Search for collective phenomena in high multiplicity events at Nuclotron and U-70

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The 3rd International Conference on Particle Physics and Astrophysics

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INTRODUCTION

Our studies were aimed at search for predictable collective phenomena in nuclear interactions at Nuclotron (JINR) and proton collisions at U-70 accelerator (IHEP) in high multiplicity (HM) events like: pion (Bose-Einstein) condensate formation; growth of neutral pion number fluctuations; excess of soft photon yield; shock waves …

Charged multiplicity measurement

SVD-2 Collaboration studied of proton interactions:

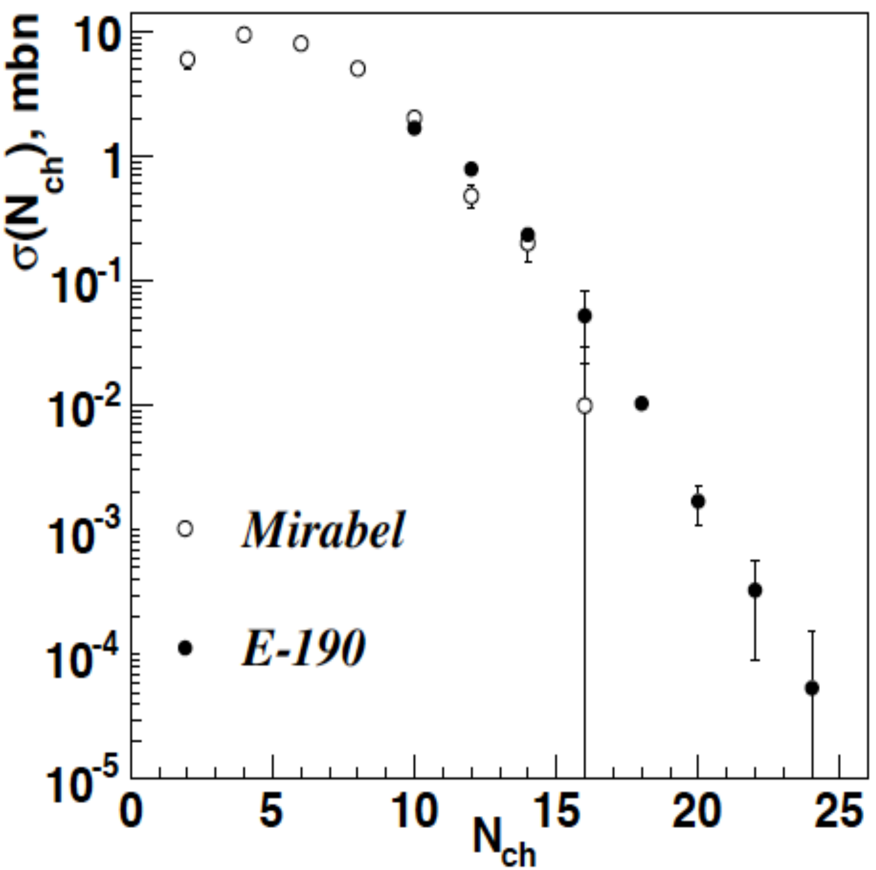
$$p + p \rightarrow 2N + \pi_1 + \pi_2 + \ldots + \pi_n,$$

***N* – nucleon, π – pion, *n* – multiplicity of neutral or charged particles (<n> – mean value), began from 2005. High multiplicity (HM) events (*n* much more than <n>) are extreme rare events. To suppress an event registration with small multiplicity (*n* no more than <n>) the scintillator hodoscope (HM trigger) has been manufactured.**

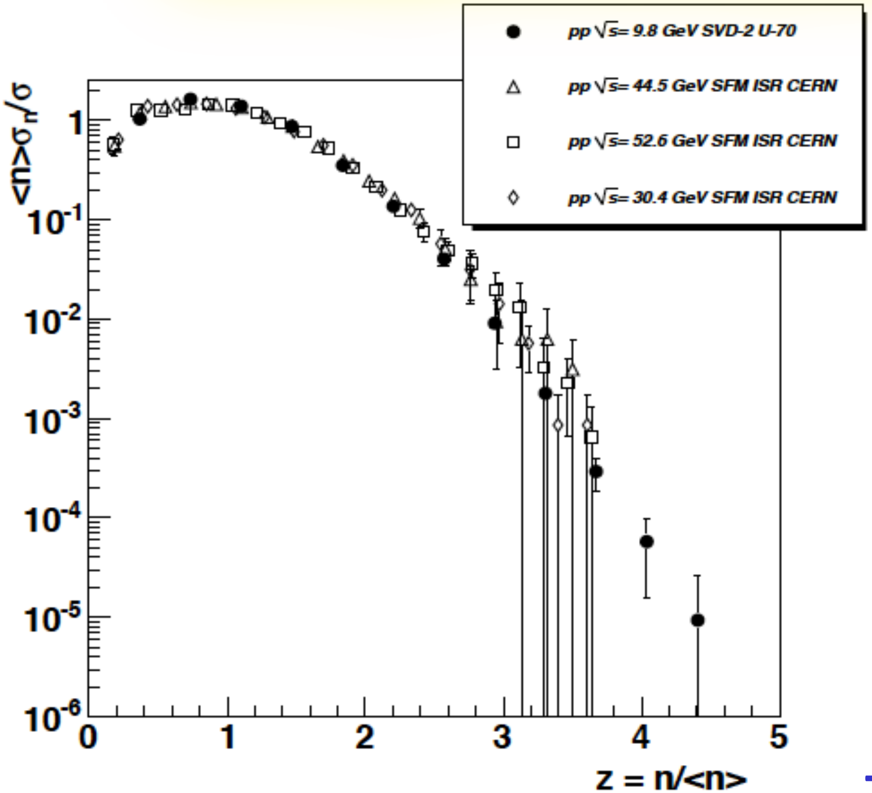
Monte Carlo codes and models gave different predictions in HM region. Up to now, they frequently underestimate experimental topological cross sections at this region (at LHC energies, especially).

Charged multiplicity measurement

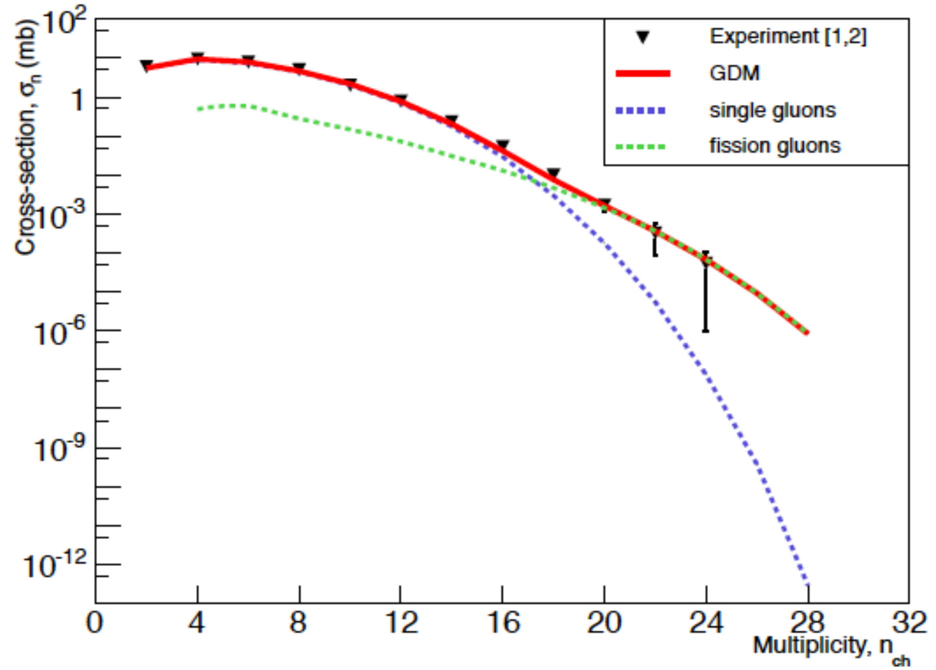
SVD-2 Collaboration carried out an experiment with the 50 GeV-proton beam of U-70 at hydrogen target. Using of HM-trigger has allowed to go down on topological cross sections on three orders in comparison with Mirabelle Collaboration (n_{ch}=16) reaching max n_{ch}=24 (at the kinematical limit 59 pions).



Charged multiplicity measurement



KNO-function



Topological cross sections (Mirabelle & SVD-2) [Phys. Atom. Nucl., 2012] & Gluon Dominance Model with *g*-splitting (a source of HM) [Phys.Part.Nucl.Lett., 2016]

Charged multiplicity measurement

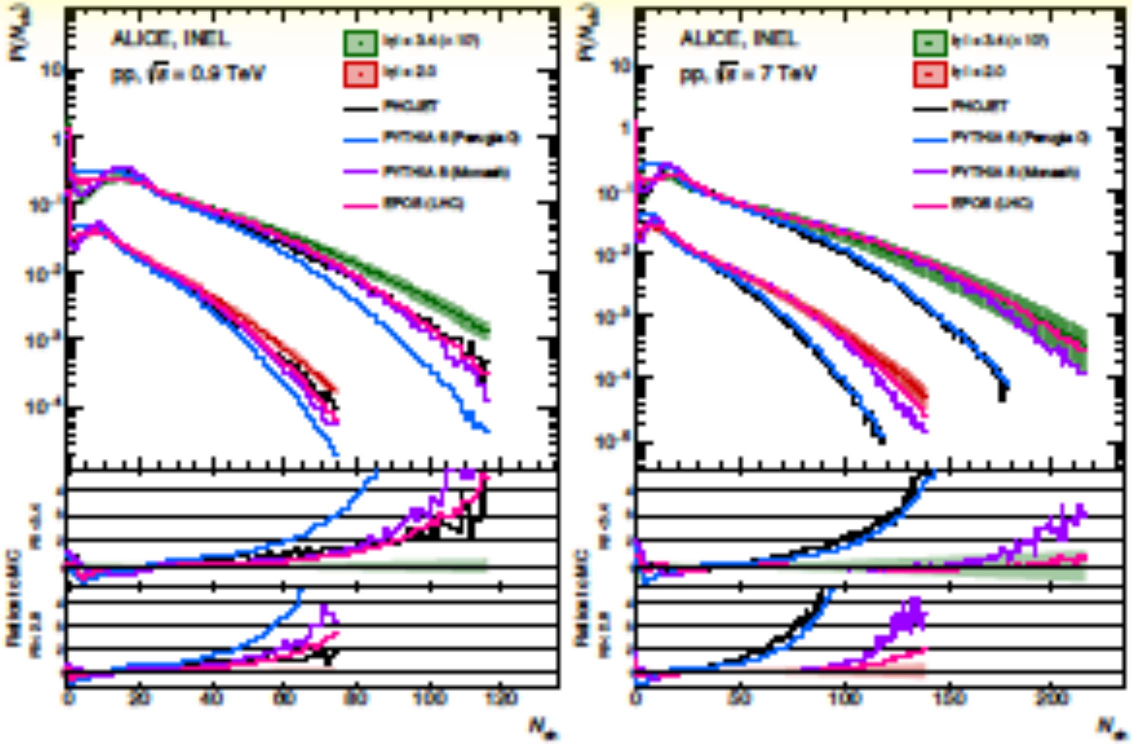
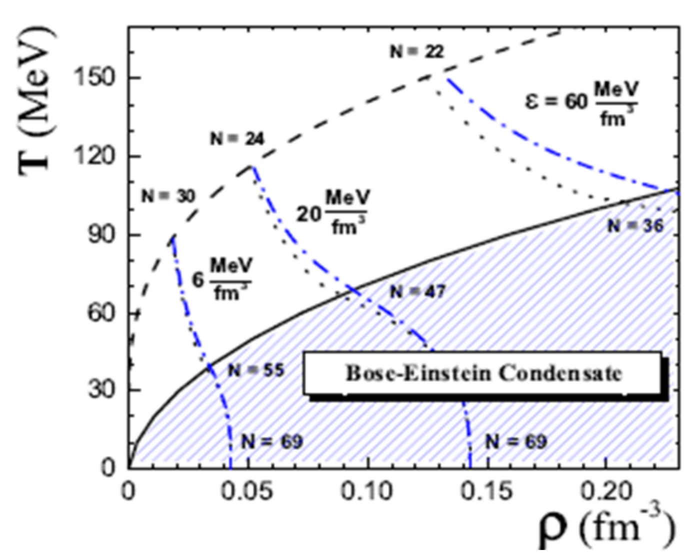


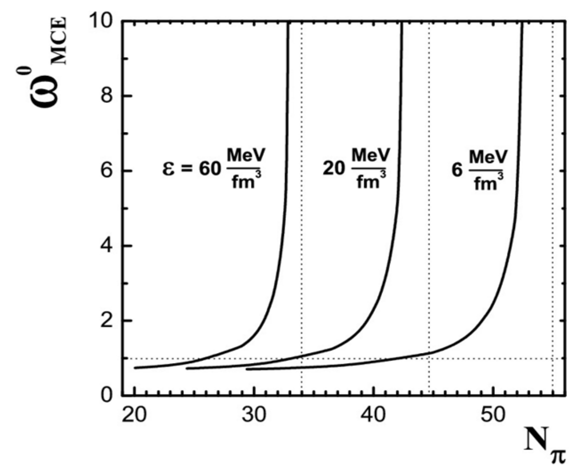
Figure 7: Comparison of multiplicity distributions for INEL events to PYTHIA 6 Perugia 0, PYTHIA 8 Monash, PHOJET and EPOS LHC at 0.9 (left) and 7 TeV (right). Combined systematic and statistical uncertainties are shown as bands.

arXiv:1708.01435 [hep-ex] "Charged-particle multiplicity distributions over a wide pseudo rapidity range in proton-proton collisions at √s = 0.9, 7 and 8 TeV" ALICE Collaboration.

Fluctuations of the π^0's number in the region of high total multiplicity (HTM)

Begun & Gorenstein [Phys.Lett.2007; Phys.Rev., 2008] predicted formation of the pion condensate (Bose-Einstein) in *pp* interactions at U-70 in a region of high total multiplicity, $N_{tot} = N_{ch} + N_0$, in the framework of the ideal pion gas model. They proposed us to measure scaled variance $\omega^0 = D/\langle N_0(N_{tot})\rangle$, $D = \langle N_0^2\rangle - \langle N_0\rangle^2$, of the neutral pion number with growth of total multiplicity. Sharp and abrupt its rise would be signal of BEC formation (thermodynamic limit) .





Fluctuations of the π^0's number in the region of high total multiplicity (HTM)

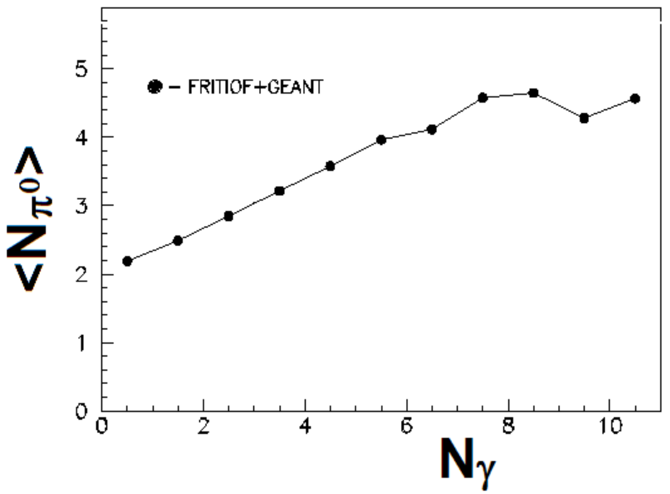
The ratio of T_C of pion to atom:
$T_C(\pi) >> T_C(A)$.

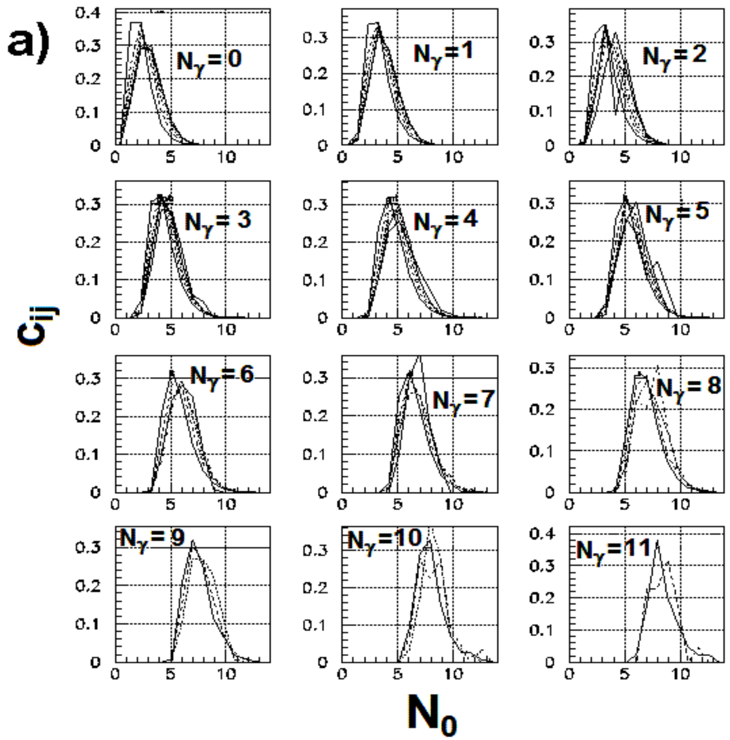
$$\frac{T_C(\pi)}{T_C(A)} \approx \frac{m_A}{m}\left(\frac{r_A}{r_\pi}\right)^2 \cong \frac{m_A}{m}10^{10}.$$

In the case of the restricted system of pions, ω^0 approaches to final value (12). MC codes and Poisson give $\omega^0 \approx 1$.

SVD-2 setup registered neutral photons by ECal. Using original method, we have retrieved number of events with defined multiplicity of π^0's at given N_{ch}. This method is based on MC simulation of multi-particle production pions.

MC simulation of π^0 –decays to photons

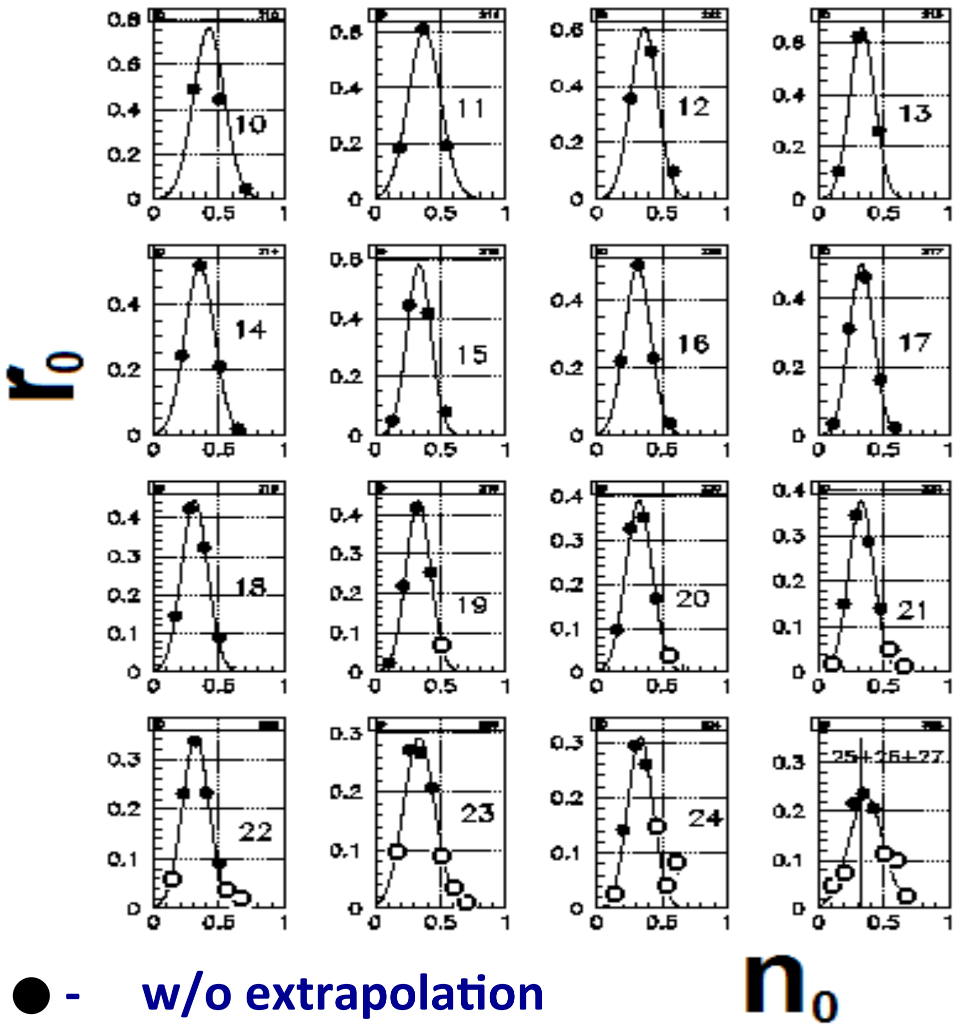




We have ascertained (found out, revealed) the linear dependence between $< N_0 >$ and N_γ. HM region for N_{tot} up to 36: N_{ch} = 8, 10, 12 .

MC method: coefficients c_{ij} – probability to register in Ecal $N_\gamma = i$ – photons at nascent $N_0 = j$ π^0’s

Fluctuations of the π^0's number in the region of HTM

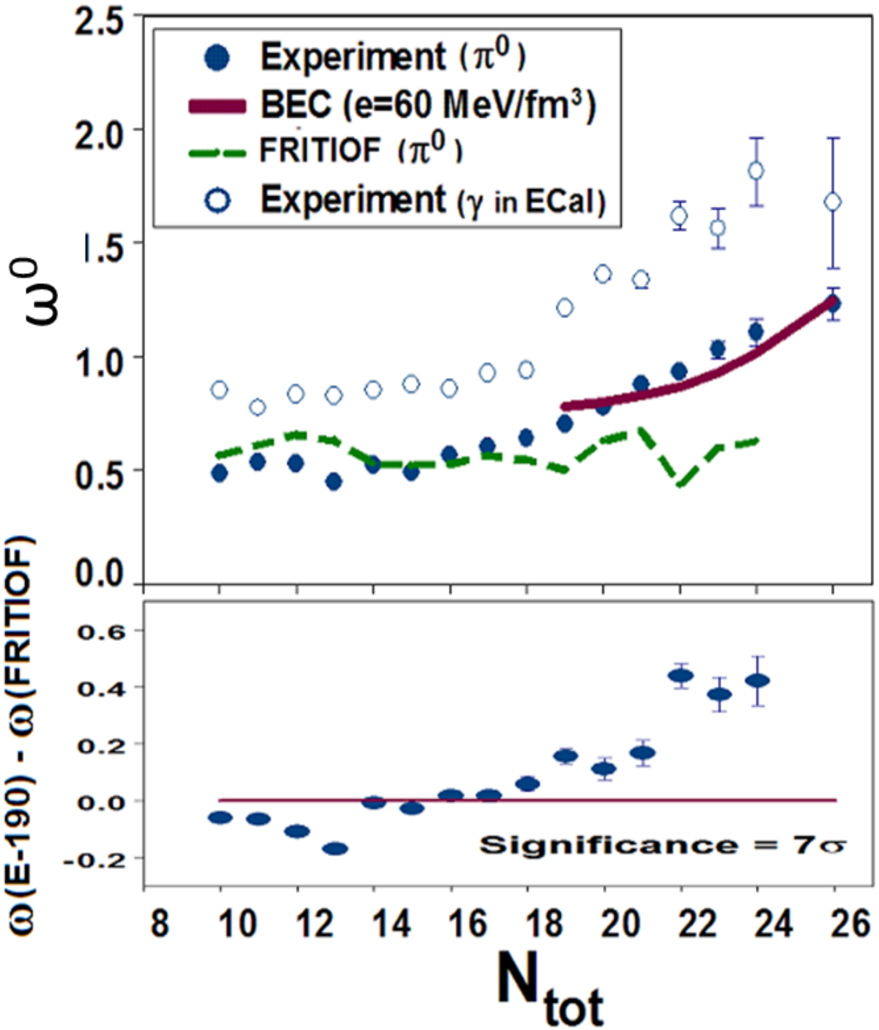


● - w/o extrapolation

○ - with extrapolation

Multiplicity distributions r_0 (MD) is a function of scaled multiplicity of π^0- mesons: $n_0 = N_0/N_{tot}$ $(0 \le n_0 \le 1)$.

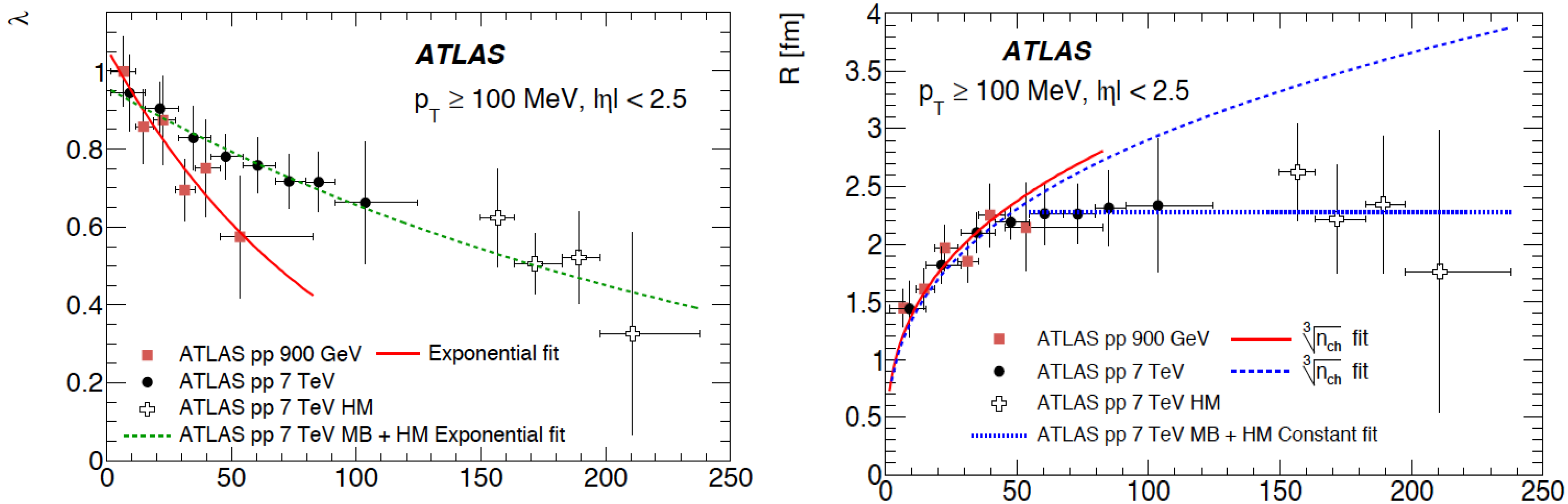
Fluctuations of the π^0's number in the region of HTM



The significance of the experimental result: a deviation of the scaled variance for neutral pions from the Monte Carlo predicted value makes up 7 standard deviations at N_{tot}~25 [SVD Collaboration, EPJ, 2012;ICHEP 2012]

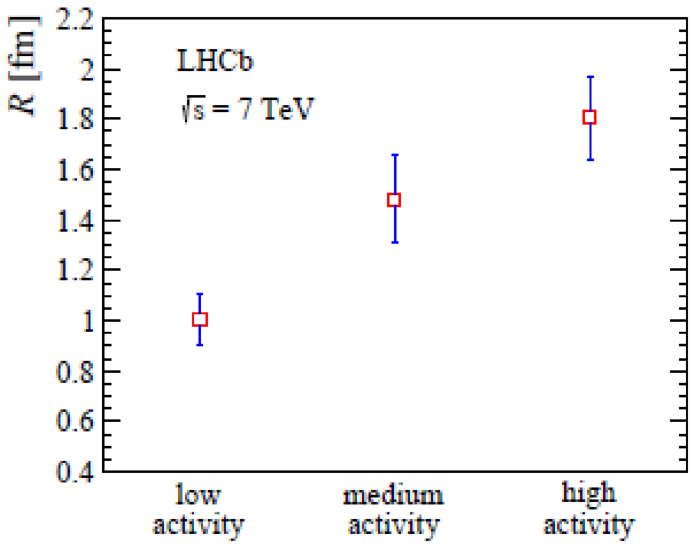
Connection BE Condensate and BE Correlation through multiplicity

"Two-particle Bose–Einstein correlations in *pp* collisions at √s = 0.9 and 7 TeV measured with the ATLAS detector" Eur. Phys. J. C 75 (2015) 466.

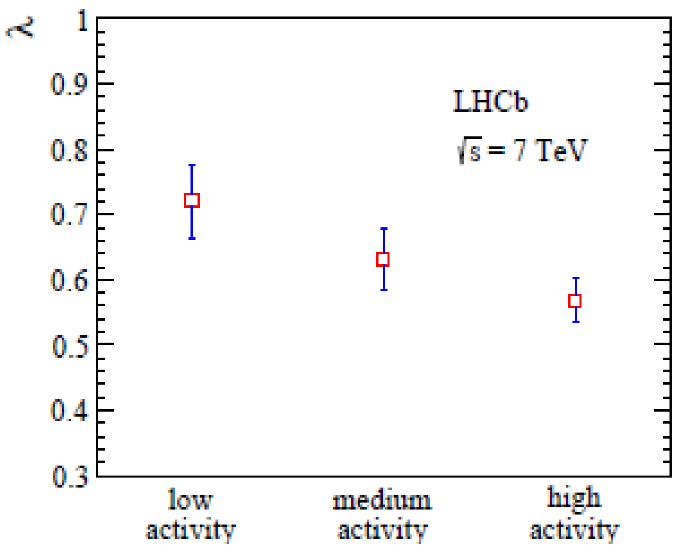


$C_2(Q) = \rho(Q)/\rho_0(Q) = C_0\,[1 + \Omega\,(\lambda, QR)](1 + \varepsilon Q)$, $Q^2 = (p_1 - p_2)^2$, where the effective radius parameter *R* and the strength parameter *λ* (the incoherence or chaoticity parameter). In a simplified scheme for fully coherent emission of identical bosons, λ = 0, while for incoherent (chaotic) emission, *λ* = 1. That behavior indicates at the approaching to BEC formation [Chaoticity and coherence in Bose-Einstein condensation and correlations. Cheuk-Yin Wong et al. hep-ph 1501.04530 (indication at BEC)

Connection BE Condensate and BE Correlation through multiplicity



Correlation radius R as a function of activity.



Chaoticity parameter λ as a function of activity.

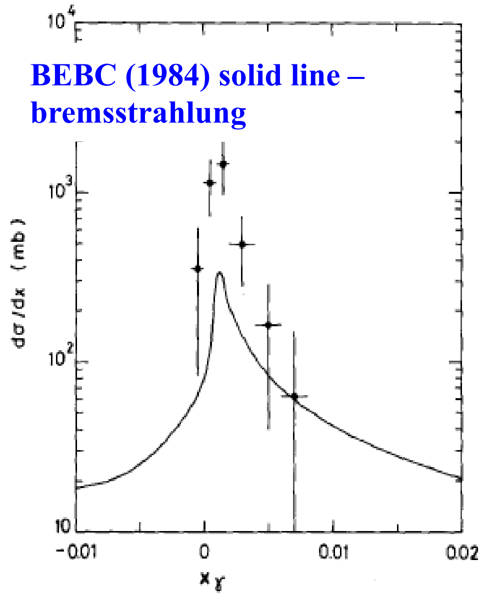
LHCb Collab. Bose-Einstein correlations of same-sign charged pions in the forward region in pp collisions at $\sqrt{s}$ = 7 TeV. 1709.01769 [hep-ex].

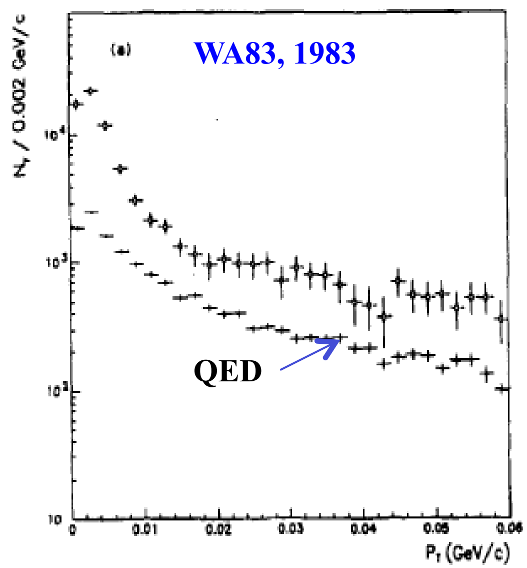
Physical program at BM@N with ECal's

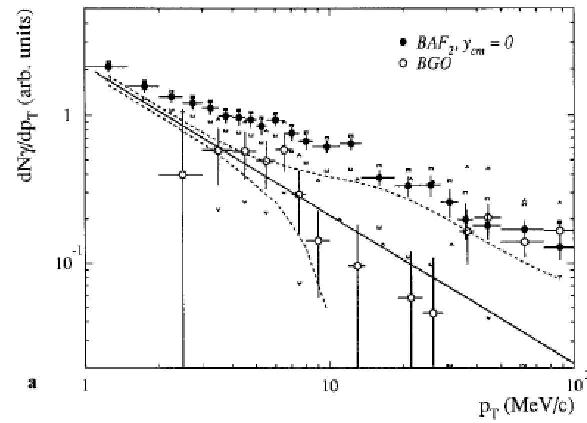
Subsequent our experiments are based on search for of connection between pion condensate and an excess yield of soft photons (SP) [S. Barshay. Anomalous SP from a coherent hadronic phase in high-energy collisions. PL, 1089].

We plan to carry out the following scientific-research program on existent in our collaboration an electromagnetic calorimeter (ECal), made of BGO crystals. At present, we build ECal ("shashlyk" type) at the recently running the BM@N (Baryon Matter at Nuclotron) setup.

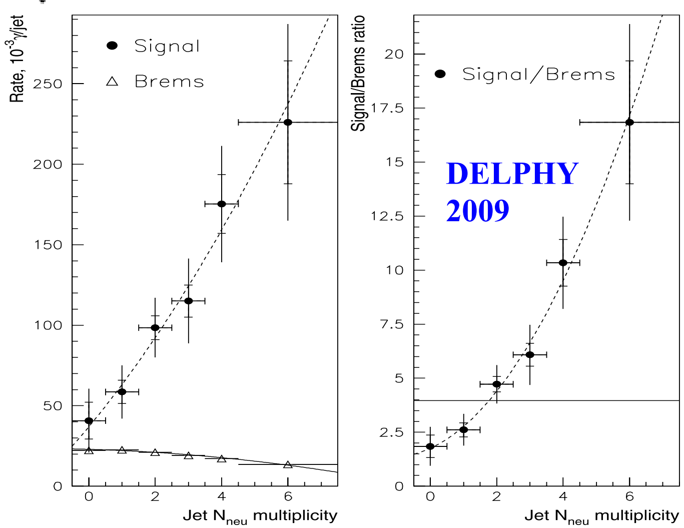
Experiments corroborating excess of SP yield

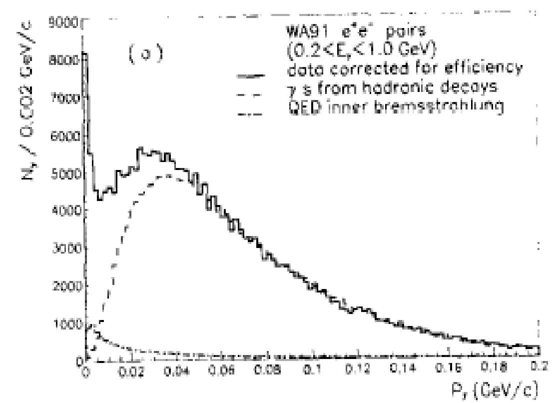






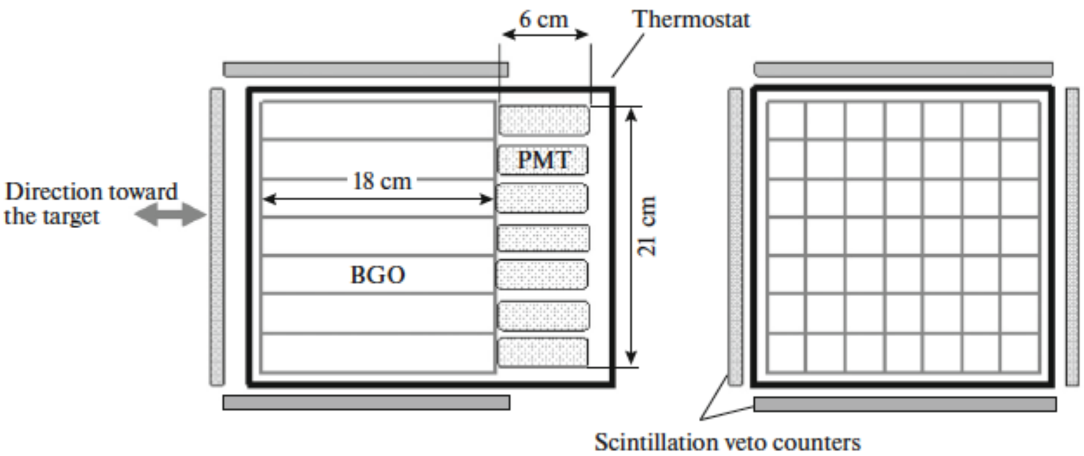
HELIOS, 1989





WA91, 2002

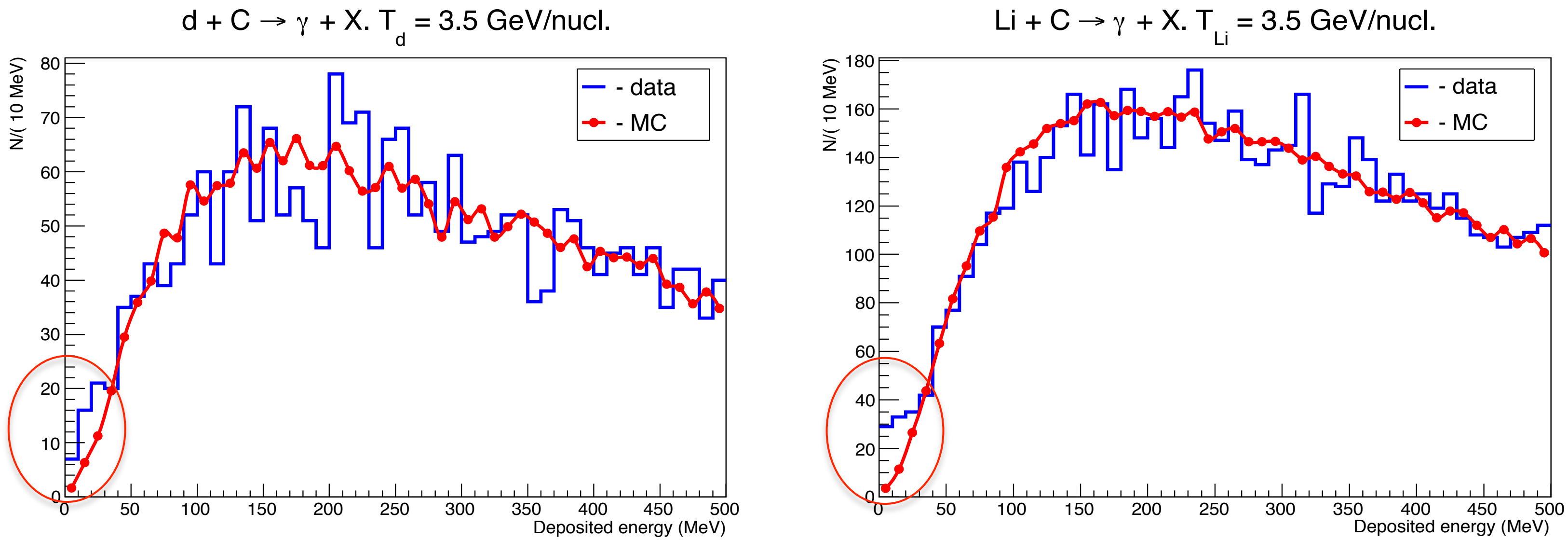
Electromagnetic calorimeter at Nuclotron



ECal scheme

General view of ECal with veto-detectors at NIS-GIBS setup

Excess of SP yield at Nuclotron



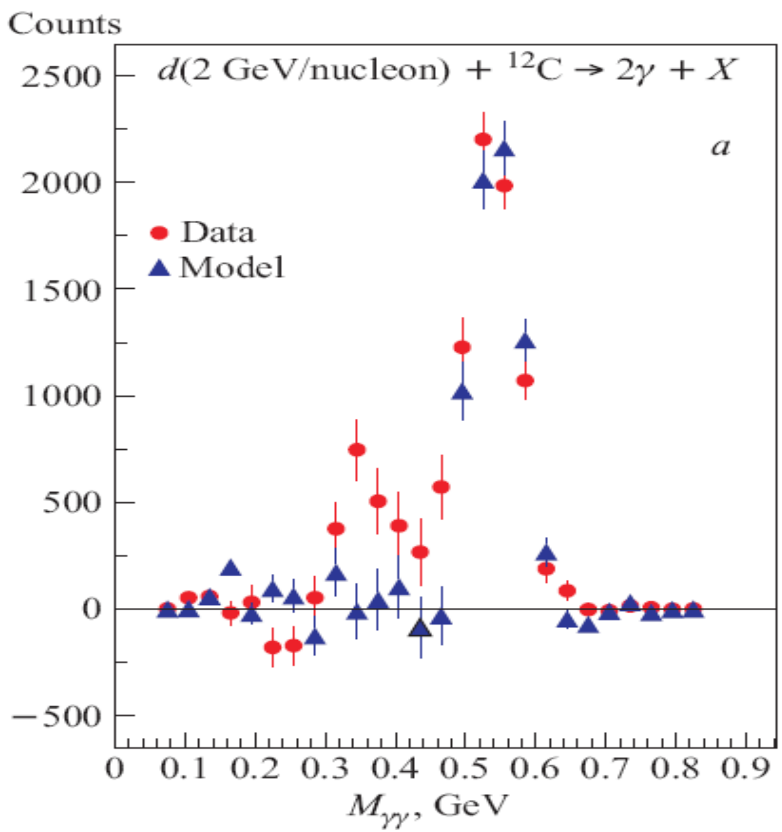
Experimental and MC spectra of energy release in ECal & a pre-shower with 3.5A GeV/*c* beams of deuterium (left) and lithium (right), 2014-15 50th and 51st runs .

Criterions of selection: 1) E in the front veto-counter < 0.3 MIPs; 2) E in pre-shower 0.5 < *E* < 4 MIPs; 3)ToF -1200 < t-tγ <600ps; 4) more than 2 MeV it is registered in 1 BGO crystal; 5) location of shower in crystal must overlay throughout vertical with the triggered pre-shower counter; 6) E deposition in the outer BGO layer should be ≤ 1/3 of a total to prevent significant leakages

Future scientific program at Nuclotron

1. BEC formation in nuclear interactions at HTM.
2. Connection between the pion condensate and an excess yield of soft photons (SP).
3. Search for new resonances in the system of two γ-quanta (f_0(500) or σ-meson, etc.).
4. Increased yield of η^0-mesons in AA-interactions;
5. γ- femtometry.
6. Search for *P*-parity violation effect in events with high p_T .
7. Coherence of SP by measurement of flow v_2 predicted of T. Kodama and T. Koide. etc.

3. Search for new resonances in system of two γ-quanta

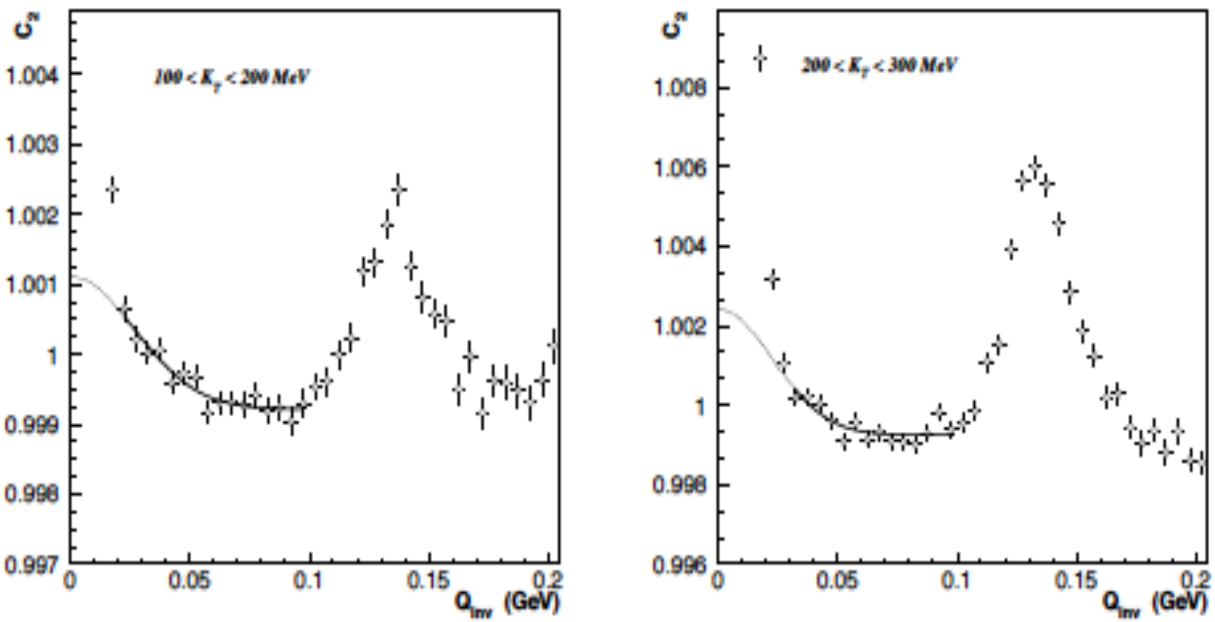


Mass spectrum of pair γ-quanta from [Kh.Abraamyan et al. Resonance structure in γγ invariant mass spectrum in pC and dC interactions. ЭЧАЯ, 2010, v. 41, p. 2043].

4. Increased yield of η^0-mesons in AA-interactions

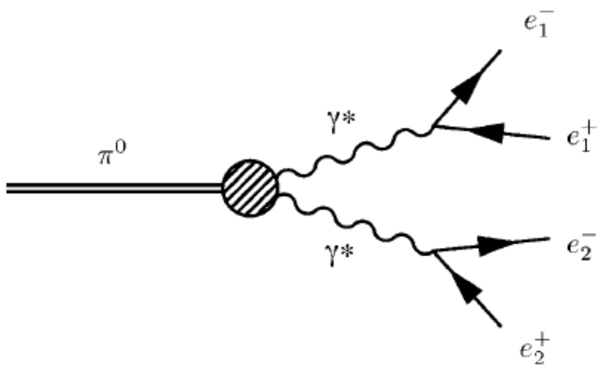
In [B.S. Yuldashev et al., Phys. Rev. D43 (1991) 2803; Phys. Rev. D43 (1991) 2792] has been shown that "The gamma multiplicity for *p* ^{20}Ne interactions is 11.43+0.23, and the ratio of n_γ for *p* ^{20}Ne and *p*N interactions is 1.48+0.05. $\langle n(\pi^0)\rangle$ =4.91+0.52 and $\langle n(\eta^0\rangle$ =1. 47+0.33. η^0 production is much higher in p ^{20}Ne interactions [R(η^0/π^0)=0.66+/-0.12 for n_p > 2] than in *p*N interactions [R (η^0 /π^0)=0. 06+0.04]. Strong correlations between $\langle n_\gamma\rangle$ and n_p, the number of secondary protons, are observed, primarily from the central and target fragmentation regions. …"

5. γ- femtometry



Two-γ correlation function calculated for the 10% most central ^{298}Pb+^{298}Pb collisions at 158 AGeV. "All" PID criterion is used and cut on minimal distance L_{12} > 20 cm is imposed [D. Peresunko et al. WA98 collaboration. Interferometry of direct photons in Pb-208 + Pb-208 collisions at 158-A-GeV. J. Phys. G30 (2004) S1056].

6. Search for *P*-parity violation effect in events with high p_T

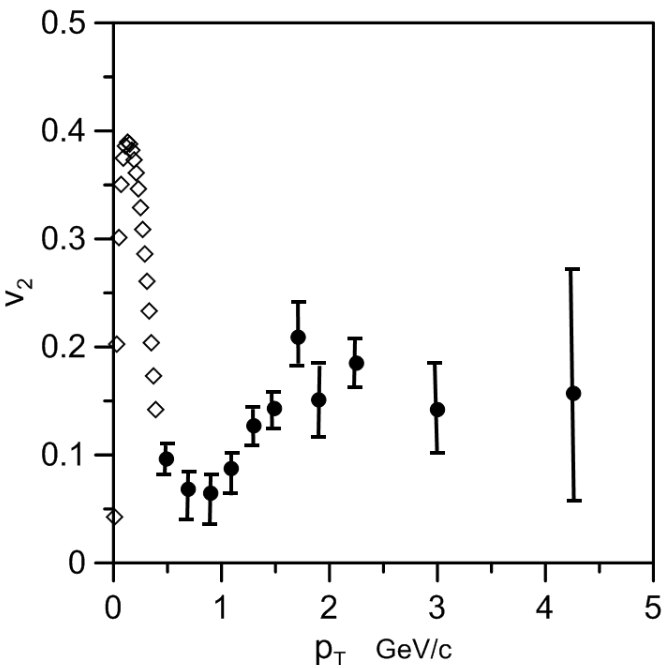


B.A.Robson. Int. Journal Mod. Phys. E, Vol. 20, No. 8 (2011) 1677.

The angle distribution on φ between planes of e^+e^- -pairs has been gotten in FNAL experiment KTeV-E799 by using of 30000 events. Contribution of the positive parity state, factor *b* in expression for the angle distribution, consisted ≤ 3.3 %:

$$\frac{dF}{d\phi} = 1 + a\cos(2\phi) + b\sin(2\phi)$$

7. Coherence of SP by measurement of flow v_2



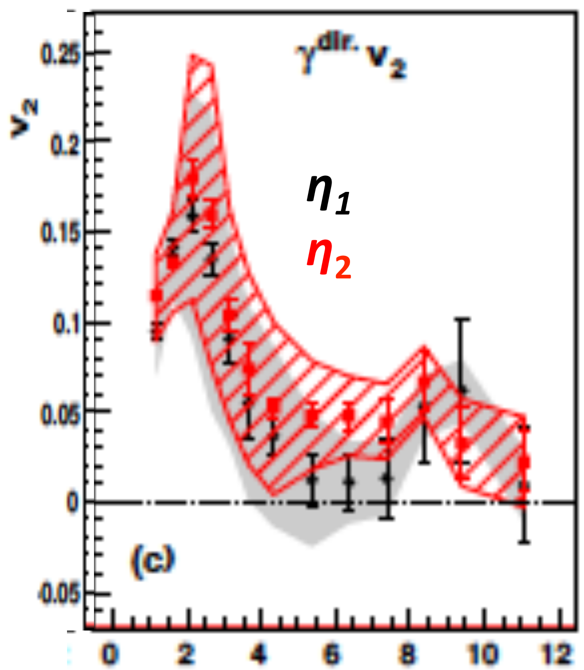
Flow v_2 as function of p_T for γ-spectra

Prediction for flow, v_2, from Direct Photons (empty diamonds). Squares denote the results with the effects of incoherent with p = 0.2 GeV. Filled circles indicate the experimental data from PHENIX T.Koide, T. Kodama. Anisotropy of Low Energy DP in Relativistic Heav Ion Collis. J. Phys. G43 (2016) 095103.

Measurement of flow v_2 for Direct Photons

$$v_2^{\gamma,dir} = \frac{R_\gamma(p_T)v_2^{\gamma,inc} - v_2^{\gamma,bg}}{R_\gamma(p_T) - 1}$$

where $R_\gamma(p_T) = N^{inc}(p_T)/N^{bg}(p_T)$ with $N^{inc}=N^{meas}-N^{hadr}$, the number of inclusive photons, while $N^{bg}(p_T)$ is the number of photons attributed to hadron decay. Values of $R_\gamma(p_T)$ above 5 GeV/*c* are taken from real photon measurement with the PHENIX ECal and below that from the more accurate, but p_T-range limited internal conversion measurement of direct photons.



[A. Adare et al. PHENIX Coll. Observation of direct-photon collective flow in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. Phys. Rev. Lett. 109, 122302 (2012)]

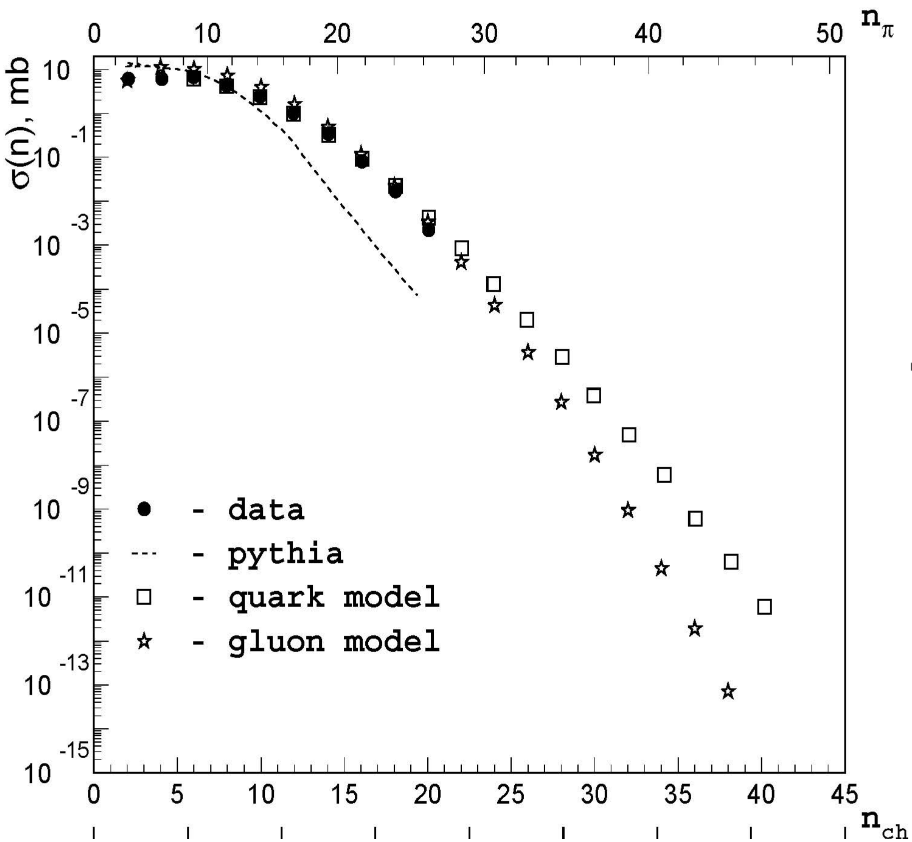
At present:

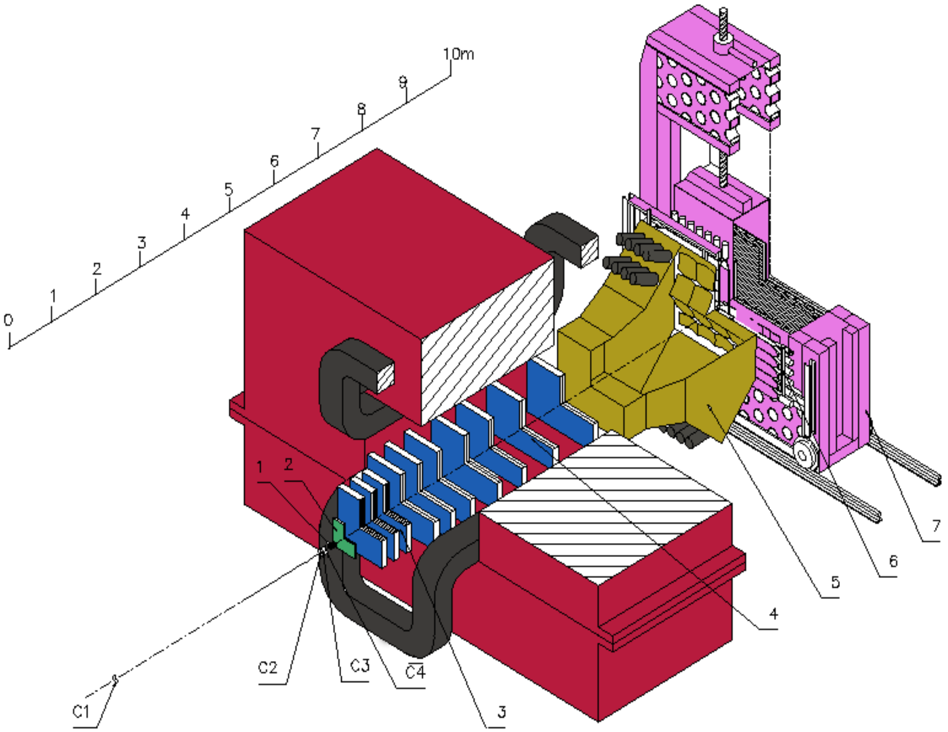
HM region is very promising in future study, especially physical programs with inclusion of electromagnetic calorimeters!

We prepare the two-arm ECal (based on "shashlyk" type) with low threshold (<10 MeV) by means the new optical "head" which permits registration photons with energy higher than 5-8 MeV.

Thank you for attention

SVD-2 setup





Collaboration «Mirabelle», IHEP, *p*-beam 69 GeV/c

Spectrometer with Vertex Detector