Tsallis Distribution in High-Energy Heavy Ion Collisions

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in collaboration

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O U T L I N E

- Motivation: just some of them...
- Where to apply Tsallis-Pareto statistics?
- Can non-extensive thermodyn. resolve this?
- Problems of high & low-p_T hadron spectra
- Tsallis-Pareto in proton-proton collisons

Basics of non-extensive thermodynamics

Non-extensive thermodynamics (Based on: T.S. Biró: EPL84, 56003,2008) associative composition rule, (non-additive) :

$$h(h(x,y),z) = h(x,h(y,z))$$

Then should exist a strict monotonic function, X(x) 'generalised logarithm' (an entropy-like quantity), for which:

$$h(x,y) = X^{-1}\left(X(x) + X(y)\right) \qquad X(h(x,y)) = X(x) + X(y).$$

Example: (i) Classical thermodynamics:

$$f(E) = e^{-\beta E}/Z \qquad h(x,y) = x + y.$$

(ii) Tsallis distribution

$$h(x,y) = x + y + axy \qquad a = q - 1$$

$$f(E) = \frac{1}{Z} e^{-\frac{\beta}{a}\ln(1+aE)} = \frac{1}{Z}(1+aE)^{-\beta/a} \qquad S = \int f \frac{e^{-a\ln(f)} - 1}{a} = \frac{1}{a}\int (f^{1-a} - f).$$

Extensive vs. non-extensive

SYSTEMS	ENTROPY S_{BG} (additive)	ENTROPY S_q ($q<1$) (nonadditive)
Short-range interactions, weakly entangled blocks, etc	EXTENSIVE	NONEXTENSIVE
Long-range interactions (QSS), strongly entangled blocks, etc	NONEXTENSIVE	EXTENSIVE

quarks-gluons, plasma, curved space ...?

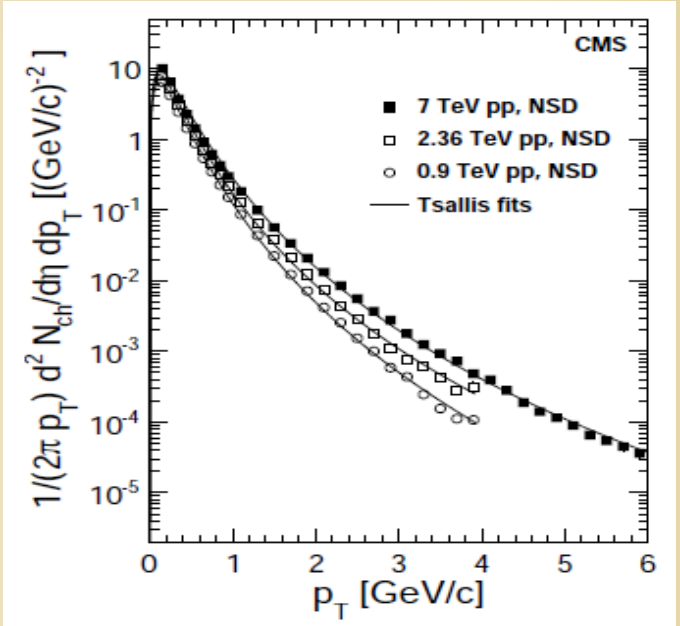
C. Tsallis: EPJ A40 257 (2009)

M O T I V A T I O N

- New LHC pp data (CMS)

  JHEP 1002:041(2010)

  fitted Tsallis distribution for p_T spectra:



$$E\frac{d^3N_{\mathrm{ch}}}{dp^3} = \frac{1}{2\pi p_T}\frac{E}{p}\frac{d^2N_{\mathrm{ch}}}{d\eta dp_T} = C(n,T,m)\frac{dN_{\mathrm{ch}}}{dy}\left(1+\frac{E_T}{nT}\right)^{-n}$$

  Parameters:

  0.9 TeV T= 130 MeV, q=1.13

  2.36 TeV T= 140 MeV, q=1.15 n := $(q-1)^{-1}$

- RHIC analysis on AuAu data (y=0)

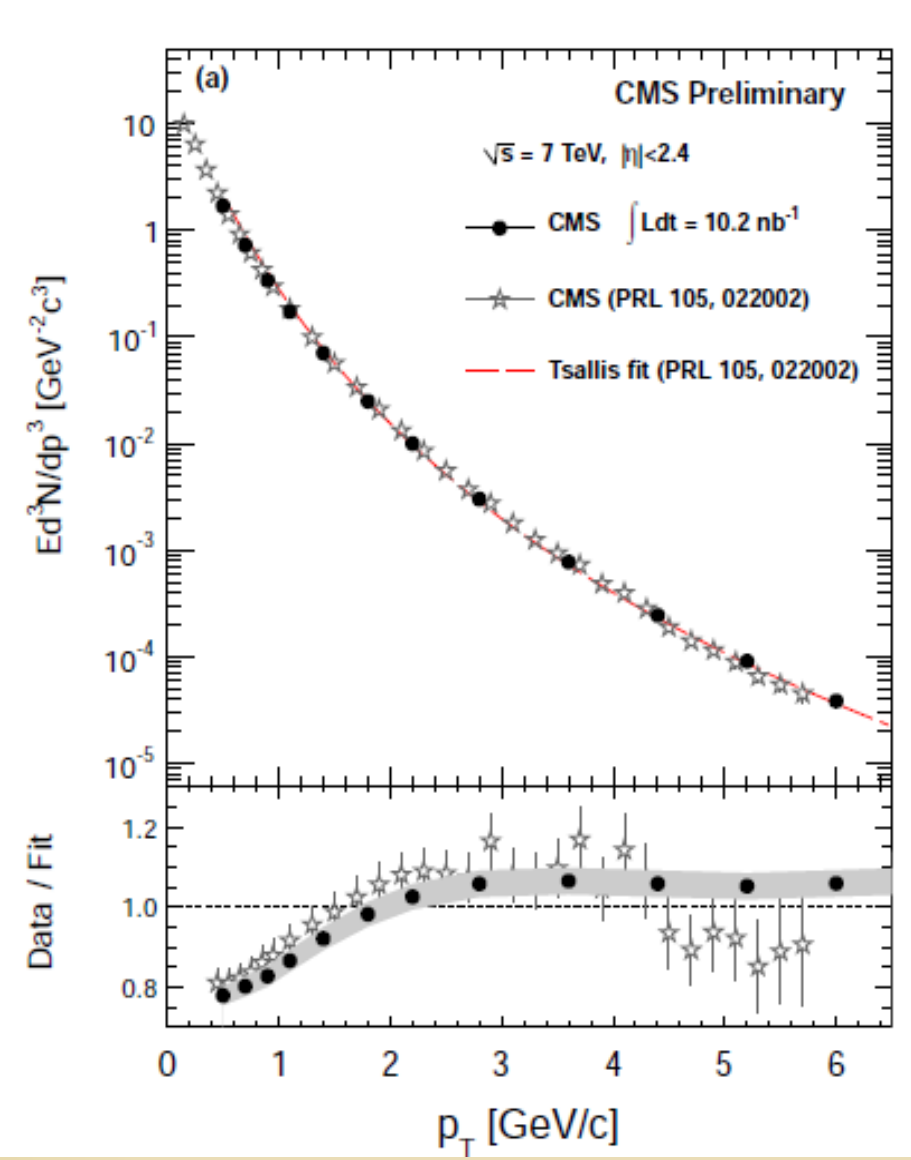
  Cooper-Frye model: K. Ürmössy, T.S. Bíró: PL B689 14 (2010)

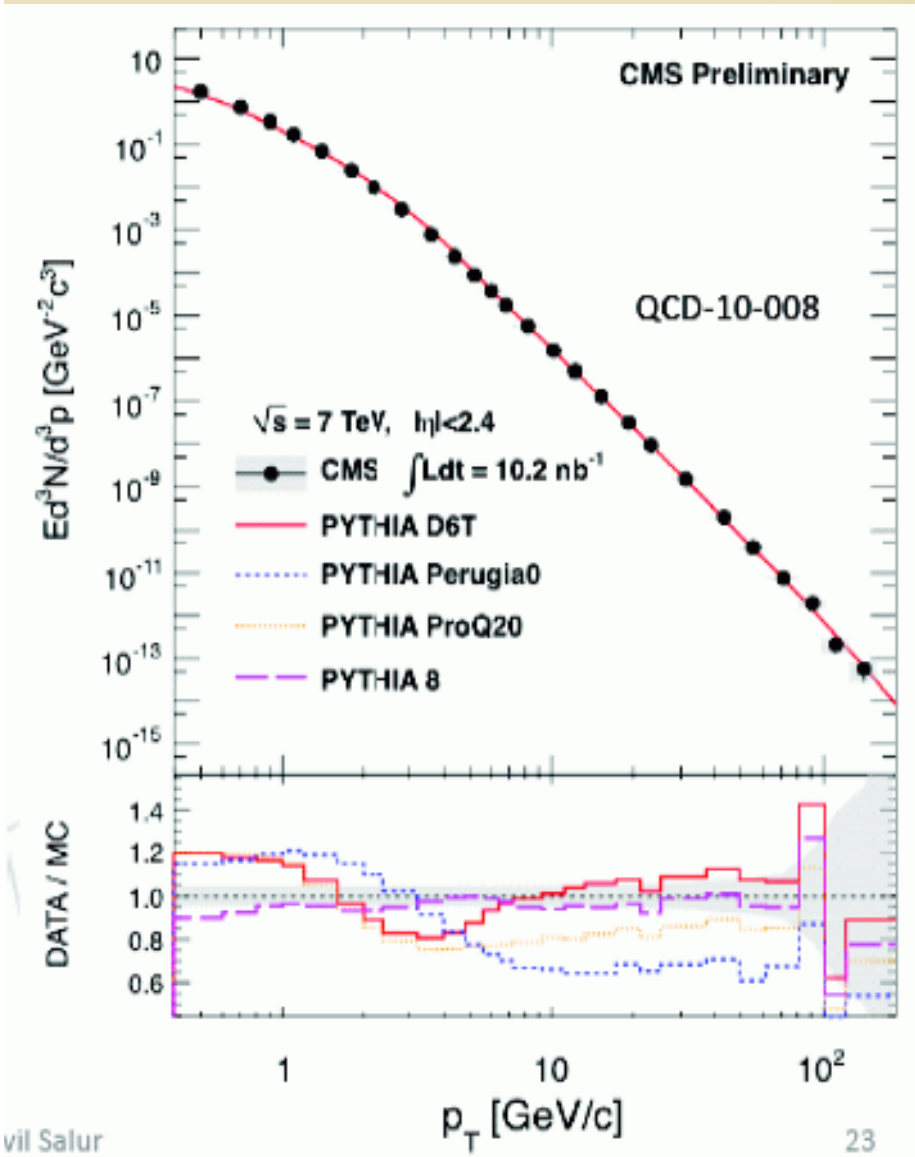
  Parameters: $f(E) = A[1+(q-1)E/T]^{-1/(q-1)}$

  200 GeV T= 51 MeV, q= 1.062 (fit for p_T < 6 GeV/c)

New data at LHC energies

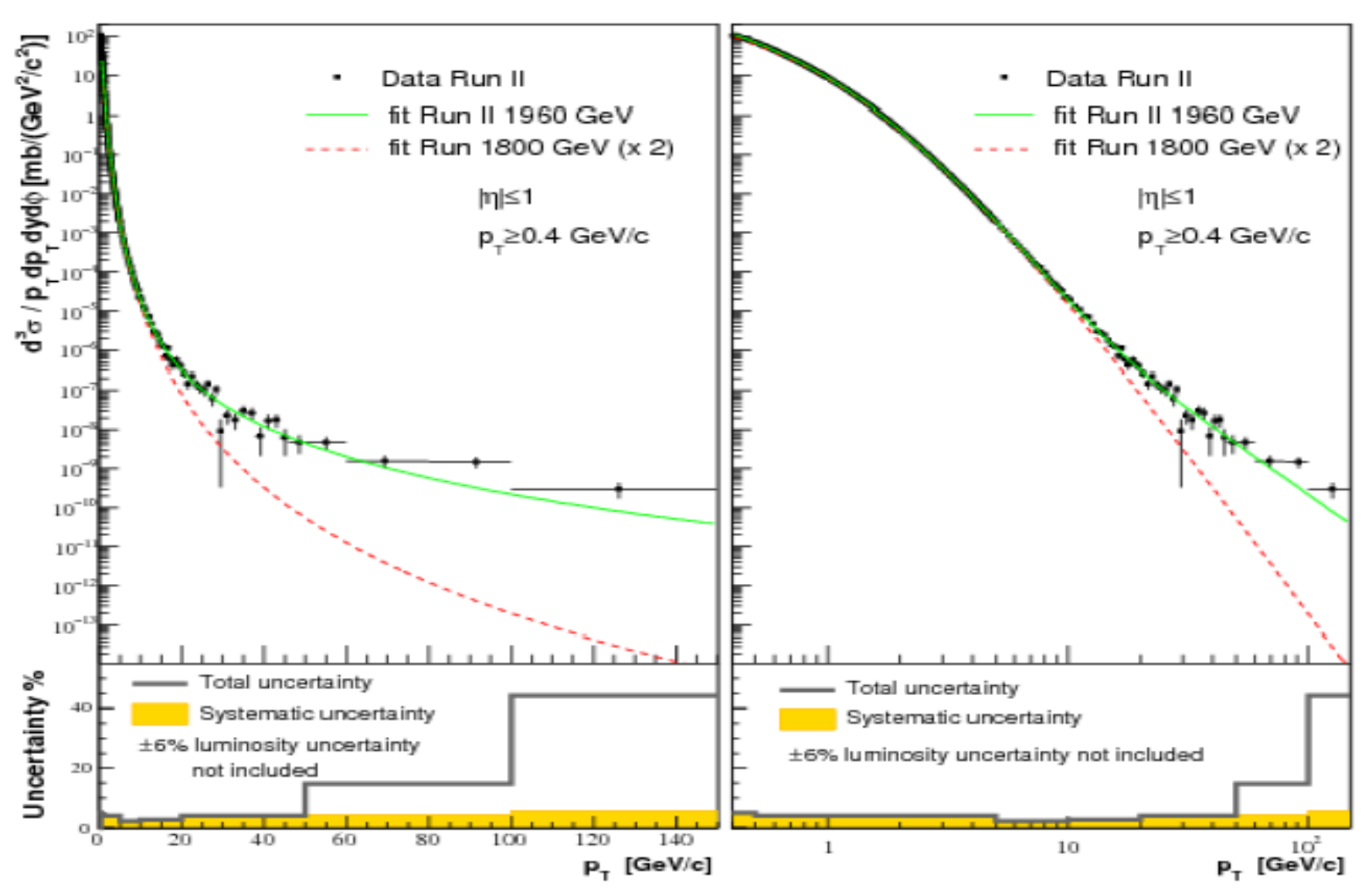
See: ALICE: Prague Jet workshop & CMS: QCD-10-008



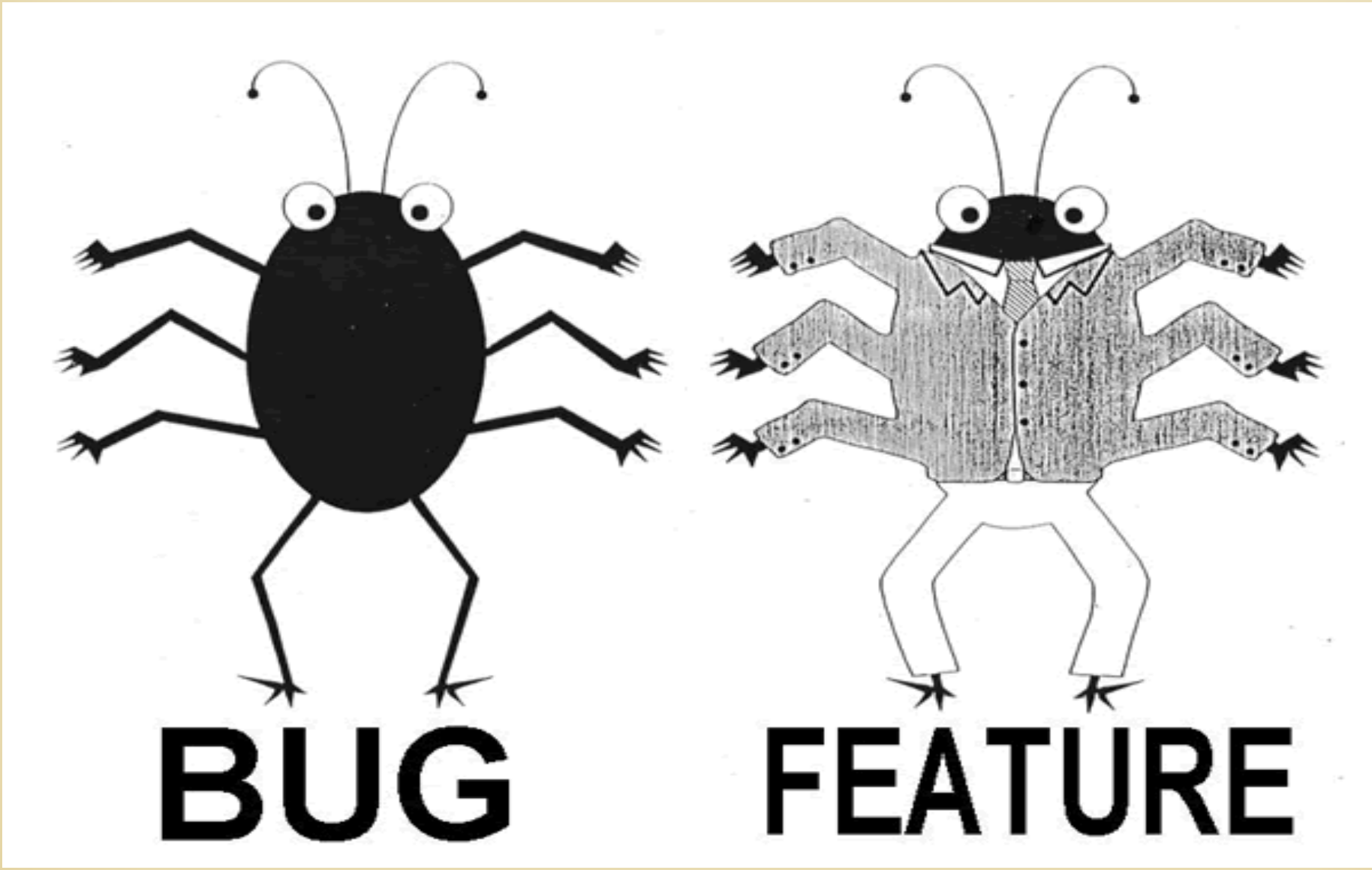


Comparision in x_T: old/new data by Tevatron

See: CDF: PRD 79 112005 (2009) & CMS QCD-10-008

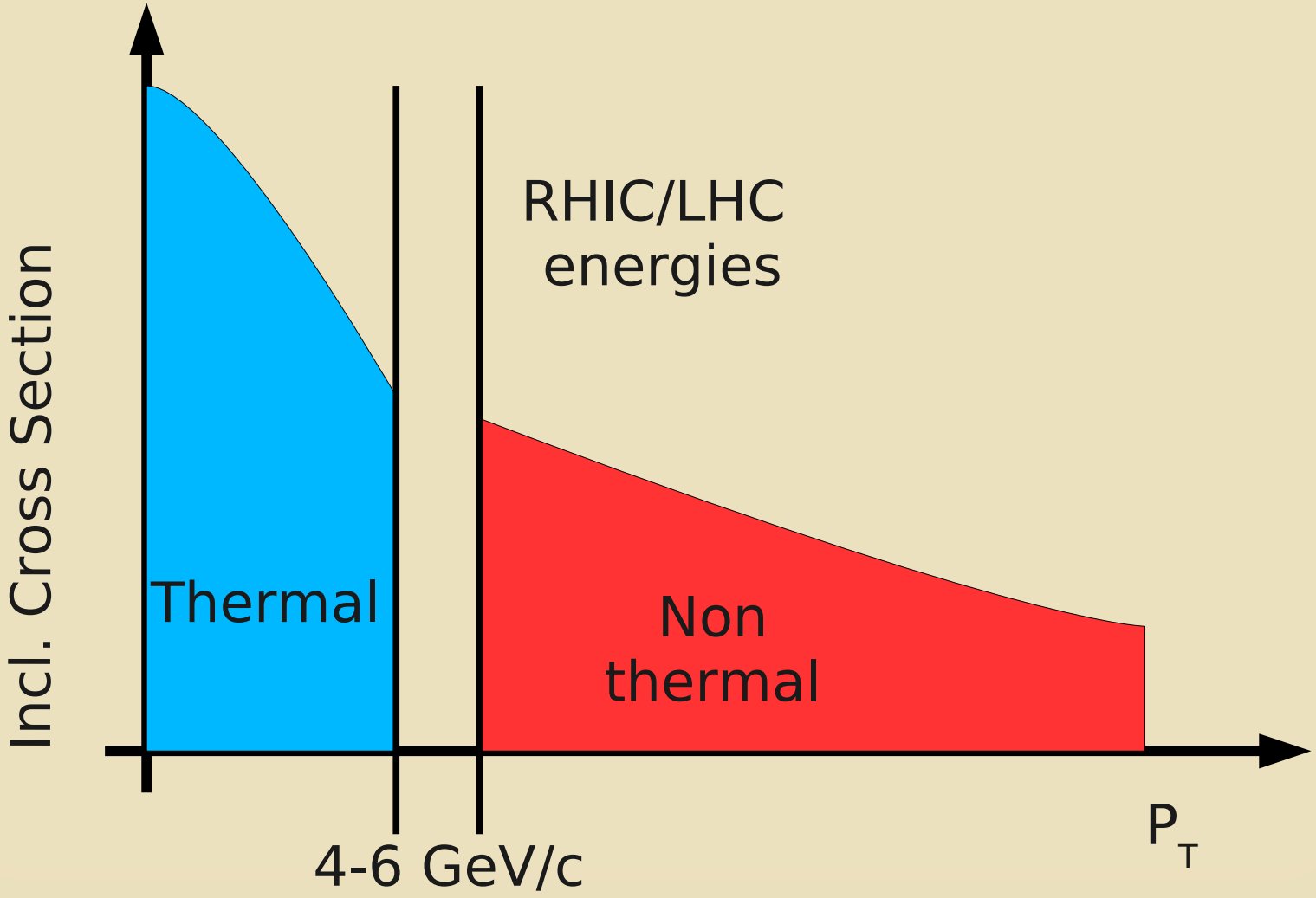


A new question on the market...



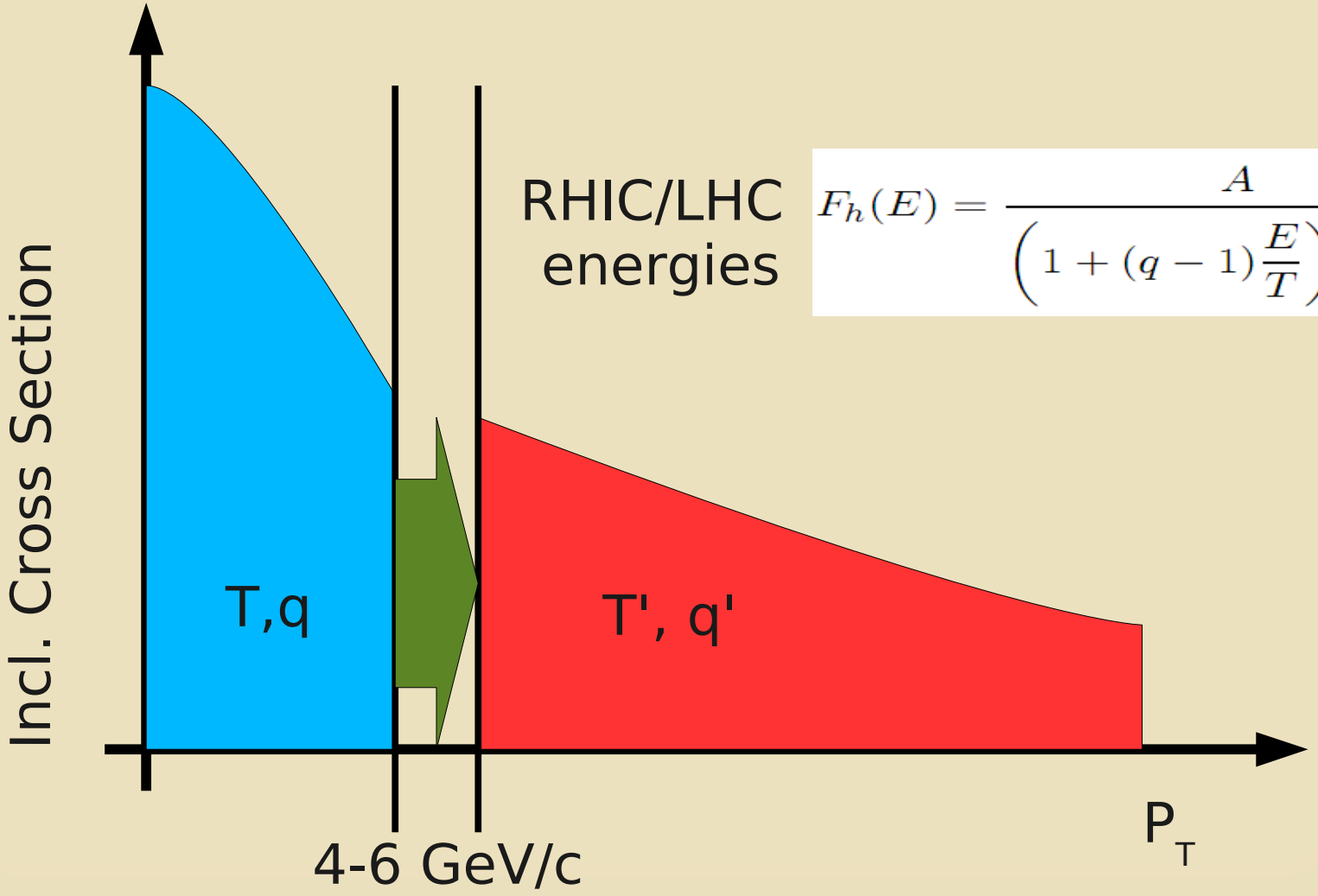
High & low p_T hadron spectra

- Old interpretation 'thermal' & 'non-thermal' models



Tsallis can fit the distribution

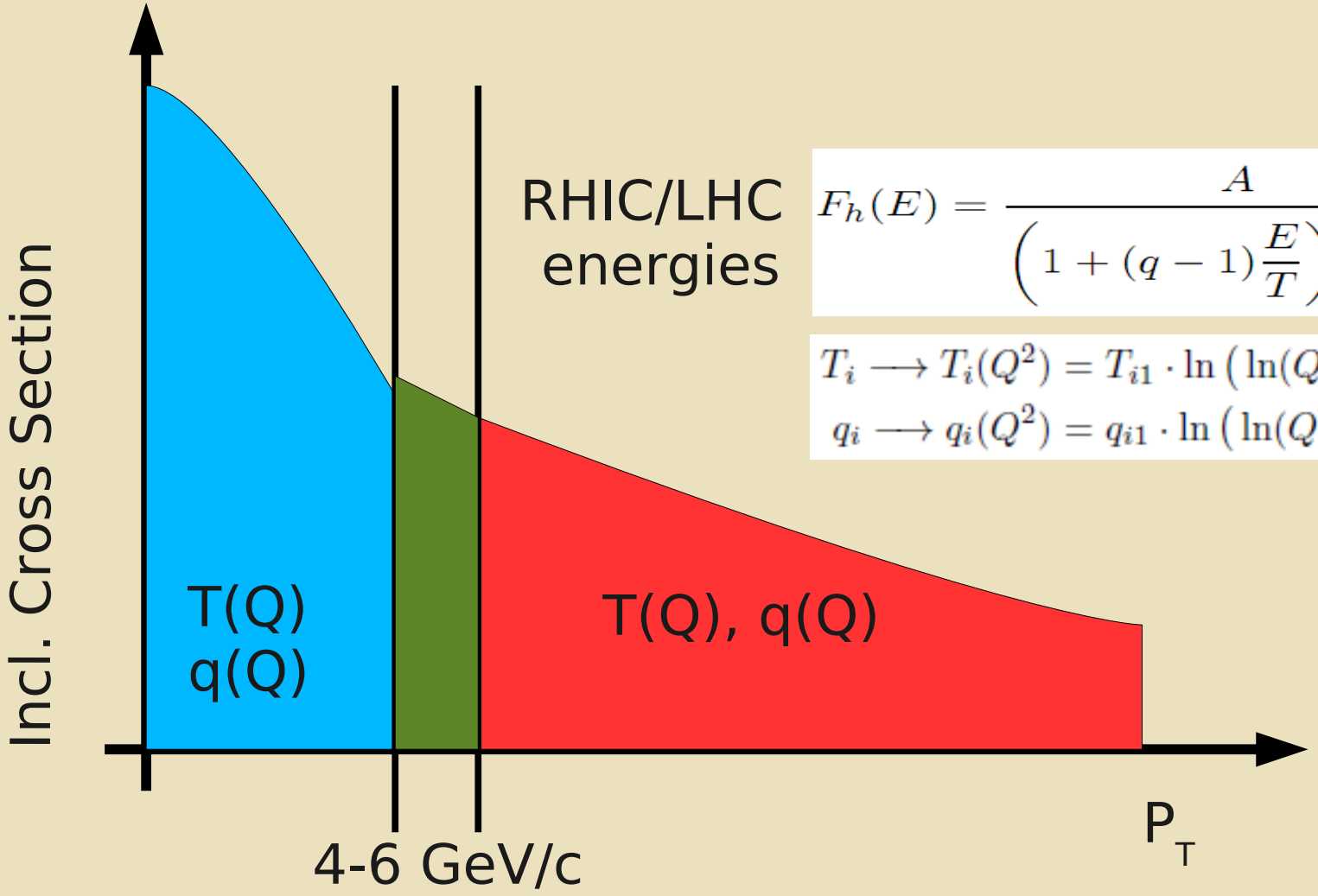
- A suggested new way: Tsallis (like) distribution



$$F_h(E) = \frac{A}{\left(1 + (q-1)\frac{E}{T}\right)^{1/(q-1)}}$$

Scale evoution can resolve the gap...

- Suggested interpetation: Tsallis + evolution

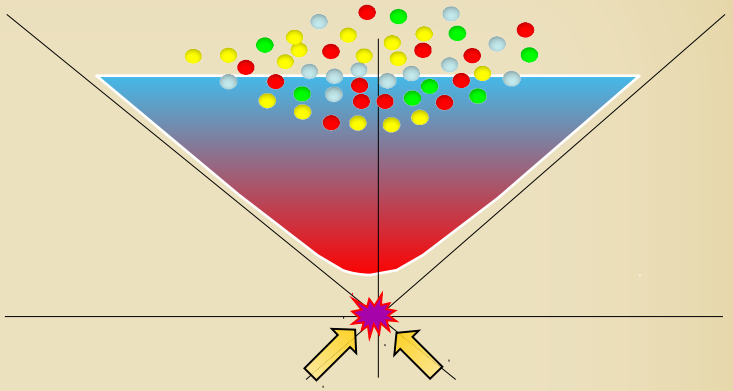


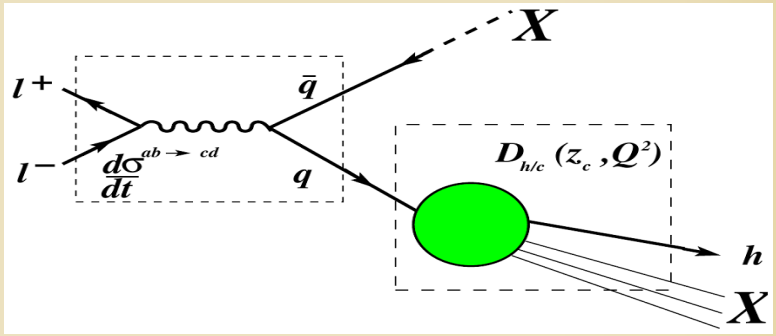
$$F_h(E) = \frac{A}{\left(1 + (q-1)\frac{E}{T}\right)^{1/(q-1)}}$$

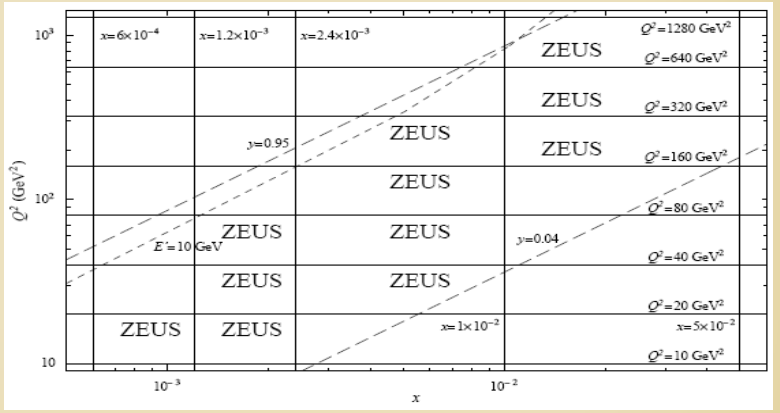
$$T_i \longrightarrow T_i(Q^2) = T_{i1} \cdot \ln\left(\ln(Q^2)\right) + T_{i0}$$
$$q_i \longrightarrow q_i(Q^2) = q_{i1} \cdot \ln\left(\ln(Q^2)\right) + q_{i0}$$

Hadronization processes & fragmentation

- Hadronization: requires a model, based on local parton-hadron duality (kvantum numbers & momenta connected to a cone around or to the leading particle.)
- Parton/hadron shower evolution comes from statistical processes (step-by-step MC evolution). → microscopical
- Fragmentation function (FF) carries integrated (phenomenological) information on how parton fragment into hadron. → integradted distribution
- Measurement lepton-antilepton annihilation, HIC, etc...







Fragmentation processes in parton model

In a pQCD based parton model, fragmentation functions (FF) gives how parton (a) fragment into a hadron (h), $D_{h/a}(z,Q^2)$.

DGLAP scale evolution:

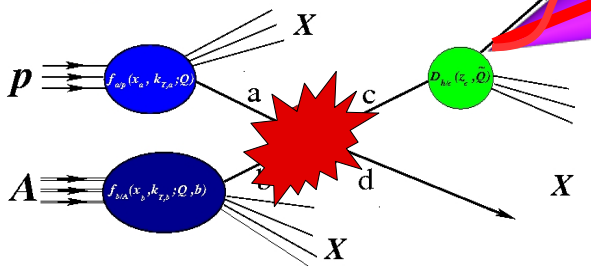
$$\frac{\partial}{\partial \ln Q^2} D_i^h(x,Q^2) = \sum_j \int_x^1 \frac{dz}{z} \frac{\alpha_S}{4\pi} P_{ji}\left(\frac{x}{z}, Q^2\right) D_i^h(z,Q^2)$$

$$E_\pi \frac{\mathrm{d}\sigma_\pi^{pA}}{\mathrm{d}^3 p_\pi} \sim f_{a/p}(x_a, Q^2; k_T) \otimes f_{b/A}(x_b, Q^2; k_T, b) \otimes \frac{\mathrm{d}\sigma^{ab\to cd}}{\mathrm{d}\hat{t}} \otimes \frac{D_{\pi/c}(z_c, \hat{Q}^2)}{\pi z_c^2}.$$

$f_{b/A}(x_a, Q^2; k_T, b)$: Parton Dist. Function (PDF), at scale Q^2

$D_{\pi/c}(z_c, \hat{Q}^2)$: Fragmentation Function for π (FF), at scale $\hat{Q}^2$

$\frac{\mathrm{d}\sigma^{ab\to cd}}{\mathrm{d}\hat{t}}$: Partonic cross section



Fragmentation via associative composition

Program:

1) Search and fit Tsallis distribution to data.

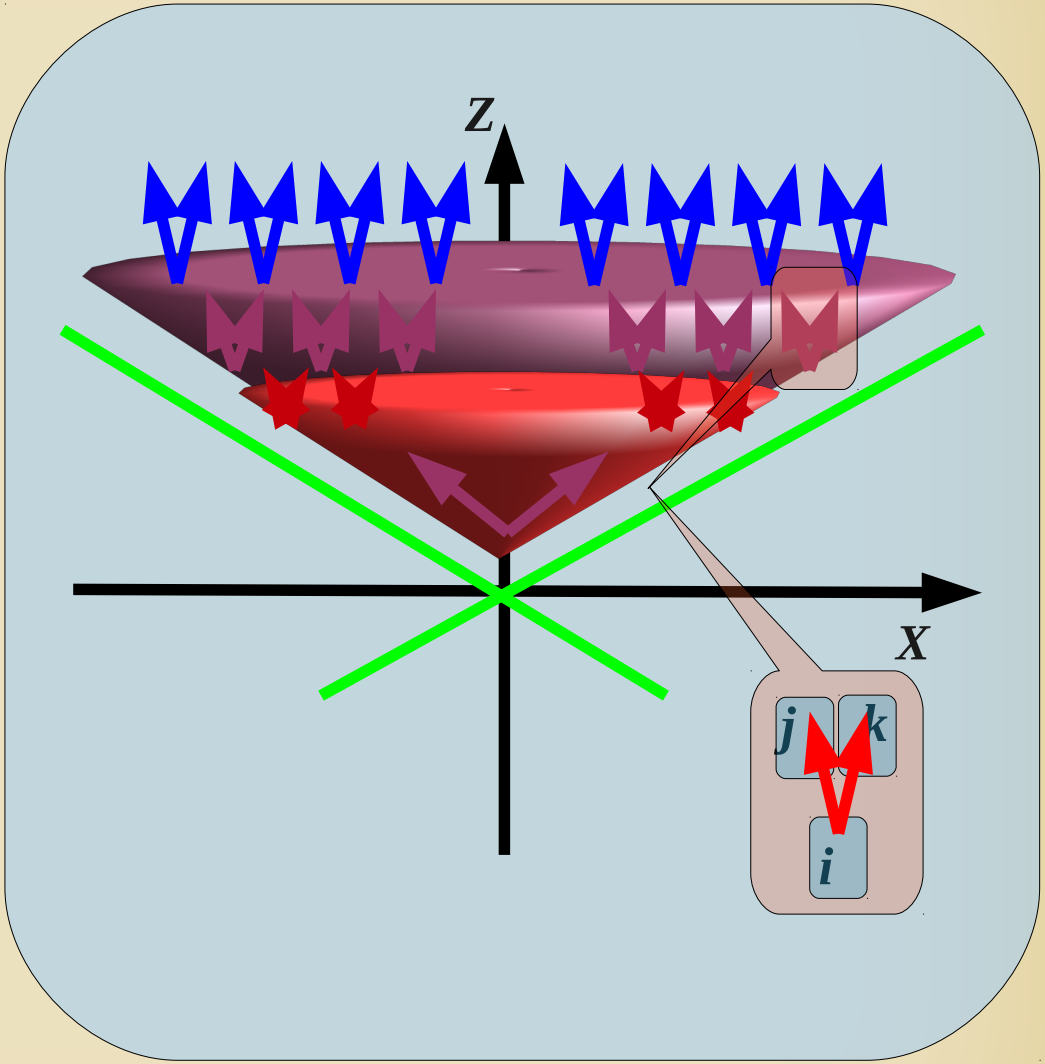
2) Search for physical meaning of T and q parameters.

3) Components of the sub-systems are e.g. 'splitting functions' $P_{q\,g}$, $P_{g\,g}$

4) Test: BFKL / DGLAP-like evolution equation ansatz can be inserted.

$$D(x,Q^2) \sim f(E,T,q) * f(\ln(Q^2))$$

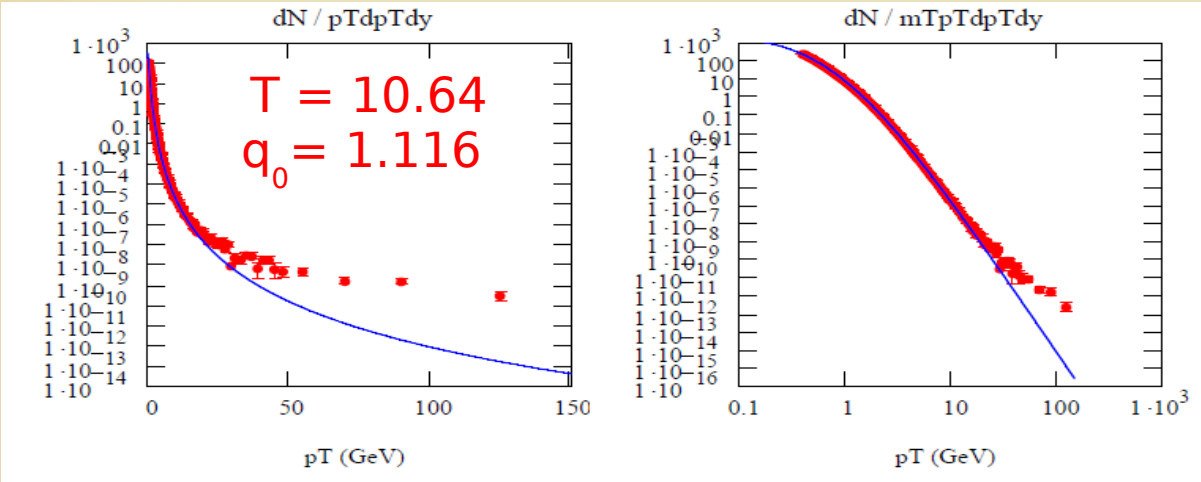
$$D(x,Q^2) \sim f(E,T(\ln(Q^2)),q(\ln(Q^2)))$$

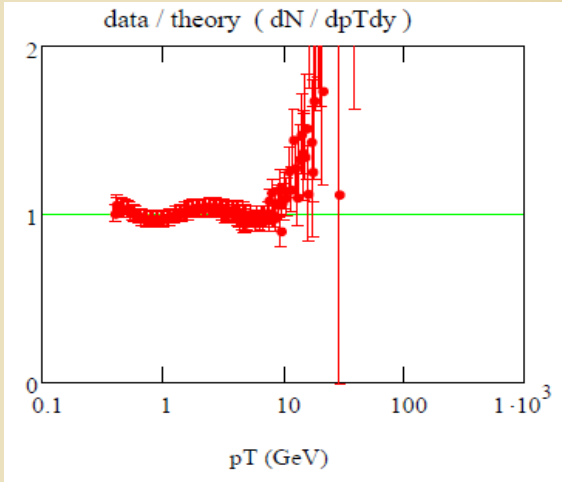


Joint model: Tsallis with evolution

- TEST on CDF ch. hadron data in pp @ 1.96 TeV |y|<1

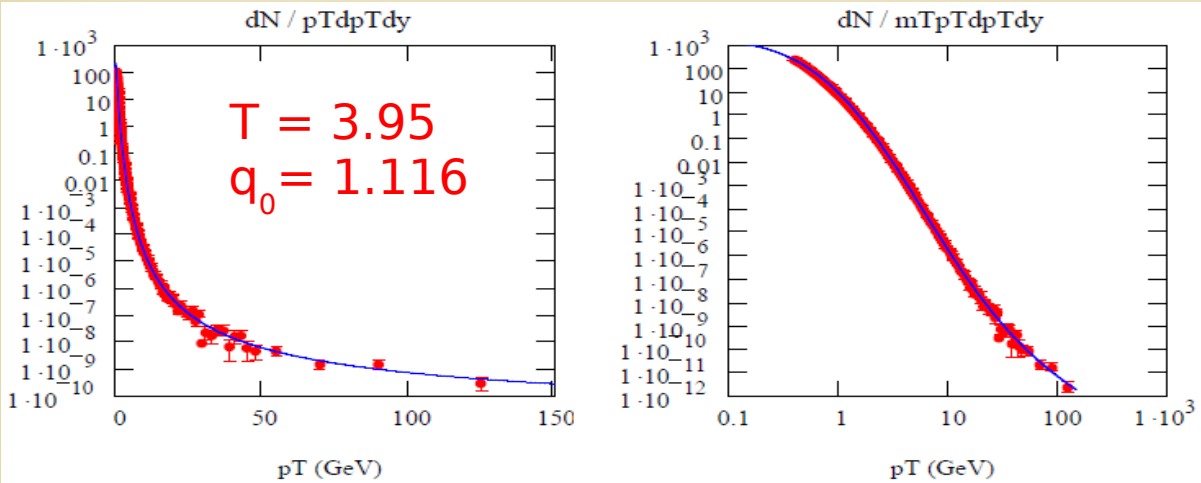
NO evolution

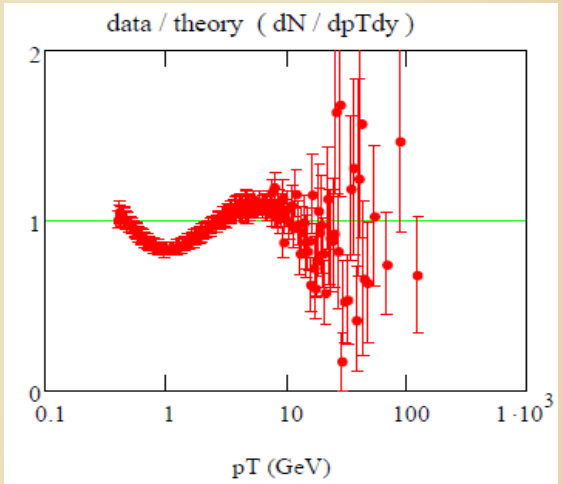




- DGLAP motivated evolution: $n = (q_0-1)^{-1} - 2*\log(\log(Q))$

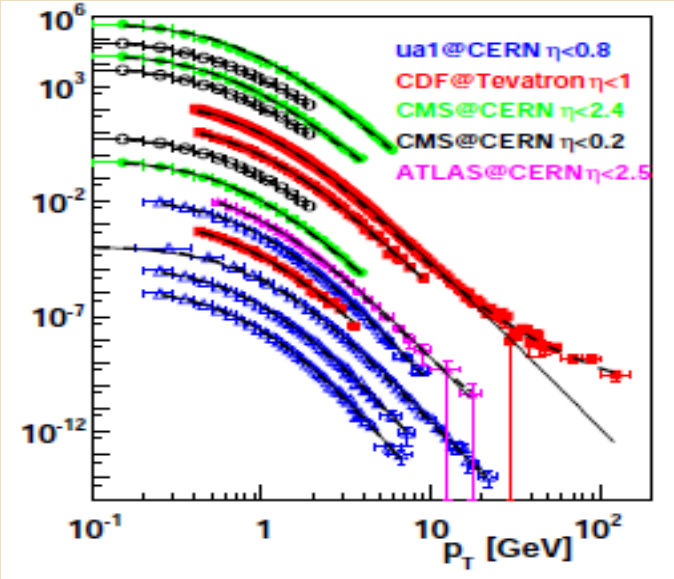
With evolution

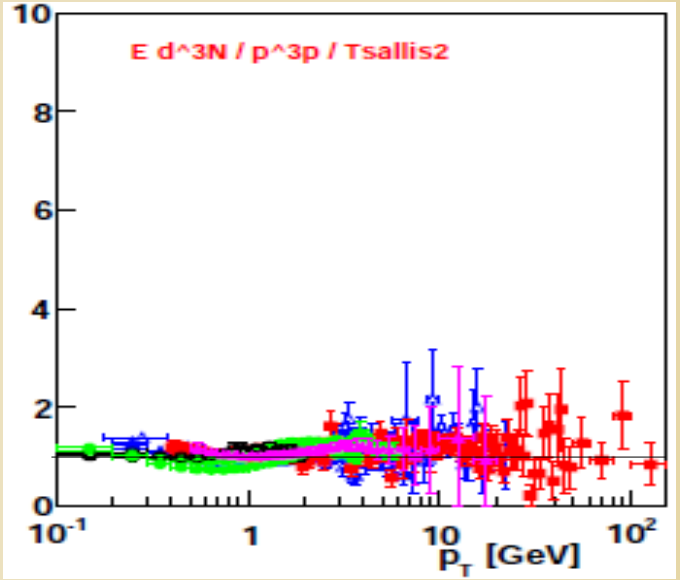




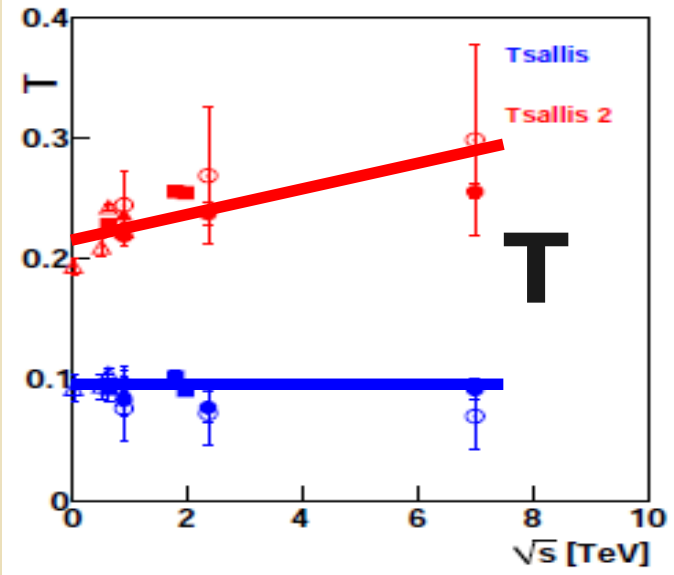
Joint model: Tsallis with evolution

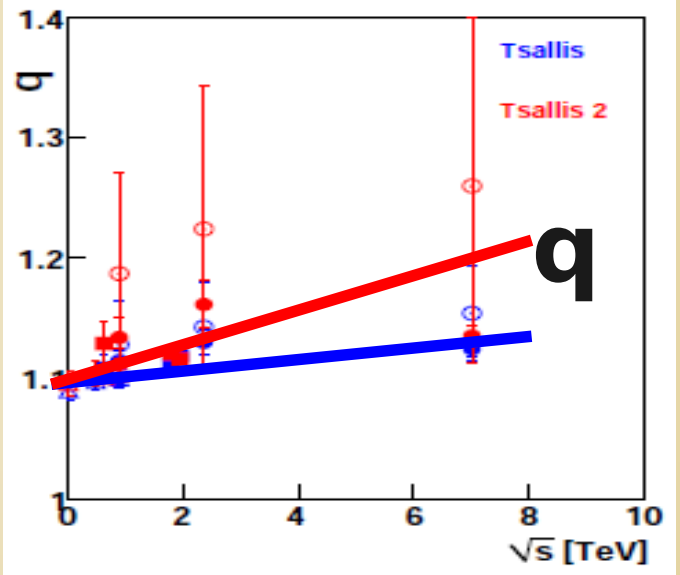
- More TEST: 0.2 - 7 TeV midrapidity data





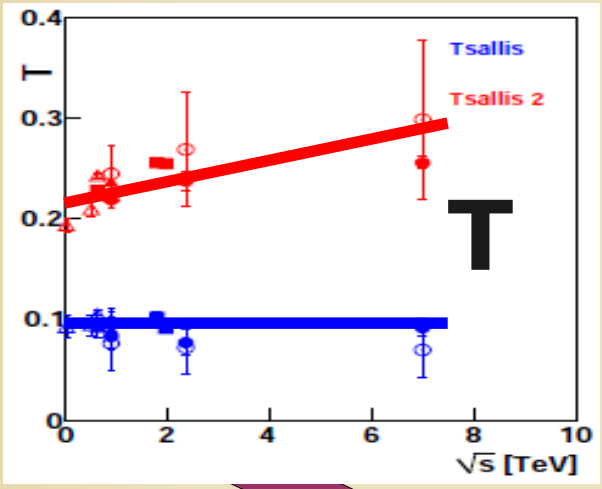
- C.m. Energy dependence of the T & q parameters

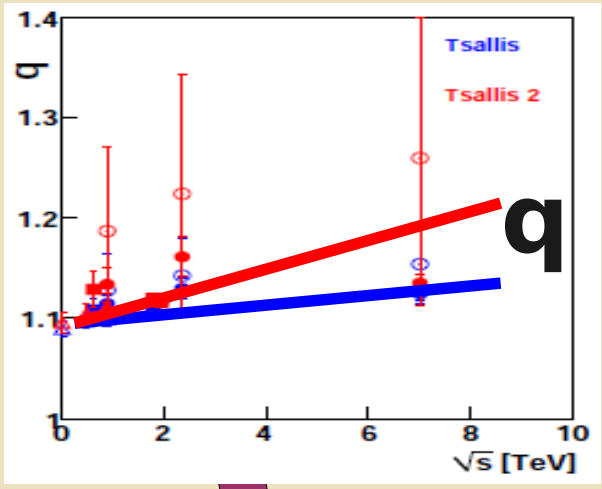


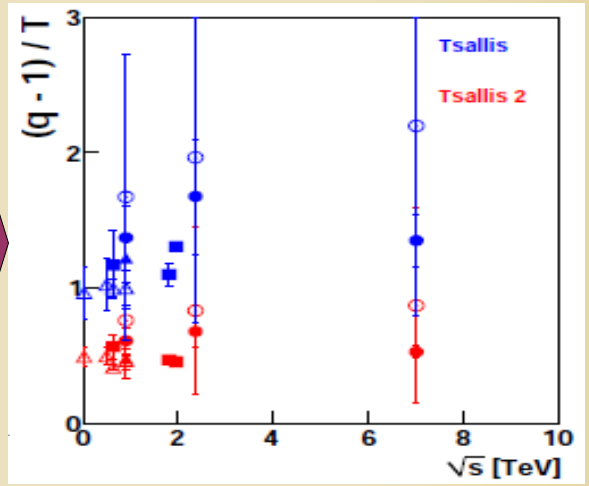


2nd joint model: Tsallis on q-T plane

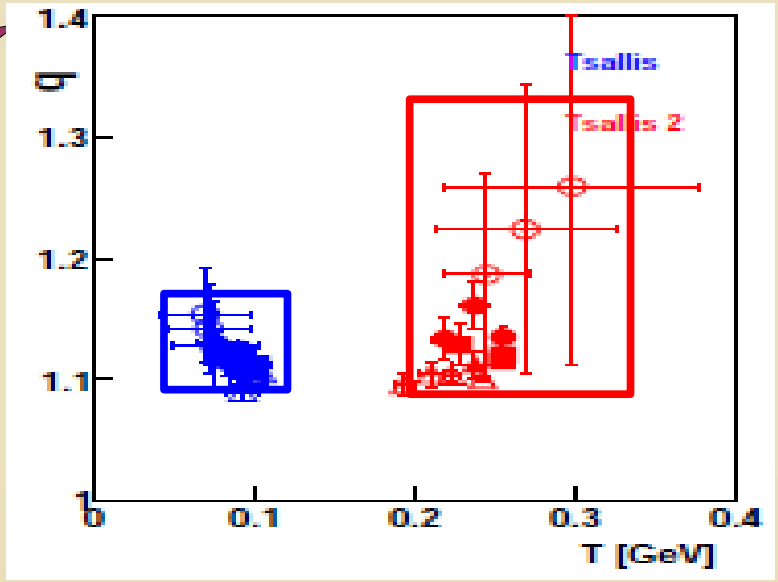
- TEST on various midrapidity data @ different cm





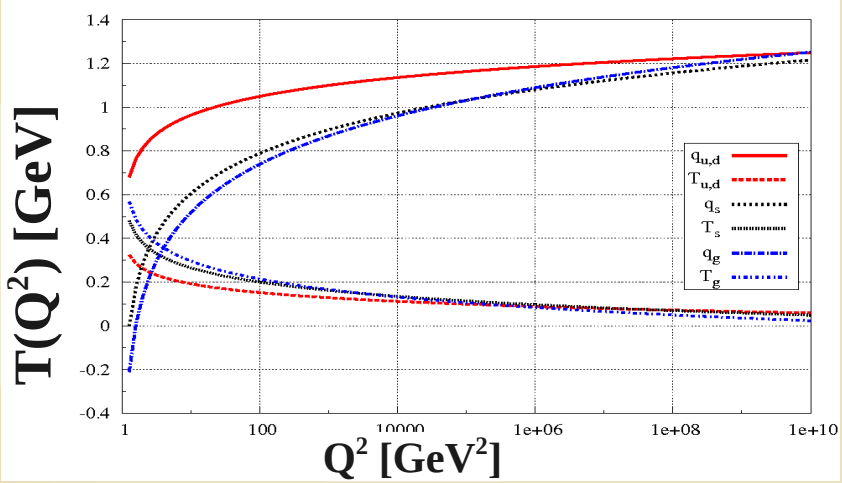


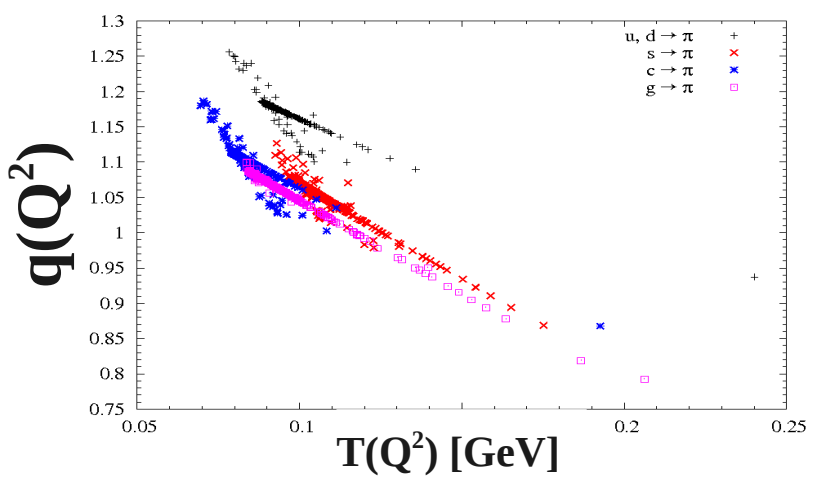
- The q-T plane



Test of the Tsallis based FF

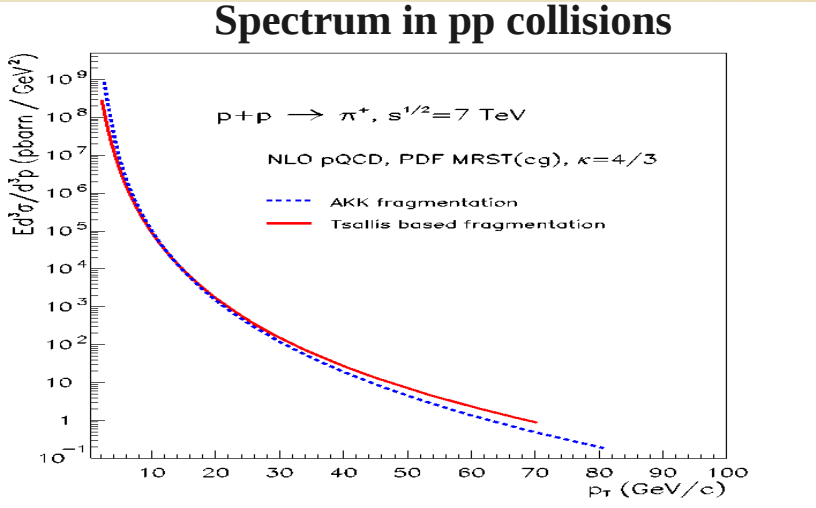
- Tsallis T & q parameters in different channels



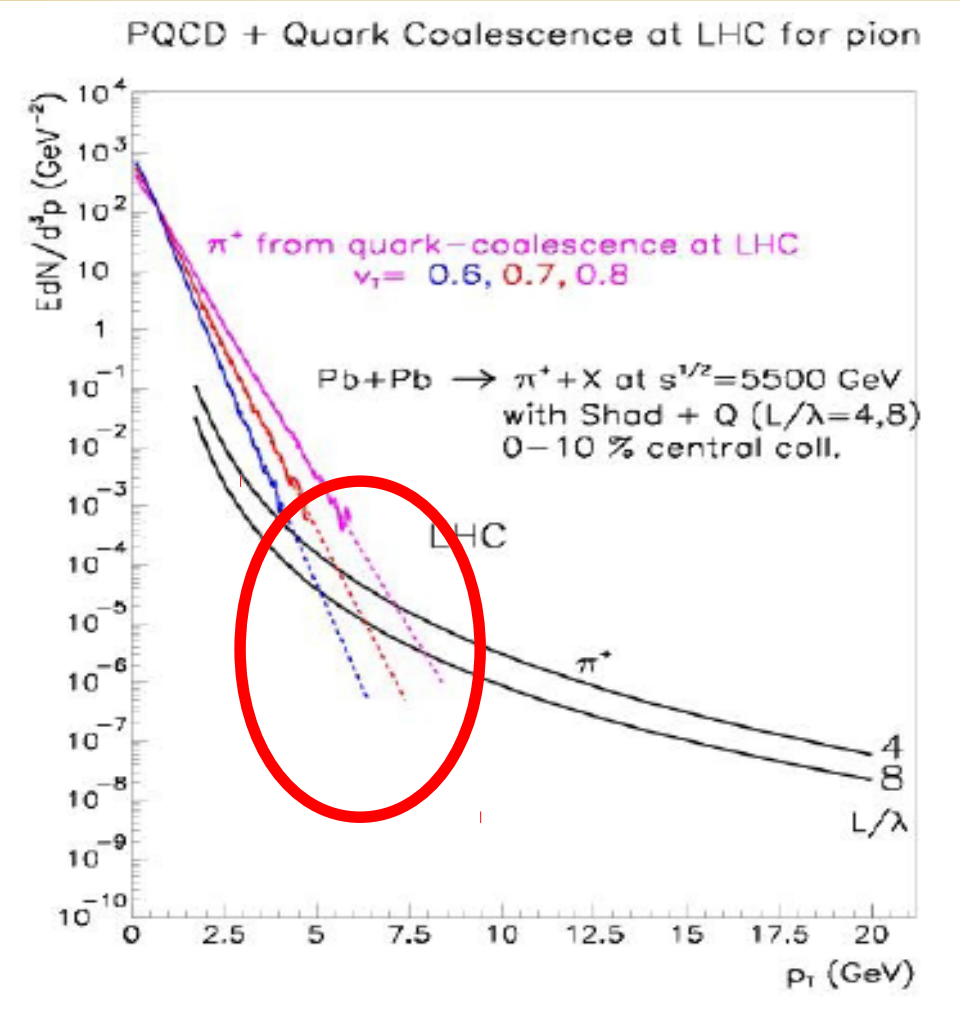


- Test of the model: pQCD vs. Tsallis based FF
  - pQCD based parton model PRC65 034903 (2002)
  - Scalig Tsallis parameters
  - DGLAP evolution
  - Sum Rule for normalization

GGB et al: Gribov '80 (2010)



Further motivation...



- pQCD based parton model:
  - QCD at T → 0 temperature
  - power law distribution
  - strong dependence on FF
  - good for high-p_T hadrons
- Quark-coalescence model
  - Thermal, finite temperature
  - exponential distribution $e^{-m / T}$
  - parton-hadron duality
  - good for high-p_T hadrons

P. Lévai, GGB, G. Fai: JPG35, 104111 (2008)

S U M M A R Y

- High & low p_T spectra has different distribution..

  ...however hadronization should not work differently.

- Non-extensive (non-equilibrium) thermodynamic

  Can be applied generally. Based on composition rules, evolution eq. can be obtain even for non-thermalised case.

- Tests and models with Tsallis assumptions

  Seems working for hadron production up to intermediate p_T, and extension to the highest p_T region is still question, however evolution need to be included.

.

... so we hope...

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Welcome to SCCS 2011

The STRONGLY COUPLED COULOMB SYSTEMS 2011 conference will be held in Budapest, Hungary, between 24 July and 29 July 2011. The Local Organizing Committee cordinally invites you to participate in the Conference, of which the scientific topics cover a wide range of phenomena taking place in many-body systems characterised by strong long-range interactions.

Budapest, the capital of the Hungarian Republic, is situated in the centre of the Carpathian Basin in Europe. The metropolis is bisected by the Danube with hills and valleys on the Buda side and the flat, low-lying Pest on the other. The riverside panorama has been declared a World Heritage site by UNESCO.

The meeting is planned to be held at the Danubius Hotel Flamenco, which is a four star hotel, situated in a green park, with a small lake and a view of the scenic Buda hills. The hotel is just minutes away from the business and shopping districts of the city, and is a short walk from the world-famous Castle District

We are looking forward to seeing you in Budapest in 2011.

The Local Organizing Committee of SCCS2011