Advanced Concepts for EIC

Ya. Derbenev

Jefferson Laboratory

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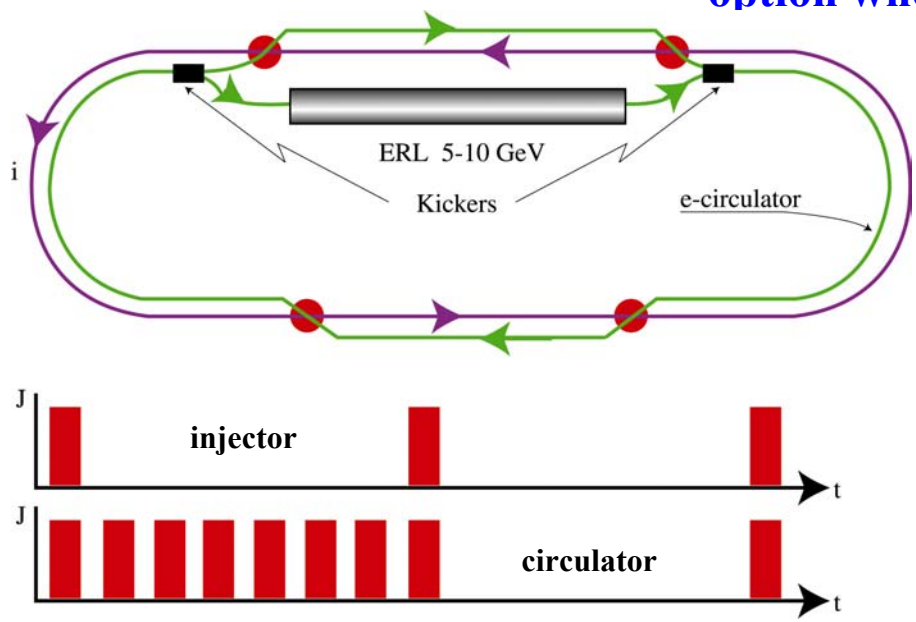
Circulator Rings for LR Collider, or LCR option

- Macropulse source regime (high pulse / low average value)
- Number of revolutions in CR = macro-duty factor
- High circulating current = macropulse value

- Still ERL CW, although:
- Pulse SRF linac in alliance with CR as damping accumulator might be an interesting option
- Naturally convertible to pure LR option when beneficial



LCR features

Respectively the RR option:

- Easy spin (no crossing resonances, no quantum depolarization)
- Emittance determined by the photoinjector (CR regime)
- Easily variable energy
- Easier interaction point (no depolarization of bends to appear)
- Larger admissible beam-beam tune shift (higher lumi)
- Larger accessible circulating current

Respectively the LR option:

- Photoinjector released of high average current
- Reduction of BBU in SRF linac
- Reduction of HOM

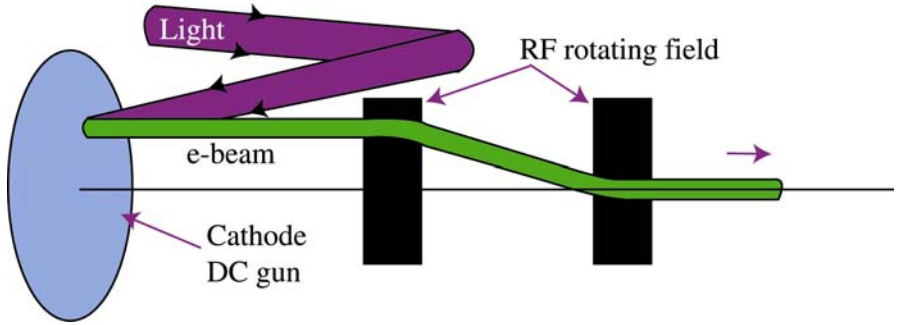
Issues:

- Fast ejection-injection (develop best kickers)
- Microwave stability of short bunches in CR
- CSR effect
- SRF in CR to maintain short bunches

Possible Advances In Photo Injector

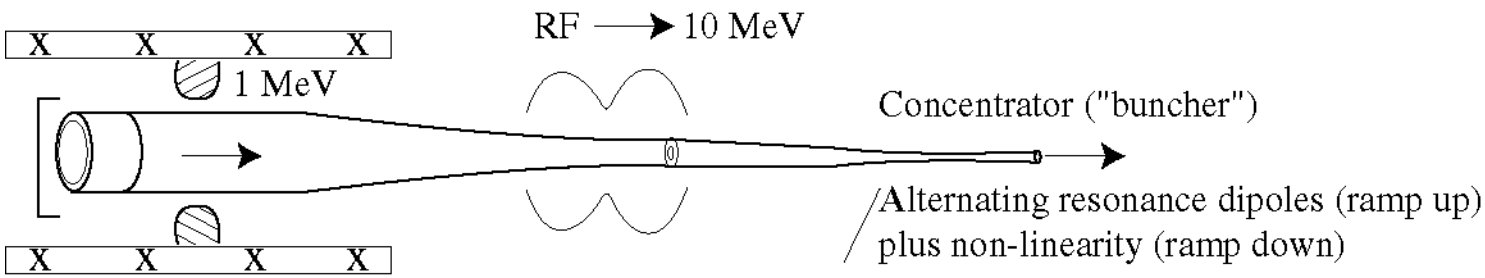
Scanned Cathode Photogun

The goal: **To extend cathode lifetime while emittance is still reduced**



Hollow Beam Injector with Beam Concentrator

The goal: **Reduction of space-charge effect on emittance**

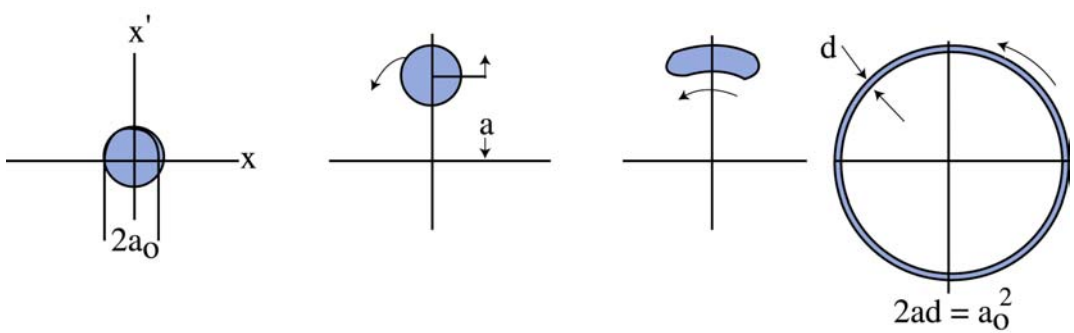


Smoky Ion Beam Injection in Booster

/ how to stack ion beam in booster over space charge limit maintaining beam emittance/

- Halo transformation of ion beam in phase space after linac /before injection in booster/

  /process similar to beam debunching in a ring: after beam kick, an introduced resonance dipole field (static) drops adiabatically along the beam path /



/Similar gymnastics in y-plane/

Beam stacking:

- Focus the smoky beam to stripping foil
- Use beam raster applying an RF dipole field (compensated)

Turning the smoky beam back to the true size:

- After beam longitudinal bunching/acceleration to a large gamma in booster, make the reverse halo gymnastics in phase space by resonance RF dipoles

Electron Cooling and Luminosity

Optimizing the Electron Cooling

Measures to undertake:

- **Equalize cooling rates using the *dispersive mechanism***
- **This allows one to avoid beam extension, hence, relax of the *alignment demands***
- ***Reduce x-y coupling outside the cooling section to a minimum***

Then, one gets a minimum critical electron current and ion equilibrium (flat beam) against IBS

Very Short Ion Bunches

- ***Electron cooling in cooperation with a strong SRF allows to obtain very short ion bunches (1cm or even shorter)***

Circulators for Electron Cooling

- **Cooling of intense ion beams (up to a few Amps) requires a high electron current (hundreds of mA), in order to defeat the IBS**

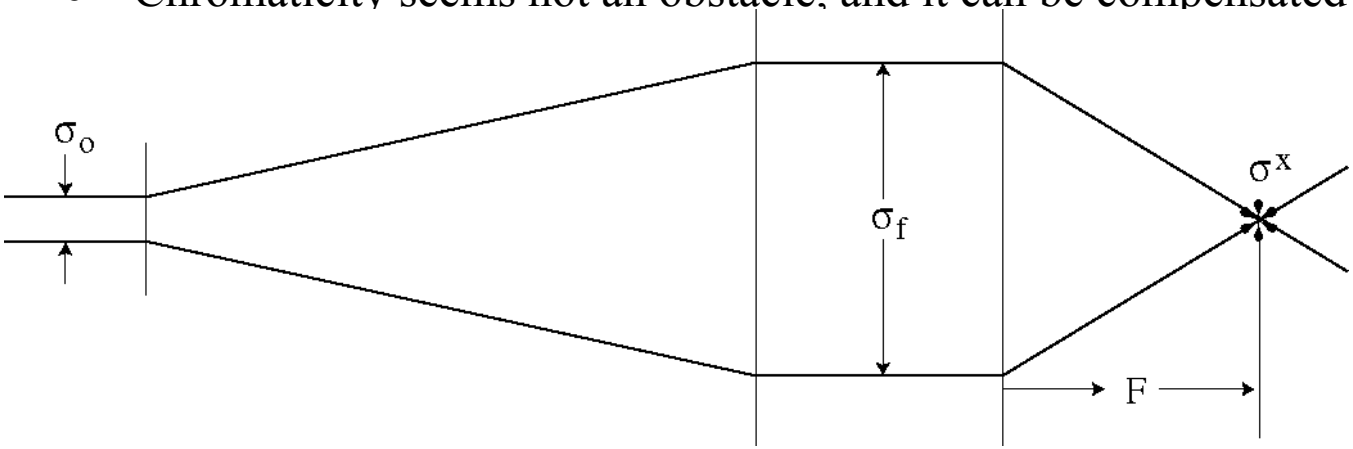
This request can be satisfied at ERL incorporated with Circulator

Low Beta-star for Ion Beam

Small transverse and longitudinal beam size (both after cooling) allow one to design quite a strong final focus:

β* about 1 cm or even shorter

- Chromaticity seems not an obstacle, and it can be compensated if needed



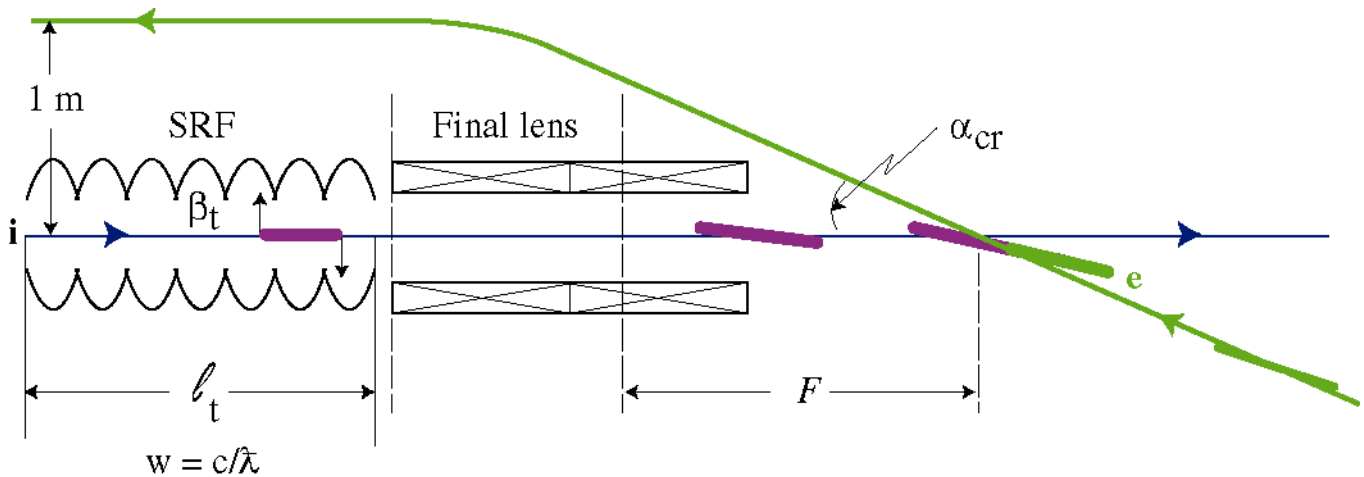
$$\beta^* = \frac{F^2}{\beta_f} = \frac{F^2}{\beta_0}\left(\frac{\sigma_0}{\sigma_f}\right)^2 = \frac{F^2}{\gamma\sigma_f^2}\varepsilon_n$$

Parameter	Units	Value
γ		100
F	m	3
σ_f	mm	2
ε_n	4×10^{-5} cm	1

β*=1 cm

Crab Crossing /R.Palmer, 1988/

- **Short bunches also make feasible the Crab Crossing:**
- **SRF deflectors 1.5 GHz can be used to create a proper bunch tilt**



$$\alpha_{cr} = 2\alpha_f = 2\theta_t \frac{F}{\lambda} \quad 2\pi$$

$$\theta_t = \frac{eB_t l_t}{E}$$

$$E = 100 \ GeV$$

$$F = 3 \ m$$

$$\lambda = 20 \ cm \quad (1.5 \ GHz$$

$$B_t = 600 \ G \quad (= 20 \ MV/m)$$

$$l_t = 4 \ m$$

$$\sigma_f = 1 \ mm$$

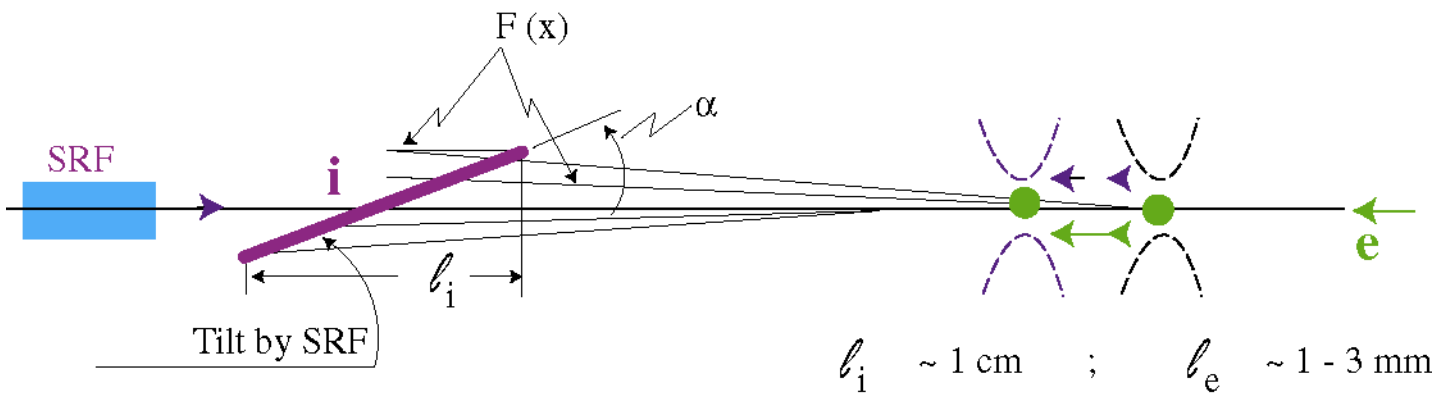
$$\alpha_{cr} = 0.1$$

$$\theta_t = 5 \cdot 10^{-4}$$

Traveling Ion Focus /R. Brinkmann, 1995, general idea /

SRF deflectors (the same as for crab crossing) also can be used for arrangement of Traveling Focus (at $l_i >> l_e$), in cooperation with sextupole non-linearity introduced in the final focusing magnets

- **Traveling Focus allows one to decrease N_i or use bunches of a larger ε_i**



$$\varphi = \frac{\omega}{c} s \qquad \alpha = \frac{dx}{ds} \qquad \beta_i^* << l_i$$

Matching condition: $\frac{dF}{ds} = \frac{1}{2}$ **hence,** $\frac{dF}{dx} = \frac{1}{2\alpha}$

$\Delta F_b \sim \frac{1}{2} l_i$ **(over the bunch)**

ΔF **over the aperture:**

$$\Delta F_A = \frac{A}{2\alpha}$$

The feasibility condition:

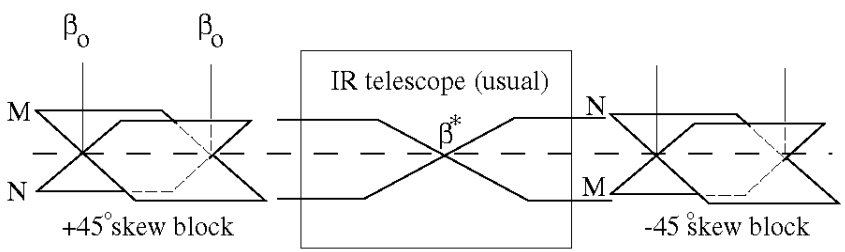
$$\Delta F_A << F \quad \Rightarrow \quad \alpha >> \frac{A}{2F}$$

Ease to satisfy

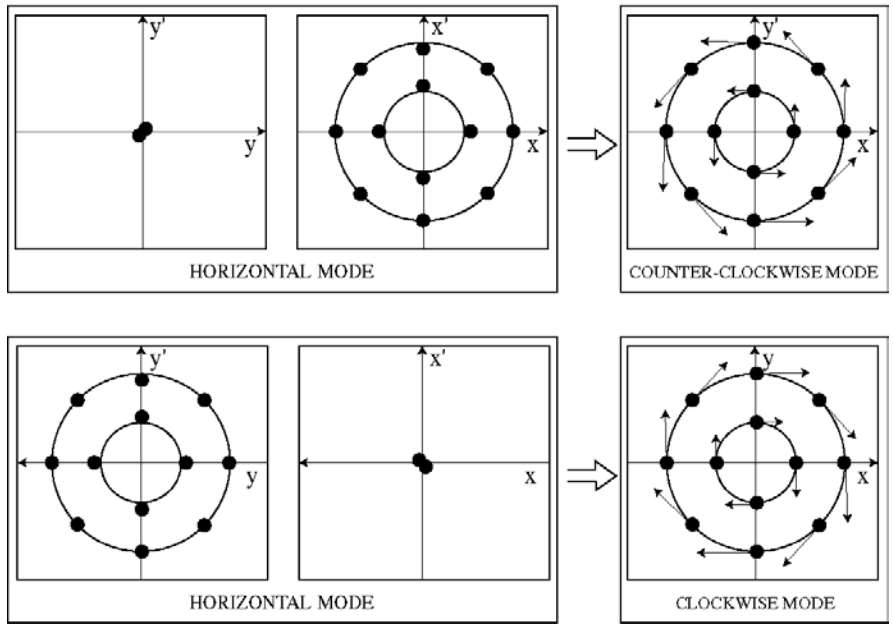
Circular Colliding Beams /since 1993/

- **Arrangement of Circular Modes at interaction point improves the beam-beam stability**

IR with Beam Rounders

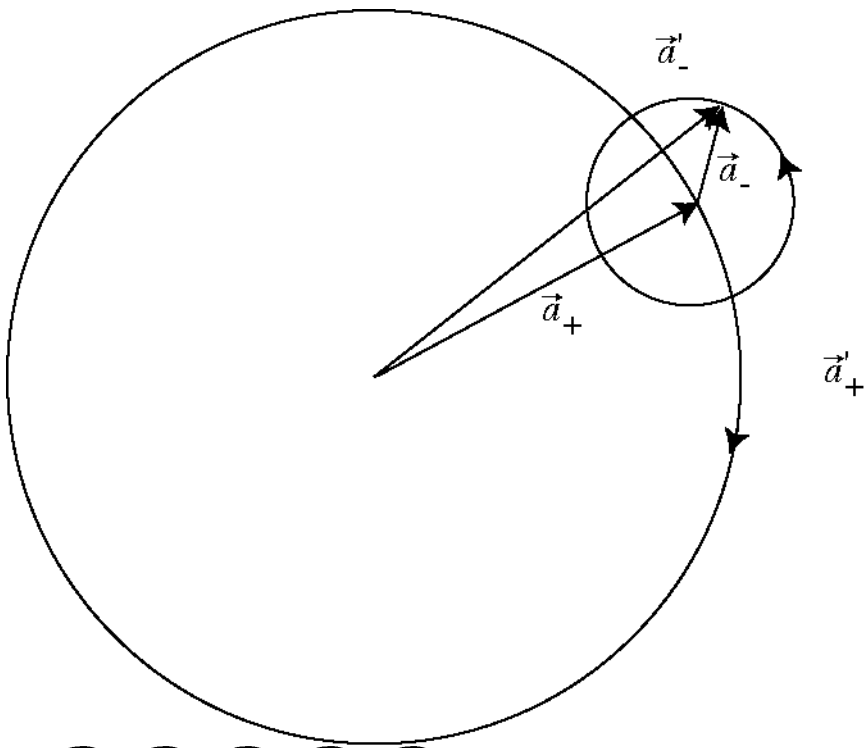


Planar to Circular Modes Transformation



Circular Colliding Beams

- Circular modes seem especially effective at a large aspect ratio ($\varepsilon_x >> \varepsilon_y$), due to a strong reduction of particle radial oscillations (i.e. effective linearization of bb interaction)

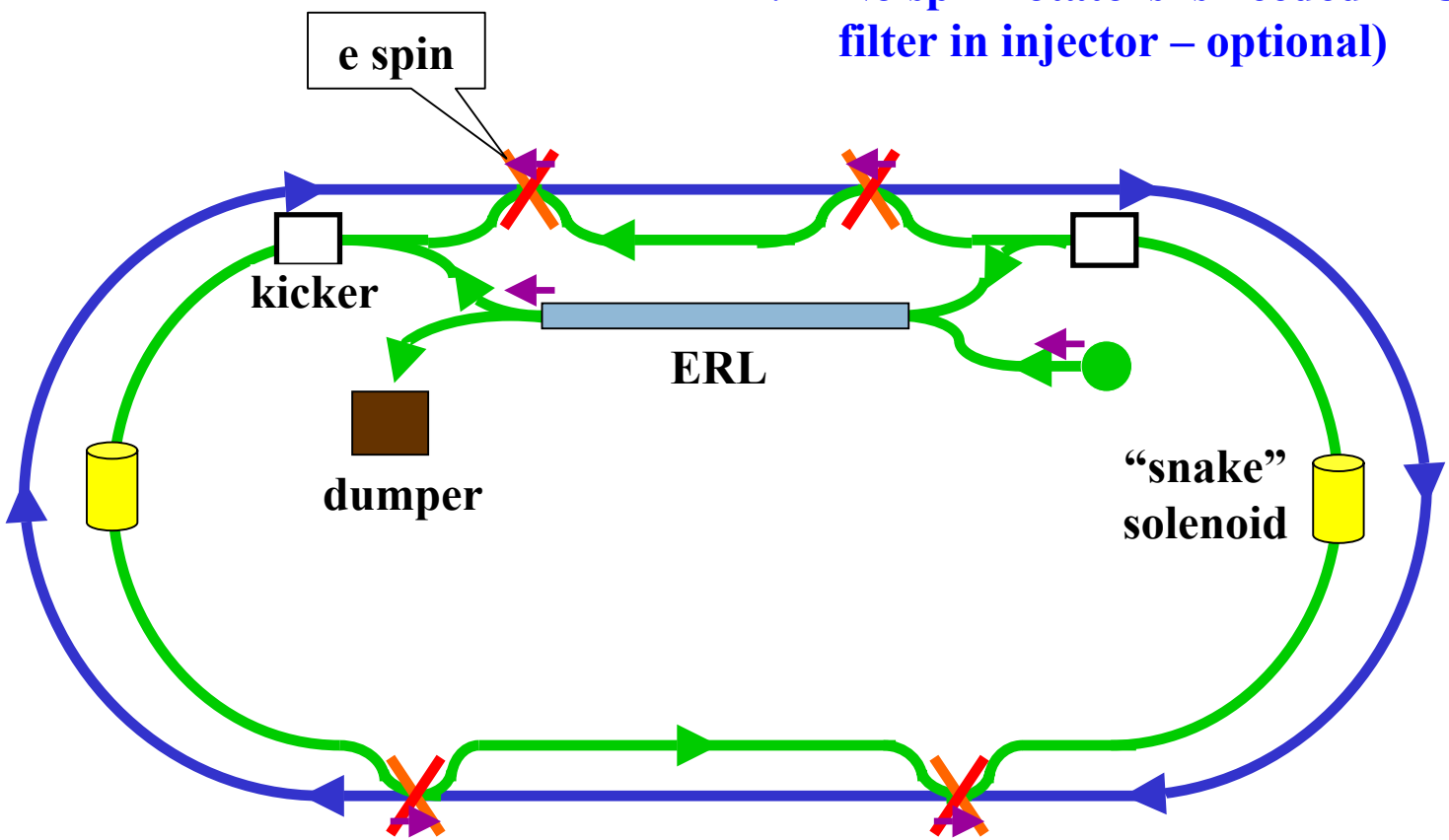


- Flat ion beams can be obtained with help of electron cooling
- Flat e-beams can be delivered to CR from a magnetized e-gun
- e-beams in storage rings are inherently flat

Spin Trends

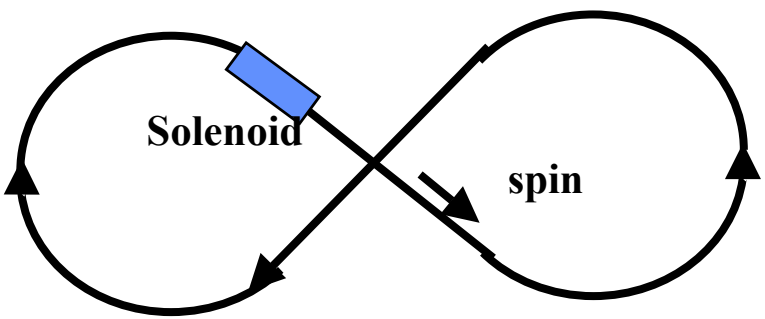
- Solenoid Snakes for electrons in CR

- Full solenoid snake at 5 GeV: 60 TM
- 10 : 120
- No spin rotators is needed in CR (Wien filter in injector – optional)



Spin Trends

Twisted Spin Synchrotrons

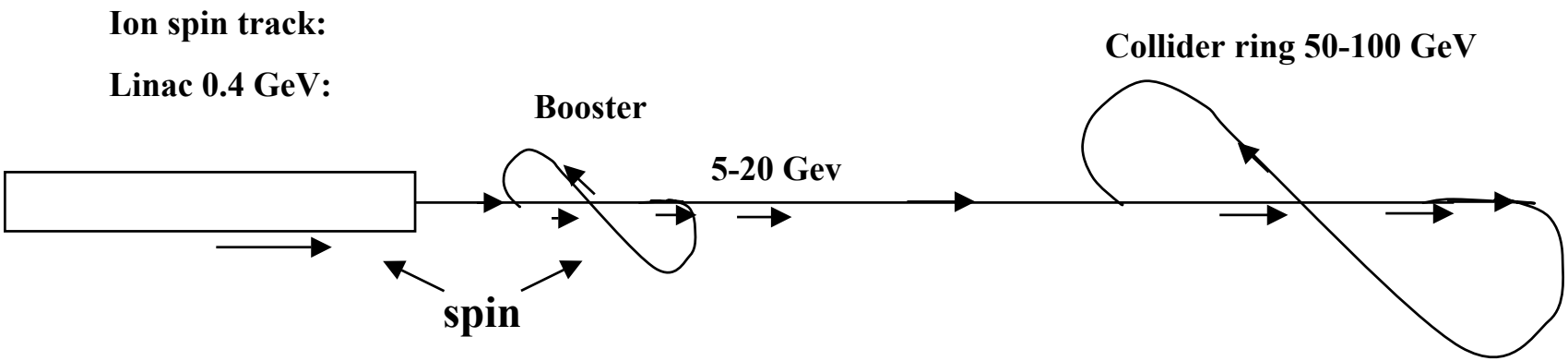


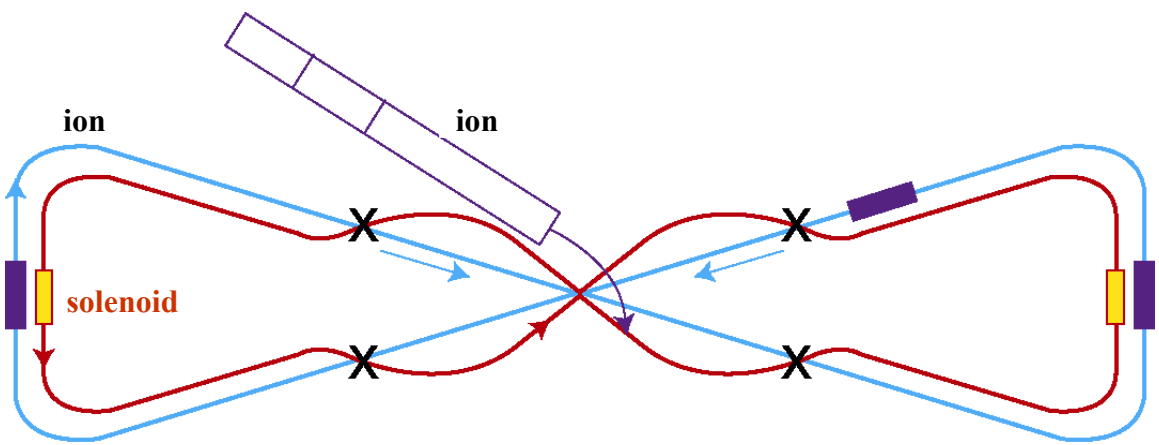
Spin features:

- Zero spin tune
- No resonance crossing
- Intrinsic spin resonance stay away
- Longitudinal either transverse polarization is easily organized, stabilized and controlled for all the particle species (p, d, He, …, and electrons)
- No spin rotators are needed
- Convenient for circulator, booster and collider rings suited for EPIC
- Easy longitudinal snakes for protons can be introduced (instead of 45 degree snake axis of RHIC), to make ½ spin tune value
- Polarized beam acceleration problem is gone

Spin Trends

Twisted Spin EIC rings





- **Longitudinal snakes for protons** (ease)
  - **e – circulator could be used as ion booster**
  - **2 or 4 IP**

Spin Trends

Spin control for D and He^3

- Longitudinal spin can be stabilized by small solenoids
- The horizontal (either transverse or longitudinal) spins can be stabilized and controlled by horizontal dipoles distributed around arcs

Flipping spin

- Protons: all the possiblities that are available in conventional rings
- D and He: varying adiabatically the controlling dipoles fild strengthes and signs

Conclusion & Outlook

1. The SRF ERL technology provide a potential for realization of high luminosity EIC (33-35 level) related to the two major elements:

- polarized 5-10 GeV electron beam
- high quality e-beam for cooling of ion beam

2. Incorporation with circulator ring raises drastically the utilization efficiency of ERL

3. Improvements of the Interaction Region (crab crossing,…) seem easily compatible with the LR version of EIC (compatibility with the RR to be studied)

4. Possible new solutions for polarized ion beam transport (twisted rings) seem to raise essentially the EIC capabilities

5. A consistent concept of EIC luminosity level 34 seems possible to compose today basing on the existing state of art of accelerator and polarized sources technology

6. Luminosity level 35 seems possible at increase of a polarized electron source peak current by a factor of 10 (to 25 A)

7. Other approaches to efficient utilization of e-beam accelerated in SRF linac should be examined, as well (say, SRF linac incorporated with electron circulator in the regime of damping ring)