Detector for beams collision monitoring and luminosity measurements in the interaction point at MPD@NICA
(Status Report)

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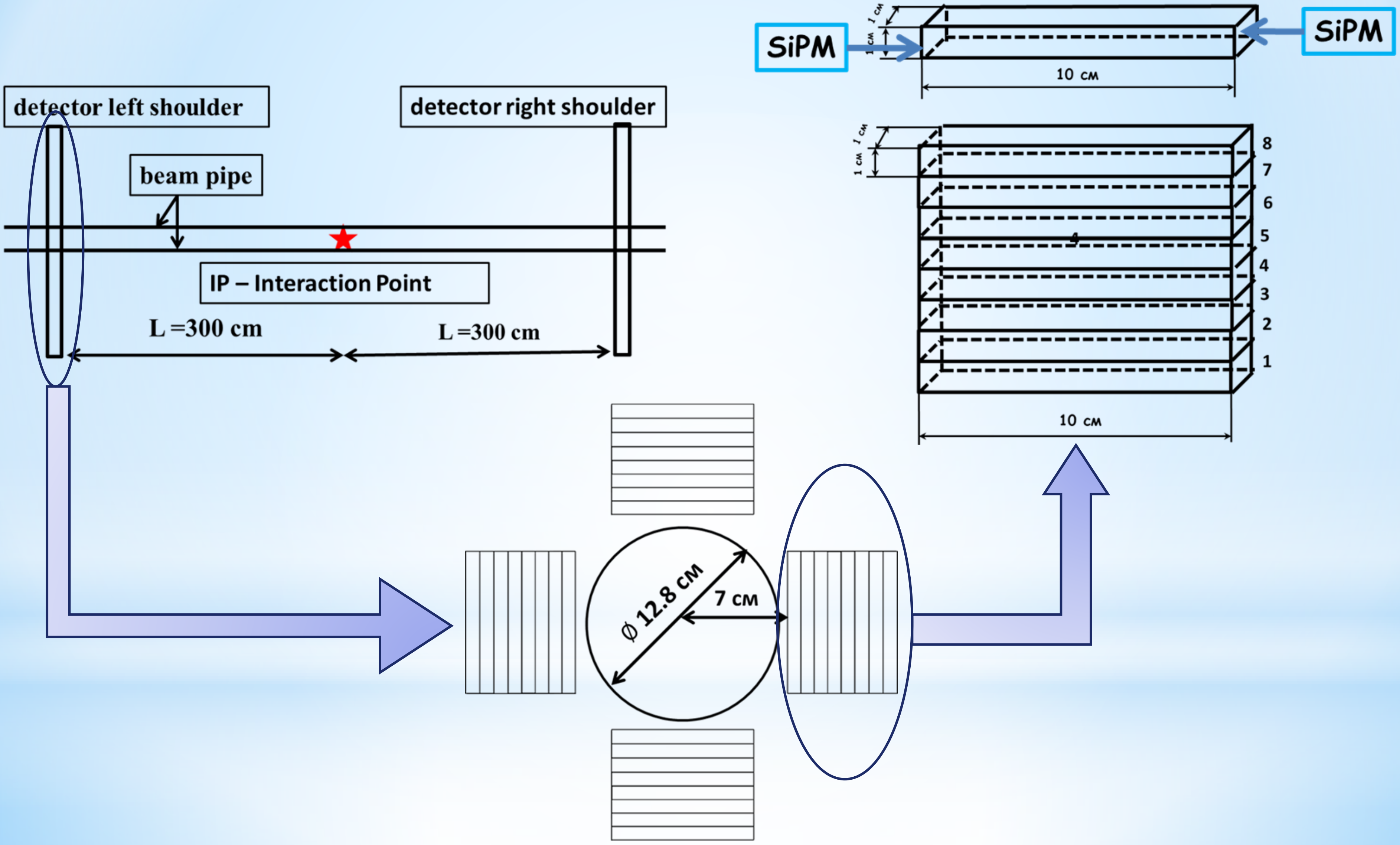
on behalf of the working group

beam convergence procedure
at the point of the interaction

Detector


SiPM
SiPM
1 см
1 см
10 см
detector left shoulder
detector right shoulder
beam pipe
IP – Interaction Point
L =300 cm
L =300 cm
1 см
1 см
8
7
6
5
4
3
2
1
10 см
ϕ 12.8 см
7 см

working group

- JINR (Dubna)

S.G.Buzin, M.G.Buryakov, V. M.Golovatyuk,
Z.A.Igamkulov, E.I.Litvinenko

- JINR (Dubna) + Dubna State University

S.P.Avdeyev, A.I.Malakhov, G.D.Milnov,
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- Institute of Physics and Technology, MAS, Ulaanbaatar, 13330 Mongolia

M.Sovd, B.Otgongerel

- Anyone wellcome

Luminosity

number of events per second

$$\frac{dR}{dt} = \mathcal{L} \cdot \sigma$$

cross section

$$[\mathcal{L}] = cm^{-2}s^{-1}$$

one of the key parameters of the collider

Time structure of AuAu collisions at NICA

Basic parameters (for $\sqrt{S_{NN}} = 11\ \text{GeV}$)

1. Length (perimeter) of the ring $L = 503,04\ \text{m}$
2. Number of bunches $N_b = 22$
3. Number of satellits $N_s = 44$
4. R.M.S. of particles in a bunch $\sigma_z = 0.6\ \text{m}$
5. Time between bunches $t_{b-b} \cong 76.2\ \text{ns}$
6. Time between bunch and satellite $t_{b-s} \cong 25.4\ \text{ns}$
7. Time of single interaction bunches $\Delta\tau_{bb} \leq (6\sigma_z)/(2c\beta) \cong 6\ \text{ns}$
8. Revolution frequency $f_r \cong 0.56 \cdot 10^6\ \text{Hz}$

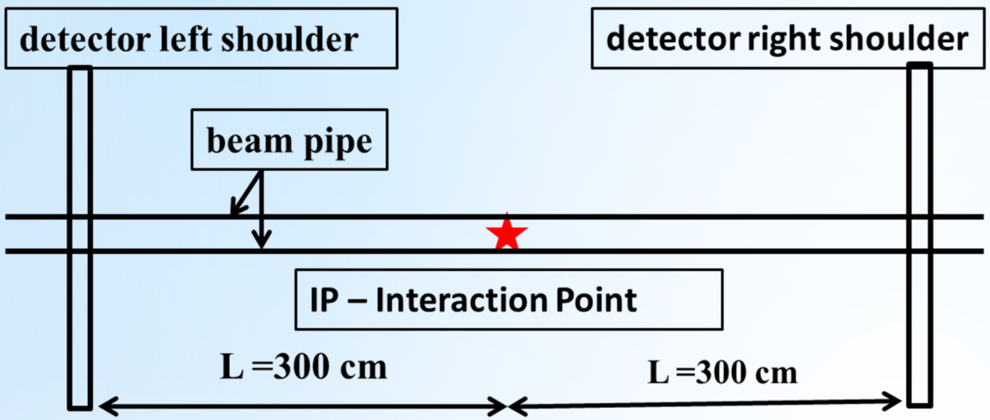
Tasks for the luminosity detector

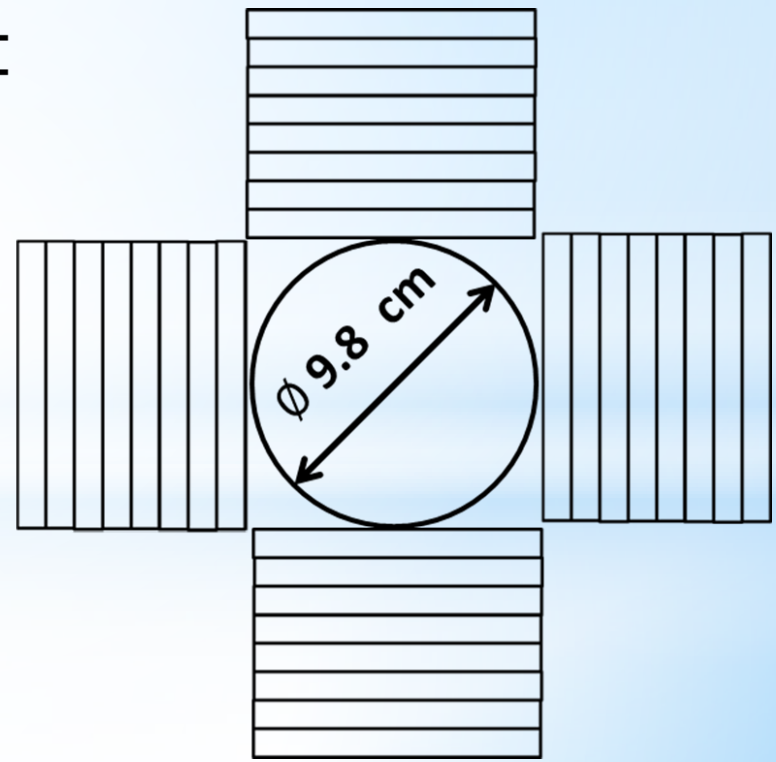
1. finding the parameters of the collider, for the most efficient hit of bunches into each other;
2. finding the parameters of the collider that optimize the transverse profile of colliding beams;
3. selection of collider parameters that optimize the longitudinal position of the interaction vertex

two observables

- ✓ the first one is the counting rate
- ✓ the second one is the distribution of interaction vertices obtained from ToF

what has changed since April this year



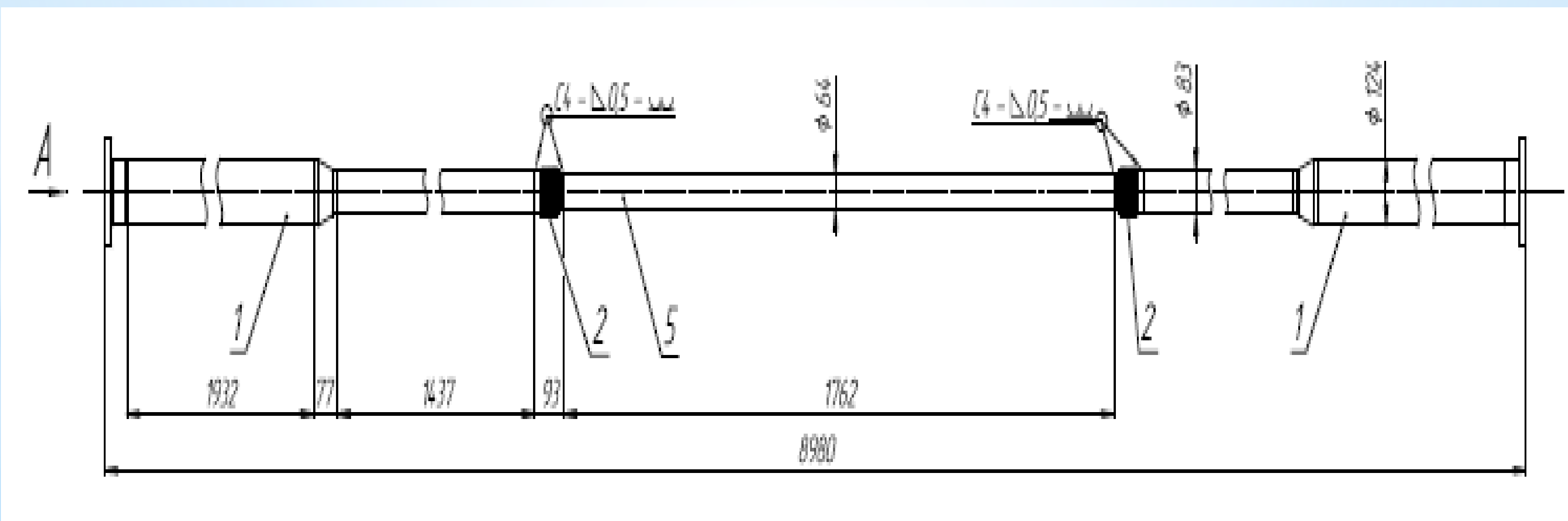


Ion guide on MPD

old

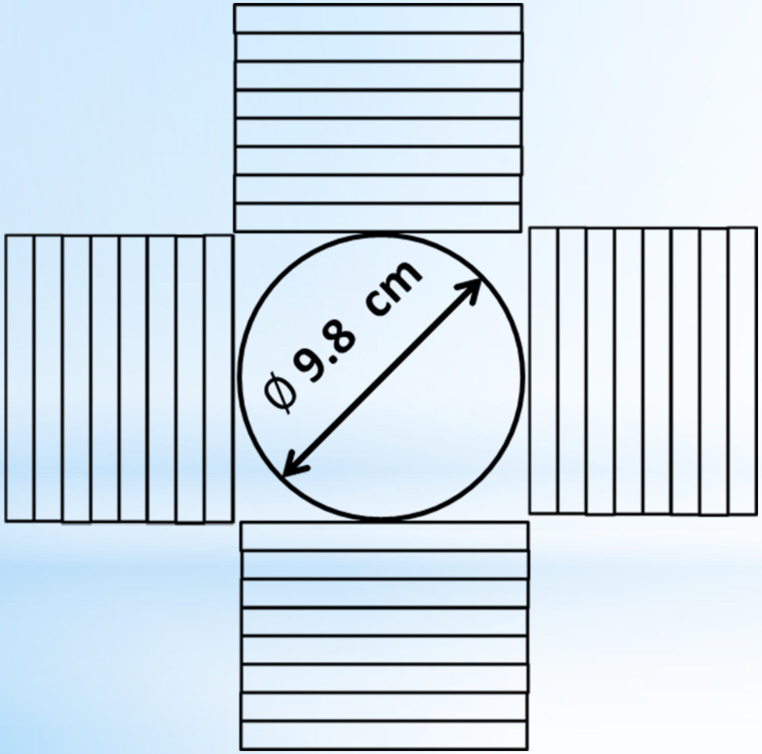
Ø 10 мм

new

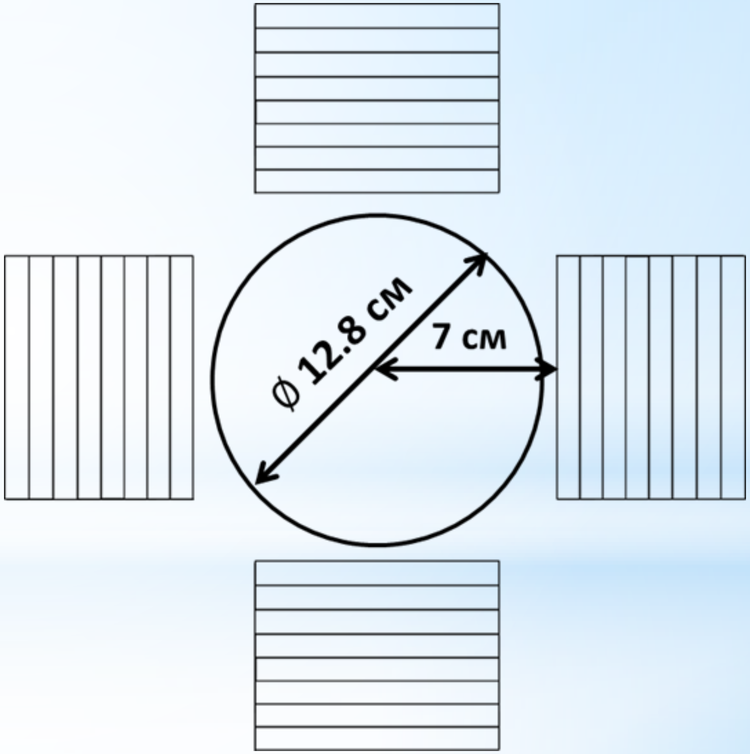


What has changed since April this year

old



new



What has changed since April this year

$\sqrt{S_{NN}} = 11\ \mathrm{GeV}$

old

$\varepsilon = 82\%$

$R \approx 4900\ \ 1/s\,;(\approx 1.4\ \%)$

new

$\varepsilon = 77\%$

$R \approx 4600\ \ 1/s\,;(\approx 1,5\ \%)$

Efficiency = Detected/Produced

DCM-SMM (M. Baznat, A. Botvina, G. Musulmanbekov, V. Toneev, V. Zhezher, //arXiv:1912.09277 [nucl-th], 2019)

Time of Flight for Left and Right Shoulders

$$\mathbf{T_{L/R} = min\{T_{L/R,\,i}\}}$$

Trigger

$$\mathbf{|T_L - T_R| \le 10}\ \text{нс}$$

Efficiency

$$\varepsilon = ~~82\%~~ \rightarrow \varepsilon = 77\%$$

Efficiency = Detected/Produced

DCM-SMM (M. Baznat, A. Botvina, G. Musulmanbekov, V. Toneev, V. Zhezher, //arXiv:1912.09277 [nucl-th], 2019)

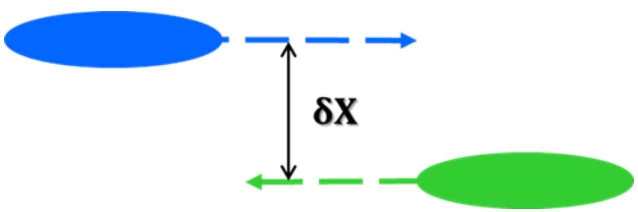
Beam convergence adjustment in the transverse plane

Luminosity structure..

$$\mathcal{L}(\delta X, \delta Y) = f_r \cdot N_b \cdot \frac{N_L N_R}{S_{eff}(\delta X, \delta Y)}$$

N_L, N_R-number of the beam ions in the left and right bunches

Van der Meer scan



For normal distribution

$$\mathcal{L}(\delta X, \delta Y) = f_r \cdot N_b \cdot \frac{N_L N_R}{4\pi\sigma_x\sigma_y} \exp\left(-\frac{\delta X^2}{2\sigma_x^2}\right) \cdot \exp\left(-\frac{\delta Y^2}{2\sigma_y^2}\right)$$

Beam convergence adjustment in the transverse plane

Conclusion I

Conclusion I

estimated time to adjust the convergence of beams in the transverse plane is about three hours
1.5 h – data taking;
1.5 h – setting collider modes;

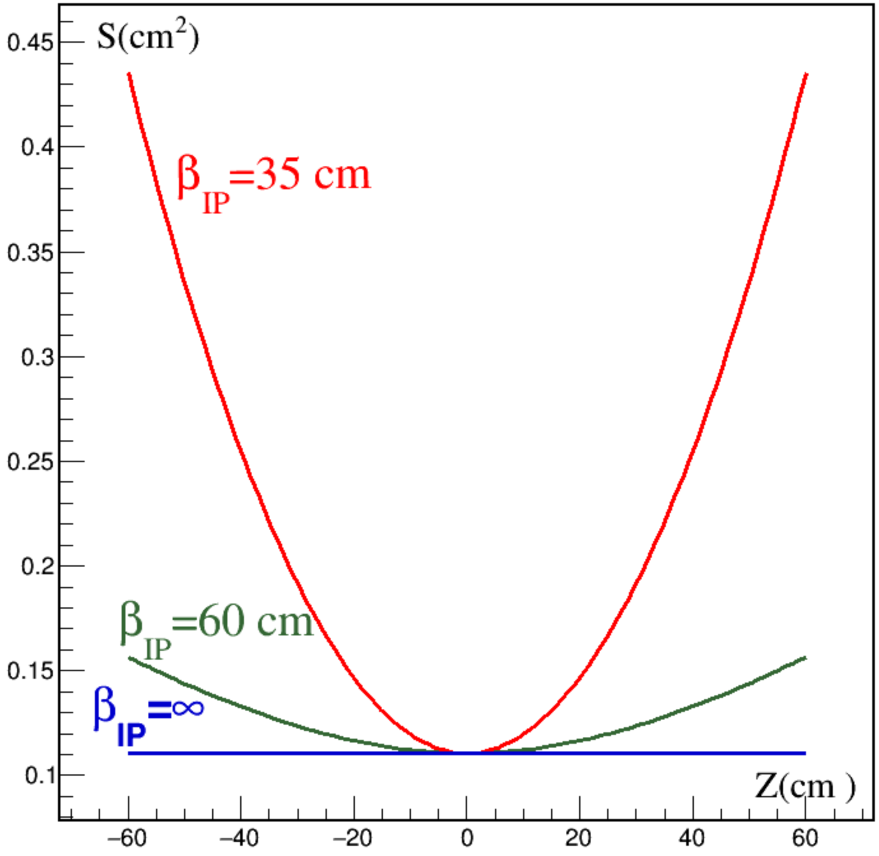
$\mathcal{L} = 10^{27}\ cm^{-2}s^{-1}$

δX	$N_{tr}/(10\ min)$	Errors
0	2 760 000	0.06 %
$\delta X = \sigma_X$	1 764 025	0.07 %
$\delta X = 2\sigma_X$	373525	0.16%
$\delta X = 3\sigma_X$	30661	0.60%

$\mathcal{L} = 10^{25}\ cm^{-2}s^{-1}$

δX	$N_{tr}/(10\ min)$	Errors
0	27600	0.6 %
$\delta X = \sigma_X$	17640	0.75 %
$\delta X = 2\sigma_X$	3735	1.6%
$\delta X = 3\sigma_X$	307	5%

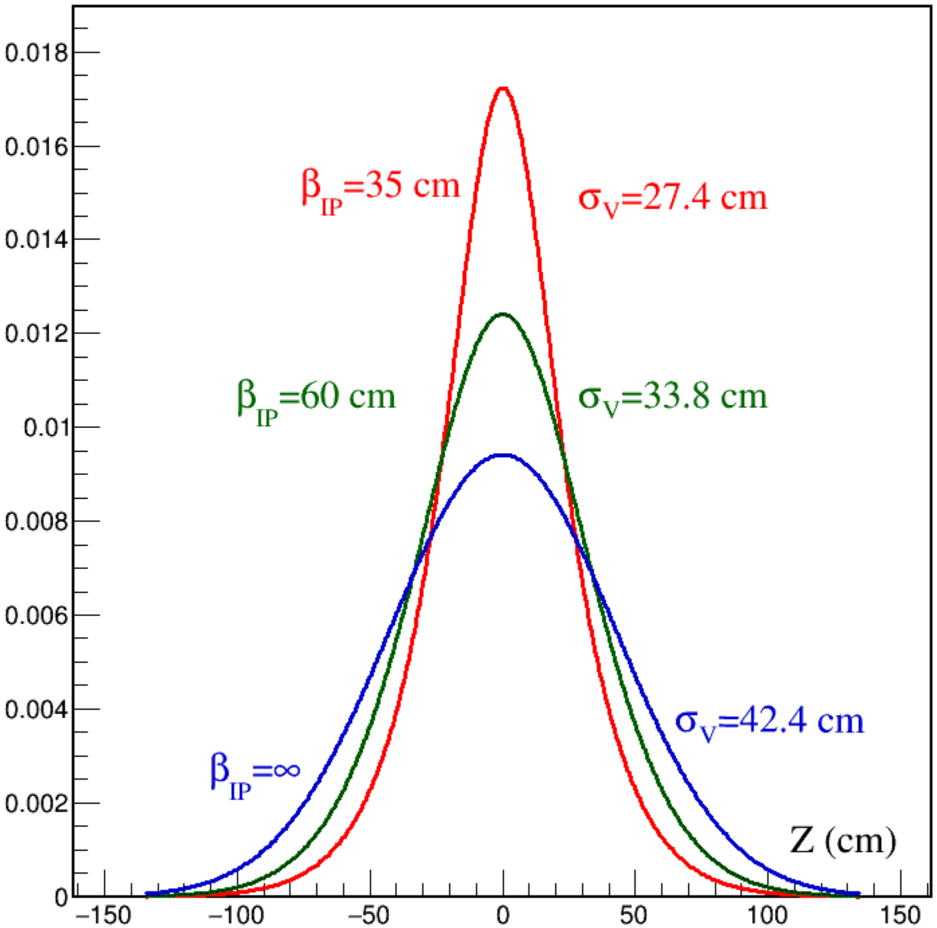
Beta function



Transverse area

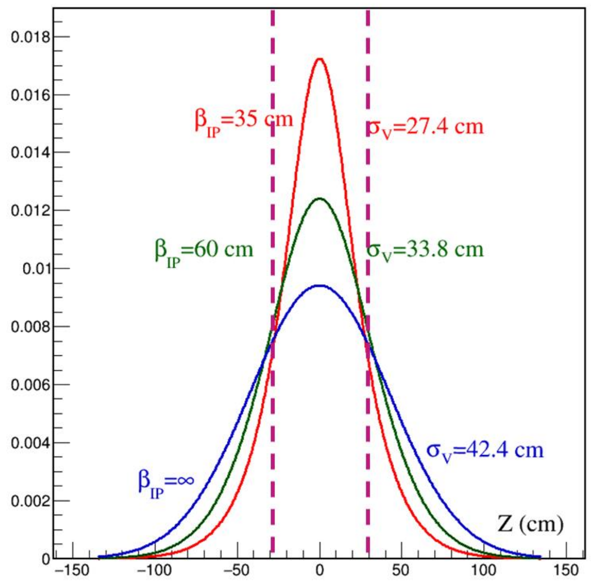
$$\mathbf{S_{eff,\perp}}(Z) = \left(\mathbf{1} + (\mathbf{Z}/\boldsymbol{\beta}_{\mathbf{IP}})^{\mathbf{2}}\right)$$

Distribution of interaction vertices



$$
\begin{cases}
P(Z_V) = N \dfrac{\exp\left(-Z_V^2/\sigma_Z^2\right)}{\left(1+\left(Z_V/\beta_{IP}\right)^2\right)} \\[2ex]
N = \dfrac{1}{\int_{-\infty}^{\infty} \dfrac{\exp\left(-Z_V^2/\sigma_Z^2\right)}{\left(1+\left(Z_V/\beta_{IP}\right)^2\right)}\, dZ_V}
\end{cases}
$$

Efficiency, Luminosity and beta function



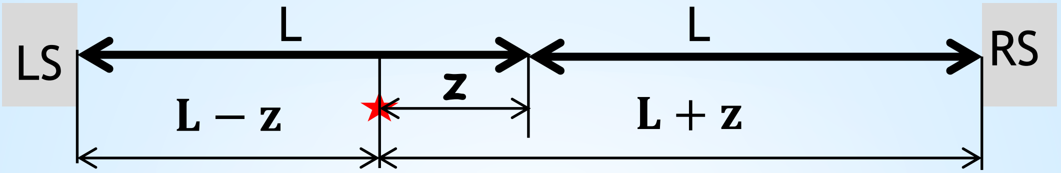
$$N_L = N_R = 2.8 \cdot 10^9$$

$$\sigma_x = 1.1\ mm;\ \sigma_y = 0.82\ mm$$

$$-30\ cm \leq Z_V \leq 30\ cm$$

	$\beta_{IP} = 35$ cm	$\beta_{IP} = 60$ cm	$\beta_{IP} = 10^4$ cm
$\mathcal{L}\ (cm^{-2}s^{-1})$	$5 \cdot 10^{26}$	$6.9 \cdot 10^{26}$	$9.1 \cdot 10^{26}$
Eff (ε)	0.756	0.635	0.517
$\mathcal{L}(cm^{-2}s^{-1})\varepsilon$	$3.8 \cdot 10^{26}$	$4.4 \cdot 10^{26}$	$4.7 \cdot 10^{26}$

Vertex position



$$T_L = \frac{L-z}{c\beta};\ T_R = \frac{L+z}{c\beta};\ \tau = T_R - T_L = \frac{2z}{c\beta}$$

$$c = 3 \cdot 10^8;\ \beta = p/E;\ \sqrt{S_{NN}} = 11 \rightarrow \beta = 0.985 \approx 1$$

$$z = \frac{1}{2} c \cdot \tau \rightarrow z(\mathrm{cm}) = 15 \cdot \tau(\mathrm{ns})$$

$$\sigma_\tau = (300 \div 400)\ \mathrm{ps};\ \rightarrow \sigma_{z,\tau} \approx (4.5 \div 6)\ \mathrm{cm}$$

Z coordinate. Maximum of interaction point distribution from ToF

$$\tilde{\sigma}_z = \sqrt{\left(\sigma_{z,V}^2 + \sigma_{z,\tau}^2\right)} = 34 \cdot (1 + 0.016)\ \mathrm{cm}$$

$$\Delta Z(\mathrm{cm}) = \frac{\tilde{\sigma}_z}{\sqrt{\mathrm{N_{tot}}}} = \frac{34 \cdot (1 + 0.016)\ \mathrm{cm}}{\sqrt{\mathrm{N_{tot}}}}$$

$$\mathcal{L} = 10^{25}\ cm^{-2}s^{-1}$$

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0	27600	0.6 %
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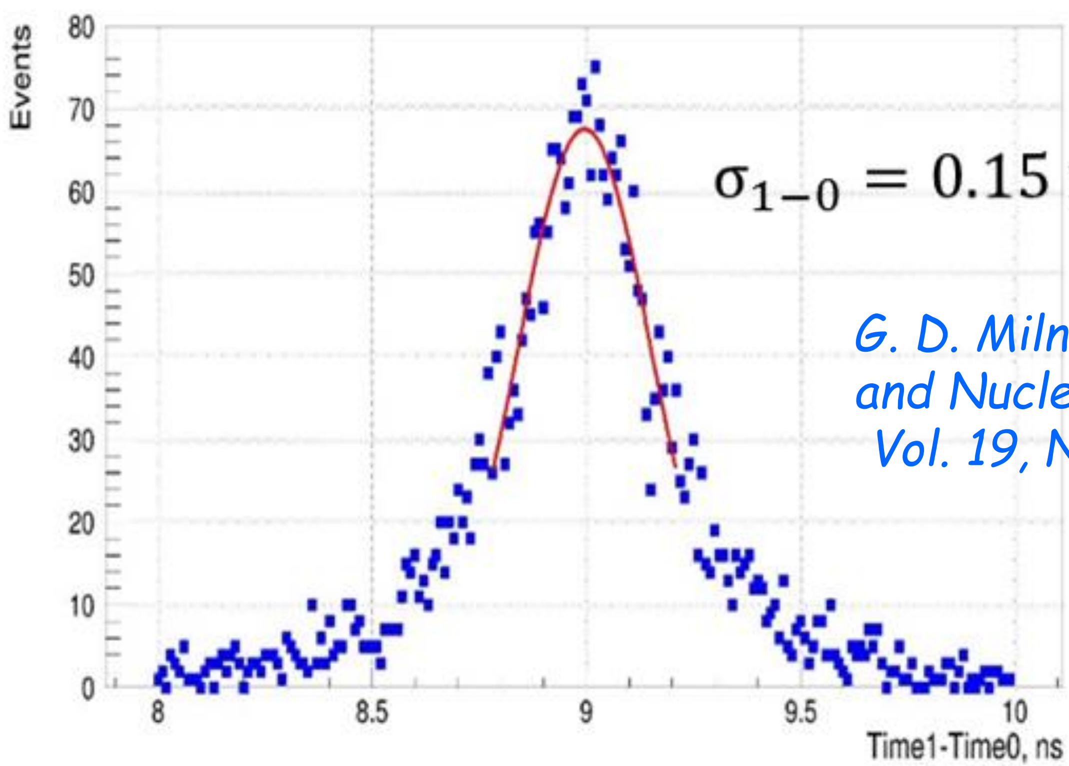
$\delta X = 3\sigma_X$	307	5%

Space muons. ToF of counters

$$\sigma_{1-0} = \sqrt{2\sigma^2} \rightarrow \sigma = \sigma_{1-0}/\sqrt{2}$$



$\sigma \approx 100$ ps

$\sigma_{1-0} = 0.15$ ns

G. D. Milnov et al., Physics of Particles and Nuclei Letters, 2022, Vol. 19, No. 4, pp. 362–367.

Adjustment of beam convergence along interaction line

Conclusion II

setting beam convergence along the collision axis does not require record time-of-flight resolutions. Even 400 picoseconds enough.

$$\Delta Z(\mathrm{cm}) = \frac{\tilde{\sigma}_z}{\sqrt{N_{tot}}} = \frac{34 \cdot (1 + 0.016)\ \mathrm{cm}}{\sqrt{N_{tot}}}$$

$$\mathcal{L} = 10^{25}\ cm^{-2} s^{-1}$$

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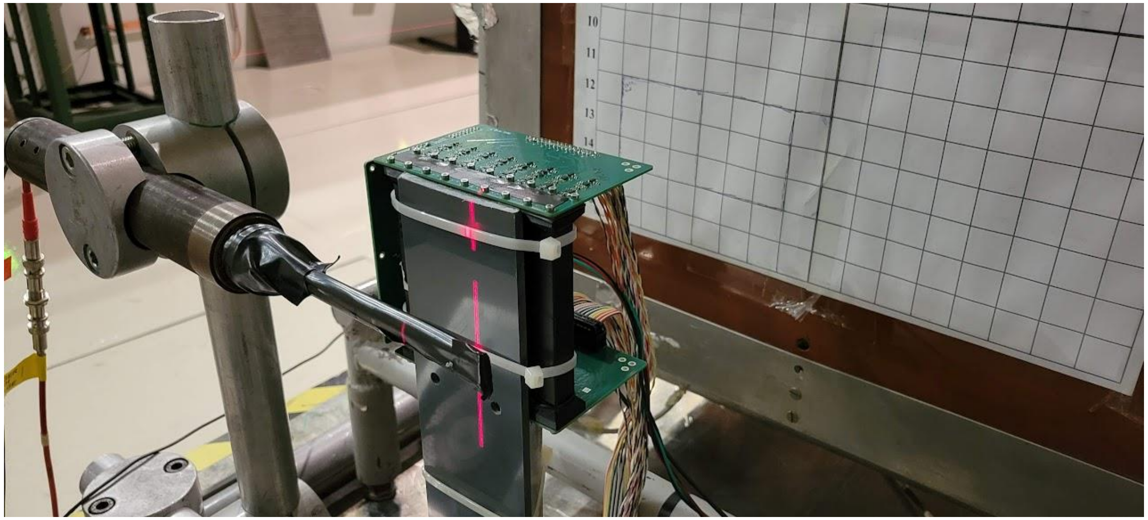
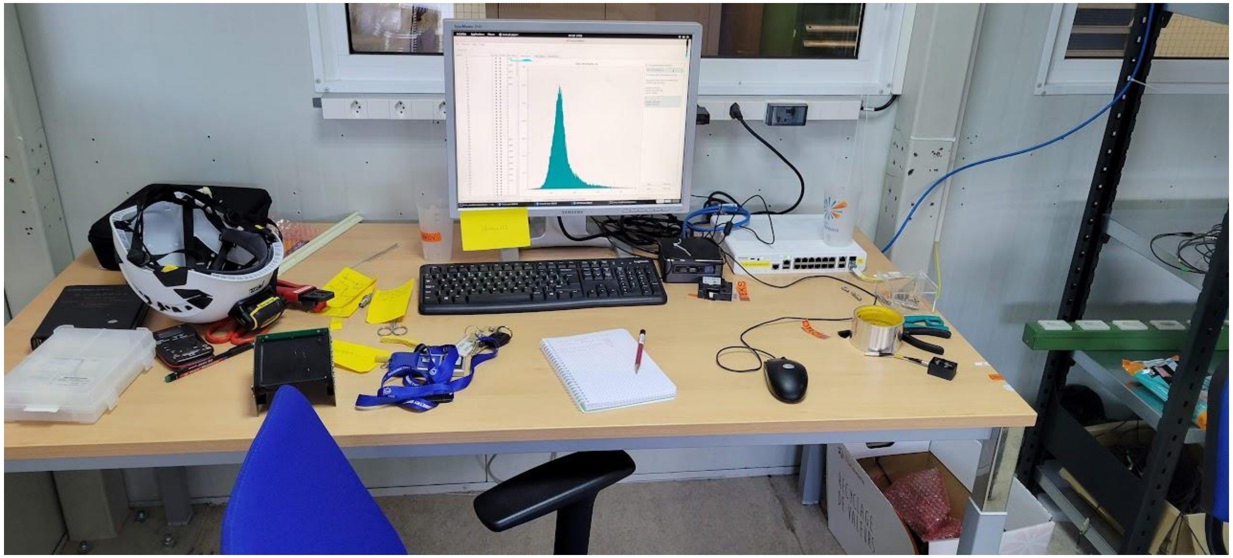
Beam test at CERN

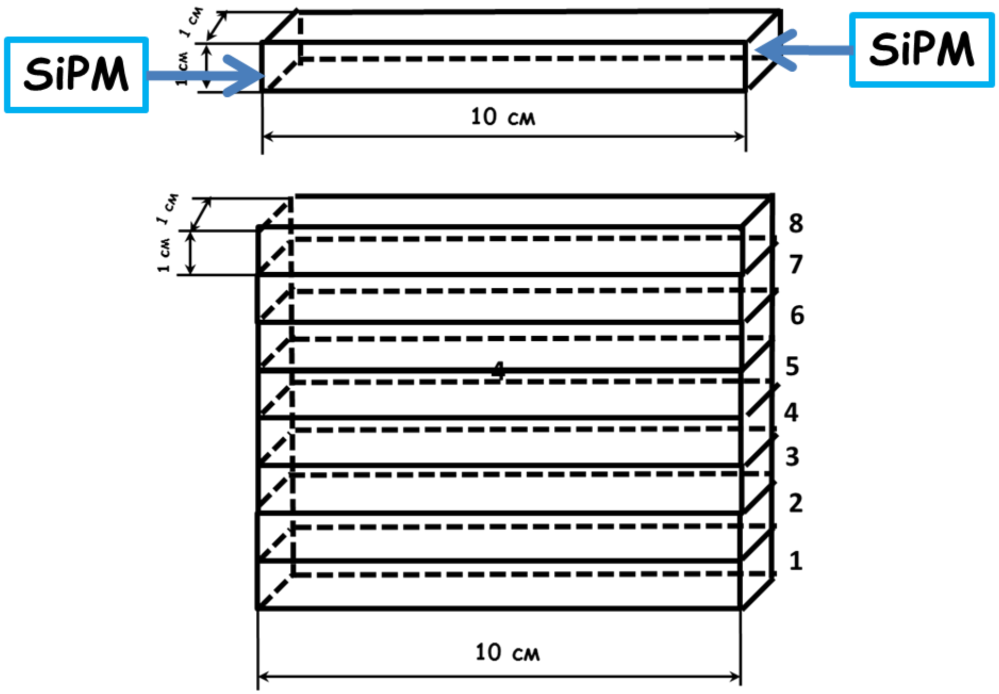
S.G.Buzin, M.G.Buryakov

Two planes





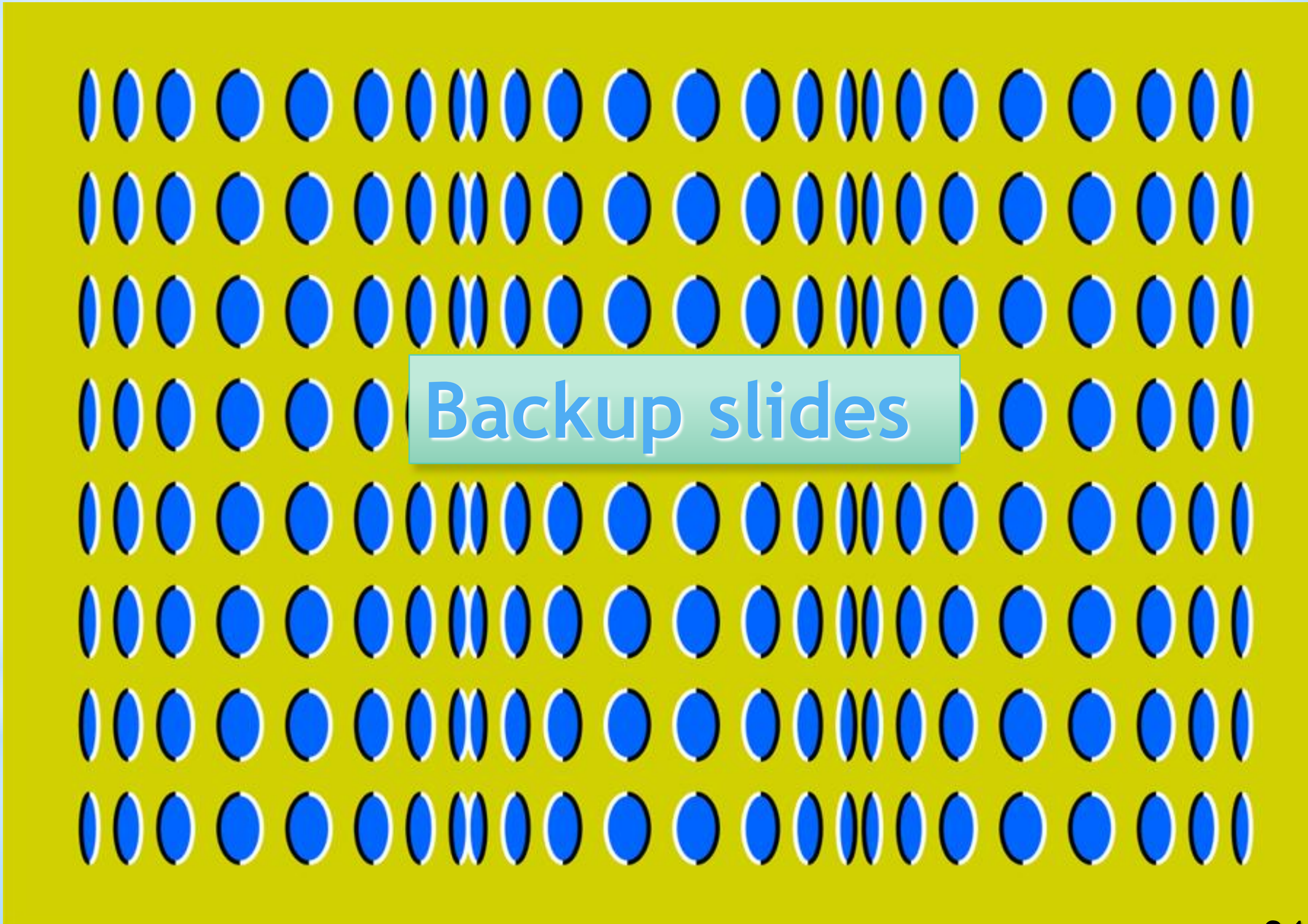
One plane of detector



The plane consists of $100 \times 10 \times 10$ mm^3 plastic scintillator (organic polystyrene (PS) scintillator with the addition of 1.5% p-terphenyl and 0.05% POPOP) strips viewed from both sides with silicon photomultipliers (SiPM HAMAMATSU S13360-6025CS)

Nearest plans

1. TDR
2. 8 detector planes
3. Closer collaboration with accelerator department

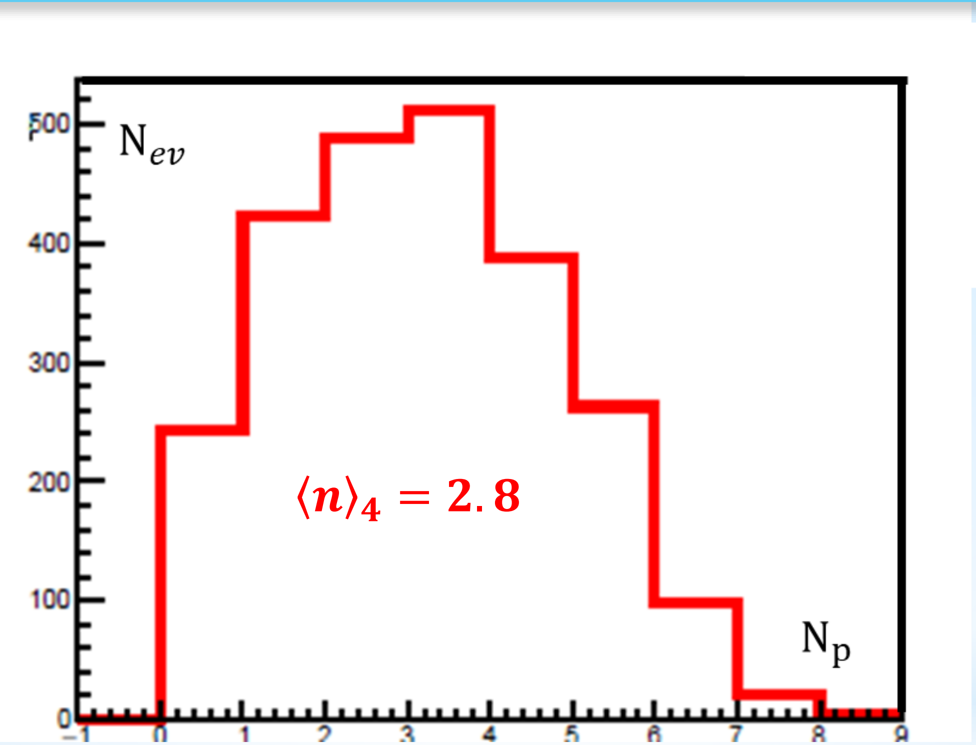


Backup slides

what has changed since April this year

$\sqrt{S_{NN}} = 11\ \text{GeV}$

strips occupancy (for the first 4 strips)



new $\langle n \rangle_1 = \frac{\langle n \rangle_4}{4} = \frac{2.8}{4} = 0.7$

old $\langle n \rangle_1 = \frac{3.4}{4} = 0.85$

Setting of beam convergence in the transverse plane

$$\mathcal{L} = 10^{27}\ cm^{-2}s^{-1}$$

δX	$N_{tr}/(10\ min)$	Errors
0	2 760 000	0.06 %
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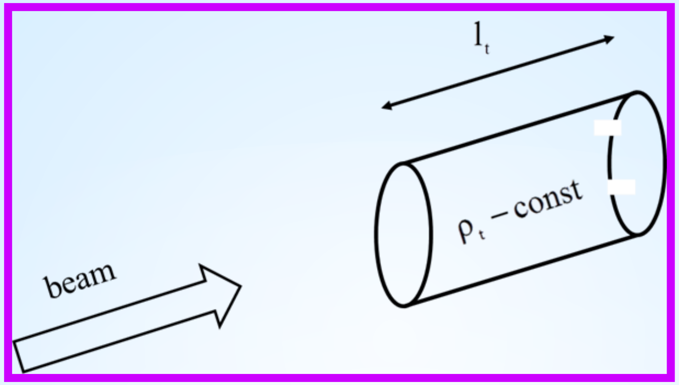
Detector for beams tuning and absolute luminosity measurements in the interaction point at MPD@NICA

A.Litvinenko ,JINR
(alitvin@jinr.ru)
on behalf of the working group

beam convergence procedure
at the point of the interaction

Fixed target luminosity



$$\mathcal{L} = \frac{N_{bm} N_t f}{S}$$

- Nt - the number of target atoms in volume through which the beam passes
- N_{bm} - numbers of particles per burst
- f - repetition rate
- S - transverse beam area

Fixed target luminosity

$$\mathcal{L} = N_{bm} N_A \frac{\rho(g/cm^3) l_t(\text{см})}{A_t} f$$

Example

Nuclotron $f = 0.1$ 1/s

$A_t = 208$ (Pb)

l_t = 0.1 cm

$N_{bm} = 10^{10}$

$$\mathcal{L} = 3.3 \cdot 10^{30}\ cm^{-2}s^{-1}$$

Time structure of AuAu collisions at NICA

Collision parameters (for $\sqrt{S_{NN}} = 11\ \mathrm{GeV}$)

1. Cross section for minimum bias event $\sigma_{AuAu} \approx 6.2\ \mathrm{b}$
2. Max Luminosity $\mathcal{L} = 10^{27}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
3. Counting rate $\mathrm{R} = 6200\ s^{-1} = \mathcal{L} \cdot \sigma_{AuAu}$

Scattering probability for a single crossing of bunches

$$w_1 = \frac{R}{f_r N_b} \approx 5 \cdot 10^{-4}$$

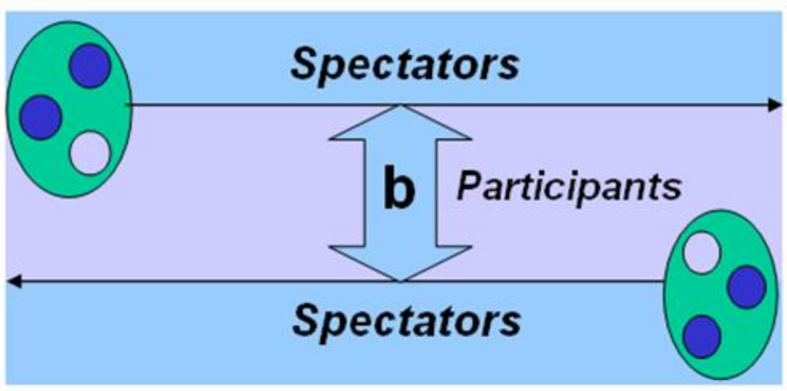
Admixture of pile up events for $t \leq 100\ ns$

$< 10^{-4}$ negligible

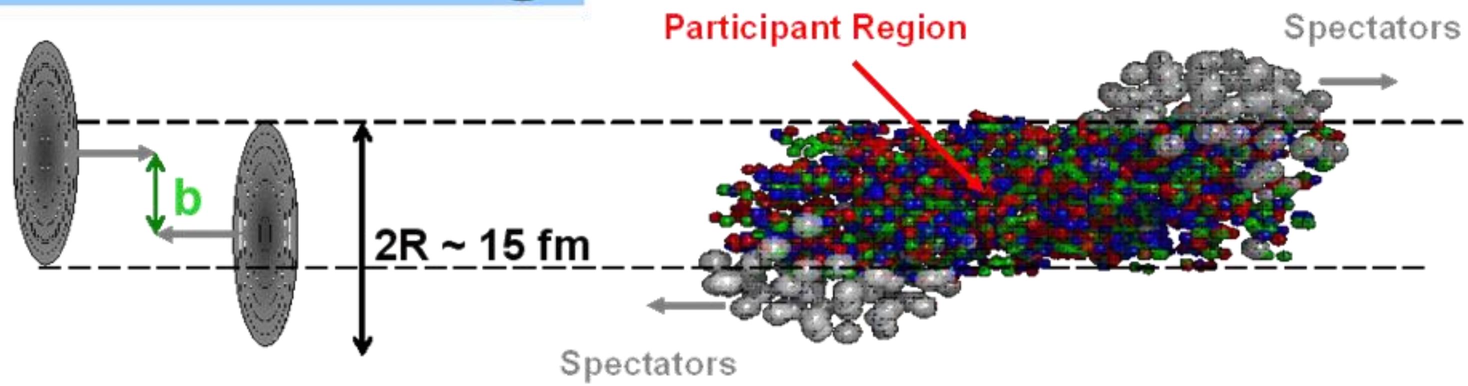
Favorable conditions for creating a "luminosity detector"

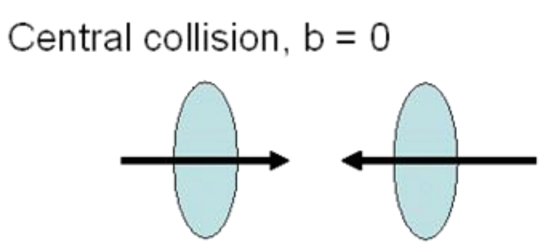
- Topology of Au + Au collisions when in a cone $\theta \leq 4^0$ along both beams many spectators are flying ($E_s \approx E_b = 5.5$ GeV) ($_{79}$Au)). Convenient for trigger.
- Long time between neighboring collisions. No overlapping events.
- The role of scattering on the residual gas is small.
  - ✓ Low counting rate.
  - ✓ Small energy.
  - ✓ Large asymmetry of events.

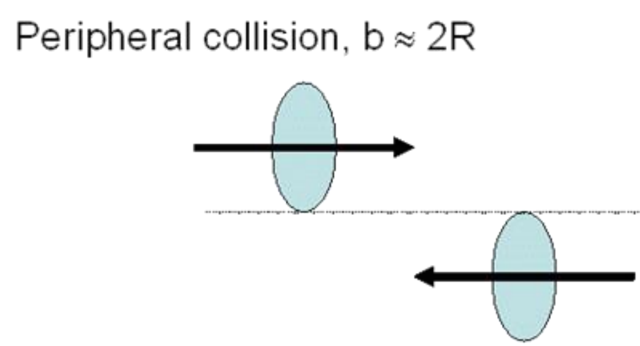
The centrality determination - the observables:



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





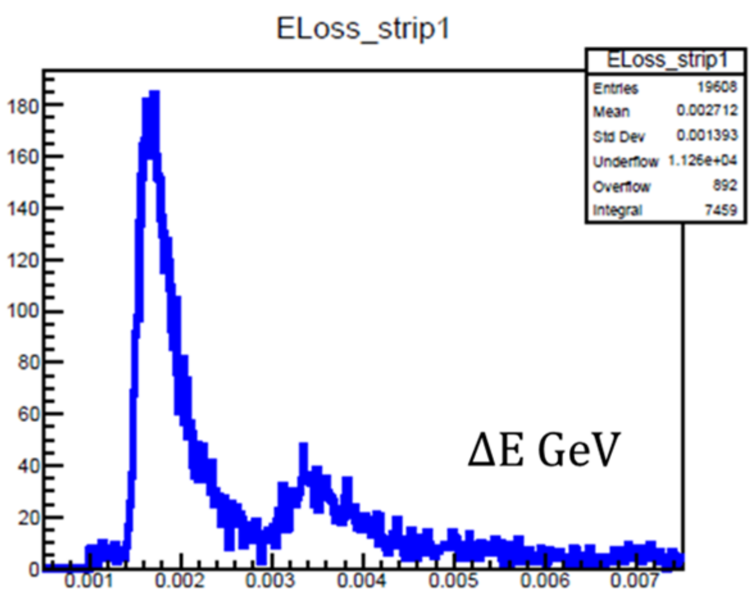


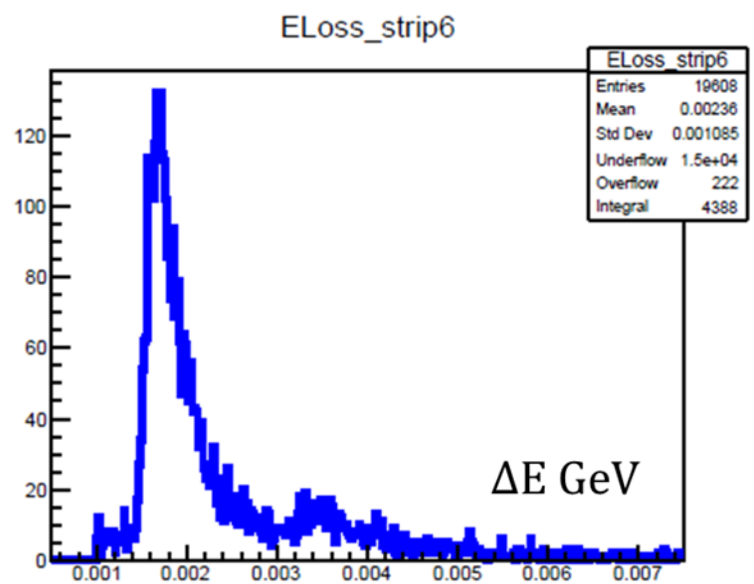
Simulation

Detector operating conditions ($\sqrt{S_{NN}} = 11$ GeV)

Spectator energy $E_S \approx 5.5$ Gev/c

Energy loss spectrum in the scintillator

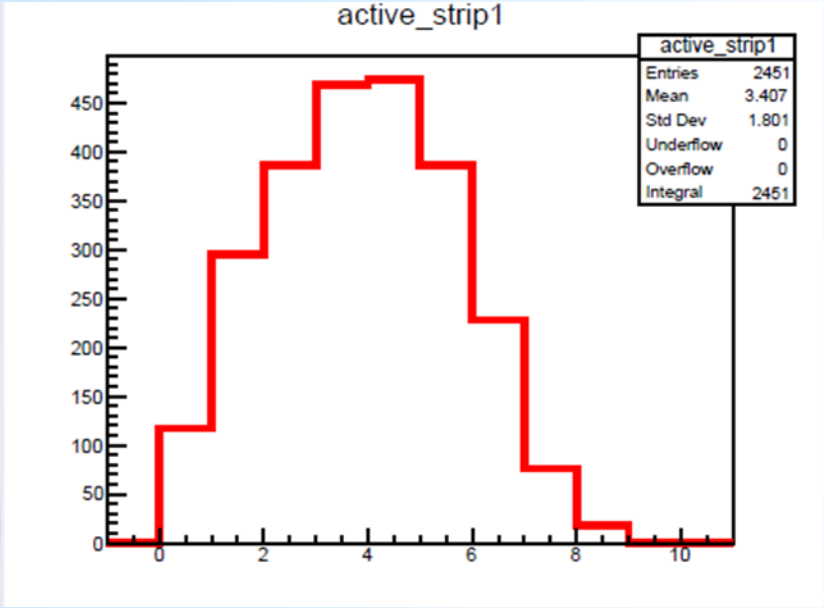


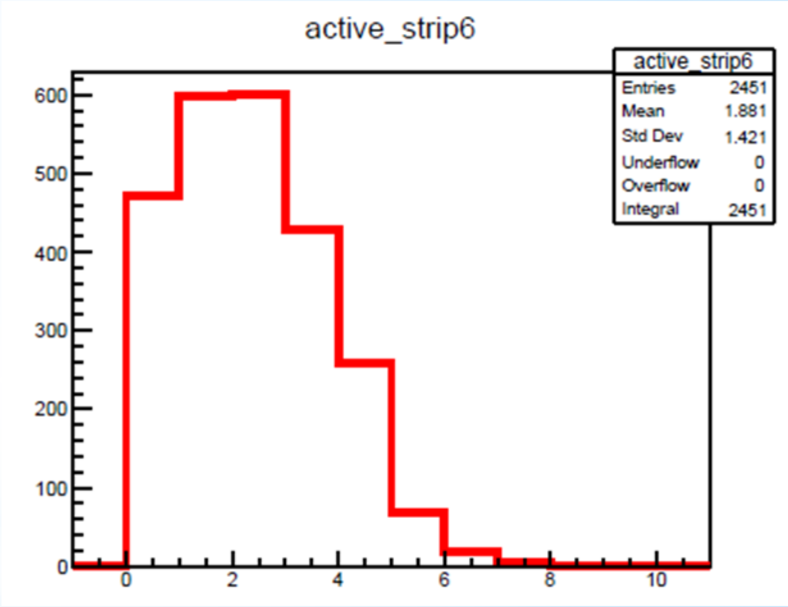


Simulation

Detector operating conditions $(\sqrt{S_{NN}} = 11\ \mathrm{GeV})$

strip occupancy (per 4 strips)





$$\langle n \rangle_1 = \frac{3.4}{4} = 0.85$$

$$\langle n \rangle_6 = \frac{1.88}{4} = 0.47$$

III. absolute luminosity

S. van der Meer, CERN-ISR-PO-68-31, 1968

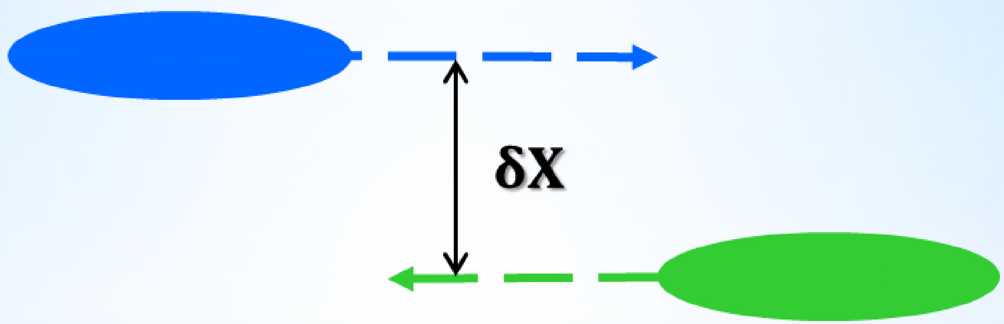
van der Meer scan

CALIBRATION OF THE EFFECTIVE BEAM HEIGHT IN THE ISR

ISR-PO/68-31
June 18th, 1968

by

S. van der Meer



at RHIC and LHC the van der Meer scan is commonly accepted procedure for calibration

Definitions and normalizations

$$\mathcal{L} = \ (N_L N_R \mathrm{f_r N_b})/(\mathrm{S_{eff}})$$

$$\frac{1}{\mathrm{S_{eff}(\delta X, \delta Y)}} = \left(\int_{-\infty}^{\infty} \mathrm{dx\, p_\perp(x - \delta X/2) p_\perp(x + \delta X/2)}\right) \cdot \left(\int_{-\infty}^{\infty} \mathrm{dy\, p_\perp(y - \delta Y/2) p_\perp(y + \delta Y/2)}\right)$$

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} d(\delta X) d(\delta Y) \frac{1}{S_{eff}(\delta \mathrm{X}, \delta Y)} = 1$$

III. absolute luminosity

$$\mathcal{L} = \frac{\frac{dR_{1,2}(0,0)}{dt}}{\iint \frac{dr_{1,2}(\delta X, \delta Y)}{dt} d\delta X d\delta Y}$$

stage 0

IN THE BEGINNING

$S \sim (N_b)^2$

$B \sim N_b$

N_b(1/bunch)	$\mathcal{L}$ ($cm^{-2}s^{-1}$)	N_{AuAu}(1/s)	$N_{\mathcal{L}D}$ (1/s)	N_{AuAu}(1/m)	$N_{\mathcal{L}D}$ (1/m)	B/S
$2 \cdot 10^9$	10^{27}	6000	4900	360000	294000	$< 10^{-5}$
$2 \cdot 10^8$	10^{25}	60	49	3600	2940	$< 10^{-4}$
$2 \cdot 10^7$	10^{23}	0.6	0.49	36	29.4	$< 10^{-3}$
$2 \cdot 10^6$	10^{21}	0.006	0.0049	0.36	0.29	$< 10^{-2}$