Accelerator Physics Around ¾ of the World

A Summary of Experiences & Planned Work at FONT

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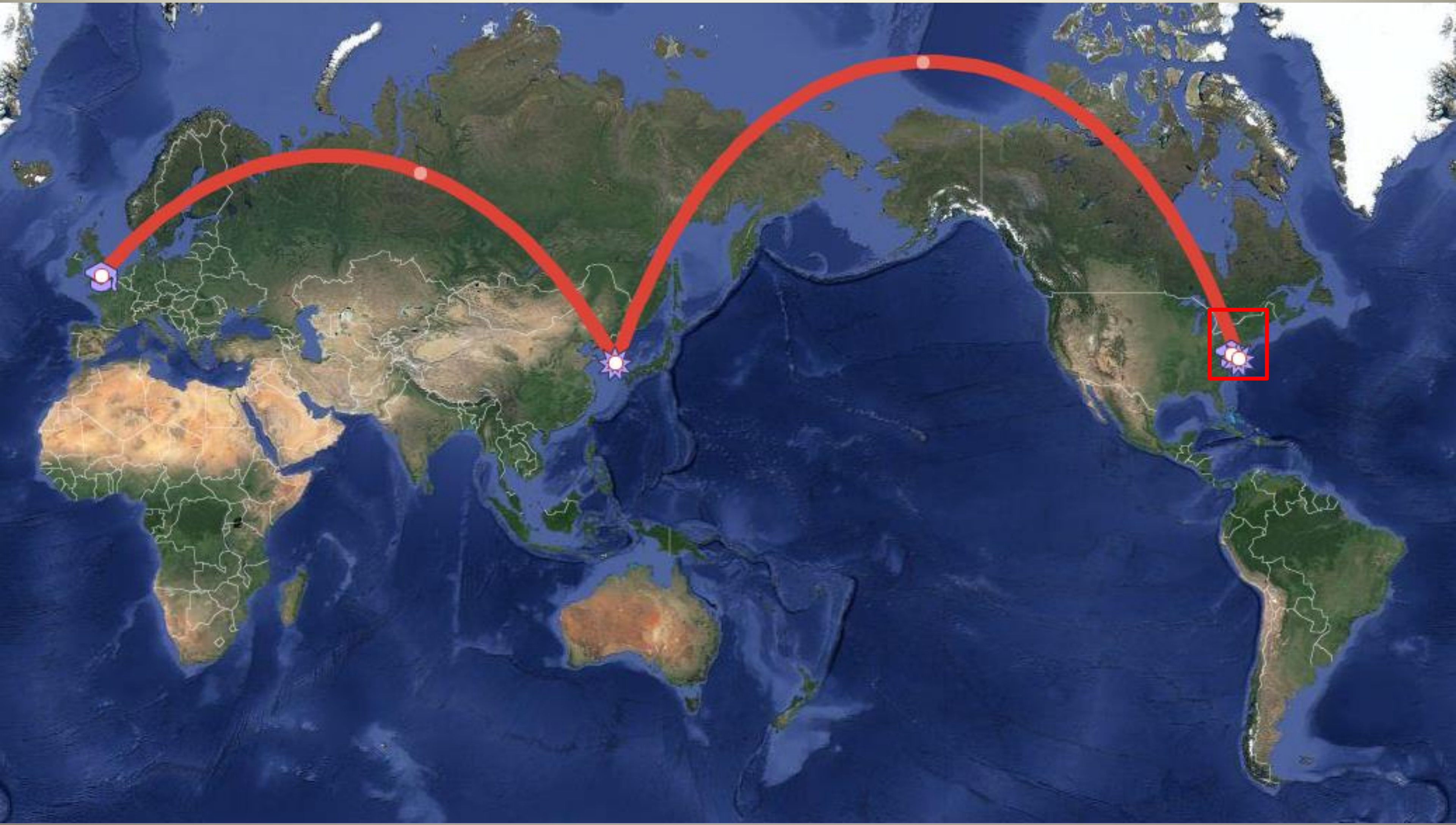
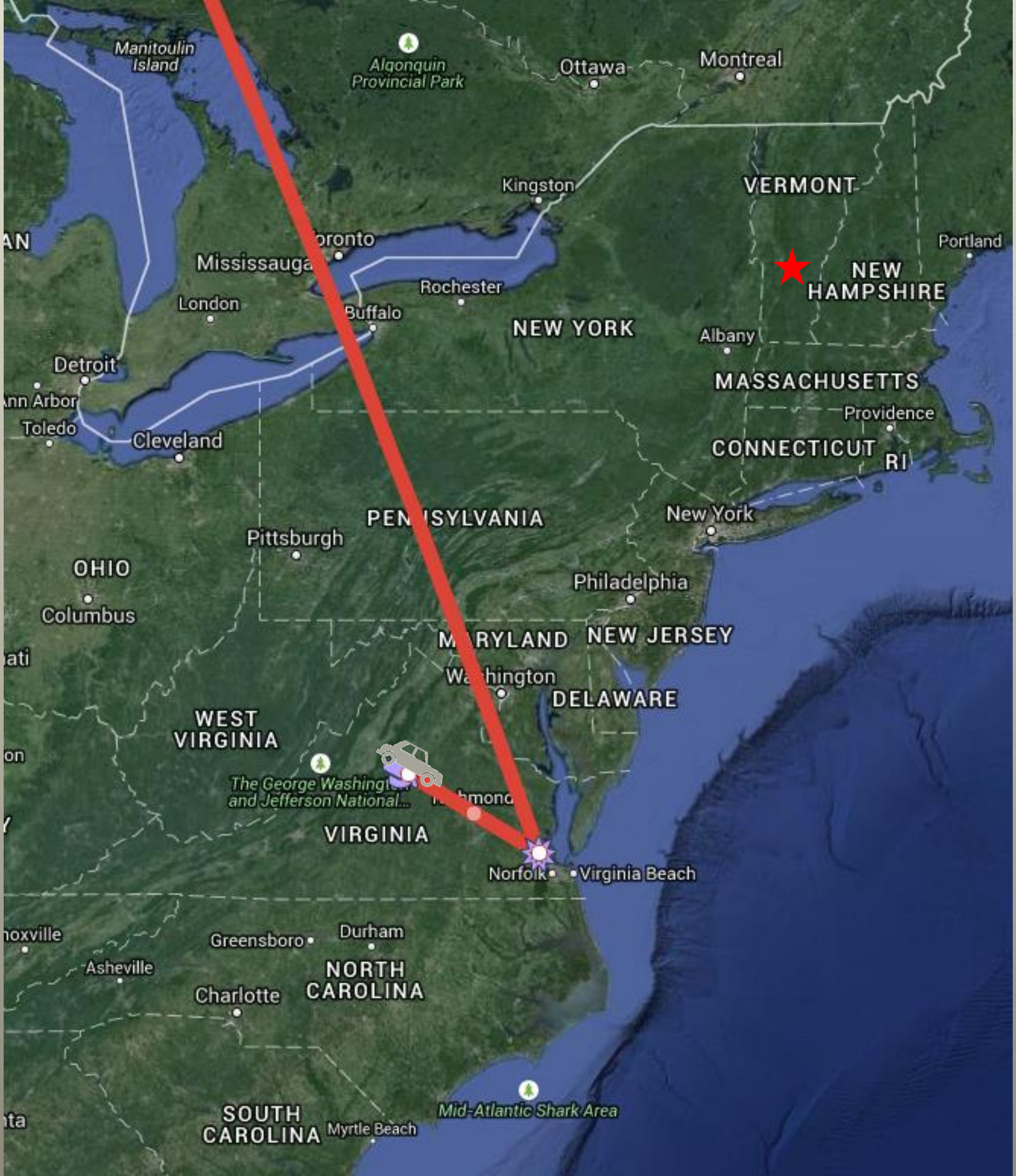
Postdoctoral Research Assistant
FONT Group – JAI
University of Oxford

Hello, 안녕하세요, Hello Again…

- Introductory talk – to introduce myself and my work.
- PhD in 2012 from University of Virginia
  - Dissertation work at Jefferson Lab in Newport News, Virginia, USA
- Research Fellow at the Rare Isotope Science Project (RISP), part of the Institute for Basic Science (IBS) in Daejeon, South Korea.
- Postdoctoral Research Assistant here in the FONT group.
- Talk will be more conceptual than quantitative.

So, where to begin…





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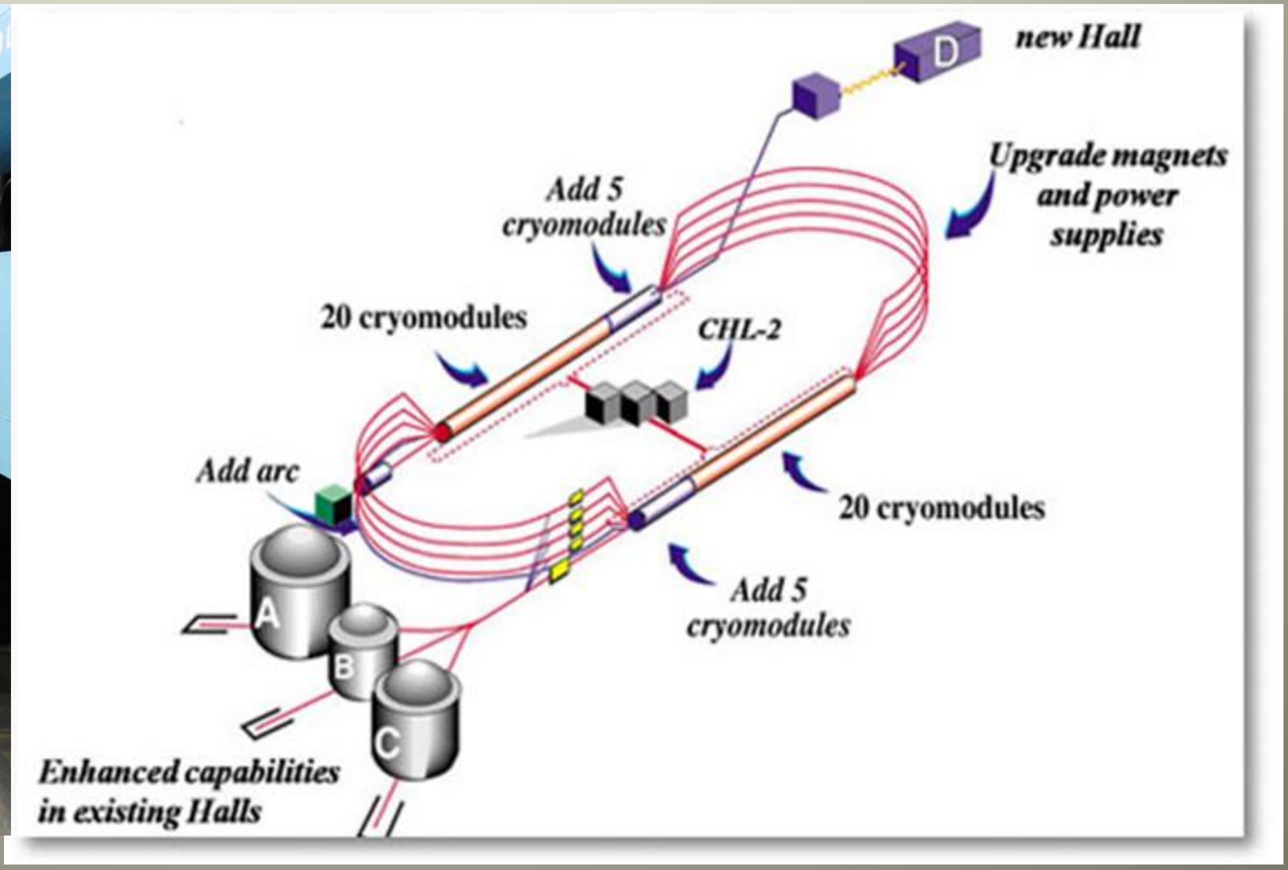
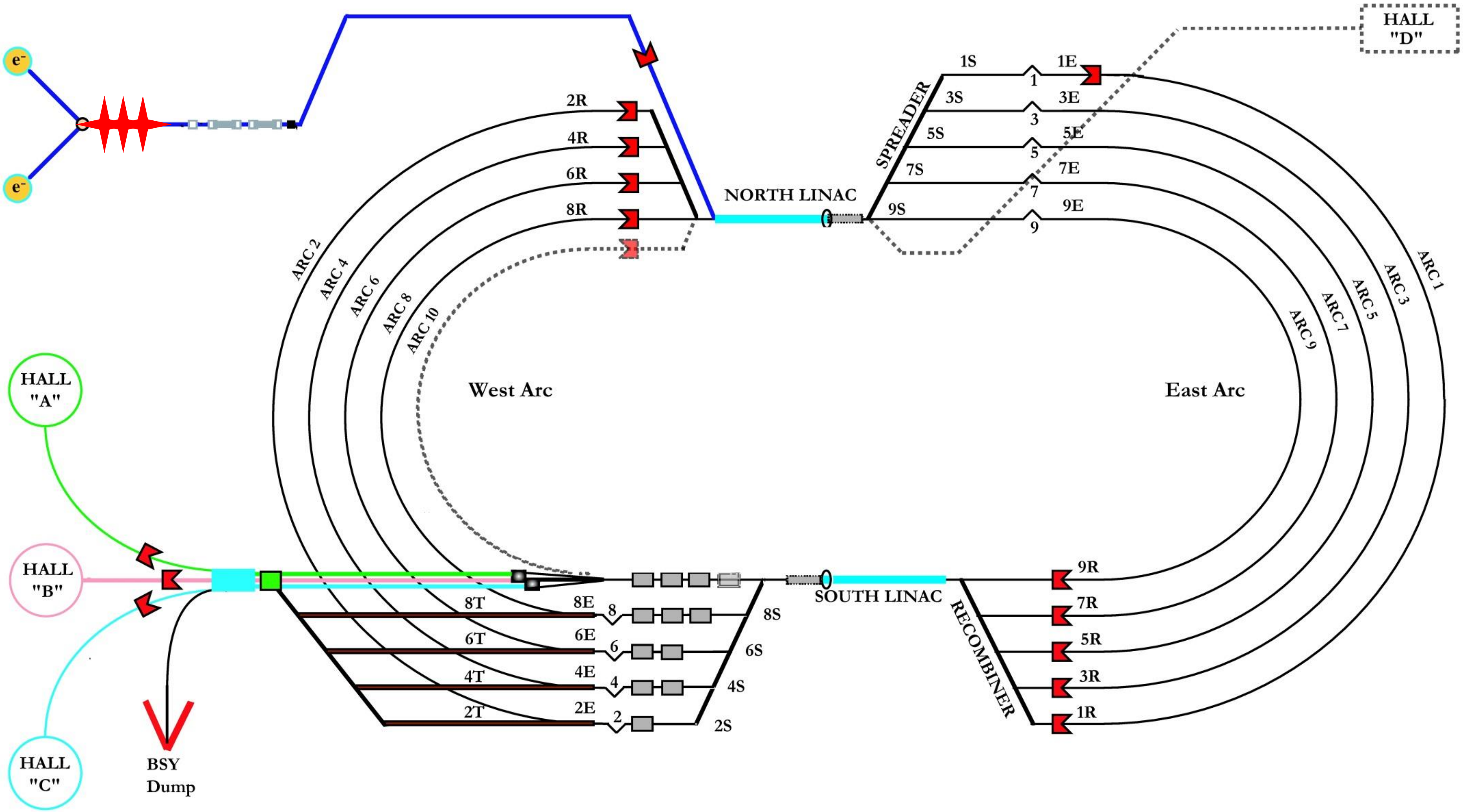
A bit about JLab

- 6 GeV (12 now) recirculating electron linac
  - Continuous Electron Beam Accelerator Facility (CEBAF)
- Essentially a linac folded over upon itself up to 5 times



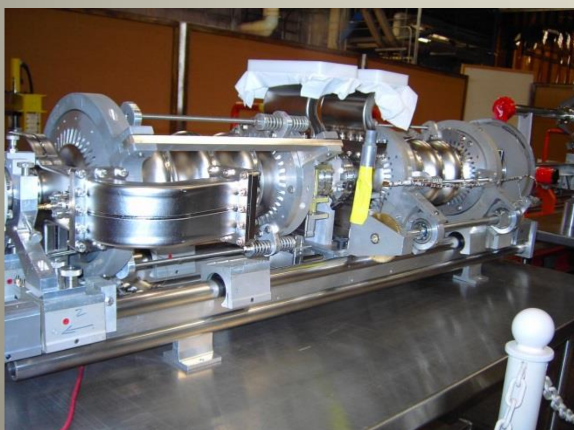
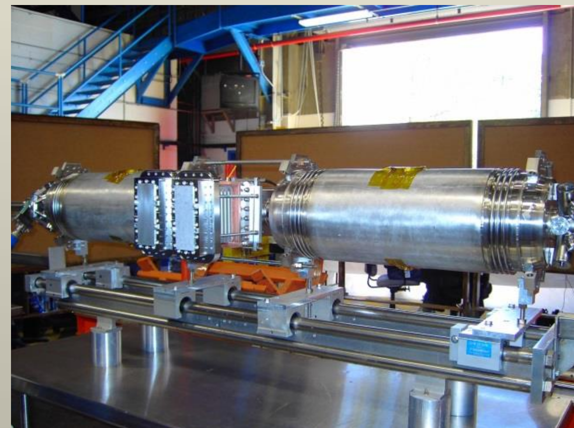
How CEBAF Works



~7/8 mile around
Each linac ~1/4 mile

What did I do at JLab?

- My first few jobs were in the SRF Institute
  - Bead pulls
  - HOM measurements in the cavity test cave
  - Vertical cavity tests


What did I do at JLab?

- Then I moved to the Center for Advanced Study of Accelerators (CASA) Group (http://casa.jlab.org/)
- Had to do a "warm-up" project

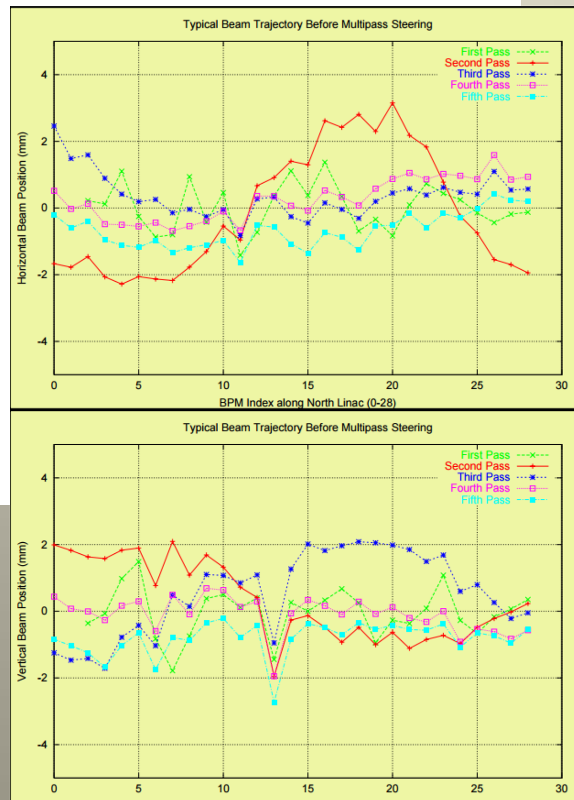
THPAS072 Proceedings of PAC07, Albuquerque, New Mexico, USA

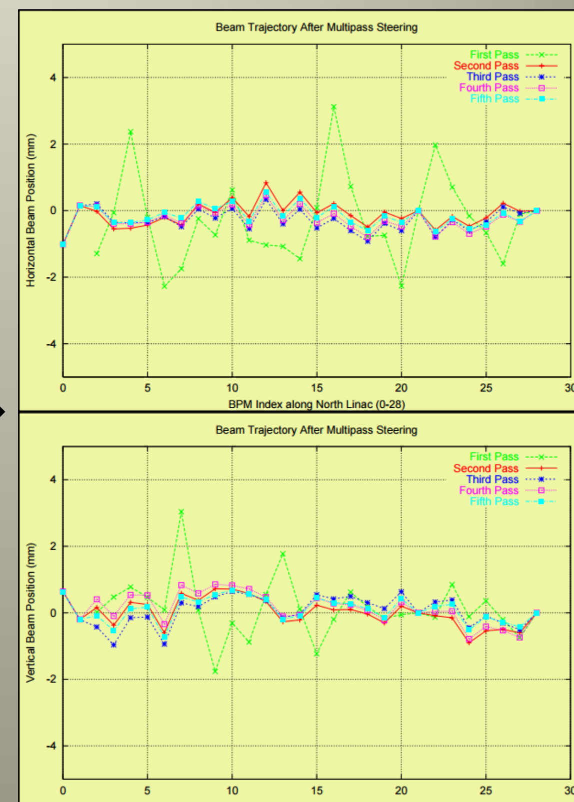
MULTIPASS STEERING PROTOCOLS AT JEFFERSON LAB*

R.M. Bodenstein#, M.G. Tiefenback, JLAB, Newport News, VA 24606, U.S.A.

Abstract

The CEBAF recirculating accelerator consists of two CW superconducting RF linacs, through which an electron beam is accelerated for up to 5 passes. Focusing and steering elements affect each pass differently, requiring a multipass steering protocol to correct the orbits. Perturbations include lens misalignments (including long-term ground motion), BPM offsets, and focusing and steering from RF fields inside the cavities. A previous treatment of this problem assumed all perturbations were localized at the quadrupoles and the absence of x-y coupling. Having analyzed the problem and characterized the solutions, we developed an empirical iterative protocol to compare against previous results in the presence of skew fields and cross-plane coupling. We plan to characterize static and acceleration-dependent components of the beam line perturbations to allow systematic and rapid configuration of the accelerator at different linac energy gains.





What did I do at JLab?

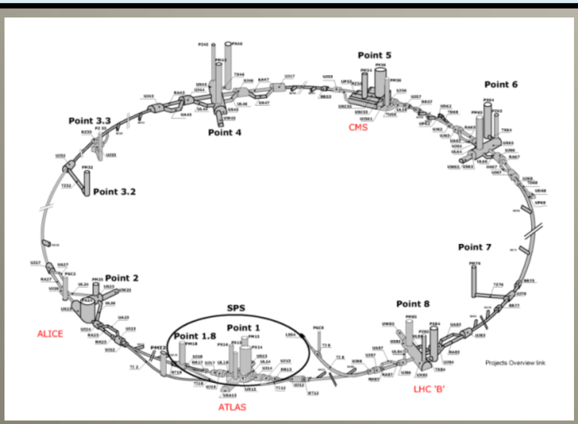
- **Once I understood the CEBAF optics, the real work began.**
- **Developed procedure to characterize and tune beam**

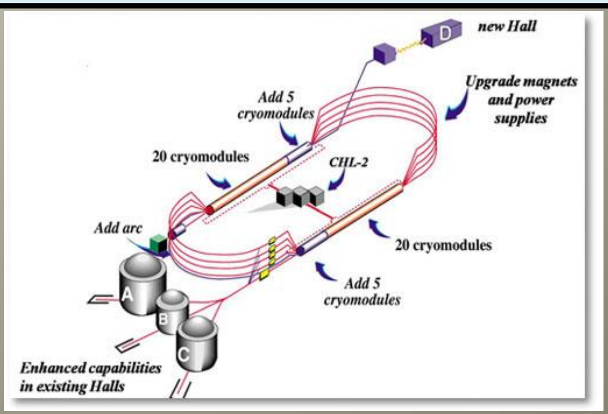
<u>Circular Machine</u>

- Many passes
  - Equilibrium orbit
- Global, self-consistent lattice
- Periodic condition
- Lattice defines Twiss Parameters
- Beam accommodates Twiss Parameters

<u>Open-Ended Machine</u>

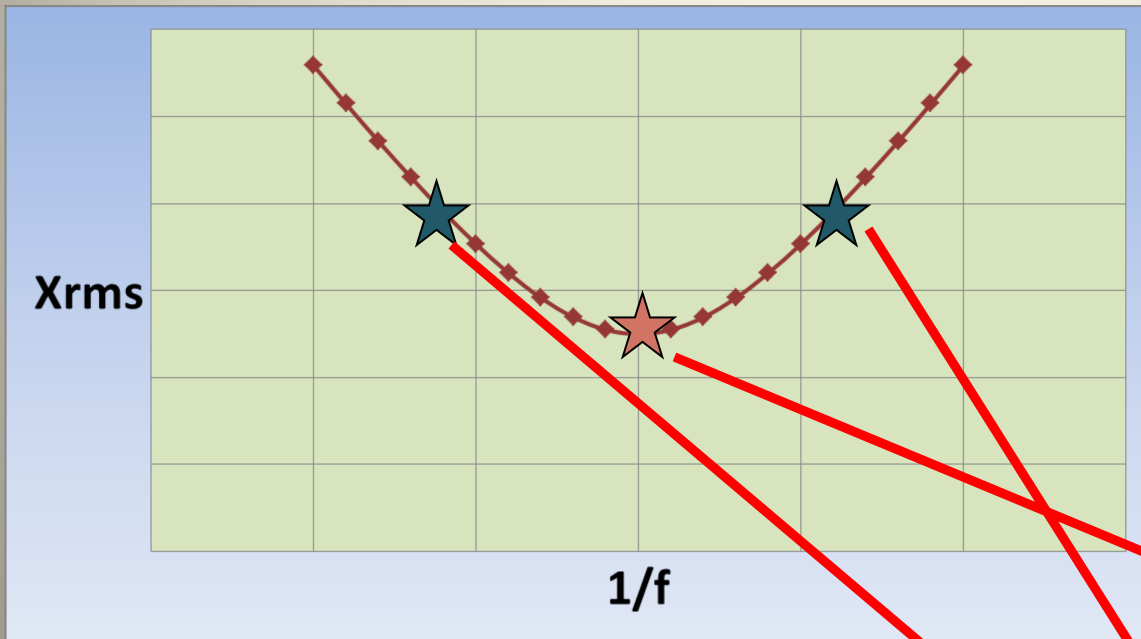
- Single pass through system
  - No equilibrium orbit
- No periodicity constraints like circular
- Lattice defines path of beam
- Lattice transforms Twiss Parameters
- How can they be measured?

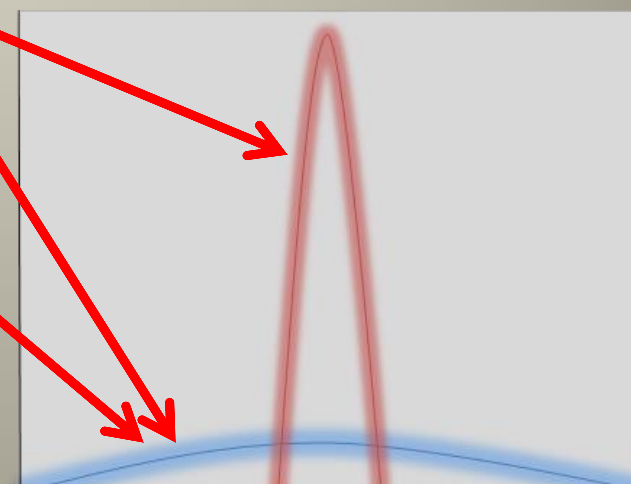




JLab’s Method 1: Quad Scan

- Adjust quadrupole by known amount
- Find smallest size at harp
- Relationship of beam radius at lens vs. waist gives emittance angle





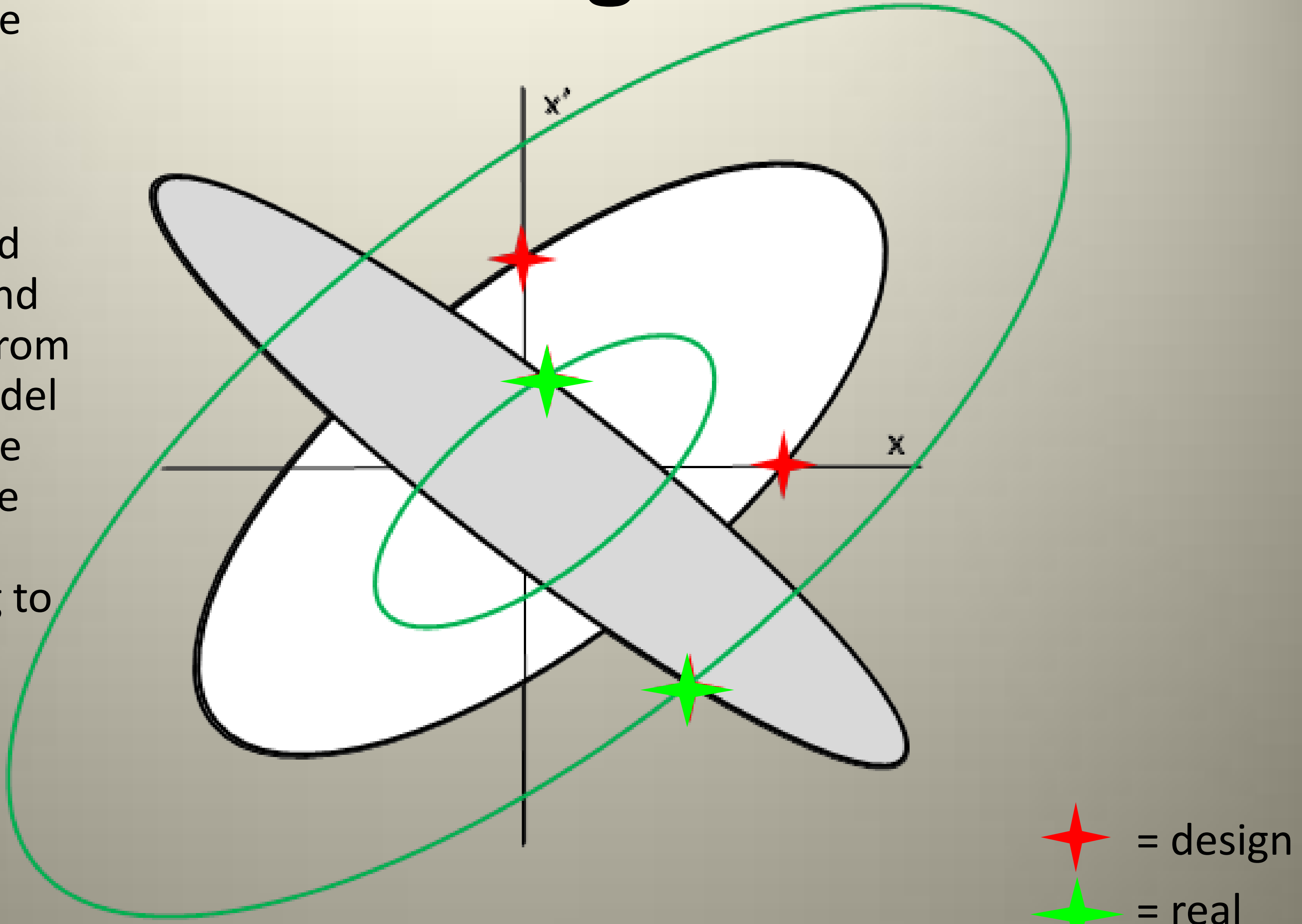
http://www.jlab.org/accel/beam_diag/harp/harp_dummy.html

JLab’s Method 1: Quad Scan The problems

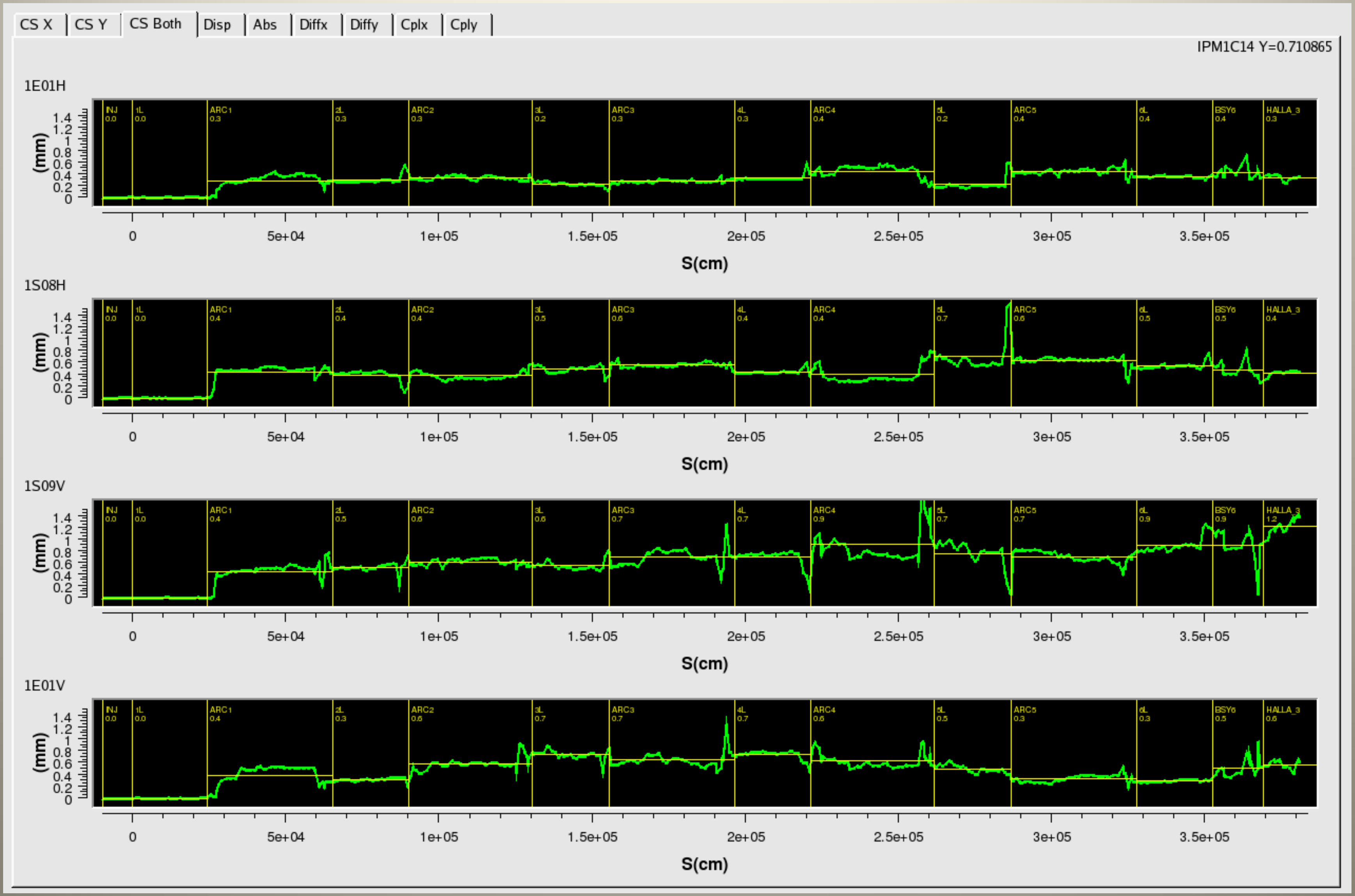
- Noisy electronics (wire scanner)
- Sparse coverage
- Small emittance
- Time consuming - takes ~30 minutes to complete for ONE location
- Invasive – more time away from nuclear physics program

JLab's Method 2: Courant-Snyder Tuning

- Used to maintain beam envelope matching
- Takes x and x' from measured trajectories, and uses α and β from the design model to calculate the matched phase ellipse corresponding to the measured trajectory



JLab's Method 2: Problems

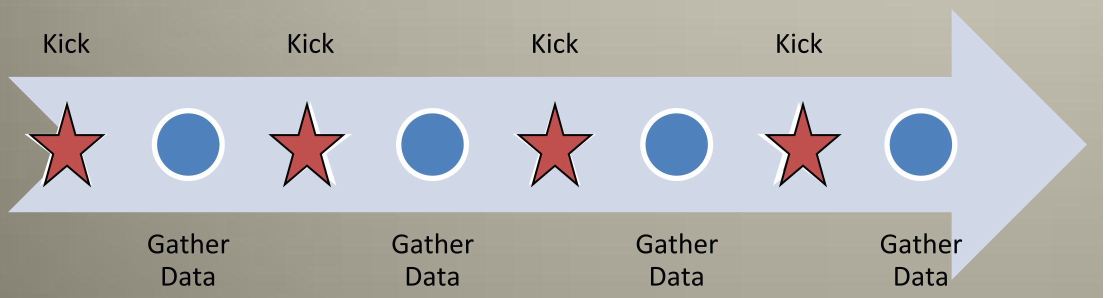


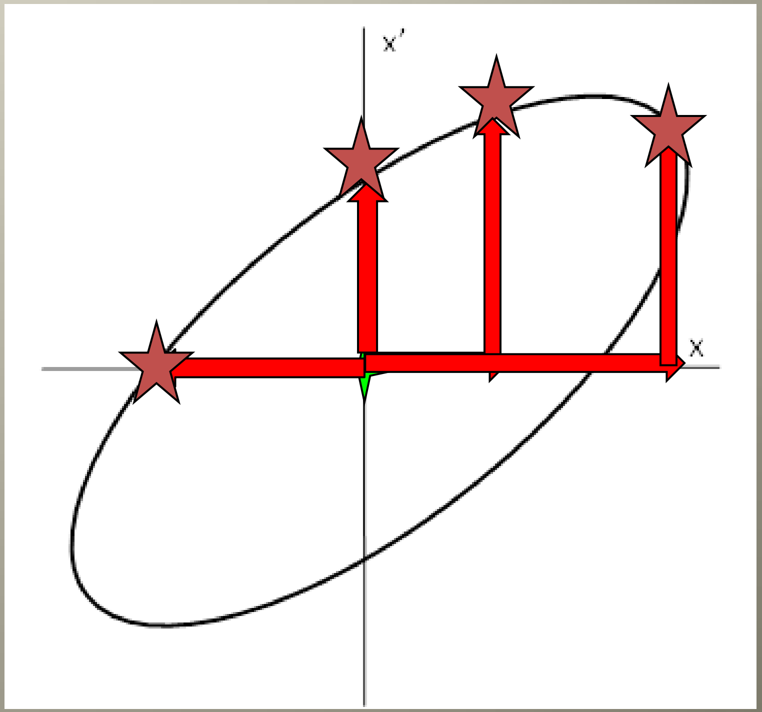
Addressing The Weaknesses

- CEBAF needed a method that is minimally invasive to the nuclear physics program
- Must be able to either take into account cumulative phase advance errors, or provide a way in which it can be ignored without detriment
- Must be able to characterize the beamline both locally and globally
- Developed rayTrace to achieve this

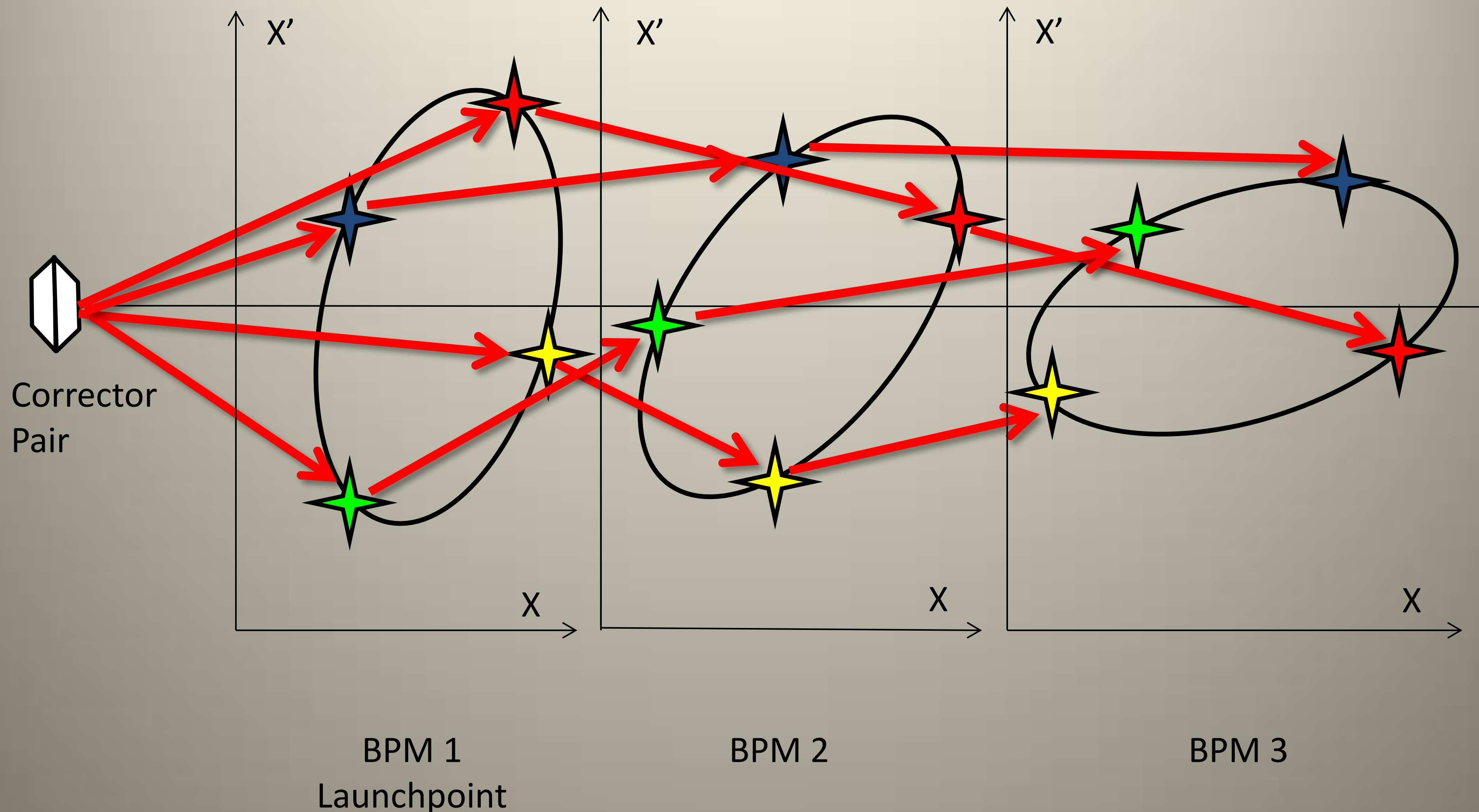
rayTrace: What is it?

- Measures the differential orbit of the real beam at every location simultaneously
- Corrector kicks are set to follow the boundary of the model's phase ellipse
- Allows for calculation of the Twiss parameters of the real beam

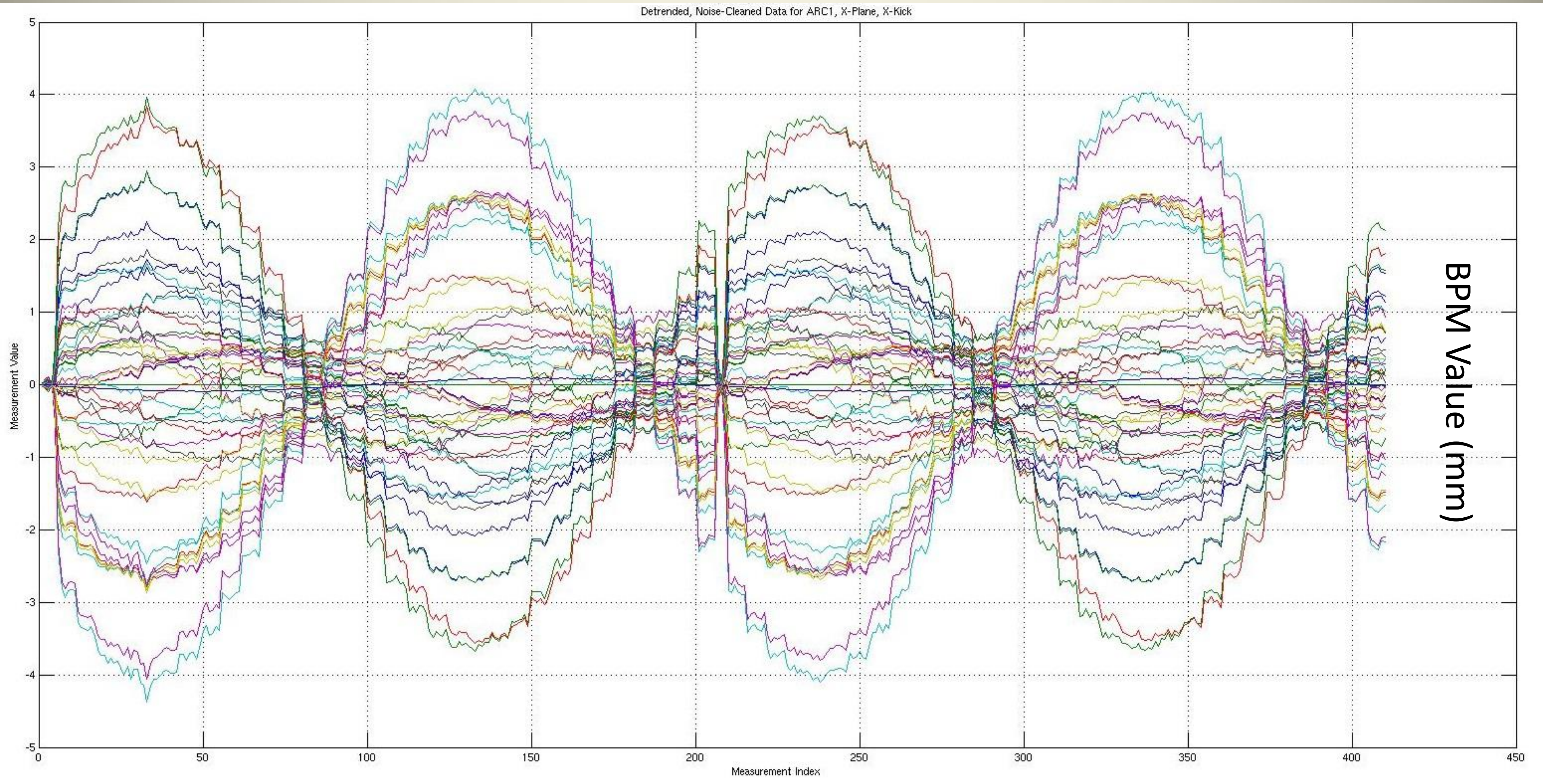




rayTrace – How it Works



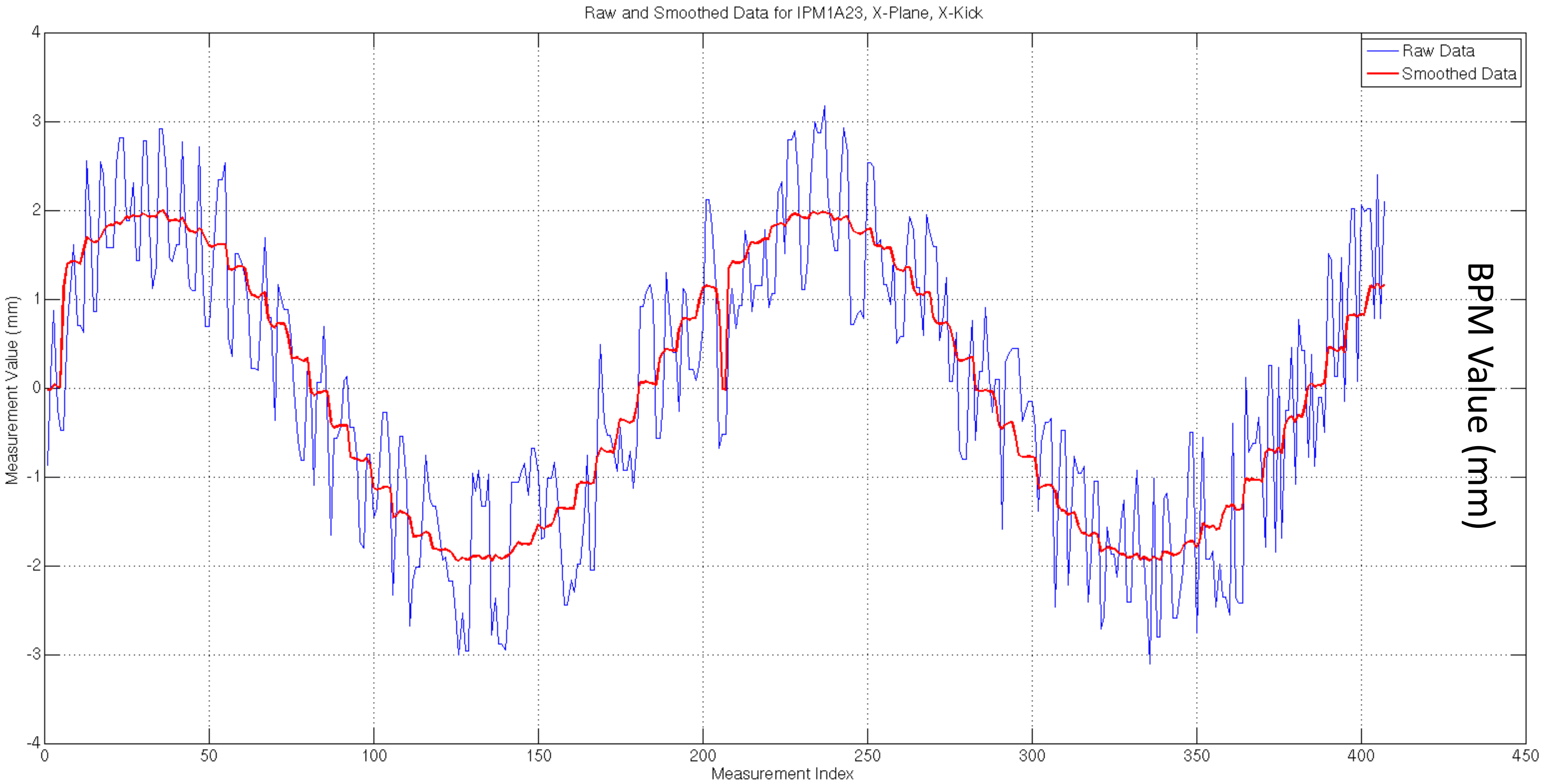
Data cleanup with SVD



BPM Value (mm)

Measurement Index

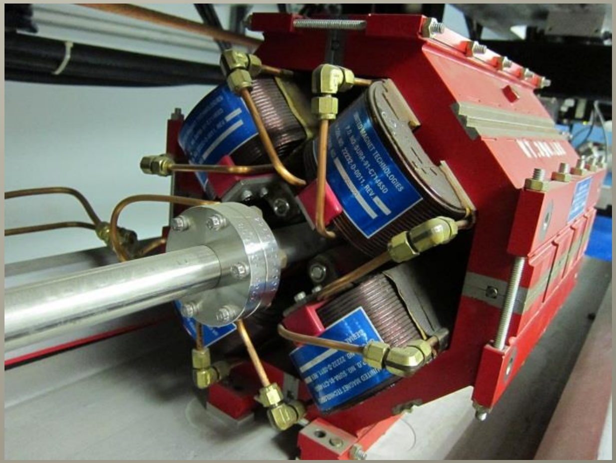
Data cleanup with SVD



Measurement Index

Resolution Test

- Devised a Resolution Test as validation of rayTrace
    - o Want basic test – simple optics change analogous to optics error
- Goals:
    1. Localize a known optics change
    2. Resolve the magnitude of optics change
- The Test:
    - o Create known optics change by varying strength of quadrupole
    - o Take Baseline Data first, then change quad setting 20% Positive from Baseline, then 20% Negative from Baseline
    - o Take second Baseline data set

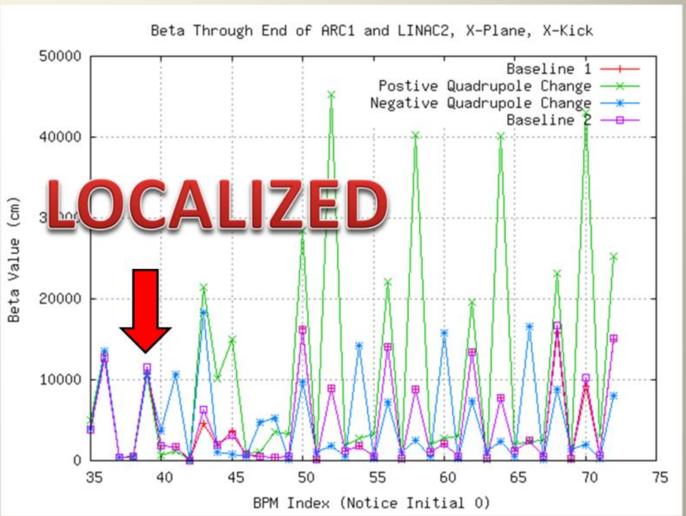


Resolution Test

- Localized optics change to region between two BPMs

- Resolved better than 95% of the change entered
- Estimated BPM system errors within expected range

Analysis – Beta Comparison



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Analysis – Resolving the Change

$$\sum_{1}^{m}(u_2 - M_{ii}u_1 - M_{kl}u_1')^2 = \sum_{1}^{m}\Delta_m^2$$

$$\sigma = \sqrt{\frac{\sum_1^m \Delta_m^2}{N-1}}$$

$$M_{11} = \cos(\sqrt{k}l) - \sqrt{k}l\sin(\sqrt{k}l)$$
$$M_{33} = \cosh(\sqrt{k}l) + \sqrt{k}l\sinh(\sqrt{k}l)$$

$$k = \frac{1}{B\rho}\frac{\partial B_y}{\partial x}$$
$$\frac{\partial B_x}{\partial y} = -\frac{\partial B_y}{\partial x}$$
$$B\rho = \frac{p/c}{0.2998}$$

RESOLVED

MQB1R01	Baseline 1	[illegible]	[illegible]	[illegible]
Calculated Quad Value (Gauss)	2937.63	3508.57	2357.89	2915.46
Percent Change From Baseline 1	0	19.44	-19.73	0.75
Archived Quad Value (Gauss)	2994.62	3593.45	2395.63	2994.63
Sigma (microns)	30.69	50.83	37.81	53.17

Proceedings of IPAC'10, Kyoto, Japan THPE050

REAL BEAM LINE OPTICS FROM A SYNTHETIC BEAM*

R.M. Bodenstein#, M.G. Tiefenback, Y.R. Roblin
Jefferson Lab, Newport News, VA 23606, U.S.A.

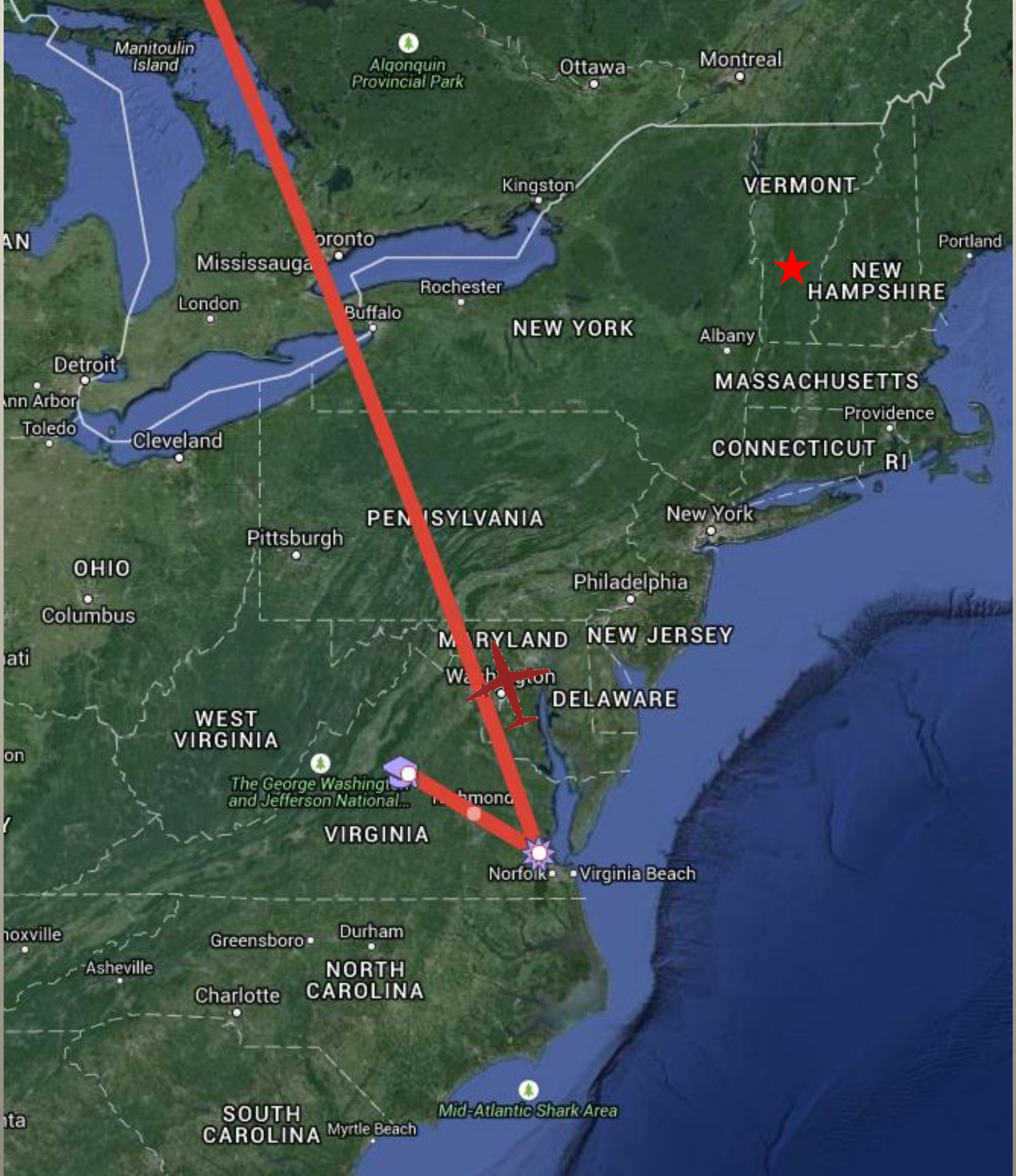
Proceedings of IPAC2012, New Orleans, Louisiana, USA TUPPC046

FURTHER ANALYSIS OF REAL BEAM LINE OPTICS FROM A SYNTHETIC BEAM*

R.M. Bodenstein#, Y.R. Roblin, M.G. Tiefenback
Jefferson Lab, Newport News, VA, USA

A Procedure for Beamline Characterization and Tuning in Open-Ended Beamlines

A Dissertation



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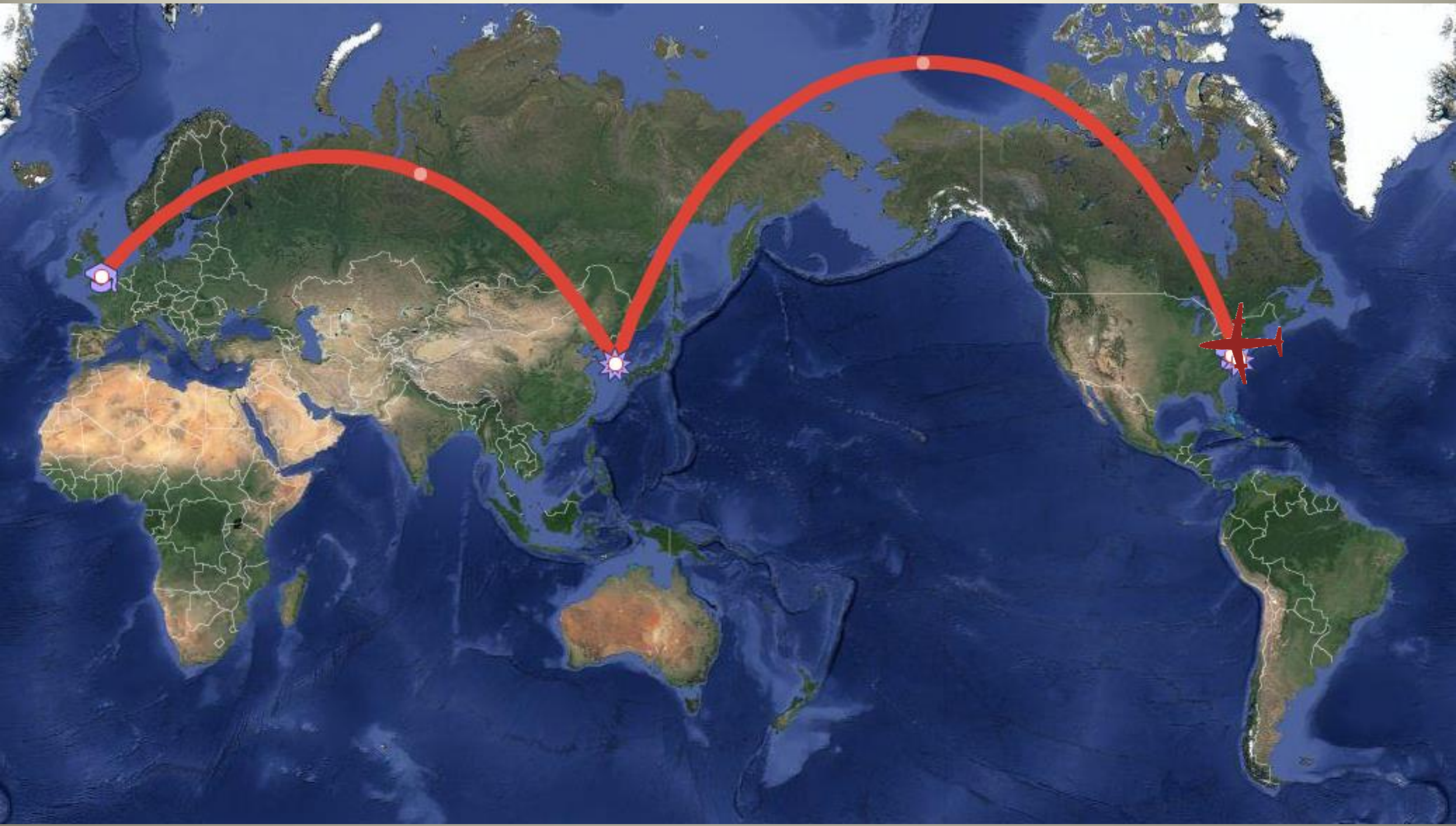

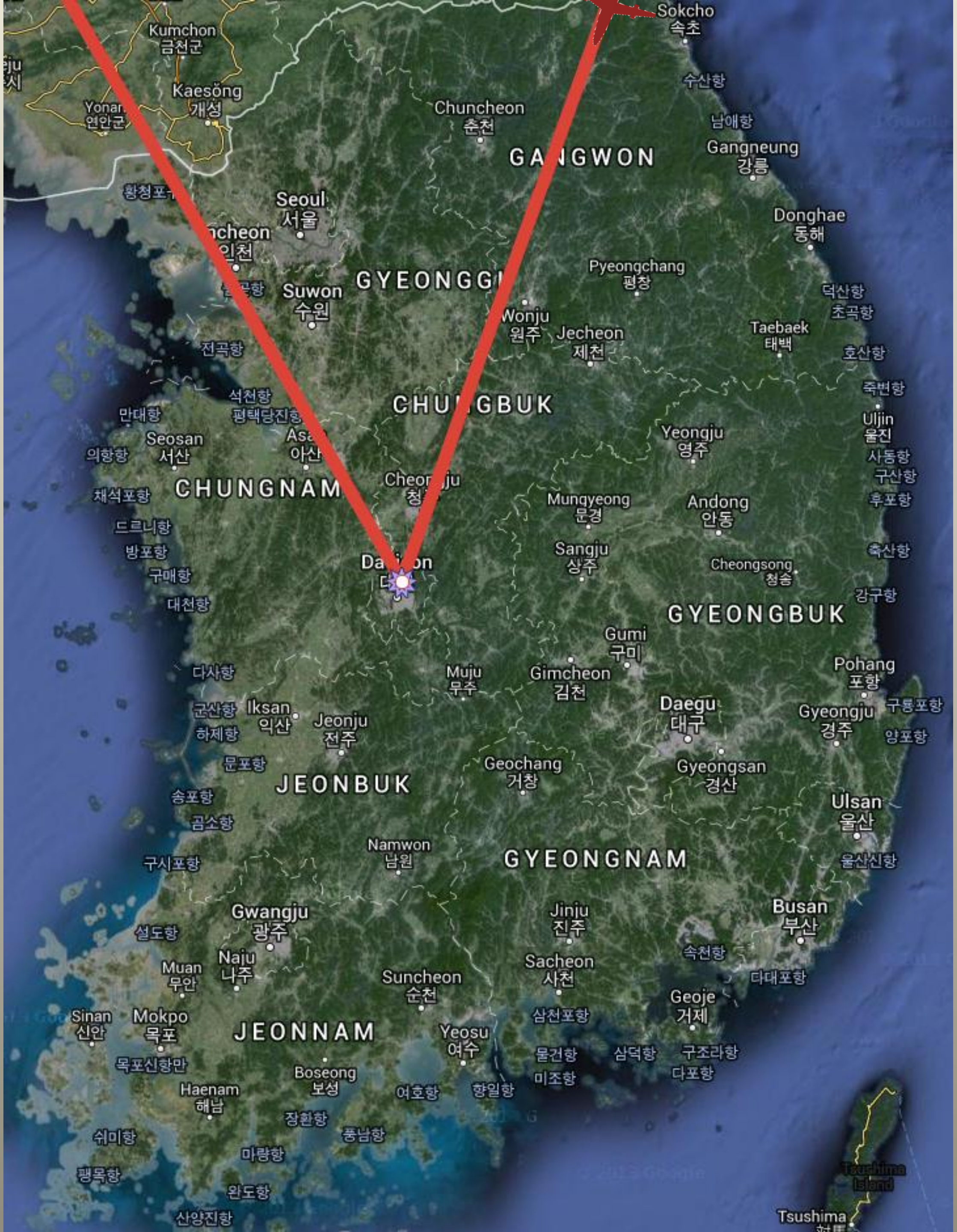

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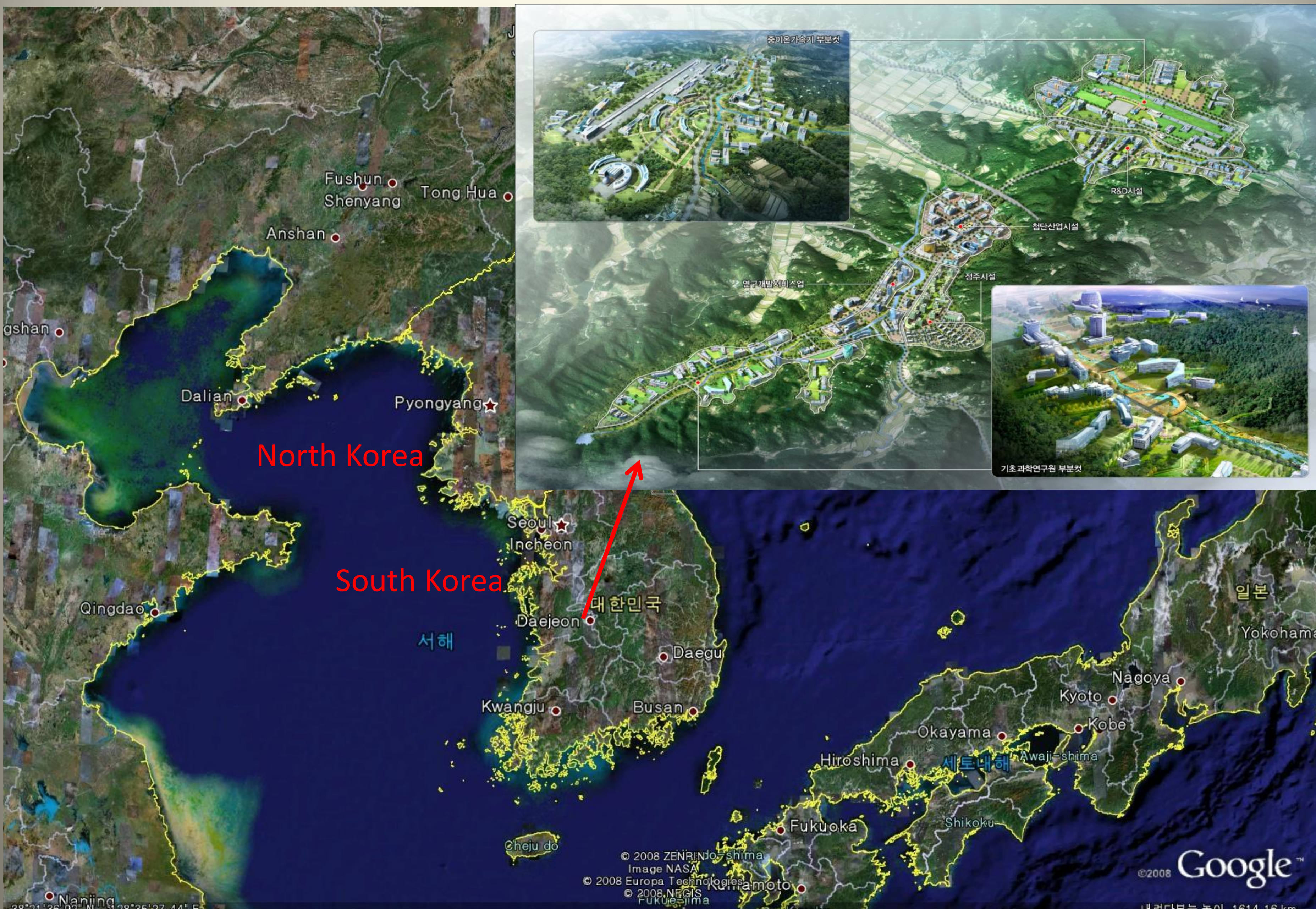
Quick Info about the Rare Isotope Science Project

- Part of the Institute for Basic Science
  - Established by Korean government in 2011
- RISP officially established in 2011
  - In 2012, accelerator facility named RAON (라온), which is a traditional Korean word that translates to delightful, joyful, or happy.
- RISP goal: produce variety of stable and rare isotope beams for use in a variety of basic scientific research and applications
- Unique aspect:
  - Isotope production using both In-Flight Fragmentation (IFF) and Isotope Separation On-Line (ISOL)



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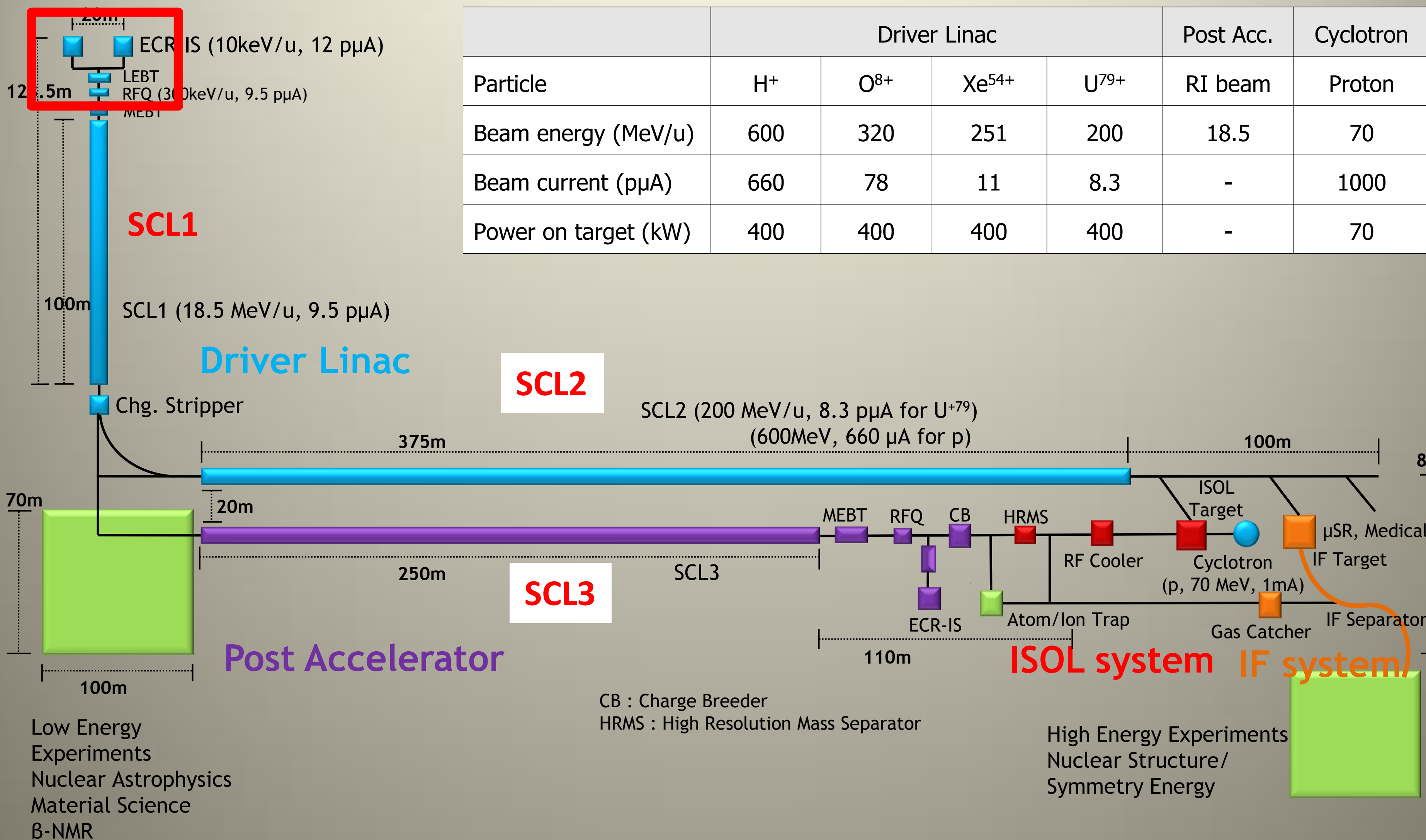
정주시설
기초과학연구원 부분컷

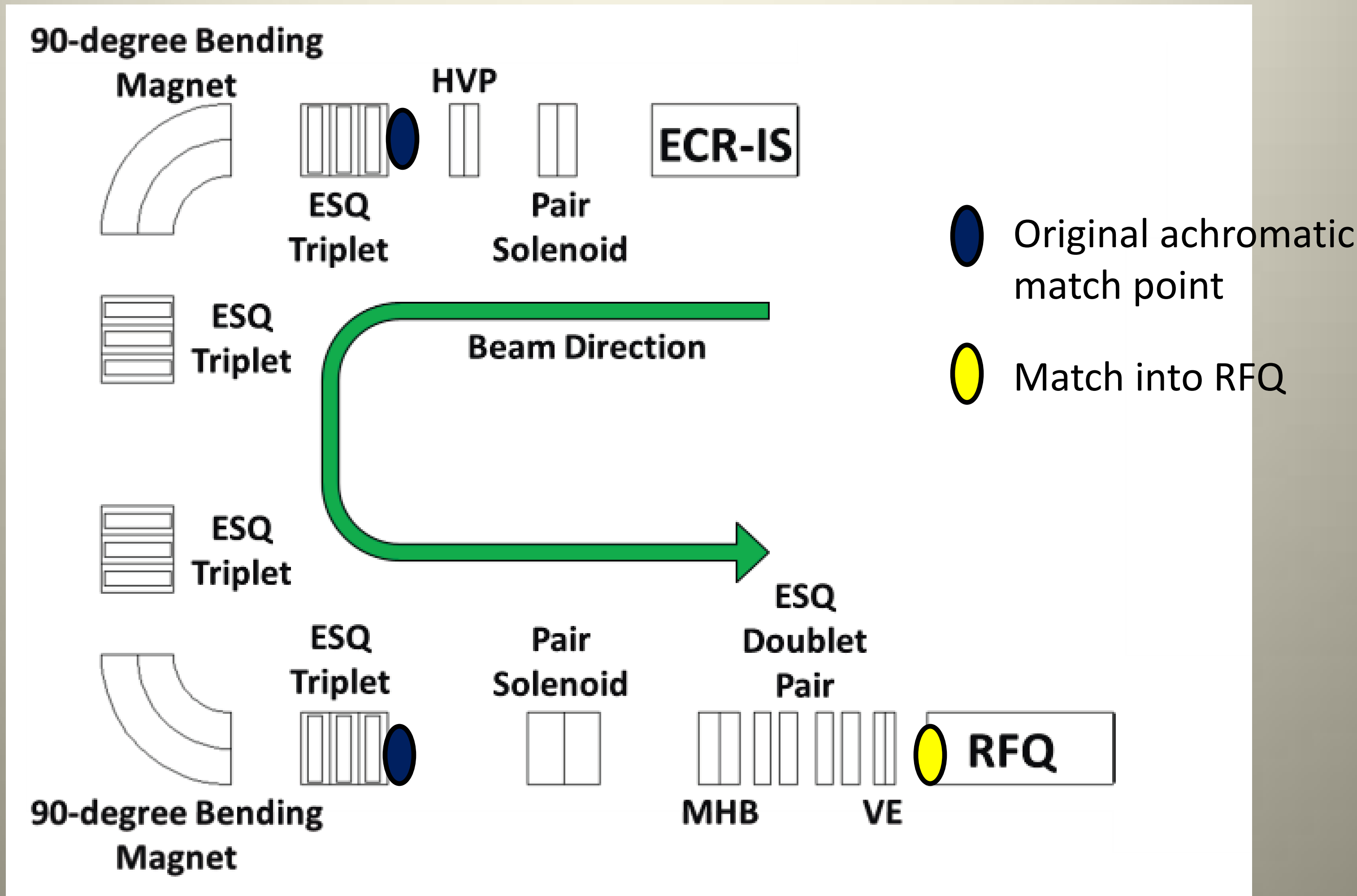

SCL2
SCL3
SCL1

(Proposed) Layout Diagram and a Few Parameters

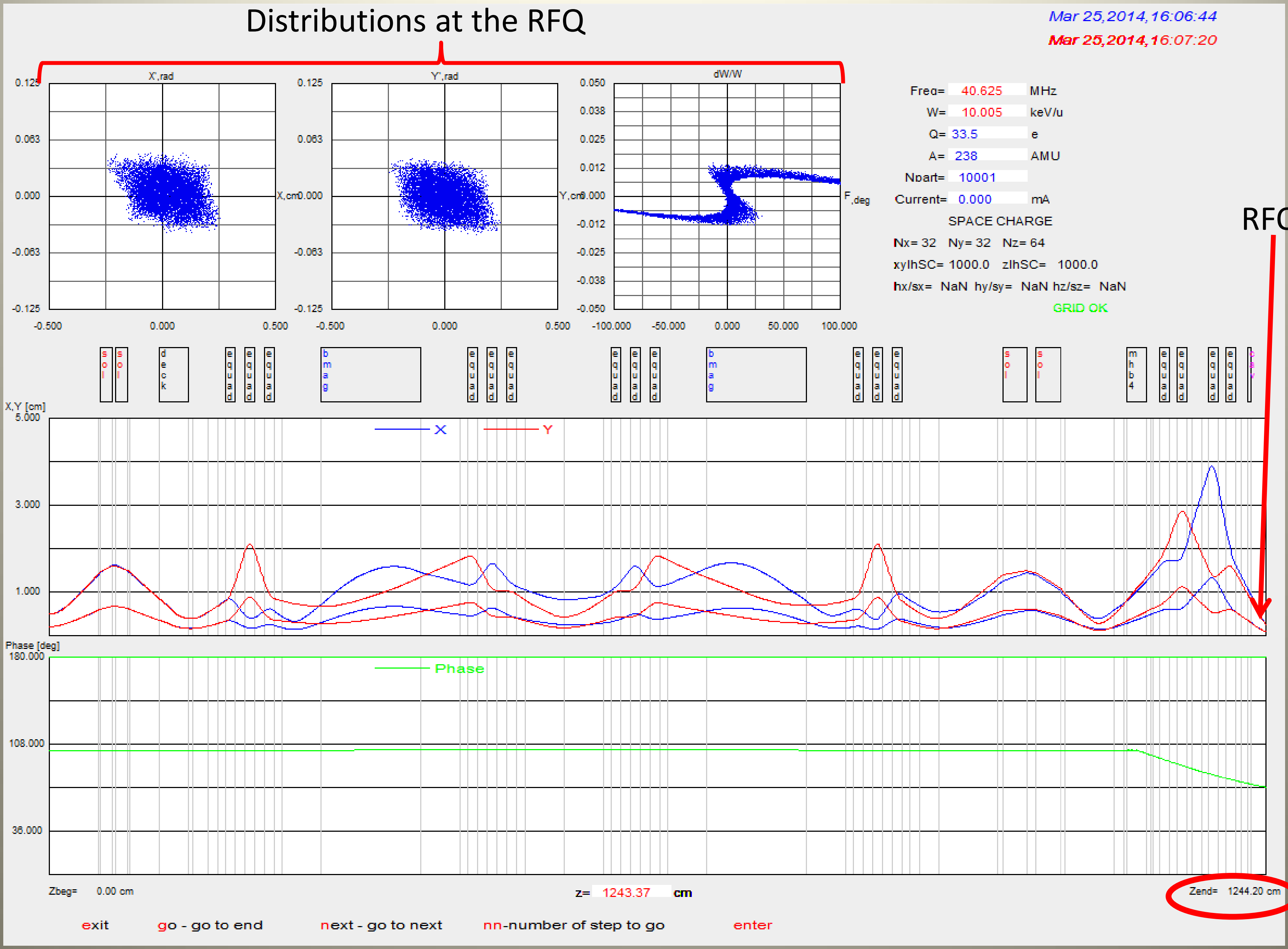
	Driver Linac				Post Acc.	Cyclotron
Particle	H^{+}	O^{8+}	Xe^{54+}	U^{79+}	RI beam	Proton
Beam energy (MeV/u)	600	320	251	200	18.5	70
Beam current (pμA)	660	78	11	8.3	-	1000
Power on target (kW)	400	400	400	400	-	70



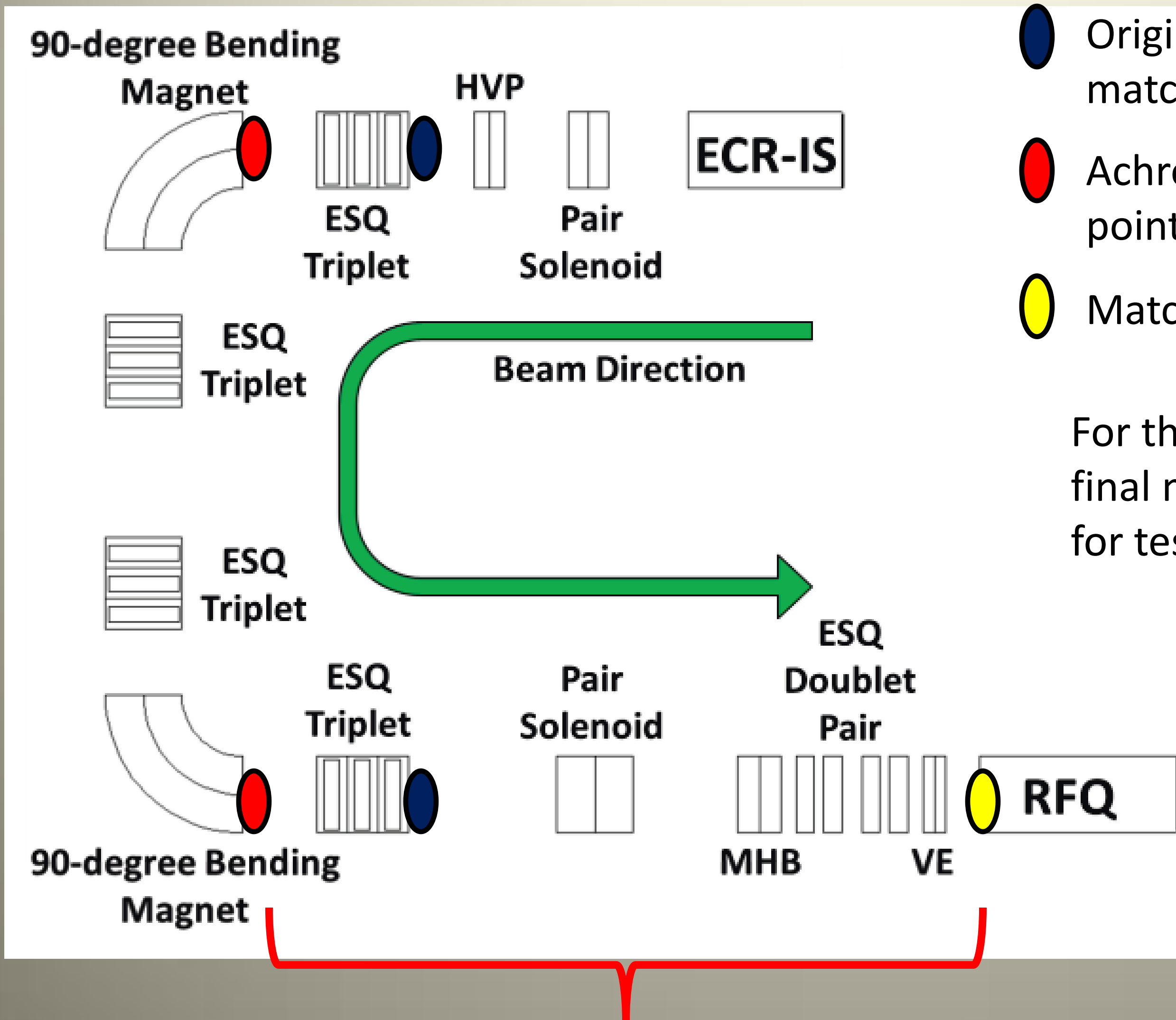
Ignoring the rest, here is the LEBT…



TRACK simulation of LEBT



LEBT Test Facility

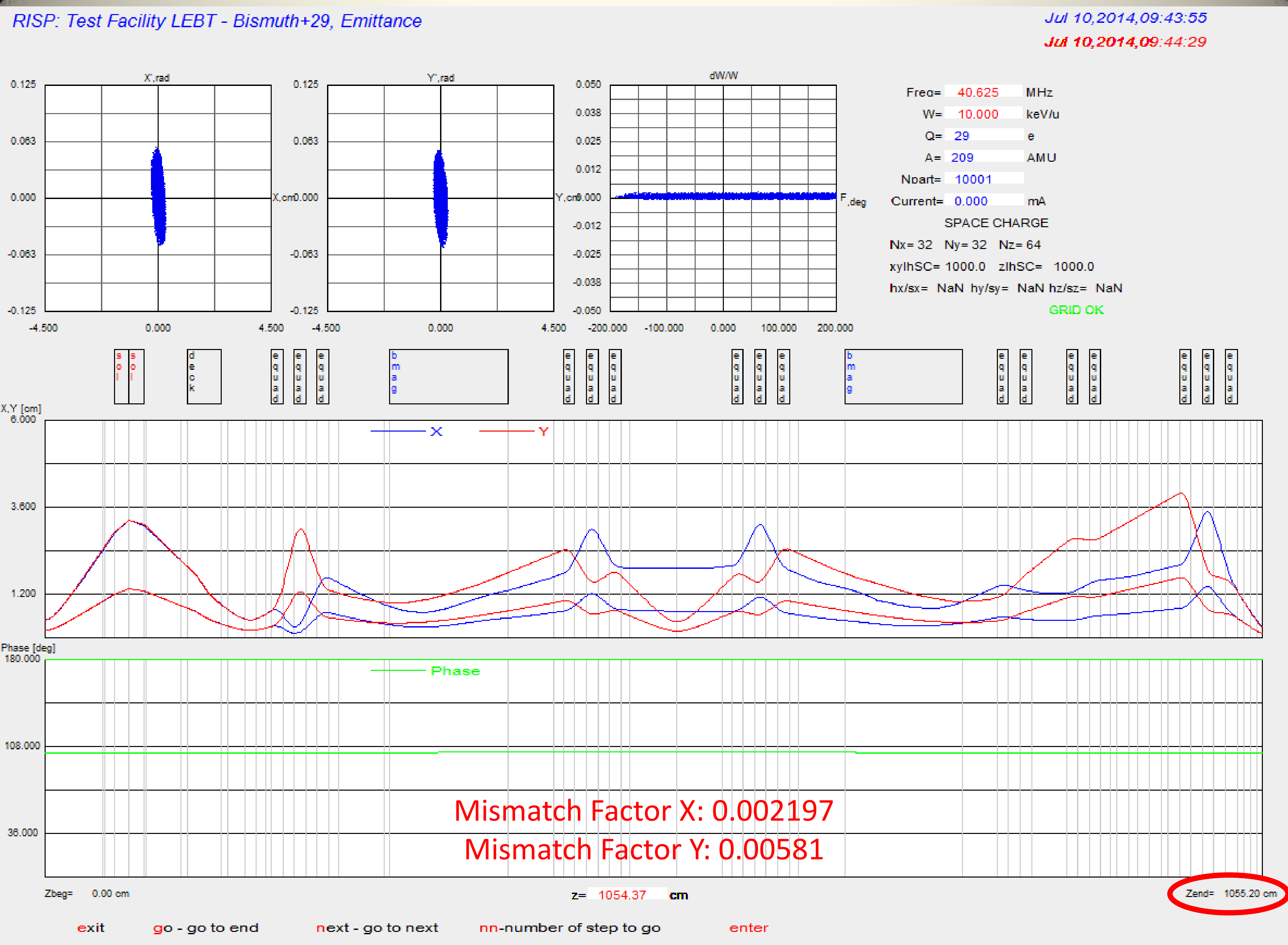


Final matching section

- Original achromatic match point
- Achromatic match point for test facility
- Match into RFQ

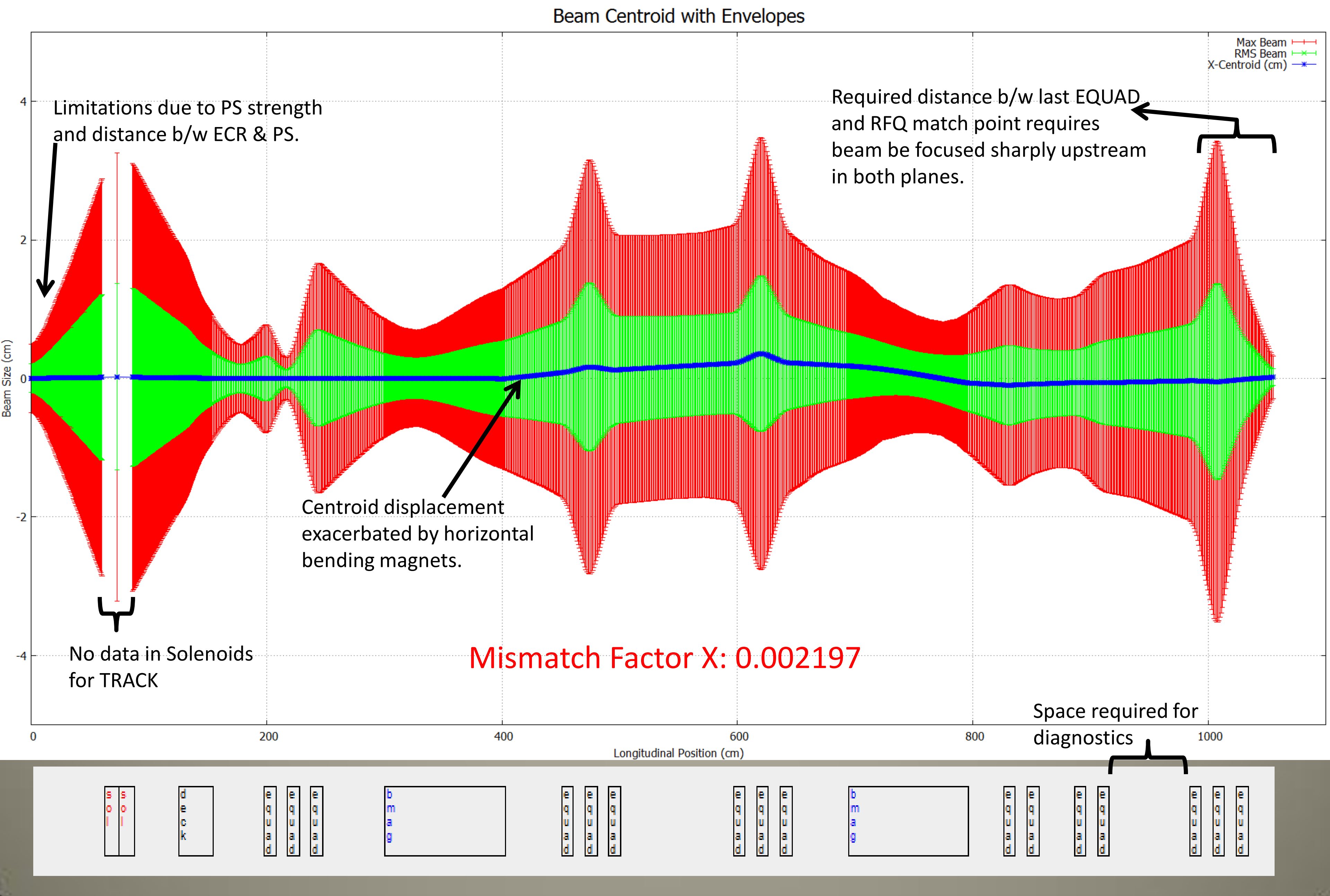
For the test facility, must shorten final matching section. Parameters for test facility shown in table.

Input Parameter	Value
Particle and Charge	Bismuth-209 29+
ECR Extraction Voltage	30 kV
HVP Voltage	42 kV
$\epsilon_{RMS,Normalized,Total}$	0.12 π-mm-mrad
$\alpha_{x,y}$	0
$\beta_{x,y}$	10.38 cm/rad
Beam Radius at ECR Exit	0.5 cm

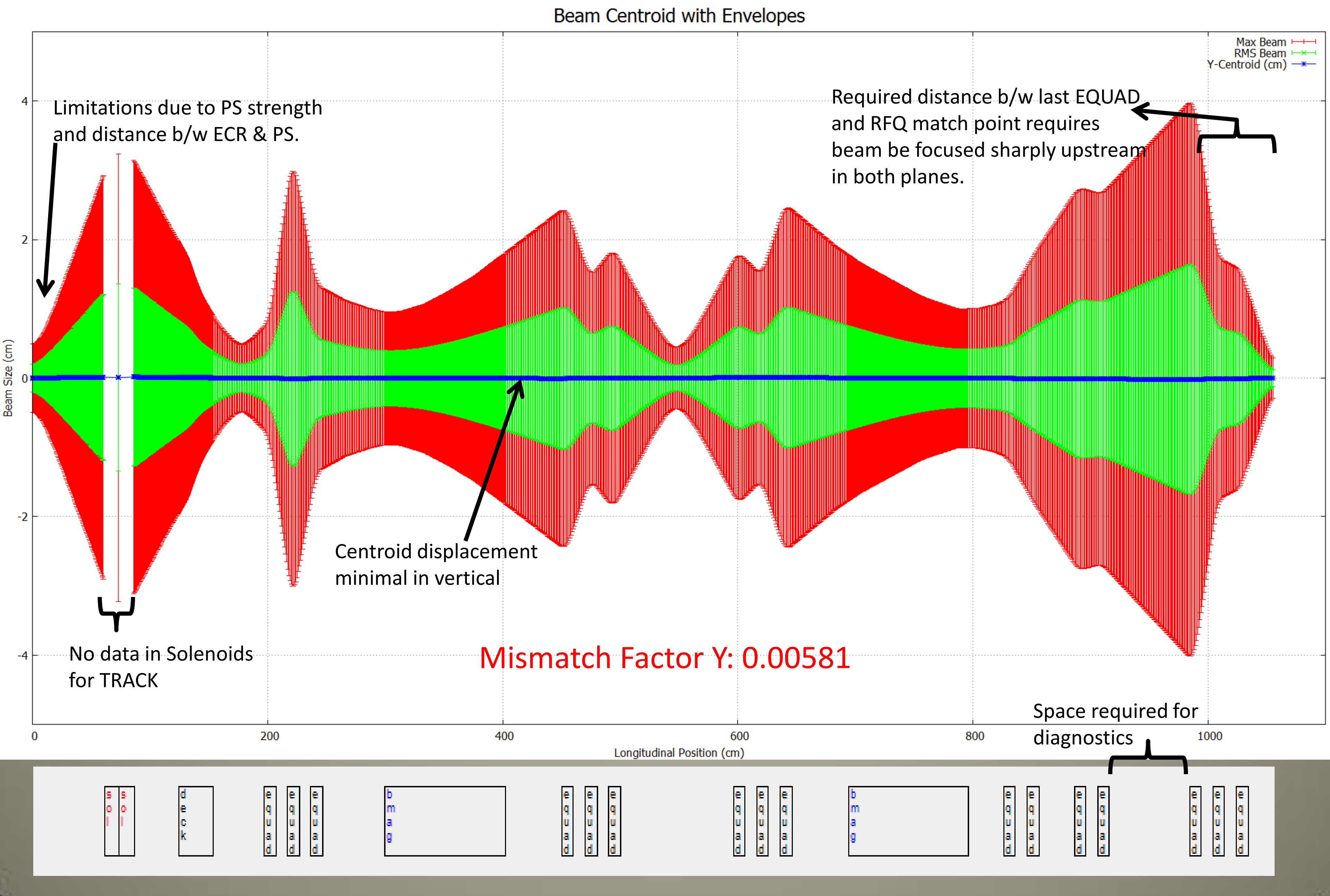


RISP: Test Facility LEBT - Bismuth+29, Emittance
Jul 10,2014,09:43:55
Jul 10,2014,09:44:29
X',rad
Y',rad
dW/W
Freq= 40.625 MHz
W= 10.000 keV/u
Q= 29 e
A= 209 AMU
Npart= 10001
Current= 0.000 mA
SPACE CHARGE
Nx= 32 Ny= 32 Nz= 64
xylhSC= 1000.0 zlhSC= 1000.0
hx/sx= NaN hy/sy= NaN hz/sz= NaN
GRID OK
X,Y [cm]
Phase [deg]
Phase
Mismatch Factor X: 0.002197
Mismatch Factor Y: 0.00581
Zbeg= 0.00 cm
z= 1054.37 cm
Zend= 1055.20 cm
exit
go - go to end
next - go to next
nn-number of step to go
enter

X-Envelopes, Bismuth 209 +29, No Space Charge



Y-Envelopes, Bismuth 209 +29, No Space Charge



LEBT Test Facility

The Baseline Model

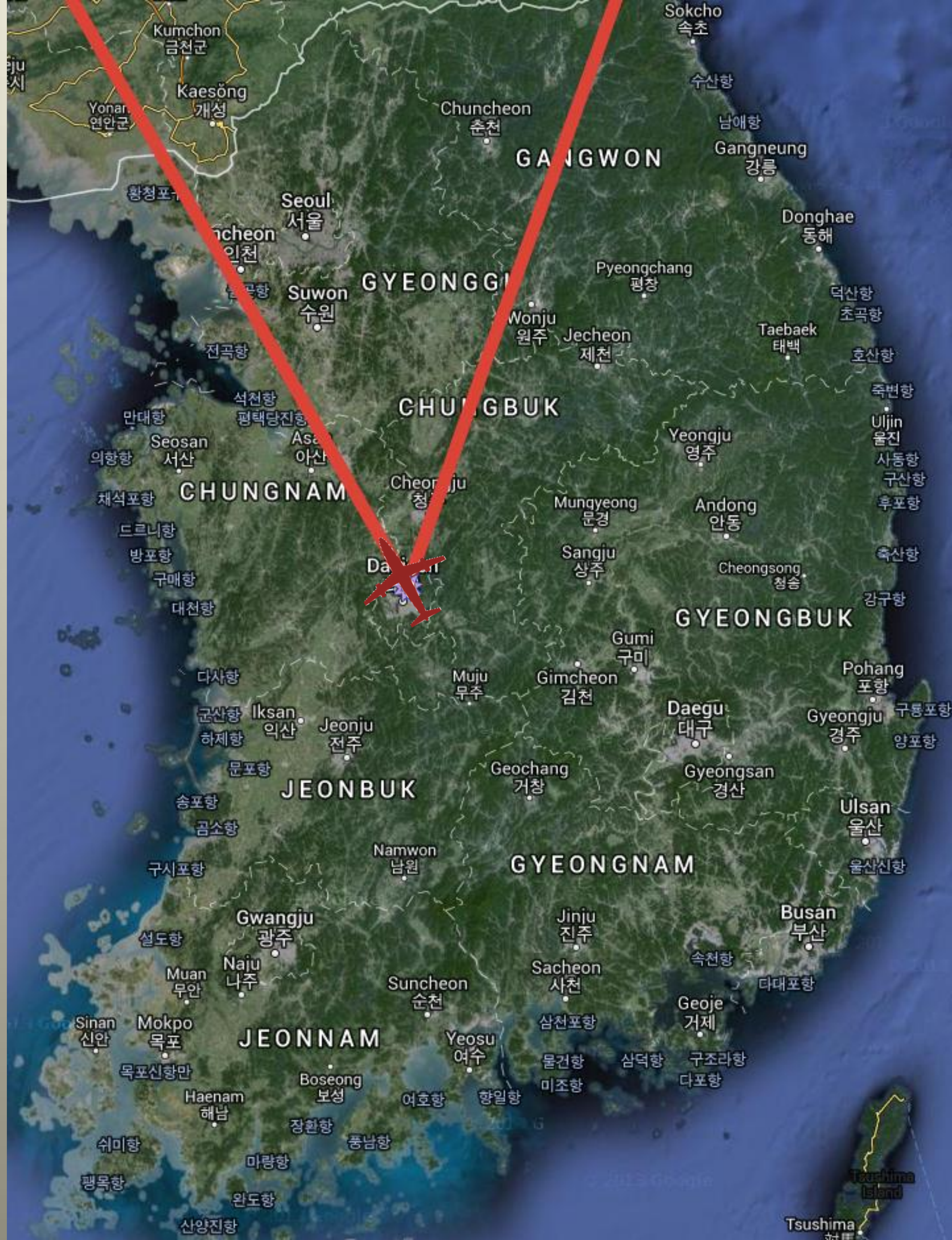
- The good:
  - Adequately small beam size
  - Matching section length reduced by nearly 2 meters
  - Excellent matching into the RFQ
- The bad:
  - Centroid offset, likely due to initial offset applied by TRACK code.
    - Not present in TRANSPORT

Baseline with Space Charge

- The good:
  - Beam size remains adequately small
  - Matching is still excellent
- The bad:
  - Difficulty adjusting mesh, which should be increased
    - Engineers using MWS need to do this.

Baseline with Alignment Errors

- The good:
  - Even with large alignment errors, beam in matching section shows resistance against errors
- The bad:
  - None yet, but further investigation will surely show some.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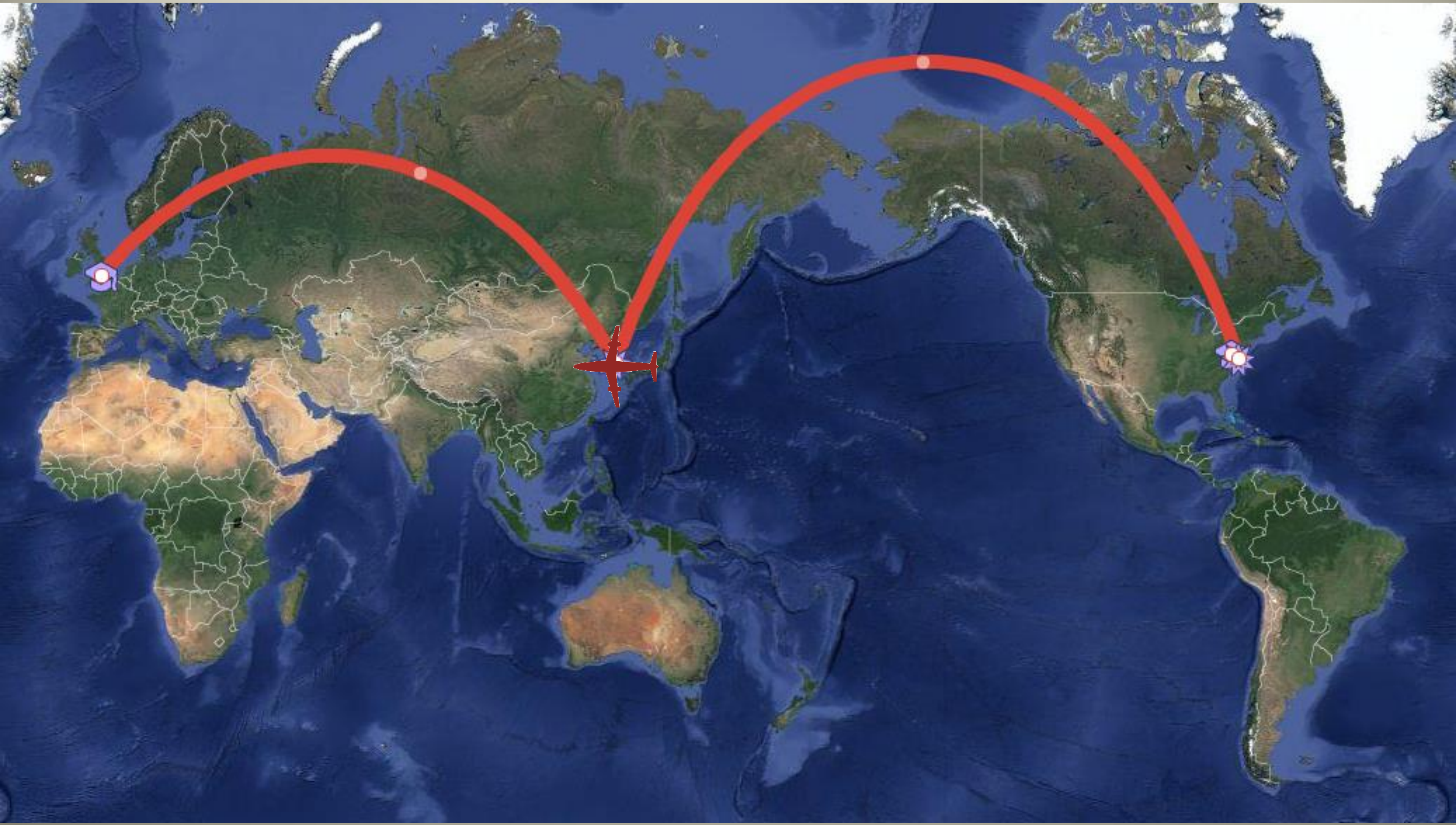
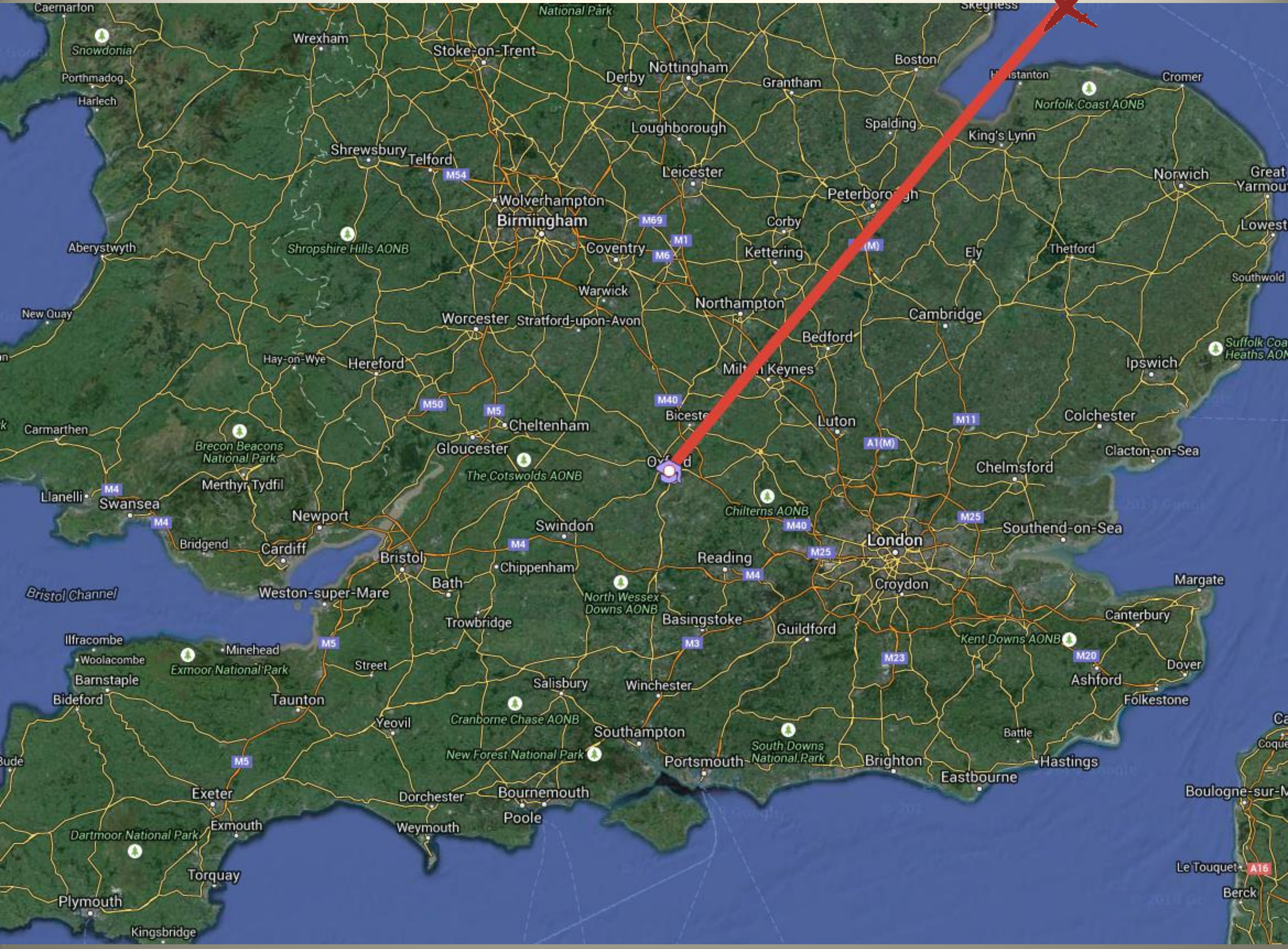
무안
Naju
나주
Suncheon
순천
Sacheon
사천
Geoje
거제
Sinan
신안
Mokpo
목포
JEONNAM
Yeosu
여수
Boseong
보성
Haenam
해남
Tsushima




Caernarfon
Snowdonia
Porthmadog
Harlech
Wrexham
Stoke-on-Trent
National Park
Derby
Nottingham
Grantham
Boston
Cromer
Norfolk Coast AONB
Spalding
King's Lynn
Loughborough
Shrewsbury
Telford
M54
Leicester
Norwich
Great Yarmout
Wolverhampton
Birmingham
M69
Peterborough
Corby
Lowest
M1
Aberystwyth
Shropshire Hills AONB
Coventry
M6
Kettering
Ely
Thetford
Southwold
Warwick
Northampton
New Quay
Worcester
Stratford-upon-Avon
Cambridge
Bedford
Suffolk Coa
Heaths AON
Hay-on-Wye
Hereford
Milton Keynes
Ipswich
M40
M50
M5
Bicester
Luton
M11
Carmarthen
Cheltenham
Colchester
Brecon Beacons
National Park
Gloucester
A1(M)
Clacton-on-Sea
Oxford
The Cotswolds AONB
Chelmsford
Merthyr Tydfil
Llanelli
M4
Swansea
Chilterns AONB
Newport
M40
M25
Swindon
Southend-on-Sea
Bridgend
Cardiff
London
Bristol
Reading
Chippenham
Bath
Croydon
Bristol Channel
Weston-super-Mare
North Wessex
Downs AONB
Margate
Basingstoke
Canterbury
Trowbridge
Guildford
Ilfracombe
Minehead
Kent Downs AONB
M20
Woolacombe
Exmoor National Park
M3
Street
M23
Dover
Barnstaple
Salisbury
Winchester
Ashford
Folkestone
Bideford
Taunton
Yeovil
Cranborne Chase AONB
Southampton
South Downs
National Park
Battle
Bude
New Forest National Park
Portsmouth
Brighton
Hastings
Eastbourne
Exeter
Dorchester
Bournemouth
Boulogne-sur-M
Poole
Exmouth
Weymouth
Dartmoor National Park
Le Touquet
A16
Torquay
Berck
Plymouth
Kingsbridge

Alright, so I'm here. Now what?

- I'm very excited to be here at JAI and Oxford
  - Opportunity to collaborate with ILC and CLIC
  - FONT provides place to both exercise and expand my experience
- Very happy to learn about feedback systems and linear colliders
  - Colliders are a different animal
  - Focus on a small but important aspect
    - How this applies to the greater aspects
- Looking forward to learning new programs and techniques for simulation
  - Taking up with Javier Resta-Lopez left off.
    - ILC & CLIC ground motion simulations for FB system
  - Overall beam delivery system simulations
- Given my background, I feel I will have much to contribute and even more to learn

Thanks!

감사합니다!