Centrality determination for the MPD@NICA

M.Golubeva, F.Guber, A.Ivashkin, A.Kurepin,
INR, Moscow

A.Litvinenko, E.Litvinenko, A.Isupov, I.Migulina,
V.Peresedov, JINR, Dubna

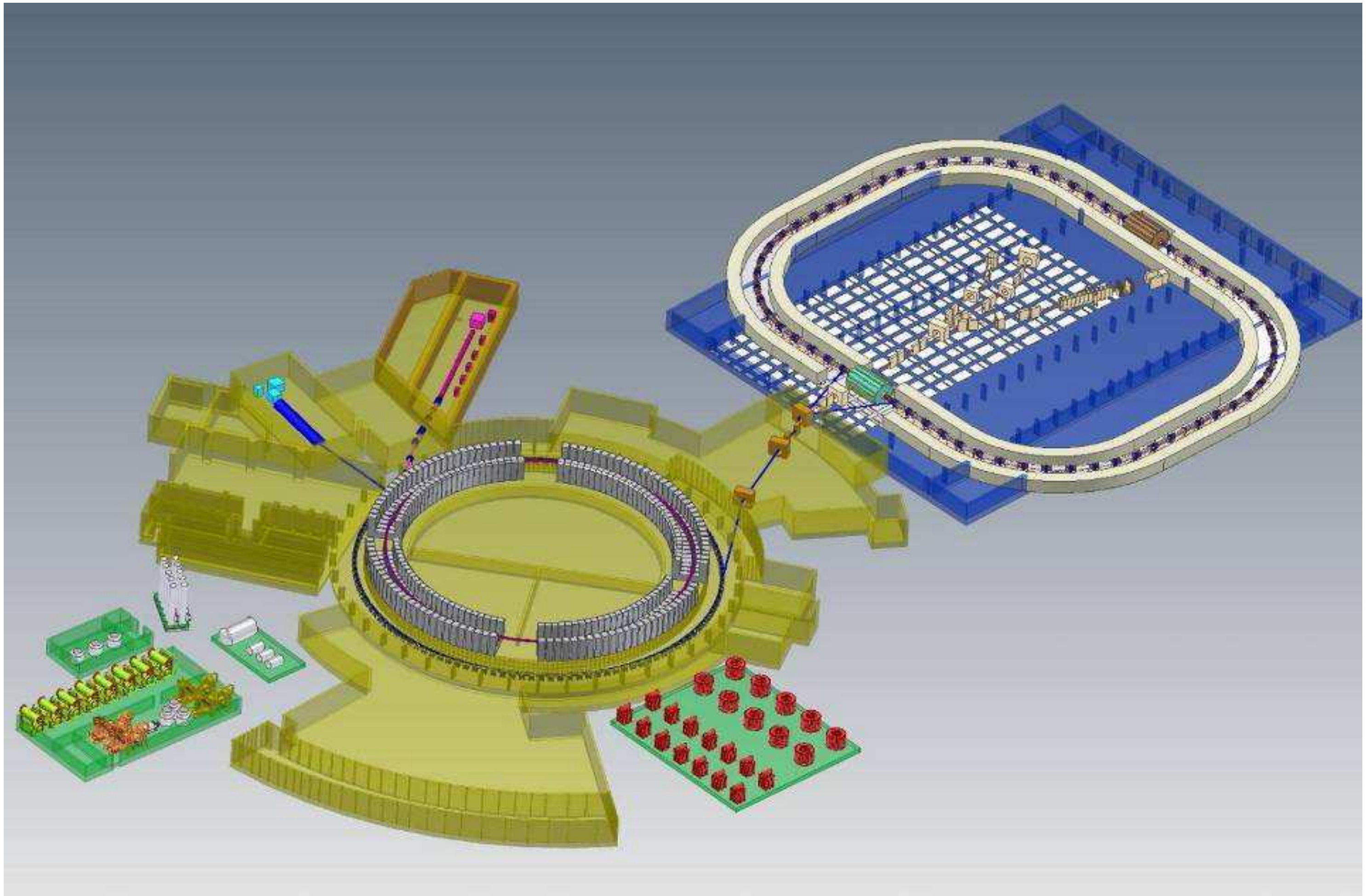
M.Baznat, K.K.Gudima,
Institute of Applied Physics, Academy of Science of Moldova, Moldova

A.Litvinenko, *litvin@moonhe.jinr.ru*

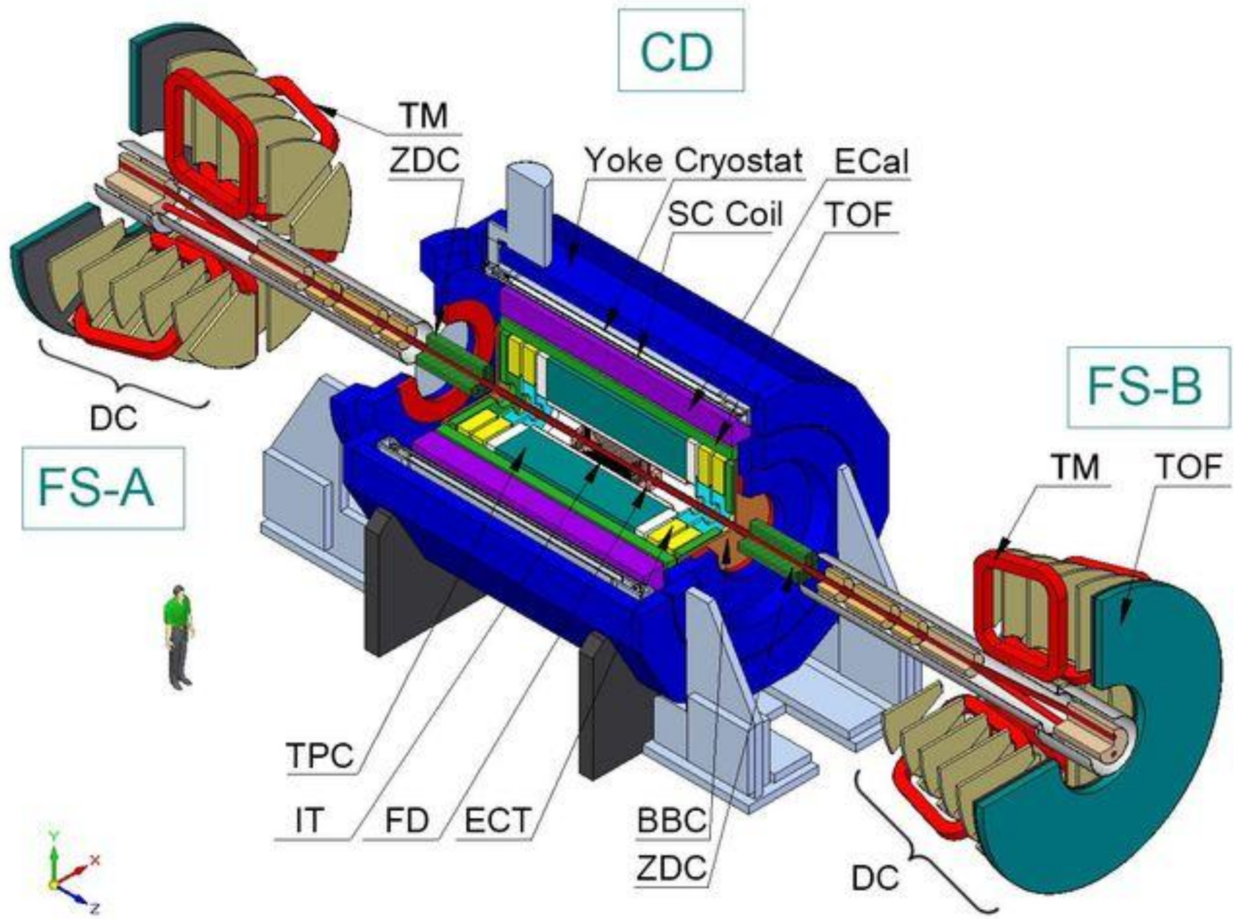
Outline

- Introduction
  - ✓ Some definitions
  - ✓ Spectators
- UrQMD generator
- LAQGSM generator
- Conclusions

NICA



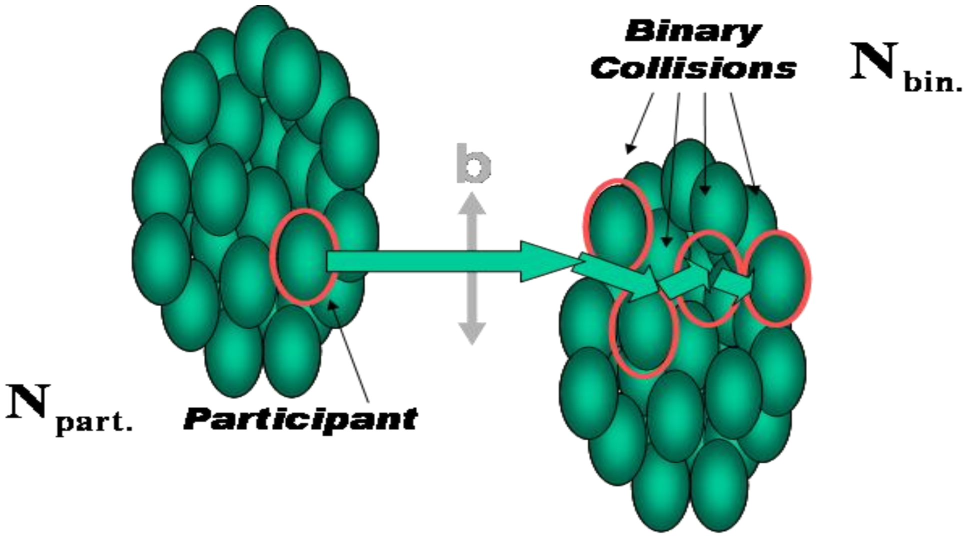
MPD

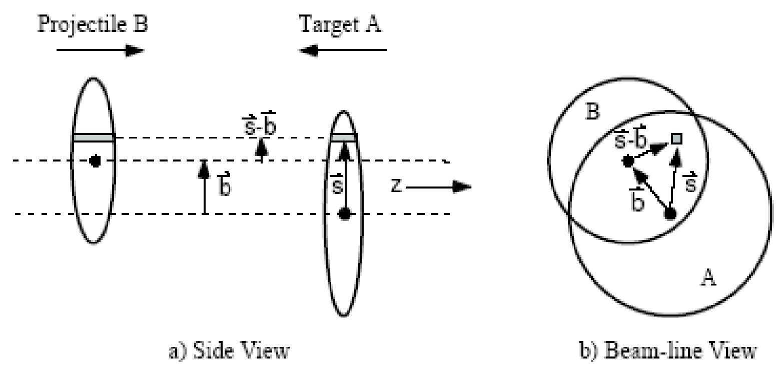


A.Litvinenko

VBLHEP JINR

Nuclear-Nuclear collisions





- Quasi-Classical picture
- b – not observable
- observables ⟺ **b**

The centrality classification

Geometrical cross section

$$\sigma_{geo} = 2\pi \int_0^{2R} b\,db = \pi(2R)^2$$

Geometrical cross section
for the fixed impact parameter

$$\sigma_{geo}(b) = 2\pi \int_0^{b} b\,db = \pi b^2$$

- Interval of impact parameter values $b = 2 \div 4\ \mathrm{fm}$
- Interval given in percents from the geometrical cross section

Centrality $40 \div 50\,\%$ corresponds to the region of the impact parameter:

$$\sigma_{geo}(b_{\min})/\sigma_{geo} = (\mathrm{b}_{\min}/2R)^2 = 0.4$$

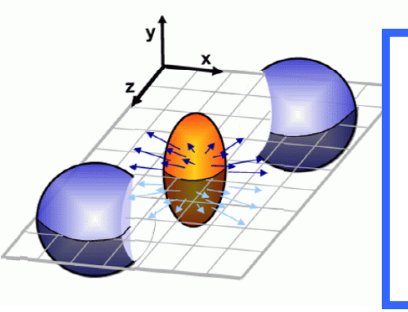
$$\sigma_{geo}(b_{\max})/\sigma_{geo} = (\mathrm{b}_{\max}/2R)^2 = 0.5$$

➡

$$b_{\min} = \sqrt{0.4}\,(2R) = 9.5\ \mathrm{fm}$$

$$b_{\max} = \sqrt{0.5}\,(2R) = 10.6\ \mathrm{fm}$$

The importance of the centrality classification



Space eccentricity

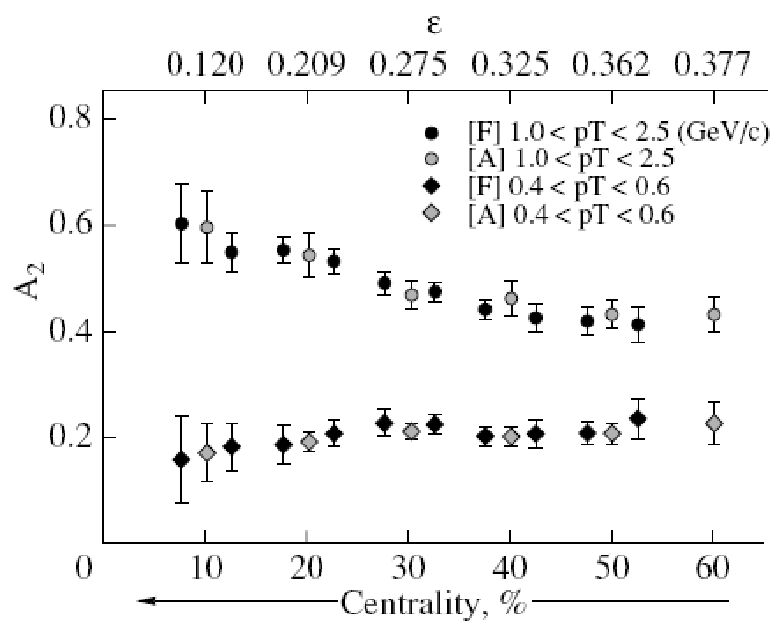
$$\varepsilon = \frac{<y^2> - <x^2>}{<y^2> + <x^2>}$$

Elliptic flow

$$\frac{\mathbf{dN}}{\mathbf{d}} = \frac{1}{2\pi}(1 + 2\mathbf{v}_1 \,\mathbf{cos} \quad + 2\mathbf{v}_2 \,\mathbf{cos}\, 2 \quad + \ldots)$$

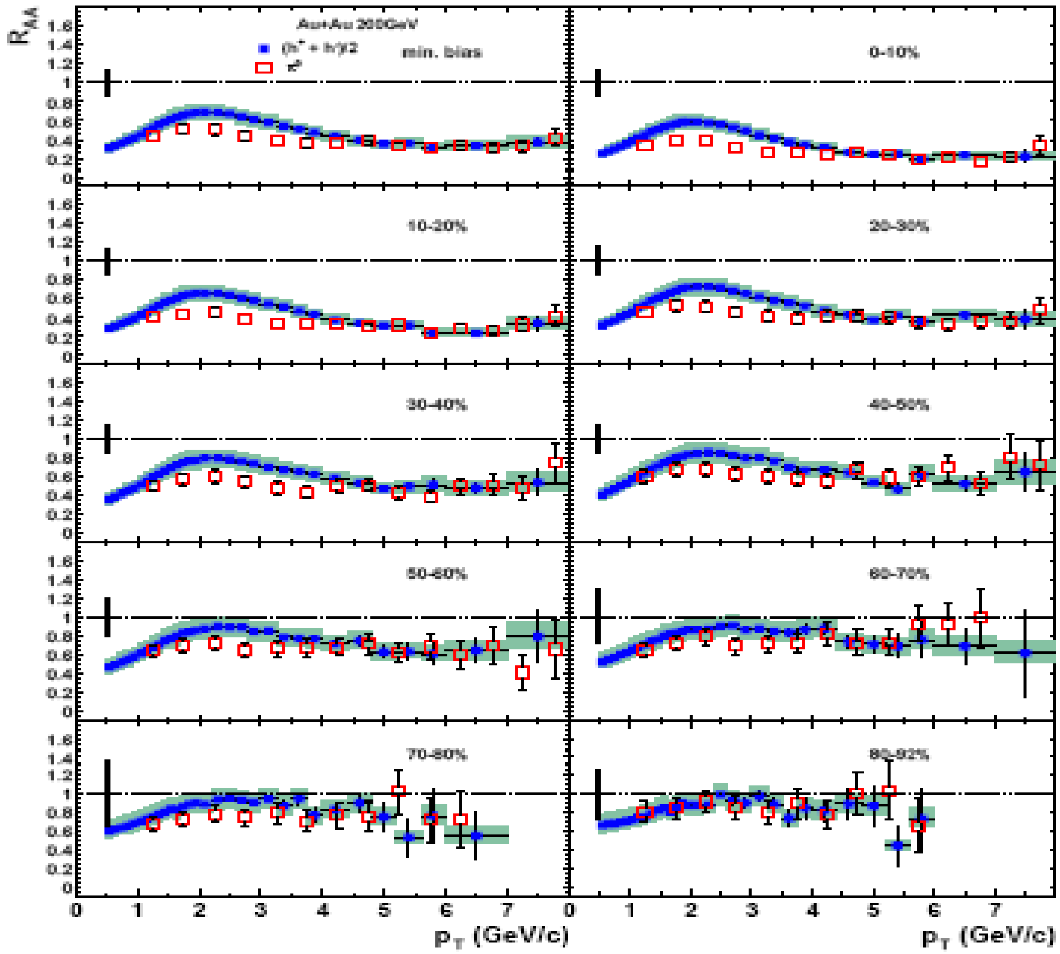
$$\mathbf{A}_2 = \frac{\mathbf{v}_2}{\boldsymbol{\varepsilon}}$$

Nuclear Physics A
V757, No. 1-2 , p.184,2005



elliptic flow scaling
with space eccentricity → short equlibration time

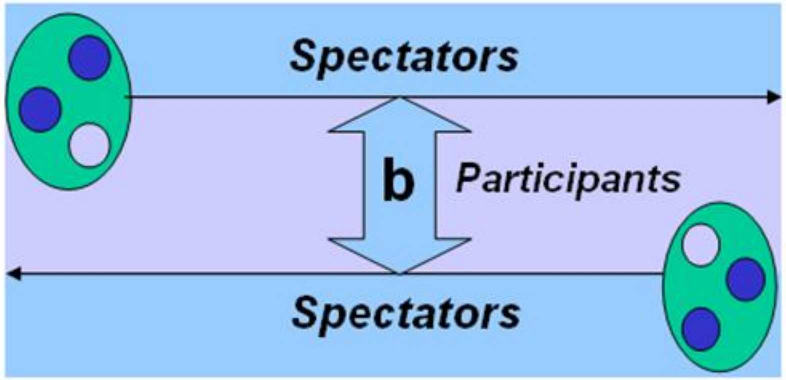
The importance of the centrality study



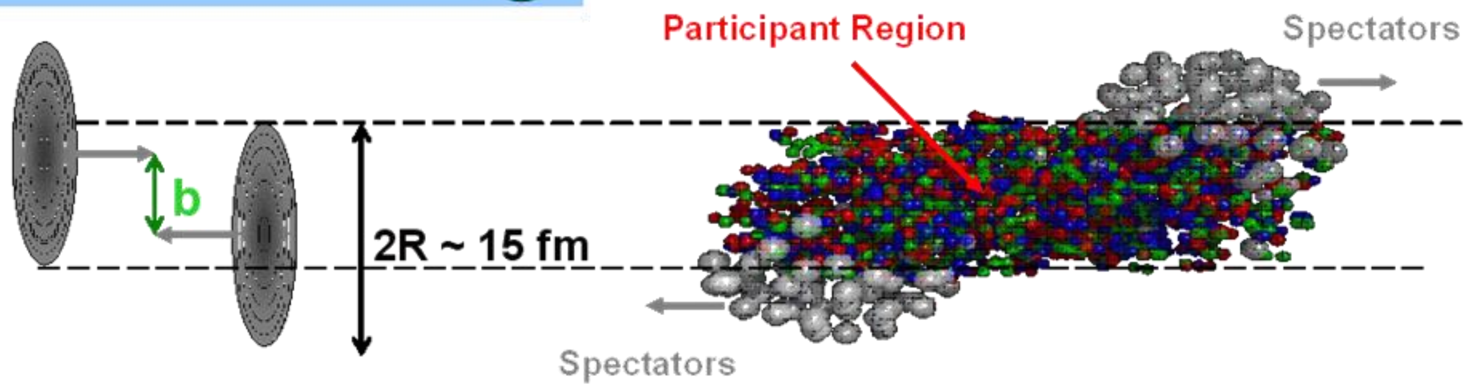
Nuclear Physics A V757, No. 1-2 , p.184,2005

Jet Quenching – nuclear modification factor vs centrality

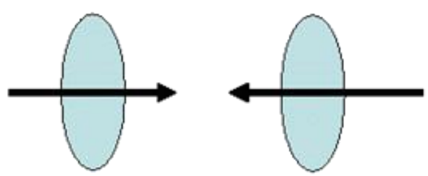
The centrality determination – the observables:



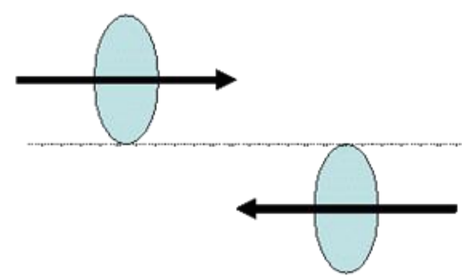
- The number of particles produced in the region of rapidity close to zero
- The total energy of spectators



Central collision, b = 0

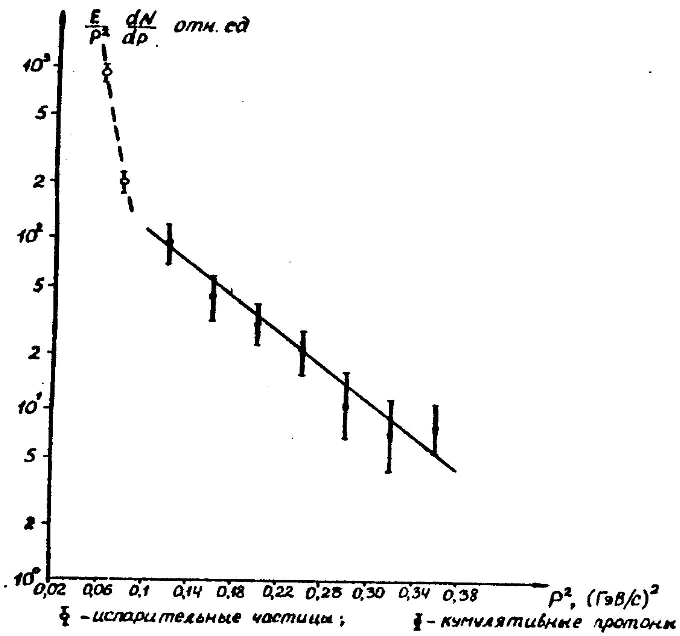


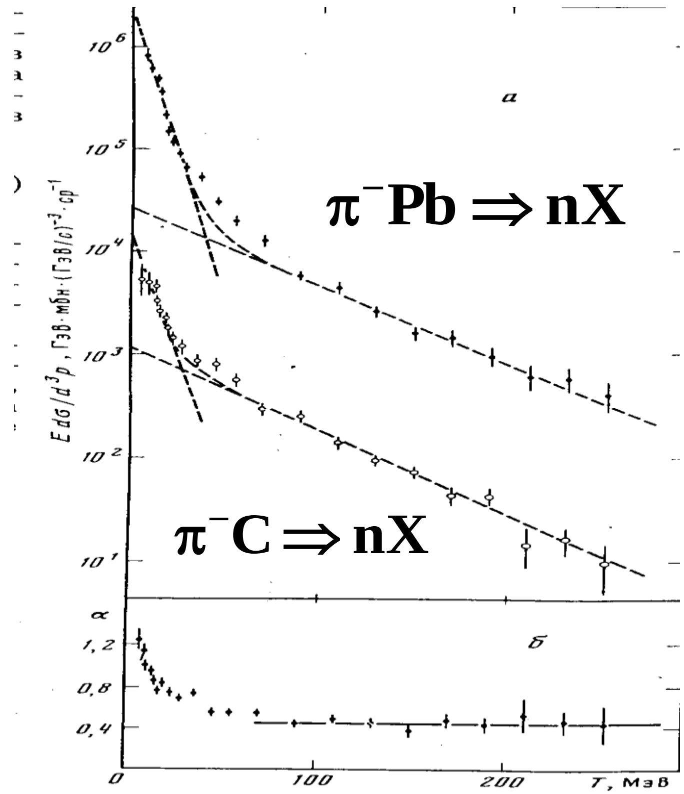
Peripheral collision, b ≈ 2R



Nucleon spectators (spectrum)

$$\breve{\nu} + Em = p(backward) + X$$





R.Ammaru et al., **Pisma v JETF, V.94, No. 4, p.189, (1989)**

Yu.Bayukov et al ., **YaF V.35, No. 4, p.960, (1982)**

Spectator spectrum

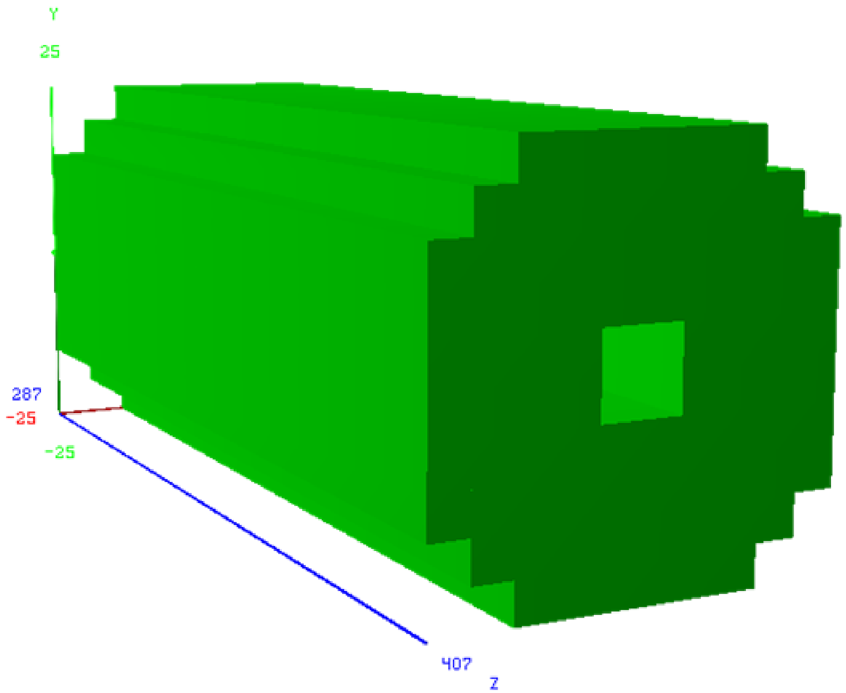
$$E\frac{d\sigma}{d^3p} = C \bullet \exp(-T/T_0) \qquad T_0 = 5 - 10\ \text{МэВ}$$

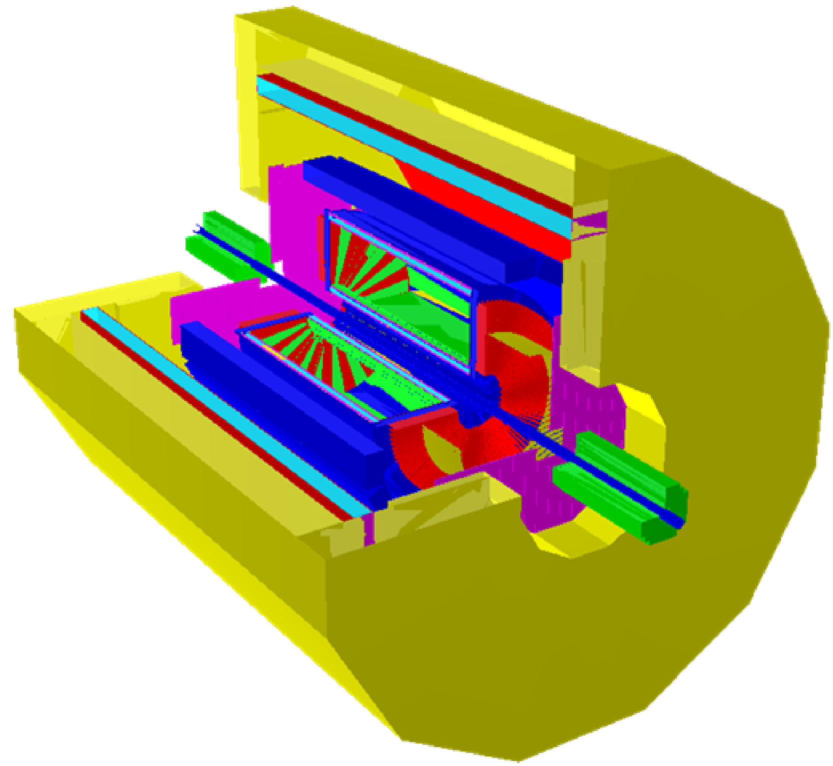
$$E\frac{d\sigma}{d^3p} = C \bullet \exp\left(-\frac{P_S P_F - m_N^2}{m_N T_0}\right)$$

$$E\frac{d\sigma}{d^3p} = C \bullet \exp\left(-\frac{(p-p_b)^2}{2\sigma_p^2}\right) \bullet \exp\left(-\frac{\Theta^2}{2\sigma_\Theta^2}\right)$$

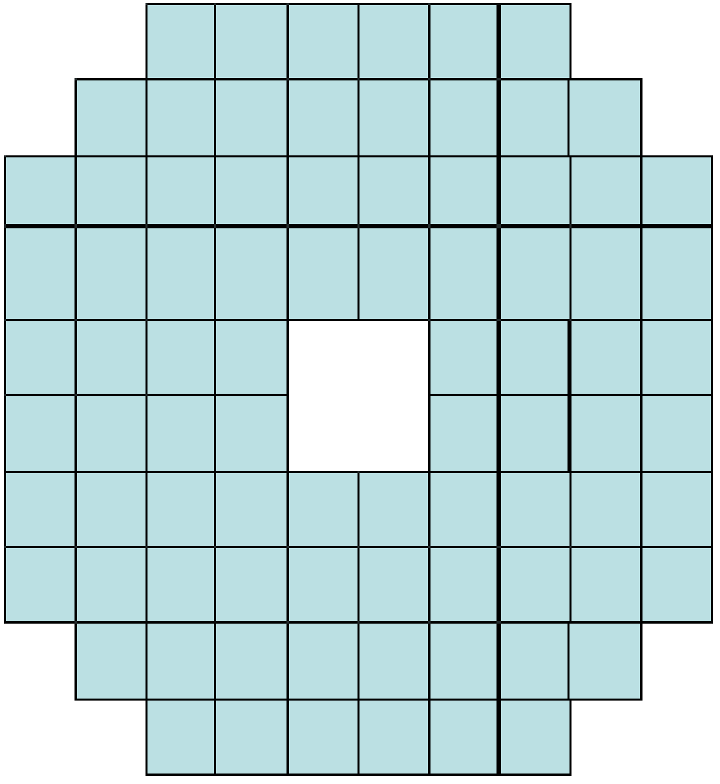
$$\sigma_p = \sqrt{\frac{E_b T_0}{m_N}} = 0.15 - 0.22\ \text{GeV/c}; \quad \sigma_\Theta = \sqrt{\frac{m_N T_0}{p_b^2}} = 0.016 - 0.022$$

ZDC for NICA/MPD (standard geometry)





ZDC consists from the modules $10x10x120cm^3$ (or $5x5x120cm^3$). Each module consists of 60 lead-scintillator sandwiches $10x10cm^2$ with thicknesses 16 and 4mm. Main attention in the technical design was paid to the method of light readout from the scintillator tiles that should provide good efficiency and uniformity of light collection.



Front view of ZDC. The squares size is 5 x 5 cm x cm

ZDC@MPD geometrical efficiency

$$\varepsilon(ZDC) = N_S(ZDC) / N_S(tot.)$$

central hole

$$\varepsilon(ZDC) = \frac{\int_{r_{int}/L_{ZDC}}^{\infty} \exp(-\frac{\Theta^2}{2\sigma_\Theta^2})\Theta d\Theta)}{\int_0^{\infty} \exp(-\frac{\Theta^2}{2\sigma_\Theta^2})\Theta d\Theta)} = 50 \div 70\ \%$$

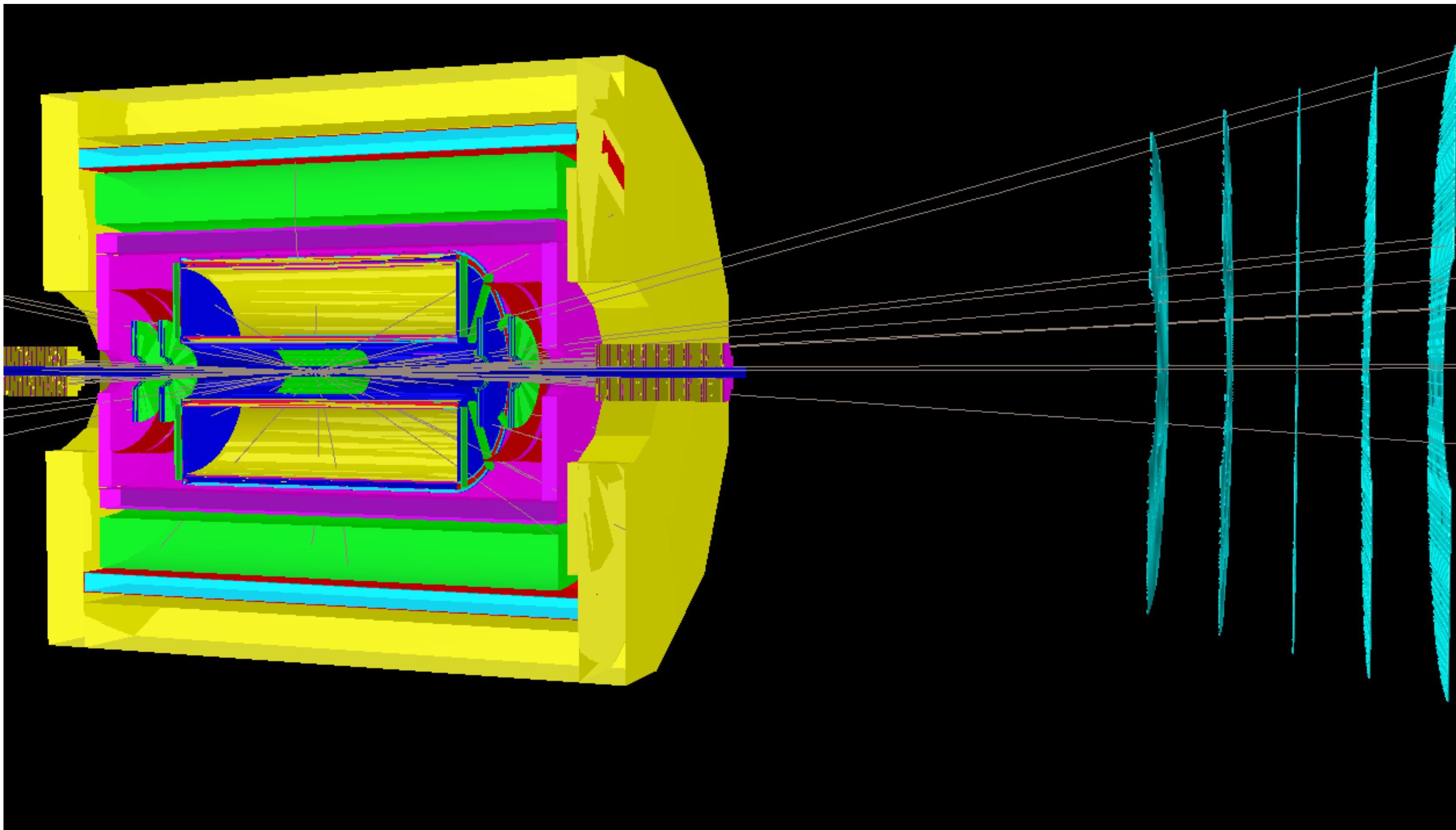
out of ZDC

$$\varepsilon(ZDC) > 0.99$$

Simulation

Transport – Geant3 and Geant4, generates UrQMD and LAQGSM

framework MpdRoot

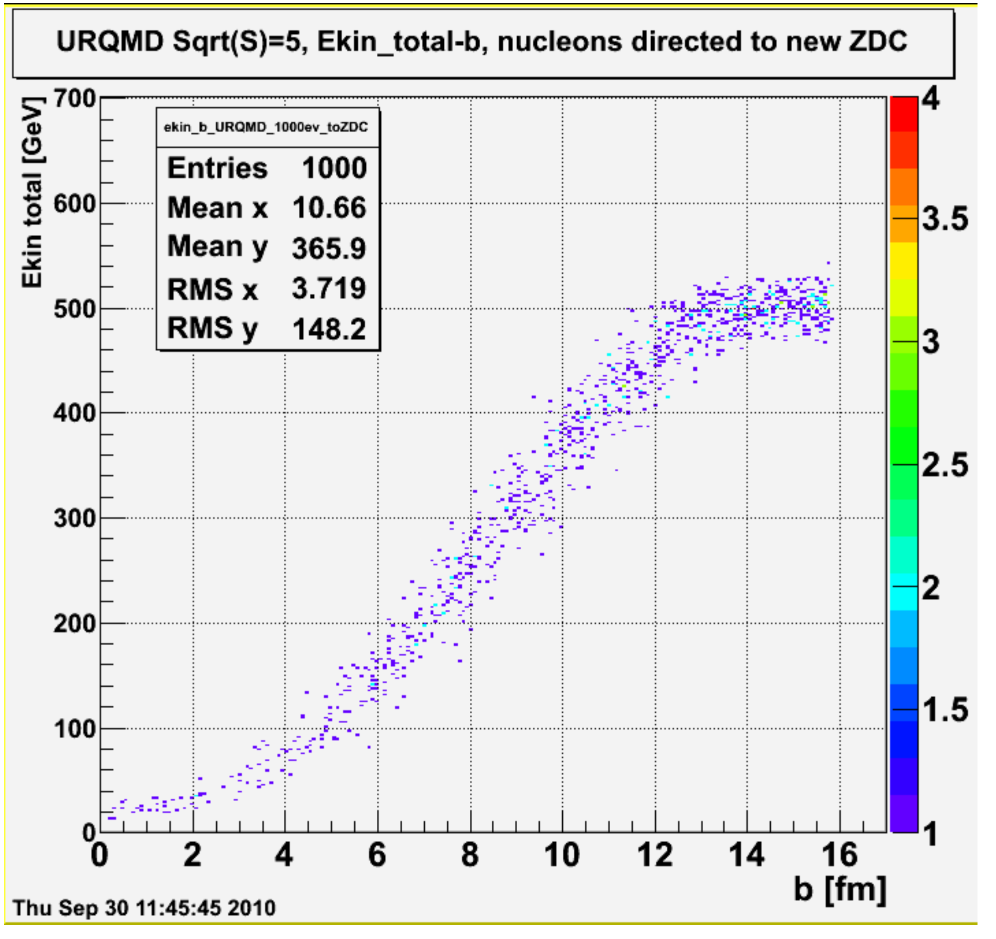


A.Litvinenko

VBLHEP JINR

Optimistic results with UrQMD

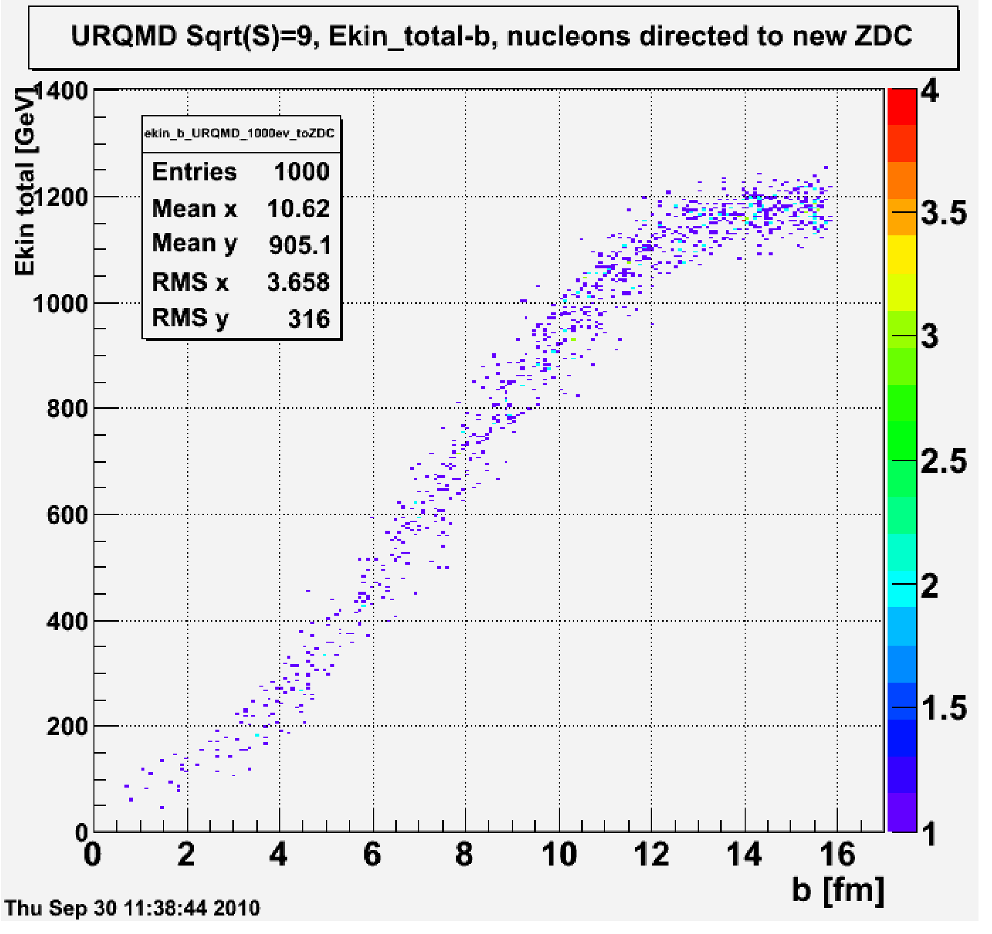
URQMD generator, Sqrt(S)=5 GeV



Total kinetic energy of all nucleons directed to ZDC

Optimistic results with UrQMD

URQMD generator, Sqrt(S)=9 GeV



$$\varepsilon = \frac{\Delta E_{ZDC}}{(\sqrt{S_{NN}} - 2m_N)A} = 0.78$$

Total kinetic energy of all nucleons directed to ZDC

The accuracy of impact parameter determination for MC with UrQMD

$$N(b) = A \bullet b + C; \Delta N = \sqrt{N}; \qquad \delta N = 1/\sqrt{N(b)}$$

$$E(b) = T_b \bullet N(b); \Delta E = T_b \bullet \sqrt{N}; \; \delta E = 1/\sqrt{N(b)}$$

$$b = \frac{N(b) - C}{A} \quad ; \Delta b = \frac{1}{A}\sqrt{N(b)}; \quad \delta b = \frac{\sqrt{N(b)}}{N(b) - C}$$

$$b = 0 \text{ fm} \quad ; \Delta b = 0.35 \text{ fm}; \quad \delta b =$$

$$E(b) = 114 \text{ GeV}; \Delta E = 20 \text{ GeV}; \; \delta E = 18\,\%$$

$$b = 5 \text{ fm} \quad ; \Delta b = 0.67 \text{ fm}; \quad \delta b = 13\,\%$$

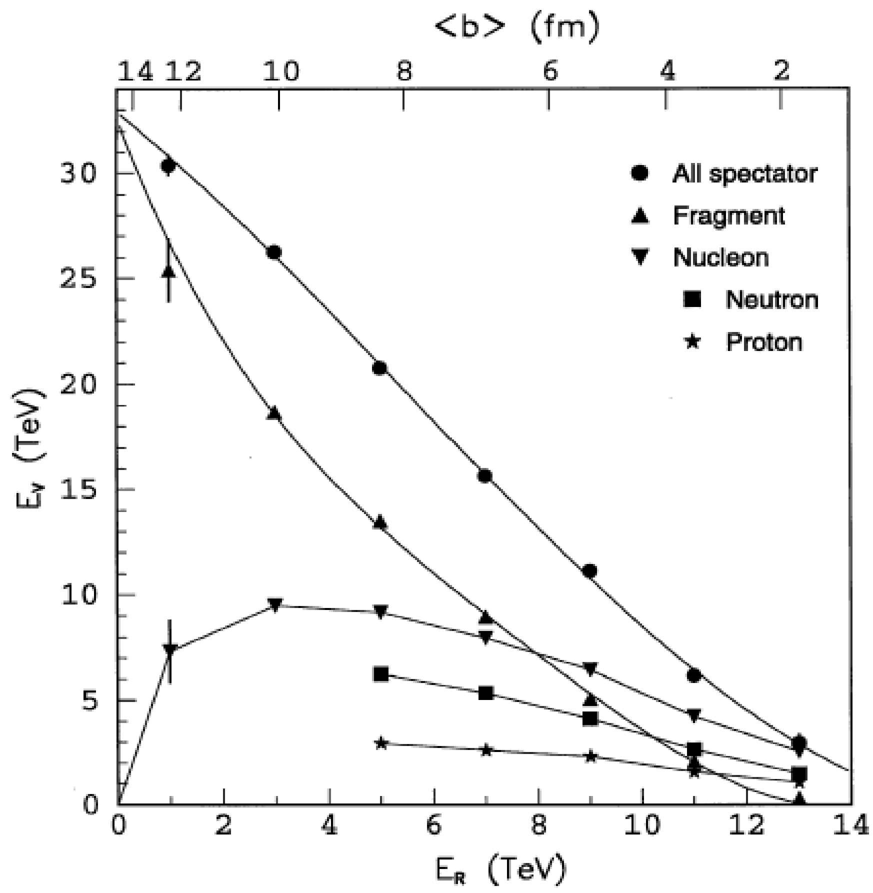
$$E(b) = 392 \text{ GeV}; \Delta E = 38 \text{ GeV}; \; \delta E = 10\,\%$$

$$b = 10 \text{ fm} \quad ; \Delta b = 0.87 \text{ fm}; \quad \delta b = 9\,\%$$

$$E(b) = 673 \text{ GeV}; \Delta E = 49 \text{ GeV}; \; \delta E = 7\,\%$$

$$\frac{\Delta E}{E} = \frac{\beta}{\sqrt{E}}; \qquad \beta << 150\,\%$$

But



The NA49 collaboration. Eur. Phys. J., ***A2****, 383, (1998)*

But

LAQGSM high-energy event generator

HSS06, FNAL, Batavia, IL, USA, September 6-8, 2006

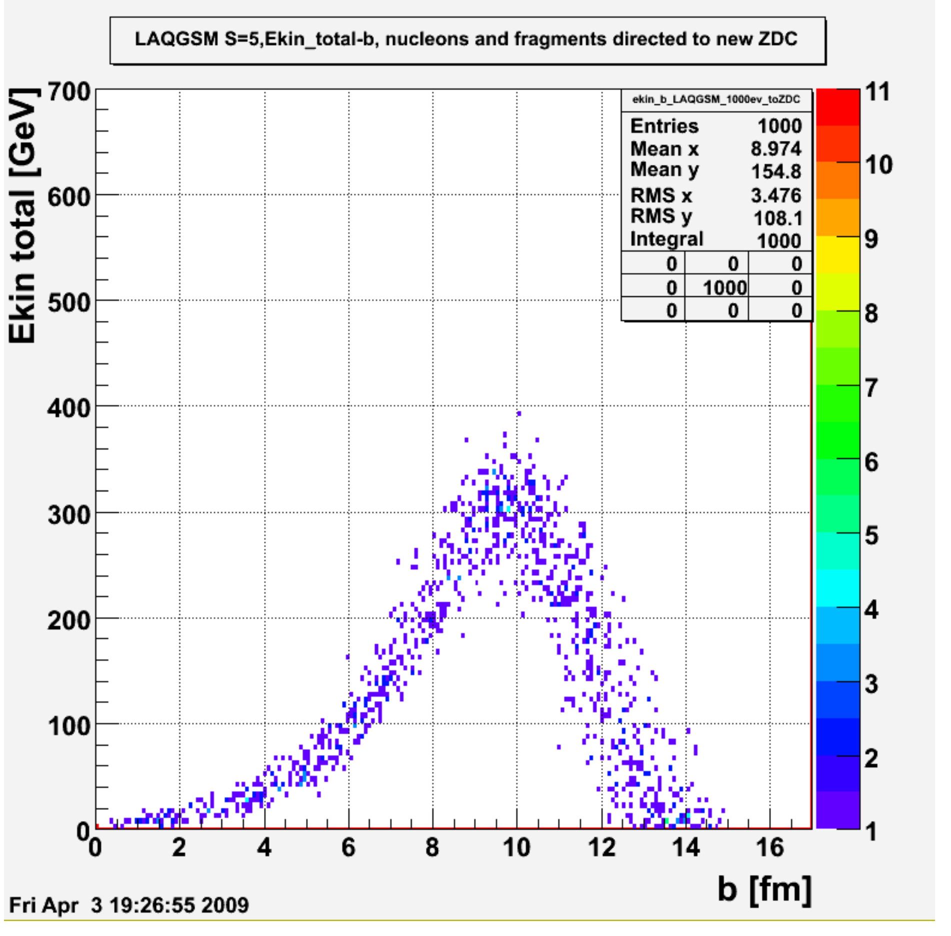
Overview and Validation of the CEM03.01 and LAQGSM03.01 Event Generators for MCNP6, MCNPX, and MARS15

S. G. Mashnik[1], K. K. Gudima[2], R. E. Prael[1], A. J. Sierk[1], M. I. Baznat[2], N. V. Mokhov[3]

[1]Los Alamos National Laboratory, Los Alamos, NM, USA
[2]Academy of Science of Moldova, Chisinau, Moldova
[3]Fermi National Accelerator Laboratory, Batavia, IL, USA

Taking into account spectator fragments

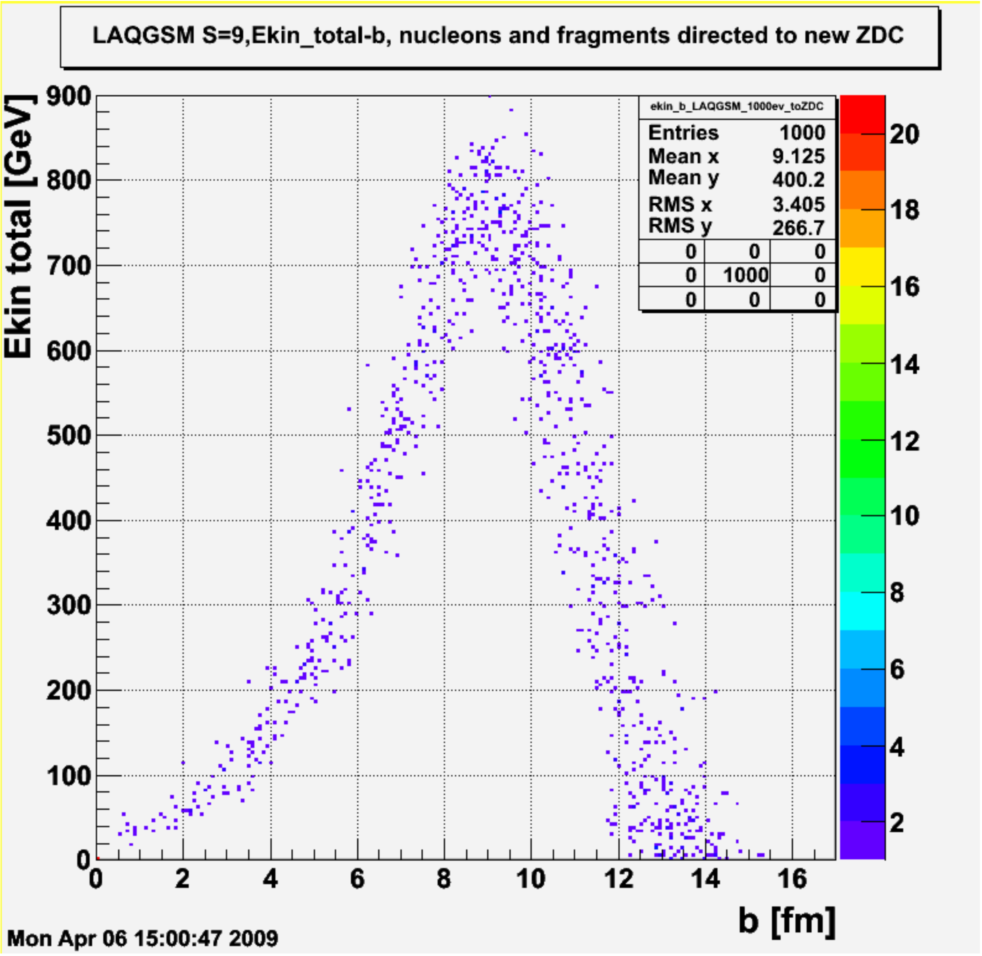
LAQGSM generator, Sqrt(S)=5 GeV



Total kinetic energy of all nucleons
and fragments directed to ZDC

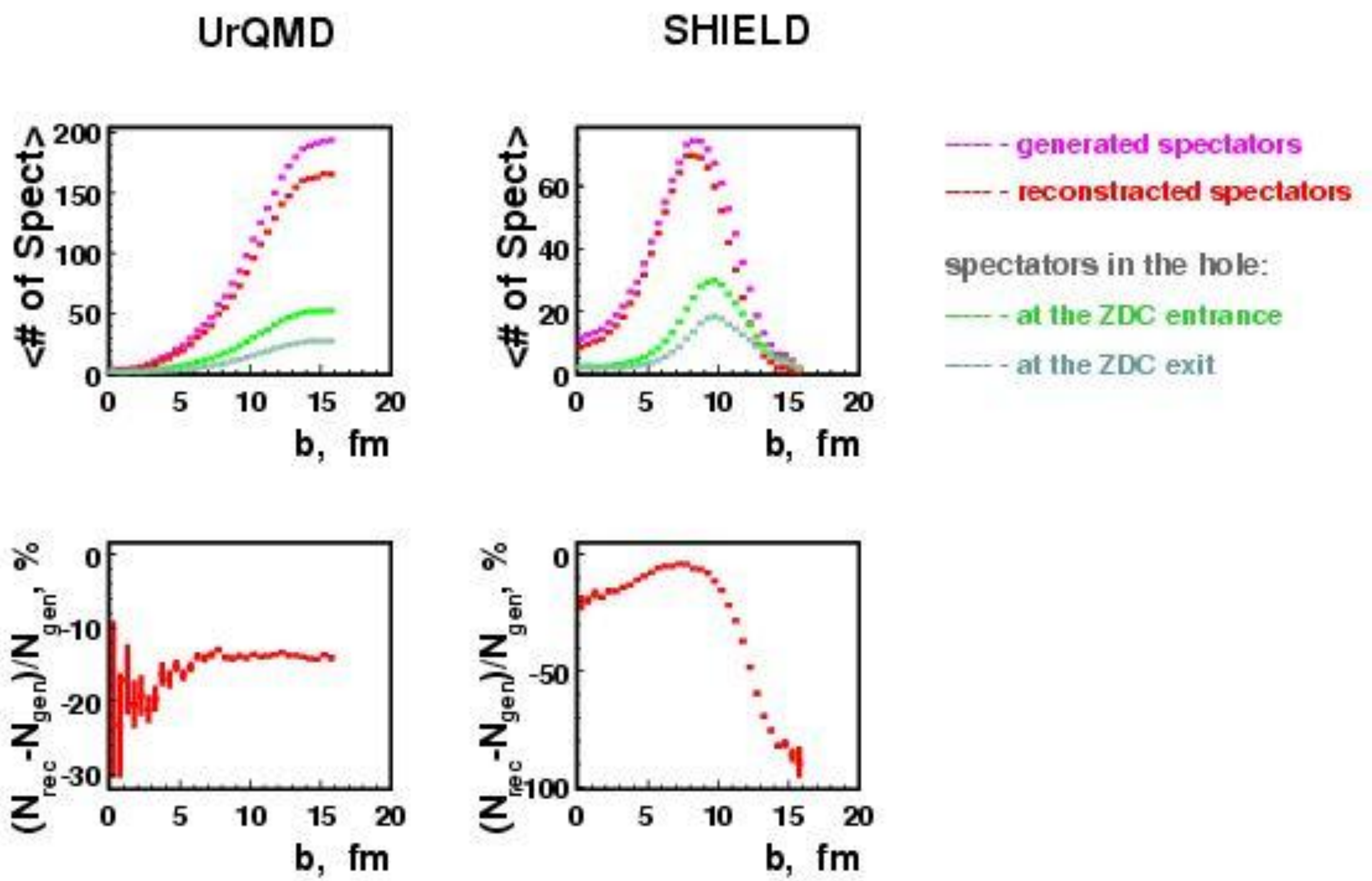
Taking into account spectator fragments

LAQGSM generator, Sqrt(S)=9 GeV

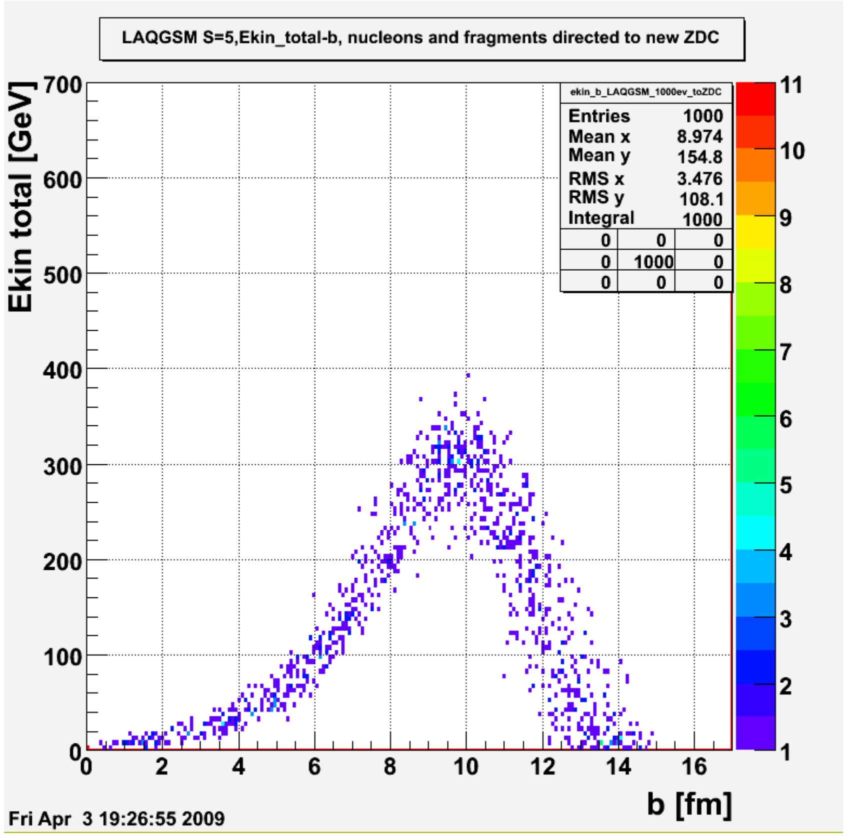


Total kinetic energy of all nucleons and fragments directed to ZDC

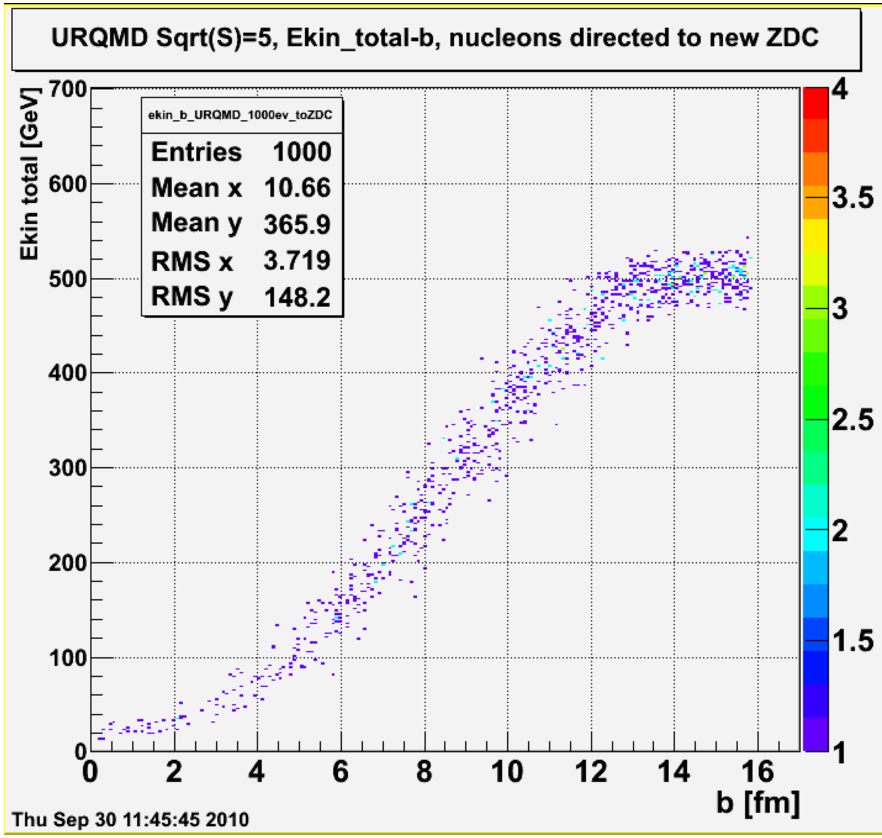
SHIELD event generator



LAQGSM, Sqrt(S)=5 GeV



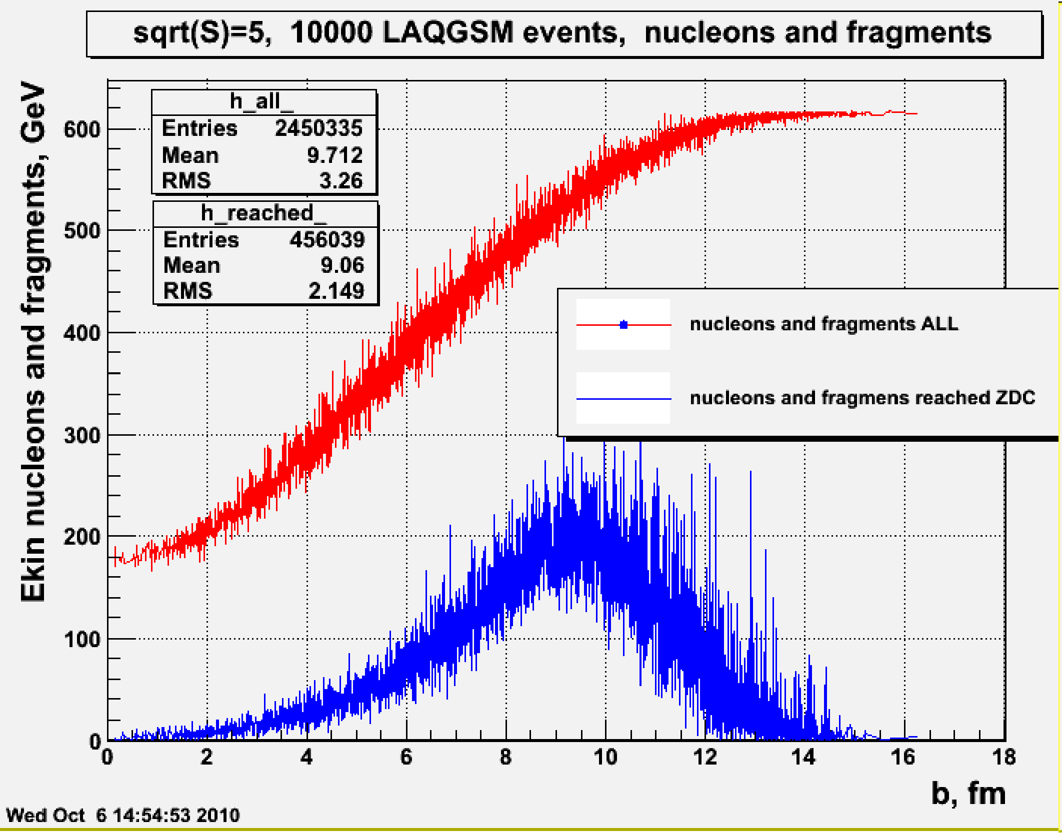
URQMD, Sqrt(S)=5 GeV

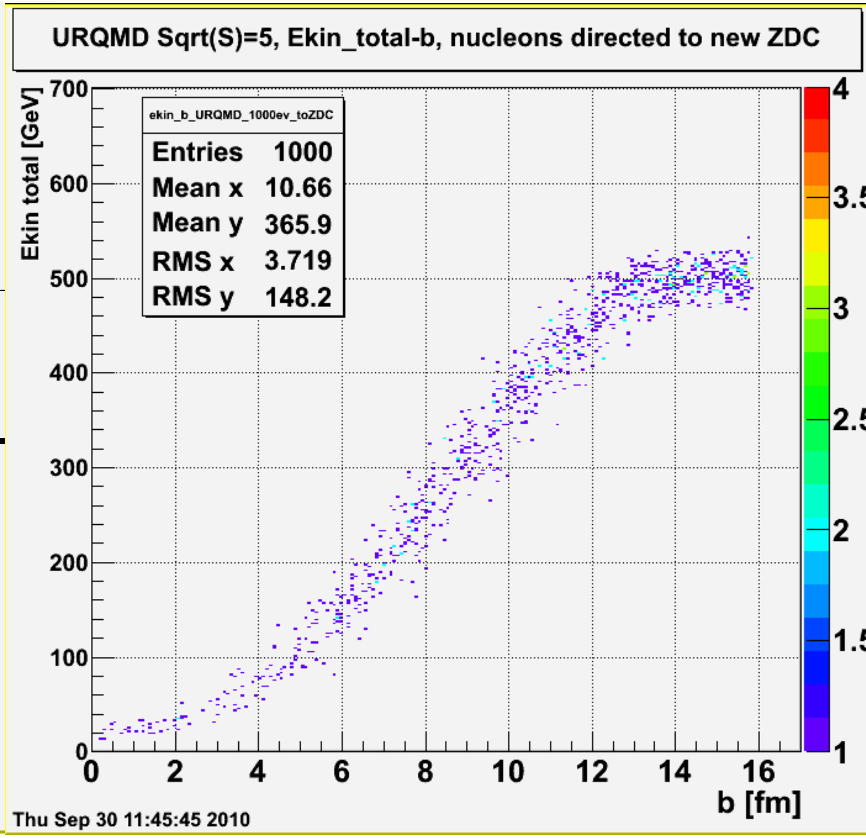


Total kinetic energy of all nucleons
and fragments directed to ZDC

LAQGSM, Sqrt(S)=5 GeV

URQMD, Sqrt(S)=5 GeV





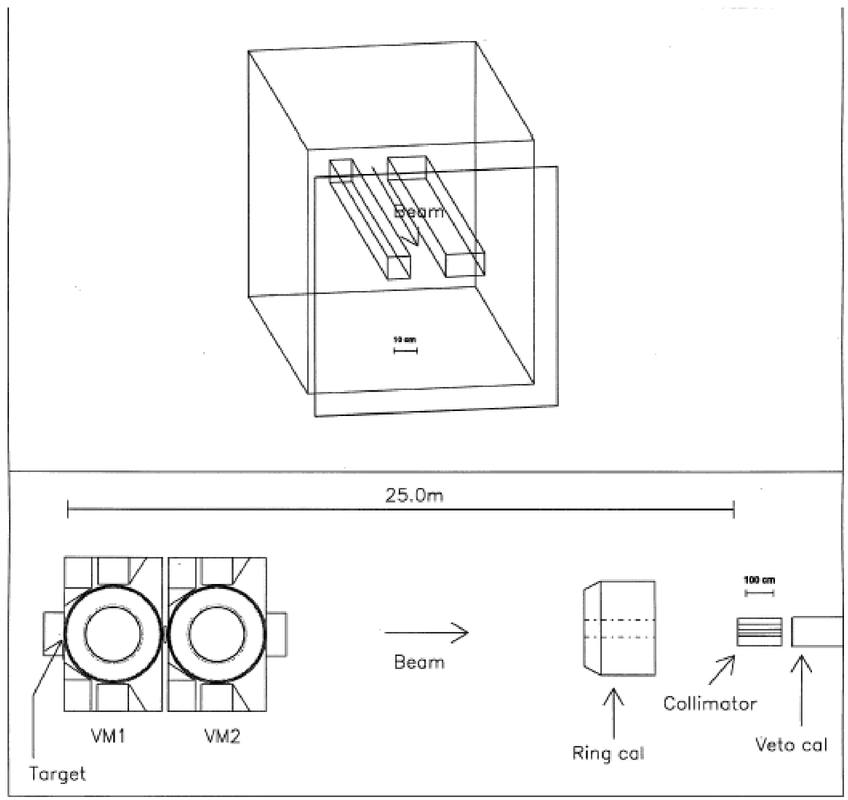
A.Litvinenko

VBLHEP JINR

Eur. Phys. J. A 2, 383–390 (1998)

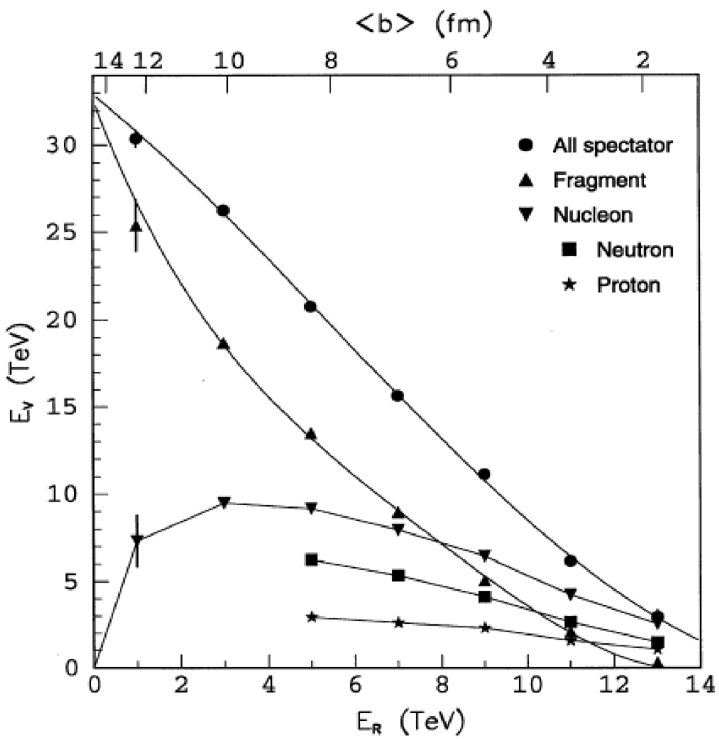
THE EUROPEAN
PHYSICAL JOURNAL A

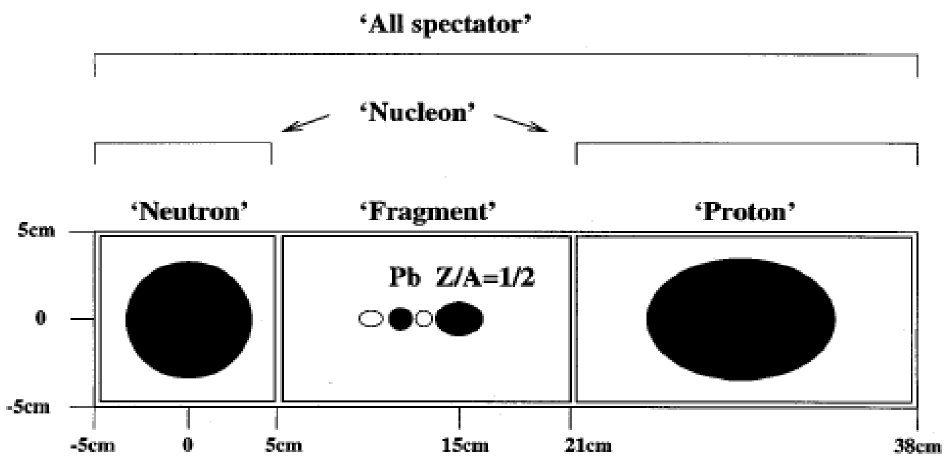
Spectator Nucleons in Pb+Pb Collisions at 158 A·GeV



Experimental data : the deposited energy for different types of spectators in dependence of the centrality

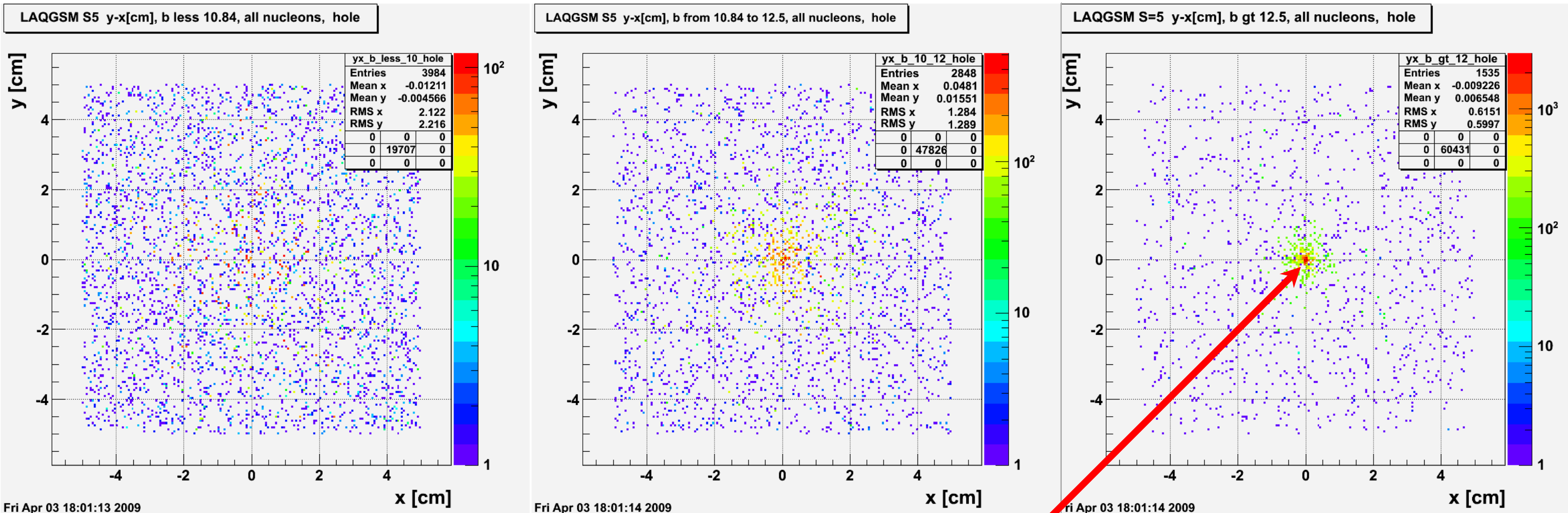
*The NA49 collaboration. Eur. Phys. J., **A2**, 383, (1998)*





At large impact parameters the most of spectator nucleons are bound in fragments.

All nucleons directed to the hole of ZDC (rectangle 10x10cm^2)



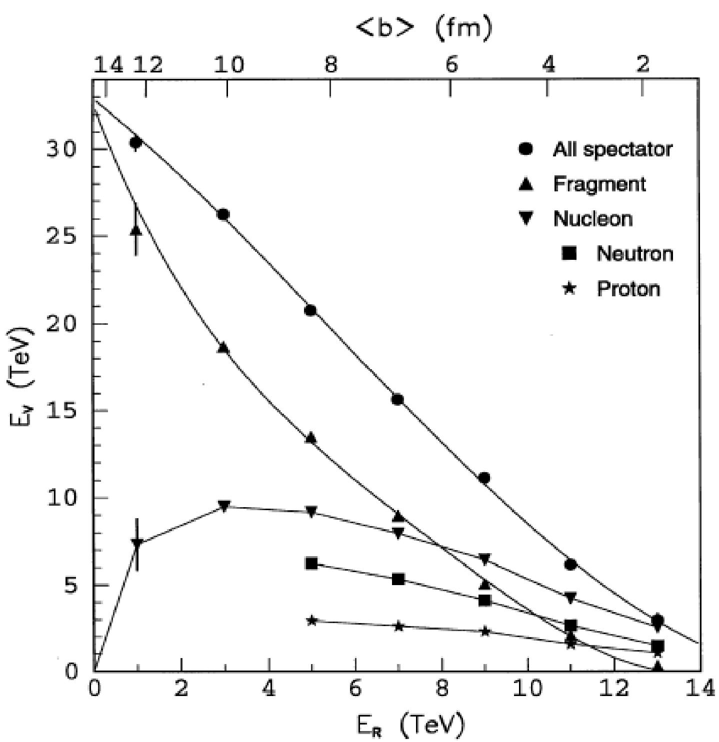
0 % - 60 % 60 % - 80 % 80 % - 100 %

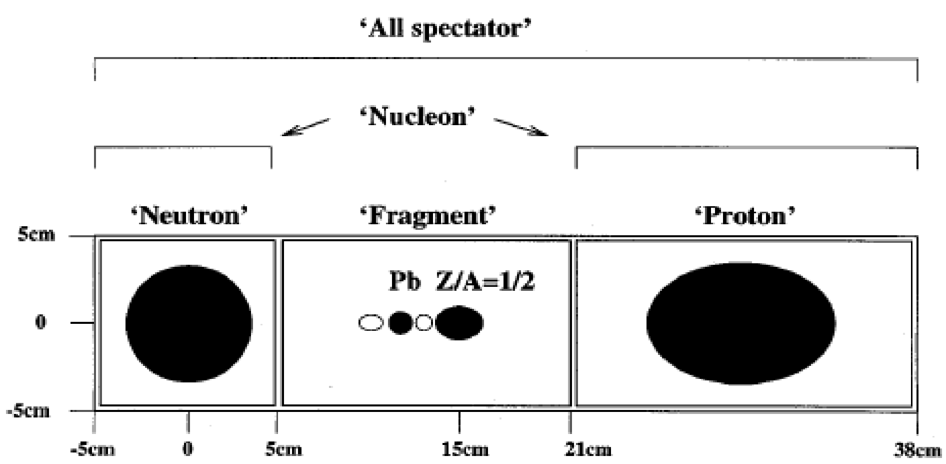
$$\theta \sim 0.3 \cdot 10^{-3}\ \text{rad} = 0.3\ \text{mrad}$$

value centrality	< 60 %	60 – 80 %	> 80 %
N_{ZDC}	71041	22848	4787
N_{hole}	19707	47826	60431
$N_{tot} = N_{ZDC} + N_{hole}$	90748	70674	65218
$\varepsilon = N_{hole}/N_{tot}$	22 %	68 %	93 %

Experimental data : the deposited energy for different types of spectators in dependence of the centrality

The NA49 collaboration. Eur. Phys. J., ***A2****, 383, (1998)*

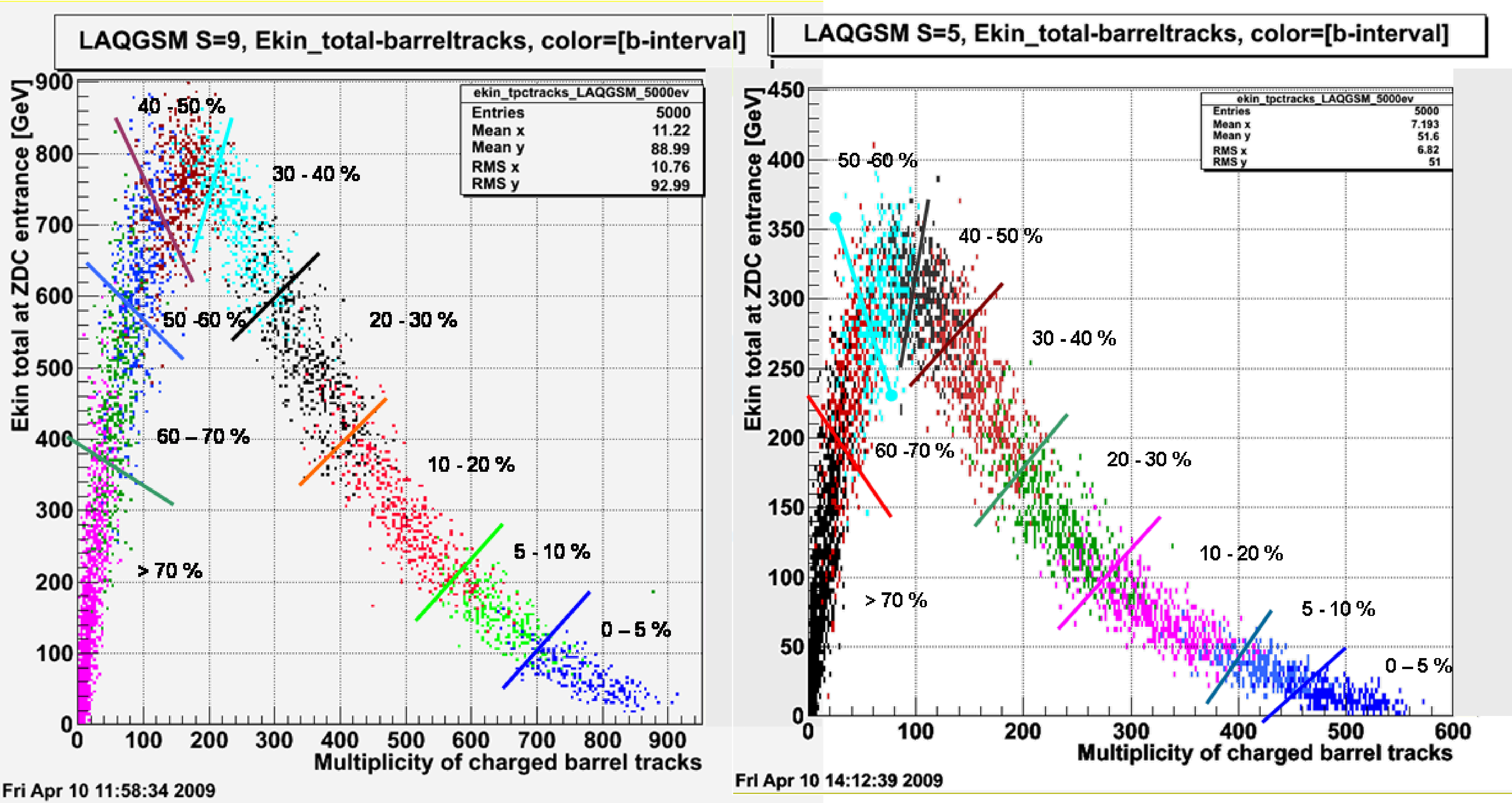




At large impact parameters the most of spectator nucleons are bound in fragments.

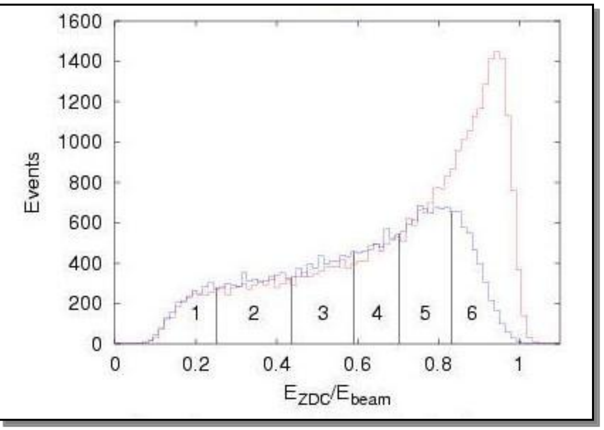
The centrality determination:

ZDC (energy) + number of charged barrel tracks

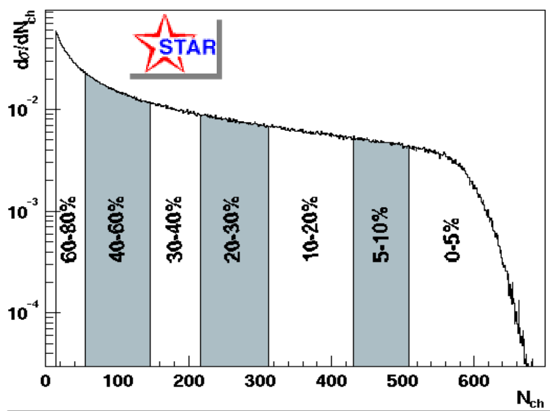


Centrality determination in some experiment

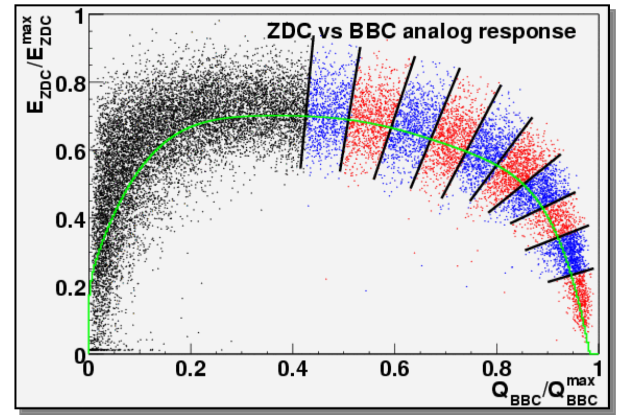
NA49

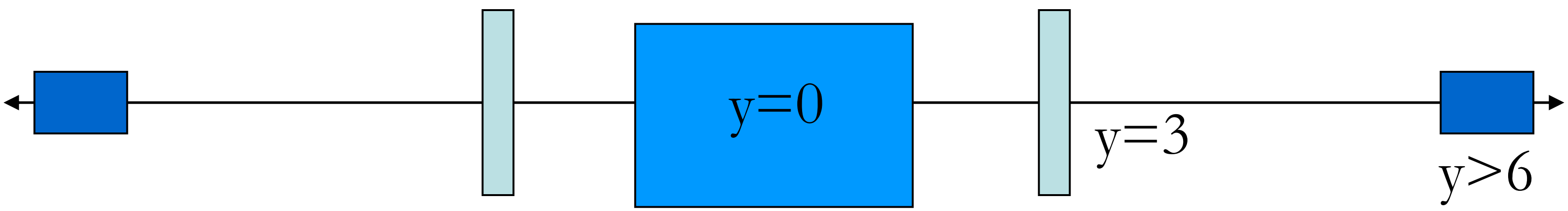


STAR



PHENIX





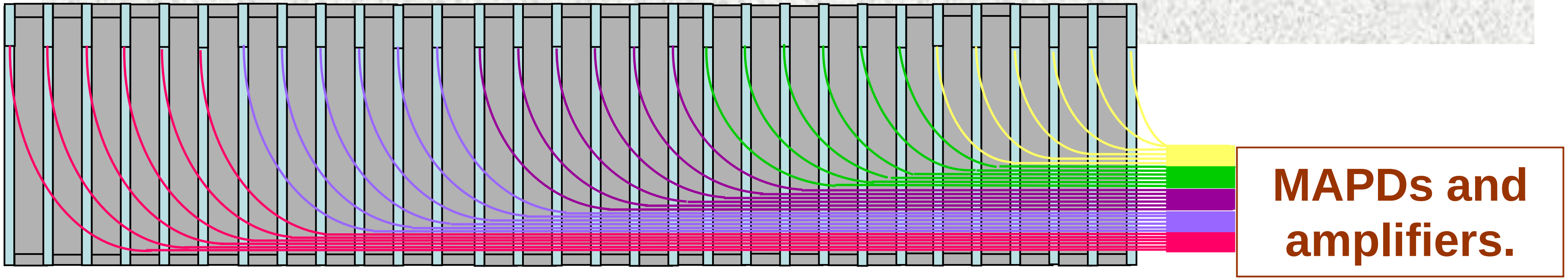
NA49	ZDC Only
STAR	TPC only
PHENIX	BBC & ZDC

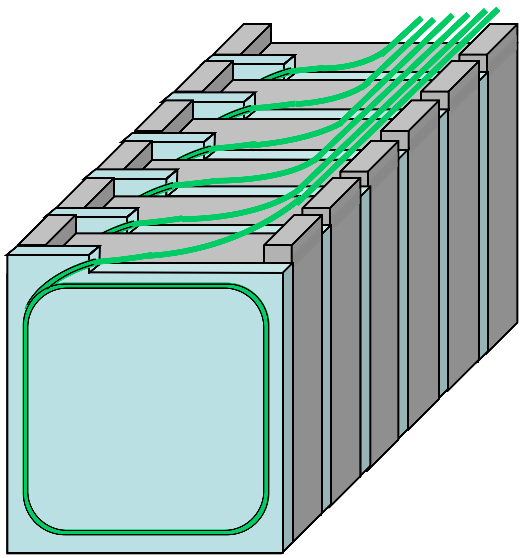
Conclusions

- The SHIELD and LAQGSM could be used for NICA/MPD simulations under mpdroot.
- The SHIELD and LAQGSM angular distributions of the spectators differ from URQMD picture.

- The experimental study of the spectator distributions and calorimeter resolution have to be performed on the extracted beam of NUCLOTRON-M at the fixed target.

Structure of ZDC module





MAPD – micro pixel avalanche photodiods

- ❑ 60 lead/scintillator sandwiches
- ➢ lead – 16 mm
- ➢ scintillator – 4 mm

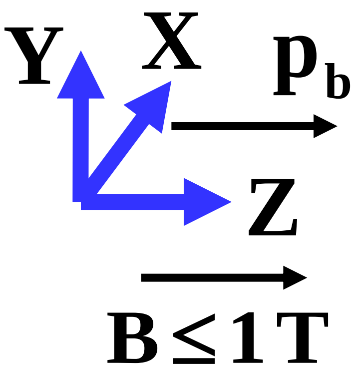
$$\frac{\Delta E}{E} = \frac{(67 \pm 12)\%}{\sqrt{E}}$$

This work is partially supported by

RFBR GRANT No. 10-02-01036-a

Backup slides

Fast evaluations: the movement of spectators at NICA/MPD



$$\begin{cases} x(z) = \dfrac{p_T A}{0.3QB} \sin\left(\dfrac{0.3QB \bullet z}{p_z A}\right) \\ y(z) = \dfrac{p_T A}{0.3QB} \cos\left(\dfrac{0.3QB \bullet z}{p_z A}\right) - \dfrac{p_T A}{0.3QB} \end{cases}$$

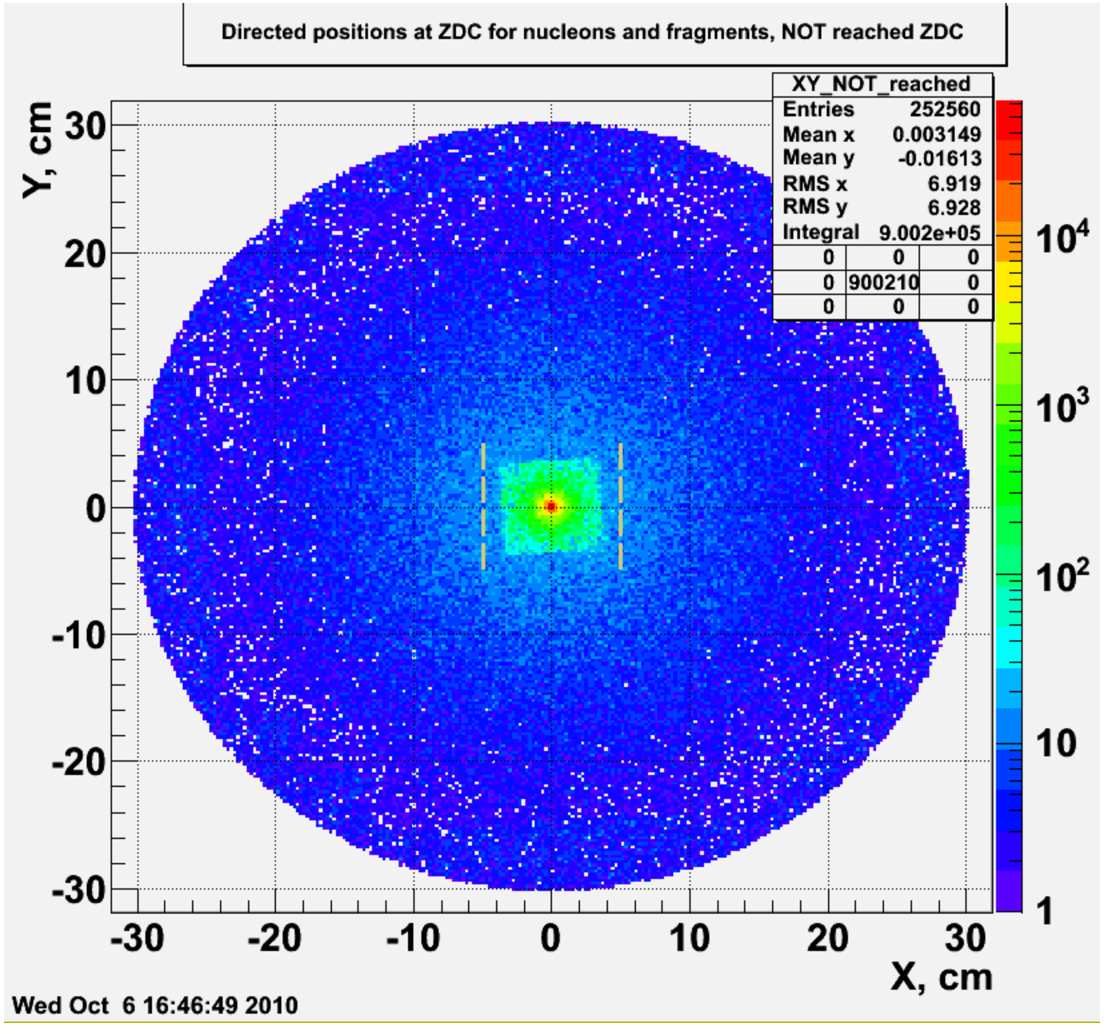
$$\rho(B, z) = \sqrt{x^2 + y^2} = \frac{p_T A}{0.3QB} \sqrt{2\left(1 - \cos\left(\frac{0.3QB \bullet z}{p_z A}\right)\right)}$$

$$\left(\frac{0.3QB \bullet z}{p_z A}\right) \leq 0.2 \Rightarrow \rho(B, z) = \frac{p_T}{p_z} z \,;\, \Delta\phi = \frac{1}{2}\left(\frac{0.3QB \bullet z}{p_z A}\right)$$

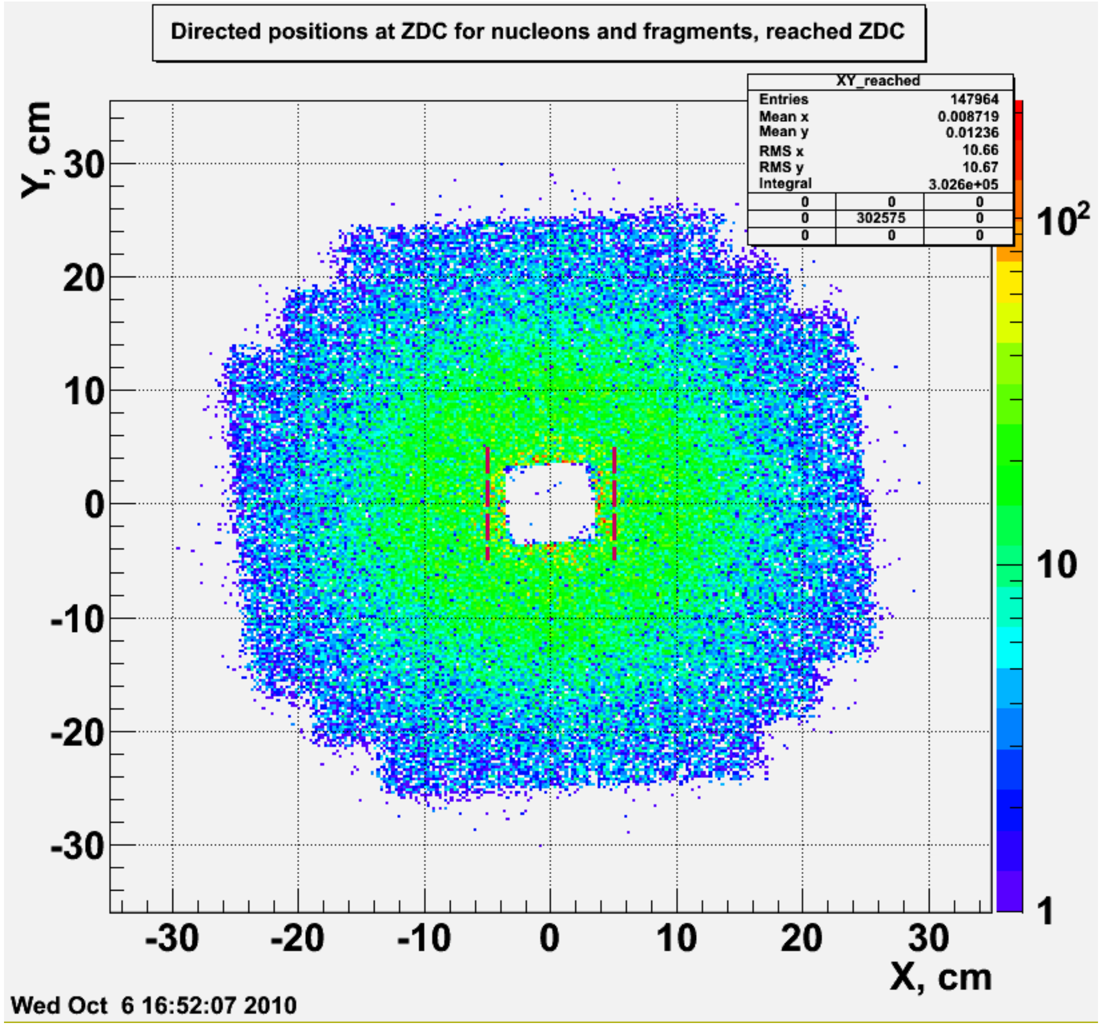
The conclusion:

✓Magnetic field of MPD will not change the polar angles for spectators at ZDC position $\Theta = p_T / p_z$

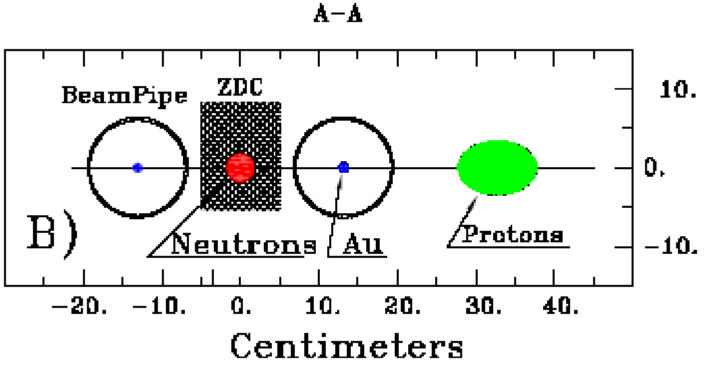
✓ it will only slightly changes the azimutal angles $\Delta\phi \leq 6^0$

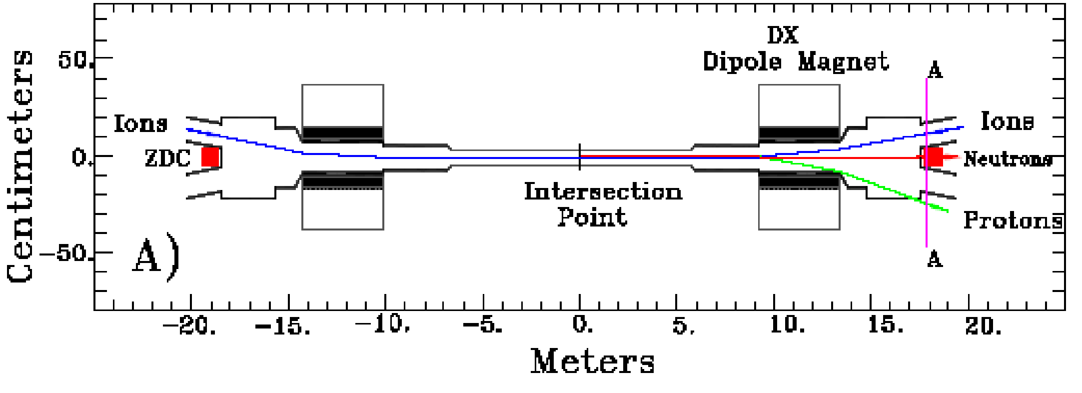


Directed positions at ZDC for nucleons and fragments, NOT reached ZDC
XY_NOT_reached
Entries 252560
Mean x 0.003149
Mean y -0.01613
RMS x 6.919
RMS y 6.928
Integral 9.002e+05
0 0 0
0 900210 0
0 0 0
Y, cm
X, cm
Wed Oct 6 16:46:49 2010

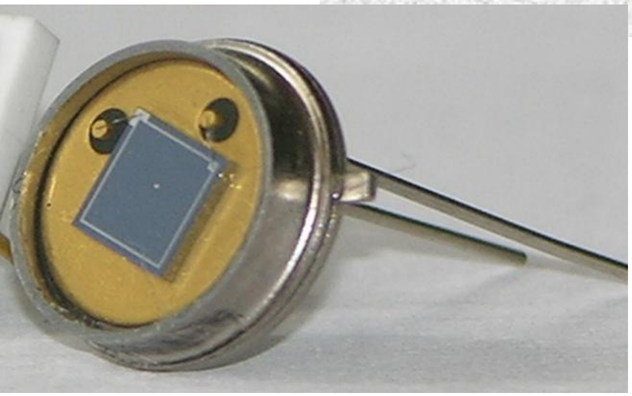

Directed positions at ZDC for nucleons and fragments, reached ZDC
XY_reached
Entries 147964
Mean x 0.008719
Mean y 0.01236
RMS x 10.66
RMS y 10.67
Integral 3.026e+05
0 0 0
0 302575 0
0 0 0
Y, cm
X, cm
30
20
10
0
-10
-20
-30
10^2
10
1
Wed Oct 6 16:52:07 2010

The RHIC Zero Degree Calorimeters



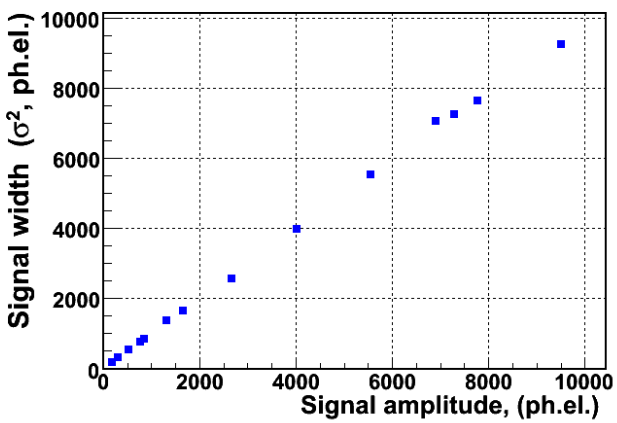


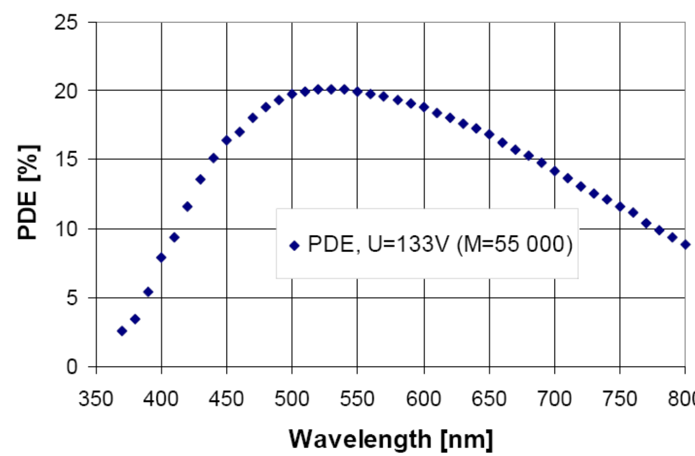
Properties of MAPDs



New generation of micropixel APD produced in Singapore by Zecotek

- -Active area: 3x3 mm^2
- - Number of pixel: up to $40000/mm^2$
- - Gain ~ few x 10^4
- -Voltage ~65 V
- - Dark current ~50 nA
- - High stability





$$N_{fired} = N_{total}\left(1 - e^{\frac{-N_{photons} PDE}{N_{total}}}\right)$$

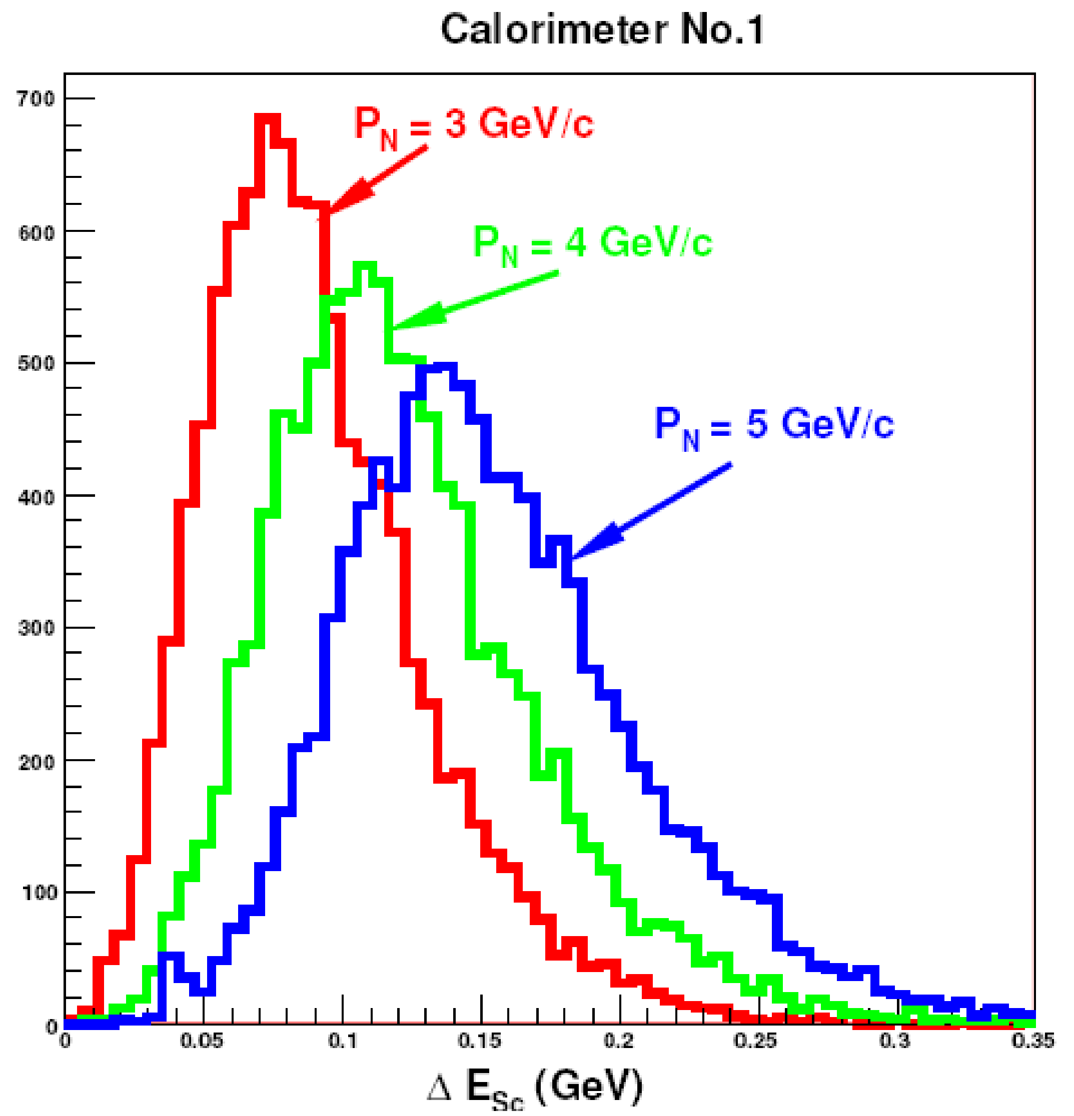
pixels

Centrality classification

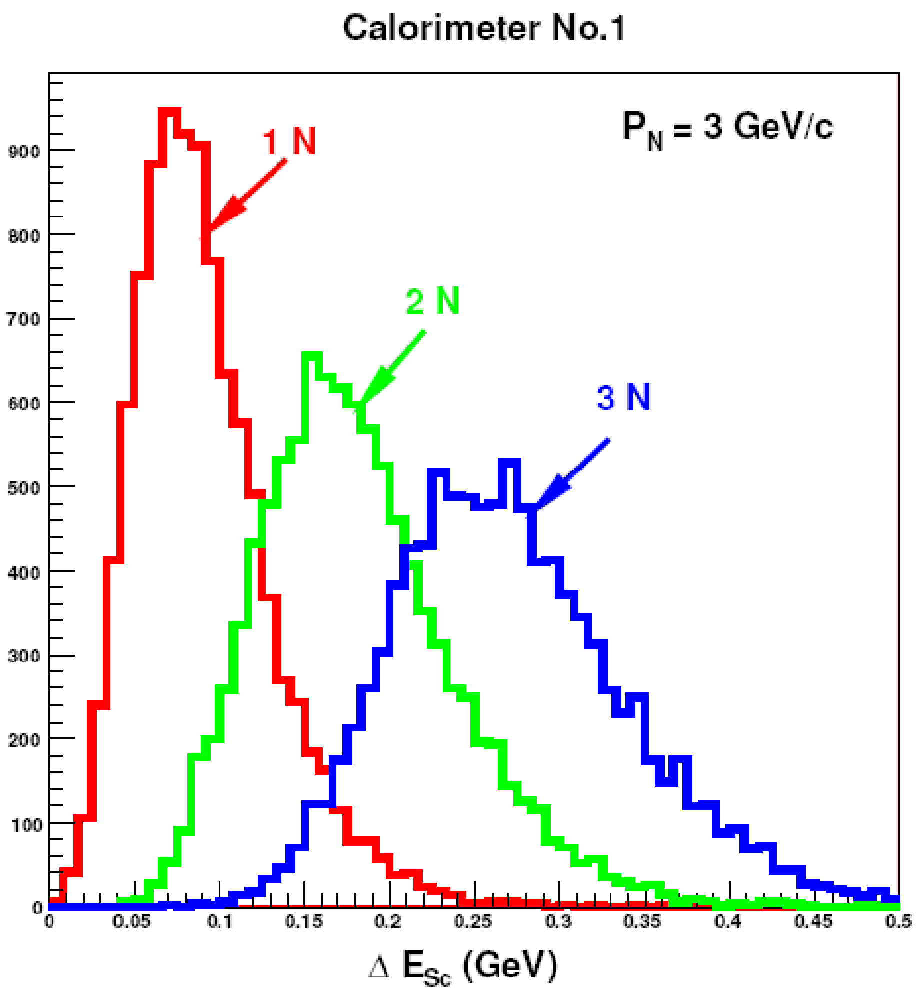
NA49 classification			N_{part} classification		b classification	
window	centrality	$< N_{part} >$	N_{part} range	$< N_{part} >$	b range in fm	$< N_{part} >$
1	0-5%	362 ± 12	320-416	358	0-3.1	364
2	5-14%	304 ± 16	230-320	268	3.1-5.2	289
3	14-23%	241 ± 16	175-230	200	5.2-6.7	220
4	23-31%	188 ± 16	145-175	158	6.7-7.8	171
5	31-48%	130 ± 14	90-145	116	7.8-9.7	117
6	48-100%	72 ± 8	0-90	35	9.7-14	35

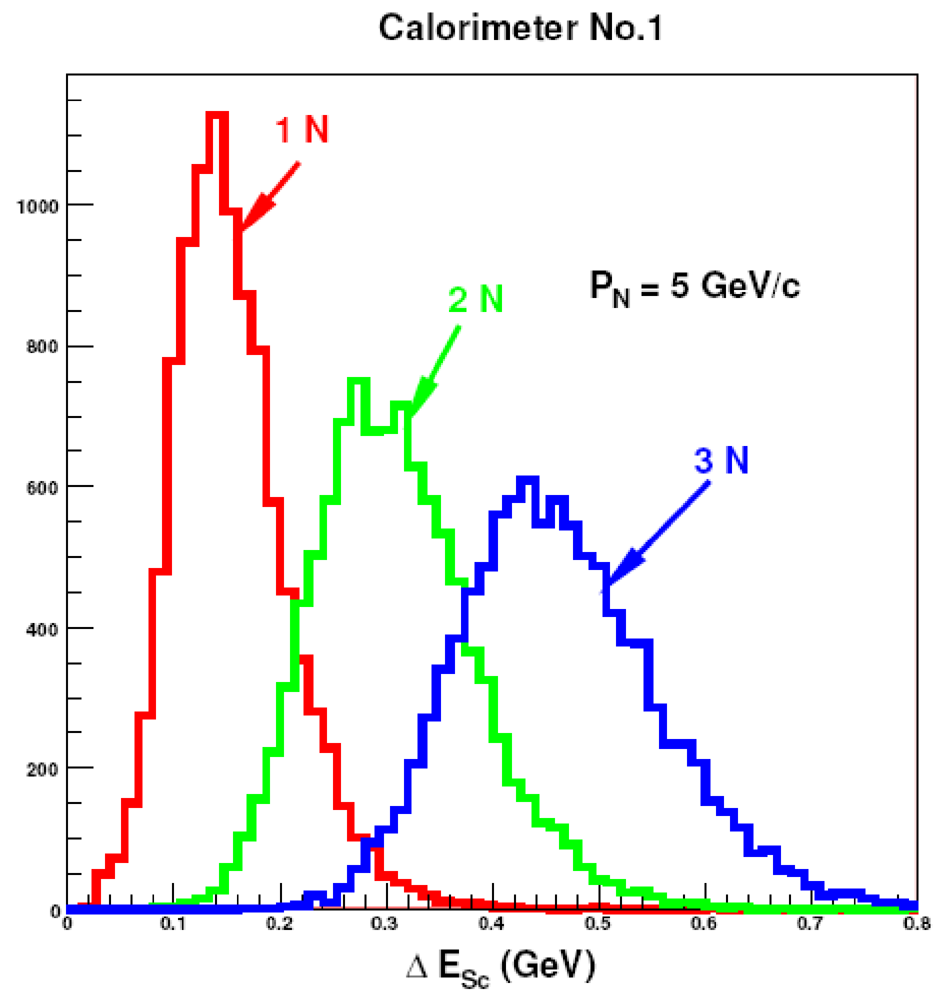
C.E.Aguilar et al., Brazilian Journal of Physics, V.34,No.1,p.319,(2004)

Calorimeter No.1



Calorimeter No.1

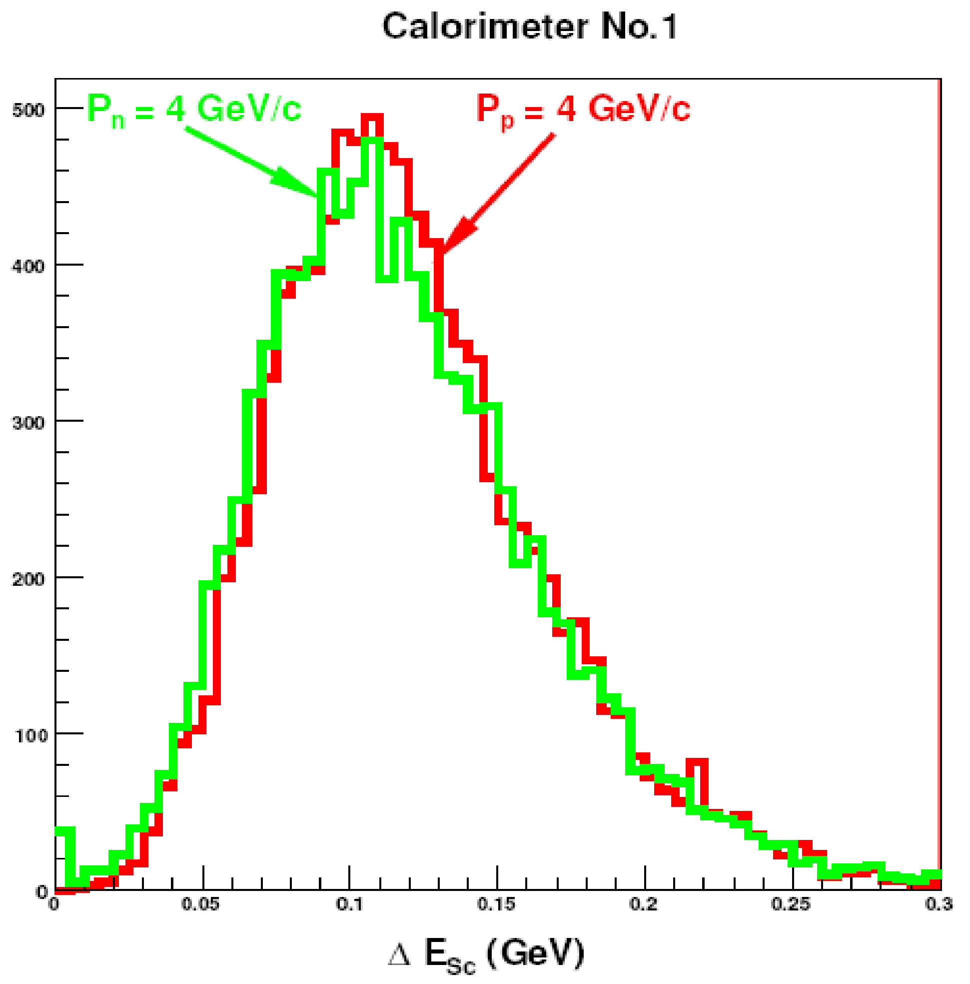




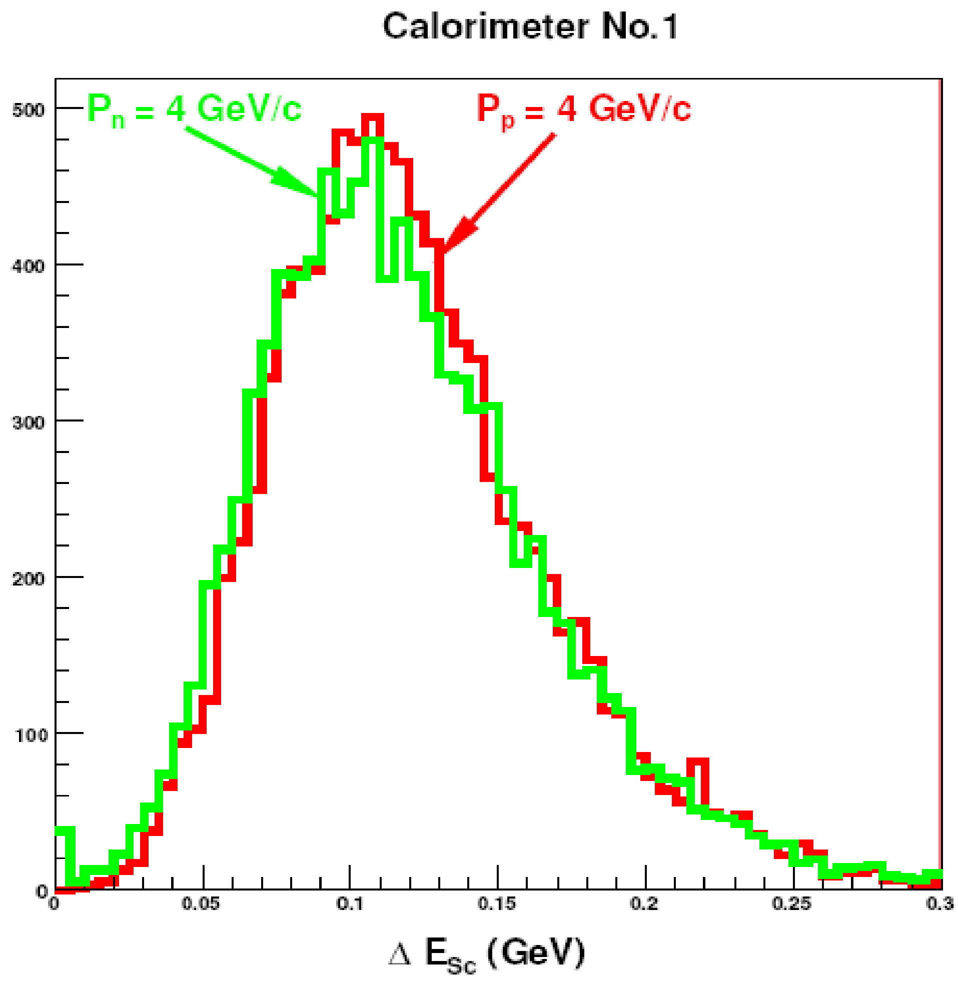
A.Litvinenko

VBLHEP JINR

Calorimeter No.1



Calorimeter No.1



A.Litvinenko

VBLHEP JINR

Linearity

$$\chi^2 = \frac{1}{N-1} \sum_{i=1,j=1,k=1}^{N_i,N_j,N_k} \left(\frac{T_{i,j,k} - \alpha \cdot \langle \Delta E_{\mathrm{Sc}} \rangle_{i,j,k}}{\alpha \cdot \sigma(\Delta E_{\mathrm{Sc}})_{i,j,k}} \right)^2$$

$$T_{i,j,k} = i \cdot T_i(p = 3\ GeV/c) + j \cdot T_j(p = 4\ GeV/c) + k \cdot T_k(p = 5\ GeV/c)$$

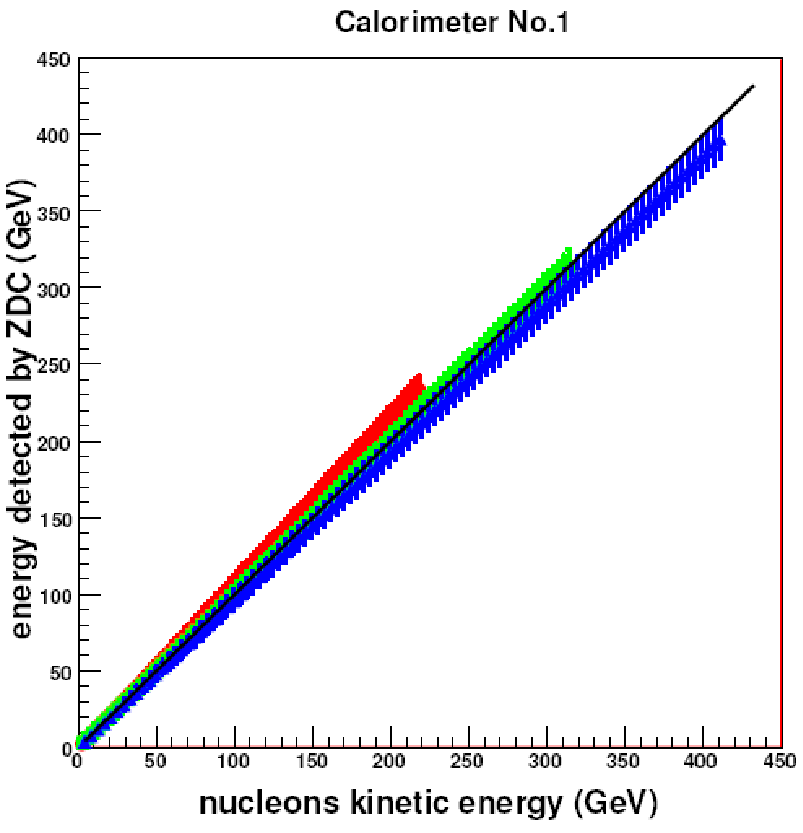
Resolution

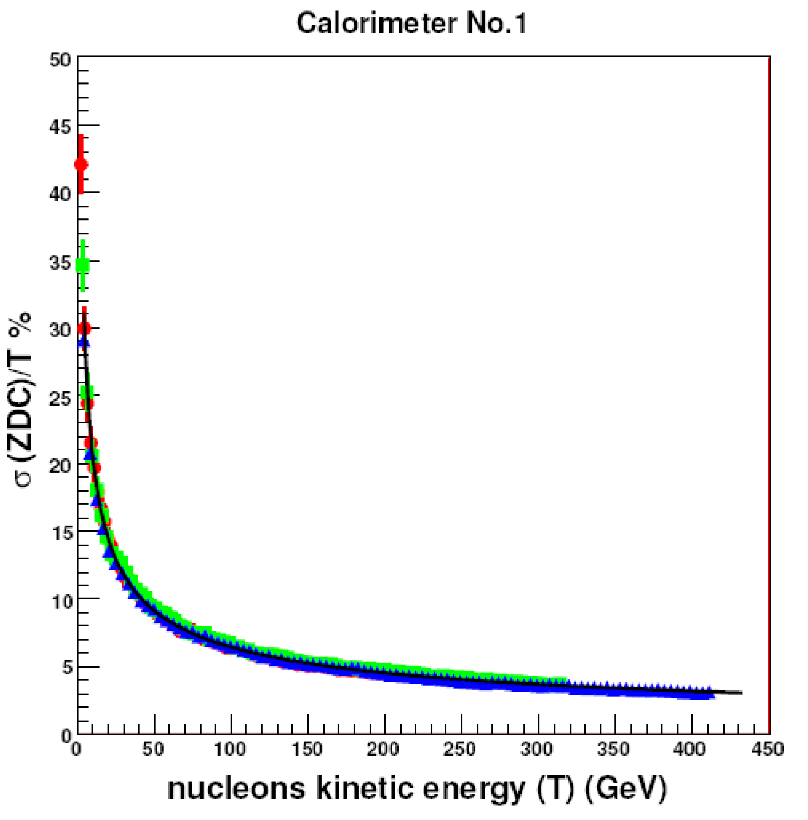
$$\frac{\sigma}{T} = \frac{\beta}{\sqrt{T}} + \gamma$$

Longitudinal distribution

$$\Delta E_{Sc} = A\sqrt{L} \cdot exp(-\delta L/\lambda_{int})$$

Calorimeter No.1



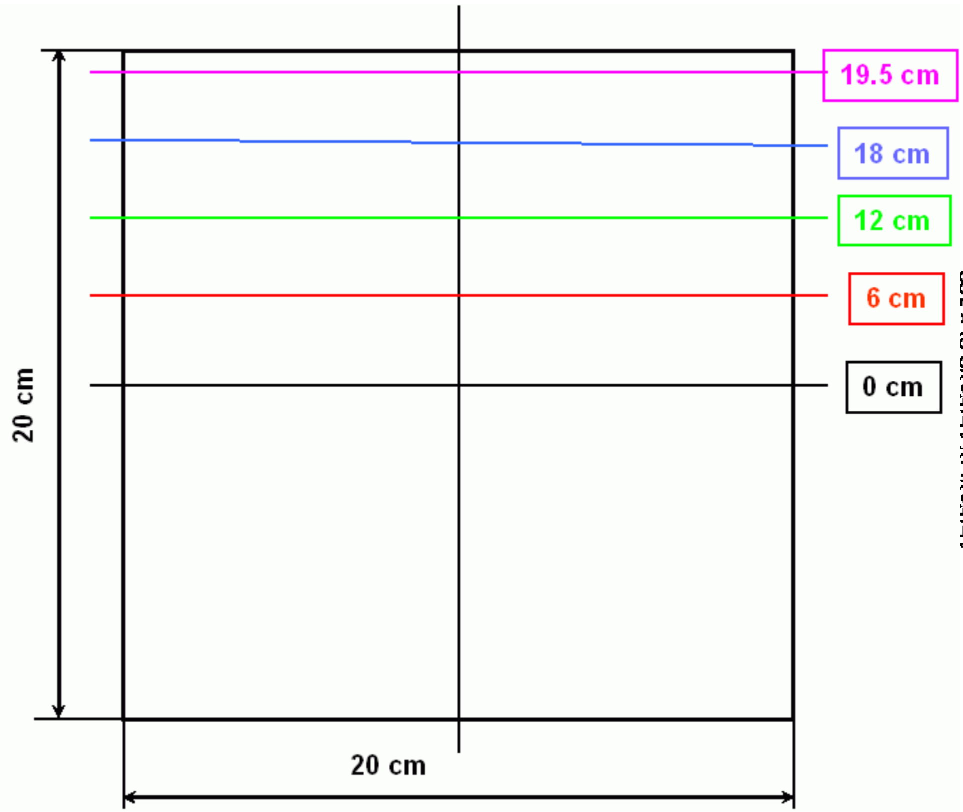


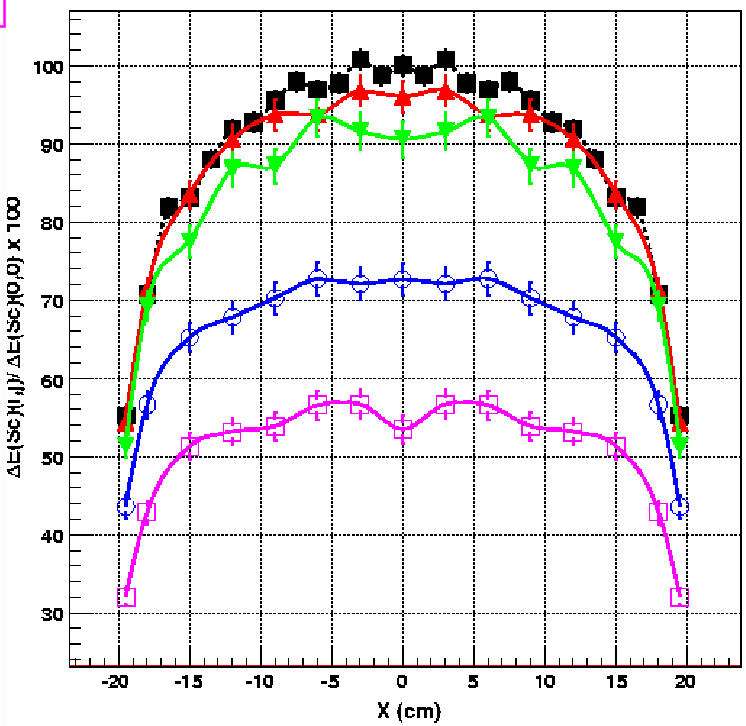
CONCLUSION

№	структура ячейки по пучку (мм)	число ячеек шт.	поперечный размер mm x mm	поверхностная плотность g/cm^2	полная длина L (mm)	длина в L/λ_{int}
1.	20 Fe + 5 Sc	40	400 x 400	649.6	1000	5
2.	20 Pb + 5 Sc	40	400 x 400	928	1000	4.9
3.	10 Pb + 2.5 Sc	80	400 x 400	928	1000	4.9
4.	16 Pb + 4 Sc	60	400 x 400	1113.6	1200	5.9
5.	5 W + 5 Sc	120	400 x 400	1218	1200	7

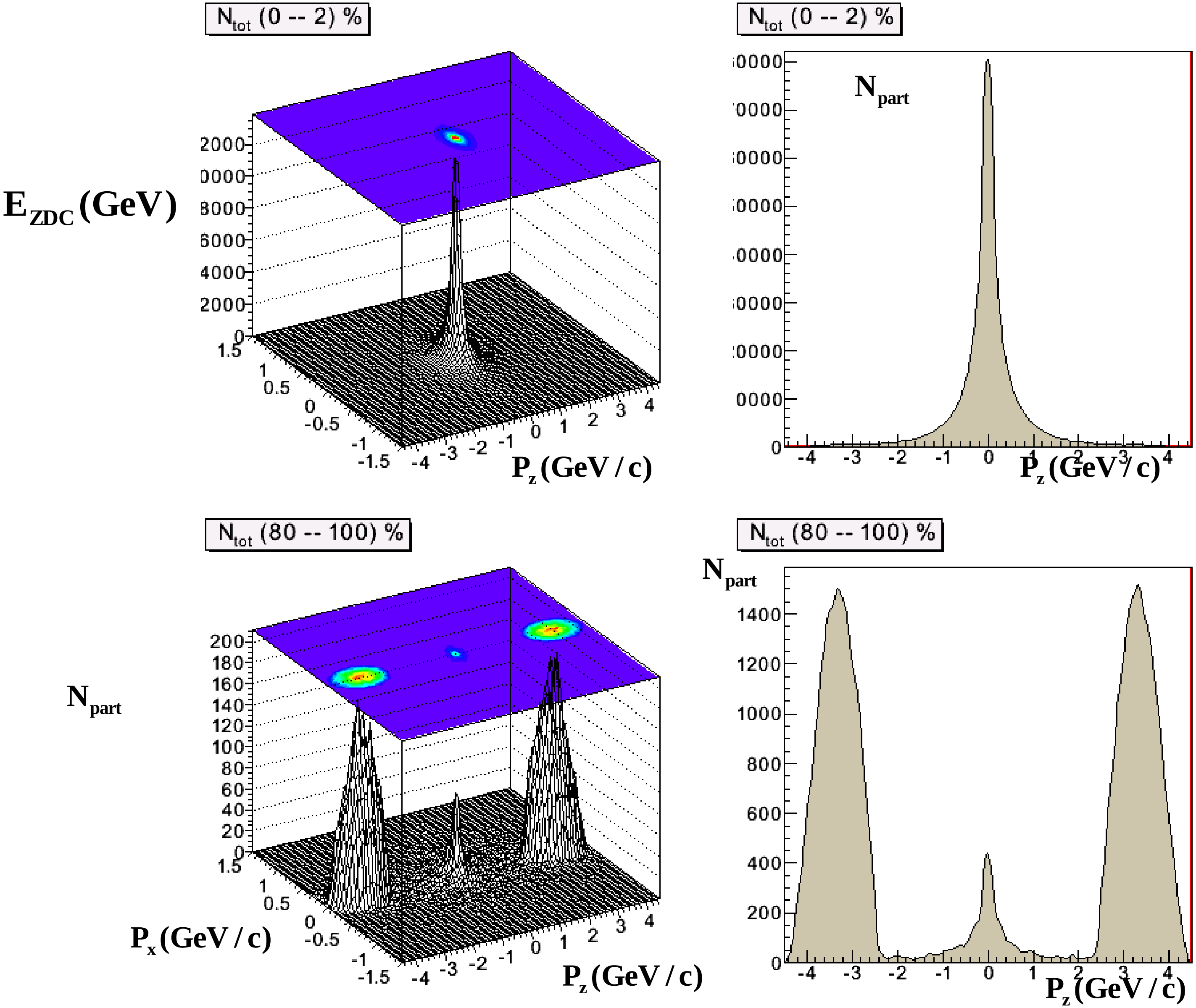
№	χ^2	α	β	γ	разрешение для протона p = 4 GeV/c
1.	0.6	26.0 ± 0.1	65 ± 11 %	0.0 ± 0.9 %	36 %
2.	0.2	33.2 ± 0.11	71.6 ± 12.8 %	$.12 \pm 0.95$ %	40.4 %
3.	0.3	32.4 ± 0.1	61.8 ± 11.0 %	0.1 ± 0.8 %	34.8 %
4.	0.2	32.6 ± 0.1	67.4 ± 12.0 %	0.1 ± 0.9 %	37.9 %
5.	0.6	13.82 ± 0.06	51.8 ± 9.3 %	0.0 ± 0.7 %	29.0 %

Пространственное разрешение





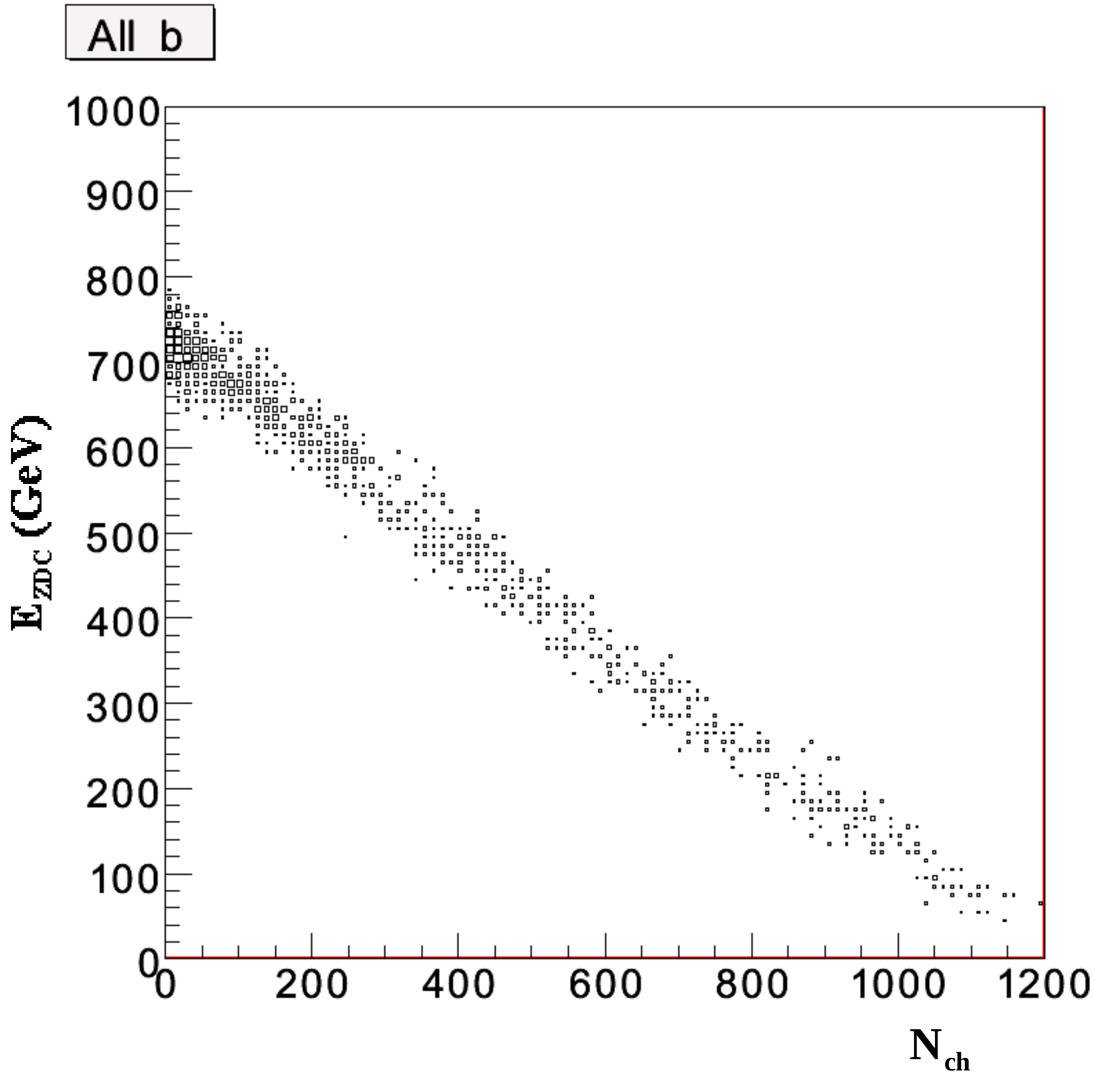
ZDC



A.Litvinenko

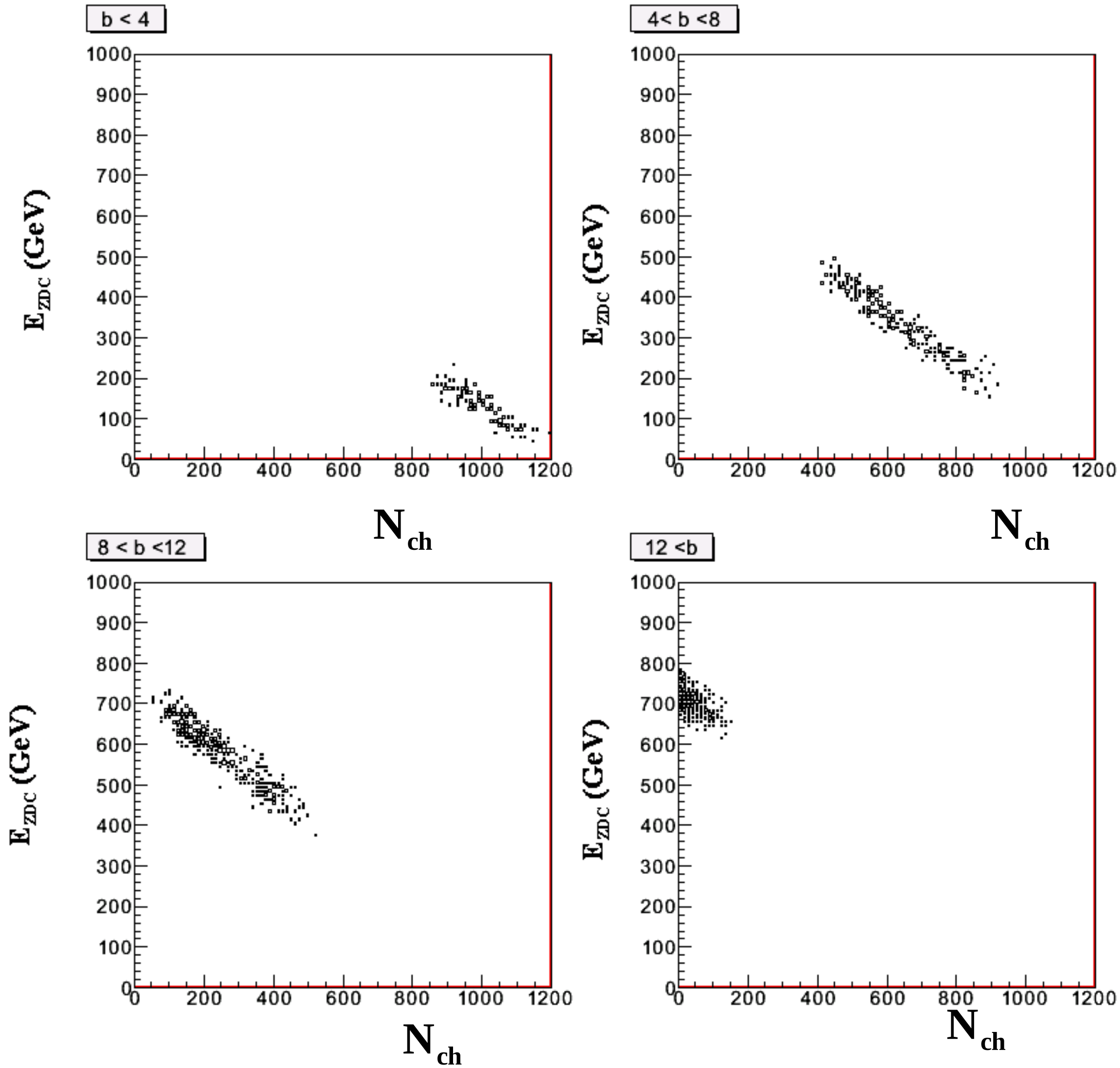
VBLHEP JINR

ZDC + Multiplicity

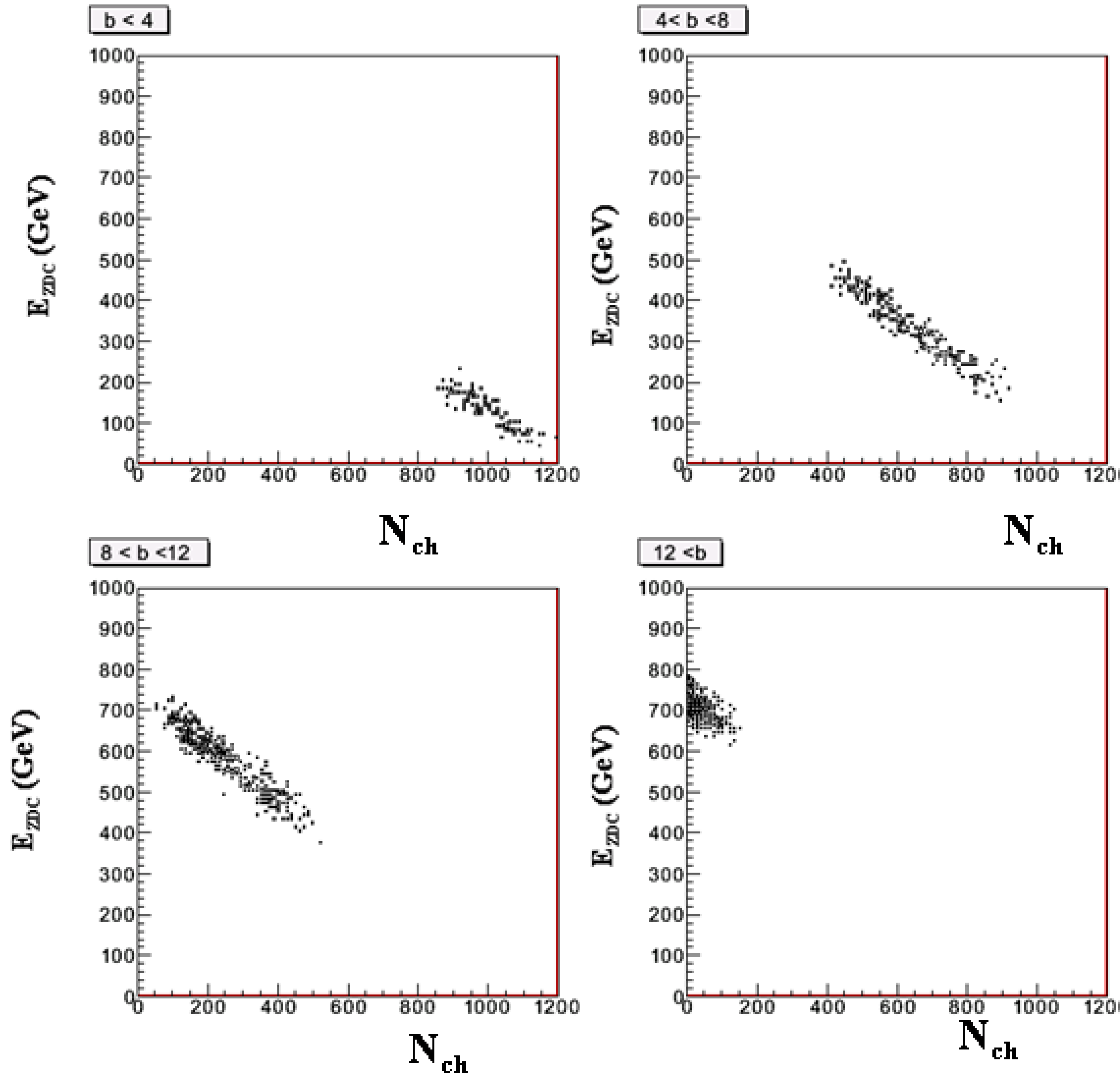


1000 Min Bias

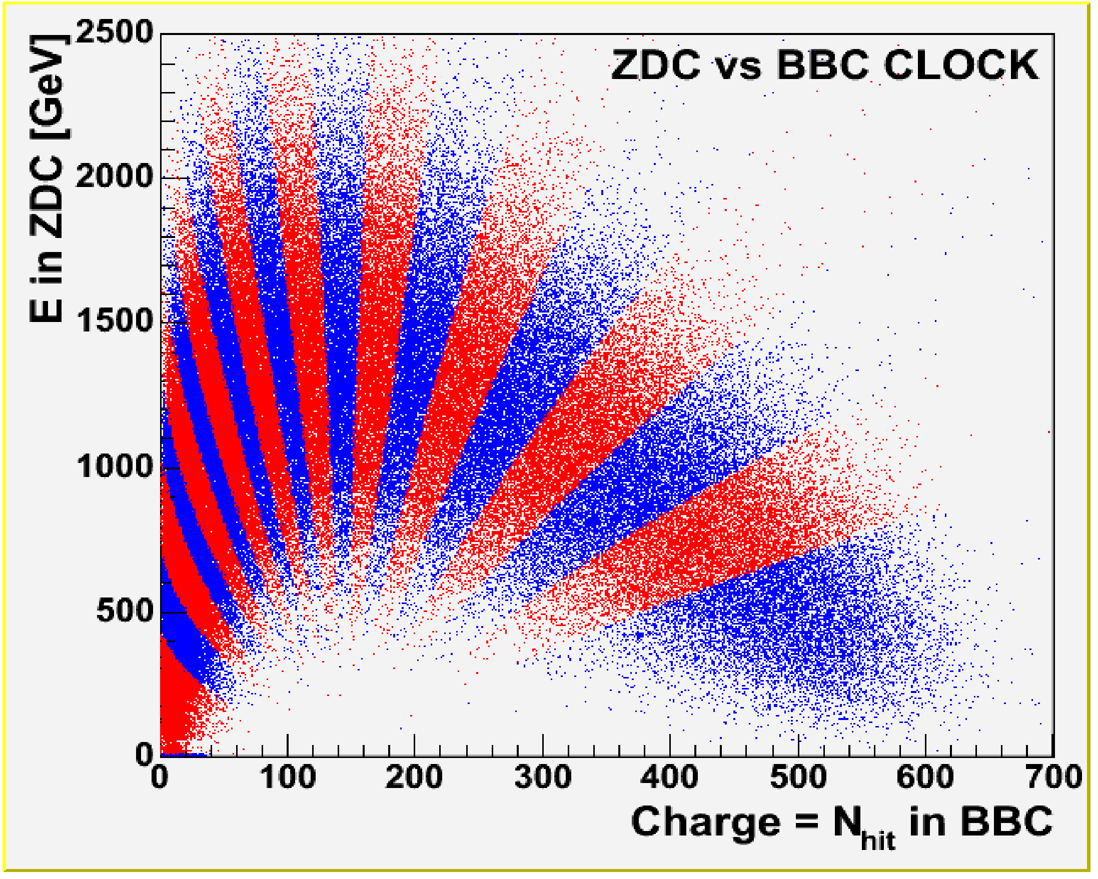
ZDC + Multiplicity



1000 Min Bias

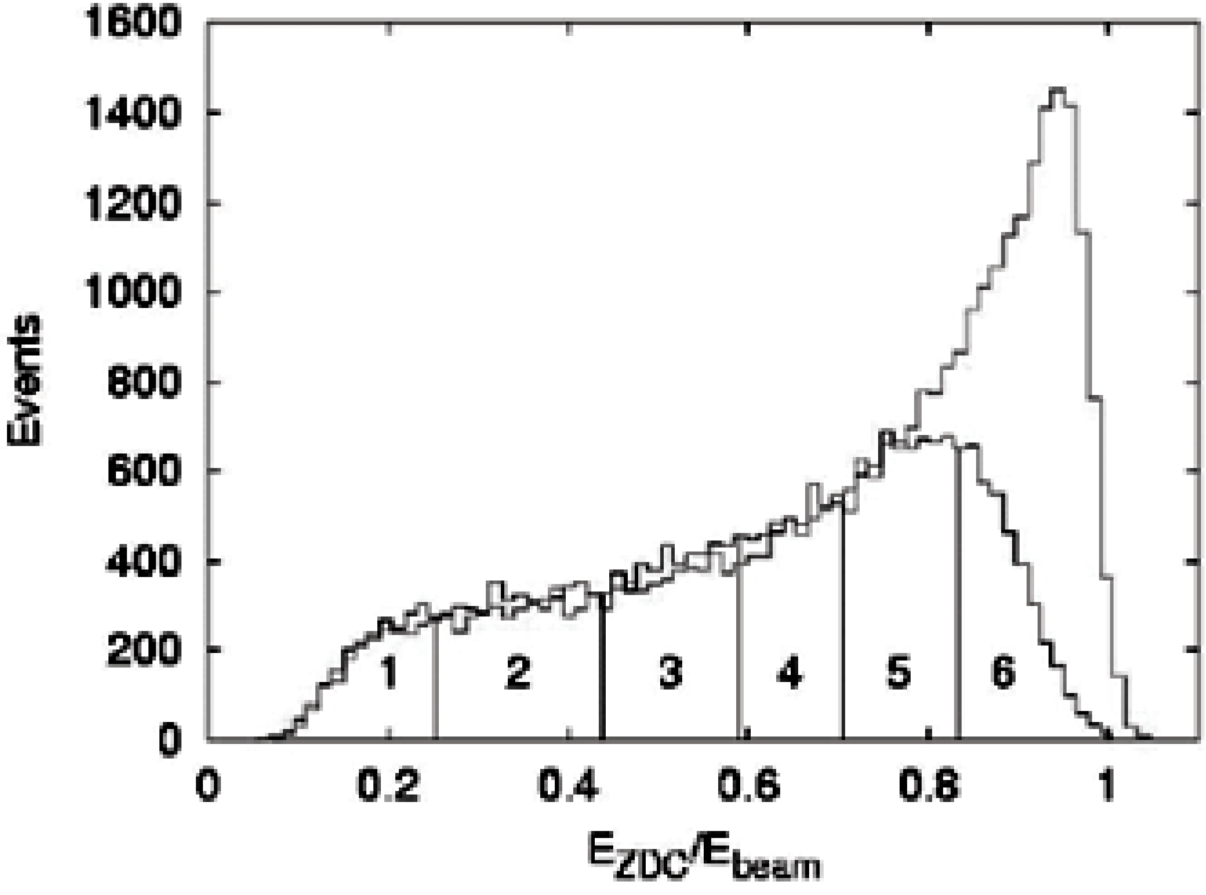

b < 4
4< b <8
8 < b <12
12 <b
E_ZDC (GeV)
N_ch
0
200
400
600
800
1000
1200
100
300
500
700
900

PHENIX



ZDC + BBC

NA49



VCAL (ZDC)