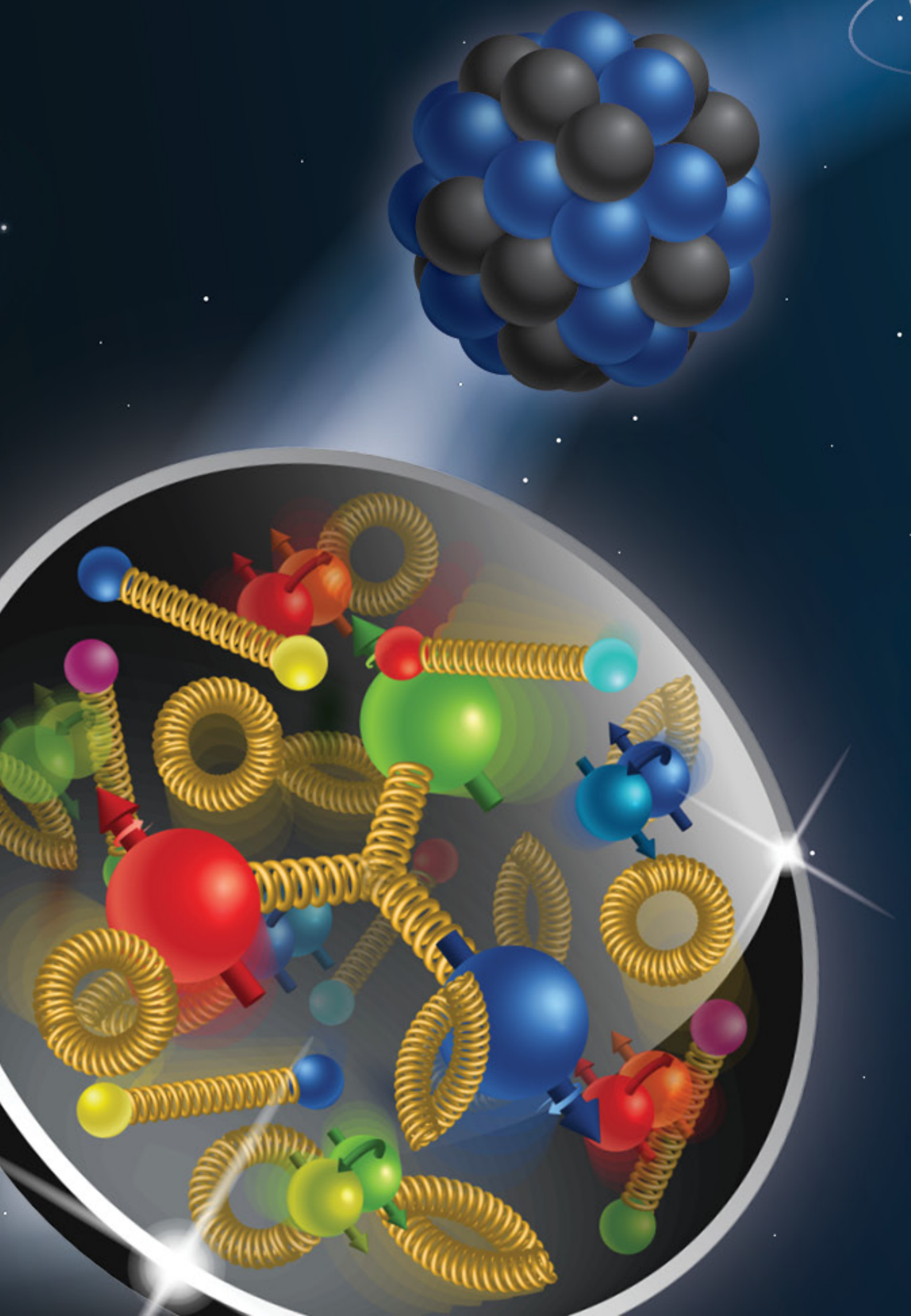


IR design overview IP8

Randika Gamage
on behalf of 2nd IR Design Team

August 03, 2021

Electron-Ion Collider

BROOKHAVEN NATIONAL LABORATORY   Jefferson Lab   U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- Requirements/Constraints
- Theory (Beam and optics parameters, acceptance)
- IP8 layout
- Hadron and electron optics
- Acceptance optimization
- Linear optics and chromaticity compensation for the HSR
- Summary

Requirements/Constraints

- Fit into the existing RHIC IP8 experimental hall.
- Match in to the ARCs on each end.
- Space for two spin rotators and a snake (~13m each).
- Reuse as many RHIC magnets as possible.

Beam and Optics Parameters

- Geometric emittance ϵ is the area occupied by bunch in (x, x') phase space.
- ϵ is a constant and made as small as possible
- Optics and ϵ determines the beam parameters at the IP
  - rms beam size $\sigma * = \sqrt{\epsilon\beta *}$
  - rms angular beam divergence $\sigma' * = \sqrt{\dfrac{\epsilon}{\beta *}}$
  - Transverse momentum spread $\sigma_{pT} = p_{beam}\sigma' *$
  - Note $\epsilon = \sigma * \sigma' *$
- Have control over $\beta *$ through optics design
- Luminosity $L \propto \dfrac{1}{\sigma_x * \sigma_y *} \propto \sigma_x' * \sigma_y' * \propto \sigma_{pTx}\sigma_{pTy} \propto \sigma_x^{max}\sigma_y^{max}$

Acceptance as a function of x_L and p_T

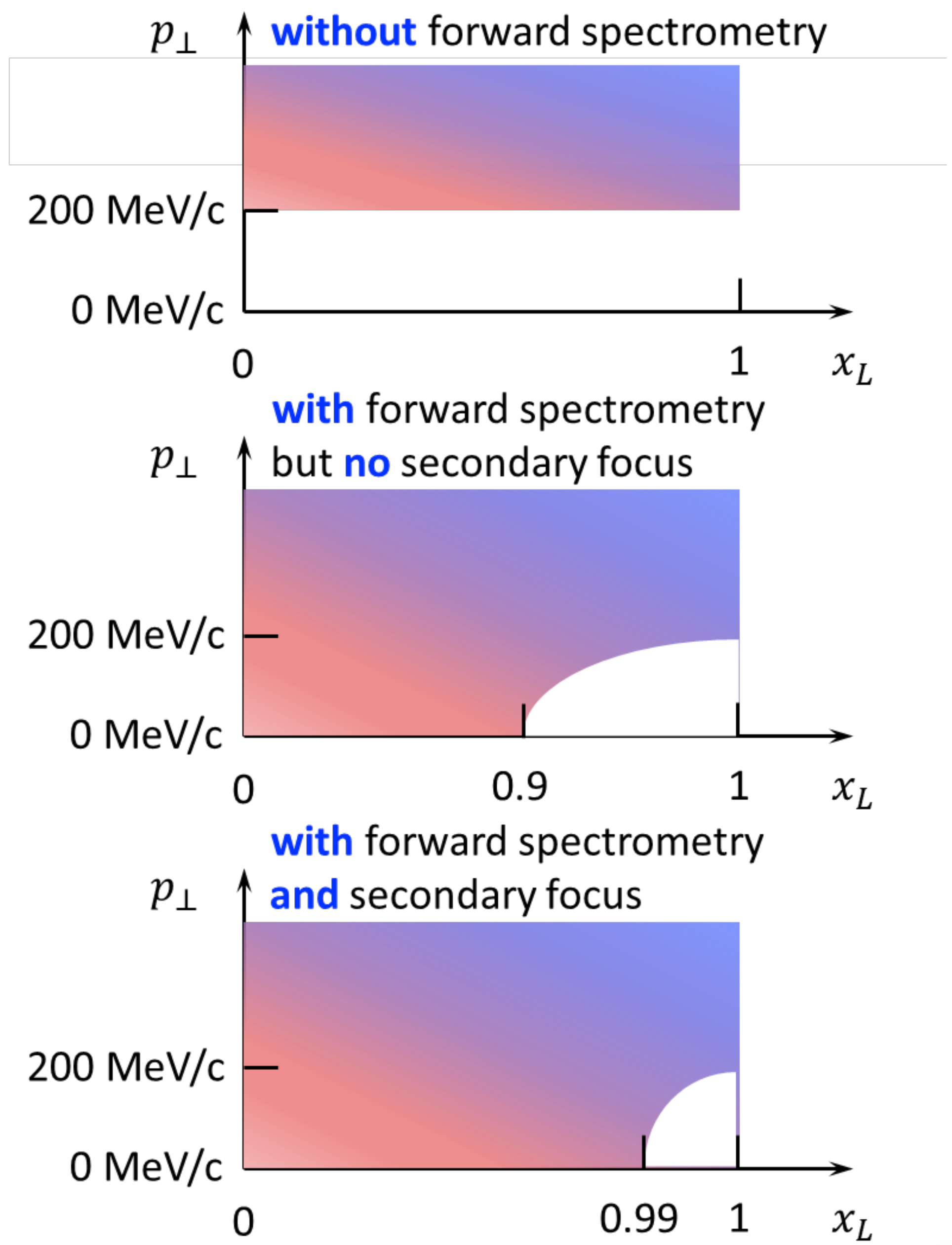
- p_T acceptance at $x_L = 1$

$$p_T^{min} > 10\ p_0 \theta_{IP} = 10\ p_0 \sqrt{\frac{\epsilon}{\beta^*}}$$

- x_L acceptance at $p_T \ = \ 0$

$$x_L \ < \ 1 - 10\ \frac{\sigma_x}{D} = 1 - 10\ \frac{\sqrt{\beta_x^{2nd}\epsilon_x + D_x^2\sigma_\delta^2}}{D}$$

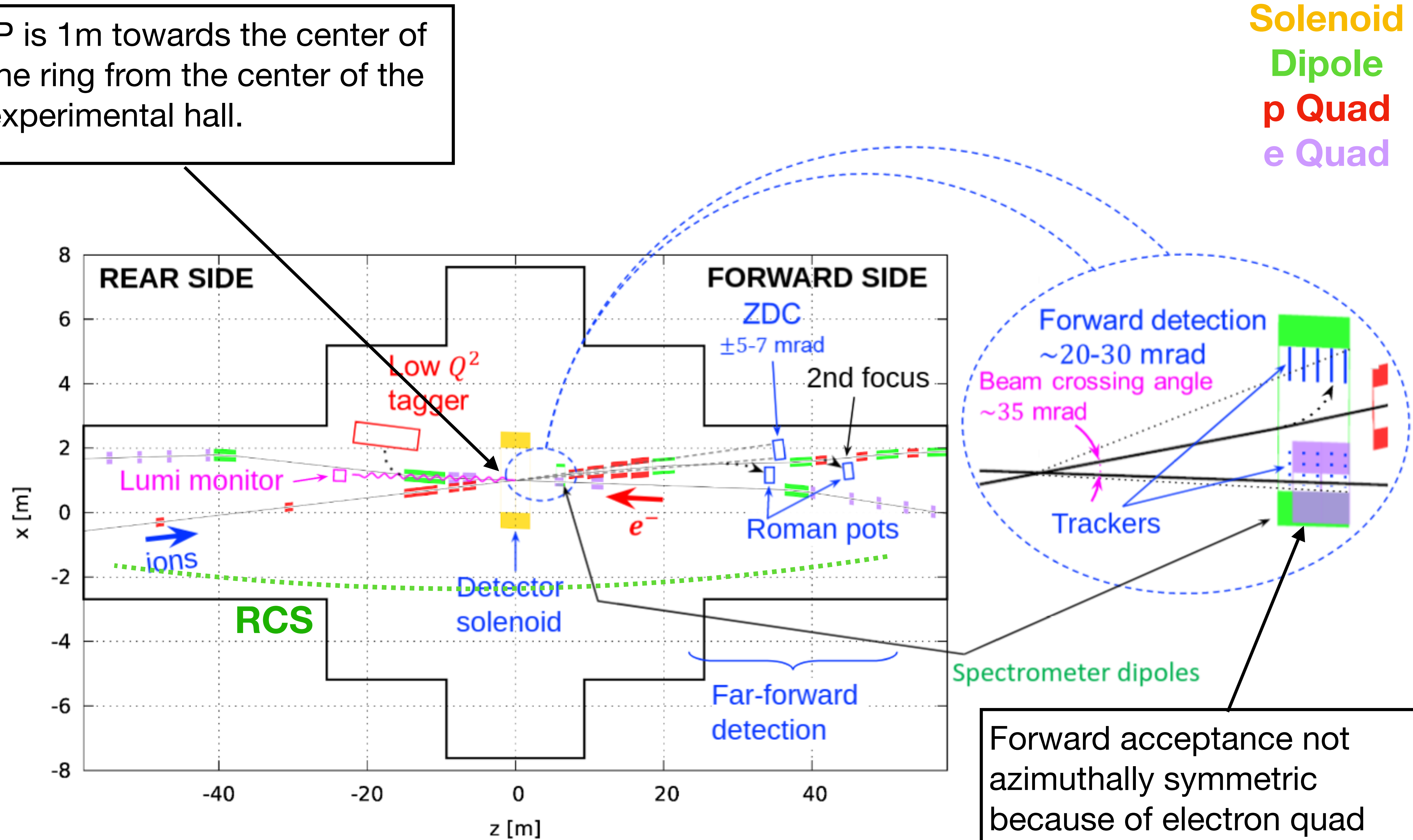
  - Secondary focus allow for $|D\sigma_\delta| >> \sqrt{\beta\epsilon}$
  - Can reach the fundamental limit $x_L < 1 - 10\sigma_\delta$



- Increase of β_x^* which in turn increase the β_x^{2nd} may result in a smaller x_L acceptance

IP8 hall layout

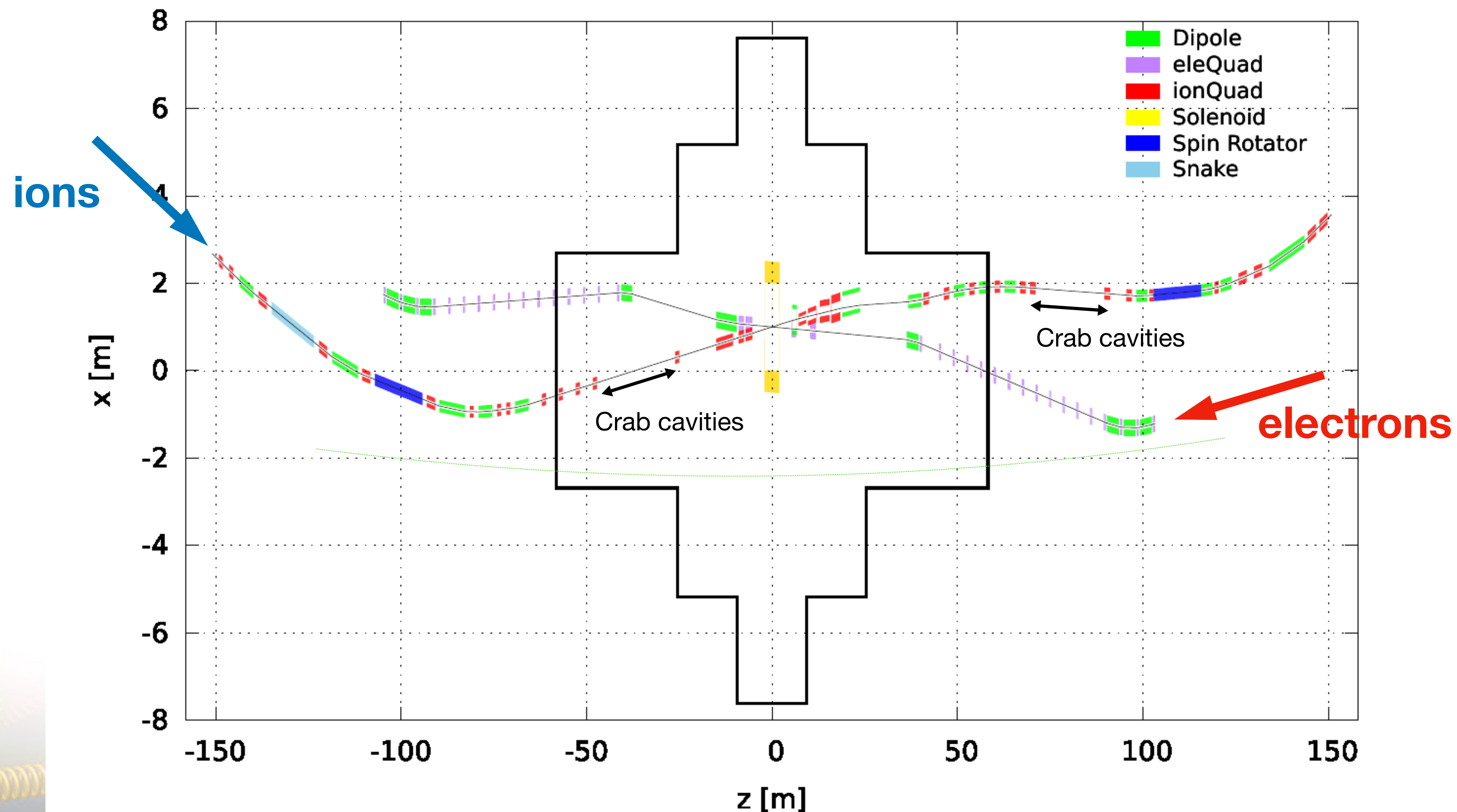
IP is 1m towards the center of the ring from the center of the experimental hall.



Forward acceptance not azimuthally symmetric because of electron quad

IP8 full layout

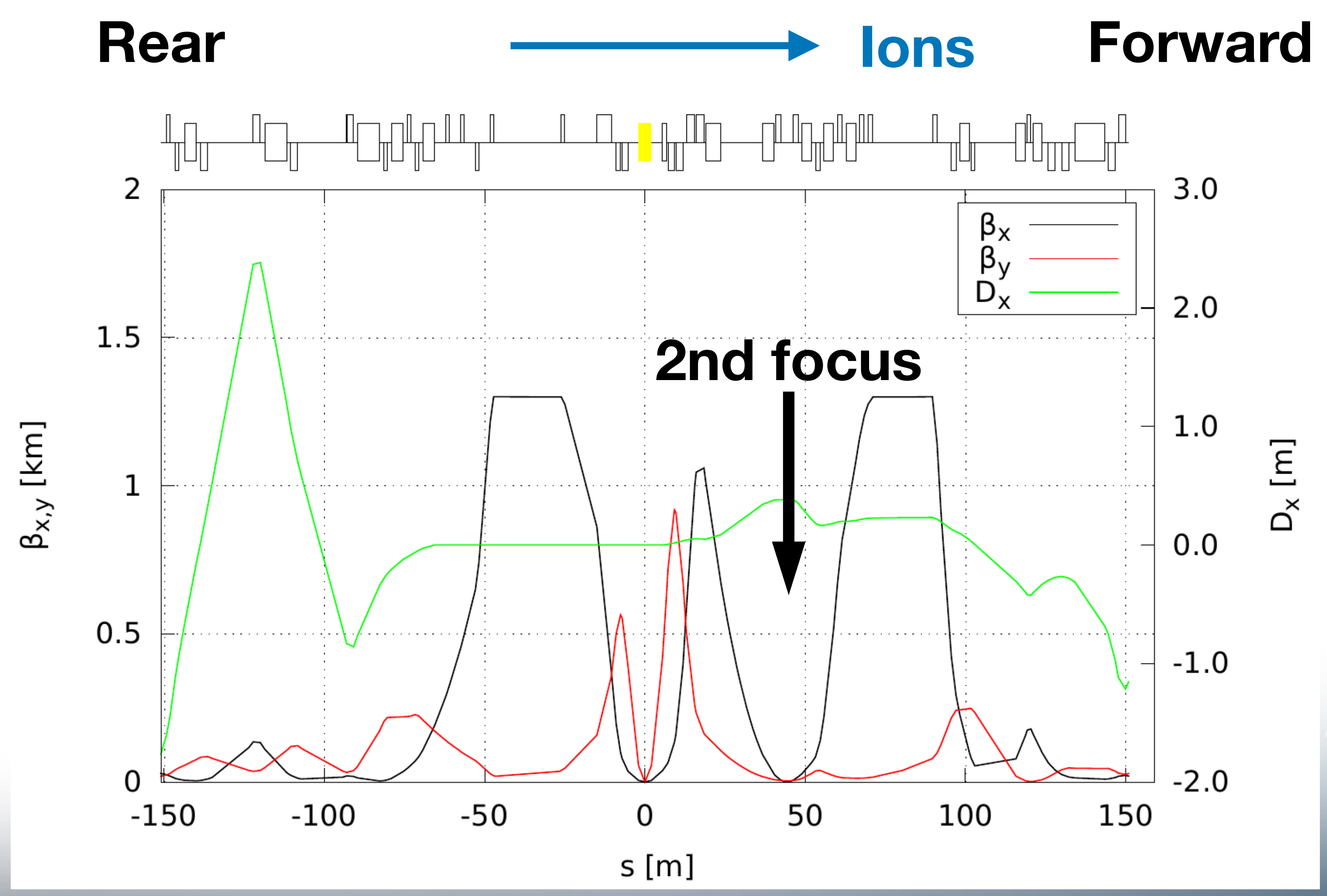
- Reserved space for spin rotators on both sides and a snake on rear side.
- Hadron beam line matched to the ARCs on each side.
- Electron beam line matched up-to the spin rotators.



IR8 ion optics

- Doublet optics with reversible polarity of the second quad depending on the energy.
  - $\beta^*_{x/y} = 80/7.2$ cm (> 135GeV)
  - $\beta^*_{x/y} = 37/2.5$ cm (< 135GeV)

- Both sides are matched in to the ARCs
- Further study and optimization is needed for reusing RHIC magnets.
- Space limitation might require new magnets in some areas.



IR8 second focus

Table 1

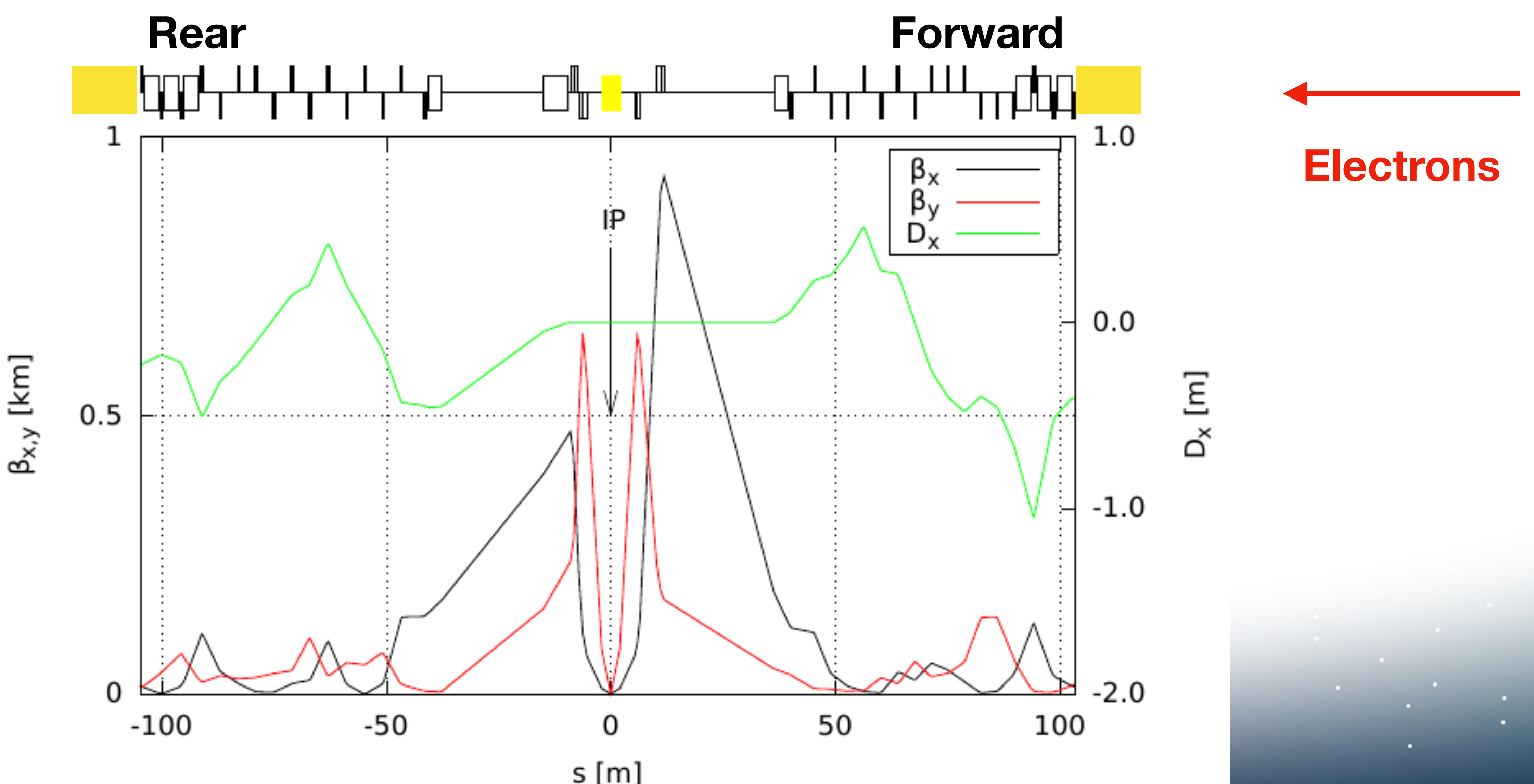
Parameter	Value	units
beta_x	0.62	m
Dx	0.38	m
emittance	11.3	nm
RMS momentum spread	6.8E-04	

$$x_L < 1 - 10\,\frac{\sigma_x}{D} = 1 - 10\,\frac{\sqrt{\beta_x^{2nd}\epsilon_x + D_x^2\sigma_\delta^2}}{D}$$

- Table 1 shows the parameters at 2nd focus that can be used to calculate the maximum detectable x_L using the equation from slide 4
- $x_L < 0.9928$

IR8 electron optics

- Electron beam line optics and geometry very similar to IP6
- Special care was going to keep the relative angle between the IP and spin rotators the same as IP6
- Not yet matched all the way to the ARCs

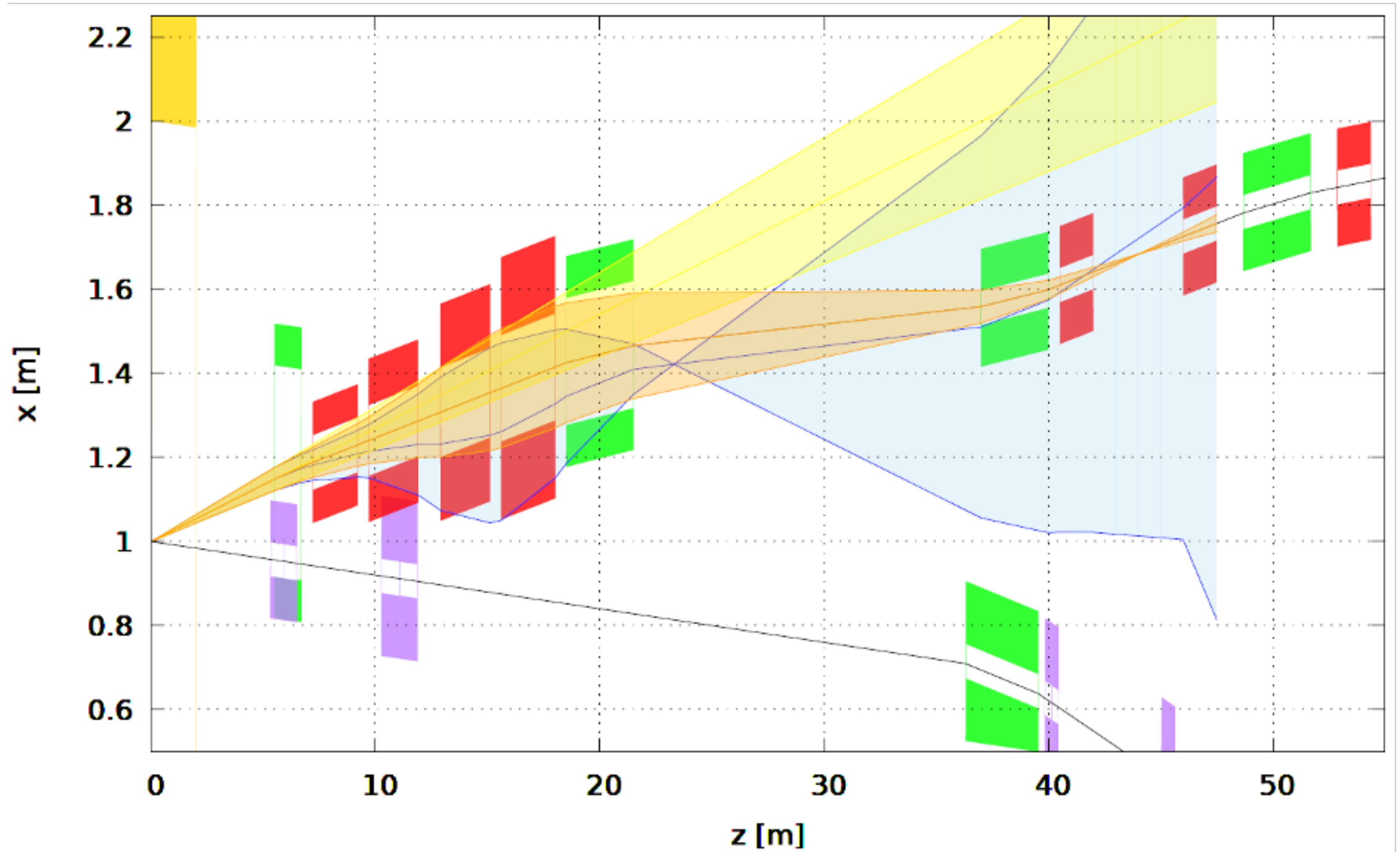


IR8 Acceptance

Neutrons $\pm 7\mathrm{mrad}$

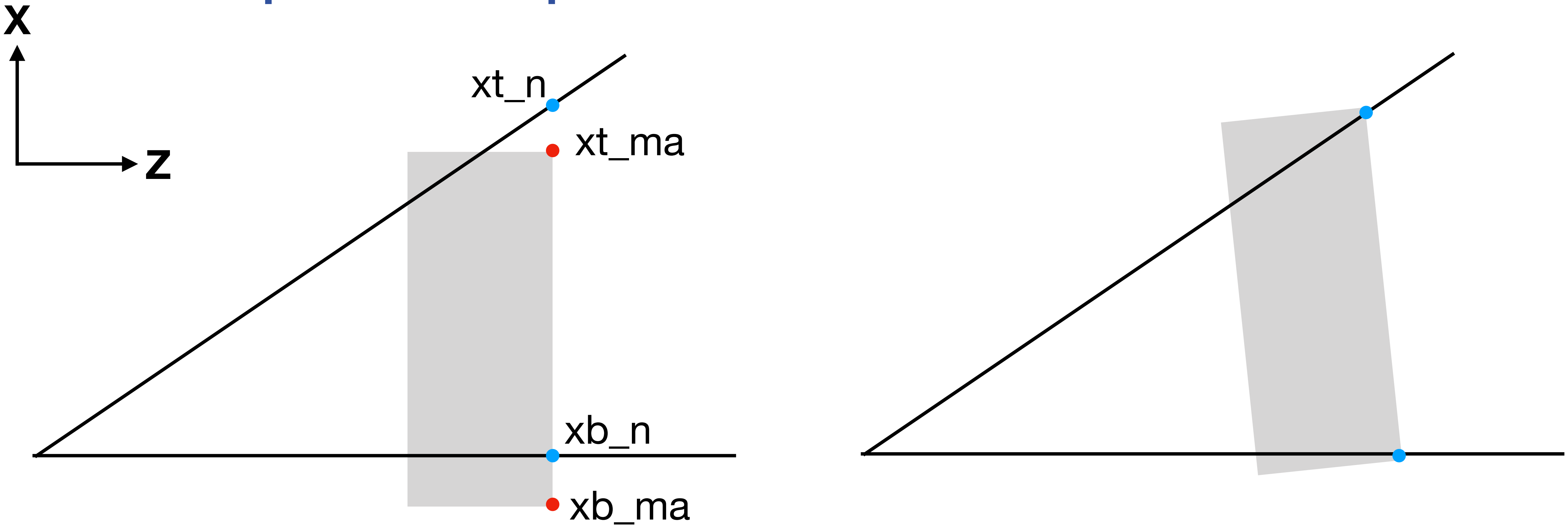
Protons $\pm 5\mathrm{mrad}$
$\Delta p/p = 0$
$p_T = 1.37\mathrm{GeV}, x_L = 1$

Protons $\pm 7\mathrm{mrad}$
$\Delta p/p = -0.5$
$p_T = 0.96\mathrm{GeV}, x_L = 0.5$



- Initial layout with magnets centered to a common axis.
- Protons and neutrons sees interference from the magnet apertures.
- How to improve the acceptance?

Acceptance optimization constraints



xt_neutron - xt_magnet <= 0
xb_neuton - xb_magnet >= 0

- Similar constraints for high p_T and $x_L = 1$protons
- Applied to both sides of the magnet
- Total of 8 constraints per magnet
- Variables that can be used: magnet shift in x, rotation around y, (magnet aperture, magnet length)

Optimized acceptance

Neutrons $\pm 7\text{mrad}$

Protons $\pm 5\text{mrad}$

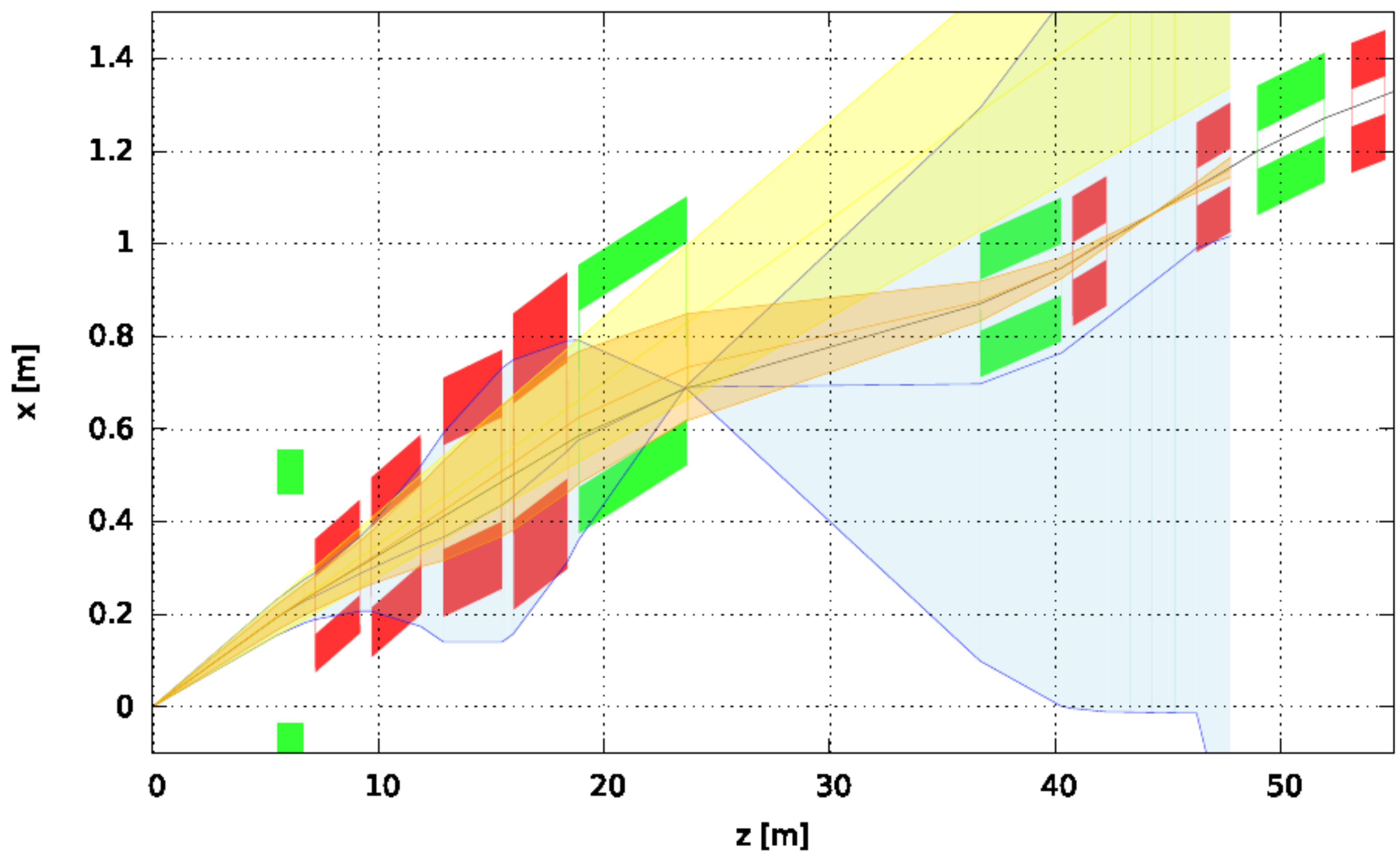
$\Delta p/p = 0$

$p_T = 1.37\text{GeV}, x_L = 1$

Protons $\pm 7\text{mrad}$

$\Delta p/p = -0.5$

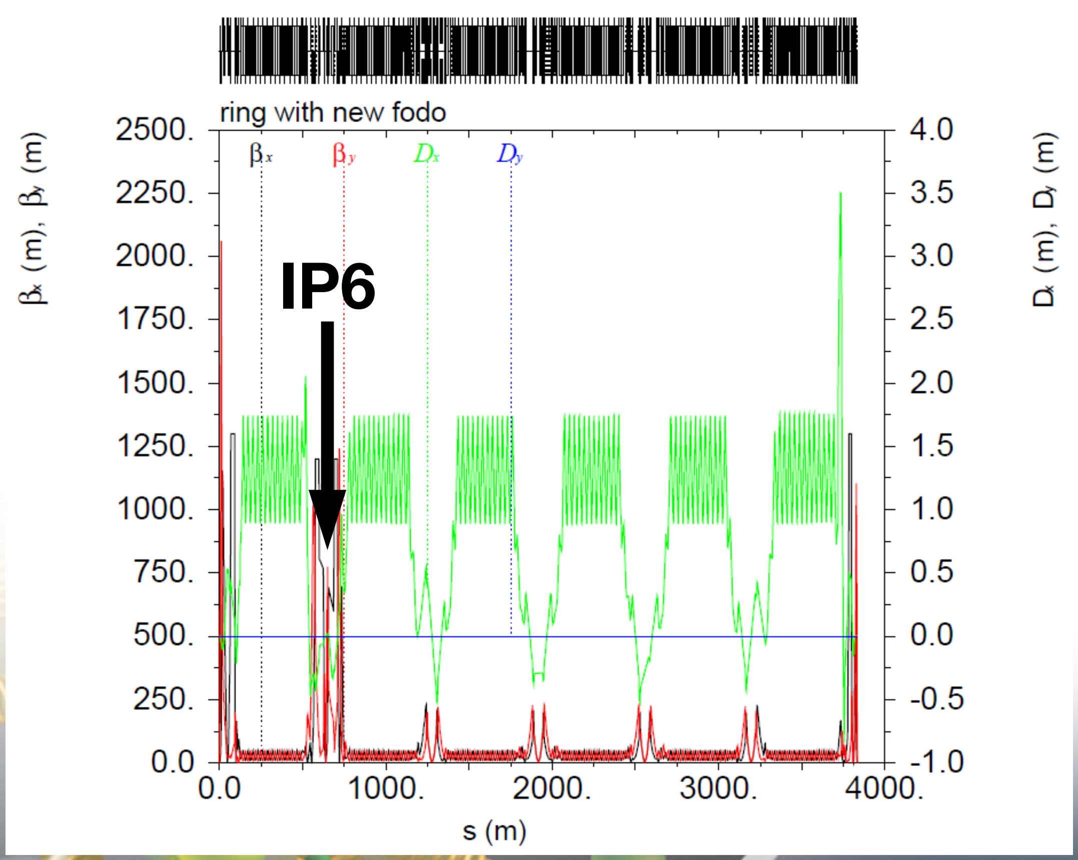
$p_T = 0.96\text{GeV}, x_L = 0.5$

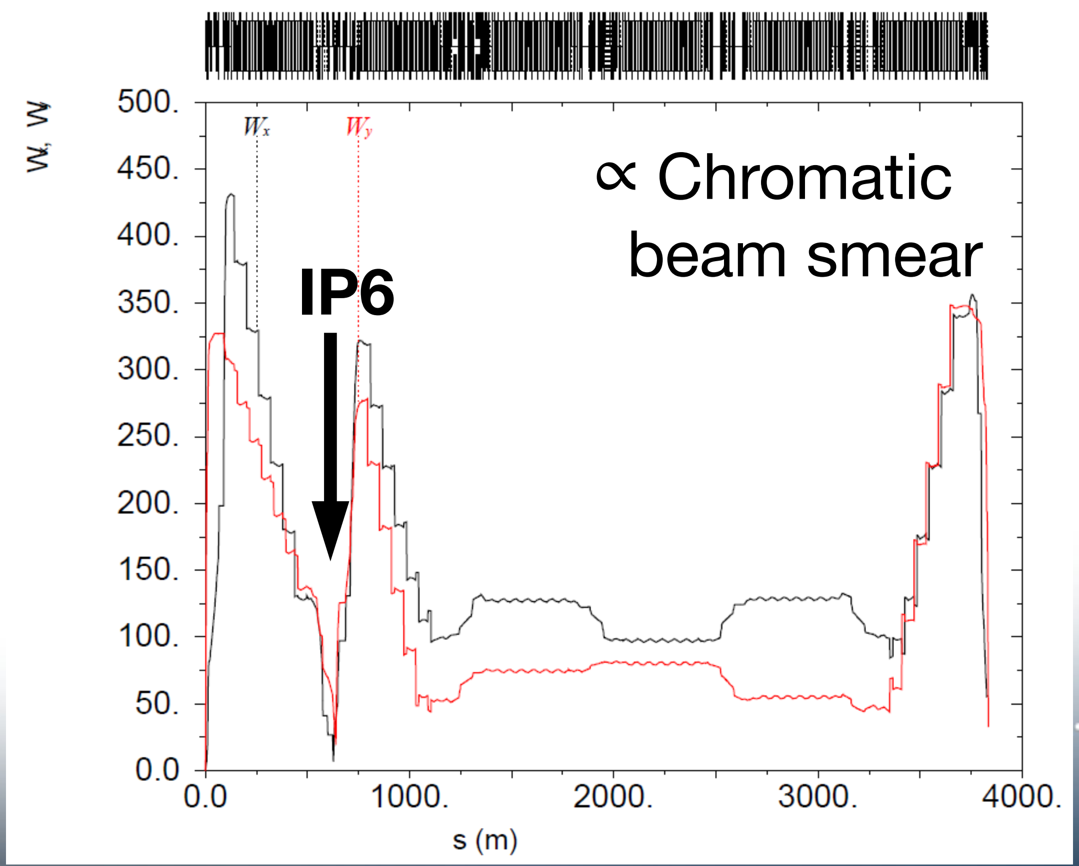


- Layout with magnets offsets introduced to the final focusing quads (FFQ) and the two dipoles.
- Improved acceptance for both neutron and protons compared to the initial layout.
- FFQ Magnet apertures and strengths are at their limits of what can be practically achieved.

Linear optics and chromaticity compensation

- How to compensate chromaticity in the collider with two IR's ?
- Make use of chromatic interference of the two IRs
- No symmetry requirements to IRs
- Control chromatic beam smear around the ring and compensate it at both IPs





Summary

- Hadron beam line
  - Magnet apertures limits the acceptance.
  - B0 dipole field and aperture needs further study.
  - Further optimization is needed to reuse RHIC magnets
- Electron beam line
  - Not yet matched to ARCs
- Both rings
  - Chromaticity correction with two IRs
  - Dynamic aperture studies
  - Magnet feasibility.

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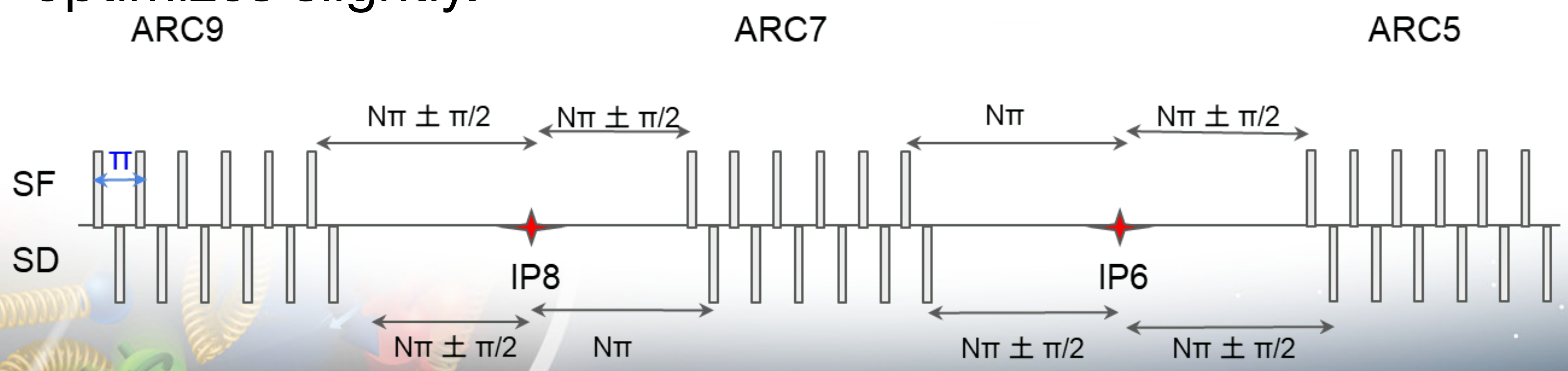
Thank you!

Backup

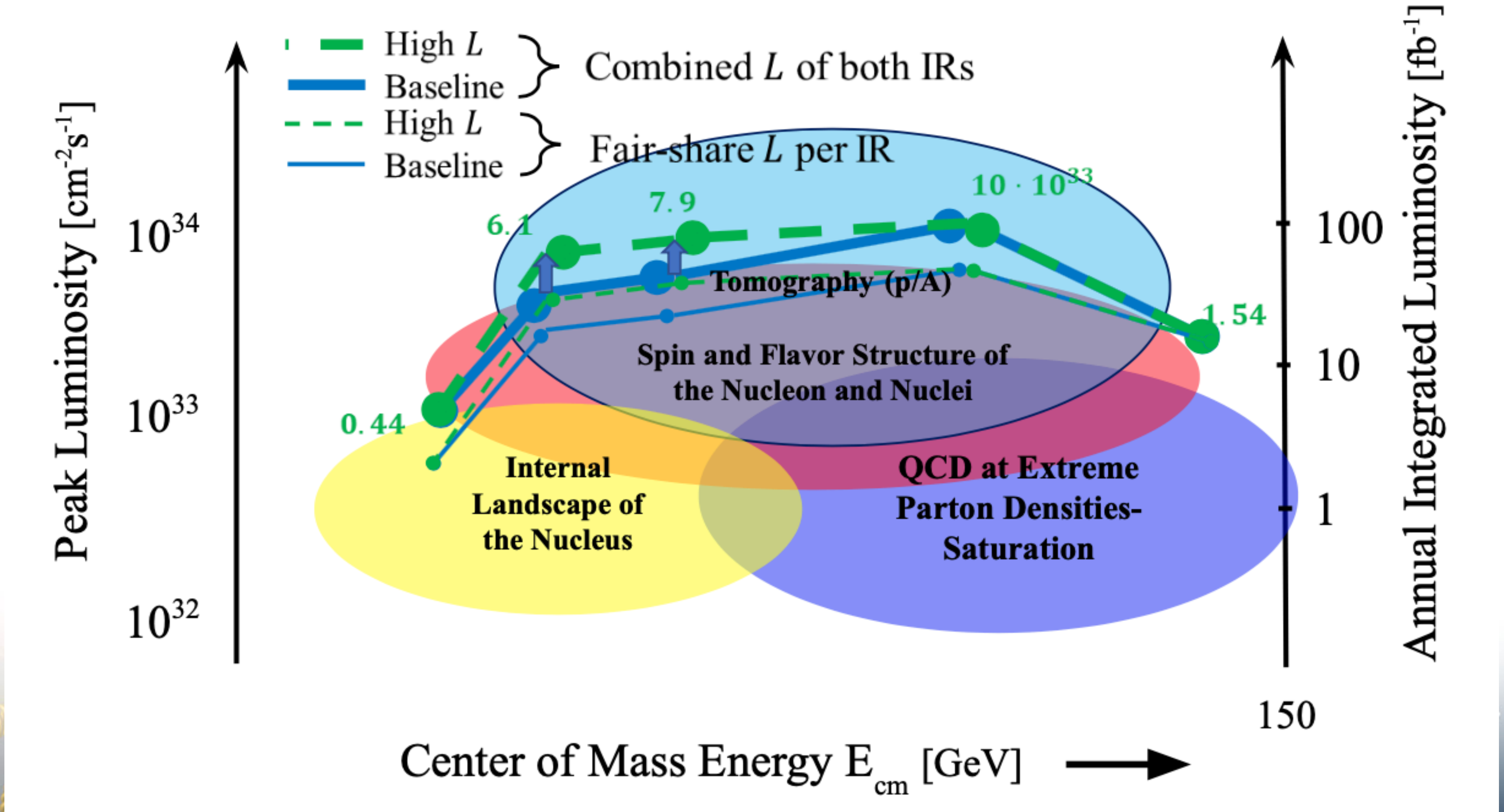
Beam and Optics Parameters

- Another focus of recent effort
- Strategy
  - ARC 9 used semi-local compensation of the rear side of IP8
  - ARC 5 used for semi-local compensation of the forward side of IP6
  - Forward side of IP8 and rear side of IP6 partially compensate each other
  - Since IP8 forward and IP6 rear are different, the difference in their chromatic kicks is compensated by sextupoles in ARC 7
  - Exact phase advance between the IPs and sextupoles optimizes slightly.



Luminosity sharing

- Conservative assumption: luminosity is shared between two detectors, different bunch pairs collide at different IPs.
- Luminosity in the medium energy range can be pushed at the expense of acceptance.



Luminosity and p_T acceptance trade off

$100 \times 10\mathrm{GeV}$ configuration