Reverse configurations in LISE^{++}

- Reverse technique
  - Coordinate systems
  - Methods
  - Application
- Creation of reverse configurations
  - Rays file generation for reverse configurations
  - Block and configuration benchmarks
  - Operations with secondary maps in Excel
- Reverse technique and detector resolution
  - S800
  - A1900
- Fission mechanism study with reverse configurations

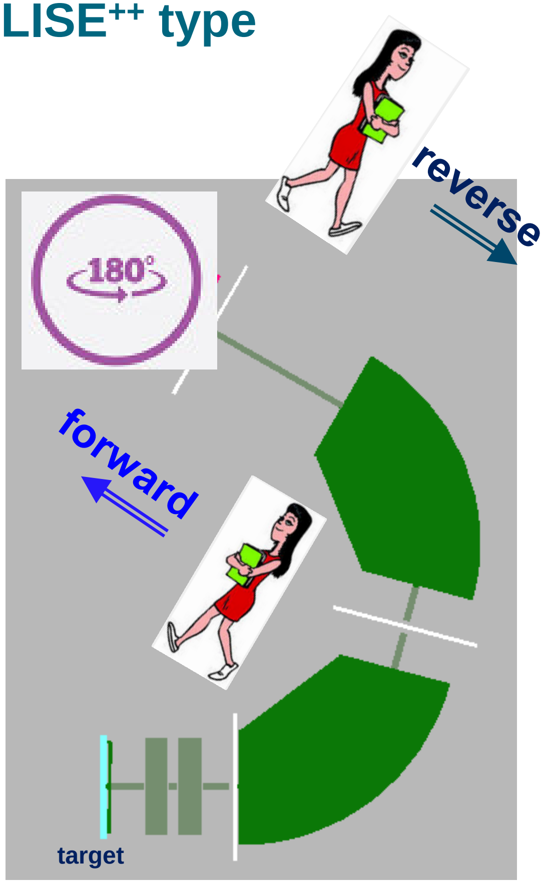
Reverse technique

- The Reverse technique is widely used in Spectrographs, so, to get a momentum vector at the S800 target, the COSY procedure "RR" based on measured X, A,Y, B values and the "global" spectrograph map reconstructs a trajectory (initial A,Y, B) with energy computing.
- The LISE^{++} reverse technique approach is assumed to applied for extended (elemental) configurations, that makes it more useful for beam dynamics and benchmarking.
- Therefore, local maps are used in reverse configurations, which can be calculated by LISE^{++}, or be entered by the user directly or linked to COSY maps (up to fifth order).

- There are two methods can be used in the LISE^{++} reverse technique:
  - ✓ LISE++ type → turn around & go forward
  - ✓ COSY type → go backwards

Reverse methods in LISE^{++}

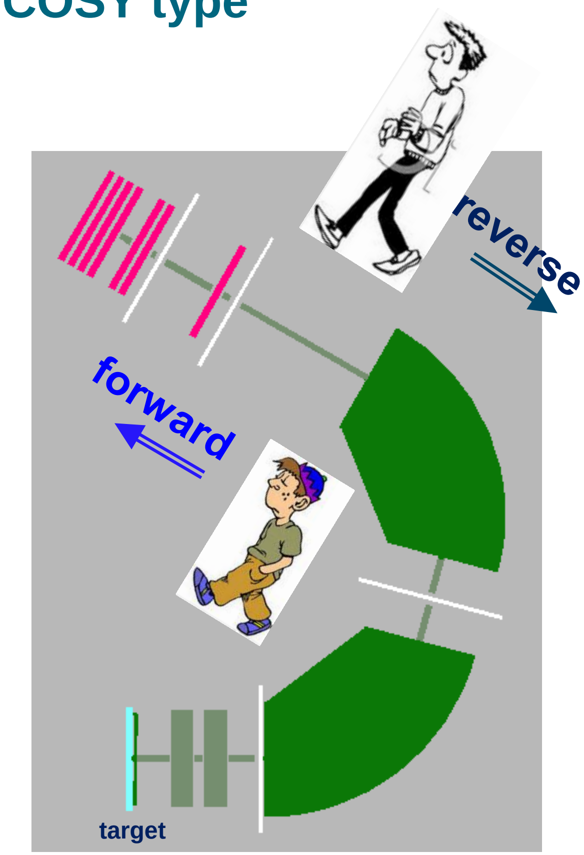
LISE^{++} type



turn around & go forward

- *The coordinate system is changed (x_n = -x, y'_n= -y_n, L_n= -L)*
- *Matrices are calculated by LISE^{++}*

COSY type



go backwards

- *The coordinate system is not changed*
- *COSY matrices are imported (linked)*
- *These maps are inverted from the "direct" maps by the COSY procedure "MI"*
- *Ideal case : invert matrices inside LISE*

Reverse technique application

- **Momentum vector after reaction in target** (for example standard S800 technique)
  - ➢ Reaction mechanism study
  - ➢ Beam spot
  - ➢ Angular acceptance vs emittance

- **Beam emittance measurement (X,A,Y,B,E)**
  - ➢ Study of correlations between beam emittance components ♈

- **Determination of location of new ions production**
  - ➢ BigRIPS case : production in the beam-dump

- **Benchmarks**♈ **based on LISE++ MC apparatus and spectrograph segmentation**
  - ➢ Beam dynamics visualization
  - ➢ Beam optics calculation verification
  - ➢ Experimental analysis and calibrations test

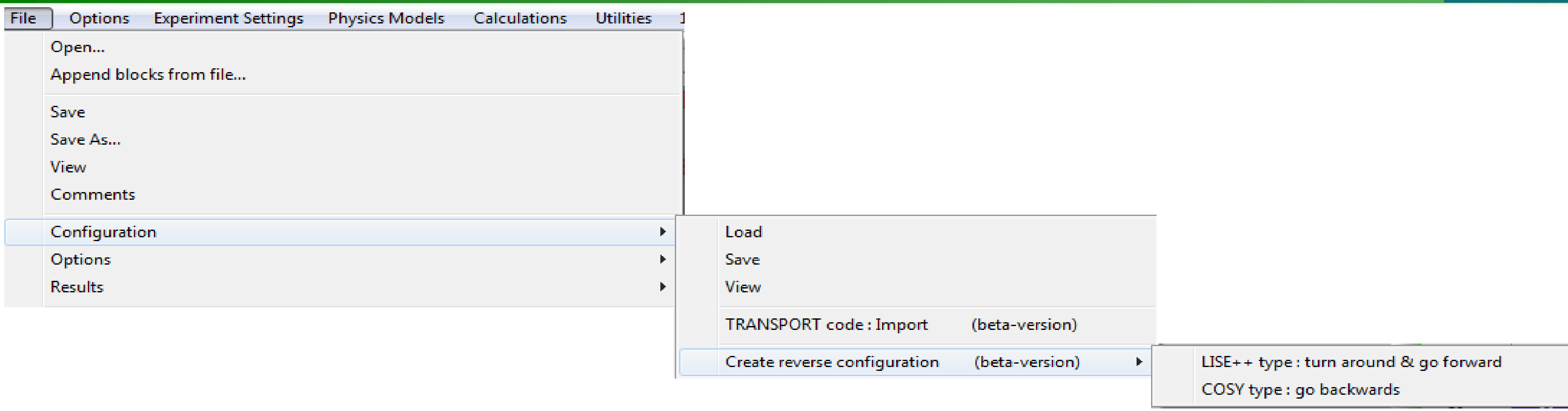
- **Experiment set-up feedback** ♉ **with LISE++**
  - ➢ Obtaining experimental information by detecting devices in some (or one) locations
  - ➢ Retracing up-stream (or down-stream) from detection locations based
  - ➢ Analysis, minimization

♈ will be demonstrated here

♉ in future

Creation of reverse configurations

Creation of reverse configuration in LISE^{++}



1. Blocks behind the stripper up to a last optic block (or Faraday cup) will be inversely located in a new file
2. The New Primary beam will be set to after the Setting Fragment in the direct configuration with energy corresponding to its energy in the last optical block of the direct configuration
3. New "tuning" dipole will be inserted behind the stripper with rigidity corresponding to the new primary beam energy
4. All materials will obtain corresponding negative thickness
5. Optical blocks with "element" properties:
   * LISE^{++} method : dispersive block bending & sextupole field signs will be changed, entrance and exit dipole faces will be swapped
   * COSY method : all standard drift blocks will be set to drift with beam-line properties, and their dx/dt and dy/dp signs will be changed; old links to map files will be destroyed
6. The separator scheme will be rotated on 180 degrees
7. Matrices of Optical blocks with the "Element" property in the case of the LISE^{++} method will be recalculated
8. The New file name will be based on old one with adding substring "_Lreverse" or "_Creverse" to the end

Note: Not all blocks can be used in reverse configurations: So no RF-blocks, FIT-constraints, Compensated dipole, Gas-filled separator

COSY-type reverse configuration

Courtesy of M.Portillo & D.Bazin

Example of COSY-file to create simultaneously
S800 direct and reverse 5th order maps to use in LISE++

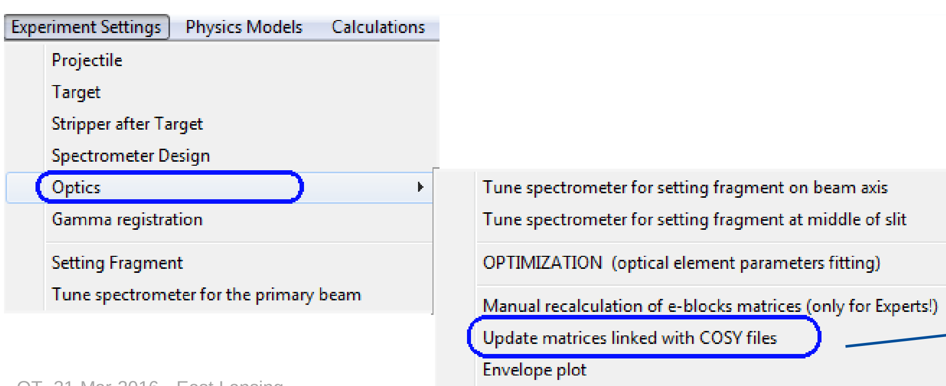
http://lise.nscl.msu.edu/doc/e12006/Br1/invmap_Br1.fox

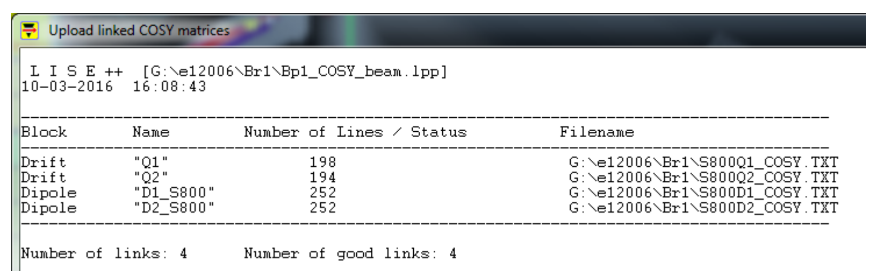
```
UM; "zeroing"
CB; rotation
FRINGED2 ;
DI RHOD2 ANGLED2 APERD2 EDGED2 0 0 0 ;          second dipole   {D2}
CB; rotation
PM_LISE 'S800D2_COSY.TXT' ;                      direct map

SM MAP1 ;     MI MAP1 MAPI 6 F_IER NO NV NM1 ;
UM; AM MAPI ;   PM_LISE 'I_S800D2_COSY.TXT' ;    inverse map
```

Important! Do not use “FR3.0” & “CB”. Use “FR2.5” for this purpose

All optical (except drift standard and rotation)
should be linked or manually entered



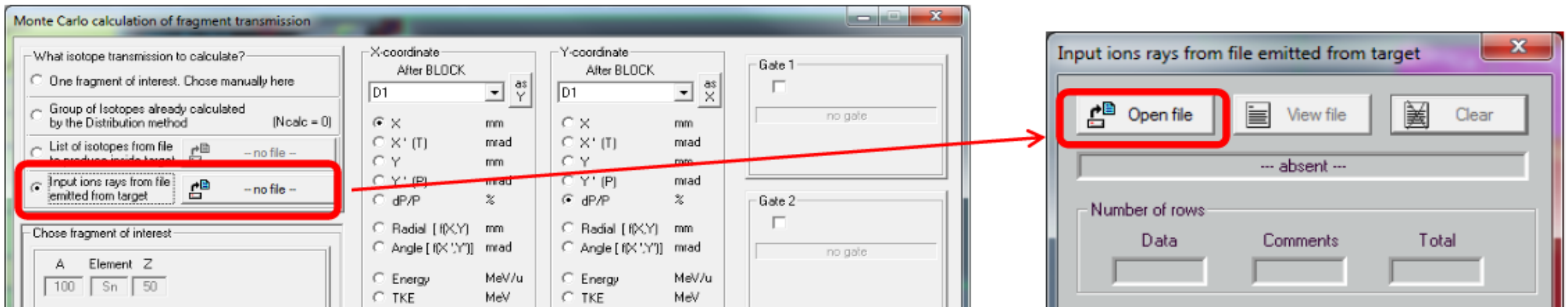


LISE++ Input ray file

http://lise.nscl.msu.edu/9_6/9_6_23.pdf#page=10

Input ions rays from file emitted from target in MC mode (1)

DJM's request



Data line structure

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	! 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	! Z	N	q	X	d(X)	X'	d(X')	Y	d(Y)	Y'	d(Y')	E	d(E)	t	d(t)
3	!			mm	mm	mrad	mrad	mm	mm	mrad	mrad	MeV/u	MeV/u	ns	ns
4	18	20	18	-0.549	1	-0.409	4	-1.521	0.8	-4.046	5	95.20	1	-0.891	2
5	18	23	18	-0.509	1	6.557	4	0.120	0.8	7.029	5	102.66	1	-0.463	2
6	16	19	16	-1.603	1	-1.041	4	-1.435	0.8	8.051	5	97.17	1	0.869	2
7	15	19	15	-2.177	1	4.244	4	1.317	0.8	-0.575	5	104.09	1	0.683	2
8	15	19	15	0.209	1	-2.225	4	1.561	0.8	1.710	5	98.53	1	0.004	2
9	14	15	14	2.412	1	-4.756	4	-1.051	0.8	0.530	5	102.42	1	-0.095	2
10	14	17	14	2.288	1	0.295	4	0.992	0.8	4.415	5	95.77	1	-0.173	2
11	14	15	14	1.495	1	1.112	4	0.580	0.8	-0.943	5	102.13	1	0.455	2
12	17	20	17	1.533	1	4.954	4	0.863	0.8	6.794	5	98.28	1	-0.404	2
13	16	17	16	2.462	1	-5.620	4	1.109	0.8	-1.494	5	104.95	1	0.424	2
14	13	15	13	1.185	1	-4.911	4	1.873	0.8	-1.027	5	99.03	1	-0.504	2
15	18	22	18	1.373	1	7.311	4	0.105	0.8	-9.834	5	98.95	1	0.191	2
16	16	19	16	0.710	1	5.501	4	-0.534	0.8	-6.920	5	98.37	1	-0.057	2

The Isotope list file is in ASCII format.
Comment string begin with "!" or ";"

The Columns can be separated by a Space, a Comma or a Tabulation. User can put comments also at the end of data line

At least 13 columns should be in the specified order.

Three first columns: "Z" , "N", "q", where Z is atomic number, N is number of neutrons, q is ionic charge

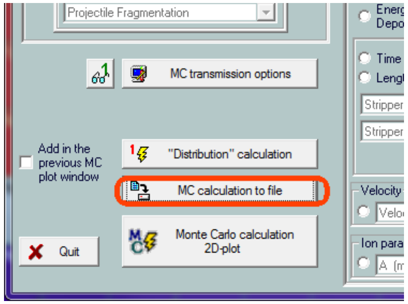
The next ten are X, dX, X', dX' , Y, dY,Y',dY', E, dE.
"d" means StDev. Set 0 if you do not want to use it.
X,Y in mm, X',Y' in mrad, E in MeV/u

Two addional columns can be used for time (t,dt) in ns

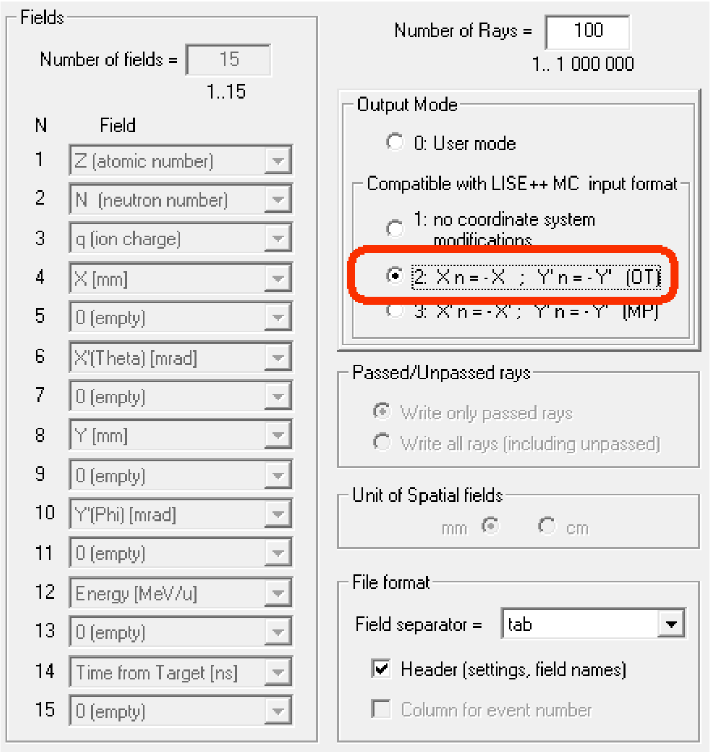
Rays file generation in LISE^{++} for reverse configurations

Besides experimental data the LISE^{++} rays can be used for benchmark purpose

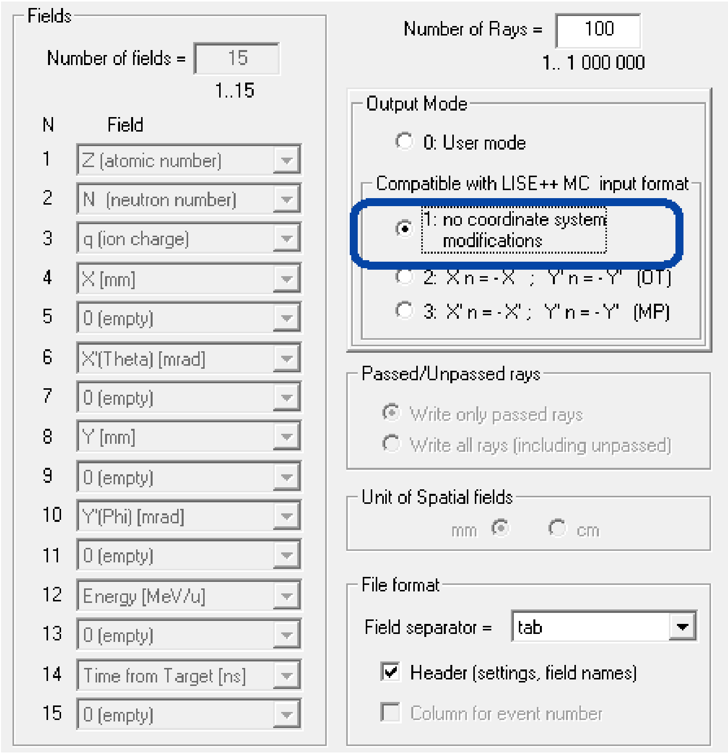
Monte Carlo dialog → **Monte Carlo Rays Generator dialog** →



LISE^{++} approach



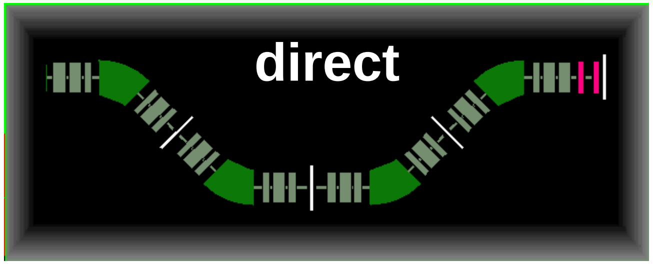
COSY approach

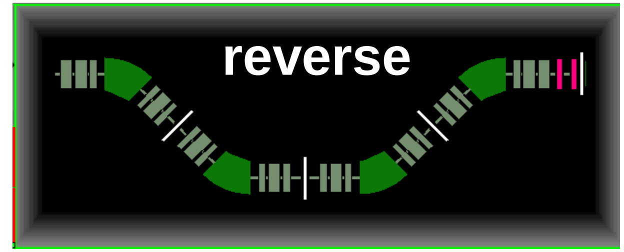


Block and configurations benchmarks

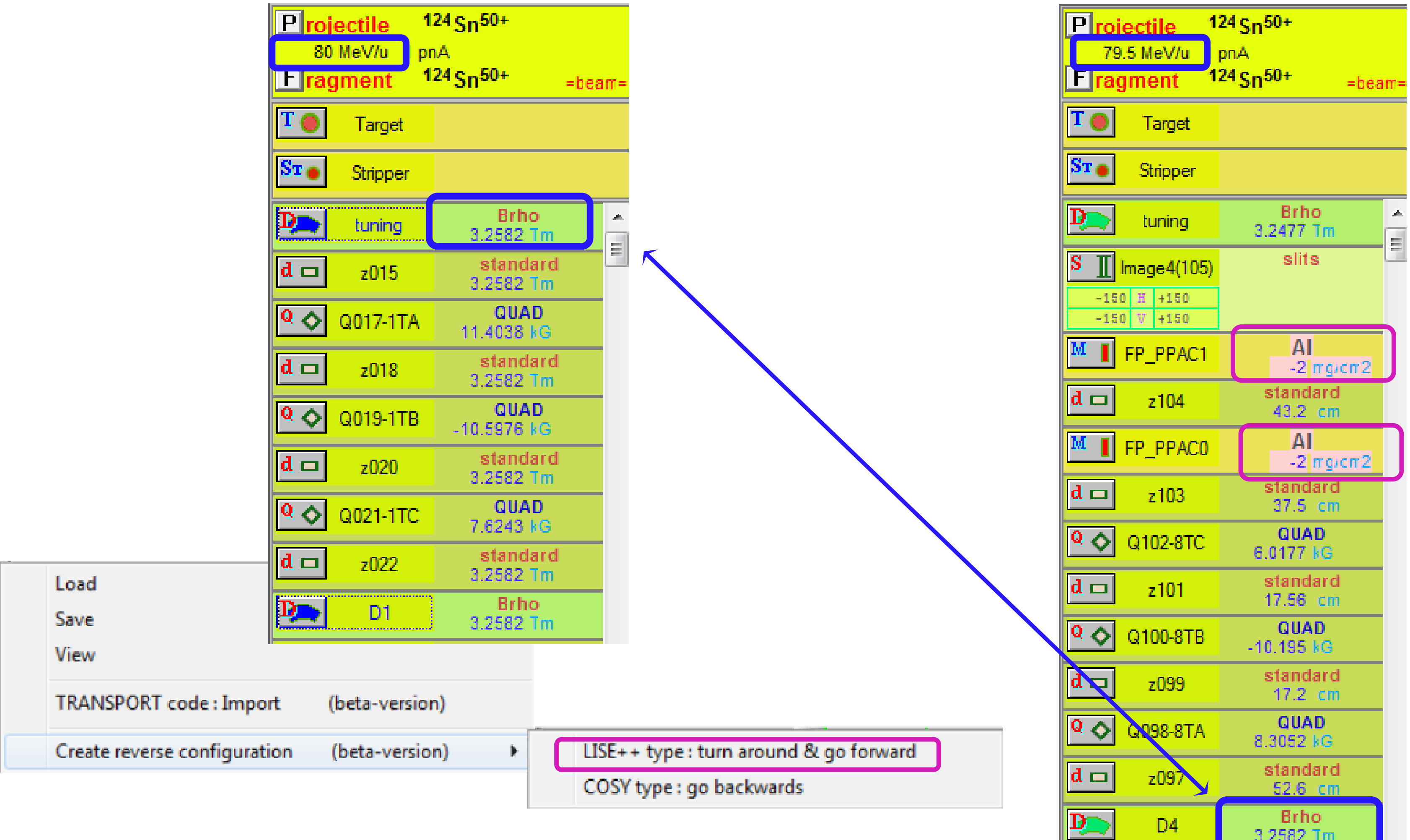
LISE-type reverse file creation

beam

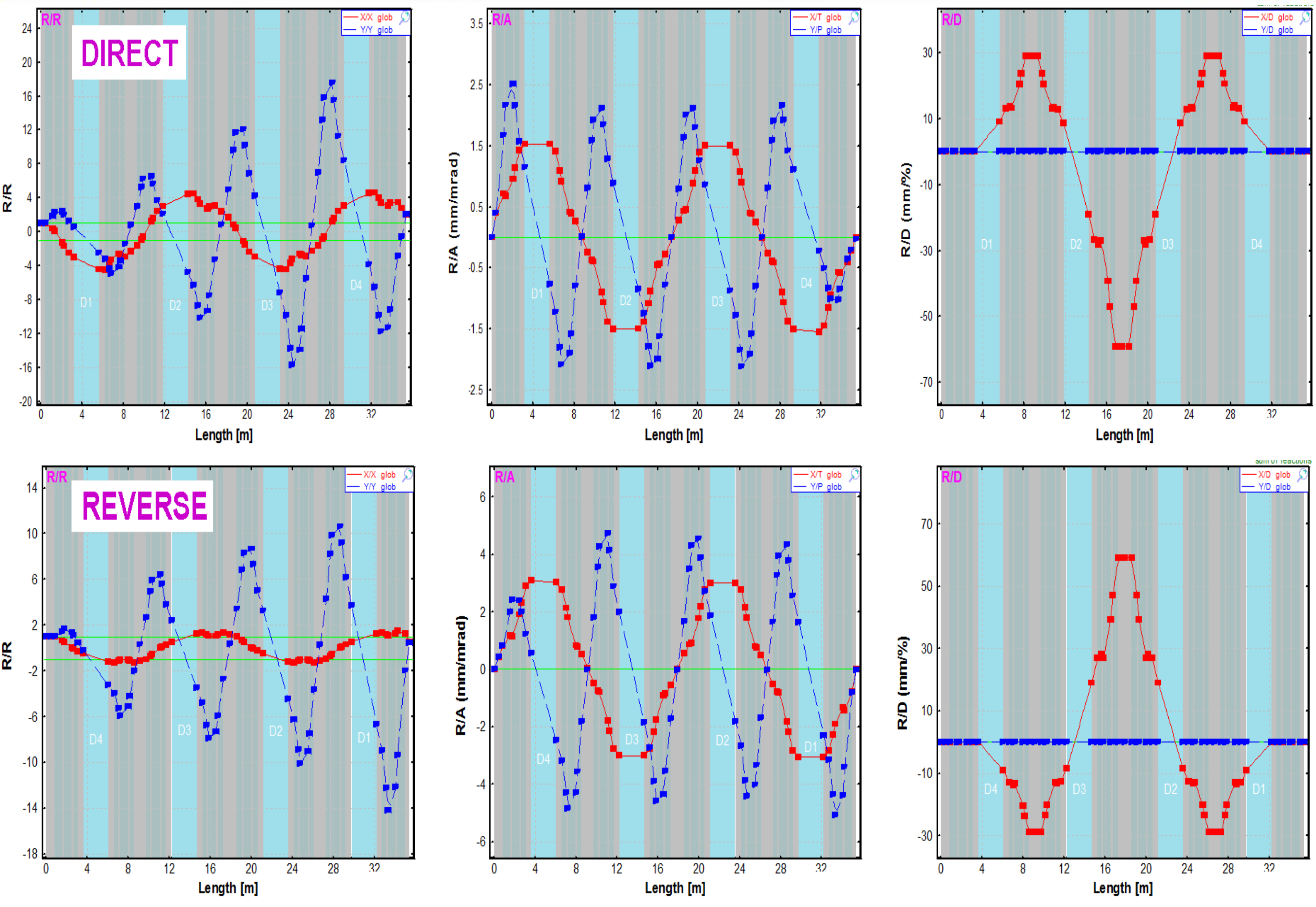




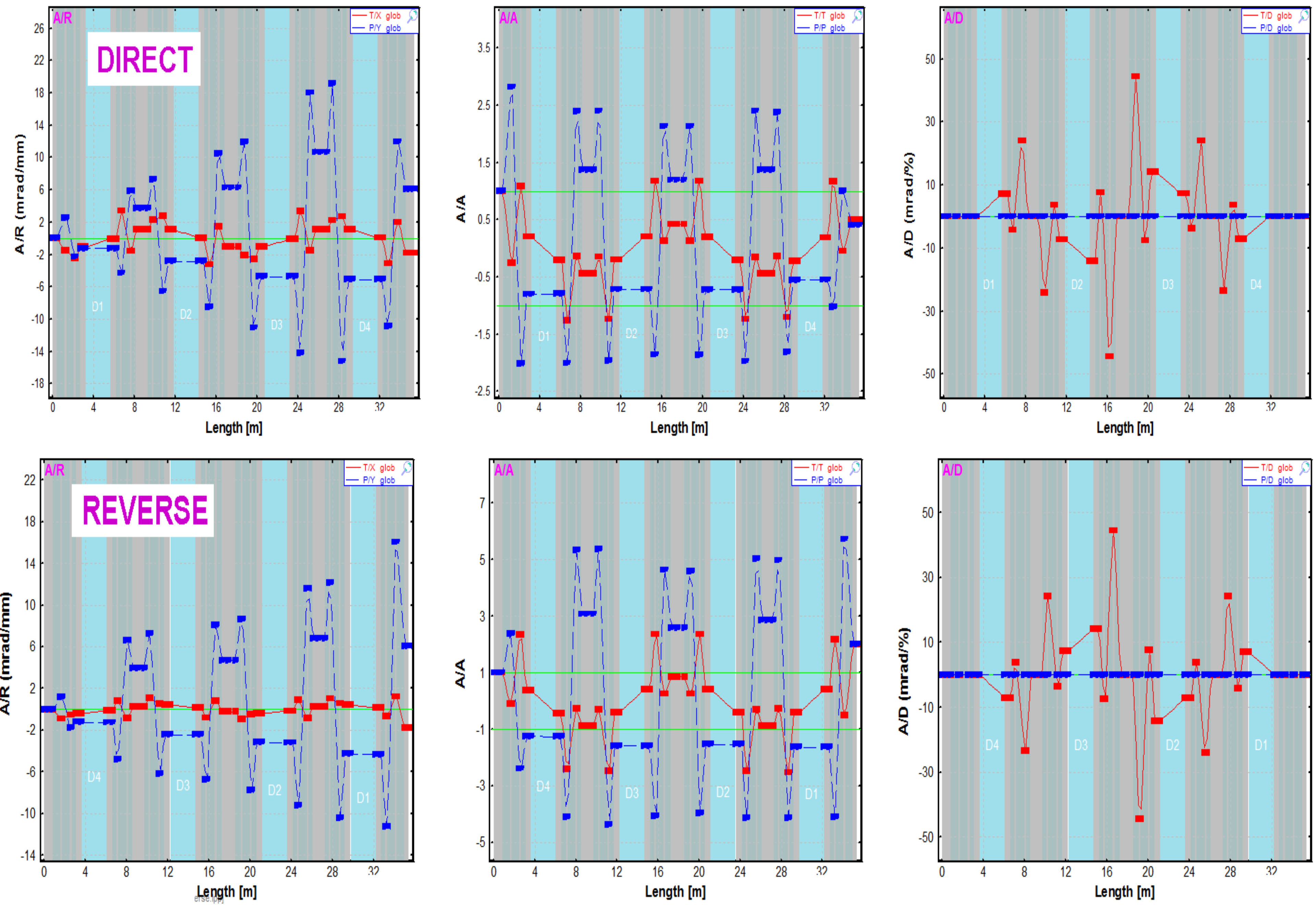
beam



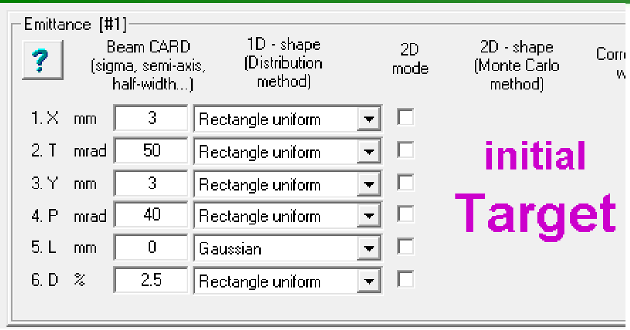
First order matrix elements: R/R, R/A, R/D

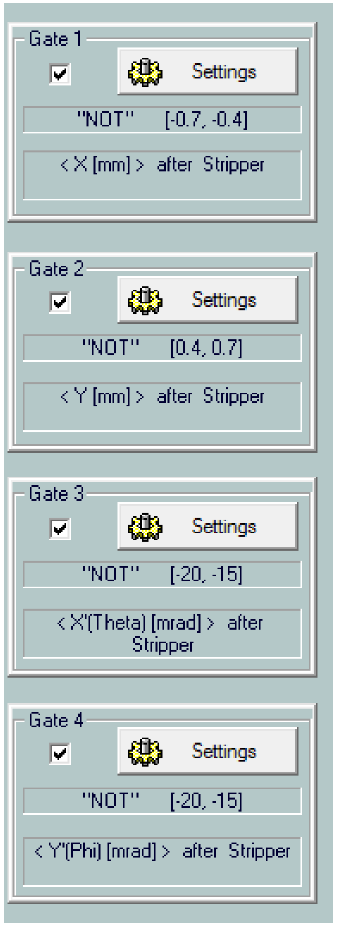


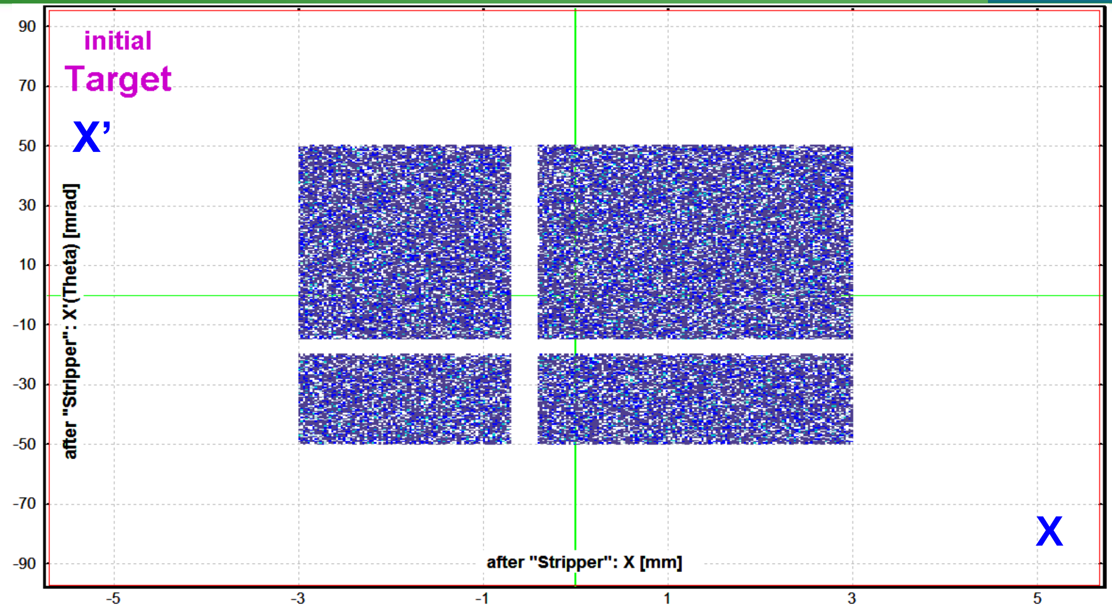
First order matrix elements: A/R, A/A, A/D

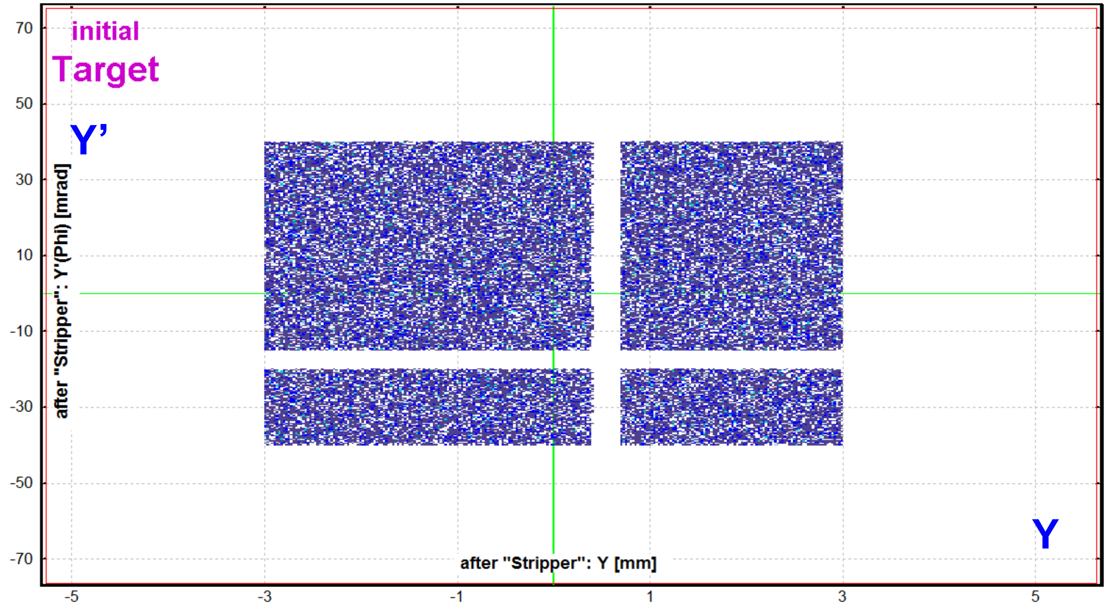


Initial emittance to generate an array of rays to benchmark







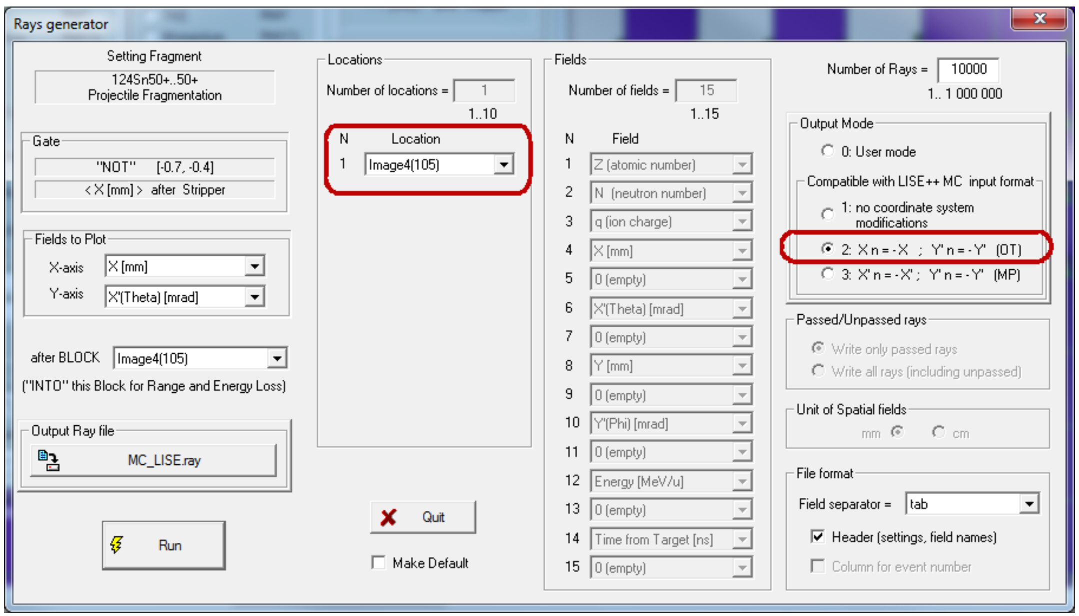


- **Pay attention to the optics order**

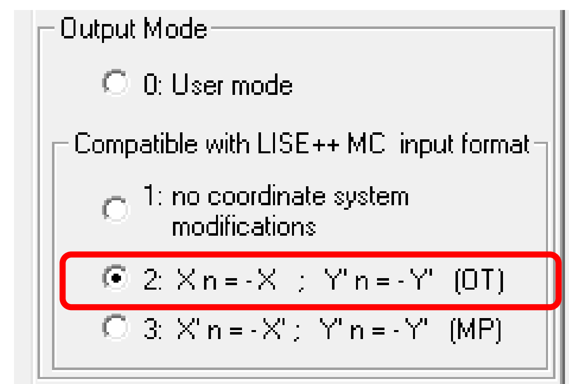
LISE-type reverse ray file creation

With reverse configurations it is possible to use

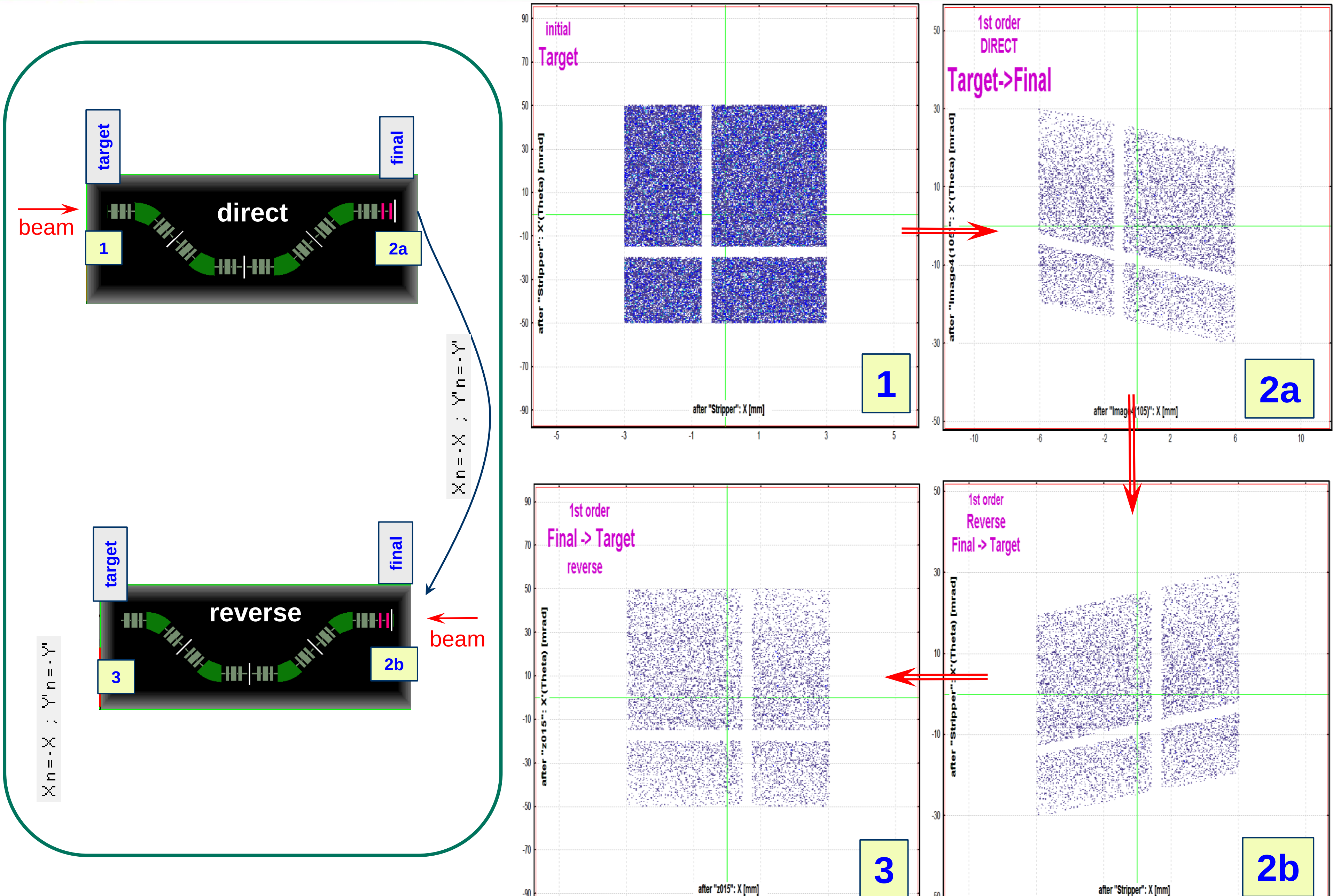
- experimental rays from the final point
- LISE^{++} rays generated for current reverse mode (LISE or COSY)



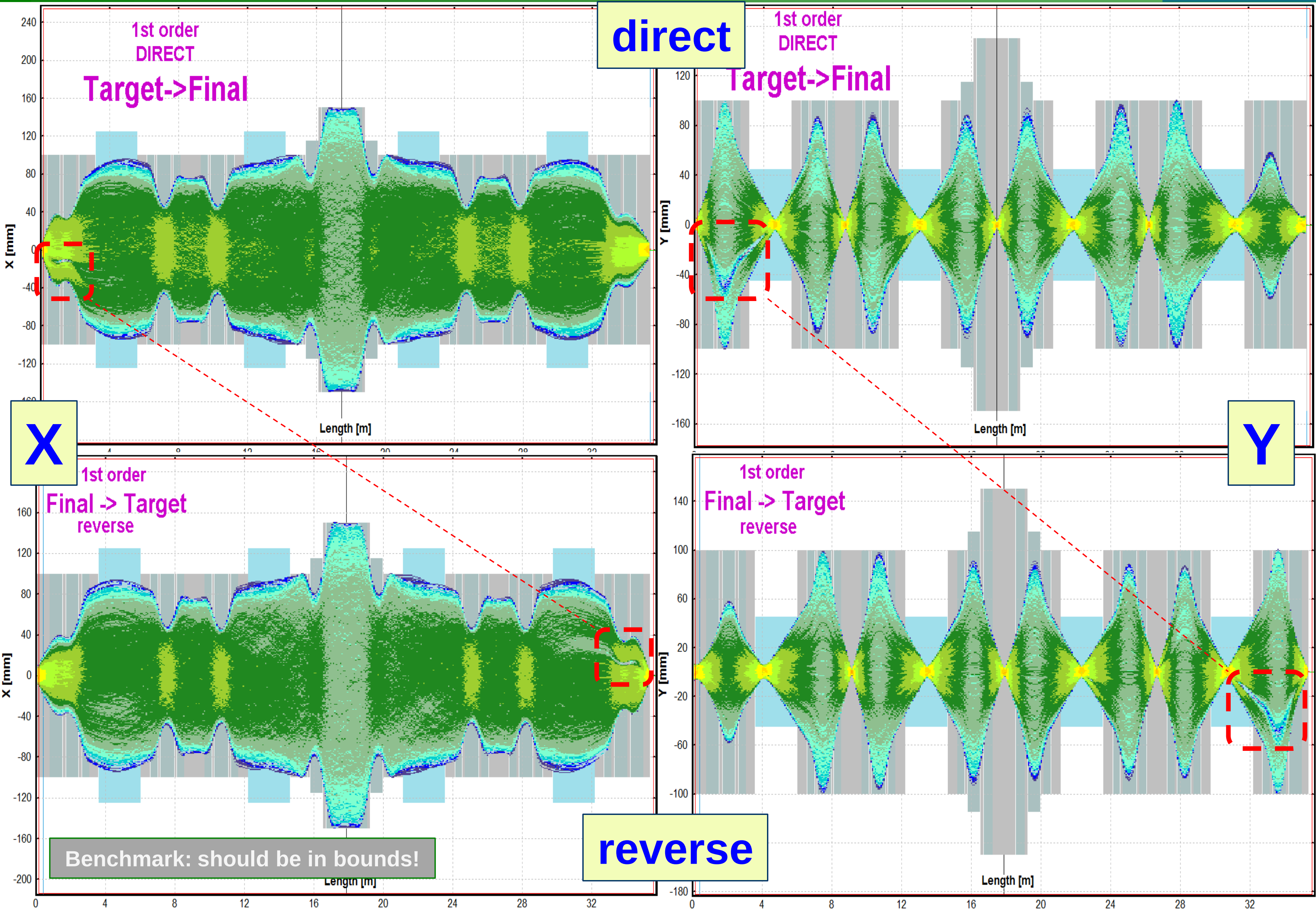
zoom



Benchmarking process of the reverse technique

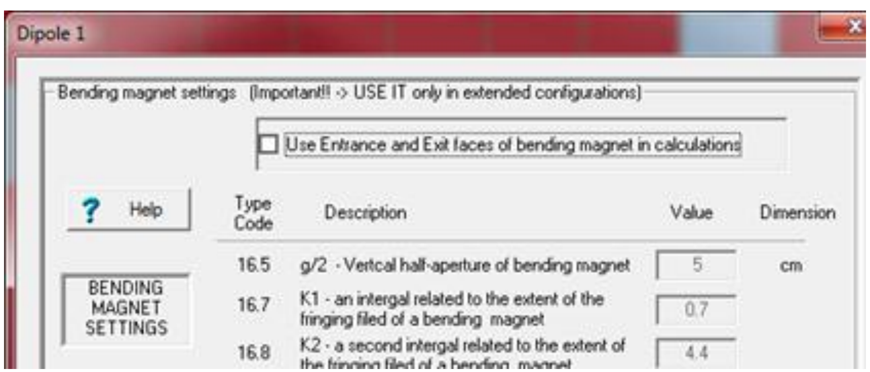


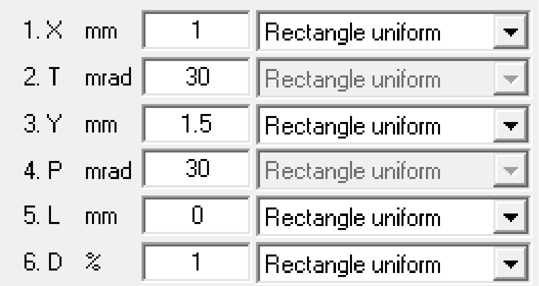
1st order optics Direct and Reverse envelopes : A1900 LISE-type

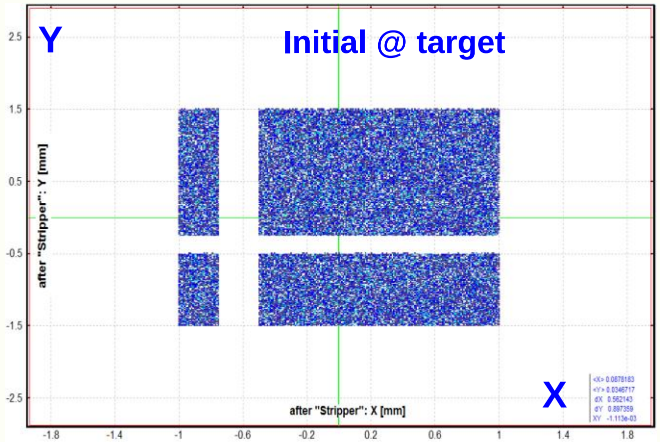


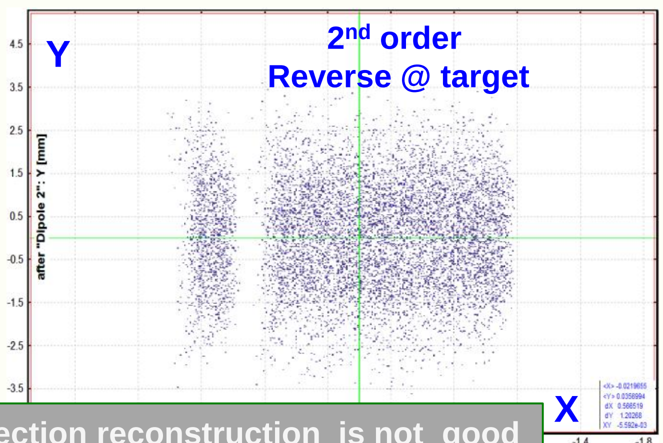
LISE-type Block Benchmarks

Block	1st order	2nd order
Drift	+	+
Quad (M)	+	+
Sextupole	+	+ with opposite field sign
Wien-fiter	+	
Dipole: no faces	+	+ very good, but not ideal
Dipole: empty faces	+	+ good
Dipole: S800	+	+/- fair



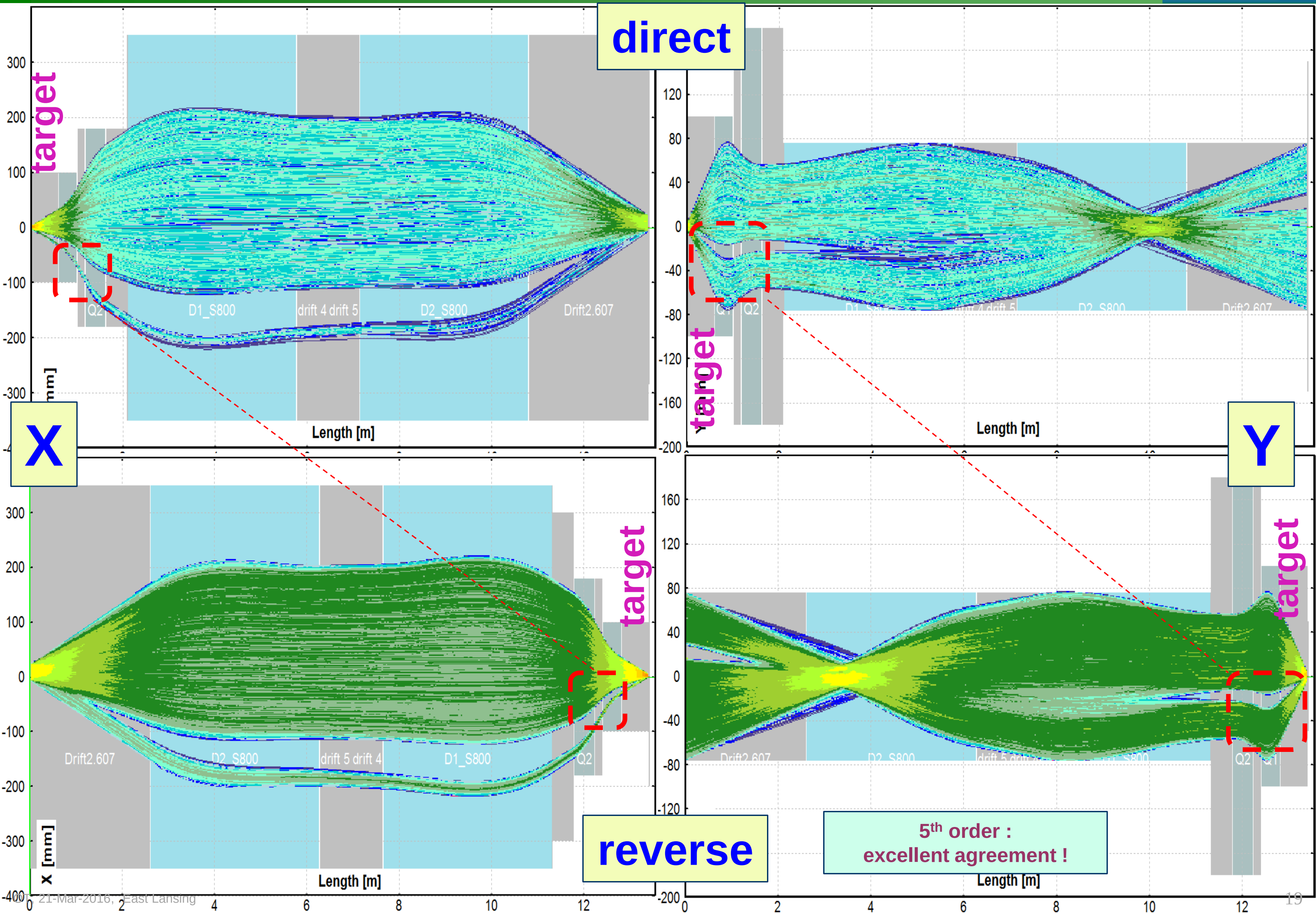






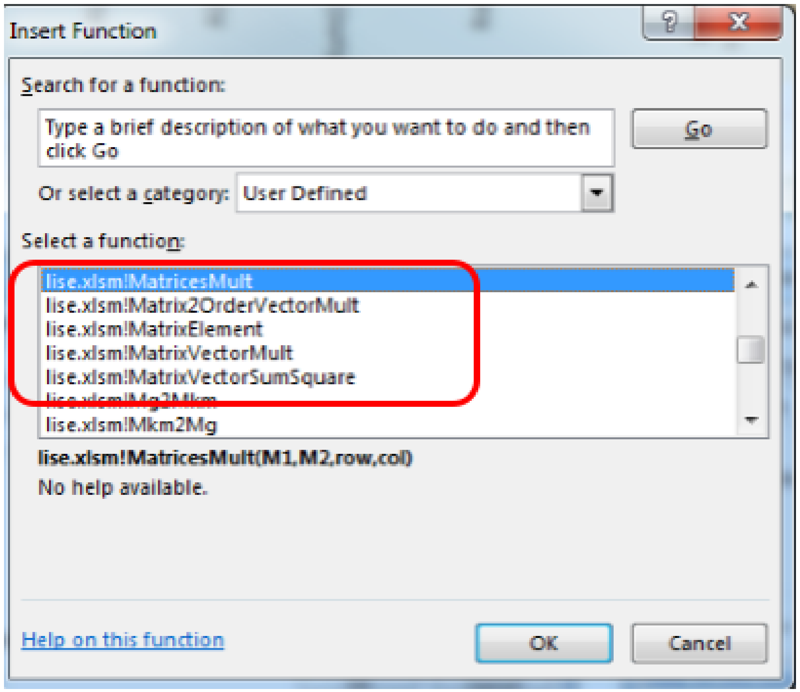
Y-direction reconstruction is not good

5th order optics Direct and Reverse envelopes : S800 COSY-type



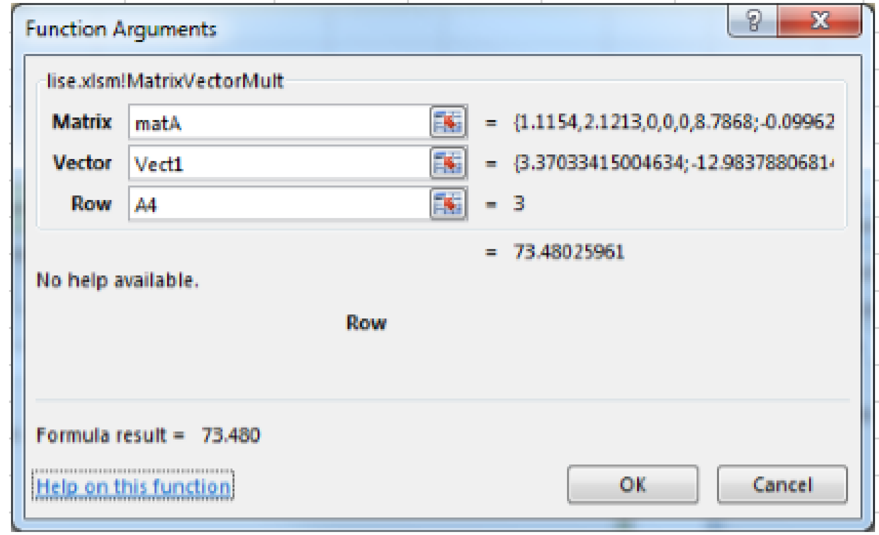
Operations with secondary maps in Excel

Lise.xlsm



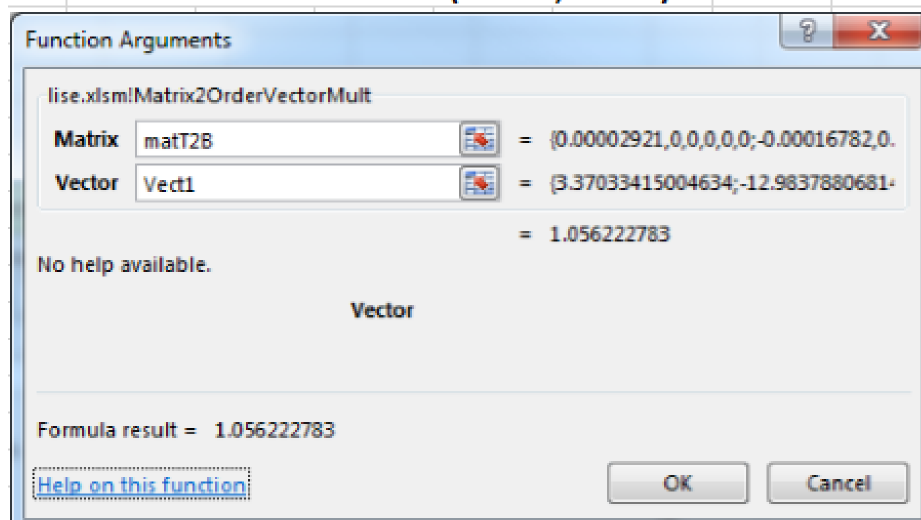
$y_{row} = A_1 * V * \delta_{row}$

MatrixVectMult (Matrix,Vector,Index)



$y_{row} = T_{2,row} * V$

Matrix2OrderVectorMult (Matrix,Vector)



Operations with secondary maps in Excel

http://lise.nscl.msu.edu/doc/e12006/Dipole_MatriceMulipl%20v3.xlsx

Where **A** is the set of 1st and 2nd order maps

$\mathbf{v_2 = A_{direct} * v_1}$

$\mathbf{v_{2R}} = \textit{rotated}\ \mathbf{(v_2)}$

$\mathbf{v_{3R} = A_{reverse} * v_{2R}}$

$\mathbf{v_3} = \textit{rotated}\ \mathbf{(v_{3R})}$

$\mathbf{A_{reverse}}$ is correct if $\mathbf{v_1 = v_3}$

Minimization of $\mathbf{| v_1 - v_3 |}$ varying $\mathbf{A_{reverse}}$

row	V1	D matr 2nd	V2 1st	V2 2nd	V2 Total	V2 Reverse	R matr 2nd	V3	V3 2nd	V3 Total	V3 Reverse	d
1	3.37	matT1	-42.981	-1.51E+00	-44.493	44.493	matT1B	-3.90	6.2E-01	-3.29	3.29	0.08
2	-12.98	matT2	-24.966	-7.56E-01	-25.722	-25.722	matT2B	-13.98	1.0E+00	-12.94	-12.94	0.05
3	-1.40	matT3	73.480	-4.65E-01	73.015	73.015	matT3B	-1.26	-1.1E-01	-1.37	-1.37	0.03
4	31.53	matT4	32.352	-2.60E-01	32.092	-32.092	matT4B	-31.30	6.4E-01	-30.66	30.66	0.88
5	-41.75	matT5	-28.161	-1.25E-02	-28.174	28.174	matT5B	42.17	-6.3E-01	41.54	-41.54	0.21
6	-2.18	matT6	-2.185	0.00E+00	-2.185	-2.185	matT6B	-2.18	0.0E+00	-2.18	-2.18	0.00
												1.24
	initial Vector	pointer to direct A2i matrix	A1*V1	A2i*V1	Sum(1st+2nd)	Reverse	pointer to reverse A2i matrix	A1R*V2R	A2iR*V2R	Sum(1st+2nd)	Reverse	| V1-V3R |

Dipole with faces

MICHIGAN STATE UNIVERSITY LISE++

http://lise.nscl.msu.edu/doc/e12006/Dipole_MatriceMulipl%20v3.xlsx

Direct 1st & 2nd order maps

A	D1_S800	Matrices:	LOCAL		
1.1154	2.1213	0	0	0	8.7868
-0.09962	0.70711	0	0	0	7.0711
0	0	0.57914	2.3562	0	0
0	0	-0.17411	1.0183	0	0
-0.87621	-0.87868	0	0	1	-2.3487
0	0	0	0	0	1

transport format [mm-mrad]

Direct

T1	-1.49E-05					
	7.95E-04	3.11E-04				
			8.99E-05			
			-5.50E-04	-1.36E-03		
	2.11E-03	6.21E-03				-7.50E-02
T2						
	1.05E-05	-3.54E-04				
			-2.59E-05			
			-1.54E-05	-3.54E-04		
	9.96E-04					-7.07E-02
T3						
	-4.54E-05	-1.20E-03				
	6.14E-04	8.79E-04				
			4.12E-03	2.35E-03		

Reversed 1st & 2nd order maps used in calculations, and varied in the minimization

Ab	REVERSE BENDING MATRIX				
0.70711	2.1213	0	0	0	-8.7868
-0.09962	1.1154	0	0	0	-8.7621
0	0	1.0183	2.3562	0	0
0	0	-0.17411	0.57914	0	0
0.70711	0.87868	0	0	1	-2.3487
0	0	0	0	0	1

Reverse (fitted)

T1B	1.11E-04					
	-4.17E-04	-6.07E-05				
			1.04E-04			
			5.20E-04	3.94E-04		
	4.65E-03	5.18E-03				7.93E-02
T2B	2.92E-05					
	-1.68E-04	7.90E-05				
			2.73E-05			
			8.93E-05	6.41E-04		
	2.58E-03	-1.02E-03				9.43E-02
T3B						
	-8.41E-05	1.03E-03				
	4.46E-05	2.42E-03				
			1.83E-05	2.35E-03		

Opposite signs

Opposite signs

9 random initial vectors compared with their reversed images

delta's — *9 random beam vectors*

	v1	v2	v3	v4	v5	v6	v7	v8	v9	sum
1	0.08	0.02	0.04	0.12	0.01	0.03	0.03	0.00	0.22	0.54
2	0.05	0.16	0.18	0.02	0.14	0.03	0.03	0.23	0.16	0.98
3	0.03	0.23	0.00	0.21	0.18	0.03	0.05	0.11	0.02	0.85
4	0.88	0.21	0.25	0.23	0.43	0.03	0.07	0.00	0.03	*2.13*
5	0.21	0.33	0.85	0.25	0.13	0.00	0.04	1.06	0.93	*3.81*
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum	1.24	0.95	1.32	0.82	0.88	0.12	0.23	1.40	1.36	**8.32**

minimized value

reverse initial from LISE

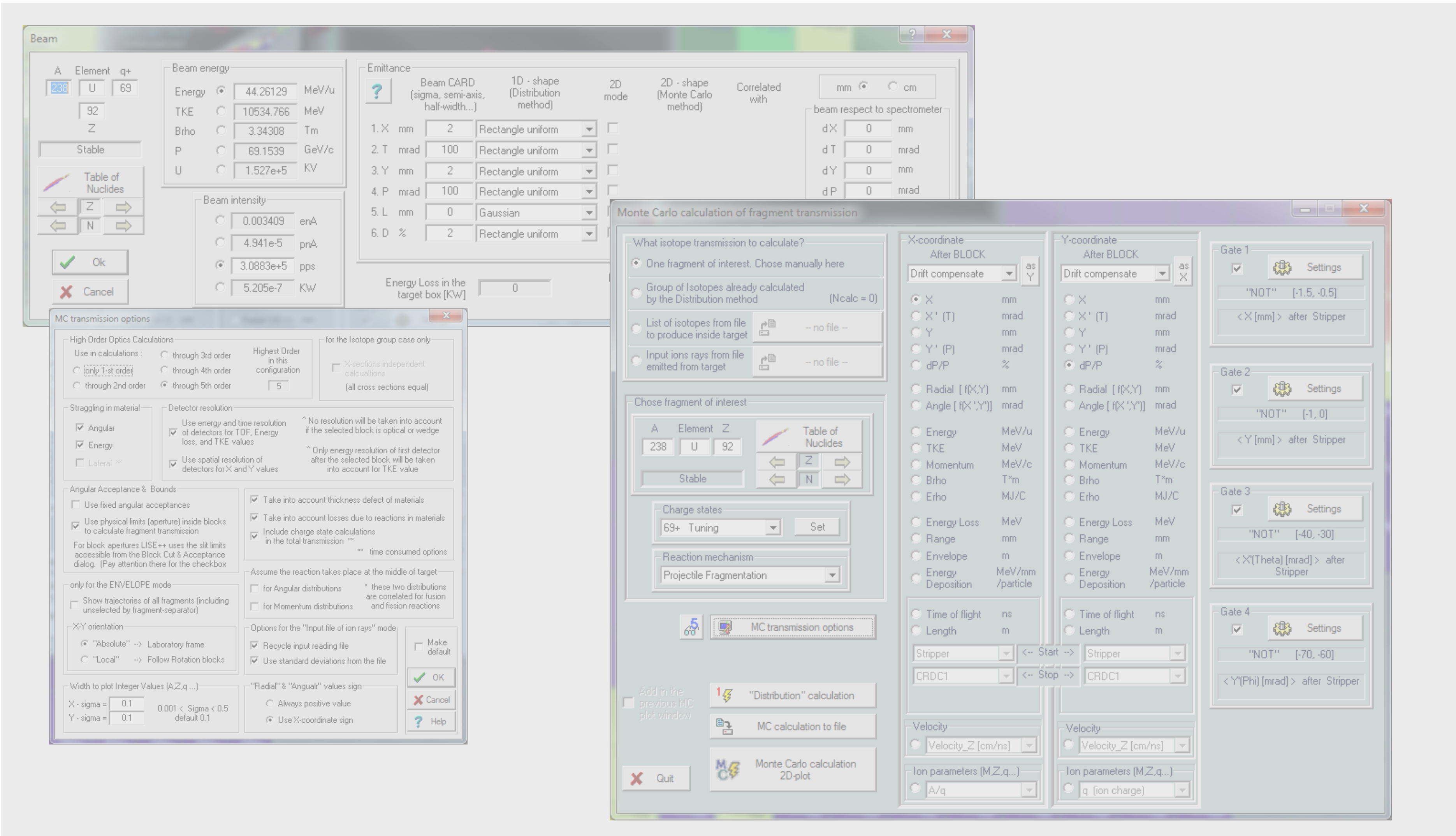
T1ir	1.11E-04					
	-4.17E-04	-6.07E-05				
			-1.04E-04			
			-5.20E-04	-7.94E-04		
	4.65E-03	5.18E-03				7.93E-02
T2ir	2.92E-05					
	-1.68E-04	7.90E-05				
			-2.73E-05			
			8.93E-05	6.41E-04		
	2.58E-03	-1.02E-03				9.43E-02
T3ir						
	-8.41E-05	-1.03E-03				
	-8.92E-04	-1.43E-03				
			1.83E-05	2.35E-03		

Reversed 2nd order maps calculated by LISE++

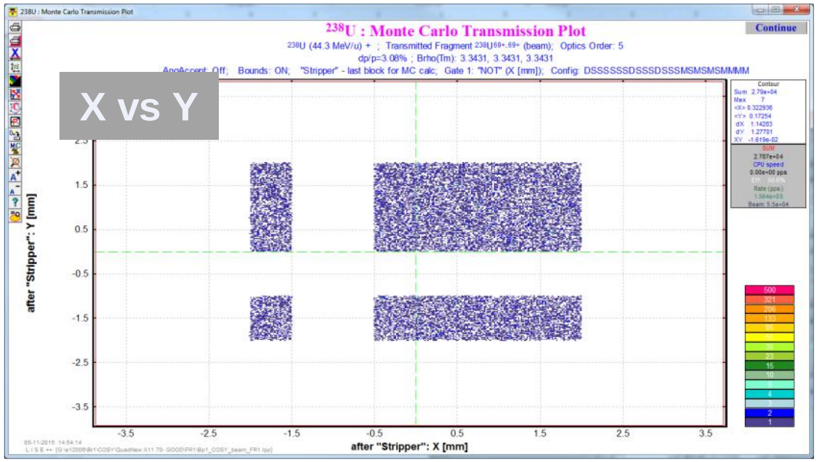
Reverse technique and detector resolution: S800

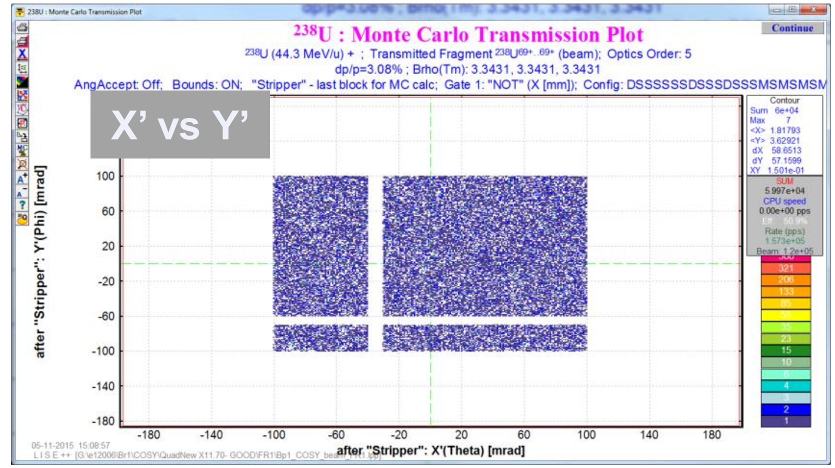
S800 reverse simulation with detector resolution and optics

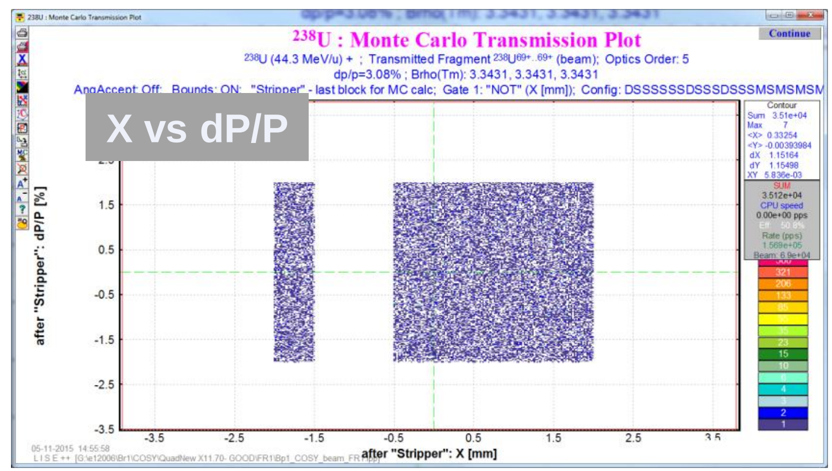
http://lise.nscl.msu.edu/doc/e12006/S800_reverse_resolution.pdf



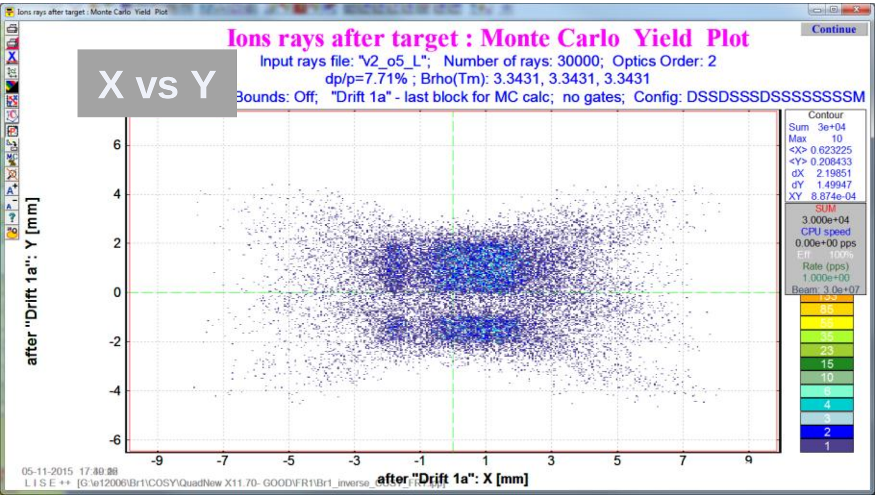
Initial @ S800 Target

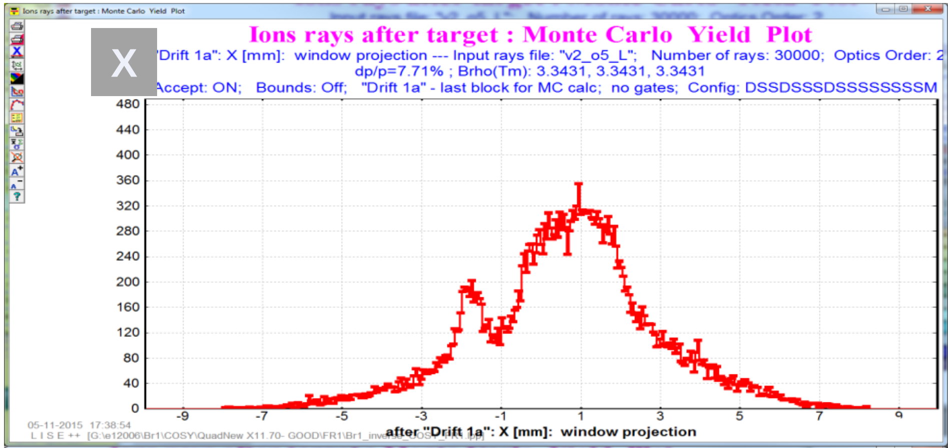


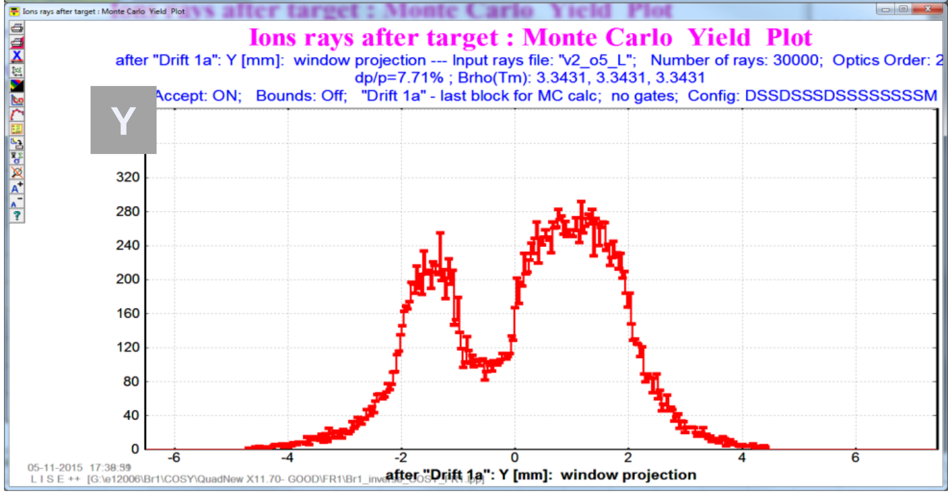




Simulation with detector resolution v.2 (order 5→2)







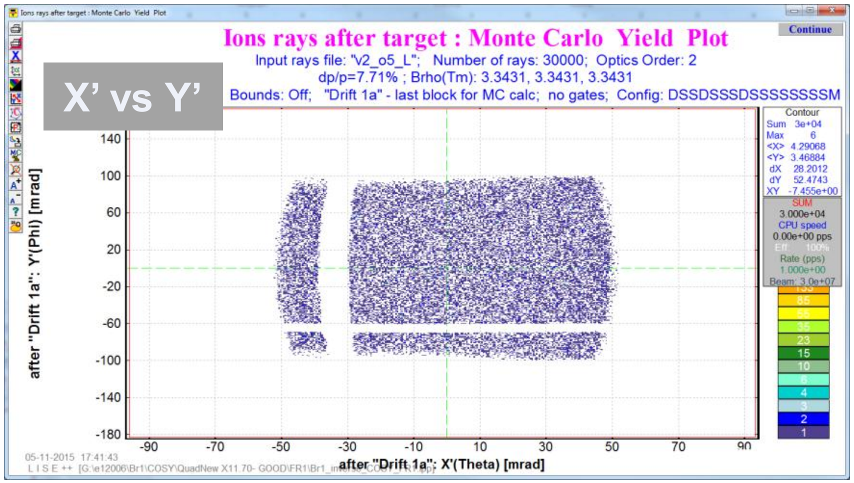
Case 2-2

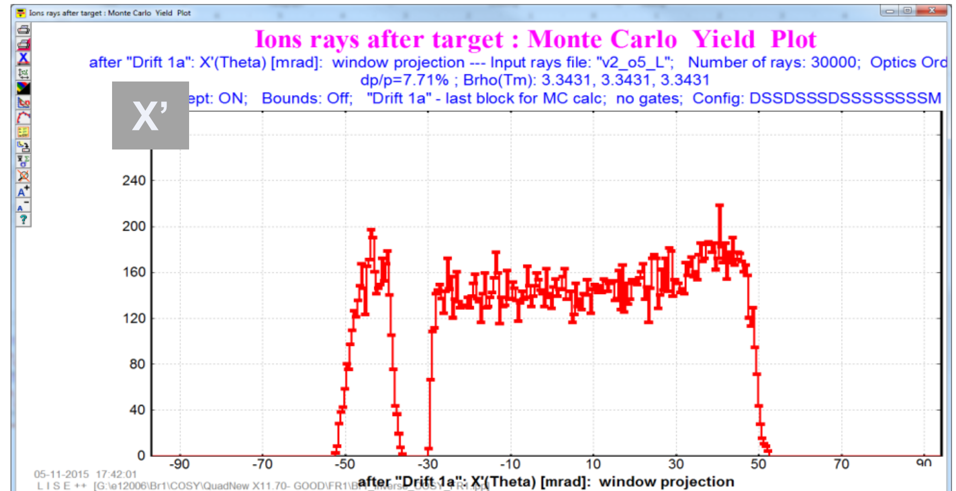
Reverse @ Target

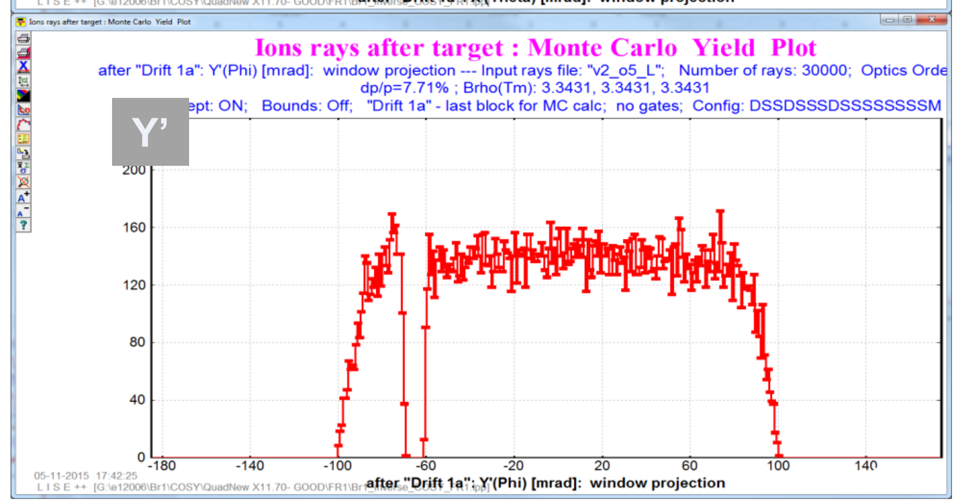
2nd order (5->2)

With Ideal detector resolution

Fair..





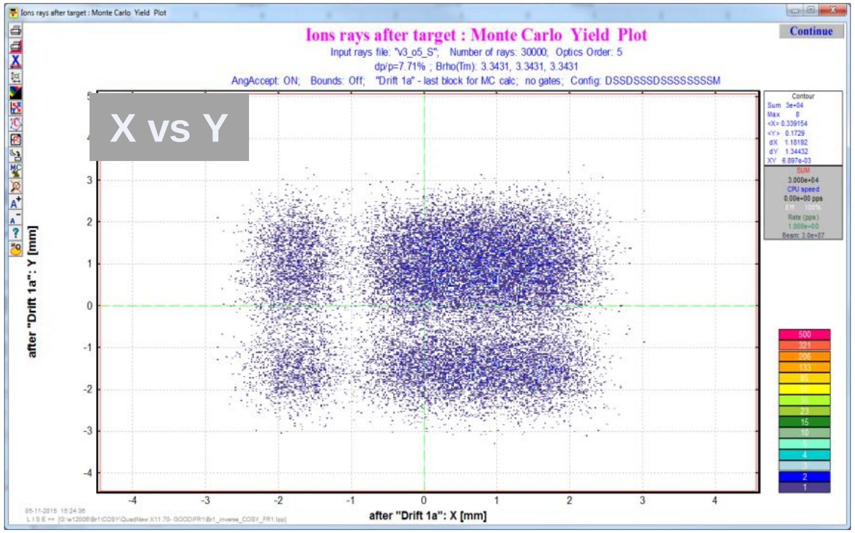


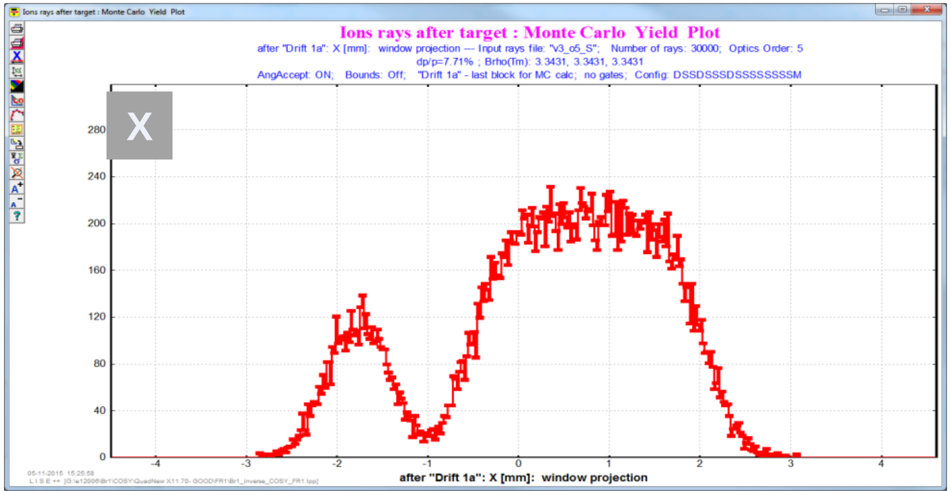
Case 2-2

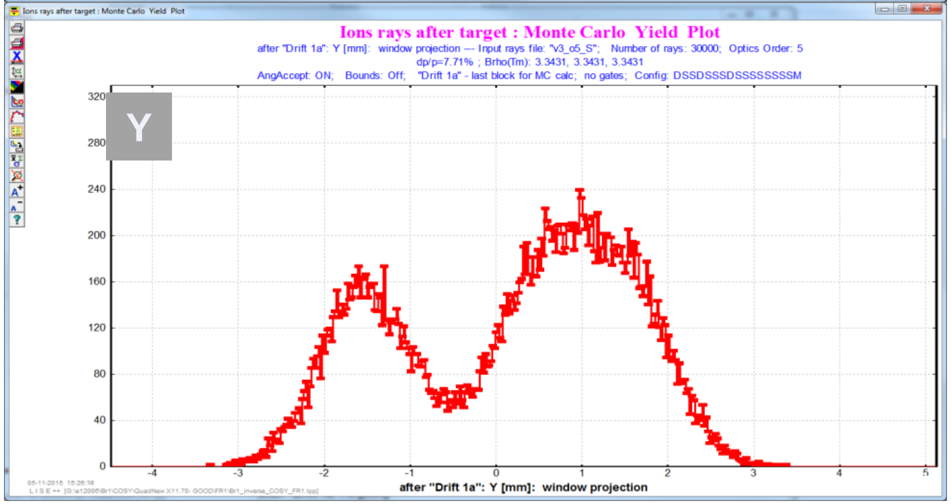
Reverse @ Target
2nd order (5->2)
Ideal resolution

Good!

Simulation with detector resolution v.3 (order 5→5 & nonzero resolution)







Case 3

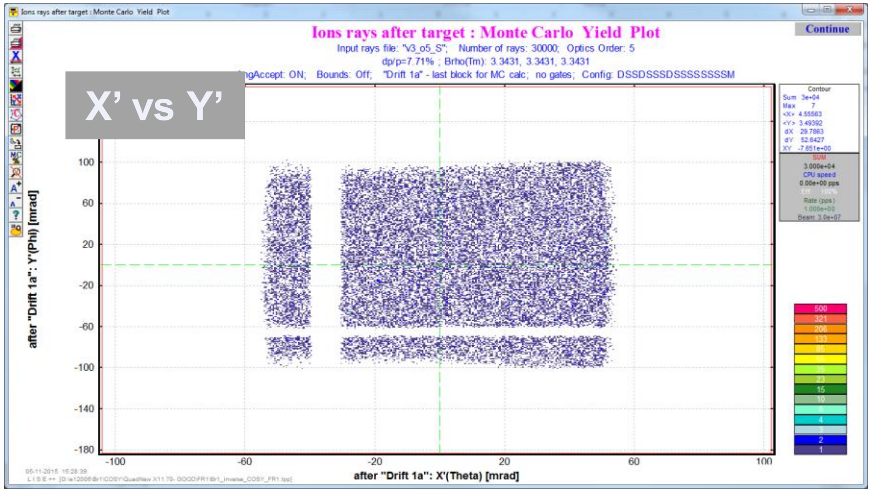
Reverse @ Target

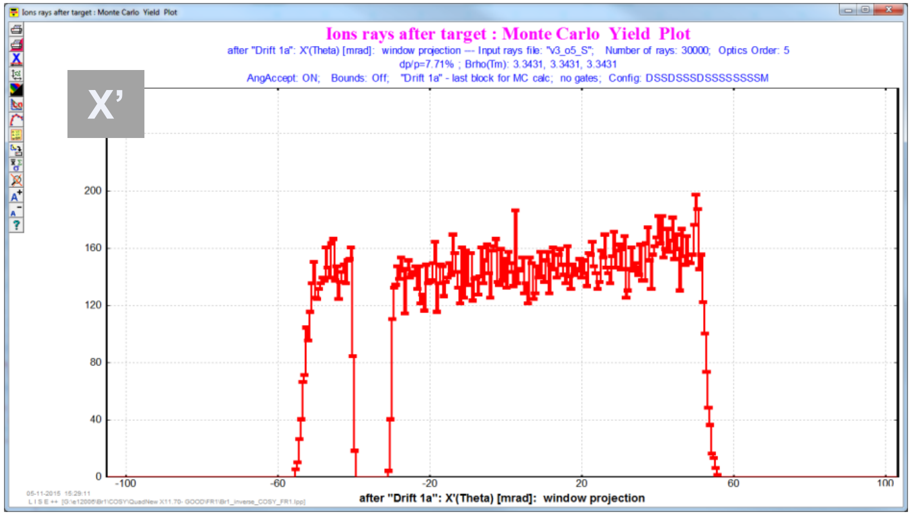
5th order (5->5)

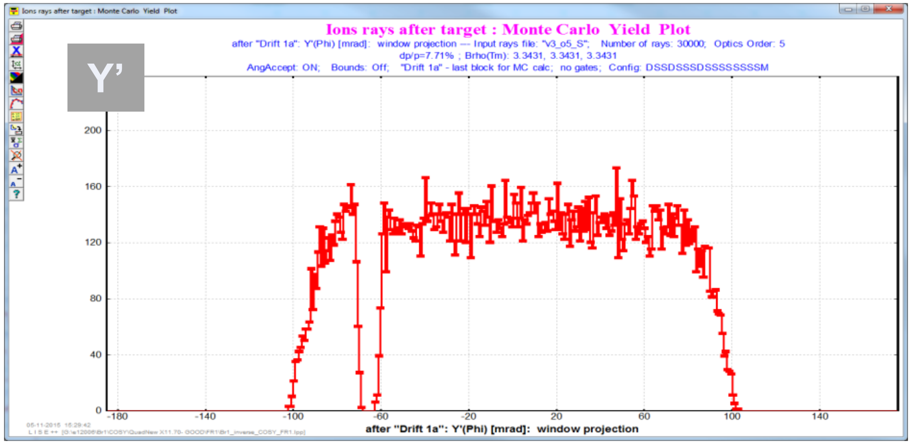
Resolution

dX = 0.25 mm
dX' = 0.25 mrad
dY = 0.50 mm
dY' = 0.50 mrad
dE = 0%

V3_o5_S.ray







Case 3

Reverse @ Target

5th order (5->5)

Resolution

dX = 0.25 mm
dX' = 0.25 mrad
dY = 0.50 mm
dY' = 0.50 mrad
dE = 0%

V3_o5_S.ray

The S800 case : Summary

				Quality of reconstruction				
Reverse Case	Optics	Spatial resolution	dE	X	Y	X'	Y'	Global
2-1	5->1	ideal	0	2	7	3	7	3
2-2	5->2	ideal	0	5	8	8	9	7
2-3	5->5	ideal	0	10	10	10	10	10
3	5->5	good	0	8	8	10	9	9
4	5->5	good	0.2%	1	8	4	9	4
5	5->5	poor	0	4	4	8	7	6

Case 3 : current analysis for #12006 experiment (S800)
Case 2-1 (inverse 1st order LISE^{++}) & 4 (E from ToF) : non-acceptable

We need $^{(MH)}$ for this S800 particular case*

(1) at least 2nd order,

(2) good spatial resolution,

(3) an energy measurement that is clearly better than a typical TOF measurement.

** for A1900 (achromatic case) the conclusions may be different*

Reverse technique and detector resolution: A1900

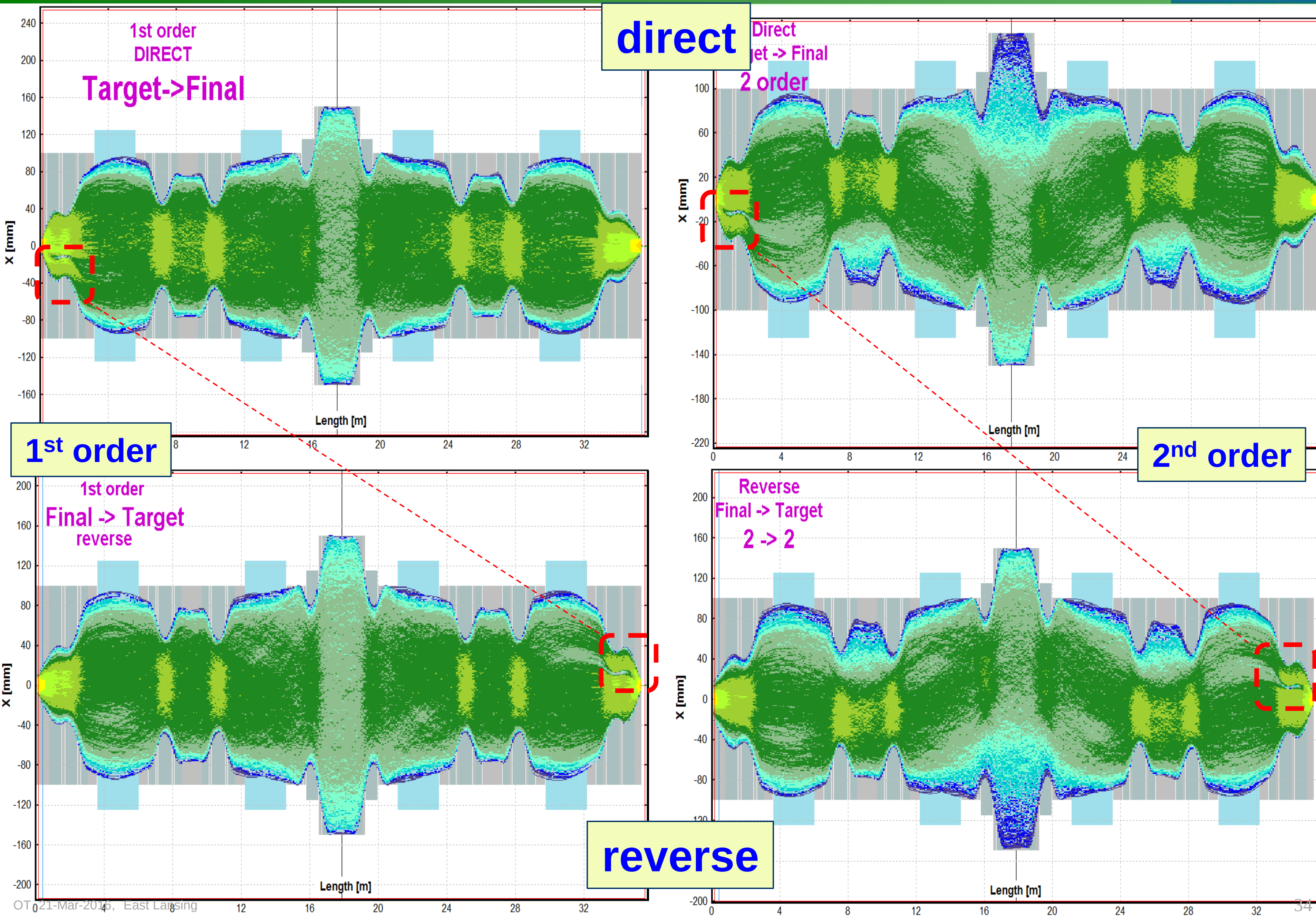
Reverse technique for A1900

http://lise.nscl.msu.edu/doc/e12006/A1900_reverse_resolution.pdf

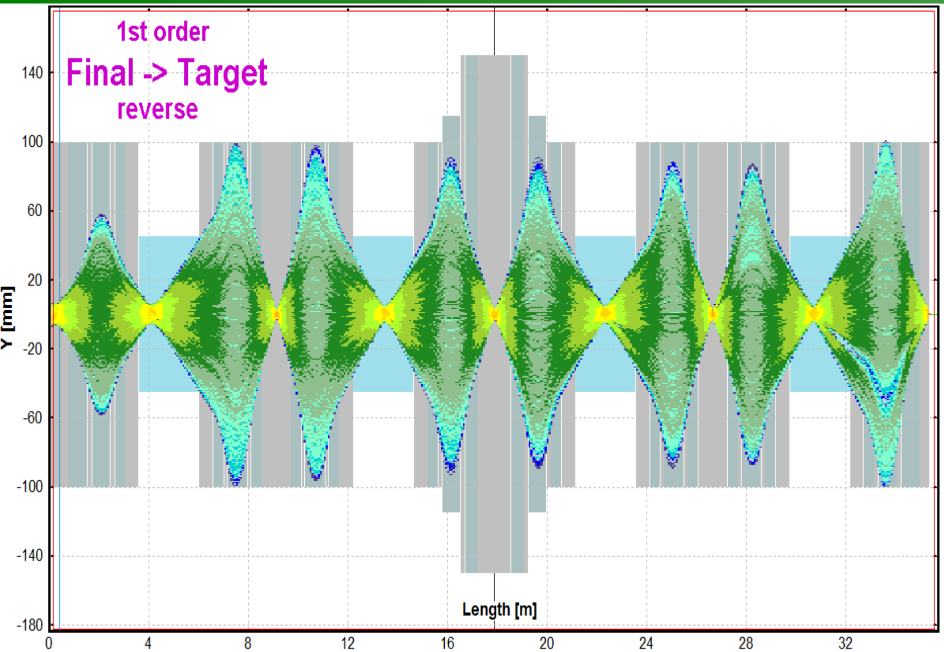
1. LISE-type reverse file creation
2. Optics (1→1)
3. Optics (2→1)
4. Detector resolution for optics (1→1)
5. Contribution of straggling in wedge
6. Some remarks: charge states
7. Summary

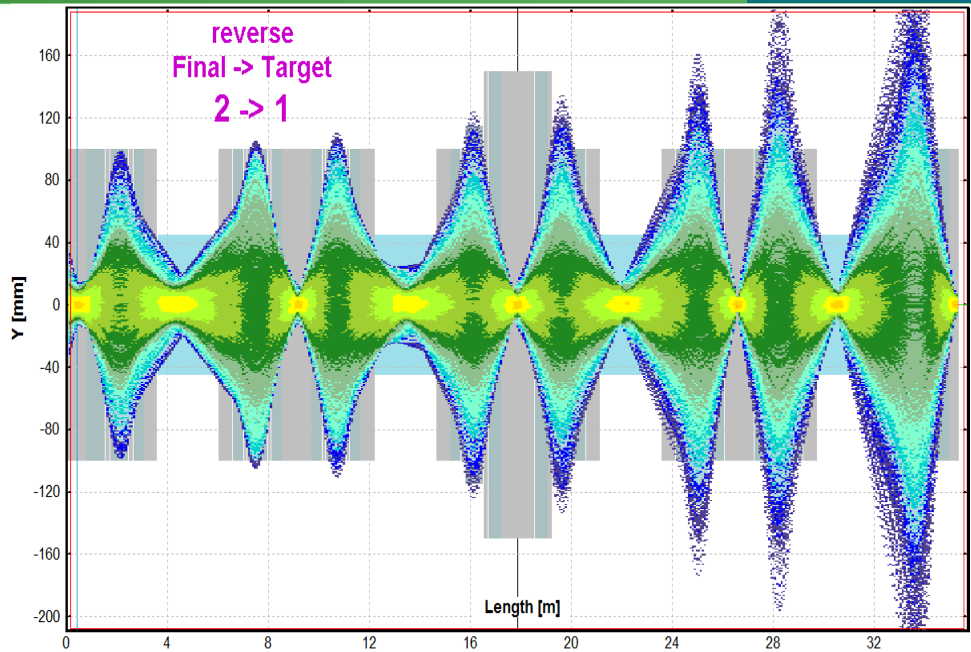
Direct file: http://lise.nscl.msu.edu/9_10/reverse/A1900_direct.lpp
Reverse file: http://lise.nscl.msu.edu/9_10/reverse/A1900_Lreverse.lpp

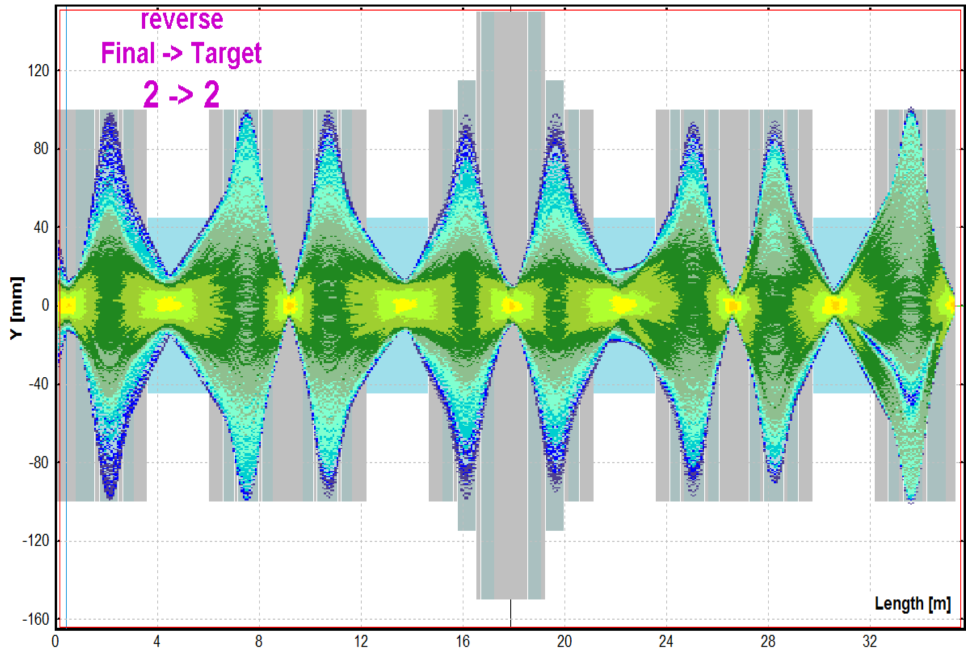
X (horizontal) direct & reverse envelopes for 1st & 2nd order optics



Y (vertical) reverse envelopes for different order optics





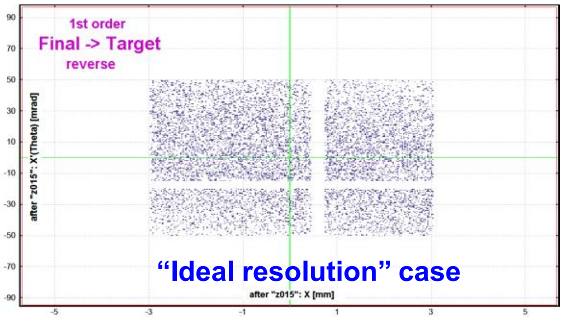


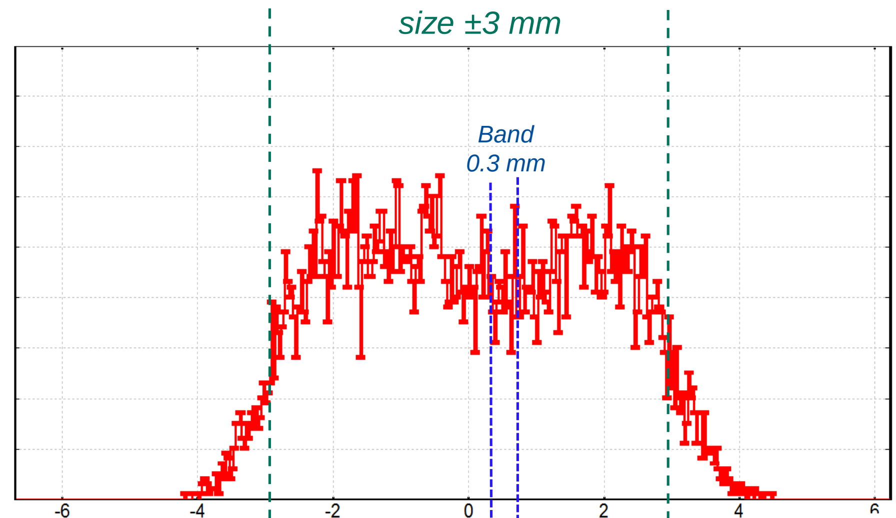
Using detector resolution (x,y) with 1st order optics : X vs X’

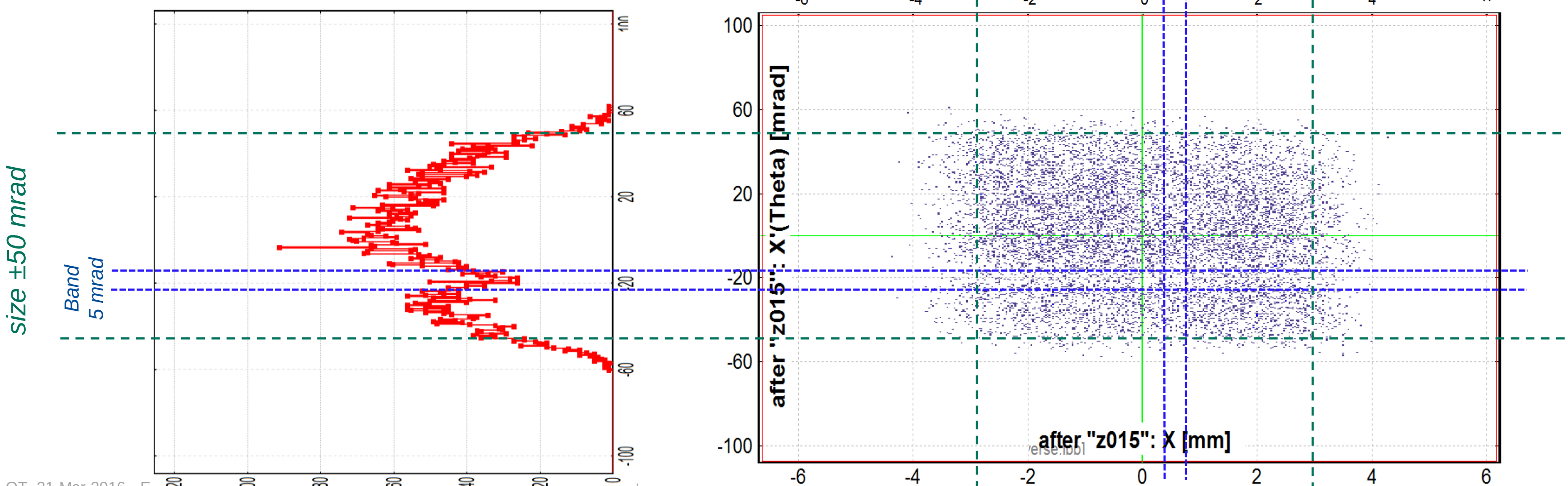
X vs X’
1st order

d(X), d(Y) = 1 mm, d(X’), d(Y’) = 2 mrad, d(E) = 0 % *manually been entered in the ray file*

! 01-Z (atomi	01-N (neutro	01-q (ion cha	01-X [mm]	01-0 (empty)	01-X'(Theta) [	01-0 (empty)	01-Y [mm]	01-0 (empty)	01-Y'(Phi) [m	01-0 (empty)	01-Energy [M	01-0 (empty)	01-Time fro	
50	74	50	-0.57374	1	-20.595	2	-1.7892	1	9.0715	2	78.559	0	304.34	
50	74	50	-2.3107	1	-15.824	2	1.3066	1	-17.313	2	82.128	0	298.7	
50	74	50	-4.3571	1	5.0458	2	2.5585	1	9.3088	2	81.03	0	300.39	0







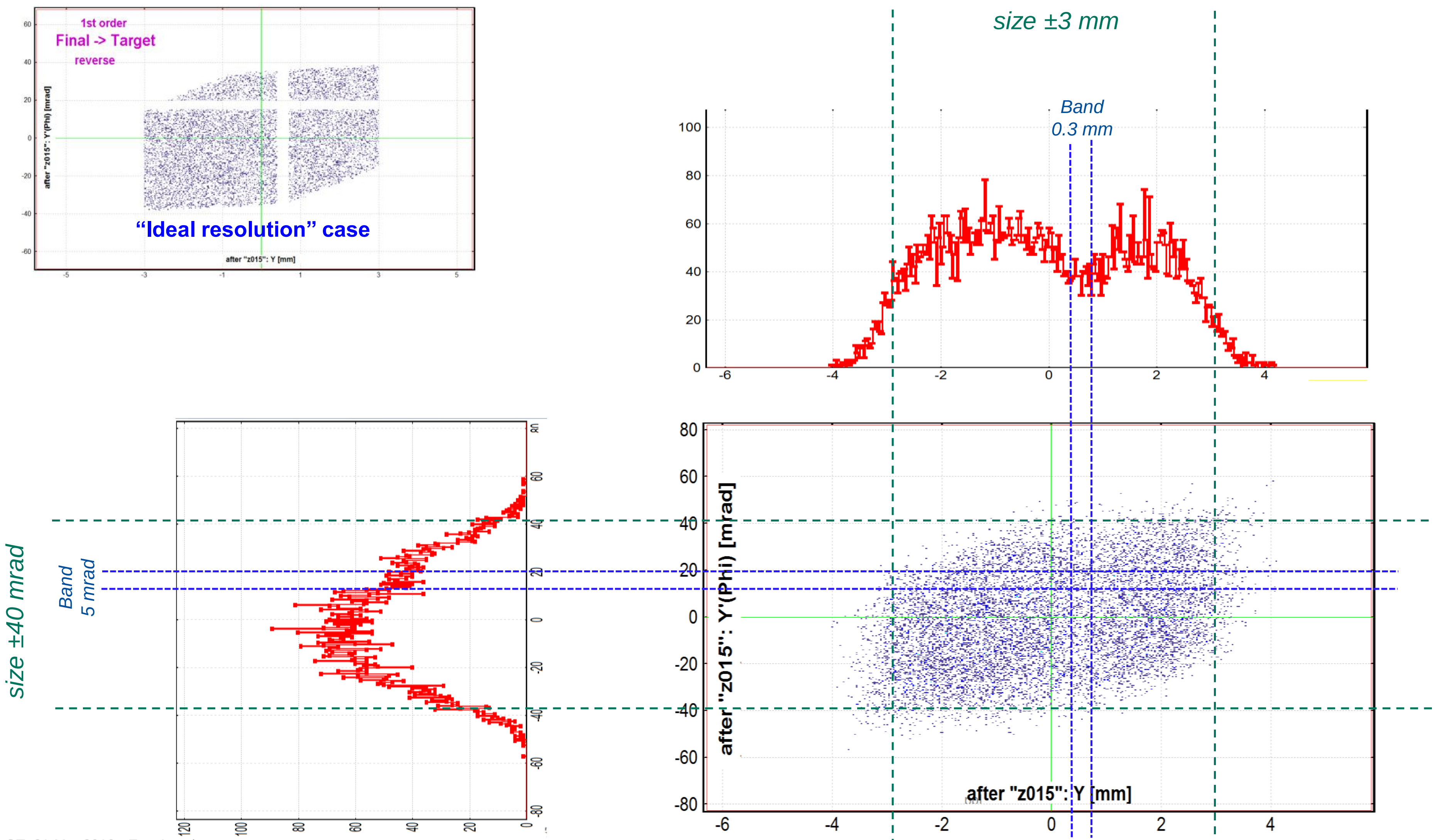
Using detector resolution (x,y) with 1st order optics : Y vs Y’

MICHIGAN STATE UNIVERSITY

Y vs Y’
1st order

d(X), d(Y) = 1 mm, d(X’), d(Y’) = 2 mrad, d(E) = 0 % *manually been entered in the ray file*

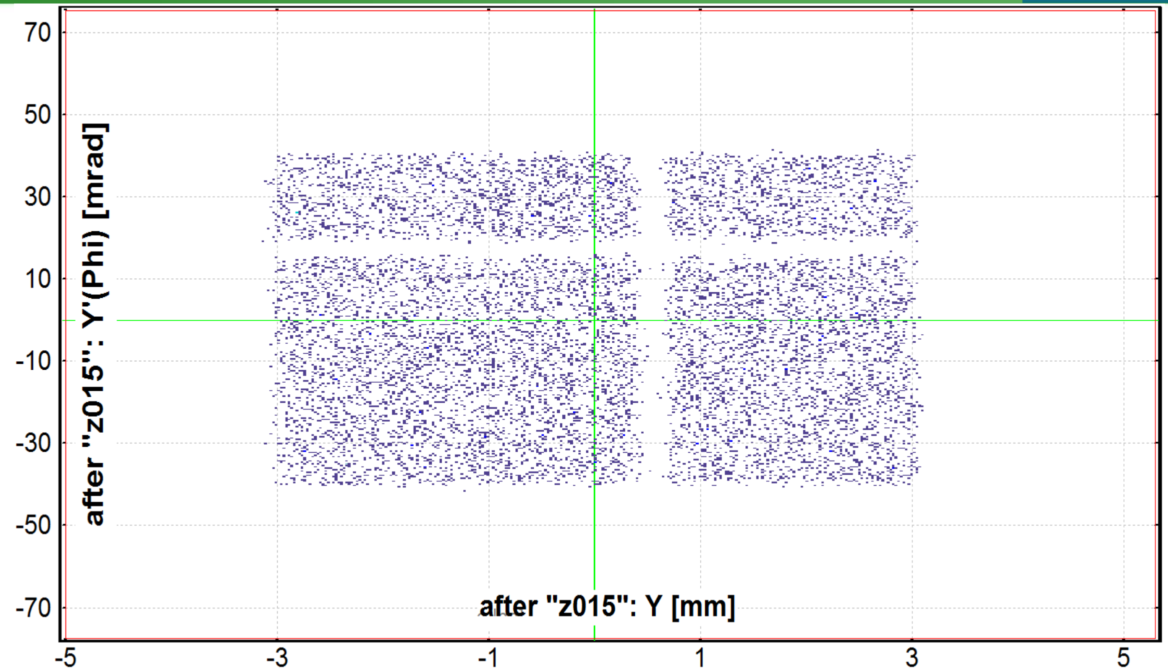
! 01-Z (atomic	01-N (neutro	01-q (ion cha	01-X [mm]	01-0 (empty)	01-X'(Theta) [	01-0 (empty)	01-Y [mm]	01-0 (empty)	01-Y'(Phi) [m	01-0 (empty)	01-Energy [M	01-0 (empty)	01-Time fron	
50	74	50	-0.57374	1	-20.595	2	-1.7892	1	9.0715	2	78.559	0	304.34	
50	74	50	-2.3107	1	-15.824	2	1.3066	1	-17.313	2	82.128	0	298.7	
50	74	50	-4.3571	1	5.0458	2	2.5585	1	9.3088	2	81.03	0	300.39	0



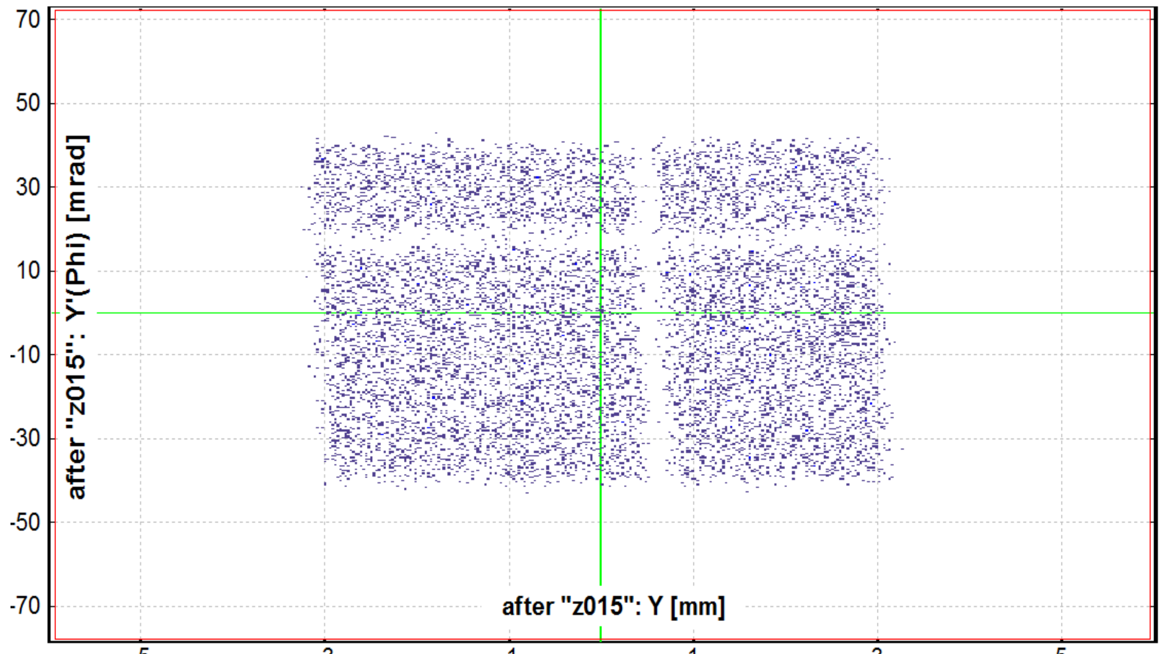
Contribution of straggling in wedge : Y vs Y'

Y vs Y'
1^{st} order

Thin wedge:
10% of range

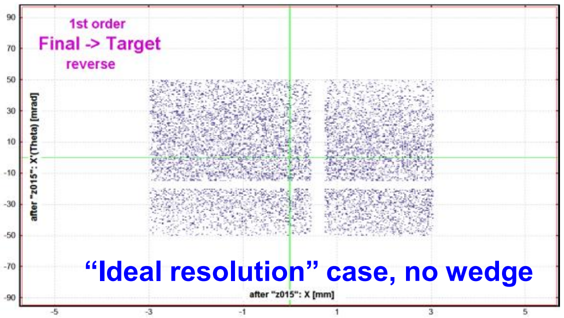


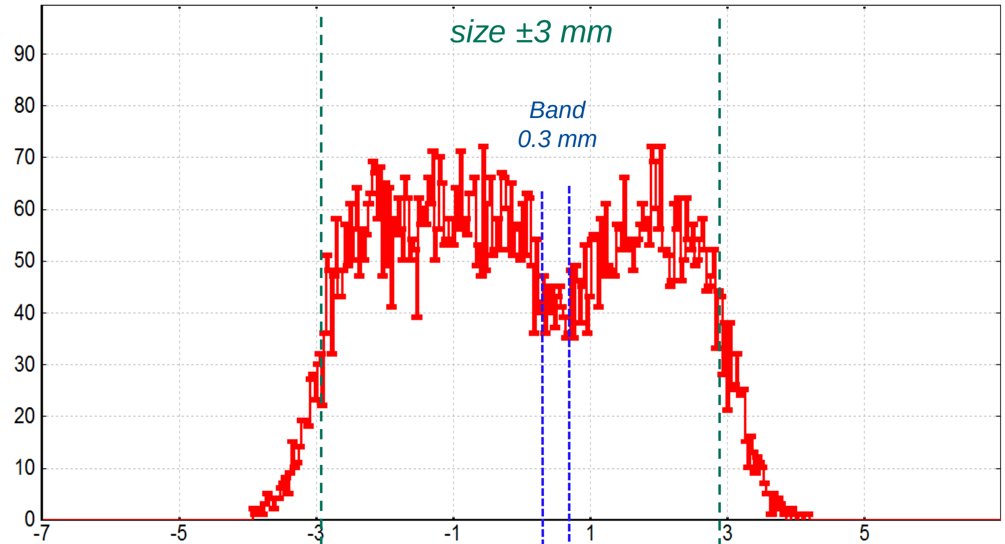
Thick wedge:
40% of range

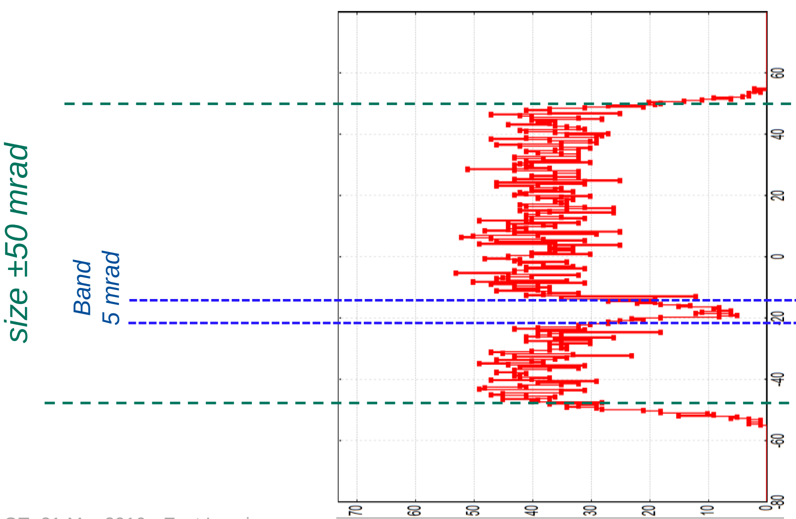


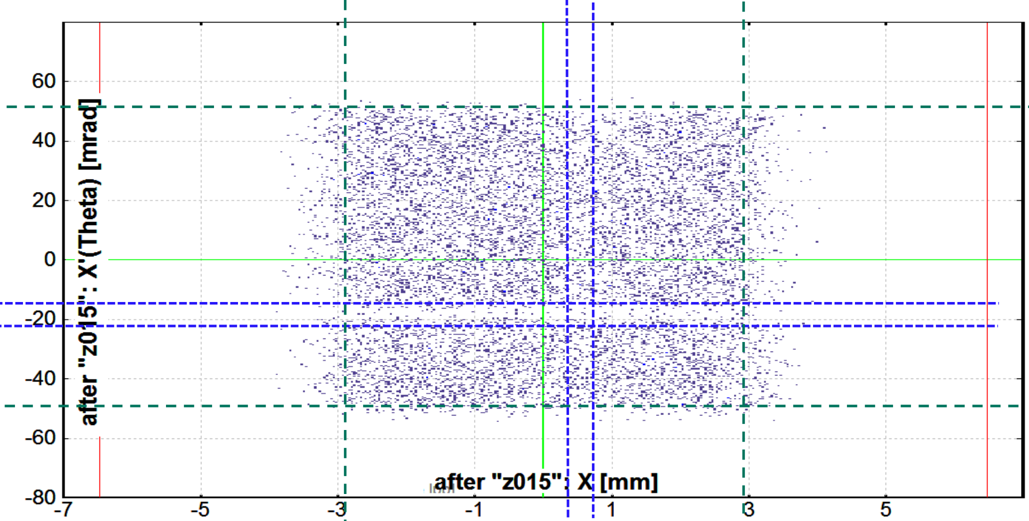
X vs X’
1st order

Thin wedge: 10% of range



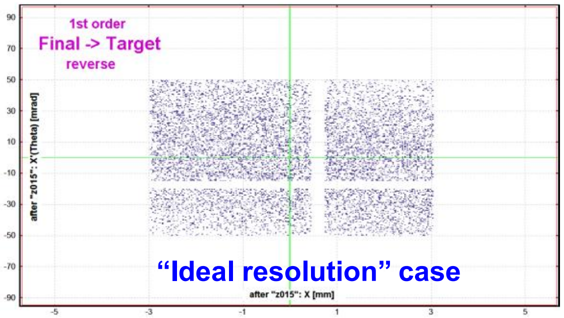


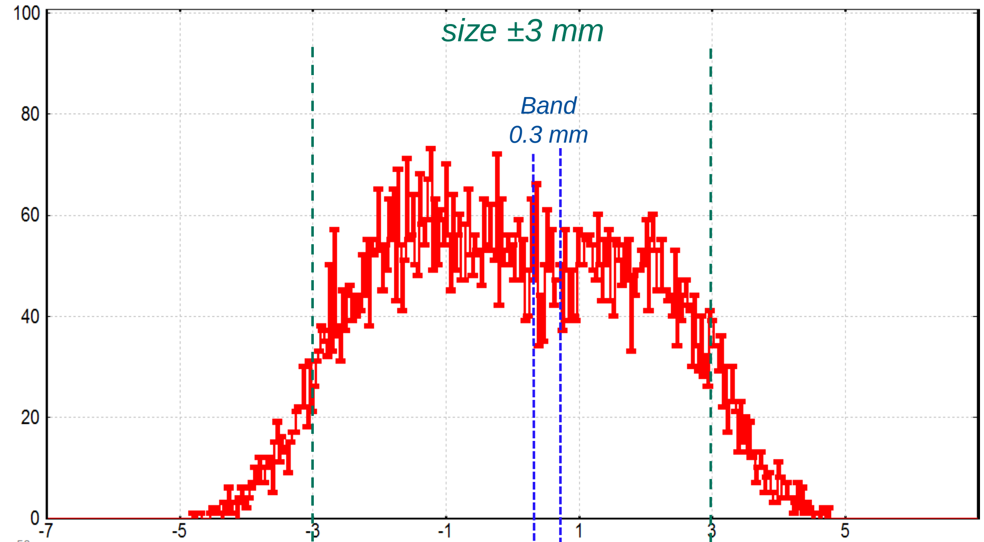


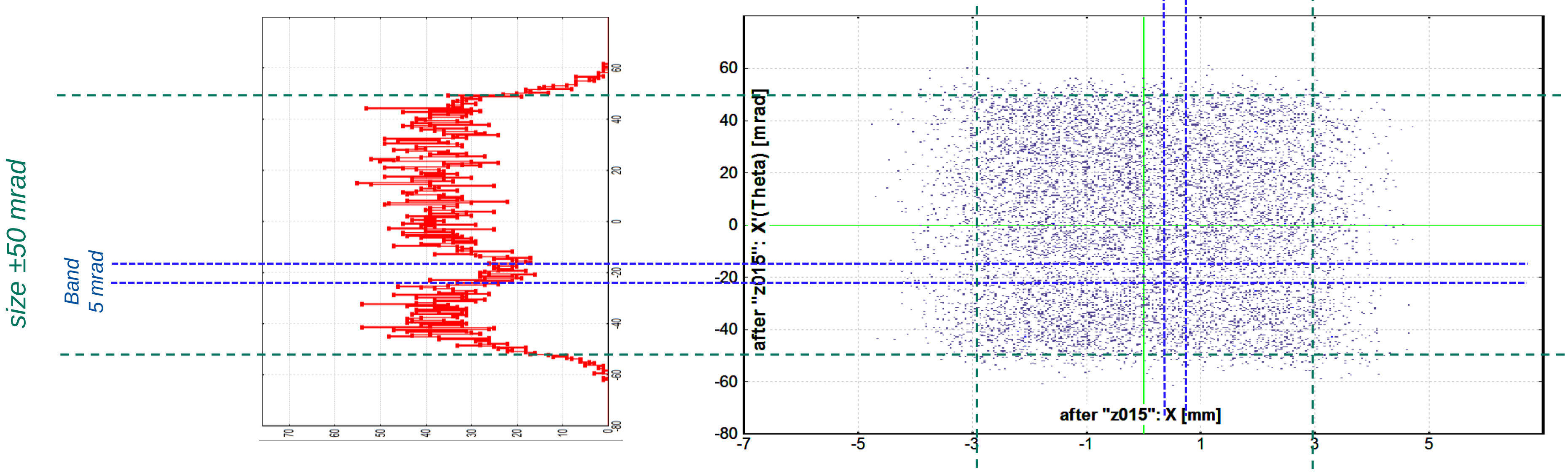


X vs X’
1st order

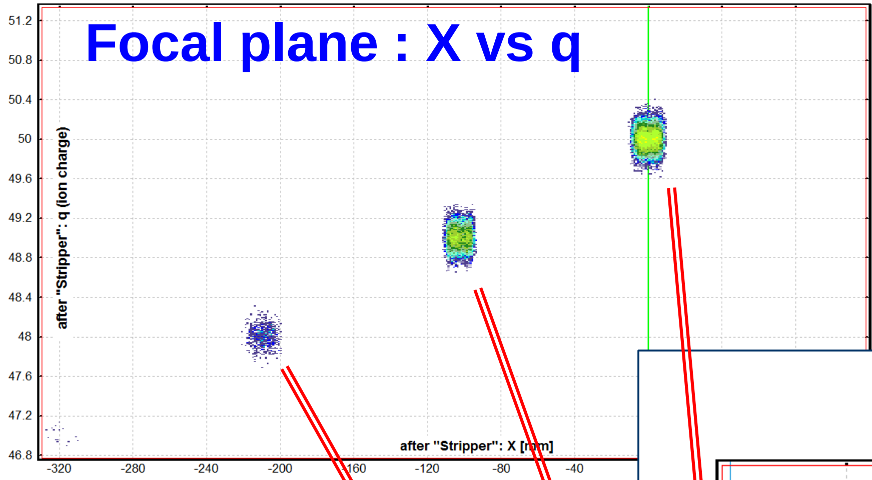
Thick wedge: 40% of range



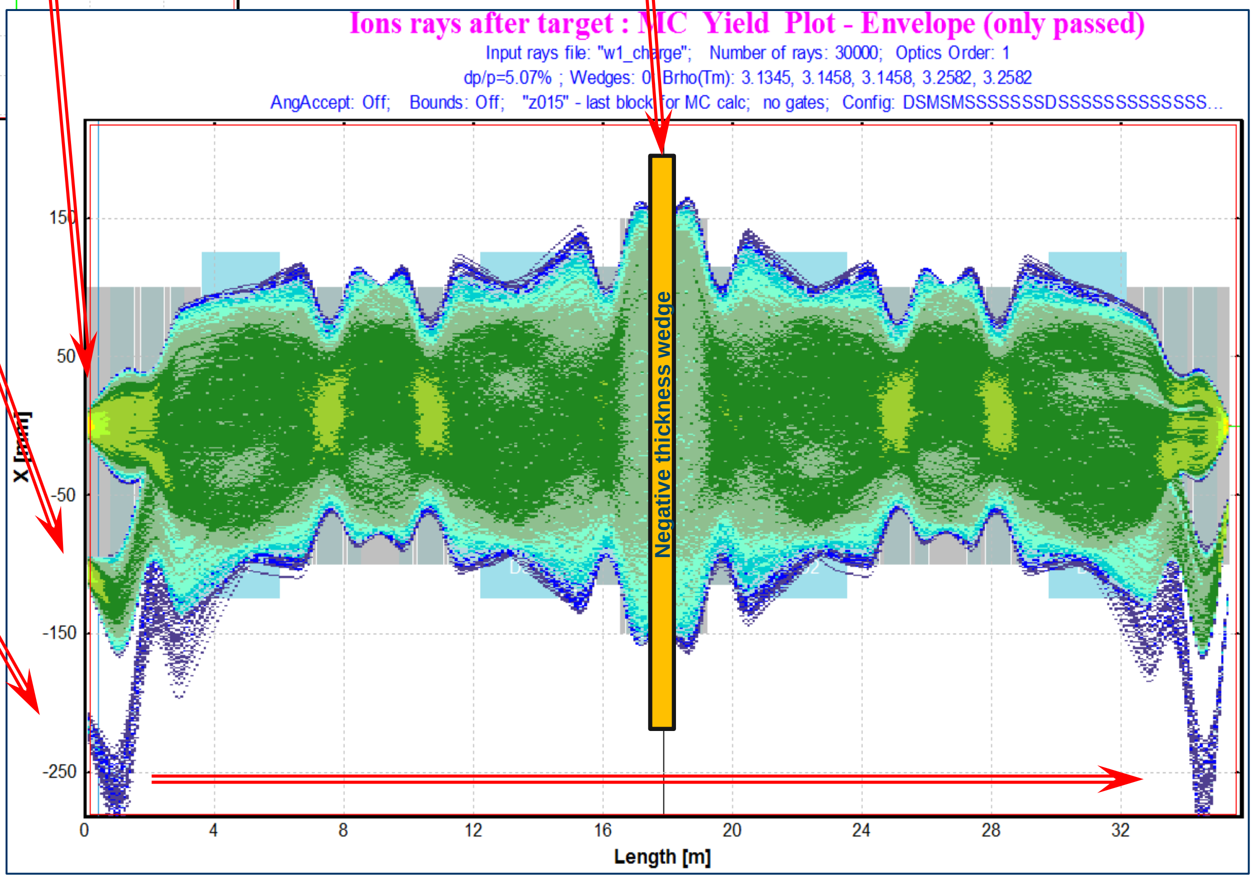




Charge states in reverse technique



Negative thickness material do not change charge state distributions!!!



The A1900 case: Summary

1. The A1900 LISE-type reverse configuration has been created, its benchmarks have been done

2. High order optics is important in the reverse A1900 case. COSY-type reverse configuration should be tested.

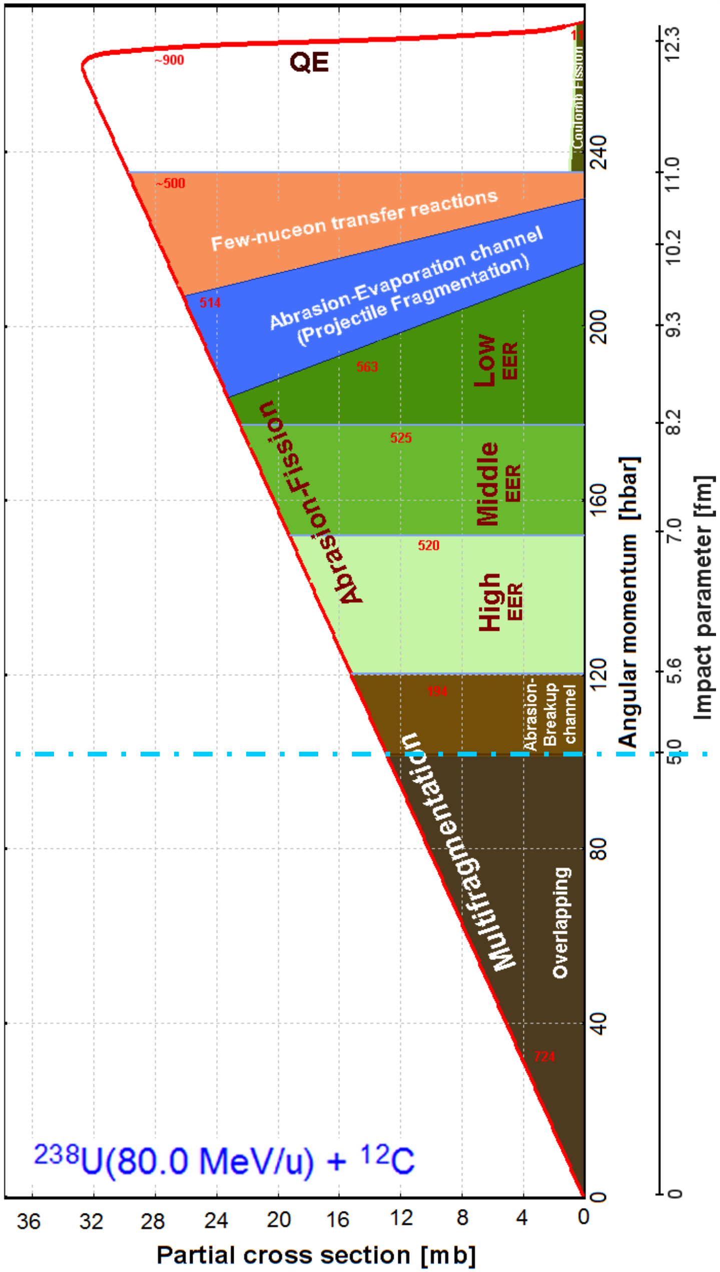
3. LISE-type second order optics operates well in the reverse A1900 case

4. Energy resolution at the final focal plane detectors is not a key factor in the reverse A1900 case comparing to the S800 case

5. Use of thick wedge destroys reverse resolution quality in the horizontal spatial plane

Reaction mechanisms,
Abrasion-Fission

^{238}U(80MeV/u) + C reaction scheme as impact parameter function

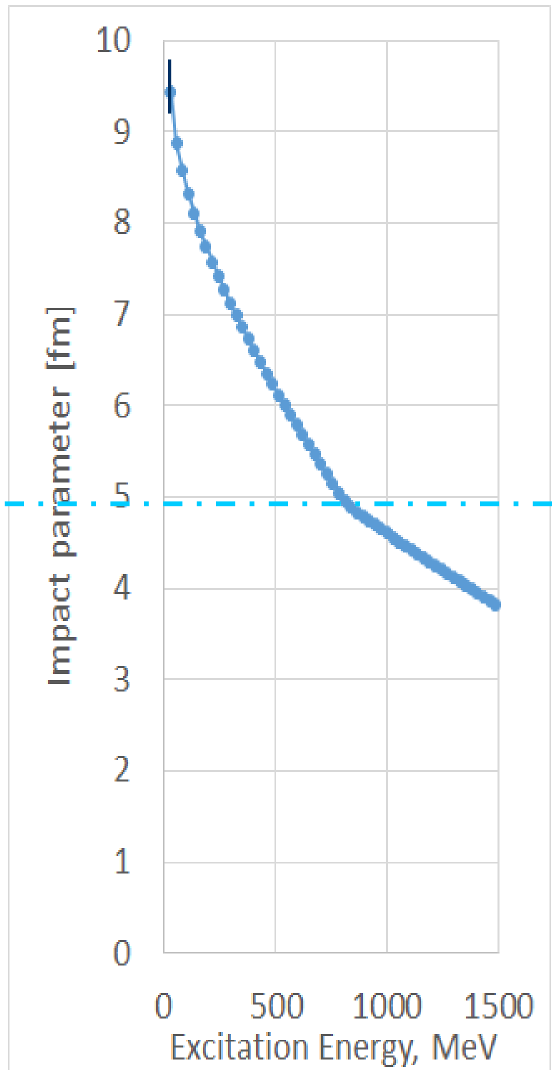


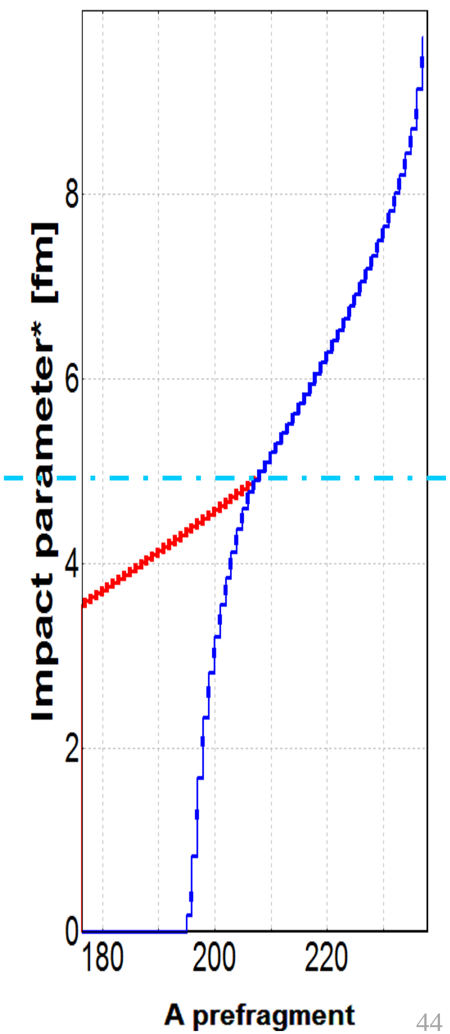
LISE^{++} calculations based on

J.-J.Gaimard, K.-H.Schmidt, Nucl.Phys. A531 (1991) 709-745;

J.Gosset et al., Phys.Rev. C16 (1977) 629.

$E^* = 27 * \Delta A_{abr}$

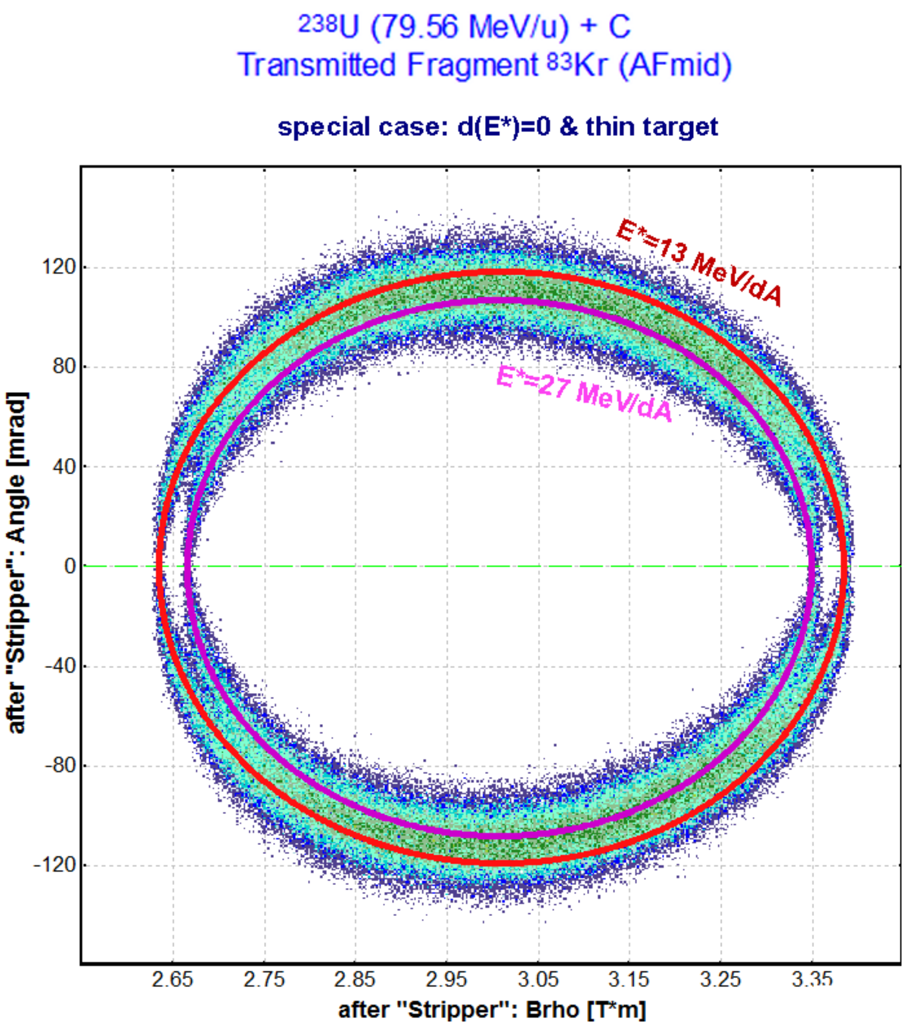


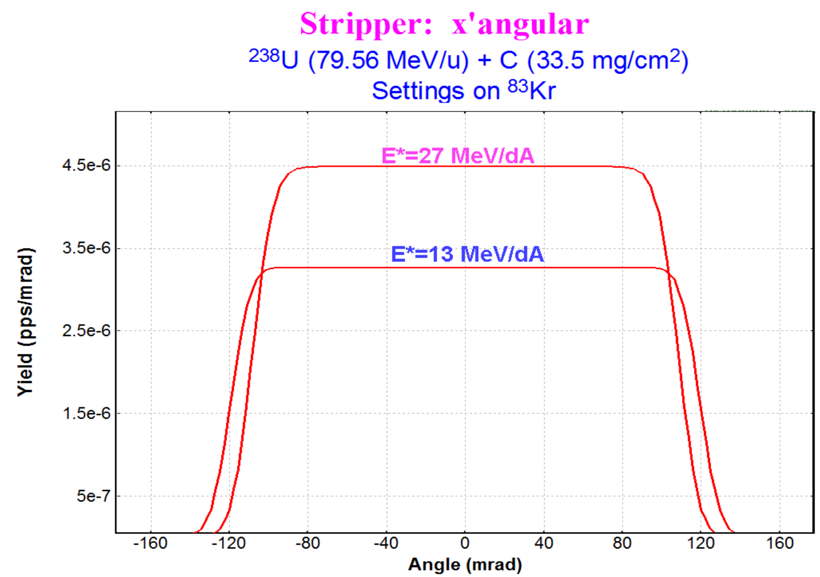


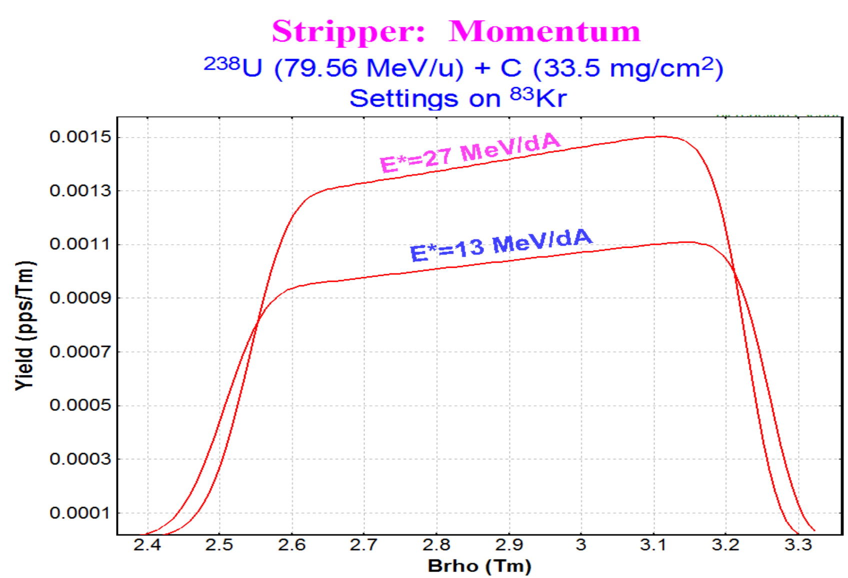
Fission kinematics and Abrasion excitation energy

Monte Carlo method

Distribution method







3D fission kinematics

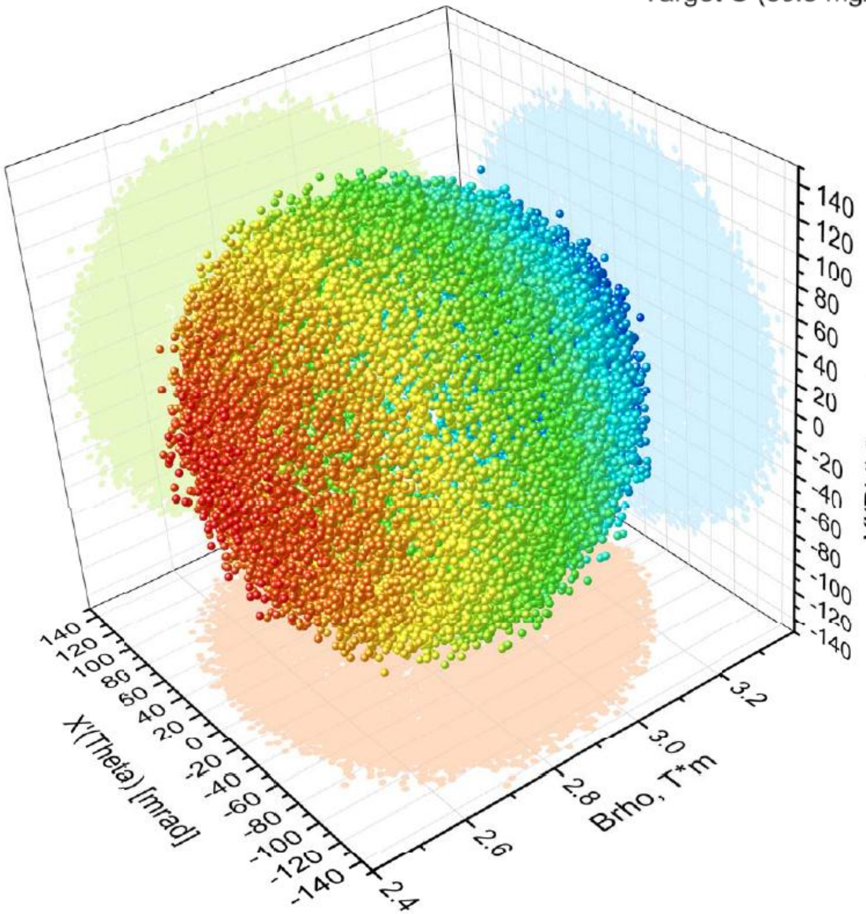
^{238}U (80 MeV/u) + C → ^{83}Kr $_{\text{Mid EER}}$

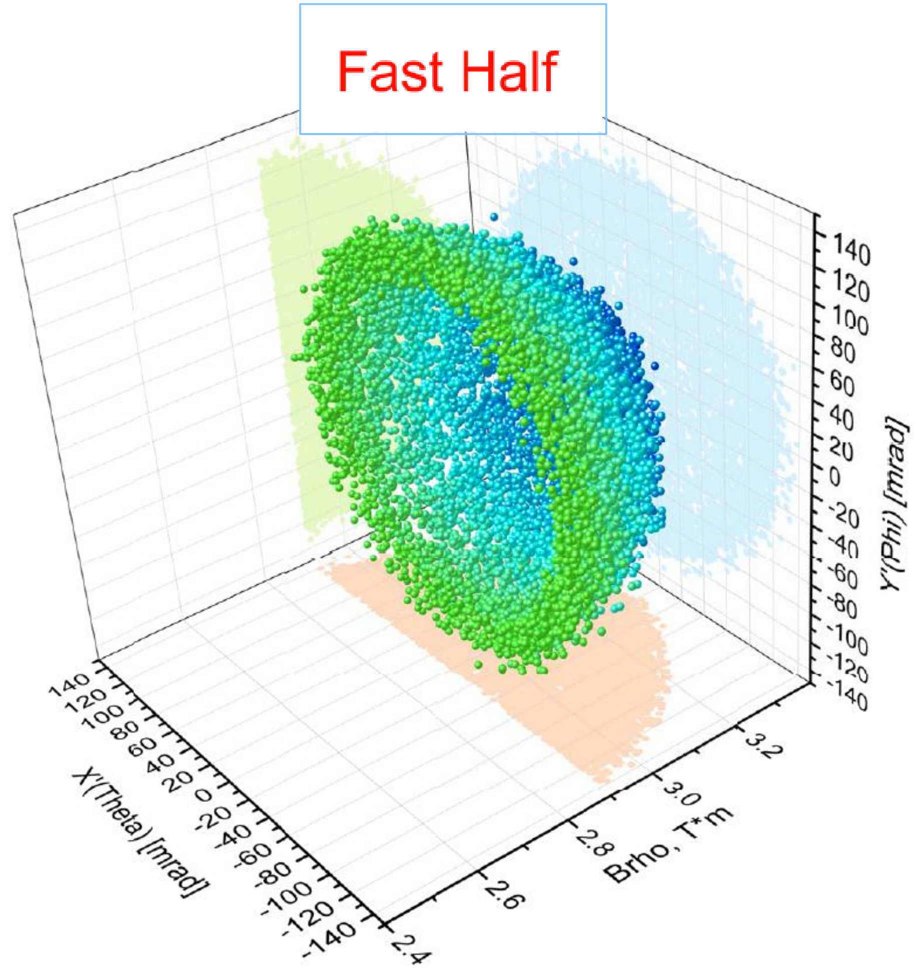
after target

LISE++

Bρ=3.1743 Tm,

Target C (33.5 mg/cm^2)





3D fission kinematics

^{238}U (80 MeV/u) + C → ^{83}Kr Mid EER

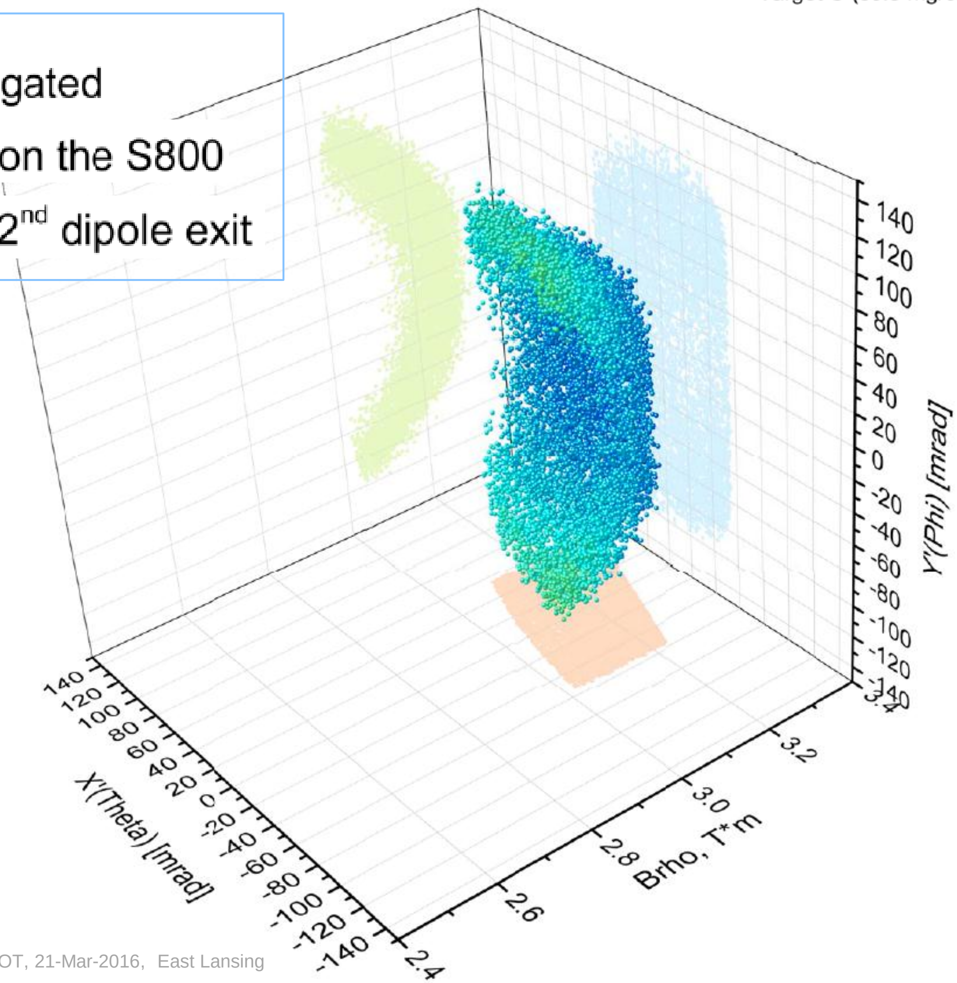
after target

LISE++

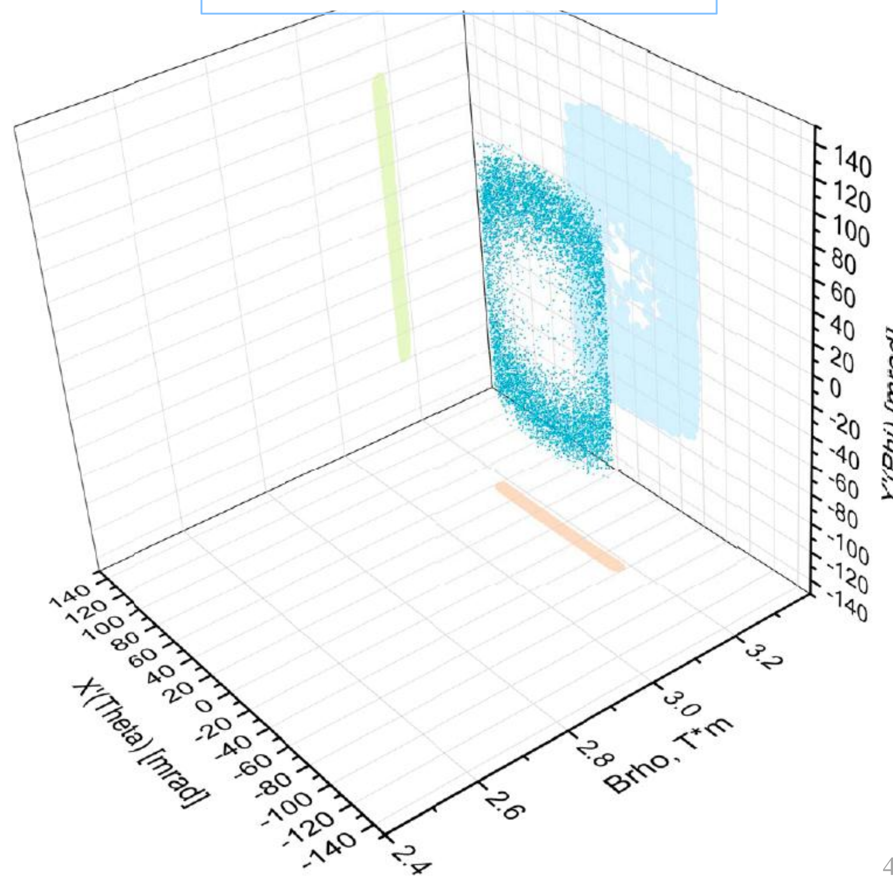
Bρ=3.1743 Tm,

Target C (33.5 mg/cm²)

gated on the S800 2nd dipole exit

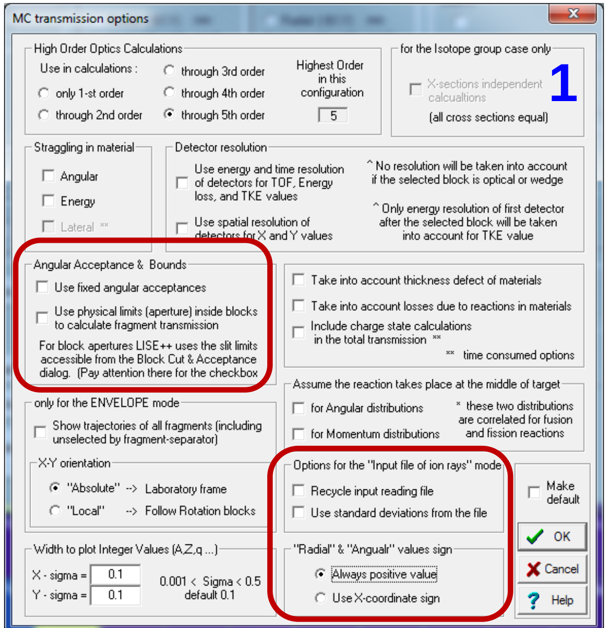


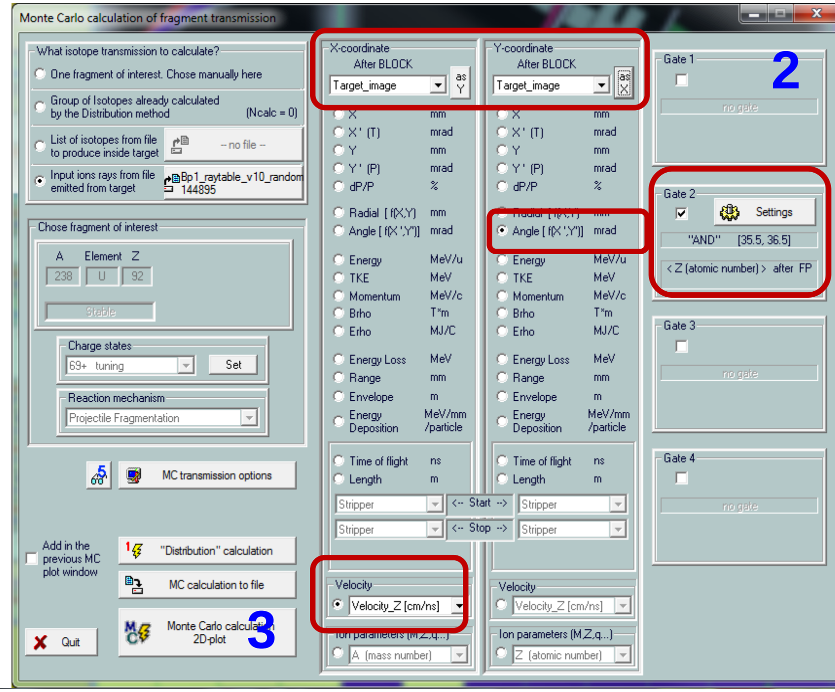
gated on the FP slits (±10mm)



Velocity-Z vs Theta plot

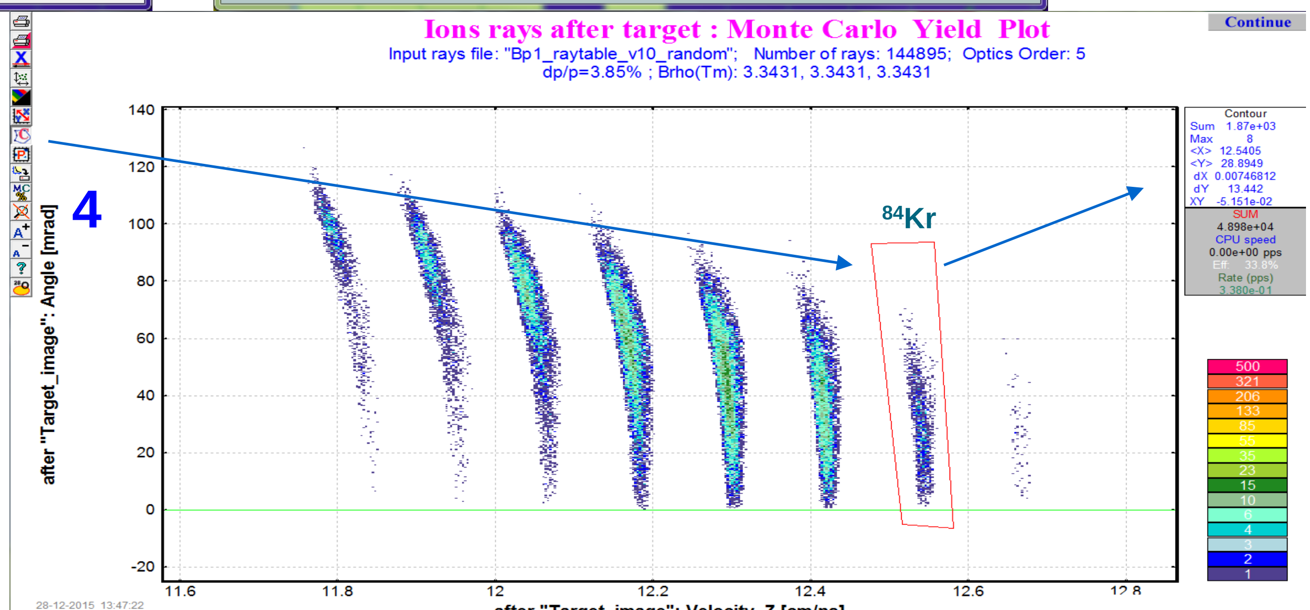
Monte Carlo options





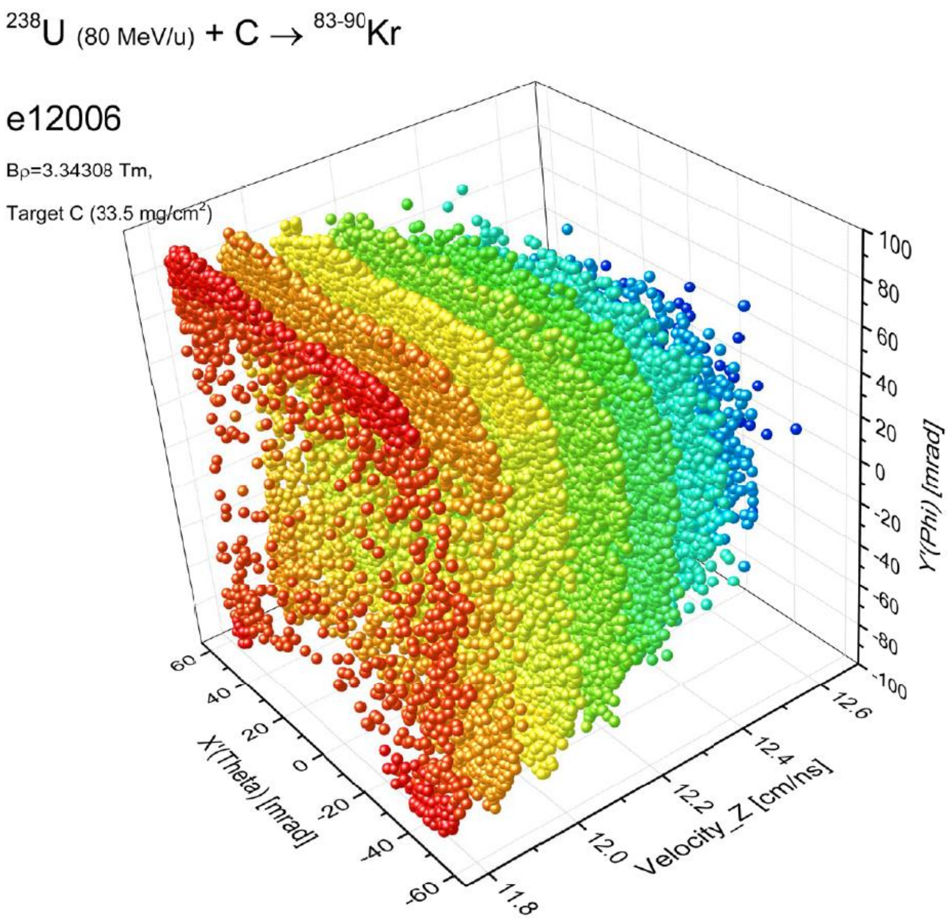
Gate for Kr isotopes

contour

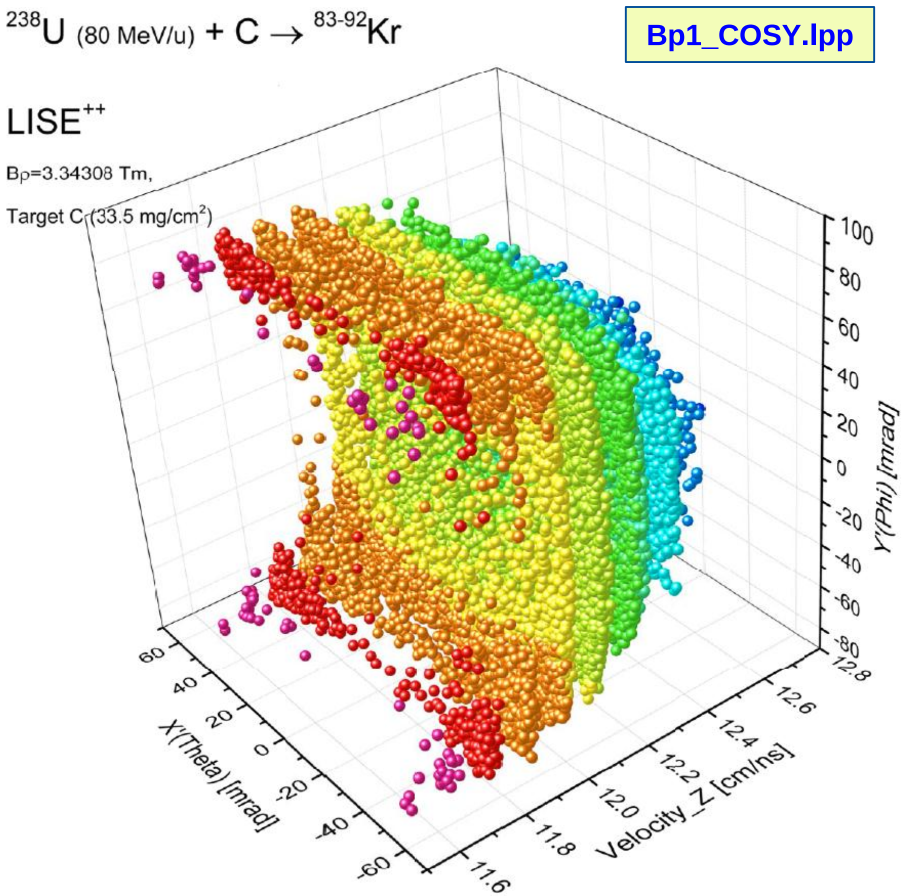


Velocity-Z vs X,Y-Angles 3D-plots @ S800 Target position

Bp1_COSY_Creverse.lpp



Bp1_COSY.lpp

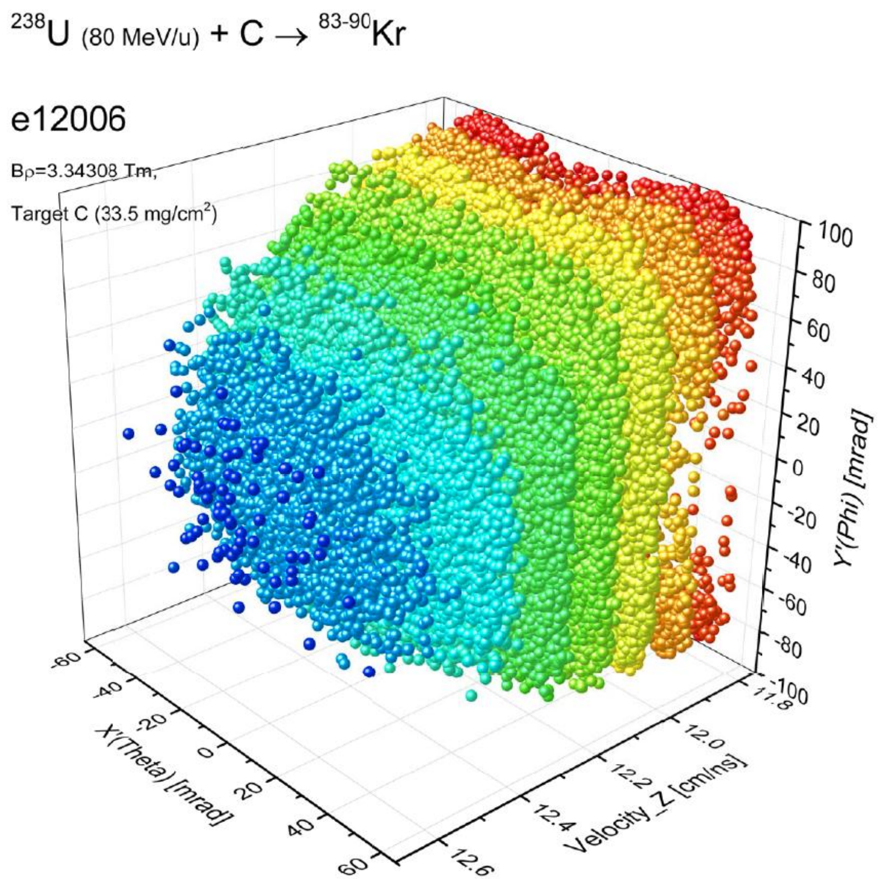


LISE++ direct calculations are gated on the Scintillator position

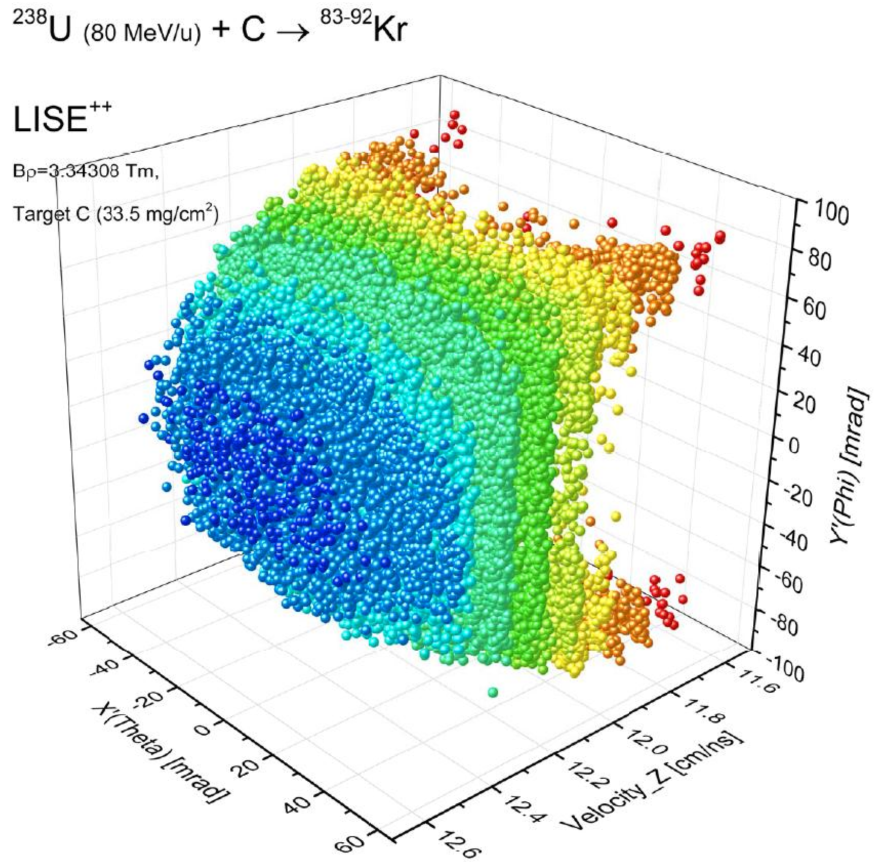
Pay attention that in LISE++ calculations the isotope range is 83-92 instead experimental 83-90

Velocity-Z vs X,Y-Angles 3D-plots @ S800 Target position

Bp1_COSY_Creverse.lpp



Bp1_COSY.lpp



LISE++ direct calculations are gated on the Scintillator position

Pay attention that in LISE++ calculations the isotope range is 83-92 instead experimental 83-90

Acknowledgements

- Thanks to a large group of MSU colleagues for discussions and help during this reverse technique development

- e12006 analysis with the reverse technique was done jointly with M.Bowry and A.Gade