Simple measurements with GREAT impact : Nuclear Modification Factors

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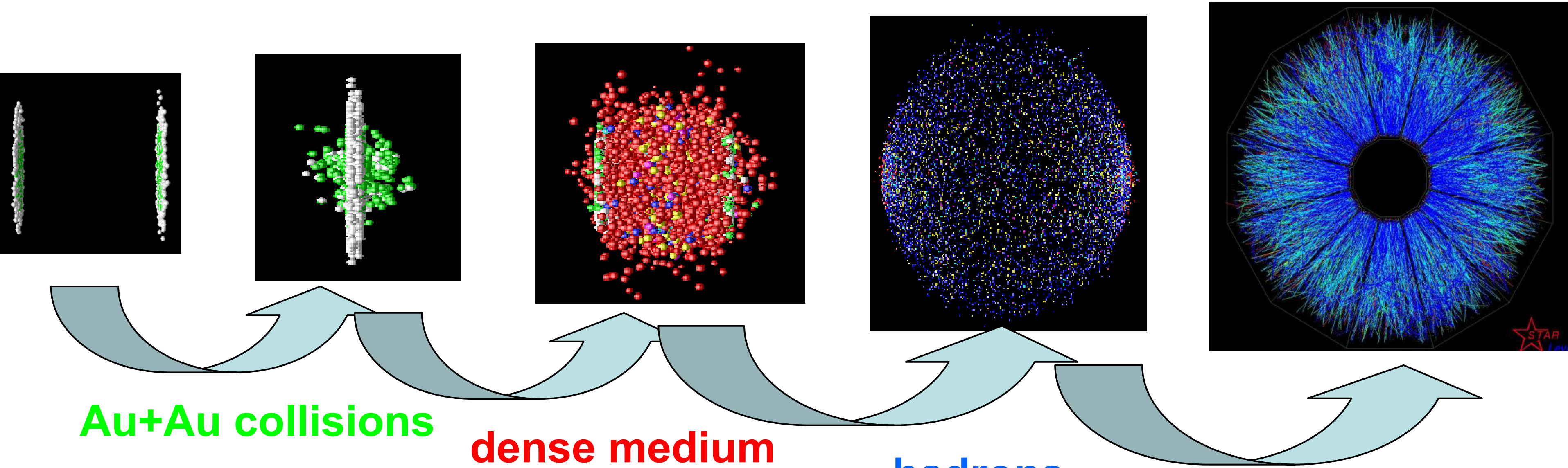

Au+Au collisions

dense medium

hadrons

detector

High p_T hadrons

➢ unidentified

➢ identified

➢ Probe

➔ hadronization mechanisms

➔ medium properties

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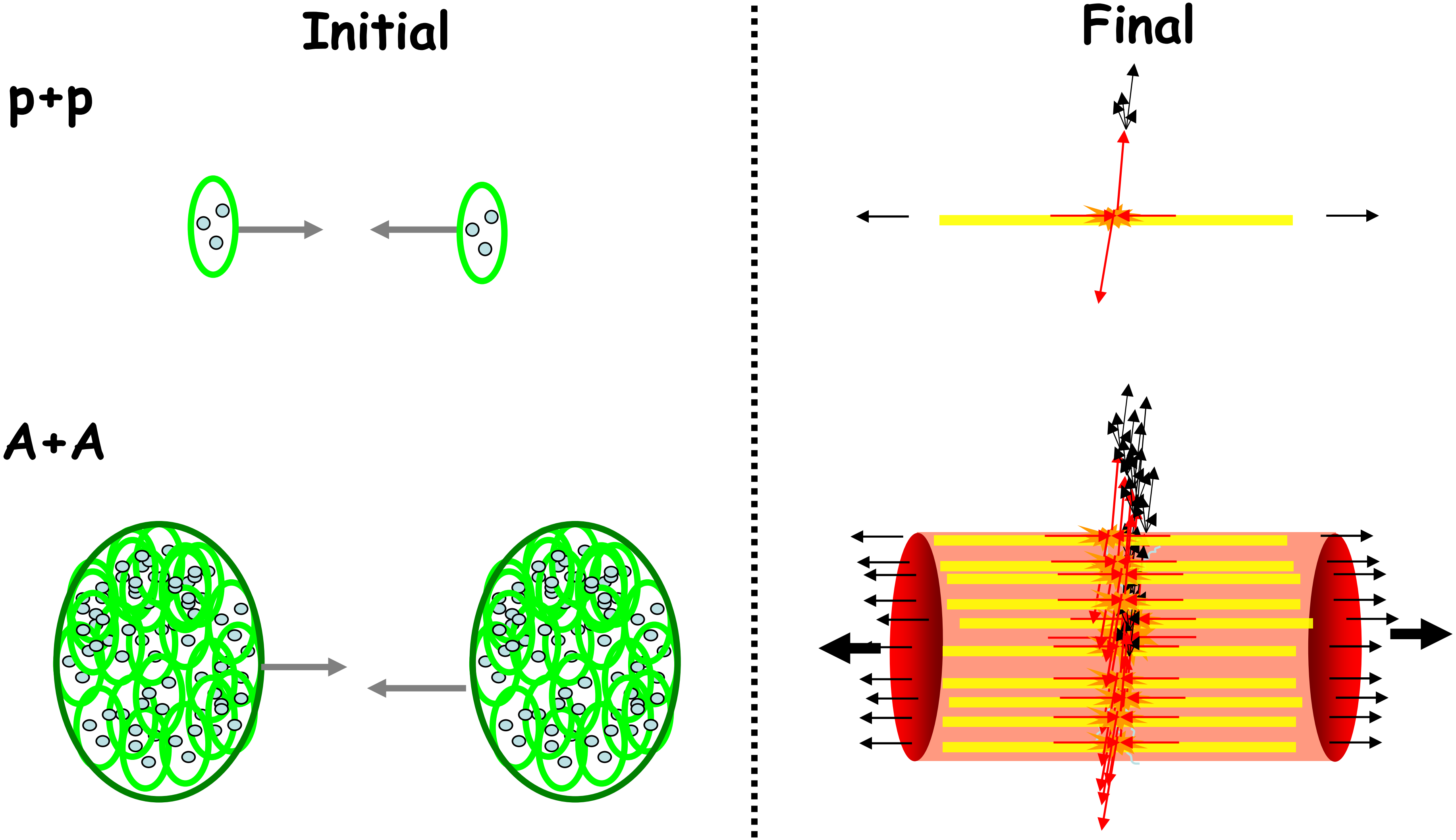
Is A+A just a 'bunch' of 'p+p'?



Initial

Final

p+p

A+A

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pQCD particle production: p+p (pT>2GeV/c)

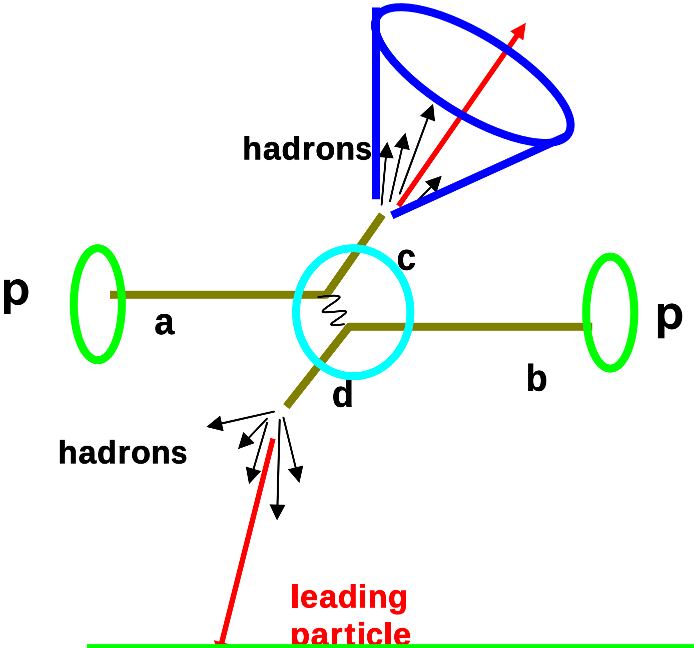
Initial

Final

Parton Distribution Functions

Hard-scattering cross-section

Fragmentation Function



$$\frac{d\sigma^{h}_{pp}}{dy\,d^{2}p_T} = K\sum_{abcd}\int dx_a\,dx_b\,\boxed{f_{a/p}(x_a,Q^2)\,f_{b/p}(x_b,Q^2)}\,\boxed{\frac{d\sigma}{d\hat{t}}(ab\to cd)}\,\boxed{\frac{D^{0}_{h/c}}{\pi z_c}}$$

pQCD particle production: Au+Au (pT>2GeV/c)

Initial

Final

Parton Distribution Functions

Intrinsic k_T

PDF modification
(shadowing)

Hard-scattering cross-section

Fragmentation Function

Partonic Energy Loss

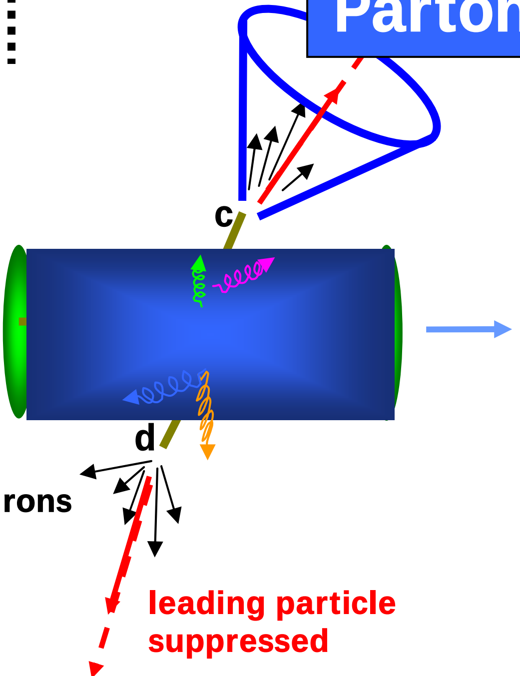
$$\frac{dN^h_{AB}}{dy\,d^2p_T} = ABK\sum_{abcd}\int dx_a dx_b \int d^2\mathbf{k}_a d^2\mathbf{k}_b$$

$$\otimes\, f_{a/A}(x_a,Q^2)\, f_{b/B}(x_b,Q^2)$$

$$\otimes\, g(\mathbf{k}_a)g(\mathbf{k}_b) \otimes S_{a/A}(x_a,Q_a^2)S_{b/B}(x_b,Q_b^2)$$

$$\otimes\, \frac{d\sigma}{d\hat{t}}(ab\to cd)$$

$$\otimes\, \frac{D^0_{h/c}(z_c^*,Q_c^2)}{\pi z_c} \otimes \int_0^1 d\varepsilon P(\varepsilon)\frac{z_c^*}{z_c}$$



Au+Au vs. p+p

Au+Au : initial +final state effects **pp** : 'simple'

We NEED ALSO A collision system *to disentangle* the initial-final states effects

→ p (d) + Au – 'no final state effects'

pQCD particle production: d+Au (pT>2GeV/c)

Initial

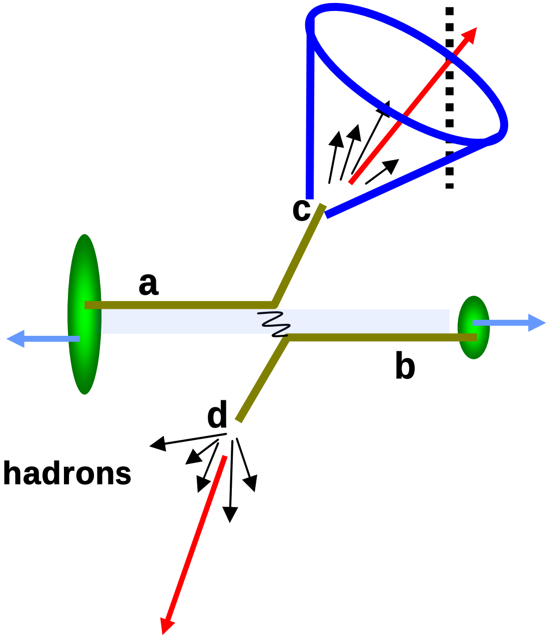
Final

Parton Distribution Functions

Intrinsic kT

PDF Modification
(shadowing)

Fragmentation Function



Quantify deviations of A+A from p+p ?

!!! Simplest: divide AA spectra to pp spectra!!!! ➔

NUCLEAR MODIFICATION FACTORS

Quantify deviations of A+A from p+p

NUCLEAR MODIFICATION FACTORS

$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_T\,dy}{\sigma_{in}^{pp}T_{AA}(b) * d^2N^{pp}/dp_T\,dy}$$

$$\boxed{N_{coll}\,(N_{binary})}$$

$$R_{CP}(p_T) = \frac{N_{coll}^{peripheral}}{N_{coll}^{central}}\,\frac{dN^2_{central}/dp_T\,dy}{dN^2_{peripheral}/dp_T\,dy}$$

→ Need one collision system

→ systematic errors cancel out

ASSUMPTION: both ratios exhibit the same behavior because of the same underlying physics

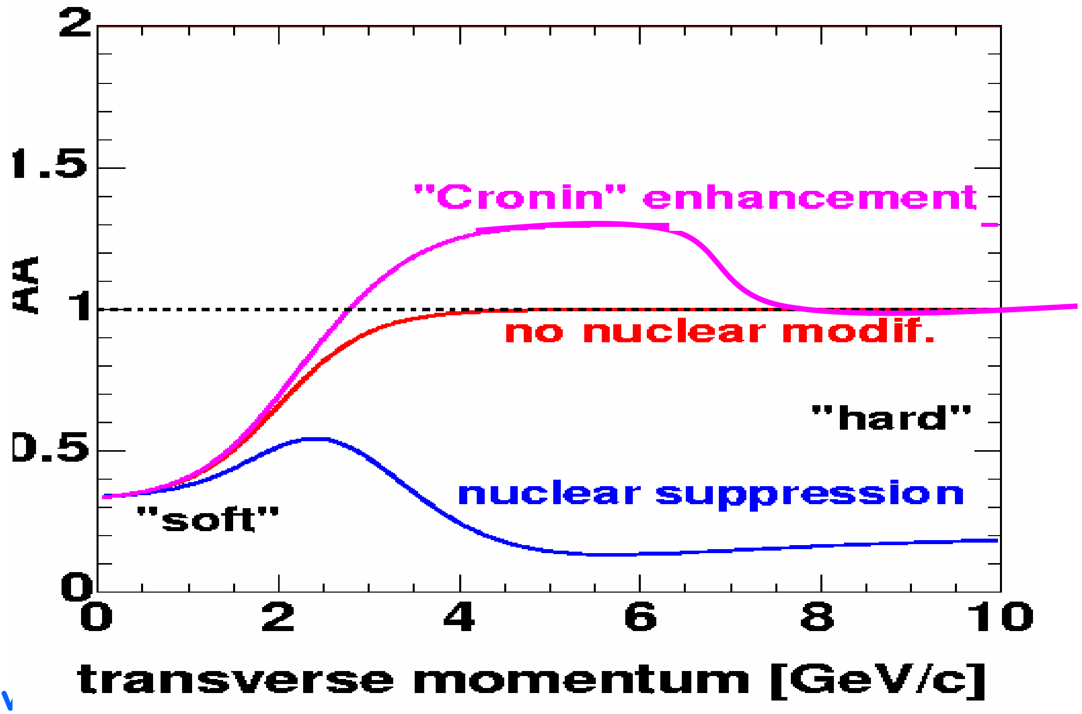
Information via R_{XX}

→ R ~1 -- no nuclear effects:A+B = C * (p+p)

➔ deviation from 1 indicate presence of nuclear effects:

→ R>1➔ enhancement (usual explanation: soft scatters before hard collision)

→ R<1➔ suppression (energy loss in dense medium)



Nuclear modification factors for h+-

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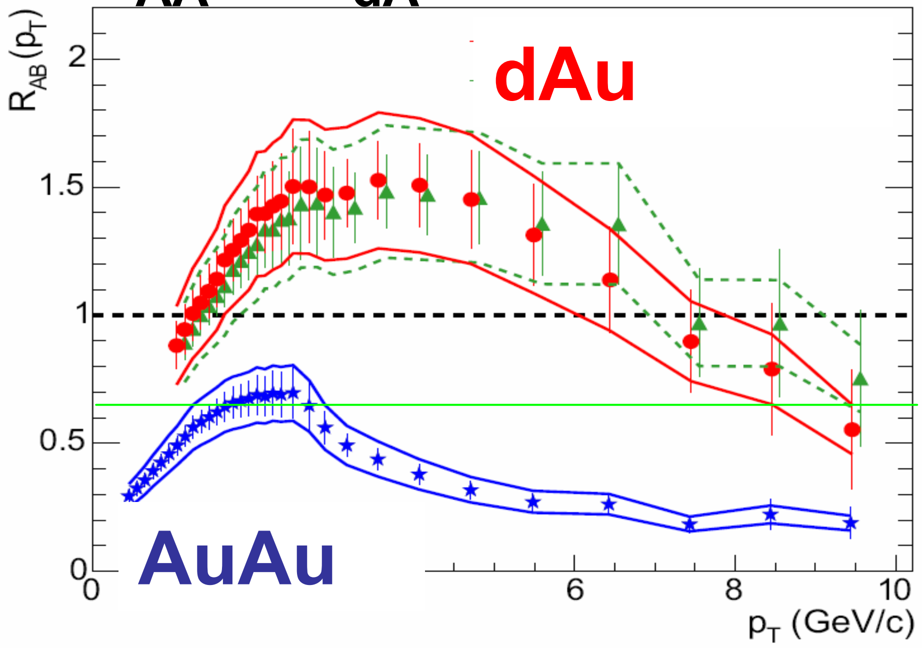
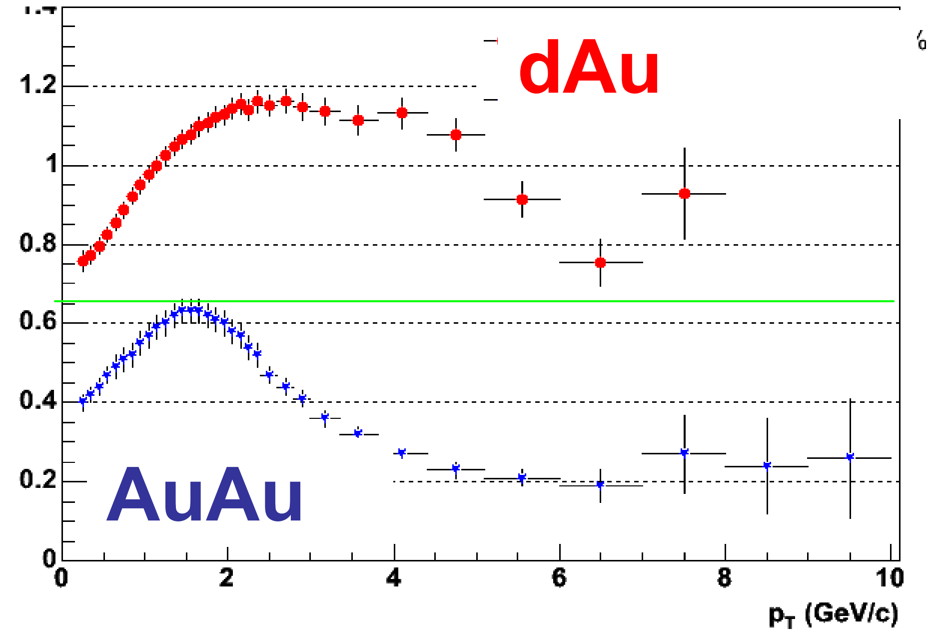
R_{AA}/R_{CP}: h±

R_{AA} & R_{dA}



R_{CP}



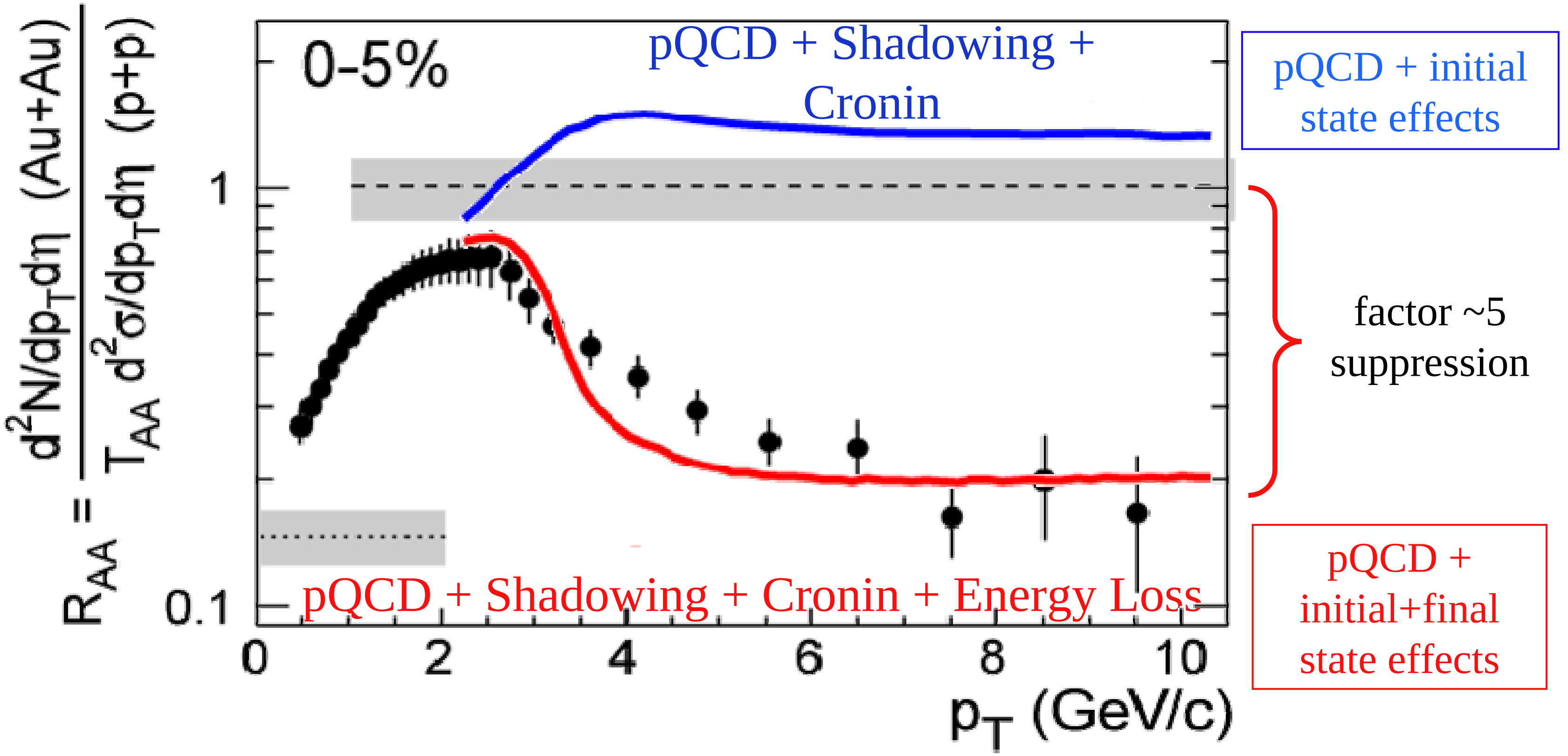
Charged Hadrons:

➔ Au + Au : R_{CP} and R_{AA} ~ suppression

➔ d + Au : R_{CP} and R_{dA} ~ enhancement (Cronin effect – experimental observation and not the explanation) ➔ initial effects 'not responsible' for AuAu suppression

Theory: R_{AA} for h+-

STAR, nucl-ex/0305015



pQCD + Shadowing + Cronin

pQCD + initial state effects

factor ~5 suppression

pQCD + Shadowing + Cronin + Energy Loss

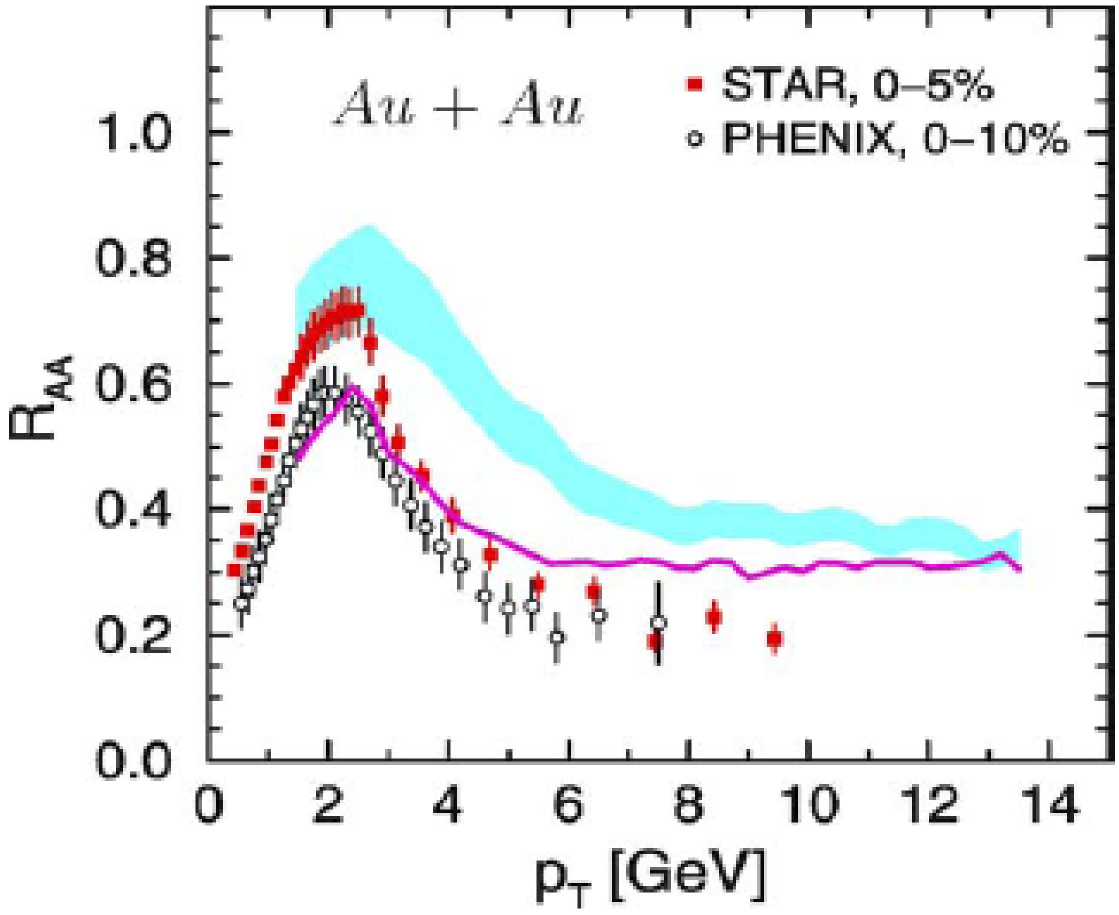
pQCD + initial+final state effects

→ pQCD+final (energy loss) + initial (Cronin+shadowing) describes data → dense medium created in central AuAu !!!!!

Final state hadronic rescattering?

➔ Final hadrons with moderate pT could be fully established inside the late stage of the hadronic fireball ➔ interaction with the bulk hadronic matter➔ suppression

Galmeister et al Nucl Phys A 735(2004), 277



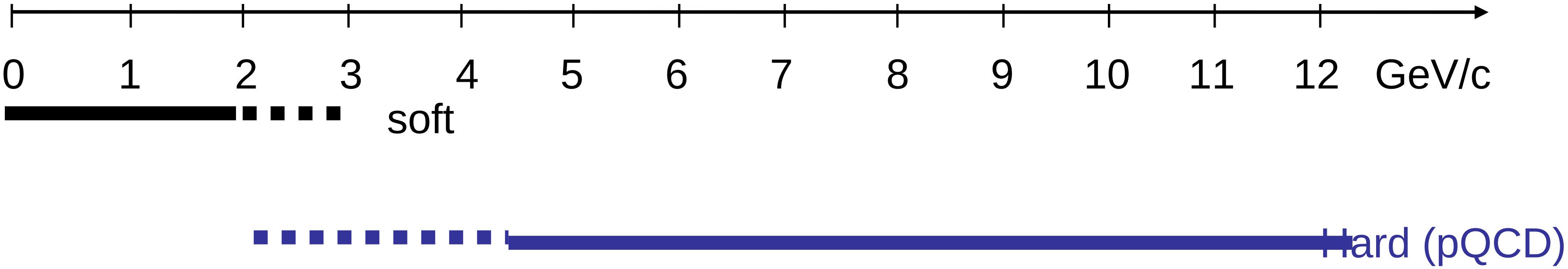
NOT (entirely)!

Conclusions from h+-

➔ R_{AA}, R_{dA} and R_{CP} give same information

➔ Au+Au suppression can NOT be explained entirely by ..:
  → hadronic rescattering
  → initial state effects

Phenomenological scale



Identified hadrons ...

$\Lambda(uds)$ 1116 (MeV/c^2)

$K(us)$ 494(MeV/c^2)

p + p d + Au Au + Au

$\Xi(dss)$ 1321 (MeV/c^2)

$K^0_s(d\bar{s})$ 498(MeV/c^2)

Do all these particles have anything extra to add to what

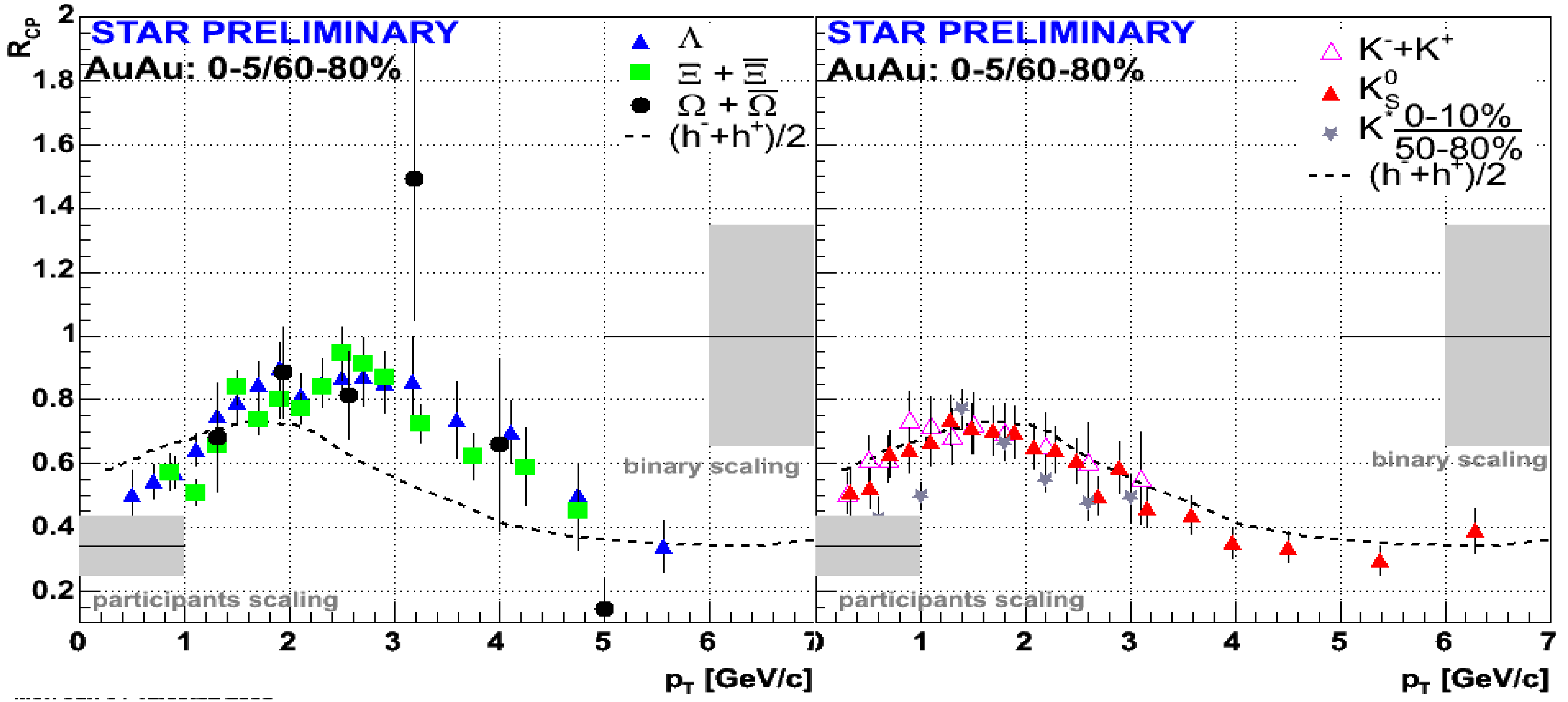
unidentified charged hadrons revealed already?

$\Omega(sss)$ 1673(MeV/c^2)

$\phi(s\bar{s})$ 1020(MeV/c^2)

Nuclear Modification Factors for K, Φ, π, Λ, Ξ, p …

R_{CP}: identified hadrons



➔***Baryons** suppressed* **~ 2.5GeV/c**

➔***Mesons** suppressed* **~ 1.5GeV/c**

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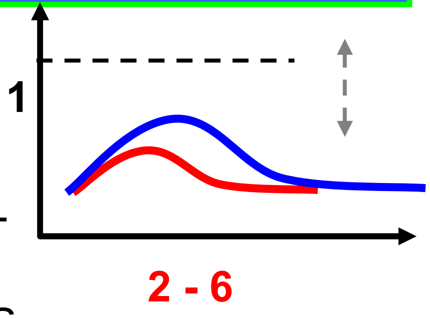
Au + Au: Theory explain R_{CP}…

Topor-Pop, Gyulassy, Barrette, Gale, Wang, Xu nucl-th/0407095



➔**HIJING/BBv2.0**: HIJING + jet quenching + shadowing + baryon junction + strong color field effects

➔ additional production mechanism for baryons (junctions)

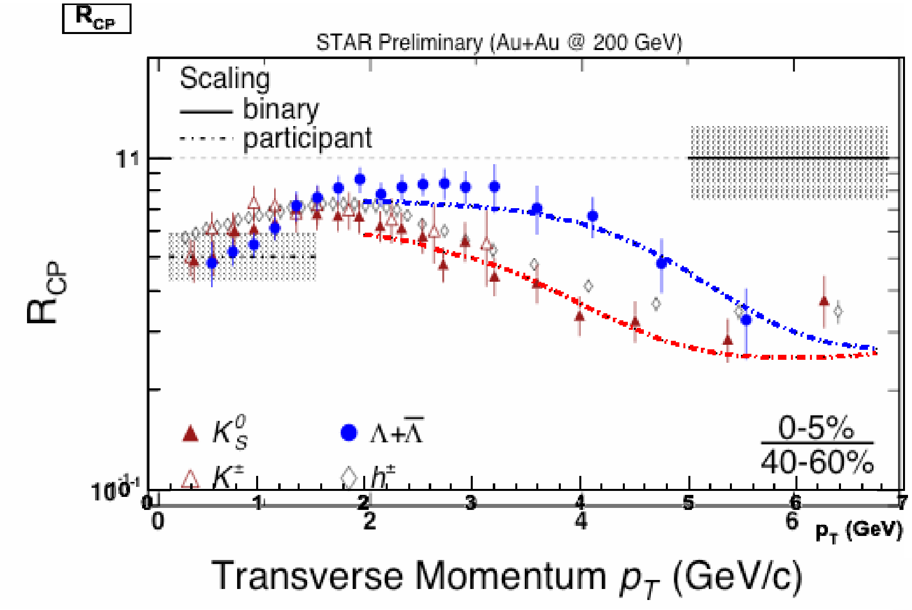
Fries, Müller, Bass, Nonaka Phys. Rev. C **68** (2003) 044902

➔***ReCombination***

-assumes the recombination of two and three low pT partons to form hadrons from an exponential parton pT spectrum**.**

➔ R_{xx} different for mesons and baryons (fragmentation dominates later for baryons than for messons) !!

R_{CP} Theory



Fries et al nucl-th/0306027

Recombination describes fairly well the baryon – mesons differences

Reco **for K0s and Λ+Λbar**

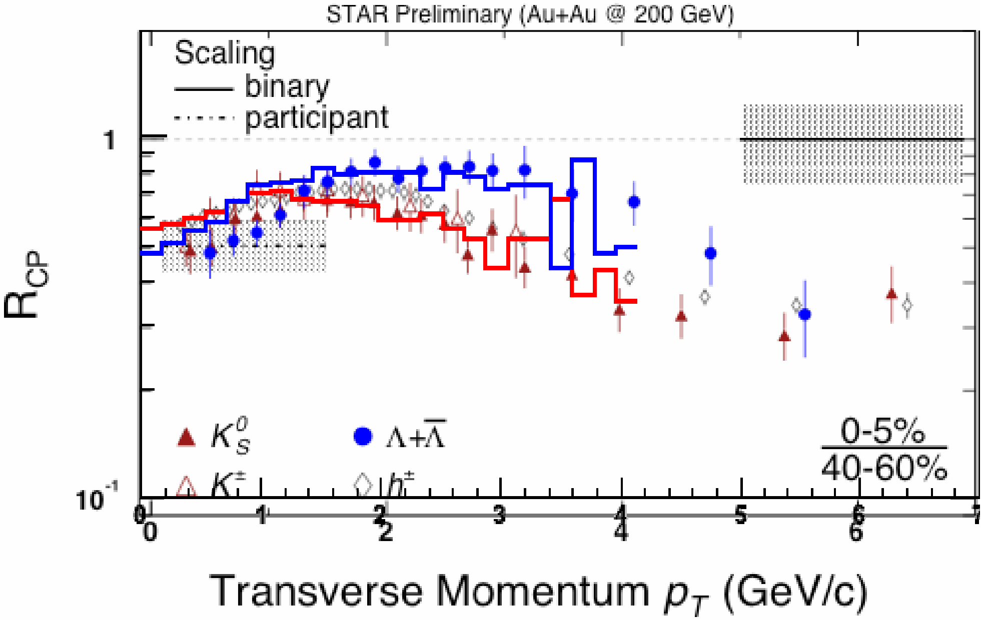
Central(b=3fm) / Peripheral (b=12fm)

Topor-Pop et al (nucl-th/0407095)

… same Hijing/BBbar v2.0

Hijing/BBbar v2 **0-10% / 60-90%**

For K^- + K^+ and Λ+Λbar



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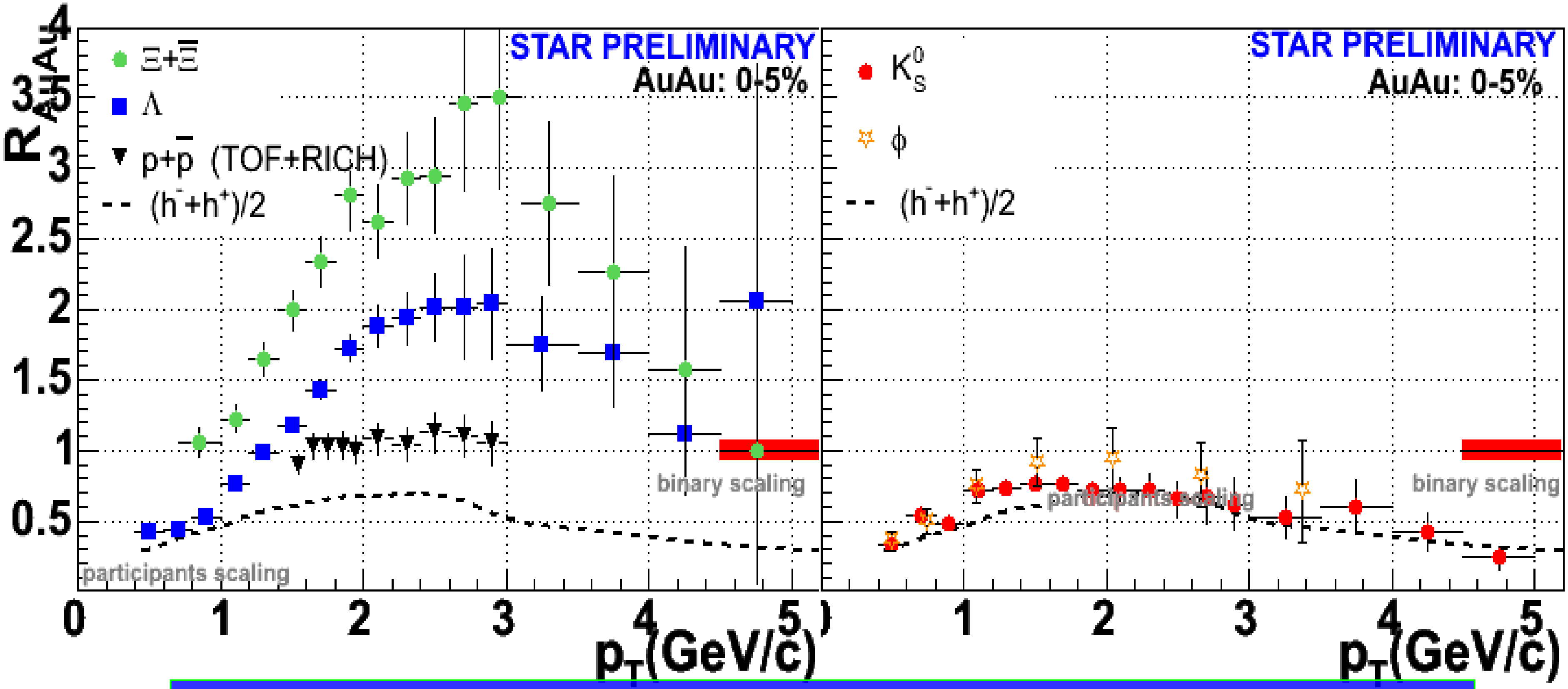
R_{AuAu}: identified hadrons



- Mesons *suppressed*
- Baryons *enhanced*

AND

$\max R_{AA}^{p(uud)} < \max R_{AA}^{\Lambda(uds)} < \max R_{AA}^{\Xi(dss)}$

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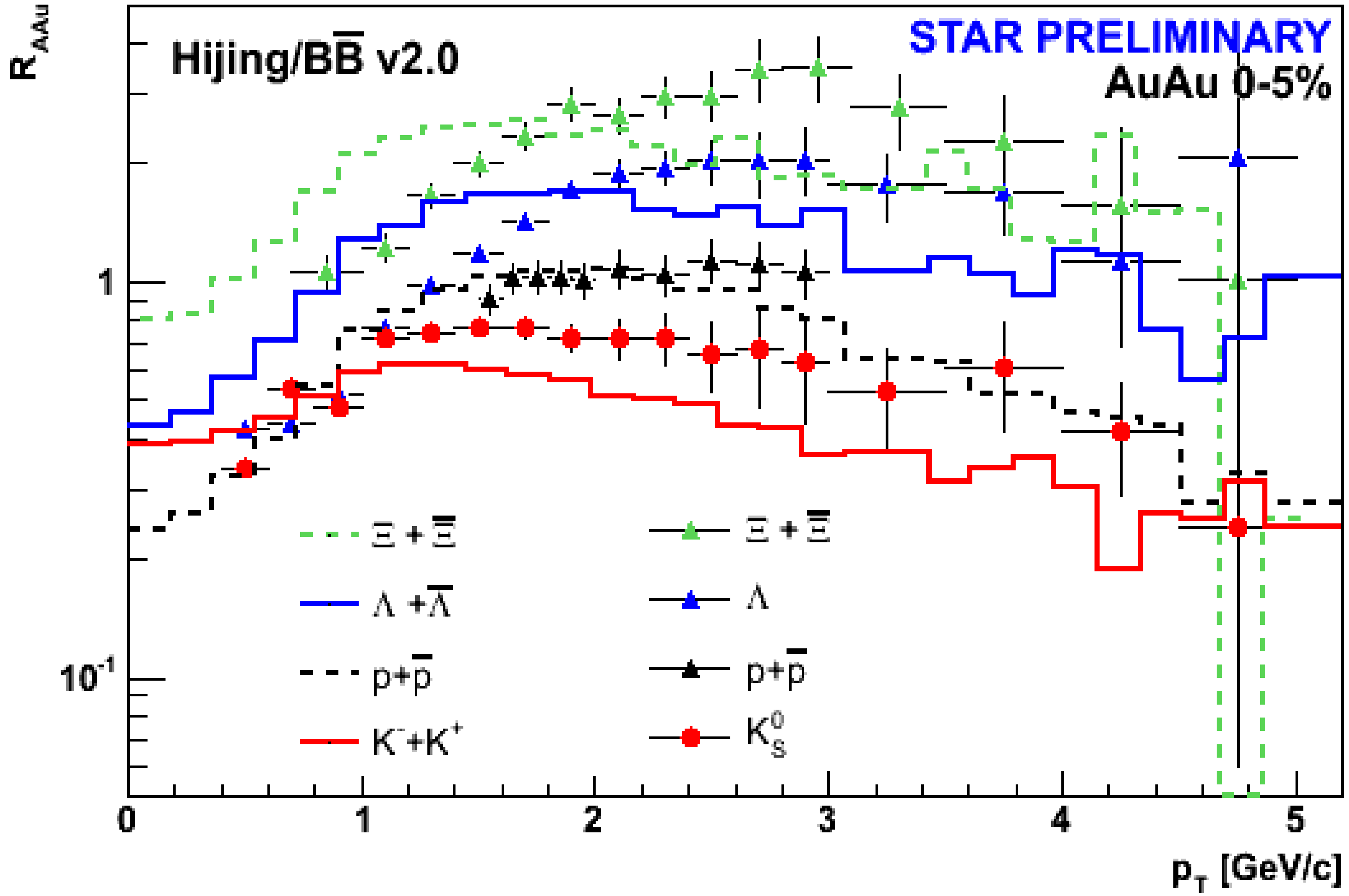
R_{AuAu} Theory …

Topor-Pop (private comunication and nucl-th/0407095)



→ Experimental pattern reproduced

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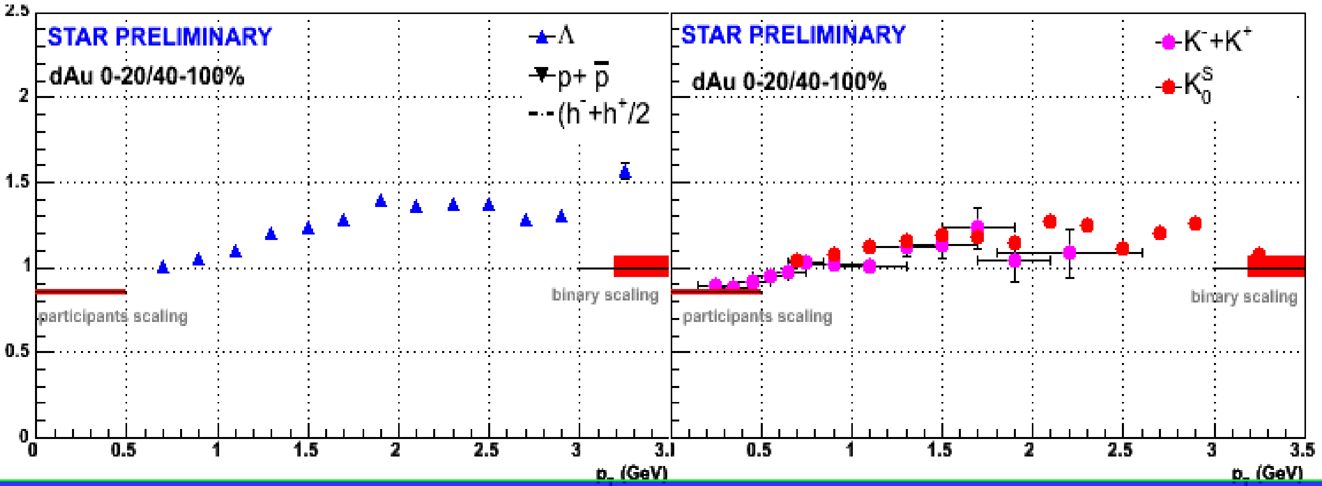
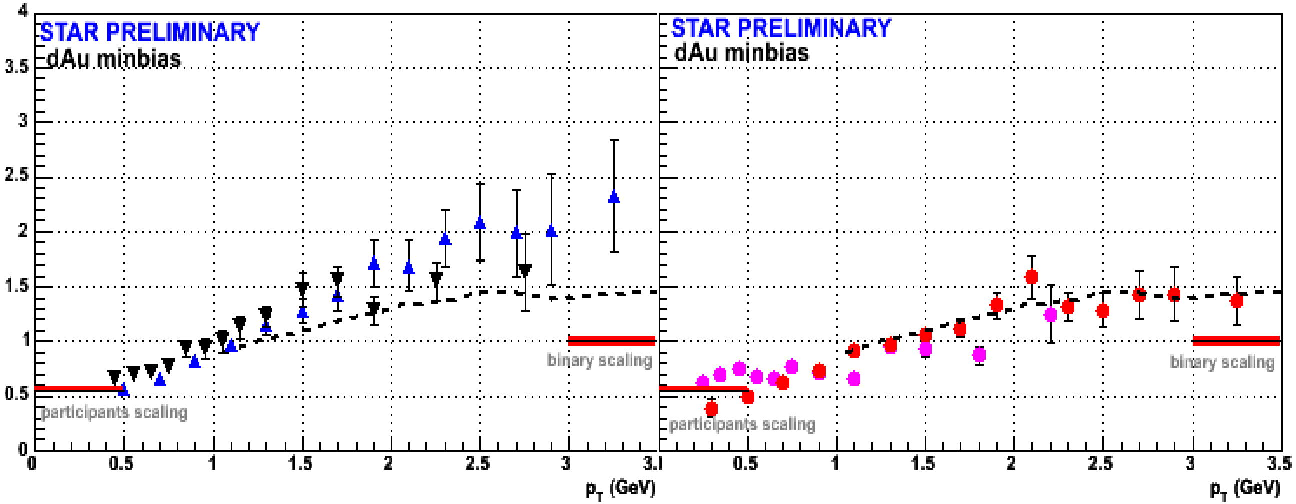
d+Au: identified hadrons

R_{CP}



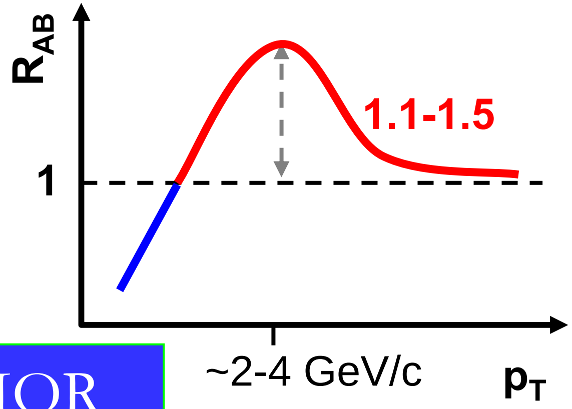
- ➔ both ratio present enhancement compared to binary scaling
- ➔ similar to AA, there seem to be a difference between mesons and baryons
- ➔ also R_{dA} (baryons) > R_{CP} (baryons) (error bars)

R_{dA}

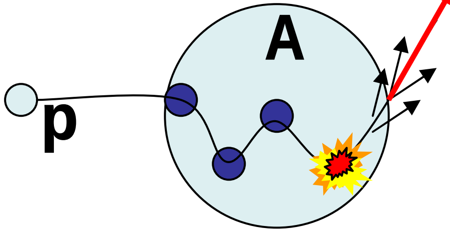


To explain…

1. Kopeliovich, Nemchik, Schafer, Tarasov – Phys. Rev. Lett. 88(2002) 232303
2. Vitev, Gyulassy – Phys. Rev. Lett. 89 (2002) 252301
3. X.N. Wang – Phys. Rev. C 61(2000) 064910
4. Accardi, Trelani –Phys. Rev. D 64(2001) 116004
5. Zhang, Fai, Papp, Bernafoldi, Levai – Phys. Rev. C 65(2002) 034903

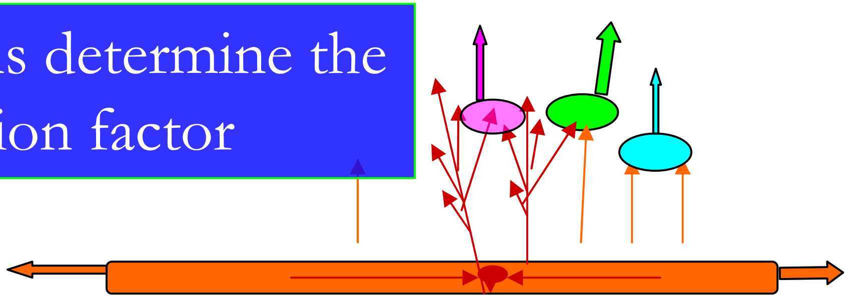


Rescatterings (projectile hadron or its partons) PRIOR to the hard collision cause a broadening of the p_T spectrum



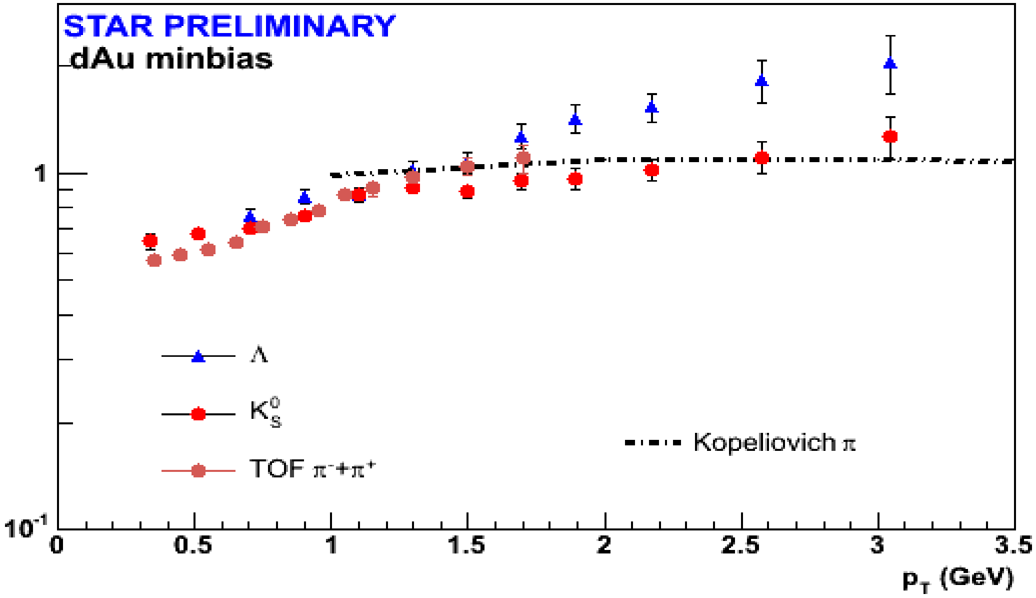
1.Hwa, Yang nucl-th/0404066 ***Recombination model (Oregon)***

FINAL STATE recombination of partons determine the enhancement of the nuclear modification factor

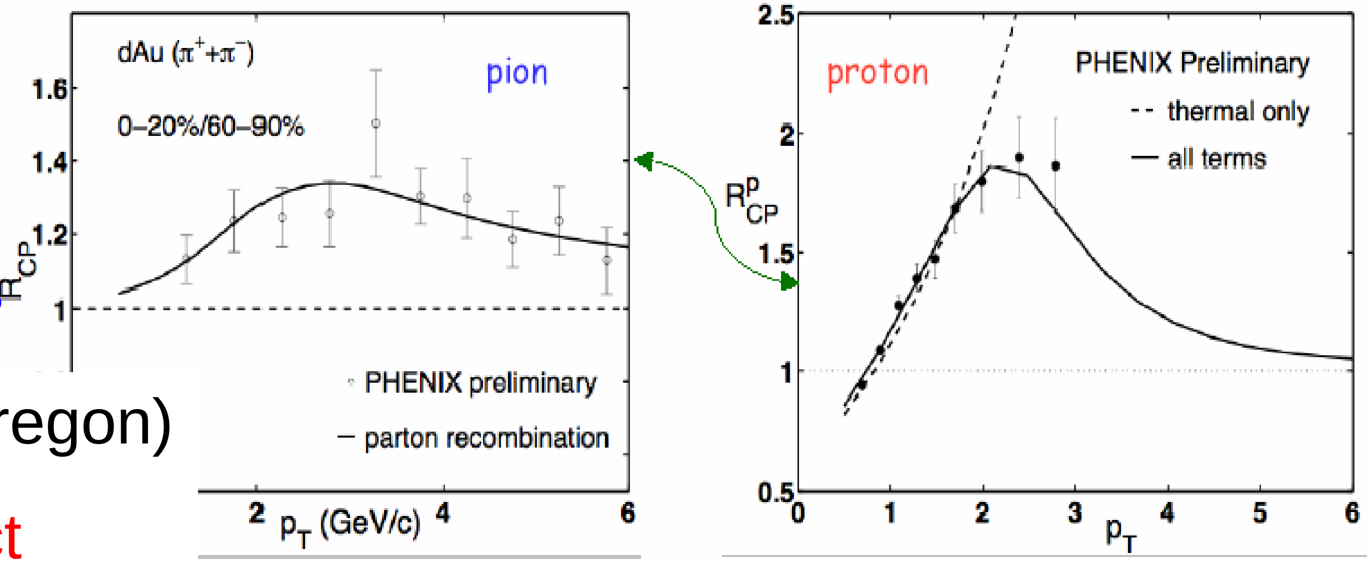


R_{dA}/R_{CP}(d+Au): theory and experiment

Kopeliovich, Nemchik, Schafer, Tarasov – Phys. Rev. Lett. 88(2002) 232303



→ *Initial state* elastic scatterings reproduce the general trend of the R_{dA} but NOT the particle species dependence



1.Hwa, Yang nucl-th/0404066

Recombination (Oregon)

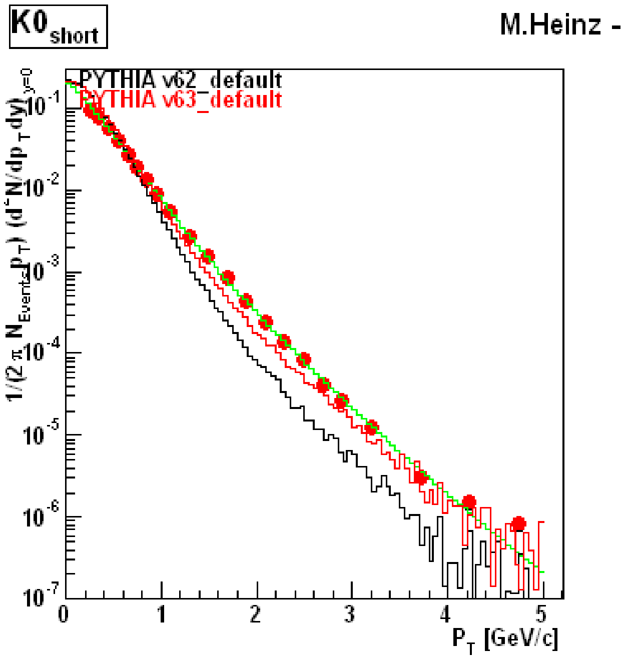
→ *Final state effect*

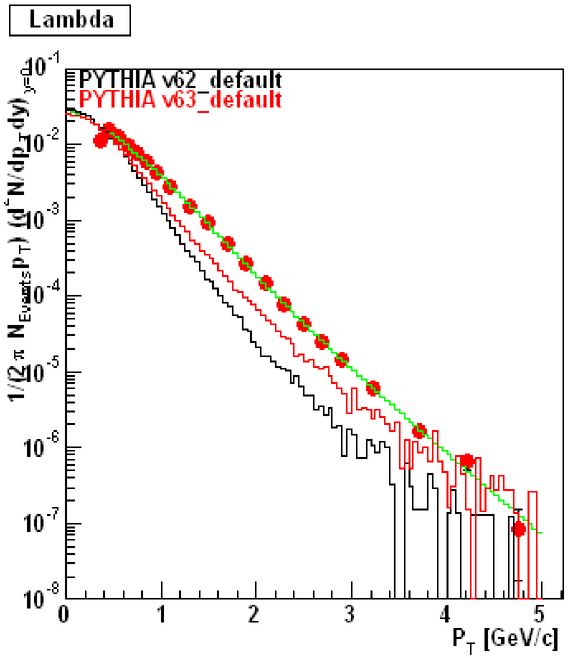
Do we understand the baseline anyway?

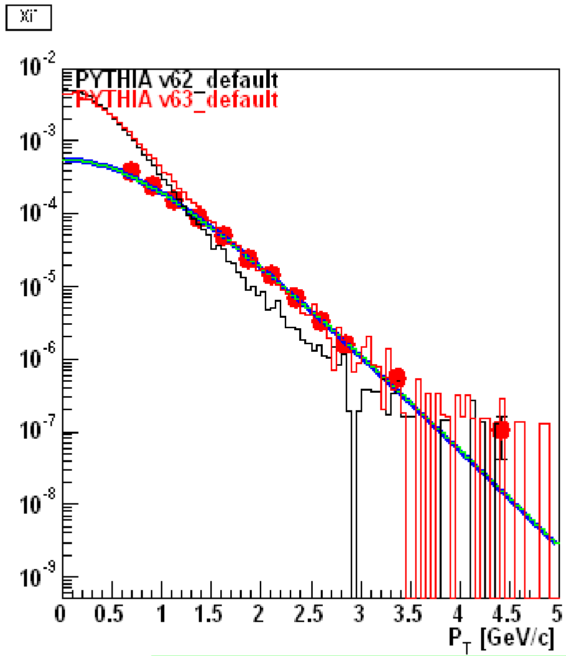
→ 2 different hadronization describe data

→ R_{CP} suppression BUT when ratio to p+p (R_{AA}) enhancement for strange baryons

DO WE UNDERSTAND THE BASELINE (p+p)?







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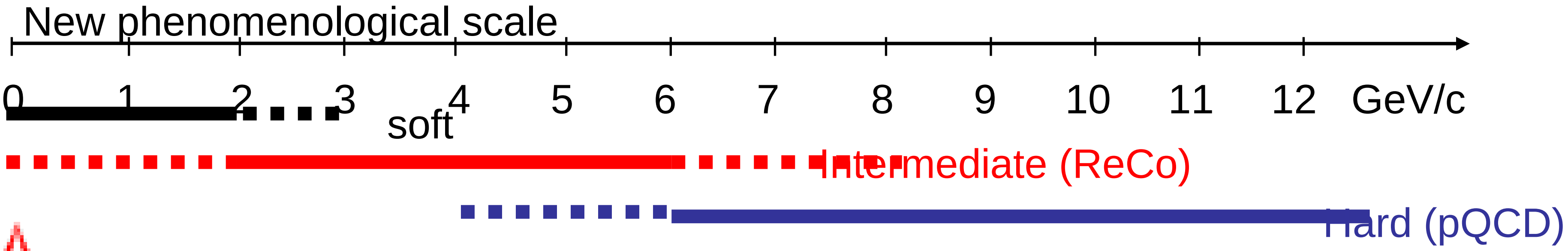
NOT really!

Conclusions from identified hadrons

➔ R_{AB}/R_{CP} HAS TO BE TREATED SEPARATELLY (at least until an explanation/scaling for the R_{AB} strangeness ordering is found)

➔ Au+Au, d+Au: difference between mesons and baryons in the intermediate pT region

➔ models assuming different hadronization scenarios, qualitatively describe data ➔ need other probes



New phenomenological scale

0 1 2 3 4 5 6 7 8 9 10 11 12 GeV/c

soft

Intermediate (ReCo)

Hard (pQCD)

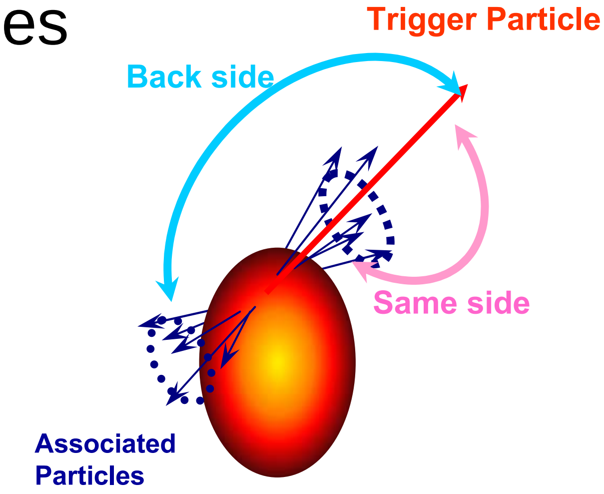
Other probes to answer the questions

DO JET ANALYSIS with identified particles

→ in p+p, d+A and A+A

→ trigger on mesons and baryons

→ trigger on strange and non-strange baryons and meson



➔Looking at near side -→ hadronization mechanisms

➔Looking at the away side → medium properties.

And the scene is set for the next (experimental) talks!

Just_in_Case plots

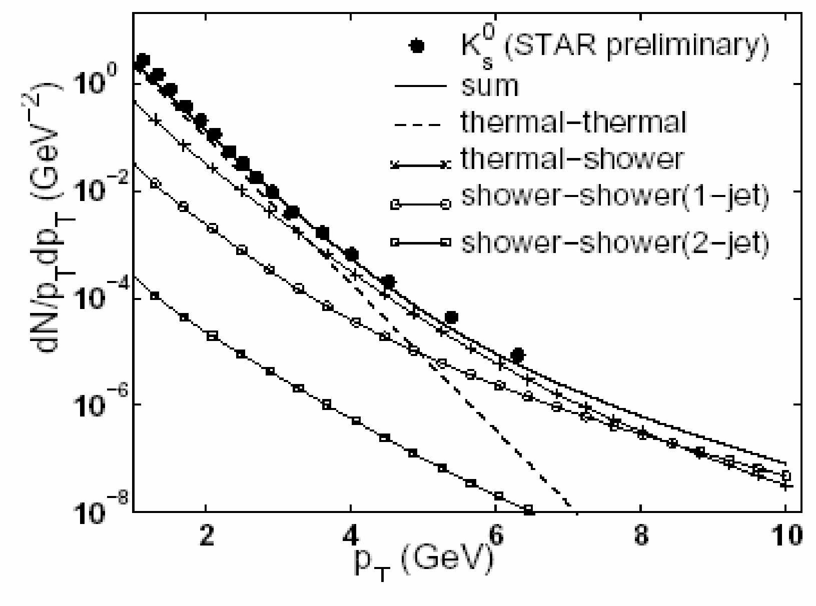
Hadronization ReCo(Oregon)...

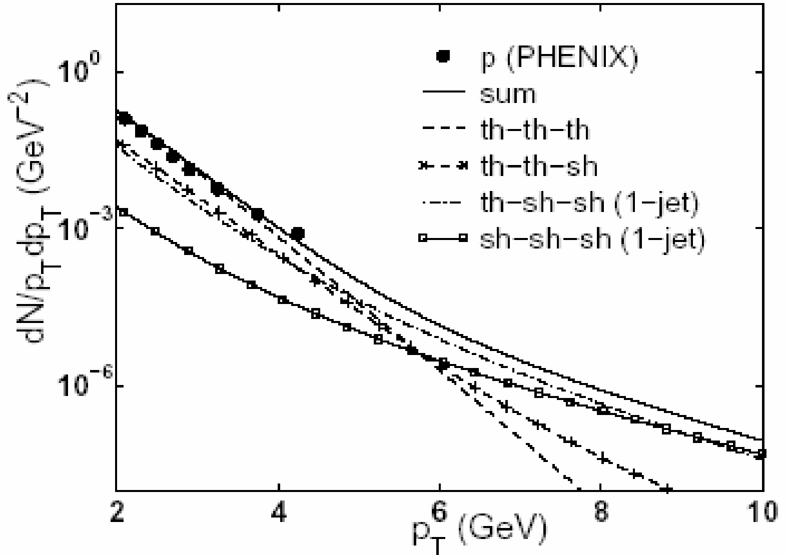
→Mesons ($\bar{q}q$)

$$p\frac{dN_M}{dp}=\int\frac{dp_1}{p_1}\frac{dp_2}{p_2}F_{q\bar{q}}(p_1,p_2)R_M(p_1,p_2,p$$

Quark-antiQuark distribution

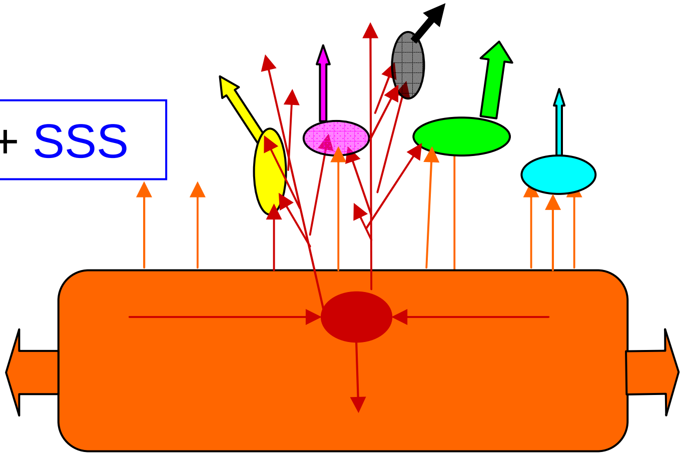
Fqq(p1,p2) = T T +





$$R_B(p_1,p_2,p_3,p)$$

+ S3+ TSS + SS2 + SSS



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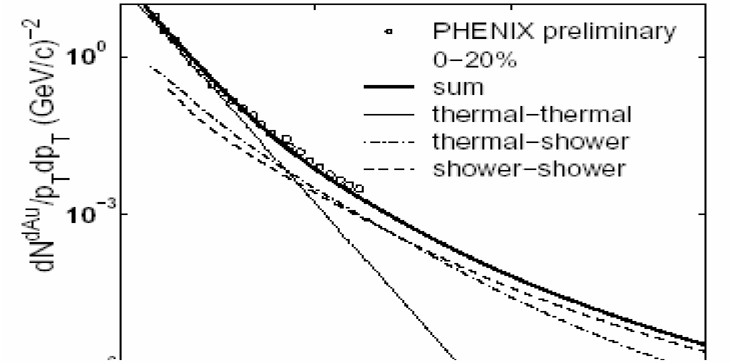
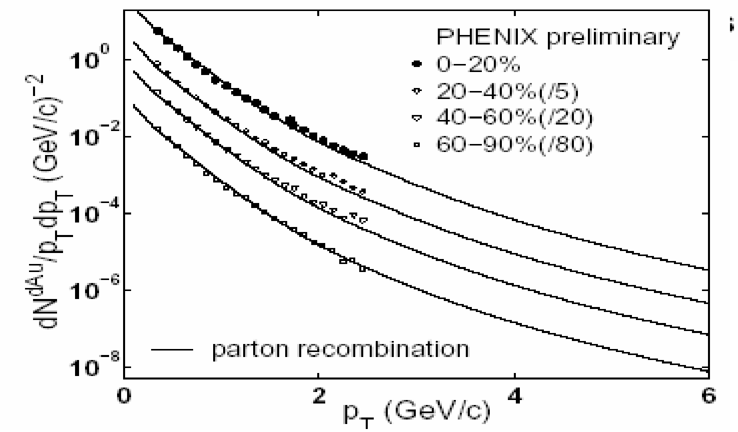
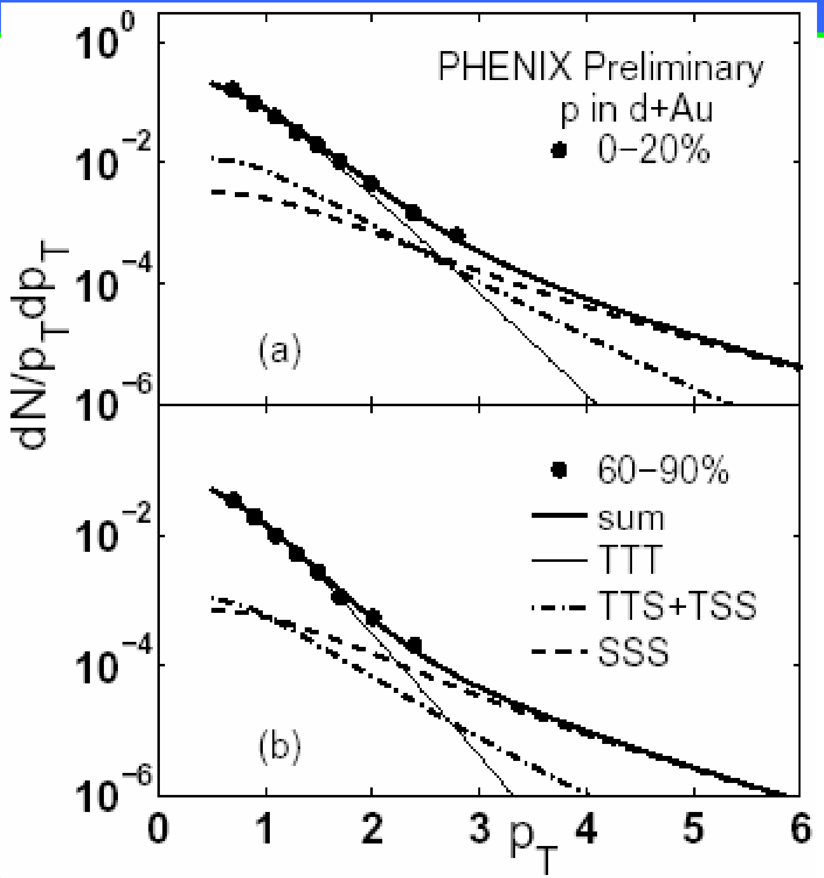


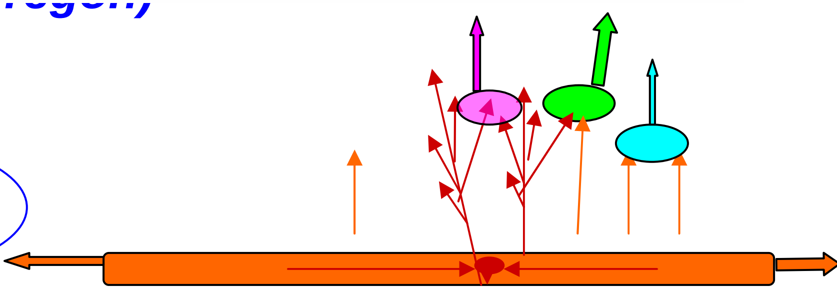




- Hwa, Yang nucl-th/0404066 ***Recombination mode. (Oregon)***

→*Mesons* $(q\bar{q})$

$$p\frac{dN_M}{dp} := \int \frac{dp_1}{p_1}\frac{dp_2}{p_2} F_{q\bar{q}}(p_1,p_2) R_M(p_1,p_2,p)$$



Quark-antiQuark distribution

Fqq(p1,p2) = T T + T S + S2 + S S