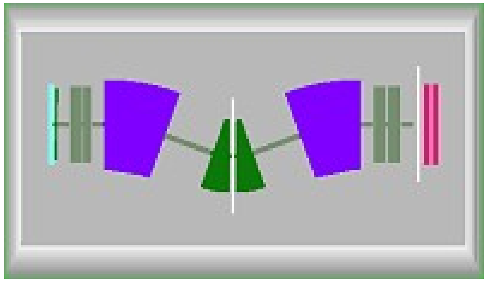
Fragment Mass Analyzer (FMA) @ Argonne N.L.

Version 9.10.177 from 09/11/2015



Link: Separator “FMA” @ ANL

- FMA extended configuration
  - Documentation
  - FMA files location
  - Optics
  - Optimization
- Angular Acceptance
- Momentum Acceptance
- Experiment ^{32}S (115 MeV) + ^{58}Ni
- Open questions

FMA documentation sources

1.

Nuclear Instruments and Methods in Physics Research B70 (1992) 358–365
North-Holland

NIM B
Beam Interactions with Materials & Atoms

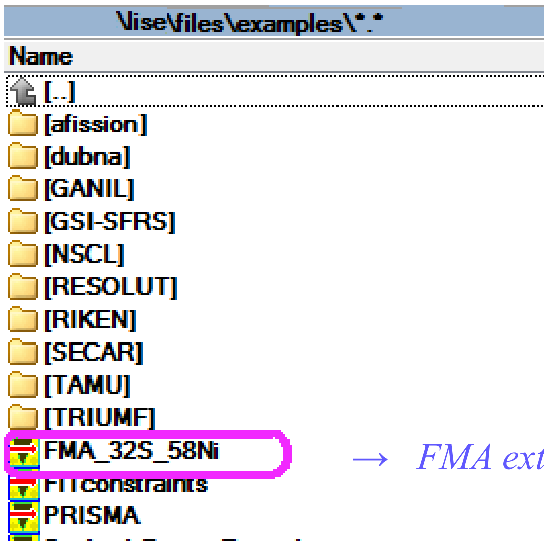
Startup of the Fragment Mass Analyzer at ATLAS

C.N. Davids, B.B. Back, K. Bindra, D.J. Henderson, W. Kutschera, T. Lauritsen, Y. Nagame [1], P. Sugathan [2], A.V. Ramayya [3] and W.B. Walters [4]
Physics Division, Argonne National Laboratory, Argonne, IL 60439, USA

2. COSY file with FMA settings example kindly provided by Darek Seweryniak (ANL)

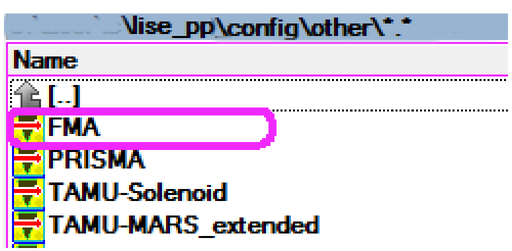
FMA files location @ LISE^{++} package

LISE^{++} file



→ *FMA extended for the reaction* $^{32}S(115MeV)+^{58}Ni(0.4\ mg/cm^2)$ **Recommended!**

LISE^{++} configuration



→ *FMA extended configuration*

FMA optics settings

Optics settings (fast editing)

Block	Given Name	Start(m)	Length(m)	B0(kG)/*U	Br(Tm)cor/*real	DriftM/*Angle	Rapp(cm)/*R(...	Leff(m)/*Ldip(m)	2 nd order	CalcMatr/*Z-Q	AngAcc,Apps,Slits	COSY | Fit	SE
= Dipole	tuning	0.000	0.0001	+1.4639	* 0.4392	* +0.0	* 3.0000	* 0.0000	-	* 24	HV -- --	-	S
drift	Drift 1	0.000	0.3000			standard					-- -- --	-	e
<Quad>	Q1	0.300	0.2990	+3.0201	0.4392	QUAD	5.0000	0.2990	yes	1 R	-- HV --	fit - Q	e
drift	Drift 3	0.599	0.0160			standard					-- HV --	-	e
<Quad>	Q2	0.615	0.1900	-3.6757	0.4392	QUAD	5.0000	0.1900	yes	1 R	-- HV --	fit - Q	e
drift	Drift 5	0.805	0.3000			standard					-- -- --	-	e
=ElecDip	ElecDip 1	1.105	1.3963	*96.4kV	0.4392	* +20.0	* 4.0000	* 1.3963	-	* 24 R	-- HV --	-	E
drift	Drift 6	2.501	1.2015			standard					-- -- --	-	e
= Dipole	DipoleA	3.703	0.3491	-4.3916	* 0.4392	* -20.0	* 1.0000	* 0.3491	yes	* 24 R	-- HV --	-	E
slits	dip slits	4.052	0.0000			SLITS					-- -- HV	-	e
= Dipole	DipoleB	4.052	0.3491	-4.3916	* 0.4392	* -20.0	* 1.0000	* 0.3491	yes	* 24 R	-- HV --	-	E
drift	Drift 8	4.401	1.2015			standard					-- HV --	-	e
=ElecDip	ElecDip 2	5.602	1.3963	*96.4kV	0.4392	* +20.0	* 4.0000	* 1.3963	-	* 24 R	-- HV --	-	E
drift	Drift 9	6.999	0.3000			standard					-- -- --	-	e
<Quad>	Q3	7.299	0.2950	-3.0702	0.4392	QUAD	7.5000	0.2950	yes	1 R	-- HV --	fit - Q	e
drift	Drift 11	7.594	0.0160			standard					-- HV --	-	e
<Quad>	Q4	7.610	0.2940	+3.6571	0.4392	QUAD	7.5000	0.2940	yes	1 R	-- HV --	fit - Q	e
drift	Drift 13	7.904	0.3130			standard					-- HV --	-	e
slits	FP slits	8.217	0.0000			SLITS					-- -- HV	-	e

FMA aperture and slit settings

Quads & Dipoles settings

! FILE: C:\user\c\lise_pp_910\files\examples\FMA_32S_58Ni.lpp

slits | apertures

1 N or	2 Block name	3 Kind of Block	4 Start (m)	5 Length (m)	6 DriftMode Angle(°)*	7 B0(kG)	8 Br-corrsp Br-dip*	9 Rapp(cm) R(m)*	10 L_eff(m) Len(m)*	11 2nd order	12 Calc Mode	13 AngAcc mode	14 Slits shape	15 Xmin slit	16 Xmax slit	17 Ymin slit	18 Ymax slit	19 Appert shape	20 Xmin limit	21 Xmax limit	22 Ymin limit	23 Ymax limit
1.	tuning	Dipole	0.000	0.000	+0.0 *	+1.464	0.4392*	3.00*	0.00*	-		HV	rectn					ellps				
2.	Drift 1	Drift	0.000	0.300	standard							--	rectn					rectn				
3.	Q1	Drift	0.300	0.299	multipole	+3.020	0.4392	5.00	0.30	yes	1	--	rectn					ellps	-50	+50	-50	+50
4.	Drift 3	Drift	0.599	0.016	standard							--	rectn					ellps	-50	+50	-50	+50
5.	Q2	Drift	0.615	0.190	multipole	-3.676	0.4392	5.00	0.19	yes	1	--	rectn					ellps	-50	+50	-50	+50
6.	Drift 5	Drift	0.805	0.300	standard							--	rectn					rectn				
7.	ElecDip 1	ElecDip	1.105	1.396	+20.0 *	96.4kV	0.4392*	4.00*	1.40*	-		--	rectn					rectn	-50	+50	-100	+100
8.	Drift 6	Drift	2.501	1.202	standard							--	rectn					rectn				
9.	DipoleA	Dipole	3.703	0.349	-20.0 *	+4.392	0.4392*	1.00*	0.35*	yes		--	rectn					rectn	-100	+100	-60	+60
10.	dip slits	Drift	4.052	0.000	SLITS							--	rectn	-100	+100	-60	+60	rectn				
11.	DipoleB	Dipole	4.052	0.349	-20.0 *	+4.392	0.4392*	1.00*	0.35*	yes		--	rectn					rectn	-100	+100	-60	+60
12.	Drift 8	Drift	4.401	1.202	standard							--	rectn					ellps	-100	+100	-100	+100
13.	ElecDip 2	ElecDip	5.602	1.396	+20.0 *	96.4kV	0.4392*	4.00*	1.40*	-		--	rectn					rectn	-50	+50	-100	+100
14.	Drift 9	Drift	6.999	0.300	standard							--	rectn					rectn				
15.	Q3	Drift	7.299	0.295	multipole	-3.070	0.4392	7.50	0.29	yes	1	--	rectn					ellps	-75	+75	-75	+75
16.	Drift 11	Drift	7.594	0.016	standard							--	rectn					ellps	-75	+75	-75	+75
17.	Q4	Drift	7.610	0.294	multipole	+3.657	0.4392	7.50	0.29	yes	1	--	rectn					ellps	-75	+75	-75	+75
18.	Drift 13	Drift	7.904	0.313	standard							--	rectn					ellps	-75	+75	-75	+75
19.	FP slits	Drift	8.217	0.000	SLITS							--	rectn	-75	+75	-75	+75	rectn				

! symbol "*" after values denotes, that these values belongs to Dipole settings, where column names are found in the second row of titles, and also marked by "*"
! Column 08: "Br-corrsp" - quadrupole(sextupole) field is scaled to this Brho-value; "Br-dip*" - dipole magnetic rigidity [T*m]
! Column 09: "Rapp(cm)" - radius(half-aperture) of quadrupole(sextupole) in cm; "R(m)-dip*" - dipole raidus [m]
! Column 10: "L_eff(m)" - effective length of quadrupole(sextupole) in m, wich is used for Optical matrix calcualtiuons; "Len(m)*" - dipole length at ther central axis [m]
! Column 12: "Calc mode" - only for quadrupole(sextupole); 0 - no actions; 1 - recalculate automatically B(field), keep matrix;
! 2 - recalculate automatically the matrix, keep B(field)
! Column 13: "AngAcc mode" - "H(V)" : horizontal(vertical) angular acceptance will be applied for this block
! Columns 15-18,20-23: slits and aperture(limit) sizes in [mm]. If slit or aperture(limit) does not have action, then its size value is absent

These aperture parameters are used to obtain angular and momentum acceptances of the separator.

This settings list can be produced in LISE++ using menu "Experimental Settings -> Optics -> Optics settings: View and Print"

- LISE^{++} does not provide information for mass dispersion
- So, this value can not be used for optimization constraint
- Quad values have been taken from COSY optimization
- All matrices have been calculated inside LISE^{++}

Final global matrices obtained with

LISE^{++}

Global matrix

-1.52806	0	0	0	0	-0.01757	[cm]
68.55995	-0.65421	0	0	0	0.4313	[mrad]
0	0	1.02387	-0.00004	0	0	[cm]
0	0	83.43027	0.97344	0	0	[mrad]
-0.05456	0.00115	0	0	1	0.7479	[cm]
0	0	0	0	0	1	[%]
/[cm]	/[mrad]	/[cm]	/[mrad]	/[cm]	/[%]	

COSY

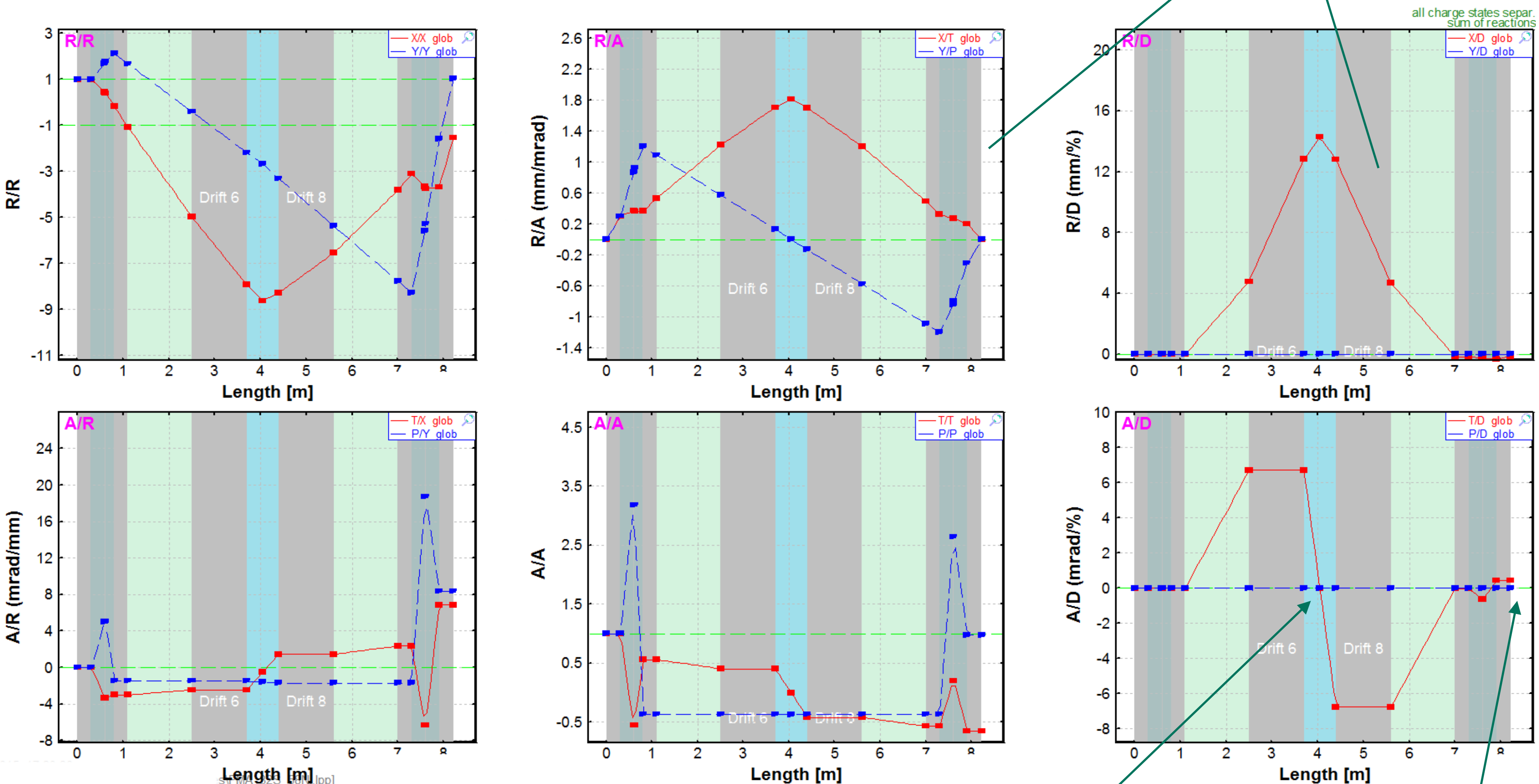
-0.15280E+01	0.10402E-04	0.00000E+00	0.00000E+00	0.00000E+00	-0.17620E-01
0.68469E+02	-0.65493E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.43196E+00
0.00000E+00	0.00000E+00	0.10263E+01	0.92528E-05	0.00000E+00	0.00000E+00
0.00000E+00	0.00000E+00	0.60684E+02	0.97495E+00	0.00000E+00	0.00000E+00
-0.54643E-01	0.11536E-02	0.00000E+00	0.00000E+00	0.10000E+01	0.74791E+00
0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.10000E+01

FMA optics

Will be zoomed on the next page

First order matrix elements

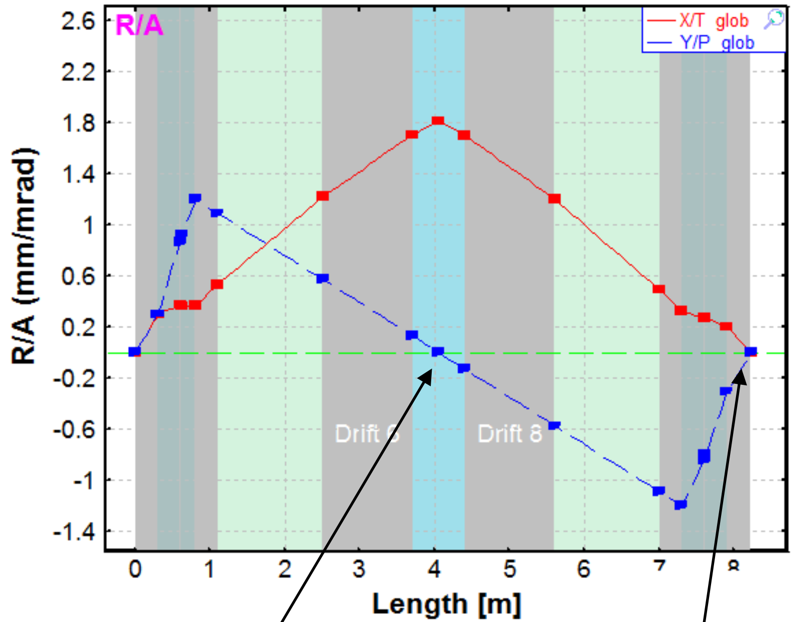
^{32}S (3.6 MeV/u) + Ni (0.4 mg/cm^2); Settings on $^{87}Mo^{18+..18+}$; Config: DSSSSSESDSDSESSSSSSMM
dp/p=14.01% ; Brho(Tm): 0.4392, 0.4392, 0.4392

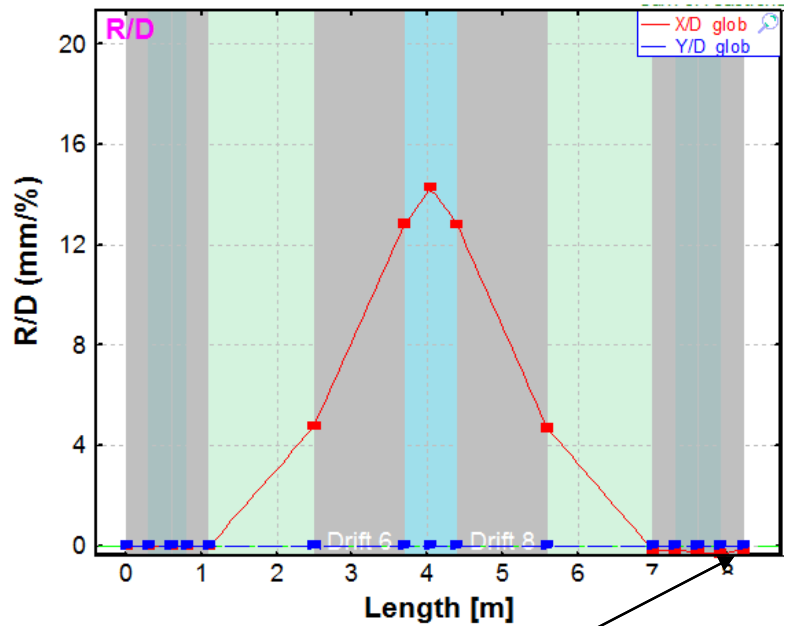


zero angular dispersion

Almost zero angular dispersion

FMA 1st order matrix elements (zoom)





vertical focus

FP – double focus, double achromatic

Attempt to optimize FMA optics without mass dispersion; keeping work after that with COSY Quad values

Optics fit

Blocks with parameters to vary		
#01-q	Position@005:	Q1
#02-q	Position@007:	Q2
#03-q	Position@018:	Q3
#04-q	Position@020:	Q4

Active Constraint blocks			
#01	@012:	R34 = 0	F_DipY
#02	@022:	R16 = 0	F_R16
#03	@023:	R12 = 0	F_R12
#04	@024:	R26 = 0	F_R26
#05	@026:	R34 = 0	F_R34

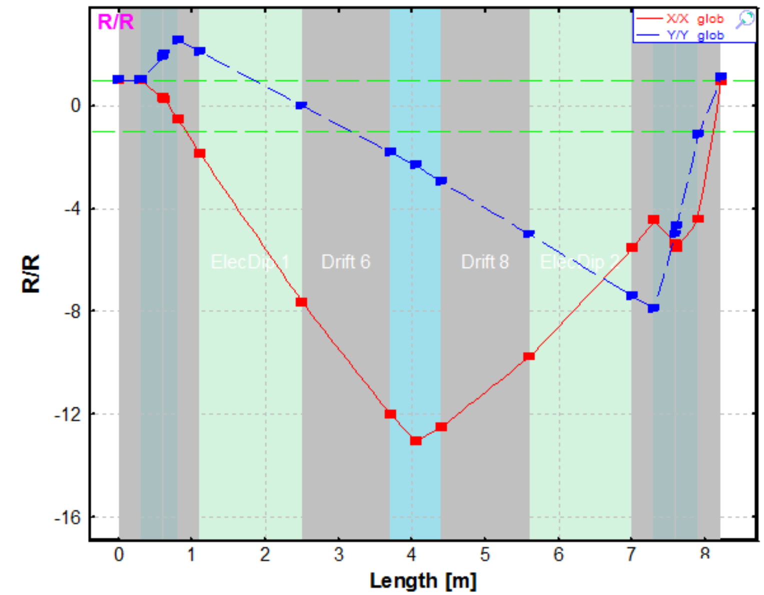
Optics fit was good. All constraints done!

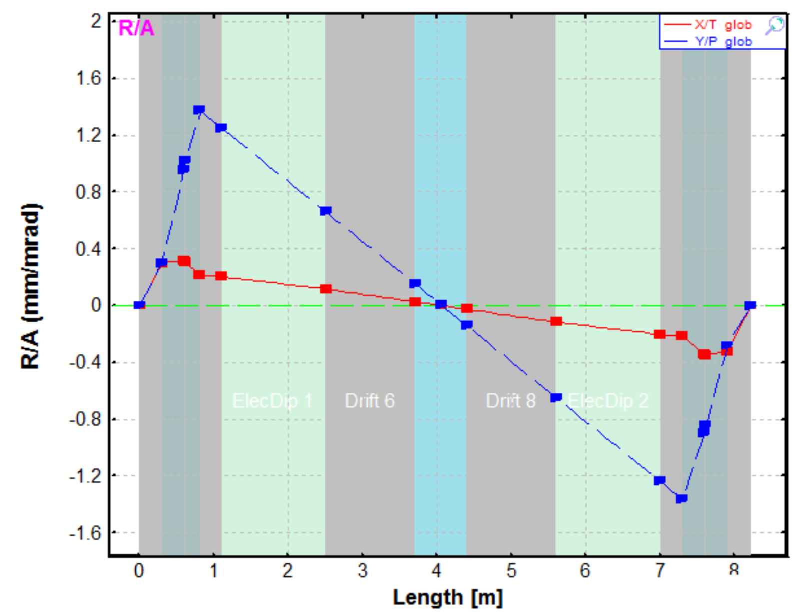
c:\program files (x86)\lise\results\FMA_v5_32S_58Ni_fit.fit_init

```
Initial  +0.273762  LISE fit reduced values

Parameters:          LeftBound      Initial      RightBound  |
#01-q: Q1            +0.0e+00  <  +4.001e+00  <  +5.0e+00   |
#02-q: Q2            -5.0e+00  <  -4.091e+00  <  +0.0e+00   |
#03-q: Q3            -5.0e+00  <  -3.525e+00  <  +5.0e+00   |
#04-q: Q4            -5.0e+00  <  +5.593e+00  <  +5.0e+00   |

----------------------------------------------------------------------------

Constraint values:    Initial      Final      Precision   (Init-Des)/P|    Desired
#01: F_DipY          +4.415e-03               1.0e-02     +4.415e-01 |   = 0
#02: F_R16           +5.741e-06               1.0e-03     +5.741e-03 |   = 0
#03: F_R12           +1.084e-05               1.0e-03     +1.084e-02 |   = 0
#04: F_R26           +8.541e-01               1.0e+01     +8.541e-02 |   = 0
#05: F_R34           -2.093e-03               1.0e-01     +2.093e-02 |   = 0

----------------------------------------------------------------------------

==> "F_R34" : last fitting block global optical matrix and sigma vector

                                              Format [mm-mrad]
==================== G L O B A L ==== matrix ==================  | Beam(sigma) |
  +9.696e-01  +1.084e-05   0           0           0    +5.741e-06 |   9.70e-01 |
  +1.721e+01  +1.032e+00   0           0           0    +8.541e-01 |   1.74e+01 |
   0           0          +1.097e+00  -2.093e-03   0     0         |   1.10e+00 |
   0           0          +7.140e+00  +8.979e-01   0     0         |   7.36e+00 |
  -8.281e-02  -5.705e-07   0           0           1.0  +7.479e+00 |   7.48e+00 |
   0           0           0           0           0    +1.000e+00 |   1.00e+00 |

----------------------------------------------------------------------------
```

But… no more any dispersion in the final focal plane including charge dispersion ☹

See right plots for this optics, and compare with the previous page



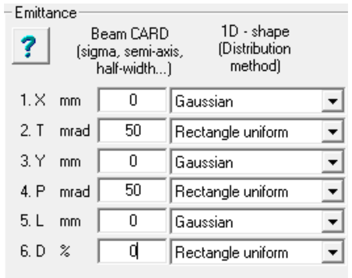


Angular Acceptance

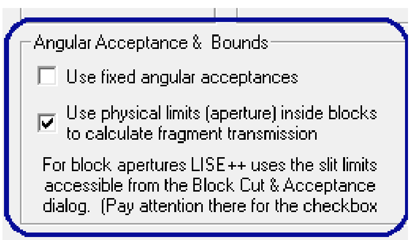
[See details for angular acceptance with the next link http://lise.nscl.msu.edu/9_8/SE_blocks.pdf#page=5](http://lise.nscl.msu.edu/9_8/SE_blocks.pdf#page=5)

Settings

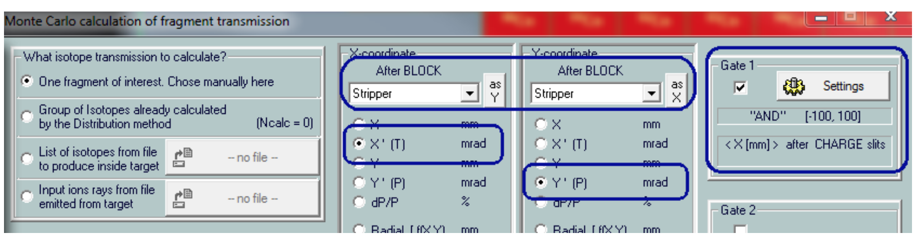
Beam dialog



Monte Carlo options

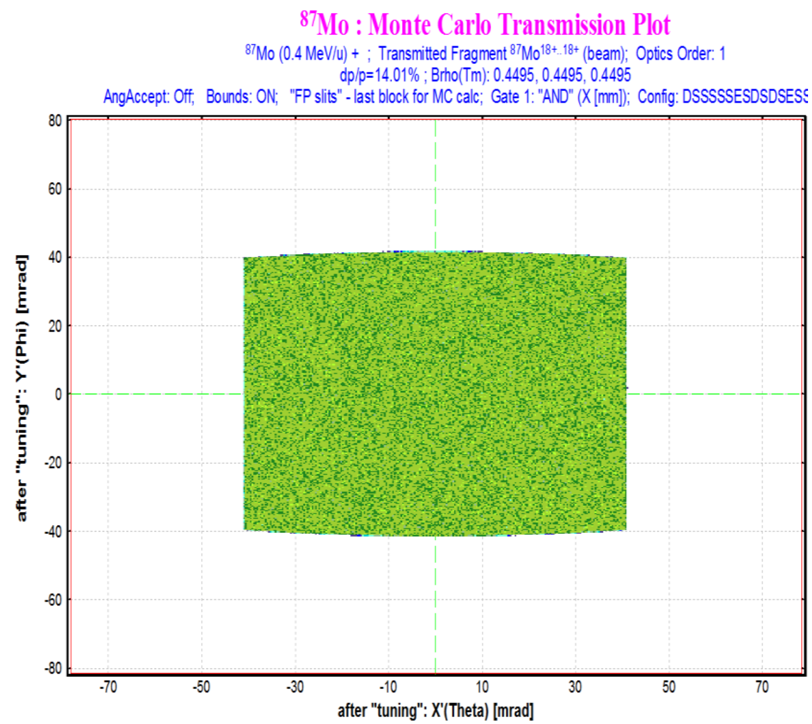


Monte Carlo Transmission settings



Coming to the FP

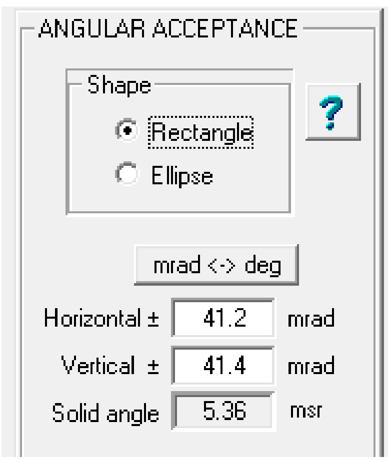
Initial emittance gated on the final focal plane

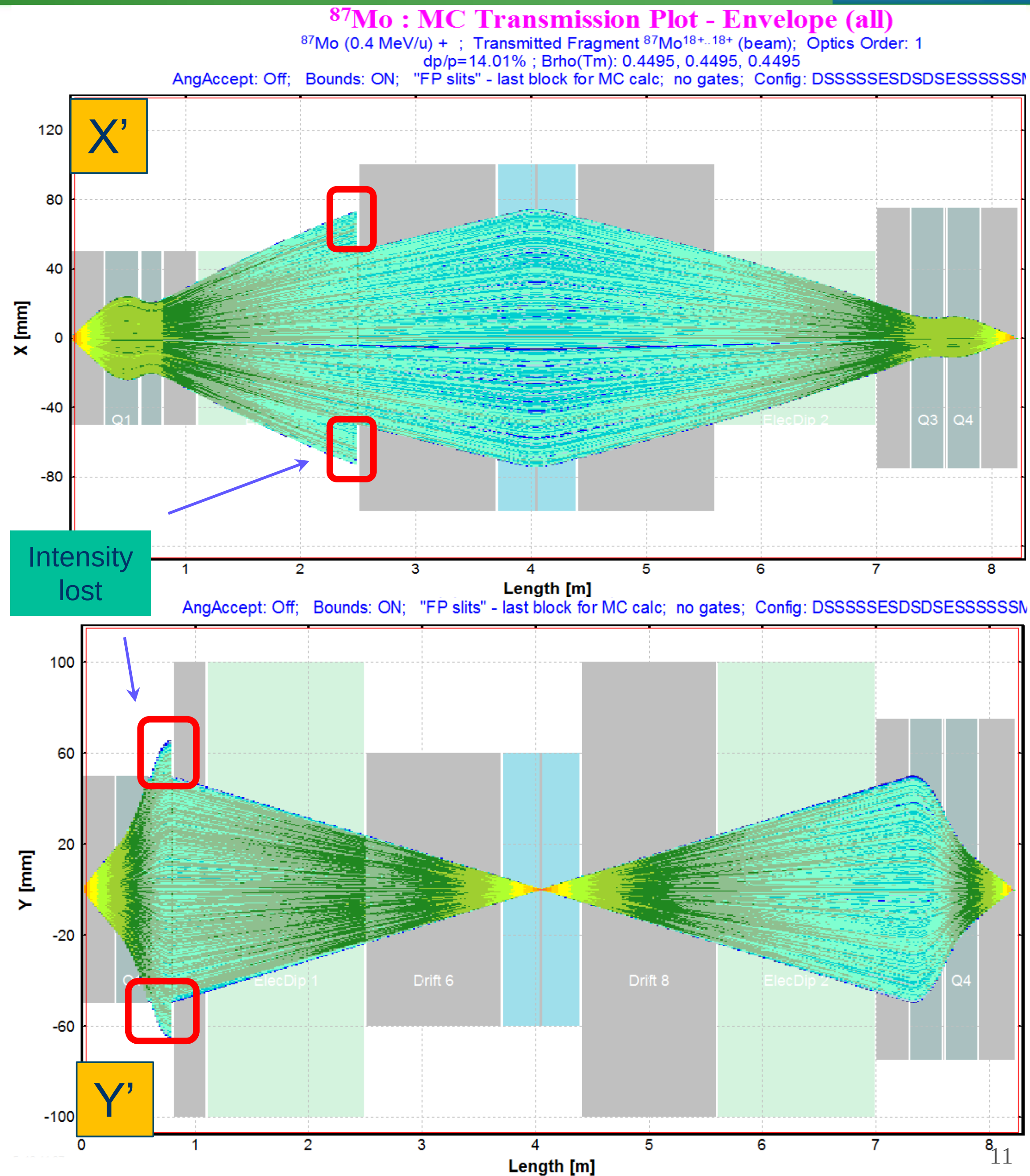


Angular acceptance is equal to ±41.2 x ±41.4 mrad, that corresponds to 5.36 msr

Angular Acceptance : Results

http://lise.nscl.msu.edu/9_10/FMA_beam.lpp





Angular Acceptances transmission benchmarks

MICHIGAN STATE UNIVERSITY

LISE++

"Distribution" method

With set Angular Acceptances

Emittance

		Beam CARD (sigma, semi-axis, half-width...)	1D - shape (Distribution method)
1. X	mm	0	Gaussian
2. T	mrad	50	Rectangle uniform
3. Y	mm	0	Gaussian
4. P	mrad	50	Rectangle uniform
5. L	mm	0	Gaussian
6. D	%	0	Rectangle uniform

87Mo Beta+ decay (Z=42, N=45)

Q1 (tuning)		18
Q2 (ElecDip 1)		18
Q3 (DipoleA)		18
Q4 (DipoleB)		18
Q5 (ElecDip 2)		18
Reaction		BEAM
Ion Production Rate	(pps)	2.35e+10
Total ion transmission	(%)	67.68
Total: this reaction	(pps)	2.35e+10
Total: All reactions	(pps)	2.35e+10
X-Section in target	(mb)	beam
Target	(%)	100
Q (Charge) ratio	(%)	100
tuning	(%)	67.68
X angular transmission	(%)	82.47
Y angular transmission	(%)	82.07

"Monte Carlo " method

With set Angular Acceptances
No bounds

Angular Acceptance & Bounds

- [x] Use fixed angular acceptances
- [ ] Use physical limits (aperture) inside blocks to calculate fragment transmission

For block apertures LISE++ uses the slit limits accessible from the Block Cut & Acceptance dialog. (Pay attention there for the checkbox

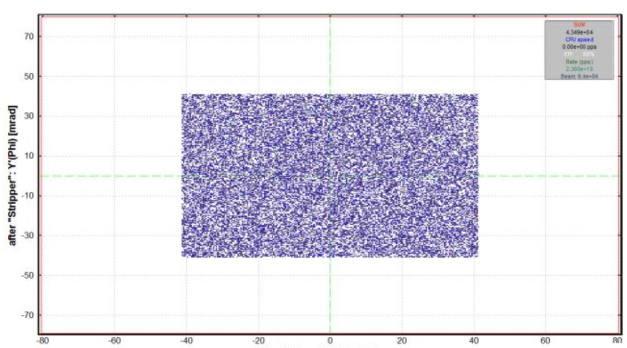
Monte Carlo transmission statistics by blocks

Isotope Group : Monte Carlo Yield Plot

87Mo (0.4 MeV/u) + ; Transmitted Fragment 87Mo18+.
dp/p=14.01% ; Brho(Tm): 0.4495, 0.4495, 0.4495
AngAccept: ON; Bounds: Off; "FP slits" - last bl

#	Ion	N of Passed	N of Initial	Transmission
All		43542	64068	67.96%
0	87Mo	43493	64000	67.96% (+/-0.33%)

Target	100.0%
tuning	67.96%
Angular acceptance	67.96%



"Monte Carlo " method

No Angular Acceptances
WITH bounds

Angular Acceptance & Bounds

- [ ] Use fixed angular acceptances
- [x] Use physical limits (aperture) inside blocks to calculate fragment transmission

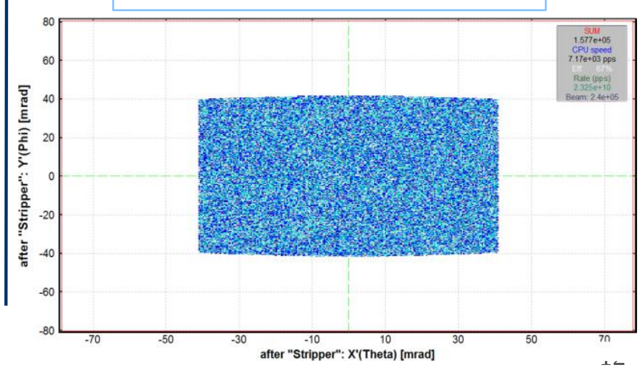
For block apertures LISE++ uses the slit limits accessible from the Block Cut & Acceptance dialog. (Pay attention there for the checkbox

Isotope Group : Monte Carlo Yield Plot

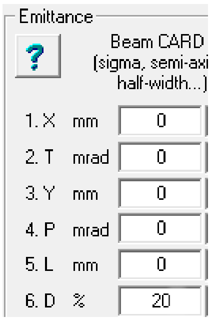
87Mo (0.4 MeV/u) + ; Transmitted Fragment 87Mo18+..
dp/p=14.01% ; Brho(Tm): 0.4495, 0.4495, 0.4495
AngAccept: Off; Bounds: ON; "FP slits" - last blc

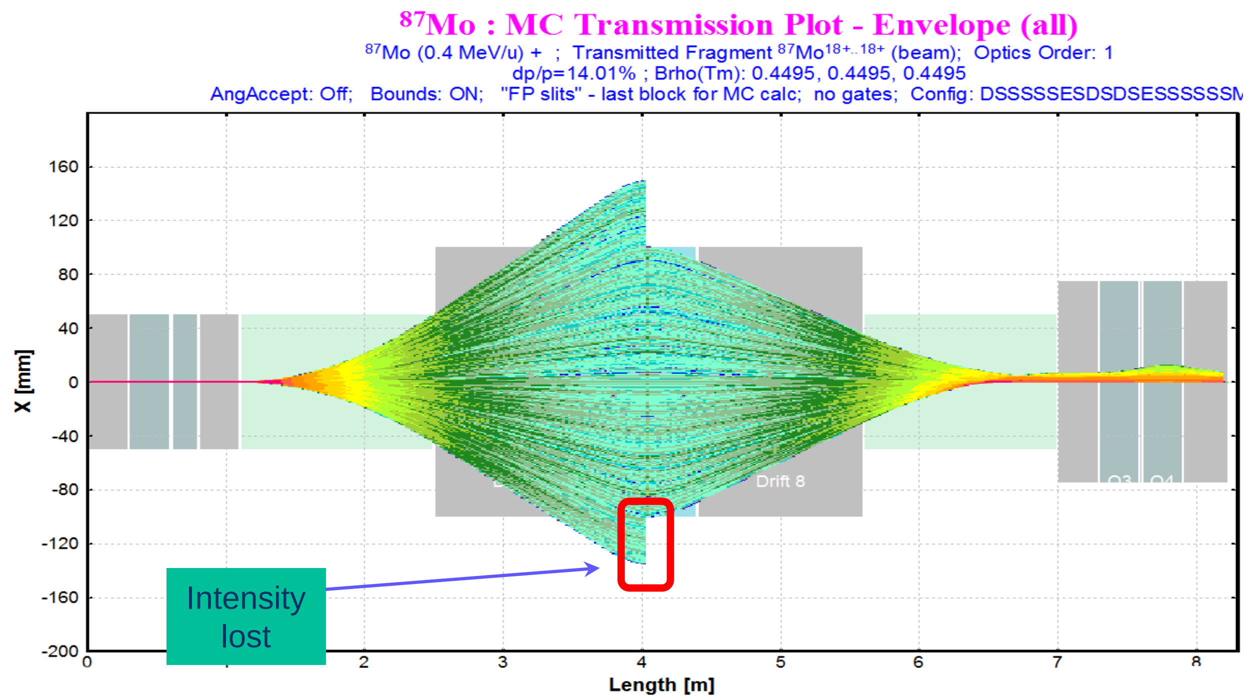
#	Ion	N of Passed	N of Initial	Transmission
All		157691	235520	66.95%
0	87Mo	229611	343040	66.93% (+/-0.14%)

Target	100.0%
tuning	100.0%
Drift 1	100.0%
Q1	100.0%
Drift 3	100.0%
Q2	81.26%
Inside of bounds	81.26%
Drift 5	100.0%
ElecDip 1	82.39%
Inside of bounds	82.39%



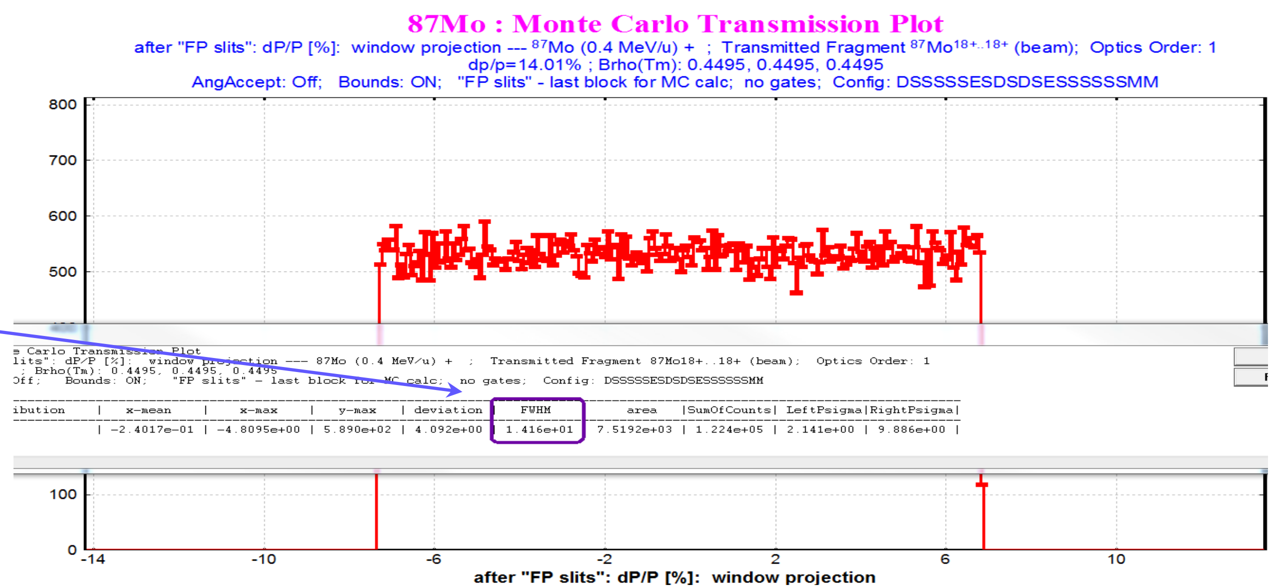
Momentum Acceptance





Corresponds to the Dipole X-aperture ± 100 mm

$\Delta P/P = \pm 7.05$ %
($\Delta E/E = \pm 14.1$ %)



FMA acceptances benchmark

Emittance corresponding to the acceptances

Emittance

		Beam CARD (sigma, semi-axis, half-width...)	1D - shape (Distribution method)
1. X	mm	0	Gaussian
2. T	mrad	41.2	Rectangle uniform
3. Y	mm	0	Gaussian
4. P	mrad	41.4	Rectangle uniform
5. L	mm	0	Gaussian
6. D	%	7.05	Rectangle uniform

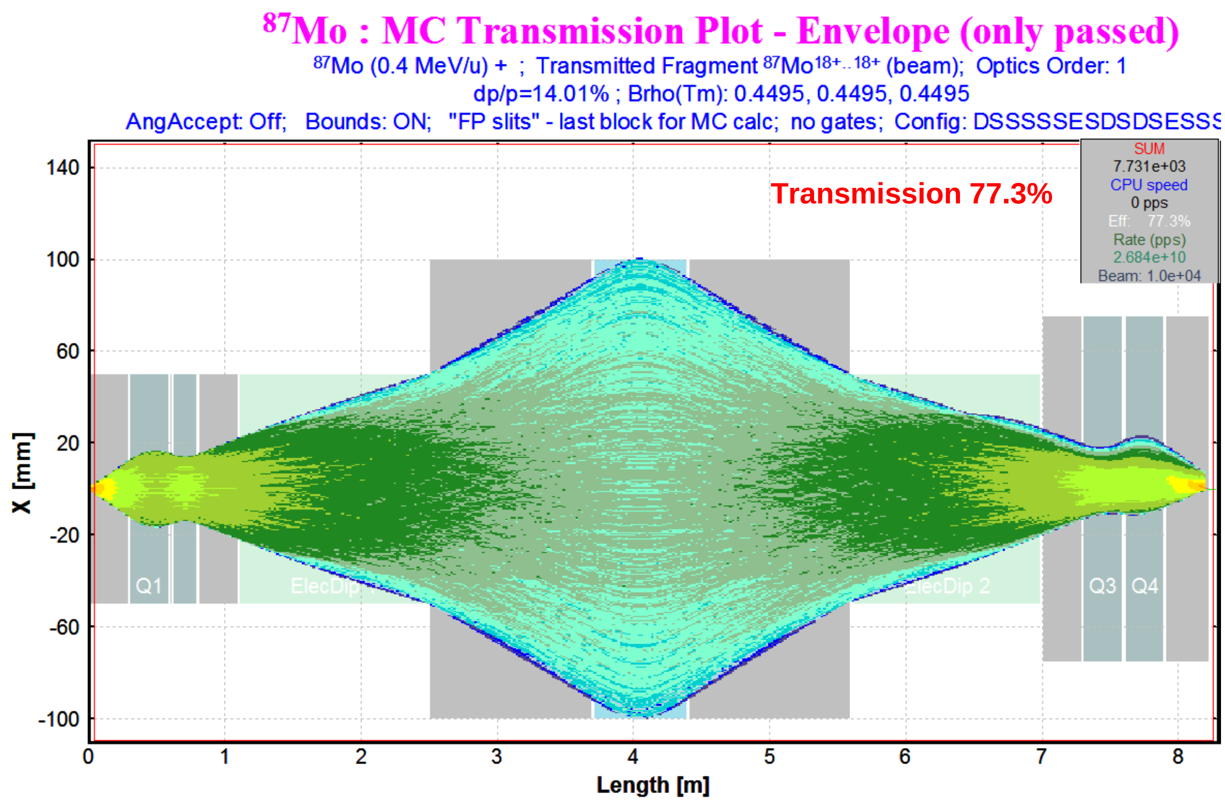
"Distribution" method

With set Angular Acceptances

87Mo Beta+ decay (Z=42, N=45)

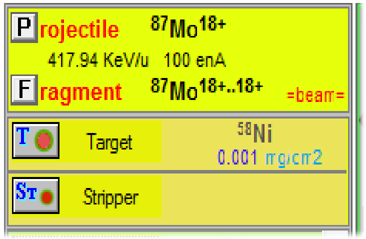
Q1 (tuning)		18
Q2 (ElecDip 1)		18
Q3 (DipoleA)		18
Q4 (DipoleB)		18
Q5 (ElecDip 2)		18
Reaction		BEAM
Ion Production Rate	(pps)	2.72e+10
Total ion transmission	(%)	78.363
Total: this reaction	(pps)	2.72e+10
Total: All reactions	(pps)	2.72e+10
X-Section in target	(mb)	beam
Target	(%)	100
Q (Charge) ratio	(%)	100
tuning	(%)	96.35
X angular transmission	(%)	98.42
Y angular transmission	(%)	97.9
Drift 1	(%)	100
Q1	(%)	100
Drift 3	(%)	100
Q2	(%)	100
Drift 5	(%)	100
ElecDip 1	(%)	100
Drift 6	(%)	100
DipoleA	(%)	100
dip slits	(%)	81.33
X space transmission	(%)	81.33
Y space transmission	(%)	100

"Monte Carlo" method; No Angular Acceptances; WITH bounds



Charge state selection

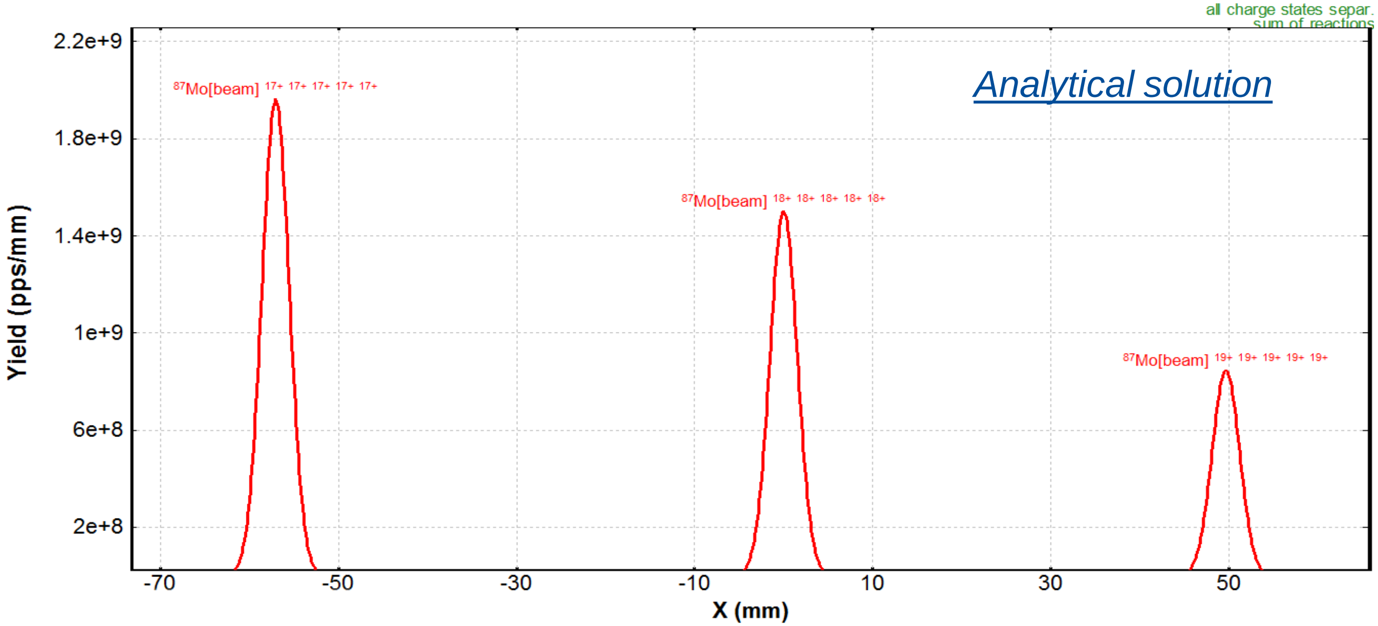
http://lise.nscl.msu.edu/9_10/FMA_beam.lpp

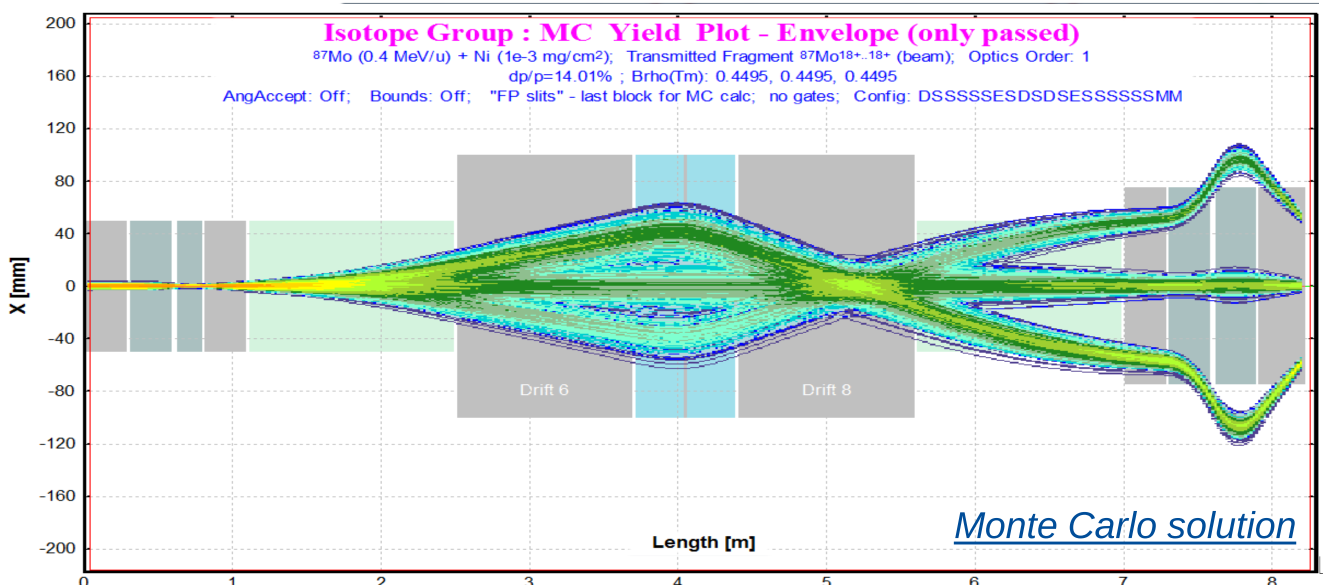


Very thin target for charge state simulation

FP slits-Xspace: output after slits

^{87}Mo (0.4 MeV/u) + Ni (1e-3 mg/cm^2); Settings on $^{87}Mo^{18+..18+}$; Config: DSSSSSESDSDSESSSSSSMM
dp/p=14.01% ; Brho(Tm): 0.4495, 0.4495, 0.4495





Envelopes : LISE^{++} Monte Carlo solution

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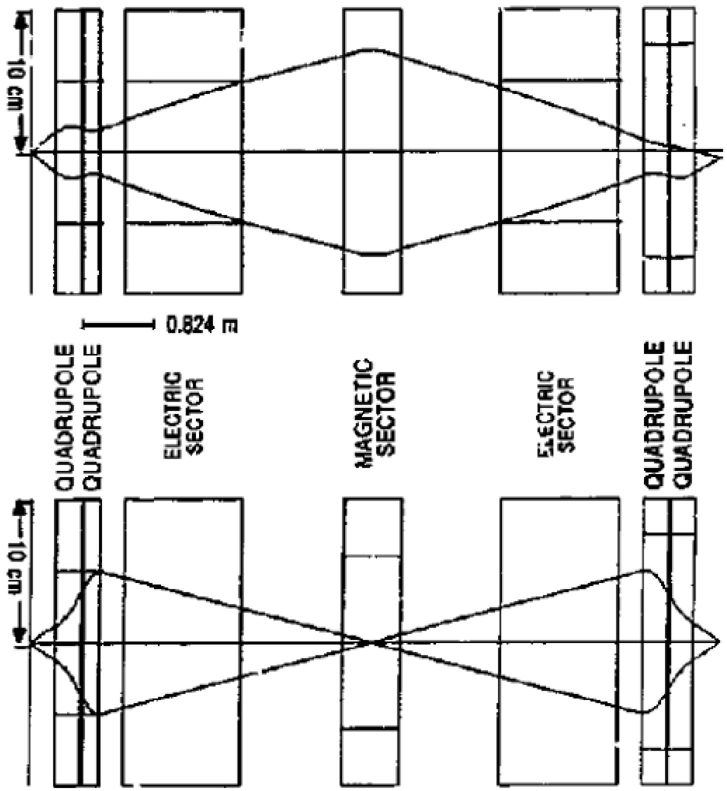
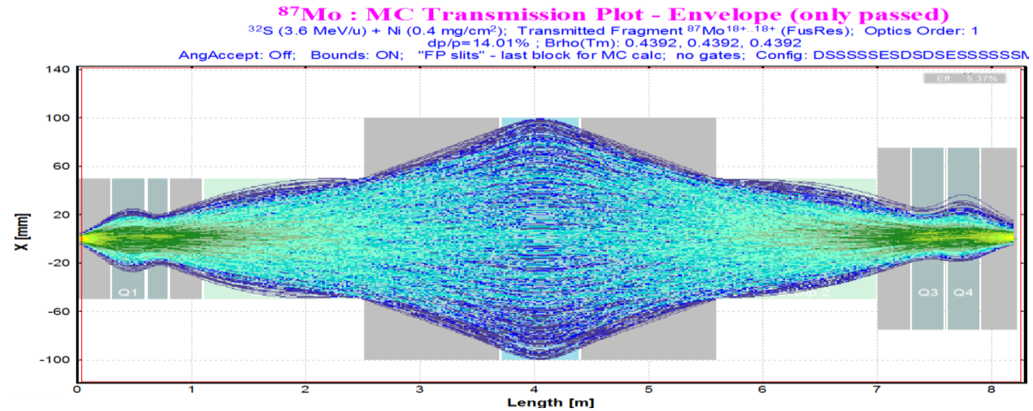
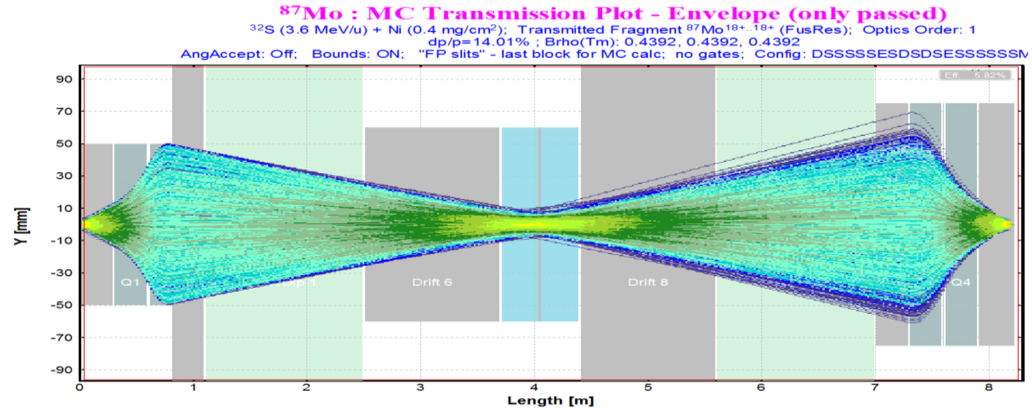
LISE^{++}

X
horizontal

Y
vertical







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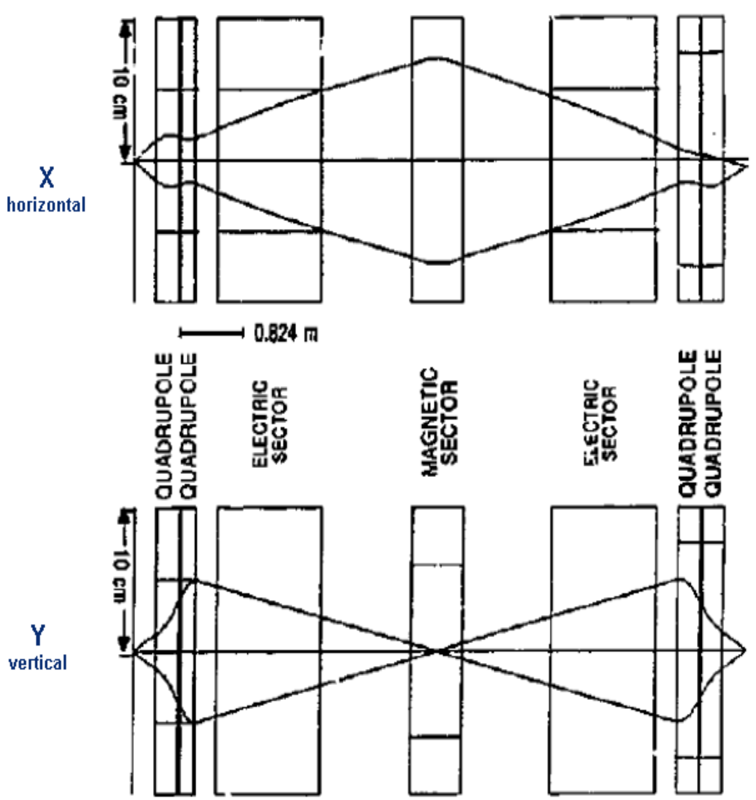
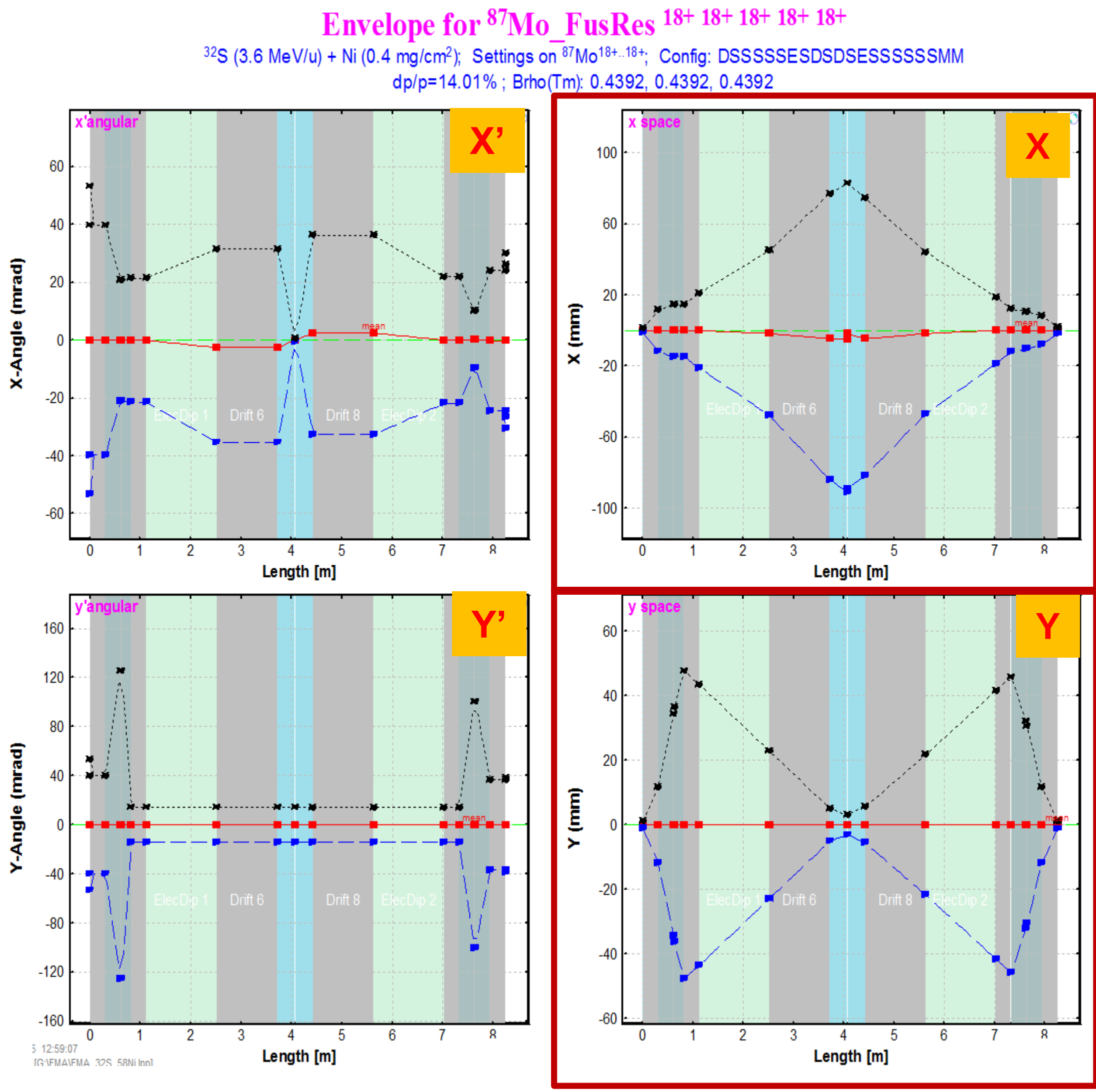
LISE++





Experiment ^{32}S (115 MeV) + ^{58}Ni

A 99% enriched ^{58}Ni target of 400 μg/cm^2 thickness was mounted in the center of the scattering chamber. A 25%-efficient Ge detector was placed in a re-entrant cup at 90° to the beam at a distance of 4 cm from the target, and a tightly collimated Si surface barrier detector was located in the scattering chamber at 45° to serve as a beam monitor. The FMA itself was placed at 0° to the incoming beam, and its fields were set for a recoil having mass 87, charge state 18, and an energy of 36.4 MeV. No charge-state reset foil was used.

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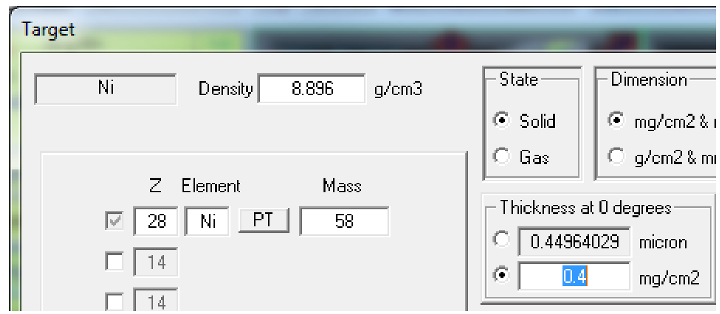
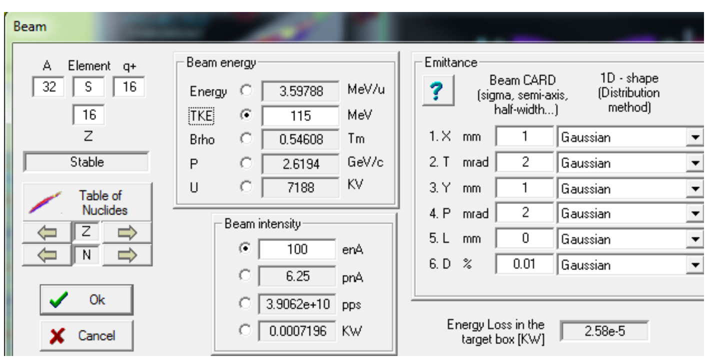
Target



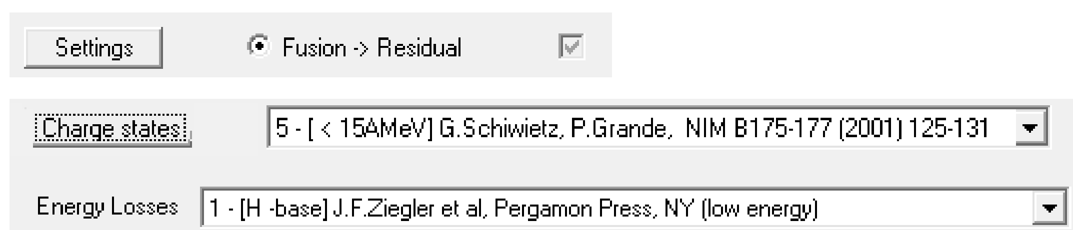
LISE^{++} settings

File: FMA_32S_58Ni.lpp

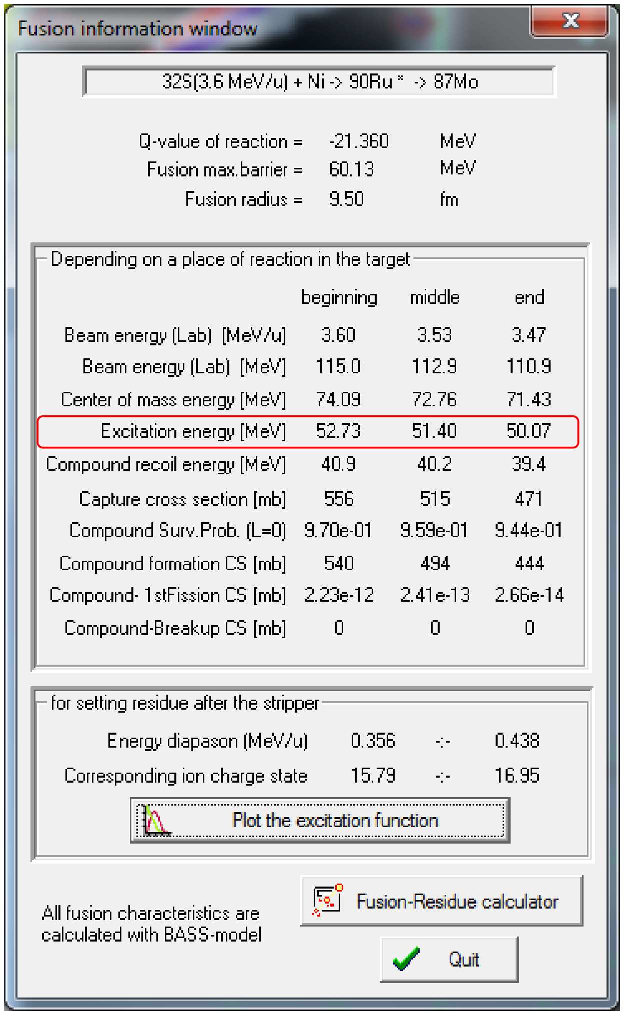
Beam



Production mechanism



Experiment ^{32}S (115 MeV) + ^{58}Ni : fusion-residue reaction



Fusion information window

32S(3.6 MeV/u) + Ni -> 90Ru * -> 87Mo

Q-value of reaction =	-21.360	MeV
Fusion max.barrier =	60.13	MeV
Fusion radius =	9.50	fm

Depending on a place of reaction in the target

	beginning	middle	end
Beam energy (Lab) [MeV/u]	3.60	3.53	3.47
Beam energy (Lab) [MeV]	115.0	112.9	110.9
Center of mass energy [MeV]	74.09	72.76	71.43
Excitation energy [MeV]	52.73	51.40	50.07
Compound recoil energy [MeV]	40.9	40.2	39.4
Capture cross section [mb]	556	515	471
Compound Surv.Prob. (L=0)	9.70e-01	9.59e-01	9.44e-01
Compound formation CS [mb]	540	494	444
Compound- 1stFission CS [mb]	2.23e-12	2.41e-13	2.66e-14
Compound-Breakup CS [mb]	0	0	0

for setting residue after the stripper

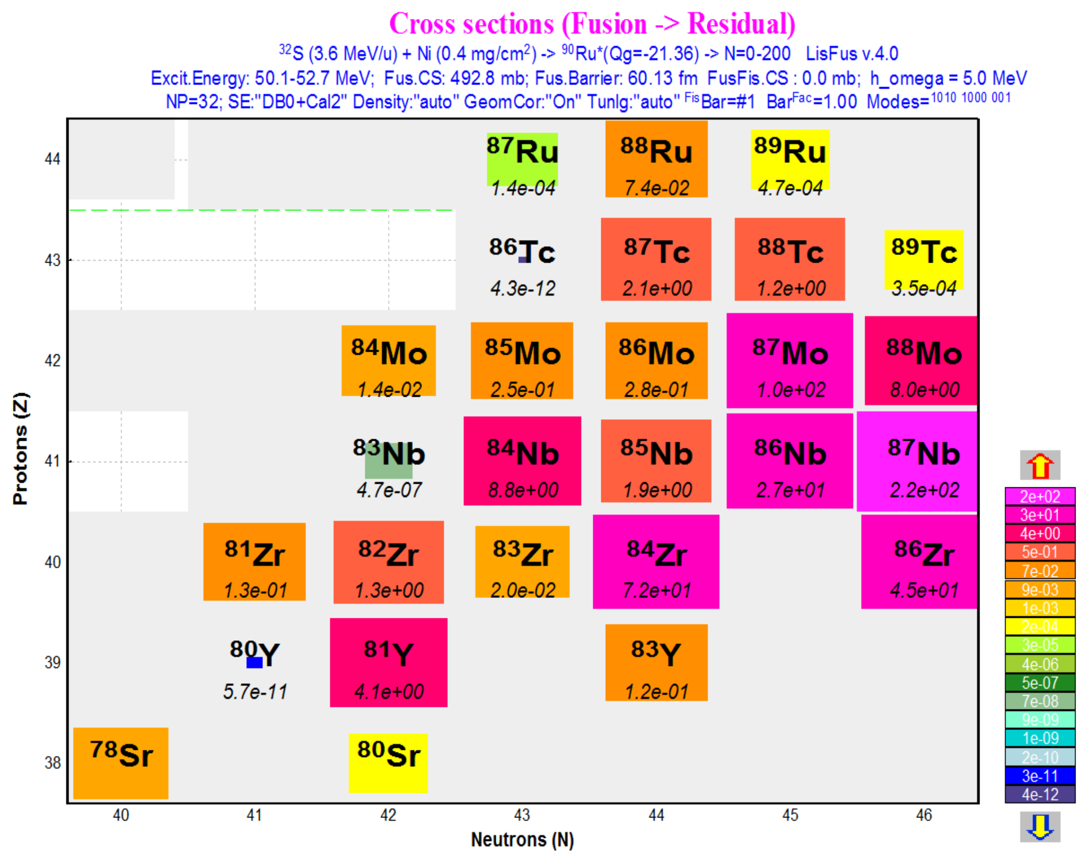
Energy diapason (MeV/u)	0.356	-:-	0.438
Corresponding ion charge state	15.79	-:-	16.95

Plot the excitation function

All fusion characteristics are calculated with BASS-model

Fusion-Residue calculator

Quit



LISE^{++}
Analytical solution

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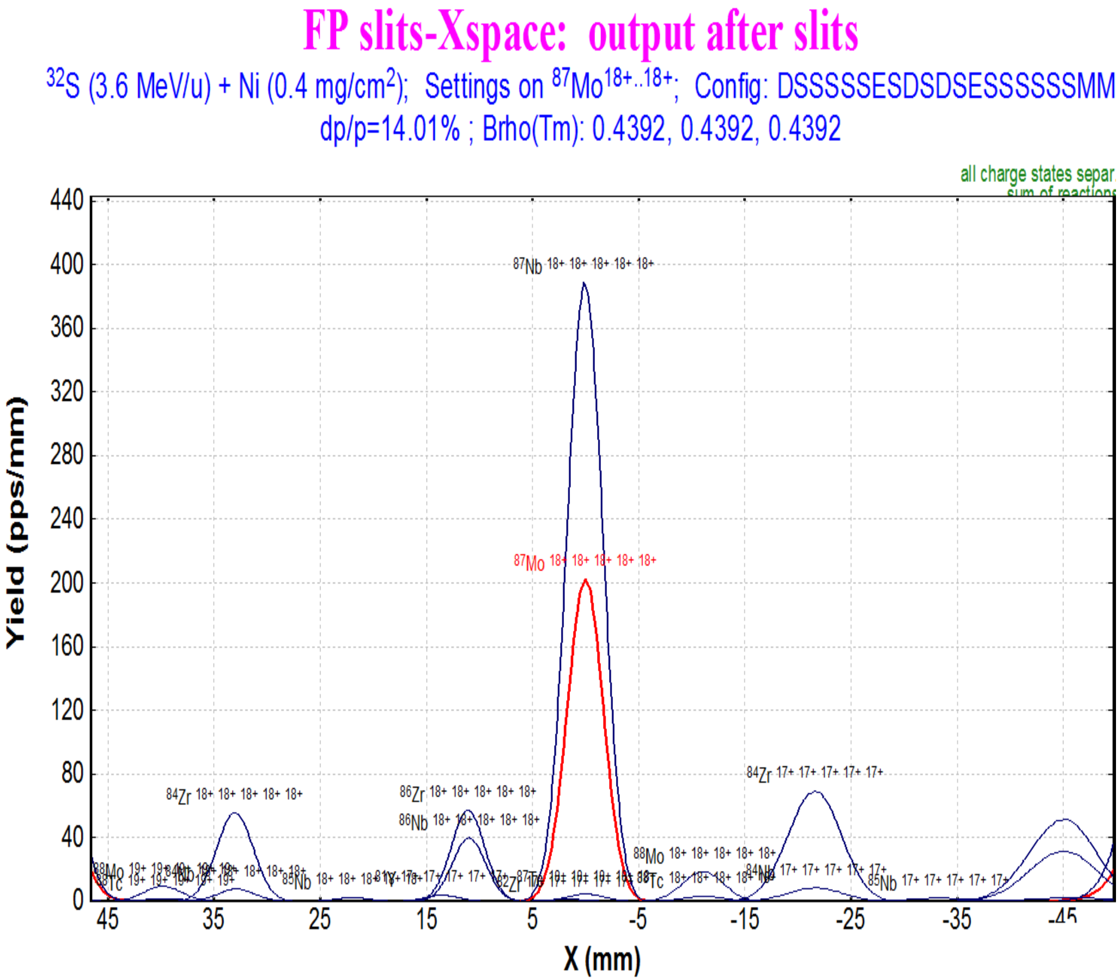


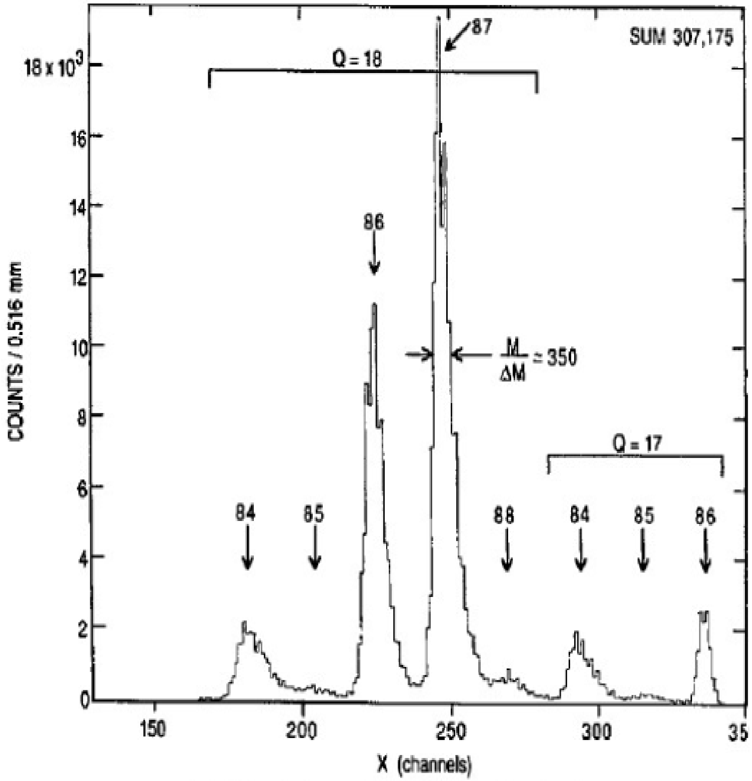
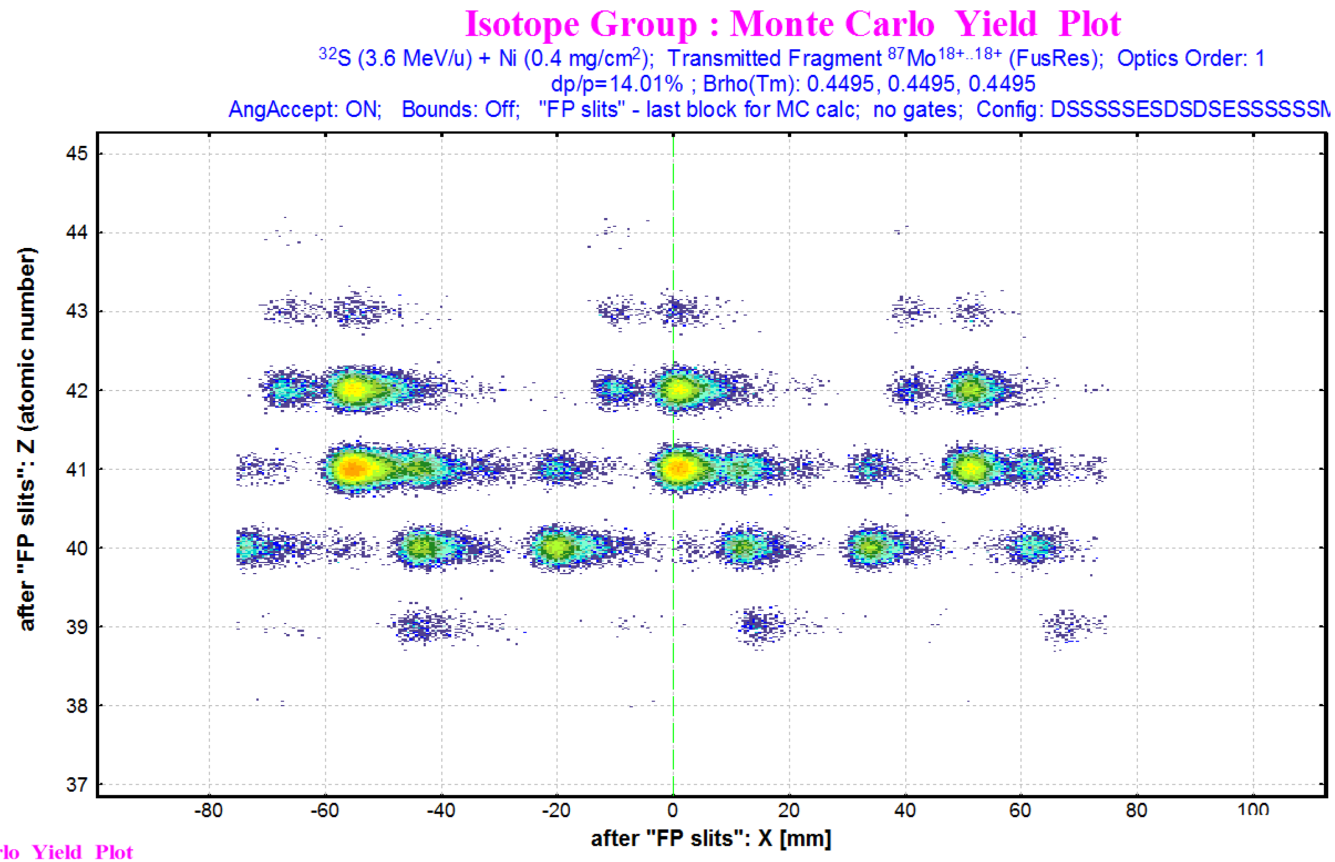
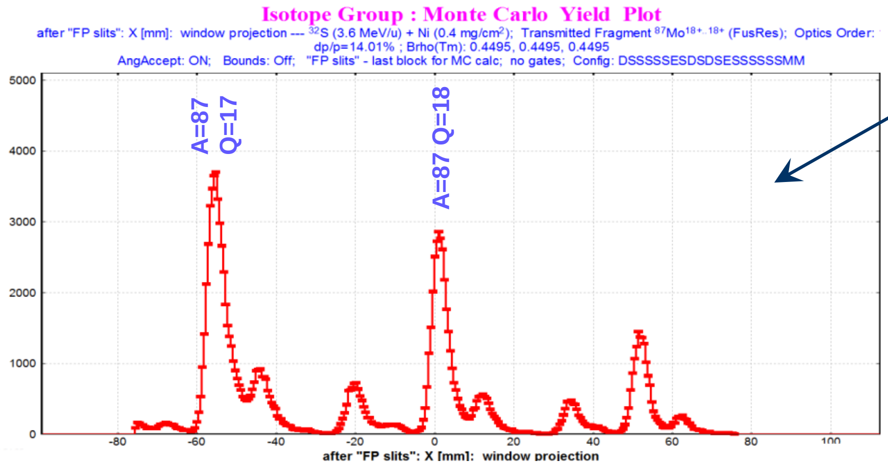


Fig. 8. X-projection of the recoil groups from fig. 7.

Experiment ^{32}S (115 MeV) + ^{58}Ni : Monte Carlo solution





Horizontal projection
(this X-inverted plot is used on the next page)

Horizontal distribution @ Final Focal plane

LISE++
Monte Carlo solution

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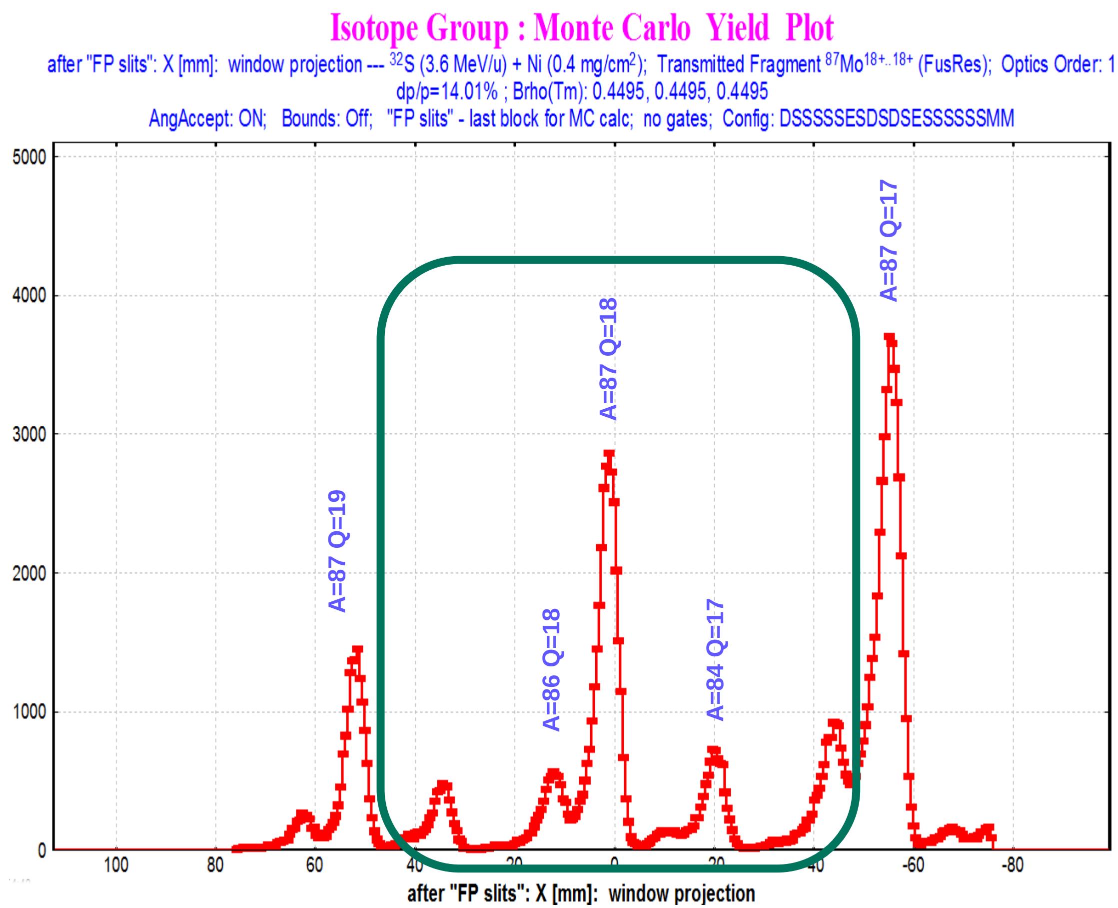


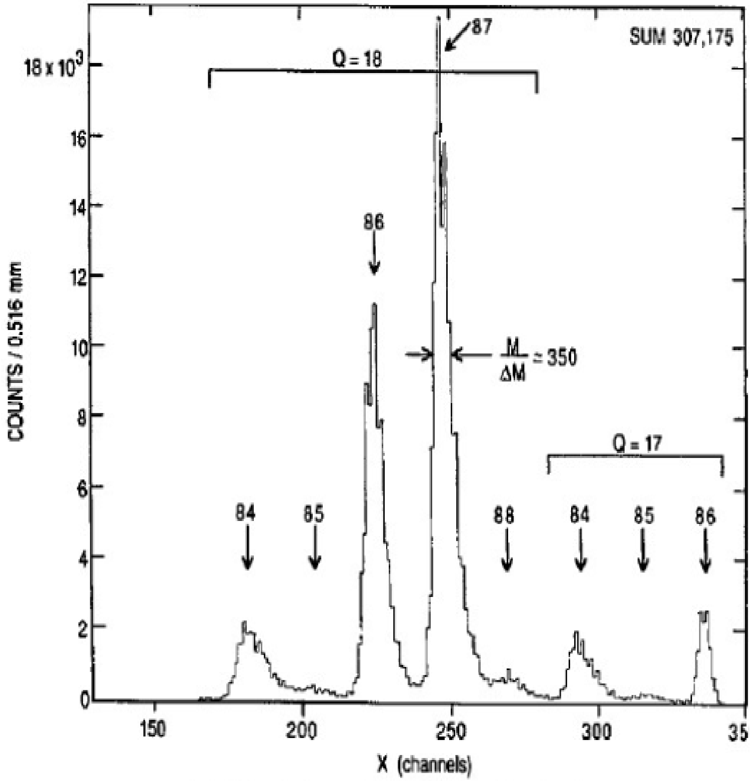


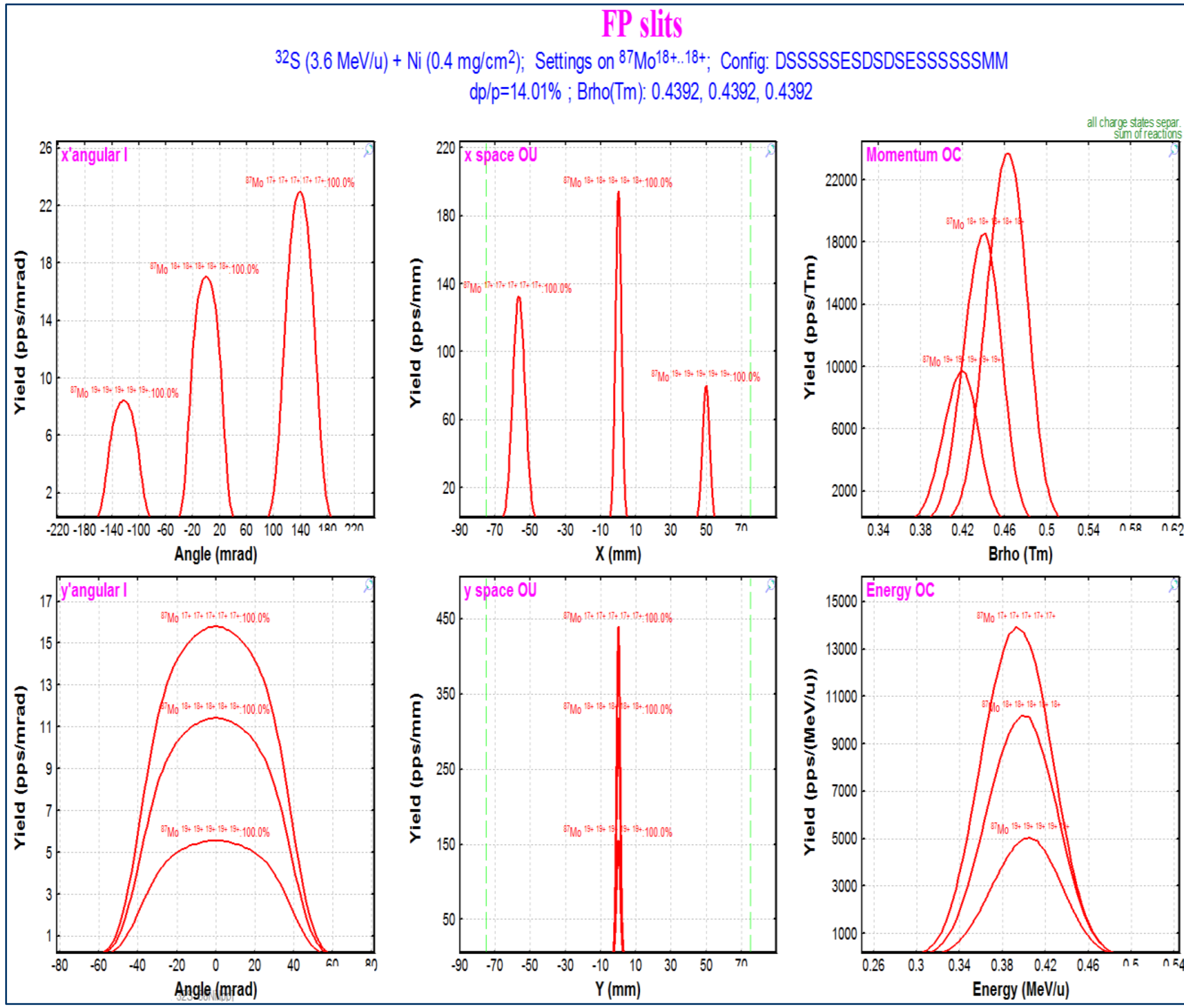
Fig. 8. X-projection of the recoil groups from fig. 7.

Experiment ^{32}S (115 MeV) + ^{58}Ni : ^{87}Mo isotopes transmission

^{87}Mo isotopes @ FP (tuning for ^{87}Mo^{18+}) : transmission 14.8 %

^{87}Mo isotopes @ FP (tuning for ^{87}Mo^{16+}) : transmission 20.9 %

87Mo		Beta+ decay (Z=42, N=45)		Molybdenum
All reactions total isotope rate		2.45e+3	pps	
and Overall isotope transmission		14.807	%	
Q1 (tuning)		19	18	17
Q2 (ElecDip 1)		19	18	17
Q3 (DipoleA)		19	18	17
Q4 (DipoleB)		19	18	17
Q5 (ElecDip 2)		19	18	17
Reaction		FusRes	FusRes	FusRes
Ion Production Rate	(pps)	3.75e+2	8.49e+2	1.23e+3
Total ion transmission	(%)	2.265	5.131	7.412
Total: this reaction	(pps)	2.45e+3	2.45e+3	2.45e+3
X-Section in target	(mb)	1.02e+2	1.02e+2	1.02e+2
Target	(%)	6.79	14.84	22.46
Unreacted in material	(%)	100	100	100
Q (Charge) ratio	(%)	6.79	14.84	22.46
Unstopped in material	(%)	100	100	100
tuning	(%)	40.98	40.98	40.98
X angular transmission	(%)	63.9	63.9	63.9
Y angular transmission	(%)	64.13	64.13	64.13
Drift 1	(%)	100	100	100
Q1	(%)	100	100	100
Drift 3	(%)	100	100	100
Q2	(%)	100	100	100
Drift 5	(%)	100	100	100
ElecDip 1	(%)	100	100	100
Drift 6	(%)	100	100	100
DipoleA	(%)	100	100	100
dip slits	(%)	81.35	84.38	80.53
X space transmission	(%)	81.35	84.38	80.53
Y space transmission	(%)	100	100	100



Outlook and Acknowledgement

Open Questions:

1. Mass & charge dispersion values calculation
2. Using Mass & charge dispersion values for optimization

Acknowledgement:

to Darek Seweryniak for documents and files providing,
to Mauricio Portillo with COSY actions