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Three years of cross-section measurements of (n,xn) threshold reactions at TSL Uppsala and NPI Řež

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Outline

- Motivation for cross-section measurements
- Requirements for cross-section measurements
- TSL Uppsala facility
- NPI Řež facility
- Evaluation and neutron background subtraction
- Results - Comparison with EXFOR and TALYS
- Conclusion

Motivation for σ measurements – Energy plus Transmutation project

Motivation

- ***E+T***
- ***(n,xn) reactions***
- ***E+T results***
- ***(n,xn) in EXFOR***

σ measurement

TSL Uppsala

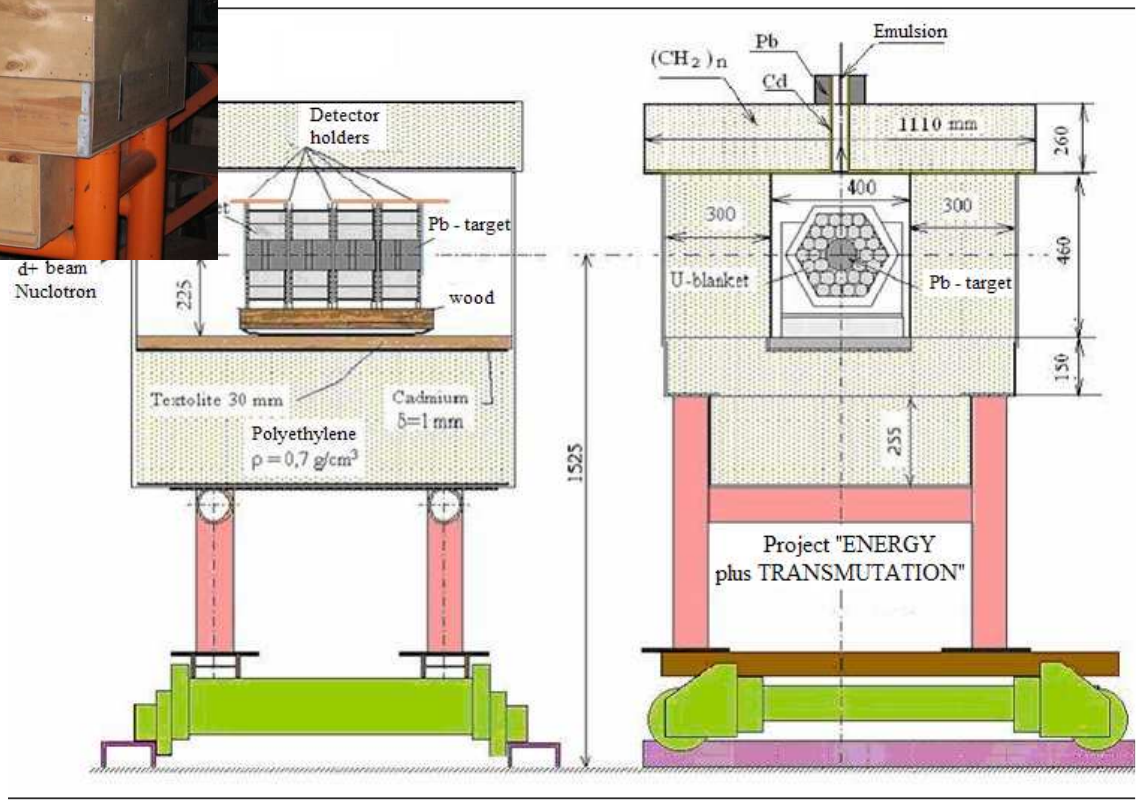
NPI Řež

Evaluation

Results

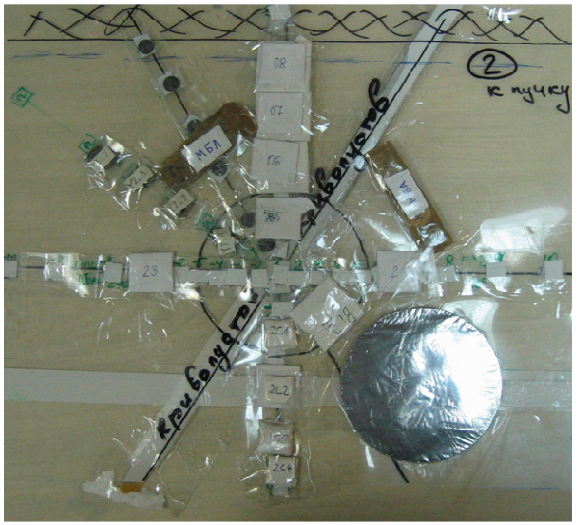
Conclusion

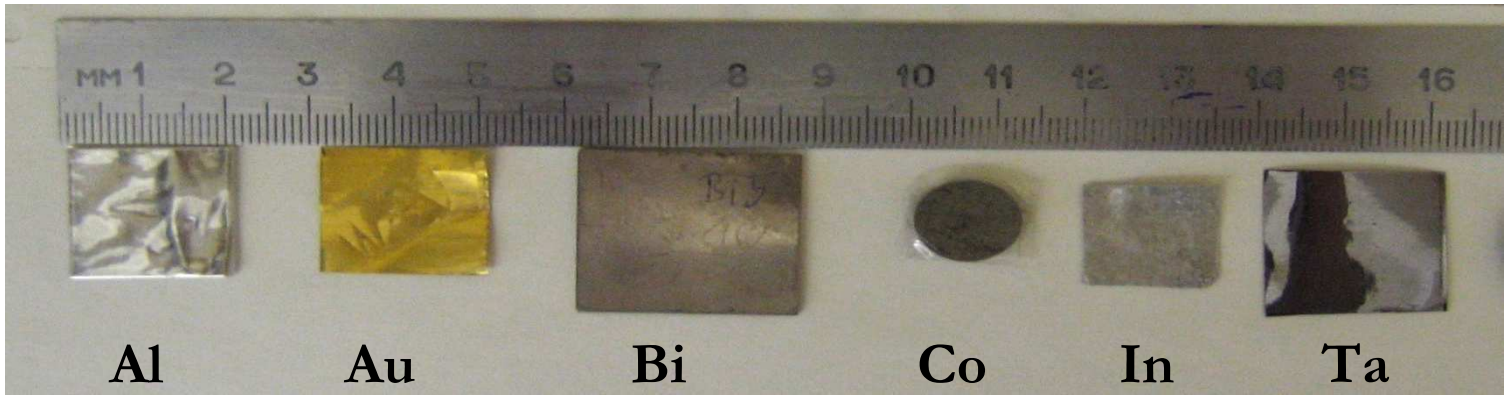
JINR Dubna, Russia



(n,xn) threshold reactions

Reaction	E_{thresh} [MeV]	Half-life
^{197}Au (n,2n) ^{196}Au	8.1	6.183 d
^{197}Au (n,3n) ^{195}Au	14.8	186.1 d
^{197}Au (n,4n) ^{194}Au	23.2	38.02 h
^{197}Au (n,5n) ^{193}Au	30.2	17.65 h
^{197}Au (n,6n) ^{192}Au	38.9	4.94 h
^{197}Au (n,7n) ^{191}Au	45.7	3.18 h

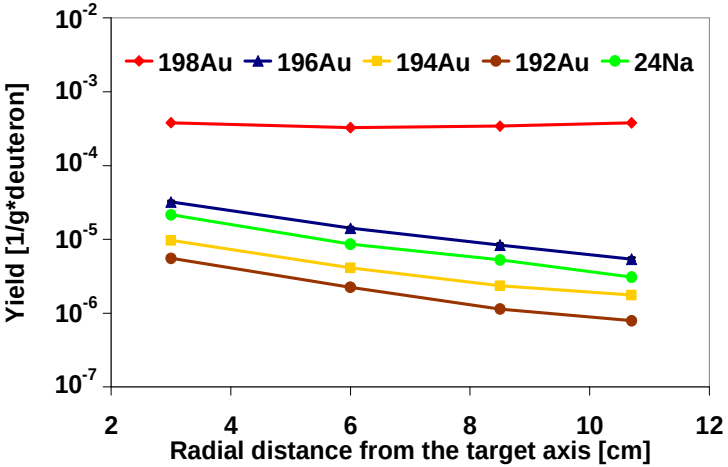




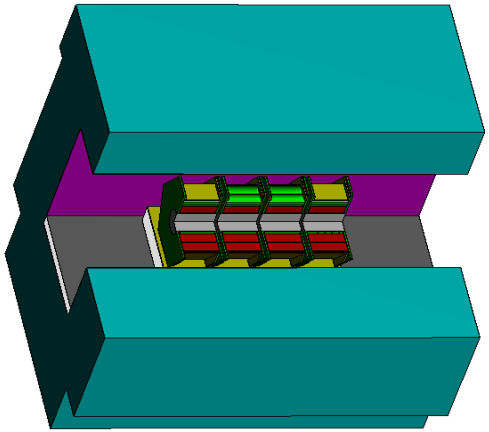
E+T results – (n,xn) cross-section fault??

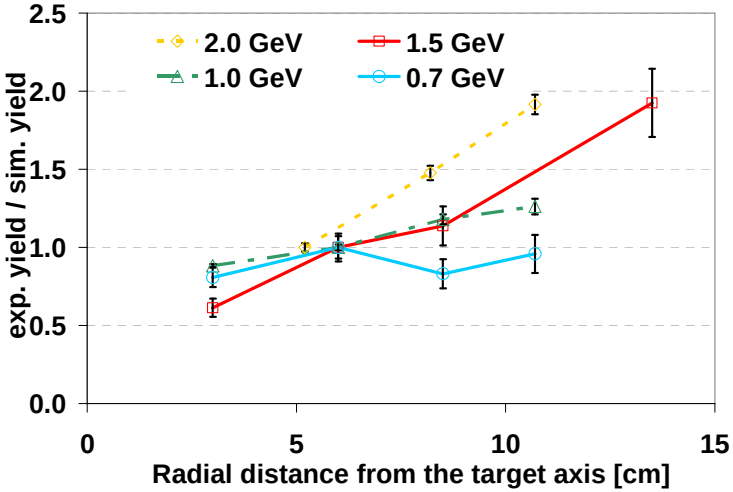
- **Motivation**
- *E+T*
- *(n,xn) reactions*
- ***E+T results***
- *(n,xn) in EXFOR*
- **σ measurement**
- **TSL Uppsala**
- **NPI Řež**
- **Evaluation**
- **Results**
- **Conclusion**

Experiment



MCNPX simulation





(n,xn) cross-sections need to be verified…

Current status of (n,xn) reaction knowledge

Motivation

- *E+T*
- *(n,xn) reactions*
- *E+T results*
- *(n,xn) in EXFOR*

σ measurement

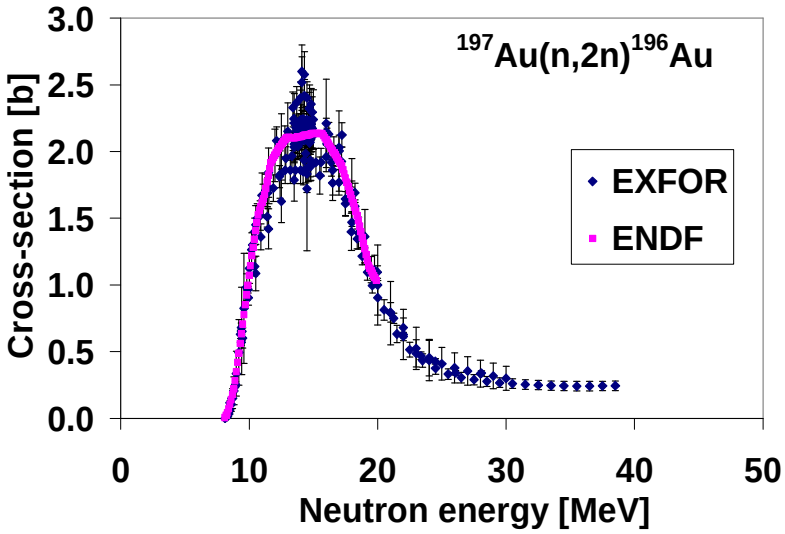
TSL Uppsala

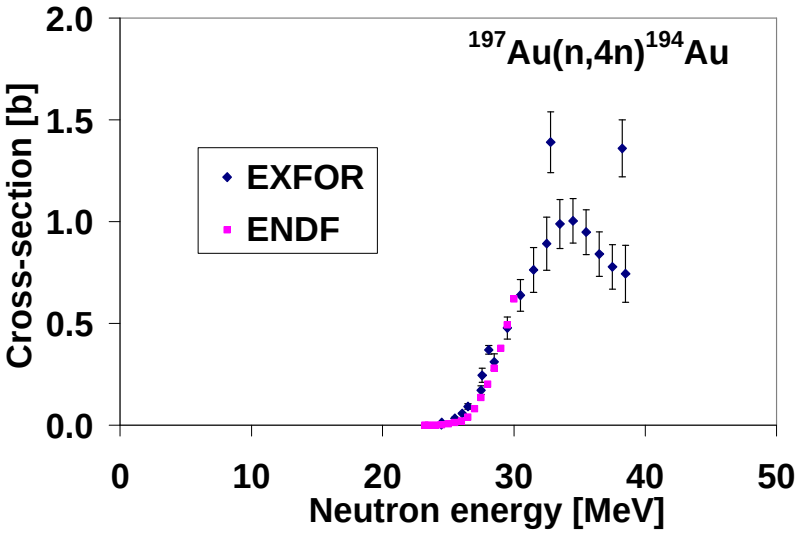
NPI Řež

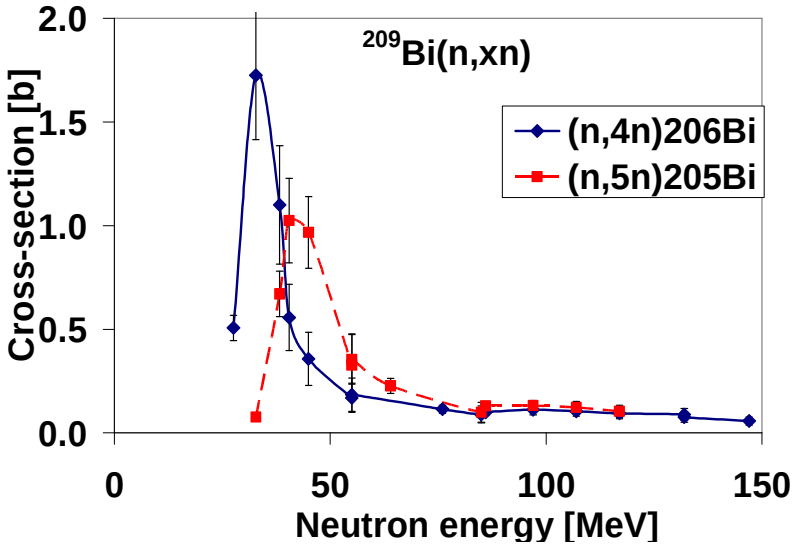
Evaluation

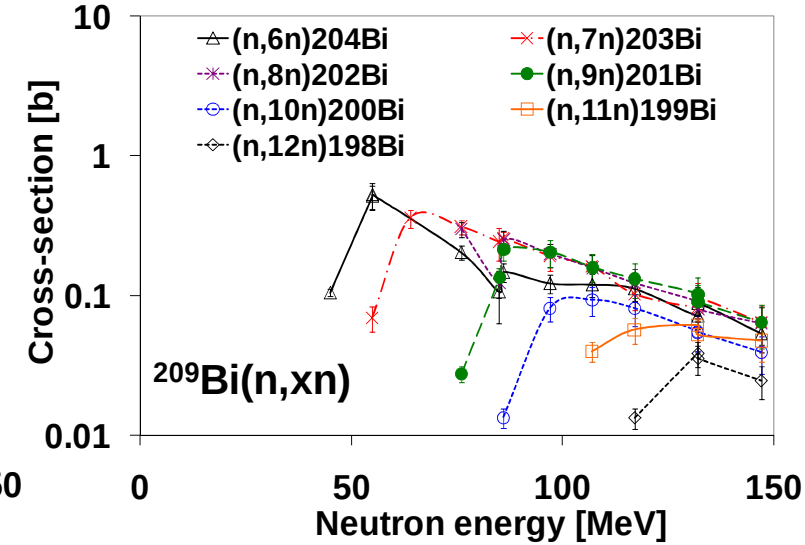
Results

Conclusion









Requirements for σ measurements

Requirements for using activation method of measurement:

- high energy neutron source with good intensity
- (quasi)monoenergetic neutrons with well known spectrum
- pure samples
- good spectroscopic equipment: shielded HPGe detectors
- knowledge about the corrections on beam fluctuation, self-absorption, non-point like emitters…

Studied (mono)isotopic materials:

In all irradiations: Al, Au, Bi, I, In, Ta

In some irradiations: Co, Cu, Fe, Mg, Ni, Y, Zn

Cross-section experiments history

2007 – Proposal to EFNUDAT on (n,xn) measurements – accepted

5/2008 – pilot/testing measurements at NPI Řež – 25MeV

6/2008 – measurement at TSL Uppsala – 25, 50, and 97 MeV

8/2008 – measurements at NPI Řež – 20 MeV

4/2009 – measurements at NPI Řež – 32.5 MeV

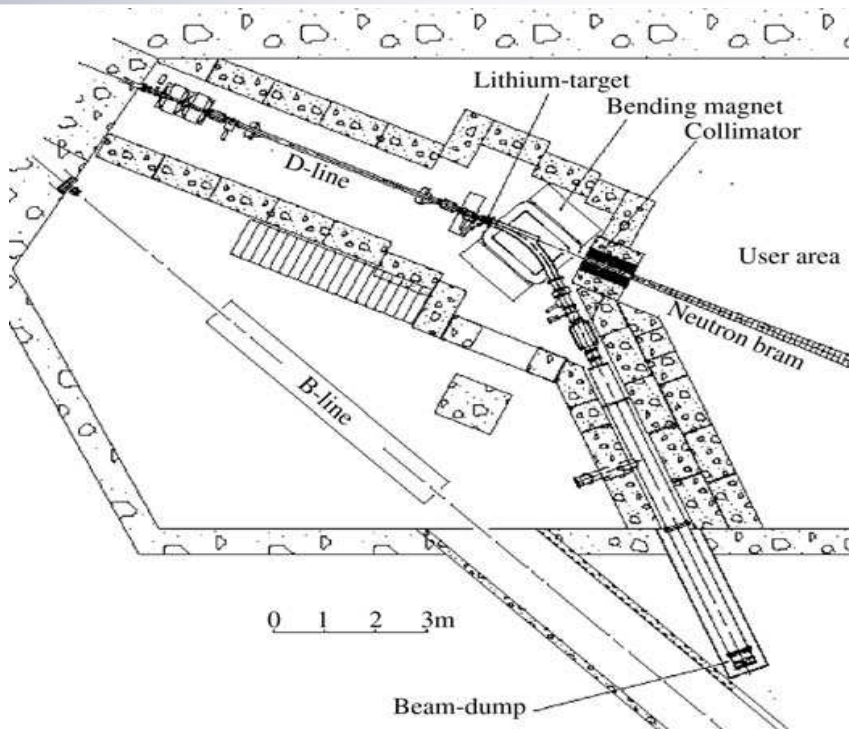
5/2009 – measurement at NPI Řež – 37 MeV

2009 – proposal to last call of EFNUDAT on further experiments at Uppsala – accepted

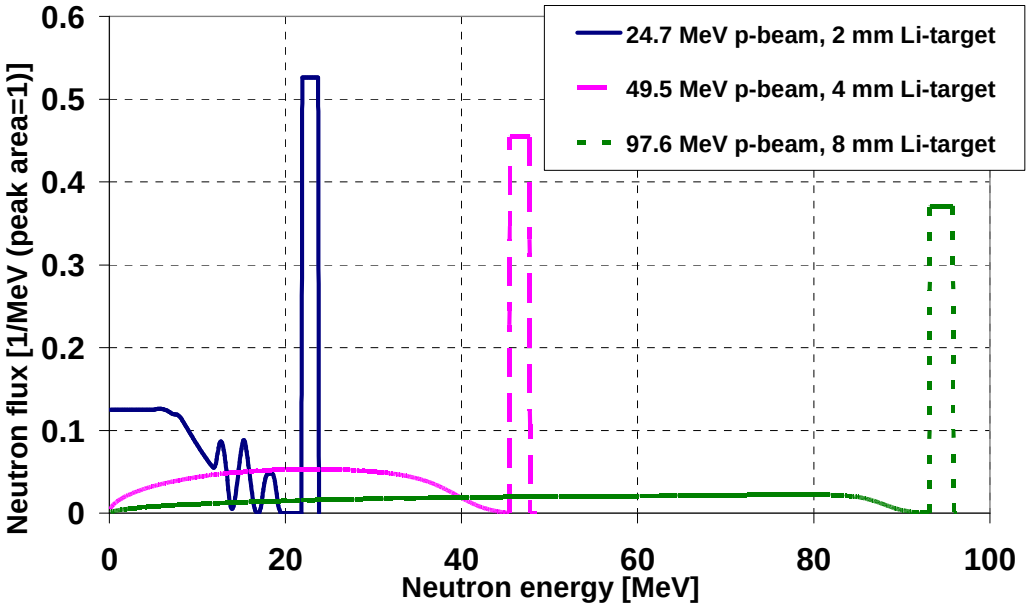
2/2010 - measurement at TSL Uppsala – 62, 70, 80, and 93 MeV

Autumn/2010 – planned new measurements in Řež

TSL Uppsala - Blue hall



Neutron spectra known for proton energies 25, 50 and 97 MeV

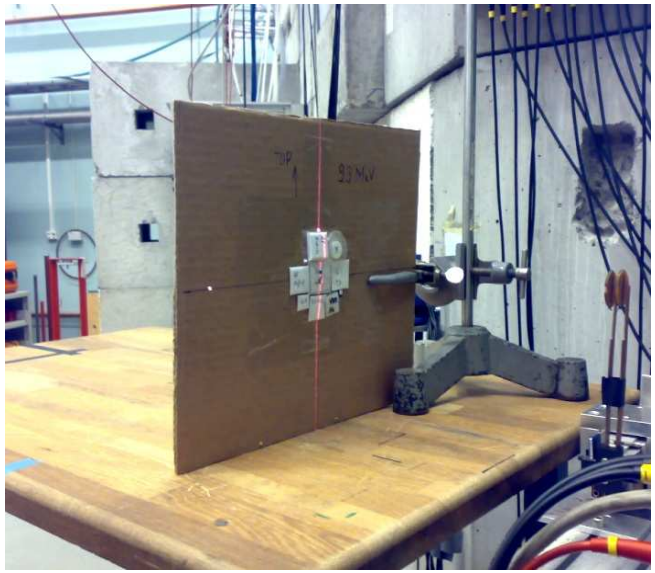


Blue hall:

quasi-monoenergetic neutron source based on reaction $^{7}Li(p,n)^{7}Be$

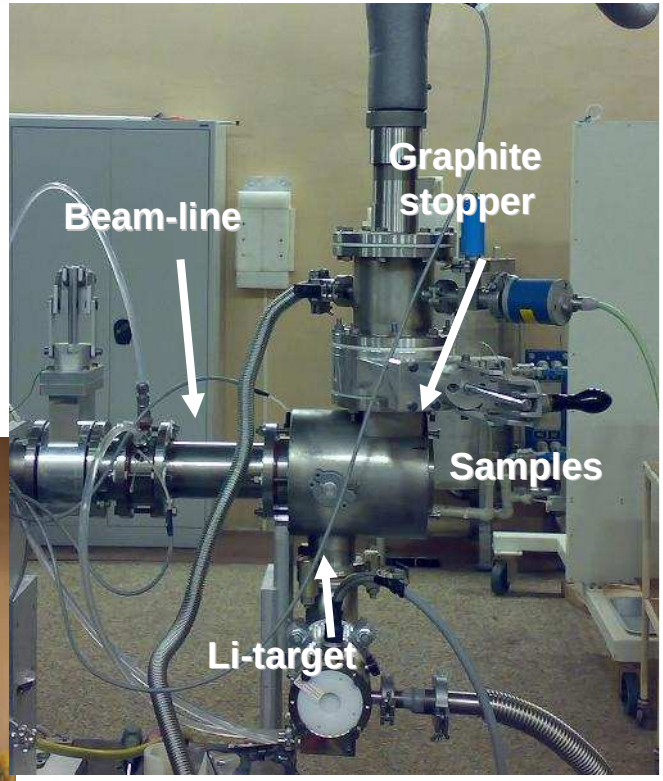
TSL Uppsala - irradiations

Proton beam energy [MeV]	25	50	97
^{7}Li-target thickness [mm]	2	4	8.5
Proton beam current [μA]	5	5	2
Average energy of peak neutrons [MeV]	22	47	94
Fraction of neutrons in the peak [%]	50	39	41
Peak neutron flux density [10^{5} cm^{-2} s^{-1}]	6	13	14.5



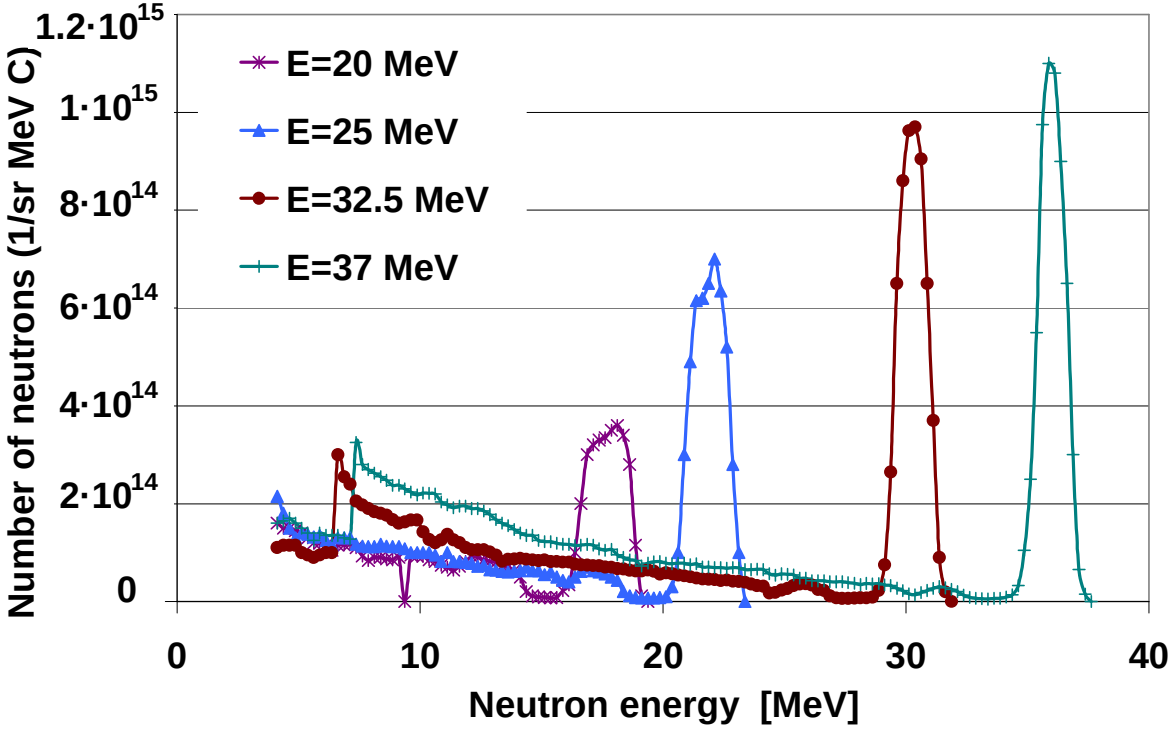
Cyclotron in NPI Řež

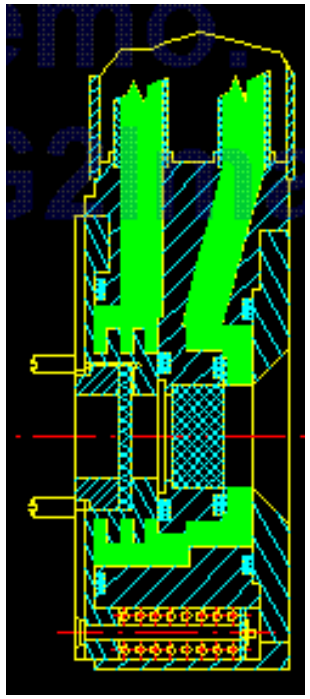
- Protons 18 – 37 MeV on ^{7}Li target
- High neutron intensities: 10^{8} cm^{-2} s^{-1}
- Well equipped spectroscopic laboratory (NSD-NPI)



Neutron spectra from p/Li source in NPI Řež

Neutron spectra known for 20, 25, 30, and 35 MeV – Y. Uwamino et al., NIM A389 (1997) 463 – similar construction of p/Li source

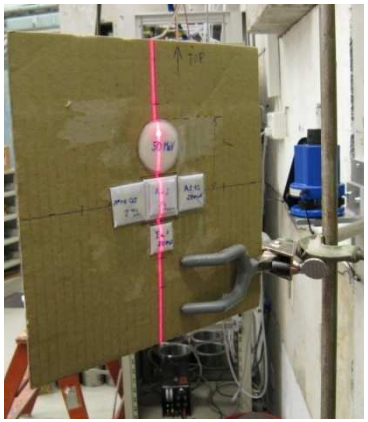




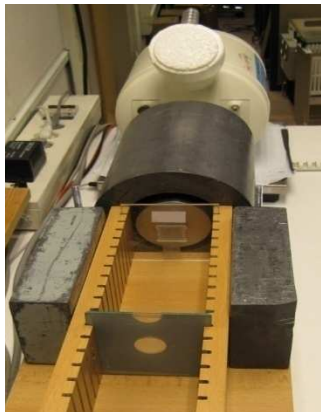
Uncertainty in spectrum determination – 10%

Evaluation process

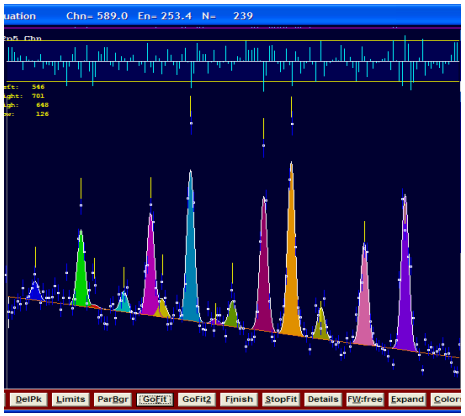
- Motivation
- σ measurement
- TSL Uppsala
- NPI Řež
- **Evaluation**
  - *process*
  - *background 1*
  - *background 2*
  - *uncertainties*
- Results
- Conclusion



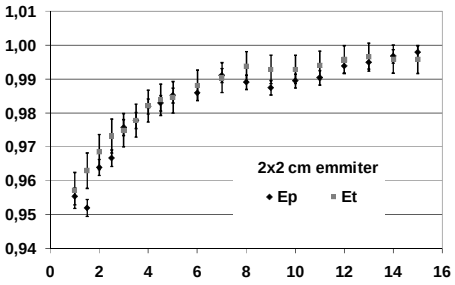
Irradiation



HPGe

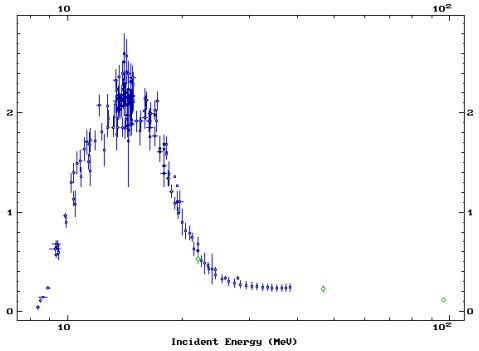


Spectra evaluation

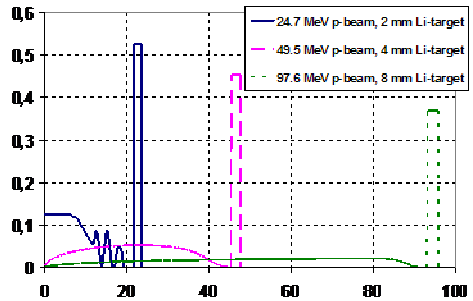


Corrections

N_{Yield}



Cross-section

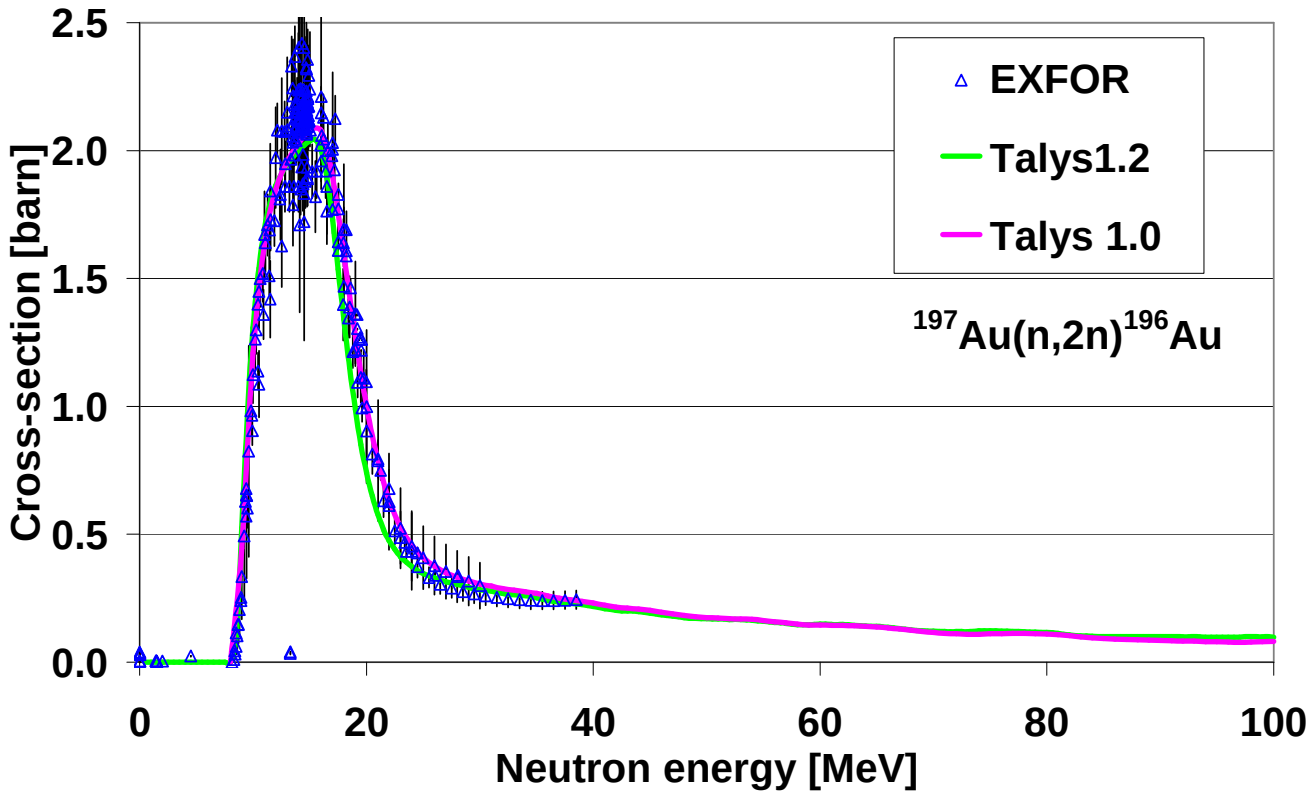


Production in peak
Talys1.0

Background subtraction 1

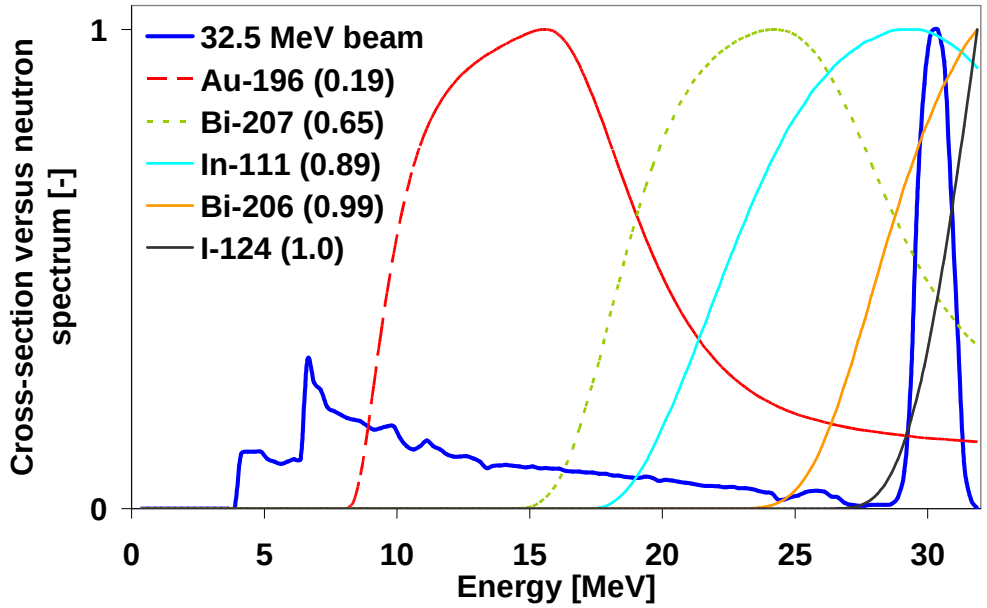
TALYS 1.0 (TALYS 1.2)

- deterministic code
- provides complete and accurate calculation of the nuclear reactions in the energy range from 1 keV to 200 MeV



Background subtraction 2

- σ comparisons between EXFOR and TALYS 1.0 – mostly good agreement
- we believe the simulated σ shape is OK, only the absolute value can be shifted



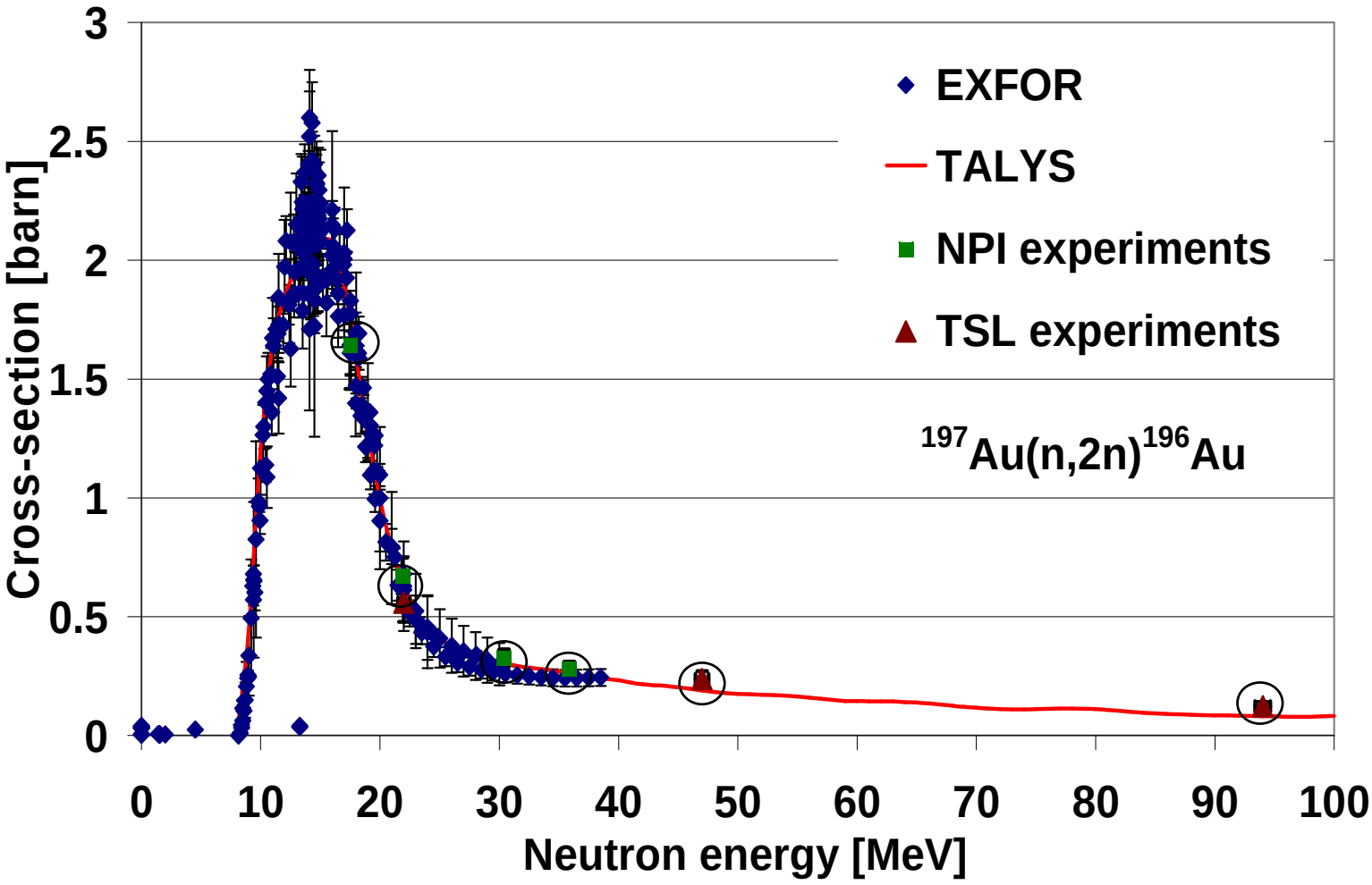
- following the neutron spectrum knowledge, we calculated ratio between production in neutron peak and total production
- with this ratio we multiplied the yields to subtract background production

Uncertainty analysis

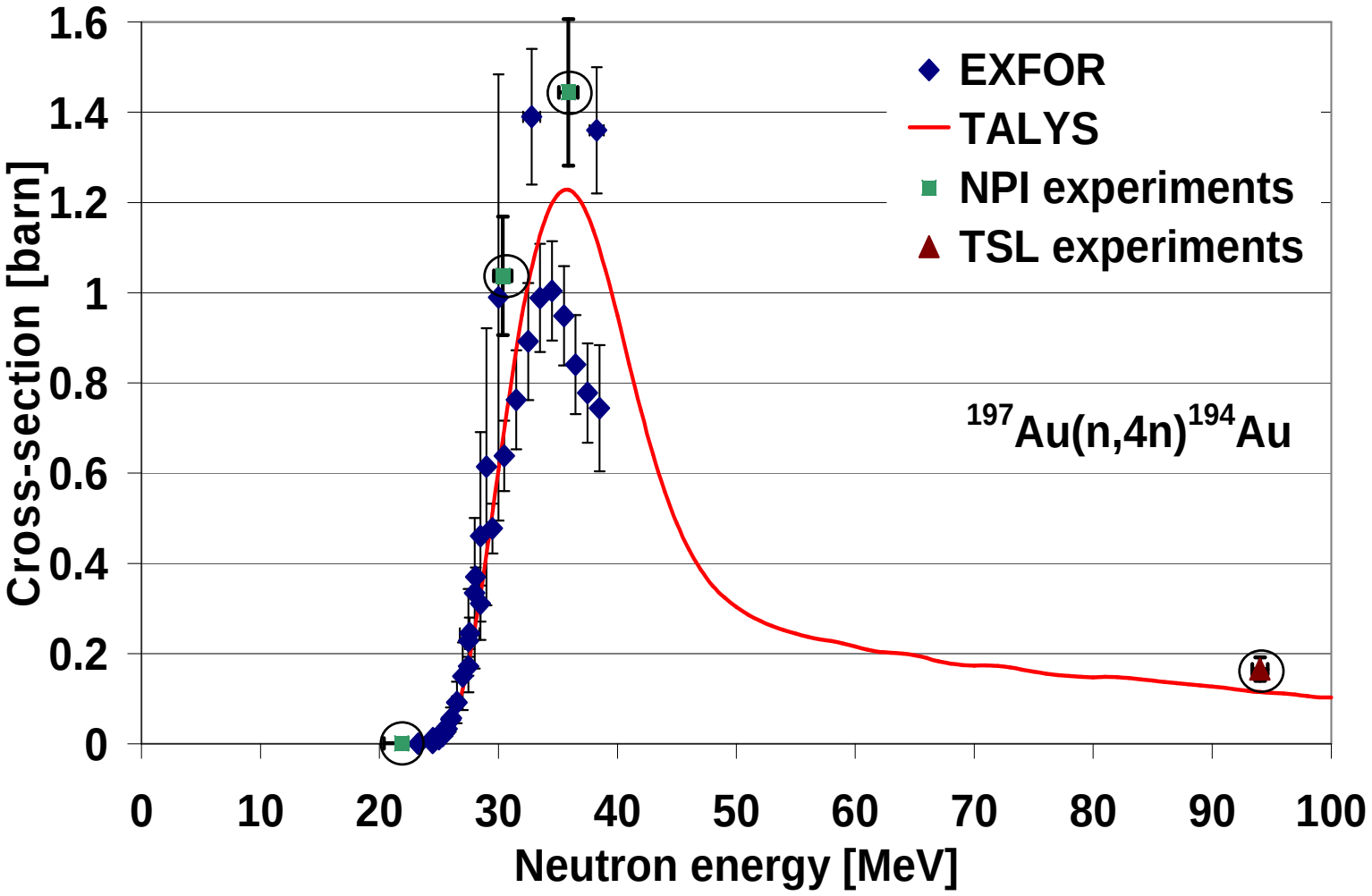
- HPGe detector calibration uncertainty: less than 3%
- Gauss-fit of the gamma peaks: > 1% (usually less than 10%)
- spectroscopic corrections uncertainty: less than 1%
- neutron spectra determination: 10%
- neutron beam intensity determination: 5% at NPI, 10% at TSL
- TALYS 1.0 versus TALYS 1.2 – differences in results around 10%
- TALYS modifications - nuclear density variations: less than 10% difference in results
- background subtraction procedure – assessed to ~10% uncertainty, but will be further studied

$^{197}Au(n,2n)^{196}Au$ results

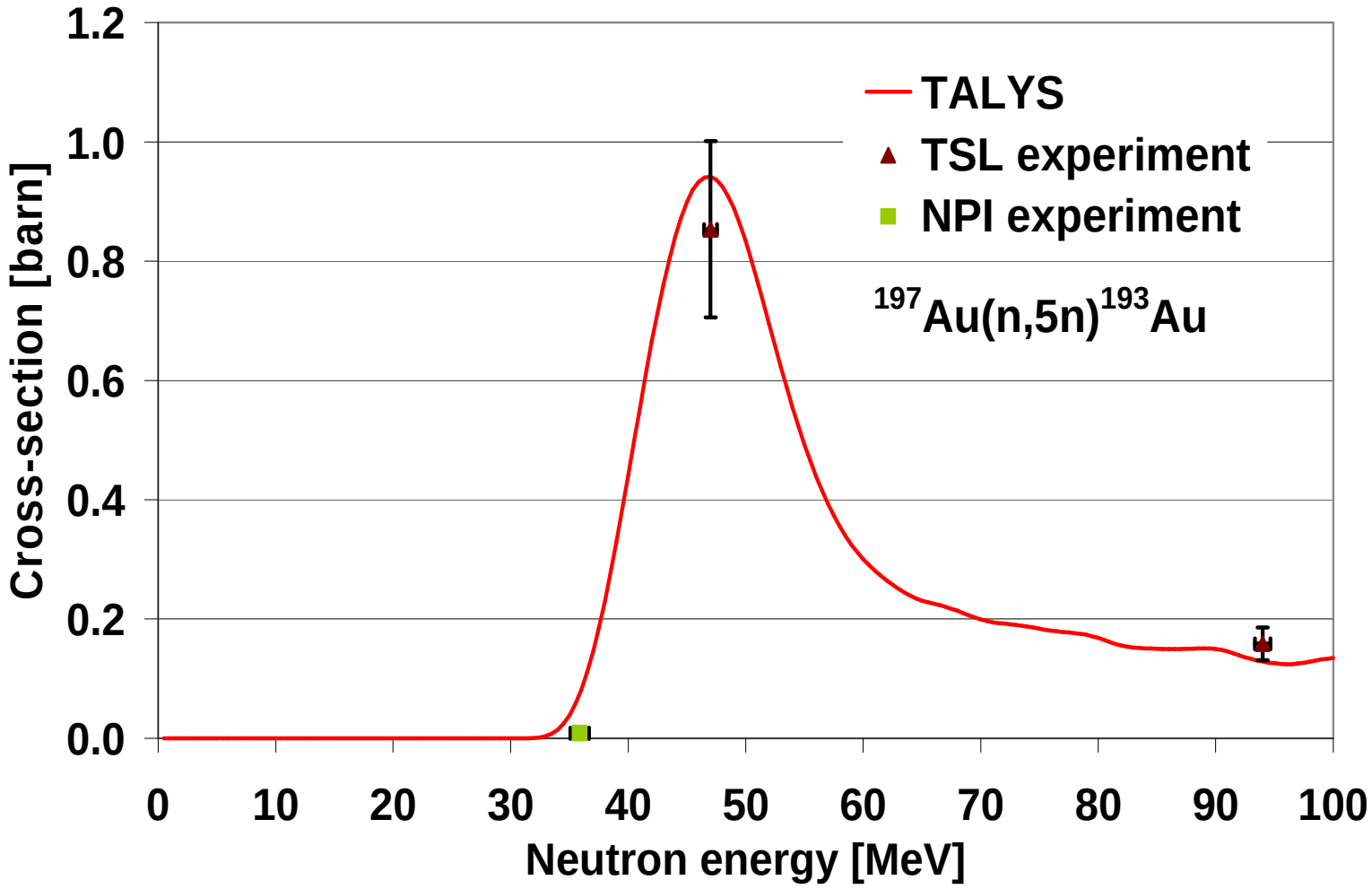
- Motivation
- σ measurement
- TSL Uppsala
- NPI Řež
- Evaluation
- **Results**
  - ^{196}Au
  - ^{194}Au
  - ^{193}Au
  - ^{192}Au
- Conclusion



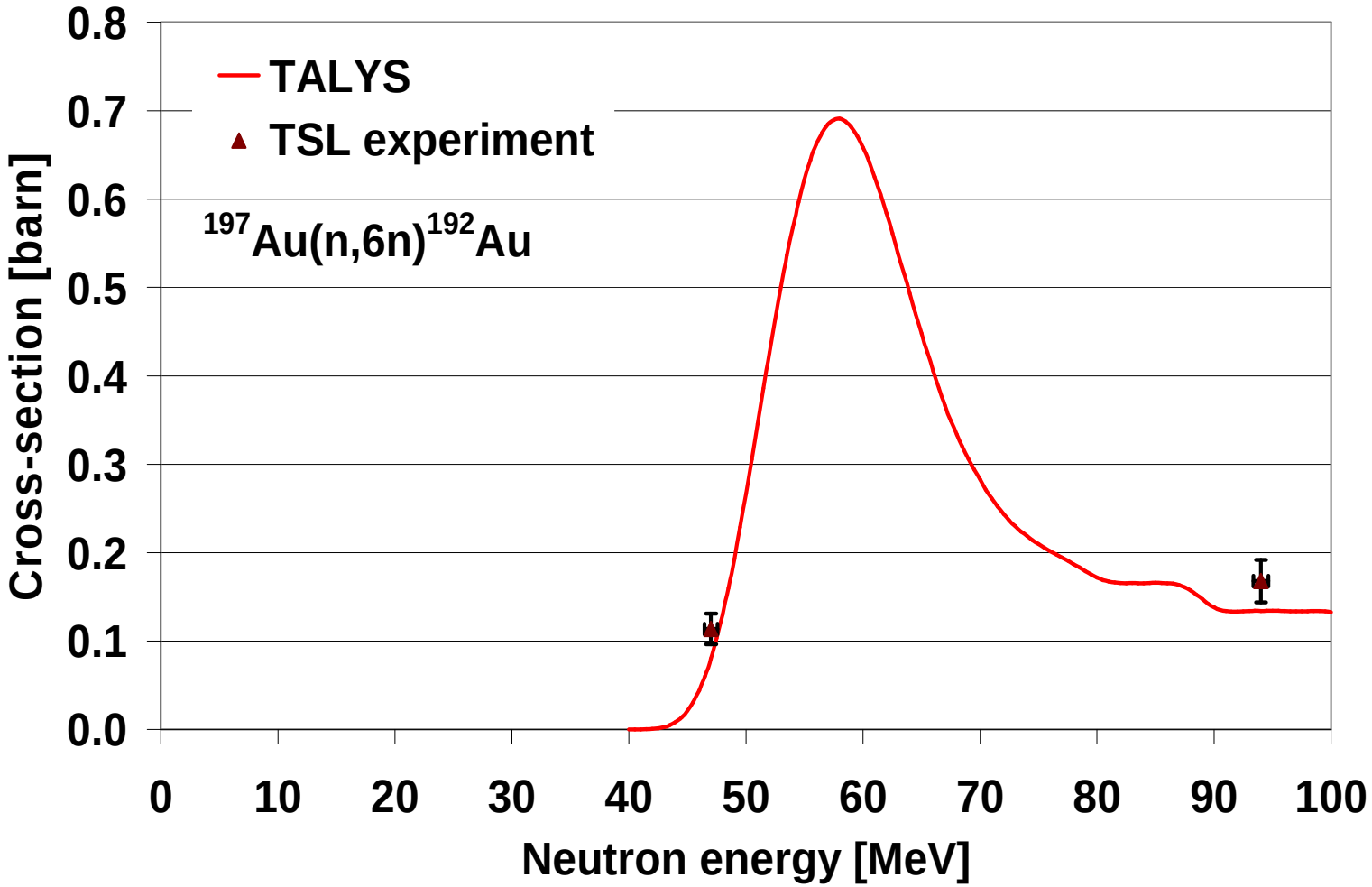
$^{197}Au(n,4n)^{194}Au$ results



$^{197}Au(n,5n)^{193}Au$ results



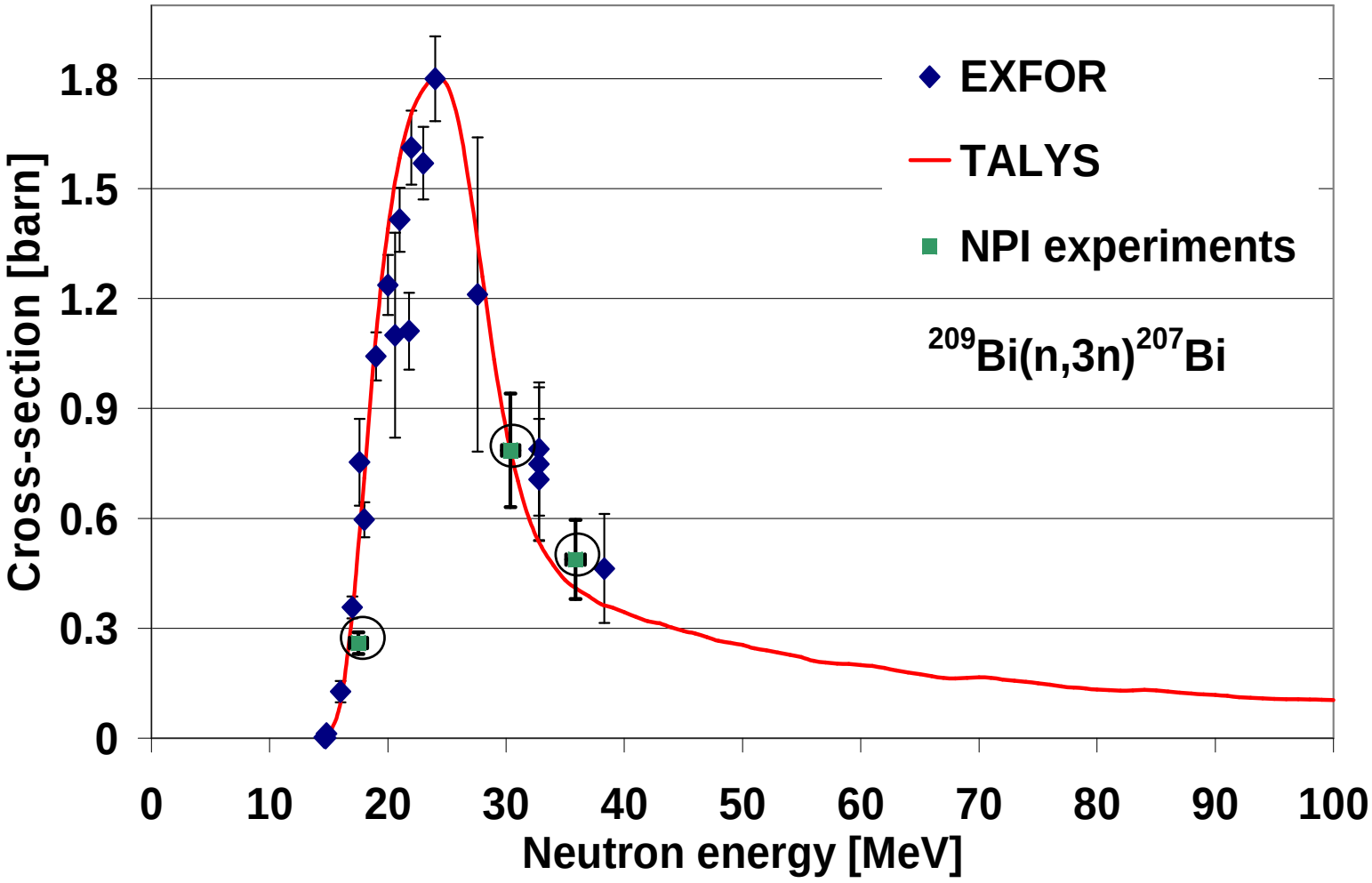
$^{197}Au(n,6n)^{192}Au$ results



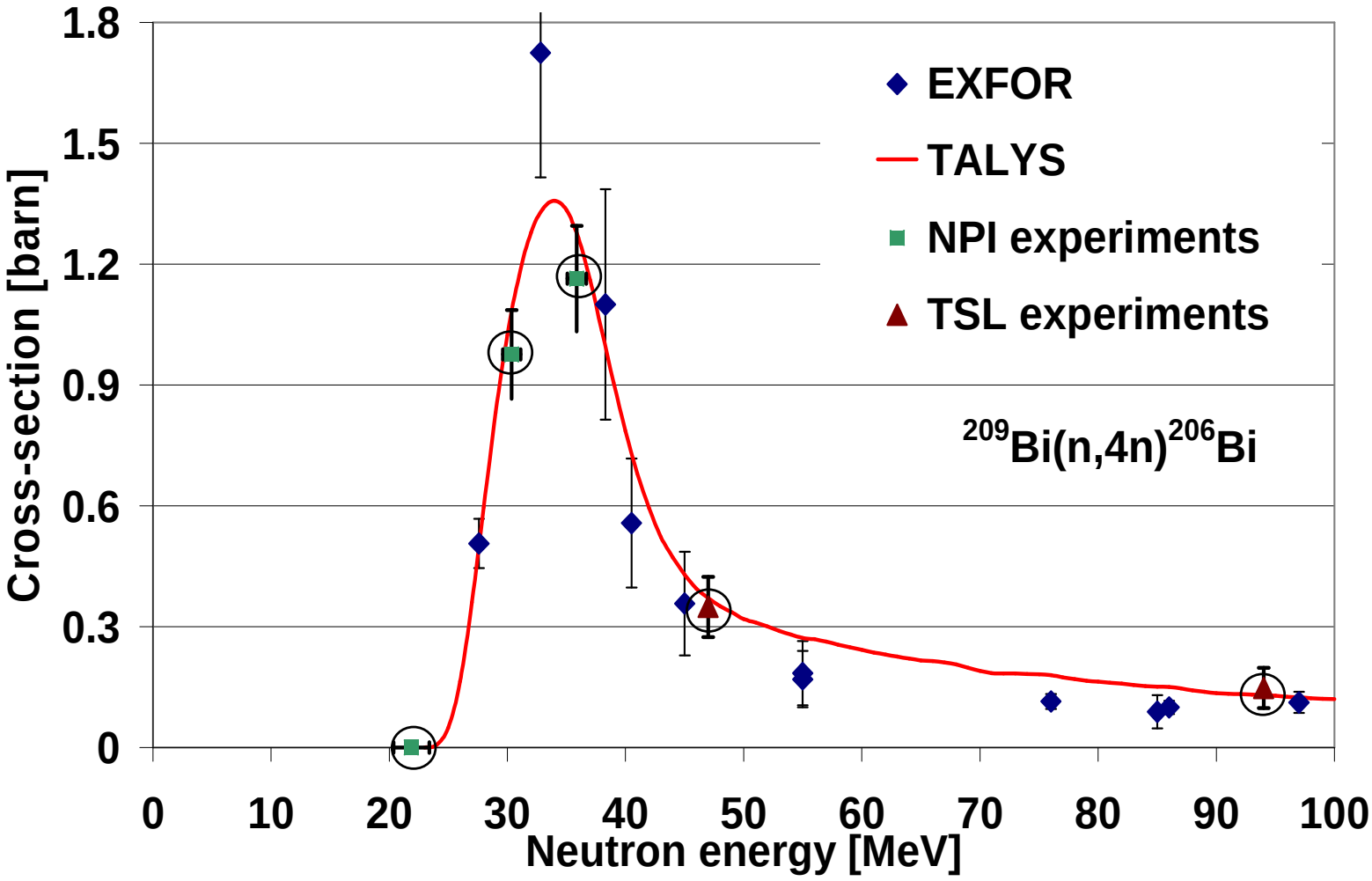
Au measured up to ^{188}Au…

$^{209}Bi(n,3n)^{207}Bi$ results

- Motivation
- σ measurement
- TSL Uppsala
- NPI Řež
- Evaluation
- **Results**
  - *^{207}Bi*
  - *^{206}Bi*
  - *Other Bi*
- Conclusion

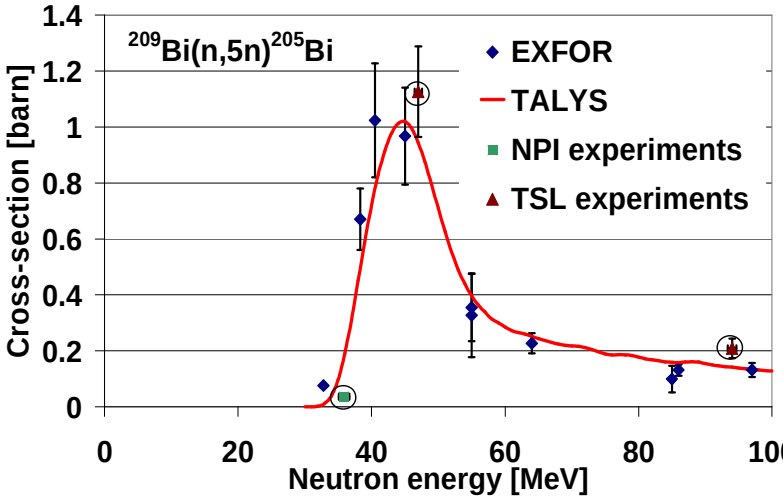


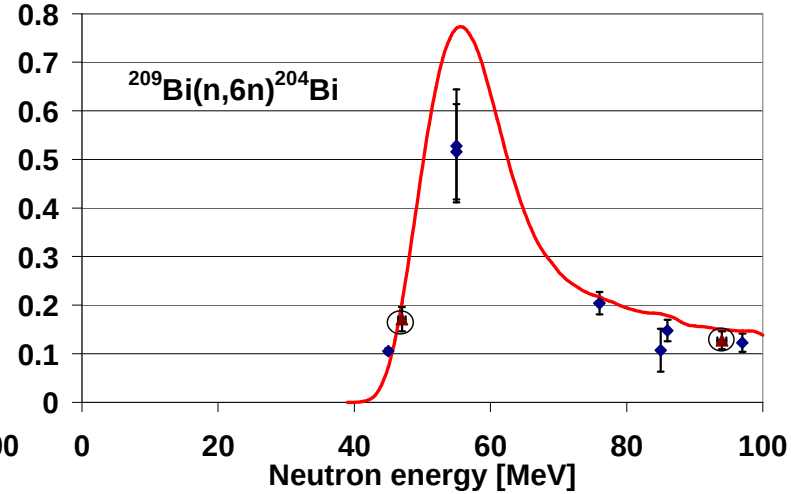
$^{209}Bi(n,4n)^{206}Bi$ results

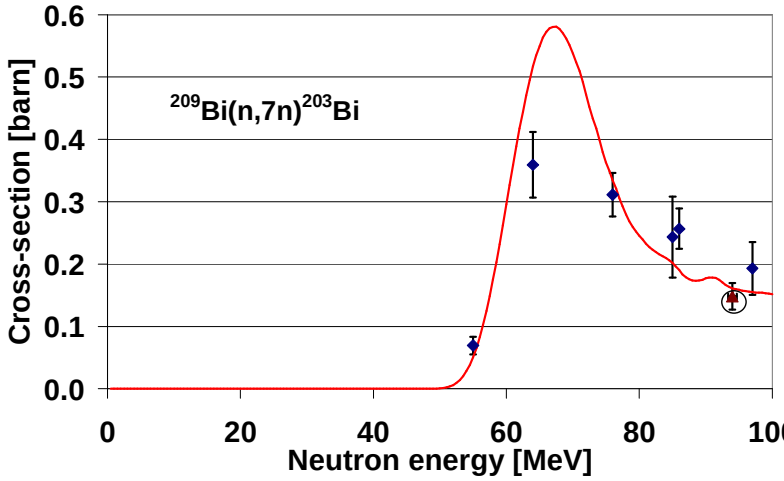


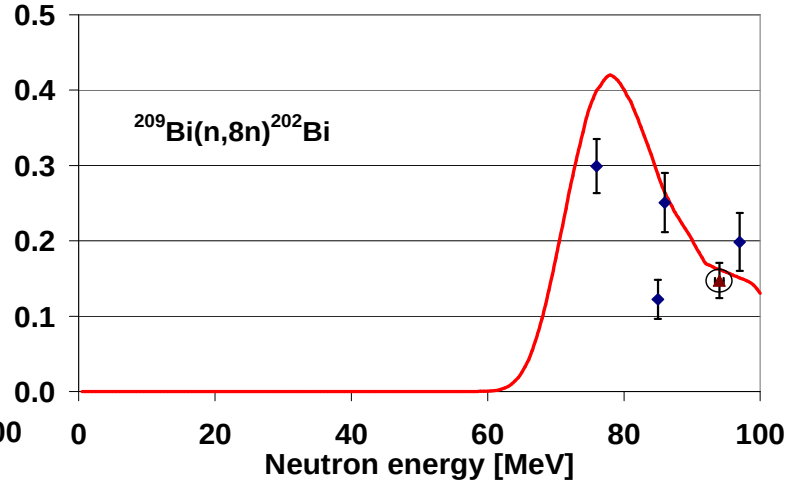
Other ^{209}Bi(n,xn) results

- Motivation
- σ measurement
- TSL Uppsala
- NPI Řež
- Evaluation
- **Results**
  - *^{207}Bi*
  - *^{206}Bi*
  - ***Other Bi***
- Conclusion





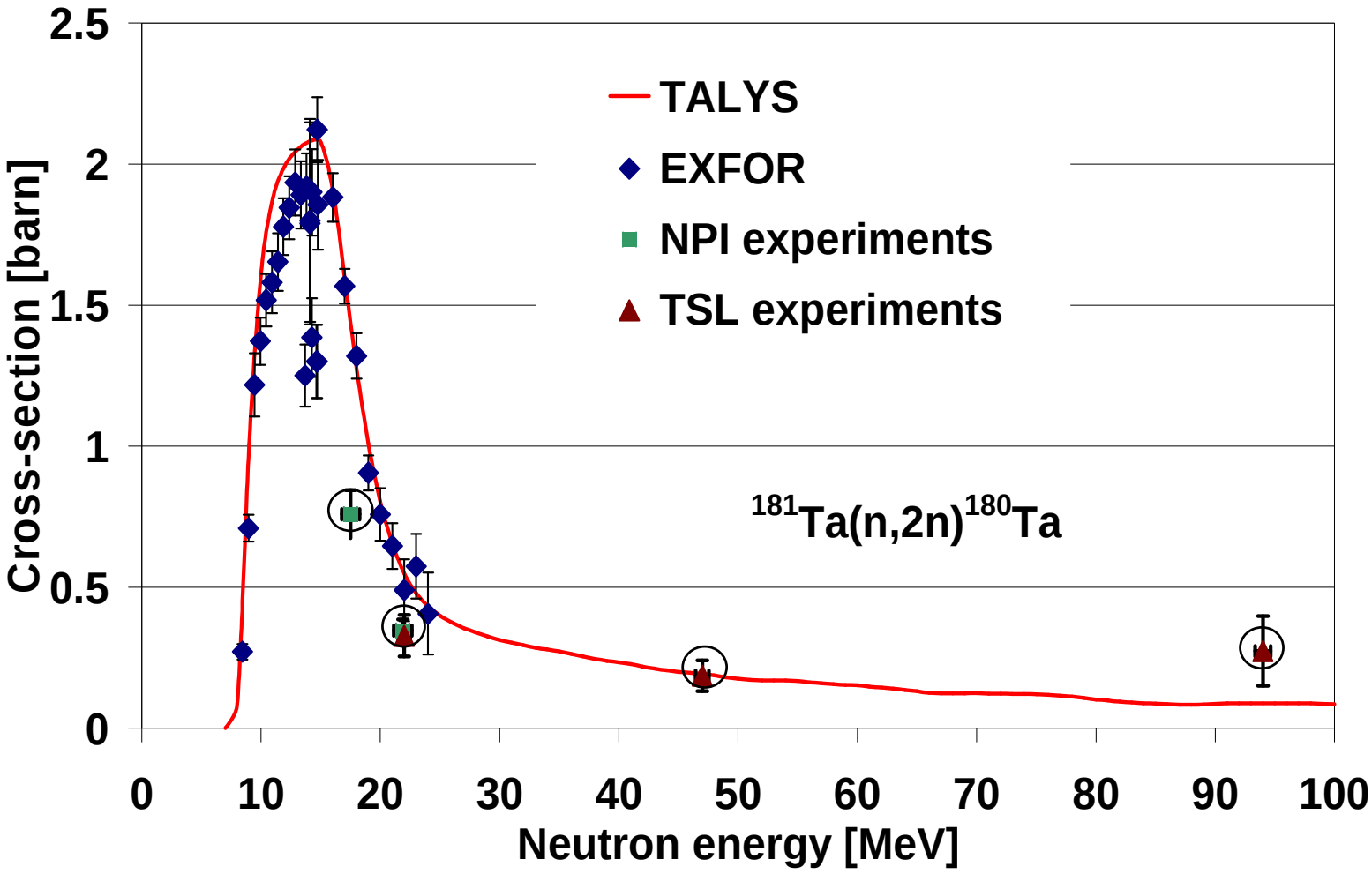




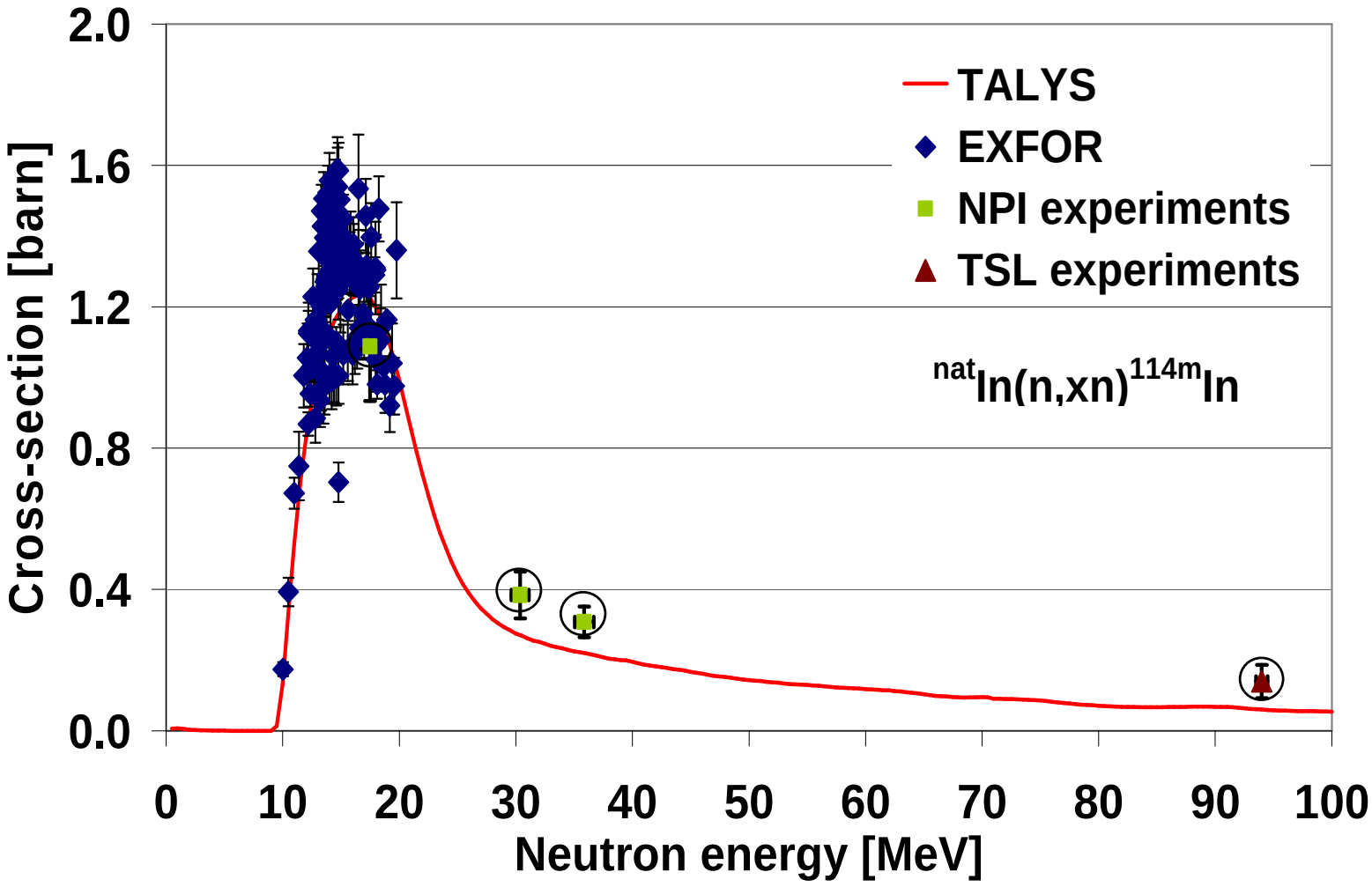
Bi measured up to ^{200}Bi…

$^{181}Ta(n,2n)^{180}Ta$ results

- Motivation
- σ measurement
- TSL Uppsala
- NPI Řež
- Evaluation
- **Results**
  - ^{181}Ta
  - ^{114m}In
  - ^{24}Na
  - ^{27}Mg
- Conclusion

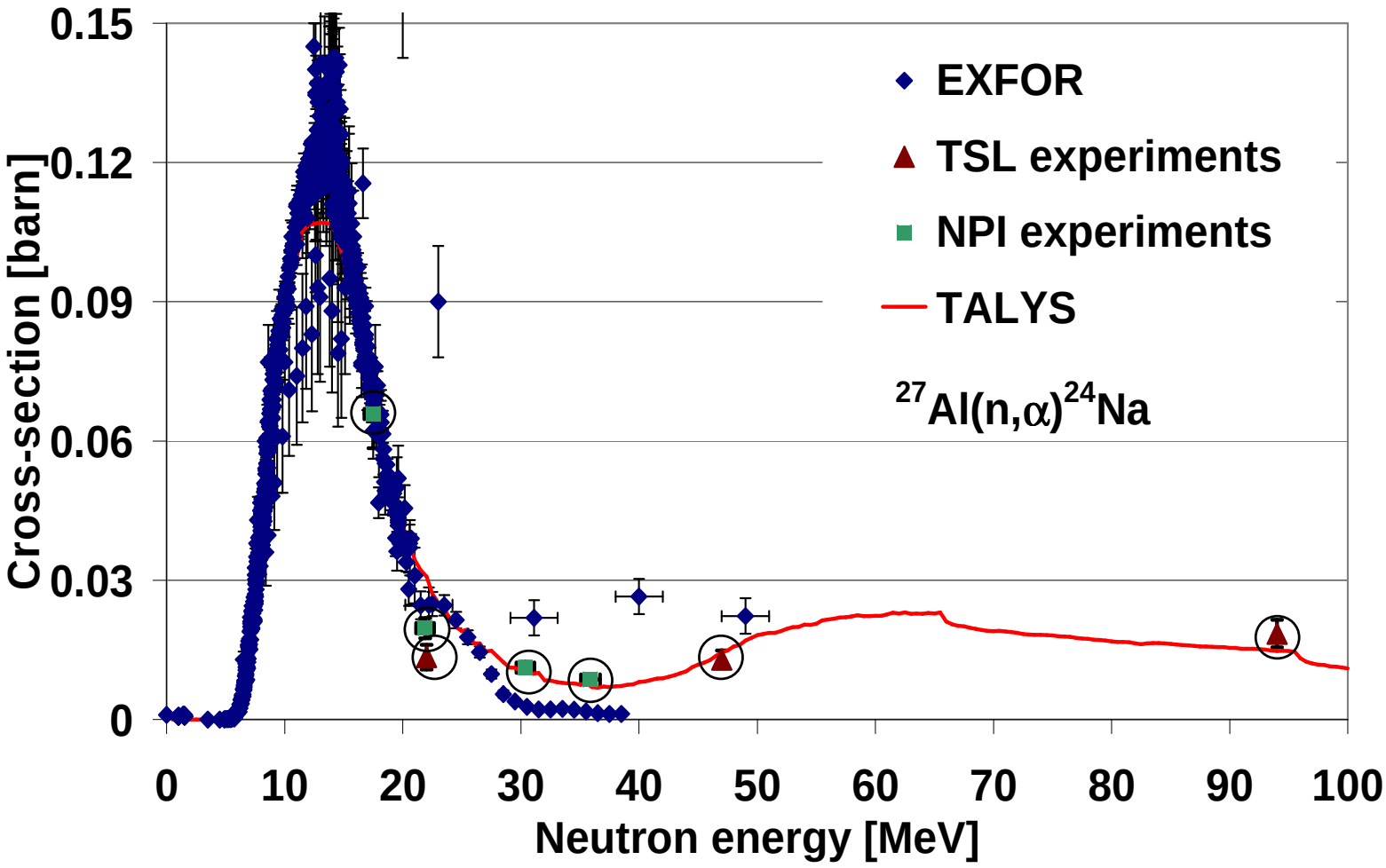


$^{nat}In(n,xn)^{114m}In$ results



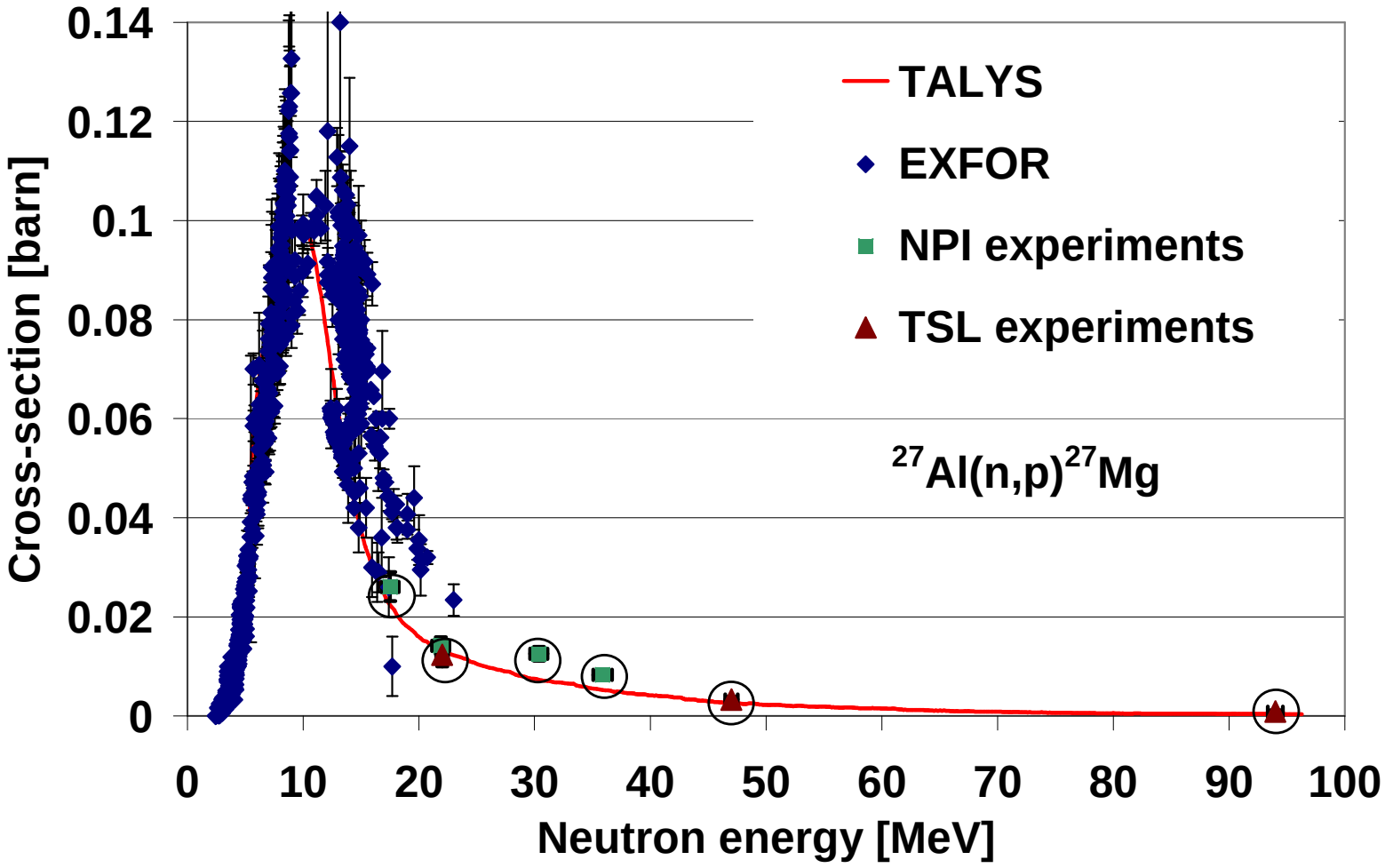
In measured up to ^{108}In…

$^{27}Al(n,\alpha)^{24}Na$ results



$^{27}Al(n,p)^{27}Mg$ results

- Motivation
- σ measurement
- TSL Uppsala
- NPI Řež
- Evaluation
- **Results**
  - ^{181}Ta
  - ^{114m}In
  - ^{24}Na
  - ^{27}Mg
- Conclusion



Conclusions

- Uppsala and Řež cross-section measurements covered wide range of energies (17 – 94 MeV)
- threshold reactions in Au, Bi, I, In, and Ta studied up to (n,10n)
- our results for well known cross-sections agree with other experimental data in EXFOR
- near future: finish the evaluation of cross-section measurements from Uppsala - February 2010
- autumn 2010 – planed next cross-sections measurements at NPI Řež
- further study of the background subtraction procedure and its uncertainty

Acknowledgements

We would like to thank to Dr. Bém and his colleagues for the possibility to joint their irradiations on cyclotron in Řež!

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Thank you for your attention..