Proton-induced reactions at the ESR

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E062 and E108 collaborations

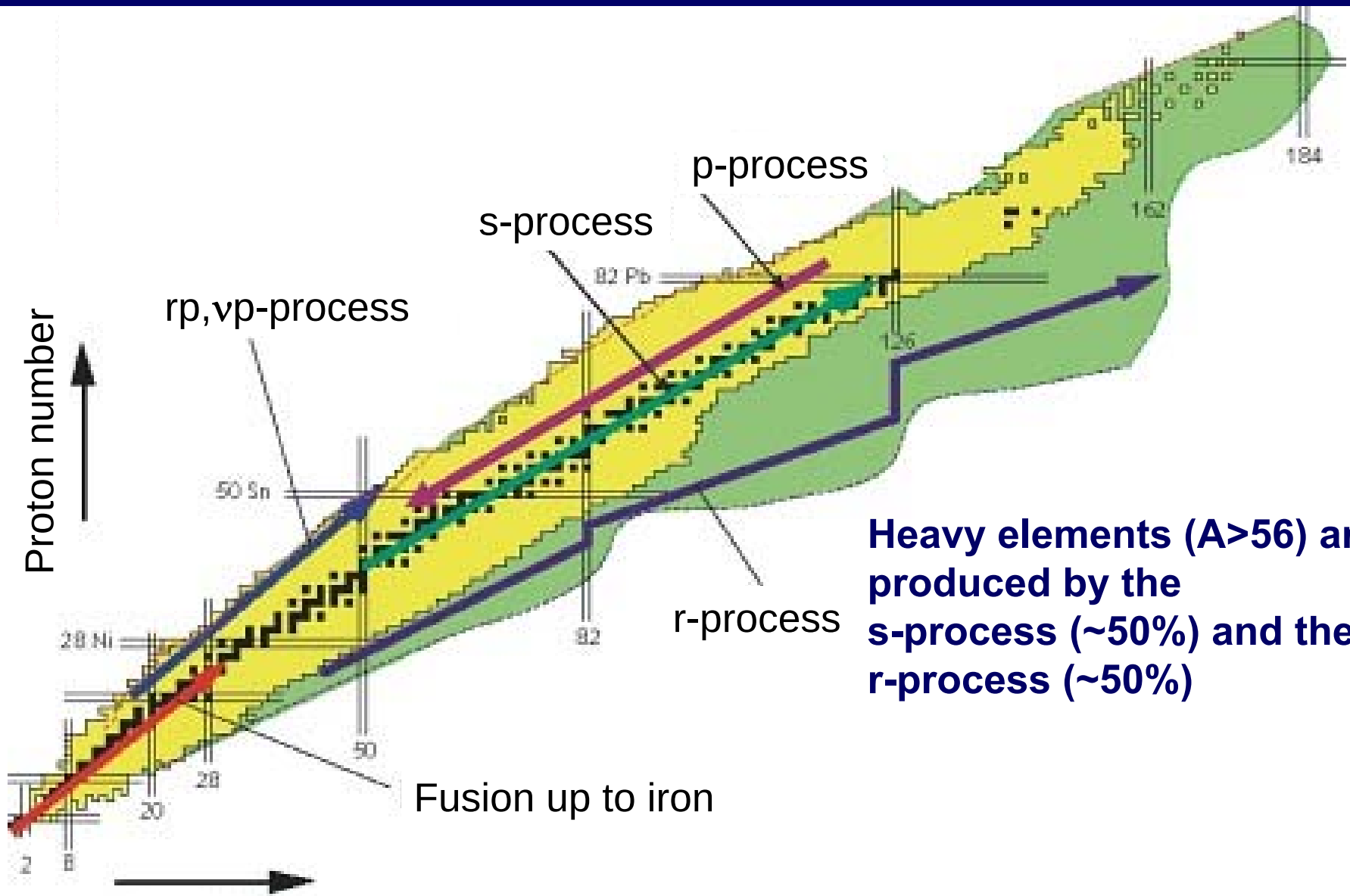
PHYSICS PROSPECTS AT THE ESR AND HITRAP

Eisenach, Germany, June 27-30, 2010

Outline

- (p,γ) @ ESR – so far
- (p,γ) @ ESR – next year
- (p,n) @ ESR – possibly

Nucleosynthesis of the elements



Heavy elements (A>56) are produced by the s-process (~50%) and the r-process (~50%)

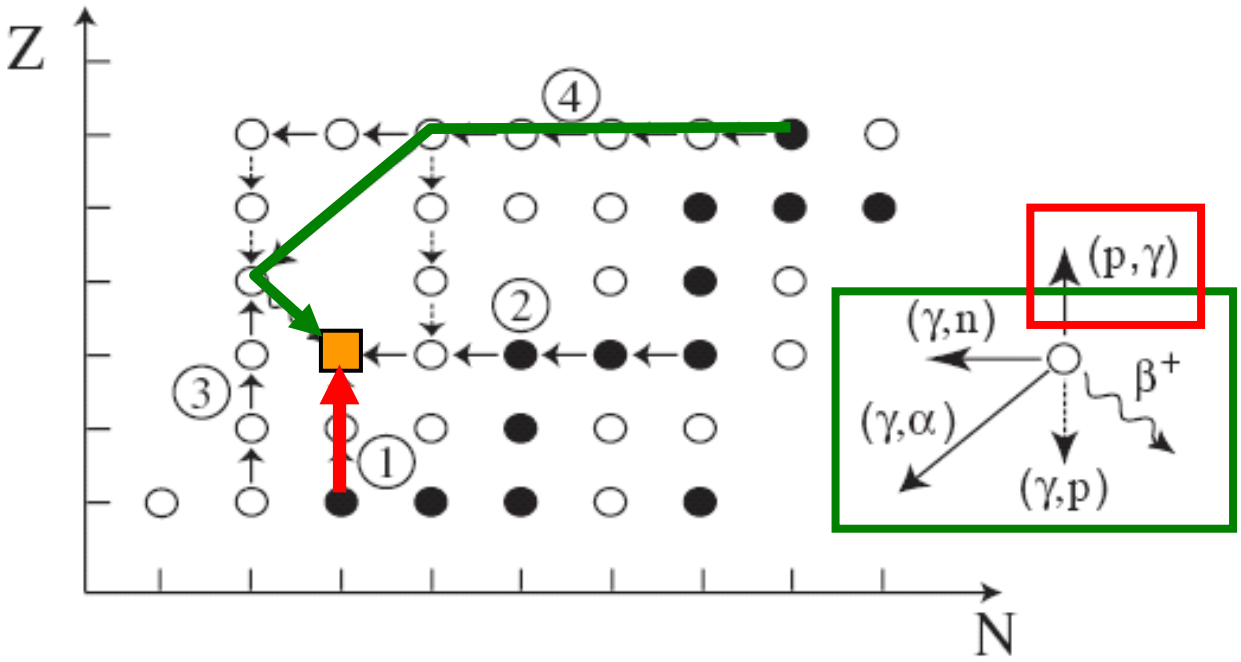
Astrophysics motivation: the p-process

- 35 stable neutron-deficient isotopes between ^{74}Se and ^{196}Hg
- Dominating reactions: **(p,γ)** for light nuclei;
  (γ,n), (γ,p), (γ,α) and **β$^+$** decays for heavier nuclei
- Temperatures of 2-3×10^9 K during time scales of a few seconds are required (type II supernovae explosions)

p-nuclide

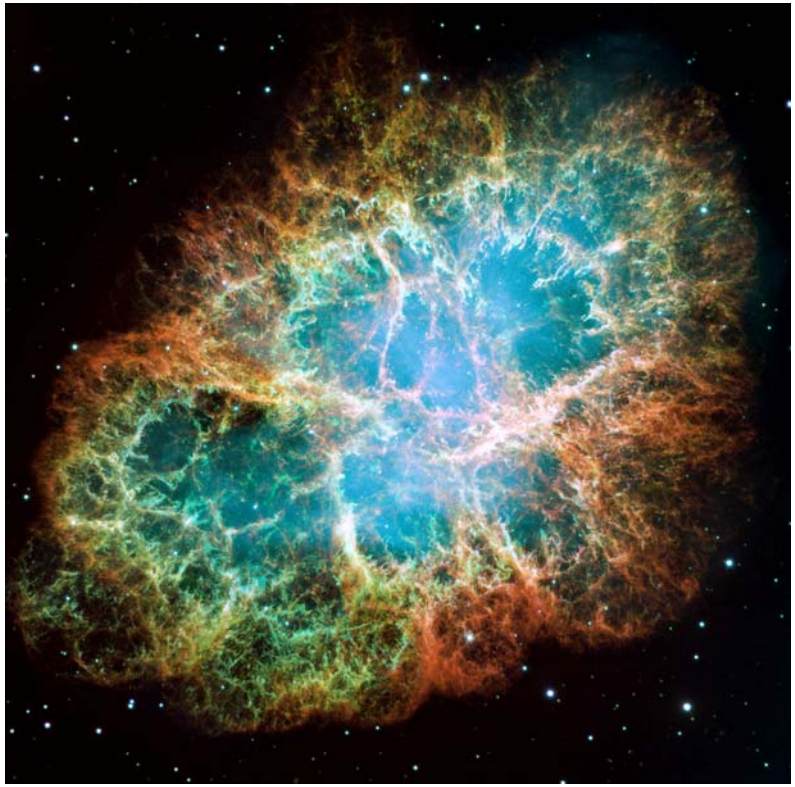
r- or s- seed nuclei

unstable nuclei

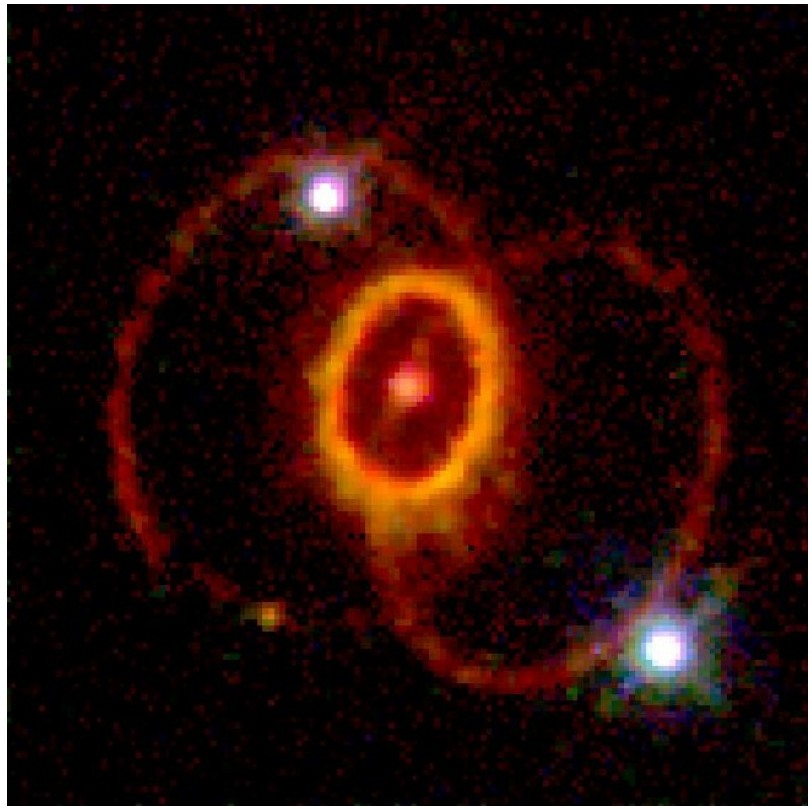


Typ II Supernovae (core collaps supernovae)

Left overs from SN form new stars and planets



crab nebula – SN 1054 (NASA)



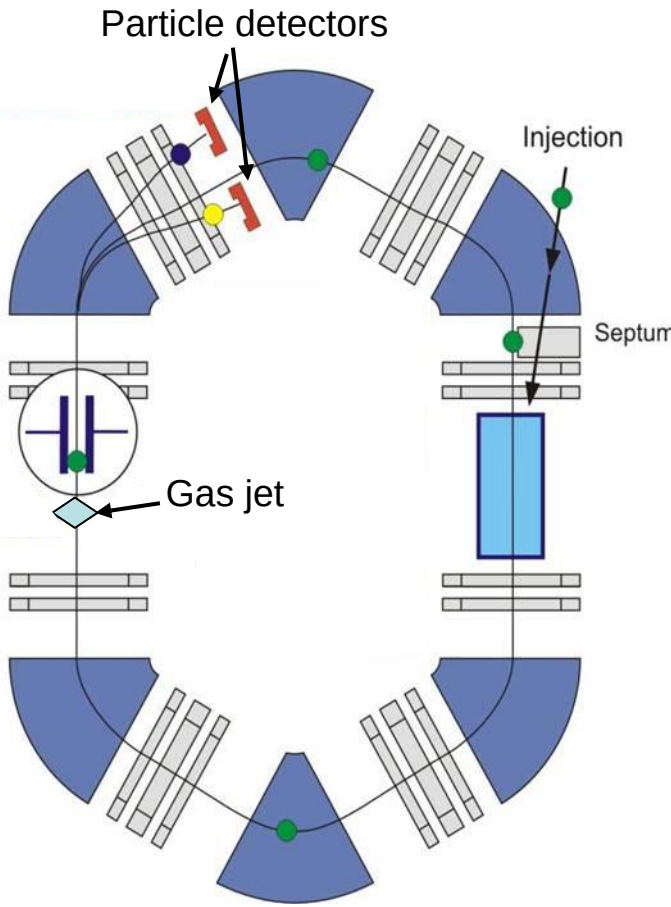
SN 1987A (NASA)

Reaction Studies at the ESR

Measurements of (p,γ) or (α,γ) rates in the Gamow window of the p-process in inverse kinematics.

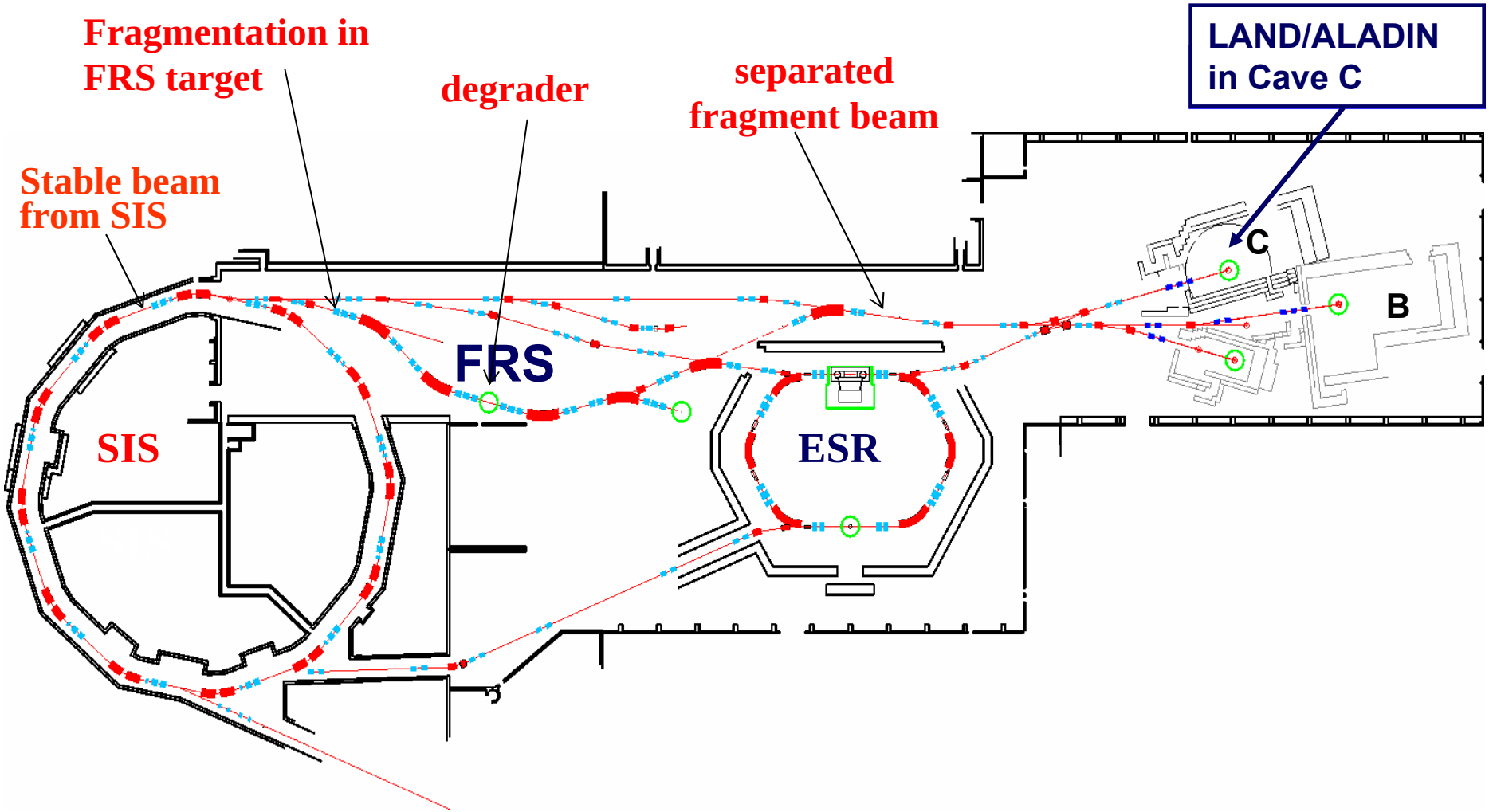
Advantages:

- **Applicable to radioactive nuclei**
- **Detection of ions via in-ring particle detectors (low background, high efficiency)**
- **Knowledge of line intensities of product nucleus not necessary**
- **Applicable to gases**



ESR

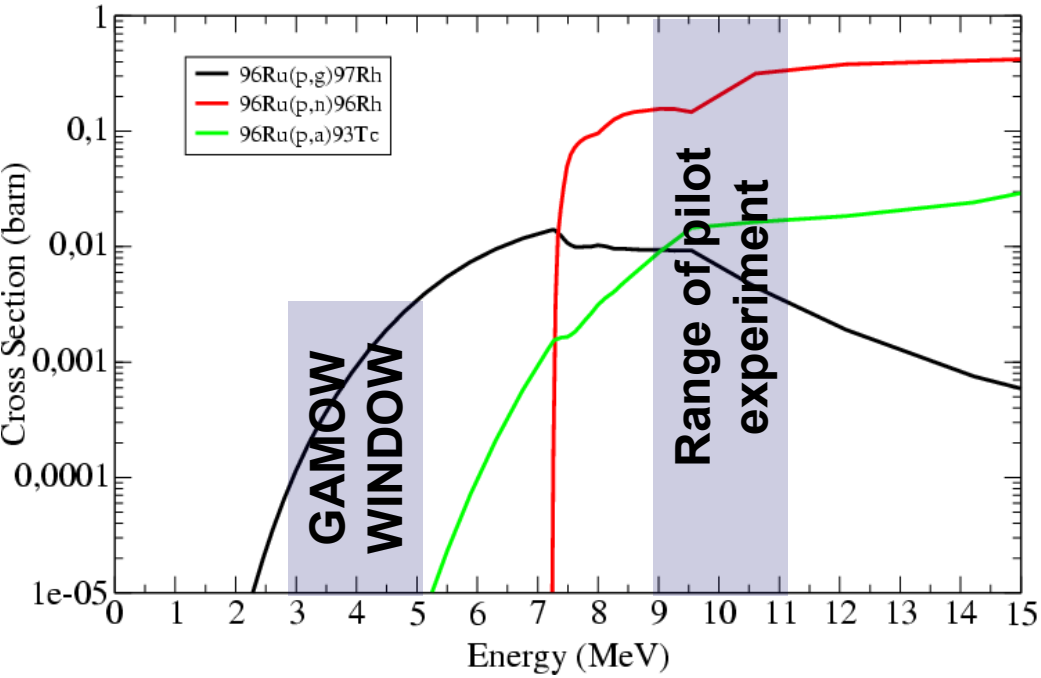
Layout of the experimental facilities at GSI

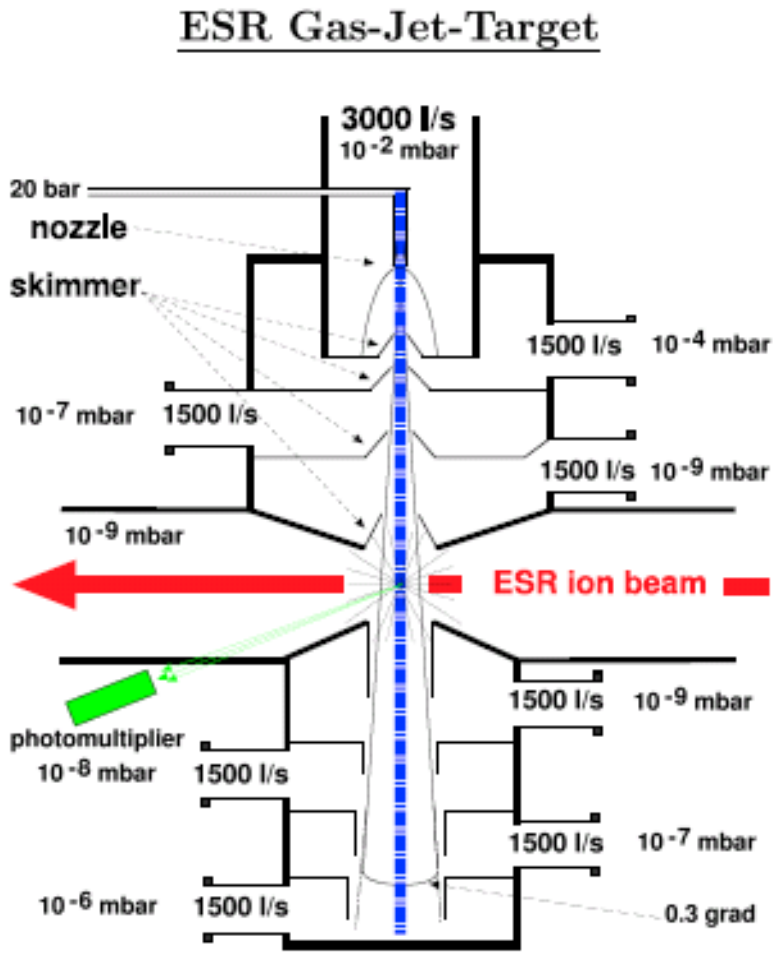


Reaction Studies at the ESR

First pilot experiment performed with stable beams: $^{96}Ru(p,\gamma)^{97}Rh$

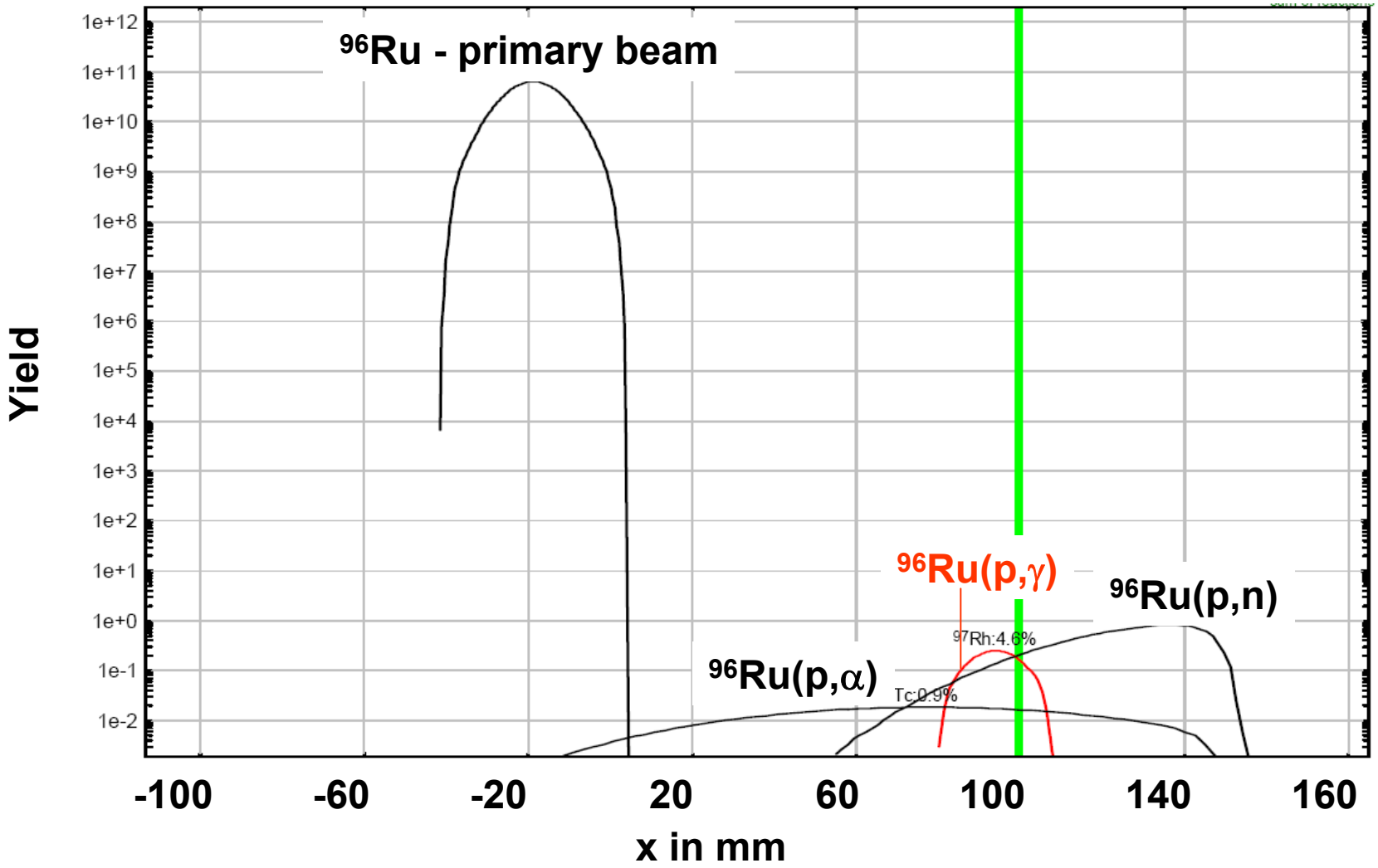
- **Measurements performed at 9, 10, 11 AMeV**
- **$5 \cdot 10^6$ particles per spill**
- **Target density $1 \cdot 10^{13}$ atoms/cm^2**
- **Luminosity $2.5 \cdot 10^{25}$**
- **Cross section 2 mbarn -> ~180 counts/h**





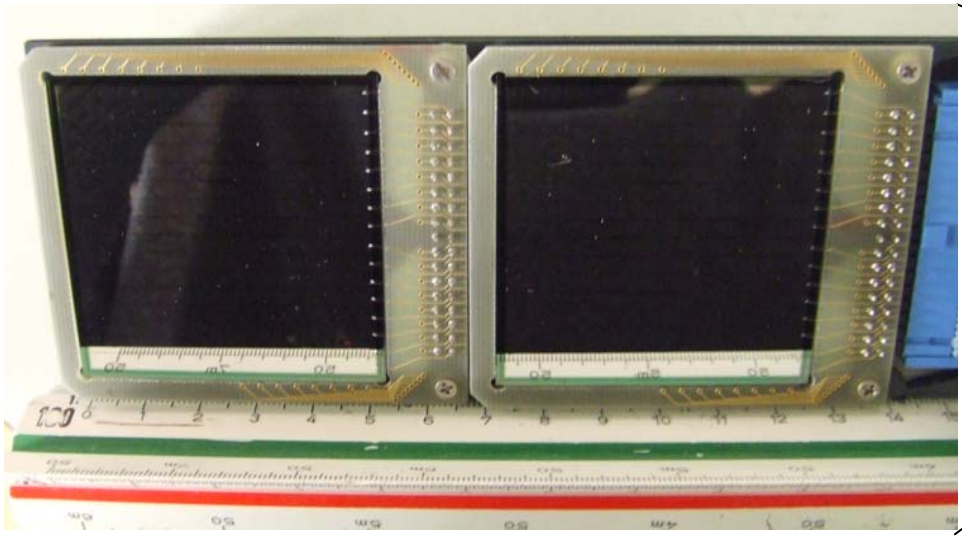
Q. Zhong et al., Journal of Physics: Conference Series, Volume 202, Issue 1, pp. 012011 (2010)

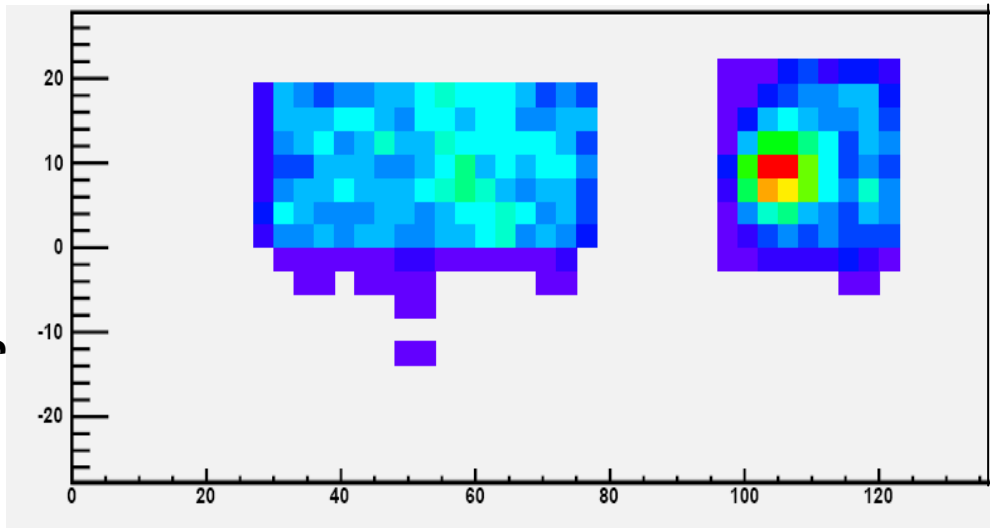
Simulations with LISE++

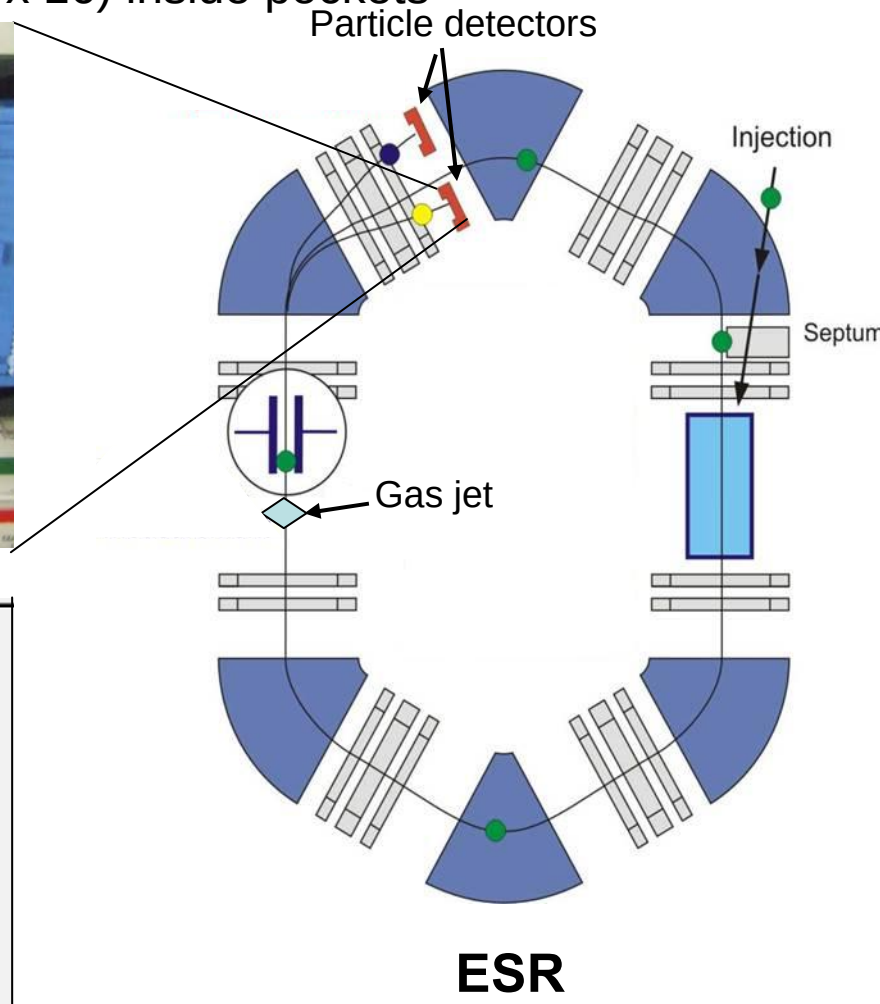


Reaction Studies at the ESR

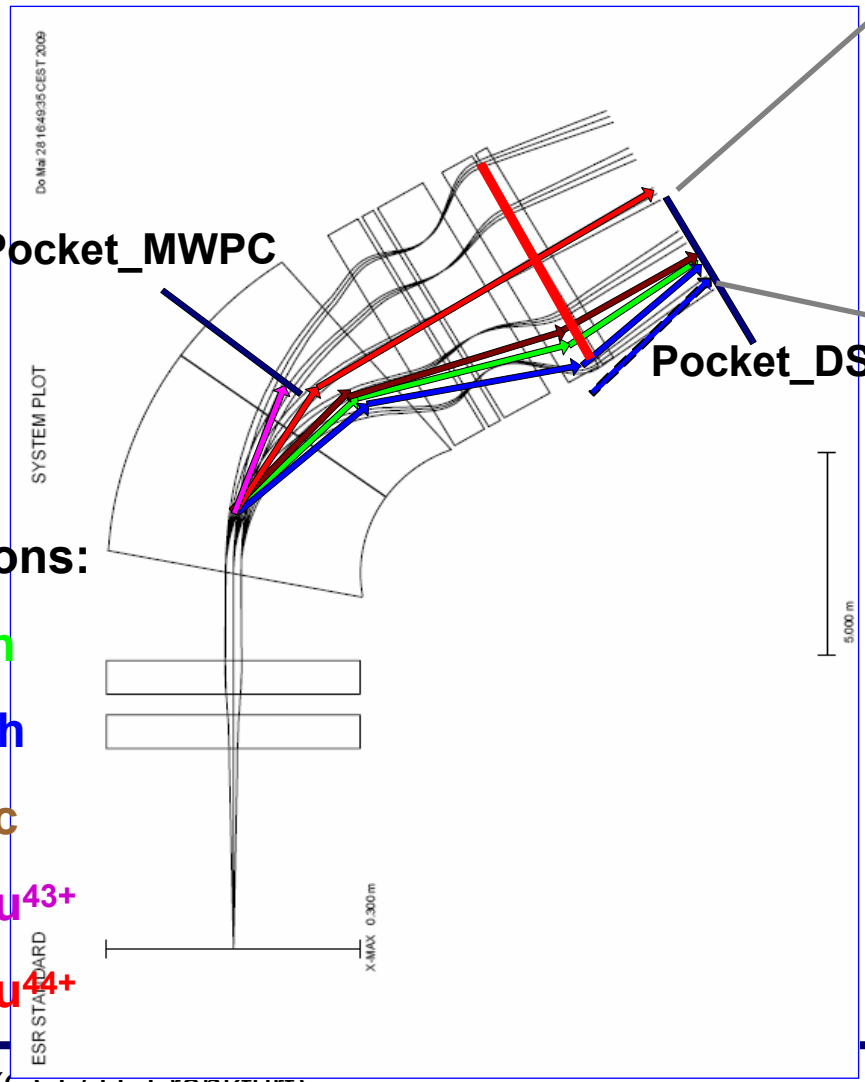
Particle detectors: Double sided silicon strip (16 x 16) inside pockets

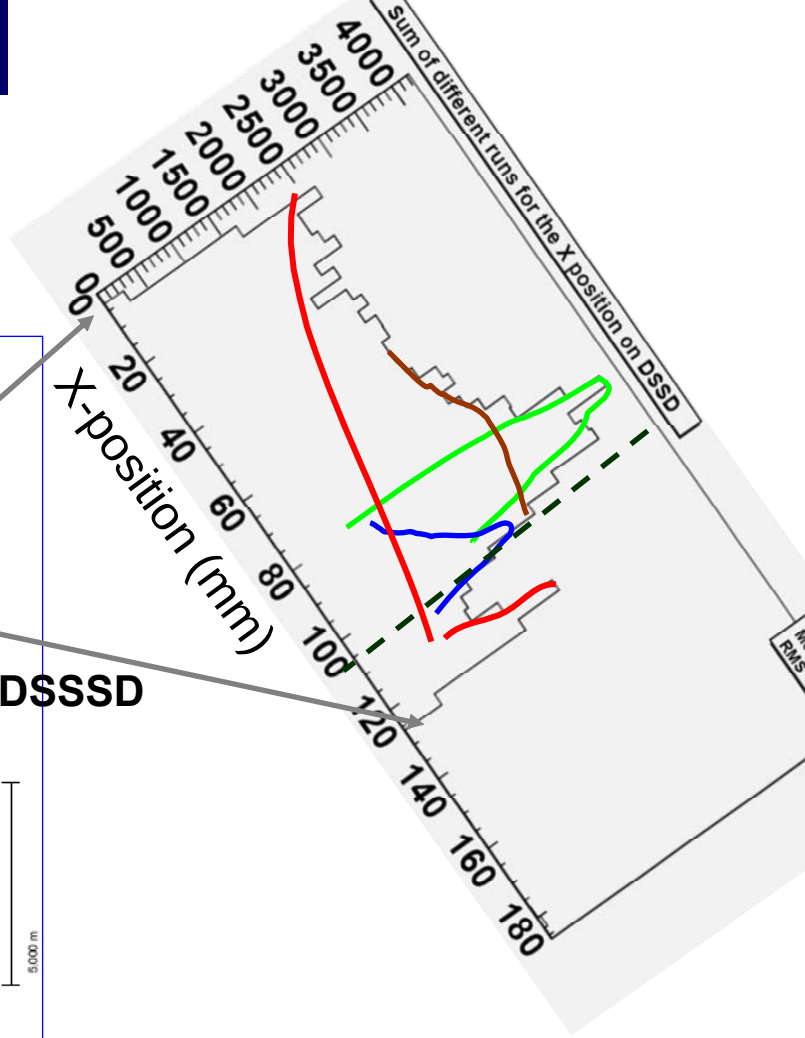






Analysis of position spectrum





Main Reactions:

$^{96}Ru(p,\gamma)^{97}Rh$

$^{96}Ru(p,n)^{96}Rh$

$^{96}Ru(p,\alpha)^{93}Tc$

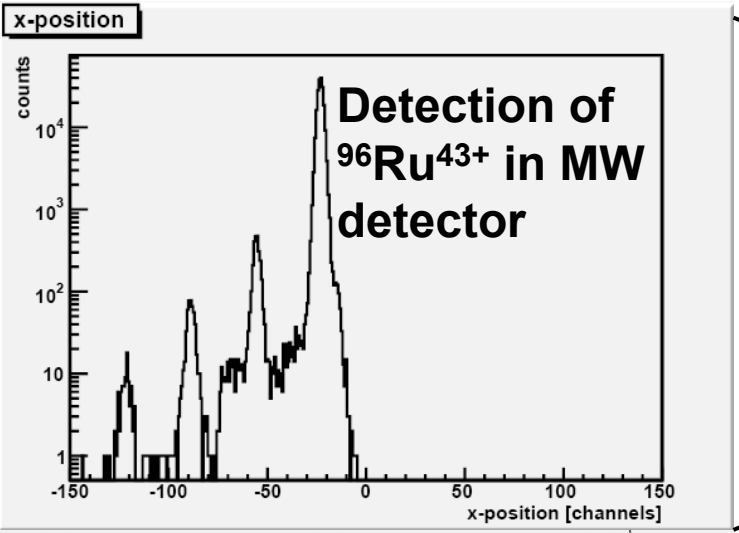
$^{96}Ru^{44+} \rightarrow {}^{96}Ru^{43+}$

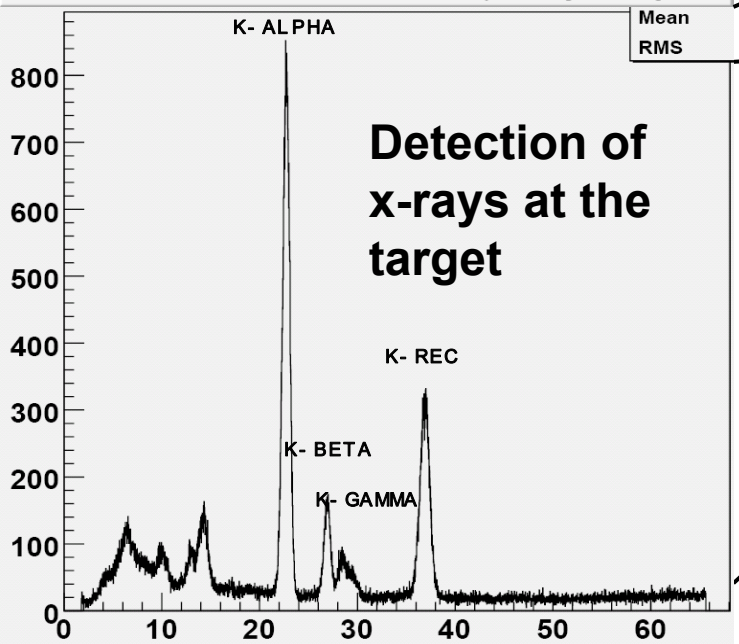
$^{96}Ru^{44+} \rightarrow {}^{96}Ru^{44+}$

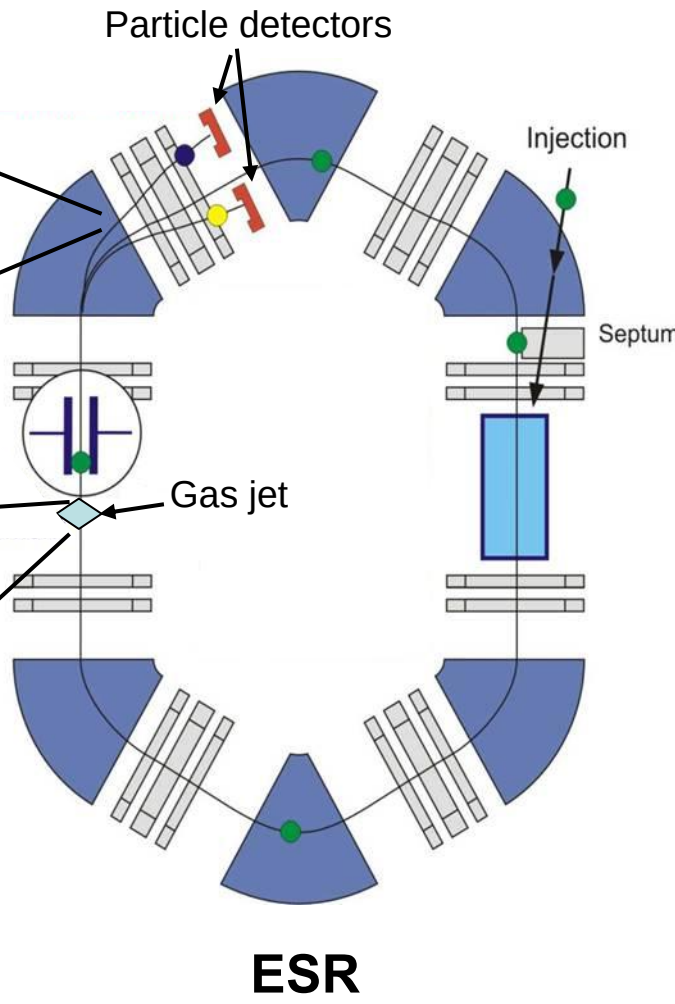
Components of the spectrum can be disentangled based on x-position

Normalization of the cross section

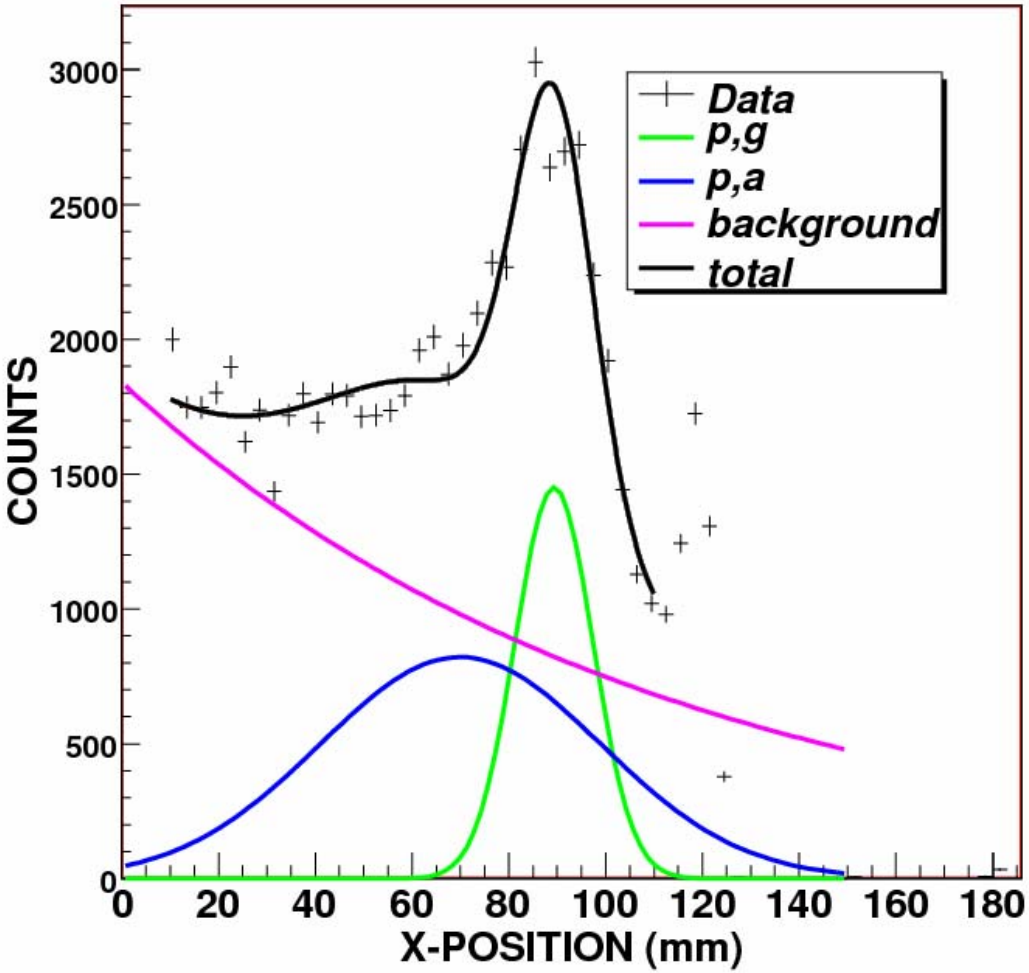
Detection of atomic electron pick-up in the gas target ($^{96}Ru^{44+} + e^{-} \rightarrow {}^{96}Ru^{43+}$):







Preliminary result @ 11 MeV – upper limit



Ignore (p,n) component – resulting in an upper limit for (p,γ)

$\sigma_{PG} \sim 4.0$ mb

Non-smoker: 3.5 mb

Outlook

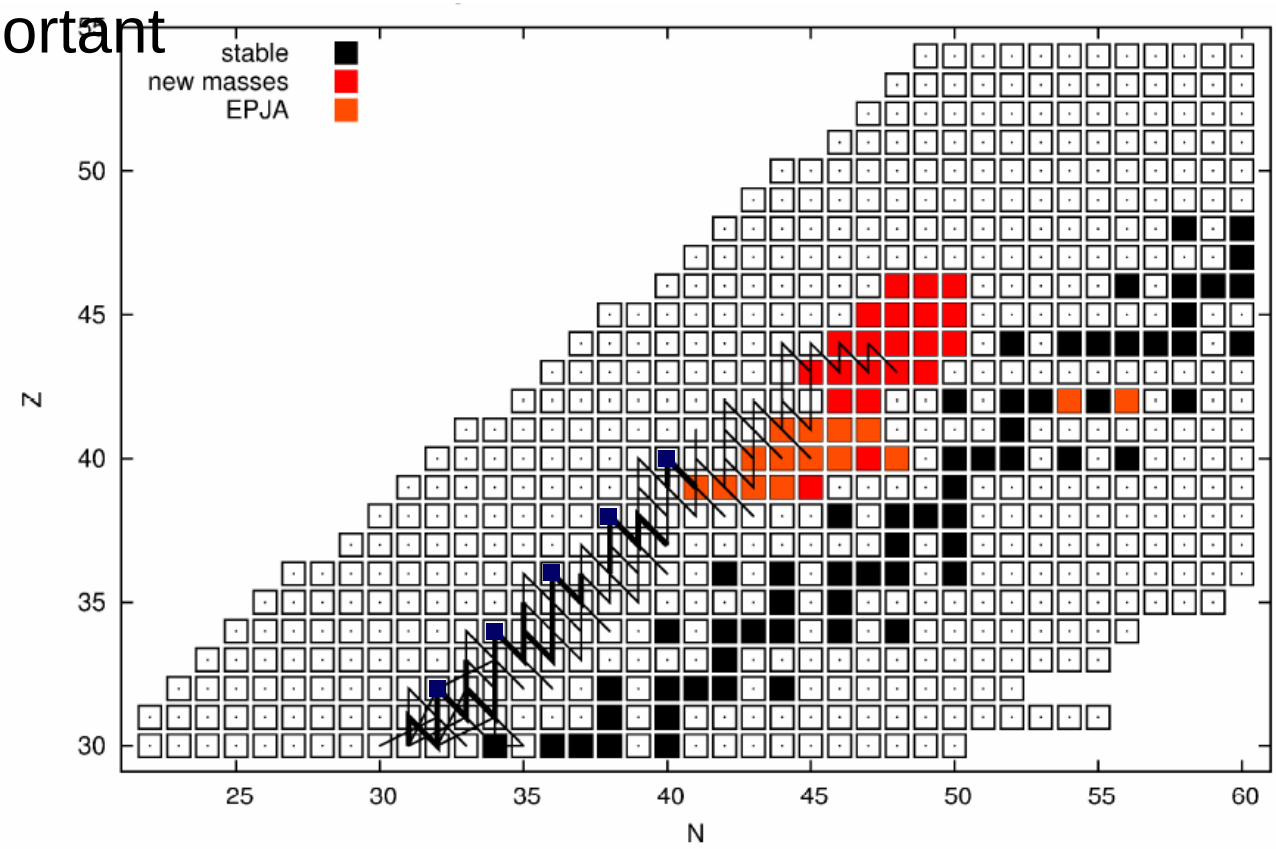
- Improvements of particle detection
  - higher position resolution
  - Z-resolution
  - inside vacuum
  - better coverage
- radioactive isotopes with FAIR

- Program to establish a grid of measured reaction rates for the p-process is possible
- (p,γ) in Gamow window planned for 2011
- (α,γ) proof of principle planned for 2011

Neutron-induced via detailed balance

- heavy α-nuclei are typically waiting points in the rp-process (small (p,γ) cross section, long EC/β^+ half-lives)
- can be overcome with small amount of neutrons coming from $\nu + p \rightarrow n + \beta^+$ reactions, the νp-process
- ^{64}Ge(n,p)^{64}Ga important

Possibly measurable via ^{64}Ga(p,n)^{64}Ge at the ESR



Thielemann et al, Journal of Physics: Conference Series **202** (2010) 012006

Summary

- Nuclear data on radioactive isotopes are extremely important for modern astrophysics (reactions and masses)
- ESR + later NESR&FAIR offer most intersting contributions to many astrophysical nucleosynthesis processes
- Experiments close to stability can already be performed with current setups, measurements in the Gamow window have to be demonstrated