Diffraction Modeling in EPOS

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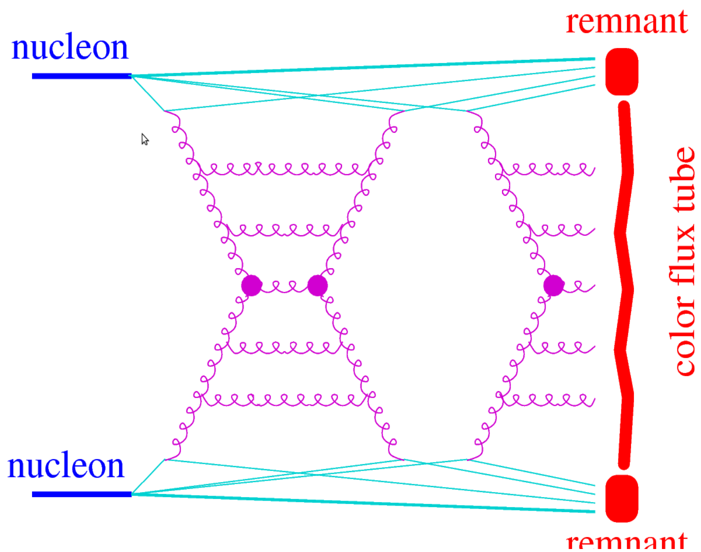
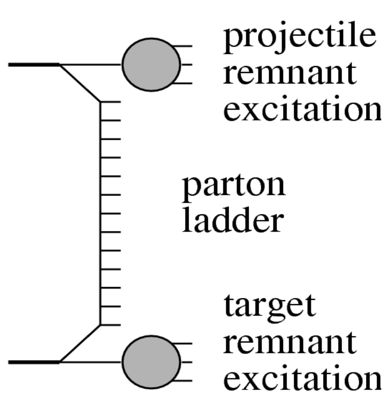
Outline

- **The EPOS model**
- **Diffraction in EPOS**
  - Cross Section
  - Low mass diffraction
  - High mass diffraction
- **Remnants in EPOS**
- **Data comparison**
  - Overview
  - Diffraction
  - LHC

The EPOS Model





EPOS* is a parton model, with many binary parton-parton interactions, each one creating a parton ladder.

- Energy-sharing : for cross section calculation AND particle production
- Parton Multiple scattering
- Outshell remnants
- Screening and shadowing via unitarization and splitting
- Collective effects for dense systems

EPOS can be used for minimum bias hadronic interaction generation (h-p to A-B) from 100 GeV (lab) to 1000 TeV (cms) : used for air shower !

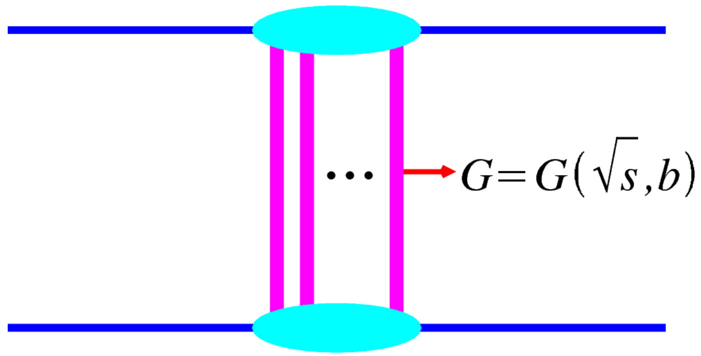
EPOS designed to be used for particle physics experiment analysis (SPS, RHIC, LHC)

*T.Pierog, S. Porteboeuf and K. Werner

EPOS : History

- **Evolution of models by K. Werner et al. :**
  - VENUS (93) : soft physic
  - NEXUS 2 (00): first realization of Parton-Based Gribov-Regge Theory (PBGRT) with soft, semi-hard and hard Pomerons
    - No screening
  - NEXUS 3.97 (03) : enhanced diagrams in PBGRT and new remnant treatment.
    - No Cronin effect and problems at high energy
  - EPOS (06) : PBGRT + remnants + Effective treatment of higher order effect and high density effect + new diffraction ...
    - Simplified collective effect
    - Only min-bias
  - EPOS 2 : 2010 ?
    - High mass diffraction
    - Real event by event hydro calculation (includ. pp)
    - Selection of hard processes (UE)

Gribov-Regge Based Models



Multiple elementary scattering

- **Using Gribov-Regge** (GR) : cross section from optical theorem :

$$\sigma_{ine}(\sqrt{s}) = \int d^2 b (1 - \exp(-G(\sqrt{s}, b)))$$

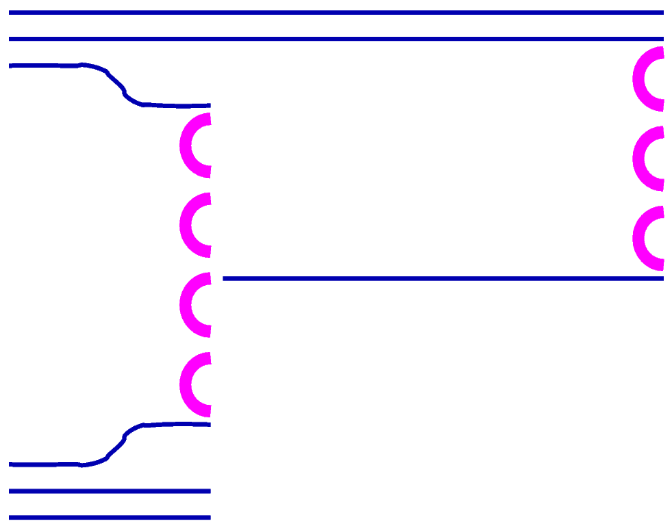
where G(energy,impact parameter) = elementary interaction

- Probability for the number of interaction per event

Successful description of hadronic cross-sections
But
Energy conservation NOT considered between the elementary interactions G

No possibility to deduce directly particle production !

Particle Production in GR based Models



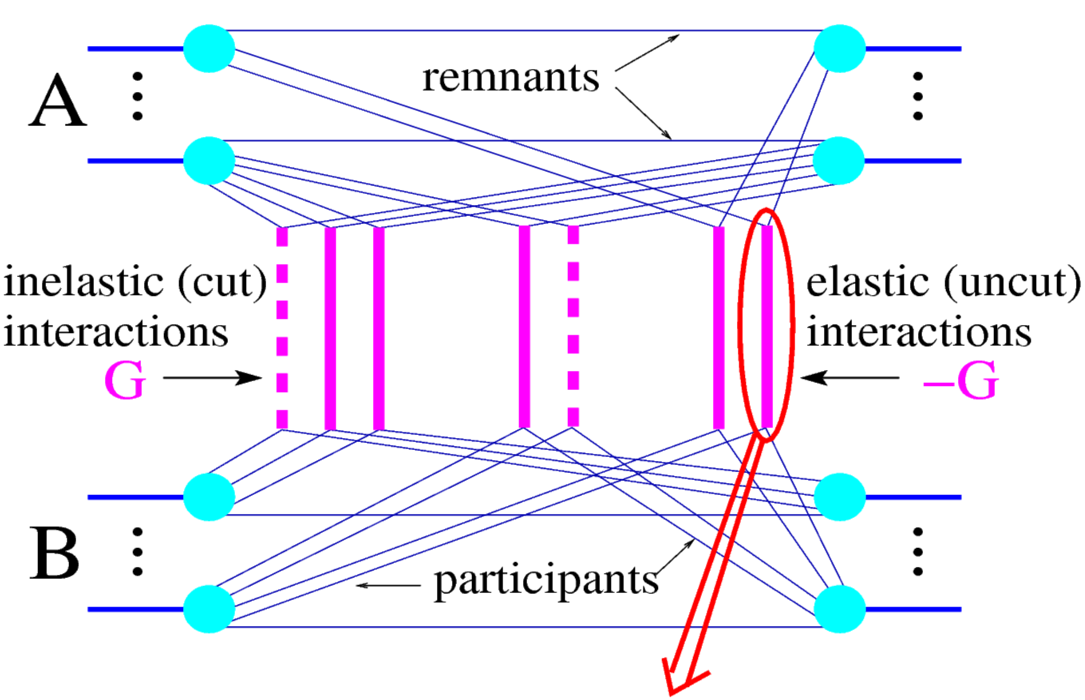
- **Number of strings from GR**
  - ➔ No energy conservation
- **Energy sharing**
  - ➔ Not consistent with cross-section
- **String fragmentation**
  - ➔ Proper energy conservation

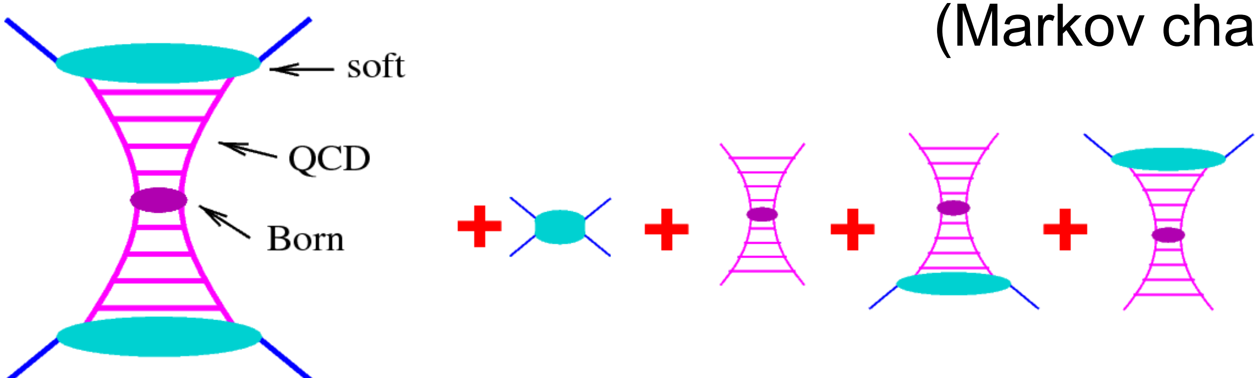
Link between cross-section and particle production lost !

Parton-Based Gribov-Regge Therory* (PBGRT) developed to solve the problem : same formalisme for cross section and particle production used first in NEXUS and now in EPOS

* H.J. Drescher et al., Phys.Rep. 350:93-289 (2001)

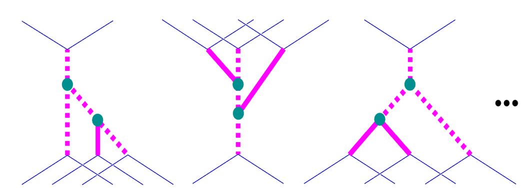
Parton-Based Gribov-Regge Theory





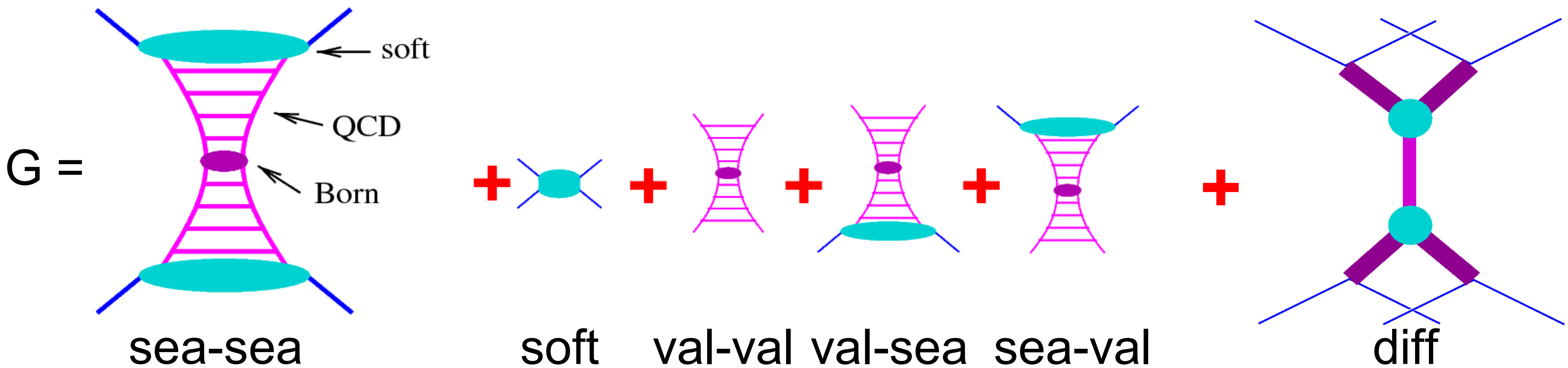
- **Energy sharing at the cross section level**
  - Energy shared between cut and uncut diagrams
  - Reduced number of elementary interactions
  - Generalization to (h)A-B
  - Particle production from momentum fraction matrix (Markov chain metropolis)

Non-linear effect (screening) absorbed in modified vertex functions

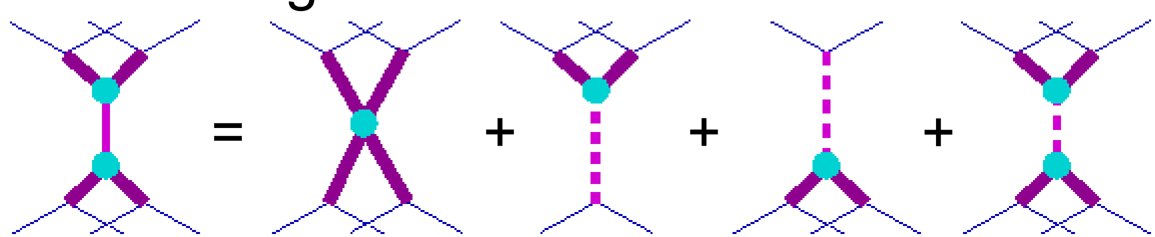


Diffraction in PBGRT

- **Using the same formalism**
  - Diffraction from an additional diagram



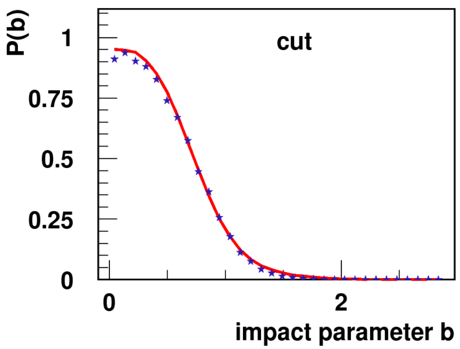
  - Same form as soft (Regge pole) but with different amplitude and width
  - Low mass and high mass diffraction from the same diagram

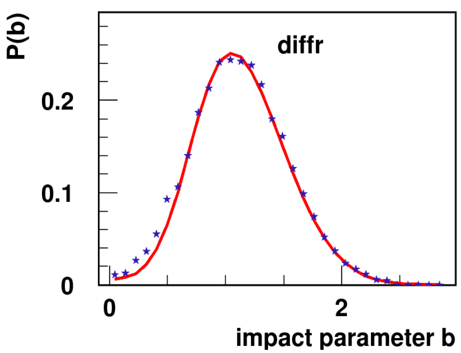


  - Parameters extracted from single diffractive (SD) cross-section
  - Events with only “diff” type diagrams are diffractive
    - Additional excitation probability for remnants (~75%)

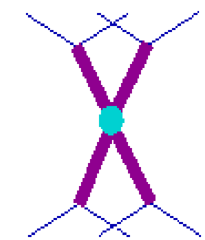
Low Mass Diffraction

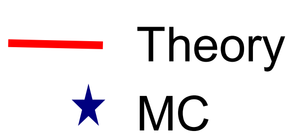
Diffractive event = event with only cut diff. diagrams

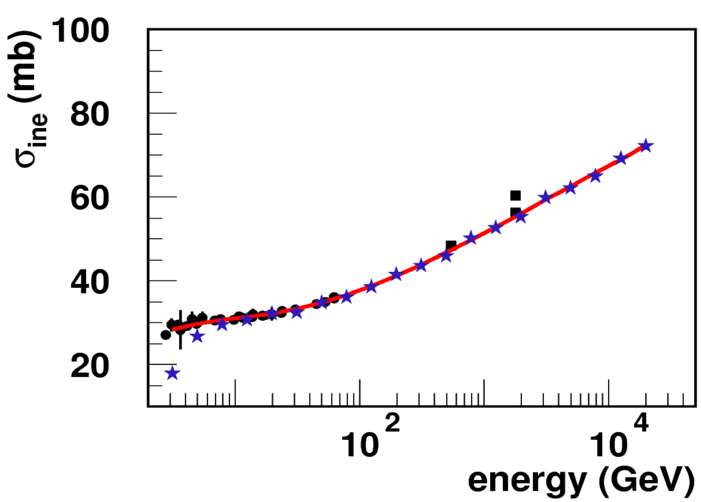


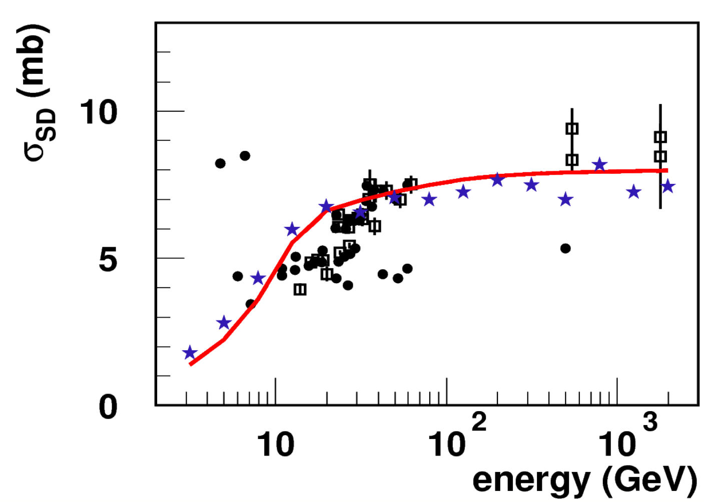


- Multiple cut-diff diagrams possible
- For each cut-diff diagram probability P_{dif} not to excite remnant
  - More cut-diff = more excitation : $(1-P_{dif}^{n})$
  - Important in pA
- No particle production directly from diagram
- P_{dif} (~0.25) fixes SD, DD (or elastic) probability.

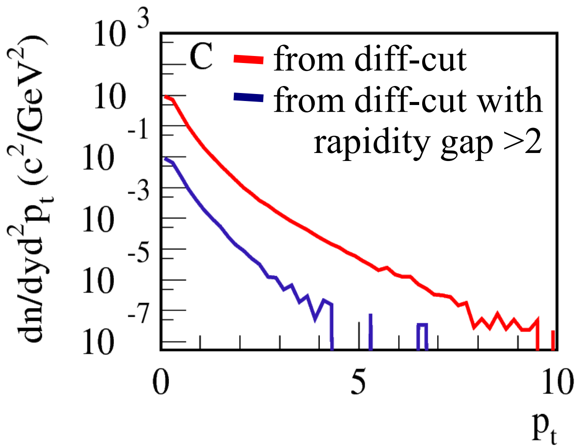








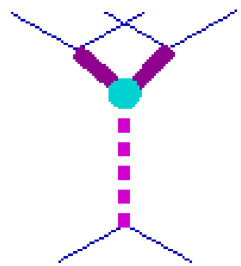
High Mass Diffraction



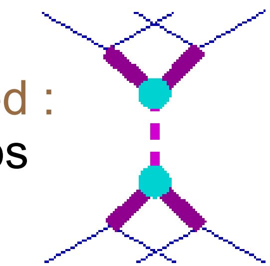
Same scheme but with particle production

- Do not change cross-section
- For each cut-diff probability P_{HM}(mass,b,...) to remain as real (soft or semi-hard) cut diagram
- 0, 1 or 2 rapidity gap depending on P_{dif}

Projectile not excited :
1 rapidity gap

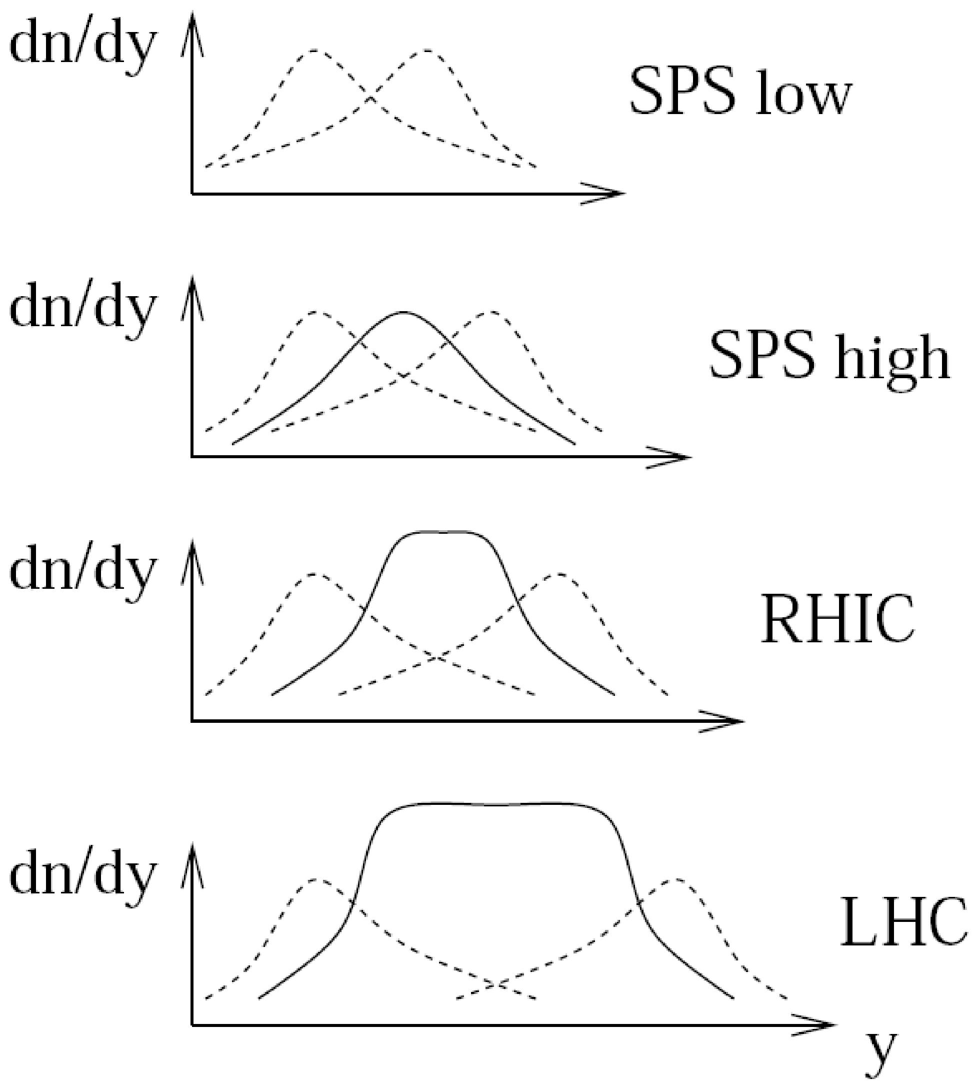


Projectile and target not excited :
2 rapidity gaps



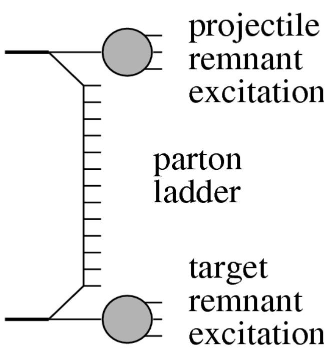
- Additional multiplicity contribution in ND events
- Work in progress

Remnants



High mass remnants in EPOS:

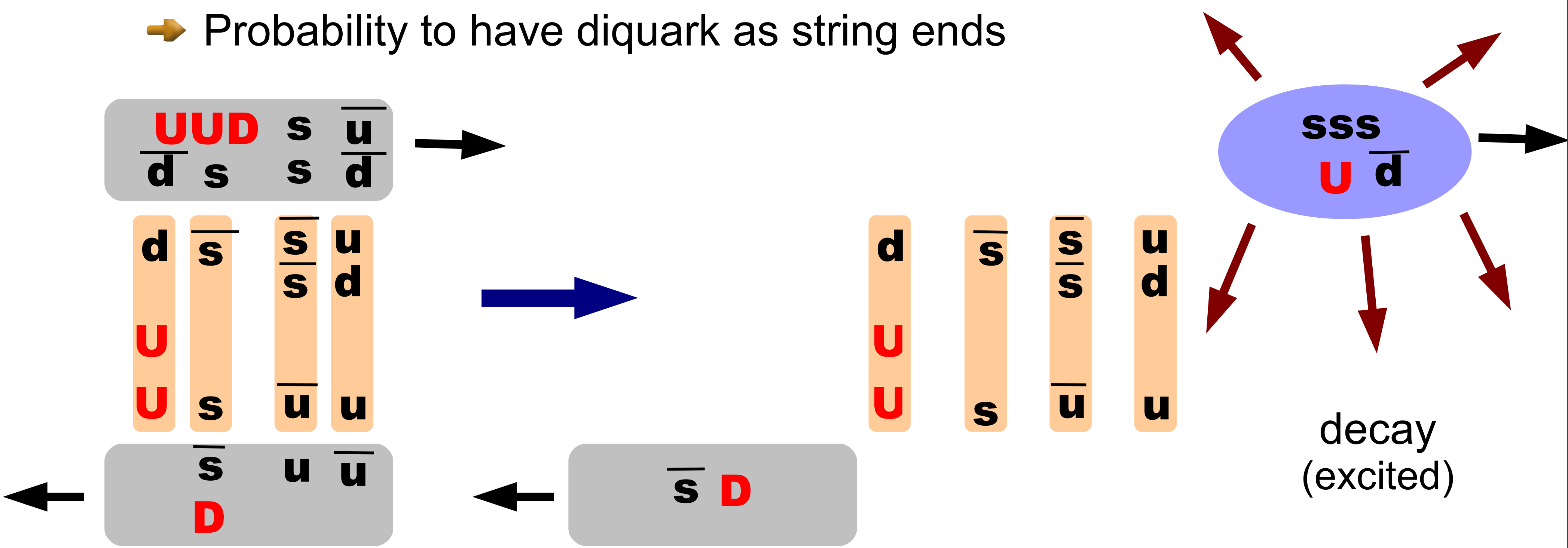
- from both diffractive or inelastic scattering
- excited state with $P(M) \sim 1/(M^2)^\alpha$
- very large contribution at low energy
- forward region at high energy
- depending on quark content and mass (excitation):
  - resonance
  - string
  - droplet (if #q>3)
  - string+droplet



Quark Transfer in Remnants

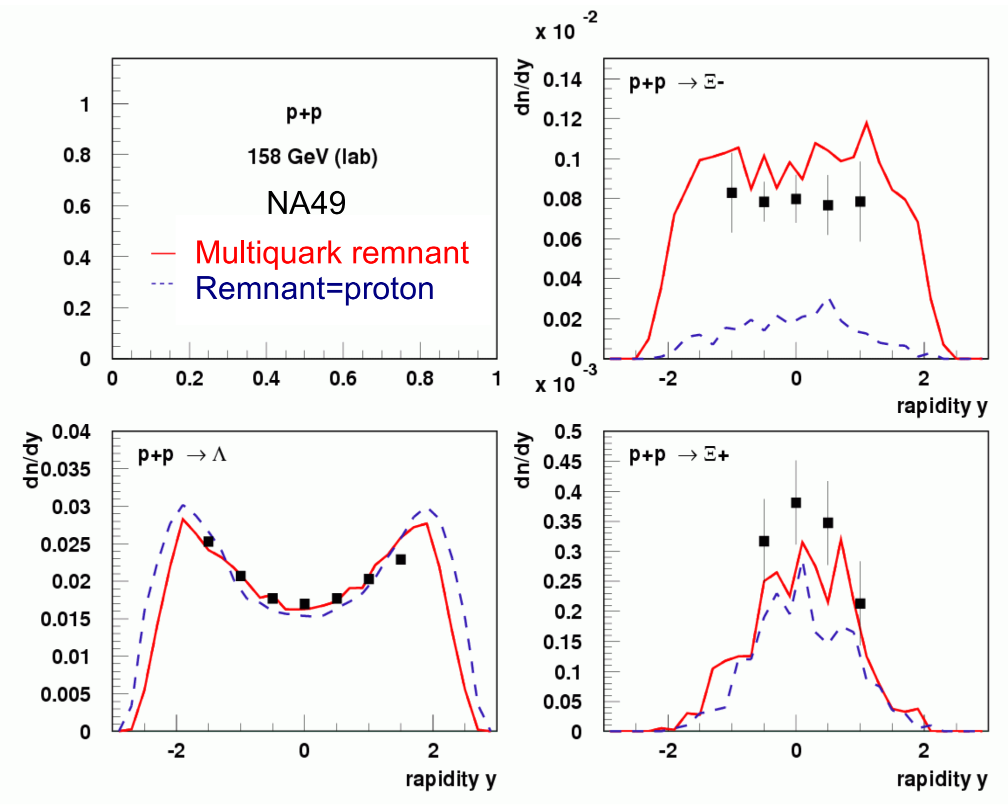
No a priori for string ends (SE) of parton ladder

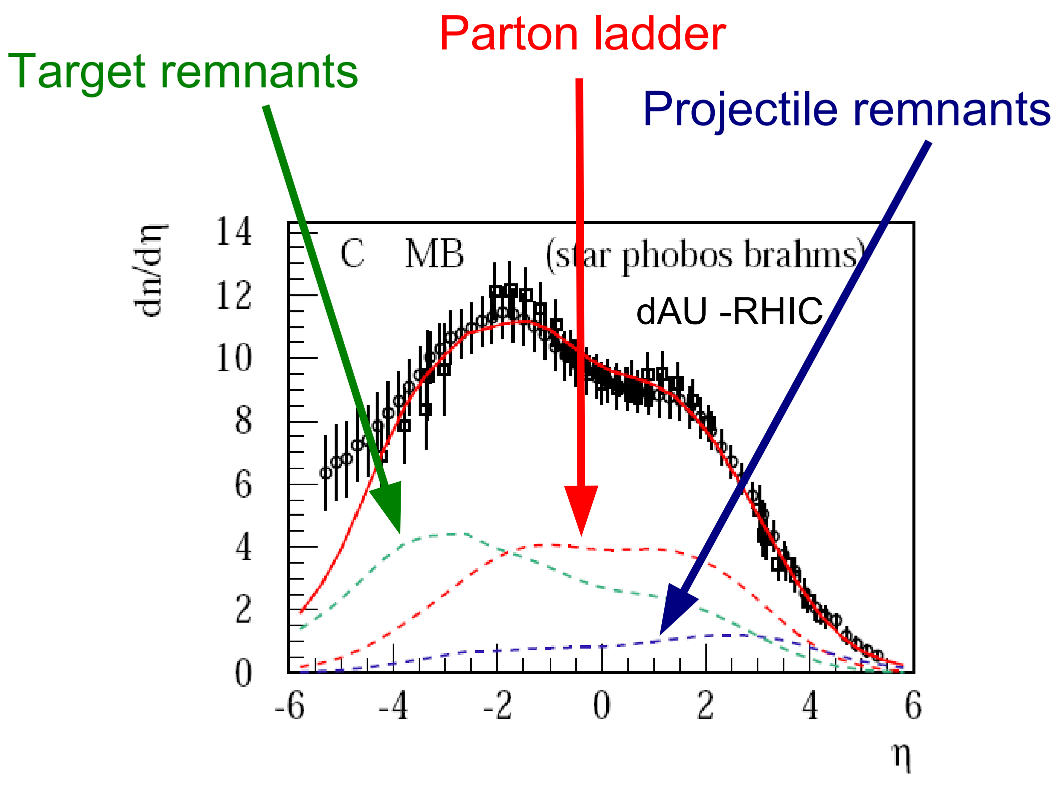
- No “first string” with valence quarks : all strings equivalent
  - Sea quarks pair production for string-ends
- Valence diquark transfer from remnant to SE can be controlled
  - Baryon stopping
- Wide range of excited remnants (from light resonances to heavy quark-bag)
- Probability to have diquark as string ends



Properties of Free Remnants

- **Valence quark not necessarily connected to parton ladder :**
  - Necessary to have aΩ/Ω < 1 (NA49 data)
  - Very broad remnant distribution
  - Can be used to describe effective enhanced diagrams (higher mass)
  - Very important for Cosmic Ray (leading particle)



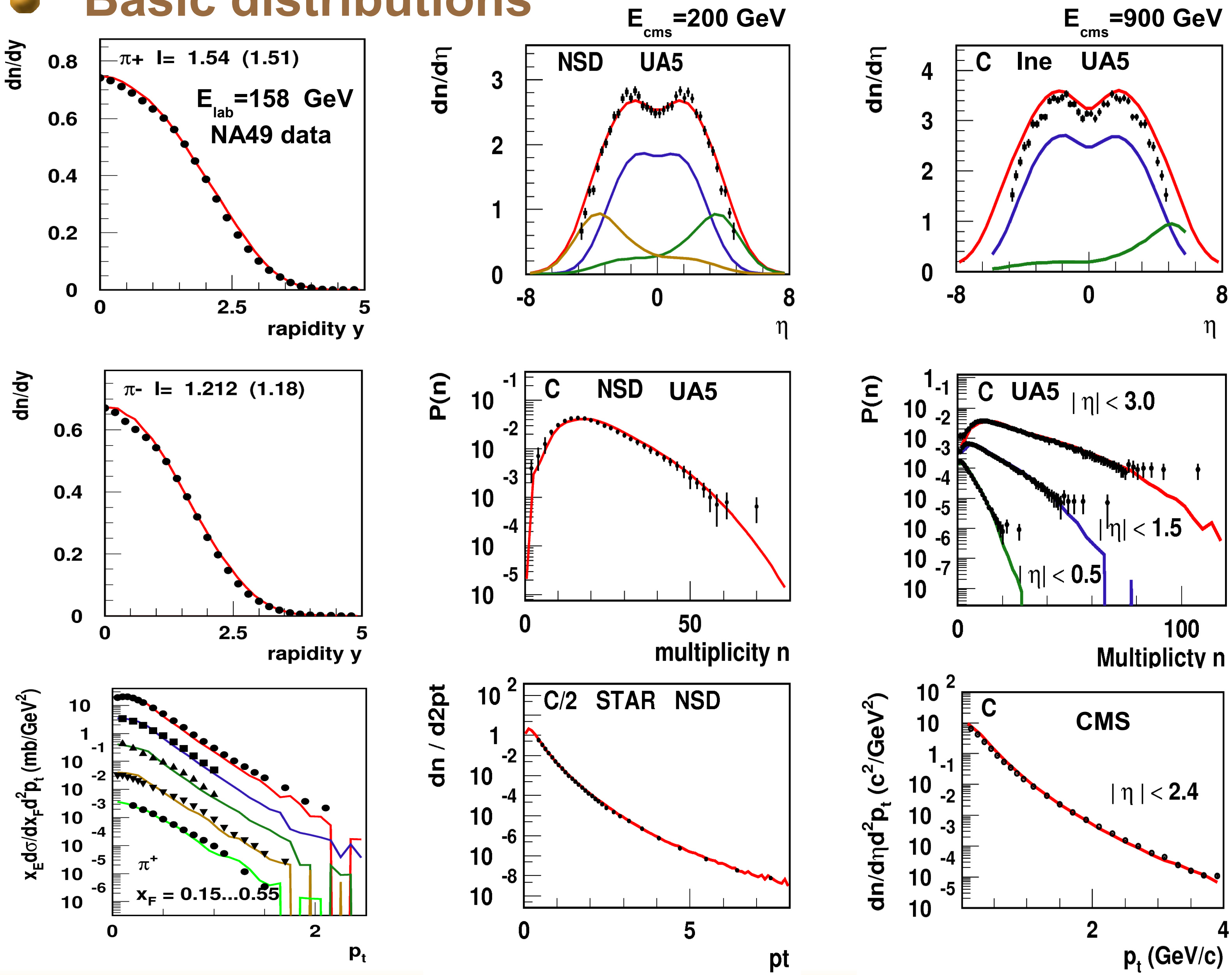


Parameters

- **Data used to constrain parameters:**
  - string fragmentation : e+e- data,
  - hard Pomeron : DIS data,
  - soft Pomeron and vertices : pp,πp,Kp, pA cross sections
  - diffraction : pp low energy diffraction and multiplicity distributions
  - excitation functions : multiplicity in pp from SPS to Tevatron,
  - string ends and remnants : NA49 data
  - collective and screening effects : RHIC
- **One set of parameters for all energies**
  - not designed to be tuned by users

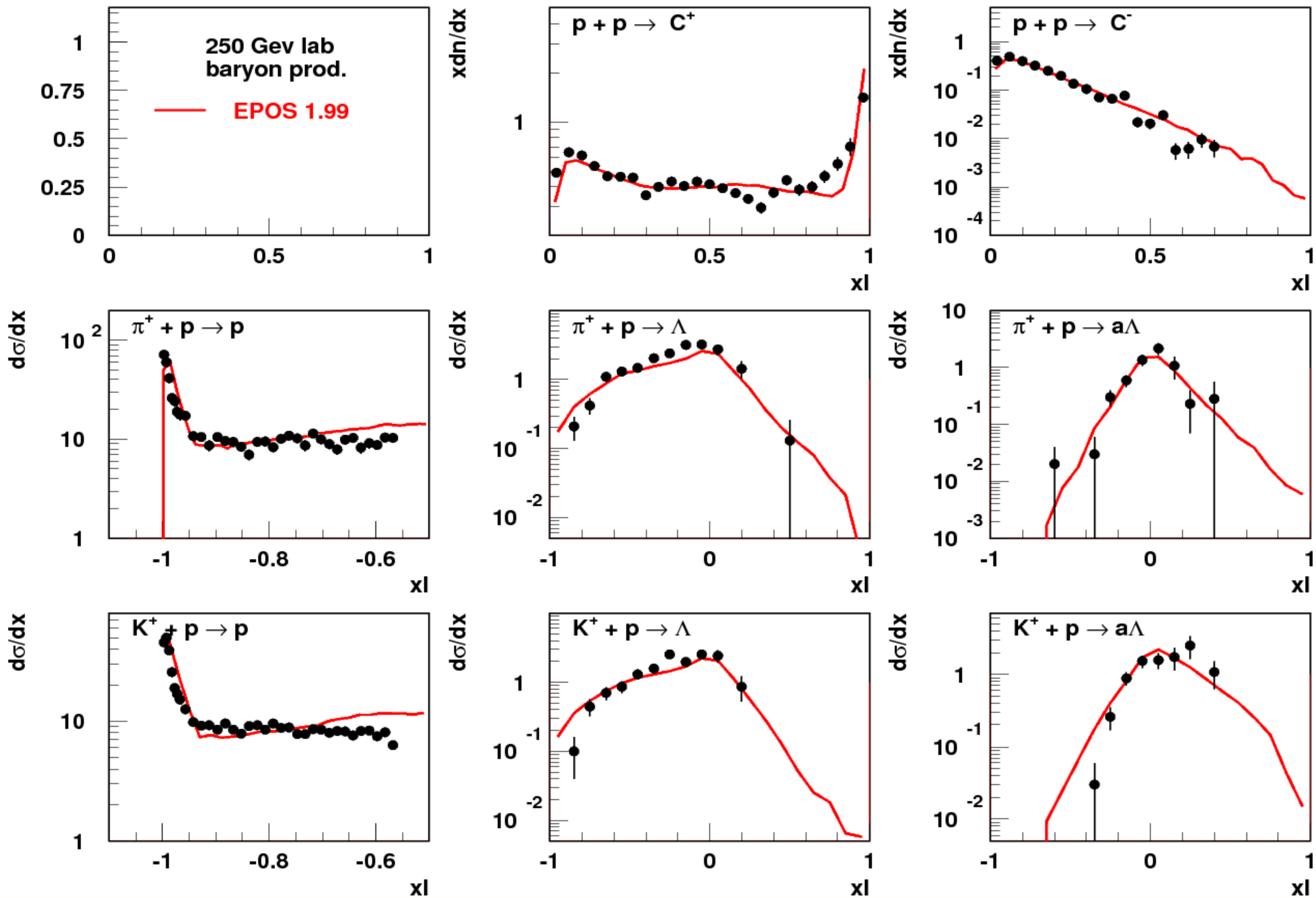
Results Overview (1)

Basic distributions



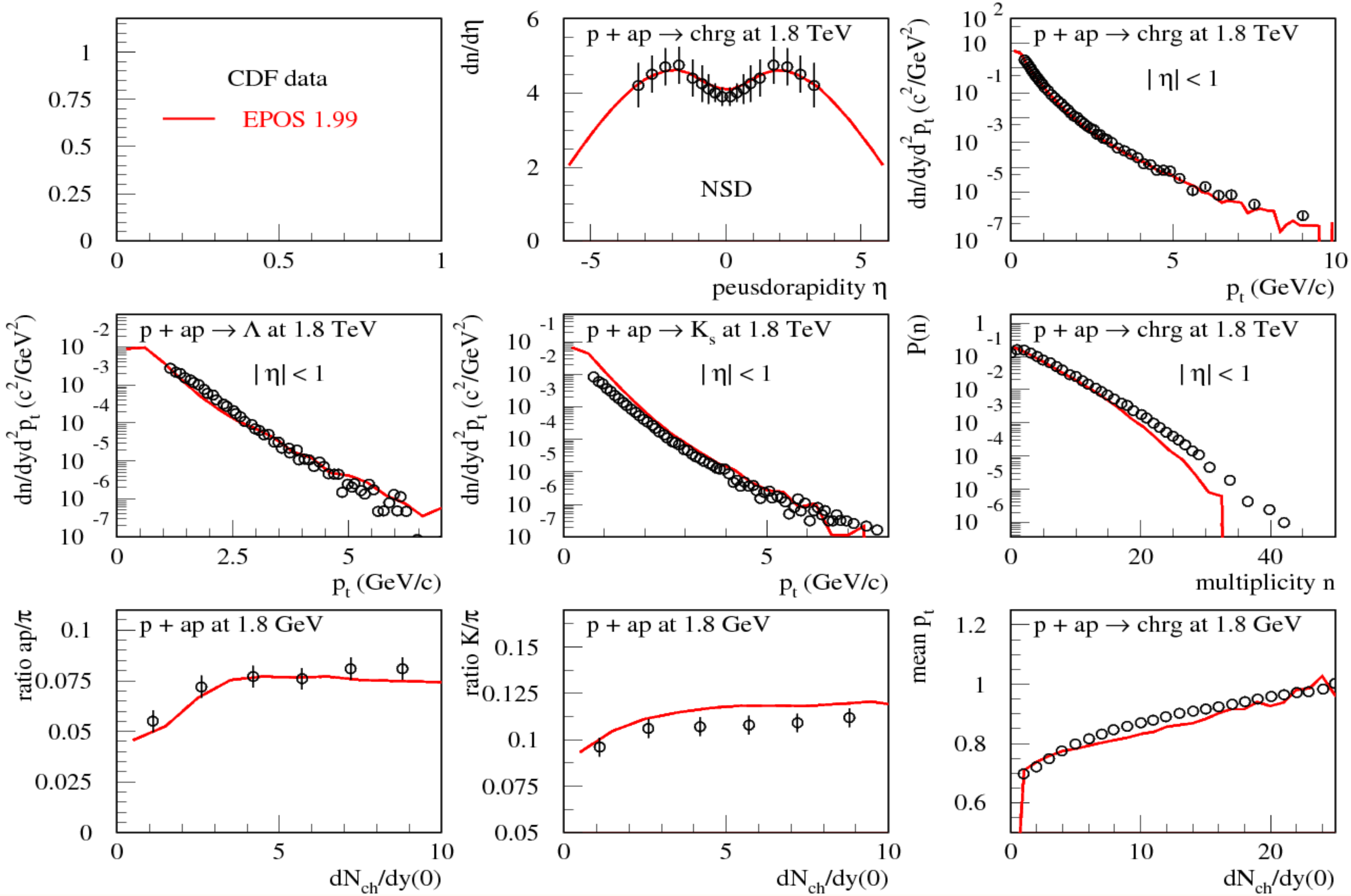
Results Overview (2)

- **Baryon production for fixed target exp.**



Results Overview (3)

- **(Some) TEVATRON data**

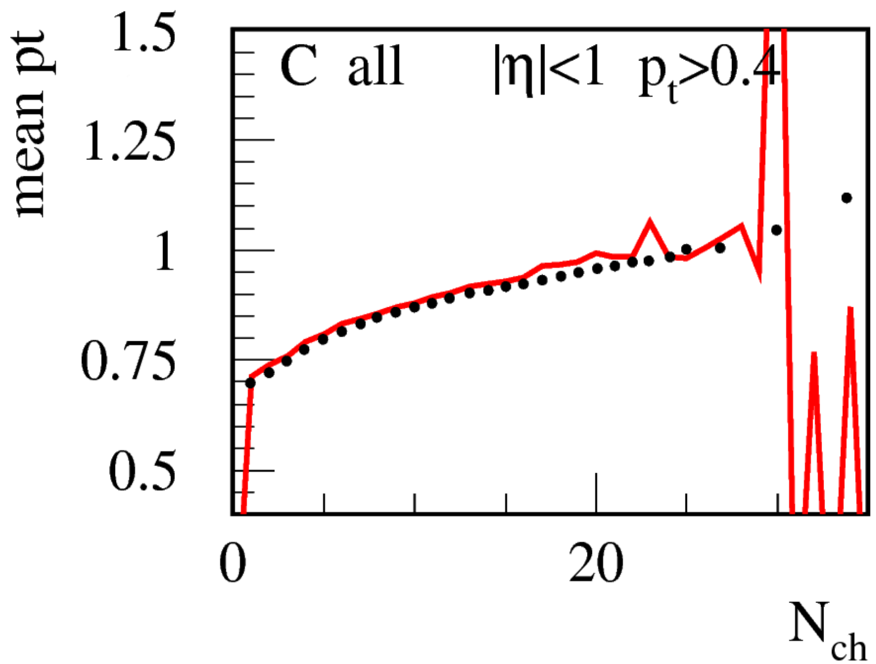


$<p_t>$ vs multiplicity

- **Since 2007 collective effects in EPOS for any system :**
  - Minimum energy density needed to start formation of "core clusters"
  - Microcanonical decay with additional flow
  - Flow parametrized from SPS HI, RHIC HI and Tevatron ap-p

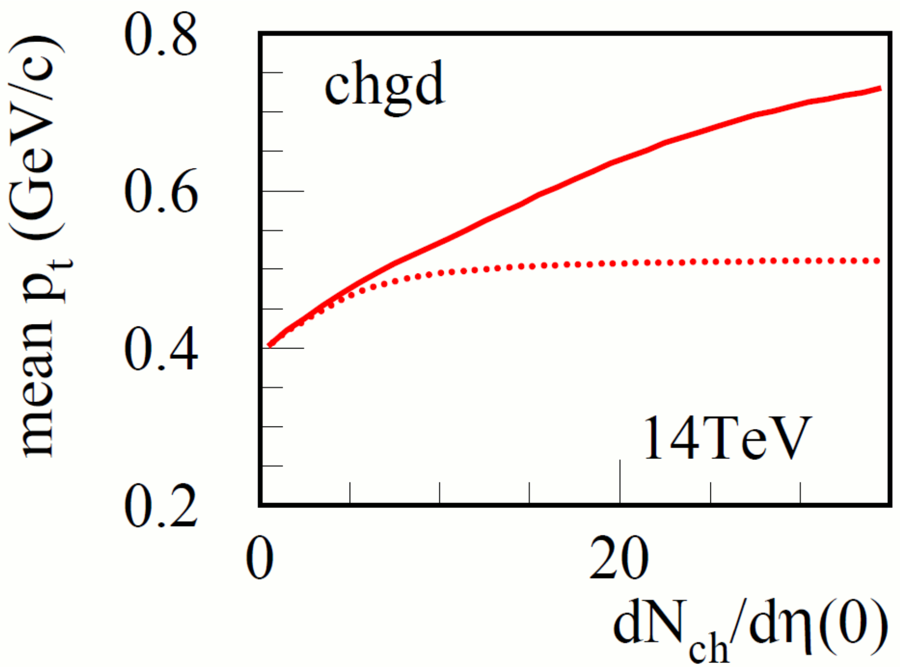
K. Werner
Phys.Rev.Lett.98:152301,2007.

ap-p 1.8 TeV (fit)



p-p 14 TeV (prediction)

"HI at LHC : Last Call for Predictions" Armesto et al.

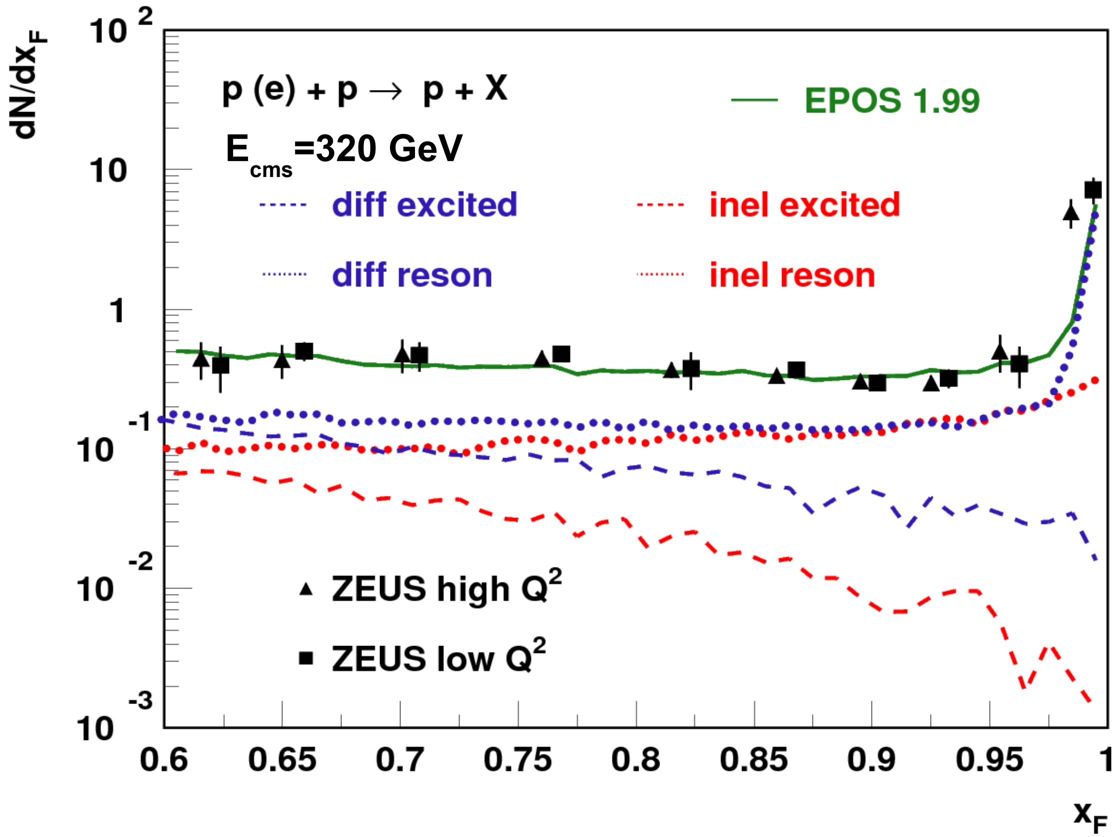


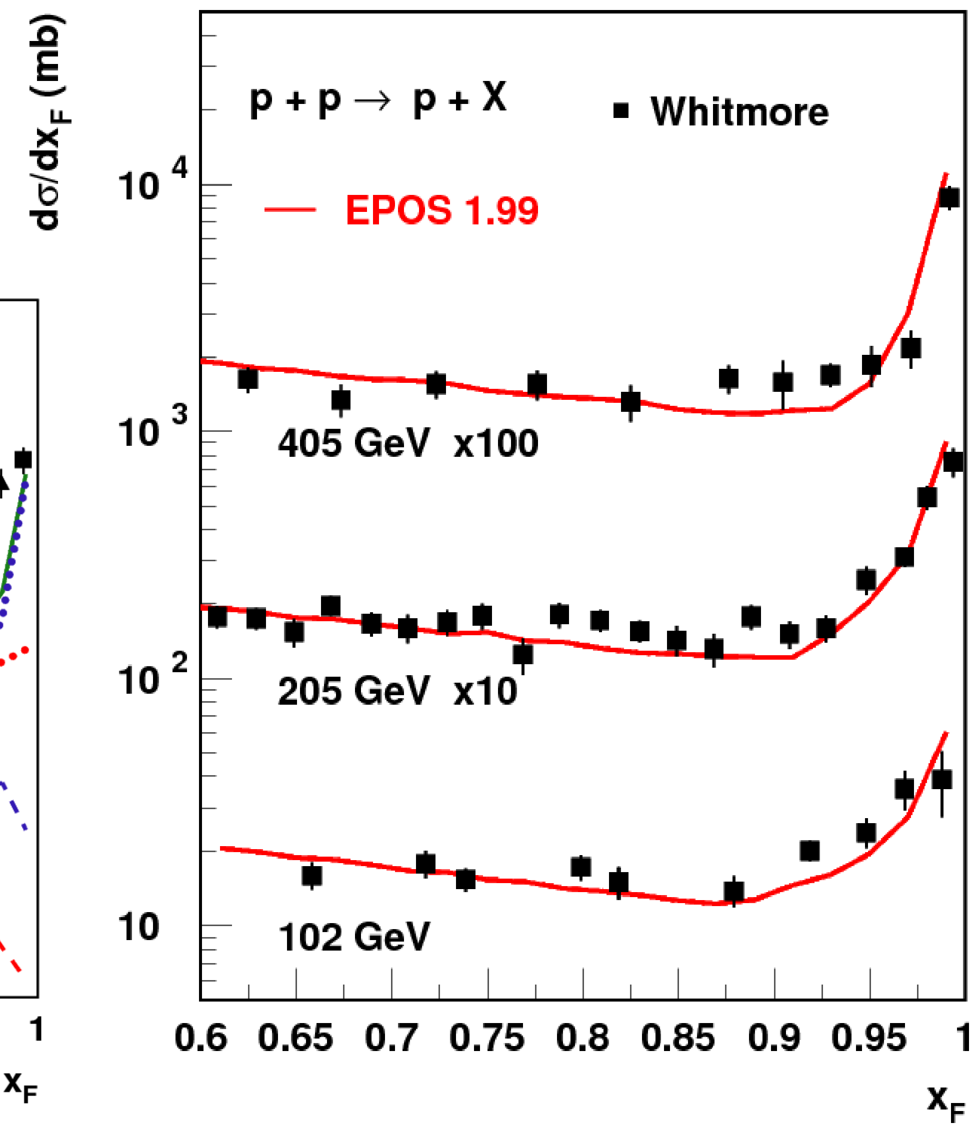
- **More development on collective effects in pp from other groups :**
  D'Enterria et al. (arXiv:0910.3029), Solana et al. (arXiv:0911.4400), Chaudhuri (arXiv:0912.2578), ...

Proton Xf Distribution

Leading proton

- Tests from 100 GeV lab to 300 GeV cms
- Very forward proton from ND events





Proton Xf Distribution

- **Leading proton**
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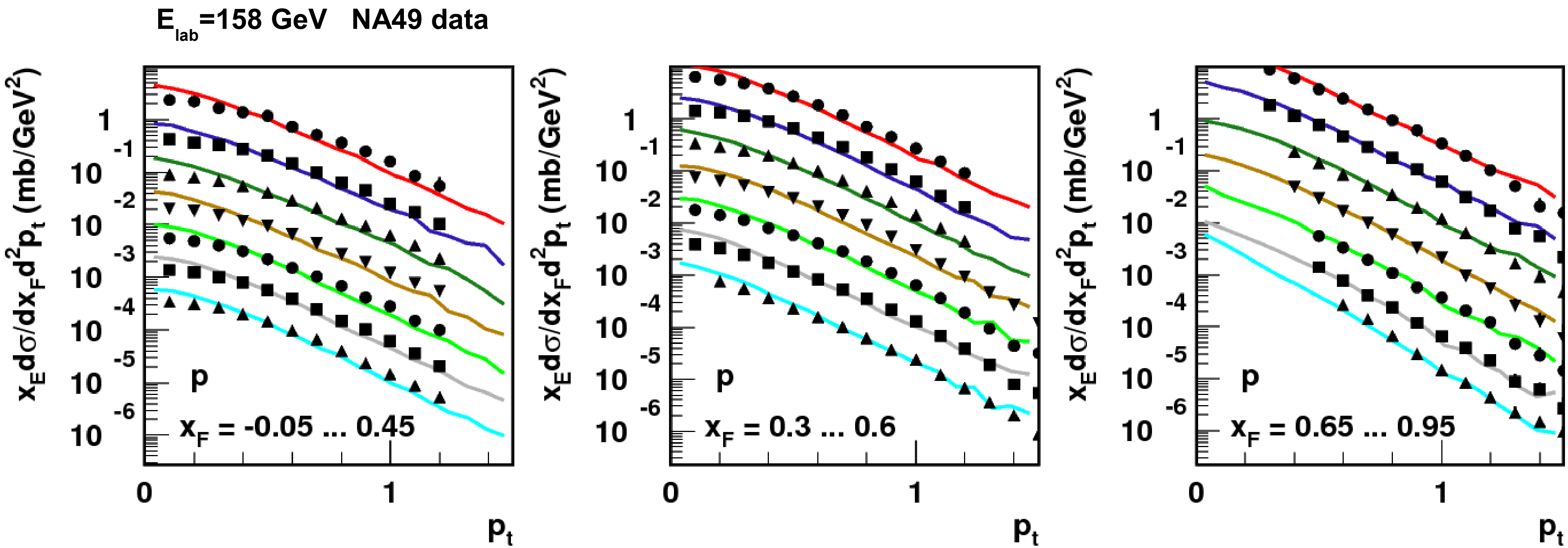
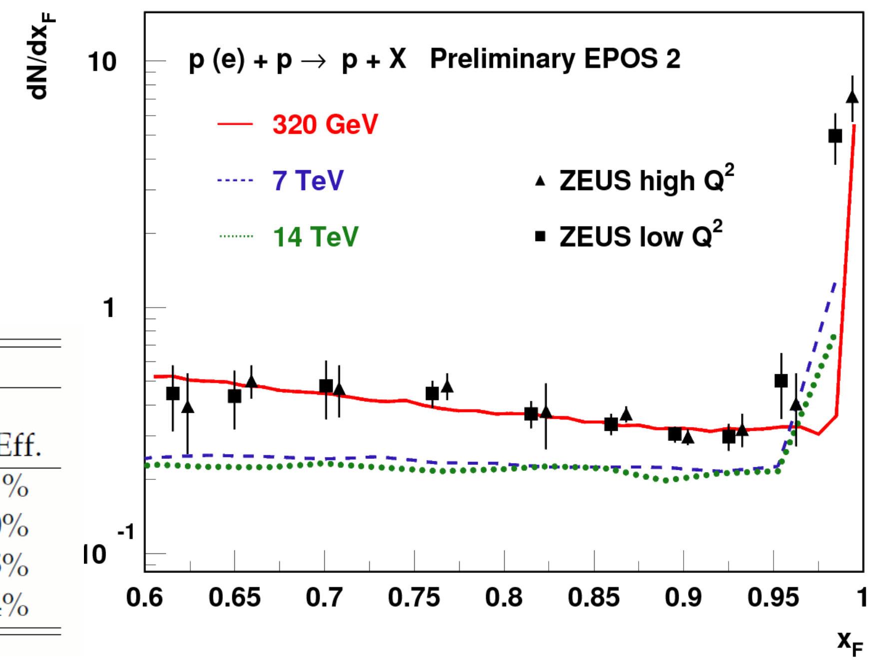


LHC

- **Scaling violation at LHC**
- **Different proportion for SD,DD and ND**



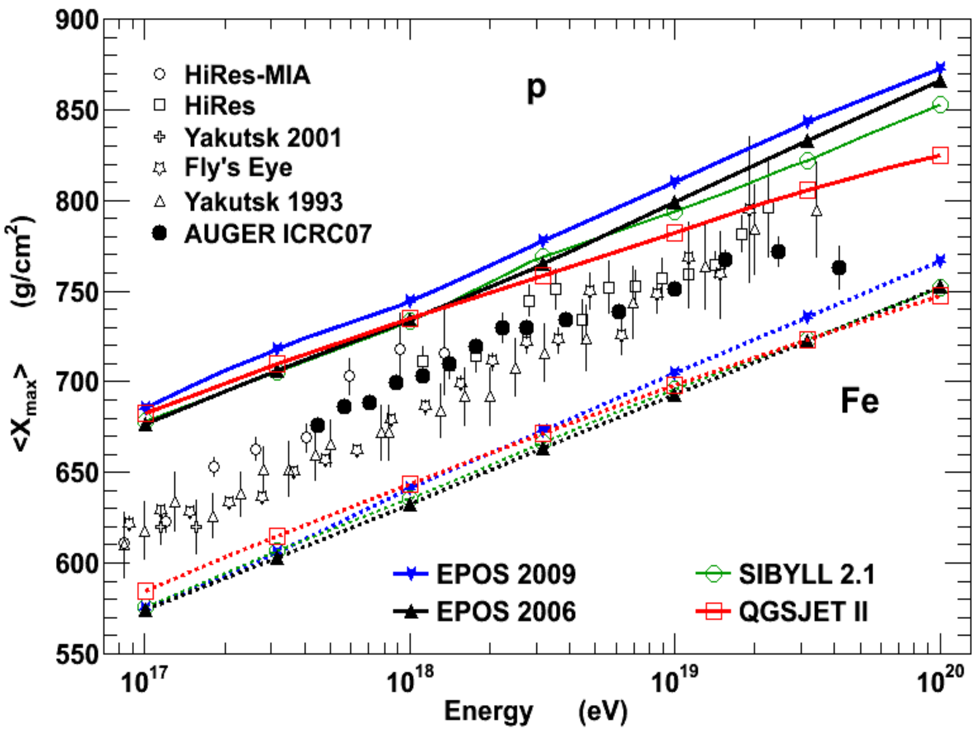
	PYTHIA				PHOJET			
Energy	0.9 TeV		2.36 TeV		0.9 TeV		2.36 TeV	
	Frac.	Sel. Eff.	Frac.	Sel. Eff.	Frac.	Sel. Eff.	Frac.	Sel. Eff.
SD	22.5%	16.1%	21.0%	21.8%	18.9%	20.1%	16.2%	25.1%
DD	12.3%	35.0%	12.8%	33.8%	8.4%	53.8%	7.3%	50.0%
ND	65.2%	95.2%	66.2%	96.4%	72.7%	94.7%	76.5%	96.5%
NSD	77.5%	85.6%	79.0%	86.2%	81.1%	90.5%	83.8%	92.4%

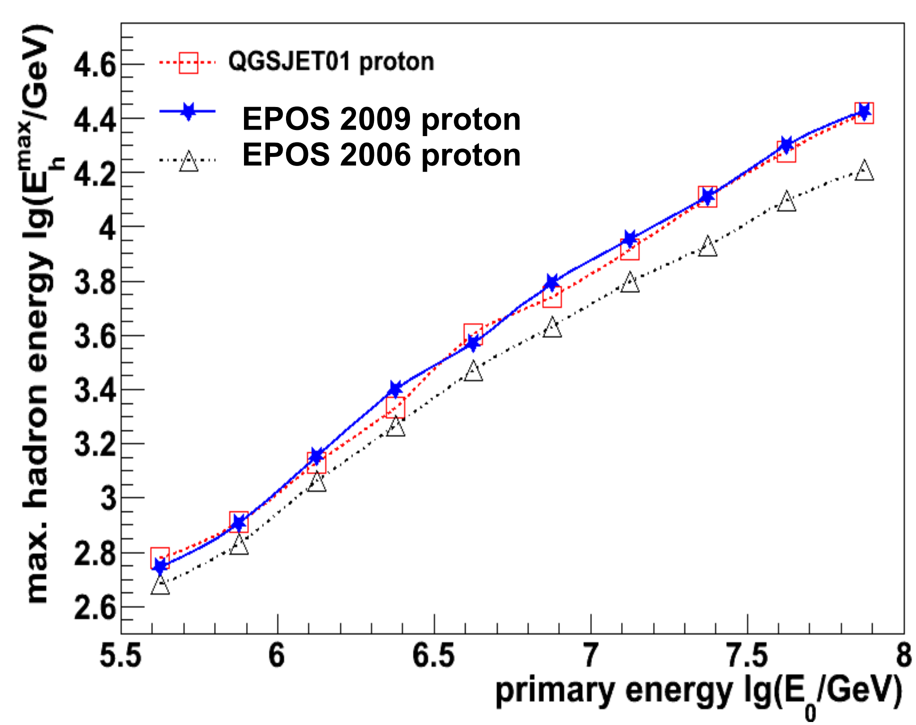
EPOS				
Energy	0.9 TeV		2.36 TeV	
	Frac.	Sel. Eff.	Frac.	Sel. Eff.
SD	13,7%	22,3%	12,4%	27,4%
DD	18,1%	71,3%	16,0%	73,8%
ND	68,2%	88,4%	71,6%	90,9%
NSD	86,3%	84,8%	87,6%	87,8%

Much more SD events pass the CMS trigger !

Check with Cosmic Rays

- **Informations from air shower development constrain forward region (remnant)**
  - Data from KASCADE (hadrons)
  - Data from Pierre Auger Observatory (longitudinal development, muon number)
  - ...





Summary

EPOS model based on Parton-Based Gribov Regge Theory

- Full coherence between inelastic cross section and particle production with MPI
- Both soft and hard physics
- Consistent treatment of diffraction (low and high mass)
- Careful treatment of remnants

EPOS 1.99 available in ALICE and ATLAS simulation software :

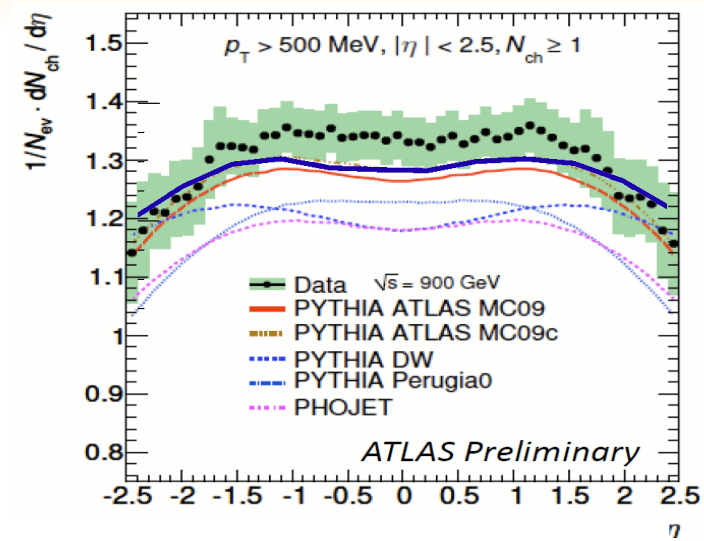
- Good description of min bias events up to 1.8 TeV (<10% error)
- Tested with cosmic ray experiments
- Collective effects done in an effective way

On-going developments : EPOS 2

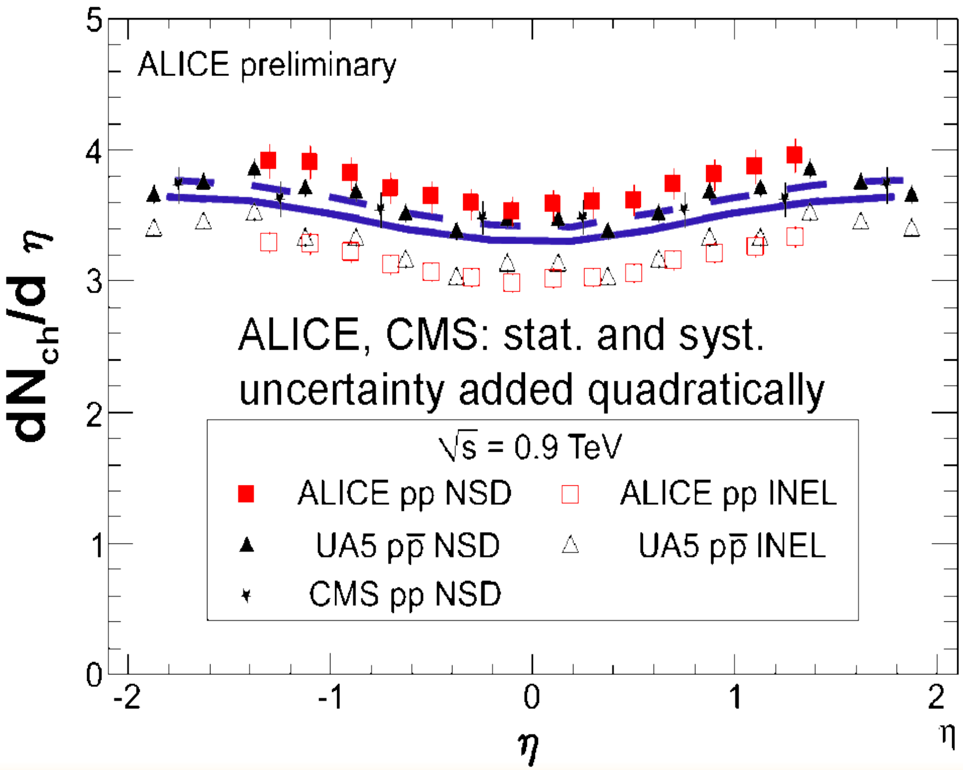
- Real hydrodynamical evolution
- Selection of hard processes
- Both at the same time : underlaying events

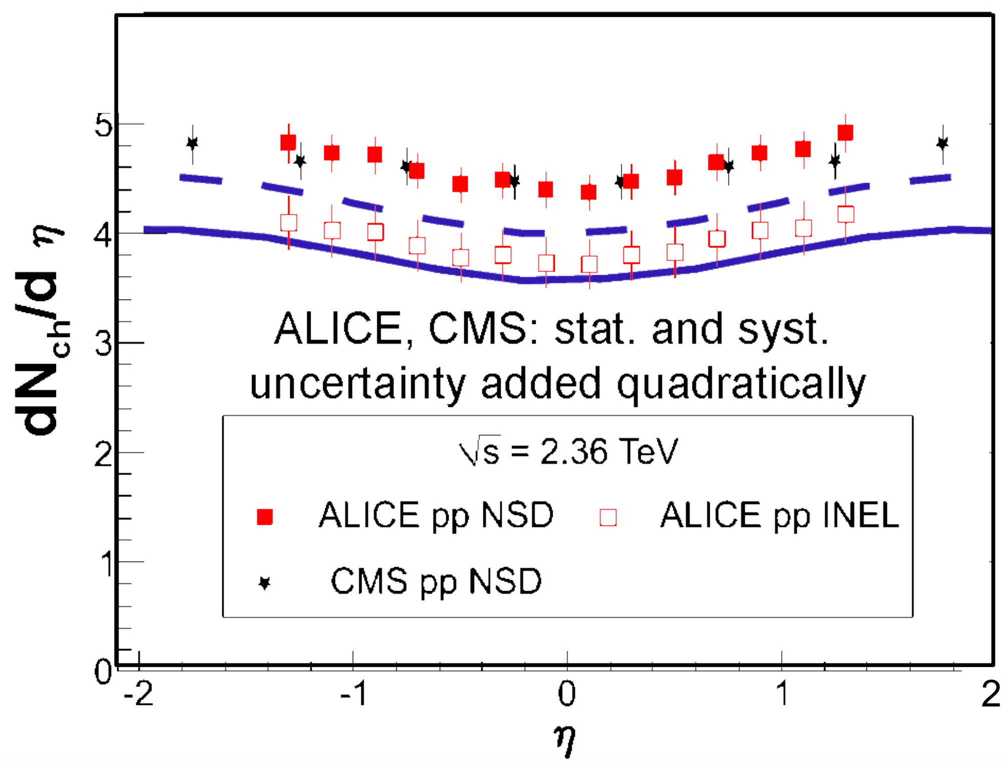
New LHC data

- **900 GeV**
  - Inelastic multiplicity a bit high
  - NSD OK
- **2360 GeV**
  - Inelastic OK
  - NSD too low

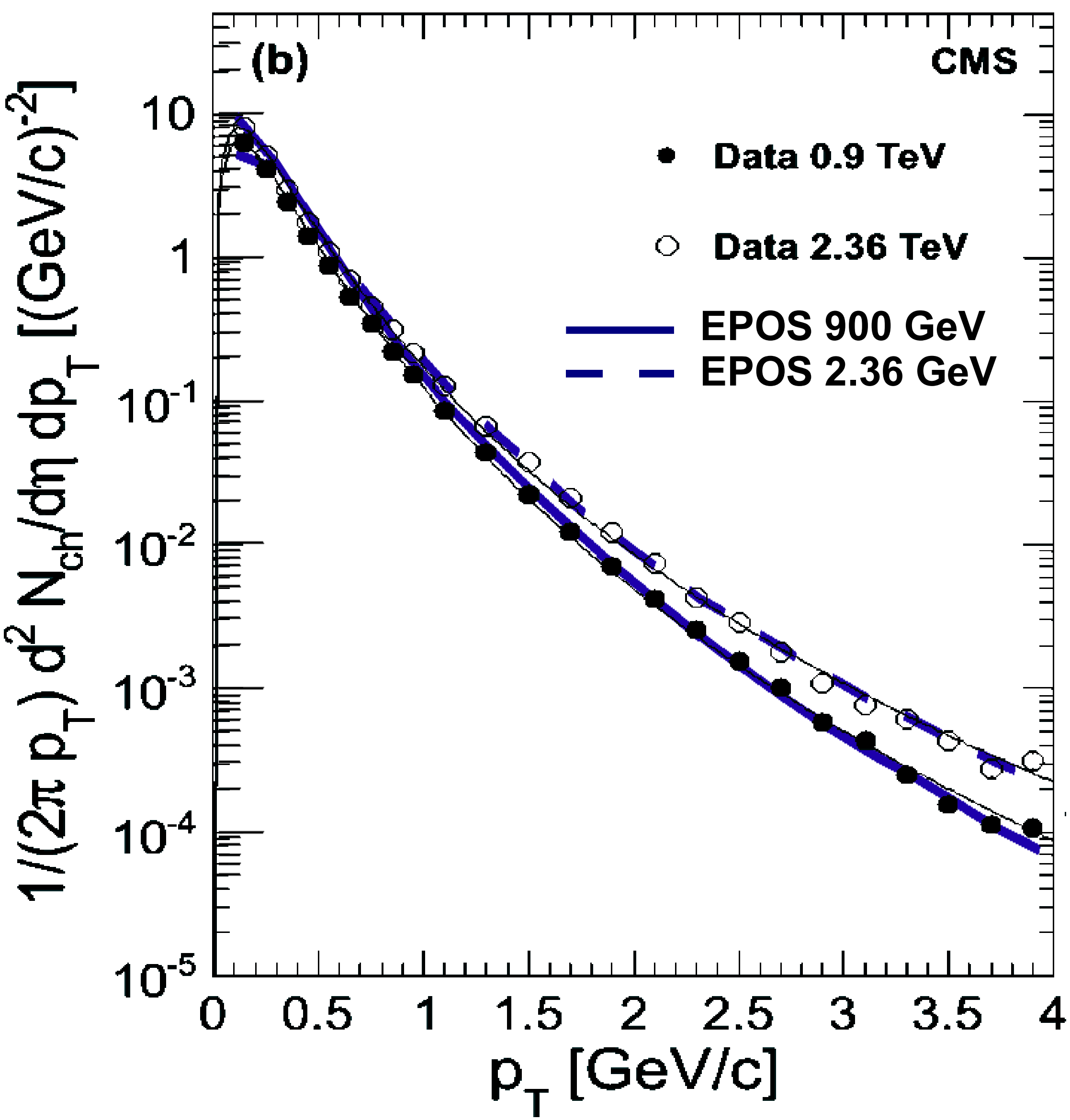


EPOS Inelastic
EPOS NSD



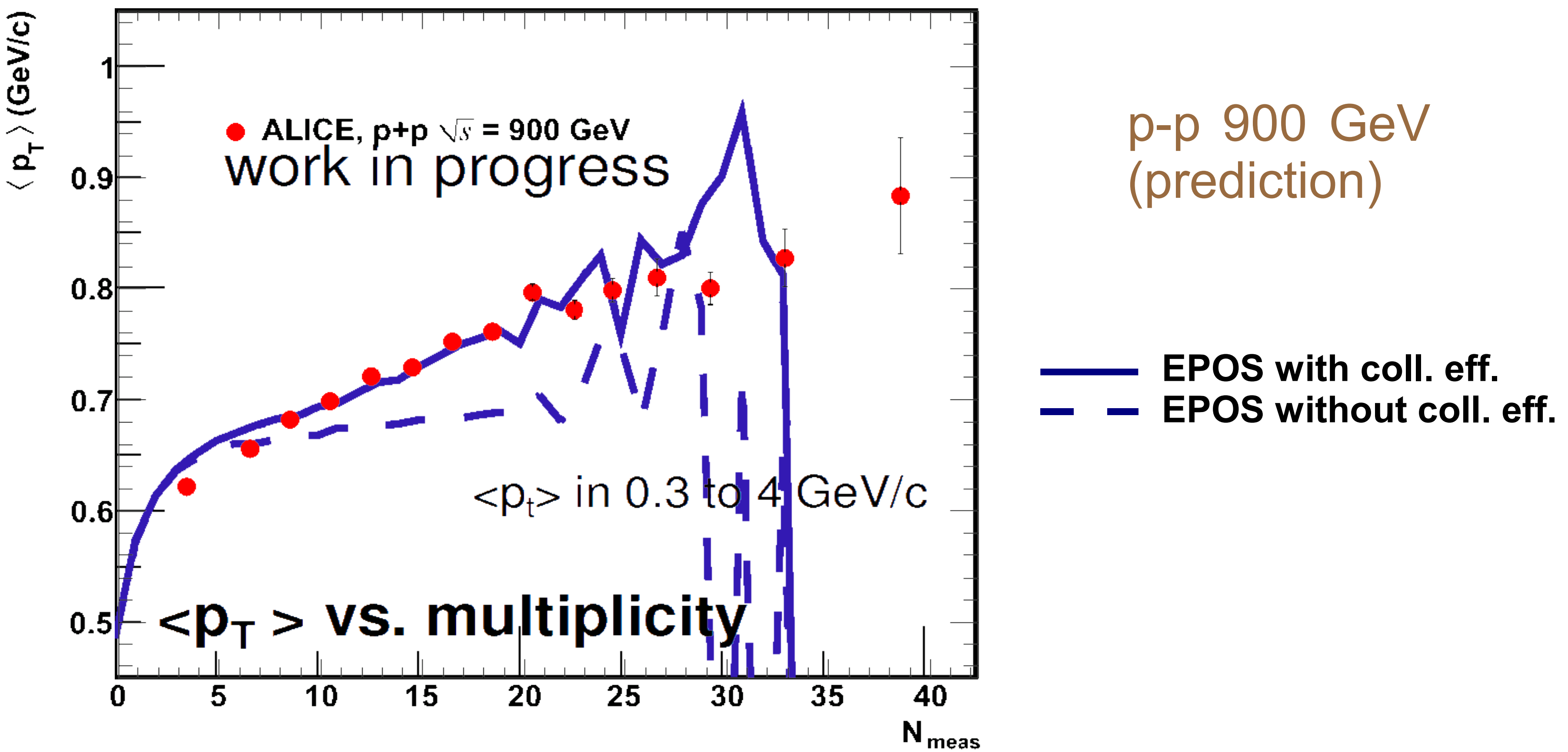


New LHC data : pt (CMS)



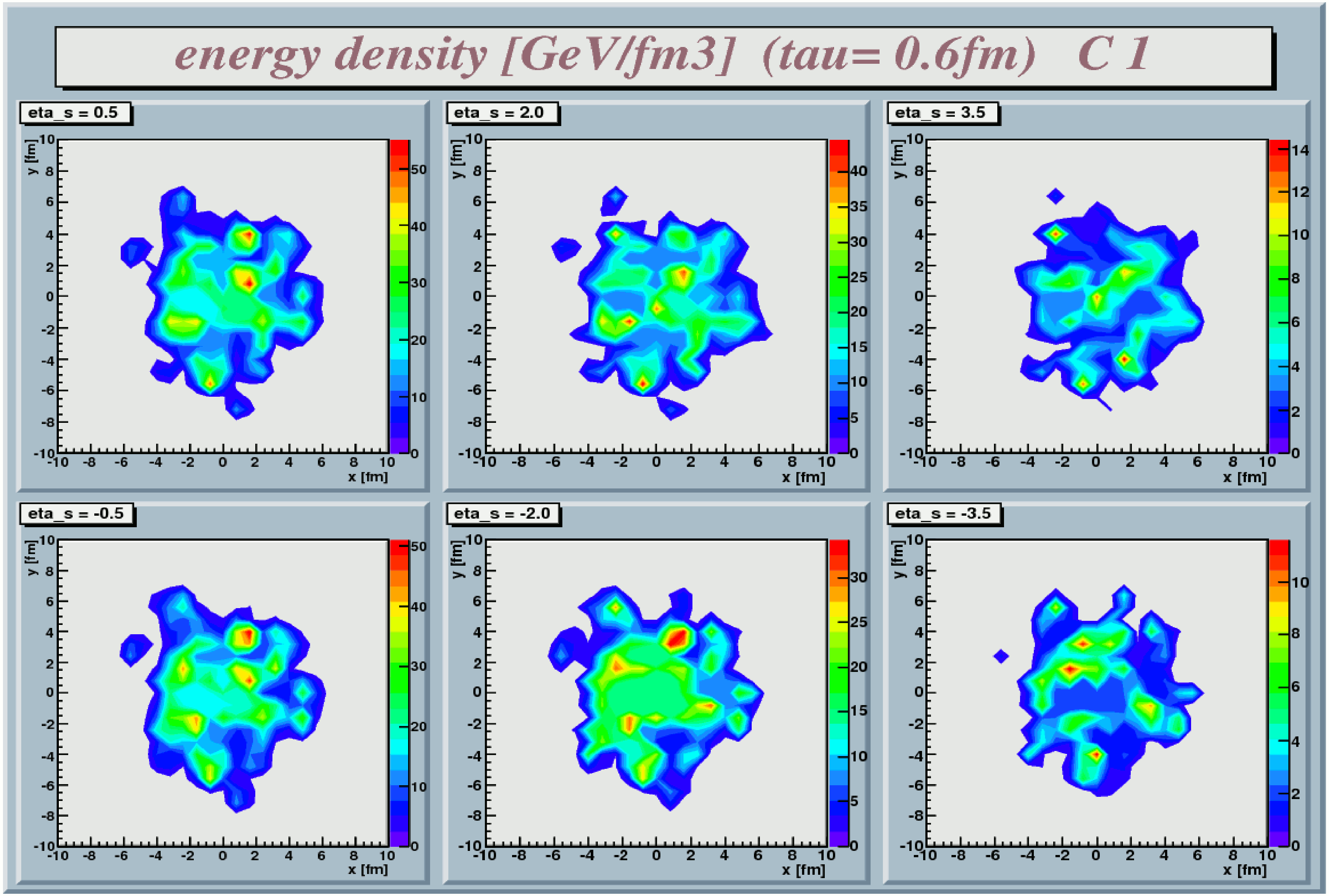
$<p_t>$ vs multiplicity : EPOS 1.99 (2009)

- **Predictions of current EPOS version :**
  - Not real hydro : effective treatment (prev. slide)
  - Already collective effect visible at 900 GeV
  - Good agreement with preliminary LHC data

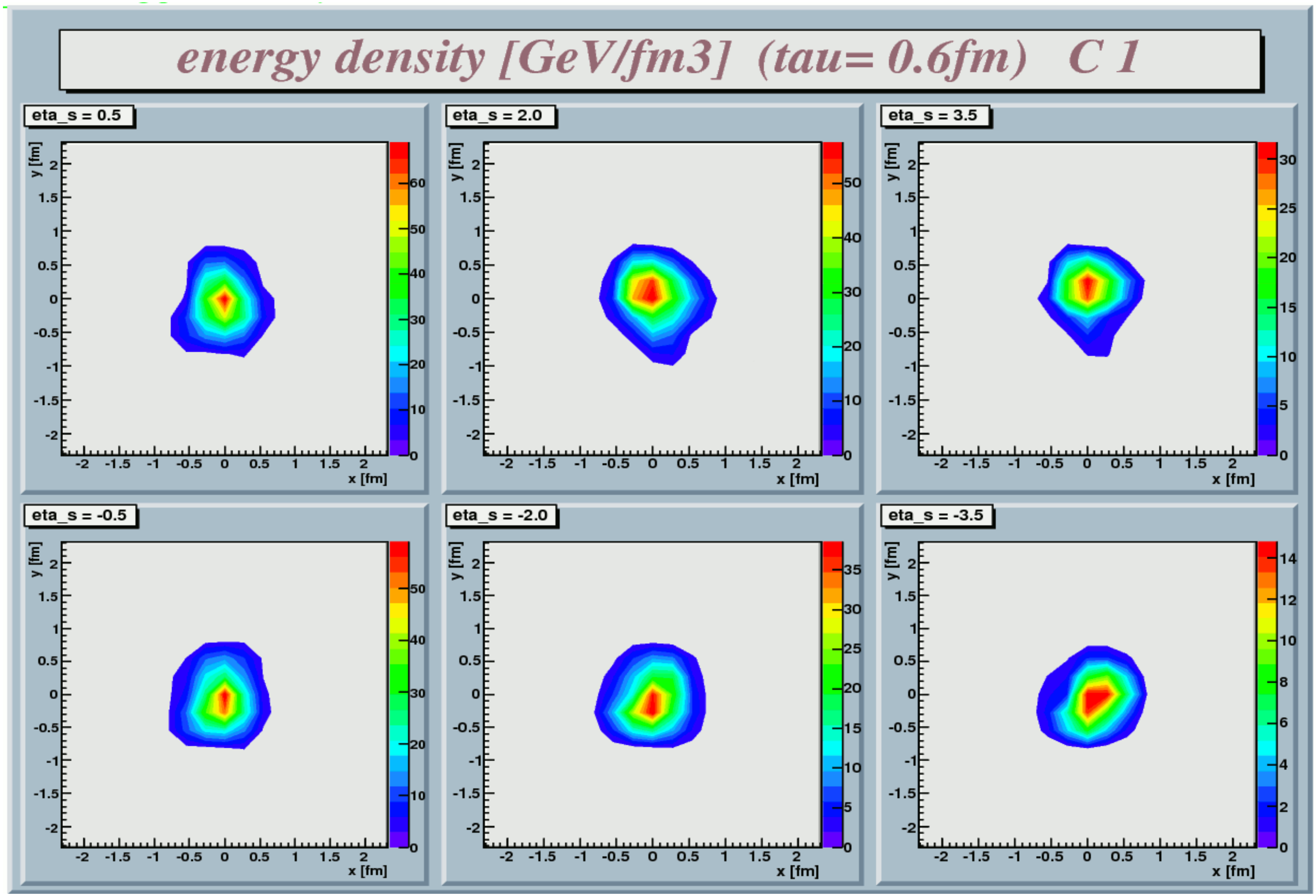


p-p 900 GeV (prediction)

Initial Conditions AuAu@RHIC



Initial Conditions ap-p@Tevatron



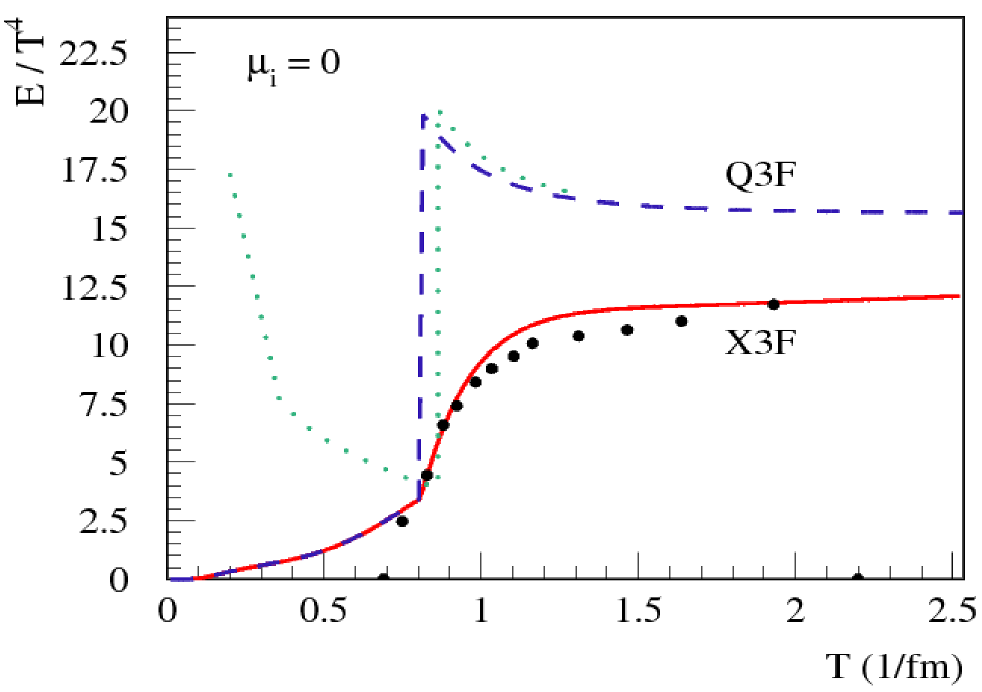
EoS

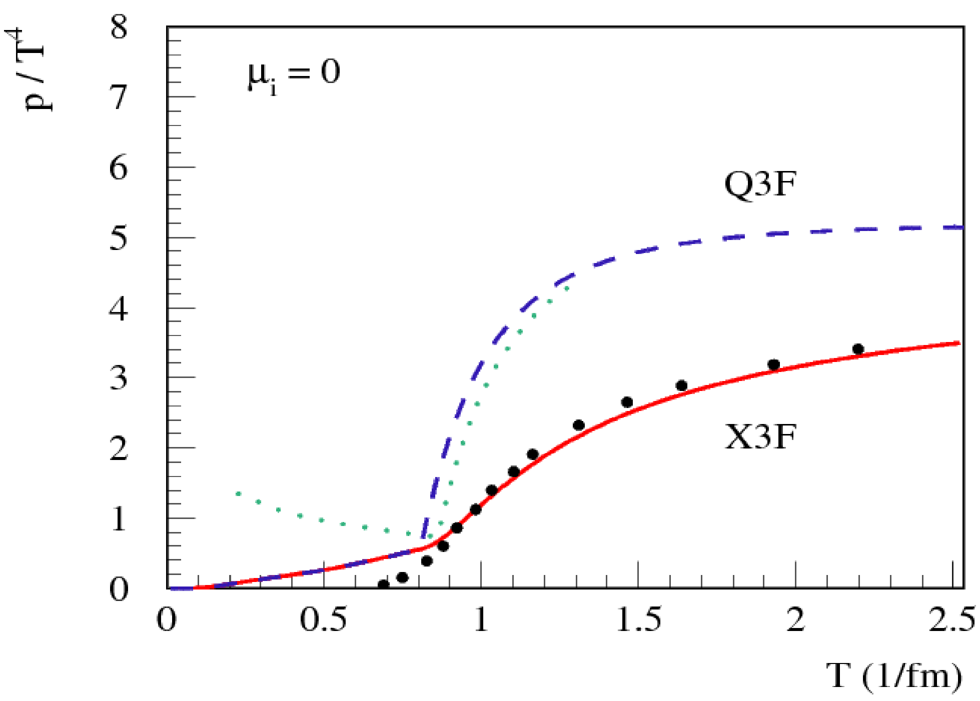
Hirano: QG & resonance gas => 1st order PT, PCE, $\mu_B = \mu_S = \mu_Q = 0$

Q3F: QG & "complete" resonance gas => 1st order PT, excl volume correction, μ_B, μ_S, μ_Q considered, parameters as in Spherio

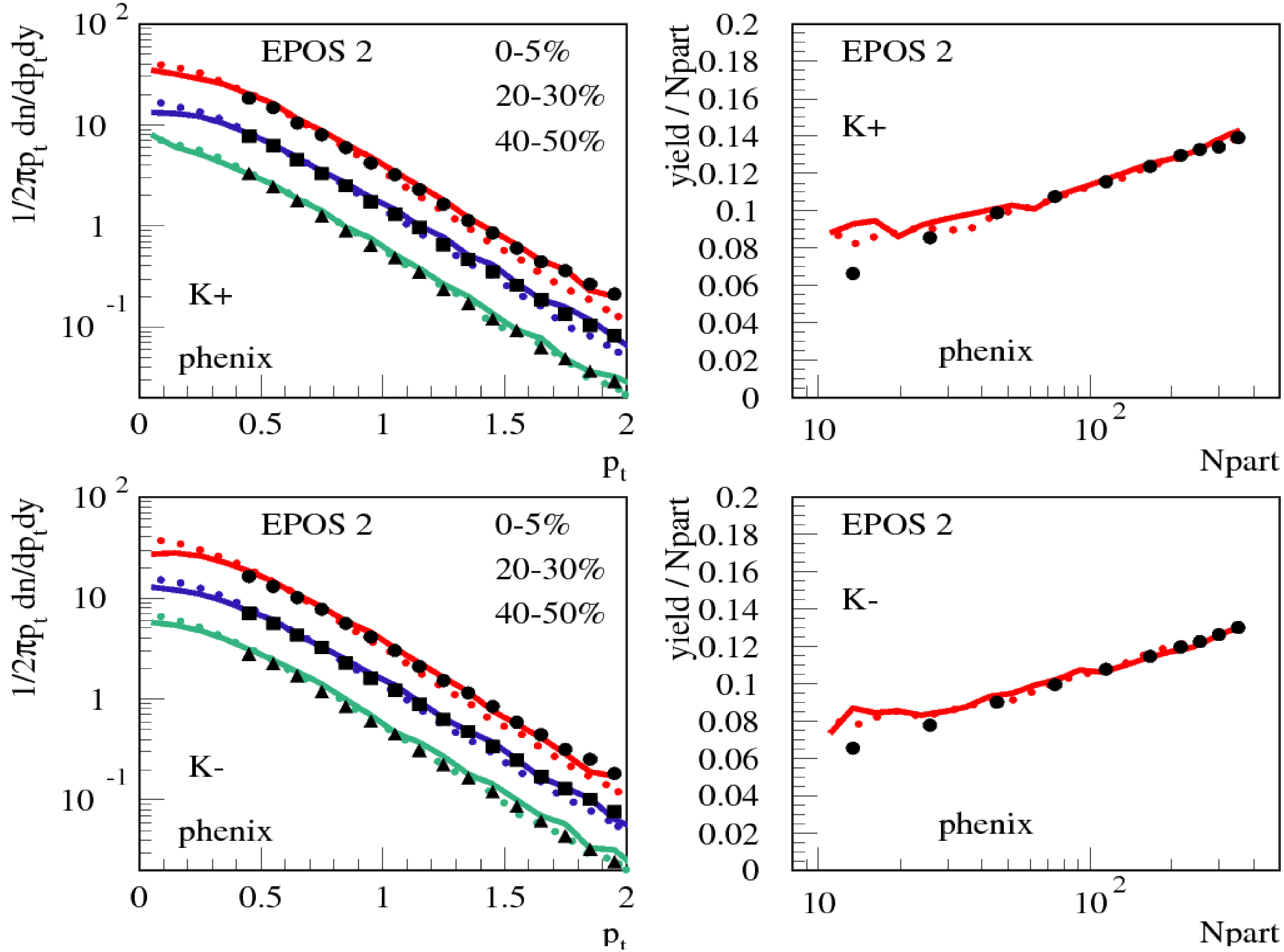
X3F: crossover : $p = p_Q + \lambda(p_H - p_Q)$, $\lambda = \exp(-\frac{T-Tc}{\delta})\theta(T - T_c) + \theta(T_c - T)$

"data": Y. Aoki, Z. Fodor, S.D. Katz , K.K. Szabo, JHEP 0601:089,2006





AuAu : Kaon



solid lines: with hadronic cascade

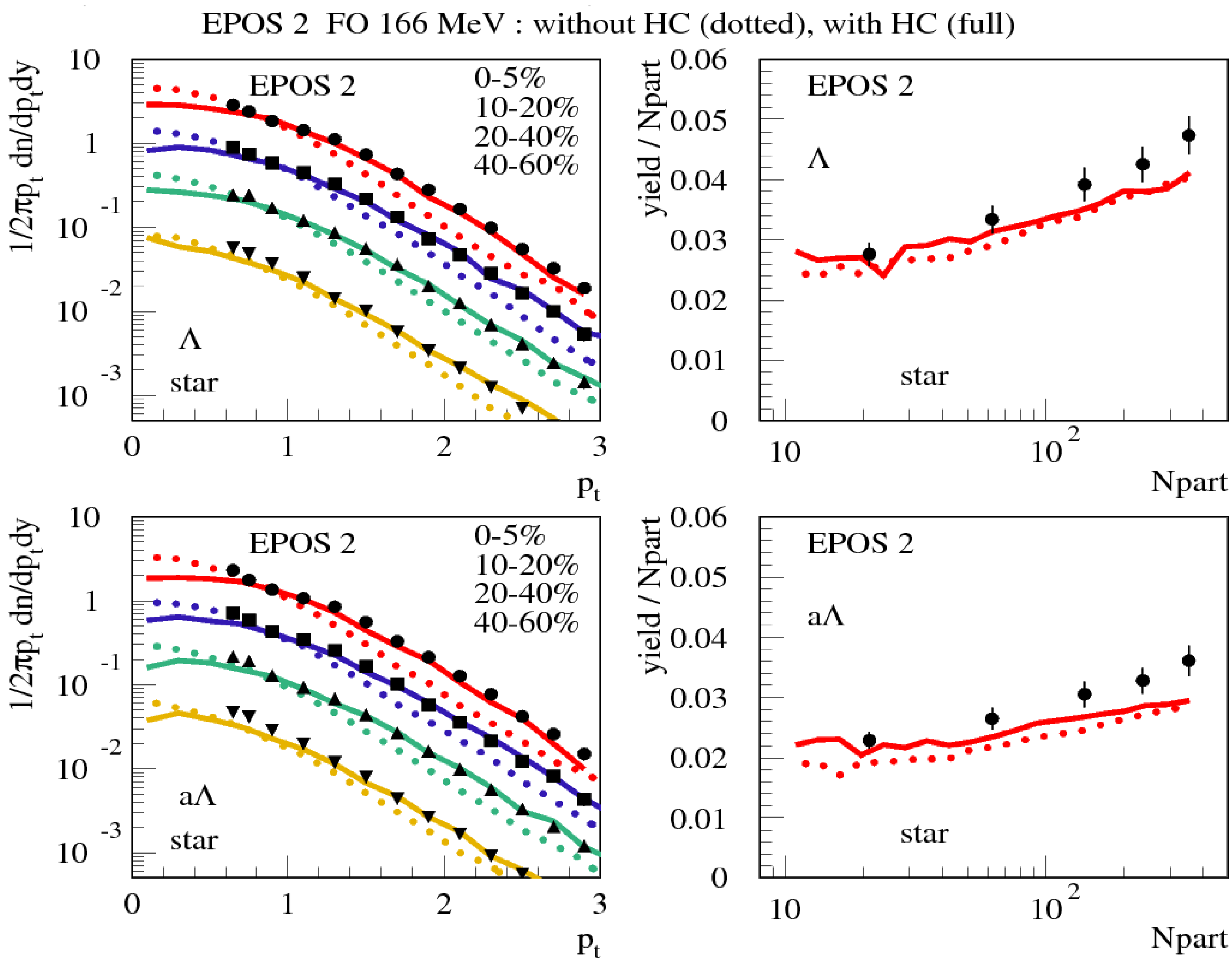
dotted lines: w/o cascade

AuAu : Lambda

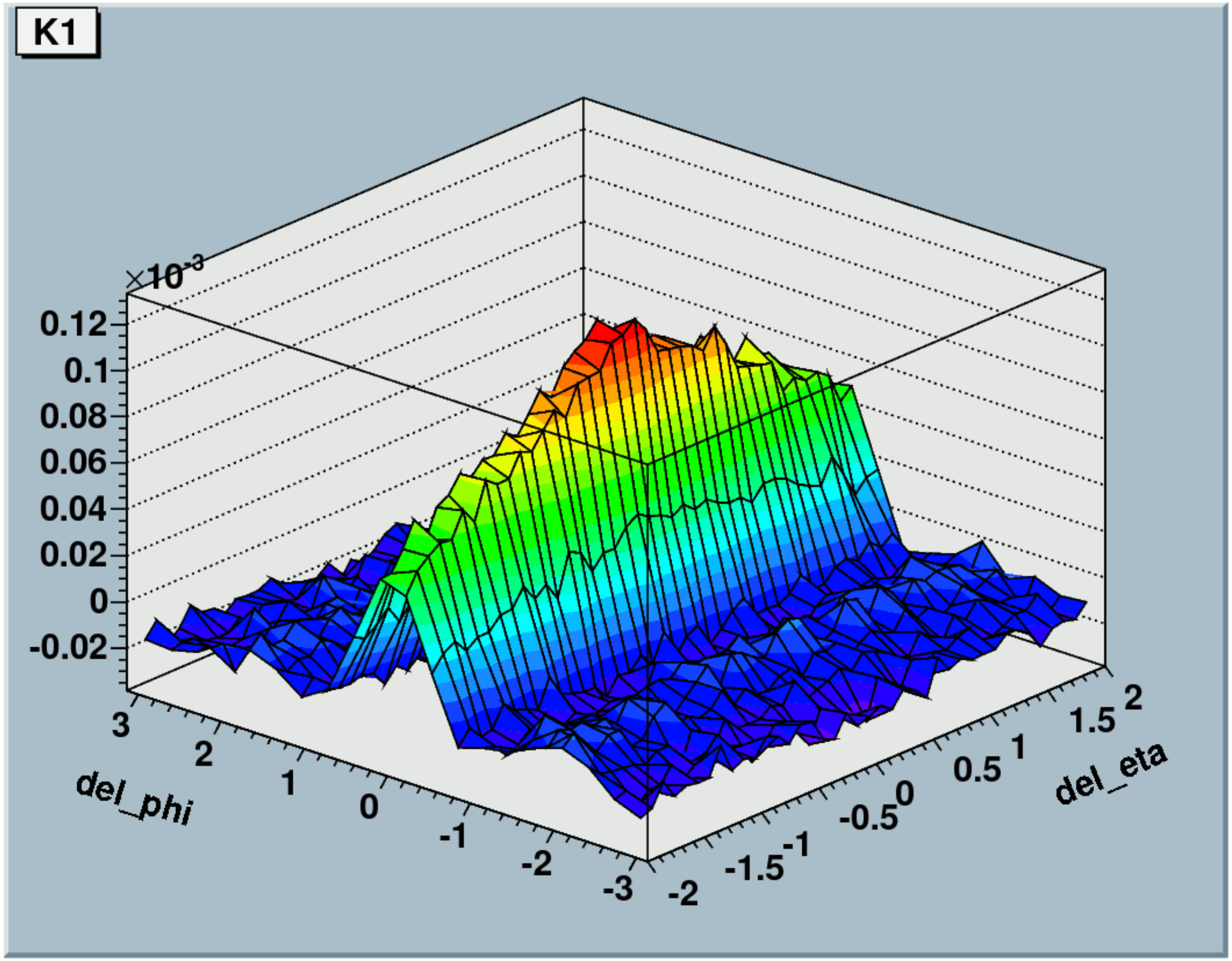
for better visibility:

pt spectra scaled by

1/2 (10-20%)
1/4 (20-40%)
1/8 (40-60%)

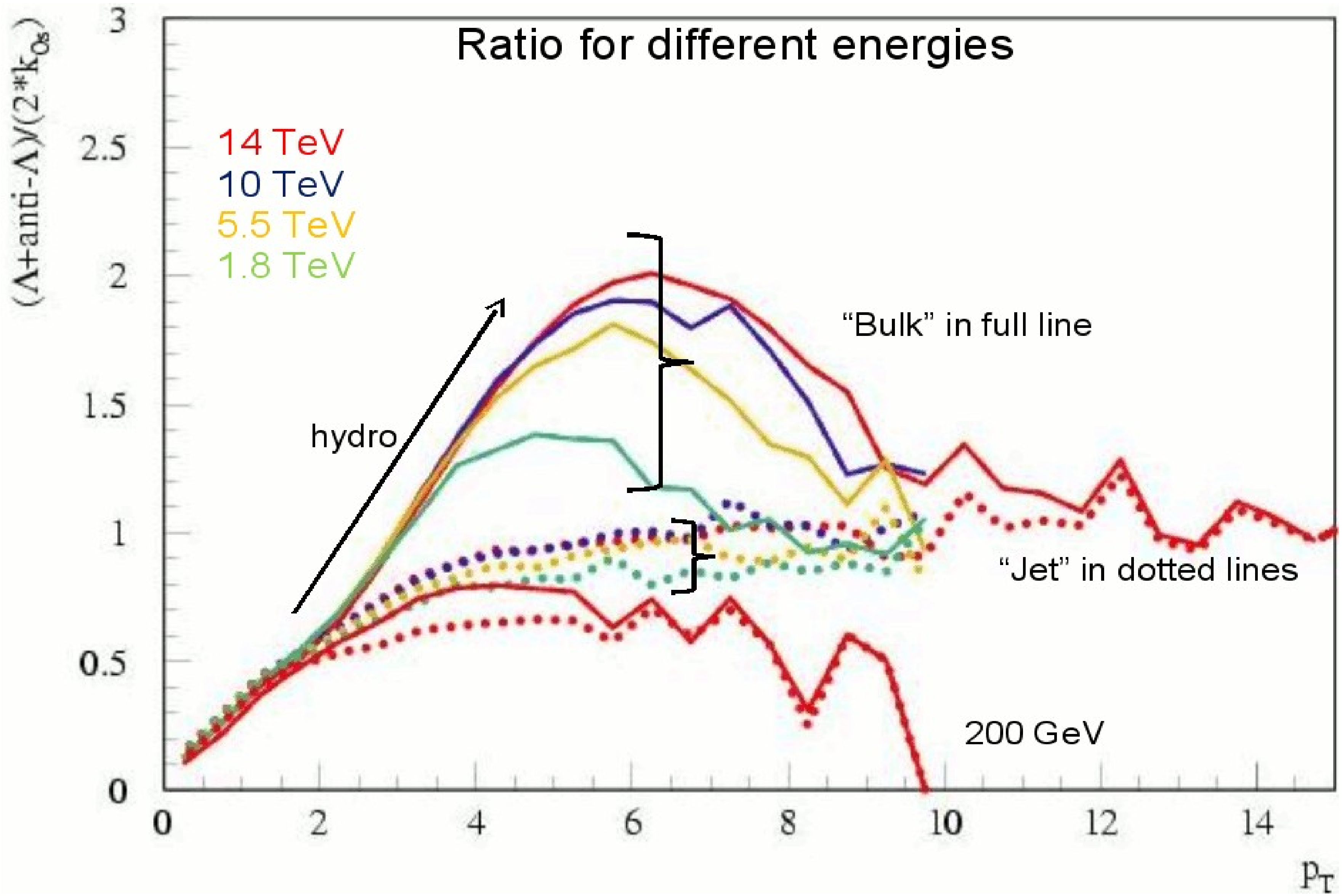


AuAu : Di-hadron correlation

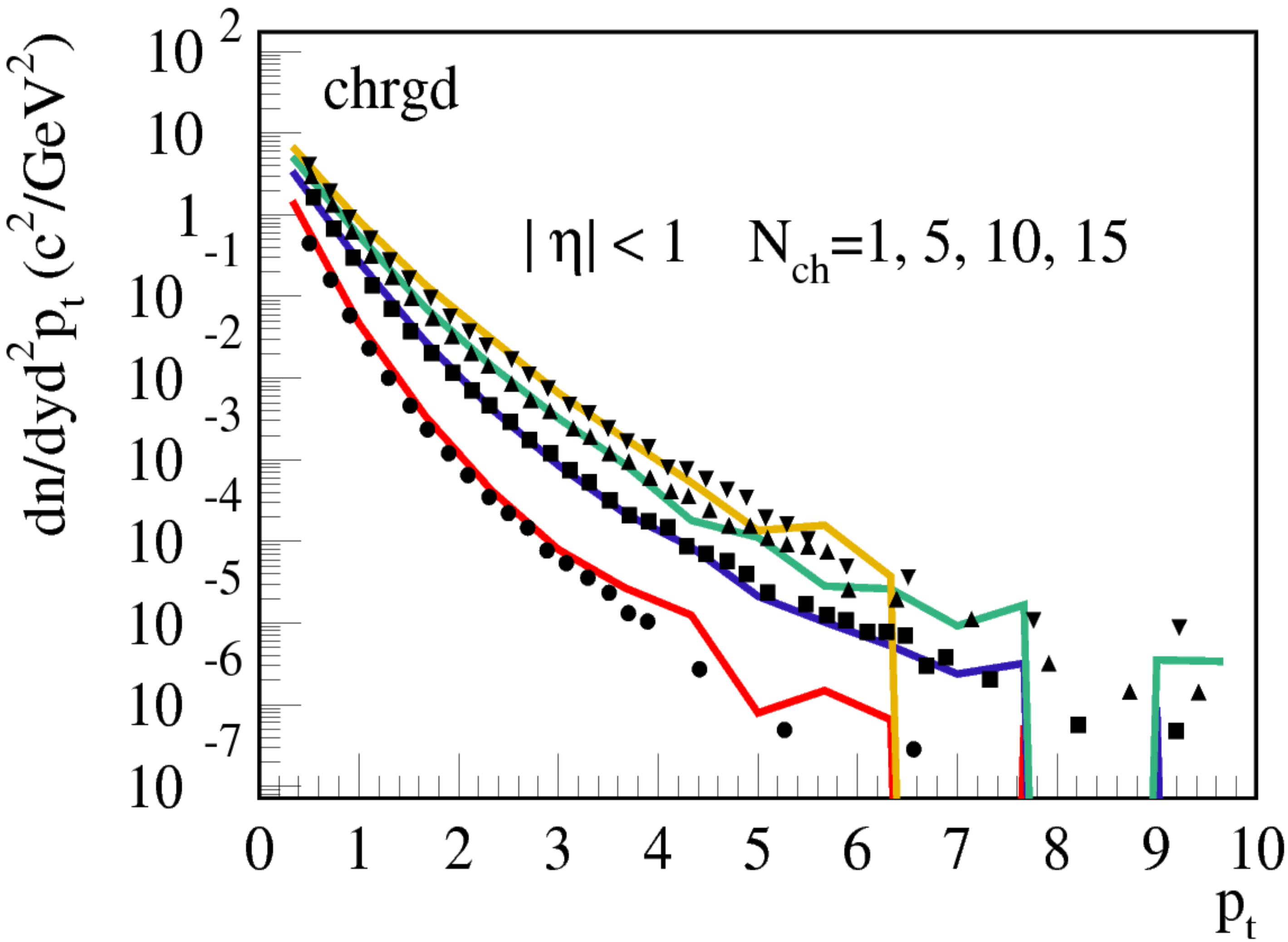


AuAu 0-10%, $3 < p_t^{\mathrm{trig}} < 4\,\mathrm{GeV/c}$ $2 < p_t^{\mathrm{assoc}} < p_t^{\mathrm{trig}}$

p-p : Other Possible Observable



Pt distribution CDF ap-p@1.8 TeV with Hydro



Pt distribution CDF ap-p@1.8 TeV without Hydro