Ganil TF e-RI

ERL AND TRAP WORKING GROUP

ETIC (2016)
Electron Trapped Ion Collisions

- Working group started at CEA/IRFU within GANIL2025 discussions on a possible electron-ion collider started in 2016
- ETIC goal: gain a factor > 100 in luminosity w.r.t. SCRIT
- 2 main options explored:
  - Electron synchrotron
  - ERL
- Work mainly focused on
  - First parameter set
  - Optics
  - First limitations because of beam stability

Luminosity

Geometric Luminosity (Gaussian beams)

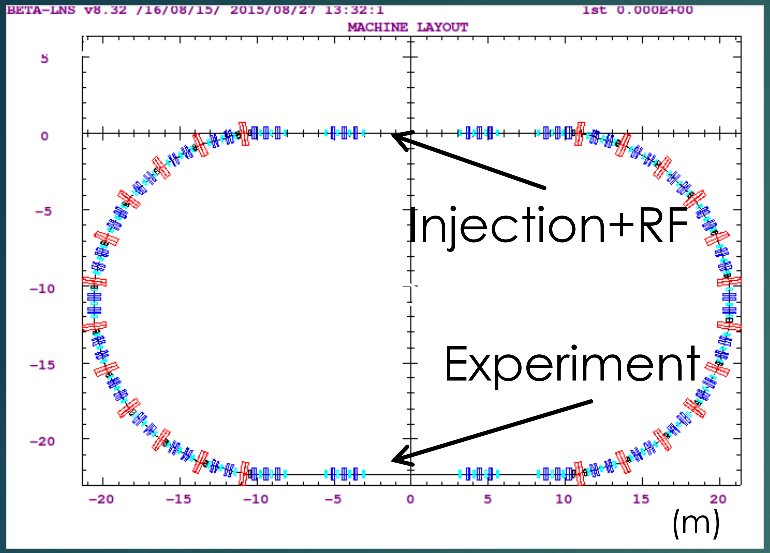
$$Lgeom = \frac{nbunch\ N_{RI} N_{e,bunch}}{4\pi\ \sigma x \sigma y\ t_{rev}} = \frac{Ibeam\ N_{RI}}{4\pi\ \sigma x \sigma y\ q_e} = \frac{N_{RI}}{4\pi q_e \kappa\ \sqrt{\beta_x \beta_y}} \frac{Ibeam}{\varepsilon x}$$

$$\kappa = \frac{\varepsilon_y}{\varepsilon_x}$$

To reach the luminosity one can play on:

- The trapped ions number N_{RI}.
- The electron beam intensity I_{beam}.
- The electron beam optics κ, β_x, β_y.
- The electron beam emittance ε_x.

Proposed synchrotron within ETIC



Ring layout

- Target luminosity: 10^{29} cm^{-2} s^{-1}
- Trapped radioactive ions: 10^6
- Beam energy: 500- 700 MeV

Element	Length (m)	#nb
Dipole	0.4033	24
Quadrupole 1	0.12	88
Quadrupole 2	0.26	24
Sextupole	0.15	94
BPM	0.15	56
Bellow	0.15	26

Circumference (m)	108.176	
Ec (MeV)	500	700
ε_x (nm.rad)	1.09	2.14
κ Coupling (%)	50	
$\beta_{x,y}$ @ IP (m)	0.15, 0.15	
$\sigma_{x,y}$ @ IP (μm)	12.8, 9.1	17.9, 12.7
σ_δ (%)	0.0343	0.0481
σ_s (mm)	4.52	6.02
V_{RF} (kV)	87	135
$Q_{x,y}$	10.702, 6.703	
I_{beam} (mA)	233	458

Synchotron limitations
Intra-beam scattering

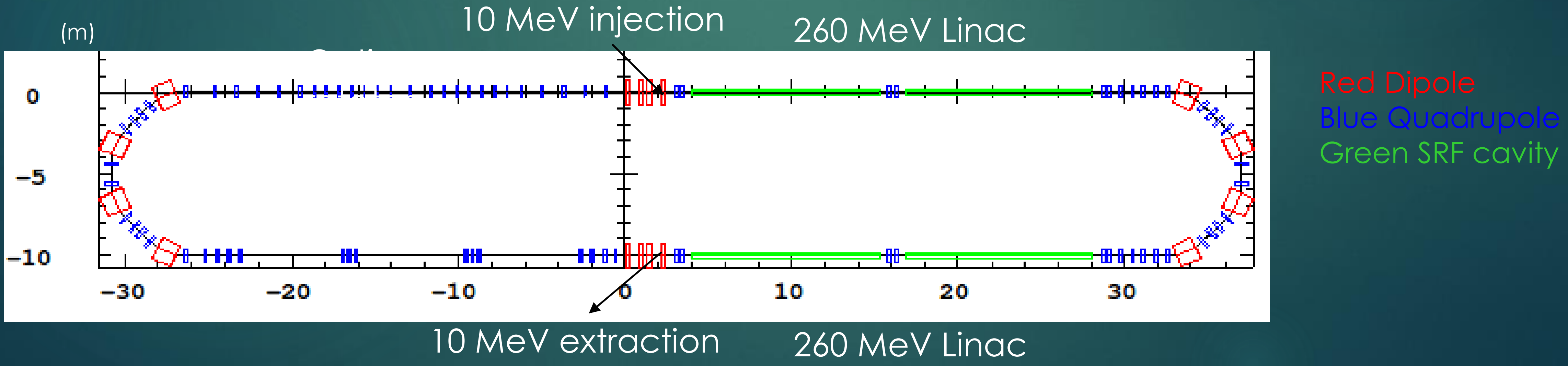
Ec (MeV)	500			600			700		
Approximation	Bane	MAX IV	CIMP	Bane	MAX IV	CIMP	Bane	MAX IV	CIMP
1.0 nm tuning	**$\varepsilon_{x,0}$ = 0.59 nm, $\sigma_{\delta,0}$ = 3.4 10^{-4}**			**$\varepsilon_{x,0}$ = 0.86 nm, $\sigma_{\delta,0}$ = 4.1 10^{-4}**			**$\varepsilon_{x,0}$ = 1.16 nm, $\sigma_{\delta,0}$ = 4.8 10^{-4}**		
$T_{x,y}$ (ms)	X	X	X	X	X	X	140	138	108
T_δ (ms)	X	X	X	X	X	X	50	49	46
$\varepsilon_{x,y}$ (nm)	X	X	X	X	X	X	1.58, 0.79	1.59, 0.80	1.78, 0.58
σ_δ (10^{-4})	X	X	X	X	X	X	6.0	6.1	6.2
1.5 nm tuning	**$\varepsilon_{x,0}$ = 0.76 nm, $\sigma_{\delta,0}$ = 3.4 10^{-4}**			**$\varepsilon_{x,0}$ = 1.10 nm, $\sigma_{\delta,0}$ = 4.1 10^{-4}**			**$\varepsilon_{x,0}$ = 1.49 nm, $\sigma_{\delta,0}$ = 4.8 10^{-4}**		
$T_{x,y}$ (ms)	X	X	X	X	X	X	218	221	166
T_δ (ms)	X	X	X	X	X	X	62	62	58
$\varepsilon_{x,y}$ (nm)	X	X	X	X	X	X	1.80, 0.90	1.79, 0.90	1.92, 0.75
σ_δ (10^{-4})	X	X	X	X	X	X	5.7	5.7	5.8
2.0 nm tuning	**$\varepsilon_{x,0}$ = 1.09 nm, $\sigma_{\delta,0}$ = 3.4 10^{-4}**			**$\varepsilon_{x,0}$ = 1.57 nm, $\sigma_{\delta,0}$ = 4.1 10^{-4}**			**$\varepsilon_{x,0}$ = 2.14 nm, $\sigma_{\delta,0}$ = 4.8 10^{-4}**		
$T_{x,y}$ (ms)	X	X	X	231	236	175	381	404	286
T_δ (ms)	X	X	X	57	58	54	75	79	73
$\varepsilon_{x,y}$ (nm)	X	X	X	2.12, 1.06	2.11, 1.05	2.38, 0.79	2.38, 1.19	2.36, 1.18	2.47, 1.07
σ_δ (10^{-4})	X	X	X	5.8	5.8	6.0	5.5	5.5	5.5

Proposed alternative: ERL

Injector Parameters	
Energy (MeV)	10
Charge per bunch (pC)	77
Normalized Emittance (mm.mrad)	1
Bunch length rms (ps)	2
Repetition Rate (CW, MHz)	1300
I_{beam} (mA)	100

ERL, IR Parameters	
Injection/Extraction energy (MeV)	10
Beam dump power (MW)	1
Energy max. (MeV)	530
Beam power @ 530 MeV (MW)	53
Emittance @ 500 MeV (nm.rad)	1.02
$\beta_{x,y}$ @ IP (m)	0.048
Beam size @ IP (μm)	7

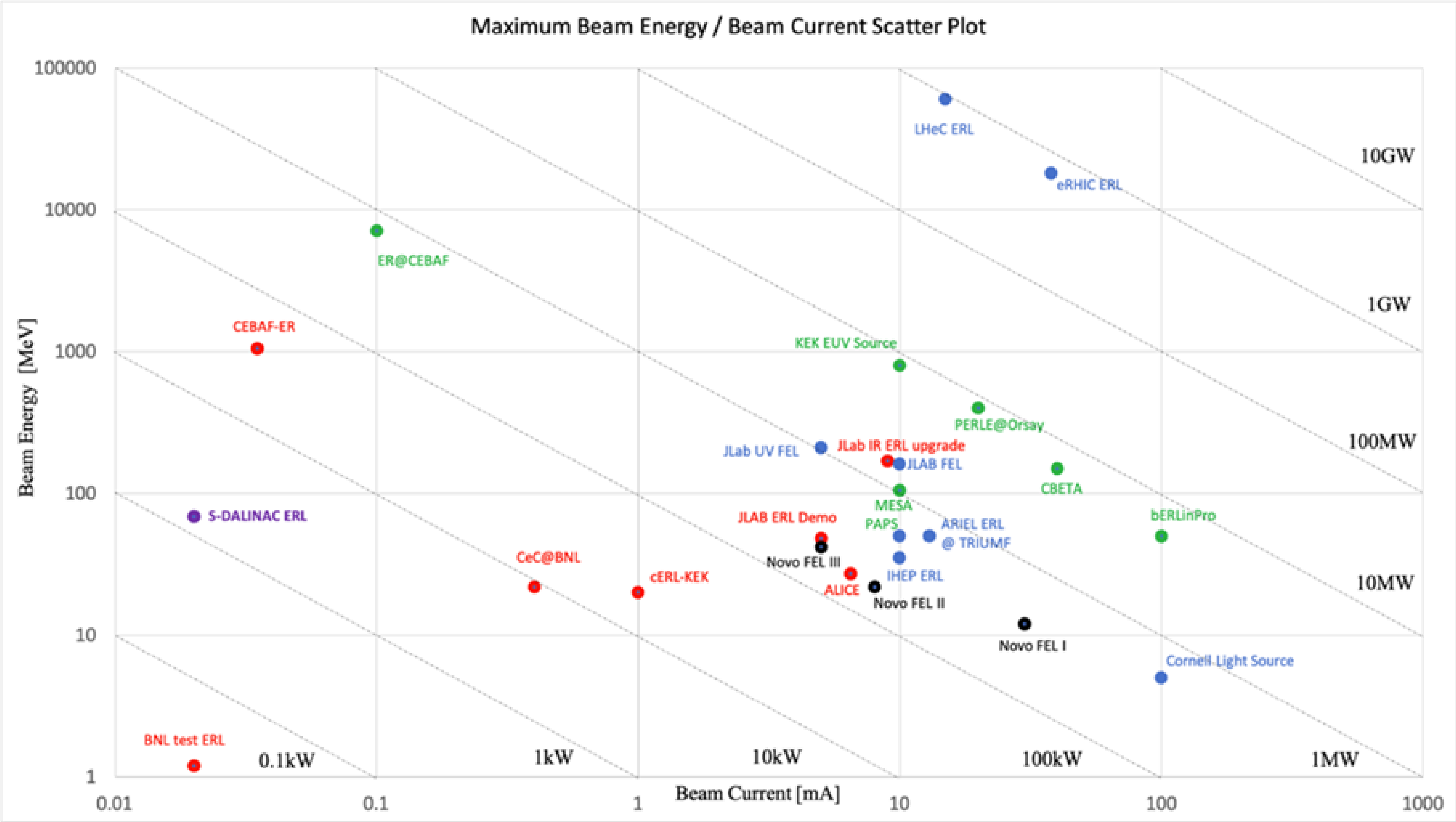
530 MeV ERL layout (130 MeV/SRF module)



Main lessons of ETIC

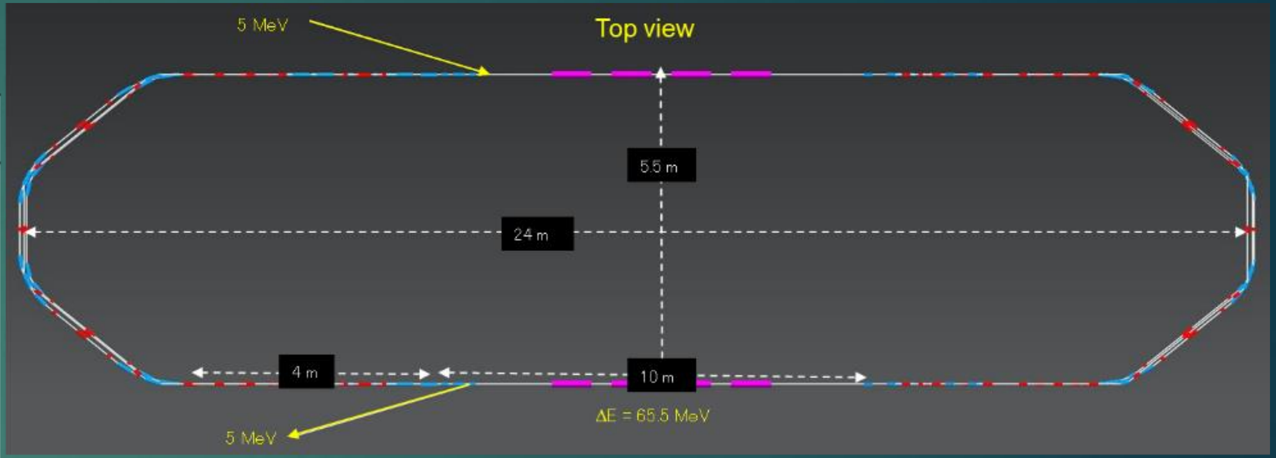
- Main limitation for an electron synchrotron is intra-beam scattering:
  - Realistic solution for electron energies above 700 MeV
  - Increasing the number of trapped ions enables to relax the contraints on beam current and thus to mitigate intra-beam scattering.
  - Sophisticated RF gymnactis may help (expensive and not covered in this study).
- ERL is a promissive alternative but
  - Solution less explored within ETIC: needs to consolidate the parameter set (beam current or emittance).
  - No cost estimate.
  - Limitations coming from the ion trap

ERLs in the world



PERLE@Orsay
Parameter set

Target Parameter	Unit	Value
Injection energy	MeV	7
Electron beam energy	MeV	500
Normalised Emittance $\gamma\varepsilon_{x,y}$	mm mrad	6
Average beam current	mA	20
Bunch charge	pC	500
Bunch length	mm	3
Bunch spacing	ns	25
RF frequency	MHz	801.58
Duty factor		CW



- Clear synergy with PERLE project:
  - Final energy in the range of 400-600 MeV and beam current of 20 mA

What is (not) covered by PERLE

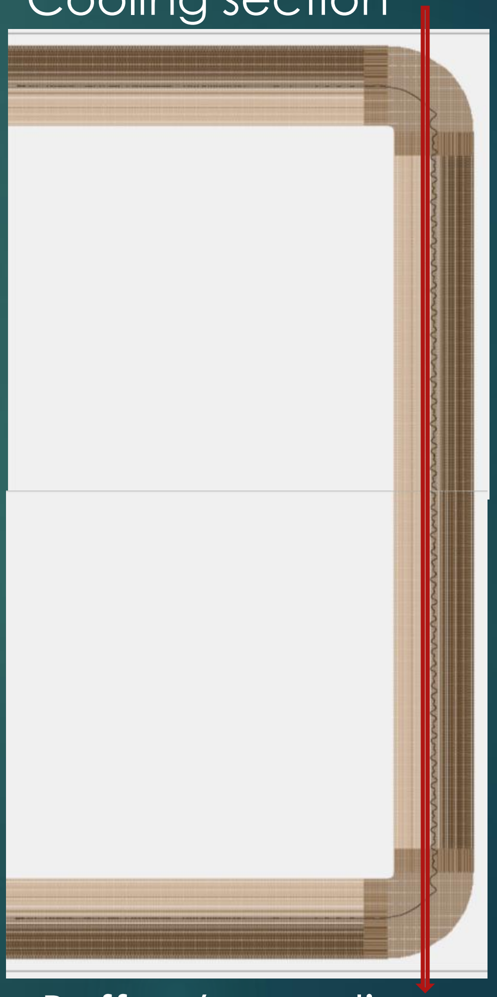
- PERLE studies have covered some topics:
  - Lattice design of the arcs
  - Design of the injector
  - Design of the cryomodules and magnets
  - Stability limitations because of beam breakup unstabilities (BBU)
- But some items are not covered:
  - Interaction region
  - Limitations because of the interaction with the trap
  - Parameter optimisation to optimise the luminosity

RF Trap dimensions

Preliminary study with SIMION, P. Delahaye

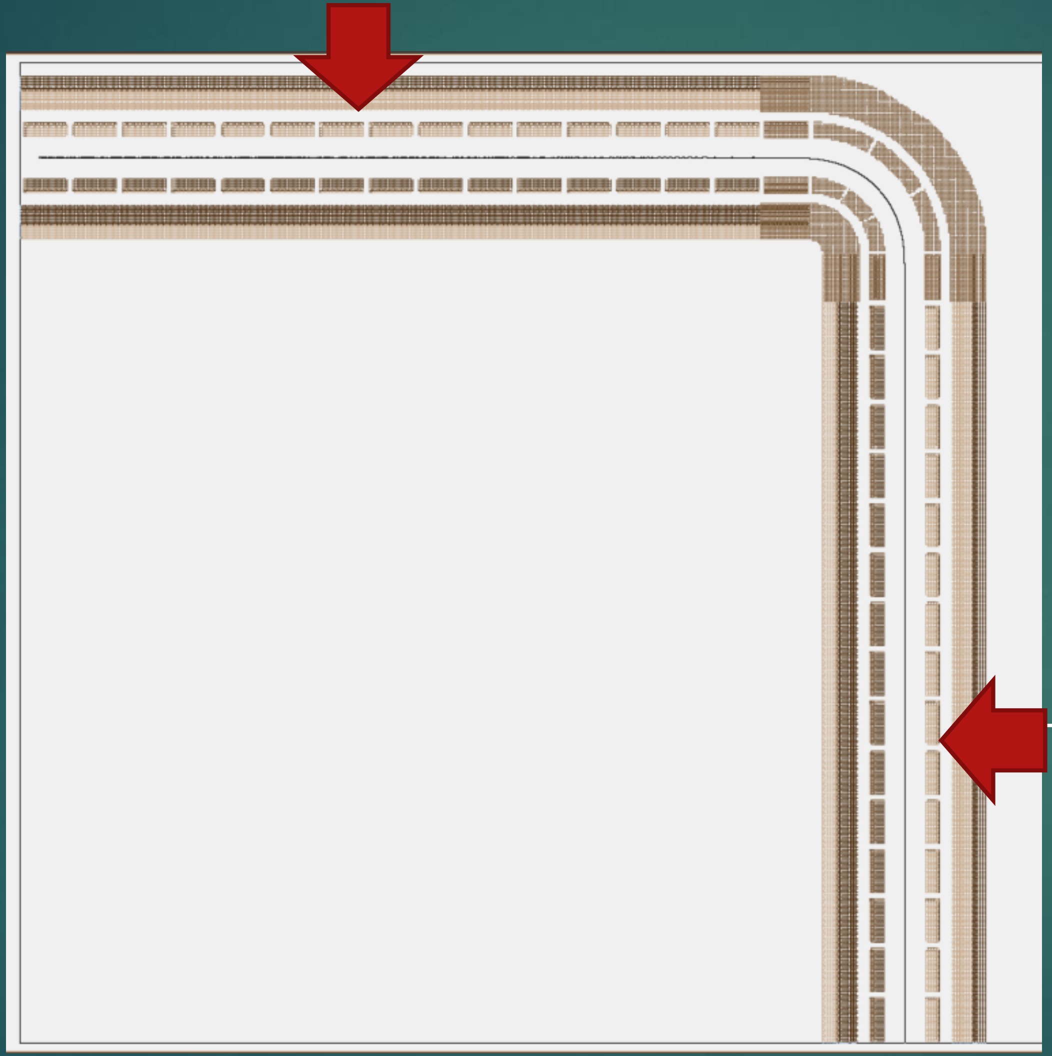
* Electrodes can be made thinner
- Of course some mechanics needed to maintain electrodes in place

Q pole section



Cooling section with 4He gas, T=77K

RF: 10 kV, 10 MHz
DC gradient ~1V/4 cm

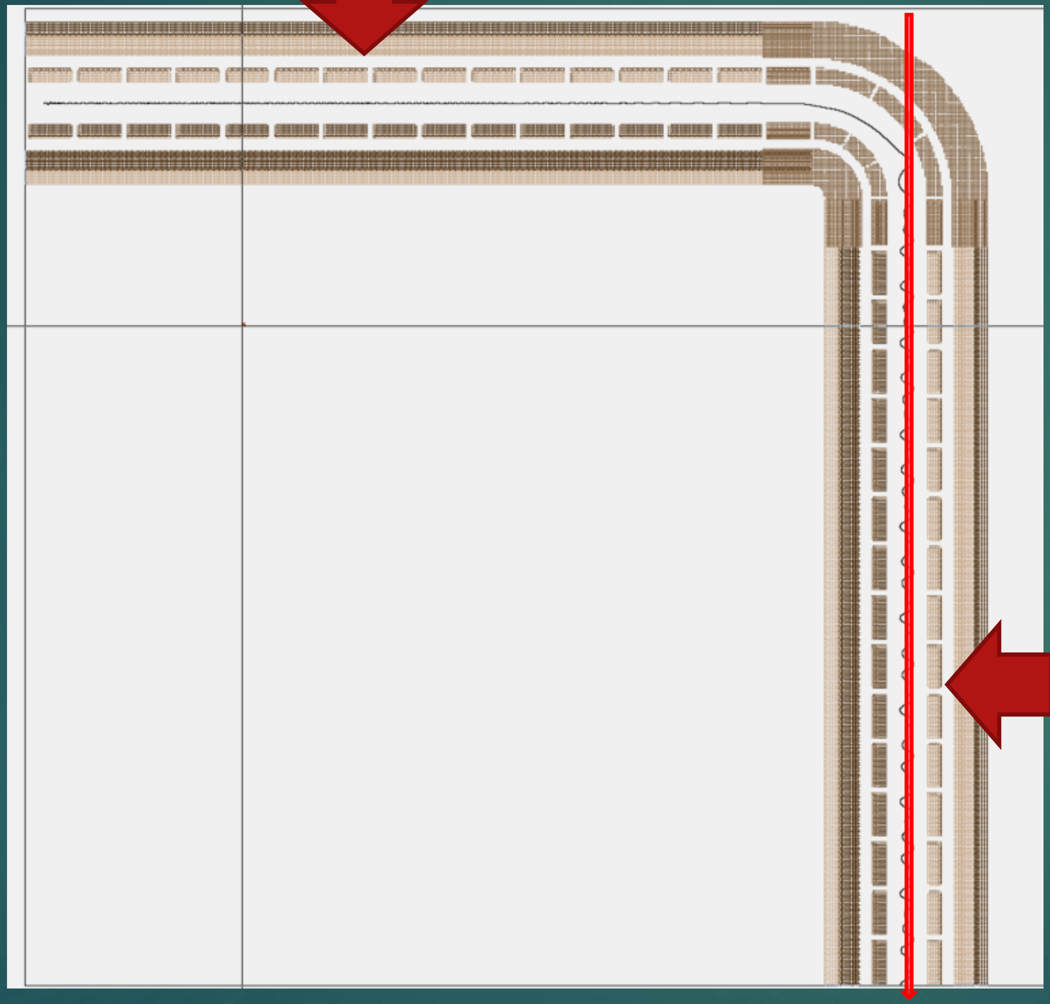


Ideal case, no ebeam
Radius ~ 0.1 mm can be achieved

Trap section, no gas

Cooling section with 4He gas, T=77K

RF: 10 kV, 10 MHz
DC gradient ~1V/4 cm



First results with I=0.2A, radius 0.1mm
Beware:
Orders of magnitude are to be checked

Trap section, no gas

E beam

With electron beam,
First simulations indicate the injection will require some tuning

Work proposed: ERL

- To integrate a compact interaction region into the design
- To identify limitations coming from the trap:
  - Minimum achievable ion beam size
  - Maximum allowed beam current
  - Maximum trapped ions (N_{RI})
- Consolidation of the parameter set and the achievable luminosity
- To explore other ERL configurations: PERLE is a multi-path ERL. Comparison with a single turn or a dogbone ERL will be explored.
- To make the cost estimate of the machine.

Work proposed: trap

- Optimizing the injection in the e- beam
- Simulate charge breeding
- Simulate ion heating
- Simulate recirculation in cooling section
- Simulate e- beam space charge compensation
- Rotate q poles every 10cm for e- beam stability
- Define q poles geometry acceptable for detection
- …