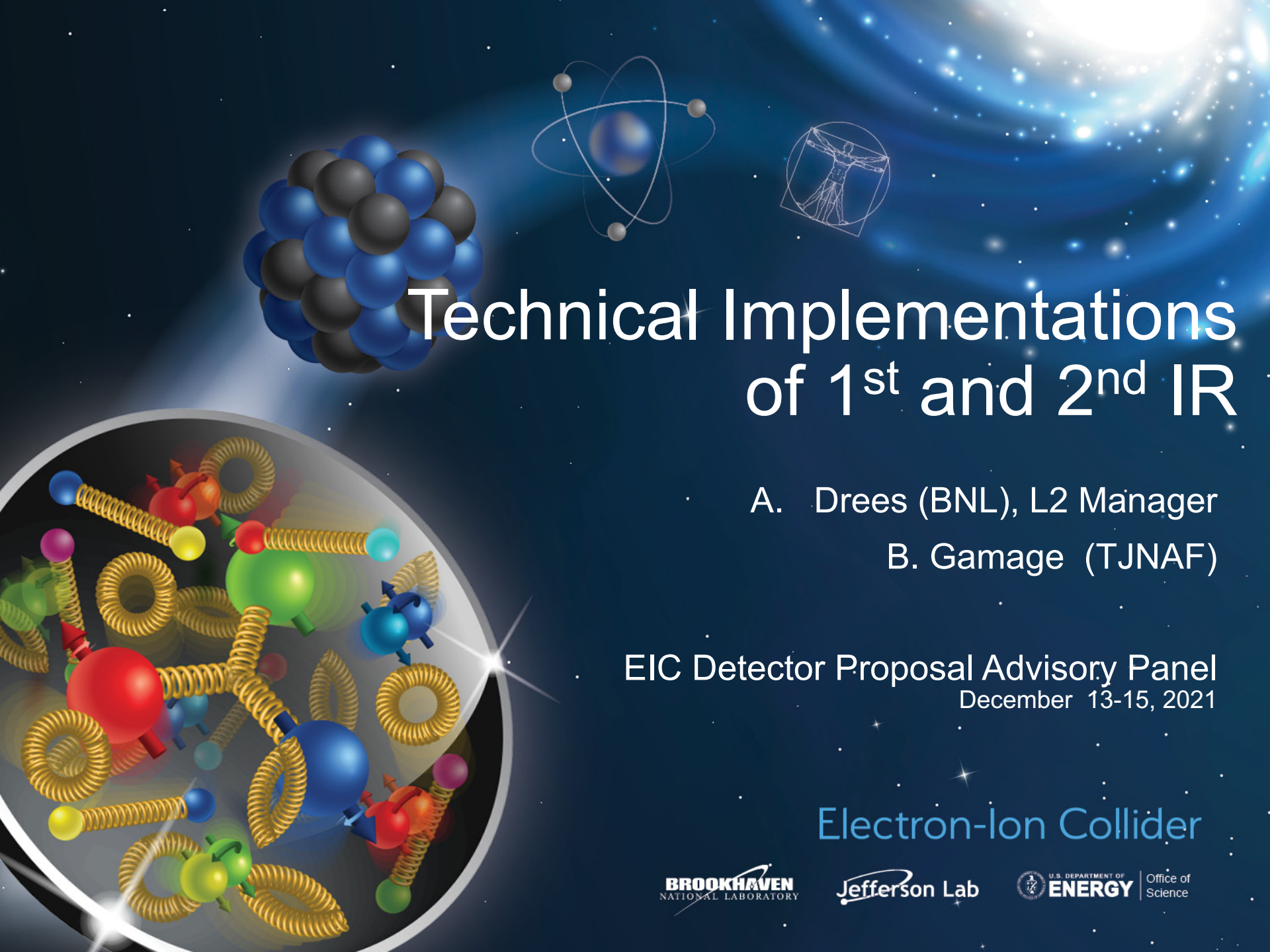


Technical Implementations of 1st and 2nd IR

A. Drees (BNL), L2 Manager

B. Gamage (TJNAF)

EIC Detector Proposal Advisory Panel

December 13-15, 2021

Electron-Ion Collider

BROOKHAVEN NATIONAL LABORATORY

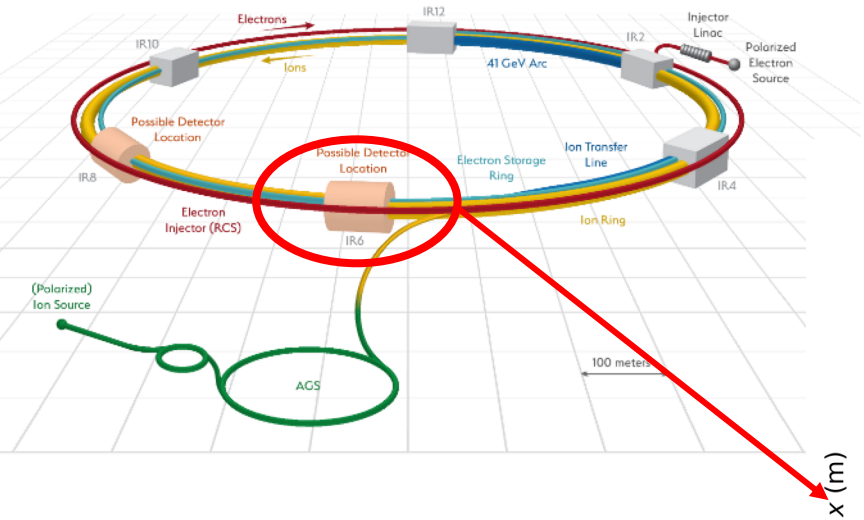
Jefferson Lab

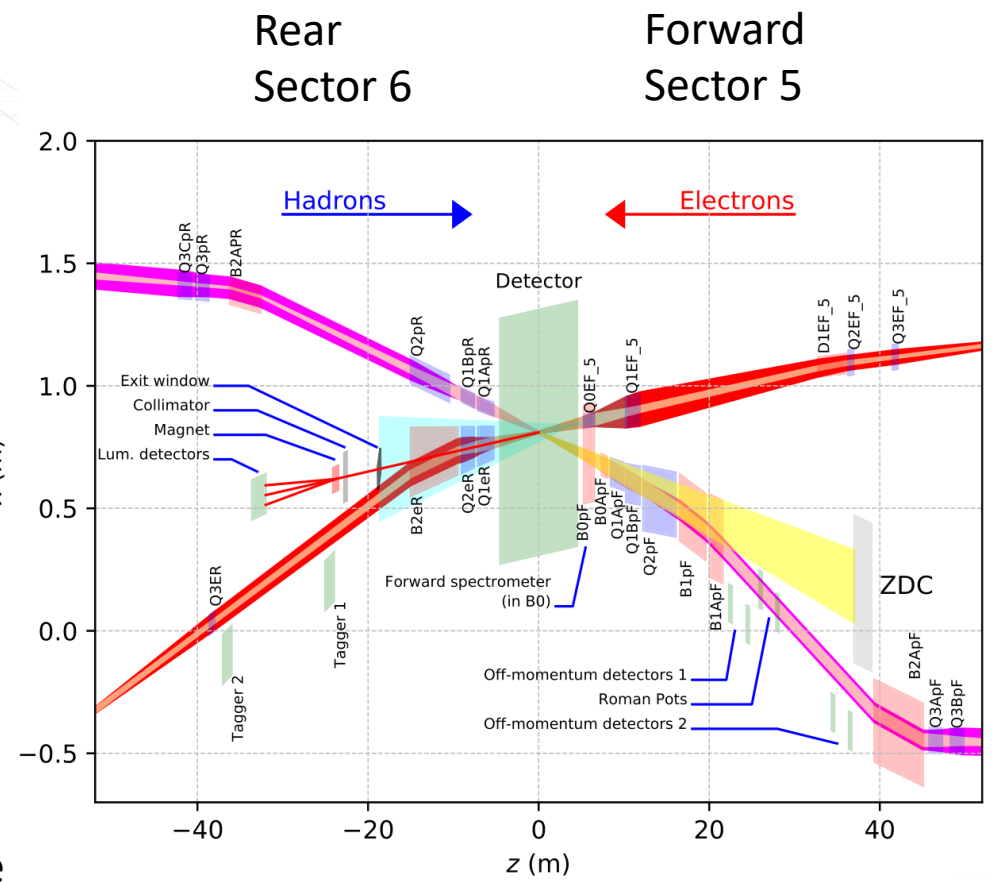
U.S. DEPARTMENT OF ENERGY | Office of Science

Content

- Overview
- First IR at RHIC IR6
  - Requirements and parameters for IR6
  - layout
    - ESR lattice
    - HSR lattice
- Summary 1st IR
- Second IR at RHIC IR8
  - Requirements and parameters for IR8
  - Layout
    - Hadron and electron optics
    - 2nd focus
- Summary 2nd IR

EIC IRs: Overview





- First IR:
  - Detector at RHIC IP6
  - Included in project baseline
- Second IR:
  - Detector at RHIC IP8
  - Not included in project baseline
  - But provisions for a 2nd detector have to be maintained

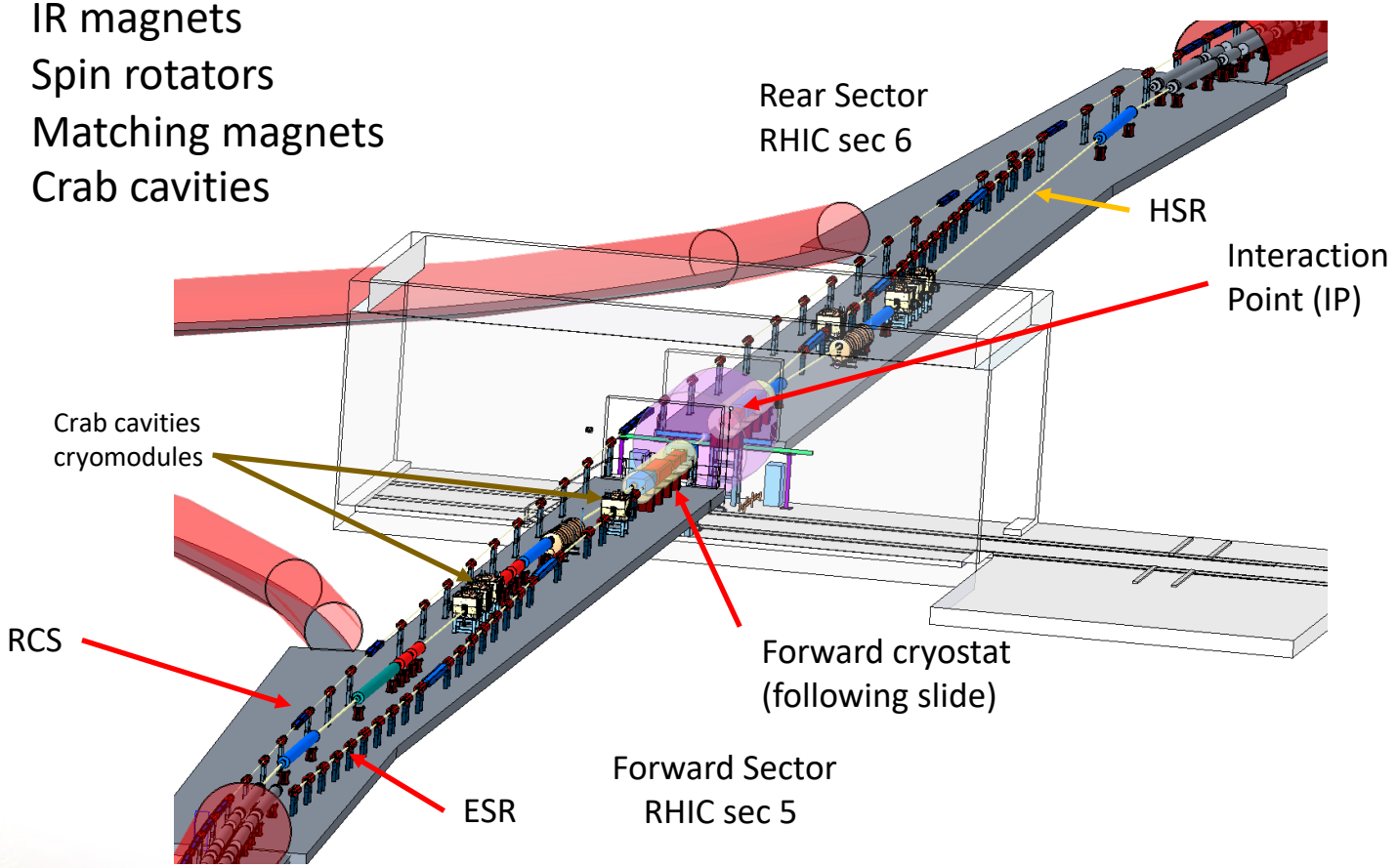
IR requirements & parameters

	1st IR		2nd IR	
	proton	electron	proton	electron
Detector occupied region	-4.5 m +5.0 m Beam elements < 1.5° in main detector		-4.5 m +5.0 m Beam elements < 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: ± 4 mrad		0.6m x 0.6m x 2m @ s≅ 40m n: ± 4 mrad	
Roman Pots	1-5 mrad, @s≅30m		0-5 mrad, @s≅30-45m	
Scattered particle acceptance	p: 0.18 GeV/c < p_T < 1.3 GeV/c		p: 0 GeV/c < p_T < 1.3 GeV/c	
Q^2 tagger		Q^2< 0.1 GeV		
Crossing angle	25 mrad		35 mrad	

First IR Layout

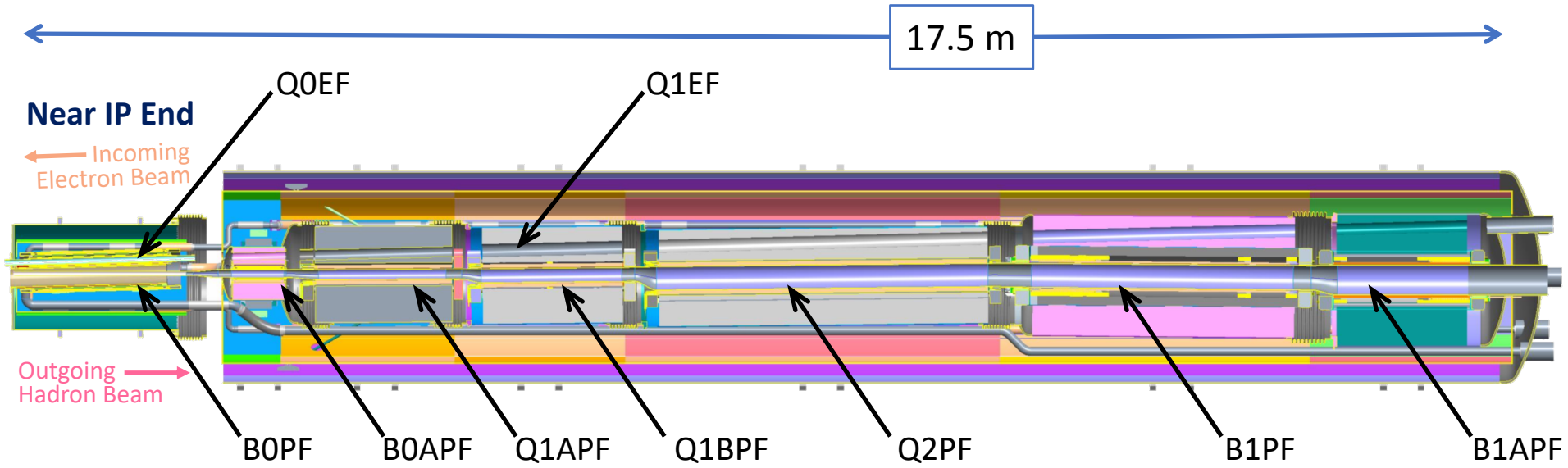
Interaction Region includes:

- IR magnets
- Spin rotators
- Matching magnets
- Crab cavities



The Interaction Region has to extend by about +/- 130 m from the IP in both directions of the appending sectors to achieve the required conditions for an experimental detector.

Forward Side, Two Cryostat Layout



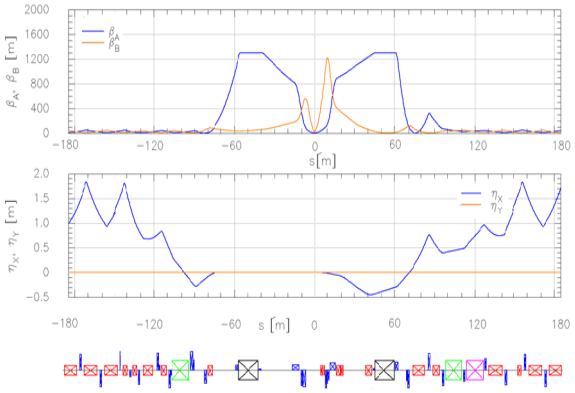
Highlights:

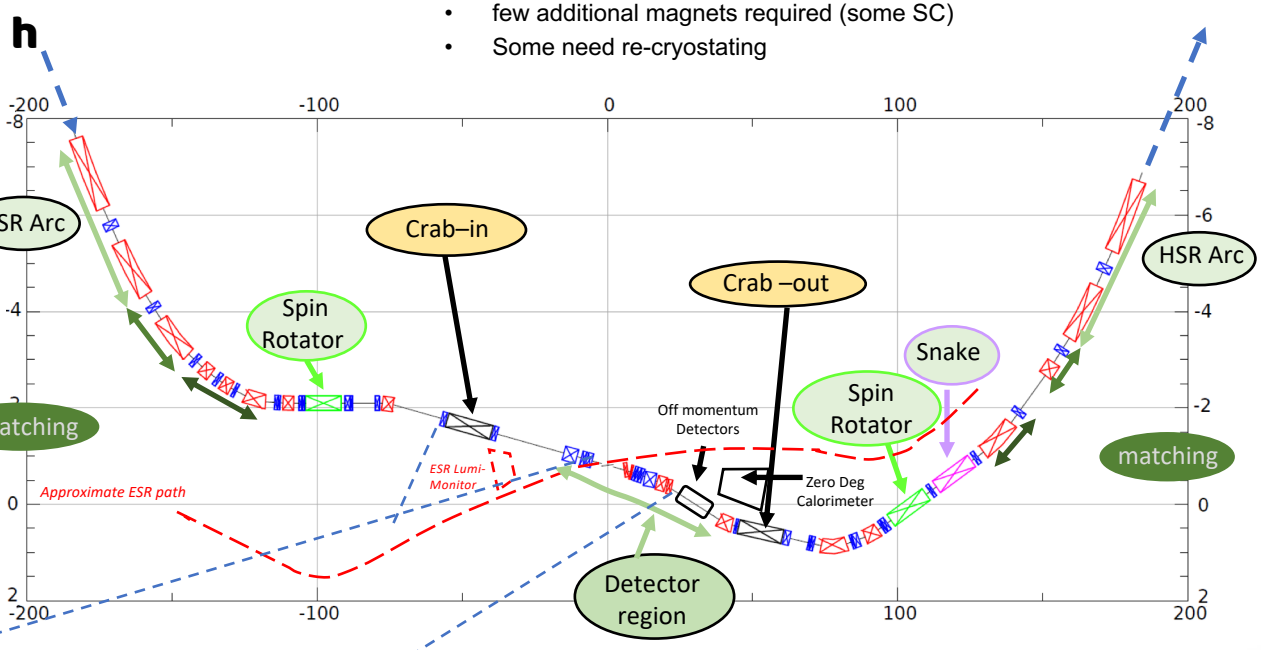
- Final assembly will be done inside the RHIC tunnel.
- Gaps between all magnets – space for coil leads (some nested in end plates), inner helium vessel welding.
- Bellows between all cold masses, at outer yoke/shells – no positional shifting due to welding.
- 2K

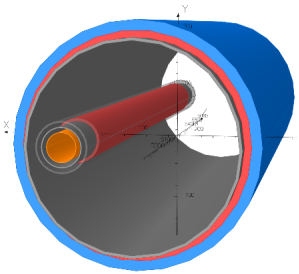
Checked for detector dimensions of -4.5 m to +5m ✓

HSR layout in 1st IR

- Forward and rear hadron lattice matched into RHIC
  - Snake at correct angle
  - 1300m at crab cavities
    - Hor. phase advance 90º
  - Matching Magnets
    - Mostly repurposed RHIC magnets
    - few additional magnets required (some SC)
    - Some need re-cryostating



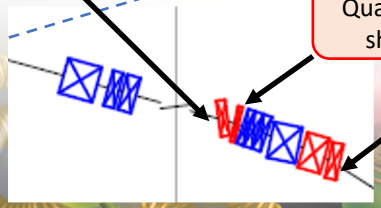




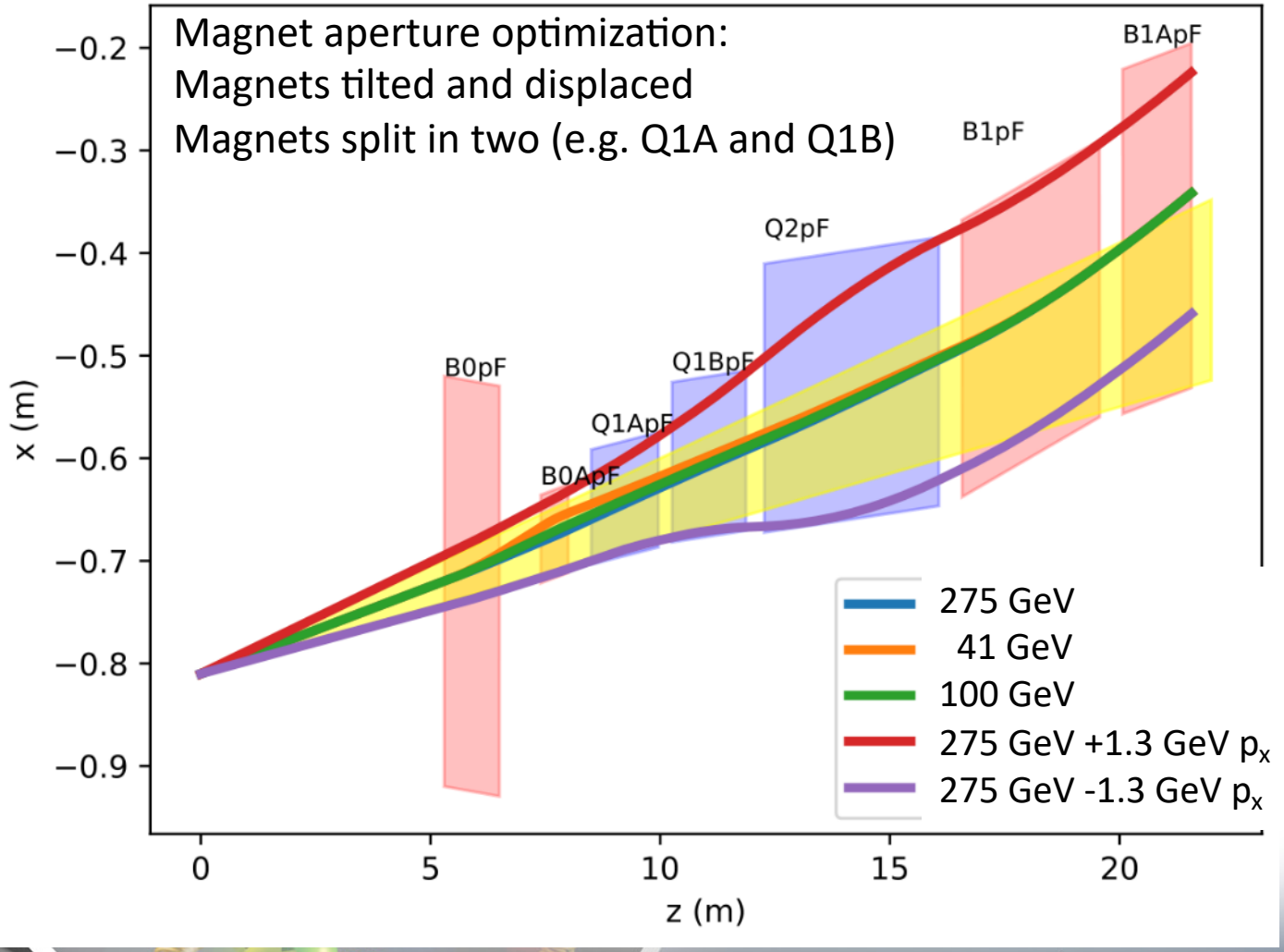
B0pF spectrometer

Nov 2021 layout

3 Dipoles and 3 Quadrupoles in one shared cryostat

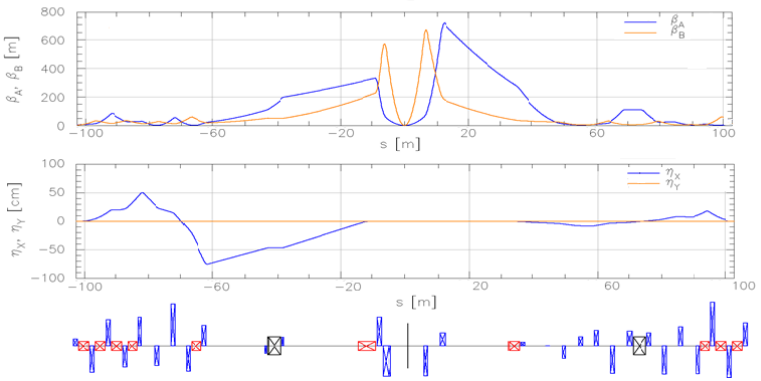


Hadron Forward - Apertures



- Under investigation: Tapered double helical magnets replacing Q1s and B1s

ESR layout in first IR

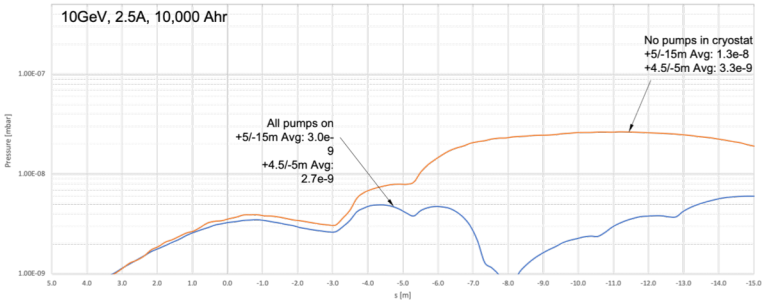


Design to:

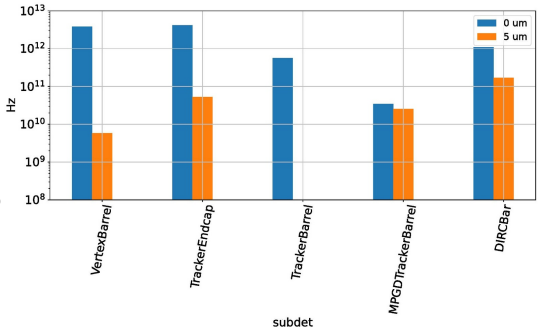
- Provide room for detector components
- Mitigate synchrotron radiation issues
- Provide longitudinal spin (new spin rotators)
- Match into the arcs
- Provide conditions for crabbing
- Allow 3 rings and beam elements

Machine-Detector-Interface

Detailed assessment of beam vacuum, pump layout in the forward and rear cryostats and synchrotron radiation



Studies on beam induced detector backgrounds

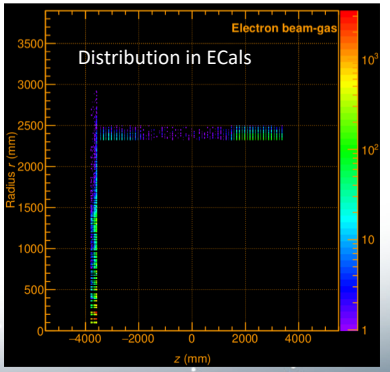


hadron beam:

- background during injection and ramp → collimators
- beam gas interactions p/A + $H^2_{restgas}$
  - detailed GEANT simulations including detector responses
  - current levels are tolerable

electron beam:

- background due to de-excitation of beam if bunches are replaced
  - collimated injected beam (6 σ) well inside aperture limits 13.5/23 σ
- beam gas interactions: e_{Beam} + $H^2_{restgas}$ → e' + γ + $H^2_{restgas}$
  - detailed GEANT simulations including detector responses
  - current levels are tolerable



- All background sources have been identified.
- Tools are developed to track the impact of design changes on the backgrounds in the detector.

Summary 1st IR (IR6)

- Mature design
- ESR and HSR lattices in the 1st IR designed
- Stable solutions
- Some details are still in flux
- Provides the conditions asked for in the requirements from detectors
- Magnet design for these solutions in progress
- Background contributions identified and effects studied

IR requirements & parameters

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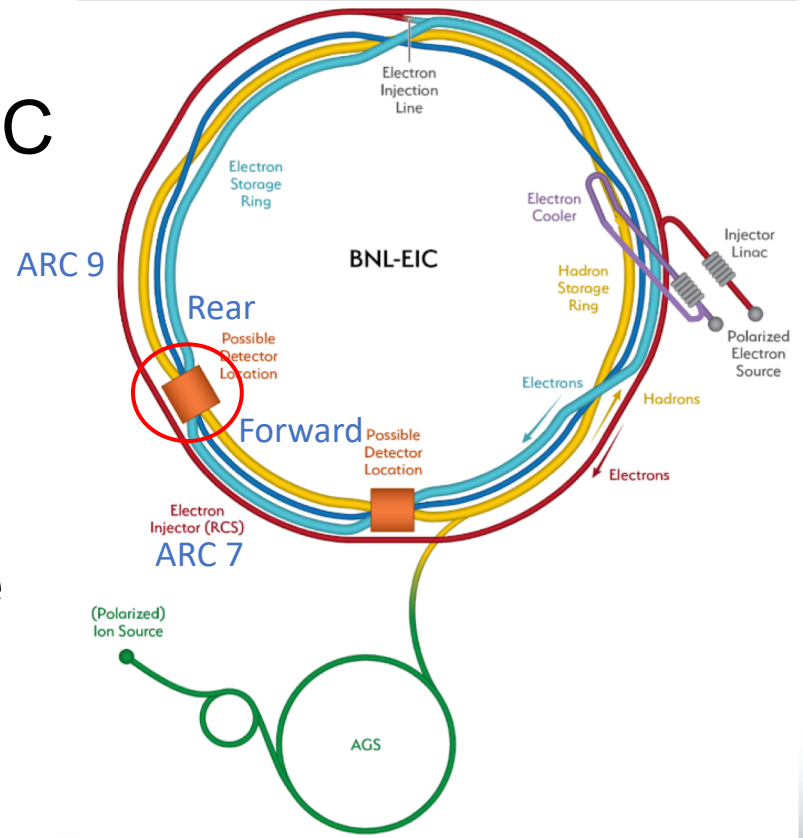
Scattered particle acceptance	p: 0.18 GeV/c < p_T < 1.3 GeV/c		p: 0 GeV/c < p_T < 1.3 GeV/c	
Q^2 tagger		Q^2< 0.1 GeV		
Crossing angle	25 mrad		35 mrad	

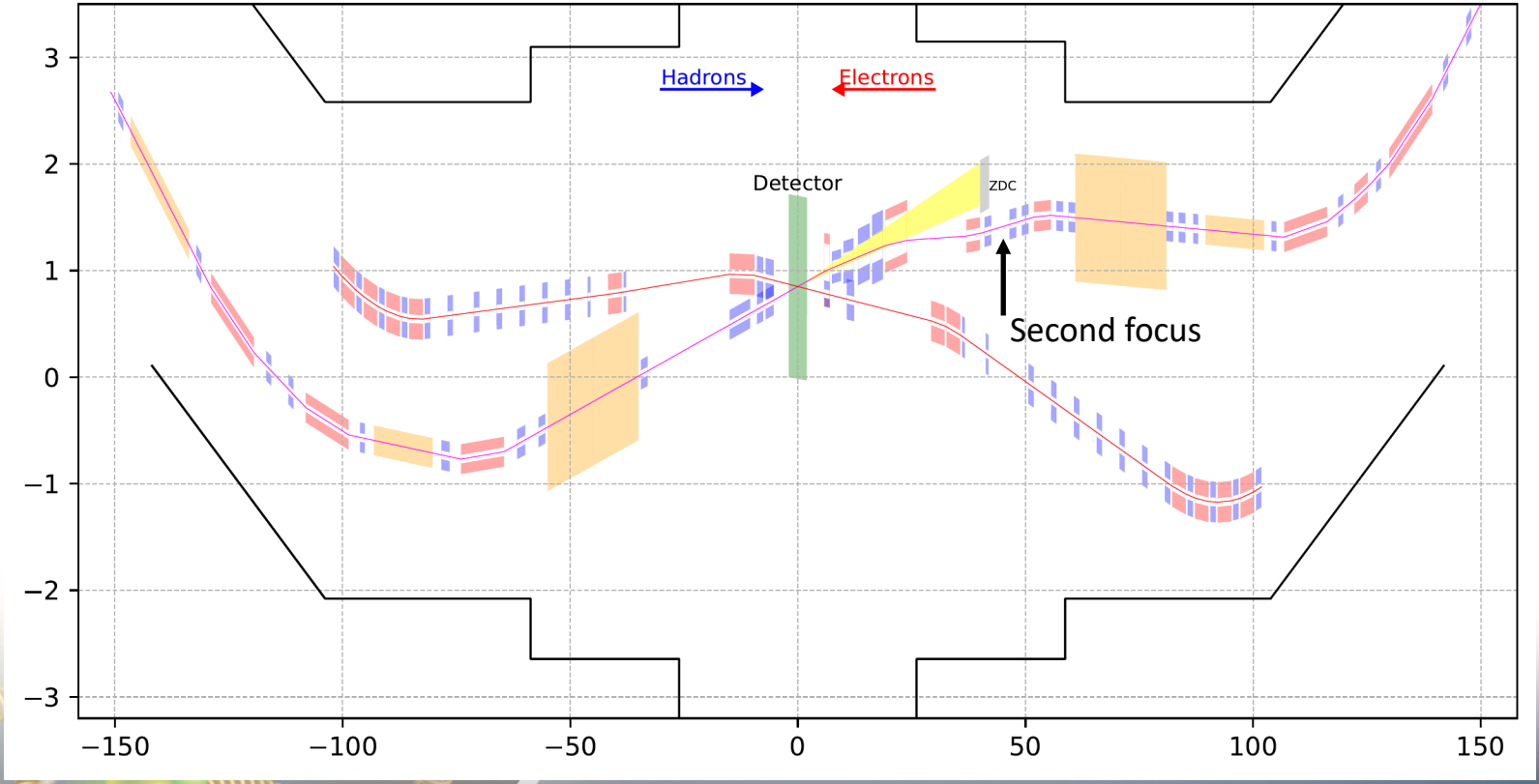
Requirements/Constraints

- Fit into the existing RHIC IR8 experimental hall between ARC 7 and 9.
- Preference for a secondary focus.
- Same accelerator equipment as in IR6 (spin rotators, snake and crab cavities).
- Not in project scope.



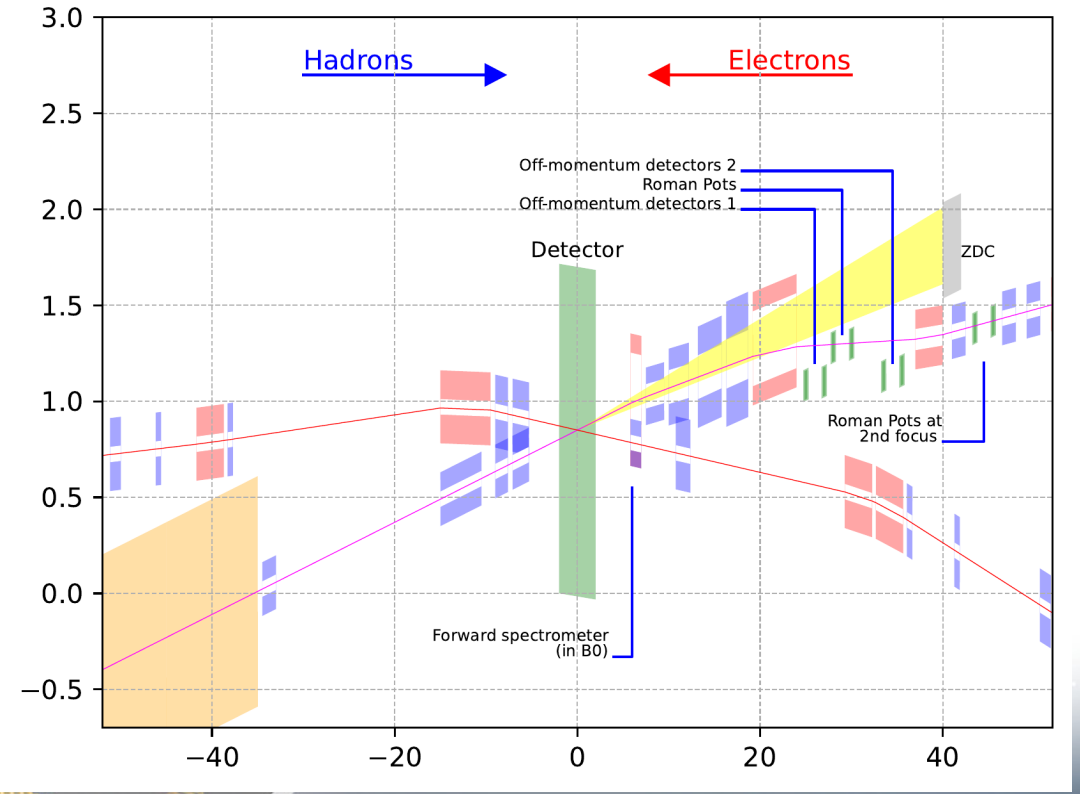
IR8 full layout

- 35 mrad crossing angle (driven by accelerator geometry).
- Second focus point at ~47m.
- Space for similar accelerator equipment as IR6.



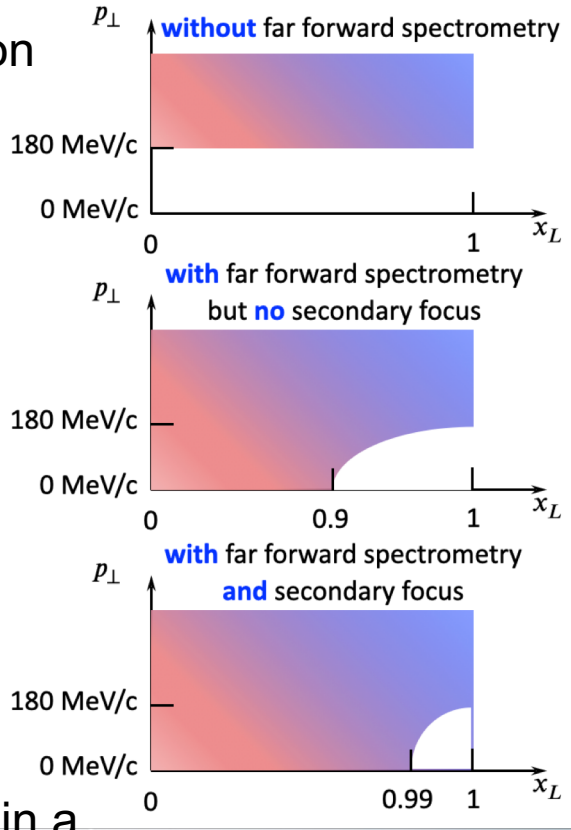
IR8 hall layout

- Space available for luminosity monitor, low Q2 tagger and local hadron polarimeter
- All ancillary detectors in outgoing hadron beam side (Forward) integrated



Acceptance as a function of x_L and p_T

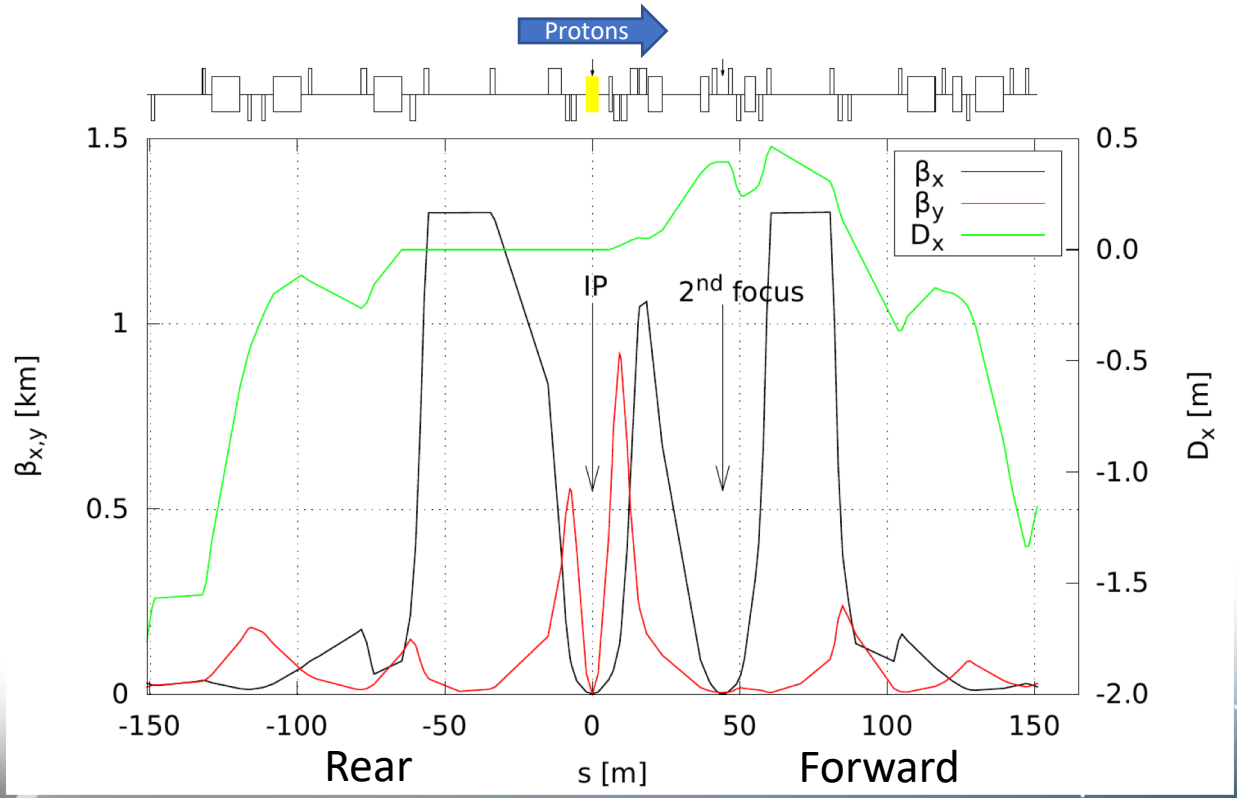
- x_L - fraction of the longitudinal momentum relative to hadron beam
- p_T - fraction of the transverse momentum relative to hadron beam (θ)
- p_T acceptance at $x_L = 0$
  - $p_T^{min} > 10 p_0 \theta_{IP} = 10 p_0 \sqrt{\frac{\epsilon}{\beta^*}}$
- x_L acceptance at $p_T = 0$
  - $x_L < 1 - 10\frac{\sigma_x}{D} = 1 - 10\frac{\sqrt{\beta_x^{2nd}\epsilon_x + D_x^2\sigma_\delta^2}}{D}$
- 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

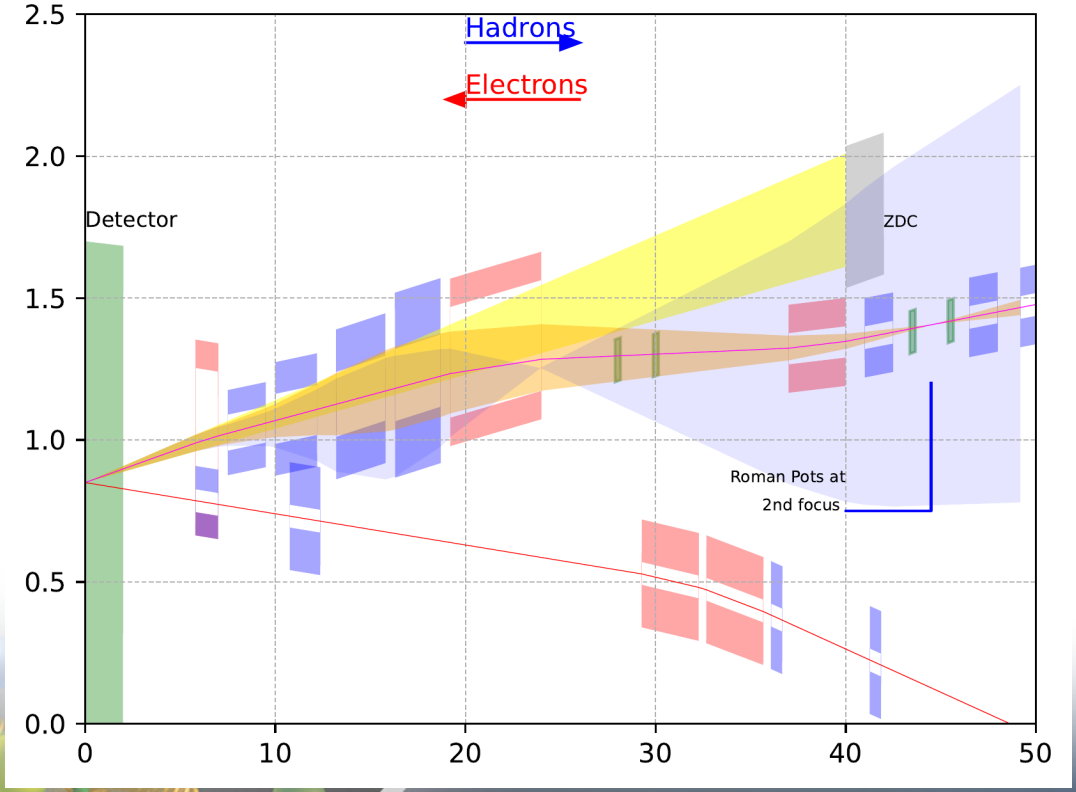
- Rear :
  - Non RHIC magnets → 3 final focusing and one wide aperture quad in the crabbing region.
  - Space reserved for the same accelerator equipment as in IR6

- Forward :
  - Limited matching space requires few high gradient magnets (quadrupoles) than what is available from existing RHIC magnets.



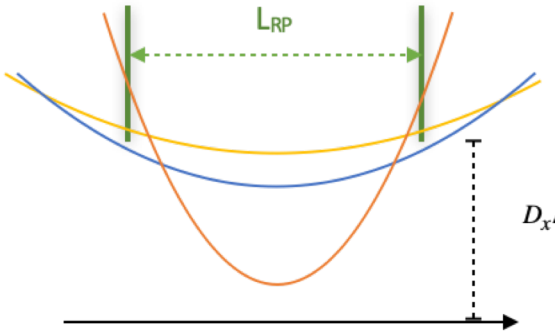
IR8 forward acceptance

- 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
$\Delta p/p = -0.5$
$p_T = 0.69\text{GeV}, x_L = 0.5$

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

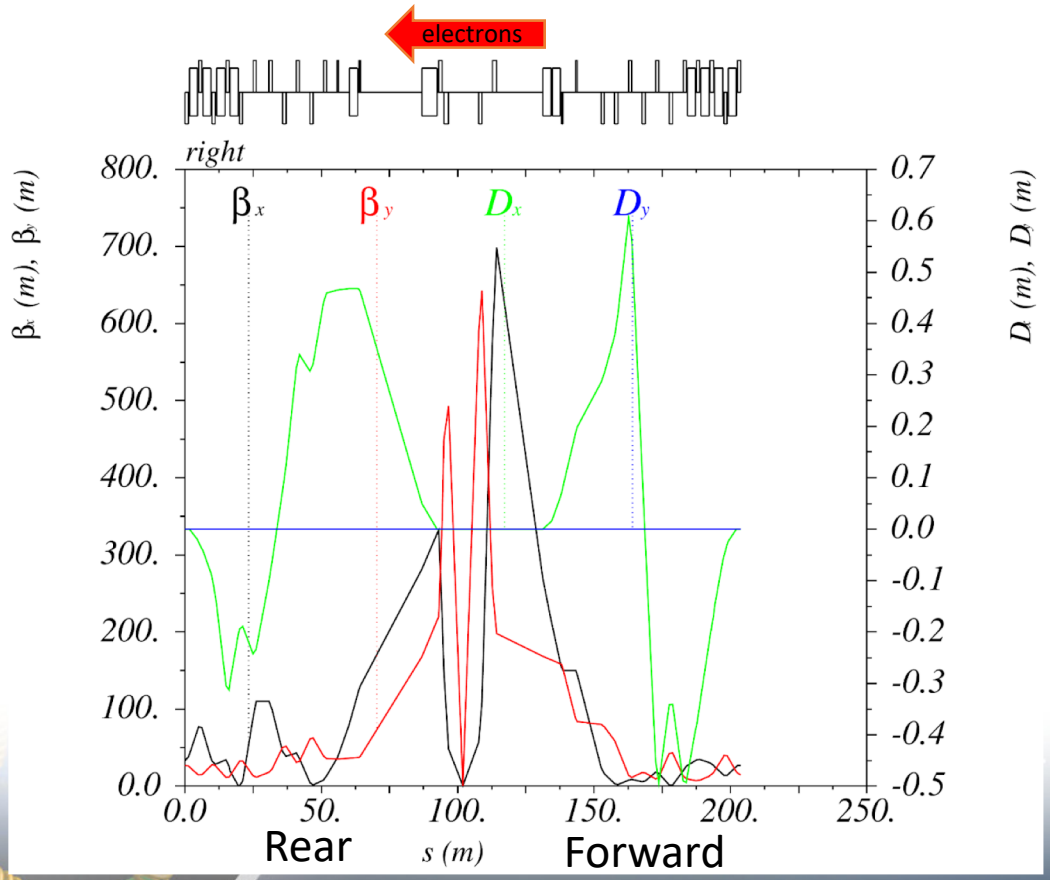
Parameter	Value	Units
β_x	0.62	m
D_x	0.38	m
ϵ_x	11.3	nm
σ_δ	$6.8e^{-4}$	-

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

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

IR8 electron optics

- Optics and design similar to IR6



Summary 2nd IR (IR8)

- This is a Pre-conceptual design.
- The IR8 with the second focus adds complementarity to IR6.
- Work to be done includes,
  - Crab cavity space requirement for the high crossing angle.
  - Clearance check for the RCS (Rapid Cycling Synchrotron) bypass.
  - Further study needed for the feasibility of the IR magnets.

Thank you for your attention!

Additional slides

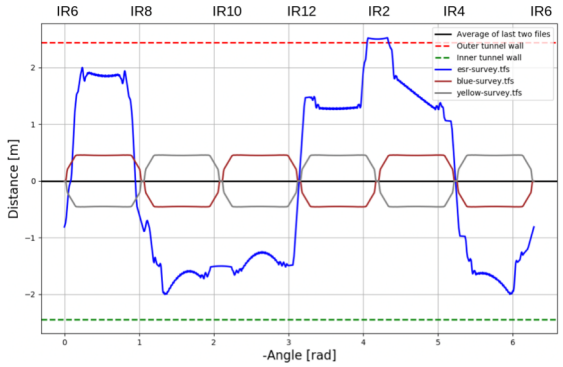
ESR Tilt

Elegant solution to some space issues in tunnel

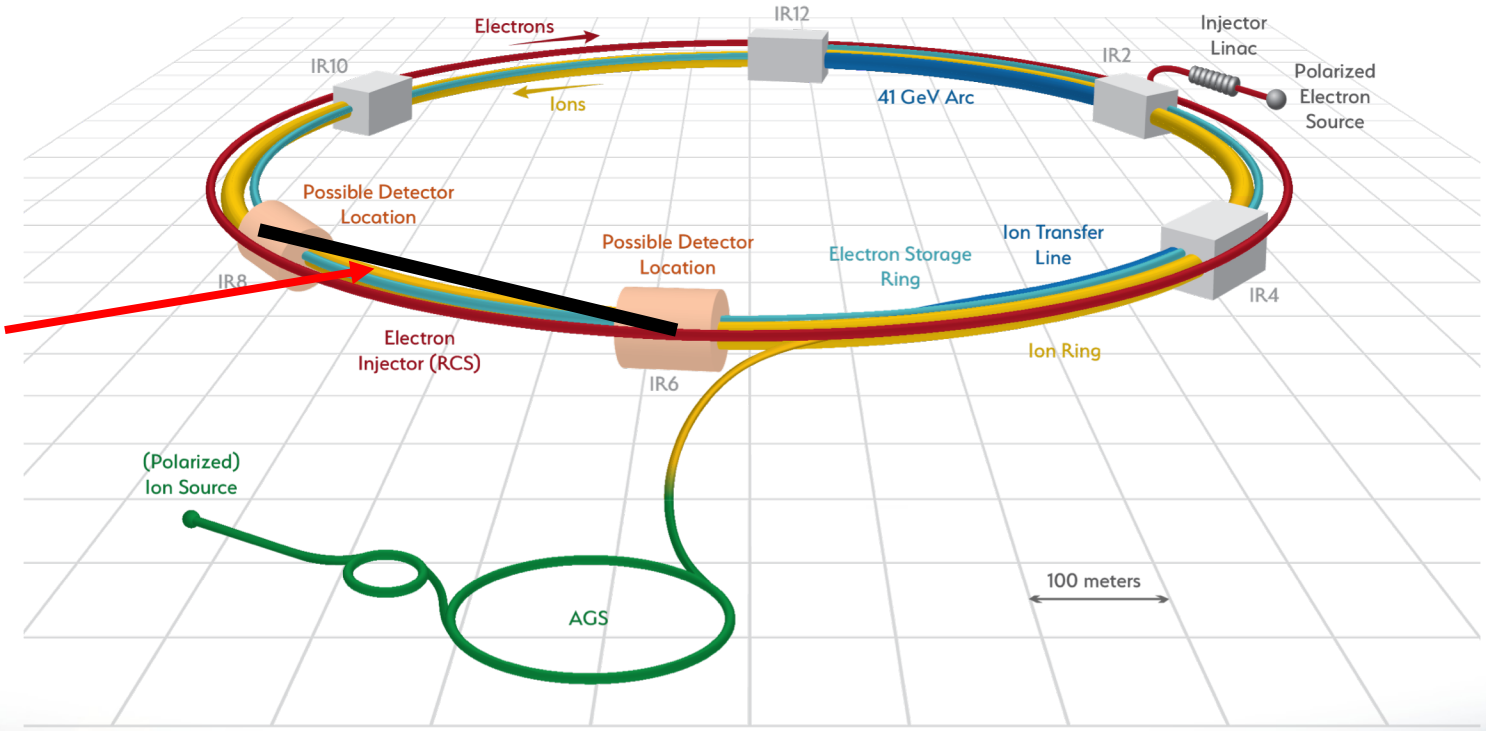
Tilt ESR: 200urad

Rotation axis: Line from IP6 to IP8

Accepted as baseline



Rotation axis



ESR and HSR cross in several places in tunnel (IP6, IP8, IR4 and IR12)

Eliminates vertical bumps in ESR, which is challenging due to spin transparency

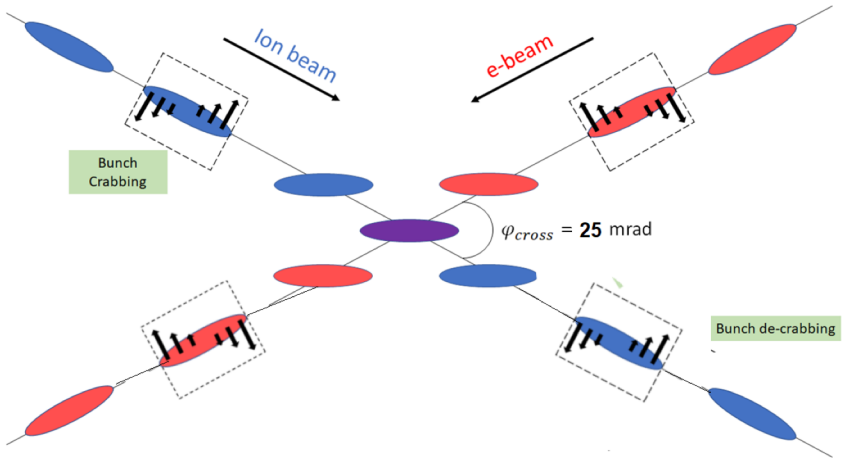
EIC Collisions with a Crossing Angle

Modest crossing angle of 25 mrad

- avoid parasitic collisions due to short bunch spacing,
- for machine elements, to improve detection
- reduce detector background,

However, crossing angle causes
- Low luminosity
- Beam dynamics issues

avoided by Crab Cavities



As a consequence:
Effective head-on collision restored
beam dynamic issues resolved

EIC IR total:
8x197 MHz cavities (HSR)
6x394 MHz cavities (2 ESR, 4 HSR)

Several transverse RF resonator (crab-cavity) prototypes built
- tested with proton beam in the CERN-SPS