A new measurement of the prompt fission neutron emission spectrum of ^{235}U(n,f) Correlation of prompt neutron emission with fission fragment properties

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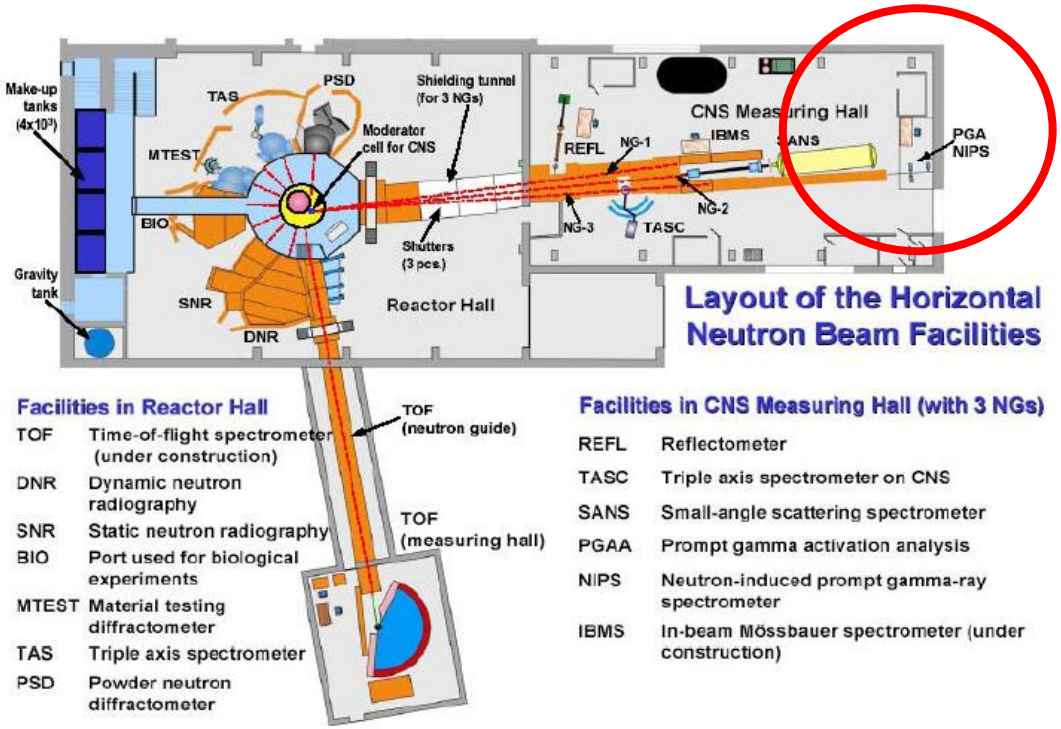
Motivation

- Measure prompt fission neutron spectrum (PFNS) at thermal to clarify discrepancies in literature
- Investigation of the emission process of prompt neutrons.
- Verify the assumption of neutron emission from fully accelerated fragments.
- Verify the existence of scission neutrons.

Experiment: Budapest Reactor



Experiment performed at Cold neutron PGAA facility (T = 100 K, beamline 1) at 10 MW Budapest Research Reactor

10 days beam time (200h) 2 weeks measurement,1st week setup & calibration, 15.09- 3.10.2008

High flux: 7 x 10^7 neutrons /cm^2/s at sample position

High stability, well- characterised beam (geometry, spectrum)

Excellent support from Hungarian colleagues

Equipment:

- Double Frisch grid ionisation chamber with thin ^{235}U target
- Parallel plate ionisation chamber with ^{252}Cf target for calibration
- NE213 equivalent neutron detectors in heavy shielding
- All electronic equipment needed
- Data acquisition system

Counting rates:

Neutron flux:	**$7 \cdot 10^7$ n/cm^2/s**
Total ^{235}U mass:	**800 μg**
Fission rate:	**$5 \cdot 10^4$ 1/s**
Neutron Coincidence rate (at 3 m):	**~3 n/s**
Background rate:	**$4 \cdot 10^2$ 1/s**
Coincidence rate: (gammas and neutrons)	**$4 \cdot 10^3$ 1/s**

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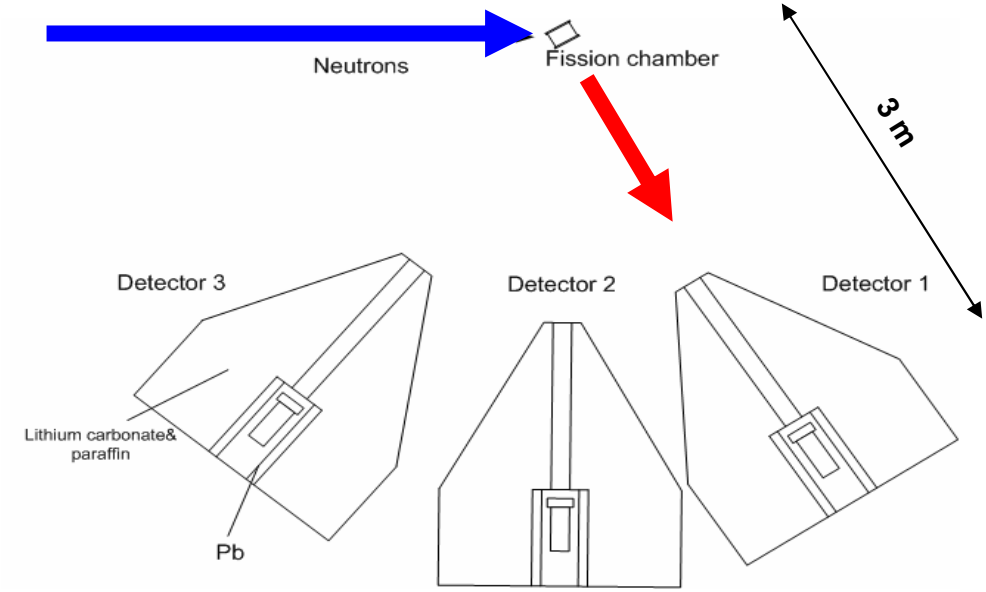
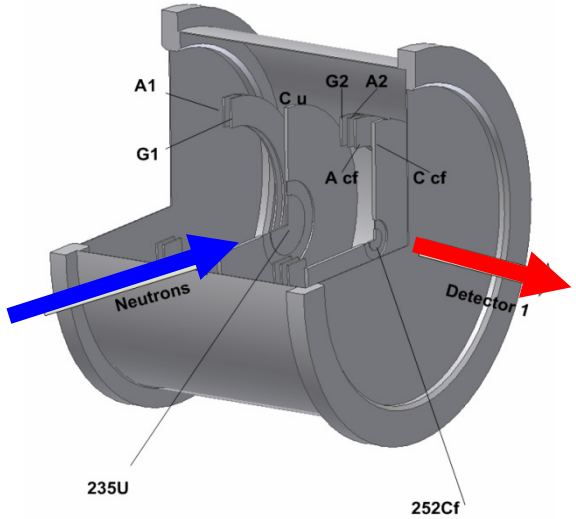
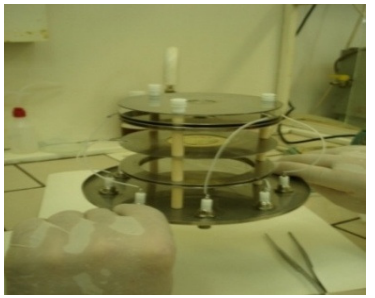
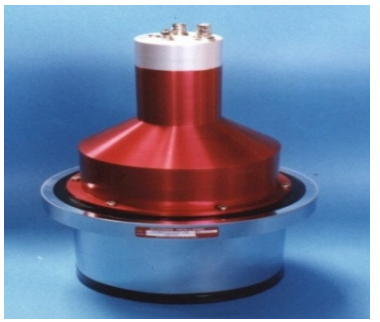
Experiment: Setup



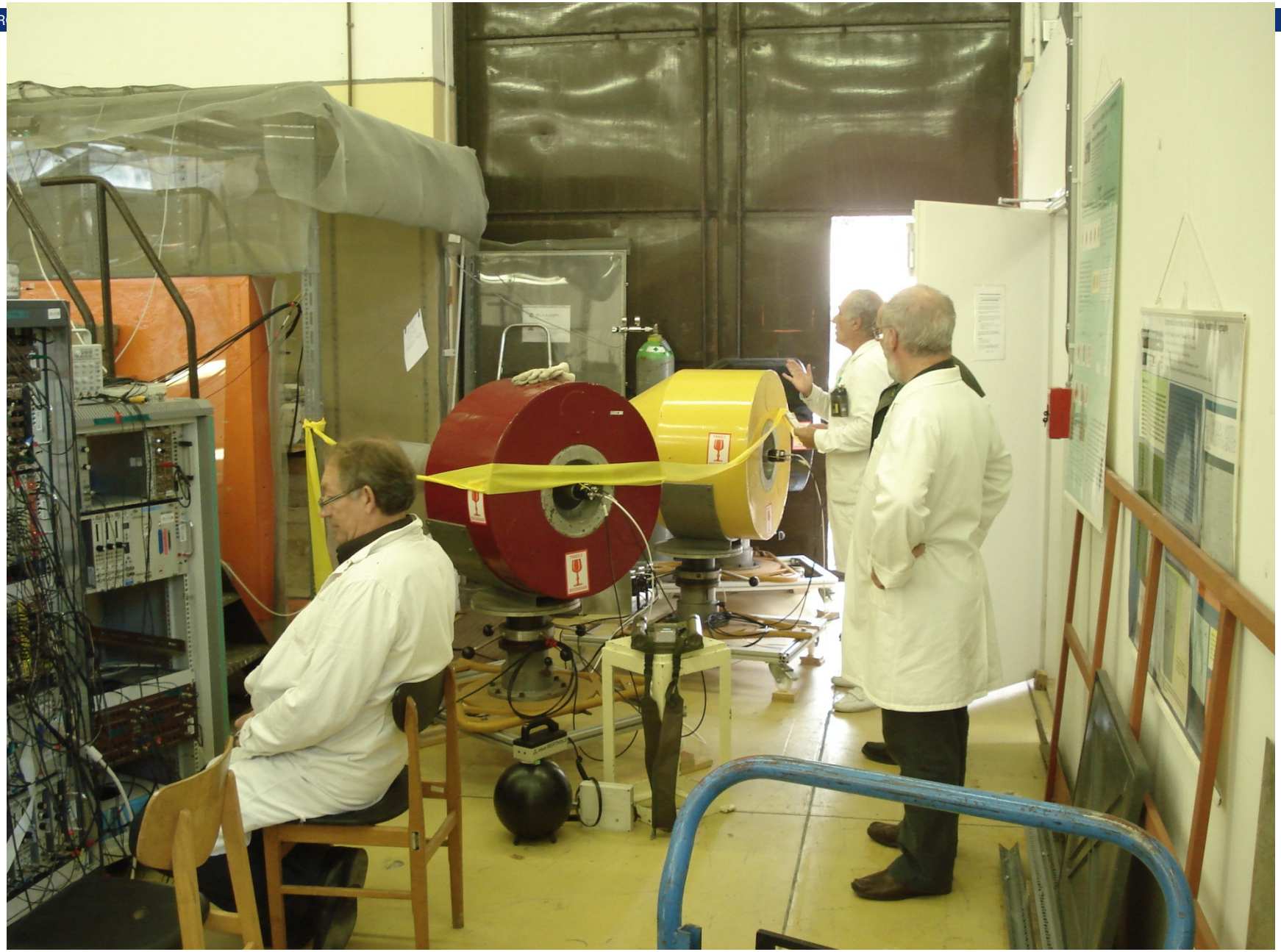




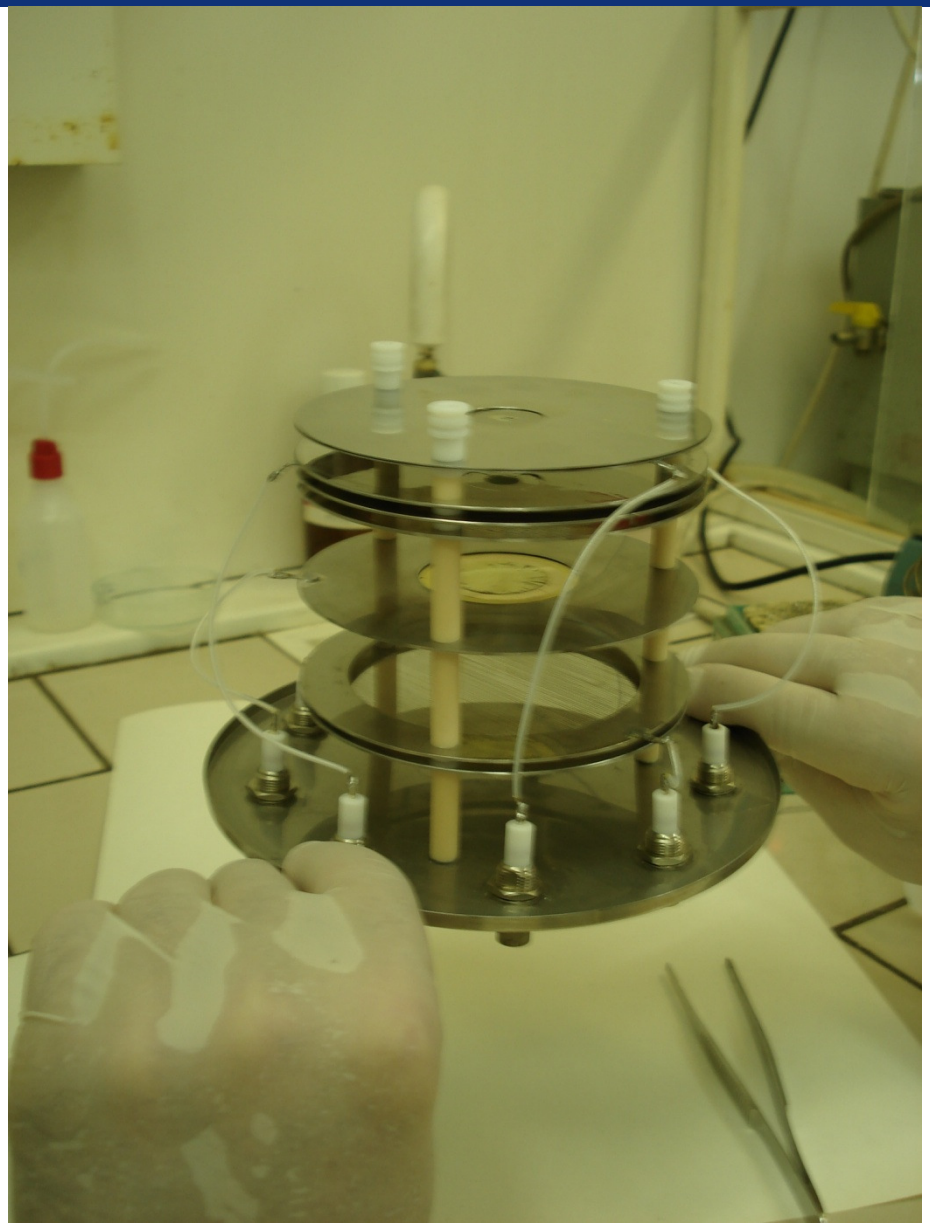


- TOF measurement technique used (L = 3 m)
- 3 neutron detectors LS301 (NE213 equivalent, size: 4'' x 2" =10.16 x 3.08 cm) SCIONIX in heavy shielding
- Thin ^{235}U (97.7%) target 112 μg/cm^2 at centre of Ionisation chamber, fission count rate 50.000 /sec
- ^{252}Cf target placed simultaneously into the same chamber shifted 5 cm relative to ^{235}U target (20.000 fissions/s)
- High Fission Fragment counting efficiency 98%

Experimental set-up at IKI



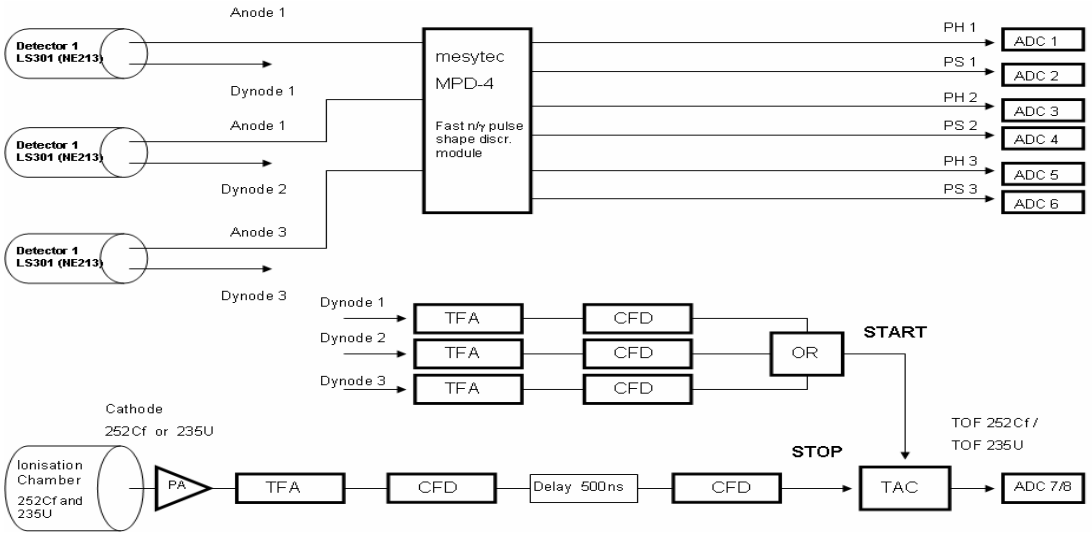
Ion chamber set-up at IKI

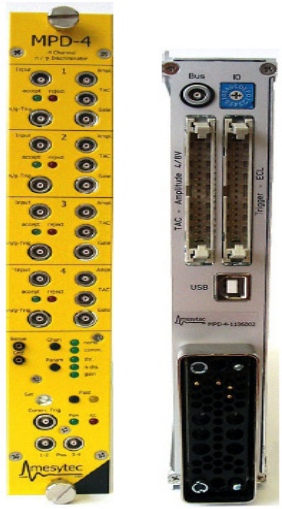


Thin ^{235}U sample

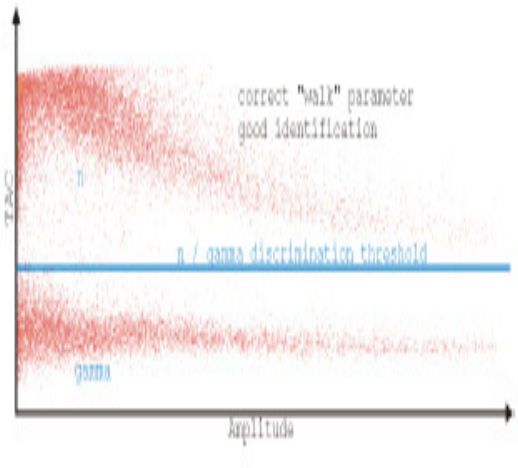
^{252}Cf reference sample

Electronic Setup





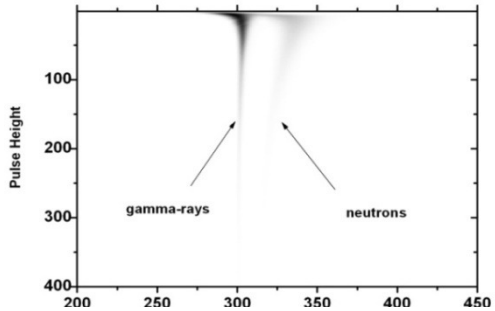
- **MPD-4 Fast neutron 4- channel PSD NIM-module from MESYTEC**
  - Fast pre-amps integrated
  - Measurement of Pulse height & Pulse shape simultaneously for n/γ discrimination. (On-line n/gamma discrimination possible)
  - Optimised for liquid scintillators
- **START by neutron detectors**
- **STOP for TOF: Fast cathode current signal used as "neutron tagger"**
- **DAQ allows to tag FF events from U cathode or Cf cathode separately**

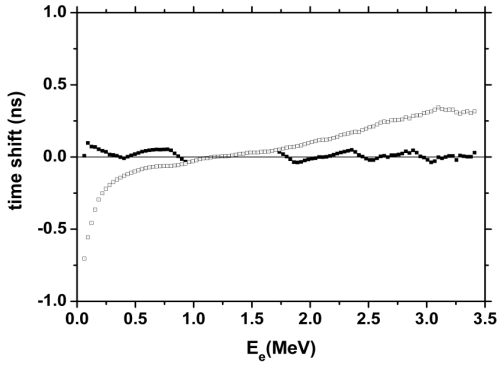


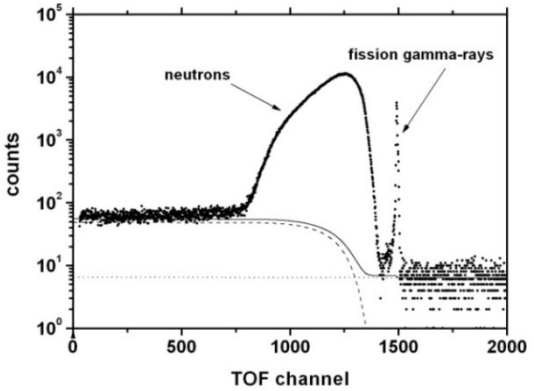
Detectors had been previously thoroughly investigated and well characterized:

Total characterization of neutron detectors with a ^{252}Cf source and a new light output determination.
N.V.Kornilov, I. Fabry, S. Oberstedt, F.-J. Hambsch, NIM A599 (2009) 226

Efficiency ε most important : Determined from ^{252}Cf – tagged events







Analysis Procedure

Calibration of PH scale with γ - sources

Neutron / γ discrimination: Gamma suppression factor: 200

TOF spectra were corrected for

- **Pulse height dependent time walk**
- **Time-independant random and uncorrelated background**

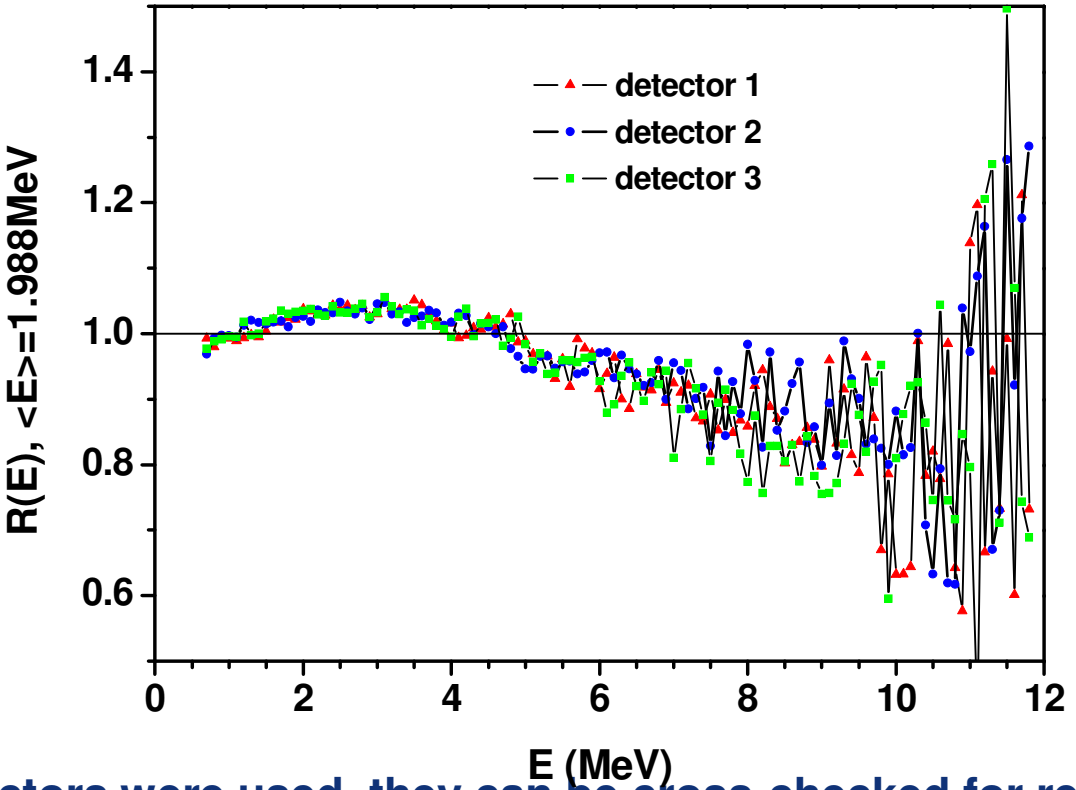
Total count rate: $5 \cdot 10^3$ 1/s (gammas and neutrons)

Total neutron events: ~ $1 \cdot 10^6$ for each detector (50 h)

Timing resolution: 1.7 ns (^{235}U) and 2.1 ns (^{252}Cf)

Neutron detector spectra

Ratio to Maxwellian

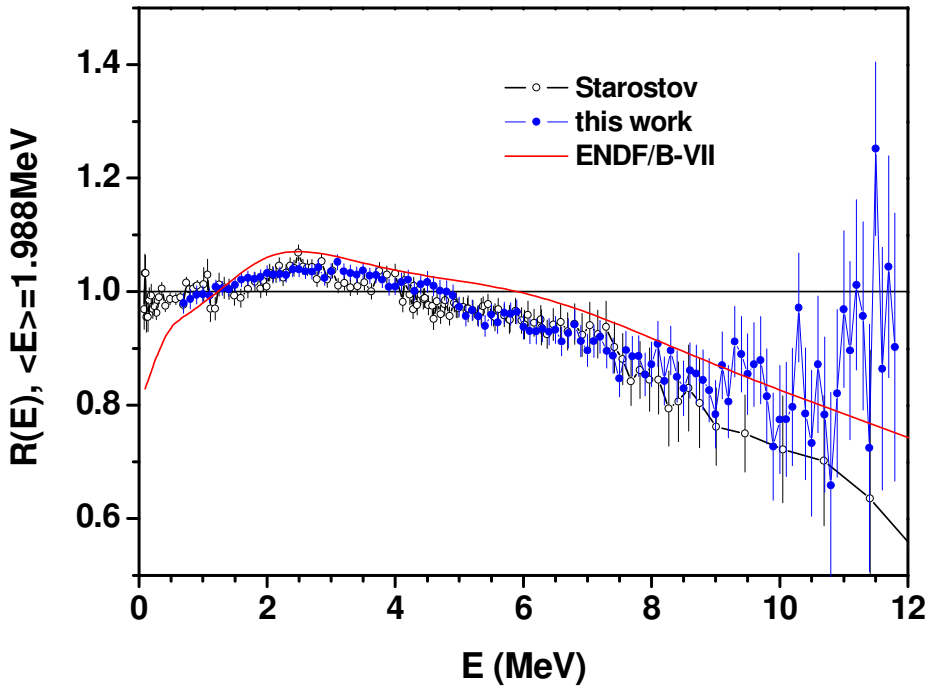


- Since 3 detectors were used, they can be cross-checked for reliability of results
- Each Run was analyzed separately to check for systematic errors
- No angular effect

⇒ Excellent agreement of 3 individual neutron detectors

Comparison to Literature Data

Ratio to Maxwellian



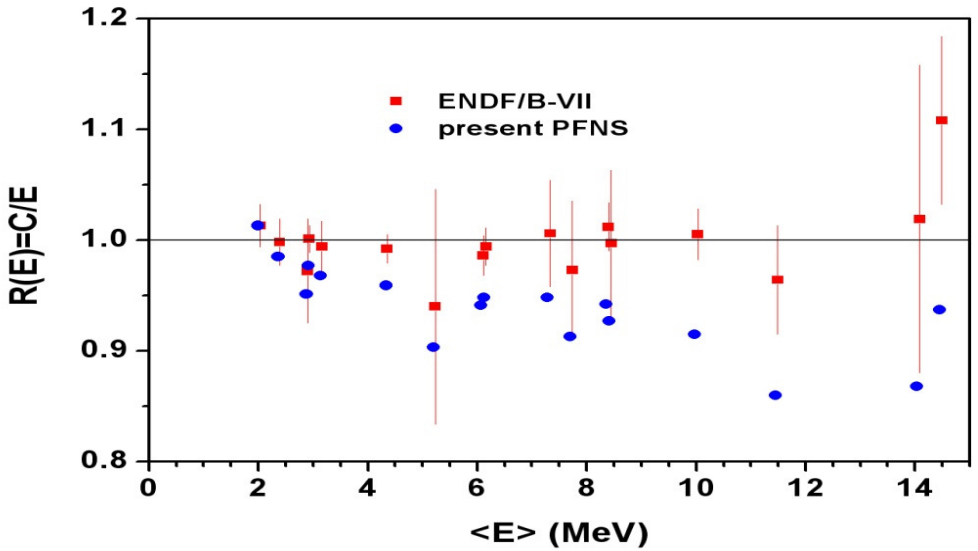
Our Data

Starostov et al. 1984 (EXFOR)

ENDF/B-VII

- Starostov et al.: Gas-scintillation-ionization detector + ^{235}U, IC, Reactor, relative to ^{252}Cf
- **Excellent agreement** with Starostov et al. over full energy range
- Our data and Starostov et. al. **contradict ENDF/B-VII** evaluation and the Los Alamos Model (Madland Nix)

Comparison to Literature Data



Source: IRDF-2002 International Reactor Dosimetry Files library

- Validation of the PFNS: Measured PFNS was used to calculate average integral cross sections and compared to set of integral measurements (activation reactions in reference neutron field)
- C/E = Calc. / Exp. spectrum-averaged cross sections $\int \sigma(E)\, N(E)\, dE / \int N(E)\, dE$
- Only reactions used with good C/E agreement for ^{252}Cf data.

C/E (our data) = 0.938±0.010 C/E (ENDF-B/VII) = 0.998±0.009

- Our ^{235}U PFNS agrees with all literature differential experimental data
- But no experimental data can describe the integral experiments

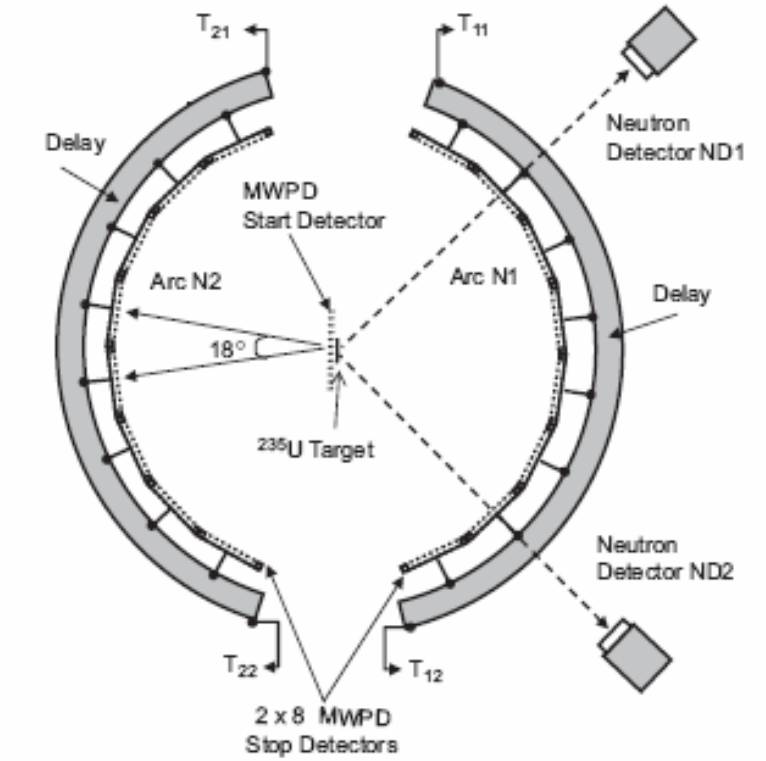
Correlation of prompt neutron emission with fission fragment properties

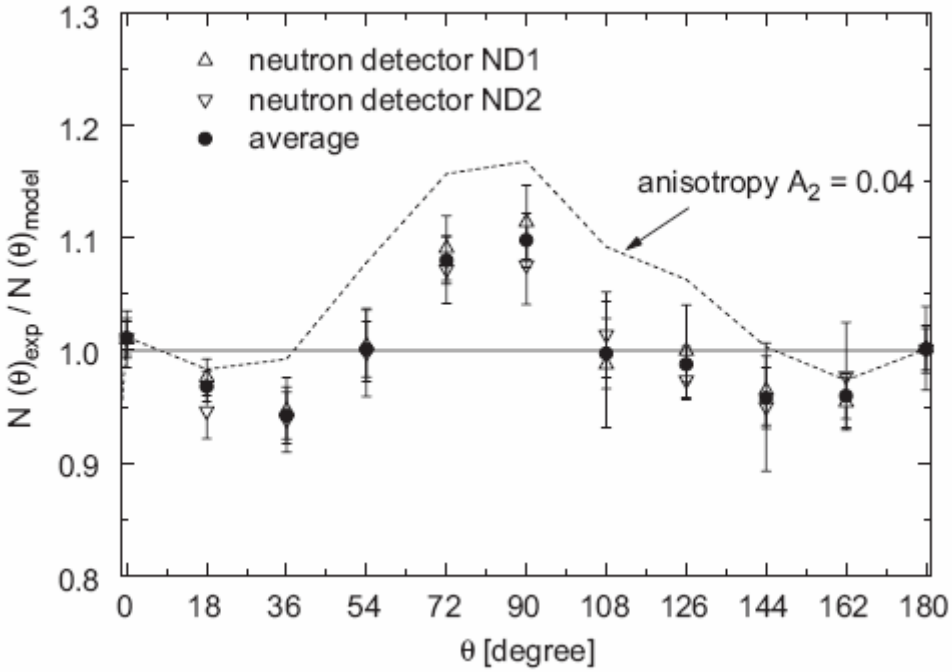
or

the search for Scission neutron emission

- Scission neutron emission postulated as early as 1962 (Bowman et al)
- Several measurements and different analysis to look for scission neutrons (SCN)
- SCN Yield varies from 1% to 20%
- No clear cut experiment to identify SCN´s
- Analysis of all experimental data showed that SCN are preferably emitted 90 degree relative to those by fully accelerated fission fragments

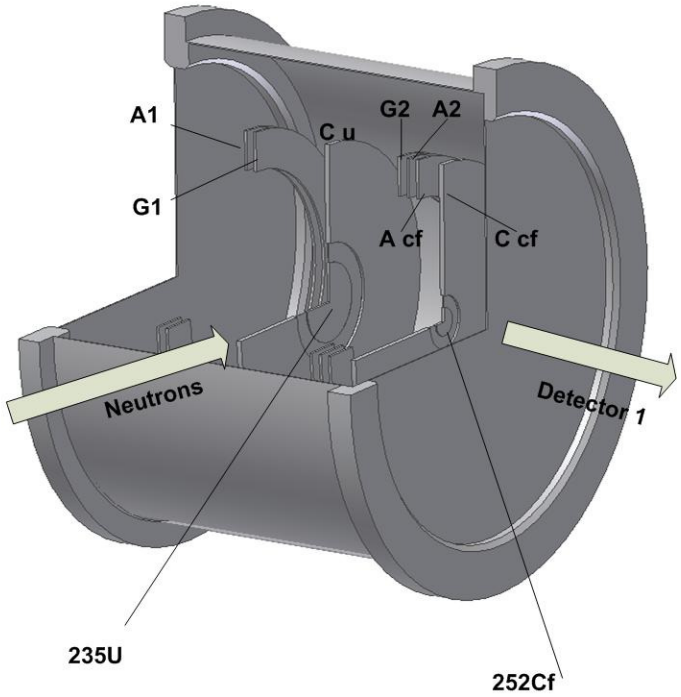
Vorobyev et al NIM A598 (2009) 795

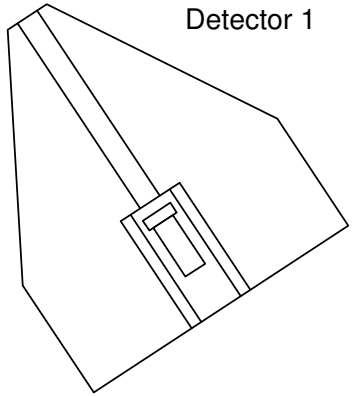




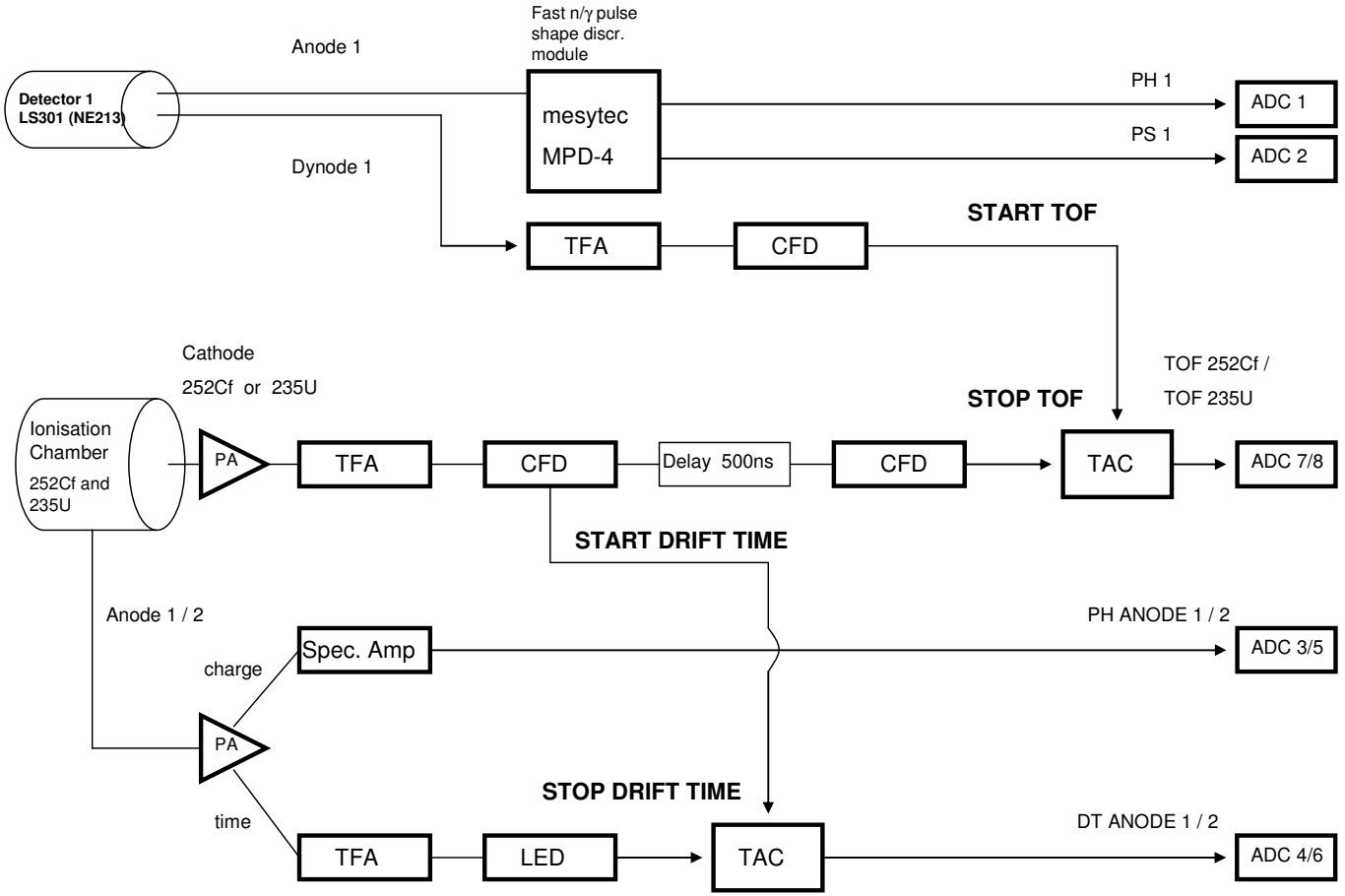
Maximum 5% overall SCN yield and at 90 degree 10%

Experimental set up

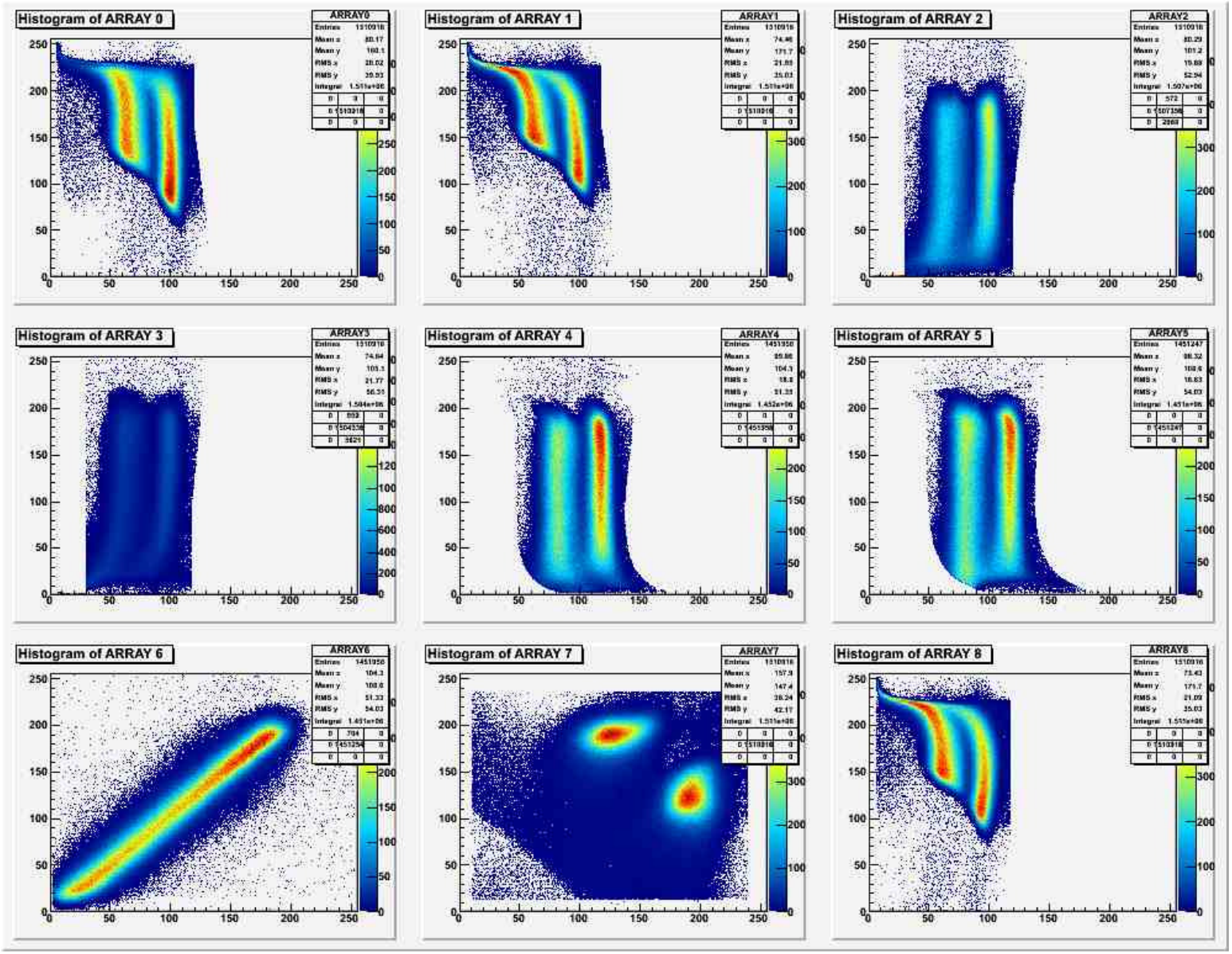




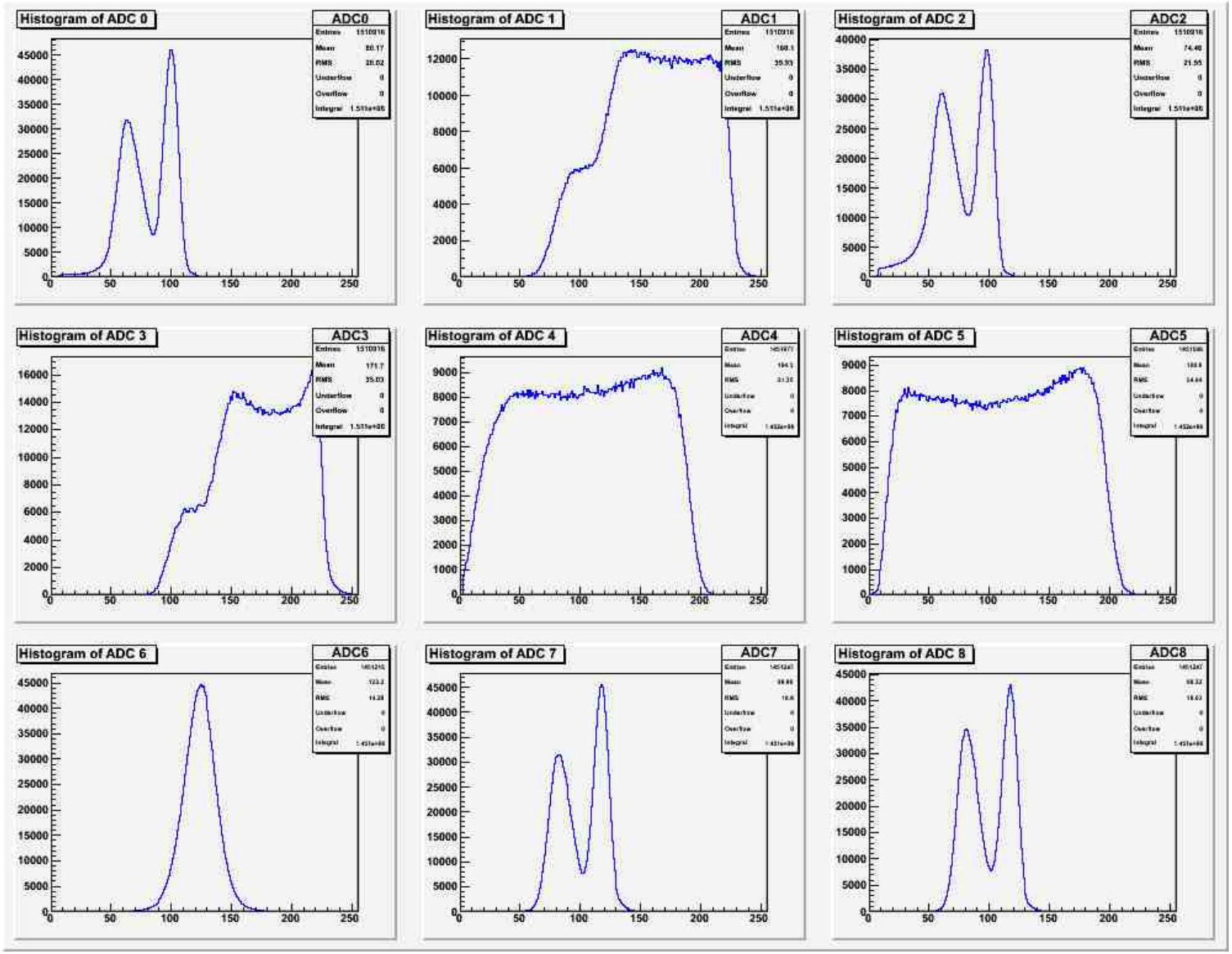
Electronic set up



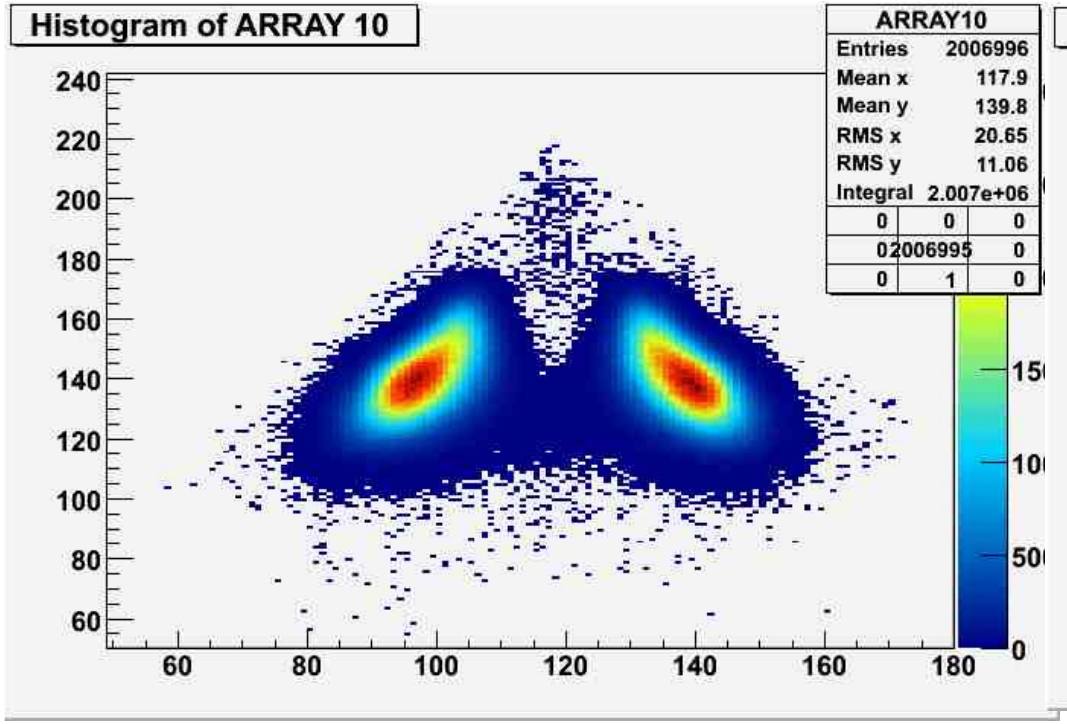
2D representation of some parameters

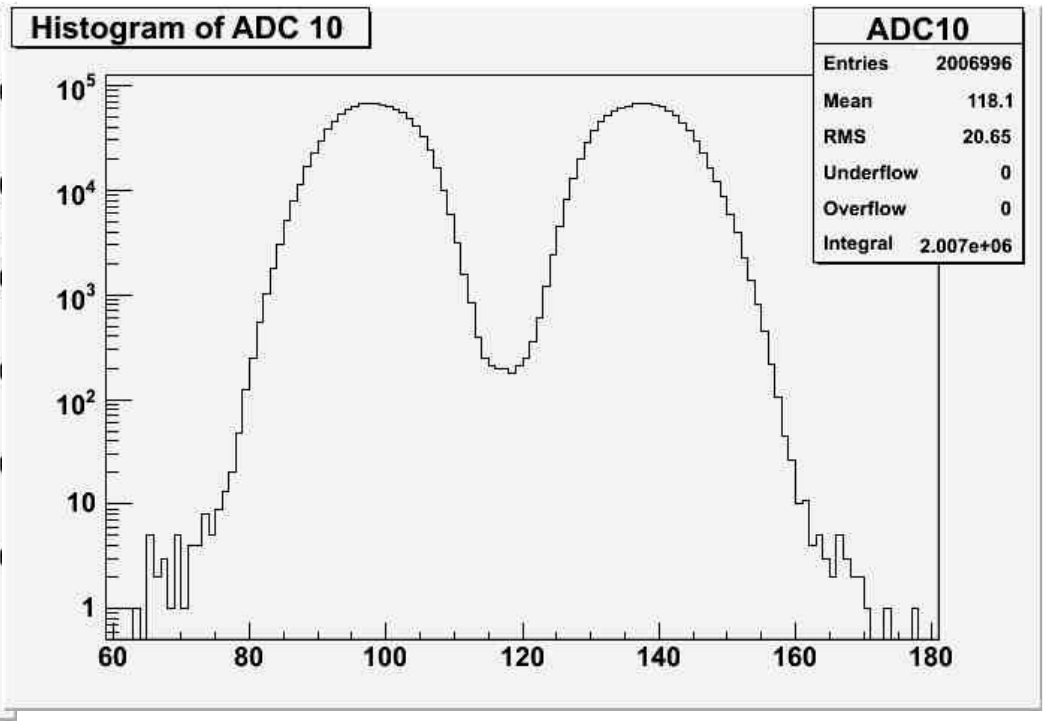


1D representation of some parameters



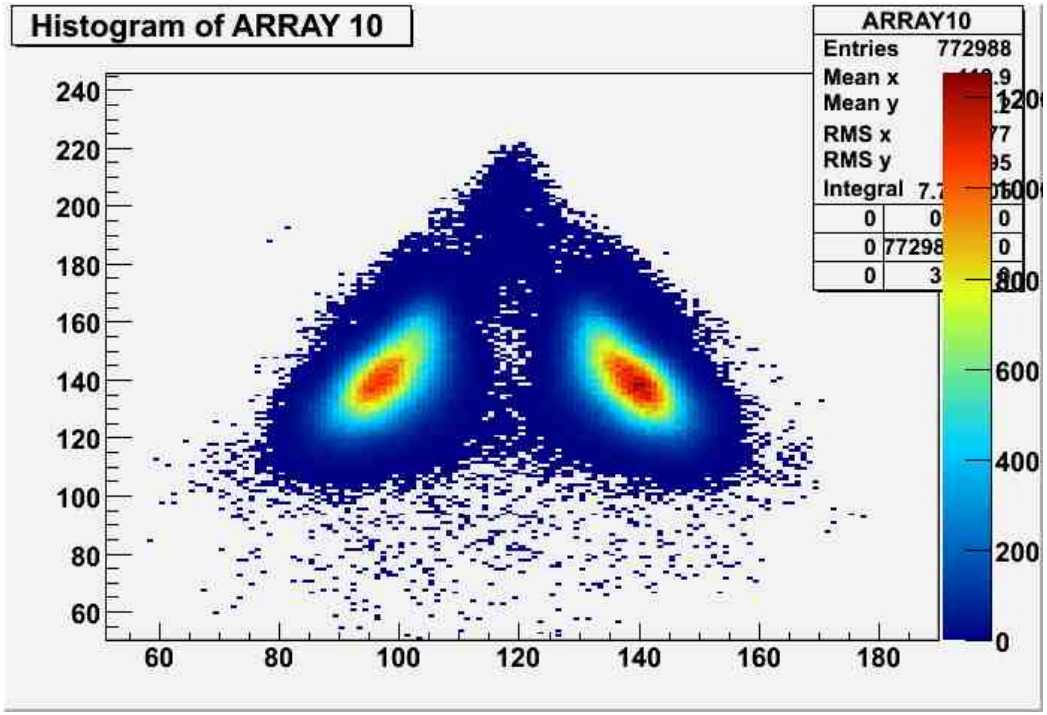
Mass Yield not in coincidence

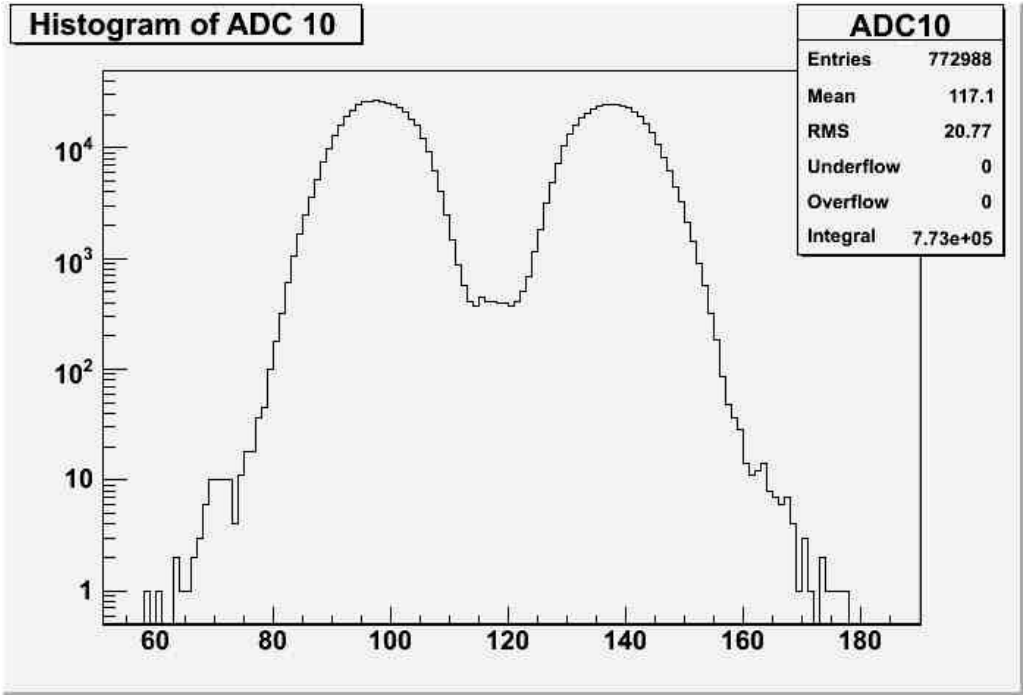




P/V ratio ~ 300

Mass Yield in coincidence

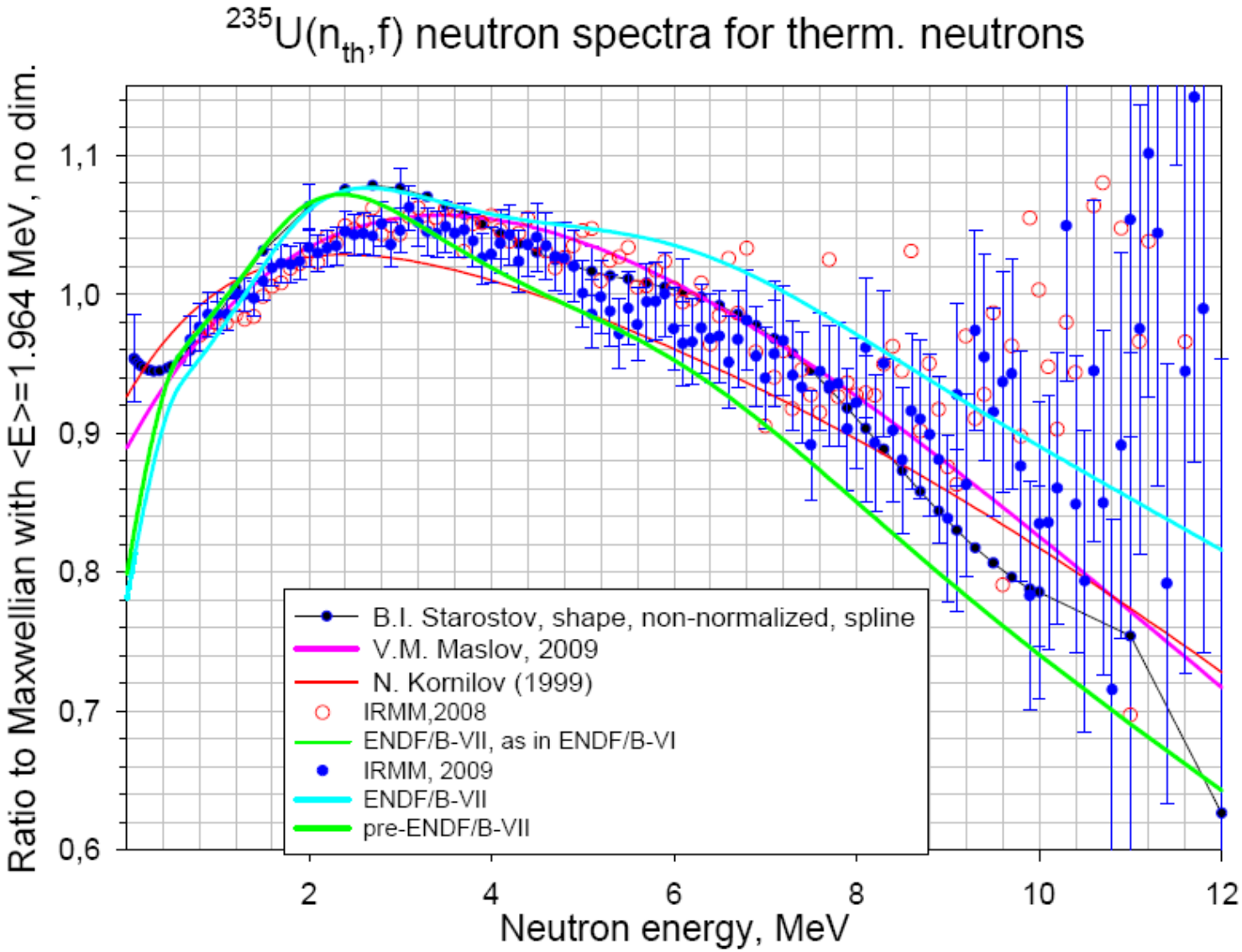


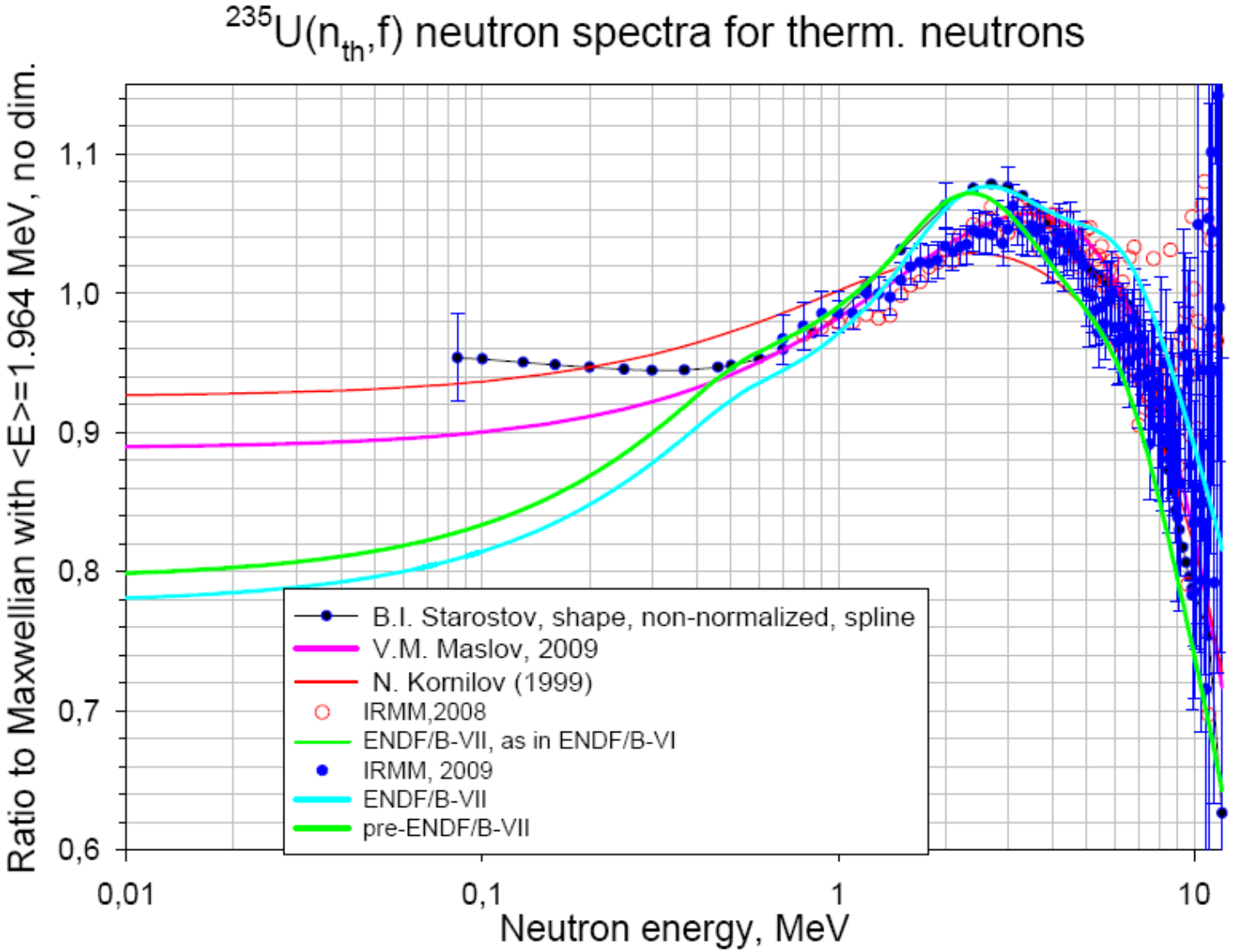


P/V ratio ~ 200

Conclusions

- PFNS in good agreement with literature but not with ENDF/B-VII
- Literature data not convincing about SCN existance
- New measurement of Russian scientists show a max of 5% of SCN and 10% at 90 degree
- Unfortunately it looks like that our new measurement at the Budapest reactor is not usable and needs repetition.


$^{235}U(n_{th},f)$ neutron spectra for therm. neutrons
Ratio to Maxwellian with <E>=1.964 MeV, no dim.
Neutron energy, MeV
1,1
1,0
0,9
0,8
0,7
0,6
2
4
6
8
10
12
B.I. Starostov, shape, non-normalized, spline
V.M. Maslov, 2009
N. Kornilov (1999)
IRMM,2008
ENDF/B-VII, as in ENDF/B-VI
IRMM, 2009
ENDF/B-VII
pre-ENDF/B-VII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1,1
1,0
0,9
0,8
0,7
0,6
0,01
0,1
1
10
Neutron energy, MeV
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ENDF/B-VII
pre-ENDF/B-VII

ratio of average cr-sec. for 235U PFNS