Tracking at the LAND/R^{3}B setup on the example of ^{17}Ne(γ,2p)^{15}O

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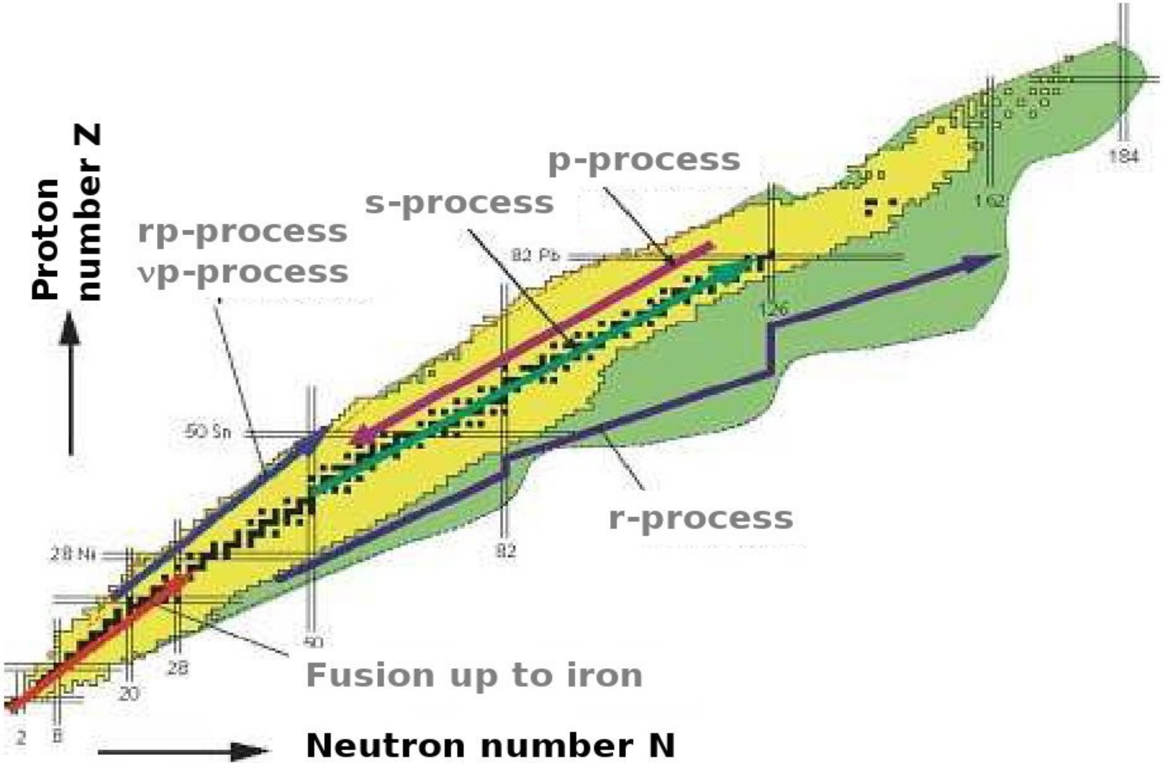
Dedicated to the students of LAND/R^{3}B

Outline

- rp process and motivation
- coulomb dissociation as a source of information on
- experimental setup
- data analysis / tracking
- results
- summary

rp process

- neutron star in binary systems (X-ray bursts)
- sequence of proton captures and β^+ decays (=> waiting points)



Motivation

1. the nucleus ^{15}O is a waiting point for the **break-out** of the CNO cycle

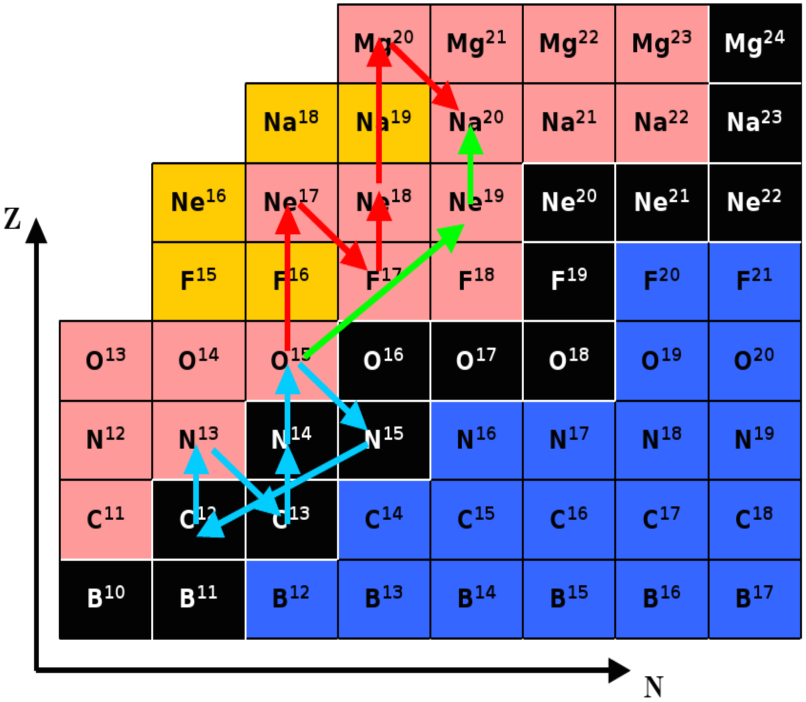
CNO cycle:

$^{12}C(p,\gamma)^{13}N(EC)^{13}C(p,\gamma)^{14}N(p,\gamma)^{15}O(EC)^{15}N(p,\alpha)^{12}C$

Heavier elements: $^{15}O(\alpha,\gamma)^{19}Ne(p,\gamma)^{20}Na$

Alternative reaction: $^{15}O(2p,\gamma)^{17}Ne(\beta^+)^{17}F(p,\gamma)^{18}Ne(2p,\gamma)^{20}Mg(\beta^+)^{20}Na$

2. the reaction rate can be enhanced by a few orders of magnitude by taking into account the three-body continuum states;

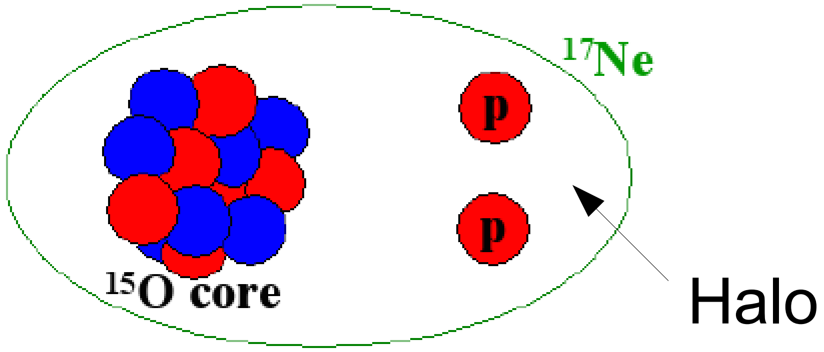


^{17}Ne ground state

The uncertain part => the configuration of the two protons outside the ^{15}O core, which occupy either *s*-wave ($[s^2]$) or *d*-wave ($[d^2]$) orbitals

$$\Psi_{g.s.} \sim \alpha[s^2] + \beta[d^2]$$

$[s^2]$ – dominant

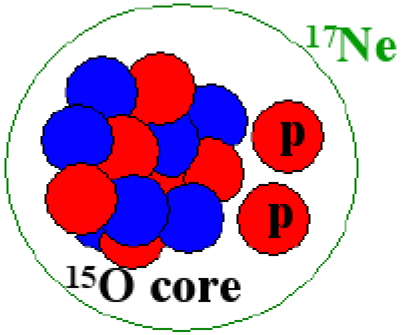


large σ_{CD}

↓

large $\sigma_{(2p,\gamma)}$

$[d^2]$ – dominant



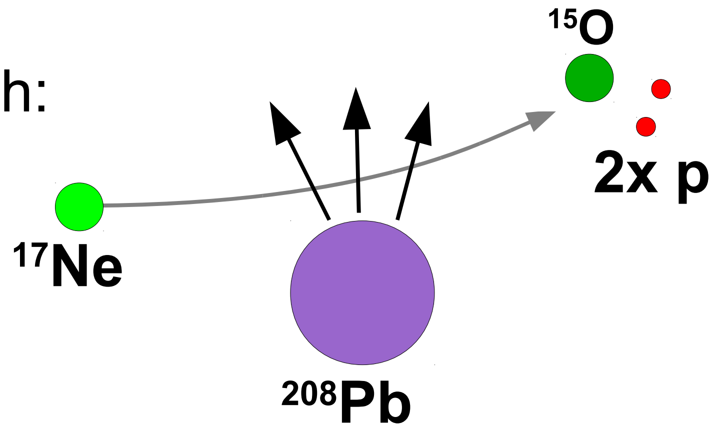
small σ_{CD}

↓

small $\sigma_{(2p,\gamma)}$

Coulomb dissociation as a source of information on radiative capture processes

Useful to measure radiative-capture reactions with:
- small cross sections;
- unstable nuclei;
- **three particles** in entrance channel.



b+c $\rightarrow$ a + γ => γ + a $\rightarrow$ b +c (time-reversed process)

the nuclear Coulomb field => a source of the photodisintegration processes

a+Z $\rightarrow$ b+c+Z

$$\frac{d\sigma_{\mathrm{CD}}}{dE_\gamma} = \frac{1}{E_\gamma} n \sigma_{(\gamma,b)}$$

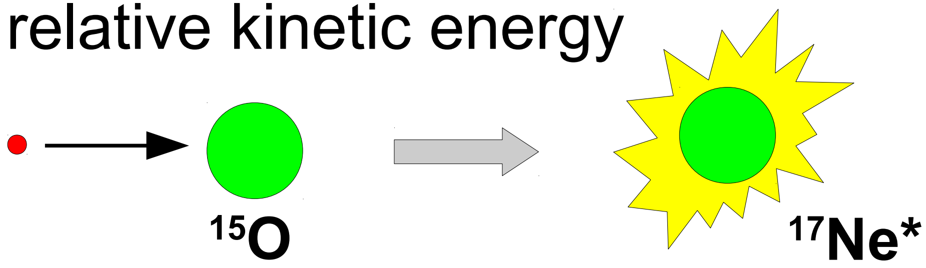
$\longleftarrow$ **virtual photon theory**

detailed balance theorem $\longrightarrow$

$$\sigma_{(b,\gamma)} = \frac{2(2j_a+1)}{(2j_b+1)(2j_c+1)} \frac{k_\gamma^2}{k^2} \sigma_{(\gamma,b)}$$

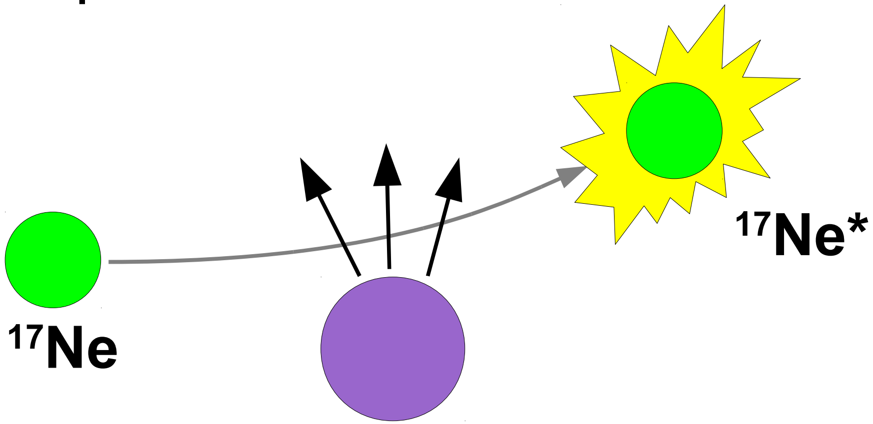
How to obtain XS vs energy?

Standard experiments:
Projectile (e.g. proton) is shot on core at rest.
Excitation energy = Q-Value + relative kinetic energy



Coulomb dissociation:
Excitation energy (relative kinetic energy) can be reconstructed if momentum vectors of all involved particles are known.

=> Kinematically complete measurement necessary!



Coulomb dissociation as a source of information on radiative capture processes

Advantages:

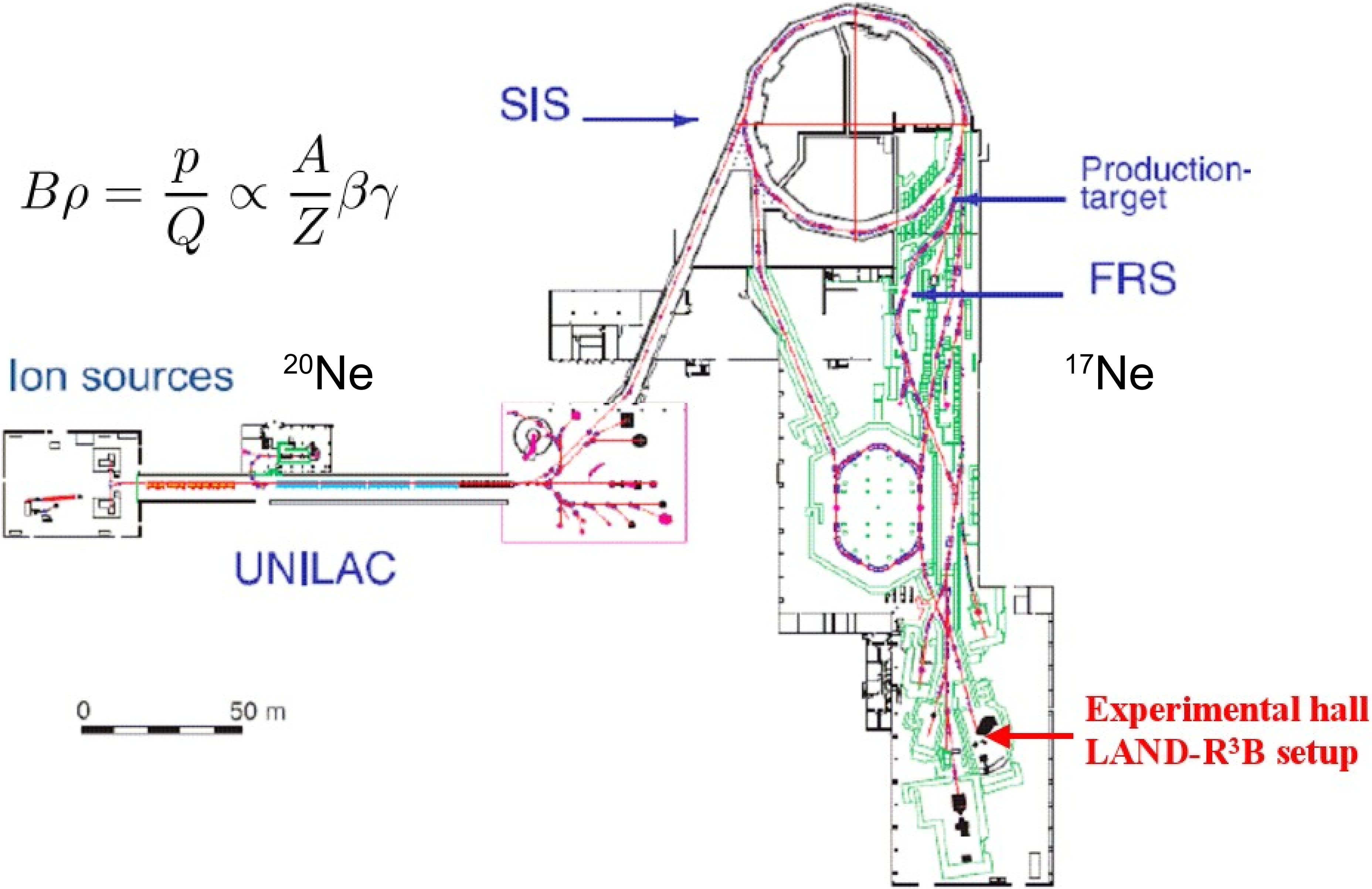
- high virtual photon flux;
- large cross section at low E_{cm};
- charged particle detection;
- kinematically focused;
- experiments with radioactive ion beams possible.

Disadvantages:

- indirect method;
- bad energy resolution;
- multipole admixtures must be disentangled;
- nuclear contributions.

Production of exotic beams

$$B\rho = \frac{p}{Q} \propto \frac{A}{Z}\beta\gamma$$



SIS

Production-target

FRS

Ion sources

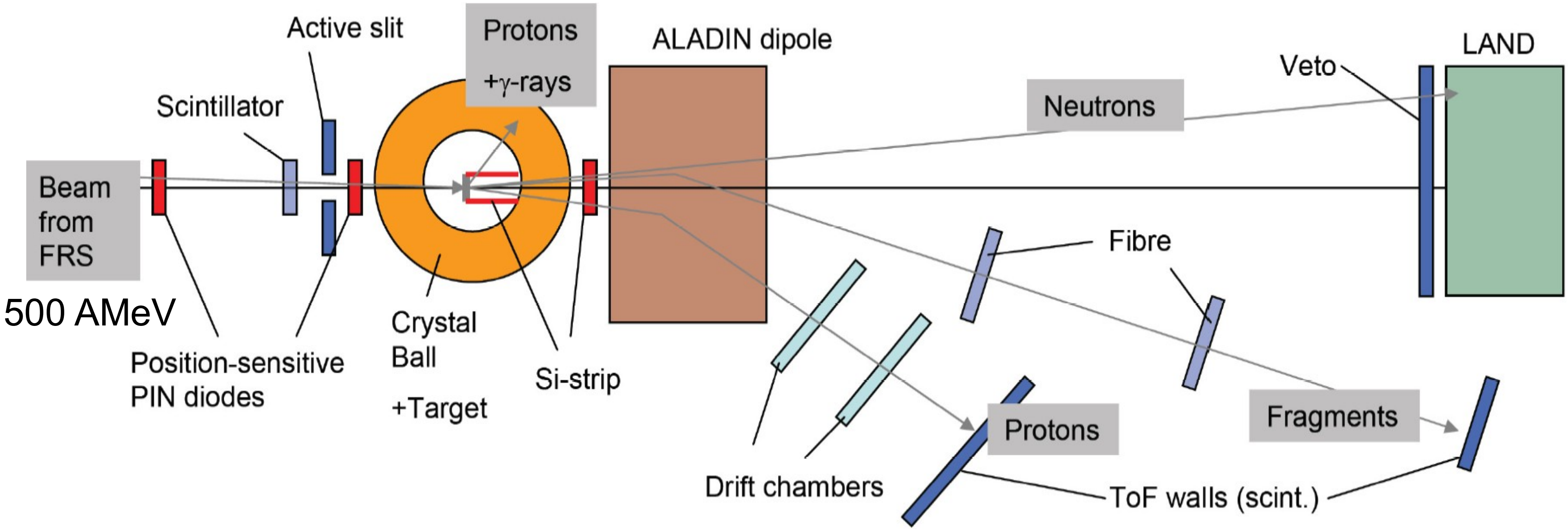
^{20}Ne

^{17}Ne

UNILAC

Experimental hall LAND-R^{3}B setup

LAND setup



To-Do-List for a kinematically complete measurement of a reaction:

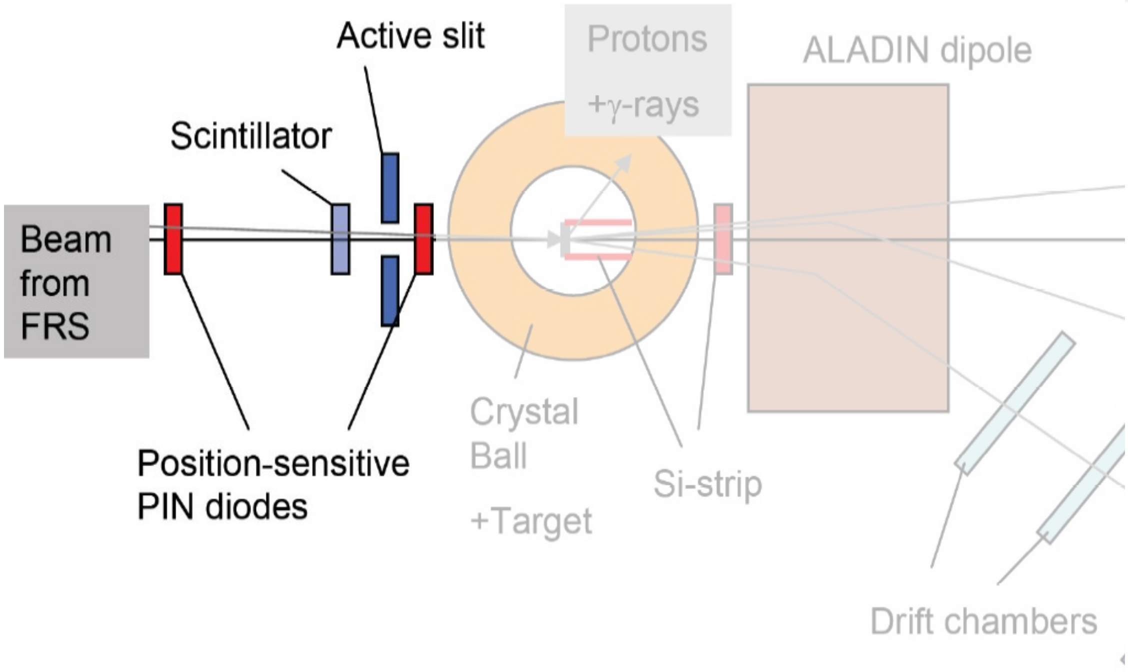
- identification and momentum vector of each ion before reaction
- identification and momentum vector of each ion after reaction
- momentum vector of emitted protons, neutrons, gammas, …

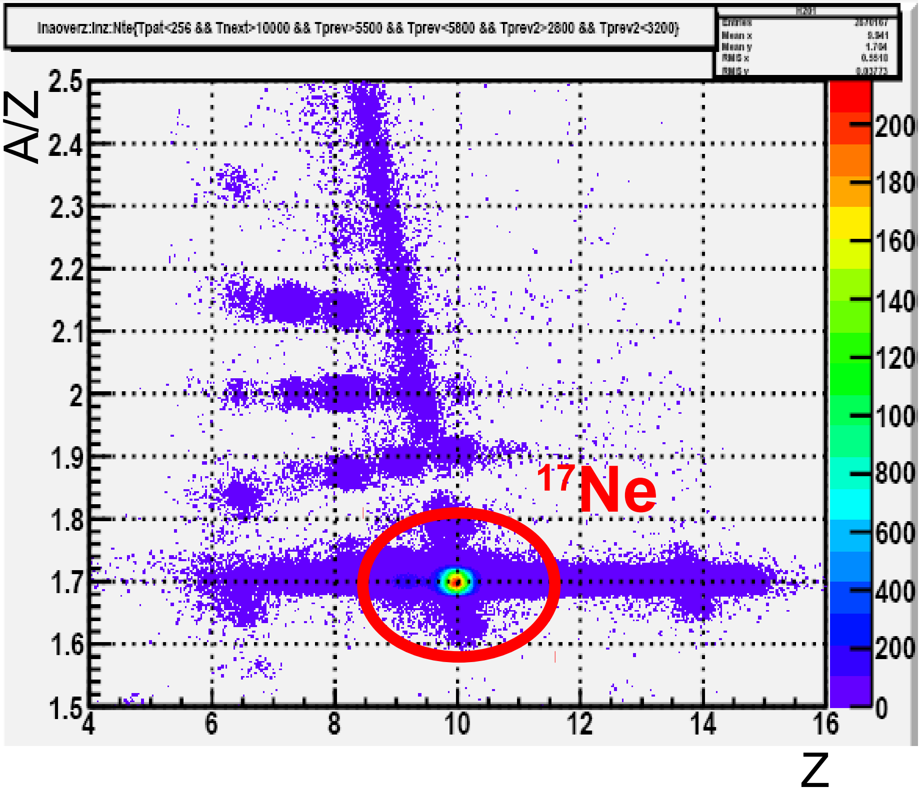
For cross section vs energy, the excitation energy needs to be precisely known => require precise momentum vectors! (0.3%)

Incoming ion

Non-relativistic particle in B-field:

$$B\rho = A/Z\ \beta$$





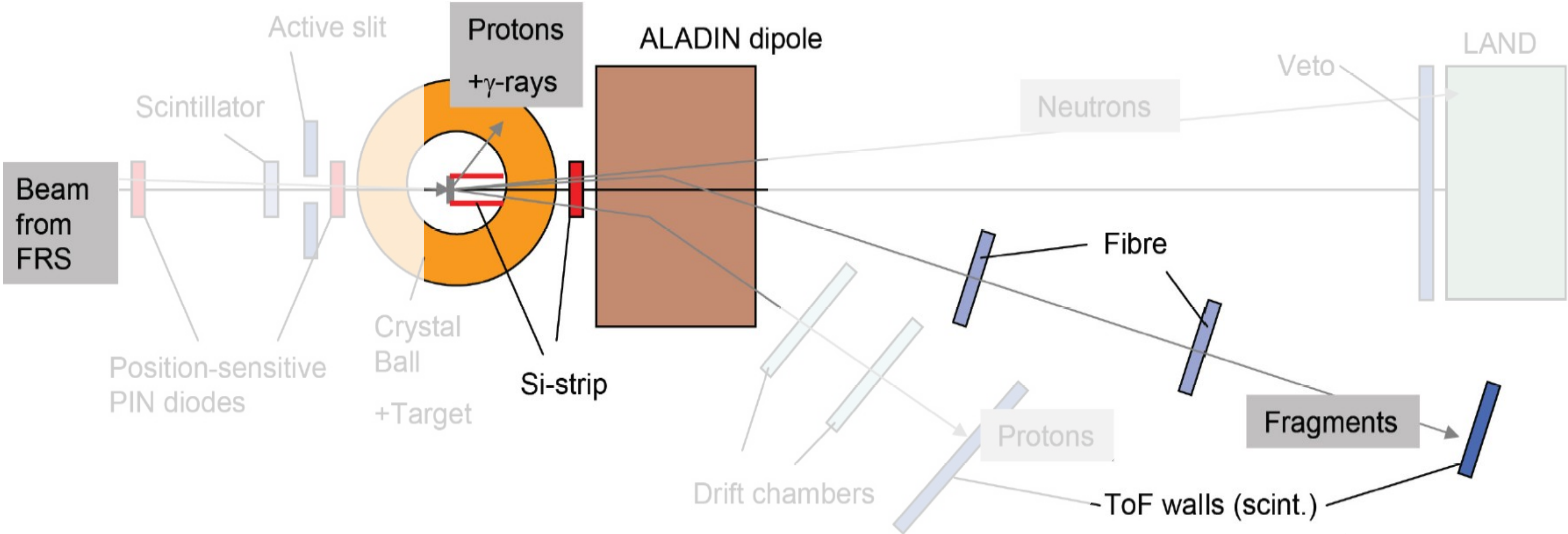
Incoming ion before reaction:

- Time-of-flight via scintillator and 50m flightpath => beta
- Bρ from FRS
  => A/Z
- energy loss in position sensitive pin diode => Z
  => A, momentum

Outoing ^{15}O

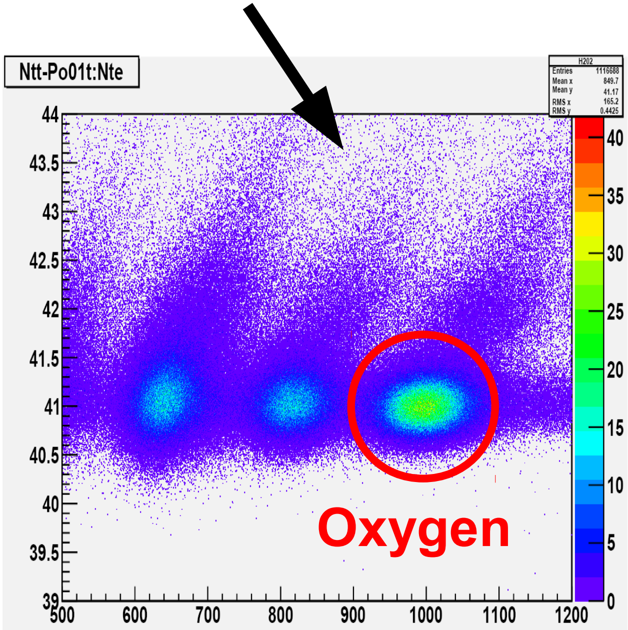
Non-relativistic particle in B-field:

$$B\rho = A/Z\ \beta$$



Outgoing **heavy fragment** **after reaction:**

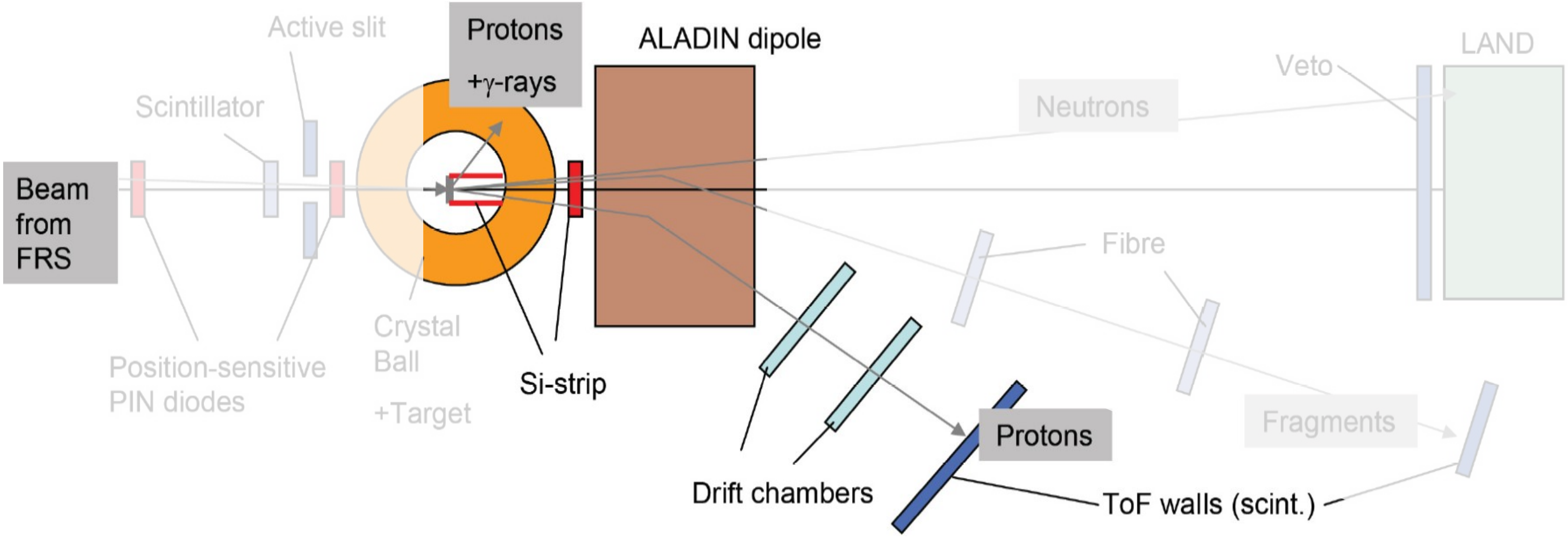
- Time-of-flight via 10m flightpath (TOF wall) => β
- Deflection in magnetic field (Aladin, Fibre) => A/Z
- Energy loss in plastic scintillator (TOF wall) => Z



Outgoing proton

Non-relativistic particle in B-field:

$$B\rho = A/Z\ \beta$$

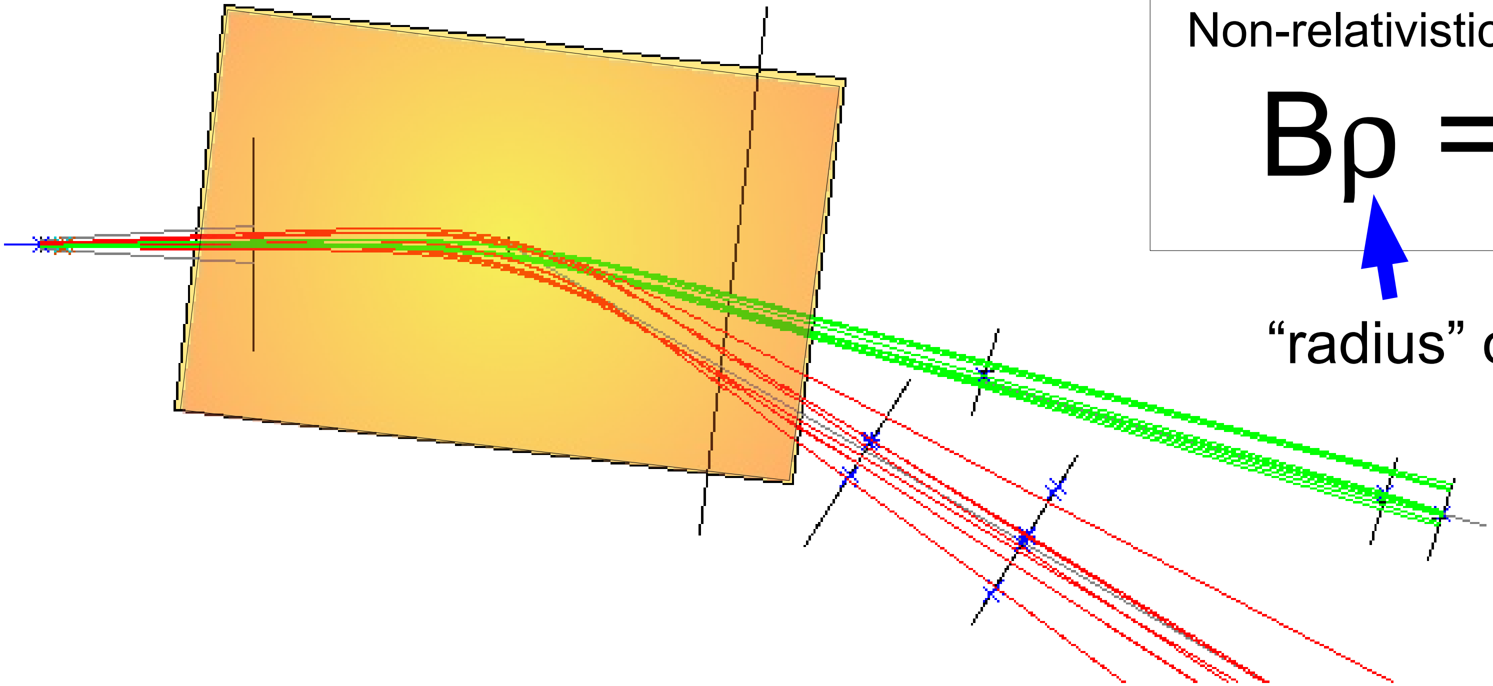


Outgoing protons after reaction:

- A and Z known
- β (momentum) from TOF not good enough
- deflection in magnetic field (Aladin, Drift chambers)

=> β

How to evaluate deflection to get Bρ?



Non-relativistic particle in B-field:

$$B\rho = A/Z\ \beta$$

“radius” of particle track

Goal: Determine Bρ of the particle, but:

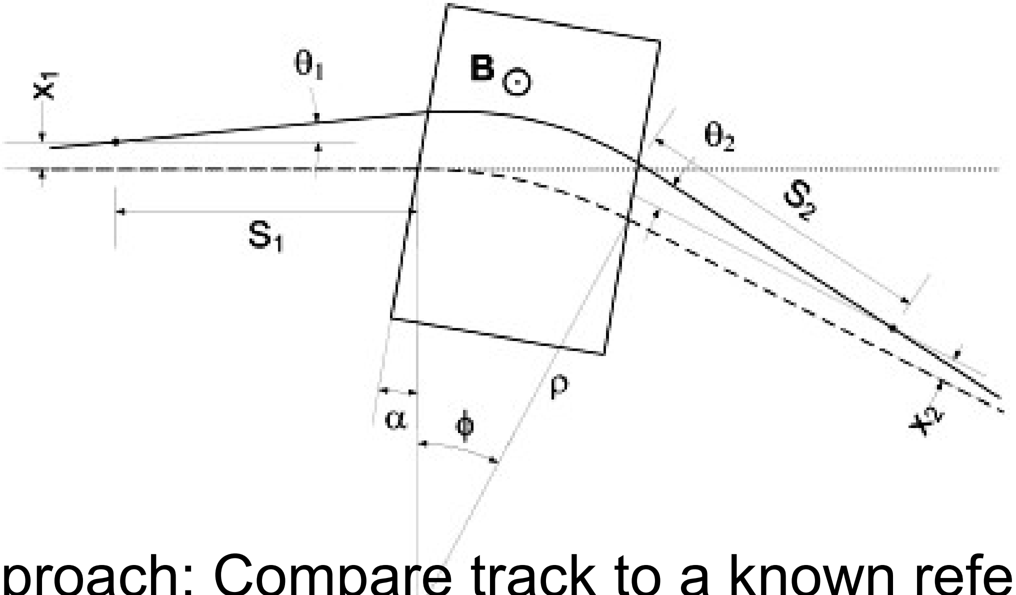
Location of particle track after B-Field depends not only on Bρ but also on incident angle and on the location of the track inside the (inhomogeneous) magnetic field!

How to get Bρ?

How to get Bρ?

Non-relativistic particle in B-field:

$$B\rho = A/Z\ \beta$$



1) Matrix-approach: Compare track to a known reference track. Works best if deviation from reference track is small and B-field constant. Fast.

2) Calculating (simulating) the track step by step through the B-field. Requires B-field to be known (field maps!) and some CPU power.

Geant4? slow, huge, and not easy to get started.

Small is beautiful => development of own “tracker”-software.

General idea

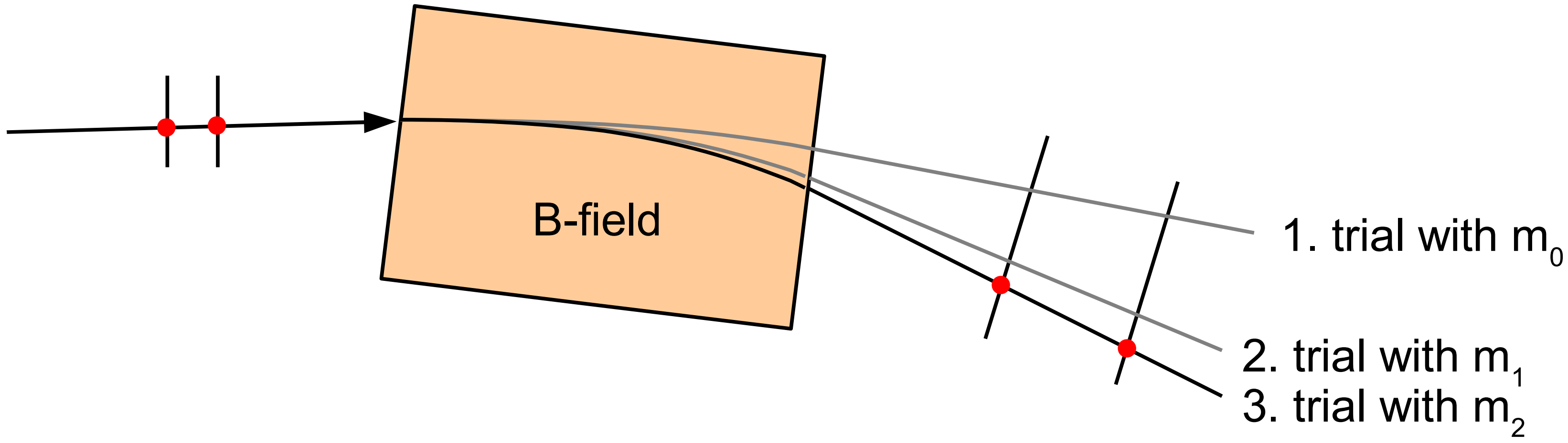
1) Position and angle before magnet are known

2) Guess Bρ (mass or β)

3) Calculate track in and after magnet

4) Compare to measured values

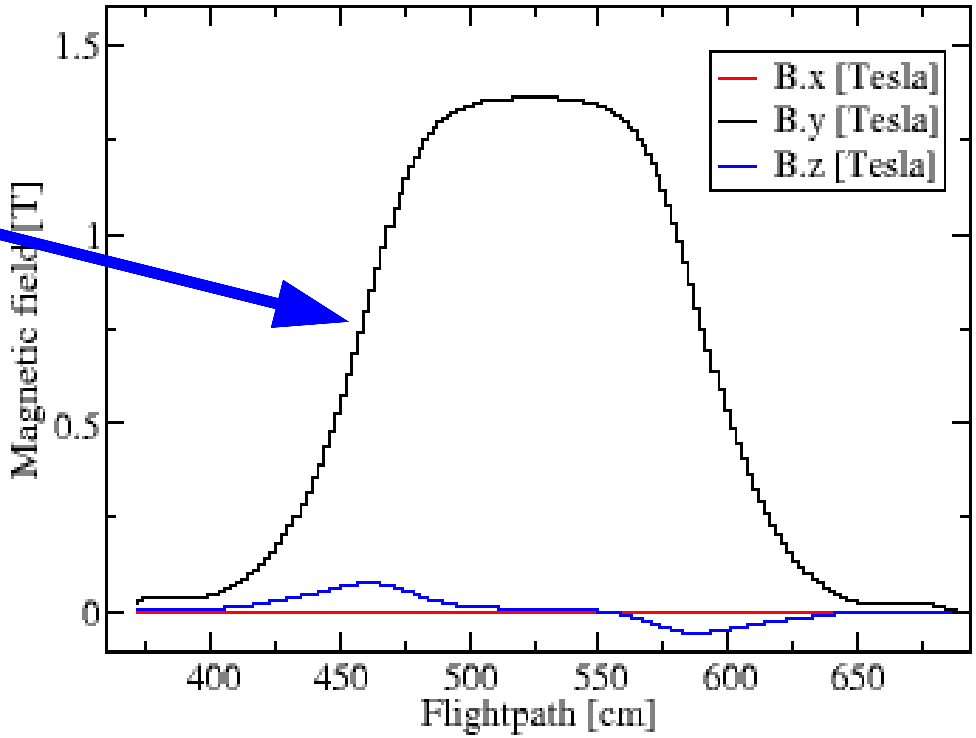
5) Go back to 2)



Avoid random trials! No need for e.g. minuit!

Field maps

- B-Field has significant “fringe-fields”
- => It is not uniform!
- Measure field for several currents using a 3D grid and produce “field maps” (=data files)
- Interpolate B-Field from these field maps for the calculation of the particle track

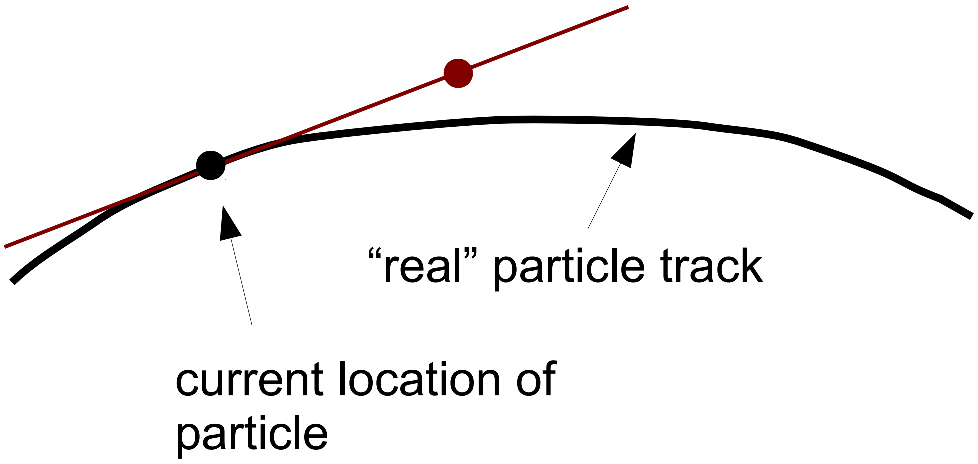


Magnetic field seen by the particle.

Tracking algorithm: Euler?

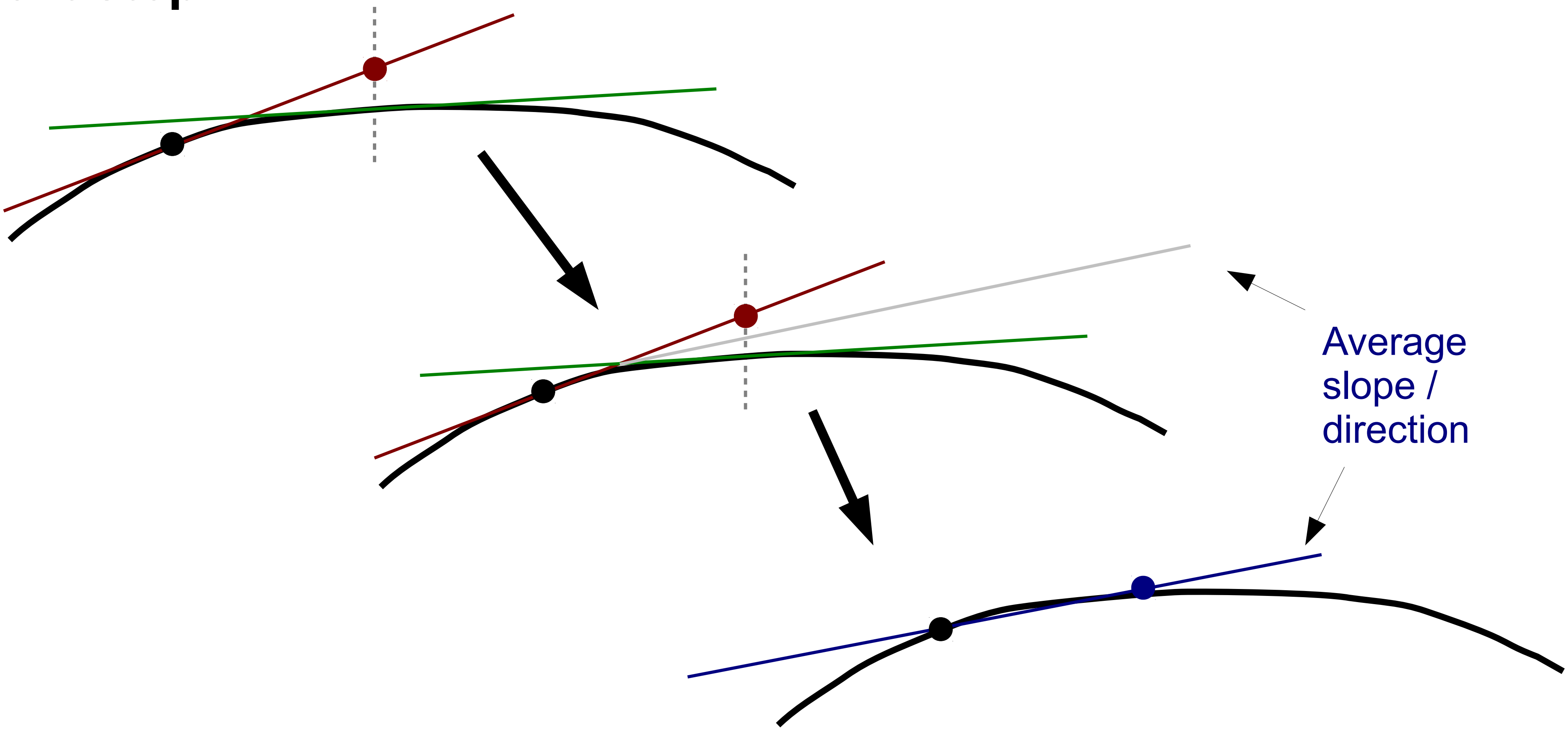
How to calculate particle track in measured, non-uniform magnetic field?

Euler method:
Calculate B-Field and Lorentz force **at current position** of particle.
Calculate new particle direction
Move particle by given step size along straight line



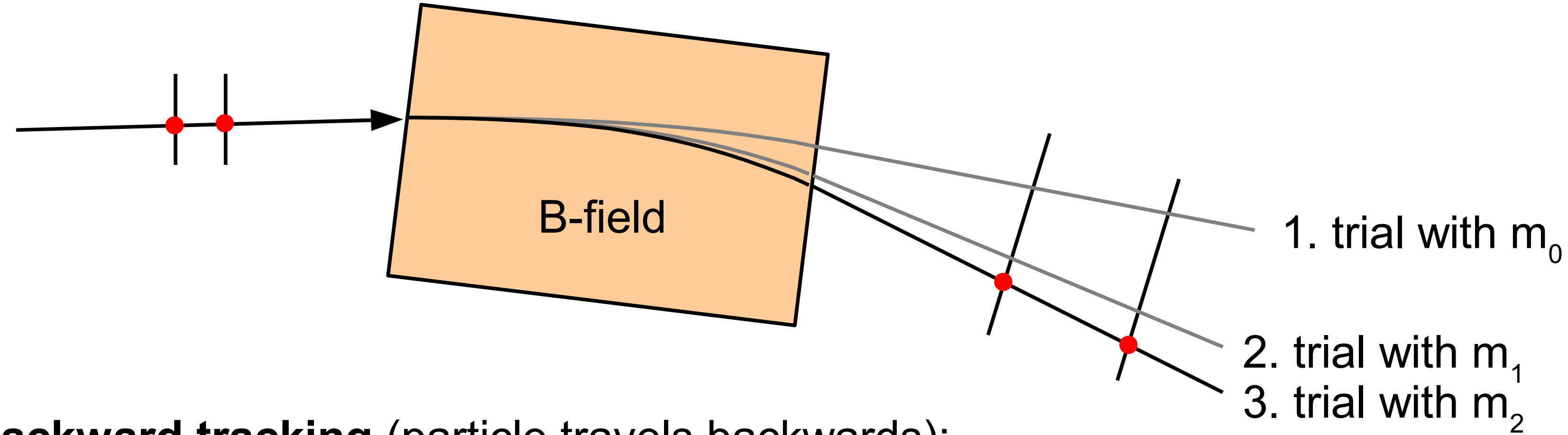
Tracking algorithm: Runge Kutta

Better: **Runge Kutta**
Recalculate velocity vector at several positions of **extrapolated next step**

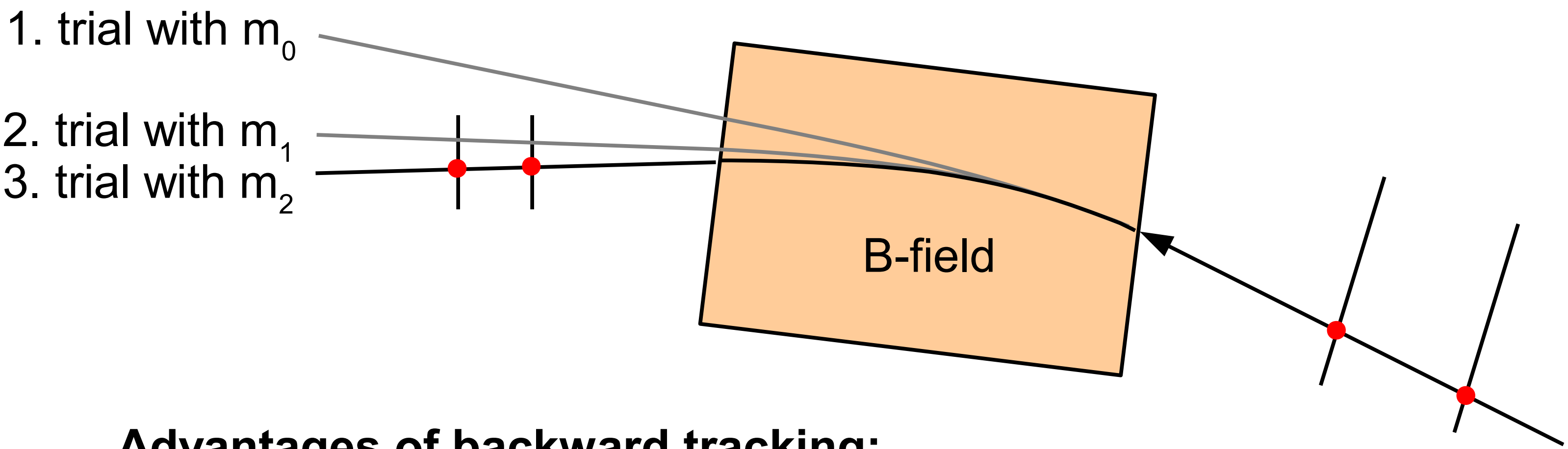


Tracking: forward or backward?

Forward tracking:



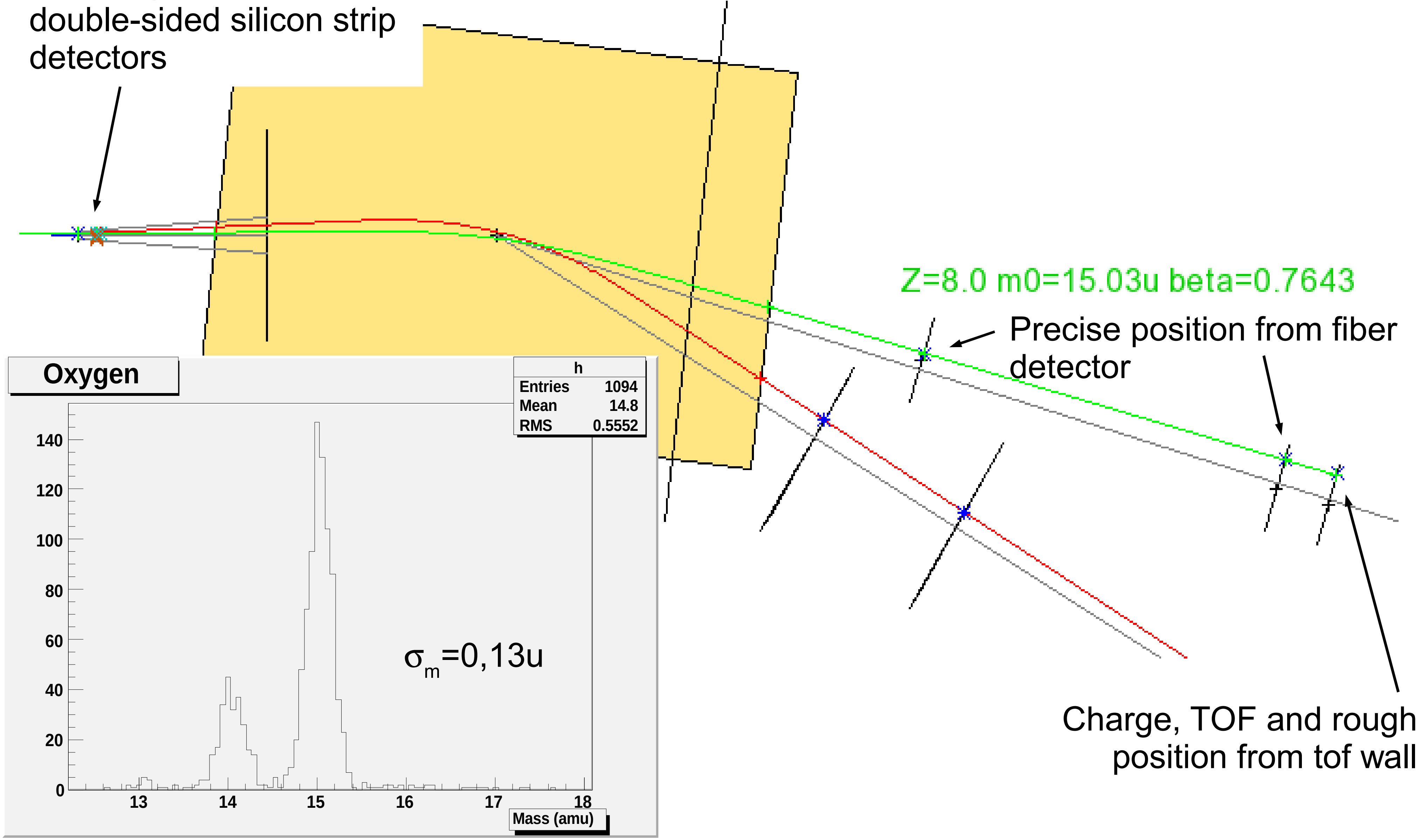
Backward tracking (particle travels backwards):



Advantages of backward tracking:

- Converges faster (in our case)
- Only one measured position before B-field necessary

Tracking fragments



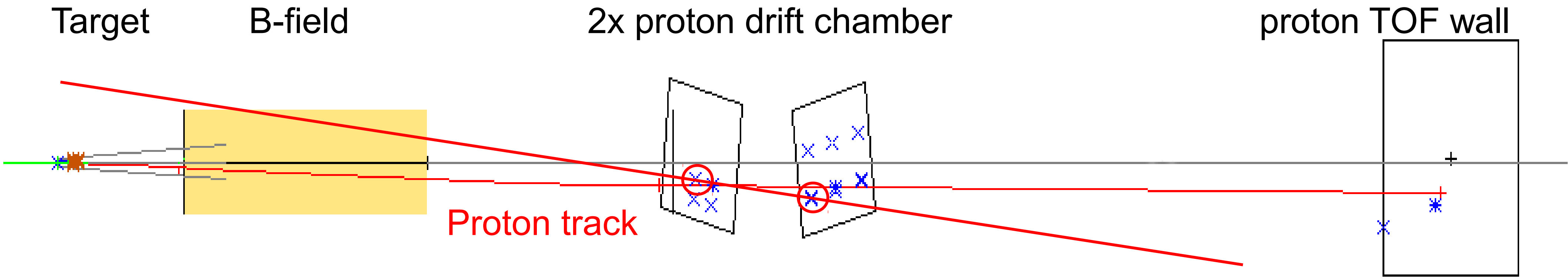
Precise position from two double-sided silicon strip detectors

Precise position from fiber detector

Charge, TOF and rough position from tof wall

Tracking protons

View from the side



All proton detectors are **multi-hit** capable and sometimes **noisy**.
X and Y are measured independently.

2*hits + n*noise = many possible proton tracks (>100)!

1) filter tracks after magnet using some confidence criteria (before time consuming tracking through B-field)

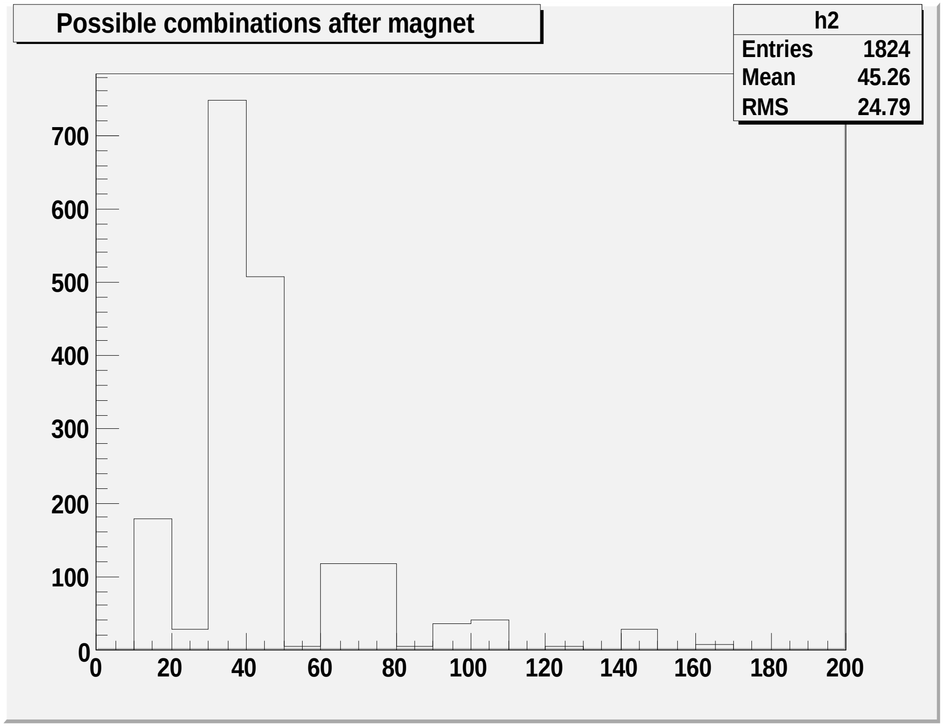
2) calculate entire track and particle properties

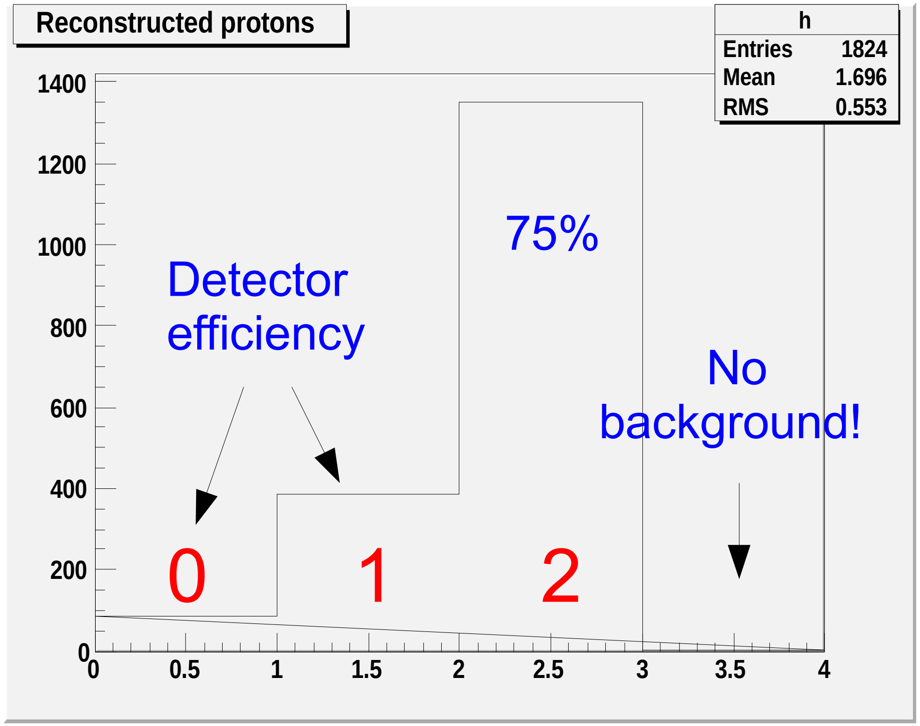
3) store best track (smallest χ^2) and throw away all other tracks that use the same X or Y

4) repeat 3) until no tracks are left

Tilting of proton drift chambers helps to find the right track!

Reconstructing proton tracks





Detector efficiency

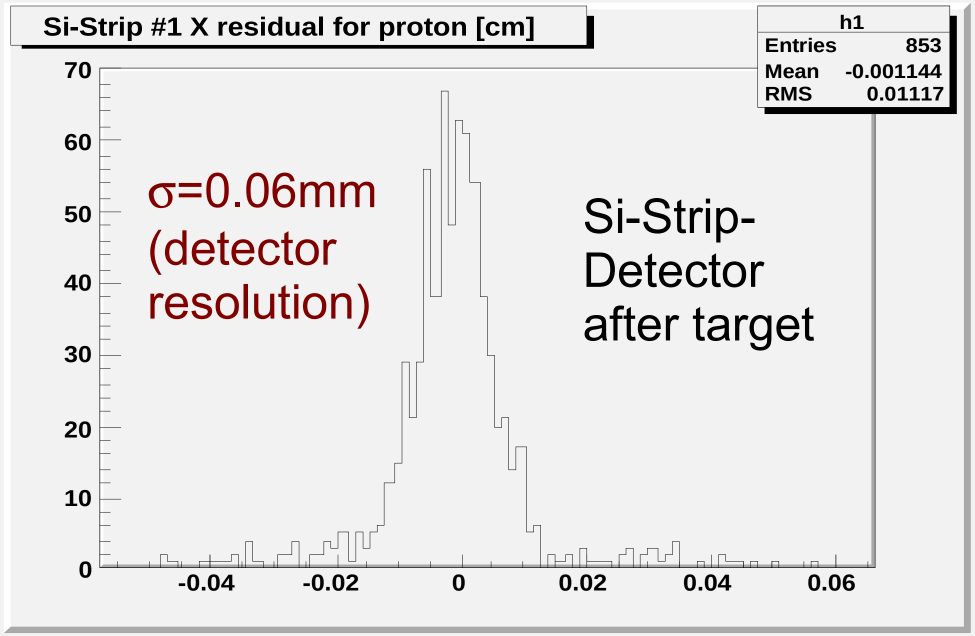
75%

No background!

Left: possible proton tracks after the magnet without any restrictions

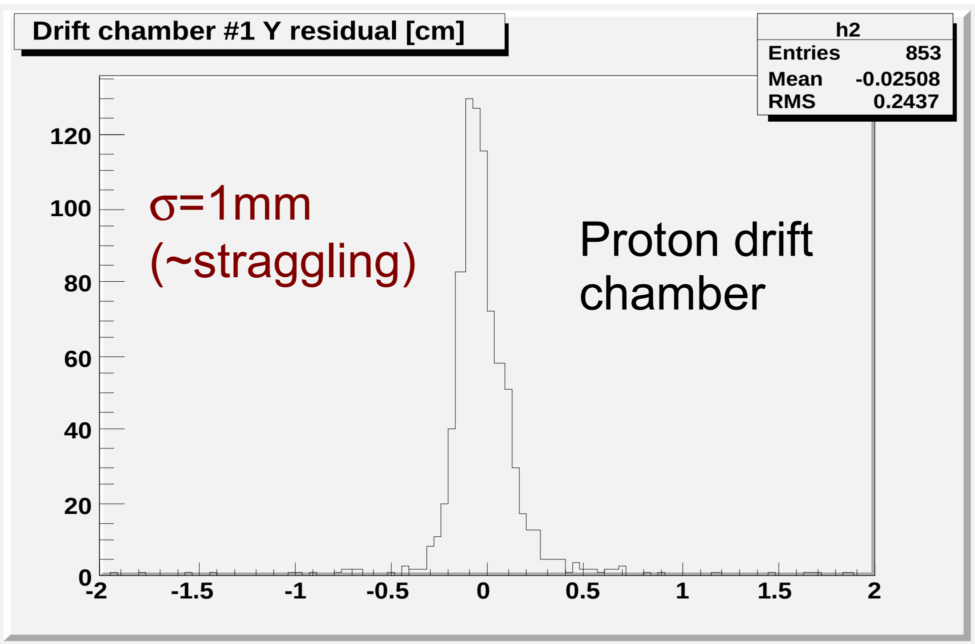
Right: reconstructed protons for $^{17}Ne(\gamma,2p)^{15}O$

Residuals


Si-Strip #1 X residual for proton [cm]

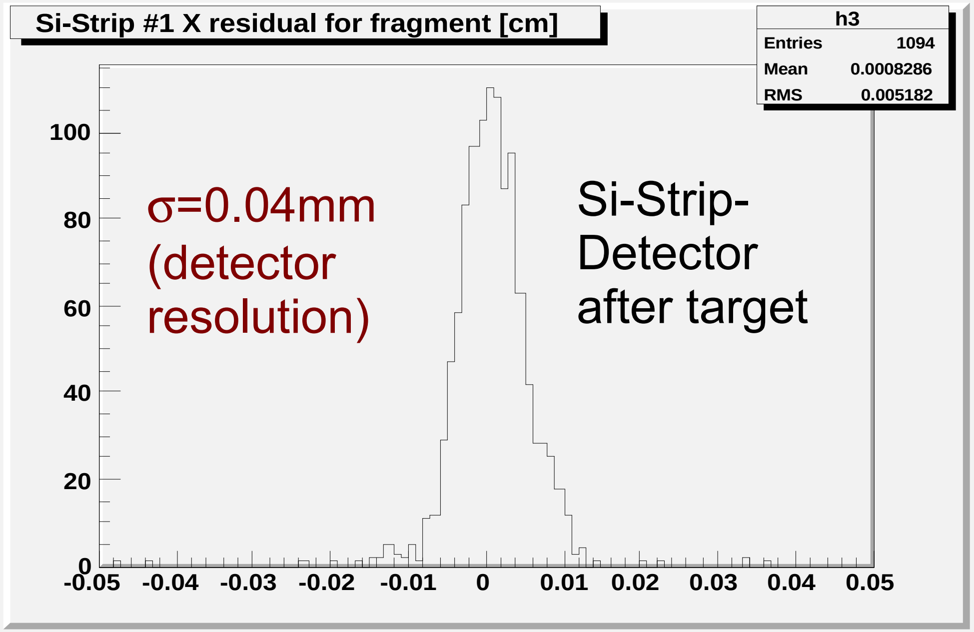
σ=0.06mm (detector resolution)

Si-Strip-Detector after target


Drift chamber #1 Y residual [cm]

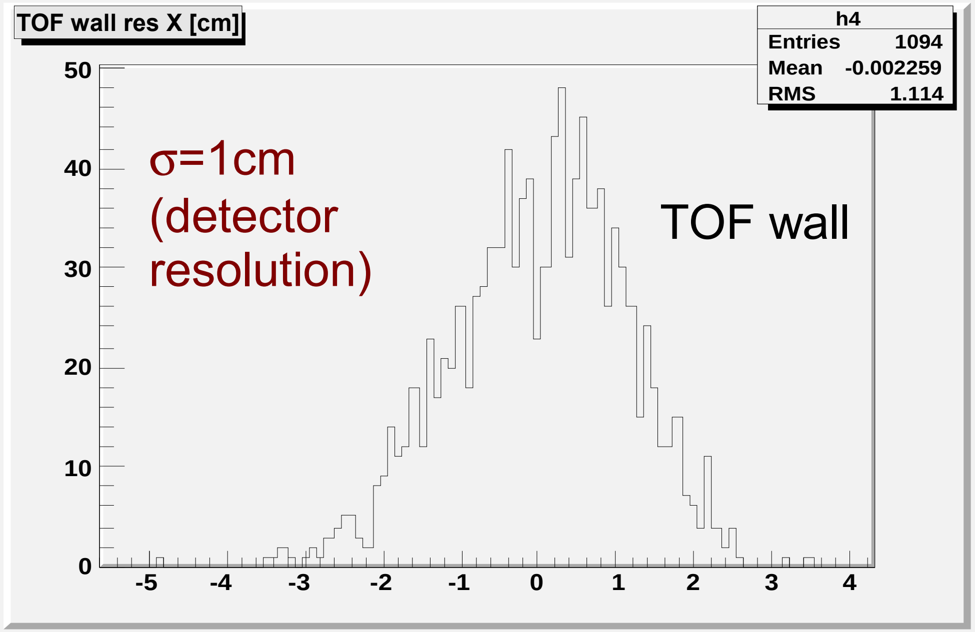
σ=1mm (~straggling)

Proton drift chamber


Si-Strip #1 X residual for fragment [cm]

σ=0.04mm (detector resolution)

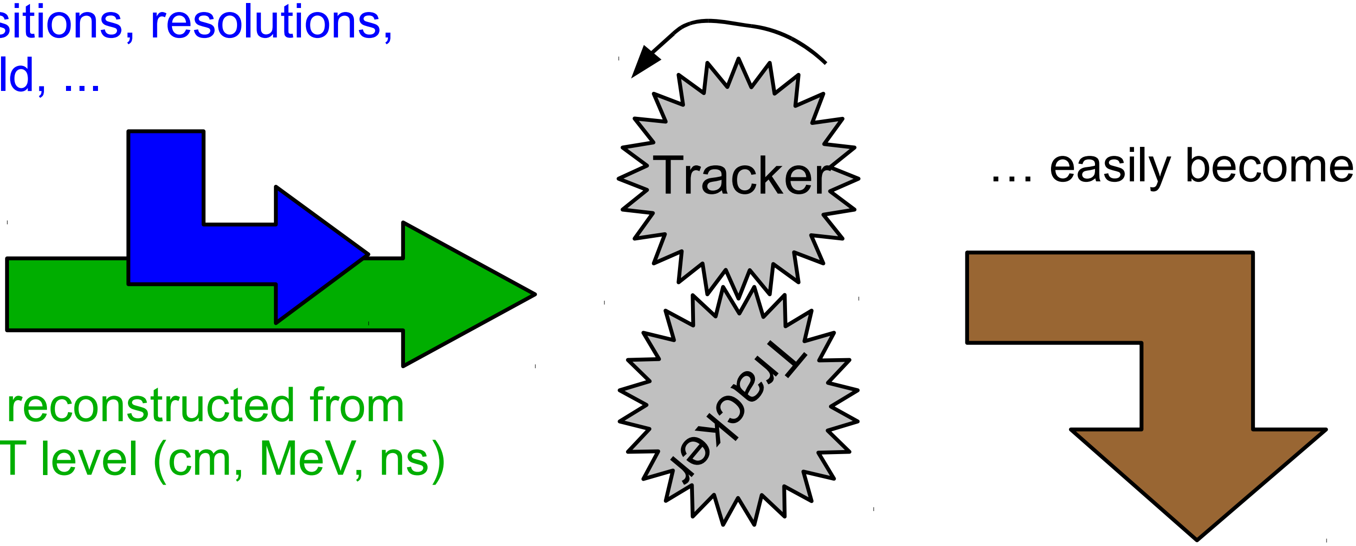
Si-Strip-Detector after target


TOF wall res X [cm]

σ=1cm (detector resolution)

TOF wall

Tracker: calibration necessary!



Detector positions, resolutions, magnetic field, ...

Detector data, reconstructed from channels to HIT level (cm, MeV, ns)

… easily becomes garbage...

Trash

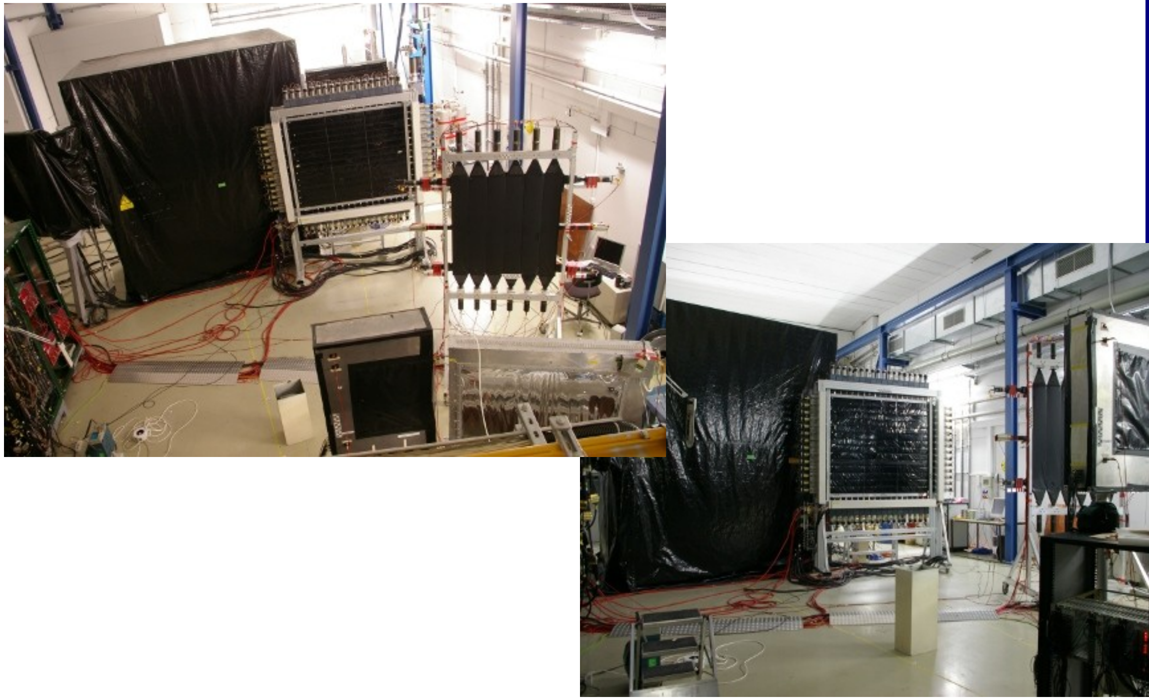
External input necessary:

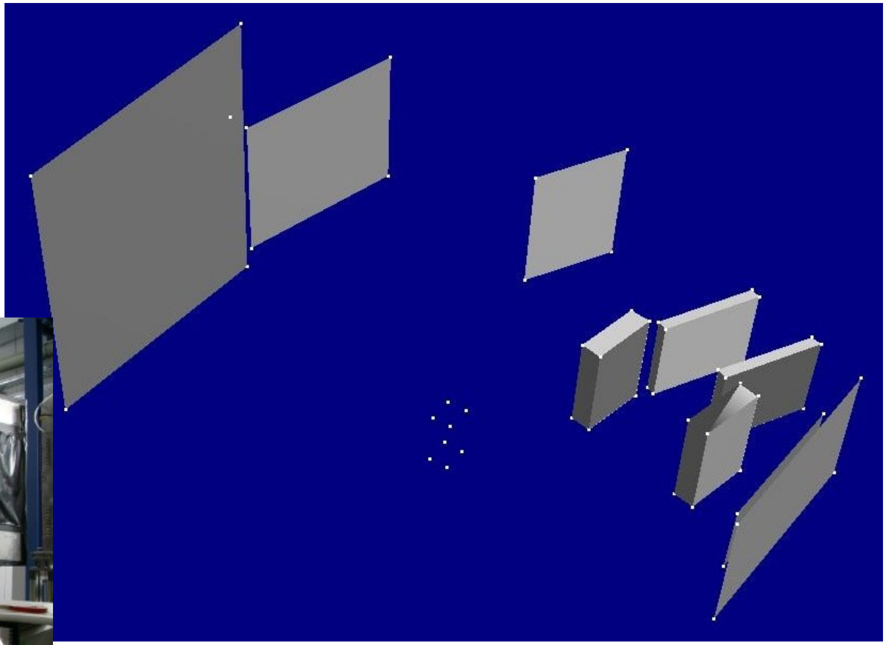
- B-field (measured: current in Amperes). Hysteresis?
- Positions of detectors in lab needed with precision of 0.1mm!
- Spatial and time resolutions of detectors

Positions of detectors

Ideally: Measured with a precision of 0.1mm. Very difficult!

1) Photogrammetry



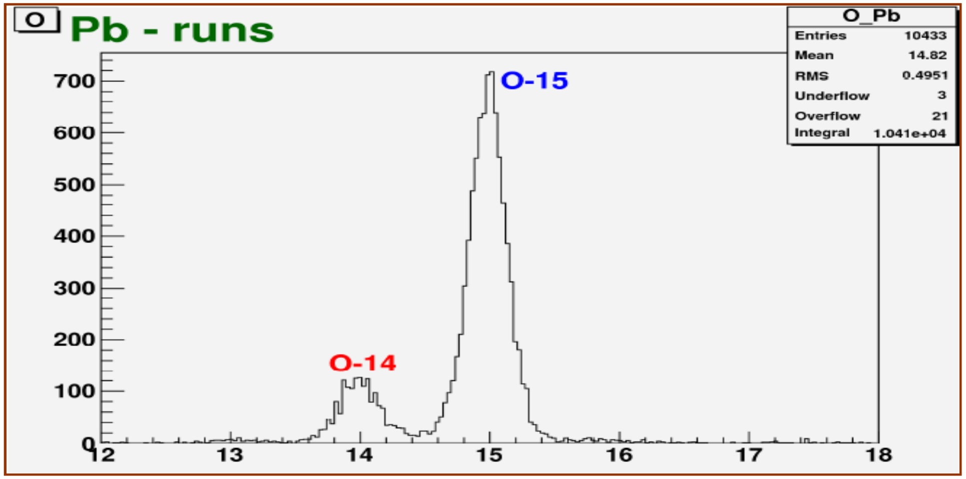


(by Marcel Heine)

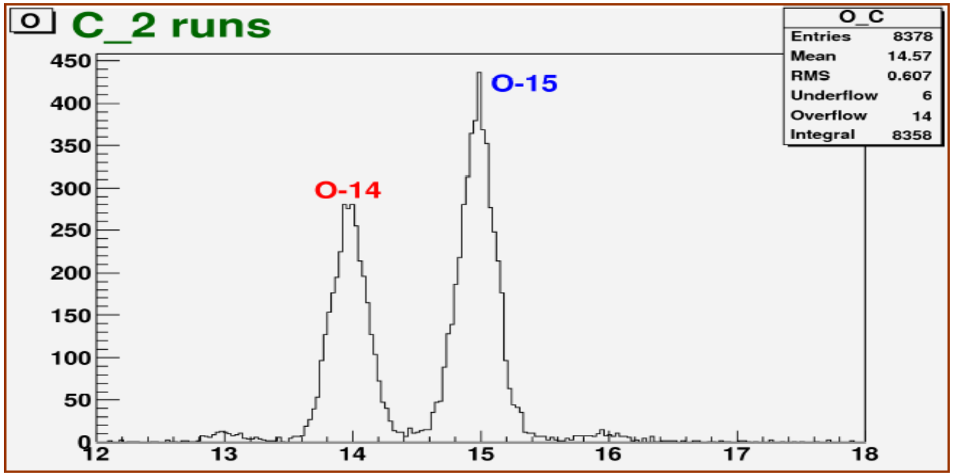
2) Use physics data
Good precision in x and y but poor for z (along beam) in proton arm!

Background subtraction

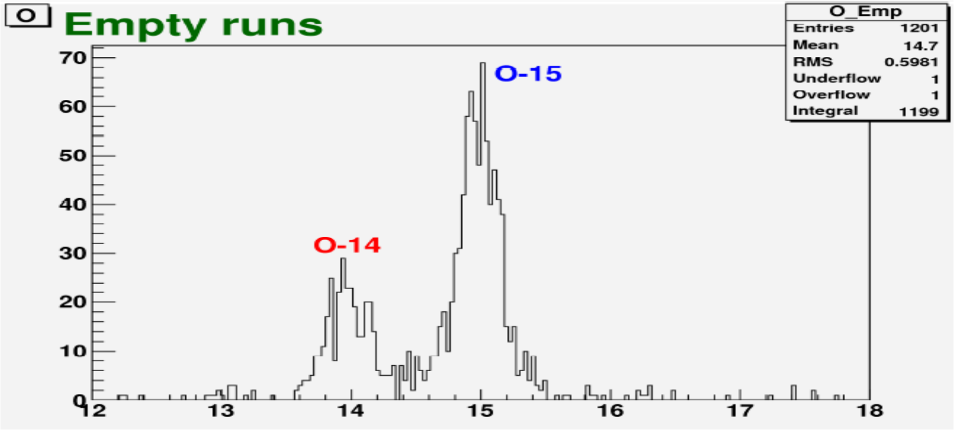
Production runs with Pb target.



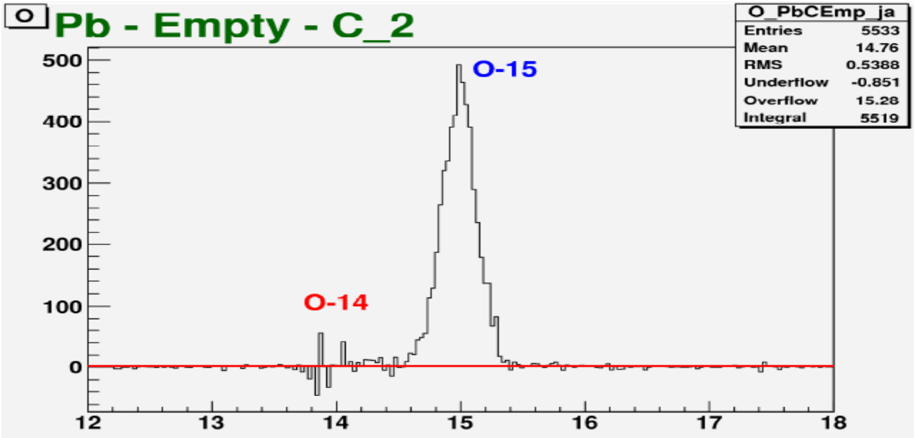
Runs with C target to subtract the nuclear contribution.



Runs without target to subtract the background.



After proper subtraction only ^{15}O remains.



Total cross section

Coulomb dissociation cross section (experiment):

242 ± 34 mb

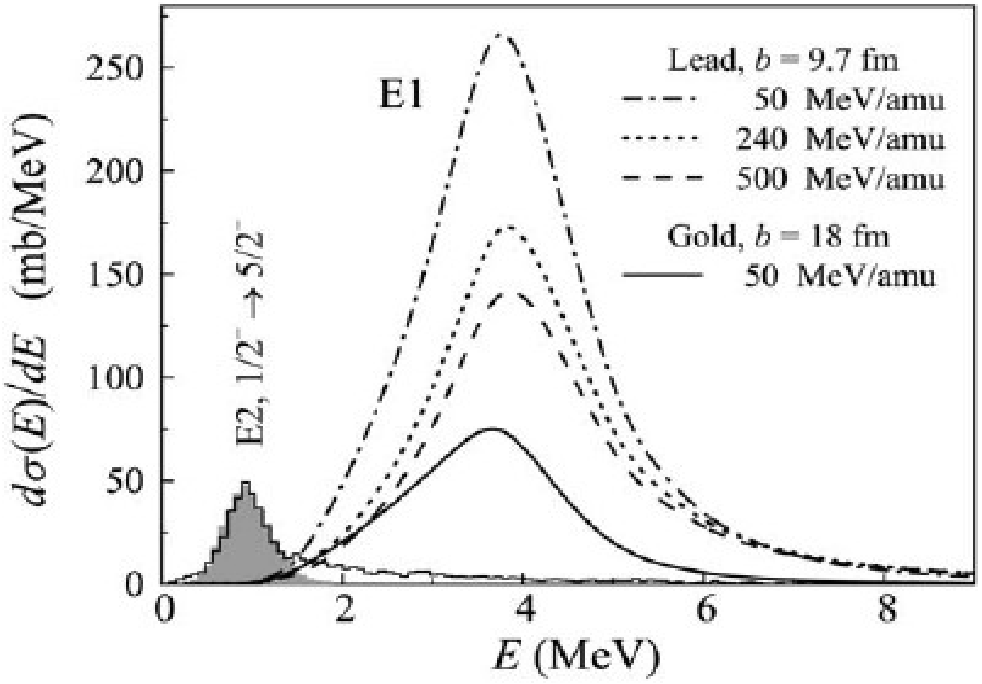
Comparison with theory yields s/d mixing ratio.

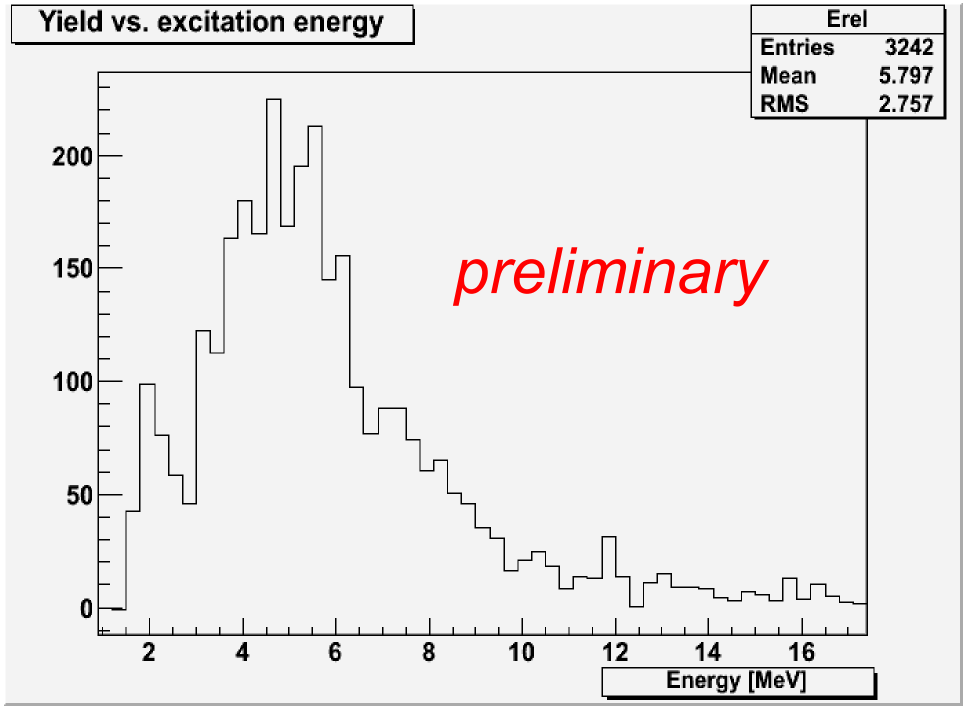
Preliminary value: at least 14% s.

Analysis still in progress.

Excitation/relative energy

Relative energy





Left: Relative energy (theory) by L. V. Grigorenko

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Right: Excitation energy (measured)

(Excitation energy = Relative Energy + 1MeV)

Summary

- Coulomb dissociation is the only way to measure reactions with three particles in the entrance channel
- Mass, charge and momentum of all involved particles need to be measured
- Tracking allows the extraction of those values from measured variables like position and TOF

- ^{17}Ne seems to be a halo nucleus
- The calculation of the $^{15}O(2p,\gamma)^{17}Ne$ cross section is still in progress.

Collaboration

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3. ExtreMe Matter Institute EMMI, GSI Darmstadt
4. TU Darmstadt

Thank you!