Detector for beams collision monitoring and luminosity measurements in the interaction point

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

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, A.G. Litvinenko

- INR RAS (Moscow)

A.B.Kurepin,

- Institute of Physics and Technology, MAS, Ulaanbaatar, 13330 Mongolia

M.Sovd, B.Otgongerel

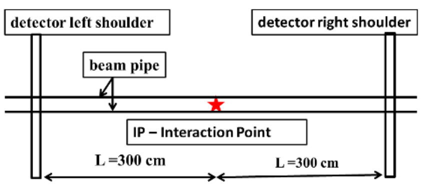
- Anyone wellcome

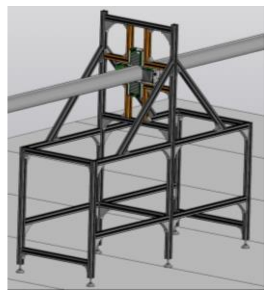
Subject of the report

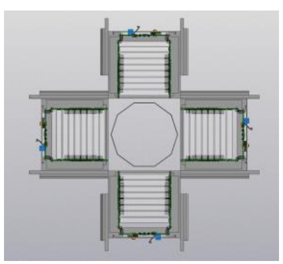
Setting up the intersection of beams in the interaction point at MPD/NICA

Luminosity measurements in the interaction point at MPD/NICA

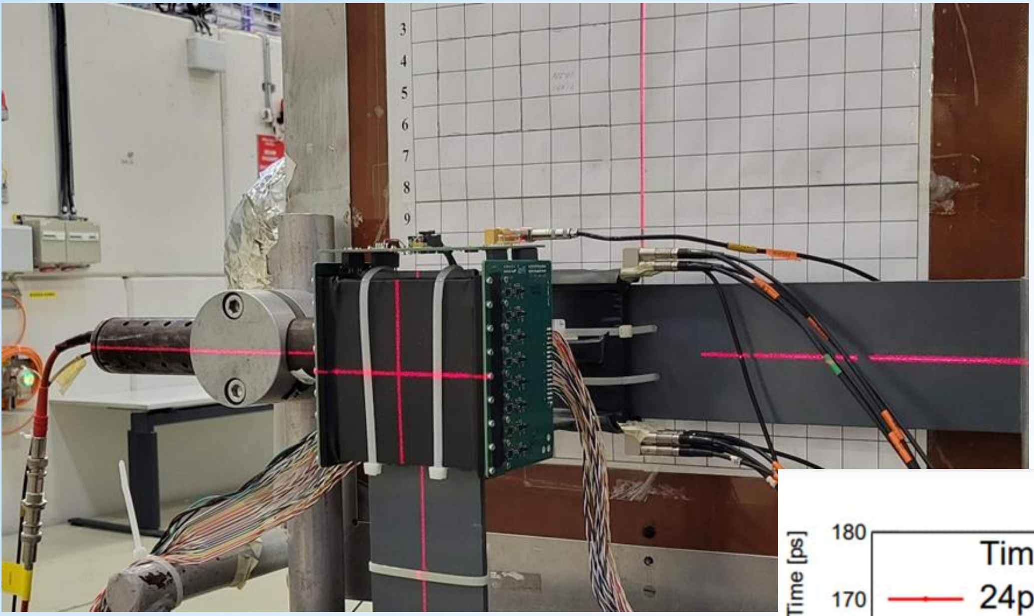
Luminosity detector

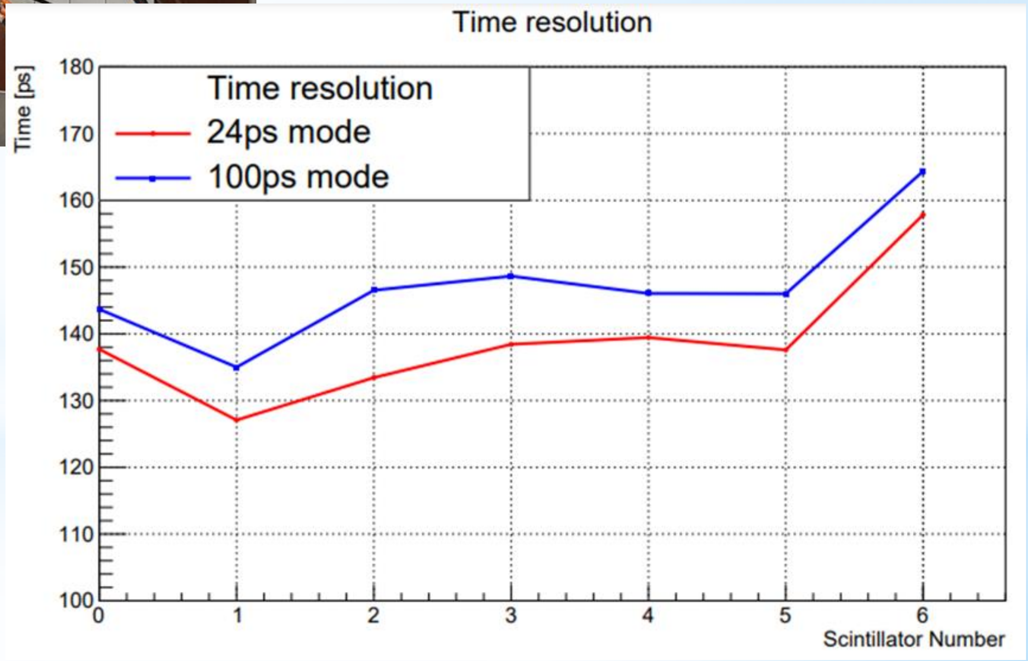




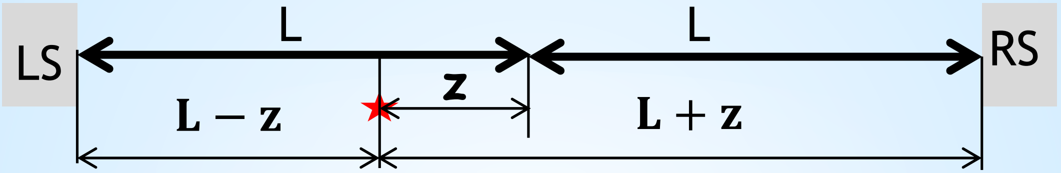


Module of the detector *(Beam test)*





Vertex position



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

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

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

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

$$\boxed{\Delta z^{max}(\mathrm{cm}) = \frac{\tilde{\sigma}_z}{\sqrt{N_{tr}}} = \frac{\sqrt{\sigma_{z,V}^2 + \left(15\cdot\sigma_\tau(\mathrm{ns})\right)^2}}{\sqrt{\varepsilon N_{tot}}}}$$

Luminosity

number of events per second

$$R = N_{tr}/T_{run} = \mathcal{L} \cdot \sigma$$

cross section

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

one of the key parameters of the collider

Relative Luminosity ($\mathcal{L}_r$)

Counting rate for reaction with unknown cross section or/and unknown detector efficiency

$$R = \varepsilon_D \cdot \tilde{\sigma} \cdot \mathcal{L} = \sigma_c \mathcal{L}_r;$$

$$\mathcal{L}_r = k \cdot \mathcal{L}; \; k = (\varepsilon_D \, \tilde{\sigma})/\sigma_c$$

Knowledge of relative luminosity is often enough to calculate physical quantities from measured experimental data. For example, when measuring polarization observables, for a given reaction, it is sufficient to know the relative luminosity.

BUT … SEE NEXT SLIDE

Knowledge of absolute luminosity is necessary for the following tasks:

1. When planning the measurements - to calculate the counting rate.
2. When planning the experiment - to calculate the overlay of signals from different events (pile-up events).
3. To calculate the absolute value of cross section from experimental data.
4. To make differential measurements.
5. …………

Luminosity for some colliders

Collider	Particles	Luminosity
(LEP)	$(\mathbf{e^-e^+})$	$\mathcal{L} = 10^{32}\,\text{см}^{-2}\text{с}^{-1}$
SuperKEKB	$(\mathbf{e^-e^+})$	$\mathcal{L} = 8 \cdot 10^{35}\,\text{см}^{-2}\text{с}^{-1}$
RHIC (BNL)	$(\mathbf{pp})$	$\mathcal{L} = 1.6 \cdot 10^{32}\,\text{см}^{-2}\text{с}^{-1}$
RHIC (BNL)	$(\mathbf{AuAu})$	$\mathcal{L} = 8.7 \cdot 10^{27}\,\text{см}^{-2}\text{с}^{-1}$
RHIC (BNL)	$(\mathbf{CuCu})$	$\mathcal{L} = 6 \cdot 10^{28}\,\text{см}^{-2}\text{с}^{-1}$
LHC (CERN)	(pp)	$\mathcal{L} = 2 \cdot 10^{34}\,\text{см}^{-2}\text{с}^{-1}$
LHC (CERN)	$(\mathbf{PbPb})$	$\mathcal{L} = 3.6 \cdot 10^{27}\,\text{см}^{-2}\text{с}^{-1}$

Luminosity for hadron colliders

Hadron colliders have the highest luminosity for (pp) collisions and several (4-6) orders of magnitude lower luminosity for heavy ion collisions. The large cross section for collisions of heavy ions, compared to proton-proton collisions, does not compensate for the drop in luminosity for ion collisions. So for the interaction cross sections and counting rates on NICA we have:

$$\boldsymbol{\sigma_{pp}} \cong \mathbf{45}\ \text{мб};\ \ \boldsymbol{\mathcal{L}} = \mathbf{10^{32}}\text{см}^{-2}\text{с}^{-1}; \boldsymbol{R} = \mathbf{4.5 \cdot 10^{6}}\ \mathbf{1}/\text{с}$$

$$\boldsymbol{\sigma_{dd}} \cong \mathbf{70}\ \text{мб};\ \ \boldsymbol{\mathcal{L}} = \mathbf{10^{31}}\text{см}^{-2}\text{с}^{-1}; \boldsymbol{R} = \mathbf{7 \cdot 10^{5}}\ \mathbf{1}/\text{с}$$

$$\boldsymbol{\sigma_{AuAu}} \cong \mathbf{6.2}\ \text{б};\ \boldsymbol{\mathcal{L}} = \mathbf{10^{27}}\text{см}^{-2}\text{с}^{-1}; \boldsymbol{R} = \mathbf{6.2 \cdot 10^{3}}\ \mathbf{1}/\text{с}$$

Approaches to luminosity determination

From the experimental data for the counting rate of some reaction

$$N_{tr} = (\mathcal{L}\varepsilon\sigma)T_{run}$$

$$\mathcal{L} = \frac{N_{tr}}{T_{run}(\varepsilon \cdot \sigma)}$$

$$\delta\mathcal{L} = \frac{\Delta\mathcal{L}}{\mathcal{L}} = \sqrt{\left(\frac{\Delta\sigma}{\sigma}\right)^2 + \left(\frac{\Delta\varepsilon}{\varepsilon}\right)^2 + \frac{1}{N_{tr}}}$$

This method is widely used to determine the luminosity of electron-electron and electron-positron colliders

absolute luminosity

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

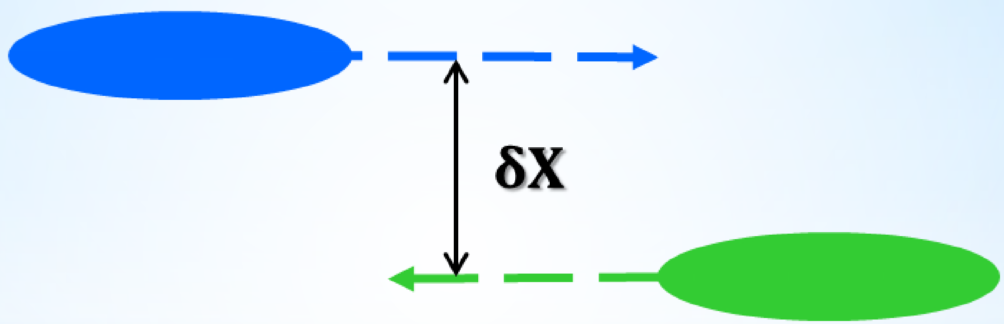
van der Meer scan

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

Luminosity structure.

$$\mathcal{L} = \sum_{b=1}^{\mathrm{N_b}} \mathrm{f_r} \frac{\mathrm{I_{b,L} I_{b,R}}}{\mathrm{S_{\perp,b}}}$$

$$\mathcal{L}_\mathrm{b} = \mathrm{f_r} \frac{\mathrm{I_{b,L} I_{b,R}}}{\mathrm{S_{\perp,b}}}$$

Luminosity is determined by the following three factors:

1. Accelerator constants:

"revolution frequency $\mathrm{f_r}$" and "number of bunches $\mathrm{N_b}$";

2. Intensity (numbers of particles in banch $\mathrm{I_{b,L/R}}$);

3. Parameters of colliding bunches, such as the distribution of particles inside the bunch and focusing conditions.

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The distribution of particles inside the bunch

For clarity, it is assumed that the distributions of particles in all bunches are identical and are described by a normal law for all coordinates:

$$\mathbf{p}_{(L,R)}(x, y, z; z_V) = \mathbf{p}_{x,L/R}(x\,; z_V) \cdot \mathbf{p}_{y,L/R}(y; z_V) \cdot \mathbf{p}_{z,L/R}(z)$$

$$\begin{cases} \mathbf{p}_{x,L/R}(x; z_V) = \left(1/(\sqrt{2\pi}\sigma_x(z_V))\right)\exp\left(-x^2/\left(2\sigma_x^2(z_V)\right)\right) \\ \mathbf{p}_{y,L/R}(y; z_V) = \left(1/(\sqrt{2\pi}\sigma_y(z_V))\right)\exp\left(-y^2/(2\sigma_y^2(z_V))\right) \\ \mathbf{p}_{z,L/R}(z) = \left(1/(\sqrt{2\pi}\sigma_z)\right)\exp\left(-z^2/(2\sigma_z^2)\right) \end{cases}$$

Effective area $S_{\perp,b}(\delta X,\delta Y)$ of beam intersection

$$\mathcal{L}_b(\delta X,\delta Y) = f_r \frac{I_{b,L} I_{b,R}}{S_{\perp,b}(\delta X,\delta Y)}$$

$$\frac{1}{S_{\perp,b}(\delta X,\delta Y)} =$$

$$= 2 \iint \iint dz_V d\xi \, dxdy \left(p_{\perp,L}(x+\delta X/2\,, x \to y; z_V) p_{\perp,R}(x-\delta X/2\,,; x \to y; z_V\,) \right)$$

$$\left(p_{z,L}(z_V-\xi)\cdot p_{z,R}\,(z_V+\xi) \right)$$

key property of $S_{\perp,b}(\delta X,\delta Y)$

$$\iint d(\delta X) d(\delta Y) \left(\frac{1}{S_{\perp,b}(\delta X,\delta Y)} \right) = 1$$

1

vdM scan

Step I

$$\{N_{tr}(\delta X_i, \delta Y_j), T_{run}(\delta X_i, \delta Y_j)\} \rightarrow R(\delta X_i, \delta Y_j) = N_{tr}(\delta X_i, \delta Y_j)/T_{run}(\delta X_i, \delta Y_j)$$

Step II

$$r(\delta X_i, \delta Y_j) = \frac{R(\delta X_i, \delta Y_j)}{(f_r I_{i,j;L} I_{i,j;R})} = (\varepsilon\sigma)\frac{1}{S_\perp(\delta X_i, \delta Y_j)}$$

reminder

$$\mathcal{L} = f_r \frac{I_{b,L} I_{b,R}}{S_{\perp,b}}; R = (\varepsilon\sigma)\mathcal{L}$$

Step III

$$\boxed{r(\delta X_i, \delta Y_j) = (\varepsilon\sigma)\frac{1}{S_\perp(\delta X_i, \delta Y_j)}} \xrightarrow{\text{approximation}} \boxed{r(\delta X, \delta Y)}$$

1

vdM scan

Step IV

$$K = \iint d(\delta X)\, d(\delta Y)\, r(\delta X, \delta Y) = (\varepsilon\sigma) \iint d(\delta X)\, d(\delta Y) \frac{1}{S_{\perp,b}(\delta X, \delta Y)} = (\varepsilon\sigma)$$

Luminosity from the experimental data:
(any run 😇)

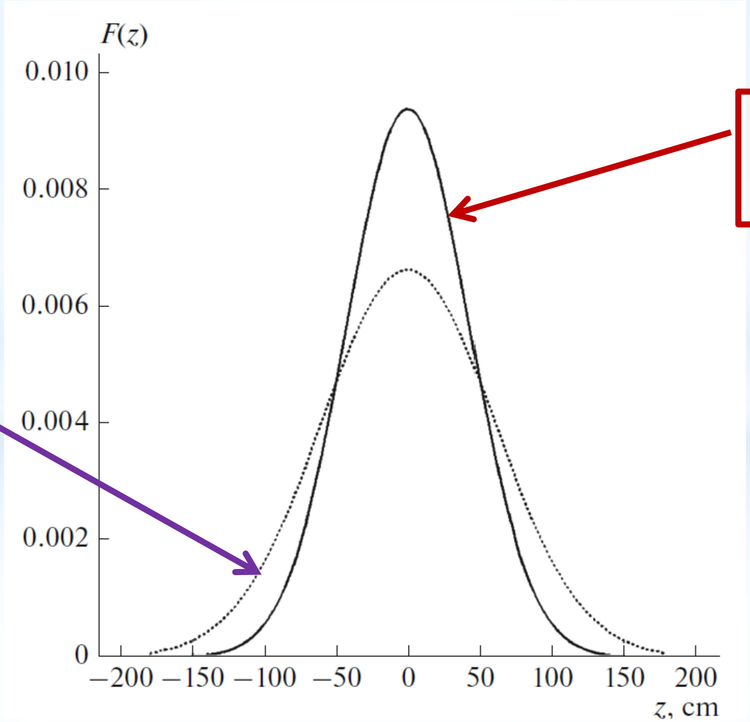
$$\mathcal{L} = \frac{N_{tr}}{T_{run}(\varepsilon \cdot \sigma)} = \frac{N_{tr}}{T_{run} K}$$

1

examples with normal distribution

without focusing

$$\frac{1}{S_{\perp,b}(\delta X,\delta Y)} = \frac{1}{4\pi\sigma_x\sigma_y}\exp\left(-\frac{(\delta X)^2}{4\sigma_x^2}\right)\cdot\exp\left(-\frac{(\delta Y)^2}{4\sigma_y^2}\right)$$



Vertexes
$\sigma_{z,V} = \sigma_{z,p}/\sqrt{2}$=42.3 cm

particles in bunches
$\sigma_{z.p} = 60\ cm$

1

examples with normal distribution

with focusing

$$\frac{1}{S_{\perp,b}}(\delta X, \delta Y) = \frac{1}{4\pi\sigma_x(0)\sigma_y(0)}\,\frac{1}{\sqrt{\pi}\sigma_z}\int_{-\infty}^{\infty} dz_V\ \exp\left(-\frac{z_V^2}{\sigma_z^2}\right)\cdot$$

$$\cdot\left[\exp\left(-\frac{(\delta X)^2}{4\sigma_x^2(0)\left(1+\left(\frac{z_V}{\beta_{IP}}\right)^2\right)}\right)\cdot\exp\left(-\frac{(\delta Y)^2}{4\sigma_y^2(0)\left(1+\left(\frac{z_V}{\beta_{IP}}\right)^2\right)}\right)\cdot\frac{1}{\left(1+\left(\frac{z_V}{\beta_{IP}}\right)^2\right)}\right]$$

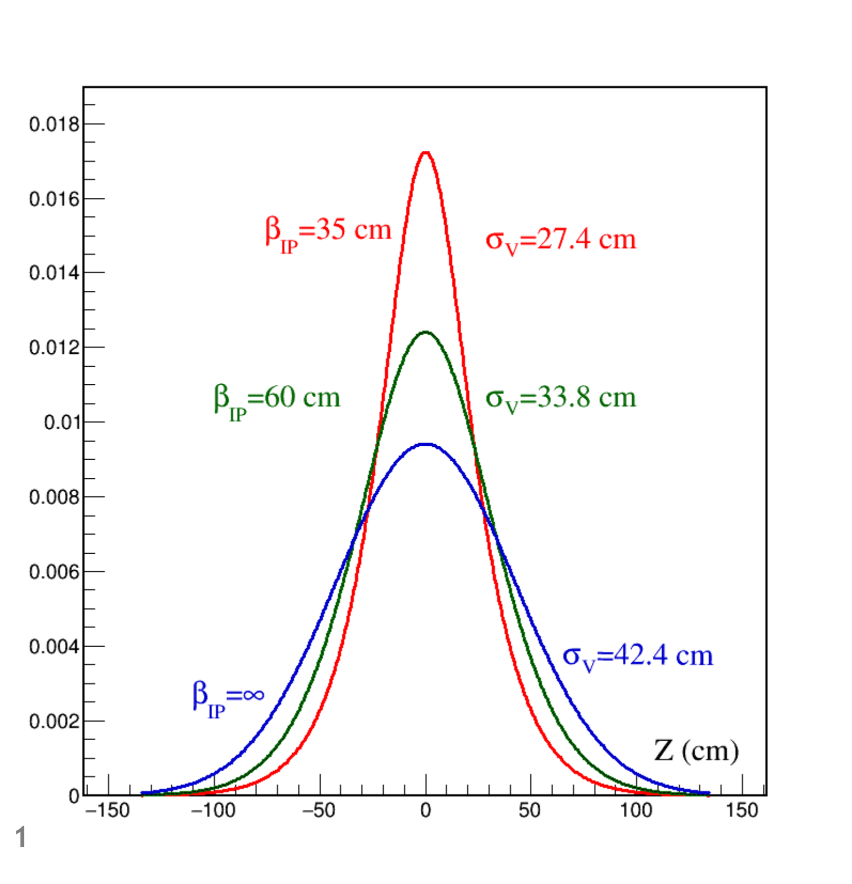
$\beta_{IP} = 60$ cm - beta function at the Interaction Point

1

examples with normal distribution

with focusing

Distribution of interaction vertices



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

Conclusion

The algorithm for obtaining absolute luminosity with "luminosity detector" at MPD/NICA has been presented

vdM scan

Step I

$$\{N_{tr}(\delta X_i, \delta Y_j), T_{run}(\delta X_i, \delta Y_j)\} \rightarrow R(\delta X_i, \delta Y_j) = N_{tr}(\delta X_i, \delta Y_j)/T_{run}(\delta X_i, \delta Y_j)$$

Step II

$$r(\delta X_i, \delta Y_j) = \frac{R(\delta X_i, \delta Y_j)}{(f_r I_{i,j;L} I_{i,j;R})} = (\varepsilon\sigma)\frac{1}{S_\perp(\delta X_i, \delta Y_j)}$$

reminder → $\mathcal{L} = f_r \frac{I_{b,L} I_{b,R}}{S_{\perp,b}}; R = (\varepsilon\sigma)\mathcal{L}$

Step III

$$\boxed{r(\delta X_i, \delta Y_j) = (\varepsilon\sigma)\frac{1}{S_\perp(\delta X_i, \delta Y_j)}} \xrightarrow{\text{approximation}} \boxed{r(\delta X, \delta Y)}$$

vdM scan

Step IV

$$K = \iint d(\delta X) d(\delta Y) r(\delta X, \delta Y) = (\varepsilon\sigma) \iint d(\delta X) d(\delta Y) \frac{1}{S_{\perp,b}(\delta X, \delta Y)} = (\varepsilon\sigma)$$

Luminosity from the experimental data: (any run 😇)

$$\boxed{\mathcal{L} = \frac{N_{tr}}{T_{run}(\varepsilon \cdot \sigma)} = \frac{N_{tr}}{T_{run} K}}$$

FUNDING

The work is partially supported by the Russian Science Foundation, project nos. 23-22-00077 and 23-22-00160.

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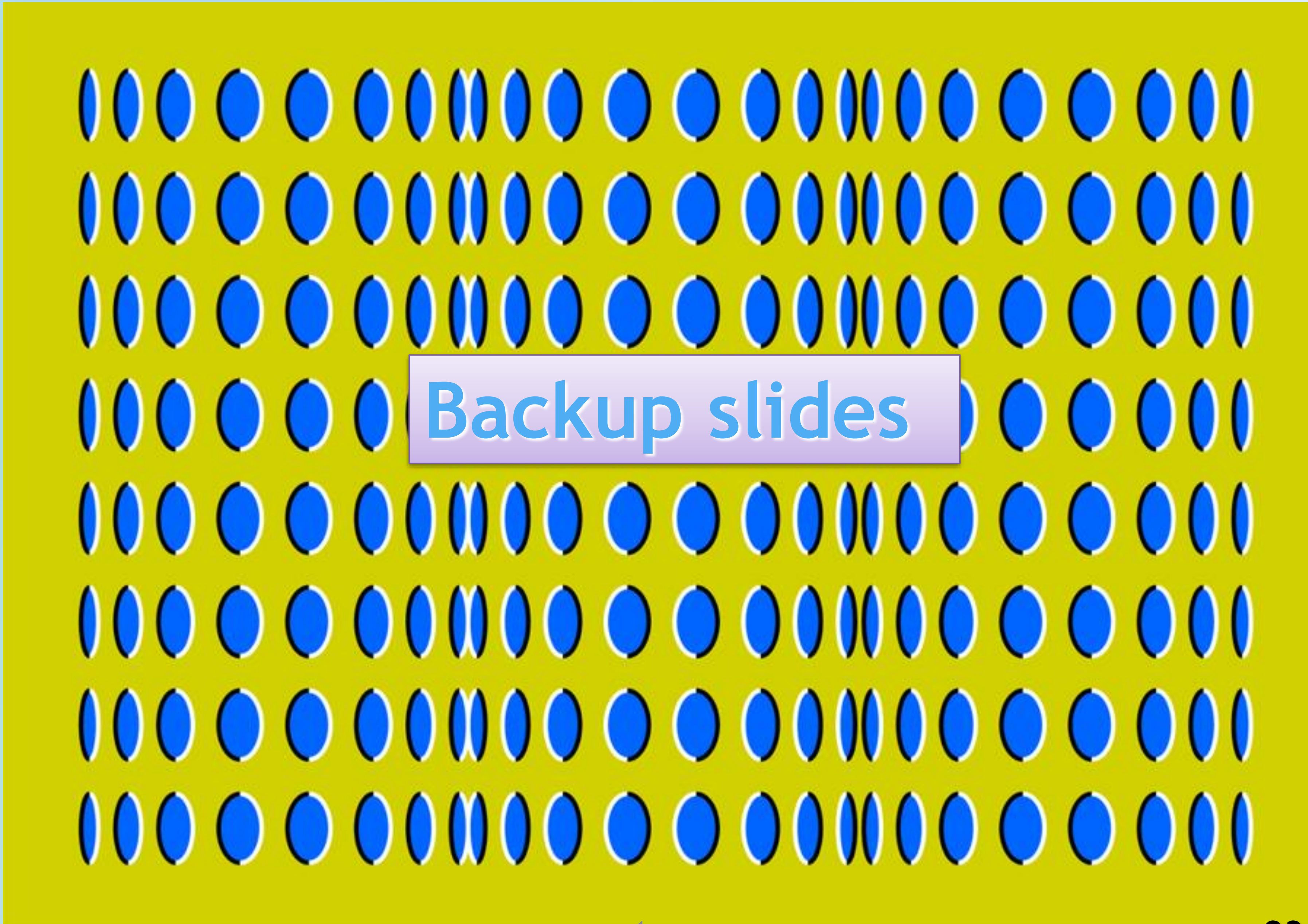


Backup slides

stage 0

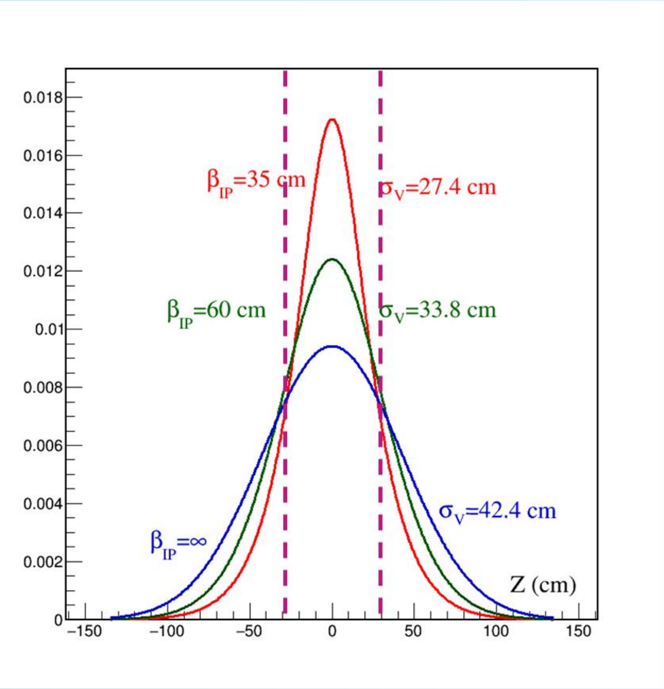
IN THE BEGINNING

$$S \sim (N_b)^2$$

$$B \sim N_b$$

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	$< 10^{-2}$

Efficiency, Luminosity and beta function



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

$$\sigma_x = 1.1\ \text{mm};\ \sigma_y = 0.82\ \text{mm}$$

$$-30\ \text{cm} \le Z_V \le 30\ \text{cm}$$

	$\beta_{IP} = 35$ 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
$\mathcal{L}(cm^{-2}s^{-1})\varepsilon$	$3.8 \cdot 10^{26}$	$4.4 \cdot 10^{26}$	$4.7 \cdot 10^{26}$

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

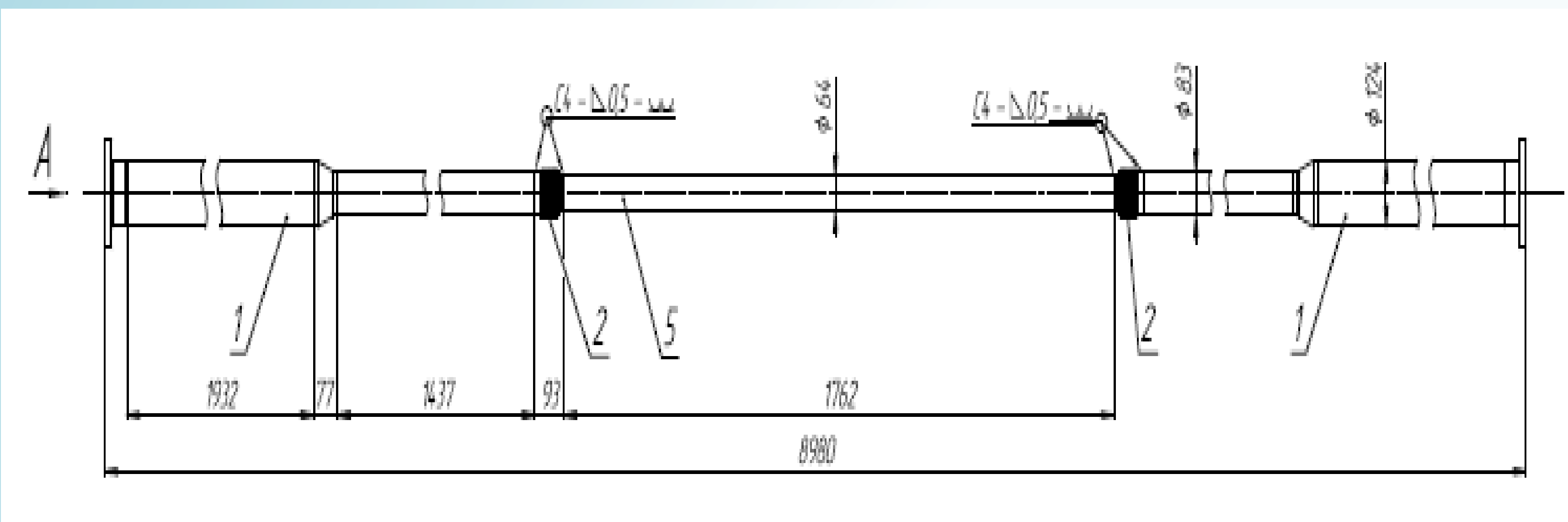
- ✓ the first one is the counting rate
- ✓ the second one is the distribution of interaction vertices obtained from ToF

Ion guide on MPD

old

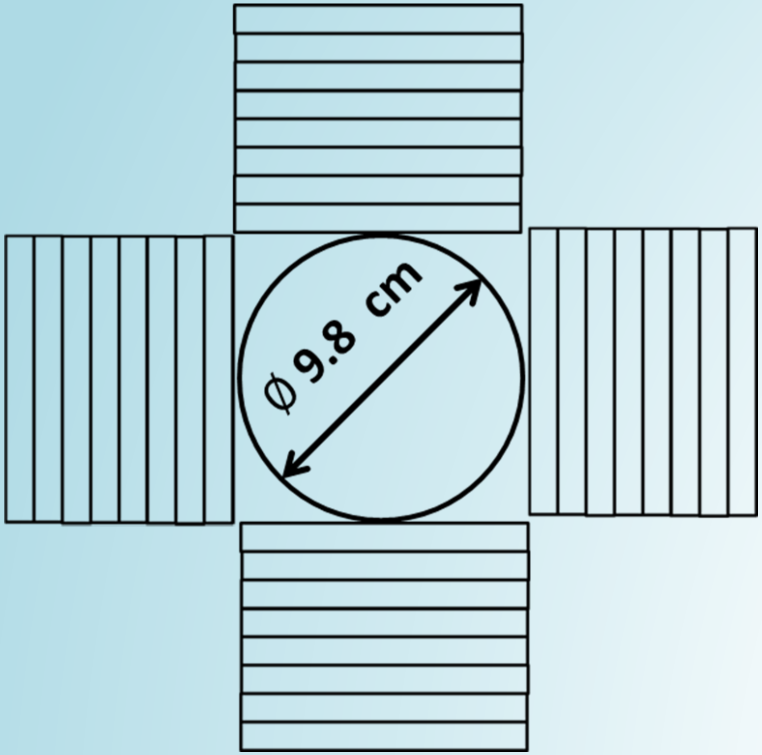
Ø 10 мм

new

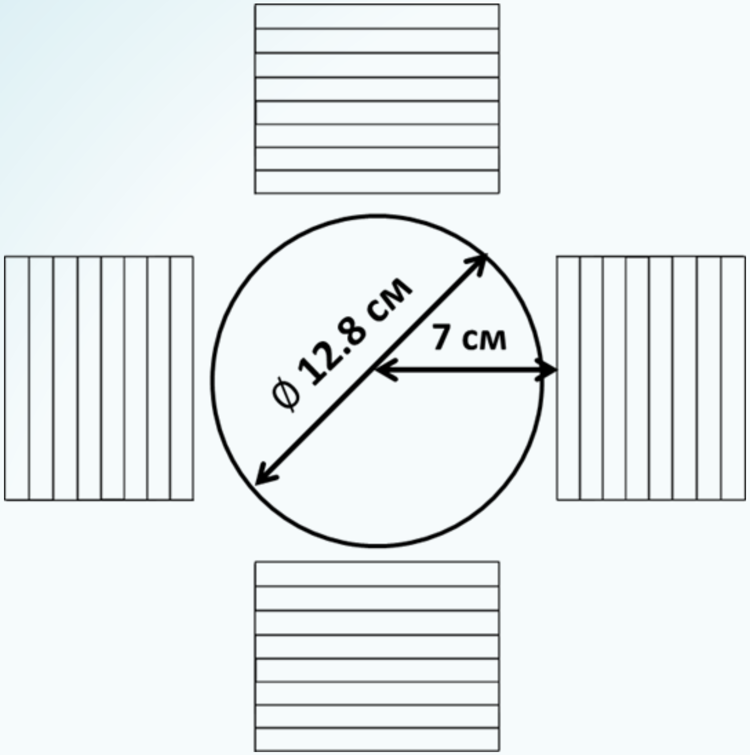


What has changed since April this year

old



new



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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

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

Efficiency

$$\varepsilon = \cancel{82\%} \rightarrow \boldsymbol{\varepsilon} = \mathbf{77\%}$$

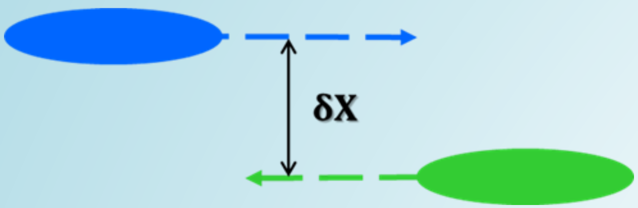
Efficiency = Detected/Produced

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

Transverse plane. Luminosity structure. Van der Meer scan.

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

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



Van der Meer scan.

For normal distribution

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

Adjustment of beam convergence in the transverse plane

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;

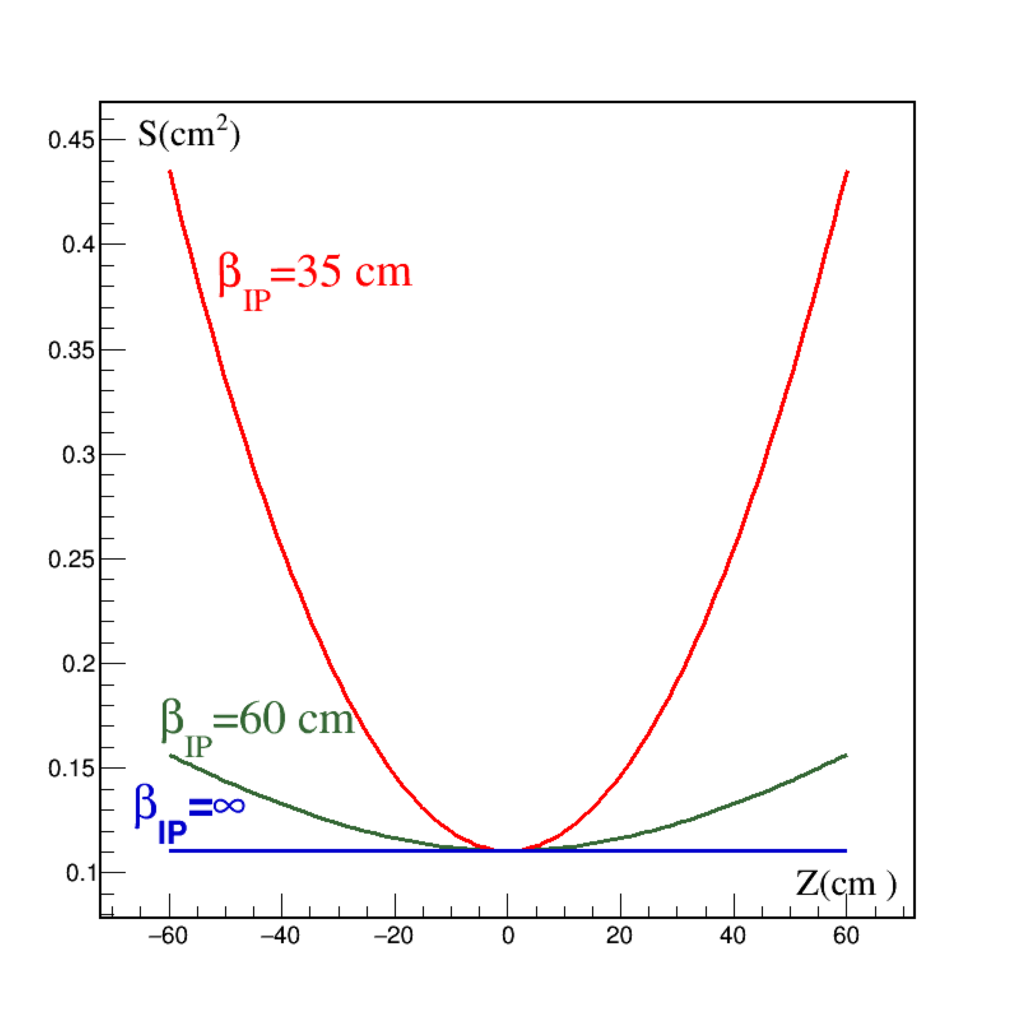
$\mathcal{L} = 10^{27}\ cm^{-2}s^{-1}$

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%

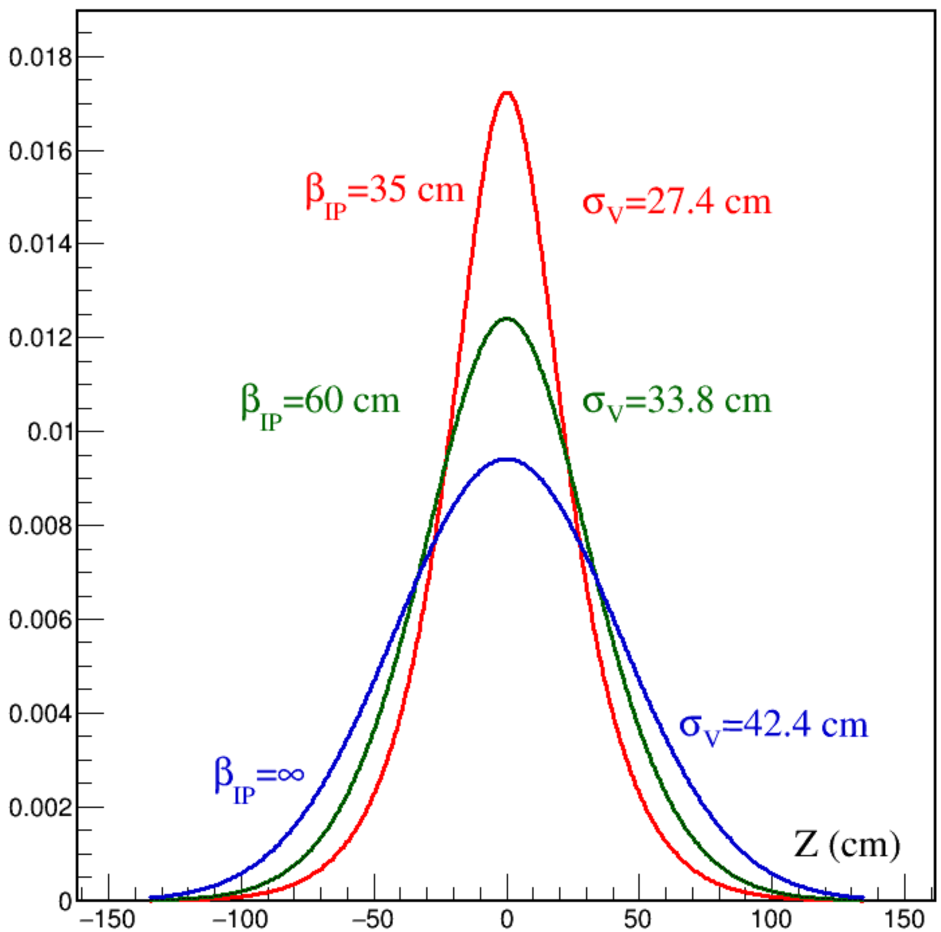
Beta function



Transverse area

$$\mathbf{S_{eff,\perp}}(\boldsymbol{Z}) = \mathbf{S_{eff,\perp}}(\mathbf{0})\left(\mathbf{1} + (\mathbf{Z}/\boldsymbol{\beta}_{\mathbf{IP}})^{\mathbf{2}}\right)$$

Distribution of interaction vertices



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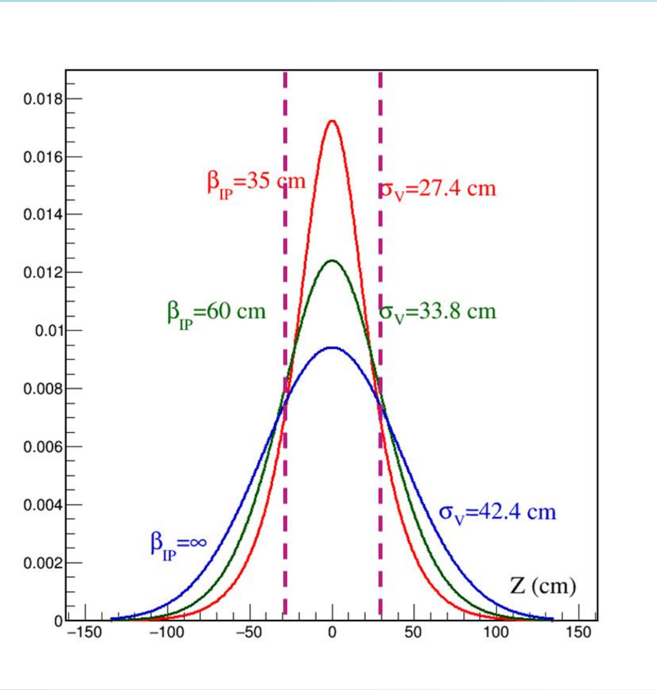
$$\begin{cases} P(Z_V) = N \dfrac{\exp\left(-Z_V^2/\sigma_Z^2\right)}{\left(1+\left(Z_V/\beta_{IP}\right)^2\right)} \\ N = \dfrac{1}{\int_{-\infty}^{\infty} \dfrac{\exp\left(-Z_V^2/\sigma_Z^2\right)}{\left(1+\left(Z_V/\beta_{IP}\right)^2\right)}\, dZ_V} \end{cases}$$

Efficiency, Luminosity and beta function



$$\mathbf{N_L = N_R = 2.8 \cdot 10^9}$$

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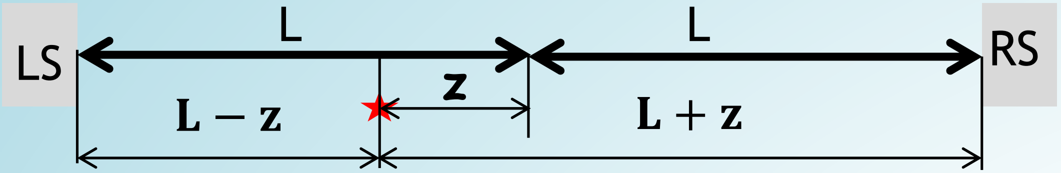
Vertex position



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

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

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

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

Z coordinate. Maximum of interaction point distribution from ToF

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

$$\Delta Z(\text{cm}) = \frac{\widetilde{\sigma}_z}{\sqrt{\text{N}_{\text{tot}}}} = \frac{34 \cdot (1 + 0.016)\ \text{cm}}{\sqrt{\text{N}_{\text{tot}}}}$$

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

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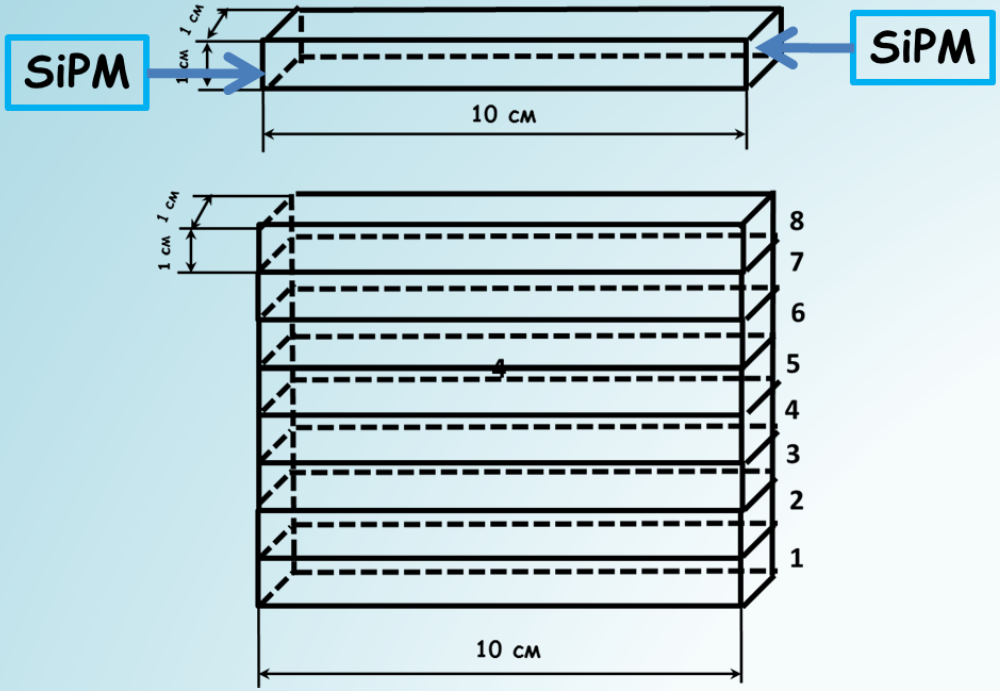
$\delta X = \sigma_X$	17640	0.75 %
$\delta X = 2\sigma_X$	3735	1.6%
$\delta X = 3\sigma_X$	307	5%

1

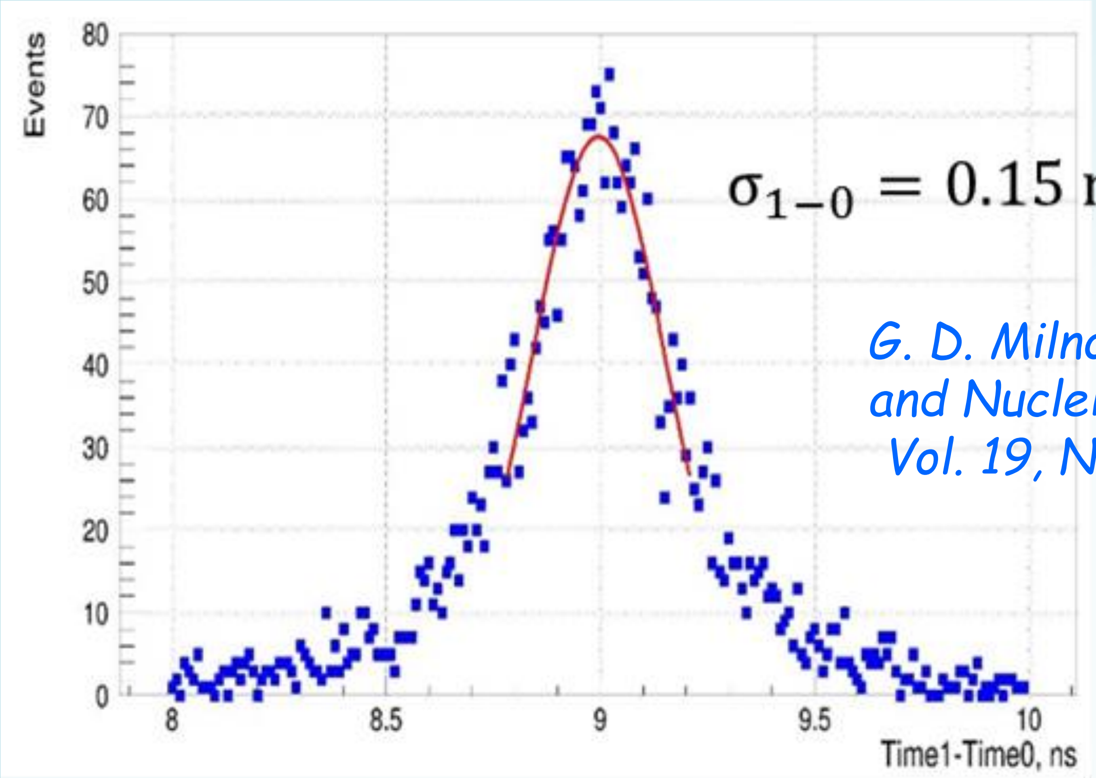
One plane of detector



The plane consists of $100 \mathrm{x} 10 \mathrm{x} 10 \ \mathrm{mm}^3$ 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)

Space muons. ToF of counters

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



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

$\sigma \approx 100$ ps

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.

Conclusion II

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

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

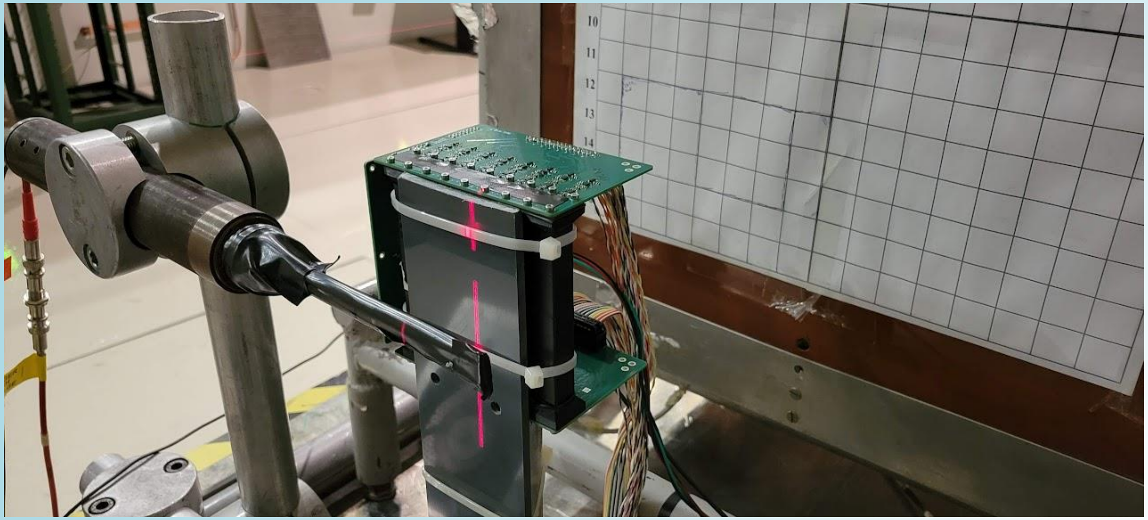
δX	$\mathrm{N_{tr}}/(10\ min)$	Errors
0	27600	0.6 %
$\delta X = \sigma_X$	17640	0.75 %
$\delta X = 2\sigma_X$	3735	1.6%
$\delta X = 3\sigma_X$	307	5%

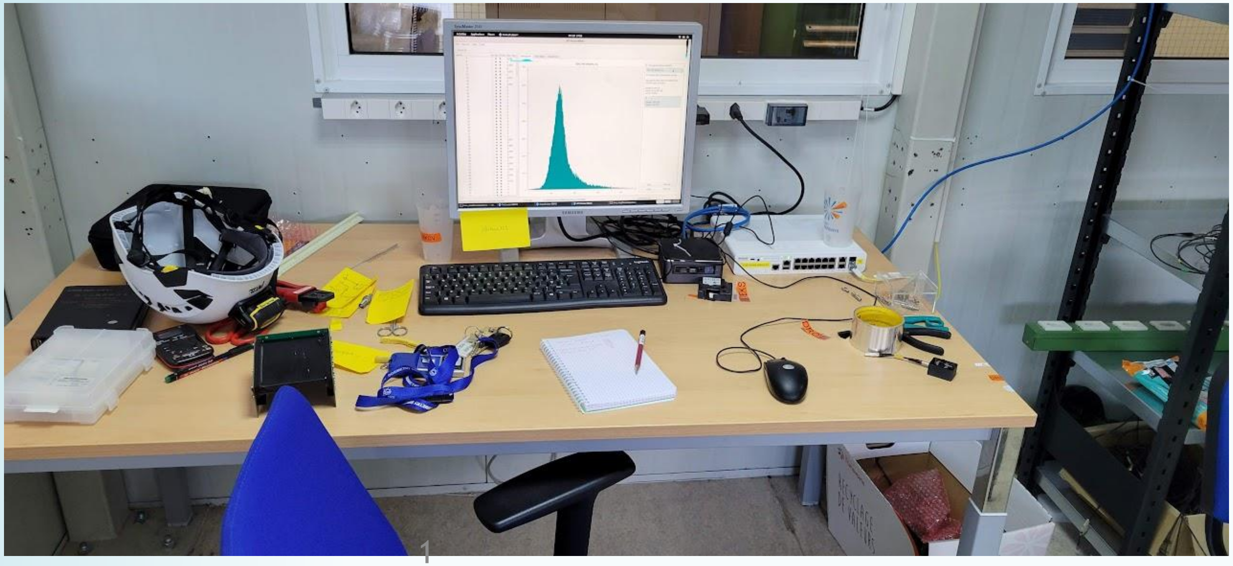
1

Beam test at CERN

S.G.Buzin, M.G.Buryakov

Two planes





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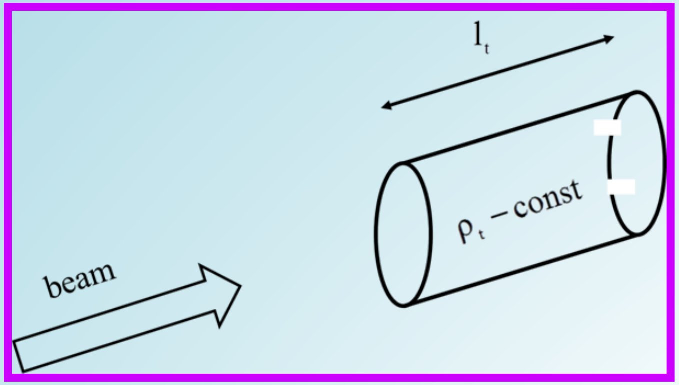
Fixed target luminosity



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

- 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

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

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

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

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

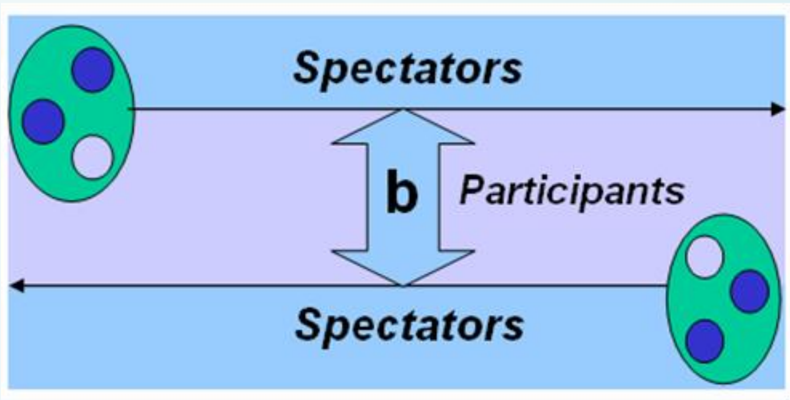
$< 10^{-4}$ negligible

1

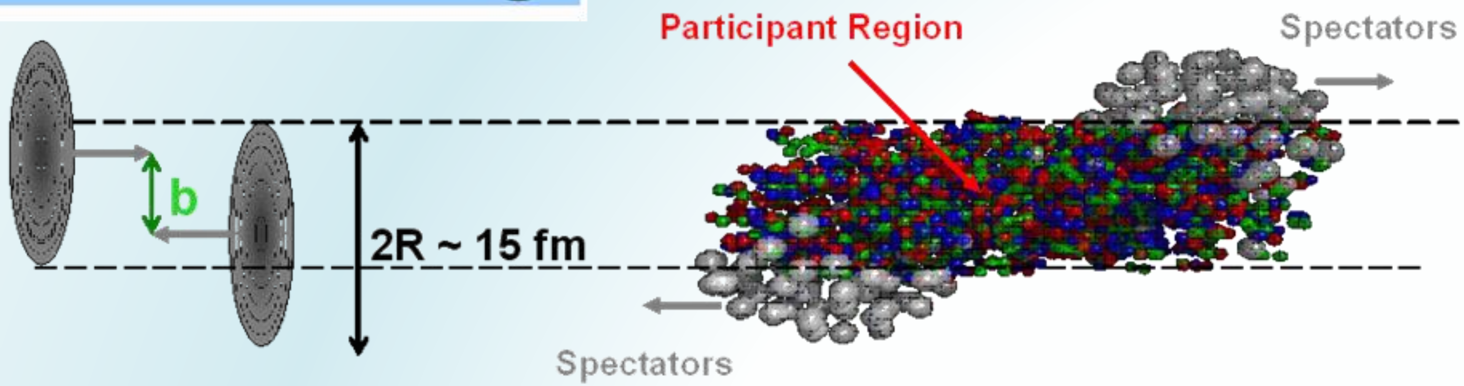
Favorable conditions for creating a "luminosity detector"

- Topology of Au + Au collisions when in a cone $\theta \leq 4^0$ along both beams many spectators are flying ($E_s \approx E_b = 5.5\ \mathrm{GeV}$) ($_{79}\mathrm{Au}$)). 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.

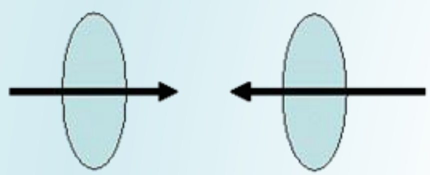
The centrality determination – the observables:



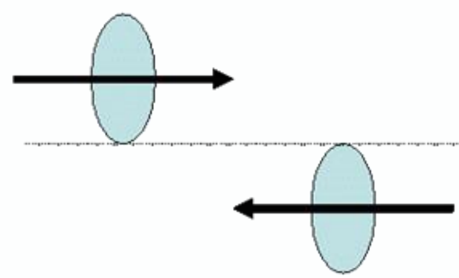
- The number of particles produced in the region of rapidity close to zero
- The total energy of spectators



Central collision, b = 0



Peripheral collision, b ≈ 2R

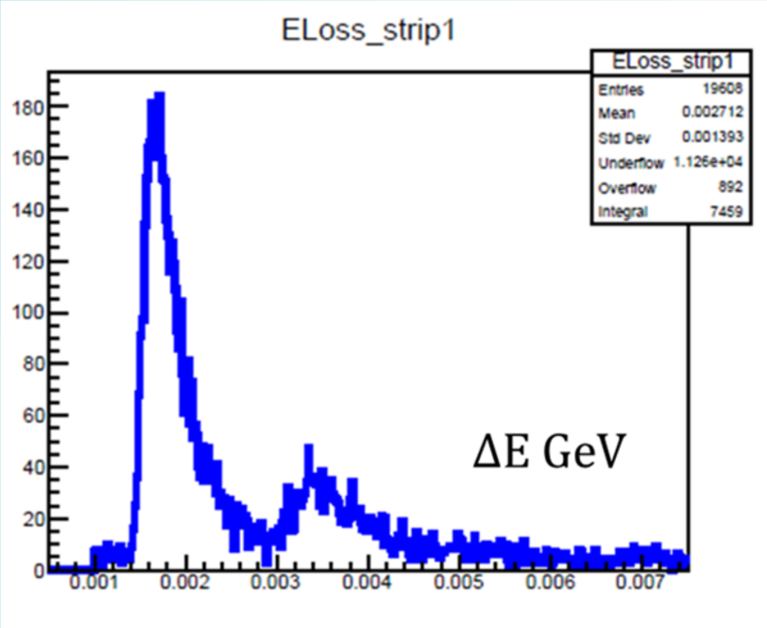


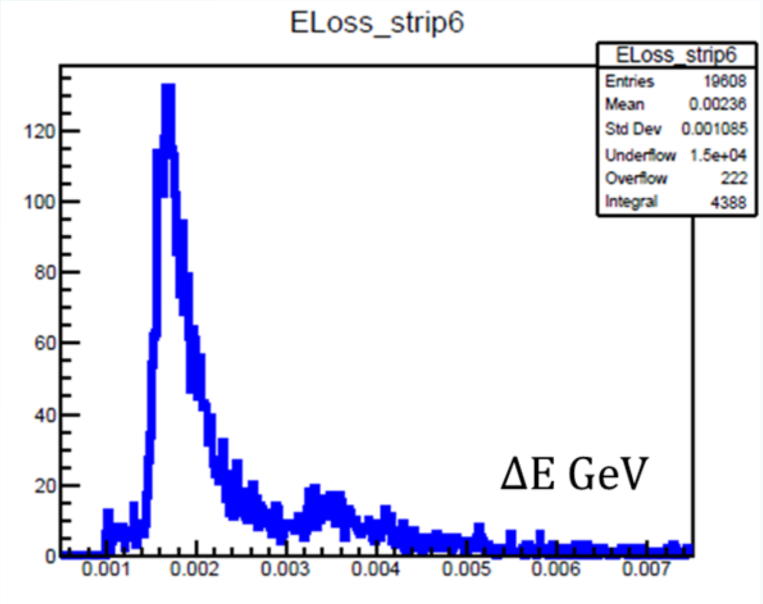
Simulation

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

Spectator energy $E_S \approx 5.5\ \mathrm{Gev/c}$

Energy loss spectrum in the scintillator

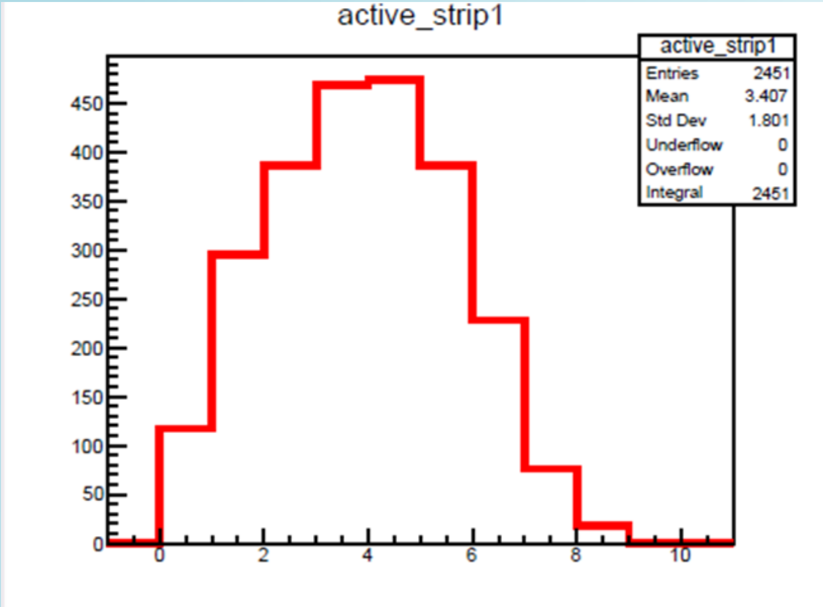


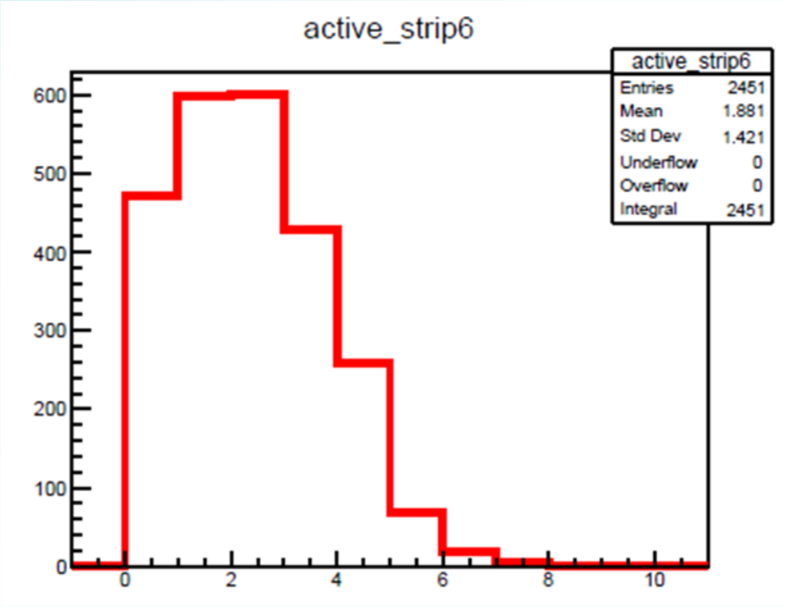


Simulation

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

strip occupancy (per 4 strips)





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

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

1

III. absolute luminosity

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

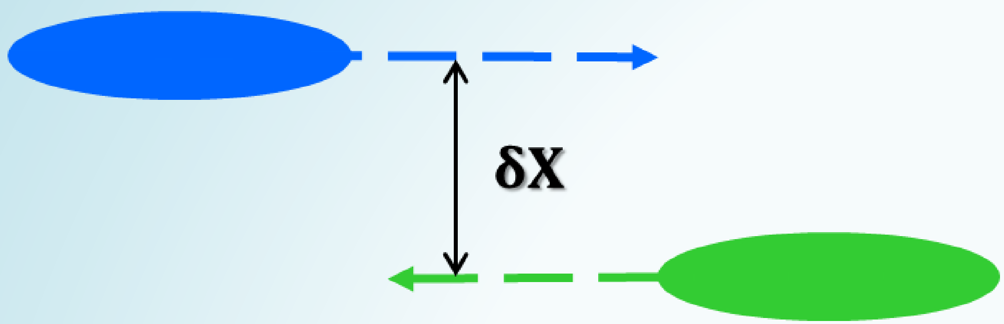
van der Meer scan

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

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

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

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

III. absolute luminosity

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

$$\frac{\int \mathrm{d}(\delta X)\left(\frac{1}{S_{\perp,x}(\delta X/2\,)}\right) = \int \mathrm{d}(\delta X)\left(\int dx\left(p_{\perp,L}(x+\delta X/2)p_{\perp,R}(x-\delta X/2)\right)\right) =}{\iint \mathrm{d}(\delta X)\, dx\left(p_{\perp,L}(x+\delta X/2)p_{\perp,R}(x-\delta X/2)\right)}$$

$$\begin{cases} u = x + \delta X/2 \\ v = x - \delta X/2 \end{cases}$$

$$\iint \mathrm{d}(\delta X)\, dx\left(p_{\perp,L}(x+\delta X/2)p_{\perp,R}(x-\delta X/2)\right) =$$
$$\left(\int du \cdot p_{\perp,L}\,(u)\right)\cdot\left(\int dv \cdot p_{\perp,R}(v)\right) = (1)\cdot(1) = 1$$

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RHIC and NICA

RHIC $\sqrt{S_{NN}} = 200$ GeV

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

Angular acceptance

$$p_{b,RHIC}/p_{b,NICA} \approx 20; \rightarrow \theta_{s,NICA}/\theta_{s,RHIC} \approx 20$$

ZDC at RHIC and NICA

$$L_{NICA} \approx 20 \cdot L_{RHIC}$$

Energy resolution

RHIC $\Delta E_s/E_s \approx 6\%$

NICA $\Delta E_s/E_s \approx 25\ \%$

more questions?