Study of fission barriers in neutron-rich nuclei using the (p,2p) reaction:

Status of SAMURAI-Experiment NP1306 SAMURAI14

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22th ASRC Workshop

December 2014

Outline

- Importance of fission
- Theoretical predictions
- Present experimental methods
- Our approach: (p,2p) measurement
- Requirements of the experiment
- Comparison with R^3B
- Proposal for test experiment at HIMAC

Importance of fission

Motivation: Origin of the abundance and distribution of nuclei beyond iron in the universe [1]

→ Core collapsing supernovae and neutron star mergers

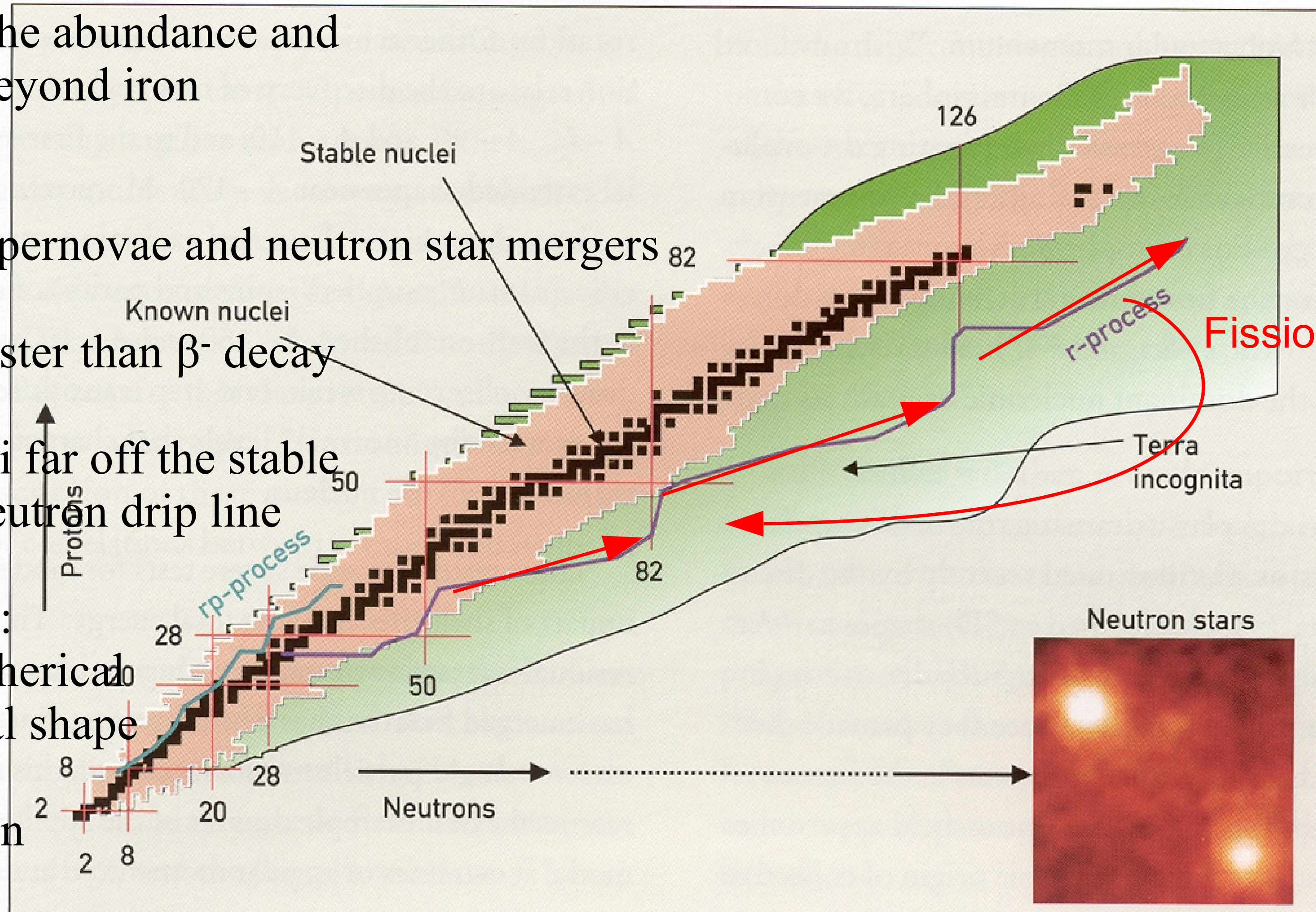
→ Neutron capture faster than β^- decay

→ Neutron rich nuclei far off the stable nuclei near or at neutron drip line

→ Liquid drop model: Transition from spherical nuclei to ellipsoidal shape

→ Spontaneous fission

→ Recycling of the r- process determines the abundance of heavy elements

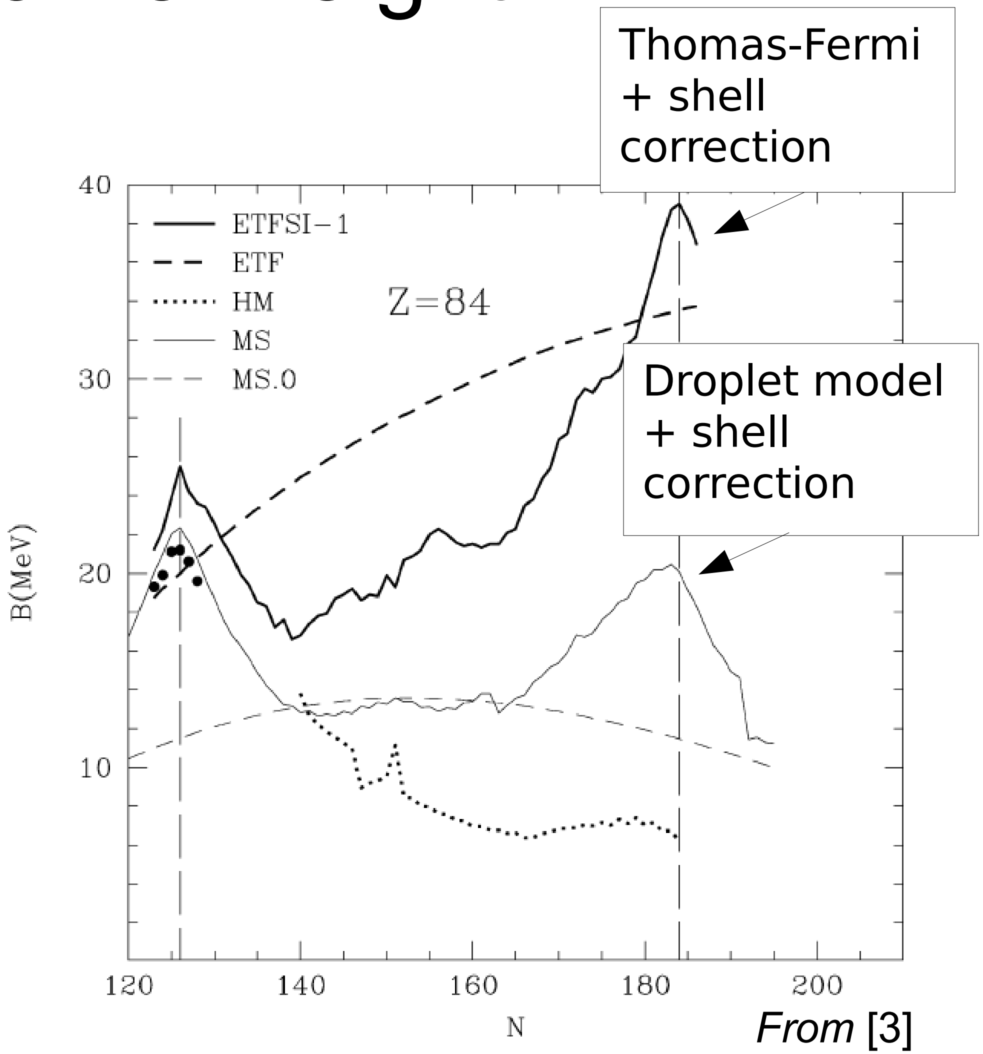


From [2]

→ Fission barrier height is the key

Theoretical predictions
for the fission barrier height

- Decreasing fission barrier
- Maxima at closed neutron shells
- Macroscopic microscopic models

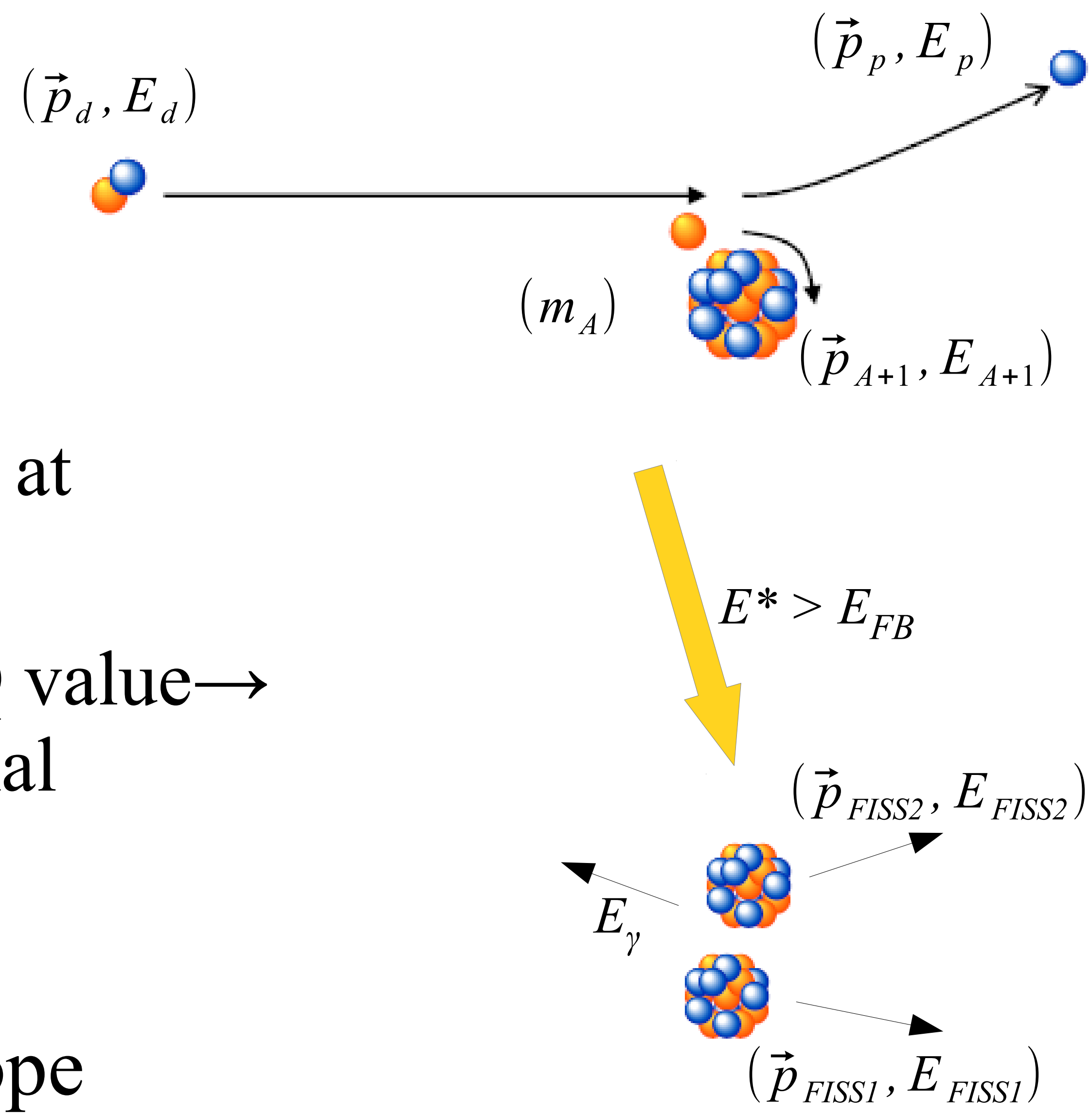


From [3]

→ Not fully understood and especially not verified by experimental data

Experimental methods: (d,p)

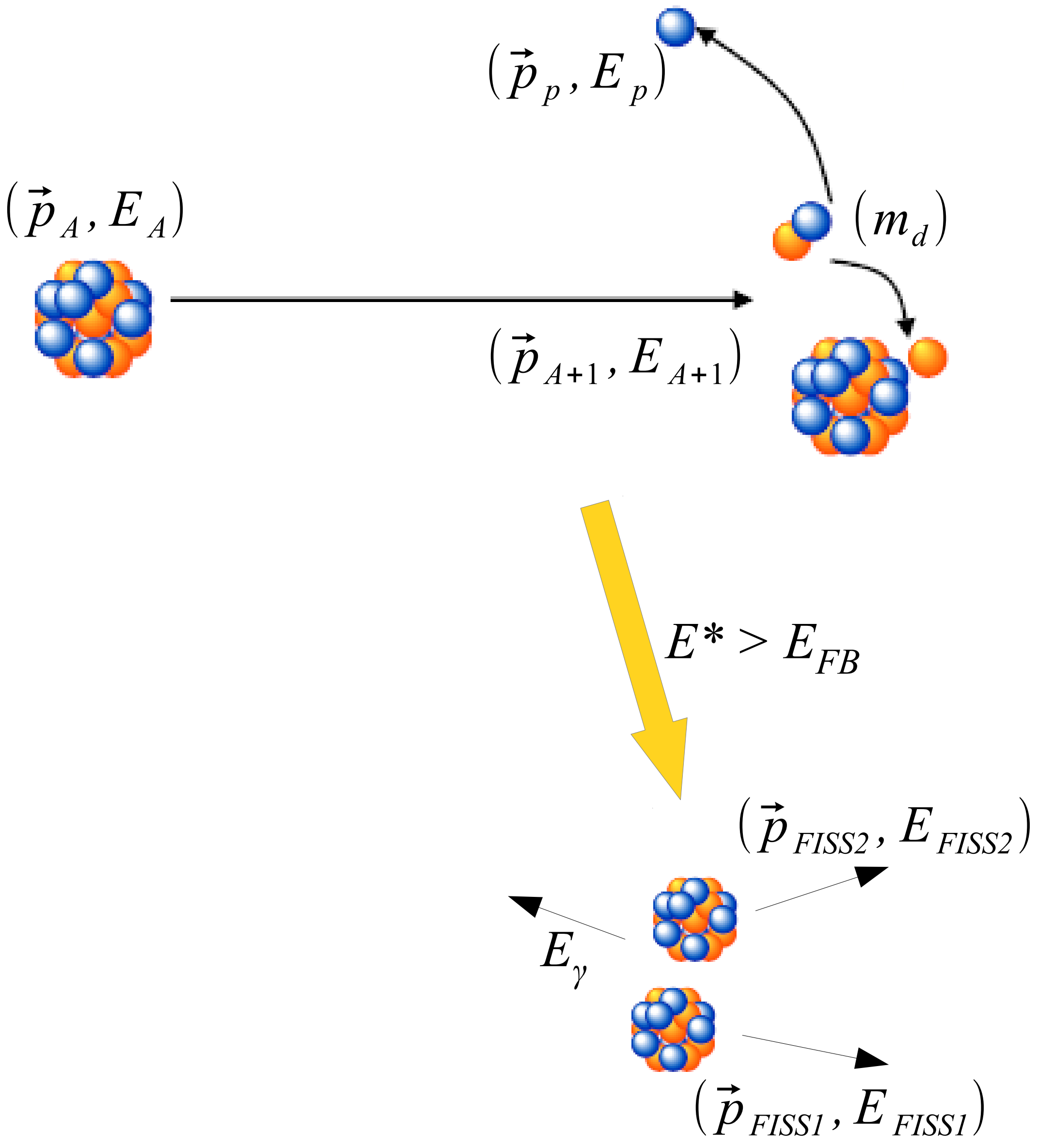
- Normal kinematics:
  - Light ion beams
  - Target material near stable isotopes
- Transfer reactions (d,p) at low beam energies
- Energy of proton and Q value→ Excitation energy in final nucleus [4,5]



→ Limited by target isotope

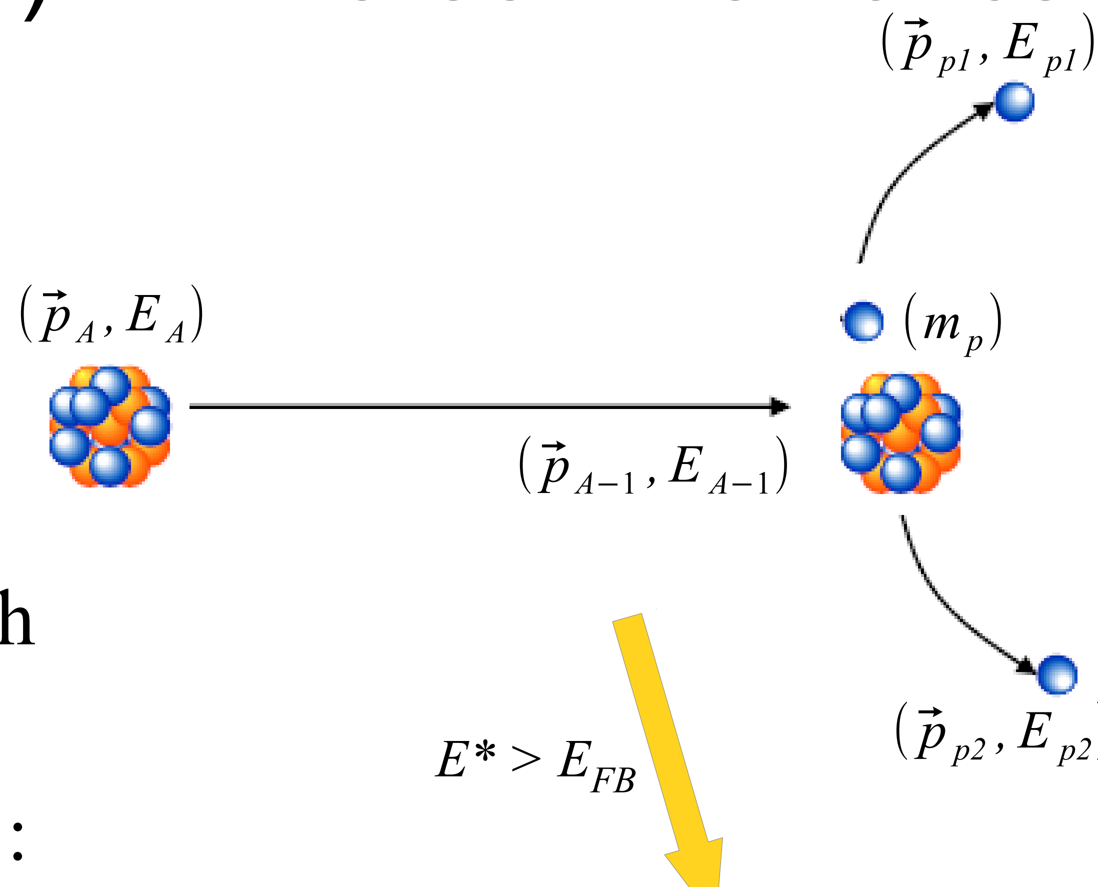
Determination of fission barrier height of nuclei far off the stability line: (d,p)

- Inverse kinematics
  - Exotic beam far off stability line
  - **Thin deuteron** target
- **Transfer reactions** with **low** proton energies



→ Low count rate

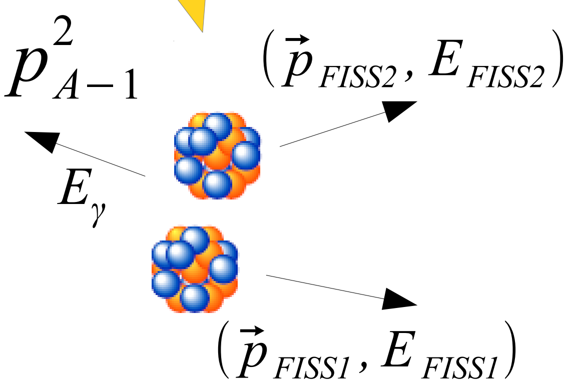
Our approach: (p,2p) in inverse kinematics



- Inverse kinematics
  - Exotic beam far off stability line
  - **Thick hydrogen** target
- **Knock out** reactions with **high** proton energies
- Missing mass in QFS [6]:

$$M_A^2 + p_A^2 + m_p^2 = m_{p1}^2 + p_{p1}^2 + m_{p2}^2 + p_{p2}^2 + M_{A-1}^2 + p_{A-1}^2$$

$$\vec{p}_{A-1} = \vec{p}_A - \vec{p}_{p1} - \vec{p}_{p2}$$



→ High count rate

Goal and requirements on the setup

- Goal:
  Fission barrier height with 1 MeV resolution (in σ)
- Requirements:
  - Energy resolution of the protons
    $\Delta E/E = 2\%$ (in σ)
  - Angular straggling of the opening angle
    $\Delta\theta_{op} = 3$ mrad (in σ)
  - Systematic uncertainty = *0.1* MeV (in σ)

'Competition' with R³B

- RIBF: Beam energy at 250 MeV/u
- Two emitted protons have 120 ± 40 MeV

→ Measuring energy: Relatively easy with TOF detectors at 1.6 m distance; ~100 ps (in σ)

→ Measuring angle: Very difficult; ~1 mrad (in σ) in tracking → Material must be minimized

- GSI: Beam energy at 700 MeV/u
- Two emitted protons have 350 ± 40 MeV

→ Measuring energy: Very difficult, only with TEDs

→ Measuring angle: Relatively easy (small ang. strgg.)

'Competition' with R³B

	SAMURAI	R³B
Beam [MeV/u]	250; Max.: 350	700; Max: 1500
Target	40 mg/cm² LH_2	100-250 mg/cm² LH_2 Active Target
Energy range for protons [MeV]	TOF detectors: 80 - 200	CALIFA: up tp 320
Proton energy E_P resolution in sigma $\Delta E_P/E_P$ for E_P=100 MeV	2%	1%
Vertex reconstruction Pitch size [µm] Inner layer thickness [µm]	Silicon detectors 100 50	Lampshade detectors 50 100
Angular resolution for the opening angle θ_{OP} in sigma [mrad]	~3	~1
Space coverage in polar angle θ [degree] in azimuthal angle φ [degree]	$2 \cdot 24$ (28 - 52) $2 \cdot 24$	125 (5 – 130) 360

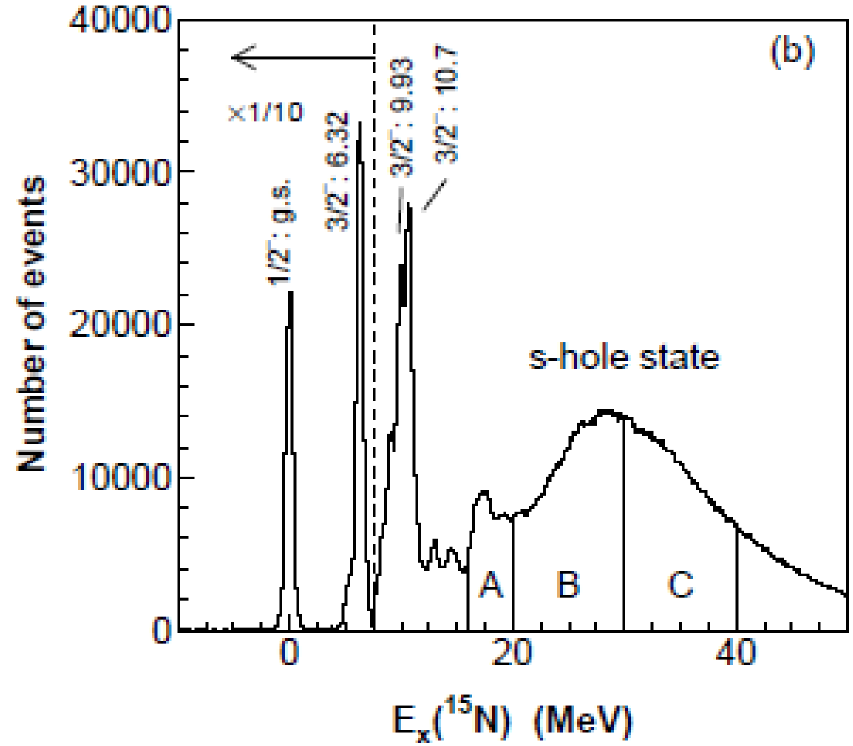
Next talk:
M. Sasano

Data from [7,8,9]

→ Setup optimized for our purpose

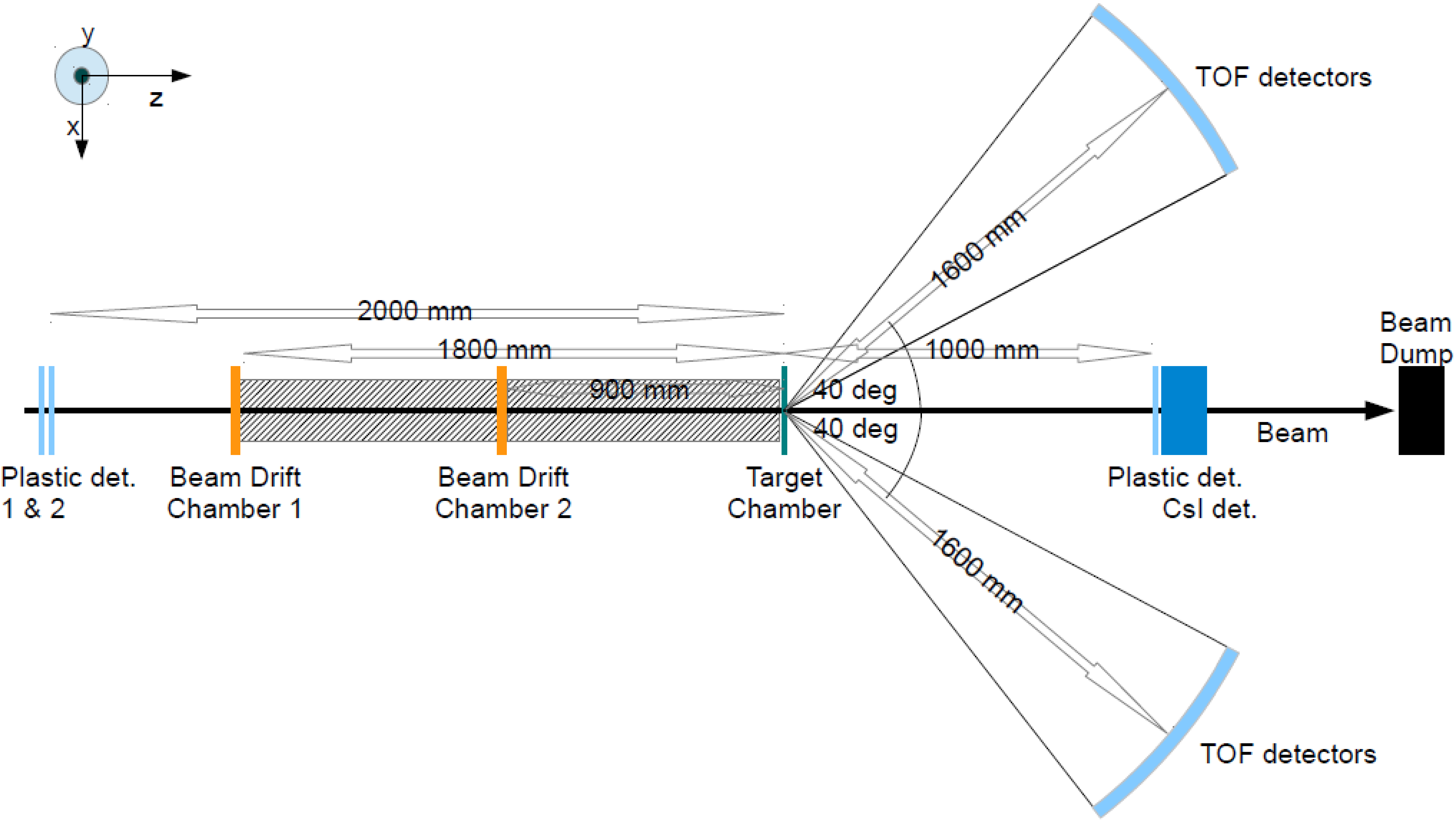
Proposal for test experiment at HIMAC

- (p,2p) setup test w/ thin Si det.
- ^{16}O at 290 MeV/u with 10^5 pps
- Known excitation spectrum with two sharp peaks at E_x = 0 MeV and 6.3 MeV



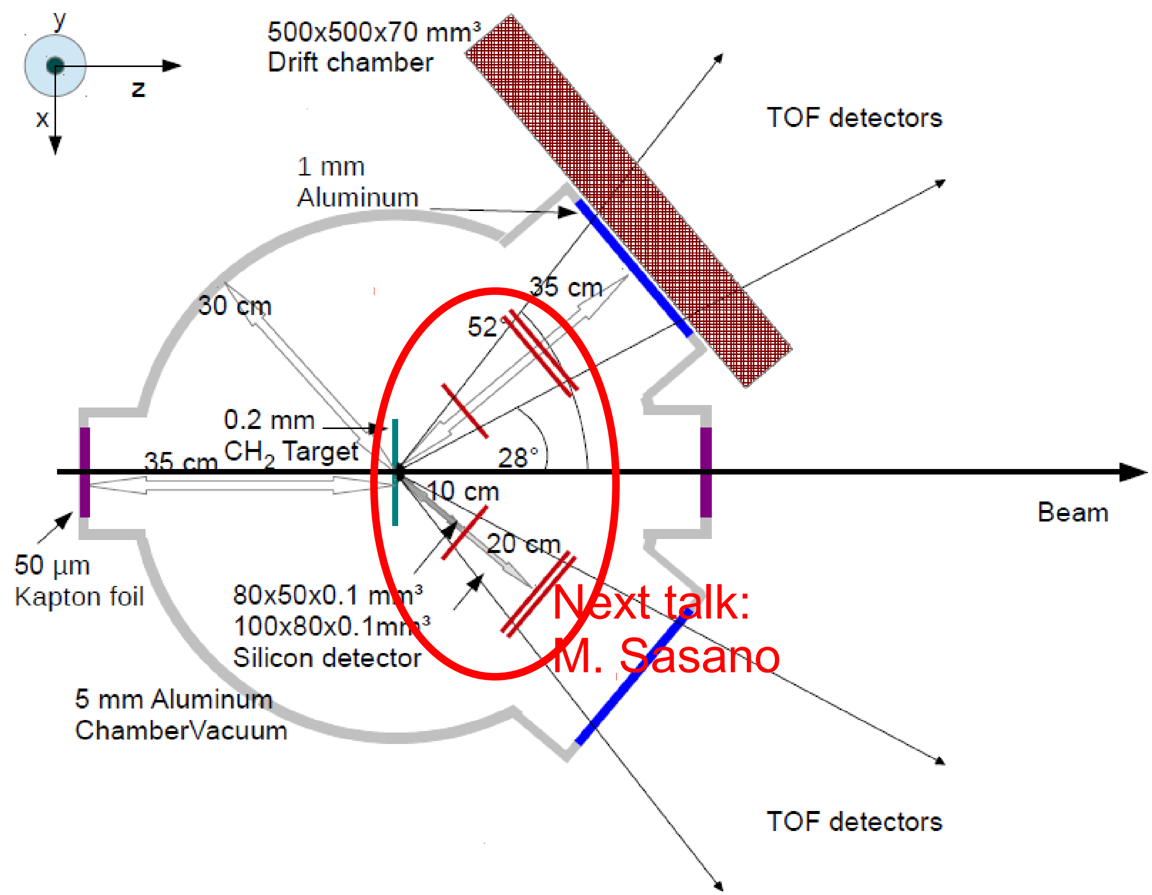
→ Goal: Determination of E_x systematic and statistical uncertainties within the required resolution

Setup at HIMAC



Setup at HIMAC

- Autumn 2015: CH_2 Target
  - Syst. uncertainties
  - Silicon detector configuration
- Spring 2016: LHT
  - Test final setup
  - Study on influence of the ang. strgg. from the target



→ Ready for RIKEN!

Conclusion

- Fission barrier height for neutron rich heavy nuclei important for the understanding of the recycling of the r- process
- Theoretically not fully understood
- Our approach: Inverse kinematics and nucleon knock-out
- Thin Si detector for the first layer is the key for the (p,2p) setup in RIBF energy domain
- Submitted proposal for test experiments at HIMAC

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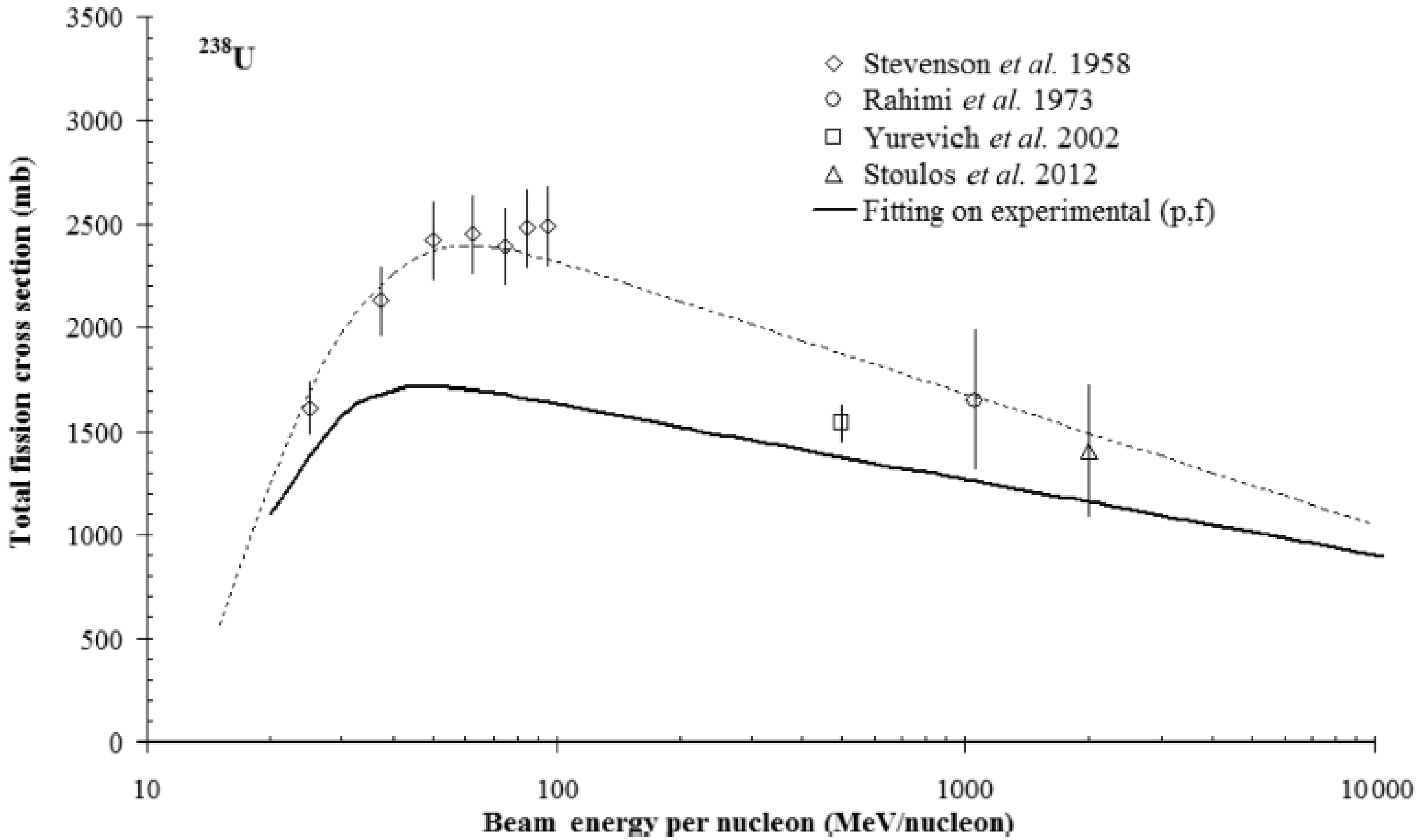

FIG. 2. Deuteron-induced fission cross section on (a) ^{232}Th and (b) ^{238}U. The solid lines represent the fitting of proton data [23], whereas, the dashed lines represent the fitting of deuteron data according to the parameters given in Table III.

PHYSICAL REVIEW C **87**, 067602 (2013)

High-energy fission cross sections induced by deuterons on ^{232}Th and protons on ^{nat}Pb targets

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