Рождение низкоэнергетических прямых фотонов в адронных взаимодействиях.

(Обзор и предложение эксперимента)

Никитин В.А. ОИЯИ.

Production of low energy direct γ in hadron interact.

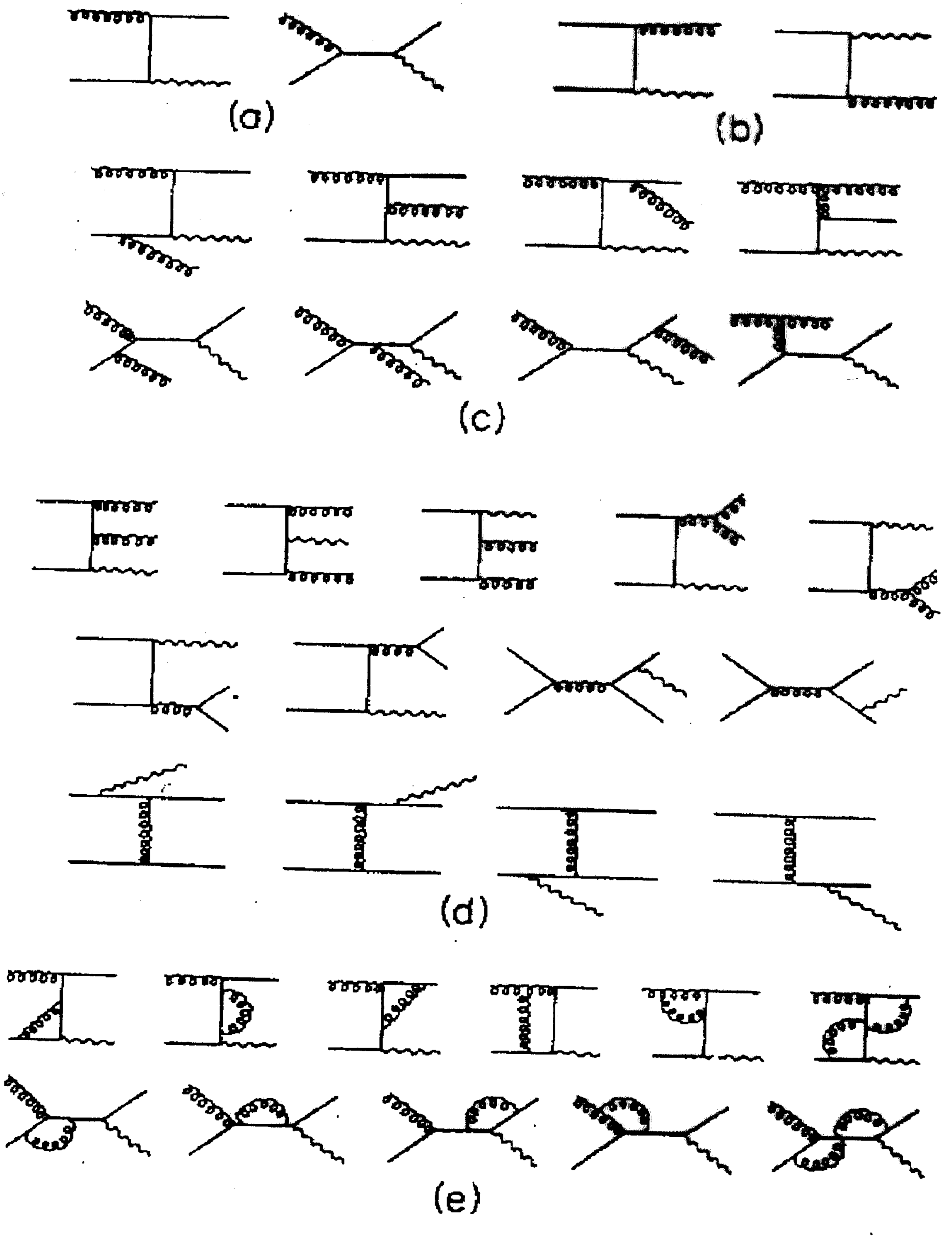


FIG. 2. Selection of Feynman diagrams for direct-photon production: (a) $O(\alpha\alpha_s)$ Compton subprocess; (b) $O(\alpha\alpha_s)$ annihilation subprocess; (c) $O(\alpha\alpha_s^2)$ subprocess $gq \rightarrow \gamma qg$; (d) $O(\alpha\alpha_s^2)$ subprocess $q\overline{q} \rightarrow \gamma gg$; (e) one-loop graphs for the Compton subprocess that contribute to the $O(\alpha\alpha_s^2)$ calculation.

$qq' \to qq'$	$\frac{4}{9}\frac{s^2+u^2}{t^2}$
$qq \to qq$	$\frac{4}{9}\left[\frac{s^2+u^2}{t^2}+\frac{s^2+t^2}{u^2}\right]-\frac{8}{27}\frac{s^2}{tu}$
$q\bar{q} \to q'\bar{q}'$	$\frac{4}{9}\frac{t^2+u^2}{s^2}$
$q\bar{q} \to q\bar{q}$	$\frac{4}{9}\left[\frac{s^2+u^2}{t^2}+\frac{u^2+t^2}{s^2}\right]-\frac{8}{27}\frac{u^2}{st}$
$gq \to gq$	$-\frac{4}{9}\left[\frac{s}{u}+\frac{u}{s}\right]+\frac{s^2+u^2}{t^2}$
$q\bar{q} \to gg$	$\frac{32}{27}\left[\frac{t}{u}+\frac{u}{t}\right]-\frac{8}{3}\frac{t^2+u^2}{s^2}$
$gg \to q\bar{q}$	$\frac{1}{6}\left[\frac{t}{u}+\frac{u}{t}\right]-\frac{3}{8}\frac{t^2+u^2}{s^2}$
$gg \to gg$	$\frac{9}{2}\left[3-\frac{tu}{s^2}-\frac{su}{t^2}-\frac{st}{u^2}\right]$
$gq \to \gamma q$	$-\frac{e_q^2}{3}\left[\frac{u}{s}+\frac{s}{u}\right]$
$q\bar{q} \to \gamma g$	$\frac{8}{9}e_q^2\left[\frac{u}{t}+\frac{t}{u}\right]$

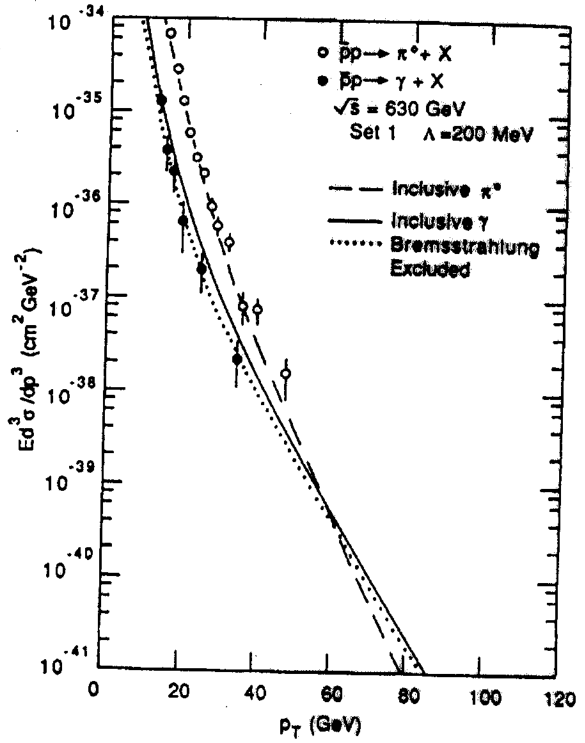


FIG. 18. Comparison between the leading-logarithm predictions discussed in the text and data for both direct-photon and π^0 production at $\eta = 1.4$ from Appel *et al.* (1986).

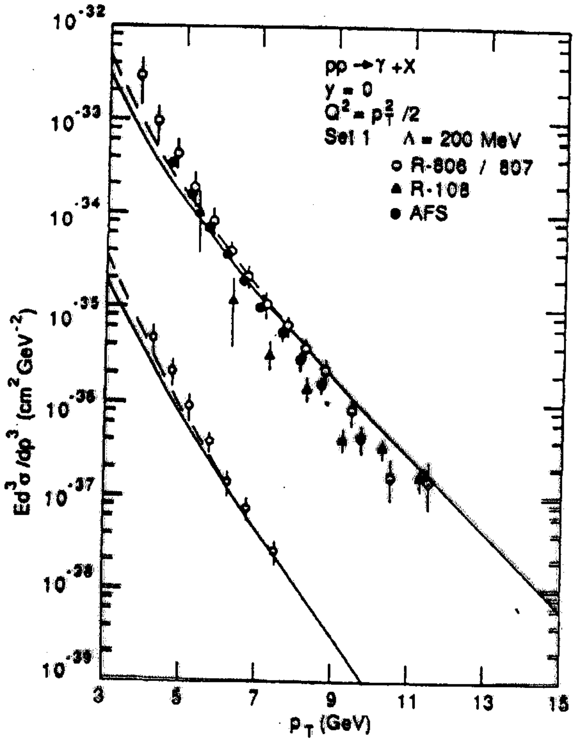
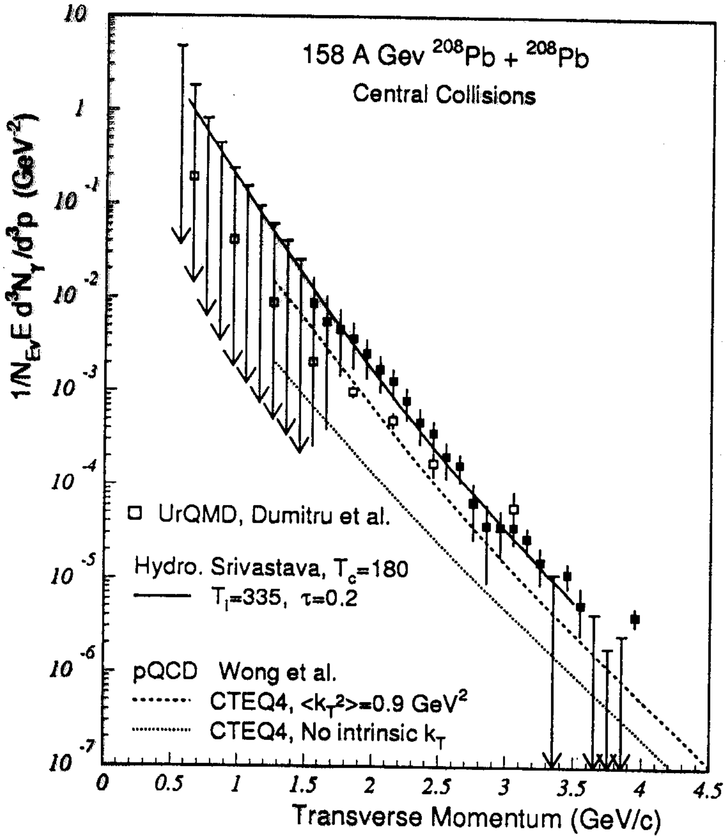


FIG. 19. Comparison between inclusive direct-photon-production data and the leading-logarithm predictions discussed in the text; ⊖ at 62 GeV, Anassontzis *et al.*, 1982; ○ at 45 GeV, Burkert, 1983; △, Angelis *et al.*, 1980; ●, Åkesson *et al.*, 1985.

GeV up to Tevatron energies ($\sqrt{s}$ = 1.8 TeV) [37]. On the other hand, these same calculations which provide a good description at high incident energy, underpredict prompt photon production at $\sqrt{s}$ = 19.4 GeV. For the results shown in Fig. 32 the E704 and NA3 results are underpredicted by about a factor of two, while the E629 result is underpredicted by about a factor of five [37]..



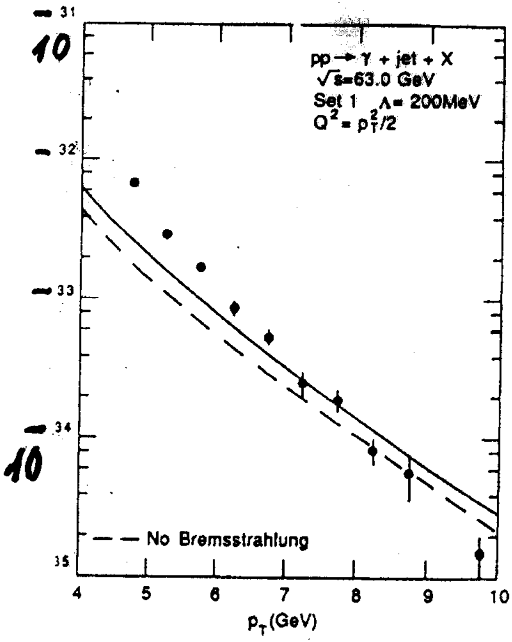
WA 98
Pb + Pb
158 A GeV

FIG. 33. The invariant direct photon multiplicity for central collisions of 158·A GeV ^{208}Pb+^{208}Pb compared to various predictions discussed in the text. The error bars indicate the combined statistical and systematical errors. Data points with downward arrows indicate unbounded 90% CL upper limits.

It has been proposed [36] that the intrinsic transverse momentum of the partons, as a consequence of confinement within the hadron, or of soft gluon radiation, may significantly increase the theoretical prompt photon predictions at low incident energies, or low transverse momenta. The effect of intrinsic k_T is normally neglected in state of the art perturbative QCD calculations due to the formidable technical difficulty to perform the integration over transverse degrees of freedom in the NLO calculations. Nevertheless, there has been a renewed interest to investigate intrinsic k_T effects in prompt photon production [98,99,33] largely motivated by recent high precision prompt photon measurements of FNAL experiment E706 [32], although the necessity for such intrinsic k_T effects remains a topic of debate [39].

Recently, Wong and Wang [98] have investigated the effects of parton intrinsic k_T on photon production under the assumption that the NLO corrections are independent of intrinsic k_T. Correction factors, or K-factors, were determined as a function of photon transverse momentum as the ratio of the NLO+LO calculation result to the leading-order (LO) result, without intrinsic k_T. The LO calculations were reevaluated with the inclusion of parton intrinsic k_T assumed to be characterized by a Gaussian distribution with $\langle k_T^2 \rangle = 4\,\langle k_T \rangle / \pi$, where $\langle k_T \rangle$ is the average intrinsic k_T of a parton. The K-factors determined without intrinsic k_T were then applied to the LO result with intrinsic k_T included to obtain the final prompt photon prediction.

With this prescription the E704 and NA3 results shown in Fig. 32 were well described with a parton intrinsic k_T of $\langle k_T^2 \rangle = 0.9$ (GeV/c)^2 [98]. The importance of the intrinsic k_T effect decreases with increasing $\sqrt{s}$ and increasing photon p_T such that the prompt photon data at higher $\sqrt{s}$ are equally well described with or without intrinsic k_T.



omparison between the theoretical predictions dis-
e text and data for γ-jet p_T distribution from the
ration (Åkesson *et al.*, 1985).

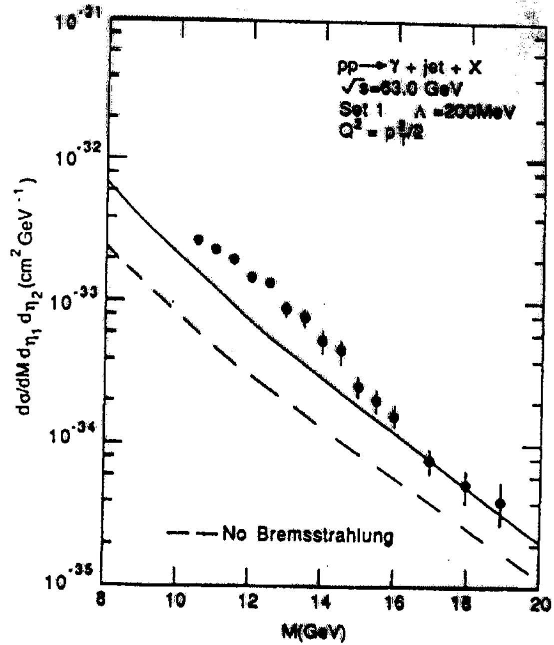
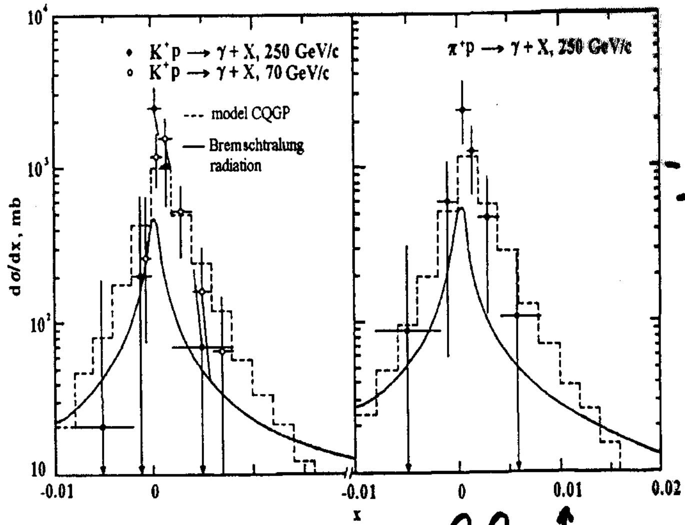


FIG. 30. Comparison between the theoretical predictions discussed in the text and data for γ-jet mass distribution from the AFS Collaboration (Åkesson *et al.*, 1985).

$\frac{d\sigma}{dx}$



-10^3 мб

$\int_{-0{,}005}^{+0{,}005} dx \frac{d\sigma_\gamma}{dx} \simeq 4$ мб.

x

0.0 ← $x = 0{,}01$

Fig. 14a. Low energy photon spectrum. Photons from decay of known particles are excluded. (P.V.Shliapnikov et al., 1984.)

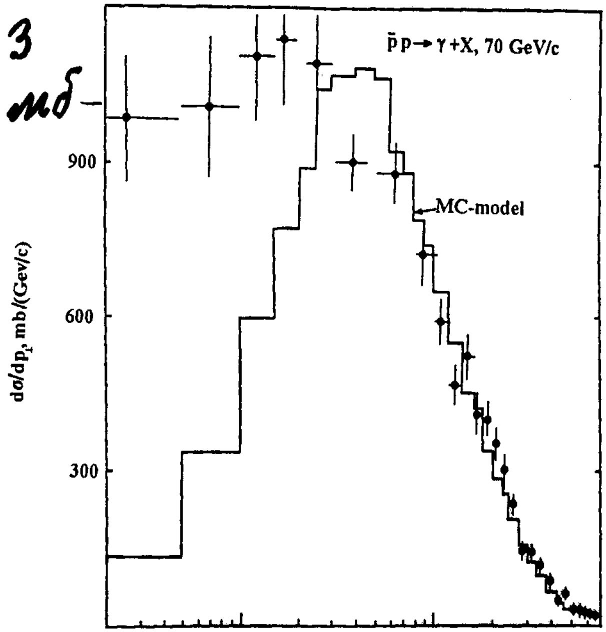
E. Shuryak

1989.

Cold spot of pionic ga

10^3 мб

$\frac{d\sigma}{dp_\perp}$



P. Lichard and L. Van Ho

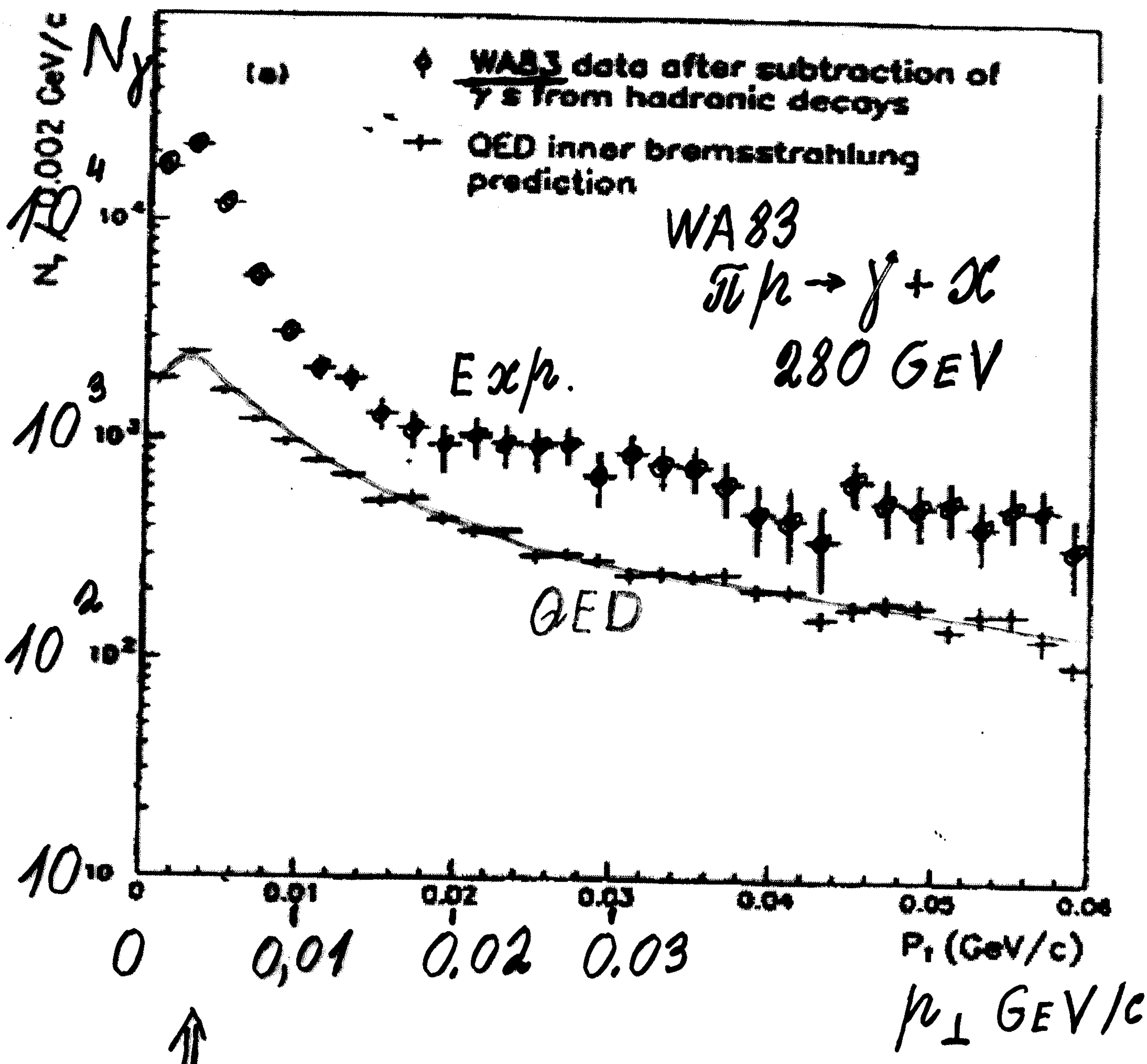
1990.

Cold spot of QGP.

$p_{\perp\gamma} = 10$ МэВ

Fig. 14b. Low energy photon spectrum. Photons from decay of known particles are represented by MC model histogram. (M.N.Ukhanov et al., 1986.)

Low energy direct γ.



$$\frac{\sigma_{exp}}{\sigma_{theor}} = 7{,}9 \pm 1{,}4$$

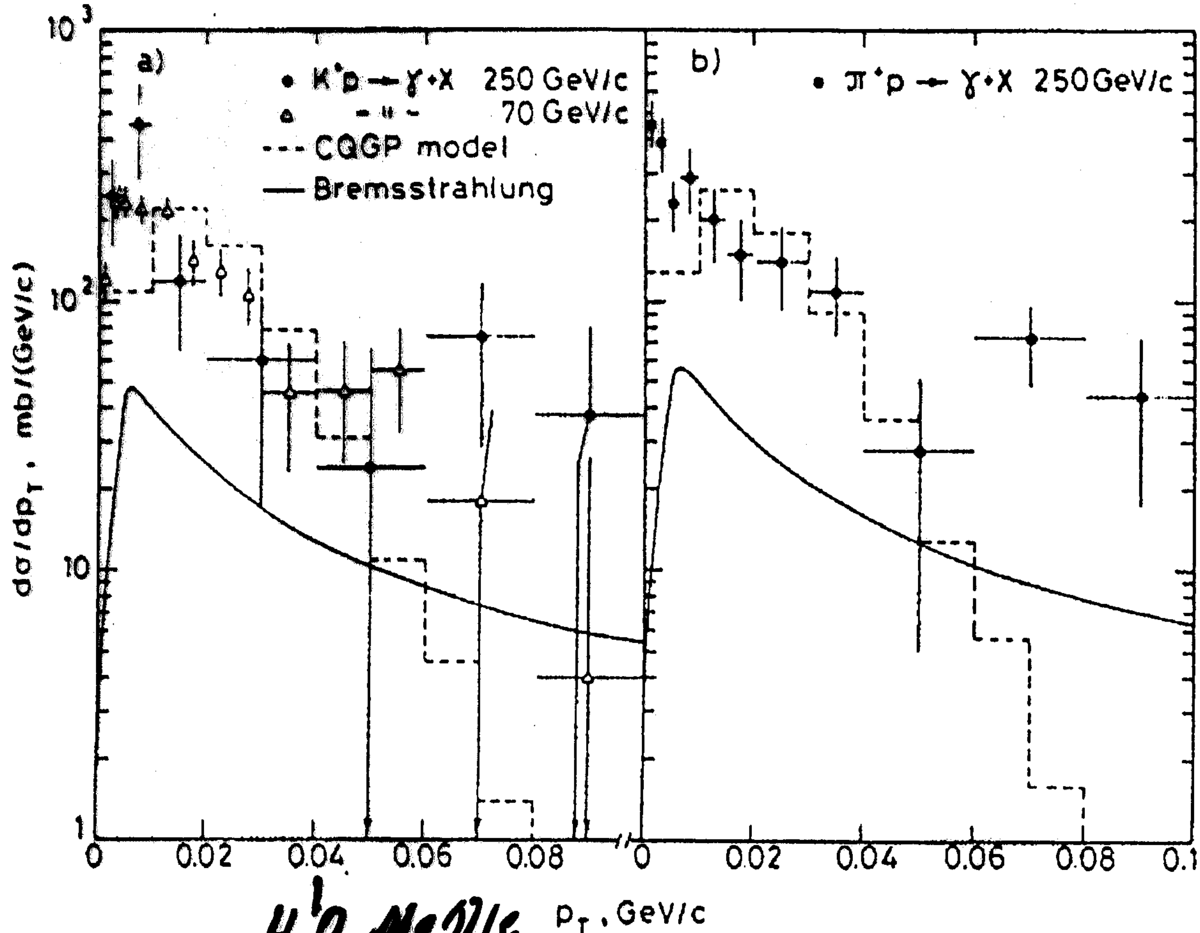


Fig. 8a, b. The $d\sigma/dp_T$ spectrum of γ's remaining after subtraction of all hadron decays in reaction (1) at 250 GeV/c and 70 GeV/c **a** and in reaction (2) at 250 GeV/c **b**. The curves show the hadronic bremsstrahlung contribution and the CQGP model prediction

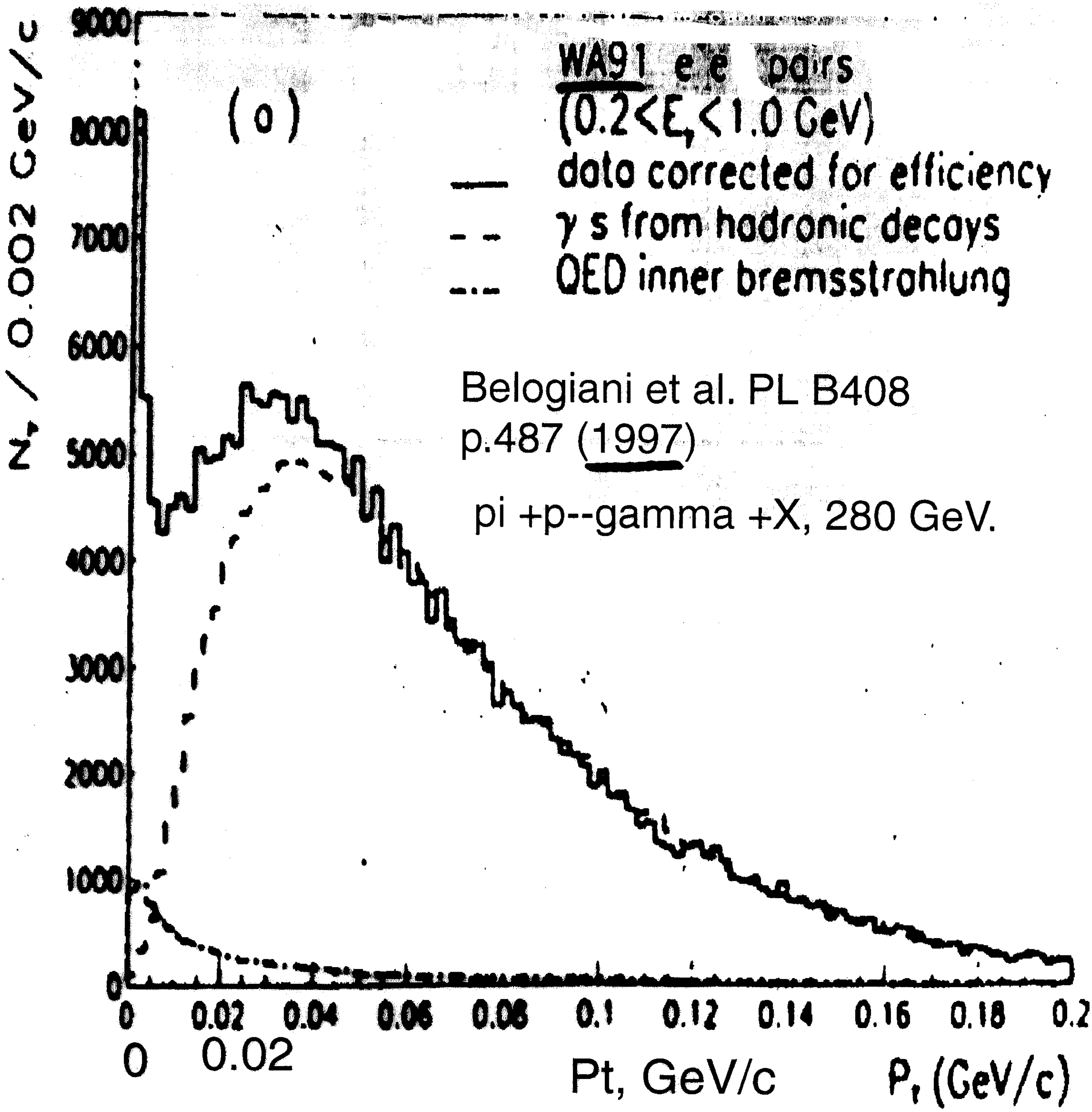
$\sigma(K^+p) = 6{,}3$ mb $\pm 1{,}6$

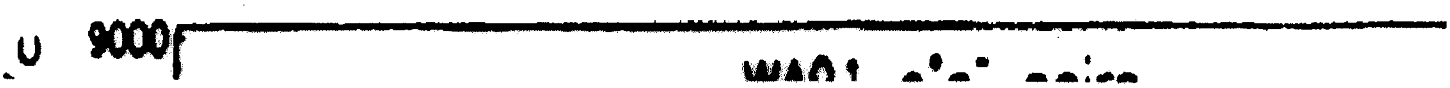
$\sigma(\pi^+p) = (8.2 \pm 1{,}5)$ mb

Direct γ production cross section for $p_\perp \leq 40$ MeV/c

EHS - NA 22

1991


(a)
WA91 e+e- pairs
(0.2<Eγ<1.0 GeV)
data corrected for efficiency
γ s from hadronic decays
QED inner bremsstrahlung
Belogiani et al. PL B408
p.487 (1997)
pi +p--gamma +X, 280 GeV.
Nγ / 0.002 GeV/c
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0 0.02
Pt, GeV/c
Pt (GeV/c)


9000

Исследование коллективного поведения частиц в процессе $pp \to n_\pi \pi + 2N$ при большой множественности.

Сотрудничество ОИЯИ - ИФВЭ.

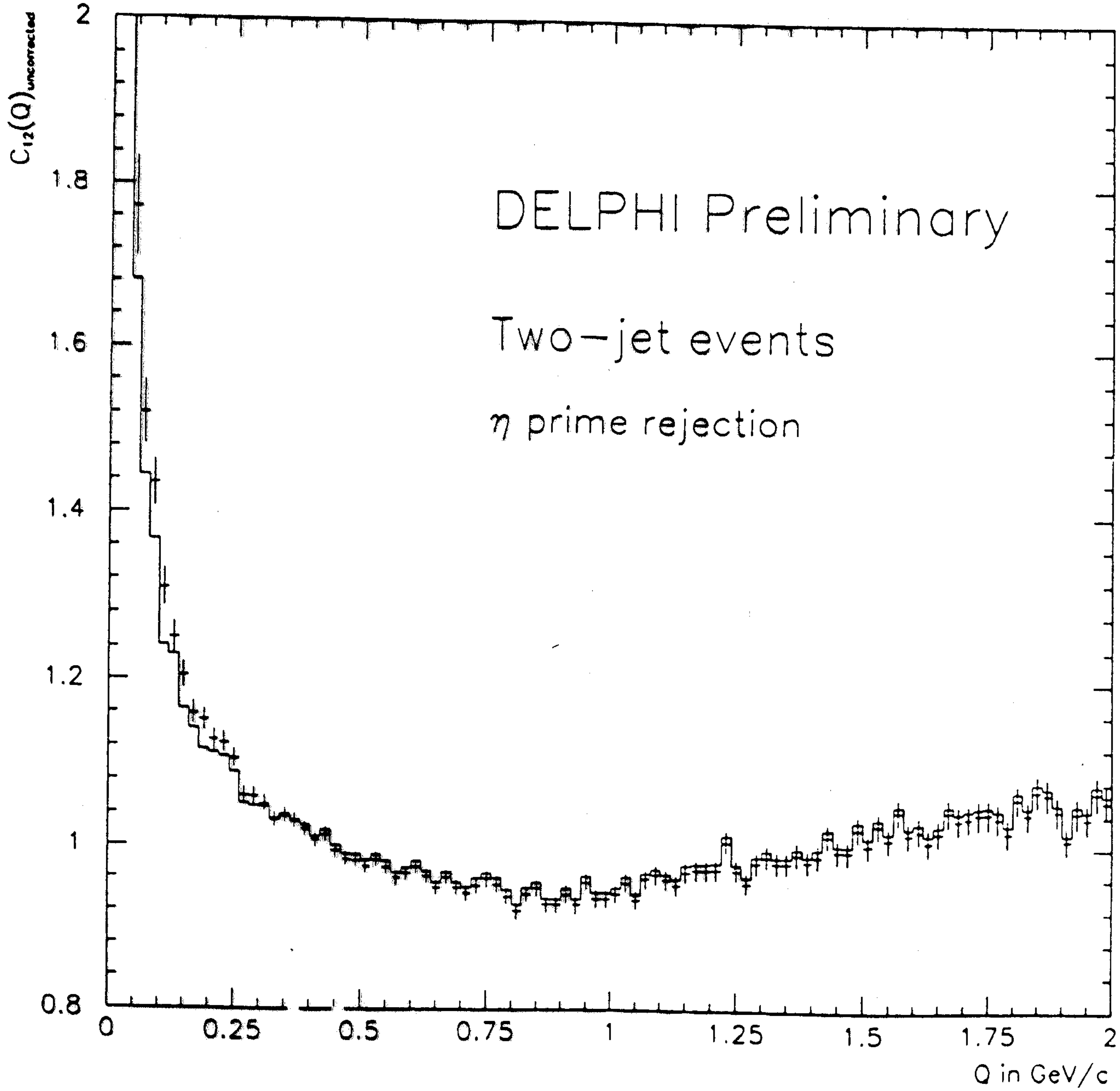
Abstract.

The goal of proposed experiment is the investigation of collective behaviour of particles in the process of multiple hadron production in pp (or pN) interaction $pp \to n_\pi \pi + 2N$ at the beam energy $E_{lab} = 70\ GeV$. The domain of high multiplicity $n_\pi = 40 \div 60$ or $z = n/\bar{n} = 4 \div 7$, will be studied. Near the threshold of reaction $n_\pi \to 69,\ z \to z_{th} = 8.2$, all particles get small relative momentum $\Delta q < 1/R$, where R is the dimension of the particles production region. As consequence of multiboson interference a number of collective effects may show up.

- Drastic increase of partial cross section $\sigma(n)$ of n identical particles production is expected.

- The jets formation may occur as result of multiboson HBT effect.

- Large fluctuation of charged $n(\pi^+, \pi^-)$ and neutral $n(\pi^0)$ components, onset of centauros or chiral condensate effects is anticipated.

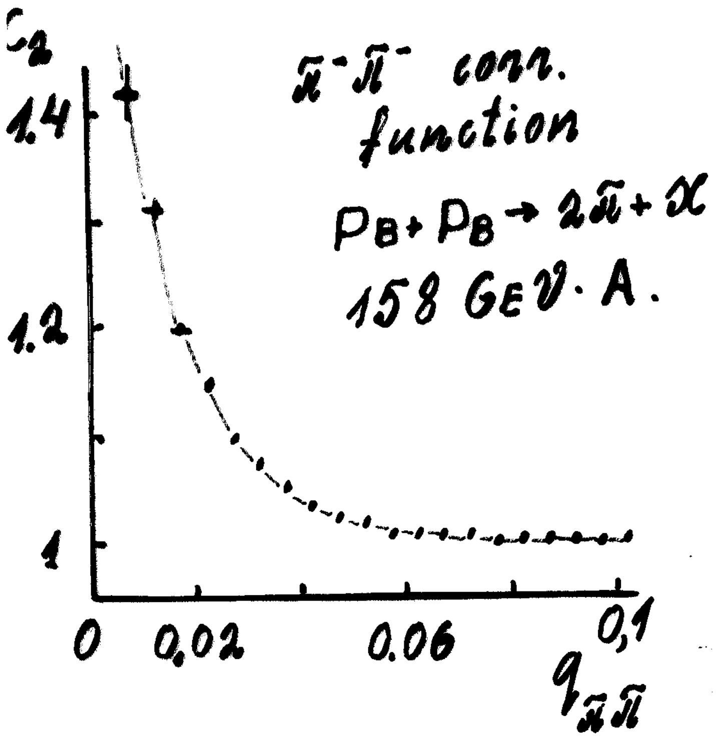


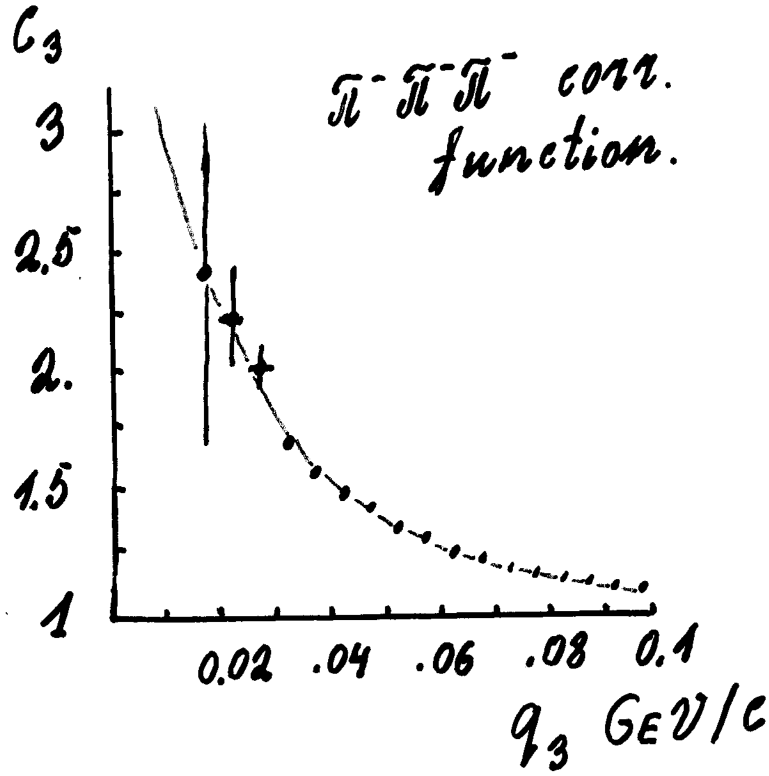
$$c_2(q) = \frac{d^2\sigma}{dp_1\, dp_2} \Big/ \left(\frac{d\sigma}{dp_1} \cdot \frac{d\sigma}{dp_2} \right).$$

Fig. 8

2 and 3 pion BE correlation.

WA98 data 2000.





$$C_2 = \frac{d^2 N(p_1, p_2)/dp_1 dp_2}{dN(p_1)/dp_1 \cdot dN(p_2)/dp_2}$$

$$C_2(q) = 1 + \lambda \exp(-2qr)$$

$r = 7.29 \pm 0.11$ fm

$\lambda = 0.75 \pm 0.013$

$q = p_1 - p_2$

$C_2(0) = C_{2,max} = 2! = 2$

Exp. value

$C_2(q=0) = 2! \cdot 0.88$

$$C_3 = 1 + \lambda \sum_{i,j} \exp(-2q_{ij} r) + 2\lambda^{\frac{3}{2}} \exp(-q_3 r) \cdot W$$

$q_3 = q_{12} + q_{23} + q_{31}$

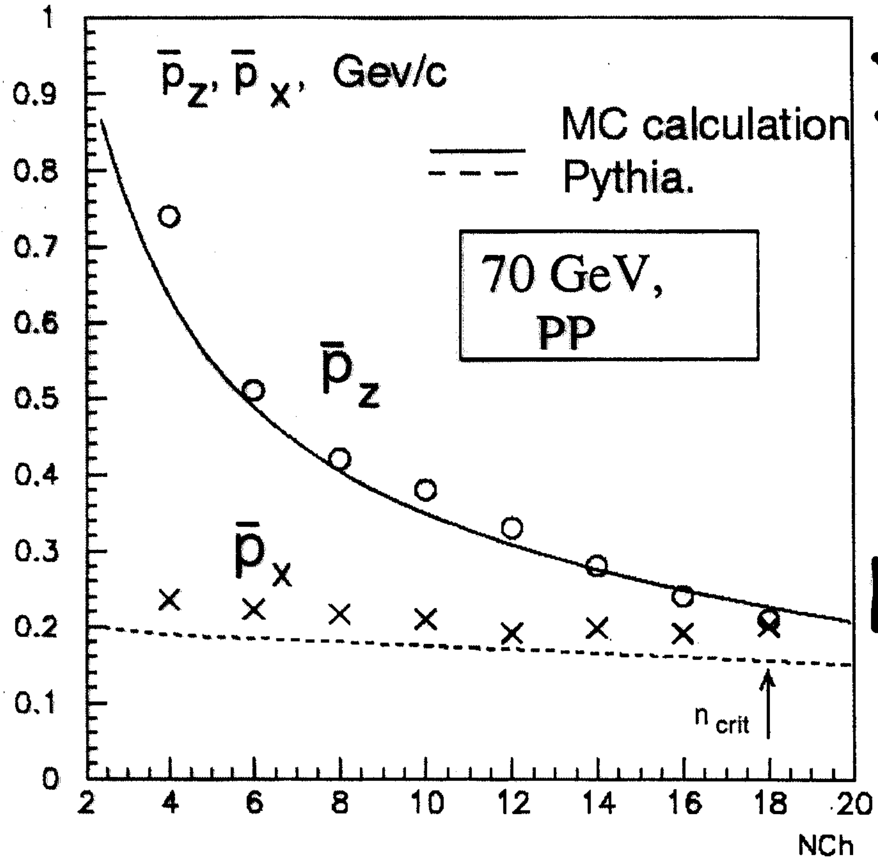
$q_{ij} = p_i - p_j$

$W = 0,6 \pm 0.18$

$C_3(q=0) = C_{3,max} = 3! = 6$

exp. value

$C_3(0) = 3! \times 0.7.$



Calculation of the critical multiplicity n_{crit}.

At $n>n_{crit}$ the leading particle venish and all particles in c.m.s. have equal averege energy $\sqrt{p_\perp^{\;2} + p_z^{\;2} + m^2} = E$

$p_Z = 1/\sqrt{2}\, p_\perp$,

$p_{\perp,exp} = 0.3$ GeV/c

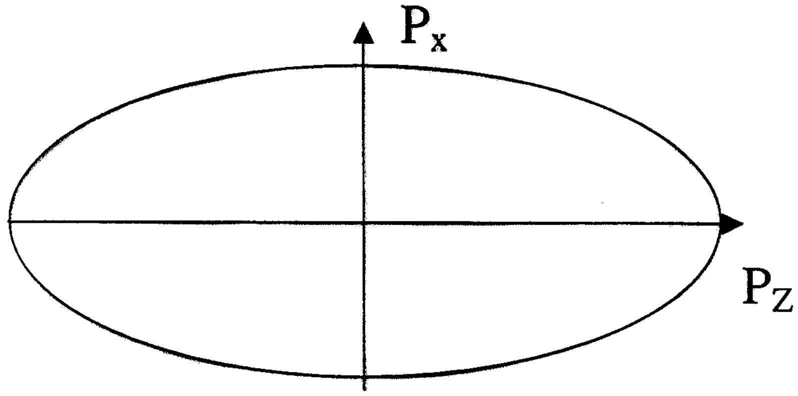
~~$\sqrt{p_\perp^2 + m^2} = \frac{E_{cm} - 2m_N}{n_{crit} + 2}$~~

Result: n_{crit}=[redacted], = 21.

to be compared with $n_{crit,\,exp}=18$.

Very good agreement !

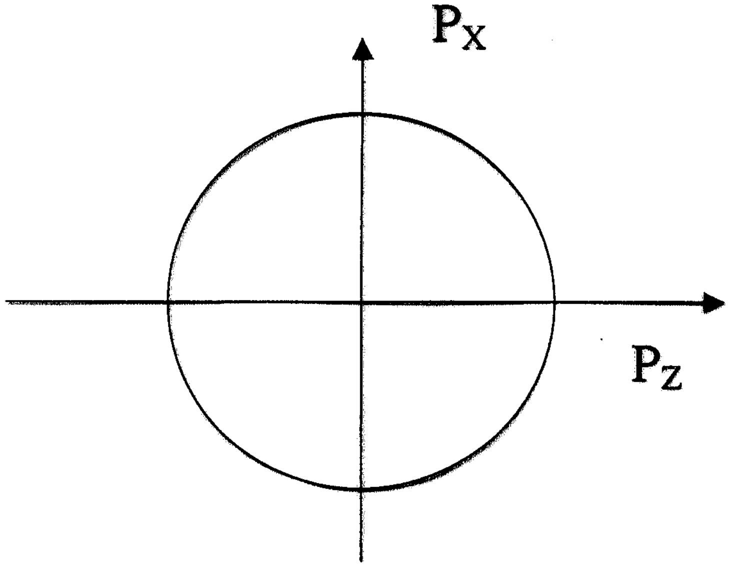
$E_{KIN} = E - m$; $E_{KIN} = \frac{E_{cm} - 2m_N - n_c \cdot}{n_{CRIT} + 2}$



$n_{ch}=6$, $n_{tot}=9$

$P_Z=0.52$ GeV/c

$P_X=P_Y=0.24$



$n_{ch}=18$, $n_{tot}=27$

$P_X=P_Y=0.25$ GeV/c

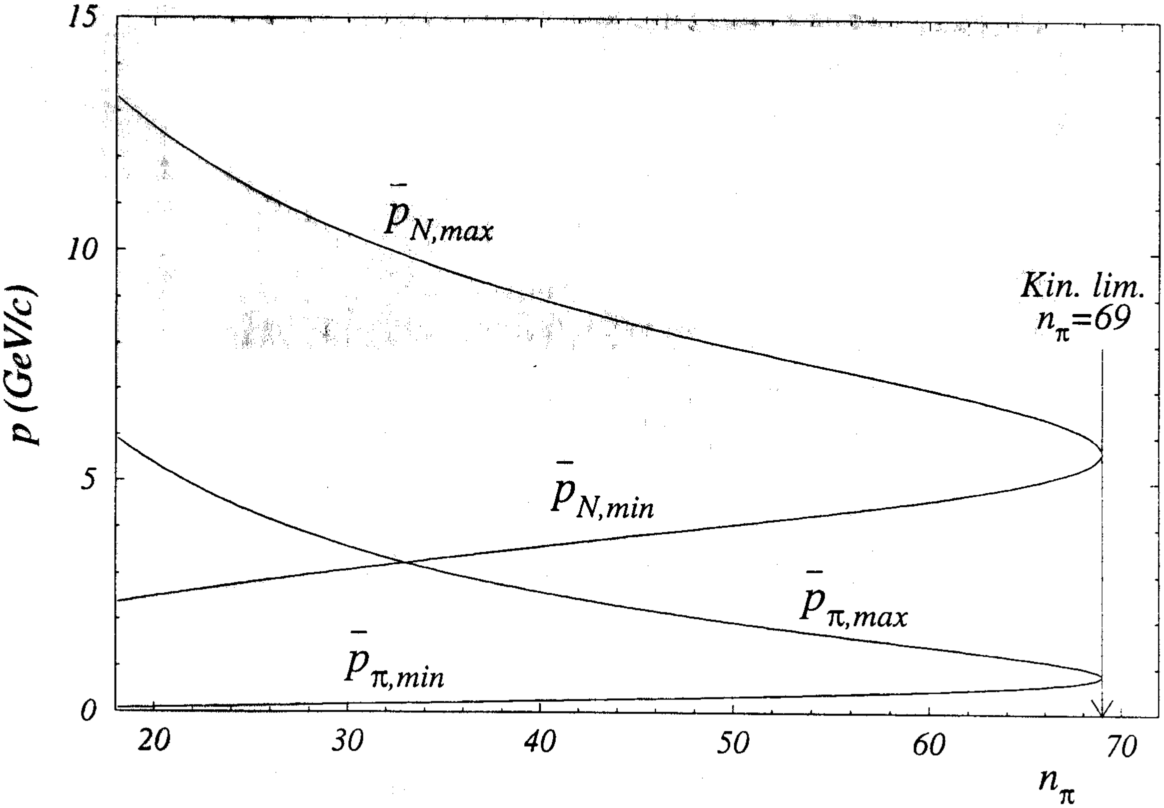


Fig. 2. Mean maximum and minimum momenta of π and N in lab system.

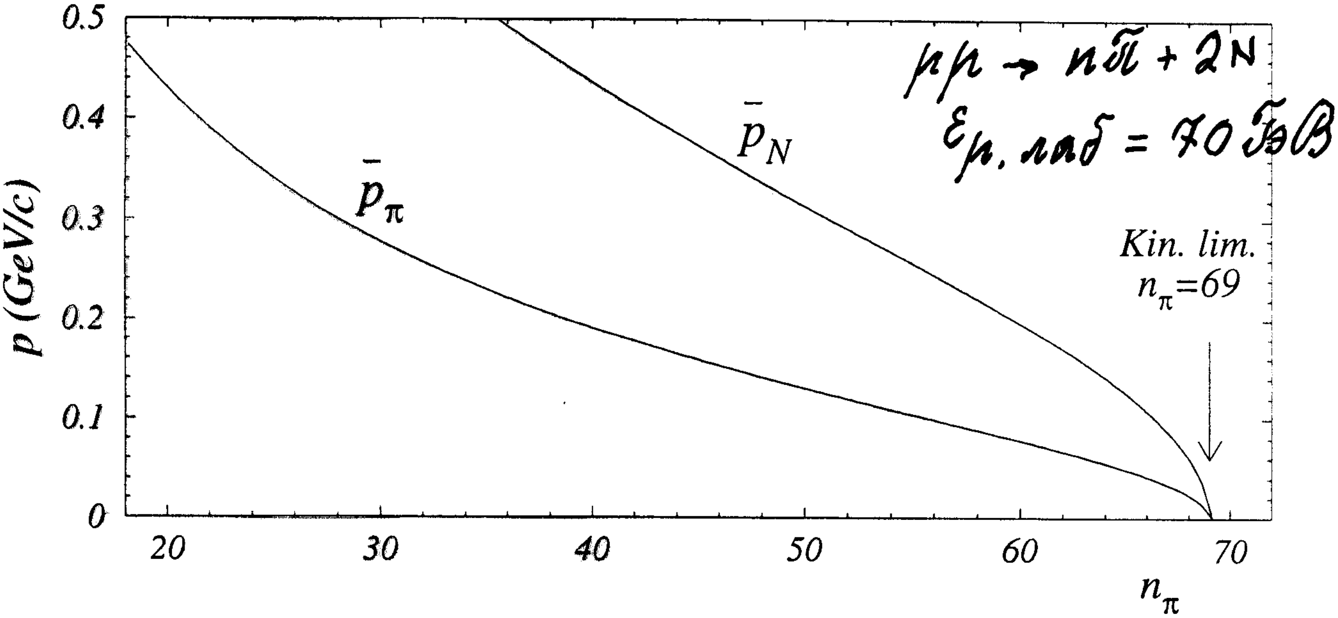


Fig. 3. Momenta of π and N in c.m s.

$$\varepsilon_{\pi\,\text{с.ц.м}} = \frac{\sqrt{s} - 2m_N - n_\pi m_\pi}{n_\pi}$$

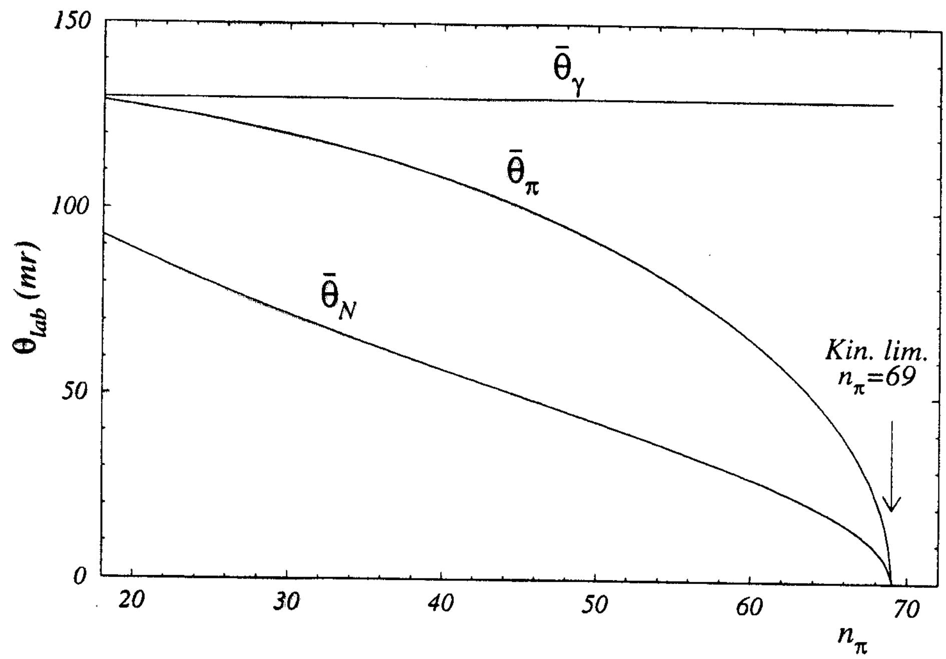


Fig. 6. Mean emission angle of N, π, γ as function of multiplicity .

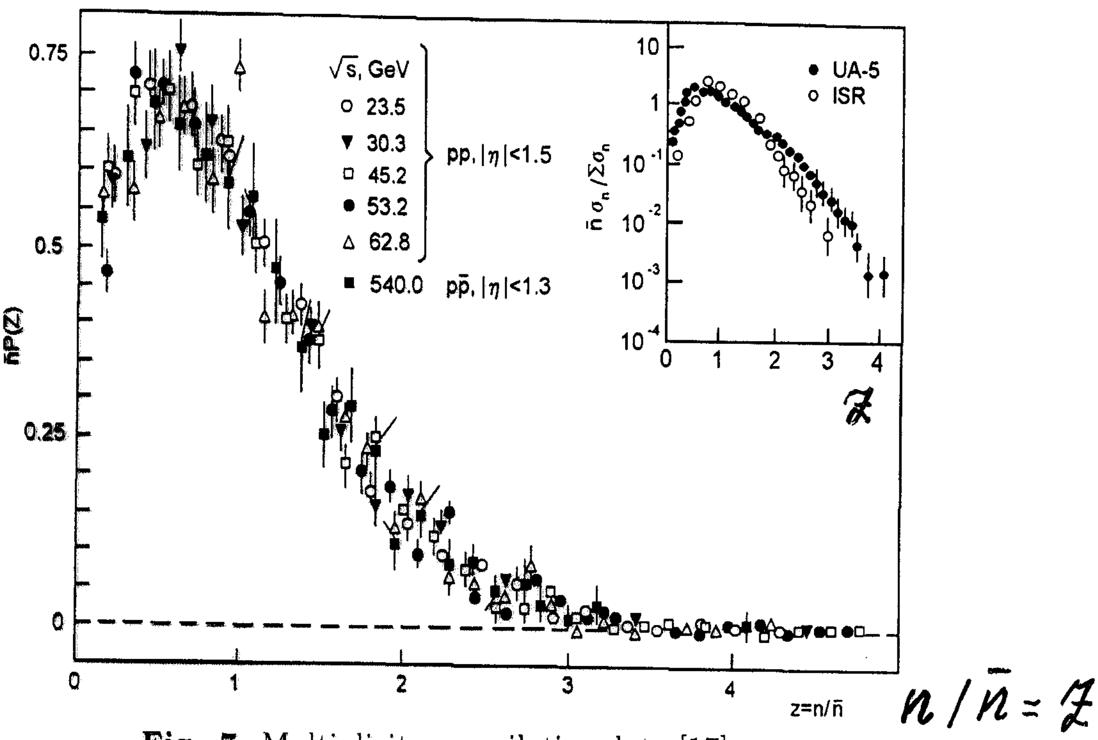


Fig. 7. Multiplicity compilation data [17].

$\bar{\theta}_\pi$, $\bar{\theta}_N$, $\bar{\theta}_\gamma$ are the mean emission angles of π, N and γ in lab. system. They are determined as $\bar{\theta} = \bar{p}_\perp / \bar{p}_{l,lab}$. The difference $\bar{p}_{max} - \bar{p}_{min}$ is the typical momentum dispersion in lab. system. It is presented in Fig. 2.

Functions $\bar{p}_\pi(n_\pi)$, $\bar{p}_N(n_\pi)$ are shown in Fig.3. The $\bar{p}_\pi$ decreases when multiplicity n_π increases. In the region $n_\pi \geq 50$ the inequality $\bar{p}_\pi \leq 1/R_{pN} \approx 0.1$ GeV/c holds, assuming the radius of pN interaction is $1 \div 2$ fm. That means major part of pions may

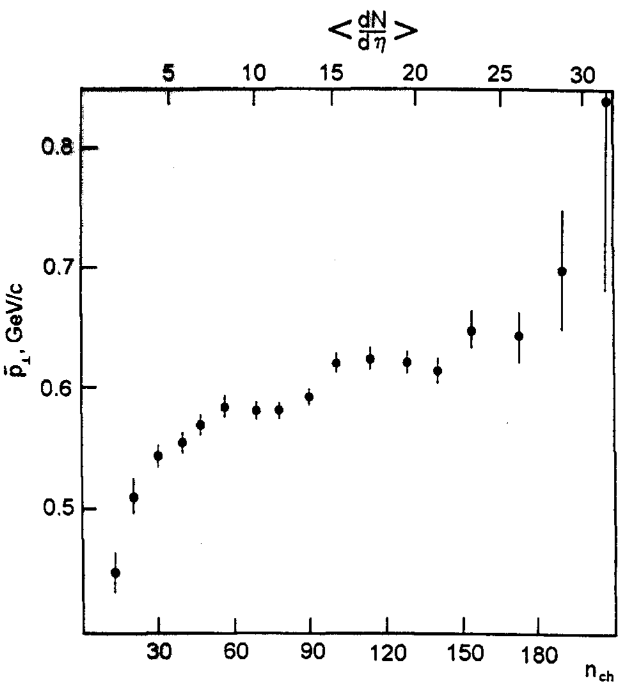


Fig. 4. Average transverse momentum of charged particles observed in $p\bar{p}$ at $\sqrt{s} = 1.8\ TeV$ as function of multiplicity [14] .

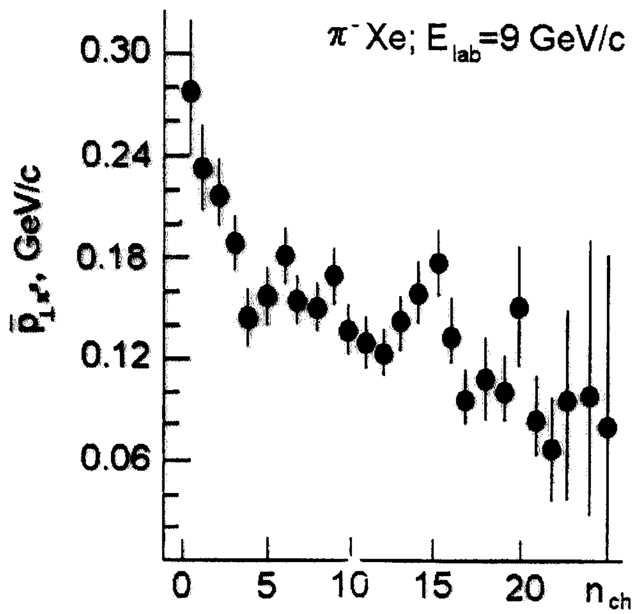
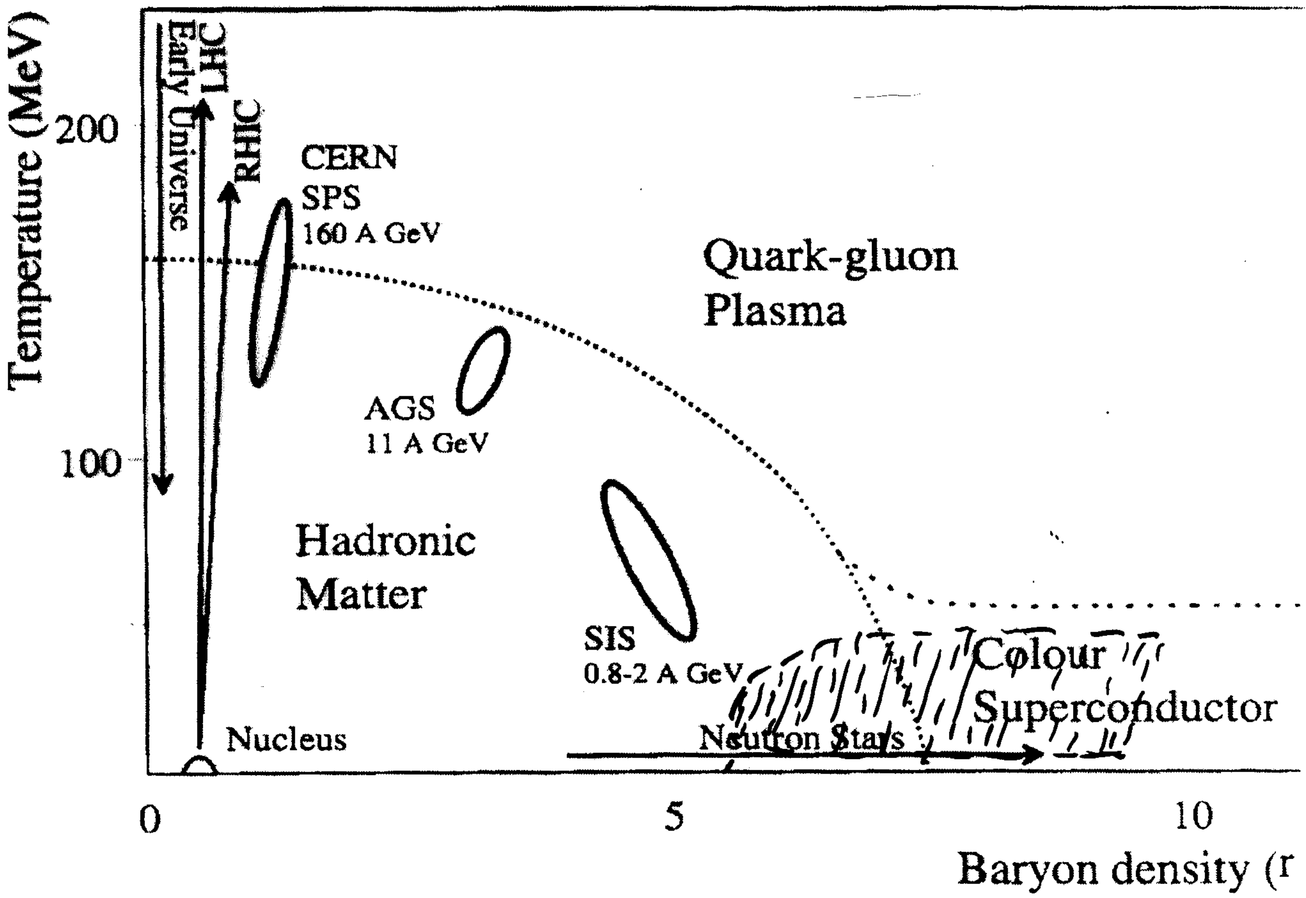


Fig. 5. Average transverse momentum of π_0 observed in πXe at 9 GeV as function of multiplicity [15] .



The main feature of proposed experiment:

Study of hadron matter at low temperature T<50 MeV and high density $\rho/\rho_0 \gtrsim 5$

Study of multiparticle dynamic at high particle density in phase sp

$$f = (2\pi)^3 \frac{d^6 n}{d^3p\, d^3r} \approx \pi^{\frac{3}{2}} \frac{N}{V_p V_r}$$

$$f > 10^2$$

For comparison: presently achievabl value is $f \approx 0,1$

PHAS SPACE VOLUME $\Omega = C\, V_R \cdot V_p = C(\sqrt{2}R)^3 \cdot \bar{p}^3$.

$$\Omega_{Au} = C \cdot (6\,ф)^3 \cdot (0,4\ ГэВ/c)^3$$

$$\Omega_{pp} = C \cdot (0,7\,ф)^3 \cdot (0,07\ ГэВ/c)^3$$

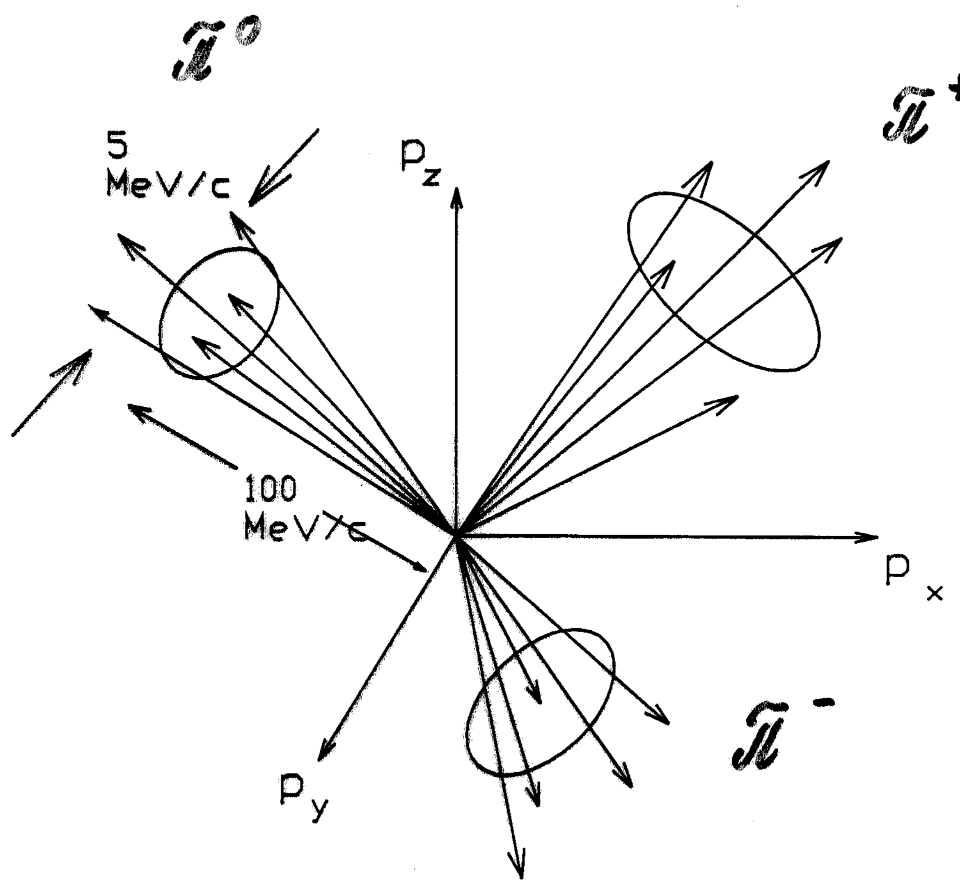
$$\Omega_{..} / \Omega_{..} \approx 10^5$$

Podgoretsky jets.

(1985) Dispersion of n identical pions in momentum space.

$$d_{cor} = \sqrt{\frac{\ln 2}{3n}}\,\frac{1}{r} = \frac{0.48}{r\sqrt{n}}\,; \quad \Theta_{cor} = \frac{d_{cor}}{p_0}$$

$$n_{\pi} = 50\,; \quad n_{\pi^+} \approx n_{\pi^-} \approx n_{\pi^0} \approx 17$$

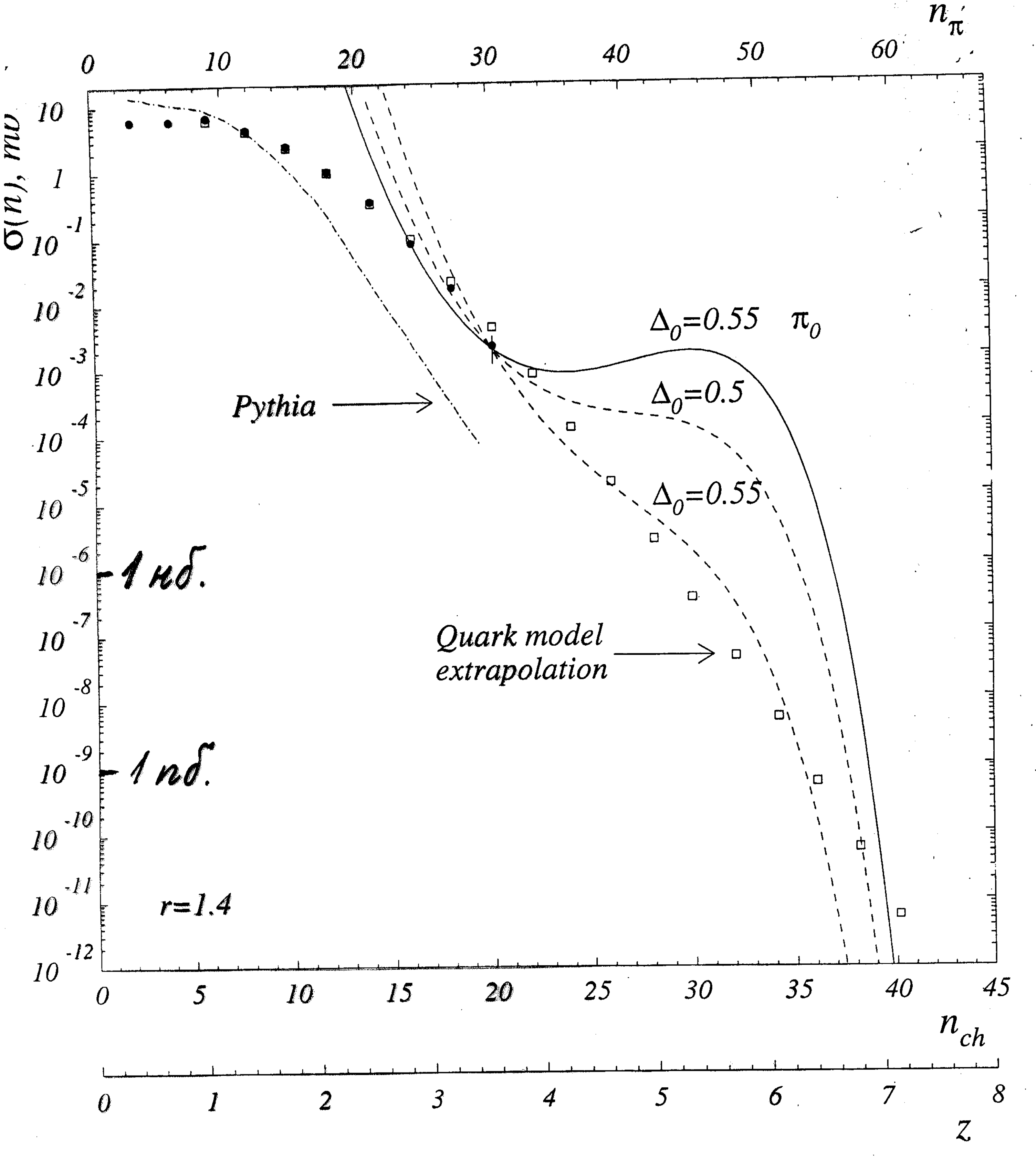


$$\sigma(n) = c\, w(n_+)\, w(n_-) \cdot w(n_0) \times V_p \cdot \sigma_{noncor}(n_t).$$

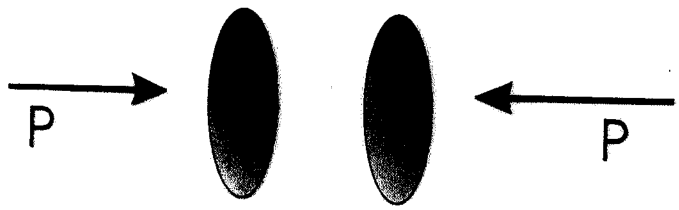
$$\sigma_{nonc} = c \exp(-b_1 n - b_2 n^2).$$

$$V_p = c\left(\frac{\bar{p}}{\Delta_0}\right)^{3 n_\pi}$$

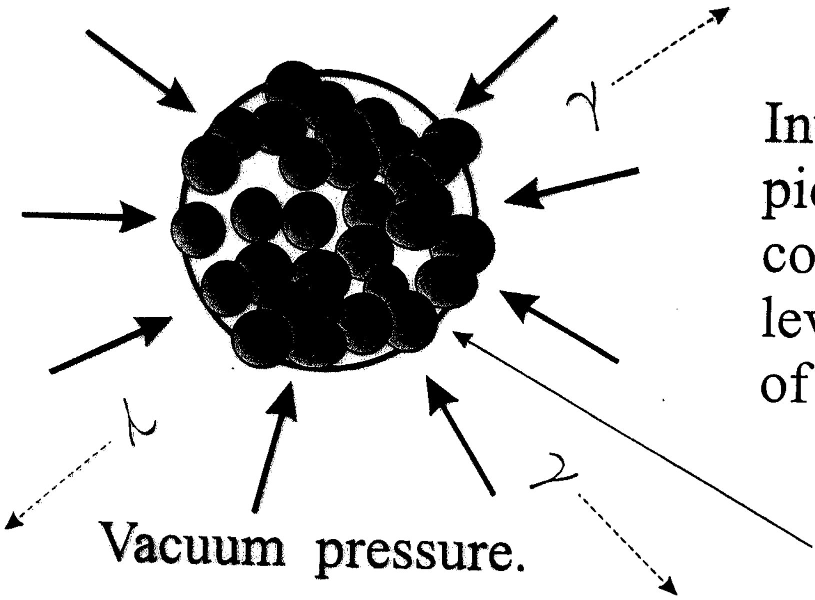
$$V_p \to 0, \quad n_\pi \to n_{\pi\, thr}$$



Discriptive (visual aid) picture of multiparticle process near threshould.

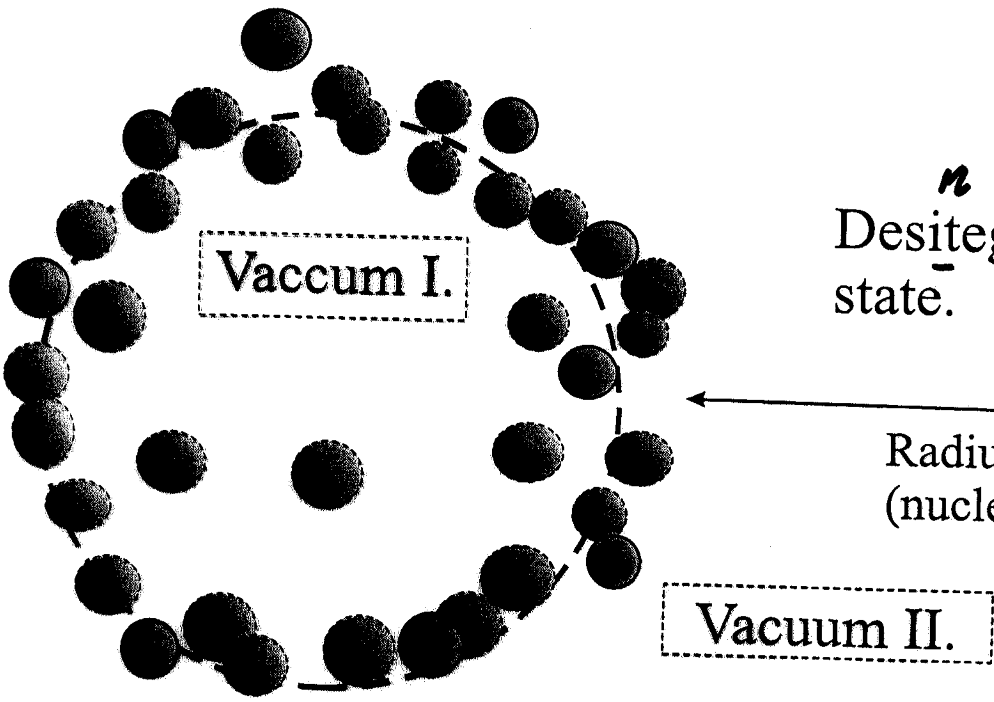


Initial state of two protons collision. A



Intermidiate state of pion condensate or cold gas with energy levels of the order of MeV. B

Radius 1 -2 fm.



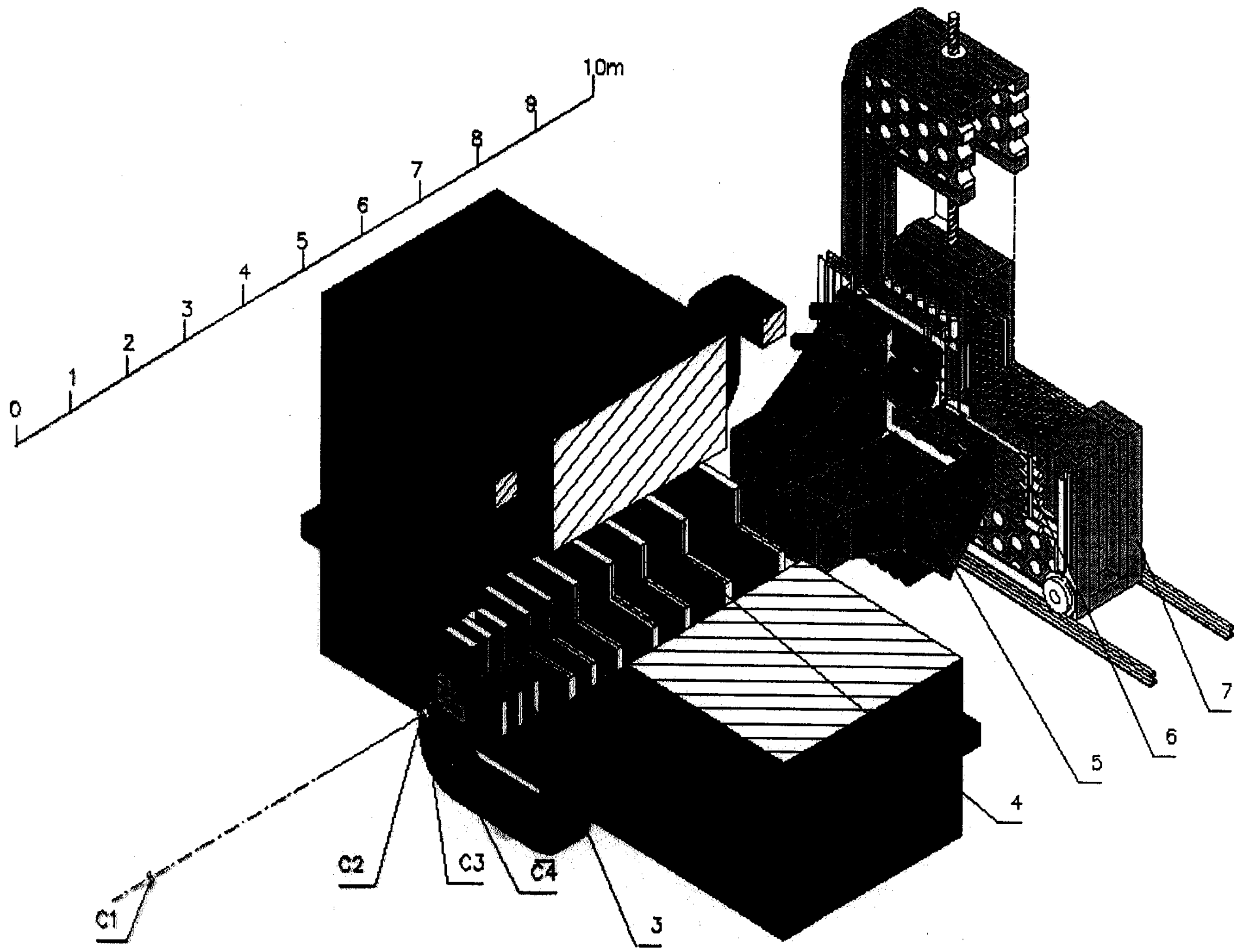
Desitegration state. C

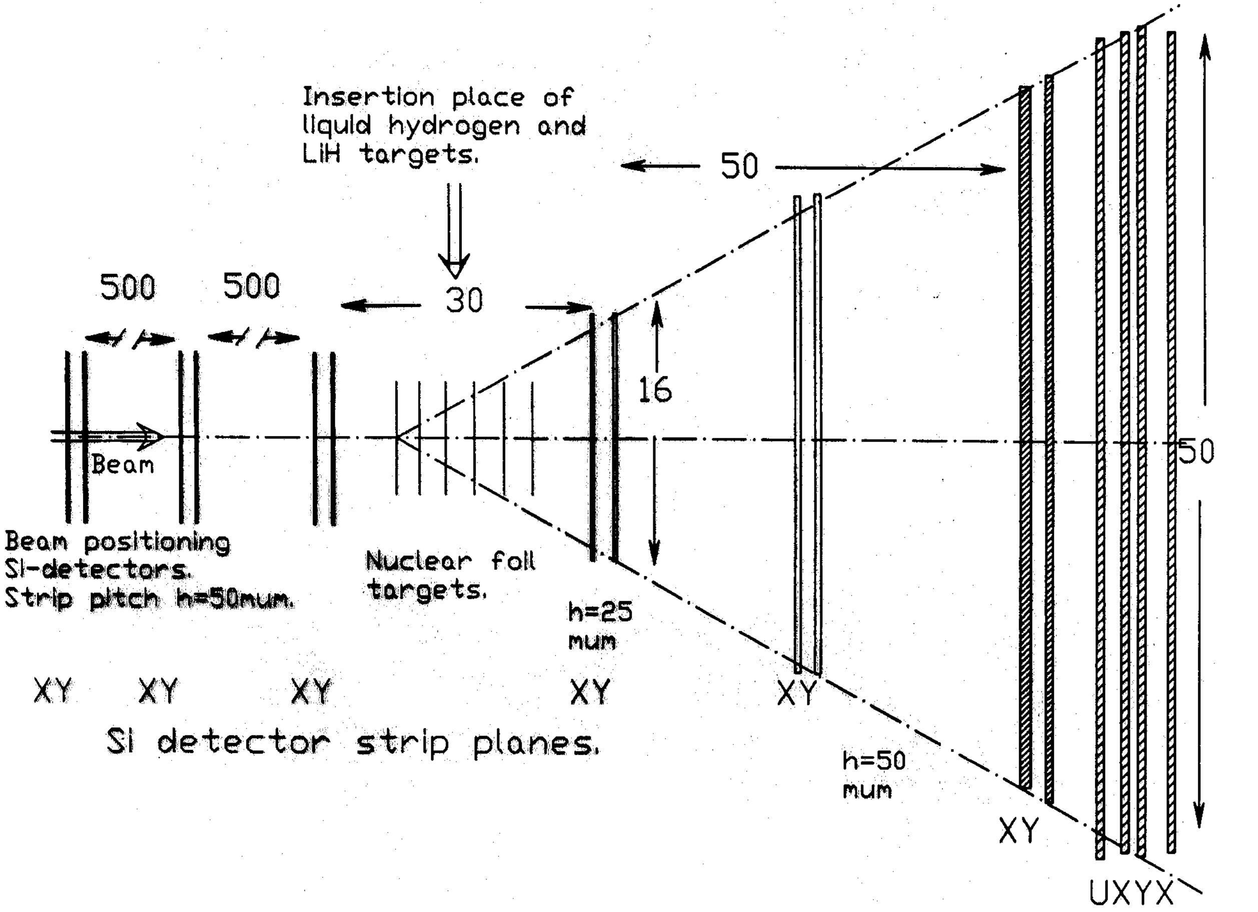
Radius 3.6 fm
(nucleus with A=30)

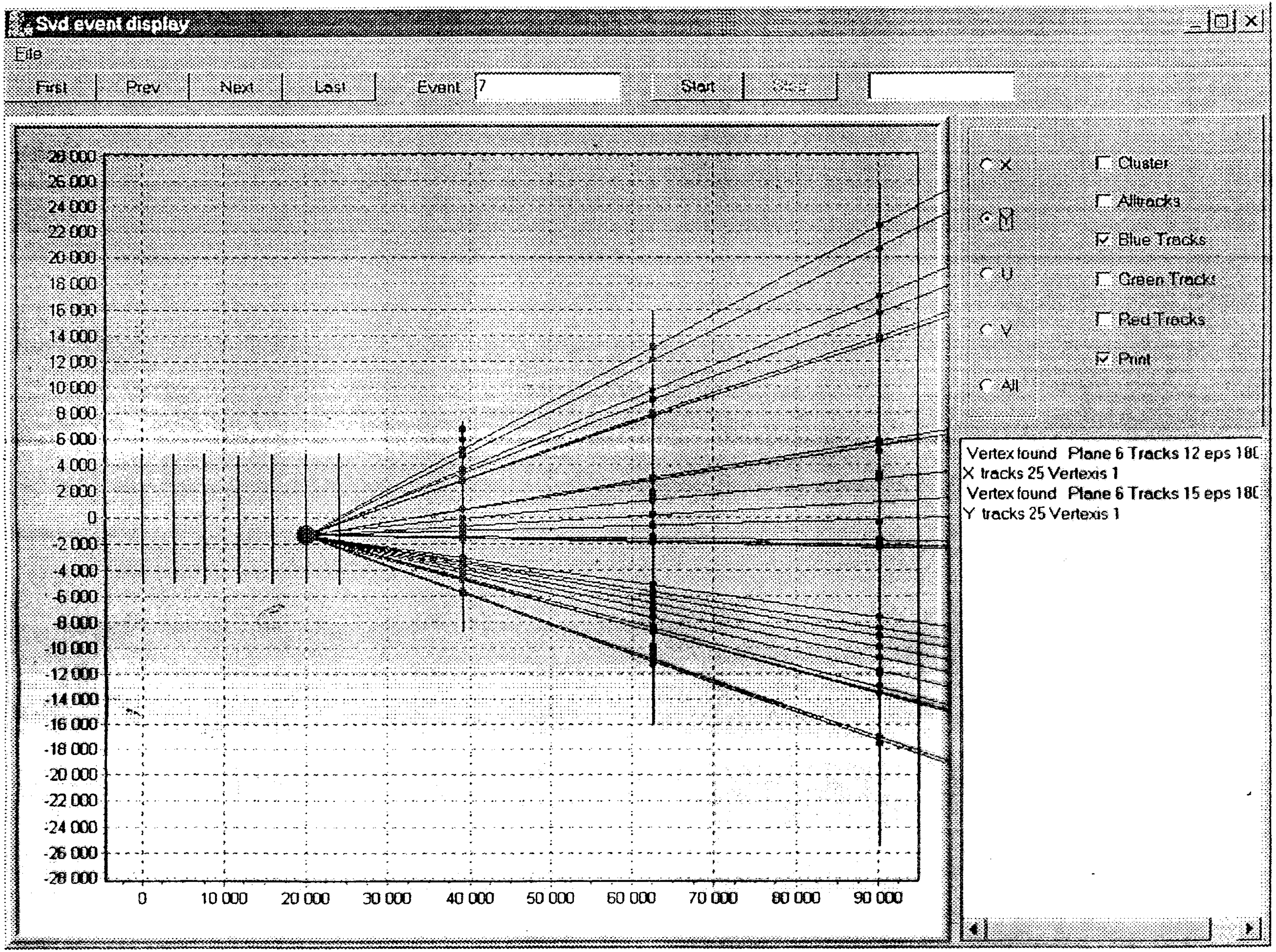
Vacuum I + Vacuum II

Vacuum recombination. D

Схема установки СВД на пучке протонов 70 ГэВ




Insertion place of
liquid hydrogen and
LiH targets.
50
500
500
30
16
50
Beam
Beam positioning
Si-detectors.
Strip pitch h=50mum.
Nuclear foil
targets.
h=25
mum
XY
XY
XY
XY
XY
Si detector strip planes.
h=50
mum
XY
UXYX


Svd event display
File
First
Prev
Next
Last
Event 7
Start
X
Y
U
V
All
Cluster
Alltracks
Blue Tracks
Green Tracks
Red Tracks
Print
Vertex found Plane 6 Tracks 12 eps 18
X tracks 25 Vertexis 1
Vertex found Plane 6 Tracks 15 eps 18
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28 000
26 000
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60 000
70 000
80 000
90 000

1 Conclusion

The goal of the proposed experiment "Hadronization" is the investigation of collective behaviour of particles in the process of multiple hadron production in pp (or pN) interaction $pp \to n_\pi\pi + 2N$ at the beam energy $E_{lab} = 70\ GeV$. ÷ 12 GEV

The physics objectives of the experiment are as followers.

1. Search for a new phenomena.

- Drastic broadening of the multiplicity distribution $\sigma(z)$ is expected due to effect of BEC. In the region $n_\pi \geq 40$, $z \geq 5$ the actual cross section $\sigma(z)$ may exceed by many order of magnitude the extrapolated function $\sigma_{extr}(z)$.

- The BEC may manifest itself by formation of narrow jets of identical particles or "cold spots" in momentum space. The other notions for this effect are pion laser, classical boson field, boson condensate.

- The particle sources may be two types: chaotic and coherent. The precision measurement of the two particle correlation function $R(q)$ makes possible to determine the sources parameters: chaoticity, space-time size, primordial correlation length and time.

- The large variation of the π^+, π^-, π^0 multiplicity is expected in framework of BEC. The multiplicity fluctuations may also manifest classical pionic field production or onset of chiral condensate.

2. The systematic and precision study of known phenomena.

- The direct photons especially with low energy $E_\gamma \leq 100\ MeV$ may manifest a new physics, in particular existence of the QGP.

- The study of stochastic intermittency is the instrument for phase transition search and also search for BEC effect of the cold spot type.

- The existence of events with regular intermittency, so called ring events, is published. This effect is referred as a gluonic Cherenkov radiation. It needs confirmation. If it really exists it will be a genuine probe of the hadronic matter properties.

- The measurement of the production rate of the particles of different species π, K, p, d, $\bar{p}$ gives data for test and development of thermodynamics models. Simultaneous analysis of the differential cross section and BE correlation functions makes possible to disentangle the hadronic system size, temperature and expansion rate.

Counting rate.

STAGE I
SVD

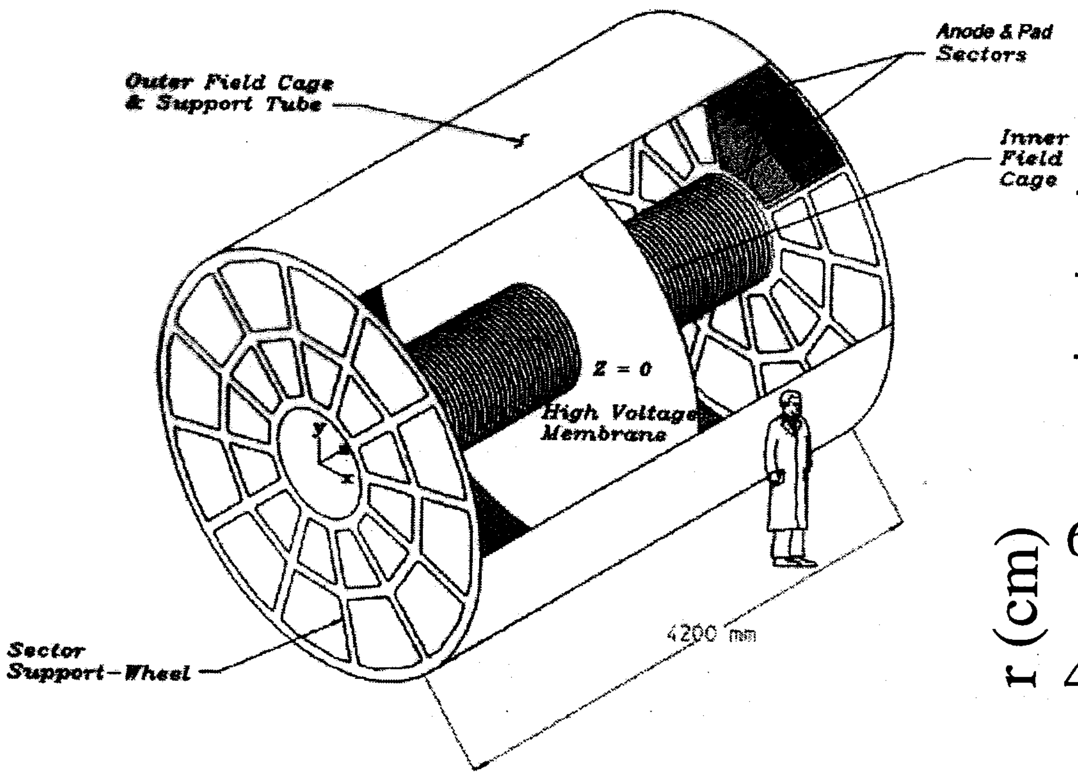
n_π	n_{ch}	**z**	$\sigma(n_\pi)$	$N\ h^{-1}$	$N\ h^{-1}$ (Stage I SVD)
30	**20**	**3.2**	**3 mcb**	2×10^6	$2 \cdot 10^4$
40	**27**	**4.3**	**1 nb**	7×10^2	7
50	**33**	**5.4**	**15 pb**	**10**	0,1
55	**36**	**6.2**	**0.5 pb**	**0.3**	

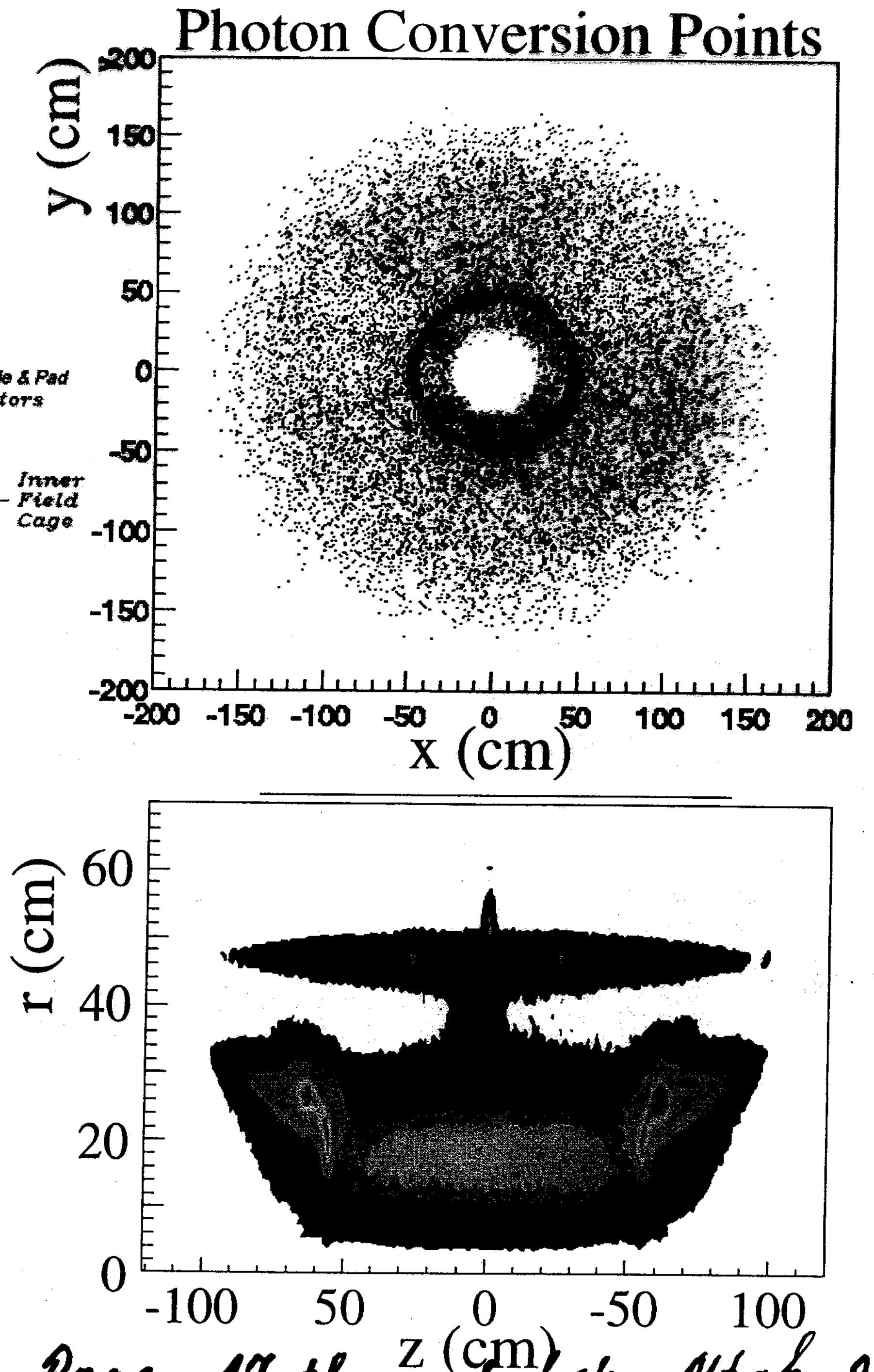
$n\pi$, n_{ch} - total and charged multiplicity. $z = n/\bar{n}$ - KNO variable. $\sigma(n_\pi)$ - partial cross section. N - counting rate per hour.

10 days run will results in collecting about 2000 events of pp interaction with multiplicity $n_\pi = 50$.

STAGE I, SVD   10 days 20 events with $n_\pi = 50$.

STAR TPC





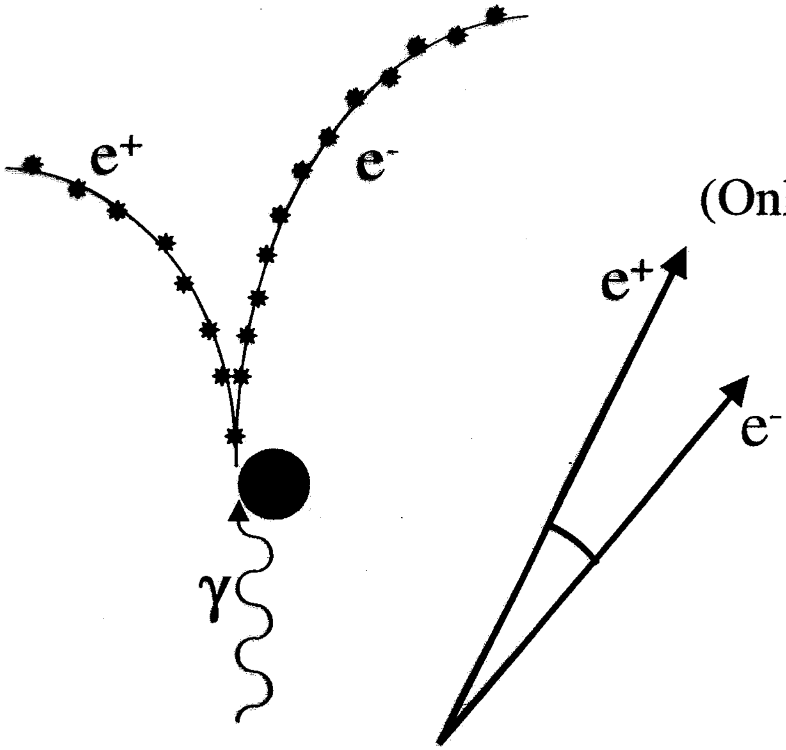
Average Conversion Probability:

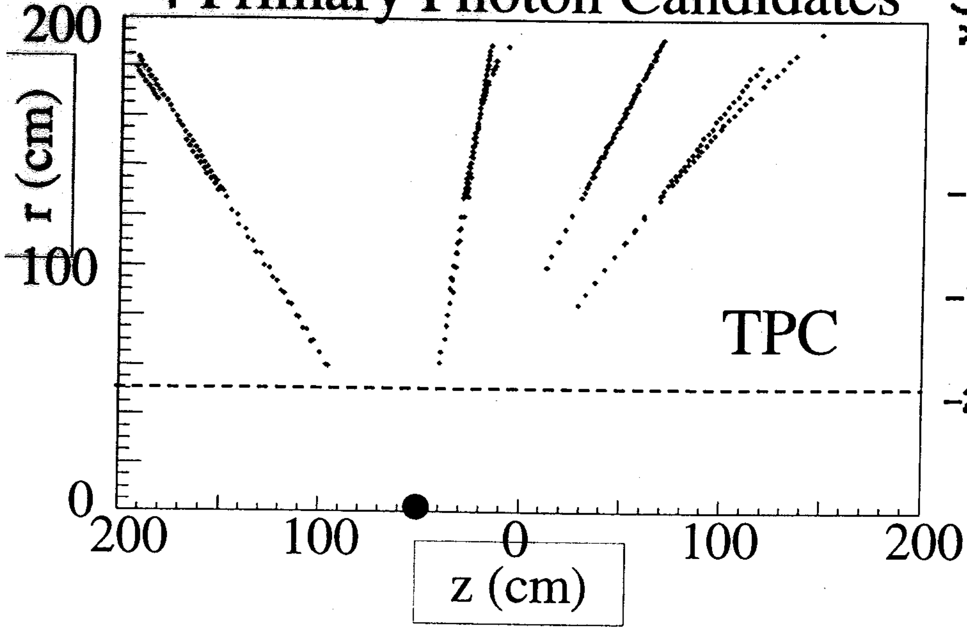
- Year 1 ~1.5%
- Year 2 ~5%

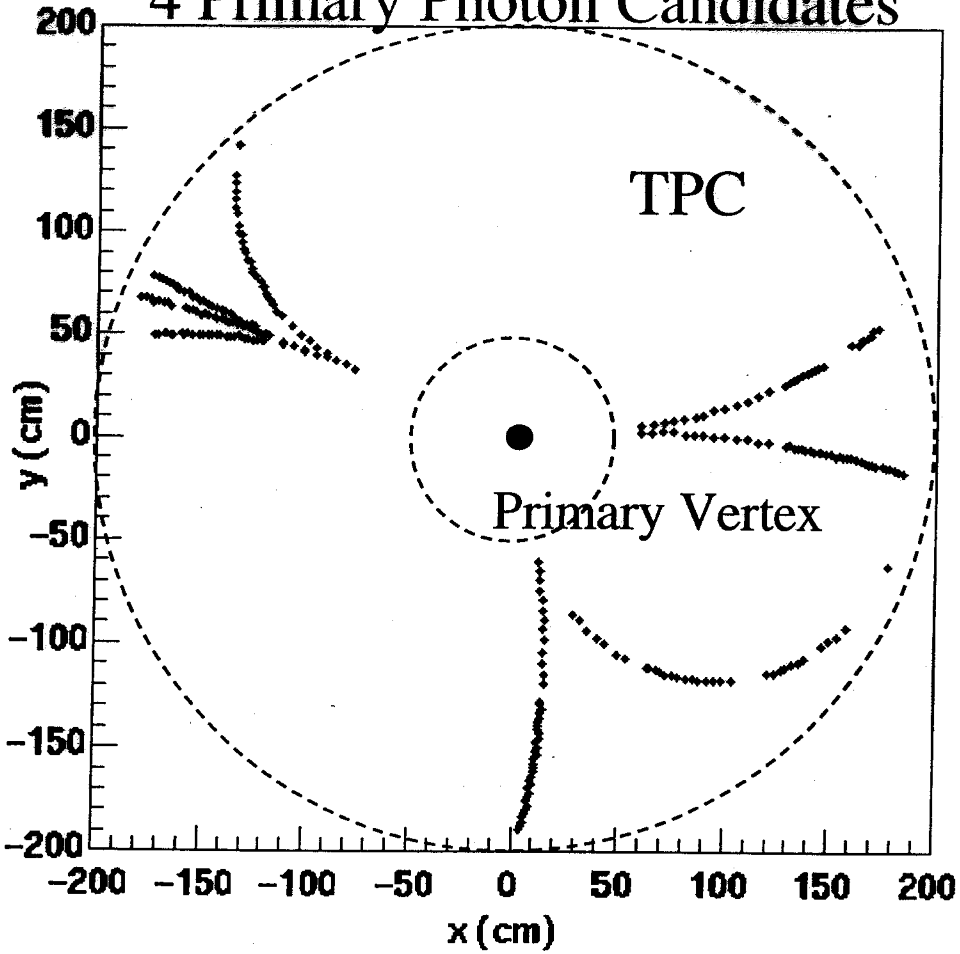
T. Jonson. Proc. 17-th workshop... Utah, 2001.

A Typical Event

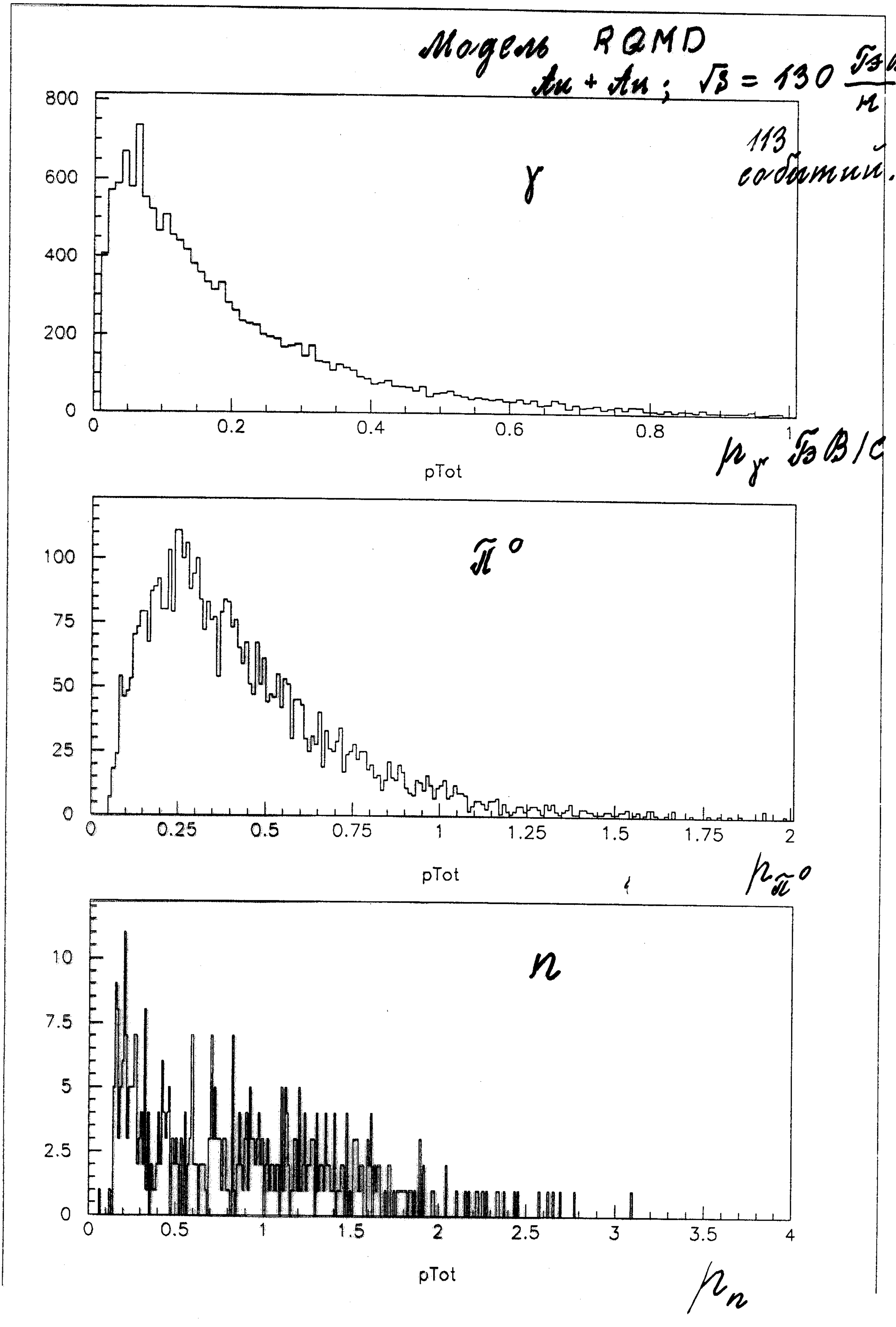
(Only primary photon candidates are shown.)







$\frac{\Delta p_\gamma}{p_\gamma} \approx 3\%$ at $p_\gamma \approx 1$ GeV

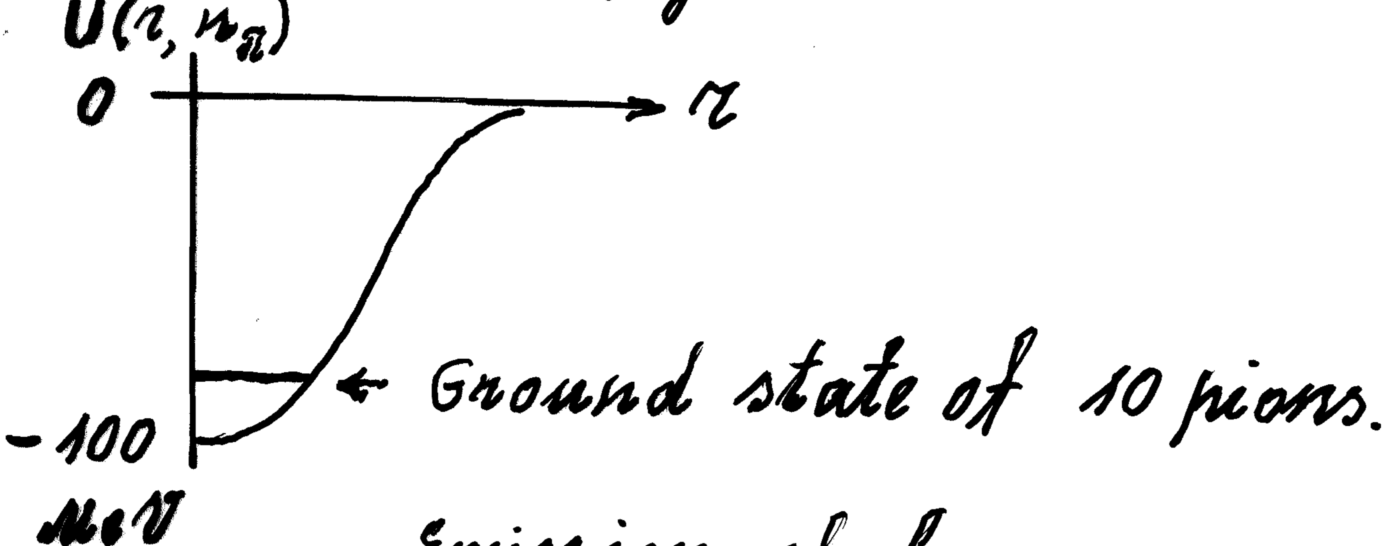


Модель RQMD
Au + Au; √s = 130 ГэВ/н
113 событий.
γ
pTot
p_γ ГэВ/с
π⁰
pTot
p_π⁰
n
pTot
p_n

A new concept: superhadron - - multipion bound state.

$(\pi\pi)$ with $T = 0$ has attractive potential.

Preliminary astimate:
10π develop ~100 MeV well.
(V. Beliaev, JINR)



Emission of low energy γ's is anticipated as result of multipion well (state) formation.

STAR. Law energy γ's.

- $\mathcal{L}(Au+Au) = 10^{28}\ cm^{-2} s^{-1}$.
- Numb. of interacting nucleons 100.
- TPC acceptance $45 \div 135°$
- TPC efficiency of $\gamma \to e^+e^-$ – 5%

counting rate of γ's – $150\ s^{-1}$

$p_\gamma < 40$ MeV/c.

URGENT !

volonteres recrutement for:

- work out event generator accounting BEC in condition of cold hadronic system $T_{kin} \approx 20 \div 50$ MeV;
- devise concret formula for BEC of $5 \div 15$ likewise pions all with $q \le 100$ MeV/c;
- work out proposal for STAR to detect law energy γ's;
- participate in experiment at U-70.