ISOSPIN EFFECTS IN RELATIVISTIC HEAVY-ION COLLISIONS

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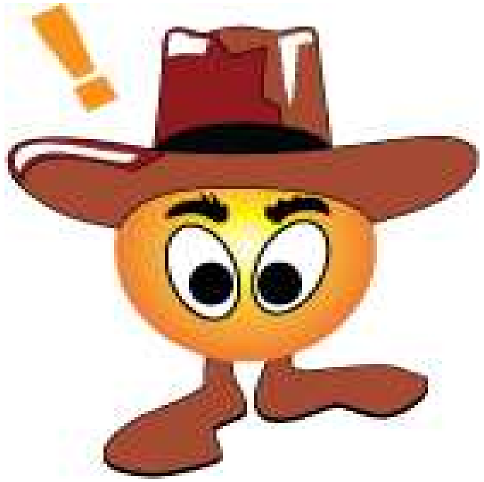

in collaboration with:
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Péter Lévai – MTA KFKI RMKI, Budapest;
Gábor Papp – Eötvös Univeristy, Budapest.

Hot Quarks 2008 – Workshop for young scientists
on the physics of ultrarelativistic nucleus-nucleus collisions
18-23 August 2008 – Aspen Lodge at Estes Park, Colorado

O U T L I N E

Motivation – effects on R_{dA} at high p_T

– EMC effect at high-p_T for π^0 at RHIC and LHC?

– Direct γ is always tricky: R_{dAu} and R_{AuAu} at high-p_T...

Isospin effect in pQCD improved parton model

– Differences from σ^{in}_{pp} and σ^{in}_{pn}

– Isospin (a)symmetry in PDFs and nPDFs (or shadowings)

– Effect in the final state (FF): hadron ratios or $R^{p/\pi}_{dAu}$

NOT included: Modifications and isospin effect at LHC

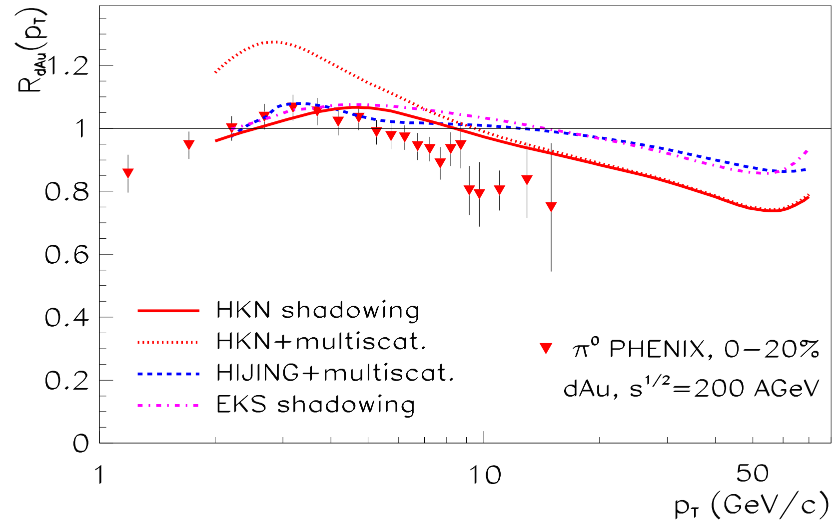
– Error estimation and results for LHC ?

– What to measure at the LHC?

M O T I V A T I O N – test on RHIC data

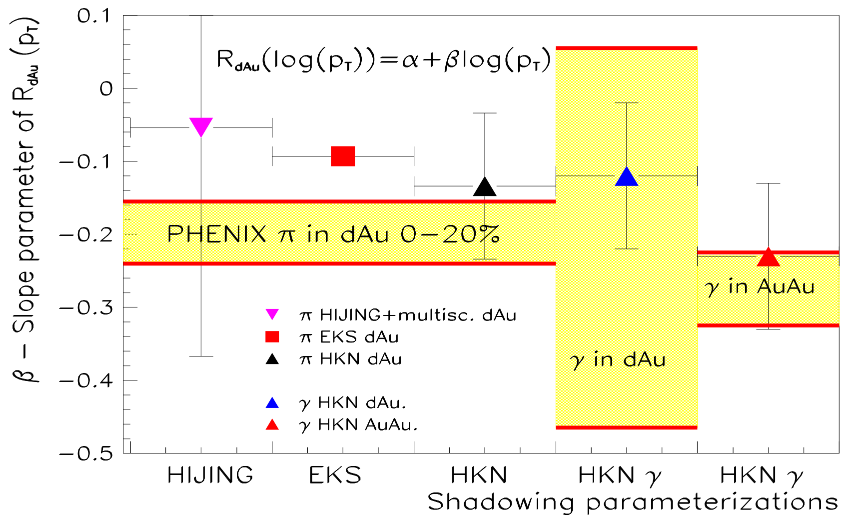
PHENIX π^0 data in dAu

- arXiv:0801.4020v1 (2008)
- $2-3\sigma$ effect in R^{π}_{dAu} at high p_T
- This should be the EMC effect, B.A. Cole *et al.*: hep-ph/0702101



Models vs. PHENIX data

- We have slope structure at high p_T
- This slope is linear in $\log(p_T)$
- π^0 and γ data are similar in dAu
- Stronger effect in R^{γ}_{AuAu}



Isospin Effects in Heavy-Ion Collisions

$$\frac{\mathrm{d}N}{\mathrm{d}^2 p_\pi \mathrm{d}y} \sim \frac{1}{\sigma^{in}} \cdot f_{a/p}(x_a, Q^2; k_T) \otimes f_{b/A}(x_b, Q^2; k_T, b) \otimes \frac{\mathrm{d}\sigma}{\mathrm{d}\hat{t}} \otimes \frac{D_{\pi/c}(z_c, \widehat{Q}^2)}{\pi z_c^2}.$$

a) Differences in inelastic cross section (σ^{in}_{NN})

– Small differences, but changes with the $\sqrt{s}$

– The pp, nn and $pn(dd)$ cross sections are different

b) The 'real' isospin effect is in the (n)PDFs by def.

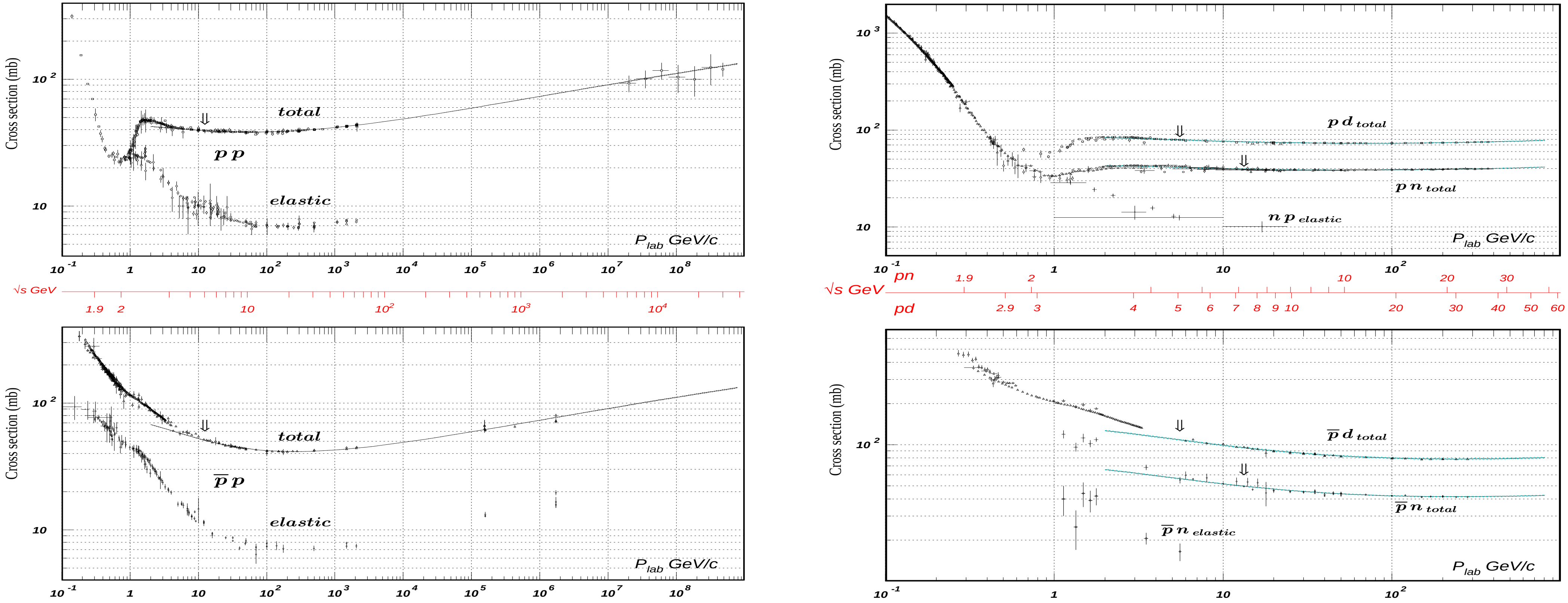
– Differences in pp, nn and $pn(dd)$ in R_{dAu}

– Isospin effect in the $S_{a/A}(x)$ is handled differently.

c) Are there isospin differences in final state (FF, etc.)?

– Can we see the effect in hadron or in R_{dAu} ratios?

a) Differences in the Inelastic Cross Section



Amsler et al., Phys. Lett. B667, 1 (2008).

– At a given c.m. energy: $\sigma_{NN}^{in} = \sigma_{NN}^{tot} - \sigma_{NN}^{el}$

– But $\sigma_{pp}^{in}(\sqrt{s})$ and $\sigma_{pn}^{in}(\sqrt{s})$ are different $\Longrightarrow$ isospin effect

[6]

Can we see such a small variation in e.g. R_{dAu}[7] or in R_{CP} ?

a) Differences in the Inelastic Cross Section

The σ^{in}_{NN} appears as a normalization in the spectra

$$\widetilde{\sigma}^{in}_{A_1A_2} = \frac{1}{A_1A_2} \times \left[Z_1Z_2\sigma^{in}_{pp} + Z_1N_2\sigma^{in}_{pn} + Z_2N_1\sigma^{in}_{np} + N_1N_2\sigma^{in}_{nn}\right]$$

$\Longrightarrow$ Assuming $\sigma^{in}_{pp} \approx \sigma^{in}_{nn}$ & $\sigma^{in}_{pn} = \sigma^{in}_{np}$, BUT $\sigma^{in}_{pp} \neq \sigma^{in}_{np}$

This gives the isospin correction to the $\sigma^{in}_{pp} + \delta \cdot \mathcal{O}([\sigma^{in}_{pp} - \sigma^{in}_{np}])$

$$\widetilde{\sigma}^{in}_{A_1A_2} \approx \sigma^{in}_{pp} + \left[2\frac{Z_1Z_2}{A_1A_2} - \frac{Z_1}{A_1} - \frac{Z_2}{A_2}\right] \times \left[\sigma^{in}_{pp} - \sigma^{in}_{np}\right]$$

$$\left[\sigma^{in}_{pp} - \sigma^{in}_{np}\right] \approx \begin{cases} \mathcal{O}(0.5) & \sqrt{s} \lesssim 10 \text{ GeV };\\ \mathcal{O}(0.1) & 10 \gtrsim \sqrt{s} \gtrsim 100 \text{ GeV};\\ ??? & \sqrt{s} \gtrsim 100 \text{ GeV}. \end{cases}$$

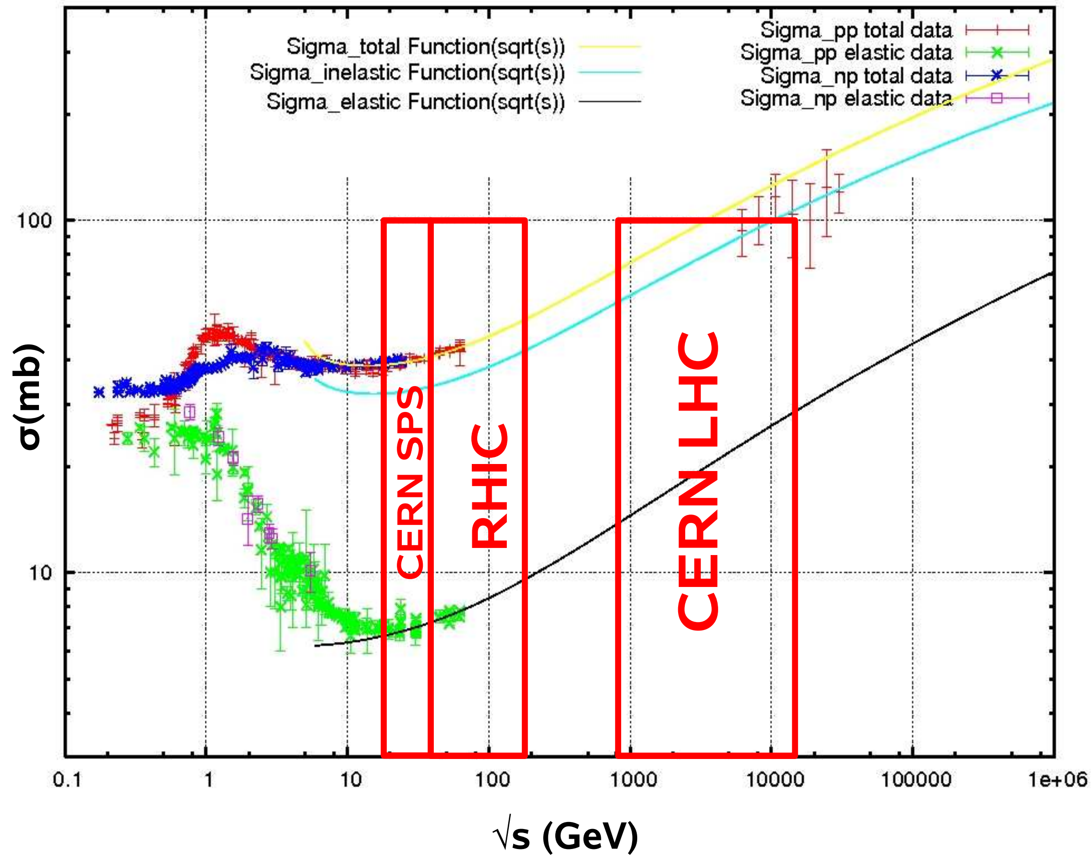
Coll.	$\delta(A_1, Z_1, A_2, Z_2)$
pp	0.0
dd	-0.50
dAu	-0.50
$CuCu$	-0.49
$AuAu$	-0.48
$PbPb$	-0.48

... which correction is small $\lesssim 5\%$ **(where it is known)**

a) Differences in the Inelastic Cross Section

Problems: Let's see the data above $\sqrt{s} \sim 10$ GeV

- NO measurements at these high energies, only σ_{pp}^{tot} COMPETE, PRL 89 (2002) 201801
- We have nuclear physics theories for σ_{nn}^{tot} $(\approx \sigma_{pp}^{tot})$
- But, NO data for these, and even for σ_{pn}^{tot}, which has NOT ONLY the singlet channel



- However the uncertainty is huge, especially in σ_{NN}^{el}, we can make parameterization for ∼TeV energies – without isospin differences

b) The 'Real' Isospin Effect is in the PDFs

PDFs are different for proton ($f_{a/p}(x,Q)$) & neutron ($f_{a/n}(x,Q)$)

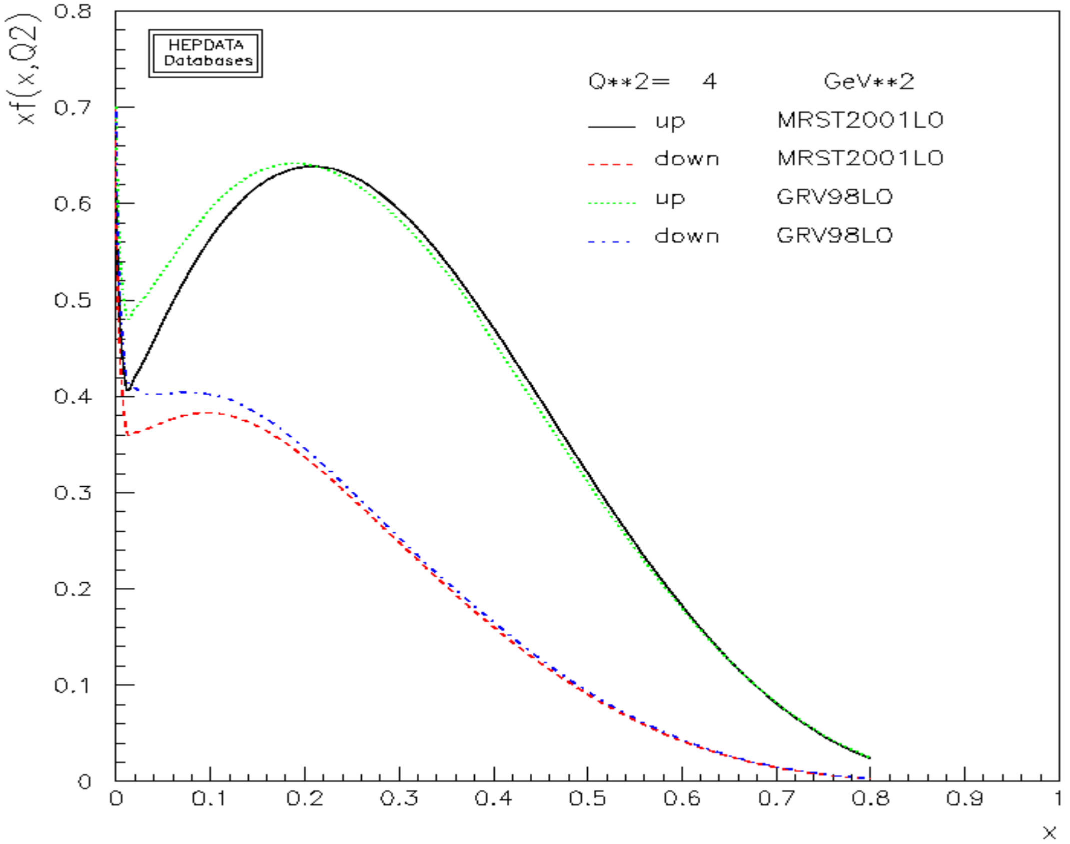
– Here are some basic rules:

$$f_{u(d)/p}(x,Q) = f_{d(u)/n}(x,Q)$$

$$f_{\bar{u}(\bar{d})/p}(x,Q) = f_{\bar{d}(\bar{u})/n}(x,Q)$$

– But s, c, b, t and g have same contributions.

– Thus symmetric nuclei like d or e.g. ^{40}Ca are OK!



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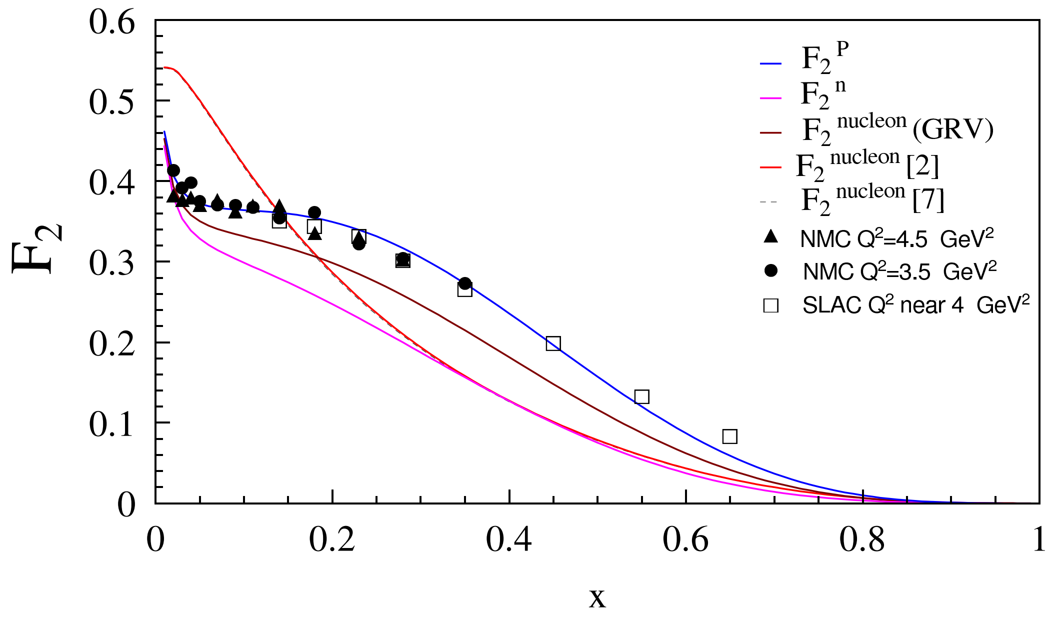
– Experimental information for pp (dp) at high-x only.



F. Zolfagharpour: arXiv:0802.1623v1

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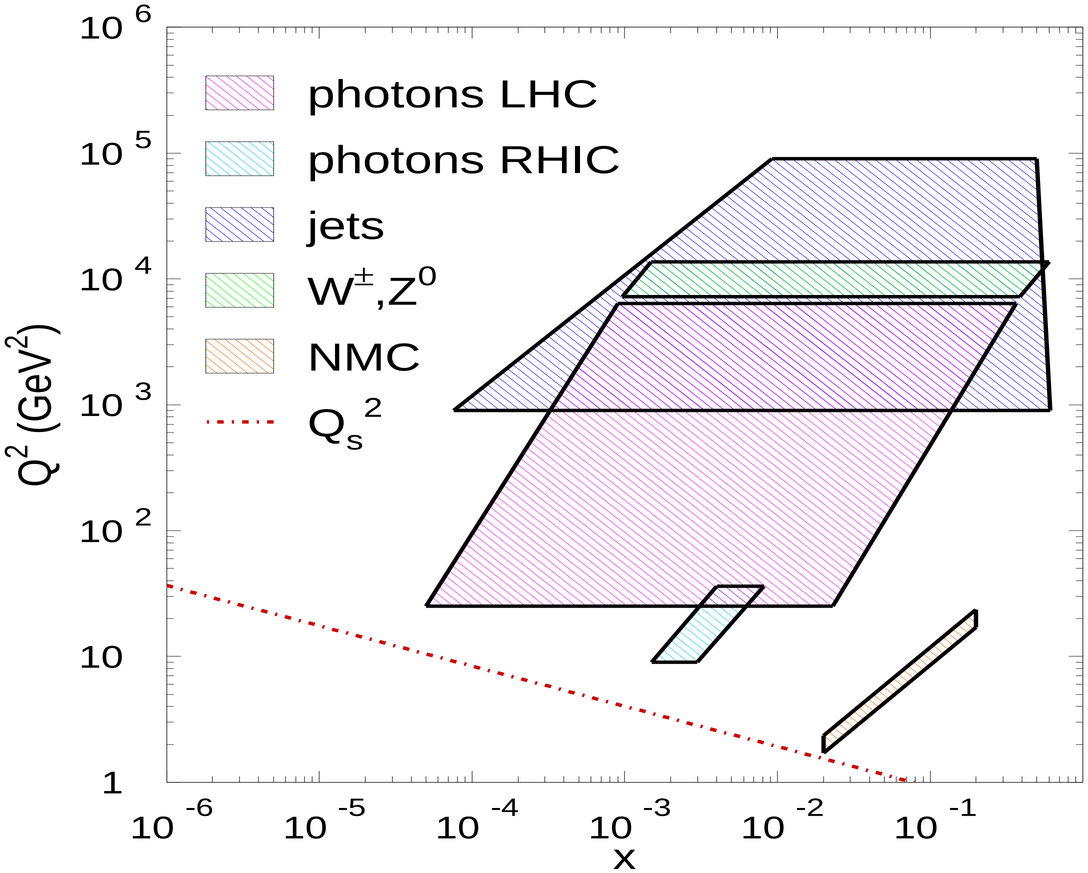


F.Arleo & T.Gousset: PLB 660 (2008) 181

b) The nPDF (Shadowing) and Isospin (A)Symmetry

PDFs are modified inside the nucleus differently:

I. PDF based: general, but model dependent (HIJING, EKS, EPS)

factorize the isospin asymmetry by the linear combination

$$f_{a/A}\left(x,Q^2\right) = S_{a/A}(x,b)\left[\frac{Z}{A} f_{a/p}\left(x,Q^2\right) + \left(1-\frac{Z}{A}\right) f_{a/n}\left(x,Q^2\right)\right]$$

$S_{a/A}(x,b)$: Shadowing function (e.g.: HIJING);
A atomic- and Z the proton number

ONLY the PDF carries isospin effect, and consequences depend on the separation between the p and n based PDFs

II. True nPDFs: only for special nuclei are more precise (HKN),

but this require more different measurements, time, money...

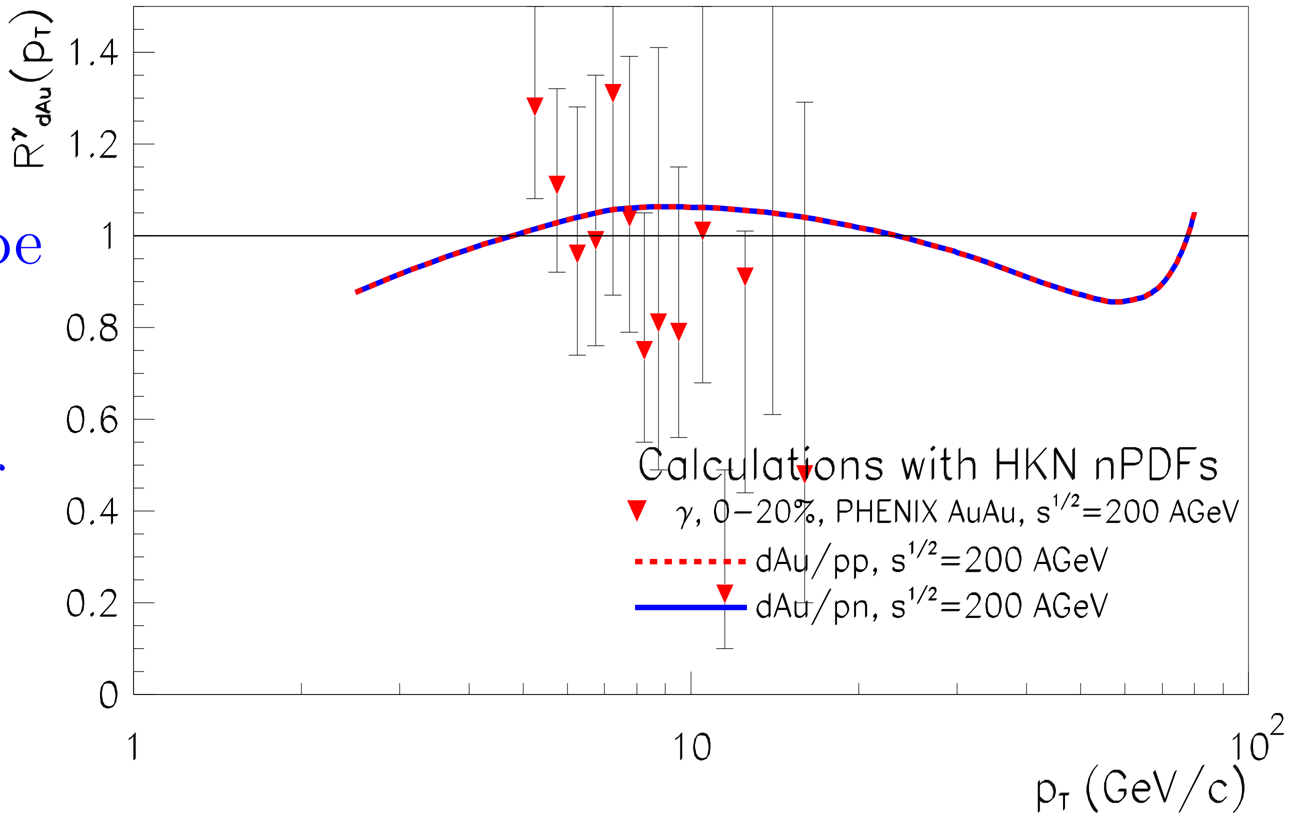
b) The 'Real' Isospin Effect is in the PDFs – $dAu \rightarrow \gamma$

LO dAu analysis for γ

– Prelim. exp. data have huge errors.

– We measured the slope of the EMC effect

– Multiple scattering or anti-shadowing can make enhancement



more precise data, but more difficult theoretical case : $AuAu$

b) The 'Real' Isospin Effect is in the PDFs – $AuAu \to \gamma$

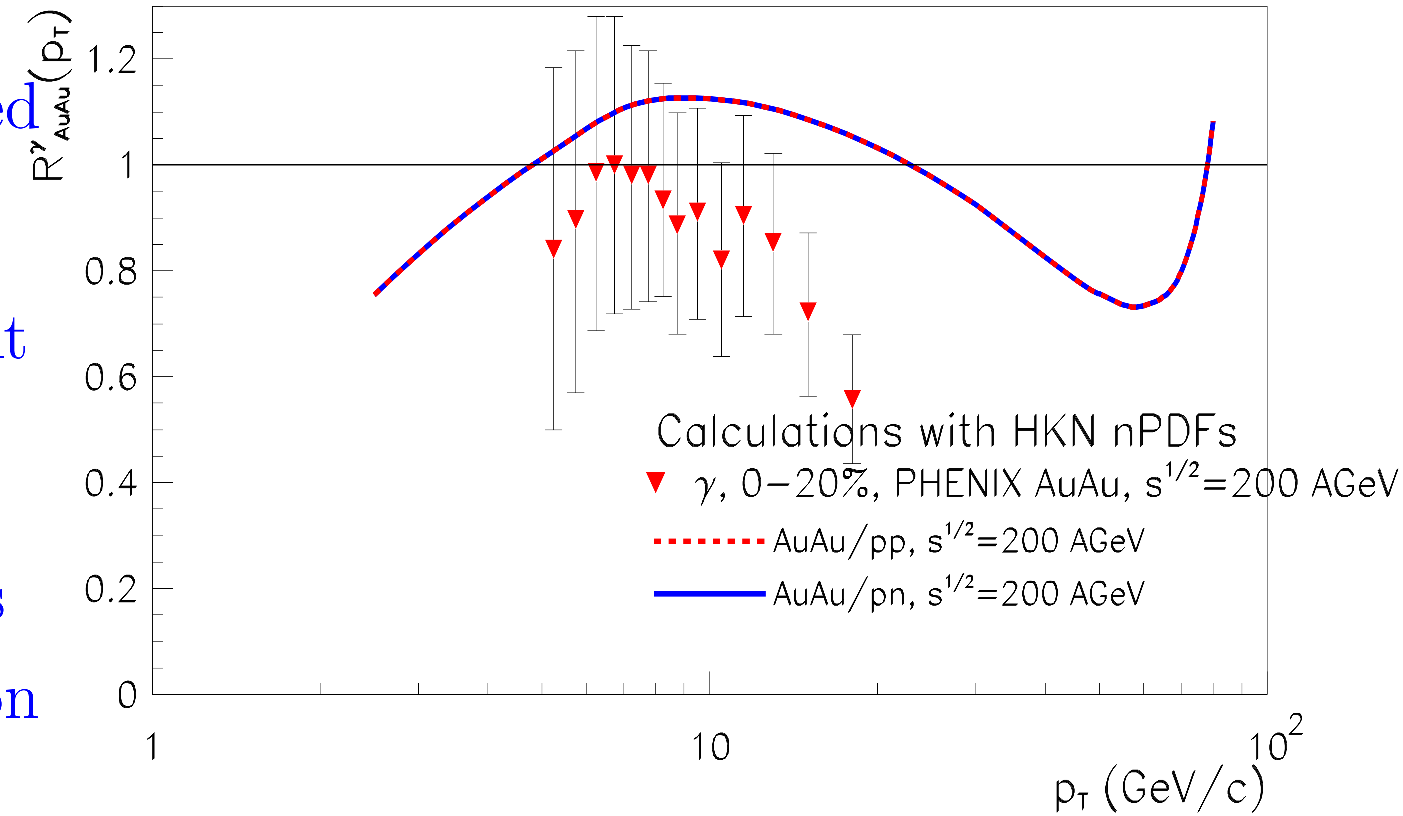
LO $AuAu$ analysis for γ production

– Initial state effects are doubled compared to the dAu case:

– stronger enhancement

– steeper suppression

– NO final state effects in direct γ production



In sense of this the $dAu \to \pi$ is more complicated

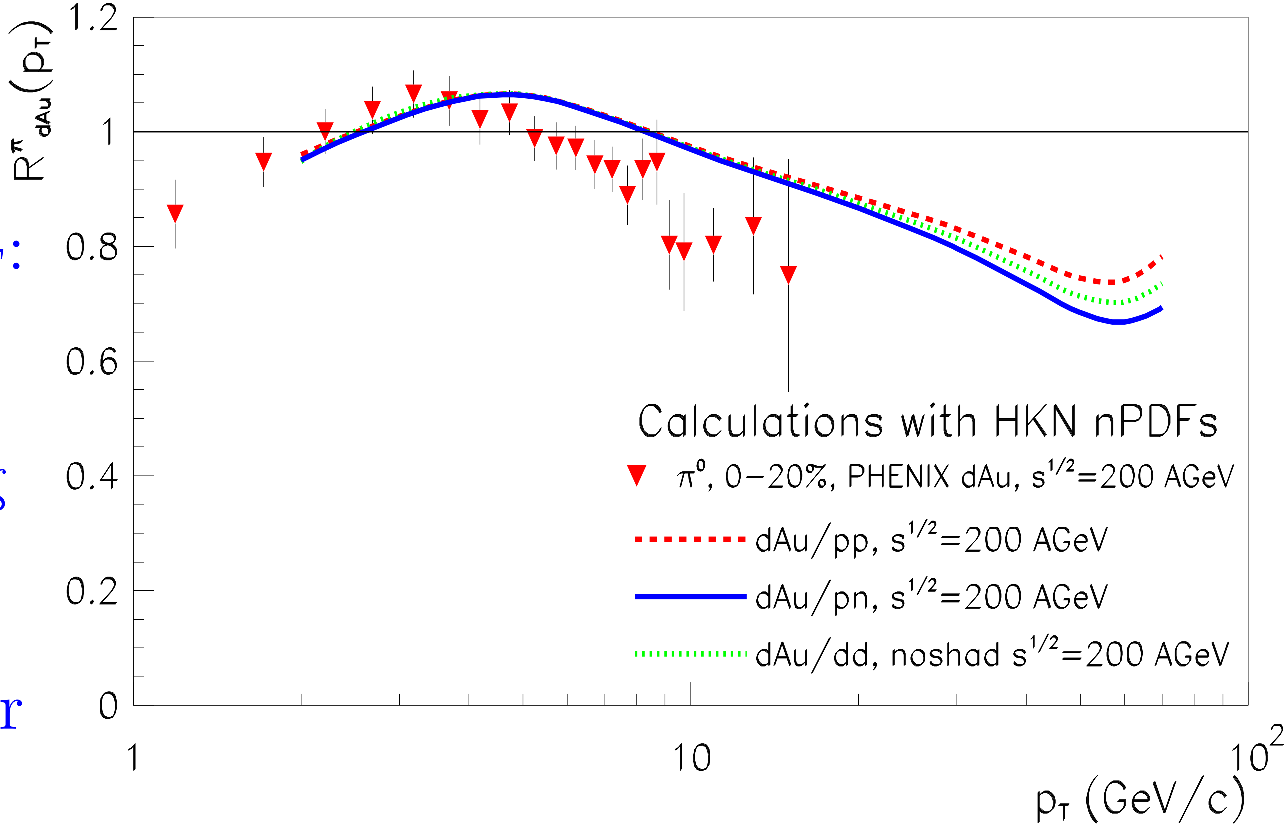
b) The 'Real' Isospin Effect is in the PDFs – π^0

LO dAu analysis for π^0

– Here the difference is really small effect only $\sim 5\%$ at high-p_T: FFs mix up channels

– dd has NO shadowing but isospin averaged

– But, slopes are similar



...and now let's try to "deconvolve" the shadowing part...

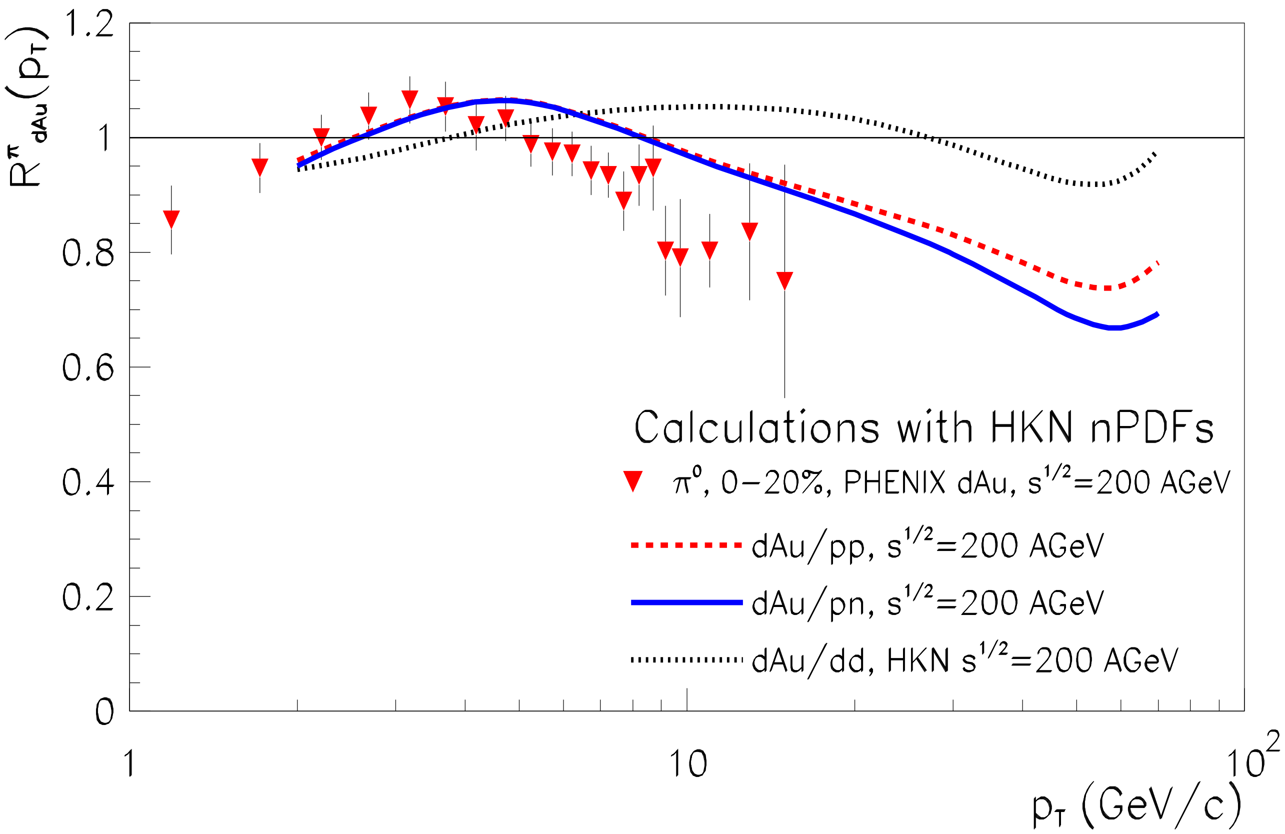
The Real 'Real' Isospin Effect or 'whatever' in dAu

Here dAu were normalized by 'true' dd from HKN for π^0

– FFs are included

– Here EMC is killed since $F_2^A(x)/F_2^d(x)$ is relative to the d.

– This is NOT ONLY the isospin effect, BUT errors are still smaller than 5%



This answers the origin of 'theoretical' slopes in R_{dAu}....

c) Is There Isospin Modification at the Final State?

Isospin symmetry is parameterized in the FFs by definition

– Based on $SU(3)$ symmetries e.g. for pions:

1. channel: $D_u^{\pi+} = D_{\bar{d}}^{\pi+} = D_d^{\pi-} = D_{\bar{u}}^{\pi-} = \xi D_{val}^{\pi} + \zeta D_{sea}^{\pi}$
2. channel: $D_u^{\pi-} = D_{\bar{d}}^{\pi-} = D_d^{\pi+} = D_{\bar{u}}^{\pi+} = (2-\xi) D_{val}^{\pi} + (2-\zeta) D_{sea}^{\pi}$

Symmetric: $D_s^{\pi+} = D_{\bar{s}}^{\pi+} = D_s^{\pi-} = D_{\bar{s}}^{\pi-} = D_{sea}^{\pi}$ and ... and c, b, t, g

Experimental hadron ratios can be fitted by ξ and ζ

Parallel, need to satisfy the sum rules...

SUMMARY

Are there signatures of isospin effect in HIC?

– Effect of $\sigma_{pp}^{in} - \sigma_{pn}^{in}$ is tiny $\lesssim 5\%$ at RHIC

– Small difference between in R_{dA} and R_{pA} (or R_{nA}) appears to be the same, only at high p_T values differs.

– Isospin symmetry is strongly parameterized in FFs

$\Longrightarrow$ Goal: EMC effect seems to be still there.

Next: Nuclear modifications and isospin effect at LHC

– CMS-TOTEM going to measure the σ_{NN} at LHC energies

– ... and RHIC capable of measure dd, $p(n)A$ collisions

– Error estimates for σ_{NN}^{in} at LHC energies

– Sensitivity of R_{NA} in 8.8 TeV pPb, nPb and dPb

BACKUP SLIDES

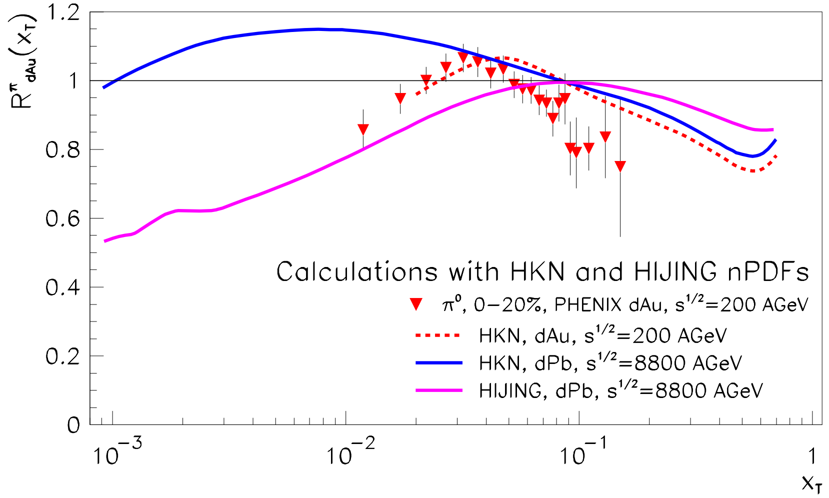
M O T I V A T I O N – predictions for LHC

Calculations for LHC in dPb

– GGB@QM'08, x scaling in $R^{\pi}_{dAu}(x)$

– Comparison with scaled RHIC data

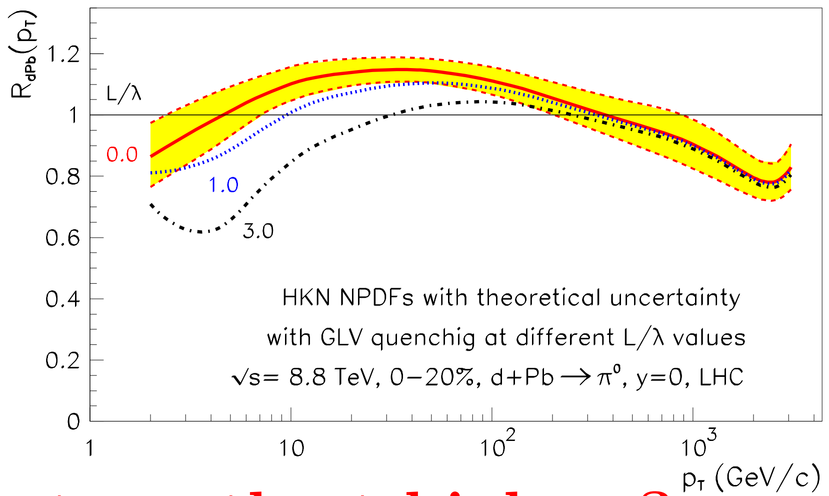
– HKN shadowing is a recent one, HIJING and EPS are the strongest.



Final(?) prediction: dPb with HKN

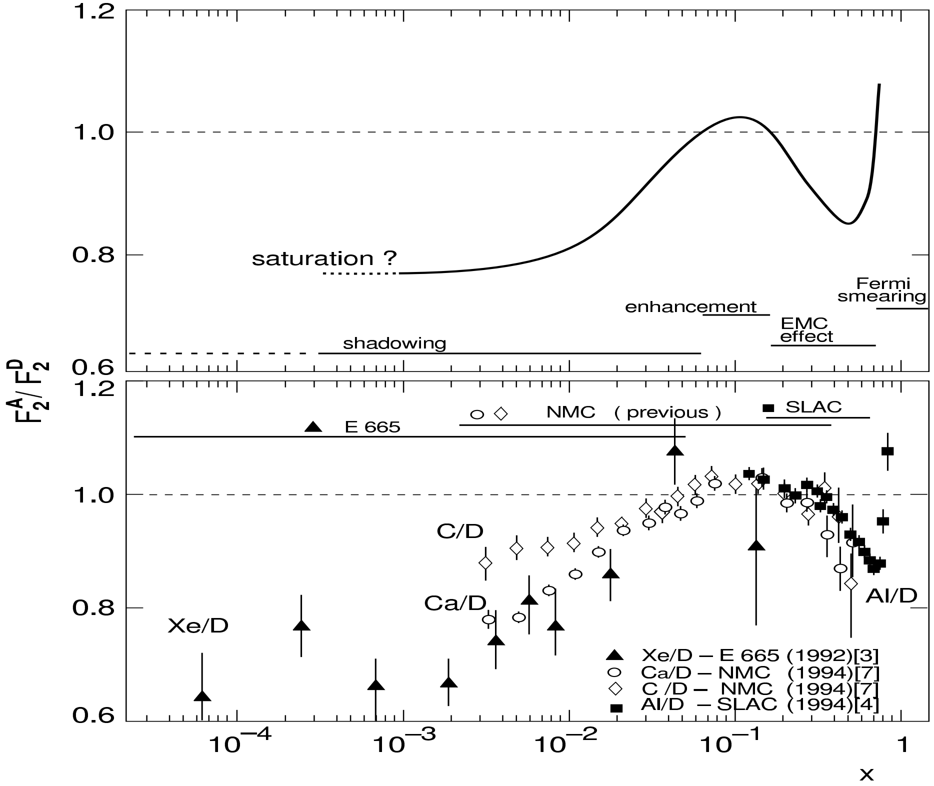
– weak suppression at low p_T

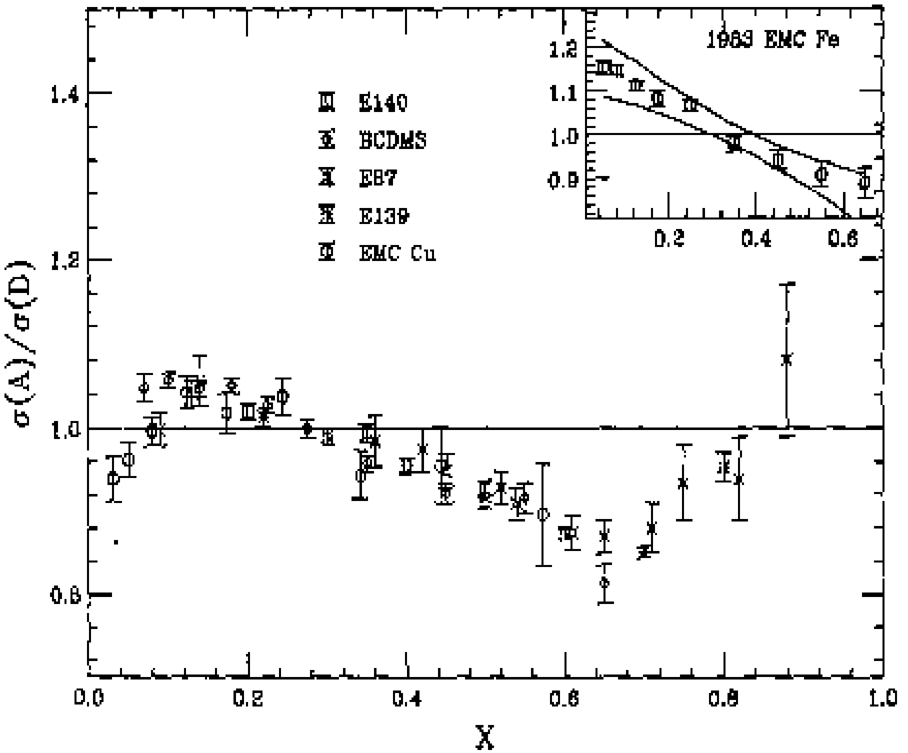
– Tested also with 'cold quenching' in the GLV framework for two cases: $L/\lambda = 1$ and 3.



Is there any new effect with same strength at high p_T?

Nominate Nuclear Modifications





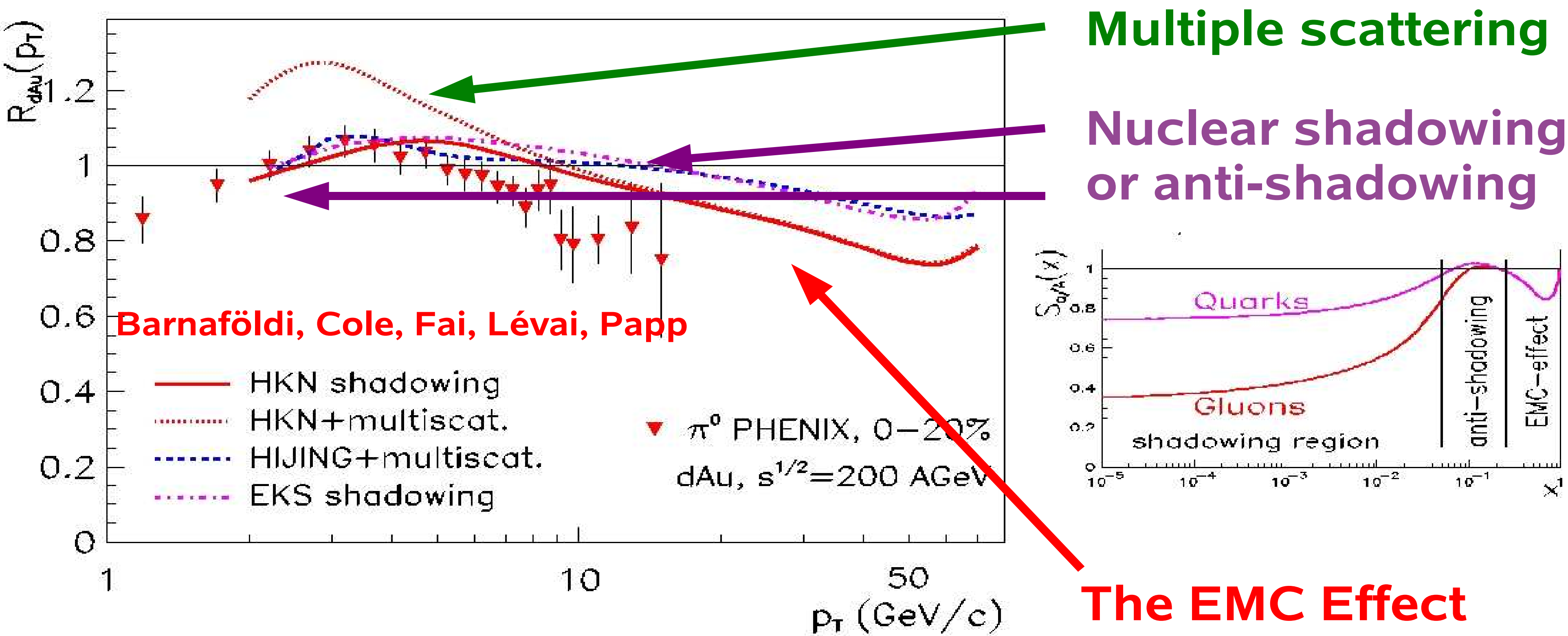
EMC were measured by many experimental collaborations

– Strict def.: EMC effect is in $[0.3; 0.8] \ni x$, where $F_2^A/F_2^D \lesssim 1$

– Non-strict: Where the slope is negative: $[0.1; 0.7] \ni x$

– at RHIC these are $[30; 80]$ and $[10; 70]$ GeV/c $\ni p_T$ respectively

Nuclear effects at very high-p_T in central dAu collision



MULTIPLE SCATTERING: $2\ \text{GeV/c} \le p_T \le 7\ \text{GeV/c}$

(GLUON) SHADOWING: $p_T \le 1 - 5\ \text{GeV/c}$

THE EMC REGION: $p_T \ge 10 - 20\ \text{GeV/c}$