NEUTRAL PION FLUCTUATION STUDIES at U-70

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On behalf of SVD Collaboration

(JINR, IHEP, SINP MSU)

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JOINT INSTITUTE FOR NUCLEAR RESEARCH JINR

ISHEPP 2012, Dubna

Aim: Search for collective phenomena in *pp* (*pA)* collisions at U-70 accelerator, IHEP (Protvino, Russia)

$$p + p(A) \rightarrow 2N + n_{\pi}$$

Multiplicity: n_{ch}, n_0, $n_{tot} = n_{ch} + n_0$; *p* = 50GeV/c.

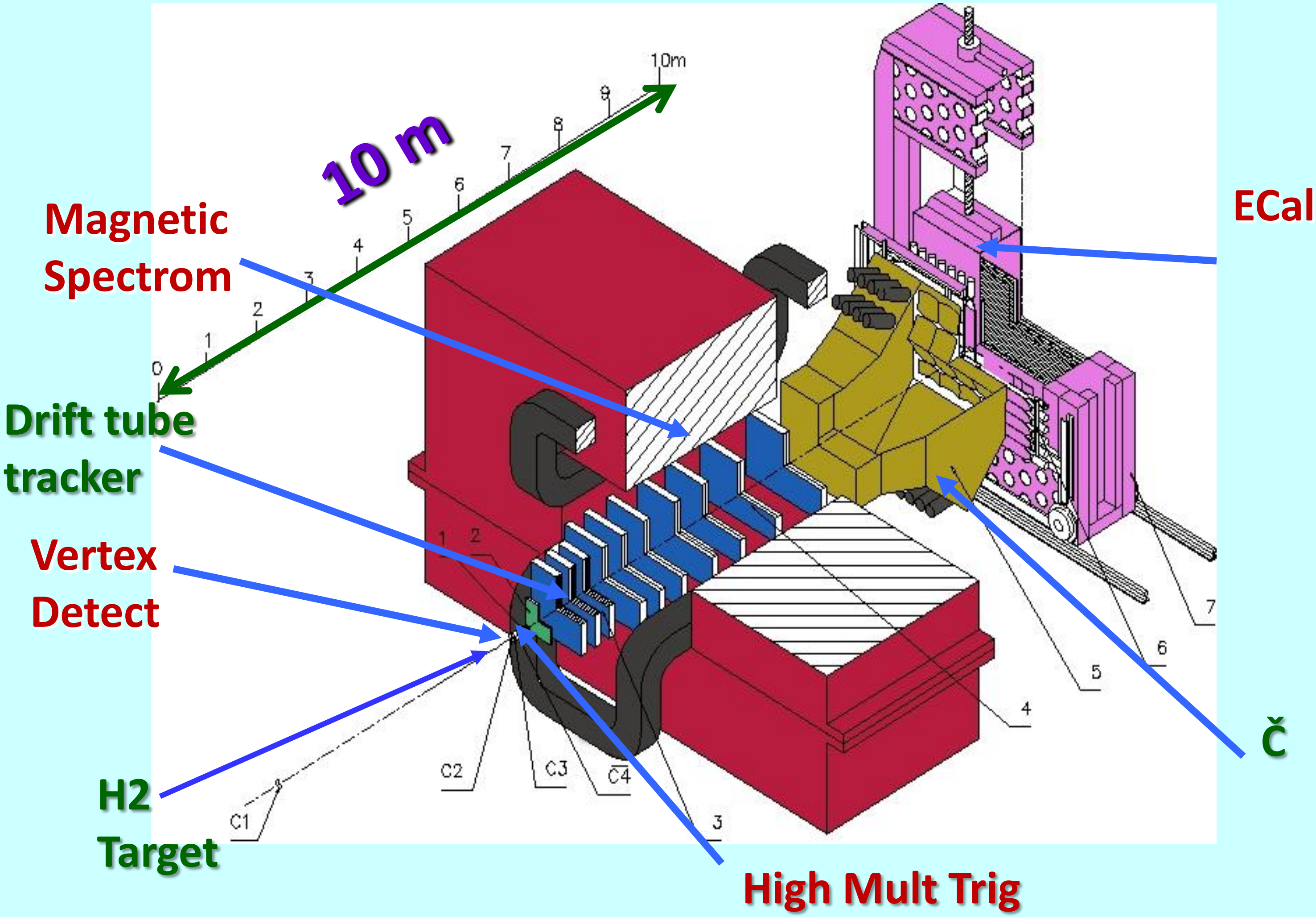
High Multiplicity (HM) region: $n >> \bar{n}.$

V.V. Avdeichikov et al., *Project "Thermalization",*
Preprint № P1-2004-190, JINR (Dubna, 2004).

SEARCH FOR COLLECTIVE PHENOMENA

- Bose-Einstein Condensation (BEC);
- Cherenkov radiation, shock waves …;
- Anomaly soft photon yield (the possible connection with BEC);
- Fluctuations, correlations, turbulence …

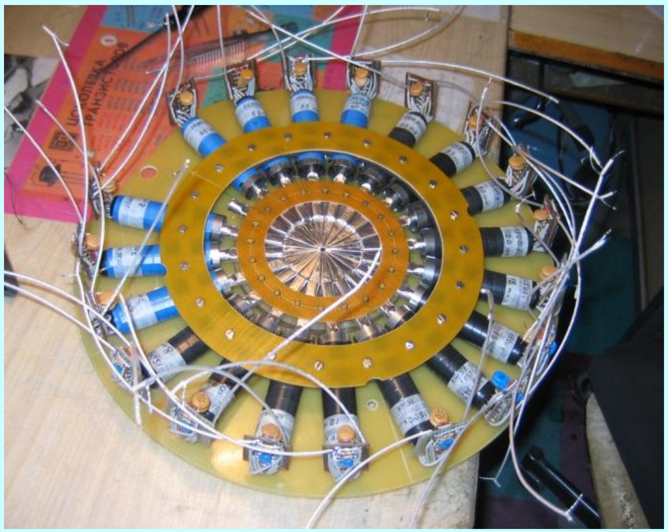
SVD-2 setup



SVD-2 (Spectrometer with Vertex Detector)

SCINTILLATOR HODOSCOPE
(HIGH MULTIPLICITY TRIGGER, HMT)

HMT suppresses low multiplicity events in 100 times!



HMT

Trigger level = n x MIP (n=8,10,12)

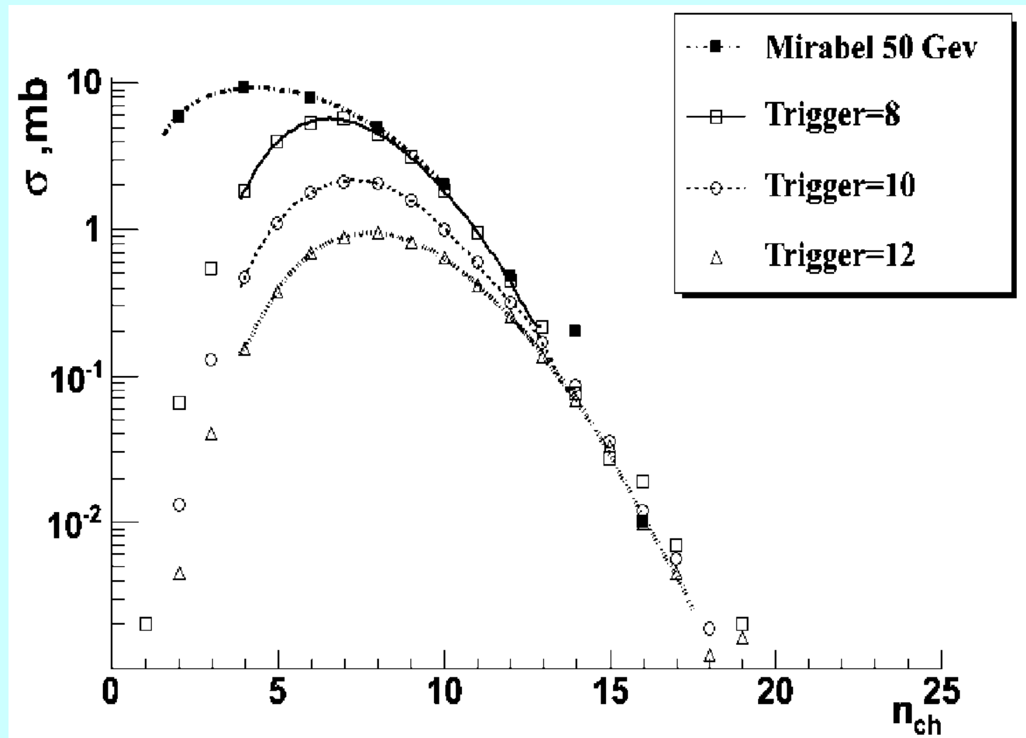


Table 1. Topological cross sections for *pp* – interactions at 50 GeV, SVD Collaboration

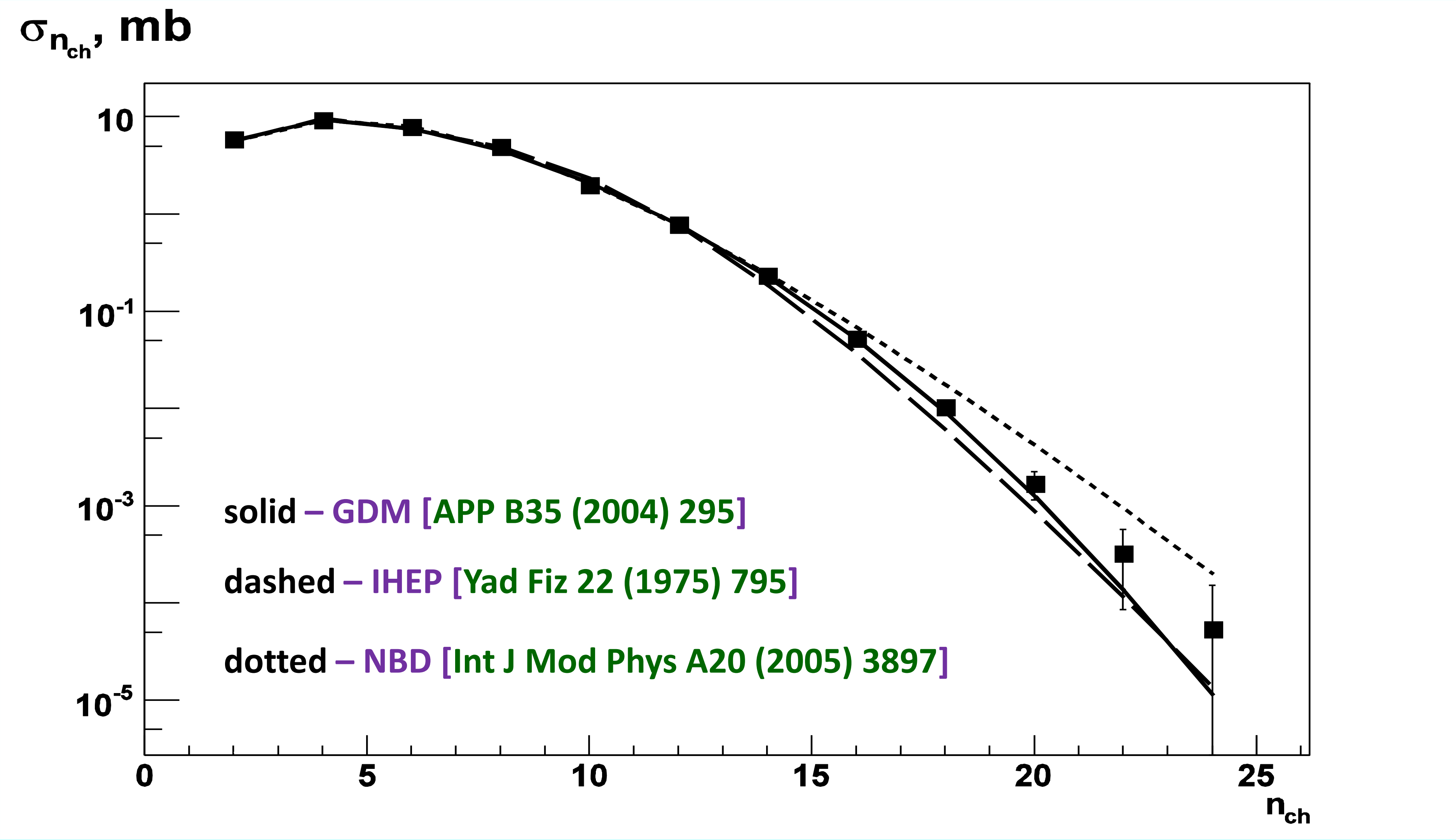
[Phys.Part.Nucl.Lett. 8 (2011) ; ЯФ,75 (2012)]

n_{ch}	10	12	14	16	18	20	22	24
σ, mb	1.685	0.789	0.234	0.0526	0.0104	0.0017	0.00033	0.000054
Δσ, mb	0.017	0.012	0.006	0.0031	0.0014	0.0006	0.00024	0.000098

Table 2. The same, Mirabelle data [PL, 42B (1972) 519].

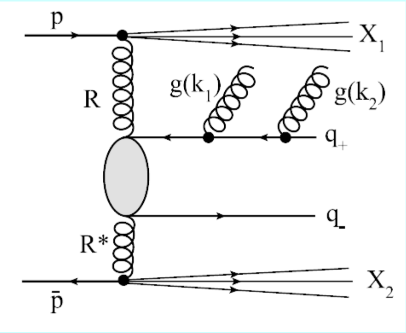
N_{ch}	2	4	6	8	10	12	14	16
σ, mb	5.97	9.40	7.99	5.02	2.03	0.48	0,20	0,01
Δσ, mb	0.88	0.47	0.43	0.33	0.20	0.10	0.06	0.02

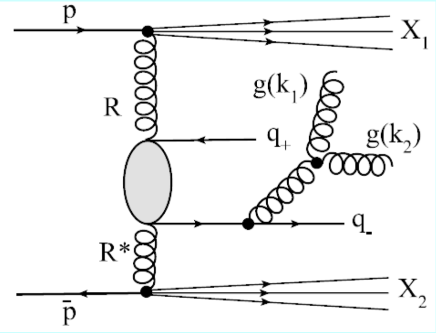
Comparison with models

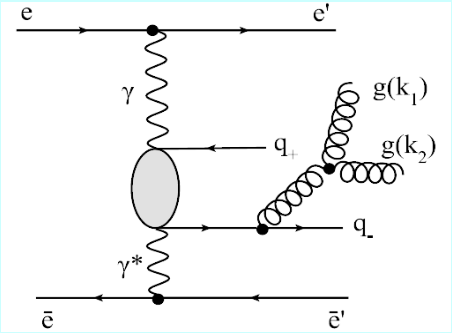


Gluon fission in pp, $p\bar{p}$ & e^+e^-

$$p(p_1) + \bar{p}(p_2) \to V(q) \to q(q_-) + \bar{q}(q_+) + g(k_1) + g(k_2)$$

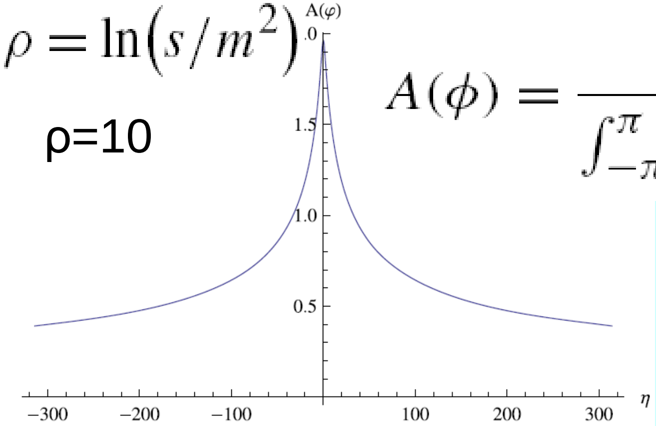






$\rho = \ln(s/m^2)$

ρ=10



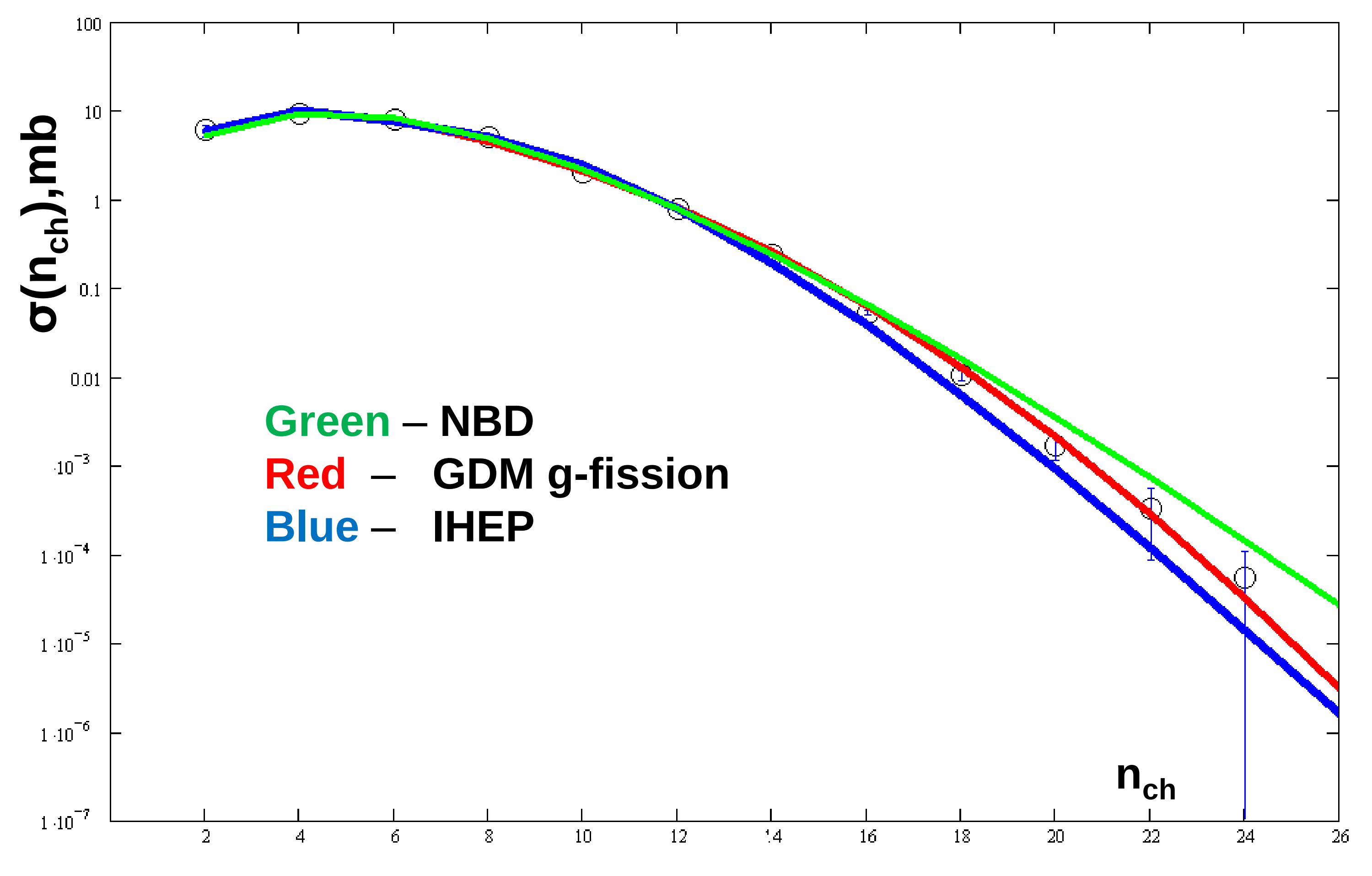
$$A(\phi) = \frac{\frac{d\sigma^{(2)}}{d\phi}}{\int_{-\pi}^{\pi} \frac{d\sigma^{(2)}}{d\phi}\, d\phi} = \frac{c_F^2 + 8 c_F c_V \pi \frac{Z(\rho,\phi)}{\rho^4}}{2\pi(c_F^2 + \frac{1}{6} c_F c_V)} = \frac{4 + 72\pi \frac{Z(\rho,\phi)}{\rho^4}}{11\pi}.$$

$$Z(\rho,\phi) = \frac{1}{4}\int_0^\rho (\rho - y)^2 \frac{1}{\sqrt{\phi^2 + e^{-y}}}\, dy$$

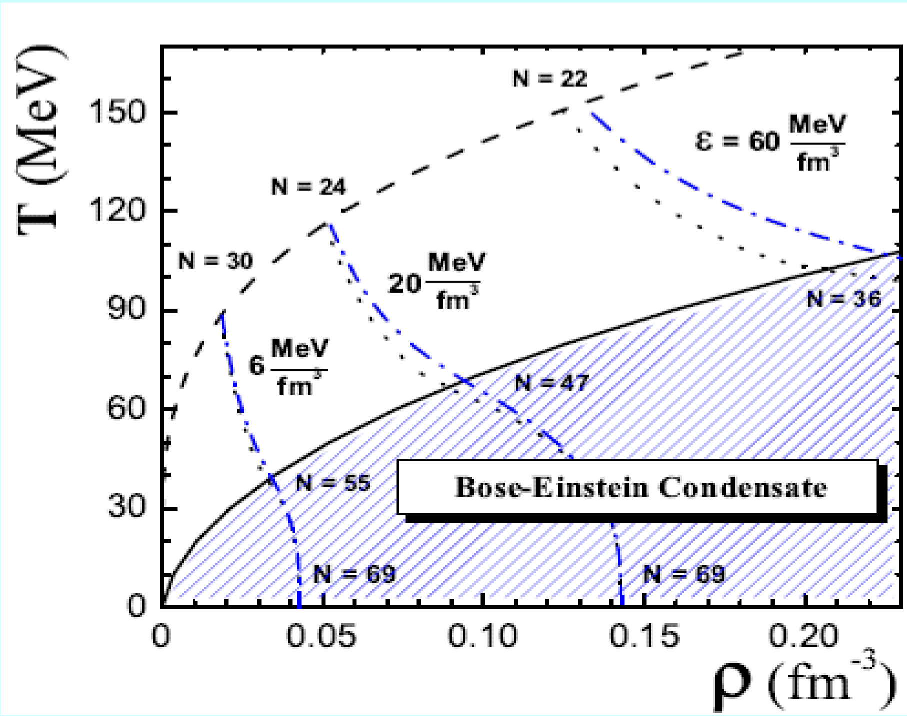
$$+ \frac{1}{|\phi|}\int_0^\rho (\rho - y)\ln\left(|\phi| e^{y/2} + \sqrt{1 + \phi^2 e^y}\right) dy + O(\rho^2).$$

[E.Kuraev, S.Bakmaev, E.K. NP B851 (2011) 551]

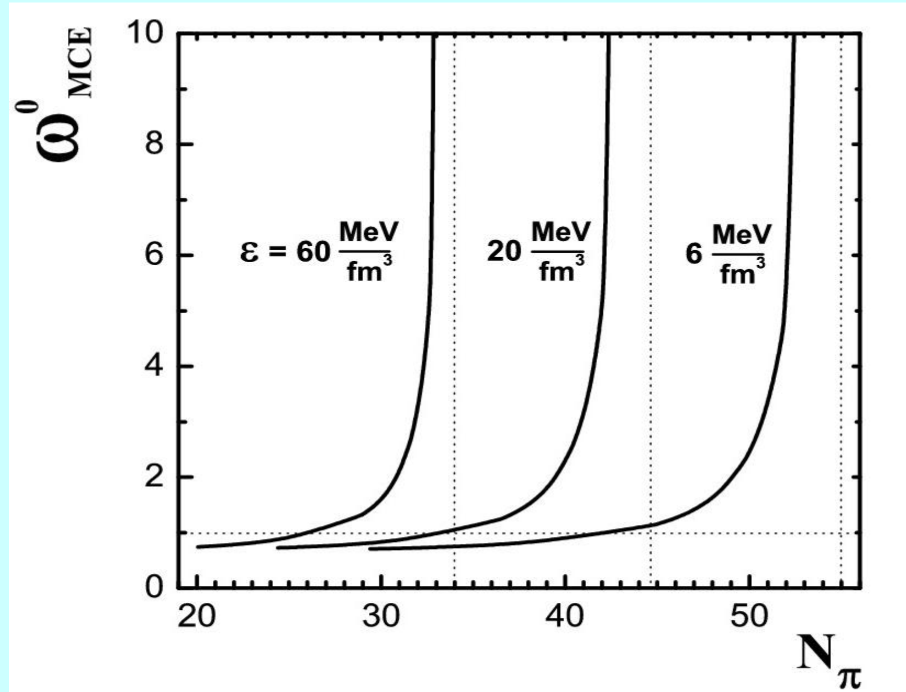
The g-fission inclusion improves essentially description of $\sigma(n_{ch})$ at the HM area



NEUTRAL PION NUMBER FLUCTUATION predictions at HM region in pp at 70 GeV/c



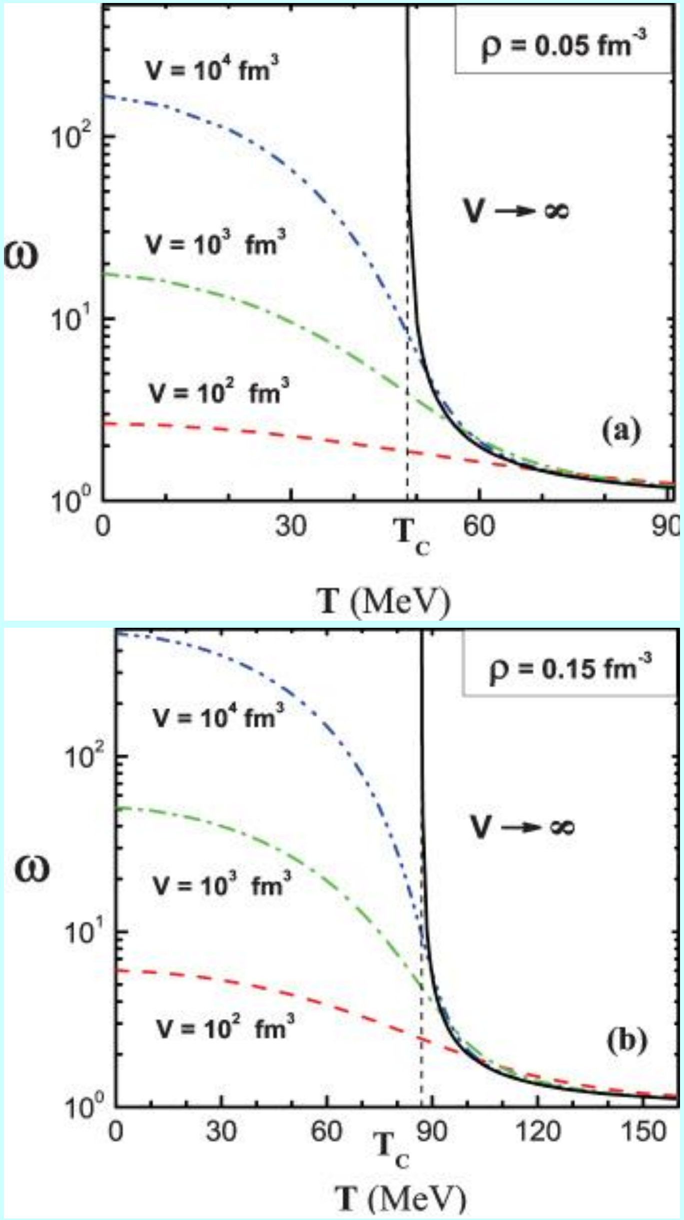
The phase diagram of the ideal pion gas. The dashed line corresponds to μ=0, the solid – BEC at $T=T_C$ (TL), the dotted lines present the trajectories in the (ρ – T) plane with fixed energy densities: ε = 6, 20 and 60 MeV/fm³ . N_π – number of pions (μ=0, T_C, T=0).



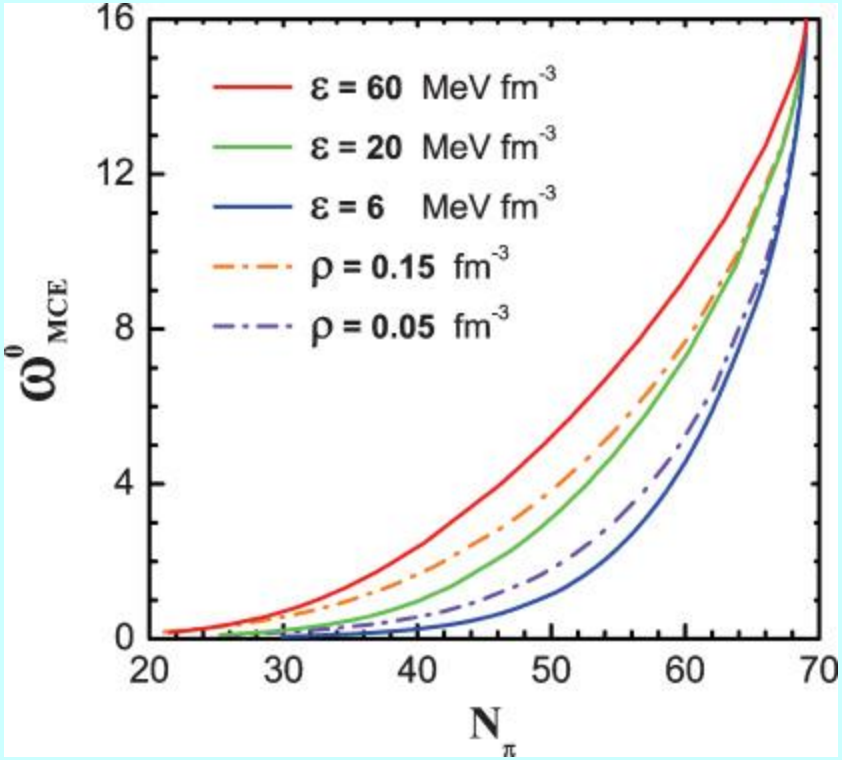
The scaled variance of neutral pions as function of the total number of pions (N_π),

$$\omega = D / < N_0 >$$

[V.V. Begun and M.I. Gorenstein, Phys. Lett. B 653, 190 (2007); Phys. Rev. C 77, 064903 (2008)]



The dashed lines show the GCE for the pion gas as a function of ω temperature T . The solid line shows the ω in the TL $V \to \infty$.

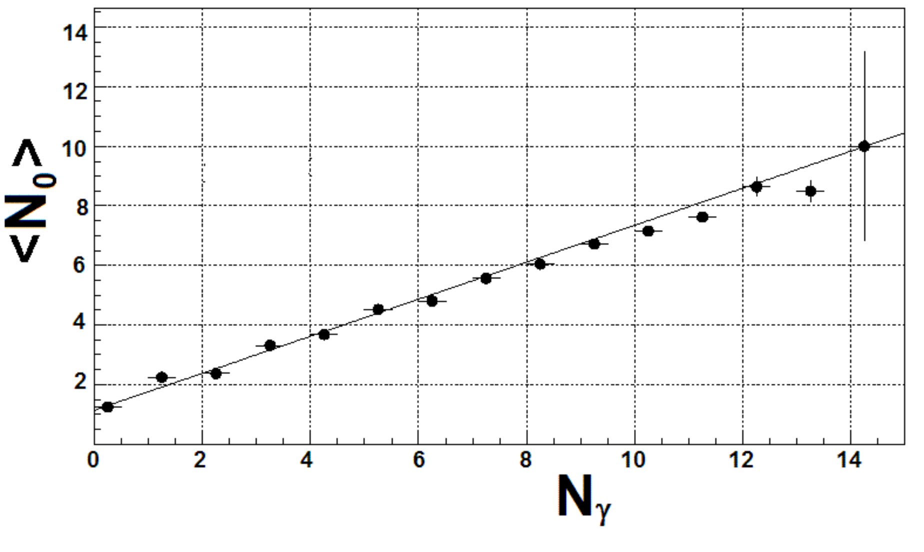


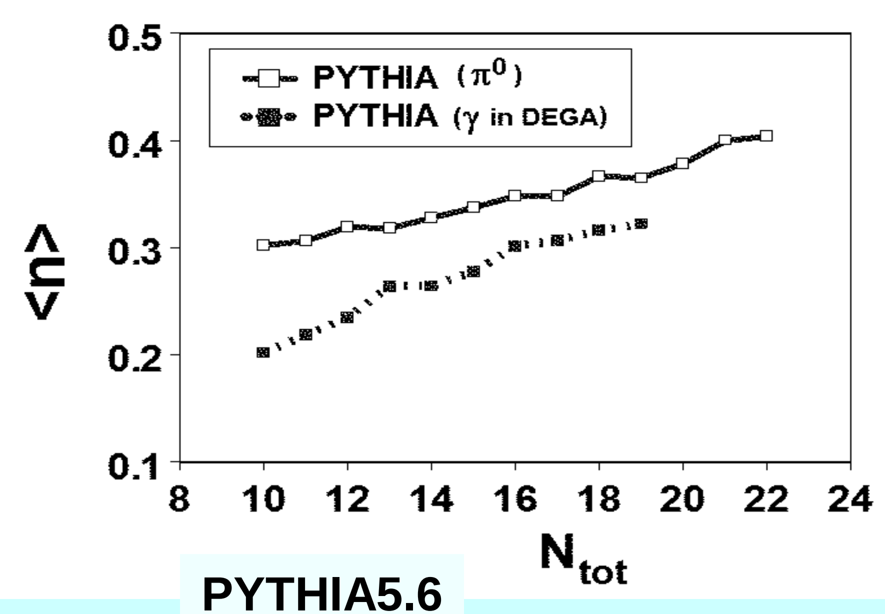
ω of neutral pions in the MCE as the function of the total number of pions N_π.

[V.V. Begun and M.I. Gorenstein, Phys. Rev. C 77, 064903 (2008)]

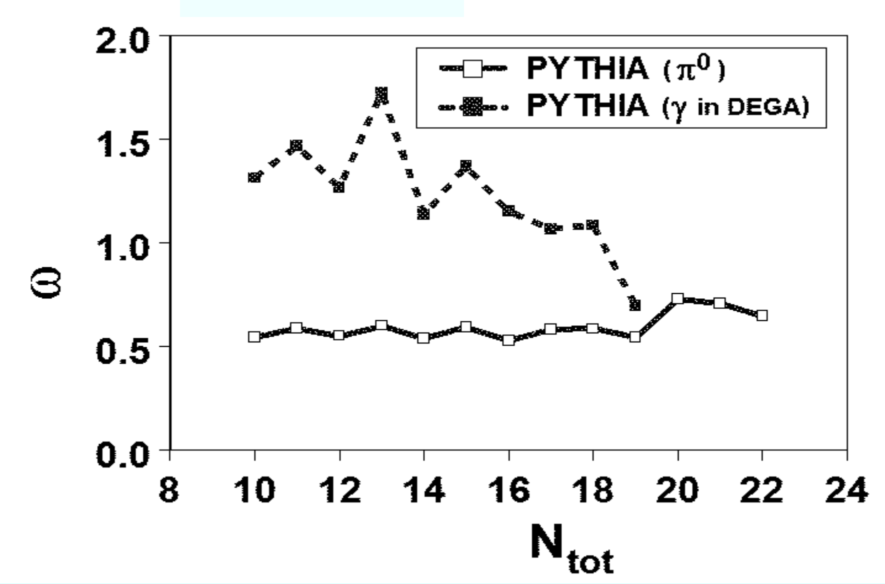
SIMULATION of NEUTRAL PION DETECTION

$$N_\gamma < 12,\ N_0 < 16$$





PYTHIA5.6



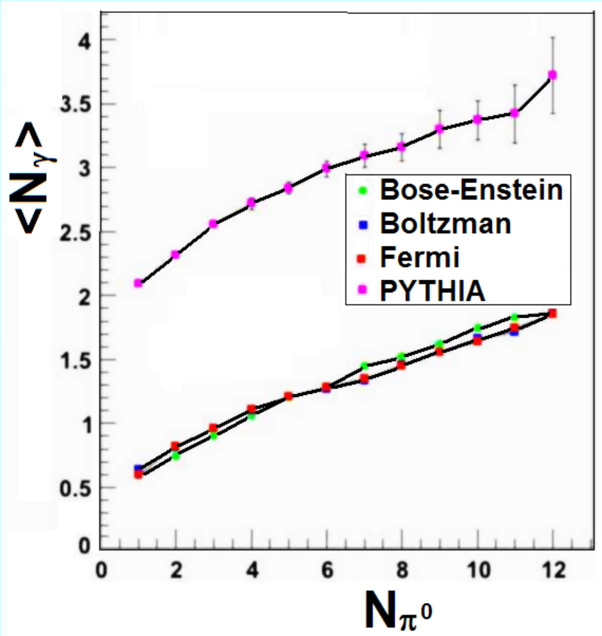
$n=N_0/N_{tot}$, $n \subset [0,1]$,

Scaled multiplicities;

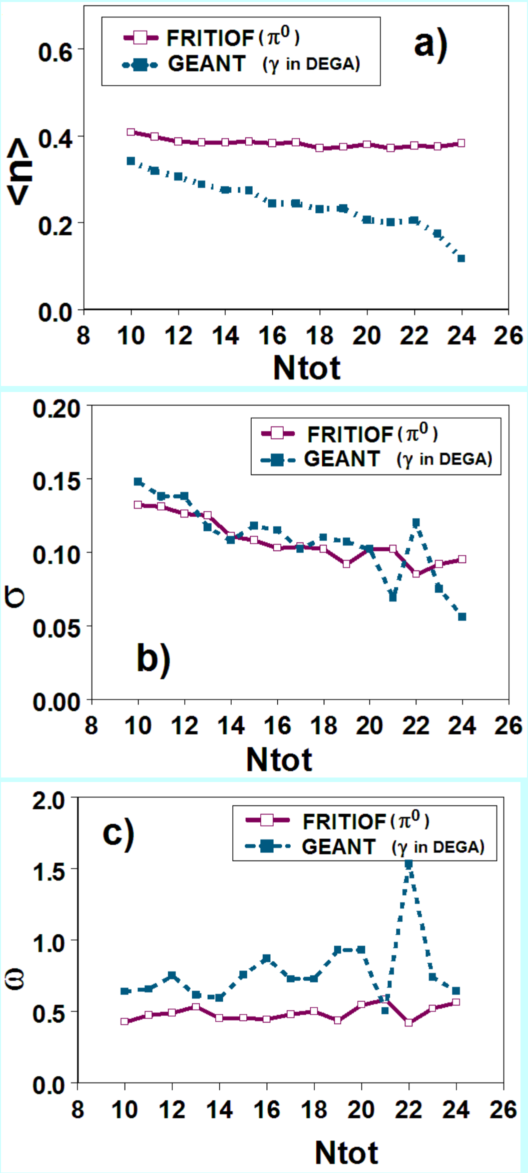
$r(N_0,N_{tot})=N_{ev}(N_0,N_{tot})/N_{ev}(N_{tot})$,

probabilities at fix n_{ch}.

There is a linear correlation between average $<N_0>$ and N_γ



Linear correlation between < N_γ > and N_0



Preliminary: 2012

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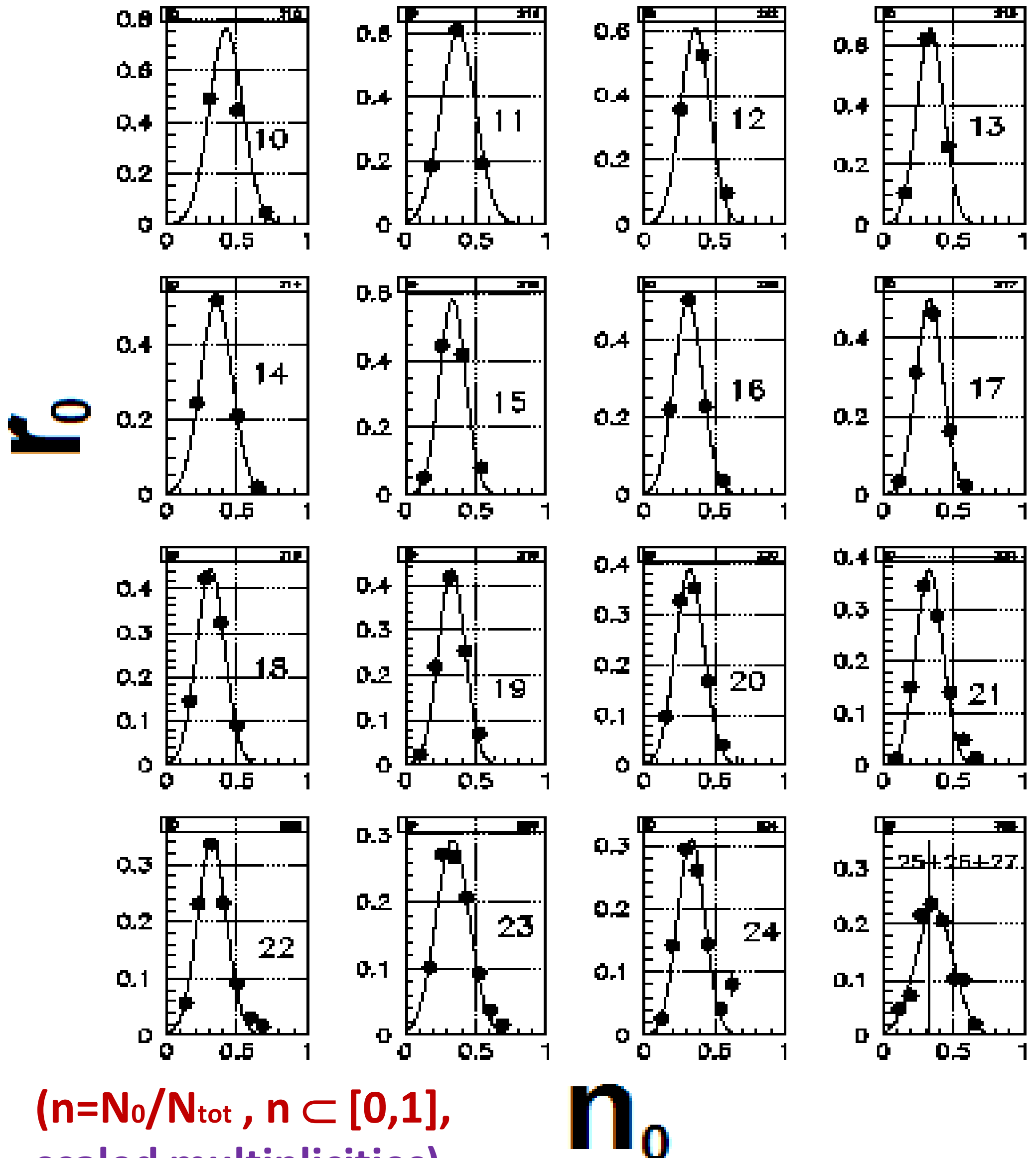
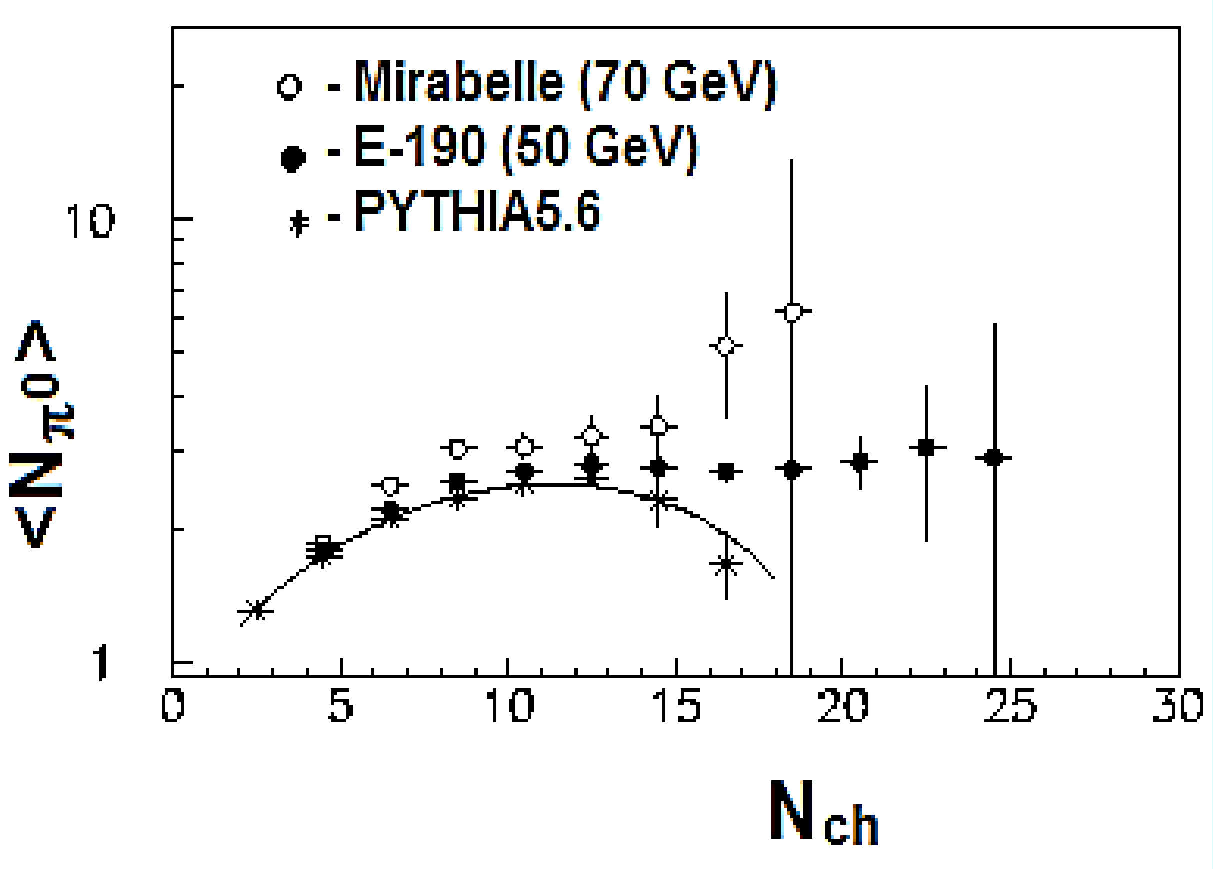


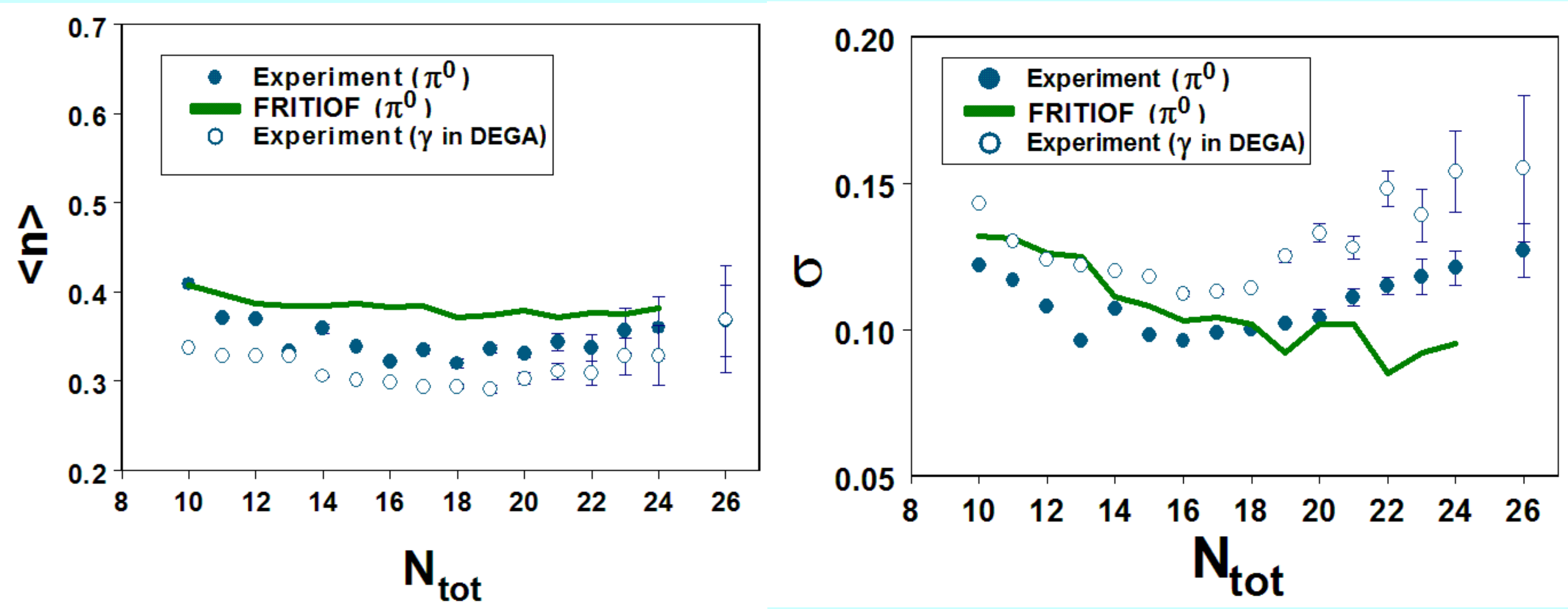
(n=N_0/N_{tot} , n ⊂ [0,1], scaled multiplicities)

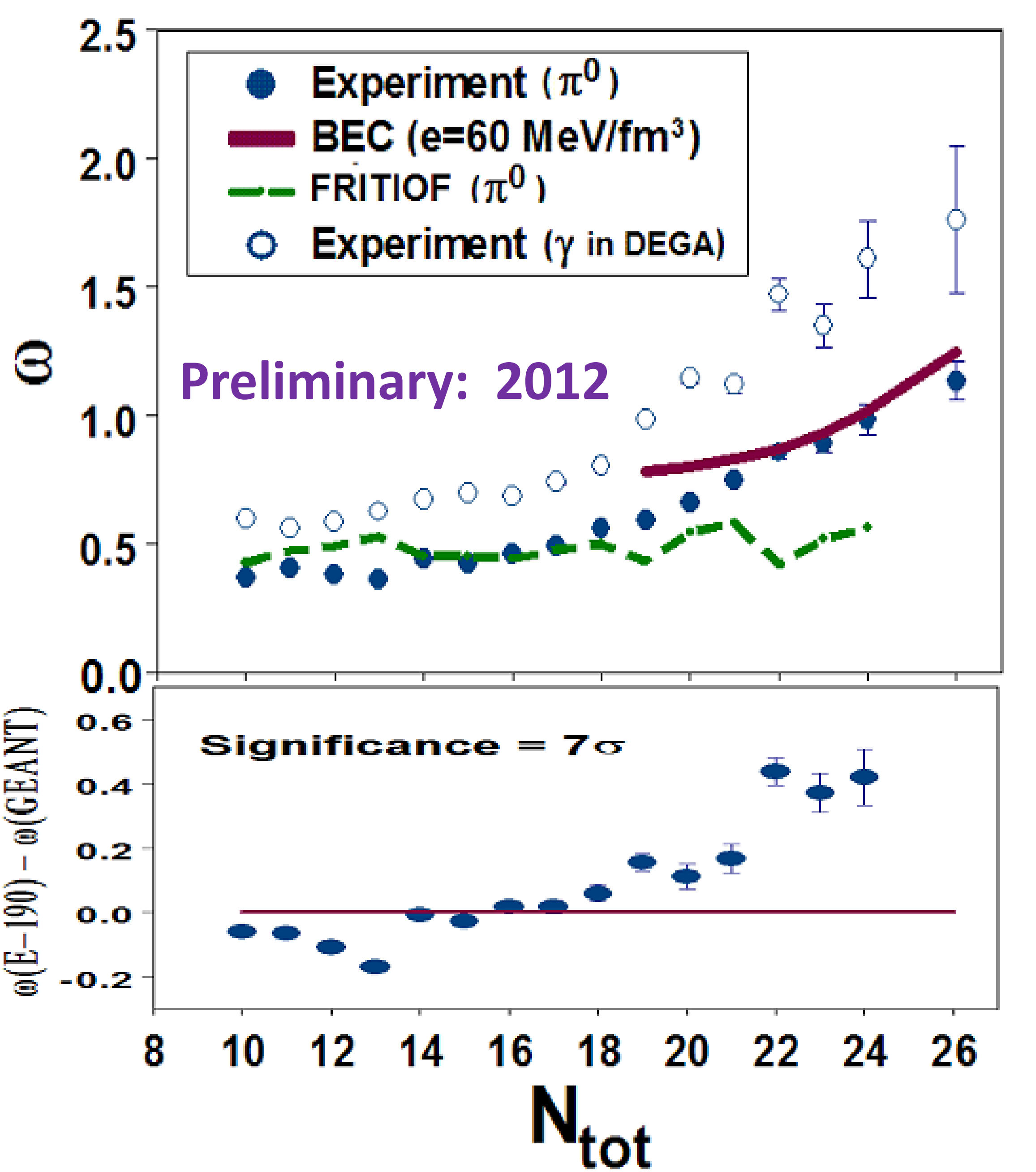
Preliminary: 2012



M.Boratov et al. Mirabelle Collab.
Nucl.Phys. 111(1976) 529.

Preliminary: 2012





2.5
2.0
1.5
1.0
0.5
0.0
ω
Experiment (π⁰)
BEC (e=60 MeV/fm³)
FRITIOF (π⁰)
Experiment (γ in DEGA)
Preliminary: 2012
0.6
0.4
0.2
0.0
-0.2
ω(E-190) – ω(GEANT)
Significance = 7σ
8
10
12
14
16
18
20
22
24
26
N_tot

BEC FORMATION CONDITIONS

Estimation of the mean energy of pion:

$$E_\pi = (E_{cms} - 2m_N - n_\pi m_\pi)/n_\pi , \qquad (1)$$

$$E_{p,\ beam} = 50\ GeV, \quad n_\pi = 30 \ \text{->} \ E_\pi = 0.12\ GeV.$$

Critical energy of condensation (Landau L.):

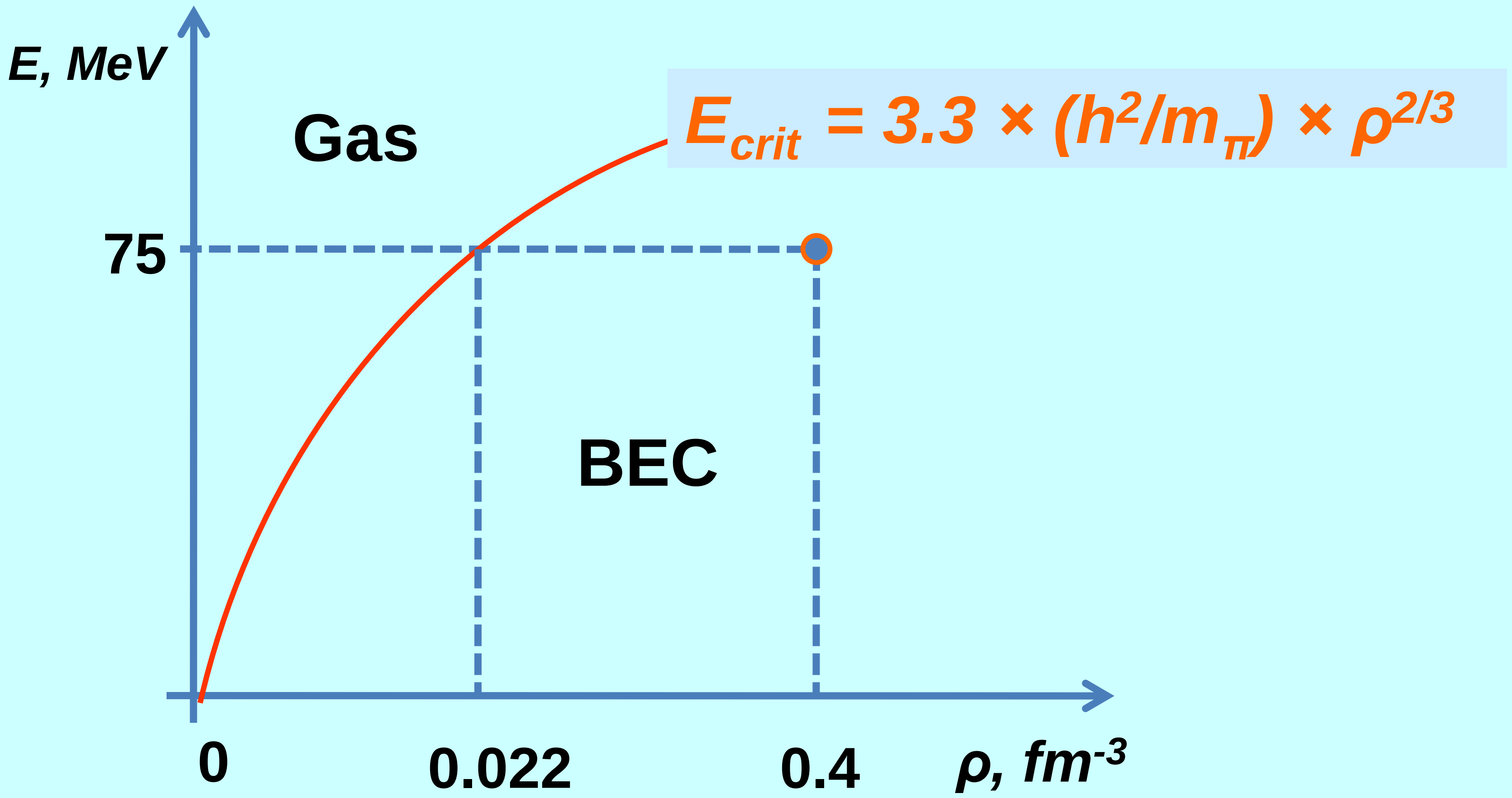
$$E_{crit} = (3,3/g^{2/3})(h^2/m_\pi)\rho^{2/3}. \qquad (2)$$

If fireball radius, r≈ 3 fm -> ρ, pion gas density:

$$\rho = 0,2\ fm^{-3}, \quad E_{crit} = 0,1\ ГэВ, \quad E_\pi \approx E_{crit}$$

The max restored π-multiplicity at 50 GeV N_{tot}=36 (N_{ch}=12&&N_0=24). BEC has chance be formed in HM region!

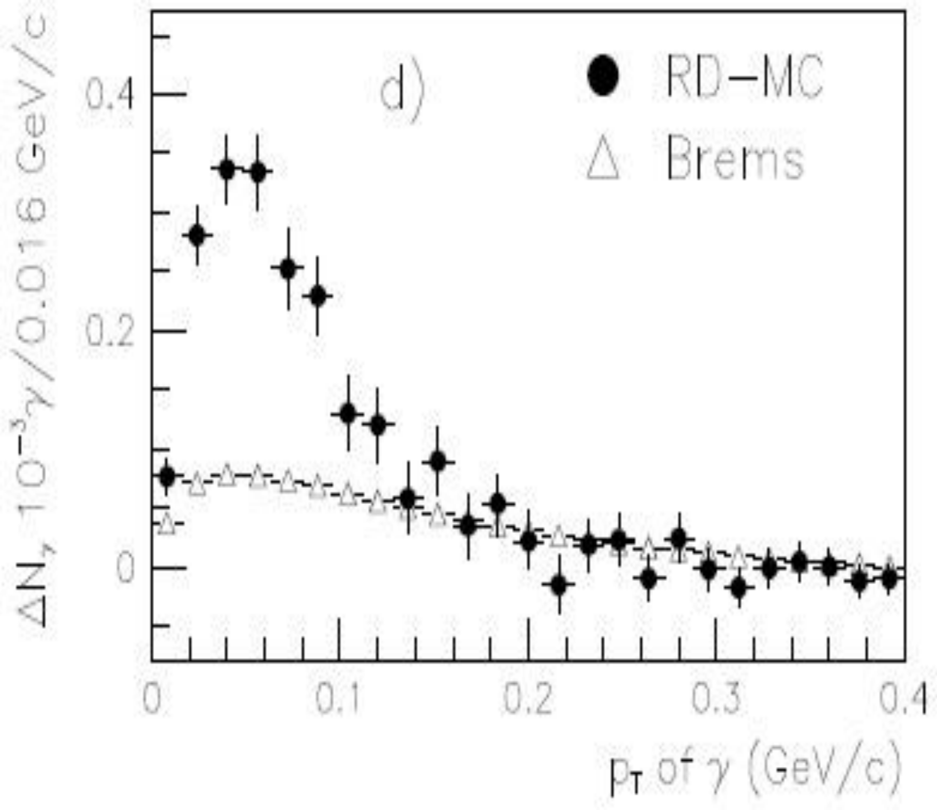
Critical energy & density of pions



CONCLUSIONS

1. The mean number of π^0 's in the event is proportional to the number of photons detected in ECal.
2. The corrections for VD acceptance, HMT action and data processing efficiency have been taken into account.
3. $r_0(n_0)$ is fitted with Gaussian and $<n_0>$, σ and $\omega = D/<N_0>$ are derived. These values are agreed with values received for PYTHIA5.6 code at $N_{tot} < 22$(FRITIOF, $N_{tot} <18$).
4. ω increases at $N_{tot} > 22(18)$, what can indicate to the BEC approaching for the HM pion system in accordance with Gorenstein and Begun predictions.
5. This effect have been observed for the first time.
6. S. Barshay: Anomaly soft photon yield is stipulated of BEC.

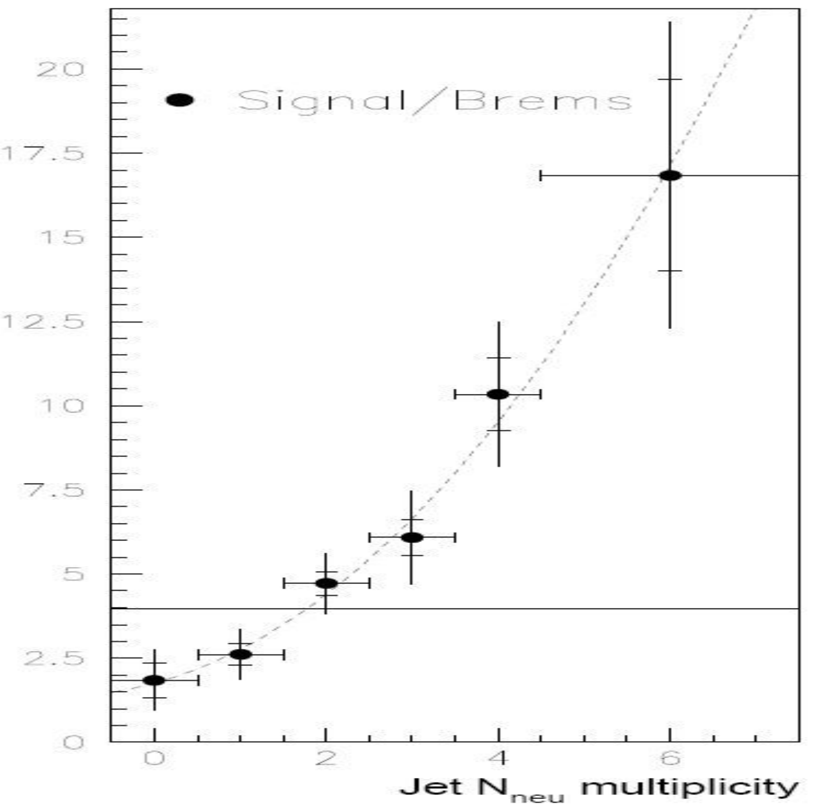
Anomaly soft photon yield



Photon spectrum in hadron jet

$e^+e^- \to Z^0 \to$ jet $\to \gamma + X$.

(RD – MC) –photon spectrum without of known particle decay contribution calculated by MC.



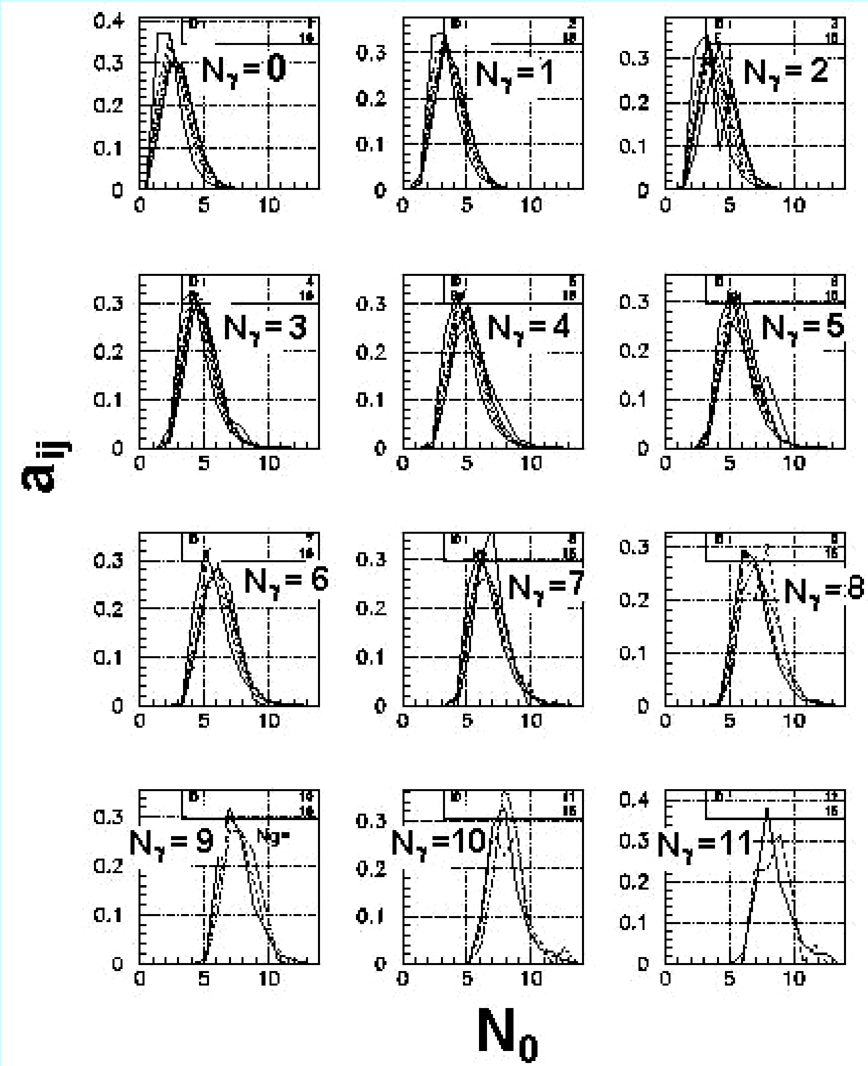
The ratio: the intensity of low energy photons to calculated value according to neutral particle number in jet.

[Eur.Phys. J. C47 (2006) 273]

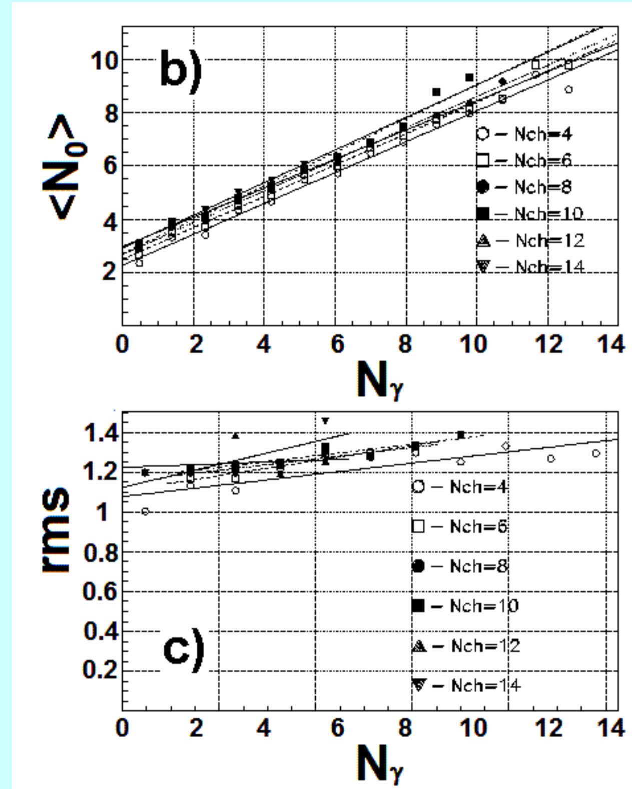
Backslides

Table 3. Experimental data: N_{ev} (N_{tot}, N_{ch}, $N\gamma$)

N_{tot}	N_{ch} = 4		6		8		10		12		14		16		18		20		22		24		ΣN_{ev}
	Nγ	Nev	Nγ	Nev	Nγ	Nev	Nγ	Nev	Nγ	Nev	Nγ	Nev	Nγ	Nev	Nγ	Nev	Nγ	Nev	Nγ	Nev	Nγ	Nev	
4	**0**	233164																					233164
5	**1**	422592																					422592
6	**2**	459512	**0**	193631																			653143
7	**3**	360538	**1**	356215																			716753
8	**4**	235720	**2**	387419	**0**	117924																	741063
9	**5**	131634	**3**	310509	**1**	220895																	663038
10	**6**	63900	**4**	203024	**2**	240271	**0**	46371															553565
11	**7**	29252	**5**	113479	**3**	195037	**1**	88136															425903
12	**8**	13348	**6**	56553	**4**	127779	**2**	95925	**0**	14598													308202
13	**9**	4970	**7**	25997	**5**	72079	**3**	77174	**1**	27805													208026
14	**10**	2840	**8**	11869	**6**	36898	**4**	50832	**2**	30726	**0**	3366											136530
15	**11**	1420	**9**	4932	**7**	17125	**5**	29301	**3**	24553	**1**	6468											83800
16	**12**	710	**10**	2555	**8**	7767	**6**	15237	**4**	16371	**2**	7170	**0**	639									50449
17	**13**	426	**11**	1218	**9**	3635	**7**	7224	**5**	9537	**3**	5724	**1**	1227									28991
18	**14**	284	**12**	629	**10**	1718	**8**	3268	**6**	4997	**4**	3904	**2**	1377	**0**	110							16287
19	**15**	142	**13**	334	**11**	781.0	**9**	1681	**7**	2438	**5**	2249	**3**	1081	**1**	206							8912
20	**16**	142	**14**	196	**12**	440	**10**	758	**8**	1186	**6**	1200	**4**	772	**2**	240	**0**	13.3					4948
21	**17**	56.8	**15**	138	**13**	206	**11**	351	**9**	609	**7**	595	**5**	437	**3**	182	**1**	27.2					2601
22	**18**	0.0	**16**	78.6	**14**	121	**12**	189	**10**	259	**8**	302	**6**	247	**4**	130	**2**	34.4	**0**	1.8			1362
23	**19**	28.4	**17**	39.3	**15**	95.8	**13**	105	**11**	141	**9**	160	**7**	120	**5**	76.3	**3**	26.0	**1**	4.0			796
24	**20**	0.0	**18**	19.6	**16**	59.6	**14**	49.1	**12**	75.9	**10**	80.0	**8**	69.3	**6**	45.8	**4**	18.1	**2**	4.7	**0**	0.3	422
25	**21**	0.0	**19**	15.7	**17**	29.8	**15**	49.1	**13**	40.3	**11**	39.0	**9**	38.8	**7**	20.7	**5**	11.5	**3**	3.7	**1**	0.7	249
26	**22**	28.4	**20**	0.0	**18**	25.6	**16**	28.1	**14**	18.6	**12**	22.0	**10**	19.7	**8**	13.1	**6**	7.2	**4**	2.4	**2**	0.8	166
27			**21**	0.0	**19**	6.4	**17**	13.3	**15**	20.1	**13**	9.0	**11**	9.6	**9**	7.8	**7**	3.1	**5**	1.7	**3**	0.4	71.6
28			**22**	15.7	**20**	4.3	**18**	10.2	**16**	8.1	**14**	5.5	**12**	6.0	**10**	3.8	**8**	2.5	**6**	0.9	**4**	0.4	57.4
29					**21**	1.4	**19**	2.5	**17**	1.9	**15**	4.7	**13**	1.5	**11**	2.6	**9**	1.9	**7**	0.4	**5**	0.2	17.1
30					**22**	6.4	**20**	6.3	**18**	2.2	**16**	1.3	**14**	0.7	**12**	1.4	**10**	1.3	**8**	0.5	**6**	0.3	20.3
31					**23**	0.0	**21**	1.8	**19**	0.8	**17**	0.7	**15**	1.2	**13**	0.4	**11**	0.4	**9**	0.2	**7**	0.1	5.6
32					**24**	1.4	**22**	2.5	**20**	4.0	**18**	0.3	**16**	0.1	**14**	0.1	**12**	0.5	**10**	0.2	**8**	0.1	9.1
33							**23**	0.0	**21**	0.3	**19**	1.0	**17**	0.2	**15**	0.2	**13**	0.1	**11**	0.0	**9**	0.3	1.8
34							**24**	1.8	**22**	0.3	**20**	0.8	**18**	0.0					**12**	0.1	**10**	0.7	3.0
35									**23**	0.0			**19**	0.3									0.3
36									**24**	0.3			**20**	0.1									0.4
ΣN_{ev}		1960707		1668866		1042908		416717		133393		31302		6048		1040		147		20.6		3.3	

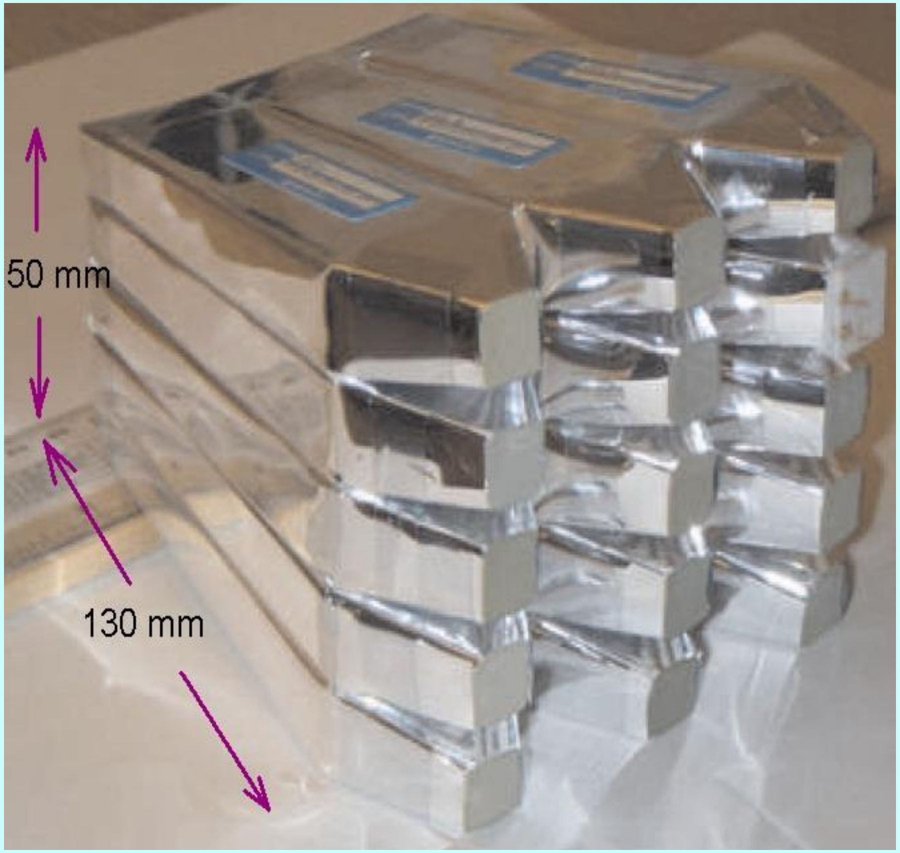


The dependence of $\mathbf{a_{ij}}$ factors on $\mathbf{N_0}$ for various $\mathbf{N_\gamma}$ and $\mathbf{N_{ch}}$

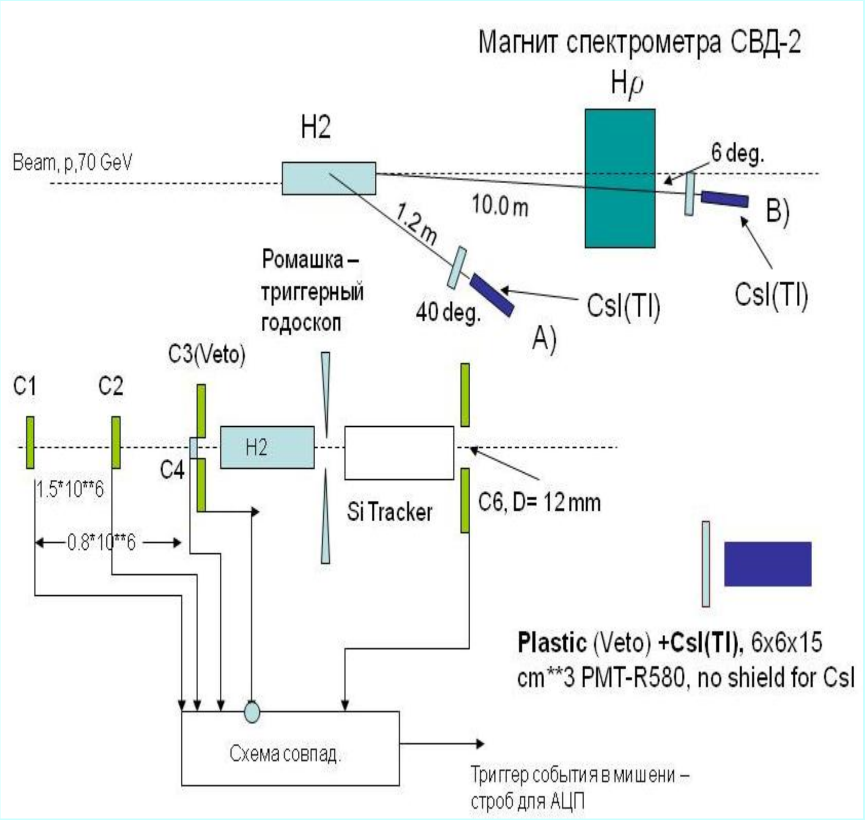


<N_0> and standard deviation **(rms)** as function of $\mathbf{N_\gamma}$ for various $\mathbf{N_{ch}}$.

Test of EMCal



Prototype of soft photon ECal on CsI(Tl) crystals.

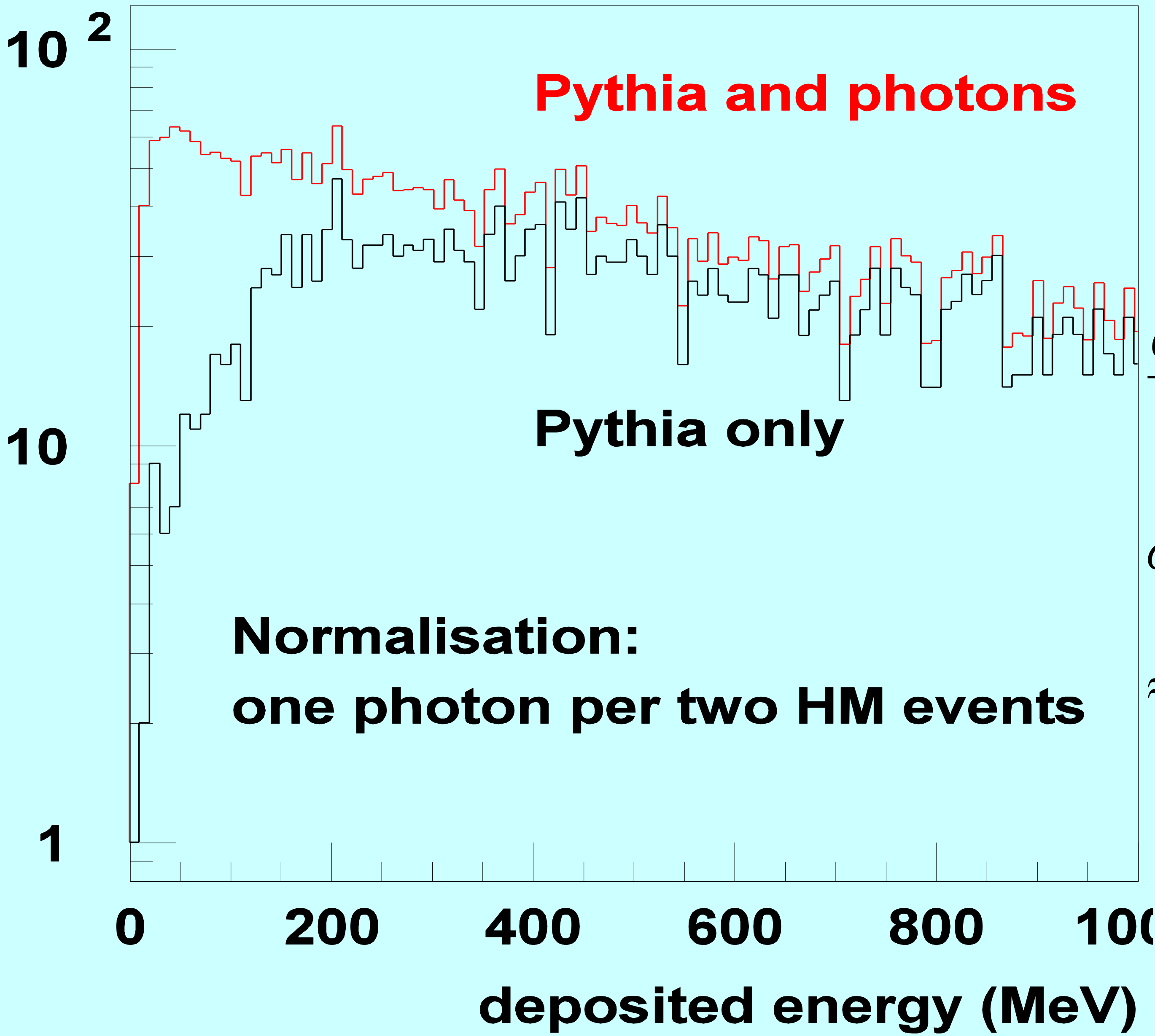


Disposition scheme of counter CsI(Tl) on its test at SVD-2.

Results of ECal prototype tests:

1. **We have obtained:** the dependence of the angle of emission in c.m.s. from the angle in lab.s.; dependence momentum in lab s. from the angle in lab.s.;
2. **Conclusion:** background loading is high. It is necessary to manufacture calorimeter with passive and active protection (anti-coincidence counter environment).
3. **Barshay S.:** Connection with BEC.

ECal simulation



Anomaly photon spectrum described by Low formula:

$$\frac{d\sigma}{dp} = \frac{C}{p};$$

$$\sigma_{SP} = \int_{10}^{30MeV/c} \frac{d\sigma}{dp} dp =$$

$$\approx 4\, mb.$$