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Puzzles of multiplicity

International Student Practice

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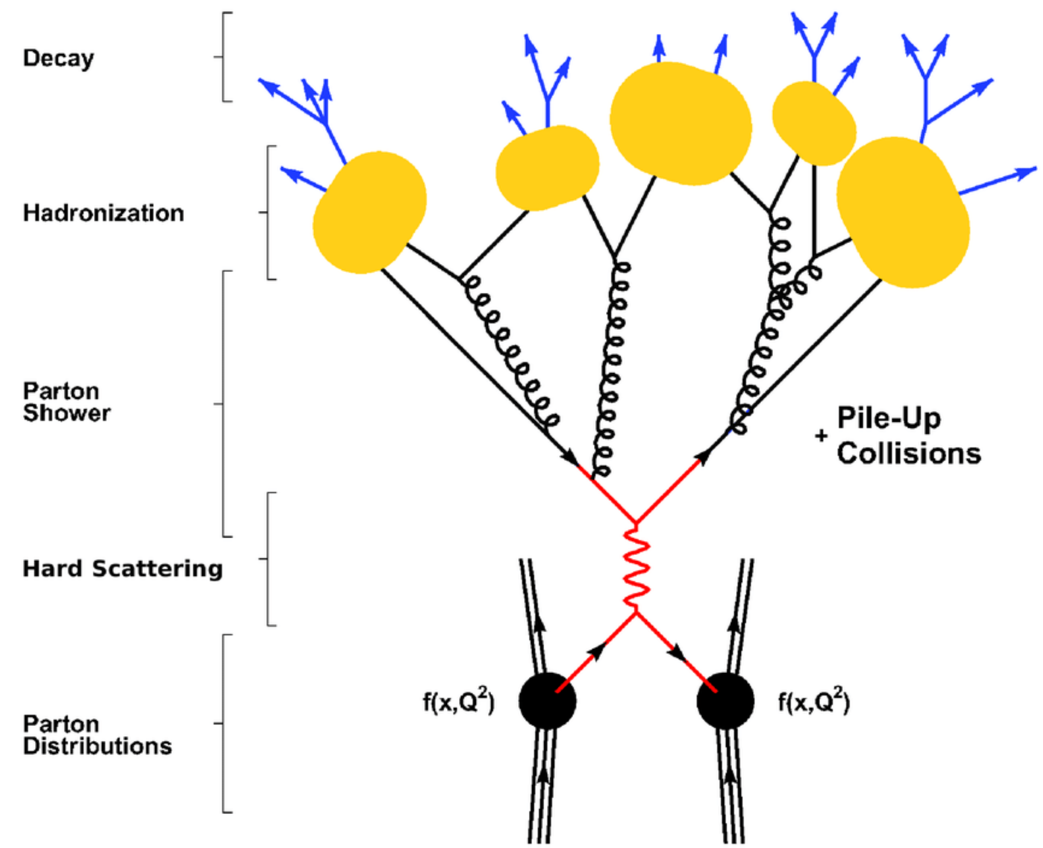
Dubna, 26. 7. 2019

Puzzles of multiplicity



Bauer, Julia & Muller, Thomas. (2019). Prospects for the Observation of Electroweak Top Quark Production with the CMS Experiment.

Multiplicity - number of created secondary particles

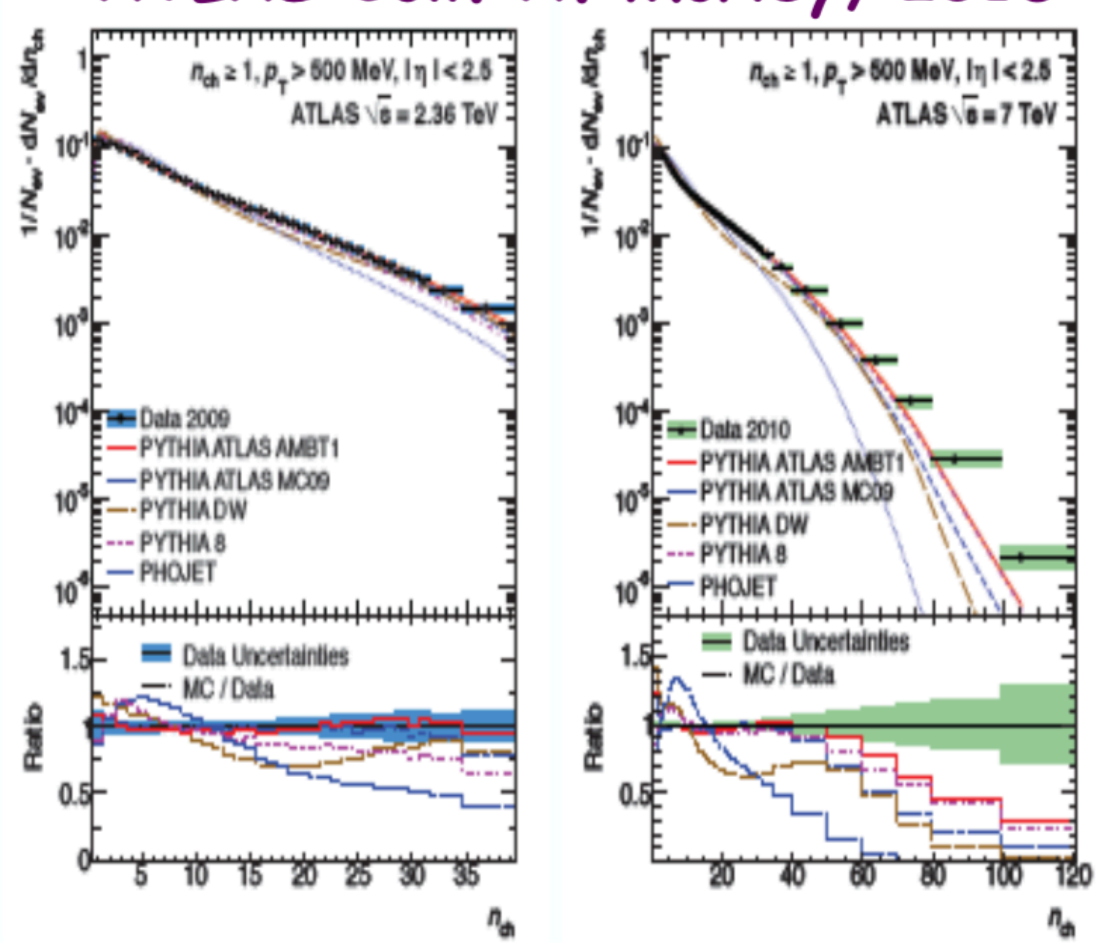
High Multiplicity (HM) events - connected with collective behaviour (ridges, flow, shock waves etc.)

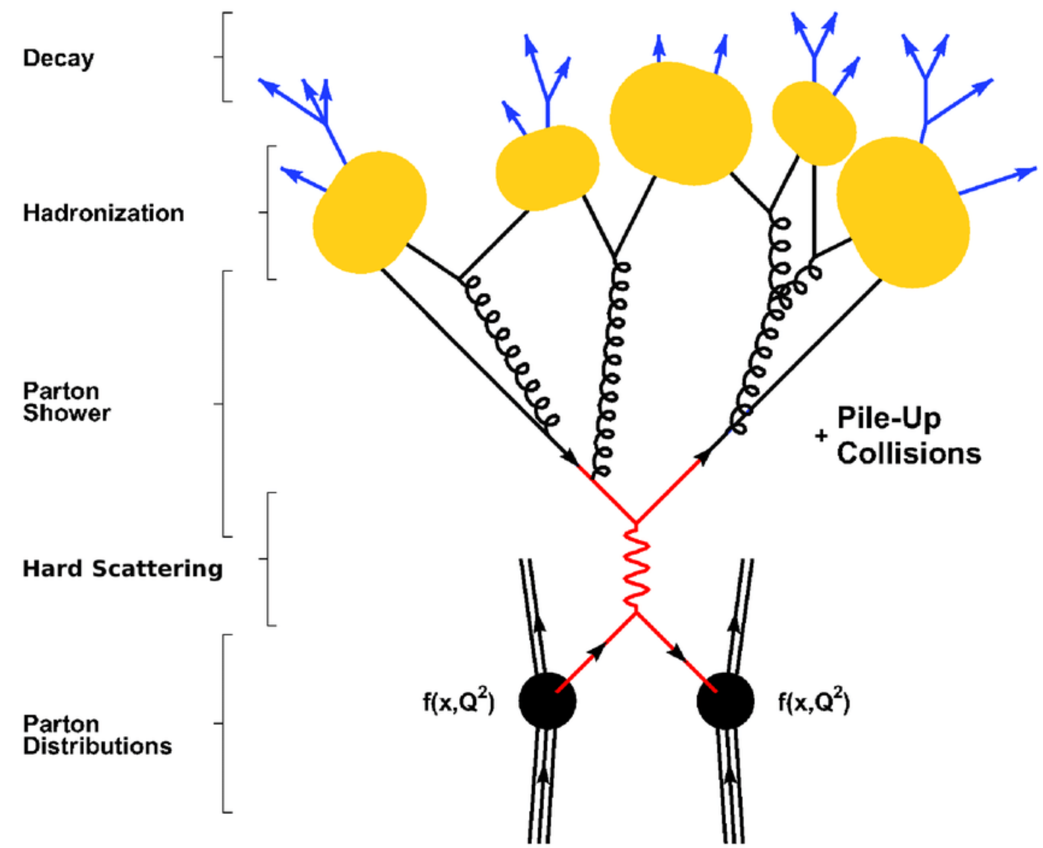
Puzzles of multiplicity

Hadronization - not fully understanded process

Model vs. Data - we have observed discrepancies for high multiplicity events

ATLAS Coll. A. Morley, 2015





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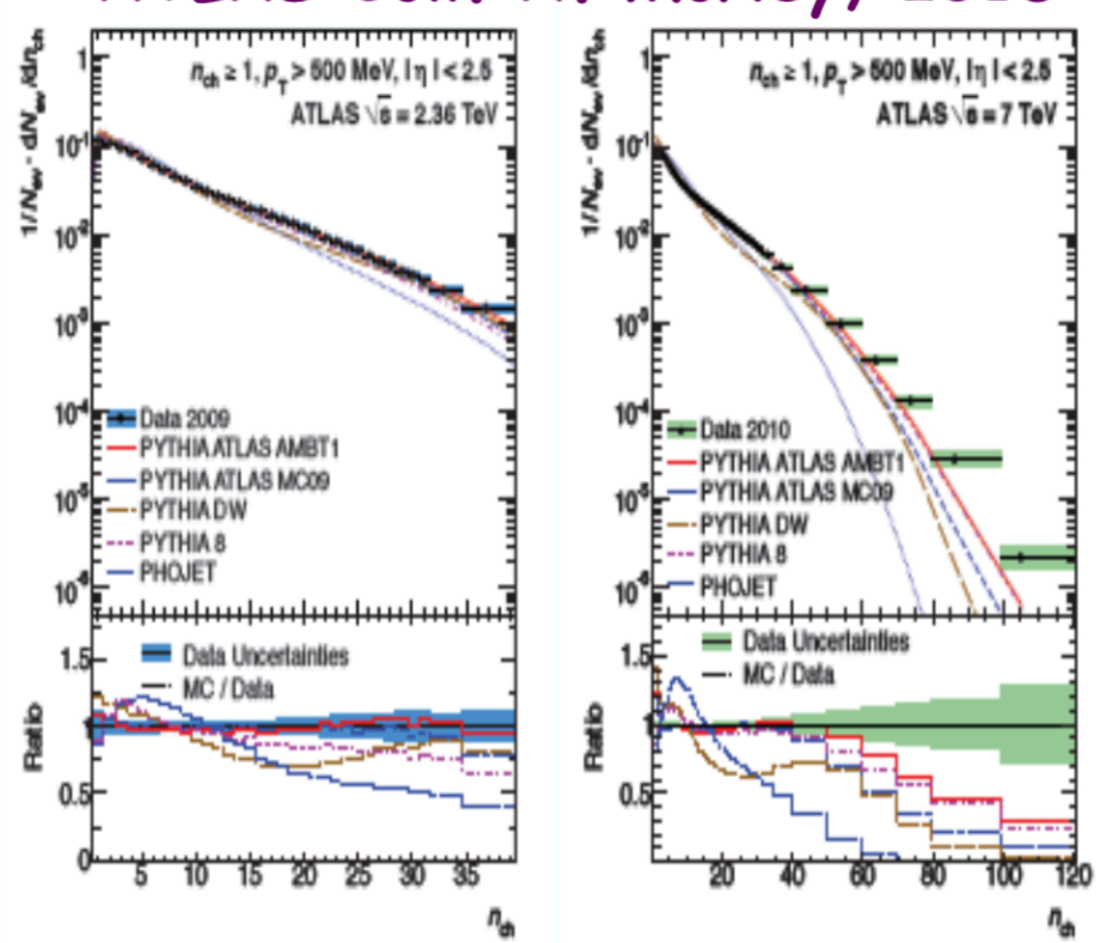
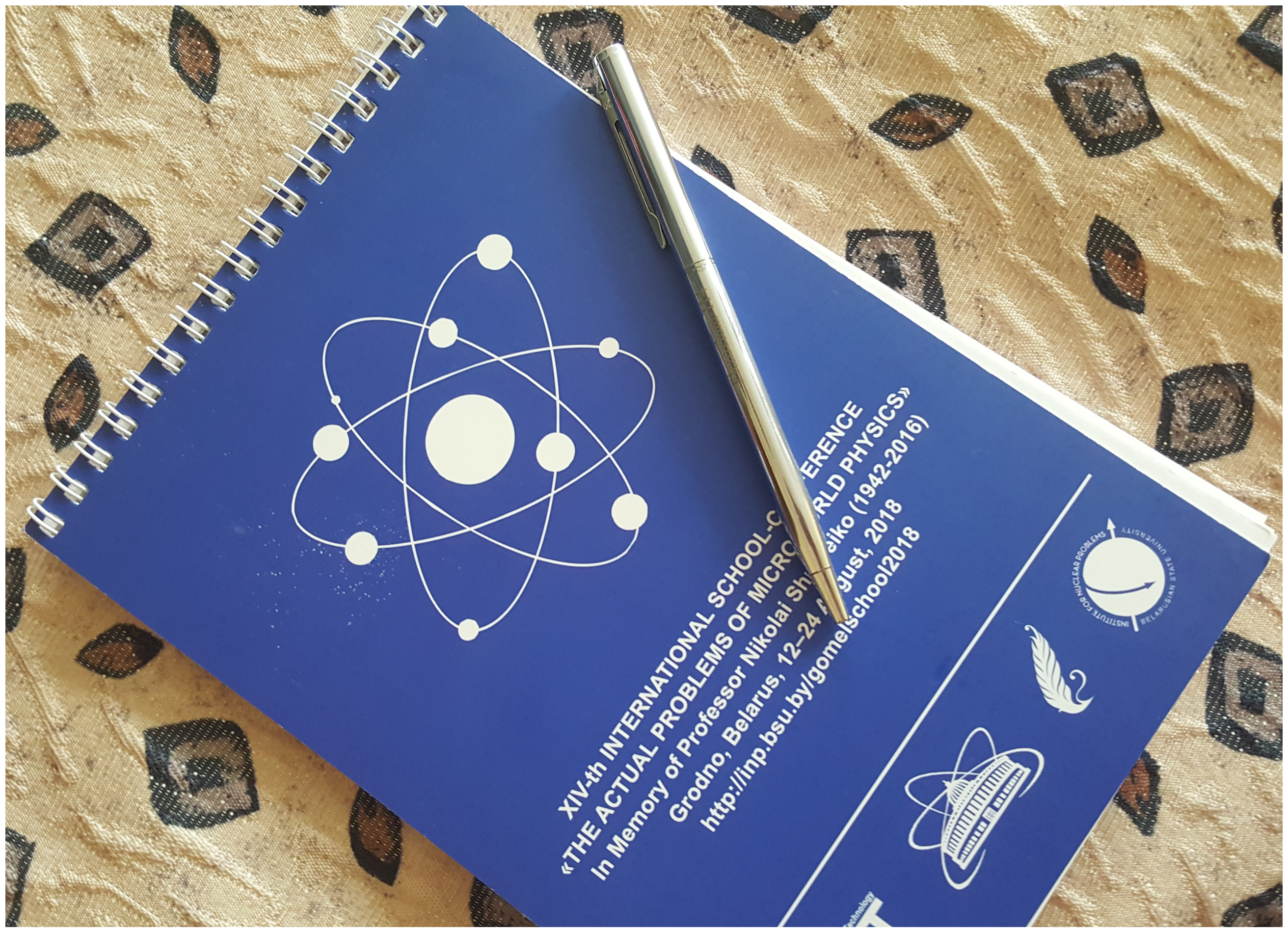


Will be presented

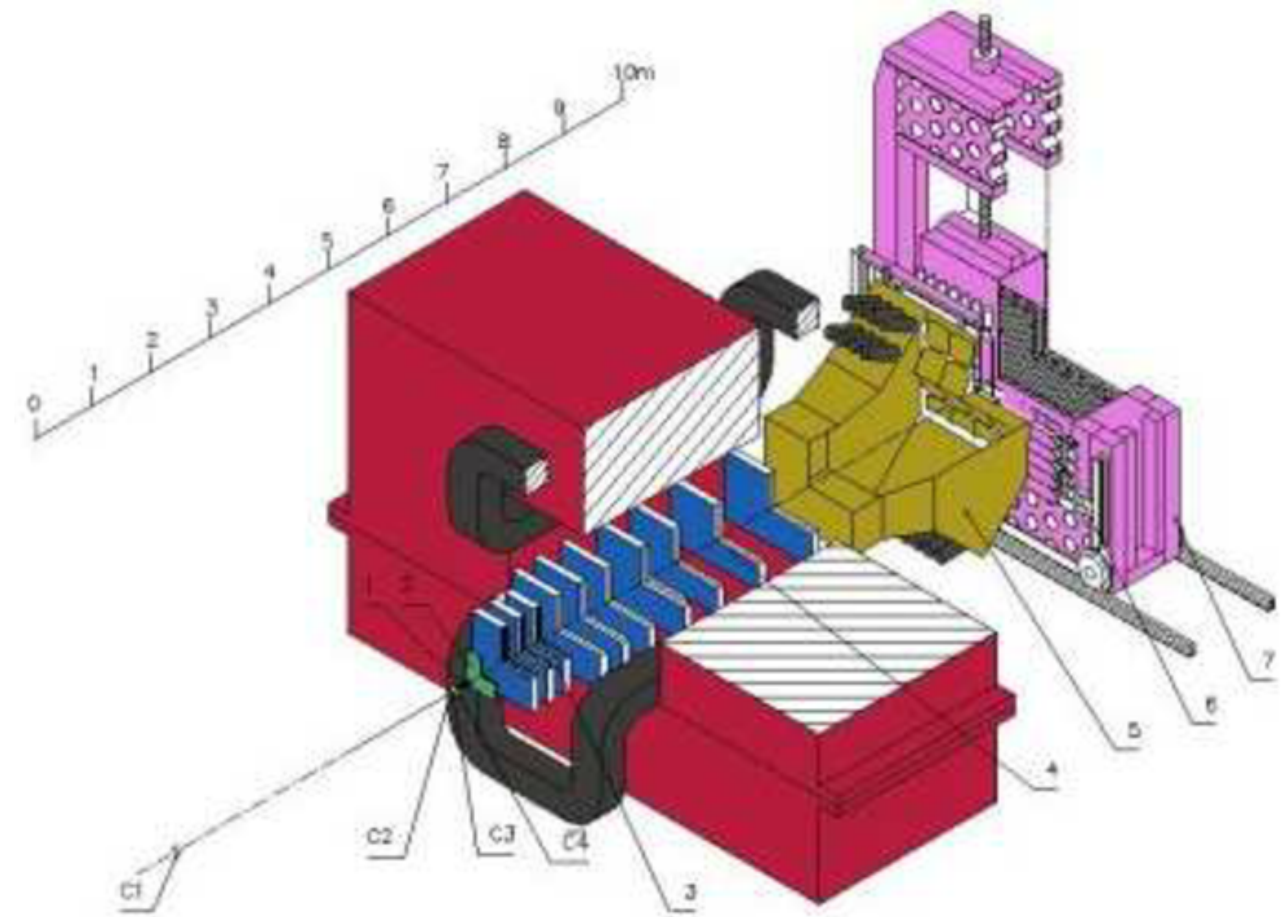
Multiparticle production in :

1. **e^-e^+ annihilation**
2. **quarkonia decay**
3. **pp interactions**
4. **p(anti)p annihilation**

Toolkit



SVD2 collaboration



Spectrometer with Vertex Detector

ROOT
Data Analysis Framework

Description of particle production
Two Stage Model (STM)

Instead of hard-working with multiplicity distribution (MD) we use **g**enerating **f**unction (**GF**)

$$G(z) = \sum_n P_n z^n$$

How to get multiplicity distribution from **GF**

$$P_n = \frac{1}{n!} \frac{\partial^n}{\partial z^n} G(z)|_{z=0}$$

For cumulants we get

$$F_1 = G'(z)|_{z=1} = \sum_n P_n\ n\ z^{n-1}|_{z=1} = \bar{n}$$

$$F_2 = G''(z)|_{z=1} = \overline{n(n-1)} = \overline{n^2} - \bar{n}$$

second correlative moment

$$f_2 = G'' - (G')^2 = F_2 - F_1^2$$

Poisson distribution (PD)

$f_2 = 0$

if $f_2 = 0$ **- independent process of formation**

Binomial distribution (BD)

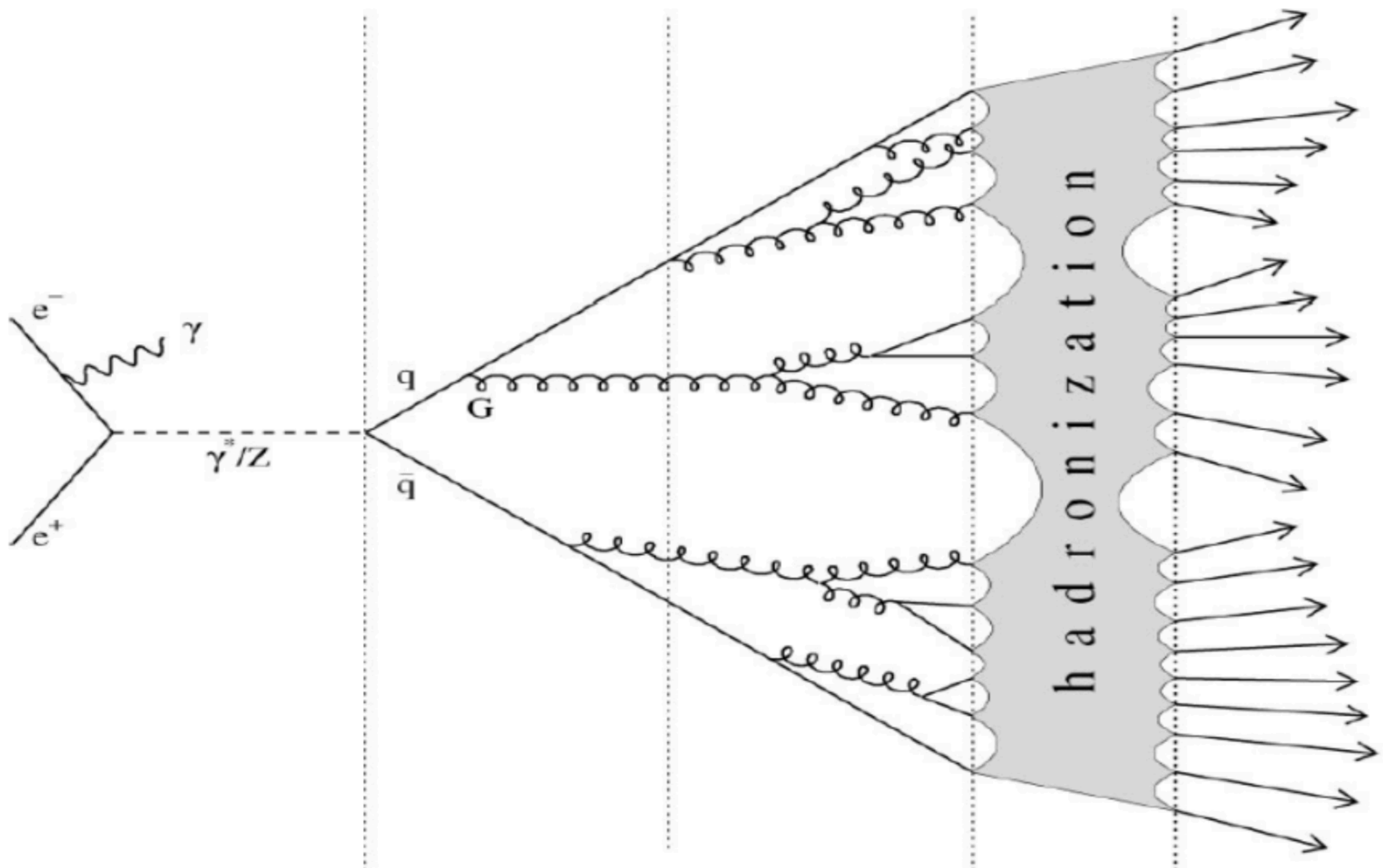
$f_2 < 0$

Negative Binomial distribution (NGB)

$f_2 > 0$

e+e- annihilation

$$e^+e^- \to \gamma(Z^0) \to (q, g) \to ? \to hadrons$$



1. stage

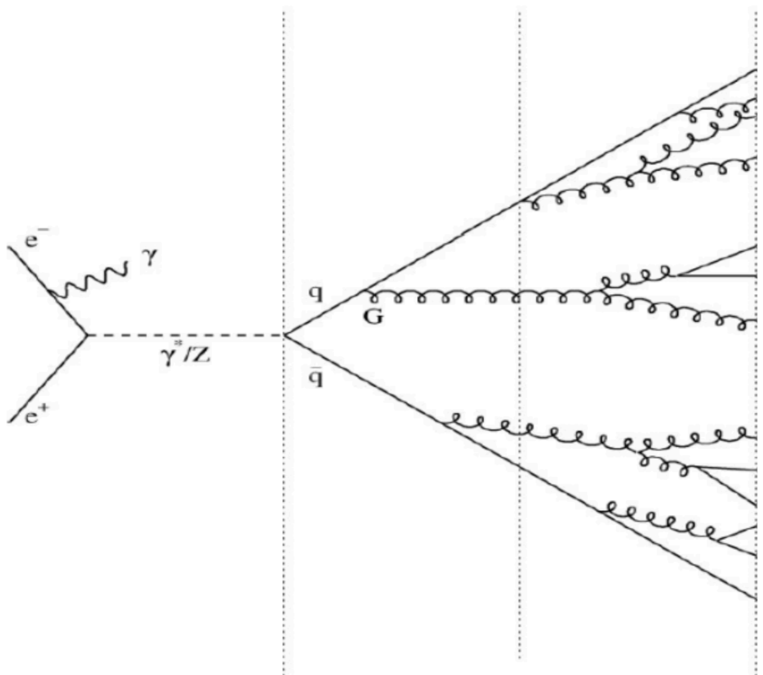
qg-cascade

2. stage

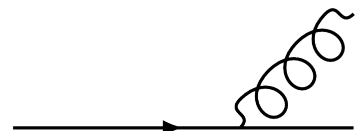
hadronization

e^+e^- annihilation - I. stage

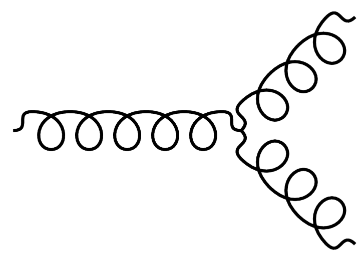
qg-cascade is based on pQCD
Three elementary processes :



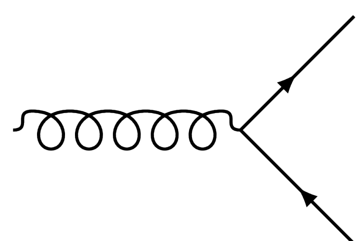
High



bremsstrahlung probability A



gluon splitting probability Ã

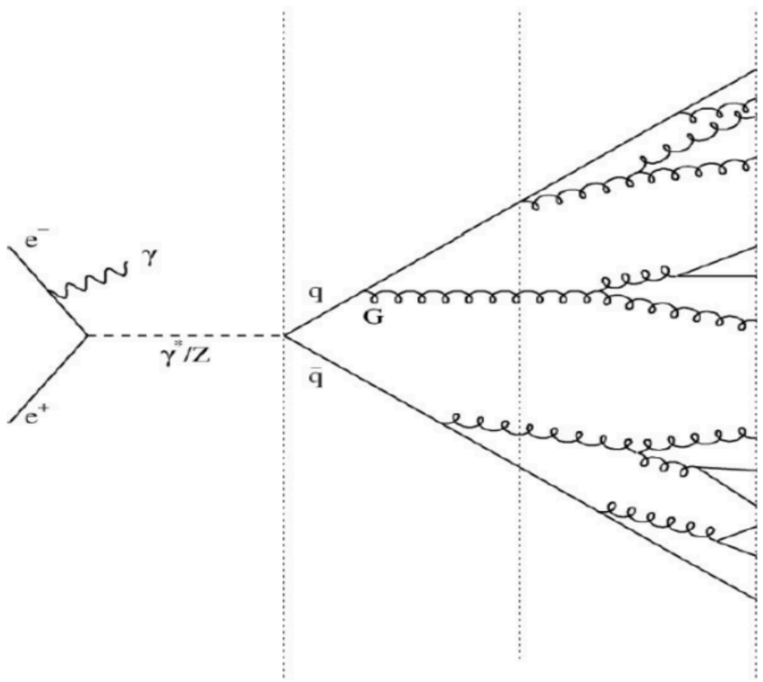


quark-(anti)quark pair creation probability B

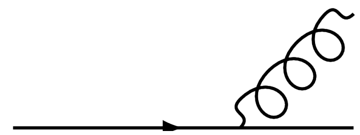
Low

e+e- annihilation - I. stage

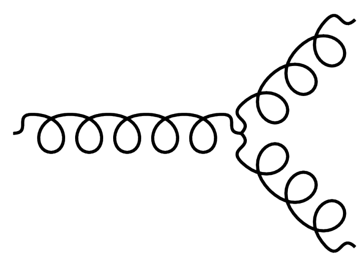
qg-cascade is based on pQCD
Three elementary processes :



High



bremsstrahlung probability A



gluon splitting probability Ã

quark-(anti)quark pair creation probability B

Low

$$k_p = \frac{A}{\tilde{A}}$$

MD

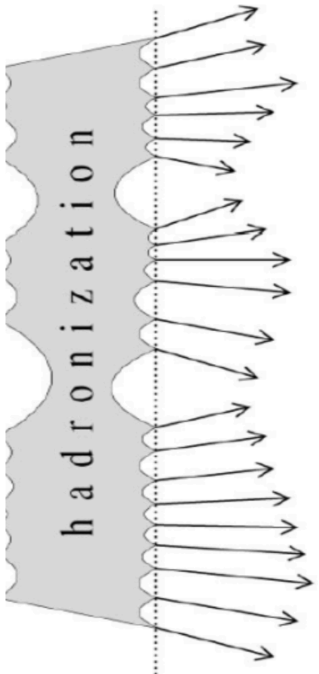
gluon jet (Farry)

$$P_m^g = \frac{1}{\bar{m}}\left(1 - \frac{1}{\bar{m}}\right)^{m-1}$$

quark jet (NBD)

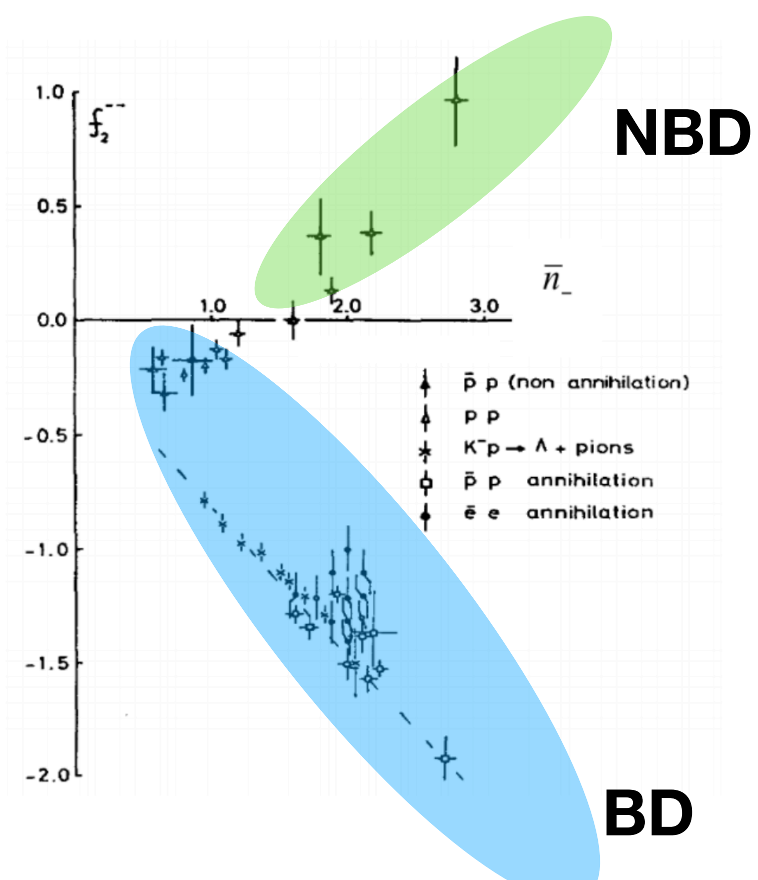
$$P_m^q = \frac{k_p(k_p+1)\ldots(k_p+m-1)}{m!}\left(\frac{\bar{m}}{\bar{m}+k_p}\right)^m\left(\frac{k_p}{\bar{m}+k_p}\right)^{k_p}$$

e+e- annihilation - II. stage



At the low energy region the contribution of hadronization is predominant => we choose BD (at low energy f2<0)

$$P_n^H = C_{N_p}^n \left(\frac{\bar{n}_p^h}{N_p} \right)^n \left(1 - \frac{\bar{n}_p^h}{N_p} \right)^{N_p - n}$$



$\bar{n}_p^h$ — **mean multiplicity**

N_p — **maximum number of hadrons formed from single parton at its passing through hadronization**

e+e- annihilation
Convolution of two stages

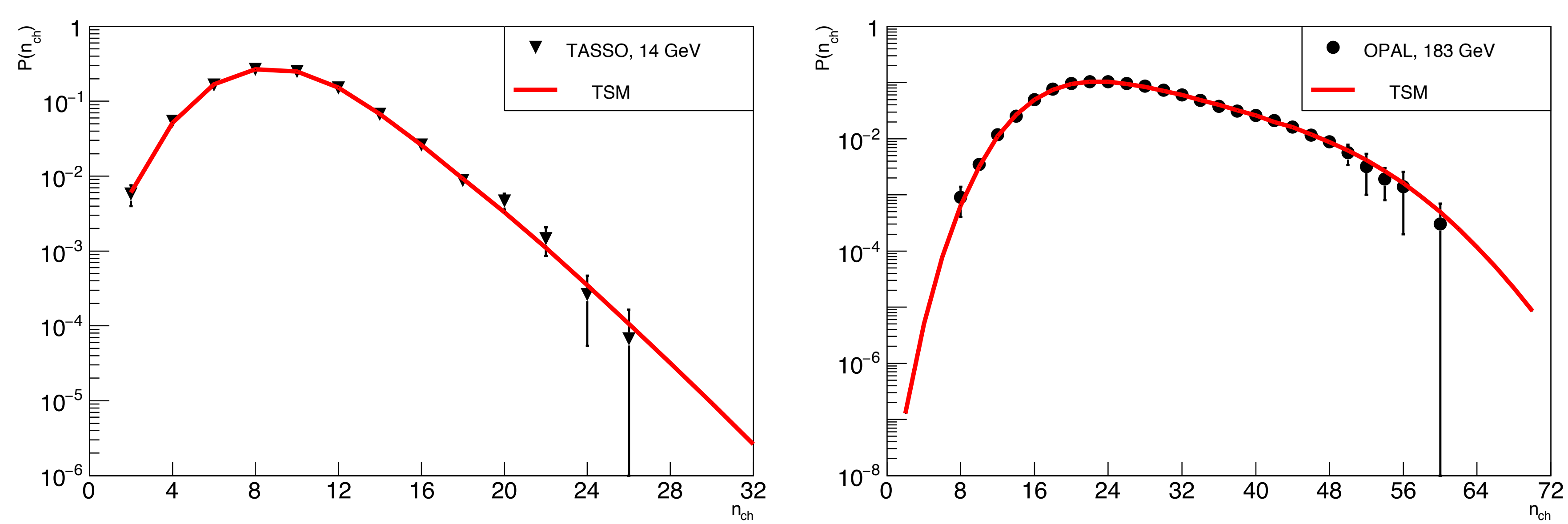
is based on :
- soft dicolouration
- equality of the hadron production probabilities from quark and gluon at the second stage

$$P_n(s) = \Omega \sum_{m=0}^{M_g} P_m^P \, C_{(2+\alpha m)N}^n \left(\frac{\bar{n}^h}{N}\right)^n \left(1 - \frac{\bar{n}^h}{N}\right)^{(2+\alpha m)N-n}$$

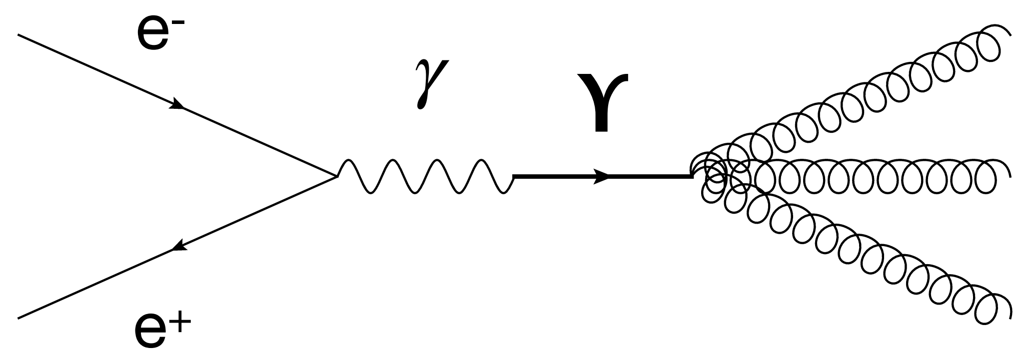
Ω **normalization factor**

M_g **number of active gluons**

Data vs. Model



Three-gluon decay of quarkonia ϒ(9.46), ϒ(10.02)



MD g-jet is Farry

$$P_n(s) = \sum_{m'=0} \frac{(m'+1)(m'+2)}{2(\bar{m}/3)^2} \left(1 - \frac{1}{\bar{m}/3}\right)^{m'} C^n_{3+m'}N_g \left(\frac{\bar{n}^h_g}{N_g}\right)^n \left(1 - \frac{\bar{n}^h_g}{N_g}\right)^{(3+m')N_g - n}$$

$$m' = m - 3$$

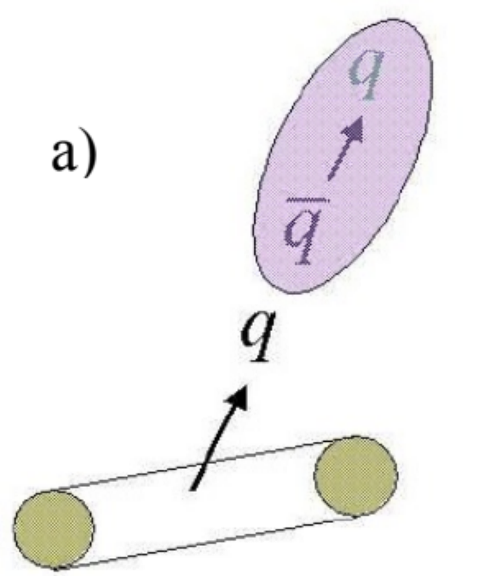
$$\Delta\bar{n} = \bar{n}(\Upsilon \to 3g) - \bar{n}(e^+e^- \to q\bar{q})$$

$$\Delta\bar{n}(s)_{exp} \approx \Delta\bar{n}(s)_{theor} \approx 0.8$$

pp interactions

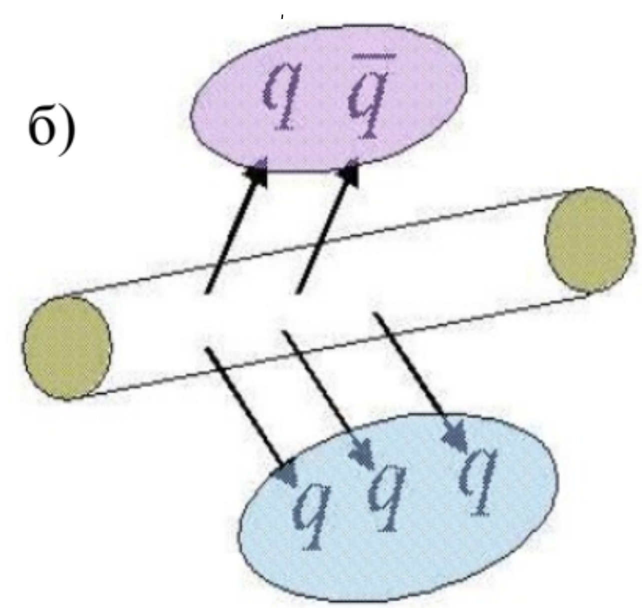
- Applying same procedure led to smaller hadronization parameters as in e^-e^+
- Decreasing number of valence quark, parameters start grow
- Gluon Dominance Model (GDM)

Fragmentation (vacuum)



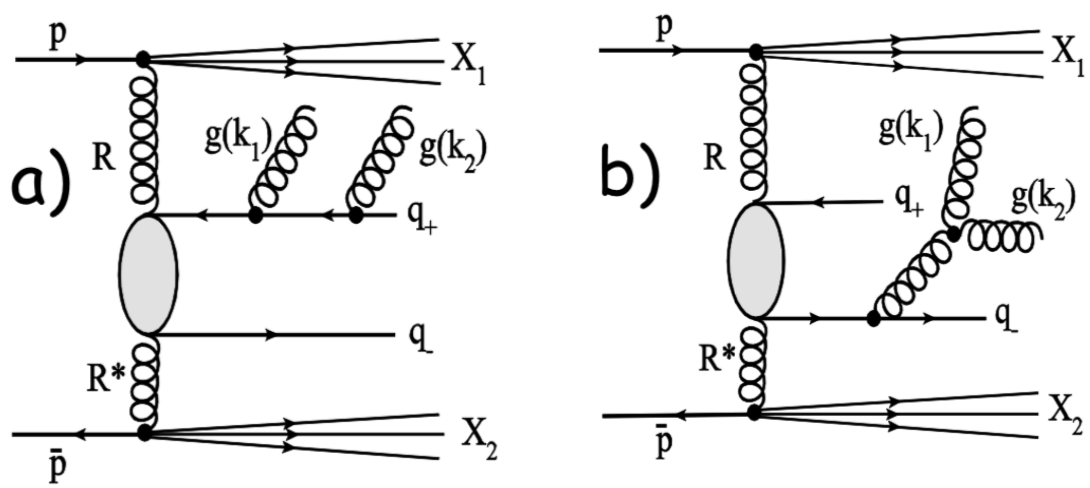
$$R = \frac{N_B}{N_{\pi^0}} \ll 1$$

Recombination (quark-gluon system)



$$R \approx 1$$

pp interactions

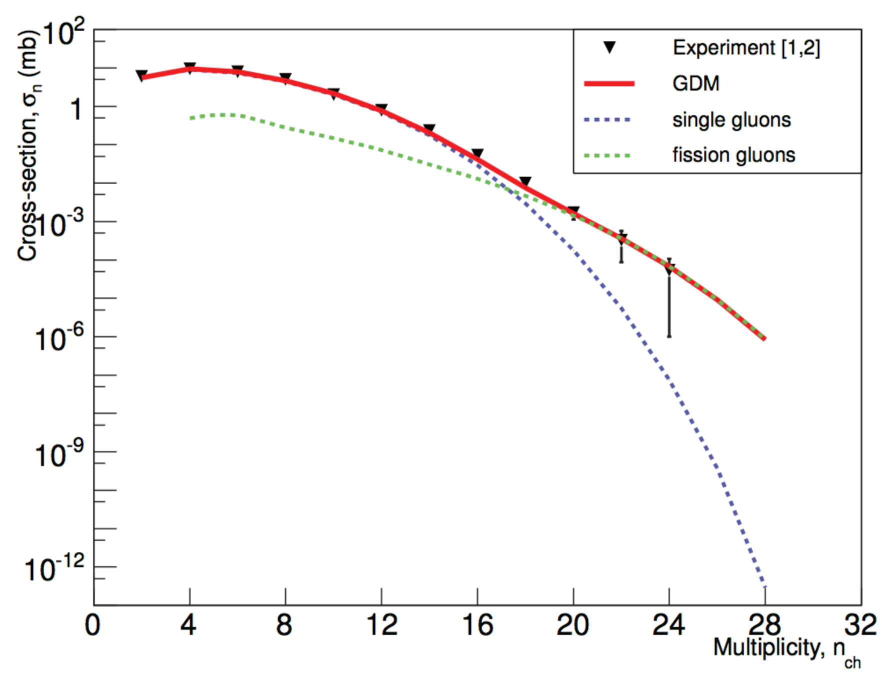


At HM region formation of two gluon jets predominates in the case b) in comparison with the case a).

Superposition of 2 distributions

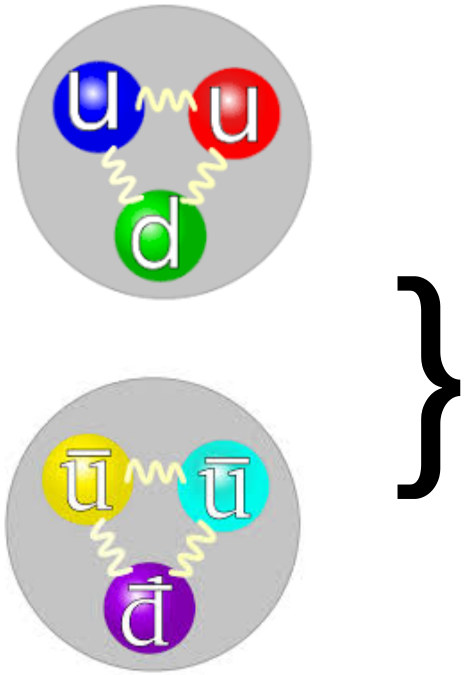
$$P_n(s) = \alpha_1 \sum_{m_1=1}^{Mg_1} \frac{\overline{m_1}^{m_1} e^{-\overline{m_1}}}{m_1!} C_{m_1 N}^{n-2} \left(\frac{\bar{n}^h}{N}\right)^{n-2} \left(1 - \frac{\bar{n}^h}{N}\right)^{m_1 N-(n-2)} + \alpha_2 \sum_{m_2=1}^{Mg_2} \frac{(2\overline{m_2})^{m_2} e^{-2\overline{m_2}}}{m_2!} C_{m_2 N}^{n-2} \left(\frac{\bar{n}^h}{N}\right)^{n-2} \left(1 - \frac{\bar{n}^h}{N}\right)^{m_2 N-(n-2)}$$

single gluons
(without branching)



fission gluons
(with branching)

p(anti)p annihilation

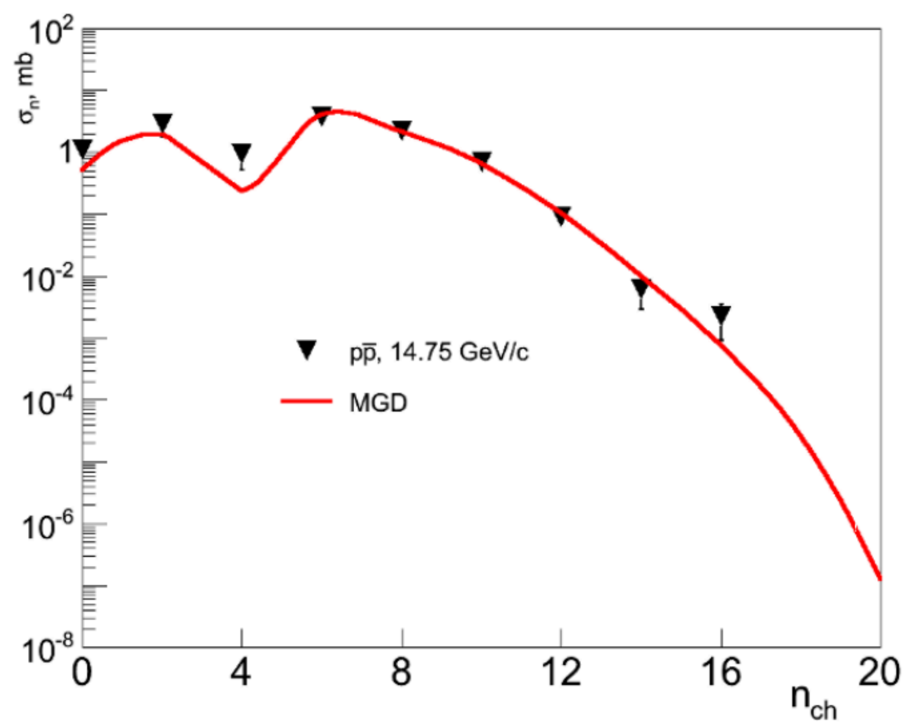


“0” topology -> 3 π^0

“2” topology -> π^0, π^-, π^+

“4” topology -> π^+, π^+, π^-, π^-

$$G(z) = c_0 \sum_m^{M_0} P_m^G \left[1 + \frac{\bar{n}^h}{N}(z-1)\right]^{mN} + c_2 z^2 \sum_m^{M_2} P_m^G \left[1 + \frac{\bar{n}^h}{N}(z-1)\right]^{mN} + c_4 z^4 \sum_m^{M_4} P_m^G \left[1 + \frac{\bar{n}^h}{N}(z-1)\right]^{mN}$$

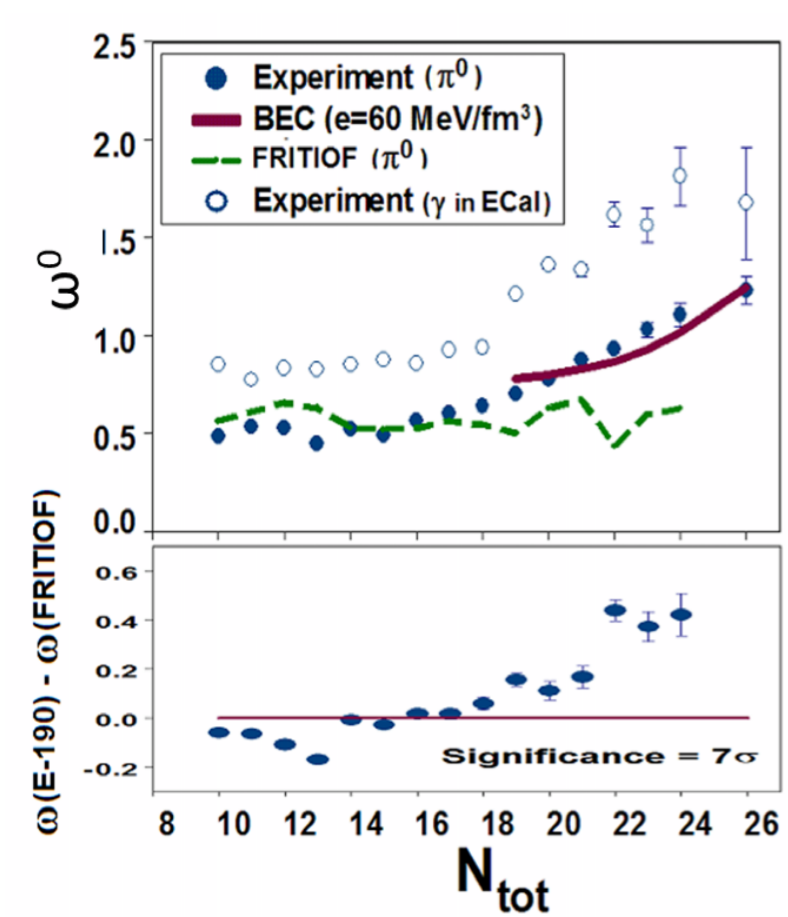


Conclusion

- description of MD in e+ e– and p(anti)p annihilation, pp interactions and 3-gluon decay of ϒ introducing the hadronization scheme in a wide energy region -> using mathematical approaches of probability theory

- fitting experimental data with GDM using ROOT packages

- Protvino: SVD2 setup - for the first time SVD Collaboration got the evidence to the pionic Bose-Einstein condensate formation in HM region



Thank you for your attention

Special thanks to:
Organisers
&
Dr. Elena Sergeevna Kokoulina