ISMD 2015

4-9 October

Searching for hidden sectors in multiparticle production @ the LHC

Miguel-Angel Sanchis-Lozano

Departamento de Física Teórica - IFIC

Universidad de Valencia – CSIC

Edward Sarkisyan-Grinbaum

University of Texas at Arlington

& PH Department, CERN

Known Facts

The study of inclusive correlations among final-state particles provides essential information on the dynamics of strong interactions in high-energy processes through:

- (Differential) 2-, 3- or many-body correlation functions
- The distribution of particle multiplicity (e.g. moments) as it contains all correlation information in an integrated form

It has been extremely useful for decades in cosmic rays, fixed target and collider experiments for ee, pp and *AA* collisions

Prospectives at the LHC - 2015 (13-14 Tev)

Maybe helpful for discovery of a new stage of matter (**Hidden Sector**) manifesting in the **parton cascade** of high-energy *pp* collisions.

Not an easy task!

Techniques related to the quest for QGP in heavy-ion collisions

What if there were a new stage of unknown matter on top of the parton cascade?

SM matter: u, d, s, c , b, t, gluons, … +

Such a **new stage of matter** could become activated **above an energy threshold**

or

become more and more relevant in multiparticle production

as its production cross section increases with energy

Examples: Hidden sectors (e.g. hidden valley models),

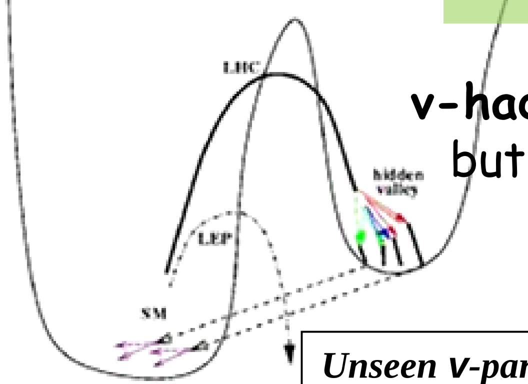
Unparticles,

Black holes, …

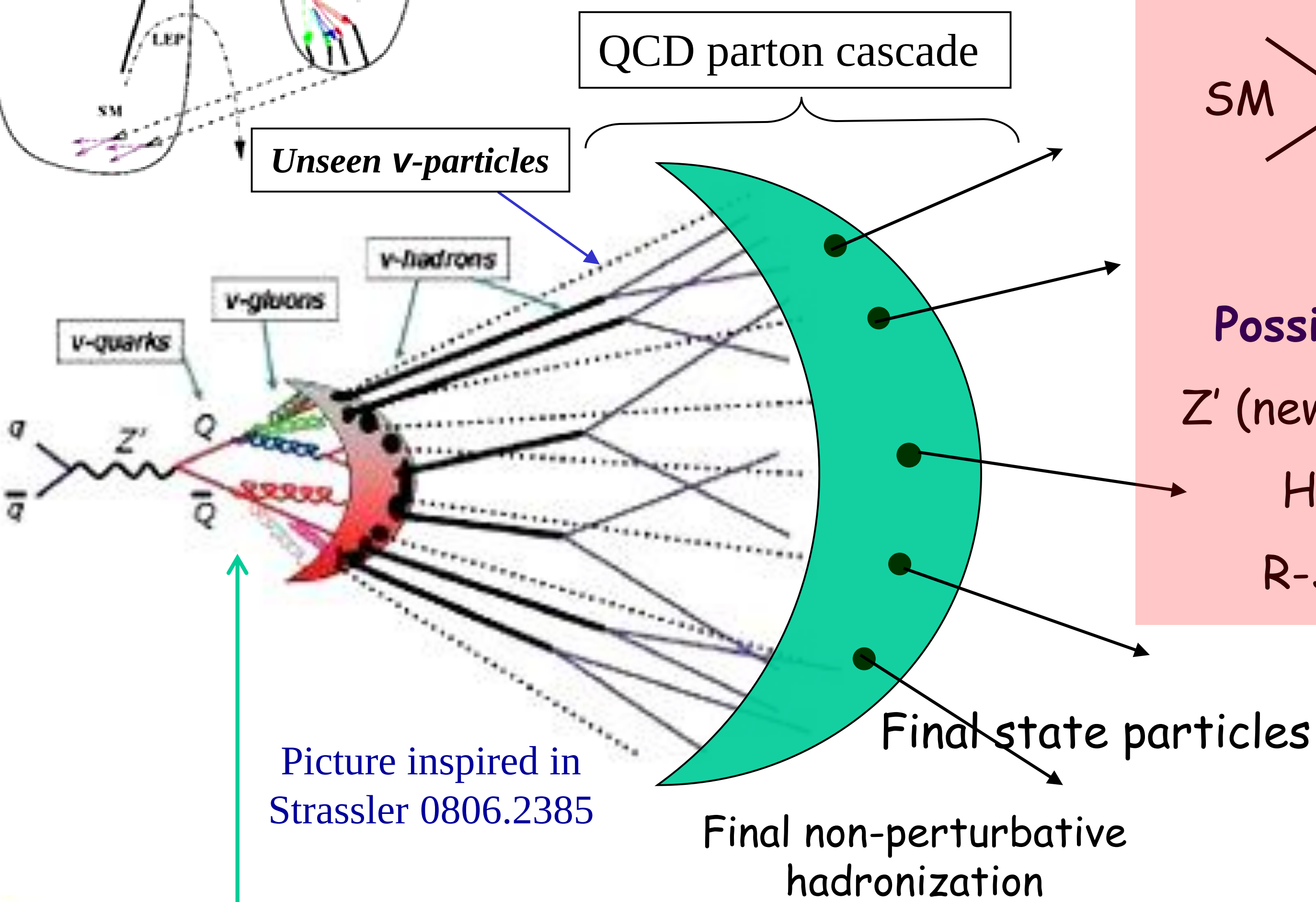
Hidden Valley models

Strassler & Zurek
hep-ph/0604261

M : scale of the mediator mass

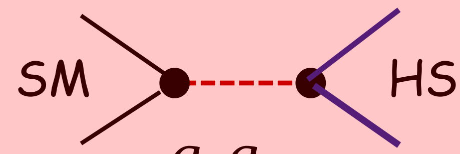


v-hadrons: smaller mass than M but larger than SM hadrons



Picture inspired in Strassler 0806.2385

Effective coupling of the two sectors



$$\frac{g_v g_{SM}}{M^k}$$

Possible mediators:

Z' (new U(1) symmetry)

Higgs sectors

R-S gravitons. …

One more step than in a conventional QCD-parton cascade

Two-particle rapidity correlations

$$C_2(y_1, y_2) = \rho(y_1, y_2) - \rho(y_1)\rho(y_2)$$ ← 2-particle rapidity correlation function

$$\rho(y) = \frac{1}{\sigma_{in}} \frac{d\sigma_{in}}{dy}, \ \rho_2(y_1, y_2) = \frac{1}{\sigma_{in}} \frac{d^2\sigma_{in}}{dy_1 dy_2}$$ one- and two-particle densities

$$f_1 = \int \rho(y)\, dy = < n >$$

$$\int dy_1 dy_2\, C(y_1, y_2) = f_2 = D^2 - < n >$$

(= 0 for independent emission)

$$K_2(y_1, y_2) = \frac{C_2(y_1, y_2)}{\rho(y_1)\rho(y_2)} = \frac{1}{\sigma_{in}} \frac{d^2\sigma_{in}}{dy_1 dy_2} / \frac{1}{\sigma_{in}^2} \frac{d\sigma_{in}}{dy_1} \frac{d\sigma_{in}}{dy_2} - 1$$

$$F_2 = \frac{< n(n-1) >}{< n >^2} = \frac{D^2}{< n >^2} - \frac{1}{< n >} + 1, \quad D^2 = < n^2 > - < n >^2$$

For a review see

Dremin and Gary Phys. Rept. 349 (2001) 301-393

Wolf, Dremin, Kittel Phys Rep. 270 (1996) 1

Higher-order

Normalized factorial moments, cumulants and ratios

$$F_q = \frac{<n(n-1)(n-2)\ldots(n-q+1)>}{<n>^q}$$

q = 2, 3, 4, ...

A.Bialas, R.Peschanski, 1986

$$F_2 = 1 + K_2, \quad F_3 = 1 + 3K_2 + K_3, \ldots$$

genuine q-order correlations

$$H_q = \frac{K_q}{F_q}$$

I. Dremin, 1993

For a **NBD** with k parameter

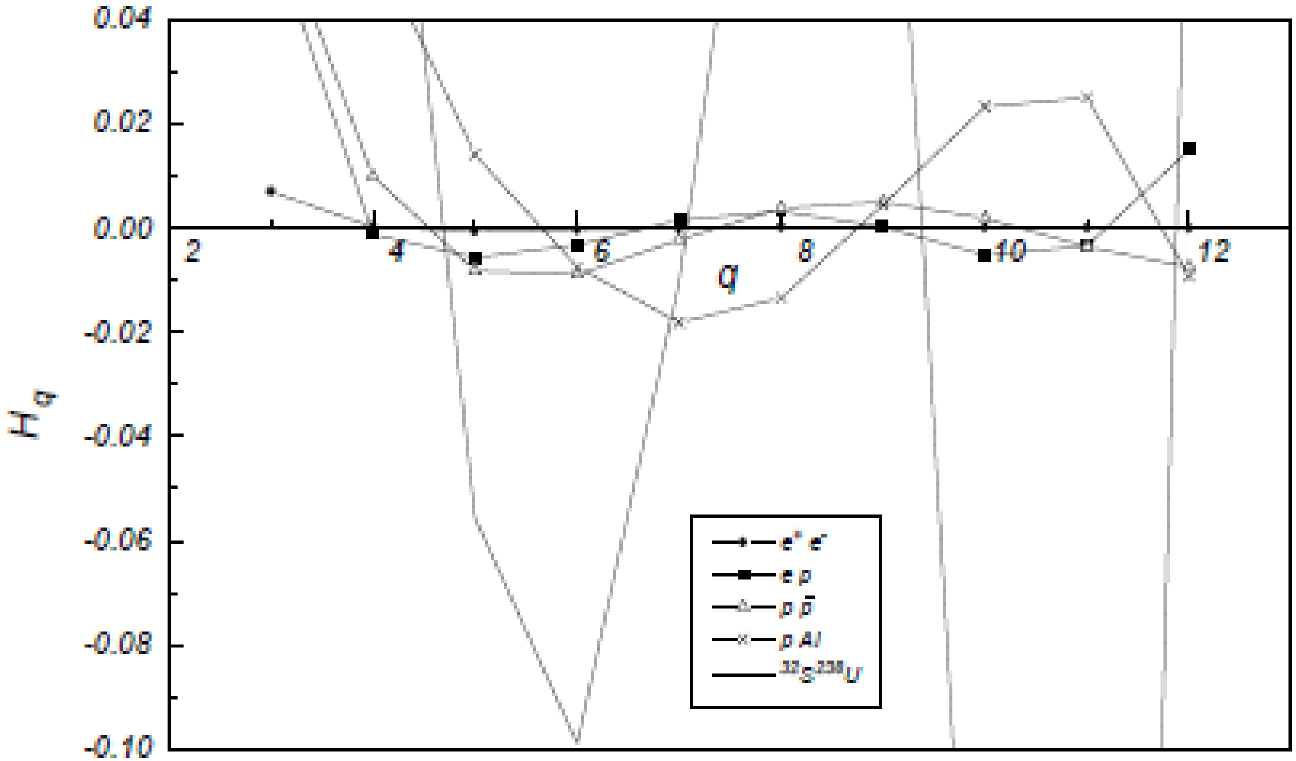
$$H_q = \frac{\Gamma(q)\Gamma(k+1)}{\Gamma(k+q)} = kB(q,k).$$

→ No oscillations!

Well known fact :

H_q oscillates as a function of the rank q over a large range of c.m.s. energy and nature of the colliding bodies

H_q Oscillations



Dremin and Gary Phys. Rept. 349 (2001) 301-393

Figure 23: The ratio H_q for e^+e^-, ep, $p\bar{p}$, pA and AA collisions [179], where A denotes a heavy ion.

The amplitude of the oscillations increases with the complexity of the interacting bodies

Oscillations are predicted by (NNL) QCD, but the true origin is still unclear!

Multiparticle production in pp collisions

Soft physics

Below *simplified* model of multiparticle production which could provide insight into the influence of a new stage of matter in the parton cascade

Multiparton interactions with a certain probabilty distribution

Weigthed superpositions of sources

Two free parameters only!

Independent Parton Pair Interaction (IPPI) I. Dremin and V. Nechitailo 2004, 2011

$$P^{(2)}(n) = \sum_{N_c} P(N_c) \sum_{n_i} \prod_{i=1}^{N_c} P^{(1)}(n_i)$$

2-step scenario (conventional)

$$P^{(3)}(n) = \sum_{N_s} P(N_s) \sum_{n_j} \prod_{j=1}^{N_s} P^{(2)}(n_j)$$

3-step scenario

$$P^{(4)}(n) = \sum_{N_h} P(N_h) \sum_{n_k} \prod_{k=1}^{N_h} P^{(3)}(n_k)$$

4-step scenario ...and more

Our extension

3-step scenario

Several examples

Primary interaction

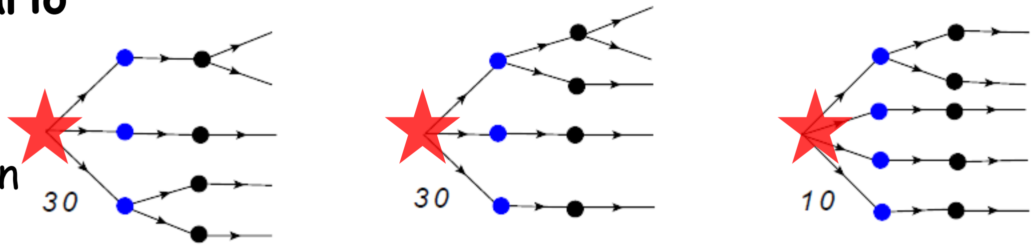
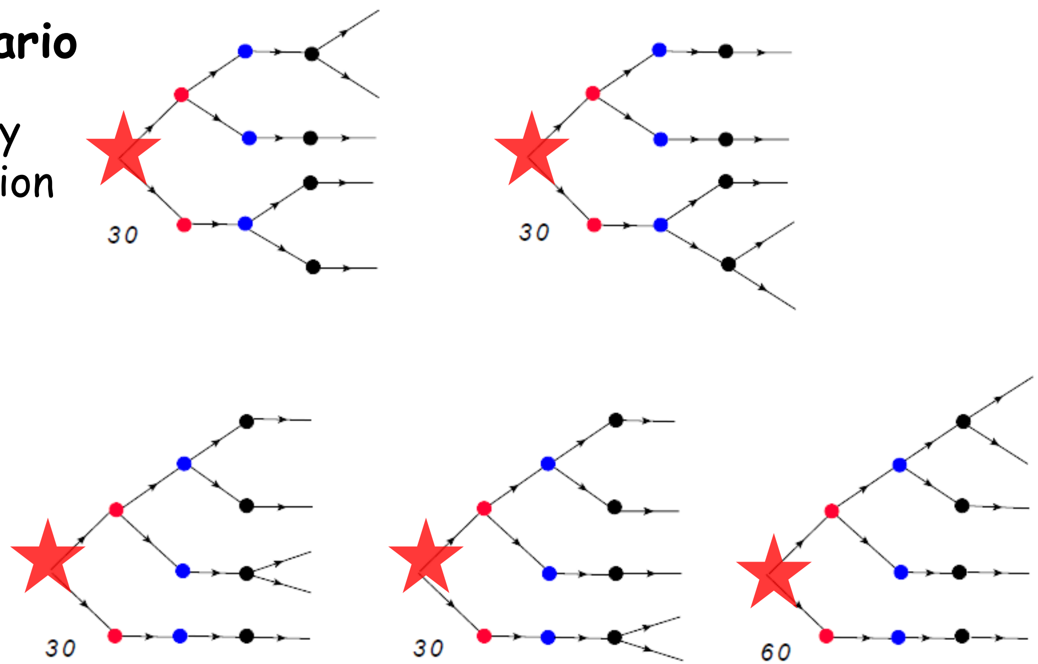


Figure 5: Left: Two different topological combinations involving $F_3^{(s)} F_2^{(c)} F_2^{(1)}$ leading to a five-particle final state. Right: diagram involving $F_4^{(s)} F_2^{(c)}$. The number below each diagram gives the number of possible final-state particle combinations.

4-step scenario

Primary interaction



Paper in preparation

Figure 6: Different topological combinations involving $F_2^{(h)} F_2^{(s)} F_2^{(1)}$ leading to a five-particle final state. The number below each diagram gives the number of possible final-state particle combinations.

3-step scenario

All these formulae represent a parameterization of the complexity of the hadronic dynamics

3 terms

$$F_2^{(3)} = F_2^{(s)} + \frac{F_2^{(c)}}{\langle N_s \rangle} + \frac{F_2^{(1)}}{\langle N_c \rangle}$$

$$F_3^{(3)} = F_3^{(s)} + \frac{F_3^{(c)}}{\langle N_s \rangle^2} + \frac{F_3^{(1)}}{\langle N_c \rangle^2} + 3\left[\frac{F_2^{(s)} F_2^{(c)}}{\langle N_s \rangle} + \frac{F_2^{(s)} F_2^{(1)}}{\langle N_c \rangle} + \frac{F_2^{(c)} F_2^{(1)}}{\langle N_s \rangle \langle N_c \rangle}\right]$$

6 terms

$$\begin{aligned} F_4^{(3)} = {} & F_4^{(s)} + \frac{F_4^{(c)}}{\langle N_s \rangle^3} + \frac{F_4^{(1)}}{\langle N_c \rangle^3} + \\ & 4\left[\frac{F_2^{(s)} F_3^{(c)}}{\langle N_s \rangle^2} + \frac{F_2^{(s)} F_3^{(1)}}{\langle N_c \rangle^2} + \frac{F_2^{(c)} F_3^{(1)}}{\langle N_s \rangle \langle N_c \rangle^2}\right] + \\ & 6\left[\frac{F_3^{(s)} F_2^{(c)}}{\langle N_s \rangle} + \frac{F_3^{(s)} F_2^{(1)}}{\langle N_c \rangle} + \frac{F_3^{(c)} F_2^{(1)}}{\langle N_s \rangle^2 \langle N_c \rangle}\right] + \\ & 3\left[\frac{F_2^{(s)} F_2^{(c)2}}{\langle N_s \rangle^2} + \frac{F_2^{(s)} F_2^{(1)2}}{\langle N_c \rangle^2} + \frac{F_2^{(c)} F_2^{(1)2}}{\langle N_s \rangle \langle N_c \rangle^2}\right] + \\ & 18\,\frac{F_2^{(s)} F_2^{(c)} F_2^{(1)}}{\langle N_s \rangle \langle N_c \rangle} \end{aligned}$$

13 terms

$< N_s >$ denotes the **average number of sources** per collision

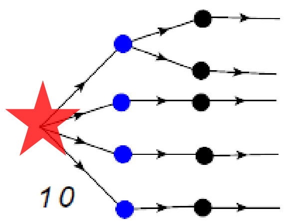
$< N_c >$ denotes the **average number of cascades** per collision

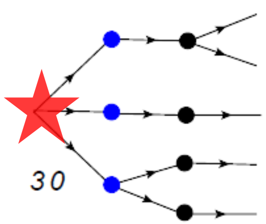
$F_q^{(s,c,1)}$: Normalized factorial moments at each step

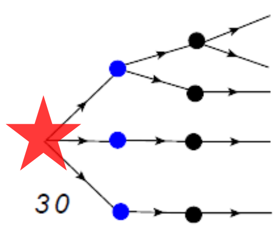
Paper in preparation

23 terms

$$
\begin{aligned}
F_5^{(3)} = \; & F_5^{(s)} + \frac{F_5^{(c)}}{\langle N_s\rangle^4} + \frac{F_5^{(1)}}{\langle N_c\rangle^4} + \\
& 5\left[\frac{F_2^{(s)}F_4^{(c)}}{\langle N_s\rangle^3} + \frac{F_2^{(s)}F_4^{(1)}}{\langle N_c\rangle^3} + \frac{F_2^{(c)}F_4^{(1)}}{\langle N_s\rangle\langle N_c\rangle^3}\right] + \\
& 10\left[\frac{F_4^{(s)}F_2^{(c)}}{\langle N_s\rangle} + \frac{F_4^{(c)}F_2^{(1)}}{\langle N_s\rangle^3\langle N_c\rangle} + \frac{F_4^{(s)}F_2^{(1)}}{\langle N_c\rangle}\right] + \\
& 10\left[\frac{F_3^{(s)}F_3^{(1)}}{\langle N_c\rangle^2} + \frac{F_3^{(s)}F_3^{(c)}}{\langle N_s\rangle^2} + \frac{F_3^{(c)}F_3^{(1)}}{\langle N_s\rangle^2\langle N_c\rangle^2}\right] + \\
& 15\left[\frac{F_3^{(s)}F_2^{(c)2}}{\langle N_s\rangle^2} + \frac{F_3^{(s)}F_2^{(1)2}}{\langle N_c\rangle^2} + \frac{F_3^{(c)}F_2^{(1)2}}{\langle N_s\rangle^2\langle N_c\rangle^2}\right] + \\
& 10\left[\frac{F_2^{(s)}F_3^{(1)}F_2^{(1)}}{\langle N_c\rangle^3} + 4\frac{F_2^{(s)}F_3^{(c)}F_2^{(1)}}{\langle N_s\rangle^2\langle N_c\rangle} + 3\frac{F_2^{(s)}F_2^{(c)}F_3^{(1)}}{\langle N_s\rangle\langle N_c\rangle^2} + \right. \\
& \left. 6\frac{F_3^{(s)}F_2^{(c)}F_2^{(1)}}{\langle N_s\rangle\langle N_c\rangle} + \frac{F_2^{(s)}F_3^{(c)}F_2^{(c)}}{\langle N_s\rangle^3} + \frac{F_2^{(c)}F_3^{(1)}F_2^{(1)}}{\langle N_s\rangle\langle N_c\rangle^3}\right] + \\
& 30\left[\frac{F_2^{(s)}F_2^{(c)2}F_2^{(1)}}{\langle N_s\rangle^2\langle N_c\rangle} + 1.5\frac{F_2^{(s)}F_2^{(c)}F_2^{(1)2}}{\langle N_s\rangle\langle N_c\rangle^2}\right]
\end{aligned}
$$







Paper in preparation

4-step scenario

Paper in preparation

$F_q^{(h)}$: Normalized factorial moment HS

$$F_2^{(4)} = F_2^{(h)} + \frac{F_2^{(s)}}{\langle N_h \rangle} + \frac{F_2^{(c)}}{\langle N_s \rangle} + \frac{F_2^{(1)}}{\langle N_c \rangle}$$

4 terms

$$F_3^{(4)} = F_3^{(h)} + \frac{F_3^{(s)}}{\langle N_h \rangle^2} + \frac{F_3^{(c)}}{\langle N_s \rangle^2} + \frac{F_3^{(1)}}{\langle N_c \rangle^2} + 3\left[\frac{F_2^{(c)} F_2^{(1)}}{\langle N_s \rangle \langle N_c \rangle} + \frac{F_2^{(s)} F_2^{(1)}}{\langle N_h \rangle \langle N_c \rangle} + \frac{F_2^{(s)} F_2^{(c)}}{\langle N_h \rangle \langle N_c \rangle} + \frac{F_2^{(h)} F_2^{(1)}}{\langle N_c \rangle} + \frac{F_2^{(h)} F_2^{(c)}}{\langle N_s \rangle} + \frac{F_2^{(h)} F_2^{(s)}}{\langle N_h \rangle} \right]$$

10 terms

$$\begin{aligned} F_4^{(4)} = {} & F_4^{(h)} + \frac{F_4^{(s)}}{\langle N_h \rangle^3} + \frac{F_4^{(c)}}{\langle N_s \rangle^3} + \frac{F_4^{(1)}}{\langle N_c \rangle^3} + \\ & 4\left[\frac{F_2^{(s)} F_3^{(c)}}{\langle N_h \rangle \langle N_s \rangle^2} + \frac{F_2^{(s)} F_3^{(1)}}{\langle N_h \rangle \langle N_c \rangle^2} + \frac{F_2^{(c)} F_3^{(1)}}{\langle N_s \rangle \langle N_c \rangle^2} + \frac{F_2^{(h)} F_3^{(s)}}{\langle N_h \rangle^2} + \frac{F_2^{(h)} F_3^{(c)}}{\langle N_s \rangle^2} + \frac{F_2^{(h)} F_3^{(1)}}{\langle N_c \rangle^2} \right] + \\ & 6\left[\frac{F_3^{(s)} F_2^{(c)}}{\langle N_h \rangle^2 \langle N_s \rangle} + \frac{F_3^{(s)} F_2^{(1)}}{\langle N_h \rangle^2 \langle N_c \rangle} + \frac{F_3^{(c)} F_2^{(1)}}{\langle N_s \rangle^2 \langle N_c \rangle} + \frac{F_3^{(h)} F_2^{(c)}}{\langle N_s \rangle} + \frac{F_3^{(h)} F_2^{(1)}}{\langle N_c \rangle} + \frac{F_3^{(h)} F_2^{(s)}}{\langle N_h \rangle} \right] + \\ & 3\left[\frac{F_2^{(s)} F_2^{(1)2}}{\langle N_h \rangle \langle N_c \rangle^2} + \frac{F_2^{(s)} F_2^{(1)2}}{\langle N_h \rangle \langle N_s \rangle^2} + \frac{F_2^{(c)} F_2^{(1)2}}{\langle N_s \rangle \langle N_c \rangle^2} + \frac{F_2^{(h)} F_2^{(1)2}}{\langle N_c \rangle^2} + \frac{F_2^{(h)} F_2^{(c)2}}{\langle N_s \rangle^2} + \frac{F_2^{(h)} F_2^{(s)2}}{\langle N_h \rangle^2} \right] + \\ & 18\left[\frac{F_2^{(s)} F_2^{(c)} F_2^{(1)}}{\langle N_h \rangle \langle N_s \rangle \langle N_c \rangle} + \frac{F_2^{(h)} F_2^{(c)} F_2^{(1)}}{\langle N_s \rangle \langle N_c \rangle} + \frac{F_2^{(h)} F_2^{(s)} F_2^{(c)}}{\langle N_h \rangle \langle N_s \rangle} + \frac{F_2^{(h)} F_2^{(s)} F_2^{(1)}}{\langle N_h \rangle \langle N_c \rangle} \right] \end{aligned}$$

26 terms

55 terms

$$
\begin{aligned}
F_5^{(4)} = {} & F_5^{(h)} + \frac{F_5^{(s)}}{\langle N_h\rangle^4} + \frac{F_5^{(c)}}{\langle N_s\rangle^4} + \frac{F_5^{(1)}}{\langle N_c\rangle^4} + \\
& 5\left[\frac{F_2^{(s)}F_4^{(c)}}{\langle N_h\rangle\langle N_s\rangle^3} + \frac{F_2^{(c)}F_4^{(1)}}{\langle N_s\rangle\langle N_c\rangle^3} + \frac{F_2^{(s)}F_4^{(1)}}{\langle N_h\rangle\langle N_c\rangle^3} + \frac{F_2^{(h)}F_4^{(s)}}{\langle N_h\rangle^3} + \frac{F_2^{(h)}F_4^{(c)}}{\langle N_s\rangle^3} + \frac{F_2^{(h)}F_4^{(1)}}{\langle N_c\rangle^3}\right] + \\
& 10\left[\frac{F_4^{(s)}F_2^{(c)}}{\langle N_h\rangle^3\langle N_s\rangle} + \frac{F_4^{(c)}F_2^{(1)}}{\langle N_s\rangle^3\langle N_c\rangle} + \frac{F_4^{(s)}F_2^{(1)}}{\langle N_h\rangle^3\langle N_c\rangle} + \frac{F_4^{(h)}F_2^{(s)}}{\langle N_h\rangle} + \frac{F_4^{(h)}F_2^{(c)}}{\langle N_s\rangle} + \frac{F_4^{(h)}F_2^{(1)}}{\langle N_c\rangle}\right] + \\
& 10\left[\frac{F_3^{(s)}F_3^{(1)}}{\langle N_h\rangle^2\langle N_c\rangle^2} + \frac{F_3^{(s)}F_3^{(c)}}{\langle N_h\rangle^2\langle N_s\rangle^2} + \frac{F_3^{(c)}F_3^{(1)}}{\langle N_s\rangle^2\langle N_c\rangle^2} + \frac{F_3^{(h)}F_3^{(c)}}{\langle N_s\rangle^2} + \frac{F_3^{(h)}F_3^{(s)}}{\langle N_h\rangle^2} + \frac{F_3^{(h)}F_3^{(1)}}{\langle N_c\rangle^2}\right] + \\
& 15\left[\frac{F_3^{(s)}F_2^{(c)2}}{\langle N_h\rangle^2\langle N_s\rangle^2} + \frac{F_3^{(c)}F_2^{(1)2}}{\langle N_s\rangle^2\langle N_c\rangle^2} + \frac{F_3^{(s)}F_2^{(1)2}}{\langle N_h\rangle^2\langle N_c\rangle^2} + \frac{F_3^{(h)}F_2^{(s)2}}{\langle N_h\rangle^2} + \frac{F_3^{(h)}F_2^{(c)2}}{\langle N_s\rangle^2} + \frac{F_3^{(h)}F_2^{(1)2}}{\langle N_c\rangle^2}\right] + \\
& 10\left[4\frac{F_2^{(s)}F_3^{(c)}F_2^{(1)}}{\langle N_h\rangle\langle N_s\rangle^2\langle N_c\rangle} + 4\frac{F_2^{(h)}F_3^{(s)}F_2^{(c)}}{\langle N_h\rangle^2\langle N_s\rangle} + 4\frac{F_2^{(h)}F_3^{(c)}F_2^{(1)}}{\langle N_s\rangle^2\langle N_c\rangle} + 4\frac{F_2^{(h)}F_3^{(s)}F_2^{(1)}}{\langle N_h\rangle^2\langle N_c\rangle} + \right. \\
& 6\frac{F_3^{(s)}F_2^{(c)}F_2^{(1)}}{\langle N_h\rangle^2\langle N_s\rangle\langle N_c\rangle} + 6\frac{F_3^{(h)}F_2^{(s)}F_2^{(c)}}{\langle N_h\rangle\langle N_s\rangle} + 6\frac{F_3^{(h)}F_2^{(s)}F_2^{(1)}}{\langle N_h\rangle\langle N_c\rangle} + 6\frac{F_3^{(h)}F_3^{(c)}F_2^{(1)}}{\langle N_s\rangle\langle N_c\rangle} + \\
& 3\frac{F_2^{(s)}F_2^{(c)}F_3^{(1)}}{\langle N_h\rangle\langle N_s\rangle\langle N_c\rangle^2} + 3\frac{F_2^{(h)}F_2^{(s)}F_3^{(1)}}{\langle N_s\rangle\langle N_c\rangle^2} + 3\frac{F_2^{(h)}F_2^{(s)}F_3^{(c)}}{\langle N_h\rangle\langle N_s\rangle^2} + 3\frac{F_2^{(h)}F_2^{(c)}F_3^{(1)}}{\langle N_h\rangle\langle N_c\rangle^2} + \\
& \left.\frac{F_2^{(s)}F_3^{(1)}F_2^{(1)}}{\langle N_h\rangle^2\langle N_c\rangle^3} + \frac{F_2^{(s)}F_3^{(c)}F_2^{(c)}}{\langle N_h\rangle\langle N_s\rangle^3} + \frac{F_2^{(c)}F_3^{(1)}F_2^{(1)}}{\langle N_s\rangle\langle N_c\rangle^3} + \frac{F_2^{(h)}F_3^{(s)}F_2^{(s)}}{\langle N_h\rangle^3} + \frac{F_2^{(h)}F_3^{(c)}F_2^{(c)}}{\langle N_s\rangle^3} + \frac{F_2^{(h)}F_3^{(1)}F_2^{(1)}}{\langle N_c\rangle^3}\right] + \\
& 30\left[1.5\frac{F_2^{(s)}F_2^{(c)}F_2^{(1)2}}{\langle N_h\rangle\langle N_s\rangle\langle N_c\rangle^2} + \frac{F_2^{(s)}F_2^{(c)2}F_2^{(1)}}{\langle N_h\rangle\langle N_s\rangle^2\langle N_c\rangle} + 1.5\frac{F_2^{(h)}F_2^{(s)}F_2^{(c)2}}{\langle N_h\rangle\langle N_s\rangle^2} + 1.5\frac{F_2^{(h)}F_2^{(s)}F_2^{(1)2}}{\langle N_h\rangle\langle N_c\rangle^2} + \right. \\
& \left. 1.5\frac{F_2^{(h)}F_2^{(c)}F_2^{(1)2}}{\langle N_s\rangle\langle N_c\rangle^2} + \frac{F_2^{(h)}F_2^{(s)2}F_2^{(c)}}{\langle N_h\rangle^2\langle N_s\rangle} + \frac{F_2^{(h)}F_2^{(s)2}F_2^{(1)}}{\langle N_h\rangle^3\langle N_c\rangle} + \frac{F_2^{(h)}F_2^{(c)2}F_2^{(1)}}{\langle N_s\rangle^2\langle N_c\rangle}\right] + \\
& 180\left[\frac{F_2^{(h)}F_2^{(s)}F_2^{(c)}F_2^{(1)}}{\langle N_h\rangle\langle N_s\rangle\langle N_c\rangle}\right]
\end{aligned}
$$

Computation of high rank $F_q^{(p)}$

Computation of expressions of $F_q^{(p)}$ ($p=2,3,4\ldots$) for high rank q

becomes increasingly complicated, impossible to calculate “by hand”.

We thus have written a Prolog code* which provides all terms and

their coefficients up to any number of steps and any rank q

(depending on the capacity of the computer of course).

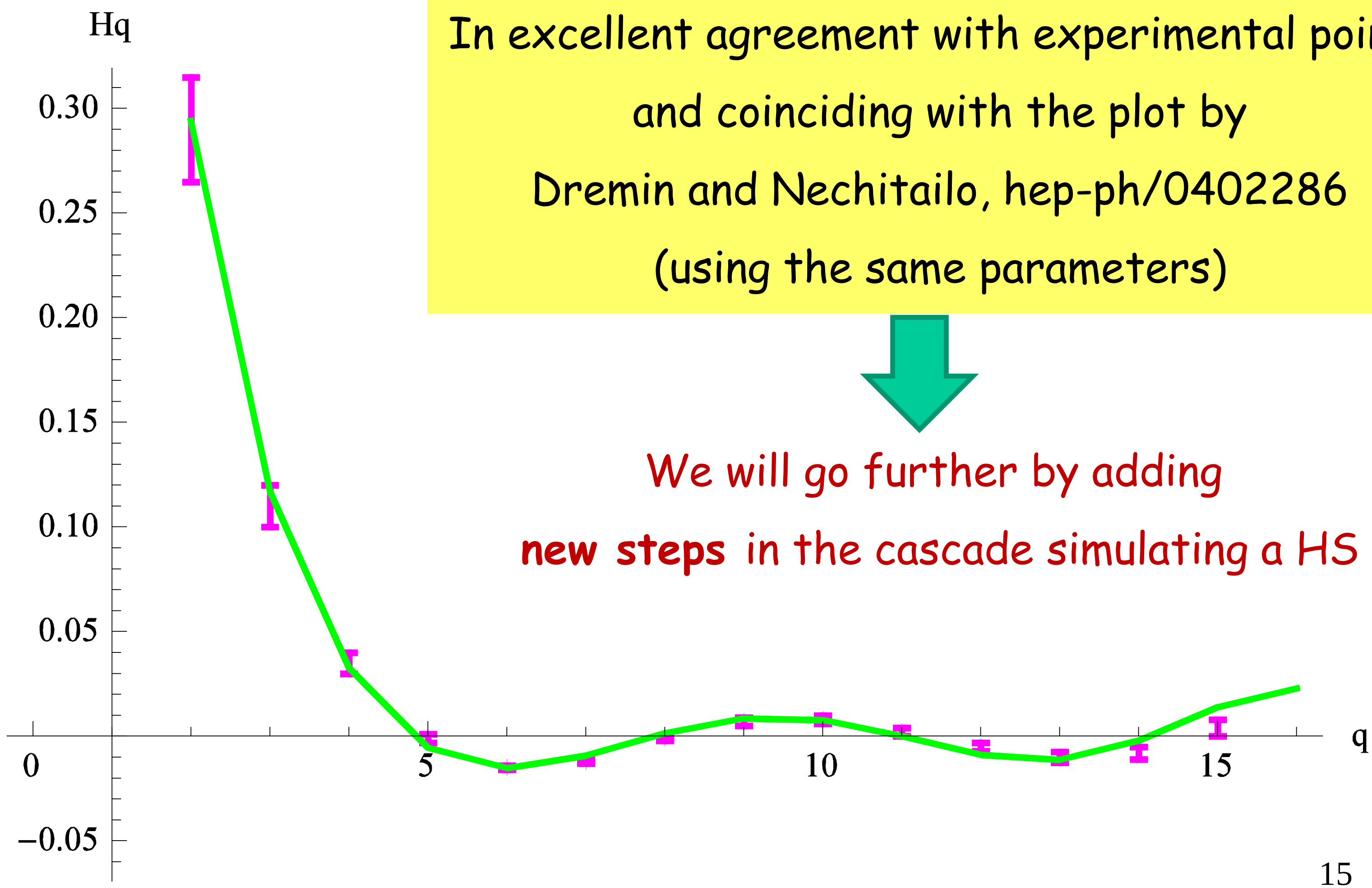
For example:

$F_{16}^{(3)}$ has about **100 000 terms** with some coefficients of **order 10^9**

*Soon available: Paper in preparation

Experimental data at 1.8 TeV versus **our fit**

2-step cascade (IPPI)



In excellent agreement with experimental points

and coinciding with the plot by

Dremin and Nechitailo, hep-ph/0402286

(using the same parameters)

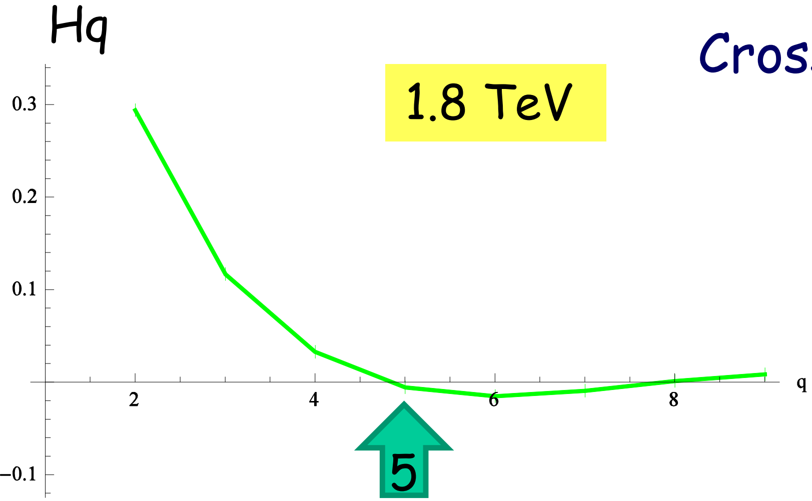
We will go further by adding

new steps in the cascade simulating a HS

Crossing point and first minimum behaviour

with increasing collision energy

2-step cascade

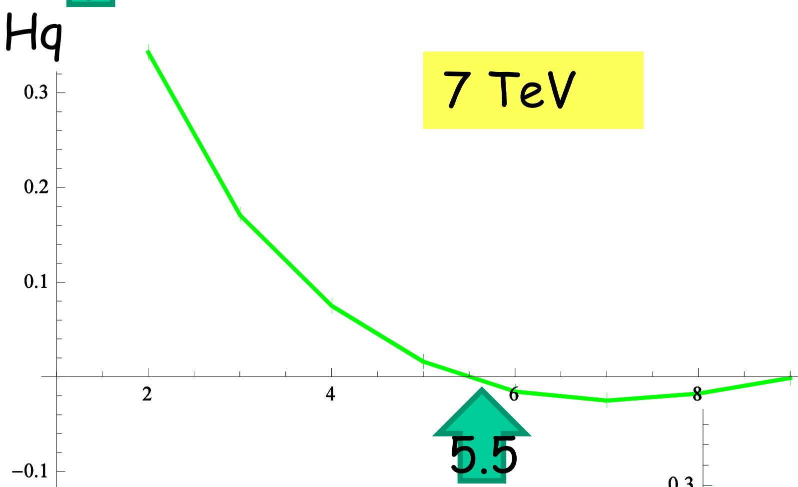


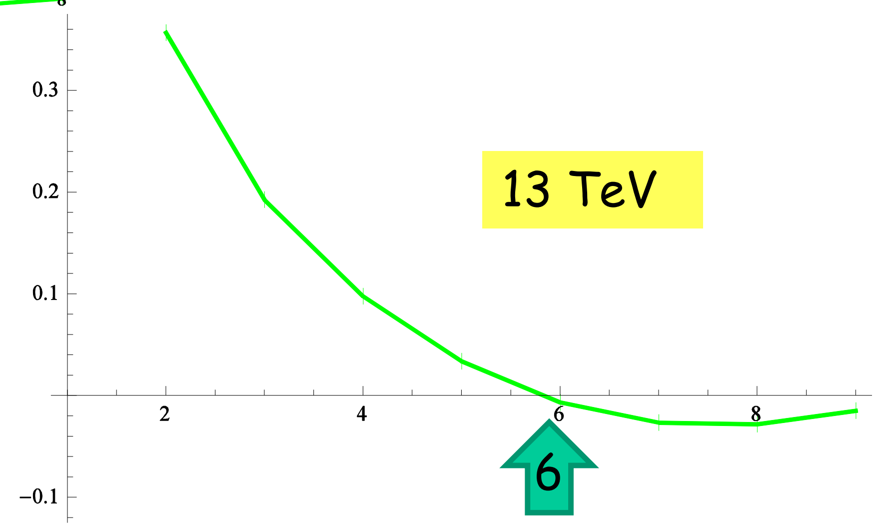
2-step cascade (IPPI)

the crossing point and

first minimum shift

to higher q values



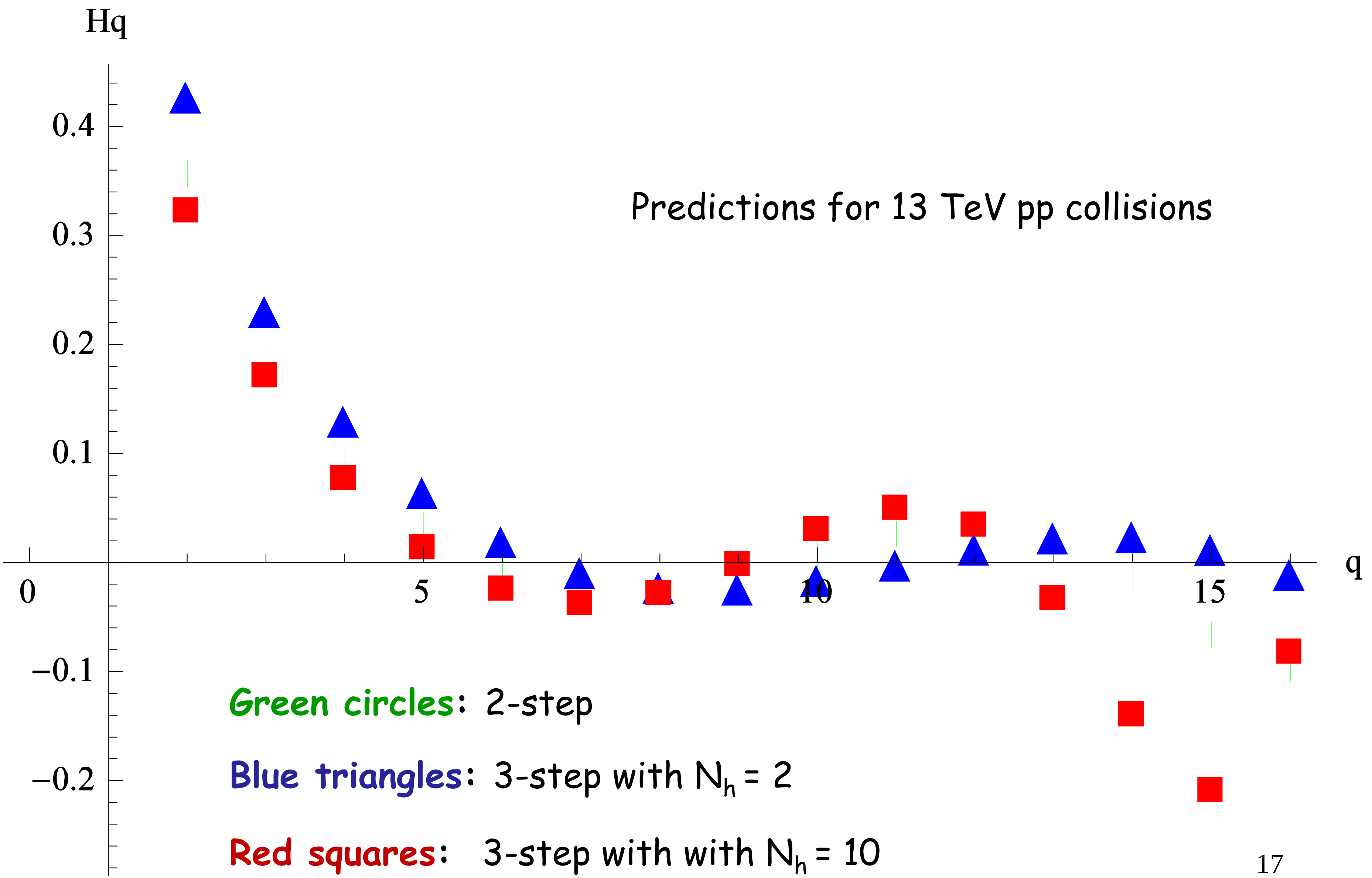


As expected according to

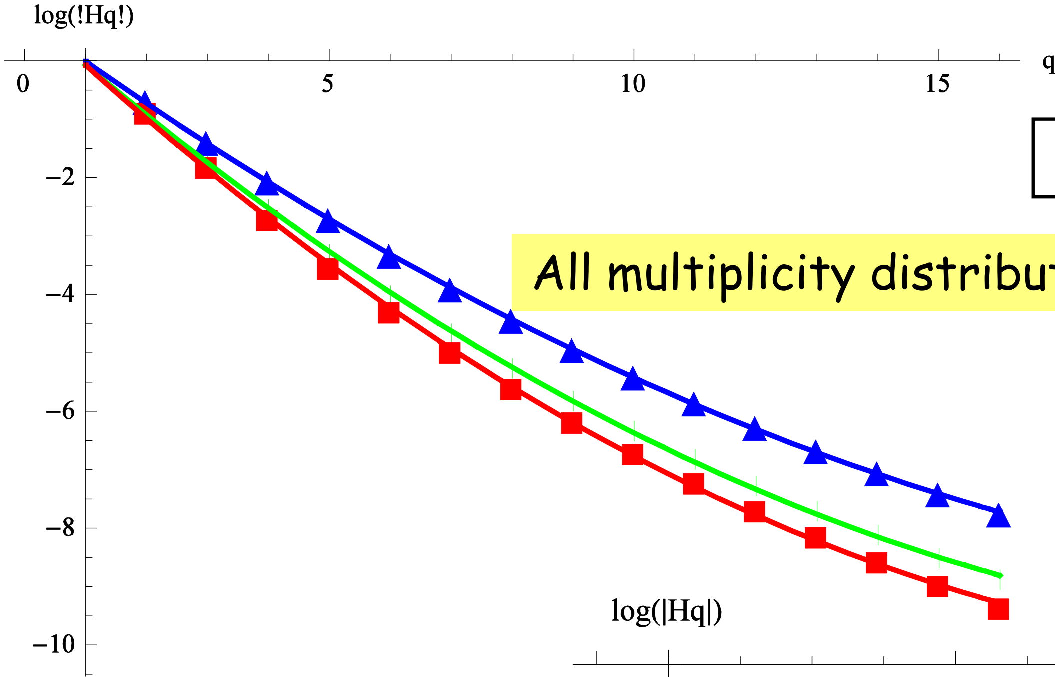
NNL QCD and

experimental observations

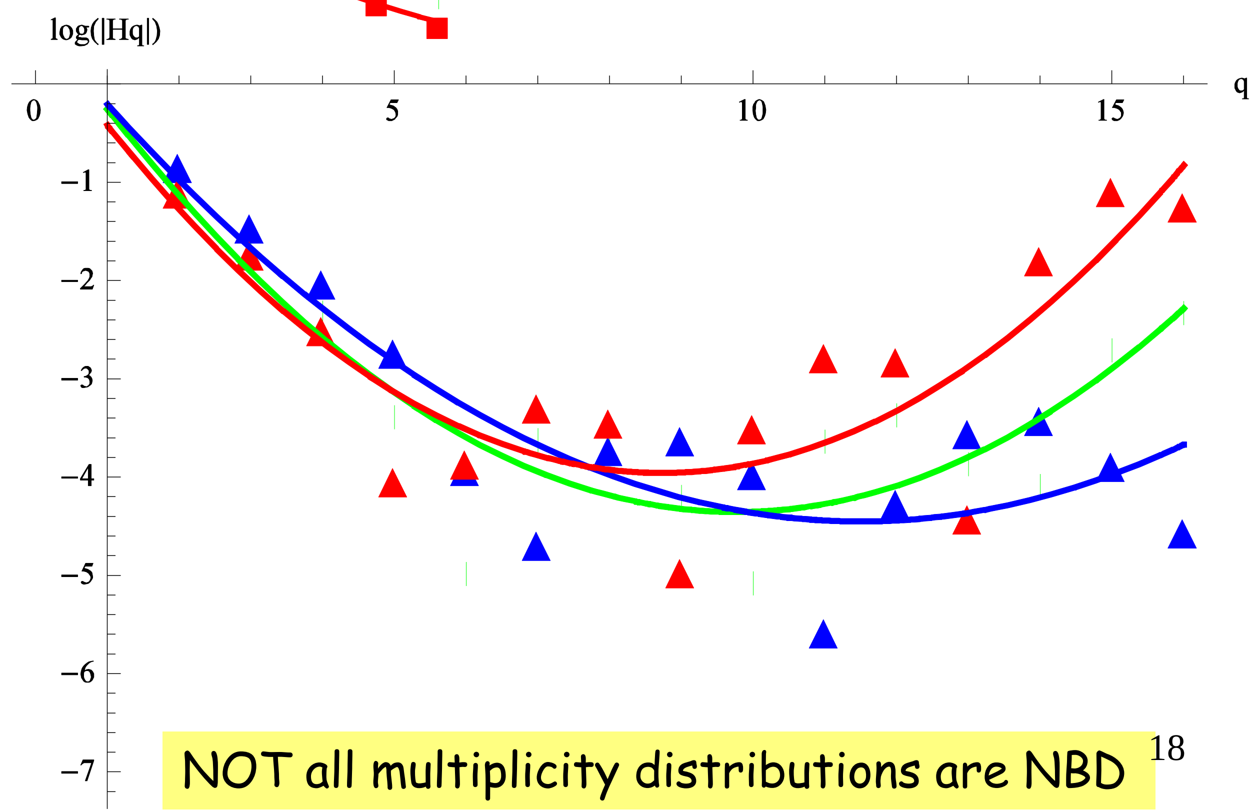
H_q as a function of the rank q



Log[$|H_q|$] as a function of the rank q



All multiplicity distributions are NBD



NOT all multiplicity distributions are NBD

Conclusions

We propose to search for new physics/phenomena **(Hidden Sectors)** in *pp* inelastic collisions by analysing **soft multiparticle production tagged** tagged by hard signals (like high-p_t leptons, missing energy …) by means of:

- Two and three (or more) particle correlation functions
- Scaled moments/cumulants of the multiplicity distributions

in particular H_q oscillations 

- H_q are very sensitive to "modifications" of the parton cascade

Care should be taken for possible bias whenever cuts are imposed to events

H_q oscillation pattern changes when a new stage (HS) is introduced

- We have computed F_q (and H_q) factorial moments using a Prolog code available for any rank and any number of steps (limited by computer)

Back up

2-step cascade (III)

$$C_2(y_1, y_2) = (\bar{\rho}^{(1)})^2 D_c^2 + \langle N_c \rangle C_2^{(1)}(y_1, y_2)$$

C_2^{LR} $\qquad$ C_2^{SR}

Long-range piece

mainly due to fluctuations (different topologies) in the number/size of particle sources

Short-range piece

$$C_2^{SR}(y_1, y_2) \approx e^{-|y_1 - y_2|/\xi_y}$$

$$C_2^{SR}(y_1, y_2) \approx e^{-(y_1 - y_2)^2/4\delta^2}$$

$$\xi_y = (\sqrt{\pi}/2)\,\delta \approx 1$$

Sensitive to the co-existence of different production mechanisms in the same sample of events !

The larger the "cluster mass" the larger the correlation length

$$\xi_y \approx \log\left[\frac{(M^*)^2}{s_0}\right]$$

Cluster invariant mass^2

$s_0 \sim 1$ GeV^2

Upon integration:

$$F_2^{(2)} = F_2^{(c)} + \frac{F_2^{(1)}}{\langle N_c \rangle}$$

$$F_2^{(c)} = \frac{D_c^2}{\langle N_c \rangle^2} - \frac{1}{\langle N_c \rangle} + 1$$

$$F_2^{(1)} = \frac{\int dy_1\, dy_2\, C_2^{(1)}(y_1, y_2)}{\langle n_1 \rangle^2} + 1$$

Poisson

$$F_2^{(c)} = F_2^{(1)} = 1$$

but $F_2^{(2)} > 1$

Three-particle rapidity correlations

3-particle density: $\rho_3(y_1,y_2,y_3) = \frac{1}{\sigma_{in}} \frac{d^3\sigma_{in}}{dy_1 dy_2 dy_3}$

Standard definition

$$C_3(y_1,y_2,y_3) = \rho_3(y_1,y_2,y_3) + 2\rho(y_1)\rho(y_2)\rho(y_3) - \rho_2(y_1,y_2)\rho(y_3) - \rho_2(y_1,y_3)\rho(y_2) - \rho_2(y_2,y_3)\rho(y_1)$$

$$\int dy_1 dy_2 dy_3\, C_3(y_1,y_2,y_3) = f_3$$

(= 0 for independent emission)

$$K_3(y_1,y_2,y_3) = \frac{C_3(y_1,y_2,y_3)}{\rho(y_1)\rho(y_2)\rho(y_3)}$$

$$F_3 = \frac{<n(n-1)(n-2)>}{<n>^3} = \frac{f_3 + 3 f_2 f_1 + f_1^3}{<n>^3}$$

Factorial moments are related among themselves

For a **Poisson** distribution (particle independent emission)

$$F_2 = F_3 = (F_q) = 1$$

Basic idea for experimental searches

Study of particle correlations using two different samples:

- A **control sample** of events (lower energy?) with the same topological cuts (i.e. same multiplicity).

- An **event sample enriched using tagging criteria** such as:

  a) high-multiplicity

  b) missing energy

  c) high-p_γ(equal sign?) leptons

  d) high-p_γ photons

  e) event-shape variables, …

  } To be motivated by **HS** models

- Complementary study using **Monte Carlo** generation

Illustrative picture of a *pp* collision with a **HS** “showing up”