

The first heavy ion collisions at the LHC - HIC10
CERN, September 3rd 2010

Predictions for the LHC heavy-ion programme: an update

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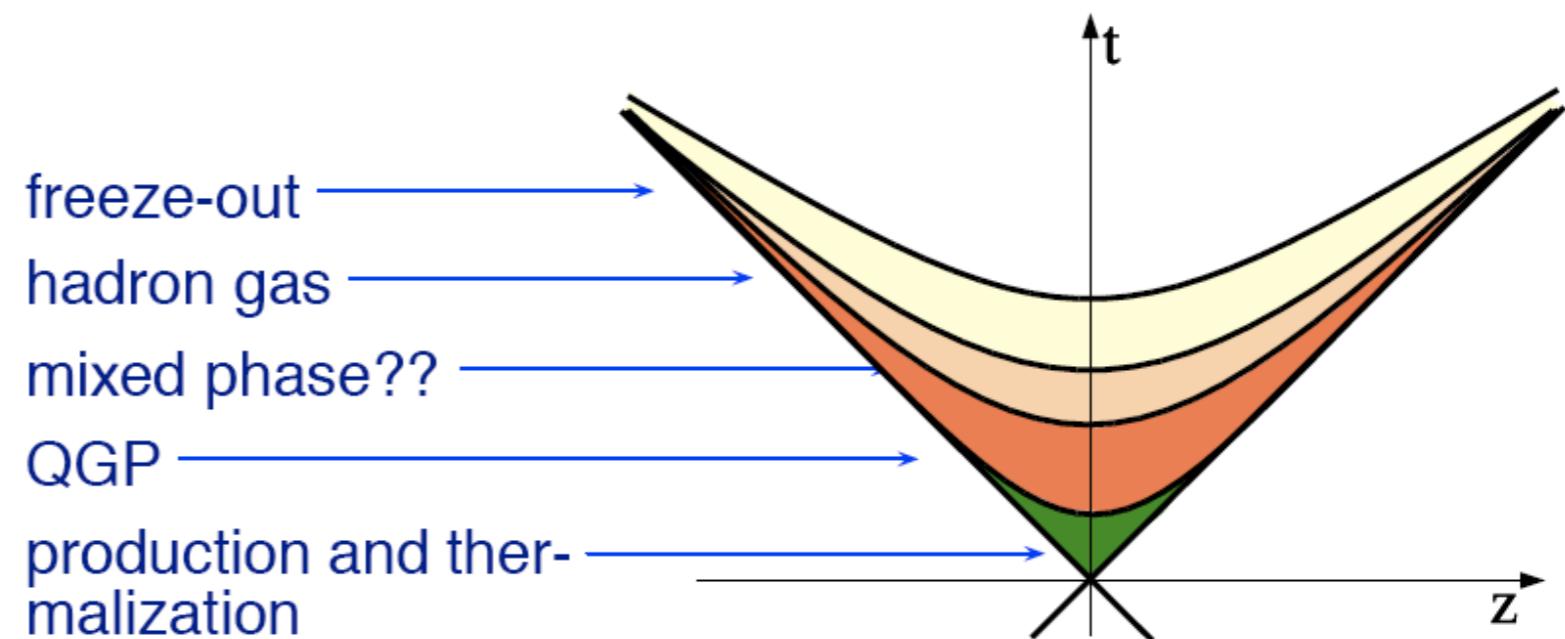
Based on the material gathered during the CERN Theory Institute on Heavy Ion Collisions at the LHC: Last Call for Predictions (14 May - 8 Jun 2007), J. Phys. G35 (2008) 05400, arXiv:0711.0974 [hep-ph], and on arXiv: 0903.1330 [hep-ph] (in QGP4), plus a few updates.

Contents:

1. Introduction (see the talks by Fodor, Müller, Pisarski, Shuryak, Ratti and Redlich).
2. Multiplicities.
3. Azimuthal asymmetries.
4. Hadronic flavor observables.
5. Correlations at low p_T .
6. High- p_T observables and jets.
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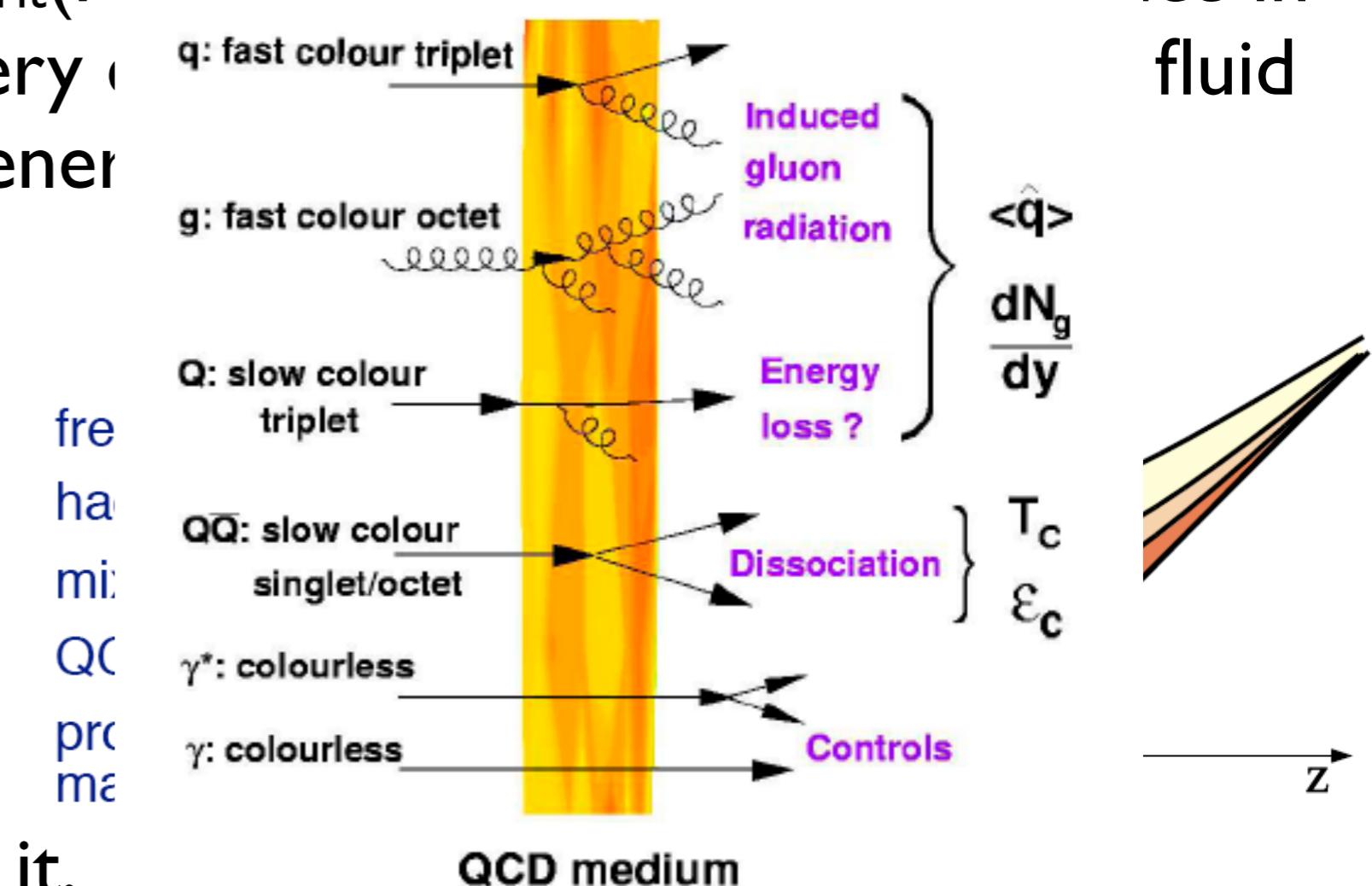
Introduction:

- **URHIC** is an interdisciplinary field, whose goal is the understanding of **confinement** through the study of matter at high parton densities → through **asymptotic freedom** → **QGP**.
- **Experiments at RHIC** claim (NPA757 '05): the creation of partonic matter with $\epsilon > \epsilon_{\text{crit}}(\text{HM} \rightarrow \text{QGP})$, with large coherence in soft particle production, very early behaving like a quasi-ideal fluid and extremely opaque to energetic partons traversing it.
- ‘**Medium**’ (‘bulk’):
momenta $\sim \langle p \rangle (T)$.
- **Hard probes**: pQCD-computable in vacuum, whose medium-modification characterizes it.



Introduction:

- URHIC is an interdisciplinary field, whose goal is the understanding of confinement through the study of matter at high parton densities → through asymptotic freedom → QGP.
- Experiments at RHIC claim (NPA757 '05): the creation of partonic matter with $\epsilon > \epsilon_{\text{crit}}$ ($H^M \rightarrow QGP$) with large enhancement in soft particle production, very hot and extremely opaque to energy.
- ‘Medium’ (‘bulk’): momenta $\sim \langle p \rangle (T)$.
- Hard probes: pQCD-computable in vacuum, whose medium-modification characterizes it.



Why?:

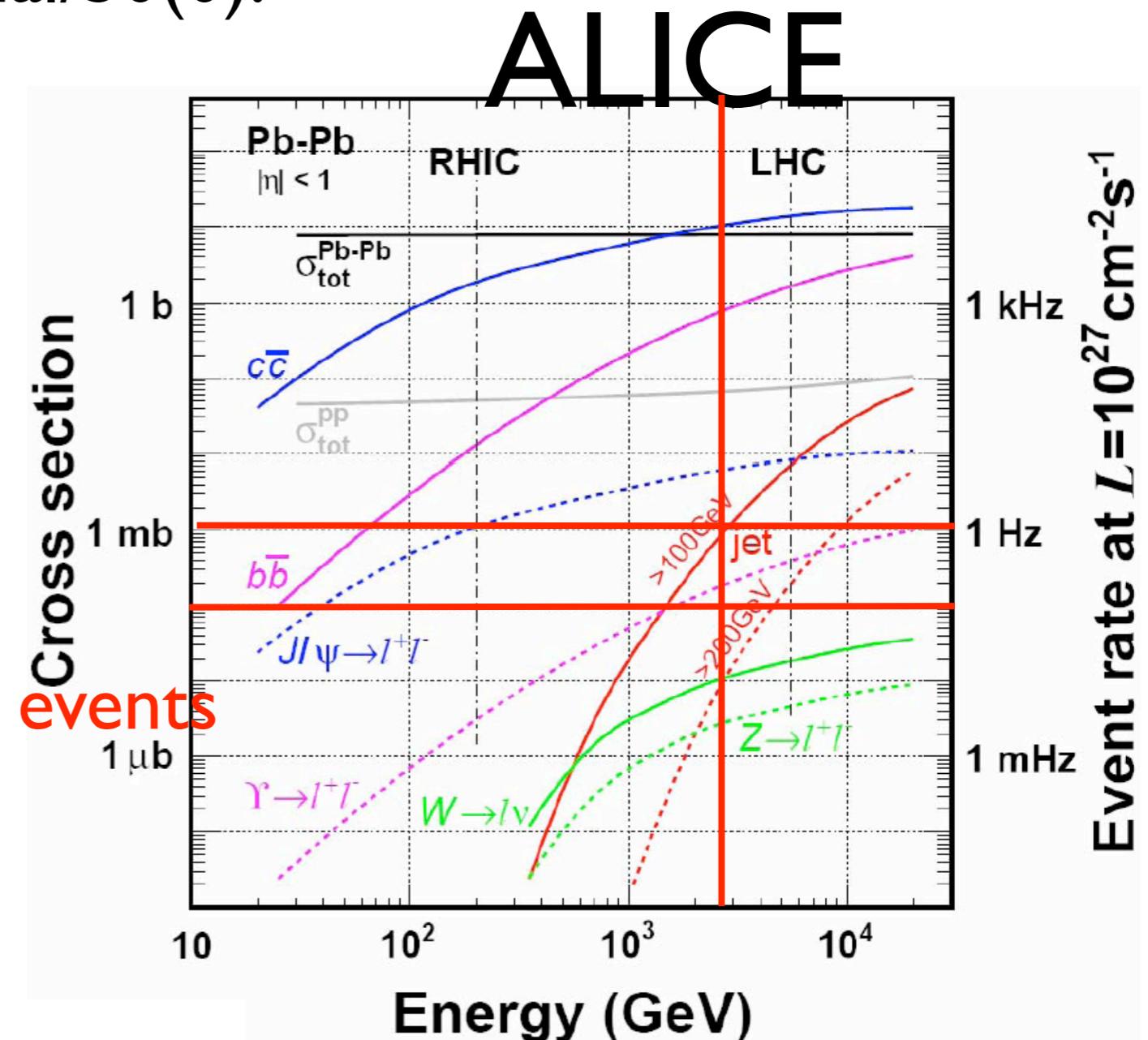
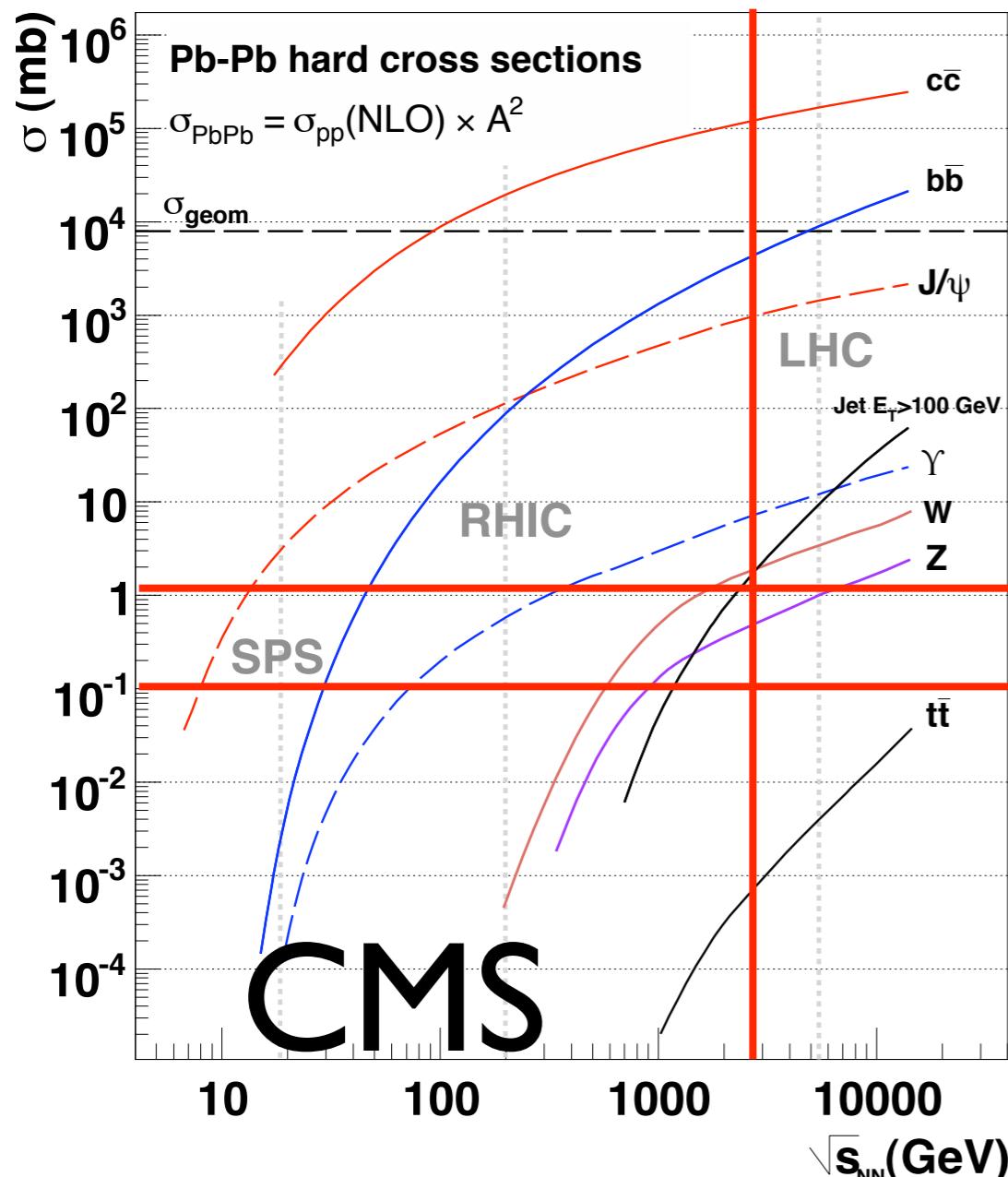
Observable at RHIC	Standard interpretation
Low multiplicity ($\sim 2/3$ expectations $dN_{ch}/d\eta _{\eta=0} \sim 1000$ for central collisions)	Strong coherence in particle production: CGC, collectivity, strong gluon shadowing!?
v_2 in agreement with ideal hydro $(\eta/s \sim 2/(4\pi)$, see Heinz's talk)	Almost ideal fluid , very fast thermalization/ isotropization, strongly/weakly coupled!?
Strong jet quenching ($R_{AA}(10 \text{ GeV}) \sim 0.2$ for π^0 , disappearance of back-to-back correlations)	Opaque partonic medium , radiative (+elastic) energy loss, weak/strong interaction with the medium!?

Comparing **predictions** - done within RHIC tested models - for different observables to LHC data, will help to:

- Check our theoretical explanations of the probes.
- Constrain our understanding of medium properties.

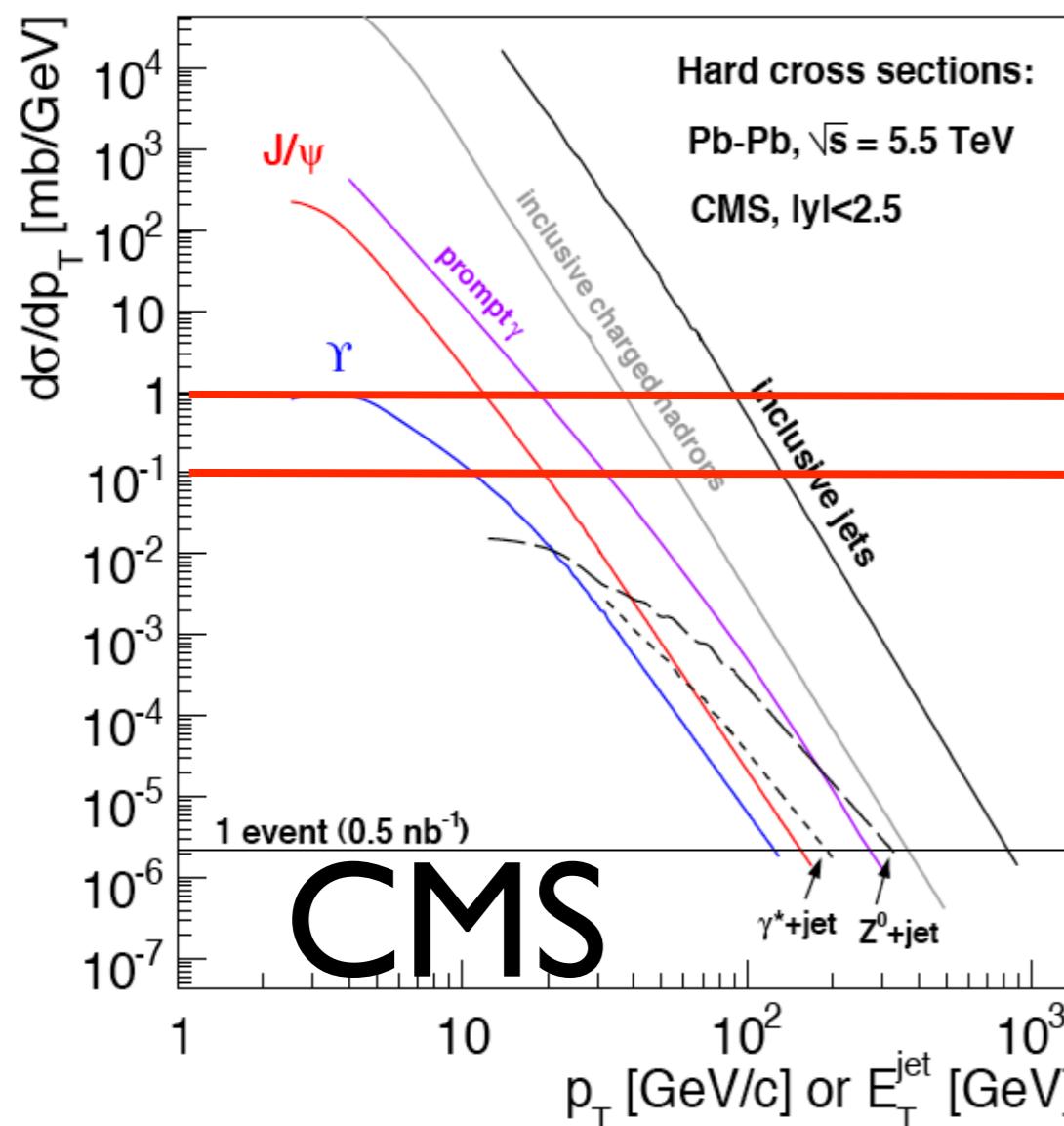
2010-2011:

- Energy will be 2.76 ATeV, not 5.5 ATeV.
- ALICE and CMS: assume $10^{(7)8}$ collisions, $\sigma_{\text{geom}} \sim 10^4 \text{ mb}$, $10^6 \text{ s} \Rightarrow$ luminosity $\sim 10^{(3)2} \text{ mb}^{-1}\text{s}^{-1}$ = nominal/50(0).

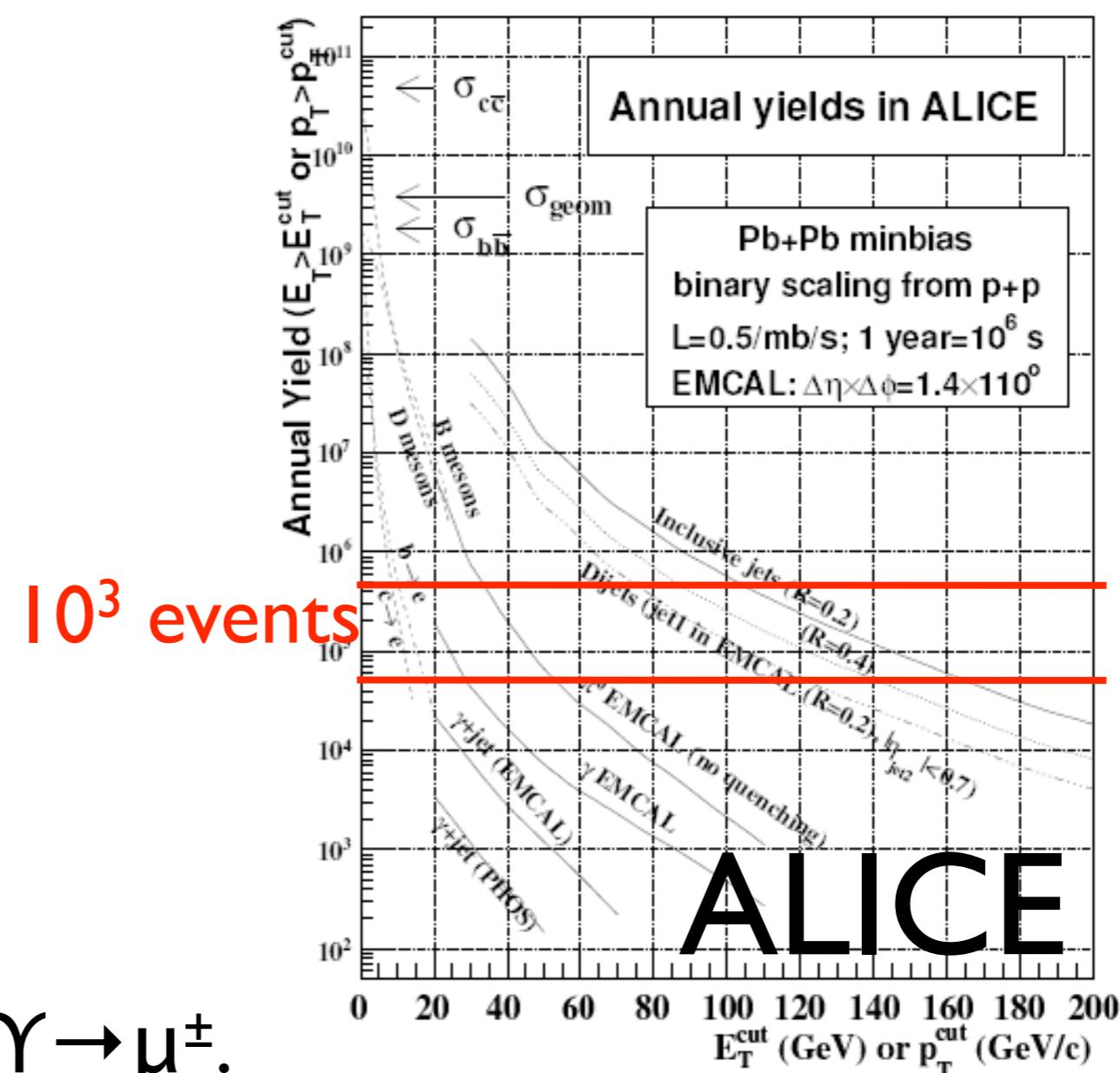


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E.g. 80 (60) $Z \rightarrow \mu^\pm(e^\pm)$, 500 $\gamma \rightarrow \mu^\pm$.



Aim of the talk:

- I will present available predictions for a collection of observables, stressing multiplicities, elliptic flow and high p_T .
- When possible, I will rescale/discuss them at 2.76 ATeV, not at 5.5 ATeV: rescaling of multiplicities driven by pp results.
- Note: charged multiplicity at midrapidity is a key observable that will determine - through ϵ, T, \dots - the predictions for most observables. E.g. Bjorken estimate plus $1+1$ expansion + CGC considerations make this connection:

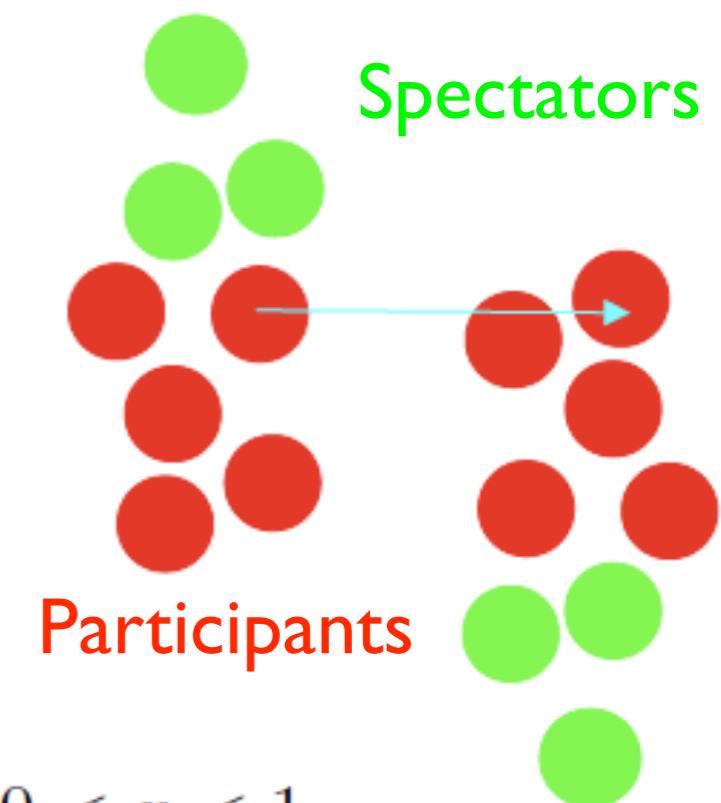
	$dN_{ch}^{AA}/d\eta _{\eta=0}$	$\langle\tau_{therm}\rangle$ (fm)	$\langle\epsilon\rangle$ (GeV/fm 3)	T_i (GeV)	s_0 (fm $^{-3}$)
RHIC	635	0.6	6.8	0.241	38
LHC	900 (I)	0.51	12.6	0.281	60
LHC	1650 (II)	0.37	32.7	0.356	123
LHC	2600 (III)	0.30	64.4	0.422	204

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Why?:

- Multiplicity is a difficult observable for theory: perturbative or not?; which factorization?; how hadronization proceeds?;...
- 1st-day observable, determines most things:
 - * T, ϵ : initial conditions.
 - * The density of the system.
 - * The background for signals: jets, γ 's, (di)leptons..
- Naive parametrization: $N_{\text{part}} \propto A$, $N_{\text{coll}} \propto A^{4/3}$

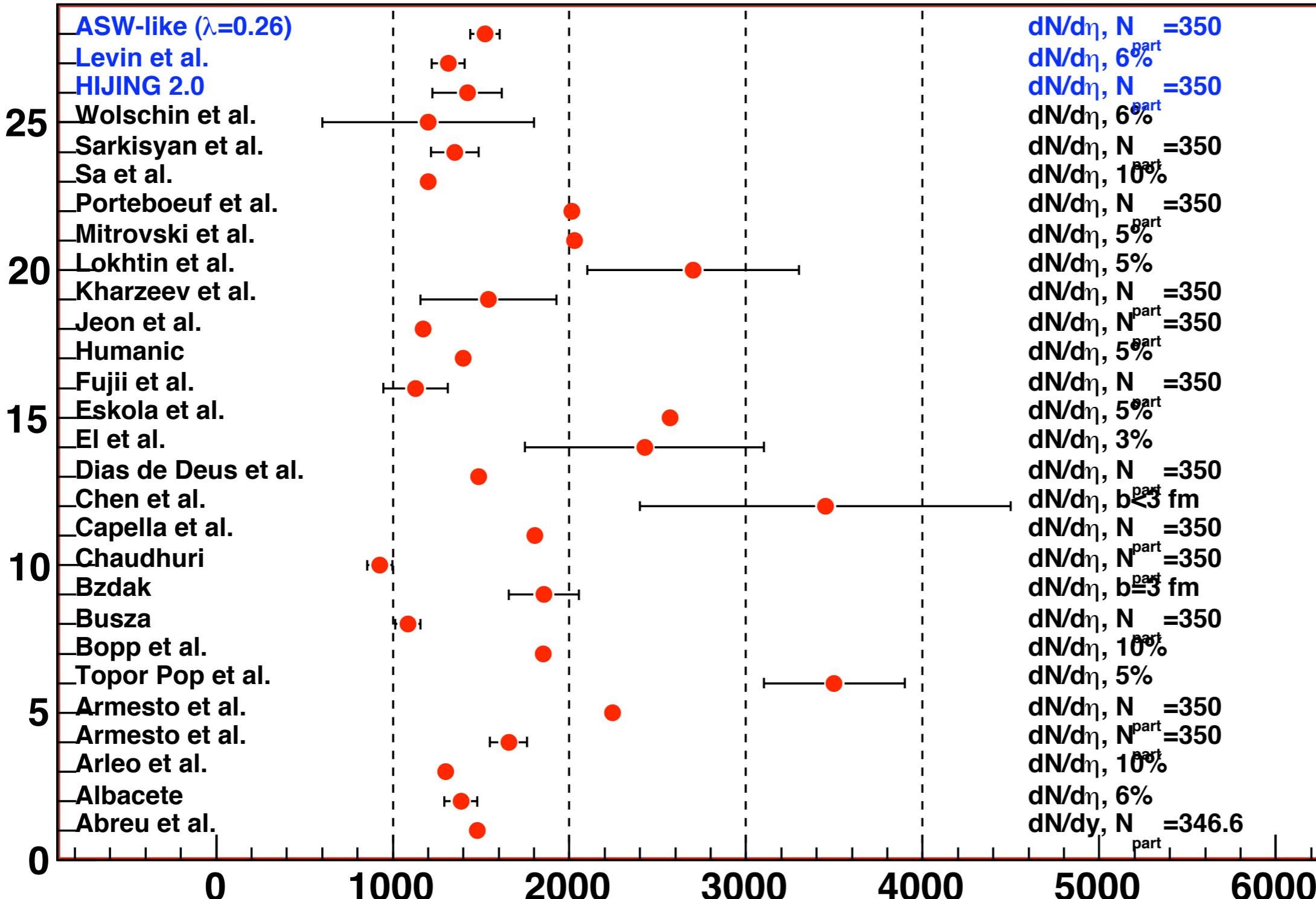


$$\left. \frac{dN_{ch}^{AA}}{d\eta} \right|_{\eta=0} = \left. \frac{dN_{ch}^{NN}}{d\eta} \right|_{\eta=0} \left[\frac{1-x}{2} N_{\text{part}} + x N_{\text{coll}} \right], \quad 0 < x < 1$$

- * $x=1$ (**N_{coll} scaling**) in collinear factorization and in many soft models at large scales/energies.
- * x diminishes with shadowing of npdf's, non-linear QCD dynamics, collective effects,... \rightarrow **N_{part} scaling**.

Raw predictions:

Charged multiplicity for $\eta=0$ in central PbPb at 5.5 TeV

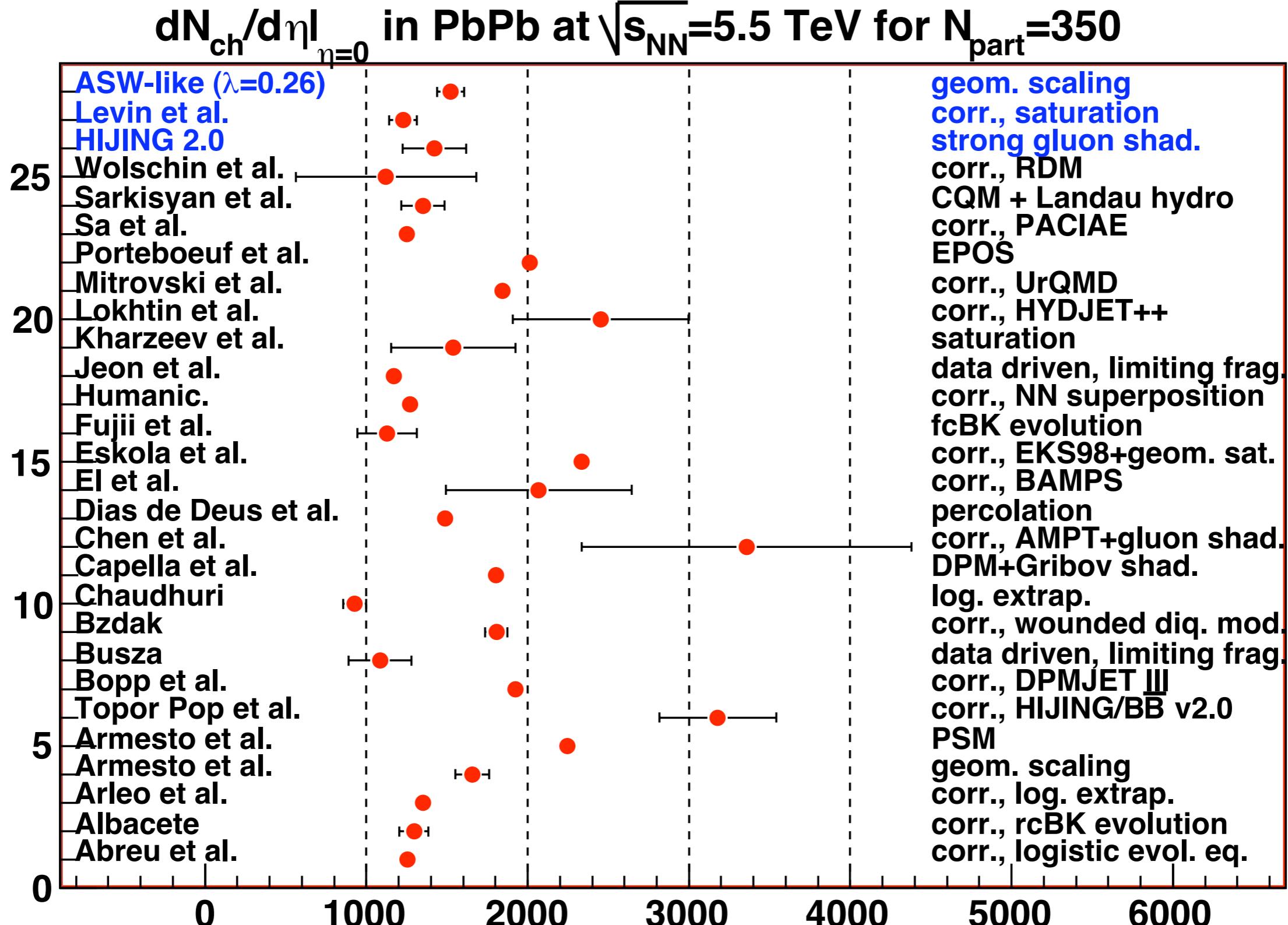


Rescaling in centrality and y/η:

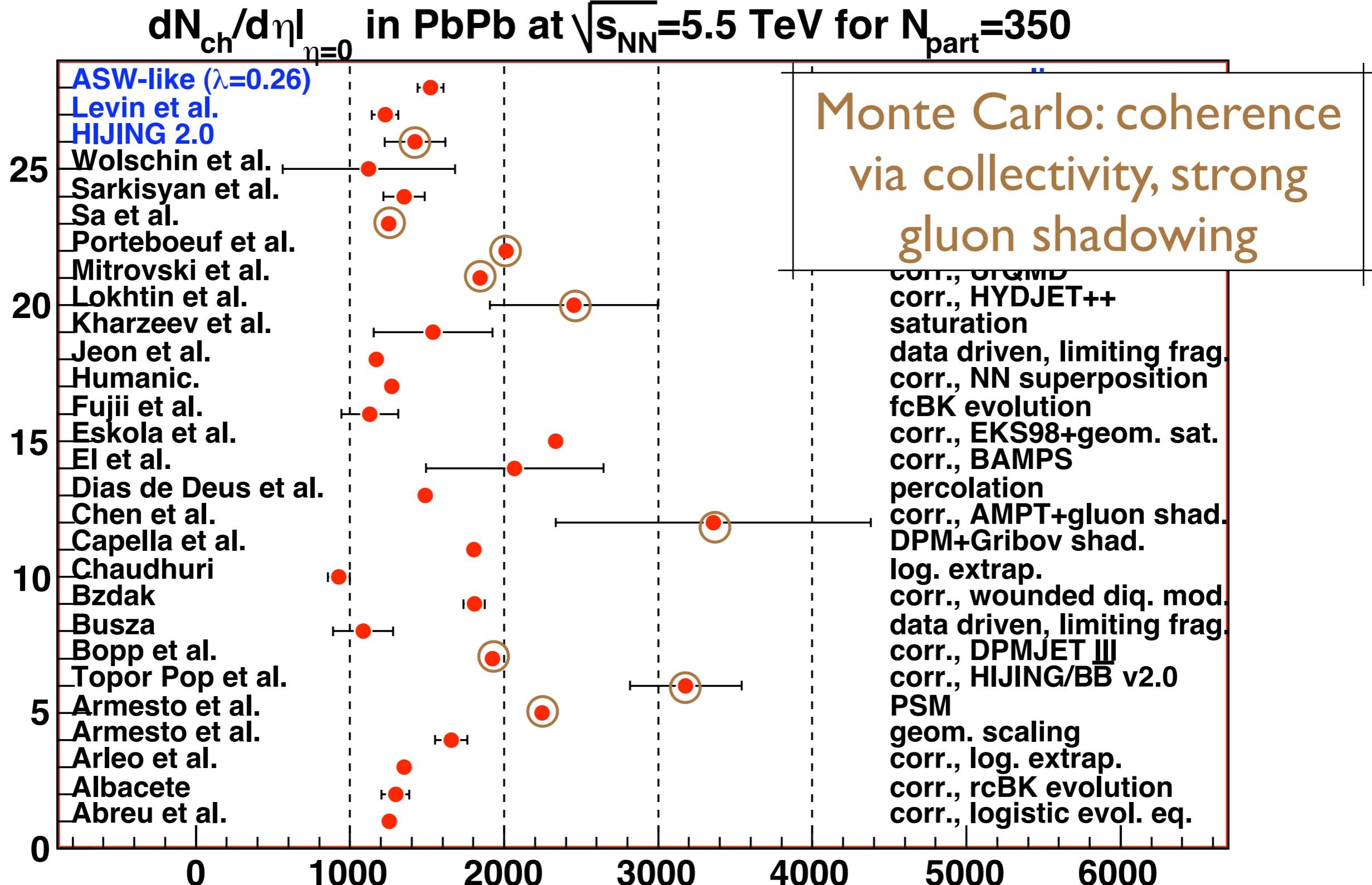
- I use a Monte Carlo model ([PSM:Amelin et al. '01](#)) to rescale to a common centrality and observable.
- It should not be more precise than 5 %.

%	$\langle b \rangle$ (fm)	$\langle N_{part} \rangle$	$\langle N_{coll} \rangle$	$dN_{ch}/dy _{y=0}$	$dN_{ch}/d\eta _{\eta=0}$
0 ÷ 3	1.9	390	1584	3149	2633
0 ÷ 5	2.4	375	1490	2956	2472
0 ÷ 6	2.7	367	1447	2872	2402
0 ÷ 7.5	3.0	357	1390	2759	2306
0 ÷ 8.5	3.1	350	1354	2686	2245
0 ÷ 9	3.2	347	1336	2649	2214
0 ÷ 10	3.4	340	1303	2583	2159

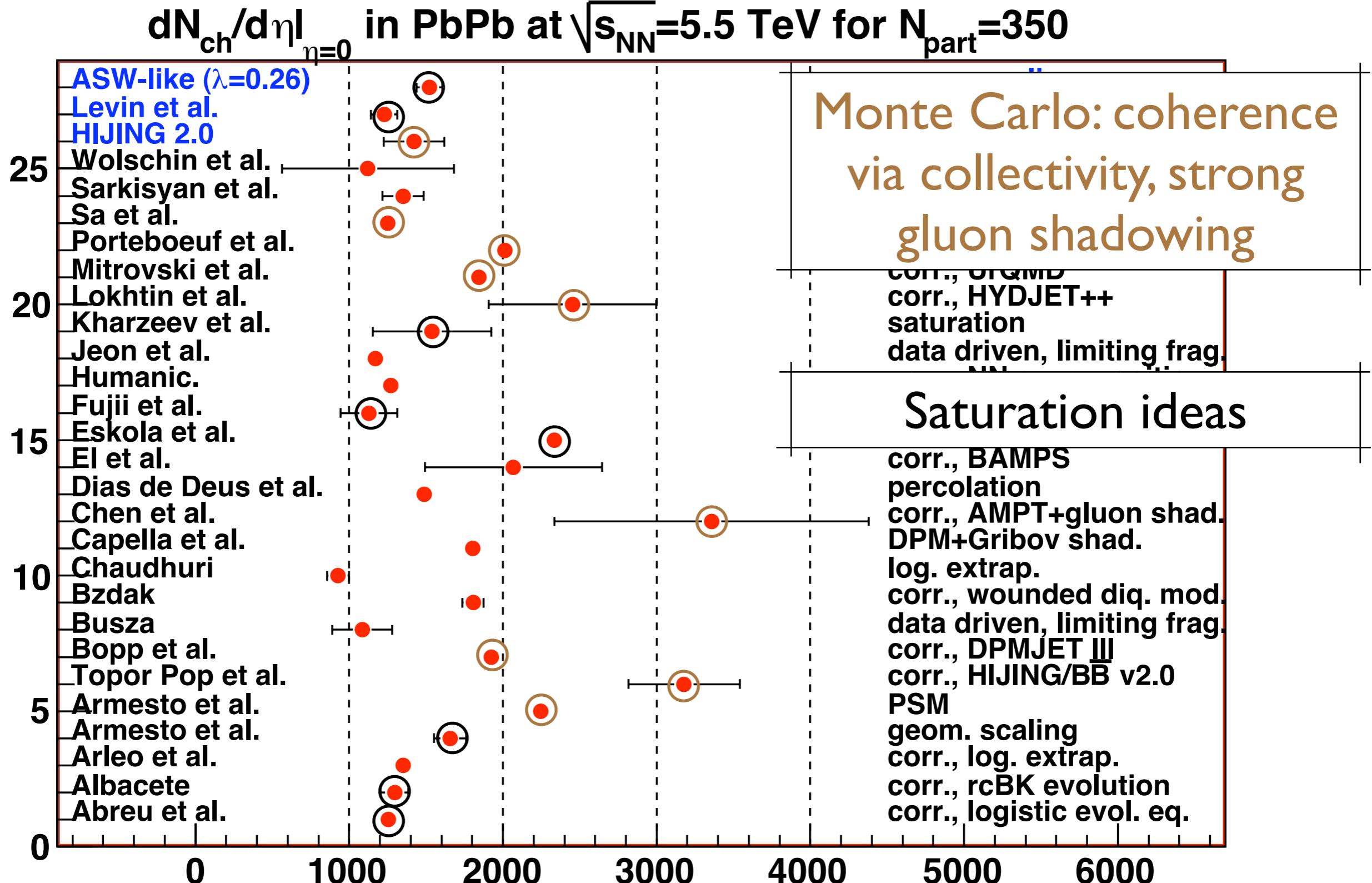
Rescaling in centrality and y/η :



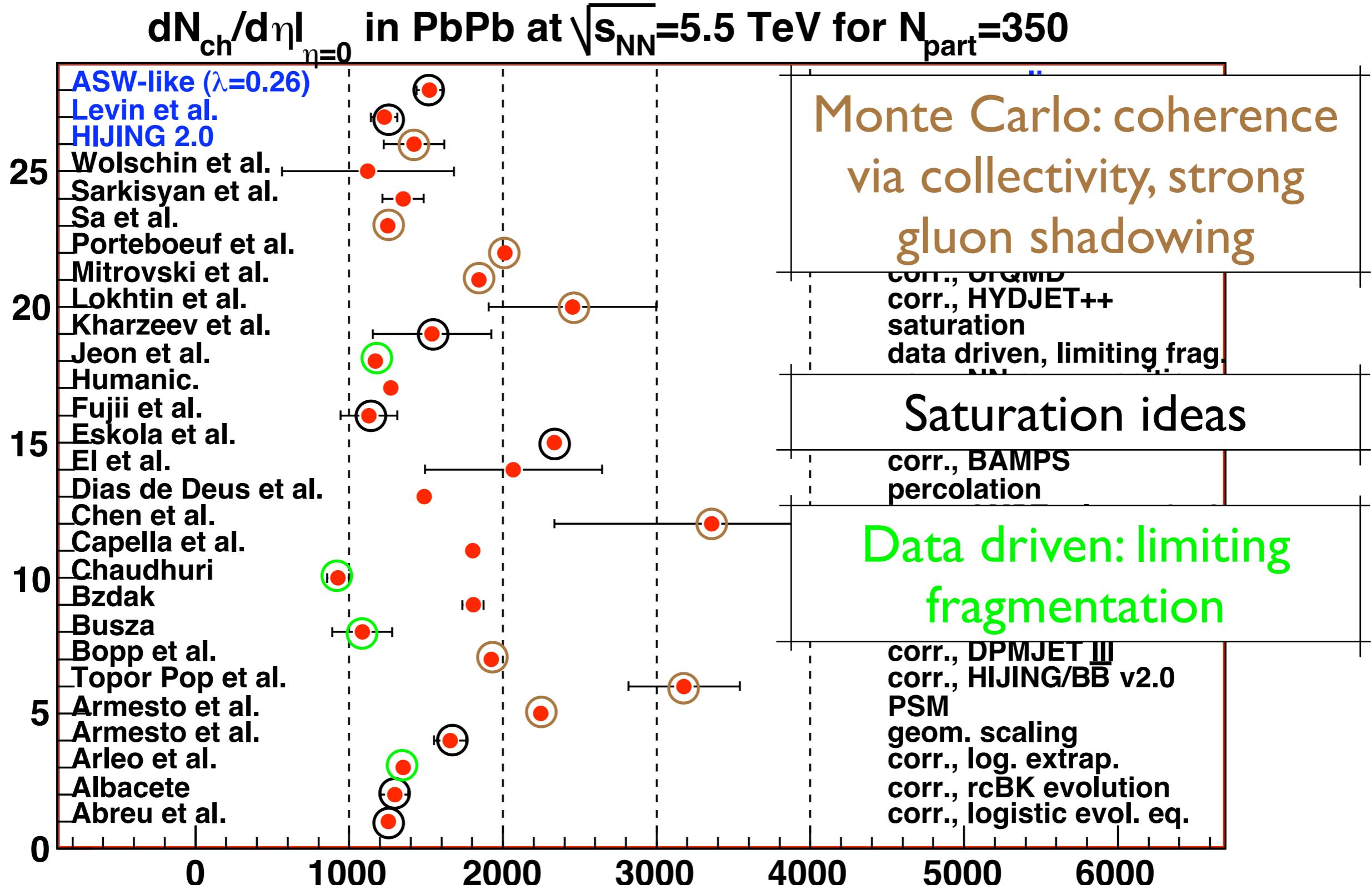
Rescaling in centrality and y/η :



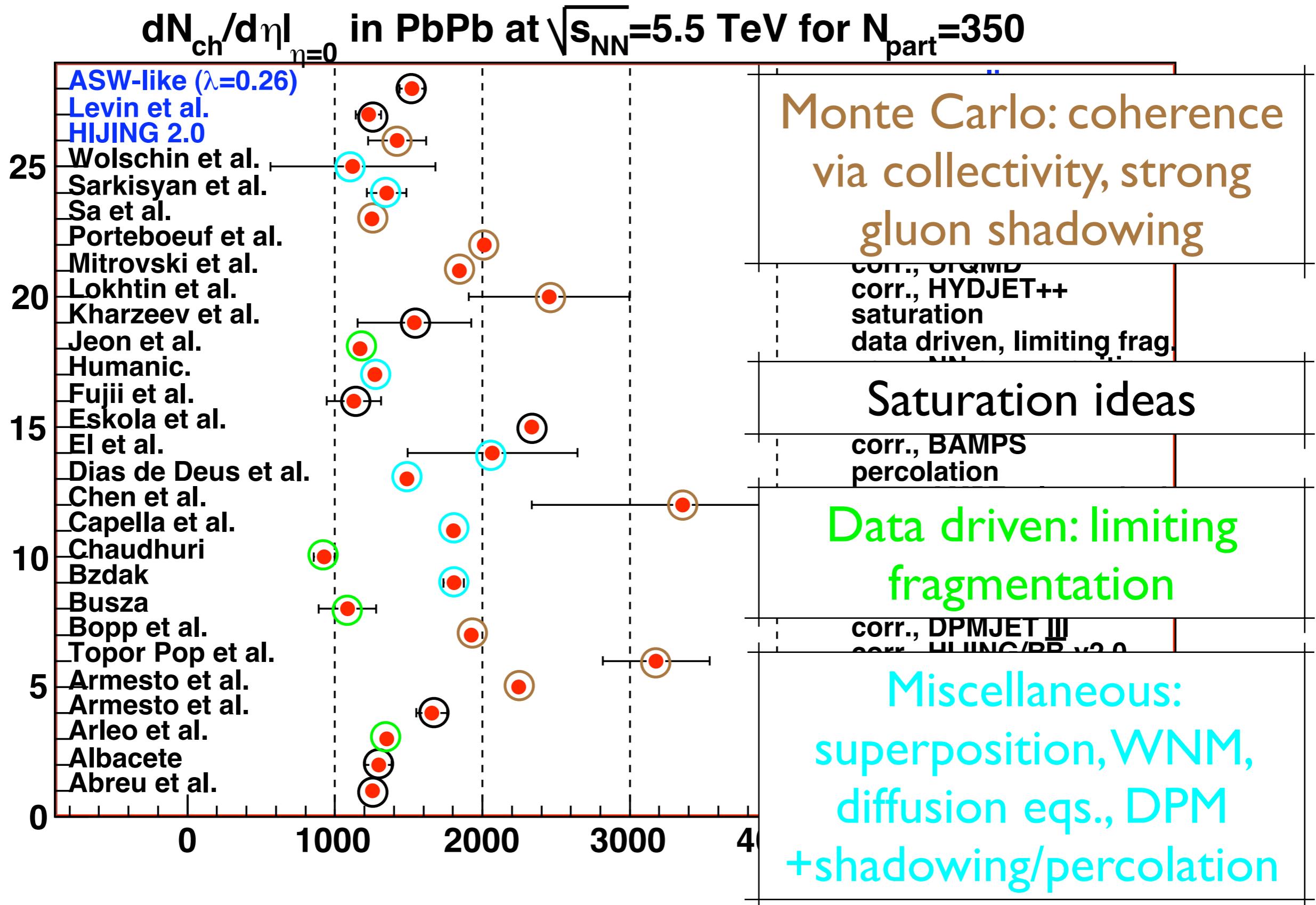
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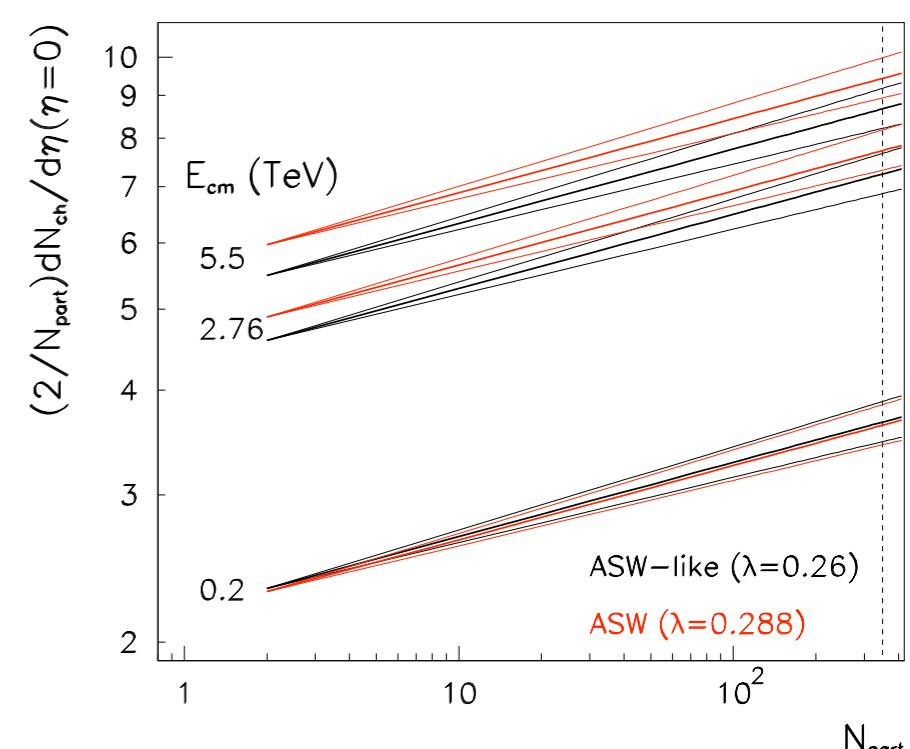
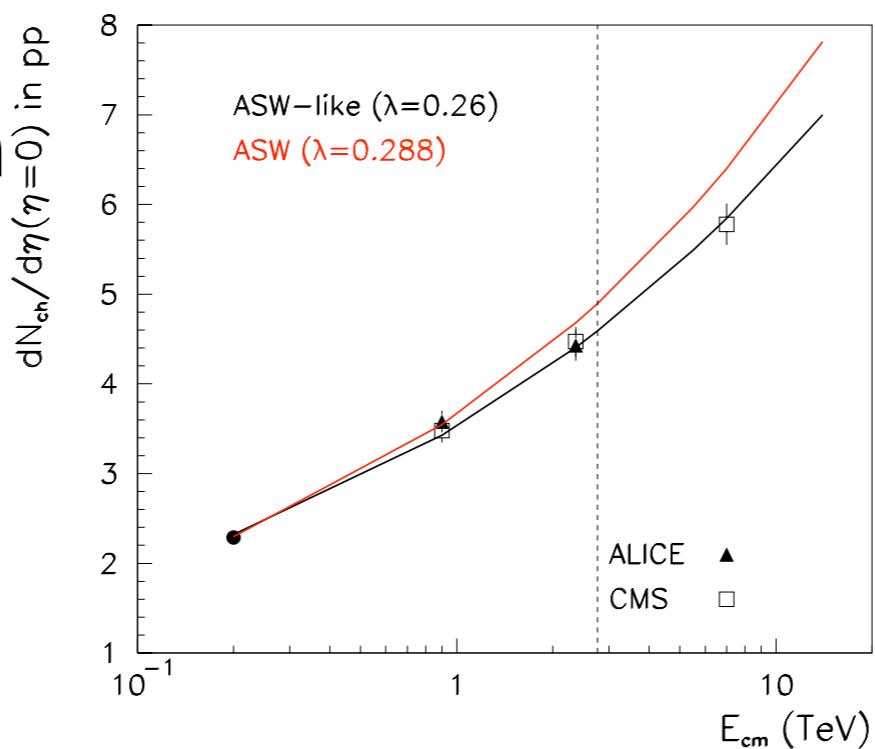
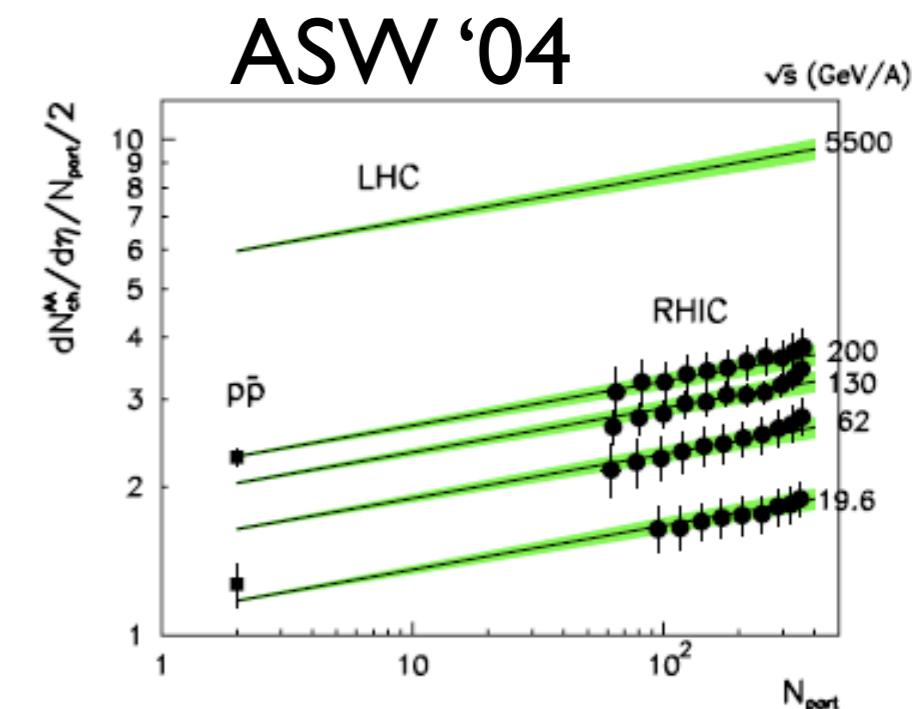
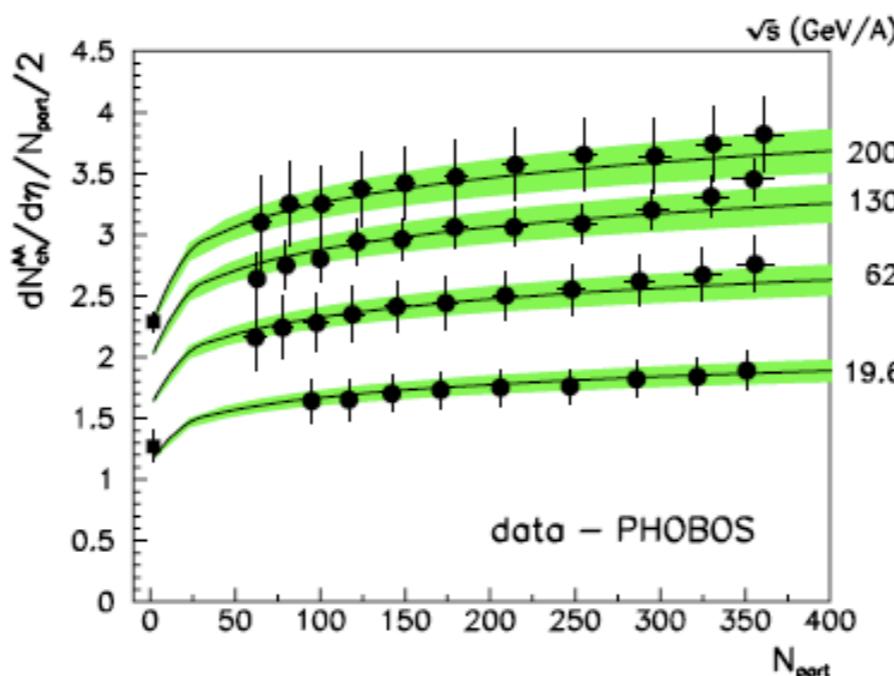


Rescaling in energy:

- Several attempts to fit $dN_{ch}^{PP}/d\eta|_{\eta=0}$: **power laws** $\propto E_{cm}^{\lambda}$

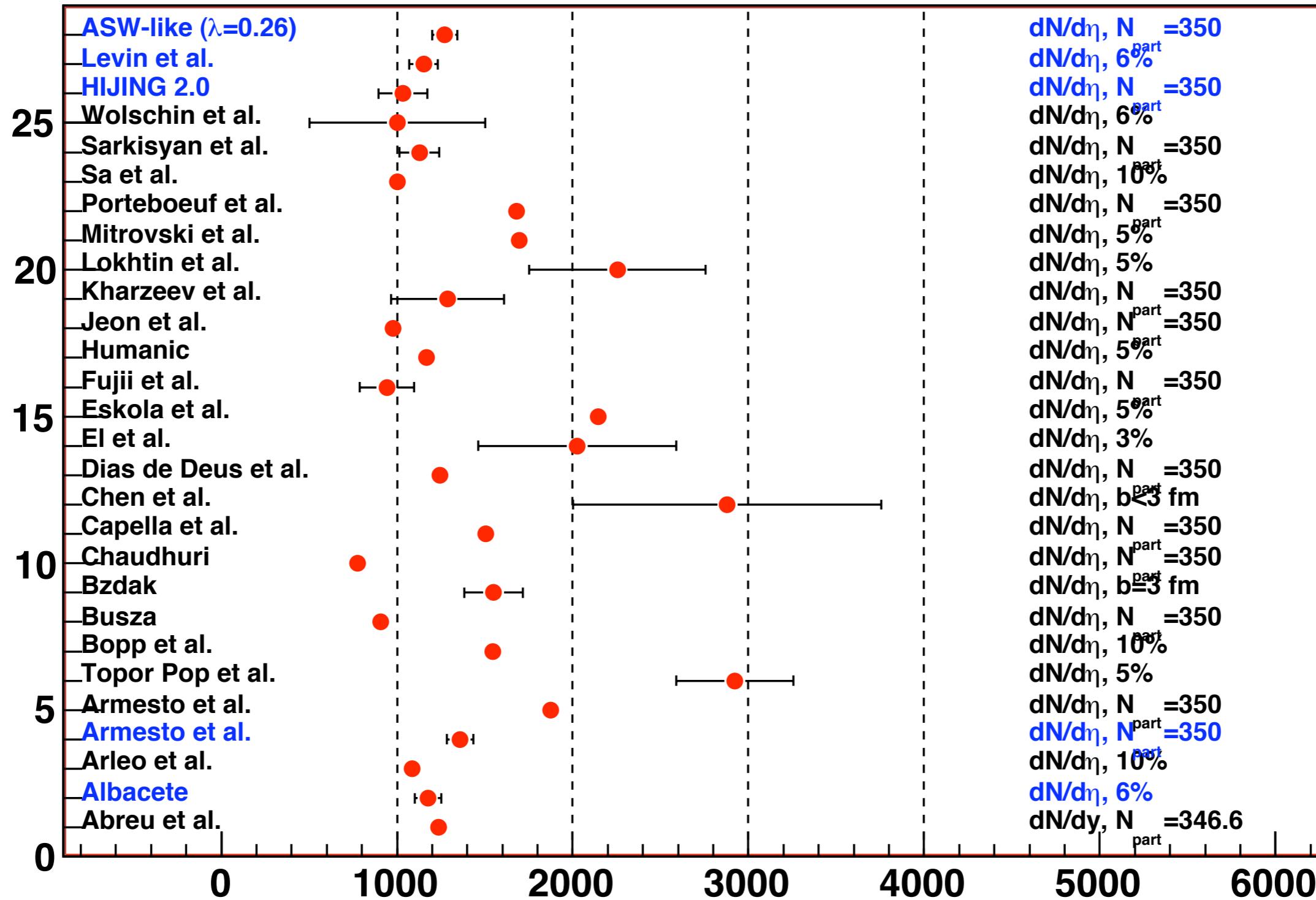
(McLerran et al. '10,
 $\lambda=0.23$; ASW,
 $\lambda=0.288$; Levin et al
'10).

- They give correction factors in the range $\lambda=0.80-0.85$. I use **0.835** and assume factorization of E - and N_{part} -dependencies.



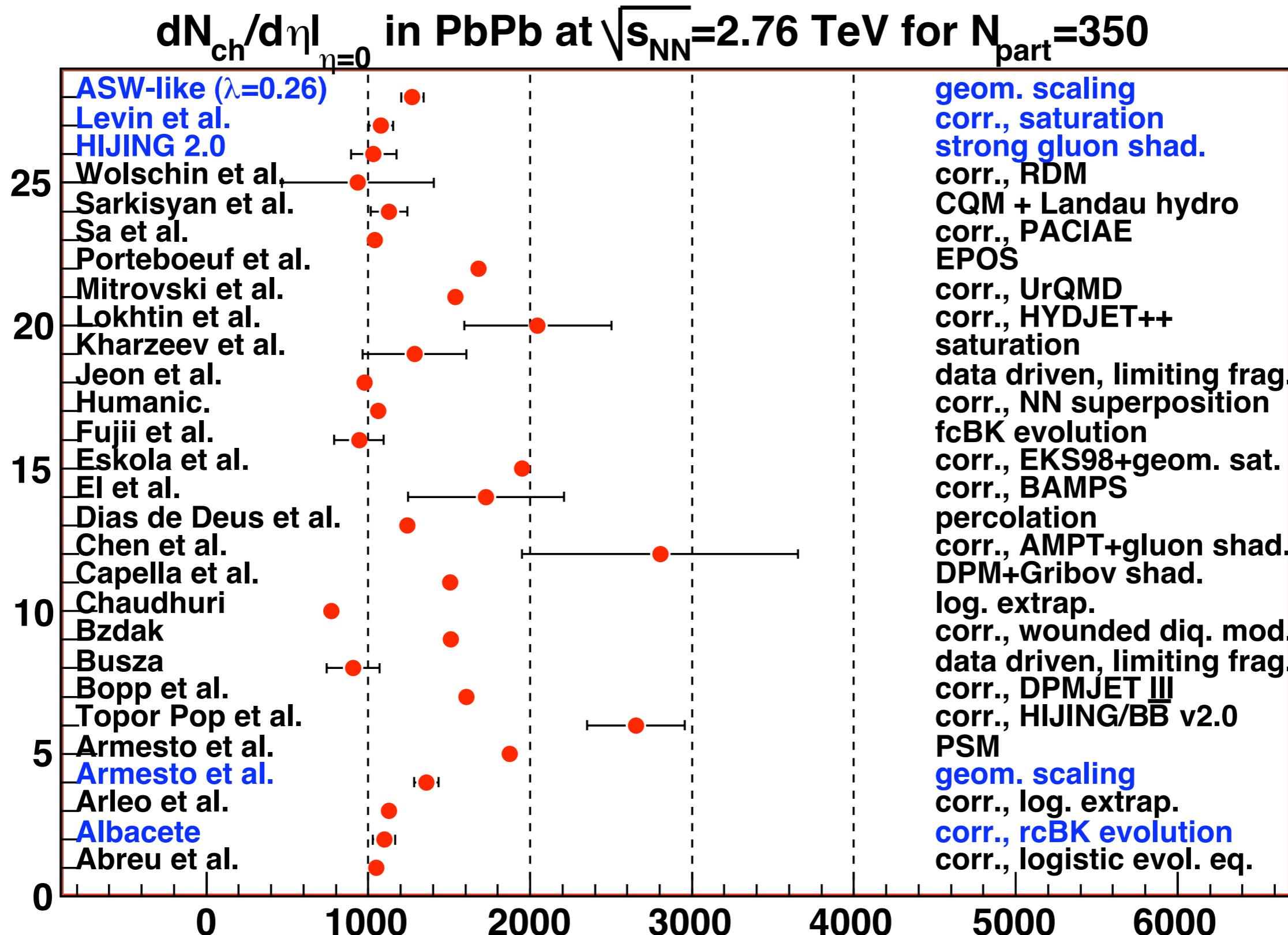
Rescaling in energy:

Charged multiplicity for $\eta=0$ in central PbPb at 2.76 TeV

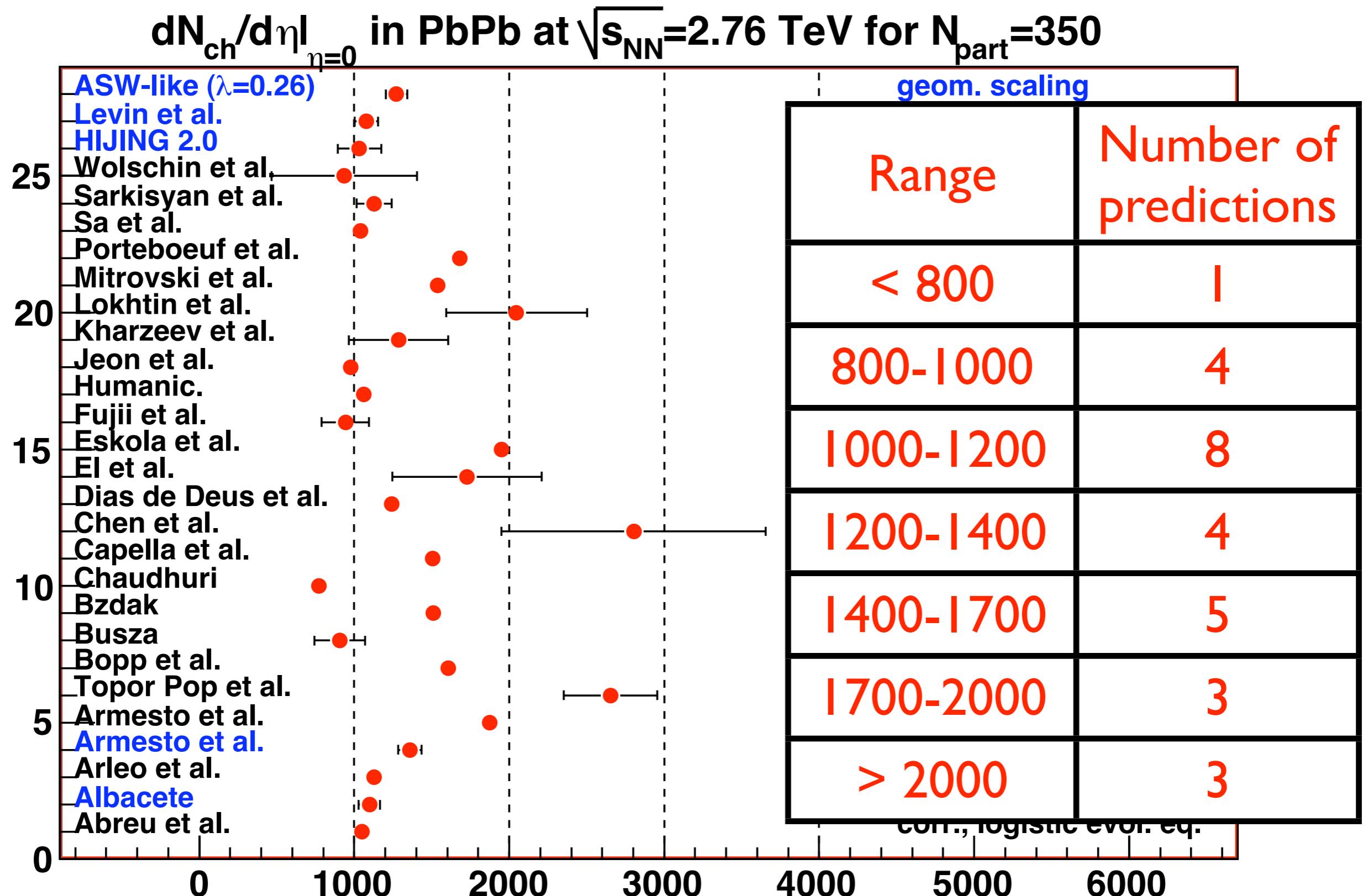


Blue: non-rescaled

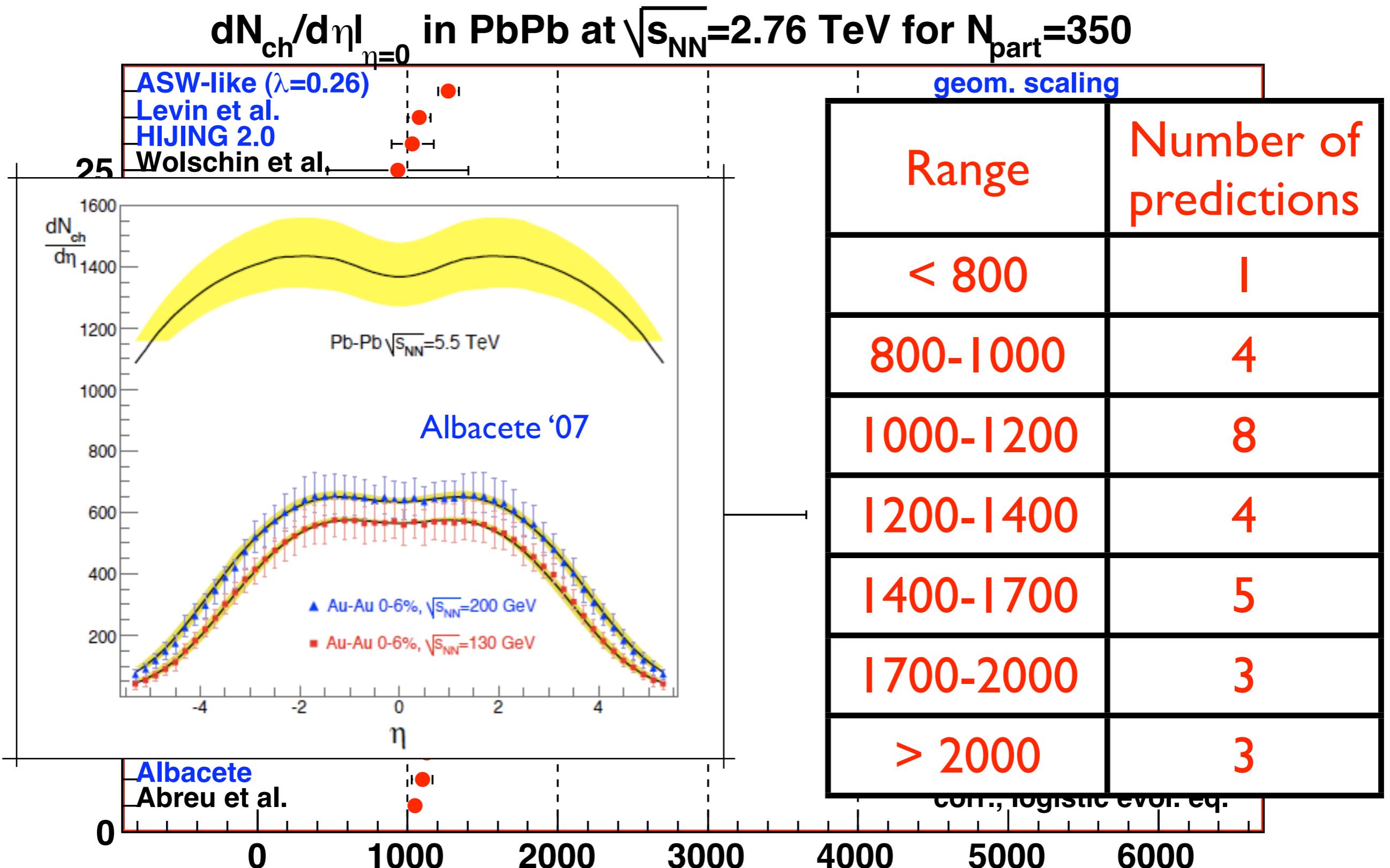
All in all:



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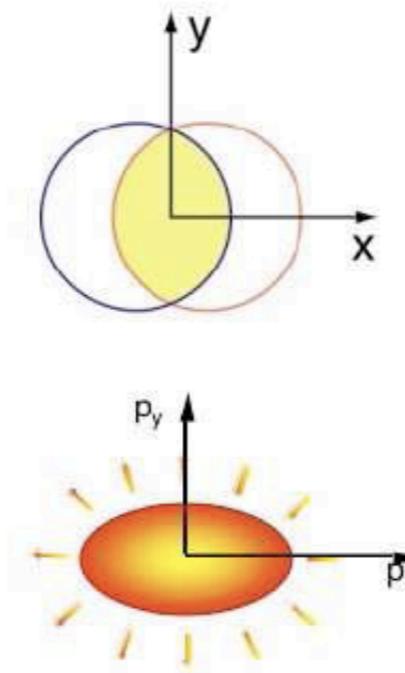
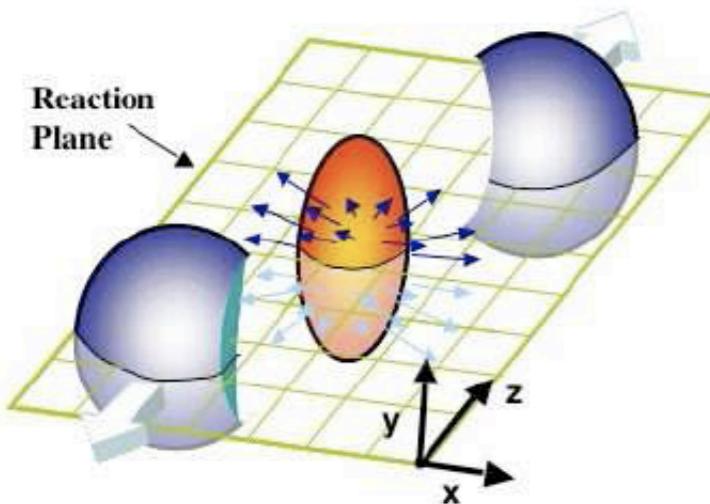
All in all:



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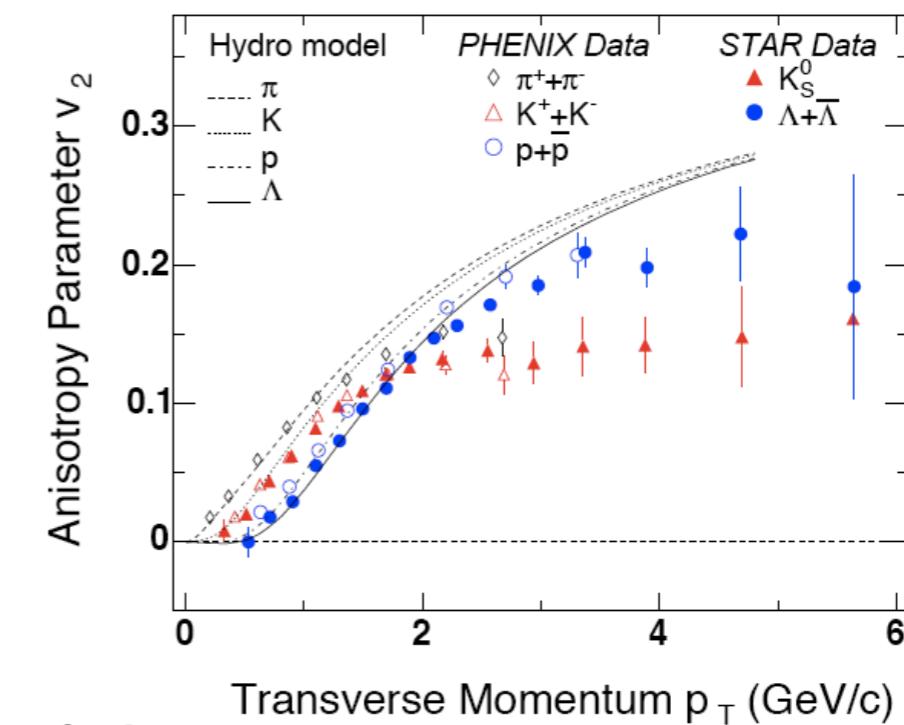
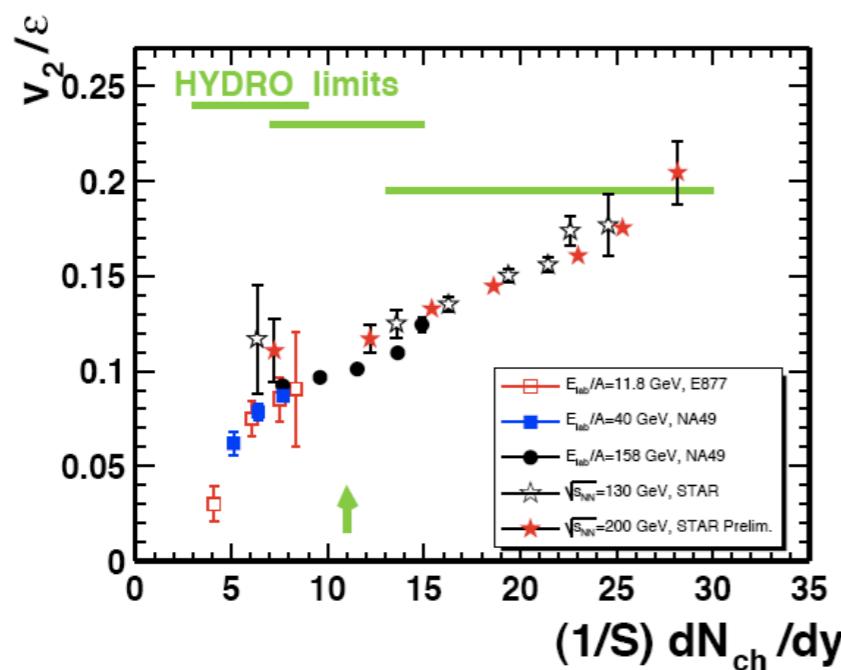


$$\frac{dN_k}{dy dp_T^2 d\phi} = \frac{dN_k}{dy dp_T^2} \frac{1}{2\pi} [1 + 2v_1 \cos(\phi - \phi_R) + 2v_2 \cos 2(\phi - \phi_R) + \dots]$$

$$v_2 = \langle \cos 2(\phi - \phi_R) \rangle = \left\langle \frac{p_x^2 - p_y^2}{p_T^2} \right\rangle$$

$$\epsilon_x = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$

- **v_2 , also called elliptic flow, is usually interpreted in terms of a final momentum anisotropy dictated by an initial space anisotropy.**



Relativistic hydrodynamics:

- **Ideal hydro**: plus an (lattice) EOS, initial conditions and a hadronization prescription.

$$u^\mu = \gamma(1, v_x, v_y, v_z)$$

$$T_{(0)}^{\mu\nu}(x) = (e(x) + p(x)) u^\mu(x) u^\nu(x) - p(x) g^{\mu\nu}$$

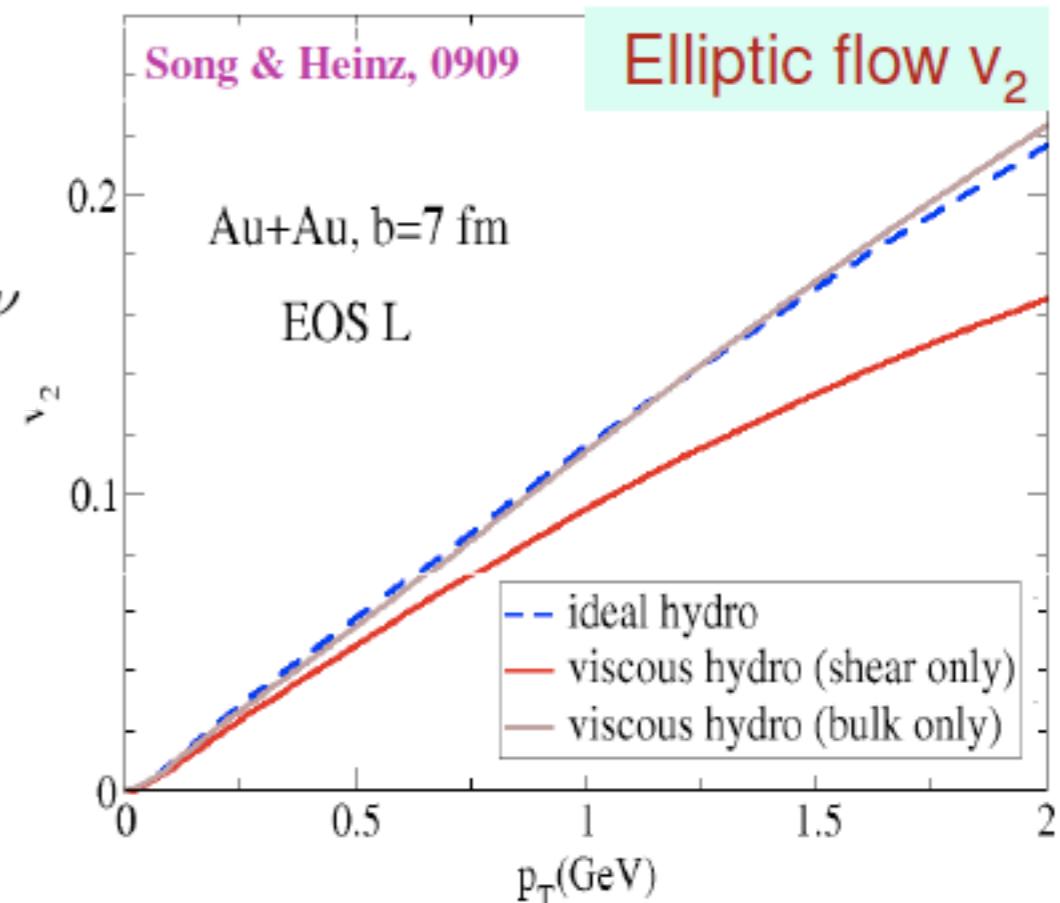
$$\partial_\mu T_{(0)}^{\mu\nu}(x) = 0, \quad (\nu = 0, \dots, 3)$$

$$\partial_\mu j_i^\mu(x) = 0, \quad i = 1, \dots, M$$

- **Non-ideal hydro**: dissipative (viscous) corrections.

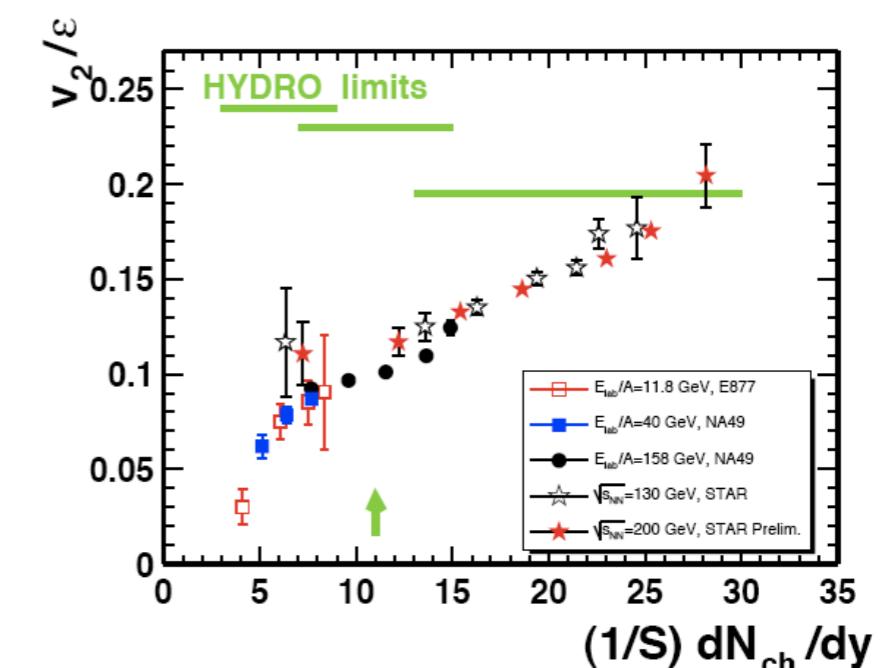
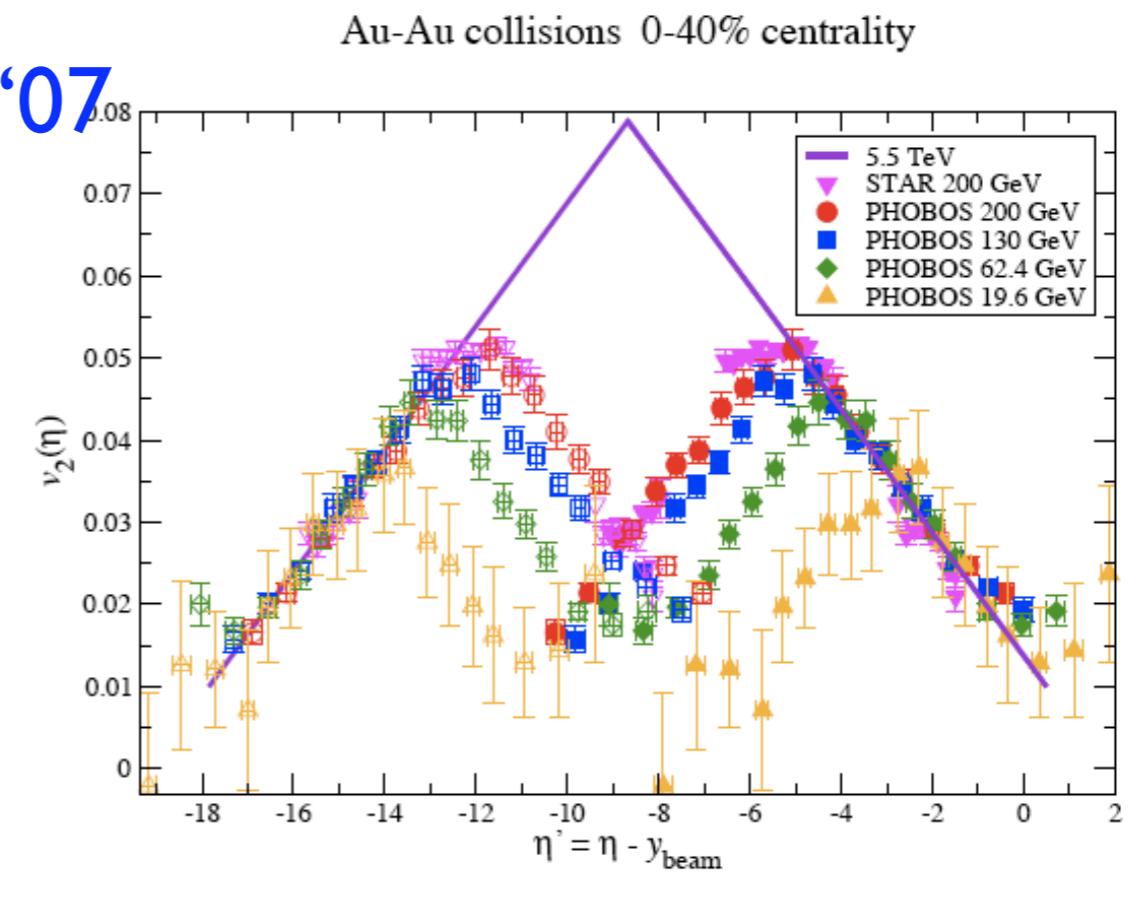
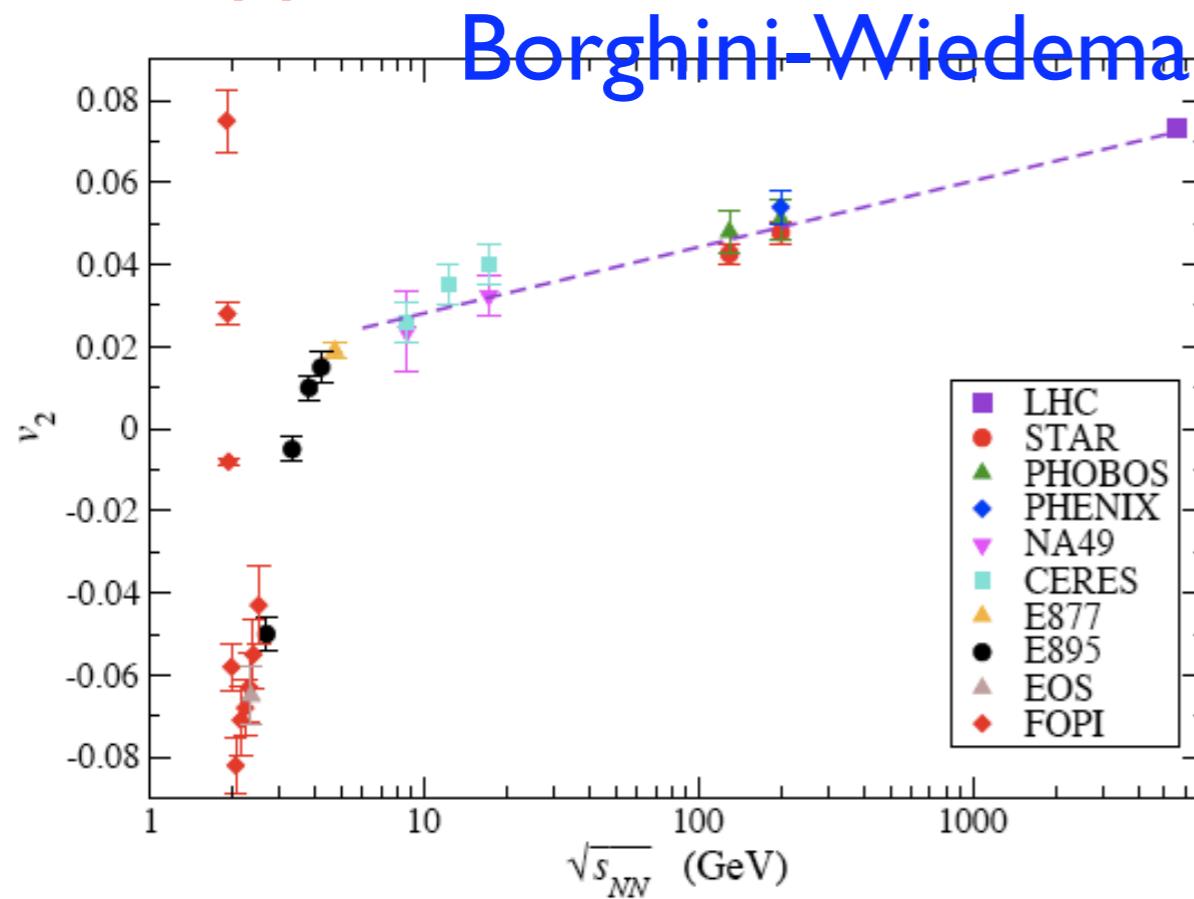
$$T^{\mu\nu} = T_{(0)}^{\mu\nu} + \Pi^{\mu\nu}$$

- $\Pi^{\mu\nu}$ introduces bulk viscosity plus gradients of u : 1st order (shear viscosity), 2nd order (5 constants for a CFT),...
- Bulk and shear viscosity decrease v_2 .
- Bulk (shear) viscosity \downarrow (\uparrow) with T for $T > T_{\text{crit}}$ (talk by Bluhm).



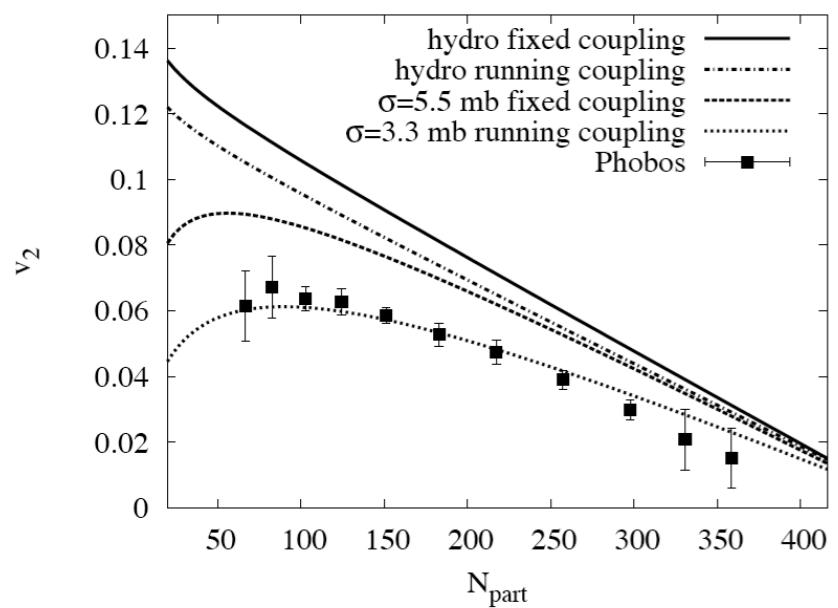
Data-driven expectations:

- p_T -integrated v_2 is expected to increase from RHIC to the LHC in all approaches.

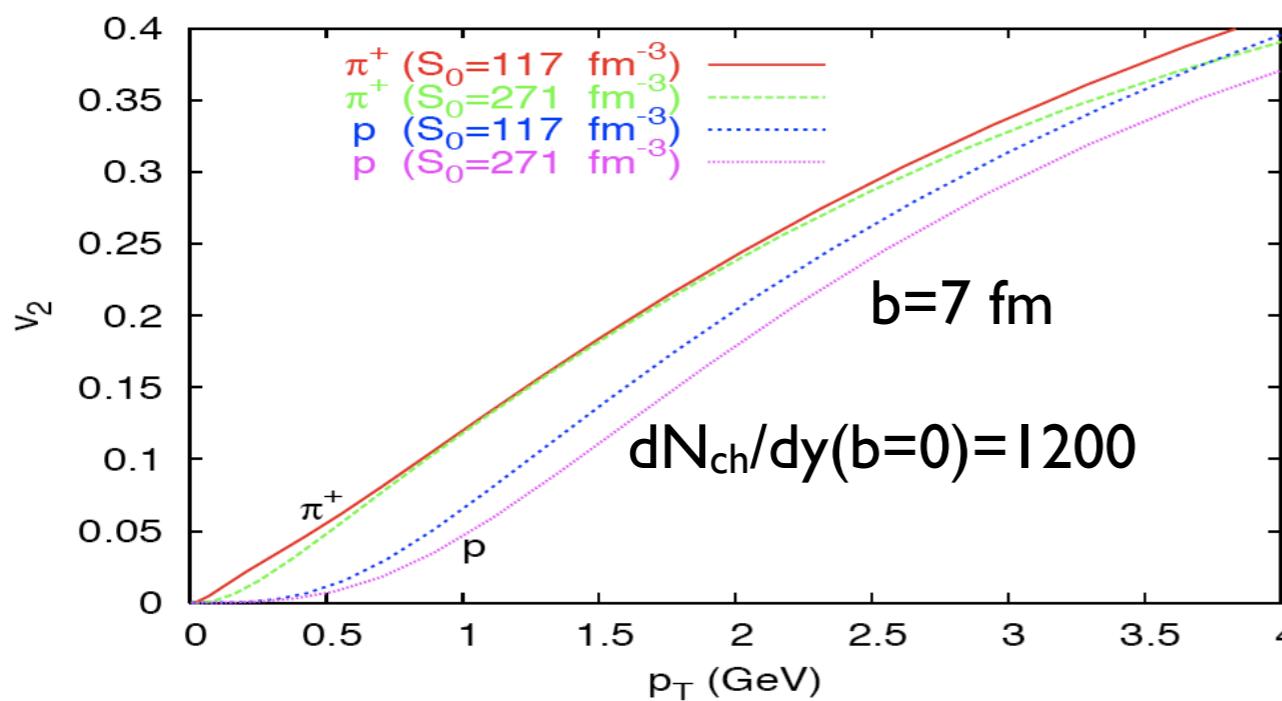


v₂ in hydro:

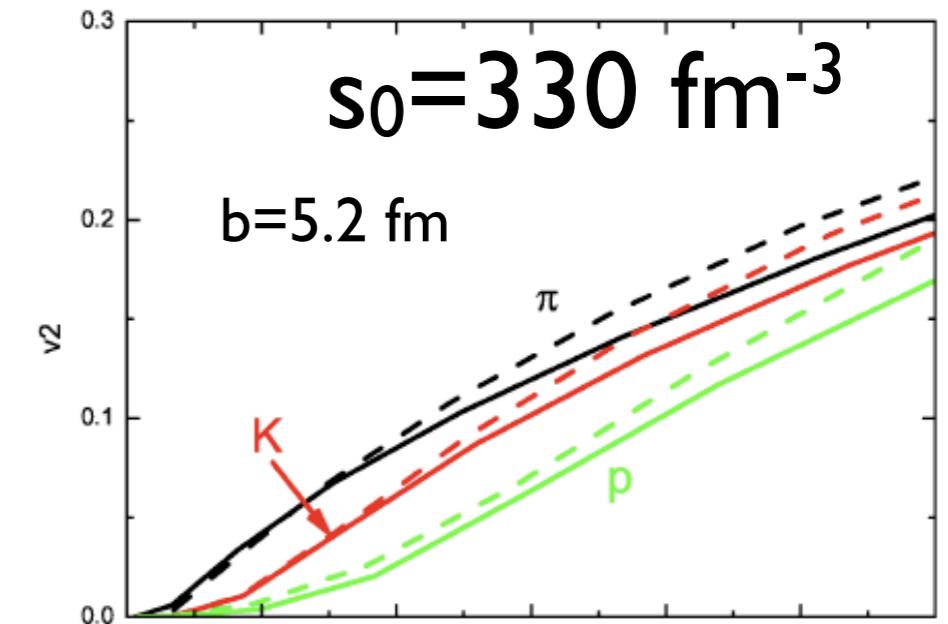
Drescher et al.,
 smaller
 deviation
 from **ideal** hydro
 limit than at
 RHIC.



$$v_2 \propto \frac{\epsilon_x}{1 + K/0.7}, \quad K^{-1} = \frac{\sigma}{S_{\text{over}}} \frac{dN_{\text{tot}}}{dy} \frac{1}{\sqrt{3}}$$

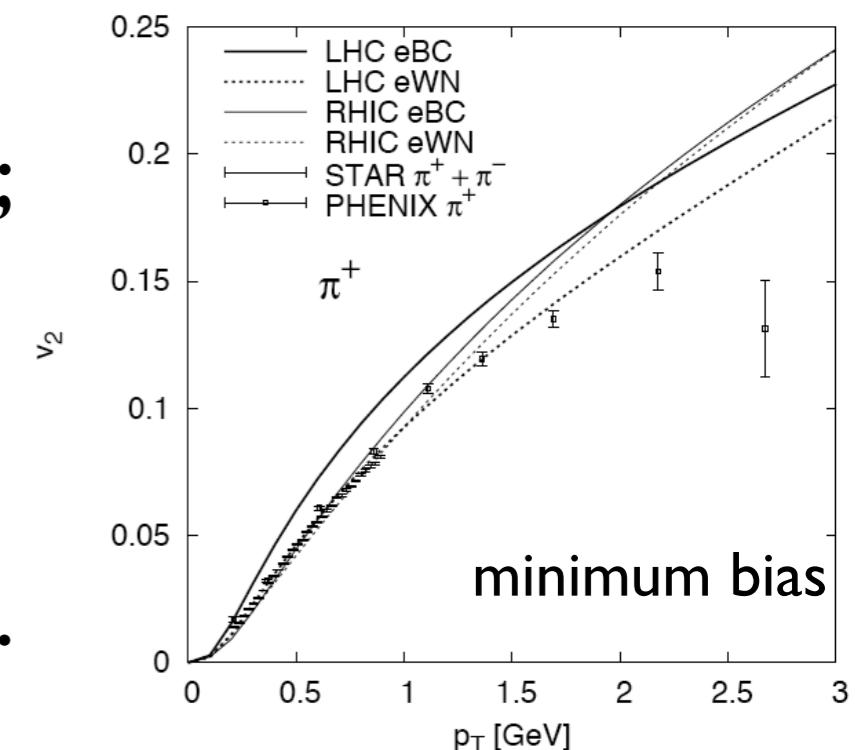


Kestin et al.



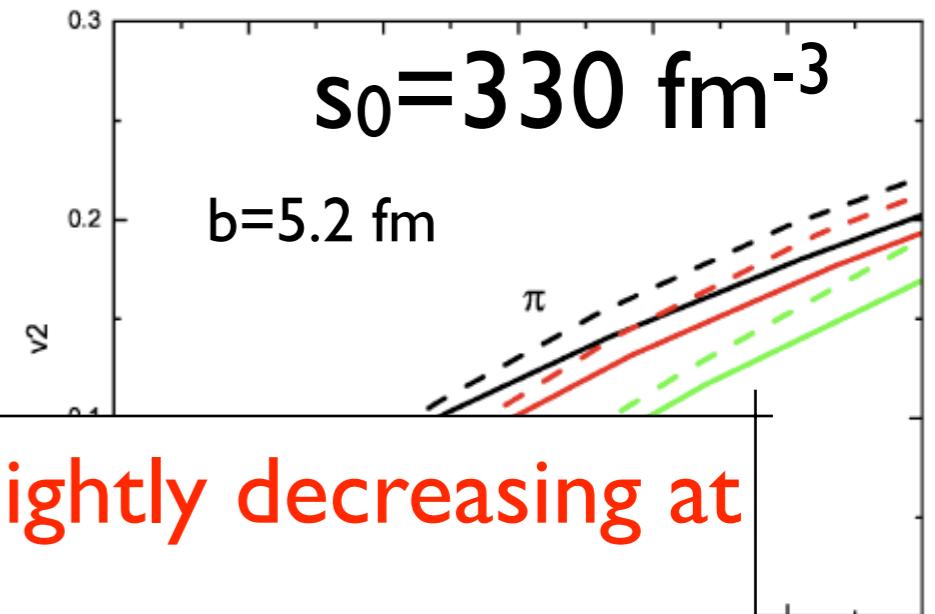
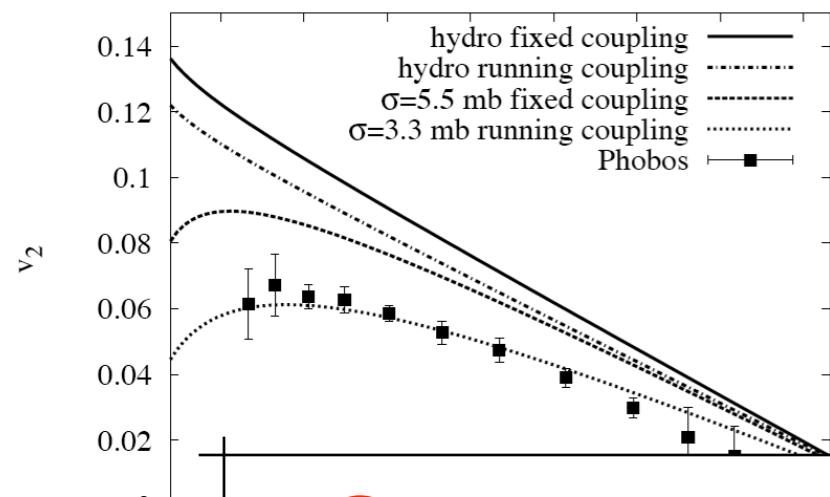
Bluhm et al., QPM EOS,
 results < RHIC at low pT.

Eskola et al.;
 hydro valid
 for $p_T < 4$
 GeV (also
 Arleo et al.).

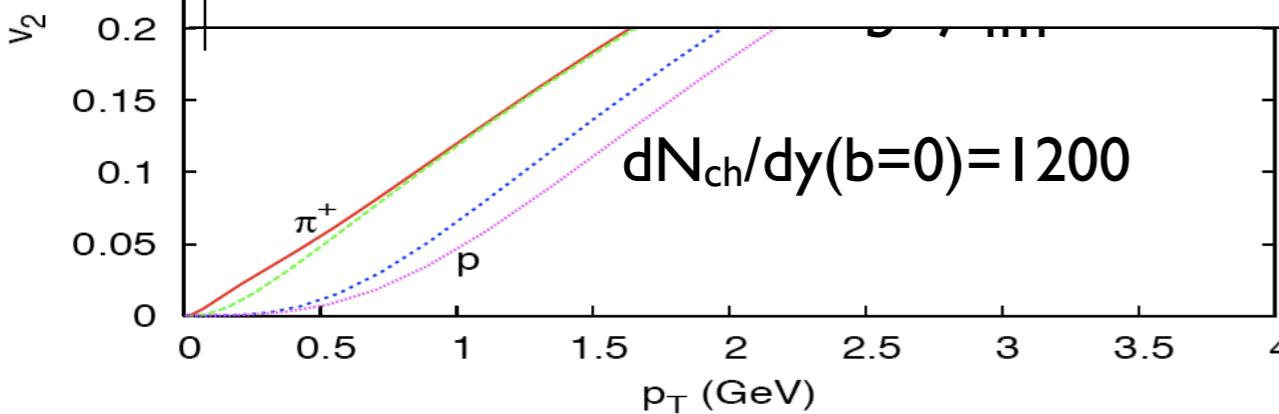


v_2 in hydro:

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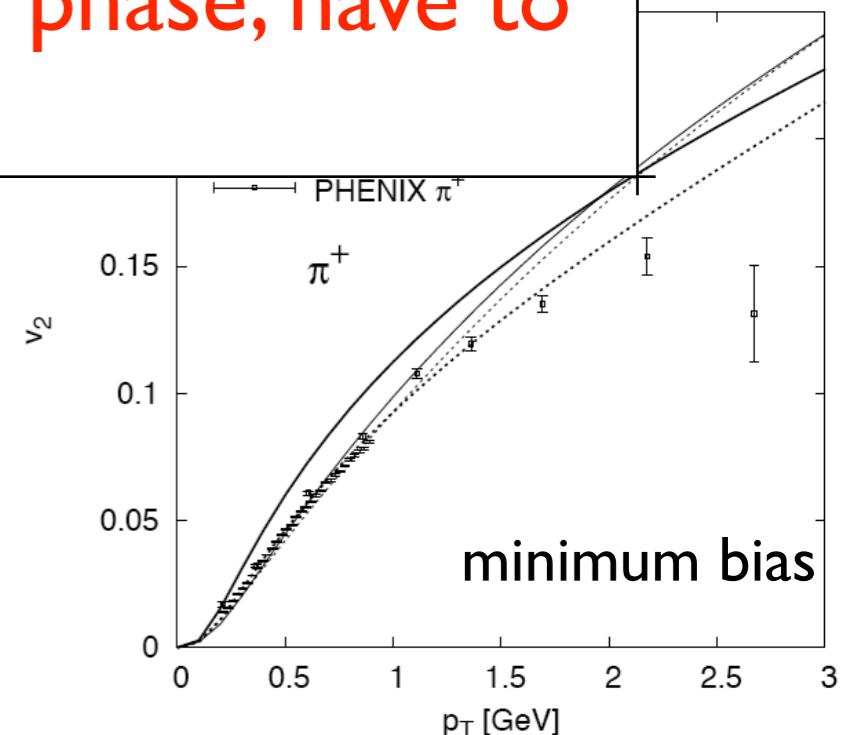


- Generic expectation: v_2 similar or slightly decreasing at low p_T .
- A strong decrease would probably signal an increase in η/s , but initial conditions, fluctuations (EoS), EOS and the role of bulk viscosity and of the hadronic phase, have to be settled.

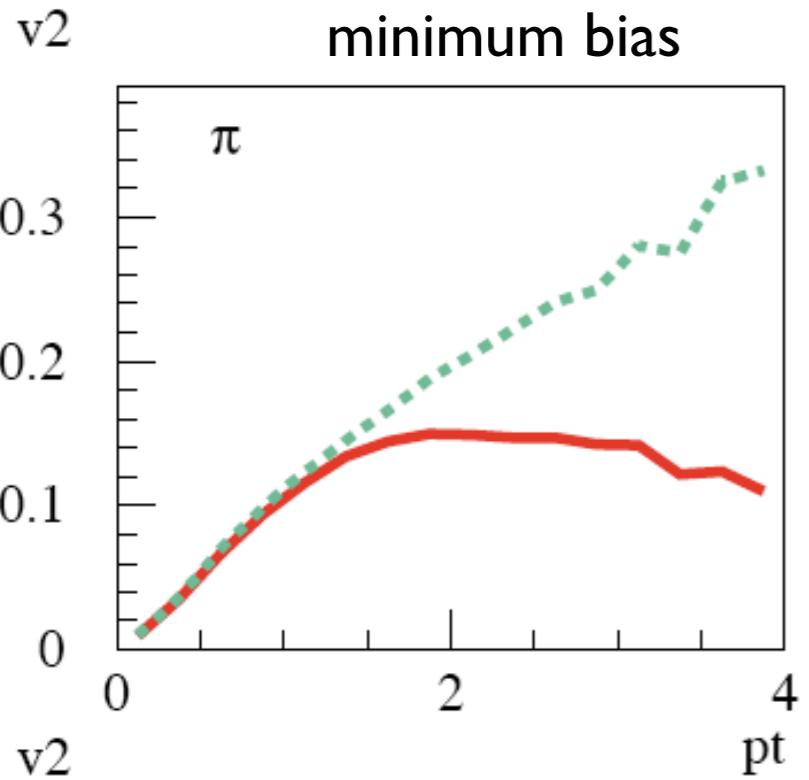


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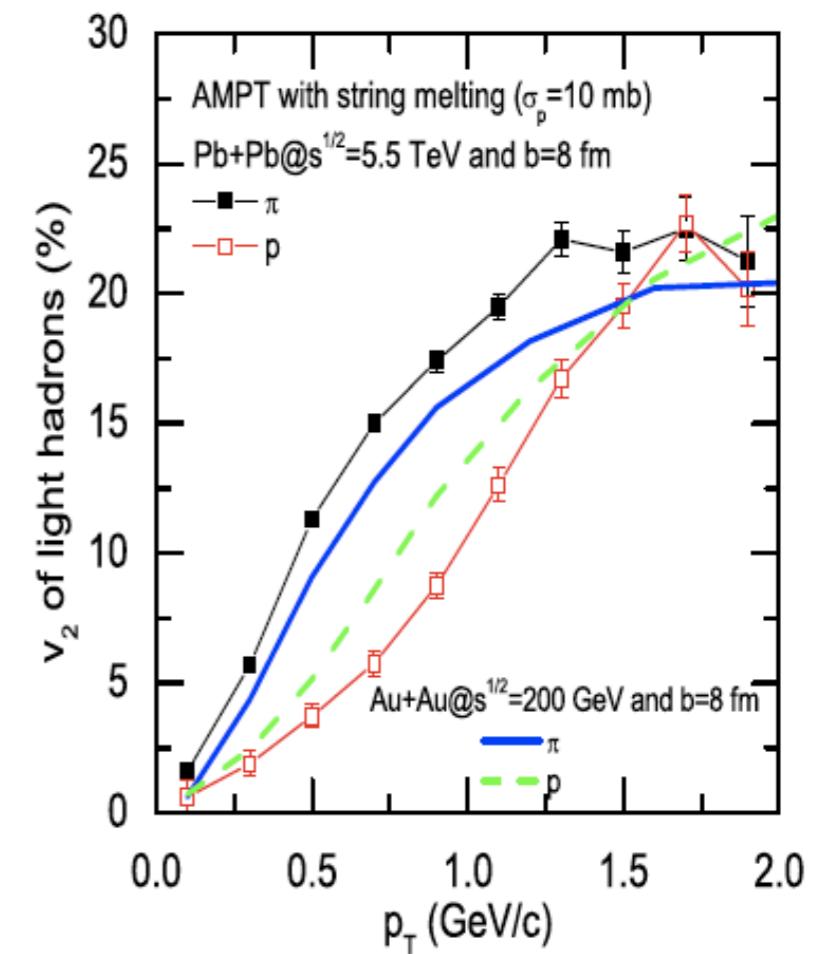


v₂ in others:

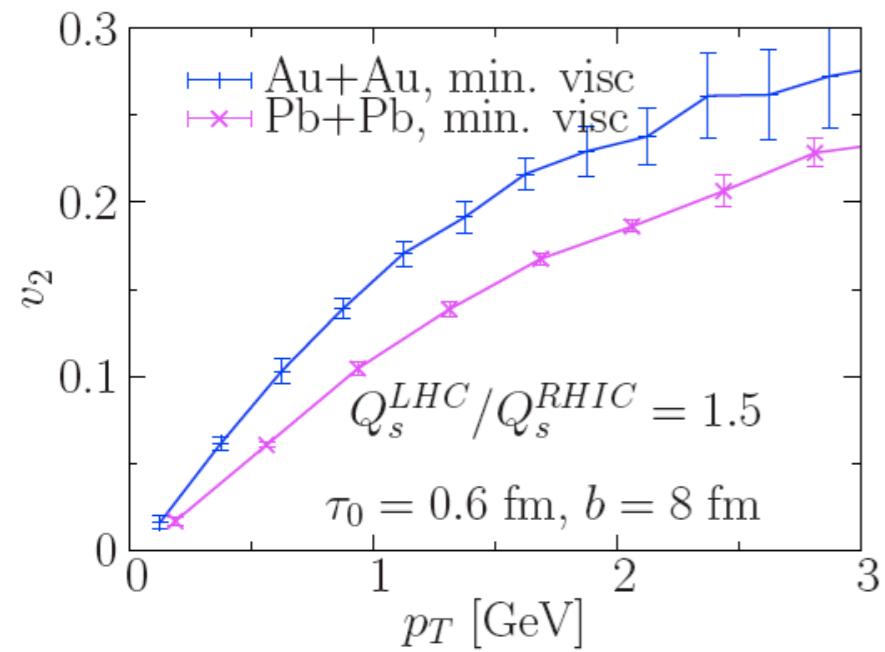


Porteboeuf
et al.,
EPOS,
hydro
core,
 $v_2 \sim \text{RHIC}$.

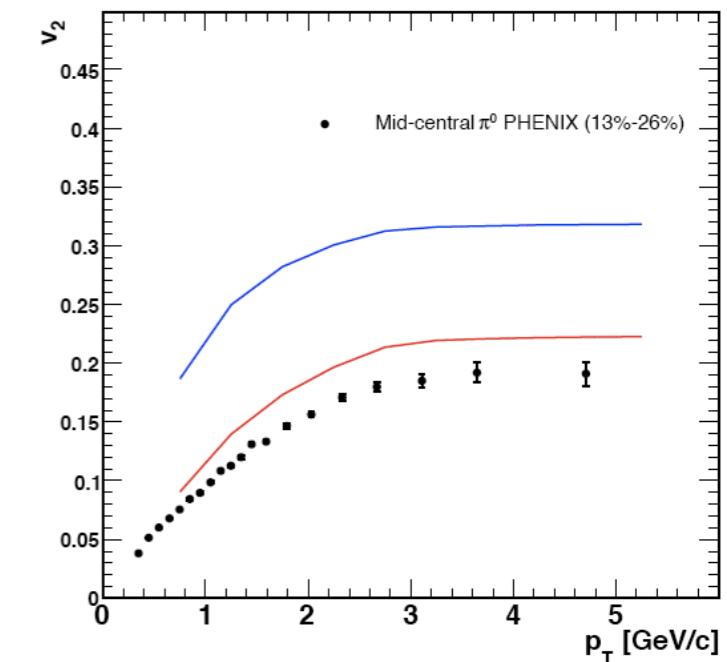
Chen et al.,
AMPT,
parton +
hadron
transport.



- Generic expectation: v₂ at low p_T higher than at RHIC.



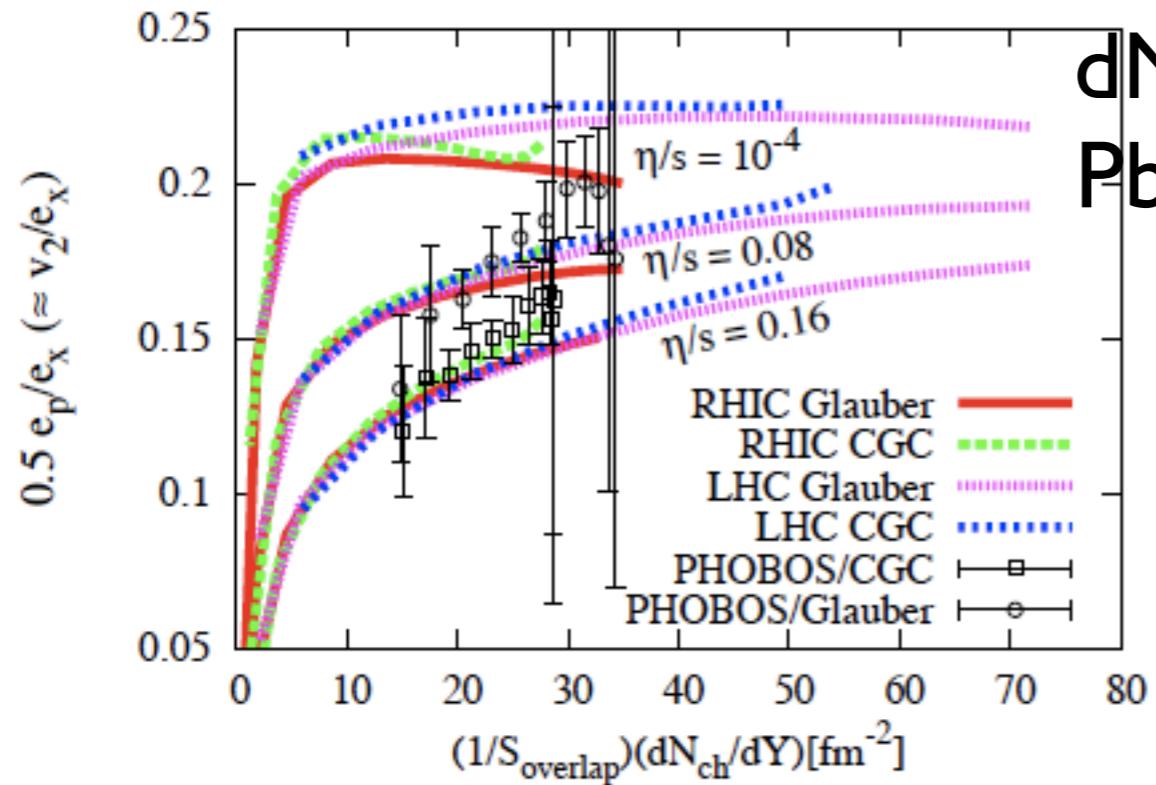
Molnar, MPC
parton cascade,
fixed $\eta/s=0.08$.



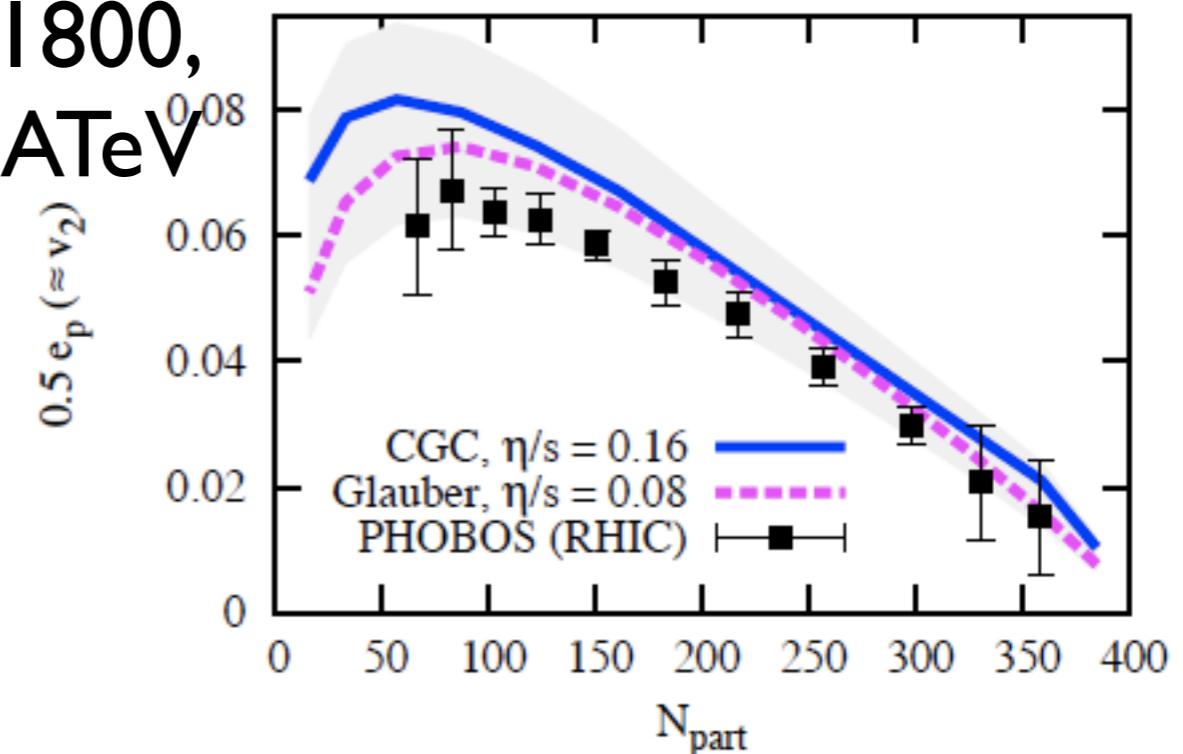
Capella et al., comovers.

Recent predictions:

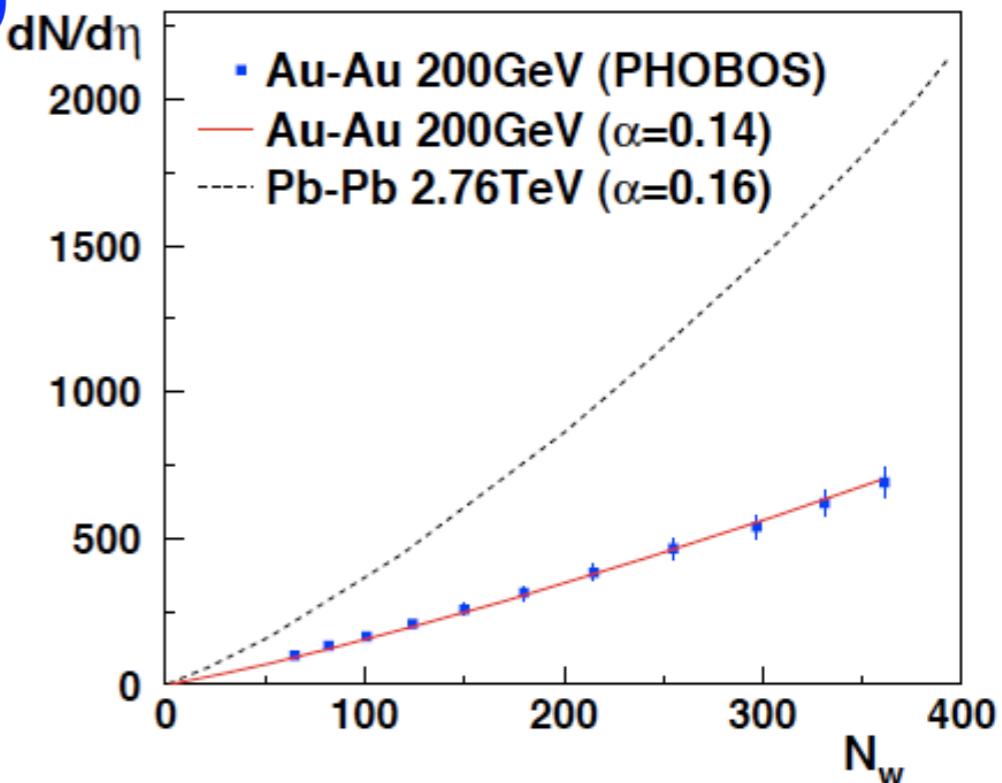
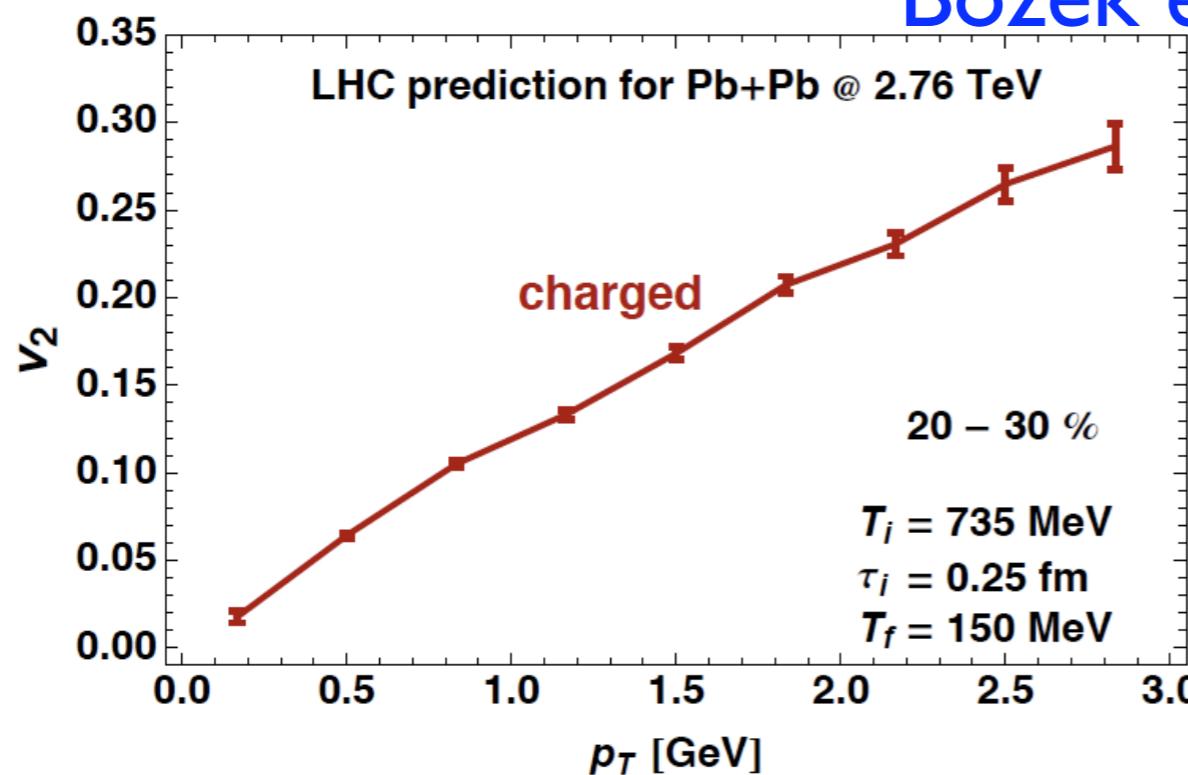
Luzum et al. '09,



$dN_{\text{ch}}/dy=1800$,
PbPb, 5.5 ATeV



Bozek et al. '10

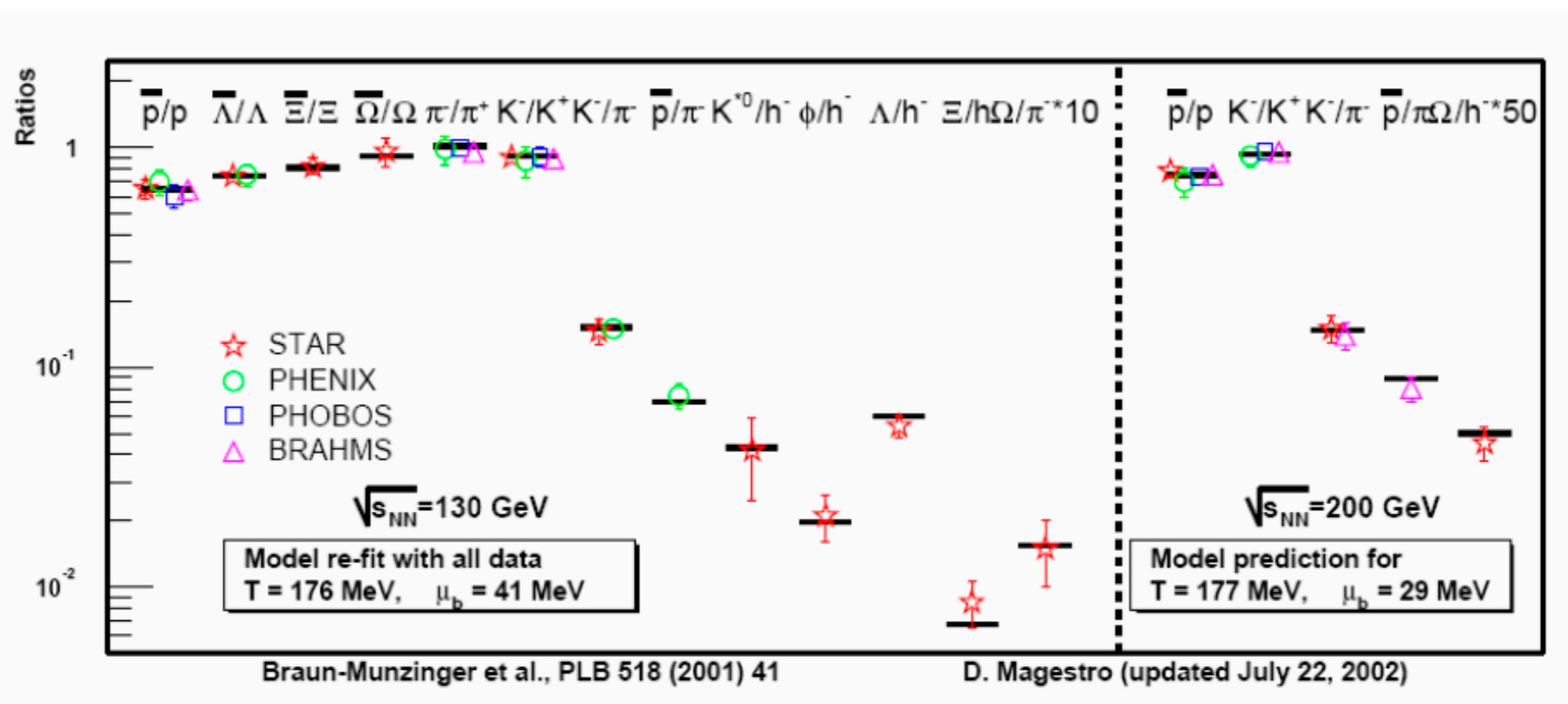


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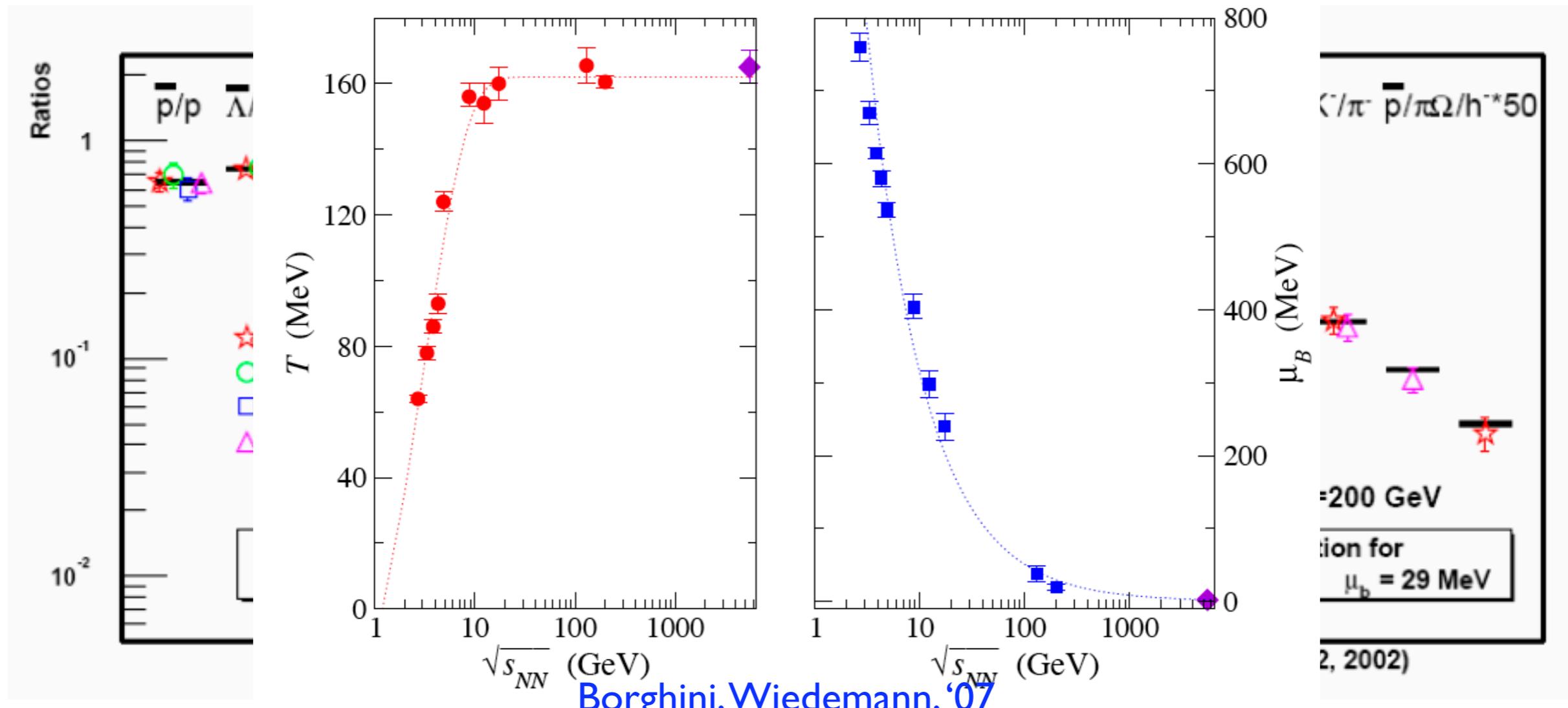
Introduction:

- Within the **grand-canonical ensemble**, equilibrium hadron/parton densities can be computed: T, μ, V (γ_s to include chemical non-equilibrium effects).
- The statistical model gives an good description of particle ratios in AB, with $T \sim T_c$ (and $\gamma_s \sim 1$ at RHIC): hint of partonic equilibrium.



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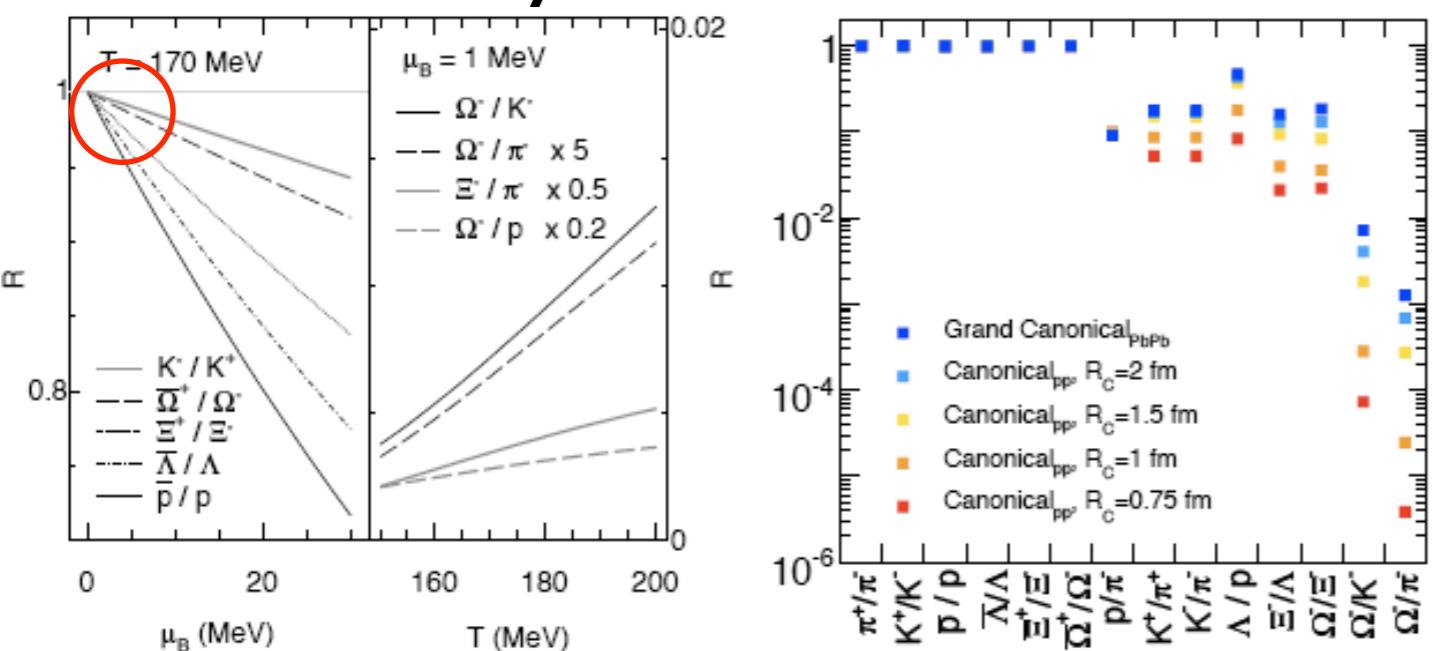
Predictions for 5.5 ATeV:

π^-/π^+	K^-/K^+	\bar{p}/p	$\bar{\Lambda}/\Lambda$	$\bar{\Xi}/\Xi$	$\bar{\Omega}/\Omega$
1.001(0)	0.993(4)	$0.948^{-0.013}_{+0.008}$	$0.997^{-0.011}_{+0.004}$	$1.005^{-0.007}_{+0.001}$	1.013(4)

Andronic et al., equilibrium values for
 $\mu_b=0.8 \text{ MeV}, T=161 \text{ MeV}$.

Note: ALICE $p_{\bar{b}}/p = 0.966 \pm 0.014 \pm 0.013$
 $(0.999 \pm 0.006 \pm 0.013)$ in pp at 0.9(7) TeV.

Kraus et al., (grand-)canonical, T and
 R_c may be determined.



	140*	140*	162*
$dV/dy [\text{fm}^3]$	2036	4187	6200*
dS/dy	7517	15262	18021
dh_{ch}/dy	1150*	2351	2430
$dh_{\text{ch}}^{\text{vis}}/dy$	1351	2797*	2797
$1000 \cdot (\lambda_{q,s} - 1)$	5.6*, 2.1	5.6*, 2.1	5.6*, 2.0
$\mu_{B,S} [\text{MeV}]$	2.4, 0.5	2.3, 0.5	2.7, 0.6
$\gamma_{q,s}$	1.62, 2.42	1.6*, 2.6	1*, 1*
s/S	0.034*	0.037*	0.025
E/b	420*	428	408
E/TS	1.02	1.05	0.86
P/E	0.165	0.164	0.162
$E/V [\text{MeV/fm}^3]$	530	538	400
$P [\text{MeV}]$	87	88	65
p	25/45	49/95	66/104
$b - \bar{b}$	2.6	5.3	6.1
$(b + \bar{b})/h^-$	0.335	0.345	0.363
$0.1 \cdot \pi^\pm$	49/67	99/126	103/126
K^\pm	94	207	175
ϕ	14	33	23
Λ	19/28	41/62	37/50
Ξ^-	4	9.5	5.8
Ω^-	0.82	2.08	0.98

Rafelski et al., non-equilibrium scenarios; non-strange resonances reduced.

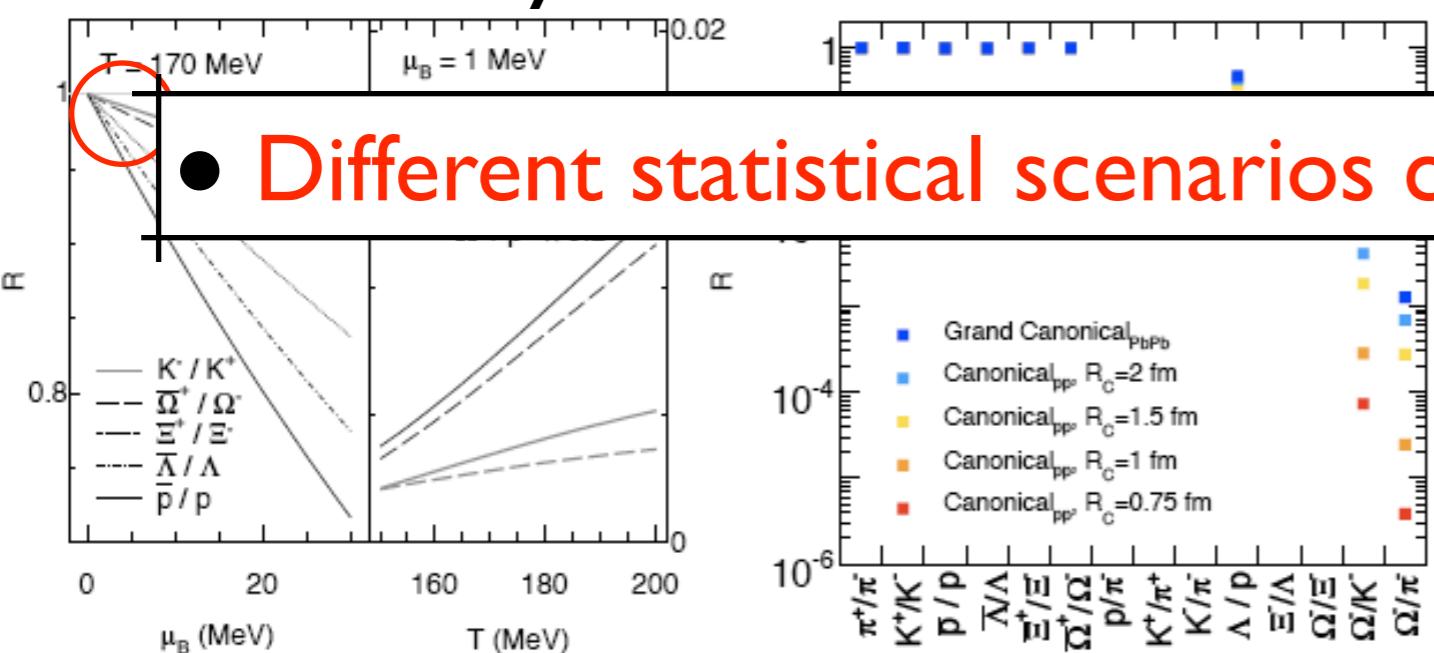
Predictions for 5.5 ATeV:

π^-/π^+	K^-/K^+	\bar{p}/p	$\bar{\Lambda}/\Lambda$	$\bar{\Xi}/\Xi$	$\bar{\Omega}/\Omega$
1.001(0)	0.993(4)	0.948 $^{-0.013}_{+0.008}$	0.997 $^{-0.011}_{+0.004}$	1.005 $^{-0.007}_{+0.001}$	1.013(4)

Andronic et al., equilibrium values for $\mu_b=0.8 \text{ MeV}, T=161 \text{ MeV}$.

Note: ALICE $p_{\bar{b}}/p = 0.966 \pm 0.014 \pm 0.013$ ($0.999 \pm 0.006 \pm 0.013$) in pp at 0.9(7) TeV.

Kraus et al., (grand-)canonical, T and R_c may be determined.

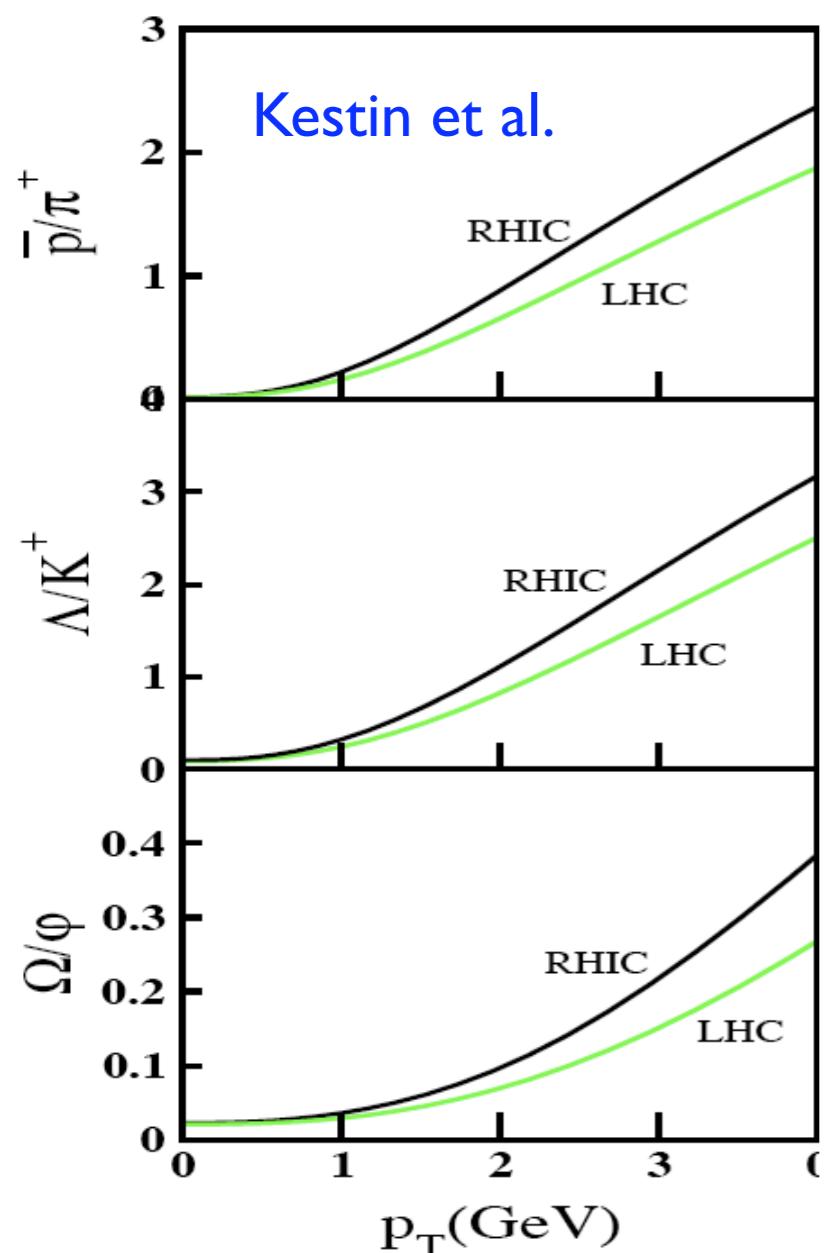


$T[\text{MeV}]$	140*	140*	162*
$dV/dy [\text{fm}^3]$	2036	4187	6200*
dS/dy	7517	15262	18021
dh_{ch}/dy	1150*	2351	2430
$dh_{\text{ch}}^{\text{vis}}/dy$	1351	2797*	2797
$1000 \cdot (\lambda_{q,s} - 1)$	5.6*, 2.1	5.6*, 2.1	5.6*, 2.0
$\mu_{B,S}[\text{MeV}]$	2.4, 0.5	2.3, 0.5	2.7, 0.6
$\gamma_{q,s}$	1.62, 2.42	1.6*, 2.6	1*, 1*
s/S	0.034*	0.037*	0.025
E/b	420*	428	408
E/TS	1.02	1.05	0.86
P/E	0.165	0.164	0.162
$E/V[\text{MeV/fm}^3]$	530	538	400
$P[\text{MeV}]$	87	88	65
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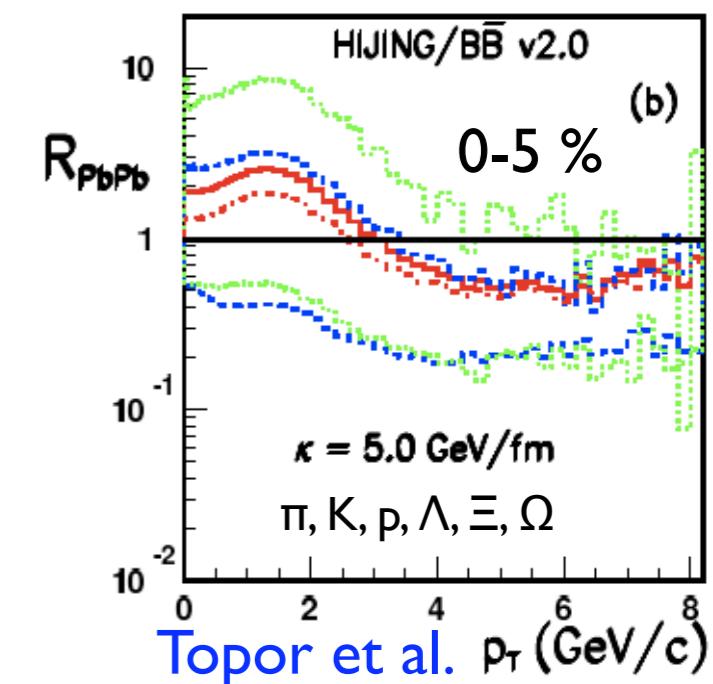
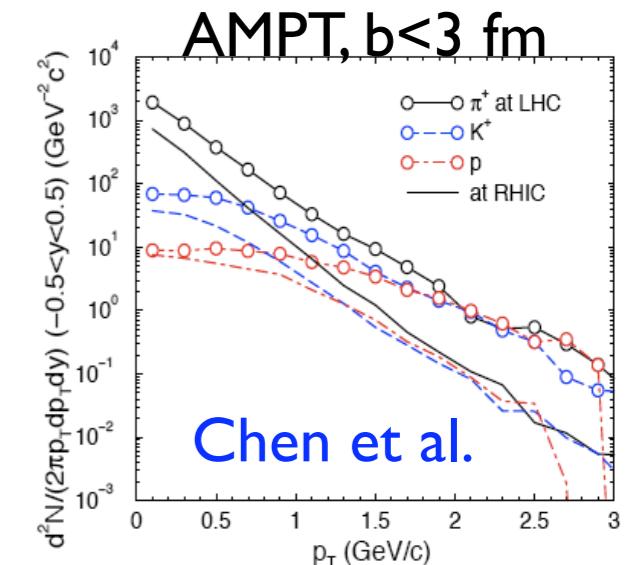
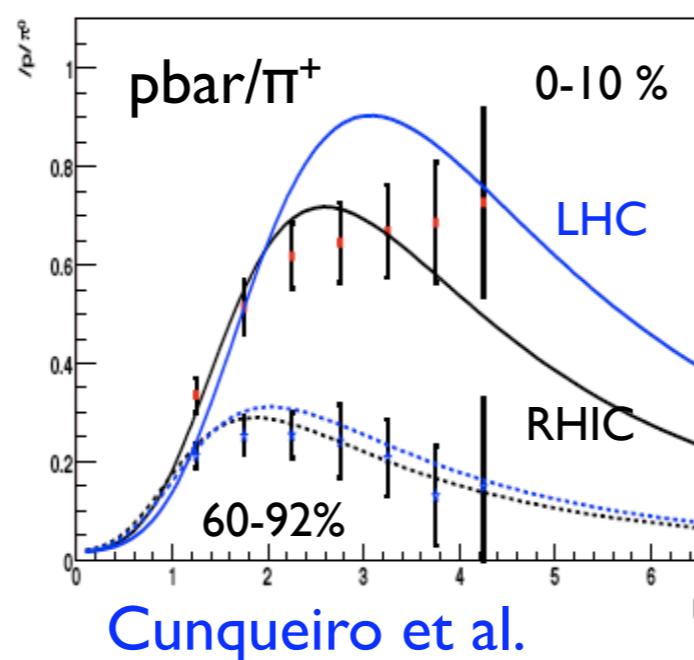
Rafelski et al., non-equilibrium scenarios; non-strange resonances reduced.

Baryons at low p_T :

- $p-pbar < 4$ at $\eta=0$ (BJ: Topor Pop et al., Bopp et al.; hydro: Eskola et al.; EPOS: Porteboeuf et al., RDM: Wolschin et al.).



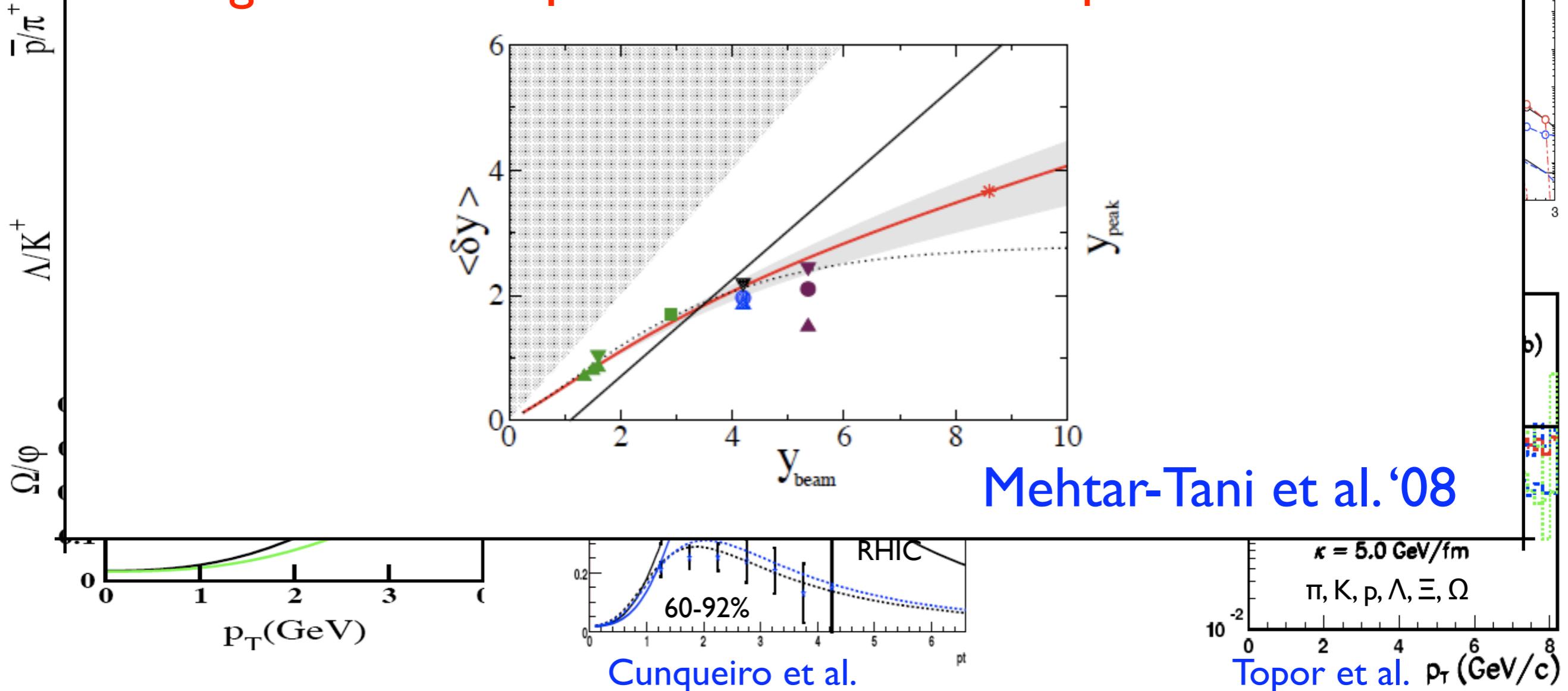
Hydro and recombination predict larger baryon/meson ratios than models with higher string tension; the latter predicts Cronin for protons.



Baryons at low p_T :

- $p_T + p_{T\bar{}} < 4$ at $\eta = 0$ (BJ: Topor Pop et al., Bopp et al.; hydro: Eskola et al.; EPOS: Porteboeuf et al. RDM: Wolschin et al.)

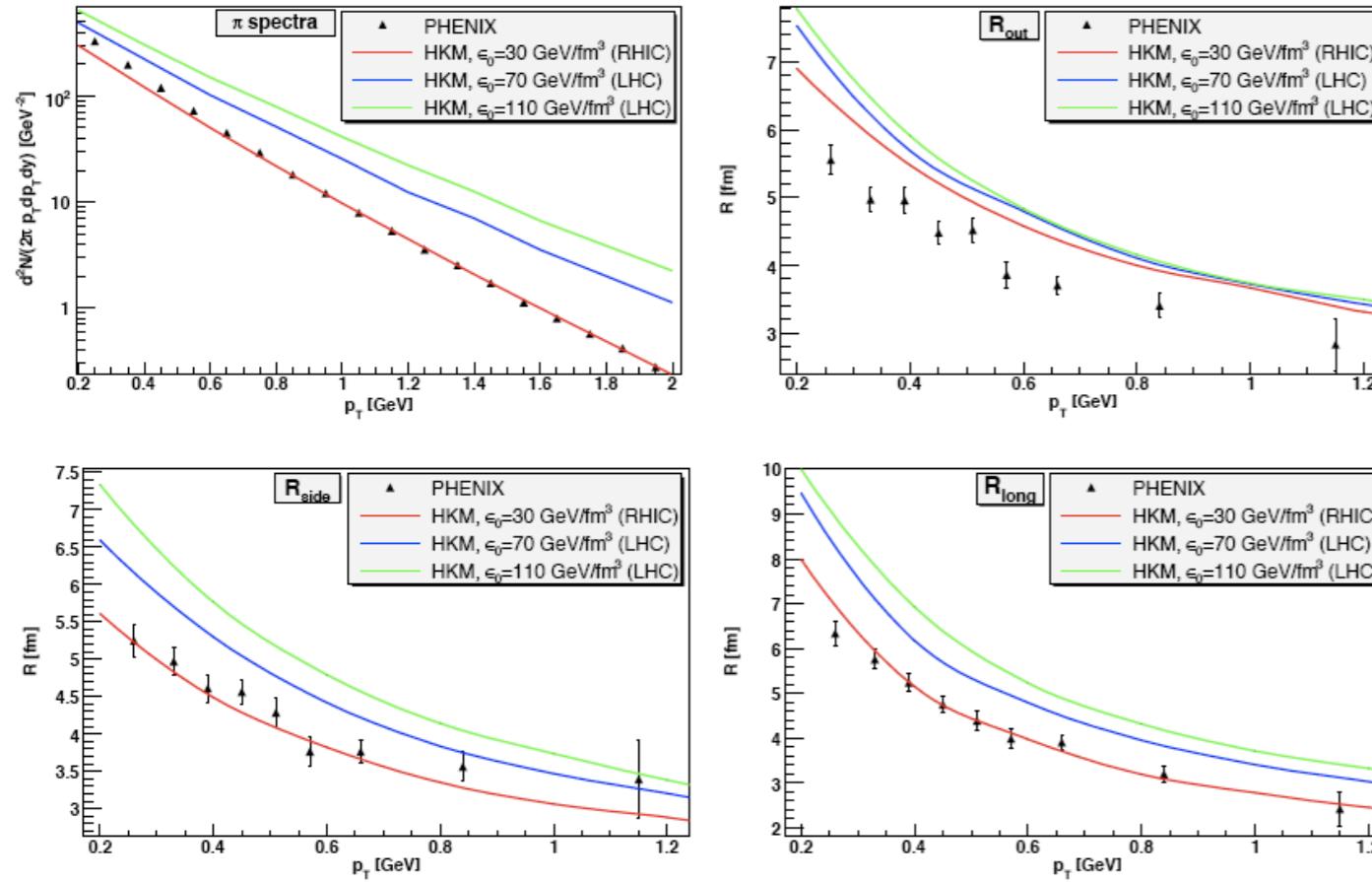
- Cronin effect for protons will strongly constrain models.
- Ratios will further clarify the hadronization mechanism.
- A large $b - b\bar{}$ at $\eta = 0$ would be a real surprise.



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Correlations at low p_T : HBT

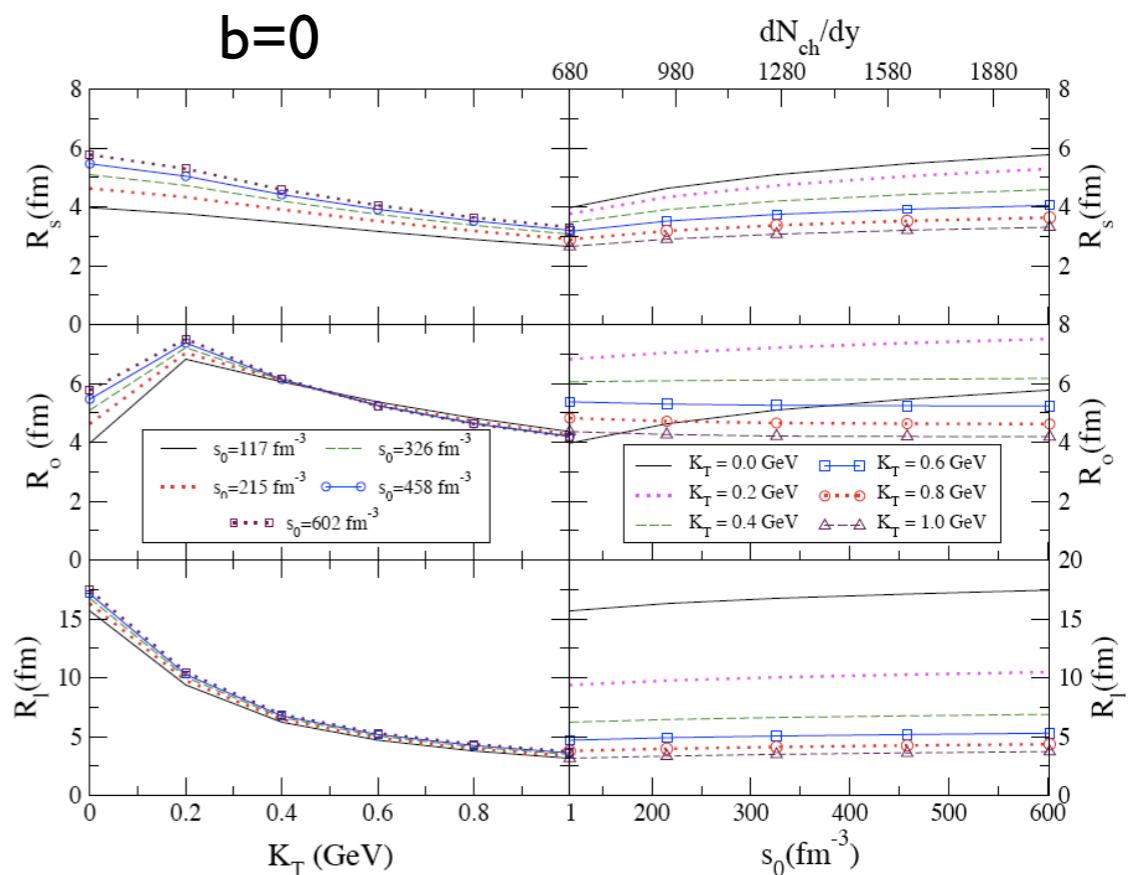


Sinyukov et al., HKM; also
Karpenko et al.,

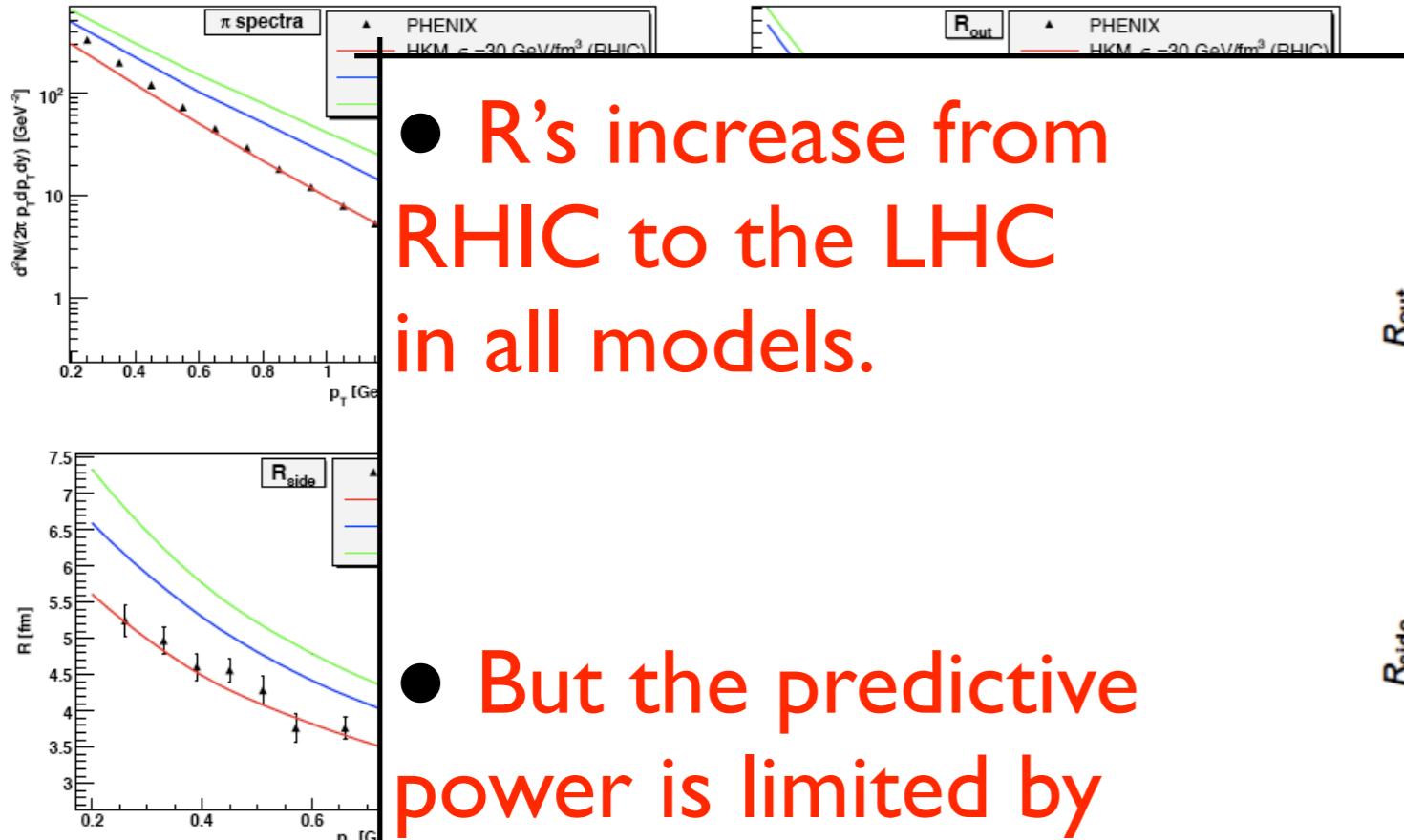
RHIC/LHC for π 's	Chen et al., AMPT, $b=0$, $0.3 < k_T < 1.5$	Chojnacki et al., hydro +stat., $b=1$ fm, $k_T=0.3$ GeV
R_{out}	3.60/4.23	5.4/6.0-6.5
R_{side}	3.52/4.70	4.3/5.3-6.3
R_{long}	3.23/4.86	6.1/7.6-8.6

- Ideal hydro: same problems as at RHIC - $R_{out}(k_T)$, $R_{side}(k_T)$, $R_{out} \gg R_{side}$; out- \rightarrow in-plane shape.

Frodermann et al.

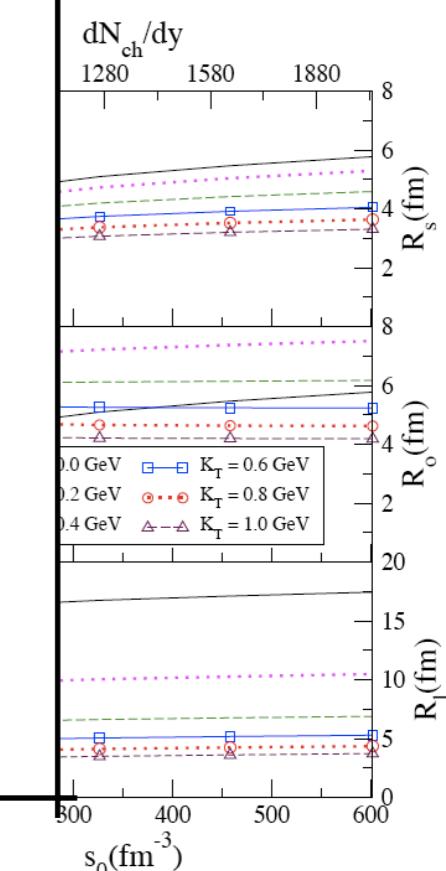
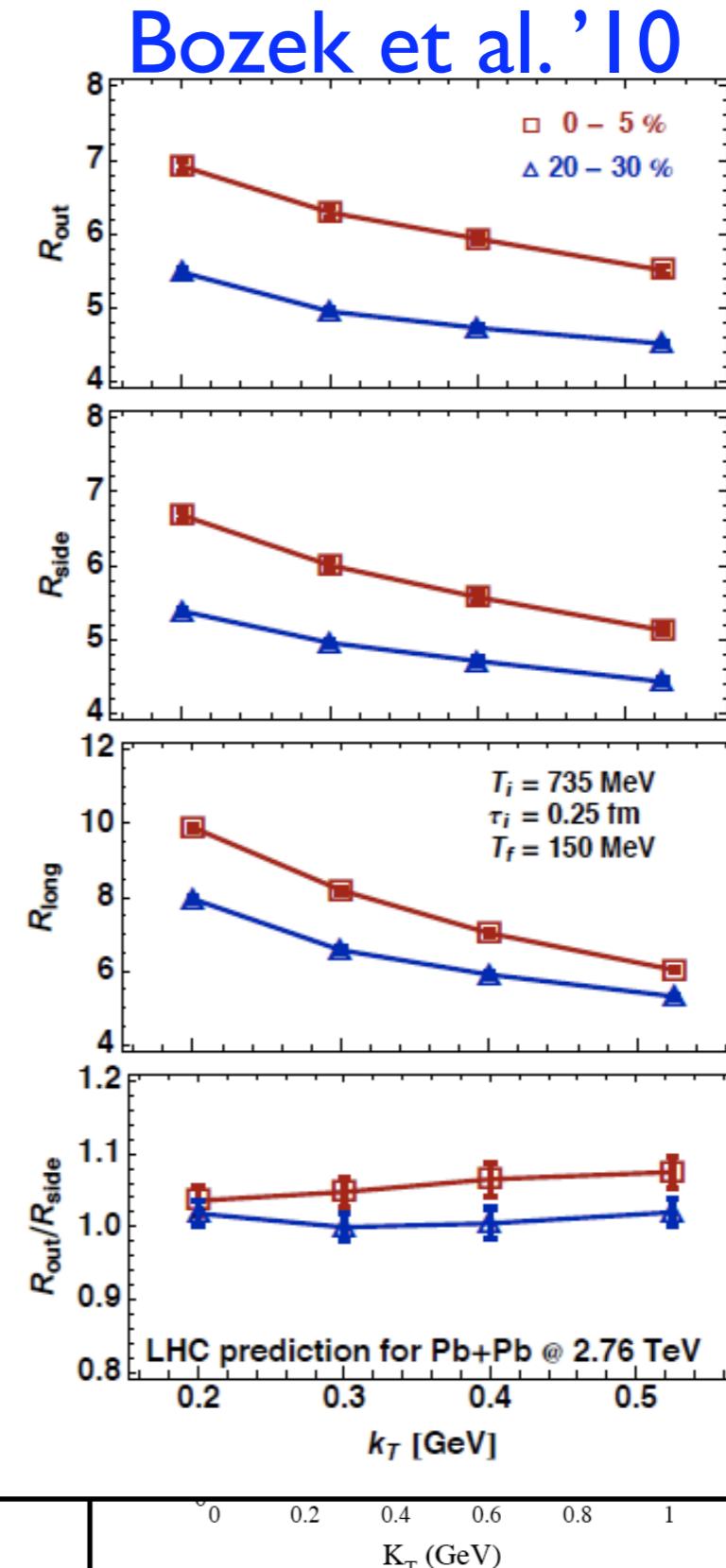


Correlations at low p_T: HBT



Sinyuk Karpen

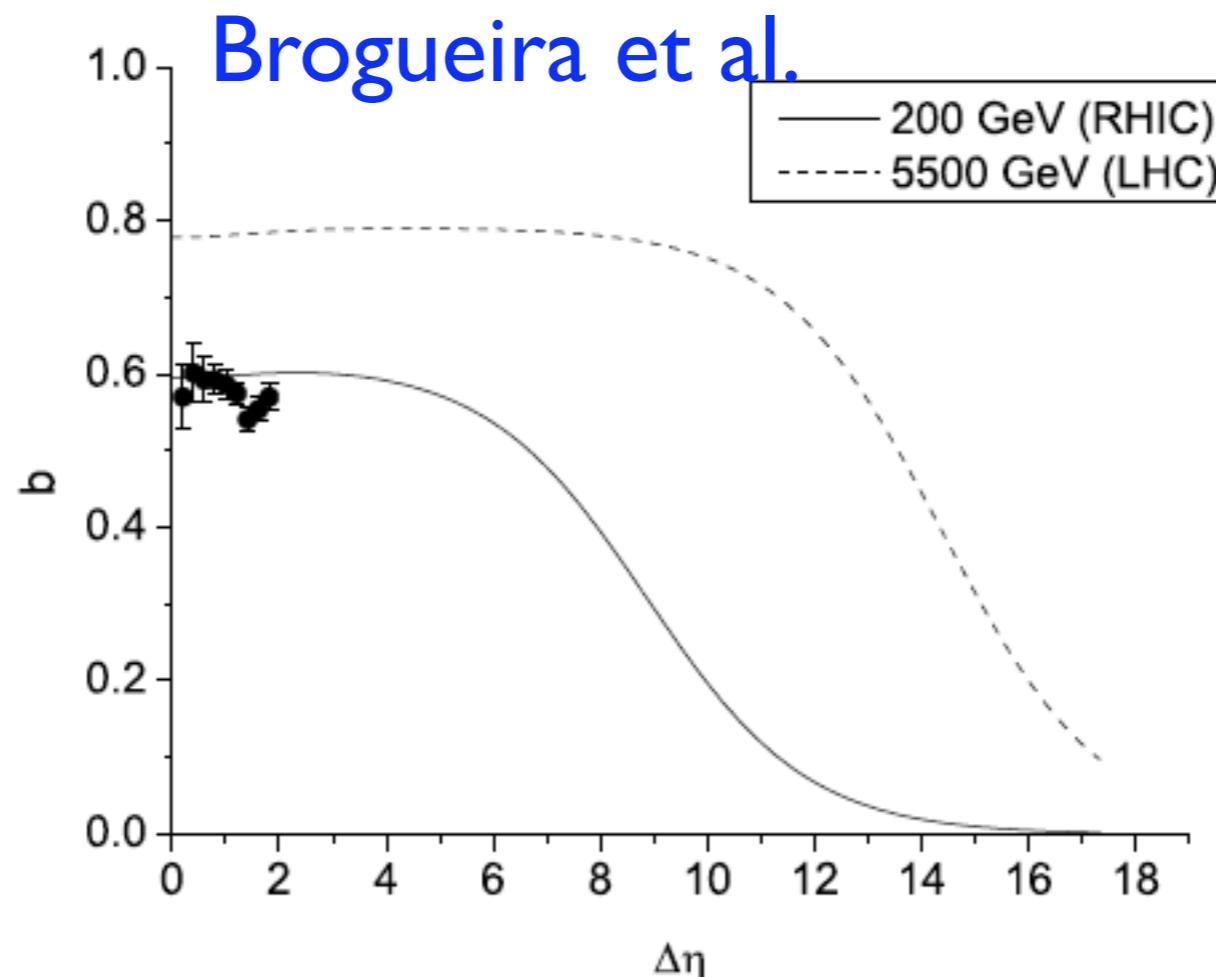
- R's increase from RHIC to the LHC in all models.
 - But the predictive power is limited by the problems at RHIC.
 - Dissipative effects on HBT are not well understood yet.
Fluctuations?



Long range γ -correlations:

- Rapidity correlations may offer information about the mechanism of particle production (flux tubes/Glasma, hydro,...).

$$\langle n_F \rangle(n_B) = a + b n_B, \quad b = \frac{D_{FB}^2}{D_{BB}^2} = \frac{\langle n_F n_B \rangle - \langle n_F \rangle \langle n_B \rangle}{\langle n_B^2 \rangle - \langle n_B \rangle^2}$$



Contents:

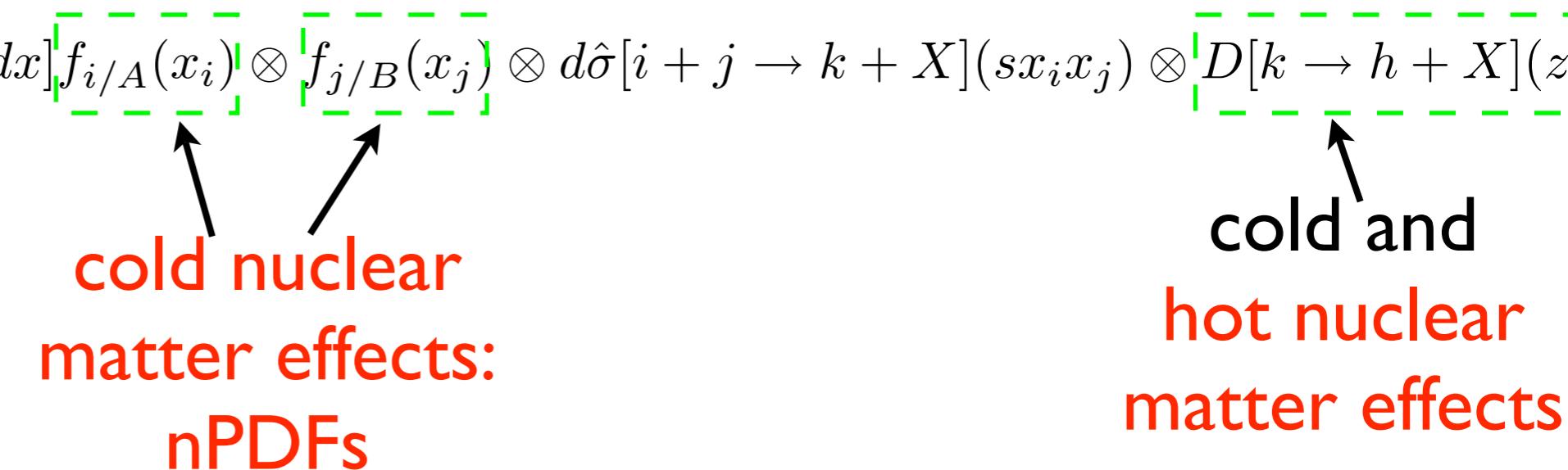
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Hard probes:

$$R_{AA}(y, p_T) = \frac{\frac{dN_k^{AA}}{dydp_T}}{\langle N_{coll} \rangle \frac{dN_k^{NN}}{dydp_T}} = 1 \text{ if no nuclear effects}$$

- Assume collinear factorization works for the reference (pp) and for the probe:

$$d\sigma[A + B \rightarrow h + X] \propto \int [dx] \left[f_{i/A}(x_i) \right] \otimes \left[f_{j/B}(x_j) \right] \otimes d\hat{\sigma}[i + j \rightarrow k + X](sx_i x_j) \otimes \left[D[k \rightarrow h + X](z) \right]$$

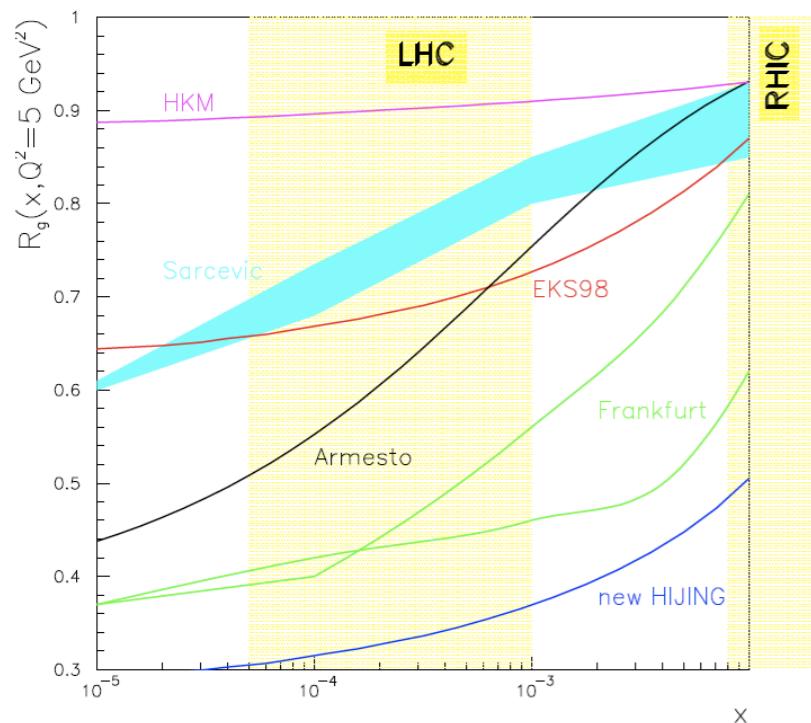


cold nuclear matter effects:
nPDFs

cold and hot nuclear matter effects

- pA, eA: check factorization and constrain cold nuclear matter effects.
- AB: (check factorization and) characterize the medium.

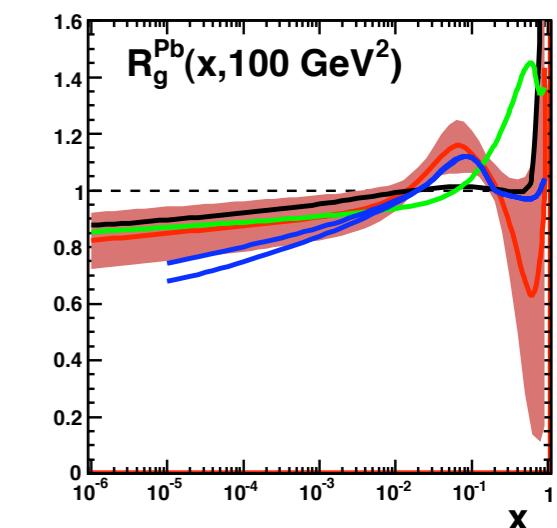
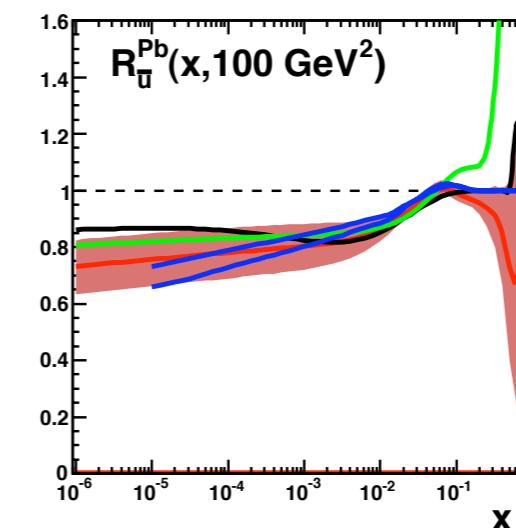
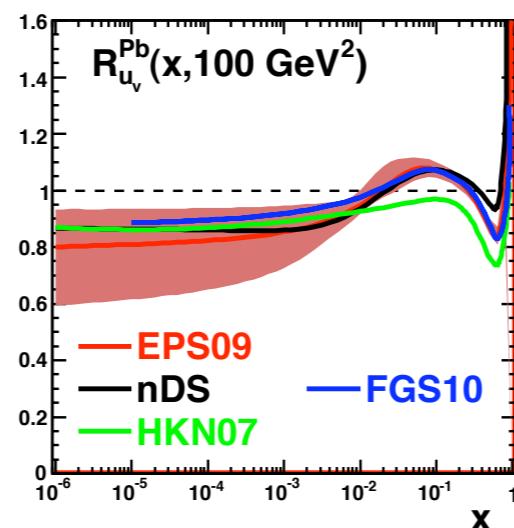
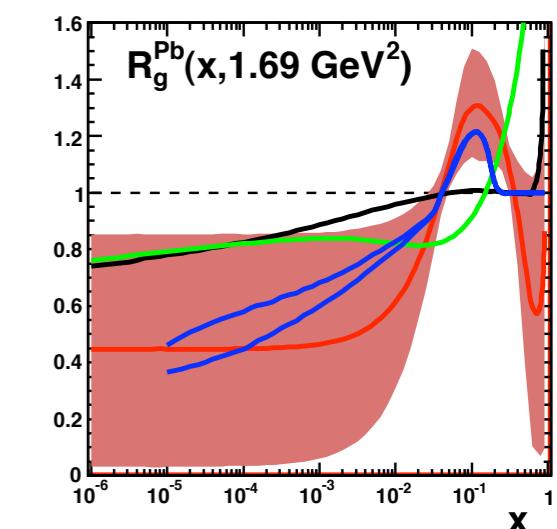
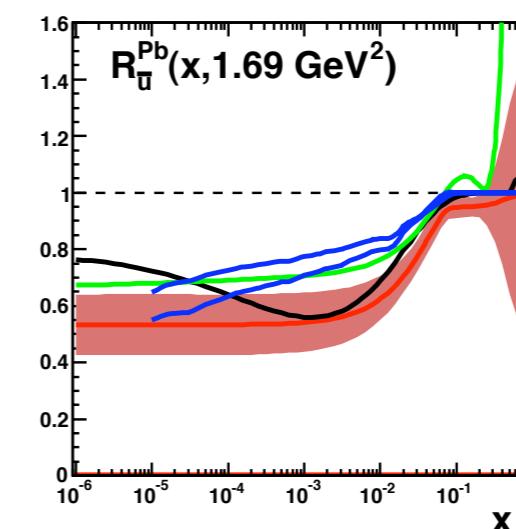
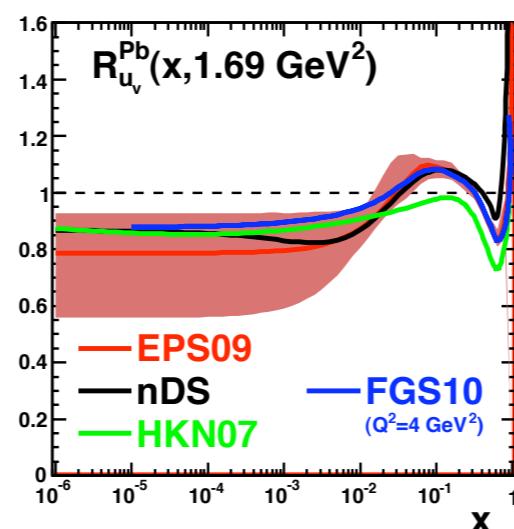
The benchmark: nPDFs



Yellow Report on Hard Probes, 2004

- Available DGLAP analysis at NLO show large uncertainties at small scales and x.

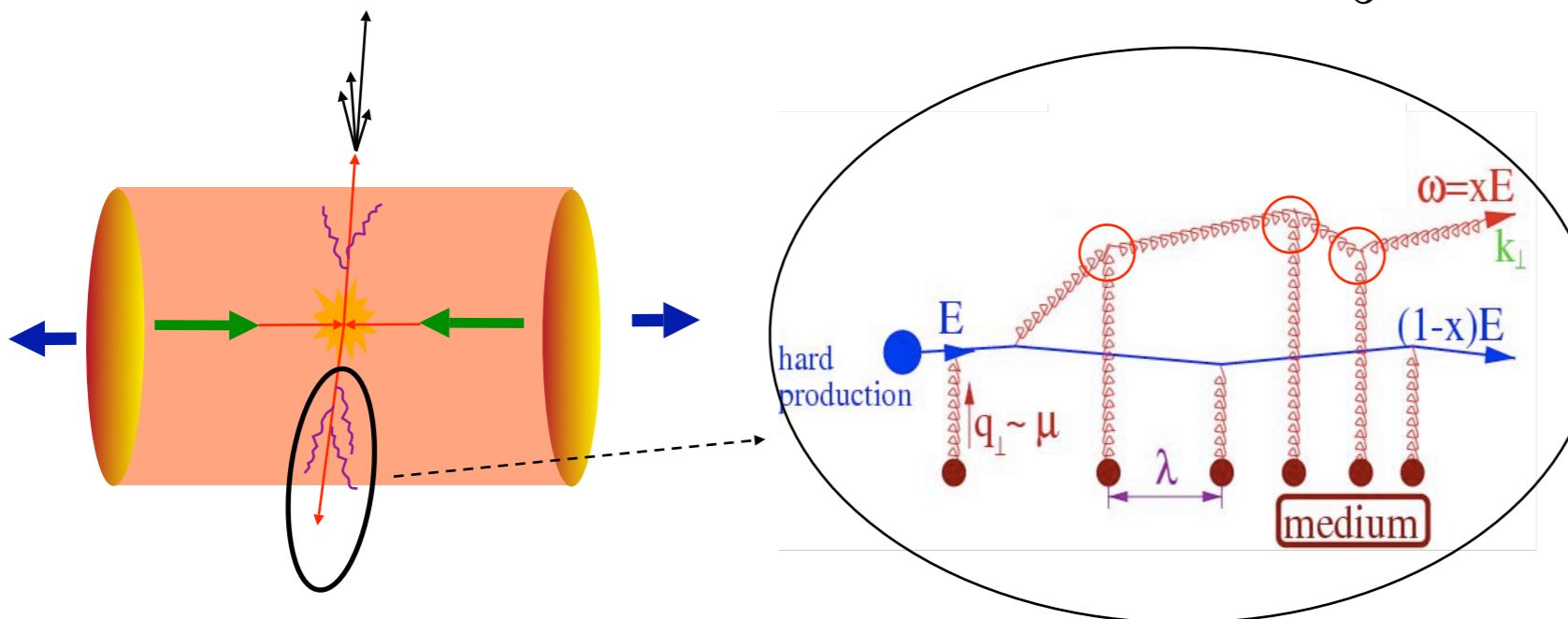
- Models give vastly different results for small scales and x.



Energy loss:

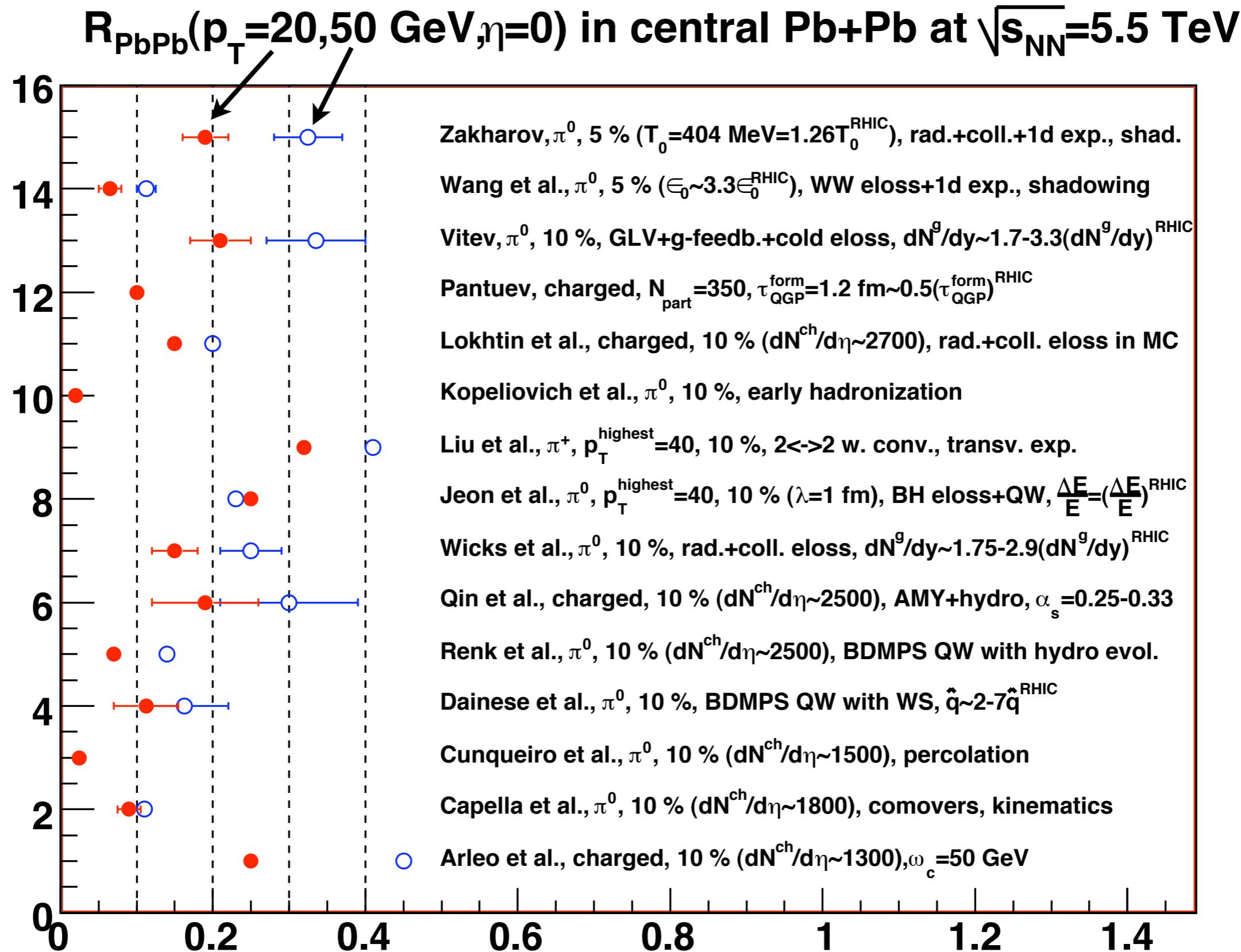
- RHIC has measured $R_{AA} < 1$ (e.g. 0.2 for π^0 at midrapidity in central AuAu), and the disappearance of back-to-back correlations.
- It is standardly interpreted as the result of **partonic energy loss**: interplay with the slope of the partonic spectrum.

$$D^{med}(z) = \int \frac{d\epsilon}{1-\epsilon} P(\epsilon) D^{vac} \left(\frac{z}{1-\epsilon} \right)$$

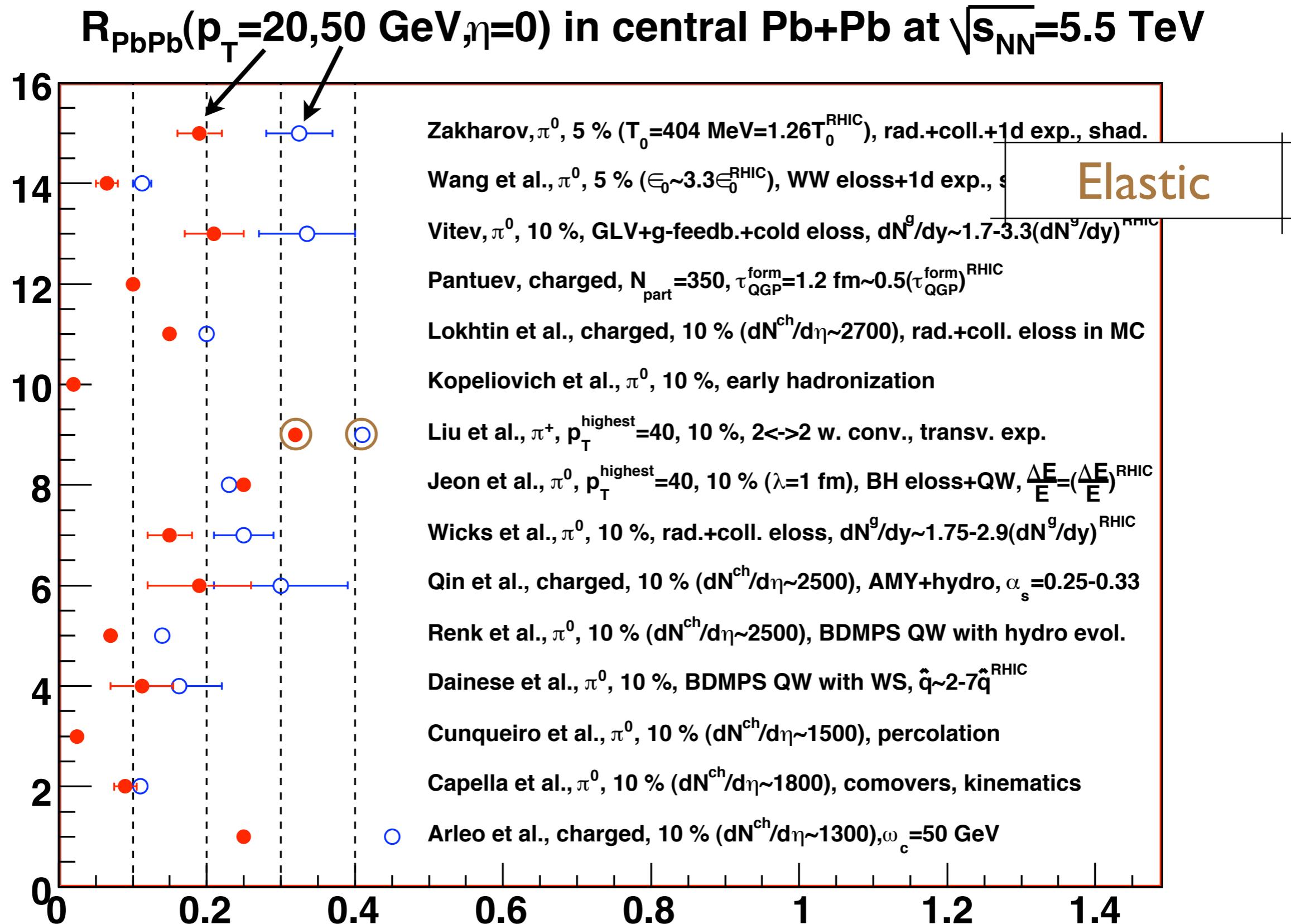


- Radiative loss characterized by different density parameters related to multiplicity:
 $\hat{q} = \langle k_t^2 \rangle / \lambda \propto \epsilon^{3/4}$.

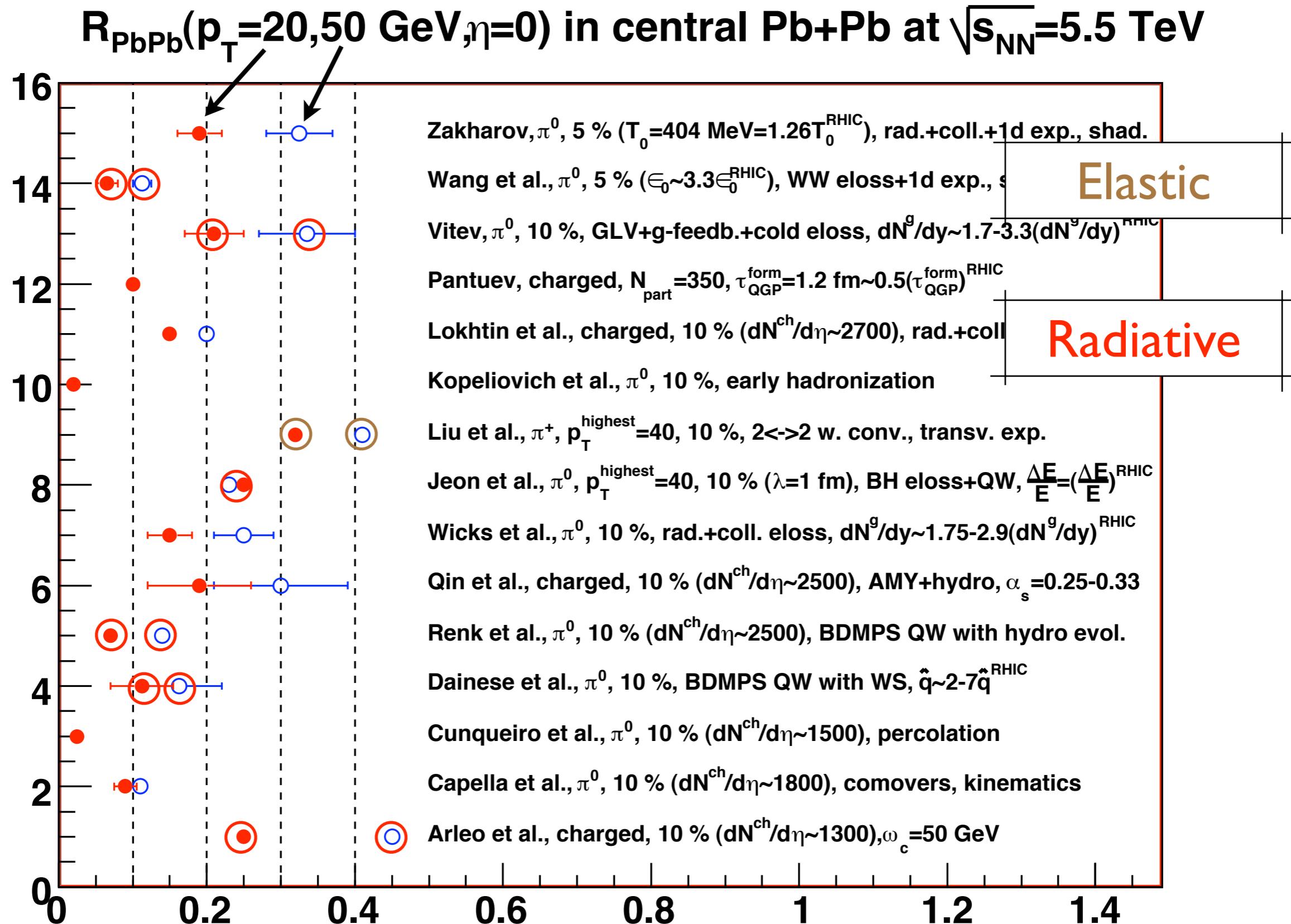
Predictions for RAA:



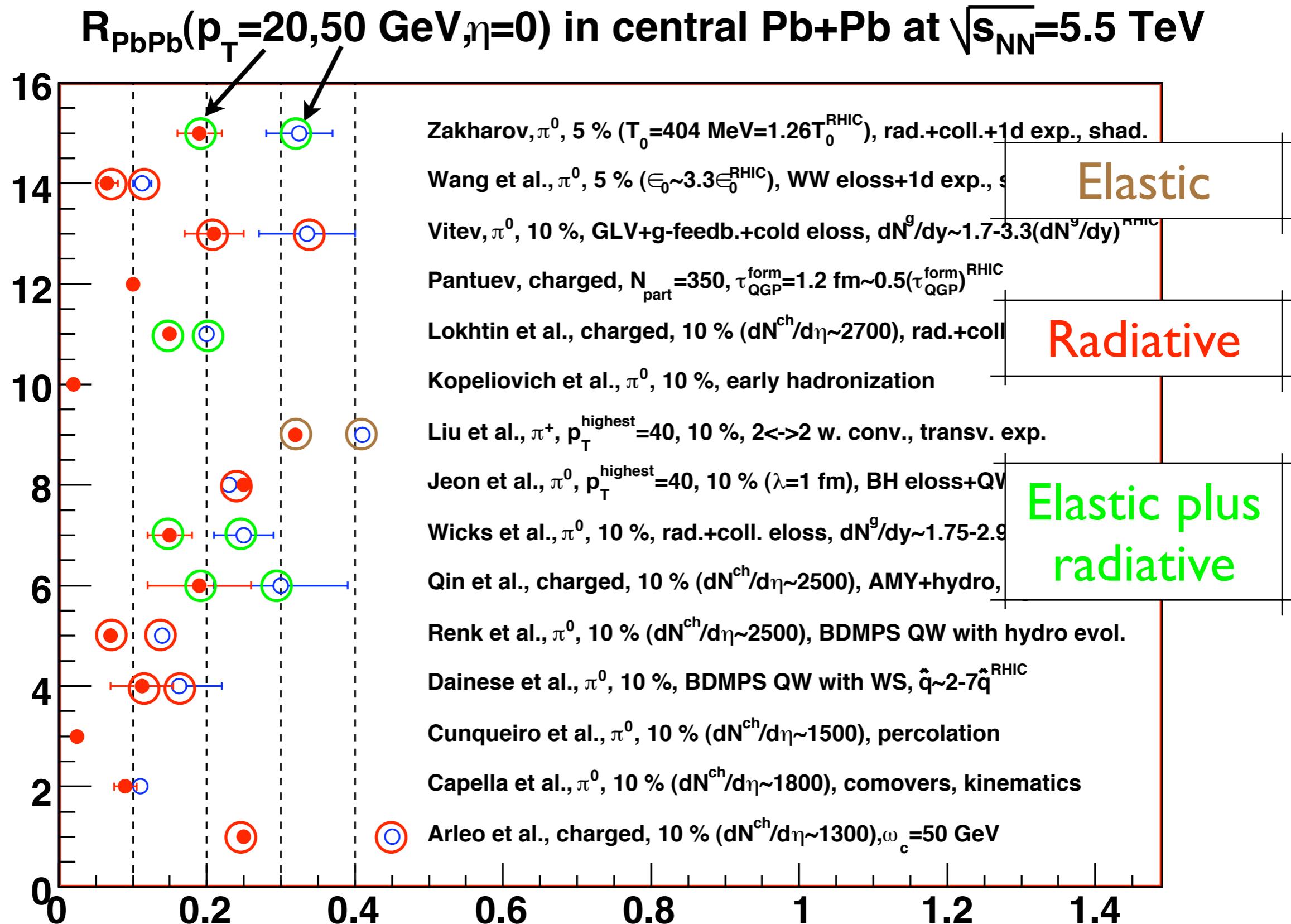
Predictions for RAA:



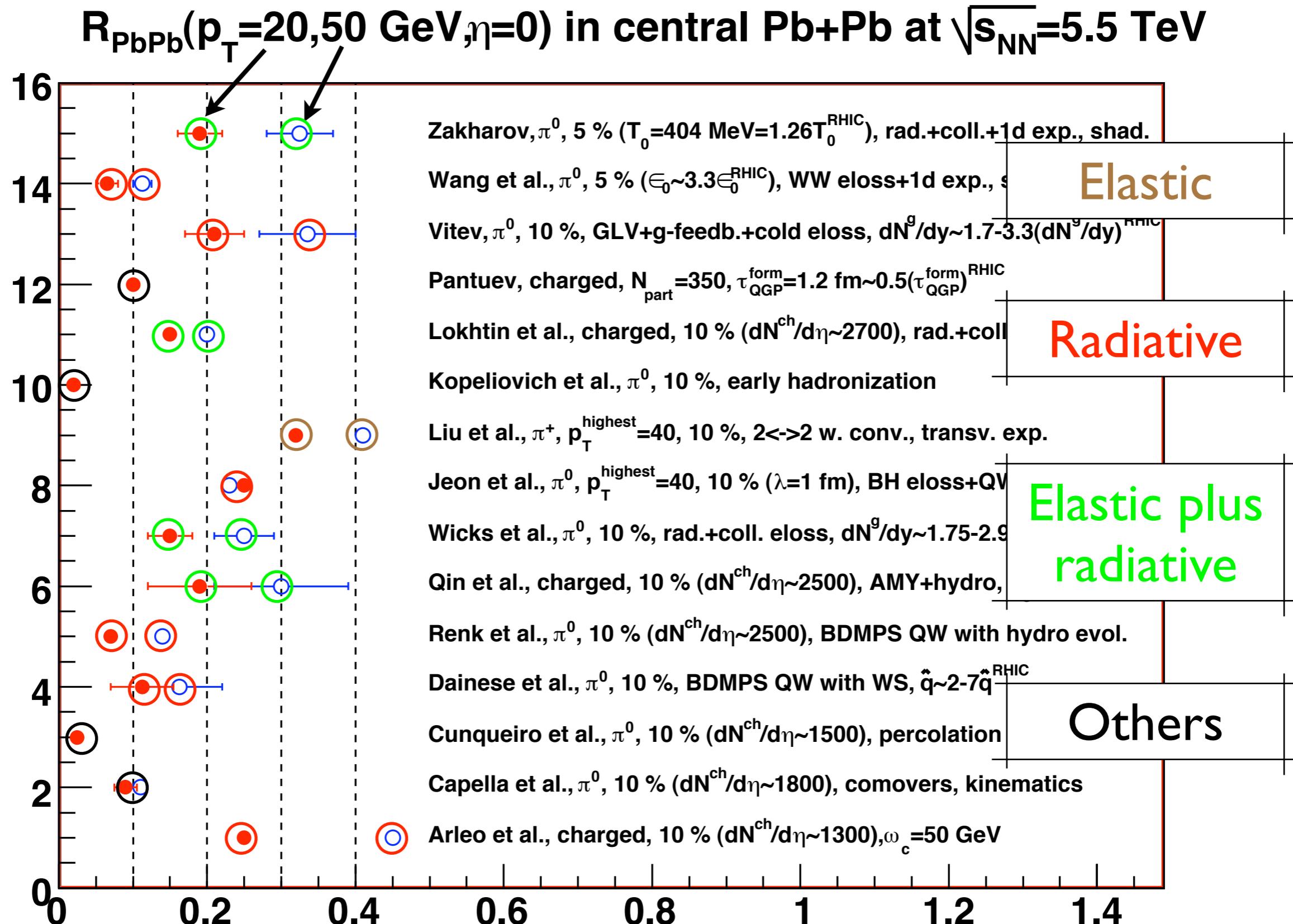
Predictions for RAA:



Predictions for RAA:

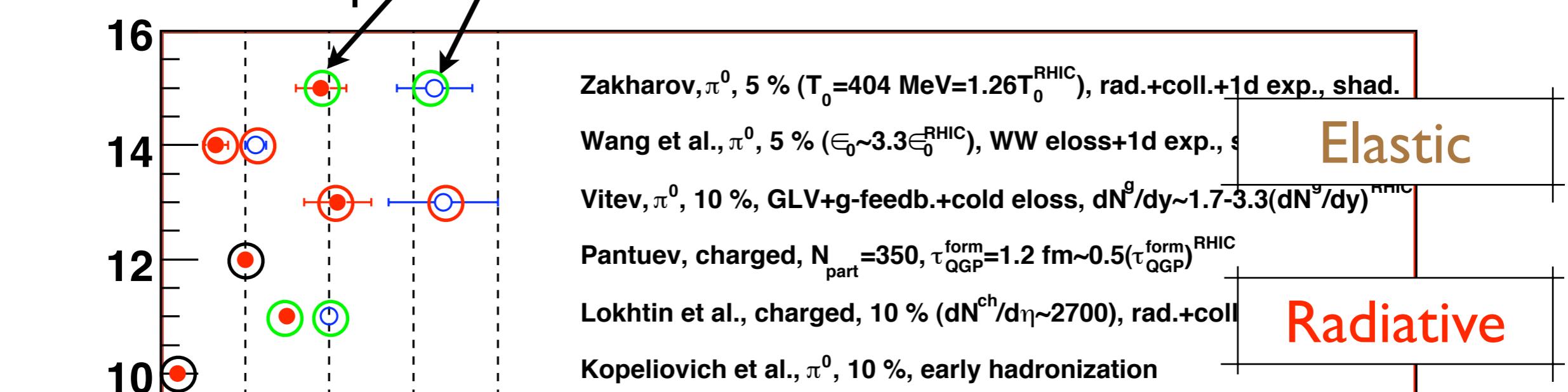


Predictions for RAA:

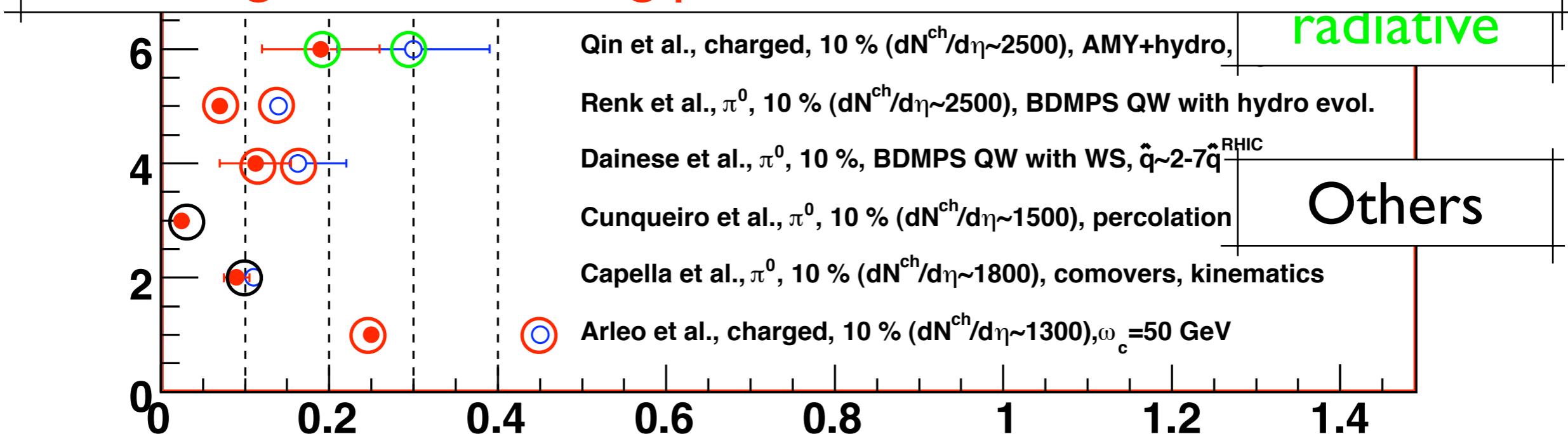


Predictions for RAA:

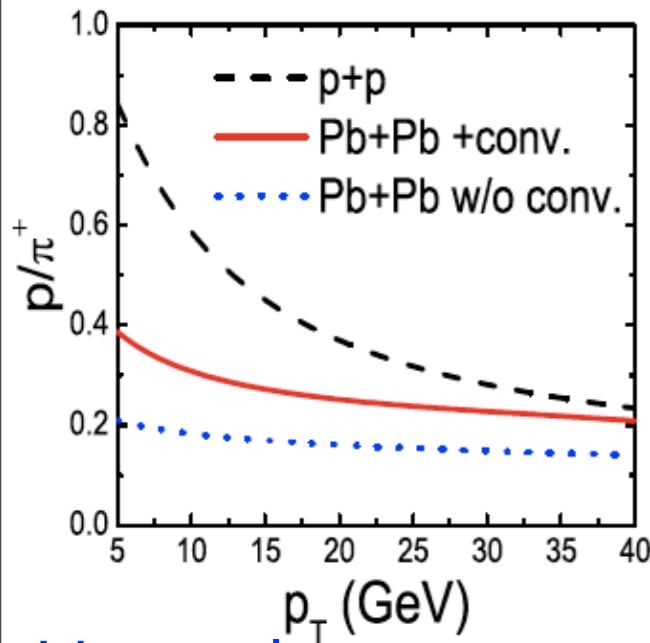
$R_{\text{PbPb}}(p_T = 20, 50 \text{ GeV}, \eta = 0)$ in central Pb+Pb at $\sqrt{s_{\text{NN}}} = 5.5 \text{ TeV}$



- Radiative energy loss favors $R_{\text{AA}} \sim 0.1 - 0.2$ at $p_T \sim 20 \text{ GeV}$ and increasing with increasing p_T .

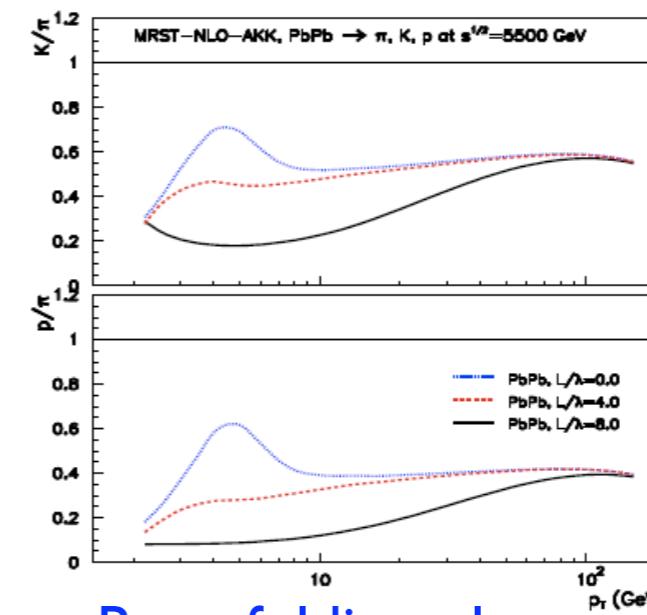


Hadrochemistry and FF:

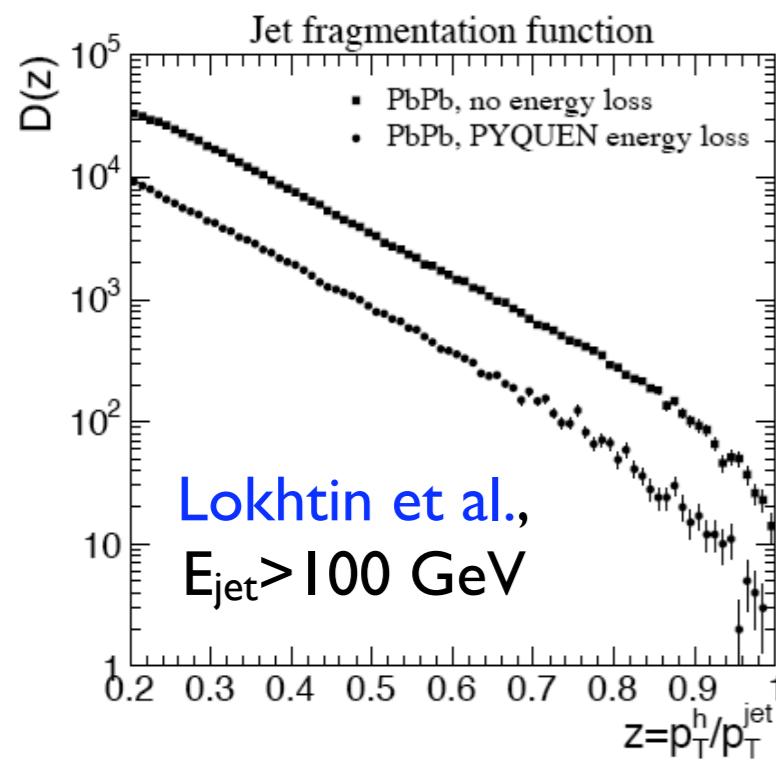
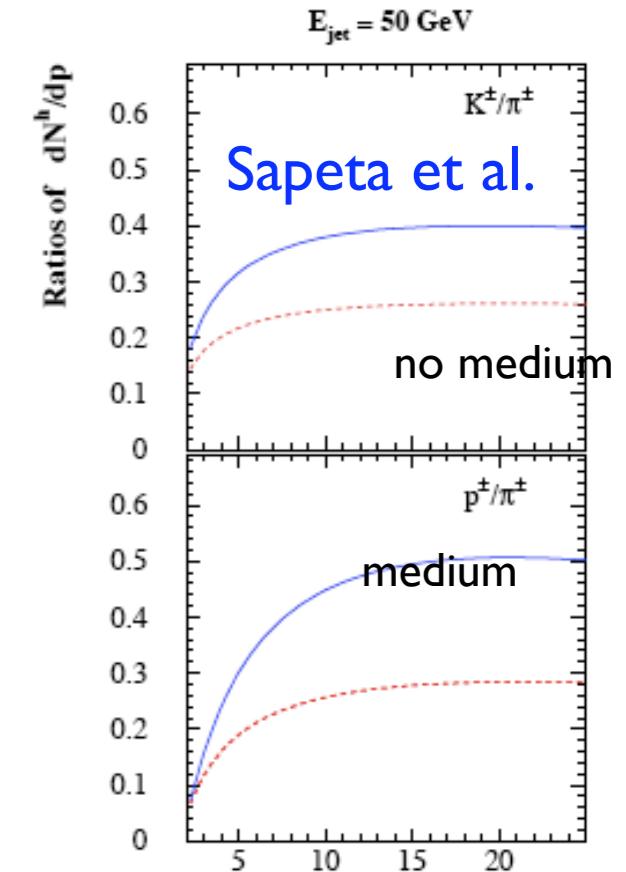


Liu et al.

Modification of hadrochemistry due to elastic +conversions, rad. eloss or modified jet radiation.

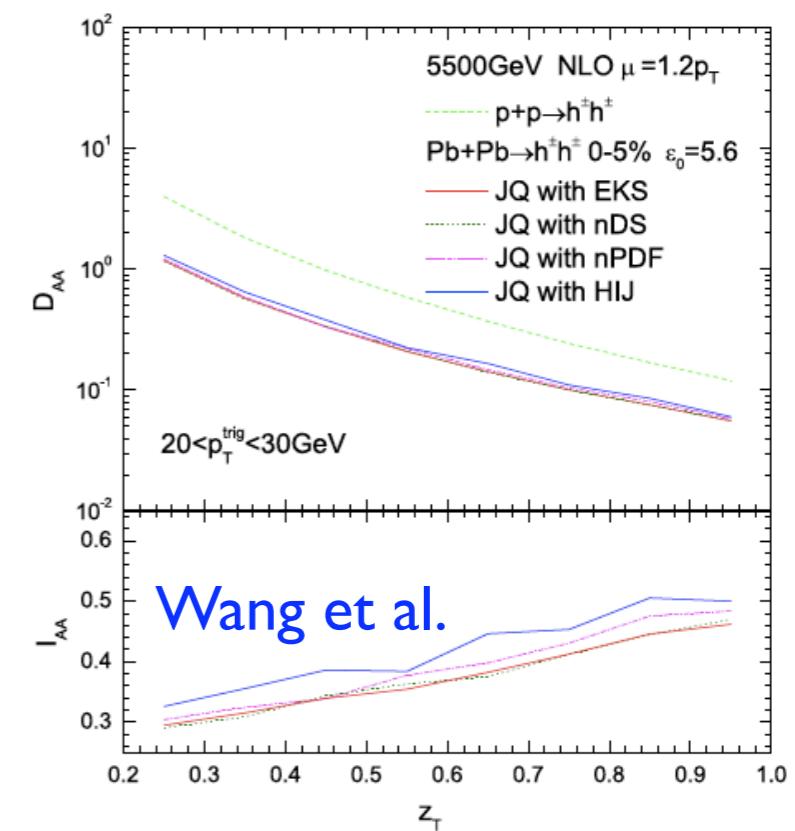


Barnafoldi et al.



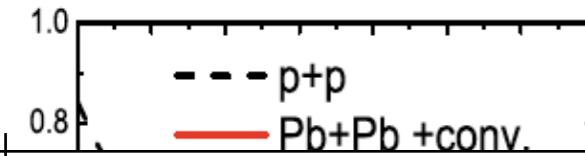
Lokhtin et al.,
 $E_{\text{jet}} > 100$ GeV

Modified fragmentation functions, both for jets (elastic+radiative in PYQUEN) and for the hadron-triggered case (WW rad. model).

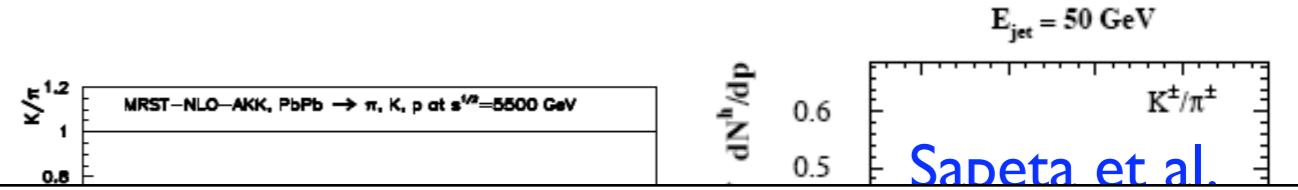


Wang et al.

Hadrochemistry and FF:

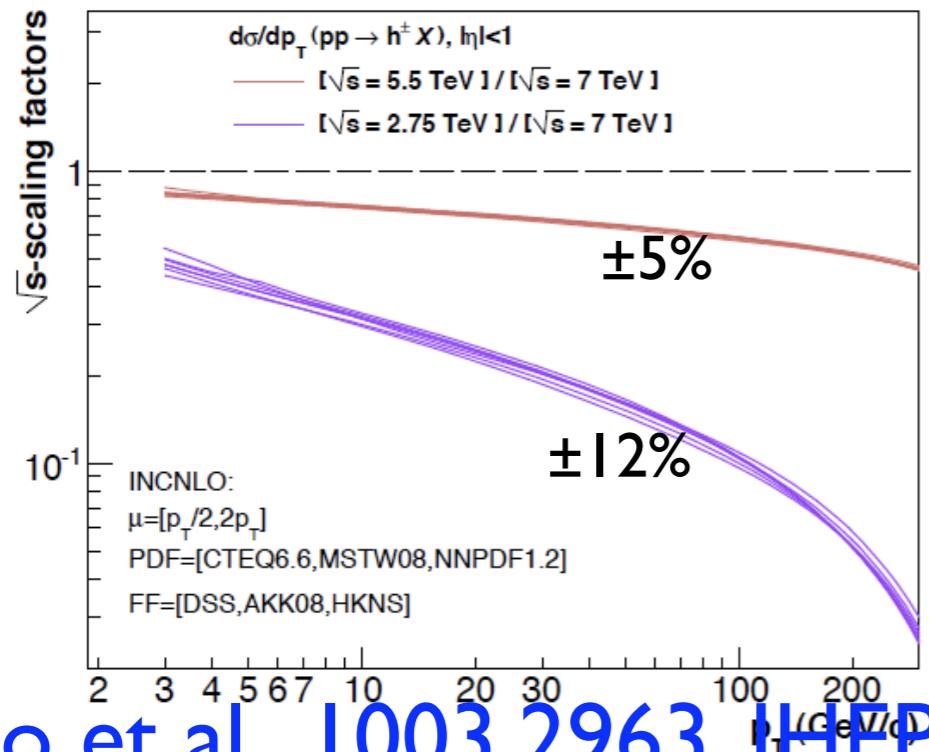


Modification of



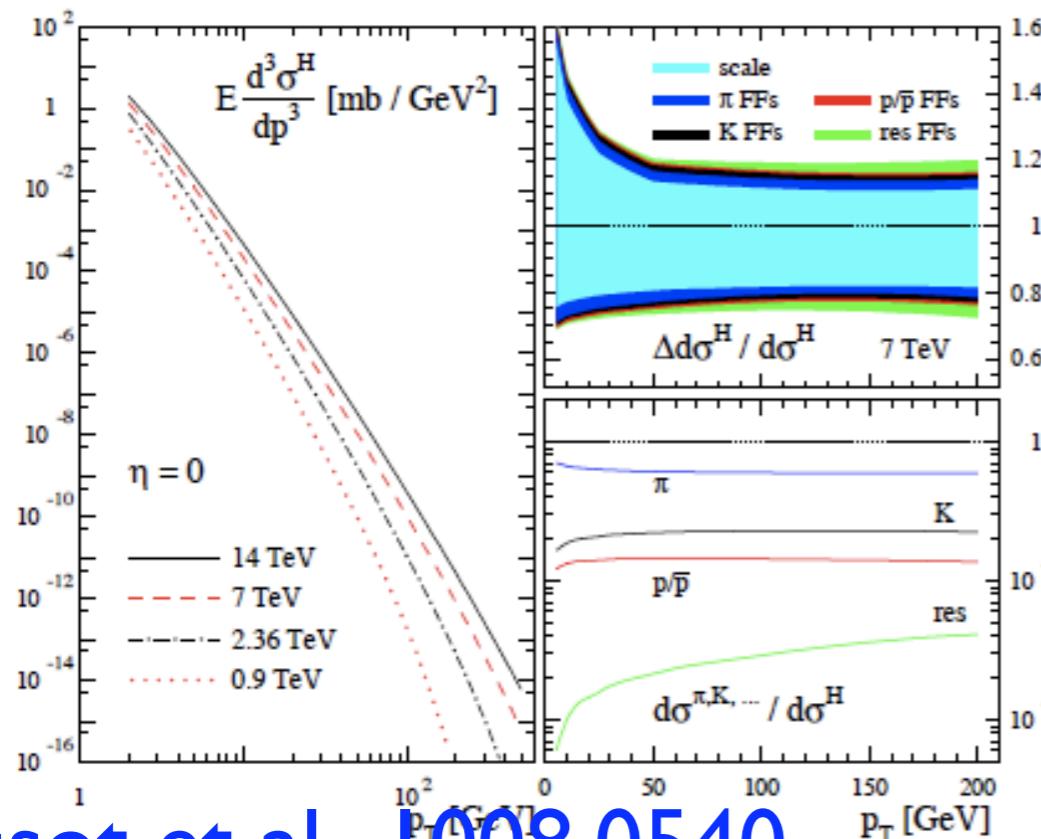
- Chemical composition and more differential observables will be key to establish the mechanism underlying jet quenching.
- Problems with pp at 2.76 TeV:
 - * Interpolation between 7 TeV and Tevatron? (Albino et al., Arleo et al., Cacciari et al., Sassot et al. '10).
 - * R_{CP} instead of R_{AA} ?
- Jets:
 - * New techniques to deal with the background.
 - * Effects of limited energy resolution in HIC?
 - * Need of MC with medium modifications.
 - * Need of strategies to disentangle medium effects.

Interpolation 7 TeV → lower \sqrt{s} :

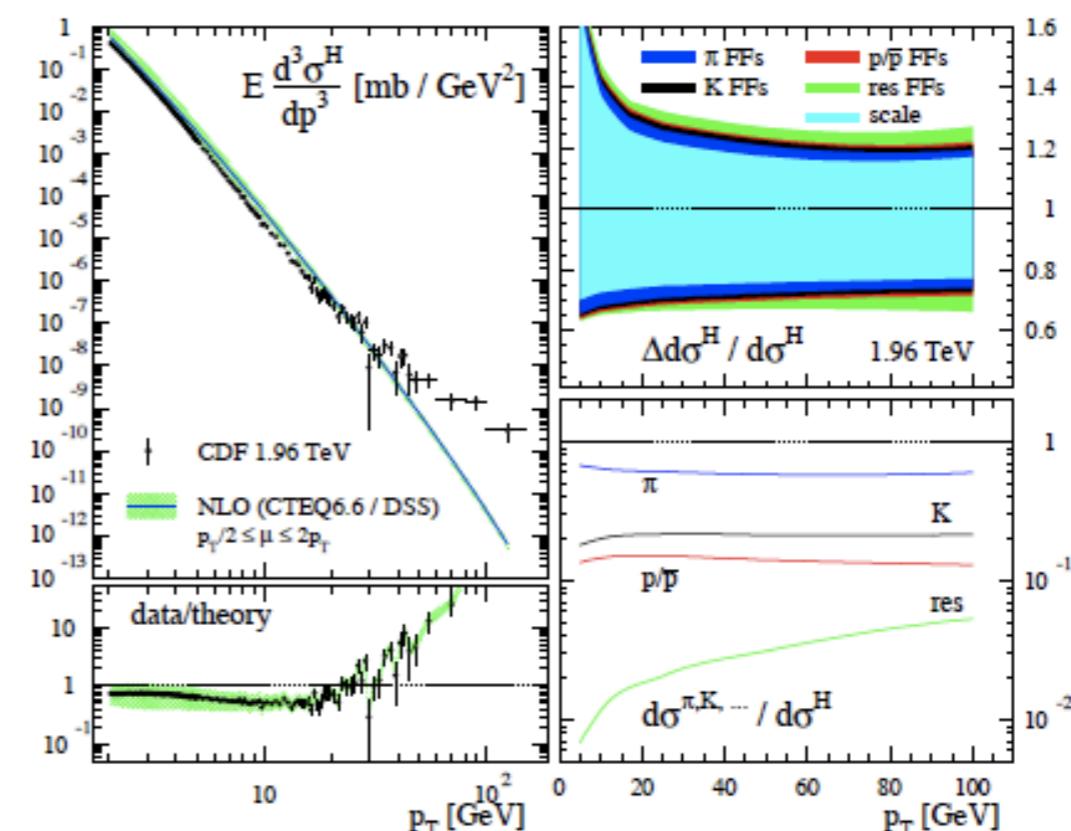


- Either you rely on NLO pQCD which works without K-factors.
- Or you make an empirical interpolation using x_T -scaling between 1.96 and 7 TeV ($\pm 20\%$, $p_T < 30 \text{ GeV}$).

Arleo et al., 1003.2963, JHEP



Sassot et al., 1008.0540



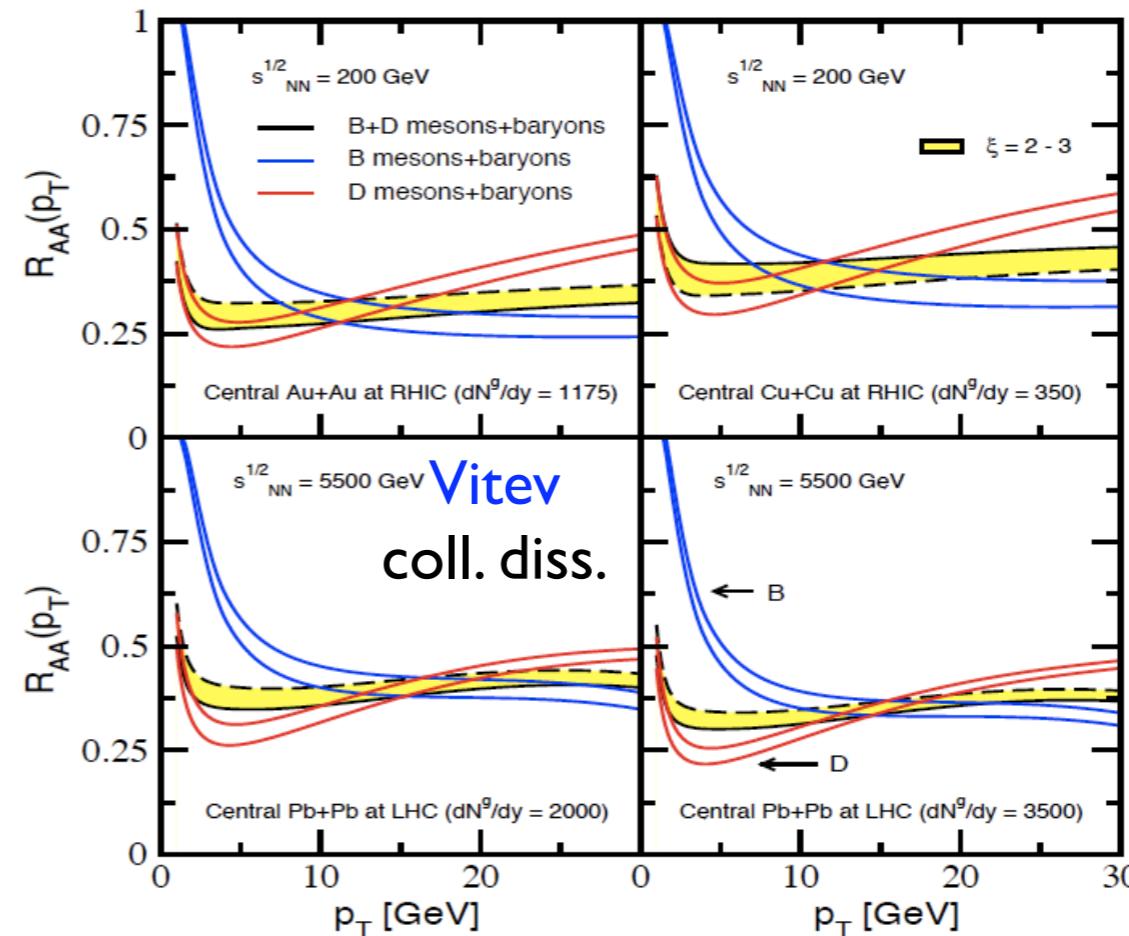
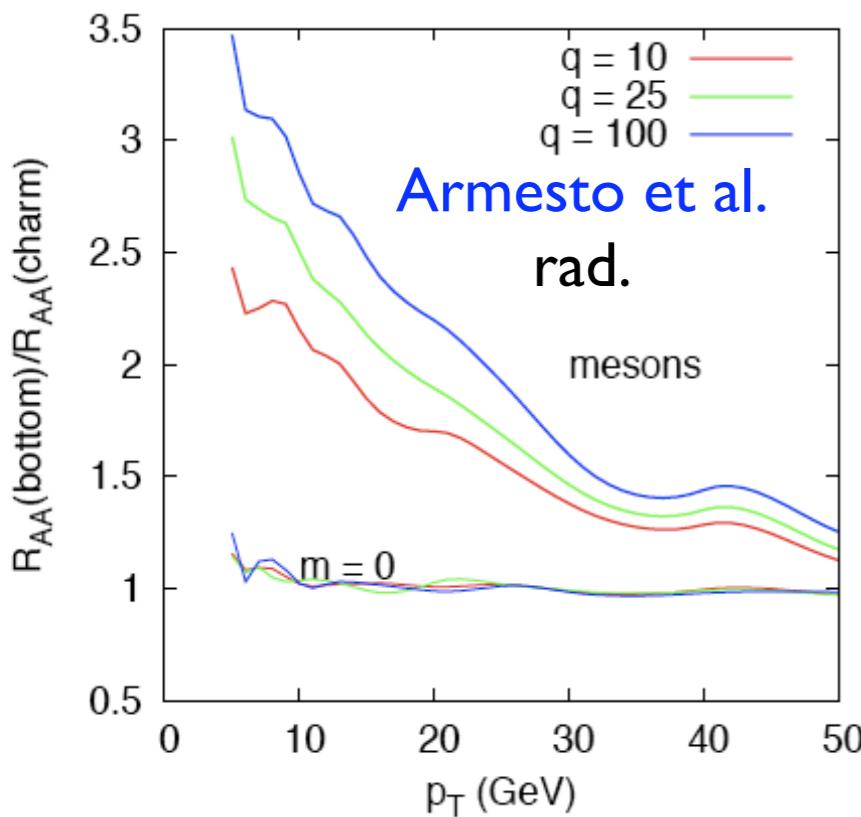
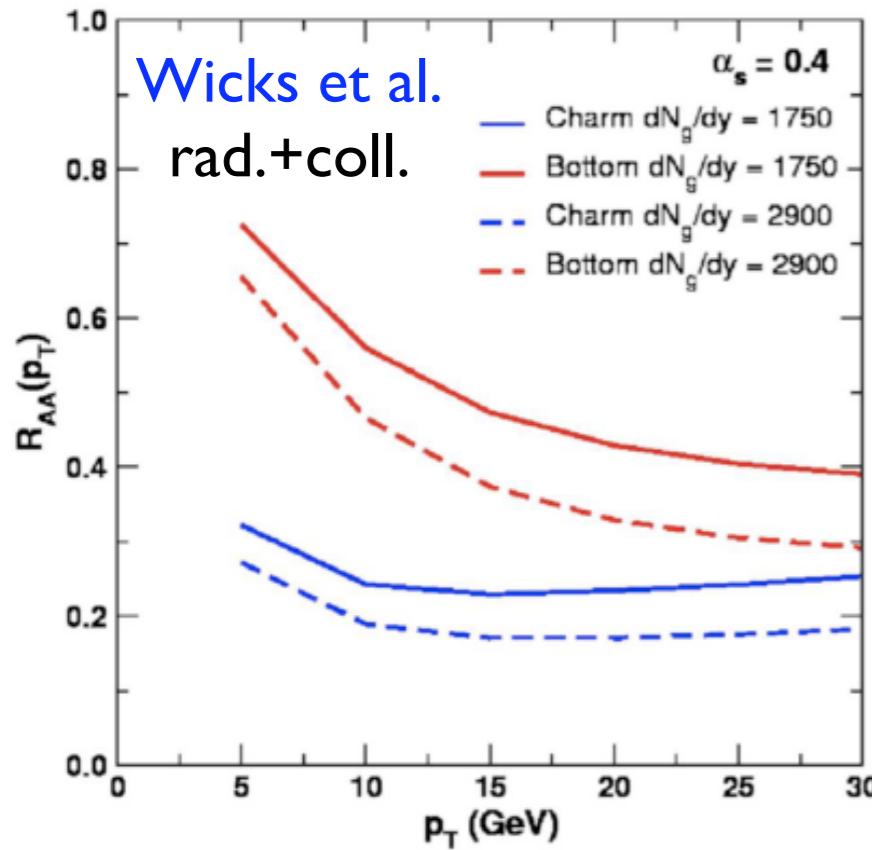
Contents:

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Introduction:

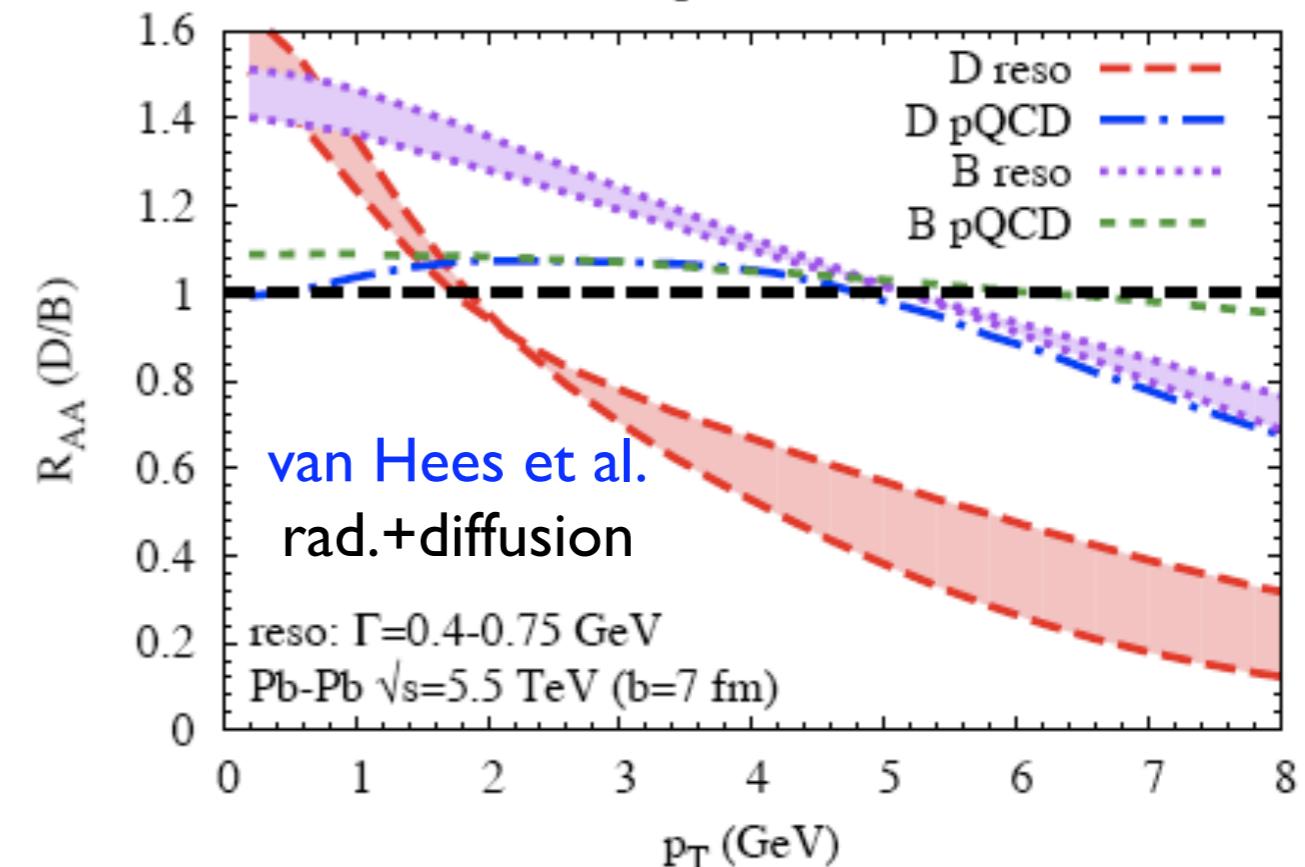
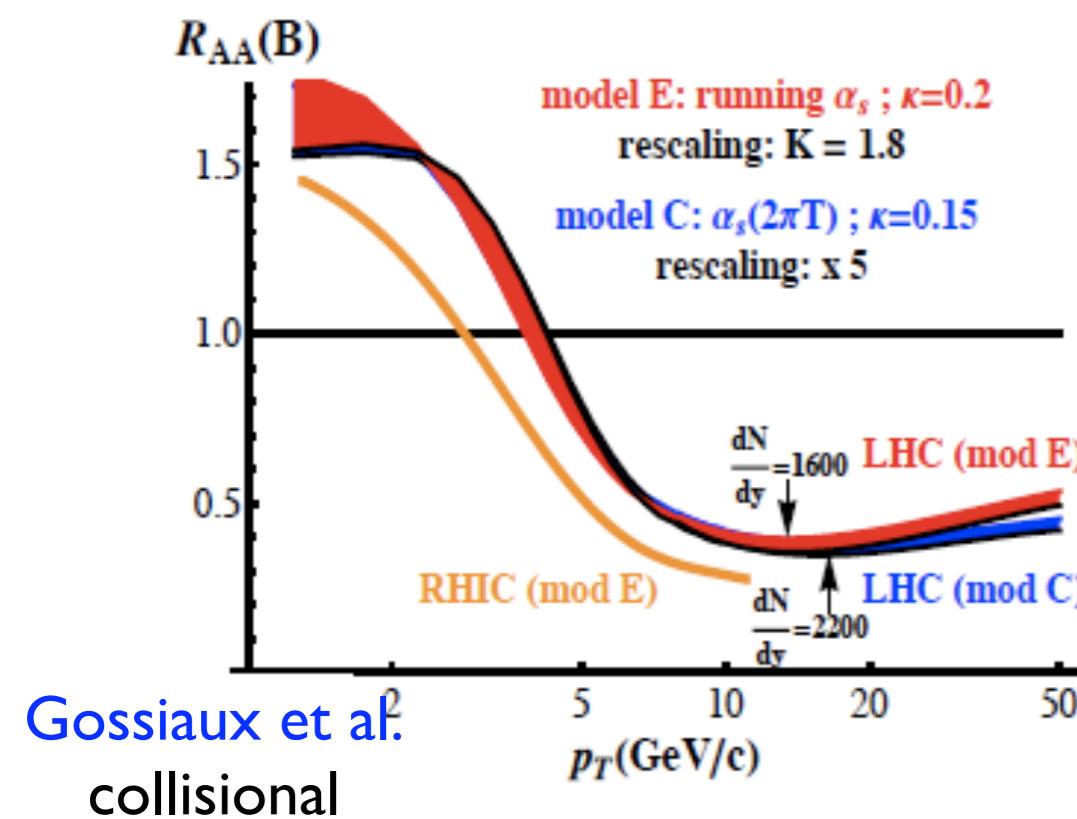
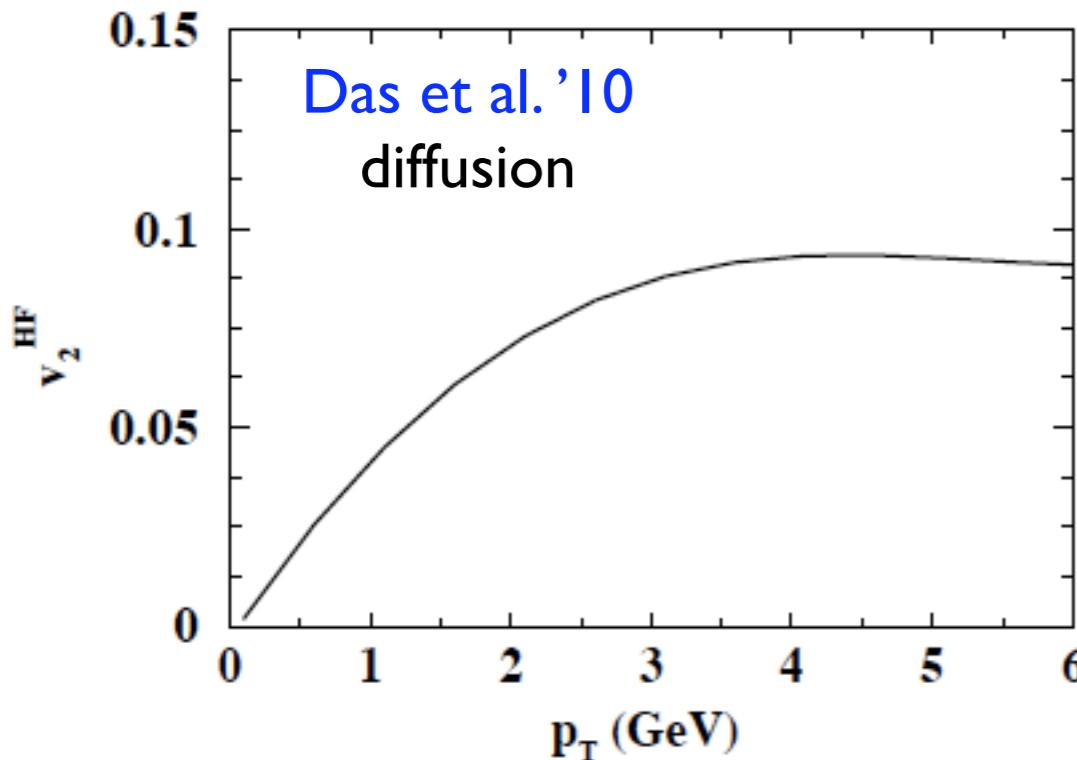
- Heavy quarks offer an additional possibility to constrain the mechanism of energy loss. In the radiative case:
 $\Delta E(g) < (\text{color charge}) \Delta E(q) < (\text{mass effect}) \Delta E(Q)$.
- $R_{AA}^e \sim R_{AA}^{\pi}$ at RHIC!!! Several mechanisms may compete:
 - * Radiative.
 - * Collisional: perturbative or not.
 - * Dissociation of mesons inside the medium.
 - * Secondary production by partonic rescattering (> at the LHC).
- Quarkonium may get dissolved in the plasma (Matsui-Satz). But the dynamics is more complex:
 - * Dissociation by Debye screening in the plasma.
 - * Dissociation by comovers.
 - * Regeneration via coalescence.

Heavy quarks: predictions (I)



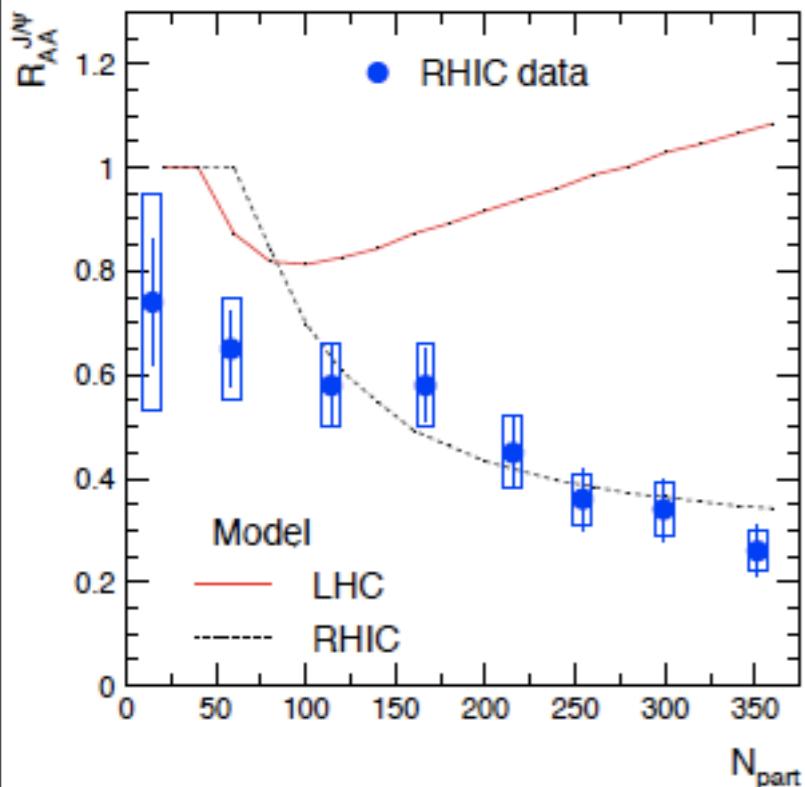
- pQCD-based models valid for **hadronization outside the medium**, so for high p_T .
- **Double ratios B/D** are sensitive to mass effects until quite high p_T and offer possibilities to discriminate models for HQ jet quenching (**Horowitz et al.**).

Heavy quarks: predictions (II)

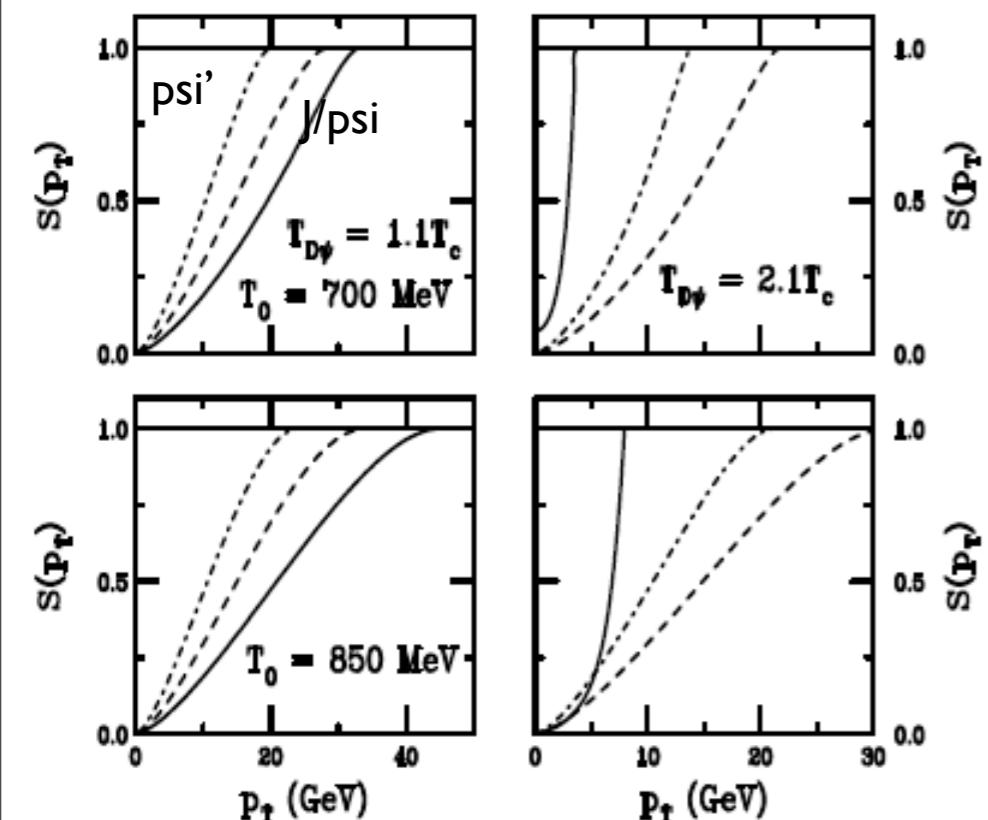
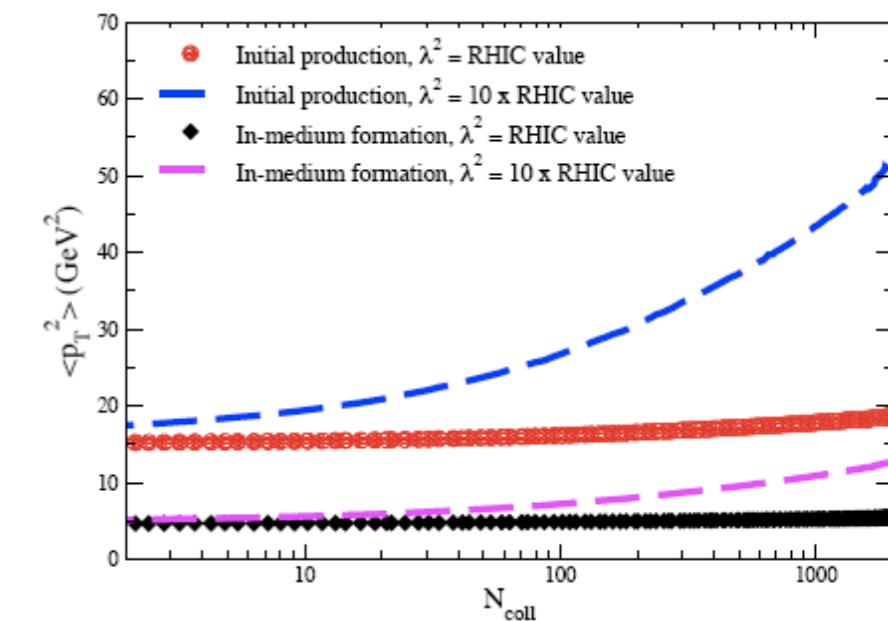


- R_{AA} for meson and leptons will be available.
- Large suppression expected, decreasing with p_T .
- The large coverage in p_T for muons makes it possible a self-calibration with EW bosons (Dainese et al.).

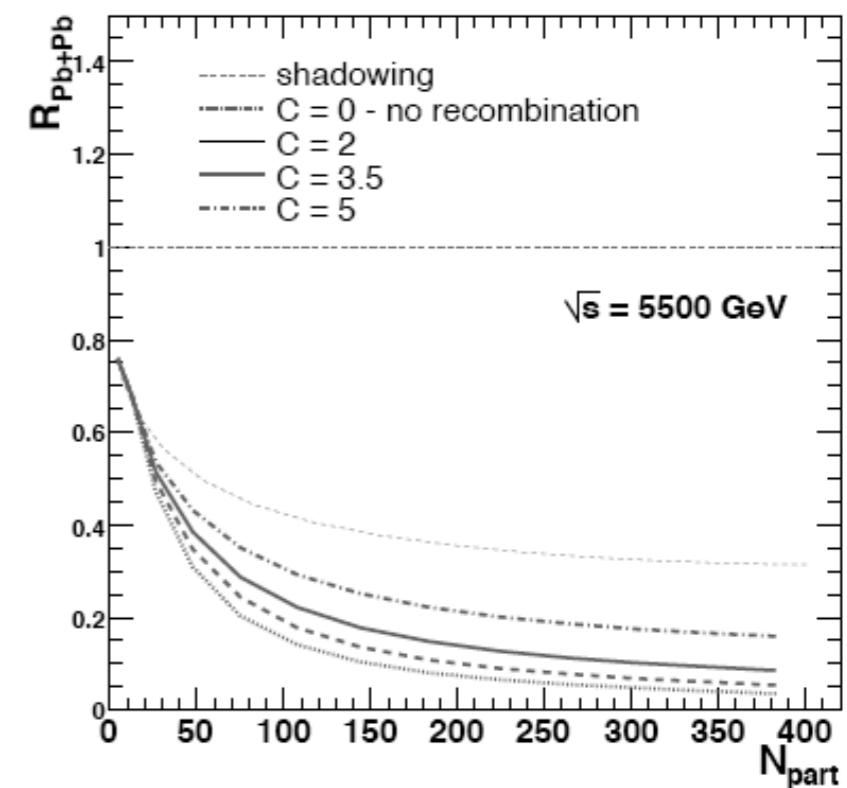
Quarkonium: predictions



Andronic et al. '10:
strong regeneration
(FONLL $\sigma^{cc\bar{c}}$); **Thews et al.:** p_T -broadening to verify recombination, with uncertainties from cold matter effects.

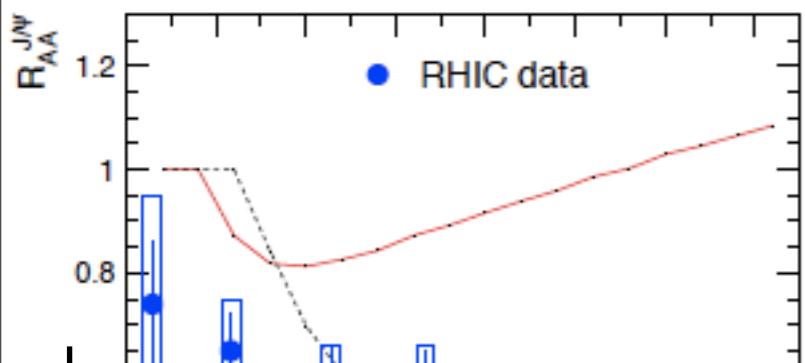


Vogt: p_T -dependent screening, no regeneration.

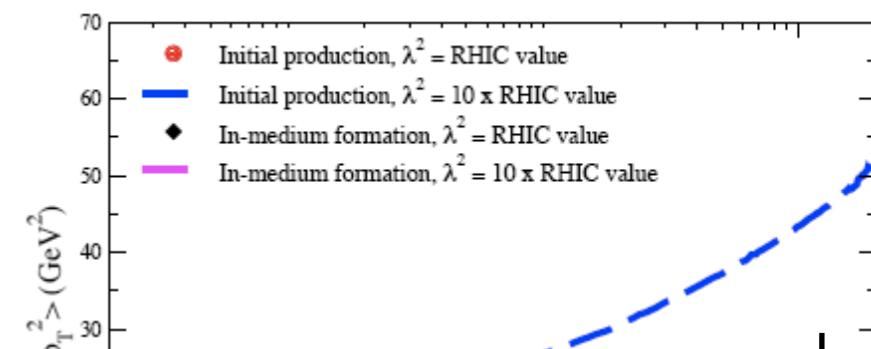


Capella et al.: comovers+reco.

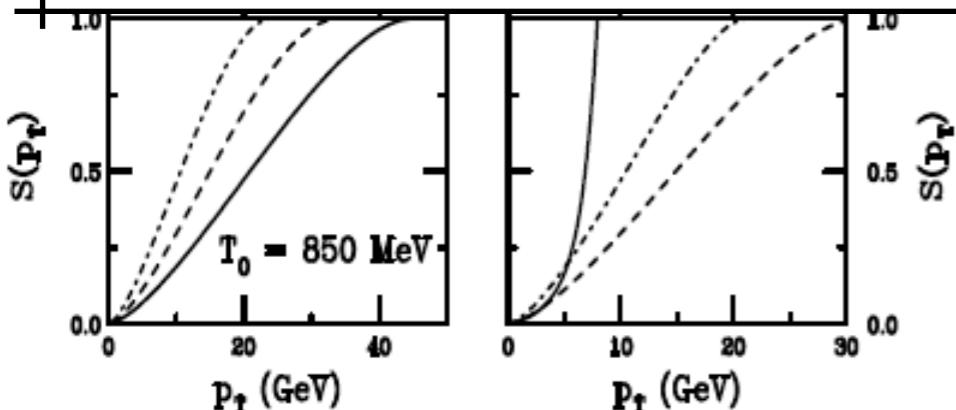
Quarkonium: predictions



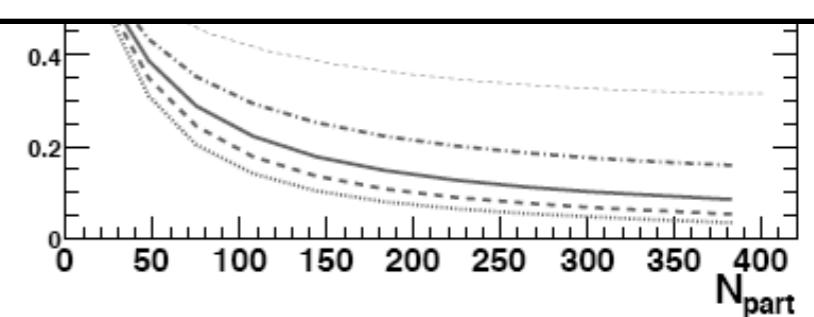
Andronic et al.'10:
strong regeneration
(FONLL $\sigma^{cc\bar{c}}$); Thews



- Considerable uncertainties both in the production and in the suppression mechanisms limit our predictive power.
- Lowering the energy should favor suppression over recombination.
- The uncertainties in the reference (pp at 2.76 TeV) will be large for charm and quarkonium.



screening, no
regeneration.



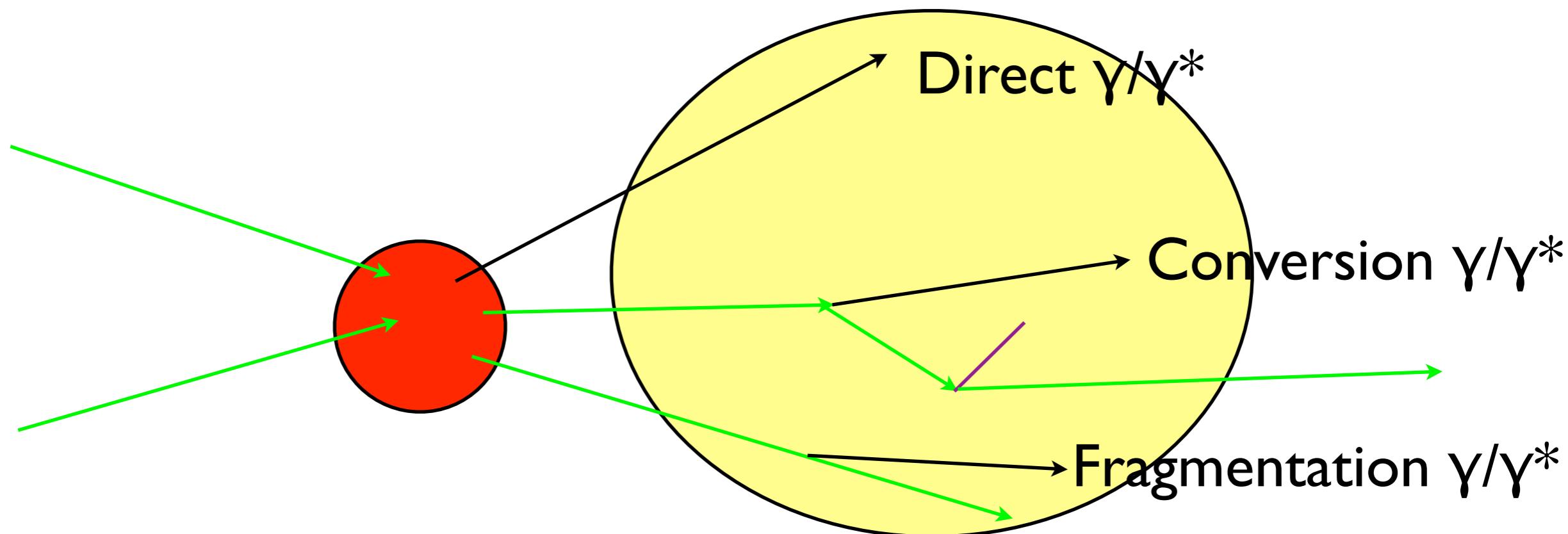
Capella et al., comovers+reco.

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Introduction:

- Photons and dileptons (**EM probes**) may be produced by decays and by **direct sources**:
 - * **Thermal (black-body) radiation, direct proof of T.**
 - * From the hard parton scattering: benchmark.
 - * From fragmentation of partons: affected by medium.
 - * From jet conversions: determined by the medium.

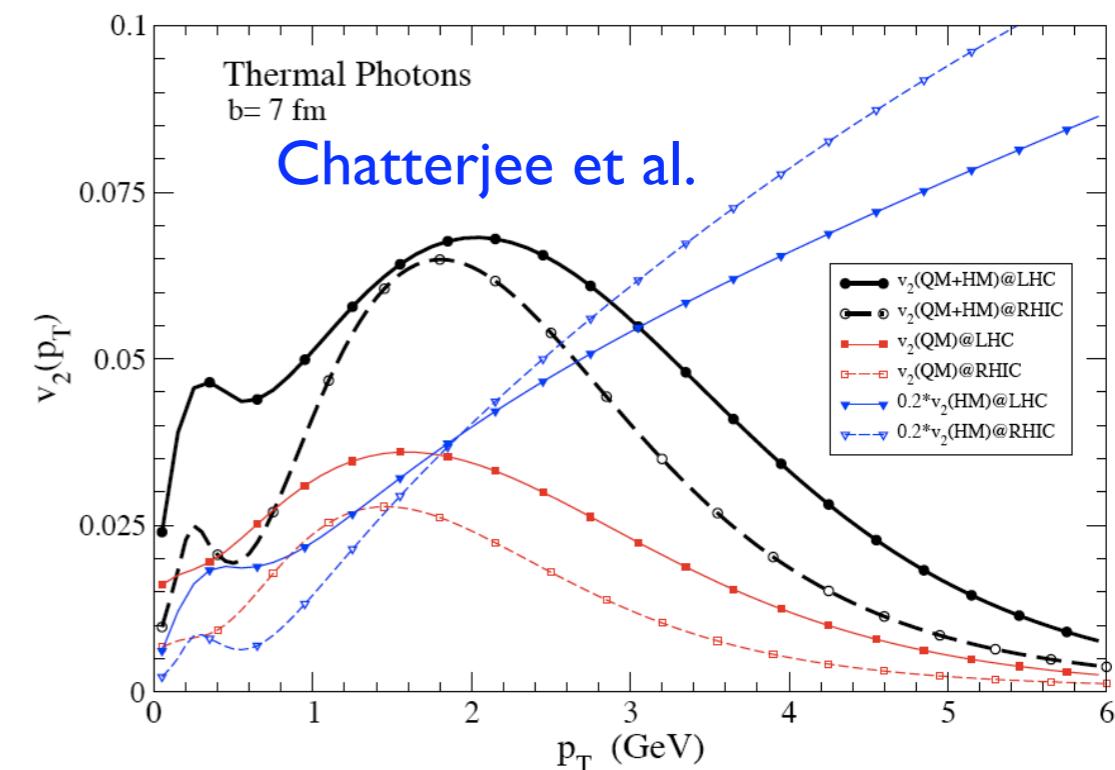
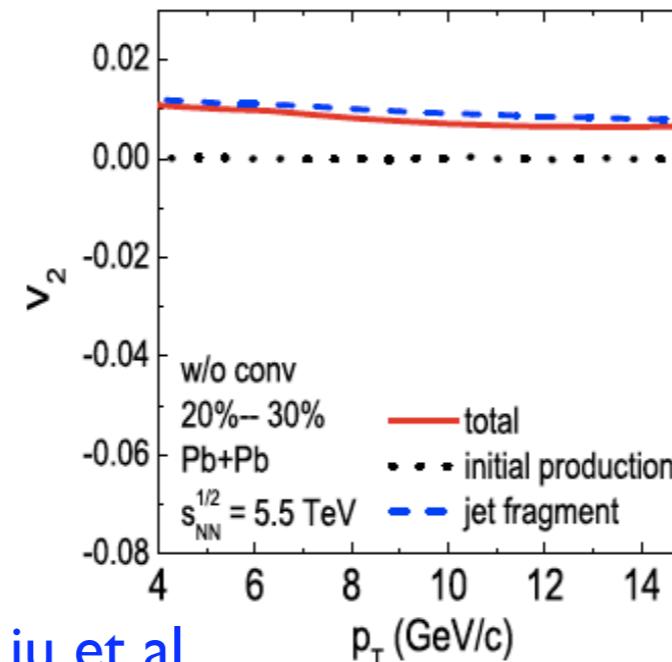
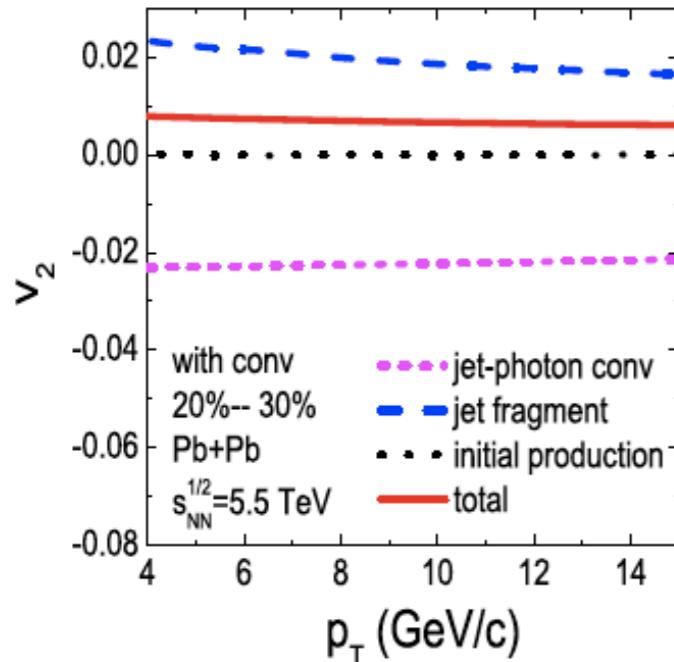
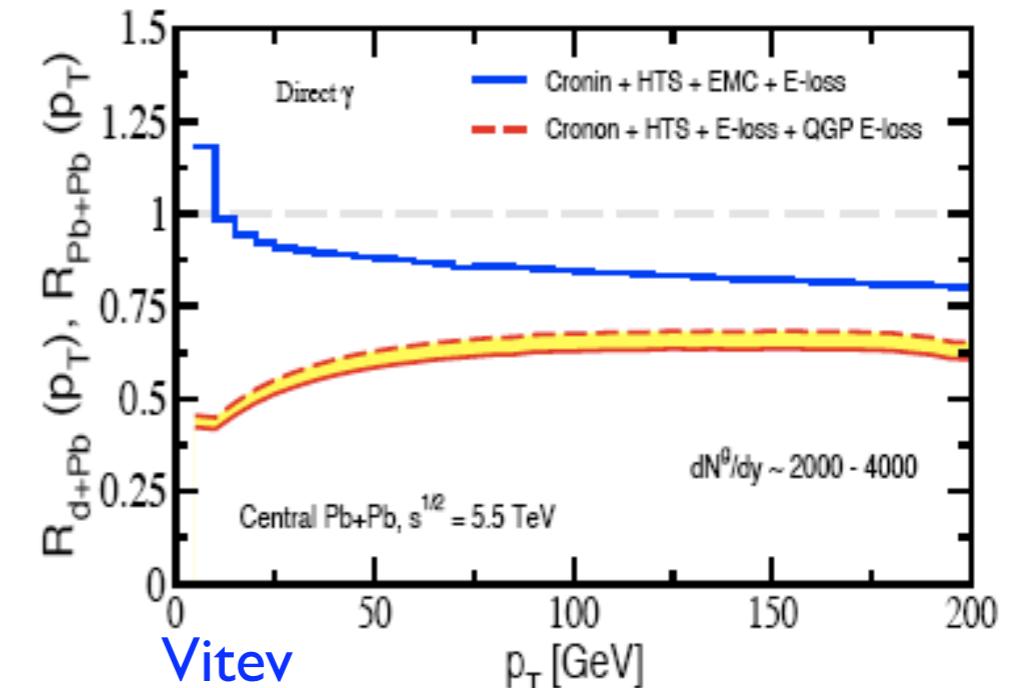
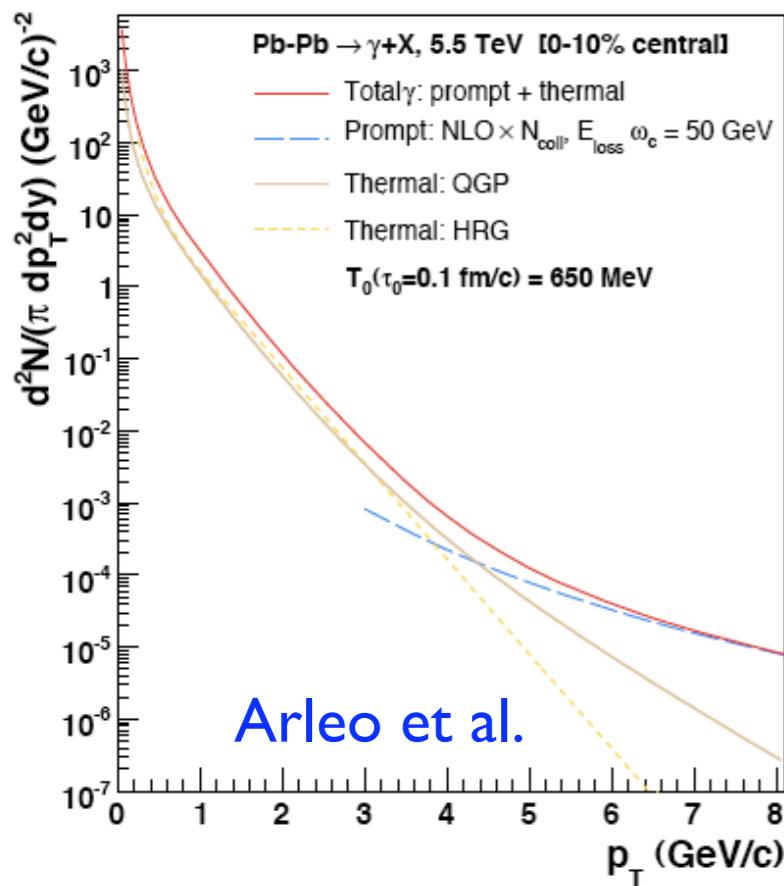


- All these mechanisms have to be implemented within a realistic medium model: density and evolution.

Photons:

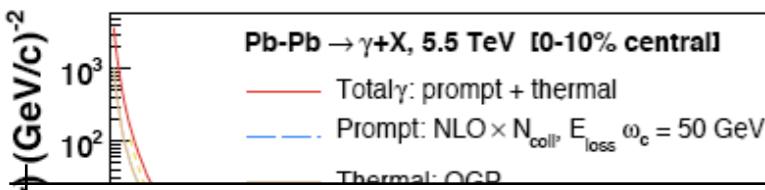
High p_T : quenching in fragmentation (also Arleo).

Low p_T : new
effects e.g.
conversions,
thermal,...
expected (also
Rezaeian et al.).



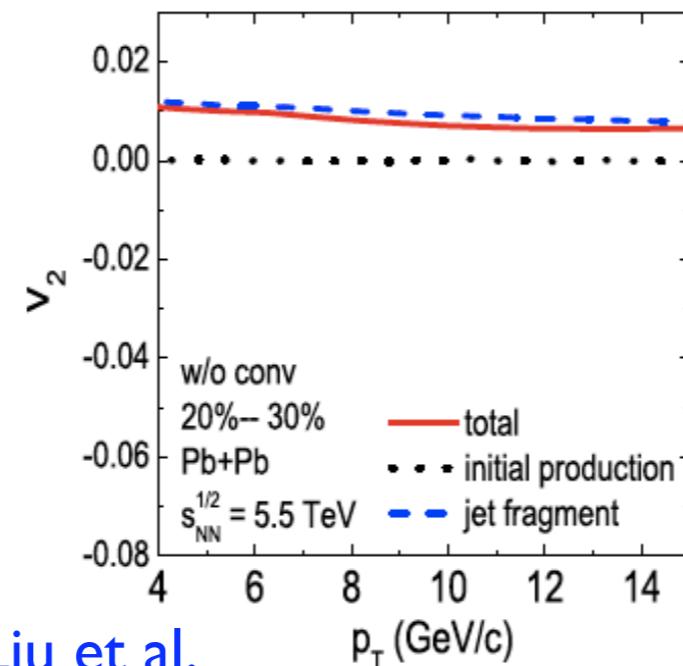
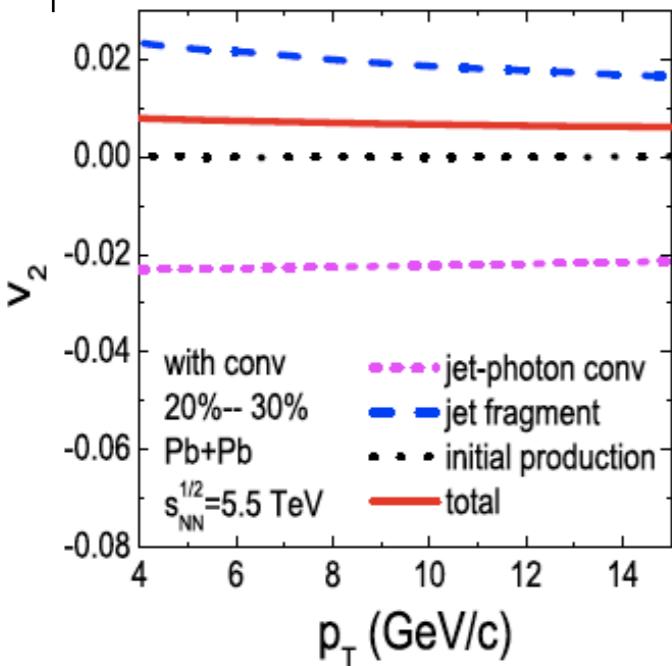
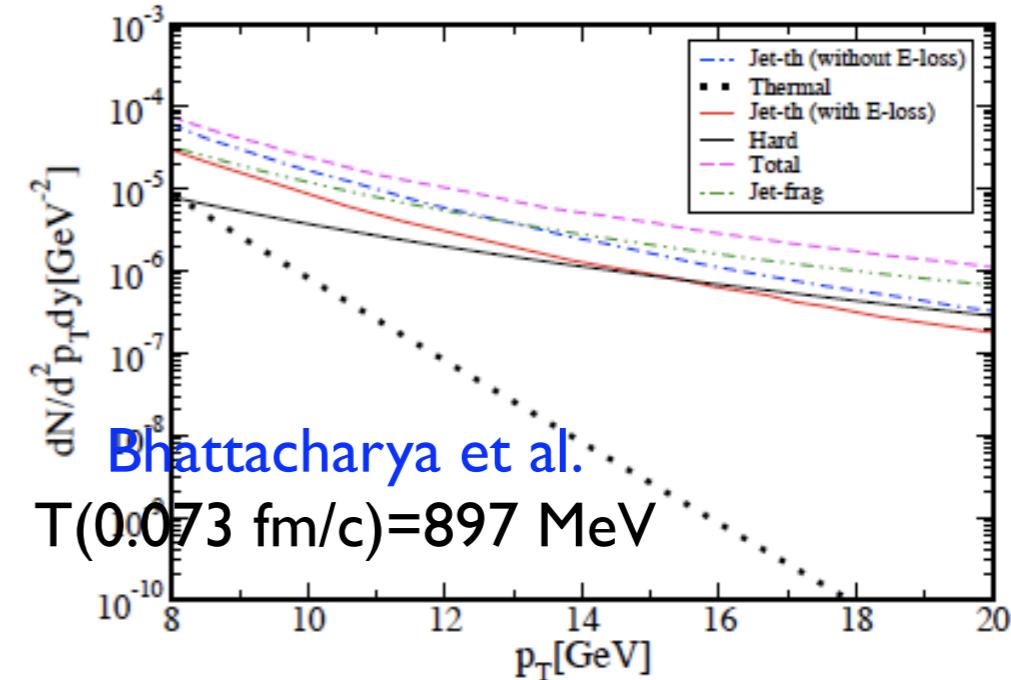
Photons:

High p_T : quenching in fragmentation

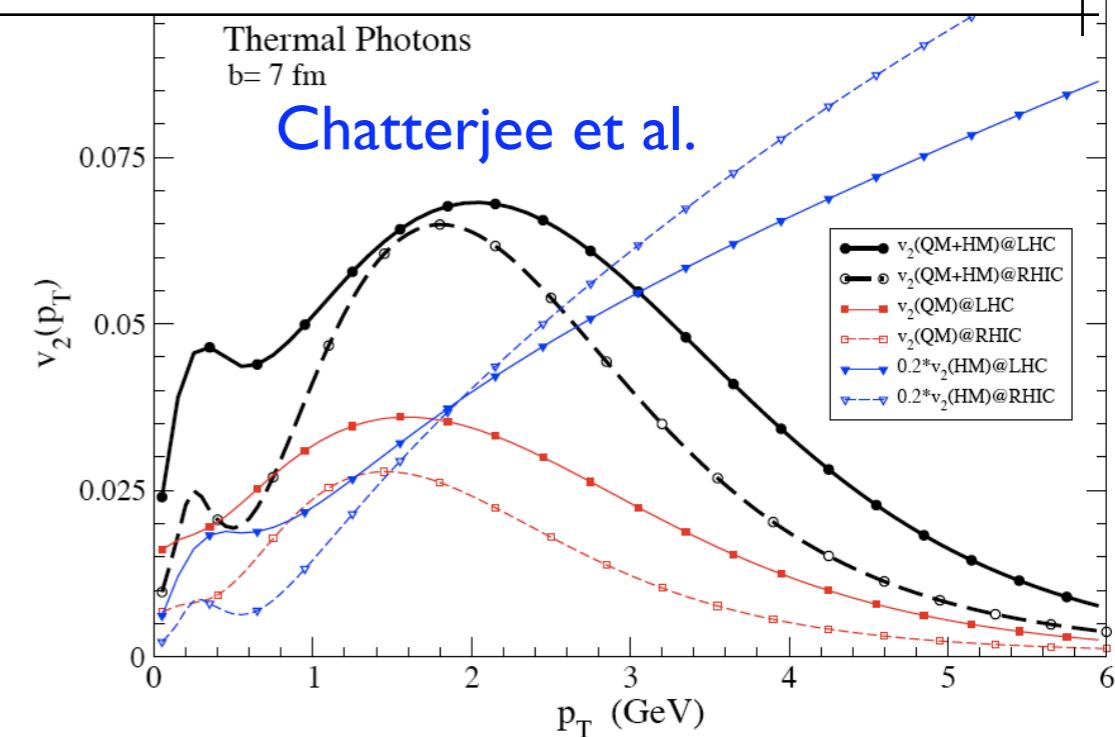


- At the LHC, all the regions up to very high p_T can be studied.

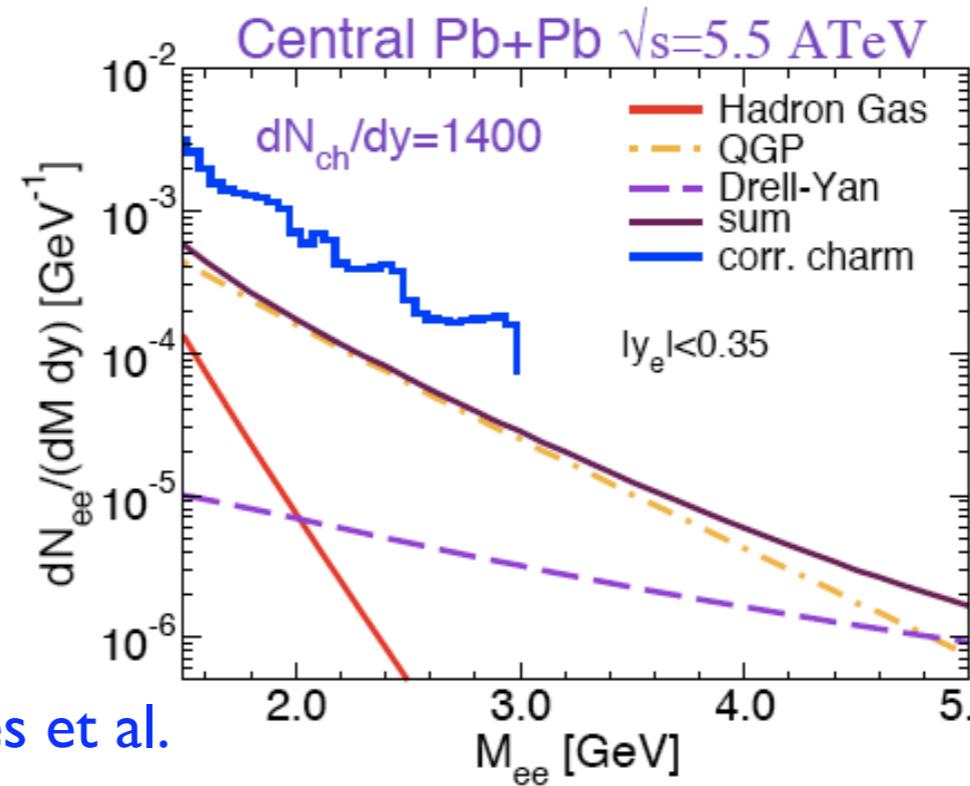
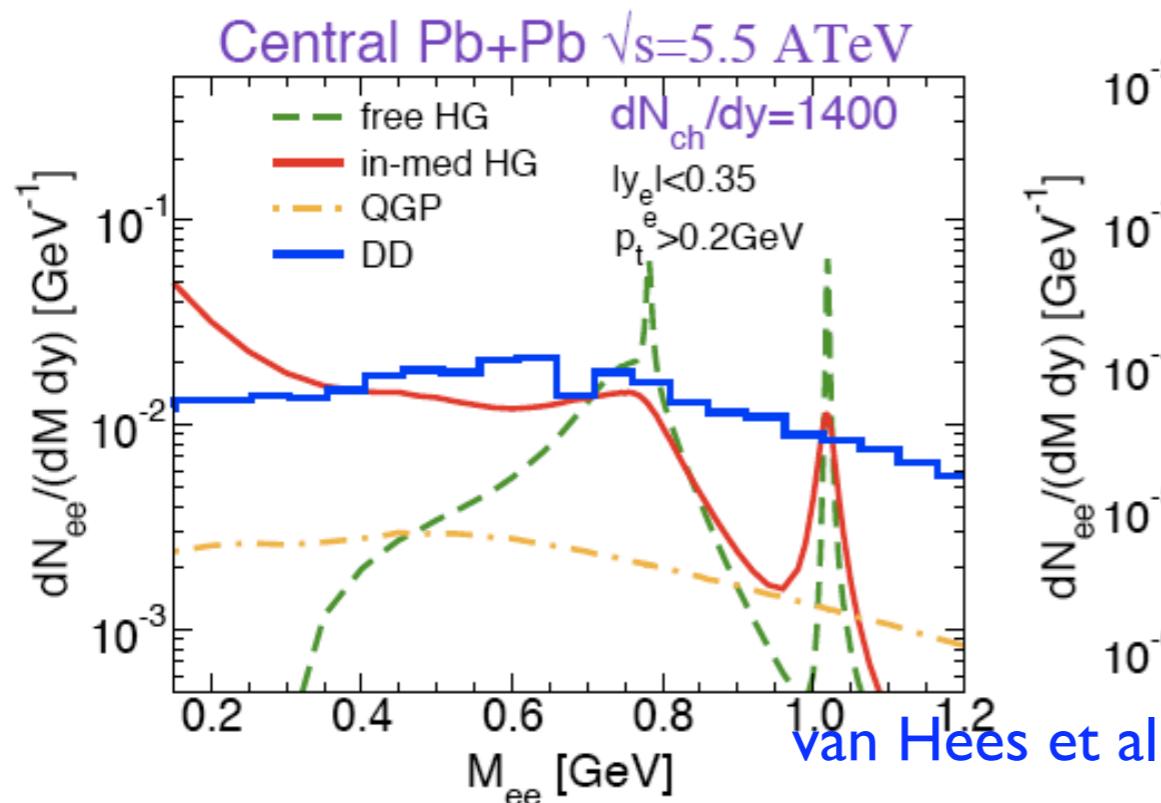
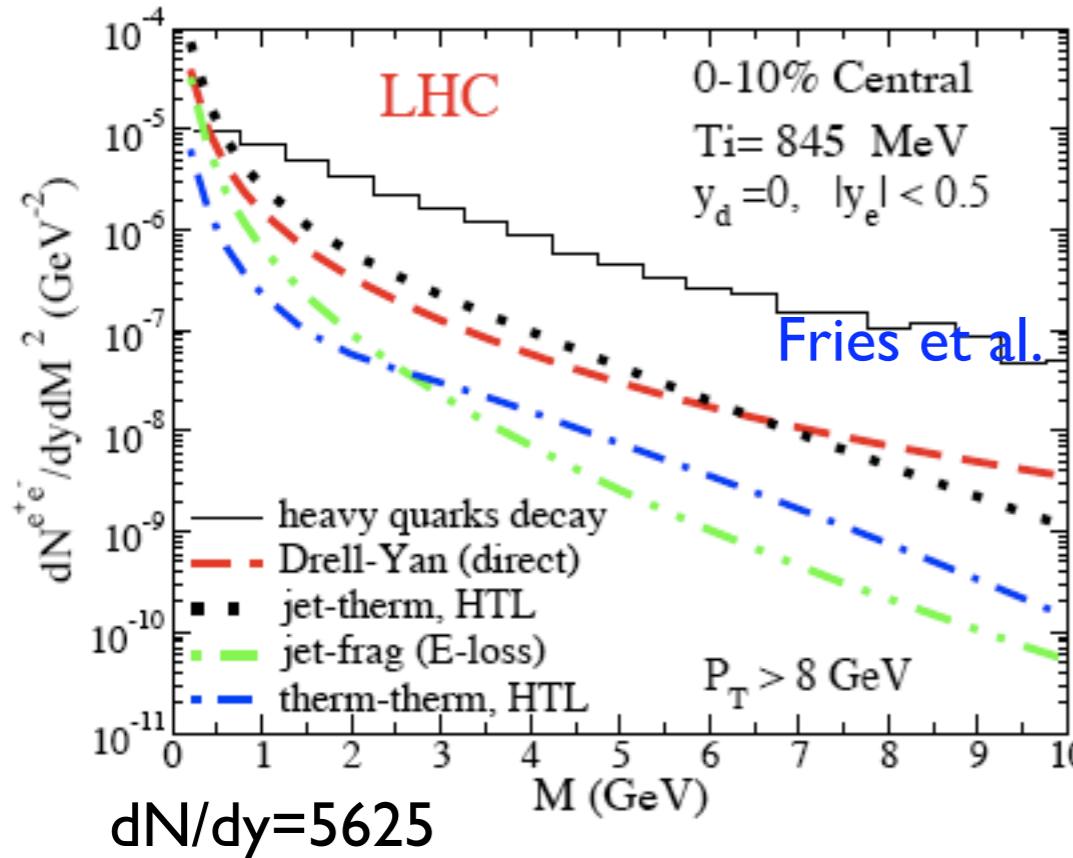
- Control of the benchmark, from pp to PbPb, key to disentangle thermal production.



Liu et al.



Dileptons:



- Both low and high M and p_T required to disentangle different mechanisms.
- But the huge HQ contribution looks really challenging.
- Anisotropies in the initial stage increase the yields of both γ and I^\pm (Martinez et al., Bhattacharya et al.).

- $E \downarrow$ decreases both signal (T \downarrow) and background.

9. Summary:

Observable at RHIC	Standard interpretation	Prediction for the LHC
Low multiplicity	Strong coherence in particle production	$dN_{ch}/d\eta _{\eta=0} < 1700$ for central collisions
v_2 in agreement with ideal hydro	Almost ideal fluid	Similar or smaller $v_2(p_T)$
Strong jet quenching	Opaque medium	$R_{AA}(20 \text{ GeV}) \sim 0.1 - 0.2$ for π^0

- Most valuable information will come from the very first day!!!
- A good amount of predictions is ready to be confronted to data. From their success or failure we will enlarge substantially our knowledge about both the medium and how to treat the probes.
- Still a lot of theoretical work is needed e.g. to deal with jets.

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- Apologies to those whose predictions I may have skipped!!!
- Thanks a lot to Andrea, David, Guilherme, Javier, Jorge, Kari, Peter and Urs for information and discussions!!!
- A good amount of **predictions** is ready to be confronted to data. From their **success or failure** we will enlarge substantially our knowledge about both the medium and how to treat the probes.
- Still a lot of theoretical work is needed e.g. to deal with jets.