NSCL

Exotic Beam Summer School 2016

Particle Identification

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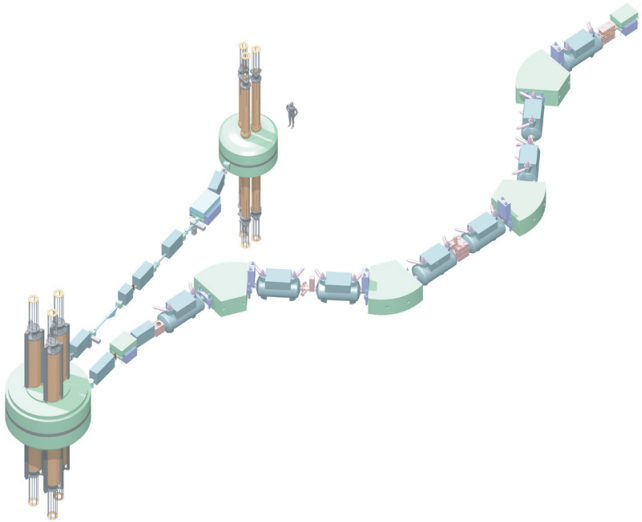
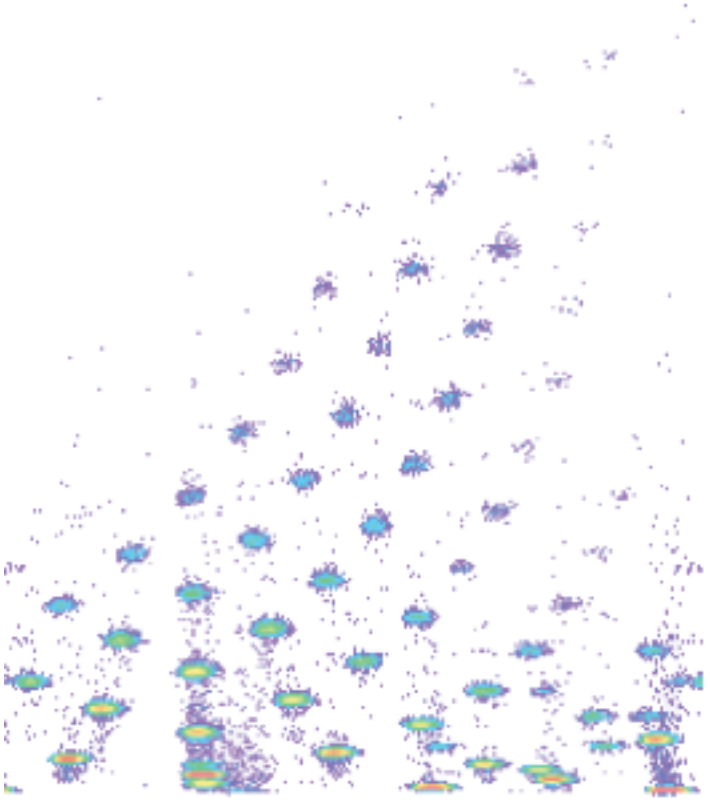
NSCL

Michigan State University





Particle Identification Techniques

Measure properties of particle

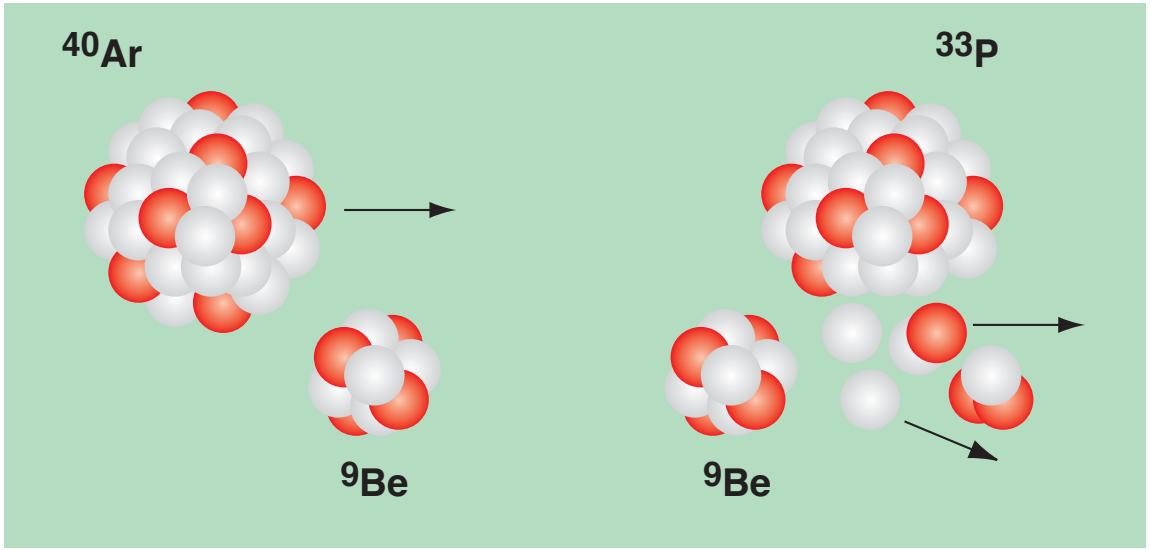
- energy
- momentum
- energy loss
- velocity (time of flight)

Detector telescopes and correlations

- ΔE - E
- ΔE - TOF

Magnetic separation in spectrometer

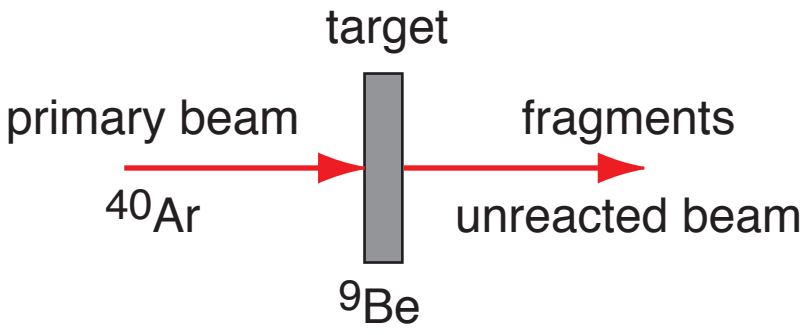
Projectile Fragmentation



Abrasion/Ablation Model

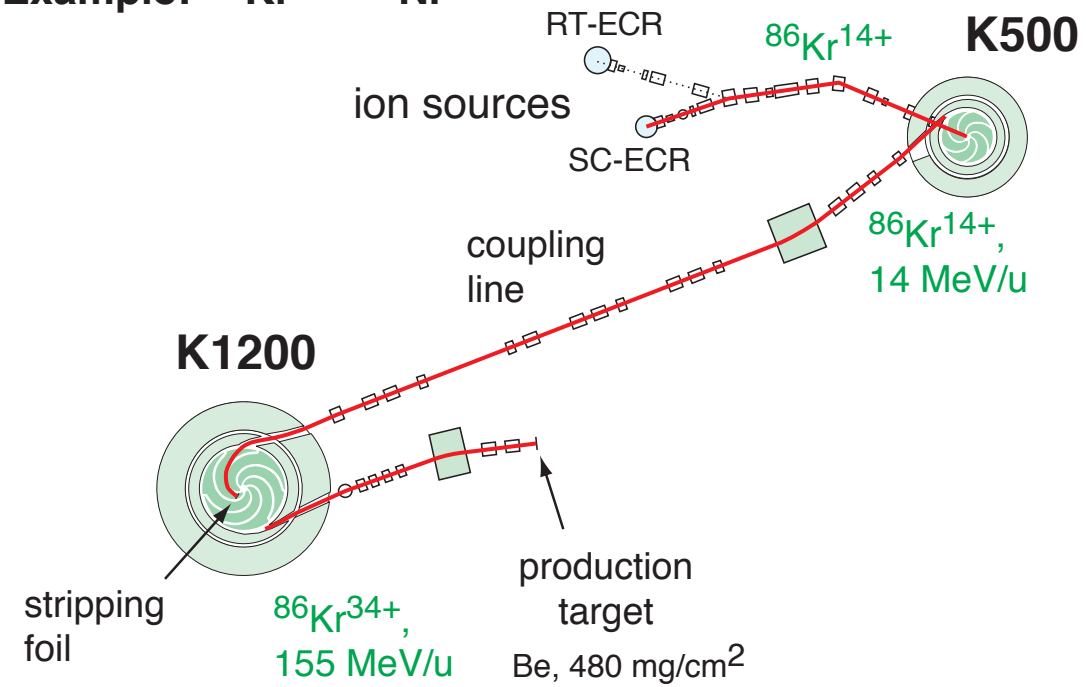
fast Abrasion step
nucleon removal in overlap region of target and projectile

slow Ablation step
equilibration of excited prefragment and evaporation of particles



Overview of the Fragment Separation Technique

Example: $^{86}Kr \rightarrow {}^{78}Ni$



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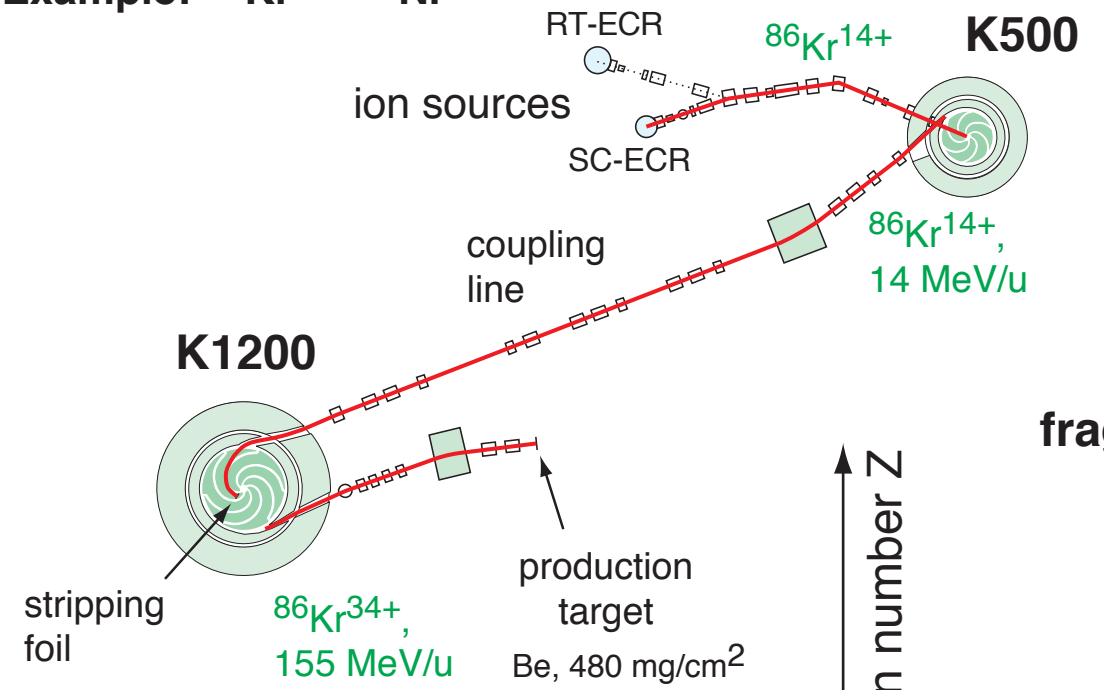
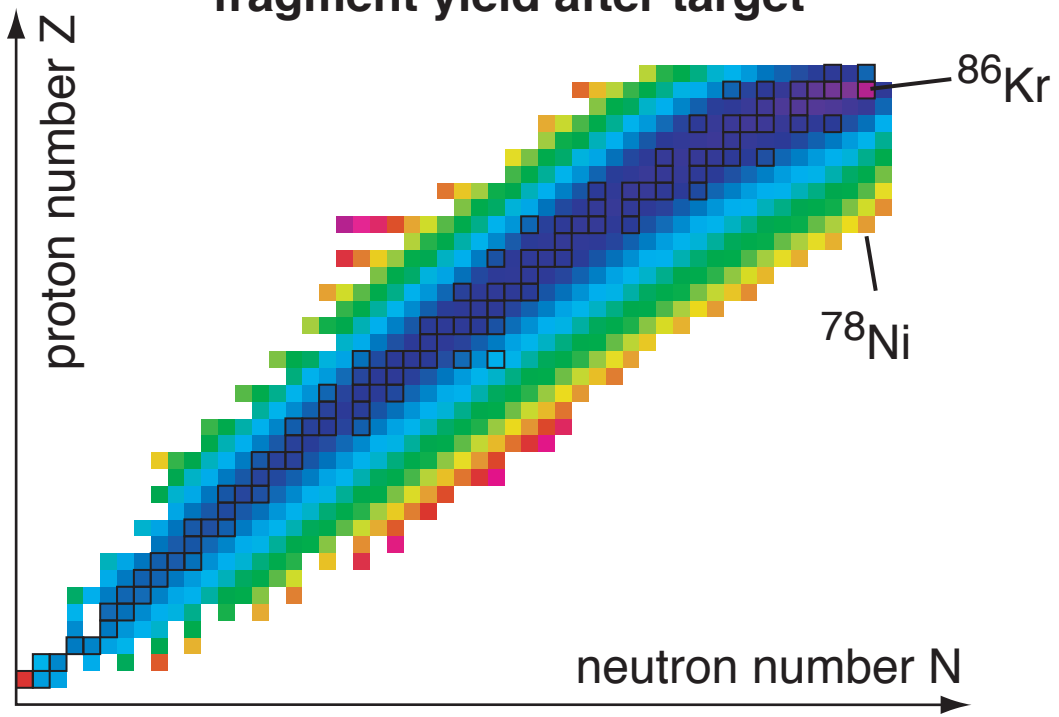


fragment yield after target



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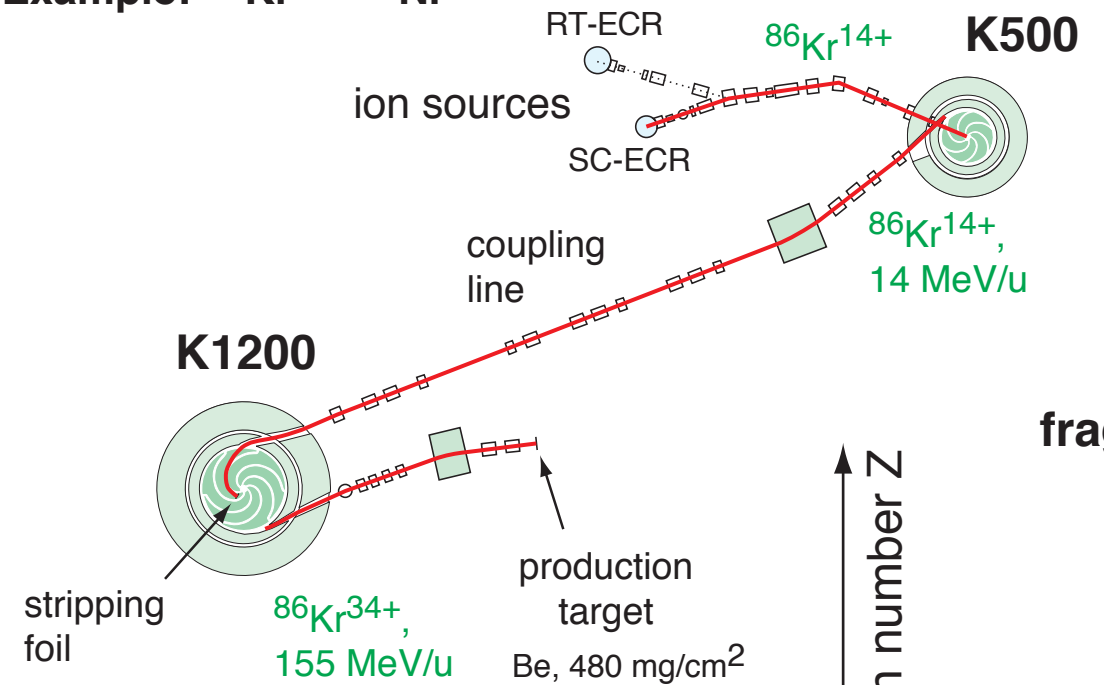

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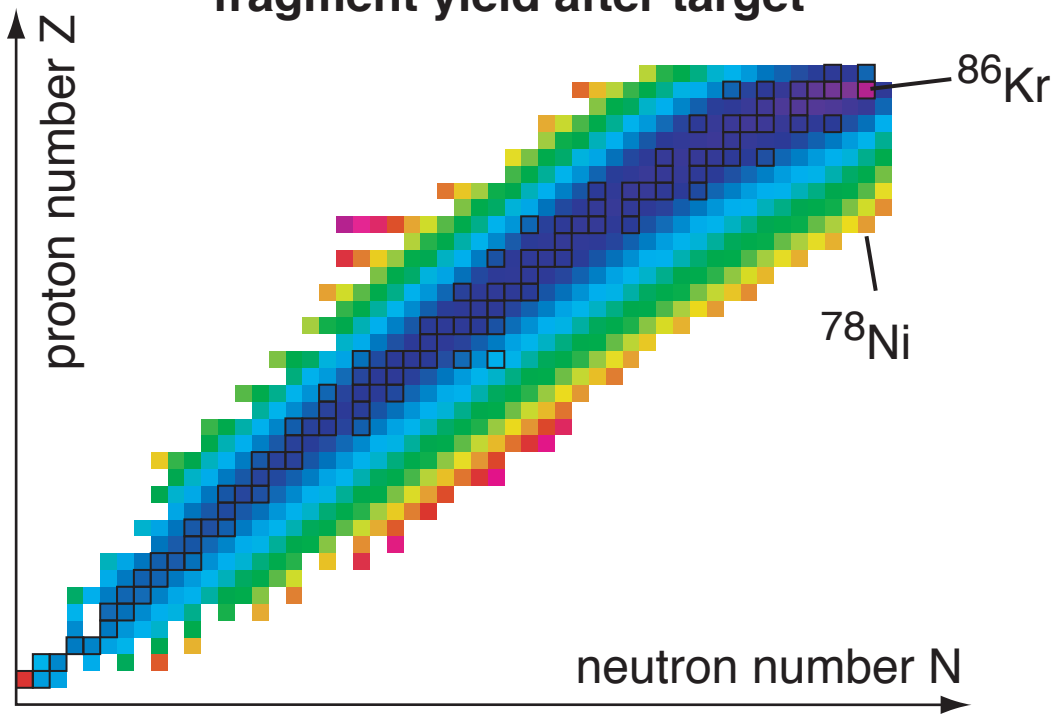
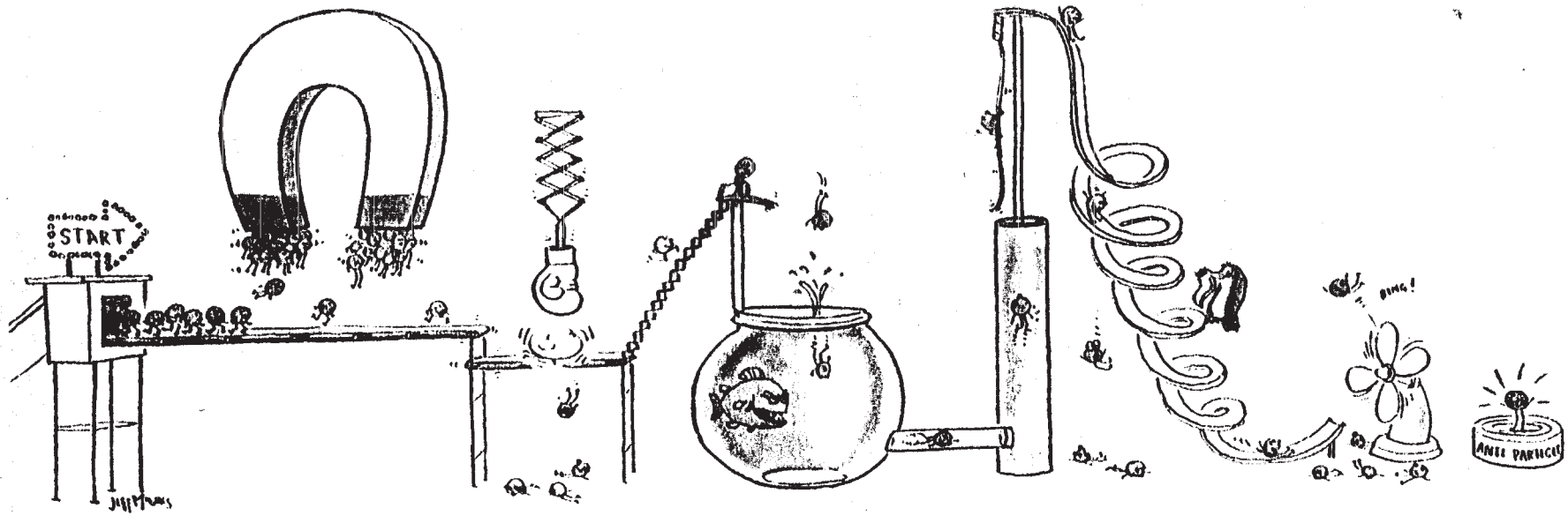


We need a filter device to select single isotopes

A Separation Device for Rare Isotopes



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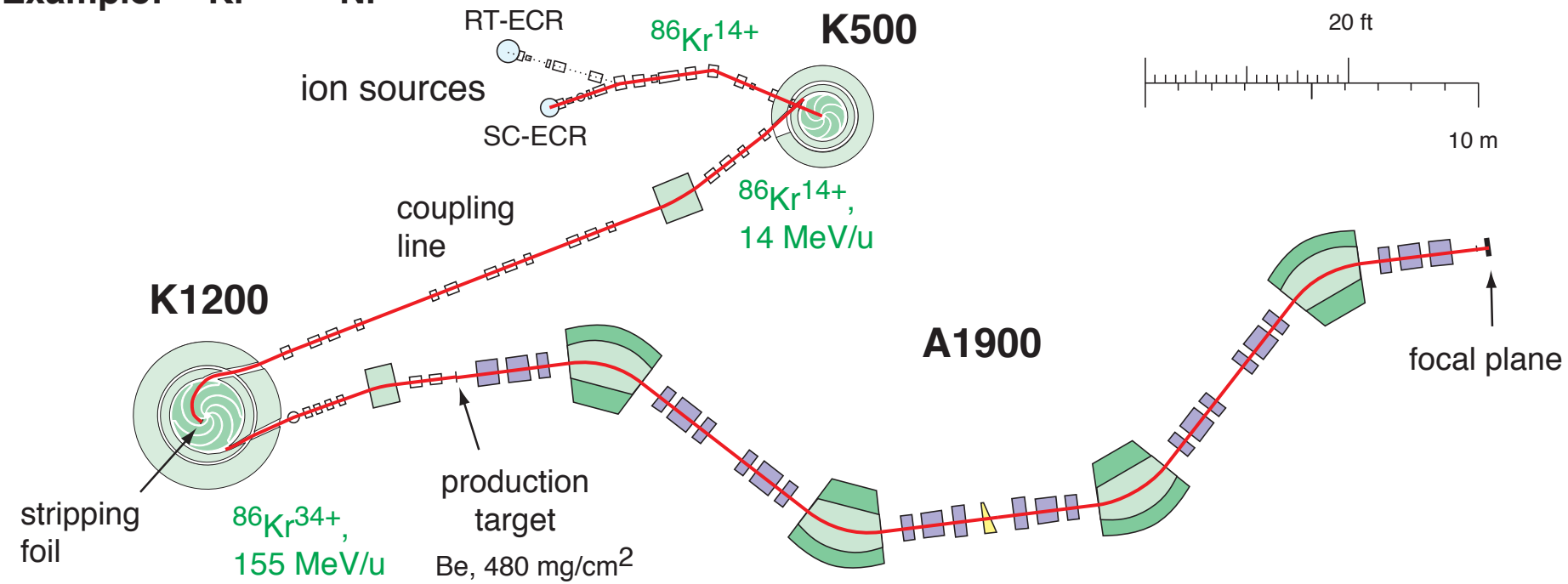
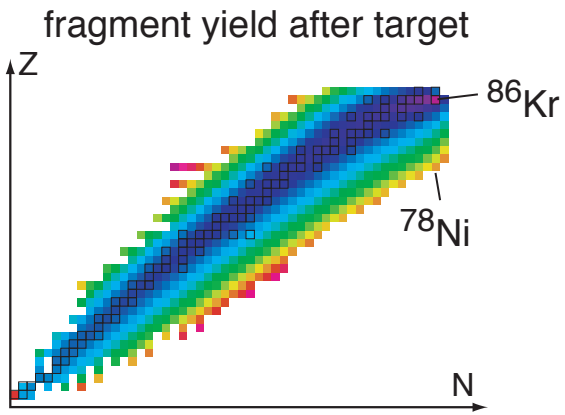
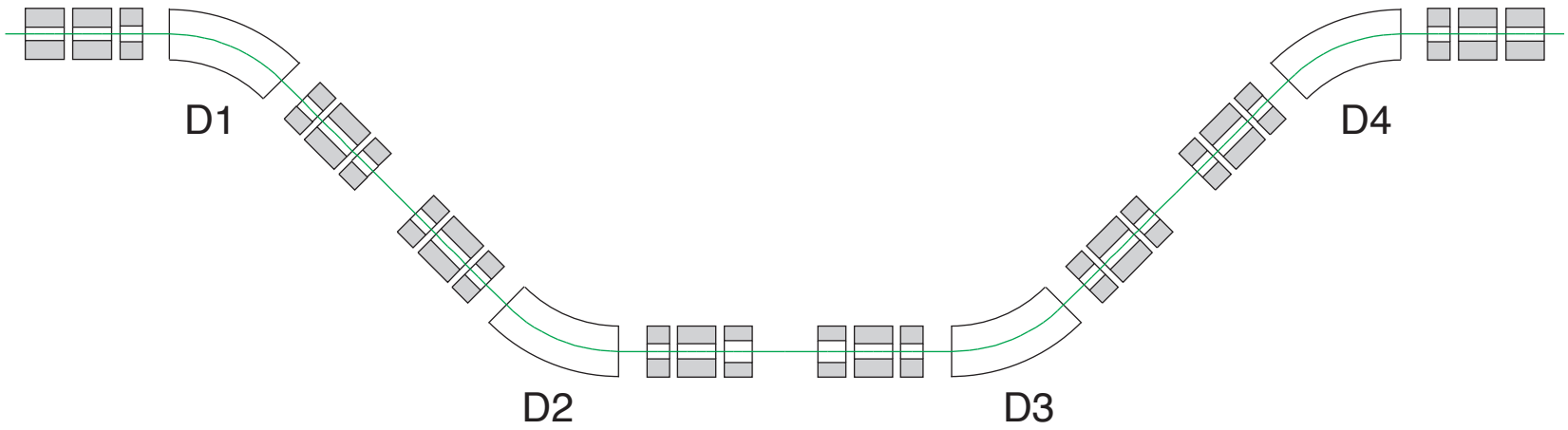




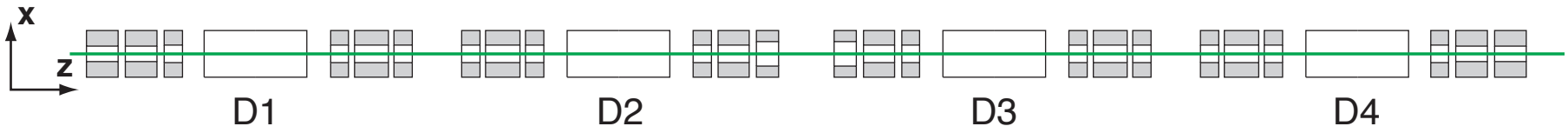
A1900

- **4 dipole magnets** to filter the fragments
- **24 quadrupole magnets** to focus the beam

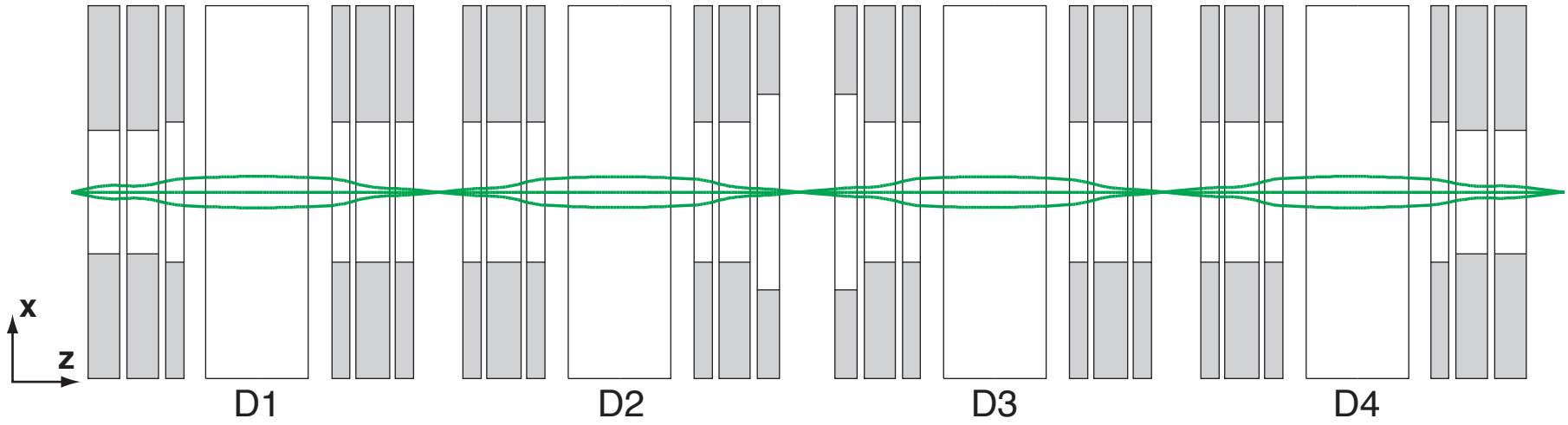
A1900 Ion Optics



A1900 Ion Optics

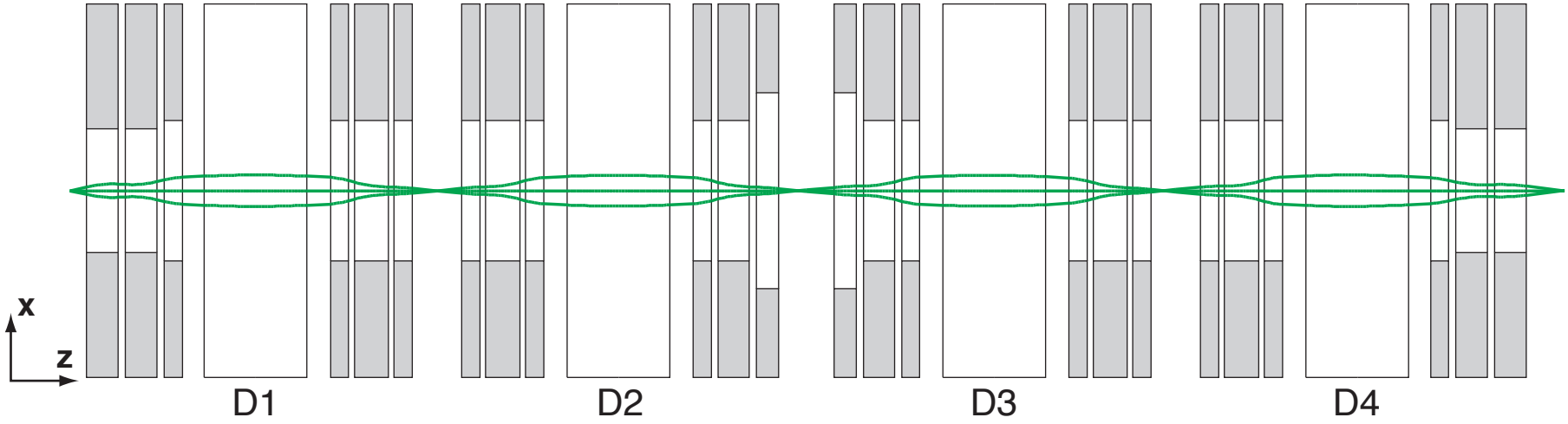


A1900 Ion Optics



centered beam: dp/p = ±0%

A1900 Ion Optics



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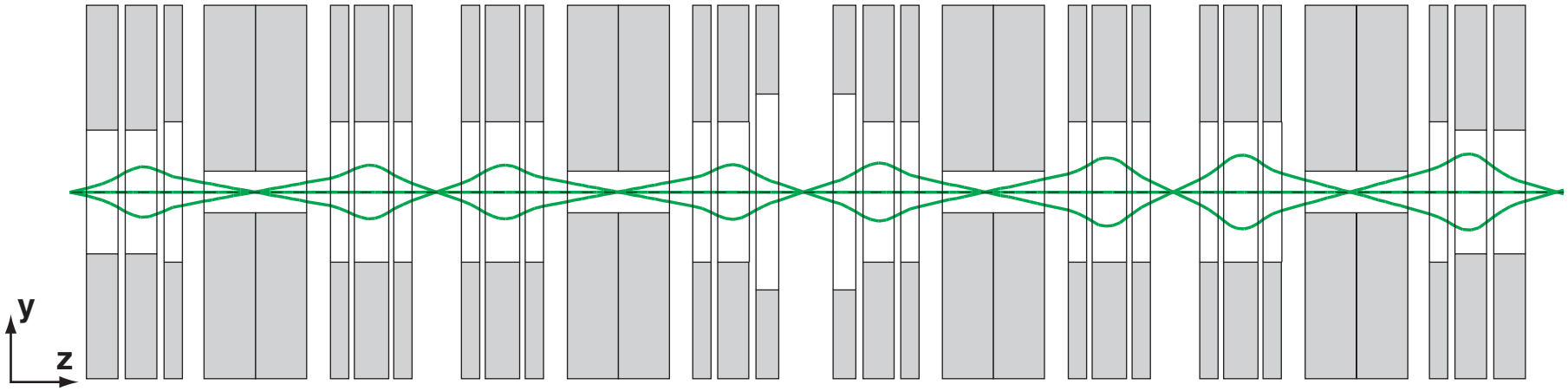

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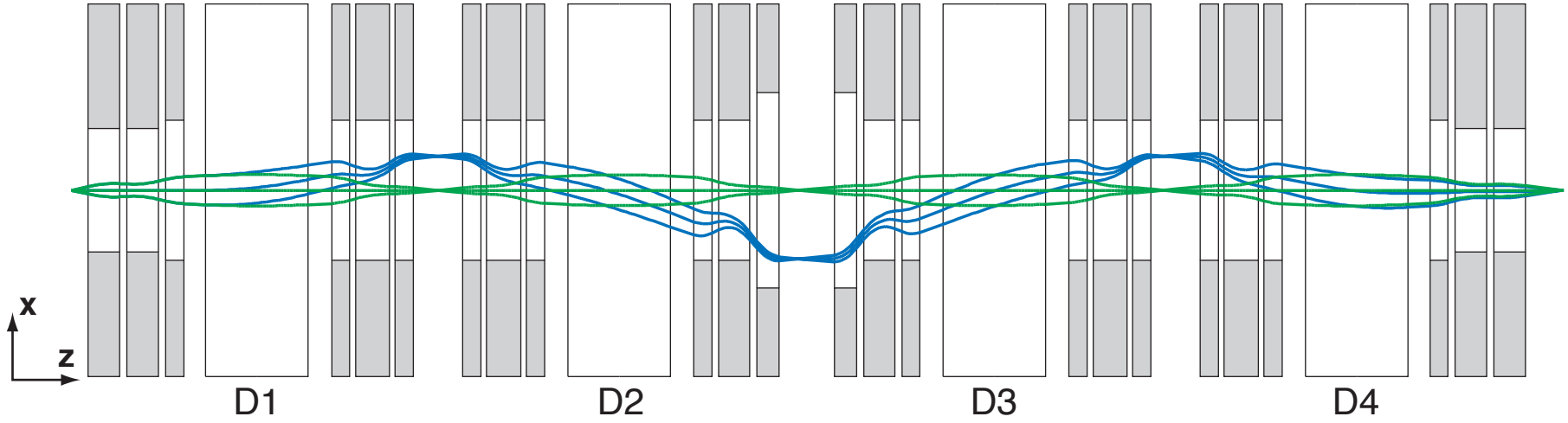
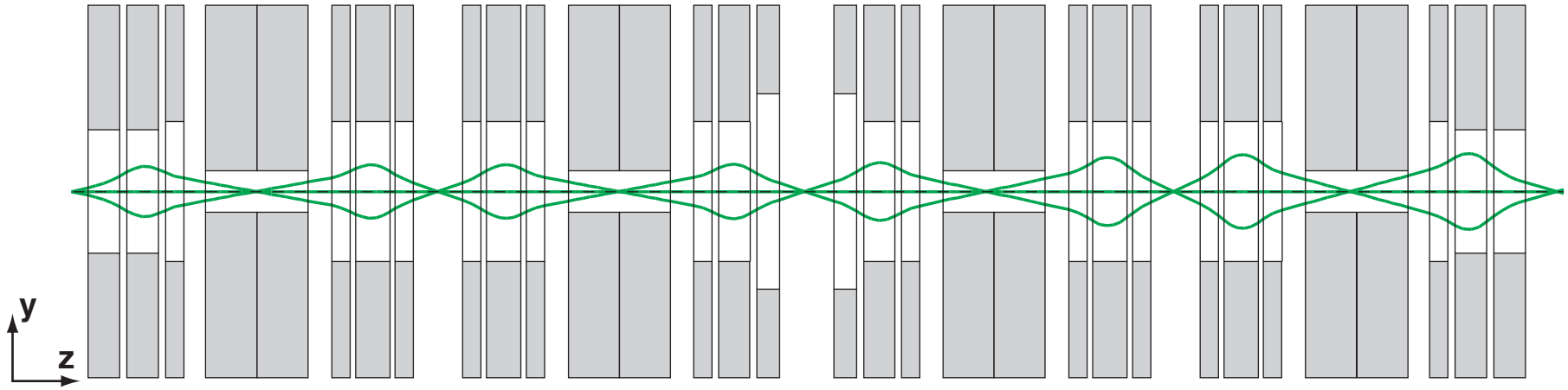


centered beam: dp/p = ±0% faster beam: dp/p = +2.5%



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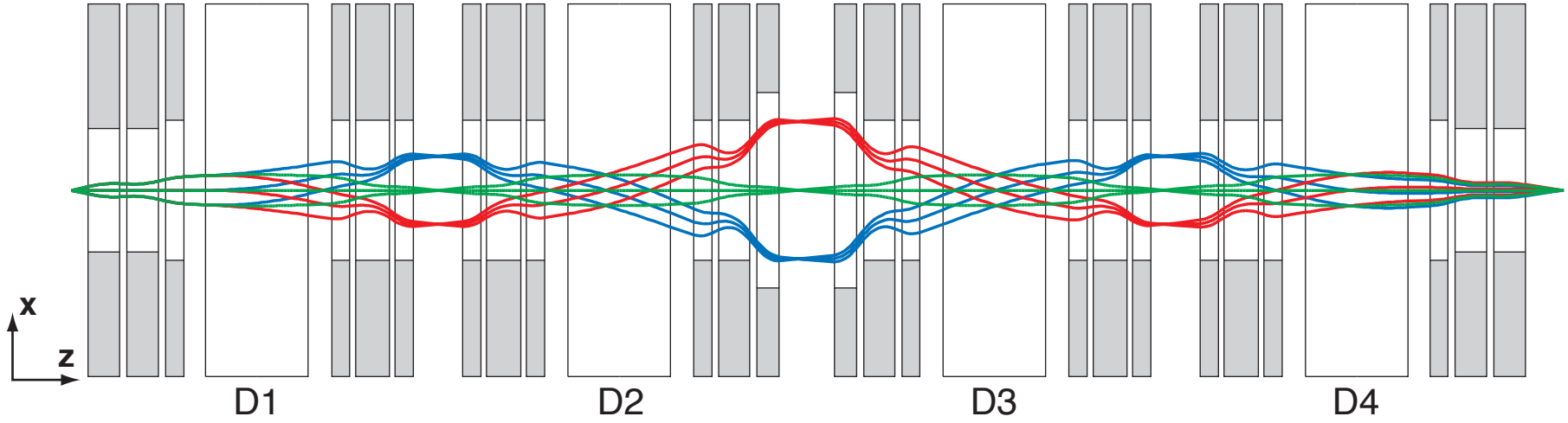
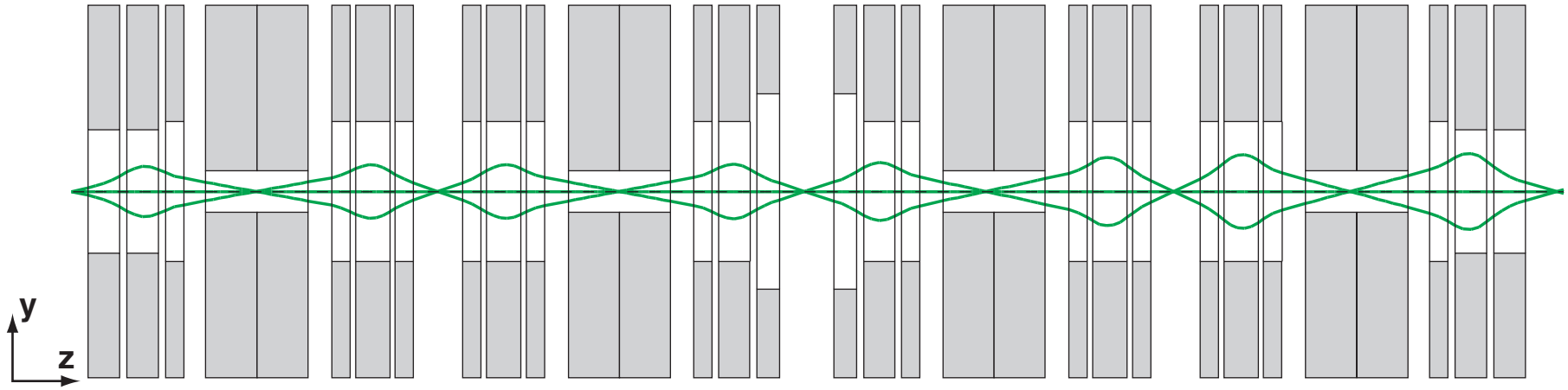


centered beam: dp/p = ±0% faster beam: dp/p = +2.5% slower beam: dp/p = -2.5%



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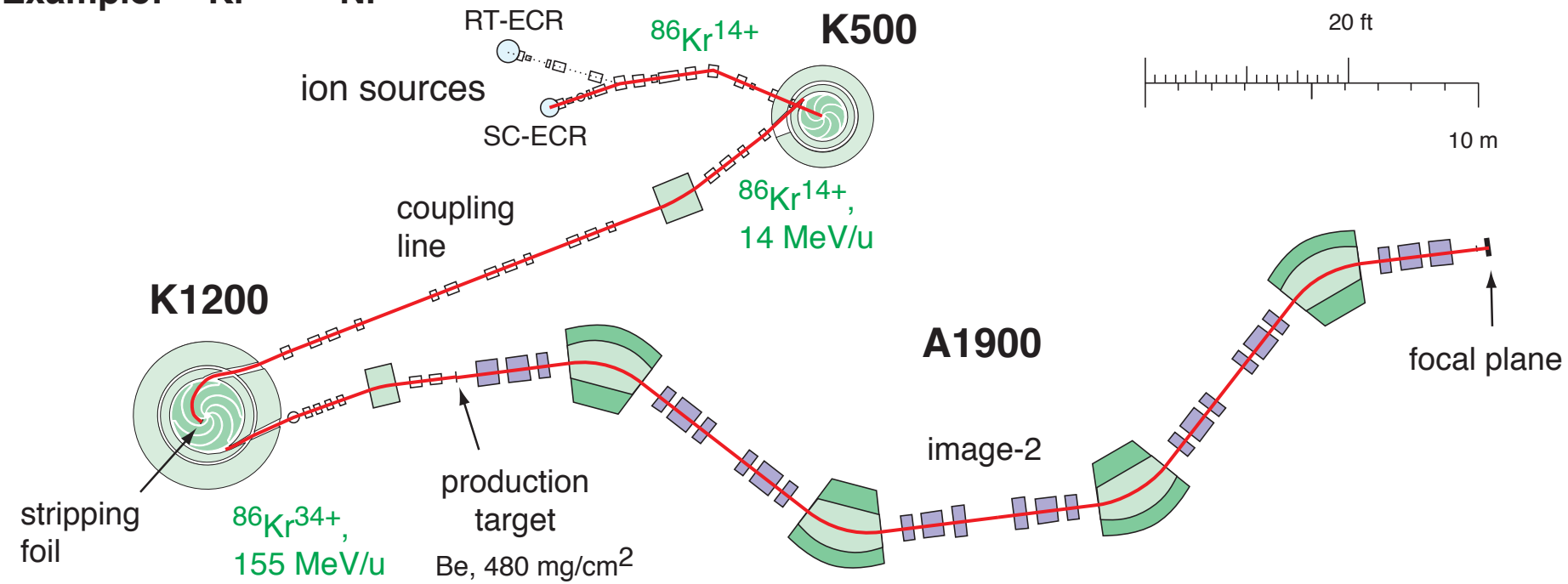

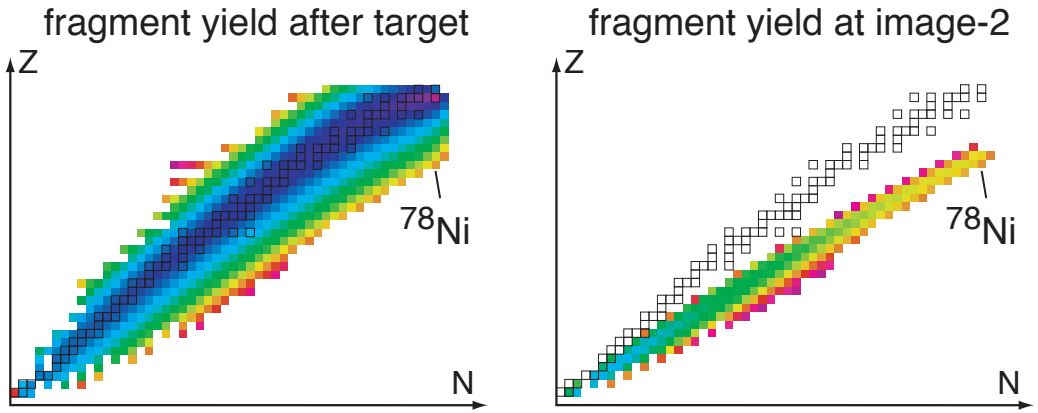

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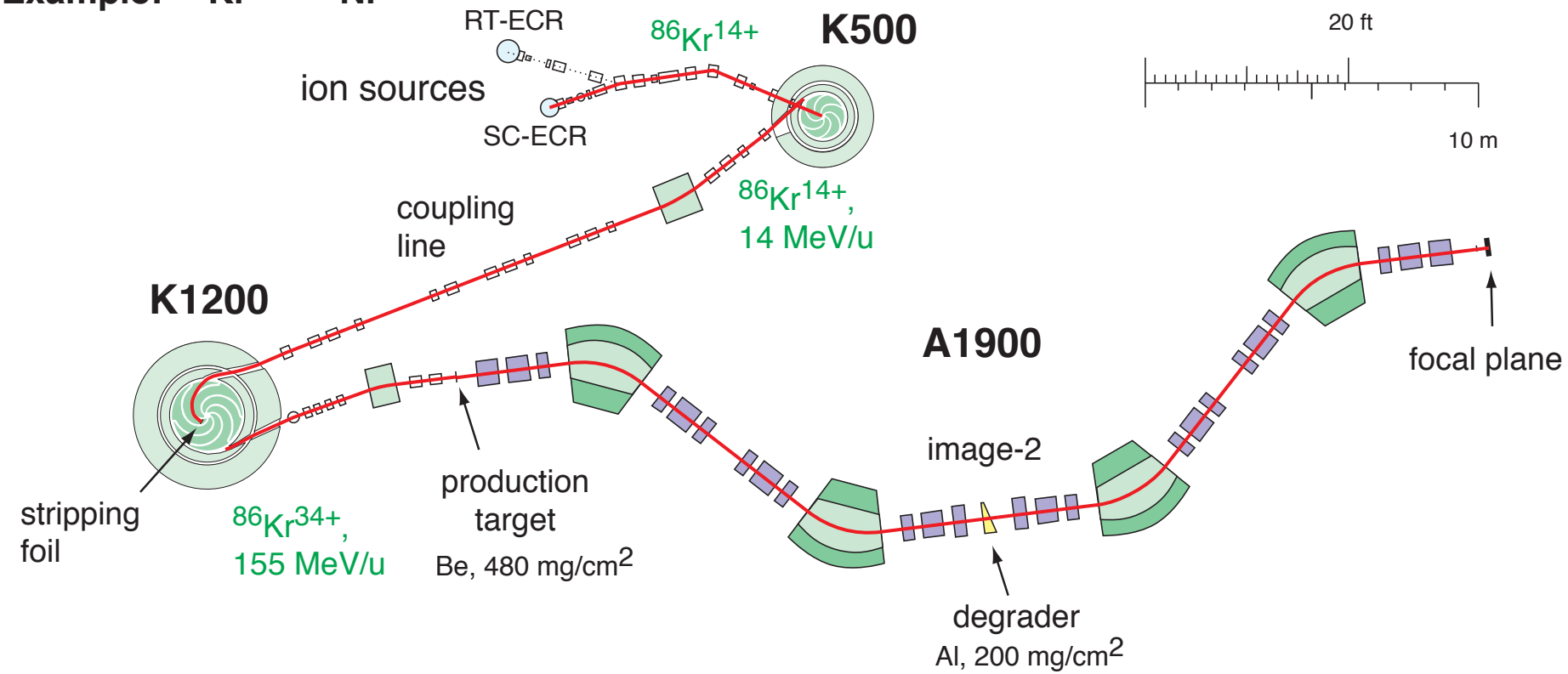
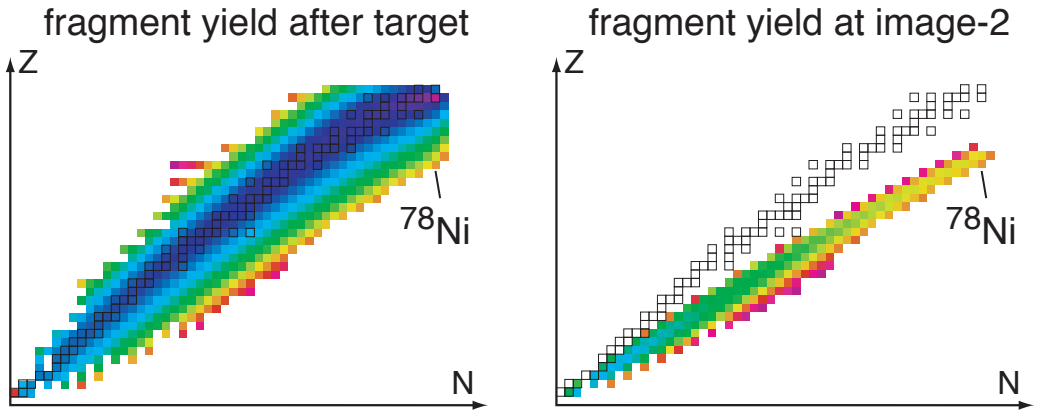
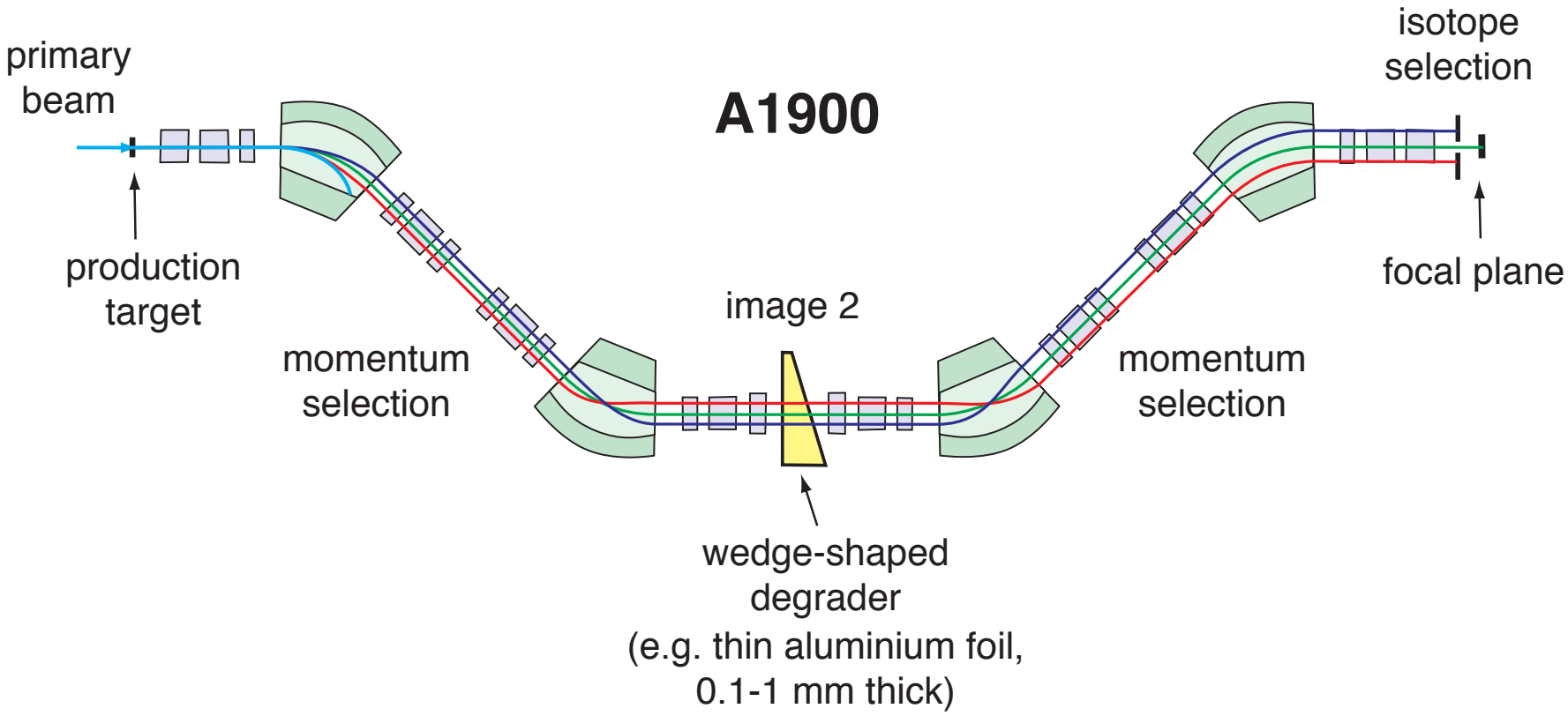




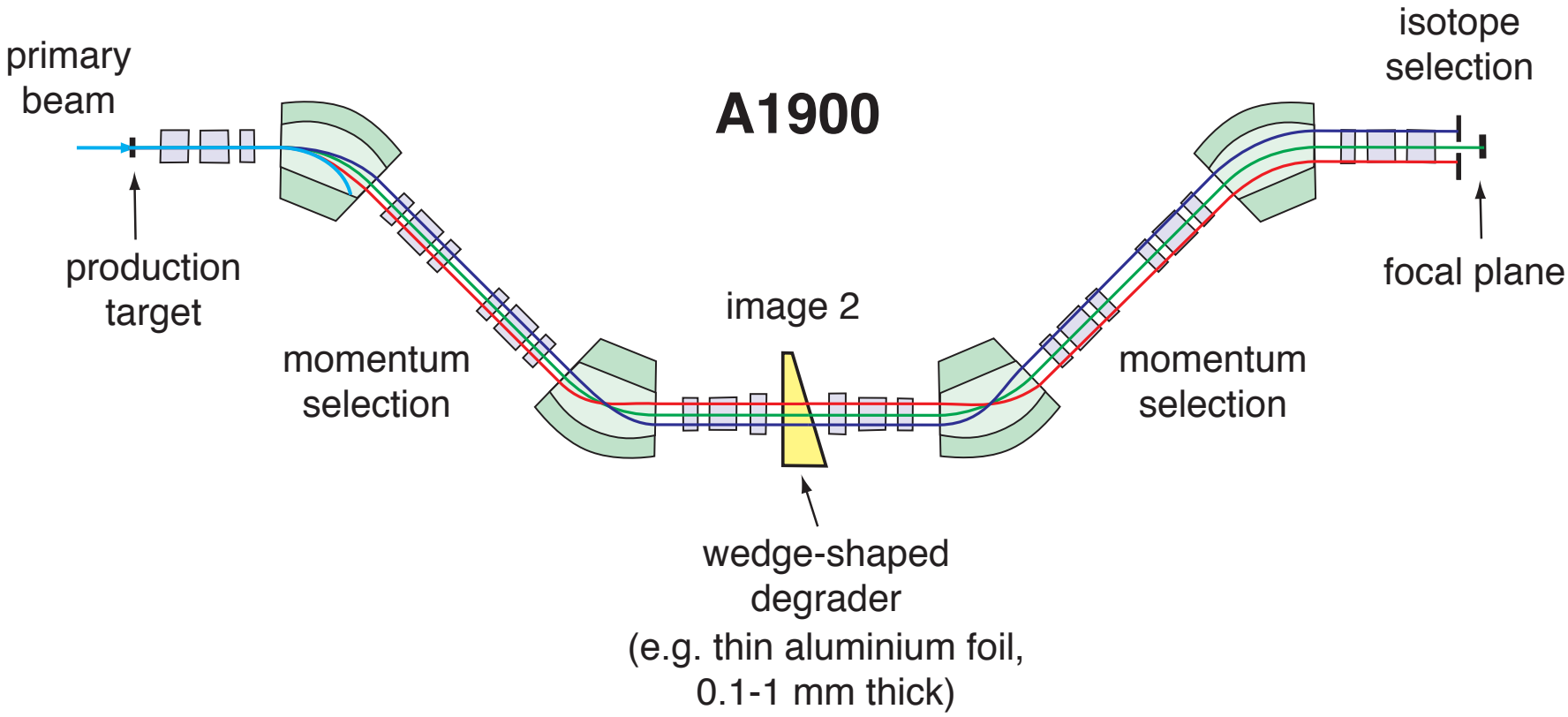
we need a degrader in the middle of the separator to achieve isotopic separation

Wedge Degrader



energy loss in degrader depends on

Wedge Degrader

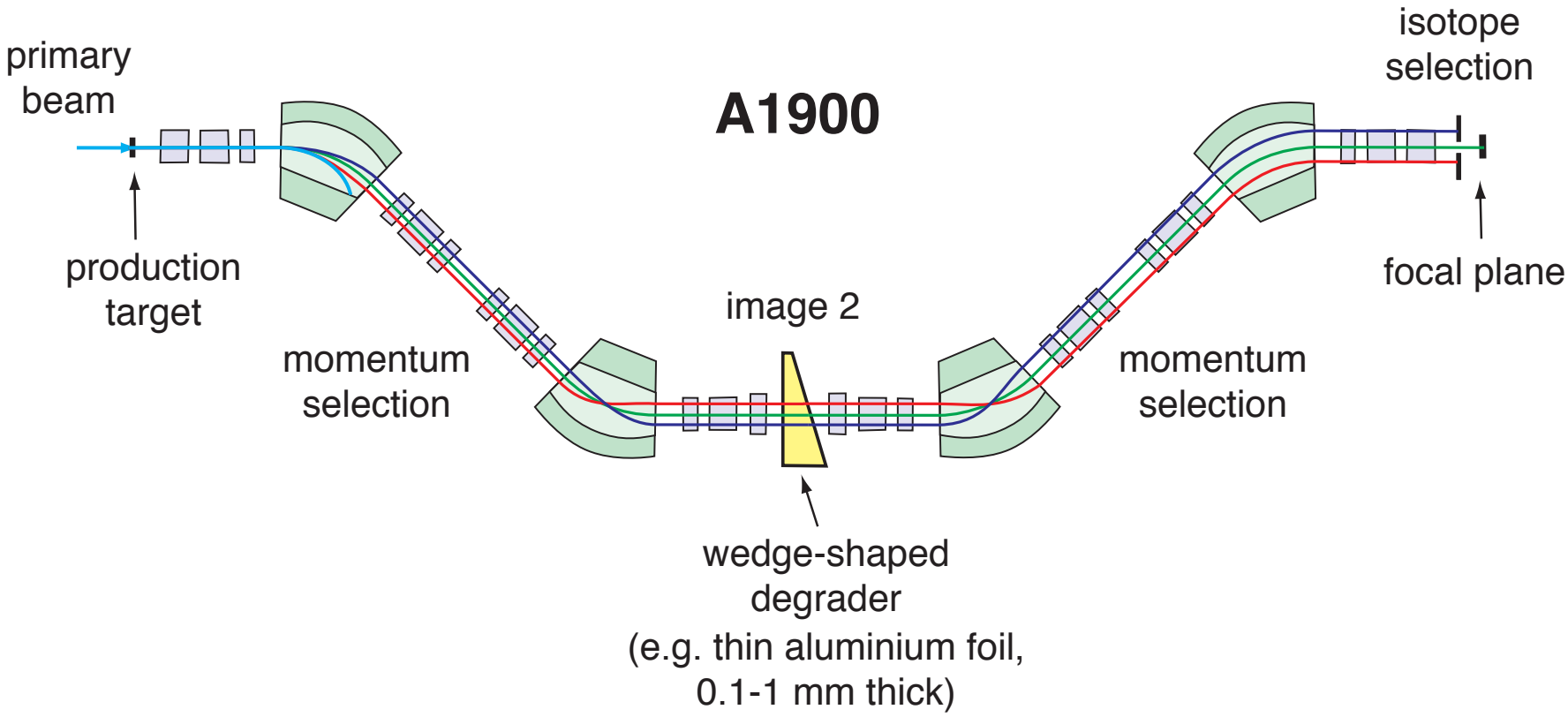


energy loss in degrader depends on

- **nuclear charge (proton number) of fragment**

  → **different isotopes can be separated**

Wedge Degrader



energy loss in degrader depends on

- **nuclear charge (proton number) of fragment**
  → **different isotopes can be separated**
- **velocity (momentum) of fragment**
  → **degrader needs a wedge shape**

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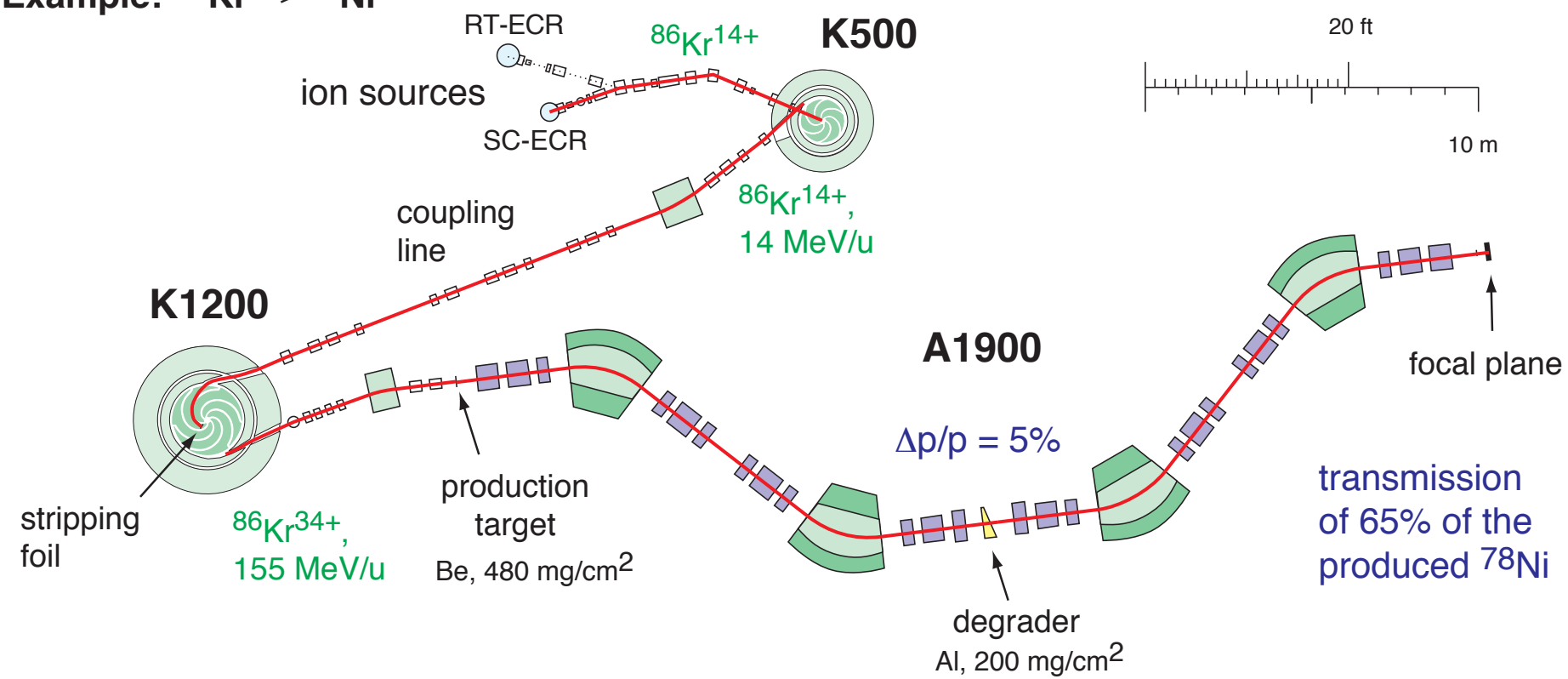
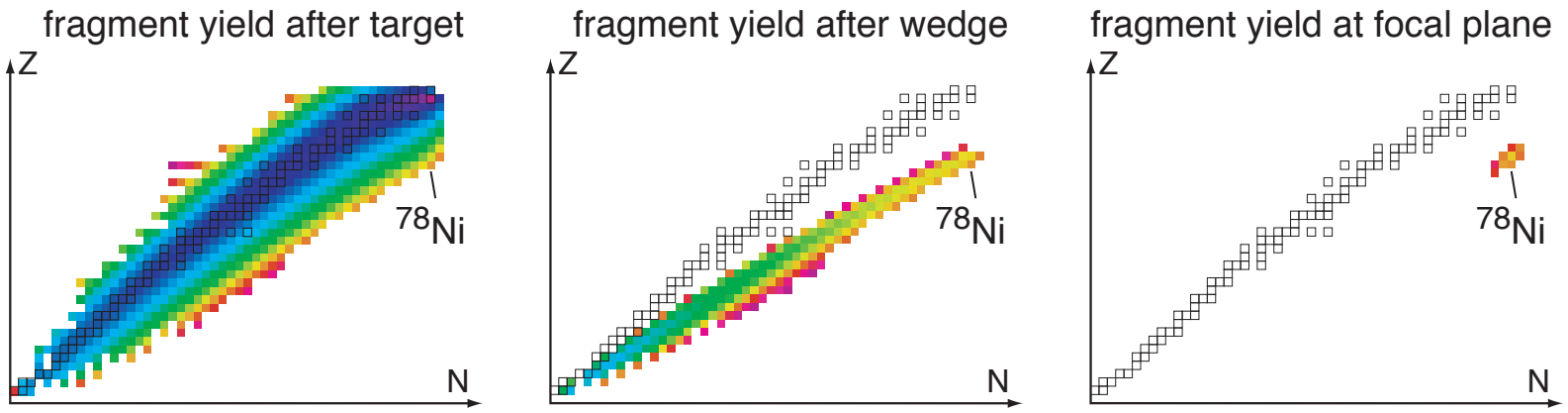




Detector Setup

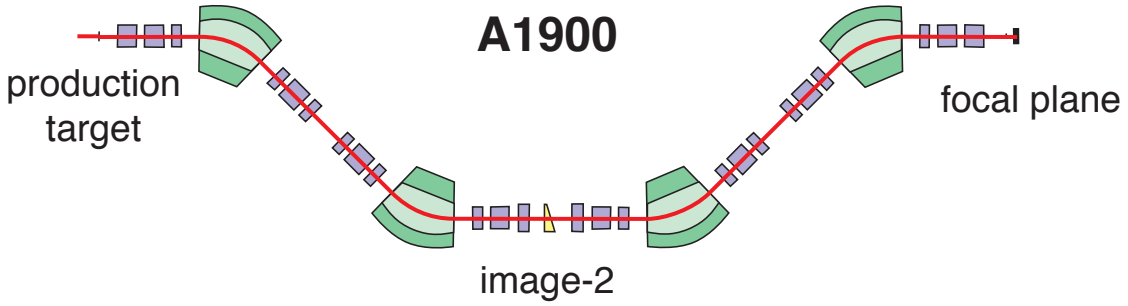
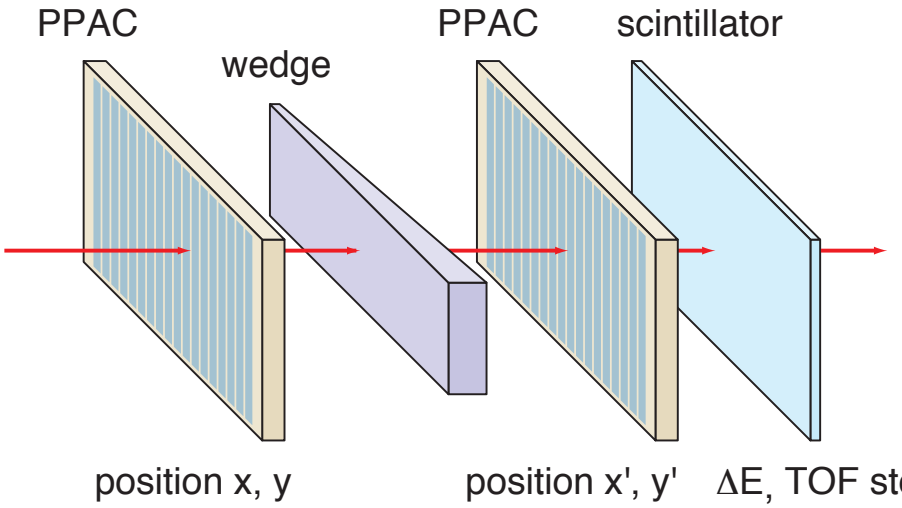
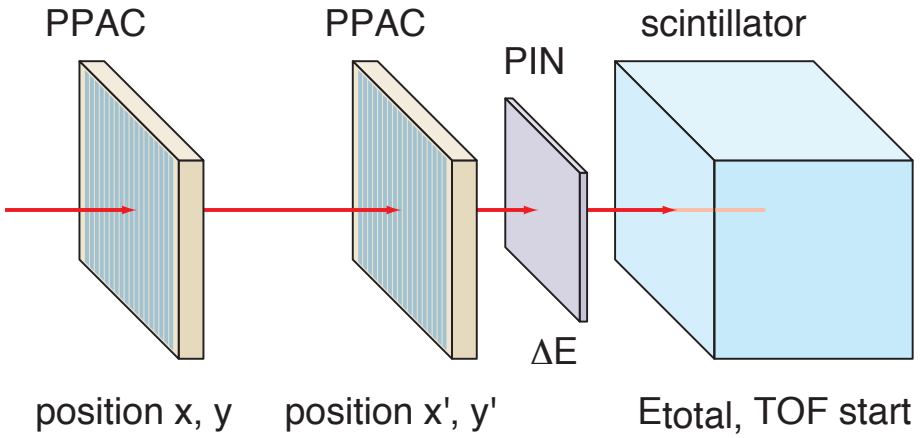


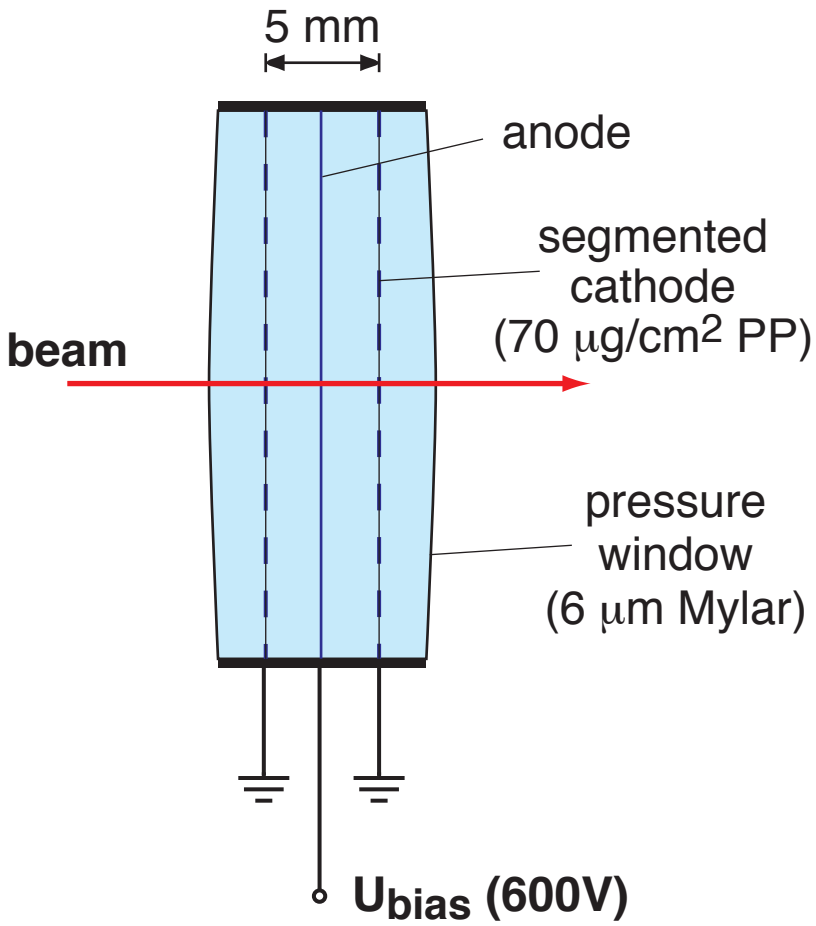
Image-2



Focal Plane

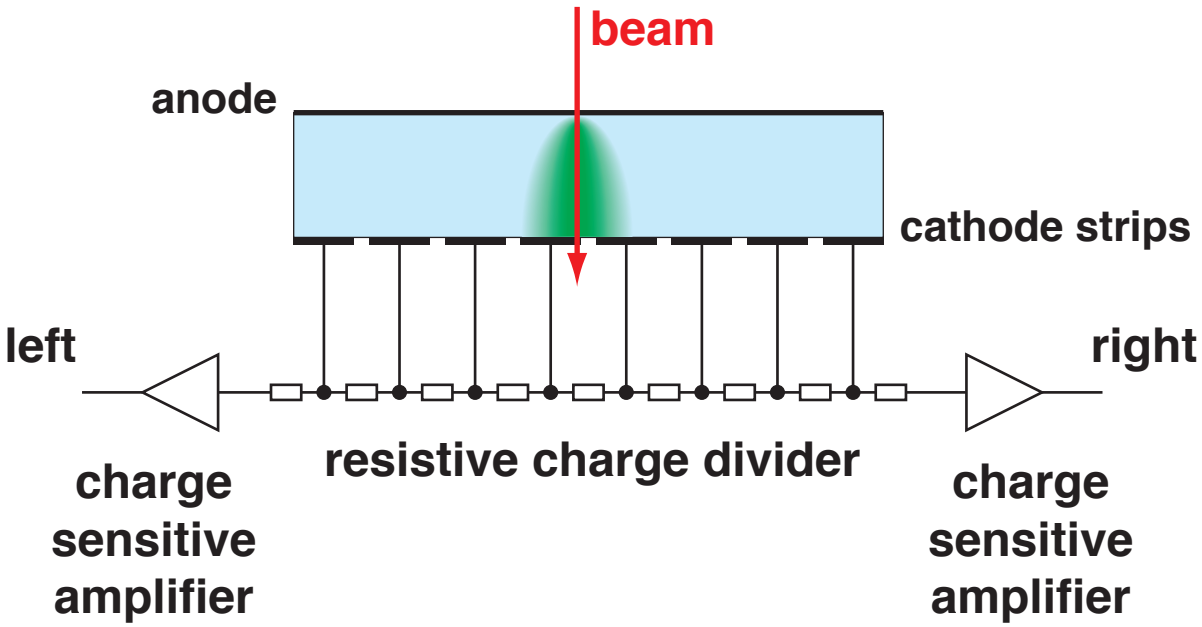


PPAC Detector



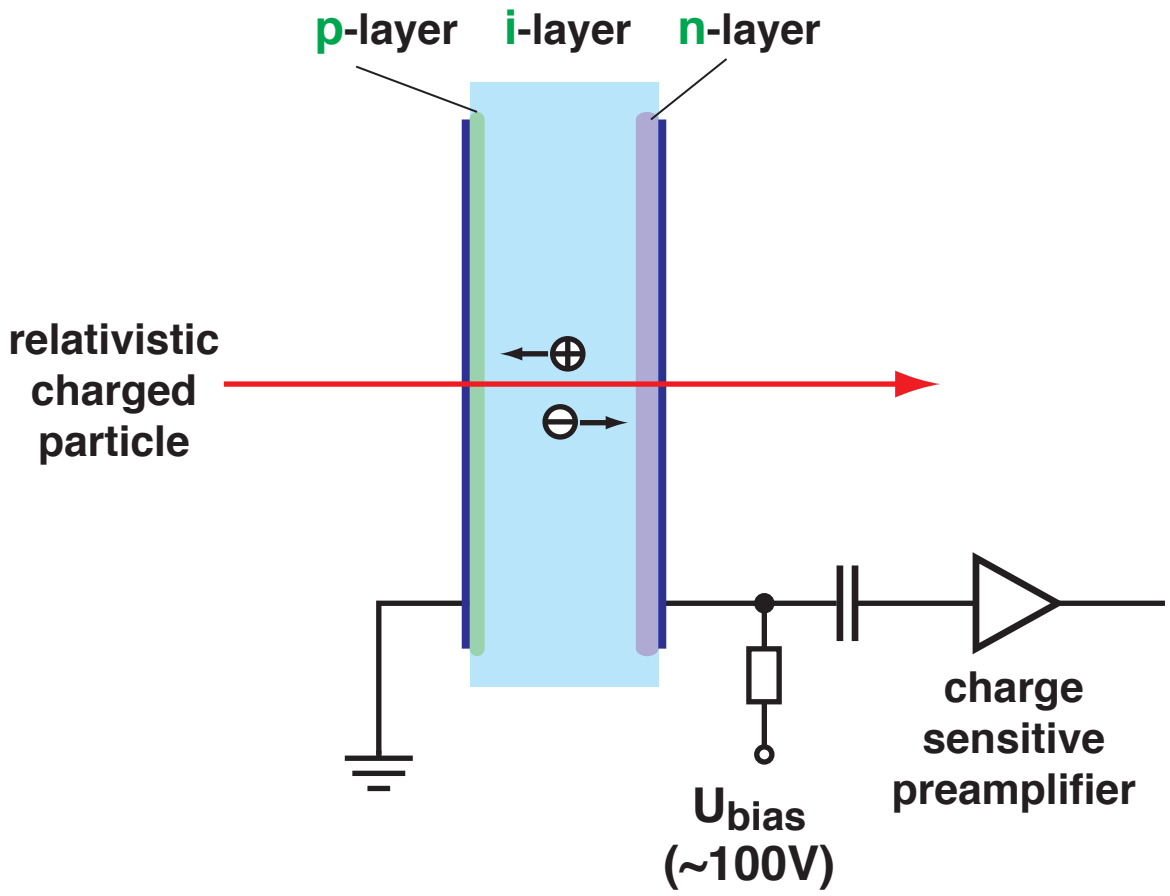
- **active area 100 mm x 100 mm**
- **streched PP foils with Al strips**
- **80 horizontal and vertical cathode strips**
- **strip pitch 1.27 mm**
- **isobutane, pressure 5 Torr**
- **mass thickness 2.2 mg/cm^2 Al equiv.**

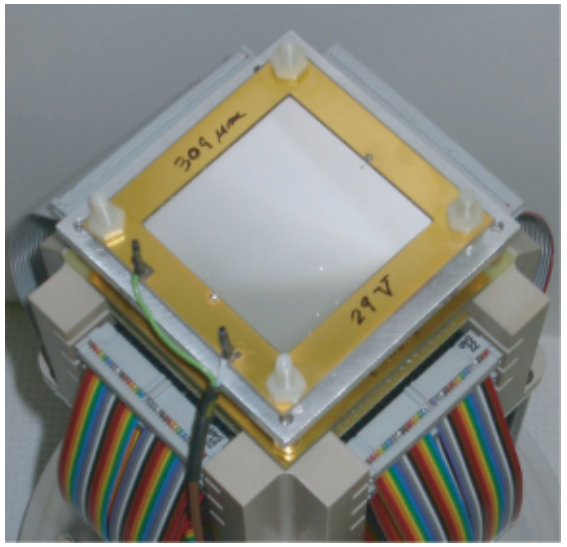
Position Measurement with PPAC



position calculation: $x = \frac{\text{right} - \text{left}}{\text{right} + \text{left}}$

Silicon PIN Detector

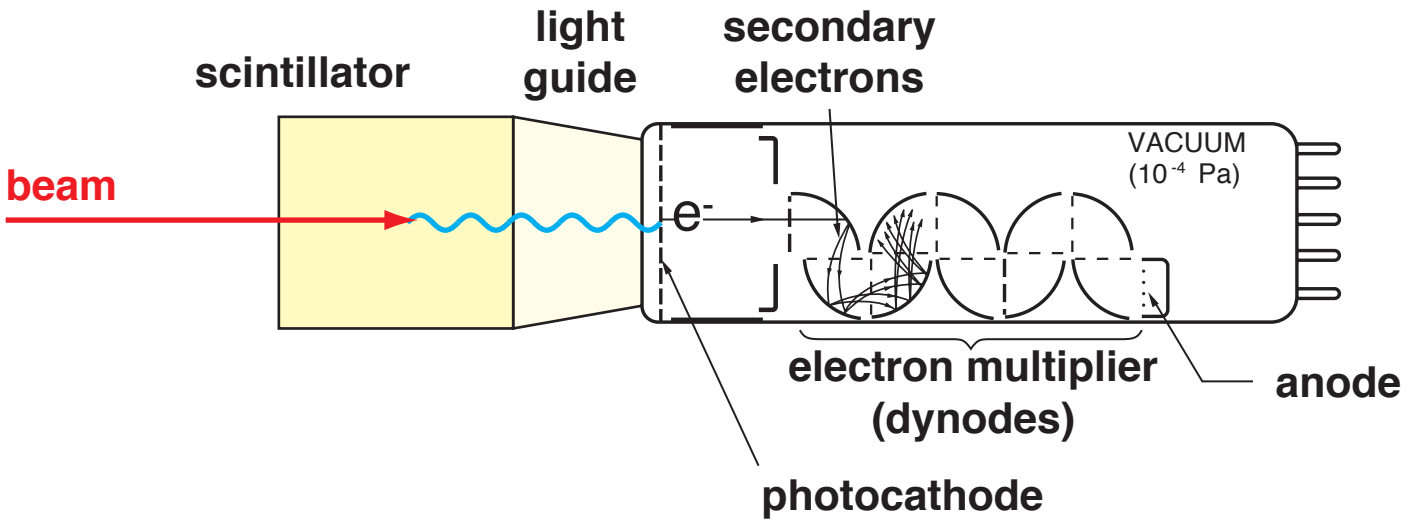




output signal proportional to collected charge
=
proportional to energy loss in detector

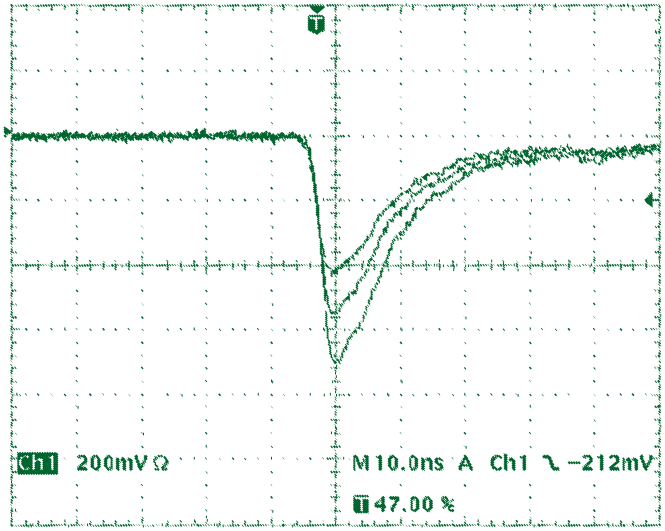
energy to generate electron-ion pair: 3.6 eV

Plastic Scintillator Detector

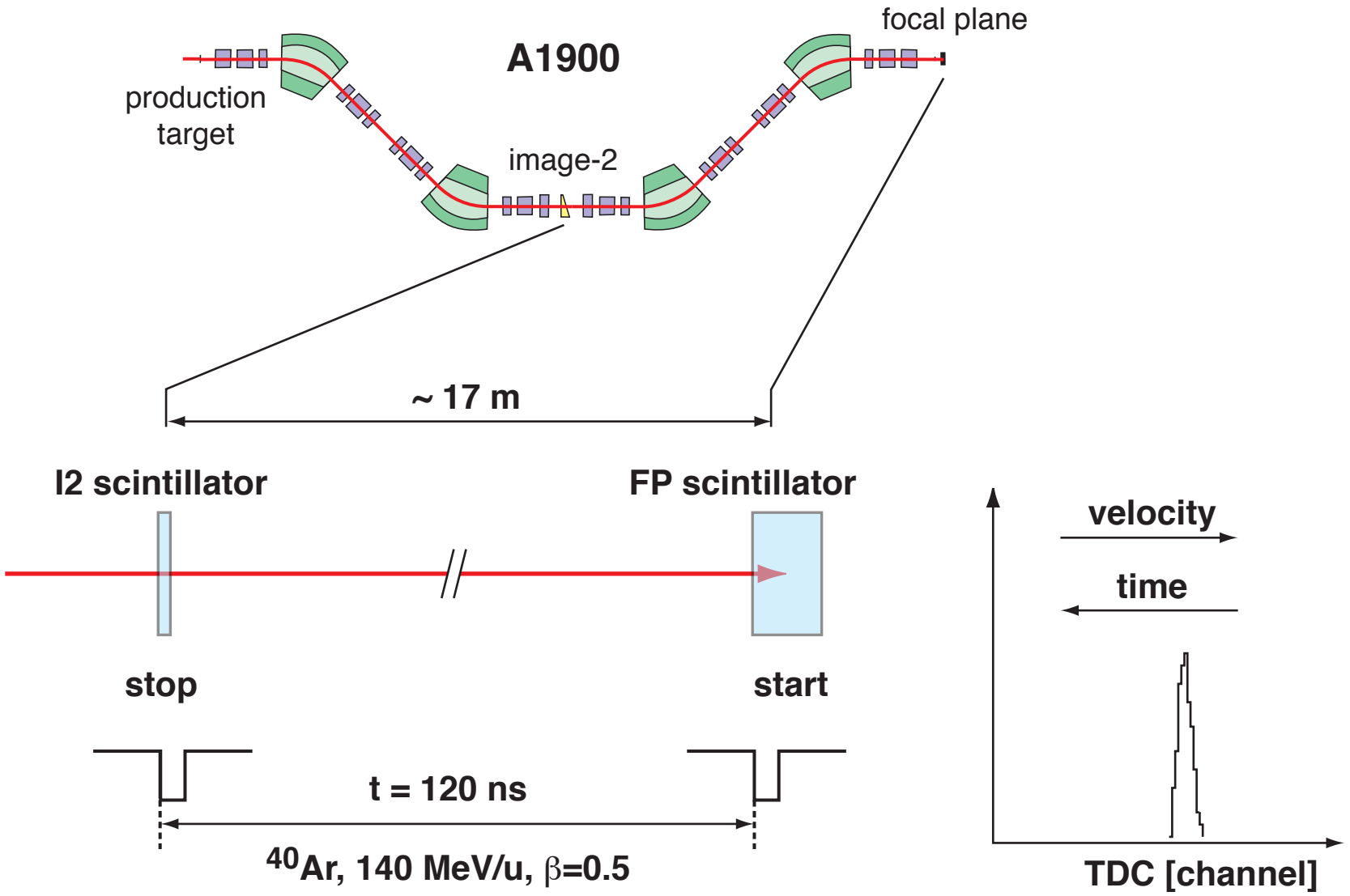


photomultiplier output:

- fast rise time (5ns) → **time**
- pulse integral → **energy**

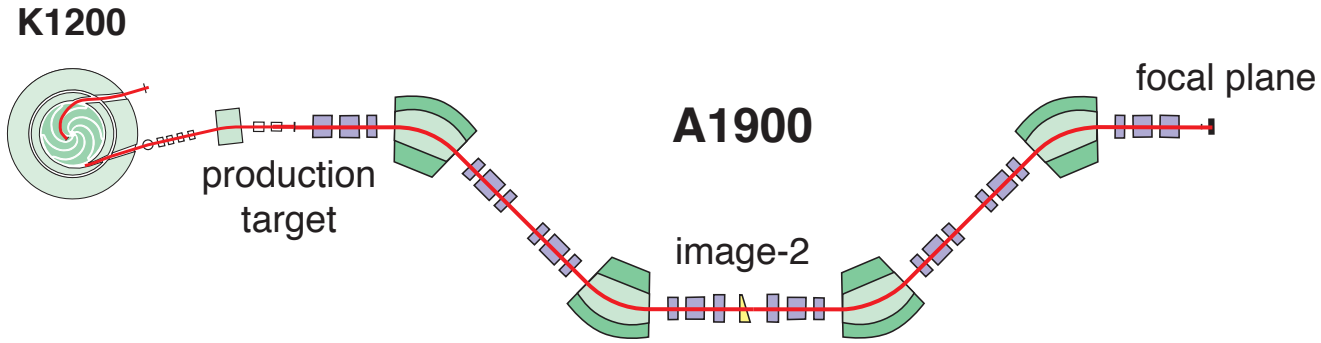


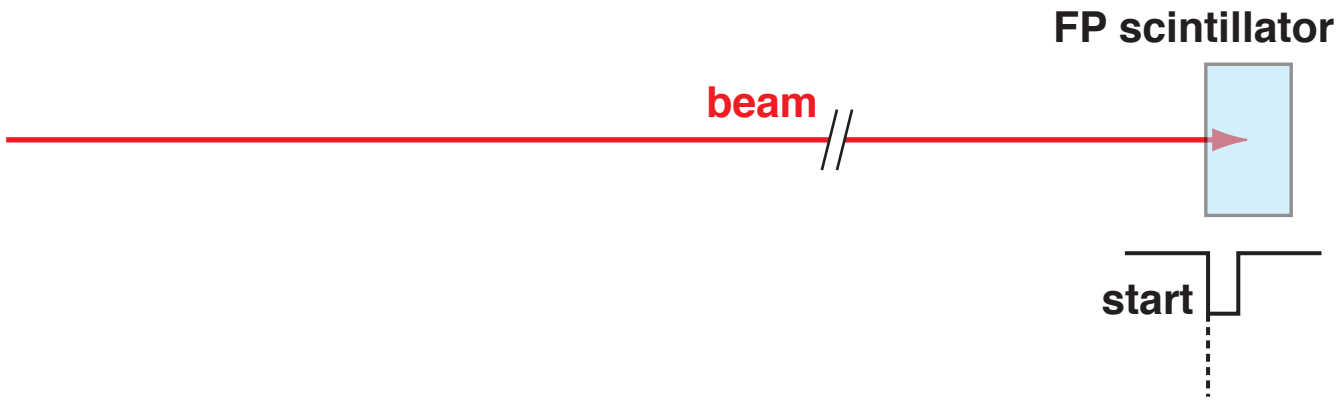
Time-of-flight measurement



TDC = Time to Digital Converter

Time-of-flight measurement (RF timing)





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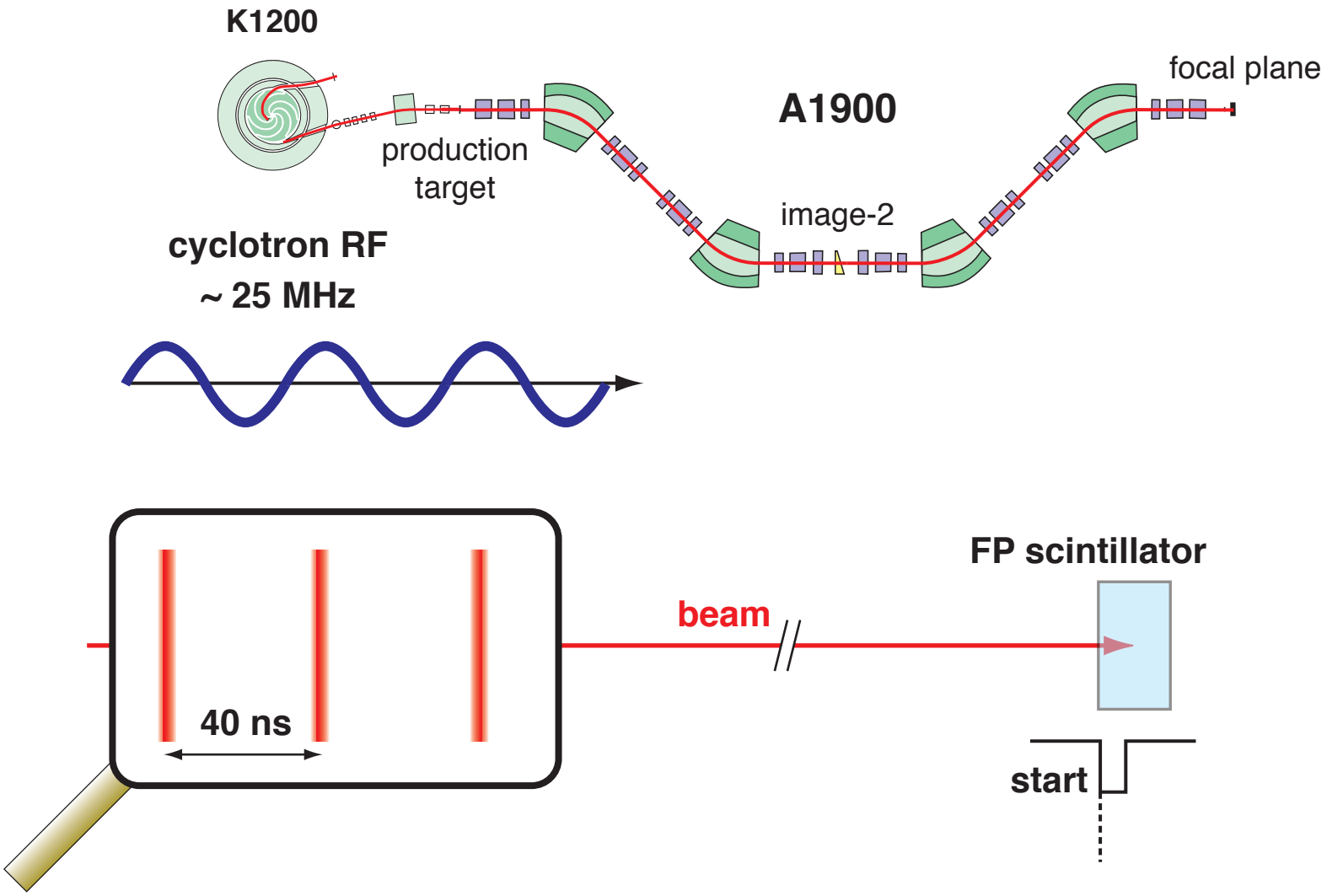

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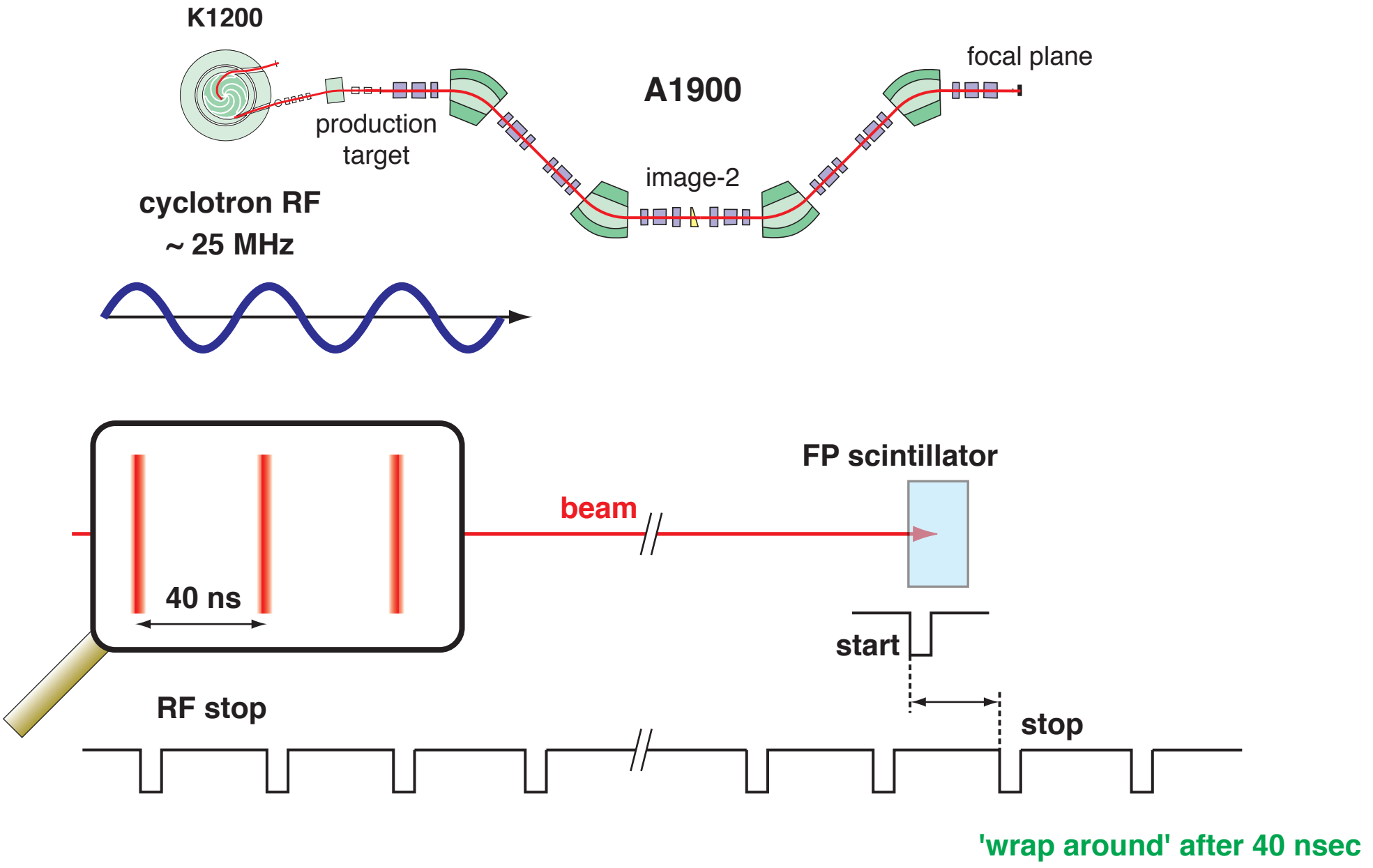
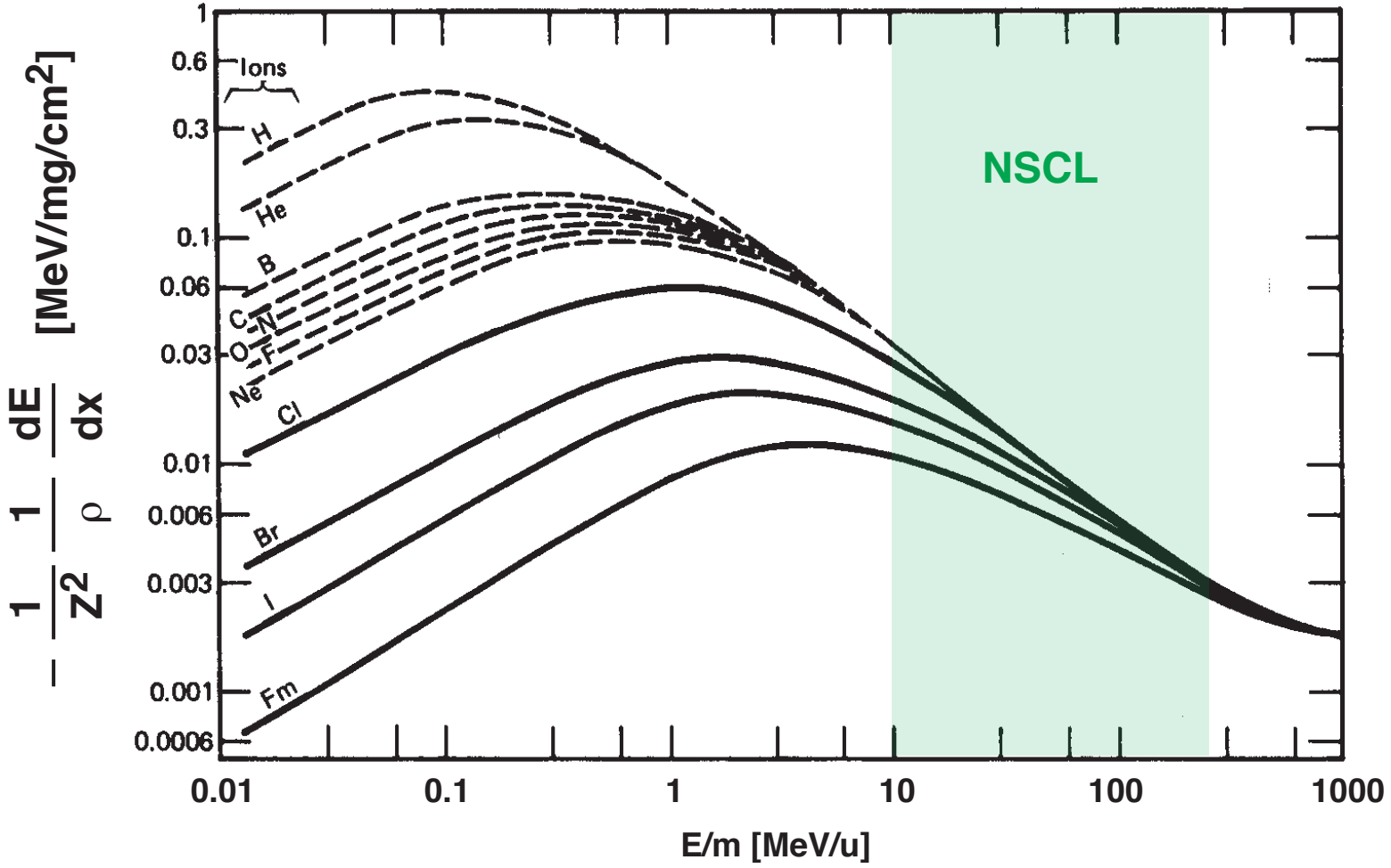


'wrap around' after 40 nsec

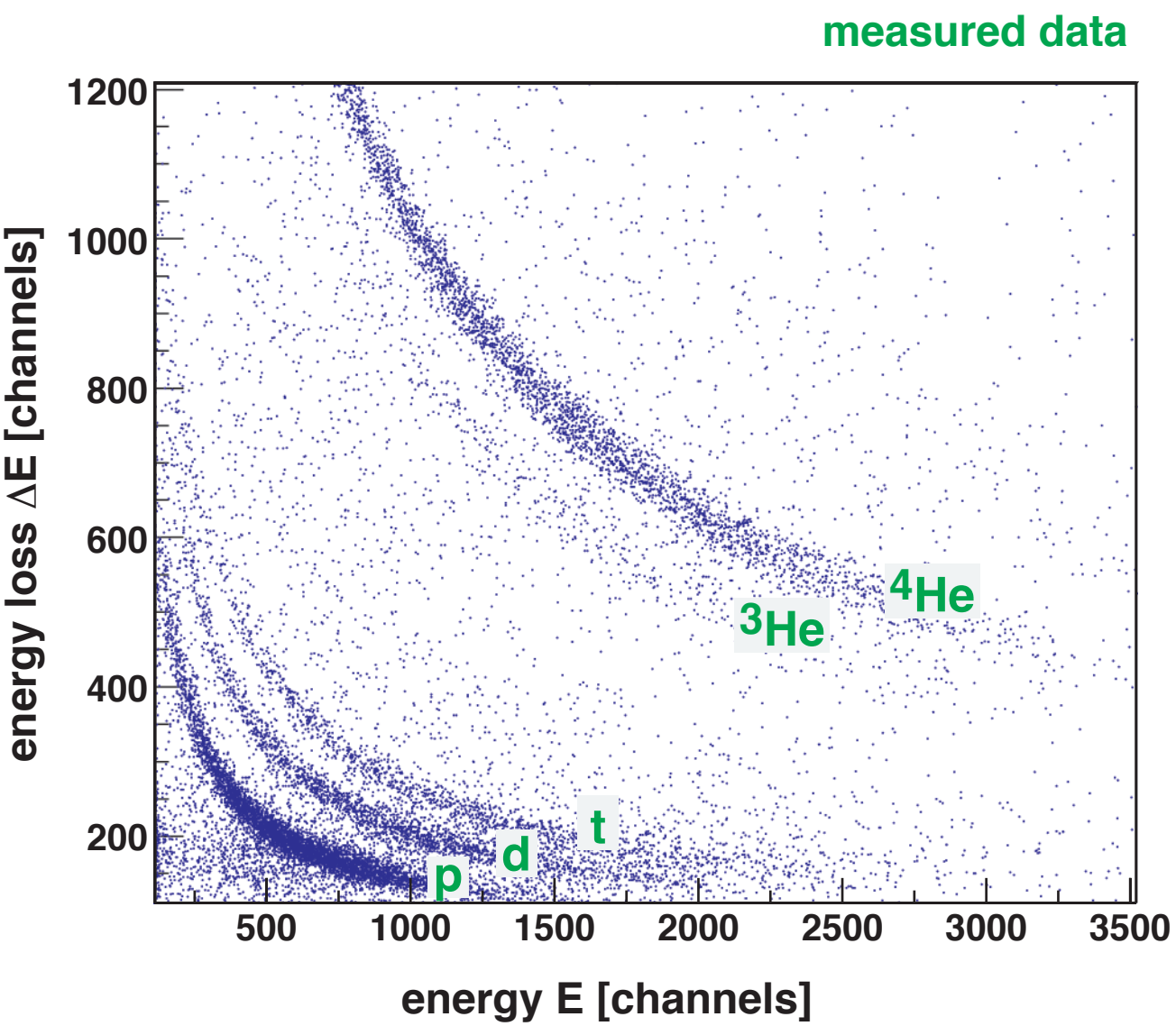
Energy loss in matter

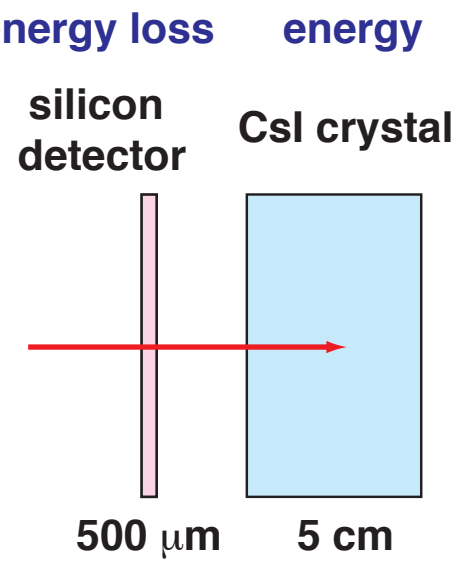
specific energy loss of heavy ions in aluminium



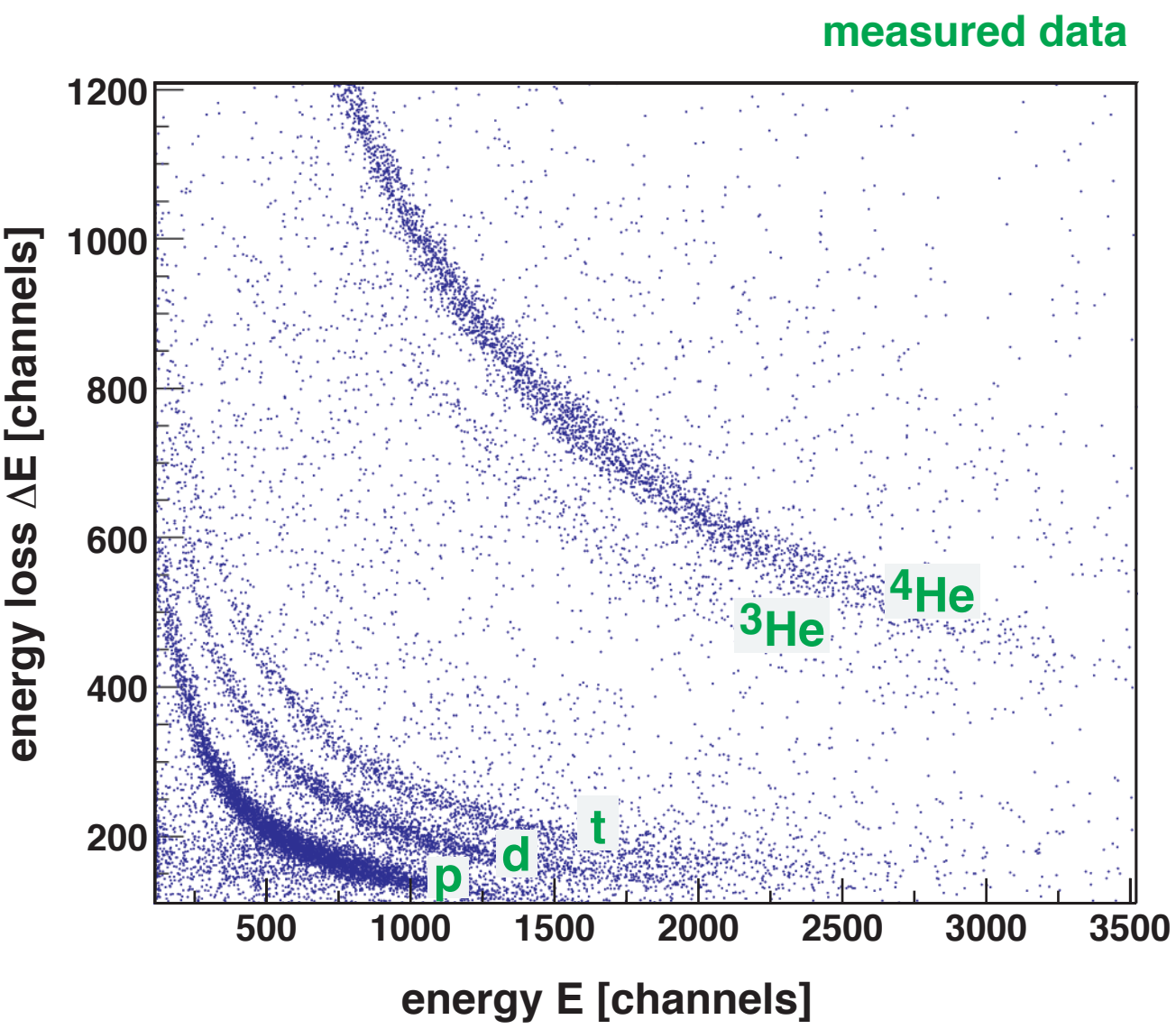
$$\frac{dE}{dx} \sim \frac{Z^2}{E}$$

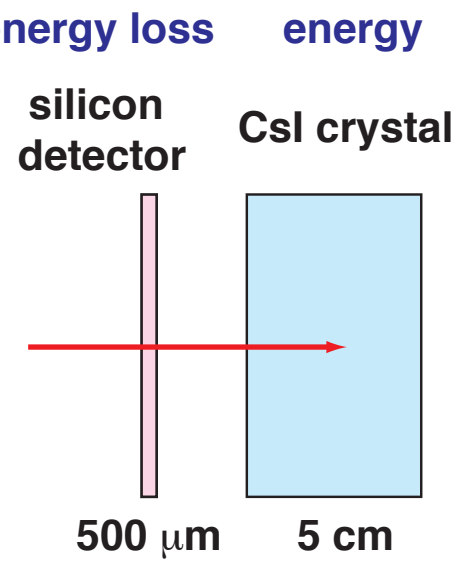
Detector Telescop

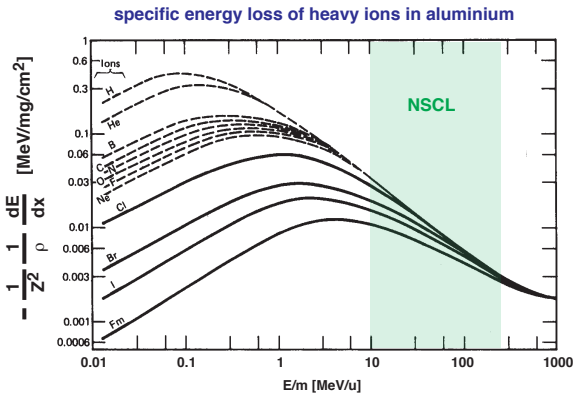




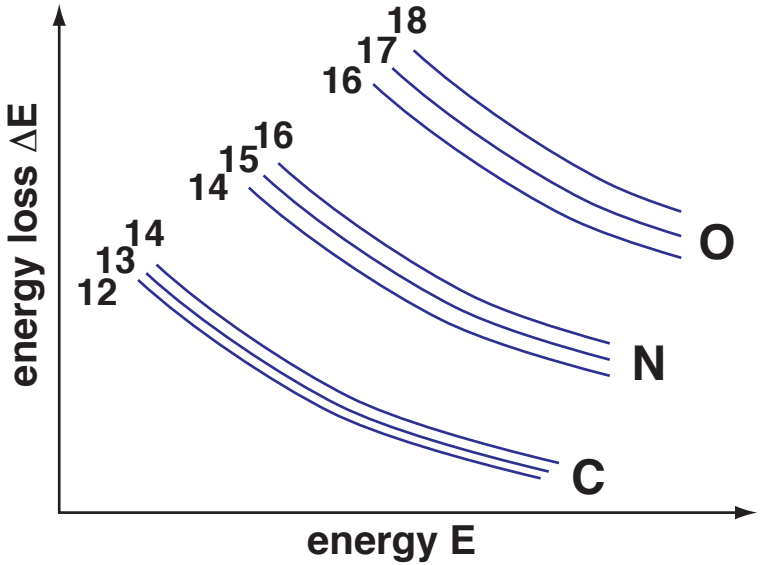
Detector Telescop







Magnetic Separation



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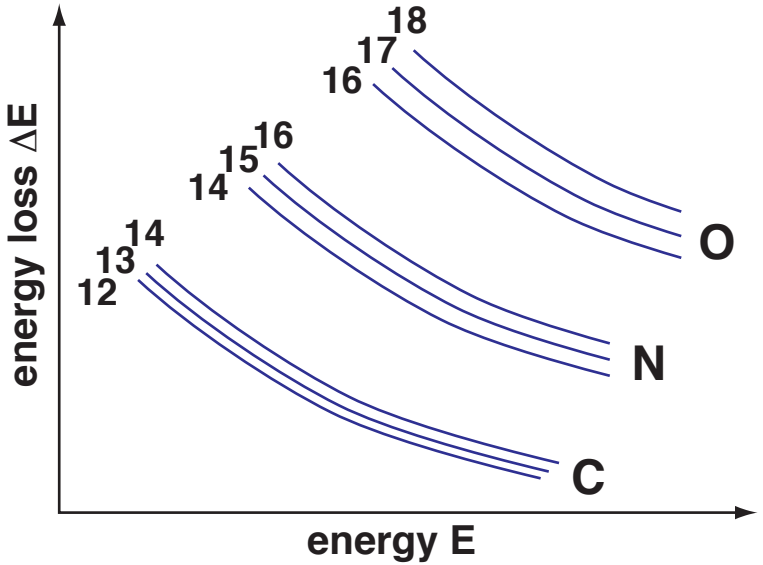

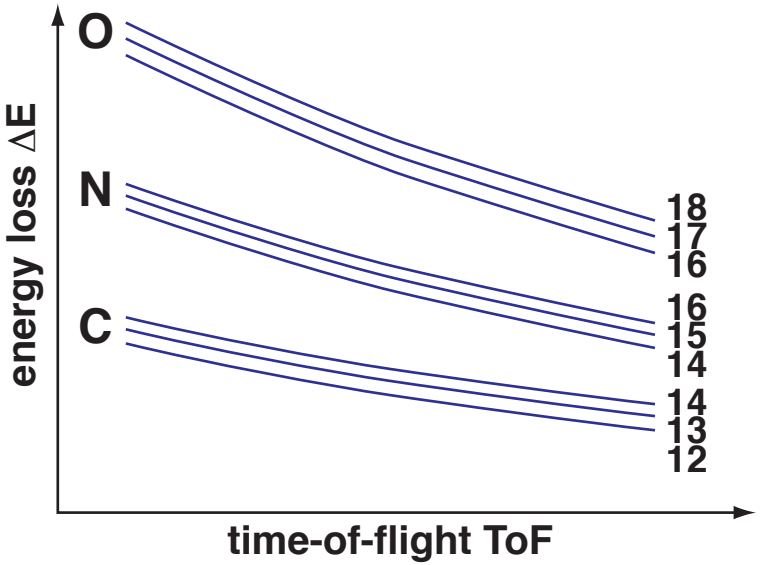

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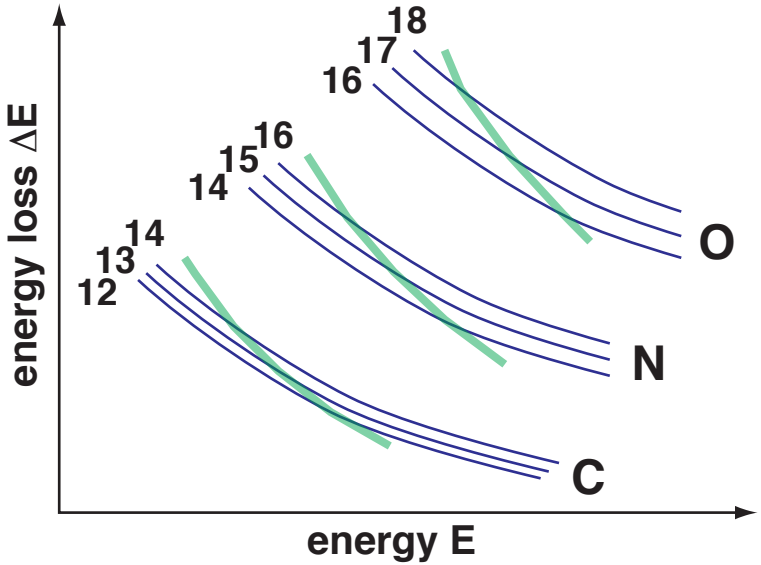
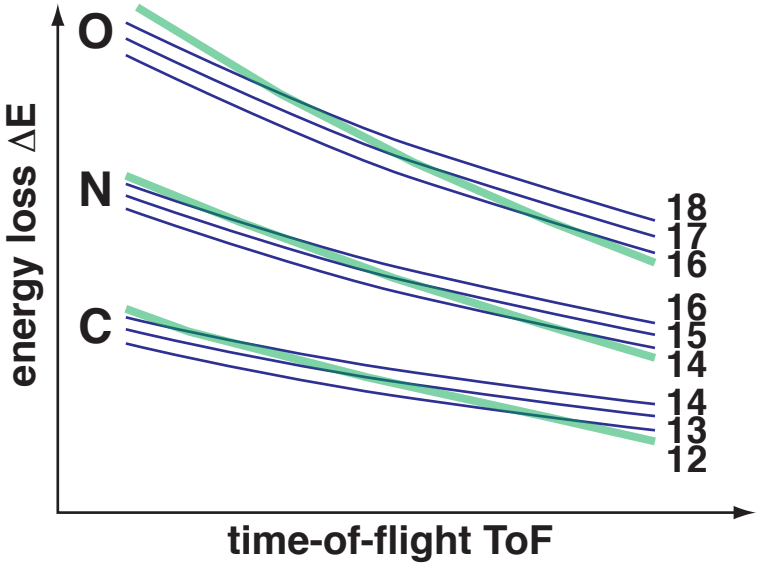
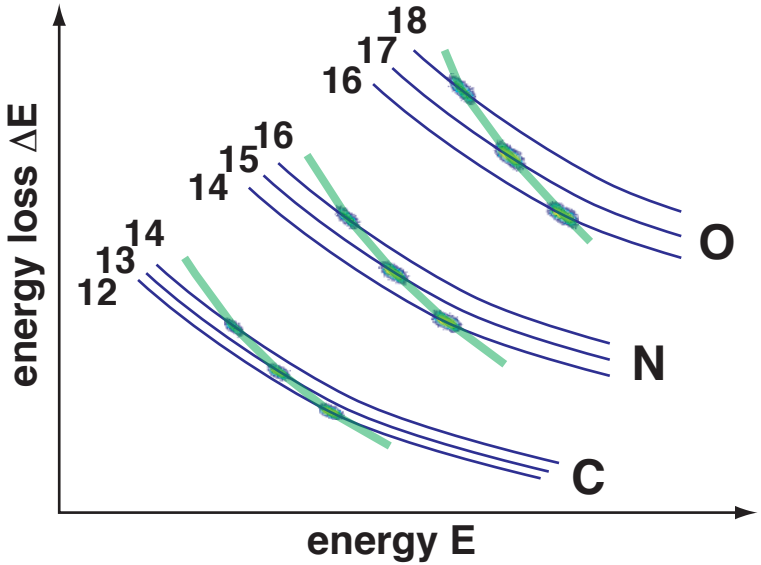
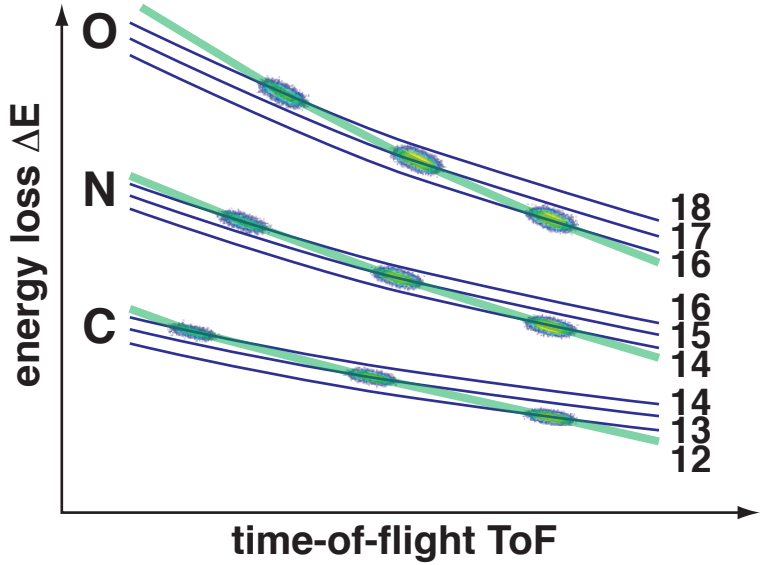




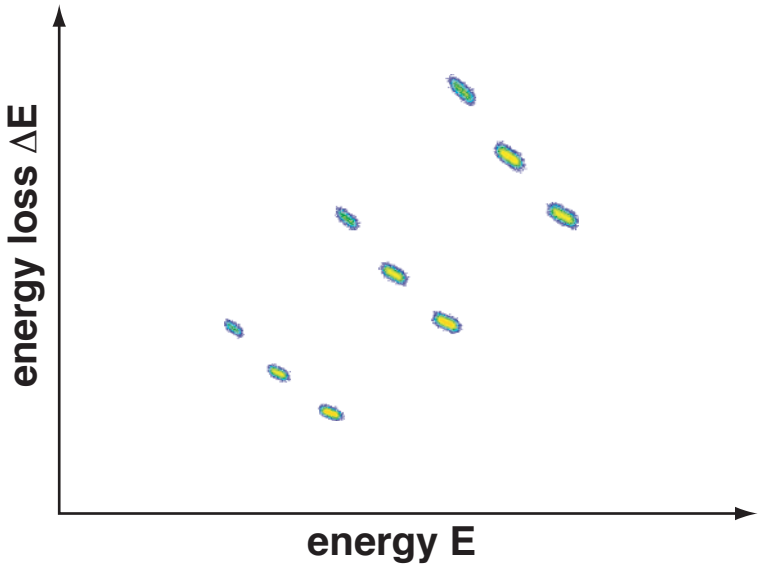
$B\rho = \text{const} = mv/Z$ for $Z = \text{const} \rightarrow v \sim 1/t \sim 1/m \rightarrow E \sim v \sim 1/m$

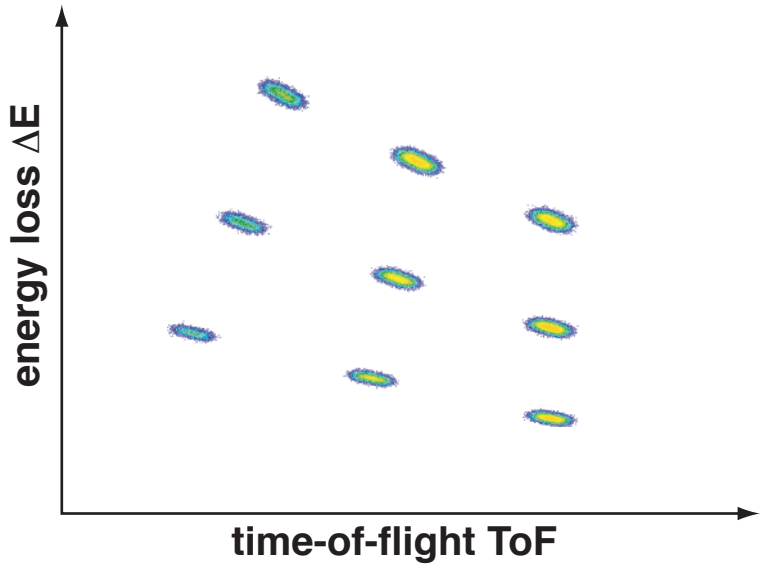
Magnetic Separation



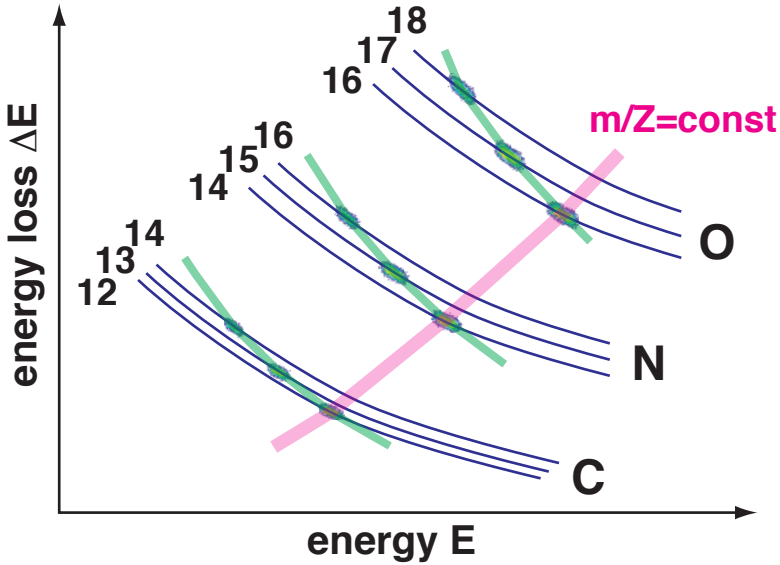


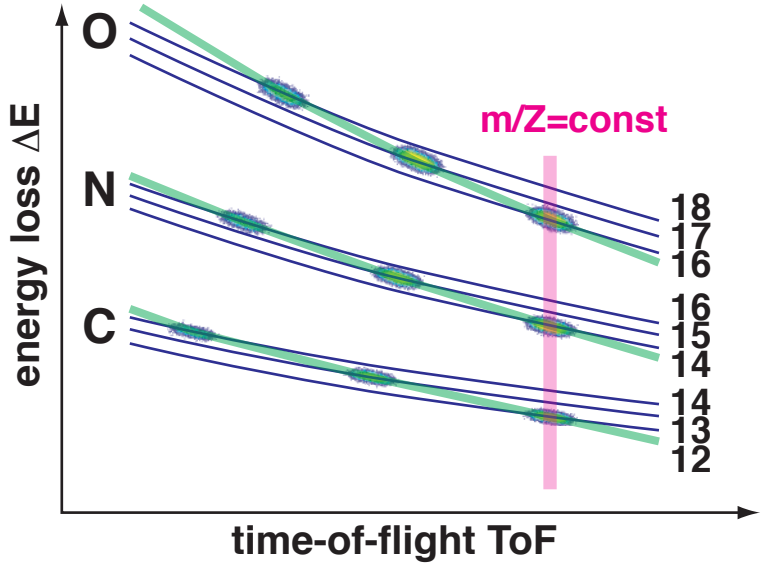
$B\rho = \text{const} = mv/Z$ for $Z = \text{const} \rightarrow v \sim 1/t \sim 1/m \rightarrow E \sim v \sim 1/m$





Magnetic Separation

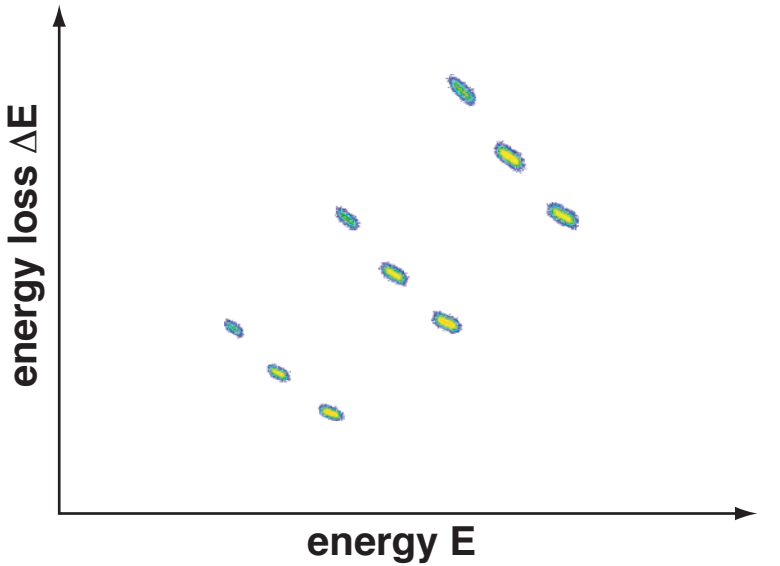


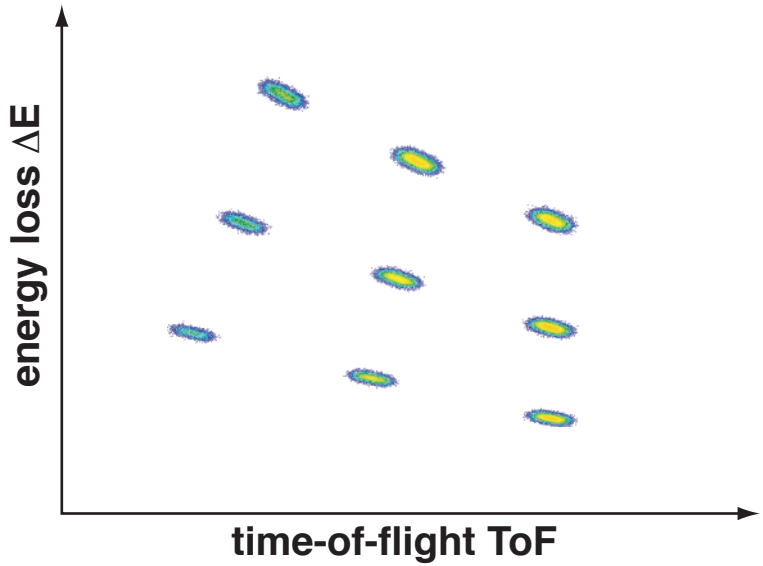


$B\rho = \text{const} = mv/Z$

for Z = const → v ~ 1/t ~ 1/m → E ~ v ~ 1/m

for m/Z = const → v ~ 1/t = const → E ~ m ~ Z





Particle Identification

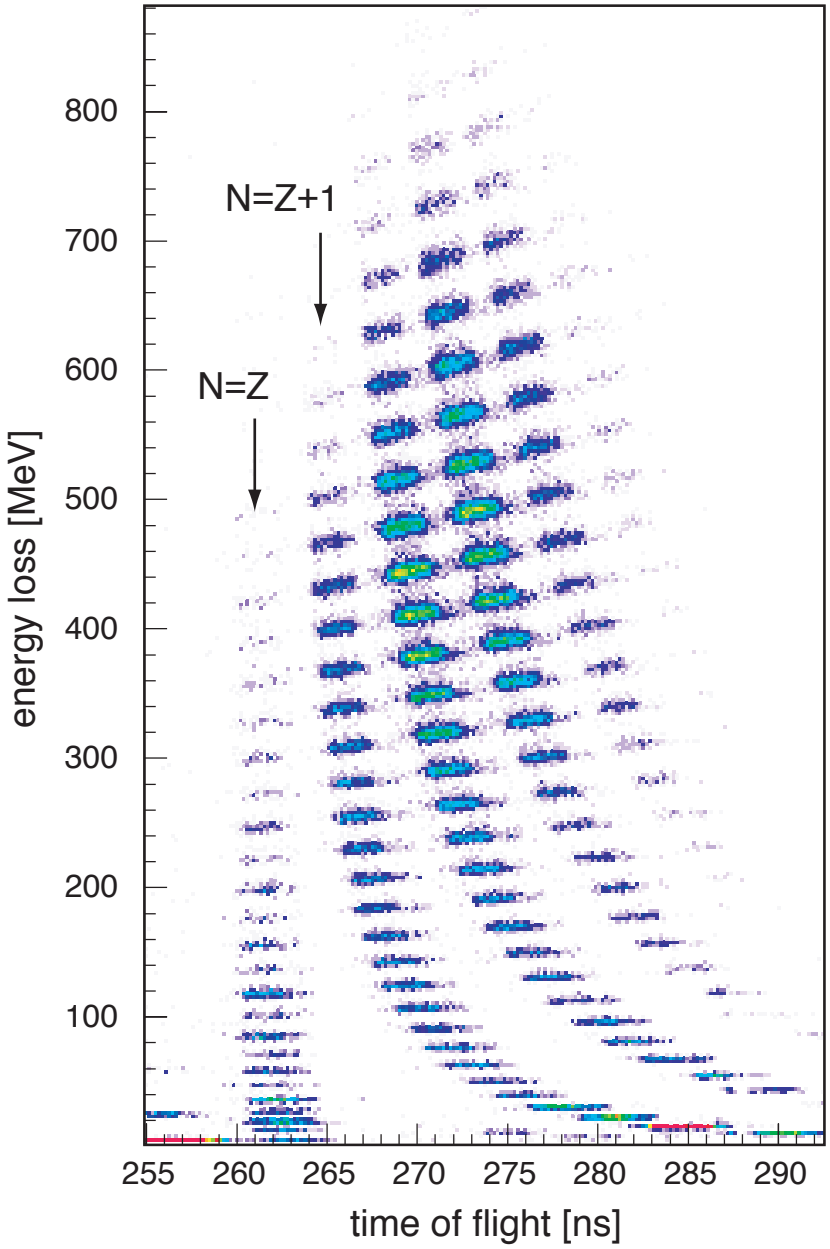
^{86}Kr (140 MeV/u) + ^{9}Be (376 mg/cm^2)

energy loss: Si PIN diode, 500 μm

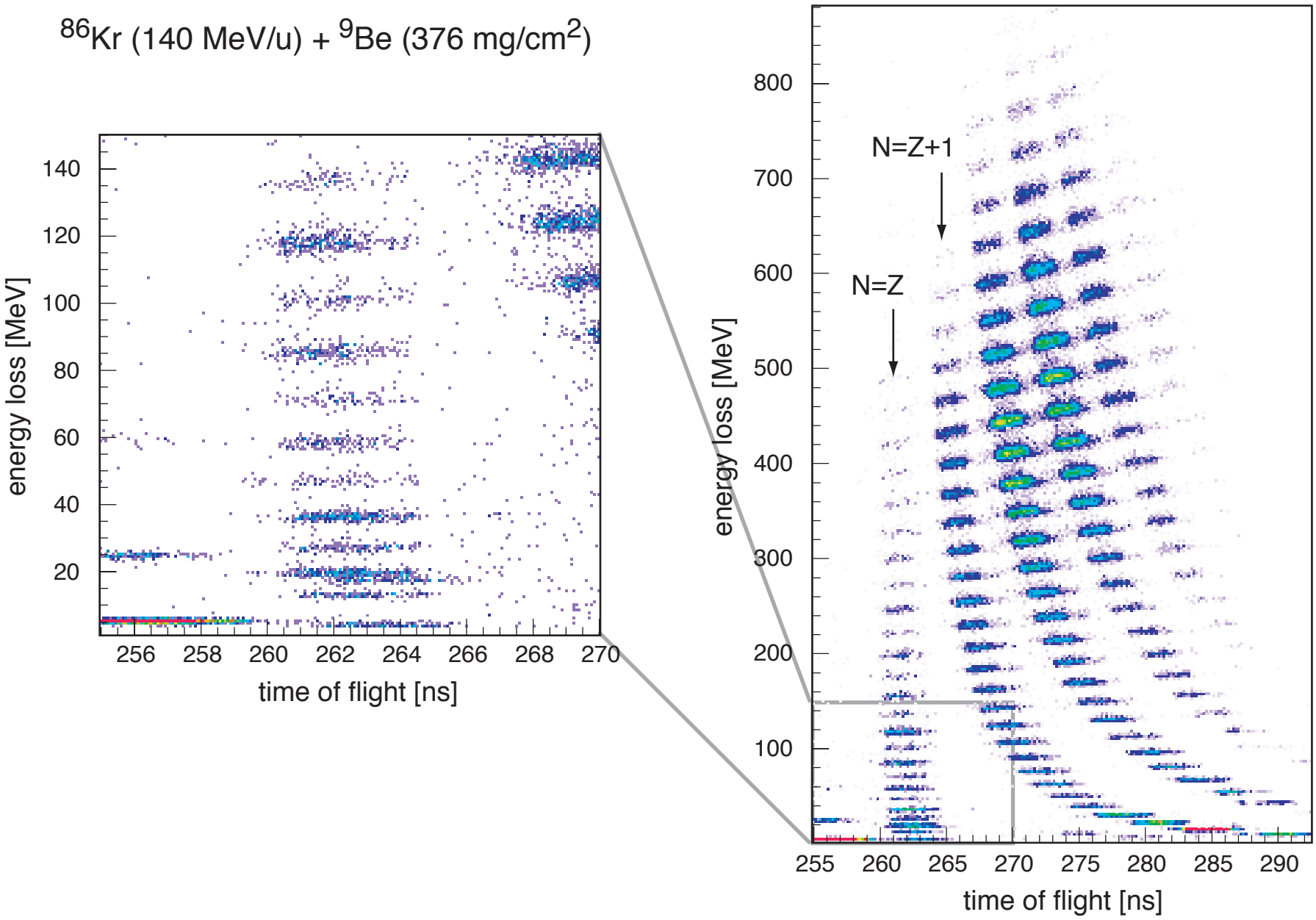
→ **proton number**

time of flight: plastic scintillator, RF

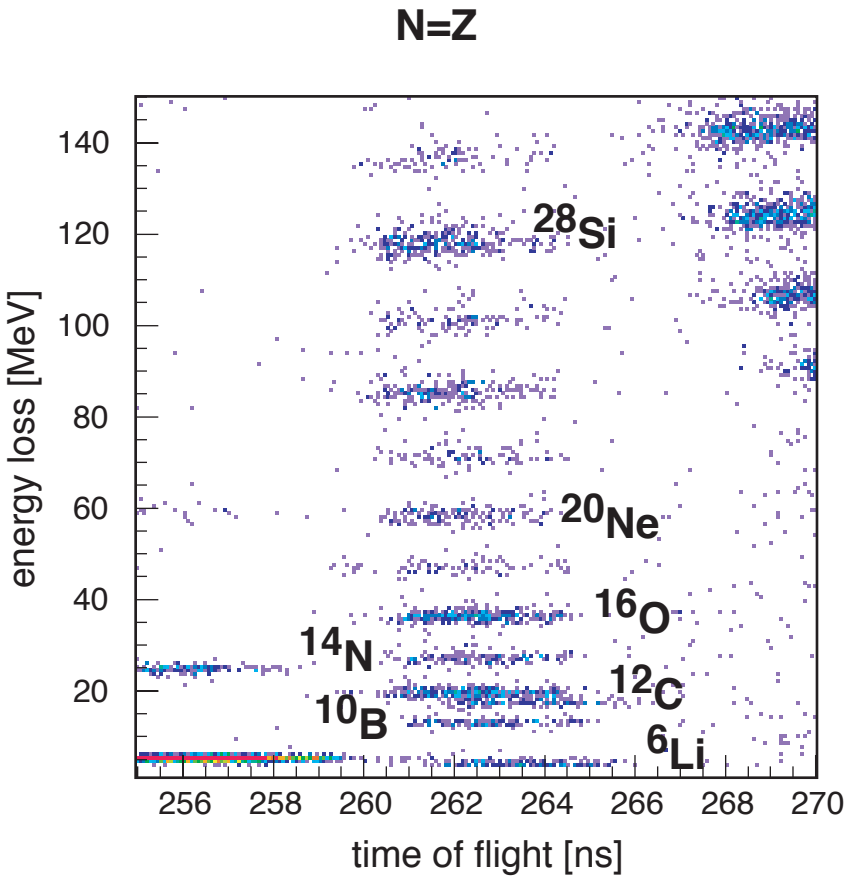
→ **mass number**



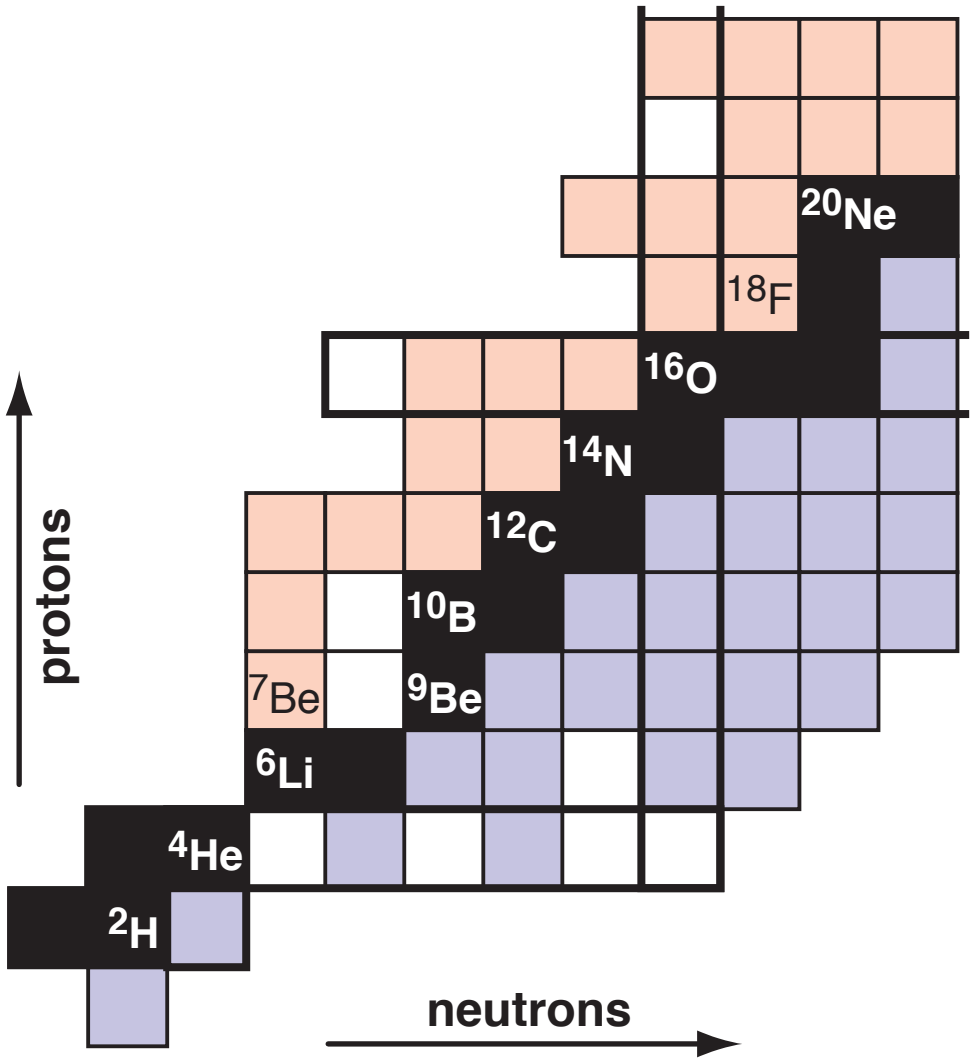
Particle Identification



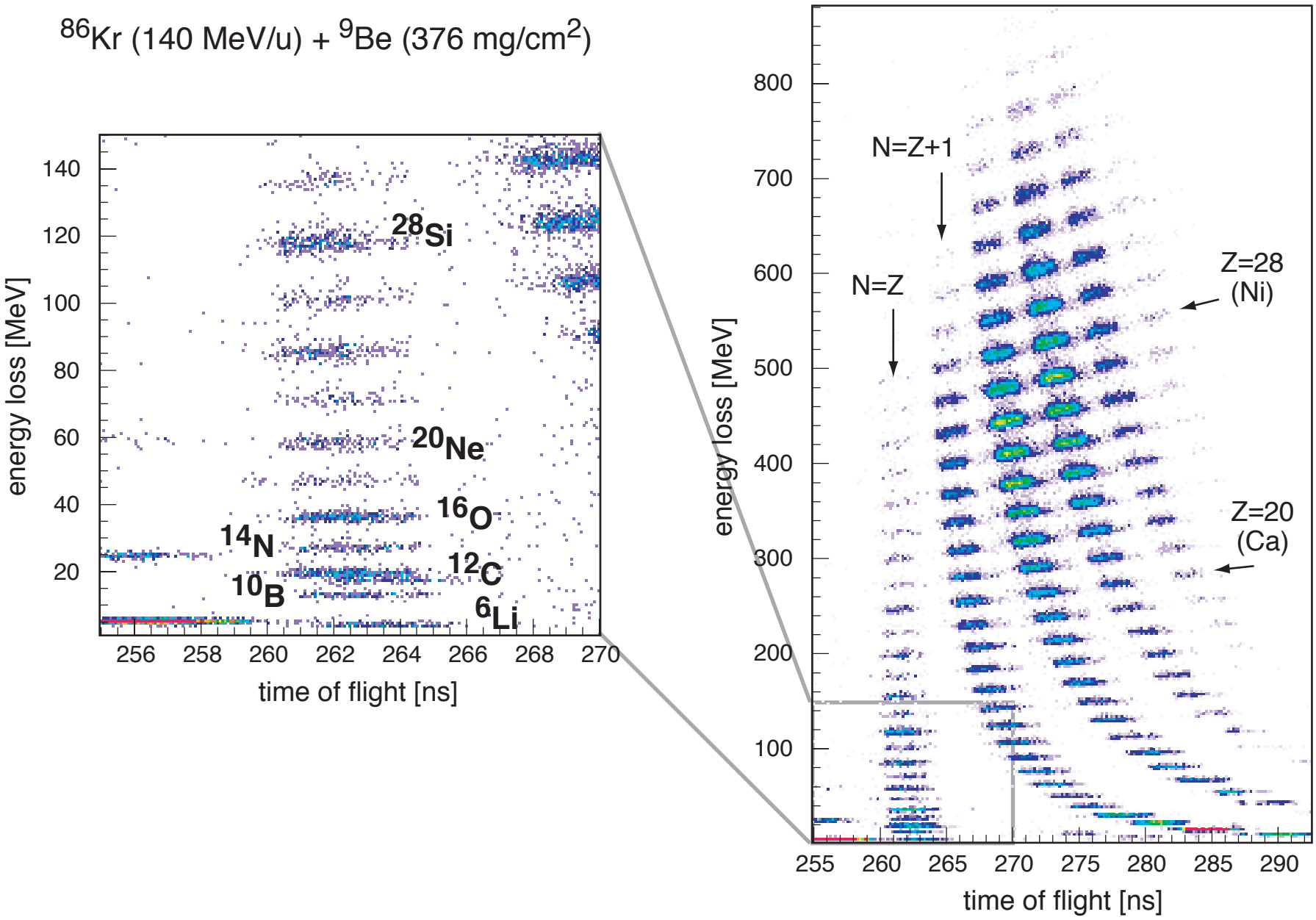
Particle Identification



^{8}Be does not exist!



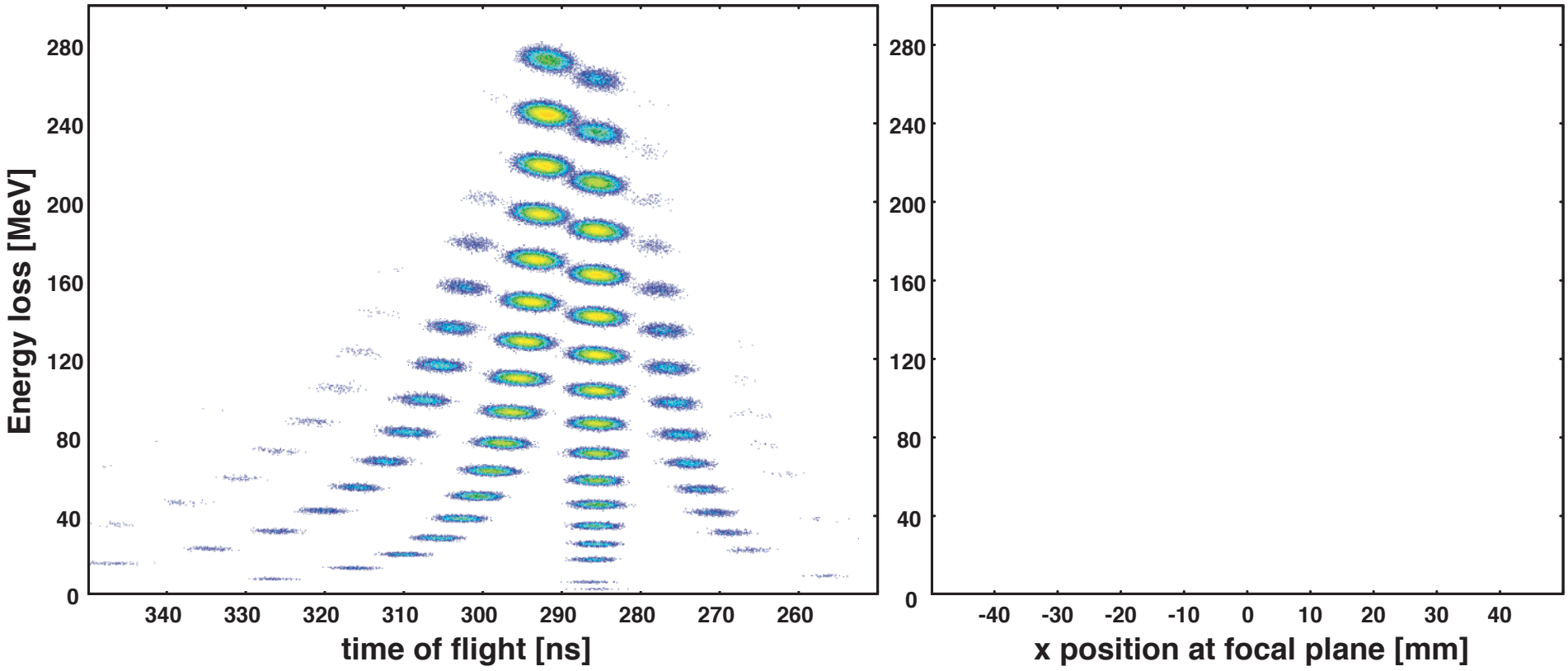
Particle Identification



Particle Identification – no wedge degrader

primary beam: ^{40}Ar, 140 MeV/u
production target: Be, 1166 mg/cm^2
selected fragment: ^{26}Al

wedge degrader: none
$B\rho_{12}$ = 2.7479 Tm; $B\rho_{34}$ = 2.7479 Tm
$\Delta p/p$ = 1%



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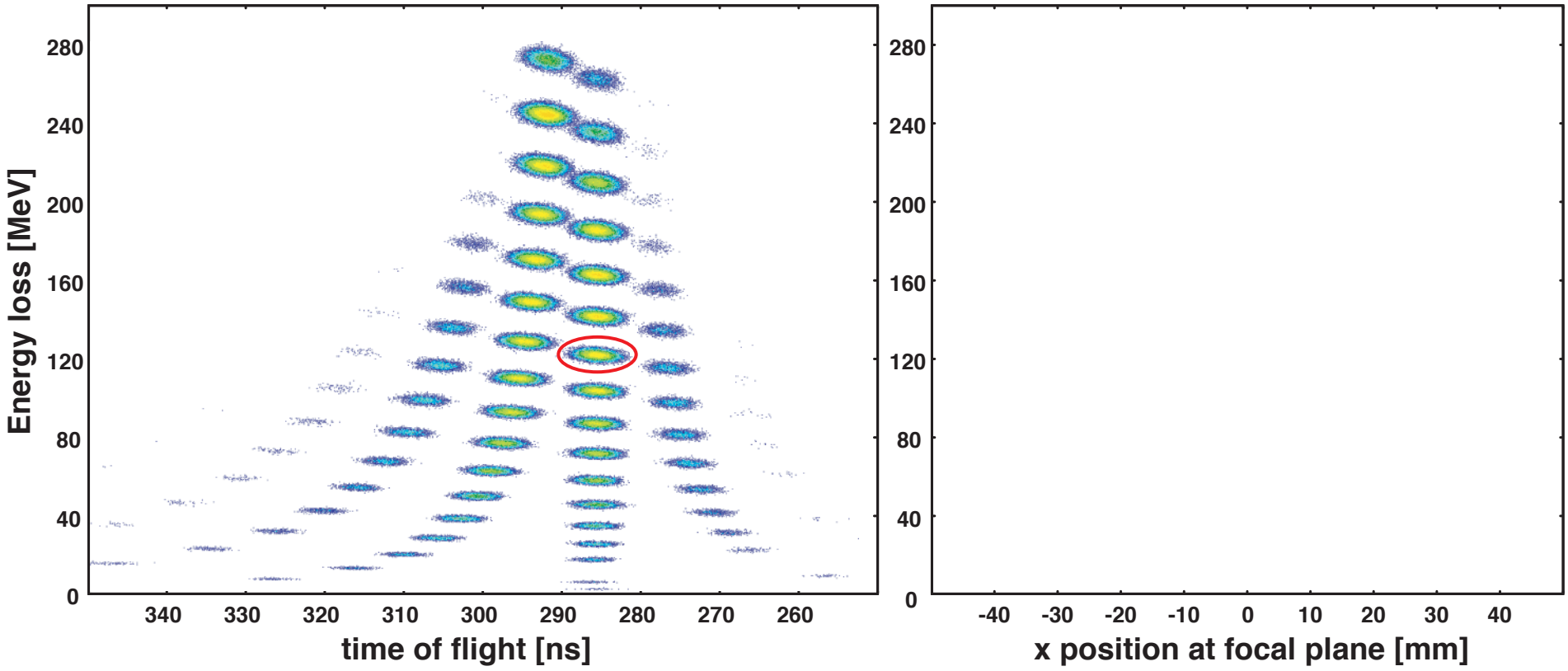
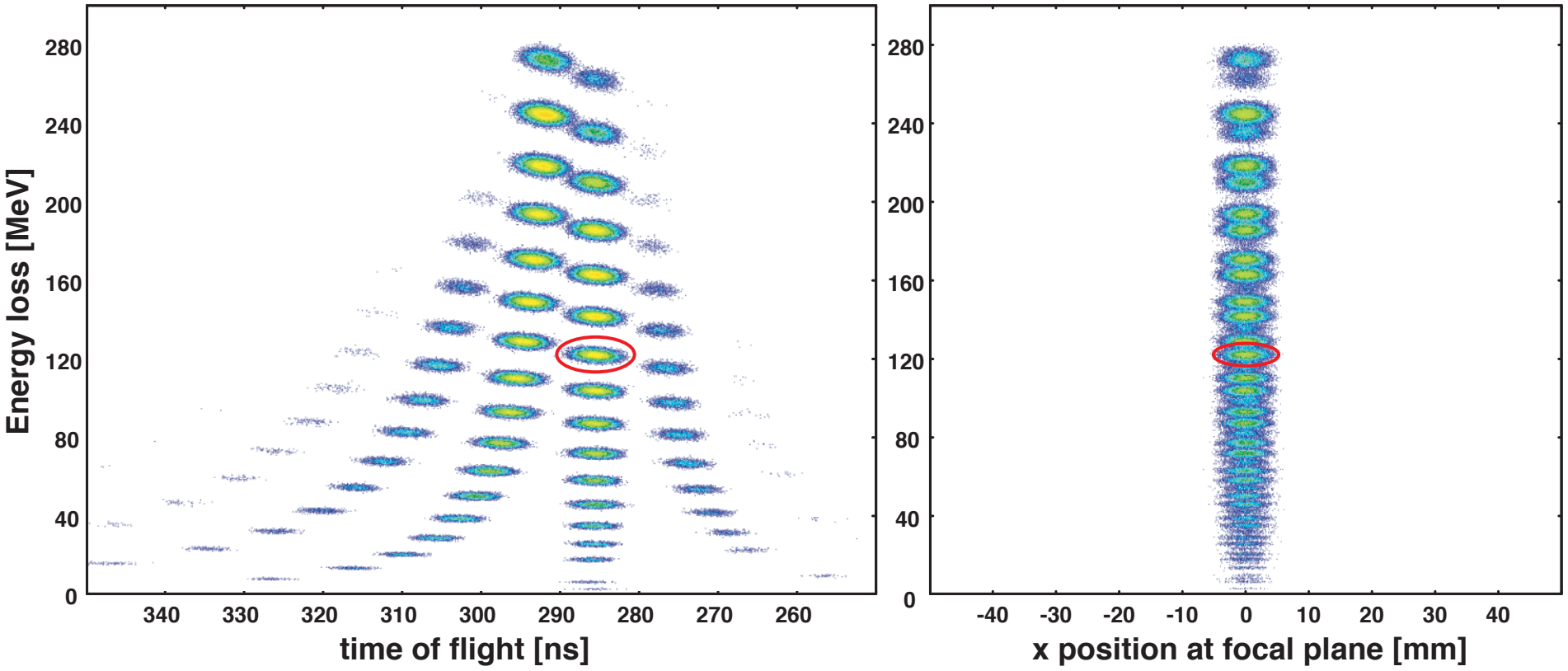


Particle Identification – no wedge degrader

primary beam: ^{40}Ar, 140 MeV/u
production target: Be, 1166 mg/cm^2
selected fragment: ^{26}Al

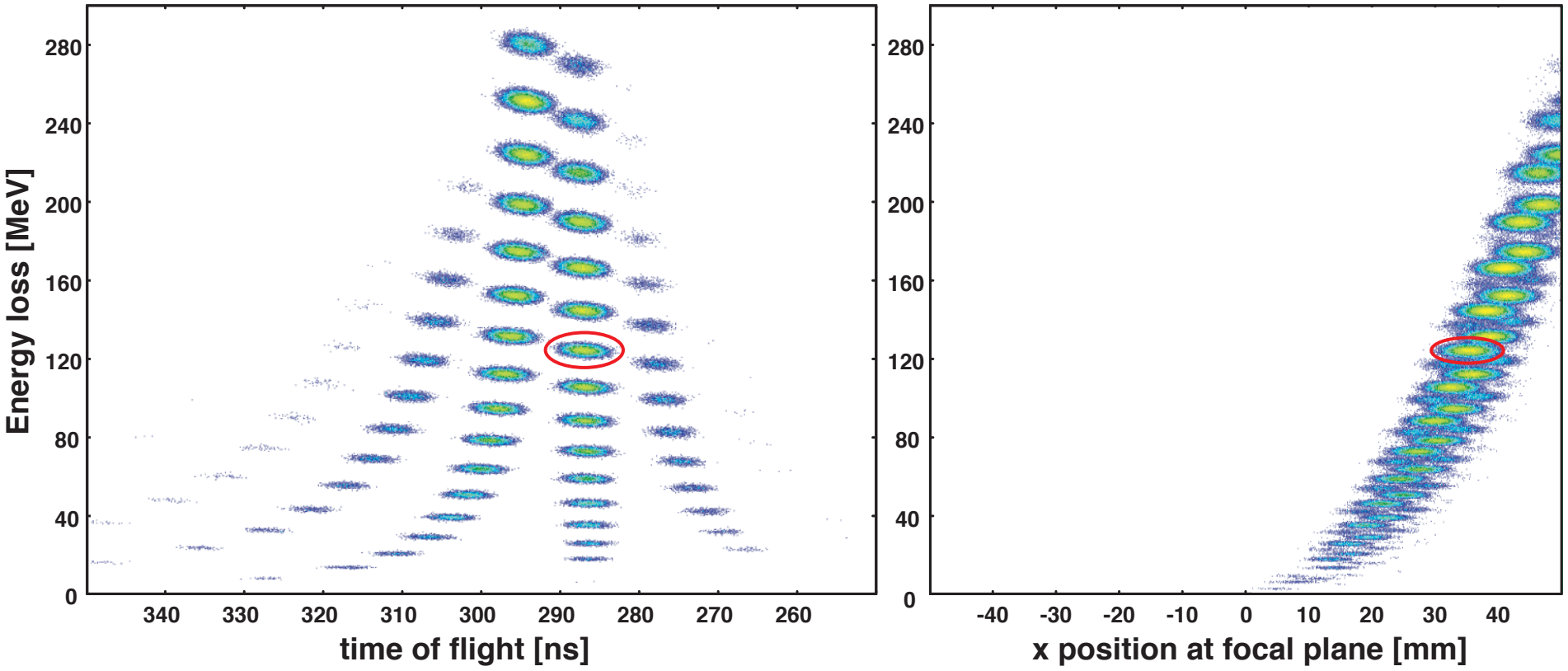
wedge degrader: none
$B\rho_{12}$ = 2.7479 Tm; $B\rho_{34}$ = 2.7479 Tm
$\Delta p/p$ = 1%



Particle Identification – thin wedge degrader

primary beam: ^{40}Ar, 140 MeV/u
production target: Be, 1166 mg/cm^2
selected fragment: ^{26}Al

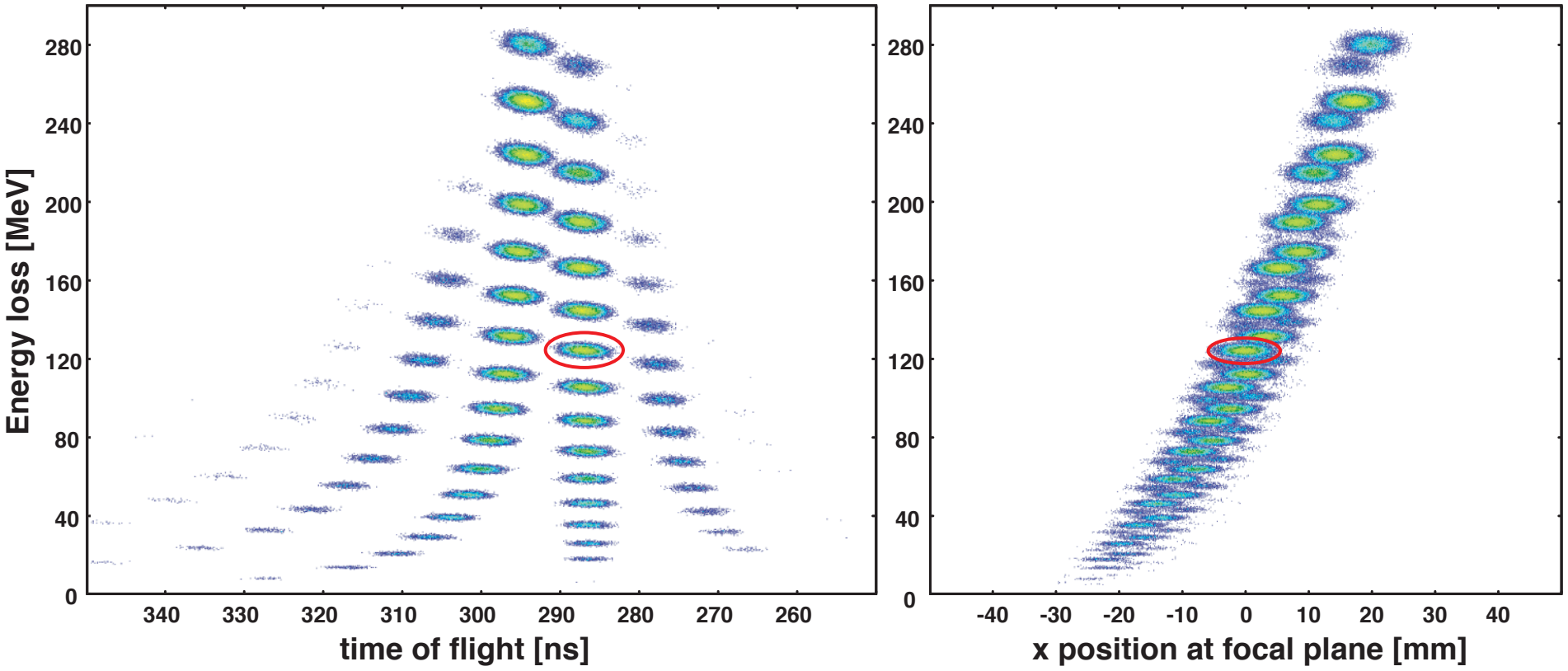
wedge degrader: Al, 50 mg/cm^2
$B\rho_{12}$ = 2.7479 Tm; $B\rho_{34}$ = 2.7479 Tm
$\Delta p/p$ = 1%



Particle Identification – thin wedge degrader

primary beam: ^{40}Ar, 140 MeV/u
production target: Be, 1166 mg/cm^2
selected fragment: ^{26}Al

wedge degrader: Al, 50 mg/cm^2
$B\rho_{12}$ = 2.7479 Tm; $B\rho_{34}$ = 2.7137 Tm
$\Delta p/p$ = 1%

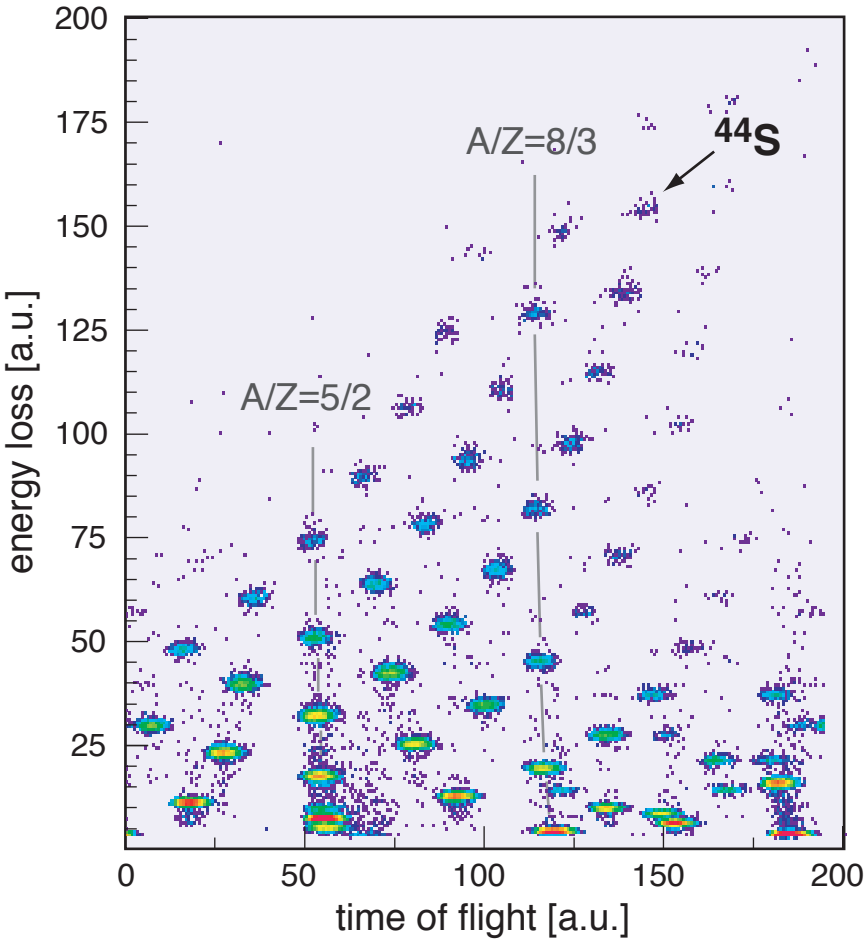


Particle ID and Beam Selection

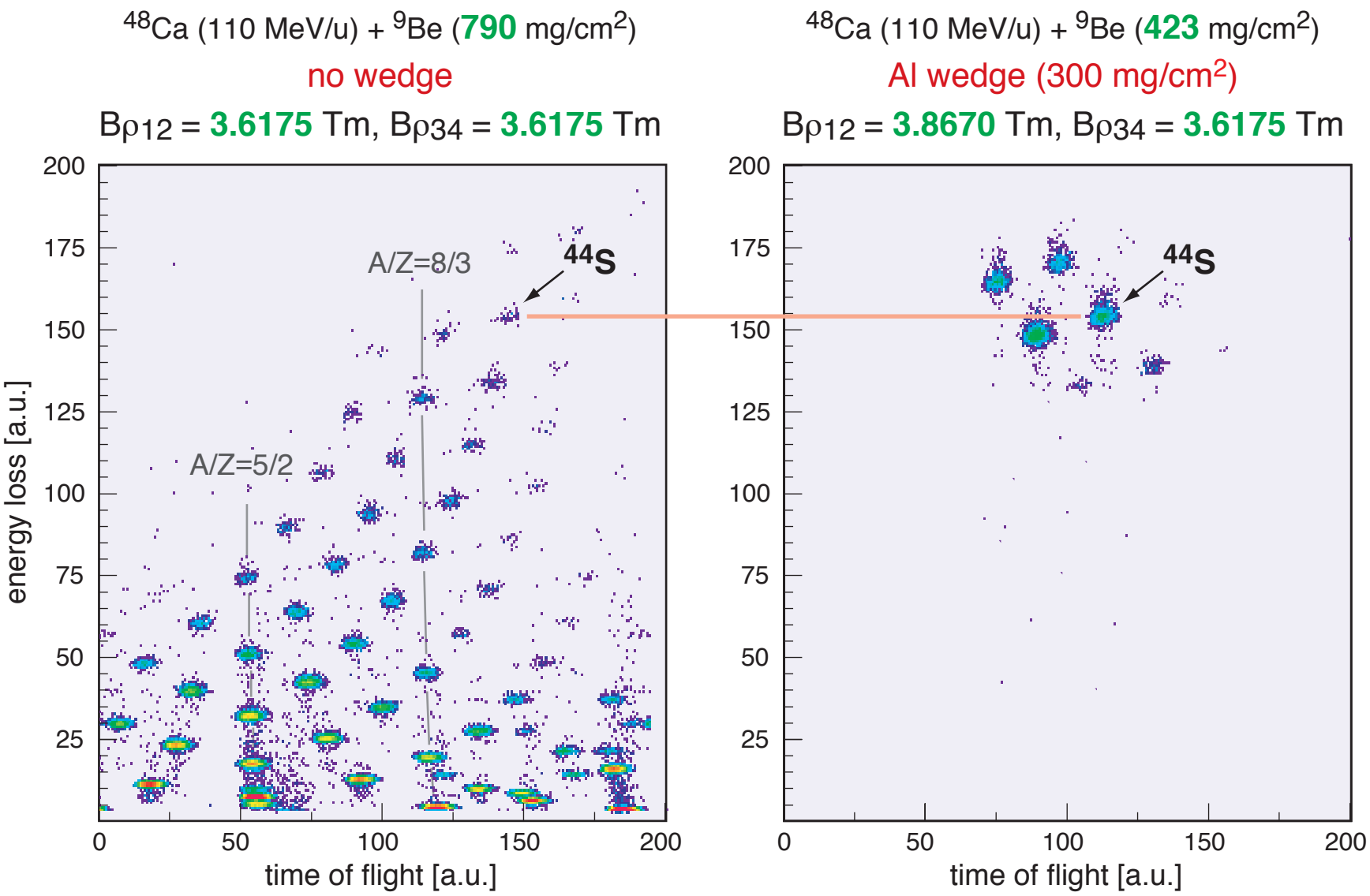
^{48}Ca (110 MeV/u) + ^{9}Be (**790** mg/cm^2)

no wedge

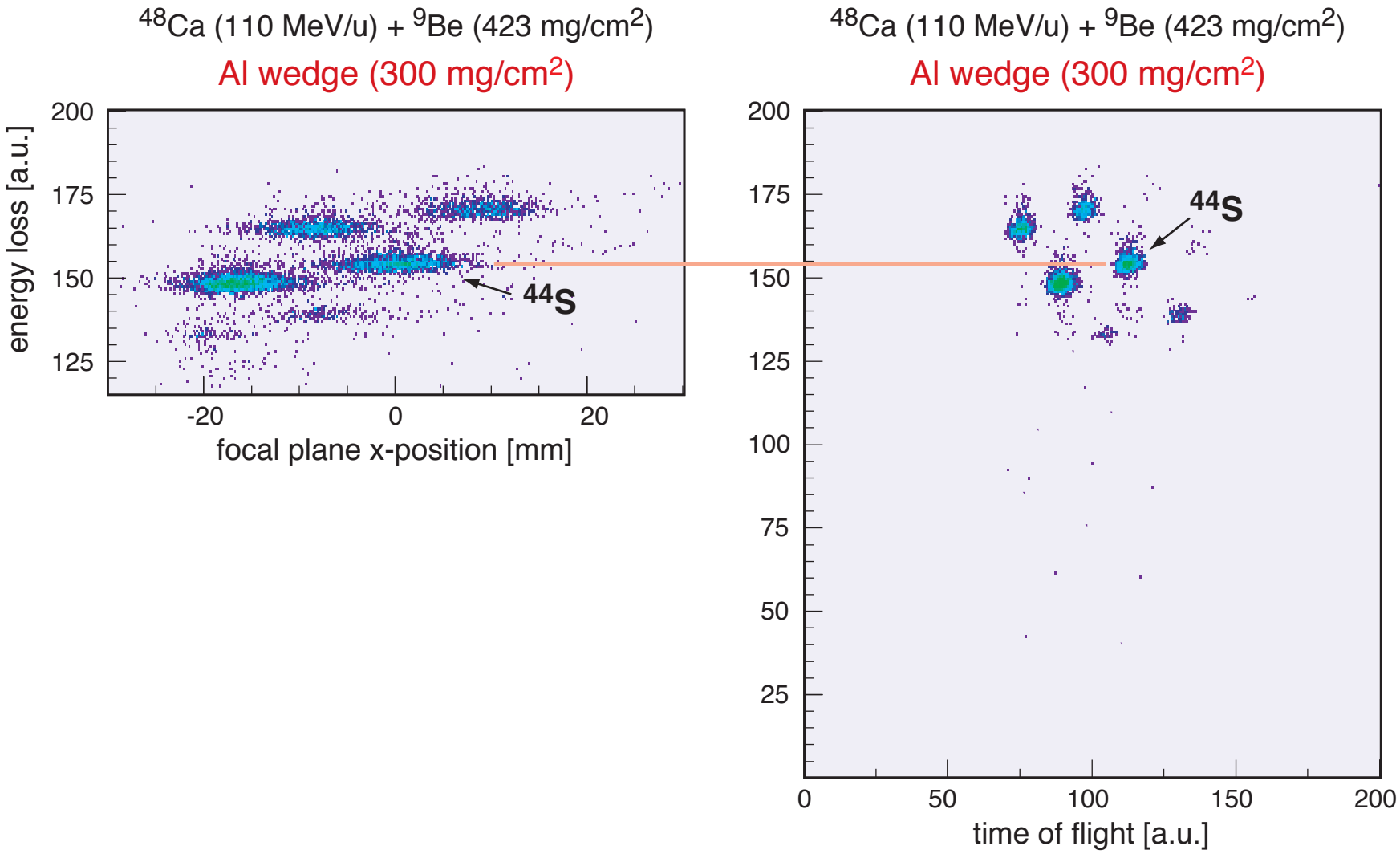
Bρ_{12} = **3.6175** Tm, Bρ_{34} = **3.6175** Tm



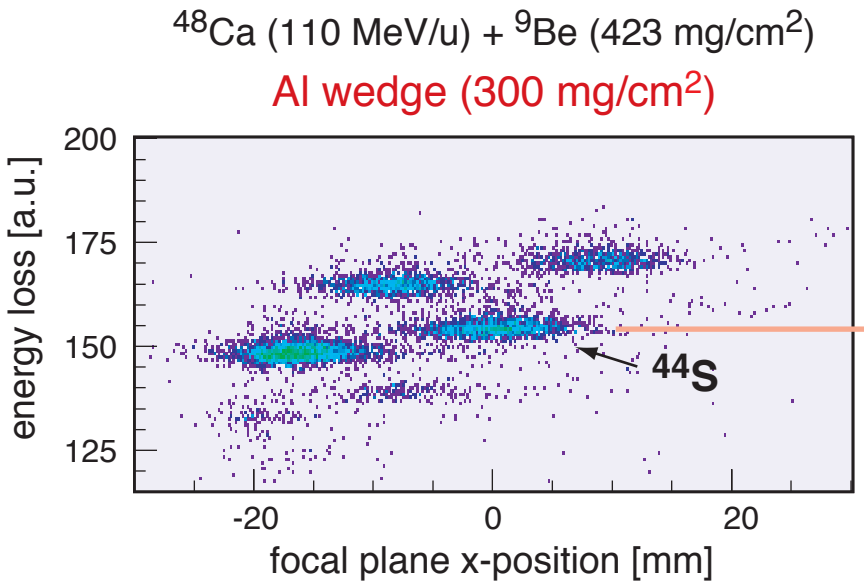
Particle ID and Beam Selection

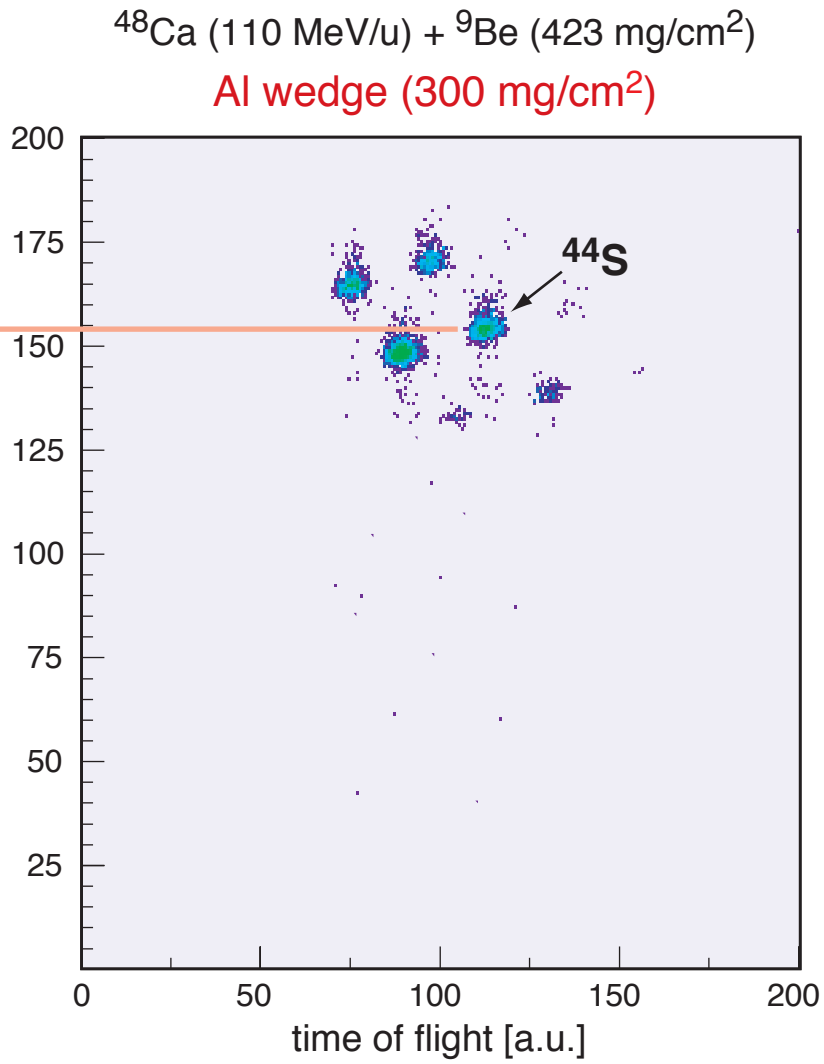


Particle ID and Beam Selection



Particle ID and Beam Selection

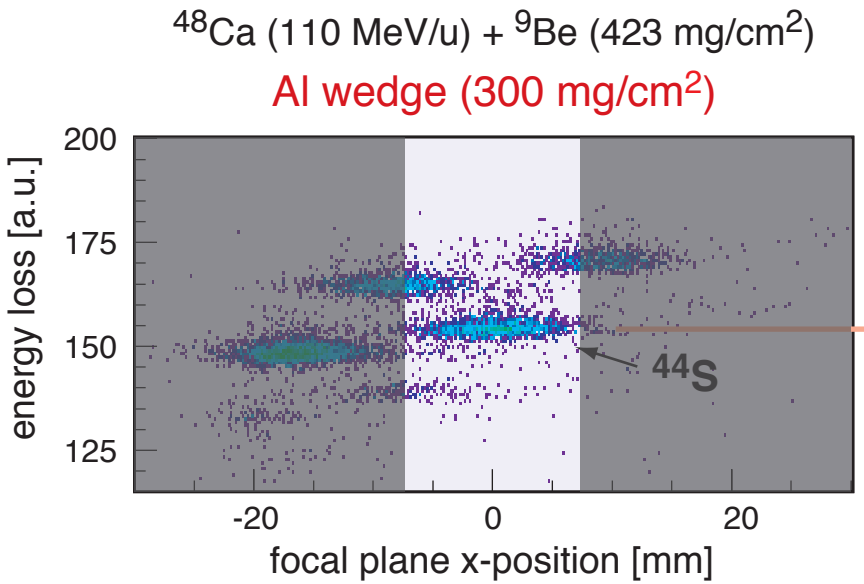


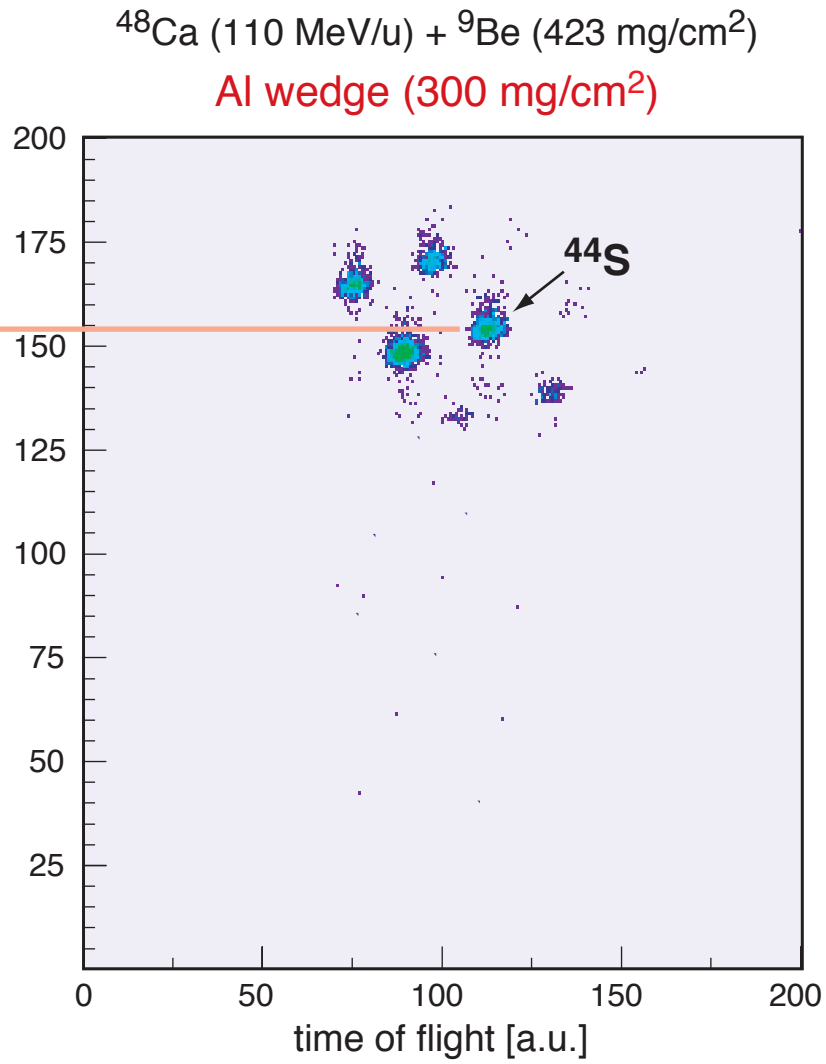


selection with position slits

send rare isotope to experiment

Particle ID and Beam Selection

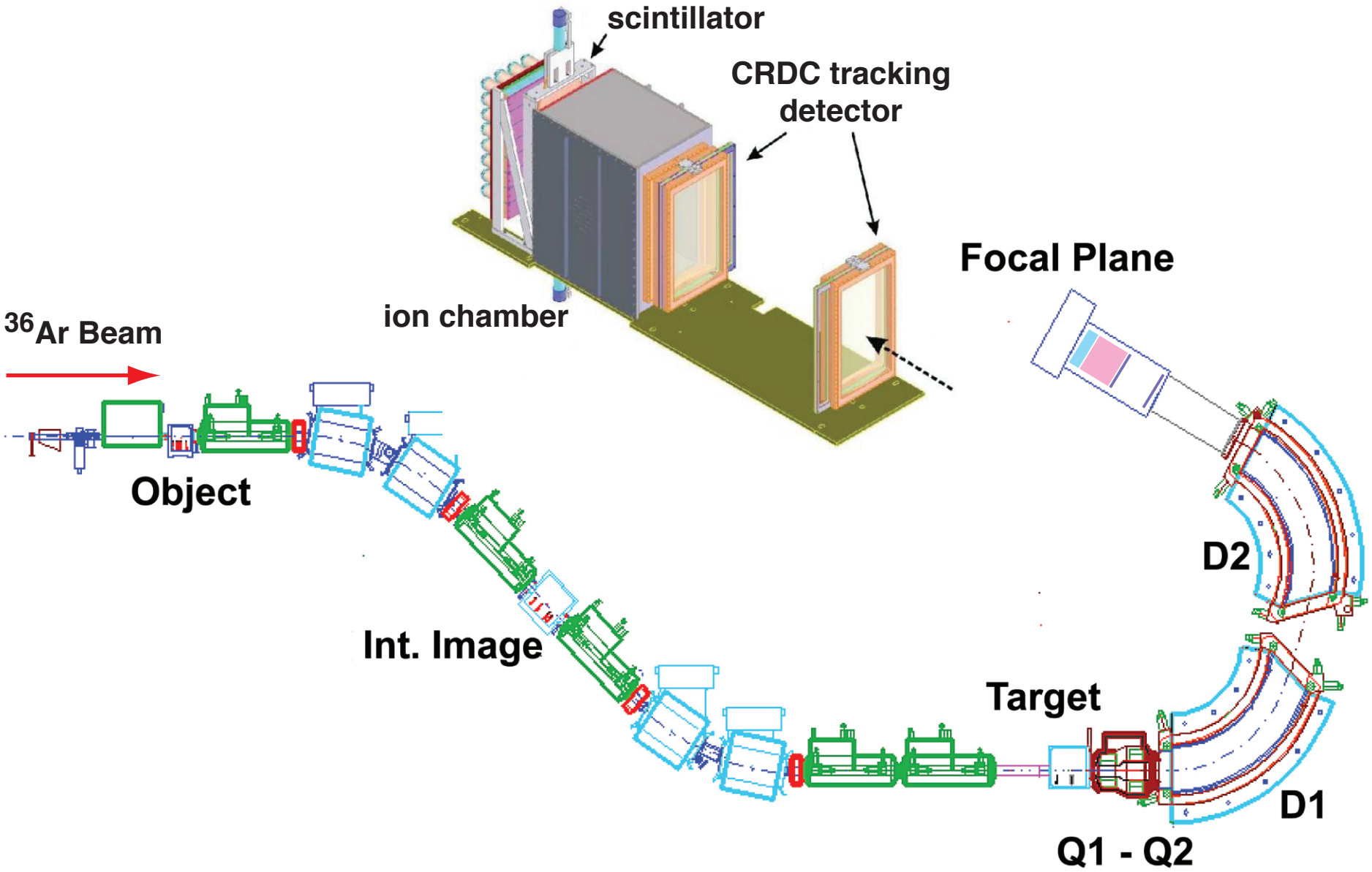




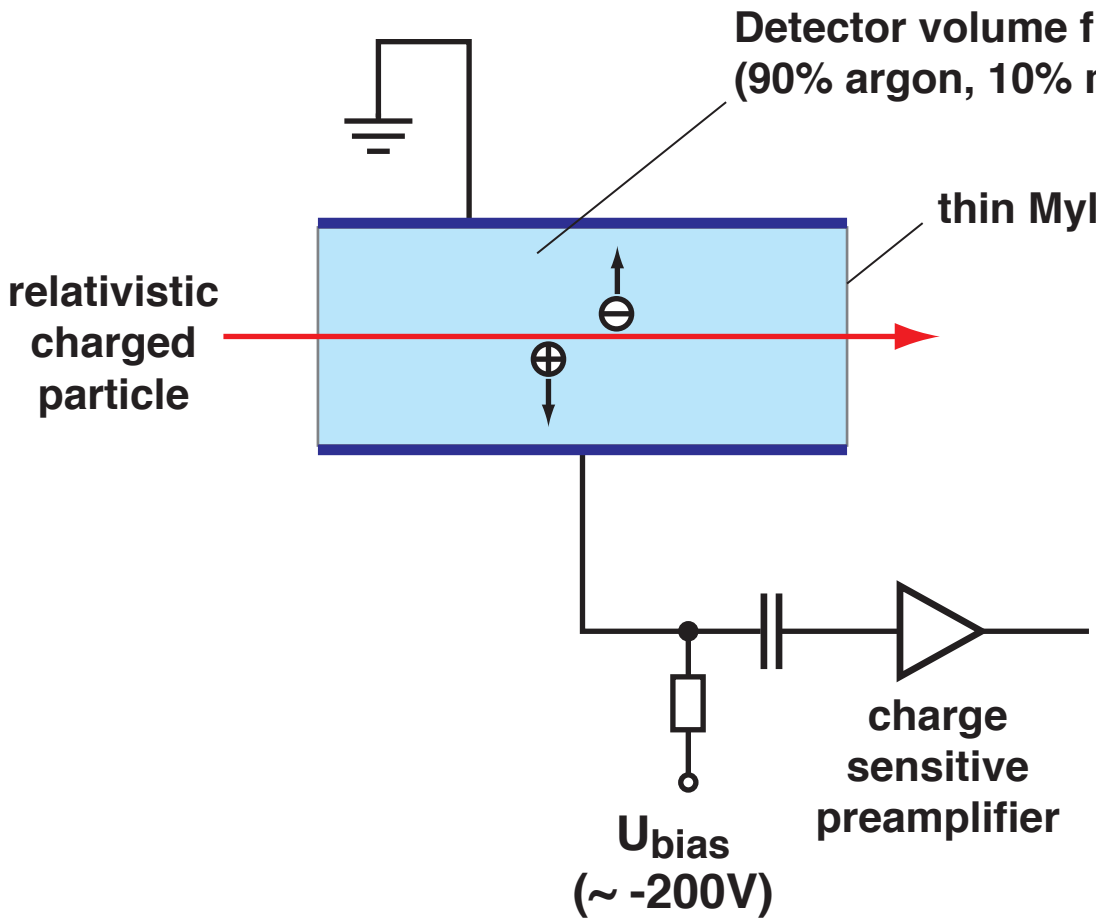
selection with position slits

send rare isotope to experiment

S800 Spectrograph

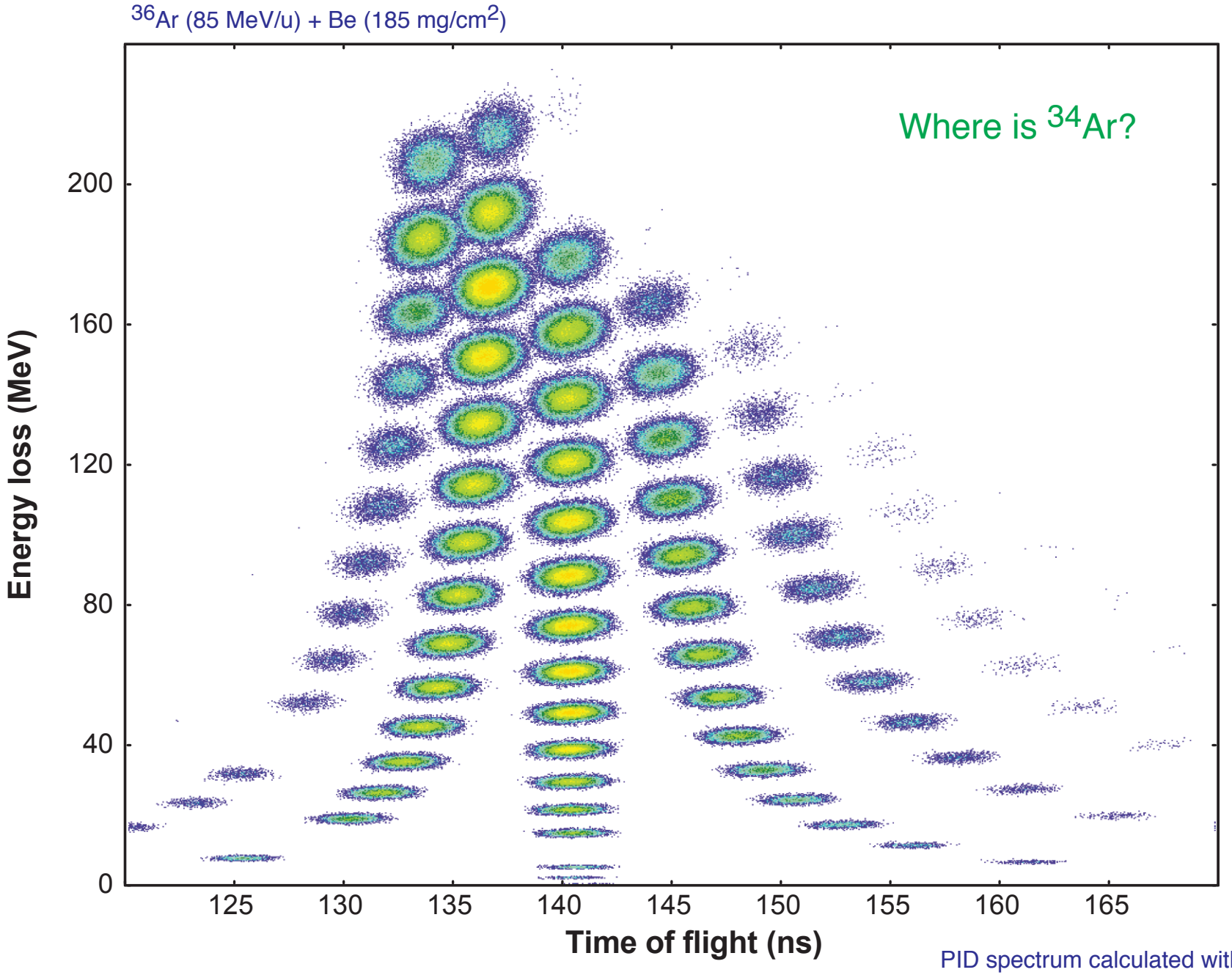


Ion Chamber Detector



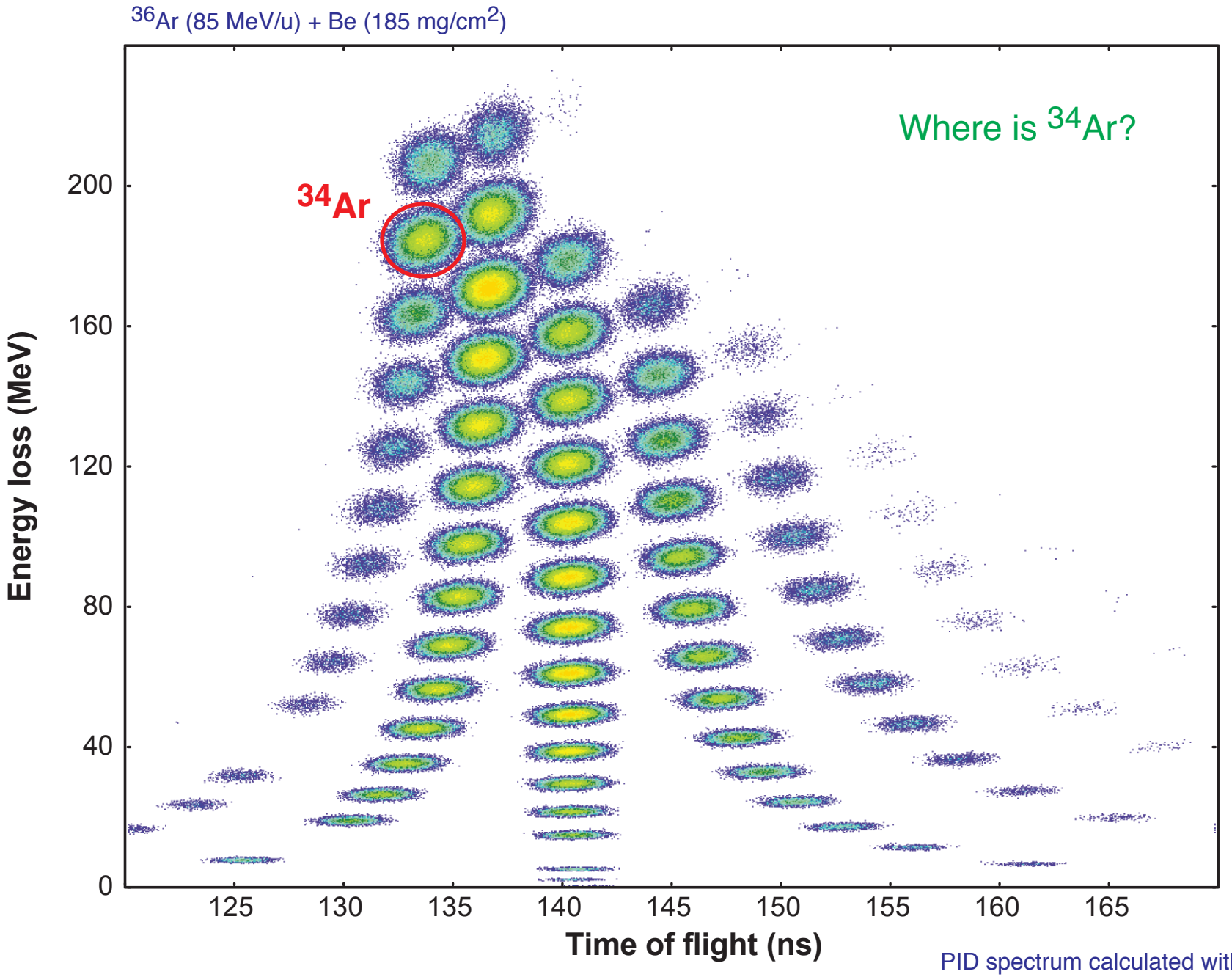
output signal proportional
to collected charge
=
proportional to energy loss
in detector

Particle ID with the S800 Spectrograph



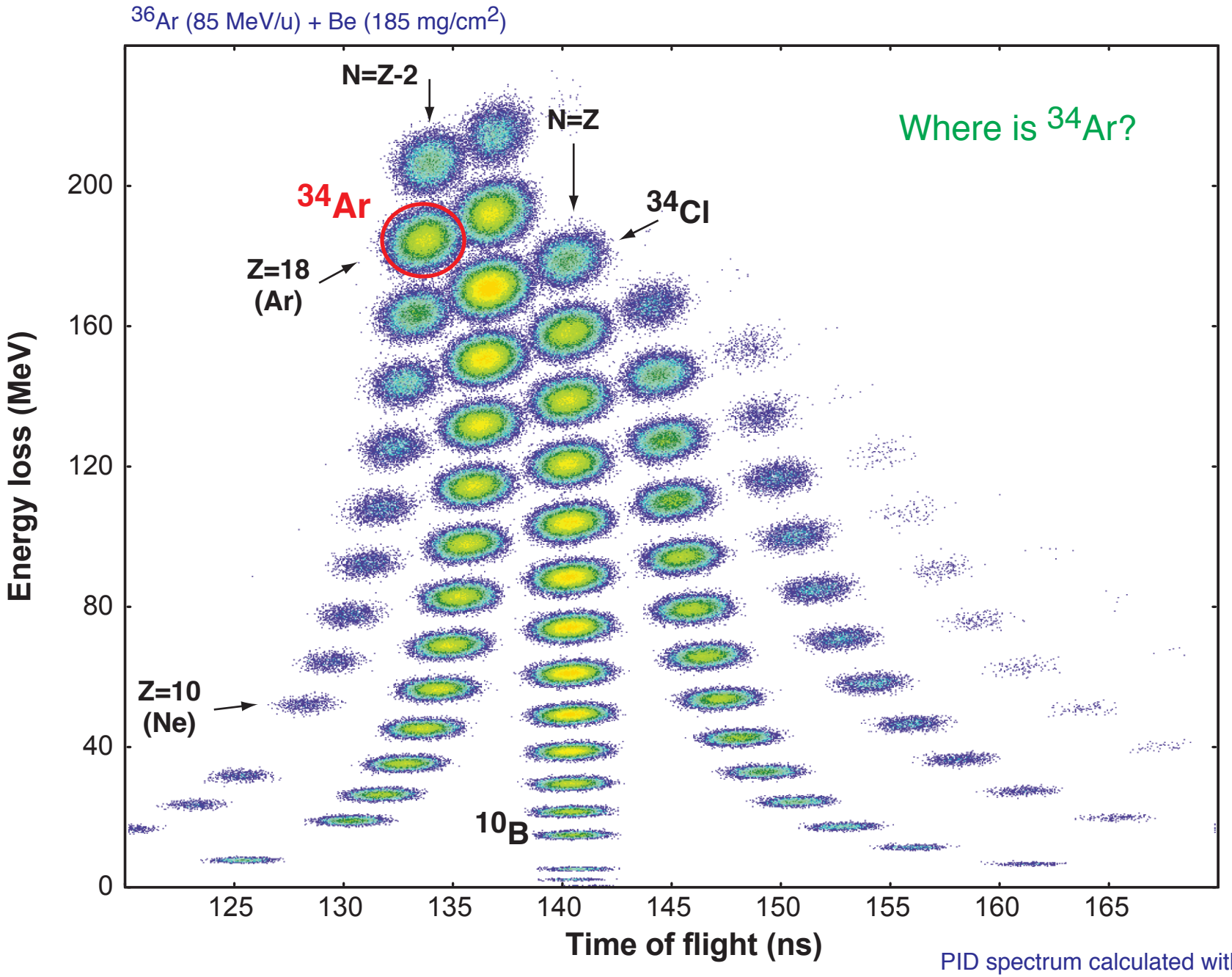
PID spectrum calculated with LISE++

Particle ID with the S800 Spectrograph



PID spectrum calculated with LISE++

Particle ID with the S800 Spectrograph



PID spectrum calculated with LISE++

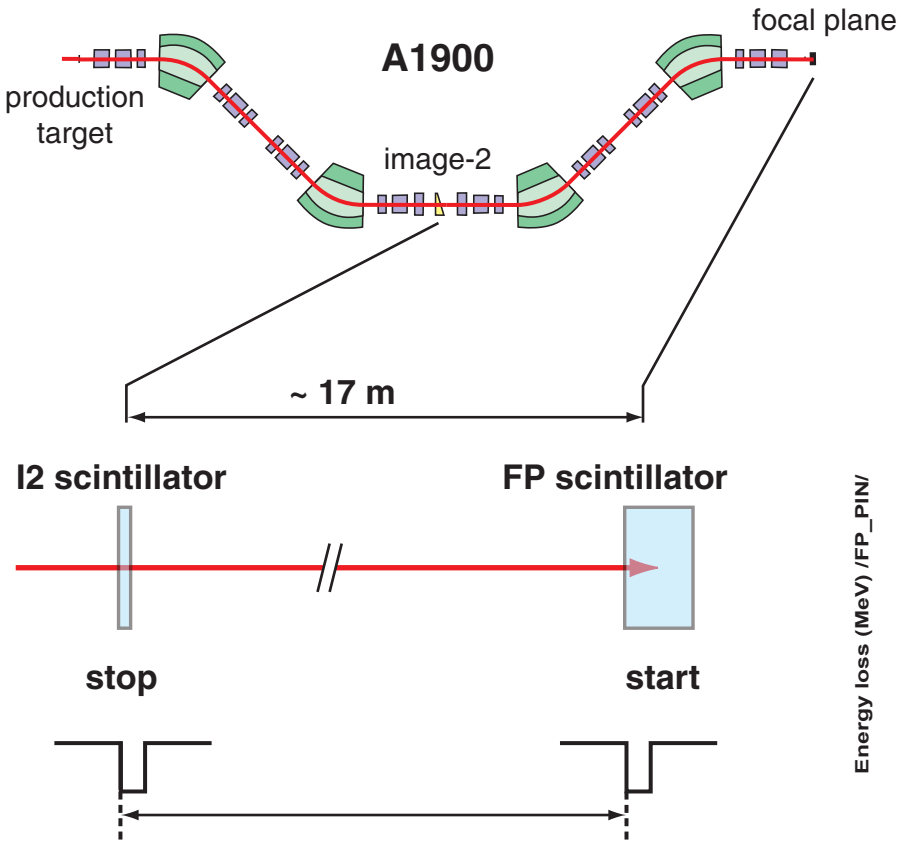
Particle Identification is not difficult !?

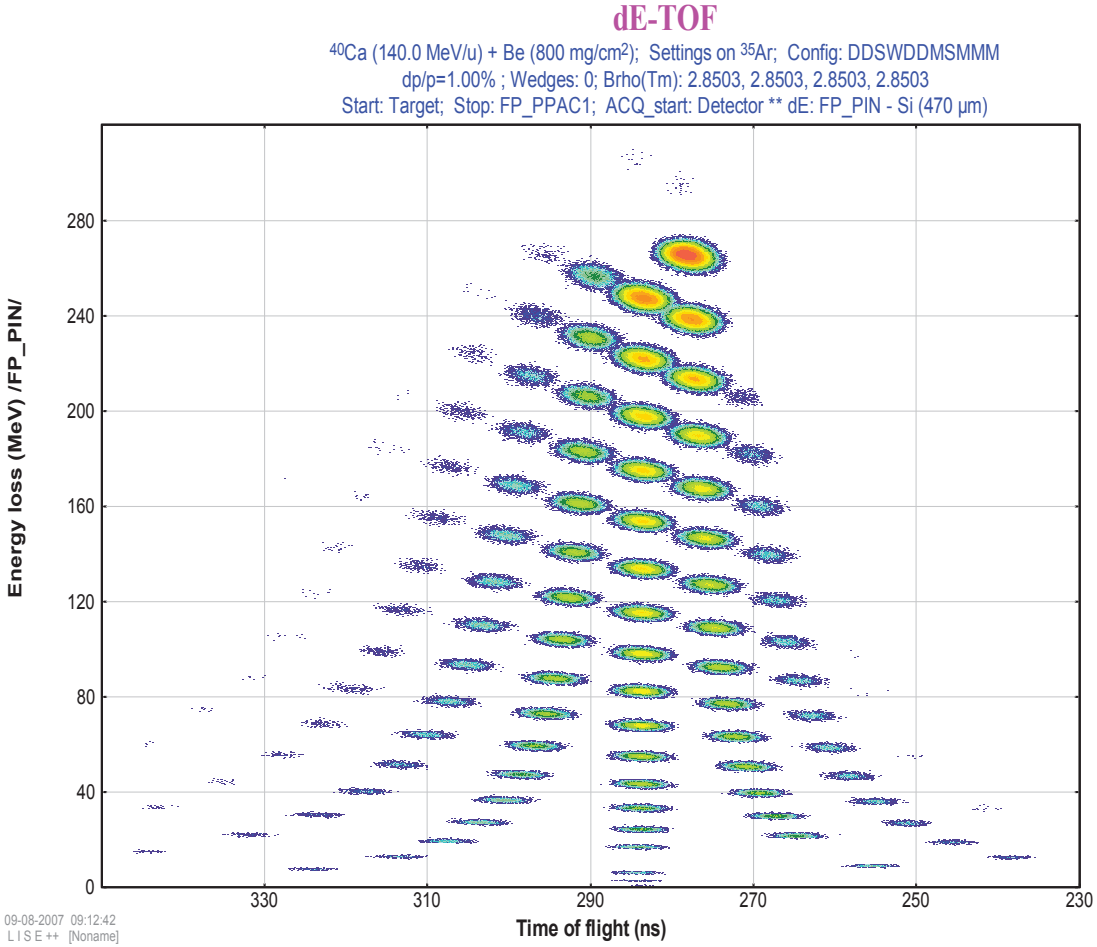
Identifying rare isotopes is like finding one person from among everyone on this planet.

total world population estimate (July 2016): 7,330,000,000

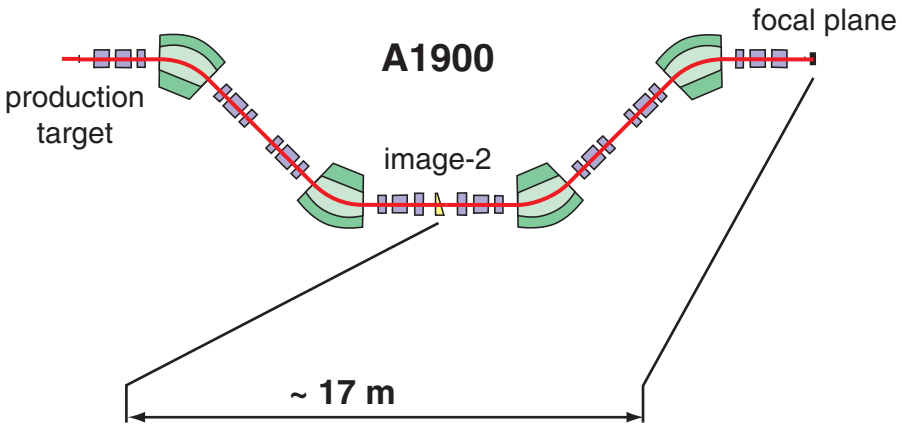
typical beam intensity: 1 pnA = $6.3 \cdot 10^9$ particles / sec

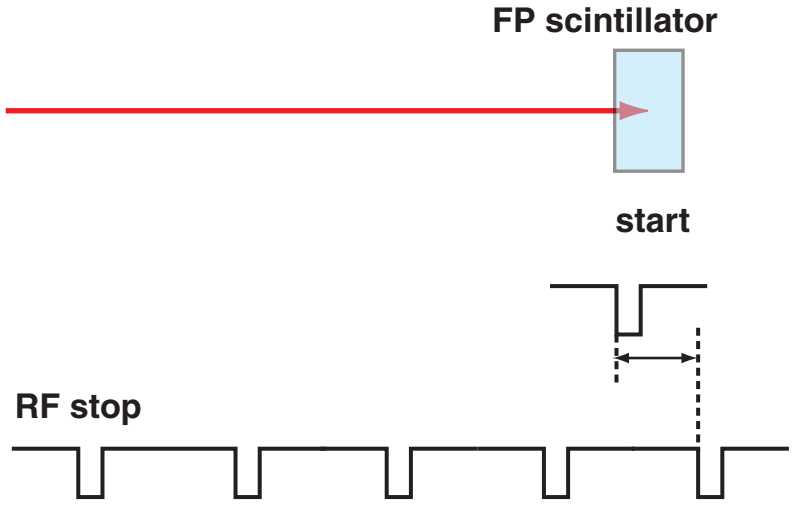
Time-of-flight measurement

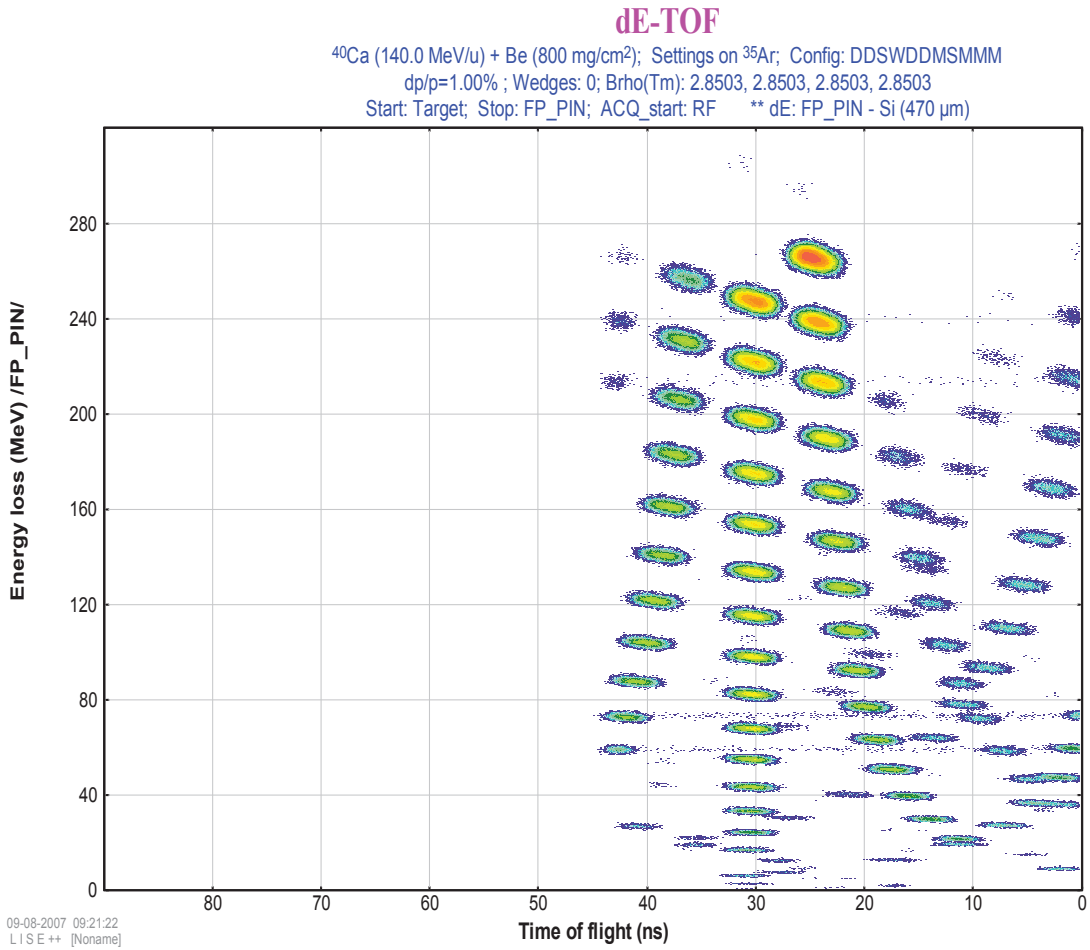




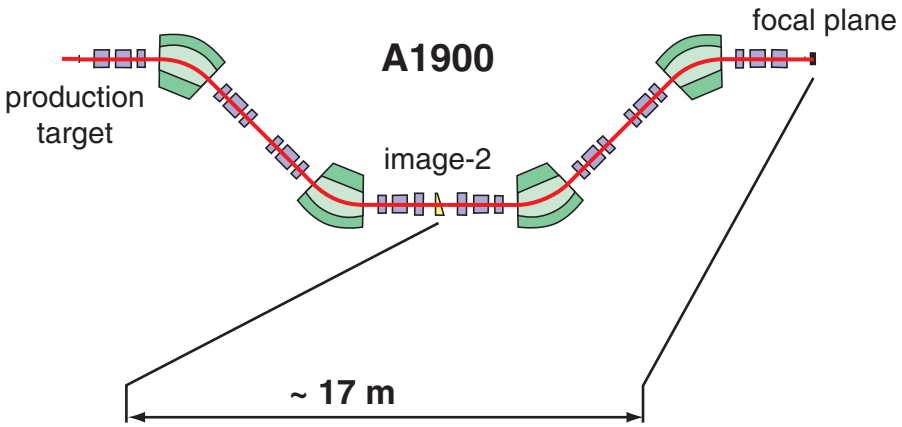
Time-of-flight measurement

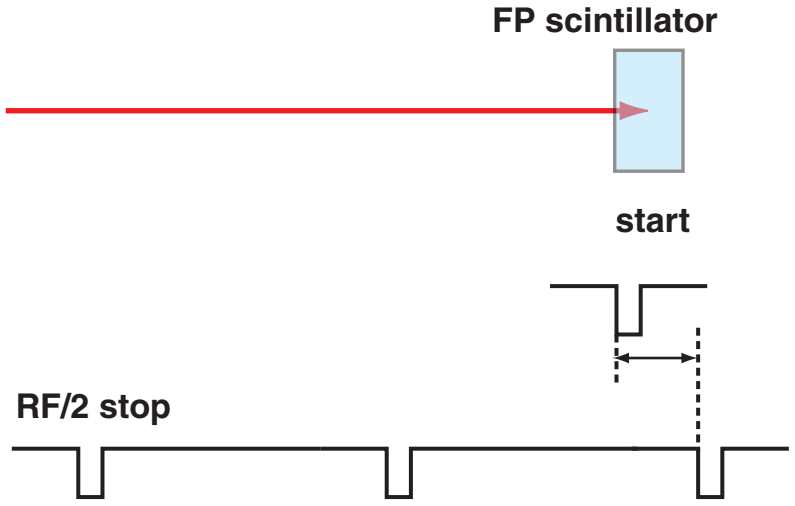




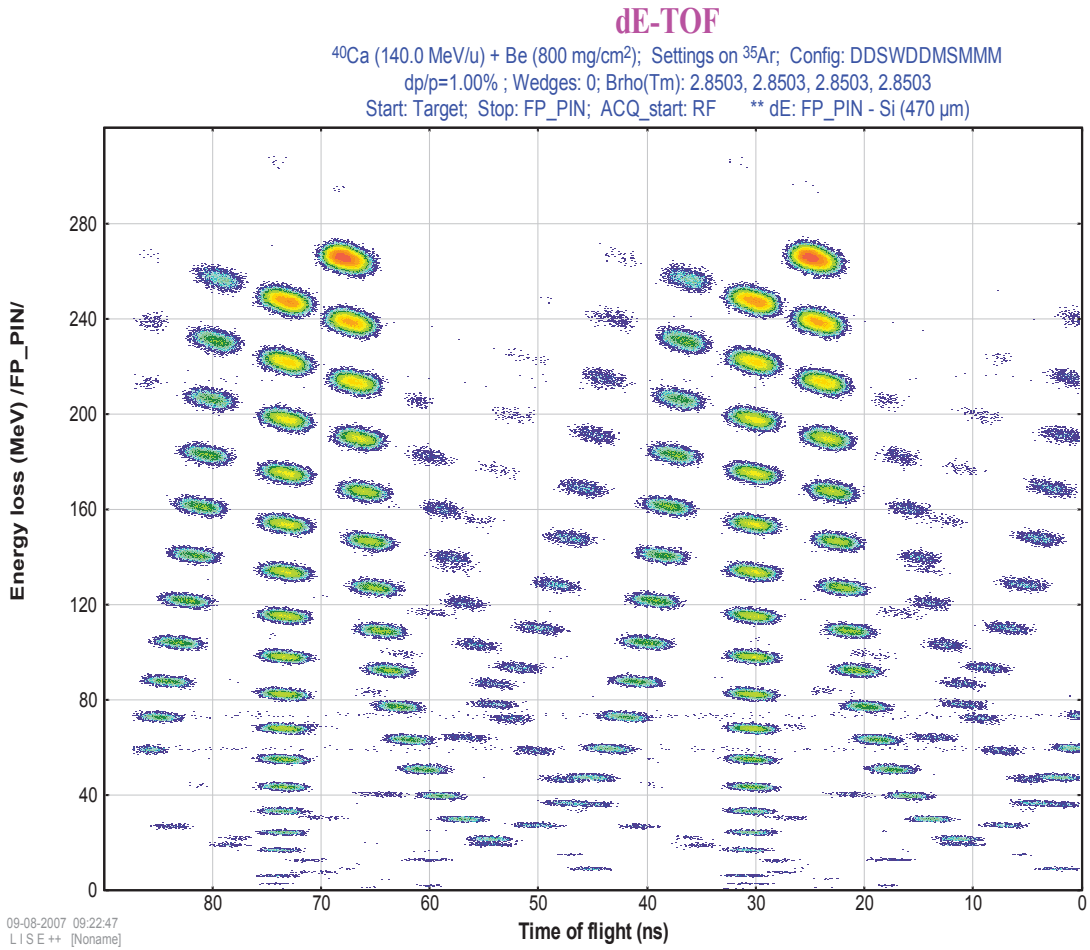


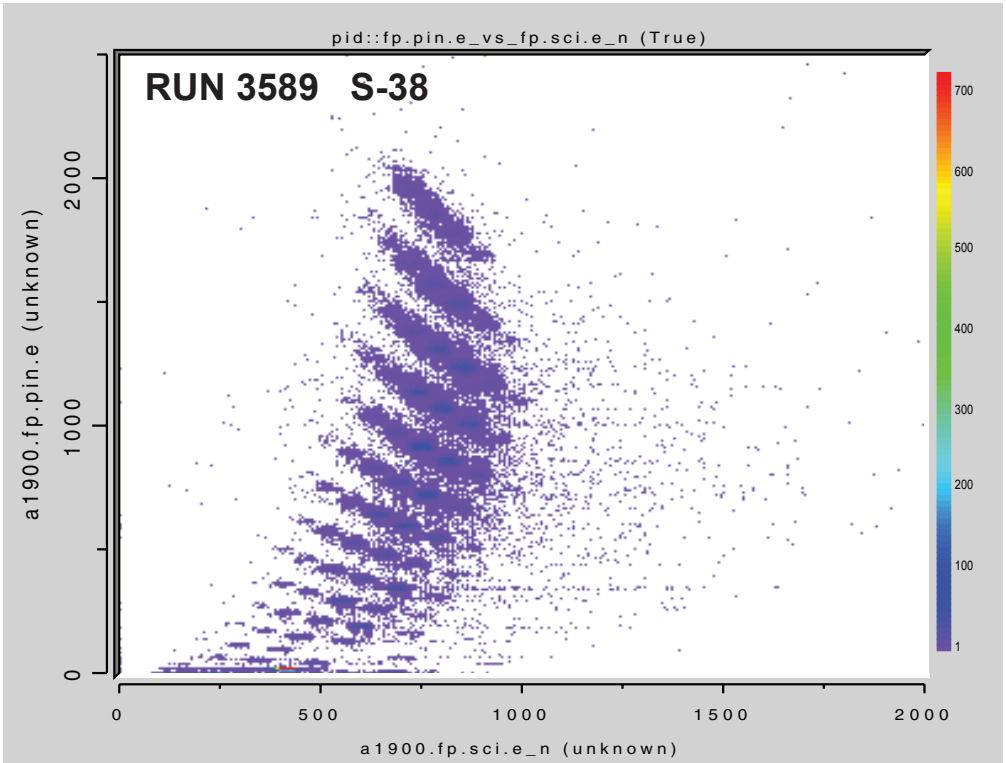
Time-of-flight measurement





stop generated for every second RF pulse

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RUN 3589 S-38
a1900.fp.pin.e (unknown)
a1900.fp.sci.e_n (unknown)
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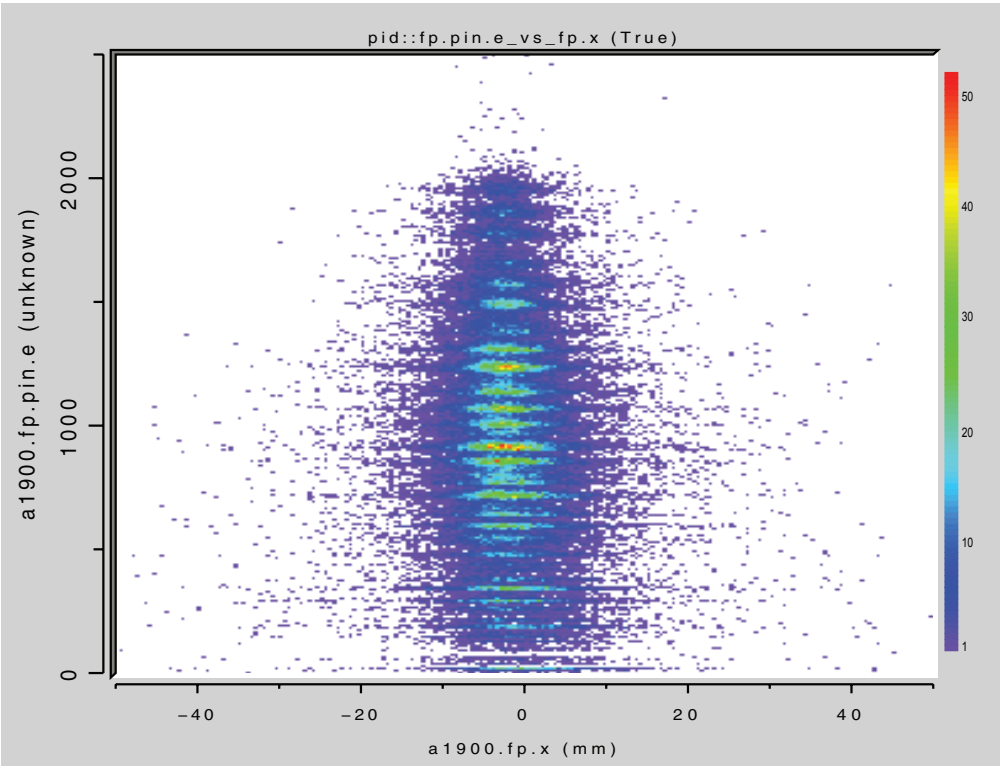
1000
1500
2000
700
600
500
400
300
200
100
1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a1900.fp.pin.e (unknown)
a1900.fp.x (mm)
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−20
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30
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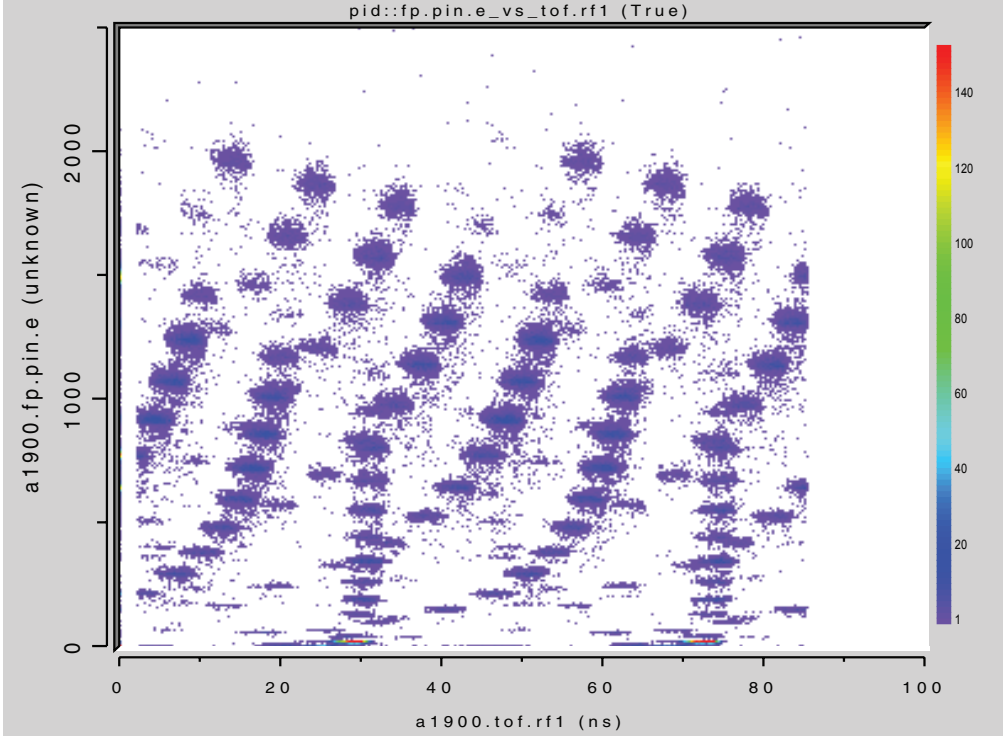
10
1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a1900.tof.rf1 (ns)
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2000
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40
60
80
100
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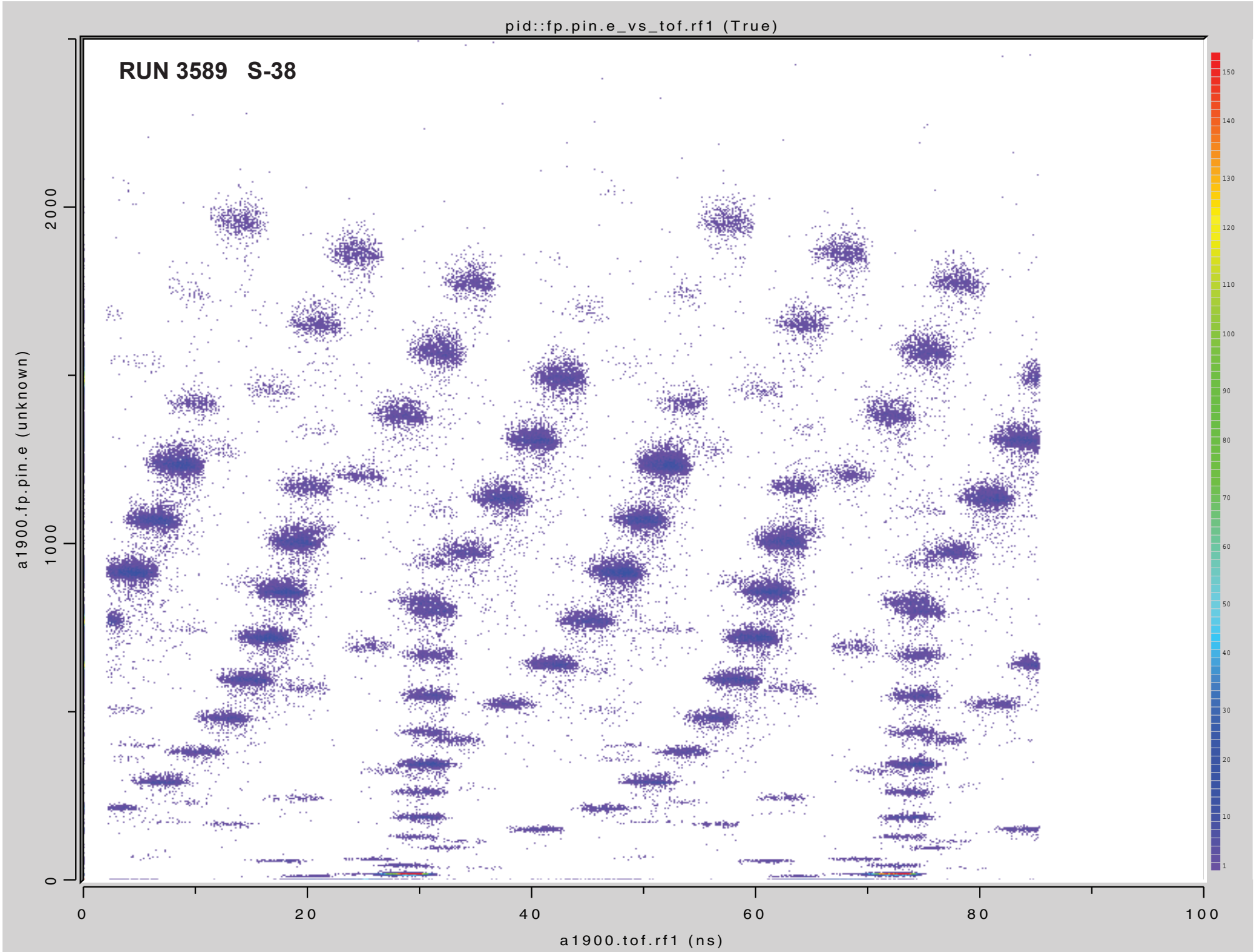
120
100
80
60
40
20
1


pid::fp.pin.e_vs_tof.rf1 (True)
RUN 3589 S-38
a1900.fp.pin.e (unknown)
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1000
2000
0
20
40
60
80
100
a1900.tof.rf1 (ns)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
1