From LEPTON *to* HADRON & NUCLEAR INTERACTIONS *at* HIGH MULTIPLICITY

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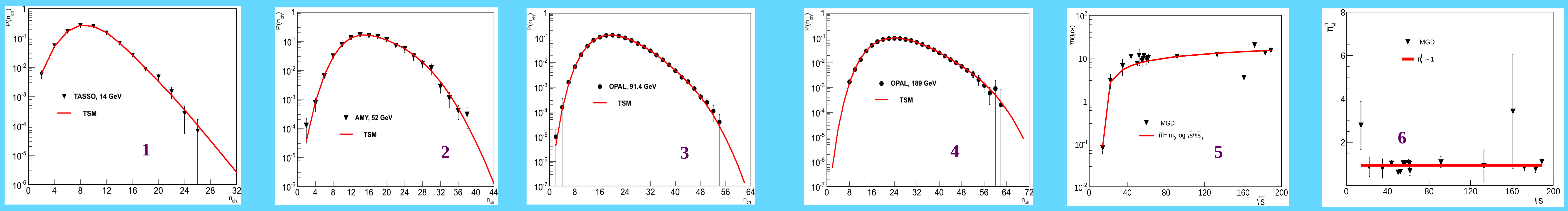
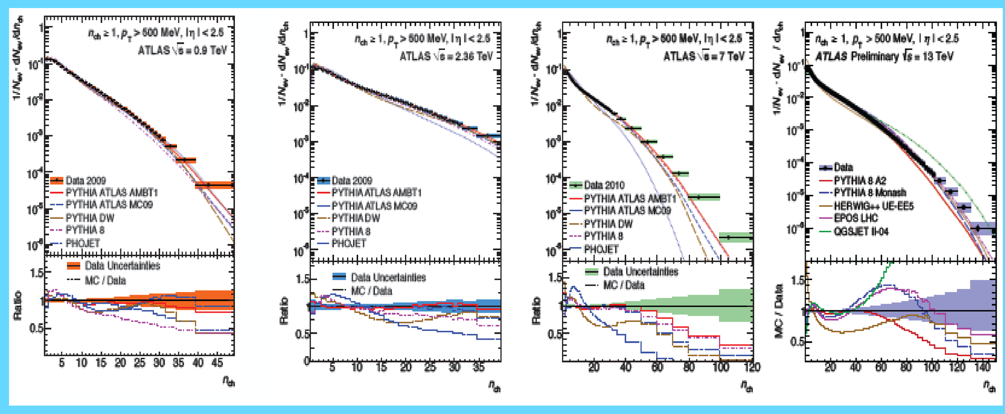
NICA

In accordance with present understanding, the multi-particle production in e^+e^- annihilation occurs through two stages: development of quark-gluon (qg) cascade & hadronisation: $e^+ + e^- \rightarrow \gamma(Z^0) \rightarrow (q, \bar{q}, g) \rightarrow h_1 + h_2 + \ldots + h_n$. For a description of multiplicity distributions (MD) in this process a two stage model (TSM) has been developed. I stage in this process is described by pQCD [Giovannini, 1978] as the branching process that leads to the negative binomial distribution (NBD) of partons for *q*-jet and to Pólya distribution for *g*-jet. Hadronisation (II stage) is described by phenomenological scheme based on experimental data: at energies lower then 10 GeV where the hadronisation stage predominates the second correlative moment ($f_2 = \langle n(n\text{-}1)\rangle - \langle n\rangle^2$) has negative values (with the increasing energy, qg-cascade is developed and f_2 changes sign from - to +). The binomial (Bernoulli) distribution is used for a description of the second stage. TSM' parameters of hadronisation have the following sense: mean and max possible number of hadrons formed from q or g at their passing through the hadronisation stage. TSM is based on the convolution of these two stages and it describes MD in e^+e^- annihilation from 10 up to 200 GeV (Fig. 1 - 4) well especially in the high multiplicity (HM) region. Hadronisation parameter of gluon stays constant and close to 1 (Fig. 6) in all investigating region (up to 200 GeV) confirming fragmentation mechanism of hadronisation. This is also has been known as hypothesis LPHD. TSM predicts the following values for the future e^+e^- experiments at ILC & CLIC: $\langle n_{ch}(500\ \text{GeV})\rangle \approx 30 \pm 5$, $\langle n_{ch}(1\ \text{TeV})\rangle \approx 50 \pm 10$.

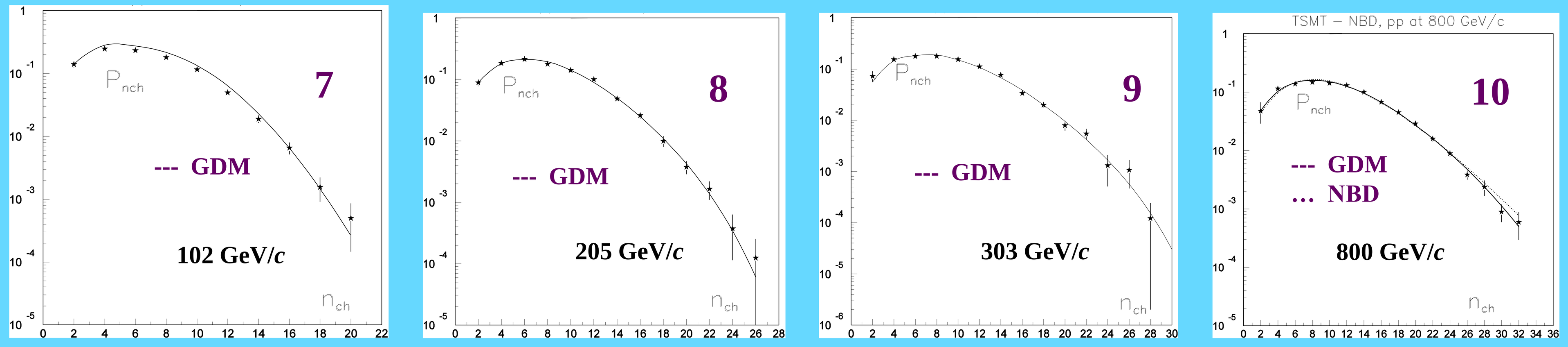


Figs. 1 – 4: MD at 14, 52, 91, 183 GeV; Fig. 5: mean number of gluons fragmenting to hadrons (logarithmic growth); Fig. 6: gluon's parameter of hadronisation.



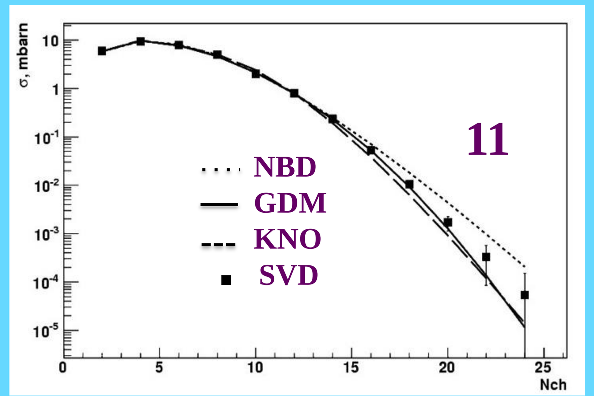
ATLAS [A. Morley] HEP-2015, Vienna. MC simulation has difficulties in the description of MD in the HM region.

The high multiplicity (HM) study experiment has been carried out at U-70 (IHEP, Protvino) with 50 GeV/*c* proton beam on H_2-target at SVD-2 setup: $p + p \rightarrow 2N + \pi_1 + \pi_2 + \ldots + \pi_n$, where *N* – nucleon, *n* – pion multiplicity. HM region: $n \gg \langle n\rangle$ - mean multiplicity. In *pp*-interactions at the high energy, multi-particle production occurs in *qg*-medium when valence quarks and lots of gluons can appear. Under QCD: valence quarks (gluons) can branch in accordance with such elementary processes as $q \rightarrow q + g$, $g \rightarrow g + g$. Gluon dominance model (GDM) is based on QCD. It also describes hadronisation as in TSM by Bernoulli. The comparison of GDM with data has shown (Figs. 7-10): valence quarks remain in the leading particles, the main sources of the secondary hadrons are gluons. But only a part of them (active gluons) is converted to hadrons, the rest gluons can be reradiated with soft photons (SP).



Figs. 7 – 10: MD in pp interactions at 102, 205, 303 & 800 GeV/*c* with NBD & GDM.

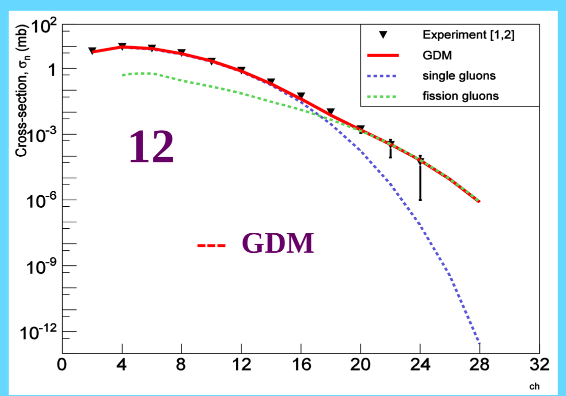
GDM confirms recombination mechanism of hadronization in *pp* interactions (the parameter of gluon hadronisation exceeds of the corresponding value for e^+e^- annihilation). At the same time, the description of MD in HM region can be improved by taking into account fission of active gluons (Fig. 11).



MD: data and three models

Topological cross sections (σ_n) for *pp*-interactions at 50 GeV/*c* describing by GDM without (Fig. 11) and with gluon fission (Fig. 12) in HM region.

Gluon fission improves significantly MD description at the HM region.



GDM with gluon fission

In 2012, SVD-2 Collaboration has found the indication of pion (Bose-Einstein) condensate (BEC) formation in *pp*-interactions in the region of the high total (charged + neutral) multiplicity. The growth of the scaled variance $\omega = D/\langle N\rangle$, $D = \langle N^2\rangle - \langle N\rangle^2$ is observed at $N_{tot} = N_{ch} + N_0 \geq 18$ and it gets 7 standard deviations relative to MC predictions (Fig. 13). We have manufactured Soft Photon Electromagnetic Calorimeter (SPEC) (Fig. 14) to verify the connection of the BEC formation and anomalous (energy < 50 MeV) SP and to carry out the next program: ★ a search of new resonances in the system of two γ-quanta; ★ a study of increased yield of η^0-mesons in AA-interactions; ★ research of pair photon interference (gamma femtometry); ★ a search of *P*-parity violation effect in the events with high p_T etc.

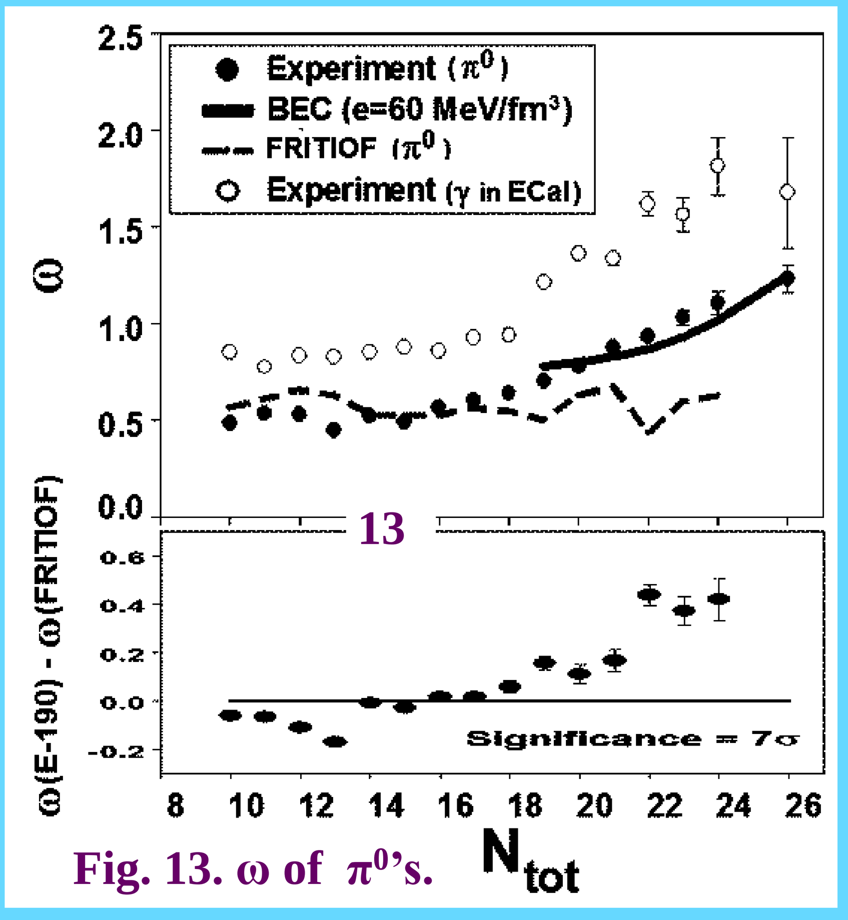


Fig. 13. ω of π^0's. N_{tot}

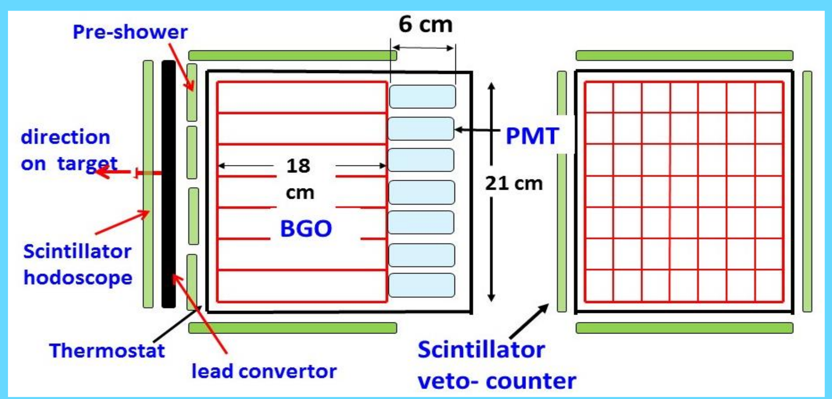
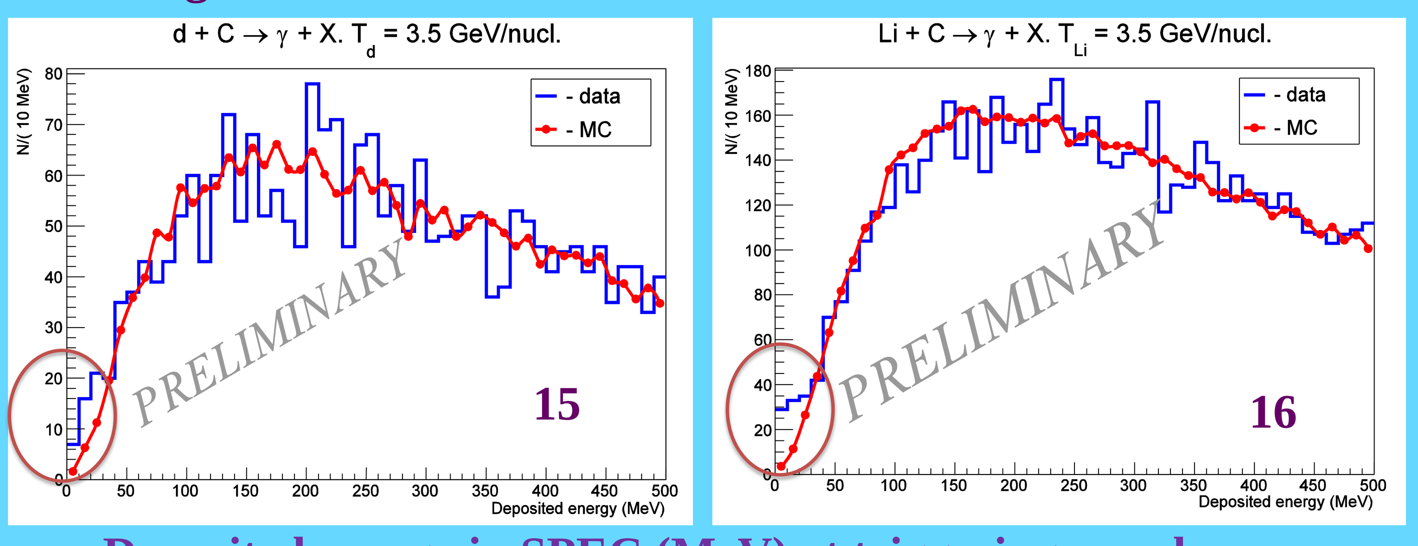


Fig. 14: scheme of SPEC

SPEC has low a threshold of photon registration (≤ 1 MeV). The first spectra of the deposited energy obtained at Nuclotron (JINR) at interactions of 3.5 GeV/*c* d and Li beams with carbon target are shown in Figs. 15 and 16. The noticeable excess is found at energy less than 50 MeV in comparison with MC models. In near future we plan to continue of soft photon study at Nuclotron and NICA facilities.



Deposited energy in SPEC (MeV) at triggering pre-shower calorimeter. 3.5 A GeV/c deuteron (Fig. 15) and lithium (Fig. 16) beams on carbon target.

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