2^{nd} IR Features and Constraints from Accelerator Side

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for the 2^{nd} IR Accel. Design Team

Electron-Ion Collider User Group Meeting – 2022

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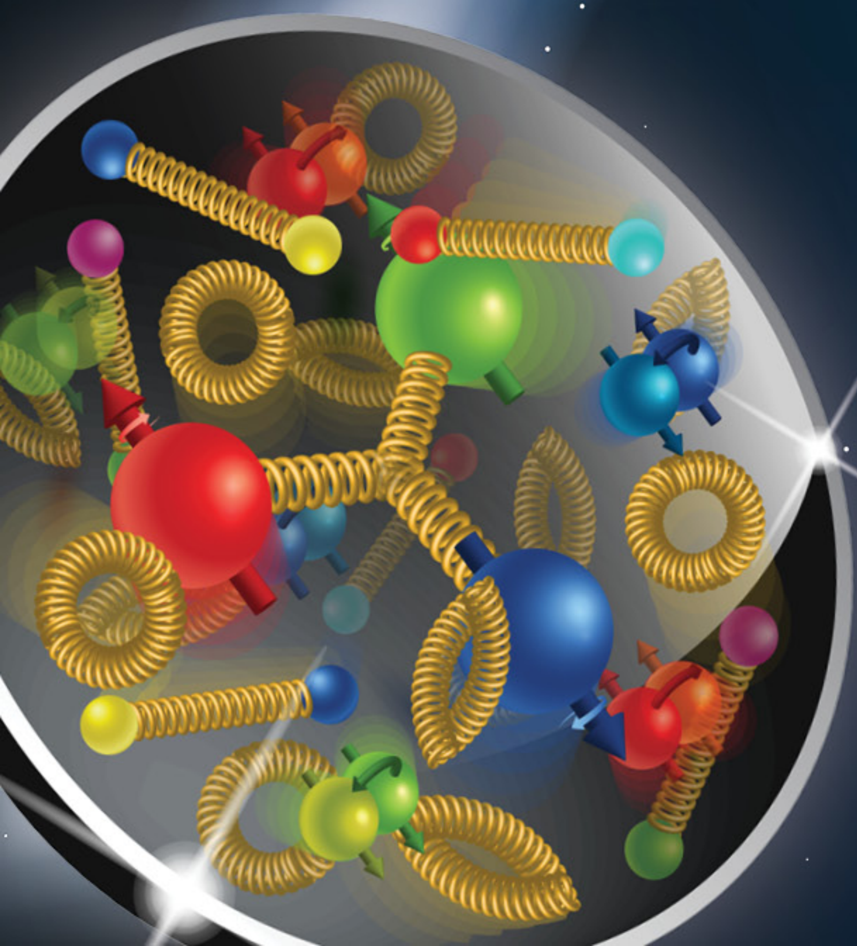


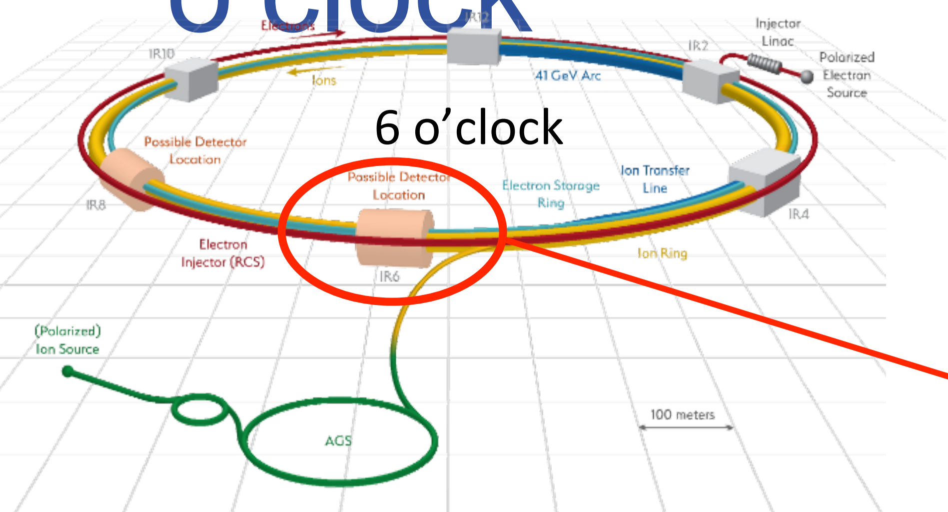
Electron-Ion Collider

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

Content

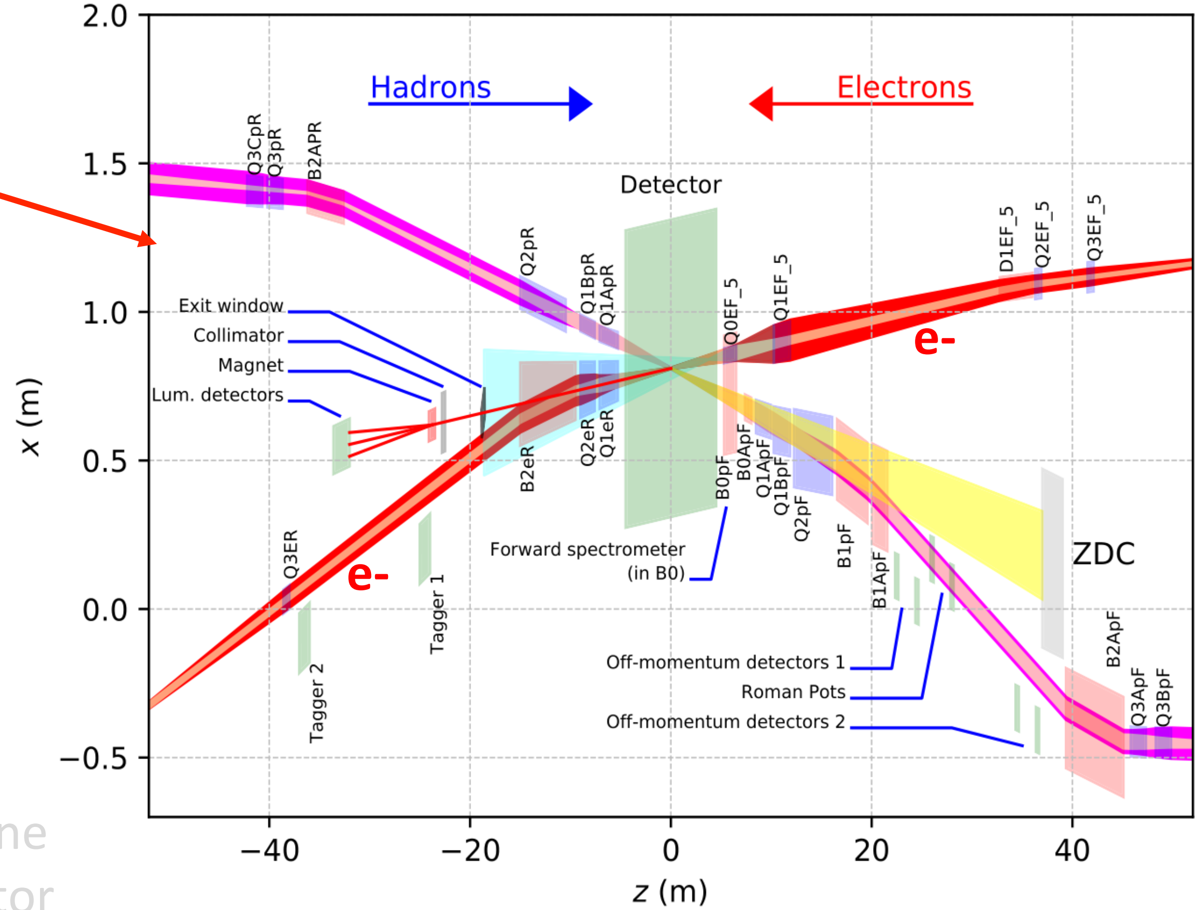
- Overview
- IR Features
- IR Constraints
- Status
- Summary

EIC IRs: Overview IR @ 6 o'clock



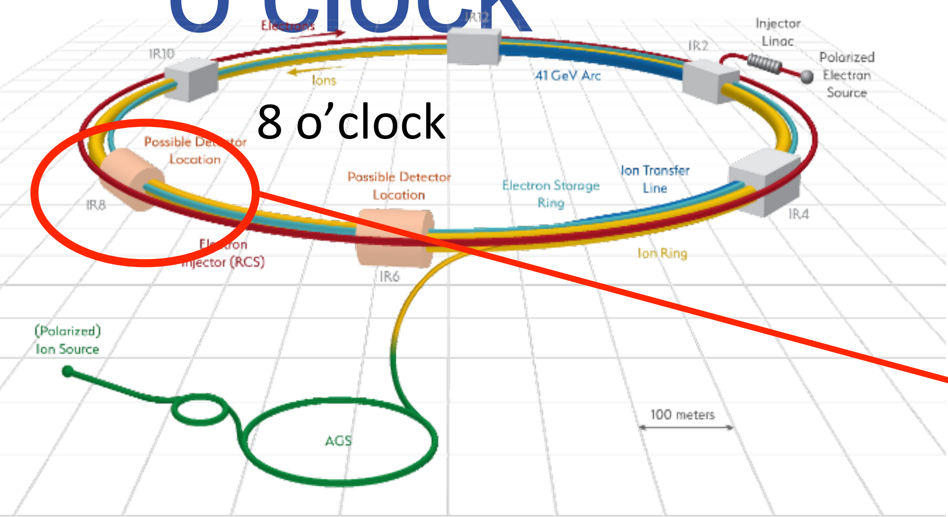
Rear Sector 6

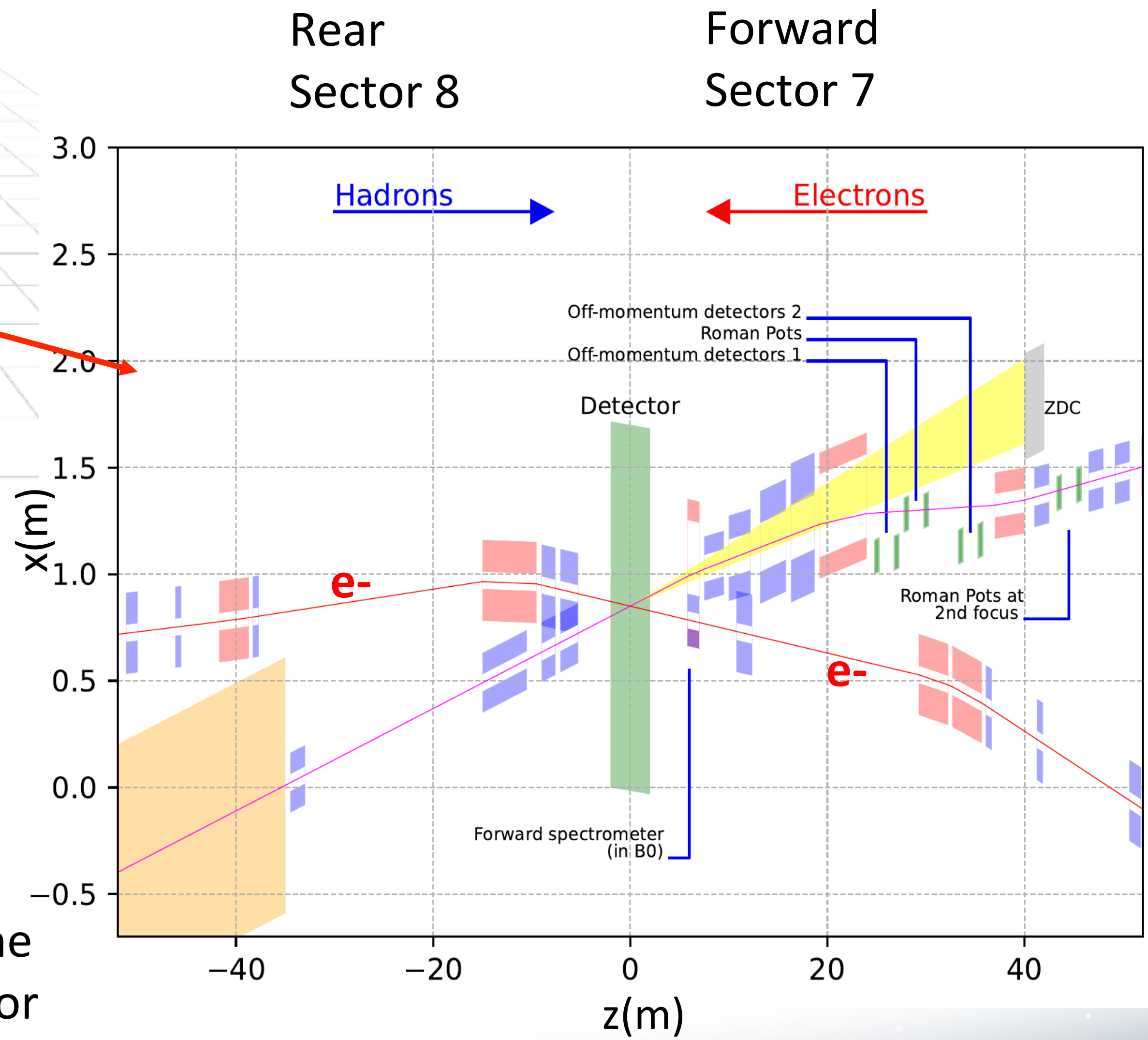
Forward Sector 5



- 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

EIC IRs: Overview IR @ 8 o'clock





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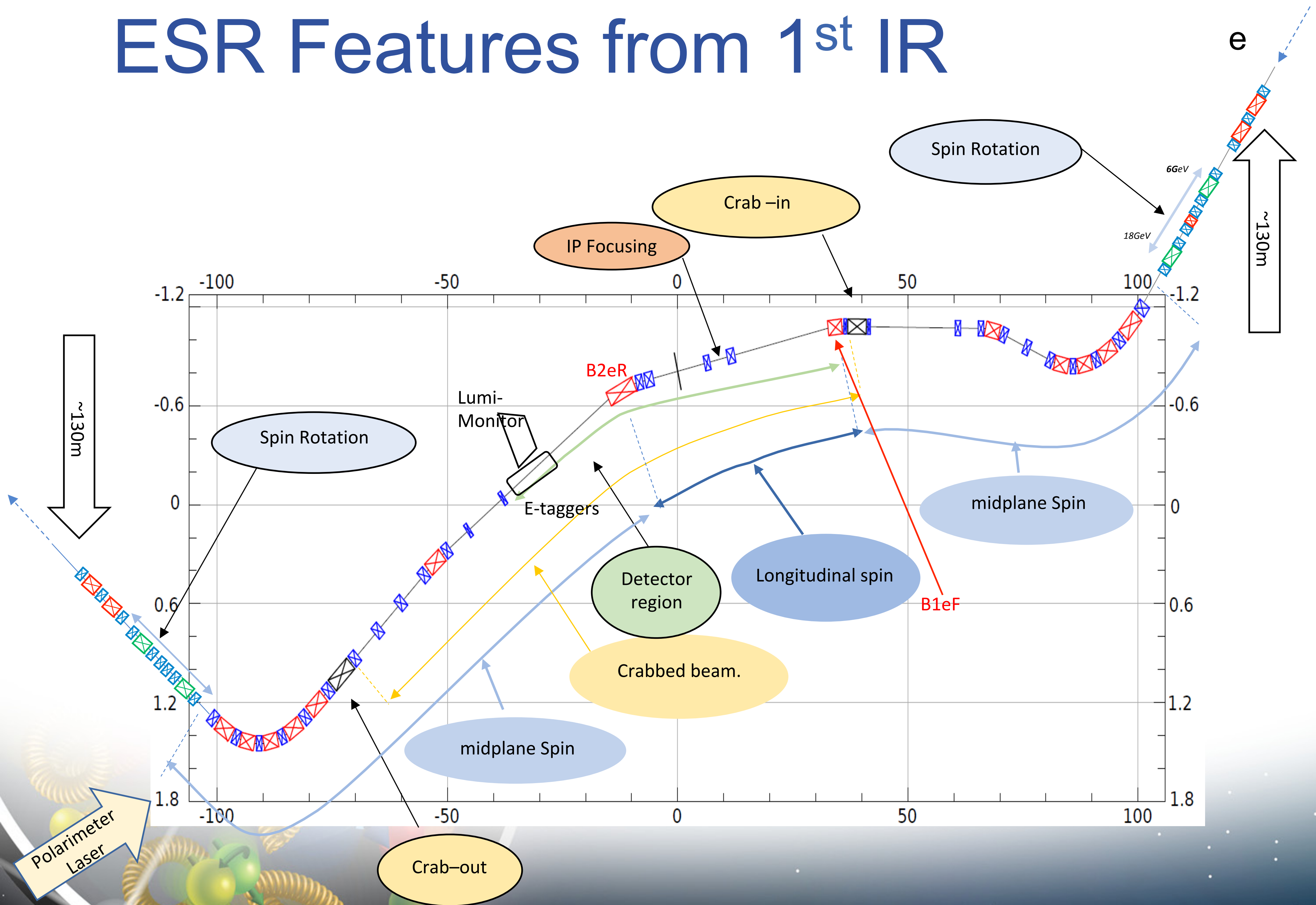
IR Features

	1st IR		2nd IR	
	proton	electron	proton	electron
Final focus for IP	yes			
2nd focus	**no**	no	**yes**	no
Crabbing	yes			
Spin rotator	yes			
Snake	yes	no	yes	no
Collider ring tilted	no	yes	no	yes
Crossing angle	yes		yes	

ESR Features from 1st IR



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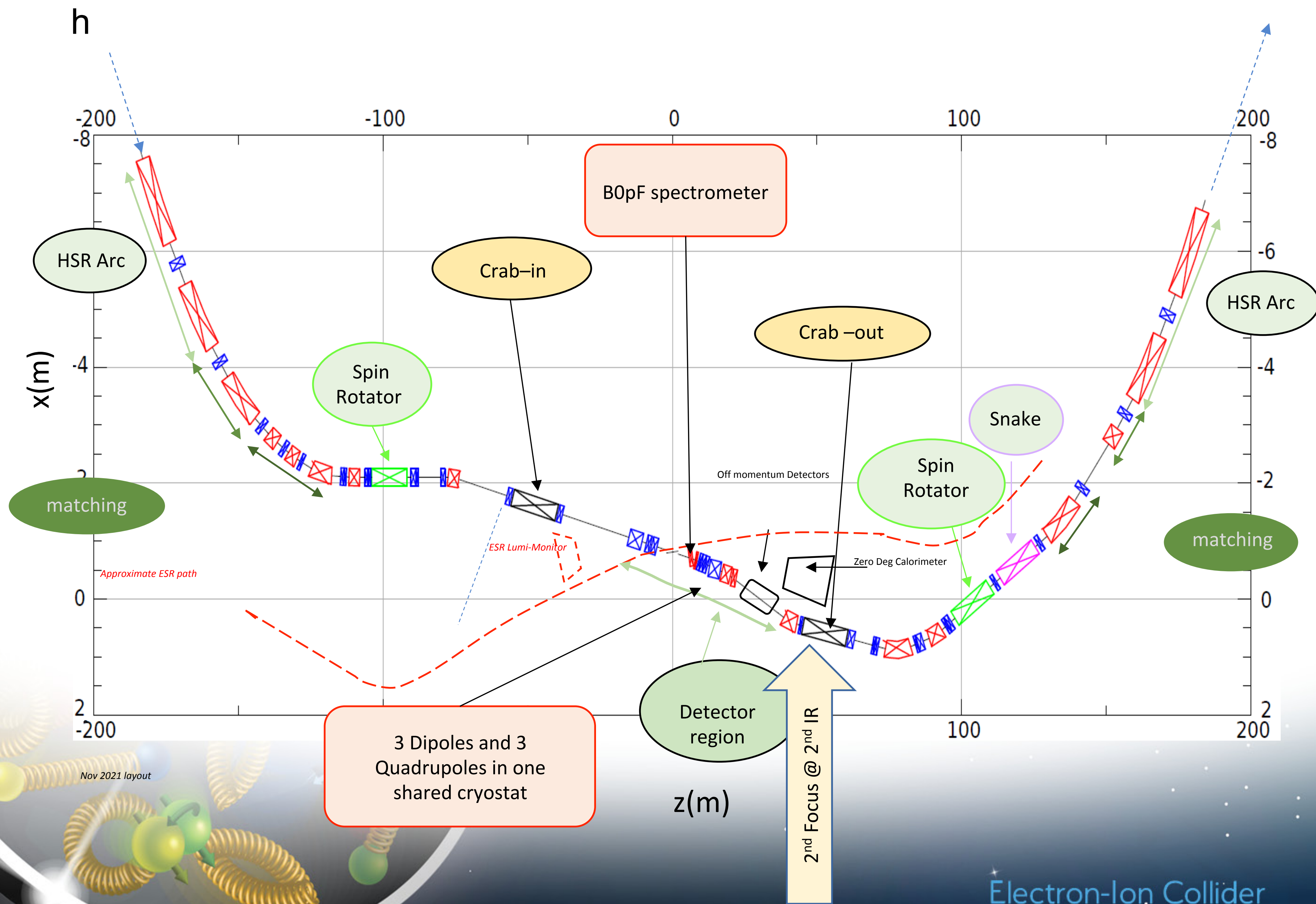
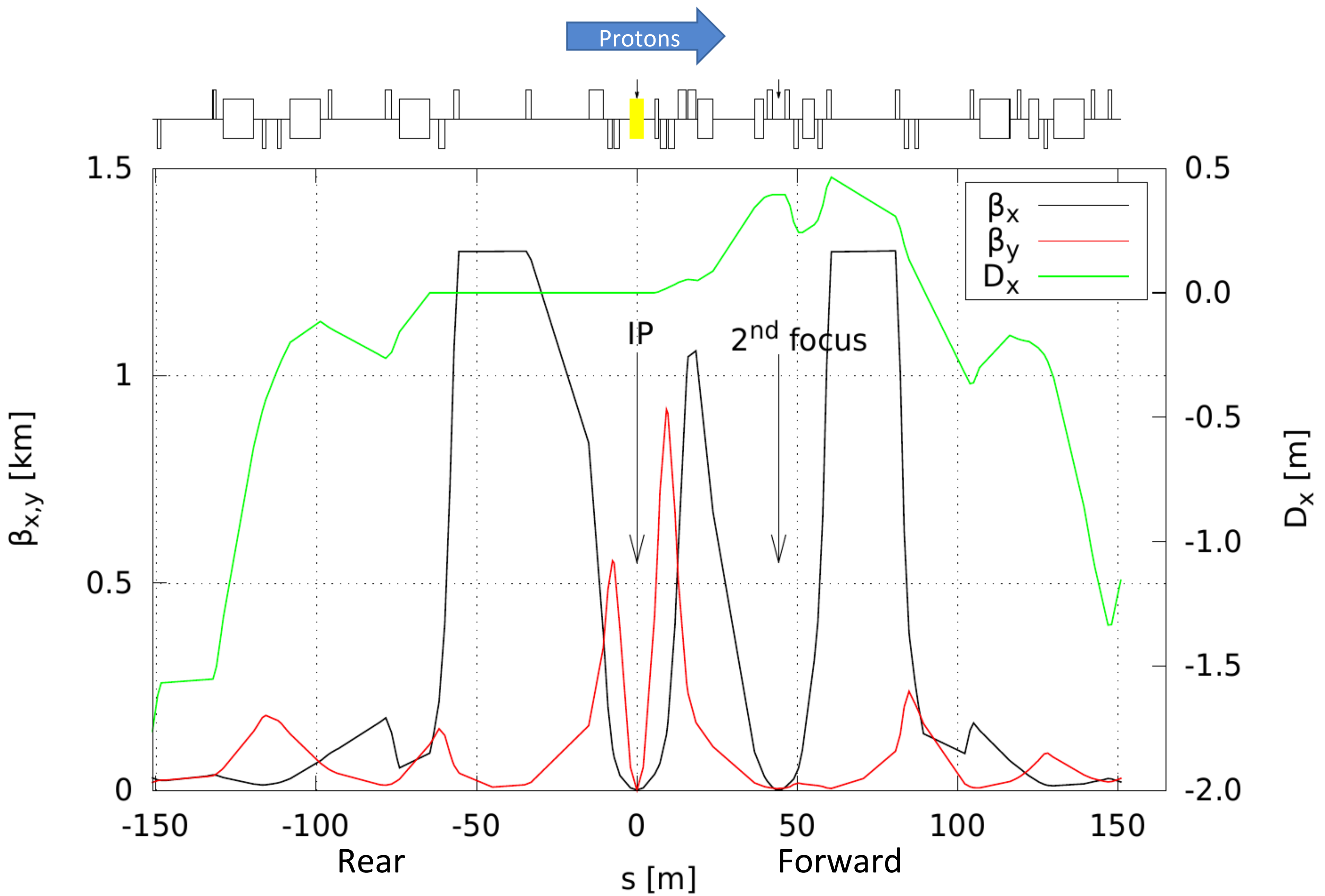
HSR Features from 1st IR

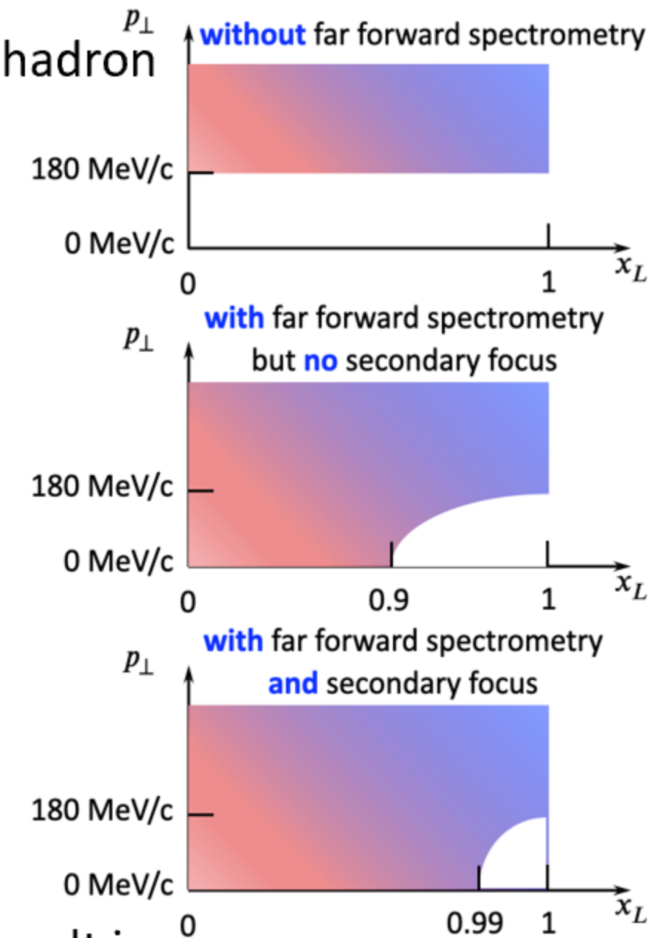


IR8 Hadron Optics with 2^{nd} Focus

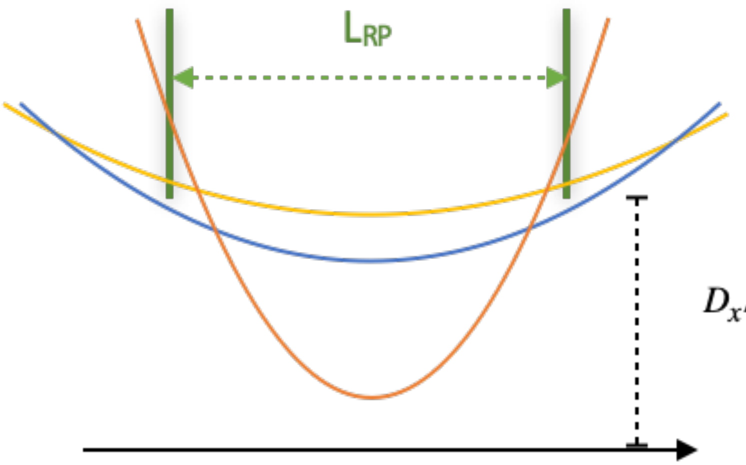


Acceptance as a Function of x_L and p_T

- 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 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	$6.8e^{-4}$	-

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

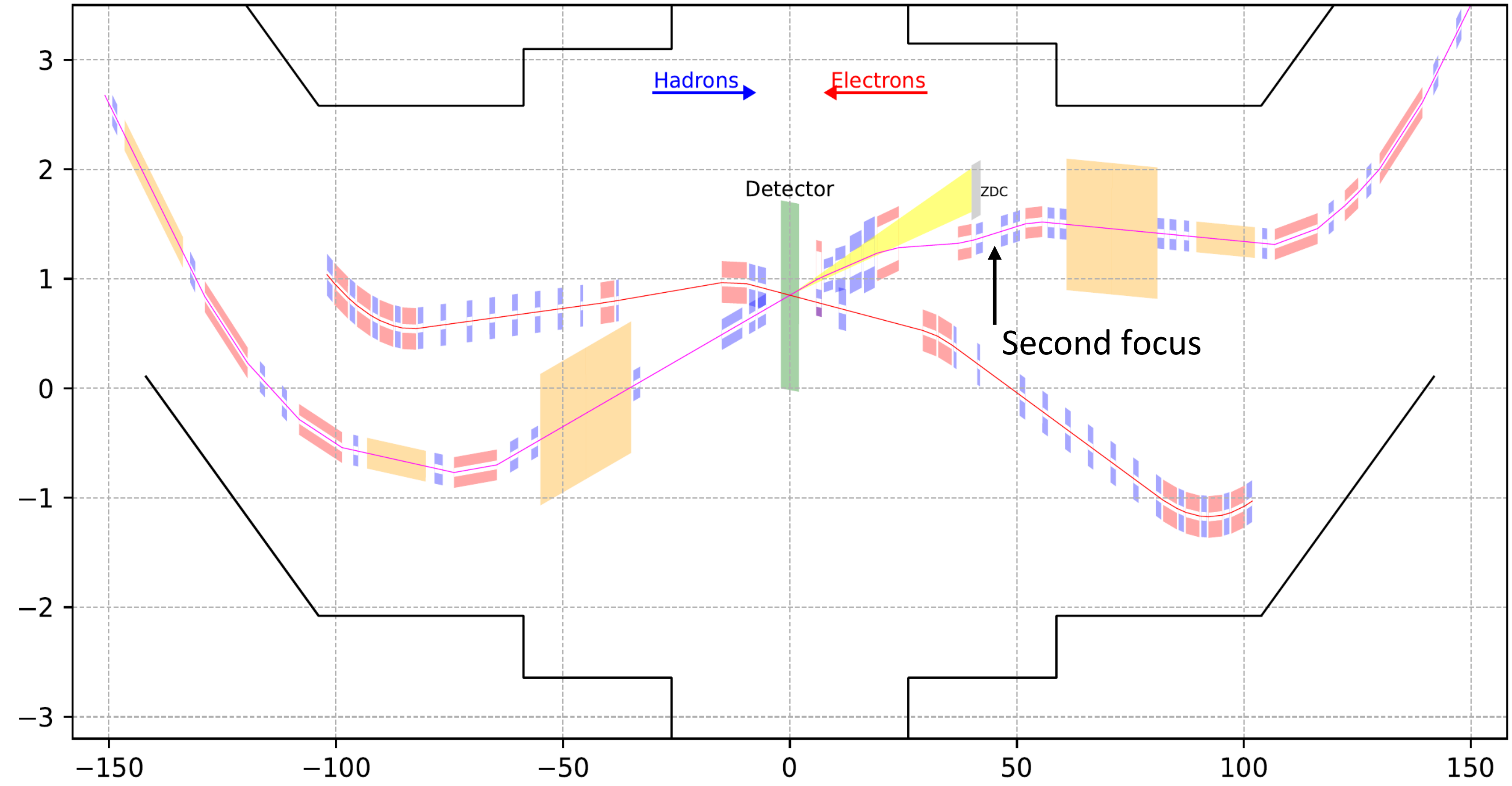
- Optimal $\beta_x^{2nd} = \frac{L_{RP}}{2}$
- For the current design, $x_L < 0.9928$
- Fundamental limit of x_L for the given momentum spread is 0.9932

IR Constraints

- Existing tunnel space (longitudinal & transverse)
- Existing hadron arcs adjacent to IR
- Space and location for experimental systems (central detector, B0 spectrometer, ZDC, Roman Pots, Q^2 tagger)
- Location & orientation of systems (crab cavities, spin rotators)
- Separation of beam lines after IP
- Tradeoff between apertures & fields for hadron forward FF magnets and magnet cross talk
- Reuse of existing magnets
- Beam dynamics
- Distance between IPs

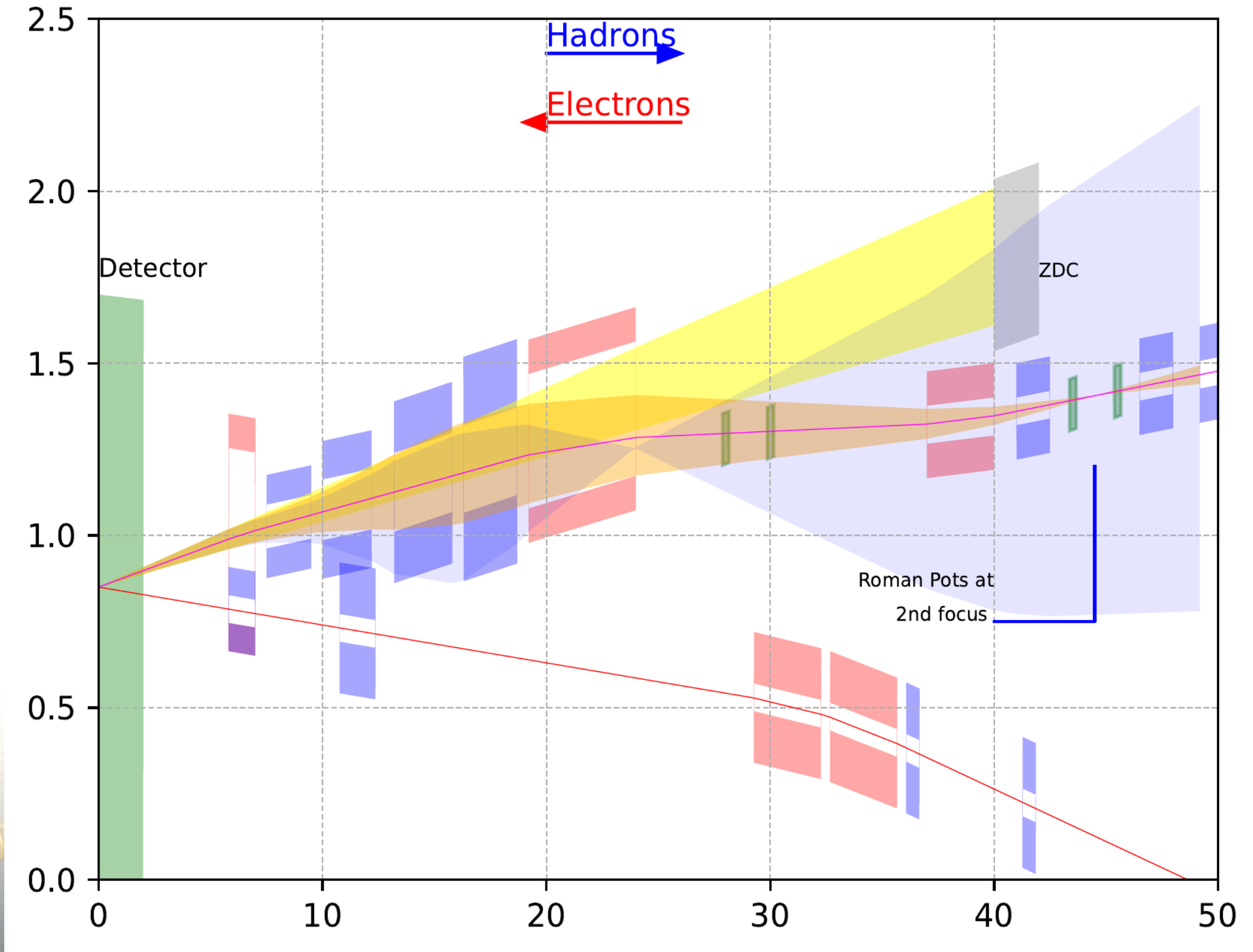
IR8 full layout

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



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

IR Requirements & Parameters

	1^{st} IR		2^{nd} 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
2^{nd} focus	**No**	No	**yes**	No
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	

Status 2nd IR @ RHIC 8 o'clock

- Completed
  - Longitudinal shift clockwise to enable two detector operation with dedicated collision
  - Dynamic aperture with two IR's simulated and workable design established
  - Increased longitudinal space for crab cavities
- Work to be done includes,
  - Transverse clearance for crab cavities needs work
  - Clearance check for the RCS (Rapid Cycling Synchrotron) bypass.
  - Further study needed for the feasibility of challenging IR magnets

Summary

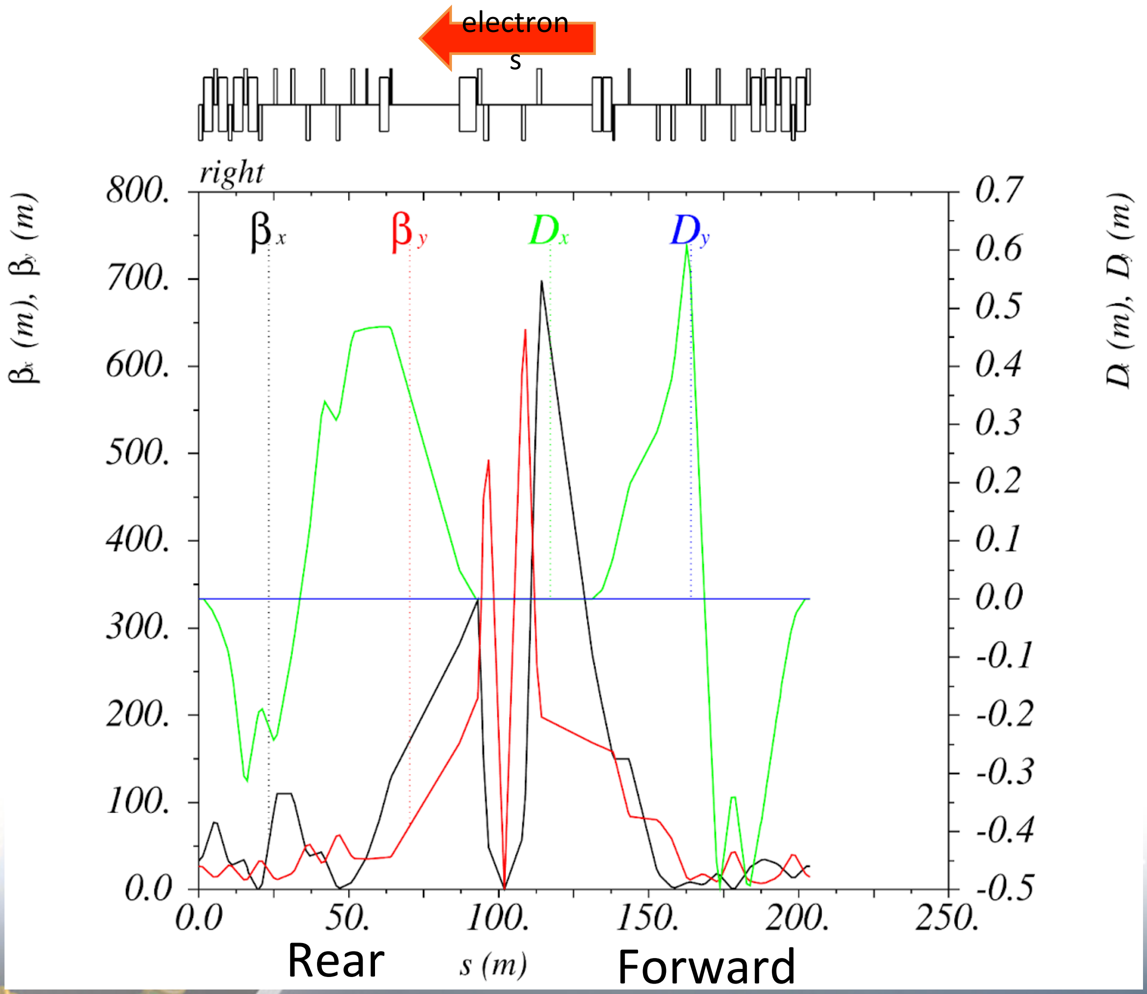
- 2nd IR design less advanced because it is NOT included in project BUT good progress addressing key feasibility questions providing required functionality
- Second focus implemented supporting complementarity to IR6
- Luminosity will be shared between IRs by colliding dedicated bunches in each IP

Thank you!

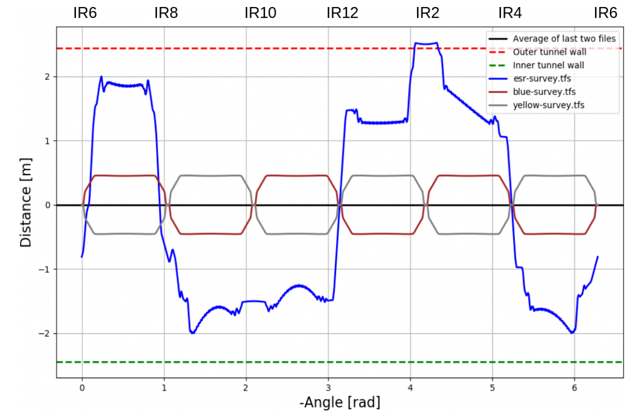
Additional slides

IR8 electron optics

- Optics and design similar to IR6



ESR Tilt



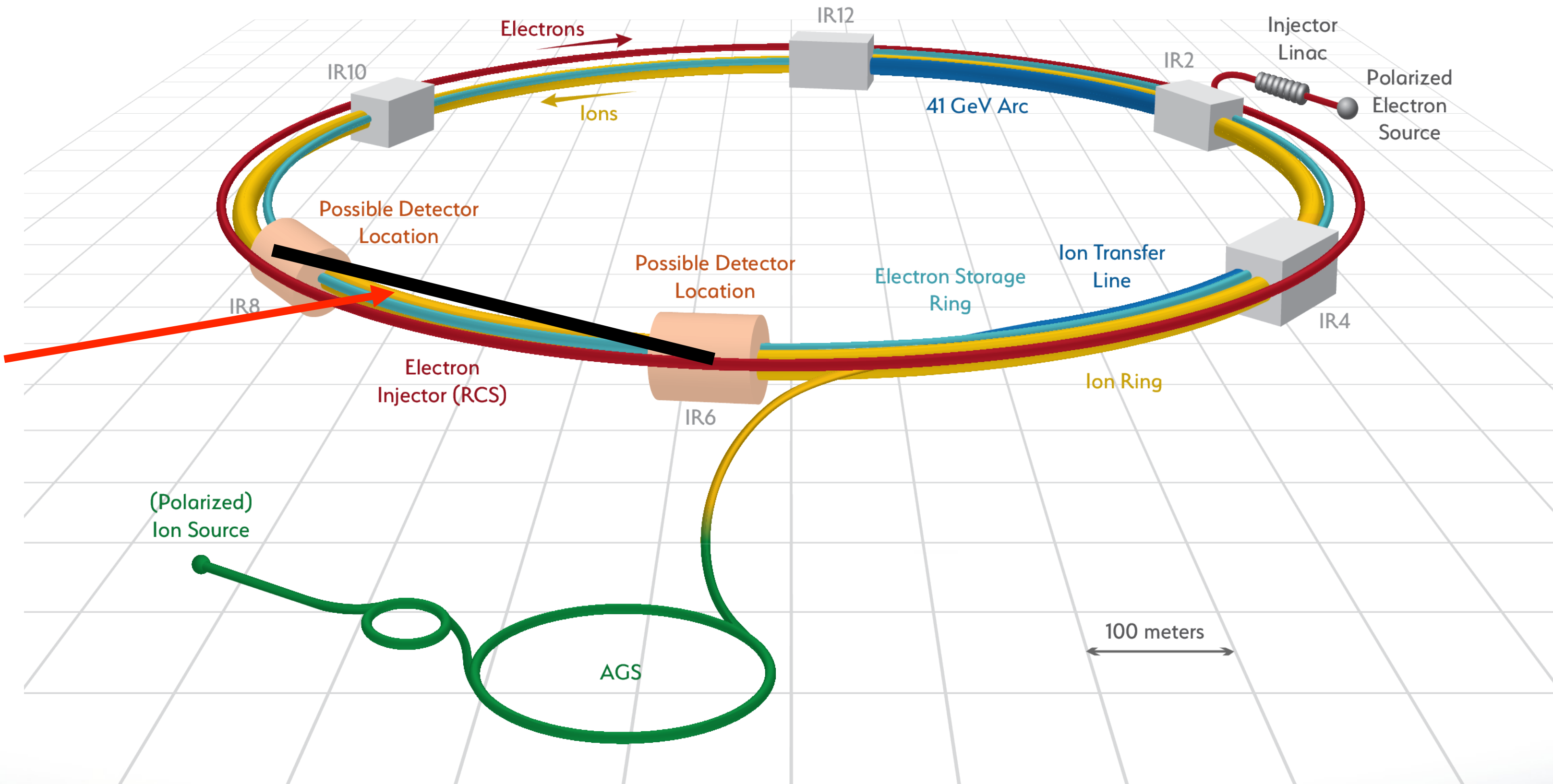
Elegant solution to some space issues in tunnel

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

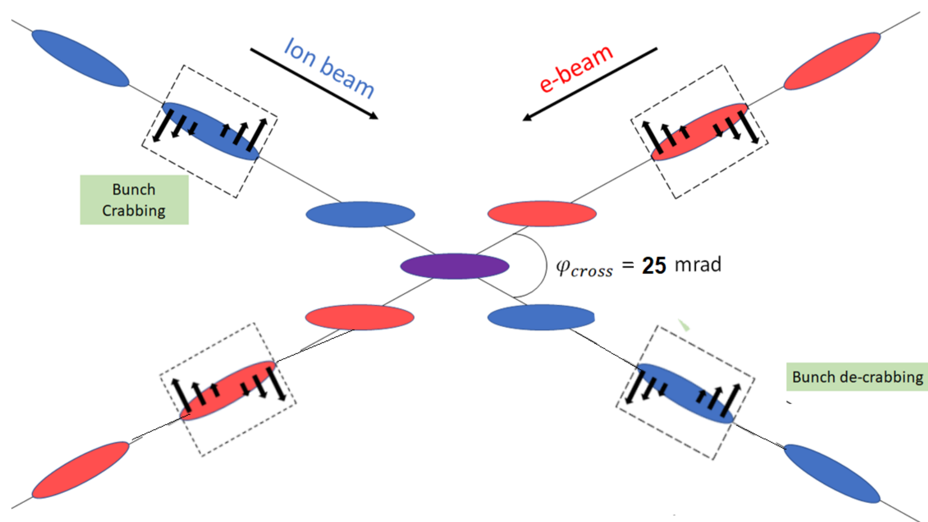
EIC Collisions with a Crossing Angle

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