Conceptual Design for a Polarized Proton-Antiproton Collider Facility at GSI

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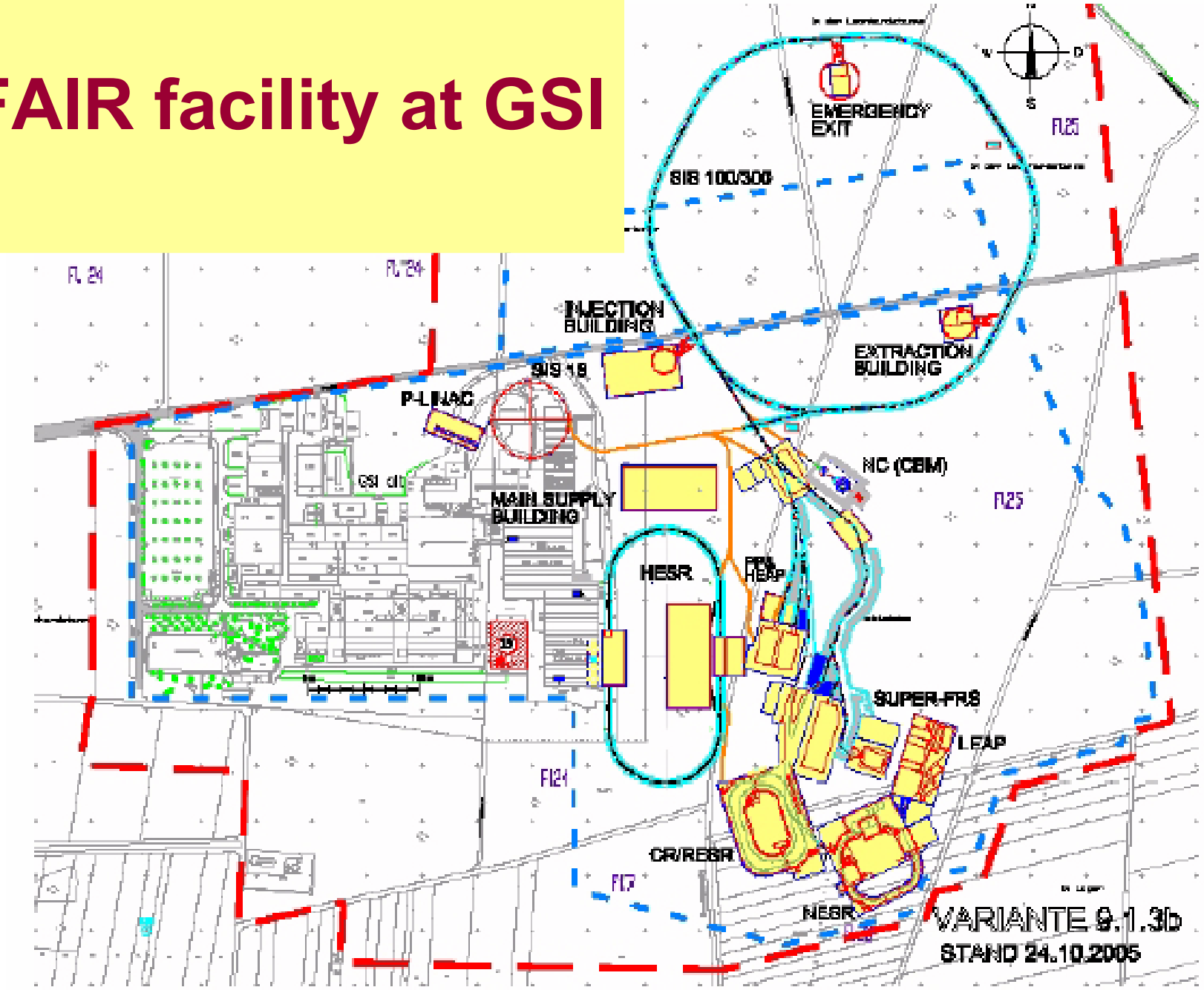
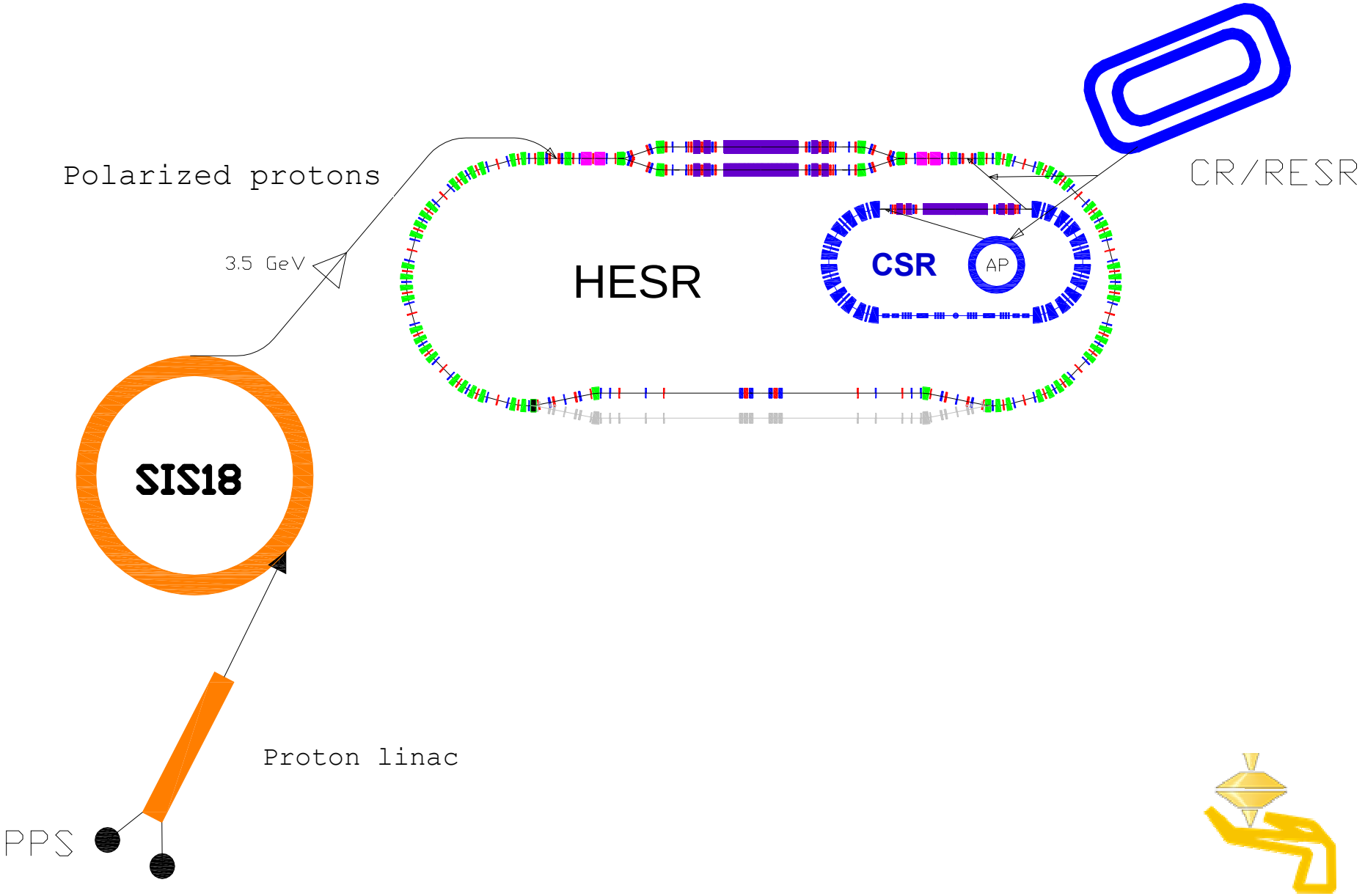
topics

- *HESR collider option (15×15 GeV)*
- *luminosity considerations*
- *intra beam scattering and electron cooling*
- *basic parameters of p-pbar collider*
- *optics of the collider*
- *asymmetric collider option (3.5×15 GeV)*
- *polarized proton acceleration at SIS-18*
- *polarized antiprotons*
- *summary*

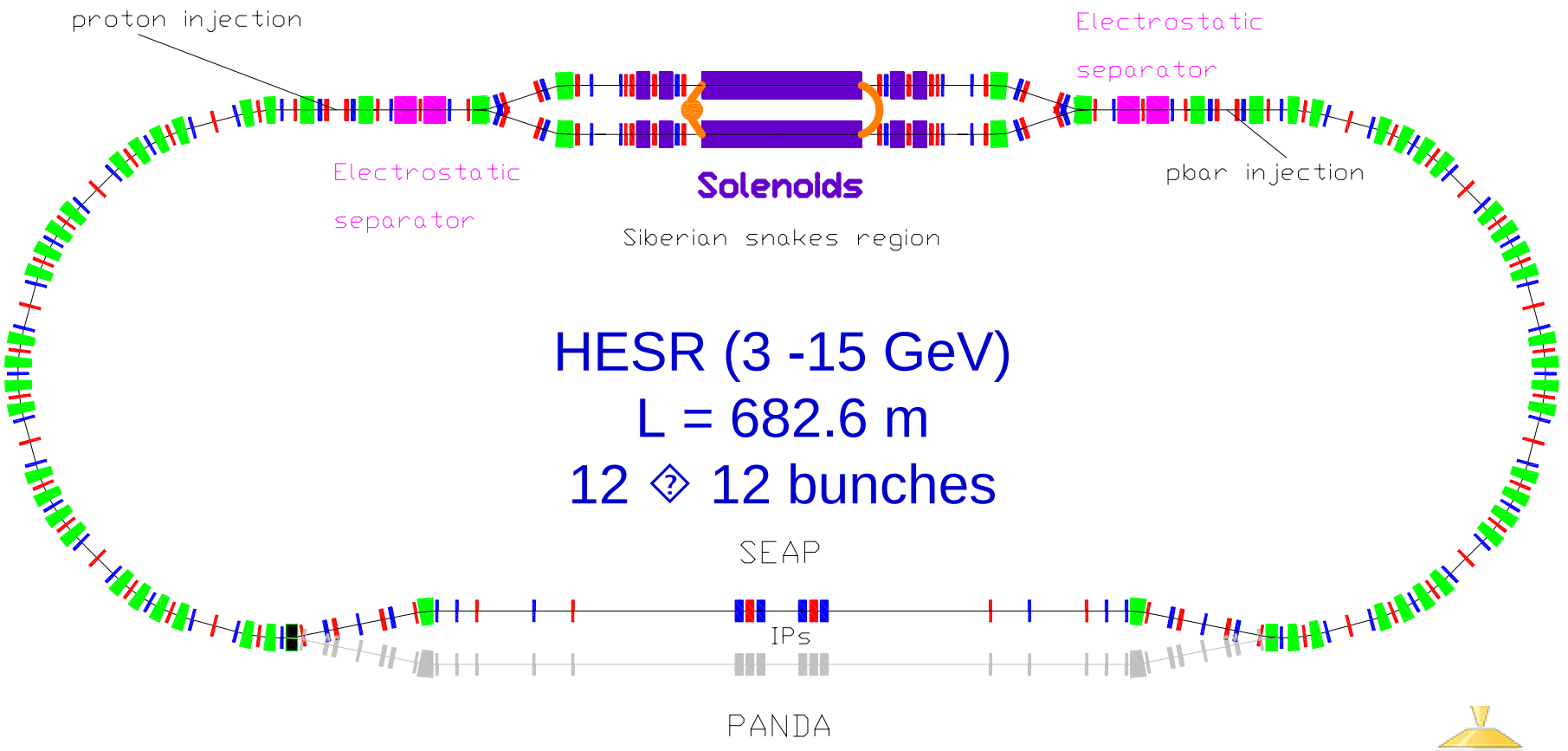
FAIR facility at GSI



Schematic layout of polarization facility



Layout of the p-pbar collider



Luminosity considerations

$\dot{N}_{\bar{P}} = 2\times10^{6}\ \mathrm{s}^{-1}$

rate of polarized p-bar production

$$L_{\max} = \frac{\dot{N}_p}{\sigma_{total}} = 5\times10^{31} cm^{-2} s^{-1}$$

$\sigma_{total} = 40$ mb

p-bar losses total cross section

Coulomb scattering cross-section: $\sigma_{Coulomb} = \dfrac{\pi r_p^{\,2}}{\gamma^2\beta^4\theta_{\max}^{\,2}} = 12\ \mu\mathrm{barn}$ $\quad(\theta_{\max} = 5\ \mathrm{mrad})$

Assumptions:

- $N_p = 10^{12}$ distributed in $n_b = 12$ bunches.
- $N_{\bar{p}} = (0.1 \leftrightarrow 1)\cdot 10^{12}$
- $\sigma_s = \beta_0 = 30$ cm
- round beams
- electron cooling will squeeze beams to the space charge limit

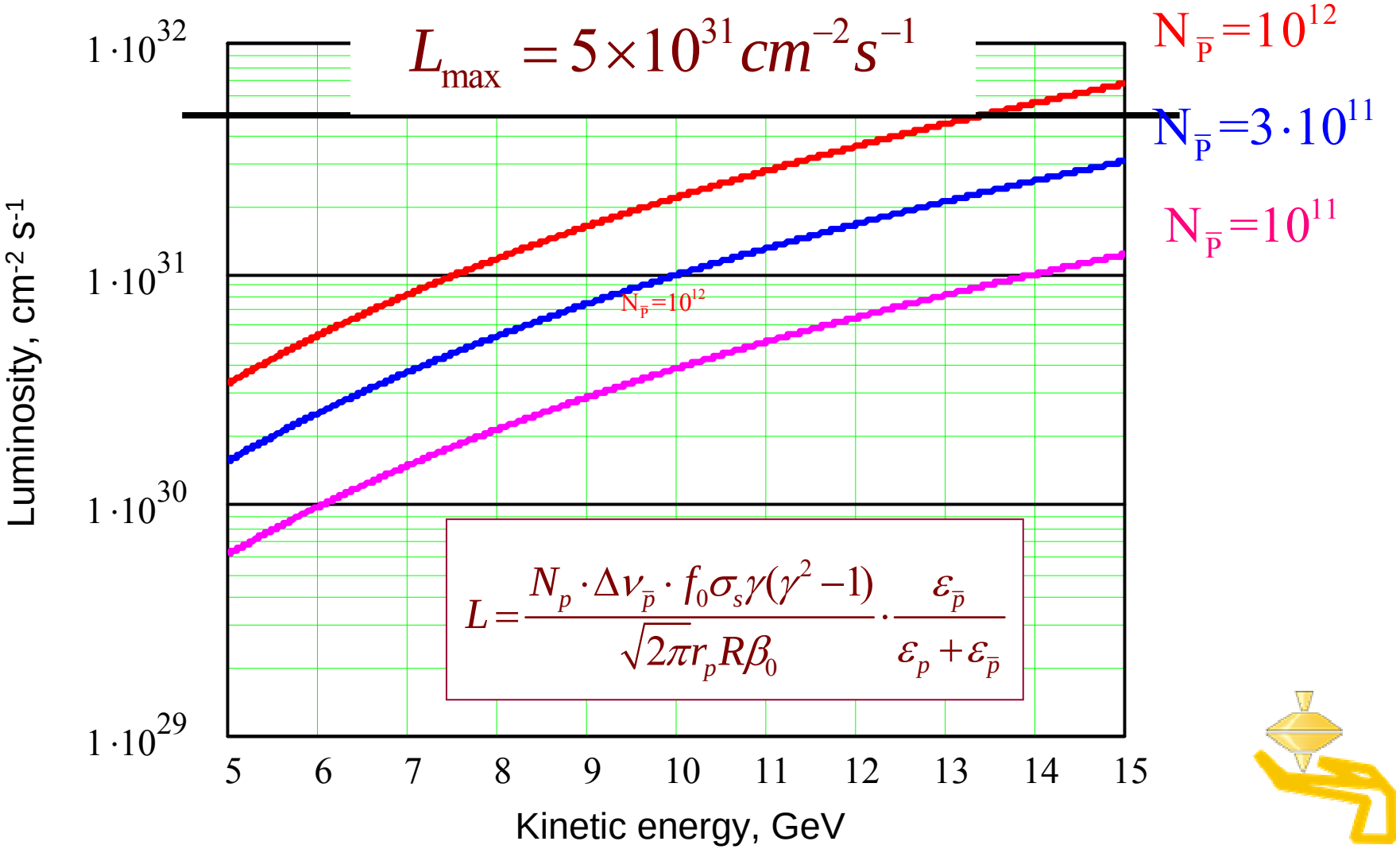
$$L = \frac{N_p N_{\bar{p}} f_0}{n_b 2\pi(\varepsilon_p + \varepsilon_{\bar{p}})\beta^*}$$

Limitations:

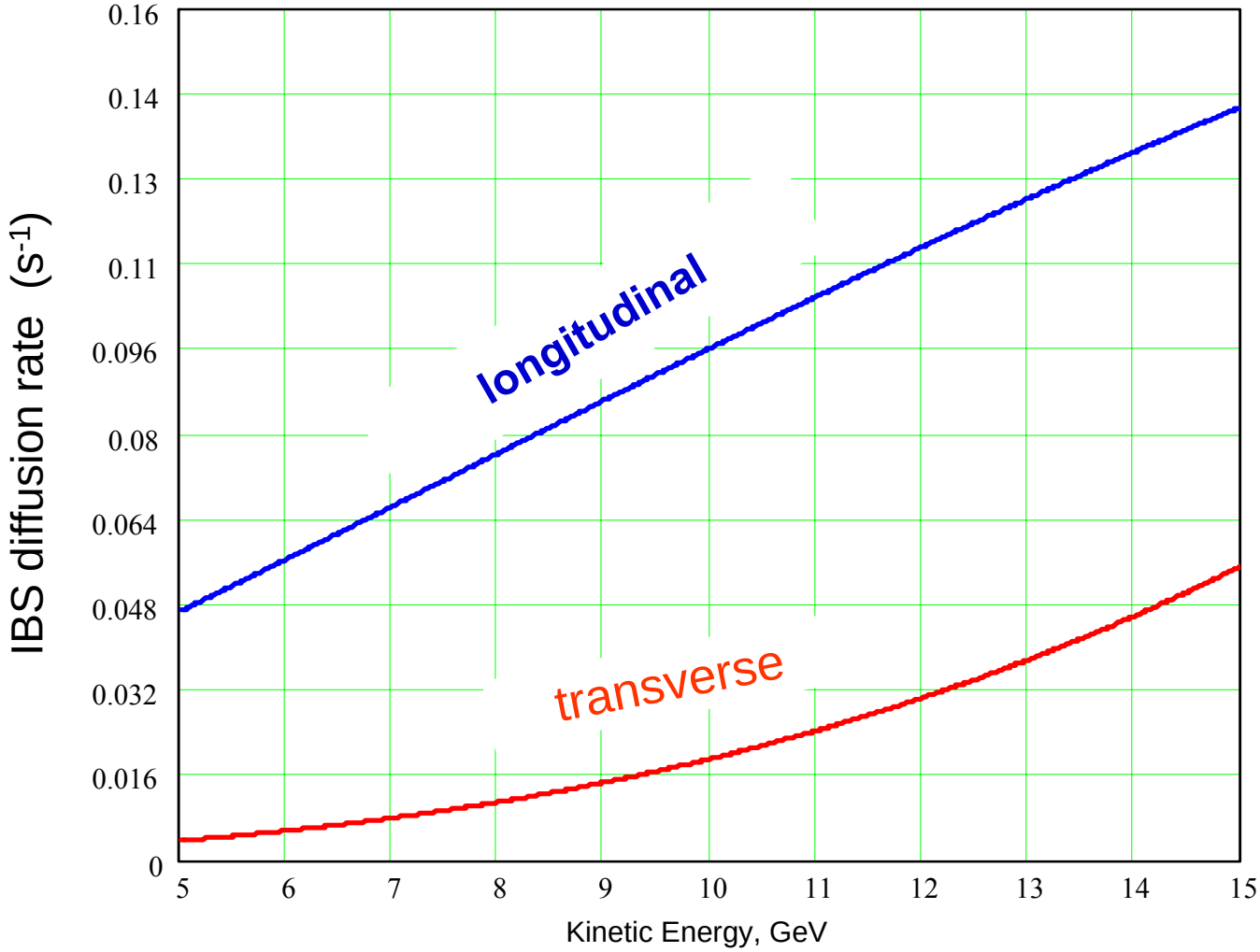
- space-charge effect $\quad \Delta\nu_p = \dfrac{N_p r_p R}{2\sqrt{2\pi} n_b \sigma_s \varepsilon_p \gamma(\gamma^2 - 1)} \le 0.1$
- instabilities in electron cooler: $\quad N_b = 0.8\cdot10^{11}$
- beam-beam effect $\quad \xi_{\bar{p}} = \dfrac{N_p r_p}{4\pi n_{p,\bar{p}} \gamma_{\bar{p}} \varepsilon_p} = 0.03$

Luminosity of p – p_bar collider

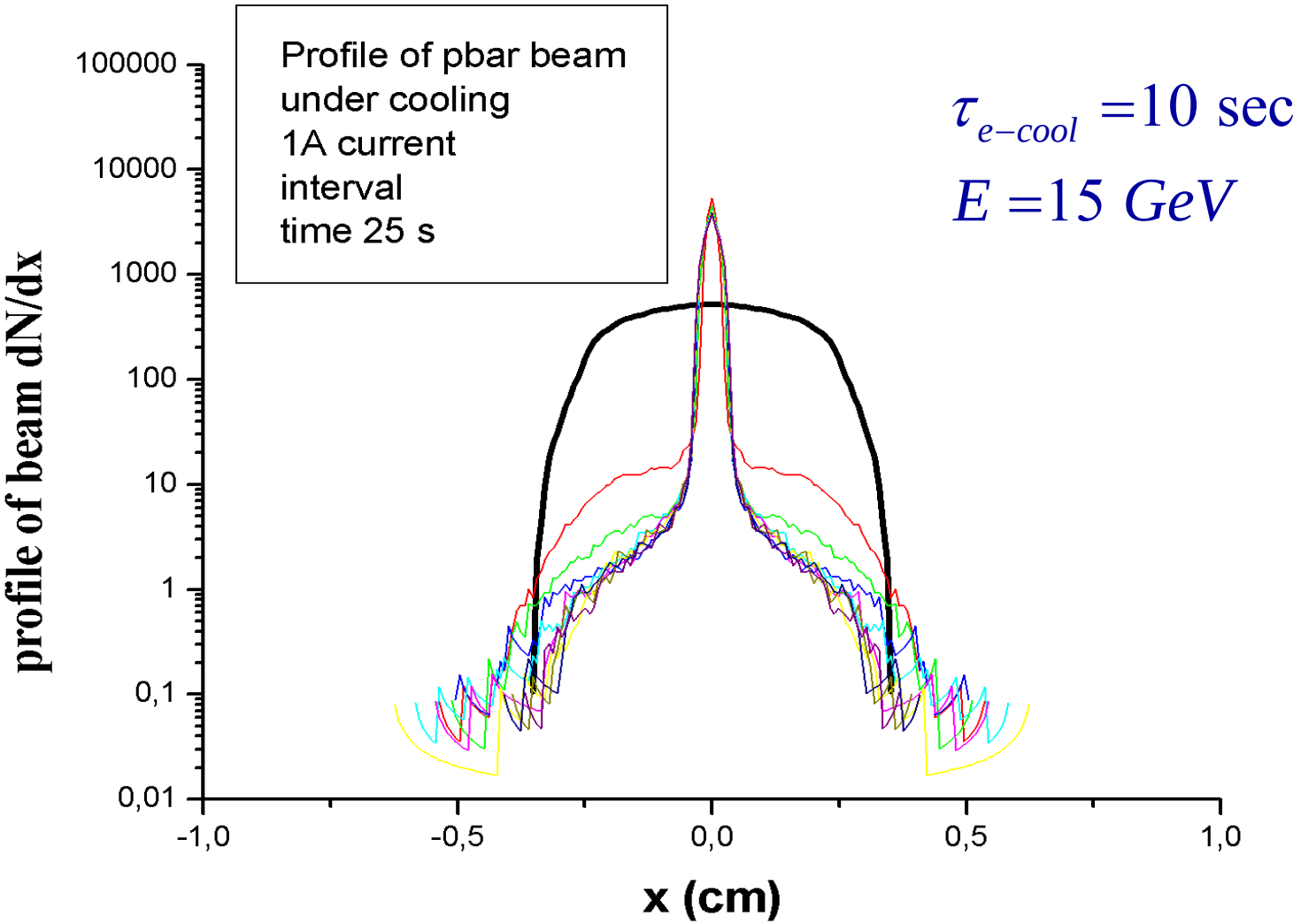
$N_P = 10^{12}$



Intra Beam Scattering



Simulation of electron cooling

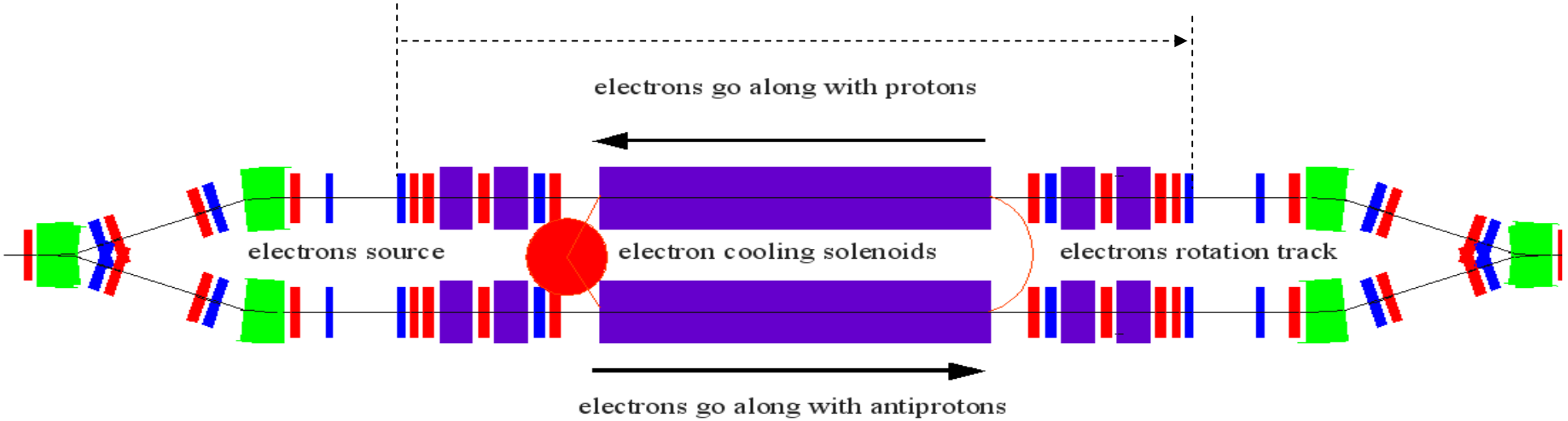


Preliminary parameters of the electron cooler for HESR

Acceleration column	
Electron energy on the output	0.44–7.9 MeV
Length	8.0 m
Electrostatic field along accelerator column	0.5–10 keV/cm
Magnetic field	500 G
Cathode diameter (beam diameter)	2 cm
Height of high-voltage vessel	13.0 m
Diameter of high-voltage vessel	6.0 m
Cooling section	
Length	30 m
Magnetic field	5 kG (E_e=1.6–7.9 MeV) 2 kG (E_e=0.44–1.6 MeV)

e-cooler and Siberian snakes

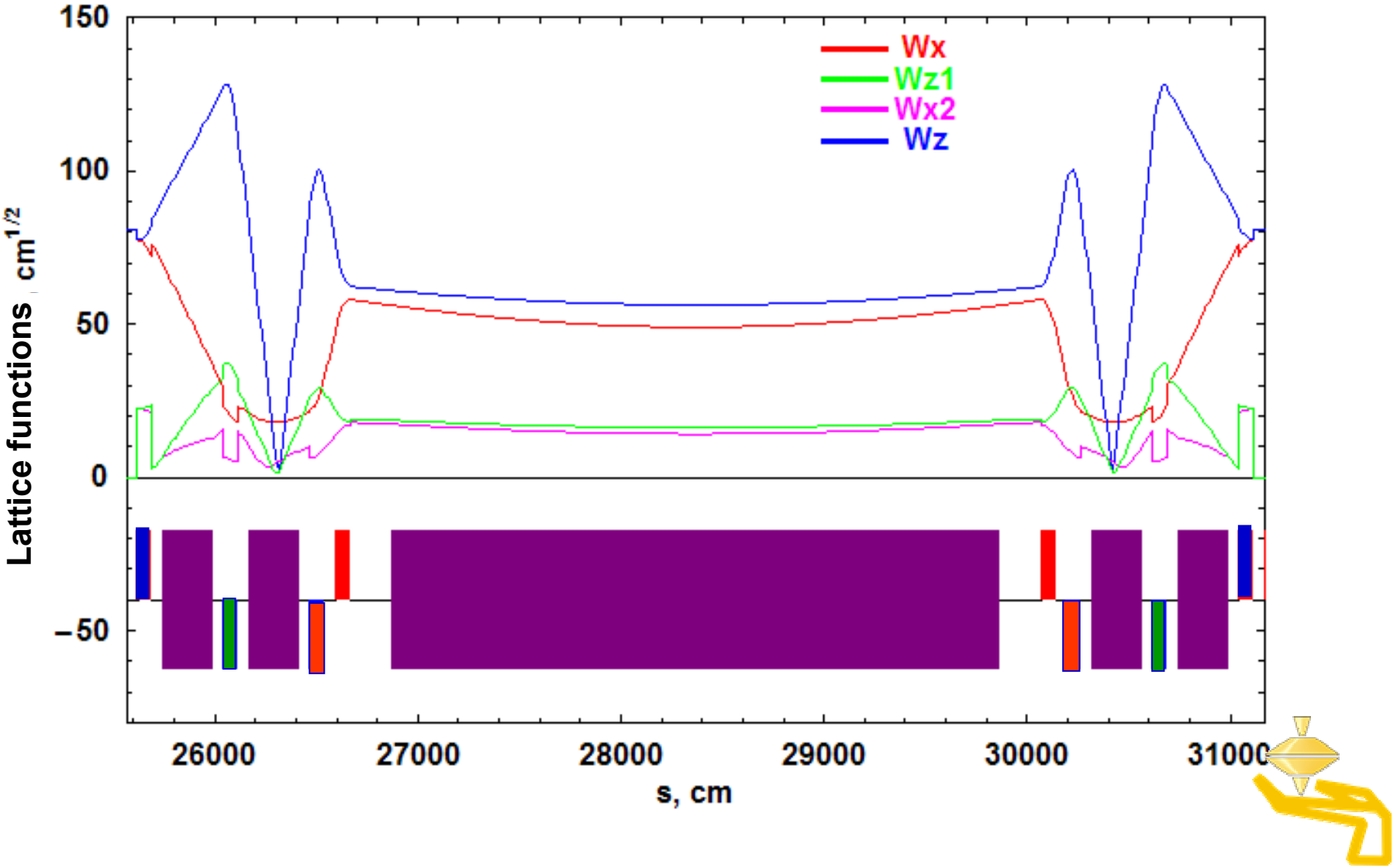
$$L = 56\ \text{m}$$



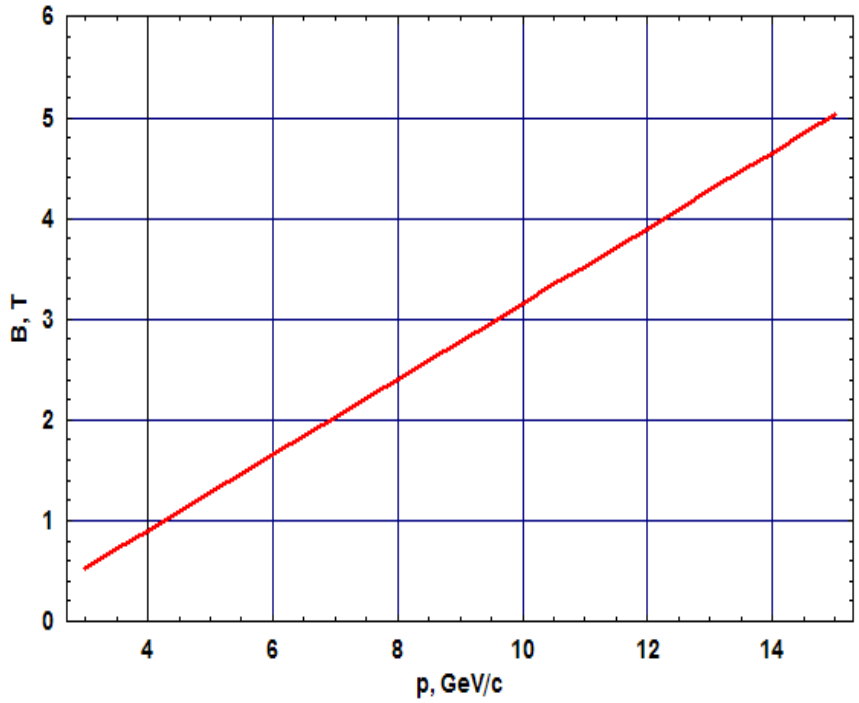
Transfer matrix

$$T_x = -T_z, \quad T_z = \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix},$$

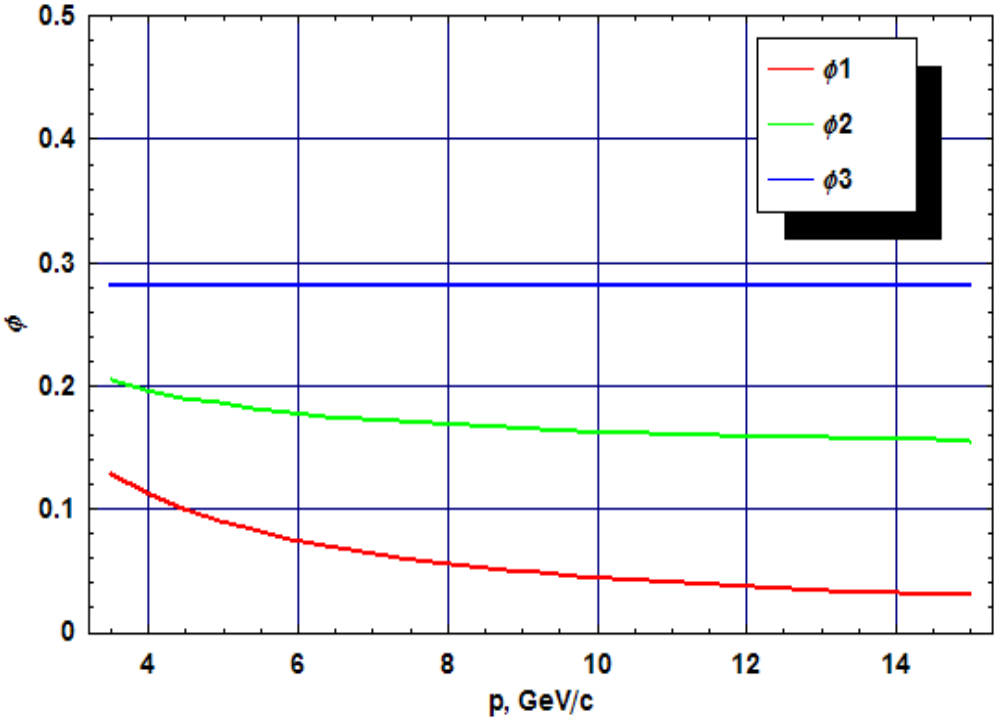
Optical structure of the cooler/snake insertion



Magnetic field in the snake solenoids vs. the beam energy



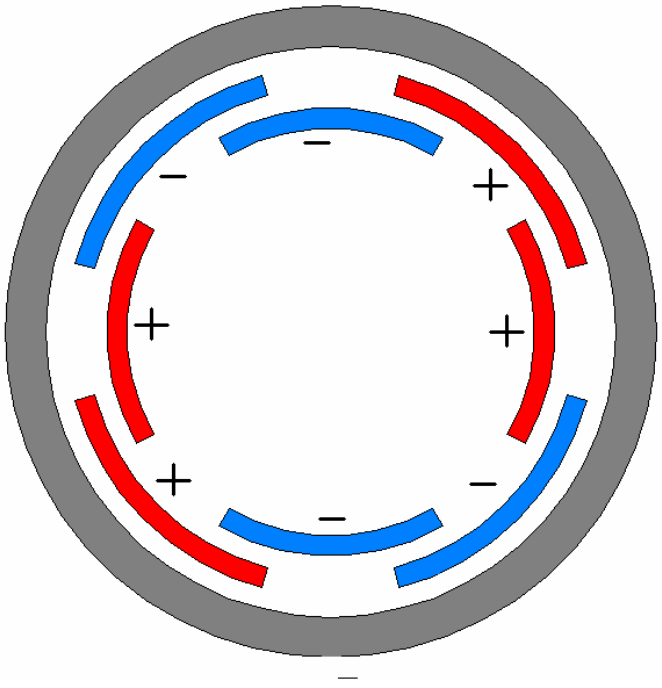
Snake skew-quads angles vs. the beam energy

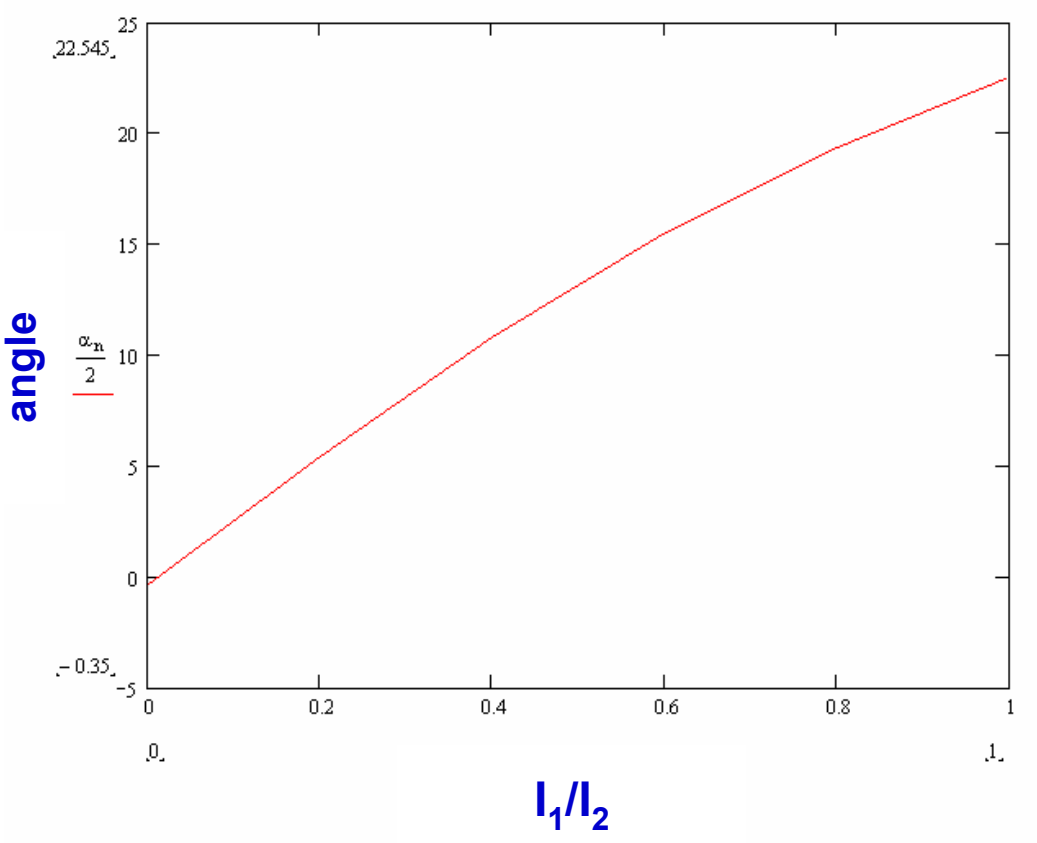


To compensate coupling from solenoids, all quads should be rotated by the angle:

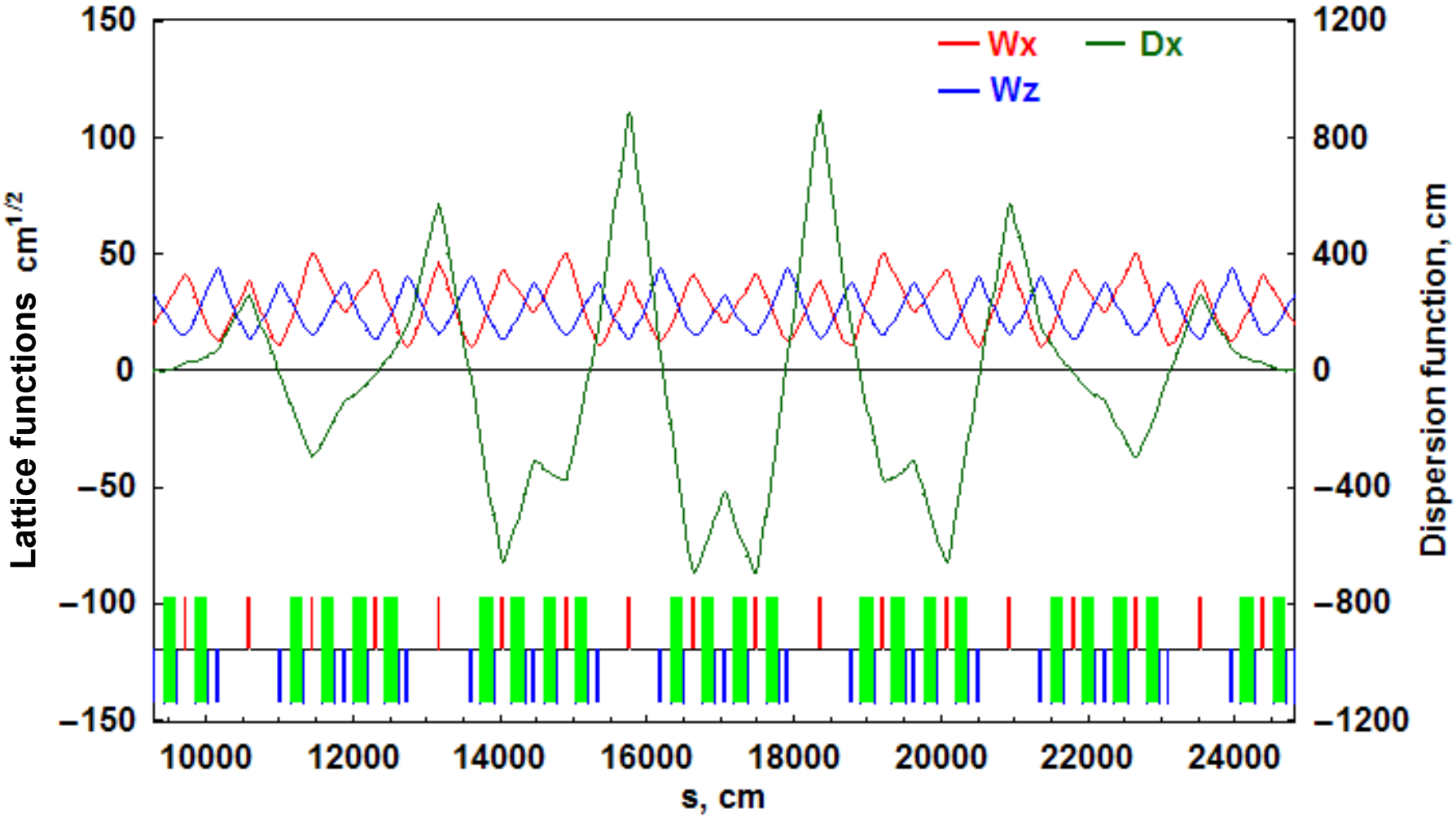
$$\phi = \frac{1}{2}\int_0^s B\,ds \Big/ B\rho$$

“Rotating” quads

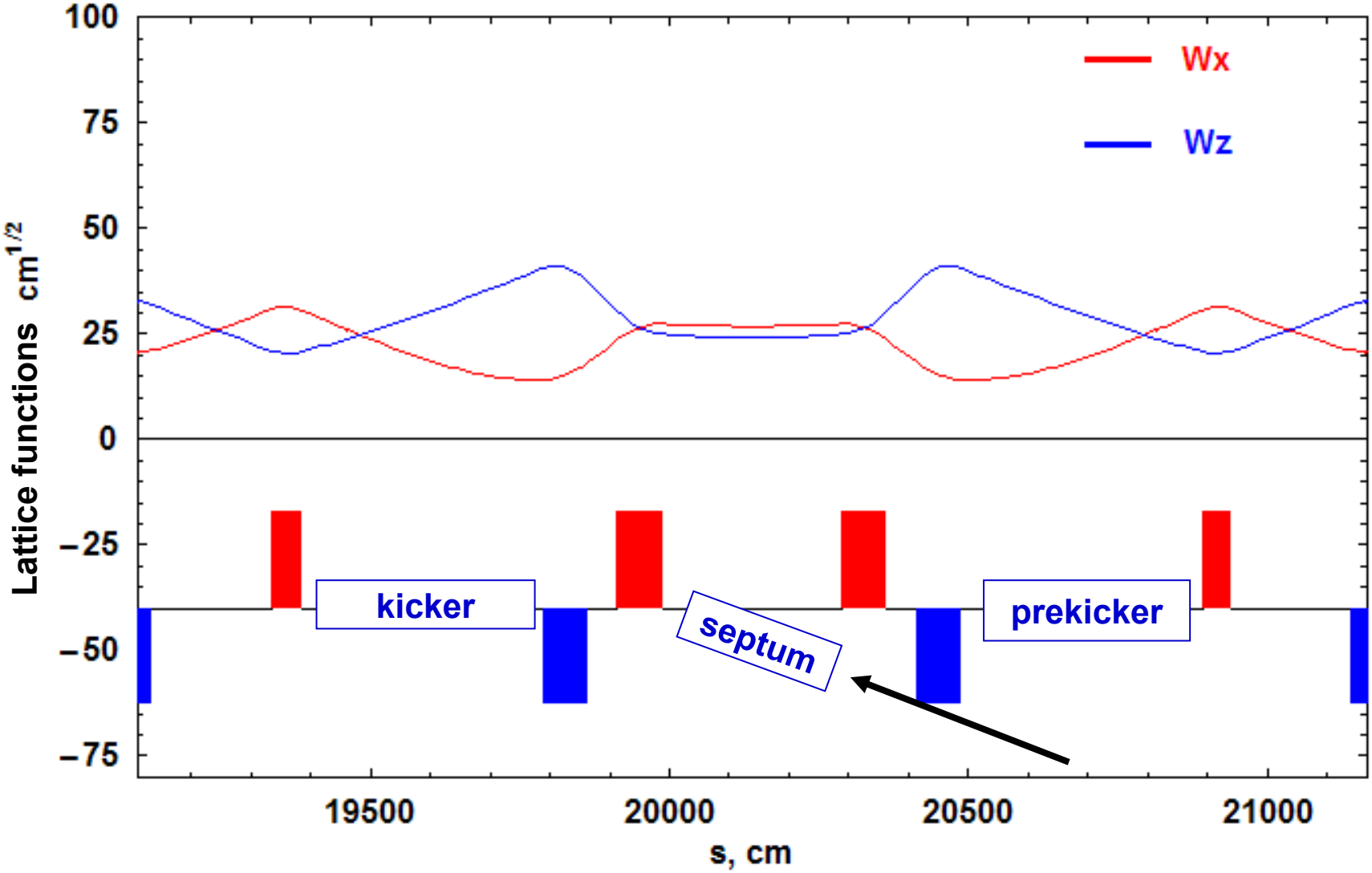




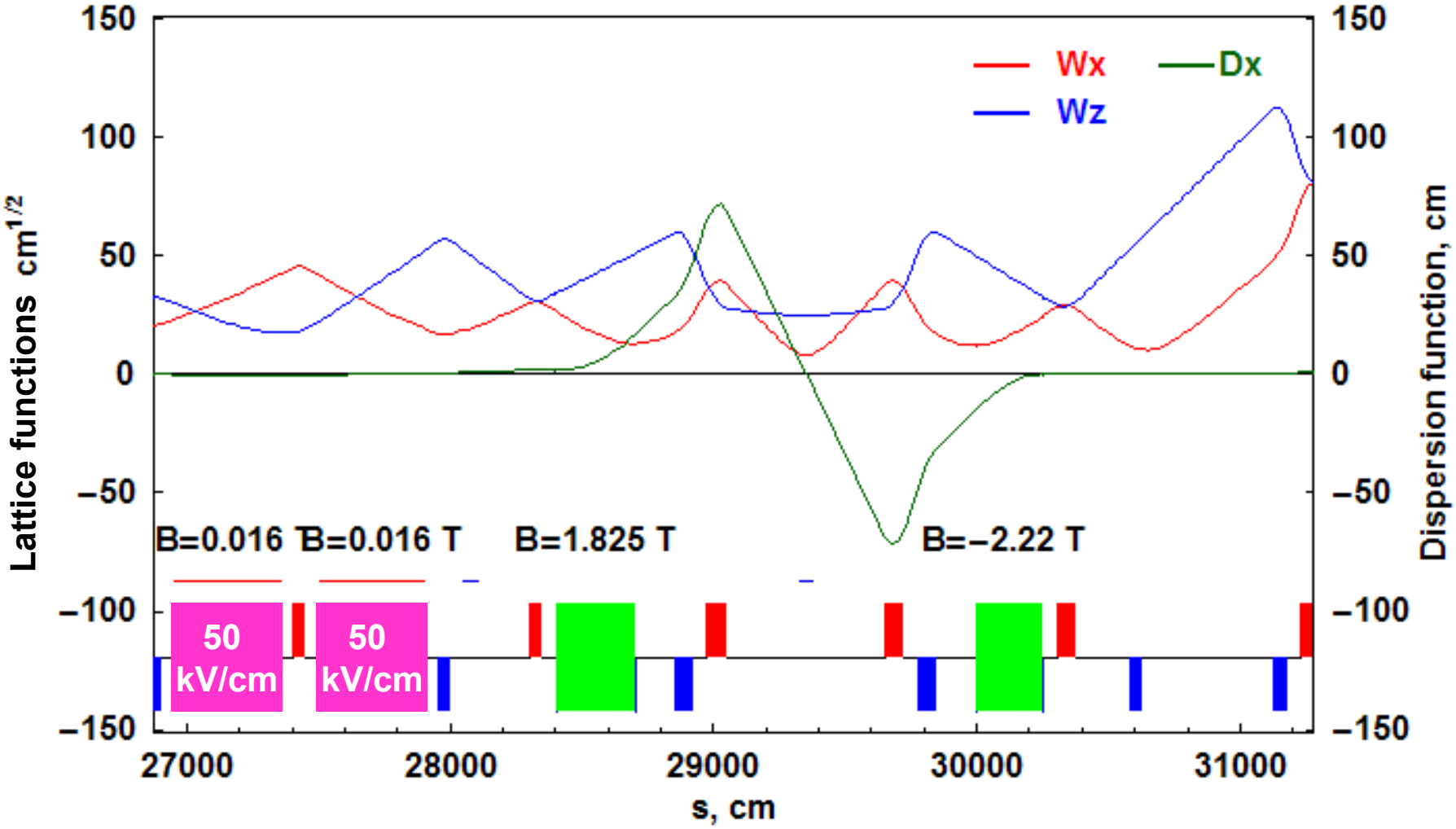
Arc lattice


Wx
Dx
Wz
150
100
50
0
−50
−100
−150
1200
800
400
0
−400
−800
−1200
10000
12000
14000
16000
18000
20000
22000
24000
s, cm
Lattice functions cm^1/2
Dispersion function, cm

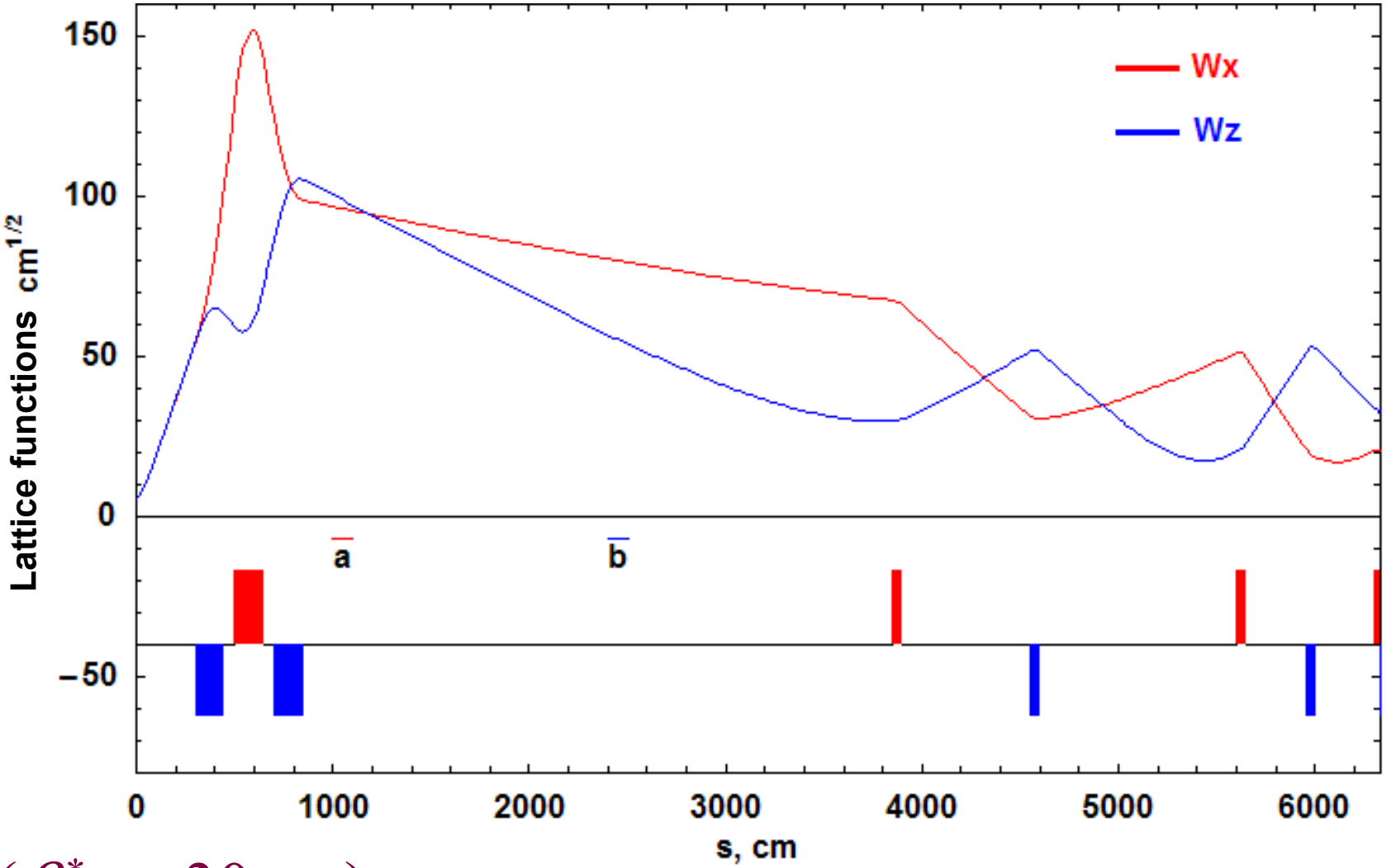
Injection insertion



p-pbar electrostatic separator

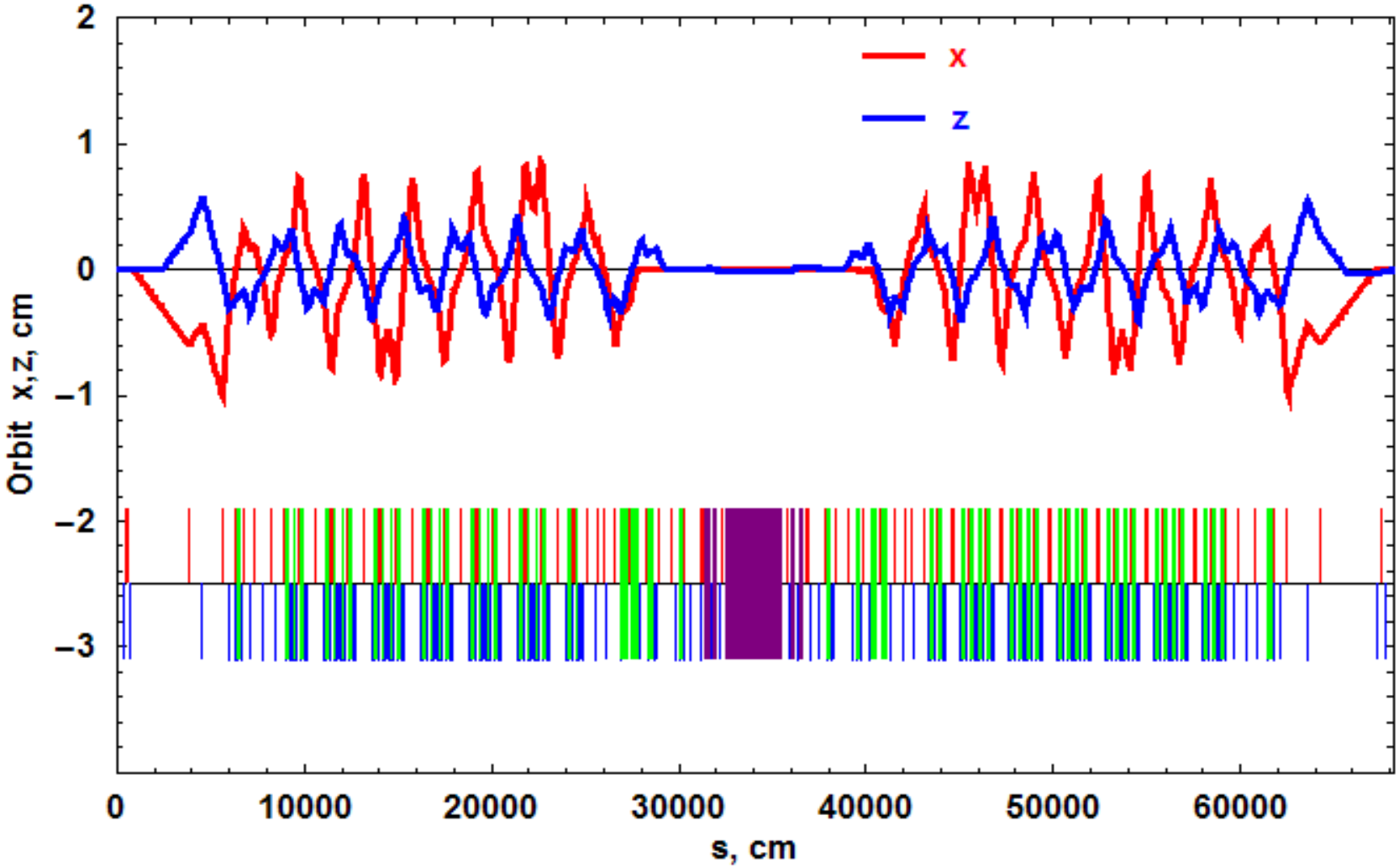


Interaction region layout



$(\beta^*_{x,z} = 30\ \text{cm})$

Electrostatic “helical” orbit separation



List of the p-pbar collider parameters

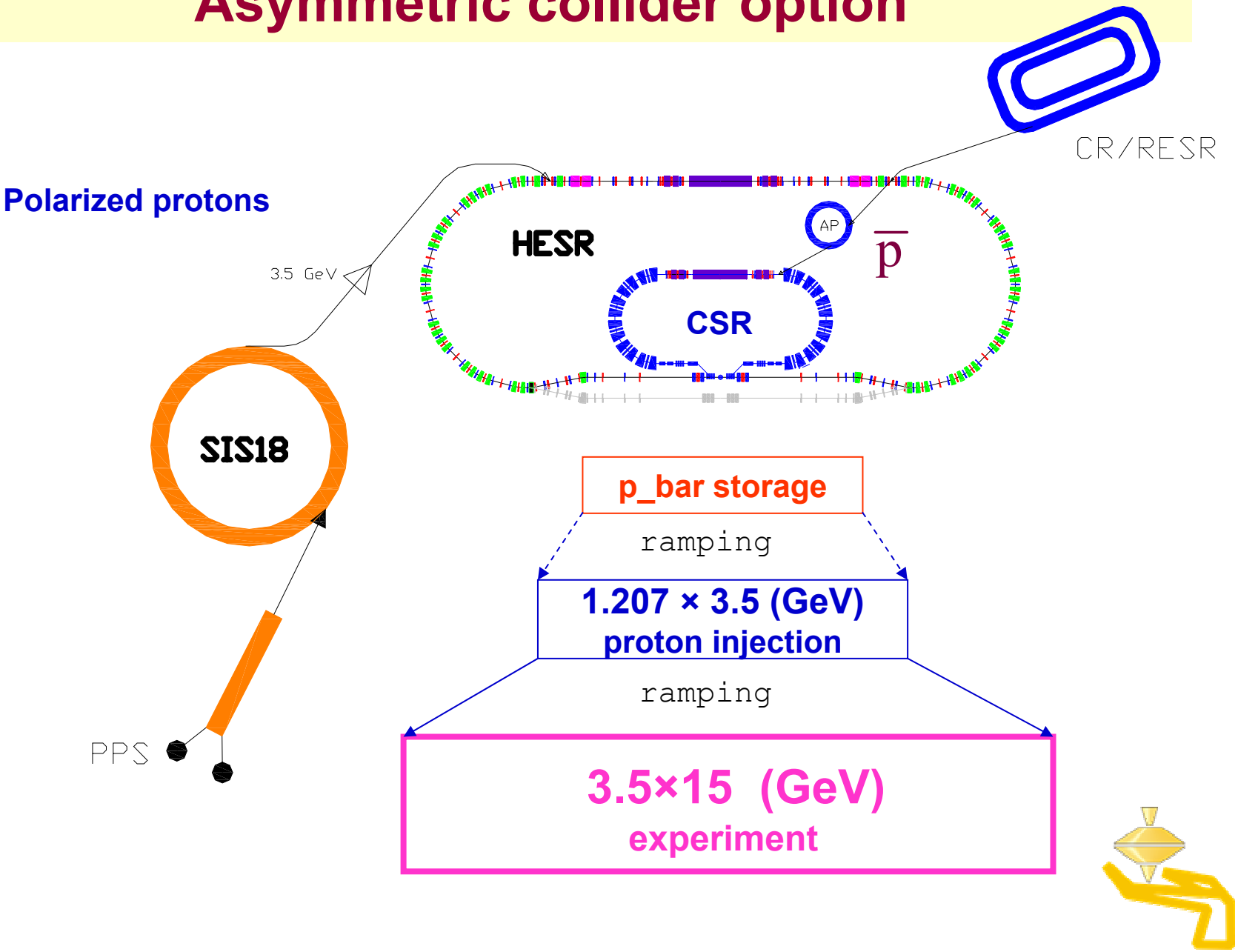
Collider circumference,	l	681.58	m
Revolution frequency,	f_0	0.445	MHz
Total number of antiprotons,	$N_{\bar{P}}$	0.1/ 0.3 / 1	10^{12}
Total number of protons,	N_P	1 / 1 / 1	10^{12}
Number of bunches per beam,	n_b	12	
Distance to first parasitic crossing,		28.4	m
Proton beam emittance,	ε_P	2 / 2 / 2	10^{-6} cm · rad.
Antiproton beam emittance,	$\varepsilon_{\bar{P}}$	02 / 0.6 / 2	10^{-6} cm · rad
Space charge tune shift,	$\Delta\nu_{P,\bar{P}}$	01/ 0.1 / 0.1	
Beam-beam parameter,	$\xi_{P,\bar{P}}$	0.03 /0.03/ 0.03	
e- cooling and IBS time	$\tau_{IBS} \approx \tau_{e\text{-}cool}$	10	s
Luminosity	L_{max}	1/ 2.3 / 5	10^{31} cm^{-2} · s^{-1}

$N_{\bar{P}} = 10^{12}$

$N_{\bar{P}} = 3 \cdot 10^{11}$

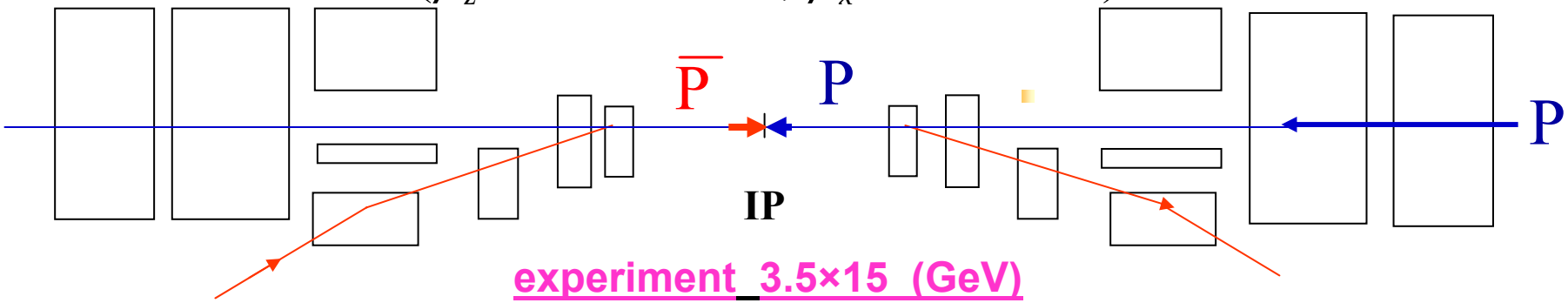
$N_{\bar{P}} = 10^{11}$

Asymmetric collider option



Sketch of the interaction area

$(\beta_z^* = 0.1 \Leftrightarrow 0.3 \text{ m};\ \beta_x^* = 0.6 \Leftrightarrow 1 \text{ m})$



experiment 3.5×15 (GeV)

$\overline{P}$ (E = 1.207 GeV) at proton injection in HESR (E = 3.5 GeV)

- space-charge effect $\Delta\nu_p = \dfrac{N_p r_p R}{2\sqrt{2\pi}\, n_b \sigma_s \varepsilon_p \gamma(\gamma^2 - 1)} \le 0.1$

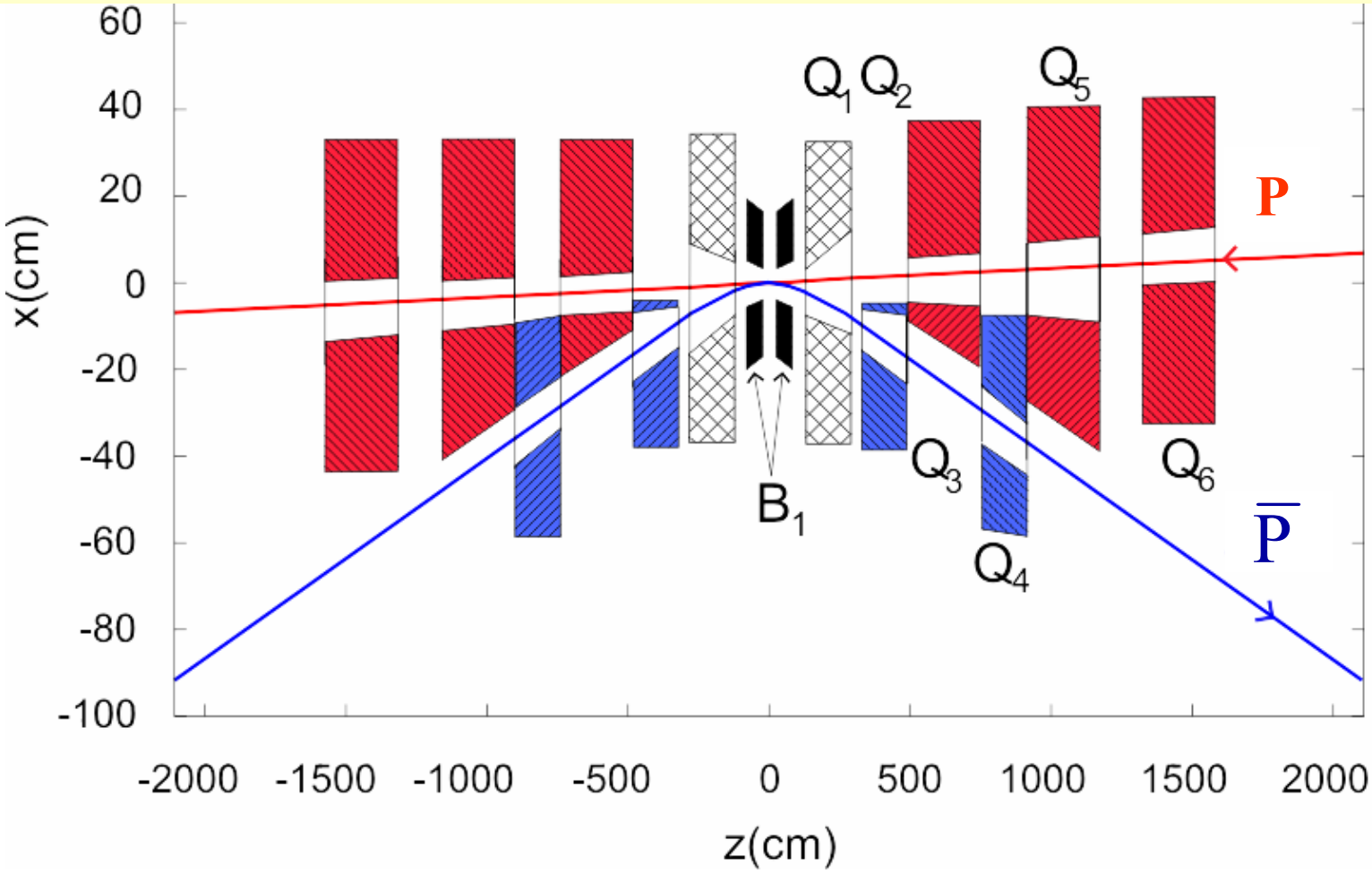
Limitations:

- instabilities in electron cooler: $N_b = 0.8 \cdot 10^{11}$
- beam-beam effect $\xi_{\bar{p}} = \dfrac{N_p r_p}{4\pi\, n_{p,\bar{p}}\, \gamma_{\bar{p}}\, \varepsilon_p} = 0.03$

Assumptions:

- $N_p = 10^{12}$ $n_b = 40$ bunches.
- $N_{\bar{p}} = 10^{11} \Leftrightarrow 10^{12}$ $n_b = 10$ bunches.
- $\sigma_s = \beta_y^* = 30$ cm

Schematic drawing of the interaction area



Asymmetric p-pbar collider parameters

$N_{\bar{P}}=10^{12}$

$N_{\bar{P}}=3\cdot10^{11}$

$N_{\bar{P}}=10^{11}$

Ring circumferences,	l_1 / l_2	**600 /144**	**m**
Beam energies	E_P / E_{P_bar}	**15 / 3.5**	**GeV**
Total number of antiprotons,	$N_{\bar{P}}$	**0.1 / 0.3 / 1**	**10^{12}**
Total number of protons,	N_P	**1 / 1/ 1**	**10^{12}**
Number of bunches per beam,	n_b	**40 / 10**	
Proton beam emittance,	ε_P	**2.5 / 2.5 / 2.5**	10^{-6} cm · rad.
Antiproton beam emittance,	$\varepsilon_{\bar{P}}$	**4.5 / 14 / 45**	10^{-6} cm · rad
Space charge tune shift,	$\Delta\nu_{\bar{P}}$	**0.1 / 0.1 / 0.1**	
Beam-beam parameter,	$\xi_{\bar{P}}$	**0.03 / 0.03 / 0.03**	
Luminosity	L_{max}	**3.7 / 4.8 / 5.5**	**10^{30} cm^{-2} · s^{-1}**

Asymmetric p-pbar collider parameters (PAX option)

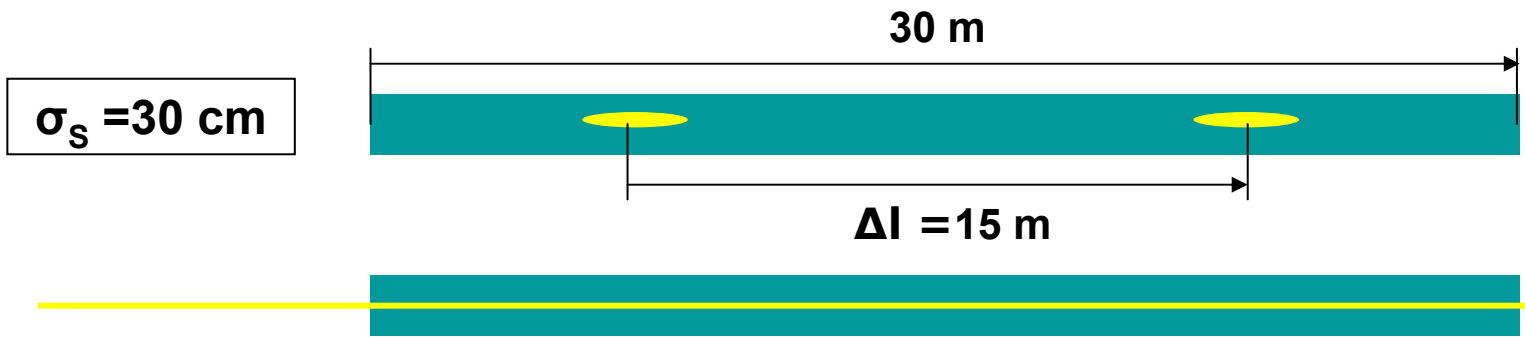
Ring circumferences,	l_1 / l_2	**600 / 144**	**m**
Beam energies	E_{P_bar} / E_P	**15 / 3.5**	**GeV**
Total number of antiprotons,	$N_{\bar{P}}$	**0.1 / 0.3 / 1**	**10^{12}**
Total number of protons,	N_P	**1 / 1 / 1**	**10^{12}**
Number of bunches per beam,	n_b	**40 / 10**	
Proton beam emittance,	ε_P	**45 / 45 / 45**	10^{-6} cm · rad.
Antiproton beam emittance,	$\varepsilon_{\bar{P}}$	**0.25 / 0.75 / 2.5**	10^{-6} cm · rad
Space charge tune shift,	$\Delta\nu_P$	**0.1 / 0.1 / 0.1**	
Beam-beam parameter,	ξ_P	**0.03 / 0.03 / 0.03**	
Luminosity	L_{max}	**0.57 / 1.74 / 5.7**	**10^{30} cm^{-2} · s^{-1}**

$N_{\bar{P}}=10^{12}$

$N_{\bar{P}}=3\cdot10^{11}$

$N_{\bar{P}}=10^{11}$

Asymmetric p-pbar collider with coasting beams



- IBS increment is weak (σ_s/ Δl)
- Limit beam emittance smaller
- Space charge

$$\Delta\nu_{1,2} = \frac{N_{1,2}\, r_p}{4\pi\, \varepsilon_{1,2}\gamma(\gamma^2-1)} \le 0.1$$

- Beam-beam

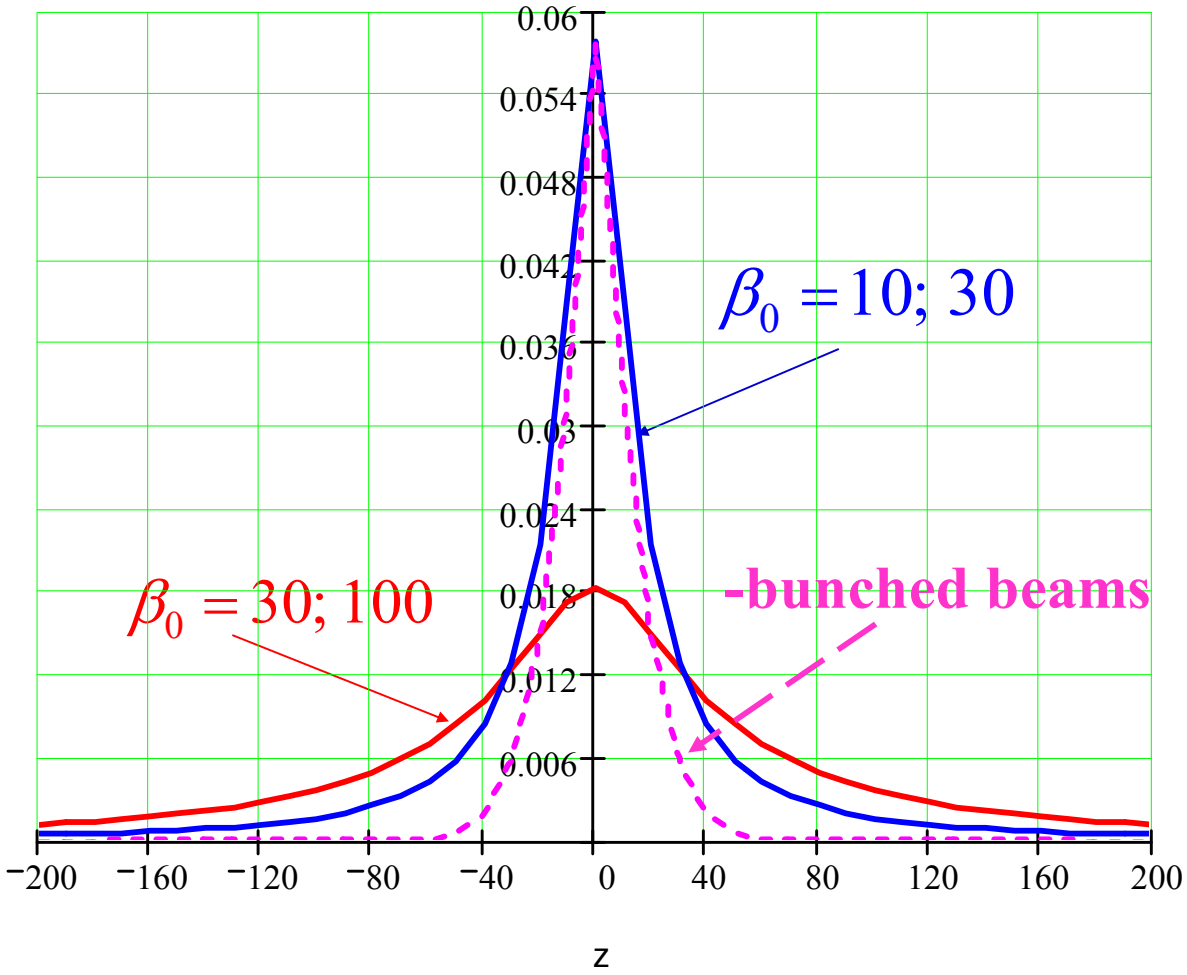
$$\xi_{1,2} = \frac{N_{2,1}\, r_p (1+\beta_1\times\beta_2)\cdot I}{8\pi^2\ \gamma_{1,2}\cdot\beta_{1,2}^2\cdot\varepsilon_{2,1}\cdot R_{2,1}} = 0.03$$

- Length of the *IR* (l >>β*)

$$L2 := \frac{N_1\cdot N_2\cdot c\cdot(\beta_1+\beta_2)}{4\cdot\pi^2\cdot R_1\cdot R_2}\cdot\frac{1}{\pi\cdot(\varepsilon_1+\varepsilon_2)}\cdot\operatorname{atan}\left(\frac{l}{2\cdot\beta_0}\right)$$

Longitudinal distribution of the luminosity

(coasting beams)



Asymmetric p-pbar collider parameters
(coasting beams)

$N_P = 7 \times 10^{12}$

$N_{\bar{P}} = 10^{12}$

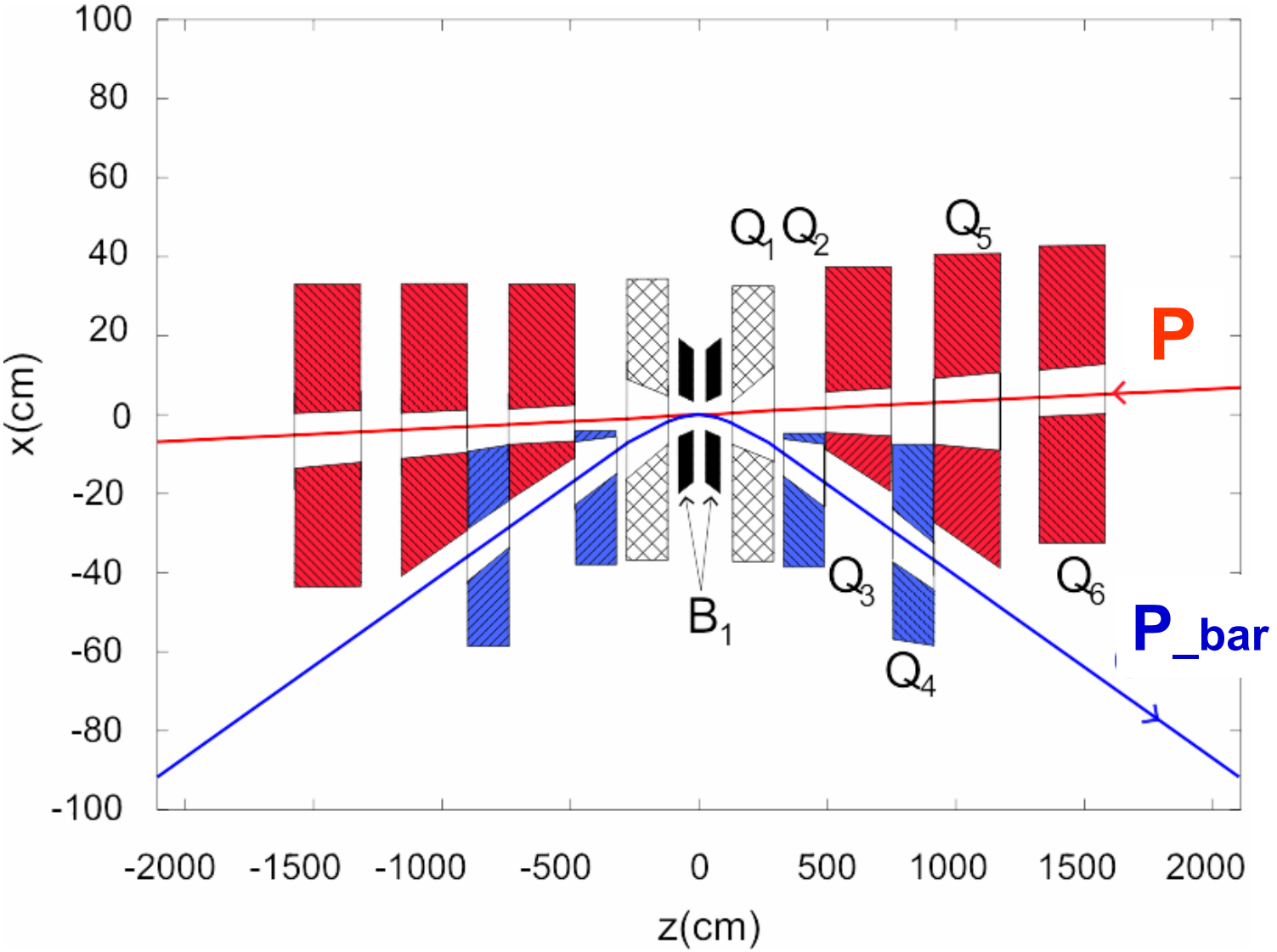
$N_{\bar{P}} = 3 \cdot 10^{11}$

$N_{\bar{P}} = 10^{11}$

Ring circumferences,	l_1 / l_2	**600 /144**	**m**
Beam energies	E_P / E_{P_bar}	**15 / 3.5**	**GeV**
Total number of antiprotons,	N_P	**0.1 / 0.3 / 1**	**10^{12}**
Total number of protons,	$N_{\bar{P}}$	**7 / 7/ 7**	**10^{12}**
Proton beam emittance,	ε_P	**2.5 / 2.5 / 2.5**	10^{-6} cm · rad.
Antiproton beam emittance,	$\varepsilon_{\bar{P}}$	**0.25 / 0.75 / 2.5**	10^{-6} cm · rad
Space charge tune shift,	$\Delta\nu_{\bar{P}}$	**0.1 / 0.1 / 0.1**	
Beam-beam parameter,	$\xi_{\bar{P}}$	**0.03 / 0.03 / 0.03**	
Luminosity	L_{max} **(I=1m)**	**7.5 / 12 / 42**	**10^{30} cm^{-2} · s^{-1}**

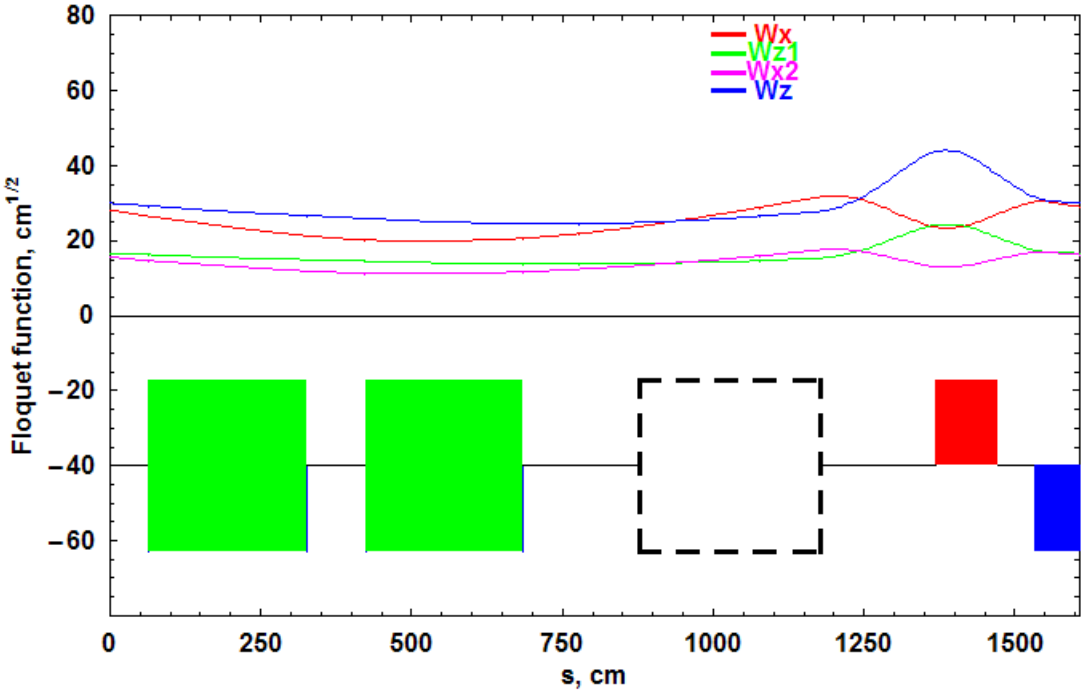
Sketch of the interaction area

($\beta^* = 10$ cm)



Polarized proton acceleration at SIS-18

1) Partial Siberian snake (pulse solenoid against resonances ν =k



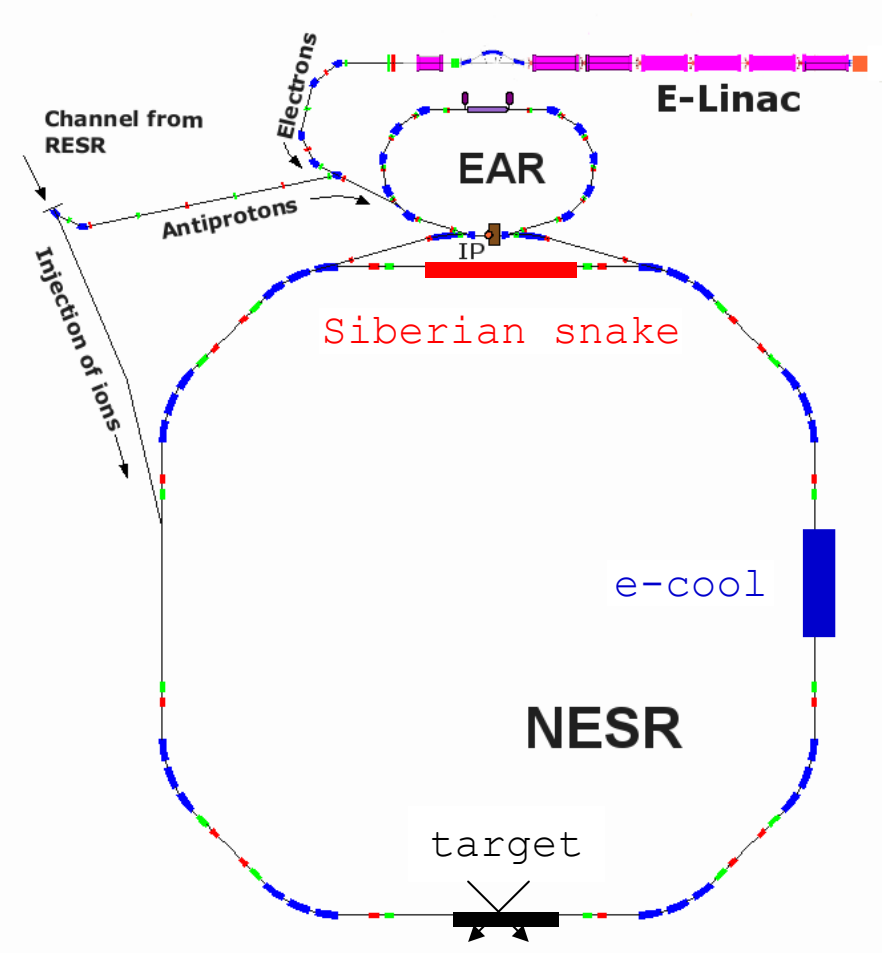
2) Q-jump on linear intrinsic resonance $\nu = Q_z = 3.28$

P_bar polarization study ?

$$d\sigma_{P\bar{P}} = d\sigma_0(\theta,E) + \zeta^{p}_{\square}\zeta^{\bar{p}}_{\square} d\sigma_1(\theta,E) + \zeta^{p}_{\perp}\zeta^{\bar{p}}_{\perp} d\sigma_2(\theta,E)$$

$$d\sigma_0 \square d\sigma_{1`} \square d\sigma_2$$

T_{kin} = 20 – 500 MeV



Conclusion

- *conceptual study of polarized p-p_bar collider at HESR is done*
- *the collider can achieved luminosity $4 \cdot 10^{31}\ cm^{-2} \cdot s^{-1}$ in symmetric and asymmetric options*
- *symmetric collider can cover energy range 10 – 30 GeV*
- *polarized protons from PPS will be accelerated up to 3.5 GeV in SIS 18*
- *polarization of antiprotons is terra incognita today*
- *proper study of the p_bar filtering can be done at NESR before construction of an antiproton polarizer*
-