IP8: Design, Options and Opportunities

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Detector-II Working Group Kick-Off Meeting

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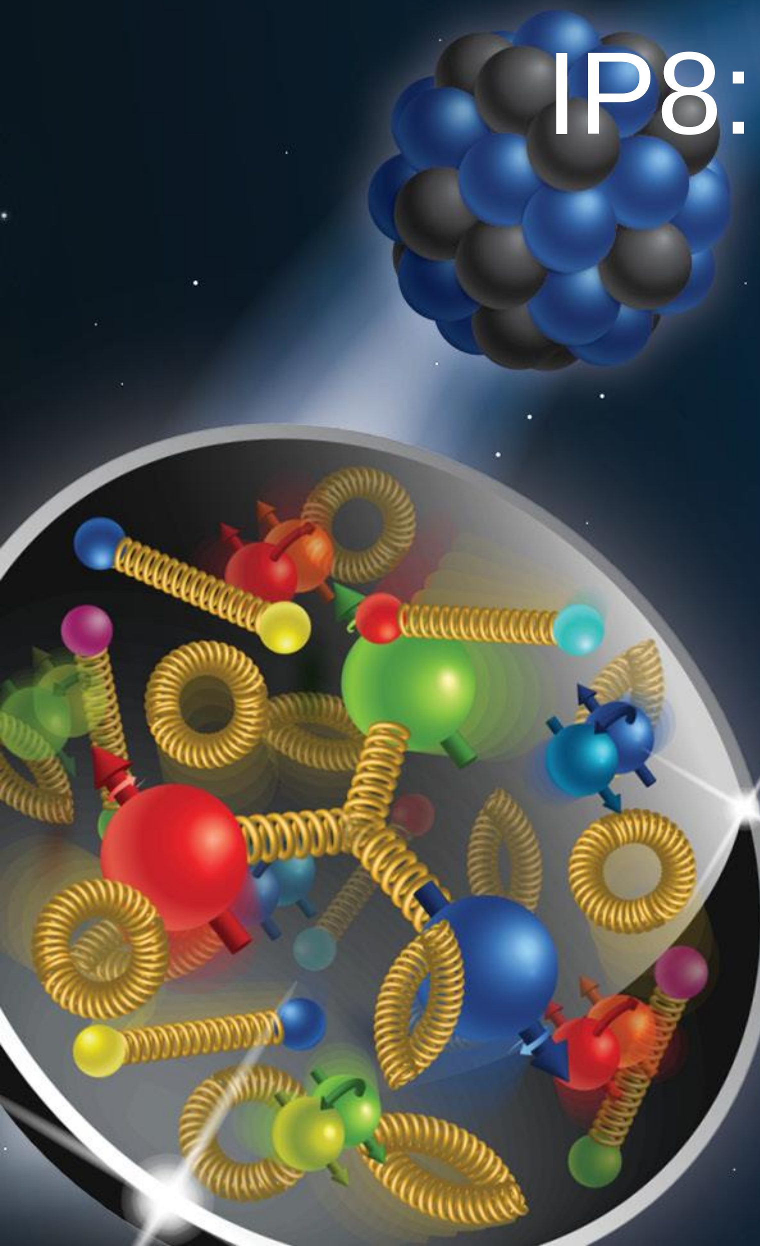


Electron-Ion Collider

BROOKHAVEN NATIONAL LABORATORY

Jefferson Lab

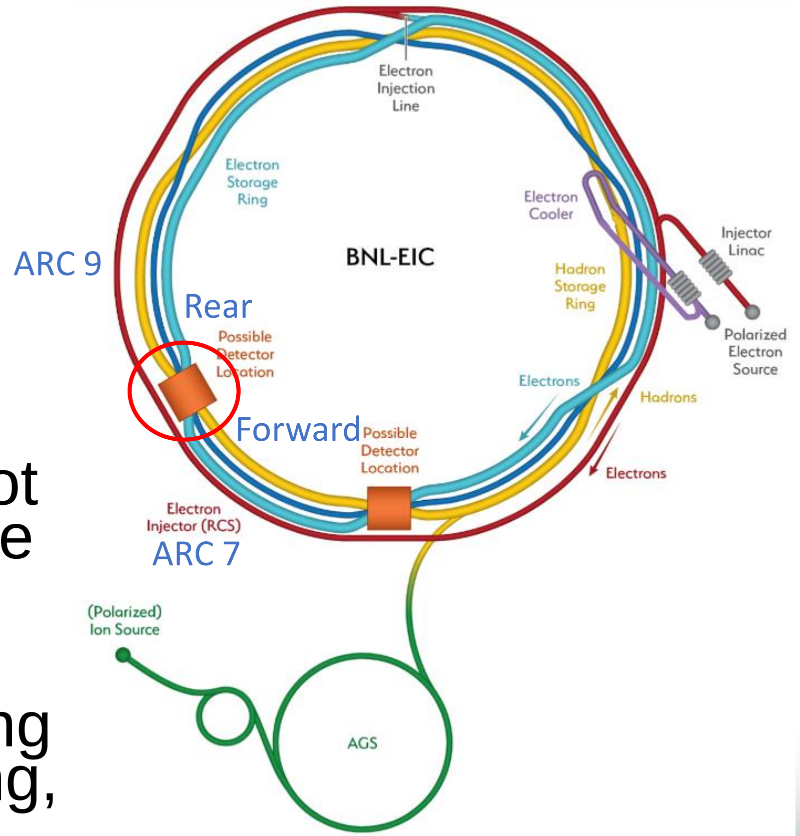
U.S. DEPARTMENT OF ENERGY | Office of Science

Thanks to ALL Contributors

- B. R. Gamage (Jlab)
- V.S. Morozov (ORNL)
- Scott Berg (BNL)
- And many more

Requirements/Constraints

- Fit into the existing RHIC IR8 experimental hall between ARC 7 and 9.
- Secondary focus.
- In addition same functionality as in IR6 (spin rotators, snake and crab cavities).
- Second colliding IR and detector not in project, but the ability to have one is in the project scope.
- Accelerator design performance is established (e.g. luminosity including sharing between IRs, bunch spacing, collision patterns, etc.)



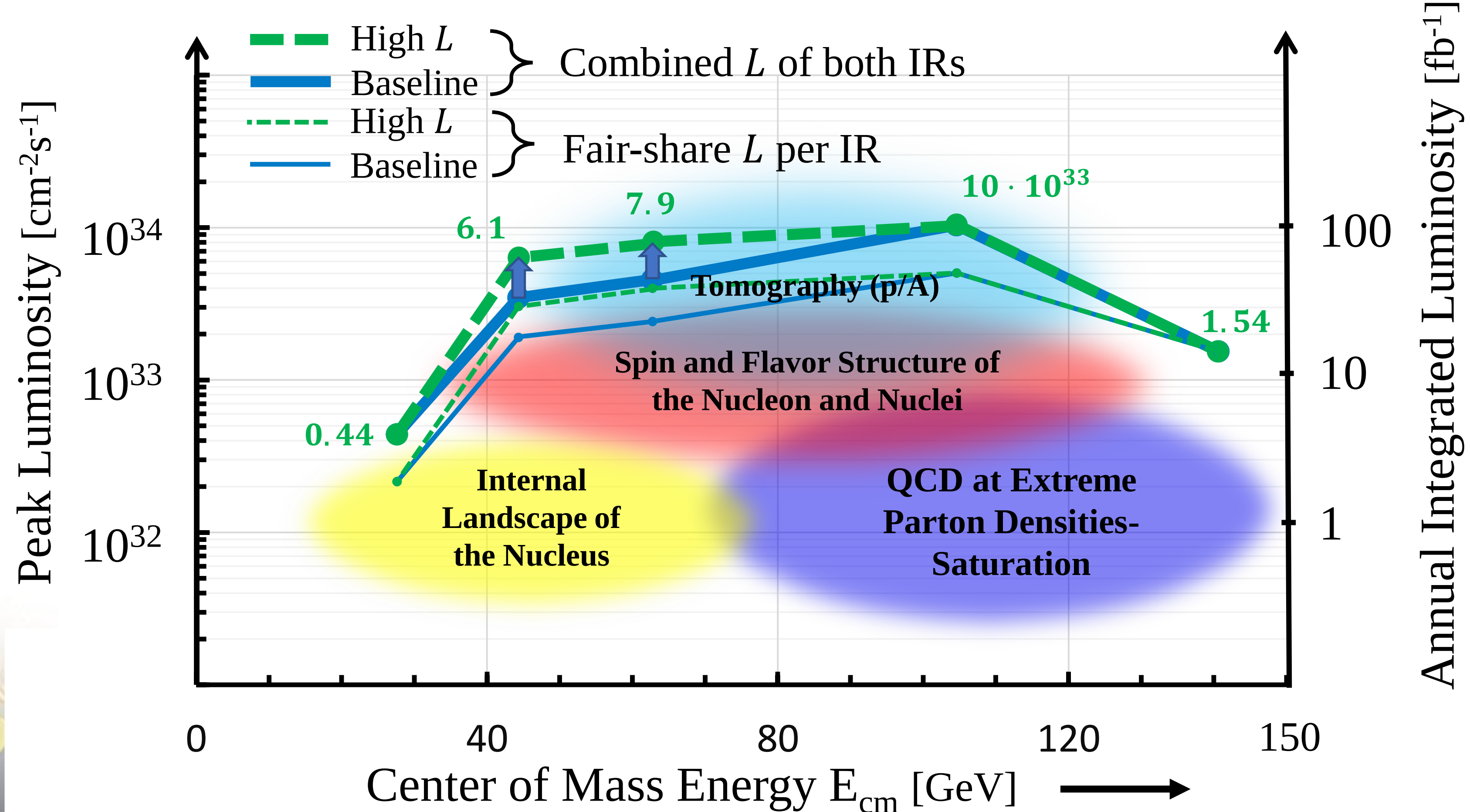
IR Requirements & Parameters

- Basic parameters have been narrowed down

	1st IR		2nd IR	
	proton	electron	proton	electron
Detector occupied region	First forward ion quad at 7.5 m Beam elements < 1.5° in main detector		First forward ion quad at 7.5 m Beam elem. < 1.5° in main detector	
Polarimetry	Yes (IR4)	local	Yes (IR4)	local
2nd focus	No		yes	
β^* @ 275 GeV (h), 10 GeV (e)	β^*_x = 80 cm β^*_y = 7.2 cm	β^*_x = 45 cm β^*_y = 5.6 cm	β^*_x = 80 cm β^*_y = 7.2 cm	β^*_x = 45 cm β^*_y = 5.6 cm
ZDC	0.6m x 0.6m x 2m @ s≅30m n: $\pm$ 4 mrad		0.6m x 0.6m x 2m @ s≅ 40m n: $\pm$ 4 mrad	
Roman Pots	1-5 mrad, @s≅30m		0-5 mrad, $@s \cong 30{-}45$ m	
Scattered particle acceptance	p: 0.18 GeV/c < p_T < 1.3 GeV/c		0 GeV/c ($x_L < 1$) < p_T < 1.3 GeV/c	
Q^2 tagger		Q^2< 0.1 GeV		
Crossing angle	25 mrad		35 mrad	

Luminosity Sharing

- Accelerator design: luminosity is shared between two detectors, different bunch pairs collide at different IPs
- In medium energy range: Luminosity can be exchanged with acceptance



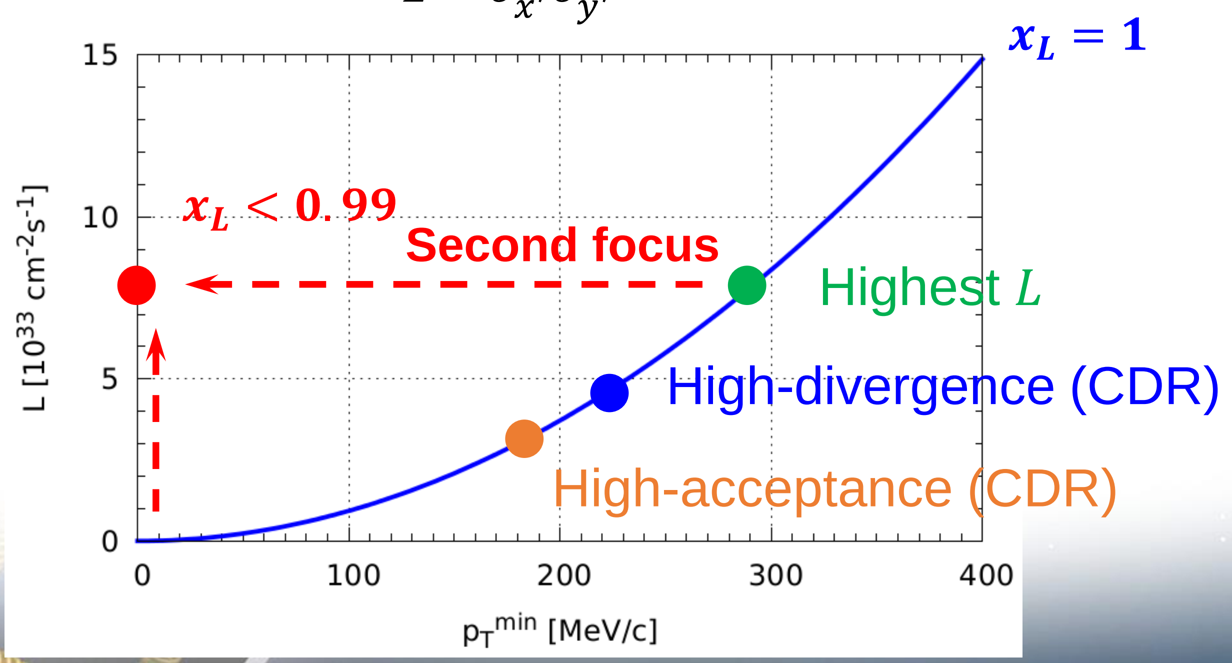
Luminosity and p_T Acceptance

- Minimum p_T acceptance

$$p_{Tx/y} > p_{Tx/y}^{min} = \begin{cases} 10 p_{beam} \sigma^*_{x'/y'}, & x_L = 1 \\ 0, & x_L < 0.99 \end{cases}$$

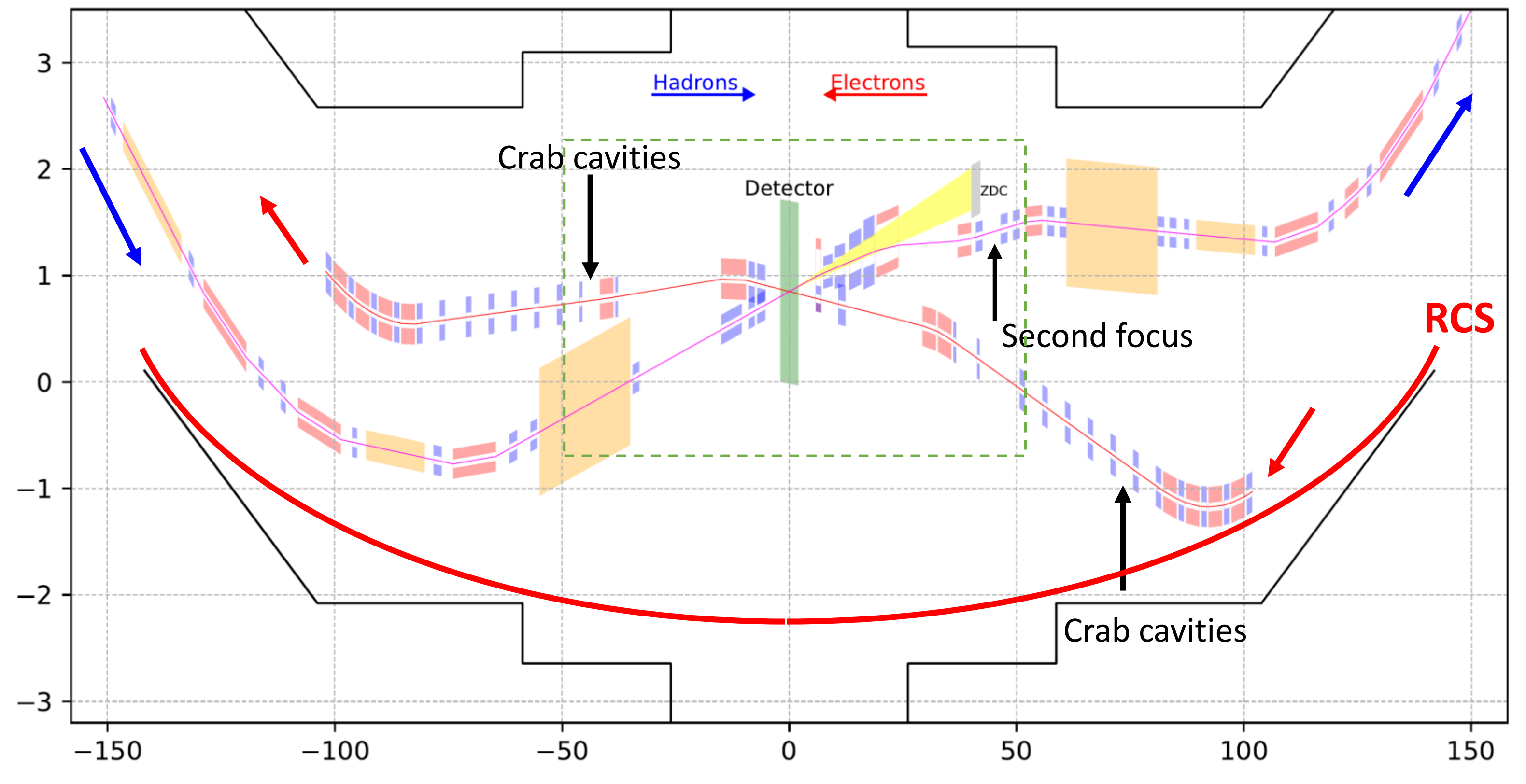
- Larger luminosity means smaller p_T acceptance at $x_L = 1$
- For same-rigidity nuclei, $p_T^{min}(Z, A) = Z p_T^{min}(p)$
- Luminosity increased by stronger focusing, i.e. increase in angular divergence

$$L \propto \sigma^*_{x'} \sigma^*_{y'}$$



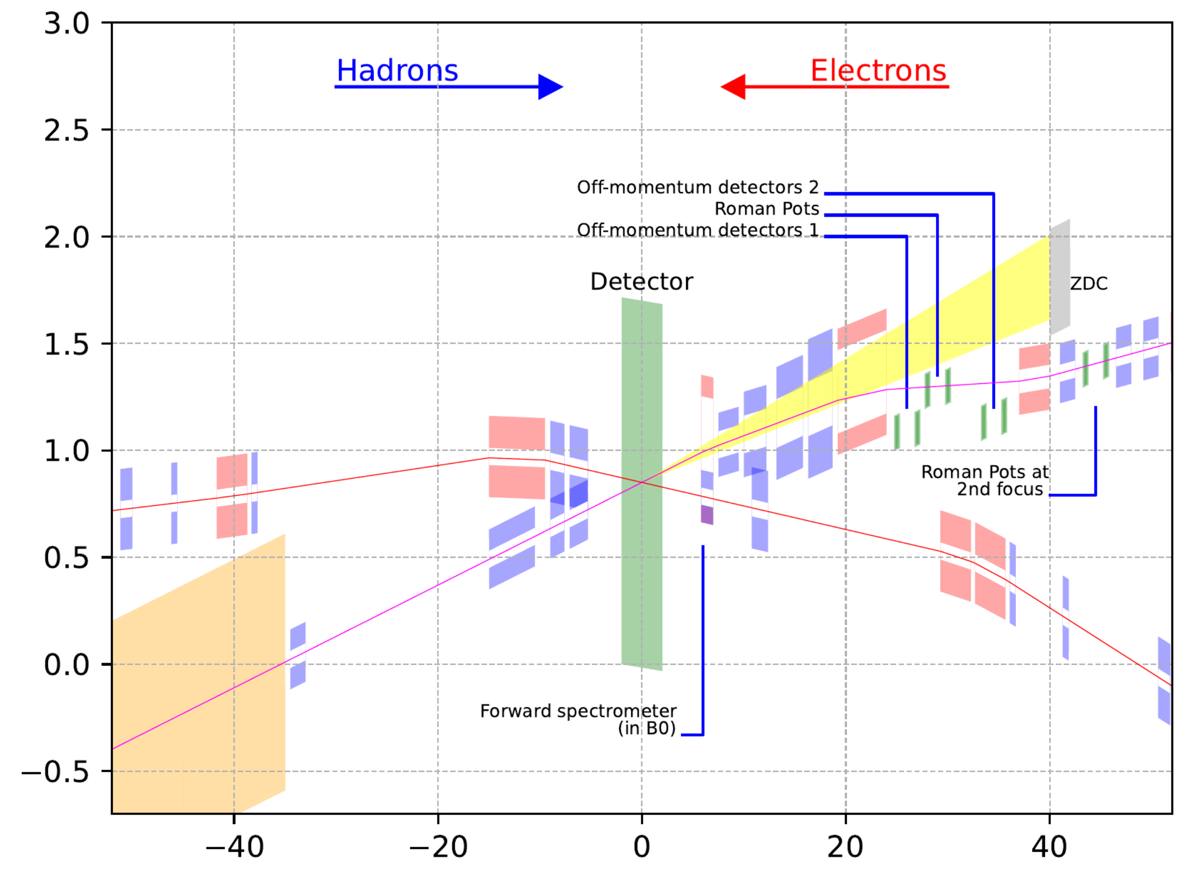
IR8 Layout

- **Main additional feature to IR#1: Second focus point at ~47m.**
- 35 mrad crossing angle is a design outcome (driven by accelerator geometry).
- Same functionality with similar accelerator equipment as IR6.
- Share space with RCS



Detector Region of IR8

- Space reserved for
  - luminosity monitor, low Q2 tagger and local electron polarimeter
  - ancillary detectors on the forward side



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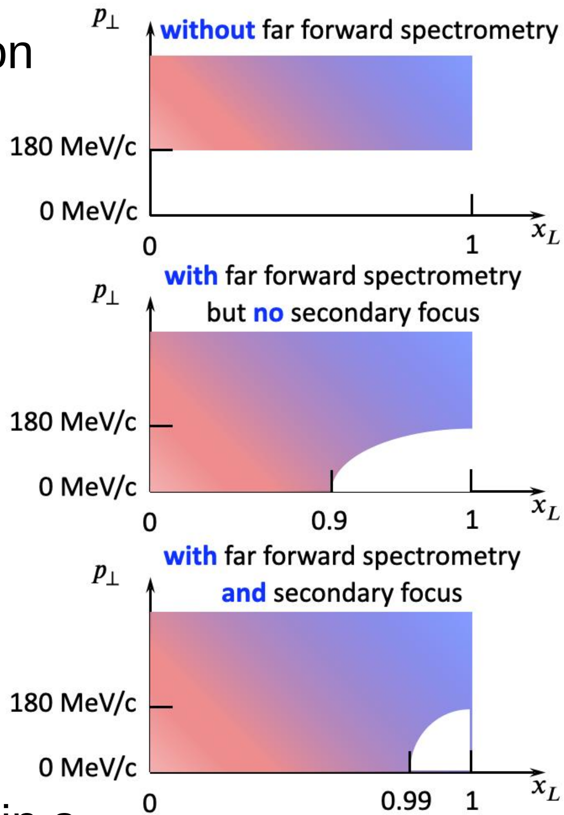
Parameter Choice

- 35 mrad crossing angle is driven by balance of
  - Detection requirements for detector systems
  - Transverse dimensions of beam line elements
  - Beam line geometry
  - Crab cavity parameters and associated beam dynamics issues
- Detector space
  - Detector size with the requirement for a general purpose detector
  - Transverse dimensions of beam line elements given the crossing angle and RCS beam-line passing on the ring outside

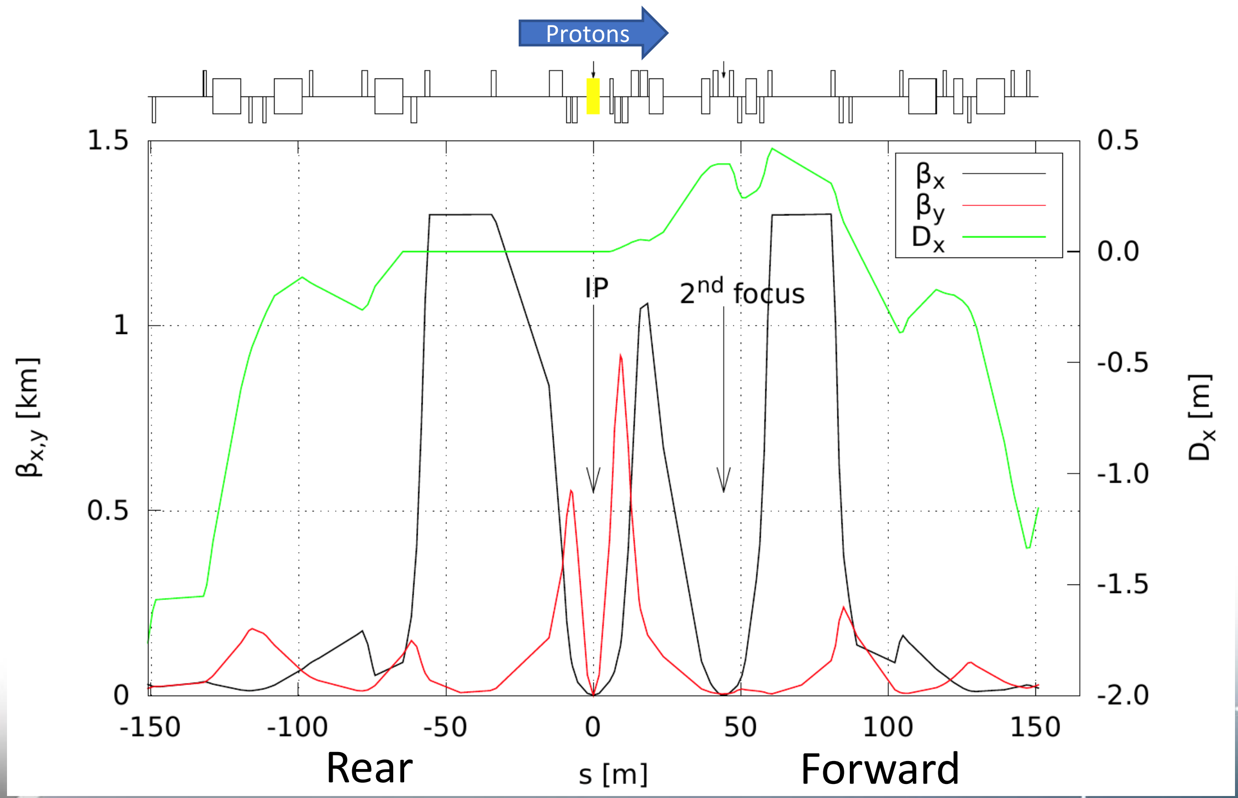
Acceptance as Function of x_L and p_T

- x_L - fraction of the longitudinal momentum relative to hadron beam
- p_T - fraction of the transverse momentum relative to hadron beam (θ)
- p_T acceptance at $x_L = 0$
  - $p_T^{min} > 10 p_0 \theta_{IP} = 10 p_0 \sqrt{\frac{\epsilon}{\beta^*}}$
- 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 $|D\sigma_\delta| \gg \sqrt{\beta\epsilon}$
- Can reach the fundamental limit
  - $x_L < 1 - 10\sigma_\delta$
- Increase of β^* which in turn increase the β_x^{2nd} may result in a smaller x_L acceptance.

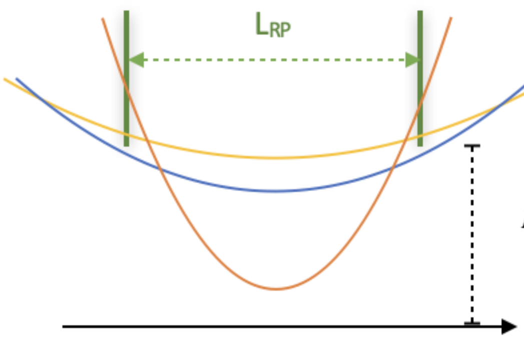


IR8 Hadron Optics

- Rear space reserved for the same accelerator equipment as in IR6
- In forward area limited space requires higher gradient than existing RHIC magnets but are within established NbTi limits; no Nb_3Sn magnets required



IR8 Second Focus



$$D_x\Delta > 10\sigma_x = 10\sqrt{\epsilon_x\left(\beta_x + \frac{L_{RP}^2}{4\beta_x}\right) + D_x^2\delta^2}$$

Parameters at the 2nd focus

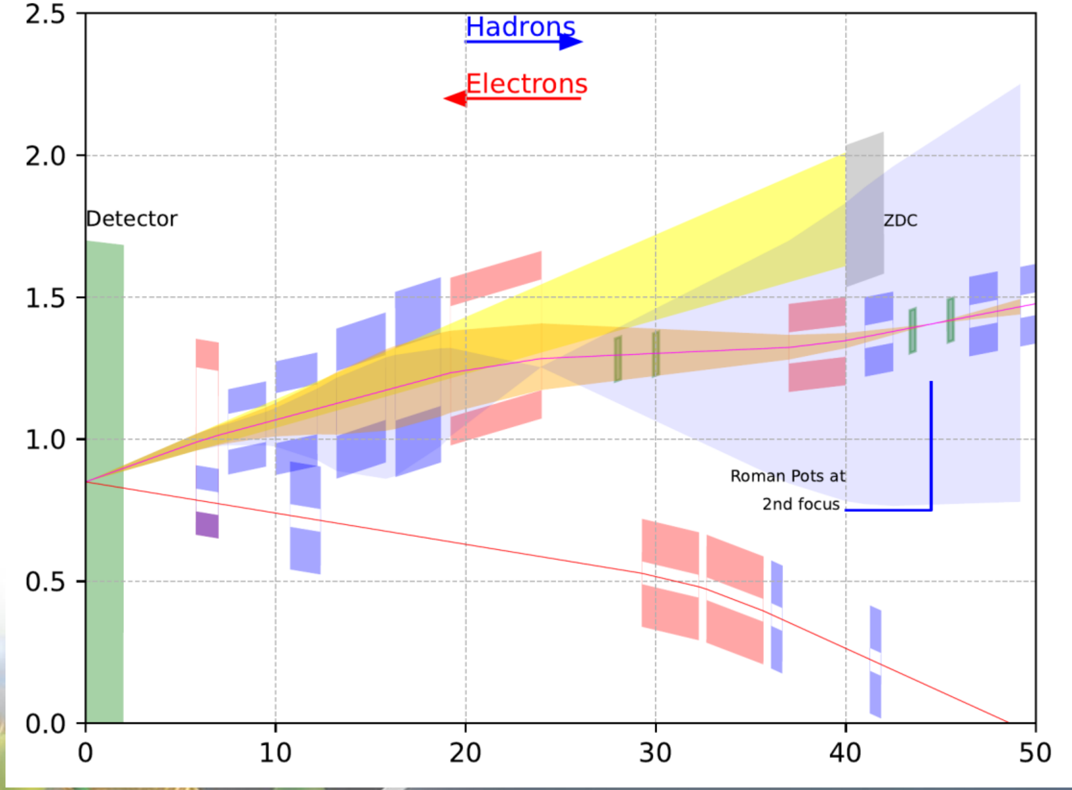
Parameter	Value	Units
β_x	0.62	m
D_x	0.38	m
ϵ_x	11.3	nm
σ_δ	$6.8e^{-4}$	-

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

- Optimal $\beta_x^{2nd} = \frac{L_{RP}}{2}$
- For the current design, $x_L < 0.9928$
- Limit of x_L for the given momentum spread is 0.9932

IR8 forward acceptance

- This is the current design of the forward region with NbTi magnets
- Final focusing quads and the dipole placements was optimized for forward scattering neutron and proton acceptance.



Neutrons ± 5 mrad

Protons ± 5 mrad

$\Delta p/p = 0$

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

Protons ± 5 mrad

$\Delta p/p = -0.5$

$p_T = 0.69\text{GeV}, x_L = 0.5$

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IR8 Design Status

- An accelerator design of the IR8 is available for 275 GeV HSR on 18 GeV ESR.
- Has all components for demonstration of physics case.
- Detailed check ongoing (e.g. comparing to Alex’s studies)
- Magnetic field and geometry data package in preparation.
- Work on 100 GeV HSR on 10 GeV ESR and 41 GeV HSR on 5 GeV ESR in progress.
- 3D model for IR8 for this design in progress.
- No big changes expected at this point.
- Possible small corrections envisioned if:
  - Physics performance improvement.
  - Cost reduction.
  - Risk reduction.
  - Reduction of technical complexity.
- Requests for corrections need to be coordinated with the project

Next Steps on Design NOT Required for Physics Evaluation

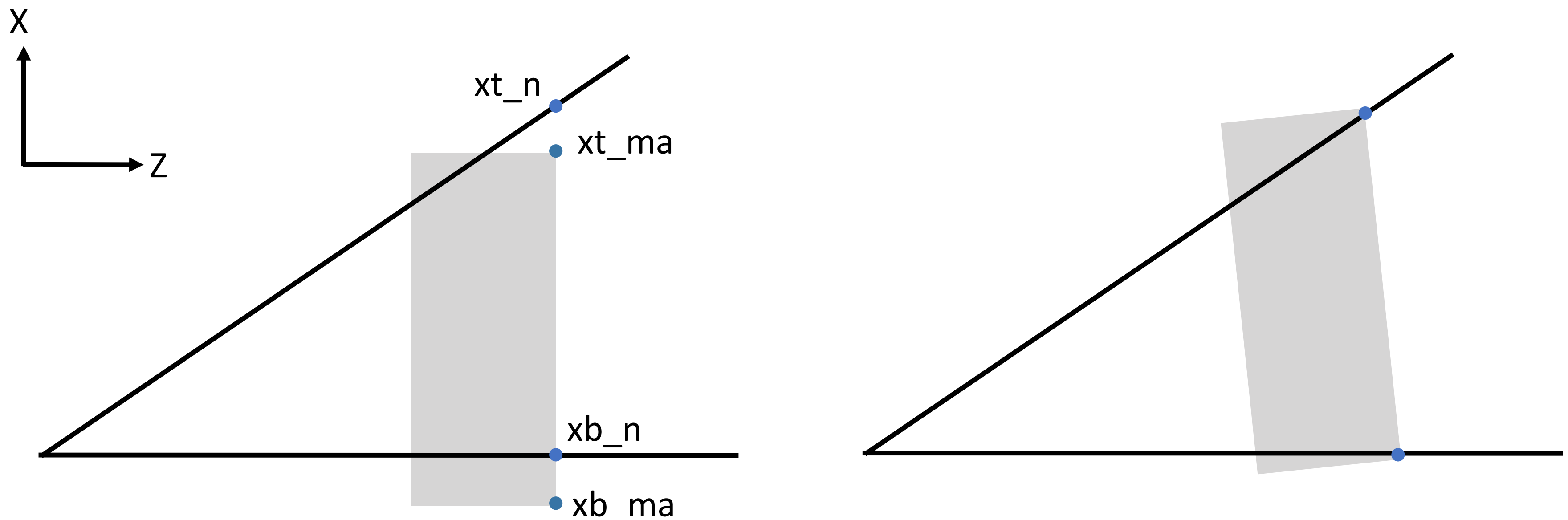
- One of the next levels of detailed design relevant to physics performance is detector solenoid integration
- A complete compensation scheme has been developed for IR6 ESR accounting for
  - Correction of transverse coupling locally at the IP and across the entire IR
  - Suppression of the momentum dispersion at the IP
  - Control of the crab dispersion at the IP and closing of the crab dispersion locally in the IR
- HSR scheme in development
- This will be leveraged for IR8

Summary

- The overall accelerator performance is established with the accelerator design basis.
- An accelerator design has been developed with all components for demonstration of physics case and is available.
- Secondary focus is integral part of design.
- We are looking forward to the see the first results from the physics studies for IR#2.

Thank you!

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)

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