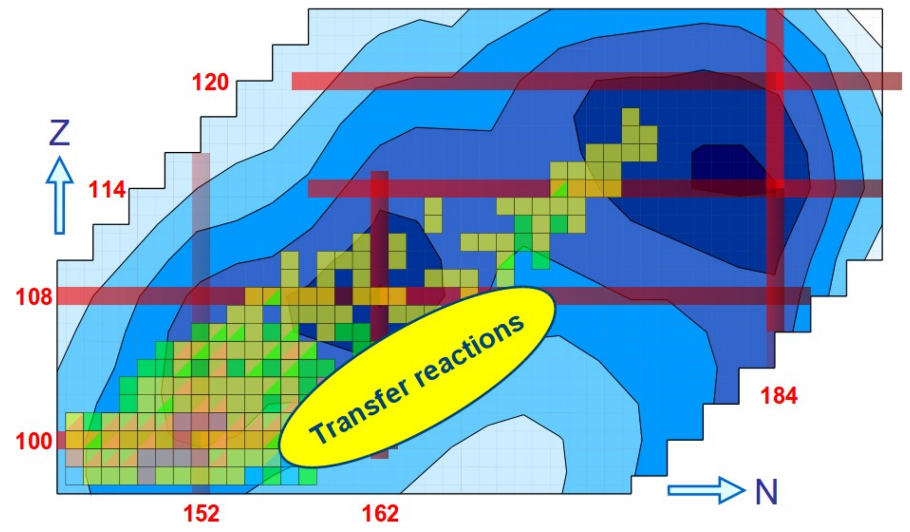

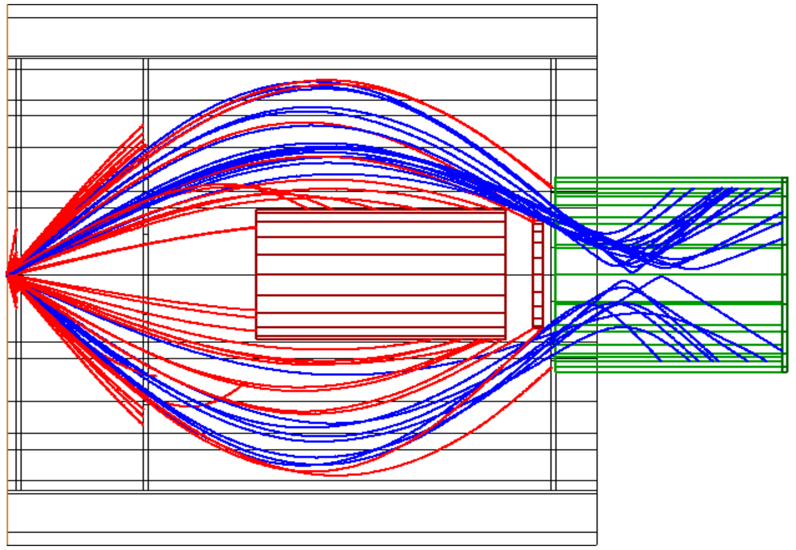

IRiS - Solenoid design

Working Group report

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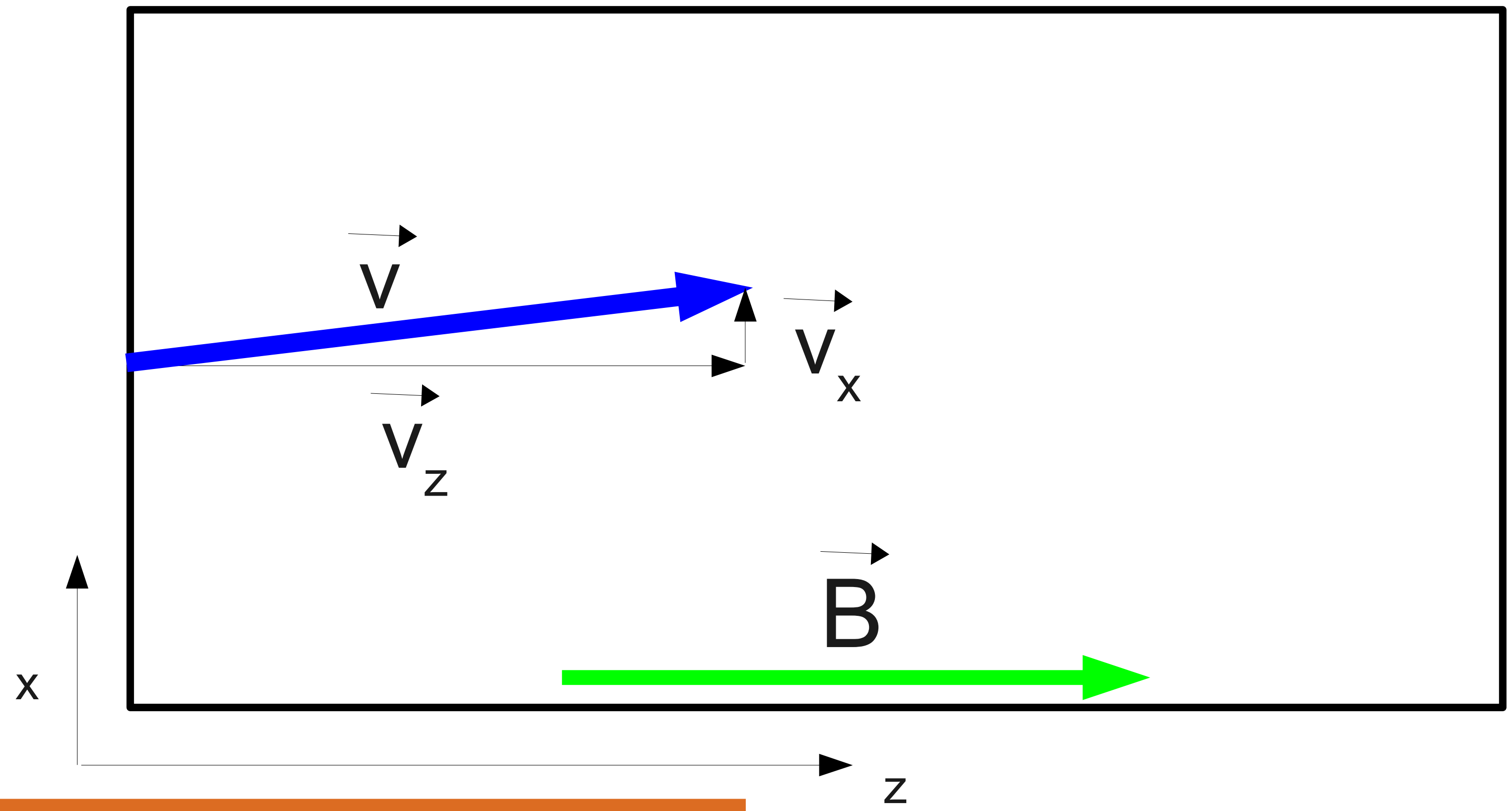
Outline

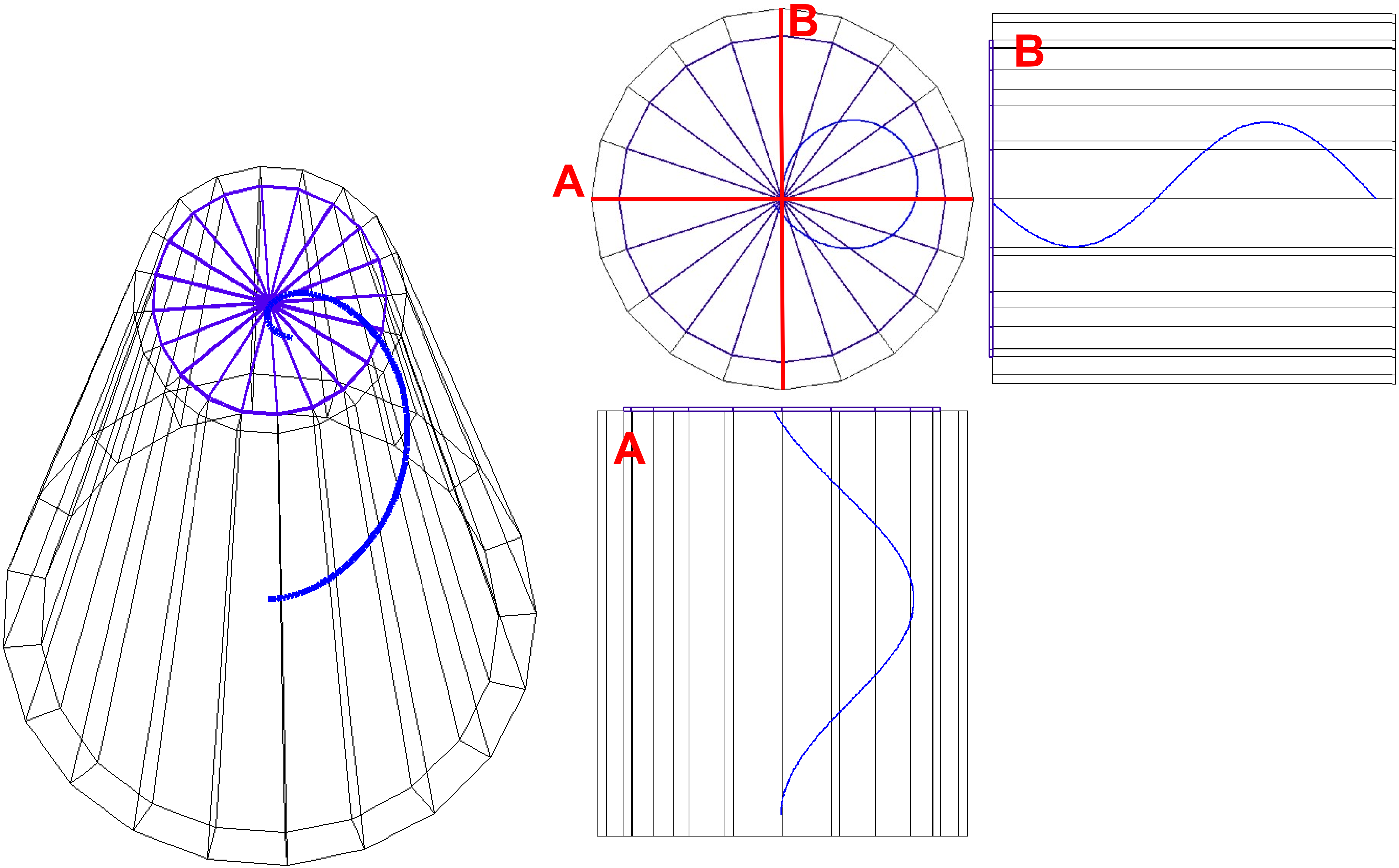
- Ion-optics of a solenoid
- Gas-filled solenoid separator
  - Symmetric and asymmetric mode
- Vacuum solenoid separator
- To do in the future

Ion trajectory in solenoid (axial magnetic field)

- $V_x \perp B \rightarrow$ Lorenz force ($F = q * v_x \times B$)
  - In XY plane ion circular motion with cyclotron frequency
  - Along z travels with velocity v_z
- Spiral trajectory



Ion trajectory in solenoid



Focusing properties of solenoid

- All ions are focused back to axis at focal length

$$F = 0.911\frac{\sqrt{Em}}{Bq}\cos(\theta)$$

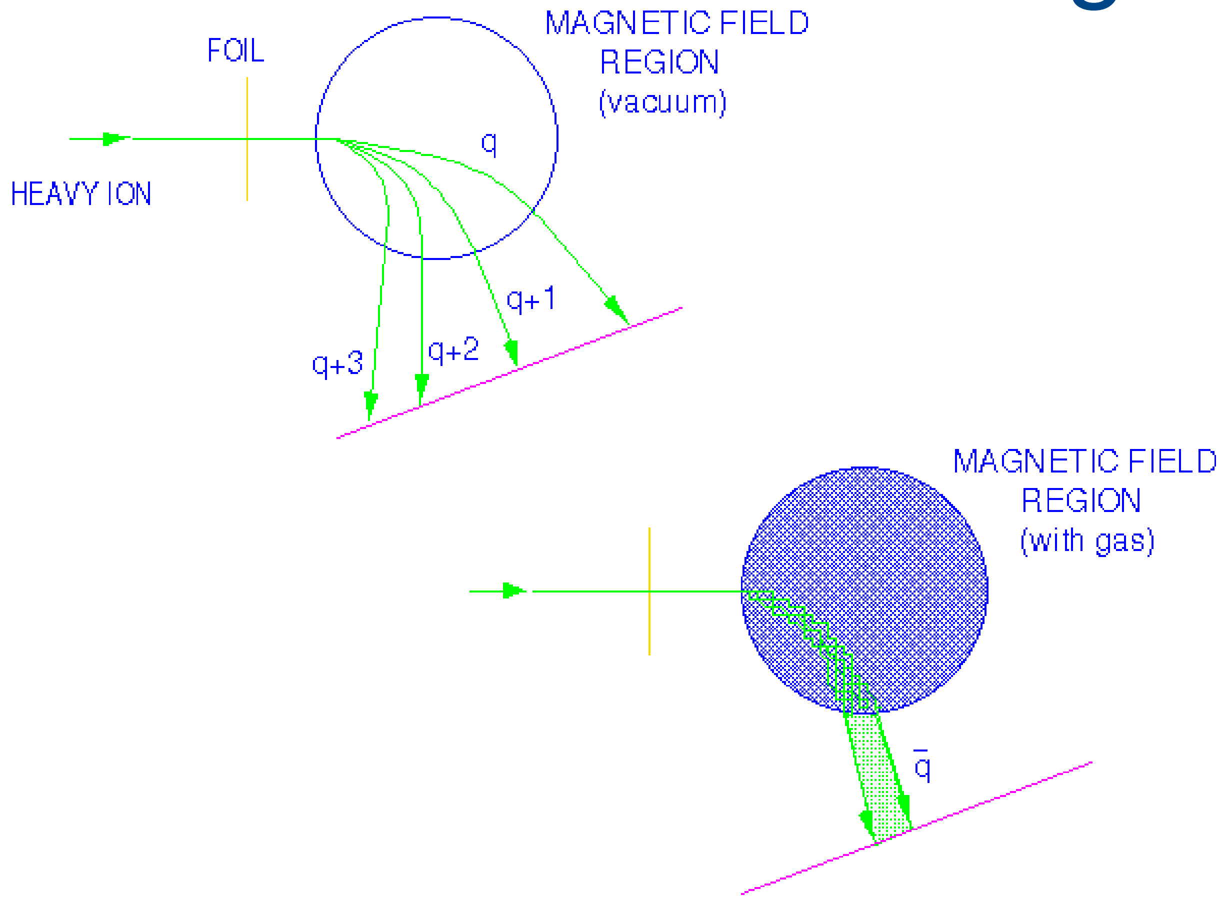
- Maximal radius of ion trajectories

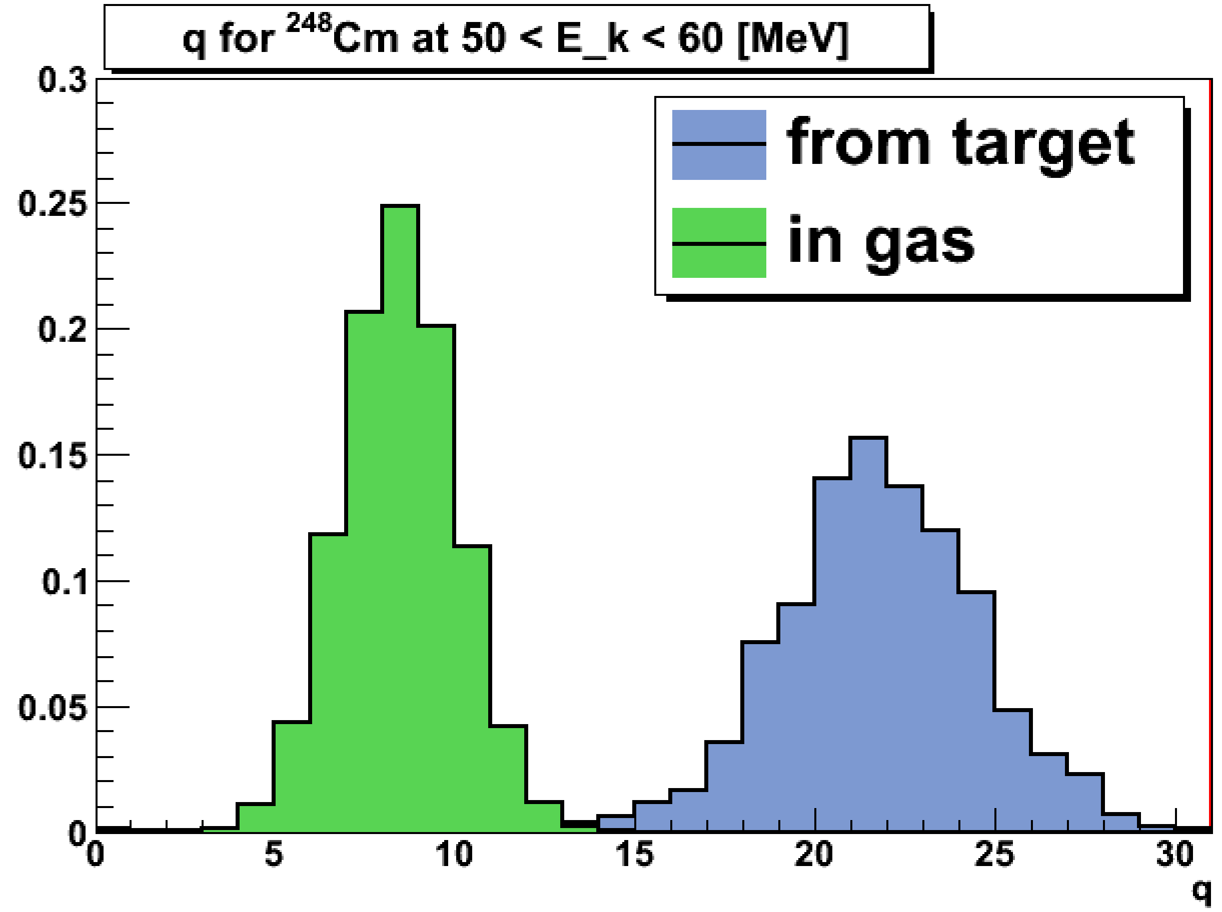
$$R = 0.29\frac{\sqrt{Em}}{Bq}\sin(\theta)$$

- Solenoid works as focal length dispersive in mv/q with dependency on θ
- Different products at constant θ have different focal points → separation

Vacuum vs. gas-filled solenoid

- Heavy ions have a distributions of charge states after recoiling from target
- In gas-filled separator charge state is averaged by collisions with gas molecules



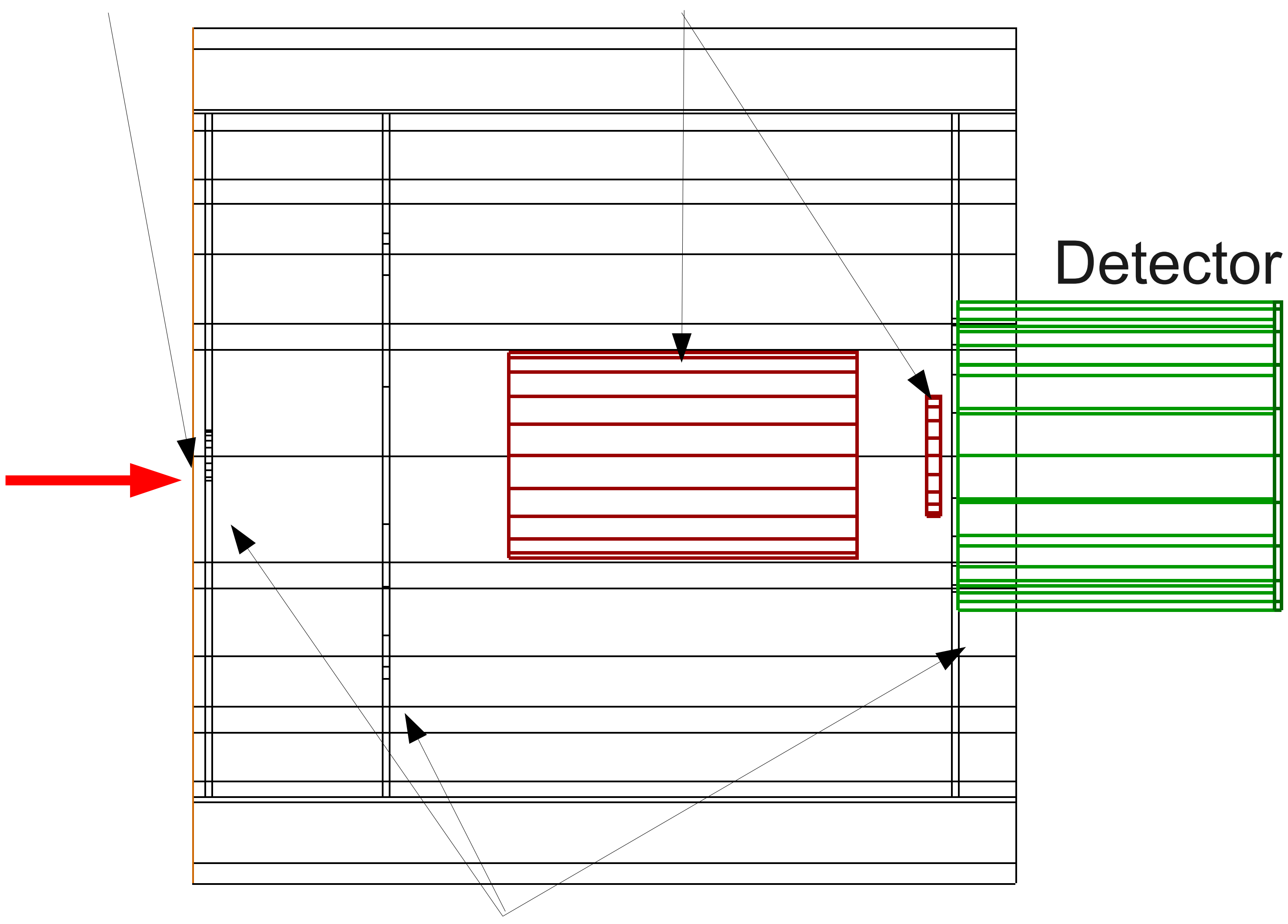


Gas-filled solenoid

Solenoid filled with He at 1-10 mbar

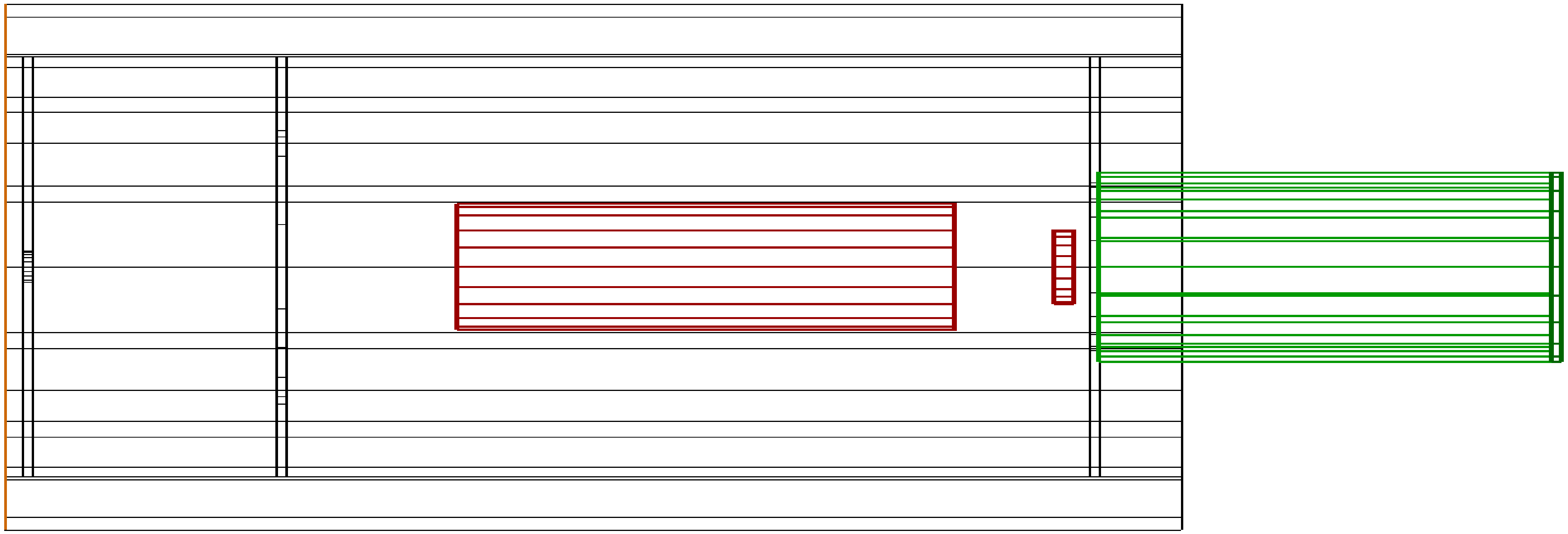
Gas-filled solenoid $^{48}Ca+^{248}Cm$ @ 209 MeV

Symmetric mode



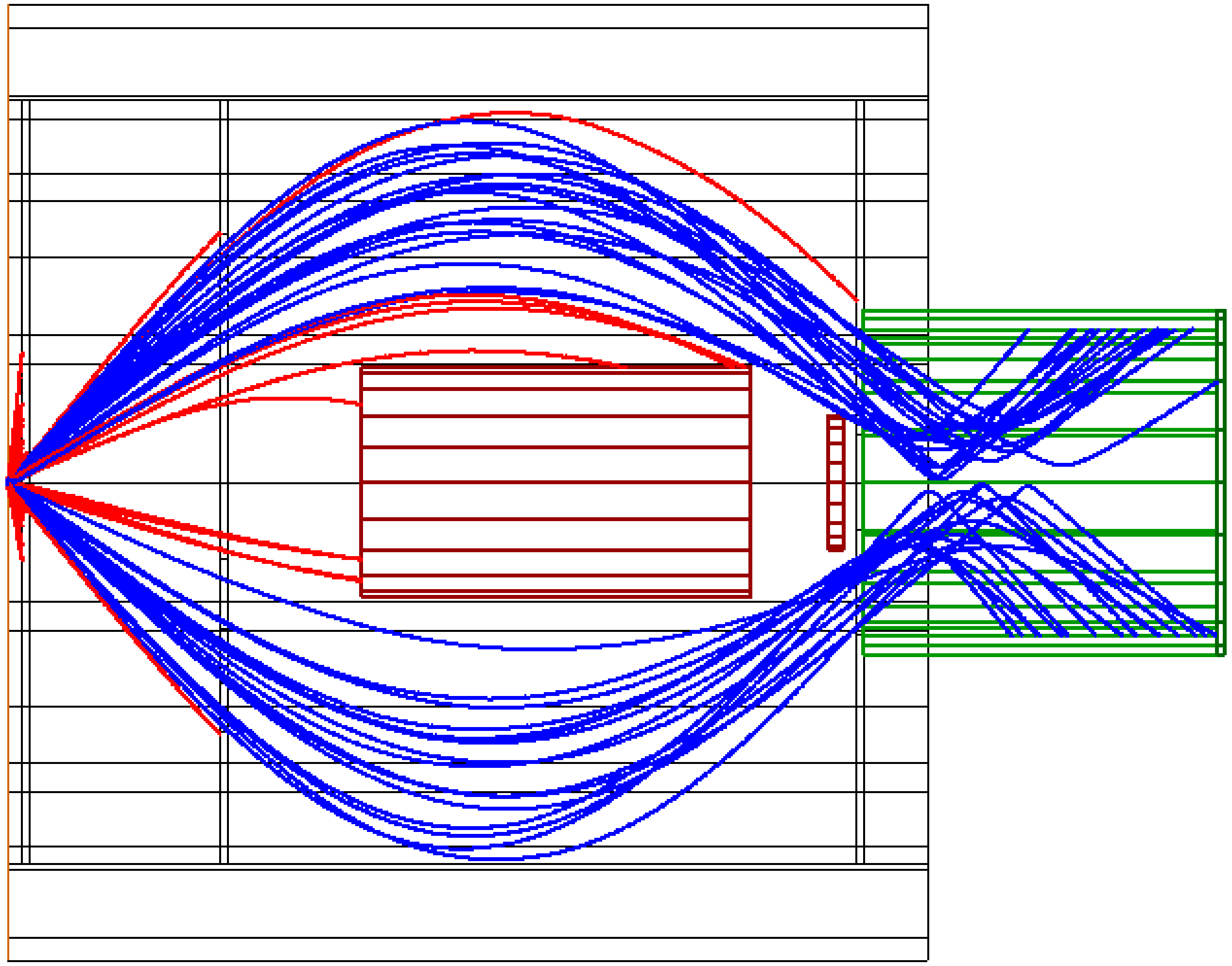
- 1.3 m long
- 40 cm bore i.d.
- 9.6 T
- 10 MJ stored energy
- 1 mbar He
- Target 1 mg/cm^2
- I_{beam} = 1 p.µA

Solenoid up to scale



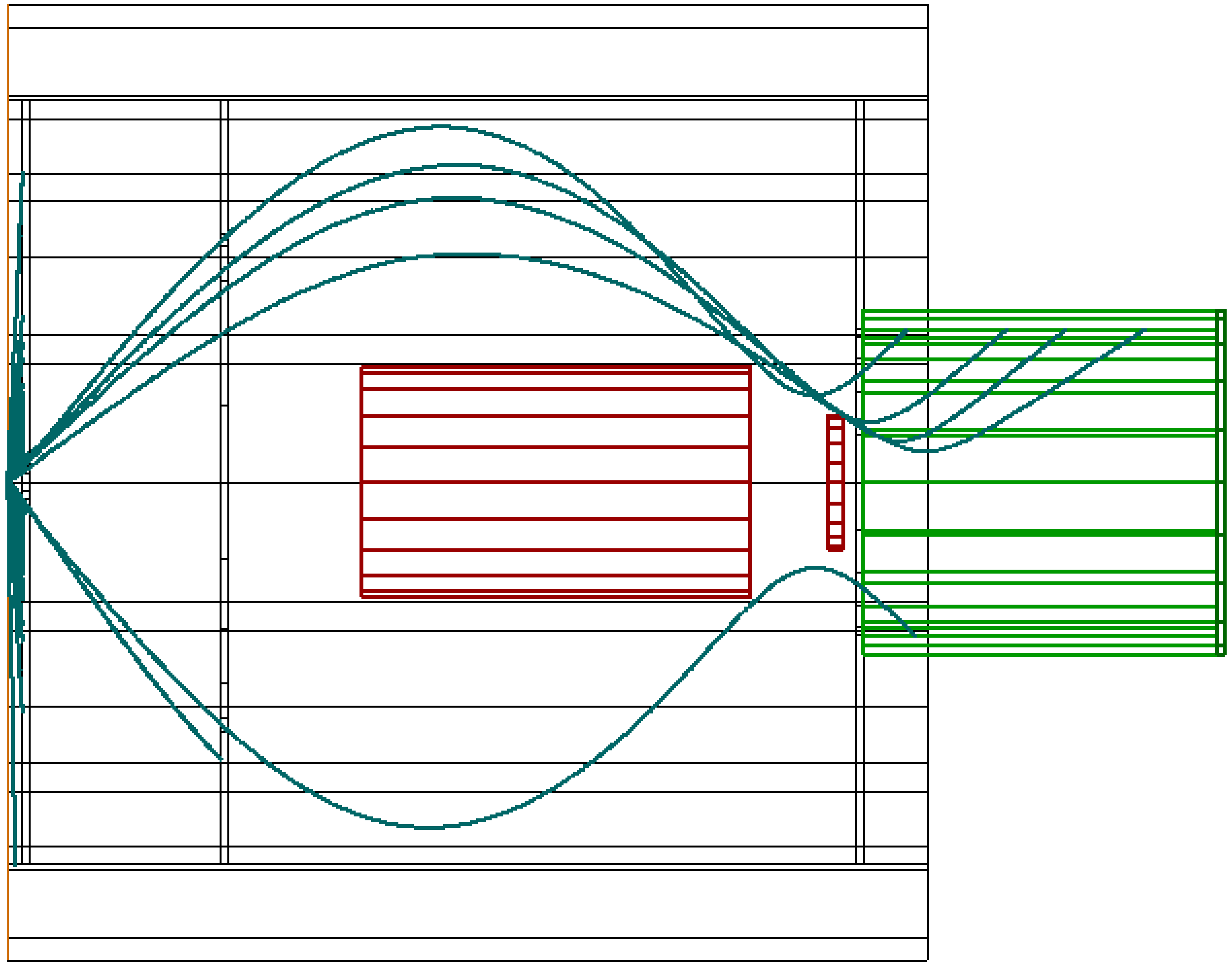
Z ≥ 102

Efficiency: 26.6 %



GRAZING (few-nucl. transfer) - target-like

Efficiency= 0.03%, Rate = $2.4*10^4$ Hz



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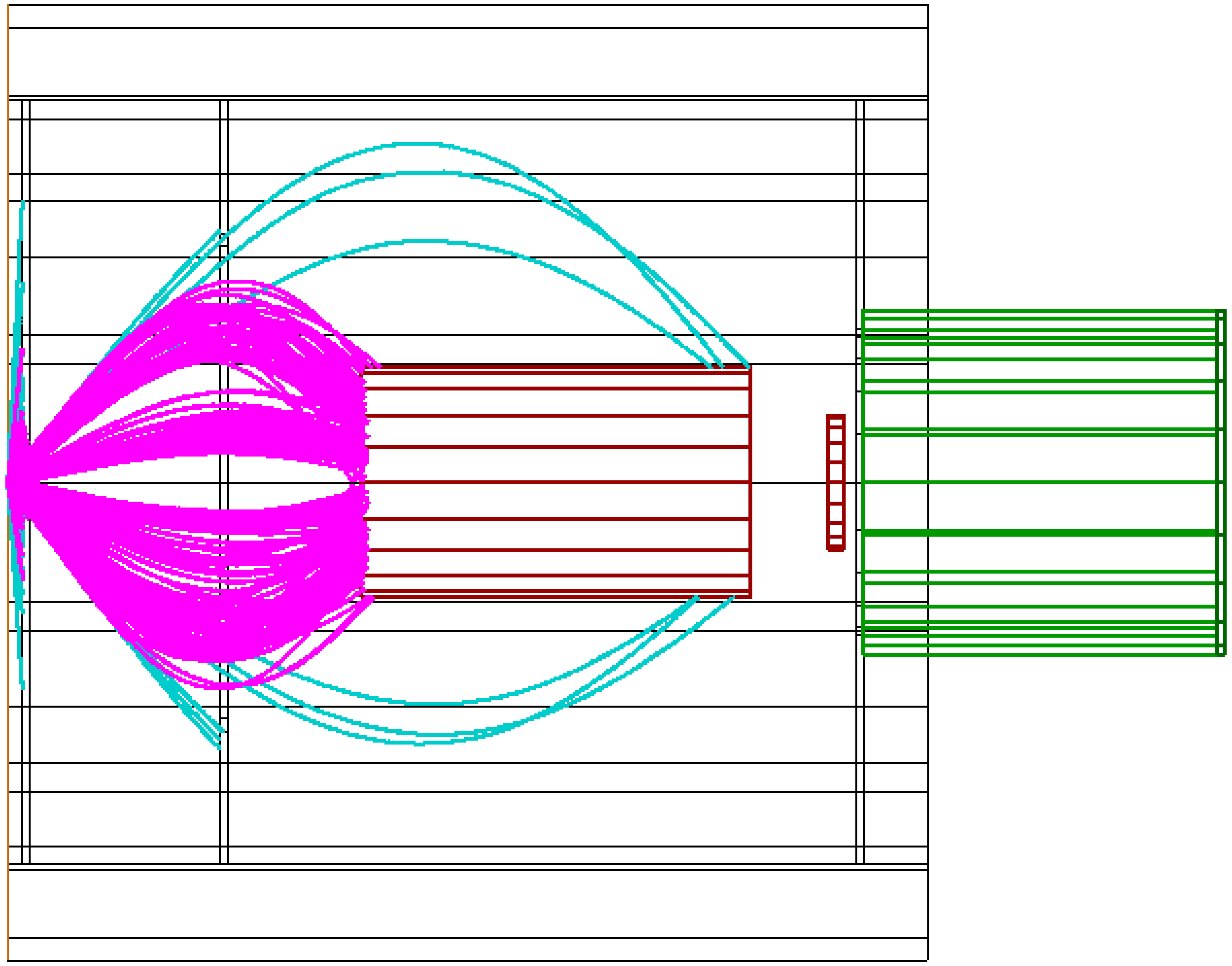
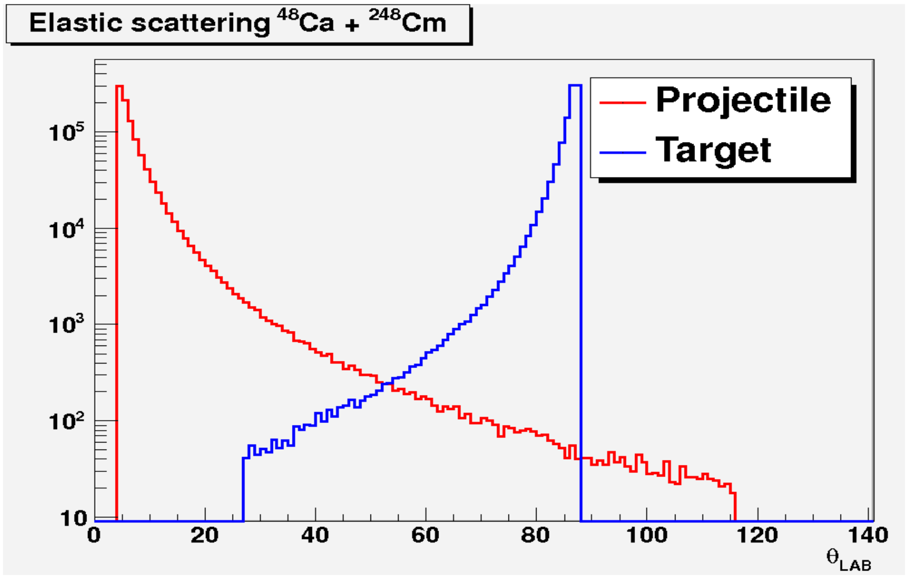
Elastic scattered target

Efficiency: 0.005% for θ_{CM} > 80°, Rate: 770 Hz

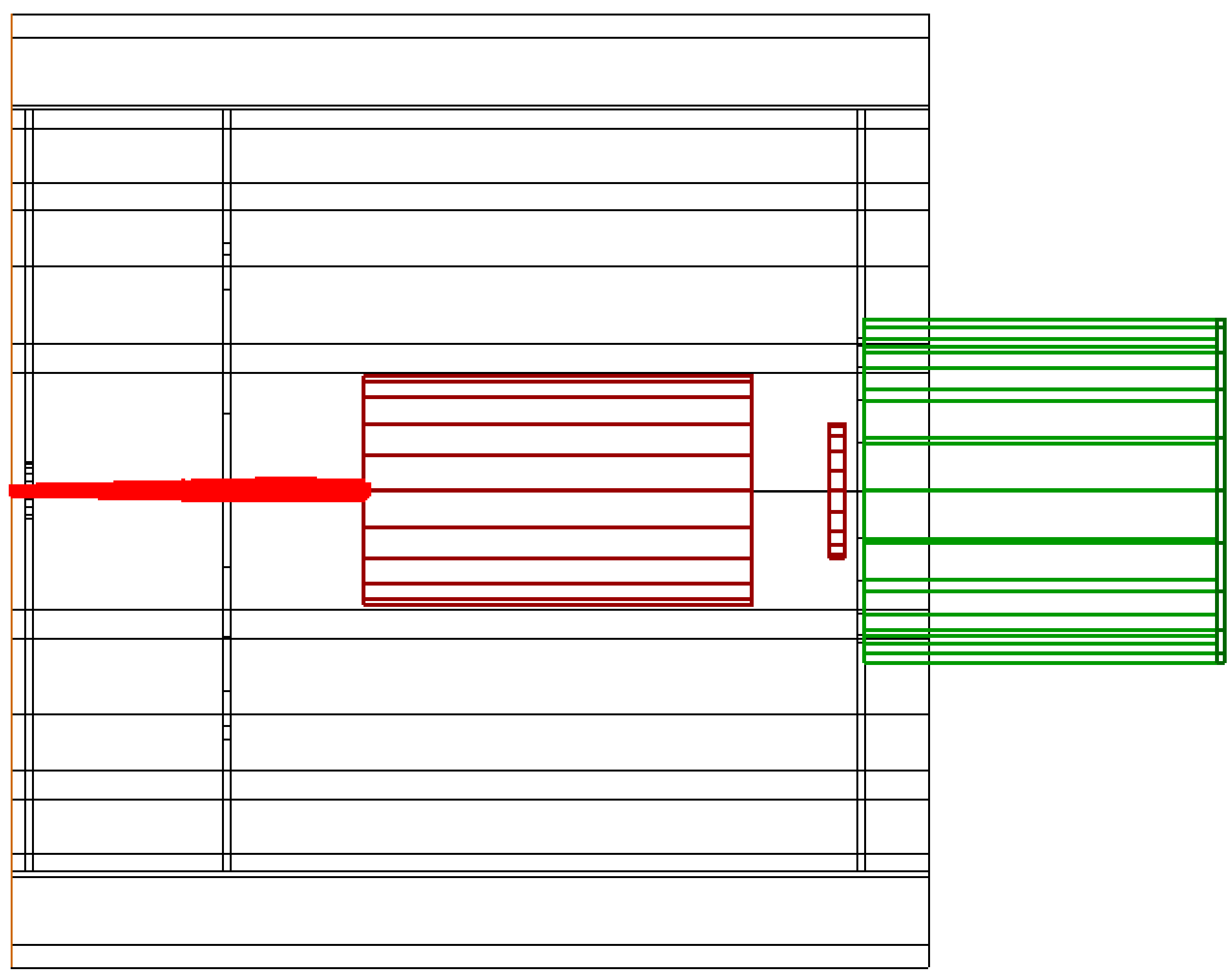




Min θ_{CM} [deg]	σ [barn]
80	1.5
10	180
1	18000

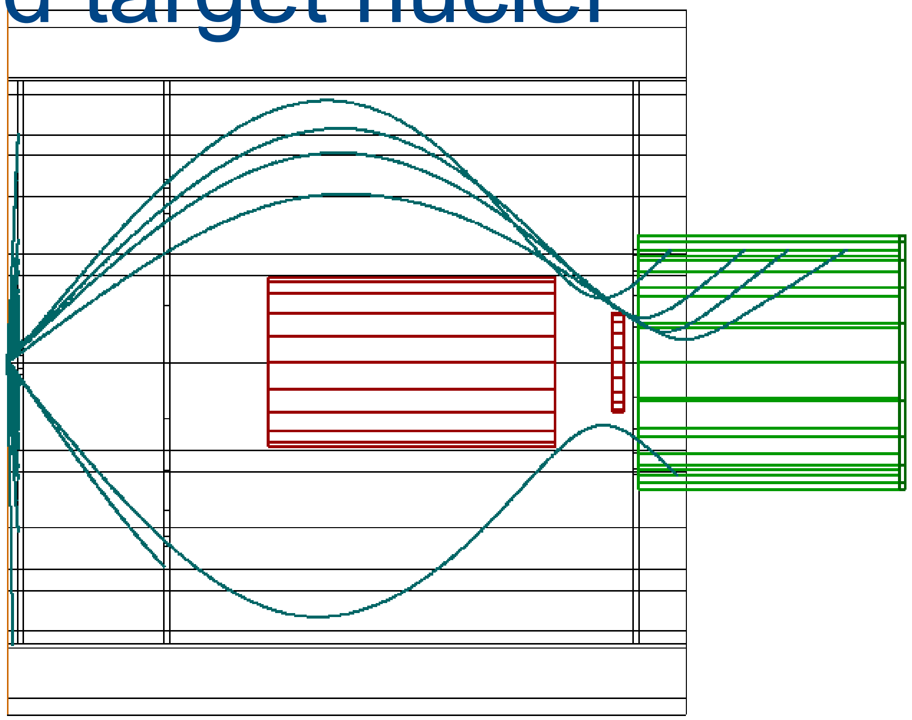
Beam

Perfect beam suppression



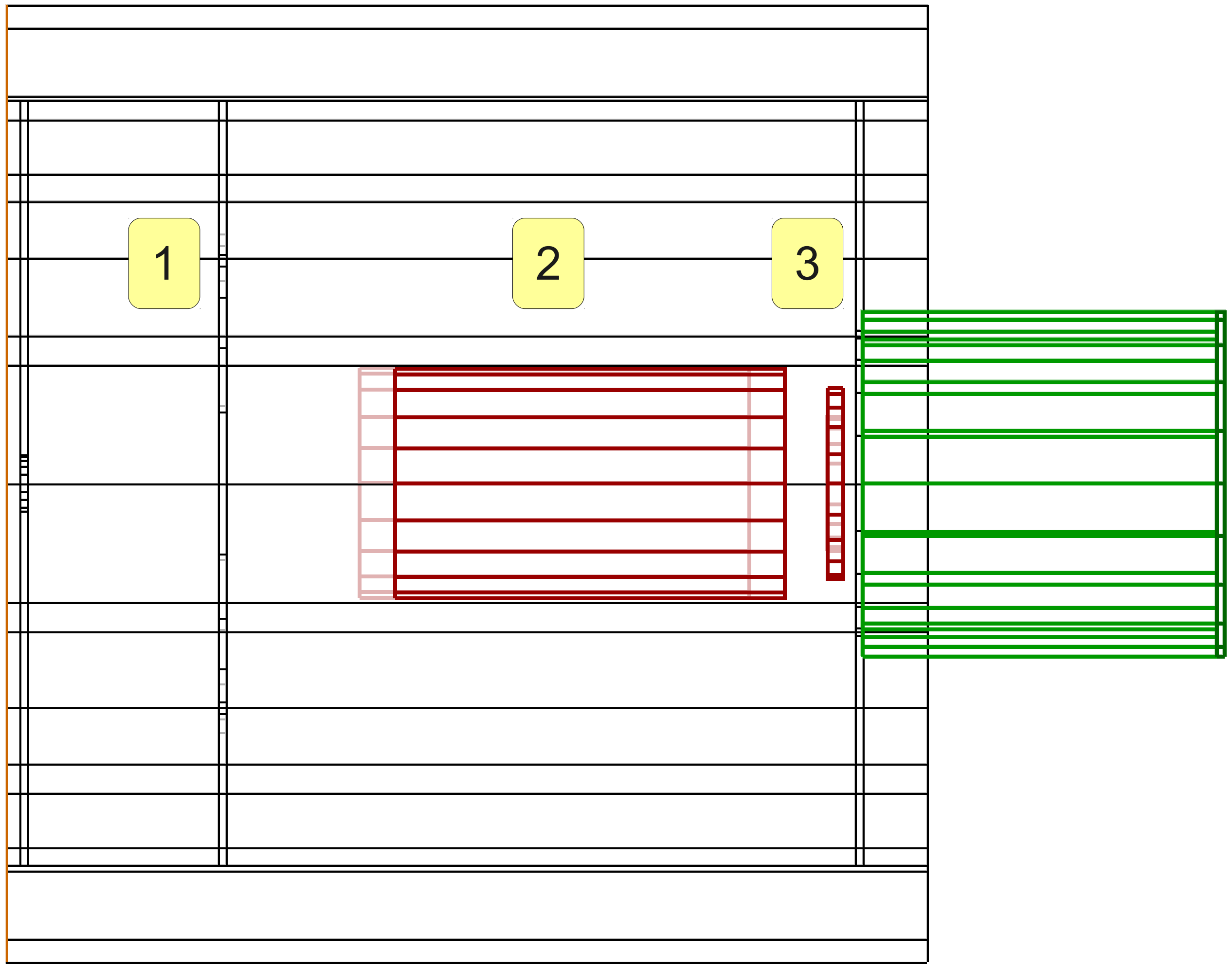
Summary for $^{48}Ca+^{248}Cm$ Gas-cell design

- 27 % efficiency for Z ≥ 102
- Background rate:
  - ~ 30 kHz
  - mostly due to inelastic - few-nucleon exchange channels
  - Small number of elastic scattered target nuclei make it to the detector
- Background can be reduced by moving (or extending) of the beamdump and closing of collimator aperture



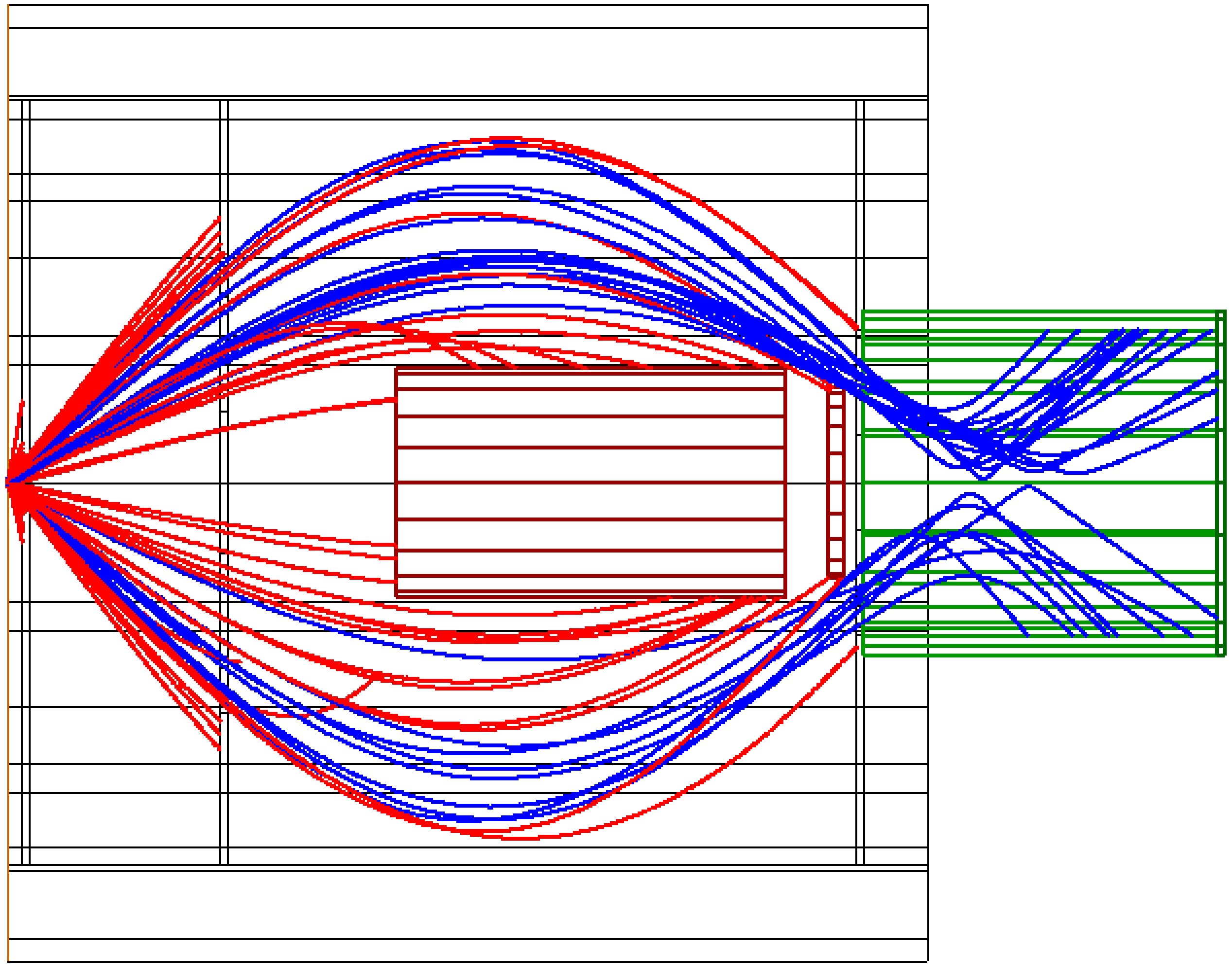
48Ca+248Cm @ 209 MeV for FPD

1) Middle collimator - radius 13 → 12 cm
2) Beam dump 1 - backwards by 5 cm
3) Beam dump 2 – radius 3.5 → 5 cm



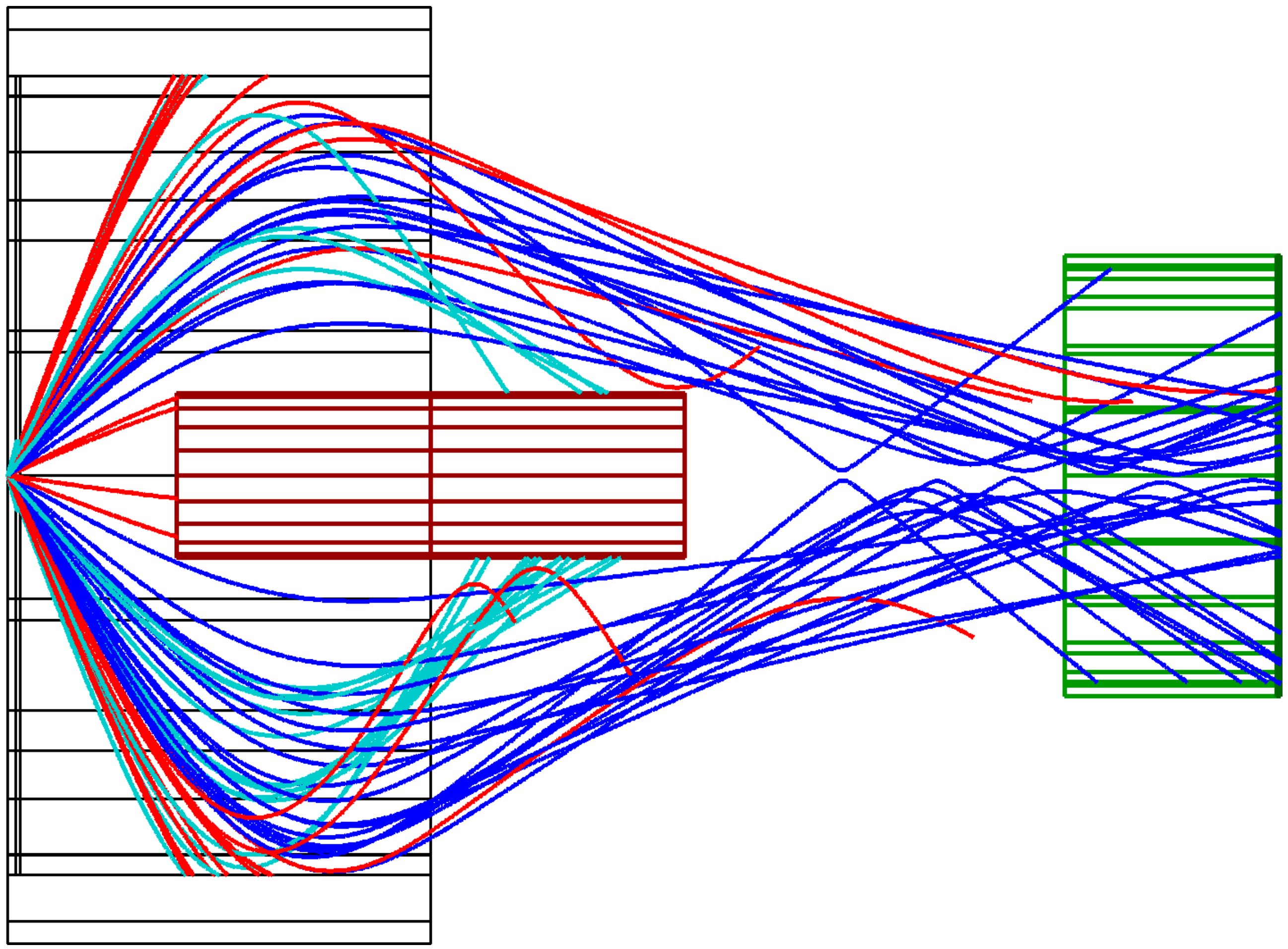
48Ca+248Cm @ 209 MeV for FPD → Result

- Reducing background from 30 kHz to 320 Hz
  (no elastic scattered target, GRAZING reduced)
- Z ≥ 102 Efficiency dropped from 27% to 17%



Gas-filled solenoid $^{48}Ca + ^{248}Cm$ @ 209 MeV

Asymmetric mode



- 1m long
- 58 cm bore i.d.
- 7.7 T
- 10 MJ
- 1 mbar He
- I_{beam} = 1 p.µA
- Focal distance = 1.5 m

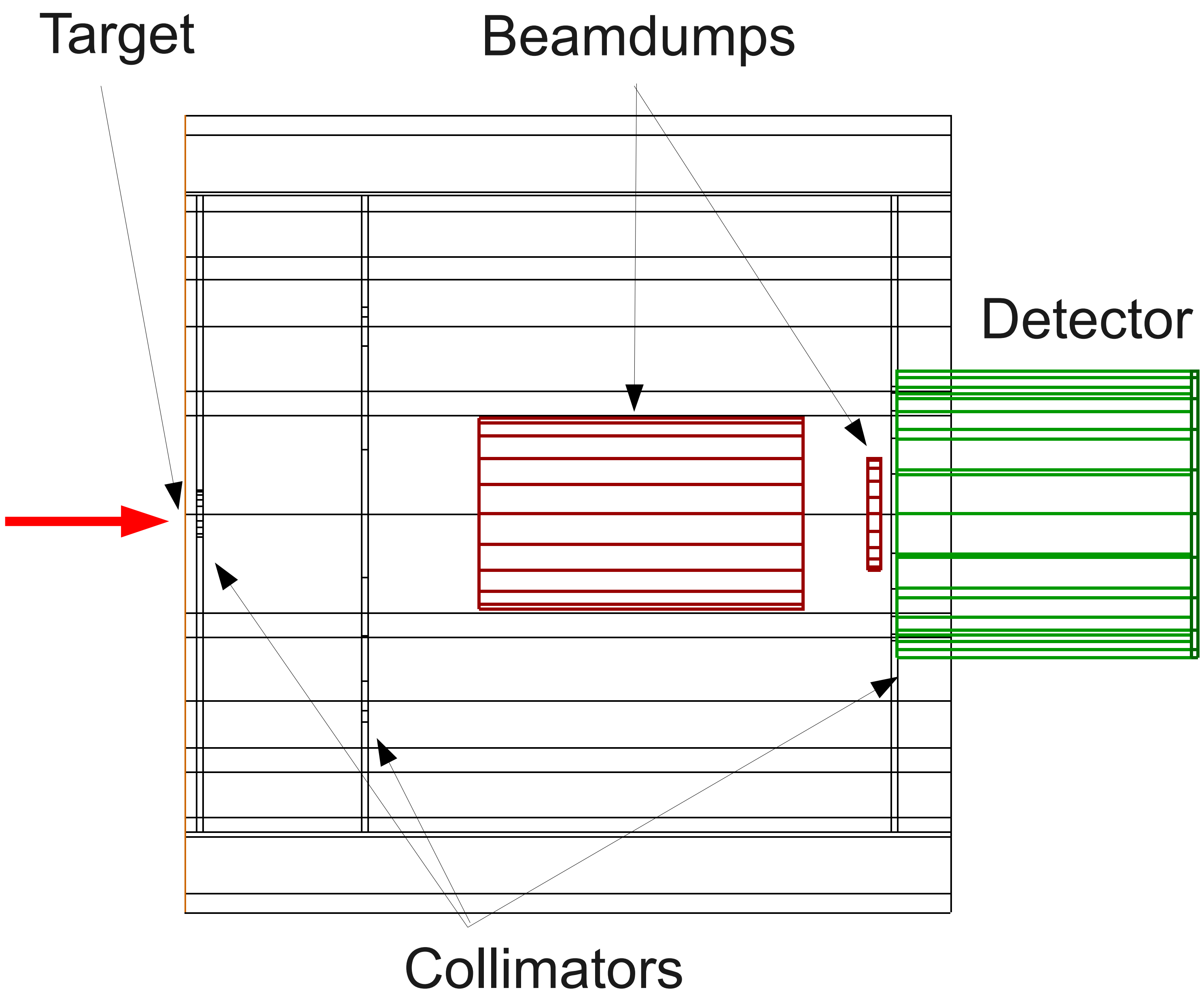
Gas-filled solenoid $^{48}Ca+^{248}Cm$ @ 209 MeV

- Asymmetric mode rocks
- Depends on the fringe field – be careful!

Type	Efficiency	Count Rate
Elastic target > 80°	< 0.003%	< 0.4 kHz
Grazing collisions	0.03%	20 kHz
Z ≥ 102	**41%**	

Gas-filled solenoid $^{238}U + ^{248}Cm$ @ 750 MeV

Symmetric mode



- 1.3 m long
- 40 cm bore i.d.
- 9.6 T
- 10 MJ stored energy
- 10 mbar He
- Target 1 mg/cm^2
- I_{beam} = 1 p.μA (probably 20 x more than what is possible)

$^{238}U + ^{248}Cm$ @ 750 MeV Gas cell -summary

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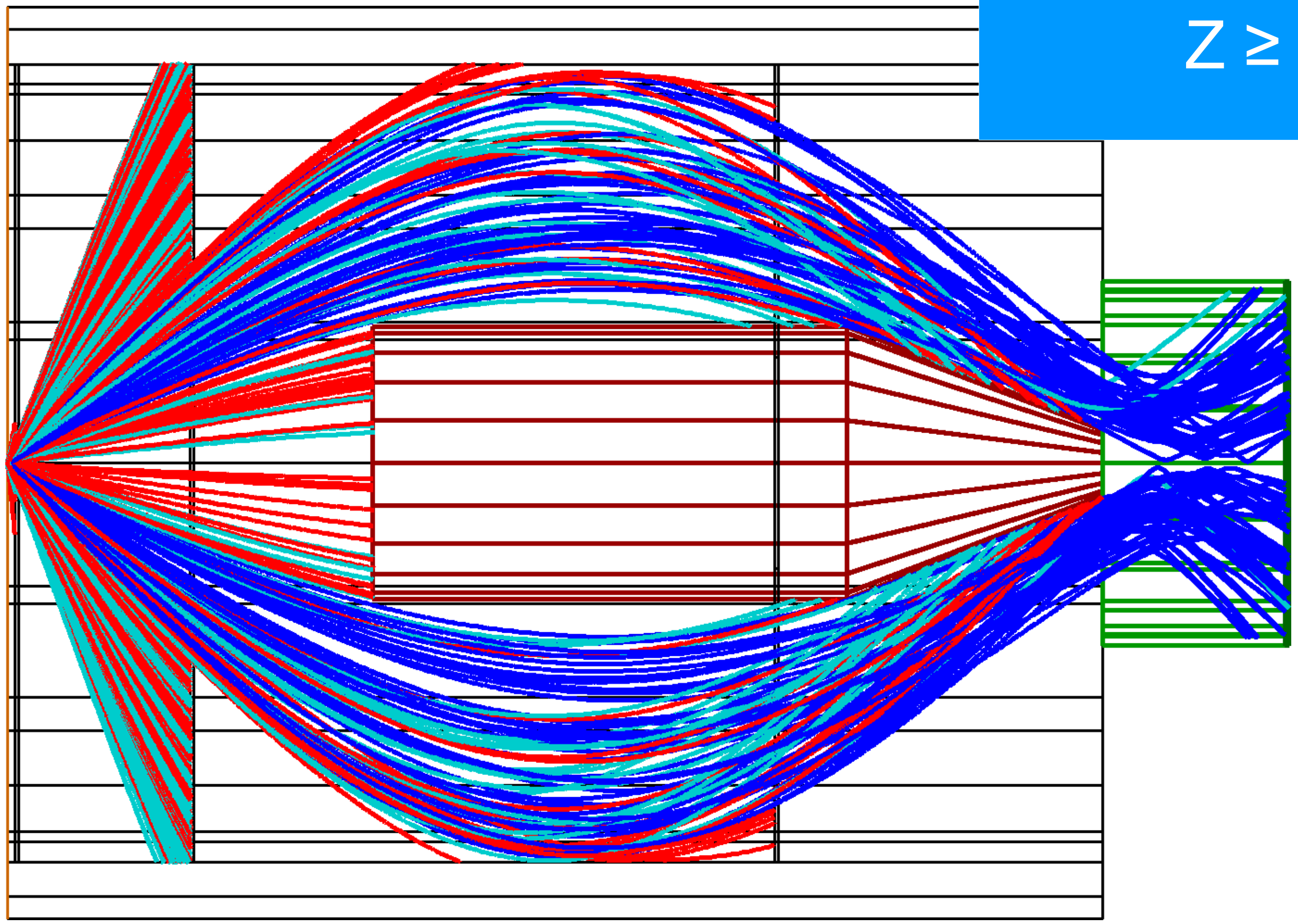
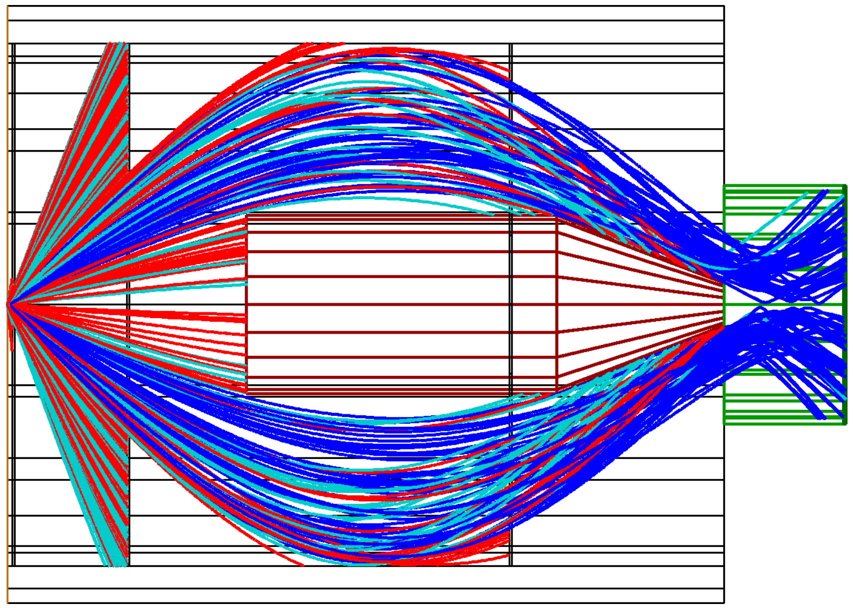
Type	Efficiency	Count Rate
Elastic target > 80°	0.1%	58 kHz
All events b<18 fm	0.03%	52 kHz
Z ≥ 102	**19%**	



$^{238}U + ^{248}Cm$ @ 750 MeV FPD

- Moving beamdump back by 5 cm
- Background reduced
- Severe cut of efficiency

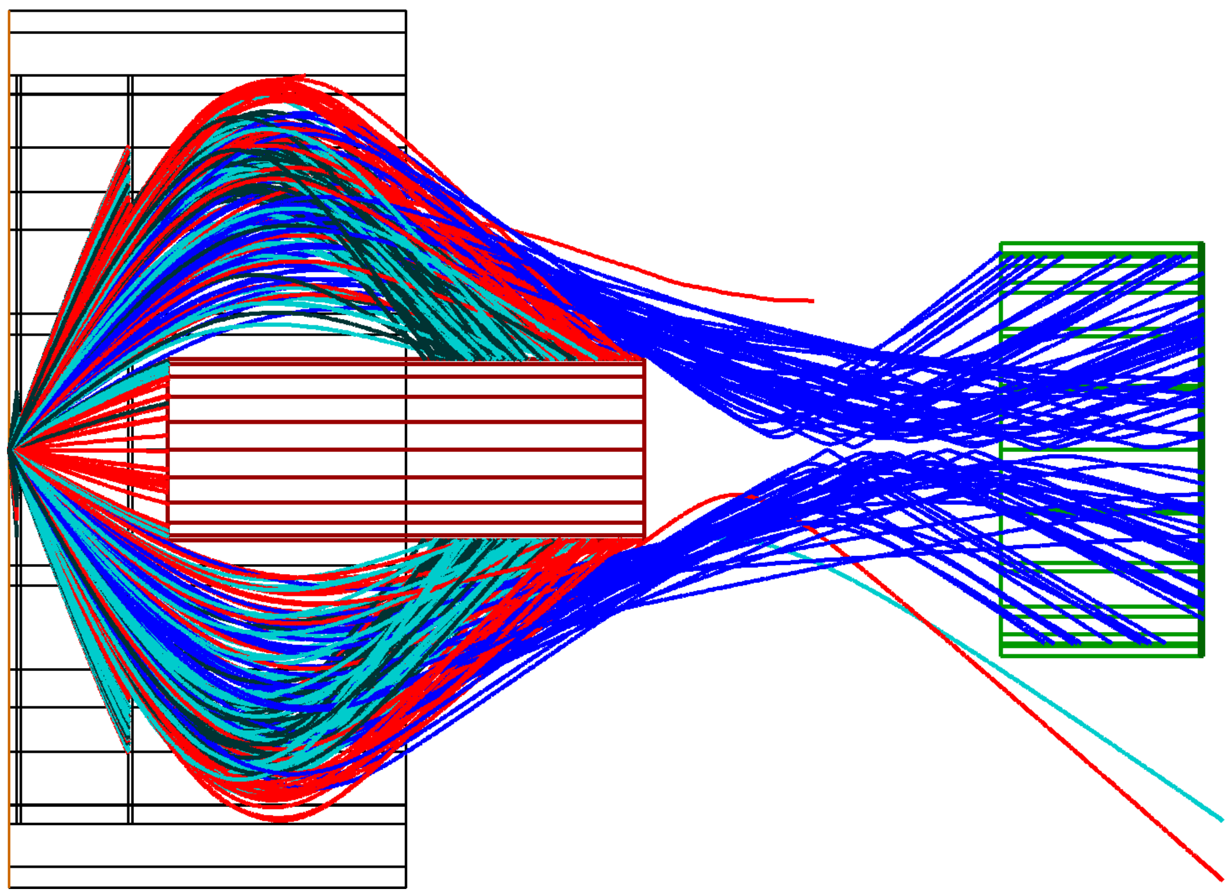
Type	Efficiency	Count Rate*
Elastic target > 80°	0.001%	700 Hz
Primary b<18 fm	0.001%	2 kHz
Z ≥ 102	**3%**	



* Assuming target thickness of 1mg/cm^2 and I_{beam} = 1 pμA

^{238}U + ^{248}Cm @ 750 MeV Gas cell

Asymmetric mode



- 1m long
- 58 cm bore i.d.
- 7.7 T
- 10 MJ
- 10 mbar He
- I_{beam} = 1 p.µA
- Focal distance = 1.5 m

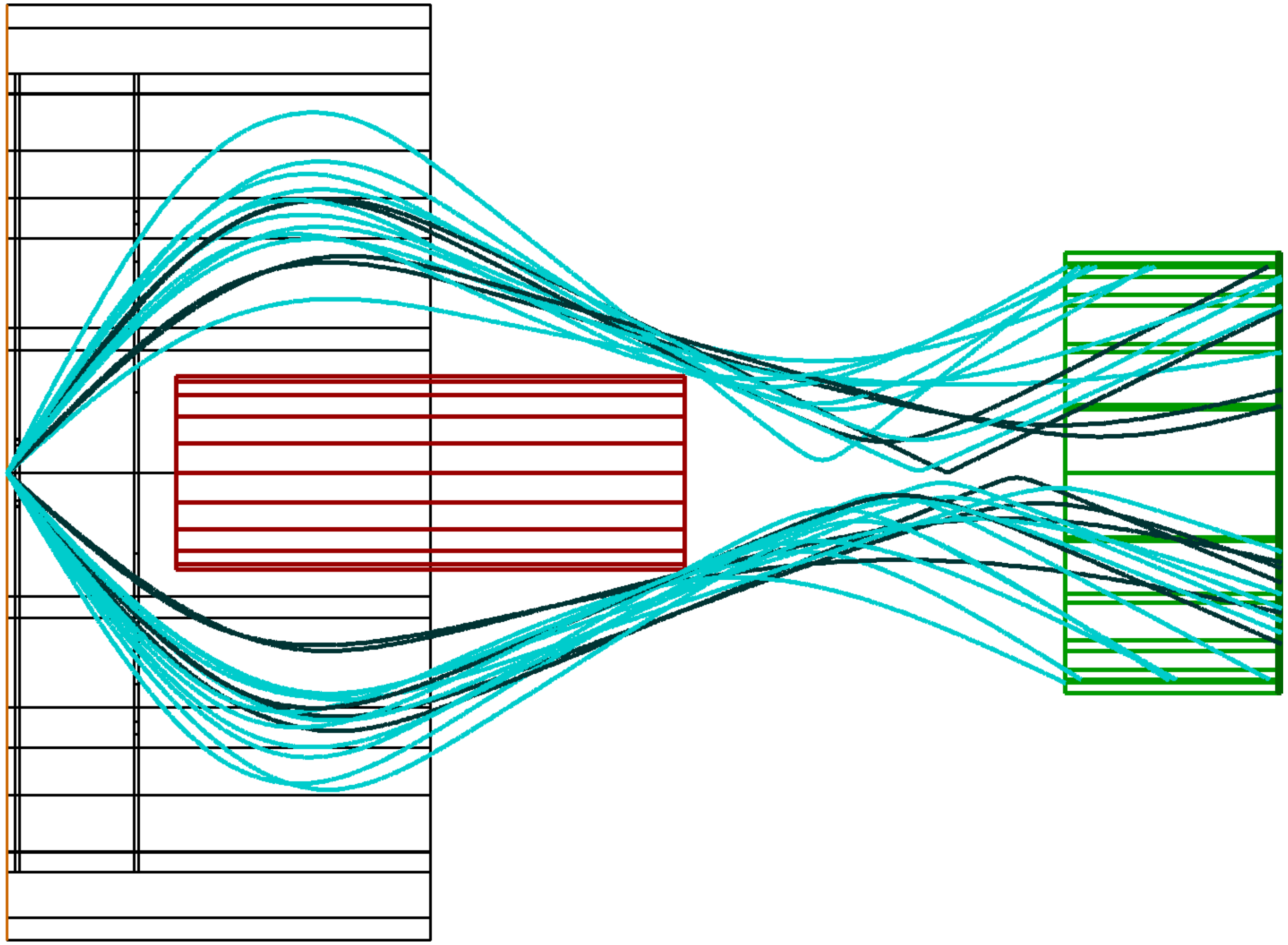
$^{238}U + ^{248}Cm$ @ 750 MeV Gas cell

- Asymmetric is better than symmetric
- Depends on the fringe field – be careful!

Type	Efficiency	Count Rate
Elastic target > 80°	0.5 %	300 kHz
Primary B < 18 fm	0.2 %	300 kHz
Z ≥ 102	**29 %**	

$^{238}U + ^{248}Cm$ @ 750 MeV FPD

- Even with asymmetric mode is background a problem
- Tracks are almost impossible to disentangle



Scaling of the magnet in symmetric mode

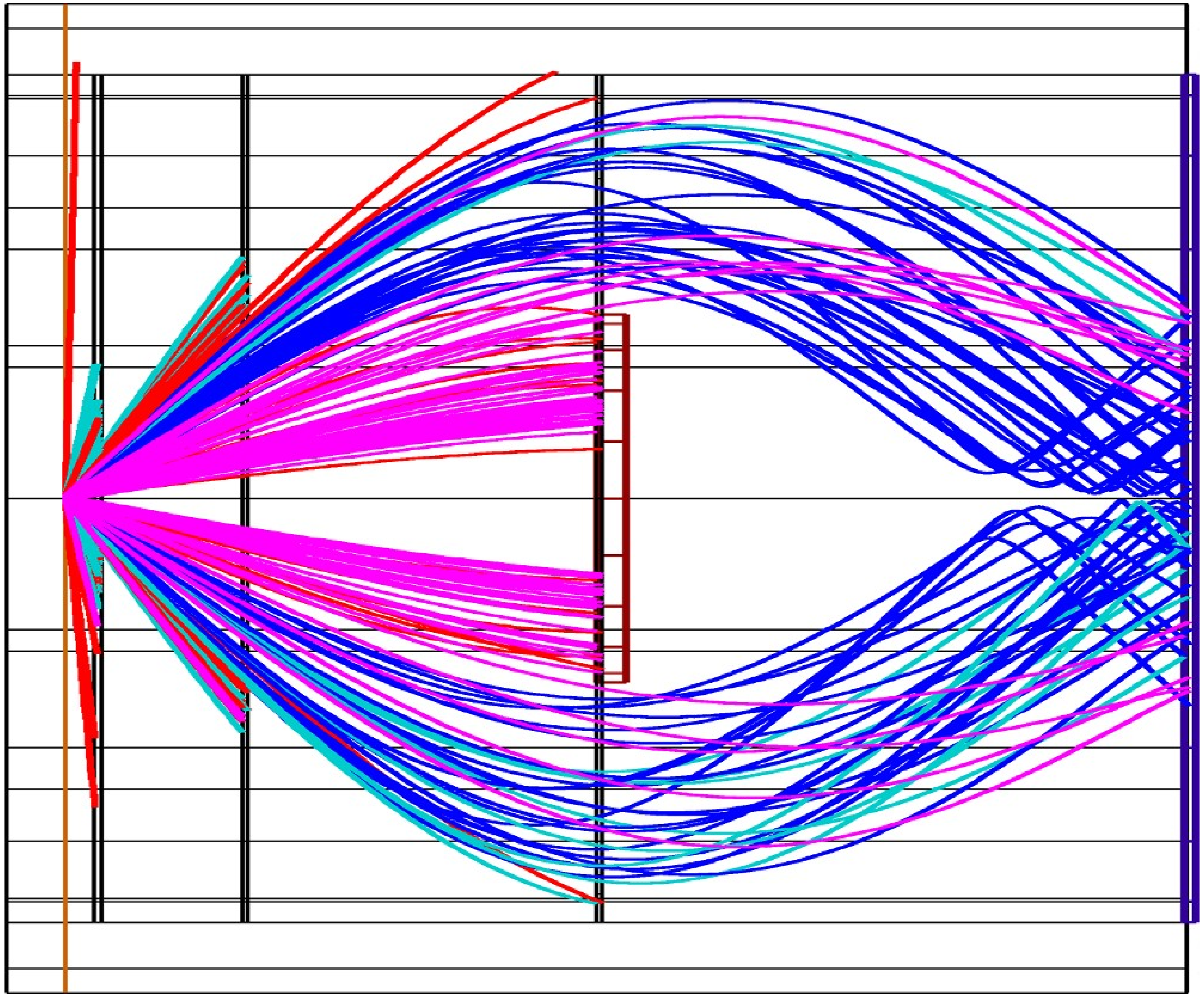
- Size and B-field can be scaled
- Optimal designs ~ 10 MJ stored energy
- NbTi can be used up to 9 T at 4.2 K, 10T significantly more expensive
- Estimated cost for NbTi solenid 1-1.2 M$

Length [m]	Bore i.d. [cm]	Max B field [T]	Stored Energy [MJ]	Efficiency for $^{238}U+^{248}Cm$
1.3	40	9.6	10	19%
2	56	6	9.8	19.5%
3	70	4	9.6	19 %

Vacuum solenoid

Vacuum solenoid

Vacuum solenoid $^{48}Ca+^{248}Cm$ @ 209 MeV



- 2 m long
- 60 cm bore i.d.
- 2.3 T
- 1.7 MJ stored energy
- Target 1 mg/cm^2

Problem with Vacuum Solenoid

- Large charge-state spread →
  - Impossible to reduce background

Type	Efficiency	Count Rate
Elastic projectile > 10°	1.0 %	280 MHz
Elastic target > 80°	4.3 %	1 MHz
Grazing	0.6 %	0.5 MHz
Z ≥ 102	14 %	

* Assuming target thickness of $1 mg/cm^2$ and I_{beam} = 1 pμA

Conclusion

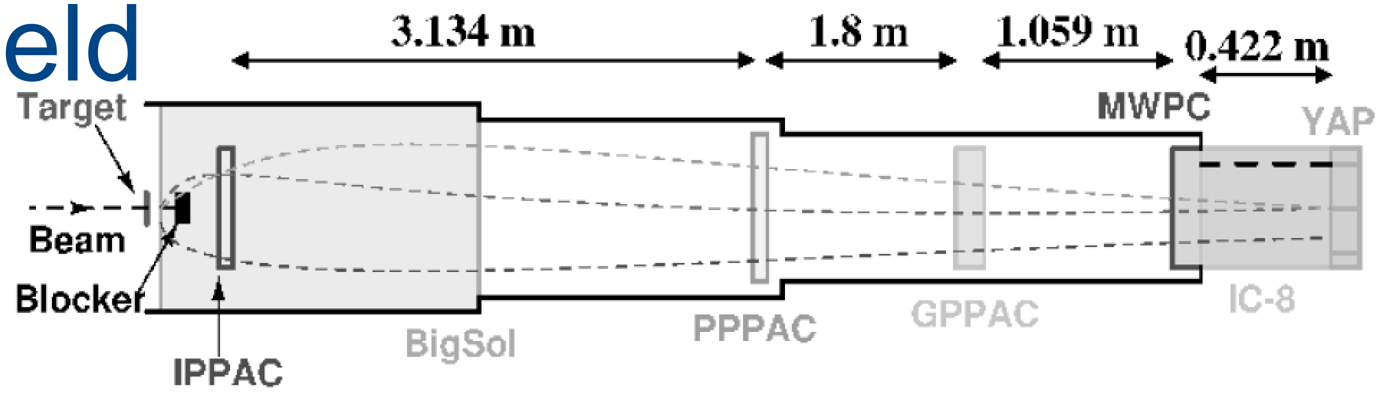
- Separation in vacuum solenoid doesn't suffice
- Gas-filled solenoid design works, but
  - Solenoid with stored energy of 10 MJ necessary
  - Estimated cost ~ 1 M$

Reaction	Design type	Efficiency Z ≥ 102	Count rate*
$^{48}Ca + ^{248}Cm$	Gas Cell	27 %	30 kHz
$^{48}Ca + ^{248}Cm$	FPD	17 %	320 Hz
$^{48}Ca + ^{248}Cm$	Asymmetric	41 %	20 kHz
$^{238}U + ^{248}Cm$	Gas Cell	19 %	11 kHz
$^{238}U + ^{248}Cm$	FPD	3 %	2 kHz
$^{238}U + ^{248}Cm$	Asymmetric	29 %	600 kHz

* Assuming target thickness of 1mg/cm^2 and I_{beam} = 1 pμA

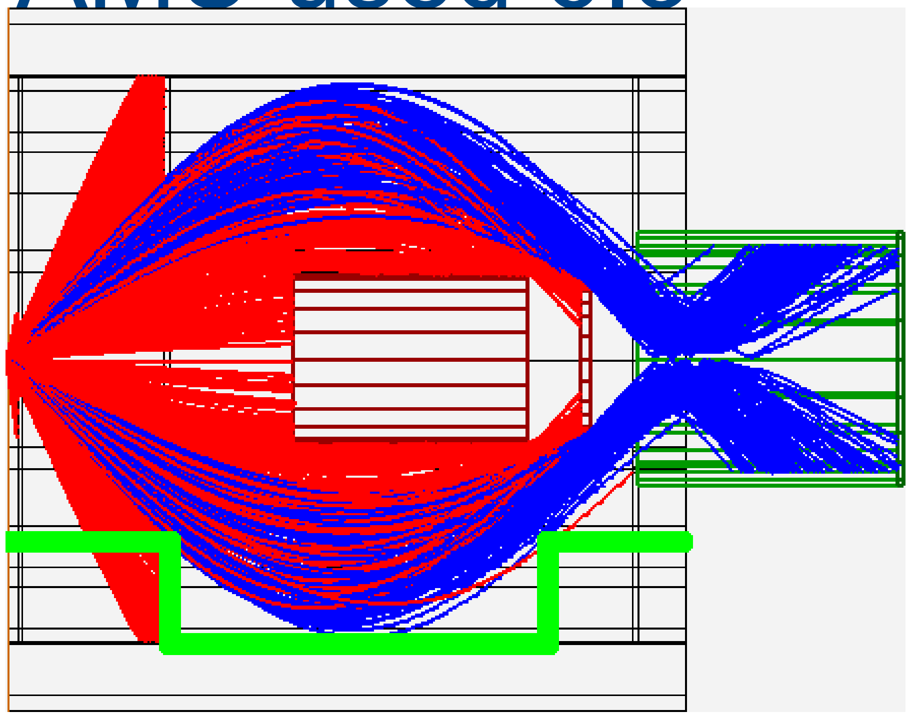
To do in the future

- Double check the gas interaction
- Double check fringe field
  - asymmetric mode



- Consider thicker targets (at TAMU used 6.3 mg/cm^2 Th)
- Consider optimization

  of solenoid bore size



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HEAVY ELEMENTS

Thank you for your attention!