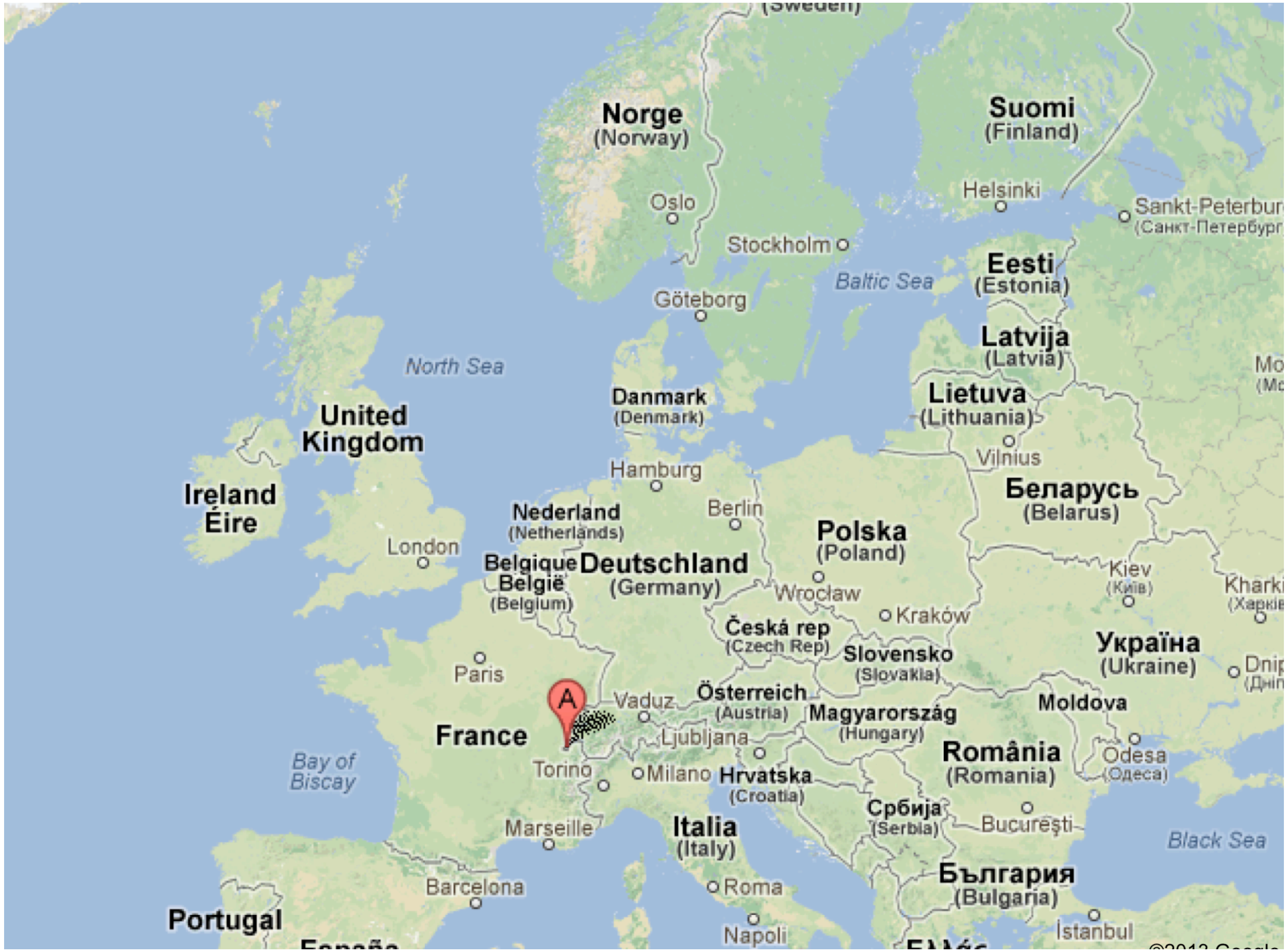
Time-of-flight measurements at n_TOF CERN

Frank Gunsing

CEA/Saclay
DSM / Irfu / SPhN
F - 91911 Gif-sur-Yvette, France
frank.gunsing@cea.fr

for the n_TOF Collaboration

CERN location

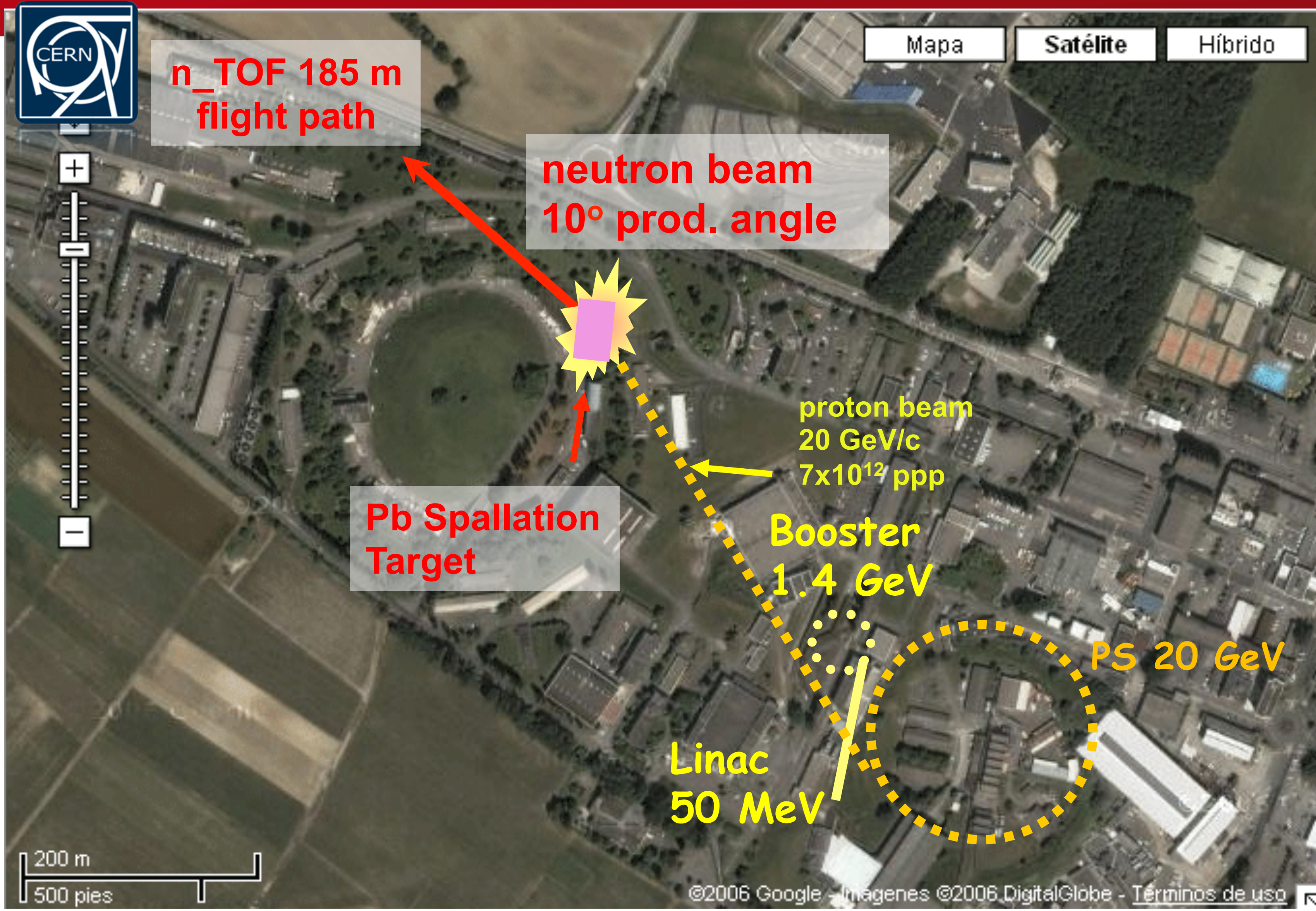


CERN location

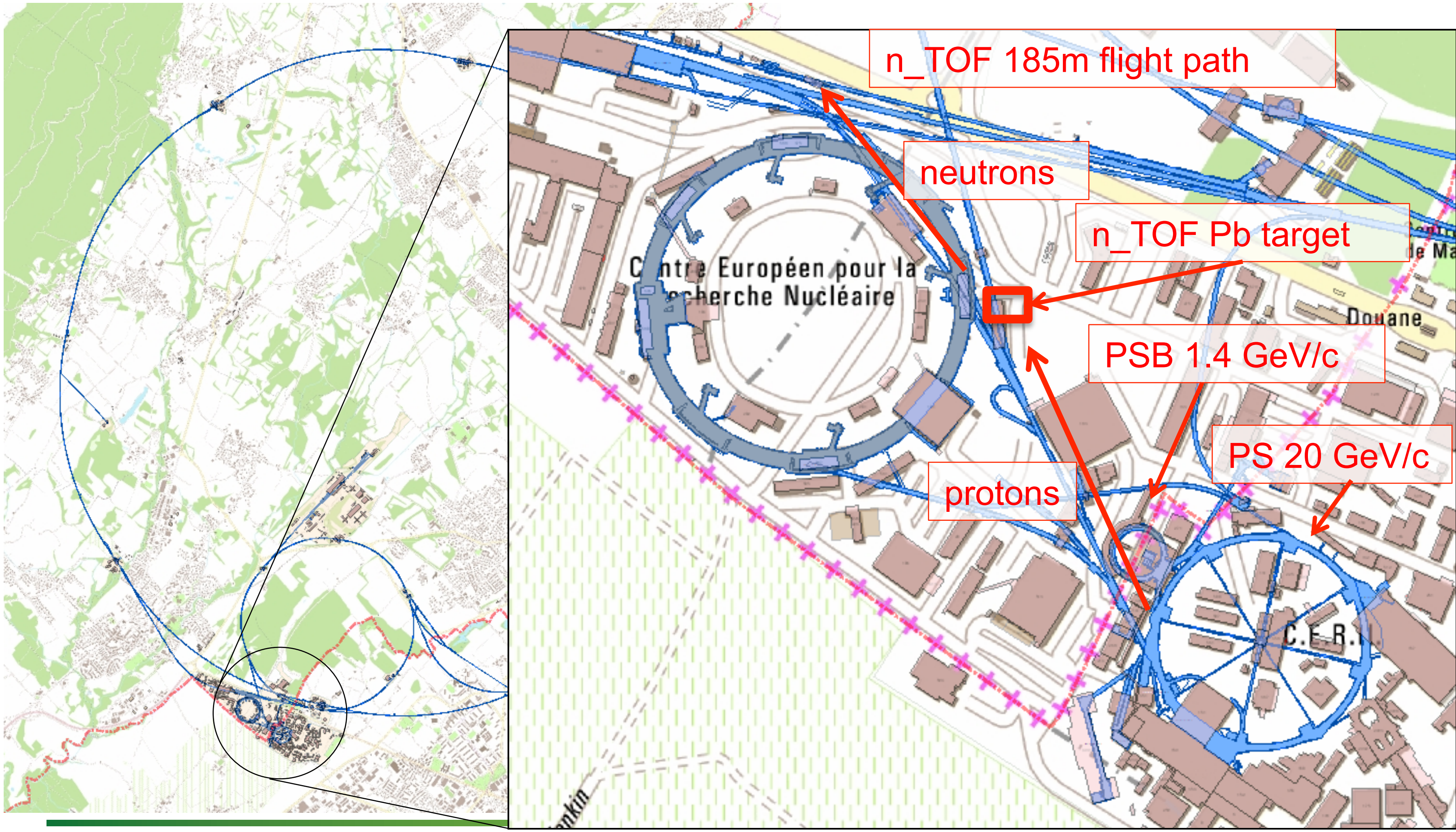
CERN location

The n_TOF facility at CERN

The n_TOF facility at CERN



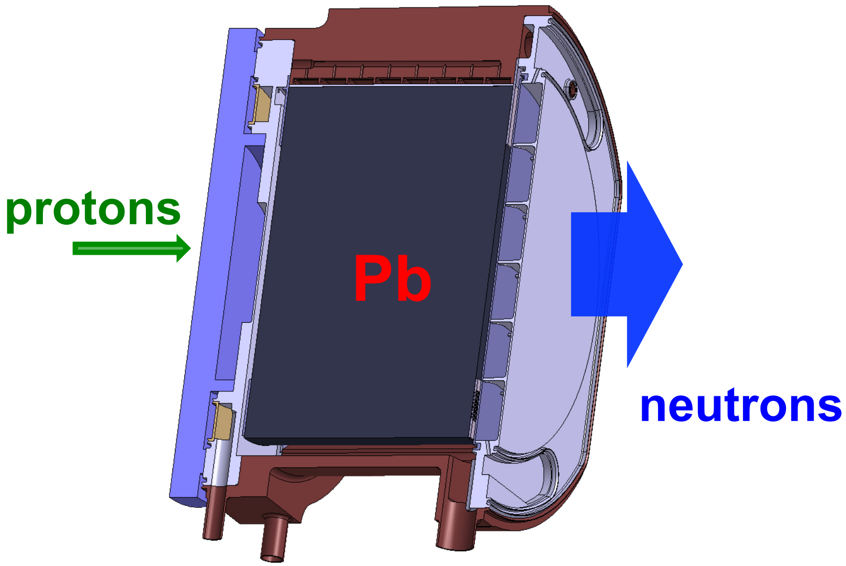
The n_TOF facility at CERN



The n_TOF facility at CERN

Pulsed white neutron source:

- 20 GeV/c protons
- neutrons from spallation
- 6 ns rms pulse width
- frequency 1 pulse/2.4 seconds
- separate cooling and moderation
- flight path length EAR1: 185 m
- @source: 7×10^{12} protons/pulse
- @source: 2×10^{15} neutrons/pulse
- @EAR1: $5 \cdot 10^{5}$(capture) – $5 \cdot 10^{7}$(fission) neutrons/pulse



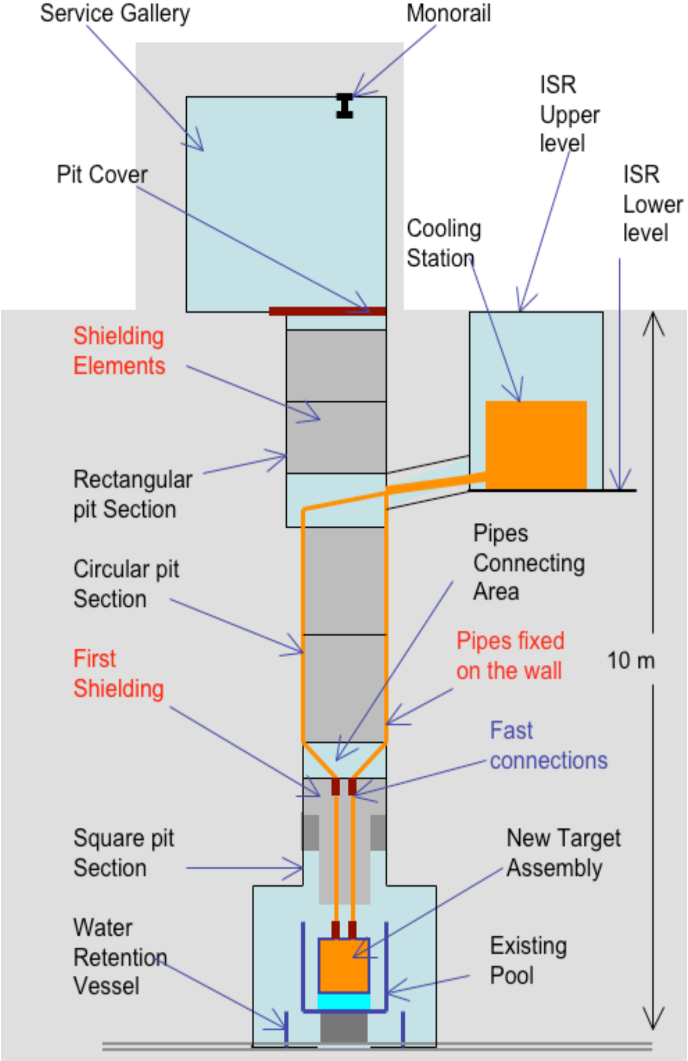
phase II target

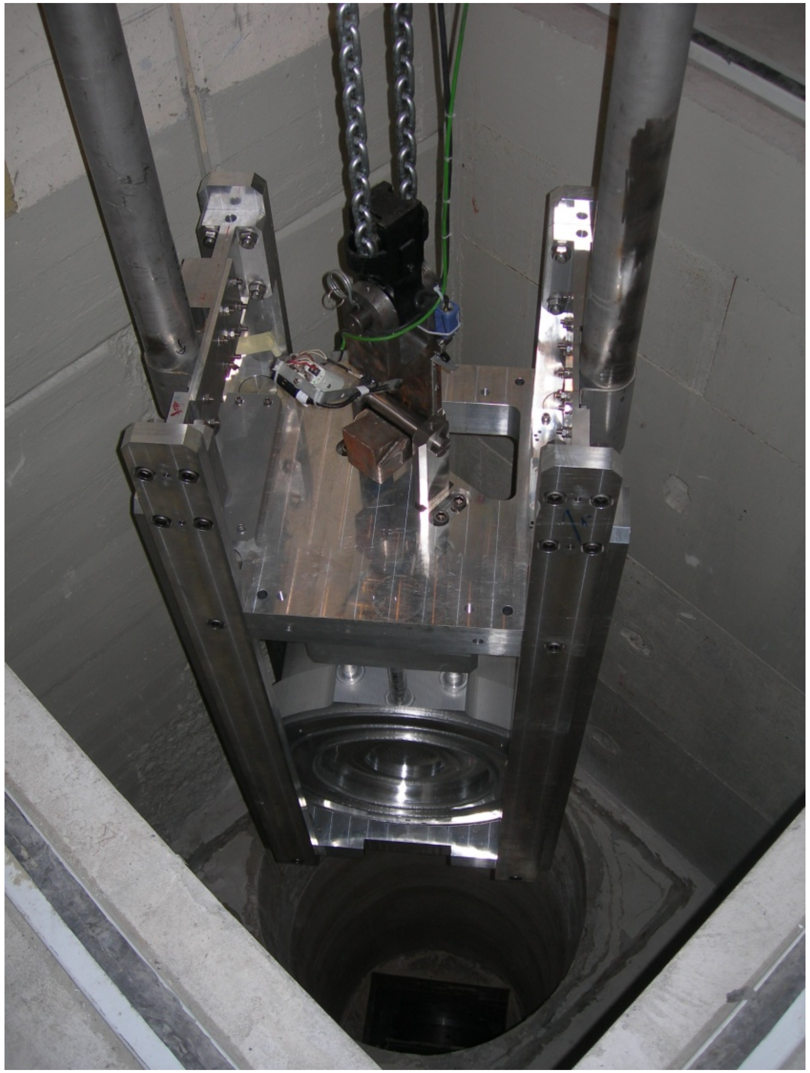
Main features:

- Large energy range in one experiment (0.1 eV - 250 MeV)
- Favorable signal to noise ratio for capture
  on radioactive isotopes (actinides, fission products)

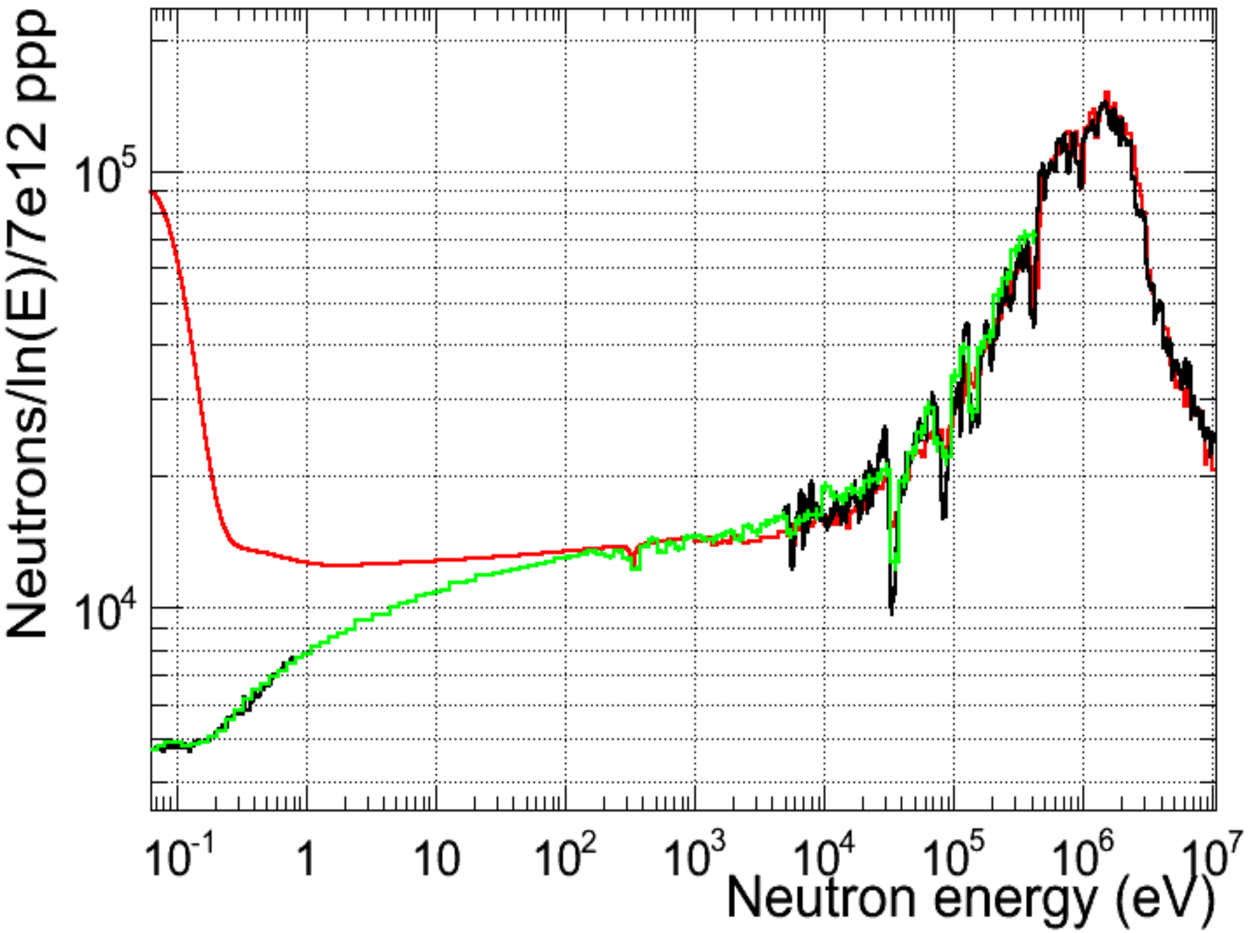
NEW SPALLATION TARGET IN 2009

New Spallation Target in 2009

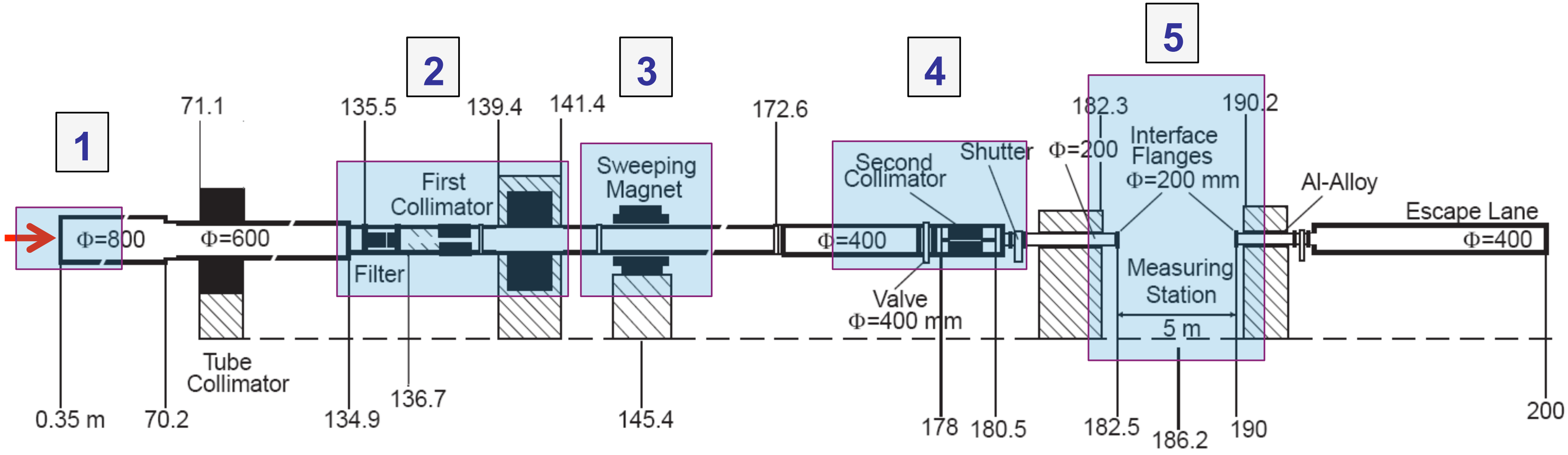




The n_TOF neutron spectrum

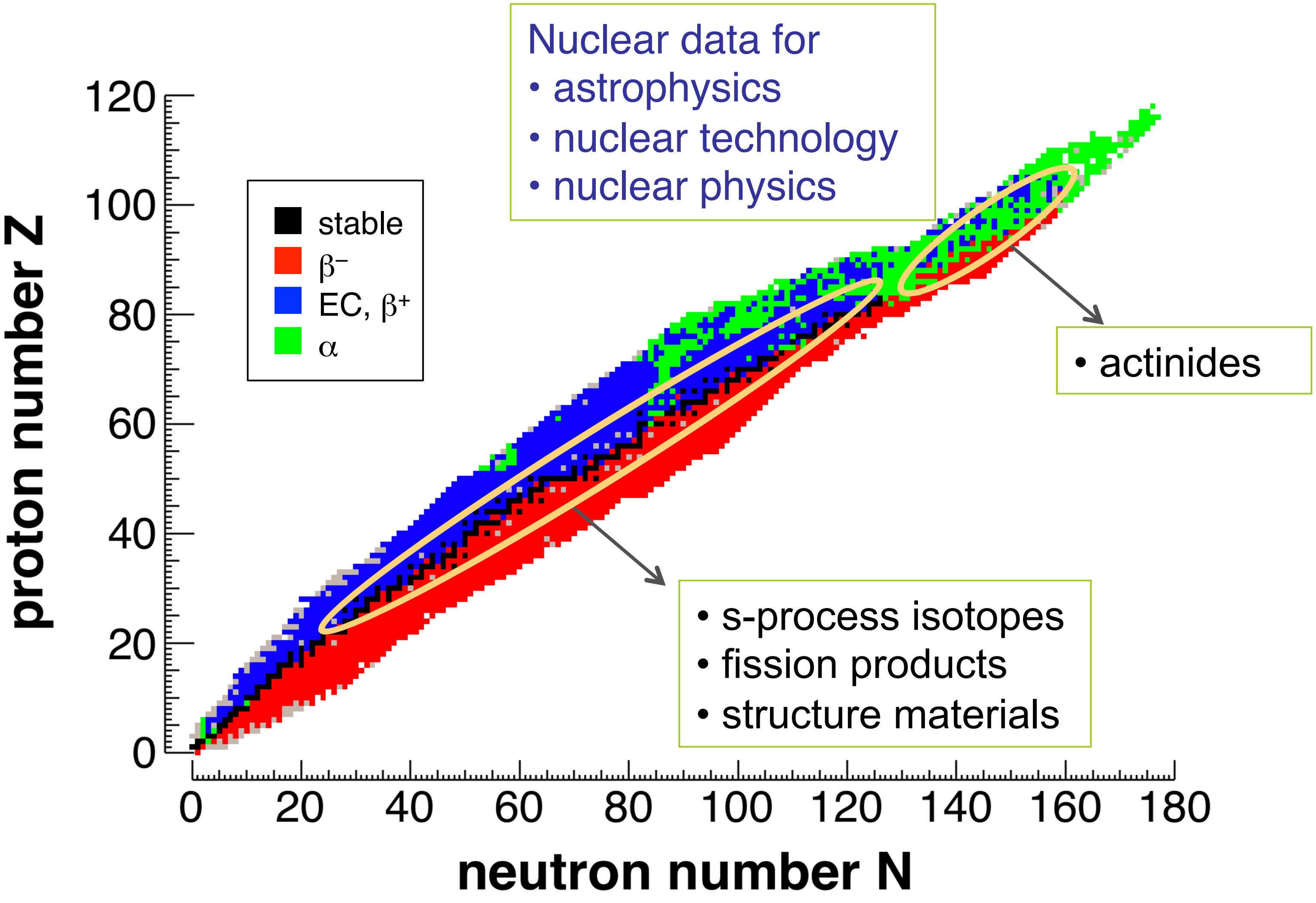


n_TOF experimental setup

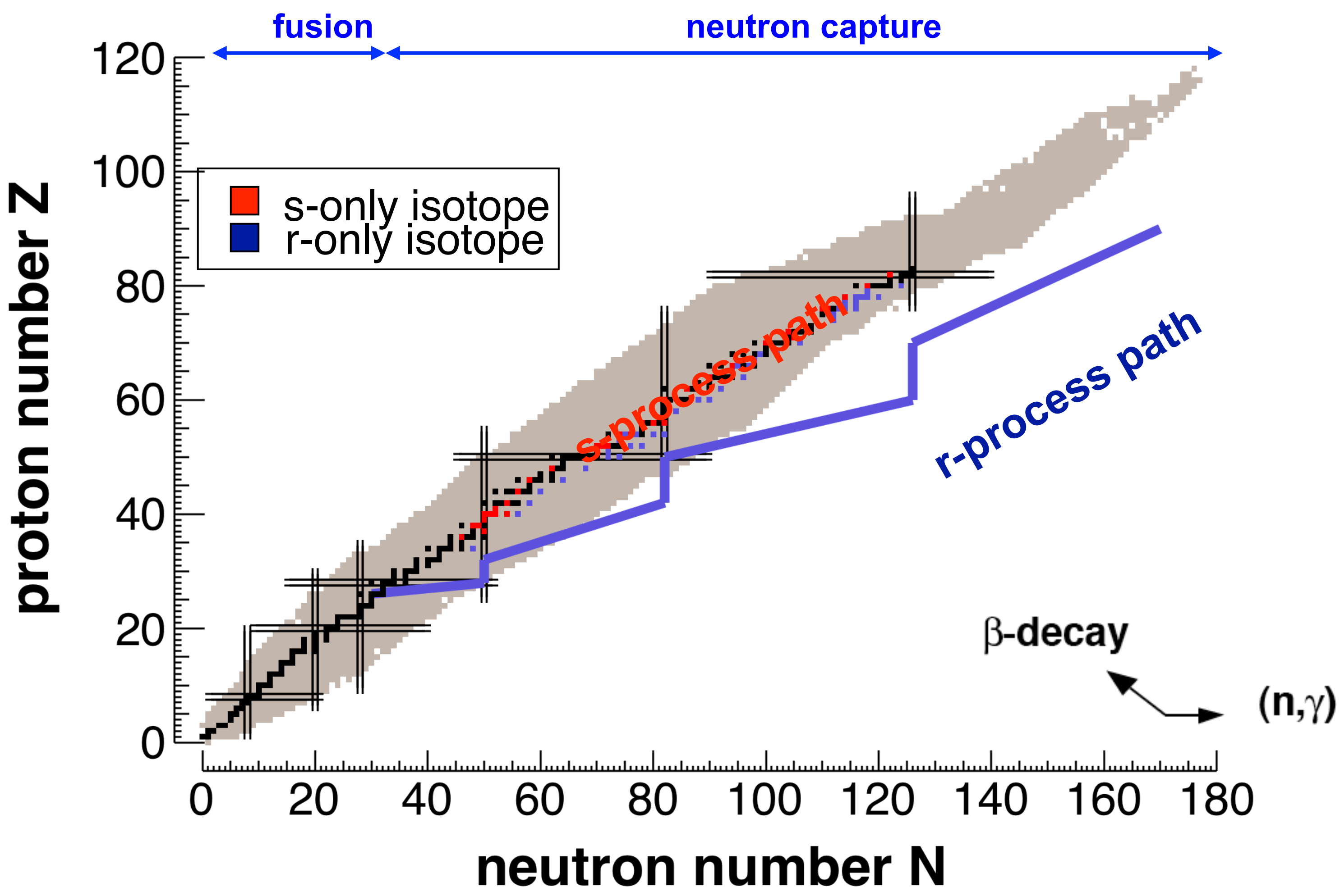


1. Spallation target and moderator producing neutrons with energies from thermal up to several GeV
2. first collimator (Ø=11 cm) for first shaping of the beam + filter station
3. Sweeping magnet
4. Second variable collimator (Ø=1.8/8 cm) – final beam shaping
5. Experimental Area 1 (EAR1), with samples and detectors

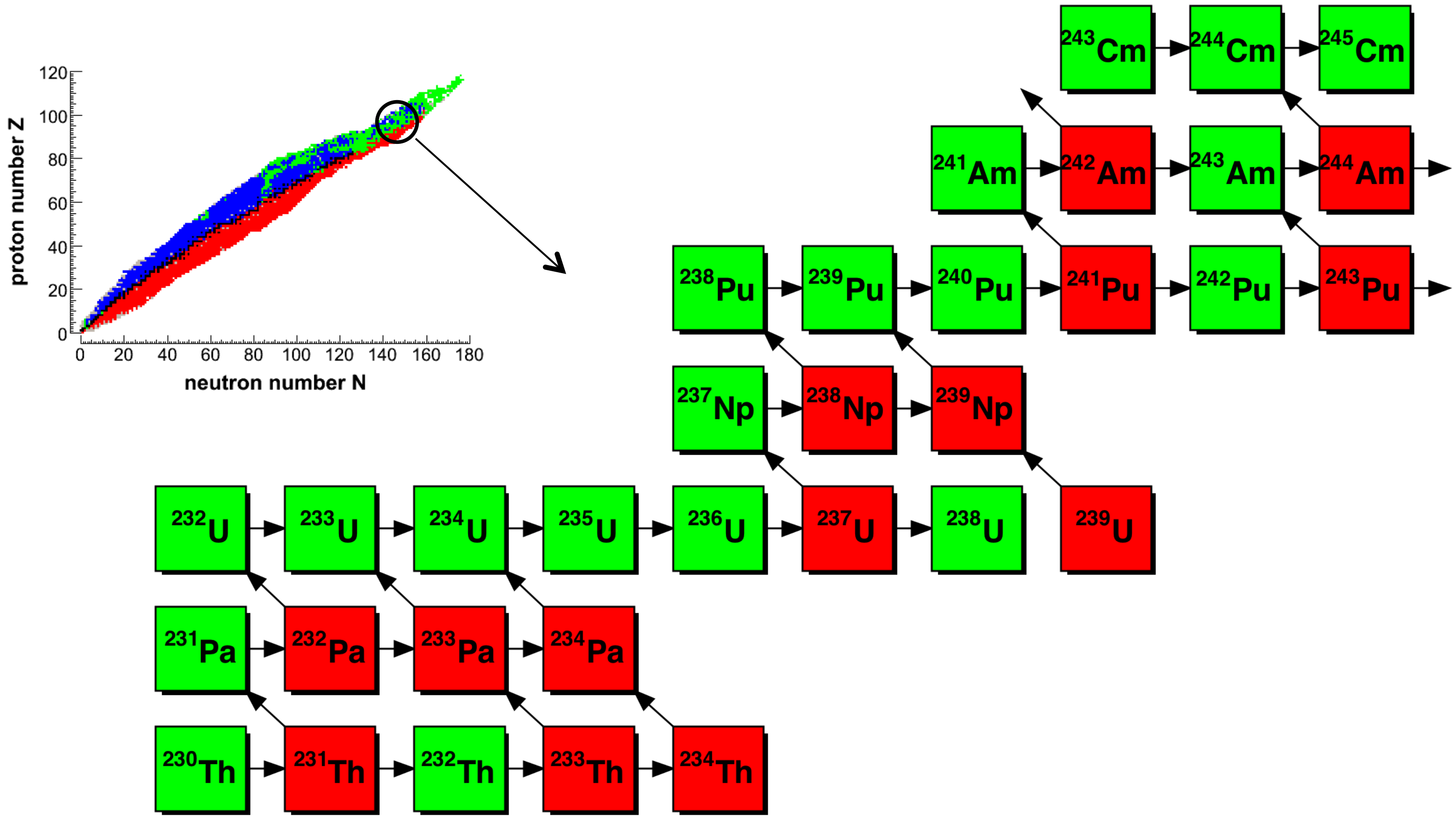
Nuclei of interest for neutron induced reactions



Stellar nucleosynthesis (s-, r-process)



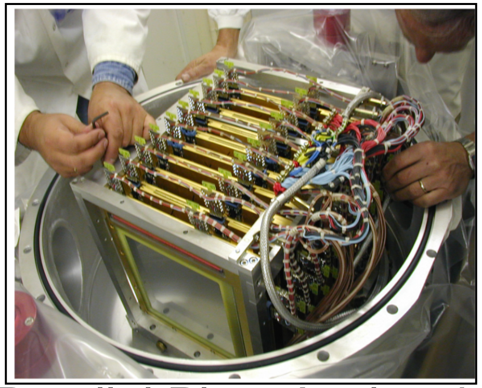
Actinide build-up in reactors (w-process)



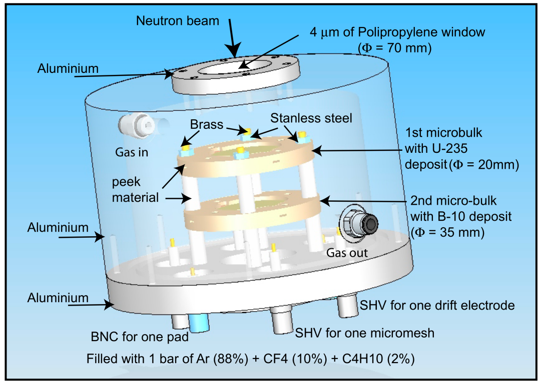
$$^{238}\mathrm{U} + \mathrm{n} \longrightarrow {}^{239}\mathrm{U} \xrightarrow{\beta^- \ (23\ min)} {}^{239}\mathrm{Np} \xrightarrow{\beta^- \ (2.4\ d)} {}^{239}\mathrm{Pu}$$

$$^{232}\mathrm{Th} + \mathrm{n} \longrightarrow {}^{233}\mathrm{Th} \xrightarrow{\beta^- \ (22\ min)} {}^{233}\mathrm{Pa} \xrightarrow{\beta^- \ (27\ d)} {}^{233}\mathrm{U}$$

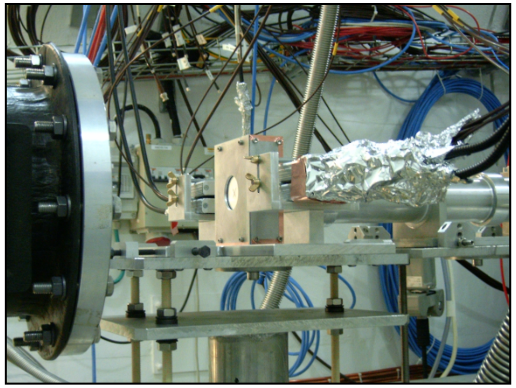
n_TOF Detectors



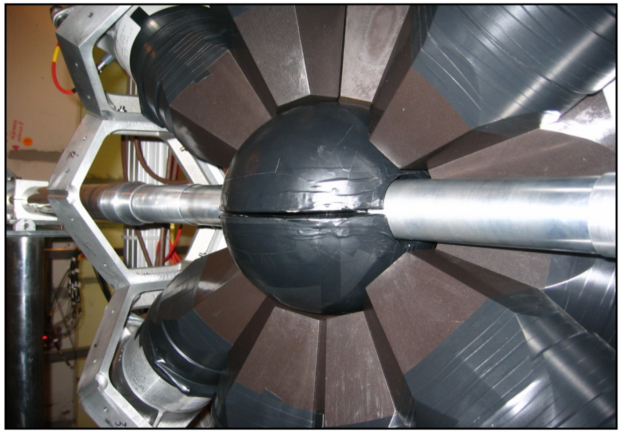
Parallel Plate Avalanche Counter (PPAC)



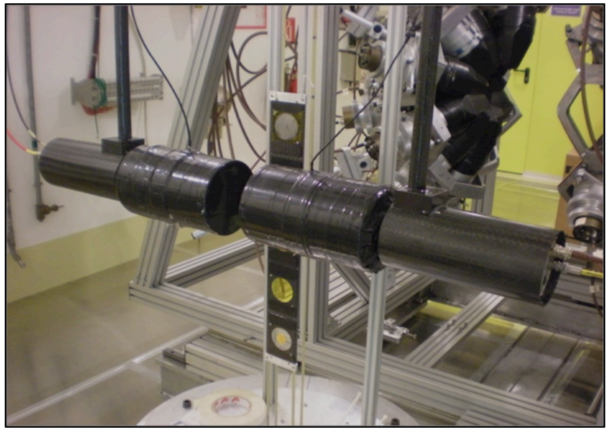
MicroMegas (MGAS)



sCVD diamond (3x3 array)

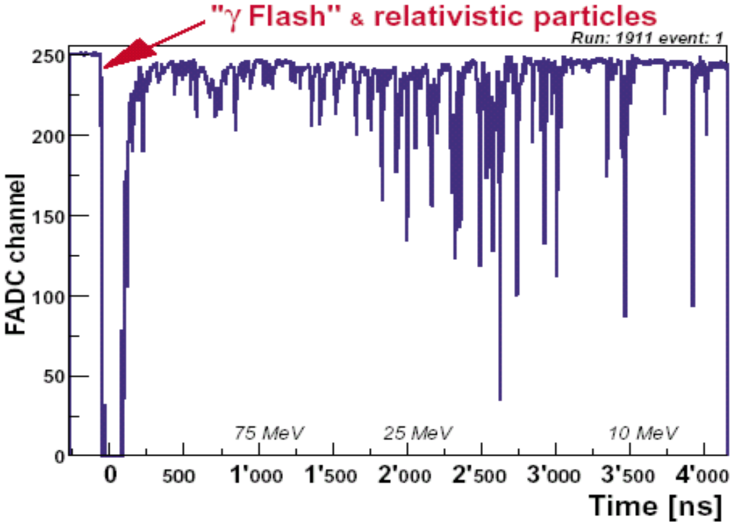


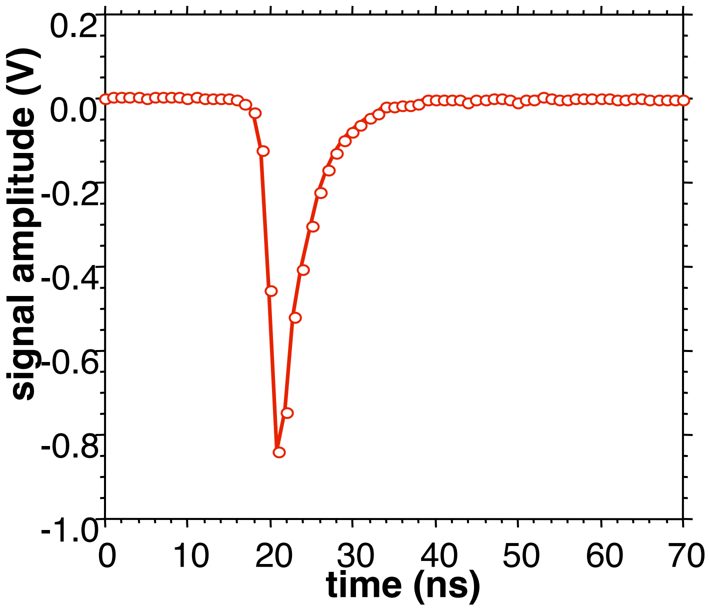
BaF_2 Total Absorption Calorimeter (TAC)

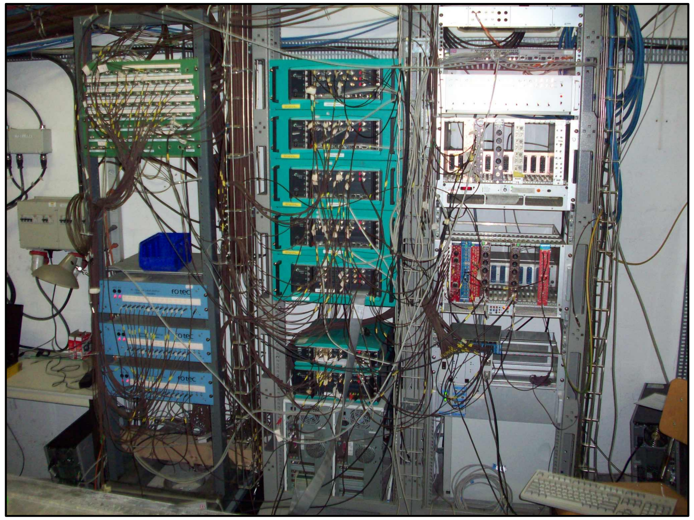


Low neutron sensitivity C_6D_6

n_TOF data acquisition system

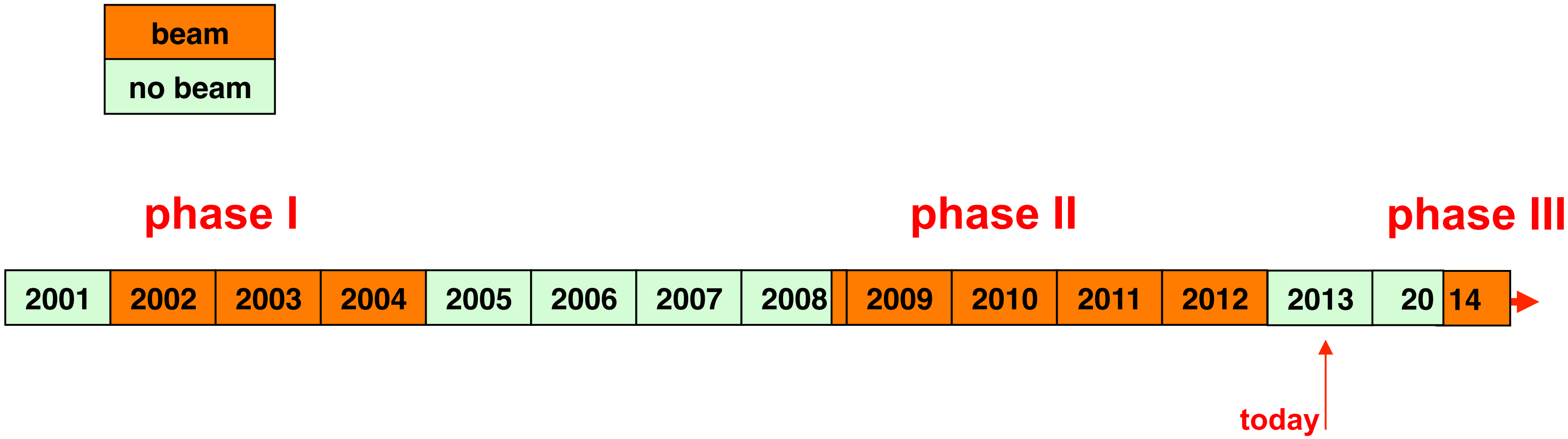






- 56 Acqiris fADC channels
- up to 1 GHz sampling rate, 8-10 bit resolution
- full recording of detector signal up to 80 ms
- Offline signal processing and event construction

The n_TOF facility at CERN



- 1998 - 2001 preparation and commissioning
- 2002 - 2004 **phase I** data taking
- 2005 - 2007 spallation target upgrade
- 2008 first protons on target
- 2009 **phase II** data taking
- 2010 - 2012 class A lab. borated water
- **2013 construction second, short flight path (20 m) EAR2**
- **2014 commissioning**

n_TOF CERN phase I (2001-2004)
Summary of measurements

capture C_6D_6

- ^{24,25,26}Mg
- ^{56}Fe
- ^{90,91,92,93,94,96}Zr
- ^{139}La
- ^{151}Sm
- ^{186,187,188}Os
- ^{197}Au
- ^{204,206,207,208}Pb
- ^{209}Bi
- ^{232}Th

capture BaF_2

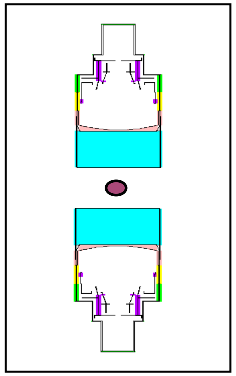
- ^{197}Au
- ^{233,234}U
- ^{237}Np
- ^{240}Pu
- ^{243}Am

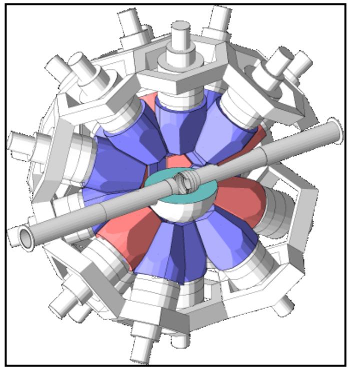
fission FIC

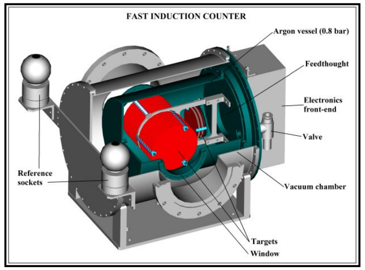
- ^{232}Th
- ^{237}Np
- ^{233,234,235,236,238}U
- ^{241,243}Am
- ^{245}Cm

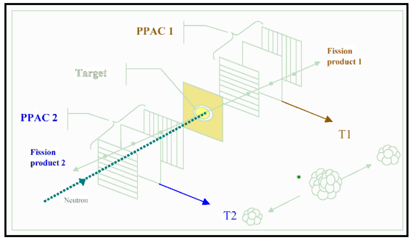
fission PPAC

- ^{nat}Pb
- ^{209}Bi
- ^{232}Th
- ^{237}Np
- ^{233,234,235,238}U









n_TOF CERN phase II (2008-2012)
Summary of measurements

capture C_6D_6
- ^{25}Mg
- ^{54,56,57}Fe
- ^{58,60,62,63}Ni
- ^{93}Zr ^{197}Au
- ^{236,238}U
- ^{241}Am
- ^{240}Pu

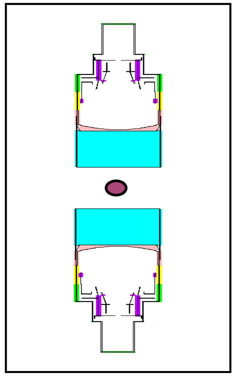
capture BaF_2
- ^{87}Sr (spin)
- ^{197}Au
- ^{235}U (+fis)
- ^{236,238}U
- ^{241}Am

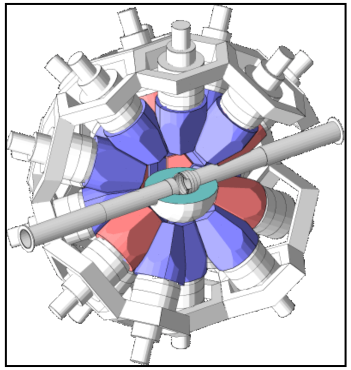
fission PPAC
- ^{232}Th (FF ang)
- ^{237}Np (FF ang)
- ^{235,238}U (FF ang)

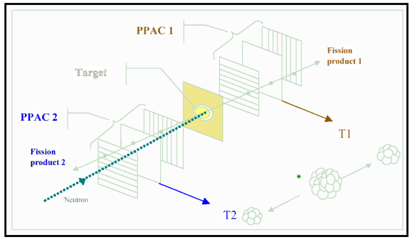
Detector tests and developments
- several

fission MGAS
- ^{240,242}Pu

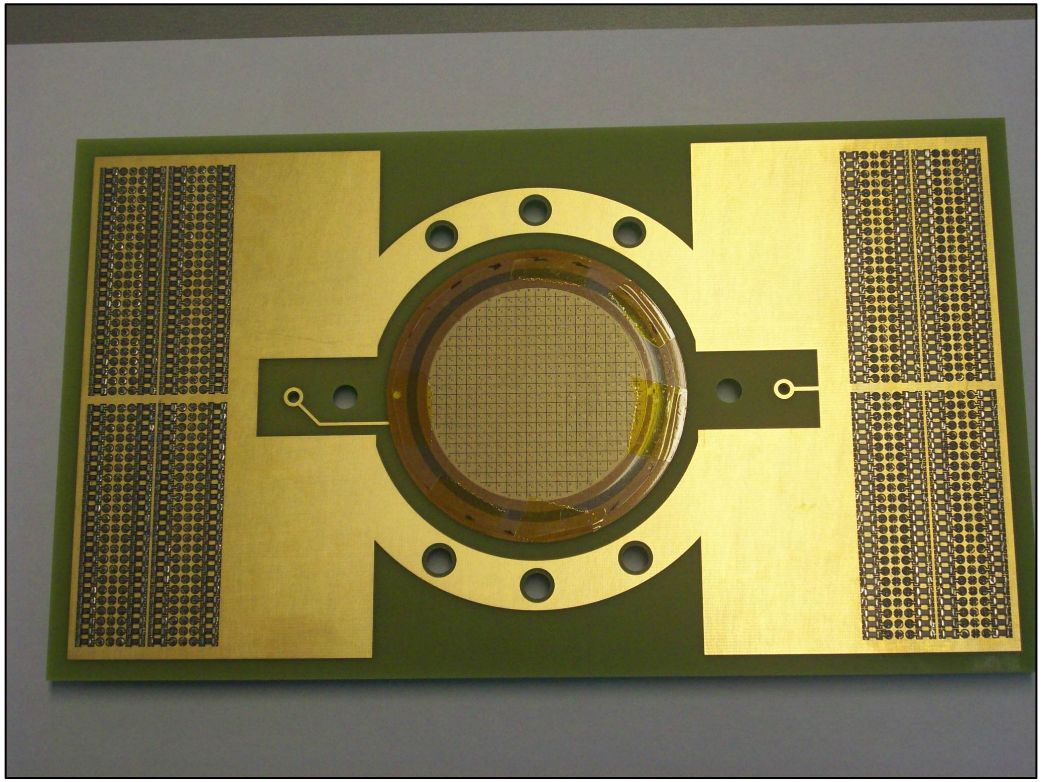
(n,a) MGAS/ CVD
- ^{59}Ni
- ^{33}S

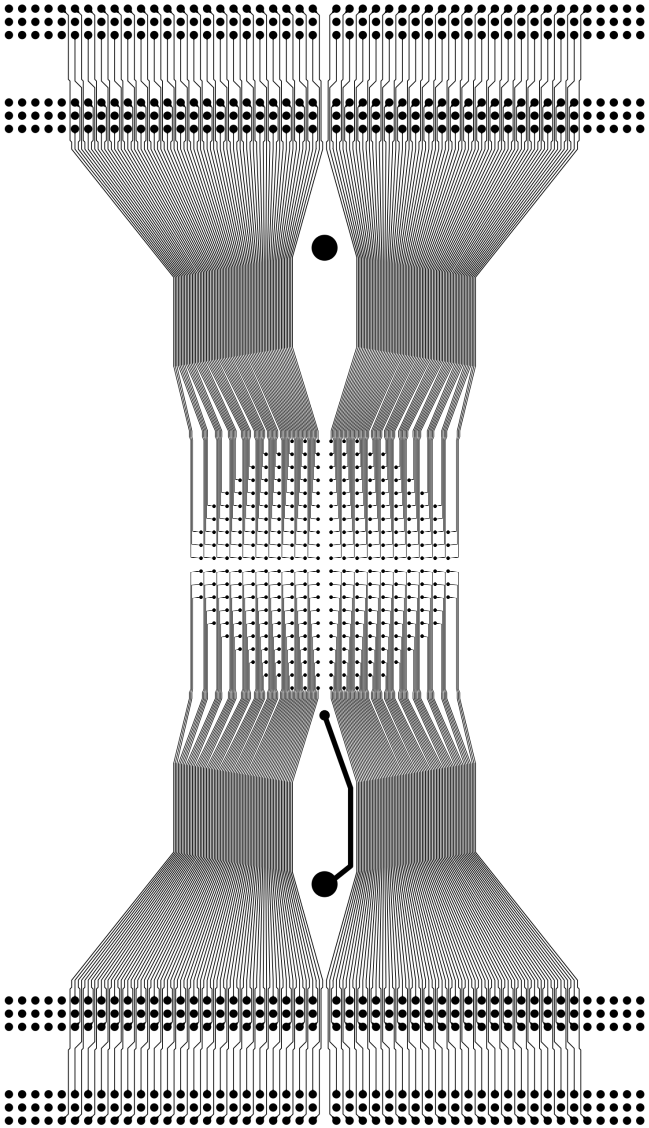




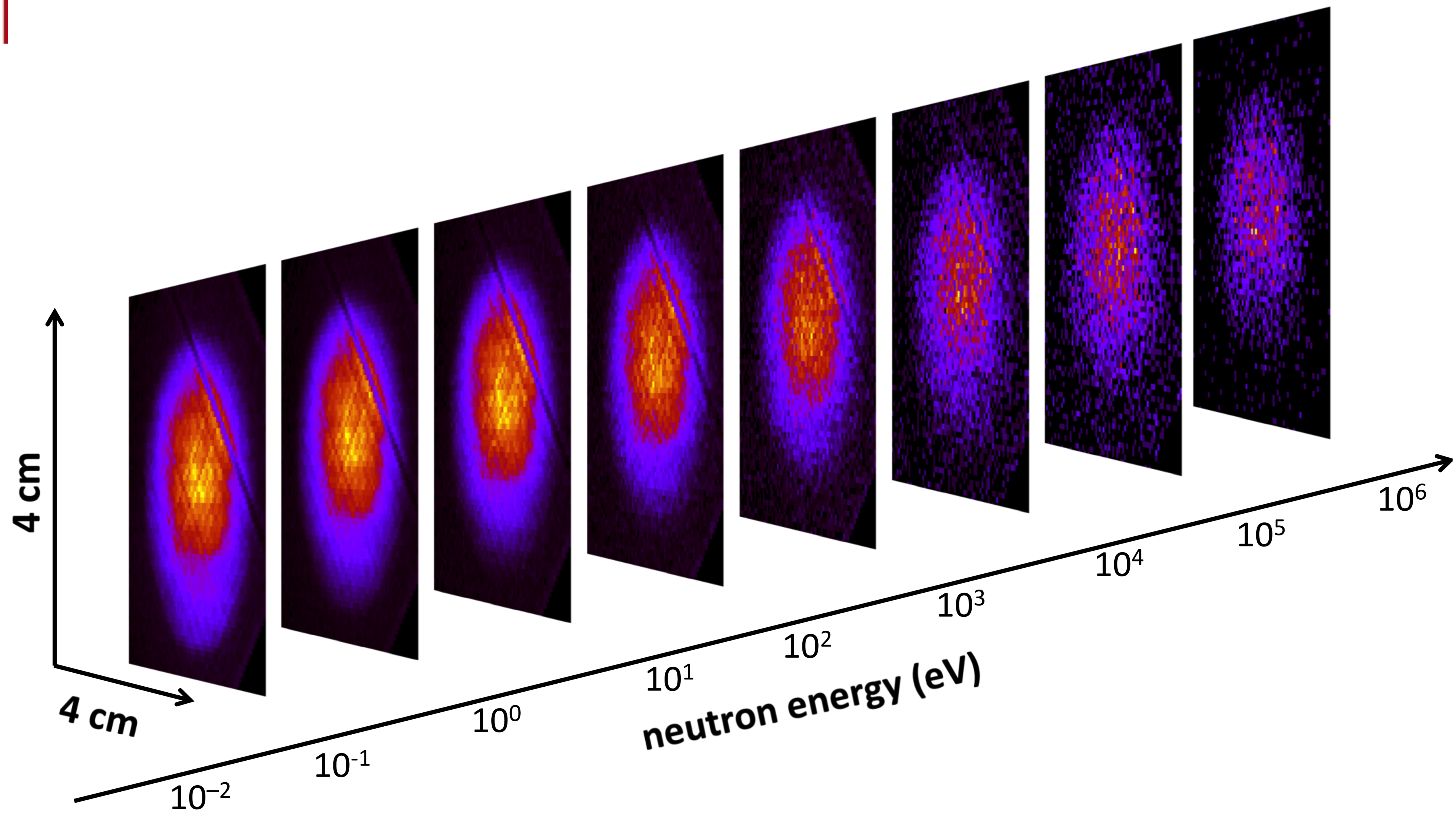


New (2012) MicroMegas pixellized detector





MICROMEGAS-BASED NEUTRON BEAM PROFILER



Spin assignments of ^{87}Sr + n resonances

Goal:

Pilot experiment to measure neutron resonance spins of ^{87}Sr with BaF_2 TAC

^{87}Sr has $J^\pi = 9/2^+$

s-waves (l=0): $J^\pi = 4^+$ or 5^+

p-waves (l=1): $J^\pi = 3^-, 4^-, 5^-, 6^-$

Development:

Optimize possible analysis methods for spin assignments using TAC.
In future, apply to other isotopes.

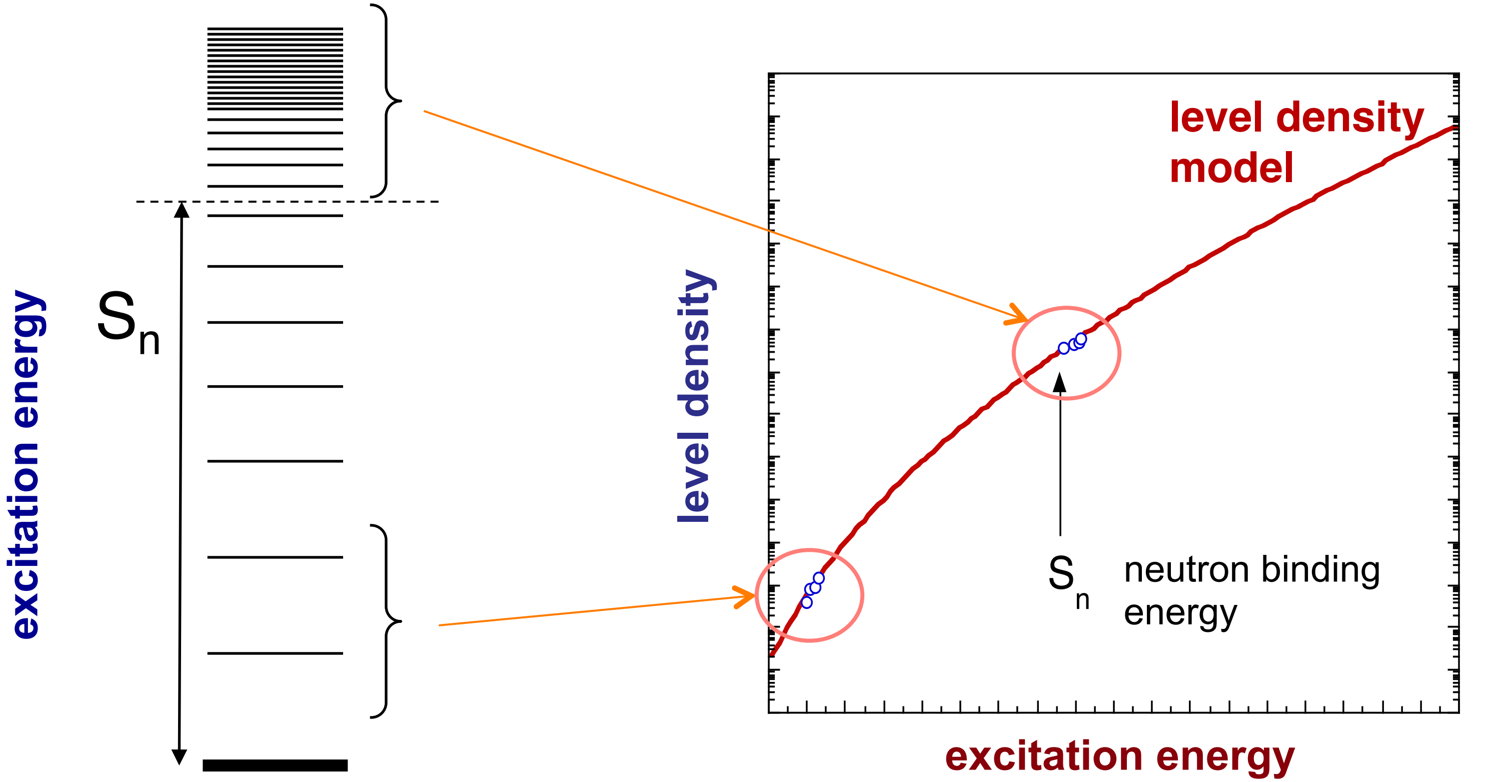
How:

- Exploit gamma-ray spectra from decay from resonance state
  - gamma-ray multiplicity spectra
  - low-level population
  - primary gamma-rays (presence, angular distribution)

Why ^{87}Sr?

- Extension of multiplicity method to p-waves
- Large spin window, large p-wave resonances (peak in p-wave strength function)
- Enriched sample is available from Los Alamos
- Additional interest for astrophysics (s-process branching through ^{85}Kr)

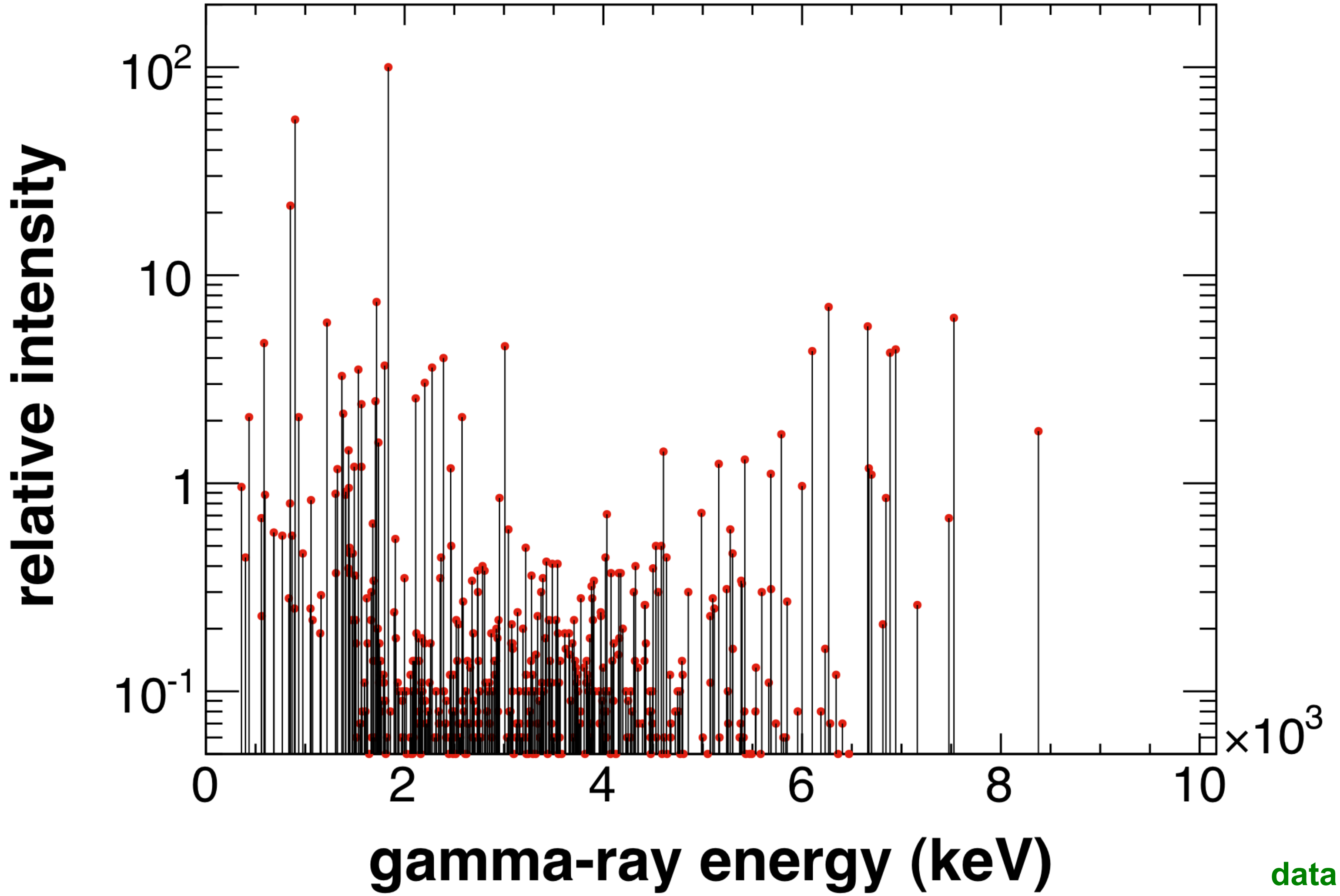
Nuclear level densities



low-lying levels:
Count levels, all J^π

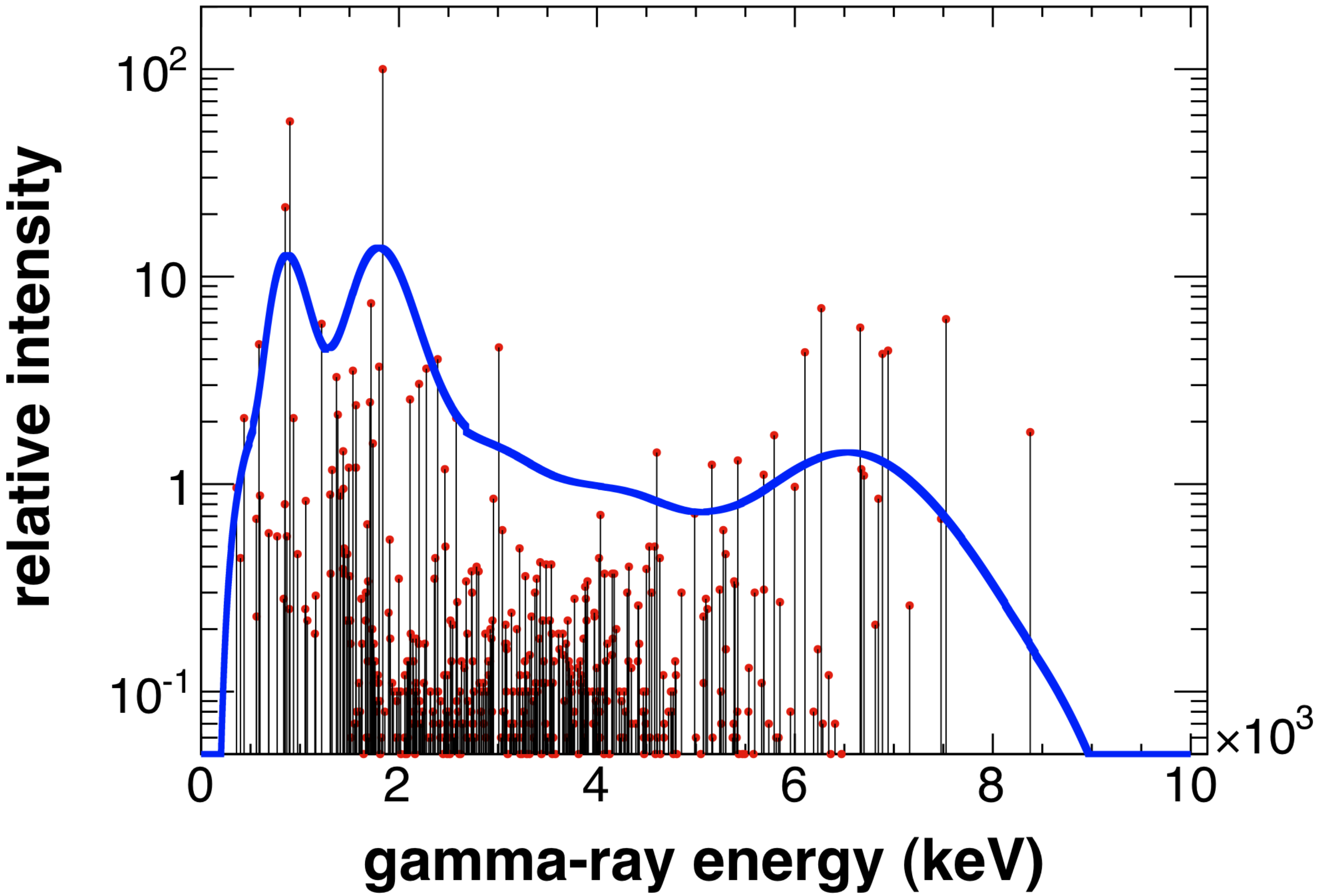
neutron resonances:
Count levels, selected J^π,
extract $\mathbf{D_0}$

$^{87}Sr(n,\gamma_{thermal})^{88}Sr$ spectrum

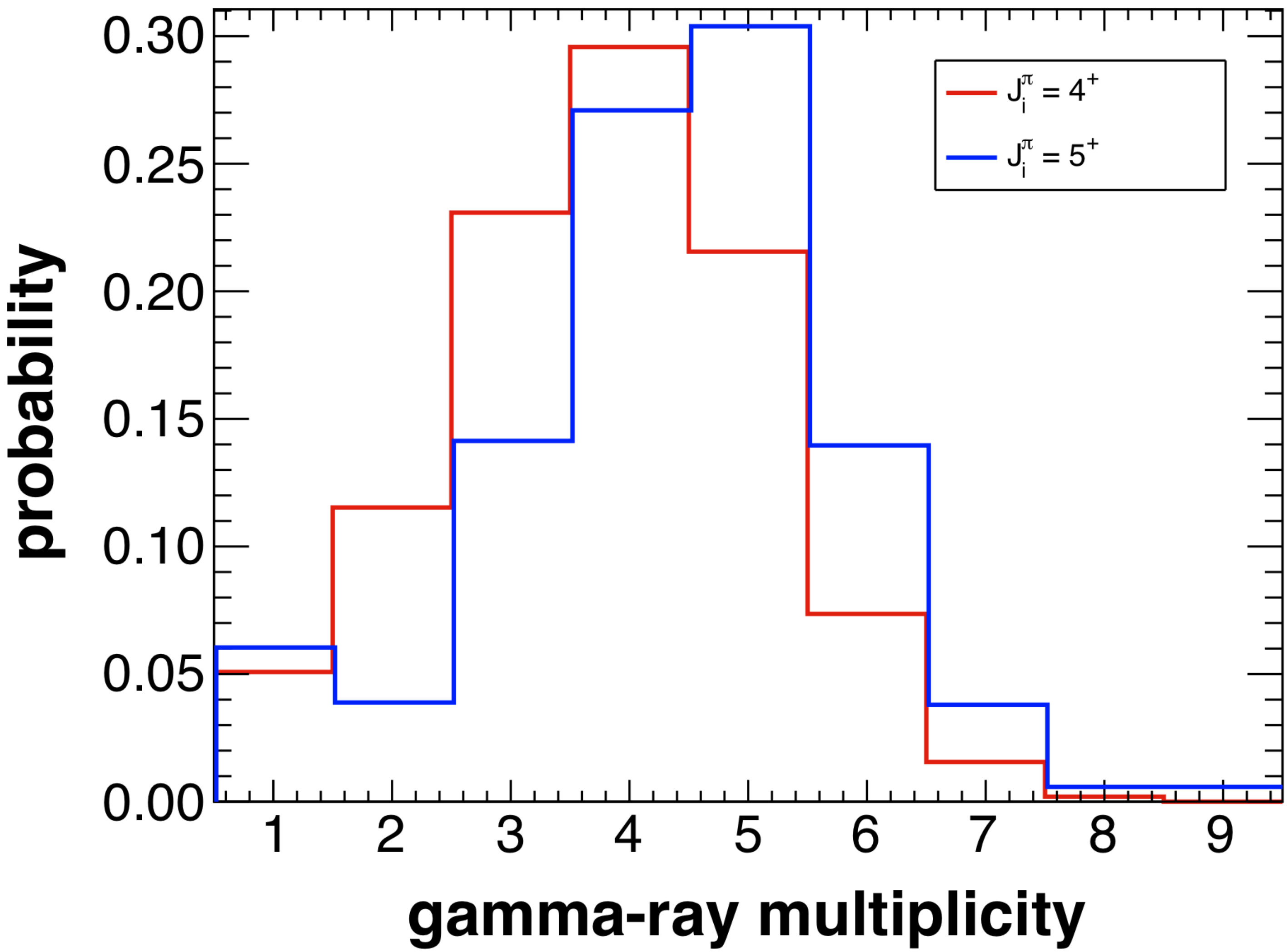


data ENSDF

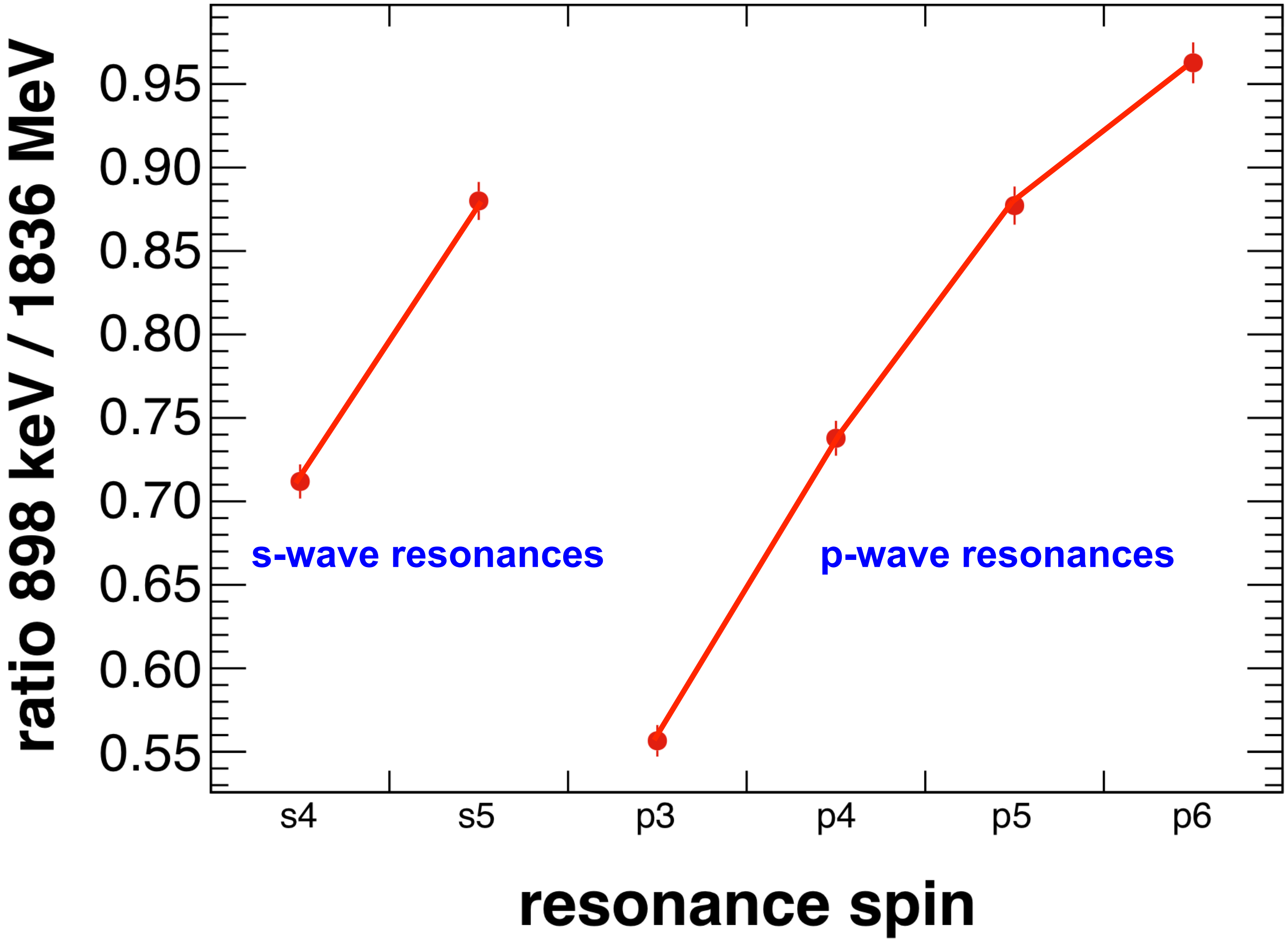
$^{87}Sr(n,\gamma_{thermal})^{88}Sr$ spectrum



Simulated decay of $^{88}Sr^*$

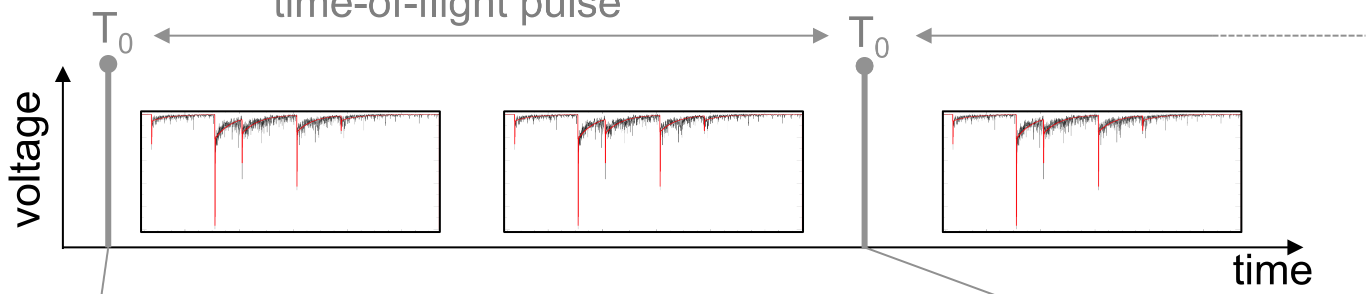


Spin dependence of population ratio

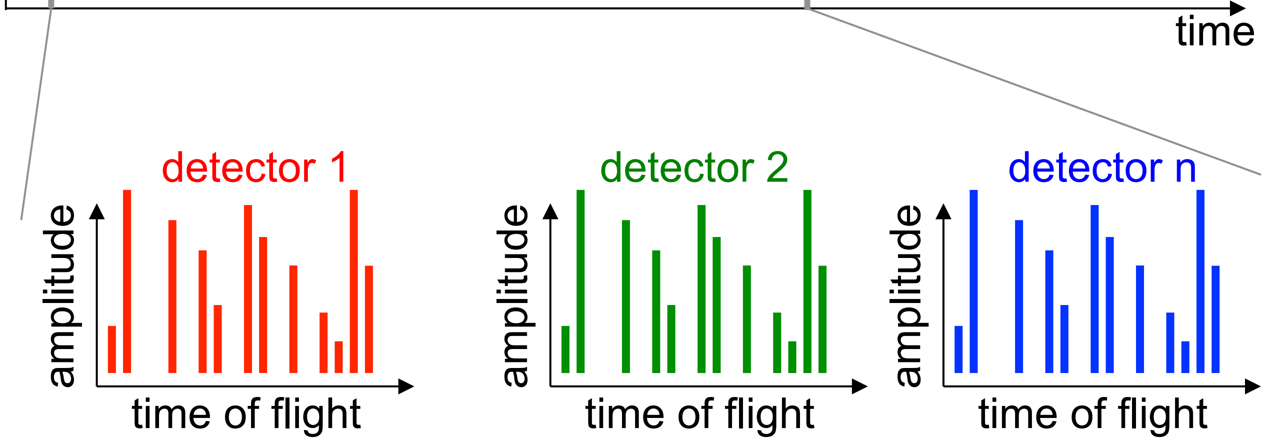


Data reduction

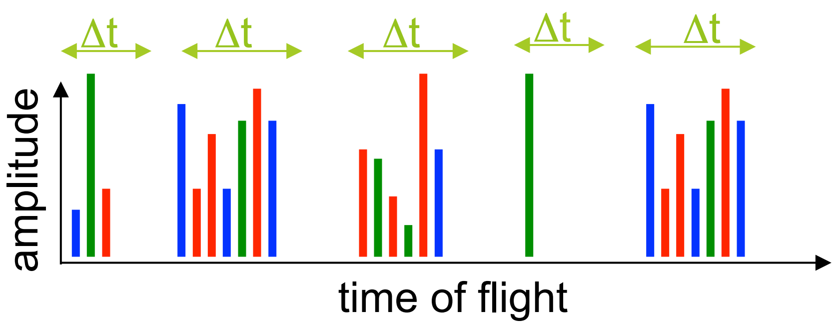
raw data, waveforms: 45000 TB



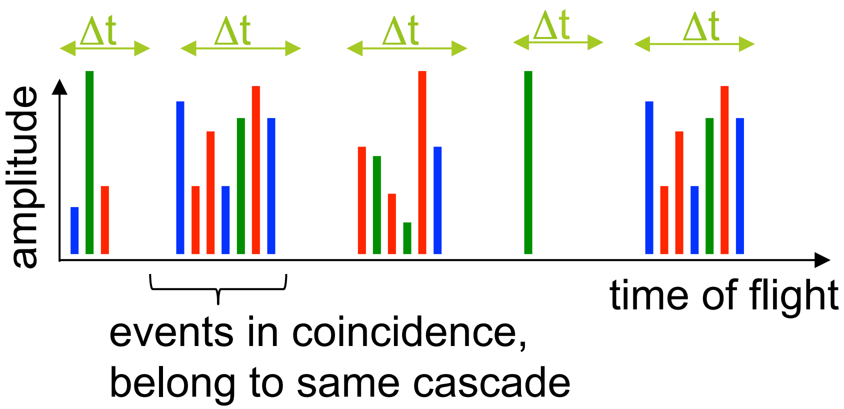
event data, list of amplitude, time for each detector: 60 TB



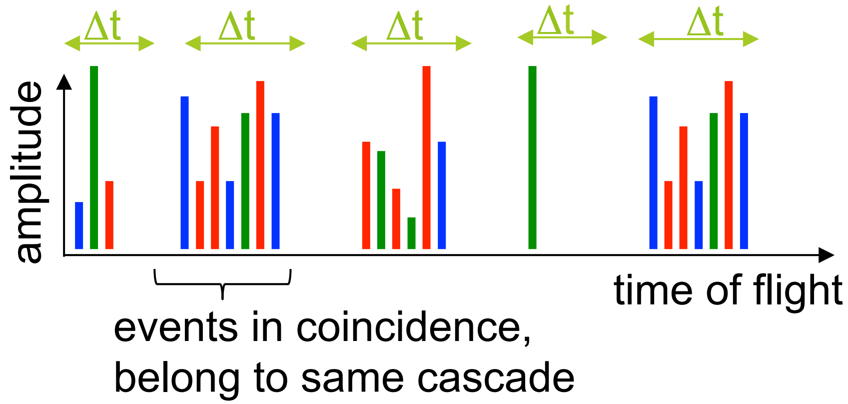
• align events in time to find coincidences

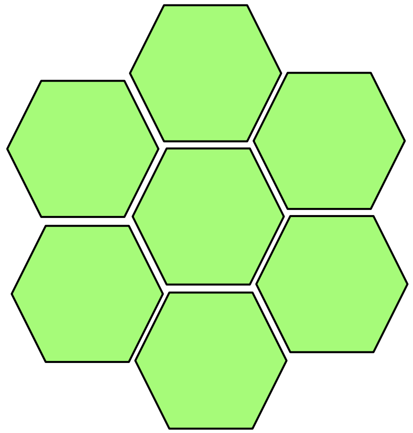


Data reduction



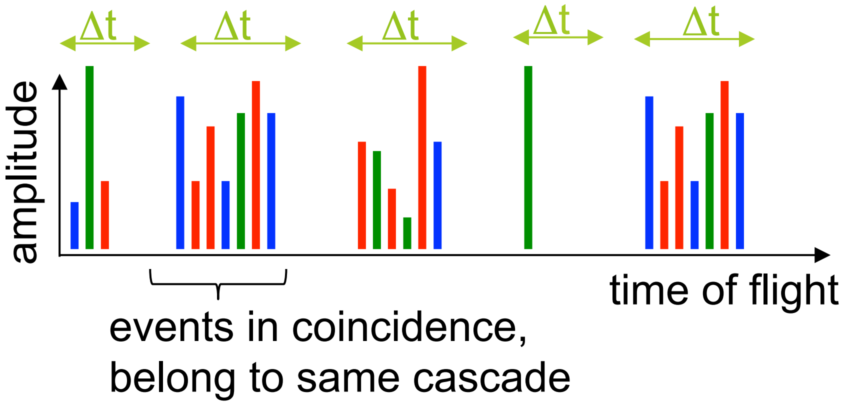
Data reduction

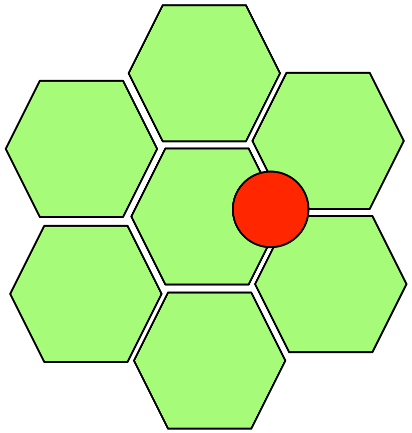




Energy deposit in BaF_2 crystals

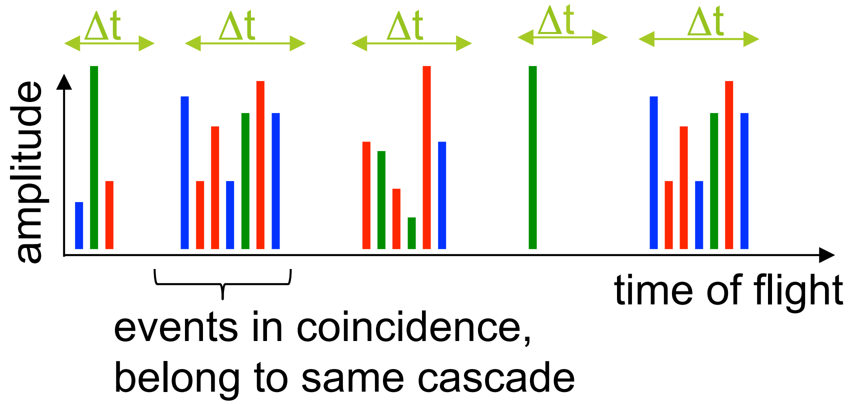
Data reduction

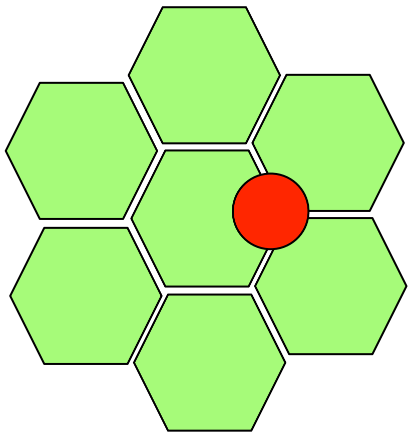


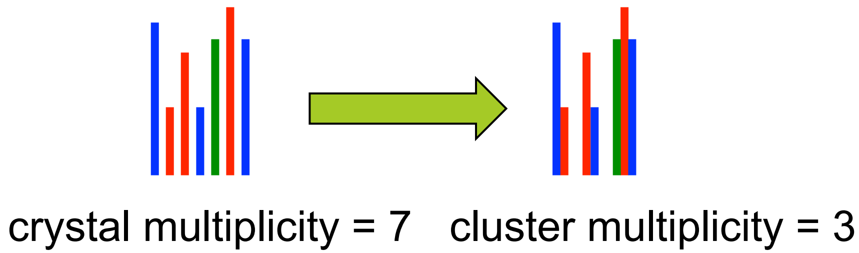


Energy deposit in BaF_2 crystals

Data reduction

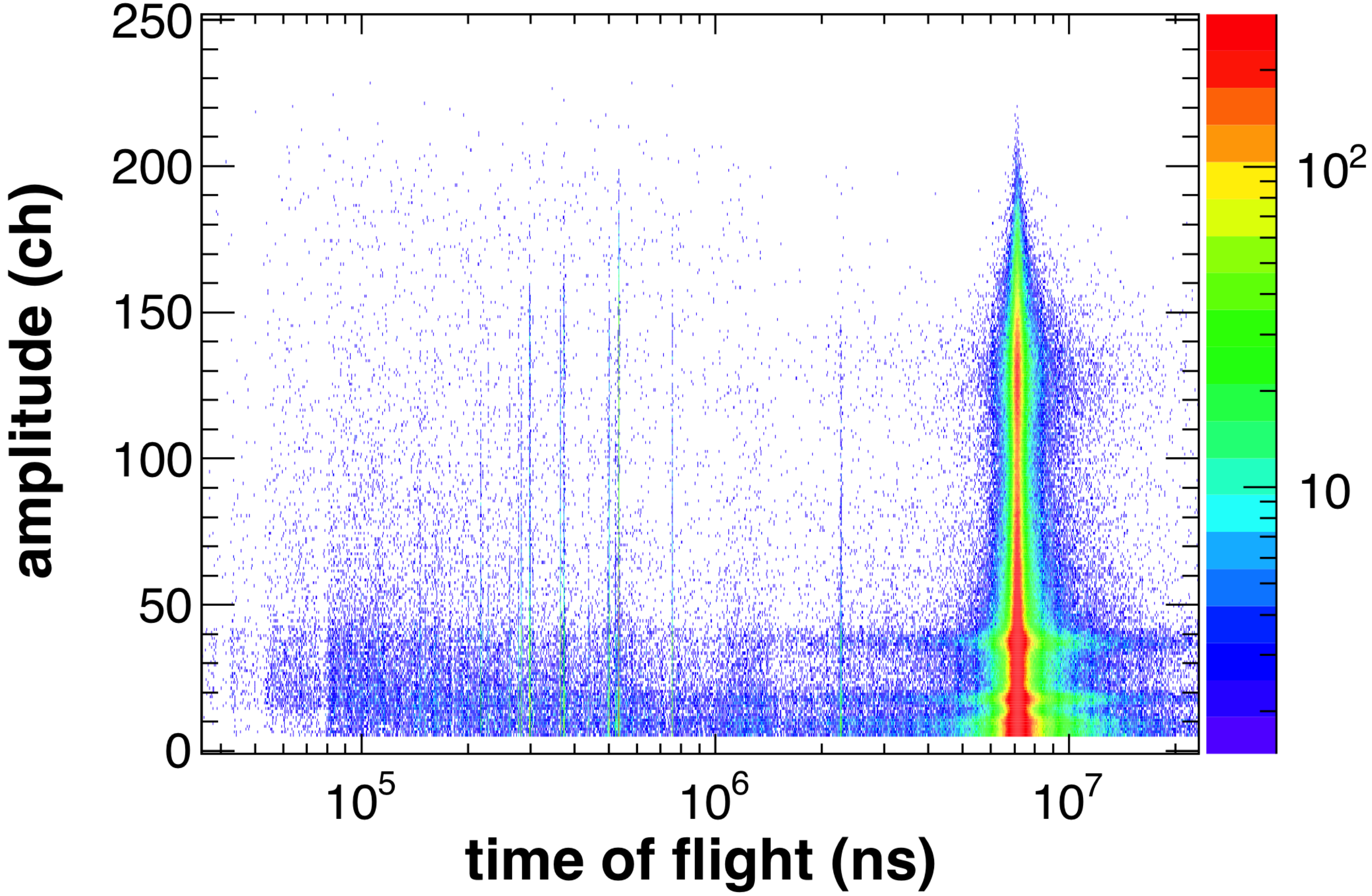




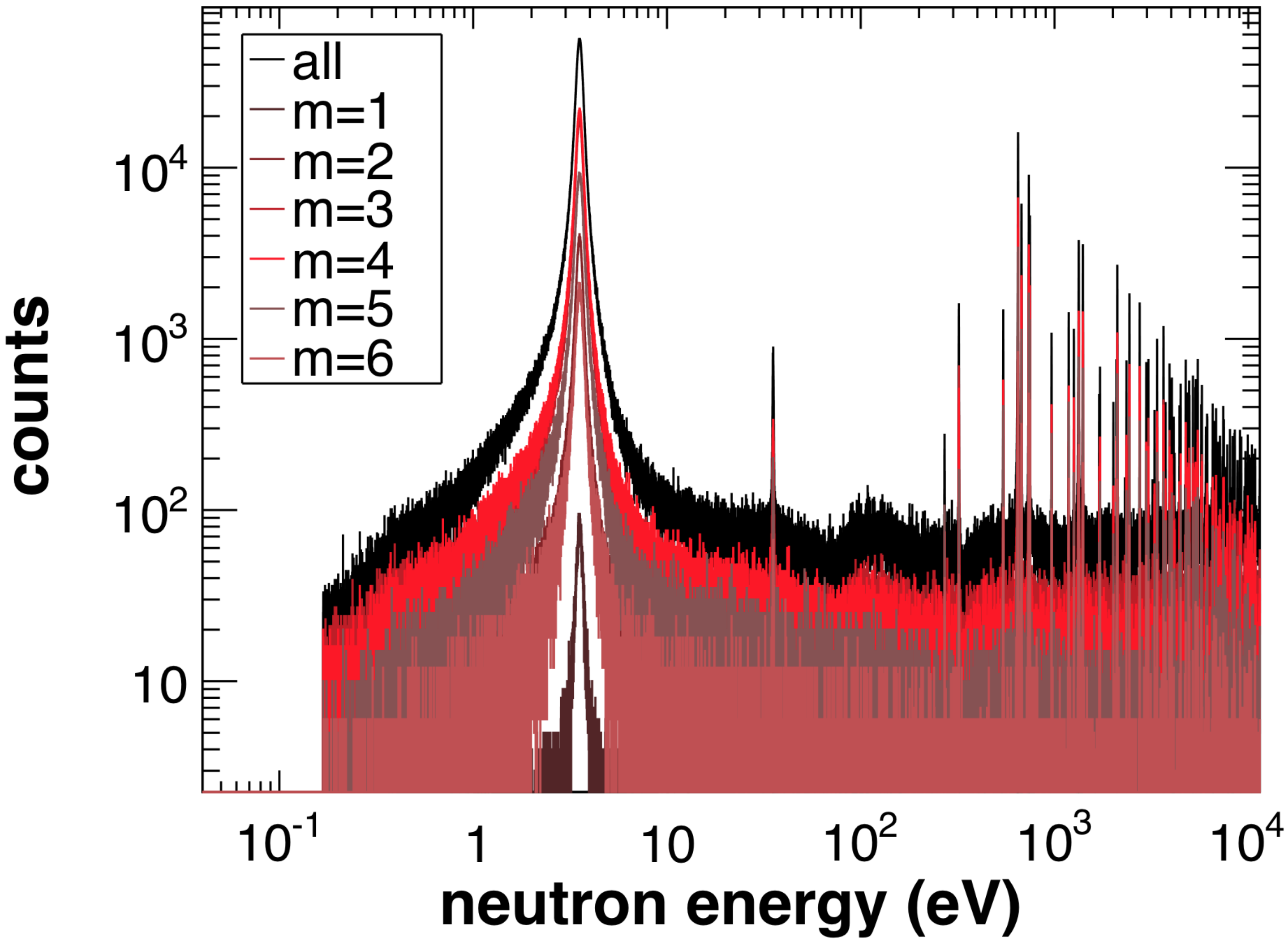


Energy deposit in BaF_2 crystals

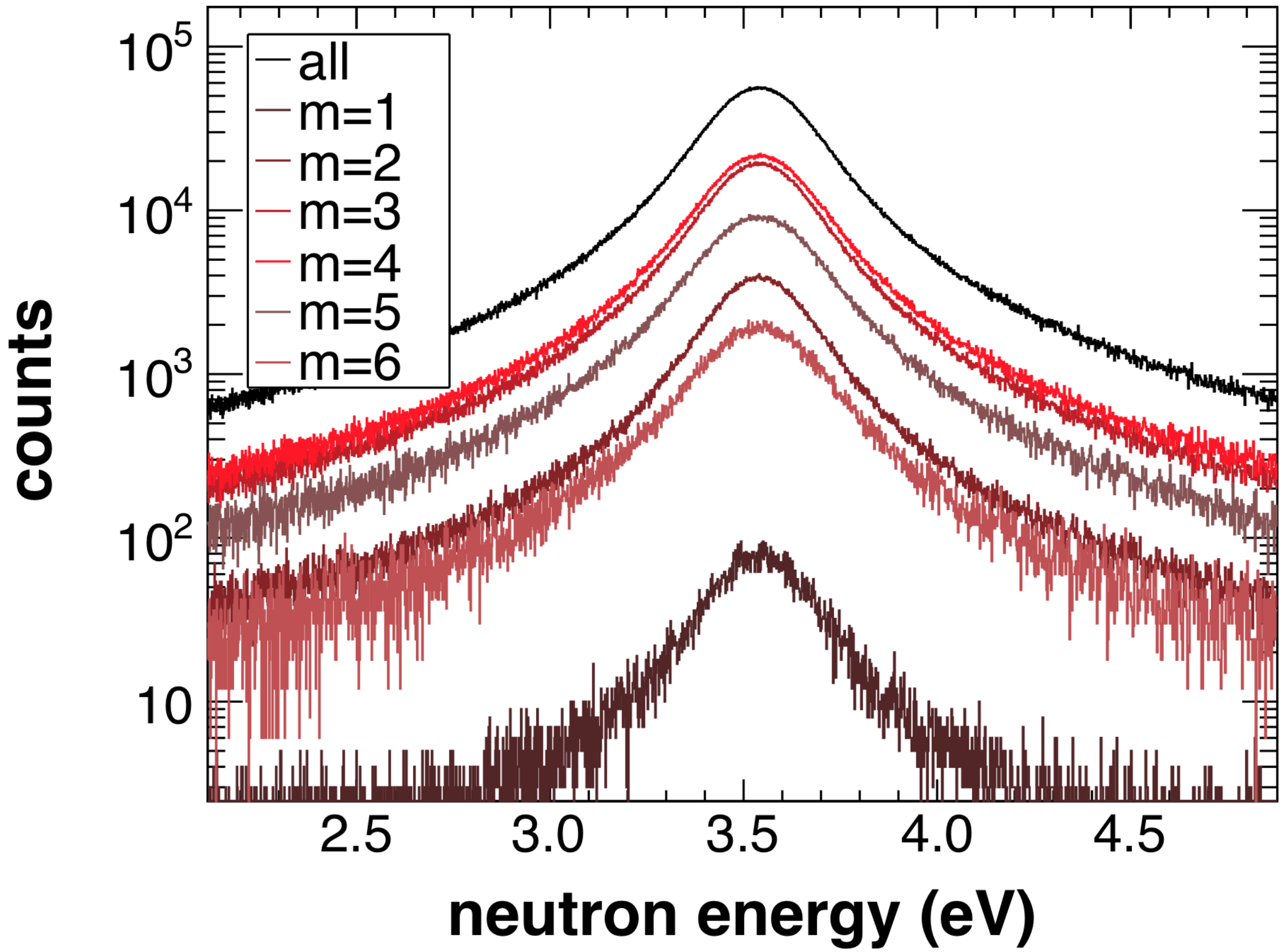
Spectrum TOF-amplitude



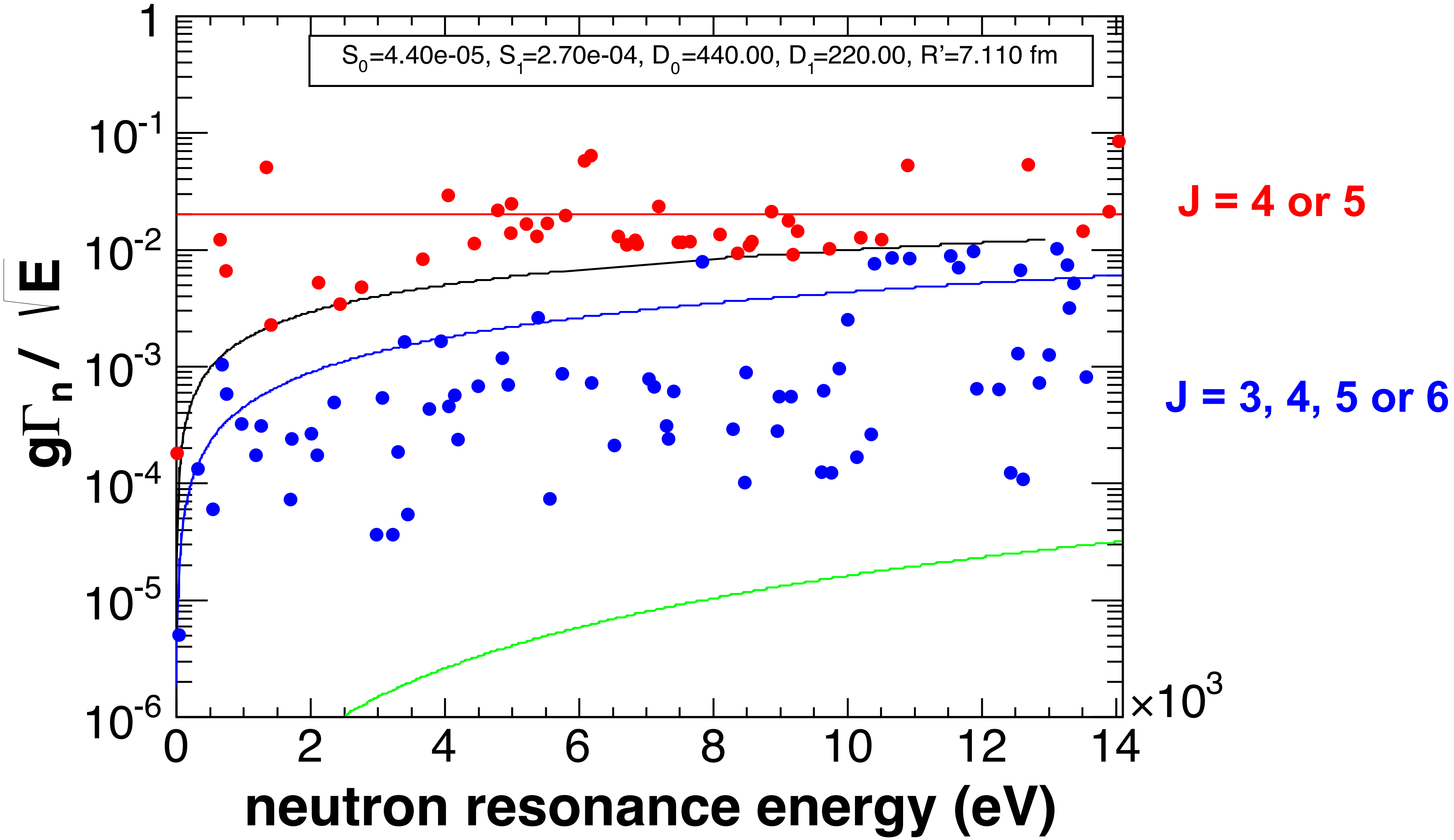
Multiplicity decomposition



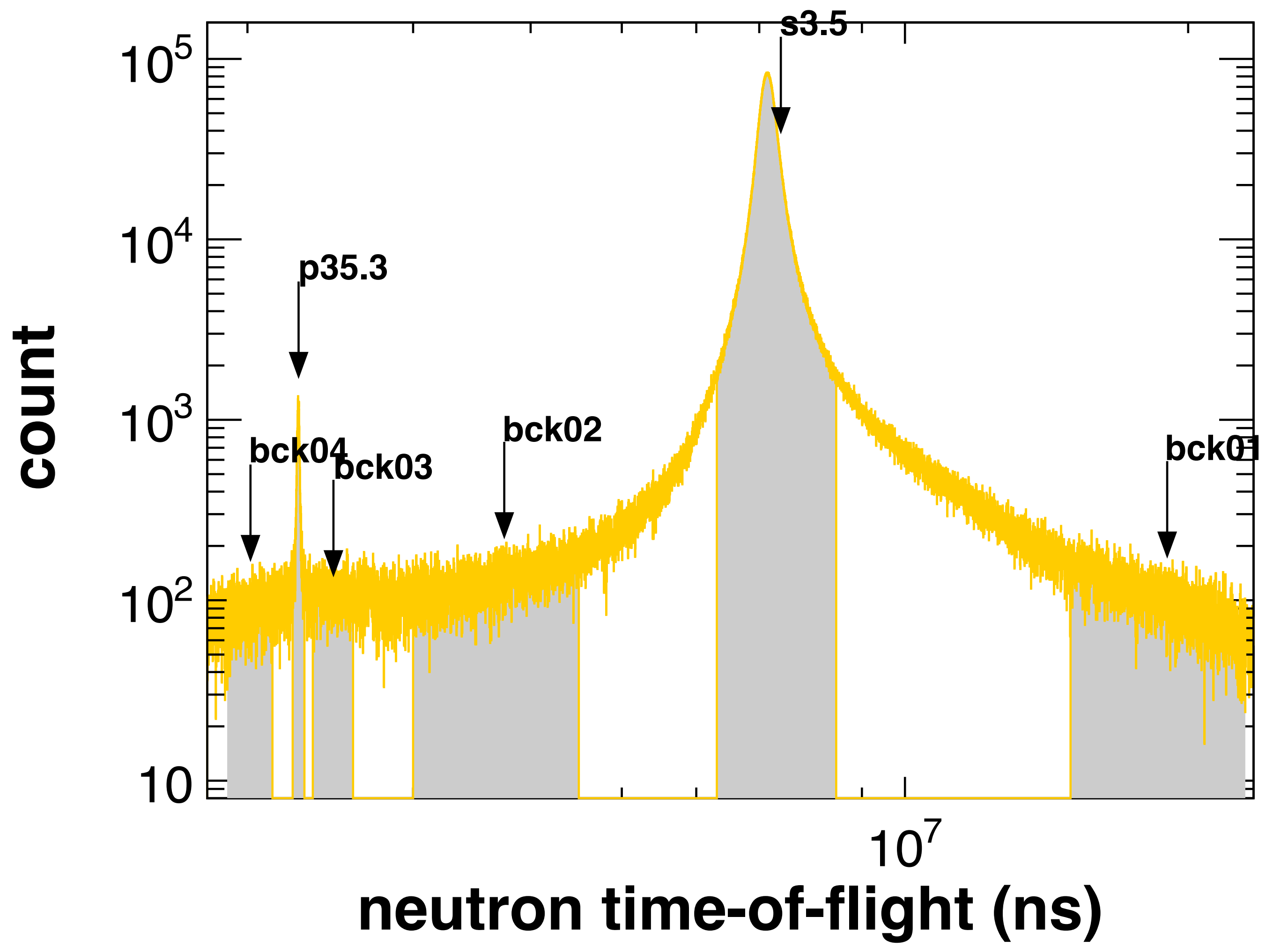
Multiplicity decomposition



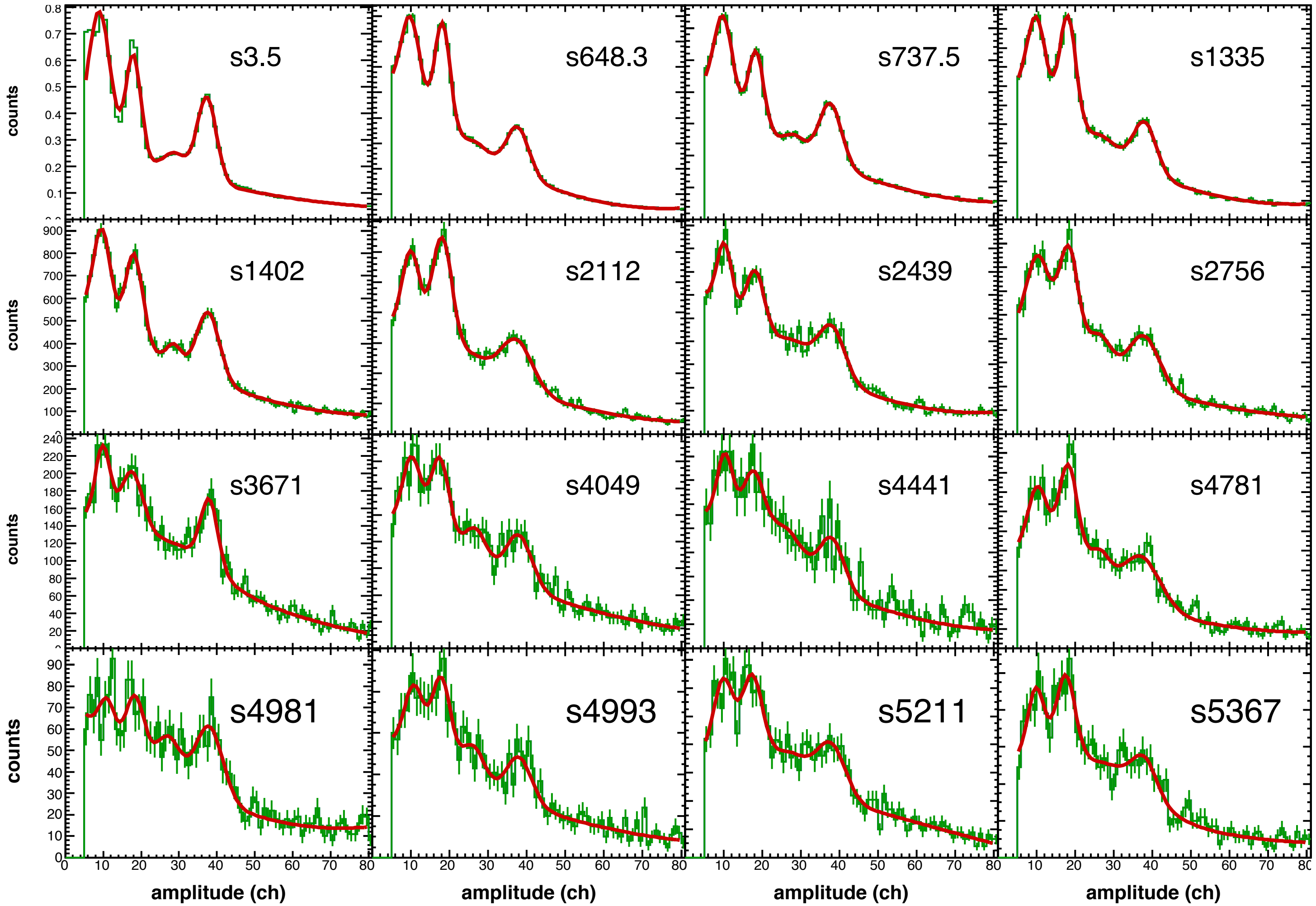
Assign orbital momentum



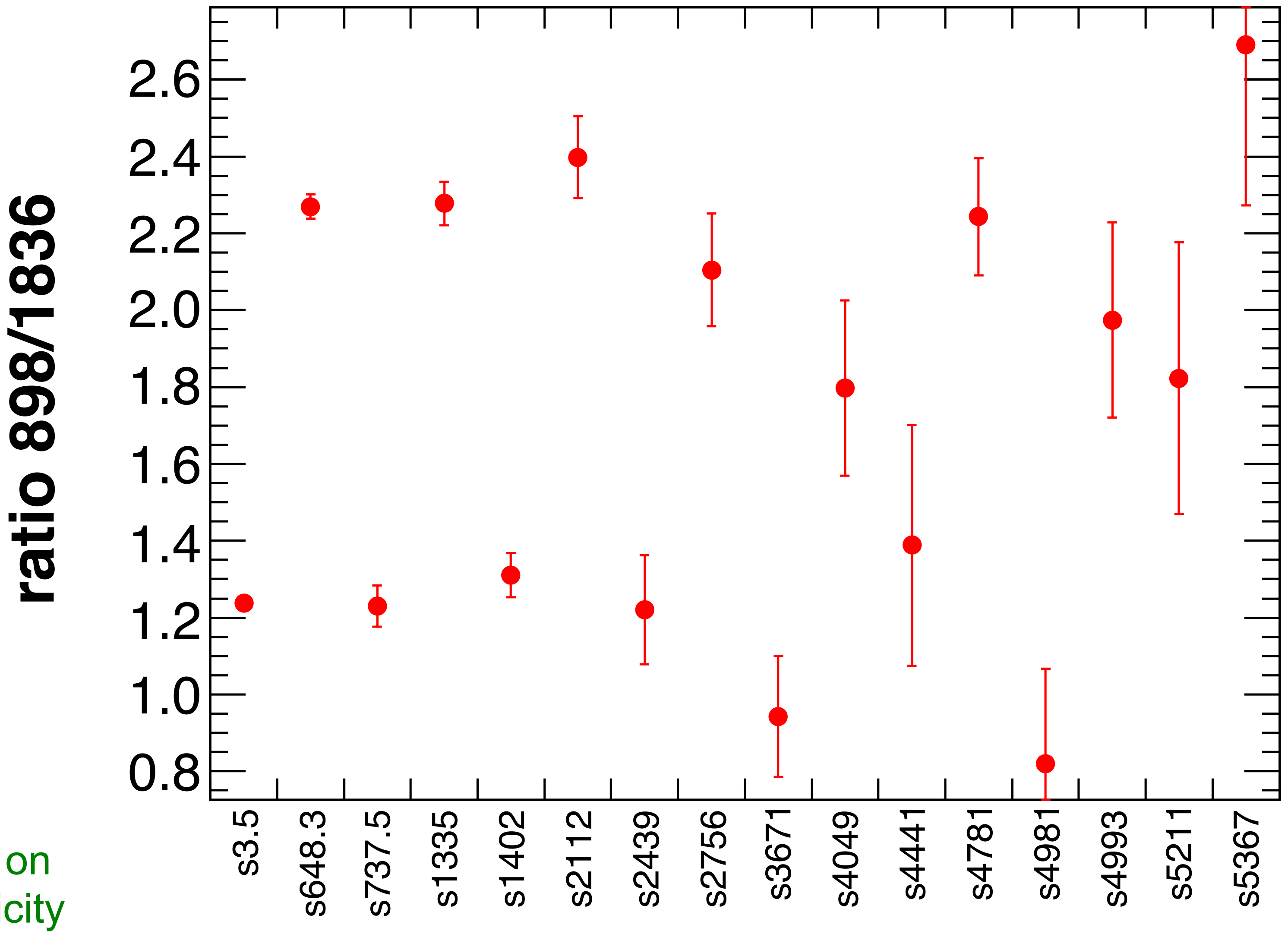
Integrate over resonances



Low-level population using pulse height spectra

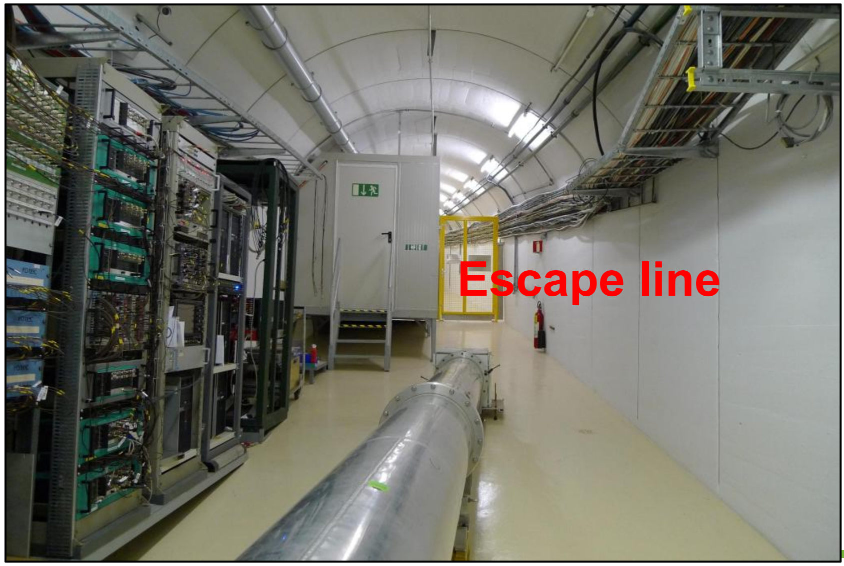


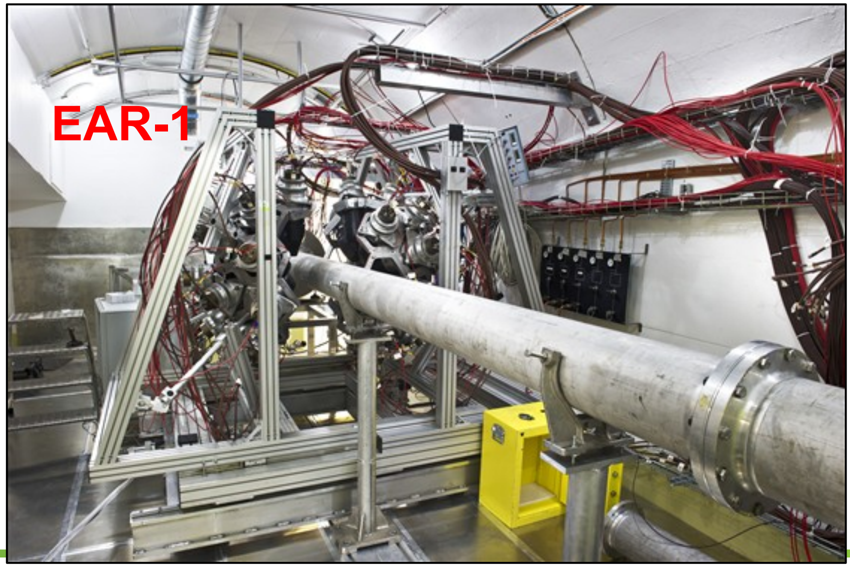
Low-level population using pulse height spectra



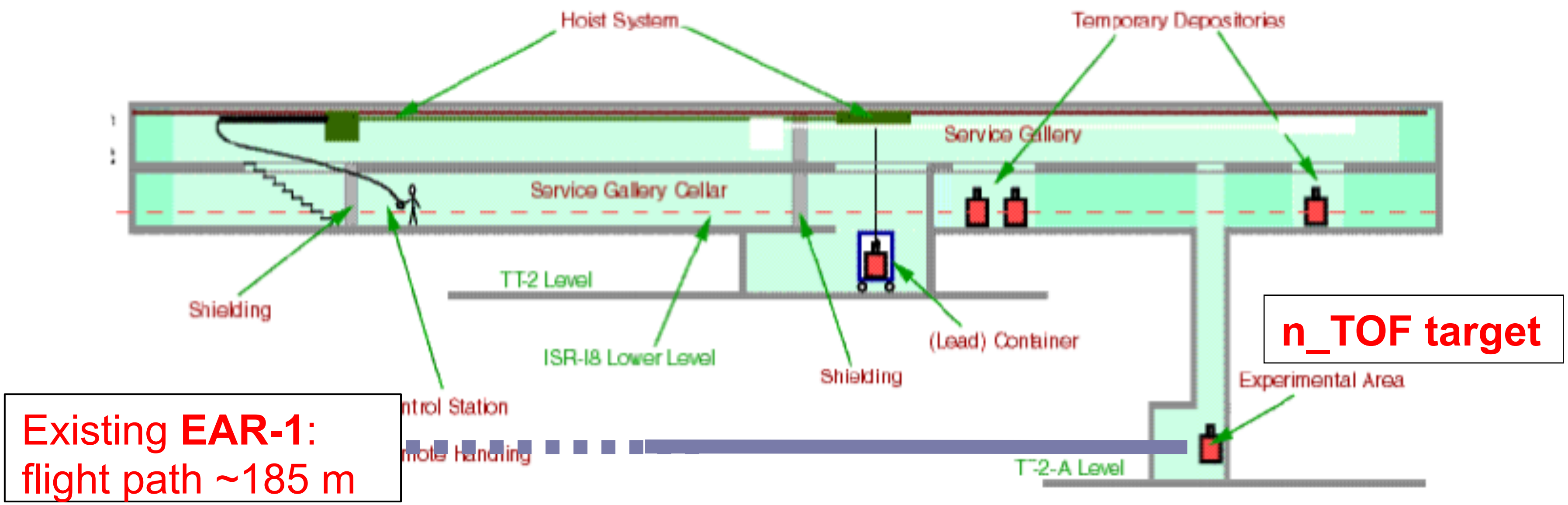
No cut on multiplicity

The n_TOF beam line EAR1



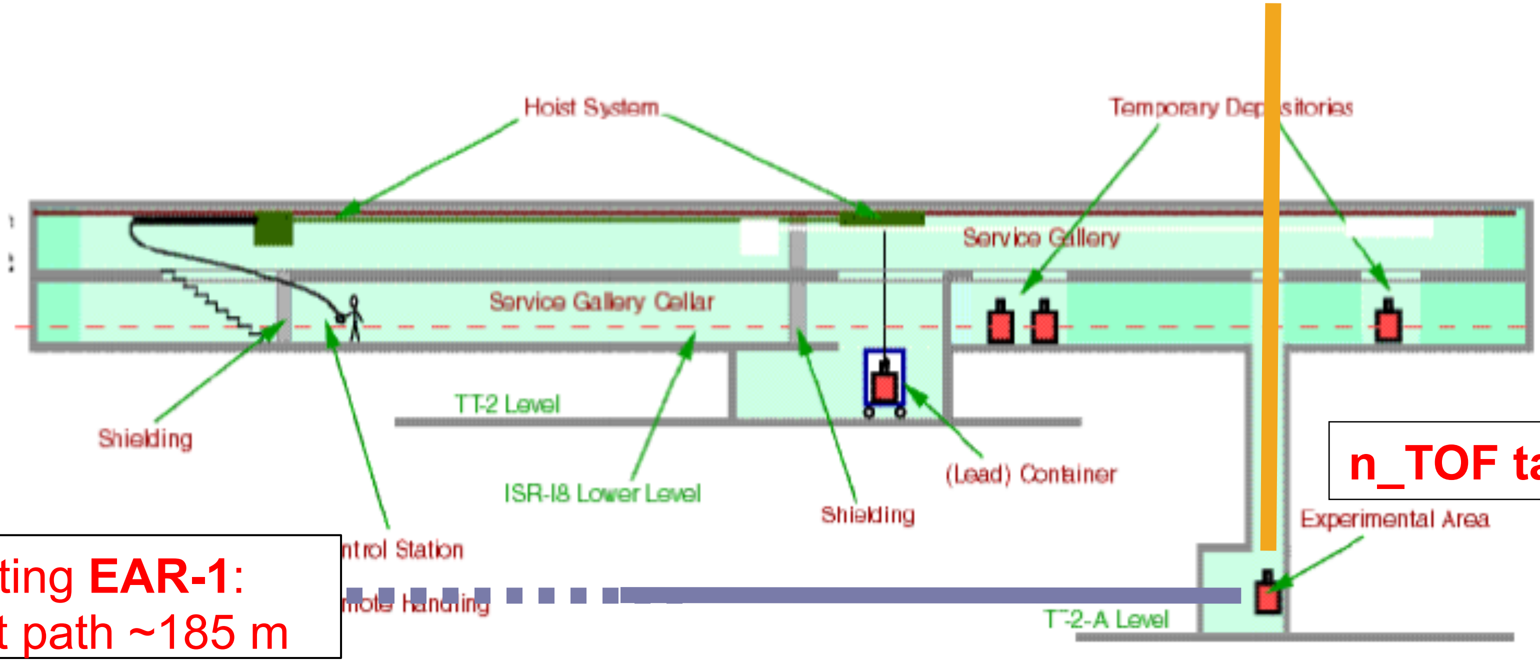


n_TOF 2nd experimental area (EAR2)



n_TOF 2nd experimental area (EAR2)

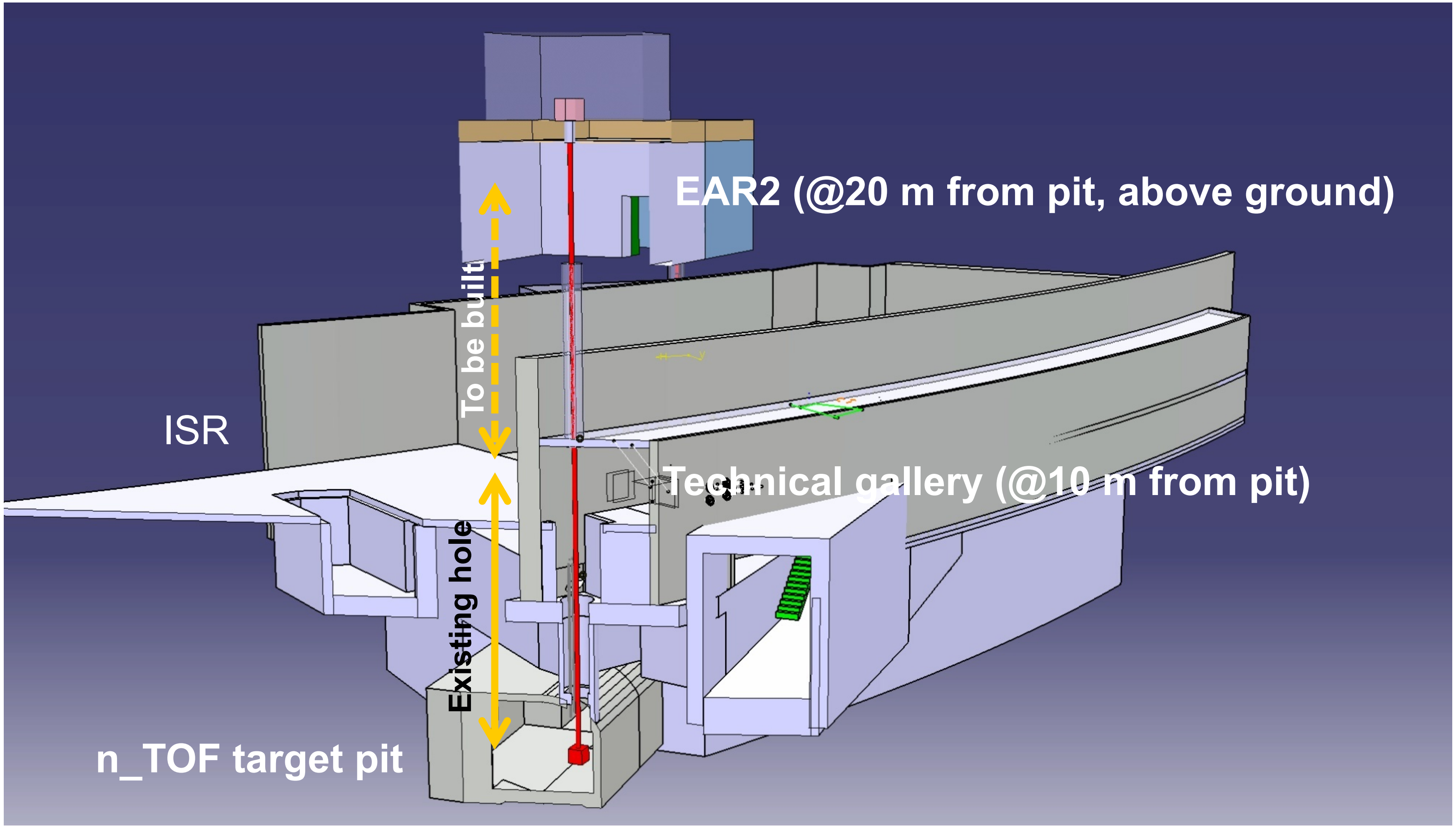
Future **EAR-2**: flight path ~20 m at 90° with respect to the proton beam



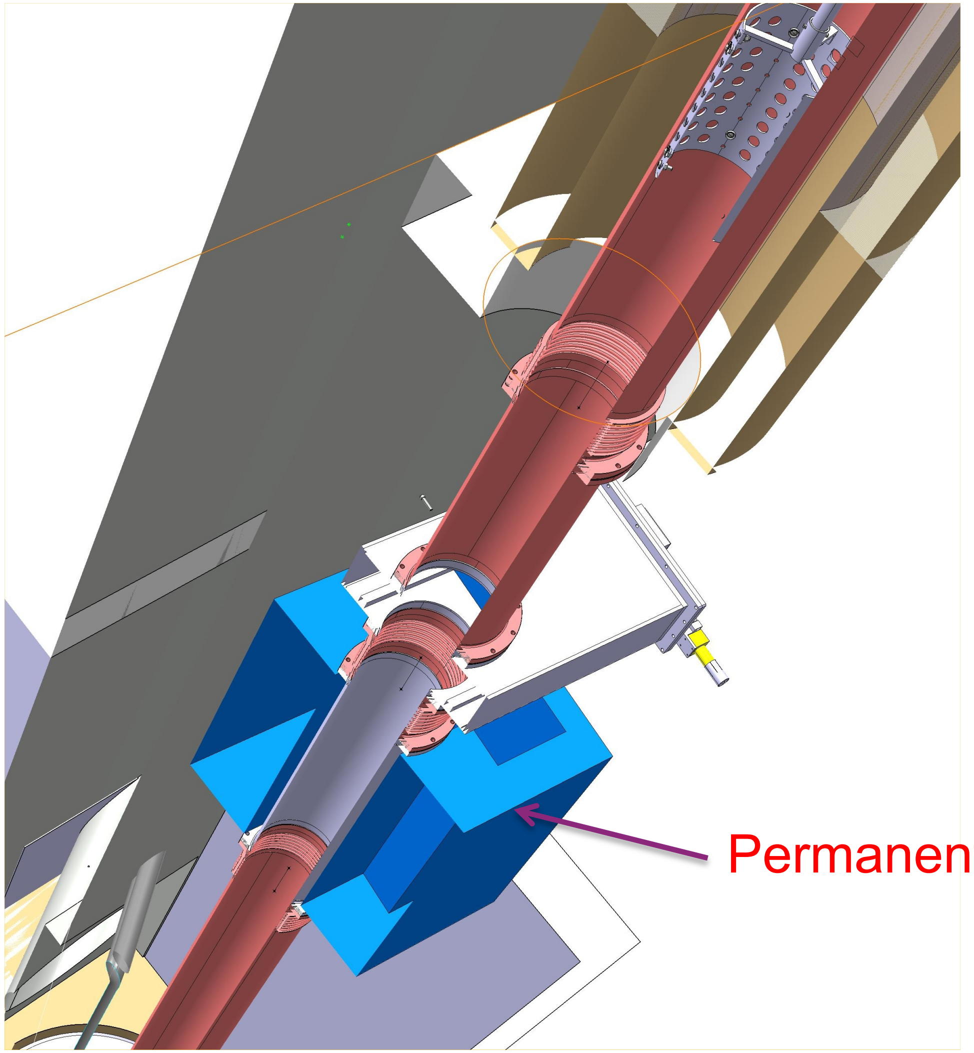
n_TOF target

Existing **EAR-1**: flight path ~185 m

The spallation target area

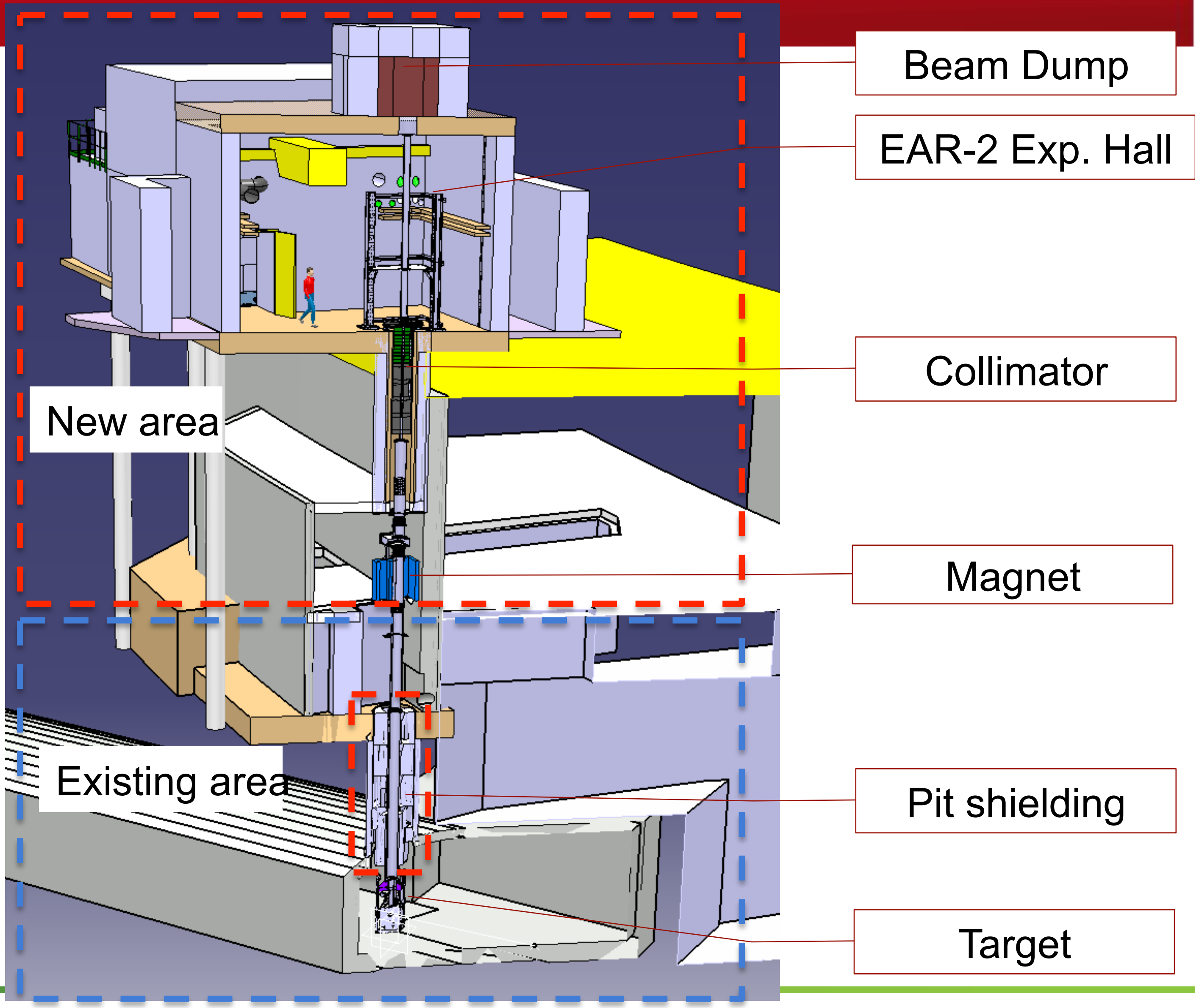


EAR2 Beam line with permanent magnet



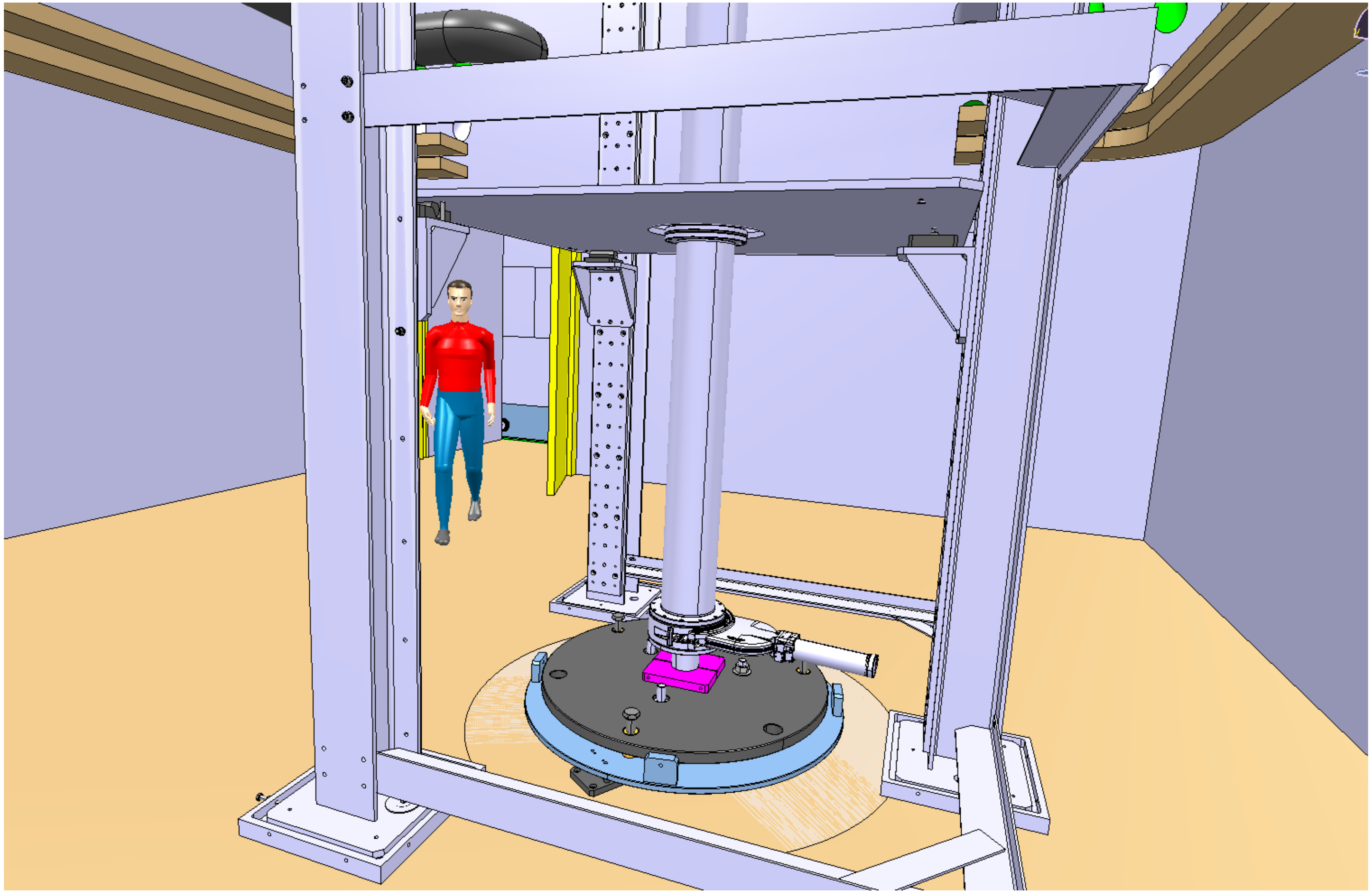
Permanent magnet

Layout EAR2

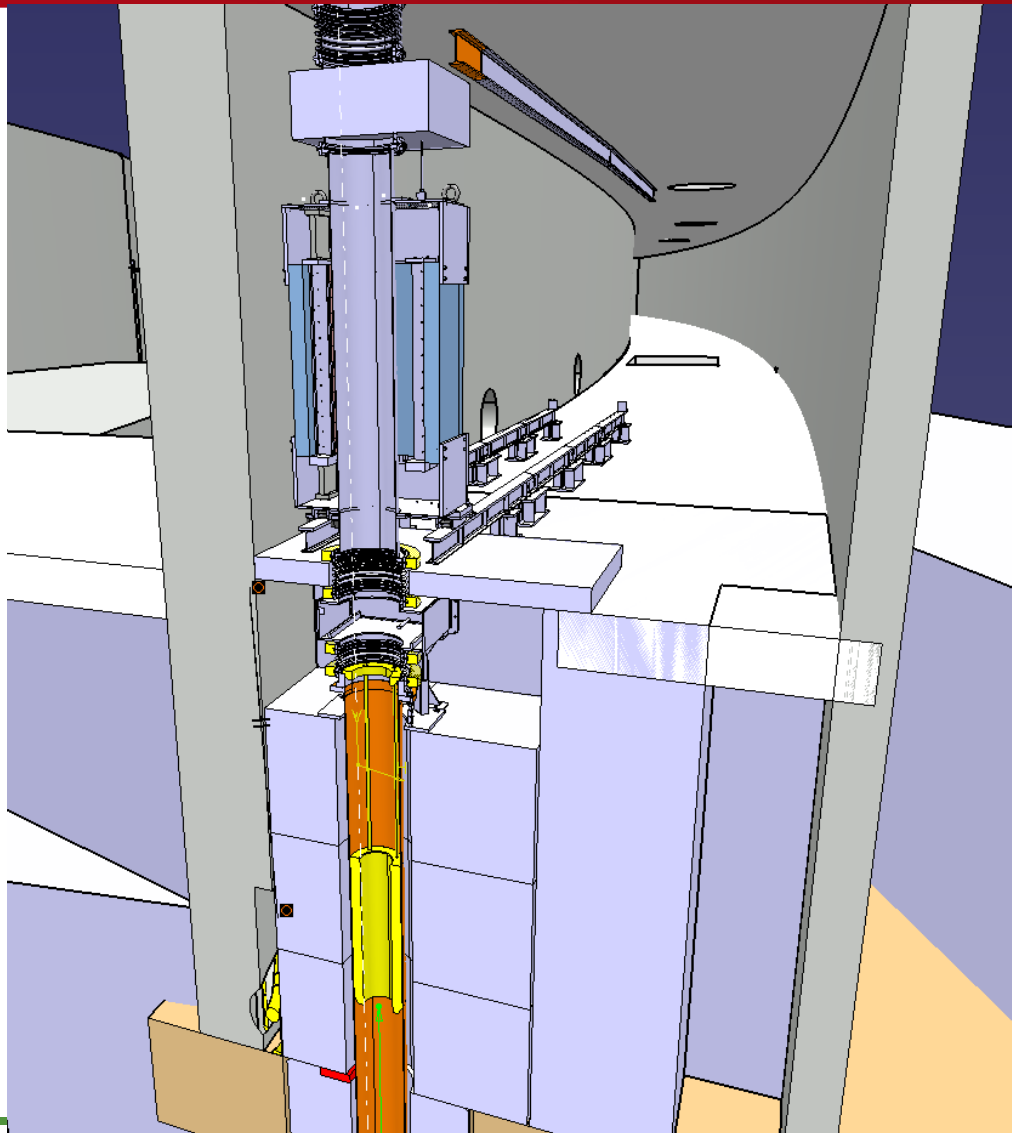


Beam Dump
EAR-2 Exp. Hall
Collimator
New area
Magnet
Existing area
Pit shielding
Target

Experimental Hall EAR2



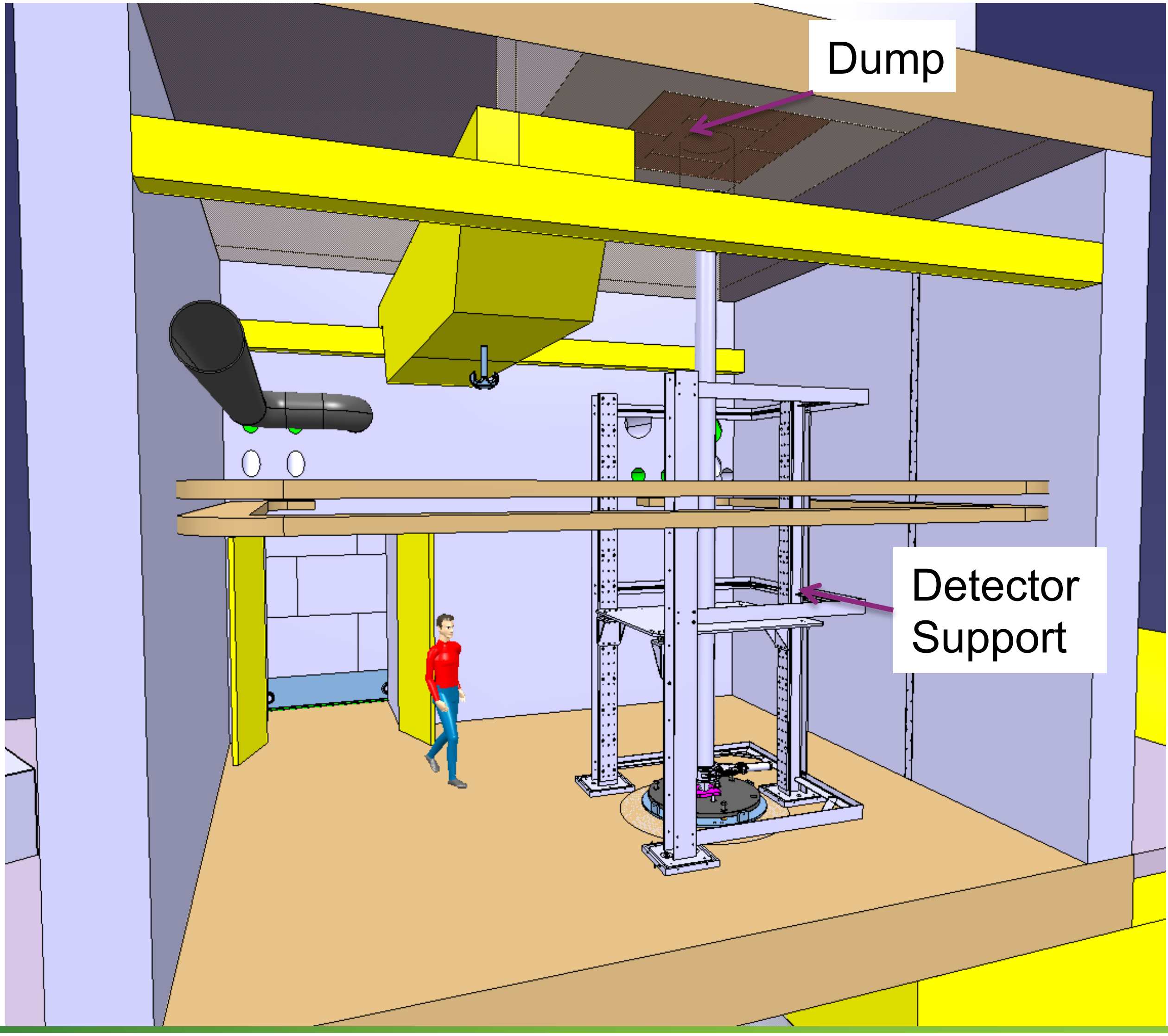
Installation of Collimator1



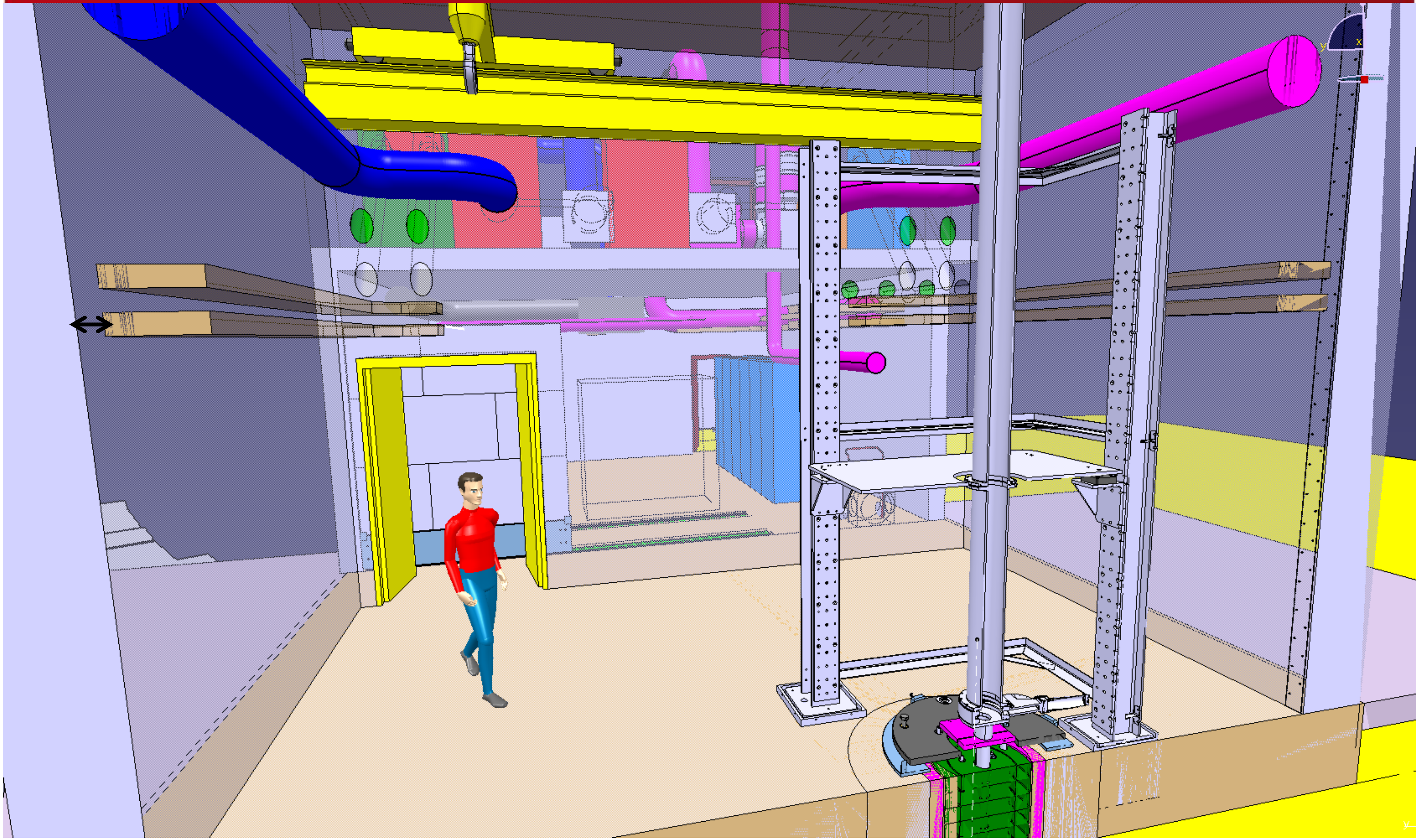
S.Girod

n_TOF Collaboration / Collaboration Board - May 2013

Experimental Hall EAR2



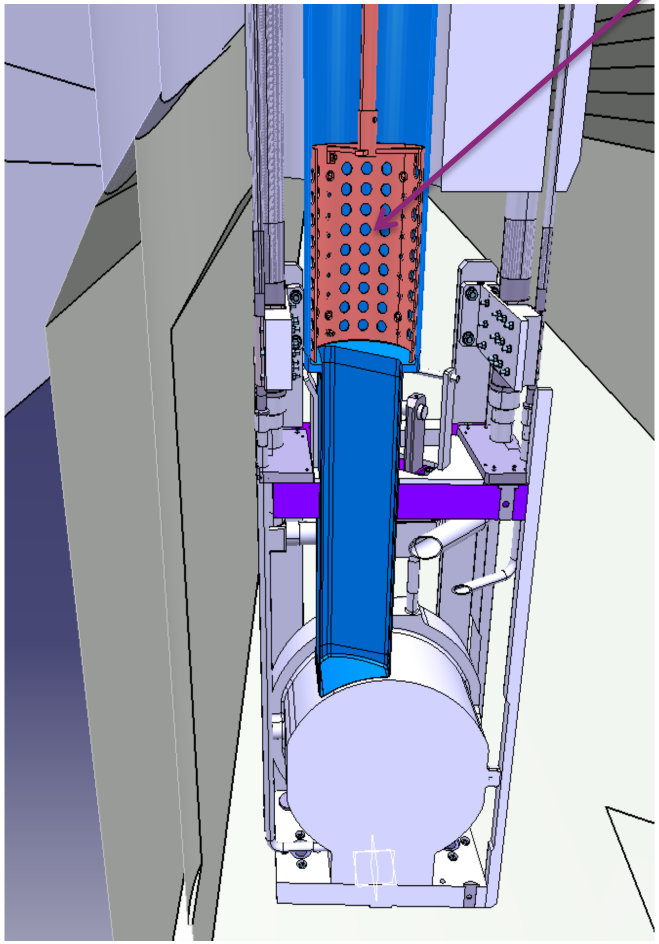
Experimental Hall EAR2

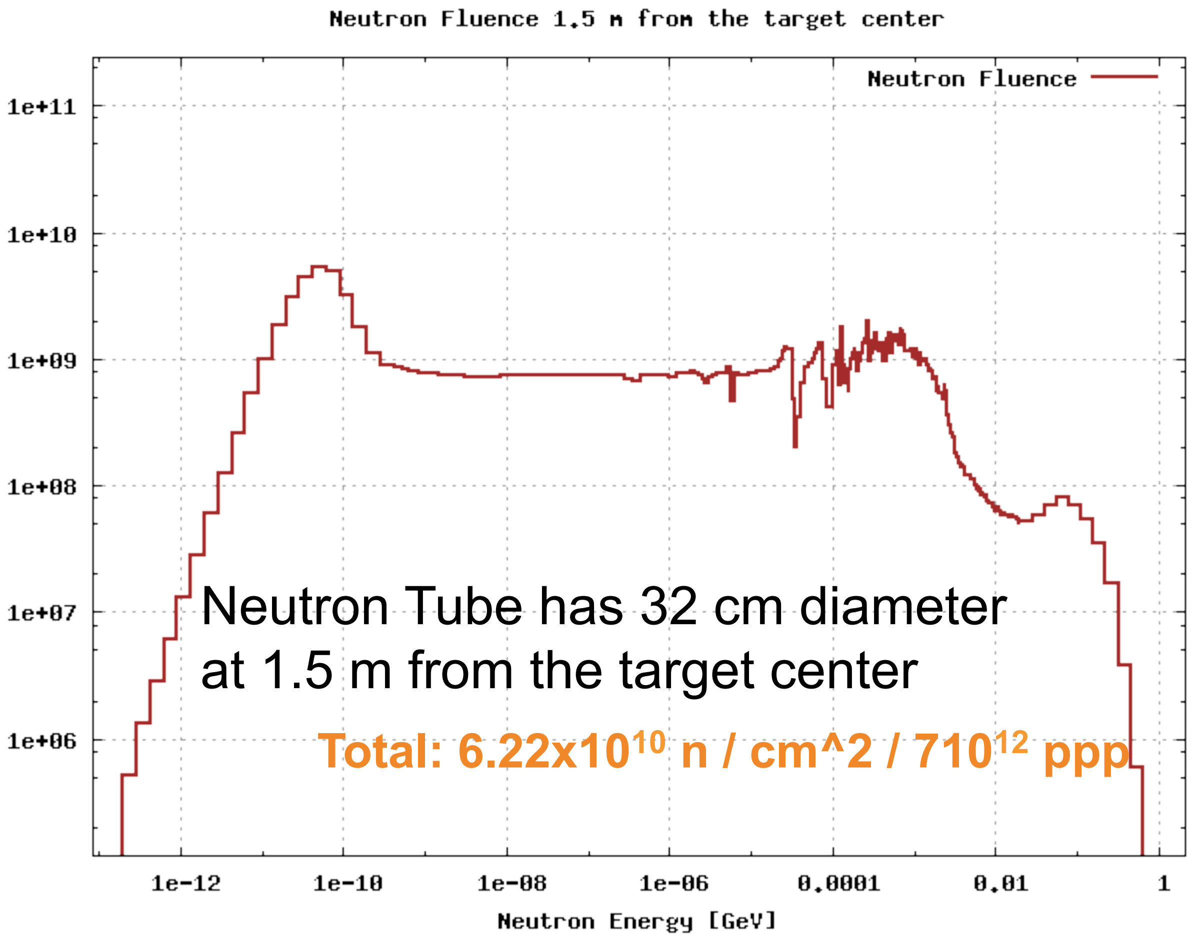


International Conference on
Nuclear Data for Science and

EAR2 material irradiation

Basket for material irradiation

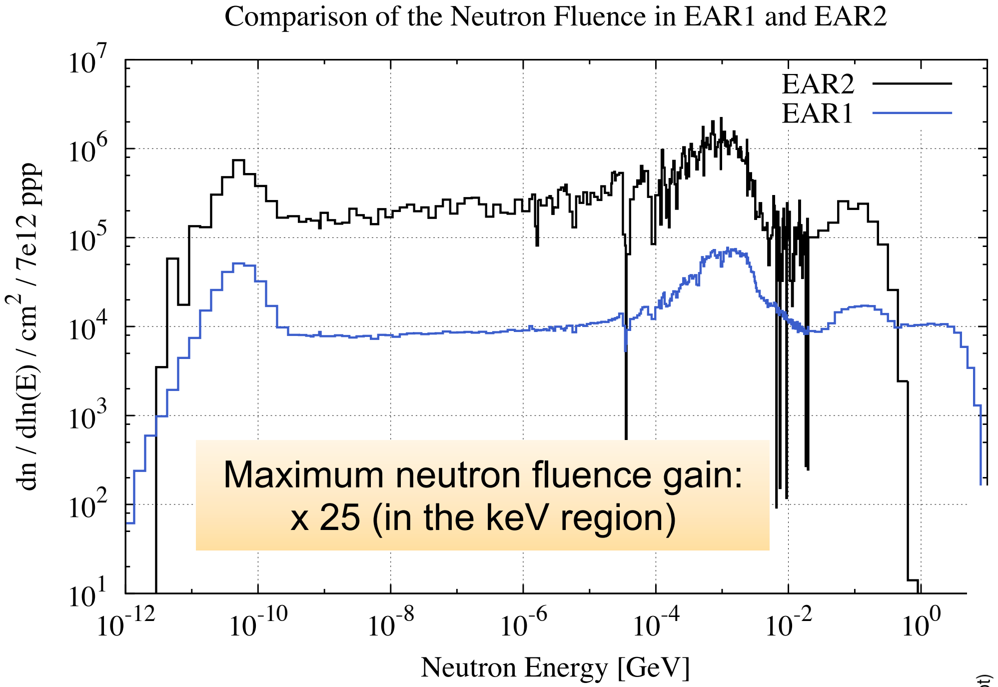




Neutron Tube has 32 cm diameter at 1.5 m from the target center

Total: 6.22×10^{10} n / cm^2 / $7 \, 10^{12}$ ppp

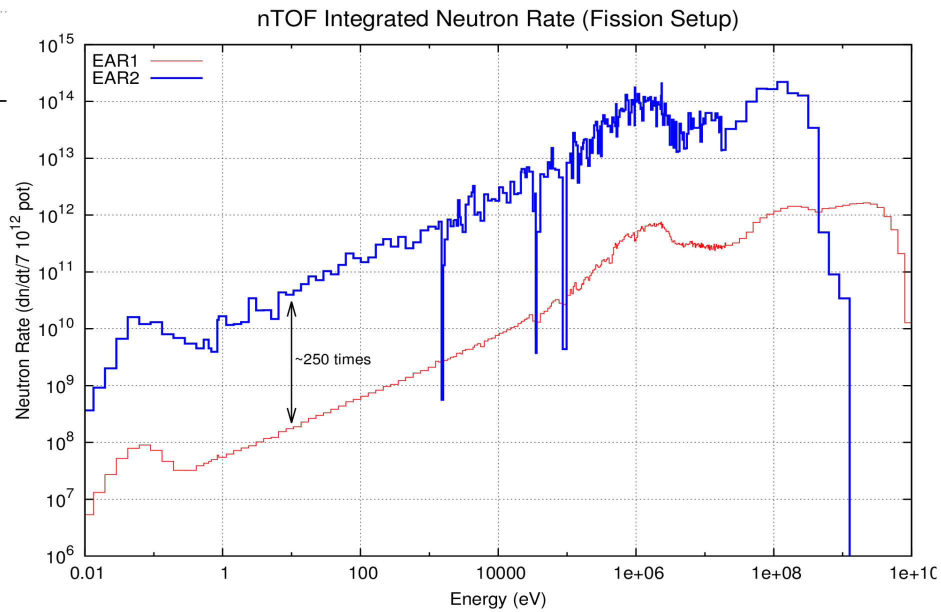
EAR2 enhanced flux



Higher flux, by a factor of 25, relative to EAR1.

The **shorter flight path** implies a factor of 10 smaller time-of-flight.

Global gain by a factor of **250 in the signal/background ratio** for radioactive isotopes!



The huge gain in signal-to-background ratio in EAR2 allows to measure radioactive isotopes with **half lives as low as a few years.**

n_TOF Collaboration

- The n_TOF Collaboration operates the facility since 2001.

- Members as of 2012 (not necessarily CERN member states):
  - 33 Institutions (EU, USA, India) + coll. with Japan and Russia
  - 100 scientists
  - 16 PhD students

- From July 2014, after the planned beam stop, n_TOF will take data again from, simultaneously in EAR1 (185 m) and EAR2 (20 m)

Thank you for your attention.

The n_TOF Collaboration

E. Chiaveri, S. Andriamonje, J. Andrzejewski, L. Audouin, V. Avrigeanu, M. Barbagallo, V. Bécares, F. Bečvář, F. Belloni, E. Berthoumieux, J. Billowes, D. Bosnar, M. Brugger, M. Calviani, F. Calviño, D. Cano-Ott, C. Carrapiço, F. Cerutti, M. Chin, N. Colonna, G. Cortés, M.A. Cortés-Giraldo, M. Diakaki, I. Dillmann, C. Domingo-Pardo, I. Duran, N. Dzysiuk, C. Eleftheriadis, M. Fernández-Ordóñez, A. Ferrari, K. Fraval, S. Ganesan, Y. Giomataris, G. Giubrone, M.B. Gómez-Hornillos, I.F. Gonçalves, E. González-Romero, F. Gramegna, E. Griesmayer, C. Guerrero, F. Gunsing, M. Heil, D.G. Jenkins, E. Jericha, Y. Kadi, F. Käppeler, D. Karadimos, P. Koehler, M. Kokkoris, M. Krtička, J. Kroll, Ch. Lampoudis, C. Lederer, H. Leeb, L.S. Leong, R. Losito, M. Lozano, A. Manousos, J. Marganiec, T. Martinez, C. Massimi, P.F. Mastinu, M. Mastromarco, M. Meaze, E. Mendoza, A. Mengoni, P.M. Milazzo, M. Mirea, W. Mondelaers, Th. Papaevangelou, C. Paradela, A. Pavlik, J. Perkowski, A. Plompen, J. Praena, J.M. Quesada, T. Rauscher, R. Reifarth, A. Riego, F. Roman, C. Rubbia, R. Sarmento, P. Schillebeeckx, G. Tagliente, J.L. Tain, D. Tarrìo, L. Tassan-Got, A. Tsinganis, S. Valenta, G. Vannini, V. Variale, P. Vaz, A. Ventura, M.J. Vermeulen, V. Vlachoudis, R. Vlastou, A. Wallner, T. Ware, C. Weiß, T.J. Wright

More information: www.cern.ch/ntof