Argonne In-flight Radioactive Ion Separator

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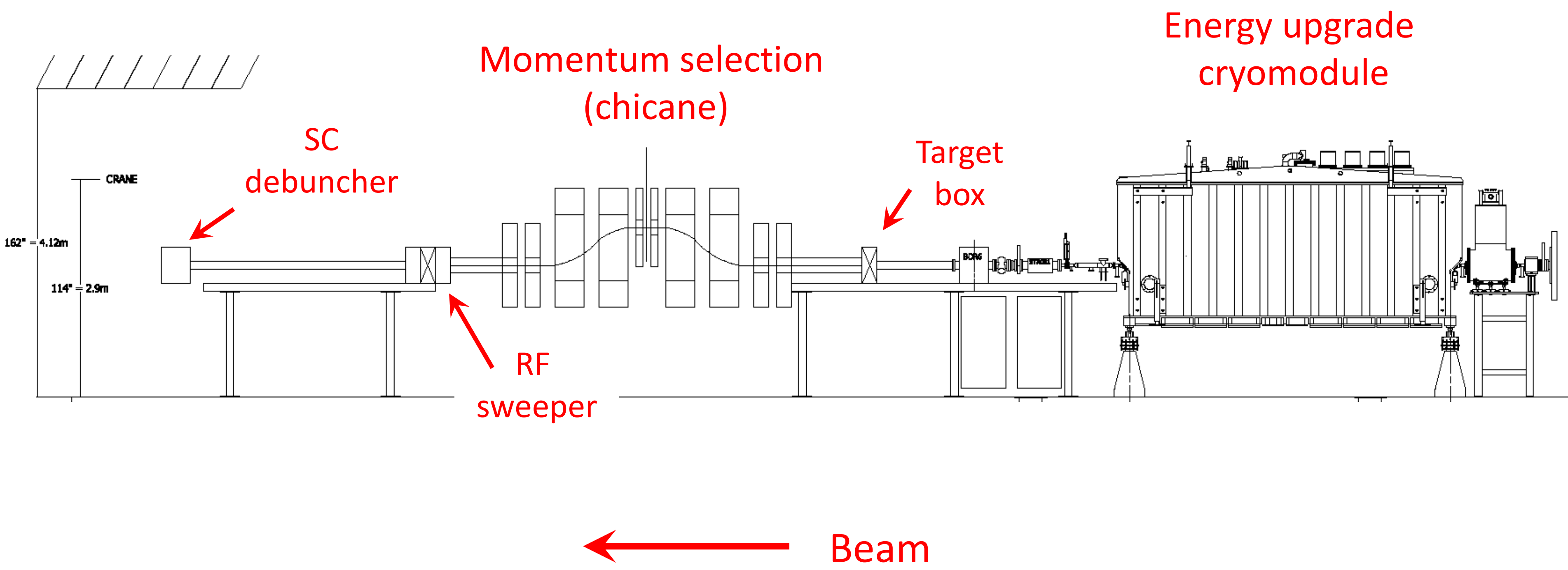
Introduction

- The Argonne In-flight Radioactive Ion Separator (AIRIS) is a new large recoil separator that is being designed as a part of proposed future upgrade of the ATLAS facility
- It will provide at least **10 times** more collection efficiency than the existing system
- In combination with other proposed upgrades it will provide a **2 orders** of magnitude gain in the intensity for the in-flight produced secondary beams compared to the existing facility
- The resulting unprecedented intensities for the recoil beam open new opportunities in several physics domains, e.g. gamma ray spectroscopy after secondary reactions, reactions for rp-, νp-, αp- processes and CNO cycle

beam	reaction	I (pnA)	E(pro)	sigma	thickn.	N_prod	ch. st.	F(q)	E(rib)	DE(r)	E(pr)	DE(p)	N(max)	achieved	contaminants
			(MeV)	*(mb)*	*mg/cm2*	*counts/s*			*MeV*	*fwhm*	*MeV*	*fwhm*	*/sec*	*/sec*	*(rate multiplier)*
14O	1H(14N,14O)n	1000	140	8	1.5	4.50E+07	8	1	124	3	132.5	0.1	4.50E+07	1.00E+05	14N, 11C(6)
33Cl	2H(32S,33Cl)n	1000	200	75	3	4.00E+08	15|16	0.3	145	7	150	0.2	1.00E+08	2.00E+04	32S, 33S(5)
56Ni	12C(52Cr,56Ni)4n	1000	450	60	1.2	2.20E+07	25|26	0.3	340	16	391	0.7	6.70E+06	2.00E+04	52Cr,56Co(10), 57Co(10),57Ni(2)
19O	2H(18O,19O)p	1000	180	37.5	3	2.10E+08	8	1	169	3	170	0.1	2.10E+08	2.00E+05	18OA

Conceptual layout of in-flight separator upgrade



- The proposed design for the AIRIS device is based on four multipole magnets and four dipole magnets arranged in a so called broadband spectrometer configuration
- This arrangement will be followed by two RF cavities to provide further selection based on velocity differences between the primary beam tail and the recoiling RIB

Design using multipoles

- Max quad poletip field=1.5T
- Half aperture=10cm
- Max Dipole field=1T
- Angle=22.5deg
- Radius=1m
- Total S-Length=5.87m (Z length 5.8m)

Design using multipoles

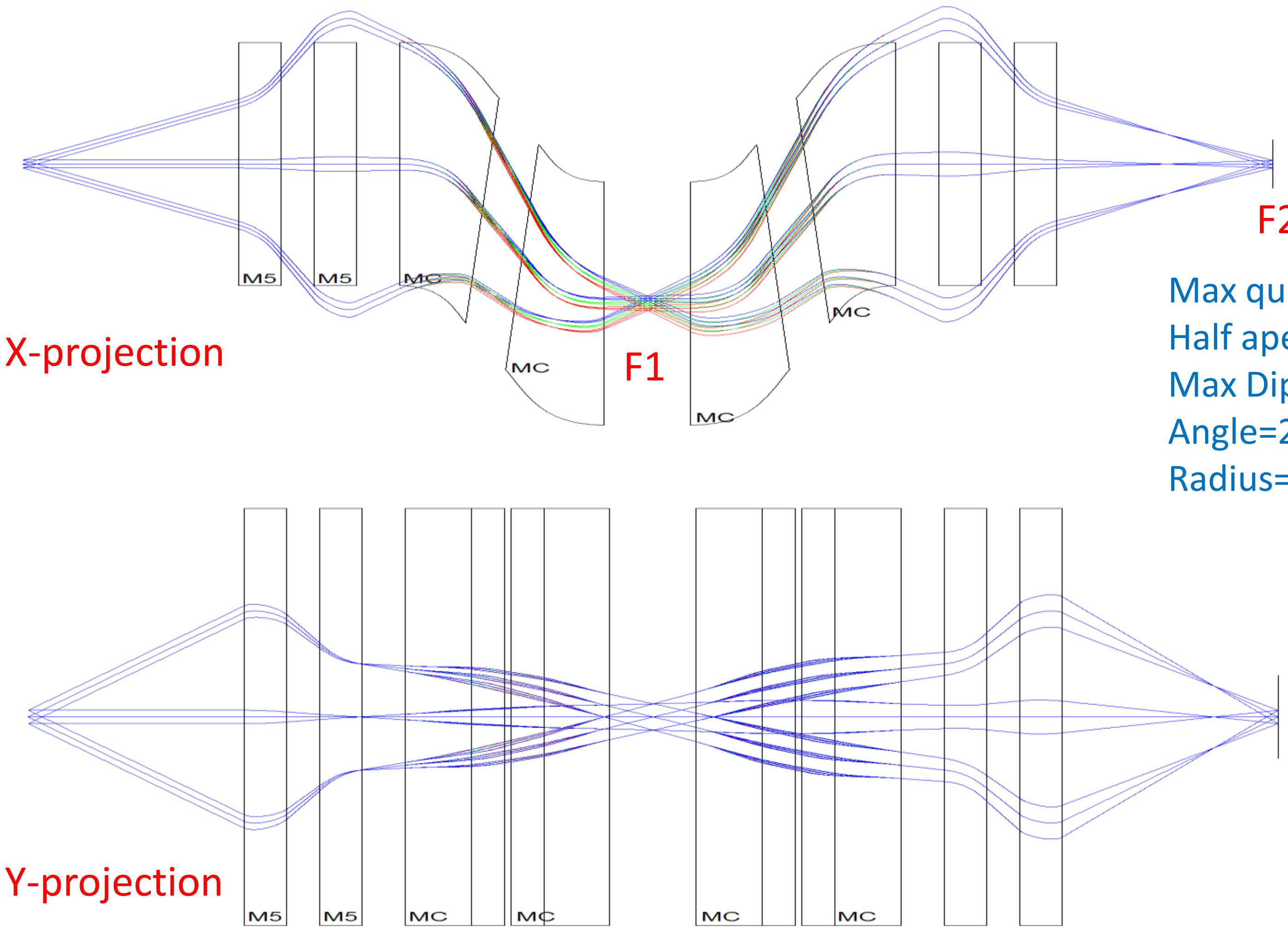
First order transfer map at the center

x	a	y	b	t	xaybtdmq
-0.6178139	-1.667354	0.0000000E+00	0.0000000E+00	-0.2131190	10000000
0.0000000E+00	-1.618610	0.0000000E+00	0.0000000E+00	-0.2068887	01000000
0.0000000E+00	0.0000000E+00	-1.981845	-0.8527079	0.0000000E+00	00100000
0.0000000E+00	0.0000000E+00	0.0000000E+00	-0.5045804	0.0000000E+00	00010000
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	1.000000	00001000
0.1278187	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.7465485	00000100
0.1266340	0.0000000E+00	0.0000000E+00	0.0000000E+00	-0.7076967	00000010
-0.2544527	0.0000000E+00	0.0000000E+00	0.0000000E+00	-0.3885182E-01	00000001

First order transfer map at the end

x	a	y	b	t	xaybtdmq
1.000000	2.027434	0.0000000E+00	0.0000000E+00	0.0000000E+00	10000000
0.1363363E-09	0.9840816	0.0000000E+00	0.0000000E+00	0.0000000E+00	01000000
0.0000000E+00	0.0000000E+00	1.000000	3.326067	0.0000000E+00	00100000
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.9840816	0.0000000E+00	00010000
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	1.016022	00001000
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	1.517020	00000100
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	-1.438071	00000010
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	-0.7894863E-01	00000001

Design 1: Using Multipole magnets

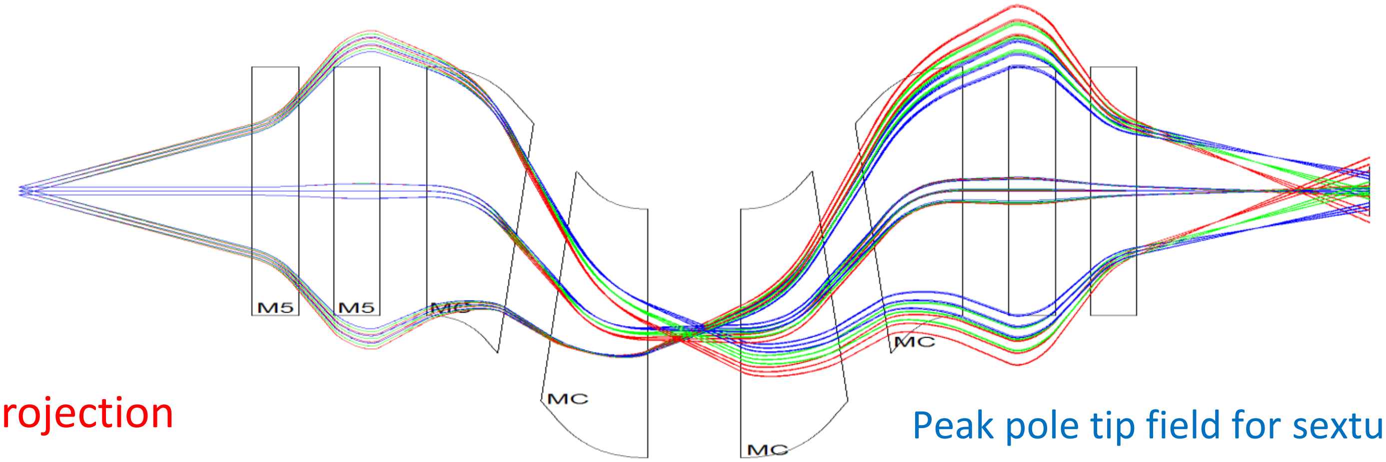


Max quad poletip field=1.5T
Half aperture=10cm
Max Dipole field=1T
Angle=22.5deg
Radius=1m

Second Order Optics

- Peak pole tip field for sextupoles = 0.05 T at 10cm.
- First half (up to center of the device, dispersive image):
  - 4 sextupoles available for 2^{nd} order aberration corrections
  - Two in multipole magnets (in the front)
  - Two in dipoles
  - Only two sextupoles (in dipoles) can be used for correcting chromatic terms
- Two options for the second half:
  - mirror symmetric to the first half
  - Independently tuned to reduce aberration at the final image

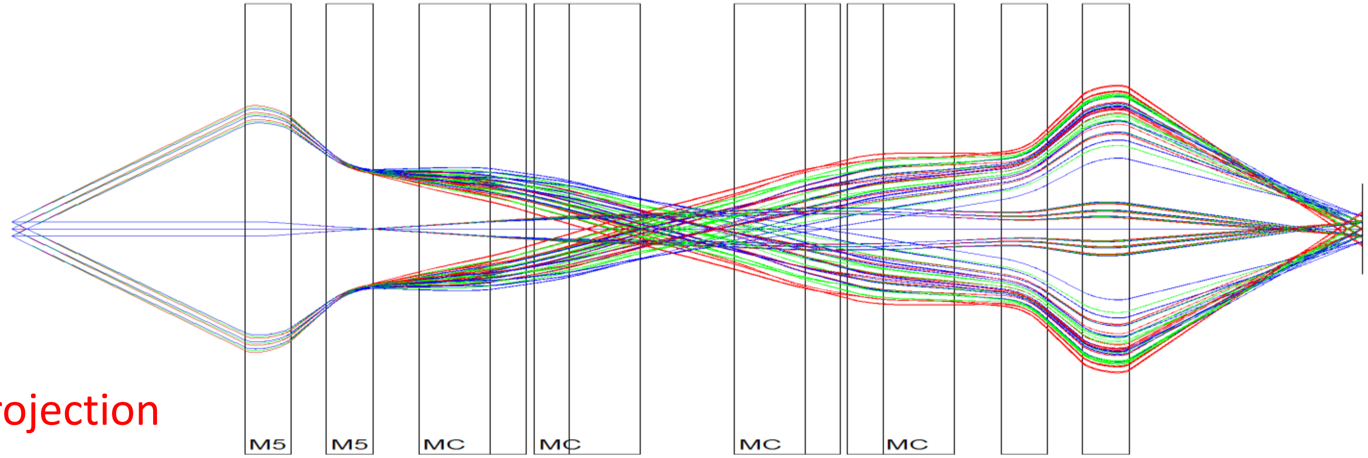
Second order plots



X-projection

Peak pole tip field for sextupoles = 0.05 T

Half aperture = 10cm



Y-projection

Aberration at the center

Aberrations at the center of In-flight separator

Aberration Term	Before Correction (mm)	After Correction (mm)
(X,AD)	4.94	4.7
(X,AA)	2.79	0
(X,XA)	0.37	0.13
(X,XD)	0.24	0.23
(X,YB)	0	0.28
(X,DD)	0	0.11
(X,BB)	0	0.07
(Y,BD)	3	3.1
(Y,YD)	0.18	0.15
(Y,AB)	0.15	0.46
(Y,AY)	0	0.9
(Y,XB)	0	0.09
(Y,XY)	0	0.03

Aberration at the End

Aberrations at the end of In-flight separator

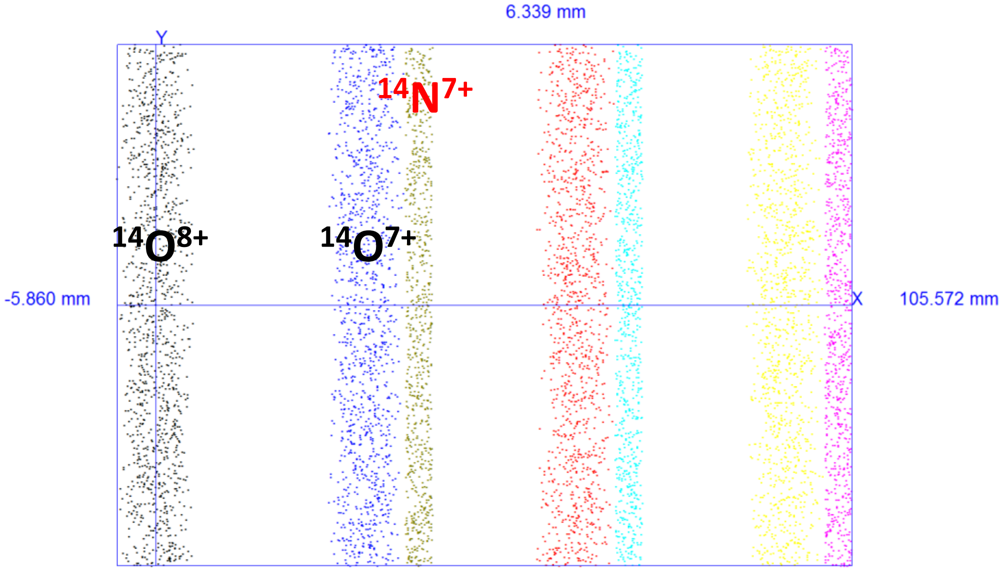
Aberration Term	Befor Correction (mm)	After Corrections-Symm (mm)	After Correction (mm)
(X,AD)	16	15.3	15.6
(X,XD)	1	1	1
(X,YB)	0.08	0.9	0.2
(X,XA)	0	0.42	0.1
(X,YY)	0	0.09	0.08
(Y,BD)	3	3.1	3.1
(Y,AY)	0.07	0.9	0.23
(Y,YD)	0.33	0.34	0.33
(Y,XY)	0	0.06	0
(Y,YB)	0	0.9	0.23

14N(p,n)14O

Ion	Mass	Charge	BRHO	DBRHO(%)	Beta	QF
Oxygen	**14**	**8**	**0.743**	**0.000**	**0.135**	**1.000**
Oxygen	14	7	0.849	14.286	0.135	0.000
Nitrogen	14	7	0.876	17.877	0.140	1.000
Oxygen	14	6	0.991	33.333	0.135	0.000
Nitrogen	14	6	1.022	37.523	0.140	0.000
Oxygen	14	5	1.189	60.000	0.135	0.000
Nitrogen	14	5	1.226	65.028	0.140	0.000

Parameters from data files:

- Average spread for 14O (**121 MeV**)
  - X=±3.2mm, Y=±3.2mm,
  - θ=±50mrad, dKE=±2.2% (**±3%**)
- Average spread for 14N (**129 MeV**)
  - X=±3.2mm, Y=±3.2mm,
  - θ=±75mrad, dKE=6.6% ±2.7% (**0.1%**)
- Average spread for 11C (114 MeV)
  - X=±3.2mm, Y=±3.2,
  - θ=±105mrad, dKE=-5.7%±2.7%



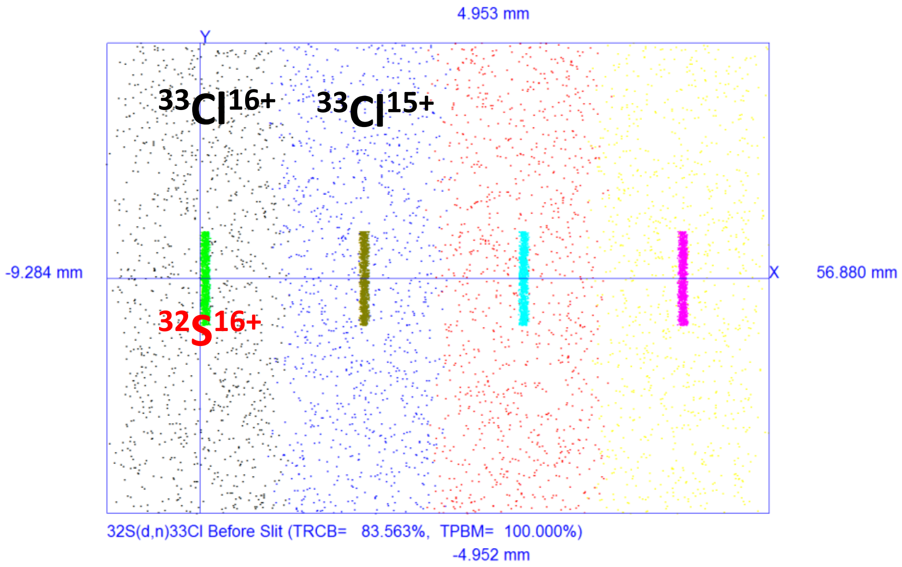
14N(p,n)14O Before Slit (TRCB= 83.529%, TPBM= 54.679%)

32S(d,n)33Cl

Ion	Mass	Charge	BRHO	DBRHO(%)	Beta	QF
Chlorine	33	17	0.587	-5.882	0.097	0
Chlorine	**33**	**16**	**0.623**	**0**	**0.097**	**0.3**
Sulphur	32	16	0.624	0.164	0.1	1
Chlorine	33	15	0.665	6.667	0.097	0.3
Sulphur	32	15	0.666	6.842	0.1	0
Chlorine	33	14	0.712	14.286	0.097	0
Sulphur	32	14	0.713	14.474	0.1	0
Chlorine	33	13	0.767	23.077	0.097	0

Assumed input:

- Average spread for 33Cl (**145 MeV**)
  - X=±2.5mm, Y=±2.5mm,
  - θ=±50mrad, dKE=±6.15%
- Average spread for 32S (**150 MeV**)
  - X=±0.5mm, Y=±0.5mm,
  - θ=±5mrad, dKE=3.45% ±0.17%

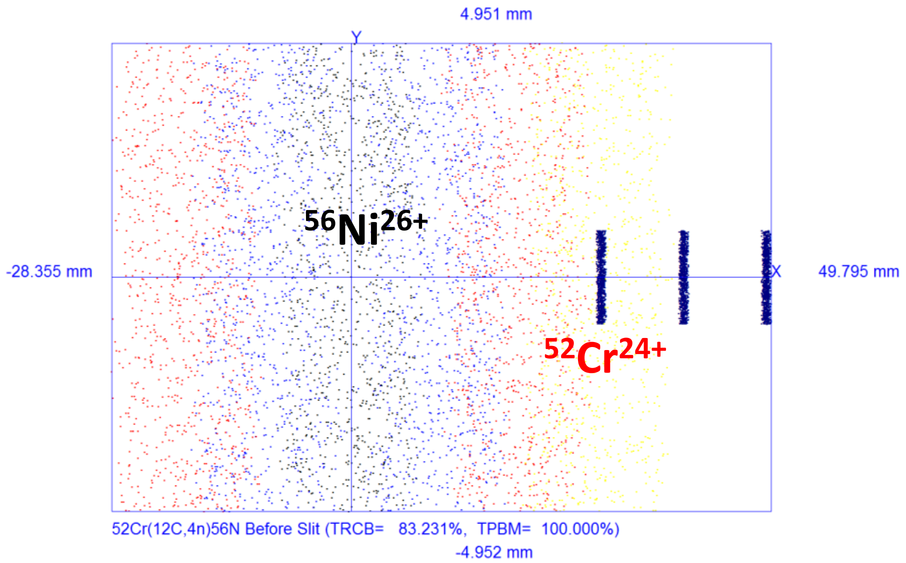


52Cr(12C,4n)56Ni

Ion	Mass	Charge	BRHO	DBRHO(%)	Beta	QF
Nickel	56	28	0.711	-7.143	0.114	0
Nickel	56	27	0.737	-3.704	0.114	0
Nickel	**56**	**26**	**0.765**	**0**	**0.114**	**0.3**
Nickel	56	25	0.796	4	0.114	0.3
Nickel	56	24	0.829	8.333	0.114	0
Chromium	52	24	0.857	11.992	0.126	1
Nickel	56	23	0.865	13.043	0.114	0
Chromium	52	23	0.894	16.861	0.126	0
Chromium	52	22	0.935	22.173	0.126	0

Assumed input:

- Average spread for 56Ni (**340 MeV**)
  - X=±2.5mm, Y=±2.5mm,
  - θ=±50mrad, dKE=±6%
- Average spread for 52Cr (**391 MeV**)
  - X=±0.5mm, Y=±0.5mm,
  - θ=±5mrad, dKE=15% ±0.23%



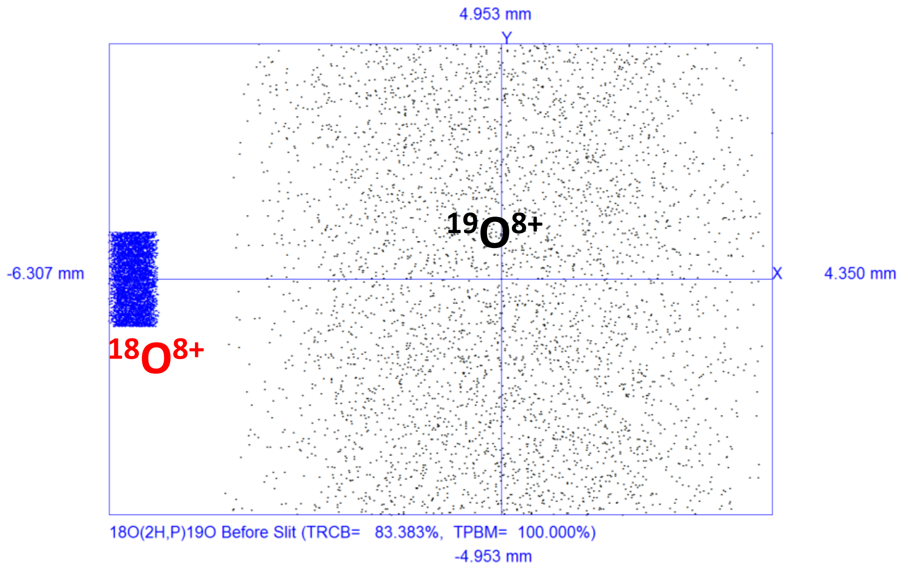
52Cr(12C,4n)56N Before Slit (TRCB= 83.231%, TPBM= 100.000%)

18O(2H,P)19O

Ion	Mass	Charge	BRHO	DBRHO(%)	Beta	QF
18Oxygen	18	8	0.998	-2.365	0.141	1
19Oxygen	**19**	**8**	**1.022**	**0**	**0.137**	**1**

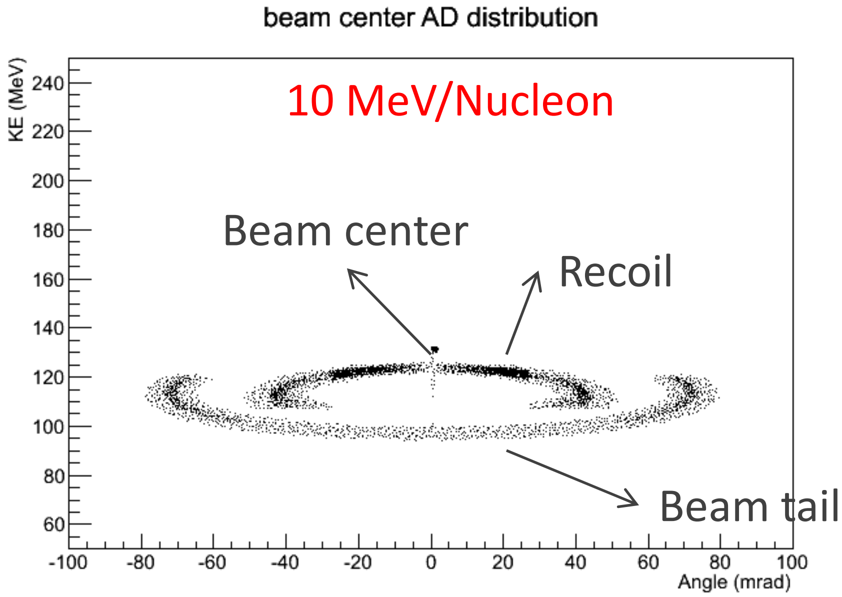
Assumed input:

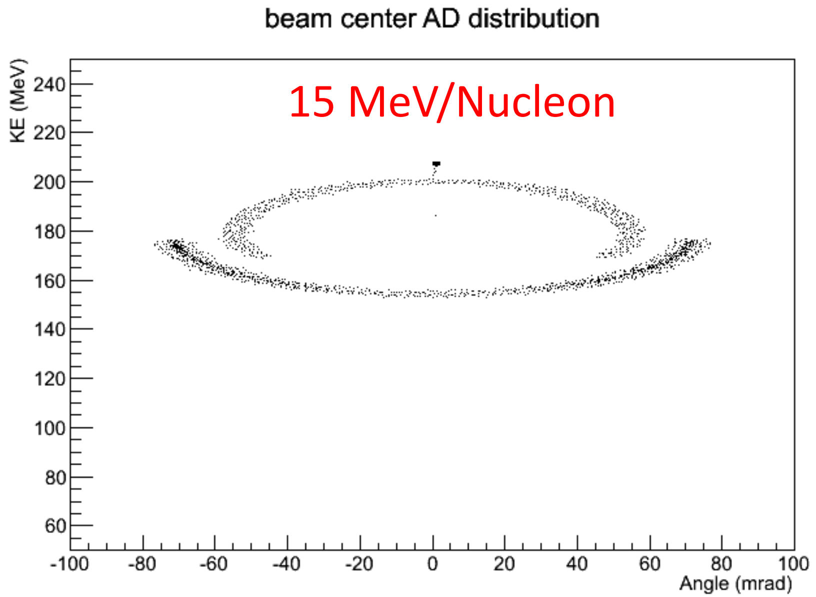
- Average spread for 19O (**169 MeV**)
  - X=±2.5mm, Y=±2.5mm,
  - θ=±50mrad, dKE=±2.26%
- Average spread for 18O (**170 MeV**)
  - X=±0.5mm, Y=±0.5mm,
  - θ=±5mrad, dKE=15% ±0.075%



High Pole tip fields for quads ≈1.35T at 10cm

14N(p,n)14O case: Initial AD distribution





Ration of number of particle in recoil/beam tail:

- 1:10 for 15MeV/Nucleon case
- 1:2.5 for 10MeV/Nucleon case

Final transmission (slit ±5mm)

15MeV/nucleon case

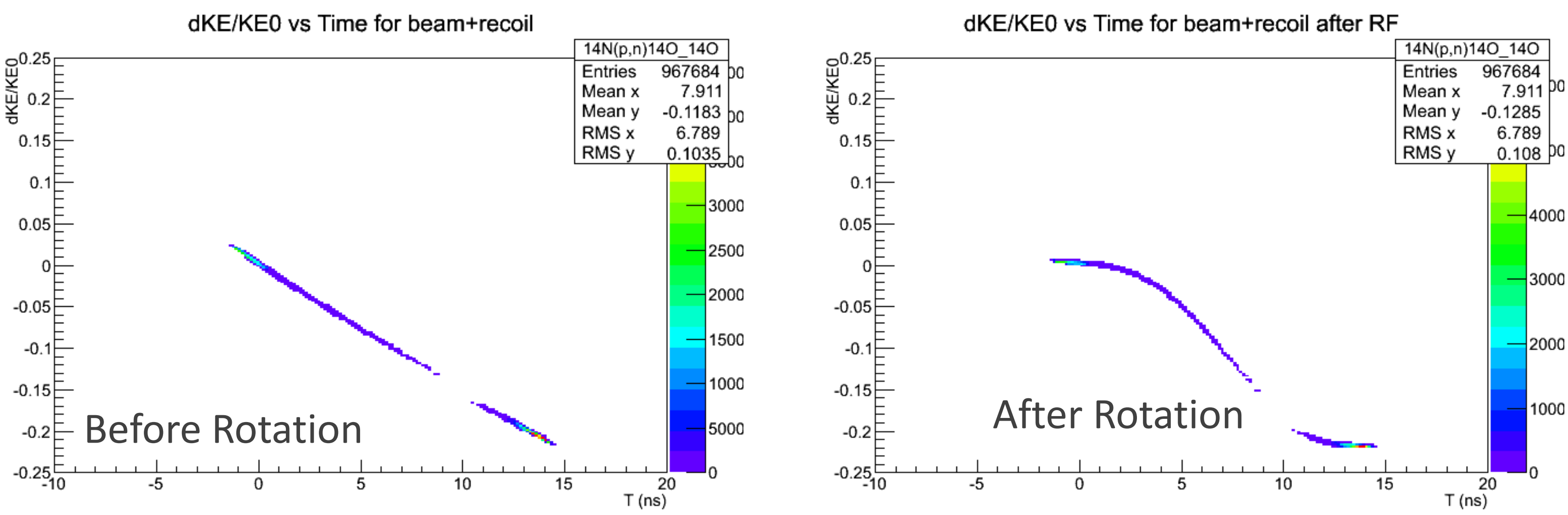
	1^{st} order	1^{st} order + Fringe fields	2^{nd} order	2^{nd} order+ Fringe fields	5^{th} order+ Fringe fields
Recoil	92.33%	91%	89.8%	88.67%	78.42%
Beam tail	5.27%	4.21%	15.7%	13.5%	11.5%
Beam Center	0%	0%	2.5E-3	2E-3%	0%

10 MeV/nucleon case

	1^{st} order	2^{nd} order	5^{th} order
Recoil	65%	66%	64%
Beam tail	1.7%	7.36%	7.6%
Beam Center	0%	1E-4%	0%

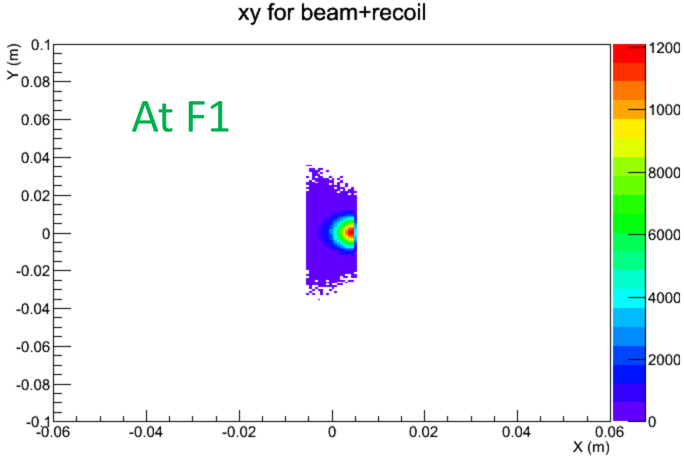
Rotation in T-dKE phase plane

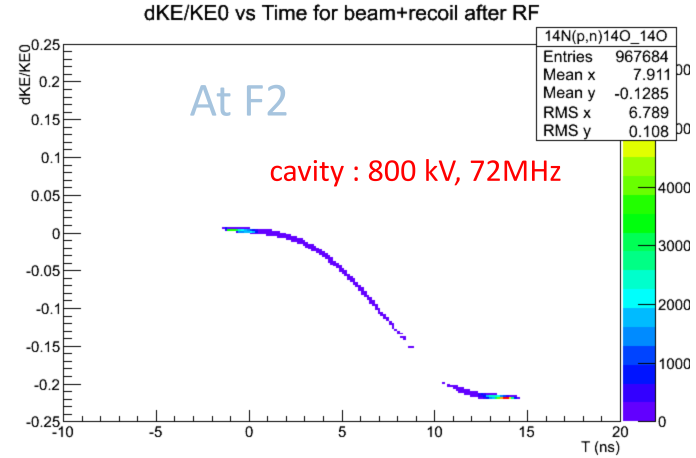
- RF Parameters:
  - Field = 4 MV/m
  - Length = 10 cm (voltage = 800 kV)
  - frequency = 72 MHz
  - Phase = 0 deg
  - Half aperture = 2cm

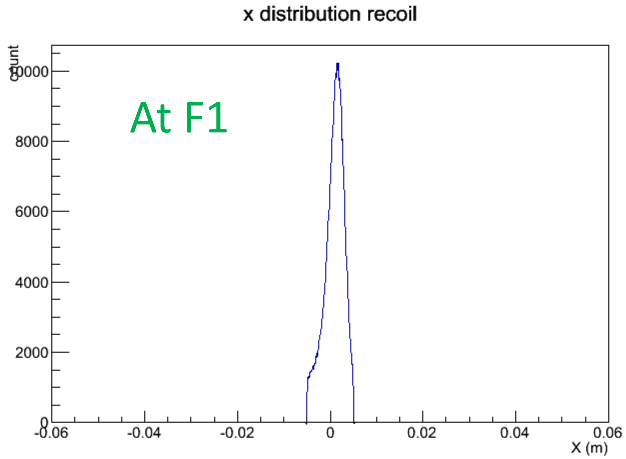


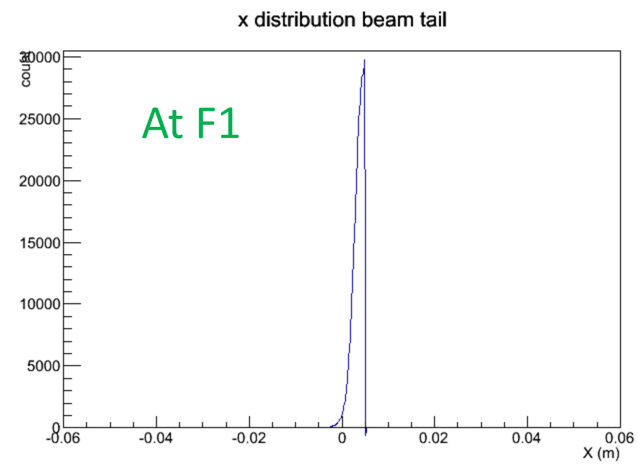
5^{th} order with Fringe fields

15MeV/nucleon case

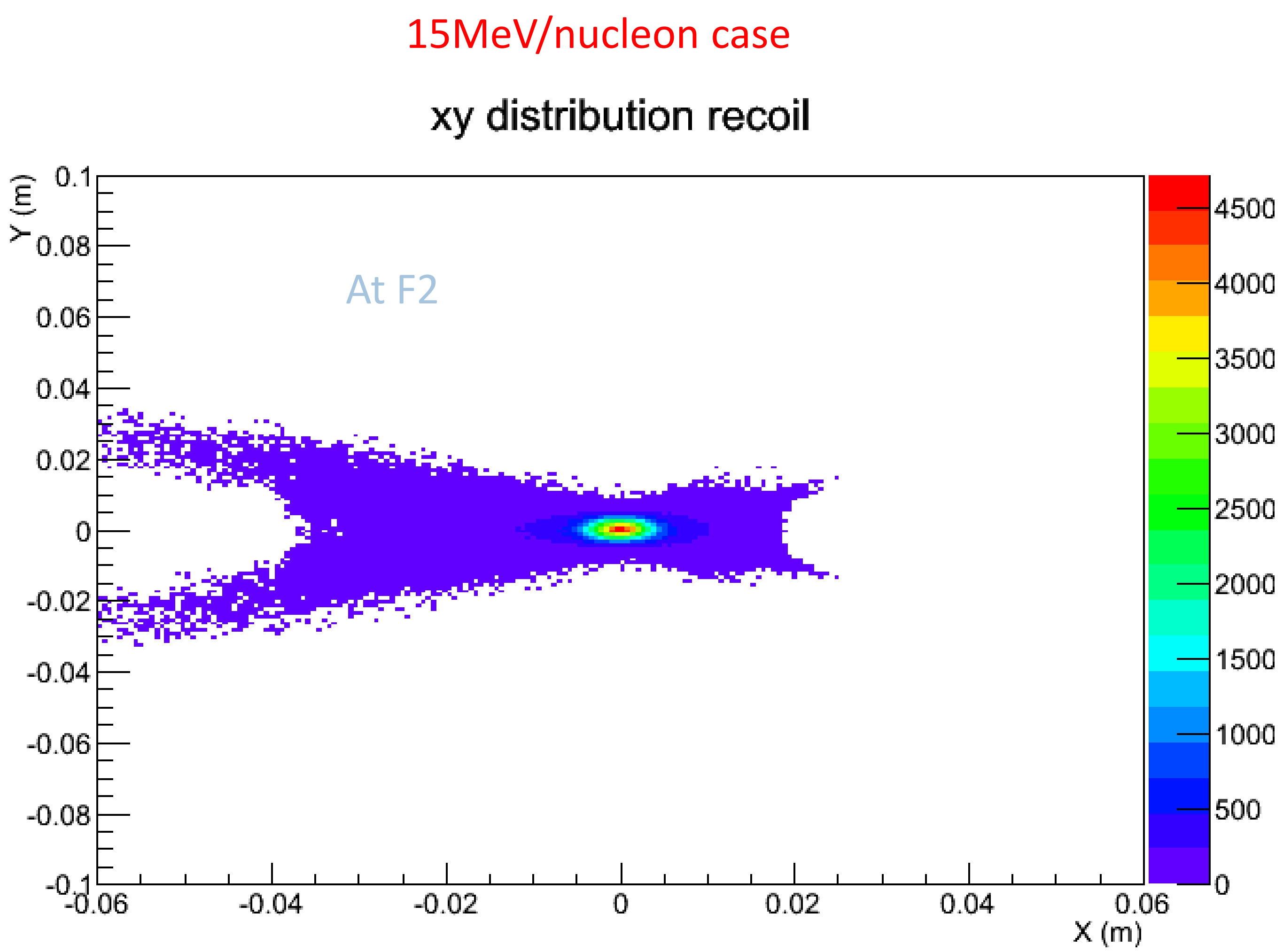




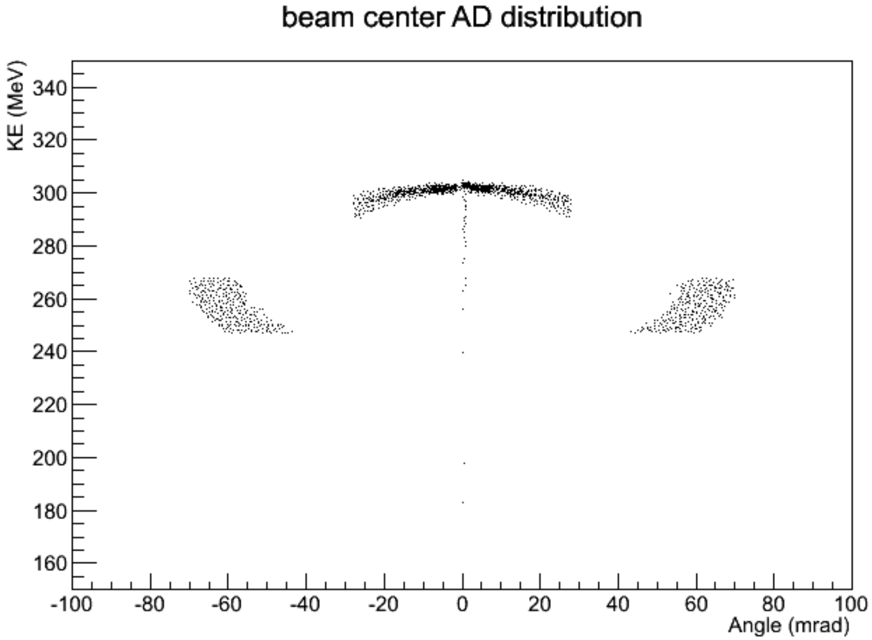




14N(p,n)14O case



32S(d,n)33Cl case

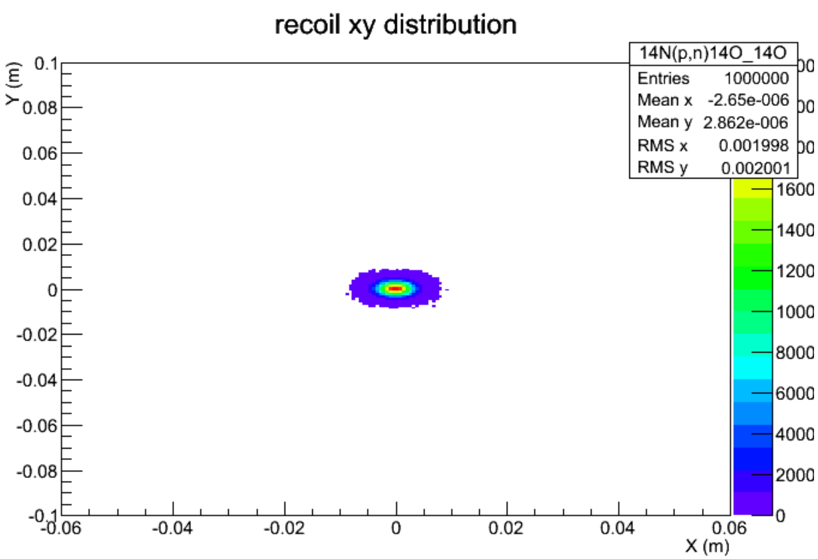


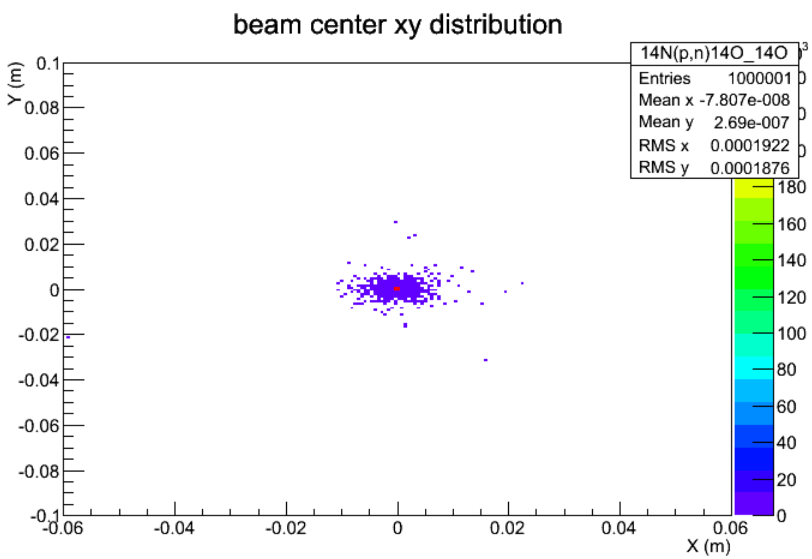
Beam tail [247,267] MeV

Ion	Mass	Charge	**BRHO**	DBRHO(%)	Beta	QF
Chlorine	33	17	**0.846**	0.000	0.139	0.618
Sulphur	32	16	0.888	5.021	0.142	1.000
Chlorine	33	16	**0.899**	6.250	0.139	0.344
Chlorine	33	15	**0.959**	13.333	0.139	0.036
Chlorine	33	14	**1.027**	21.429	0.139	0.001

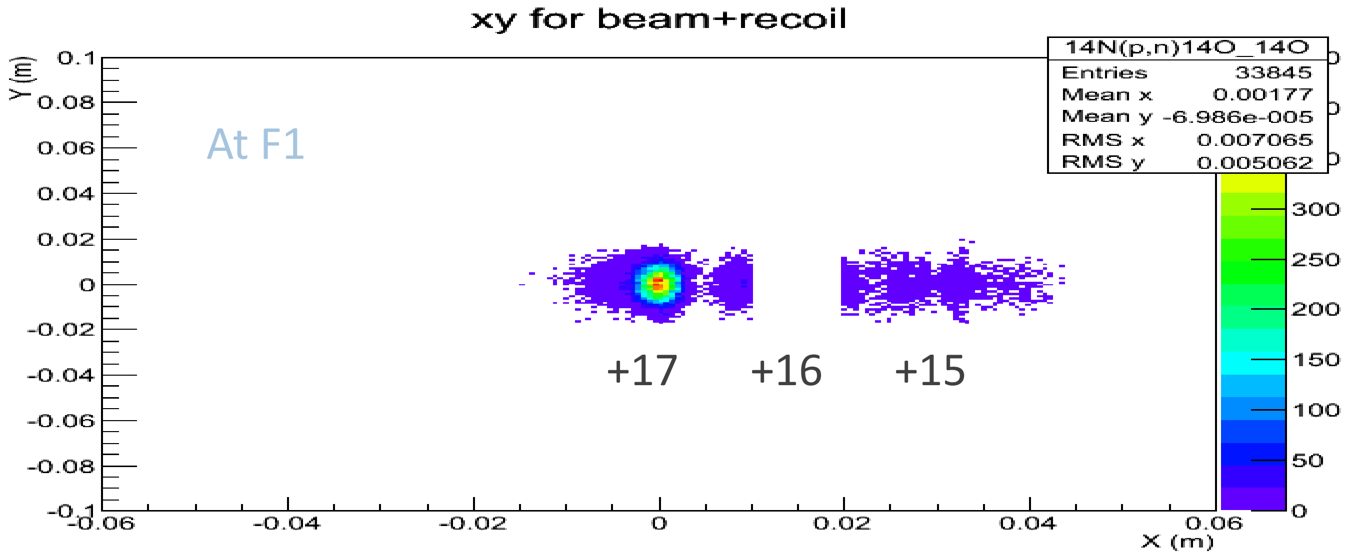
Input beam

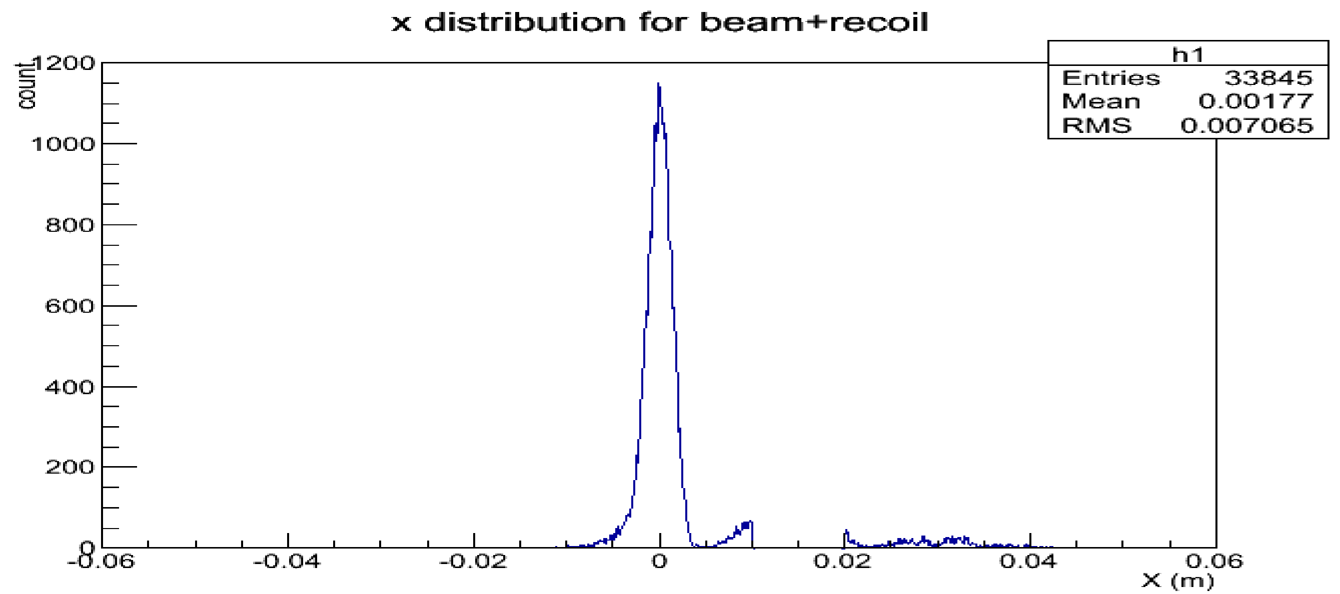
- 9 MeV/nucleon average energy for 33Cl (+17)
- beam blocker at the center of the device (15mm±5mm)
- Slit at the final focus (±5mm)





Design 1: 5th order with Fringe fields





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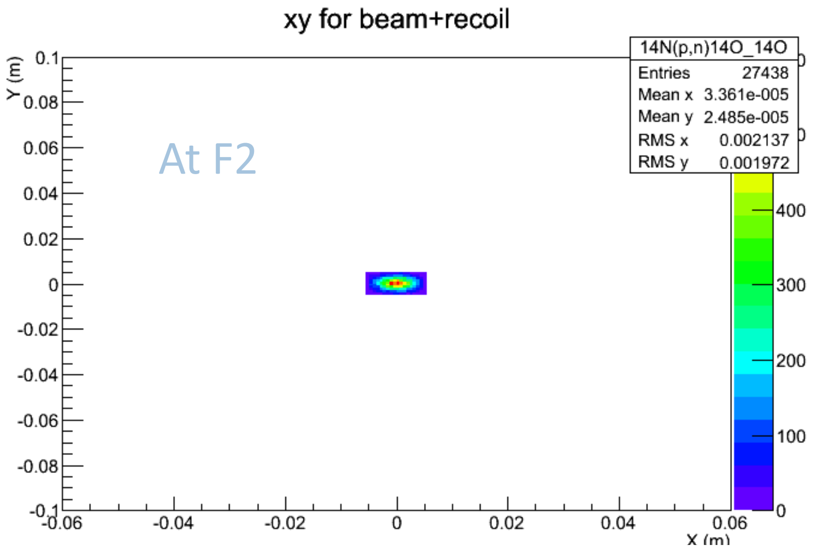

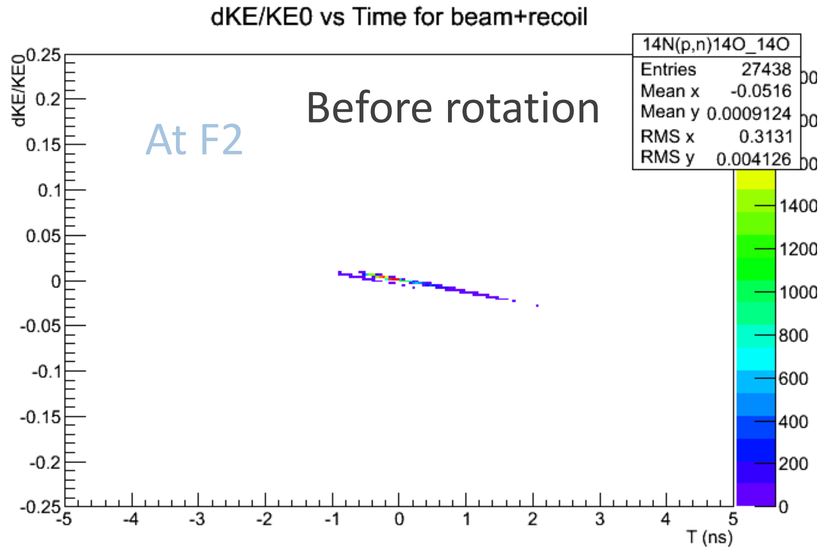

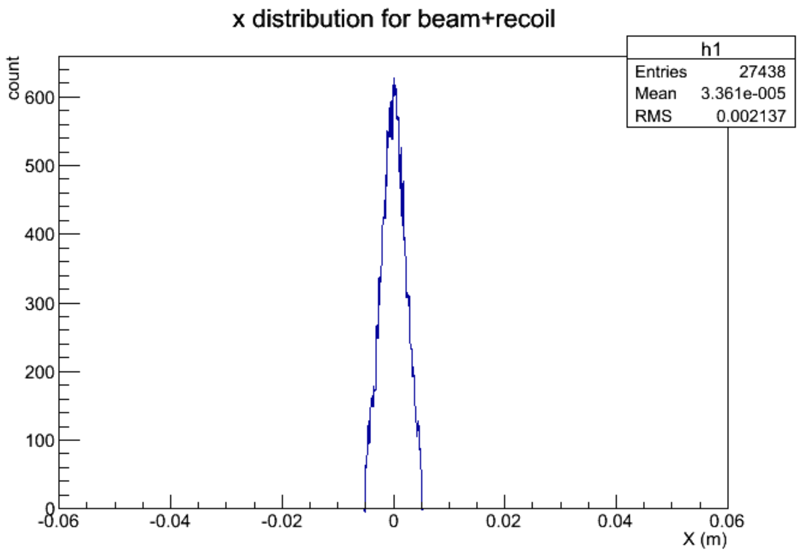

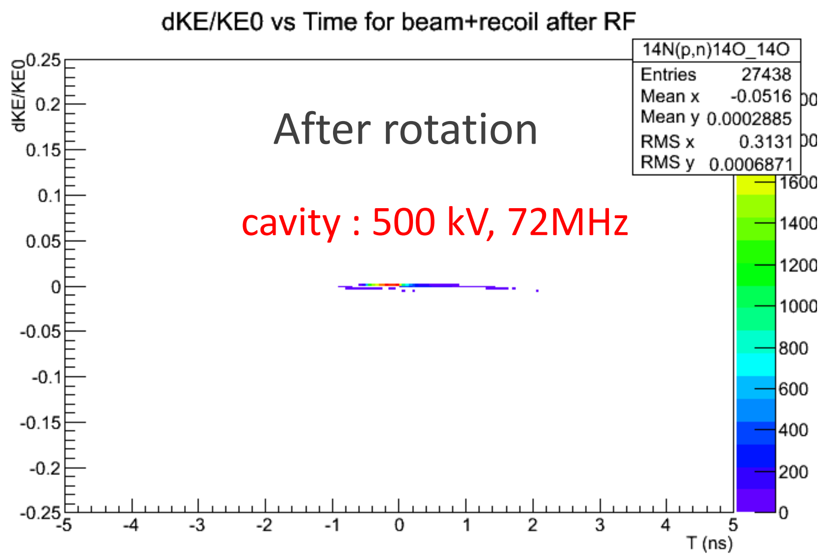

Transmission

	Fraction	5^{th} order+ Fringe fields	5^{th} order+ Fringe fields (with beam blocker)	5^{th} order+ Fringe fields (beam blocker+endslit)
Recoil (+17)	61.8%	100%	100%	87.3%
Recoil (+16)	34.4%	100%	8%	0%
Recoil (+15)	3.6%	100%	93%	28.3%
Recoil (+14)	0.1%	100%	100%	27.5%
Beam Center	NA	100%	0.04%	0
Beam Tail				

Recoil transmission with beam blocker=**68**%
Recoil transmission with beam blocker + end slit=**55%**

Conclusion and Future Work

- The advantages of AIRIS design was presented
  - Proposed second order corrected design achieves a combination of beam suppression, evaporation residue transmission
  - 10 times collection efficiency improvement
  - 2 orders of magnitude gain in intensity when combined with other ATLAS upgrades
- Performance of the device for two representative reaction cases was shown
- Future work :
  - Realistic simulation of more reaction cases
  - Higher order optimization to improve transmission as well as separation
  - Simulations with inclusion of realistic fringe fields

Thank you!