Polarized Electrons in JLEIC

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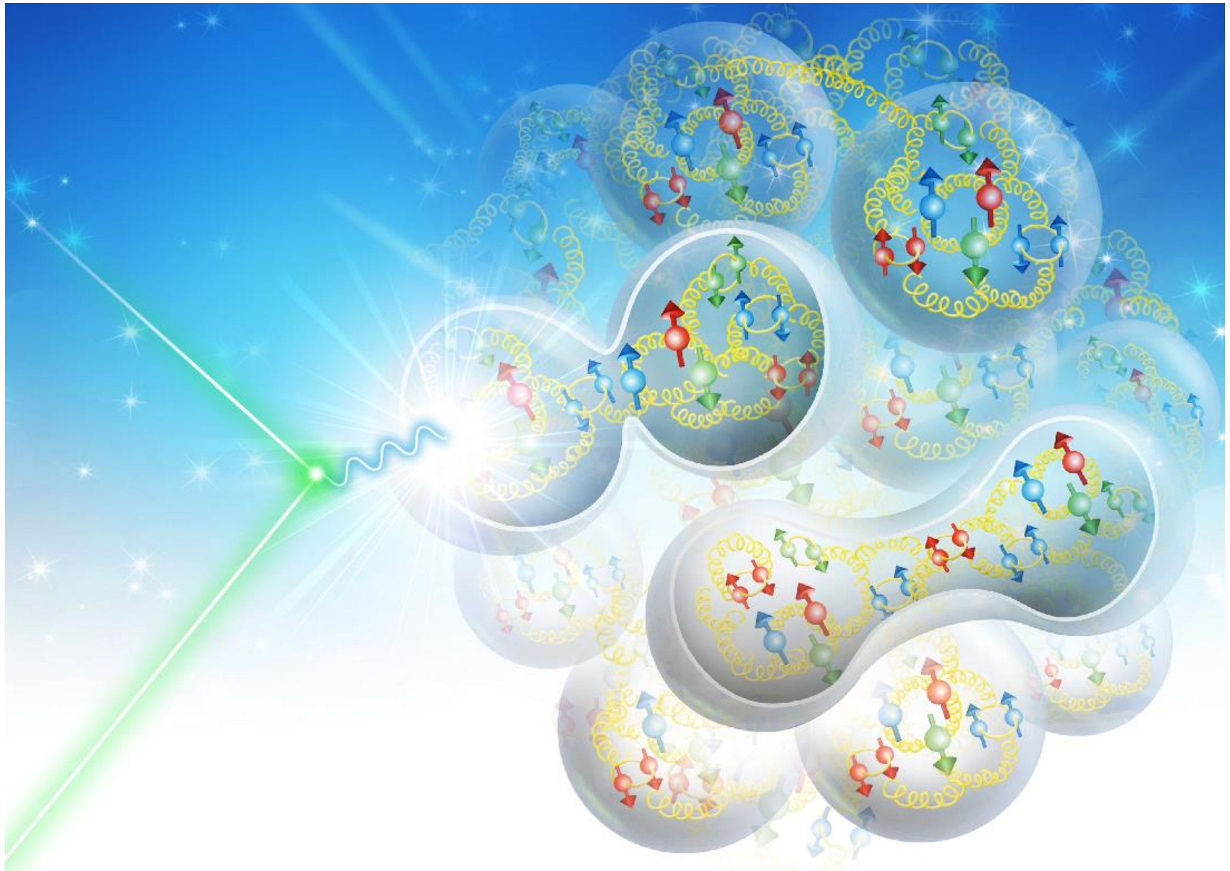
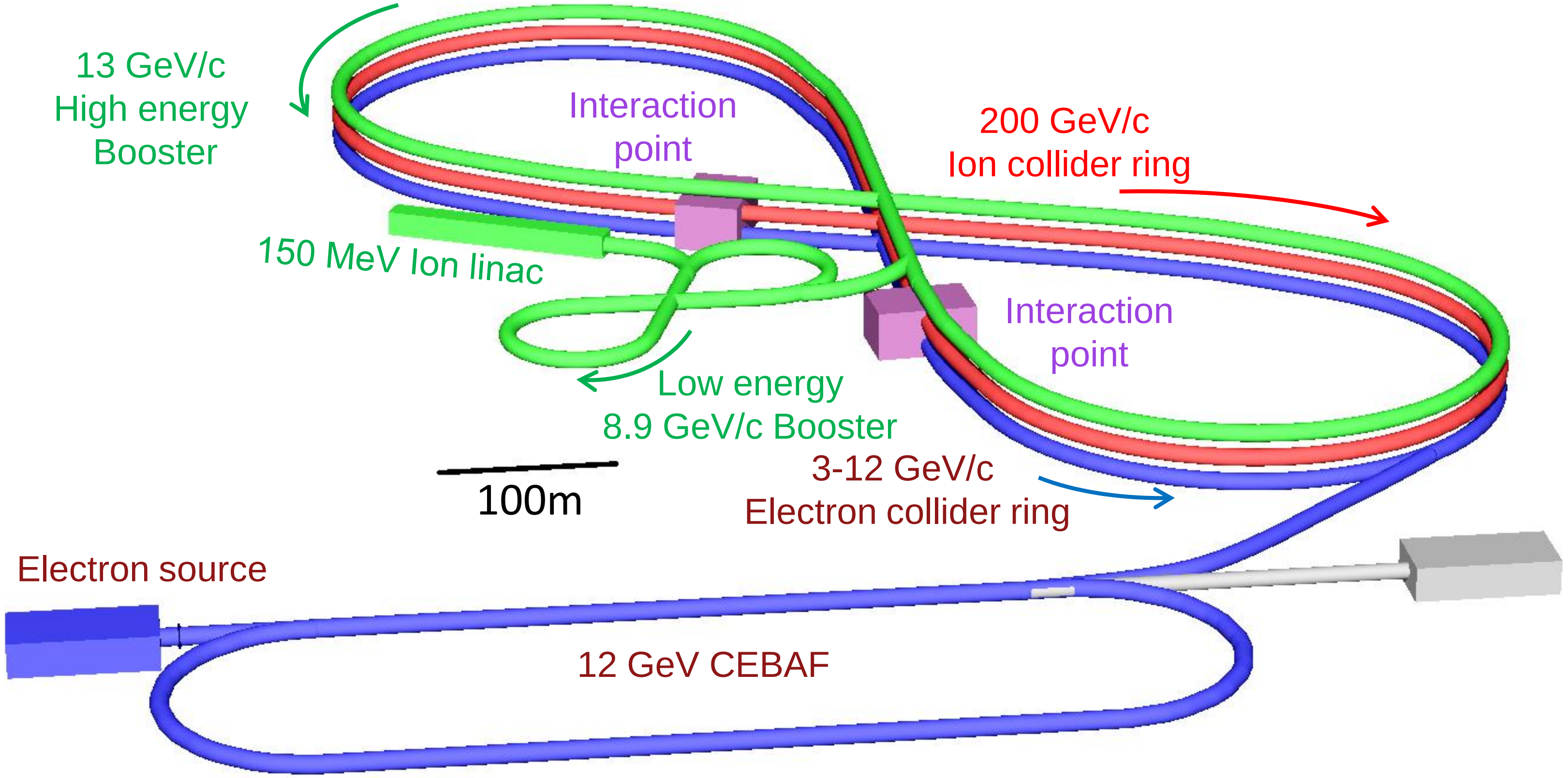
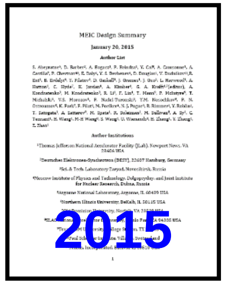


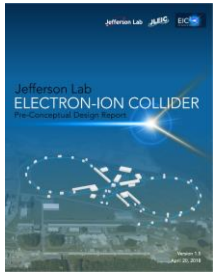
Zgoubi Workshop 2019
Boulder, CO, August 27, 2019

JLEIC Layout

- Electron complex
  - CEBAF
  - Electron collider ring: 3-12 GeV/c
- Ion complex
  - Ion source
  - SRF linac: 150 MeV for protons
  - Low Energy Booster: 8.9 GeV/c
  - High Energy Booster: 13 GeV/c
  - Ion collider ring: 200 GeV/c
- Up to two detectors at minimum background locations
- Upgradable to 140 GeV CM by doubling ion energy







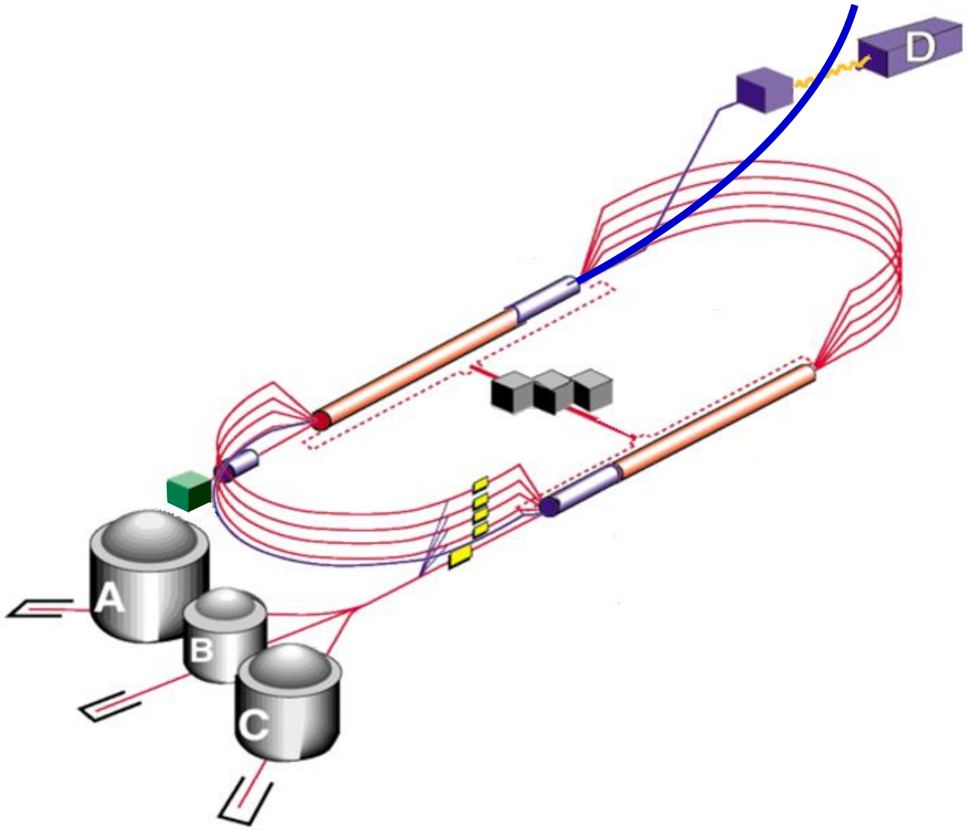
arXiv:1209.0757
arXiv:1504.07961

pCDR
August 2019

12 GeV CEBAF as Injector

- Extensive fixed-target science program
  - Fixed-target program compatible with concurrent JLEIC operations
- JLEIC injector
  - Fast fill of collider ring
  - Full energy
  - ~85% polarization
  - Enables top-off
- New operation mode but no hardware modifications

Up to 12 GeV to JLEIC



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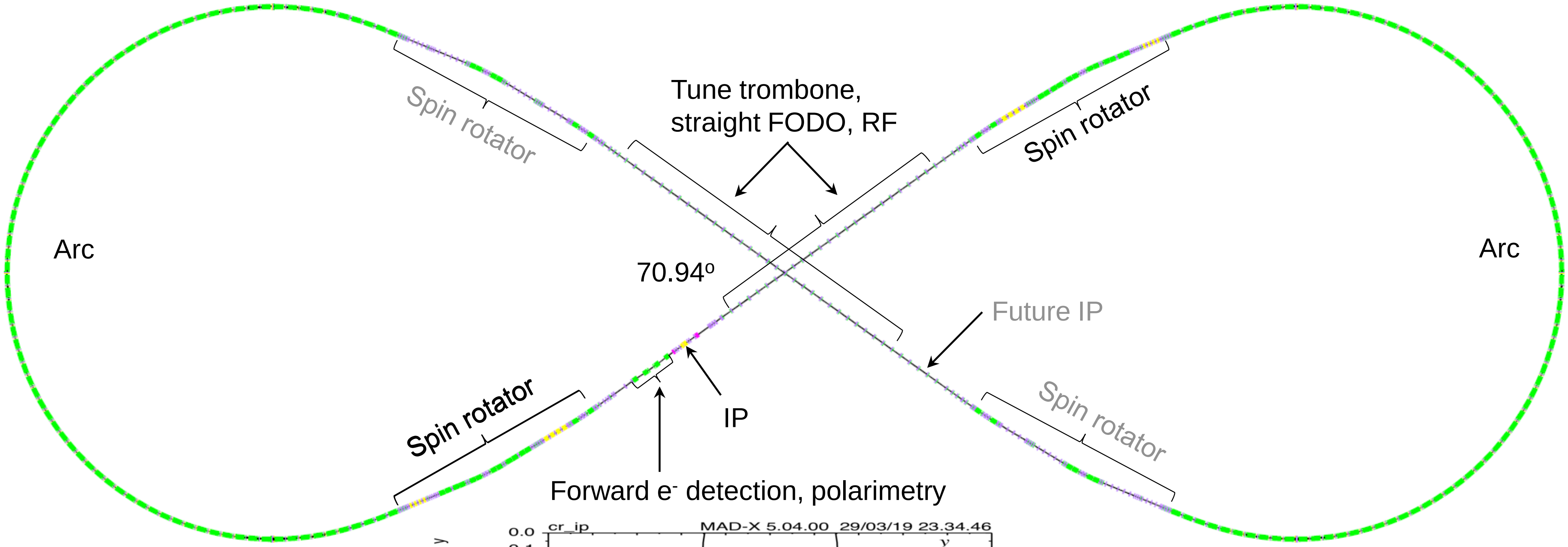
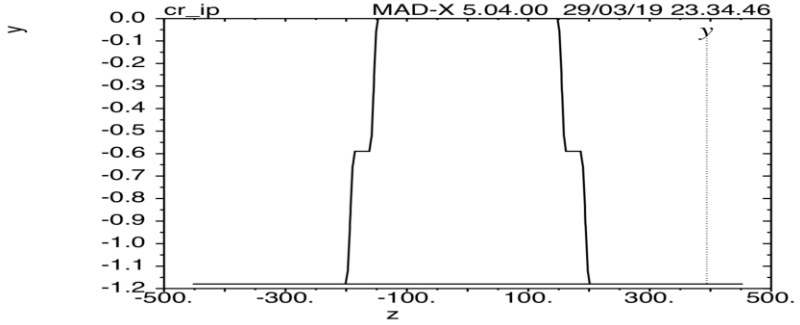
Electron Collider Ring Layout

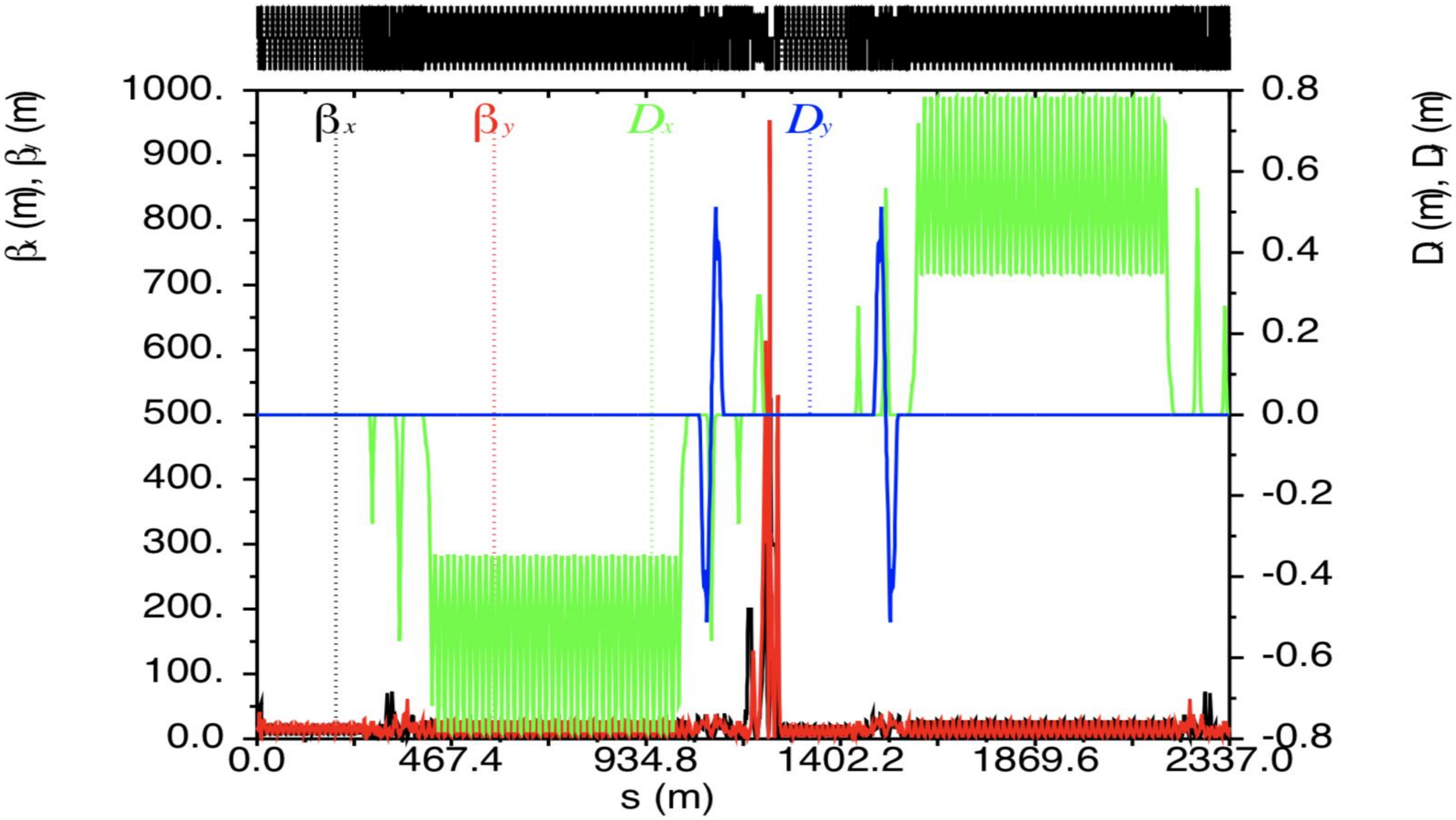
- Cost reduction by reusing PEP-II magnets, RF and vacuum pipe in the electron ring





Electron Collider Ring Optics: Complete Ring

- Global chromaticity compensation scheme



Beam size

$\sigma = \sqrt{\beta\varepsilon + (D\Delta p/p)\hat{}2}$

$\varepsilon p/mc^2$ is a constant

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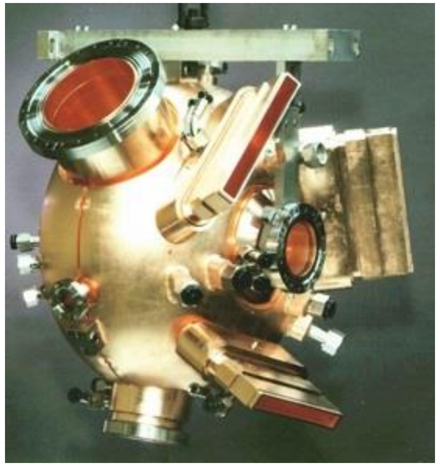
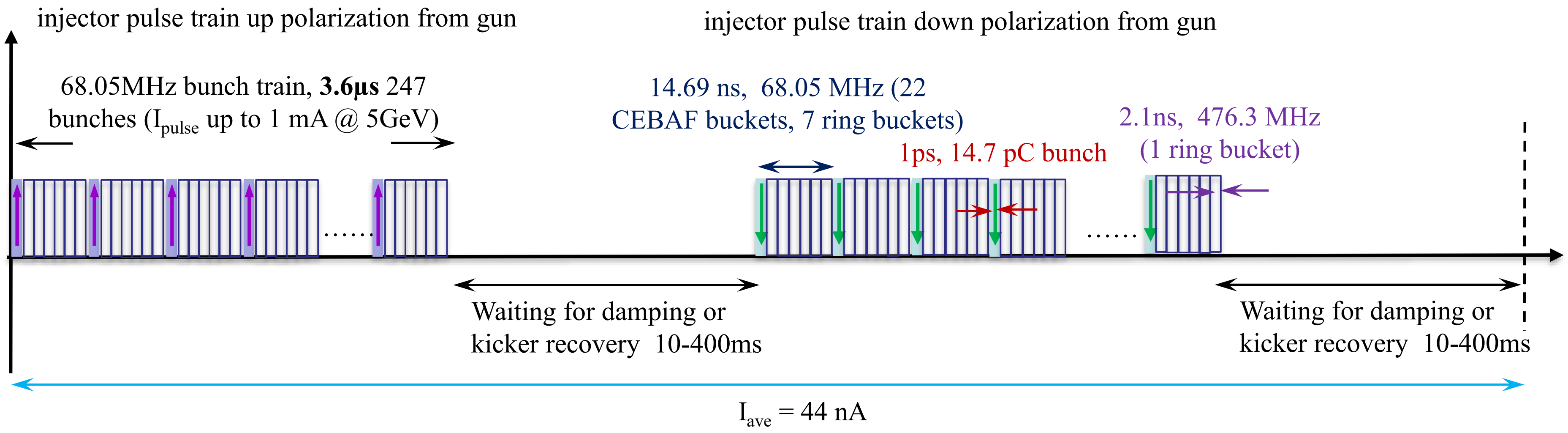
Electron Injection

- Electron injection from CEBAF
  - Existing CEBAF electron gun
  - **Two polarization state** injection
  - f_{ring} / f_{CEBAF} = 476.3 MHz / 1497 MHz = 7 / 22
- Test of CEBAF in JLEIC injector mode completed



476.3 MHz e-ring (NCRF PEP-II)

Mid-cycle 1, inject the 1st of every 7 buckets in the ring



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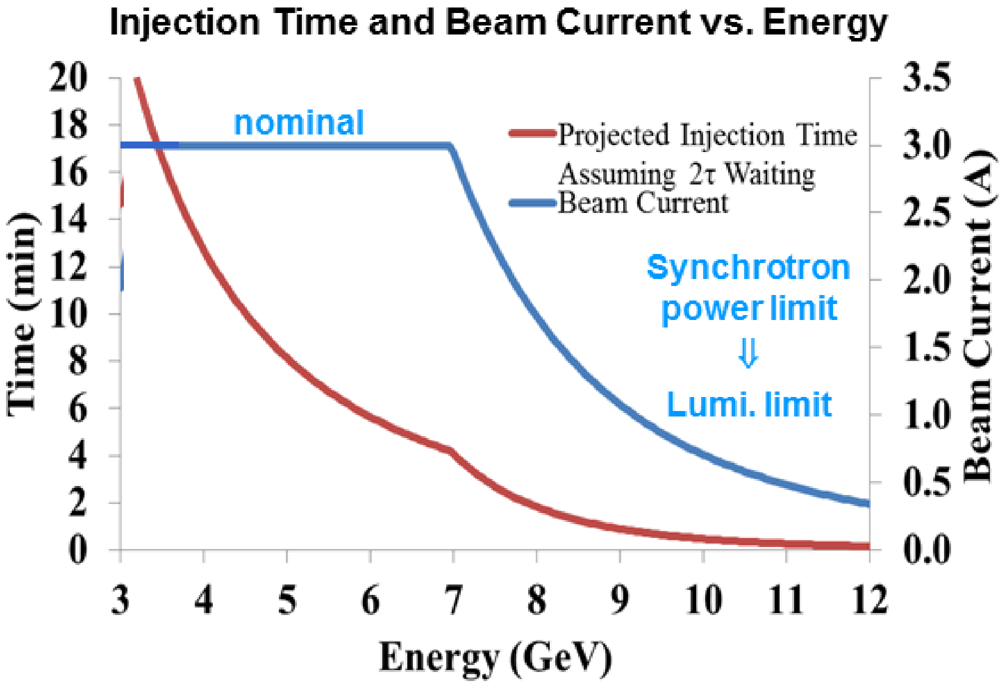
Electron Beam

- Electron beam
  - **3 A** at up to 7 GeV
  - Normalized emittance **85 µm** @ 5 GeV
  - Synchrotron power density < **10 kW/m**
  - Total power up to **10 MW**



Parameter	Units					
Energy	GeV	3	5	7	10	12
Beam current	A	3	3	3	0.8	0.39
Total SR power	MW	0.30	2.28	8.76	9.73	9.84
Energy loss per turn	MeV	0.10	0.76	2.92	12.17	25.23
Energy spread	10^{-4}	2.5	4.1	5.8	8.2	9.9
Transverse damping time	ms	474	102	37	13	7
Longitudinal damping time	ms	237	51	19	6	4
Normalized horizontal emittance	um	18	85	234	683	1180
Normalized vertical emittance	um	1.3	6.0	16.6	48.3	83.5
Bunch length	cm	1	1	1	1	1.32

Radiative Polarization Effects

- Sokolov-Ternov polarization change rate

$$\tau_{ST}^{-1} = \frac{5\sqrt{3}}{8}\frac{r_e\gamma^5 h/2\pi}{m_e}\frac{1}{C}\oint ds \left\langle \frac{1-\frac{2}{9}(\hat{n}\cdot\hat{s})^2}{|\rho(s)|^3} \right\rangle_s$$

$\hat{n}$ is the invariant spin field, a 1-turn periodic unit 3-vector field over the phase space satisfying the T-BMT equation along particle trajectories, $\hat{s}$ is a unit vector along the particle velocity, and $2\pi\hbar$ is Planck's constant.

- Depolarization rate due to spin diffusion

$$\tau_{SD}^{-1} = \frac{5\sqrt{3}}{8}\frac{r_e\gamma^5 h/2\pi}{m_e}\frac{1}{C}\oint ds \left\langle \frac{11(\partial\hat{n}/\partial\delta)^2}{18|\rho(s)|^3} \right\rangle_s$$

$\partial\hat{n}/\partial\delta$ is the spin-orbit coupling function

- Total polarization change rate

$$\tau_{DK}^{-1} = \tau_{ST}^{-1} + \tau_{SD}^{-1}$$

- Equilibrium polarization

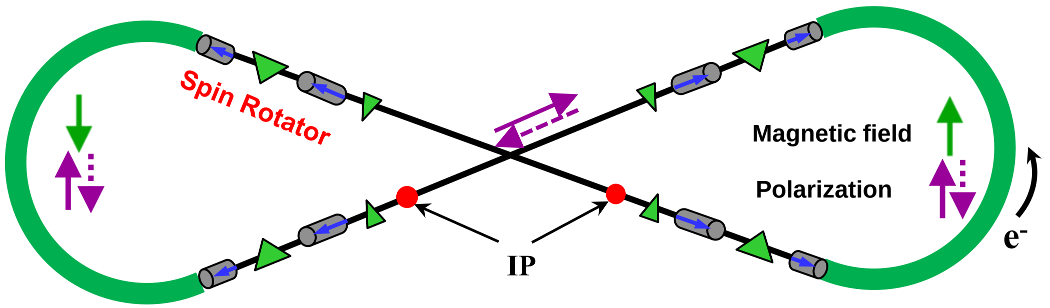
$$P(t) = P_{ens,DK}\left(1 - e^{-t/\tau_{DK}}\right) + P_0 e^{-t/\tau_{DK}}$$

where $P_{ens,DK} = P_{DK}\langle\hat{n}\rangle_s$ is the value of ensemble average of P_{DK} independent of s and P_0 is the initial polarization

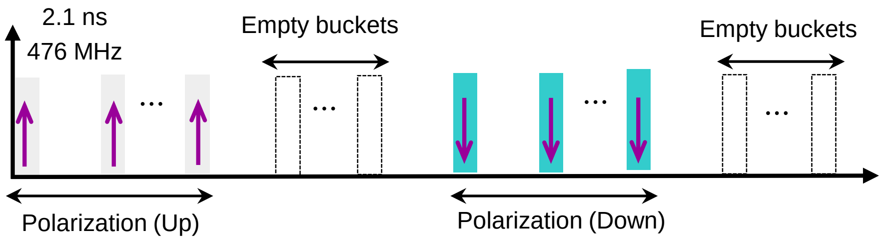
Electron Polarization Strategies

- Highly vertically polarized electron beams are injected from CEBAF
  - avoid spin decoherence, simplify spin transport from CEBAF to MEIC, alleviate the detector background
- Polarization is designed to be vertical in the JLEIC arc to avoid spin diffusion and longitudinal at collision points using spin rotators
- Universal spin rotator (fixed orbit) rotates the electron polarization from 3 to 12 GeV
- Desired spin flipping is implemented by changing the source polarization
- Polarization configuration with figure-8 geometry removes electron spin tune energy dependence, significantly suppress the synchrotron sideband resonance
- Continuous injection of highly-polarized electrons from CEBAF is considered to maintain high equilibrium polarization
- Spin matching in some key regions is considered to improve polarization lifetime
- Compton polarimeter provides non-invasive measurements of the electron polarization

Polarization configuration

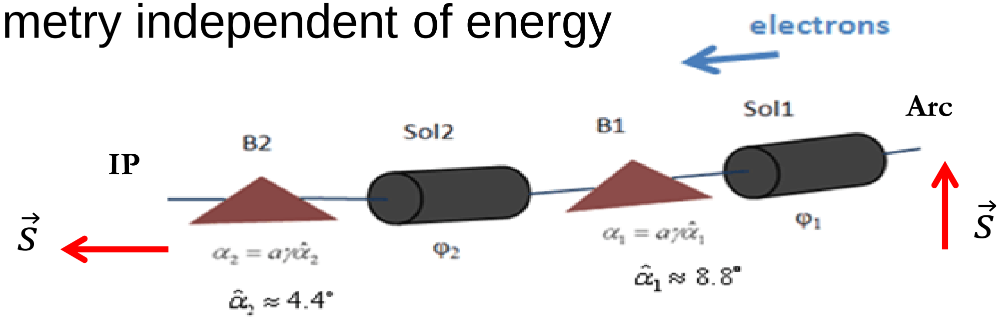


bunch train & polarization pattern (in arcs)



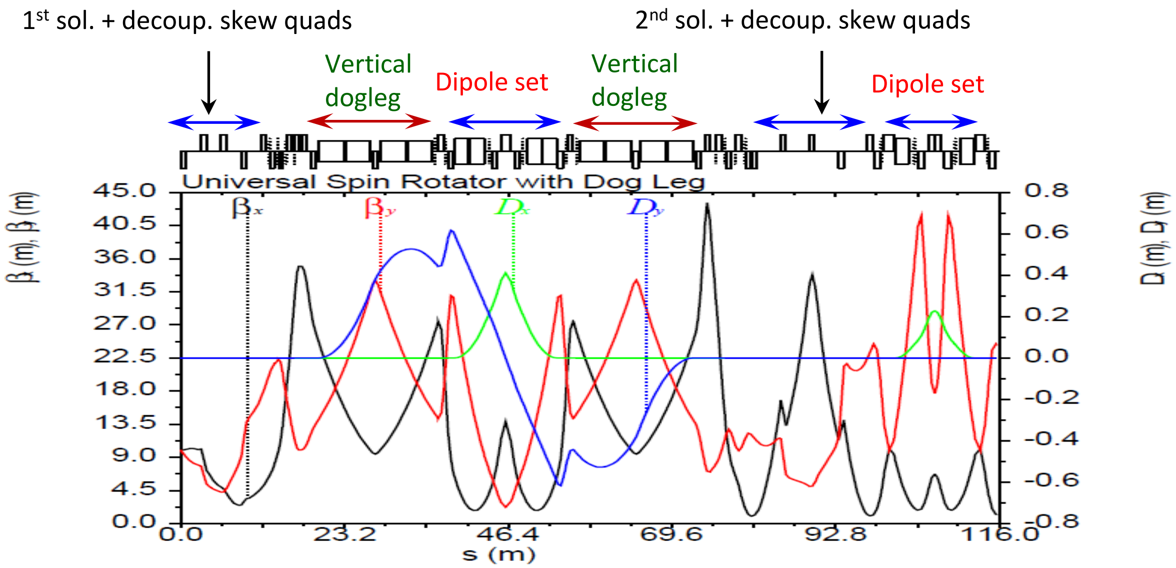
Universal Spin Rotator

- Changes polarization from vertical in the arcs to longitudinal in the straights
- Sequence of solenoid and dipole sections
- Geometry independent of energy



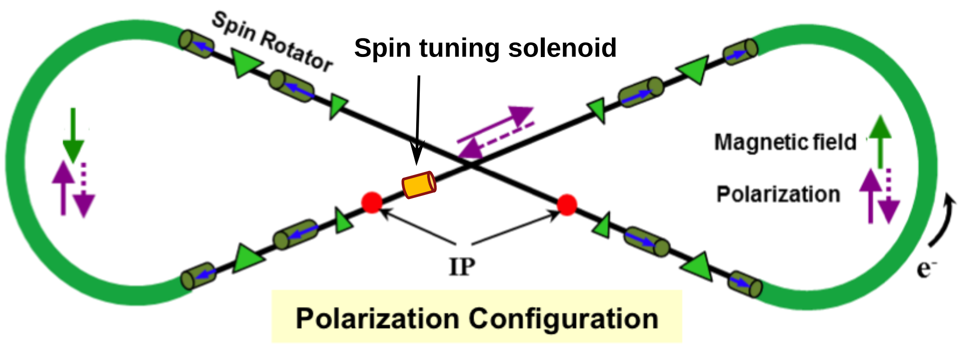
E	Solenoid 1		Dipole set 1	Solenoid 2		Dipole set 2
	Spin Rotation	BDL	Spin Rotation	Spin Rotation	BDL	Spin Rotation
GeV	rad	T·m	rad	rad	T·m	Rad
3	π/2	15.7	π/3	0	0	π/6
4.5	π/4	11.8	π/2	π/2	23.6	π/4
6	0.62	12.3	2π/3	1.91	38.2	π/3
9	π/6	15.7	π	2π/3	62.8	π/2
12	0.62	24.6	4π/3	1.91	76.4	2π/3

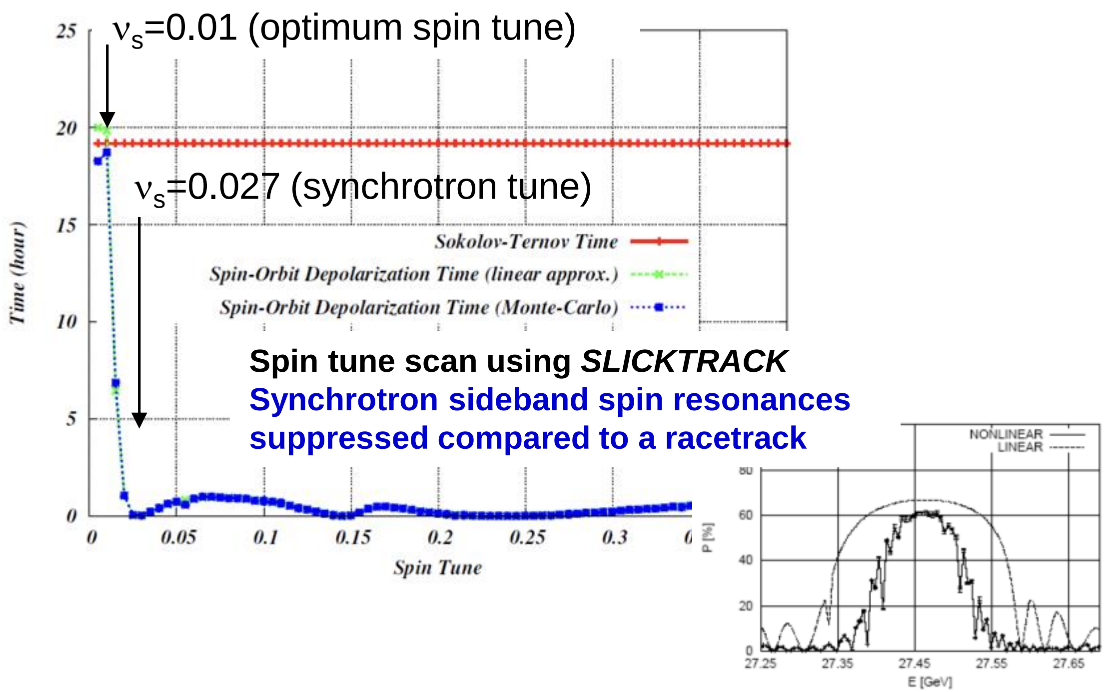
- Dispersion suppressed in solenoids and each solenoid is individually decoupled
- Two polarization states with equal lifetimes
- Electron beam rotators house vertical doglegs for stacking the electron and ion beams in arcs and bring them to same plane in the straights

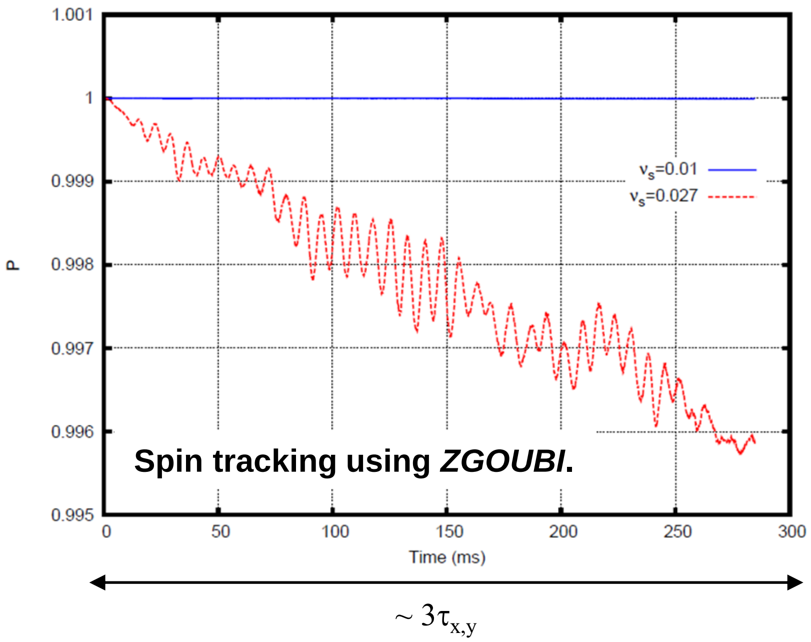


Spin Tracking

- Spin tune scan using a spin tuning solenoid in SLICK/SLICKTRACK
- Demonstrates suppression of synchrotron sideband spin resonances
- Verified by Zgoubi's Monte-Carlo spin tracking







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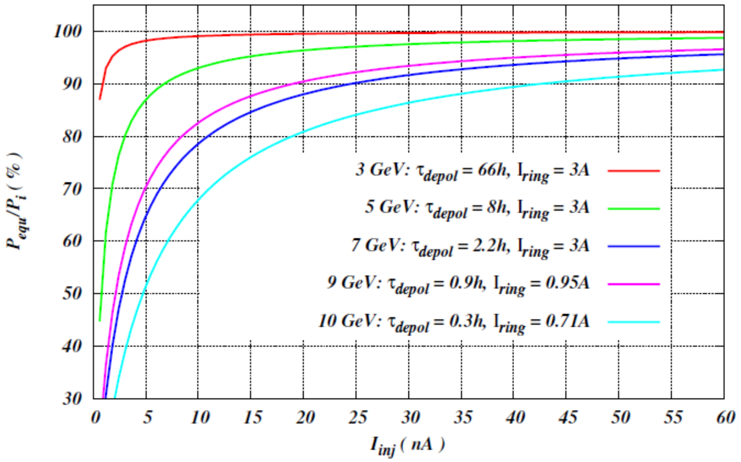
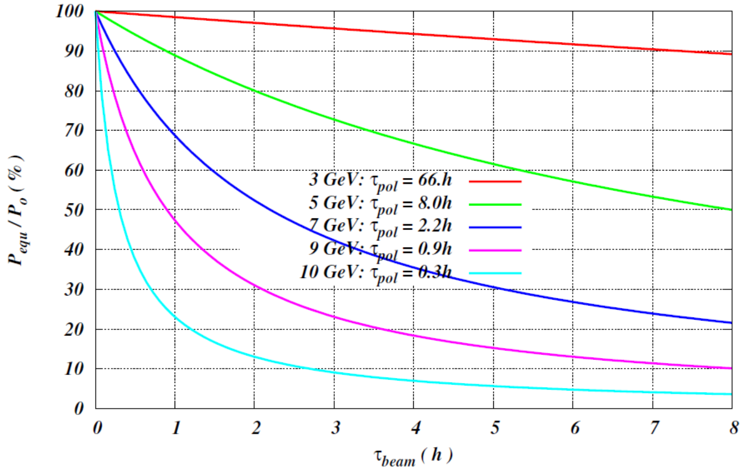
Polarization Lifetime and Continuous Injection

- Estimated polarization lifetime

Energy (GeV)	3	5	7	9	12
Lifetime (hours)	116	9	1.7	0.5	0.1

- Constant polarization is maintained by continuous injection of highly polarized electron beam from CEBAF
- Equilibrium polarization $$P_{equ} = P_0 \left(1 + \frac{T_{rev} I_{ring}}{\tau_{DK} I_{inj}}\right)^{-1}$$
- A relatively low average injected beam current of tens-of-nA level can maintain a high equilibrium polarization in the whole energy range
- Beam lifetime must be balanced with the beam injection rate and $\tau_{beam} \ll \tau_{pol}$





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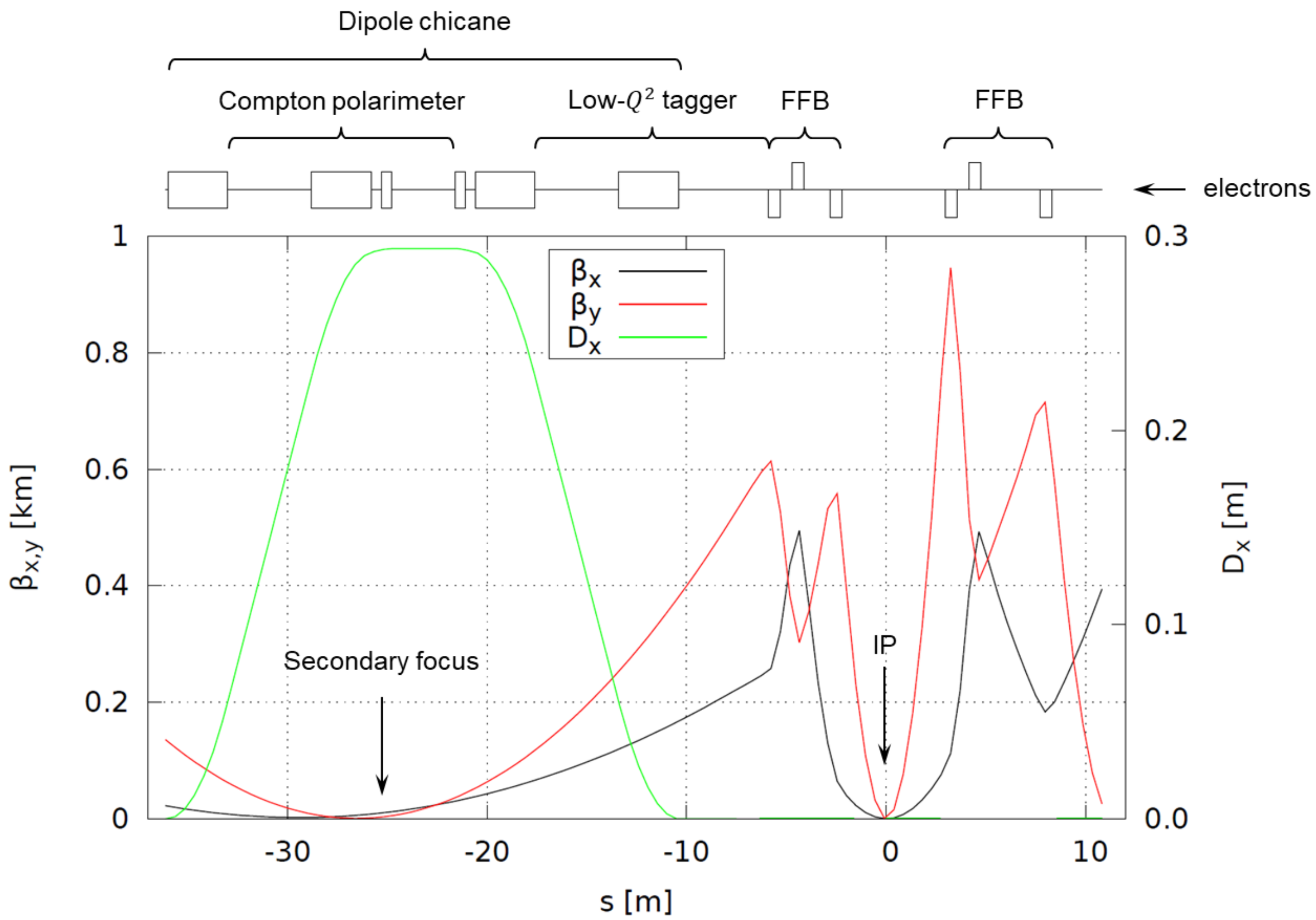
Electron Interaction Region

- Downstream chicane for low-Q^2 tagging and polarimetry



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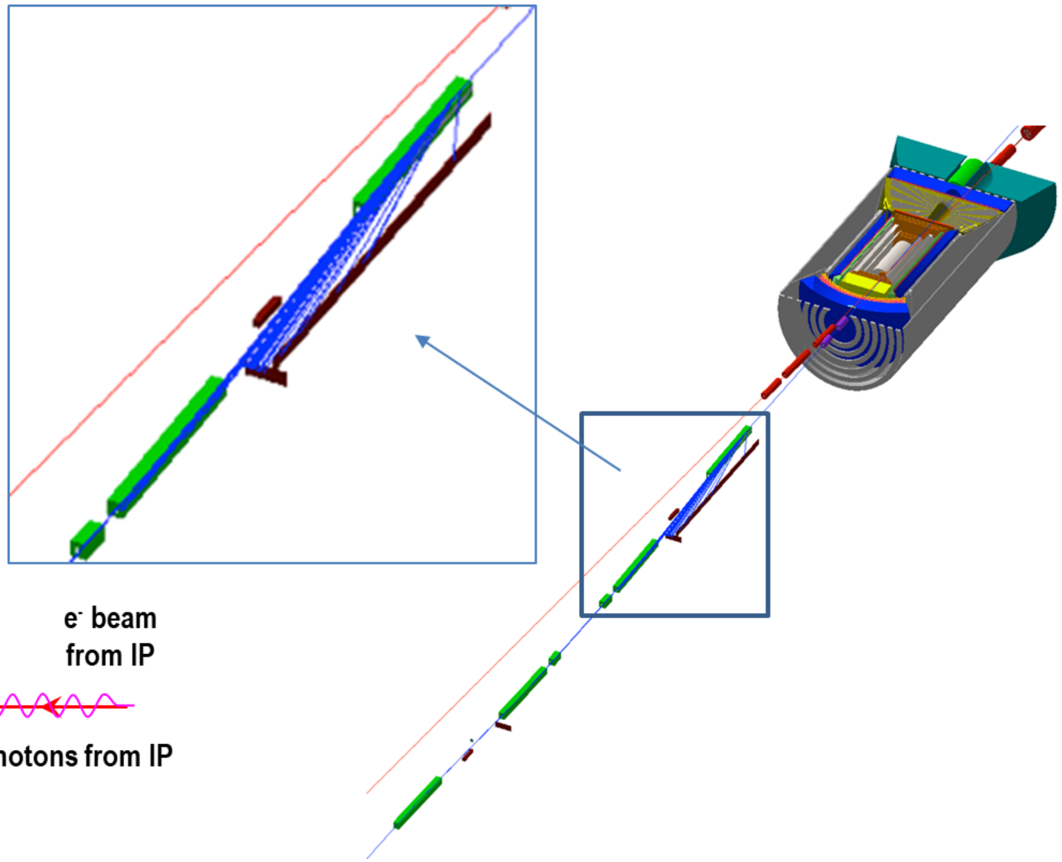
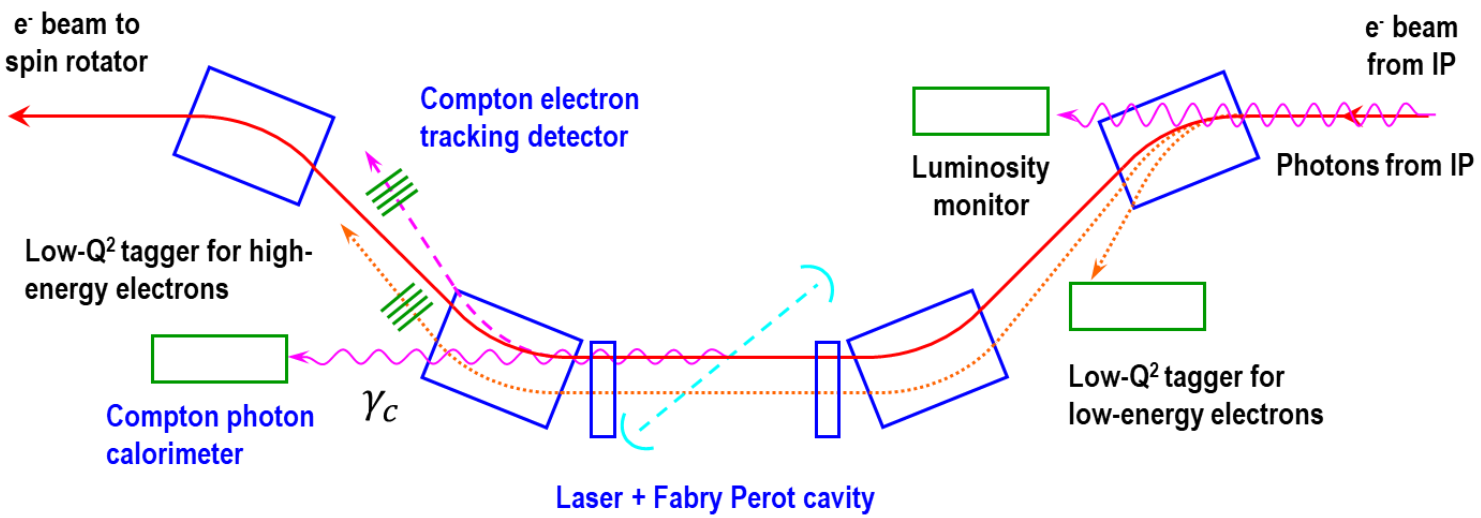
Low Q^2 Tagger in JLEIC

- Dipole chicane for high-resolution detection of low-Q^2 electrons
- Compton polarimetry has been integrated to the interaction region design
  - same polarization at laser as at IP due to zero net bend
  - non-invasive monitoring of electron polarization





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Summary

- JLEIC electron polarization design
  - High polarization level maintained by full-energy top-off injection of highly polarized electrons from CEBAF
  - Polarization is vertical in the arcs to minimize the spin diffusion
  - Universal fixed-geometry spin rotators to provide longitudinal polarization at the IP
  - Equal lifetimes of the two polarization states
  - No energy dependence of the spin tune
  - Compton polarimetry
- Preliminary simulations confirm theoretical expectations
- Future work
  - Spin matching
  - Spin tracking
    - Polarization lifetime
    - Top-off process
    - Invariant spin field
    - Spin dynamics at different energies
    - Optimization