Study of *pp* interactions at high multiplicity at U-70

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(IHEP-SINP MSU-JINR)

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High Multiplicity Region (HMR)

Thermalization project (U-70, IHEP)

is aimed at studing of *pp* interactions

$p + p \rightarrow 2N + n\pi$

50 GeV proton beam, multiplicity

$n_{ch} >> \langle n_{ch}(s) \rangle \approx 5$,

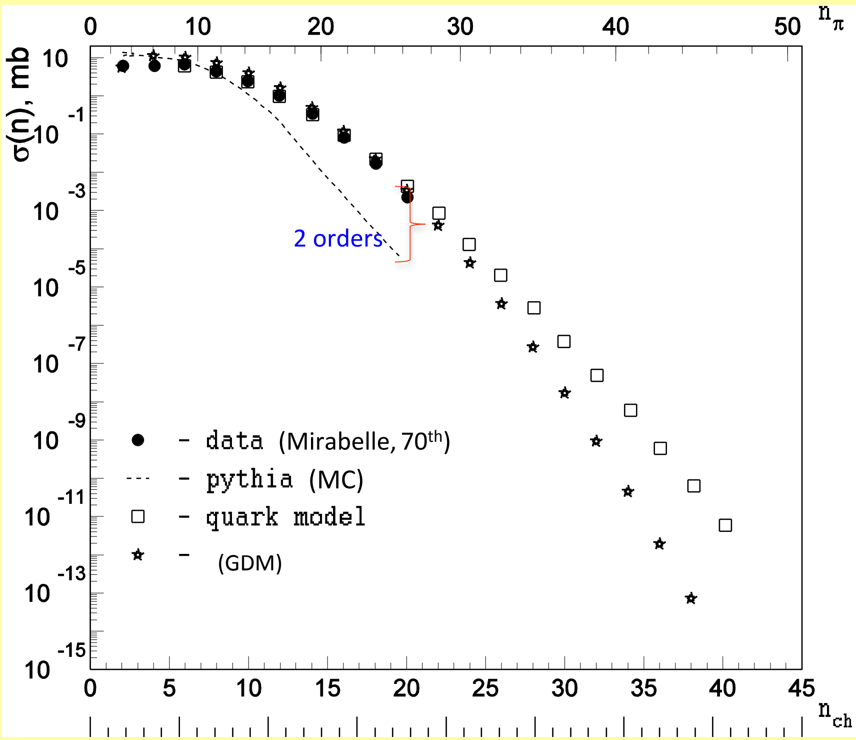
the kinematical limit:

$n_{thresh} \approx (\sqrt{s} - 2m_p)/m_\pi$, $n_{thresh} \sim 57$

SVD-2 setup registers $\pi^{\pm}$ & γ's

pions are copiously formed at U-70

At HMR MC event generators are mistaken, models predict diverse topological cross section values

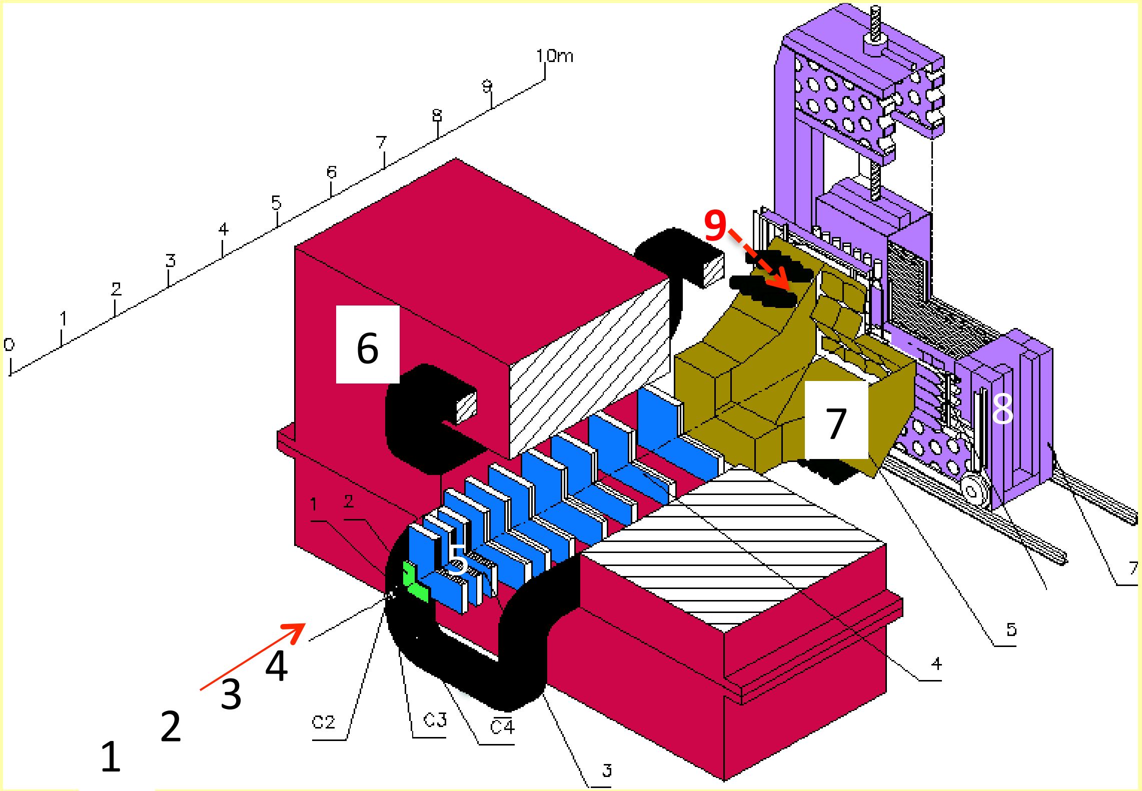


Search for collective phenomena in pp interactions at HMR: Bose-Einstein Condensation (BEC) in system of charged & neutral pions:

$N_{tot}=N_{ch}+N_0$

THE SPECTROMETER WITH VERTEX DETECTOR

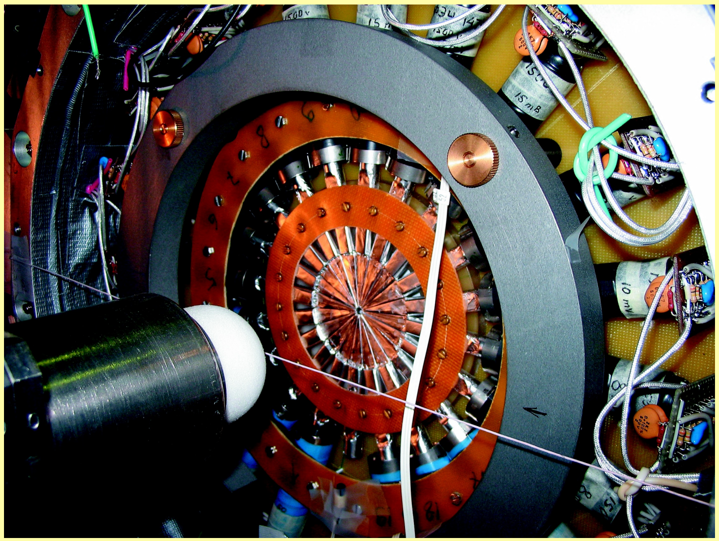
SVD-2 setup

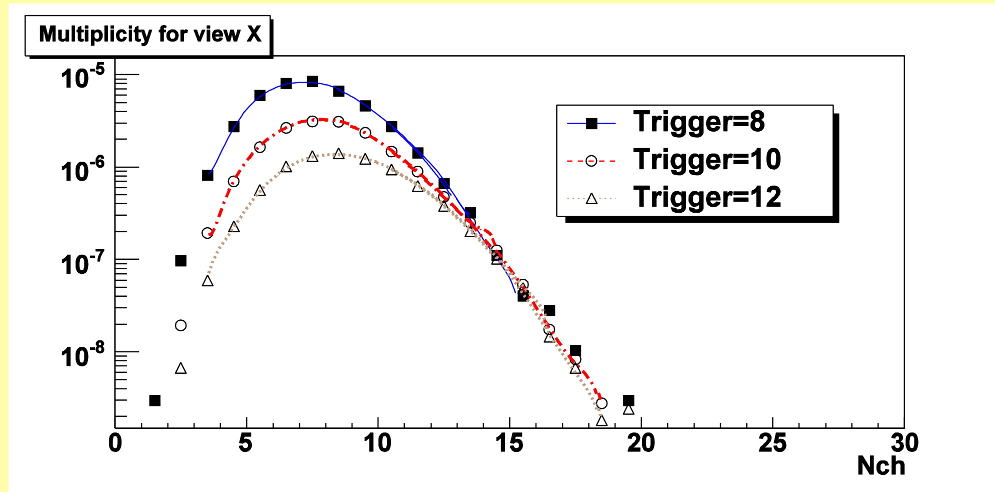


1 – Beam Stations
2 – Hydrogen Target
3 – Vertex Detector
4 – High Multipl Trigger
5 – Drift Tube Tracker
6 – Magnet &Proportion Chambers (MS)
7 – Cherenkov Counter
8 – ECal
9 – SPEC (soft photon ECal)

THE SPECTROMETER WITH VERTEX DETECTOR

SVD-2 setup





Trigger level, *l* : *n* ≥ *l* (*l*=2, 4, 6, 8, 10, 12)

Scintillator hodoscope – **suppression of low multiplicity events**

SVD
THE SPECTROMETER
WITH VERTEX DETECTOR

Selection, reconstruction & corrections

Redistributed equation system gives: Correction of previous data and addition of new points, n=18, 20, 22, 24.

σ = 31.50 ±1.14 *mb*

Software is based on Kalman Filter technique. It takes into account heterogeneous magnetic field, multiple scattering, energy losses. ~1 mln events have been selected, VD data, run 2008 (l=8), H_2

MC simulation (GEANT3.14). Corrections: acceptance and efficiency of PVD work, algorithm of track reconstruction efficiency.

$\langle n_{ch} \rangle$ = 5.45 ±0.24

D = 7.21 ± 2.80 f_2 = 1.75

Gluon Dominance Model (GDM)

GDM describes well multiplicity distributions (MD) in *e^+e^-* annihilation as two stage model based on QCD quark-gluon cascade (PT QCD) and hadronization:

$$e^+ + e^- \rightarrow \gamma(Z^0) \rightarrow q\bar{q} \rightarrow (q\bar{q}g) \rightarrow h_1 + h_2 + \ldots + h_n$$

I stage

qg-cascade: a) g ->gg; b) q->qg; c) g->qqbar

NBD

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

II stage

hadronization

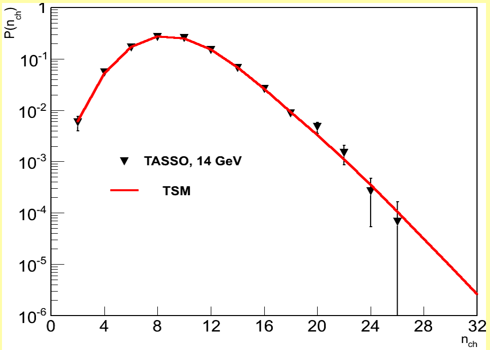
BD

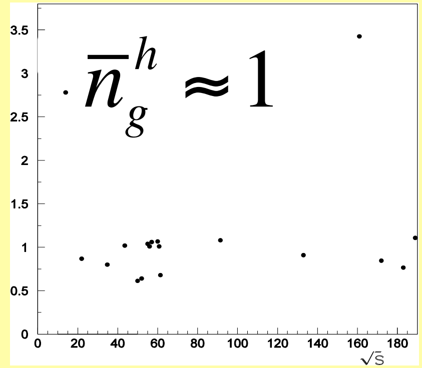
$$P_n = C_{N_p}^n p^n (1-p)^{N_p-n}, \quad p = \frac{\bar{n}^h}{N}.$$

Convolution of two stages

$$P_n = \sum_{m=0} P_m^G \cdot C_{(2+\alpha m)N}^{n-2} p^{n-2}(1-p)^{(2+\alpha m)N-(n-2)}.$$

GDM, e^+e^- annihilation





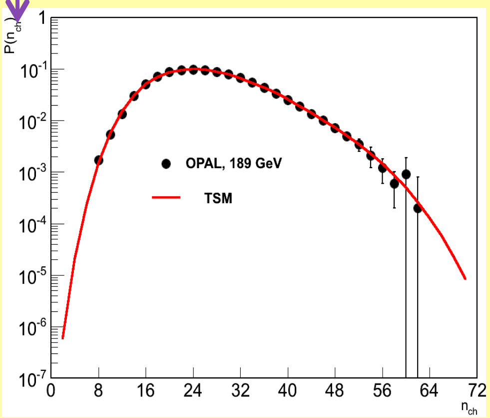
$$\frac{Baryon}{Meson} << 1$$

Hadronization in vacuum (fragmentation mechanism) is confirmed:

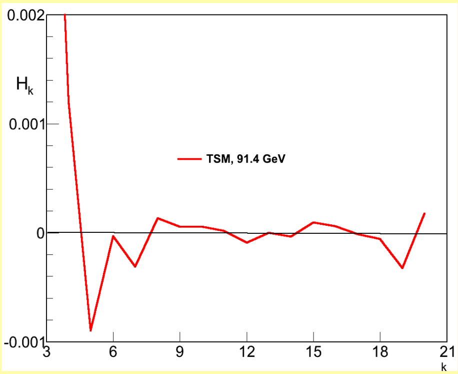
1 parton → 1 hadron (LoPAD)

P_n

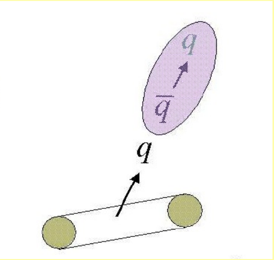
MD 14-189 GeV



$H_k = K_k/F_k$, 91GeV



B Muller, nucl-th/0404015



$\bar{n}_g^h$ - **average number of hadrons nascent from single gluon source at its passage through hadronization stage**

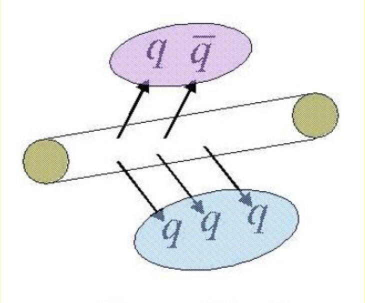
SVD THE SPECTROMETER WITH VERTEX DETECTOR

GDM: pp & $p\bar{p}$ interactions

GDM: quarks of initial protons stay in leading particles (U70 - ISR). Multiparticle production is realized by active gluons. Two schemes (with/without gluon branching): g-cascade × hadronization (BD)

Recombination mechanism of hadronization is confirmed in *pp*, $p\bar{p}$, AA interactions.

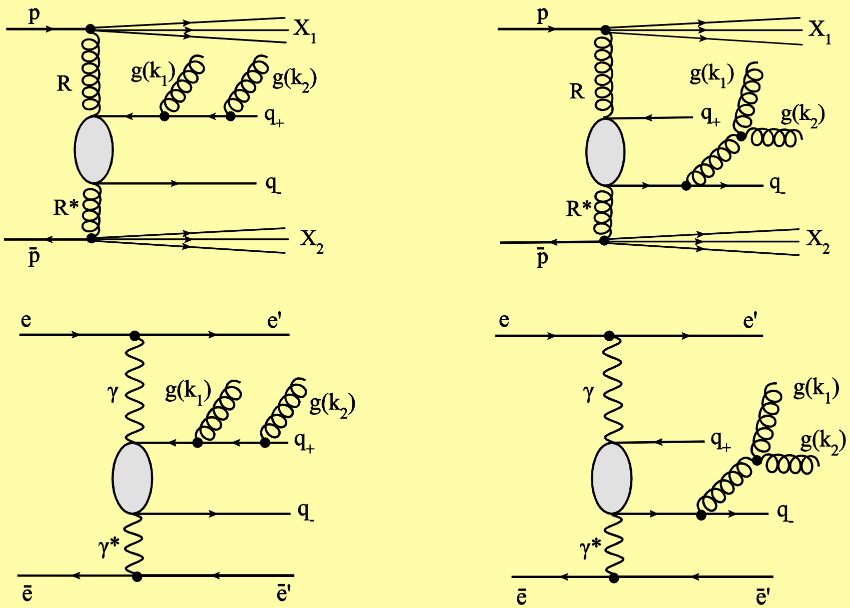
Growth $\bar{n}^h$ in *pp*:
1.5 (50 GeV/c, U-70) ->
3.3 (62.2 GeV, ISR)
hadronization occurs in quark-gluon medium

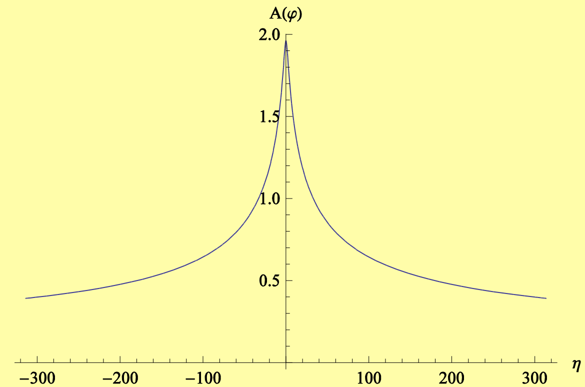


B Muller, nucl-th/0404015

$$\frac{Baryon}{Meson} \approx 1, RHIC$$

Gluon fission (gf) in pp, $p\bar{p}$, e^+e^-

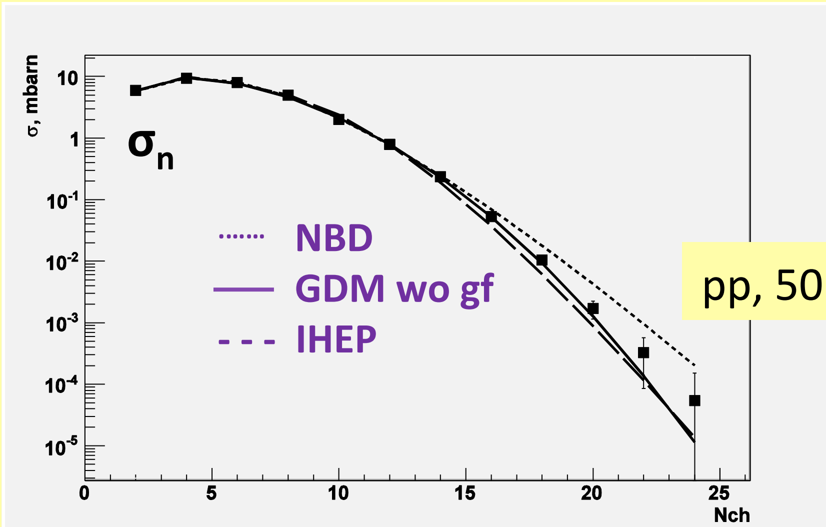




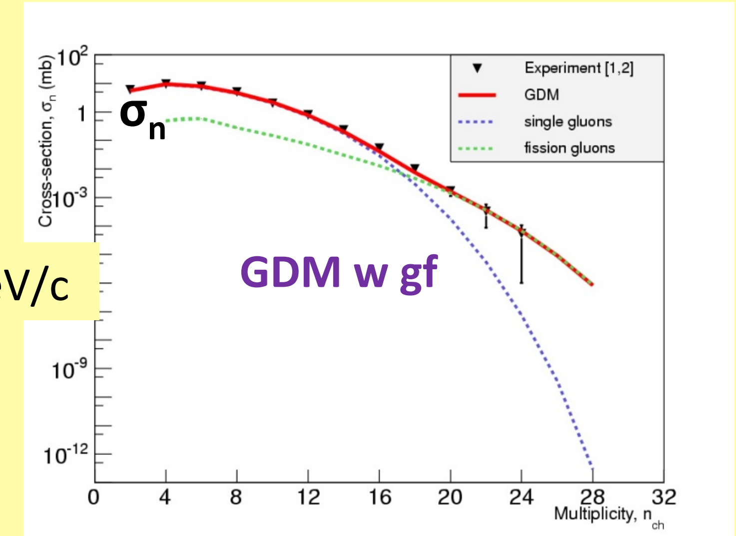
E.Kuraev, S.Bakmaev, E.K. Nucl.Phys B851 (2011)

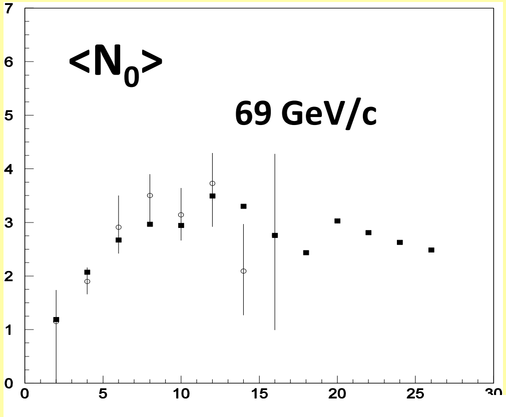
In double-logarithmic approximation the emission of two g-jets explains the angle broadening of distributions at high energies (interference). At U-70 it can be realized.

COMPARISON: GDM and other models

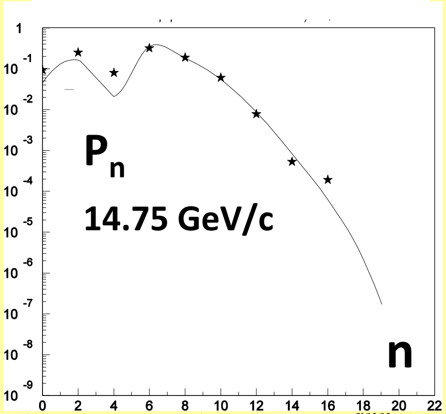


pp, 50 GeV/c

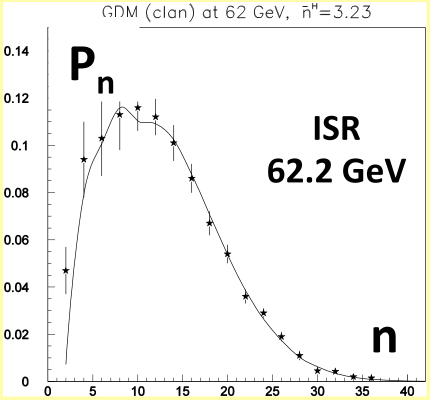




N_{ch}



$$\sigma_n(p\bar{p}) - \sigma_n(pp) = \sigma_n^{ann}(p\bar{p})$$



The Charged Exchange (CE)

First indications were observed in $\pi^{+}p$ *and pp in* experiments on proportional chambers and CR:

CE: p + p -> n + π^{+} + p + N (π^{+} π^{-})

$$\sigma_2 = \sigma_{2,el} + \sigma_{2,inel}, \quad \sigma_{2,inel} = \sigma_{2,-exch} + \sigma_{2,+esch}, \quad k_2 = \frac{\sigma_{2,+esch}}{\sigma_{2,inel}} \cdot 100\%$$

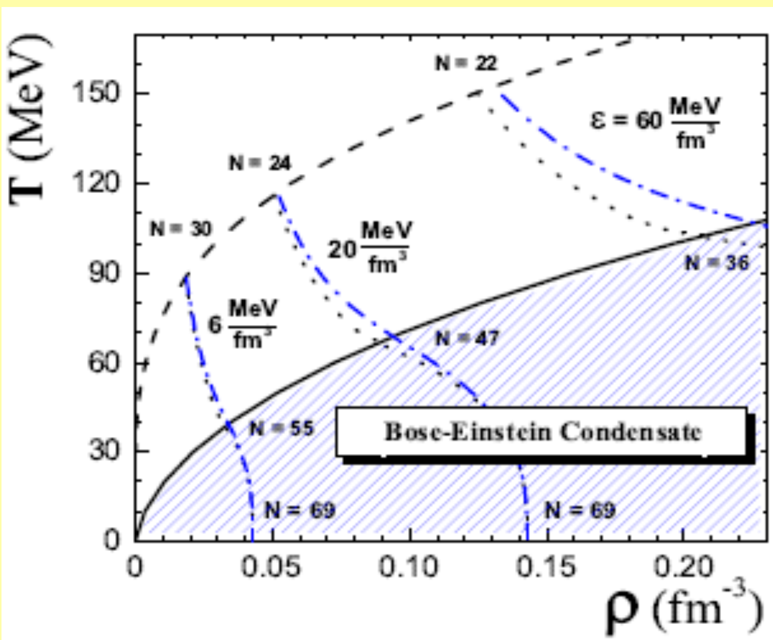
GDM:

$$\sigma_{2,el} = e^{-\overline{m}}, \quad \sigma_{2,-exch} = \sum_{m=0}^{Mg} e^{-\overline{m}} \frac{\overline{m}^{m}}{m!} C_{mN}^{n-2} \left(1 - \frac{\overline{n}^{h}}{N}\right)^{mN}.$$

1) Data description of σ_n, $2 \le n \le 24$, $\sigma_{2,inel} = p_2 \cdot \sigma_{2,-exch}$
2) Fitting data by GDM -> p_2 -> $k_2 = p_2/(p_2-1)*100\%$
3) $k_2 \approx 50 \pm 5\%$ is comparable with data [Murzin, Sarycheva]

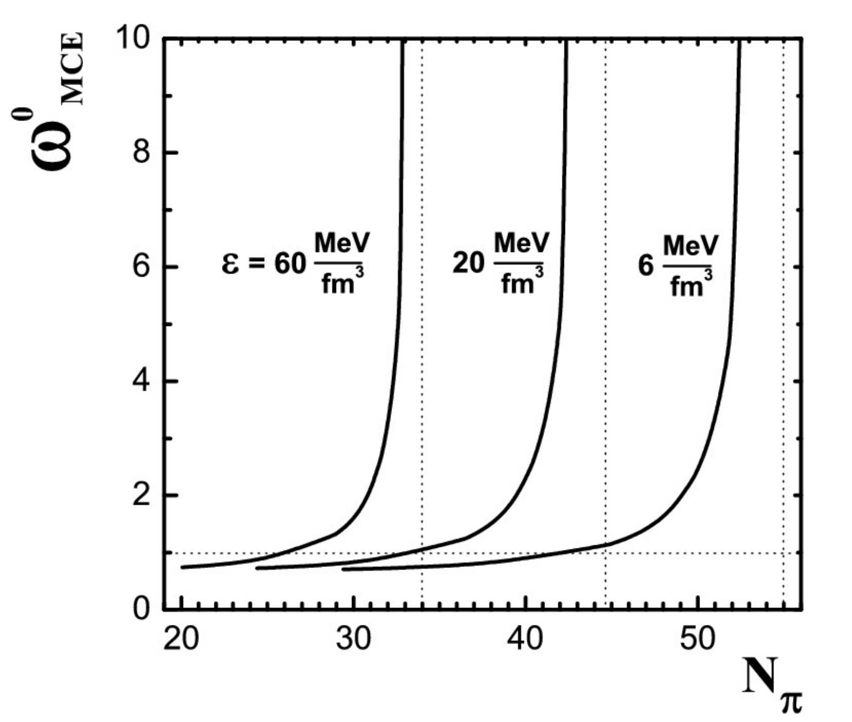
Search for collective phenomena

V.Begun and M.Gorenstein (PL, 2007; PR, 2008) have predicted possibility of the Bose-Einstein Condensation (BEC) formation in *pp* interactions at U-70 at high total multiplicity, $n_{tot}=n_{ch}+n_0$, based on ideal pion gas model.



The phase diagram of pion gas with μ_Q=0. The dashed line corresponds to $\rho_\pi(T, \mu_\pi=0)$ and the solid line to BEC. The dotted lines show the states with fixed energy densities, ε=6, 20, 60 MeV/fm^3. N_π numbers correspond to μ_π=0 and $\mu_\pi=m_\pi$ at these densities for total pion energy, E=9.7 GeV.

Search for Collective phenomena



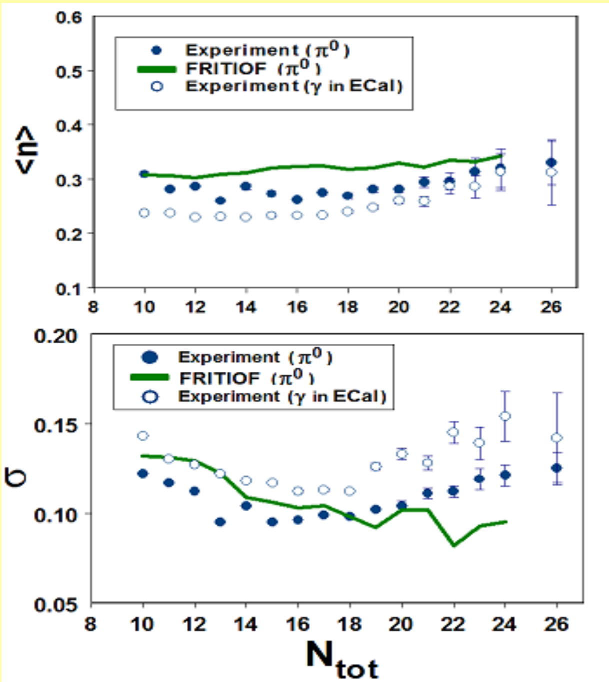
Scaled variance, ω^0=D/<N_0>,
D is variance for π^0-mesons,
N_{tot}= N_π – fixed.
MC, Poisson give ω=1.
B-G predictions – ω^0 for the number fluctuations of π^0 & $\pi^\pm$ increases dramatically and abruptly if the pion system approaches the BEC line at TL

The case of the finite size system, relativistic pion gas: 1) T-> T_C (T<T_C), ω^0 ~V; 2) T=T_C, ω^0 ~V⅓.

$$T_C(\pi) >> T_C(A)$$

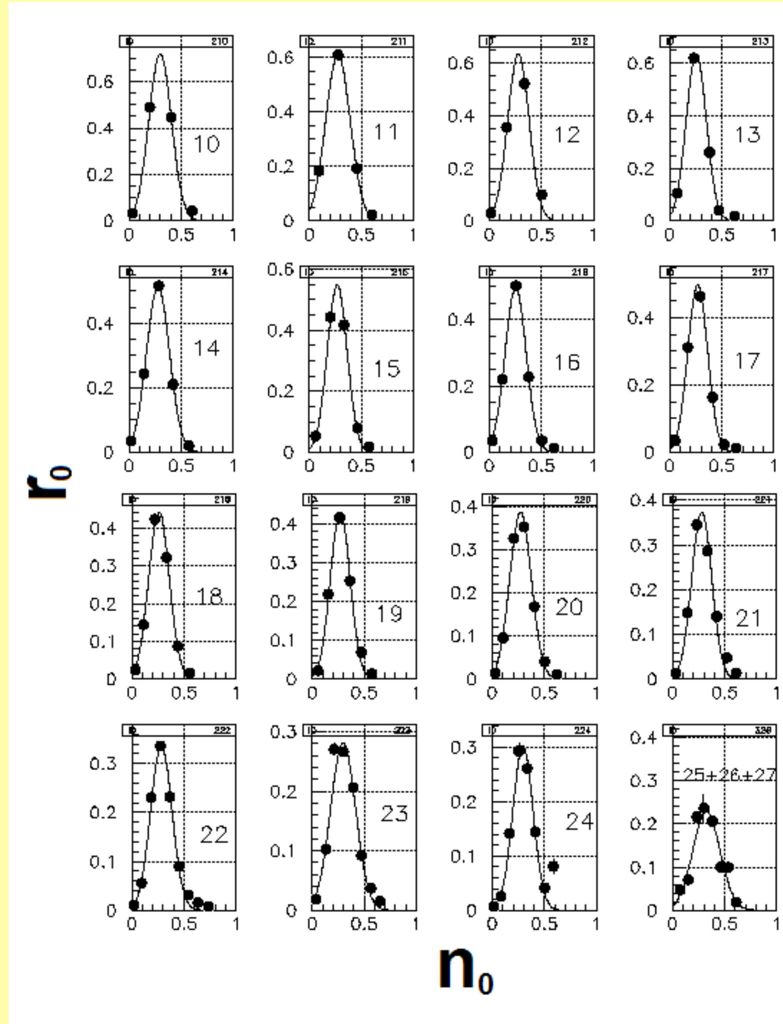
$$\frac{T_C(\pi)}{T_C(A)} \approx \frac{m_A}{m}\left(\frac{r_A}{r_\pi}\right)^2 \cong \frac{m_A}{m}10^{10}$$

Experimental Results



$D=\sigma^2$

SVD Collaboration, EPJ, 2012; ICHEP 2012.

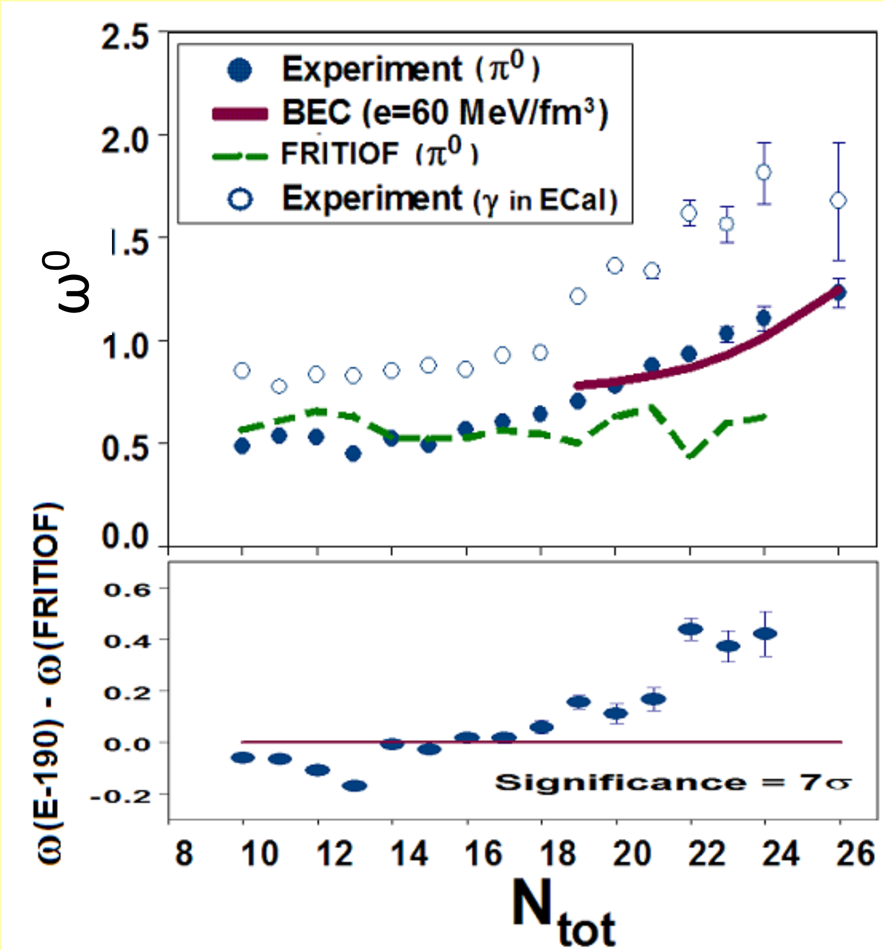


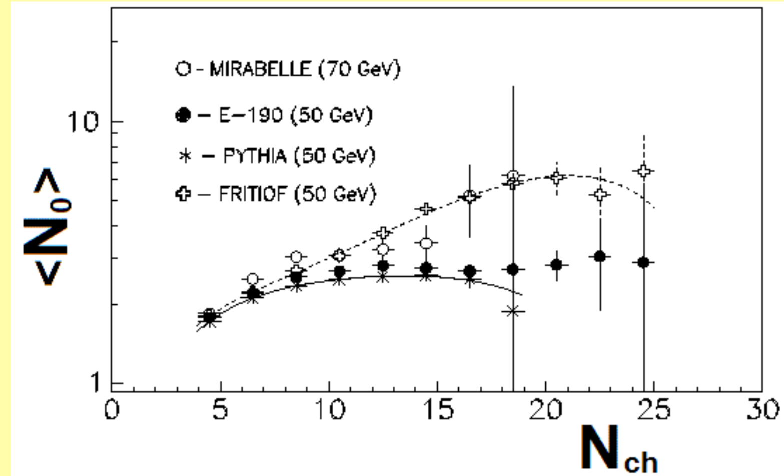
Scaled variable,
$n_0=N_0/N_{tot}$,
$(0\leq n_0 \leq 1)$
$r_0=P(N_0,N_{tot})$

Multiplicity distributions of π^0`s at fixed N_{tot}

THE SPECTROMETER WITH VERTEX DETECTOR

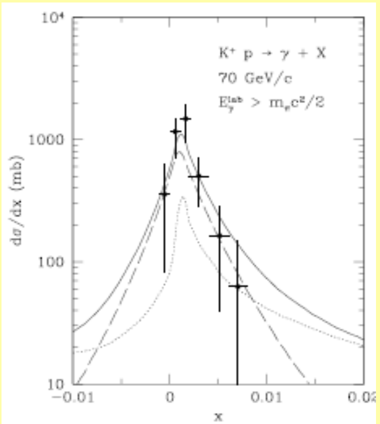
Experimental Results



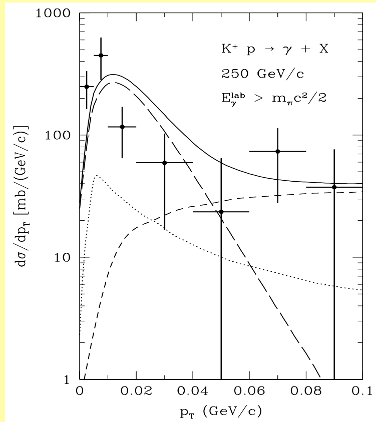


SVD Collaboration EPJ, 2012

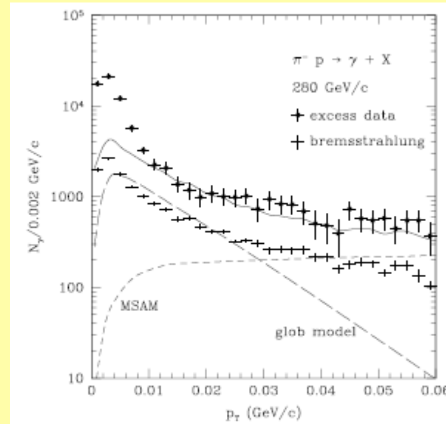
Experiment: σ_γ for soft direct photons are considerably above than expected from hadronic bremsstrahlung



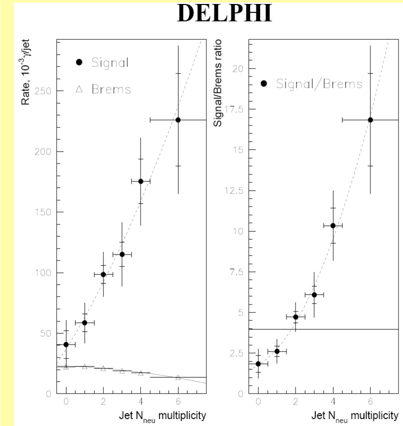
BEBC, 1984



NA22, 1991



WA83, 1993



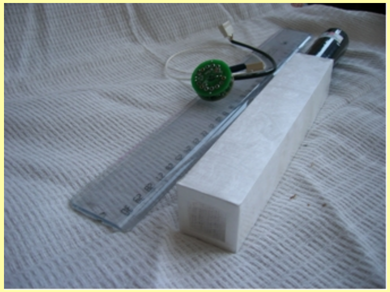
DELPHI, 2004

Lichard & Van Hove (1990) – model cold QGP describes data well

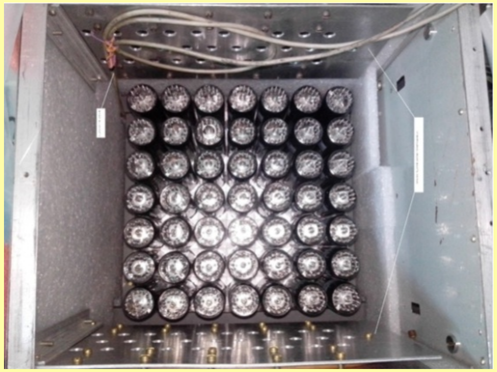
S. Barshay PL B227(1989) – excess of soft photon yield can be stipulated of BEC formation

THE SPECTROMETER WITH VERTEX DETECTOR

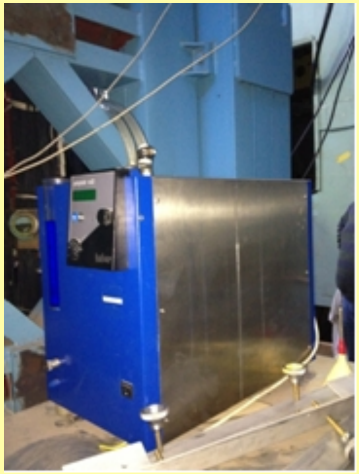
ECal of Soft Photons (SPEC)



BGO crystal

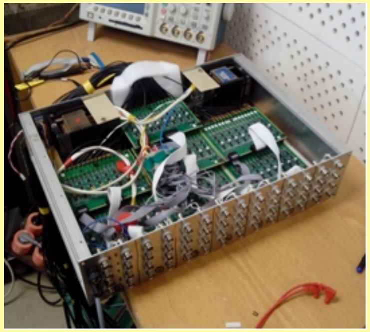


PMP butt ends assembly



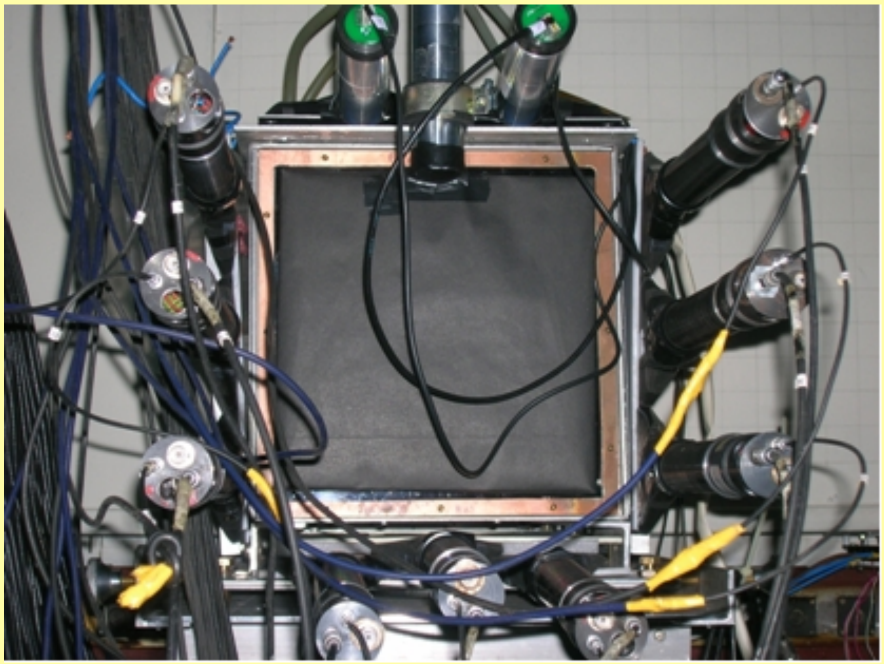
cooling system of thermo-stabilization of whole assembly)

HV power source plateau

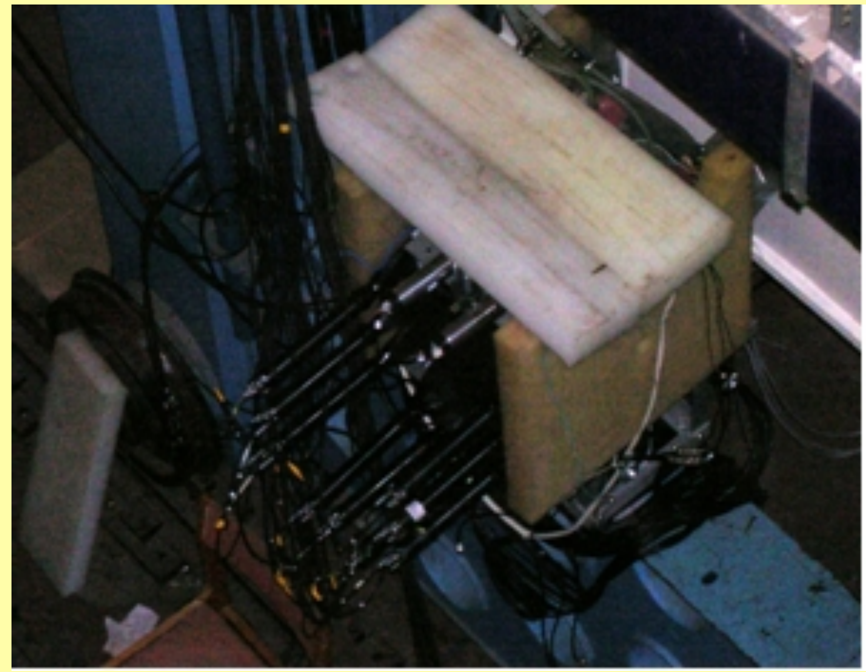


matching amplifier between ADC & preamplifier (IHEP)

ECal of Soft Photons

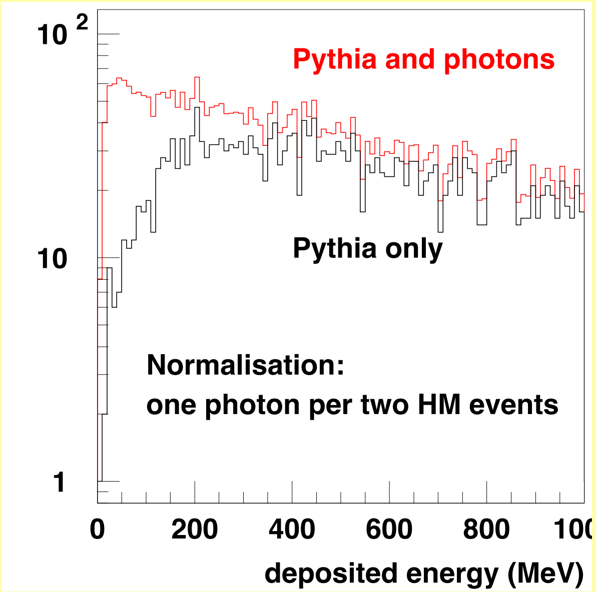


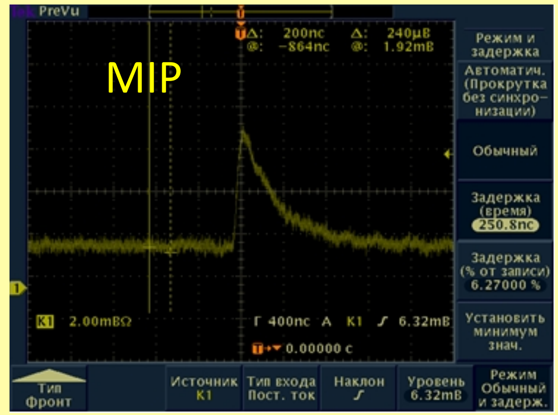
Protecting system



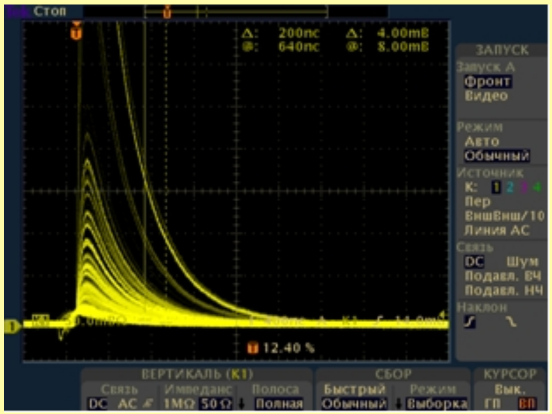
Polyethylene neutron-background protection (abatement of neutron background)

RUN 2013

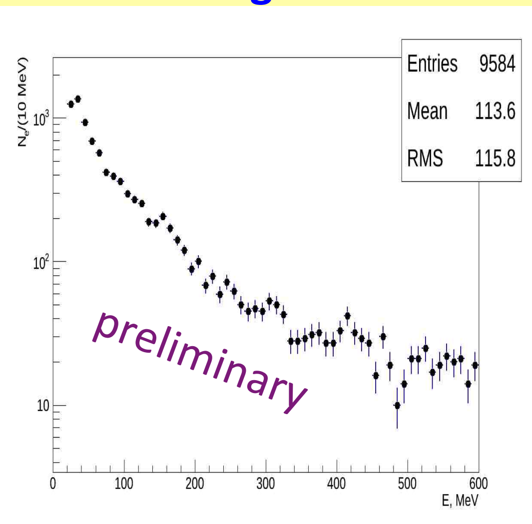




Response of SPEC on ^{137}Cs line (661.6кeV)



Beam signal



Low formula of SP spectra

$$\frac{d\sigma}{dp} = \frac{C}{E}$$

$$\sigma_{SP} = \int_{10}^{30(MeV)} \frac{d\sigma}{dp} dp \approx 4mb$$

features:

Radiation length	≈ 16
Solid angle	10 sr
dynamic range	0 .5 –10^3 MeV
noise level	< 80 keV
thermo stability	18±.1 ° C
amplifiers & HV bias	buid in
guard system	12 counters
Power consumption	13 Wt

CONCLUSIONS & OUTLOOK

1. HMR is unique and hopeful region
2. Study of total HM is fruitful
3. Collective phenomena exist in HMR
4. Active role of gluons is confirmed at HMR by GDM
5. Study of Soft Photon yield at U-70 & Nuclotron versus multiplicity