Optics considerations for ERL test facilities

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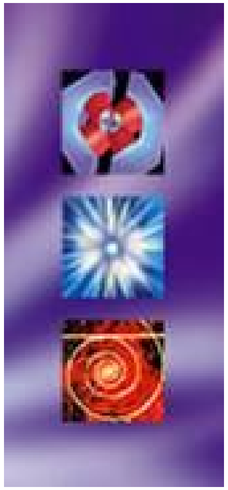
ASTeC Daresbury Laboratory

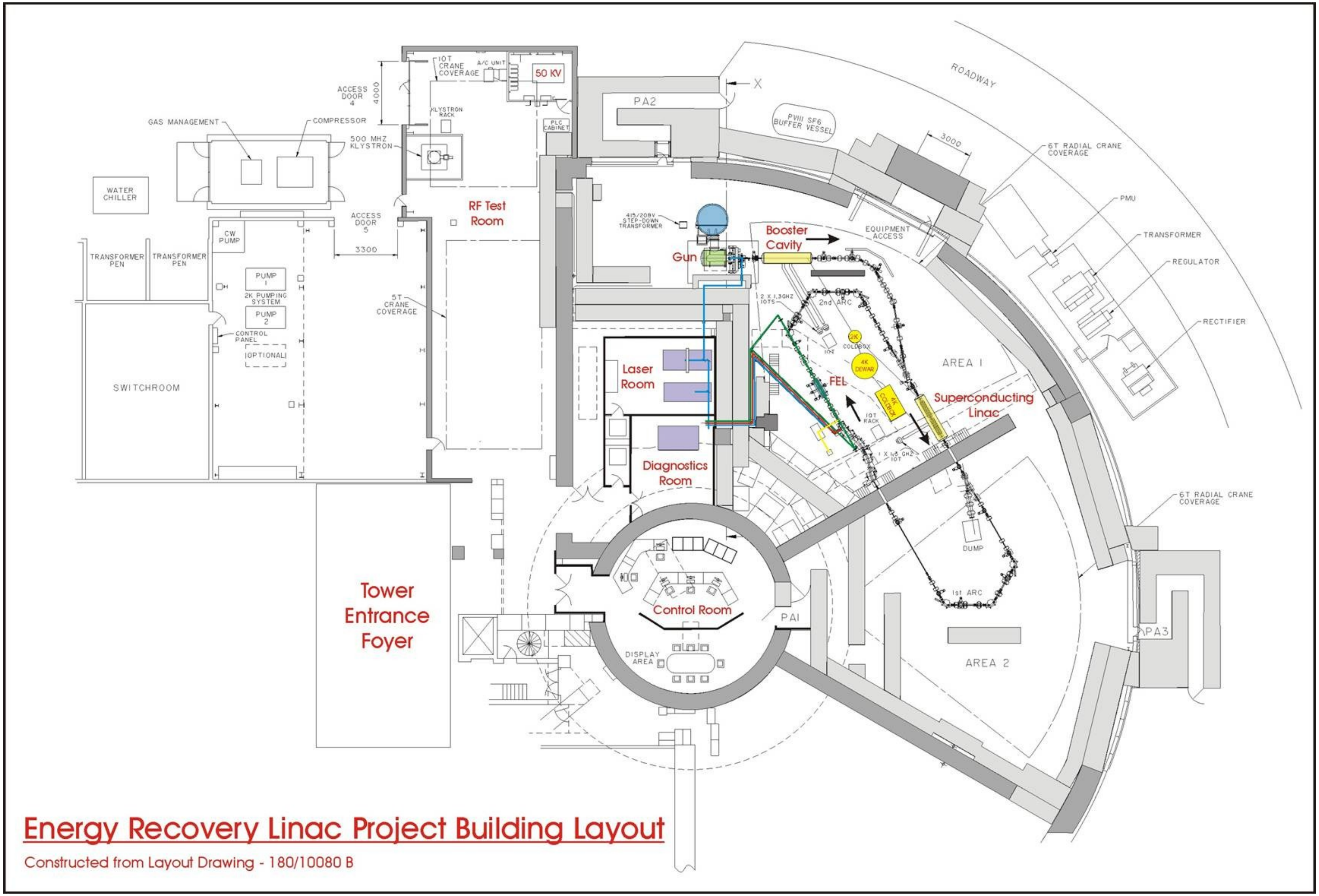


(M. Bowler, C. Gerth, F. Hannon, H. Owen, B. Shepherd, S. Smith, N. Thompson, E. Wooldridge, N. Wyles)

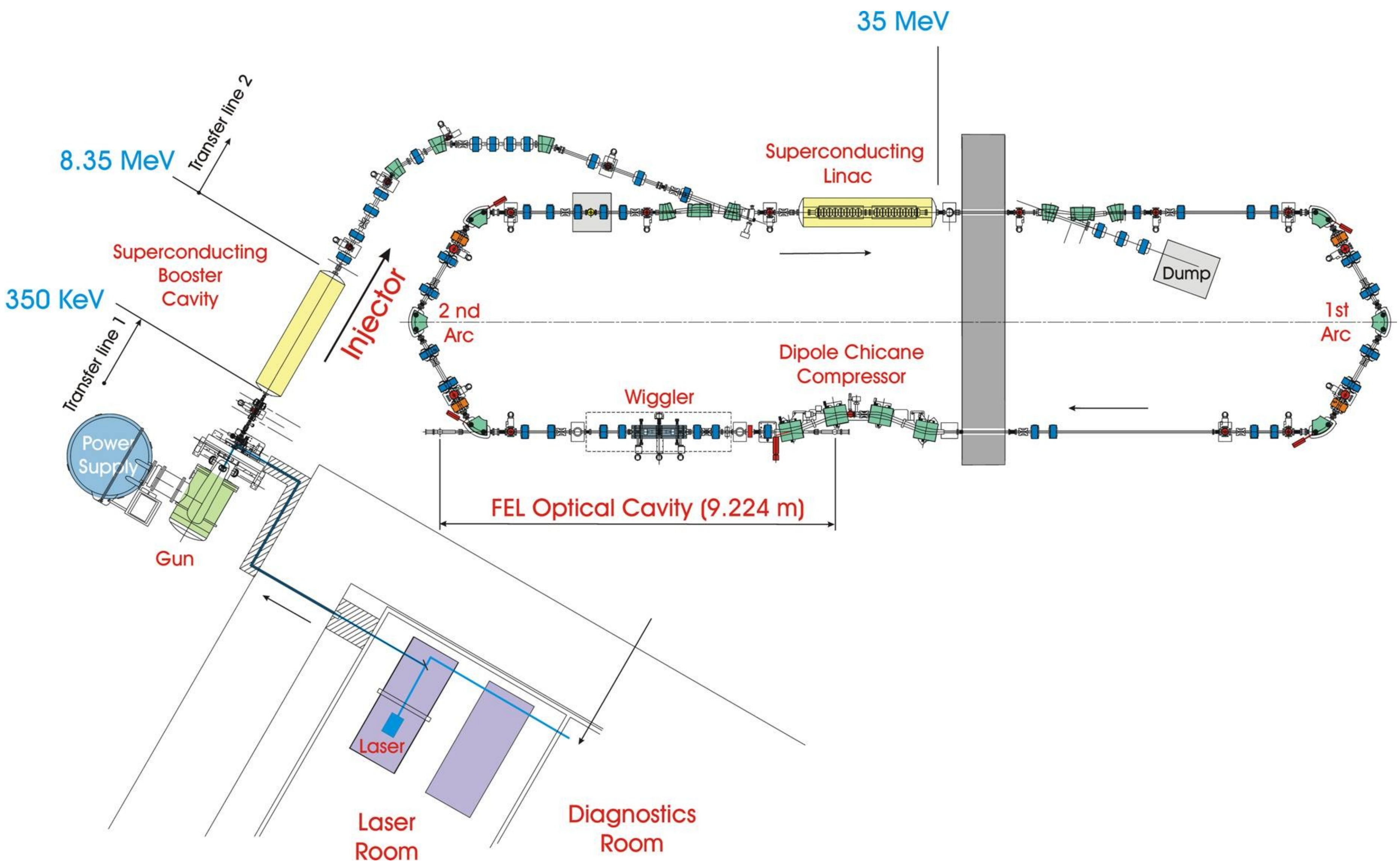
Overview

- Optics Layout strategy for ERLP
  - MAD8
- Space Charge for the ERLP
  - Analytical
  - ASTRA
  - GPT
- Start to End (S2E) models for the ERLP
  - MAD8
  - ELEGANT
  - GENESIS
- Beam Breakup for the ERLP
  - BI

ERLP Building Layout



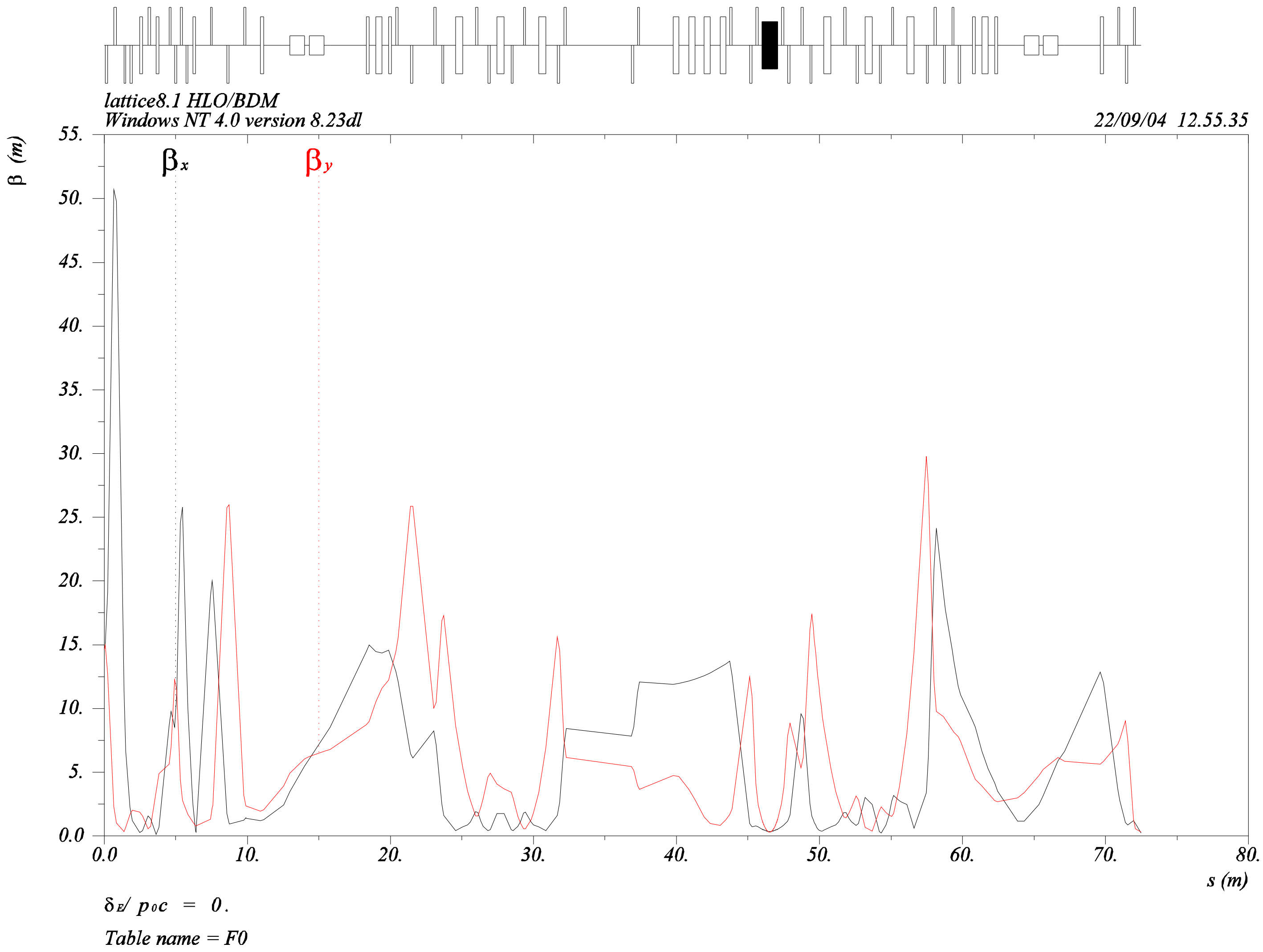
Energy Recovery Linac Prototype



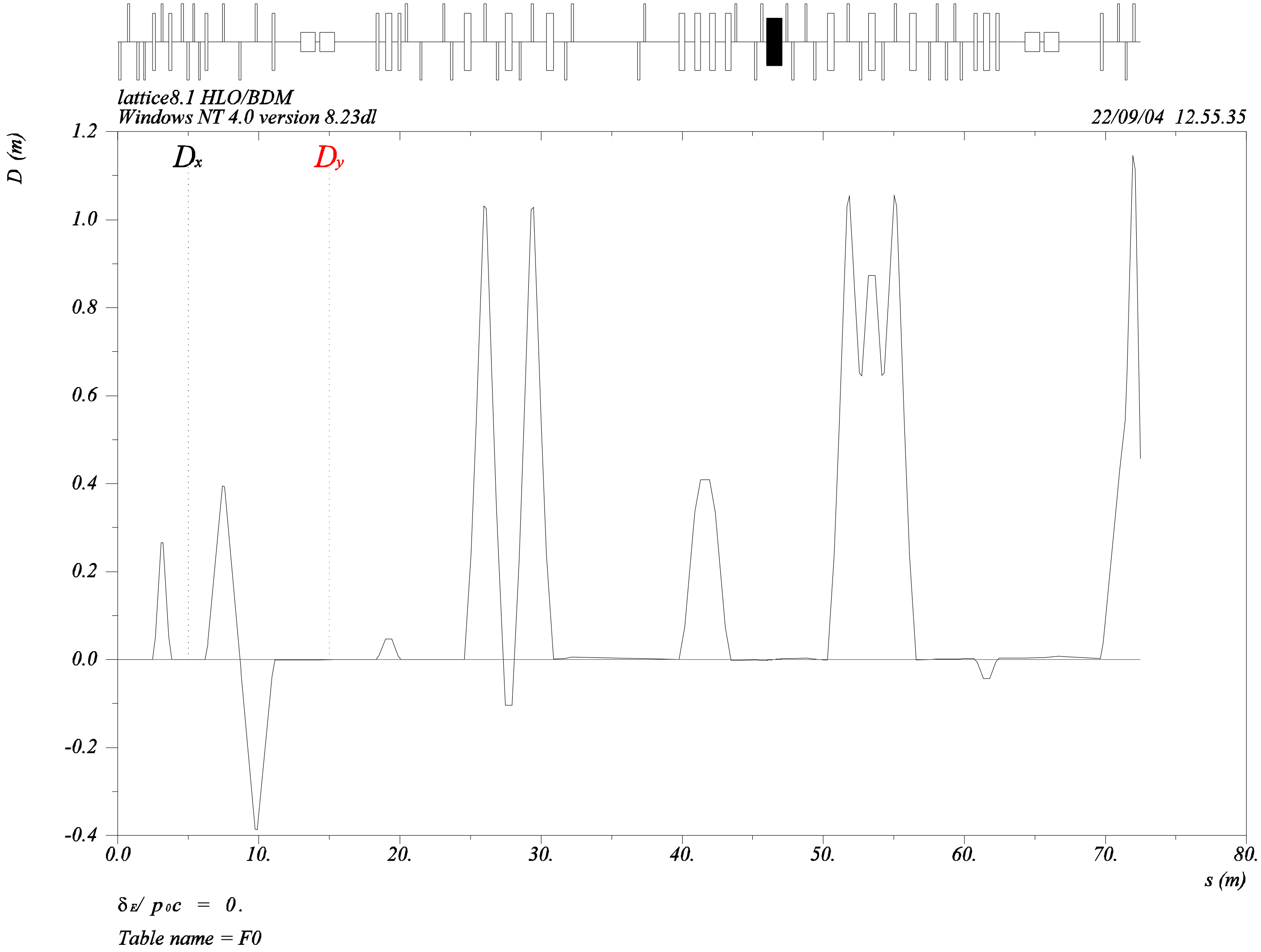
Parameters for ERLP

- 4 ps long bunches, 80 pC
- 8.35 MeV Injection line (TL2) between 10 m and 15 m
- 35 MeV Beam Transfer System (BTS)
- Initial emittance (norm) between 1 mm mrad and 2 mm mrad
- Transverse beam size ~ 1-16 mm

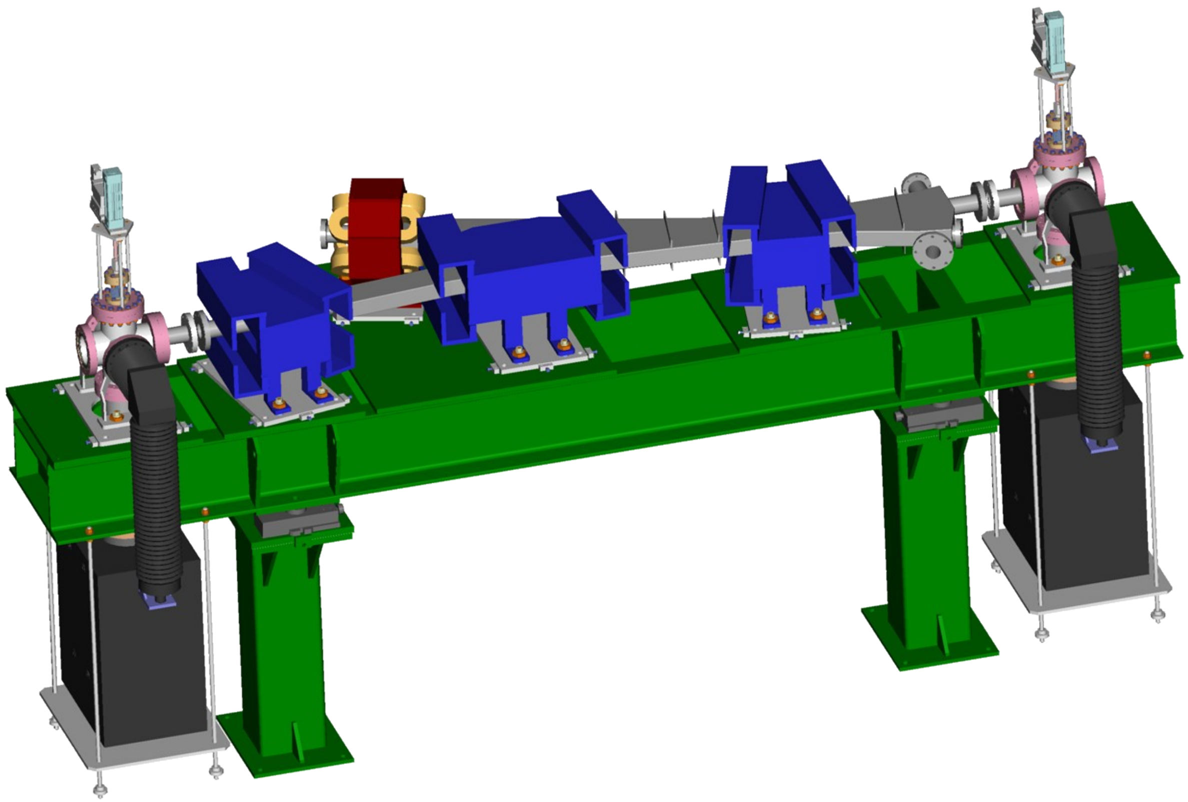
Beta Functions for ERLP



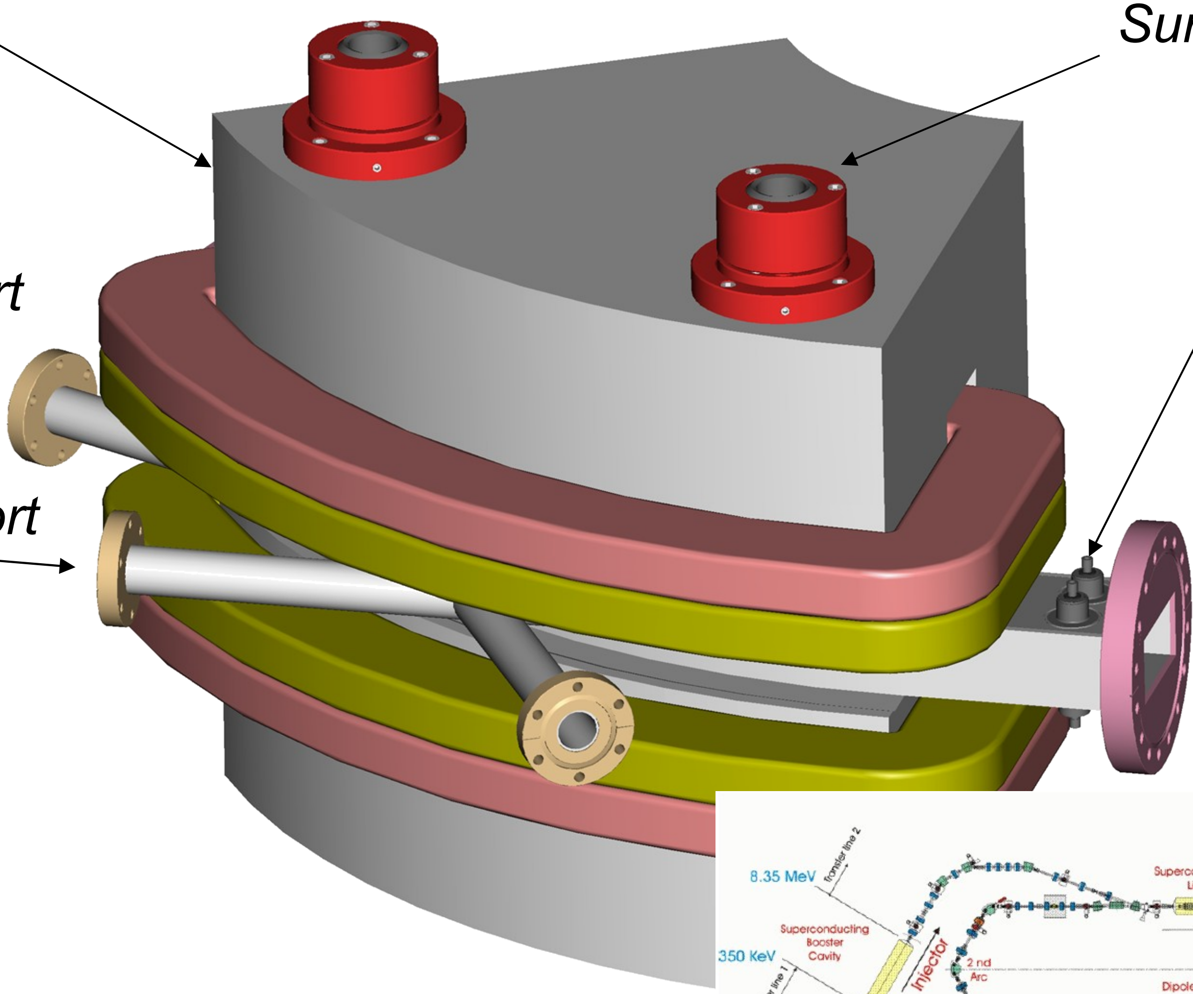
Dispersion for the ERLP

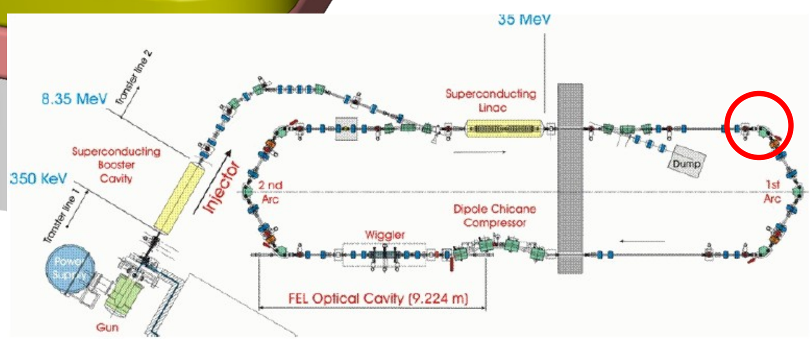


Injection & Extraction Chicanes (from JLab with thanks)

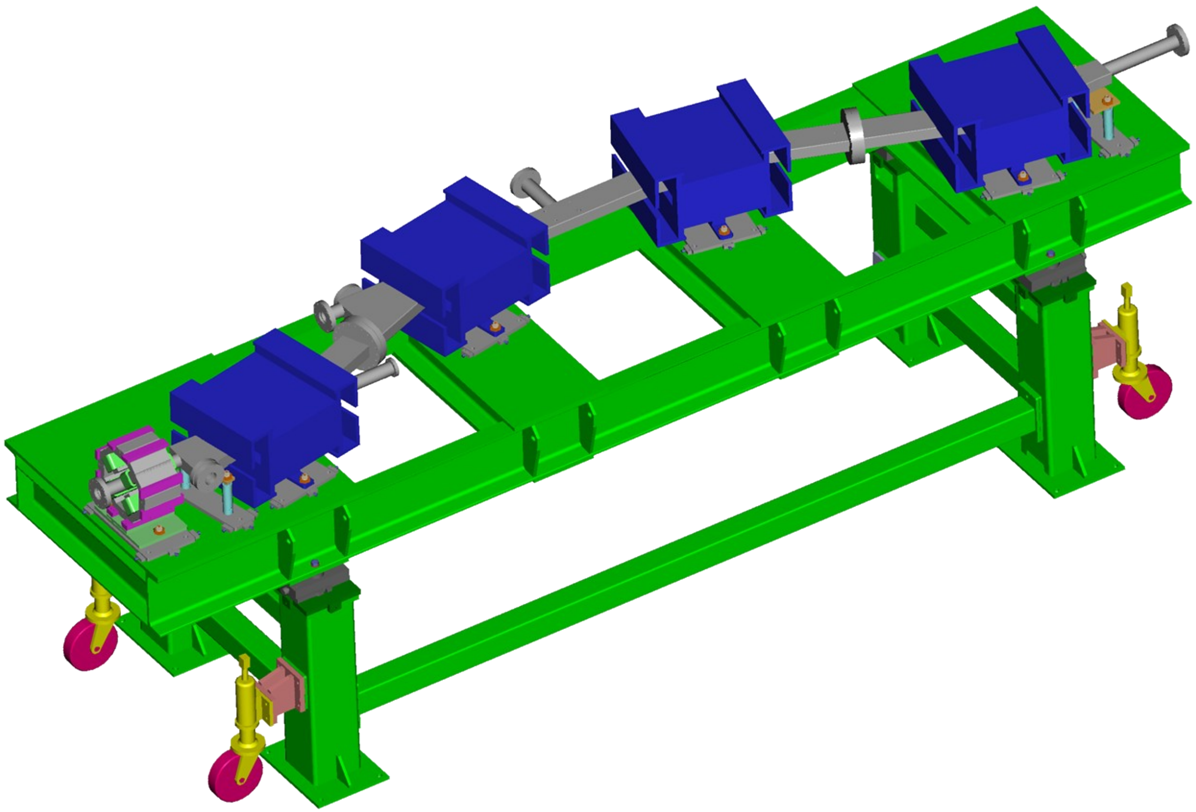


Ali

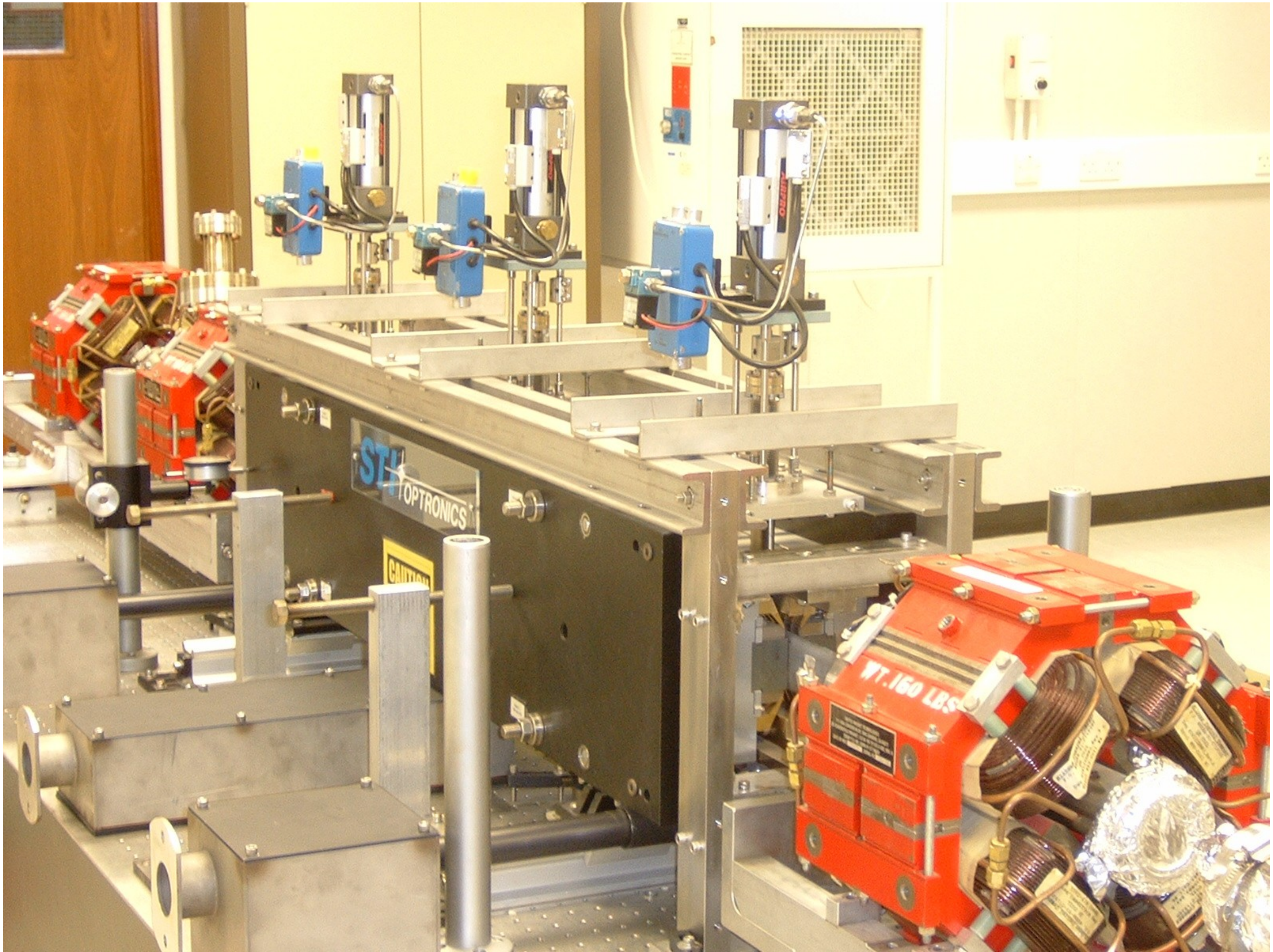

Arc Dipole Magnet
Survey Target Holders
30 deg. extraction port
EBPMs
0 deg. extraction port


35 MeV
8.35 MeV
transfer line 2
Superconducting Linac
Superconducting Booster Cavity
350 KeV
Injector
2 nd Arc
1st Arc
Dump
transfer line 1
Dipole Chicane Compressor
Wiggler
FEL Optical Cavity (9.224 m)
Gun

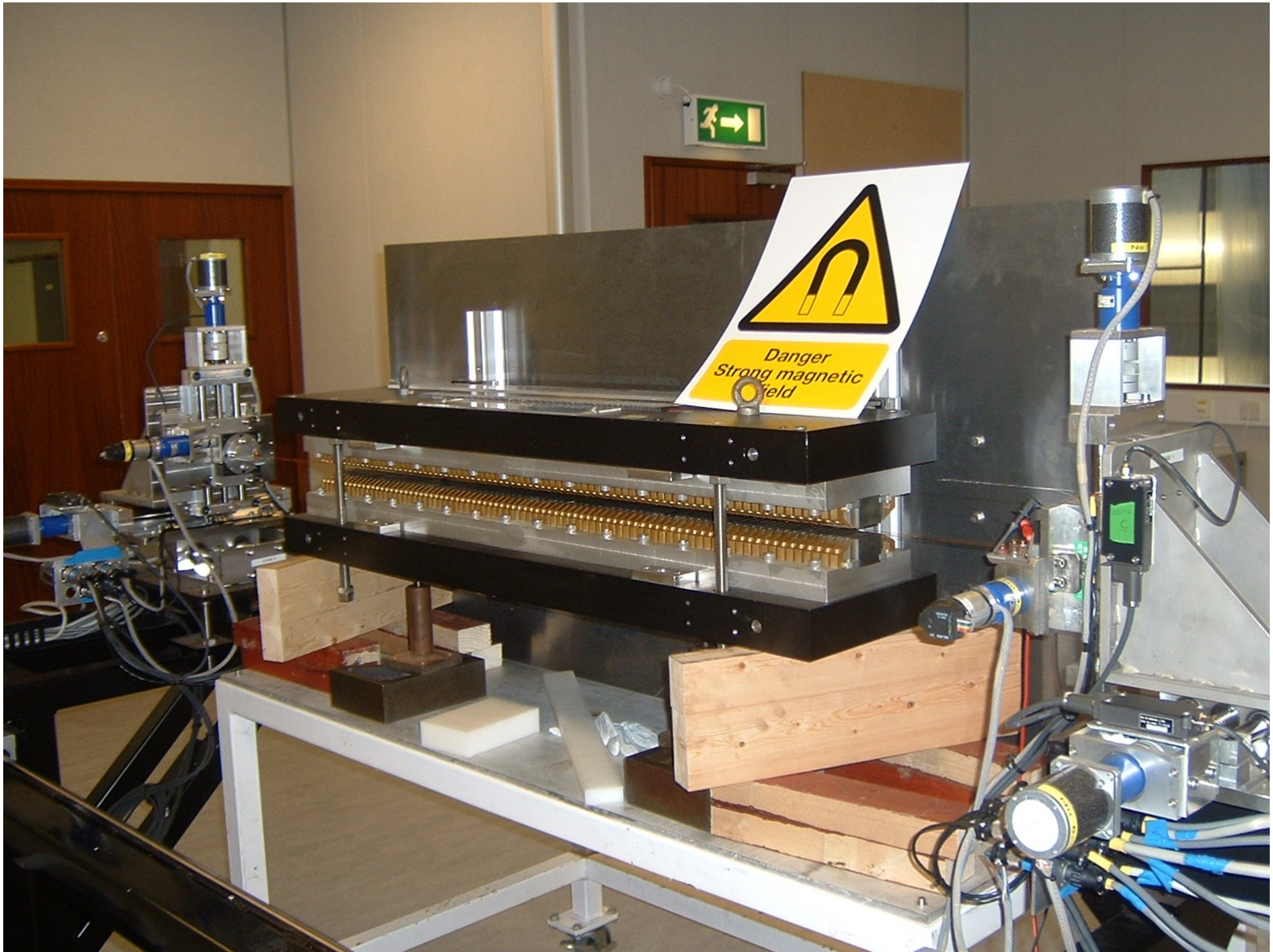
Compression Chicane (from JLab with thanks)



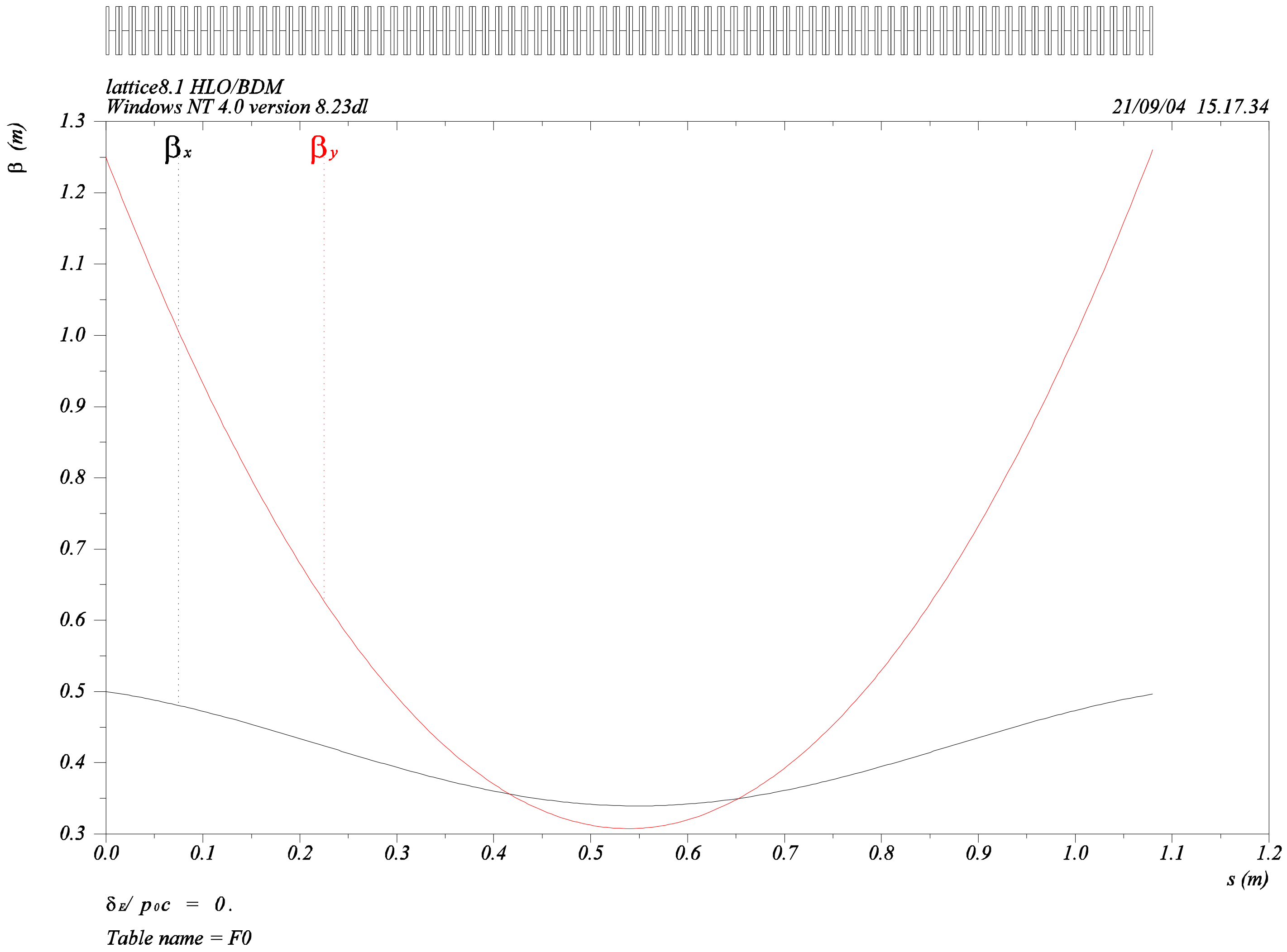
JLab Wiggler



JLab Wiggler – Testing



JLab Wiggler Model – Beta Functions



ASTRA & Drifts - Analytical Approach

- Horizontal focusing given by (equivalent for vertical)

$$\frac{1}{F_x} = -\frac{4I(s)}{(\beta\gamma)^3 I_0}\frac{L}{a(a+b)}$$

- Sigma matrix transformation

$$J = TJ_0T^{-1}$$

$$J = \begin{pmatrix} 1 & 0 \\ -\frac{1}{F_x} & 1 \end{pmatrix}\begin{pmatrix} \alpha_{x0} & \beta_{x0} \\ -\gamma_{x0} & -\alpha_{x0} \end{pmatrix}\begin{pmatrix} 1 & 0 \\ \frac{1}{F_x} & 1 \end{pmatrix} = \begin{pmatrix} \alpha_{x0} + \frac{\beta_{x0}}{F_x} & \beta_{x0} \\ -\gamma_{x0} - \frac{2\alpha_{x0}}{F_x} - \frac{\beta_{x0}}{F_x^2} & -\alpha_{x0} - \frac{\beta_{x0}}{F_x} \end{pmatrix}$$

- New emittance

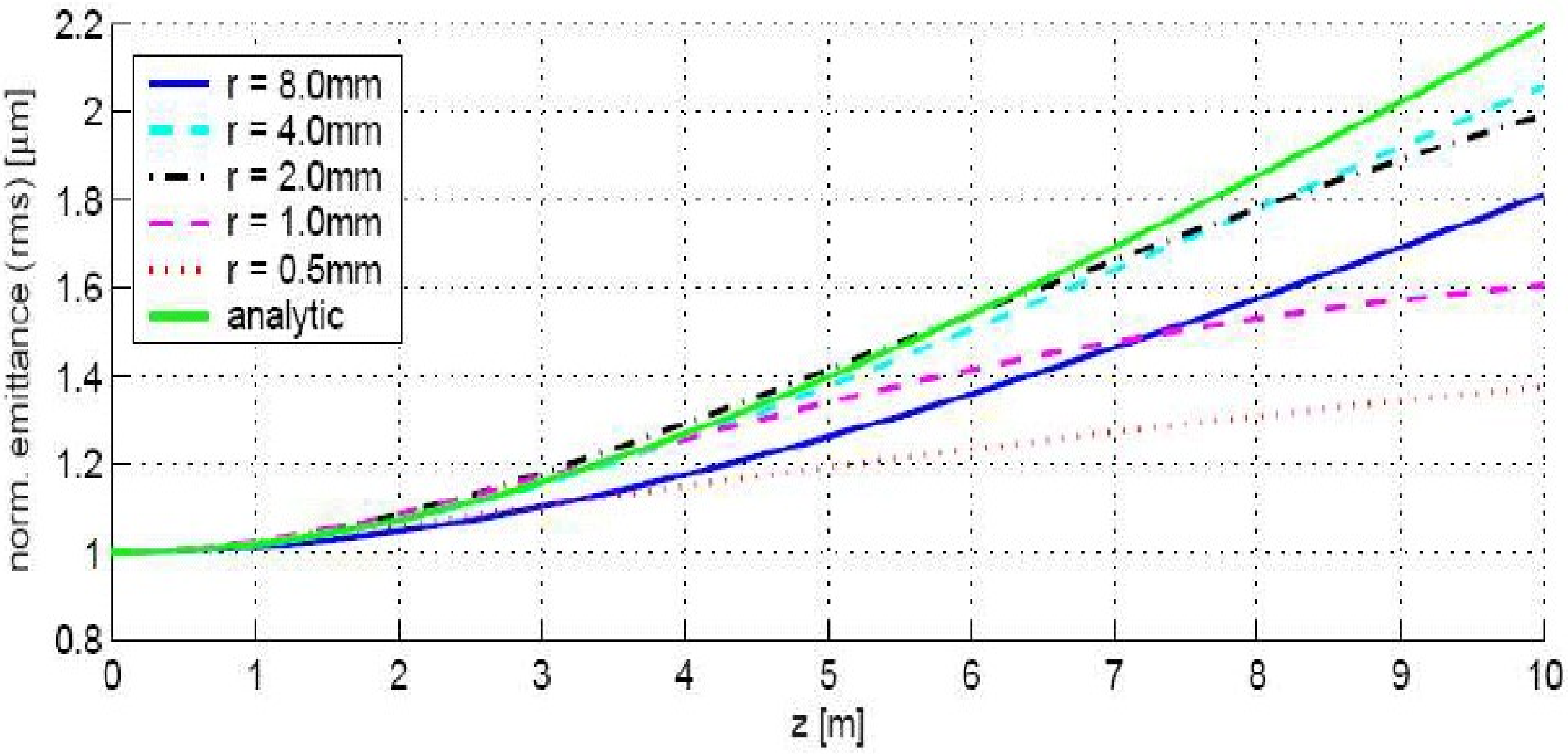
$$\epsilon_x = \epsilon_{x0}\sqrt{1 + \beta_{x0}^2\left[\left\langle\frac{1}{F_x^2}\right\rangle - \left\langle\frac{1}{F_x}\right\rangle^2\right]}$$

- Gaussian bunch (in s)

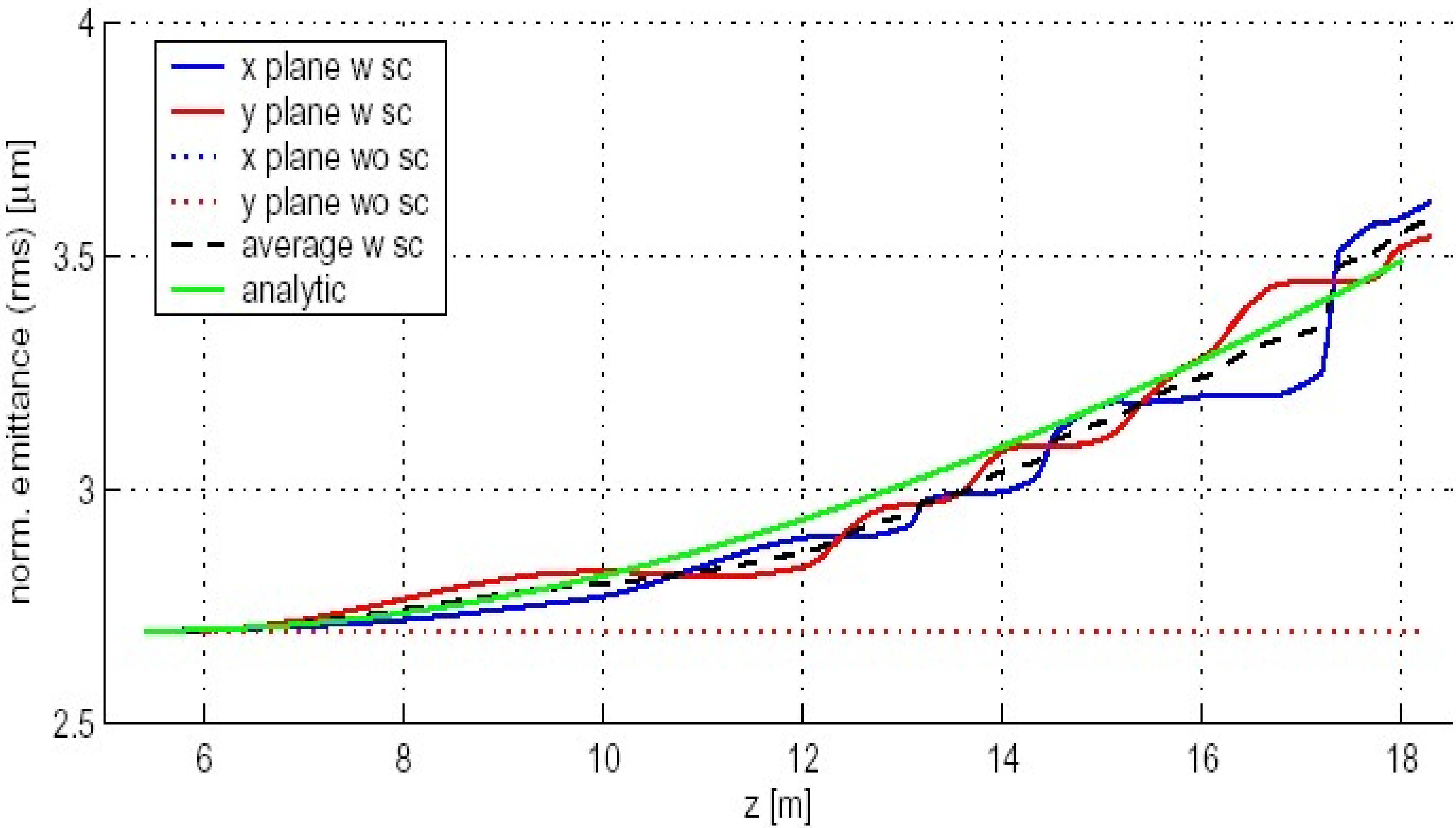
$$I(s) = I_{\max}\exp\left(-\frac{s^2}{2\sigma^2}\right)$$

$$\left\langle\frac{1}{F_x^2}\right\rangle - \left\langle\frac{1}{F_x}\right\rangle^2 = \left(\frac{1}{F_x}\right)^2_{\max}\left(\frac{1}{\sqrt{3}} - \frac{1}{2}\right)$$

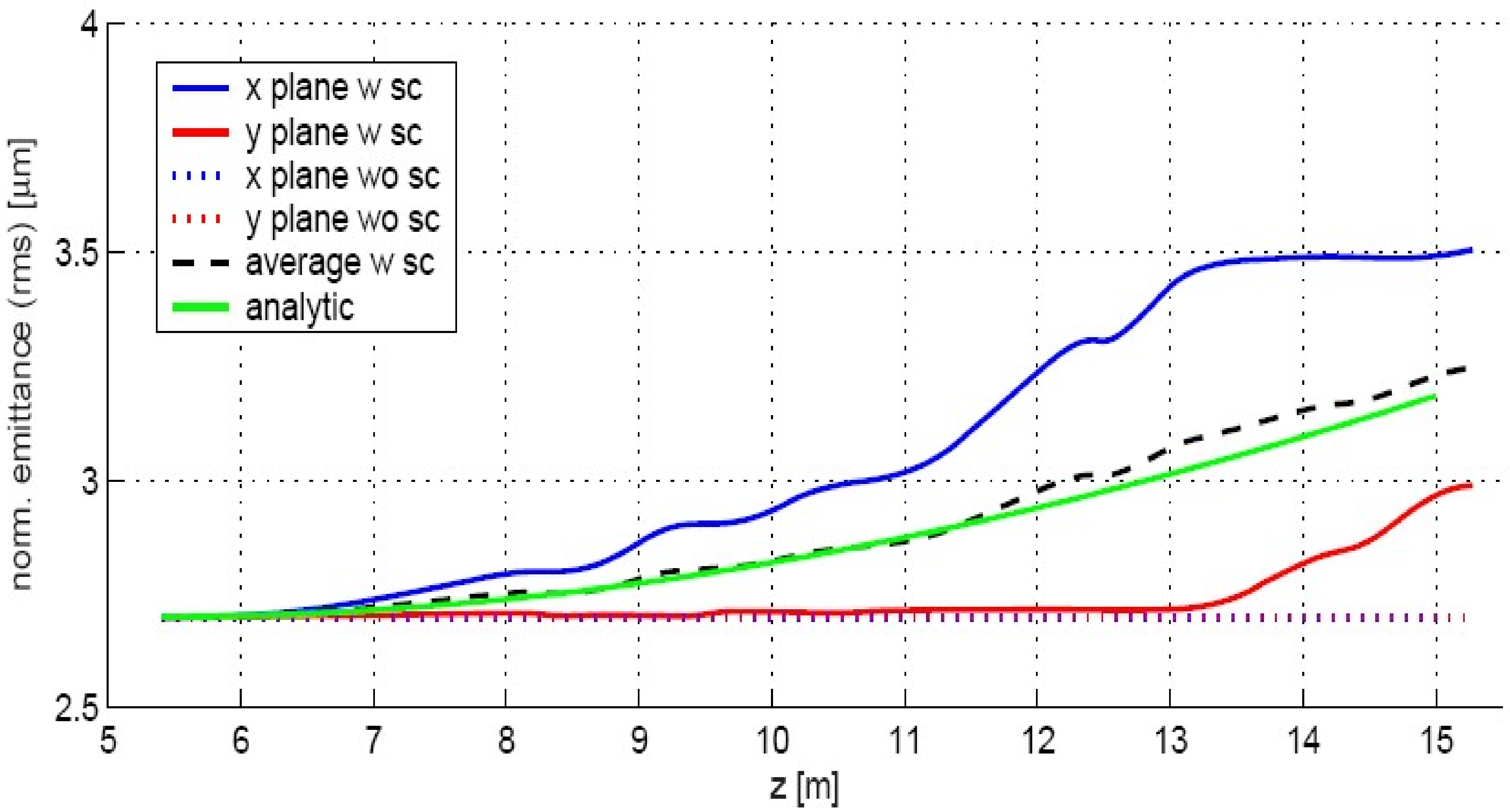
Results & Comparisons for ASTRA & Drifts – 1 mm mrad



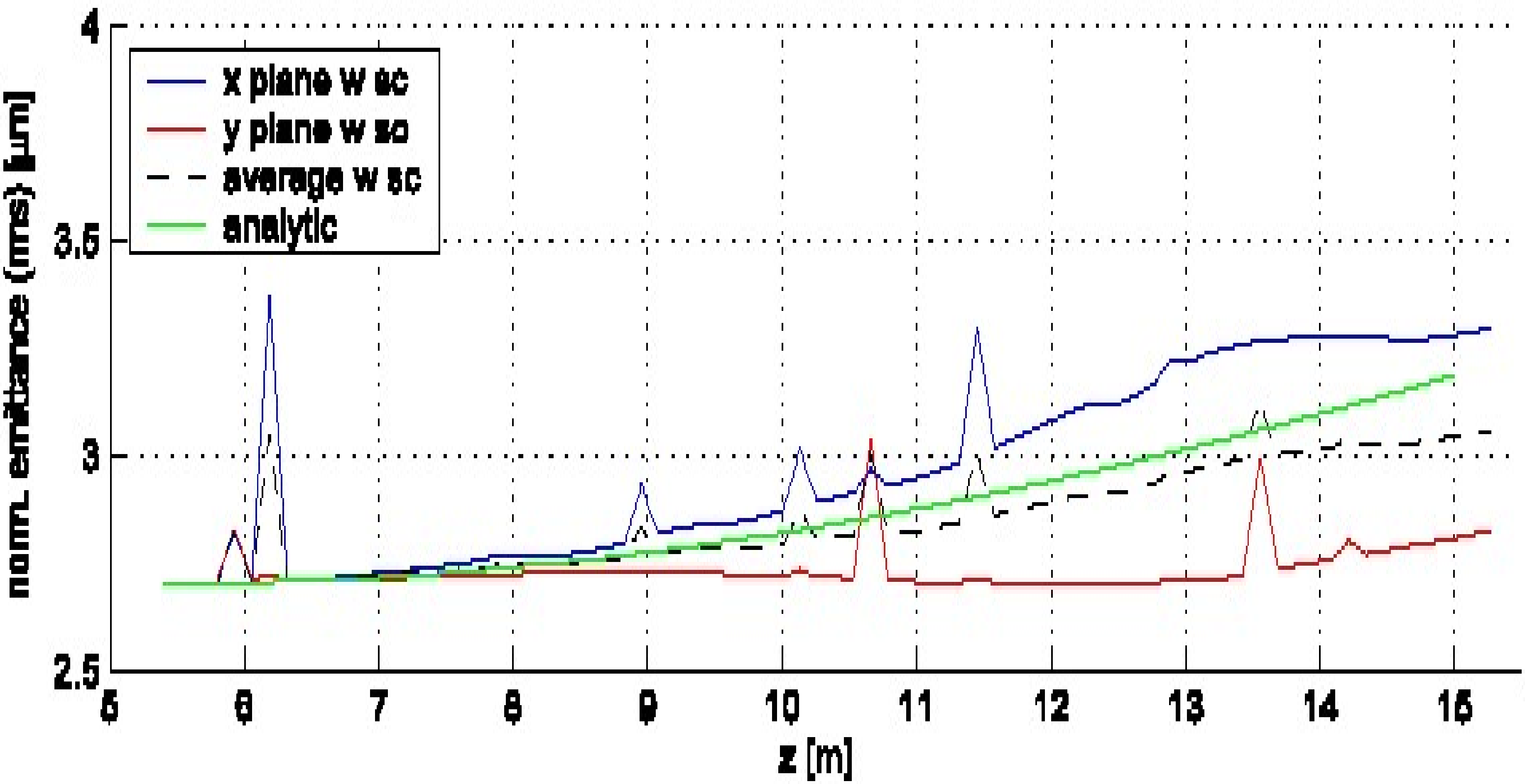
ASTRA & Quadrupoles for TL2 – Long model



ASTRA & Quadrupoles for TL2 – Short model

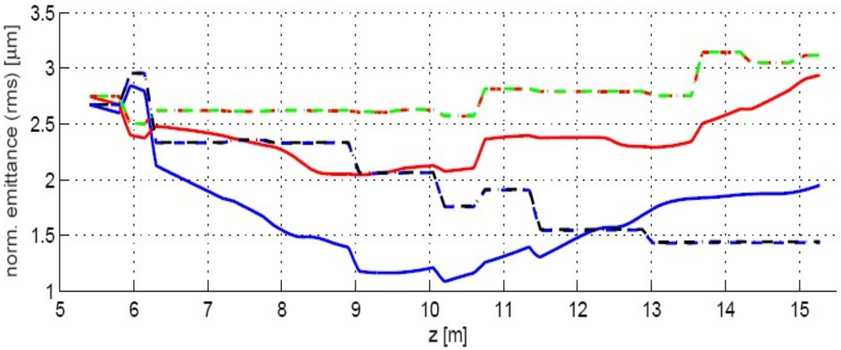


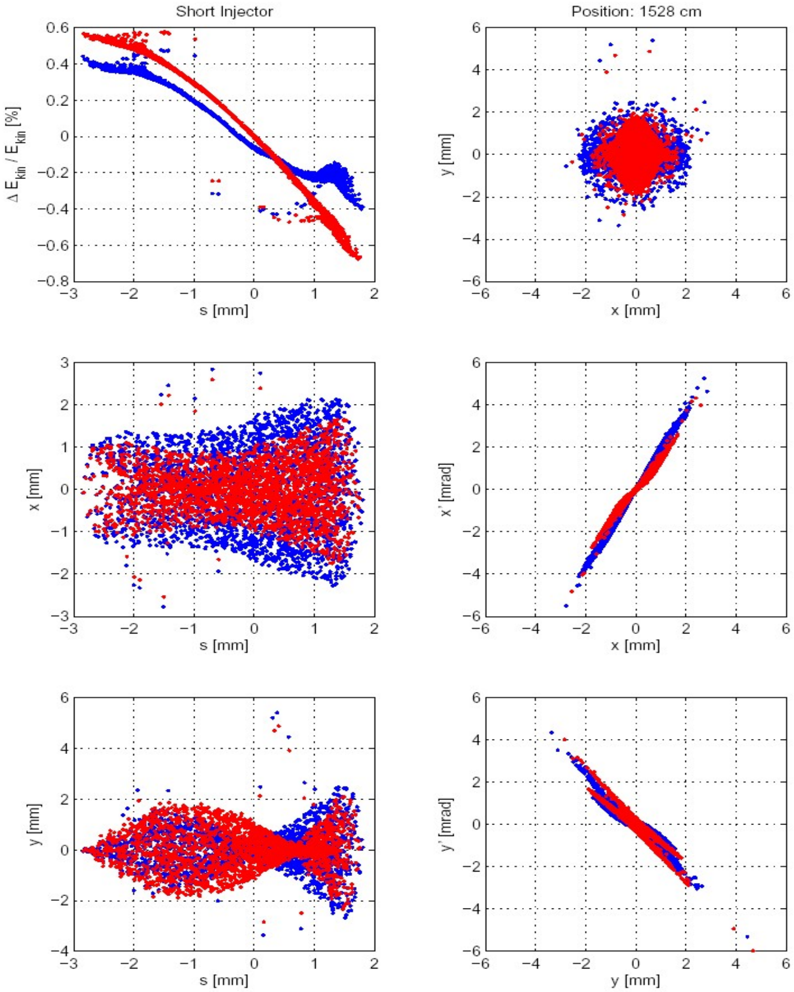
GPT & Quadrupoles for TL2 – Short model



ASTRA & Quadrupoles for TL2 – Short model

- ASTRA distribution from gun and booster (CG & FH)
- Emittance outside transverse plane
- Gaussian good approximation for emittance growth estimate

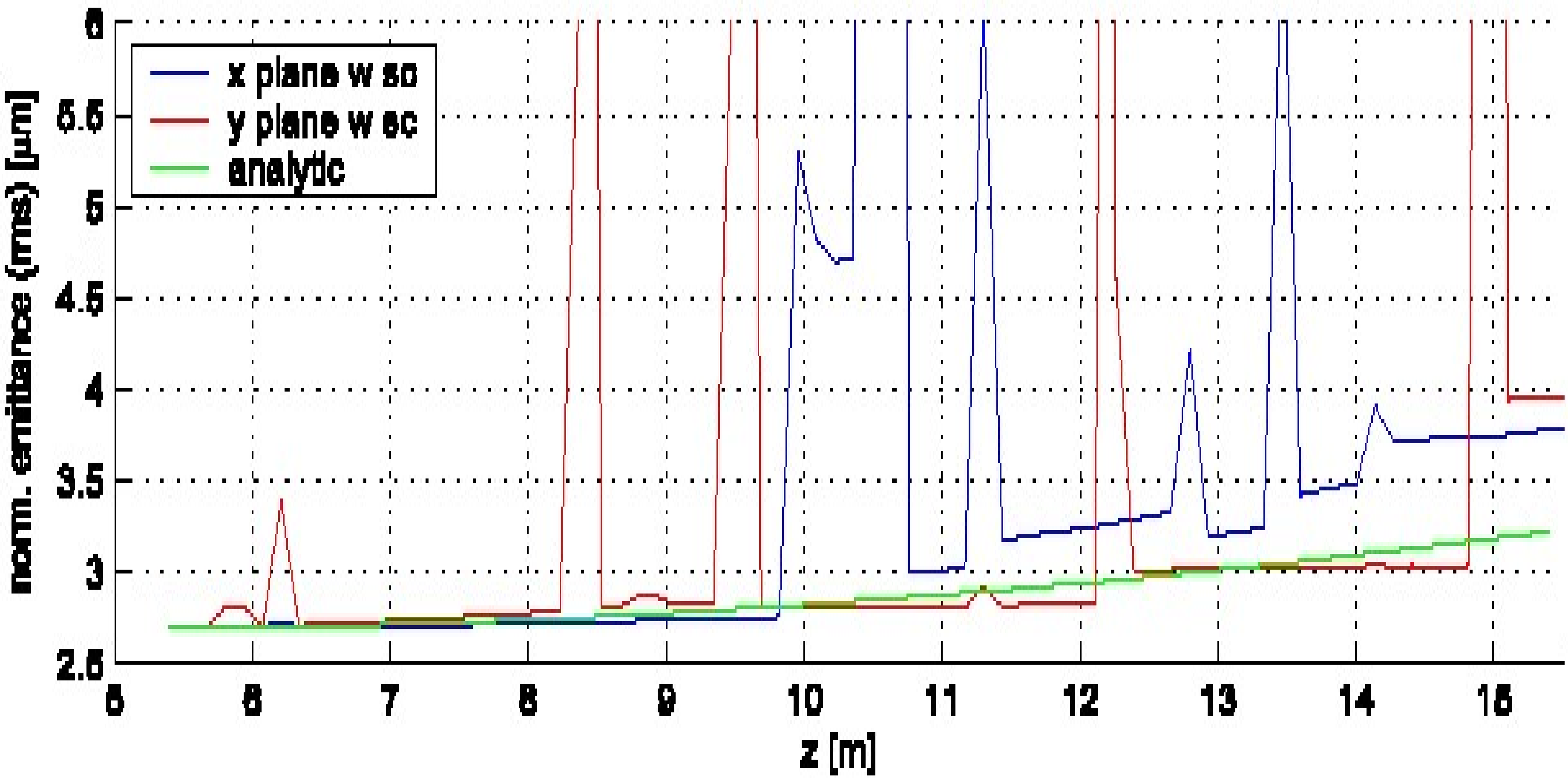




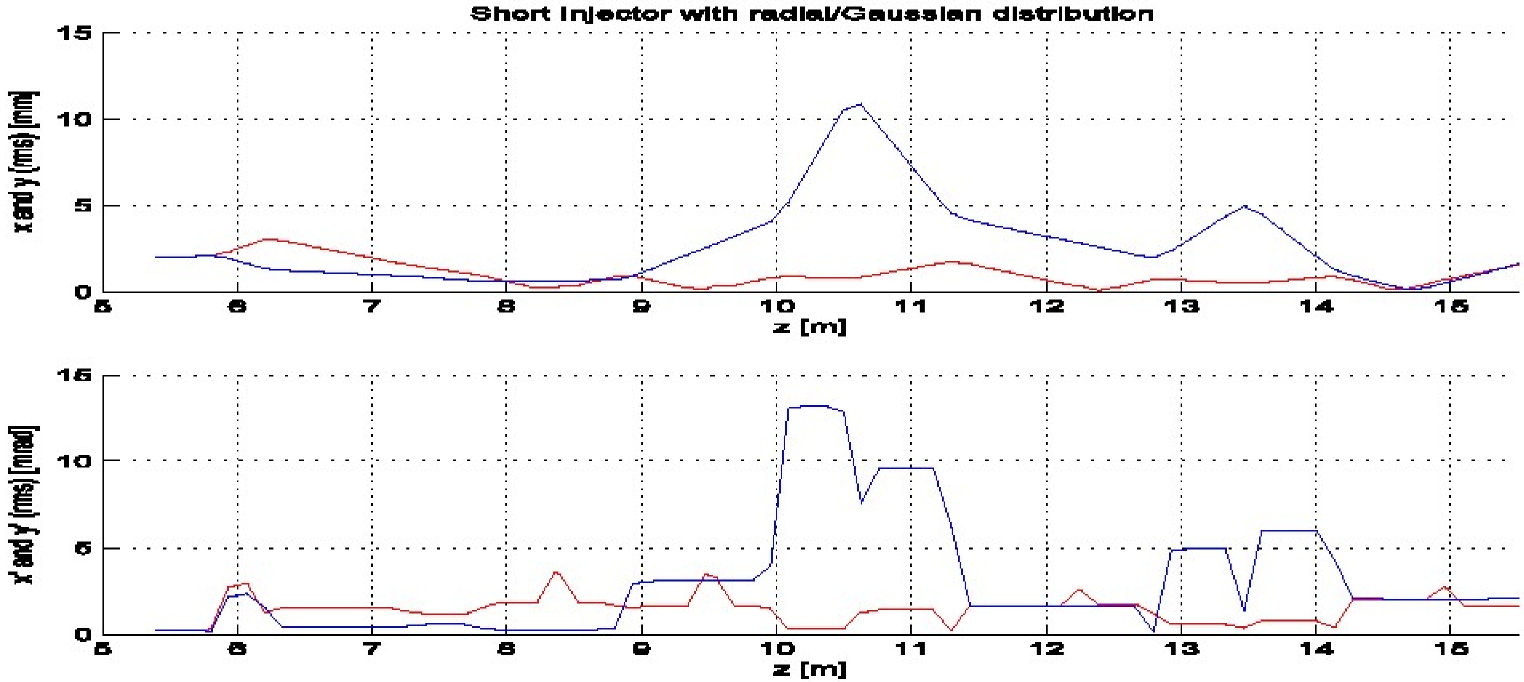
GPT

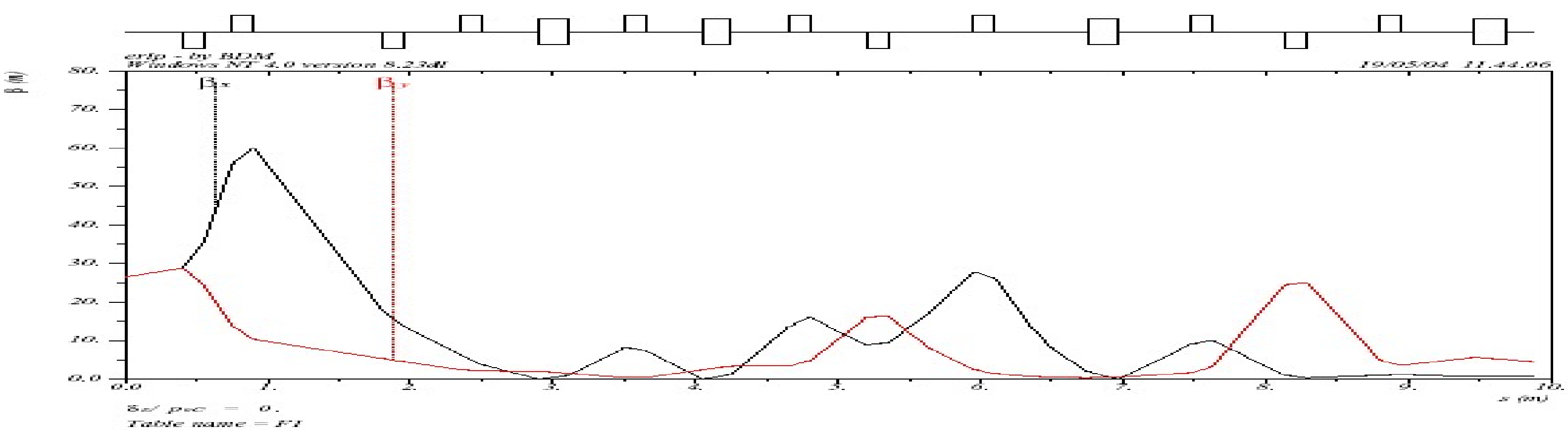
- All results so far in good agreement
- Different algorithms also agree
- Emittance increase appears to be comparable to the analytical estimate in all cases considered
- Dispersion may be left out for a rough estimate
- Next: Include bends …

GPT & TL2 with dipoles (short model) – first results

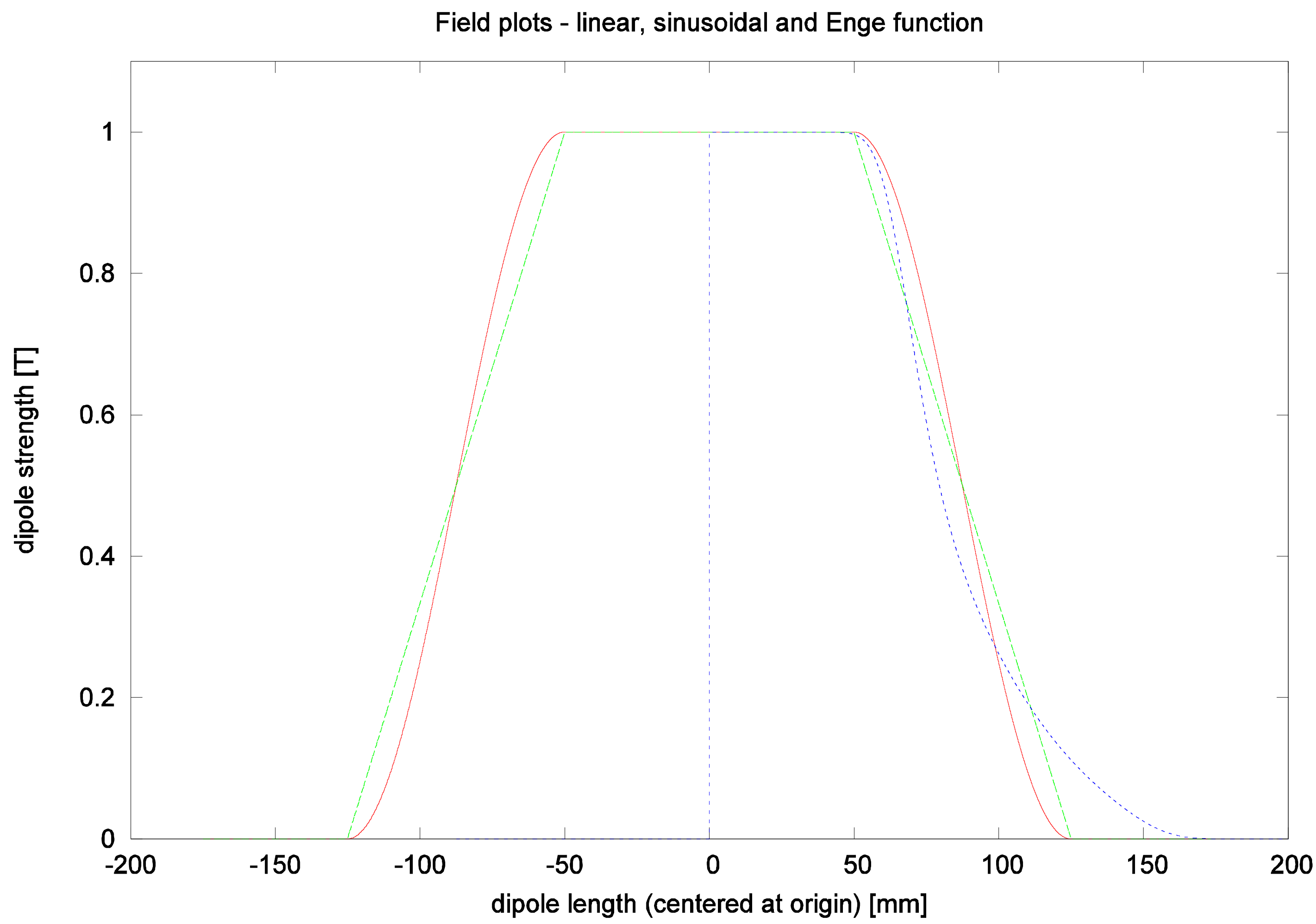


GPT & Quadrupoles for TL2 – Short model





Problem: Fringe Fields, Solution: Enge Function



Transfer Line 2 / Linac

- Lattice matching with MAD8
  - keep Twiss parameters at reasonable values (e.g. β < 50m)
  - Dispersion free after injection/extraction bends and arcs
  - 1st arc: isochronous
  - 2nd arc: $R_{56} = -R_{56}$ bunch compressor
  - Only exact matching point in transverse and longitudinal phase space is at the entrance of the FEL

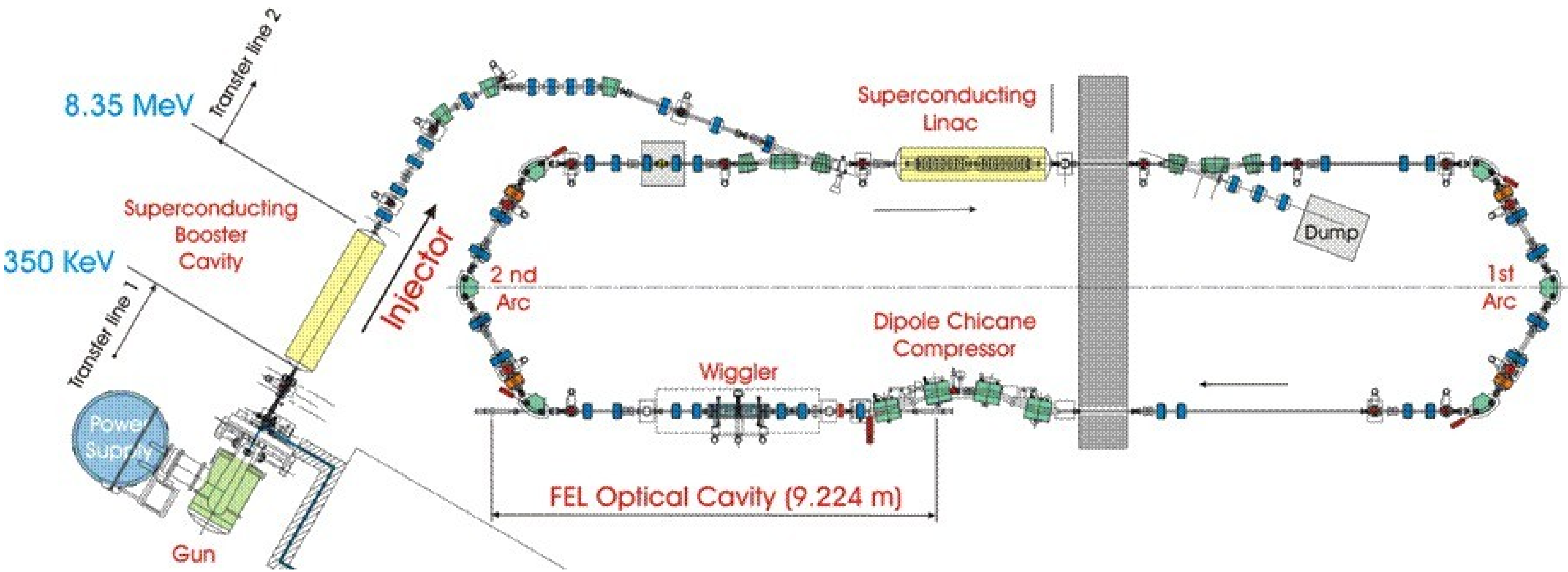
- Tracking with elegant
  (TL2: E = 8.35MeV, l = 15m, 4 dipoles, 12 quads)
  Space charge effects ignored

Start to End Model

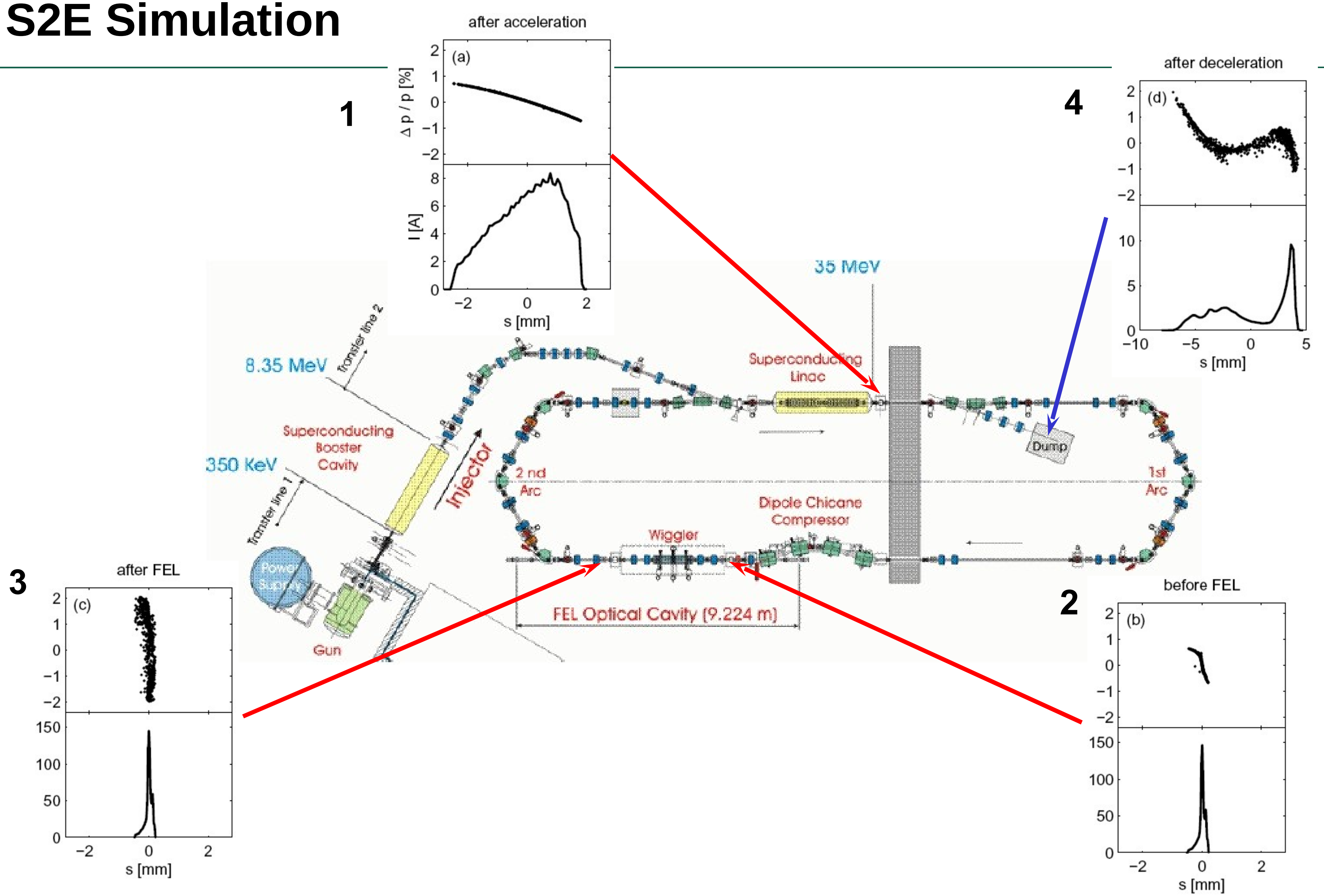
MAD8
Lattice Matching

MAD8
Lattice Matching

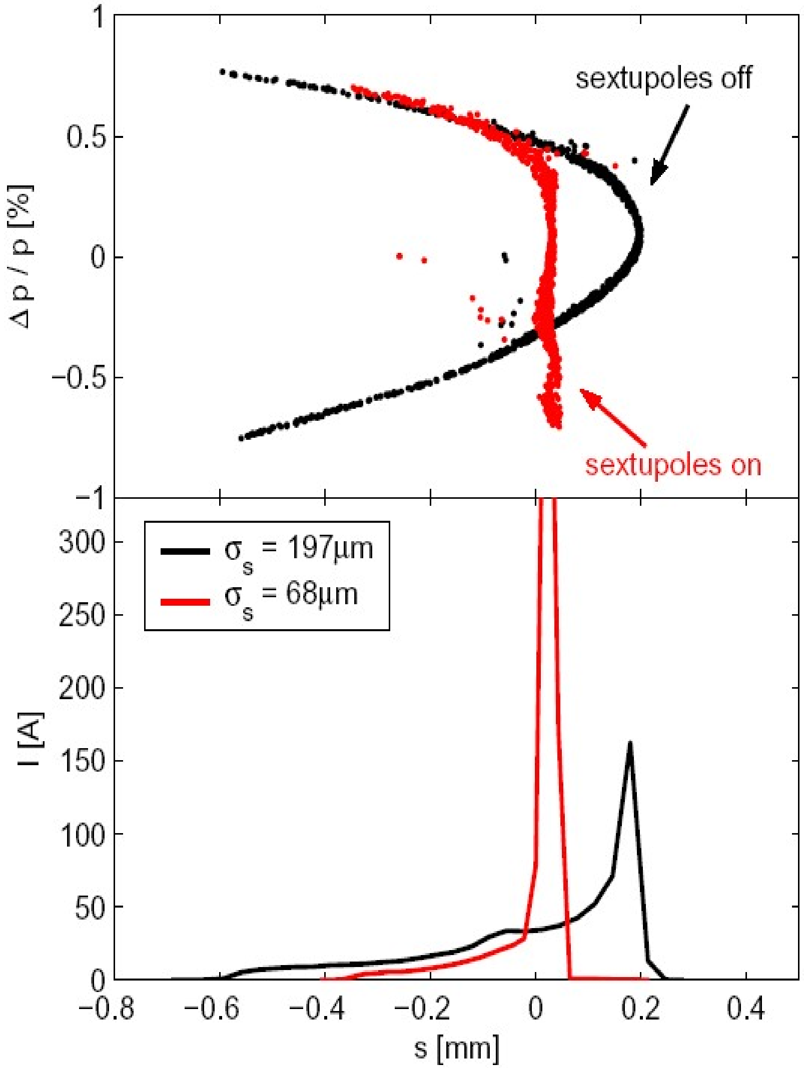
ASTRA 250k particles — **Gun to Booster** 0 to 8.35MeV
→ **Elegant** 250k particles — **Booster to FEL** 8.35/35MeV
→ **GENESIS** 10^6 particles — **FEL Interaction**
→ **Elegant** 250k particles — **FEL to Dump** 8.35/35MeV



S2E Simulation



Sextupole Linearisation



- Sextupoles in the outward arc help to achieve the shortest possible bunch length
- Can actually make bunch length too short for lasing! (in theory)
- Adjustable in real machine to optimise lasing properties
- In practice we are likely to see disruptive effects not apparent in the model

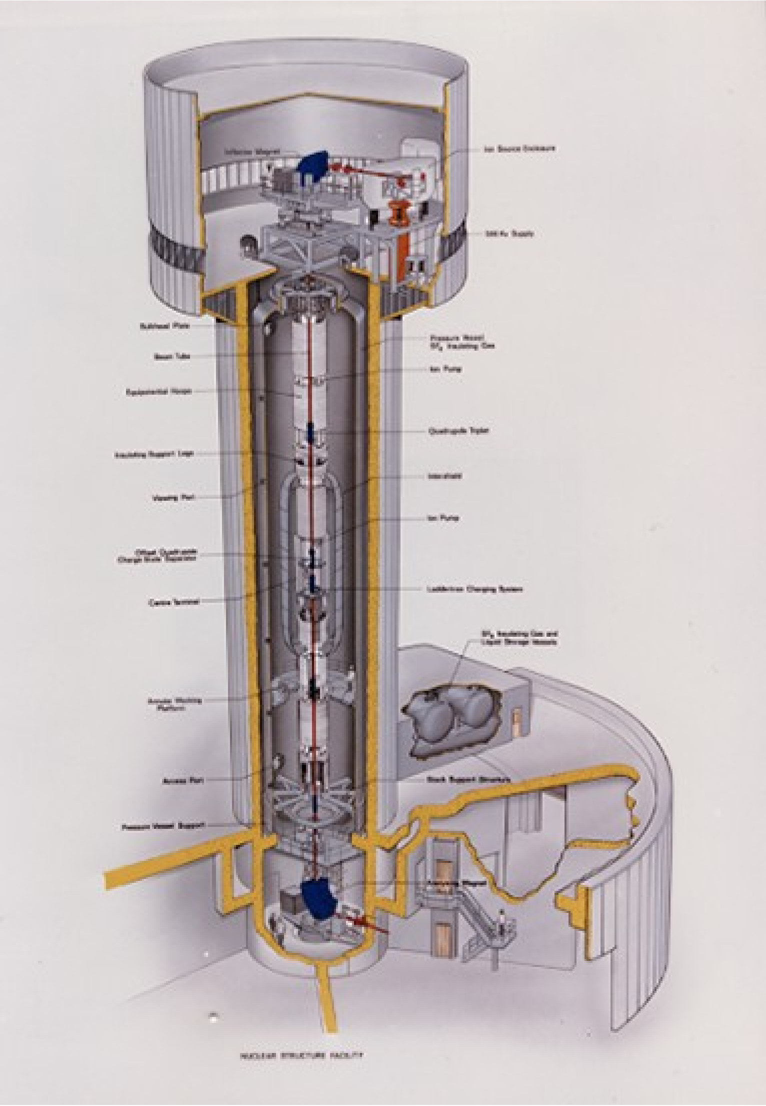
Beam Breakup and the ERLP

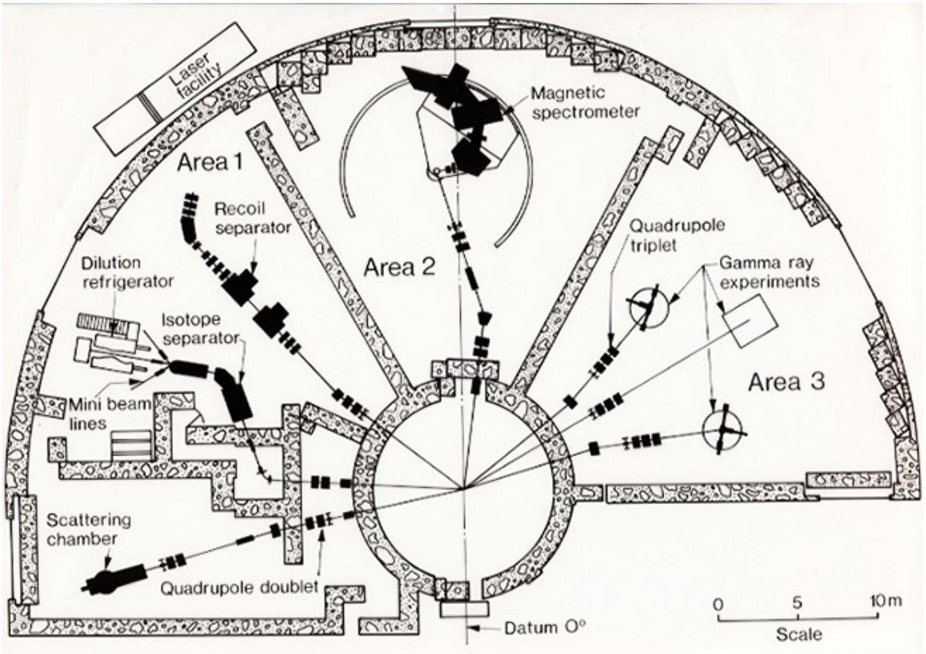
- Initial calculations & running the code BI (E. Wooldridge)
- Assume TESLA HOM's
- Threshold current 5.12 mA
- Beam Breakup not a problem for ERLP at this low current

Conclusions

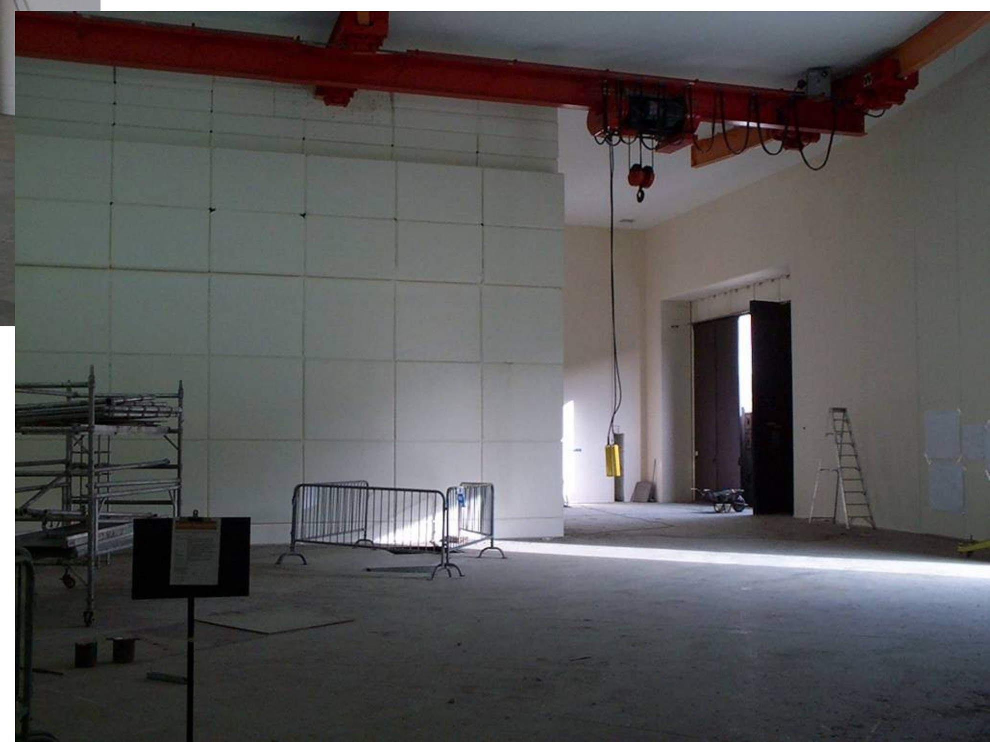
- Optics with no real problems so far
- Good agreement between ASTRA and GPT and analytical result for drifts (provided flow is laminar)
- All to be redone with dipoles correctly modelled
- Can analytical estimate be used as an upper bound in all cases ? or at least a reasonable 'rough guess' ?
- Try to take into account space charge by rematching at several stages in injector line. However, this cannot take into account transverse & longitudinal coupling
- BBU not a problem
- Start to end simulations only real answer to see if bunch is acceptable for lasing at FEL (to be redone with dipoles)

Daresbury Laboratory - Tower Building





Internal shielding complete



External shielding in construction

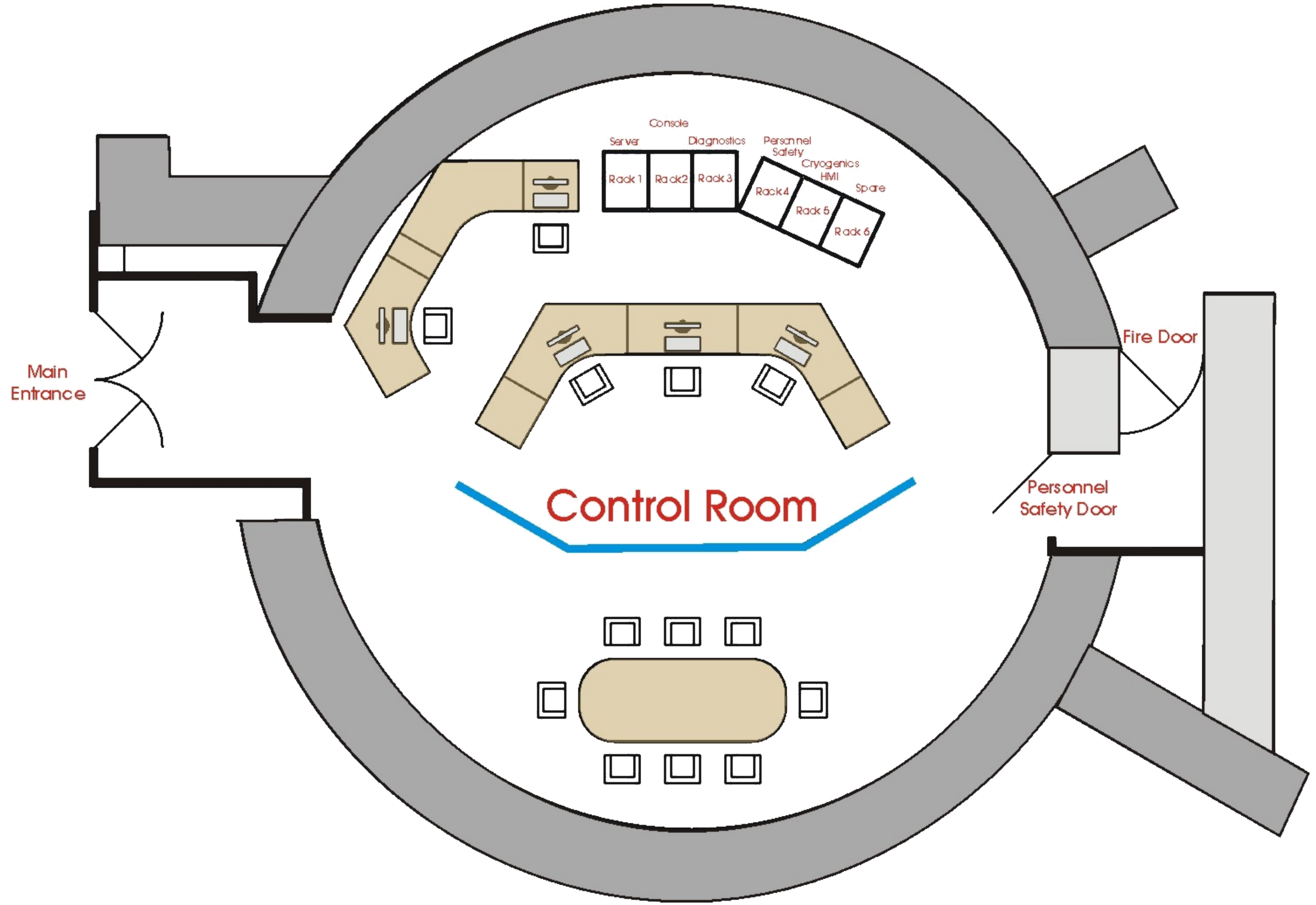
Inside Control Room

Assembly Building

Class 100 (ISO 5) Clean Room

Magnet Test Room

Control Room



TRACE-3D

- Include z component for E field
- Update continuously (no averaging)
- Would be nice to take into account longitudinal dispersion
- 1) Match transfer matrix cpt. R16 (dispersion) to zero
- 2) Match R26 (angular dispersion) to zero
- 3) Match R15 (bunch spatial width) to zero
- 4) Match R25 (bunch angular spread) to zero
- Usually only first two done (e.g. in MAD8)

$$E_x = \frac{1}{4\pi\varepsilon_0}\frac{3I\lambda}{c\gamma^2}\frac{(1-f)}{r_x(r_x+r_y)r_z}x \quad ,$$

$$E_y = \frac{1}{4\pi\varepsilon_0}\frac{3I\lambda}{c\gamma^2}\frac{(1-f)}{r_y(r_x+r_y)r_z}y \quad ,$$

$$E_z = \frac{1}{4\pi\varepsilon_0}\frac{3I\lambda}{c}\frac{f}{r_x r_y r_z}z \quad ,$$

$$p \equiv \frac{\gamma r_z}{\sqrt{r_x r_y}}$$

$$f(p) = \begin{cases} \frac{1}{1-p^2} - \frac{p}{(1-p)^{3/2}}\cos^{-1} p & \text{if } p < 1 \\ \frac{p\cosh^{-1} p}{(p^2-1)^{3/2}} - \frac{1}{(p^2-1)} & \text{if } p > 1 \\ \frac{1}{3} & \text{if } p = 1 \end{cases}$$