# Progress on MEeIC Design

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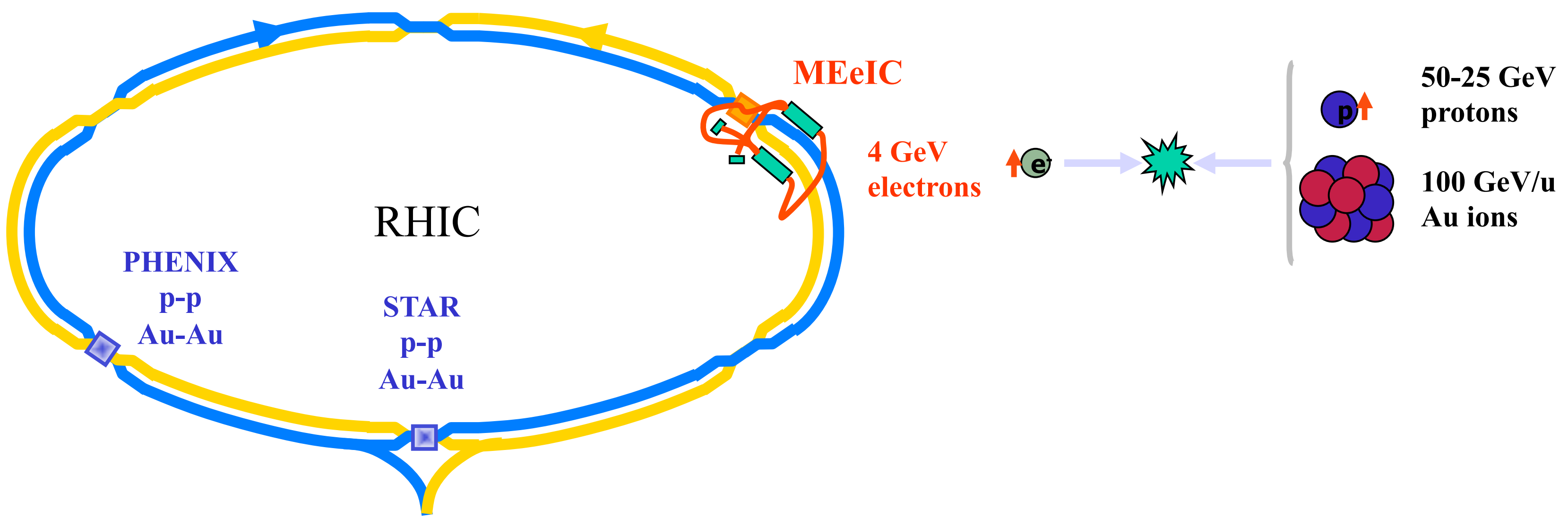
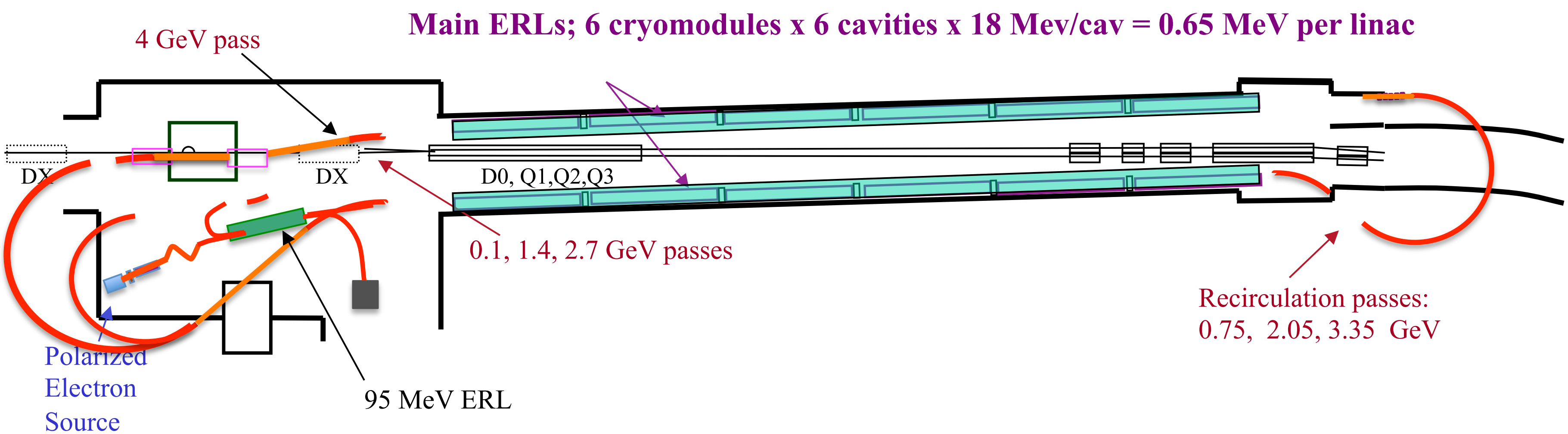
# RHIC and MEeIC




- MEeIC – Medium Energy electron-Ion Collider.
- Takes advantage of the existing RHIC machine. Electrons collide with protons and ions from RHIC Blue ring.
- Electron-proton, electron-heavy ion collisions in IR2 RHIC region with up to 63 GeV center-of-mass energy.
- Polarized electron and proton beams. Longitudinal polarization orientation at the collision point for both beams.
- Parallel operation with the p-p (or ion-ion) collisions at PHENIX and STAR detectors.
- Electron accelerator is based on energy-recovery linacs.

# MEeIC at IR2 region



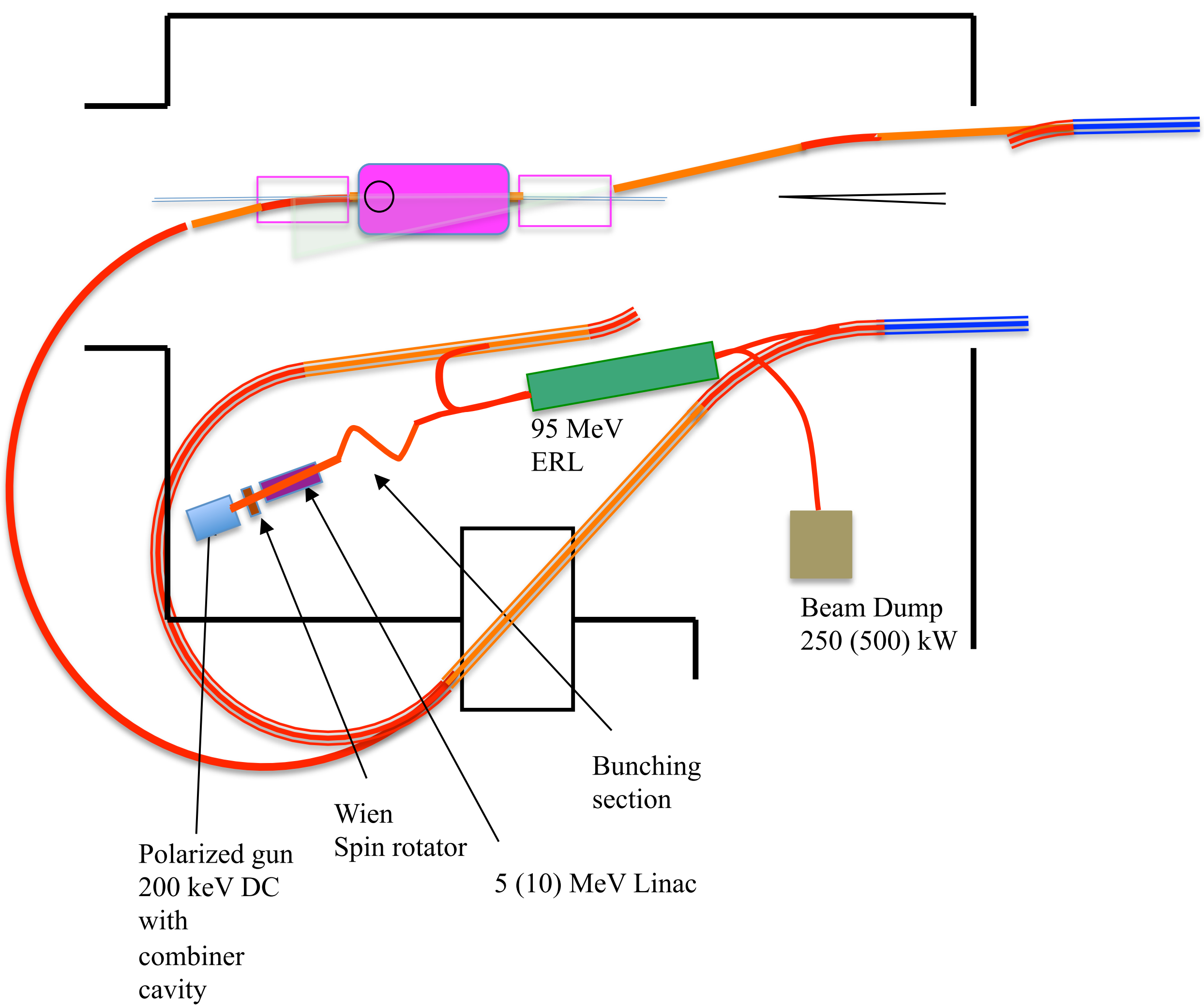

IR2 region:

- asymmetric detector hall is very appropriate for asymmetric detector for e-p collisions
- long wide (7.3m) tunnel on one side from the IR is good to place the ERLs

Detector hall accommodates also the injector system (polarized gun, bunching system, pre-accelerator ERL) and the beam dump.

Recirculation passes are going outside of the existing tunnel: warm magnets, acceptable synchrotron radiation power.
Corresponding tunnel reconstruction is estimated to about $2M.

# IR2 Hall : Detector and Injector System



# Machine luminosity

Limiting factors:

- Maximum average electron current as allowed by the polarized source, SR losses, BBU.
- Electron charge/bunch (or peak current): wakes
- Electron beam disruption
- Minimum collision beam size: proton beta* is limited by existing RHIC triplets.
- Maximum proton current: electron cloud, beam-beam from p-p collision points .

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**Main design line: no cooling assumed for the proton beam.**

**Upgrade options (with higher luminosity):**
**-pre-cooling (e-cooling) at the injection energy (like in eRHIC)**
**-cooling at high (store) energy (CEC). No parallel p-p operation possible.**

# MEEIC parameters for e-p collisions

| | not cooled | | pre-cooled | | high energy cooling | |
|---|---|---|---|---|---|---|
| | p | e | p | e | p | e |
| Energy, GeV | **250** | **4** | **250** | **4** | **250** | **4** |
| Number of bunches | **111** | | **111** | | **111** | |
| Bunch intensity, $10^{11}$ | **2.0** | **0.31** | **2.0** | **0.31** | **2.0** | **0.31** |
| Bunch charge, nC | **32** | **5** | **32** | **5** | **32** | **5** |
| Normalized emittance, 1e-6 m, 95% for p / rms for e | **15** | **73** | **6** | **29** | **1.5** | **7.3** |
| rms emittance, nm | **9.4** | **9.4** | **3.8** | **3.8** | **0.94** | **0.94** |
| beta*, cm | **50** | **50** | **50** | **50** | **50** | **50** |
| rms bunch length, cm | **20** | **0.2** | **20** | **0.2** | **5** | **0.2** |
| beam-beam for p /disruption for e | **1.5e-3** | **3.1** | **3.8e-3** | **7.7** | **0.015** | **7.7** |
| Peak Luminosity, 1e32, $cm^{-2}s^{-1}$ | **0.93** | | **2.3** | | **9.3** | |

# Proton and ion beam for MEeIC

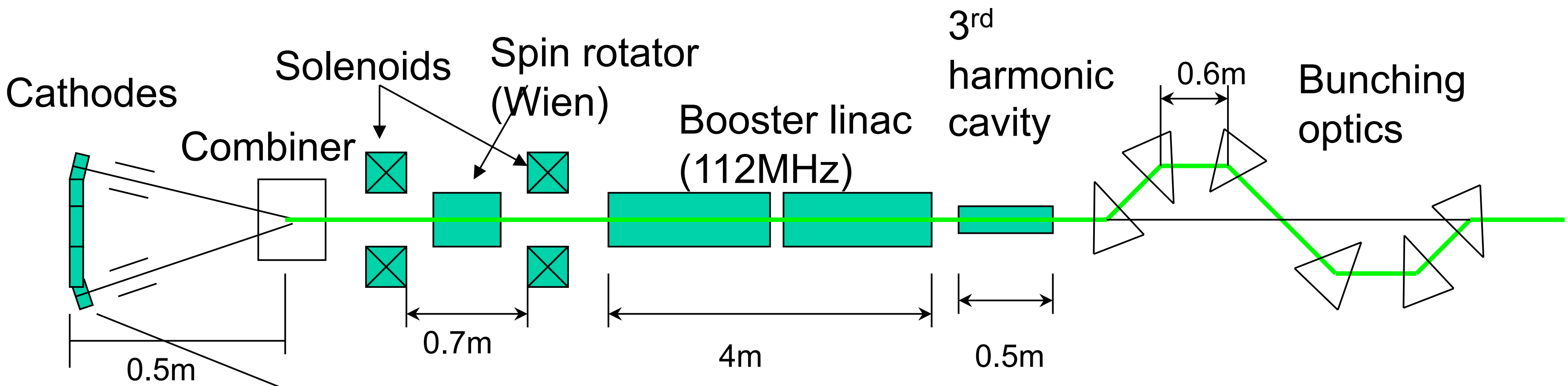
- Goal: modifications for proton beam should be minimal
- IR design: existing triplets, removal of IR2 DX magnets
- Also will take advantages of planned improvements in RHIC (for RHIC operation): 56 MHz SRF, stochastic cooling (for ions) …

# Proton beam parmeters

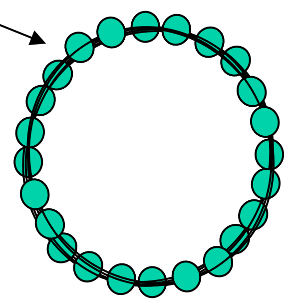
| | For MEeIC | Presently achieved |
|---|---|---|
| Energy, GeV | **250** | **Several runs at 100 GeV.<br>First 250 GeV run is underway** |
| Number of bunches | **111** | **111** |
| Bunch intensity, $10^{11}$ | **2.0** | **1.7 (at 100 GeV)** |
| Normalized 95% emittance, 1e-6 m | **15** | **<10 mm*mrad at the injection<br>~18 mm*mrad at the store on average in previous runs** |
| beta*, cm | **50** | **70** |
| rms bunch length, cm | **20** | **50 cm with 28 MHz system<br>In future, shorter bunches with combination of 9 MHz RF (ramp) + 56 MHz<br>SRF (store)** |
| Polarization, % | **70** | **60 (at 100 GeV)** |

# Injector configuration

X. Chang




200 kV DC gun
with multiple cathodes
50 mA CW current
~1ns pulses (5nC)
(E.Tsentalovich)

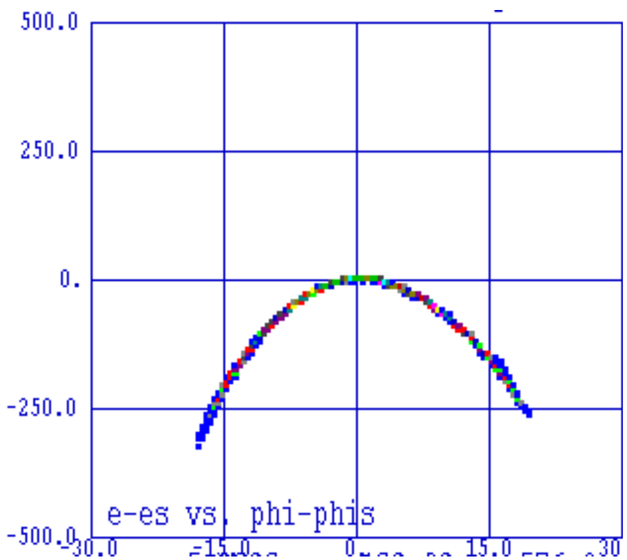


V.Litvinenko's idea

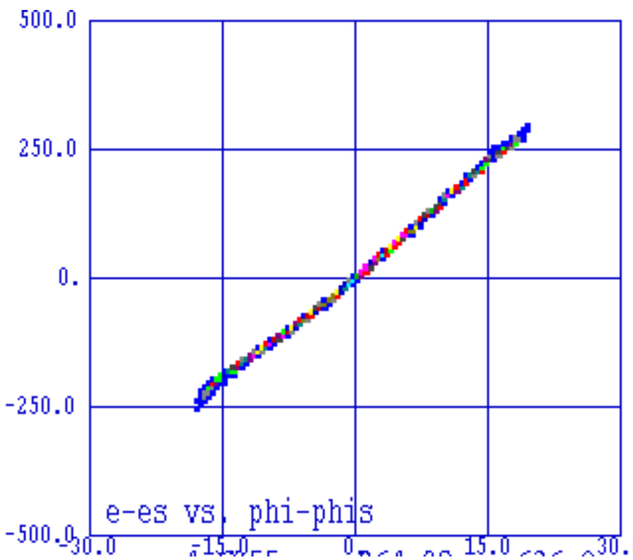
## Injector design:

- Transport of the beam from the source to the pre-accelerator ERL with minimal emittance deterioration
- Bunch compression (to 2mm rms)
- Spin rotation (if needed)

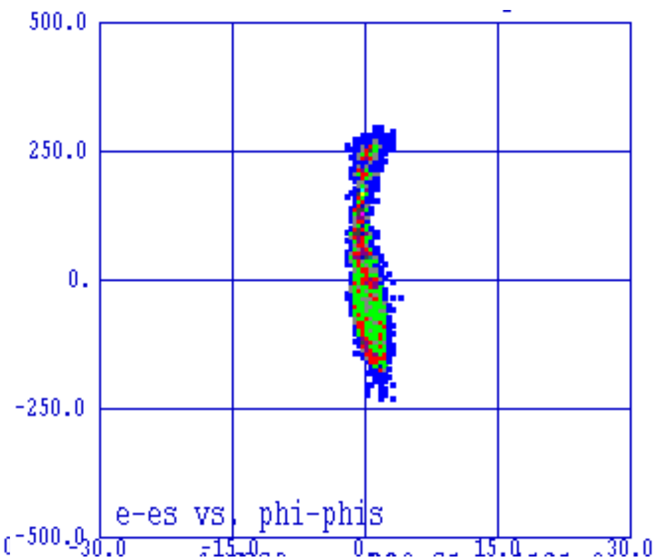
# Longitudinal phase space
# Beam compression process




After Booster linac



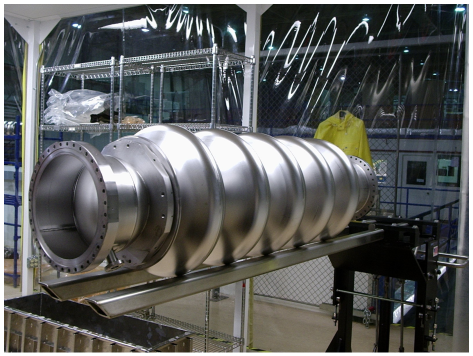

After 3rd harmonic cavity




After buncher optics

# SRF Linac

I. Ben-Zvi, A.Burrill, R.Calaga, H.Hahn, L.Hammons …



The ERLs will use 703 MHz superconducting RF cavities for the acceleration and the energy recovery.
State-of-the-art cavity design for high current beam operation.

Recently: successful cooldown of a test cavity (ERL Test Facility), first measurements of EM modes.

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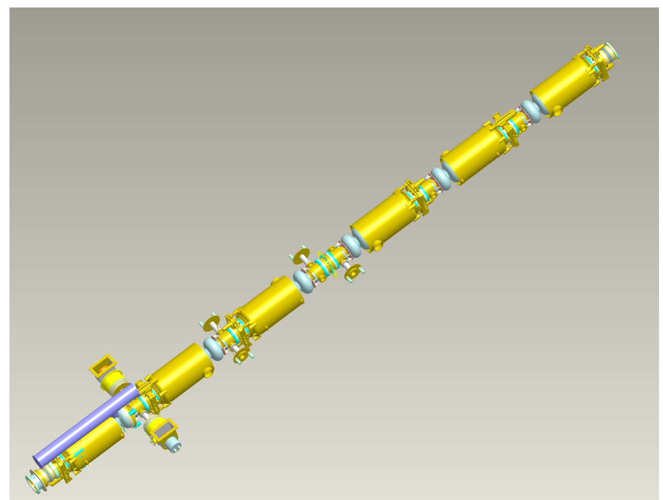
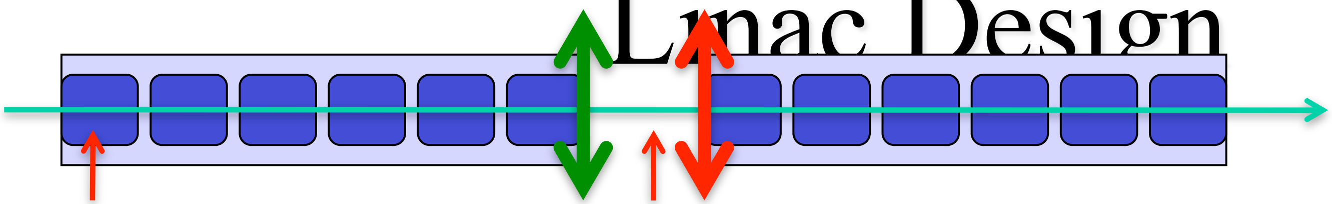
36 cavities per linac. Design of individual crymodule, incorporating 6 SRF cavities is under development.

The challenge: to make the design (fundamental couplers, HOM dampers, tuners ..) as compact as possible, to fit the existing straight section of the tunnel.



# Linac Design

E.Pozdeyev



703.75 MHz
1.6 m long

Drift
1.5 m long

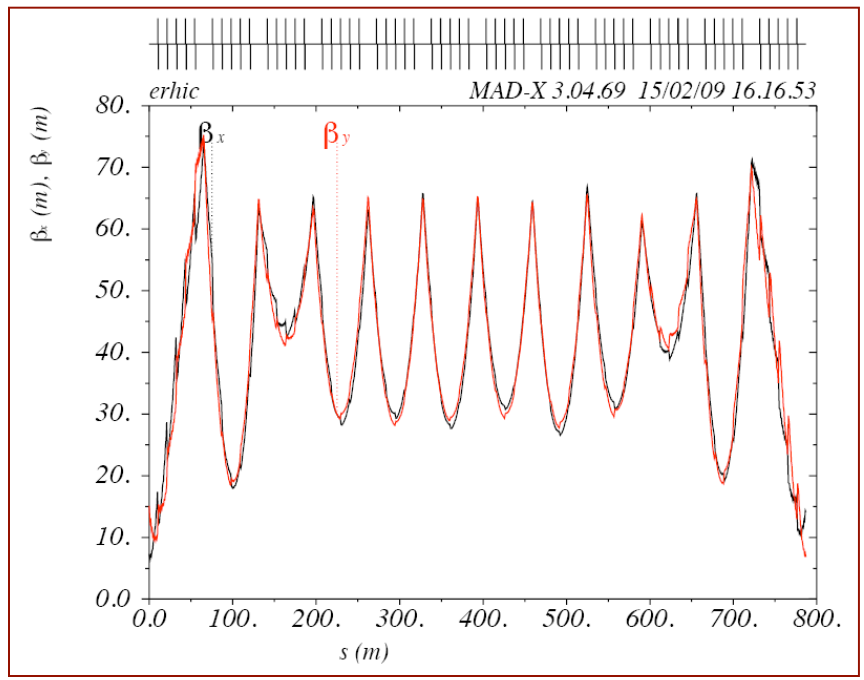
65m total linac length
All cold: no warm-to-cold transition

**Constant quadrupole gradient lattice**
**Avoids beta-function increase with beam energy**
**Simplifies requirements for mergers/splitters**

### Current breakdown of the linac

- **N cavities = 6 (per module)**
- **N modules per linac = 6**
- **N linacs = 2**
- **L module = 9.6m**
- **L period = 10.6 m**
- **$E_f$ = 18.0 MeV/m**
- **$\langle dE/ds \rangle$ = 10.2 MeV/m**

**100 MeV** → **4 GeV** → **100 MeV**



# Recirculation Passes and IR Lattice Design

Lattice requirements/issues:

-asynchronous recirculation passes ( $M_{56}$=0 )

-control of path length and $M_{56}$ parameter

-minimize the dispersion function

-warm dipole and the quadrupole magnets
-merging/splitting beams in different recirculation passes with proper matching to the linacs

-managing the synchrotron radiation through detector region

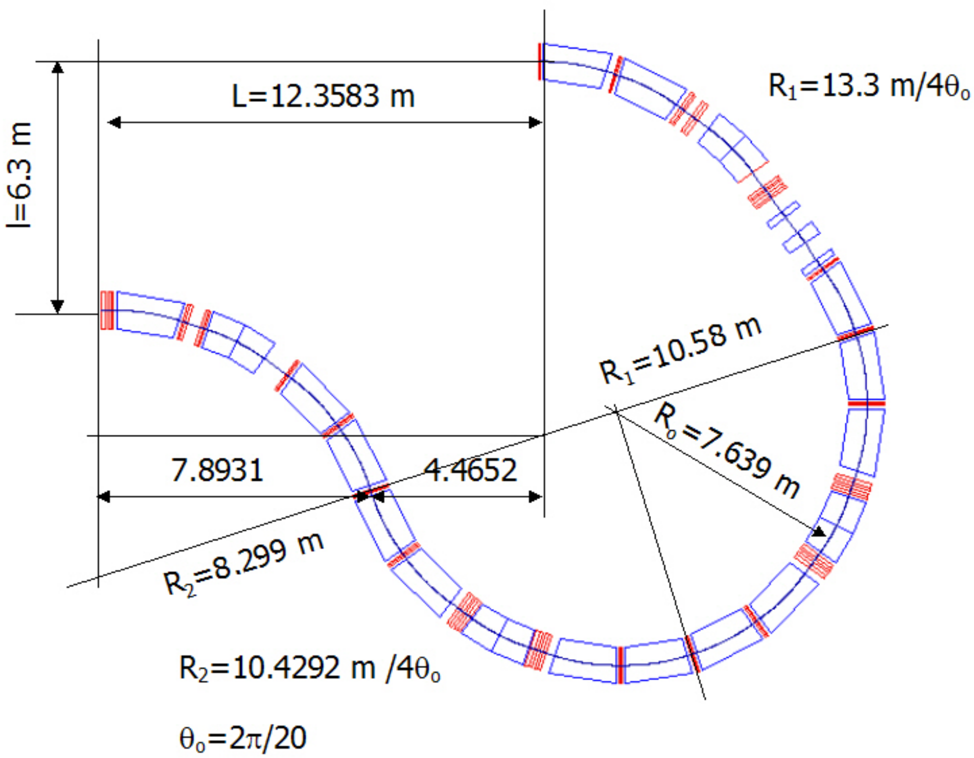
-integration of the accelerator and detector design (detector magnets …)

-low energy transport optics for high momenum spread beam

Lattice design development:

D.Trbojevic, D.Kayran, C.Montag, B.Parker, S.Tepikian,N.Tsoupas

# Asynchronous arcs: 3.35 GeV
## Dmitri Kayran, Dejan Trbojevic



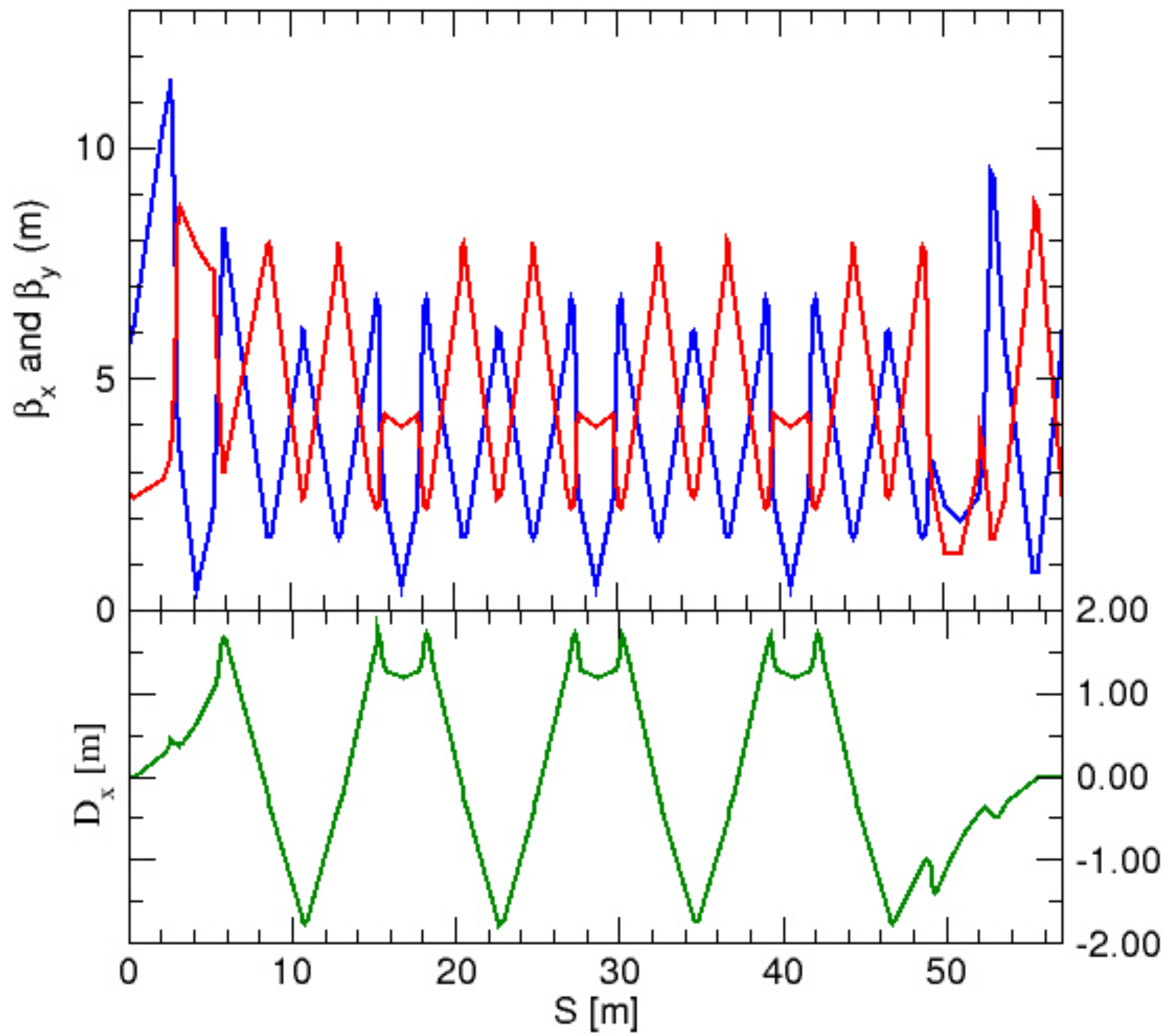

Nice solution has been found for recirculation pass lattice:

- high dipole filling factor leads to the compact lattice
- $M_{56}$ adjustments using doublets

Max dipole field 1.84 T

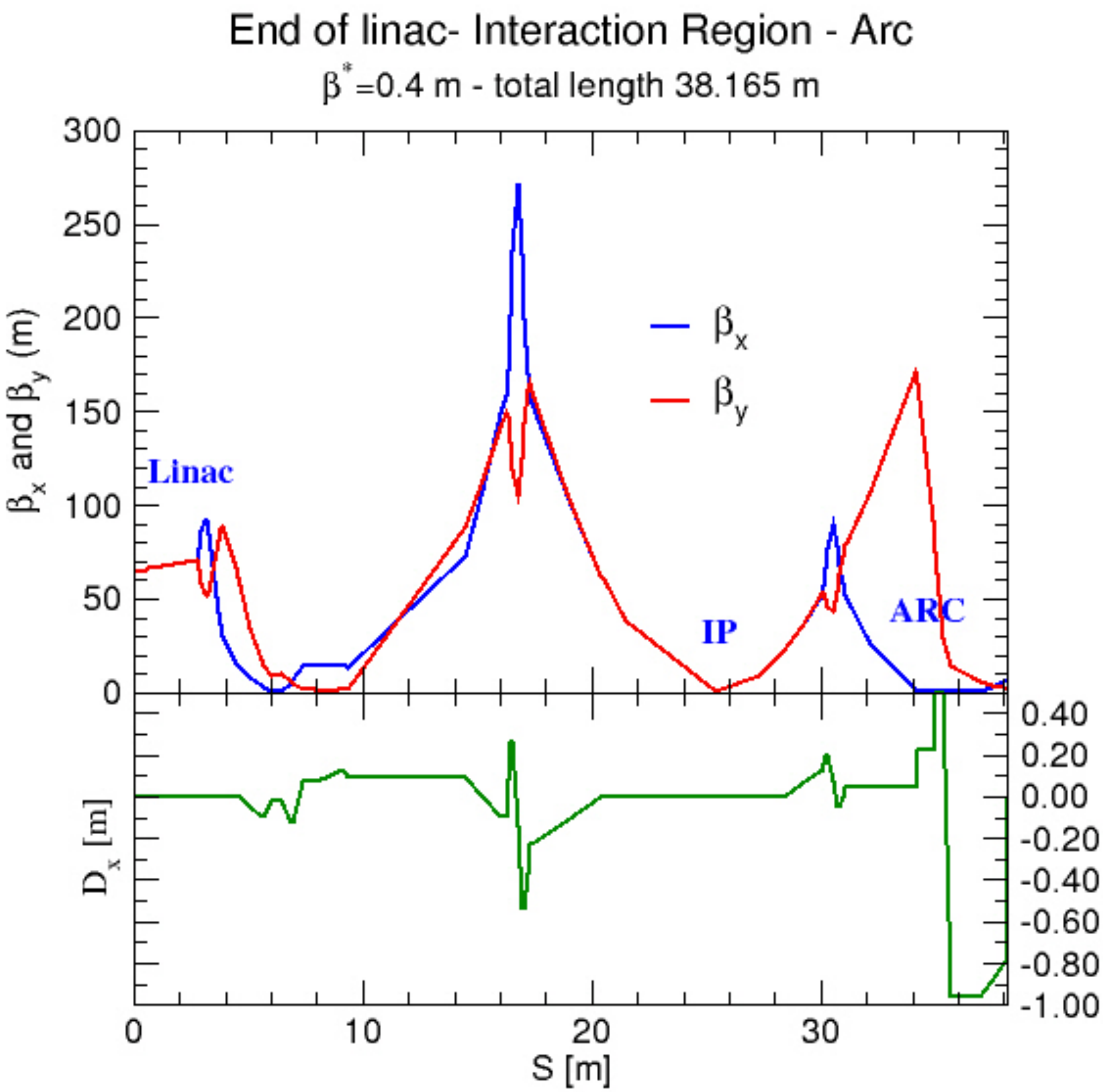
SR radiation power load <2kW/m

**Example of recirculation pass optics (for 3.35 GeV pass)**
**D.Kayran, D.Trbojevic**



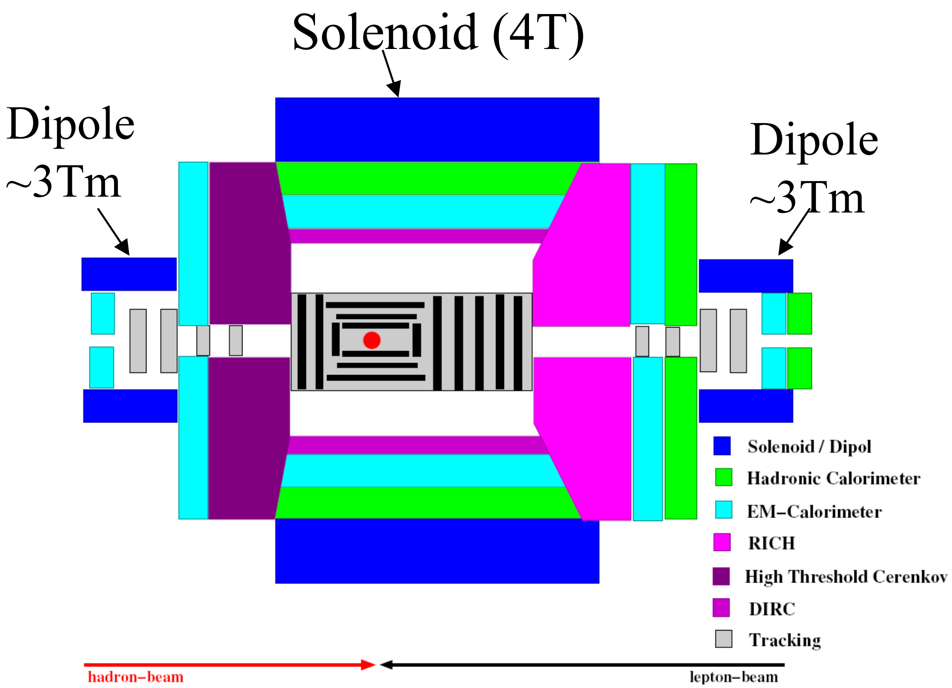
# Electron IR Lattice

D.Trbojevic

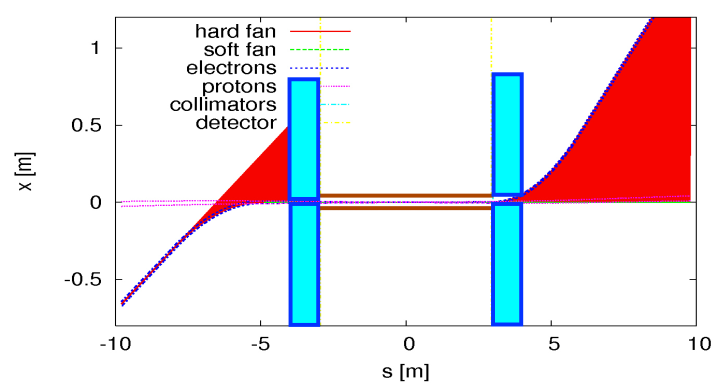


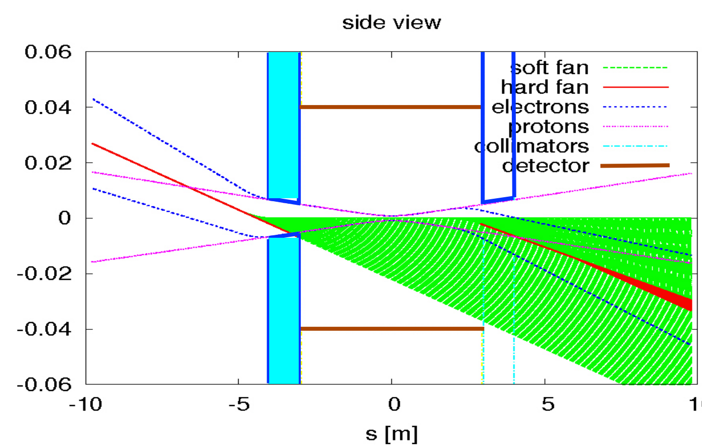
# Accelerator and detector integration and SR protection

J.Beebe-Wang, C.Montag, B.Parker

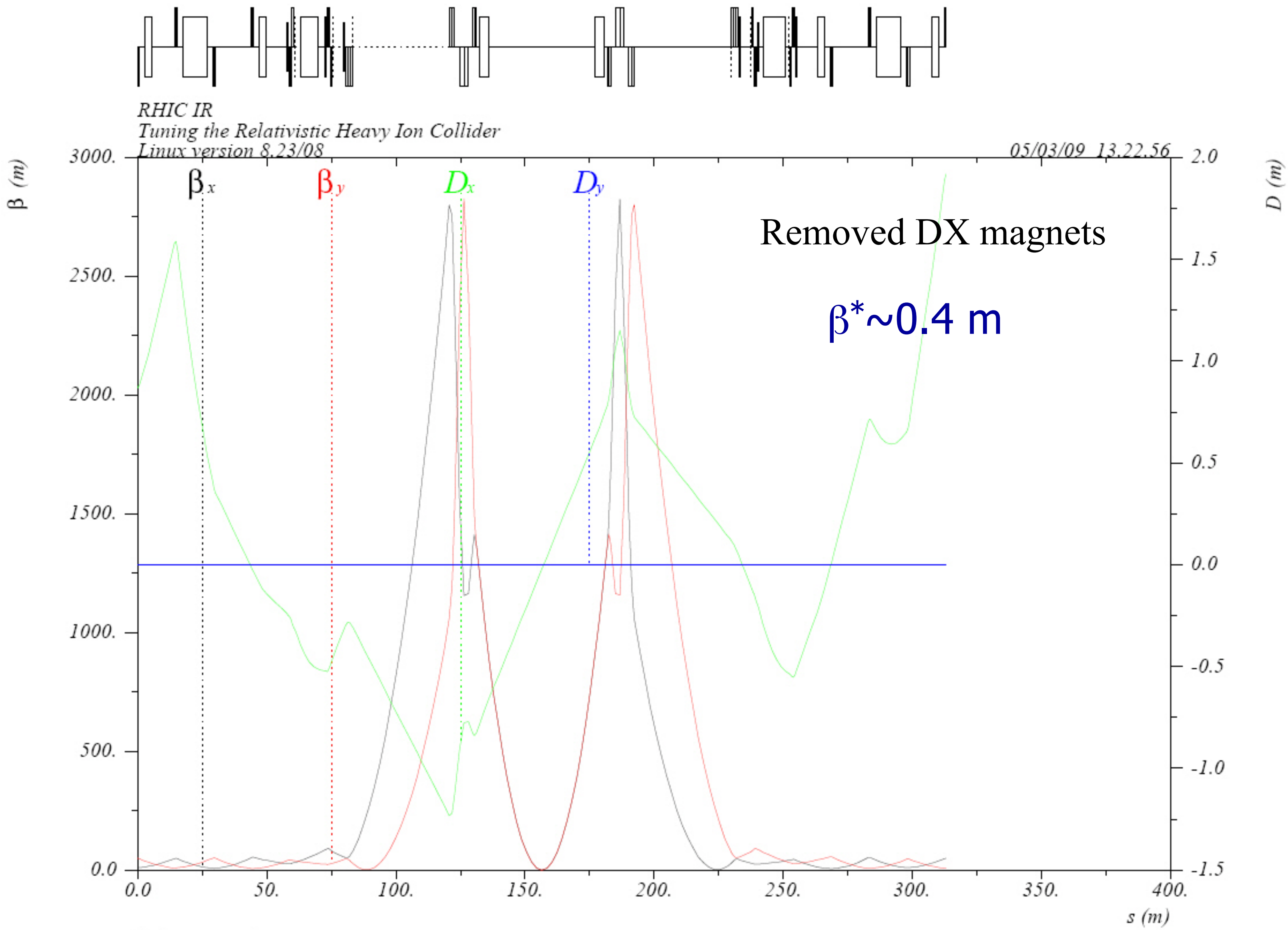



To provide effective SR protection:
-soft bend (~0.05T) is used for final bending of electron beam
-combination of vertical and horizontal bends



# RHIC lattice modification – Steven Tepikian



# Beam Dynamics Studies

E.Pozdeyev, A.Fedotov, Y.Hao, G.Wang

**Main factors affecting the beam dynamics have been evaluated:**

**-Beam-beam interactions, including kink instability (protons) and electron beam disruption**
**-BBU instability**
**-Energy losses due to cavity wakes**
**-Toushek and Beam-gas scattering**
**-Coherent Synchrotron Radiation (possible experiment at ATF )**

# Beam energy losses

E.Pozdeyev

Energy losses happen due to:

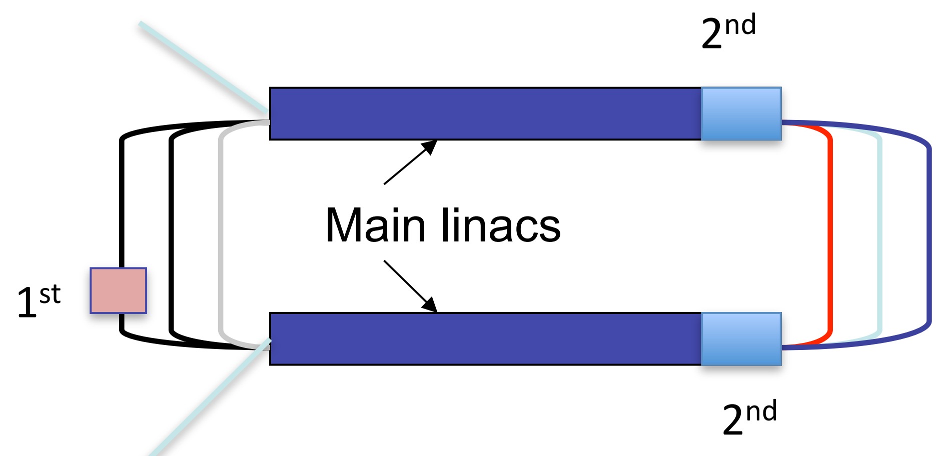
Wakefield losses-> mainly in linac cavities

Synchrotron radiation emission -> in dipoles of the recirculation passes

As results: average beam energy loss and momentum spread increase.

Wakes in Linac (ABCI simulations) 0.54 MV/linac. Total energy loss to SR and wakes: 15.3 MeV.
Total power loss 765 kW.
Energy diff. at 750 MeV is 2%.

Best compensation scheme includes additional cavities:
two 2nd harmonic RF cavities (0.7 MV,210 kW)
one 1st harmonic cavity (6.5 MV, 325 kW)



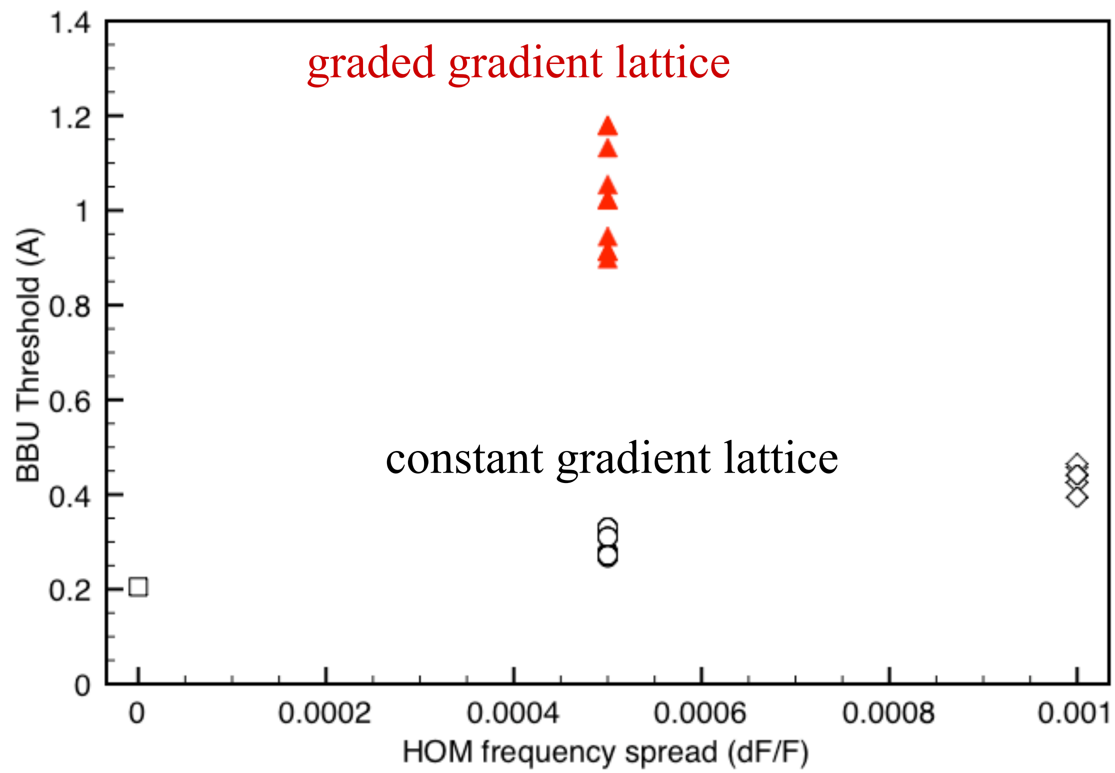

With the compensation the energy difference between accelerated and decelerated beam in any pass: $\Delta E < 0.06\%$

Energy spread after linac 10%.

# Beam Break Up simulations

- 70 dipole HOM's to 2.7 GHz
- (R/Q) × Q < 45000 Ohm
- Polarization either 0 or 90°
- 6 different random seeds
- Frequency spread 0 – 1e-3

E.Pozdeyev

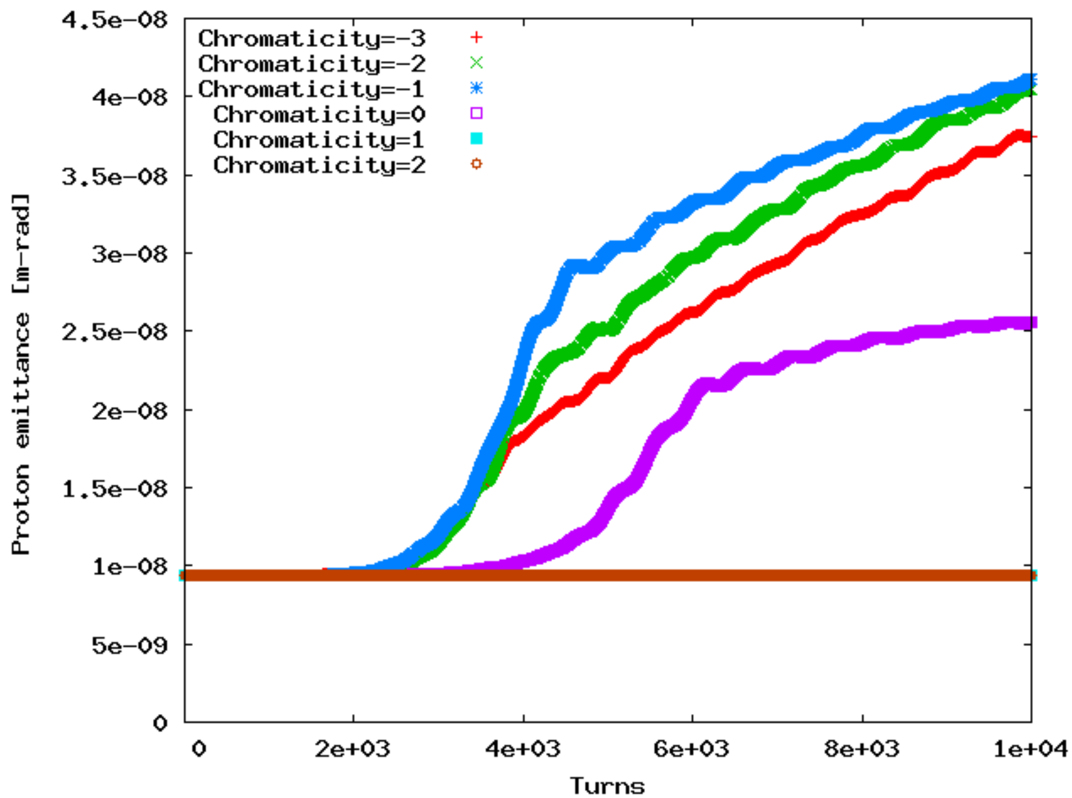


# Beam-Beam: Kink Instability of proton beam

The beam parameters are above the threshold of kink instability for proton beam.
Proper energy spread is needed to suppress the emittance growth.

From simulations of the kink instability:

Y.Hao



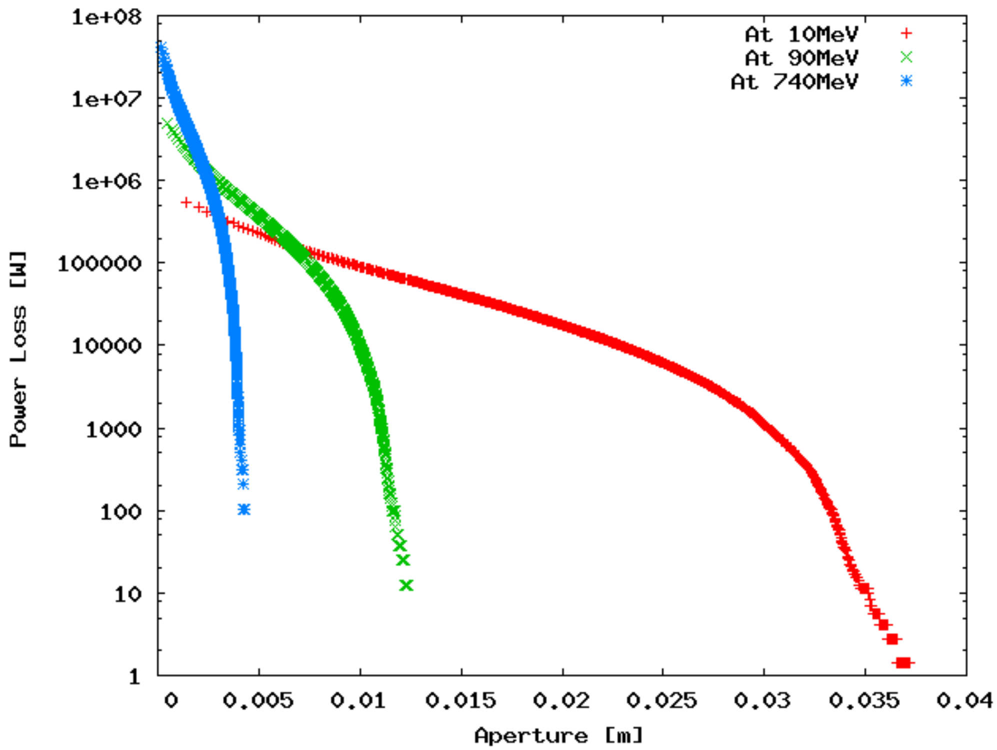

**Not Cooled case**

Chromaticity=1 is needed

# Electron beam disruption

Y.Hao

Electron beam disrupted during the collisions has to be transported and decelerated with minimal losses.




The required aperture if 1KW power loss is required.

| Energy | Aperture |
|---|---|
| **740 MeV** | **4 mm** |
| **90MeV** | **11 mm** |
| **10MeV** | **38 mm** |

# Polarization Control

- Protons:

  helical spin rotators, similar to those used in present experiments at IR6 and IR8.

- Electrons:
  - Rotation around horizontal axis: Wien Filter type spin rotator at 200 kV
  - Rotation around vertical axis: by synchronous small readjustments of energy gains in main linacs.
  - Combination of those rotation will provide wanted polarization orientation at the IP.
  - For longitudinal polarization: ~0.1 rad spread of spin directions due to momentum spread.

# Summary:

- Intensive design development of medium energy electron-ion collider is underway.
- Lattice design of all major machine component has been done:
  - Main linacs
  - Recirculation passes
  - Interaction region
- Main factors affecting  the beam dynamics have been evaluated.
- Design development of high current polarized source, based on multiple cathods is underway.
- Design development continues for the linac cryomodule.

The work accent is shifting now to the technical design of accelerator hardware (magnets, vacuum chamber, cryomodule) and to the evaluation of effects of machine imperfection/errors on the beam.