Overview of JLEIC beam physics simulations

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Overview

- Machine specifications
- CEBAF machine as an electron injector
- Electron ring
- Ion linac
- Ion booster
- Ion ring
- Conclusions

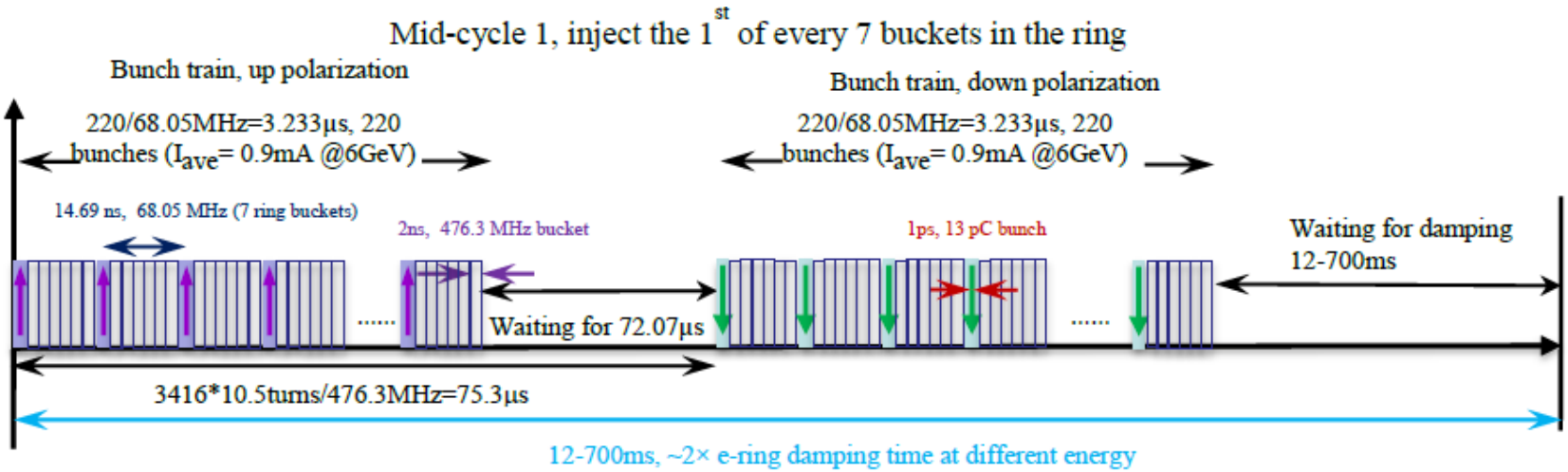
Machine specifications

Table 3.1: MEIC main design parameters for a full-acceptance detector.

CM energy	GeV	21.9 (low)		44.7 (medium)		63.3 (high)	
		p	*e*	*p*	*E*	*p*	*e*
Beam energy	GeV	30	4	100	5	100	10
Collision frequency	MHz	476		476		159	
Particles per bunch	10^{10}	0.66	3.9	0.66	3.9	2.0	2.8
Beam current	A	0.5	3	0.5	3	0.5	0.72
Polarization	%	>70	>70	>70	>70	>70	>70
Bunch length, RMS	cm	2.5	1.2	1.0	1.2	2.5	1.2
Norm. emittance, vert./horz.	μm	0.5/0.5	74/74	1/0.5	144/72	1.2/0.6	1152/576
Horizontal and vertical β^*	cm	3 (1.2)	5 (2)	2/4 (1.6/0.8)	2.6/1.3 (1.6/0.8)	5/2.5 (2/1)	2.4/1.2 (1.6/0.8)
Vert. beam-beam parameter		0.01	0.02	0.006 (0.004)	0.014 (0.021)	0.002 (0.001)	0.013 (0.021)
Laslett tune-shift		0.055	small	0.01	small	0.01	small
Detector space	m	7/3.6 (4.5/4.5)	3.2/3 (3/3)	7/3.6 (4.5/4.5)	3.2/3 (3/3)	7/3.6 (4.5/4.5)	3.2/3 (3/3)
Hour-glass (HG) reduction factor		0.89 (0.67)		0.89 (0.74)		0.73 (0.58)	
Lumi./IP, w/HG correction, 10^{33}	$cm^{-2}s^{1}$	1.9 (3.5)		4.6 (7.5)		1.0 (1.4)	

(Values for a high-luminosity detector with a 4.5 m ion detector space are given in parentheses.)

CEBAF as an Electron Injector

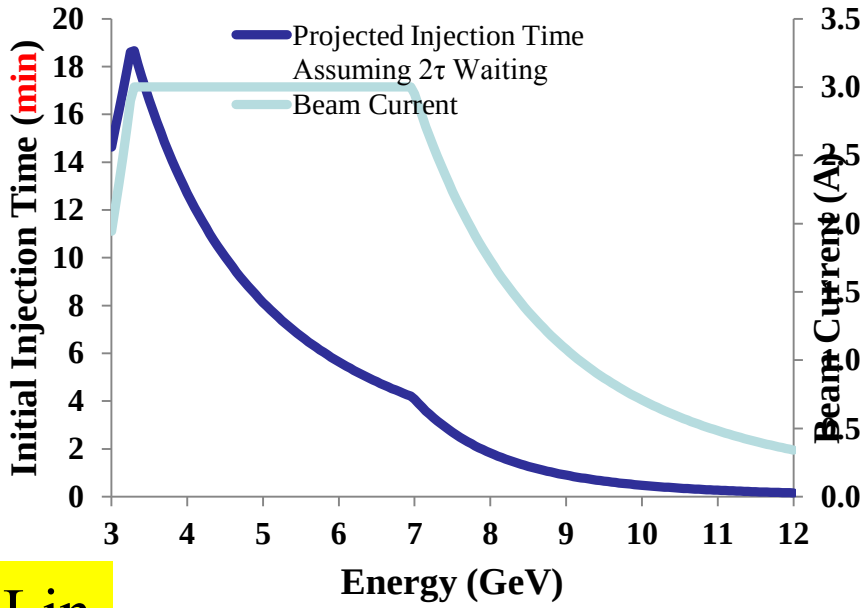


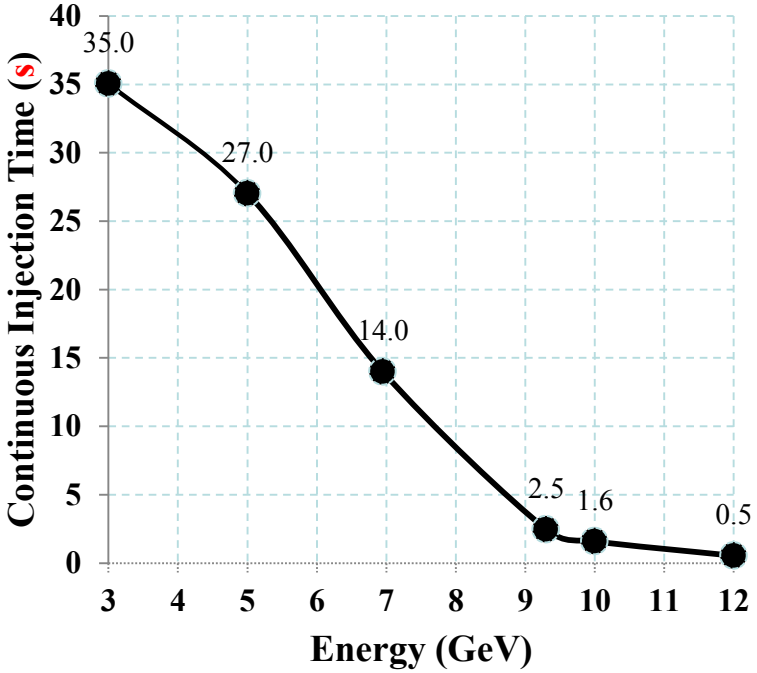
We studied various scenarios. Bunch pattern for filling the Ring will require a 13 pC injector.

Design for such injector will be carried out in GPT/ASTRA
We have experience doing so for other machines.
A design for 40pC/300 kV gun was studied for another application

Injection into Electron Ring

- Extensive studies on baseline designs for :
  - Reusing PEPII magnet, lowering Emittance in ring
- Chromatic corrections/dynamic aperture and other single particle dynamics done using MAD-X/ELEGANT.
- Top-off injection scheme calculated:





F. Lin

Injection into electron ring (cont)

- Actual injection will use a vertical septum. Similar to PEPII design.
- Still need to do this. Plan to simulate using ELEGANT.

Electron Polarization

- Equilibrium electron polarization:
  (Derbenev-Kondratenko formula)

$$P_{dk} = -\frac{8}{5\sqrt{3}} \frac{\oint ds \left\langle \frac{1}{|\rho(s)|^3} \hat{b} \cdot \left(\hat{n} - \frac{\partial \hat{n}}{\partial \delta} \right) \right\rangle_s}{\oint ds \left\langle \frac{1}{|\rho(s)|^3} \left(1 - \frac{2}{9} (\hat{n} \cdot \hat{s})^2 + \frac{11}{18} \left(\frac{\partial \hat{n}}{\partial \delta} \right)^2 \right) \right\rangle_s}$$

- Polarization lifetime:

$$\tau_{dk}^{-1} = \frac{5\sqrt{3}}{8} \frac{r_e \gamma^5 h / 2\pi}{m_e} \frac{1}{C} \oint ds \left\langle \frac{1 - \frac{2}{9} (\hat{n} \cdot \hat{s})^2 + \frac{11}{18} \left(\frac{\partial \hat{n}}{\partial \delta} \right)^2}{|\rho(s)|^3} \right\rangle_s$$

Spin-orbit coupling function

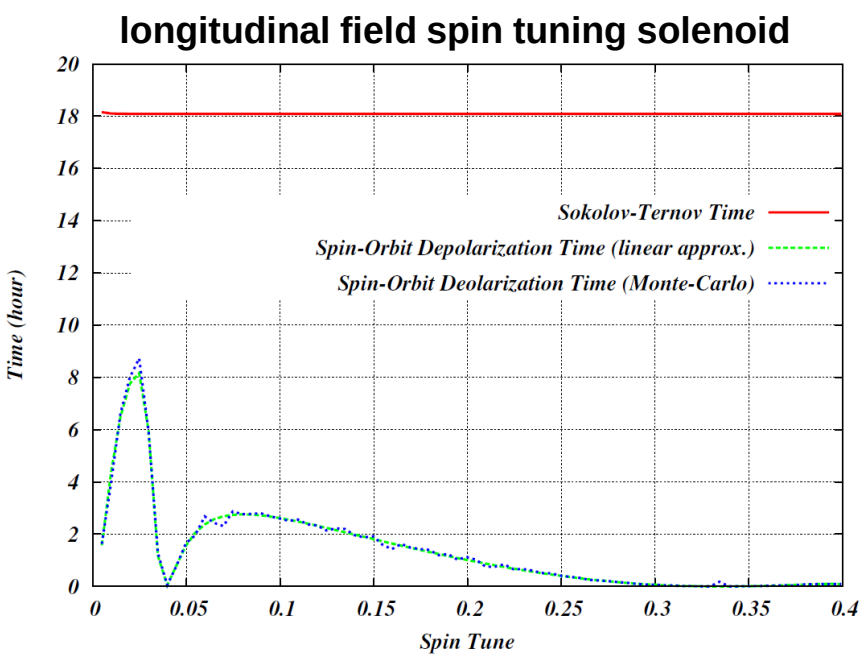
- Computer algorithm for estimating the equilibrium polarization and lifetime
  - **Analytically**, method based on evaluating $\hat{n}$ and $\left| \frac{\partial \hat{n}}{\partial \delta} \right|^2$ in the D-K formula
    - SLICK (8x8 matrices) : linearized orbit motion + linearized spin motion
    - Only first order resonance behavior: $\nu_{spin} = k_0 + k_I \nu_I + k_{II} \nu_{II} + k_{III} \nu_{III}$, with $|k_I| + |k_{II}| + |k_{III}| = 1$
  - **Numerically**, Monte-Carlo simulation in which particles and their spins are tracked while photon emission is simulated approximately and the depolarization rate is estimated.
    - SLICKTRACK (9x9 matrices) : linearized orbit motion + non-linearized spin motion
    - Higher order resonance behavior: $\nu_{spin} = k_0 + k_I \nu_I + k_{II} \nu_{II} + k_{III} \nu_{III}$, with $|k_I| + |k_{II}| + |k_{III}| > 1$

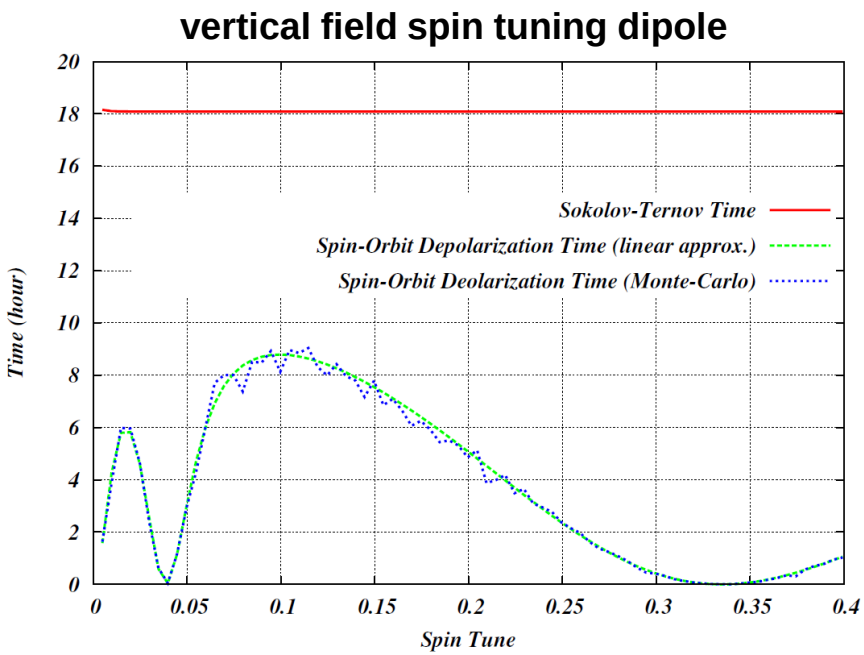
F. Lin, D. Barber

Spin tune calculations

- Carried out using SLICK (F.Lin, D. Barber)

- Figure-8 shape means no synchro-betatron resonances





5 GeV calculation. Need to redo at 10 GeV

Other instabilities

- Longitudinal microwave instability was estimated (R.Li)

R. Li

	PEP-II (LER)	JLEIC Electron Ring		
E (GeV)	3.1	4	5	10
I_p(A)	113	44.6 $\xrightarrow{N_b\,-}$	62.35	62.35
h (10^{-3})	1.31	2.2	2.2	2.2
s_d (10^{-4})	8.0	3.64	4.55	9.1
$\lvert Z_{\parallel}/n\rvert_{\mathrm{eff,th}}$ [Ω]	0.14	0.12	0.23	2.56

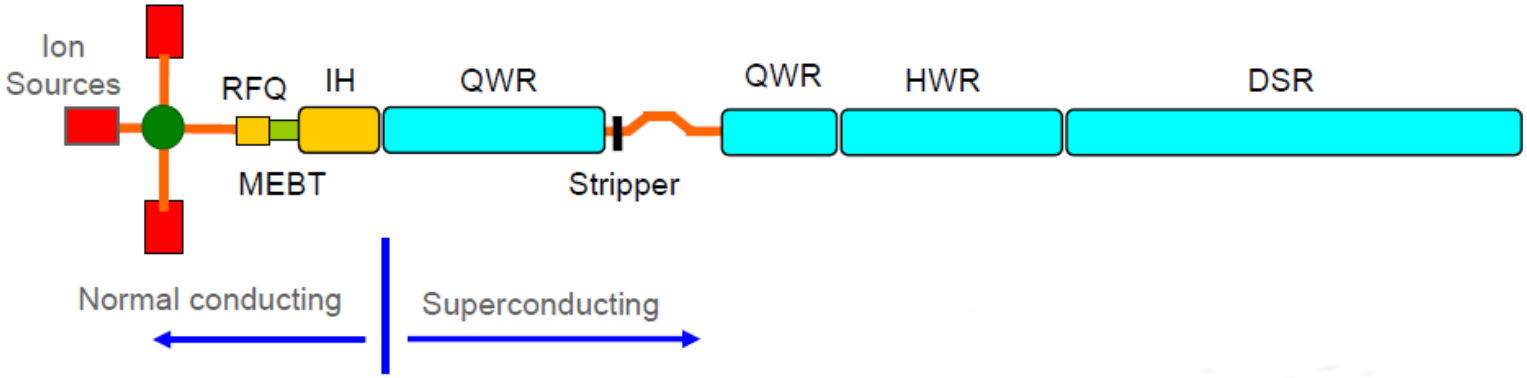
Conclusion: Mostly safe from it unless one runs at lower energy.

TODO: Detailed impedance budget of the ring. Critical for this and other types of longitudinal unstabilities.

Other instabilities

- Ion trapping instability, fast ion instability
- Need to make careful estimates. We have not done the simulations yet. Aware of studies for ILC (L. Wang, T. Raubenheimer, A. Wolsky) where such simulations were done.
- Suggestions welcomed on how to proceed.

Ion Sources+Ion Linac



Based on a heavy ion driver design for RIA.
Extensively studied By P. Ostroumov and collaborators.
They did:

- Start to end from linac to injection into then prebooster.
- Polarization preservation studies,
- Stripping optimization, space charge optimizations, etc…
- Is there a need for more simulations? Not sure. We can use the output of Peter's simulations to feed the booster simulations.

Ion booster

- We have a complete lattice. It is imaginary gamma-t. single particle dynamics design was done in Optim and ELEGANT.

Many effects to study:

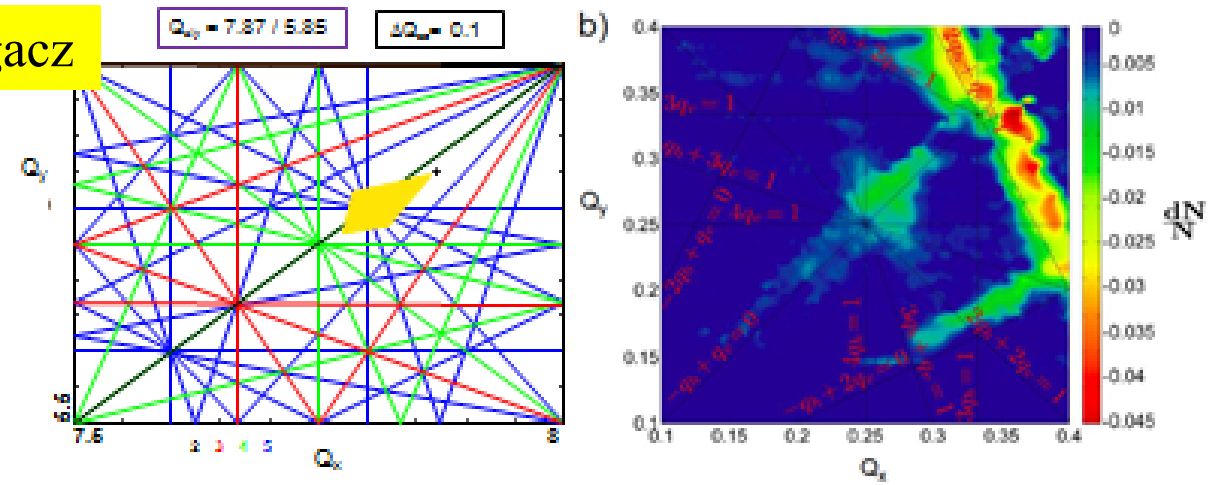
- Injection from ion linac (phase-space painting scheme for ions, stripping injection for protons ?)
- Incoherent space charge tune shift effects
- Resonance crossing
- Halo Generation
- Bunching in the booster
- DC cooling
- Ramping
- Extraction and filling into the ion collider.

Ion booster (cont)

Ion Booster Optimization for Extreme Space-Charge

- The goal of the simulation is to compose the so-called **beam-loss tune scan** – a fractional beam-loss as a function of the horizontal and vertical tunes – similar to the one carried out for the PS Booster at CERN.

A. Bogacz



a) Tune diagram for MEIC booster: the sum and difference resonances and the working point.
b) Normalized beam loss as a function of tunes - composed for the PS Booster

Particle Tracking – Simulation Studies

A. Bogacz

- Study beam conditions at the injection plateau, where the effect of space-charge is considerable (e.g. Laslett tune shift greater than 0.3), and a bunched beam is stored for a long time (10^5 or more turns).

- When the machine tunes cross a stable resonance it increases the transverse amplitude of particles, leading to halo formation and eventually beam loss.

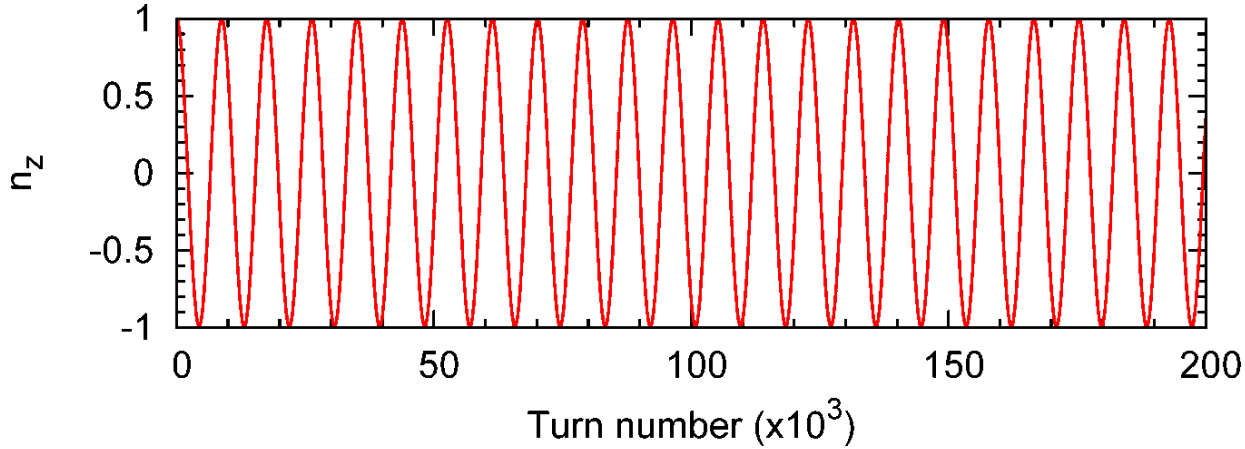
- These processes will be studied numerically via multi-particle tracking **SYNERGIA** through a realistic booster lattice in the presence of magnet multipole errors (super-ferric magnet design).

Ion booster (cont)

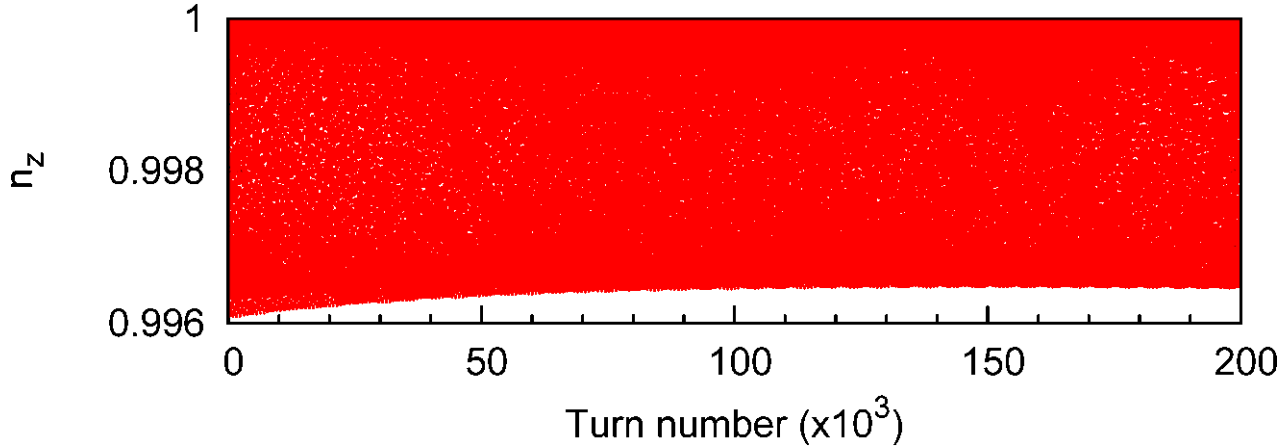
- Extensive spin tracking studies performed by A.M. Kondratenko, M.A. Kondratenko, and Yu.N. Filatov
- Was done with original booster design using ZGOUBI
- May need to be redone with the new imaginary gamma-t booster for final CDR. Results not expected to change from the previous 8GeV booster lattice.

Ion booster spin tracking

- One arc dipole rolled by 0.2 mrad, no closed orbit correction



- After addition of a 1° spin rotator solenoid in the straight



Ion collider

- Extensive work was done on lattice dynamics. See past talks by V. Morozov et al. It was designed using MAD-X.
- Fruitful collaboration with SLAC. (Y. Nosochkov)
  - Chromatic correction scheme
  - Dynamic aperture studies
  - effect of multipole errors on DA
  - Specifications for ion lattice magnets . Done with ELEGANT. (Wei)
  - Spin tracking, polarization preservation, spin flip . Still in progress. This is affected by other things such as the beam-beam effects. We will use ZGOUBI to do so once we have optimized the ion lattice for the other effects

Ion collider (cont)

- Injection scheme from the booster
- Bunch-splitting in collider

We have a grad student Randika Gamage (T.Satogata's student) who will do his phD on the collider and develop the bunch splitting.
They started using ESME (for longitudinal) and are planning to use SYNERGIA to do the full study of injection, ramping and bunch splitting

Ion collider (cont)

- Beam-Beam effects
  - We will use a combination of several codes to assess the beam beam effects as well as the implications of gear changing (for synchronizing ion with e-BeamBeam3D, GHOST (see talk by B. Terzic) and Guinea-pig (LHC) are candidates.
  - Bunched beam cooling
    Working group led by Steve Benson.
    Using ASTRA, IMPACT, TSTEP, ELEGANT, BETACOOL, MAD-X.

Ion collider (cont)

- Electron cloud effects
  - Short bunch+high intensity => ion cloud
  - Estimates by Zimmerman et al. show that one might be affected by it for the high energy running (100GeV proton). Even that was on the edge of being ok.
  - Probably need to redo these estimates for the final JLEIC setup. They used ECLOUD and PEI.
  - Is it a problem in the cooler ? Needs to be estimated.(see ECLOUD02 paper by Rumolo et al.)
  - **Likely need help to do these simulations**

Summary

- Framework in place to carry out simulations for pre-CDR
- Focus is to validate the design.
- Would welcome suggestions on particular topics such as the electron cloud and ion trapping
- Any suggestions on anything else ?