Coulomb dissociation of ^{17}Ne – a tool for nuclear structure and astrophysics

Justyna Marganiec
TU Darmstadt, Germany
j.marganiec@gsi.de

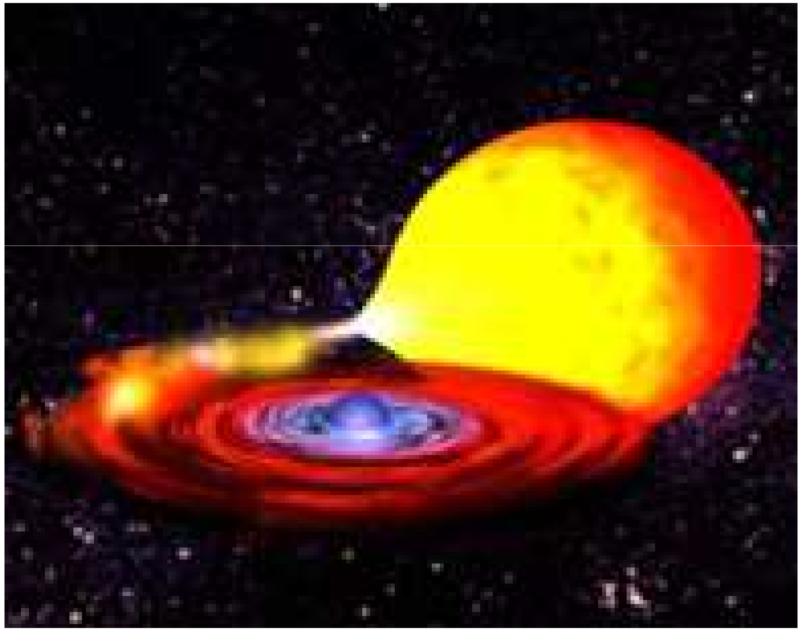
Nuclear Astrophysics Virtual Institute

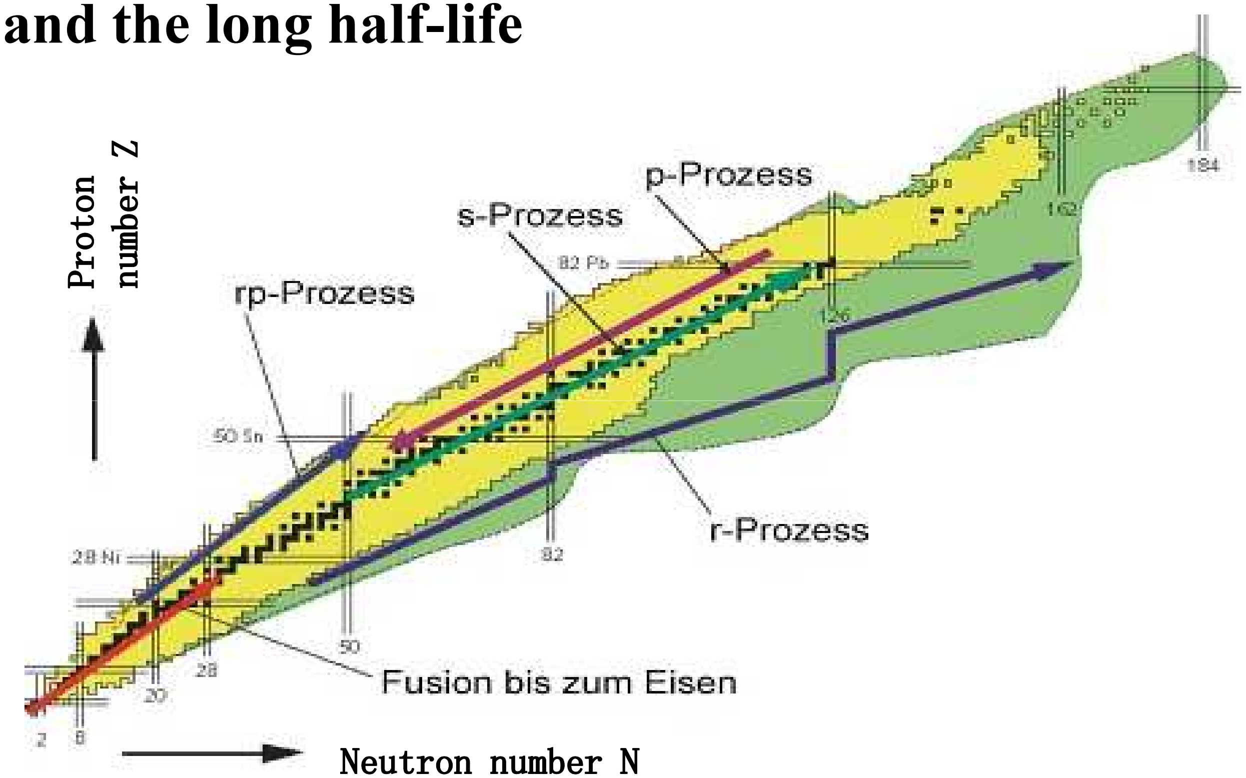
outline

- the rp process and the nuclear astrophysical motivation;
- the doubts of ^{17}Ne nuclear structure;
- Coulomb dissociation as a source of information on radiative capture processes;
- experimental setup;
- necessary corrections (efficiency, acceptance, ect.);
- preliminary results;
- future work;
- summary.

rp process

- in cataclysmic binary systems (X-ray bursts);
- sequence of proton captures and β^+ decays;
- the proton capture is inhibited and the long half-life
  => the waiting points.





motivation

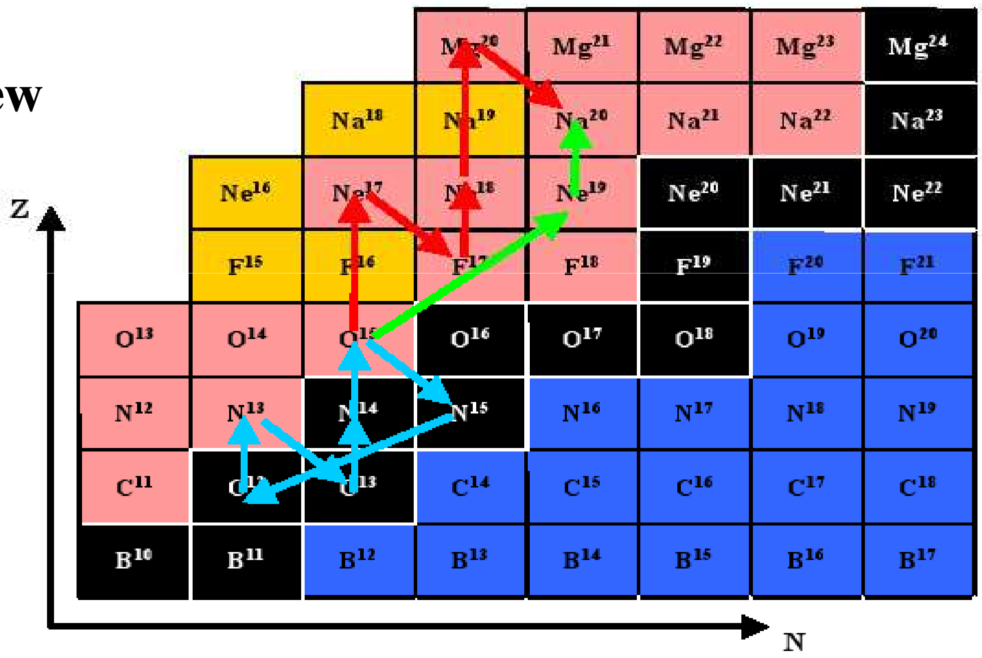
1. the nucleus ^{15}O => a waiting point for the break-out of the CNO cycle

CNO cycle: $^{12}C(p,\gamma)^{13}N(e,\nu)^{13}C(p,\gamma)^{14}N(p,\gamma)^{15}O(e,\nu)^{15}N(p,\alpha)^{12}C$

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;



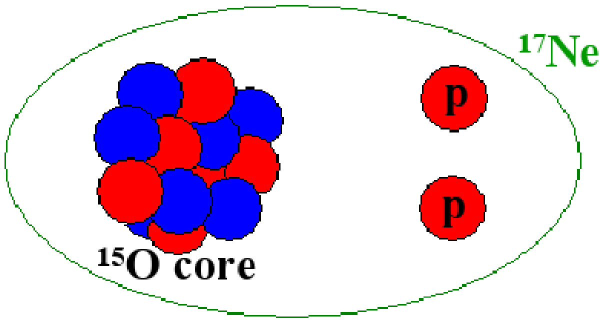
^{17}Ne ground state

TECHNISCHE UNIVERSITÄT DARMSTADT

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

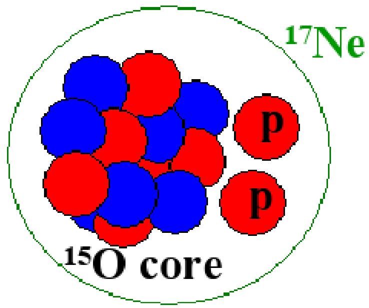


large σ_{CD}

↓

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

$[d^2]$ – dominant



small σ_{CD}

↓

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

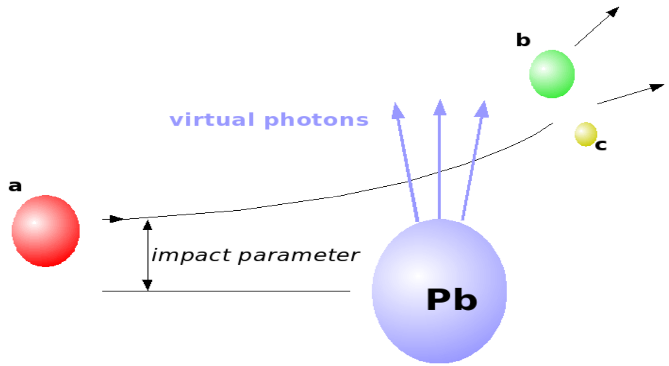
NAVI
Nuclear Astrophysics Virtual Institute

Coulomb dissociation method

TECHNISCHE UNIVERSITÄT DARMSTADT

Useful to measure radiative-capture reactions with:

- **small cross sections;**
- **unstable nuclei;**
- **three particles in entrance channel.**



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

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

a + Z $\longrightarrow$ 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 $\longrightarrow$

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

Coulomb dissotiation method

TECHNISCHE UNIVERSITÄT DARMSTADT

advantages:

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

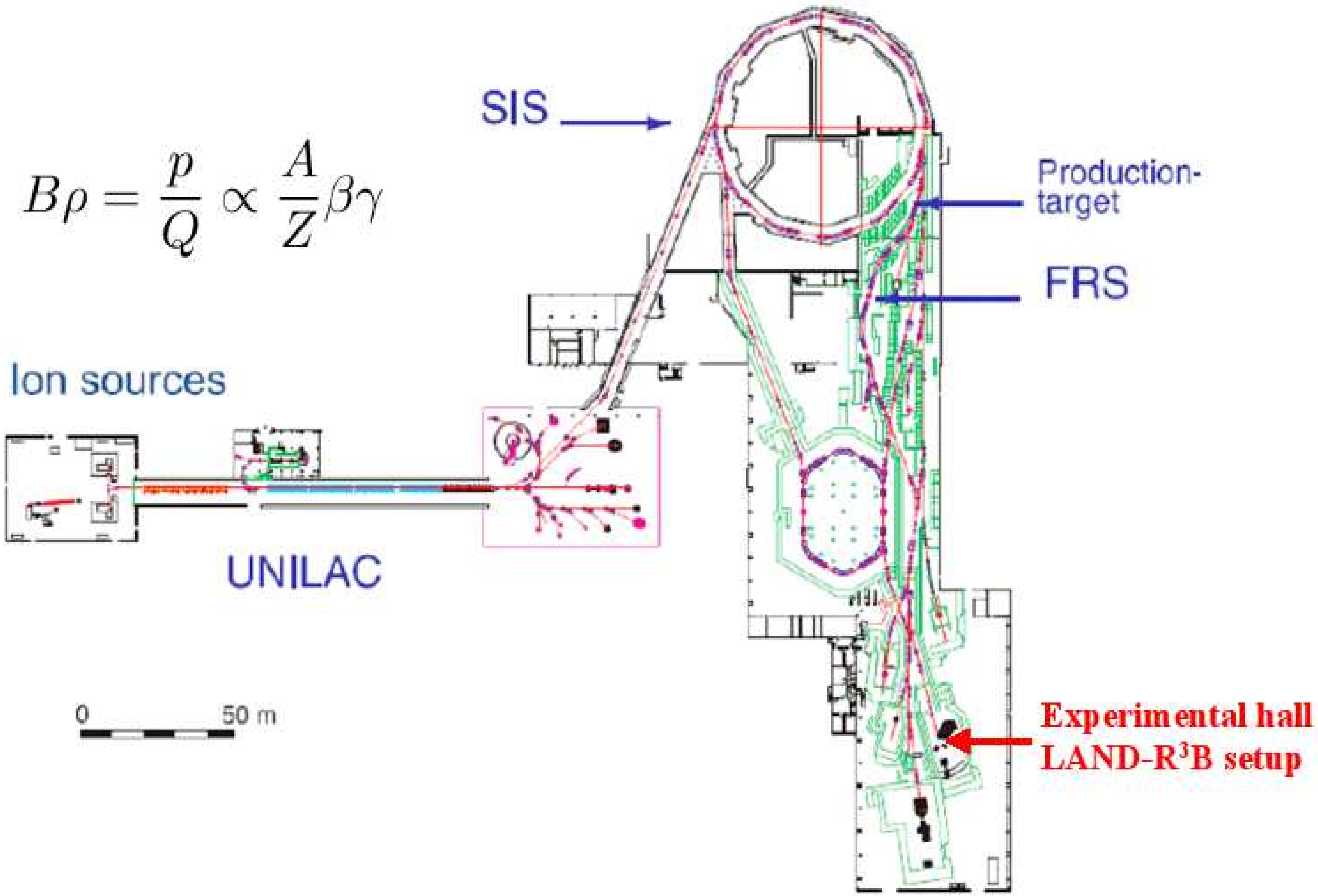
disadvantages:

- **indirect method;**
- **multipole admixtures must be clarified;**
- **nuclear contributions.**

production of exotic beam setup

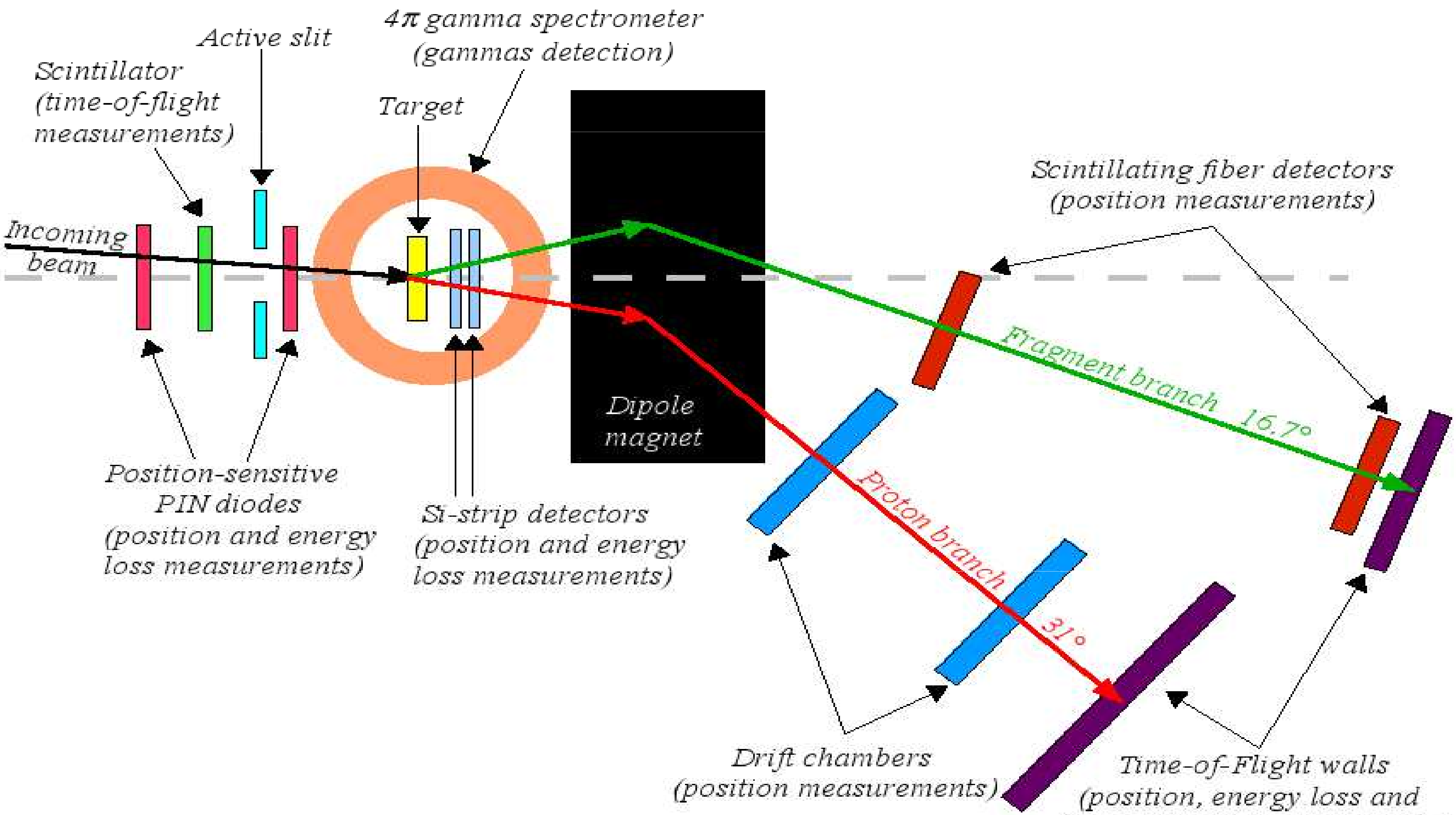
TECHNISCHE UNIVERSITÄT DARMSTADT

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



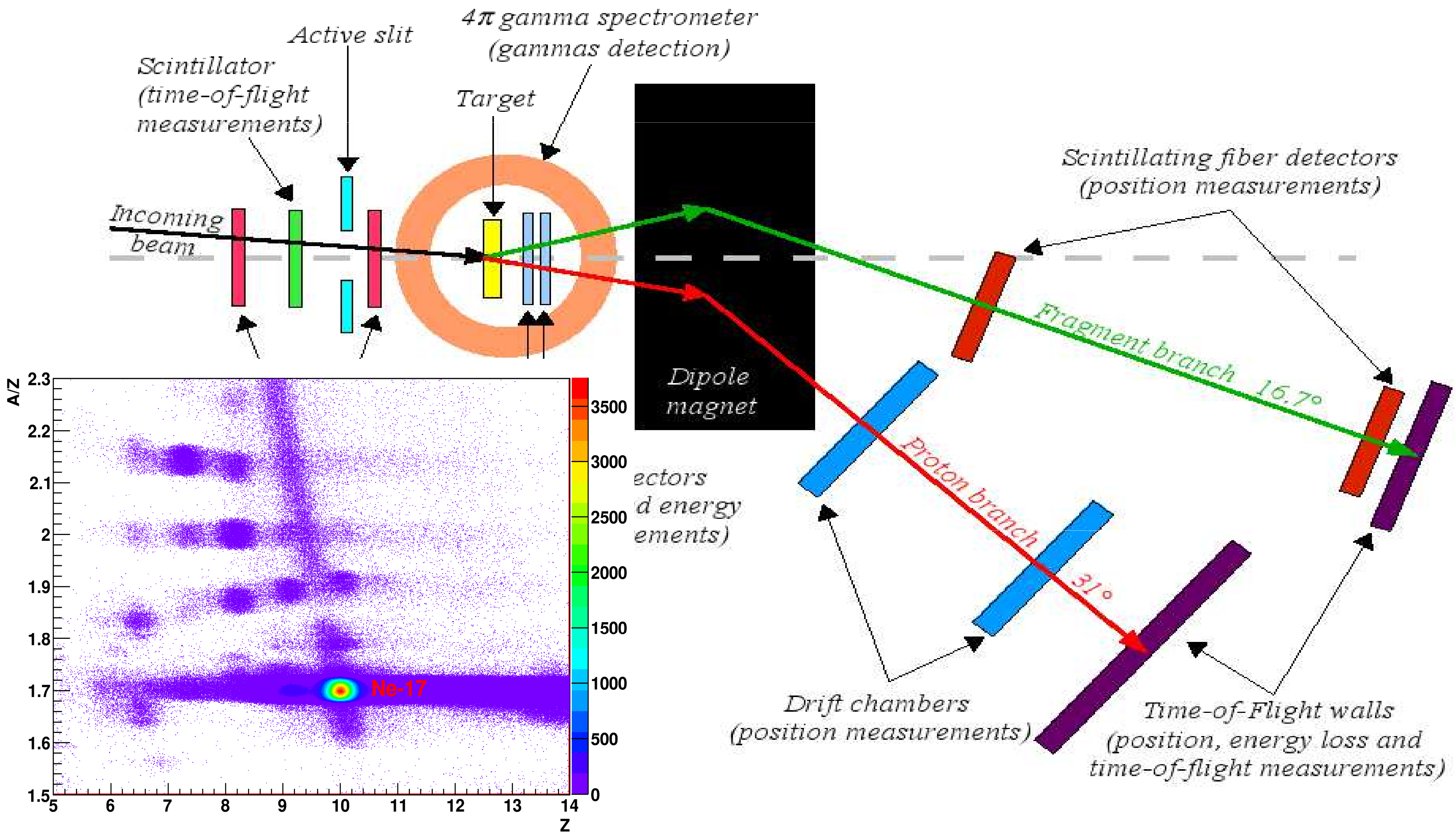
NAVI
Nuclear Astrophysics Virtual Institute

LAND-R^{3}B experimental setup

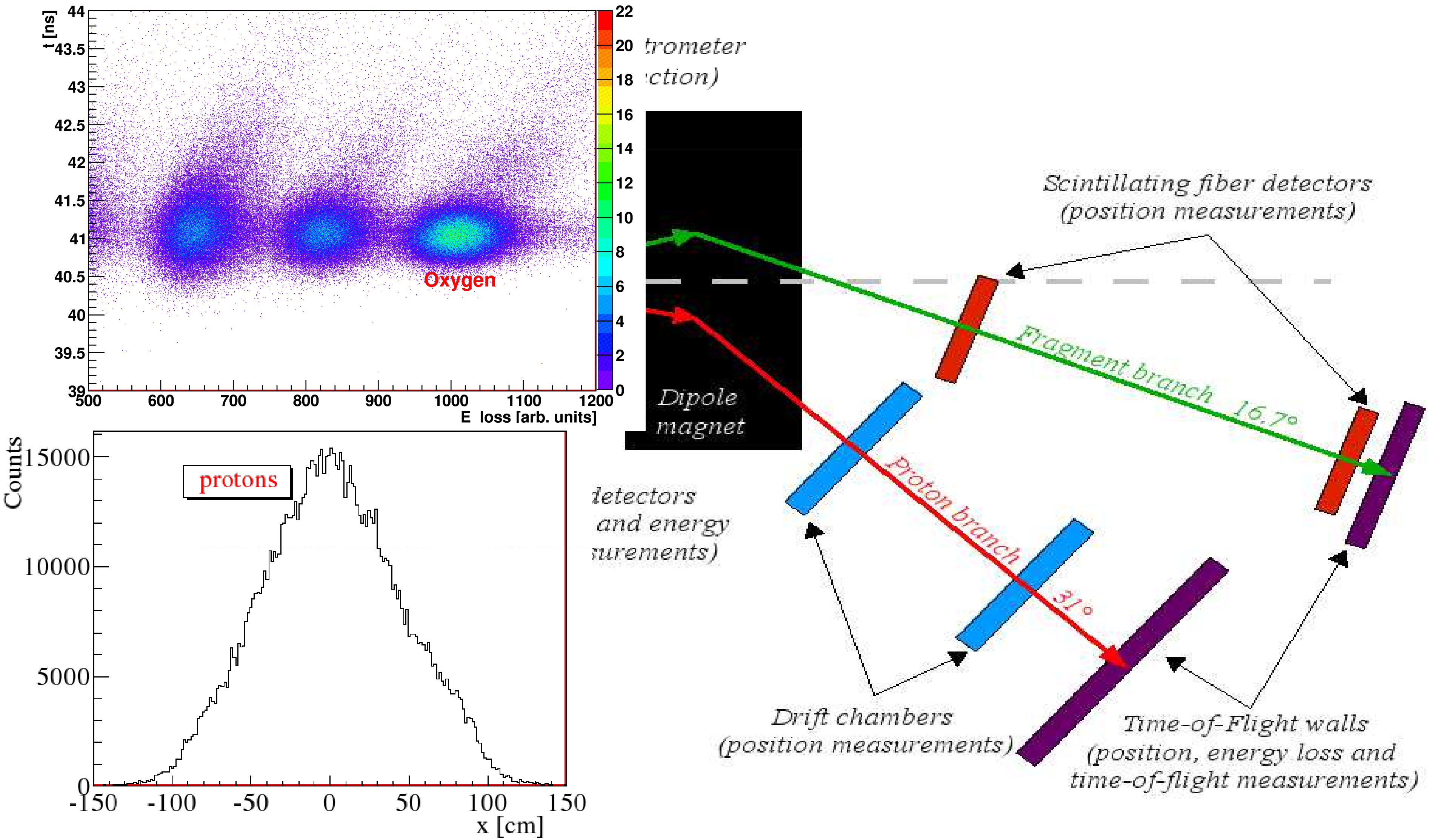


The energy of incoming beam = 500 MeV/u

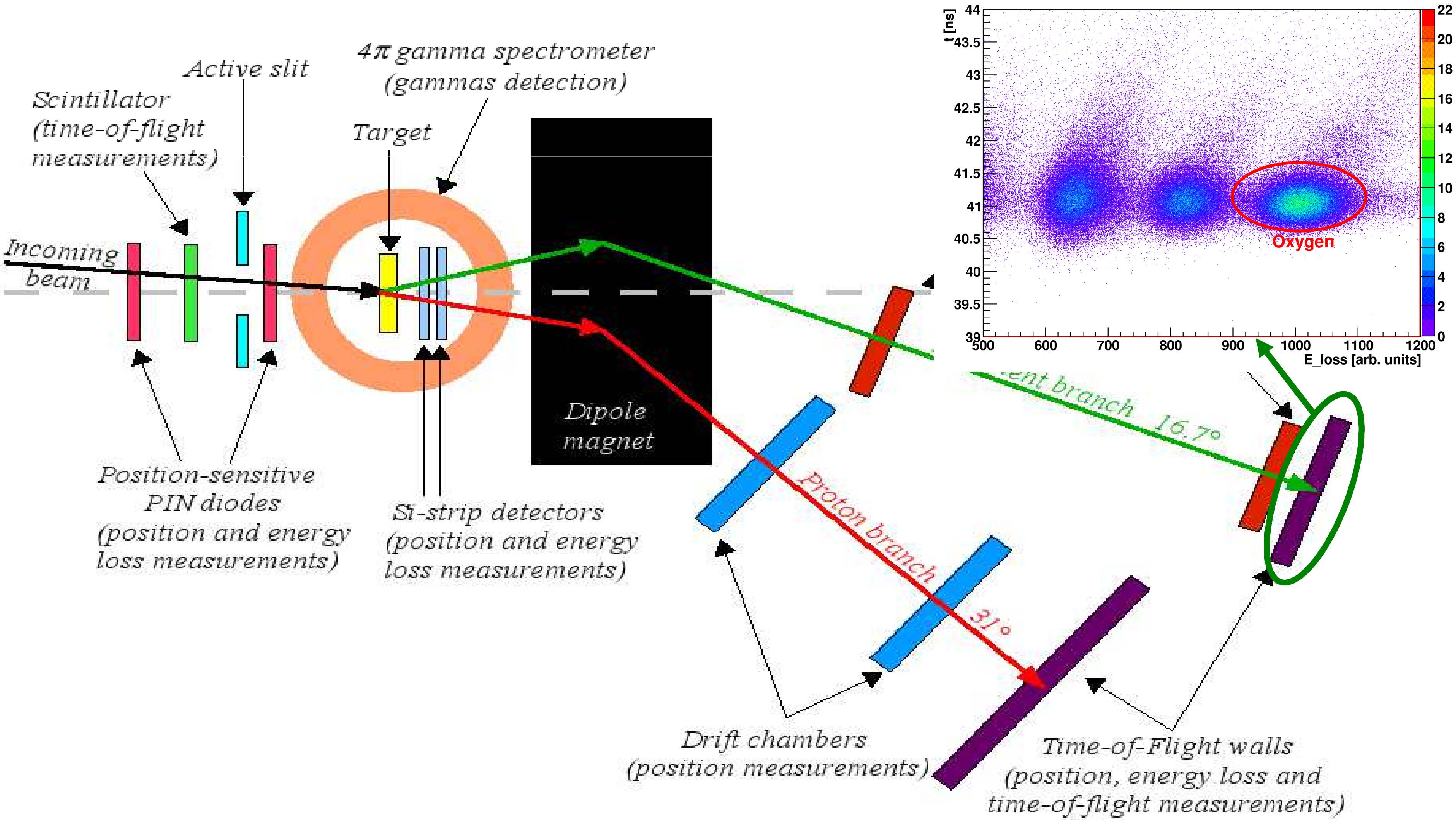
LAND-R^{3}B experimental setup



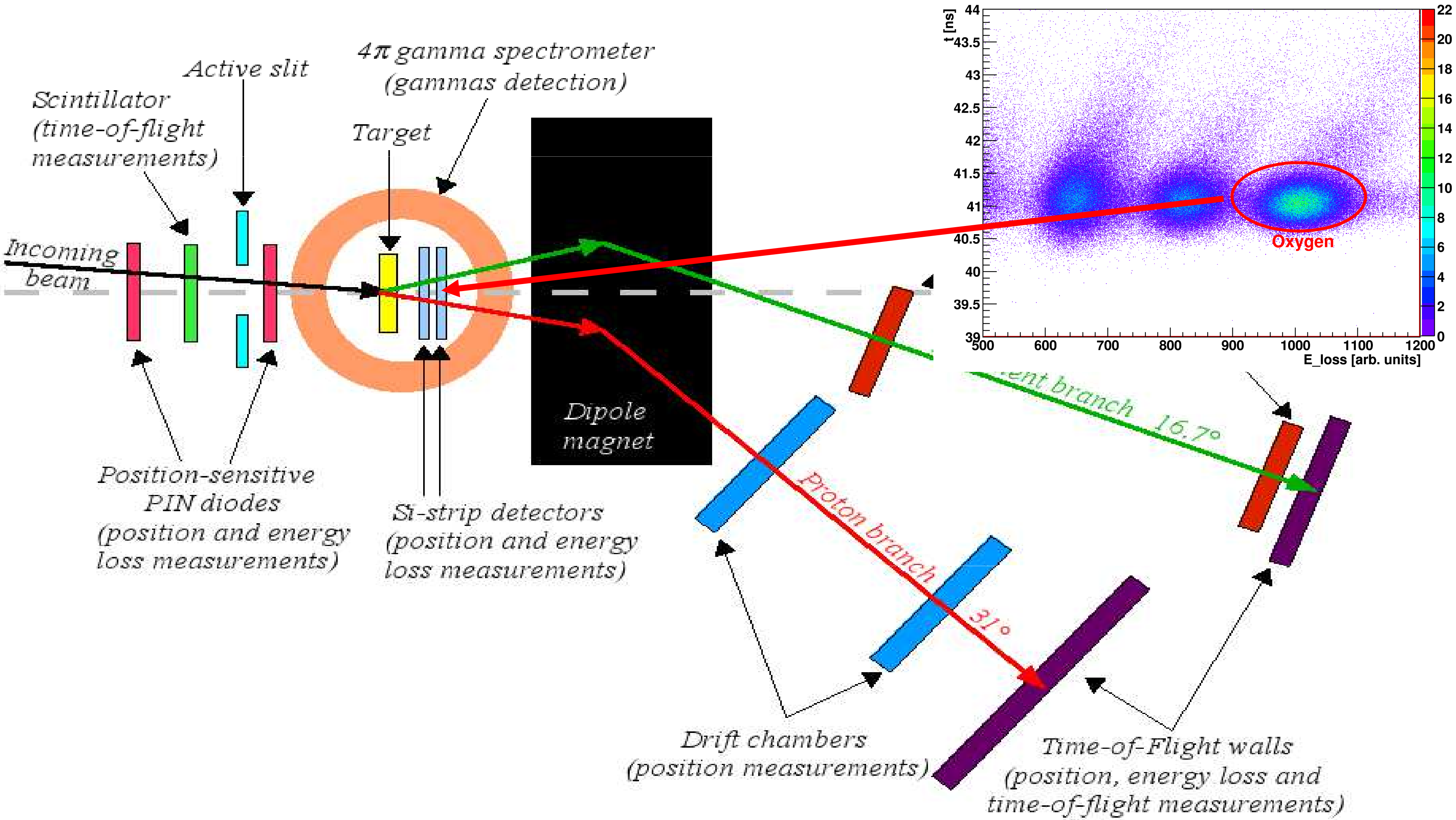
LAND-R^{3}B experimental setup



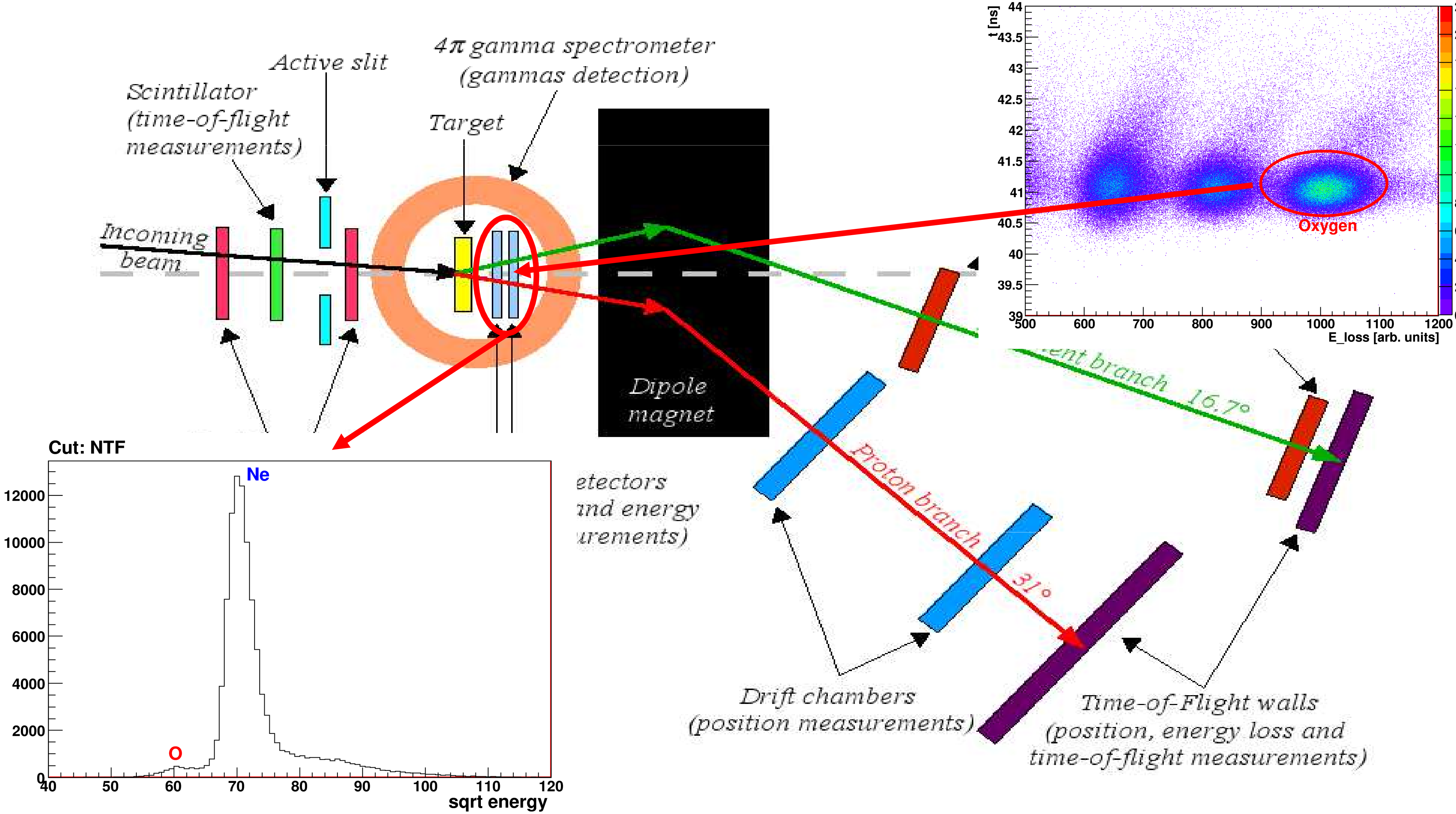
LAND-R^{3}B experimental setup



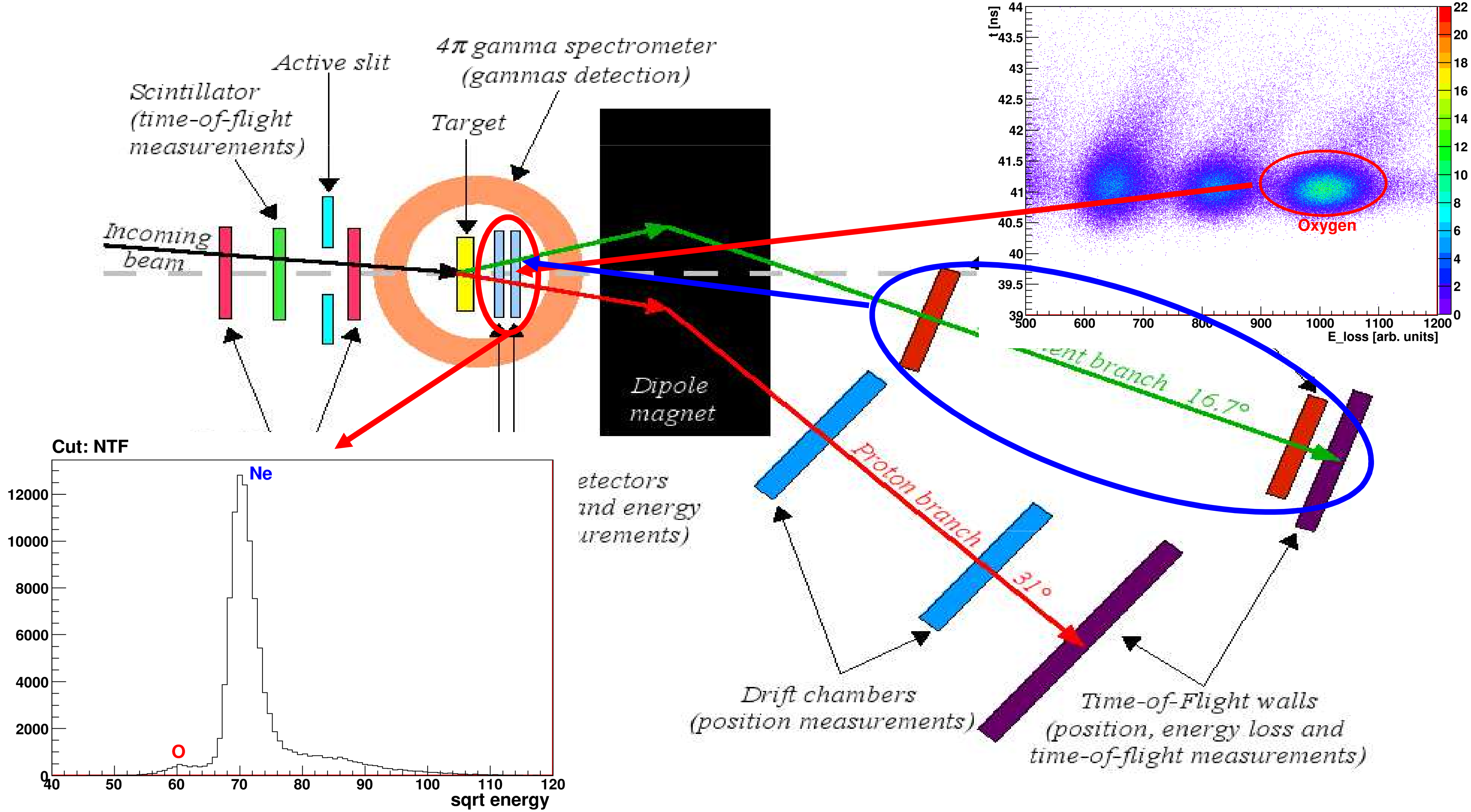
LAND-R^{3}B experimental setup



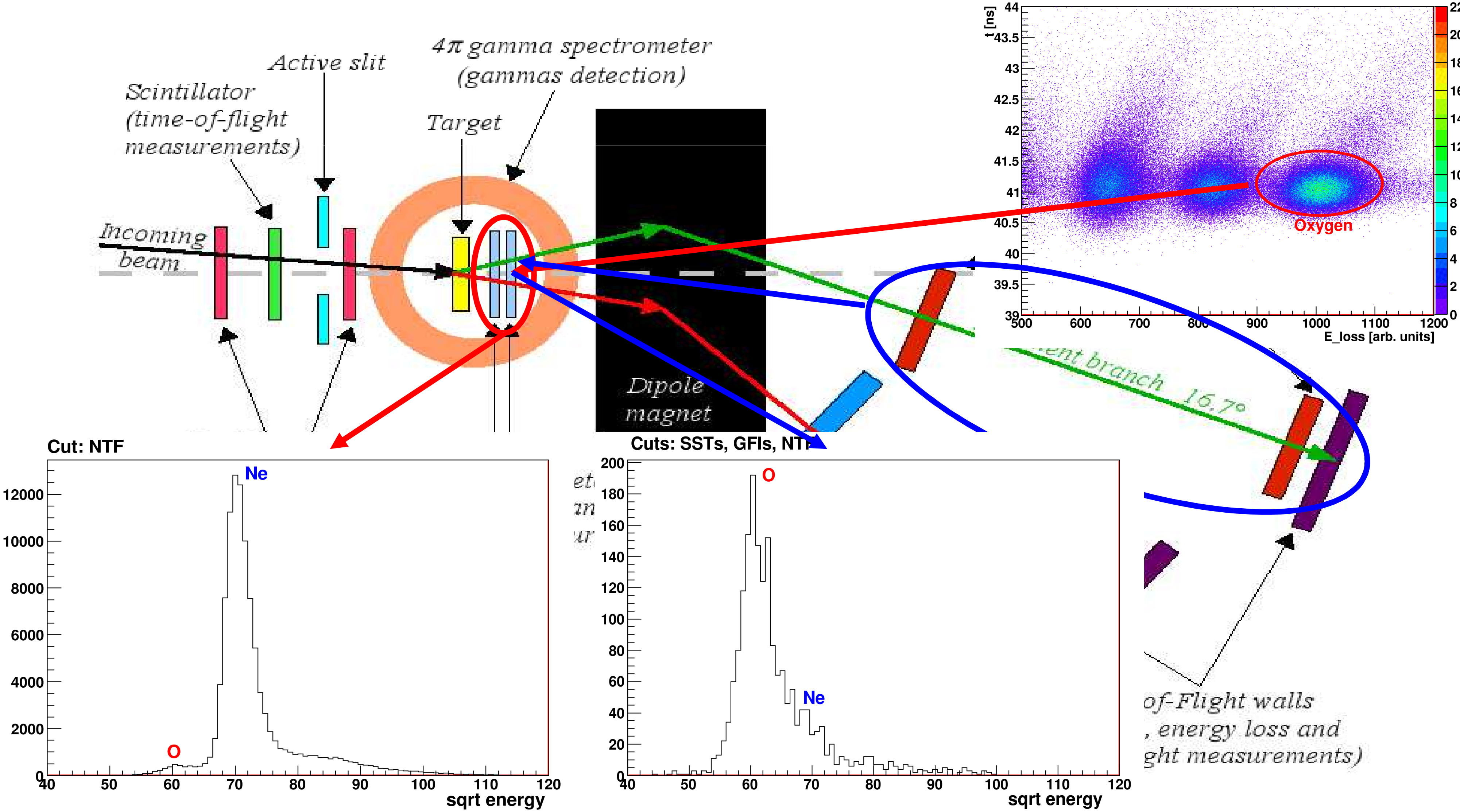
LAND-R³B experimental setup



LAND-R³B experimental setup

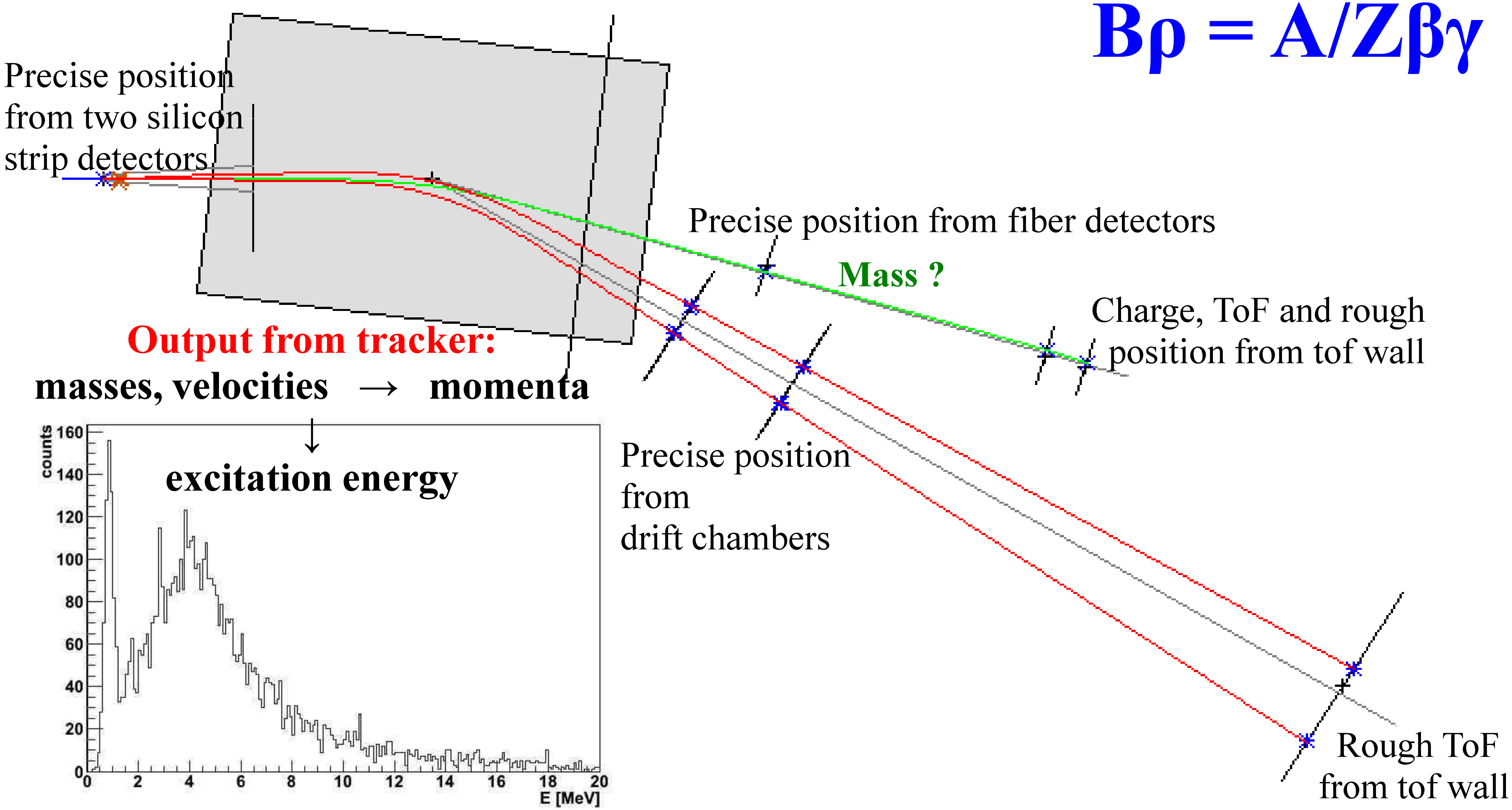


LAND-R³B experimental setup

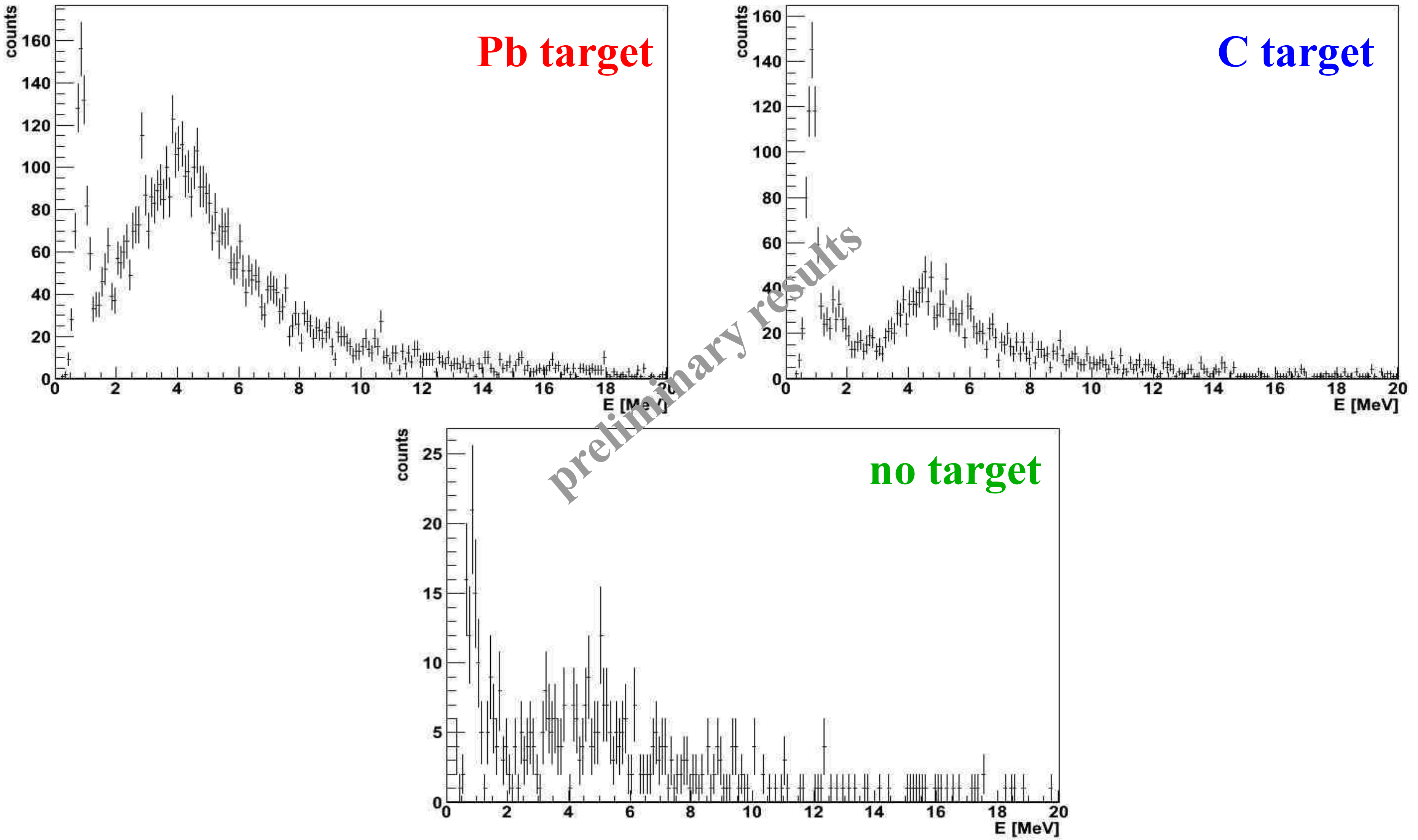


tracking

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

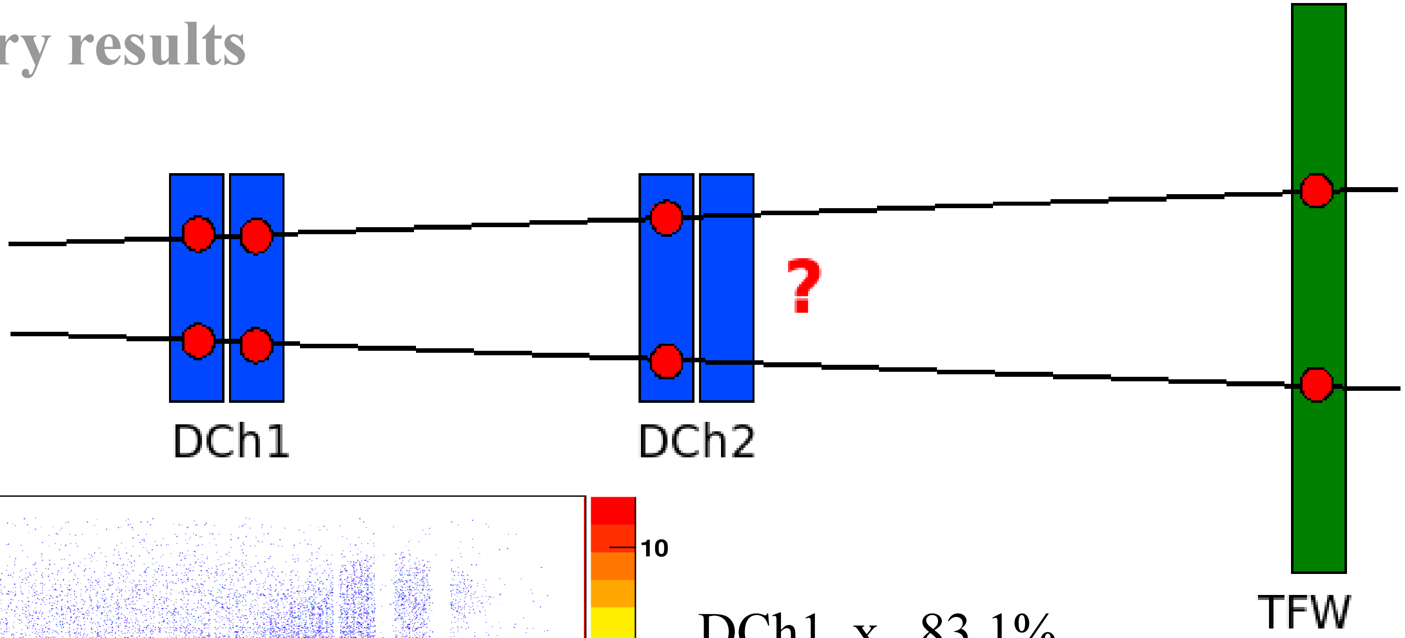


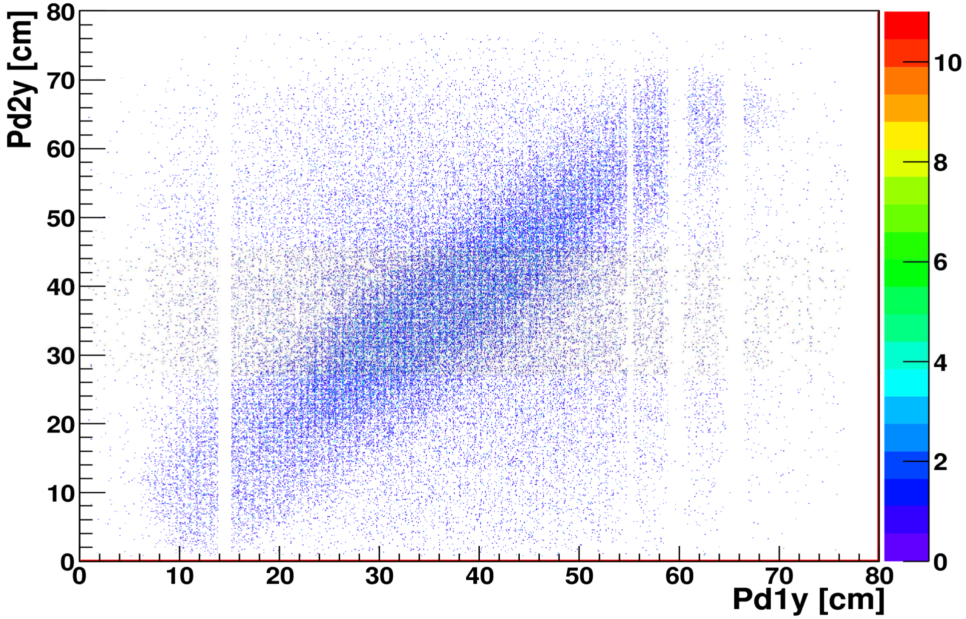
relative energy



proton arm efficiency

preliminary results





DCh1_x 83.1%

DCh1_y 75.6%

DCh1 62.8%

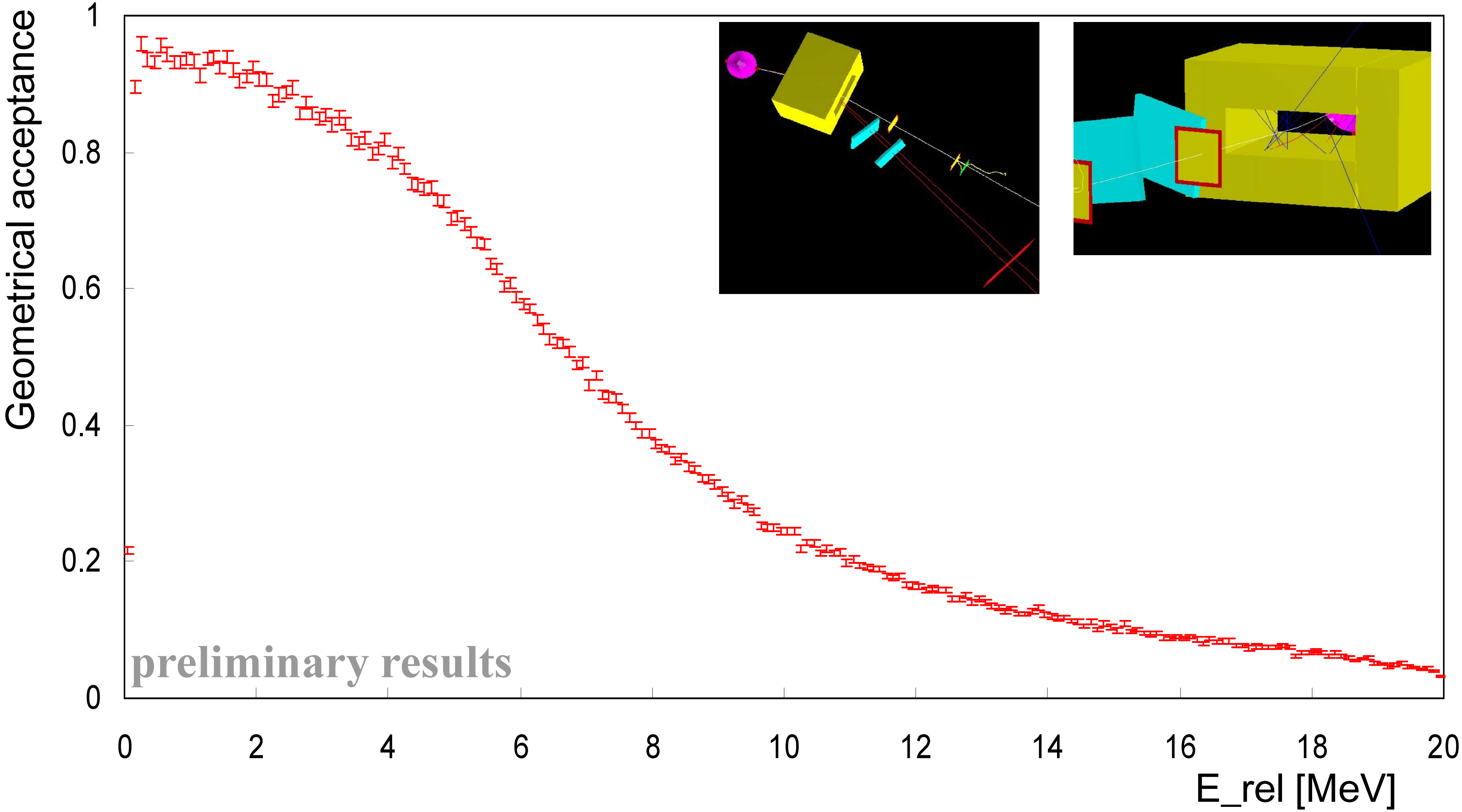
DCh2_x 89.8%

DCh2_y 91.1%

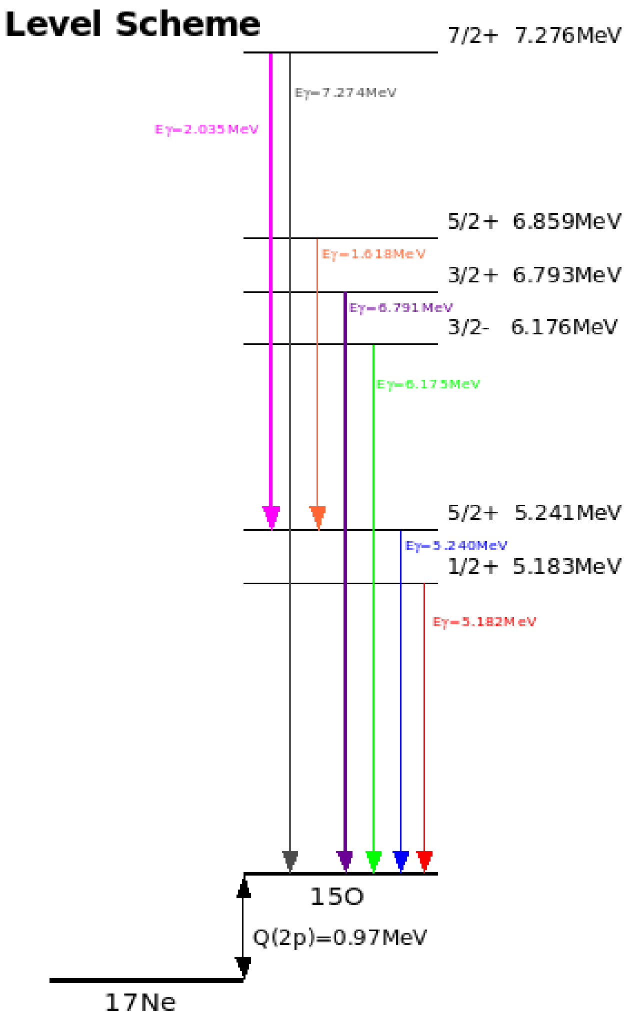
DCh2 81.8%

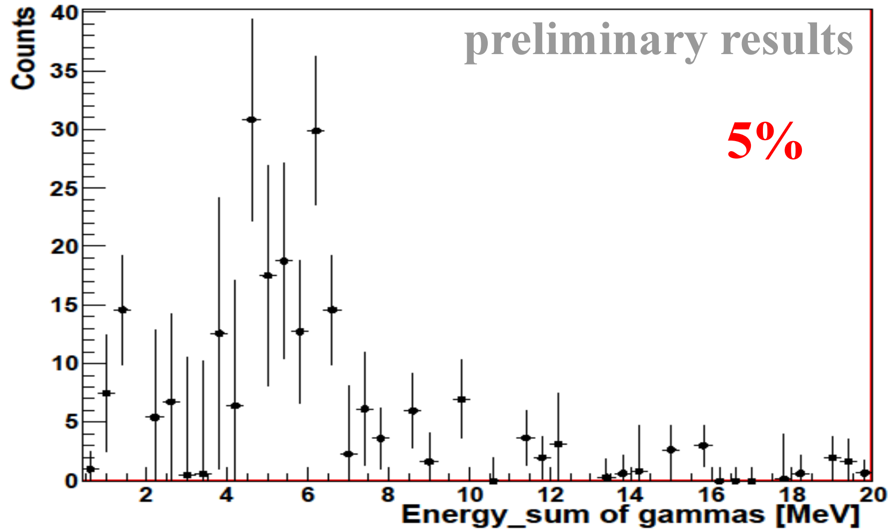
Total 51.4±1.4%

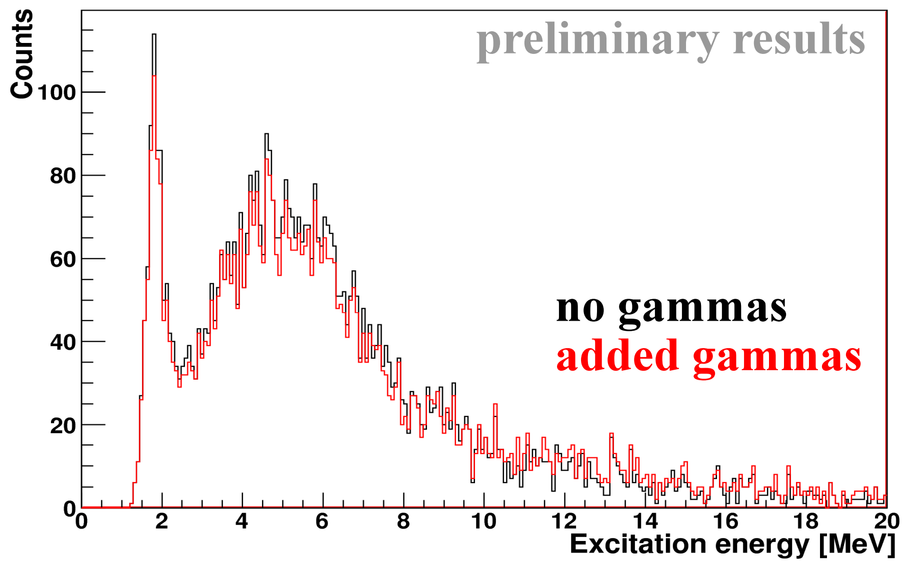
geometrical acceptance



excitation state







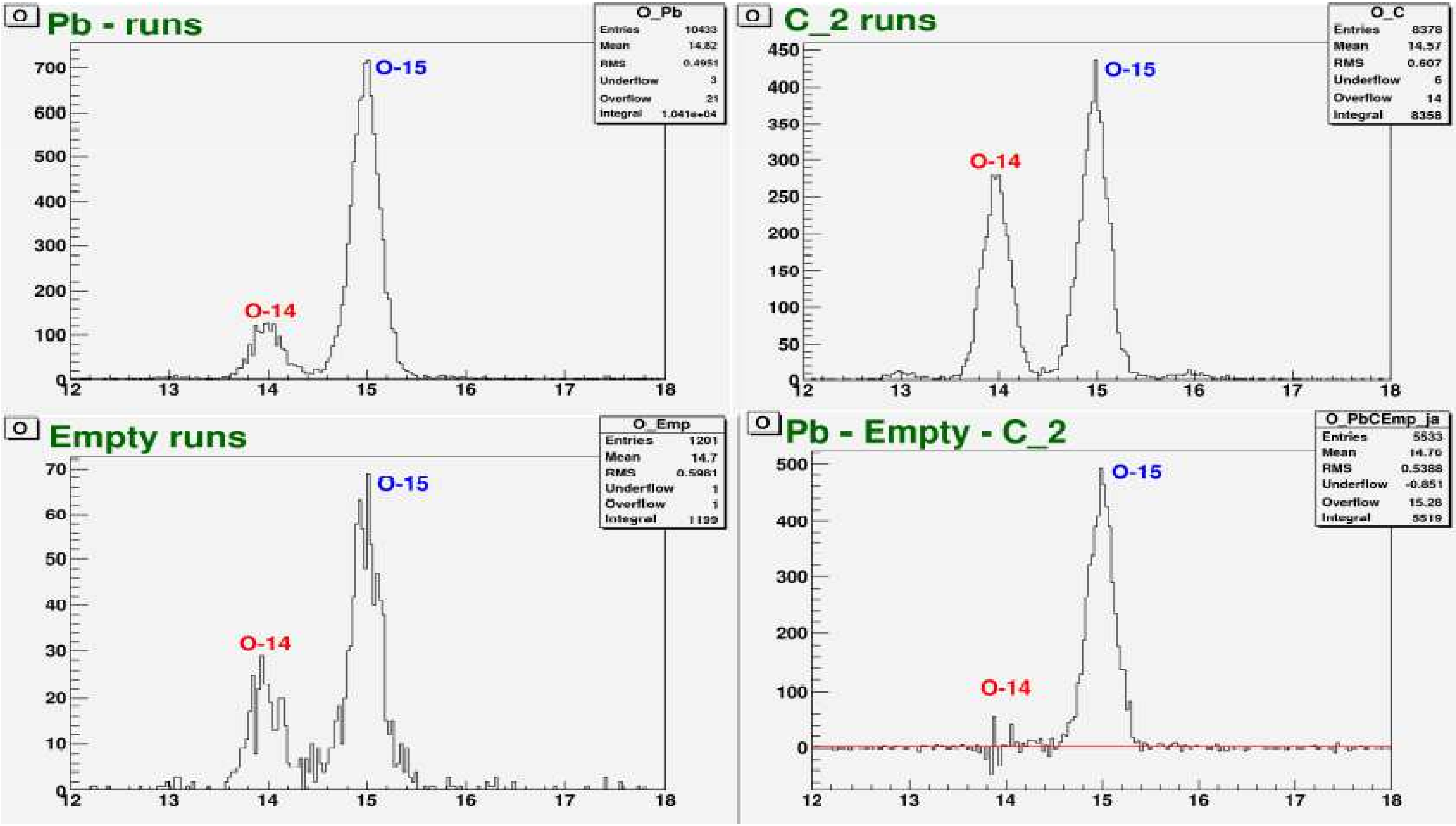
Coulomb dissociation cross section

$$\sigma_{Coulex} = p_{Pb} \cdot \left(\frac{M_{m(Pb)}}{(d_{Pb} \cdot N_{Av})} \right) - p_C \cdot \left(\frac{\alpha_{Pb} \cdot M_{m(C)}}{(d_C \cdot N_{Av})} \right) - p_{Emp} \cdot \left(\frac{M_{m(Pb)}}{(d_{Pb} \cdot N_{Av})} - \frac{\alpha_{Pb} \cdot M_{m(C)}}{(d_C \cdot N_{Av})} \right)$$

Coulomb dissociation cross section

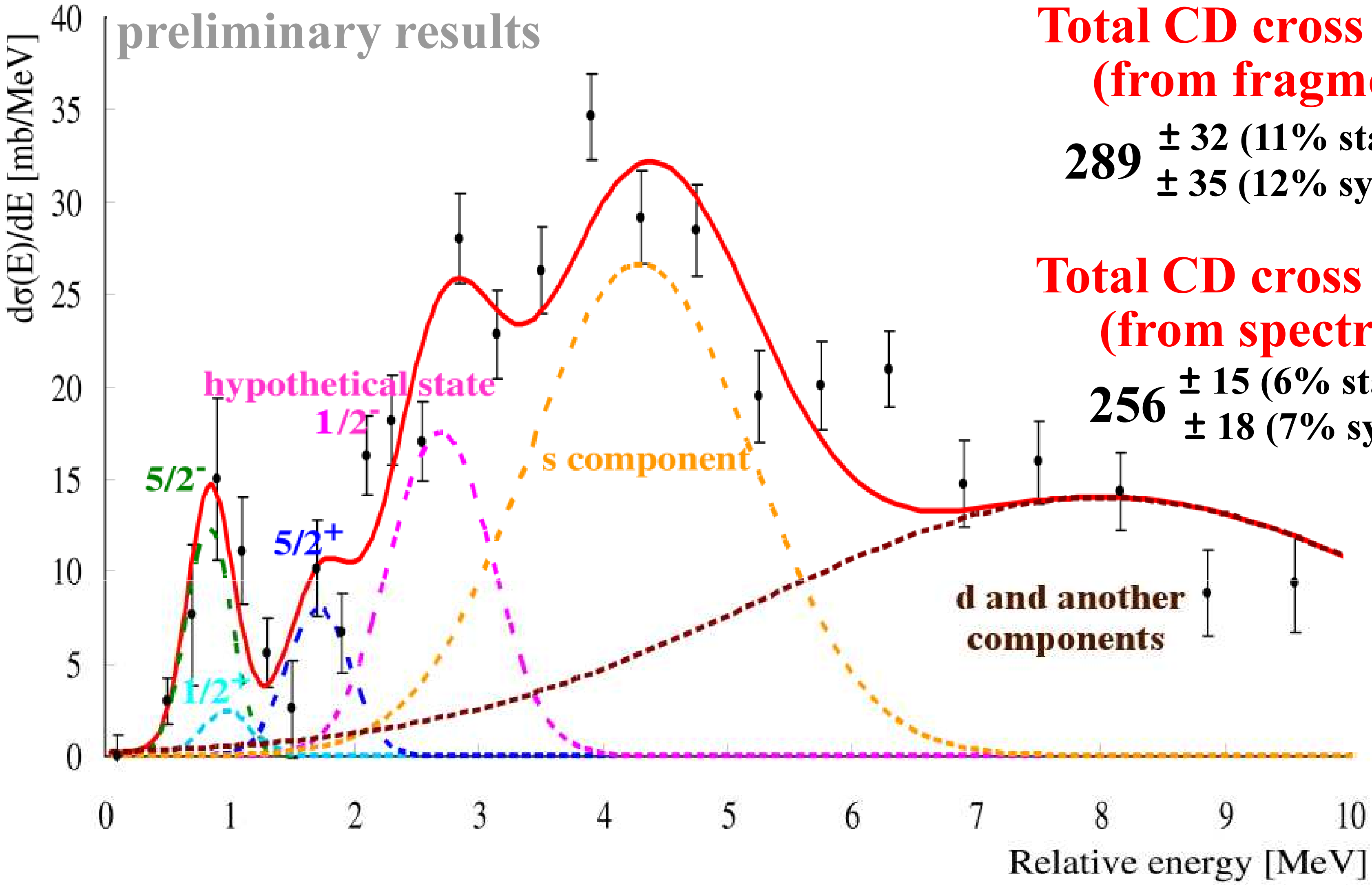
$$\sigma_{Coulex} = p_{Pb} \cdot \left(\frac{M_{m(Pb)}}{(d_{Pb} \cdot N_{Av})} \right) - p_C \cdot \left(\frac{\alpha_{Pb} \cdot M_{m(C)}}{(d_C \cdot N_{Av})} \right) - p_{Emp} \cdot \left(\frac{M_{m(Pb)}}{(d_{Pb} \cdot N_{Av})} - \frac{\alpha_{Pb} \cdot M_{m(C)}}{(d_C \cdot N_{Av})} \right)$$

α – factor estimation



Nuclear Astrophysics Virtual Institute

Coulomb dissociation cross section



Total CD cross section (from fragments)

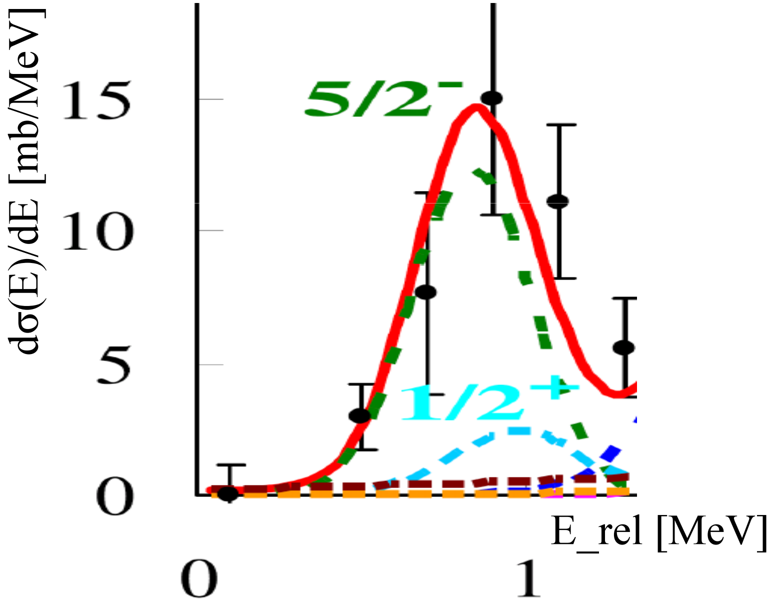
$289 \begin{matrix} \pm 32 \text{ (11\% stat.)} \\ \pm 35 \text{ (12\% syst.)} \end{matrix}$ mb

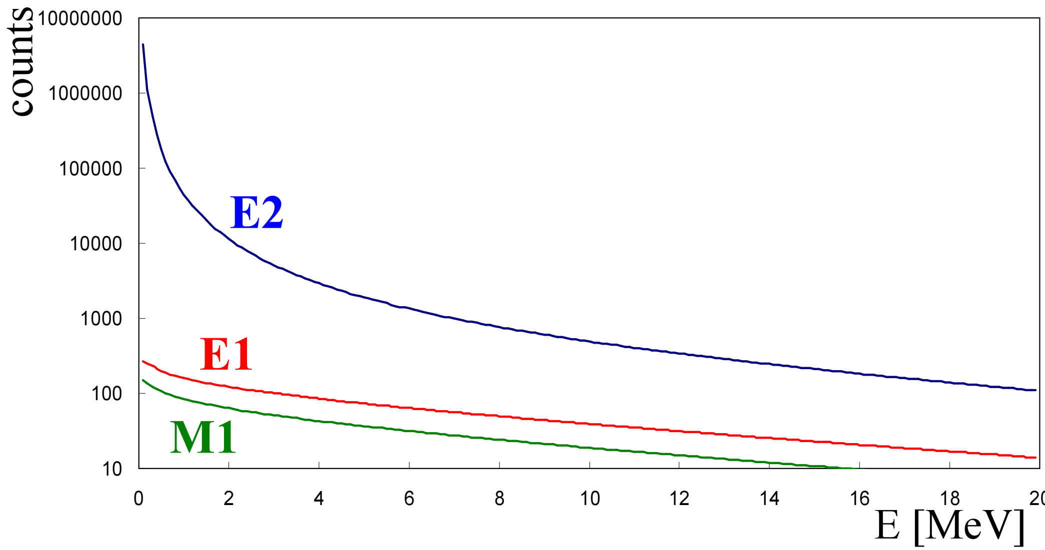
Total CD cross section (from spectrum)

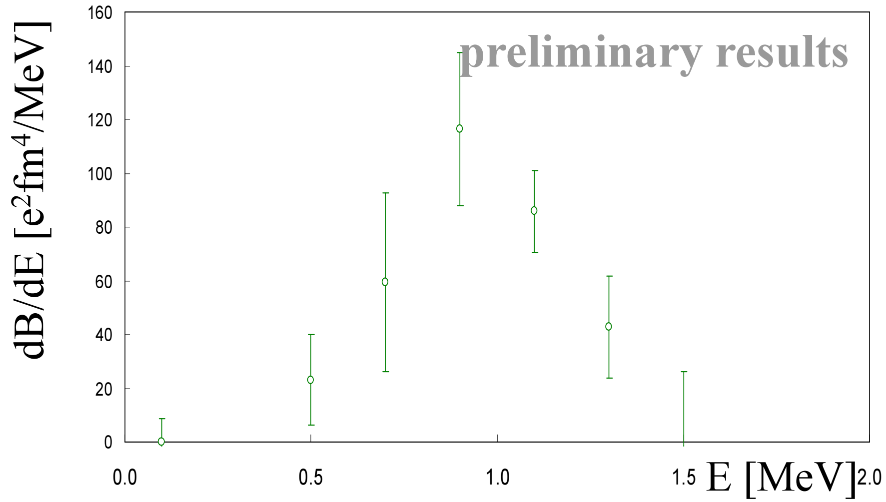
$256 \begin{matrix} \pm 15 \text{ (6\% stat.)} \\ \pm 18 \text{ (7\% syst.)} \end{matrix}$ mb

$\Delta = 11\%$

E2 strength







M.J. Chromik *et al.*, Phys. Rev. C 66, 024313 (2002)

(^{197}Au target, 58.7 AMeV, assumption from a deflection angle – only Coulomb excitation contribution)

$B(E2, {}^{17}Ne, 1/2^- \rightarrow 5/2^-) = 124 \pm 18\ e^2fm^4$

This work

$B(E2, {}^{17}Ne, 1/2^- \rightarrow 5/2^-) = 63 \pm 12\ e^2fm^4$

Jacobi coordinates

TECHNISCHE UNIVERSITÄT DARMSTADT

In order to understand the observed system the knowledge of their internal structure is needed. This information can be extracted from the correlations between decay products.

For the description of three-body systems, it is convenient to introduce a set of so called Jacobi coordinates. The Jacobi momenta are constructed as:

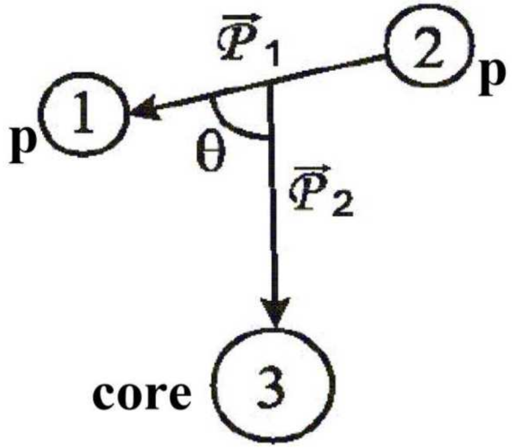
$$\begin{cases} \vec{\mathcal{P}}_1 = \left(\frac{\vec{p_i}}{m_i} - \frac{\vec{p_j}}{m_j}\right)\frac{m_i m_j}{m_i + m_j} \\ \vec{\mathcal{P}}_2 = \left(\frac{\vec{p_l}}{m_l} - \frac{\vec{p_i} + \vec{p_j}}{m_i + m_j}\right)\frac{m_l(m_i + m_j)}{m_i + m_j + m_l} \\ \vec{\mathcal{P}}_{cm} = \vec{p_i} + \vec{p_j} + \vec{p_l} \end{cases}$$

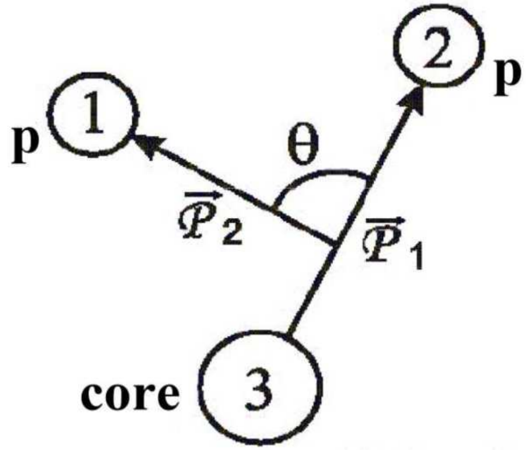
Source:
Y. Aksyutina
PhD thesis

NAVI
Nuclear Astrophysics Virtual Institute

Jacobi coordinates

In the case when two out of three particles are identical, there are two choices of Jacobi coordinate system, the so called „T" and „Y" systems, where (ijl)=(123) and (ijl)=231, respectively.



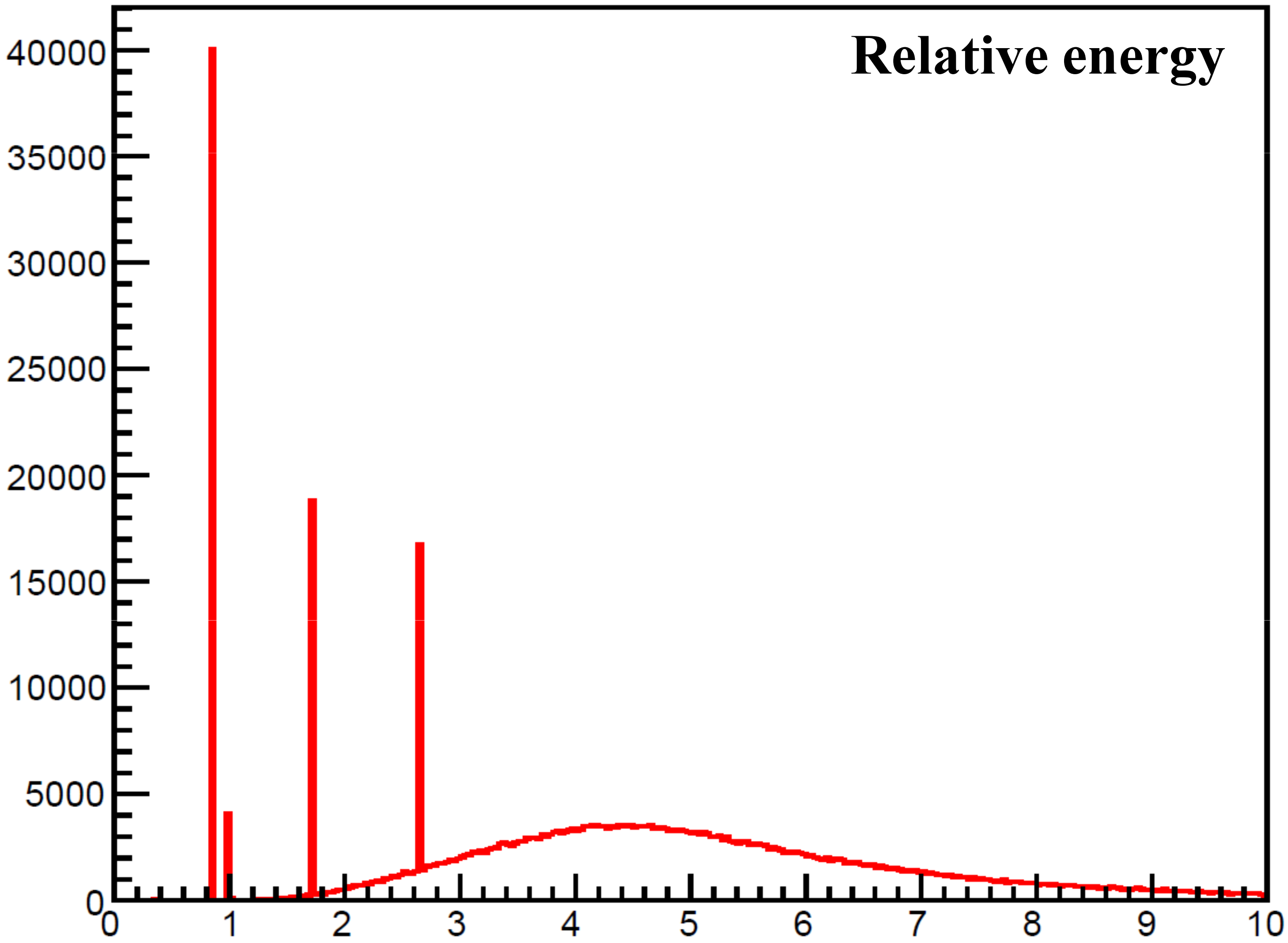


Source:
Y. Aksyutina
PhD thesis

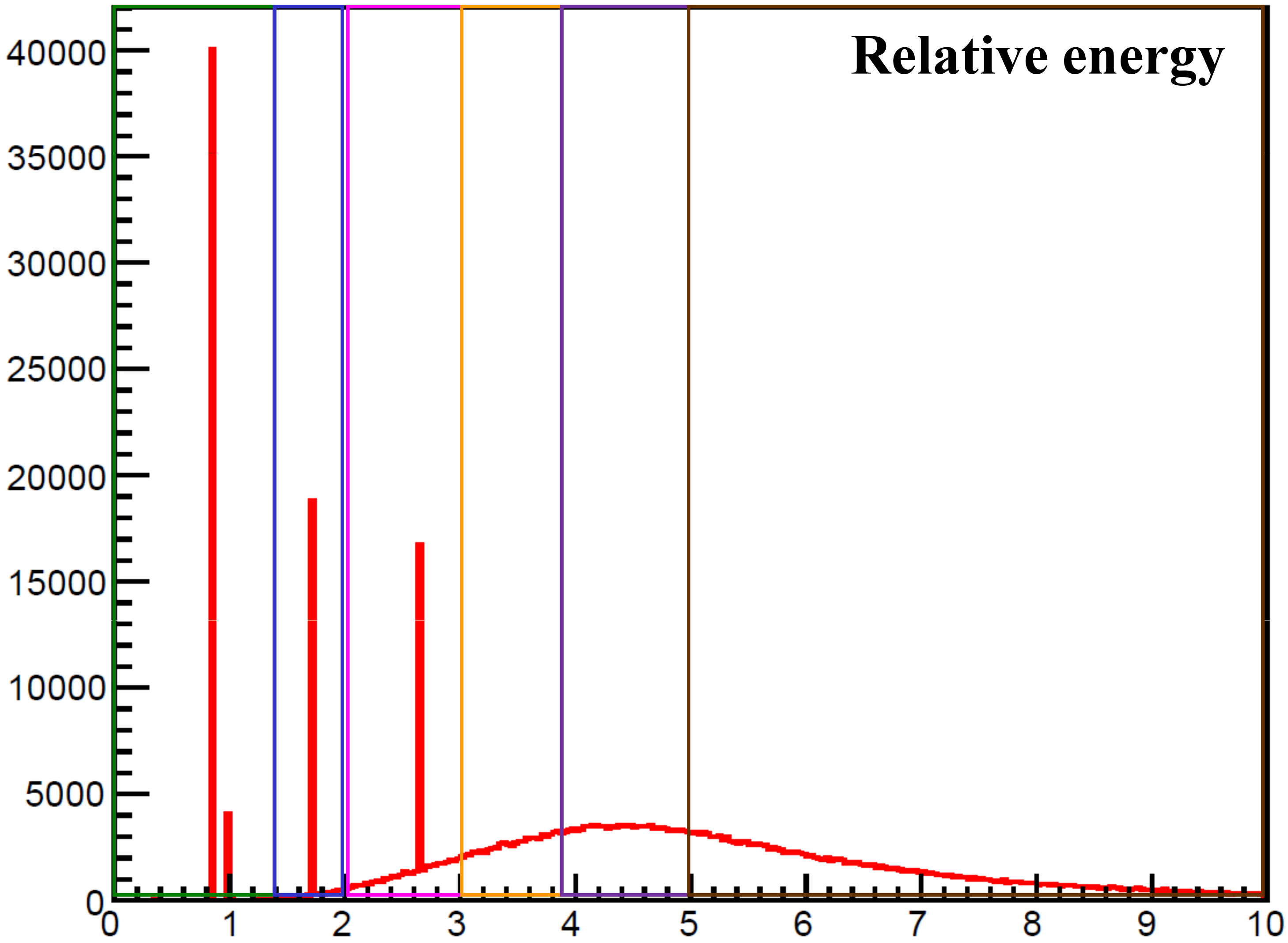
For each three-body system the energy and angular correlations in „T" and „Y" Jacobi coordinate systems can be obtained.

The energy ε in the T-system characterizes the energy correlations between the two protons. In the Y-system describes the energy correlations between the core fragment and one of the protons.

Jacobi coordinates



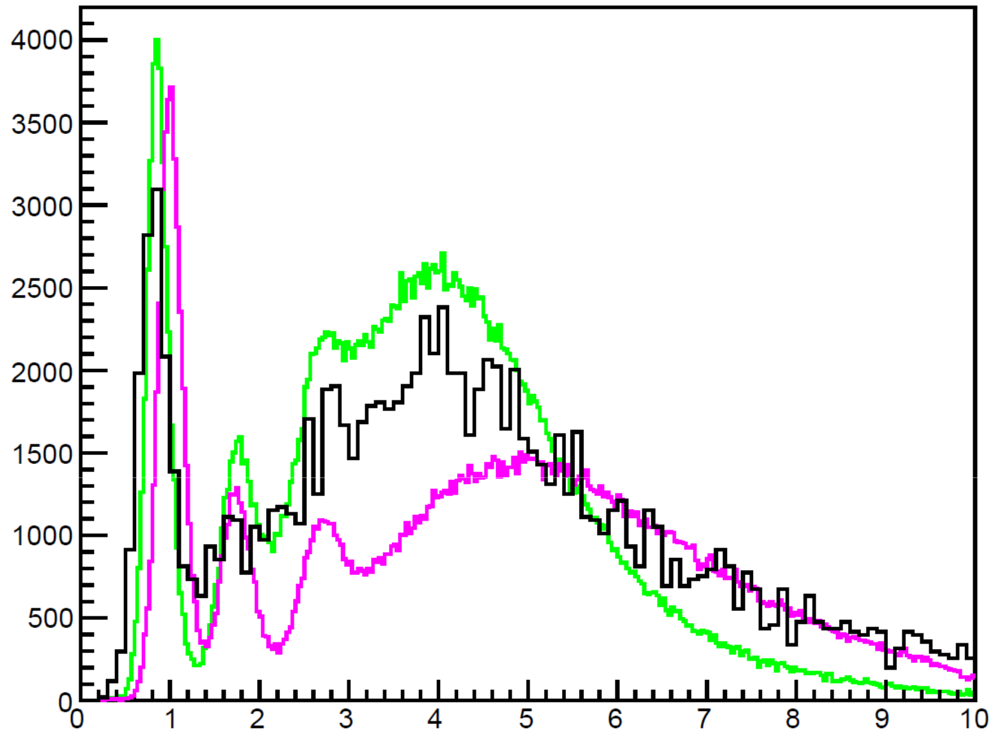
Jacobi coordinates



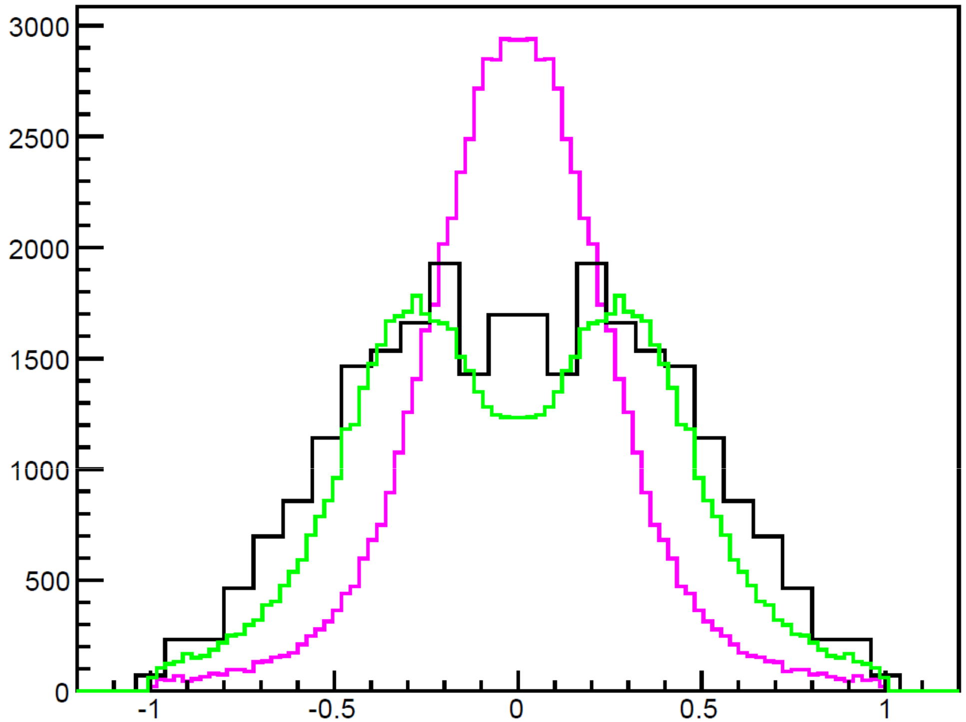
Jacobi coordinates

100% of s – state   100% of d – state   experimental data

Relative energy



Tcos_theta E_rel(0,1.4) track

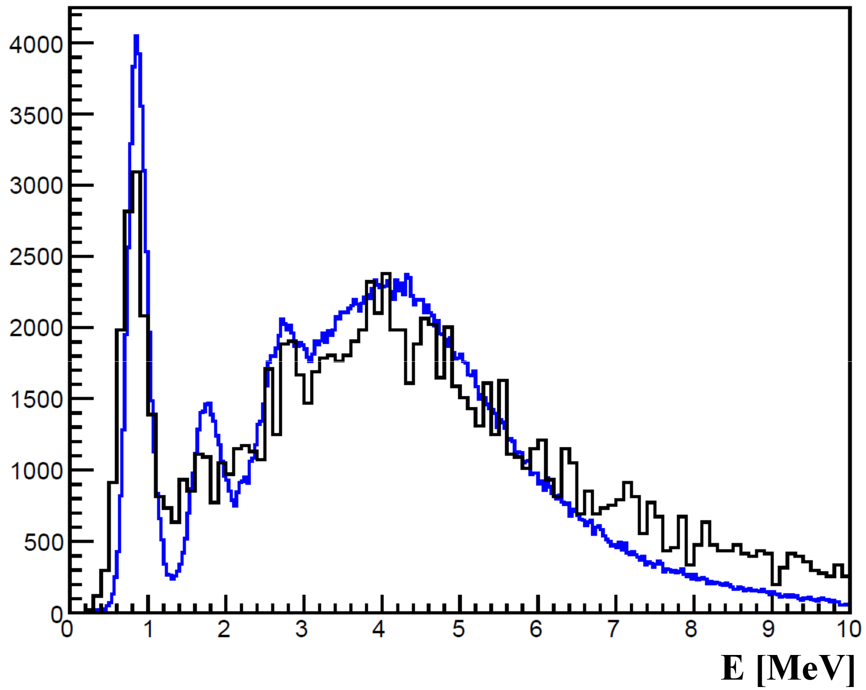


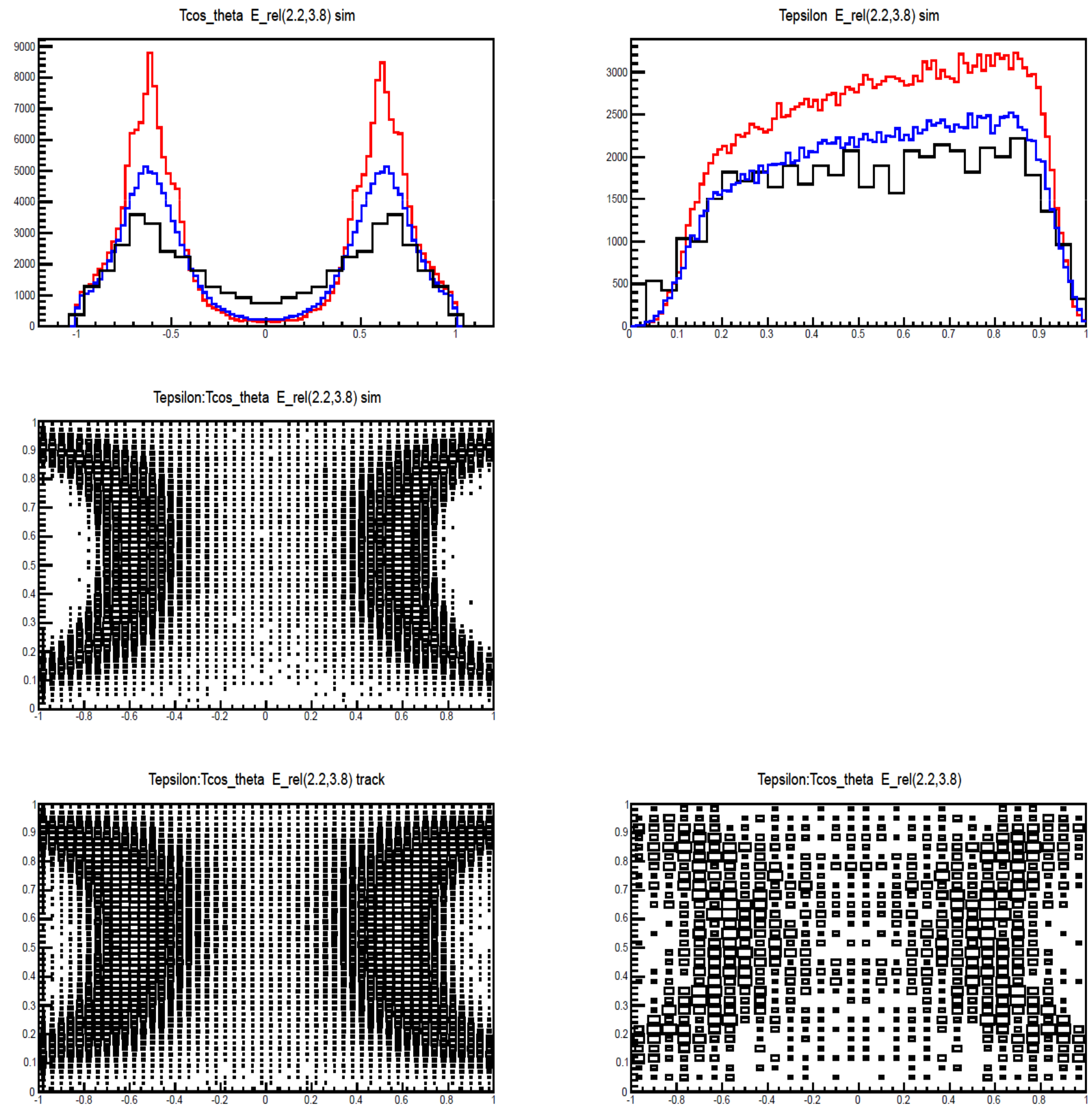
Jacobi coordinates

TECHNISCHE UNIVERSITÄT DARMSTADT

preliminary results

Relative energy





future work

TECHNISCHE UNIVERSITÄT DARMSTADT

What has to be done:

1. **a XB efficiency simulation;**
2. **final estimation of s^2 contribution and confirmation of ^{17}Ne model;**
3. **determine a radiative capture cross section;**
5. **uncertainties calculation;**

NAVI Nuclear Astrophysics Virtual Institute

summary

- **the Coulomb dissociation method => usefull tool for nuclear structure and astrophysics (e.g. only one way to the three particles in entrance channel measurements);**
- **$^{15}O(2p,\gamma)^{17}Ne$ => maybe the alternative break-out reaction of CNO cycle;**
- **the coulomb dissociation cross section determined;**
- **the previous experimental E2 strength – twice bigger that in this work;**
- **the s^2 contribution estimation and the calculation of $^{15}O(2p,\gamma)^{17}Ne$ cross section => in progress.**

collaboration

TECHNISCHE UNIVERSITÄT DARMSTADT

T. Aumann[1,2], I. Egorova[3], L.V. Grigorenko[3],

M. Heil[1], Yu. Parfenova[3,4], R. Plag[1], F. Wamers[2,5]

for LAND-R^{3}B collaboration

[1] Kernreaktion und Nuklear Astrophysik, GSI Darmstadt, Germany

[2] Institut für Kernphysik, TU Darmstadt, Germany

[3] Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia

[4] Institute of Nuclear Physics, Moscow State University, Russia

[5] ExtreMe Matter Institute EMMI, GSI Darmstadt, Germany

Thank you!

outline