GEANT4 simulation project on the AMS facility,

ARTEMIS,
at LMC14 in Saclay, France

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14th Geant4 Users and Collaboration Workshop

15-22 October 2009

Laboratori Nazionali del Sud-INFN

The LMC14 laboratory

- *The accelerator mass spectrometry : detecting naturally long-lived radio-istopes.*
- *ARTEMIS facility: AMS installed at Saclay in France in 2003, dedicated to radiocarbon dating.*
- *New research project at LMC14: simulating the ion beam across all the elements.*

GEANT4 simulation project on the AMS facility, ARTEMIS, at LMC14 in Saclay, France

I. *Introduction*

I. *ARTEMIS, an Accelerator Mass Spectrometer facility*

I. *TRANSPORT Tool*

I. *GEANT4 Toolkit*

I. *Conclusion*

Radiocarbon dating : principle

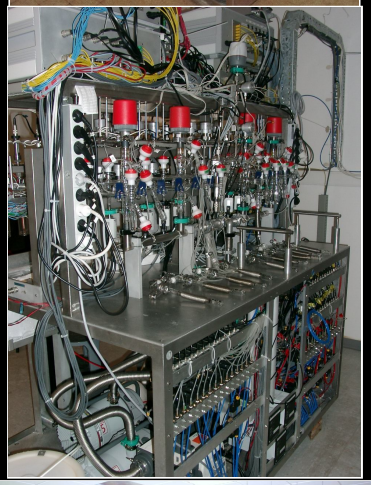
✓ Determination of the $^{14}C/^{12}C$ and $^{13}C/^{12}C$ rates of a died organism

✓ Comparaison of

$$\frac{^{14}C/^{12}C \text{ ratio of the sample}}{^{14}C/^{12}C \text{ ratio of a known sample}}$$

↓

Age of the dead organism



New technical approach: the accelerator mass spectrometry

↓

Measure of very small samples (less than 1mg of carbon)

ARTEMIS facility :

A 3 MV NEC Pelletron Accelerator coupled to a spectrometer

✓Measuring the ^{12}C and ^{13}C currents

✓Counting the ^{14}C ions by isobaric discriminations

AIMS OF THE ARTEMIS SIMULATION PROJECT

The simulation of the ARTEMIS facility consists in:

- *Finding out the most sensitive points of the machine*
- *Comparing the experimental parameters of the facility with an ion optic simulation*
- *Controlling for each tuning that there is no bad tuning (e.g beam lost during transportation)*
- *Studing annoyances like isobaric beam (CH problem, beam interaction with residual gas…)*

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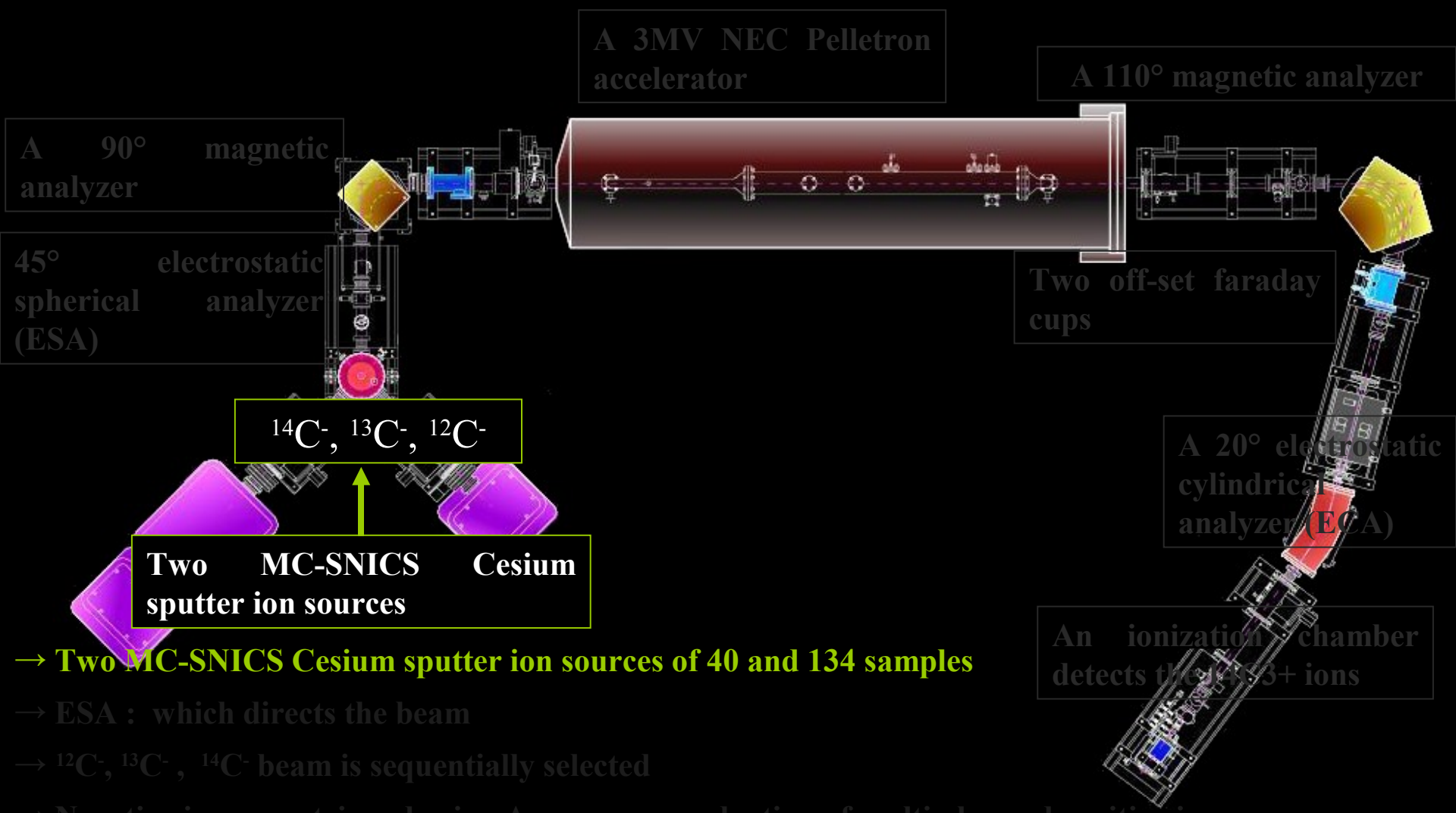
ARTEMIS,
an Accelerator Mass Spectrometer facility



→ Two MC-SNICS Cesium sputter ion sources of 40 and 134 samples

→ ESA : which directs the beam

→ $^{12}C^-$, $^{13}C^-$, $^{14}C^-$ beam is sequentially selected

→ Negative ions are stripped using Argon gaz, production of multi-charged positive ions.

→ $^{14}C^{3+}$ ions are selected and driven into the rare isotope beamline

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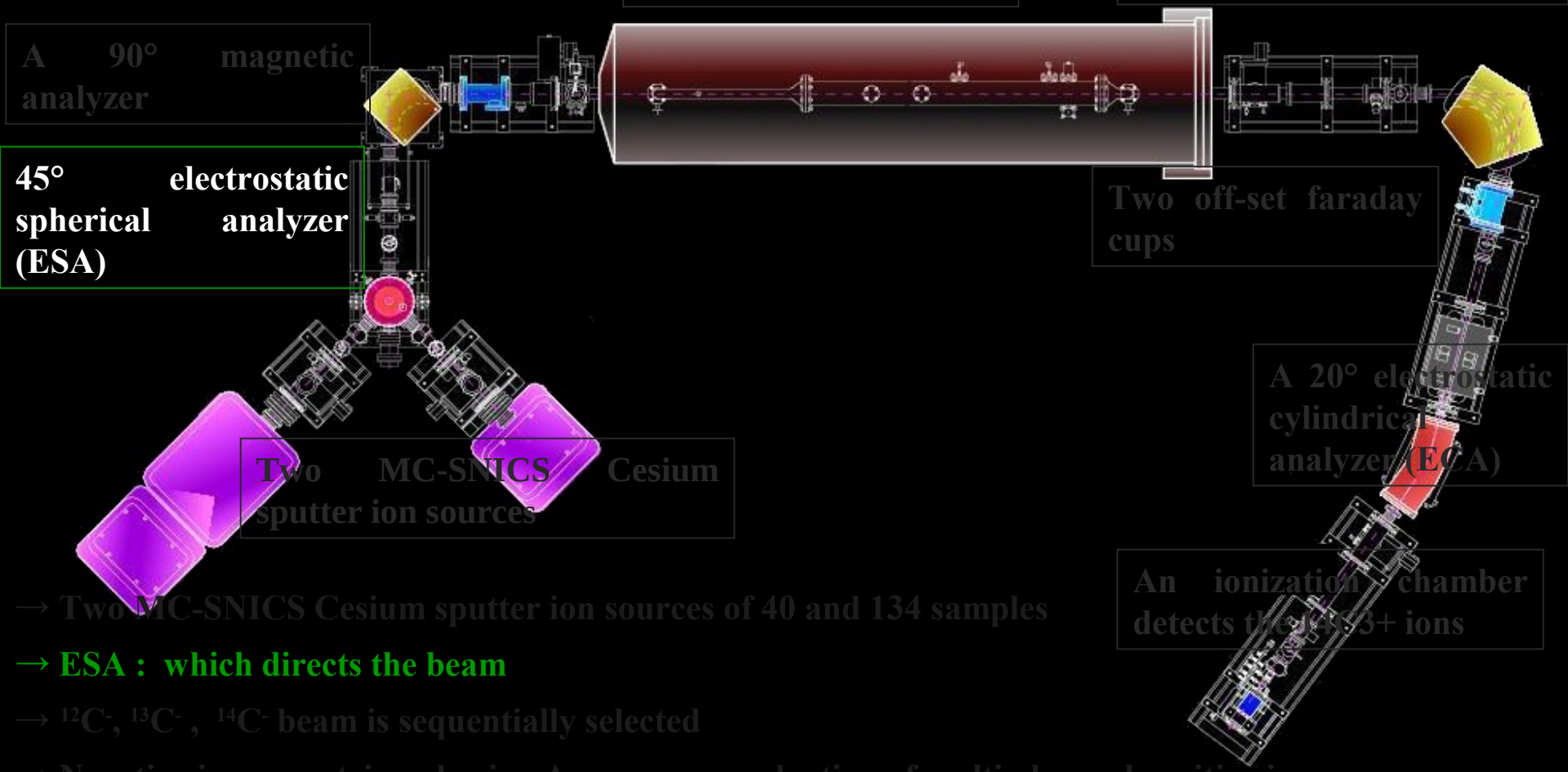
→ An ionization chamber detects the 14C3+ ions



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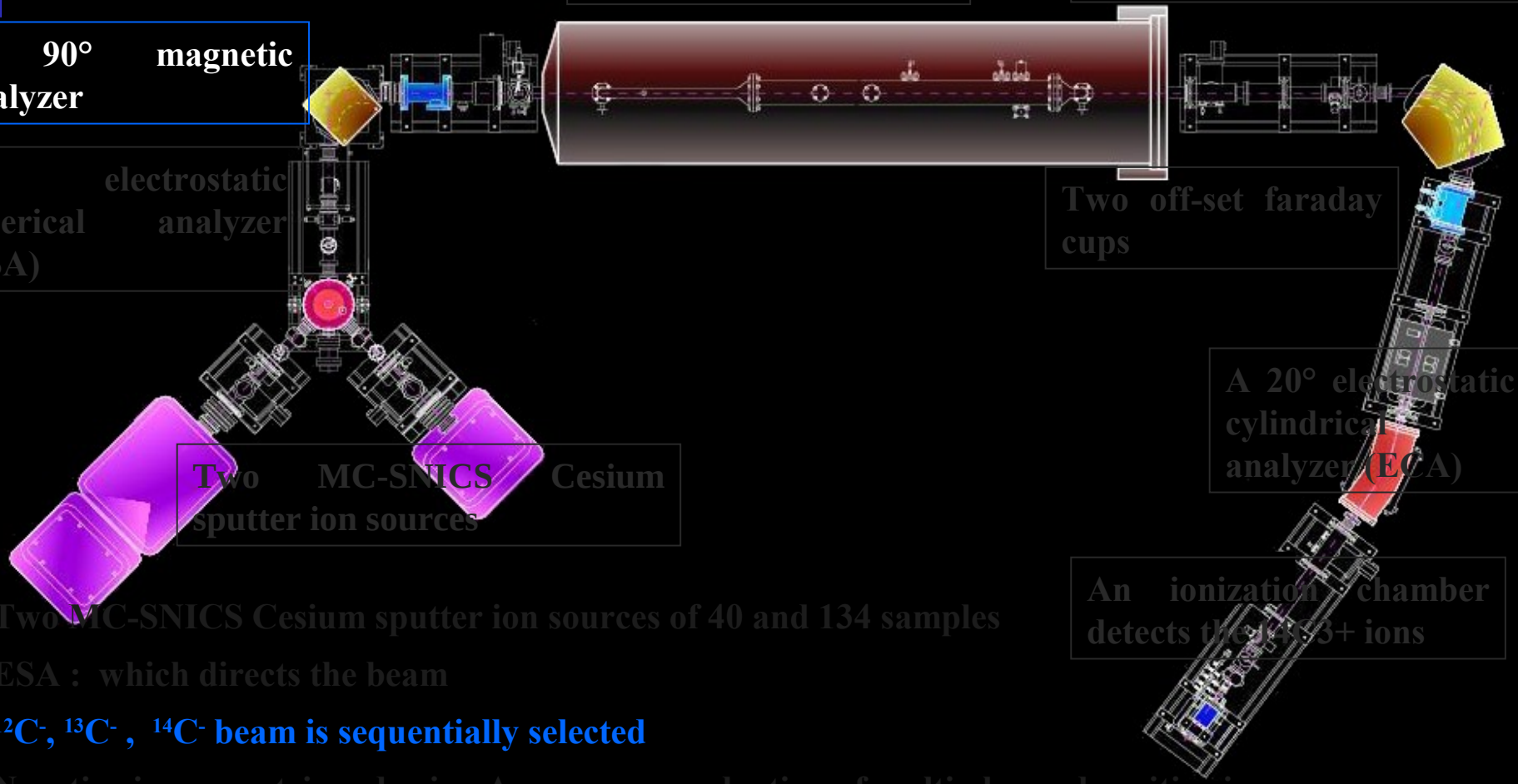
Selection of different carbon isotopes beam



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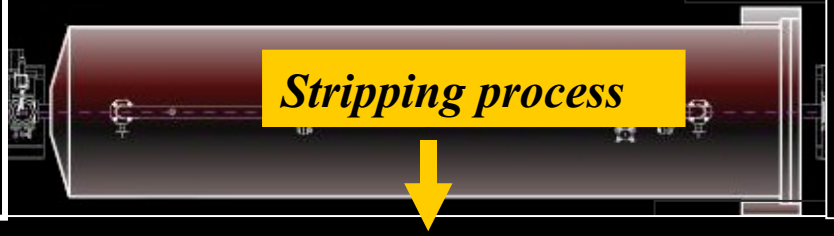
A 3MV NEC Pelletron accelerator

INPUT:

$^{12}C^{-}$,

$^{13}C^{-}$,, $^{12}CH^{-}$,

$^{14}C^{-}$, $^{13}CH^{-}$, $^{12}CH^{2-}$



OUTPUT:

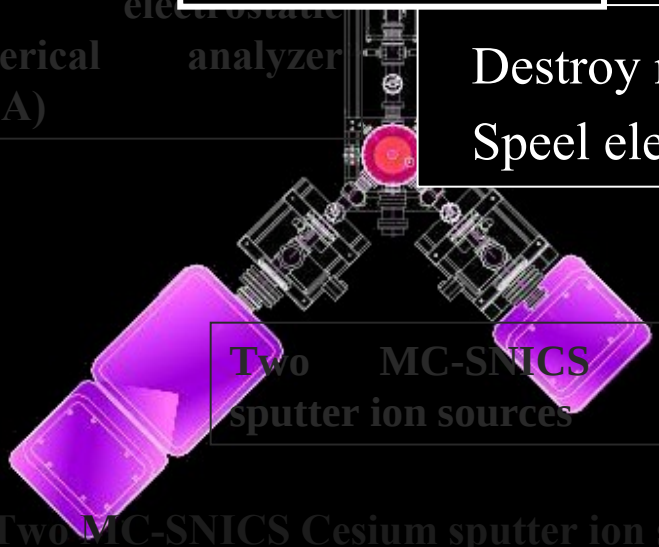
$^{12}C^{3+}$, $^{13}C^{3+}$, $^{14}C^{3+}$…

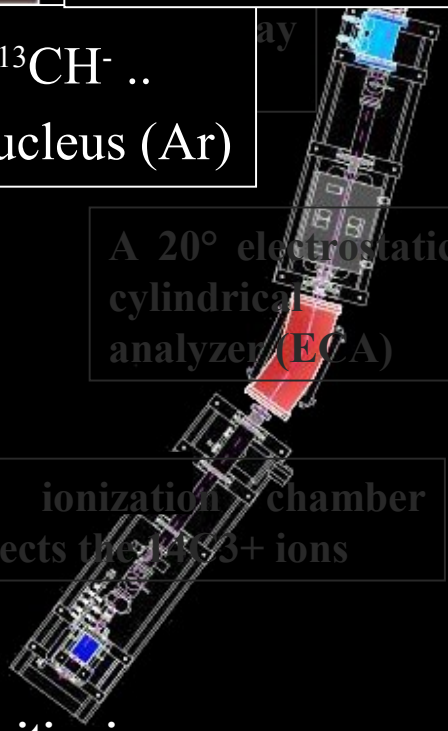
$^{12}C^{2+}$, $^{13}C^{2+}$, $^{14}C^{2+}$…

$^{12}C^{+}$, $^{13}C^{+}$, $^{14}C^{+}$…

Destroy molecular system: $^{12}CH_2^-$, $^{12}CH^-$, $^{13}CH^-$ ..

Speel electron by collisions with heavy nucleus (Ar)





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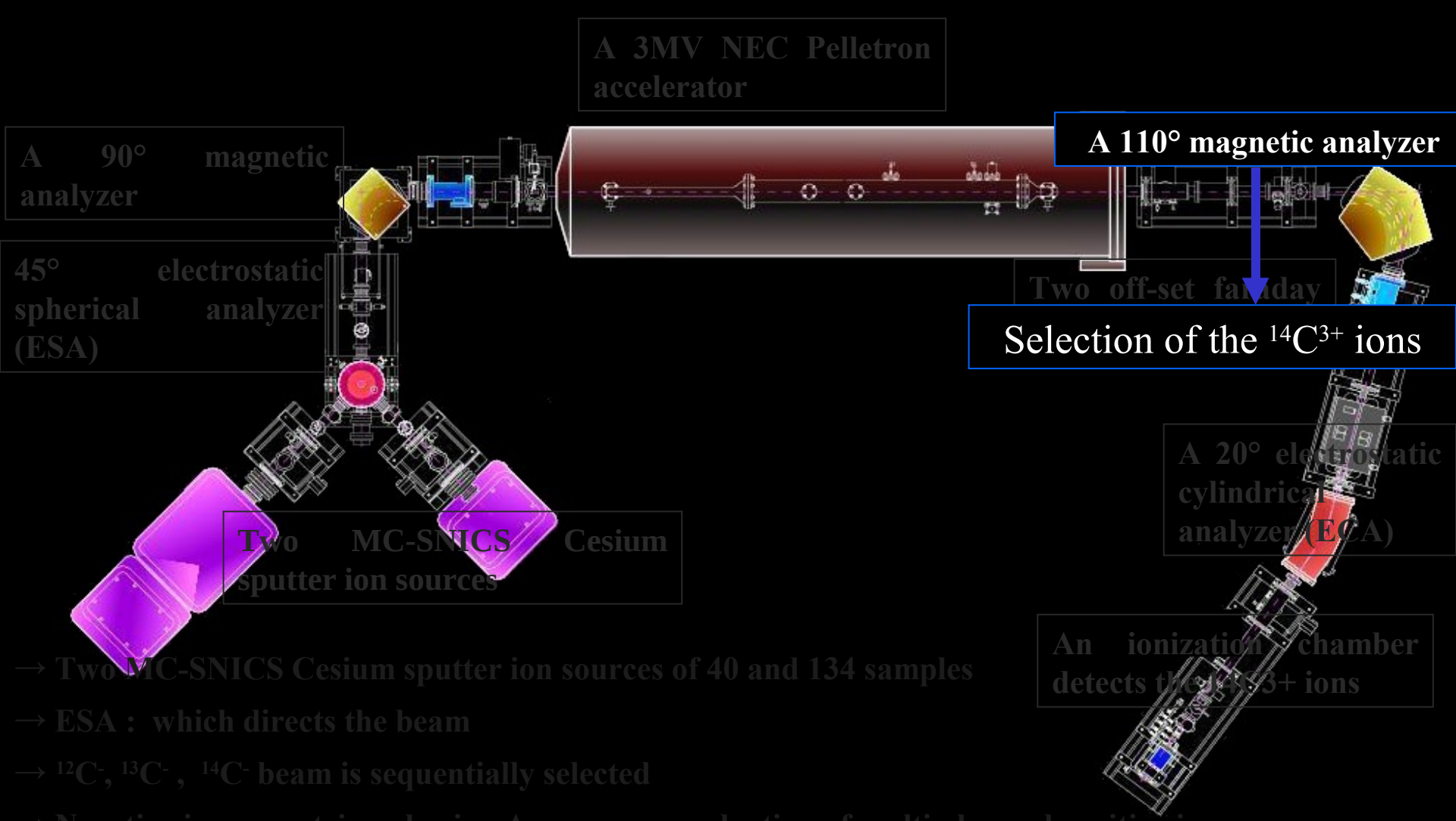

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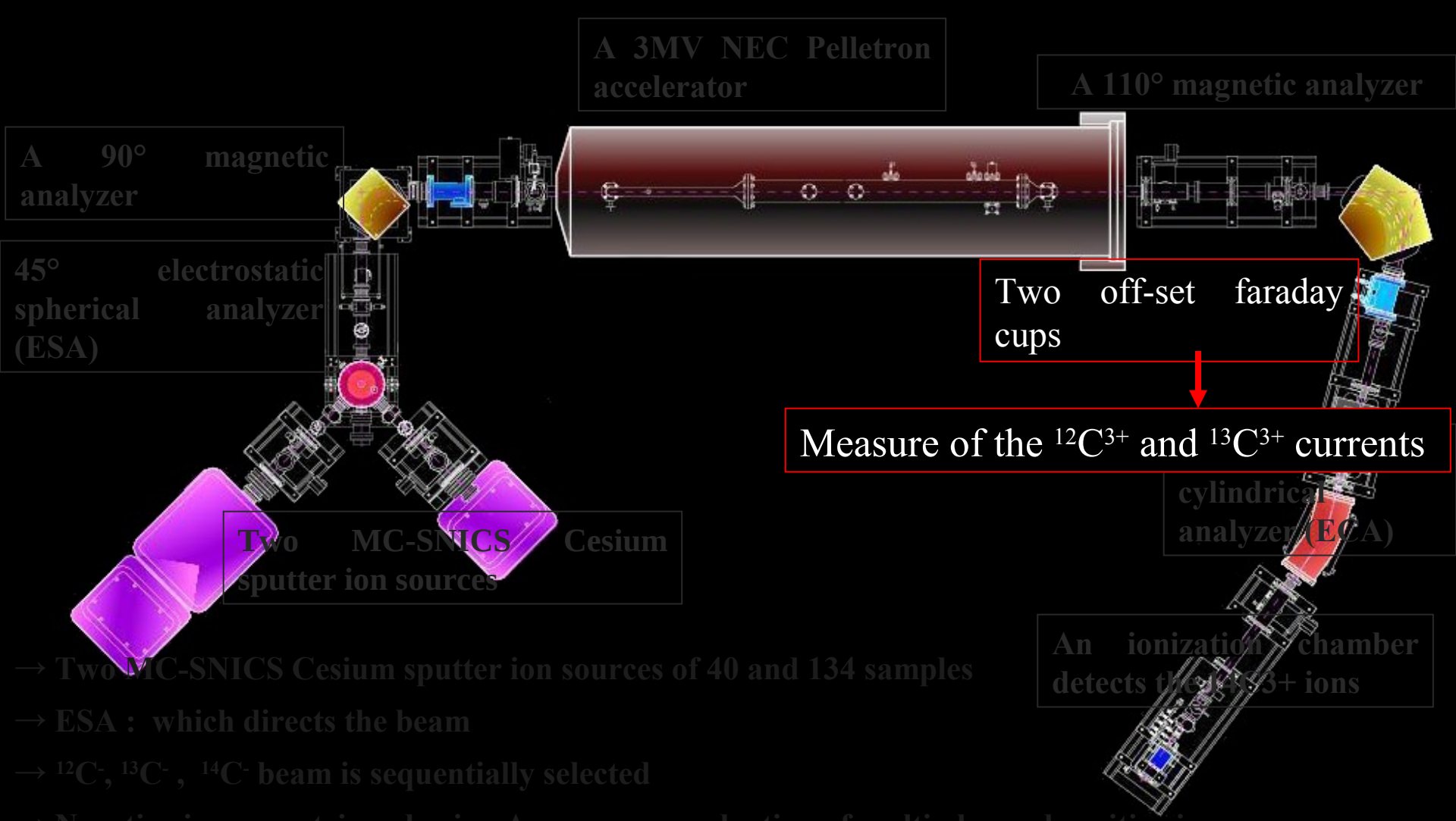

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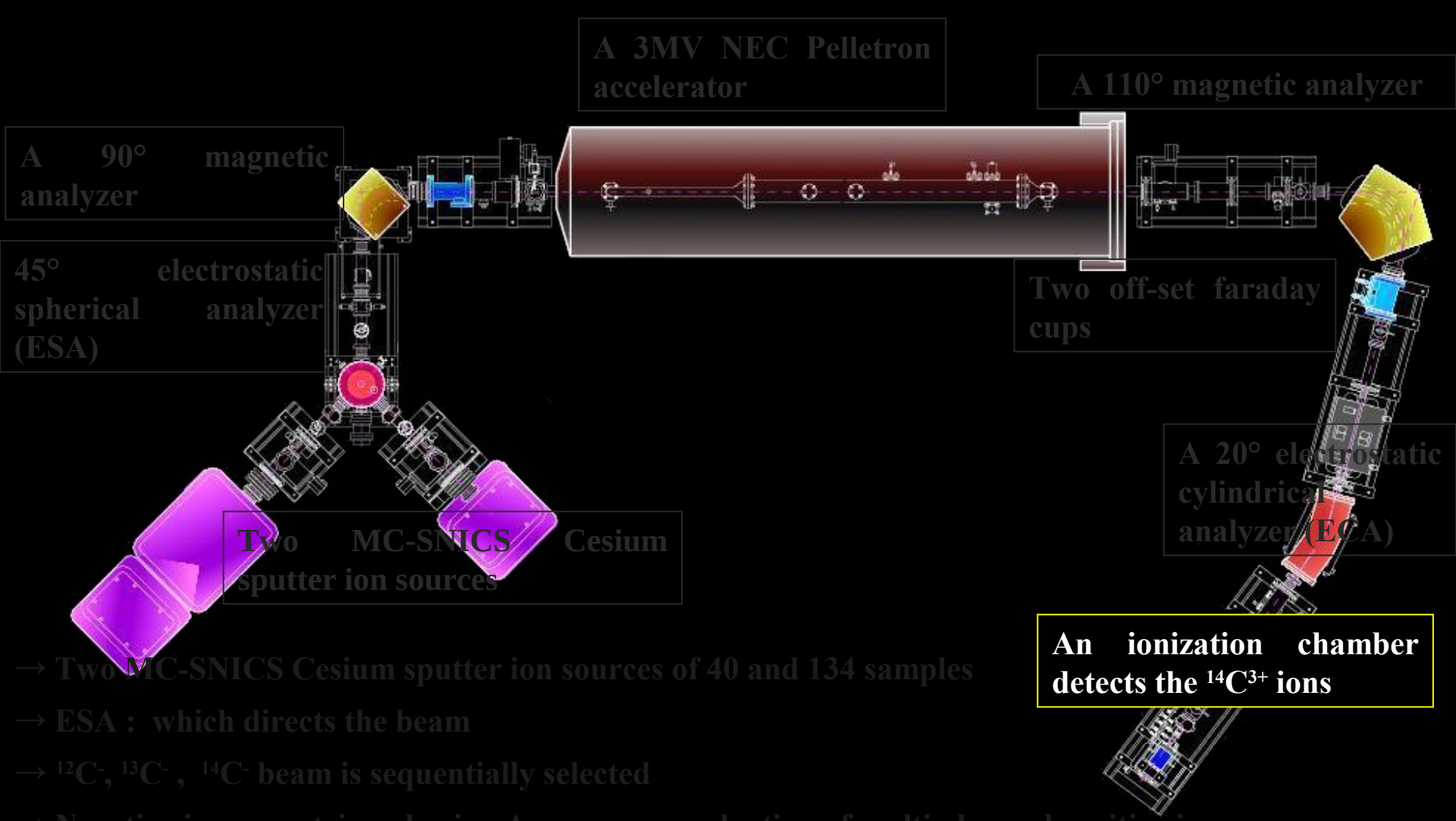

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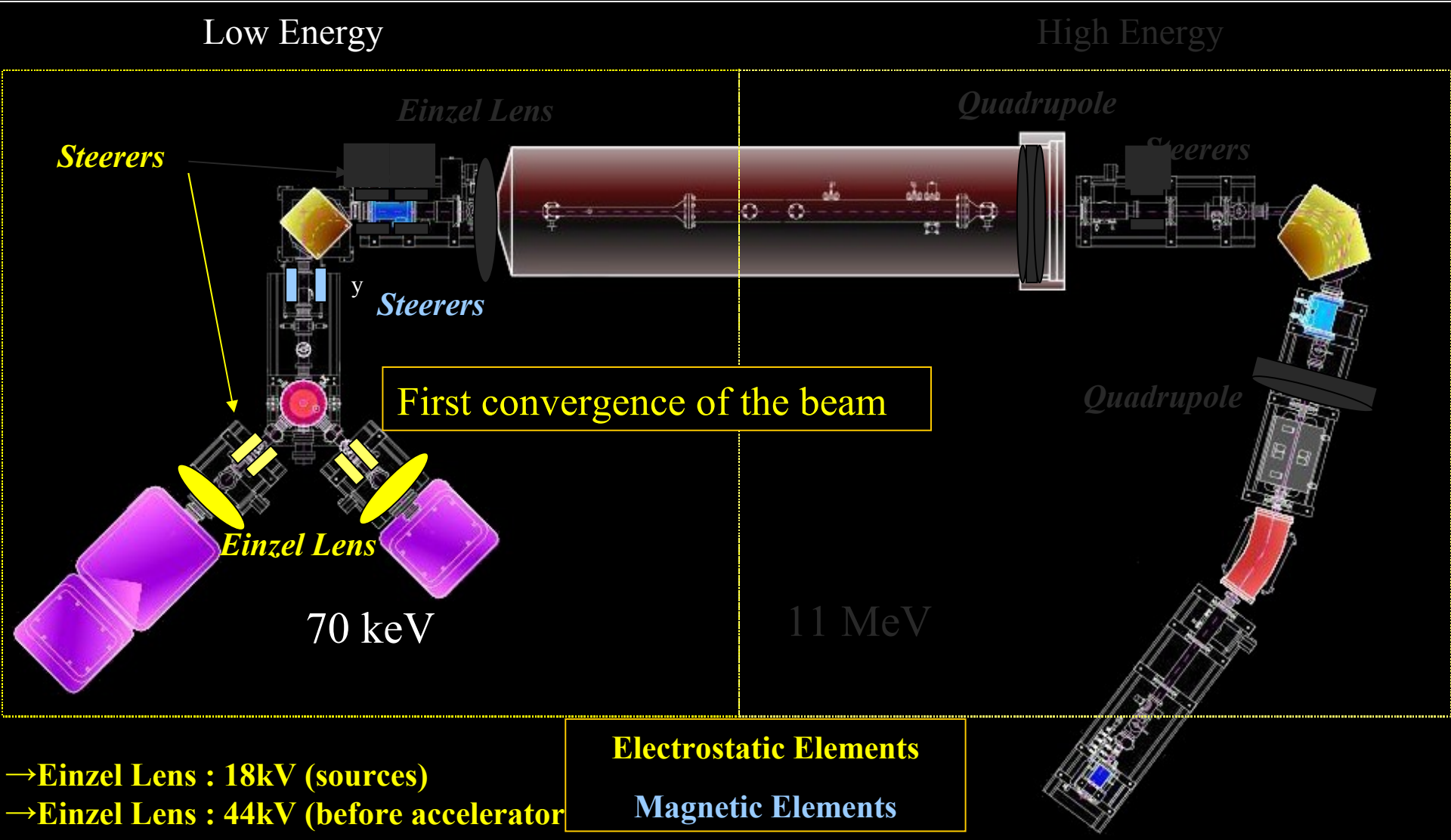
Optical Elements of the beam Line



Electrostatic Elements

Magnetic Elements

→Einzel Lens : 18kV (sources)

→Einzel Lens : 44kV (before accelerator

→Steerers (electrostatic and magnetic)

→Triplet Electrostatic Quadrupole

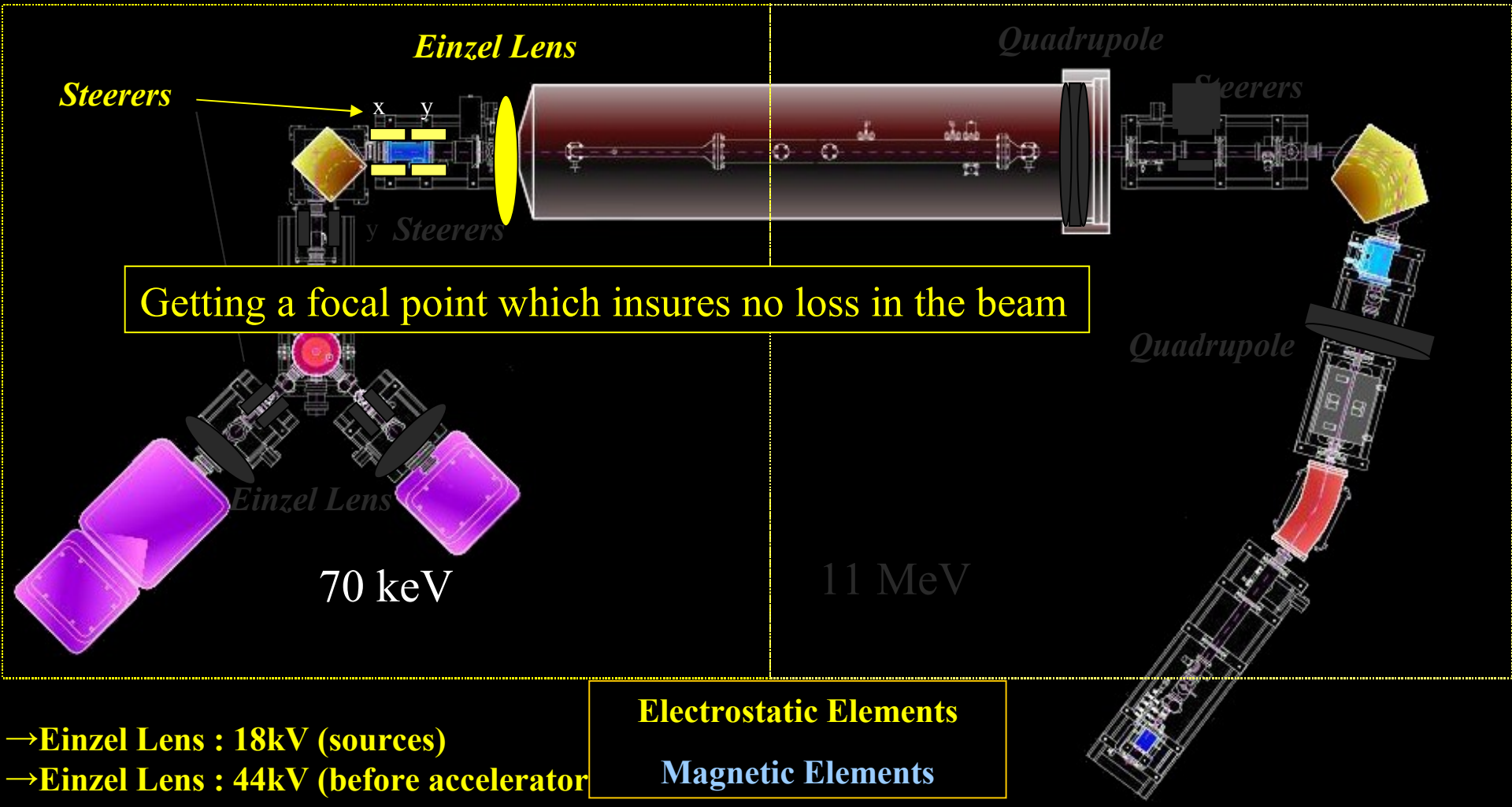
→Doublet Magnetic Quadrupole

→Steerer

Optical Elements of the beam Line

Low Energy

High Energy



Getting a focal point which insures no loss in the beam

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Optical Elements of the beam Line

Low Energy

High Energy

Getting a perfect focal point x-y for entering into the spectrometer

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Optical Elements of the beam Line

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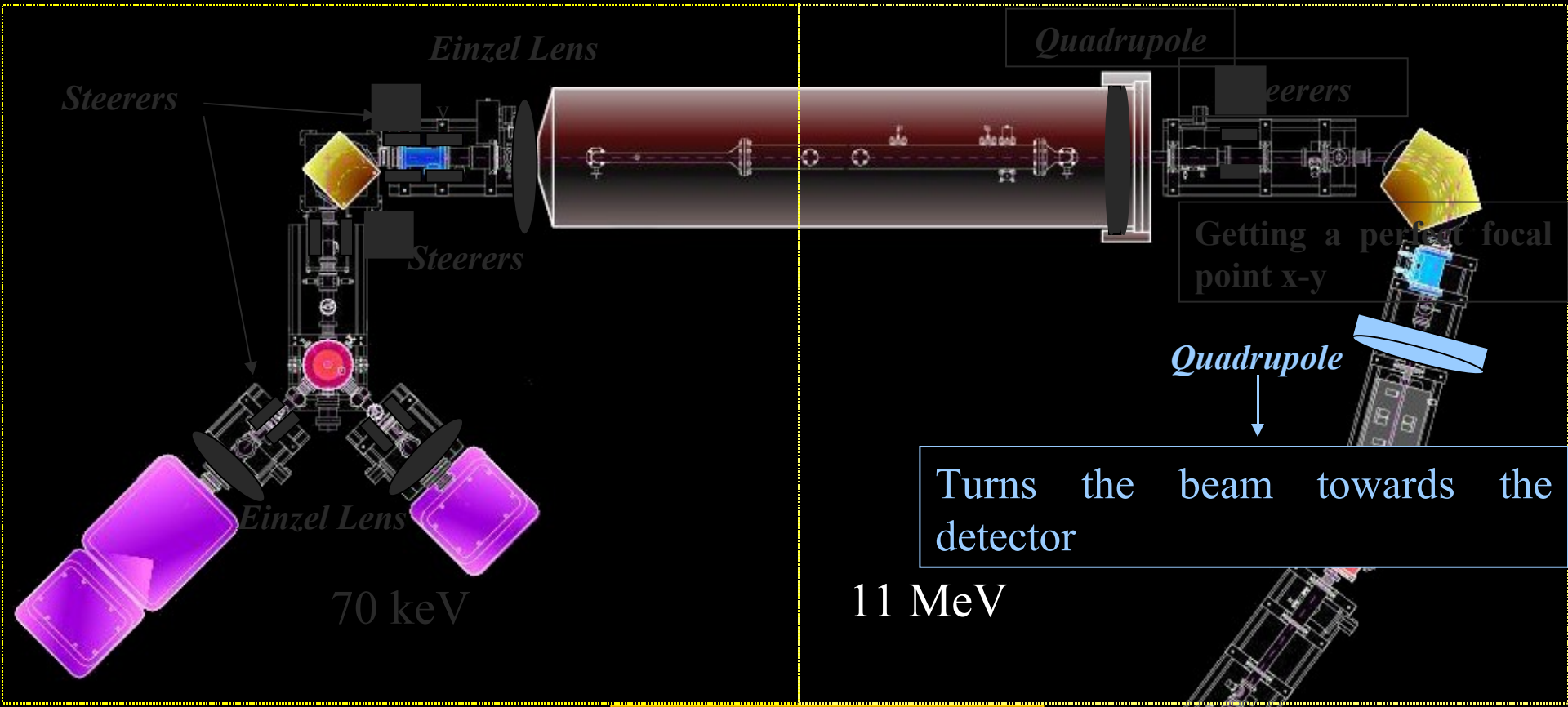

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TRANSPORT Tool

TRANSPORT Tool

TRANSPORT[1] program, first approach to

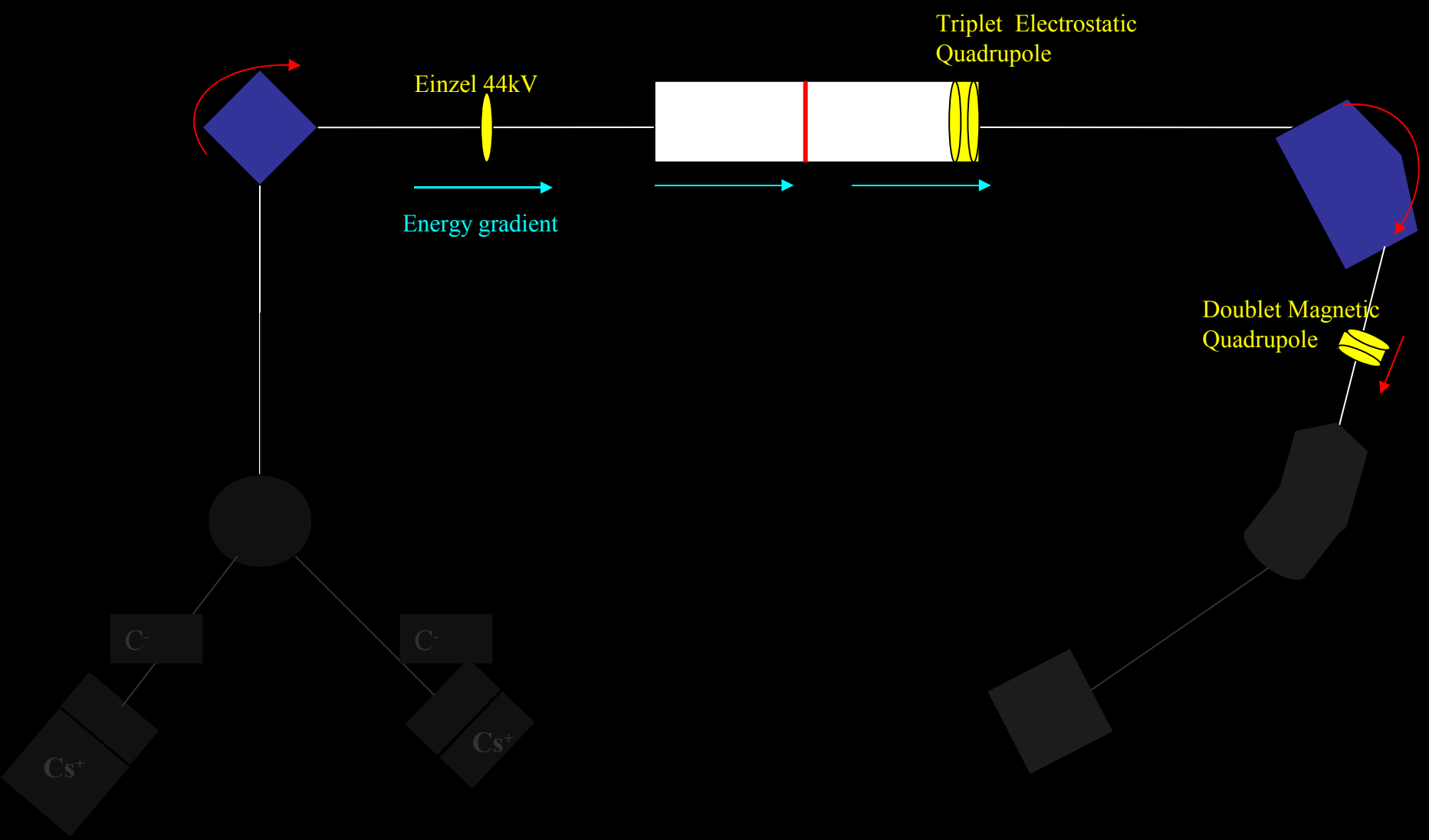
- ✓ *understand the design*
- ✓ *observe the behavior of electrostatic and magnetic elements.*

TRANSPORT calculates

- ✓ *transfer matrix*
- ✓ *beam matrix*
- ✓ *properties of the beam…*

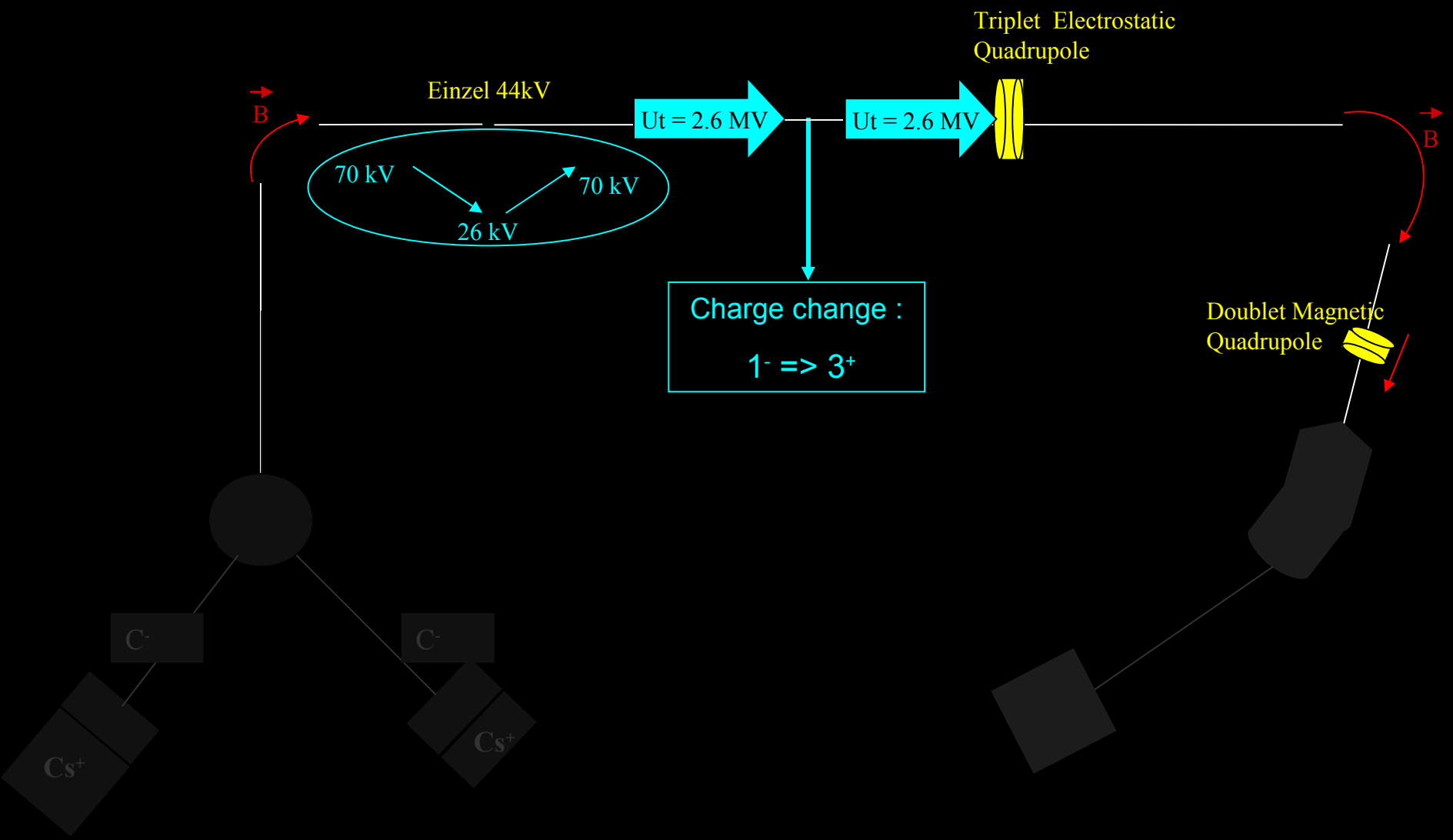
1 : PSI Graphic Transport Framework by U. Rohrer based on a CERN-SLAC-FERMILAB version by K.L. Brown et al

What was simulated by TRANSPORT tool ?



Optic elements | **Electrostatic field** | **Magnetic field**

How elements were simulated by TRANSPORT tool ?



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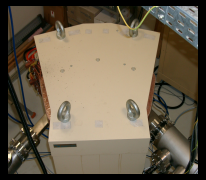
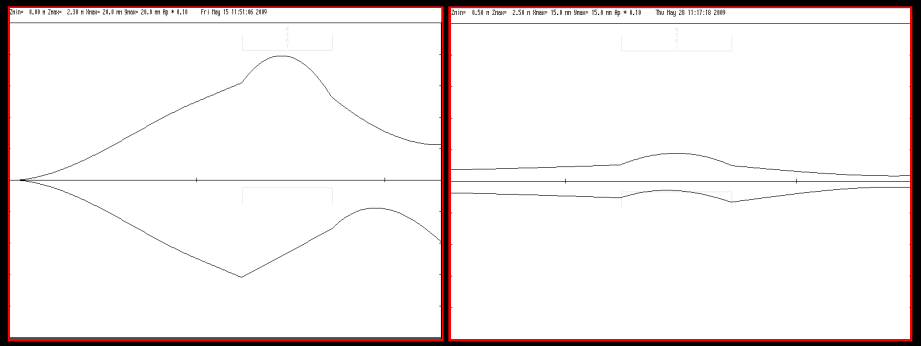
TRANSPORT Tool

Theorical Simulations

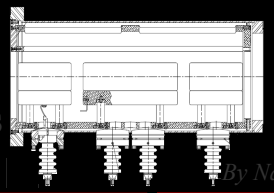


Experimental Simulations



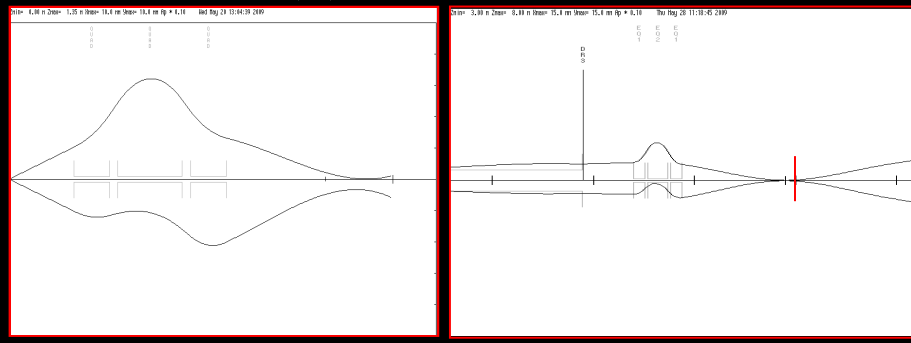
Bending magnet

Theorical Simulations



Experimental Simulations

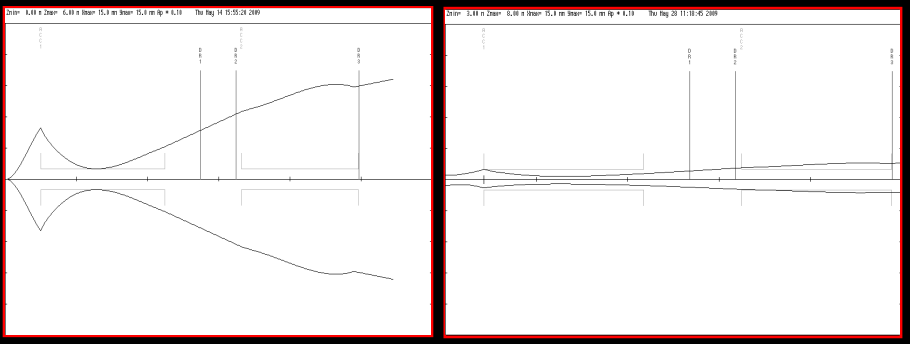
By National Electrostatic Corporoation²



Triplet electrostatic quadrupole

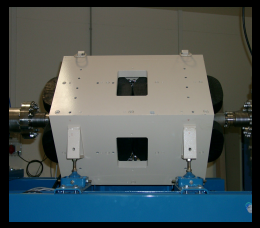
Theorical Simulations

Experimental Simulations



Two stage accelerator

Theorical Simulations



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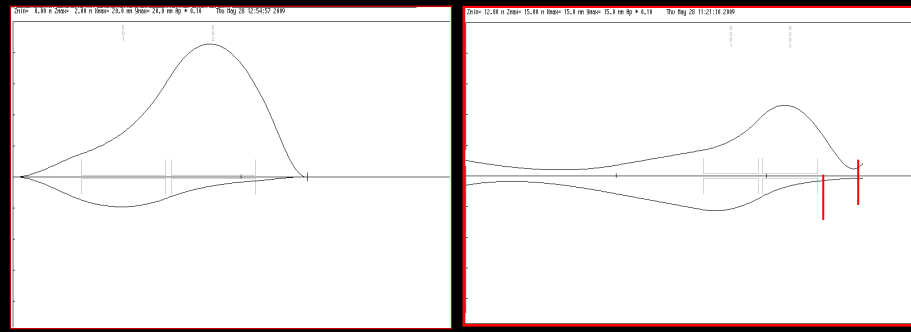
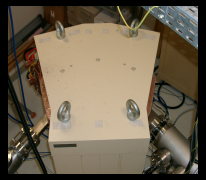


Doublet magnetic quadrupole

TRANSPORT Tool

Theorical Simulations



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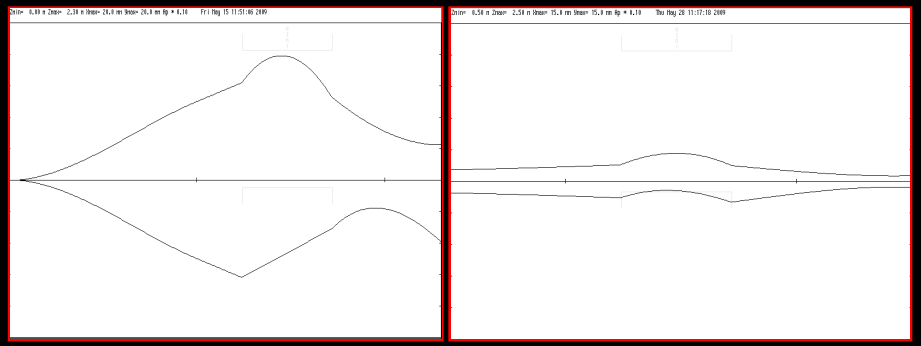

Bending magnet

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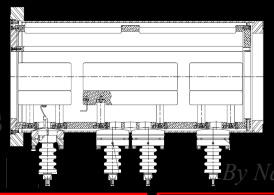

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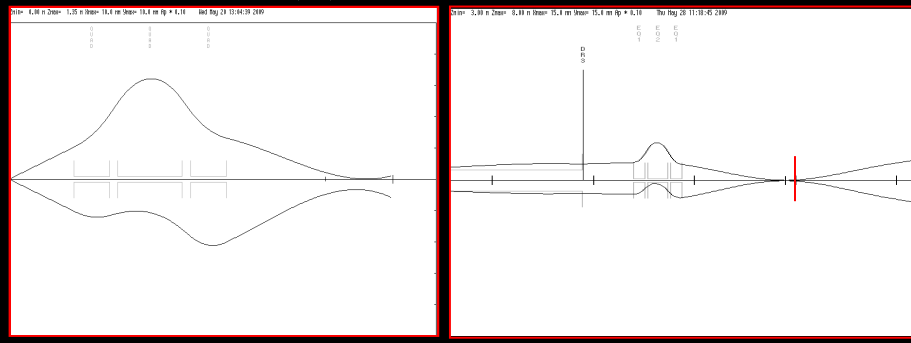
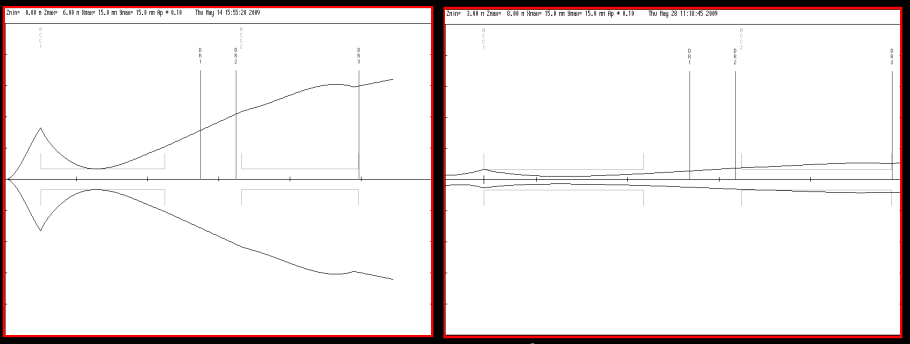


Triplet electrostatic quadrupole

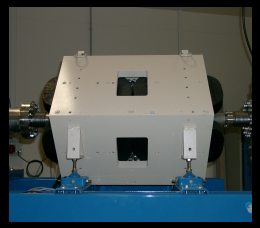
Theorical Simulations

Experimental Simulations



Two stage accelerator

Theorical Simulations



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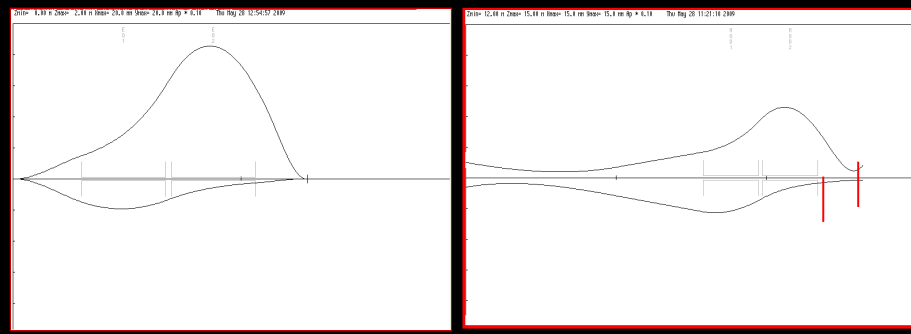
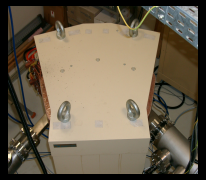


Doublet magnetic quadrupole

TRANSPORT Tool

Theorical Simulations



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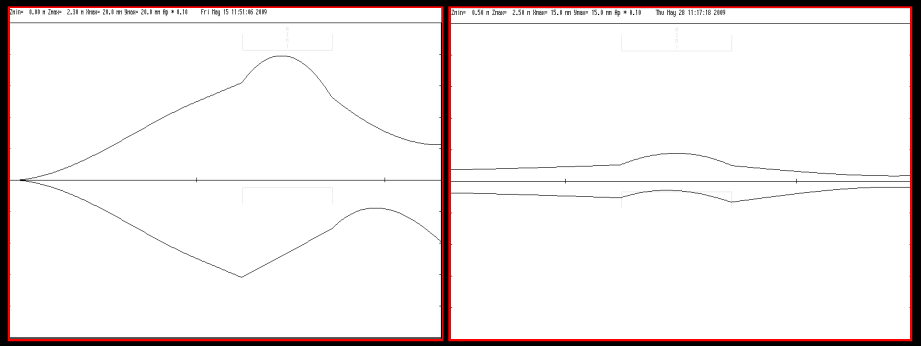

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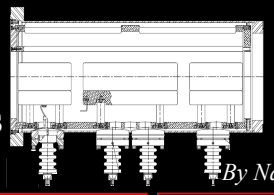

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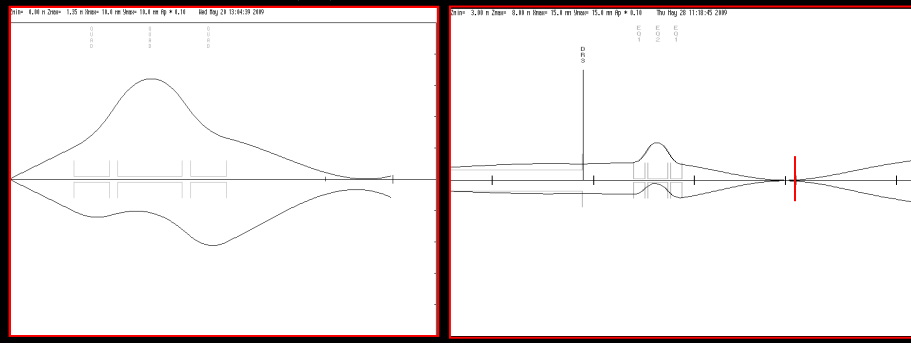

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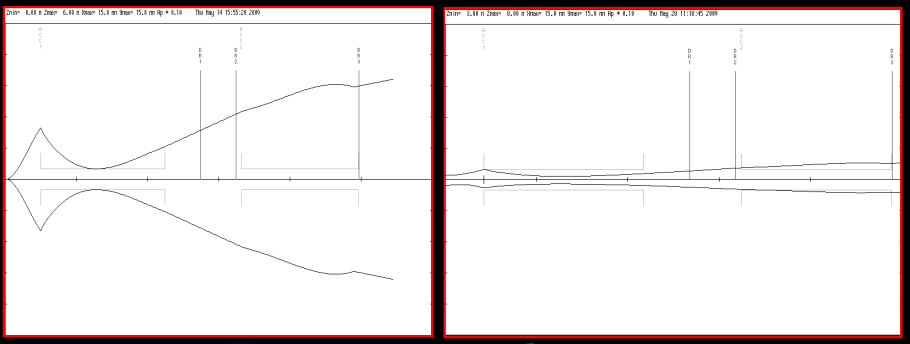

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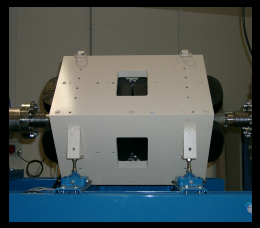

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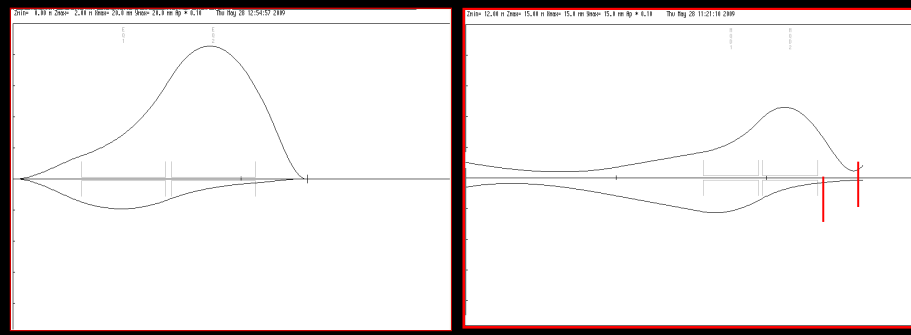
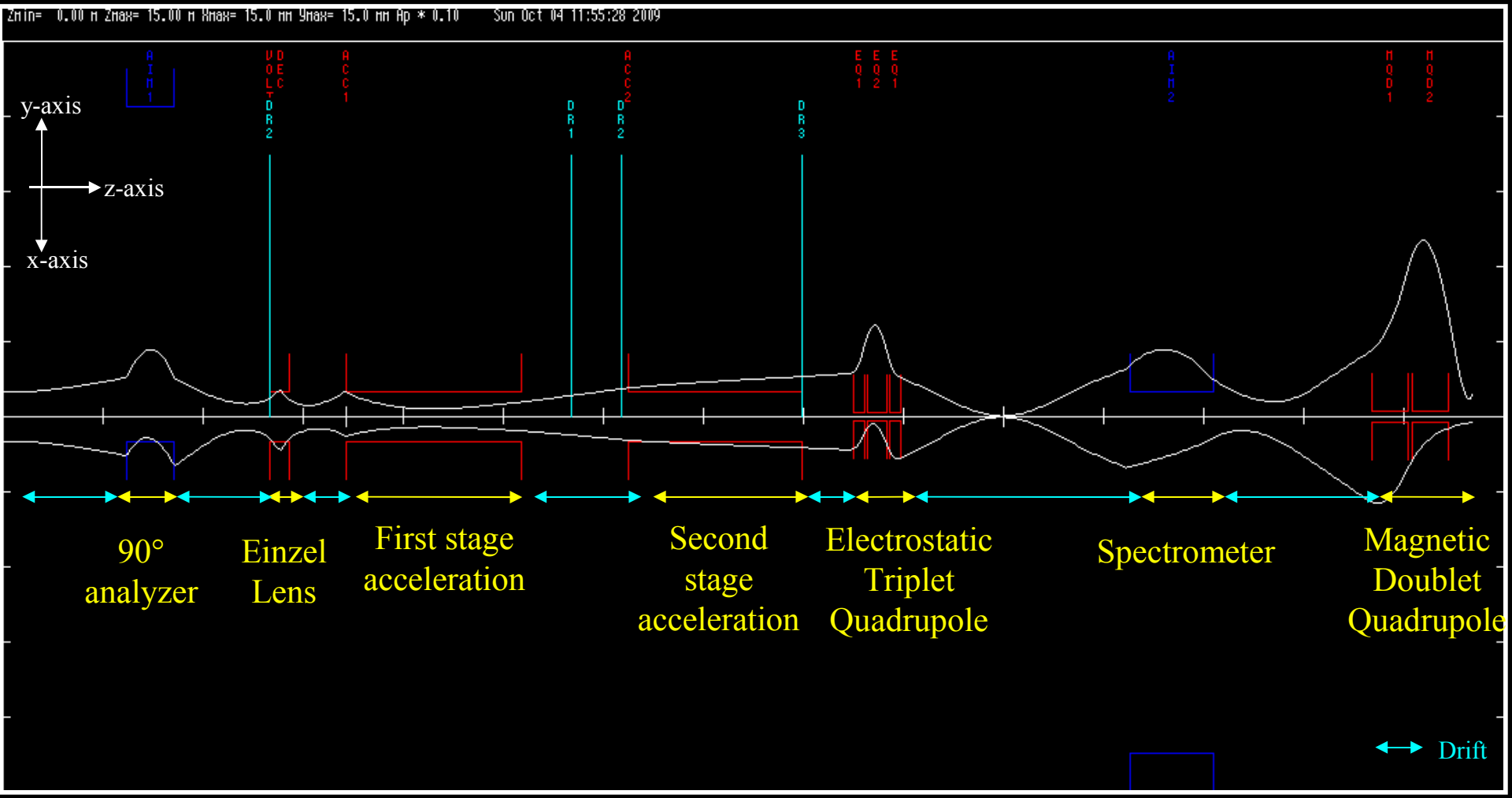


Doublet magnetic quadrupole

ARTEMIS beam emittance



First conclusions thanks to TRANSPORT Tool

- TRANSPORT gives a global view of the beam emittance :
  - Maximum spatial extend of the beam : magnetic quadrupole doublet
  - Focal point (minimum extent) between electrostatic quadrupole Triplet and Bending Magnet 110°

- TRANSPORT assets :
  - Great simulations of the quadrupole (magnetic and electrostatic)
  - Emittance behavior

- TRANSPORT limitations :
  - No good modeling for electrostatic elements such as Einzel lens or deflectors…
  - No physical processes taking into account (stripping, …)

GEANT4 ToolKit

Why using GEANT4 ToolKit ?

We are just at the beginning of the project !!!

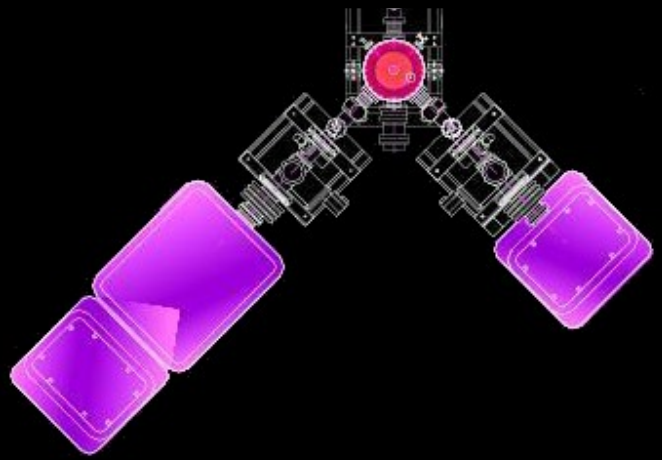
✓ Detecting if there are recombinations (^{13}CH, ^{12}CH, $^{12}CH_2$) and in which abundance

✓ Choosing the most relevant detector

✓ Predicting and controlling the settings of ARTEMIS facility

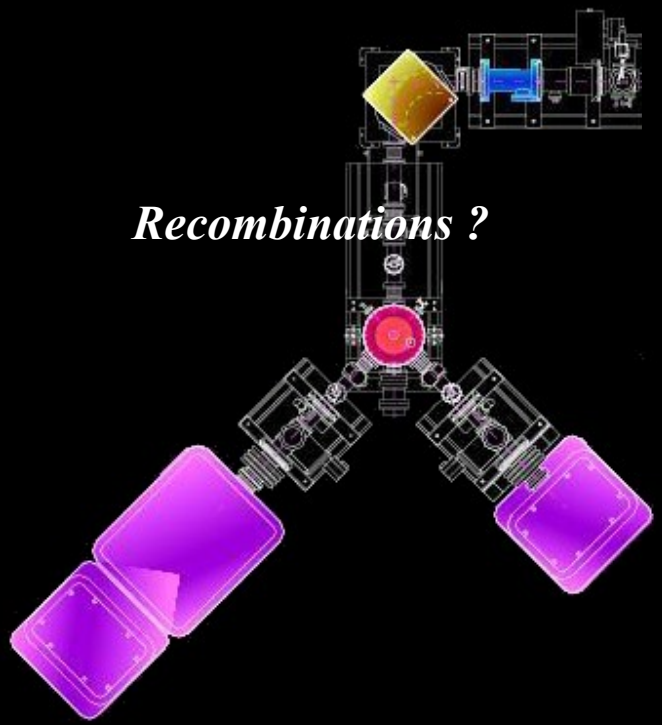
Physics Lists : particles and processes

$^{12}C^{-}$, $^{13}C^{-}$, $^{14}C^{-}$ → $^{12}C^{-}$, $^{13}C^{-}$, $^{12}CH^{-}$, $^{14}C^{-}$, $^{13}CH^{-}$, $^{12}CH^{2-}$ → $^{12}C^{n+}$, $^{13}C^{n+}$, ….n = 1,2,3,4 …. , $^{14}C^{n+}$ → $^{12}C^{3+}$, $^{13}C^{3+}$, $^{14}C^{3+}$ → $^{14}C^{3+}$



Physics Lists : particles and processes

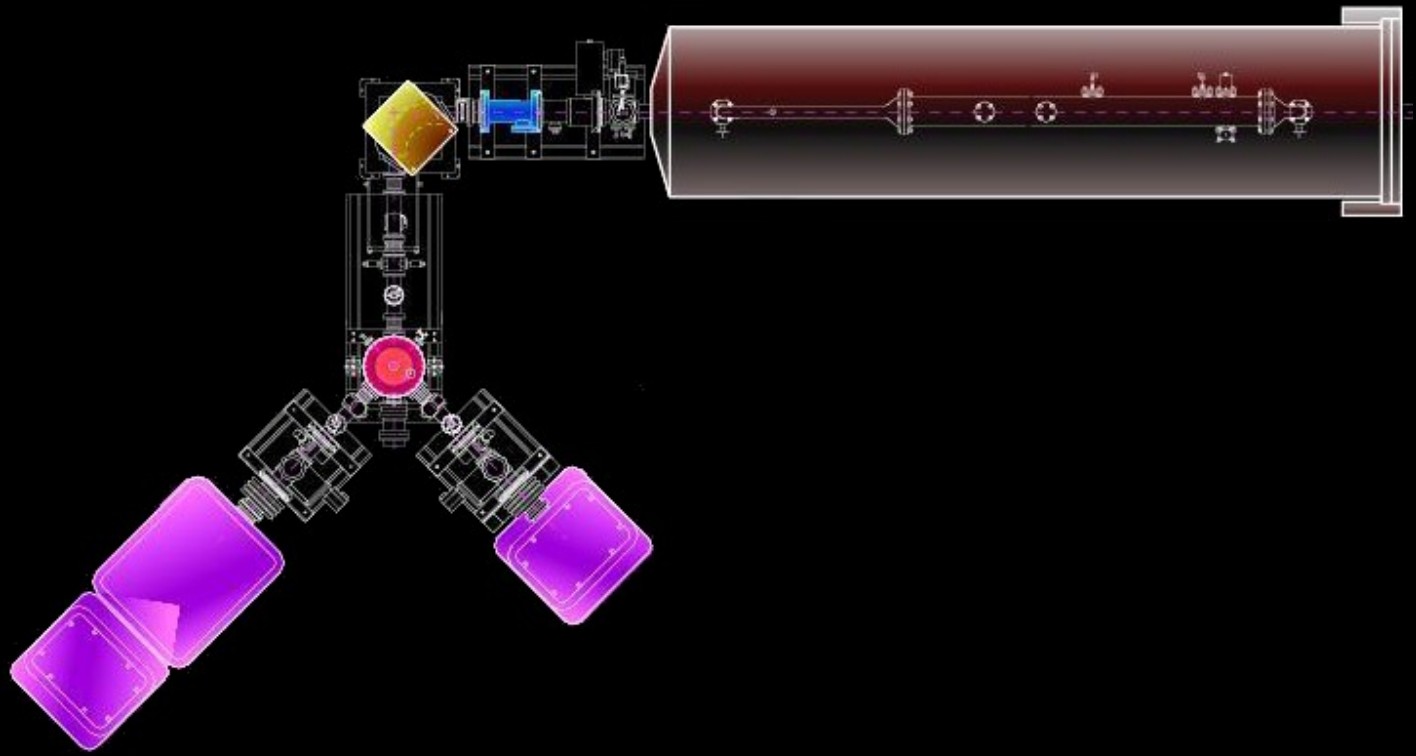
$^{12}C^-$, $^{13}C^-$, $^{14}C^-$ → $^{12}C^-$, $^{13}C^-$, $^{12}CH^-$, $^{14}C^-$, $^{13}CH^-$, $^{12}CH_2^-$ → $^{12}C^{n+}$, $^{13}C^{n+}$, ….n = 1,2,3,4 …., $^{14}C^{n+}$ → $^{12}C^{3+}$, $^{13}C^{3+}$, $^{14}C^{3+}$ → $^{14}C^{3+}$



Recombinations ?

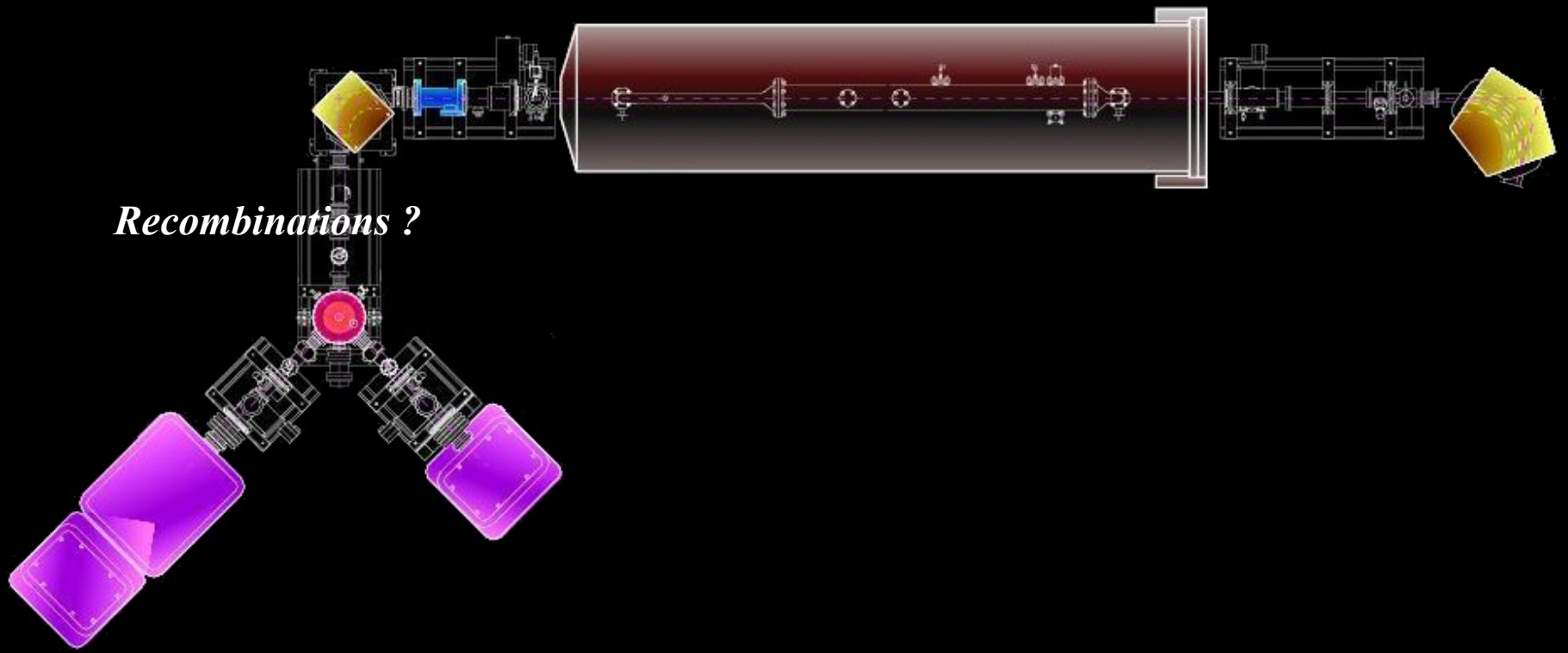
Physics Lists : particles and processes

$^{12}C^{-}$, $^{13}C^{-}$, $^{14}C^{-}$ → $^{12}C^{-}$, $^{13}C^{-}$, $^{12}CH^{-}$, $^{14}C^{-}$, $^{13}CH^{-}$, $^{12}CH^{2-}$ → $^{12}C^{n+}$, $^{13}C^{n+}$, ….n = 1,2,3,4 …. $^{14}C^{n+}$ → $^{12}C^{3+}$, $^{13}C^{3+}$, $^{14}C^{3+}$ → $^{14}C^{3+}$



Physics Lists : particles and processes

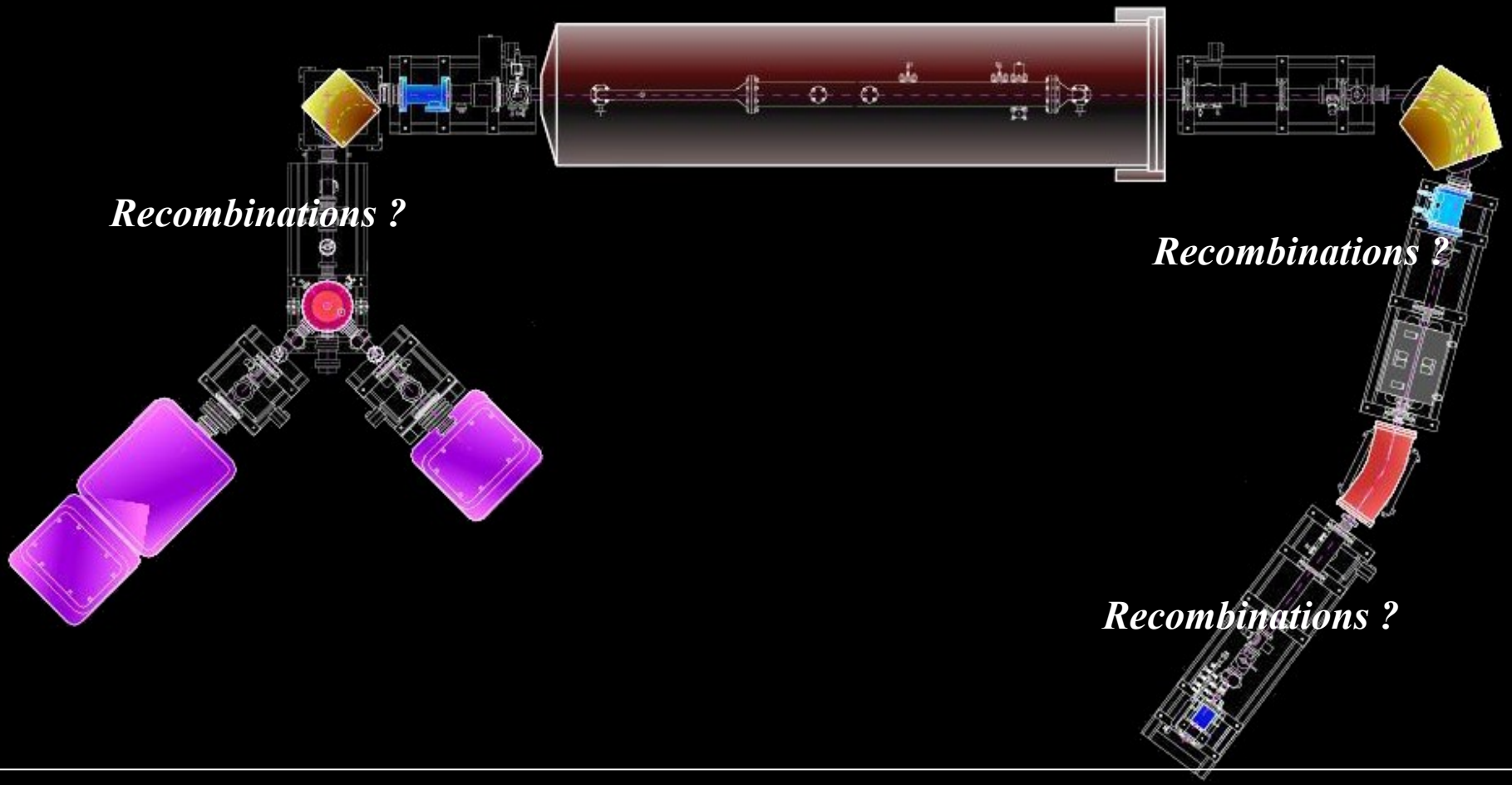
$^{12}C^{-}$, $^{13}C^{-}$, $^{14}C^{-}$ → $^{12}C^{-}$, $^{13}C^{-}$, $^{12}CH^{-}$, $^{14}C^{-}$, $^{13}CH^{-}$, $^{12}CH^{2-}$ → $^{12}C^{n+}$, $^{13}C^{n+}$, ….n = 1,2,3,4 …. $^{14}C^{n+}$ → $^{12}C^{3+}$, $^{13}C^{3+}$, $^{14}C^{3+}$ → $^{14}C^{3+}$



Recombinations ?

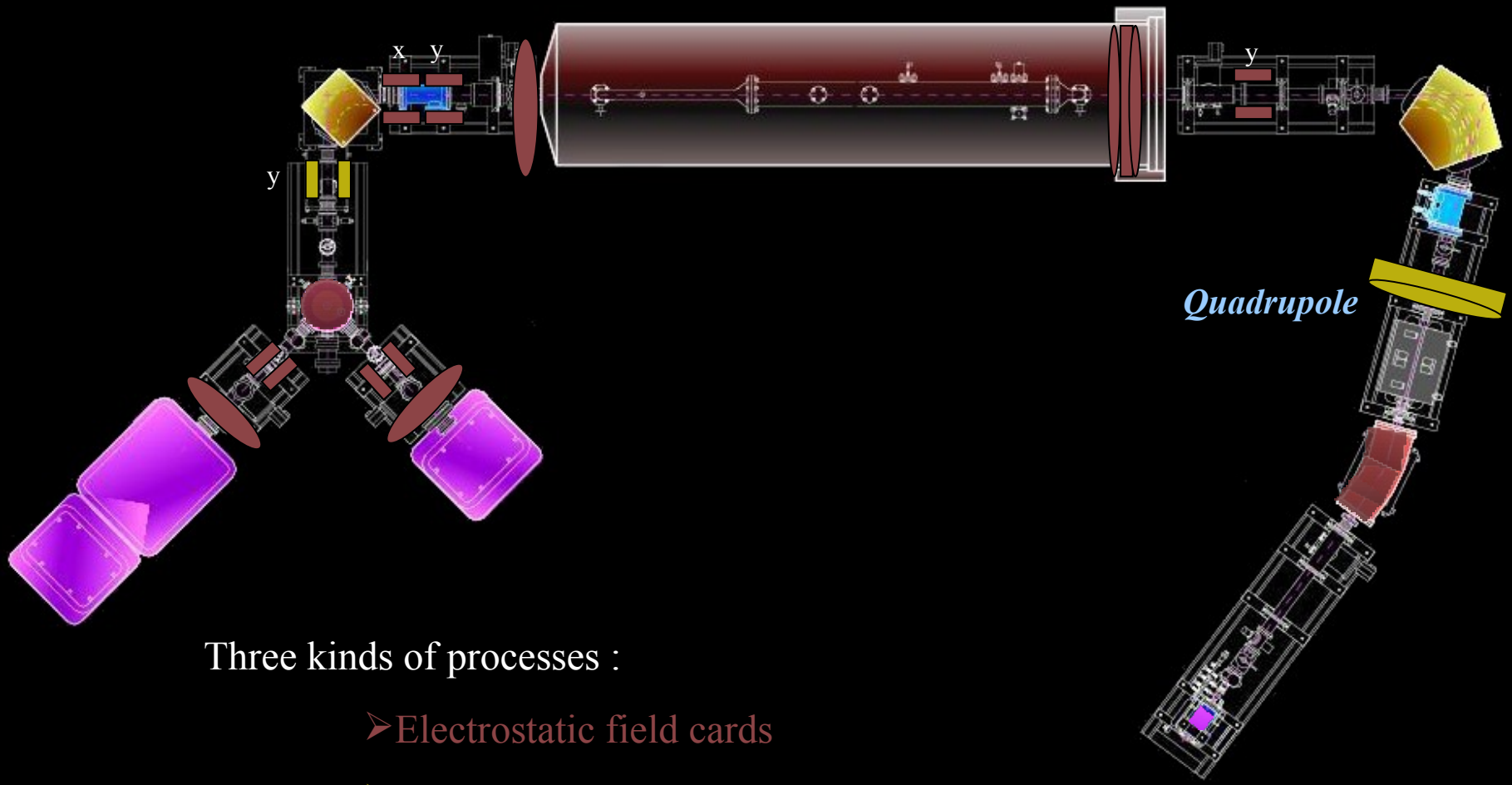
Particles and processes

$^{12}C^{-}$, $^{13}C^{-}$, $^{14}C^{-}$ → $^{12}C^{-}$, $^{13}C^{-}$, $^{12}CH^{-}$, $^{14}C^{-}$, $^{13}CH^{-}$, $^{12}CH^{2-}$ → $^{12}C^{3+}$, $^{13}C^{3+}$, $^{14}C^{3+}$… $^{12}C^{2+}$, $^{13}C^{2+}$, $^{14}C^{2+}$… $^{12}C^{+}$, $^{13}C^{+}$, $^{14}C^{+}$… → $^{12}C^{3+}$, $^{13}C^{3+}$, $^{14}C^{3+}$ → **$^{14}C^{3+}$**



Particles and processes

Electrostatic elements | **Magnetic elements** | **Ionization process**



Three kinds of processes :

- Electrostatic field cards
- Magnetic field cards => getting field cards?
- Ionization processes

GEANT4 Simulation of the beam Line

So, the ARTEMIS facility simulation requires:

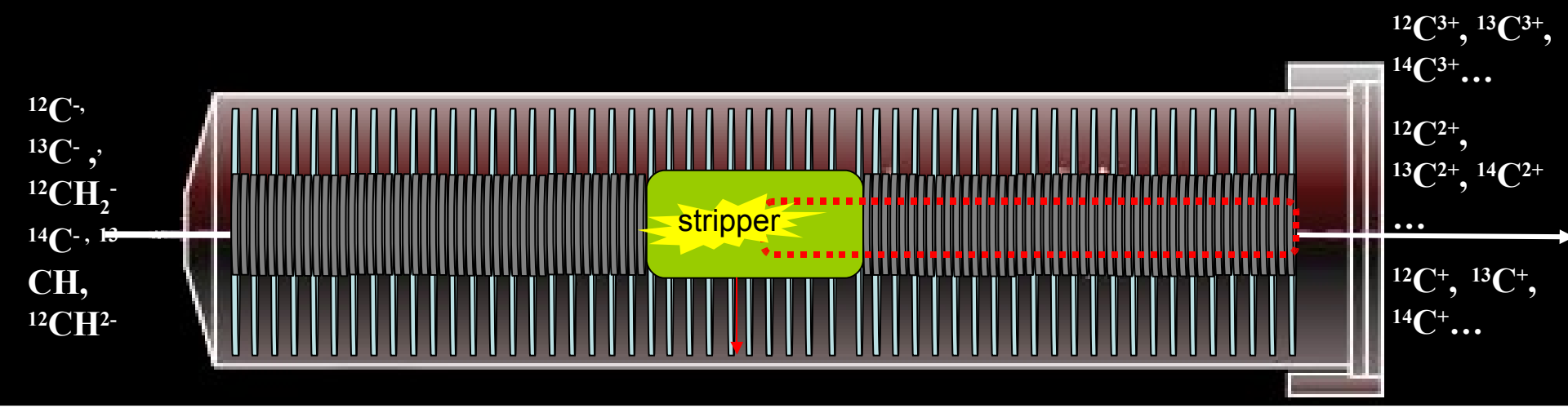
- ✓ Create $^{14}C^{-}$, $^{14}C^{3+}$, $^{13}C^{-}$, $^{13}C^{3+}$, $^{12}C^{-}$, $^{12}C^{3+}$ ions
- ✓ Get field cards :
  - ➢ Magnetic ones for : magnet, quadrupoles, steerers
  - ➢ Electrostatic ?(deflectors, quadrupoles, steerers, accelerator)
- ✓ Ionization processes
- ✓ Specifical application for detectors: choose the most relevant one

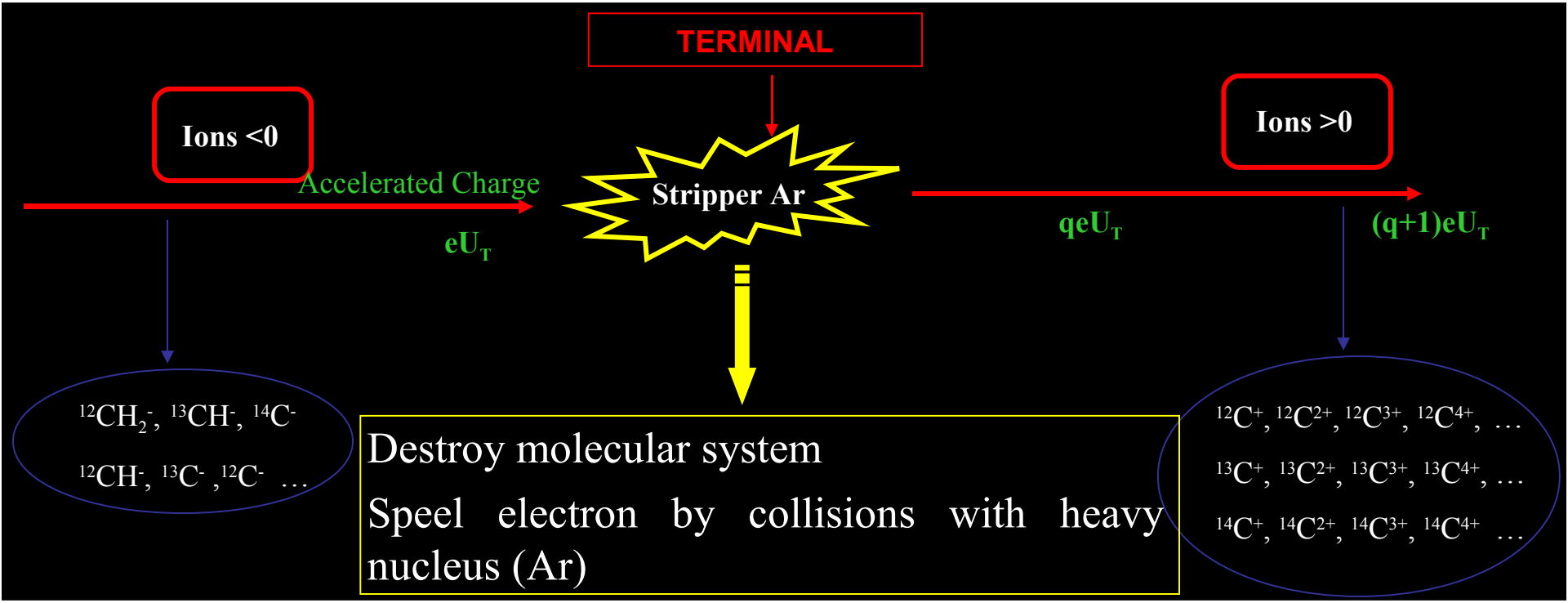
Technical questions …

Identication of difficult points for the simulation:

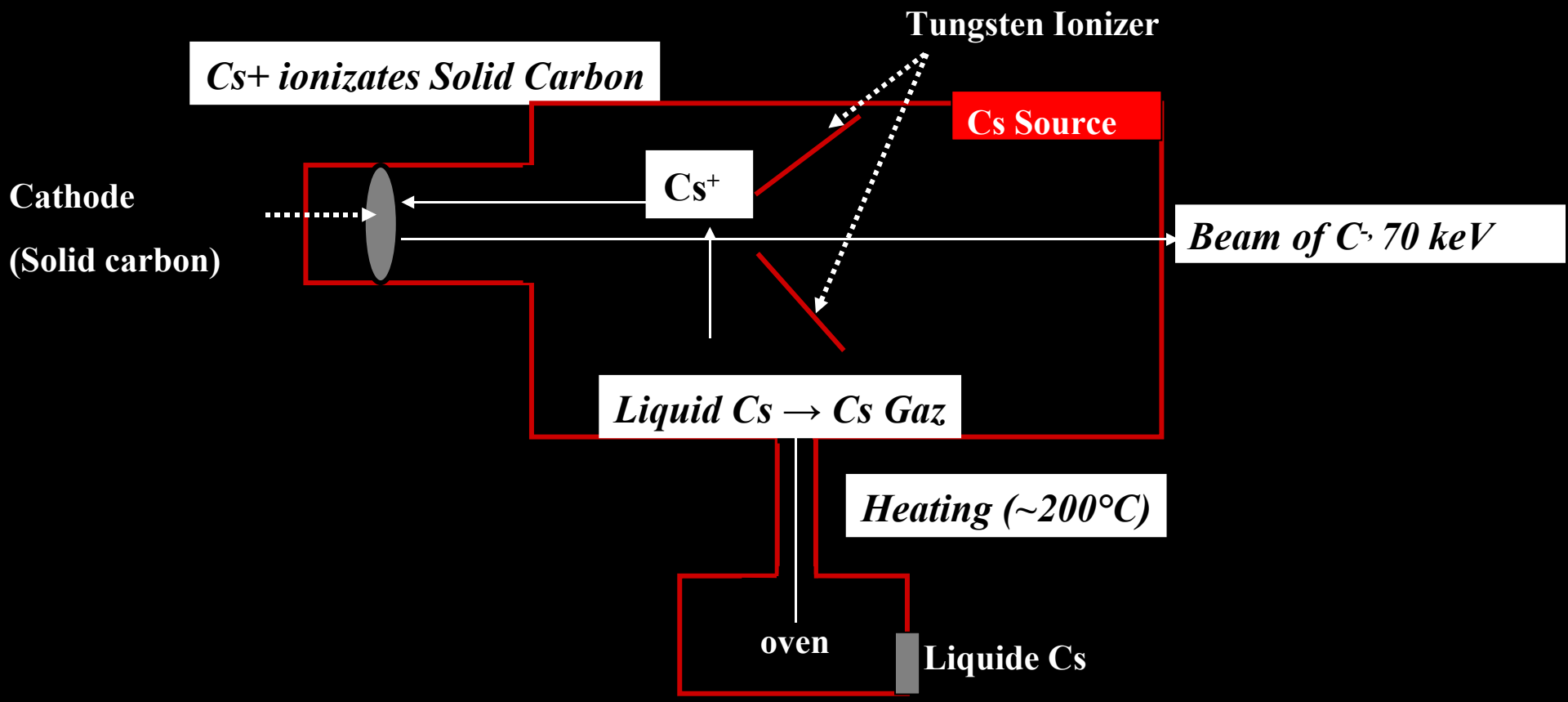
- ✓ How to simulate the stripping process?
- ✓ How to simulate the Cs Sources?
- ✓ How can we get and use field card for the magnetic elements.

How to simulate the stripping process ?





Do we need and how to simulate the Cs Sources ?



Physical Processes : *heating (oven at about 200°C)*

Cs vaporization (state change)

Cs Ionization to get Cs^+

C ionization to get C^-

CONCLUSION

- First step of the project:

  TRANSPORT Tool => get emittance behavior of the beam

- Second Step of the Project: GEANT4 Toolkit

  ✓ Aims

  - ❖ Detecting if there are recombinations
  - ❖ Choosing the most adapted detector
  - ❖ Predicting and controlling the settings of ARTEMIS facility

  ✓ Difficulties meeting with:

  - ❖ Cs Sources
  - ❖ Stripping process
  - ❖ Accelerator

Thank you for your attention!

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