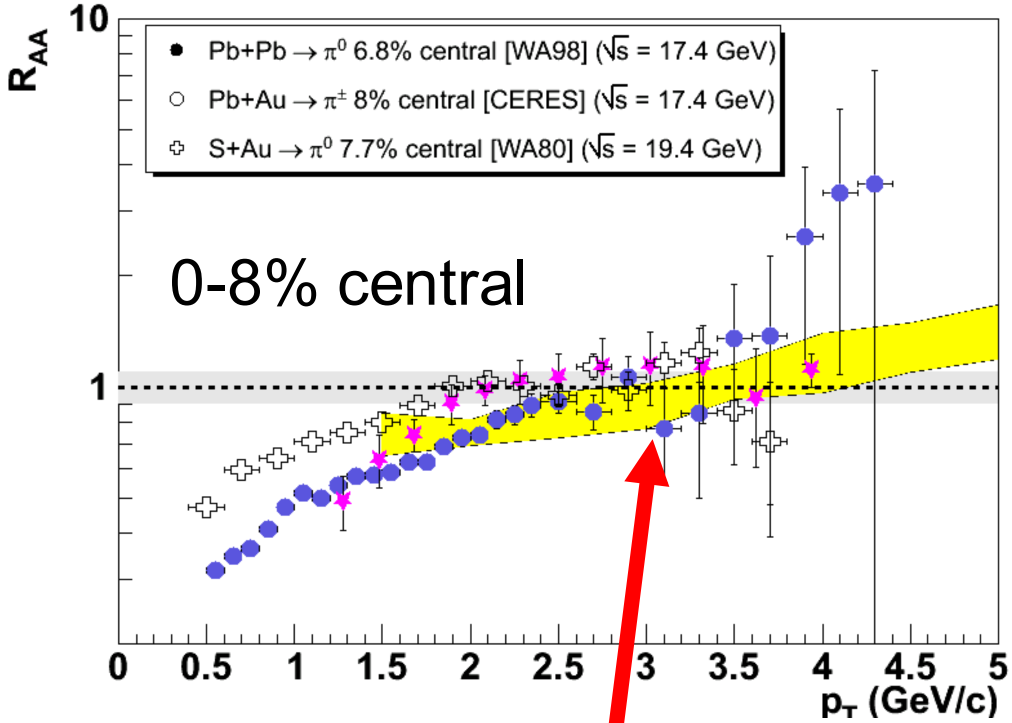


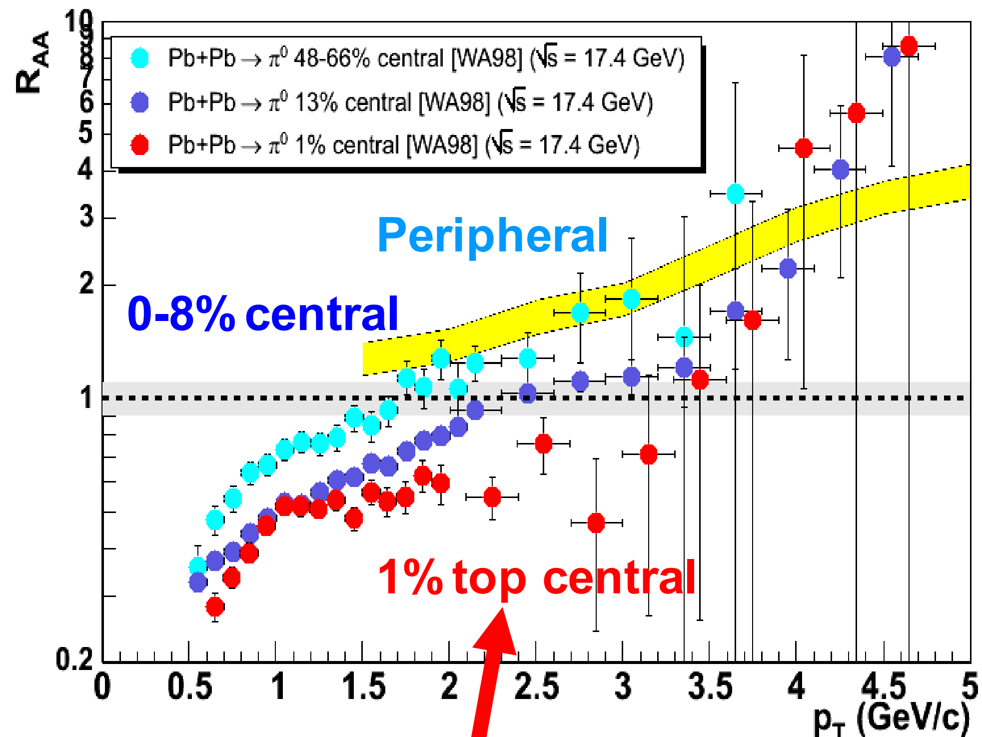
R_{AA} at SPS are not enhanced but consistent with “collision scaling”.

Agreement with parton energy loss calculations [I.Vitev nucl-th/0404052] in moderately dense system (dN^g/dy ~ 400-600)

Indications of high p_T suppression @ SPS

- Centrality evolution of high p_T π^0 production at SPS:





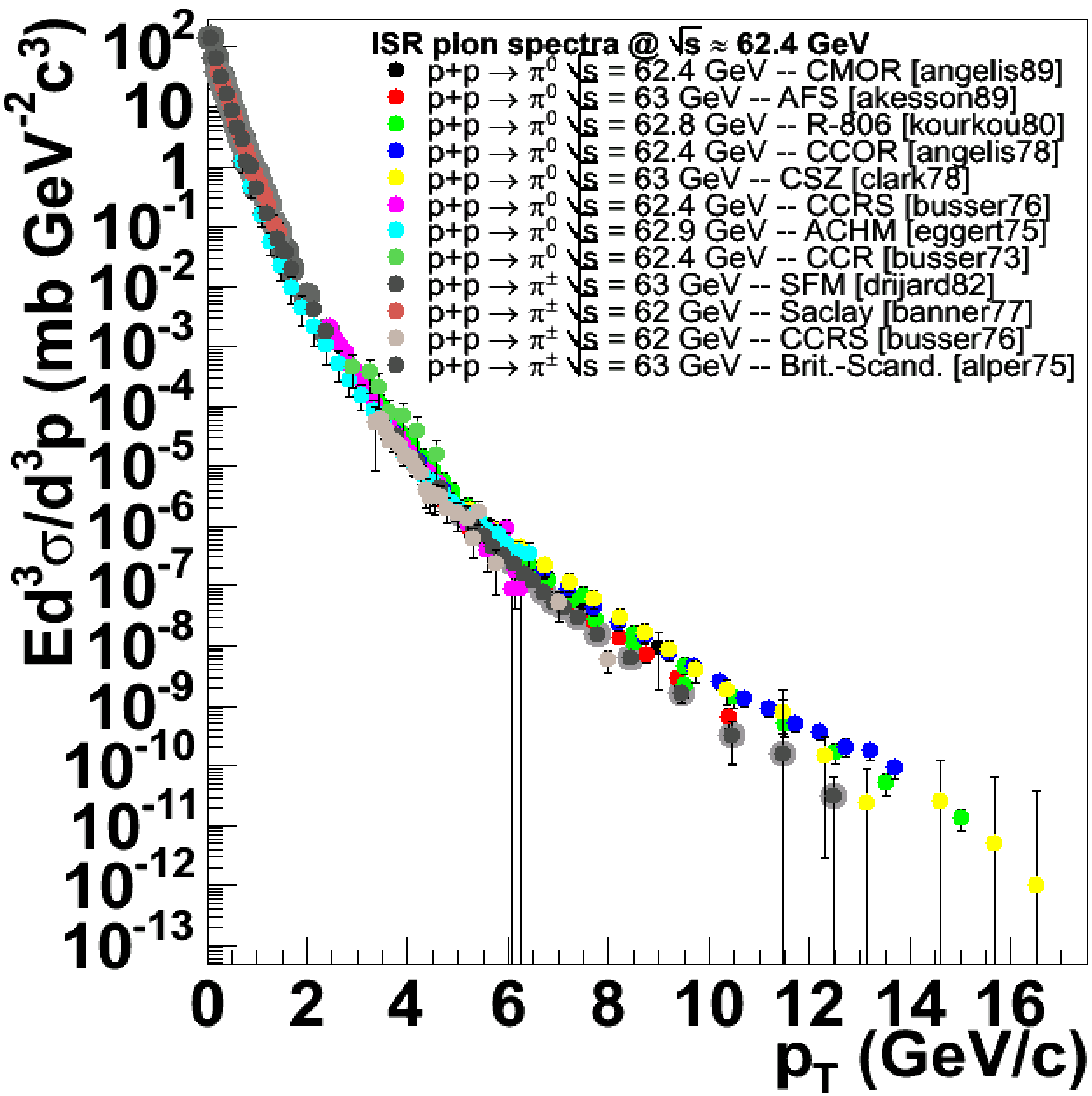
- "Collision scaling" in 0-8% central collisions (R_{AA} ~ 1).
- "Cronin" enhancement in peripheral … and suppression in 1% most central

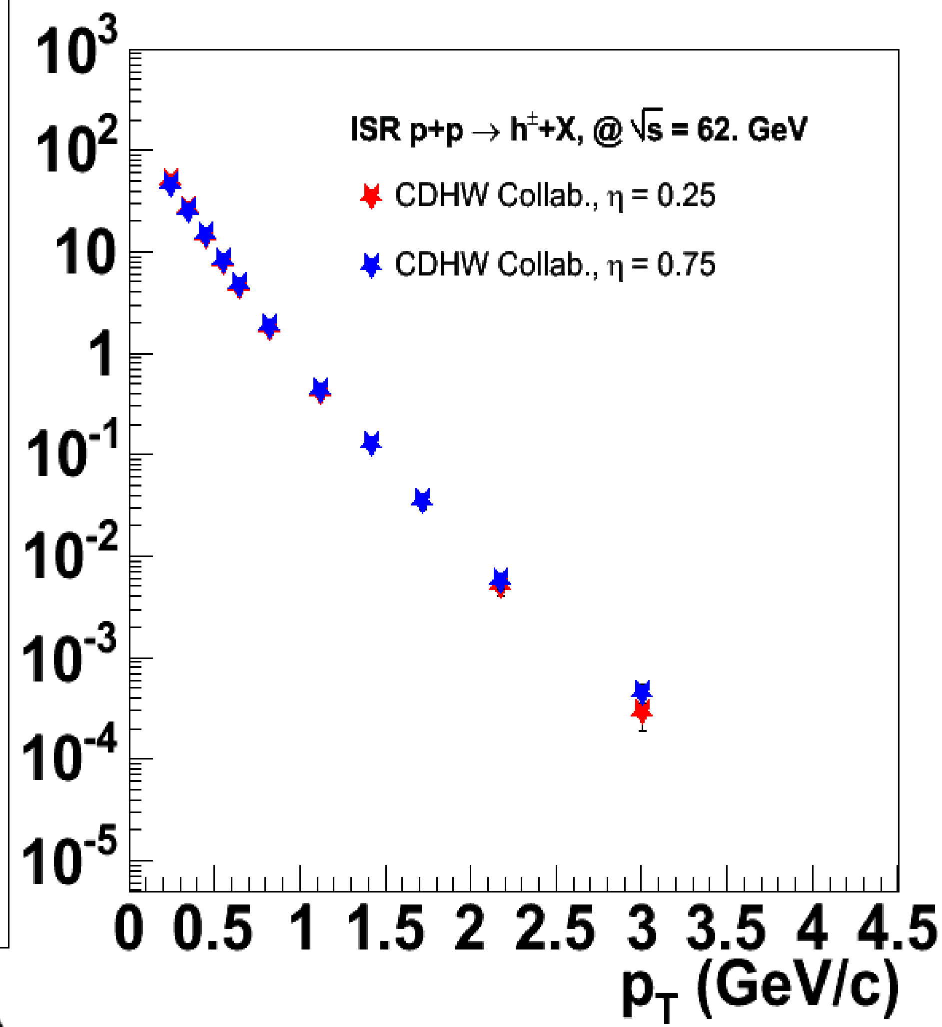
- Wish list (1): Run RHIC Au+Au, p+p @ $\sqrt{s_{NN}} \approx$ 20 – 30 GeV (onset of suppr.)

Case II:
p+p high p_T reference at $\sqrt{s} = 62.4$ GeV

p+p high p_T data @ 62.4 GeV

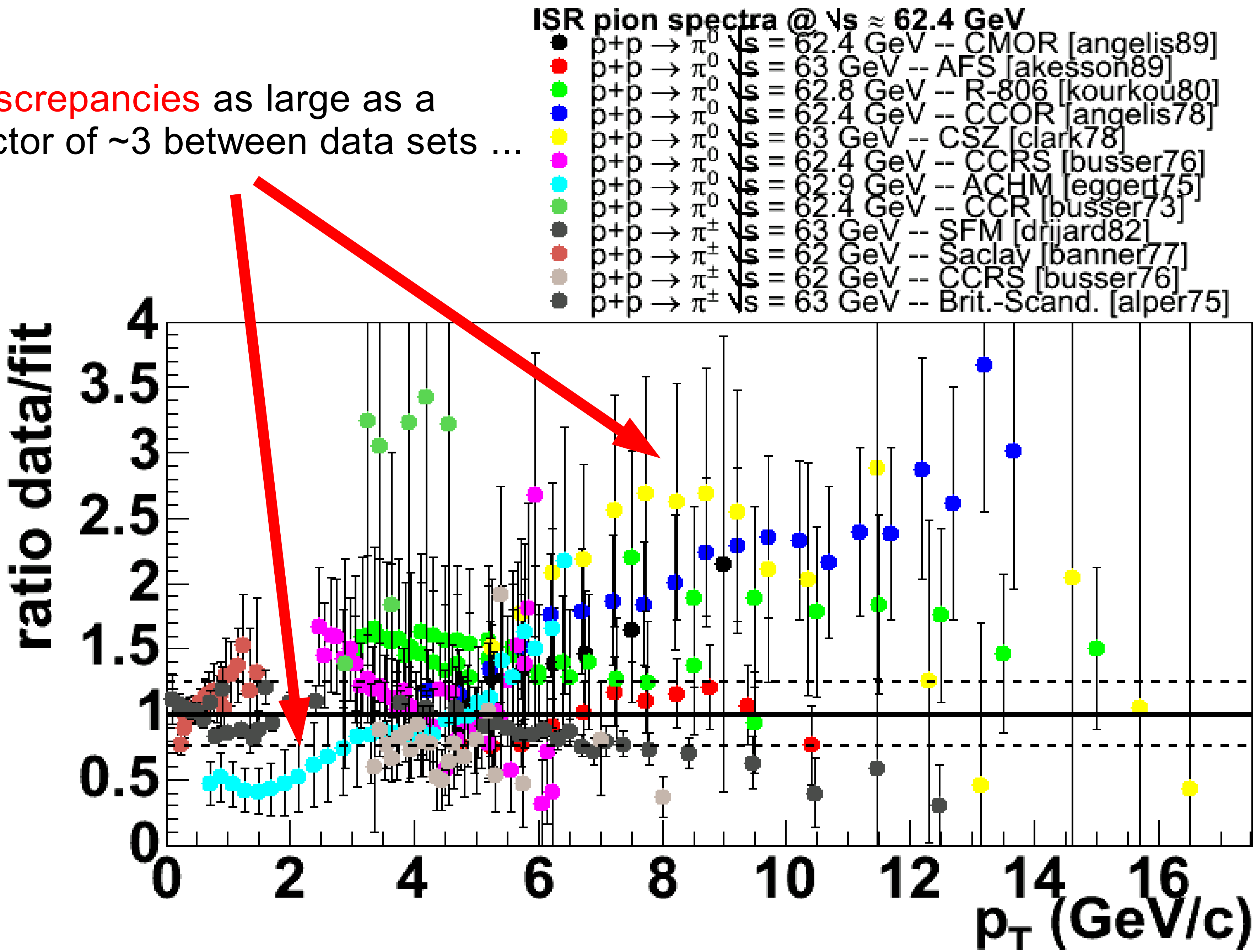
- Au+Au @ 62.4 GeV measured at RHIC in Run-4. But no concurrent p+p ...
- p+p @ 62–63 GeV measured at ISR: pions: π^0 (8), $\pi^\pm$ (4); charged hadrons (1)





How consistent are the p+p → π+X spectra @ 62.4 GeV ?

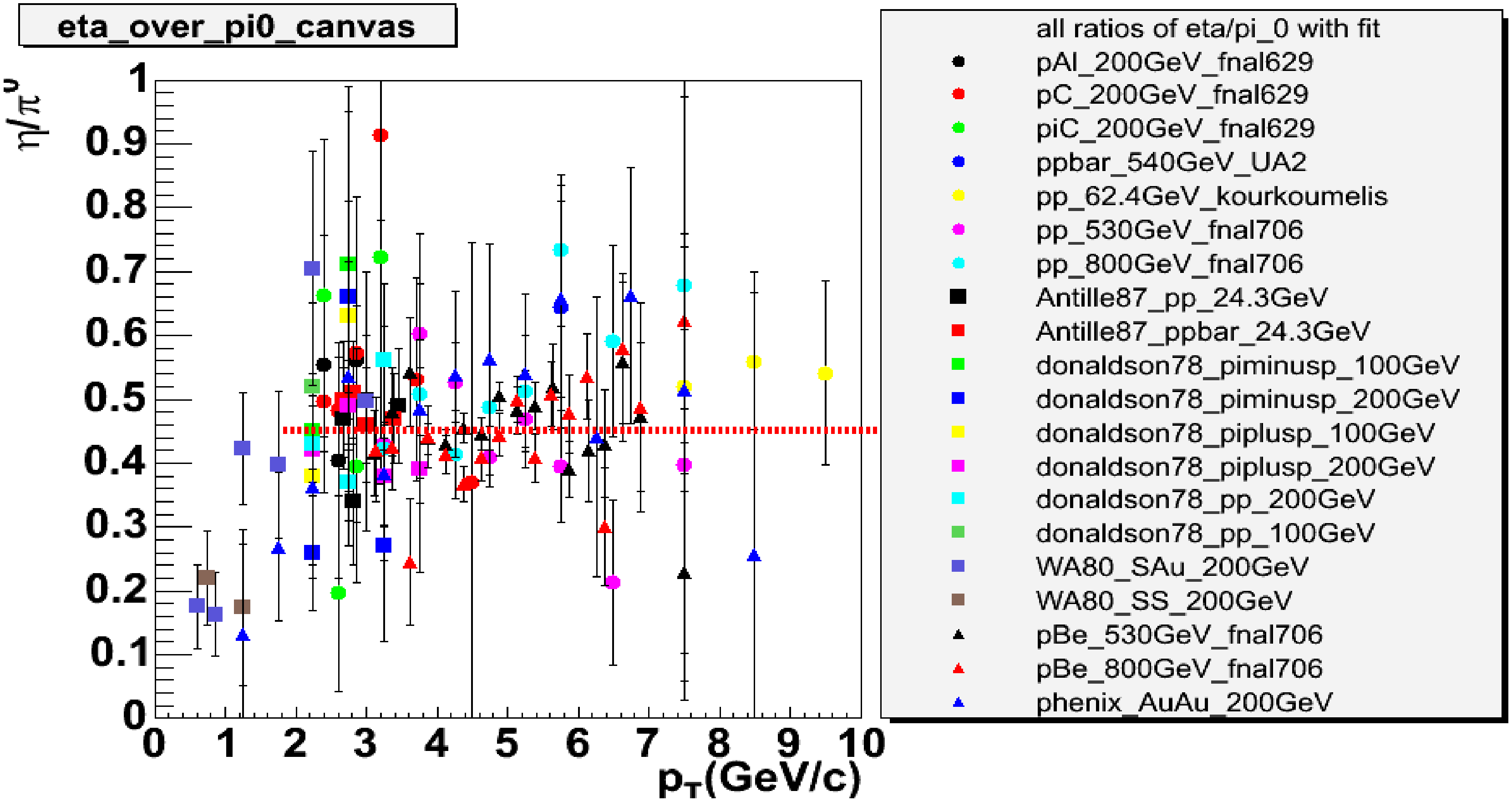
- Discrepancies as large as a factor of ~3 between data sets ...



Unsubstracted π^0 “contaminations” at ISR (1)

All but one measurement at ISR didn't substract the η and direct-γ

- “World average” η/π^0 ~0.45 ratio at high p_T in hadronic colls.



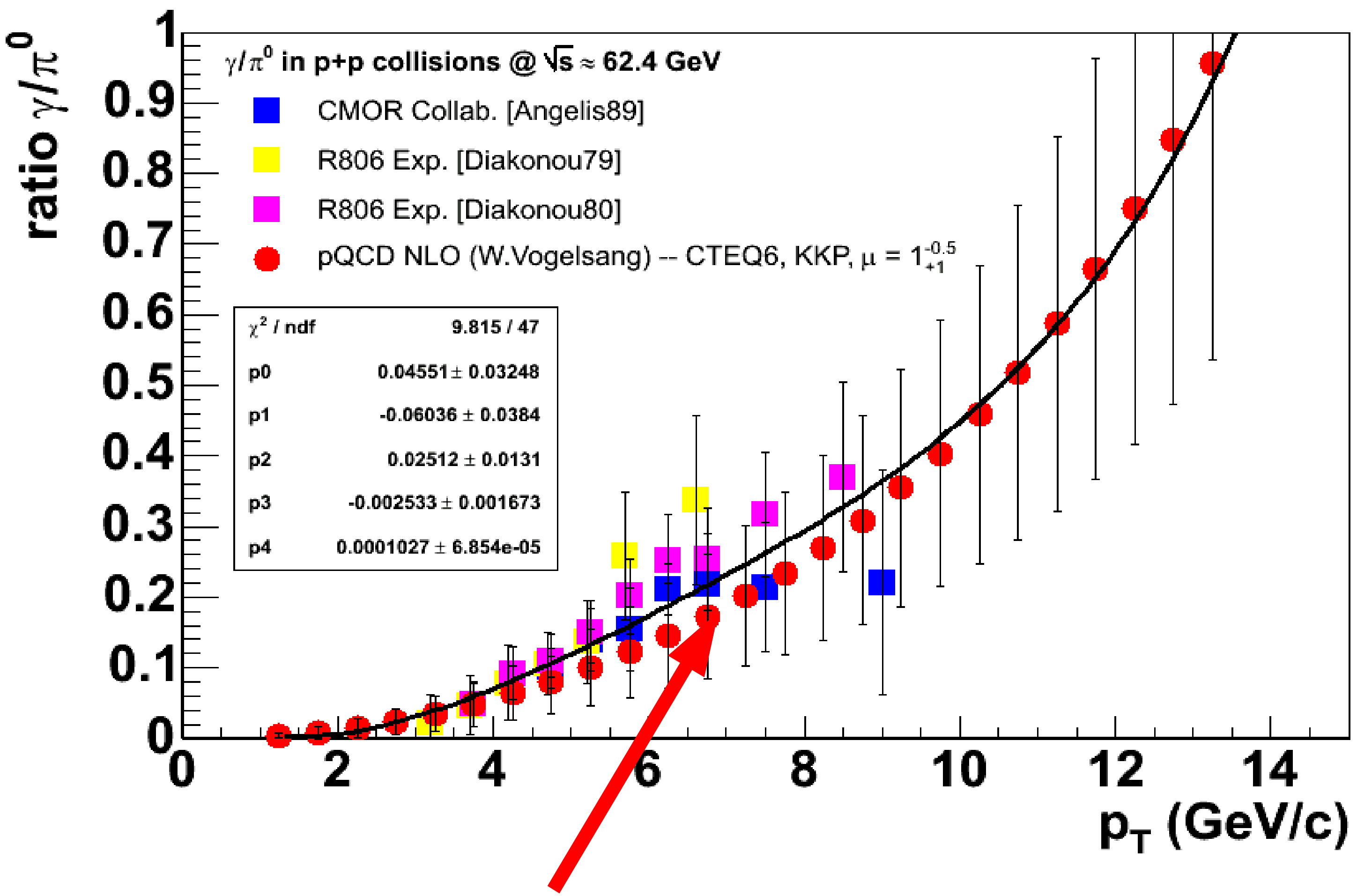
$$BR_{\eta\rightarrow\gamma\gamma} \cdot R_{\eta/\pi 0} = 0.39 \cdot 0.45 \approx 0.18$$

- 18% η contribution needs to be substracted from “unresolved” π^0 spectra.

Unsubstracted π^0 “contaminations” at ISR (2)

All but one measurement at ISR didn't substract the η and direct-γ

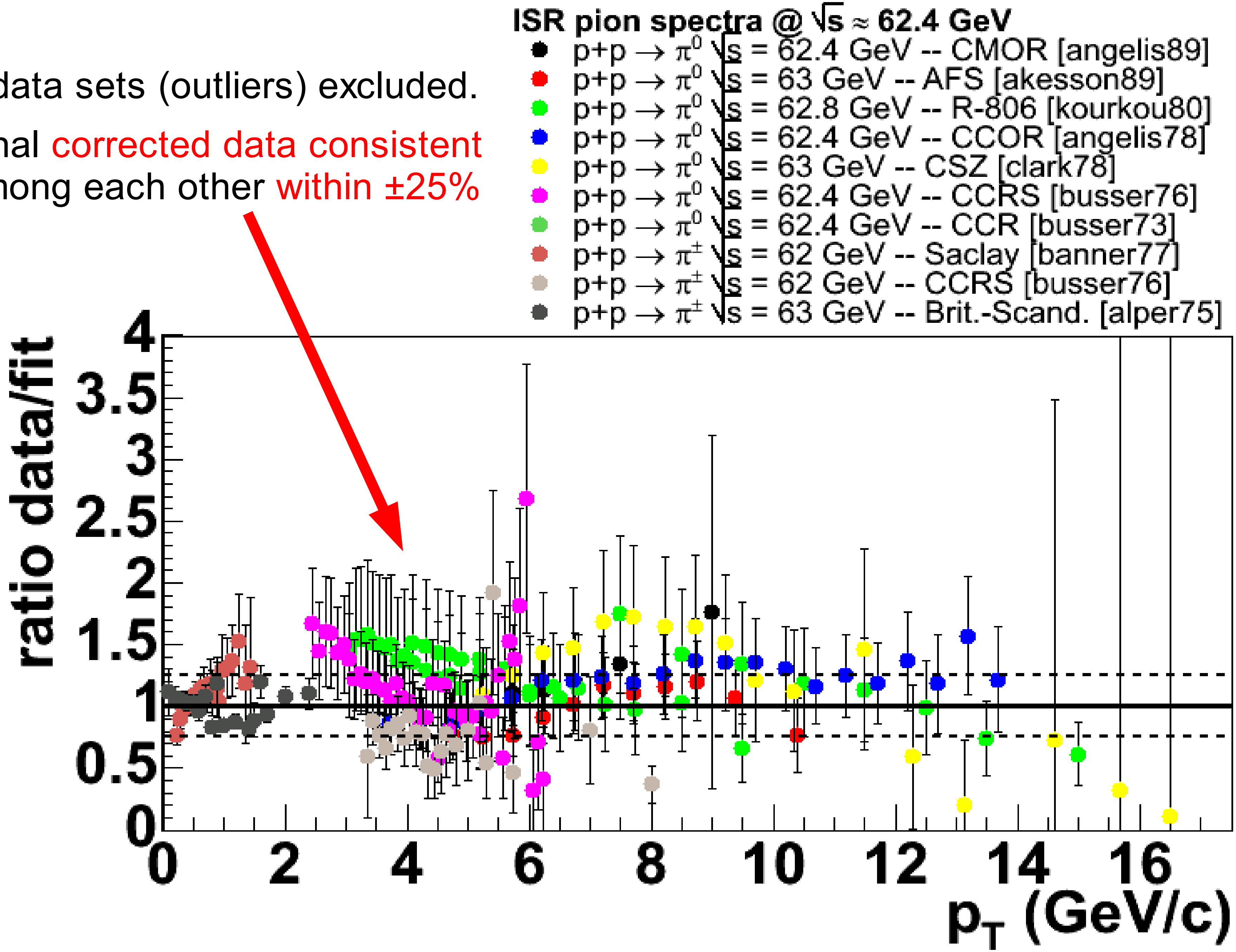
- γ/π^0 ratio at high p_T in p+p at 62 GeV (data compared to NLO pQCD):



- Prompt γ are a significant source of e.m. clusters above p_T~6 GeV/c that needs to be substracted too

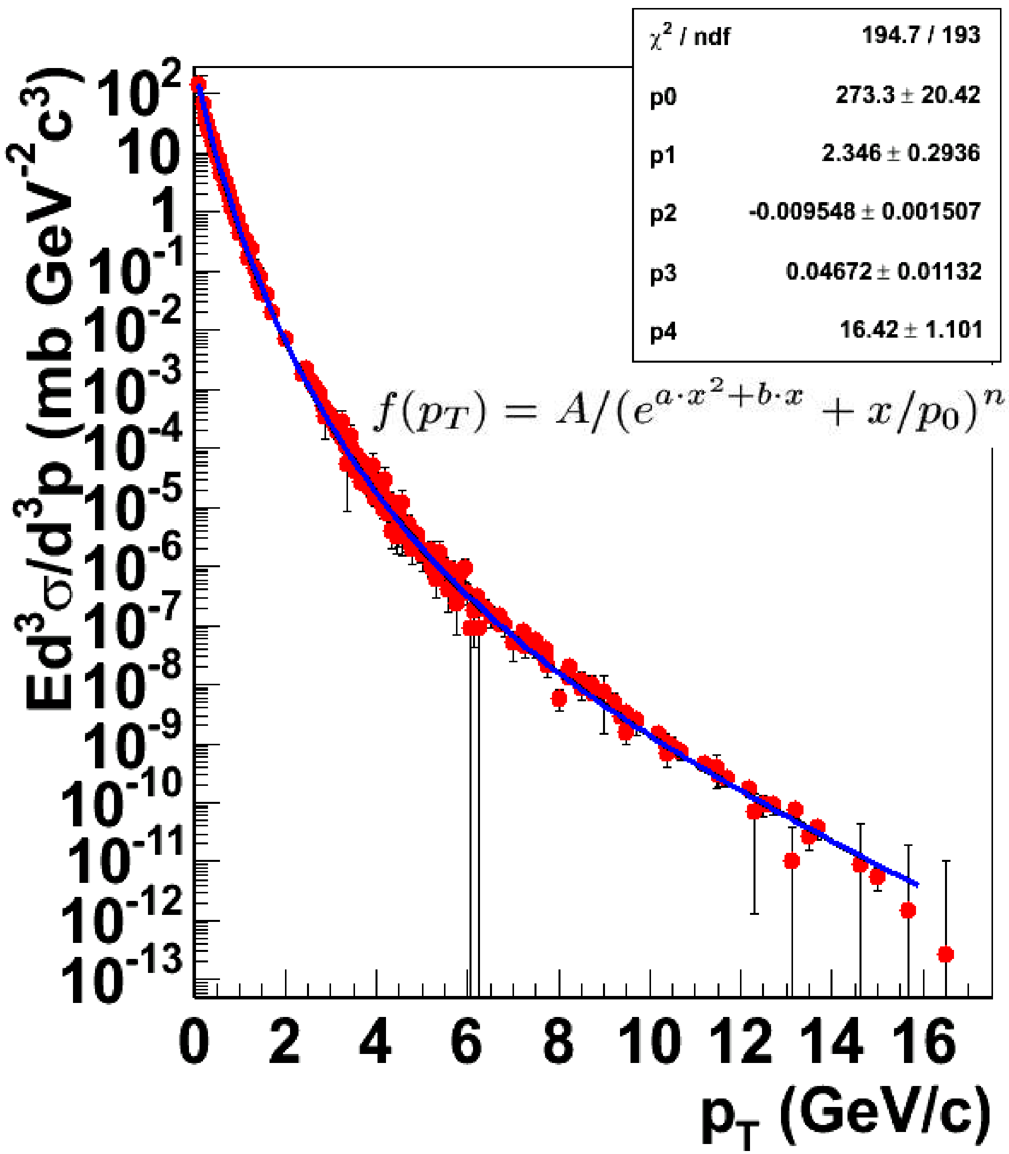
Final corrected p+p spectra @ 62.4 GeV

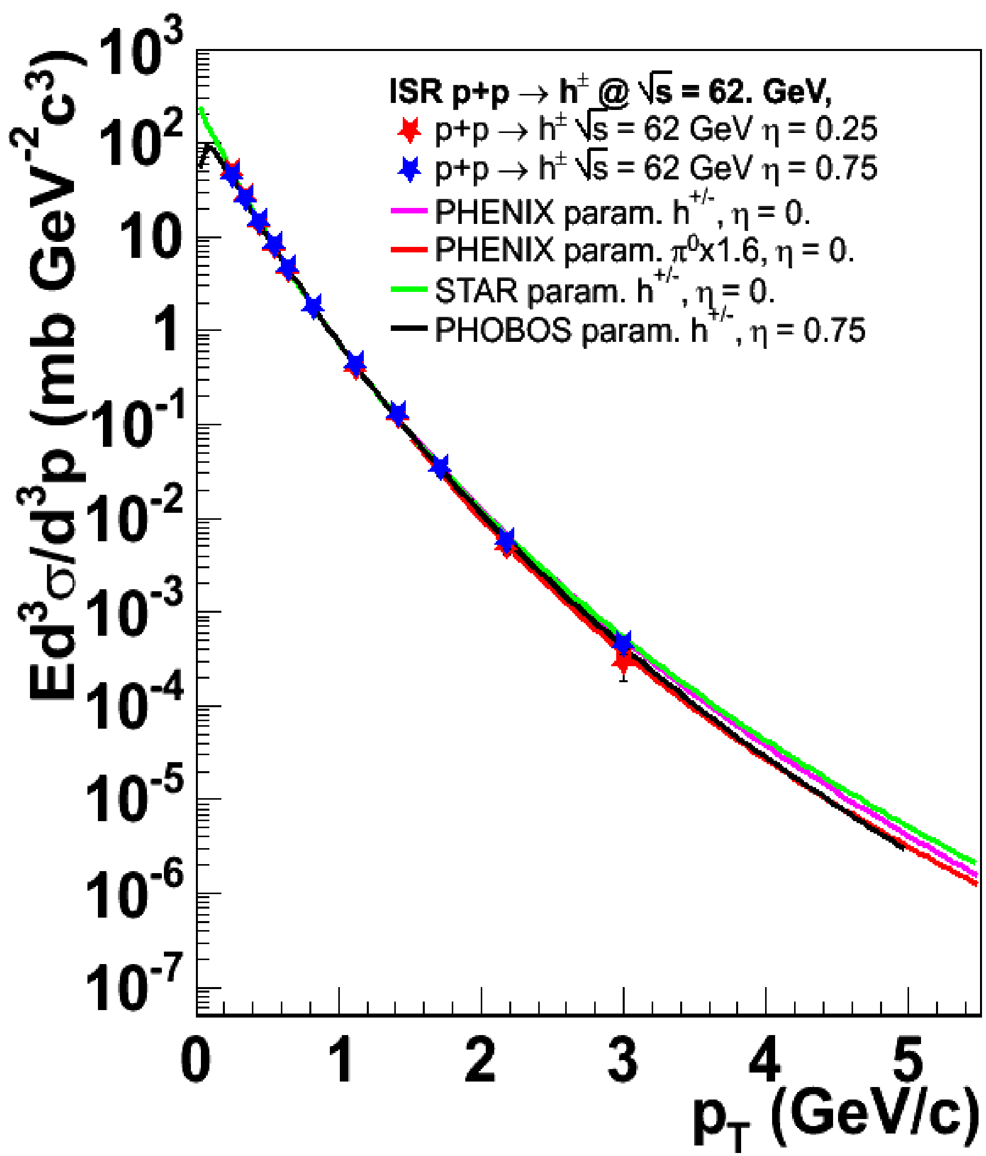
- 2 data sets (outliers) excluded.
- Final corrected data consistent among each other within ±25%



Uncertainties of final p+p high p_T refs. @ $\sqrt{s}$ = 62.4 GeV

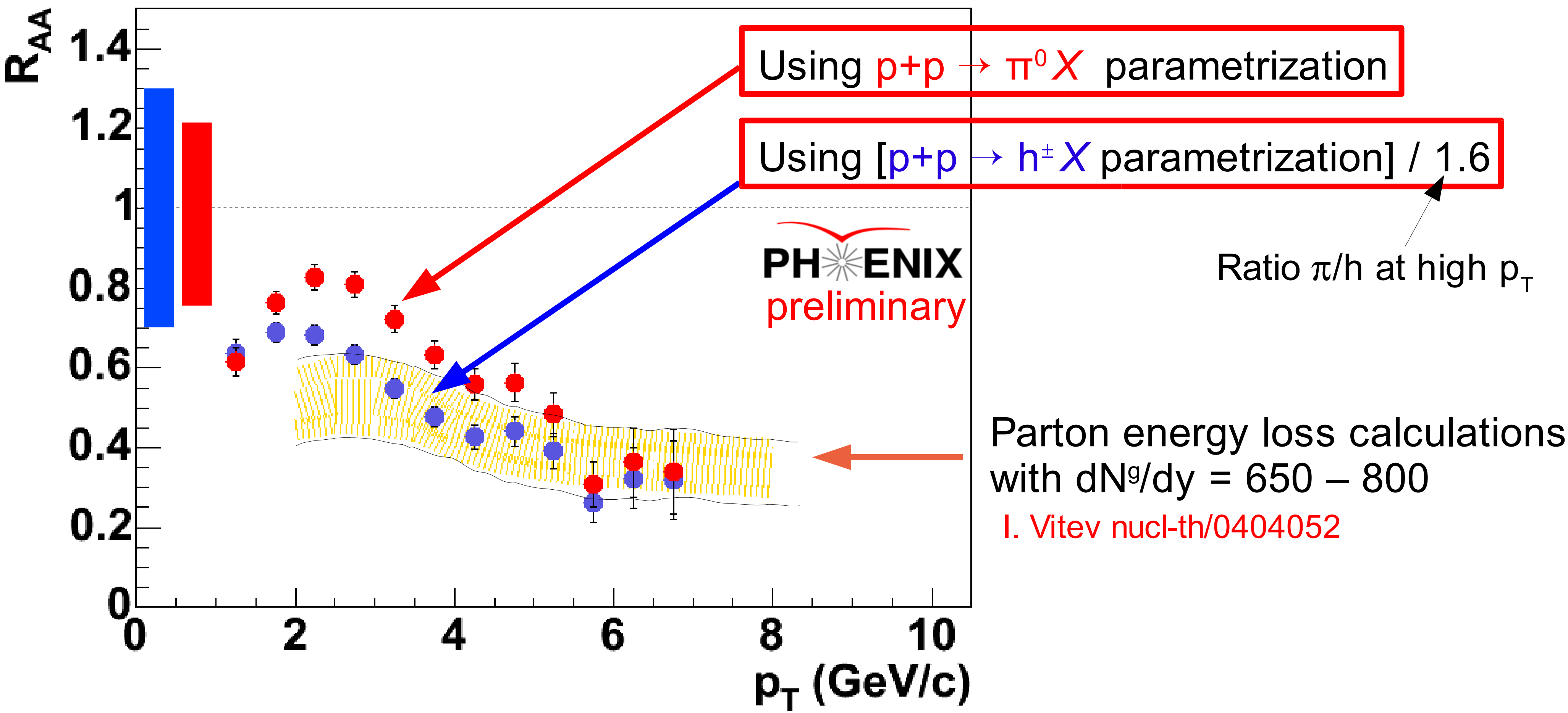
- Neutral pions: ± 25%
- Charged hadrons: ± 35%





High p_T suppression in Au+Au @ 62.4 GeV

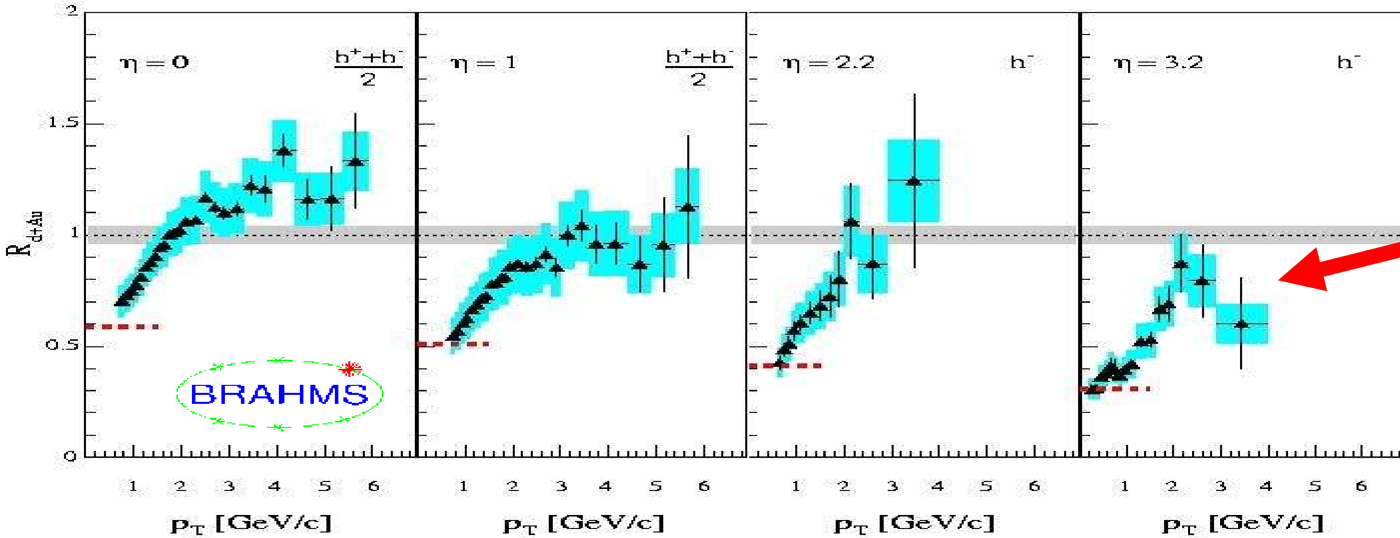
- Propagated uncertainties in the R_{AA} for π^0: p_T dependent, mimic physical (e.g. "Cronin"-like) effects



- Wish list (2): Run RHIC p+p @ $\sqrt{s_{NN}}$ = 62.4 GeV (detailed quantitative study of $\sqrt{s}$-dependence of high p_T suppression)

Case III:
p+p high p_T reference at $\sqrt{s}$ = 200 GeV at forward rapidities

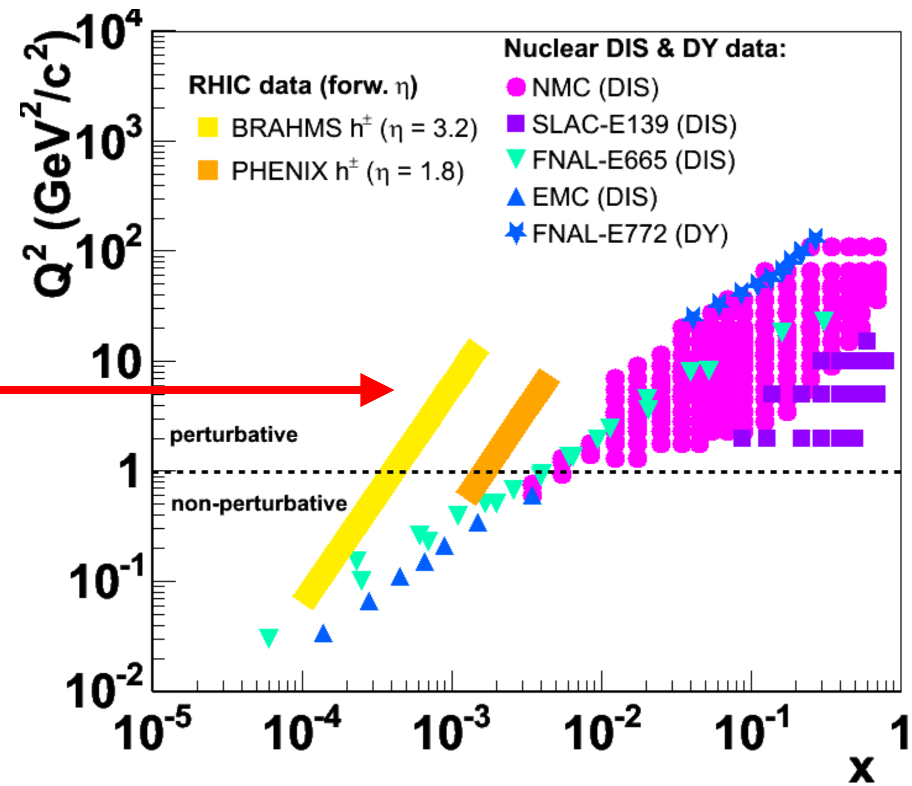
d+Au nuclear modification factor @ η = 3.2



- Factor ~2 suppression in hadron production:
  p_T = 1-3 GeV/c, η = 3.2
  $x_2 \sim 10^{-4}$ in Au(*)

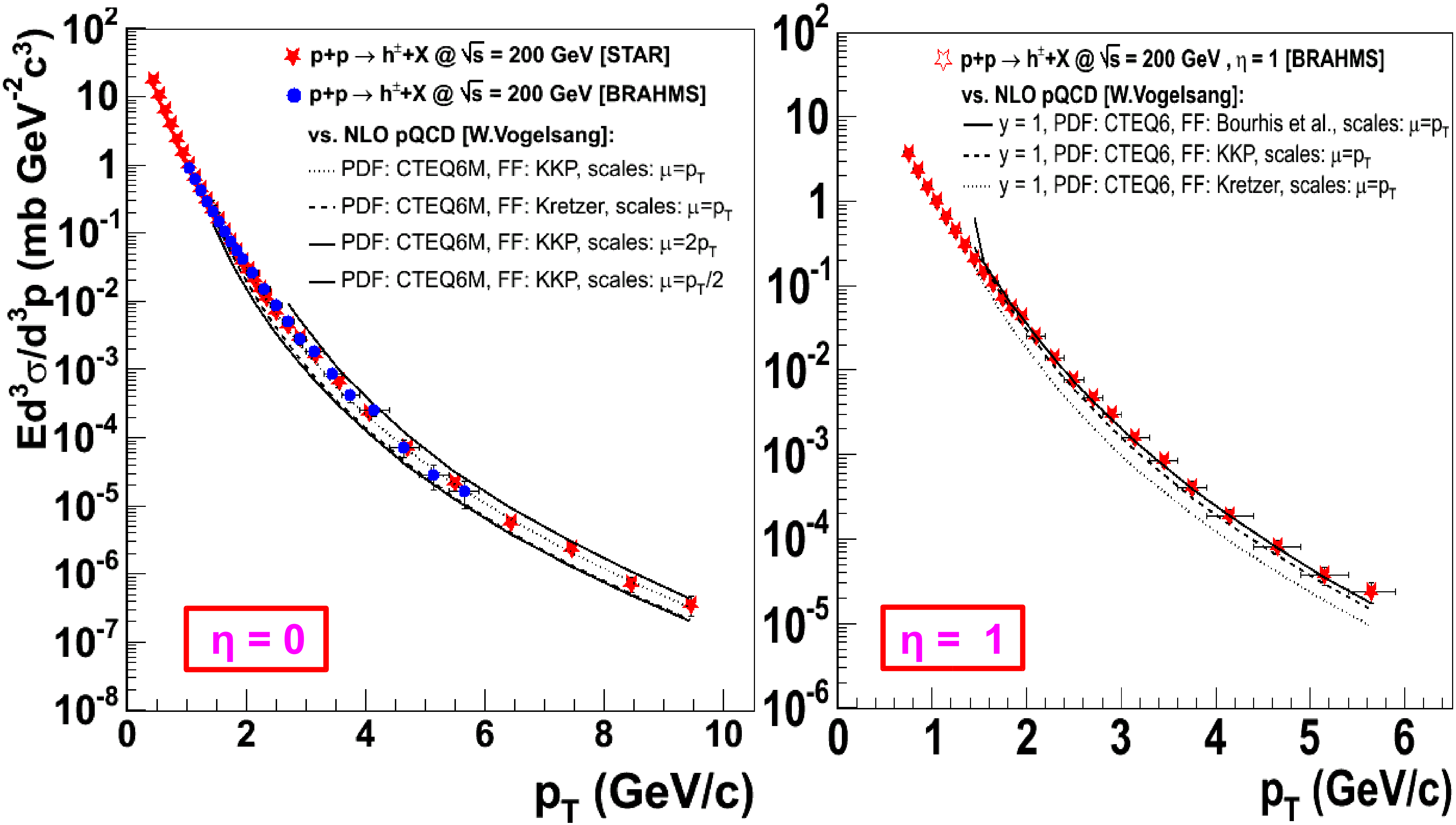
- First time a large "shadowing" is seen at small-x and high p_T in nuclear syst.

- So far unexplored(*) perturbative region of nuclear (x,Q^2) plane.



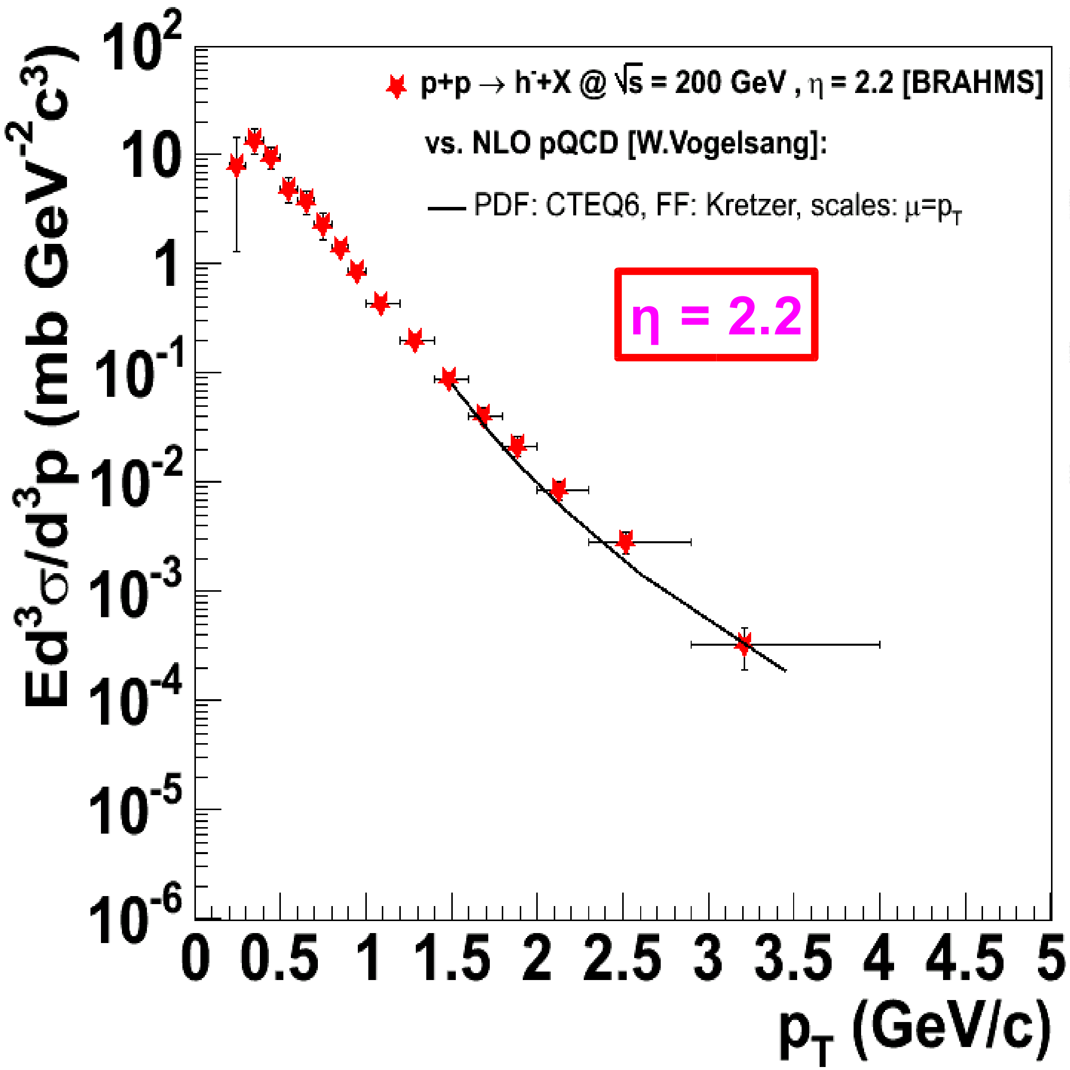
(*) Caveat: The "back-of-the-envelope" estimates ($x \sim p_T e^{-y}$) of the small-x values probed at forw. rapidities at RHIC provide usually too low values. Effective $\langle x_2 \rangle$ values are at least ~10 times larger.

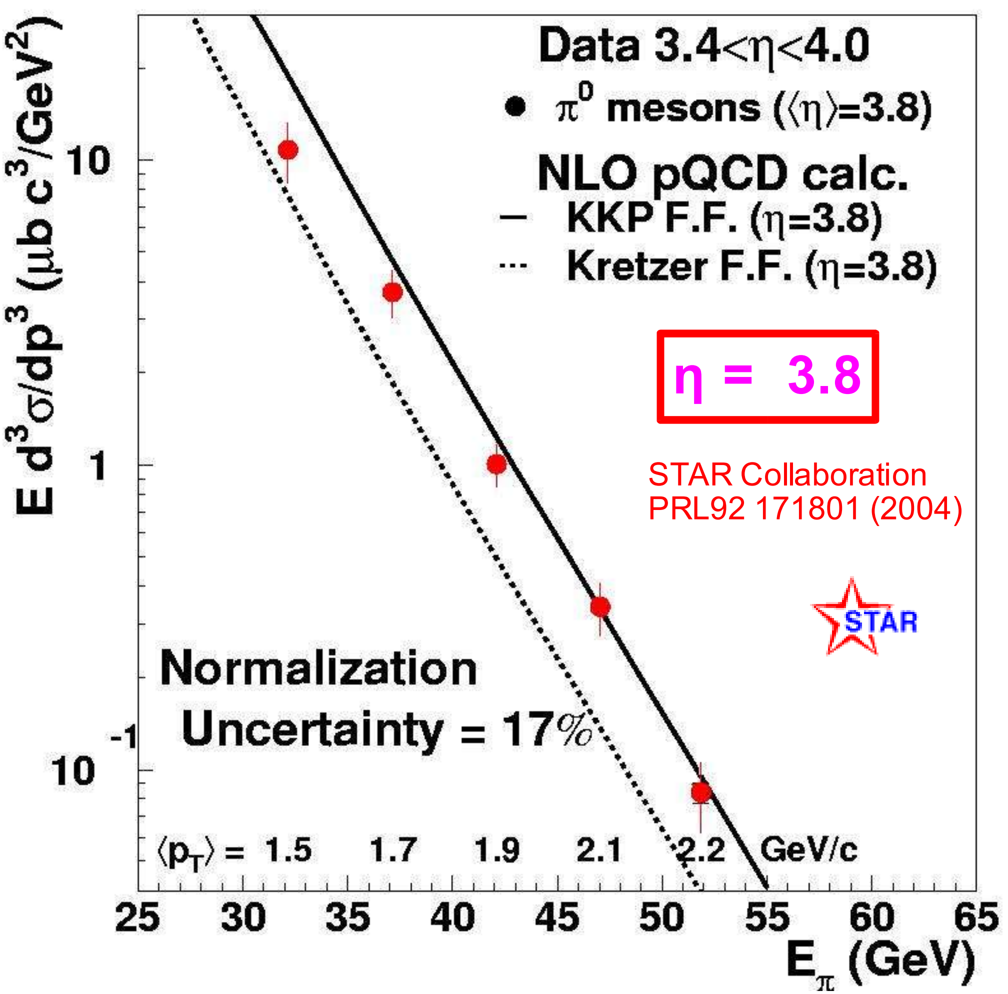
High p_T p+p reference spectra vs pQCD (mid-rapidity)



- Good agreement with NLO pQCD [calculations by W. Vogelsang]

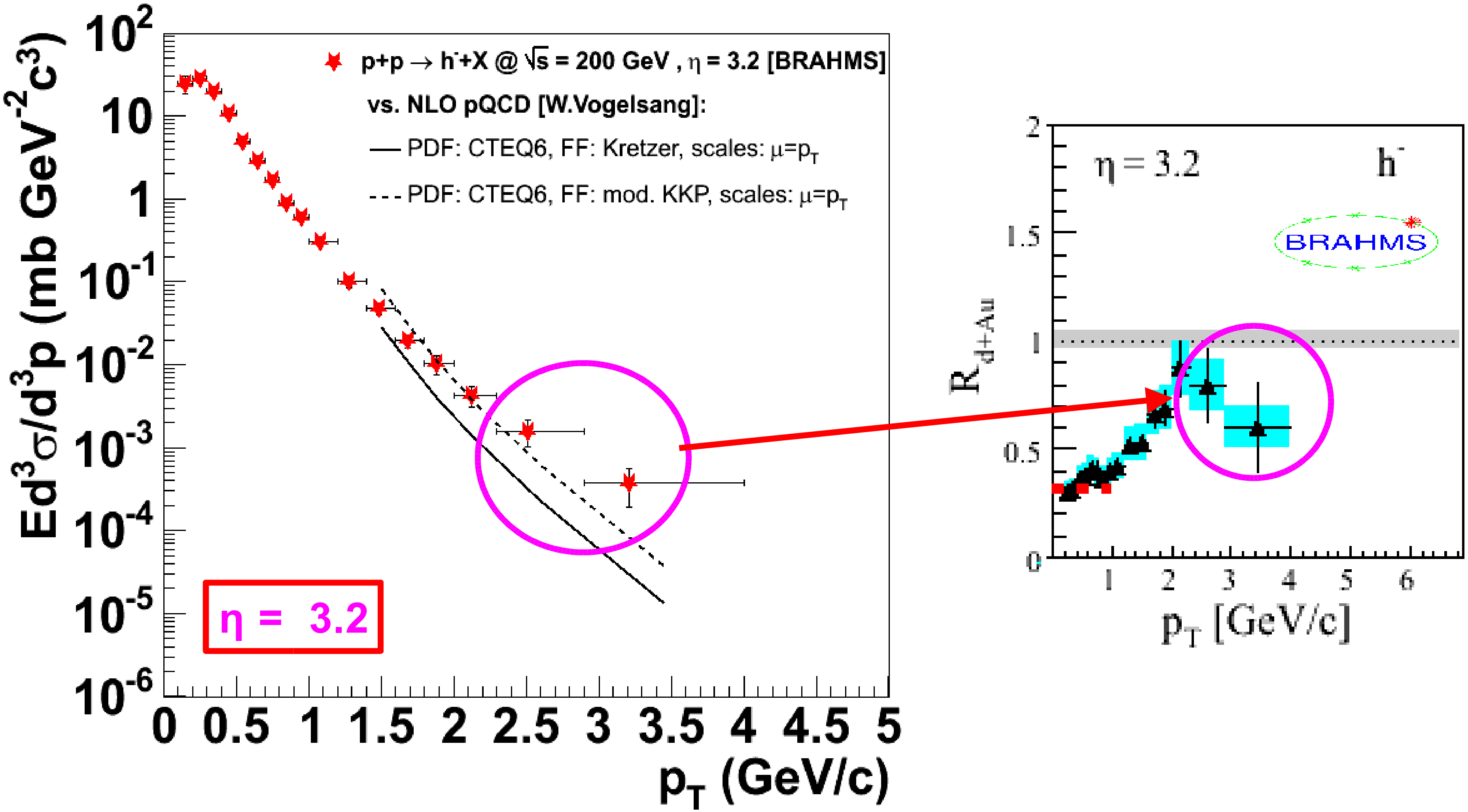
High p_T p+p reference spectra vs pQCD (forward η)





- Good agreement with NLO pQCD [calculations by W. Vogelsang]

High p_T p+p reference spectrum vs pQCD (η=3.2)

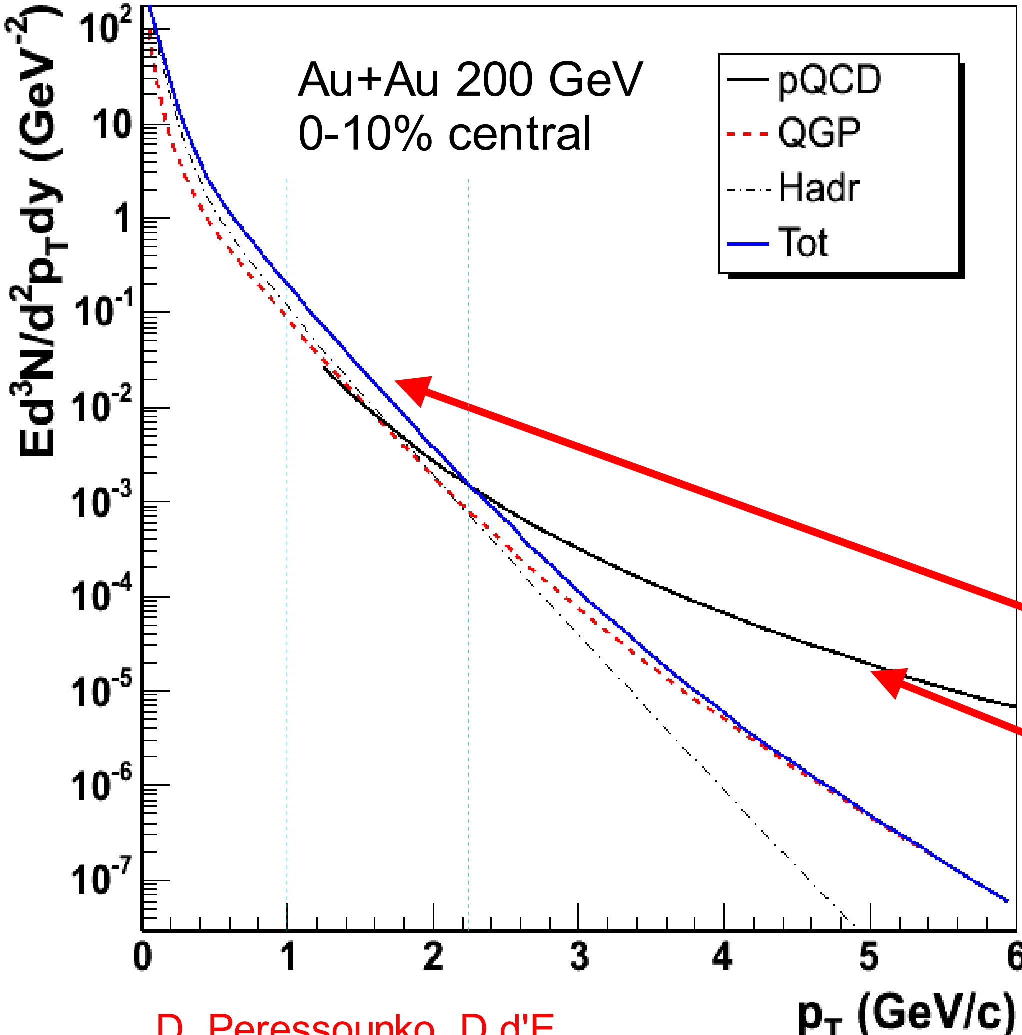


- Two highest p_T points (there where the R_{dAu} "suppression" appears) are "enhanced" w.r.t. NLO (which describes all other rapidities, even y = 3.8 !).
- Let's be provocative ... Is there d+Au suppression or ("genuine" ?) p+p "enhancement" ?

Case IV:
p+p high p_T photon reference at $\sqrt{s}$ = 200 GeV

Thermal photon production in Au+Au @ $\sqrt{s_{NN}}$ = 200 GeV

- Thermal (real&virtual) γ are the most direct (the only ?) probe sensitive to the thermodynamical state (EOS) of underlying matter.



D. Peressounko, D.d'E.
(in preparation)

2+1 hydro predictions:

Initial conditions:

τ_0 = 0.15 fm/c

T_0 = 580 MeV

(reproduces bulk π, K, p dN/dp_T)

EOS:

QGP (2.5 flavors) + hadron res. gas + 1st order phase transition (ΔE=0.8 GeV)

Thermal (QGP+HG) component

NLO pQCD x T_{AB} scaling

- Thermal production (only) apparent within $p_T \approx 1 - 2.5$ GeV/c

Medium effects in Au+Au→ γ+ X @ √s = 200 GeV

- However, (part of the) prompt photons can be distorted by the dense QCD medium (esp. in the region p_T< 4 GeV/c).
- Photon production in p+p @ 200 GeV:

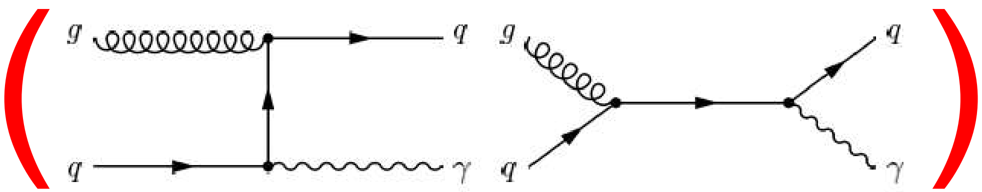


Figure 2.1: Compton diagrams.

+

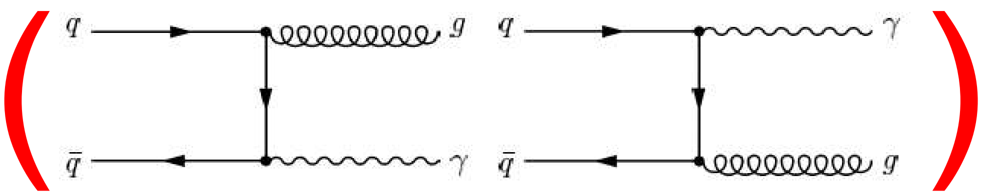


Figure 2.2: Annihilation diagrams.

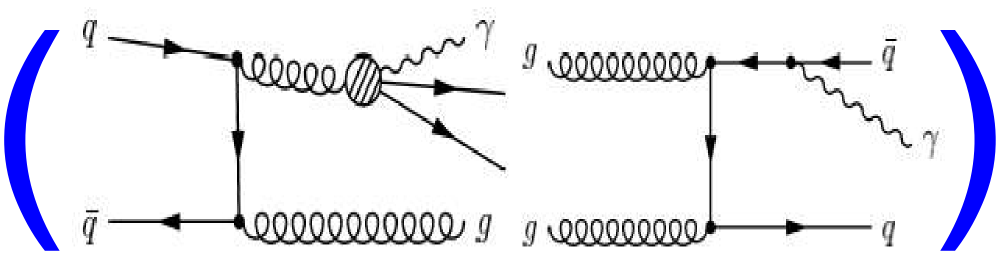
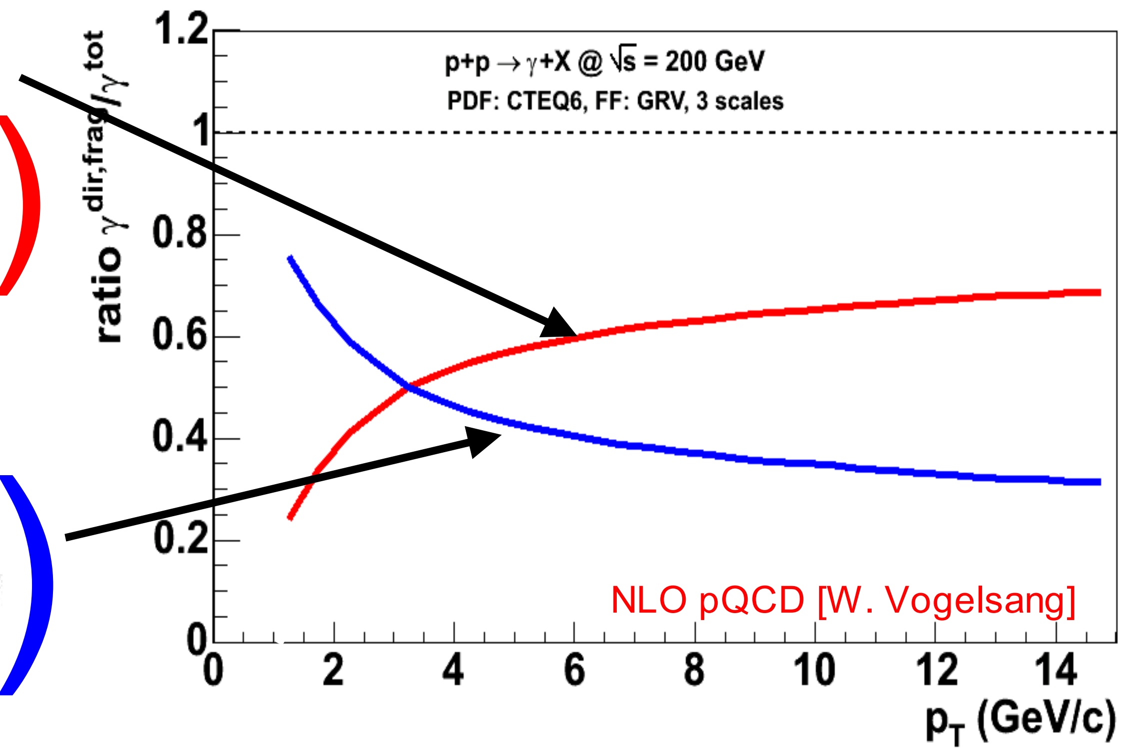


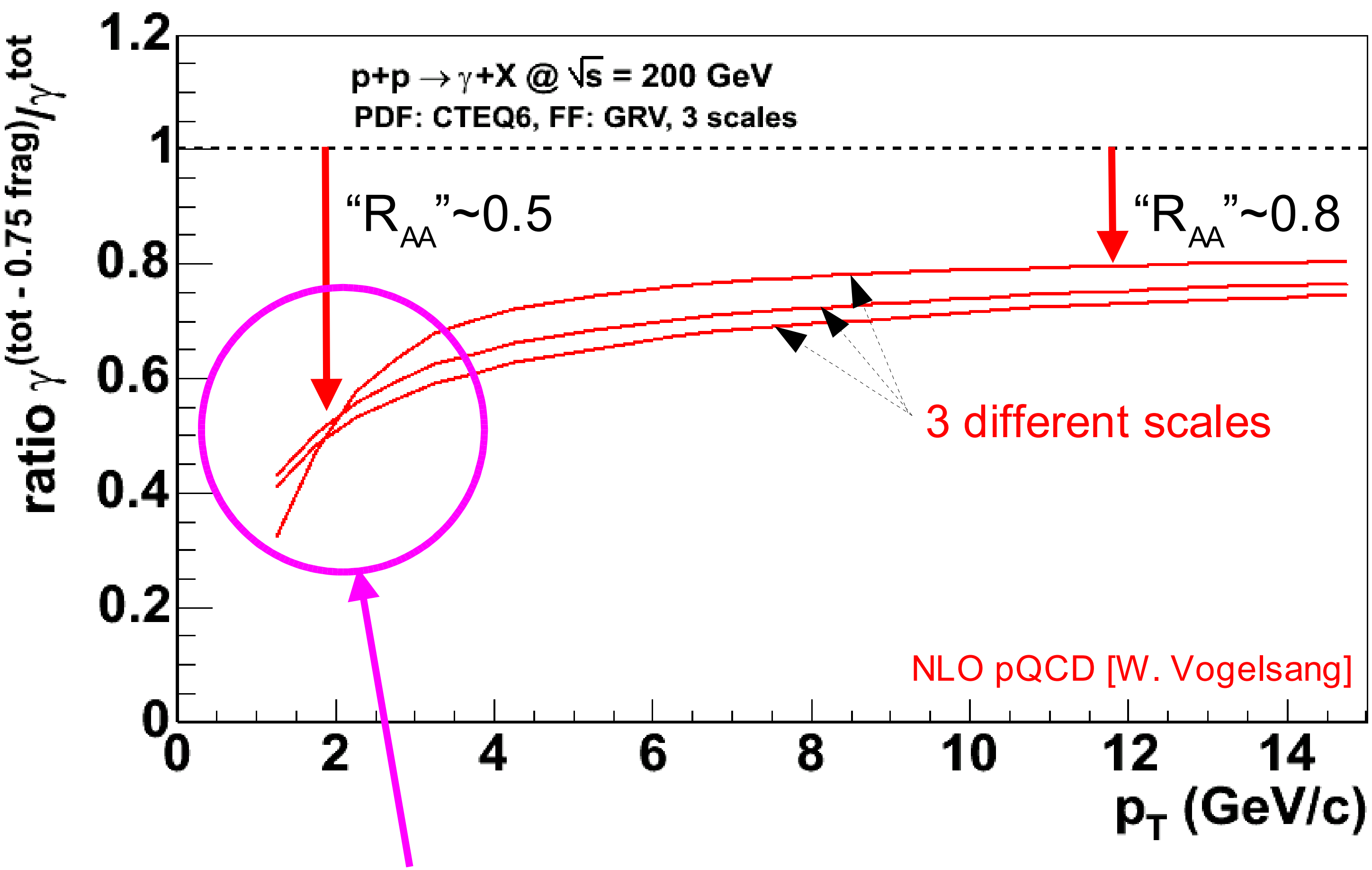
Figure 2.3: Bremsstrahlung diagrams.

Below p_T ≈ 4. GeV/c dominated by γ from collinear q,g fragmentation



"Nuclear modif. factor" Au+Au→ γ+ X @ $\sqrt{s}$ = 200 GeV

- Back-of-the-envelope ansatz for γ suppression: R_{AA}(γ frag.) = R_{AA}(q,g) ≈ 0.25
- R_{AA}≈ Ratio of γ(tot – 0.75*frag)/γ(tot):



(No shadowing corrs. included)

Results confirmed by more involved calculations: F.Arleo: hep-ph/0406291

- ~50% depleted prompt photon yield could mask the expected (enhanced) thermal emission around p_T = 2 GeV/c

Disentangling "thermal" γ from quenched prompt γ

- **Step 1:** Measure p+p → γ(isolated) + *X*
  down to p_T = 1 GeV/c
  with uncertainties ~10%

Handle on γ from qg-Compton, qqbar annihilation

- **Step 2:** Measure p+p → γ(total) + *X*
  down to p_T = 1 GeV/c
  with uncertainties ~10%

Handle on fragmentation γ production

- **Step 3:** Measure Au+Au → γ(total) + *X*
  down to p_T = 1 GeV/c
  with uncertainties ~10%

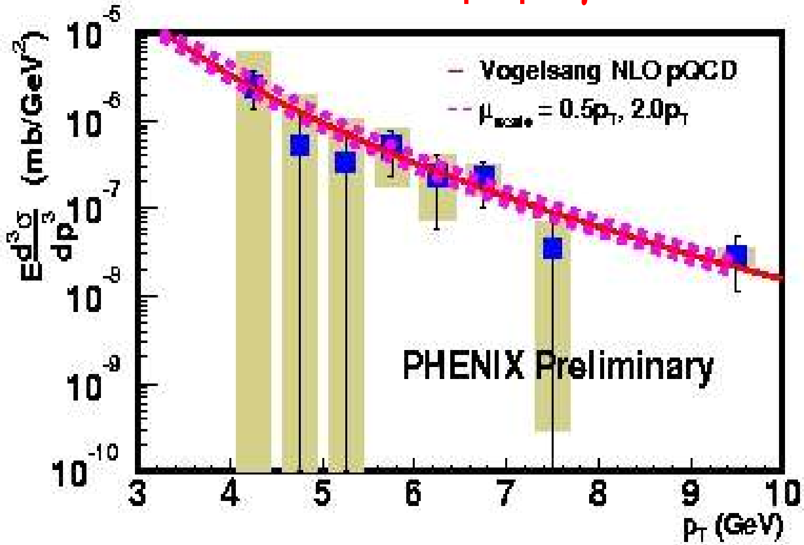
- **Step 4:** (AuAu γ_{total}) – T_{AB}•(pp $\gamma_{isolated}$)

  Upper limit on thermal spectrum.

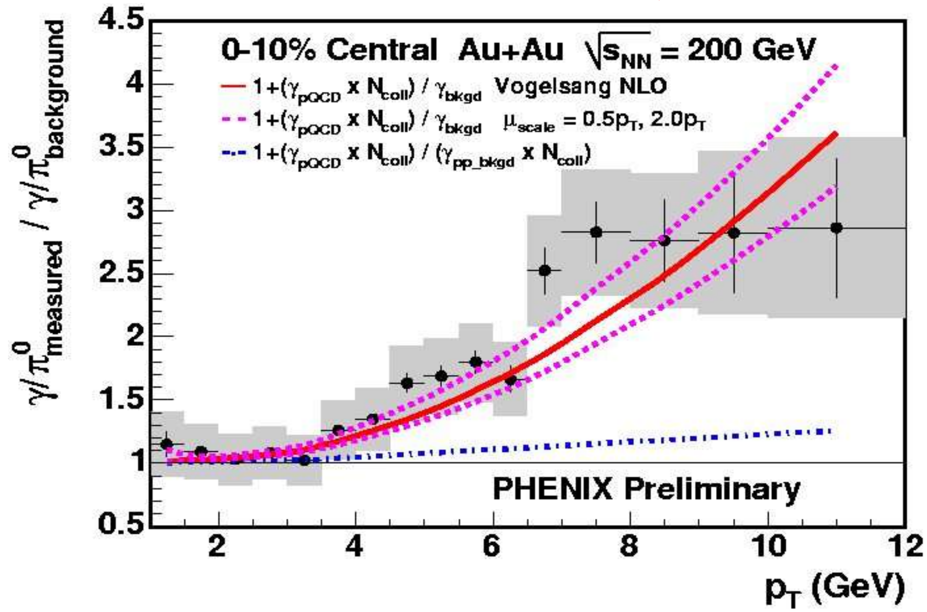
- **Step 5:** (AuAu γ_{total}) – T_{AB}•(pp γ_{total})

  Lower limit on thermal spectrum.

Daunting tasks ! ...
Current best p+p γ data:



Current best Au+Au γ data:



High p_T p+p baseline spectra: Summary

- Case I: $p+p \to \pi+X$ at $\sqrt{s} \approx 20$ GeV

  Fact: High p_T A+A hadroproduction @ SPS is (slightly) suppressed.
  Wish: Measuring p+p, Au+Au at RHIC at $\sqrt{s}$ = 20 – 30 GeV (Run-6 ?)

- Case II: $p+p \to \pi,h^{\pm}+X$ at $\sqrt{s}$ = 62.4 GeV

  Fact: Current ISR-averaged p+p refs. have uncertainties of order ~30% precluding detailed quantitative study of $\sqrt{s}$-dependence of high p_T A+A suppr.
  Wish: Measuring p+p at RHIC at $\sqrt{s}$ = 62.4 GeV (Run-5 ?)

- Case III: $p+p \to h^{\pm}+X$ at $\sqrt{s}$ = 200 GeV at forward y

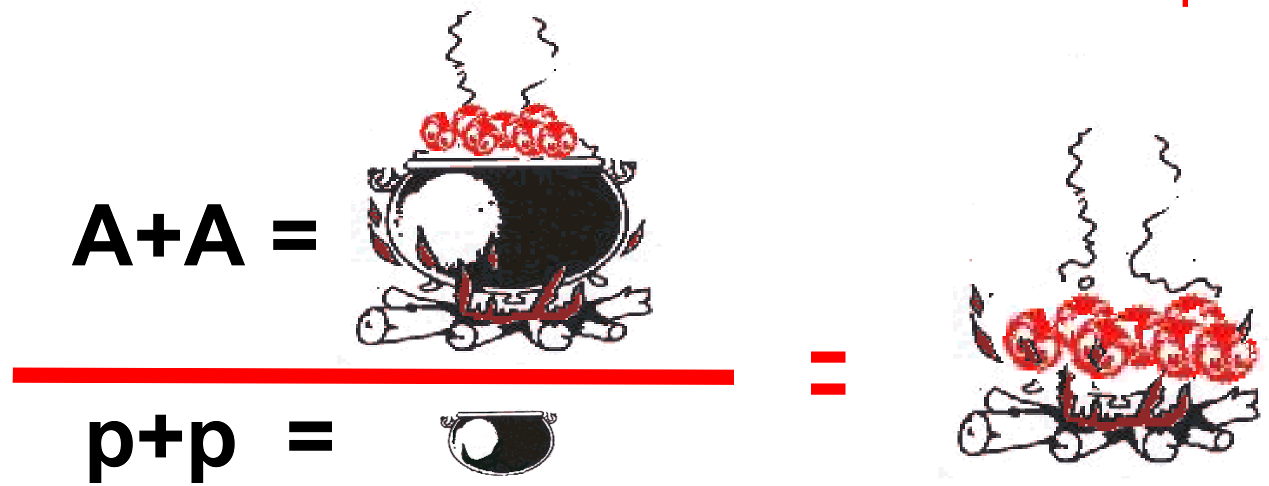
  Fact: High p_T spectra at η=0,1,2.2,(3.2),3.8 are (not) well reproduced by pQCD putting (perhaps) into question the claimed d+Au suppression.
  Wish: Independent confirmation of p+p h^- spectrum at η=3.2

- Case IV: $p+p \to \gamma+X$ at $\sqrt{s}$ = 200 GeV

  Fact: Depleted prompt γ (from quenched jet fragmentation) can hide the thermal photon signal in Au+Au at RHIC.
  Wish: Measure isolated and non-isolated γ in p+p at $\sqrt{s}$ = 200 GeV

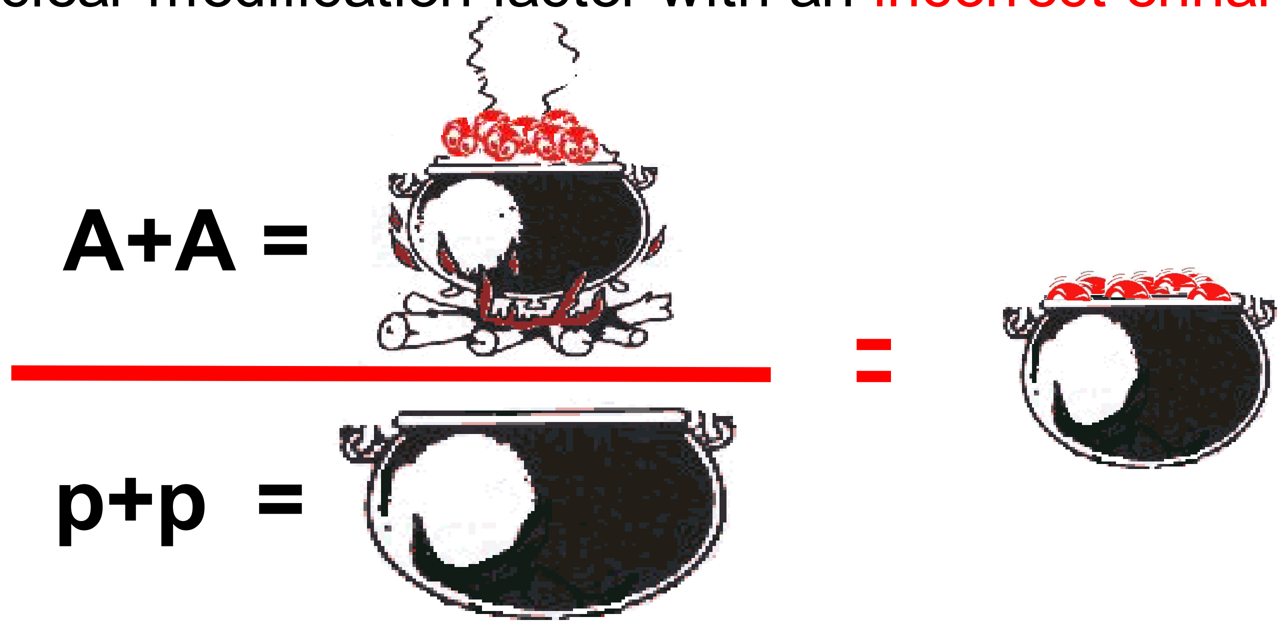
hot quarks cooking guide (I)

Nuclear modification factor with a incorrect depleted reference:



"burnt" quarks

Nuclear modification factor with an incorrect enhanced reference:

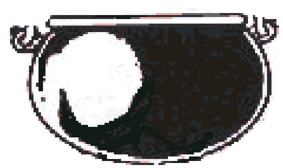


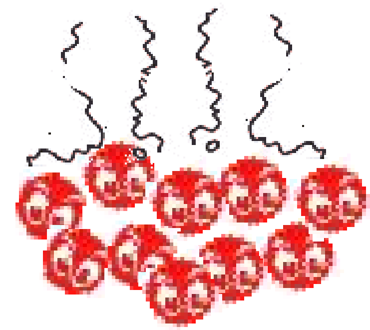
"cold" quarks

hot quarks cooking guide (II)

Nuclear modification factor with a correct baseline:

A+A = 

p+p = 

= 

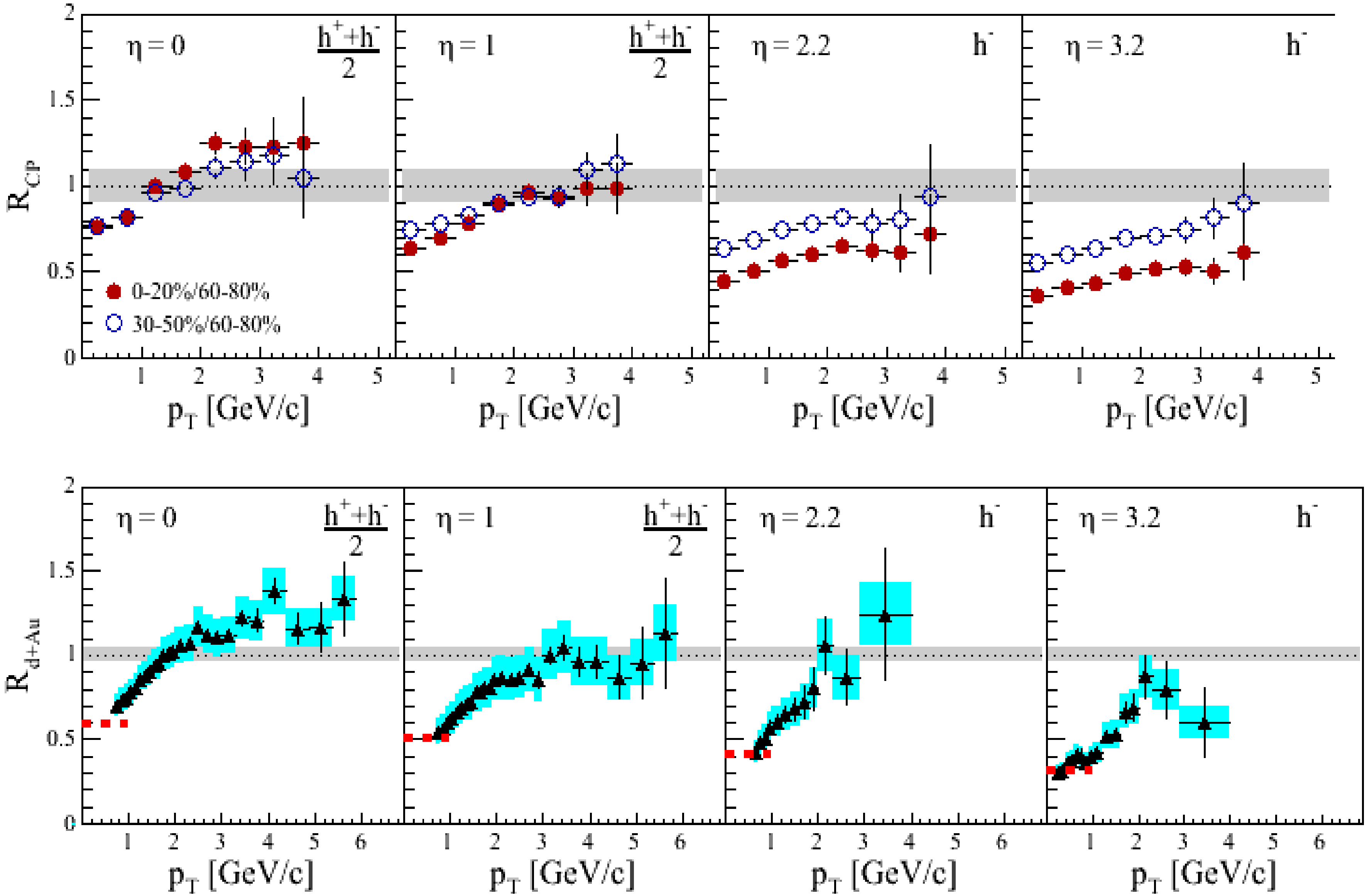
Enjoy the hot quarks !

“because we can” © ...

©*Richard Witt*

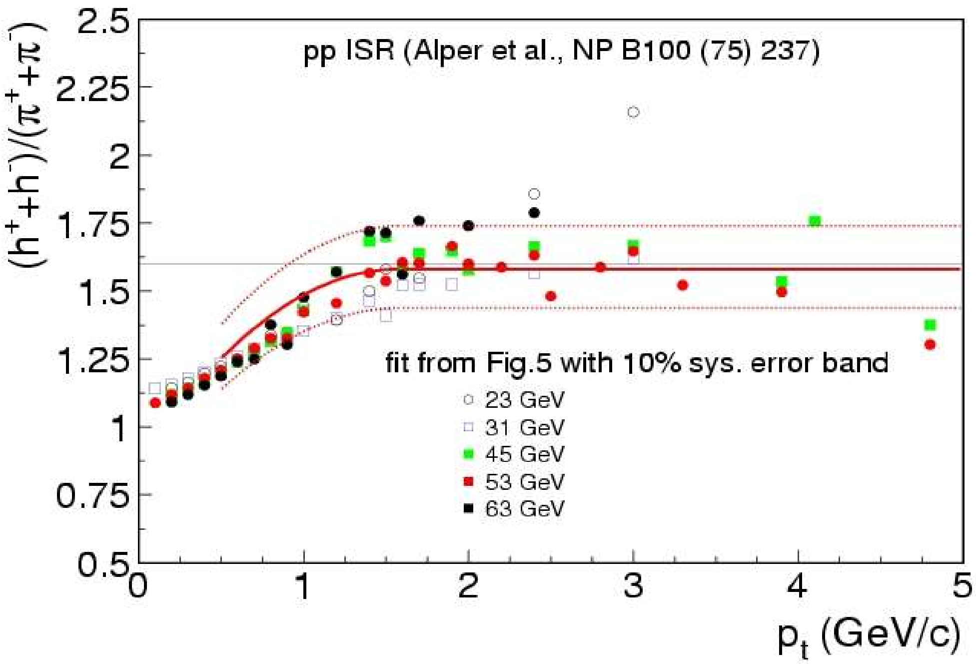
backup slides ...

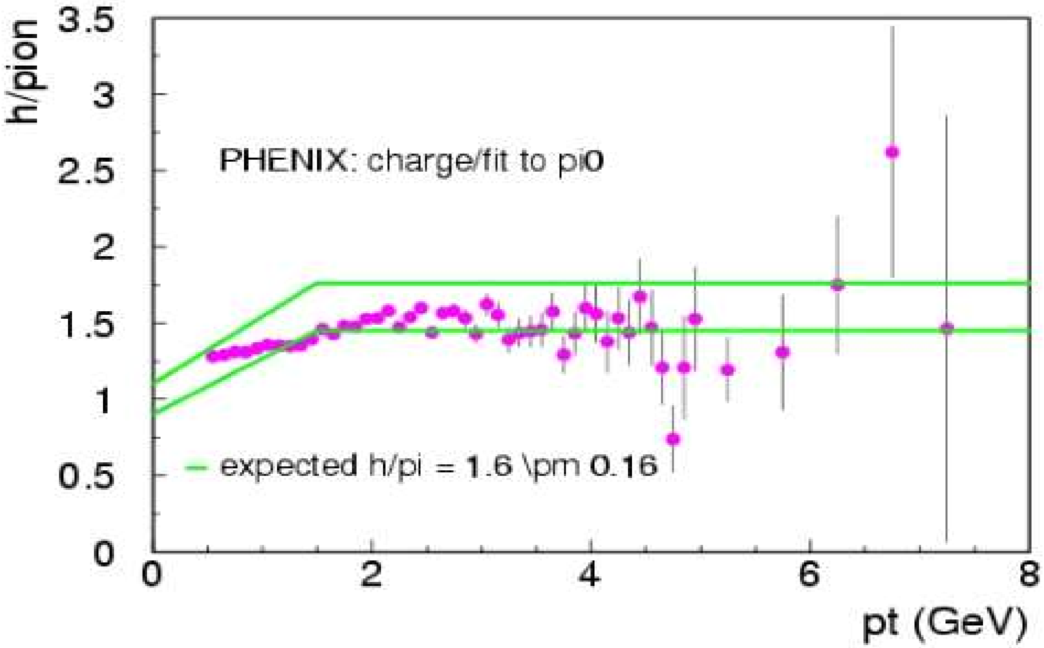
BRAHMS R_{cp} vs R_{dAu}



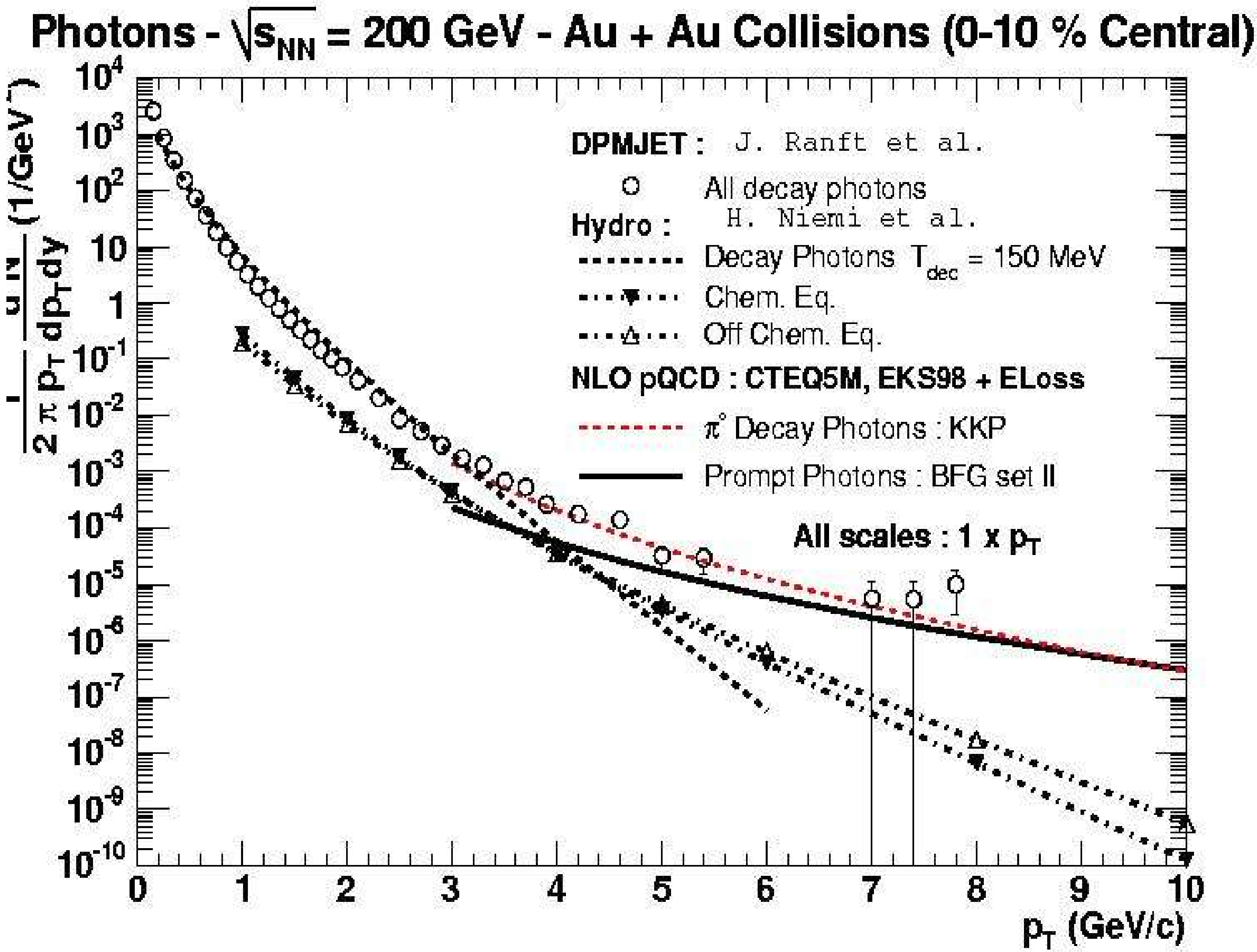
Charged hadron over pion ratio at high p_T

.



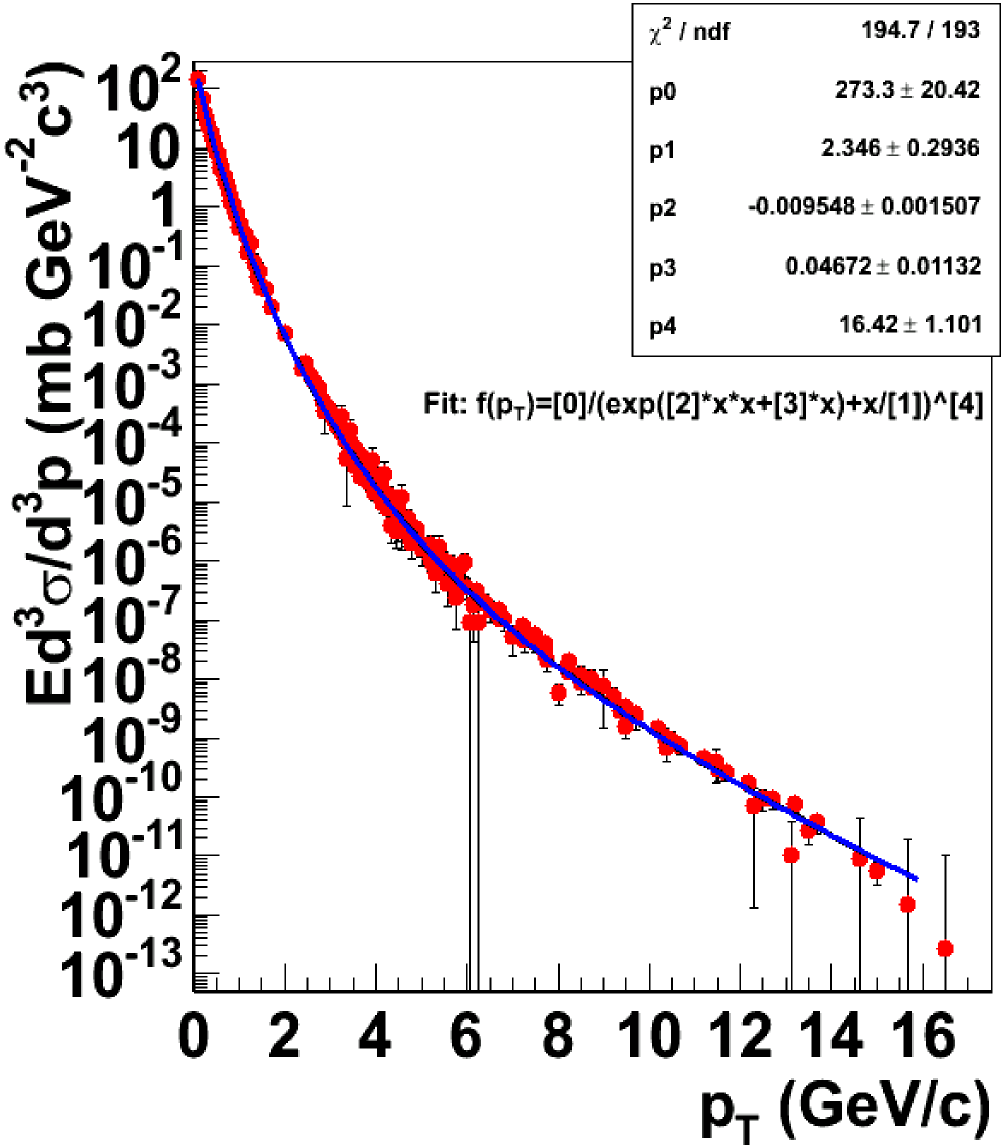


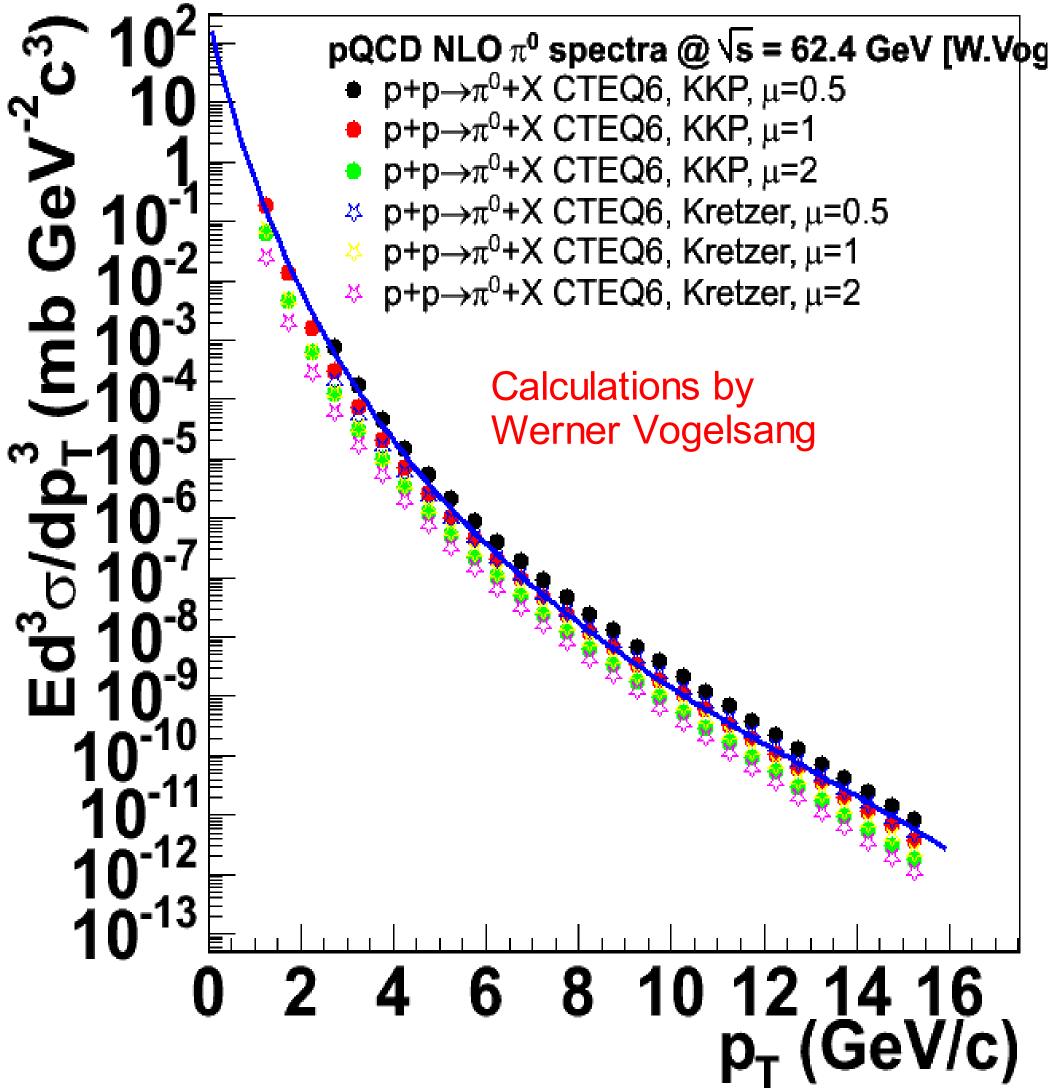
Thermal photons from other hydros



Final p+p → π+X reference @ √s = 62.4 GeV

- Parametrization: $f(p_T) = A/(e^{a\cdot x^2+b\cdot x} + x/p_0)^n$
- Good agreement with NLO:





Nuclear modification factors below RHIC energies

- High p_T π^0 production in ~0 –10% central A+A at SPS and ISR energies: