# Beam Physics Activities

Rick Baartman

Accelerator Division

2017-12-15

Discovery, accelerated

Members:

- R. Baartman
- Carla Barquest
- Fred Jones
- Dobrin Kaltchev
- (Shane Koscielniak)
- Marco Marchetto
- Thomas Planche
- Suresh Saminathan
- Yi-Nong Rao

2 Graduate students :

- Kyle Gao
- Paul Jung

(usually) 2 undergrad (co-op):

- Daniel Sehayek
- Matthew Wilson

--Carla Barquest, Thomas Planche, various co-op students.

# Web-based Control Room Applications at TRIUMF

(IPAC18 abstract)

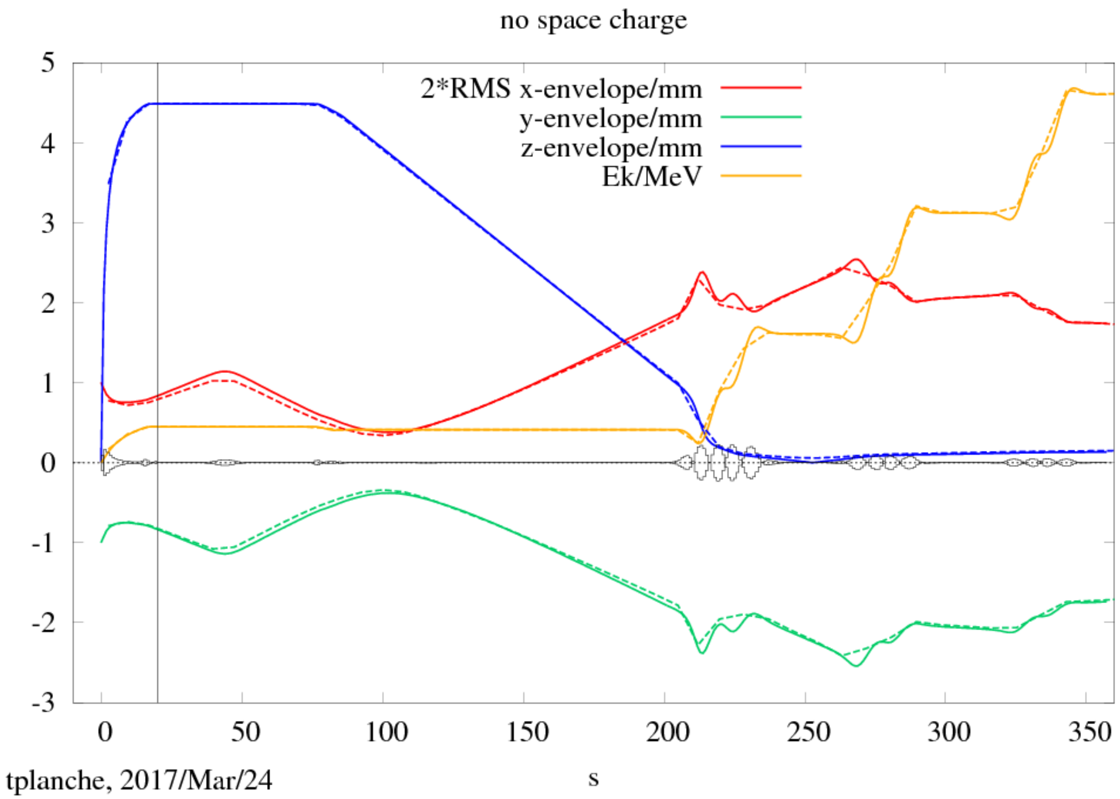
High level applications in accelerator facilities are programs that interface with control systems and beam physics models. These tools range from real-time diagnostic visualizations to post-processing data analysis. **At TRIUMF, the concept of web-based high level applications has been adopted to advance the capabilities of these applications and facilitate operations.** This **online model** takes advantage of three key features: server-based continuous integration, an open-source code base, and a centralized middleware layer. Continuous integration of server-based applications allows for easy deployment and maintenance. Open-source applications eliminate the dependence on licensed software. A centralized middleware layer allows a single application to work for many different accelerator configurations. Some motivating examples of deployed web-based high level applications are presented, demonstrating this online approach to be an effective method for deploying high level applications for use in the control room and beyond.

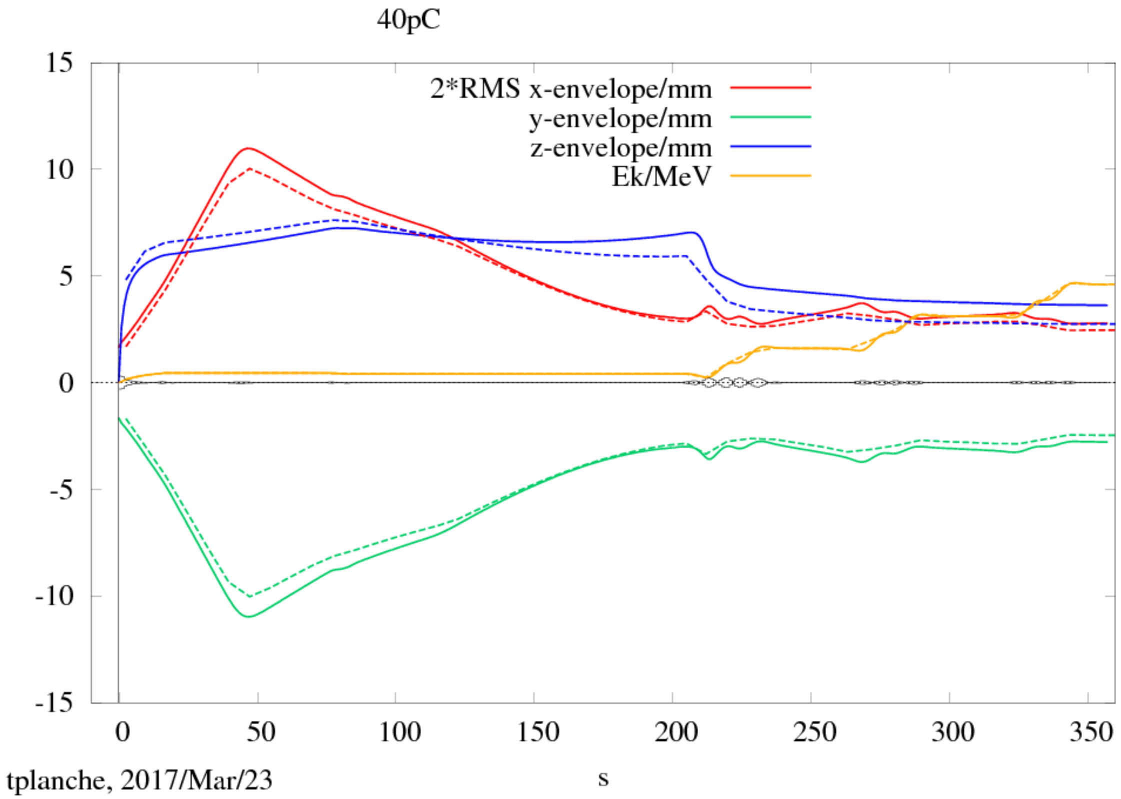
TL;DR: Use Higher level tools to reduce tuning time.

beam envelope browser-based app

# **KEK cERL** (visit by Thomas Planche, March 2017)

TRANSOPTR envelope calculation (solid) versus
GPT multiparticle model (dashed)
GPT is ~10000 times slower.



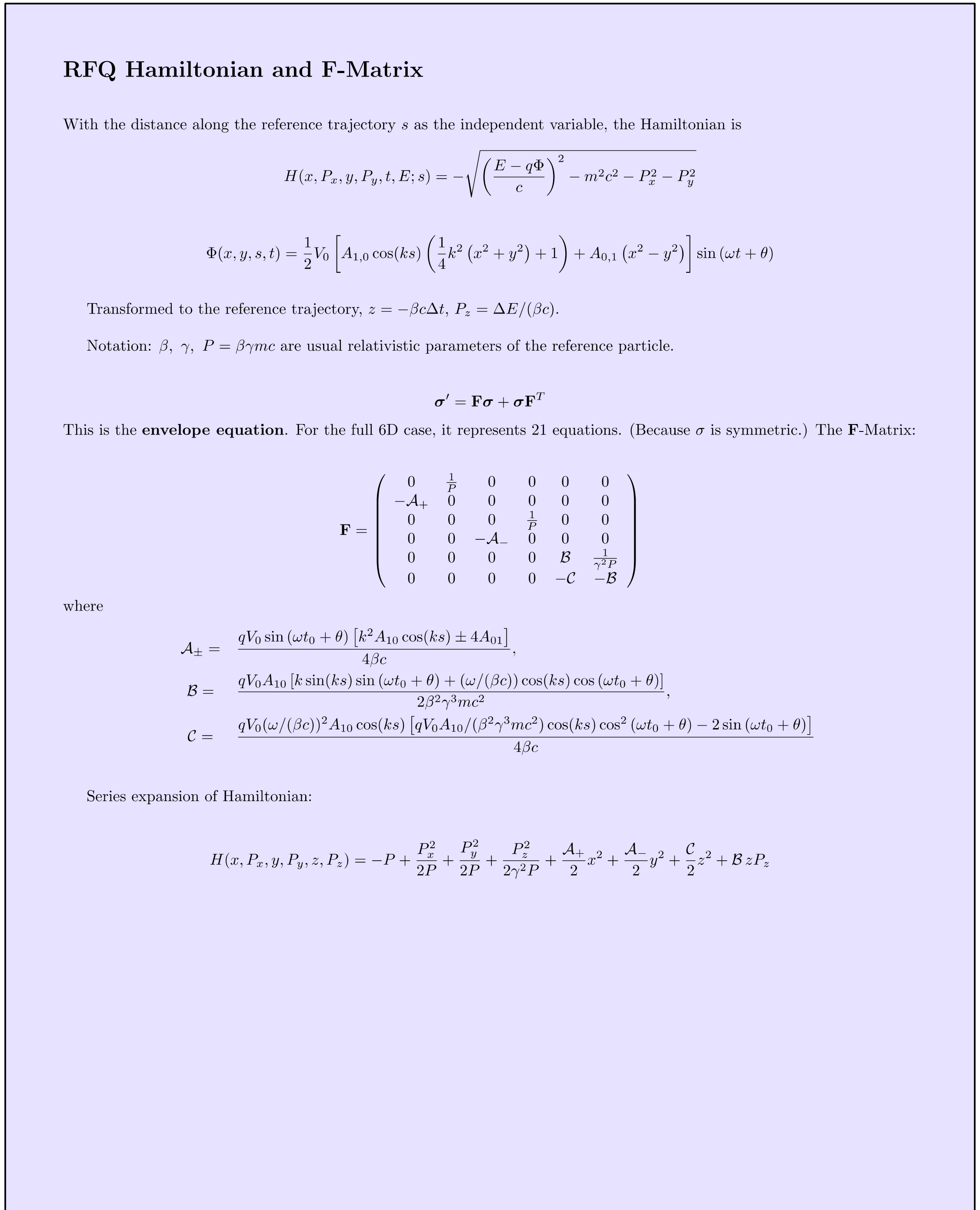


# Towards end-to-end envelope simulations with TRANSOPTR: Database & Code development

--Baartman, Olivier Shelbaya

This will include all linacs, bunchers, beam transport. Olivier is gathering the ISAC data to add to our database.
But: We did not have code for RFQ. →

Other participants: Spencer Kiy, Tiffany Angus, Stephanie Raedel



### RFQ Hamiltonian and F-Matrix

With the distance along the reference trajectory $s$ as the independent variable, the Hamiltonian is

$$H(x,P_x,y,P_y,t,E;s) = -\sqrt{\left(\frac{E-q\Phi}{c}\right)^2 - m^2c^2 - P_x^2 - P_y^2}$$

$$\Phi(x,y,s,t) = \frac{1}{2}V_0\left[A_{1,0}\cos(ks)\left(\frac{1}{4}k^2\left(x^2+y^2\right)+1\right) + A_{0,1}\left(x^2-y^2\right)\right]\sin\left(\omega t+\theta\right)$$

Transformed to the reference trajectory, $z=-\beta c\Delta t$, $P_z = \Delta E/(\beta c)$.

Notation: $\beta,\ \gamma,\ P=\beta\gamma mc$ are usual relativistic parameters of the reference particle.

$$\boldsymbol{\sigma}' = \mathbf{F}\boldsymbol{\sigma} + \boldsymbol{\sigma}\mathbf{F}^T$$

This is the **envelope equation**. For the full 6D case, it represents 21 equations. (Because $\sigma$ is symmetric.) The **F**-Matrix:

$$\mathbf{F} = \begin{pmatrix} 0 & \frac{1}{P} & 0 & 0 & 0 & 0 \\ -\mathcal{A}_+ & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{P} & 0 & 0 \\ 0 & 0 & -\mathcal{A}_- & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \mathcal{B} & \frac{1}{\gamma^2 P} \\ 0 & 0 & 0 & 0 & -\mathcal{C} & -\mathcal{B} \end{pmatrix}$$

where

$$\mathcal{A}_\pm = \frac{qV_0\sin\left(\omega t_0+\theta\right)\left[k^2A_{10}\cos(ks)\pm 4A_{01}\right]}{4\beta c},$$

$$\mathcal{B} = \frac{qV_0A_{10}\left[k\sin(ks)\sin\left(\omega t_0+\theta\right)+(\omega/(\beta c))\cos(ks)\cos\left(\omega t_0+\theta\right)\right]}{2\beta^2\gamma^3mc^2},$$

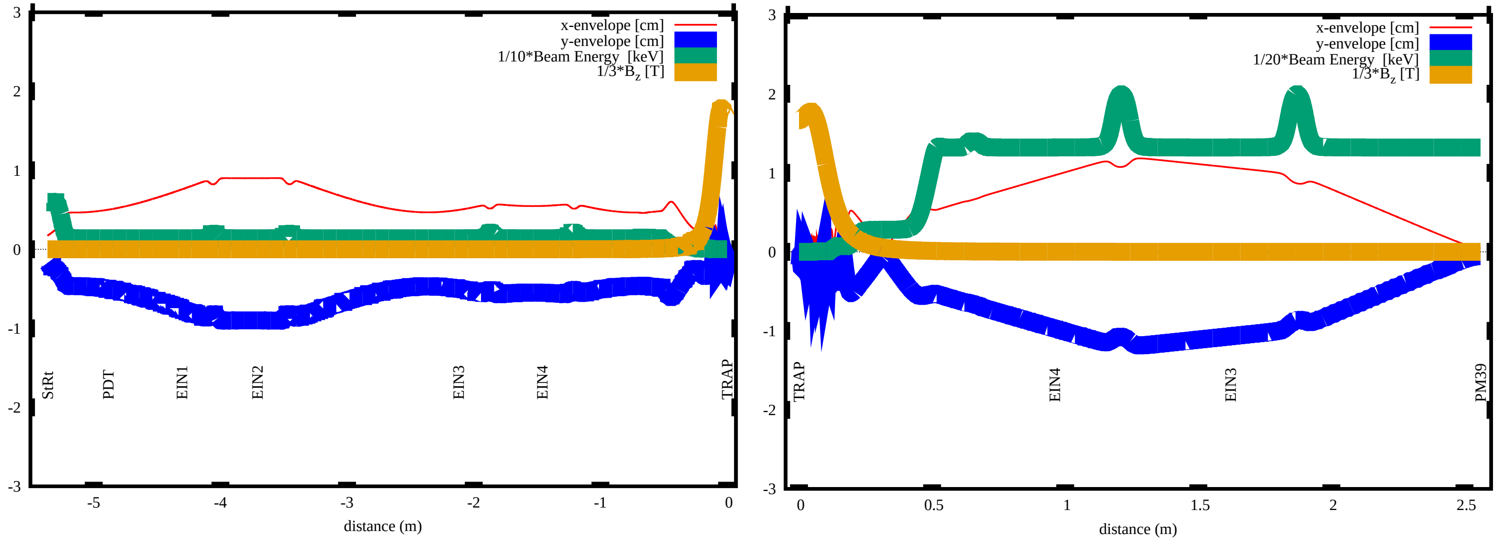
$$\mathcal{C} = \frac{qV_0(\omega/(\beta c))^2A_{10}\cos(ks)\left[qV_0A_{10}/(\beta^2\gamma^3mc^2)\cos(ks)\cos^2\left(\omega t_0+\theta\right)-2\sin\left(\omega t_0+\theta\right)\right]}{4\beta c}$$

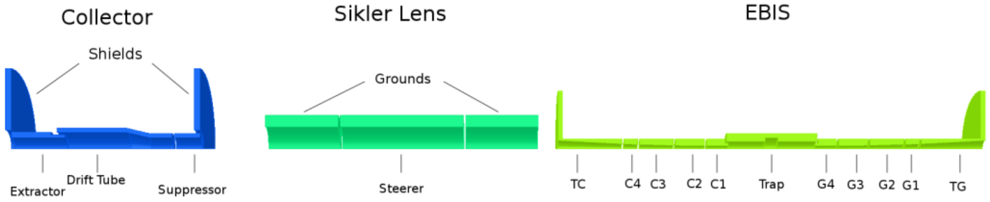
Series expansion of Hamiltonian:

$$H(x,P_x,y,P_y,z,P_z) = -P + \frac{P_x^2}{2P} + \frac{P_y^2}{2P} + \frac{P_z^2}{2\gamma^2P} + \frac{\mathcal{A}_+}{2}x^2 + \frac{\mathcal{A}_-}{2}y^2 + \frac{\mathcal{C}}{2}z^2 + \mathcal{B}\,zP_z$$

# EBIT modelling in TRANSOPTR.

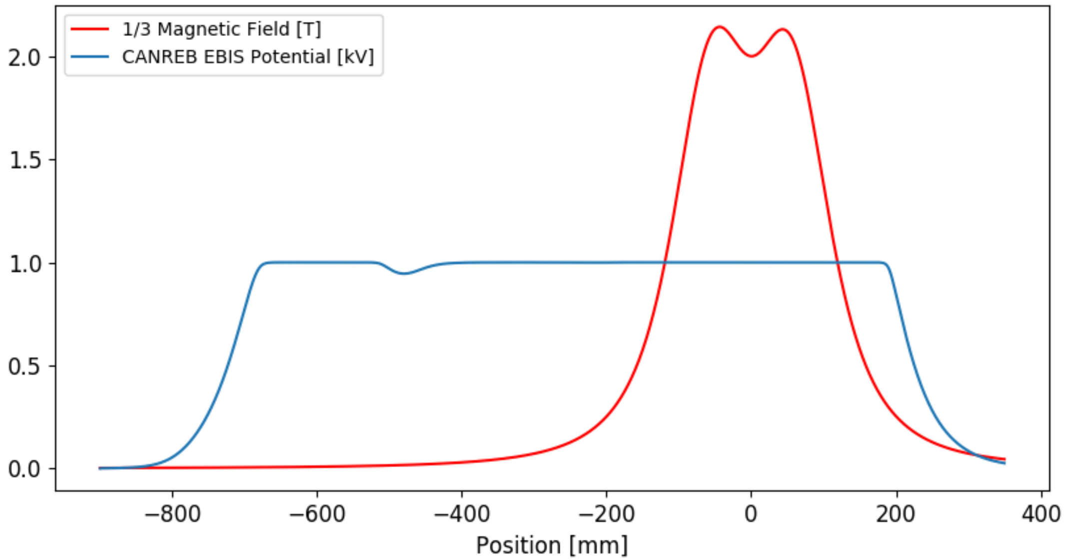
## Suresh Saminathan and Matthew P-Wilson (co-op student)





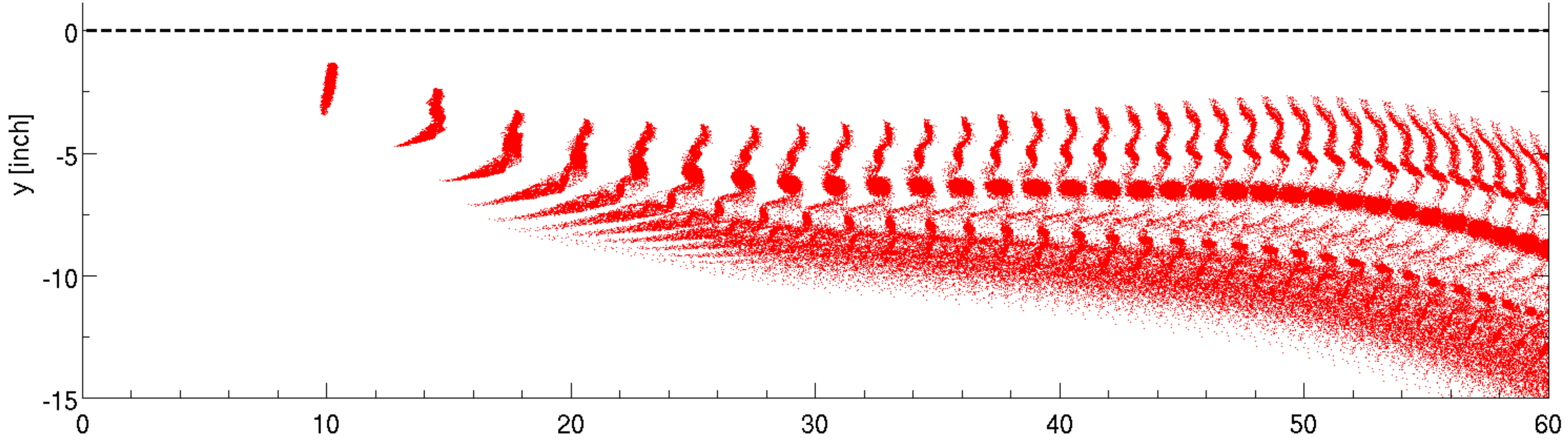
This was undertaken to establish matching parameters into and out of the EBIS charge breeder. It's never been done before in an envelope code.

Sum of all EBIS electrode potentials at 1 kV

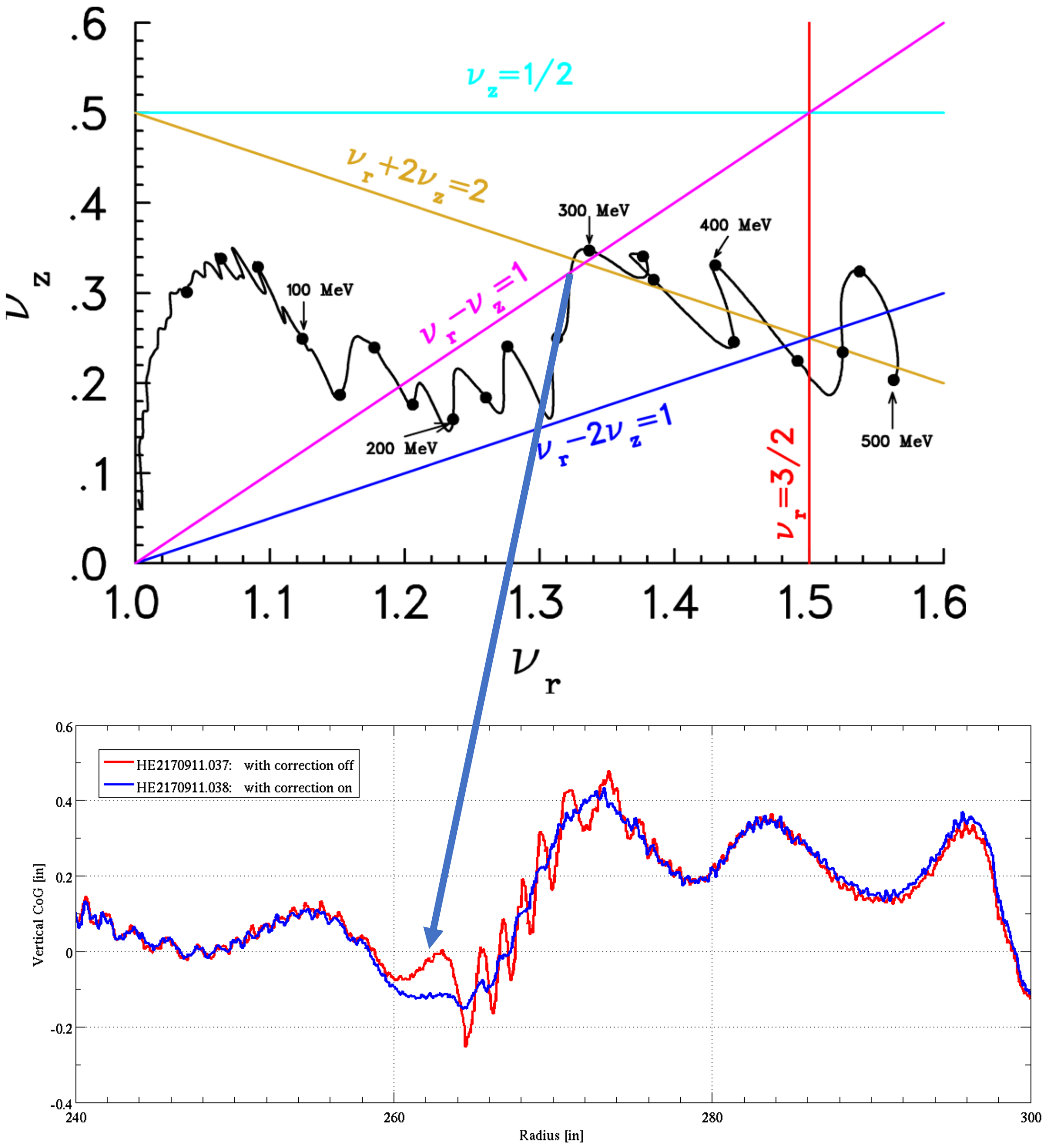


# TRIUMF Cyclotron Simulations with Space Charge – Y-N Rao. T. Planche

The multi-particle simulation for the long bunch in TRIUMF cyclotron shows that the space charge force induces vortex motion, causing beam break-up and leading to a lot of structure in the bunch. This is part of a project to increase cyclotron output to 0.4 to 0.5 mA.



# Resonance Compensation, Cyclotron –Y-N Rao



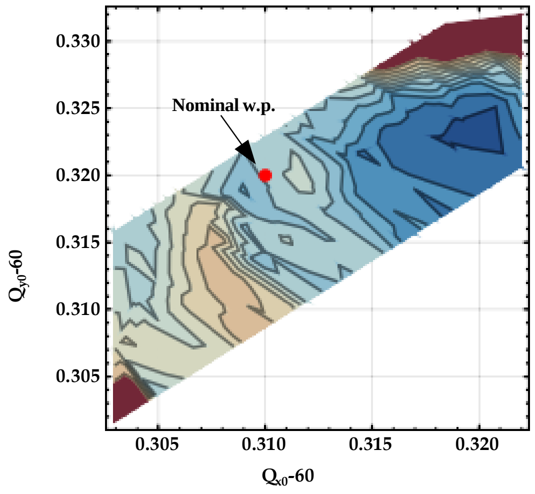
The TRIUMF next 5YP proposal is to have 4 simultaneous high energy, high intensity beams of 450 μA for the beam-lines 1A, 2A, 2C & 4N. But very small changes in the circulating beam orbit can result in large oscillations to the height of the beam centre (due to coupling resonance $\nu_r - \nu_z = 1$), causing beam loss in the cyclotron and even down the beam-lines.

Compensation can be achieved by correcting the coupling resonance using the existing $B_r$ harmonic coils.

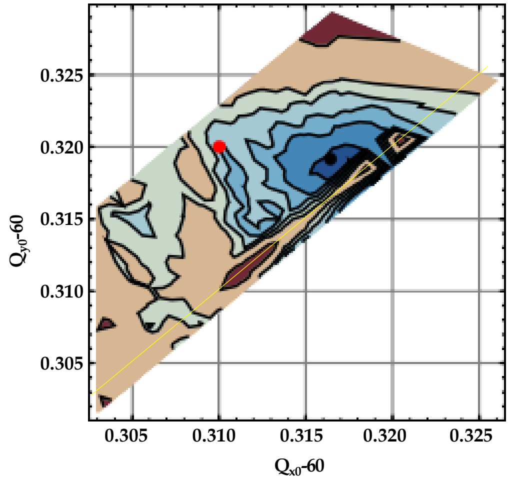
# LHC Beam-Beam Effect studies for High Luminosity Upgrade: Dynamic Aperture Scans (2D)

-- Dobrin Kaltchev

Tune space



(a) $N_b = 1.1 \times 10^{11}$



(b) $N_b = 2.2 \times 10^{11}$

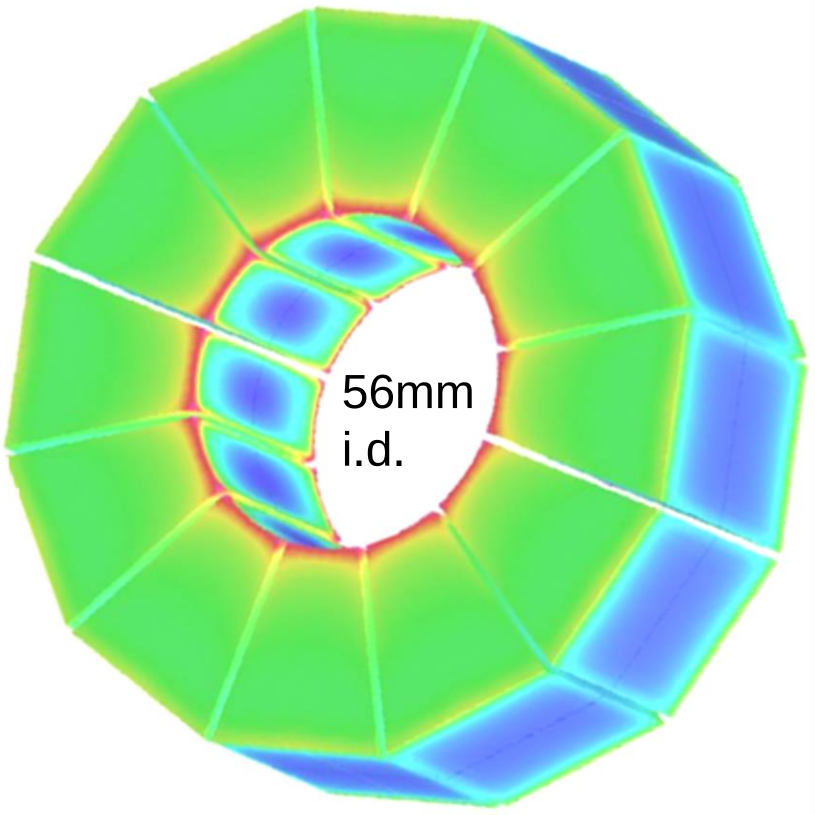
*Beam-beam and sextupoles.* **Shown are contours of minimum dynamic aperture**

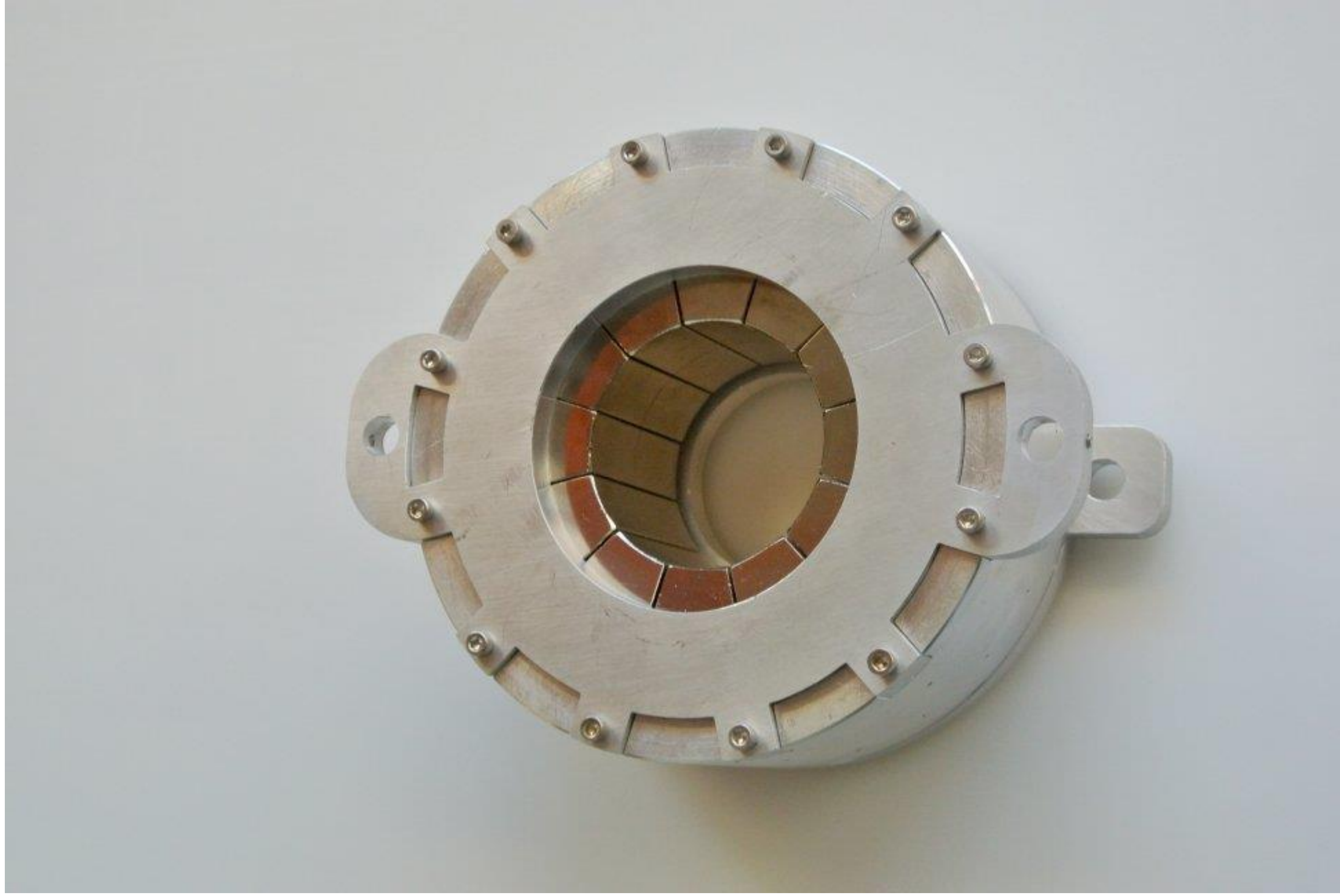
**IR1,5 X-ing half-angle 295 $\mu$rad, $\beta^*$ = 15 cm, Q' = 3, octupoles OFF**

- *as suggested by CERN, the linear domain extended towards the diagonal. Found DA above* **6** *sigma (b) even with unrealistic (high pileup) bunch intensity at end of fill:* $\mathbf{2.2 \times 10^{11}}$ Dec. 2016.
- *A similar result for a high chromaticity Q' and with octupoles ON.*
- *Currently using* $\mathbf{1.2 \times 10^{11}}$, *$\beta^*$ = 15 cm, 250 $\mu$rad (no pileup).*

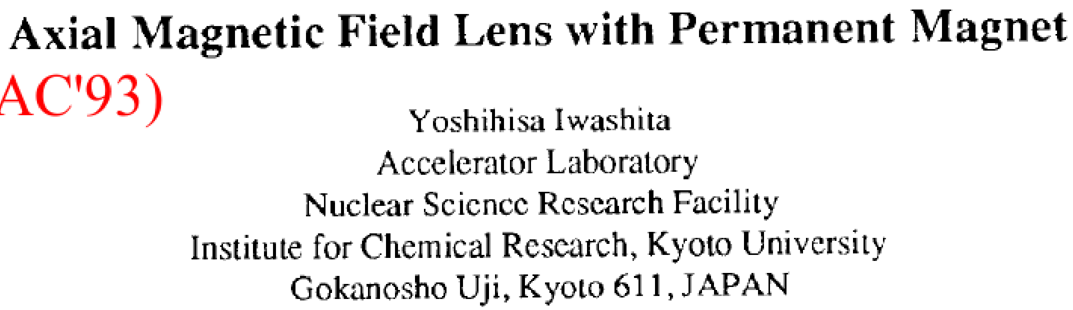
# Permanent Magnet Lens – Baartman, Planche, (Jayamanna/Minato/Lovera)

Simulated and built a new type of permanent magnet lens (like Iwashita, but single). To be used to create higher brightness H- beams.





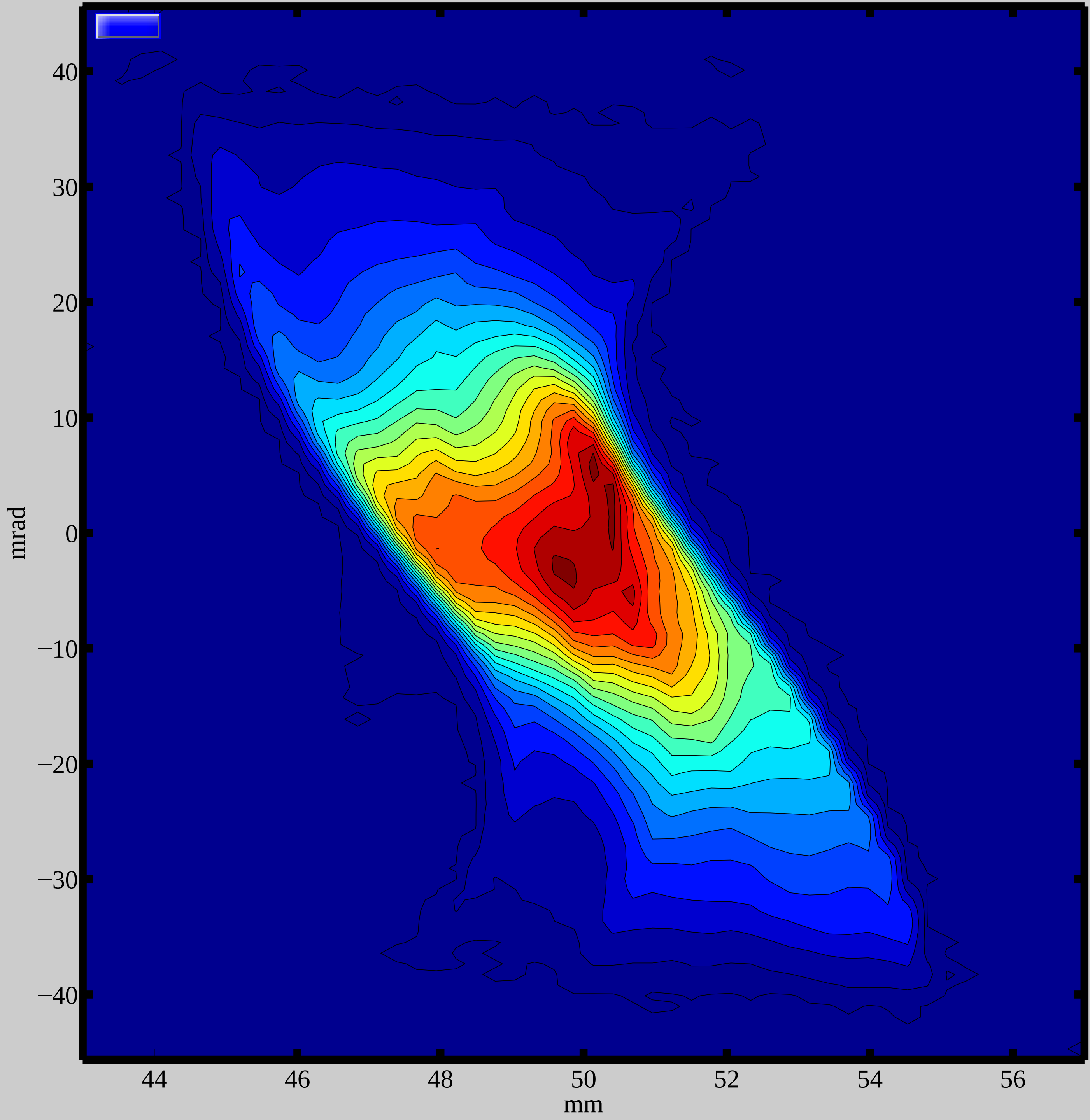
(PAC'93)


**Axial Magnetic Field Lens with Permanent Magnet**

Yoshihisa Iwashita
Accelerator Laboratory
Nuclear Science Research Facility
Institute for Chemical Research, Kyoto University
Gokanosho Uji, Kyoto 611, JAPAN

# Permanent Magnet Lens

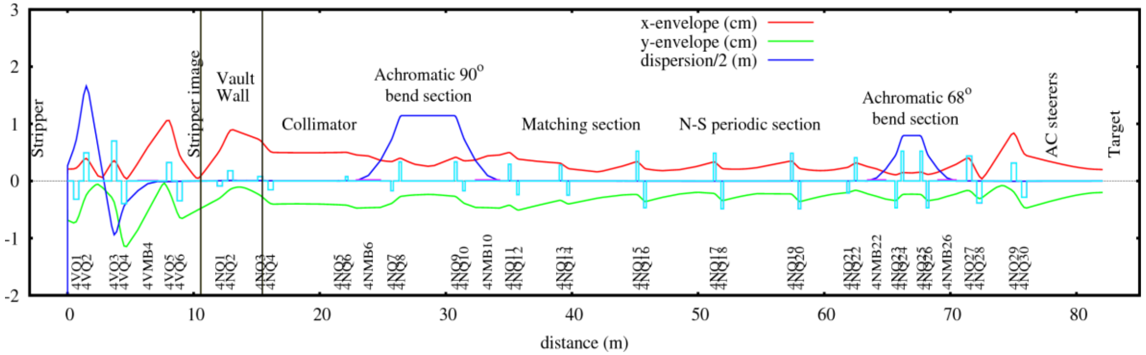
Allison emittance scanner shows the expected S-shape (non)linearity.



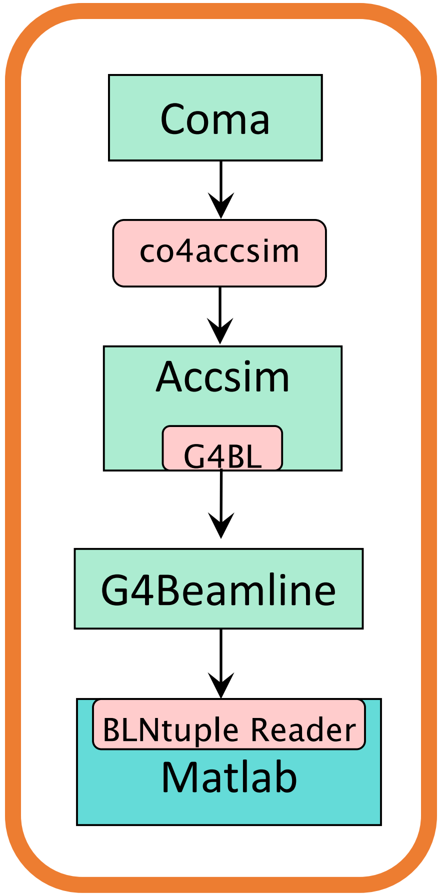
# New Proton Beamline Collimation & Loss Study

– Fred Jones

Multi-code tracking simulations are used in this study to optimize collimation of the proton beam halo resulting from scattering in the cyclotron extraction foil. The simulation stages are: (1) tracking in the cyclotron with COMA, (2) extraction foil simulation by ACCSIM and (3) tracking through the beam line in G4BEAMLINE, which incorporates a 3D geometry of the collimator and beam line and monte carlo simulation of particle interactions in matter. Results indicate that the proposed single-stage collimation will reduce proton losses to less than 1 W/m and allow hands-on maintenance of the beam line.



**Layout and Optics** The beam line is tuned to obtain point-to-parallel focusing from the stripper foil to the collimation straight section (16--21m) just outside the cyclotron vault, whereby angles are mapped to displacements allowing large-angle collimation.



Coma

co4accsim

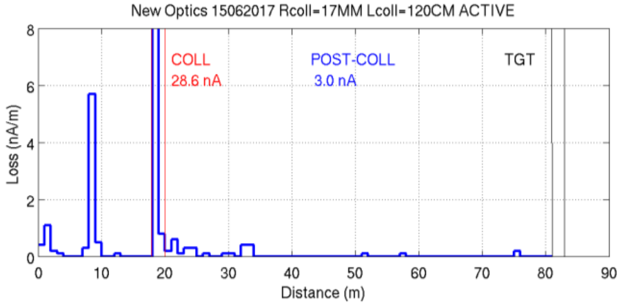
Accsim

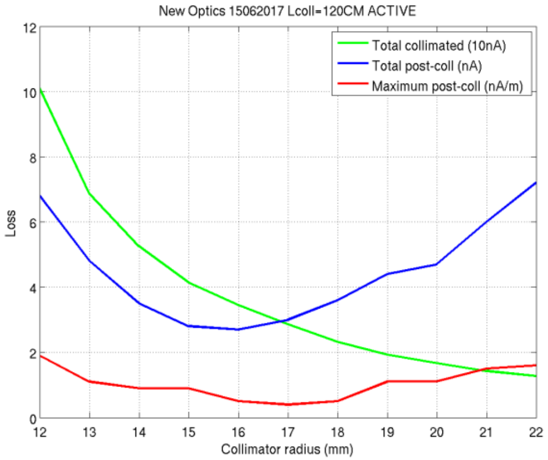
G4BL

G4Beamline

BLNtuple Reader

Matlab

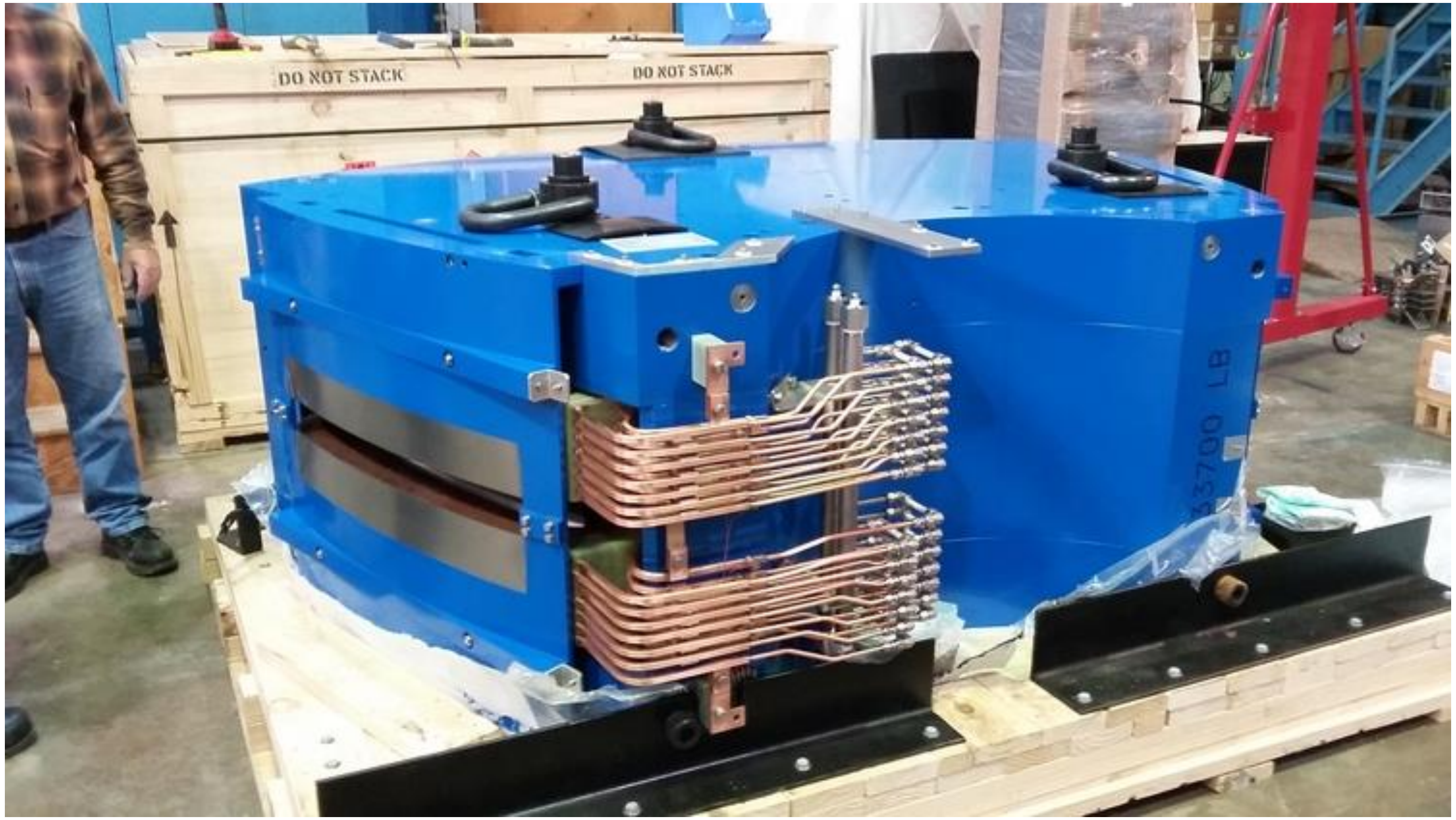


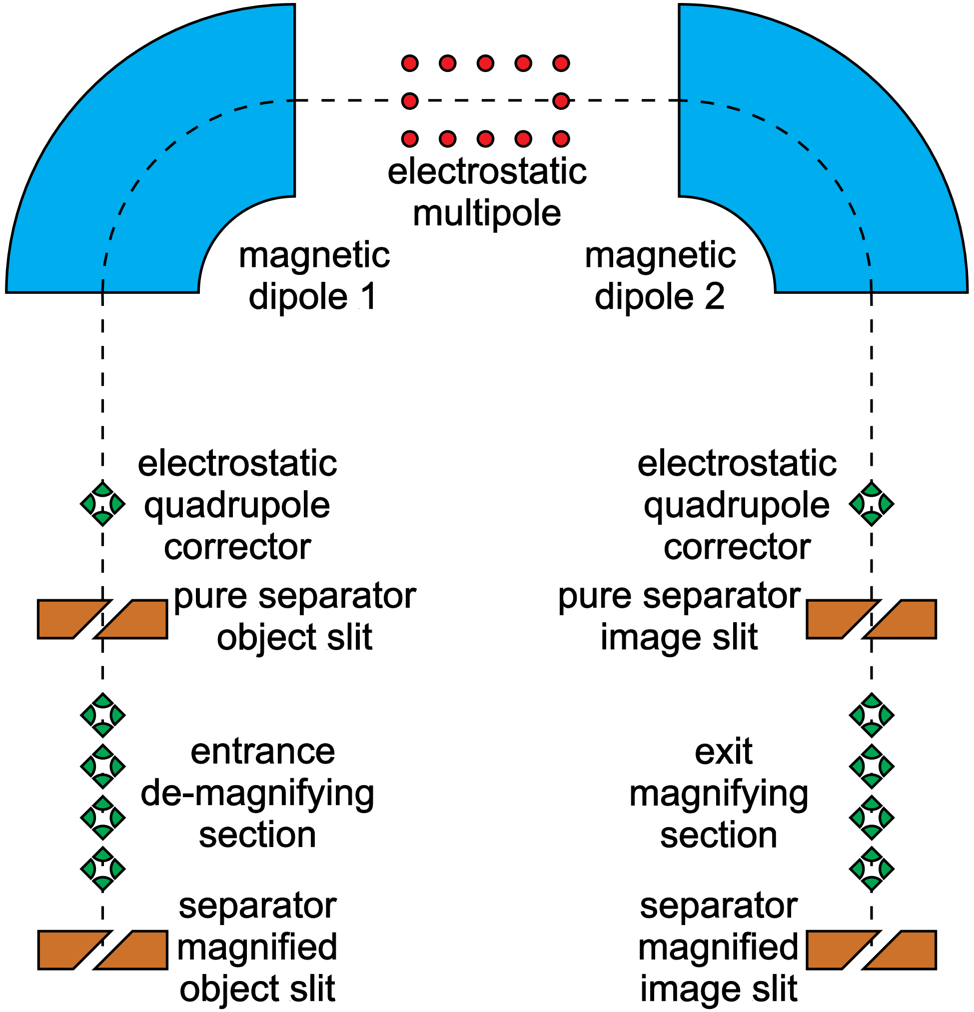


# Mass Separator: Dipole design

(M. Marchetto thesis)

Designed an innovative High Resolution (20,000) Isotope Separator. Dipoles have been delivered.

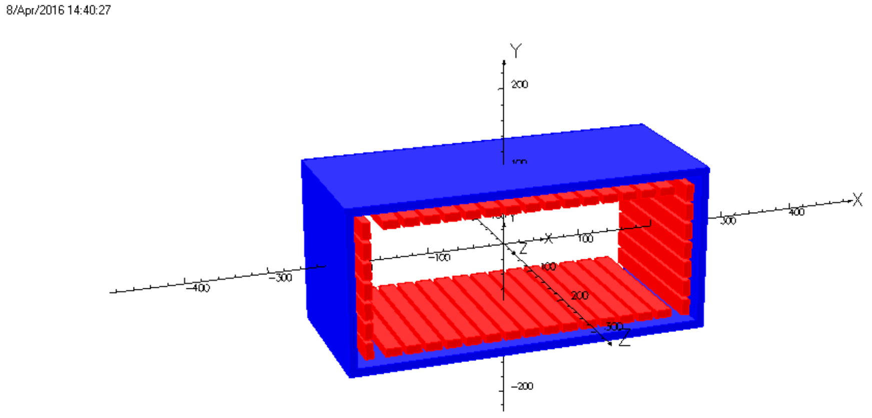




Separator design: Baartman, Planche, Marchetto, Maloney

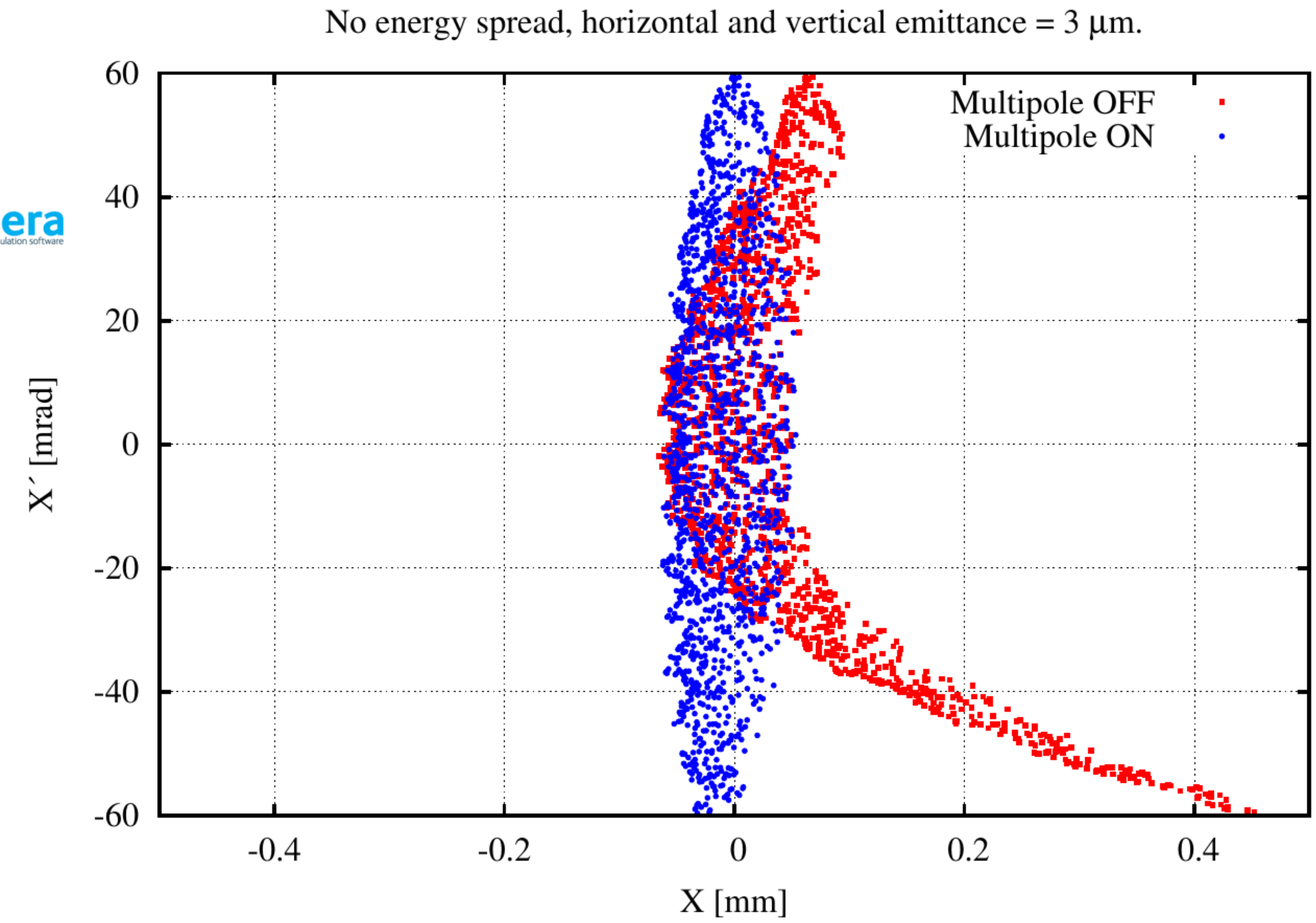
# High Resolution Separator – Automatic Multipole Tuning Technique

– Carla Barquest, Thomas Planche, Dan Sehayek



opera simulation software

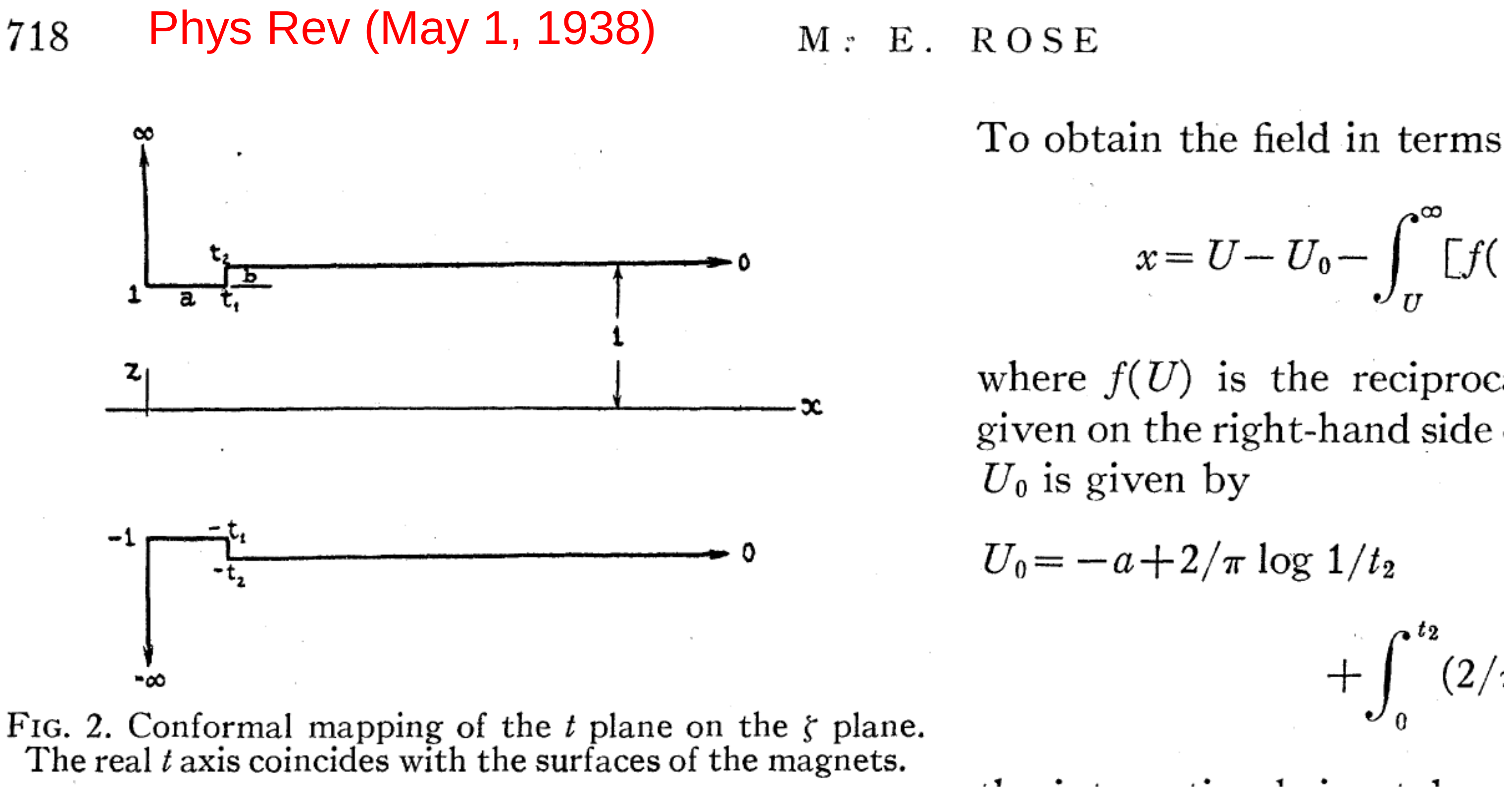
- CANREB High Resolution Separator (HRS) designed with resolution of 1:20,000 for beams with $\varepsilon_T$ = 3 µm
- To reach this high resolution, high-order aberrations must be corrected using a multipole corrector
- Unique geometry of multipole --> Novel tuning method
- Algorithm determines desired pole voltages directly from measured emittance



# Shimmed Electrodes (and Magnets)

--Thomas Planche and Matthew Basso (genius co-op student)

Formalized technique, flattens field (or reduces size). From conformal mapping.



718 Phys Rev (May 1, 1938) M. E. ROSE

FIG. 2. Conformal mapping of the *t* plane on the ζ plane. The real *t* axis coincides with the surfaces of the magnets.

To obtain the field in terms

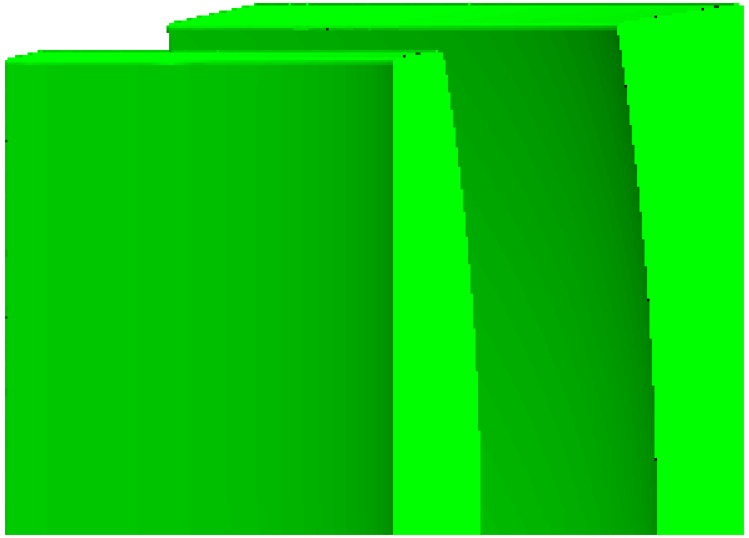
$$x = U - U_0 - \int_U^\infty [f($$

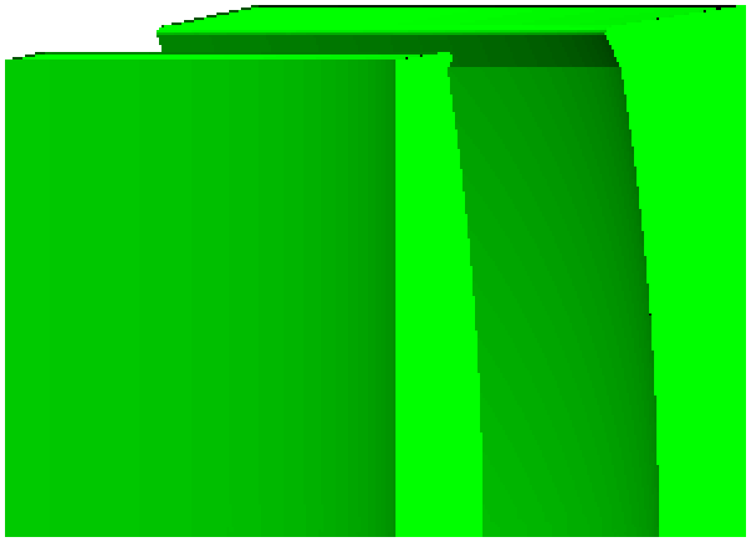
where $f(U)$ is the reciproc
given on the right-hand side
$U_0$ is given by

$$U_0 = -a + 2/\pi \log 1/t_2$$

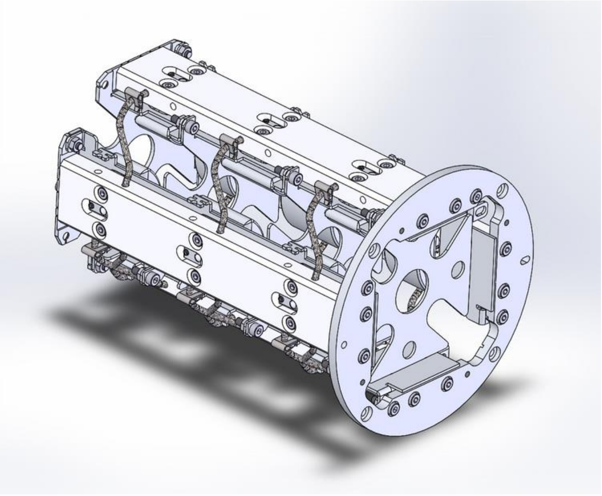
$$+\int_0^{t_2} (2/$$

Suresh's application to ARIEL pre-separator Electric bender:

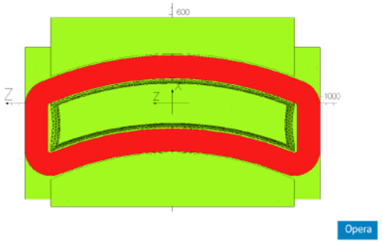




# Other Optics Elements, Electrostatic, Magnetic…



- Electrostatic 60keV prototype section
- 45 degree, space-efficient dipole magnet



- Short quadrupoles with spherical poles

- Etc.

# Summary

- Web-based Control Room Applications at TRIUMF
- Towards end-to-end envelope simulations with TRANSOPTR: Database & Code development
- EBIT modelling in TRANSOPTR
- TRIUMF Cyclotron Simulations with Space Charge
- Resonance Compensation, Cyclotron
- LHC Beam-Beam Effect studies for High Luminosity Upgrade
- Permanent Magnet Lens
- New Proton Beamline Collimation & Loss Study
- High Resolution Separator (HRS) Dipoles
- HRS – Automatic Multipole Tuning Technique
- Shimmed Electrodes (and Magnets)
- Optics Elements Design: Electrostatic, Magnetic…

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# Thank you
# Merci

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