ISLA

ISOCHRONOUS SEPARATOR WITH LARGE ACCEPTANCES FOR RE-ACCELERATED RADIOACTIVE BEAMS FROM REA12

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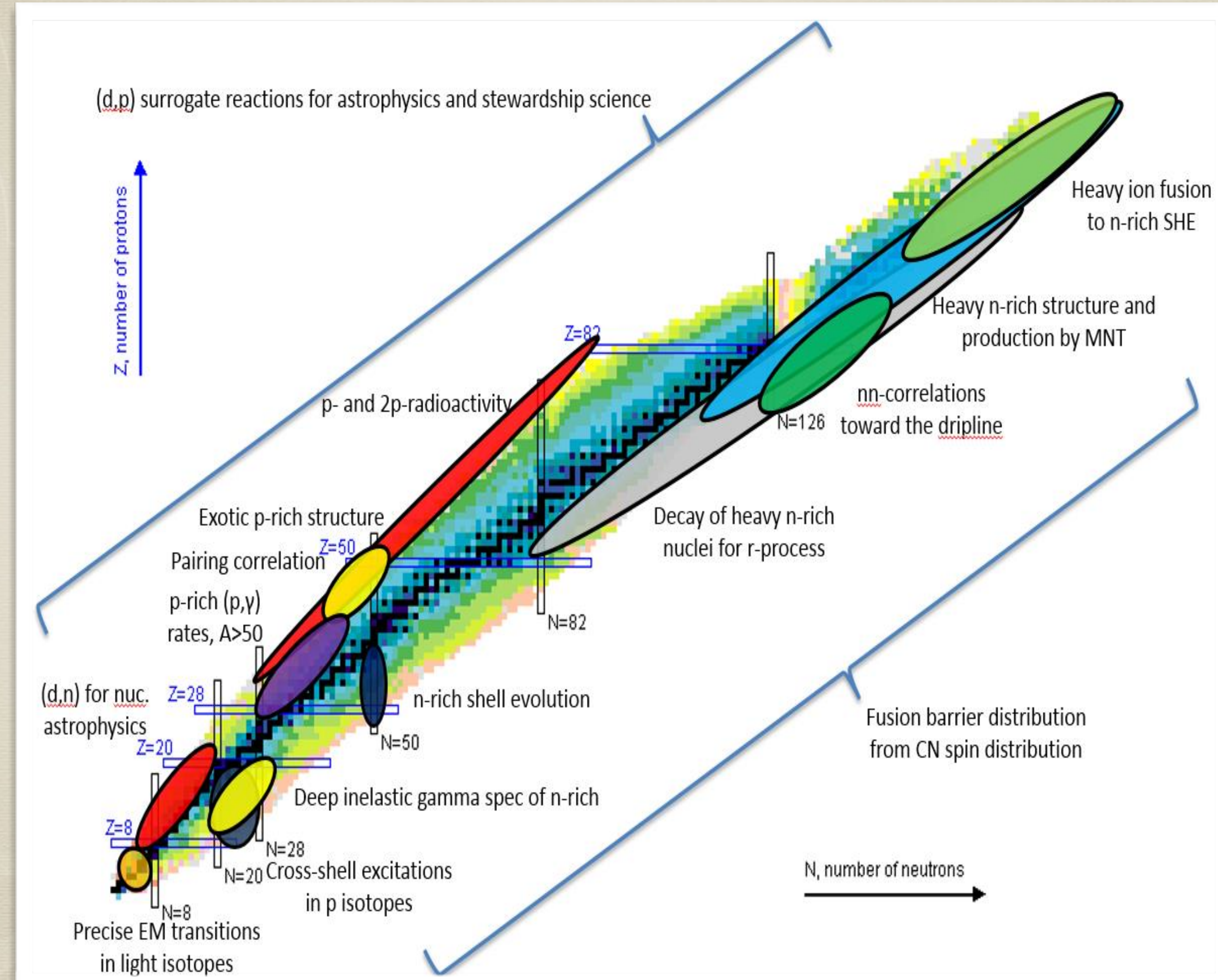
Recoil separator for ReA12

- Workshop in July 2014
  - Convergence towards the ISLA design
- White paper
  - Published in Feb. 2015
  - Scientific case for a recoil separator coupled to ReA12 re-accelerated beams
- FRIB working group
  - http://fribusers.org/workingGroups/isla.html
  - Download white paper
- Preliminary layout & magnet studies
  - S. Debord (SupMeca student, France)

Science goals with ISLA

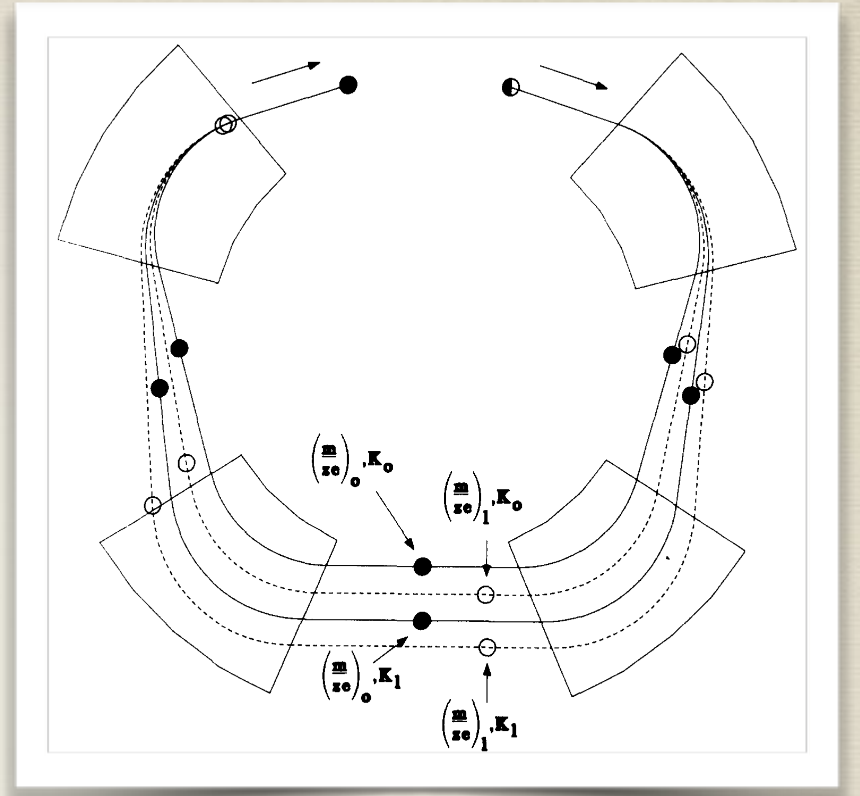


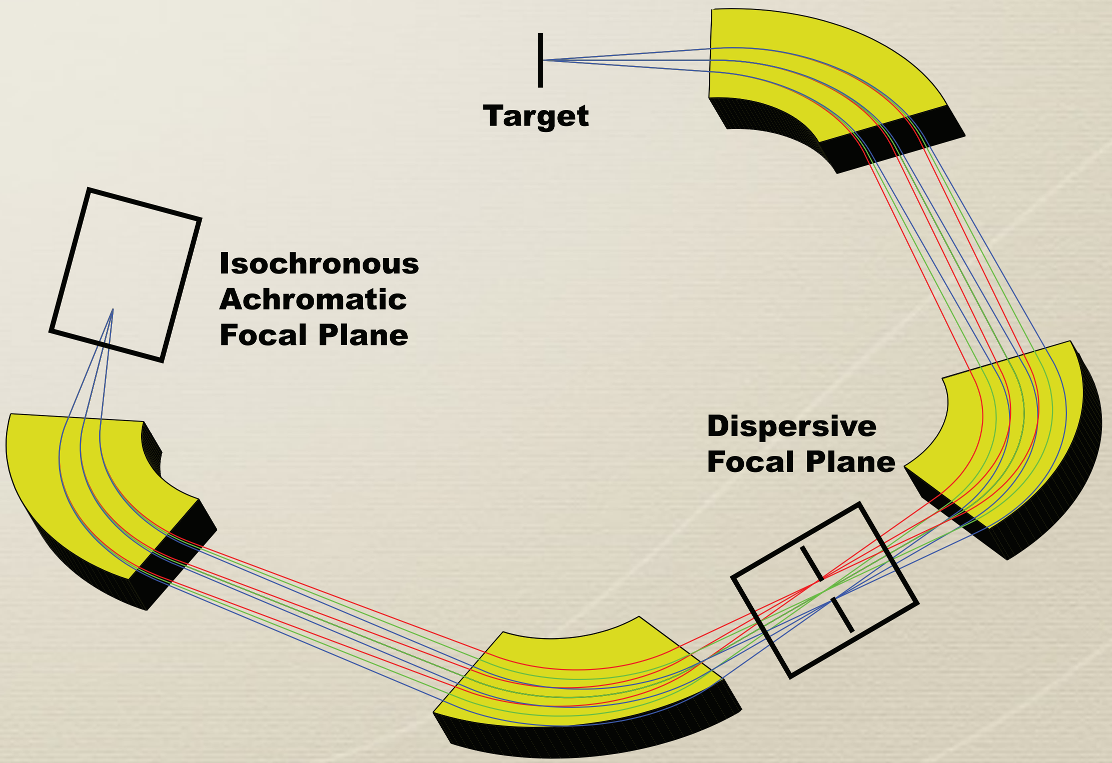
Best of both worlds

- Compromises between acceptance, resolution and focal plane size
- Small acceptance spectrometers
  - Small acceptances 🙁, small aberrations 🙂, small focal plane 🙂, good resolution 🙂
  - Examples: FMA, RMS, Wien filters
- Large acceptance spectrometers
  - Large acceptances 🙂, large aberrations 🙁, large focal plane 🙁, poor resolution 🙁 can only recover using large tracking detectors
  - Examples: VAMOS, PRISMA, MAGNEX
- Gas-filled spectrometers
  - Large charge state acceptance 🙂, poor resolution 🙁
- ISLA combines large acceptances with excellent resolution

ISLA: conceptual design

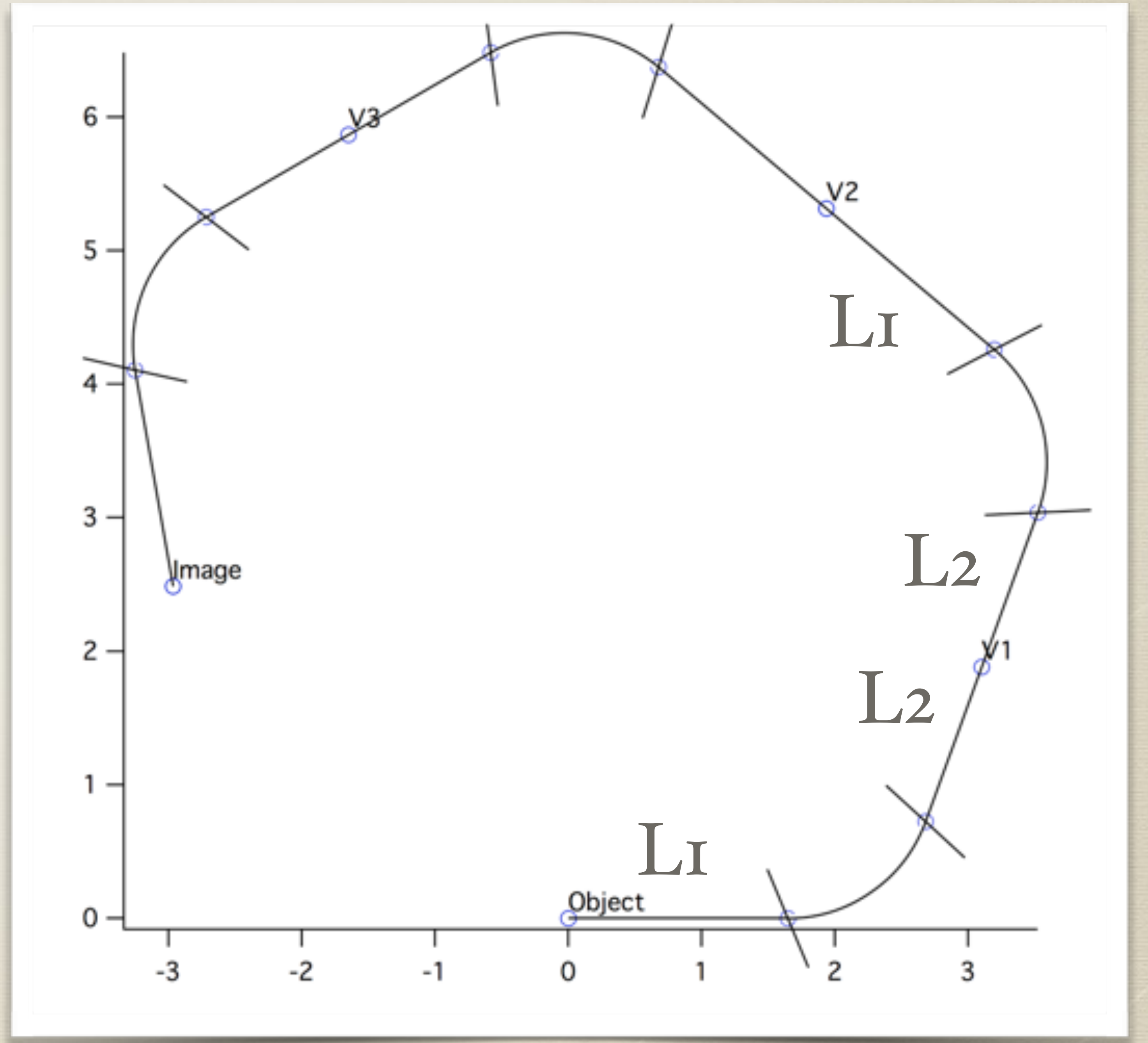
- Inspired from the TOFI design at LANL
  - Isochronous device: time-of-flight independent of momentum vector
  - Dispersive focal plane used to reject beam (similar to S3)
  - Selected ions in focus at final focal plane
- Characteristics
  - High M/Q resolution < 1/1000
    - Dominated by beam packet time resolution
  - Large acceptances
    - Momentum: ±10%
    - Solid angle: 64 msr (±200 mrad H, ±80 mrad V)
  - Small aberrations < 5.10^{-4}
  - Adapted to beams 12-15 MeV/u
    - Maximum rigidity: 2.6 T.m.





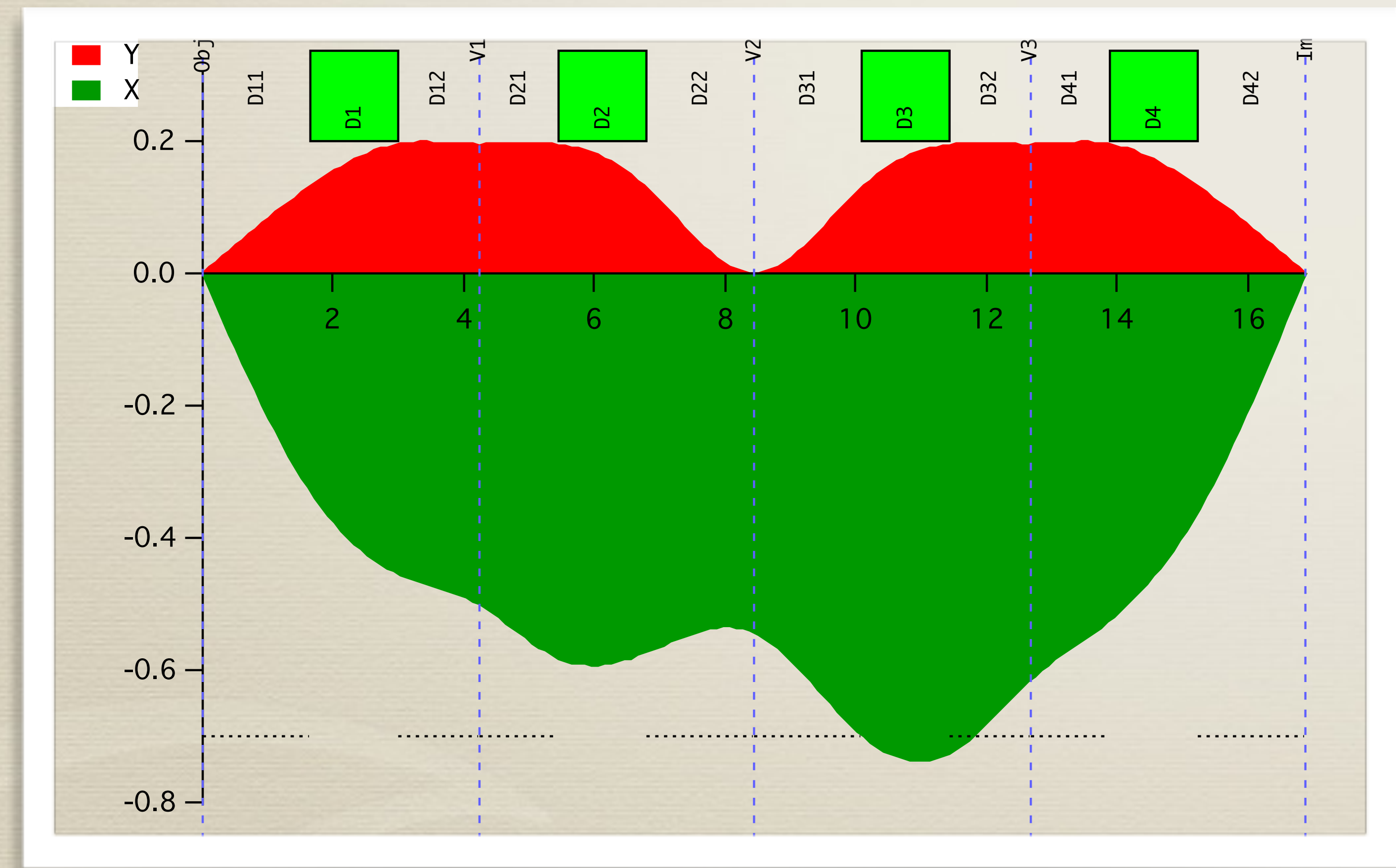
Asymmetric design

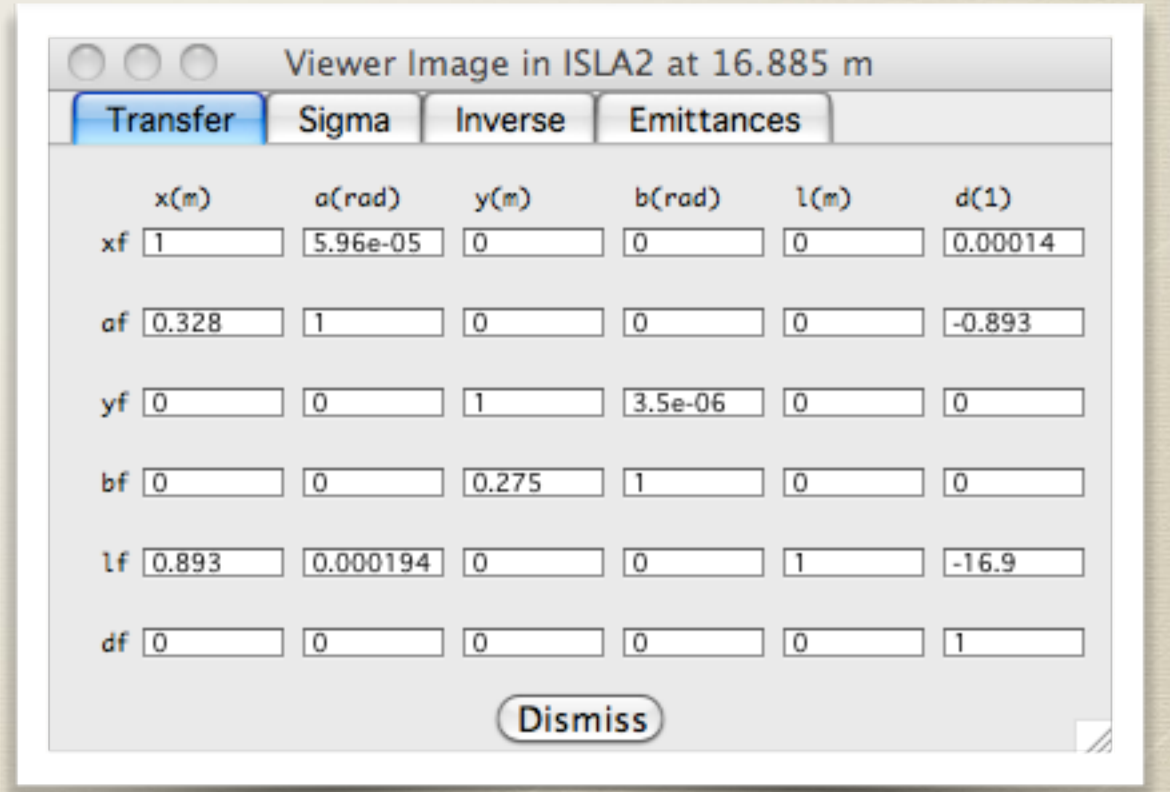
- Fitting L1-D-L2 cells
  - Bend fixed at 70° to keep enough distance between Object and Image
  - L1 & L2 constrained by isochronous condition
  - Pole face rotation constrained by focussing
  - L1: 1.645 m, L2: 1.233 m, pole face rotation: 22.64°
- Distance between object and image: 3.87 m
- Total length: 16.9 m



Optical features

- Achromatic and isochronous double imaging at final focus
- Dispersion at middle focal plane: 5.4 cm/%
- Scattering angle after target can be measured at focal plane
- Beam swinger to rotate beam from 0° to 45°
- Space around reaction target for gamma-ray or charged particle array

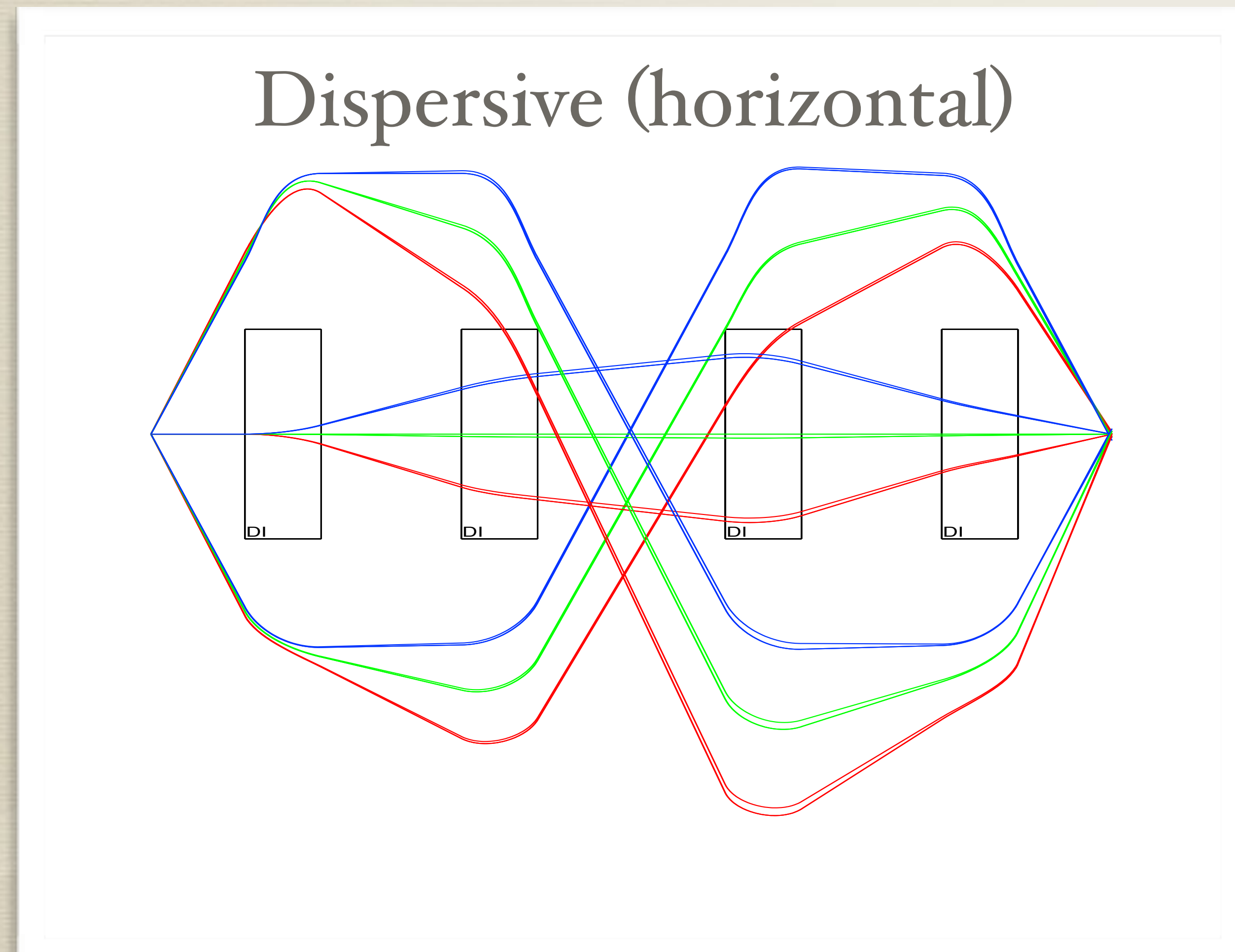


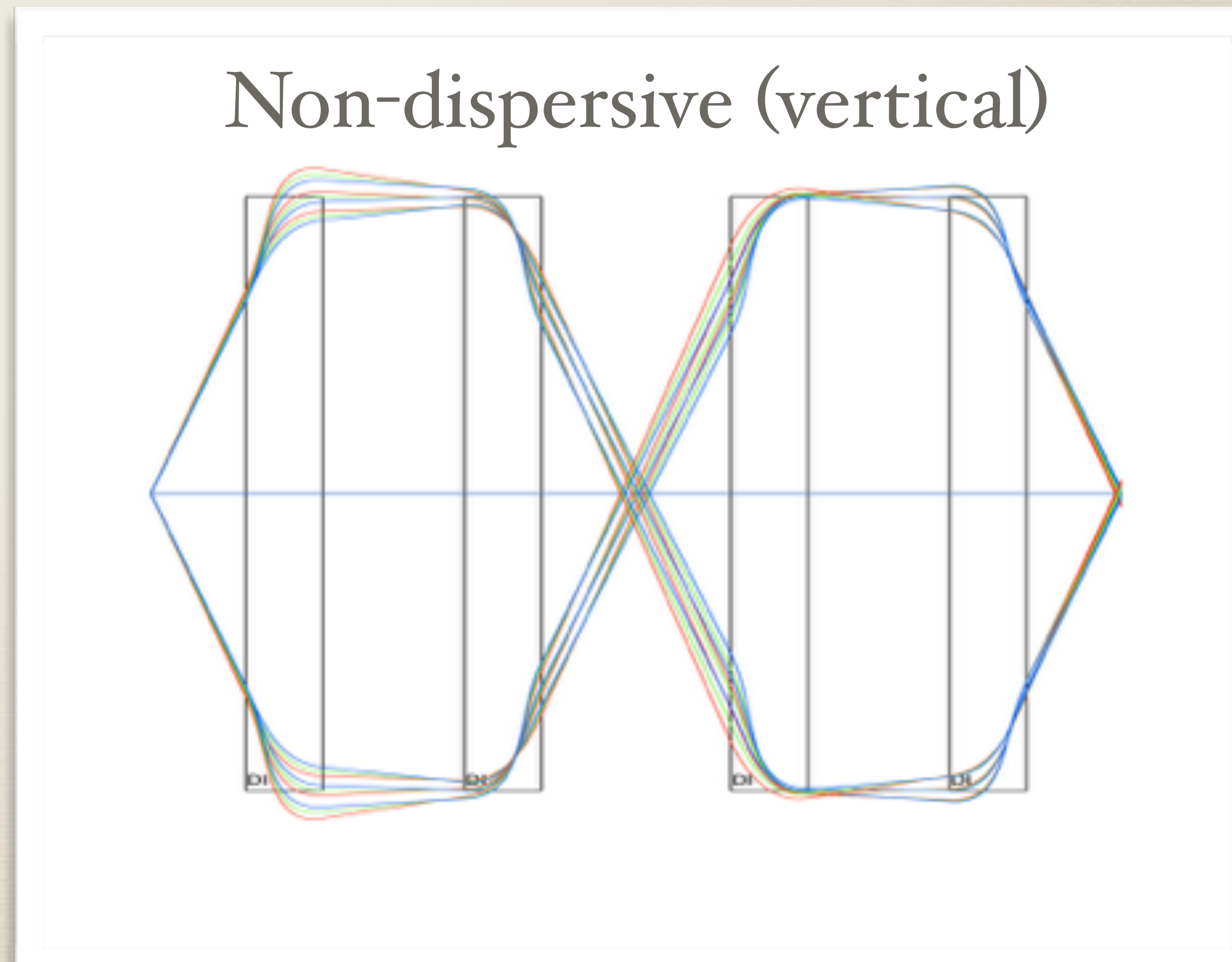


	x(m)	a(rad)	y(m)	b(rad)	l(m)	d(1)
xf	1	5.96e-05	0	0	0	0.00014
af	0.328	1	0	0	0	-0.893
yf	0	0	1	3.5e-06	0	0
bf	0	0	0.275	1	0	0
lf	0.893	0.000194	0	0	1	-16.9
df	0	0	0	0	0	1

Small aberrations

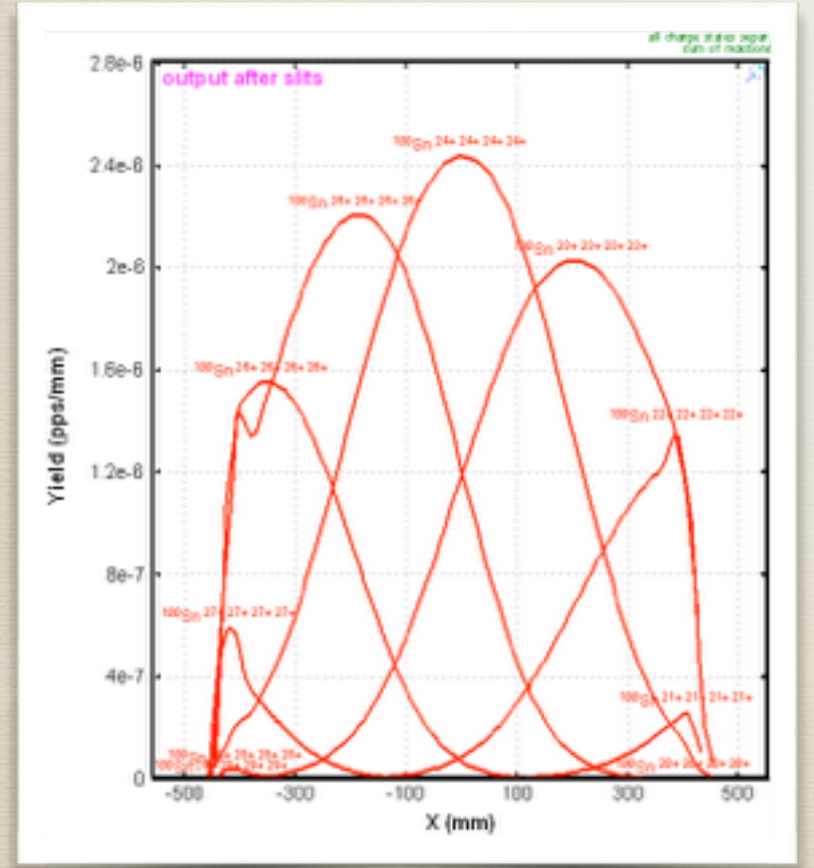
- Greatly reduced due to symmetry of the design
- Path length largest aberrations: (l/bb): -3.6 mm at ± 80 mrad, (l/aa): 8.4 mm at ± 200 mrad
- 8.4 mm corresponds to 1/2000 resolution
- Calculated with COSY Infinity using standard dipole design

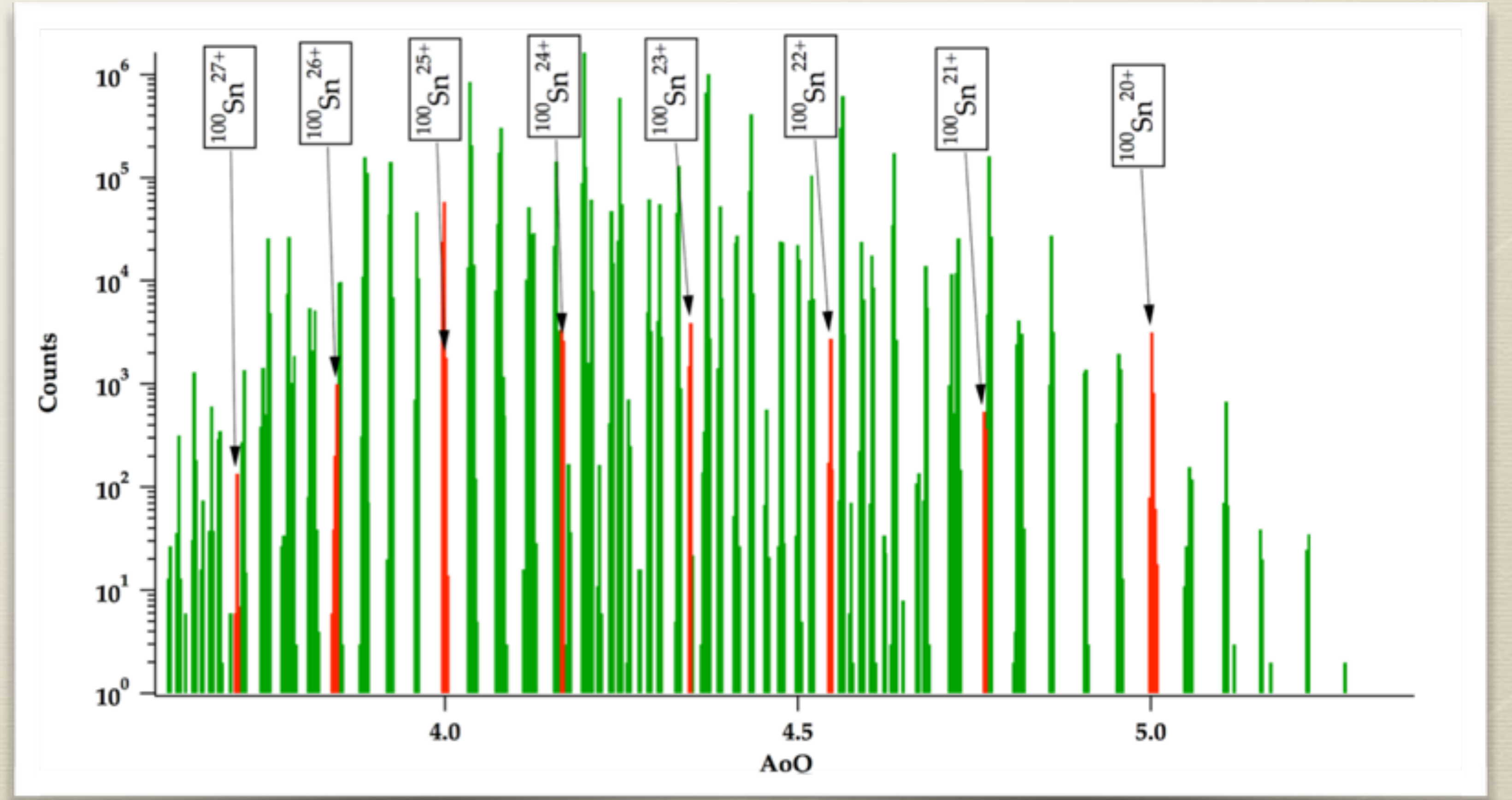




Example of simulation

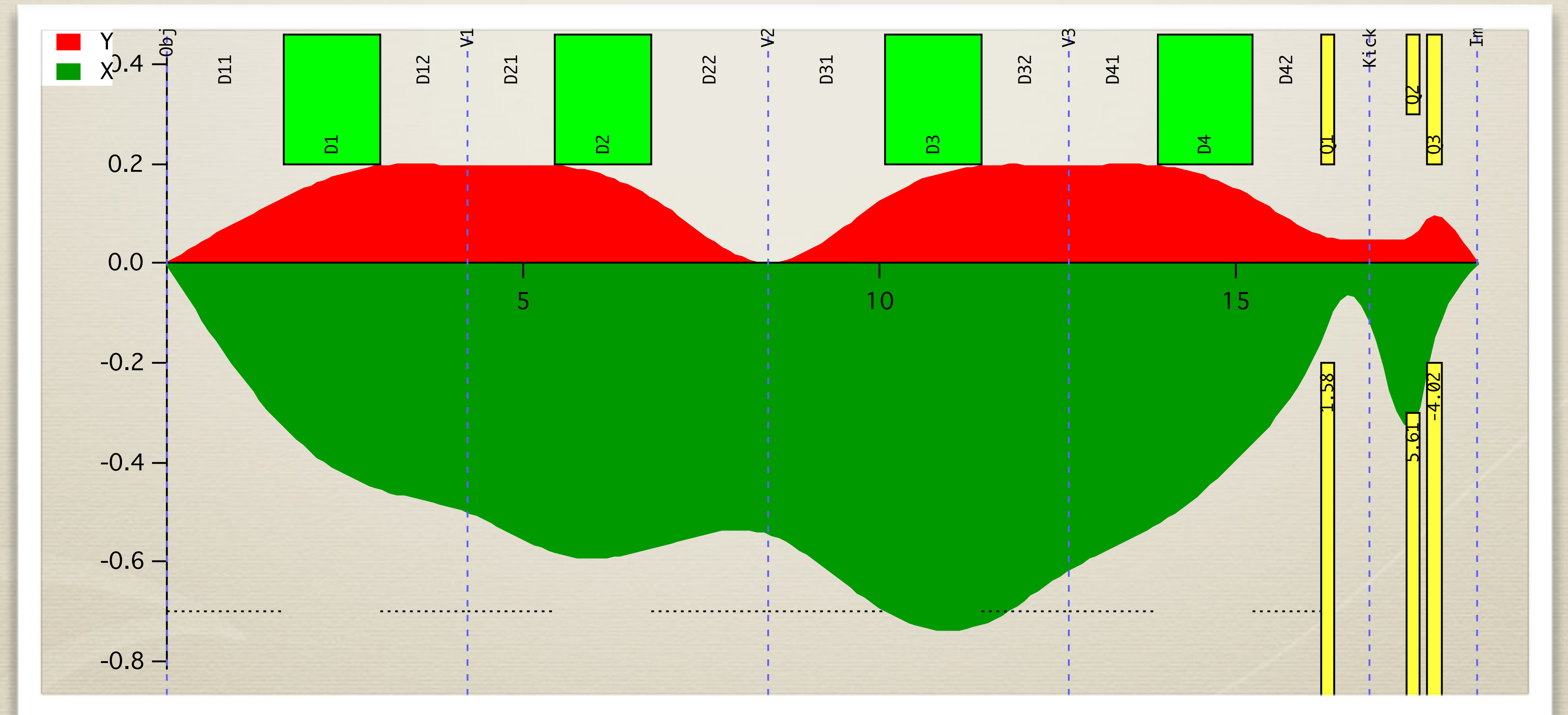
- LISE++ simulation of $^{50}Cr(^{56}Ni, \alpha 2n)^{100}Sn$ at 3.7 MeV/u
- m/q resolution depends on velocity and beam packet width
- Simulation shows m/q spectrum with 1 ns beam packet width
- Beam packet ambiguity of 12.5 ns period can be resolved
  - Bunching schemes of ReA12 and charge breeder
  - Gamma-ray or charged particle detection around reaction target





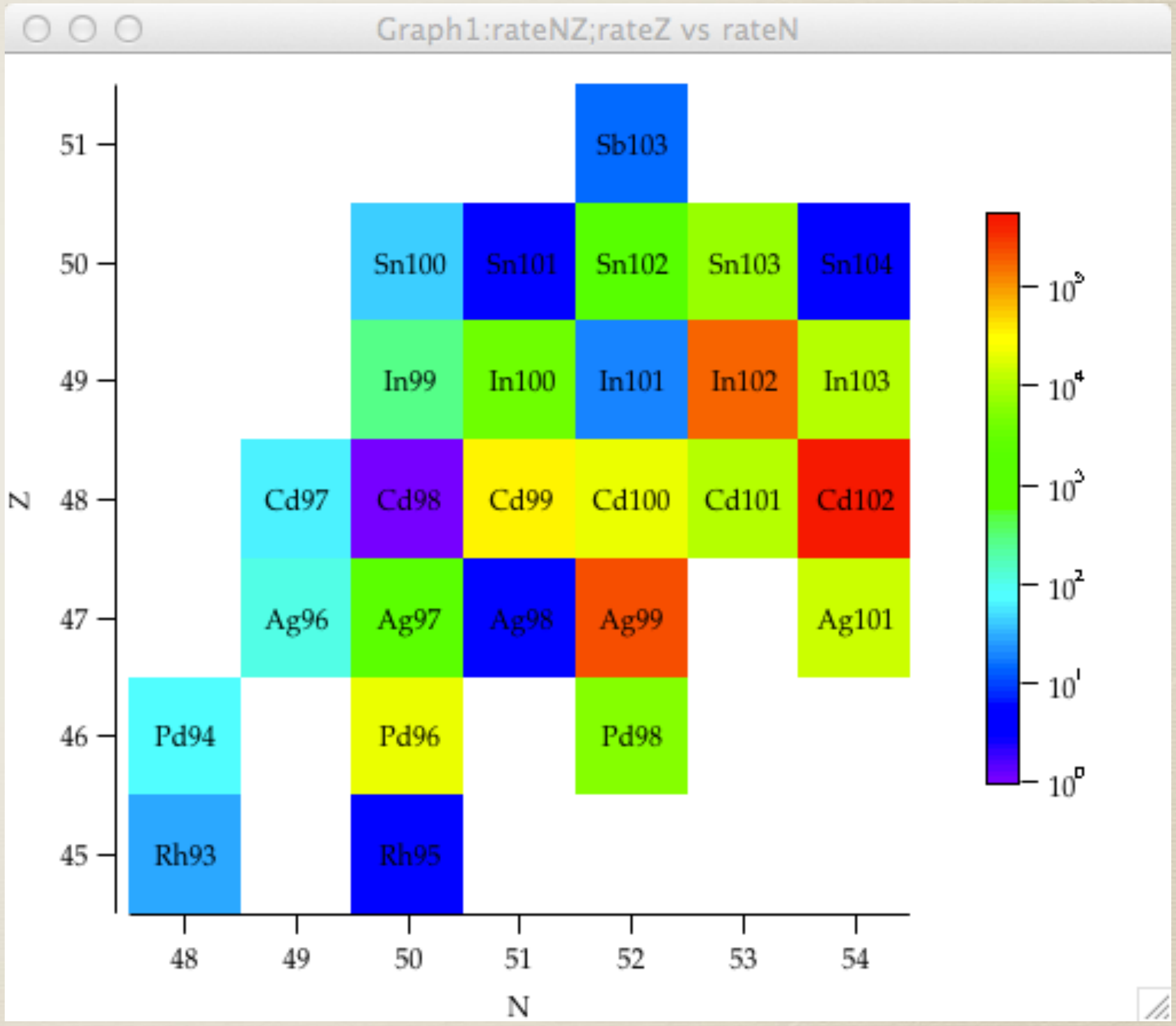
Physical separation with RF kicker

- First quadrupole: prepare vertical parallel beam in cavity
- RF cavity located at isochronous point
- Second and third quadrupoles: rotate beam ellipse to achieve vertical (and horizontal) focusing
- Vertical deflection in cavity translated into vertical offset at focus



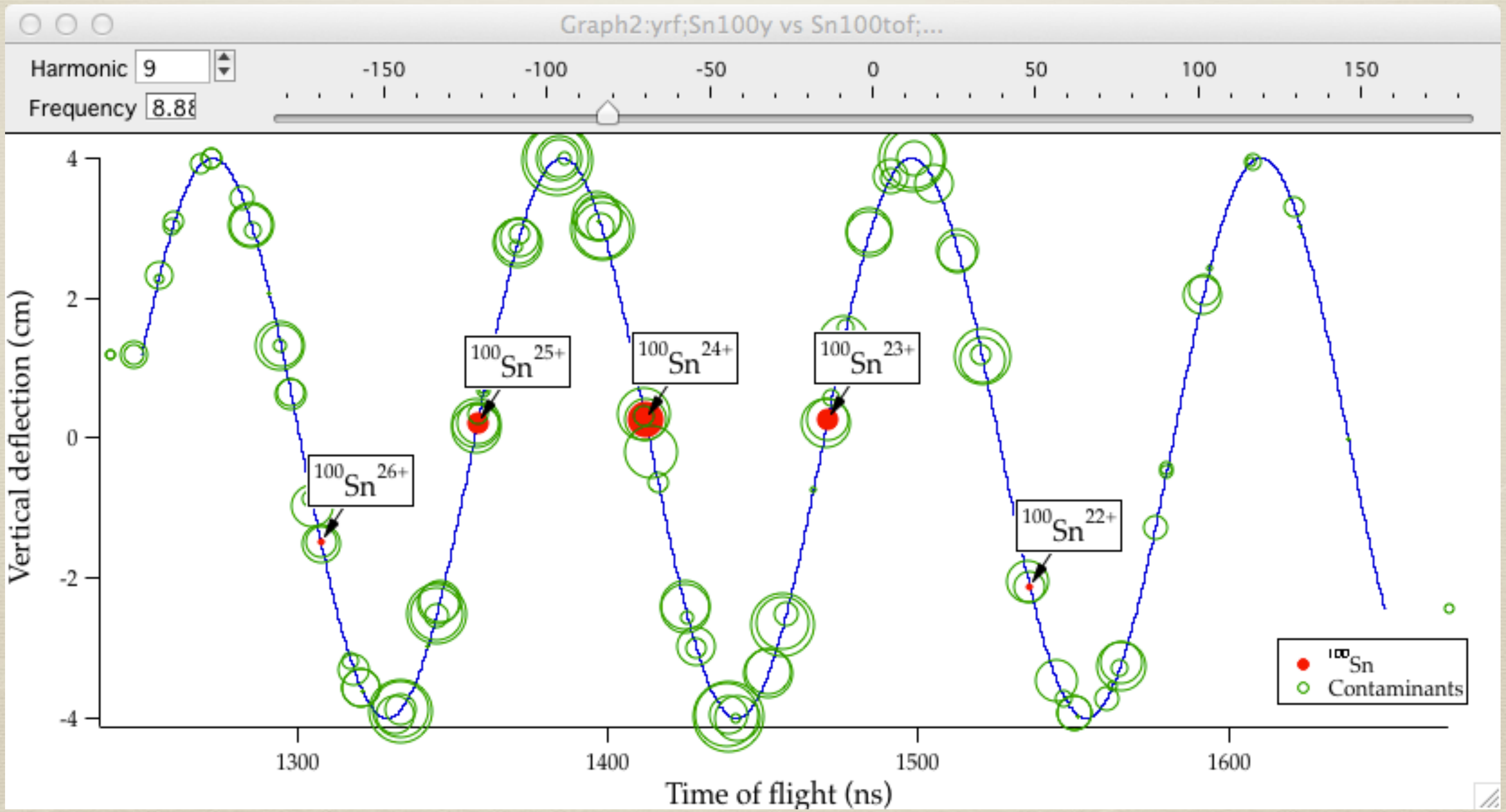
LISE++ simulation

- Monte-Carlo simulation of $^{50}Cr(^{56}Ni, \alpha 2n)^{100}Sn$ at 3.7 MeV/u
  - 10^6 reactions simulated
  - 41 ^{100}Sn events
  - Cross section: 0.009 mb
  - Purity 4.10^{-5}
- ^{100}Sn transmission
  - 5 charge states: 22+ to 26+
  - Total transmission: 48.6%
- Main contaminants
  - ^{102}Cd (50%)
  - ^{99}Ag (20%)
  - ^{102}In (16%)



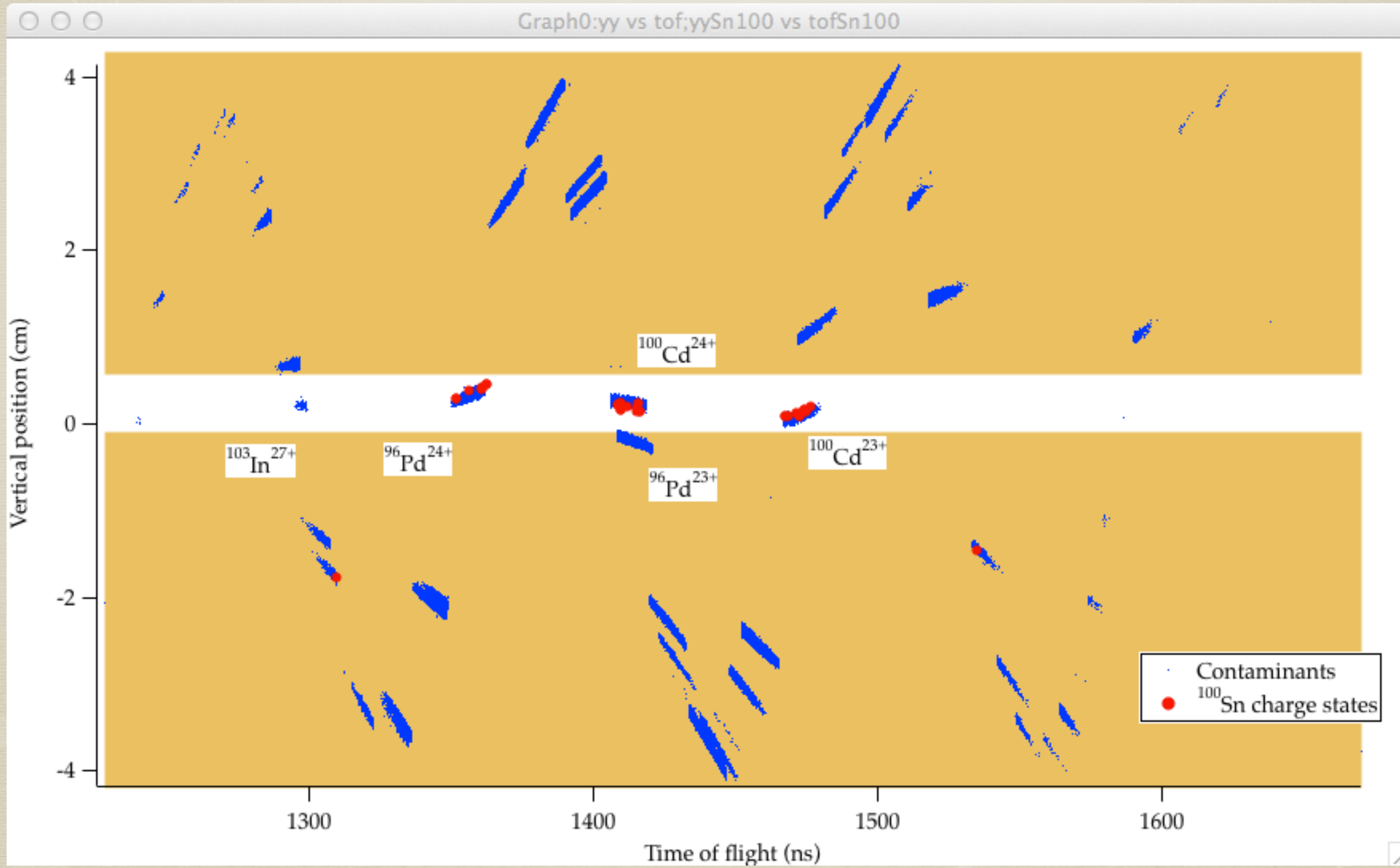
Best harmonic

- At harmonic 9 (8.89 MHz), most intense contaminants are not in phase with ^{100}Sn charge states anymore
- 3 most intense ^{100}Sn charge states can be phase-aligned



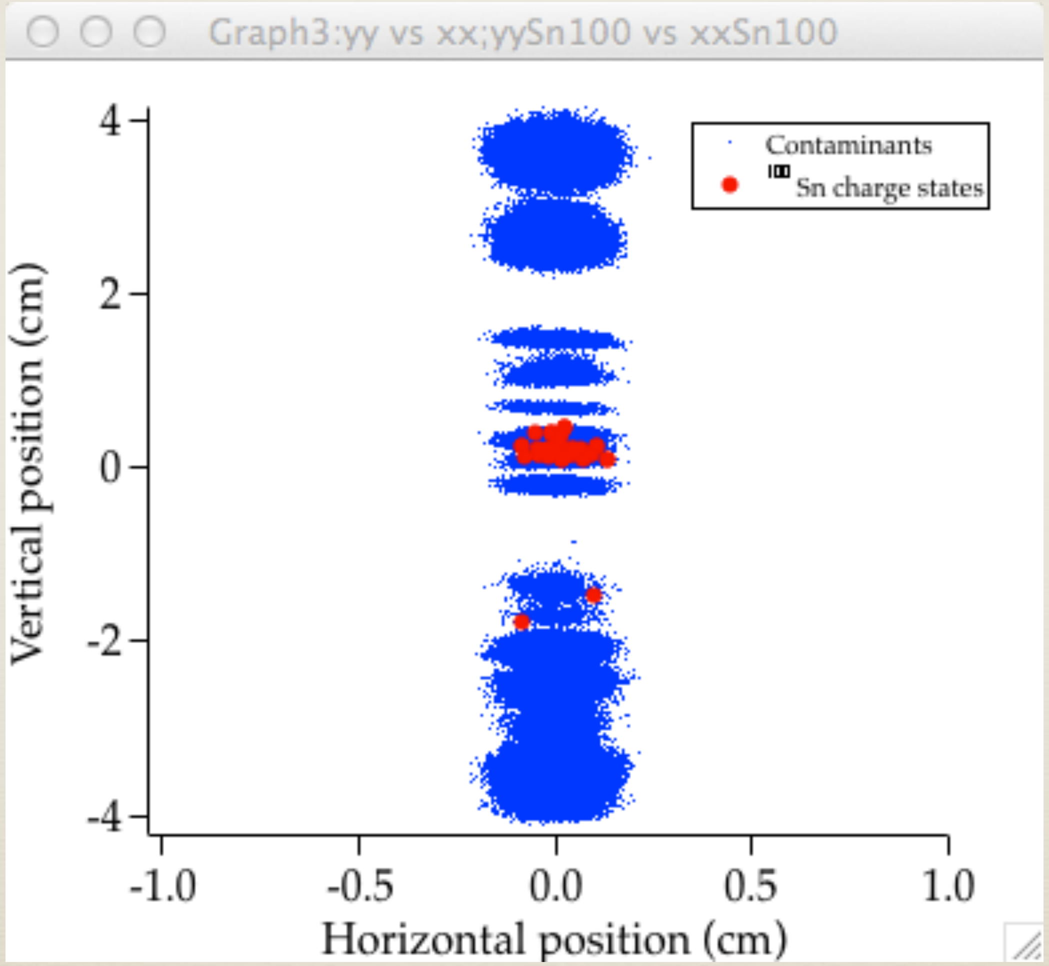
Vertical position vs TOF

- After slit selection: ^{100}Sn purity = 1.4 10^{-3} (factor 35 better)



Charge state focussing

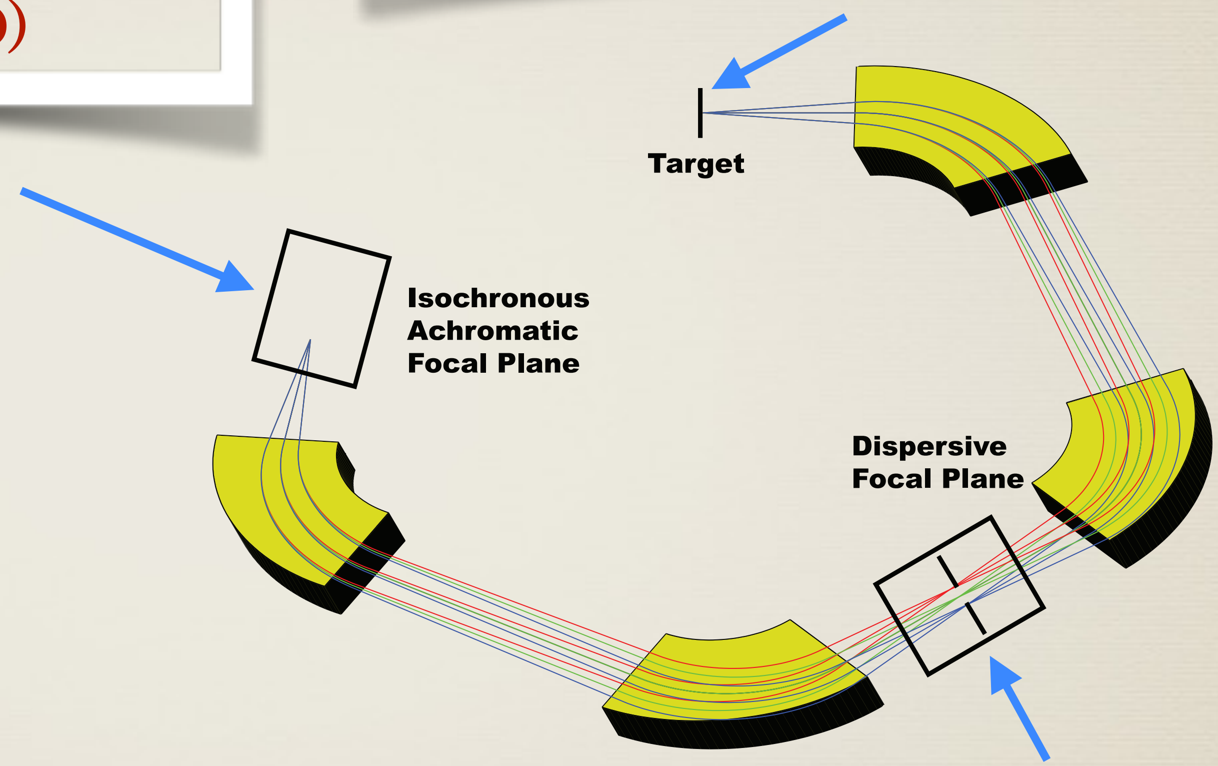
- Most intense ^{100}Sn charge states focalized within 1 cm^2
- Possibility to implant in DSSD or tape system for longer half-lives



Versatile spectrometer

- Tracking detectors (MCP, PPAC, TPC)
- Energy loss detectors (IC)
- Implant-decay detectors (DSSD)

- Tracking (MCP, IC)
- Gamma-ray array (GRETA, LaBr3)
- Charged particle array



- Use only first half (VAMOS-like)
  - Brho measurement
  - Reaction studies
  - Isochronous in momentum
- Several options for use
  - Many configurations possible depending on reaction, energy, purpose of experiment

Thin foil detector (100 μg/cm²) for position and time
- Brho

Gas-filled mode

- Preliminary study made by VAMOS group in GANIL
- Study of symmetric and asymmetric fusion-evaporation reactions, both direct and inverse kinematics
- Follow unreacted beam and ER in spectrometer
- Neglect straggling and scattering in gas
- Cases calculated:
  - ^{48}Ca (214 MeV) + ^{208}Pb → ^{254}No: easy
  - ^{208}Pb (1039 MeV) + ^{48}Ca → ^{254}No: possible
  - ^{54}Fe (195 MeV) + ^{58}Ni → ^{110}Xe: easy
  - ^{238}U (1200 MeV) + ^{48}Ca → ^{284}112 & ^{238}U (1350 MeV) + ^{64}Ni → ^{300}120: challenging
  - ^{136}Xe (870 MeV) + ^{208}Pb → ^{204}Pt (15° & 45°): possible
- Courtesy of M. Rejmund and C. Schmitt

^{208}Pb (1039 MeV) + ^{48}Ca → ^{254}No

Inverse kinematics

more challenging → add the differential plunger

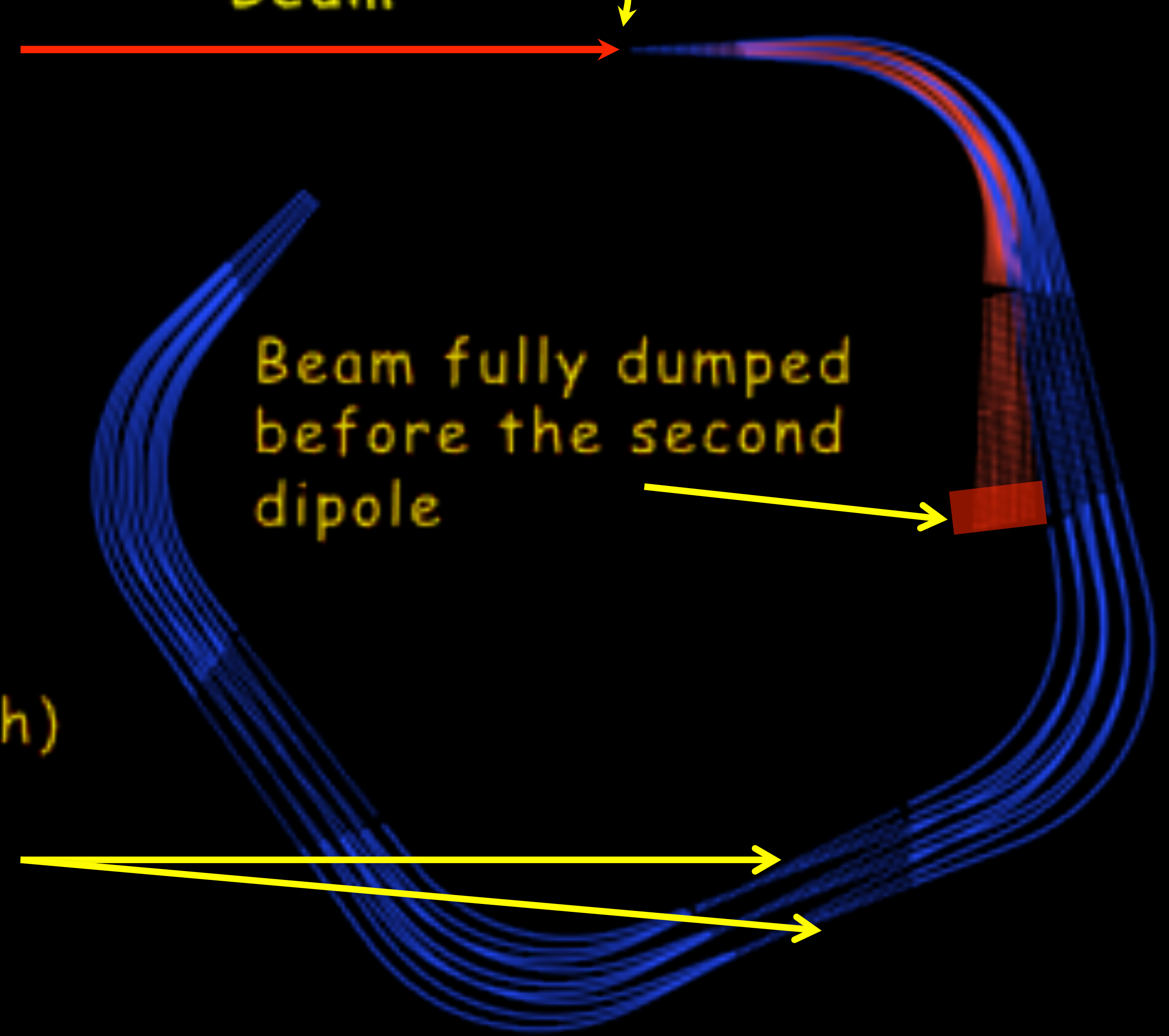
- Target: 0.5mg/cm² Au + 0.5mg/cm² ^{48}Ca + 2mg/cm² Au
- Degrader: 5mg/cm² Au

Beam

- $B\rho$ = 1.55 Tm
- $dB\rho$ = 3%
- $d\theta$ = 30 mrad

ER

- $B\rho$ = 1.77 Tm
- $dB\rho$ = 3%
- $d\theta$ = 60 mrad



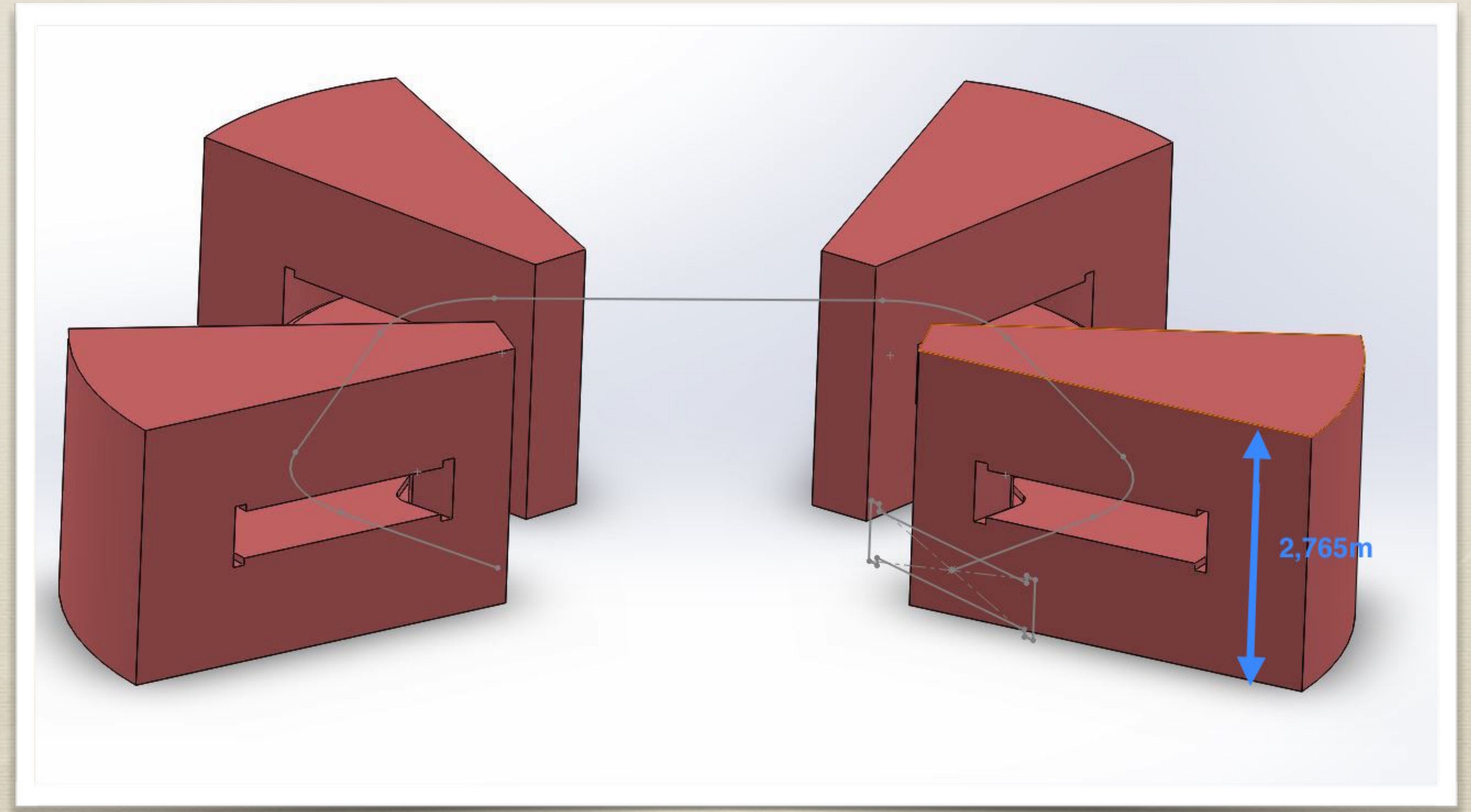
Residues: $B\rho \pm 3\%$ (full width) transmitted

- advantage high velocity

Highly asymmetric inverse kinematics POSSIBLE !!

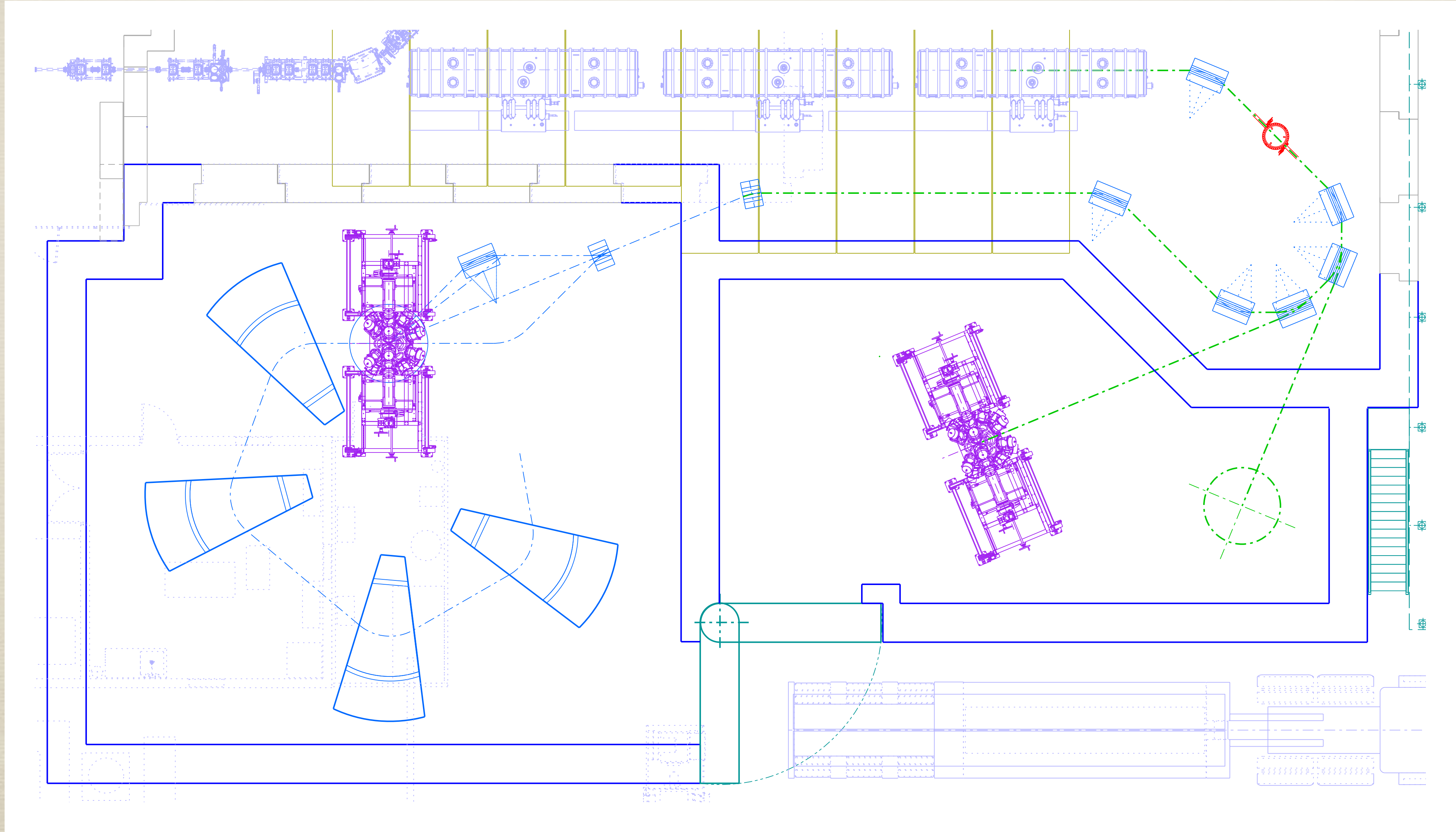
Magnet mechanical design

- Radius increased to 1.25 m, maximum field lowered to 2 Tesla
- Aperture 40 cm (± 20 cm)
- Weight (iron only): 115 Tons (462 Tons total)
- $5k/Ton (China) gives 2.3 M$ (total)



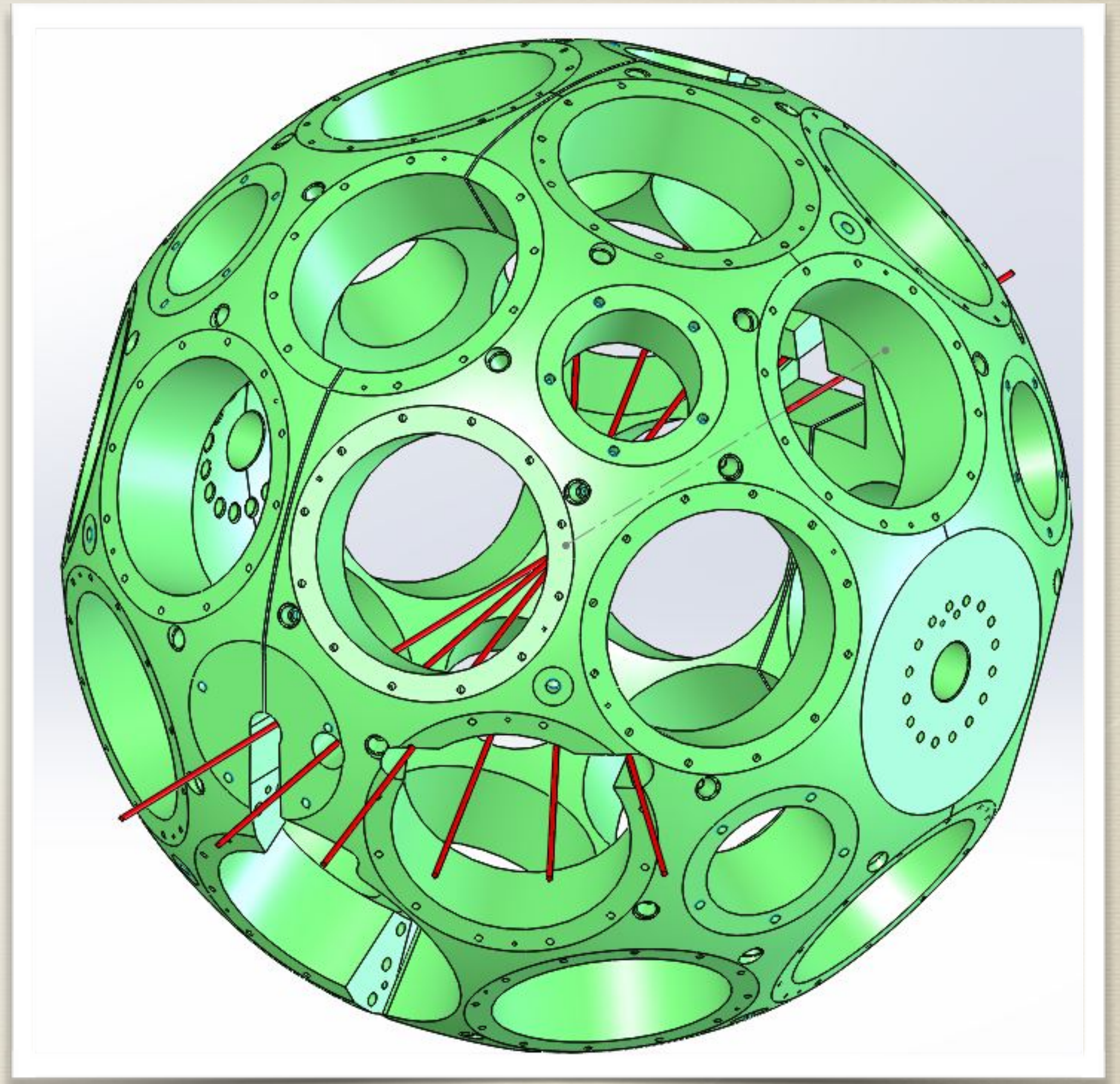
Swinger & possible layout

- Horizontal swinger allows angle on target from 0° to 45°
- GRETA stationary relative to ISLA



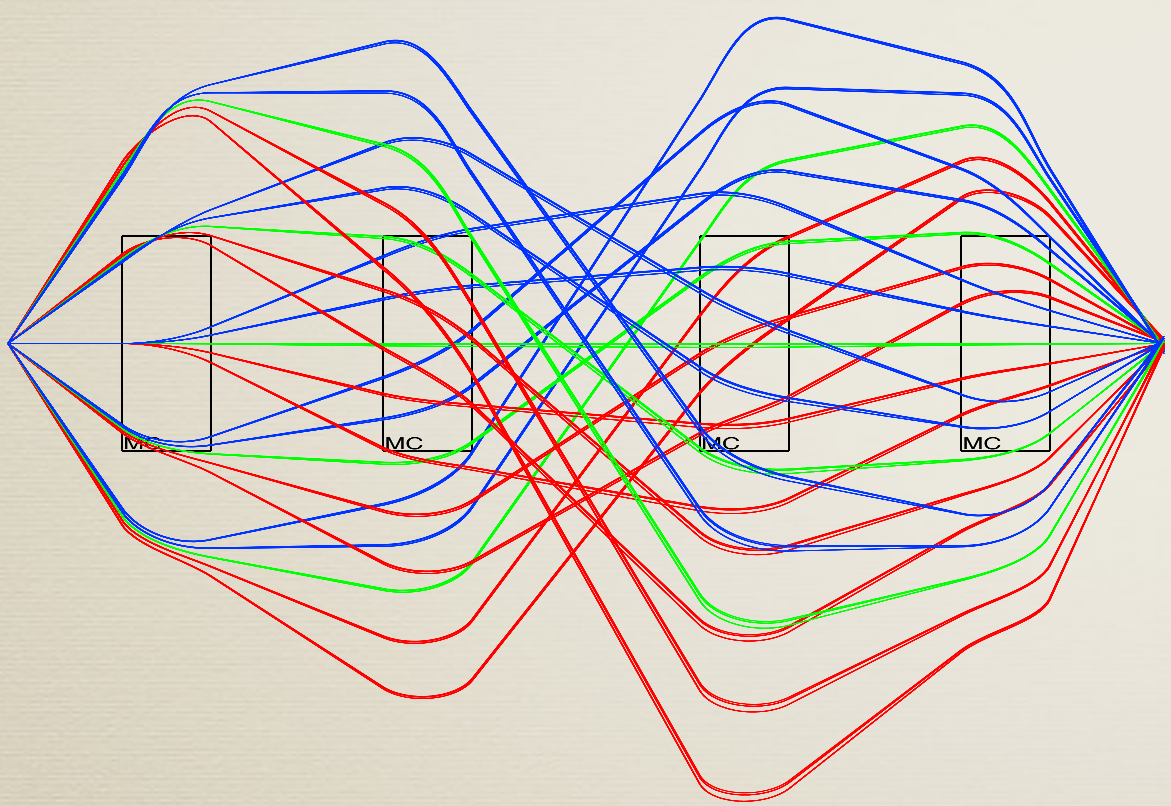
Coupling to GRETA

- Gretina ball shown
  - Remove modules that collide with entrance beam pipe
  - GRETA ball design implicated in angle variation
- Unreacted beam
  - For angles between 0° and 10°: stopped within ISLA acceptance (±10°)
  - For larger angles: beam dump pipe needed

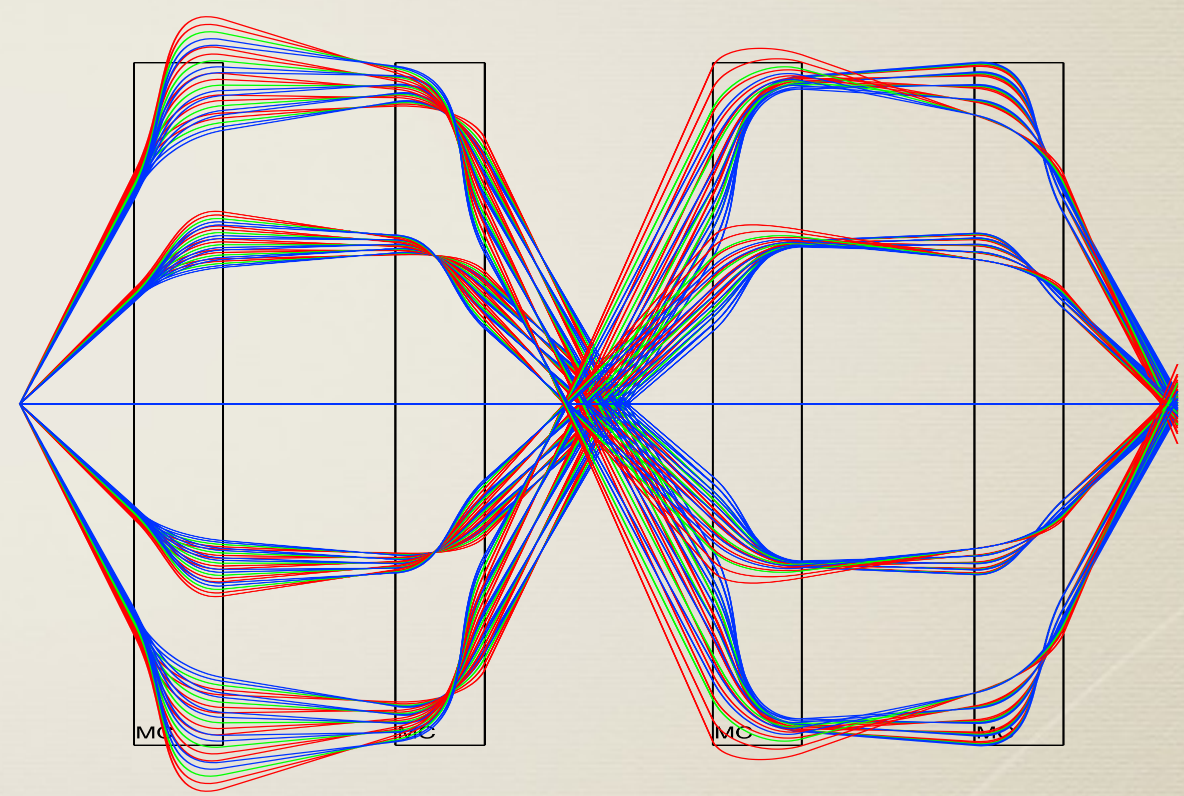


Homogeneous Dipoles

- Fringe fields from defaults parameters in COSY
- Emittances: a=±200mrad, b=±80mrad, d=±10%
- 5 rays per dimension



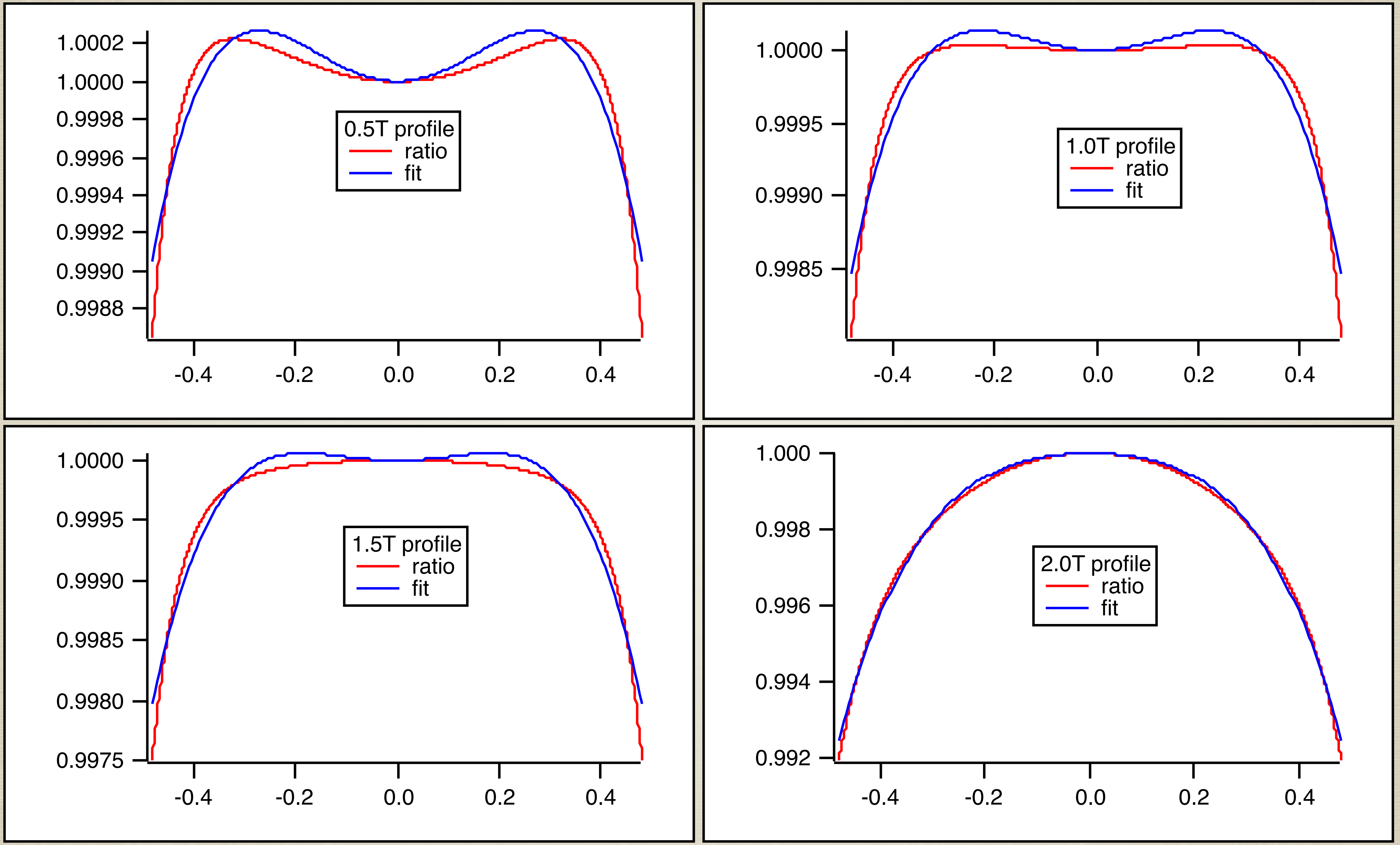
x (dispersive)



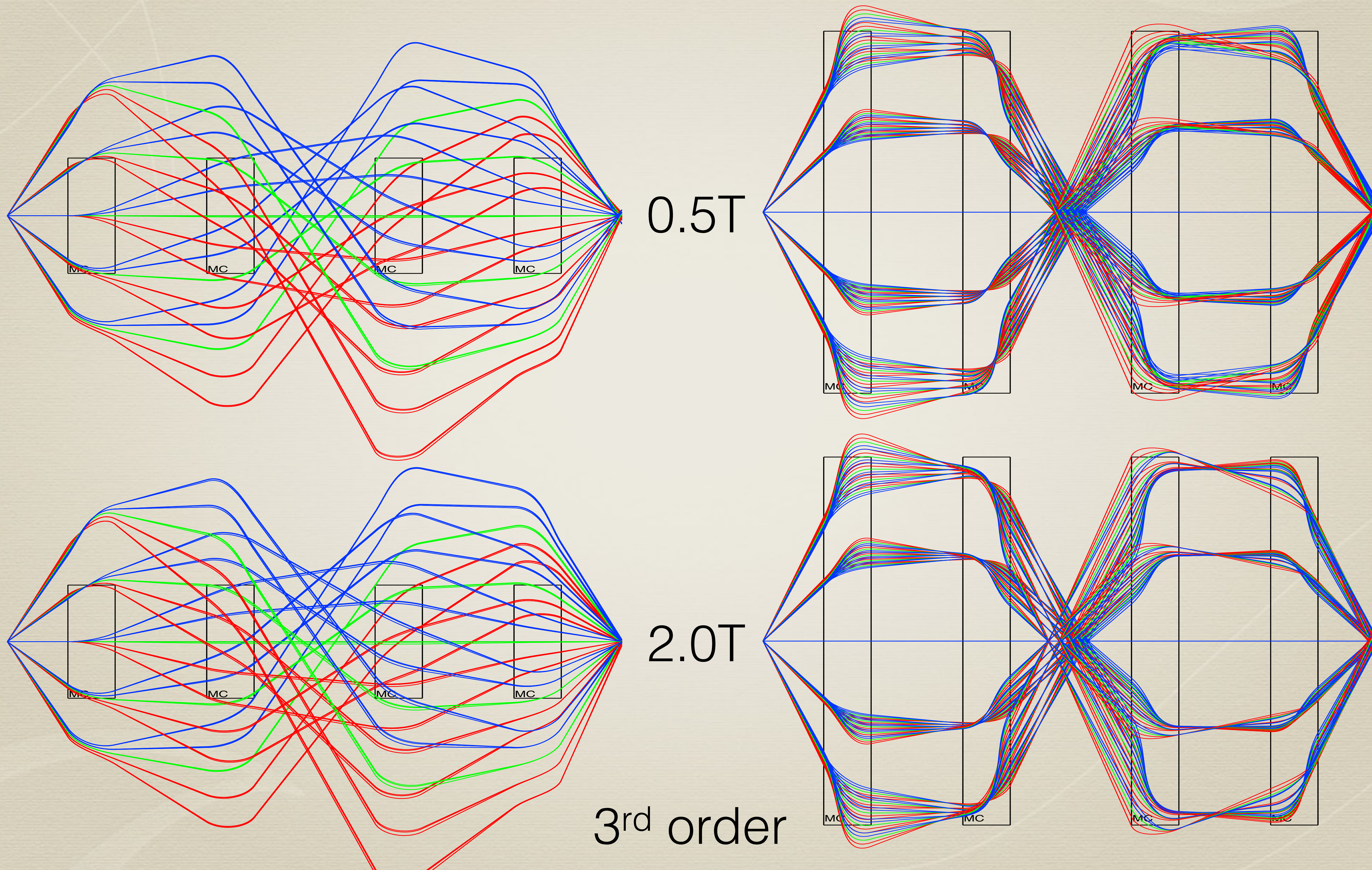
y (non-dispersive)

3rd order

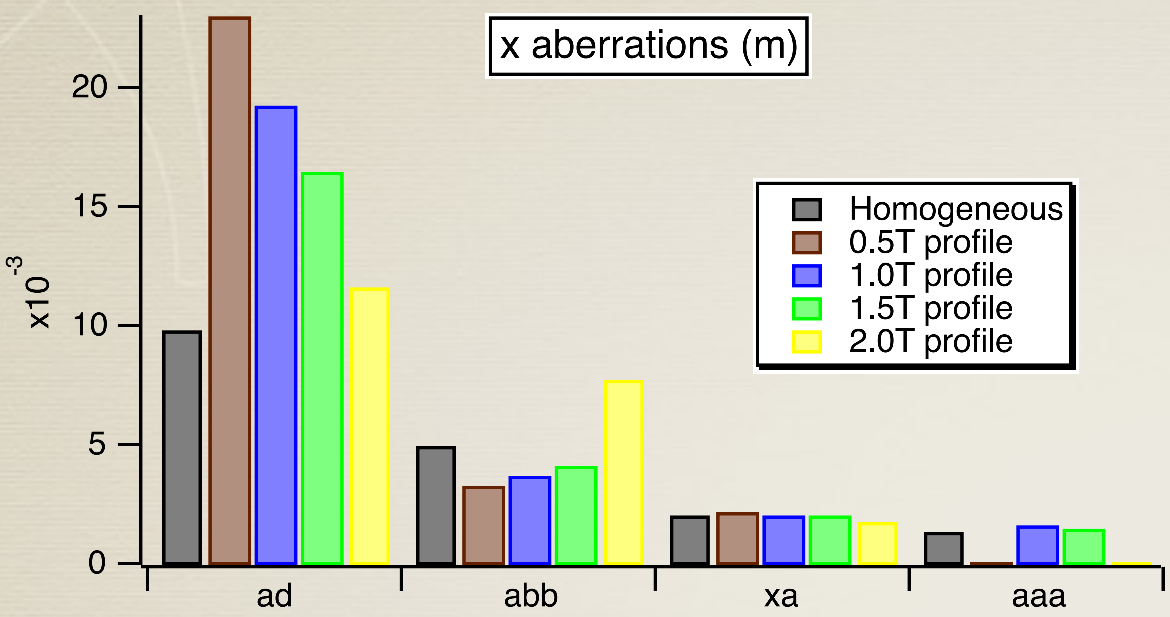
Radial profiles

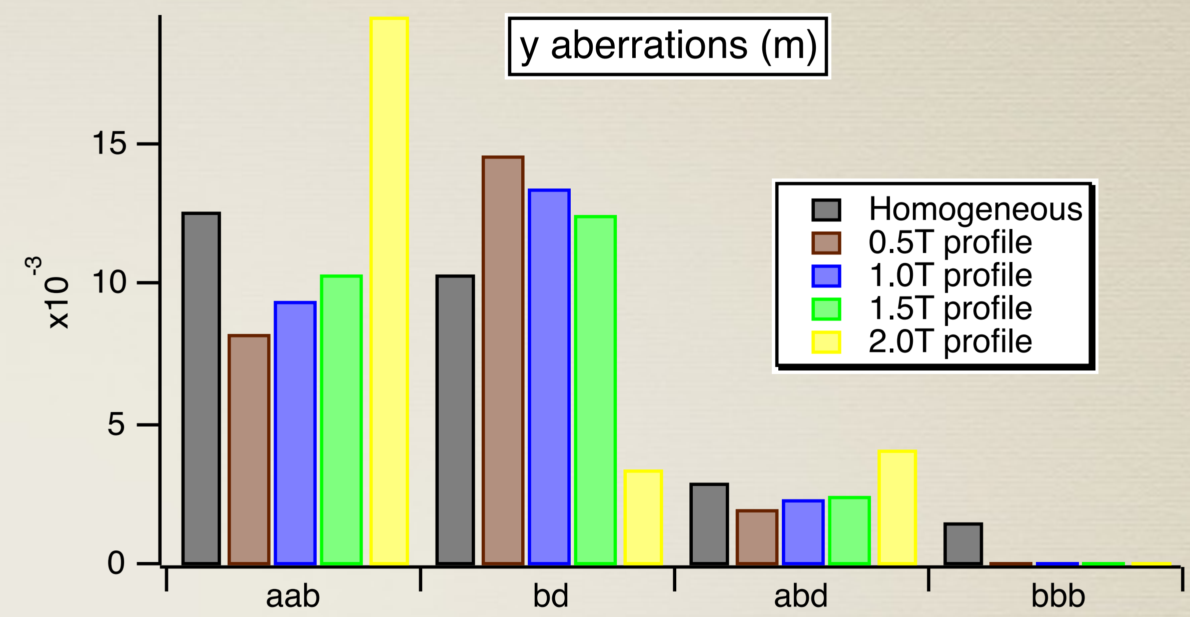


Effect on envelopes

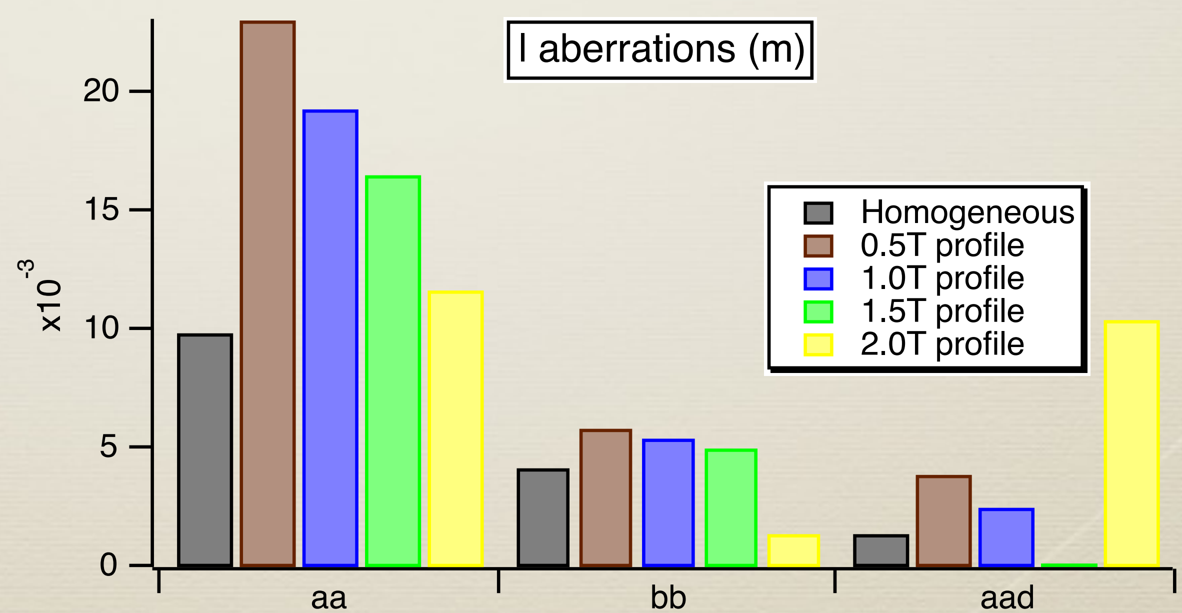


Aberration analysis



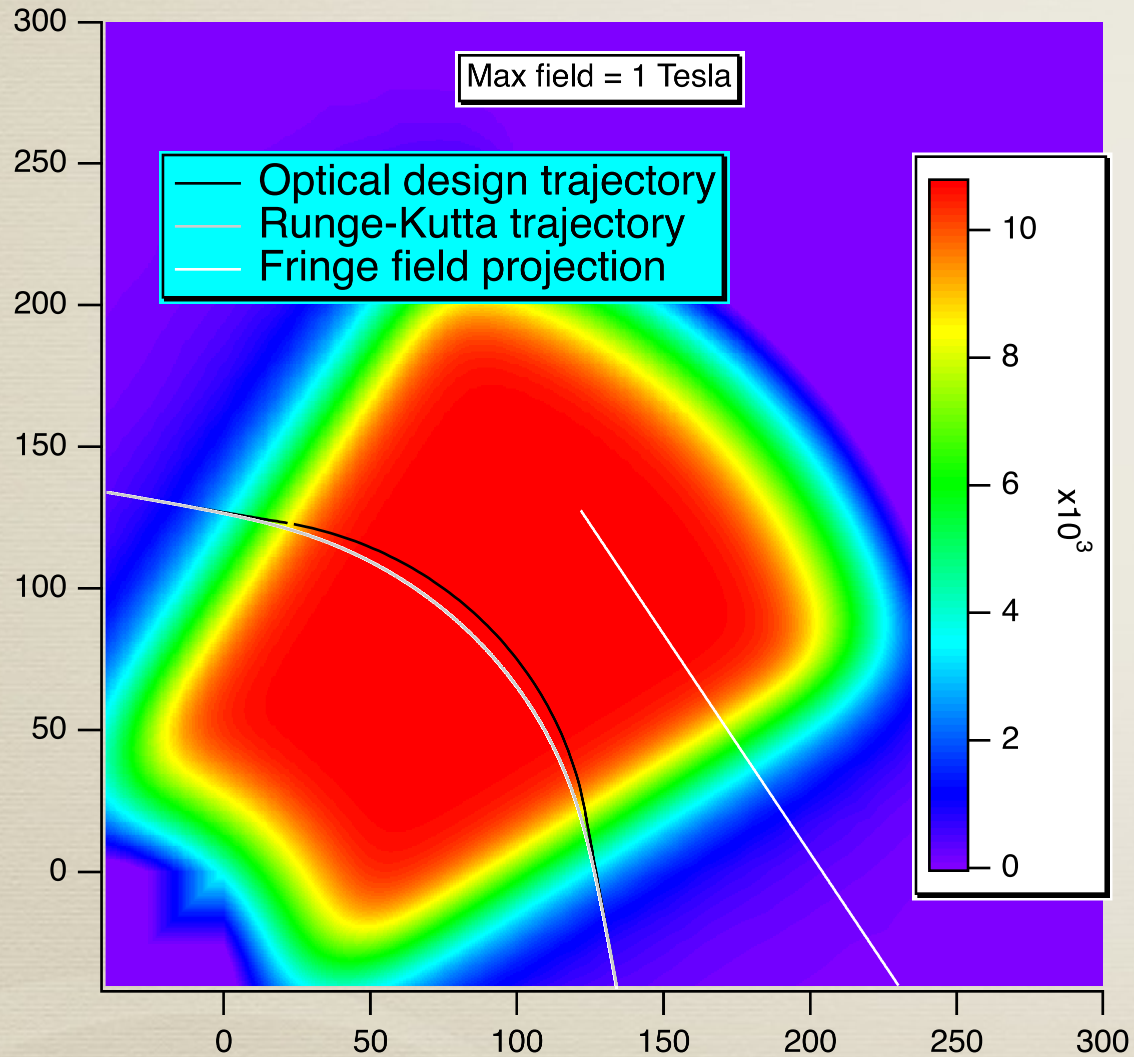


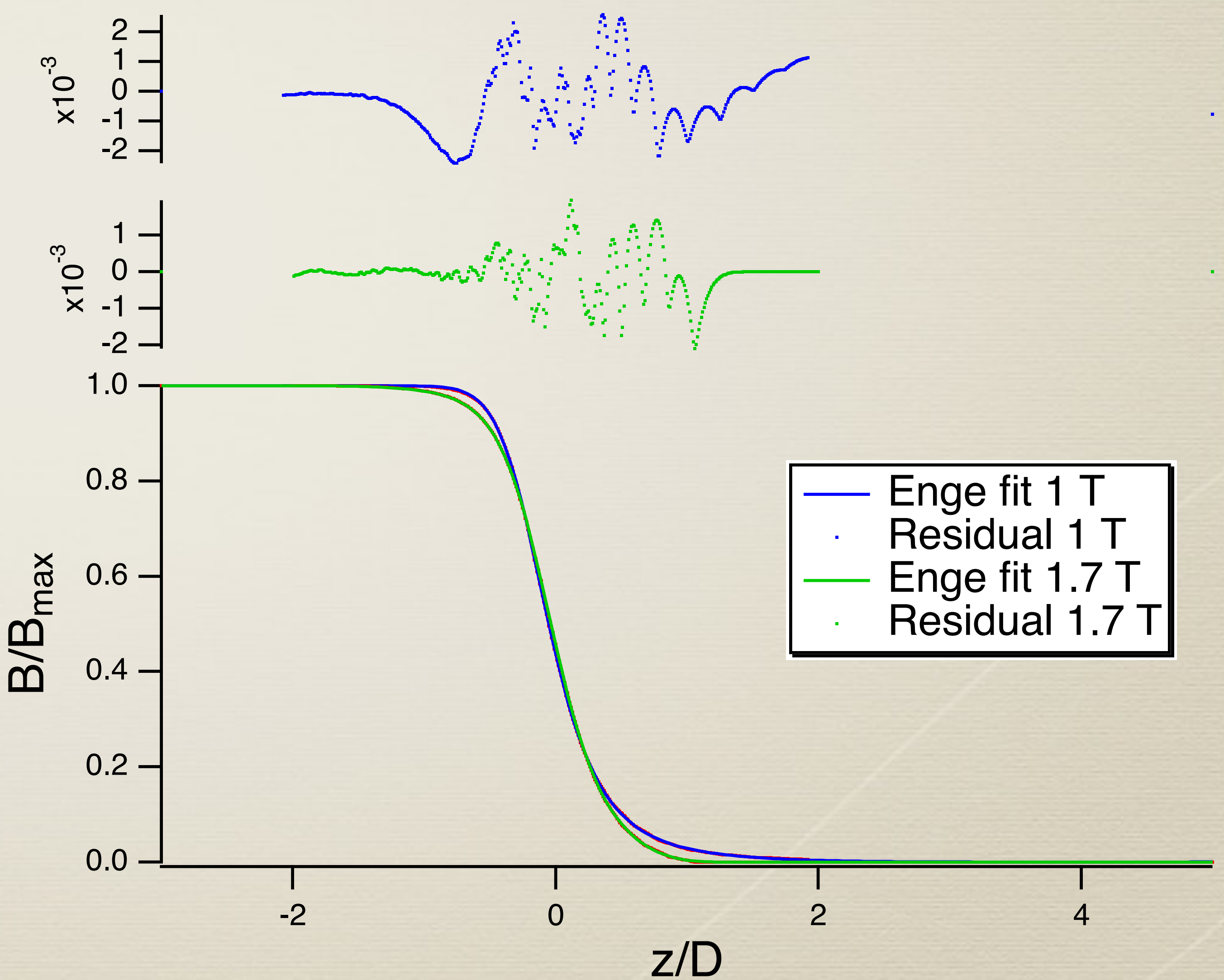
Total length
19.85 m



More realistic dipoles

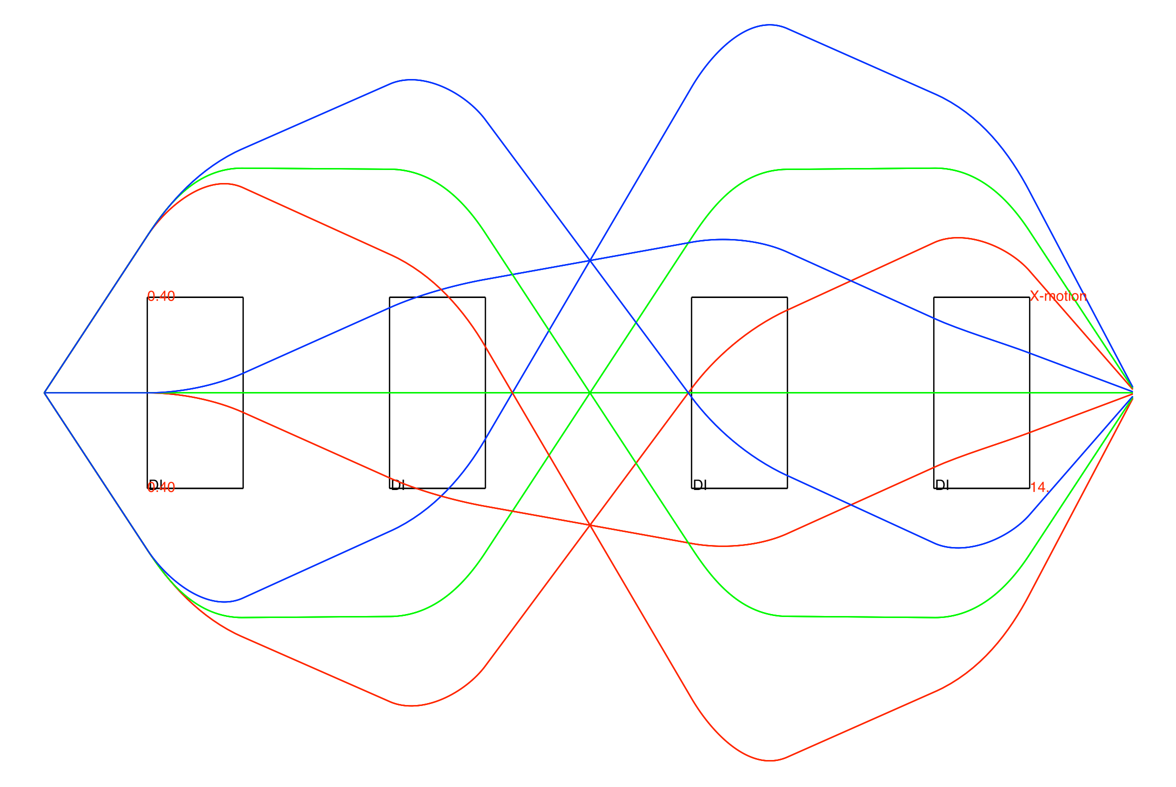
- Mid-plane field maps calculated by S. Chouhan
- Enge function fits perpendicular to field boundary
- Field maps calculated at 1 T and 1.7 T

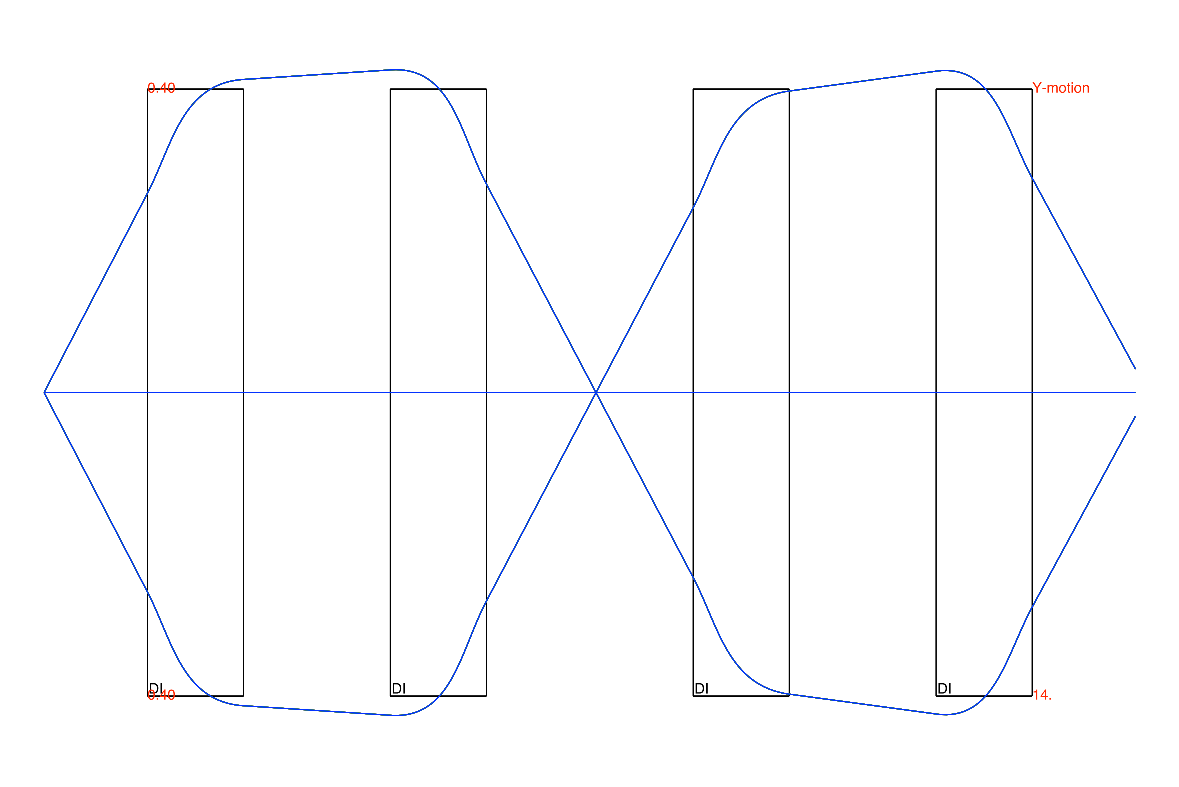




Effect on Brho scaling

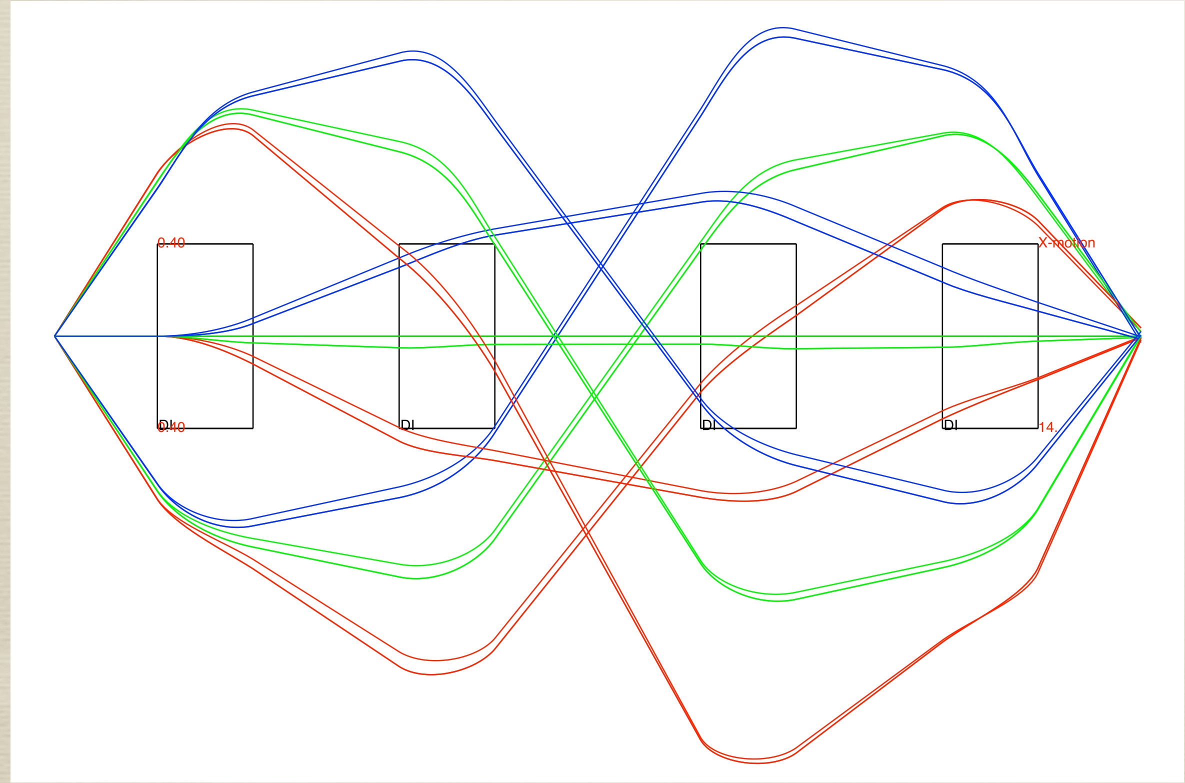
- Fitted parameters for focussing and isochronism at 1 Tesla
    - Edge angles: 21.03°, TOF detector position in focal plane: 1.642 meters
- First order optics at 1.7 Tesla
    - No longer x/y focus, isochronous position off by 55 cm
    - Fit individual edges and TOF detector position to recover
    - Edge1: 20.29°, Edge2: 21.57°, Edge3: 21.33°, Edge4: 21.44°, TOF position: 1.758 m
    - Dipoles with tunable edge angle? TOF detector on z drive (20-30 cm)

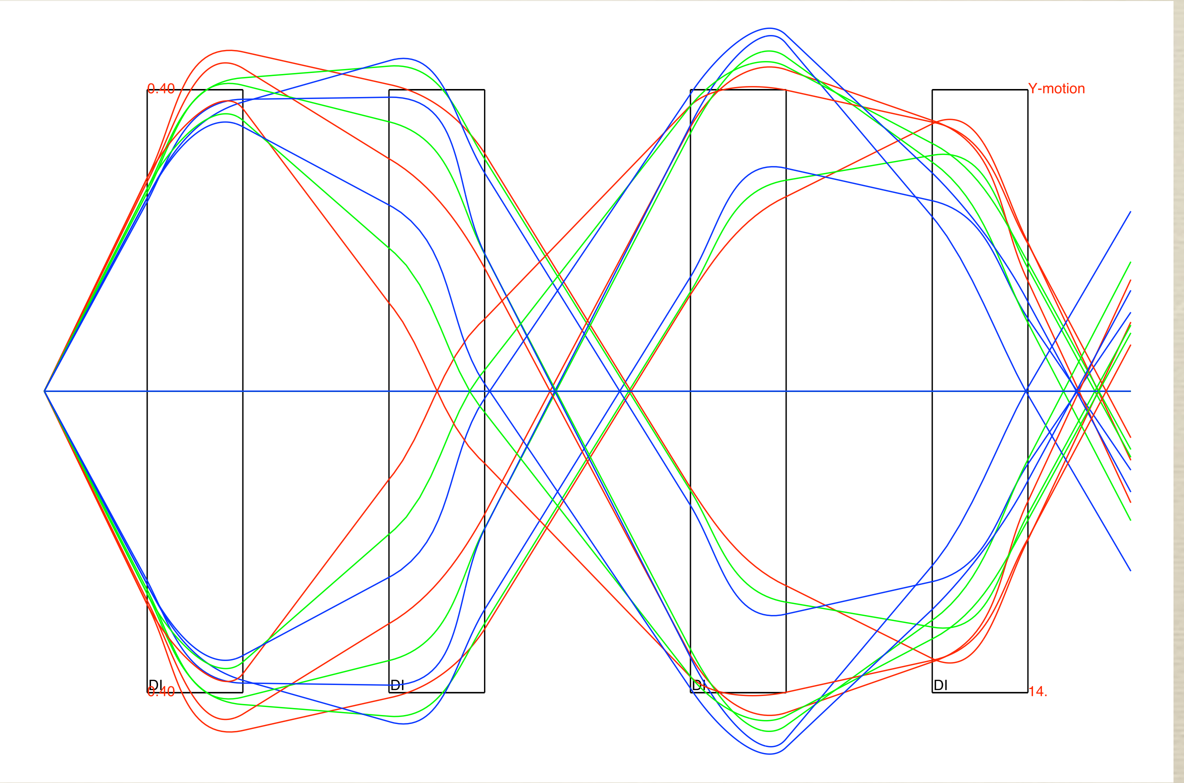




Effect on aberrations

- Chromatic aberrations still in check (< 1 cm)
- Length aberrations also small (< 1 cm)
- Geometrical aberrations in vertical seem to blow up ([y/b³]=10 cm, [y/a²b]=-5 cm
- Need to explore aberration corrections (pole face curvature?)

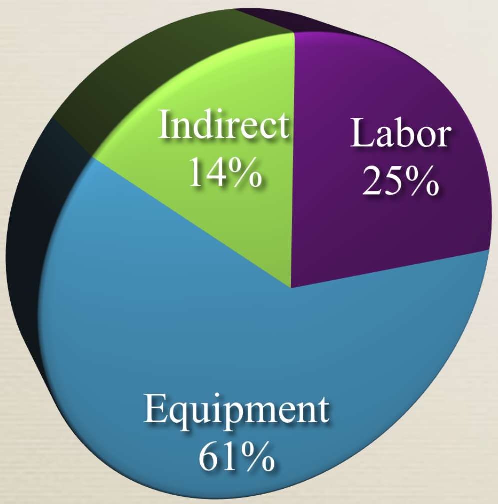


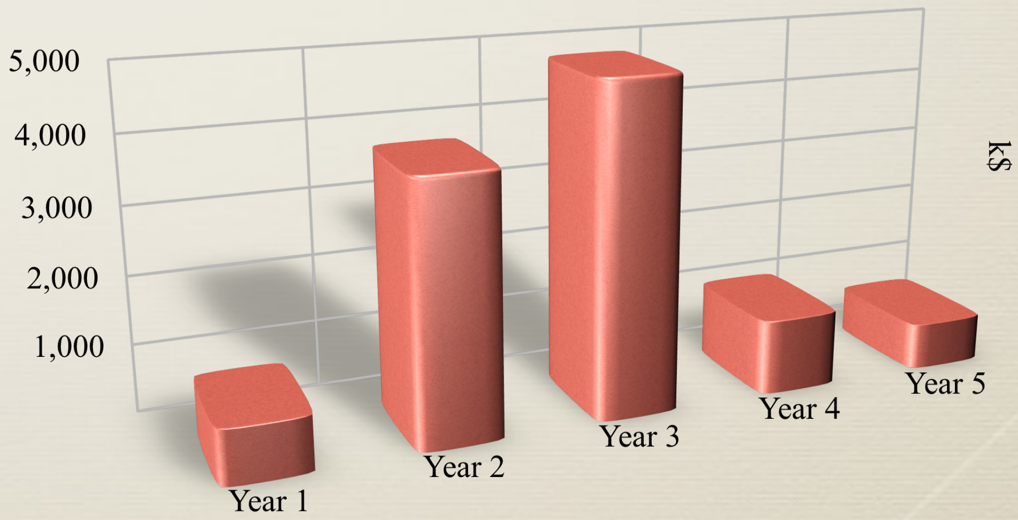


3rd order

Conclusion

- ISLA is a unique instrument that is essential to the realization of FRIB physics goals based on re-accelerated radioactive beams
- ISLA is intimately tied to the development of the ReAx re-accelerator
- ReAx energy upgrade white paper now published
- Design of ISLA should be parallel to early implementation of the ReAx energy upgrade

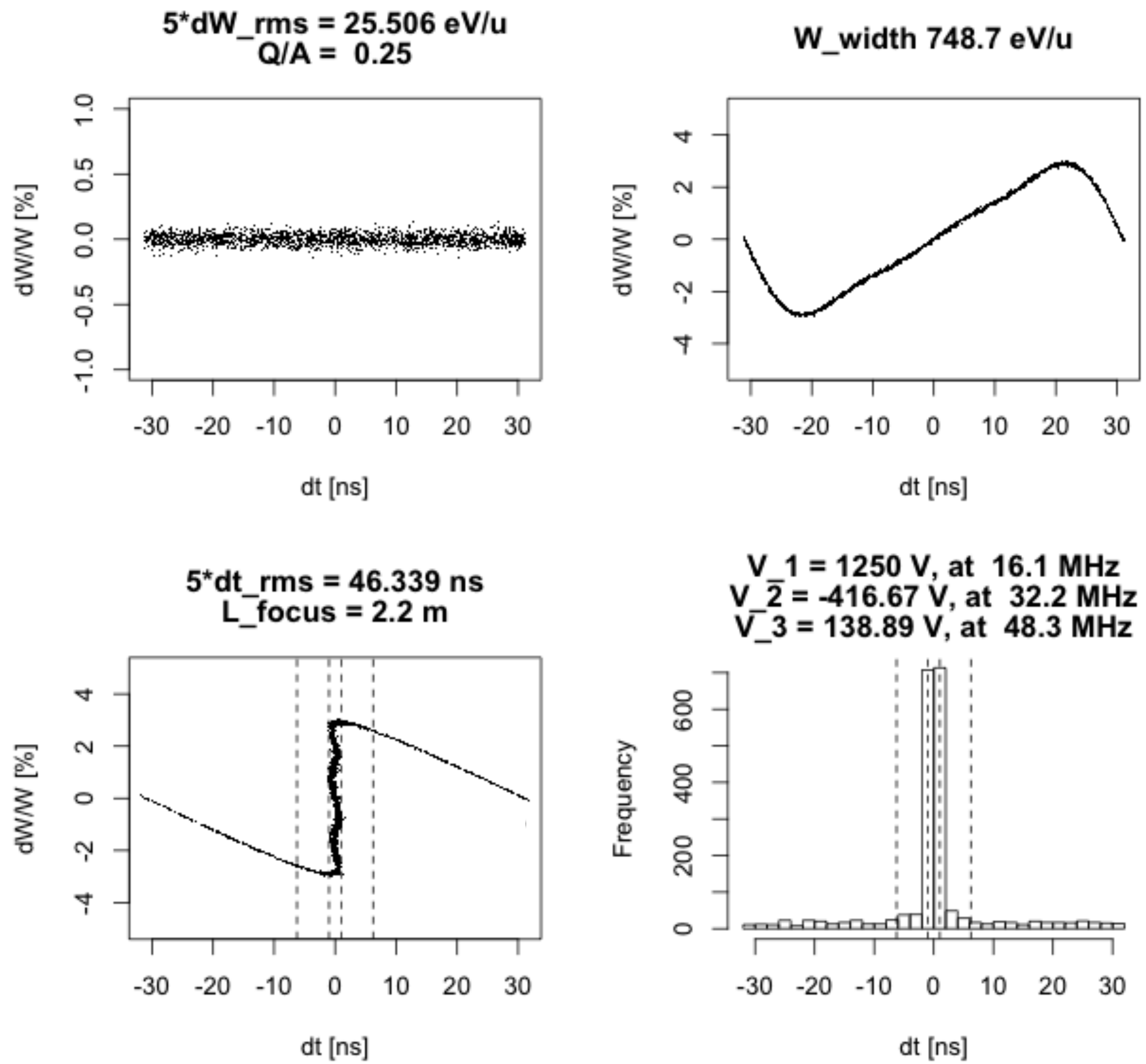




A Buncher for ReA Timing Enhancements

- Near-term Strategy
  - Build a 16.1 MHz buncher (we're calling it a pre-buncher) to compress every 62.5 ns of beam to one linac "bucket"
  - The RFQ acceptance (roughly +/-5% in dW/W and +/- 1.5 ns) along with the energy spread from the EBIT (~ +/- 0.1%) help determine the desired placement of the PB and its voltage level
  - The level of "cleanliness" of neighboring 80.5 MHz RF buckets remains a possible issue (more later)
- Longer-term Strategy …
  - Create ~50 ns pulses from EBIT to optimize for new buncher
  - Switched system would create the 50 ns pulses at a variable rate
  - Result – beam frequency at the target = repeat rate of switch

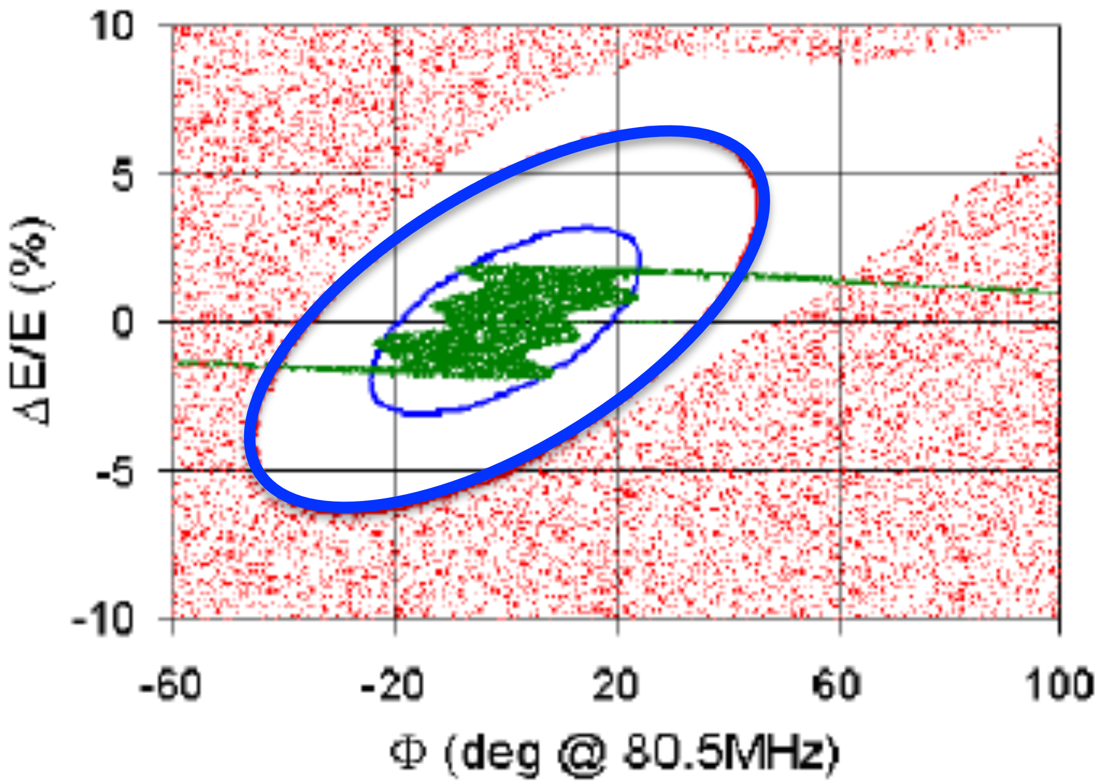
16.1 MHz buncher + 2 harmonics

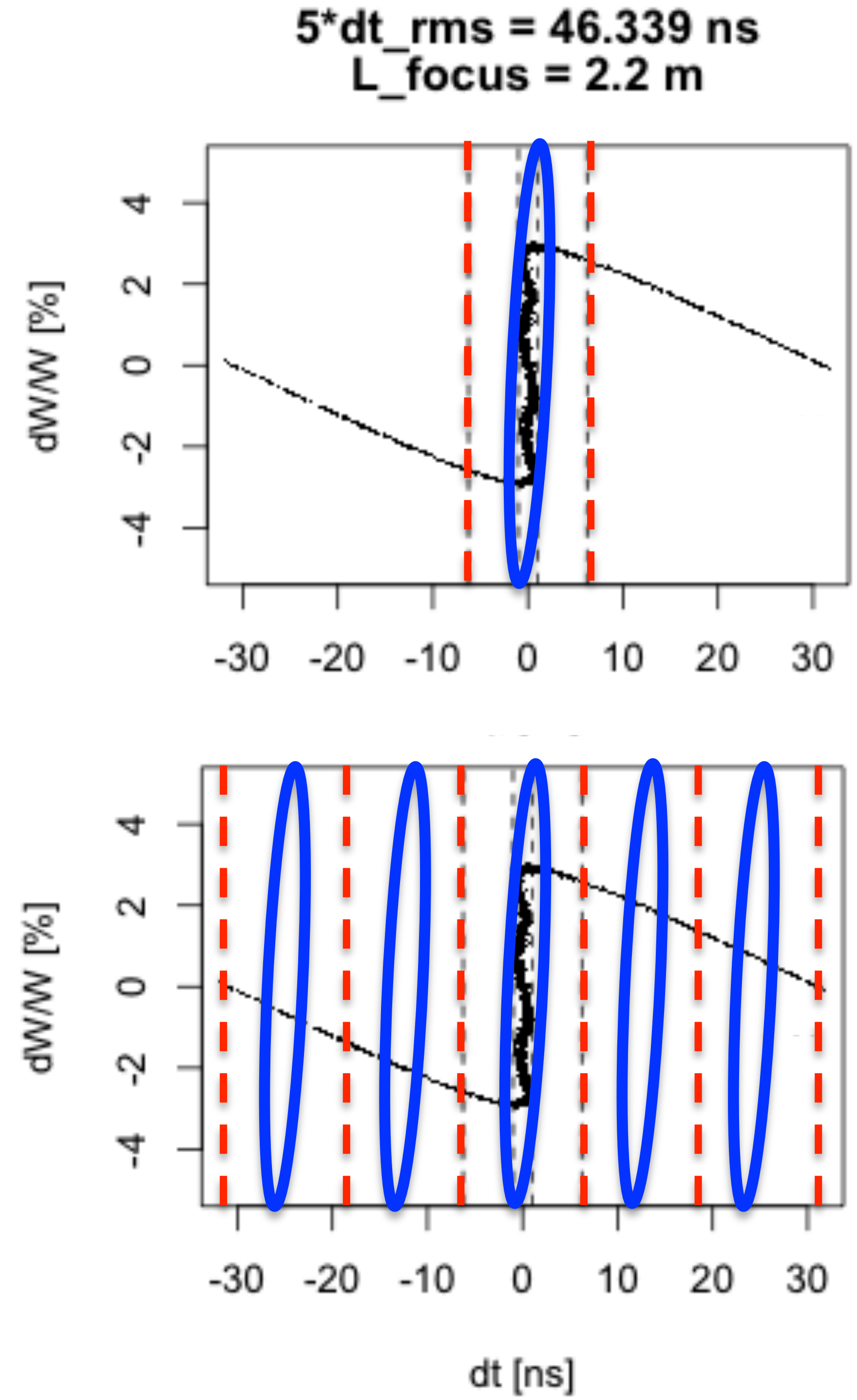


At entrance
to RFQ

16.1 MHz Bunches into RFQ

- If the distribution to the right is divided amongst 5 neighboring 16.1 MHz buckets, what particles in the "satellite" bunches survive through the RFQ?

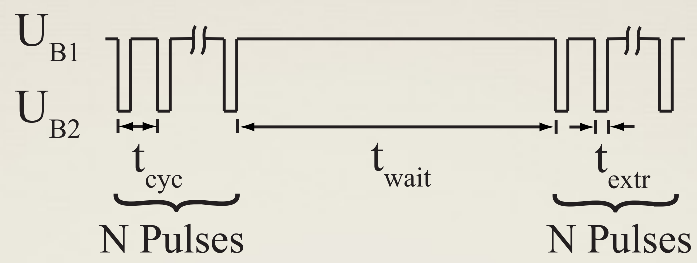




- Yet to perform a full analysis…

Bunching in EBIT

- Short time pulse extraction achieved in Dresden EBIT
- U. Kentsch *et al.*, Rev. Sci. Instrum. **81**, 02A507 (2010)



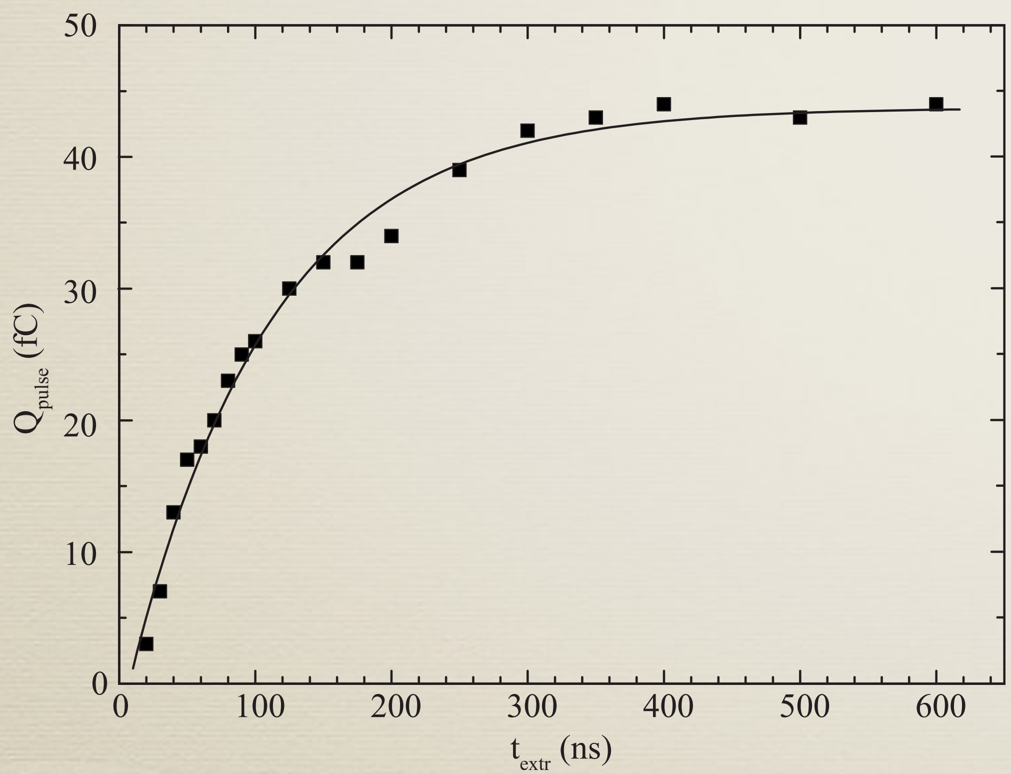


FIG. 3. Extracted ionic charges per Ar^{16+} pulse in dependence on the extraction time t_{extr} (U_0=4.0 kV, I_e=24 mA, t_{cyc}=100 μs, t_{wait}=1 s, p=3.1×10^{-9} mbar). The solid line is a guide to the eye.

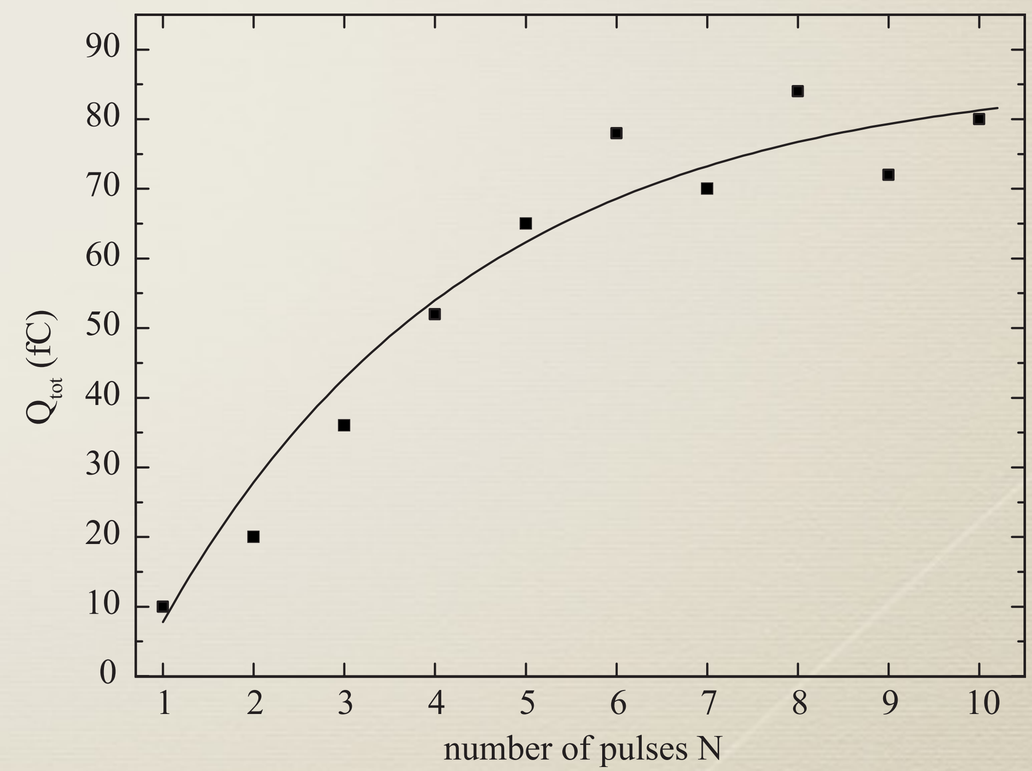
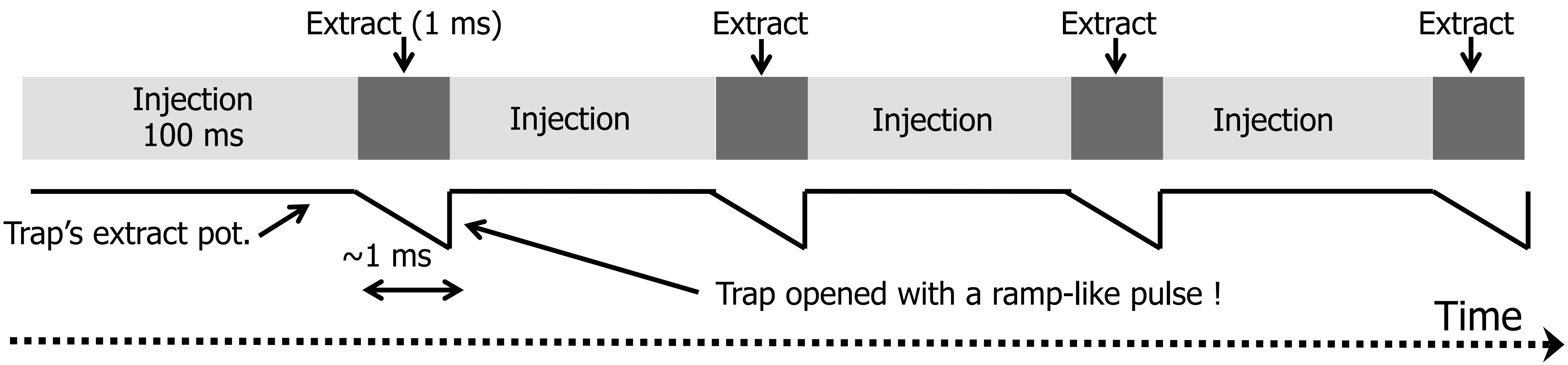


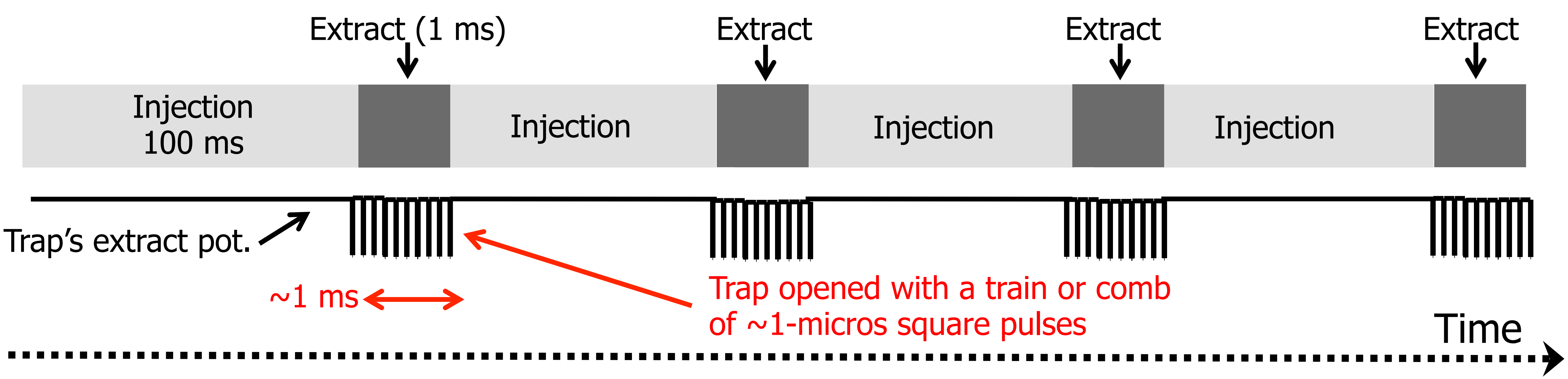
FIG. 4. Extracted ionic charge in dependence on the number of extracted ion pulses (U_0=4.0 kV, I_e=29 mA, t_{extr}=50 ns t_{cyc}=100 μs, t_{wait}=1 s, p=3×10^{-9} mbar). The solid line is a guide to the eye.

Two time structures being tested

The "RAMP"



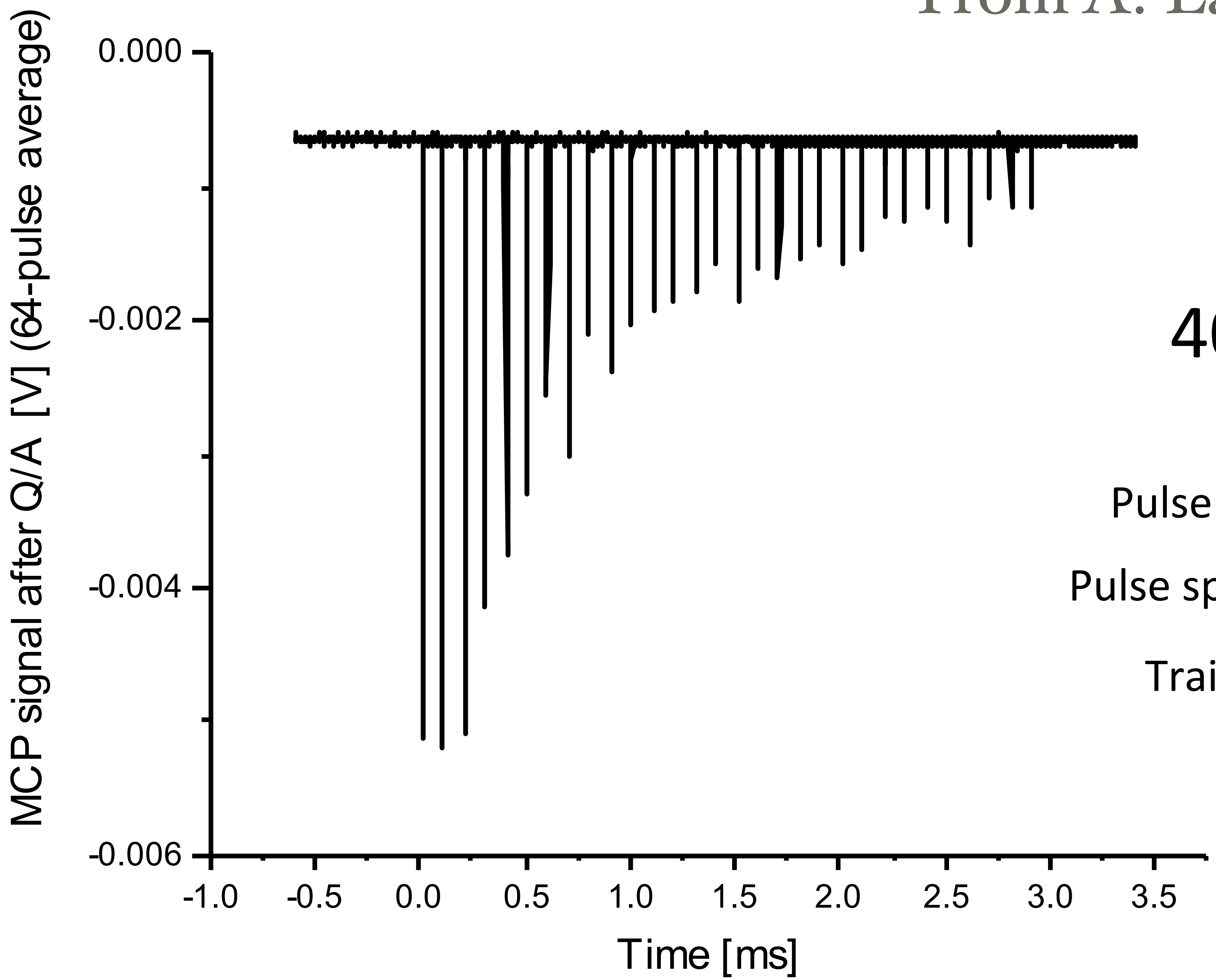
The "TRAIN"



From A. Lapierre

Extracted ion distribution with the trap open for 2 micros, with a train of 30 square pulses

From A. Lapierre



$^{40}Ar^{16+}$

Pulse width ~2 micros

Pulse spacing ~100 micros

Train width ~ 3 ms

Note: ca produce up to 100 pulses for a total pulse train width 10 ms