Measurement of the ^{240,242}Pu neutron-induced fission cross sections

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Outline

- Introduction
- Experimental setup
- Data analysis: Problems and solutions
  - α pile-up rejection
  - Efficiency determination
- Results
  - Spontaneous fission
  - Fission cross section
- Summary

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Target accuracy assessment

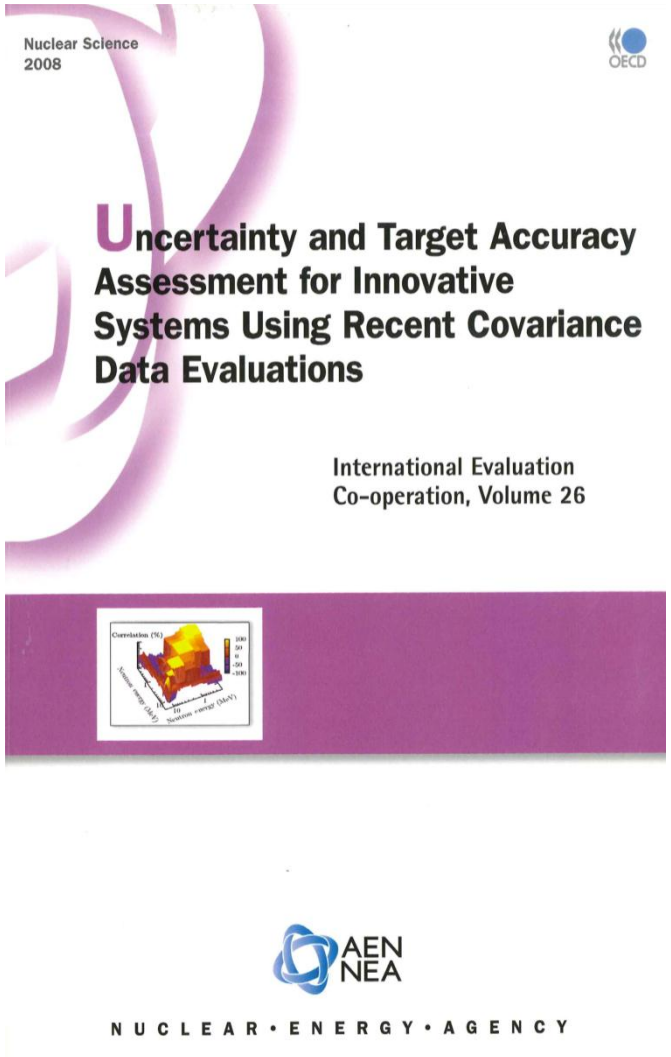

Table 32. Summary of Highest Priority Target Accuracies for Fast Reactors

		Energy Range	Current Accuracy (%)	Target Accuracy (%)
U238	σ_{inel}	6.07 ÷ 0.498 MeV	10 ÷ 20	2 ÷ 3
	σ_{capt}	24.8 ÷ 2.04 keV	3 ÷ 9	1.5 ÷ 2
Pu241	σ_{fiss}	1.35MeV ÷ 454 eV	8 ÷ 20	2 ÷ 3 (SFR,GFR, LFR) 5 ÷ 8 (ABTR, EFR)
Pu239	σ_{capt}	498 ÷ 2.04 keV	7 ÷ 15	4 ÷ 7
Pu240	σ_{fiss}	1.35 ÷ 0.498 MeV	6	1.5 ÷ 2
	ν	1.35 ÷ 0.498 MeV	4	1 ÷ 3
Pu242	σ_{fiss}	2.23 ÷ 0.498 MeV	19 ÷ 21	3 ÷ 5
Pu238	σ_{fiss}	1.35 ÷ 0.183 MeV	17	3 ÷ 5
Am242m	σ_{fiss}	1.35MeV ÷ 67.4keV	17	3 ÷ 4
Am241	σ_{fiss}	6.07 ÷ 2.23 MeV	12	3
Cm244	σ_{fiss}	1.35 ÷ 0.498 MeV	50	5
Cm245	σ_{fiss}	183 ÷ 67.4 keV	47	7
Fe56	σ_{inel}	2.23 ÷ 0.498 MeV	16 ÷ 25	3 ÷ 6
Na23	σ_{inel}	1.35 ÷ 0.498 MeV	28	4 ÷ 10
Pb206	σ_{inel}	2.23 ÷ 1.35 MeV	14	3
Pb207	σ_{inel}	1.35 ÷ 0.498 MeV	11	3
Si28	σ_{inel}	6.07 ÷ 1.35 MeV	14 ÷ 50	3 ÷ 6
	σ_{capt}	19.6 ÷ 6.07 MeV	53	6

ANDES European project

→ Accurate Nuclear Data for nuclear Energy Sustainability

- 3-year project (started mid 2010)
- 20 partners from 15 countries in Europe (CIEMAT, IRMM, n_TOF – CERN, CNRS, etc)
- WP1: Measurements for advance reactor systems

↳ 3 different experiments on $\sigma_{^{240,242}Pu}(E_n)$ → IRMM, n_TOF, CNRS

↳ relative to different standards (^{235}U, ^{237}Np, ^{238}U, ^{1}H)

secondary standards

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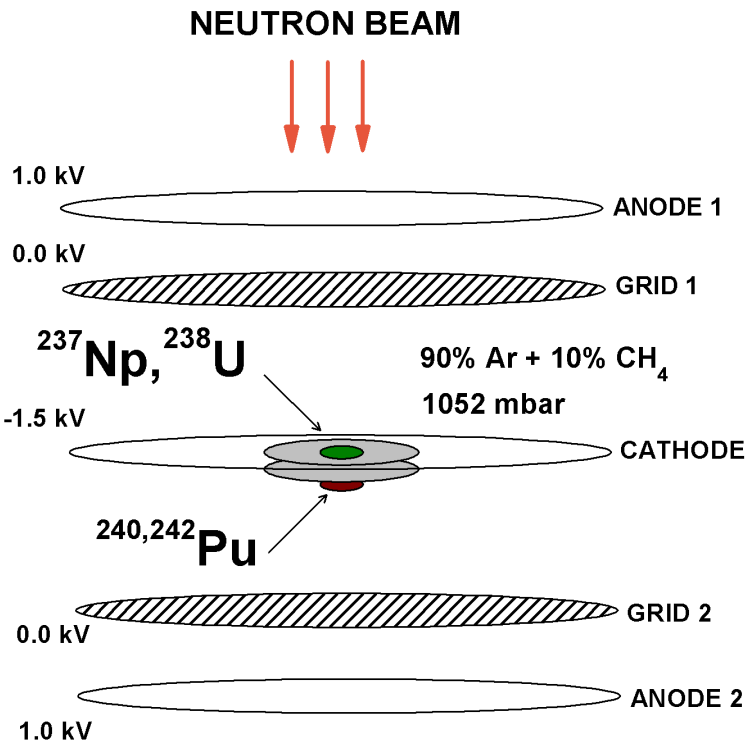
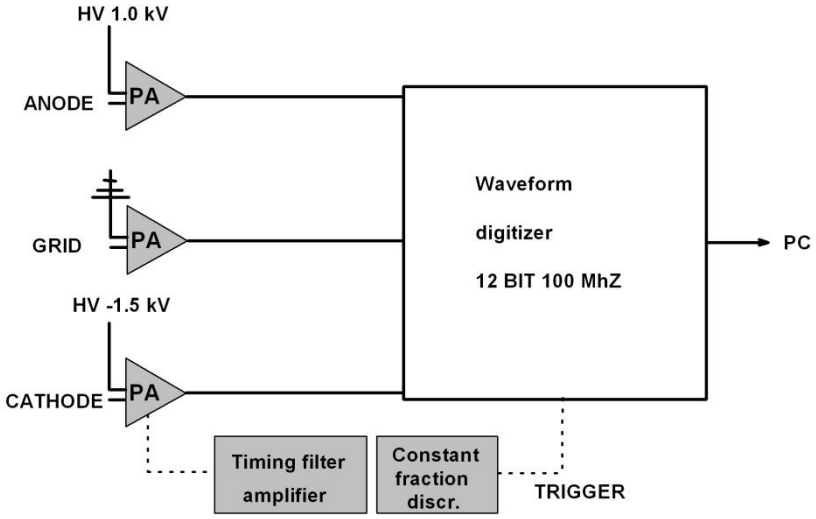
Experimental setup

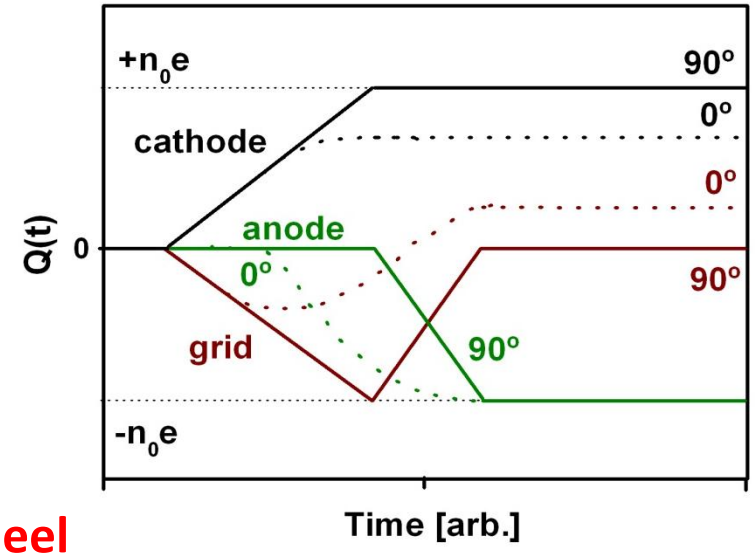
TFGIC:



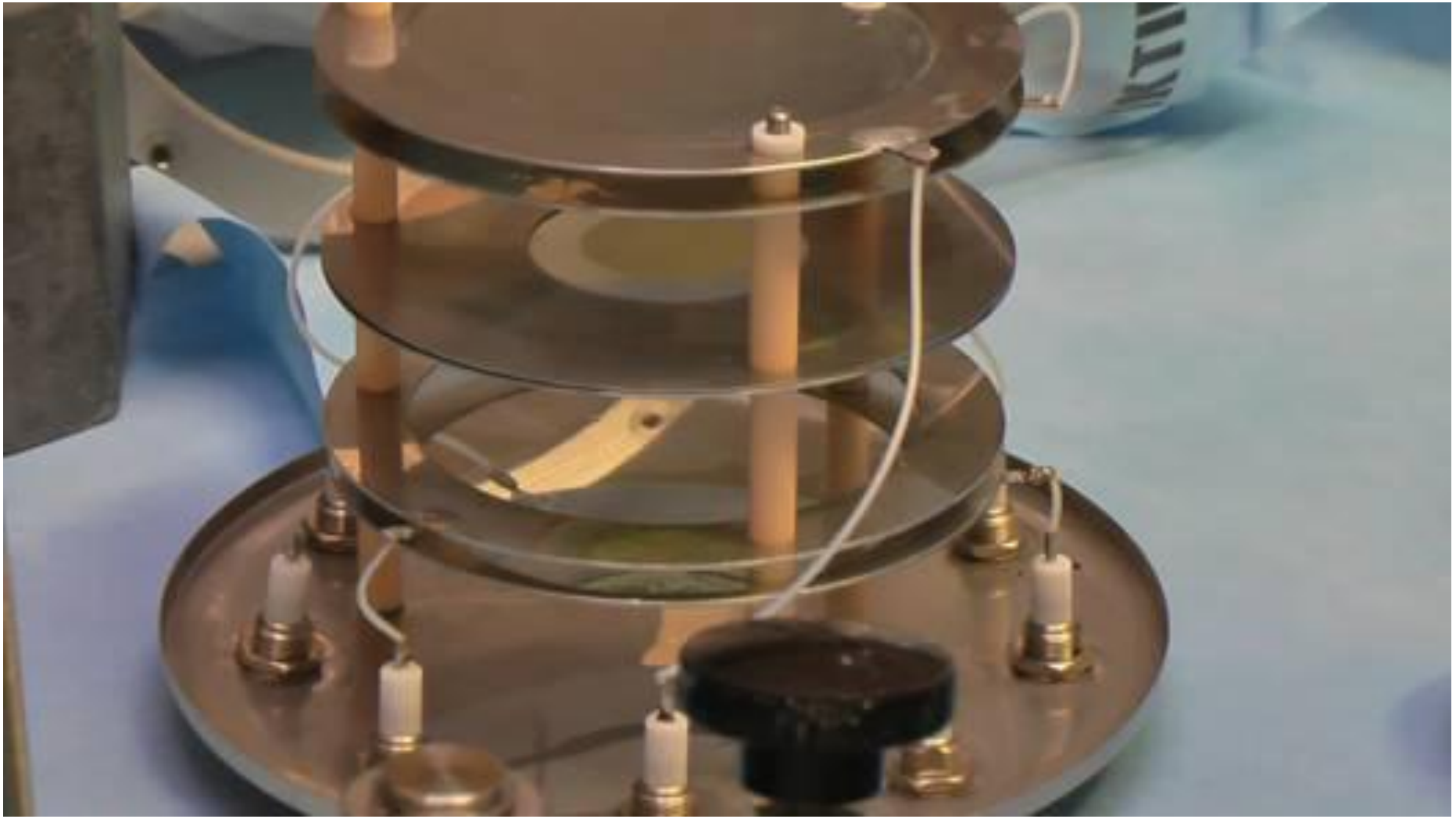
Electronic scheme:



Signals:



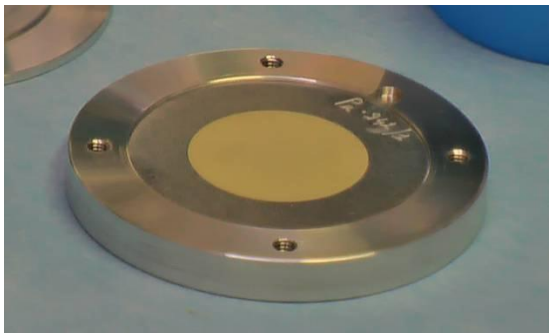
→ At the Van de Graaff accelerator in Geel



Sample description*

Reference samples

	^{240}Pu	^{242}Pu	^{237}Np	^{238}U
Method	electrodeposition	electrodeposition	electrodeposition	vacuum deposition
Mass (µg)	92.9 (0.4%)	671 (0.9%)	391.3 (0.3%)	614 (0.5%)
Diameter (mm)	29.95 (0.01%)	29.95 (0.01%)	12.7	30
Areal density (µg/cm²)	13.19 (0.4%)	95.3 (0.9%)	308.9	86.9
Backing	aluminium	aluminium	stainless steel	aluminium
α-activity (MBq)	0.780 (0.4%)	0.0948 (0.3%)	10193×10^{-6} (0.1%)	7.64×10^{-6} (0.5%)
% ^{238}Pu	0.0733	0.0027		
% ^{239}Pu	0.0144	0.0044		
% ^{240}Pu	99.8915	0.0192		
% ^{241}Pu	0.00041	0.0081		
% ^{242}Pu	0.02027	99.9652		
% ^{244}Pu	0.00005	0.0004		



*Samples made at IRMM

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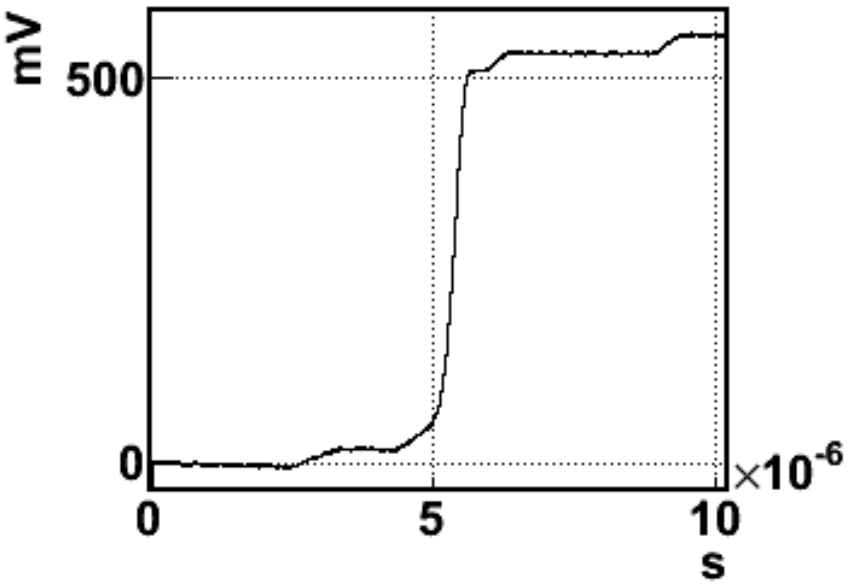
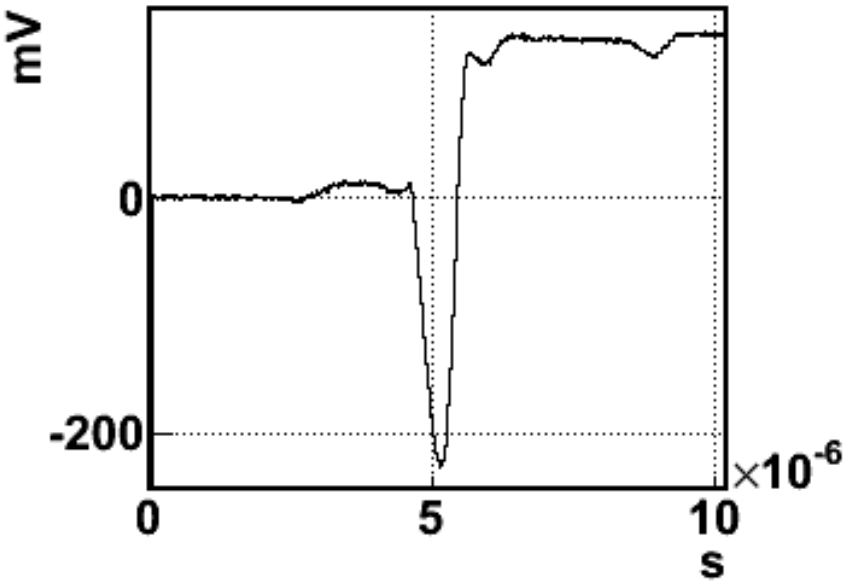
α pile-up rejection: case ^{242}Pu (0.1MBq)

anode signal



FF energy

grid signal



FF energy
FF emission angle

α pile-up rejection: case ^{242}Pu (0.1MBq)

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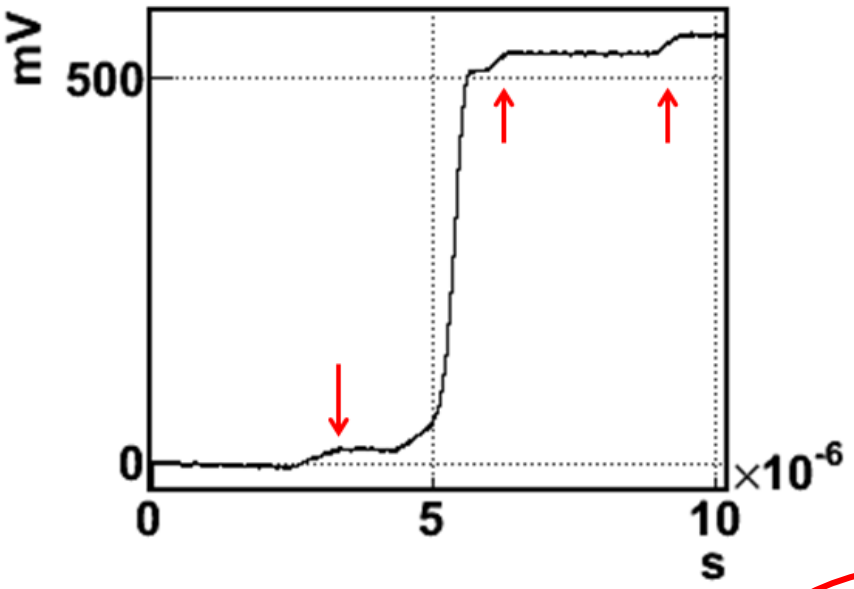
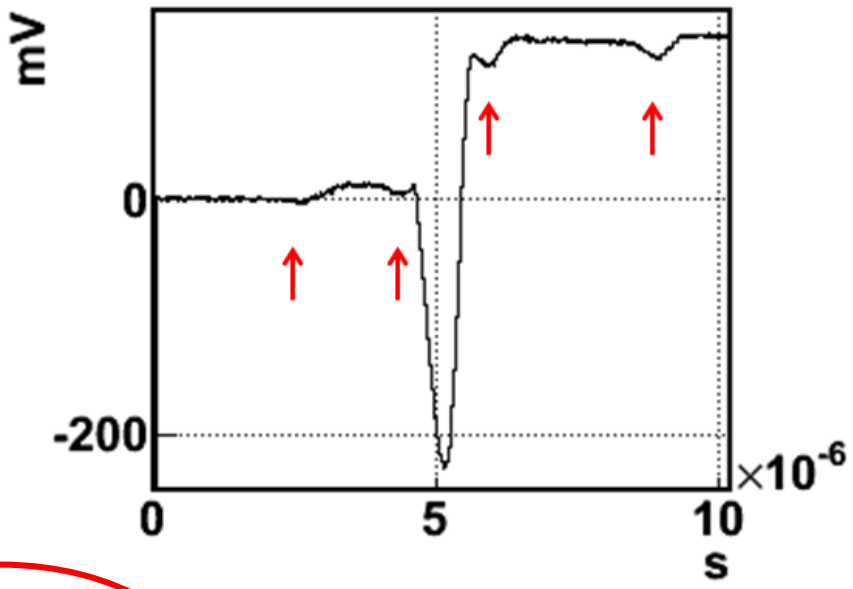


grid signal



FF energy

α particle pile-up

FF energy
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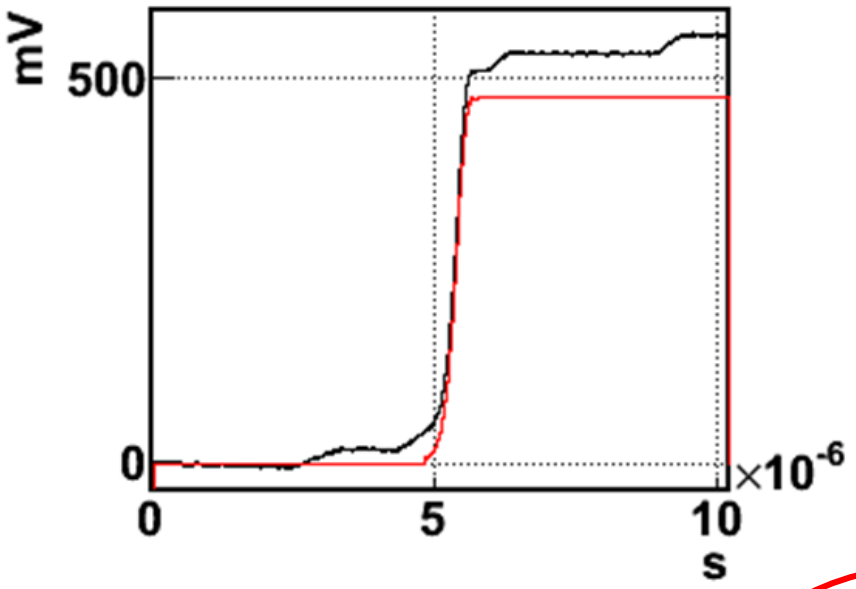
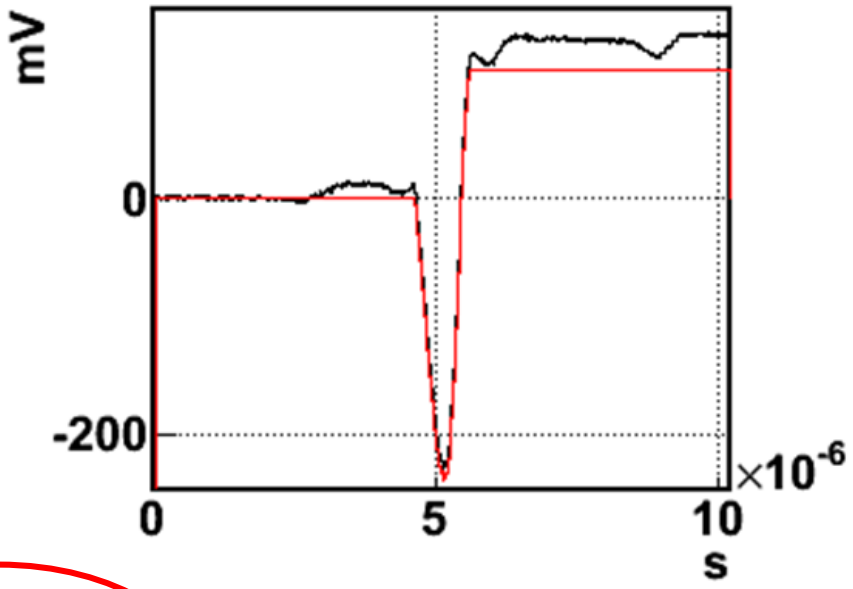


FF energy

corrected signal

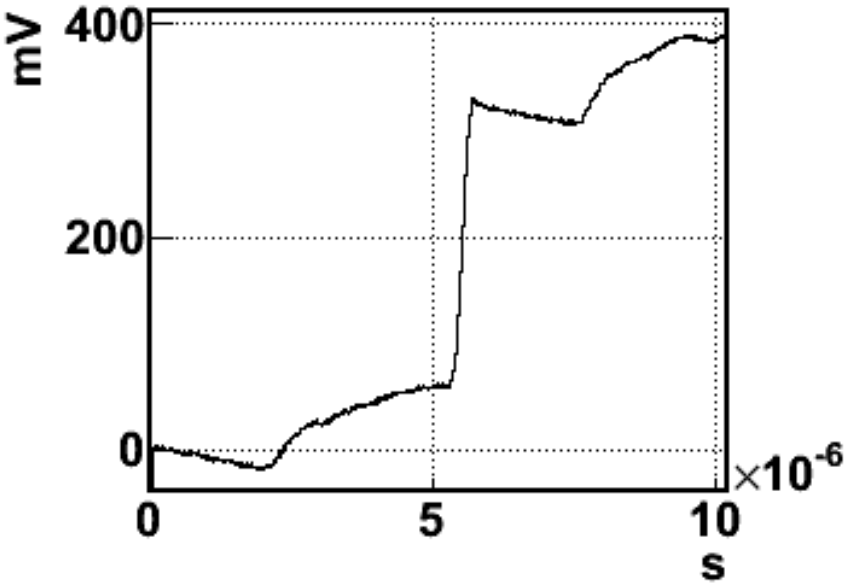
grid signal



FF energy
FF emission angle

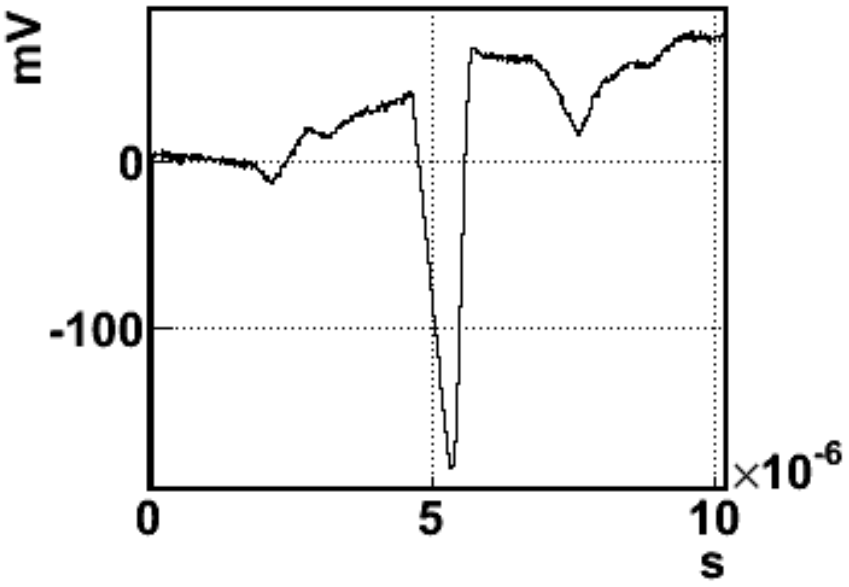
α pile-up rejection: case ^{240}Pu (0.8MBq)

anode signal



FF energy

grid signal



FF energy
FF emission angle

α pile-up rejection: case ^{240}Pu (0.8MBq)

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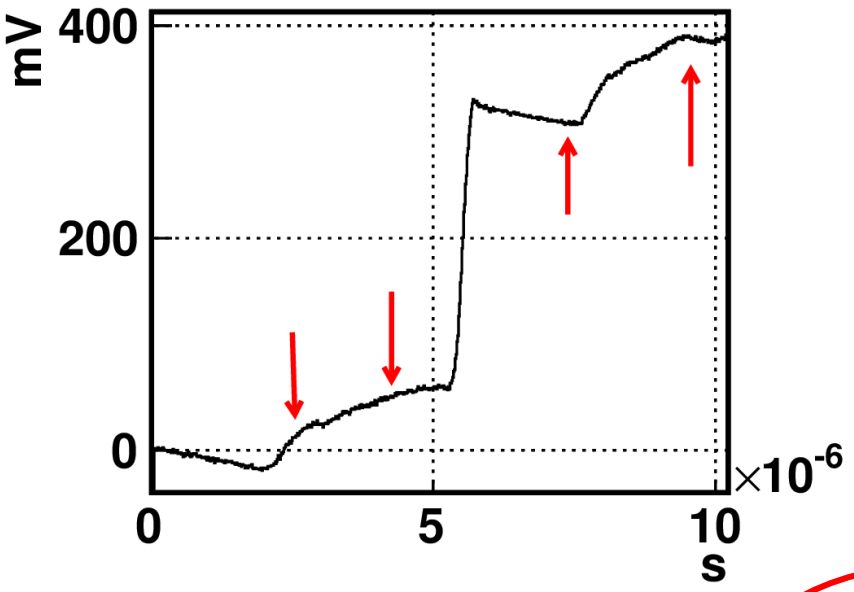
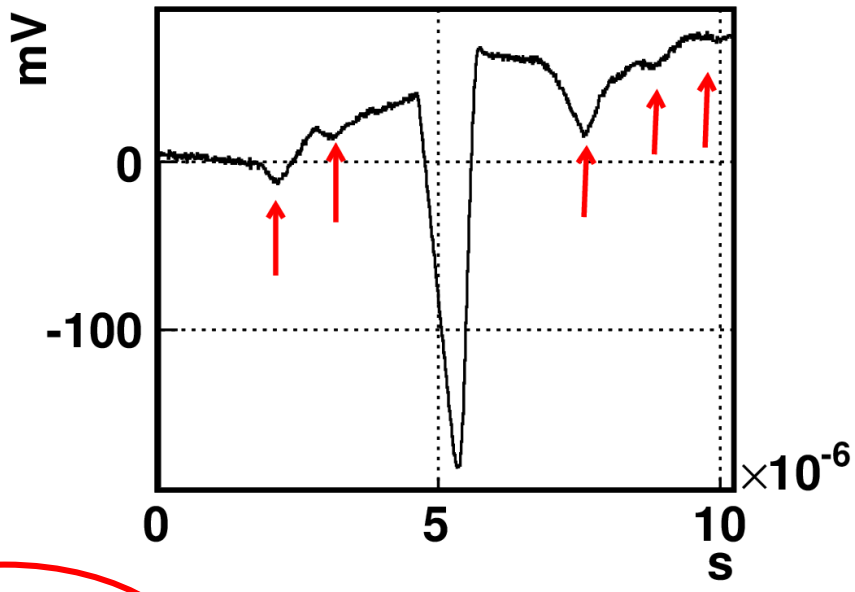


FF energy

α particle pile-up

grid signal



FF energy
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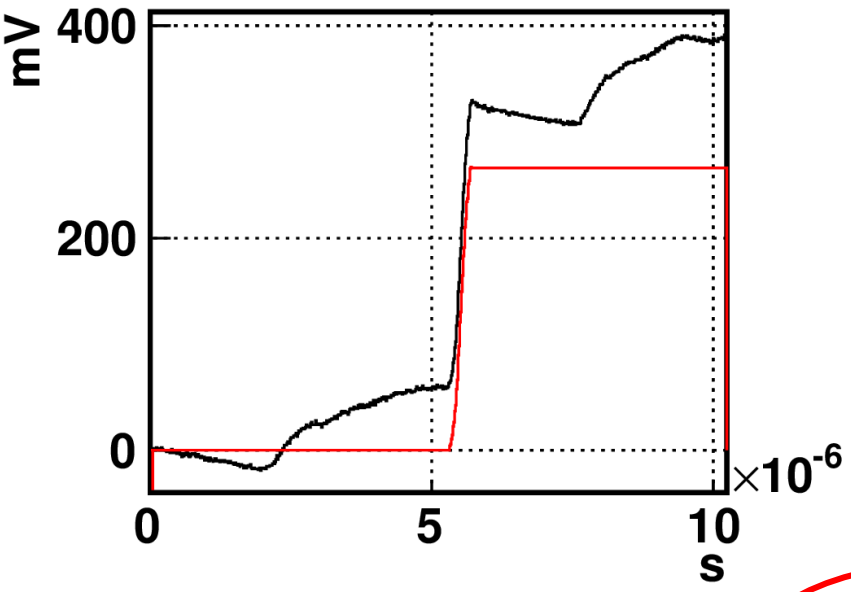
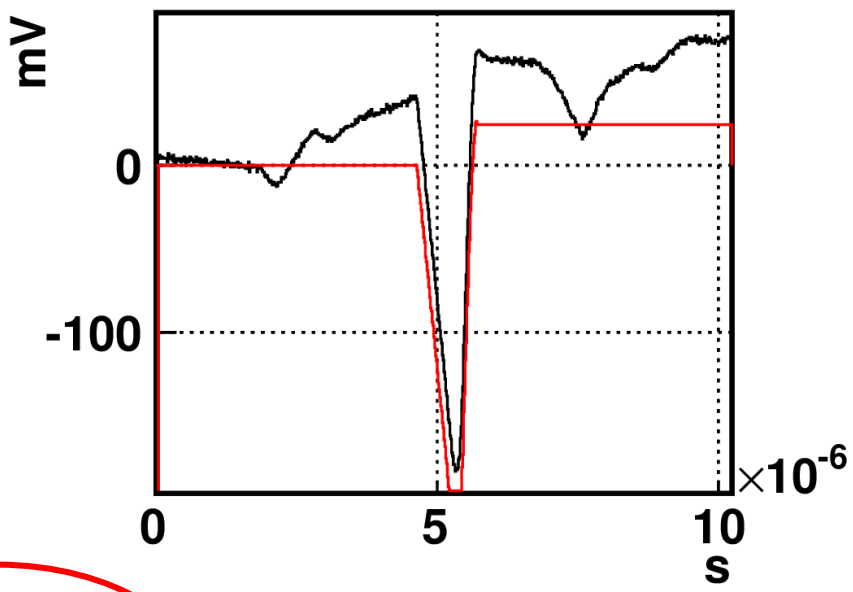


FF energy

corrected signal

grid signal

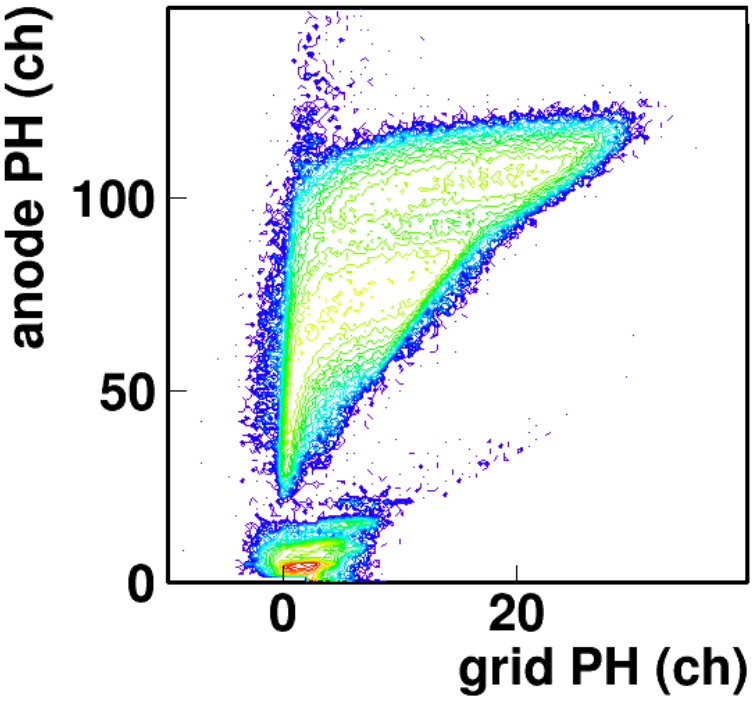


FF energy
FF emission angle

Efficiency determination: fission fragment loss

- How? Grid method for determining the FF emission angle
- Data used: Spontaneous Fission ⟶ isotropic emission

Case: ^{242}Pu



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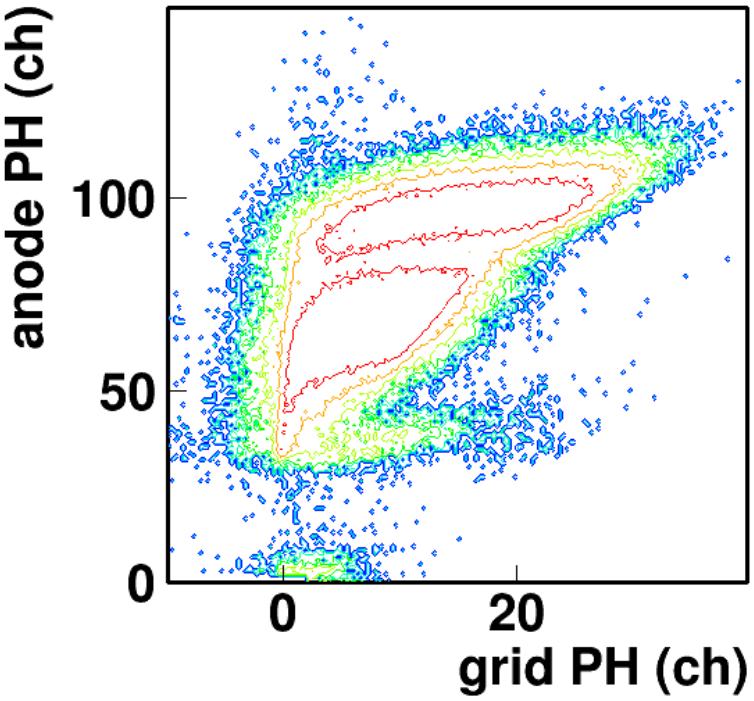

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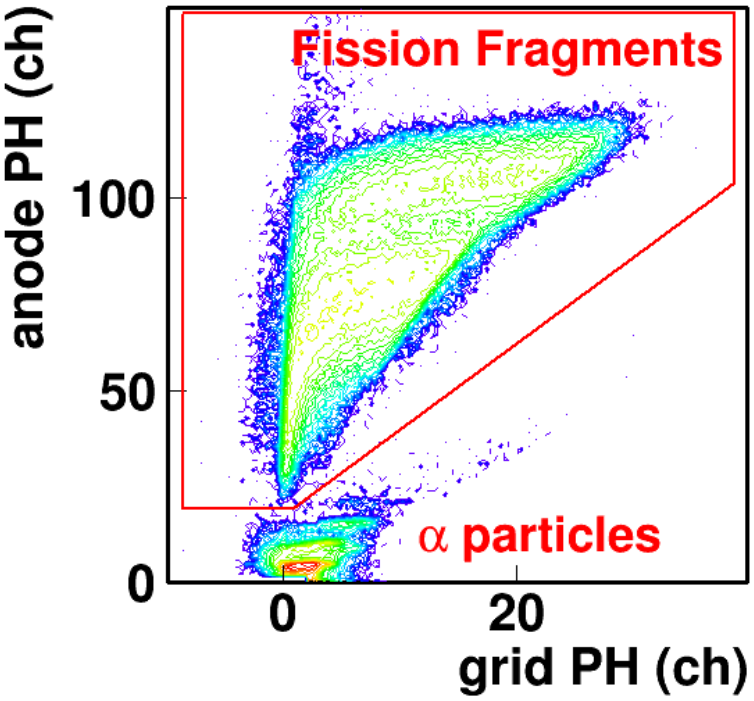

Budtz-Jørgensen, C., Knitter, H.-H., *Investigation of fission layers for precise fission cross-section measurements with a gridded ionization chamber*. Nucl. Sci. & Eng. 86, 10-21 (1984)

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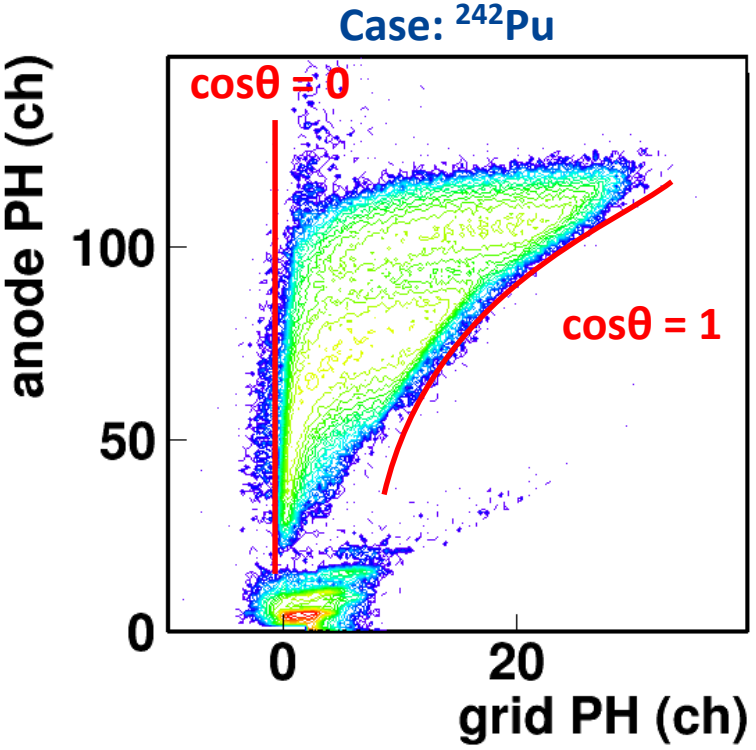

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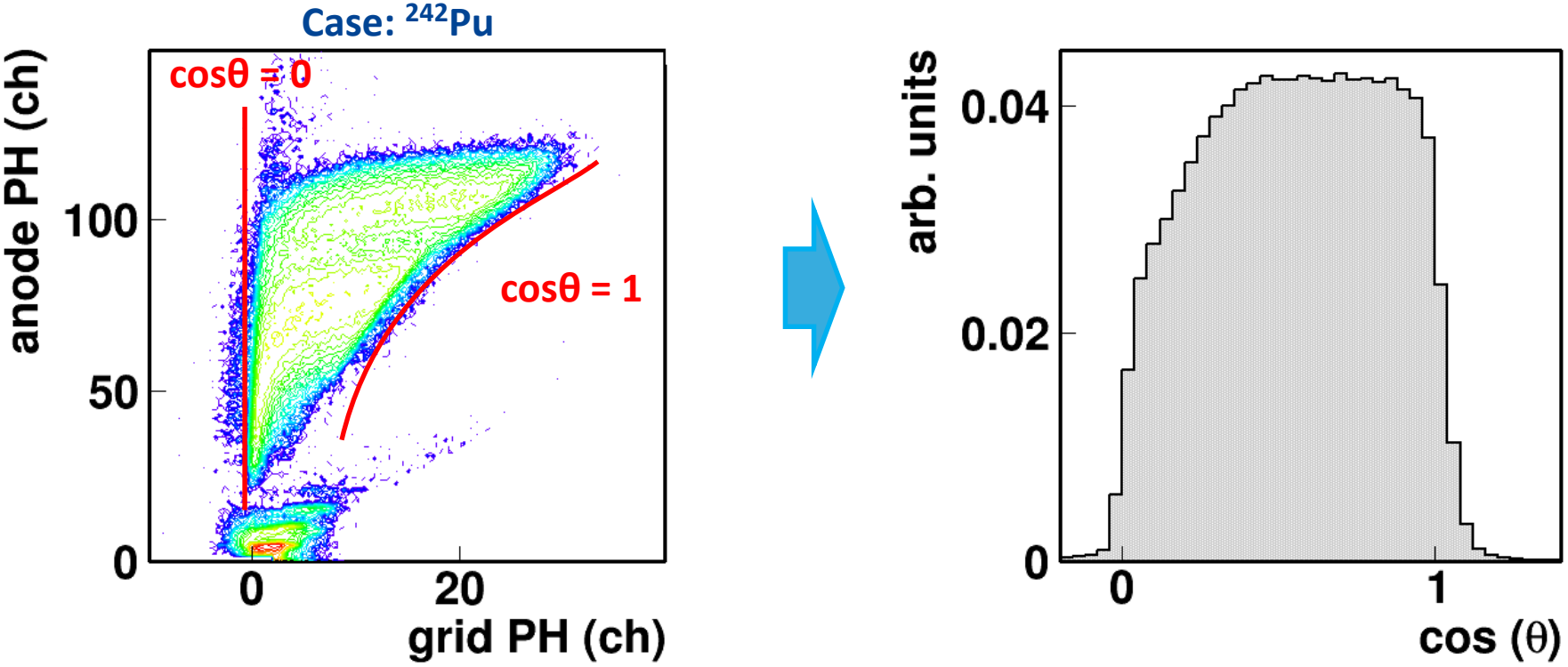

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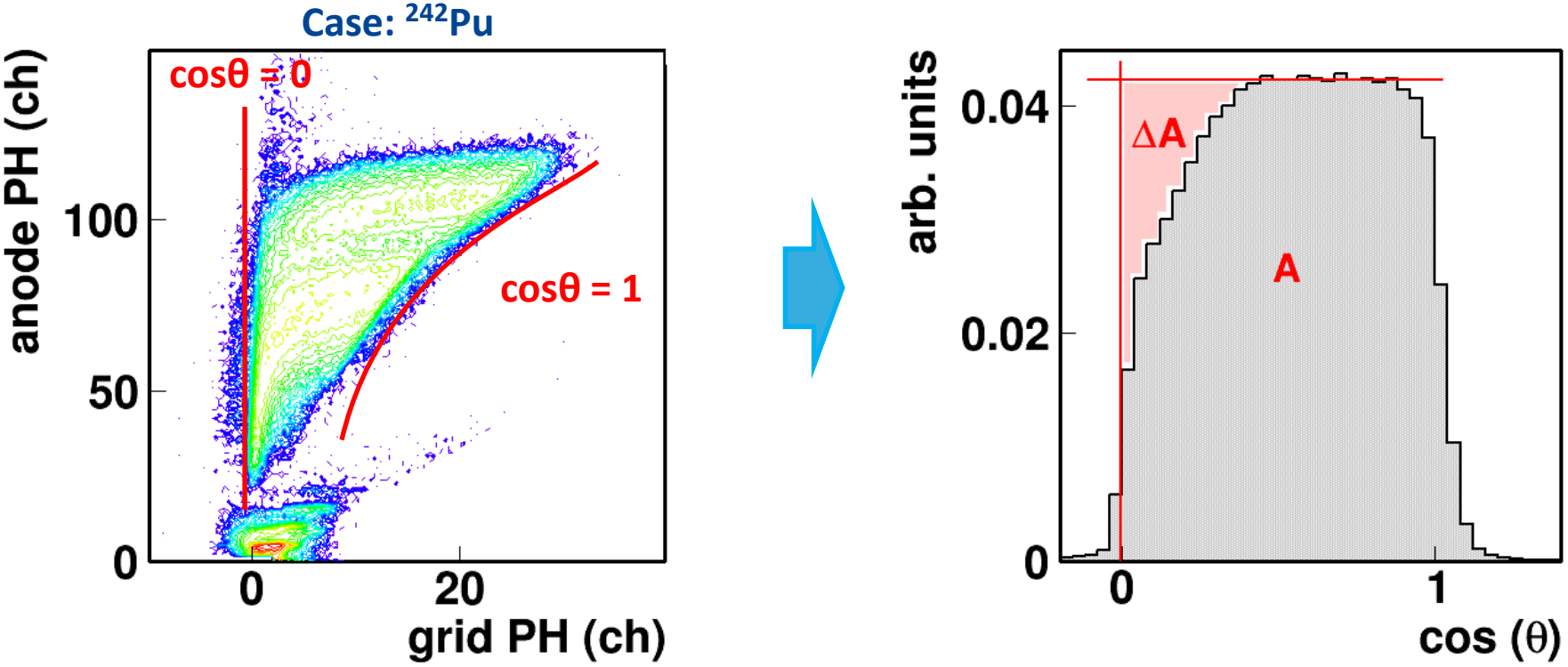

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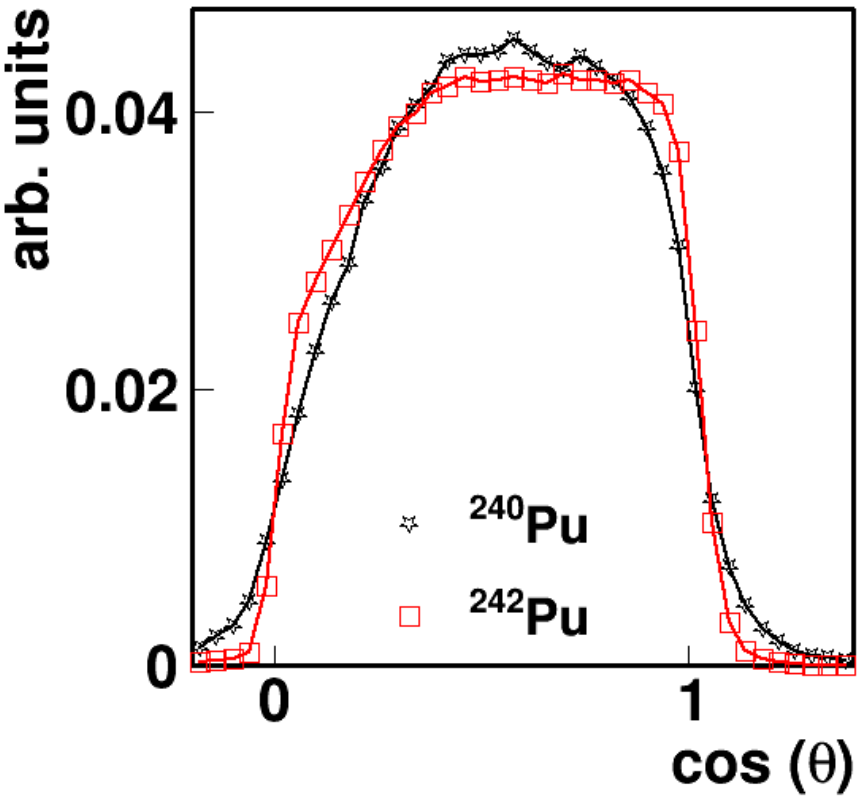
Efficiency determination: fission fragment loss

^{242}Pu (0.1MBq) vs ^{240}Pu (0.8MBq)



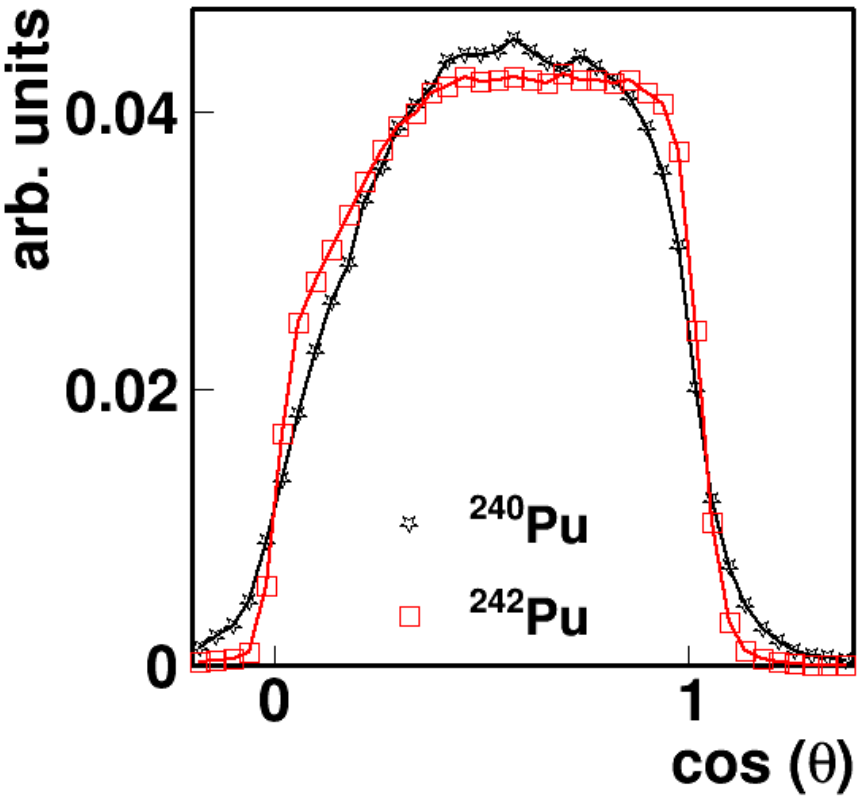
Experimentally

^{242}Pu (122μg/cm^2) ⟶ ε ~ 94-95±1%

^{240}Pu (16.9μg/cm^2) ⟶ ε ~ 94±1%

Efficiency determination: fission fragment loss

^{242}Pu (0.1MBq) vs ^{240}Pu (0.8MBq)



Experimentally

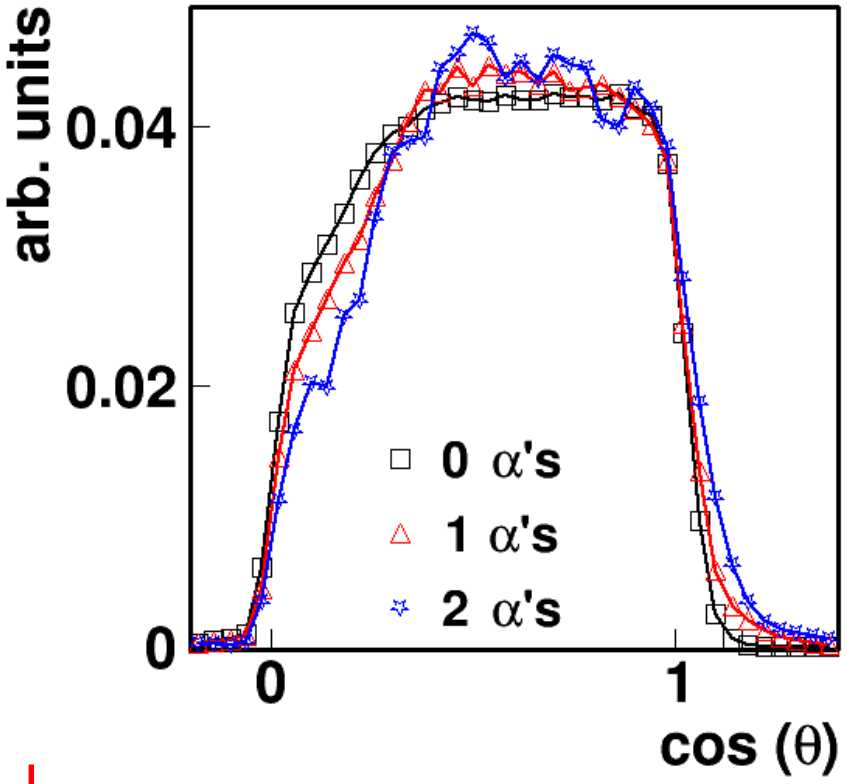
^{242}Pu (122μg/cm^2) ⟶ ε ~ 94-95±1%

^{240}Pu (16.9μg/cm^2) ⟶ ε ~ 94±1%

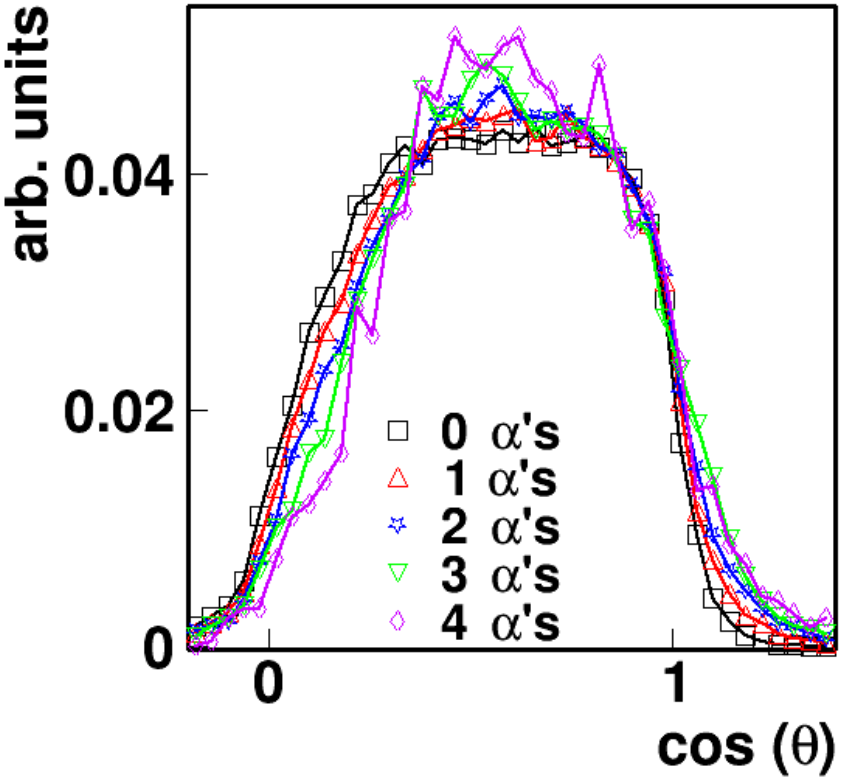
But ^{240}Pu is much thinner than ^{242}Pu

Influence of the α pile-up with P10 as counting gas?

case ^{242}Pu



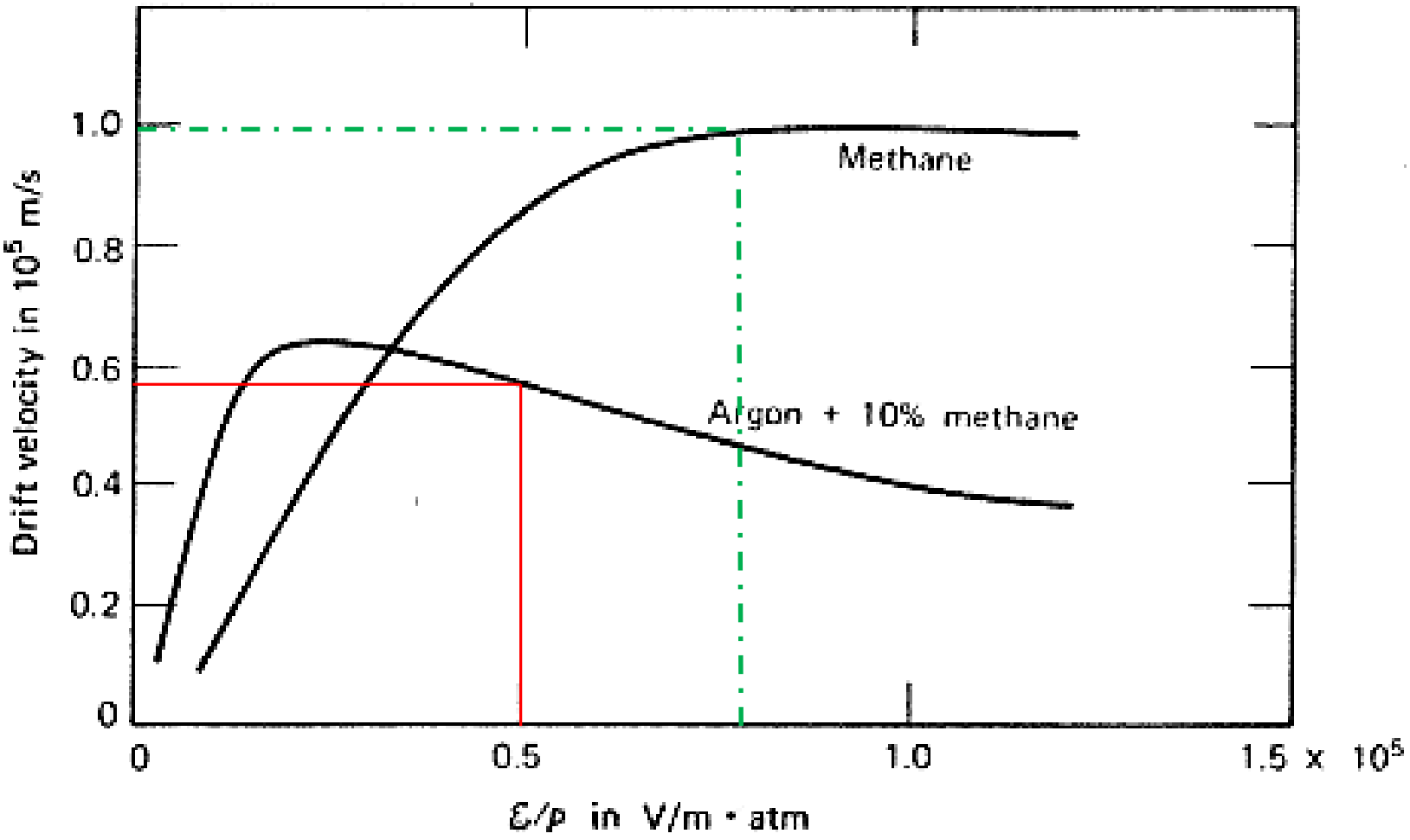
case ^{240}Pu



↳ **Before the fission fragment event**

Improving signal rise time

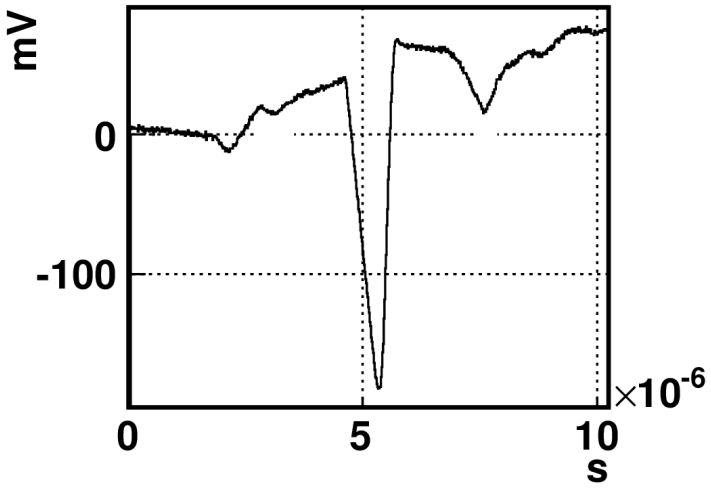
Drift velocities in gases: P10 vs Methane



Knoll, G.F. *Radiation detection and measurement*. 3d edition. p. 133

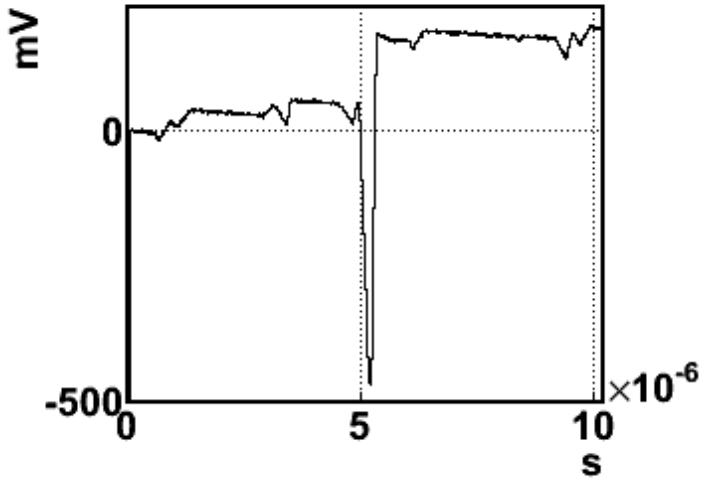
Drift velocities in gases: P10 vs Methane

(i) Signal with P10



⟶ Rise time ~ 0.20µs

(ii) Signal with Methane



⟶ Rise time ~ 0.077µs

Drift velocities in gases: P10 vs Methane

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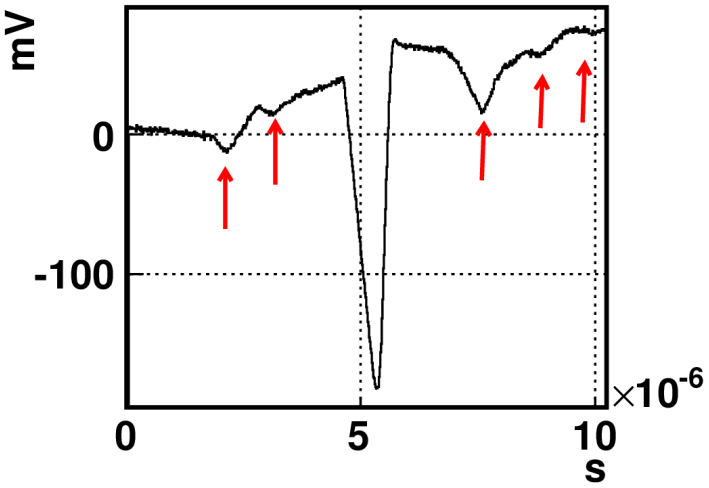
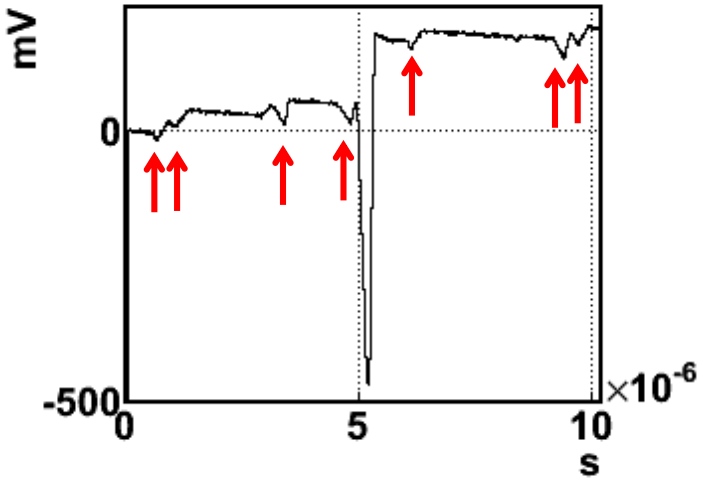


⟶ Rise time ~ 0.20µs

α particle pile-up

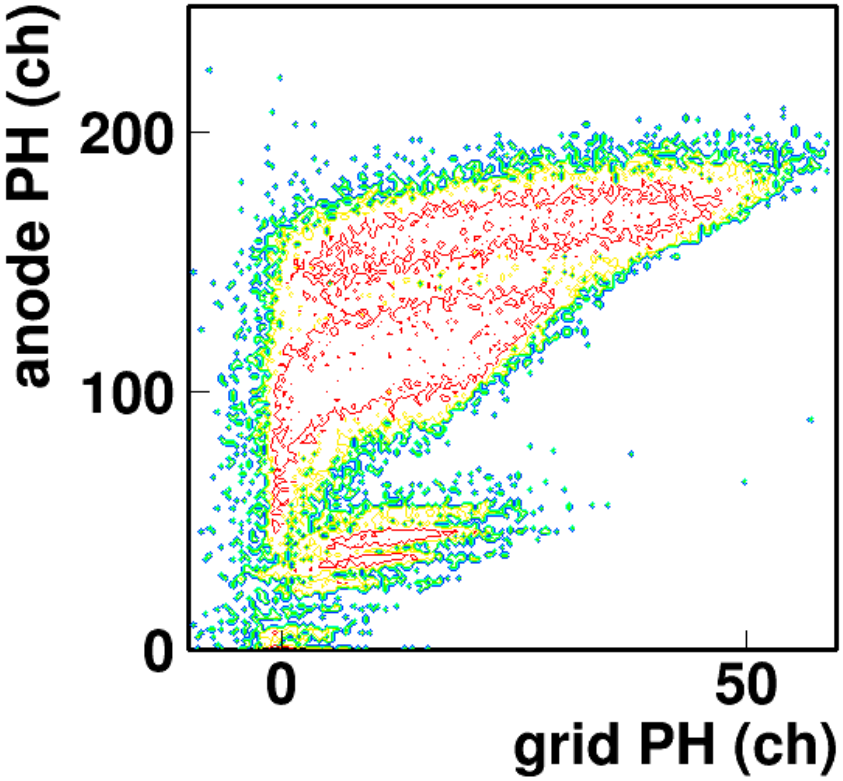
(ii) Signal with Methane

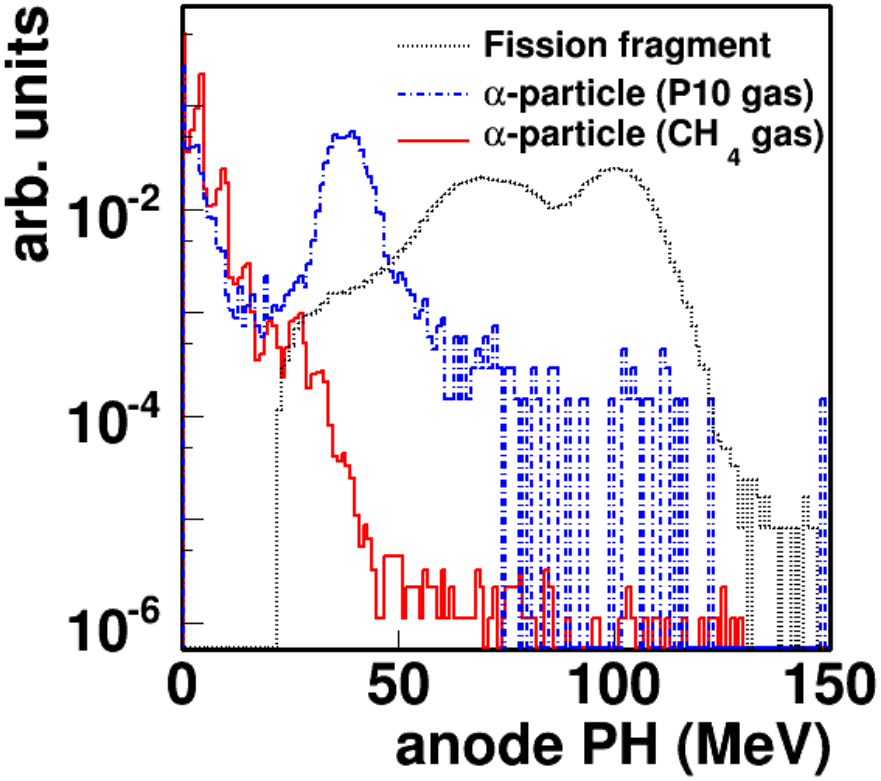


⟶ Rise time ~ 0.077µs

Pulse Height distribution: P10 vs Methane

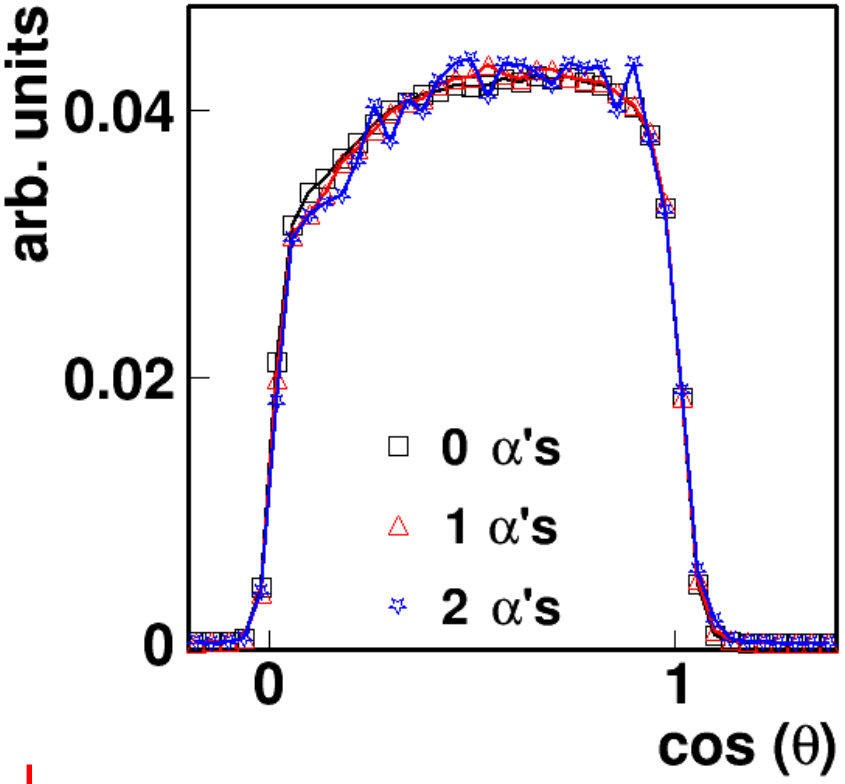
case ^{240}Pu



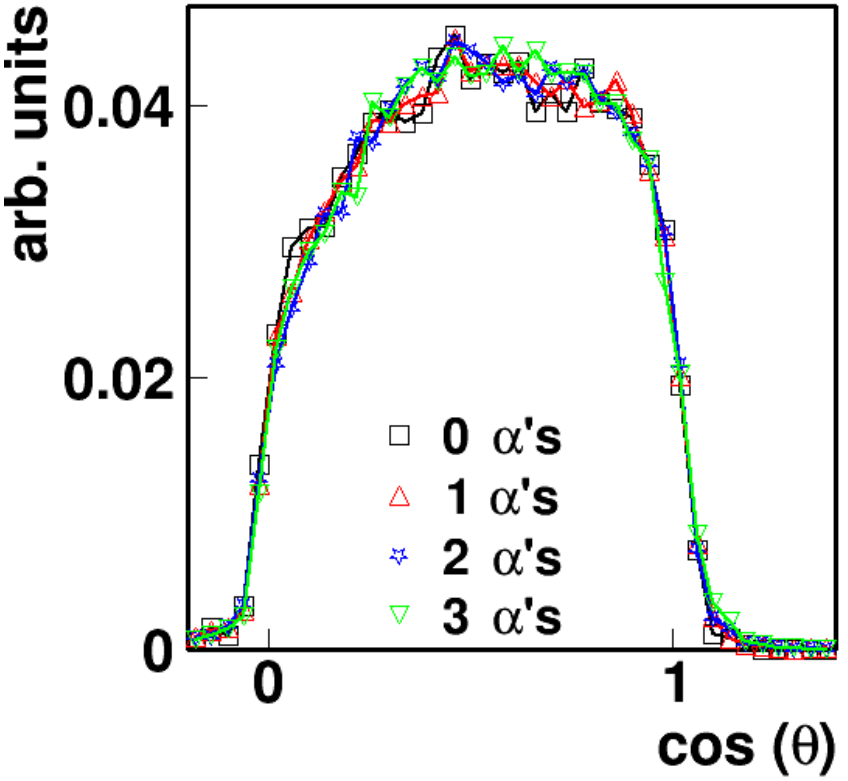


Influence of the α pile-up with CH_4 as counting gas?

case ^{242}Pu



case ^{240}Pu



↳ **Before the fission fragment event**

Efficiency results

$$\Delta_{sample} = \frac{t}{2R_{sample}} \qquad \frac{1}{R_{sample}} = \sum_i \frac{W_i}{R_i}$$

t = sample thickness
R_i = range isotope i
W_i = weight fraction isotope i in the sample

		^{240}Pu (16.9µg/cm^2)	^{242}Pu (122µg/cm^2)
Theory		99.7%	98.1%
GEANT4		99.2%	97.4%
Experiment (P10)	All events	94 ± 1%	94-95 ± 1%
	0-α	97 ± 1%	95-96 ± 1%
Experiment (CH_4)	All events	98-100 ± 1%	98-100 ± 1%
	0-α	100 ± 1%	100 ± 1%

Budtz-Jørgensen, C., Knitter, H.-H., *Investigation of fission layers for precise fission cross-section measurements with a gridded ionization chamber*. Nucl. Sci. & Eng. 86, 10-21 (1984)

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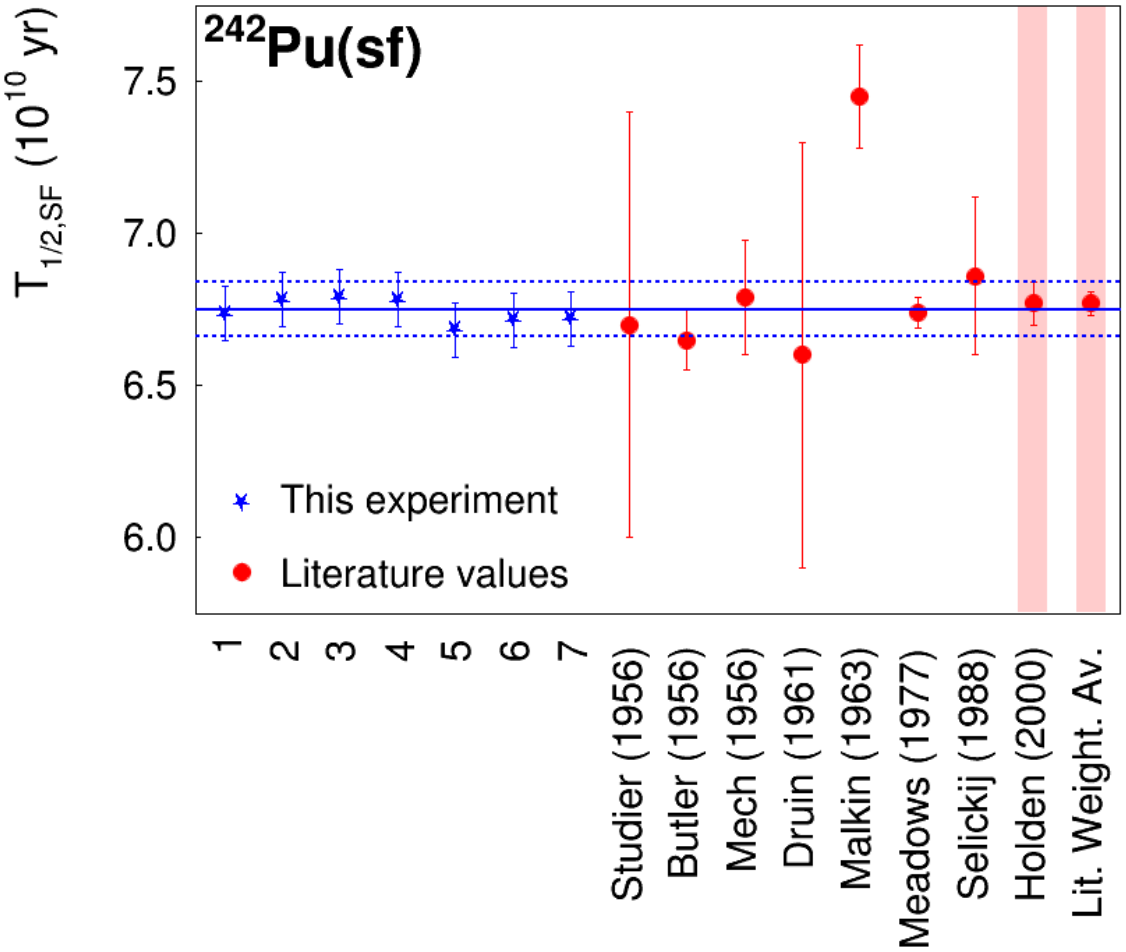
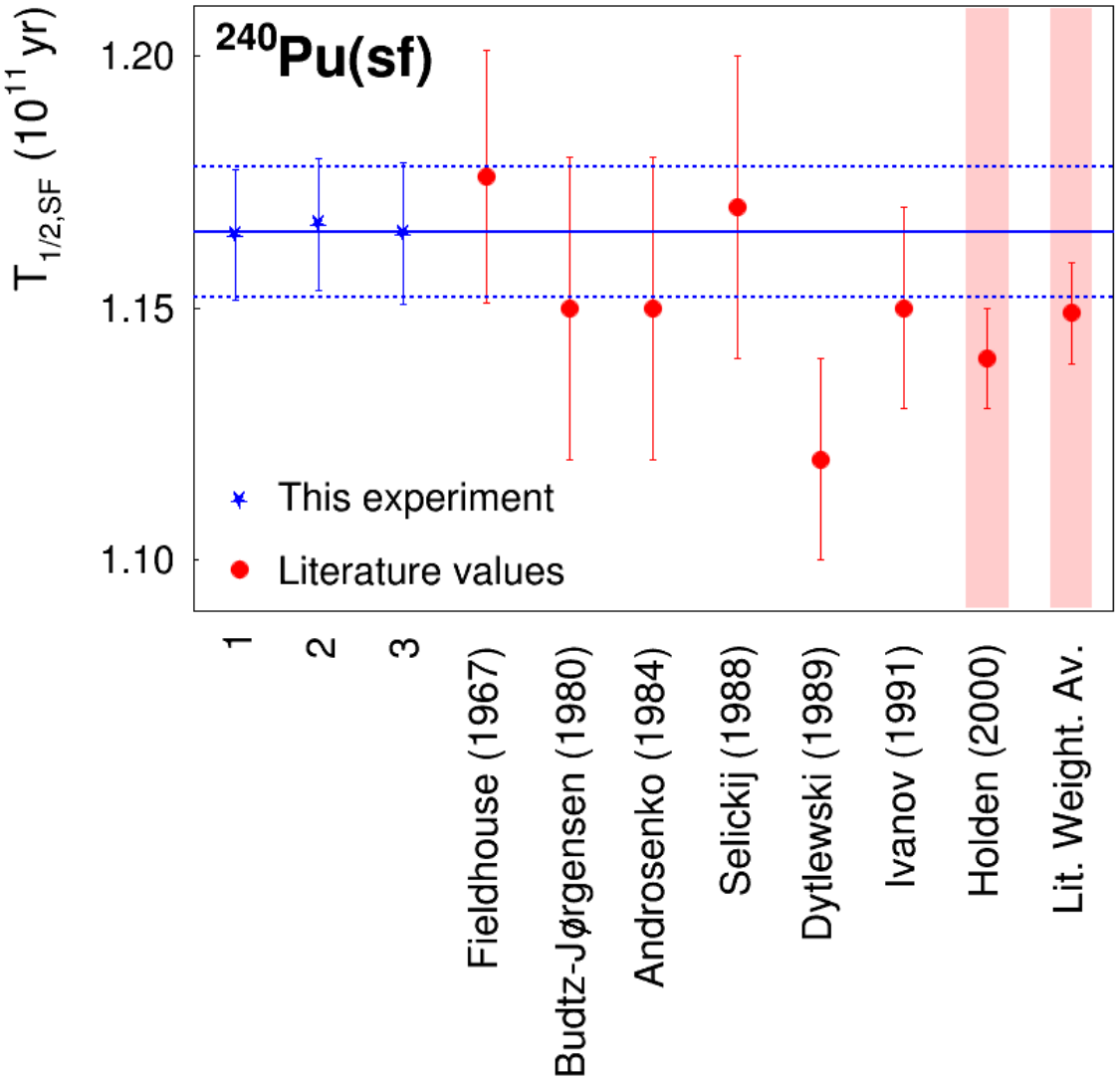
Spontaneous fission results: case ^{242}Pu

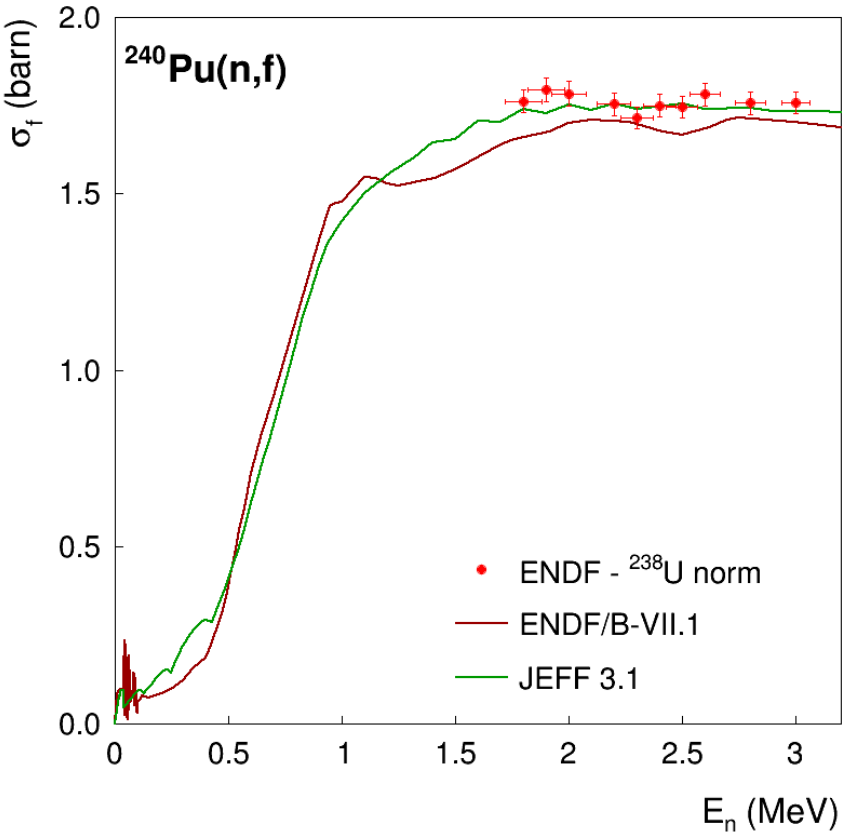


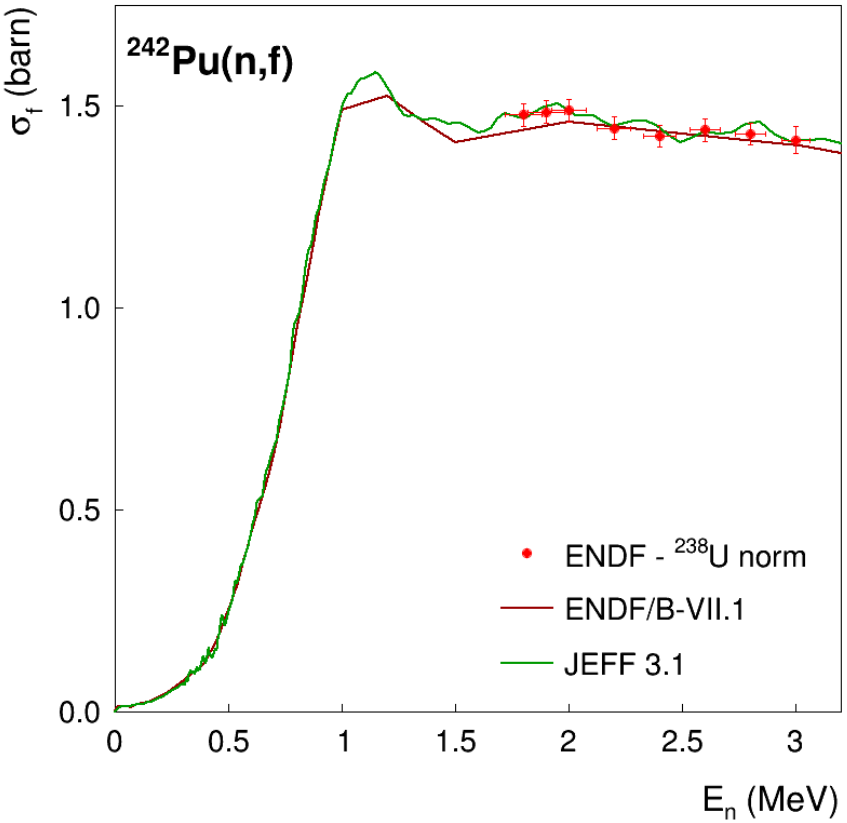
Spontaneous fission results: case ^{240}Pu



Neutron-induced fission cross section (preliminary):

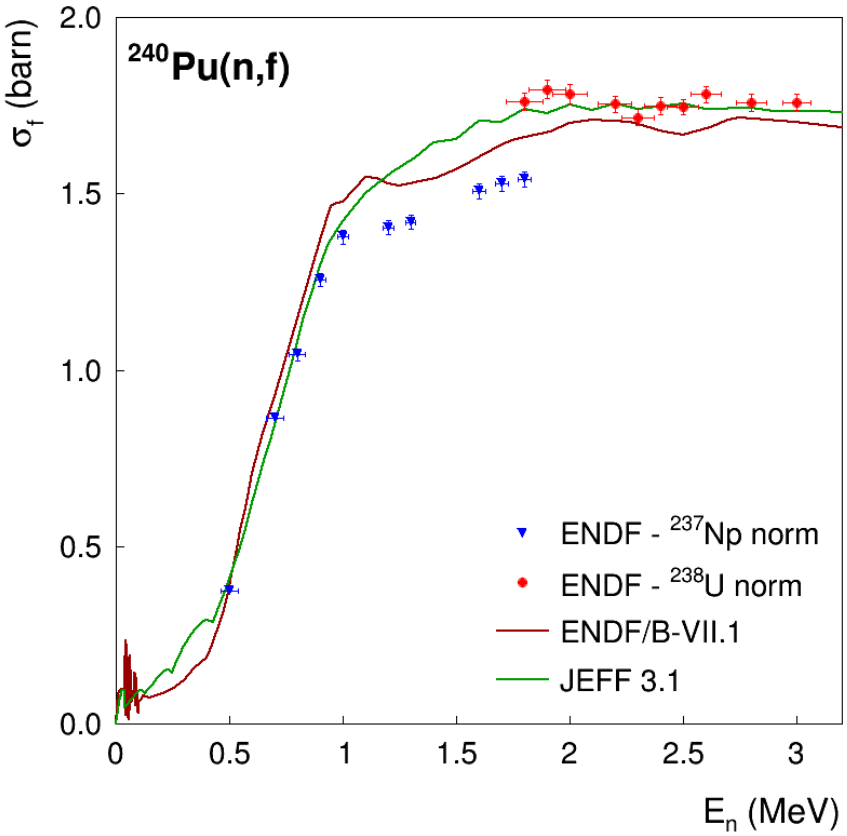
Data relative to ^{238}U ⟶ secondary standard (unc. ~0.7%) included

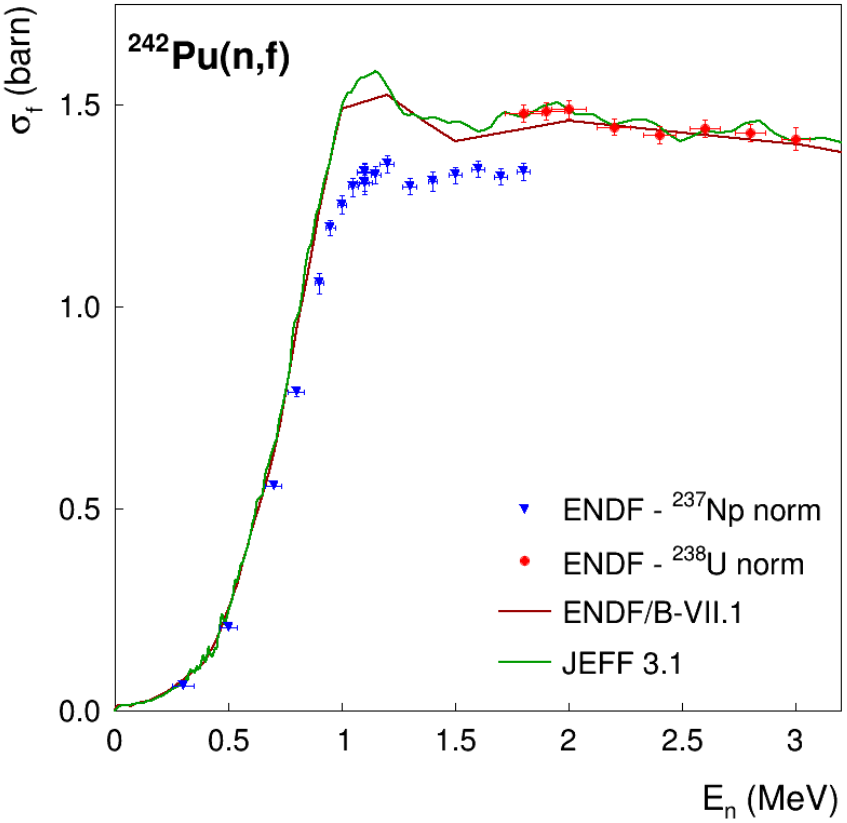




Neutron-induced fission cross section (preliminary):

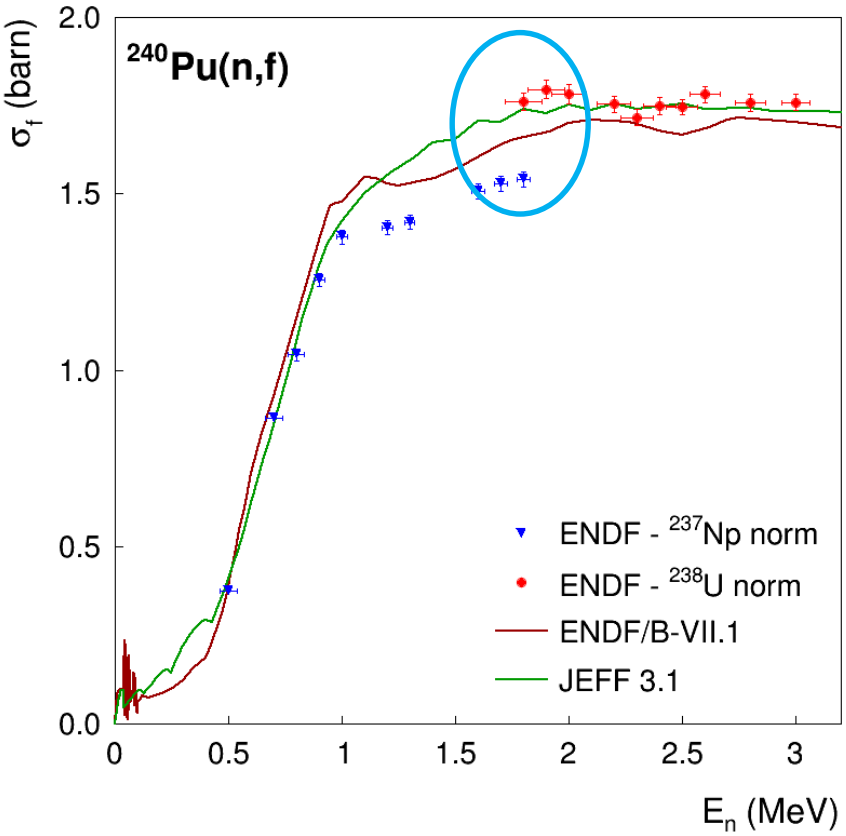
Data relative to ^{238}U ⟶ secondary standard (unc. ~0.7%) included
Data relative to ^{237}Np ⟶ secondary standard (unc. 3.5-5%) not included



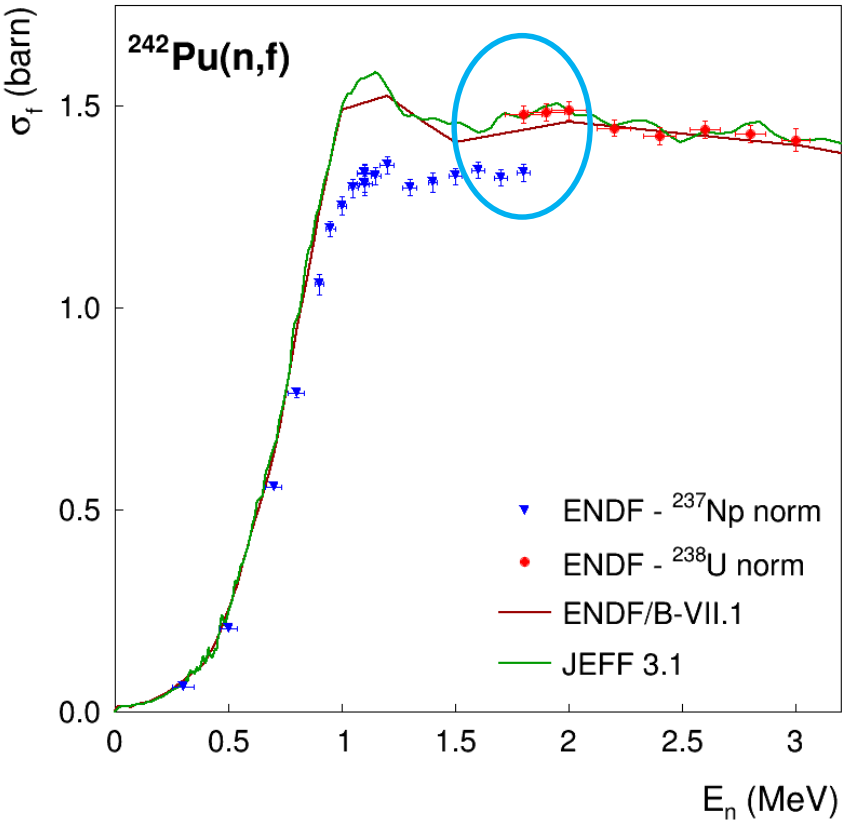


Neutron-induced fission cross section (preliminary):

~13%

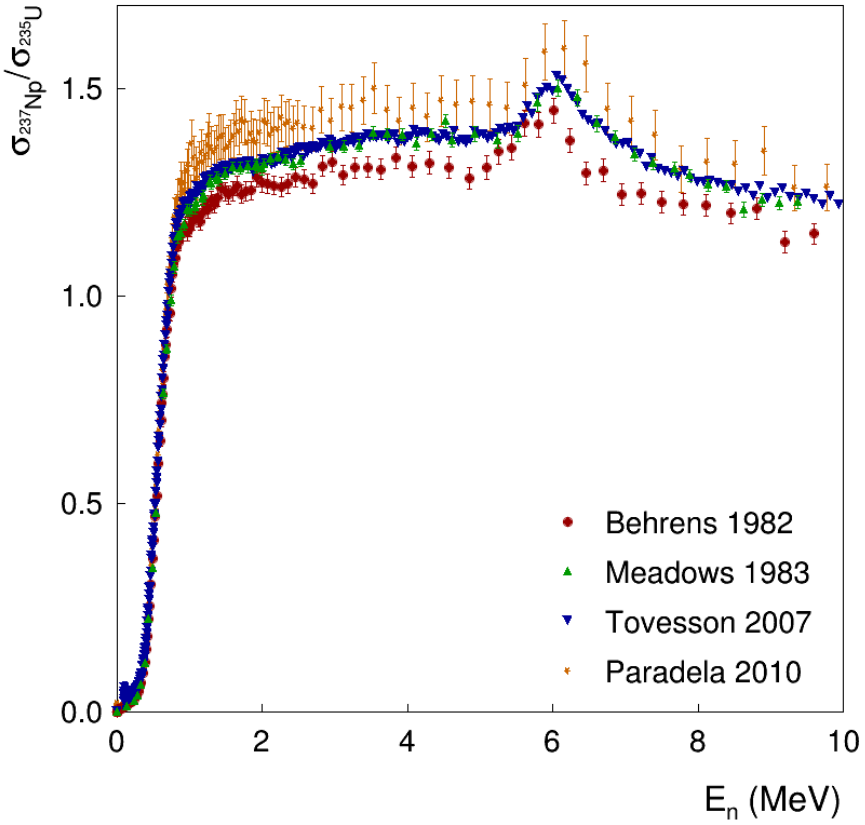


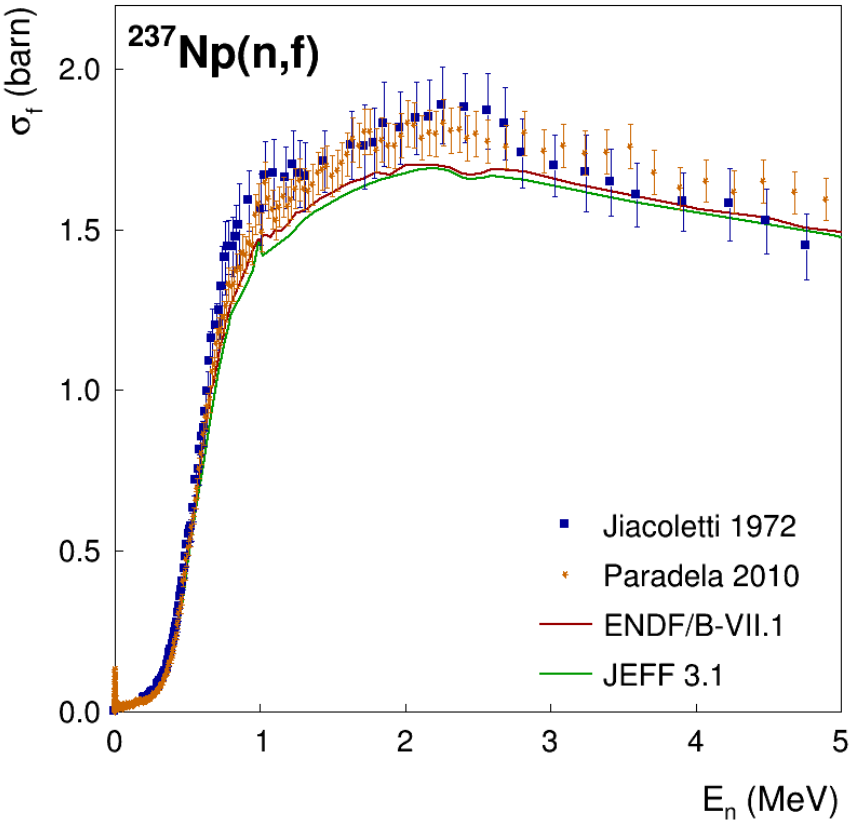
~10%



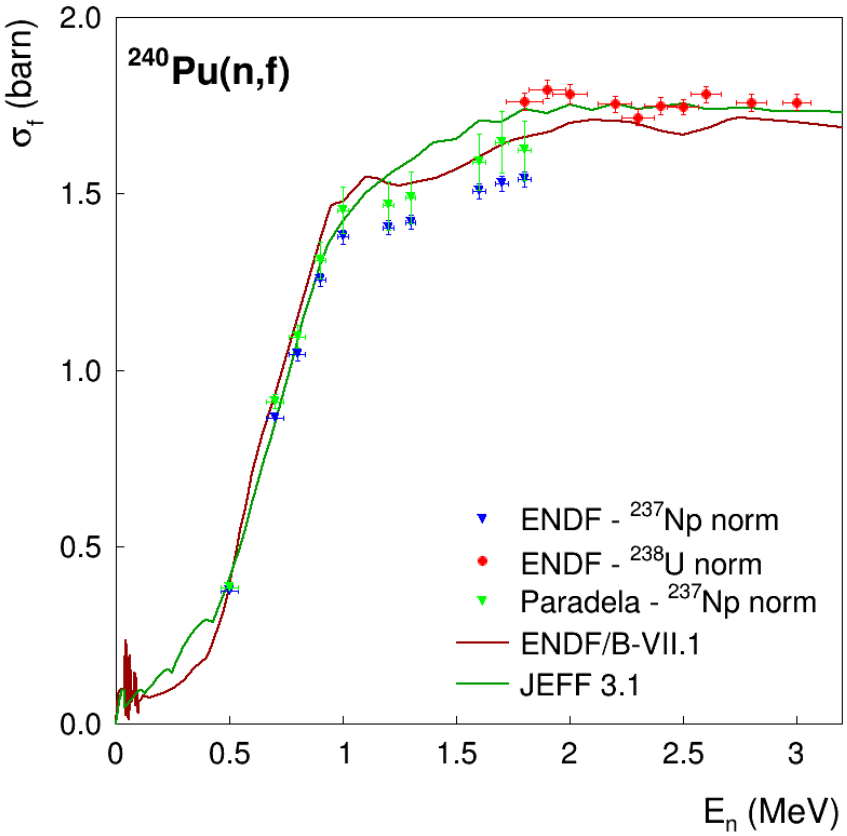
Neutron-induced fission cross section ^{237}Np:

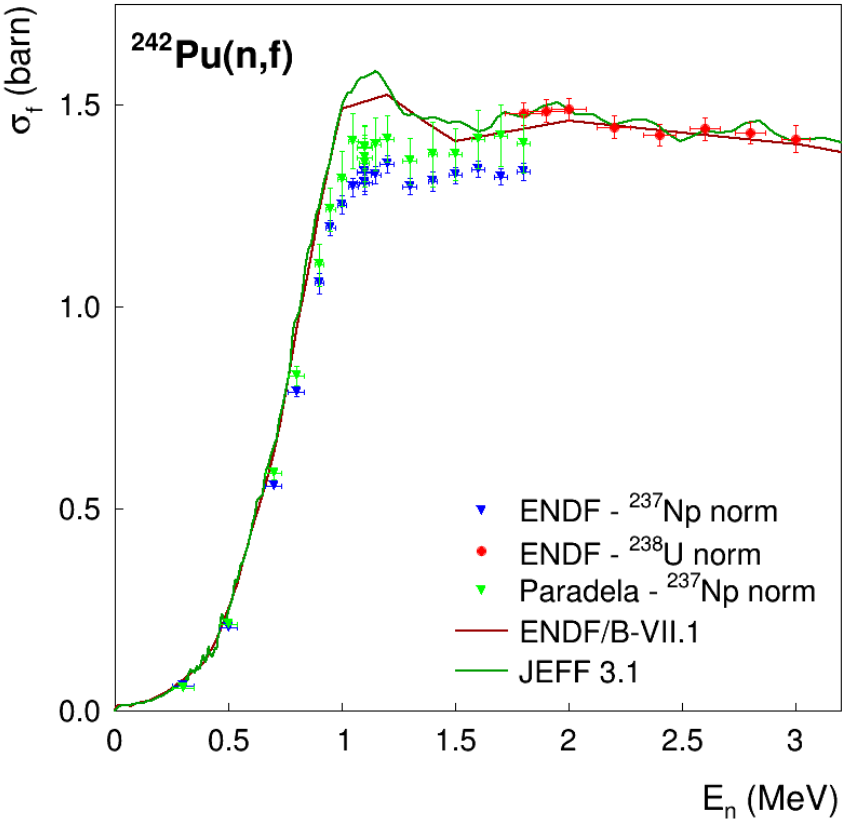
C.Paradela, *et al.* Neutron-induced fission cross section of ^{234}U and ^{237}Np measured at the CERN Neutron Time-of-Flight (n_TOF) facility. Phys. Rev. C 82, 034601 (2010)





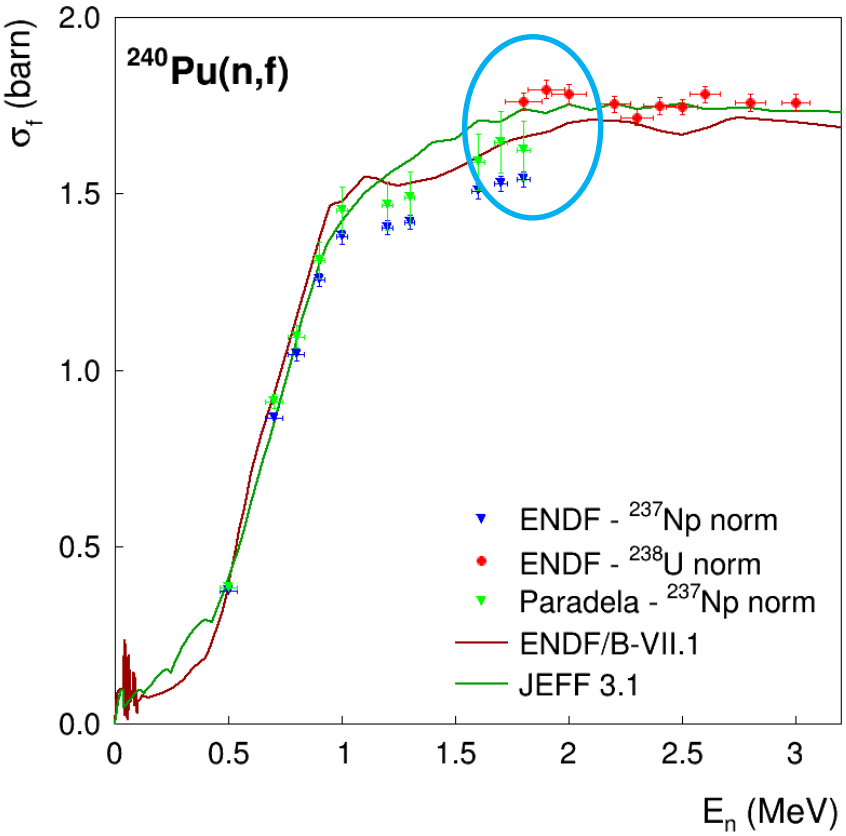
Neutron-induced fission cross section (preliminary):



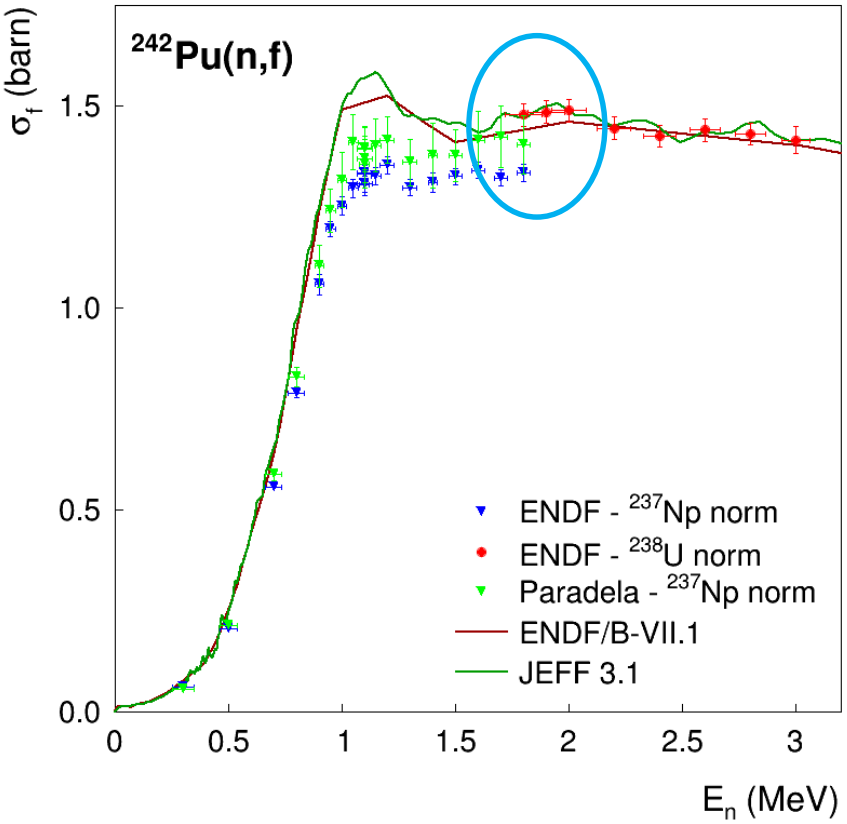


Neutron-induced fission cross section (preliminary):

~8%

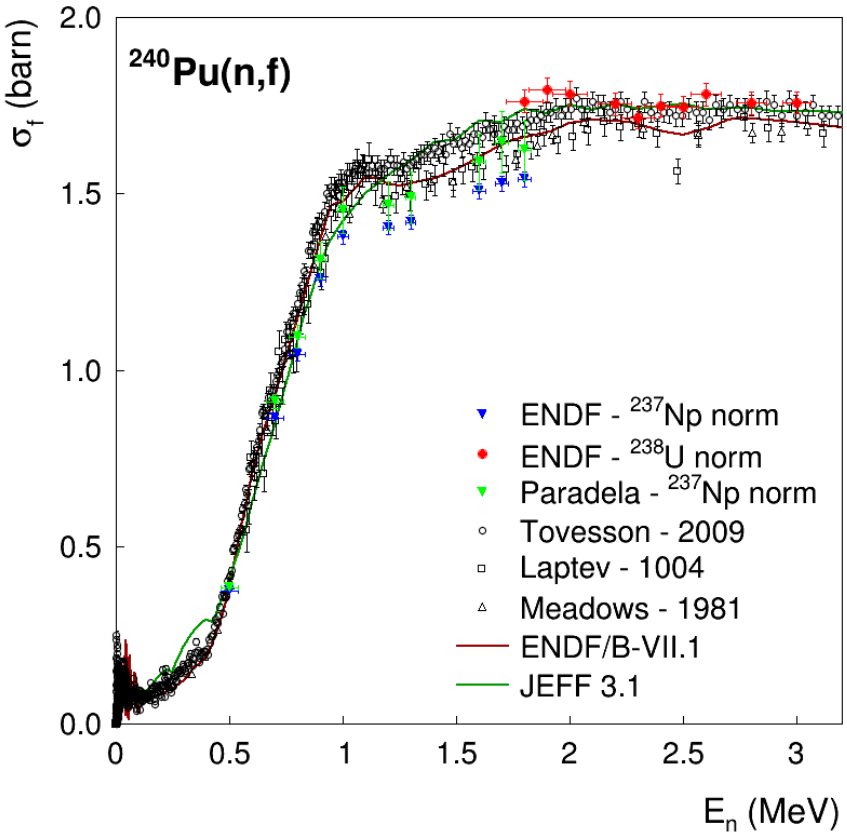


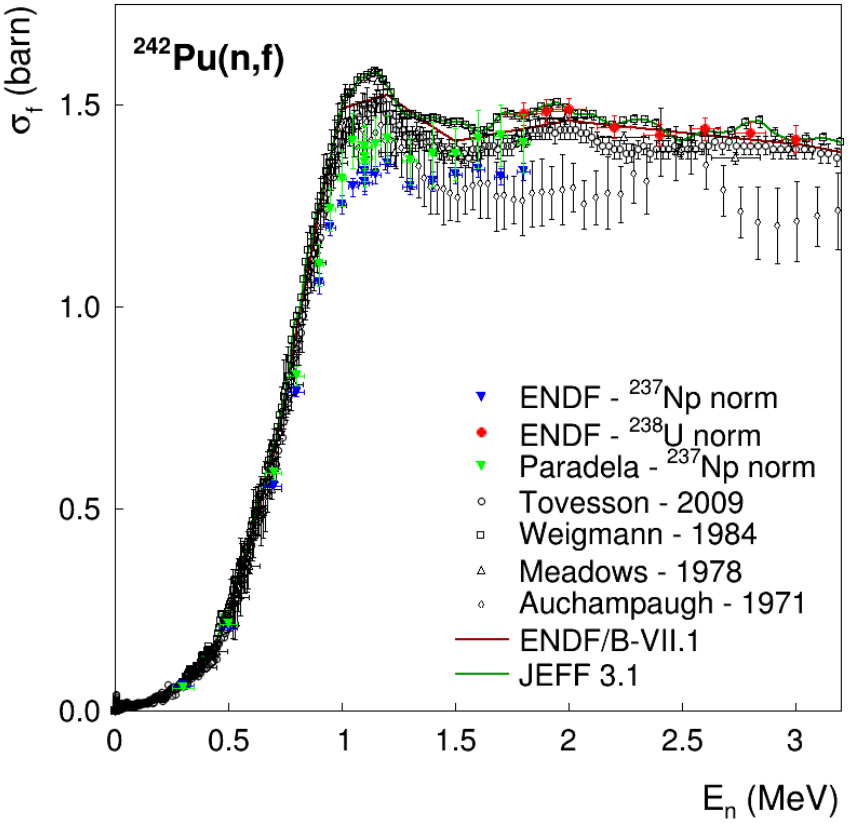
~5%



Neutron-induced fission cross section (preliminary):

Comparison with previous literature values





Outline

- Introduction
- Experimental setup
- Data analysis: Problems and solutions
  - α pile-up rejection
  - Efficiency determination
- Results
  - Spontaneous fission
  - Fission cross section
- **Summary**

Summary

- Study of the chamber efficiency
- Determination of spontaneous fission half-lives

$T_{1/2,SF}$ (yr)	^{240}Pu	^{242}Pu
Holden (2000)	1.14×10^{11} (0.9%)	6.77×10^{10} (1.0%)
This experiment (weighted average)	1.165×10^{11} (1.1%)	6.75×10^{10} (1.3%)
systematic uncertainty	0.4% mass 1.0% ε	0.9% mass 1.0% ε

Holden, N.E., Hoffman,D.C., *Spontaneous fission half-lifes for ground-state nuclides*. Pure and Applied Chemistry 72, 1525-1562 (2000)

Summary

Measurements relative to ^{237}Np (~300 µg/cm^2) & ^{238}U (~85 µg/cm^2)

Neutron energy: 0.2 – 3 MeV

i. Good agreement at threshold (data relative to ^{237}Np)

ii. Systematically lower from 0.9 MeV till 1.8 MeV (data relative to ^{237}Np)

iii. Good agreement above 1.8 MeV (data relative to ^{238}U)

iv. Discrepancies between corresponding energies taken relative to ^{237}Np and ^{238}U

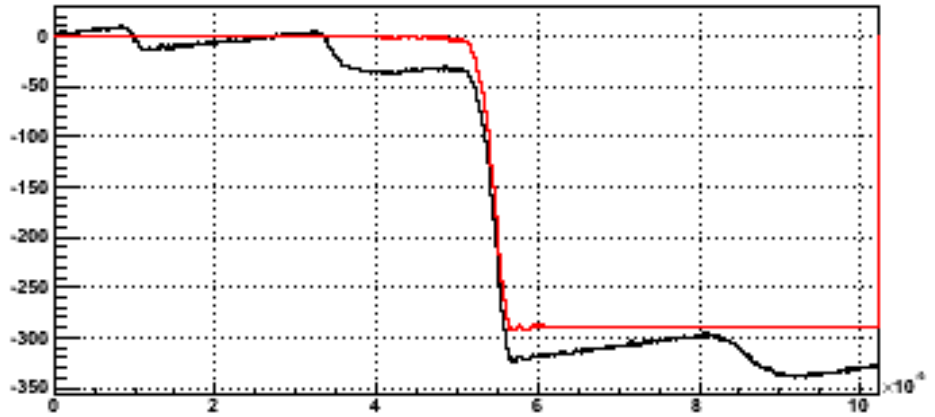
v. Improvement when using Paradela data for ^{237}Np, but it is not enough

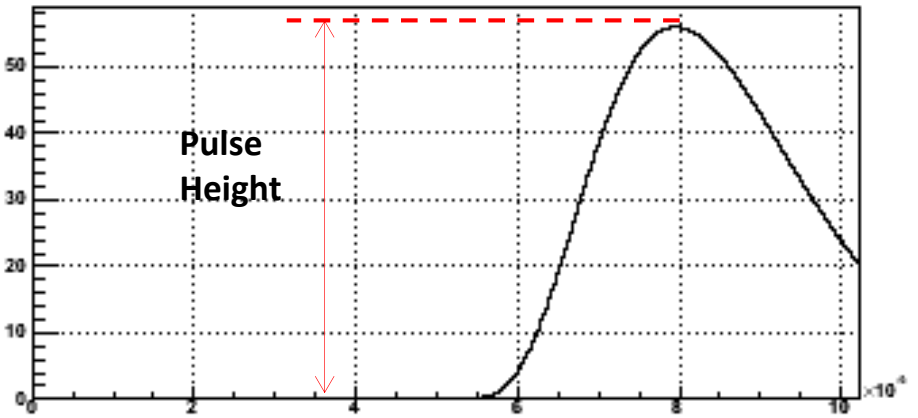
Thank you for your attention!

Digital-Signal Processing (dsp)

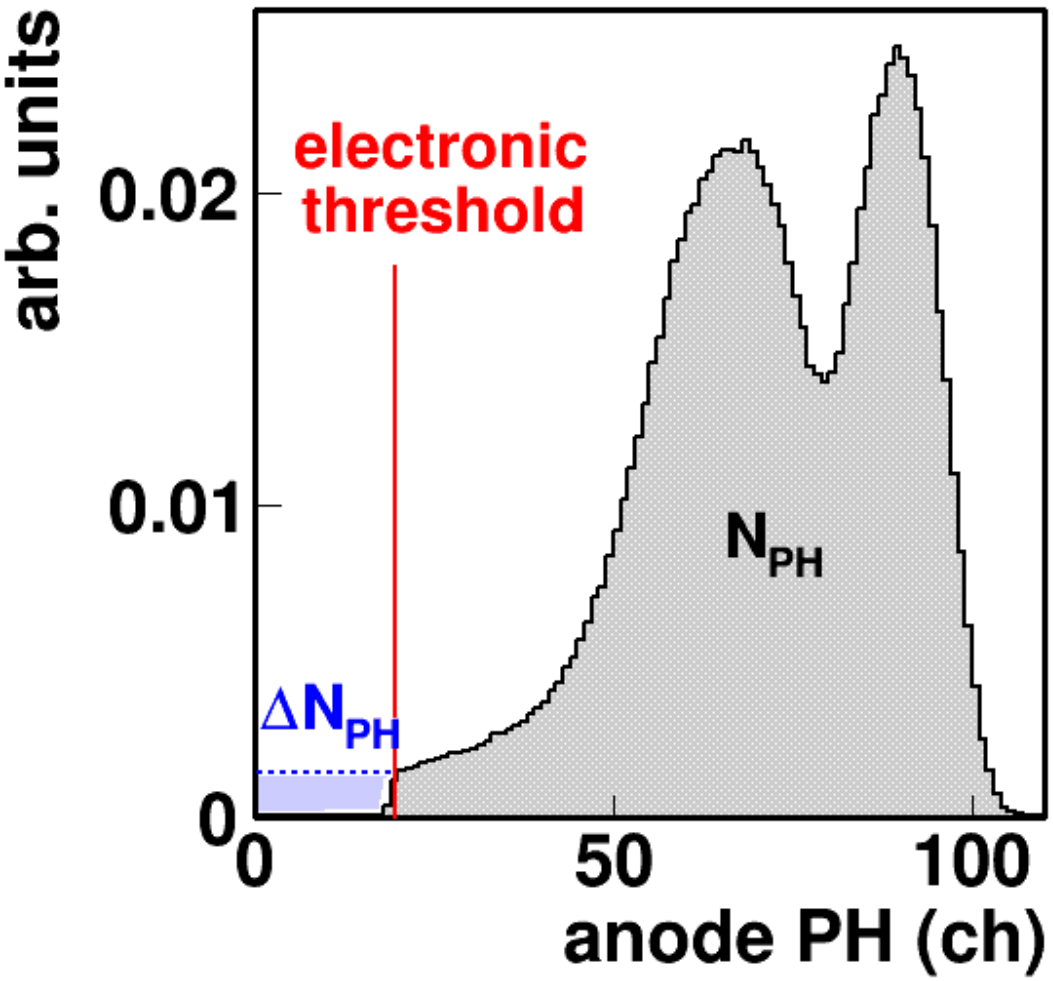
- baseline correction
- ballistic deficit correction
- alpha pile-up correction
- filter CRRC4

Anode signal

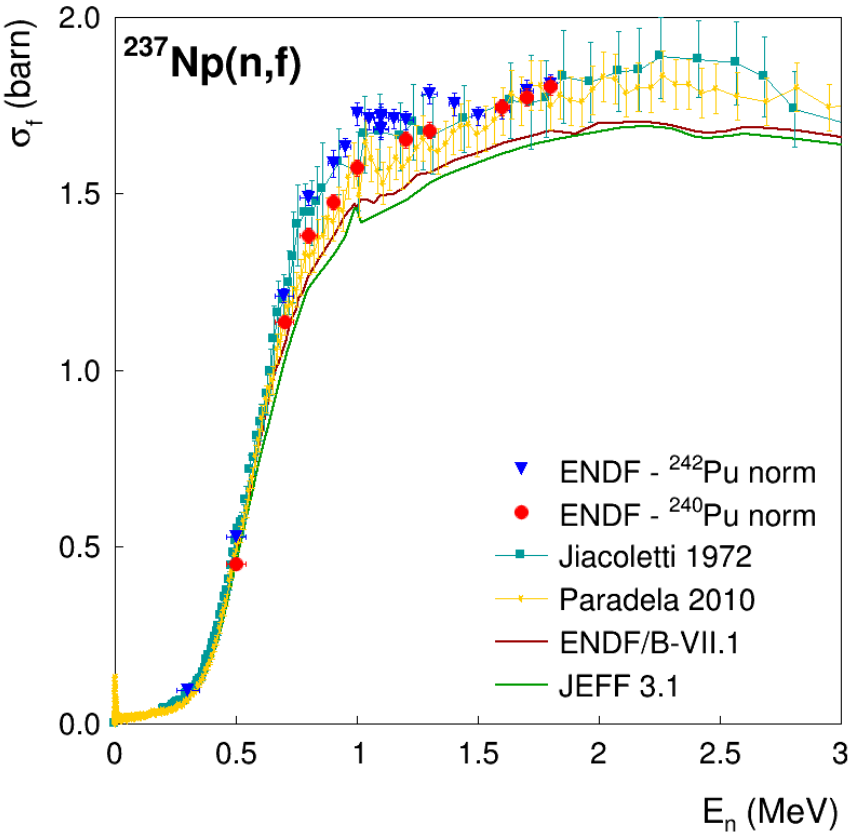


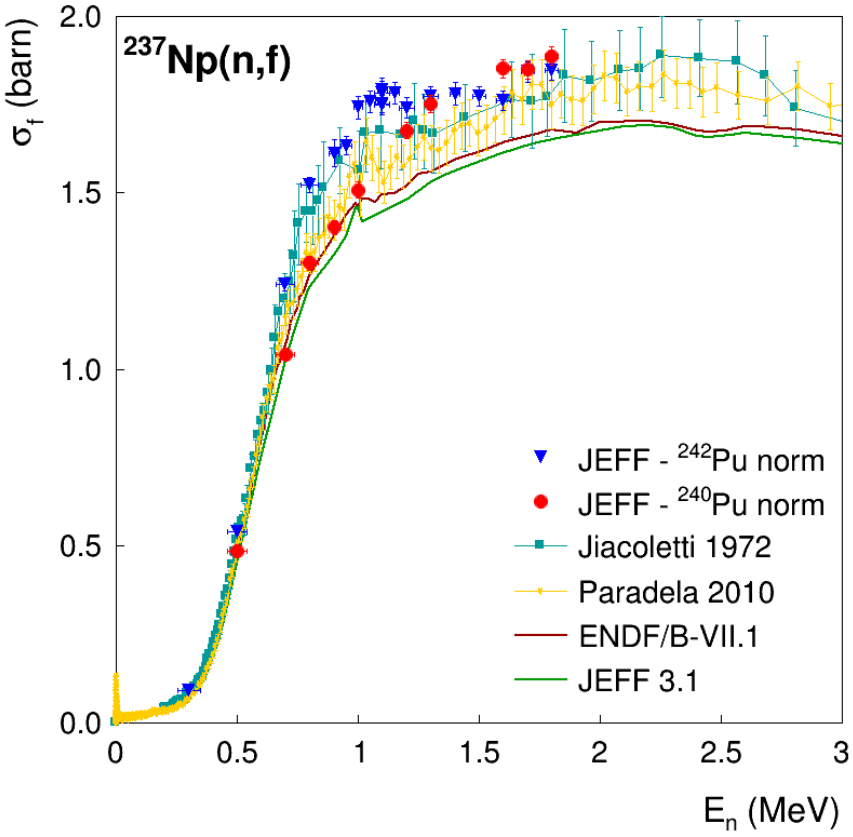


Pulse Height distribution



Cross sections of ^{237}Np





Cross sections of ^{238}U