Experimental Uncertainties

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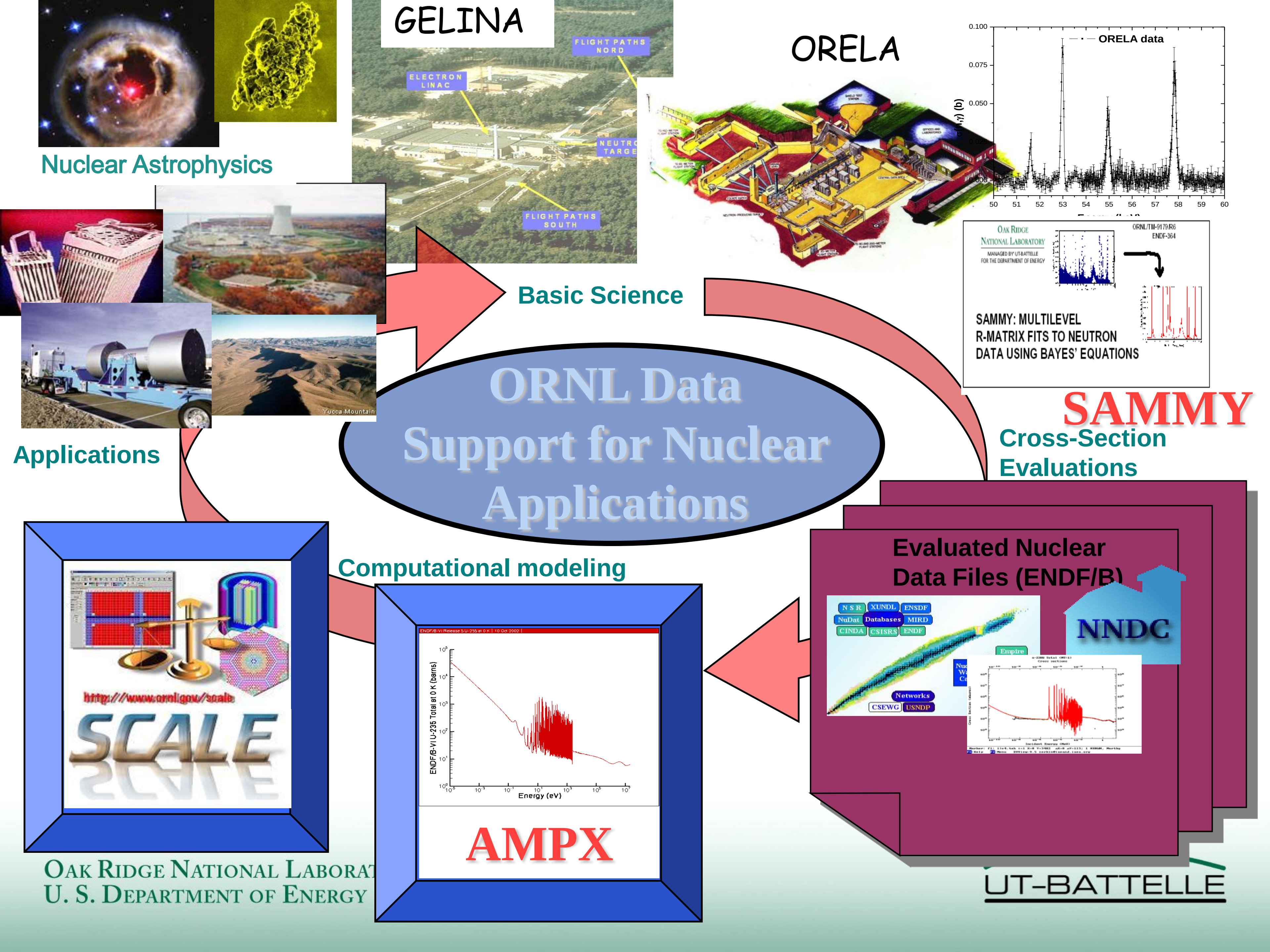

GELINA
FLIGHT PATHS NORD
ELECTRON LINAC
FLIGHT PATHS SOUTH
ORELA
ORELA data
Nuclear Astrophysics
Basic Science
OAK RIDGE NATIONAL LABORATORY
ORNL/TM-9179/R6
ENDF-364
SAMMY: MULTILEVEL R-MATRIX FITS TO NEUTRON DATA USING BAYES' EQUATIONS
SAMMY
Applications
ORNL Data Support for Nuclear Applications
Cross-Section Evaluations
Evaluated Nuclear Data Files (ENDF/B)
NSR
XUNDL
ENSDF
NuDat
Databases
MIRD
CINDA
CSISRS
ENDF
Empire
Networks
CSEWG
USNDP
NNDC
Computational modeling
http://www.ornl.gov/scale
SCALE
Energy (eV)
AMPX
OAK RIDGE NATIONAL LABORAT
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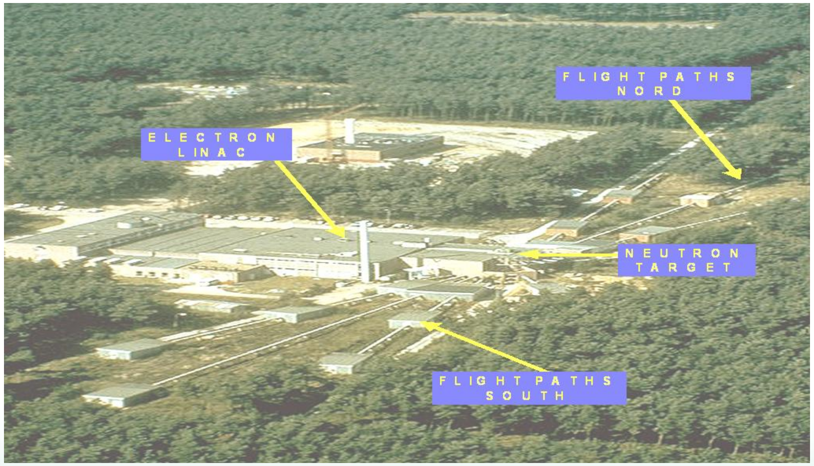
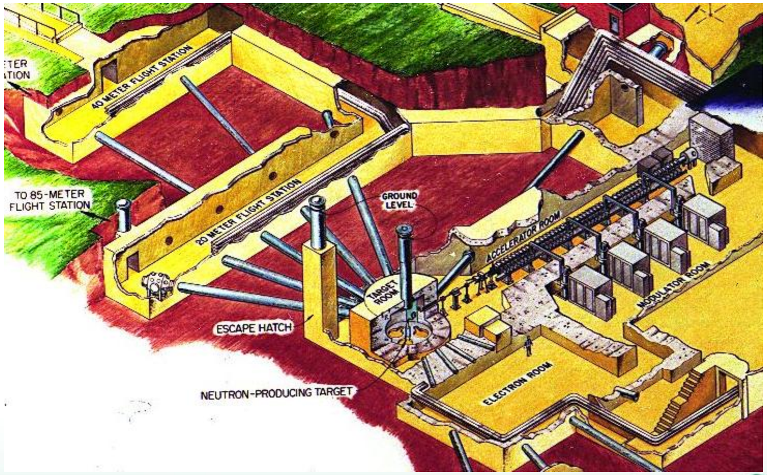
Experimental Techniques

Type	White Source	Monoenergetic
Facilities	Van de Graaff, Electron and Proton Linacs, Lead Slowing-Down Spectrometer	Van de Graaff, Reactor, Electron Linac
Pros	All energies at once. Wide energy range. Moderate to high flux. Excellent to modest resolution. Simultaneous experiments. More information (e.g. resonance parameters).	High flux. Simpler experiments. Activation and quasi-Maxwellian spectrum possible.
Cons	Backgrounds may be more troublesome: γ-flash, neutron sensitivity and other sample-dependent backgrounds. More complicated analysis.	Only one energy and one experiment at a time. Poor or no resolution.

Ingredients for Cross Section Measurements

- Neutron source (spallation or e^- driven)
- Sample (oxide compounds problematic, stoechiometrie of the sample)
- Flux monitor (Standard Cross Section)
- Detector (Efficiency, PHW, Backgrounds)
- Normalization (Standards, Au, Fe, ^{235}U, …)





Cross-Section Measurement Facilities

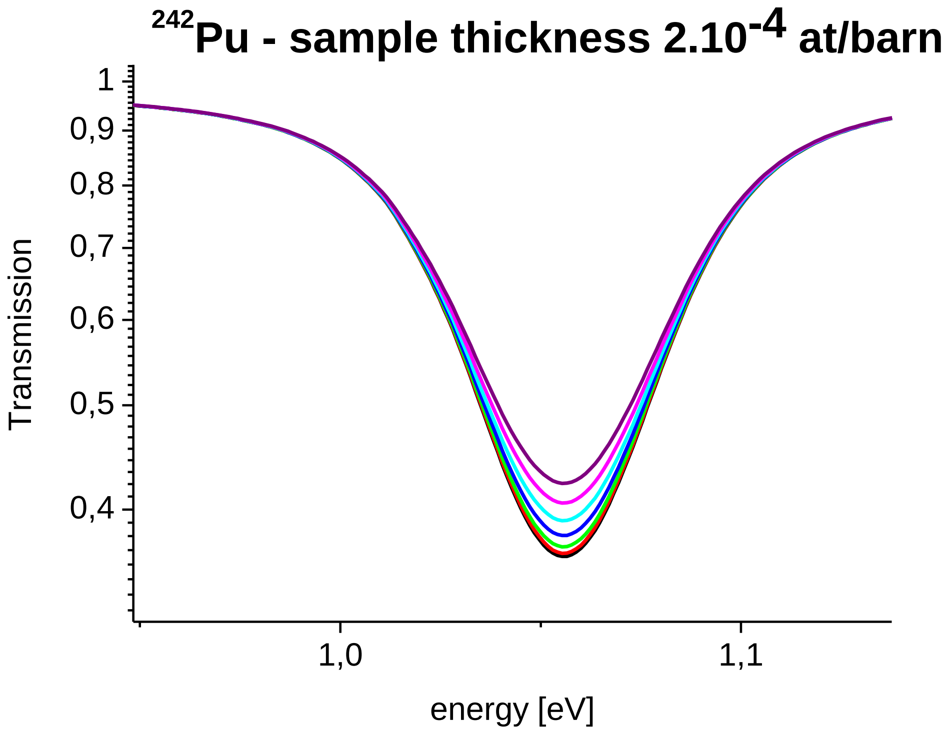
Facility Parameters	United States				Europe	
	ORELA	LANSCE	IPNS	RPI	GELINA	n_TOF
Source	e^- linac	p spallation	p spallation	e^- linac	e^- linac	p spallation
Particle E (MeV)	140	800	450	>60	120	20000
Flight Path (m)	10-200	7-55	~6-20	10-250	8-400	185
Pulse Width (ns)	2-30	125	70-80	15-5000	1-2000	7
Max Power (kW)	50	64	6.3	>10	11	45
Rep Rate (Hz)	1-1000	20	30	1-500	Up to 900	0.278-0.42
Best Intrinsic Resolution (ns/m)	0.01	3.9	3.5	0.06	0.0025	0.034
Neutrons/s	1×10^{14}	7.5×10^{15}	8.1×10^{14}	4×10^{13}	3.2×10^{13}	8.1×10^{14}

Samples I

- Usually enriched isotopes are used in gram size quantities. Inventory form in most cases oxides, sometimes other compounds (e.g. ^{41}KCl).
- Oxide are problematic, since produce unwanted background due to neutron scattering. Difficult to correct, was source of error in old experiments. Oxide are hygroscopic, e.g. do you have $Sm(OH)_3$ or Sm_2O_3.
- Metallic samples are preferred.
- Surface quality.

Samples II

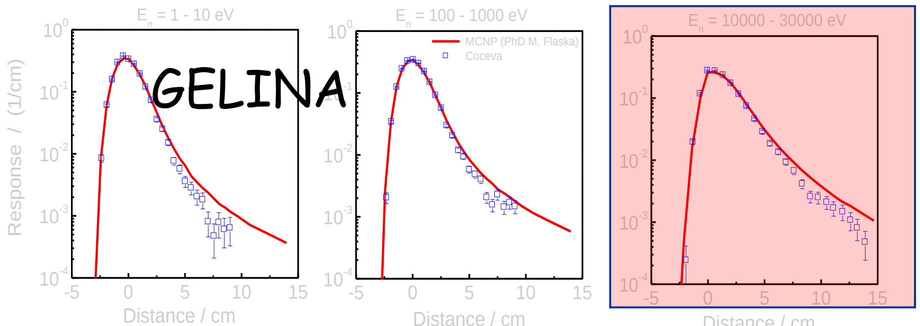
- Thin powder samples are problematic.
  - Uniformity
  - Stability
- Thickness distribution
- Homogeneity of mixtures with other material.

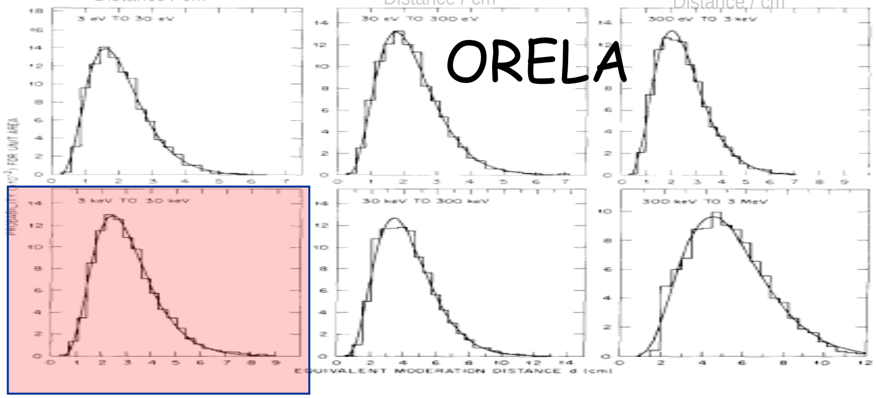


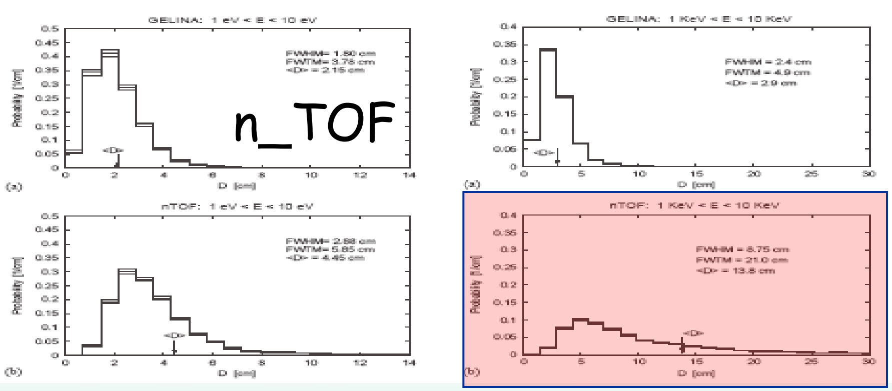
σ of thickness distribution is varied between 0 to 0.6 in steps of 0.1

Kopecky et al. ND2007

Moderation Distance Distribution

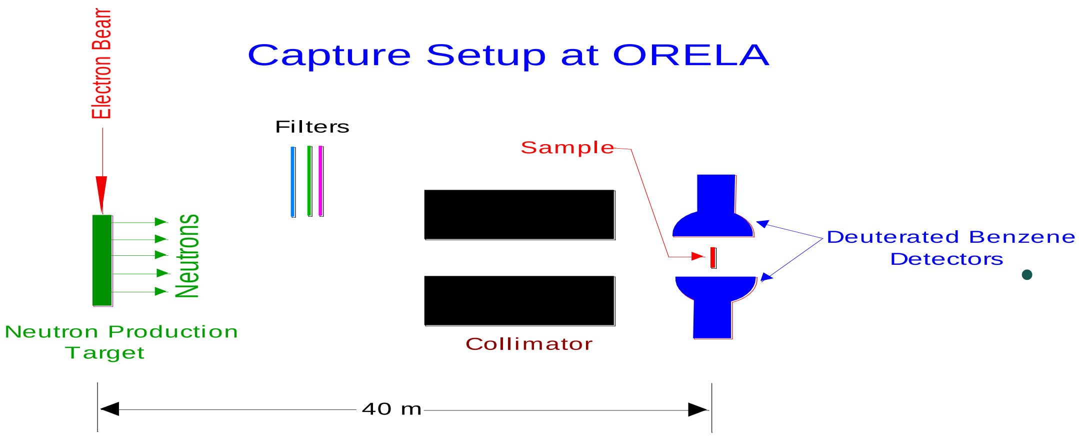


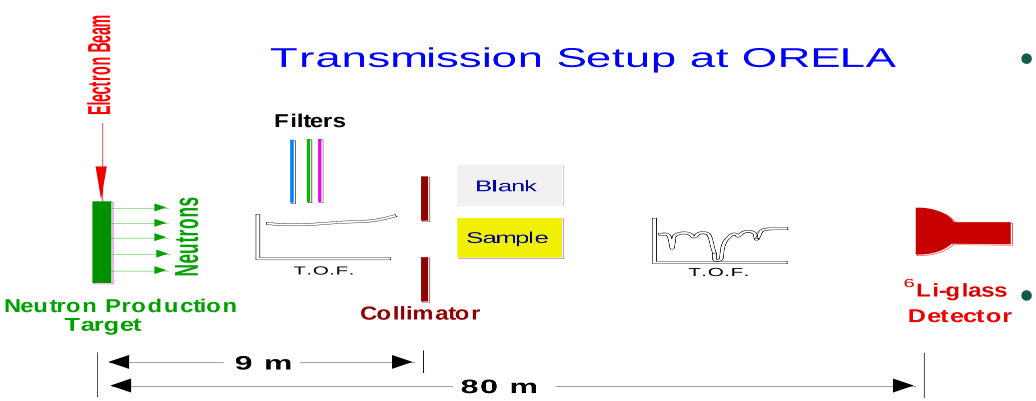




- The uncertainty of the creation location of the neutron inside the moderator has to be taken into account for the resolution function.
- This can be quite sizeable for large target and moderator assemblies.
- The effect is that it will put tail on the resonances in the resolved neutron energy region.
- Additionally it will produce a back-ground in the unresolved region which can not be corrected for.
- This effect is of the order of 16% for 20 keV (Coceva et al. 2002) for n_TOF and can not be estimated quantitatively.

Neutron Capture and Total Cross Section Experiments at ORELA

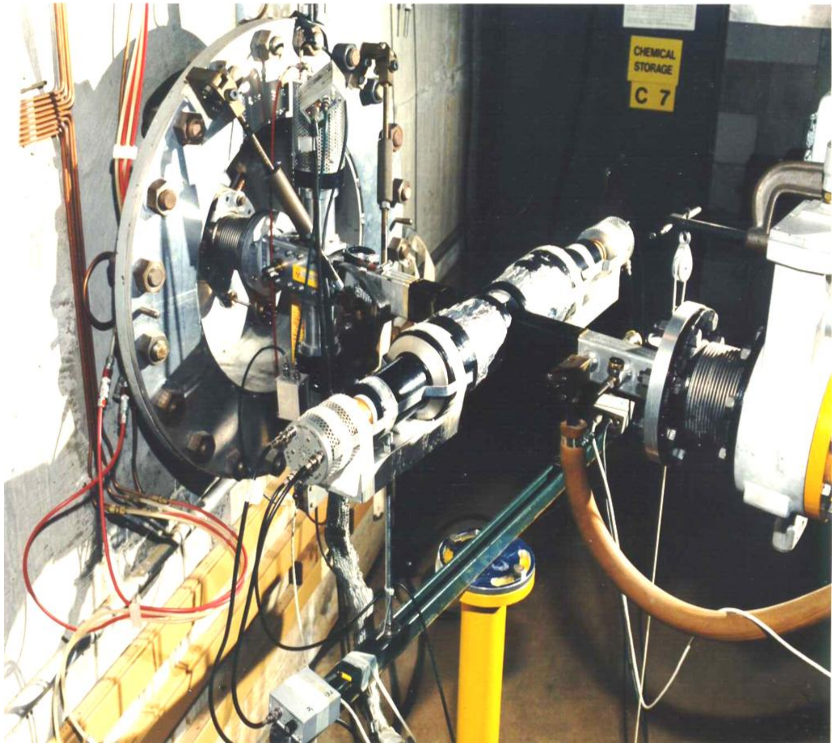




- Time-of-flight technique used to determine incident neutron energy. "Clocks" used have typically 1nsec resolution.
- Pulsed electron beam starts clock. γ-ray or neutron detector stops clock.
- $v_n = L/t$
  $E_n = m_n v^2/2$
- Filters used to reduce frame-overlap background from low-energy neutrons and to reduce γ-flash effects.

Neutron capture 40m FP

- C_6D_6 detectors using Pulse-Height-Weighting technique.
- Flux monitor 1mm ^{6}Li glass
- Normalization to 4.9 eV resonance in ^{197}Au.
- Background correction for sample scattered neutrons.



Results for ^{56}Fe with Weighting Functions for C_6D_6 Detectors

Exp. Type	Lab	Year	Det.Type	WeightF.	$g\Gamma_n\Gamma_\gamma/\Gamma$ [meV]	Γ_n [meV]
Capture	Geel	1991	C_6D_6	Experim.	56.7 ± 1.9	62.9 ± 2.1
Capture	Harwell	1988	C_6D_6	EGS4	59.5 ± 3.0	66.4 ± 3.3
Capture	Oak Ridge	1988	C_6F_6	EGS4	58.0 ± 2.9	64.5 ± 3.0
Capture	Oak Ridge	1988	C_6D_6	EGS4	56.8 ± 2.3	63.0 ± 2.5
Capture	Oak Ridge	1994	C_6D_6	EGS4	55.8 ± 1.7	61.8 ± 1.9
Trans-mission	Oak Ridge	1985			55.7 ± 0.8	61.7 ± 0.9

WF depends on resonance strength

Reliable WF by MC simulations provided that the geometry input accounts for γ–ray transport in sample.

$\Rightarrow$ Weak resonance : WF1

$\Rightarrow$ Strong resonance : WF2

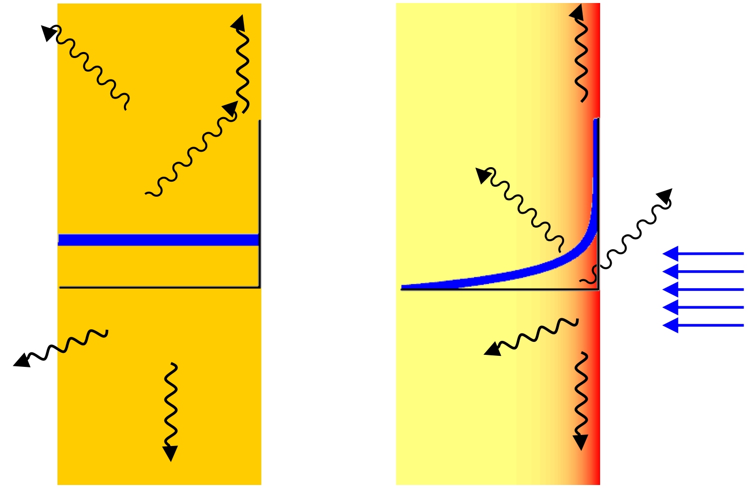
(Affects also the observed shape)

Procedure :

(1) Apply WF1 on experimental data

(2) Correction factor on calculated yield

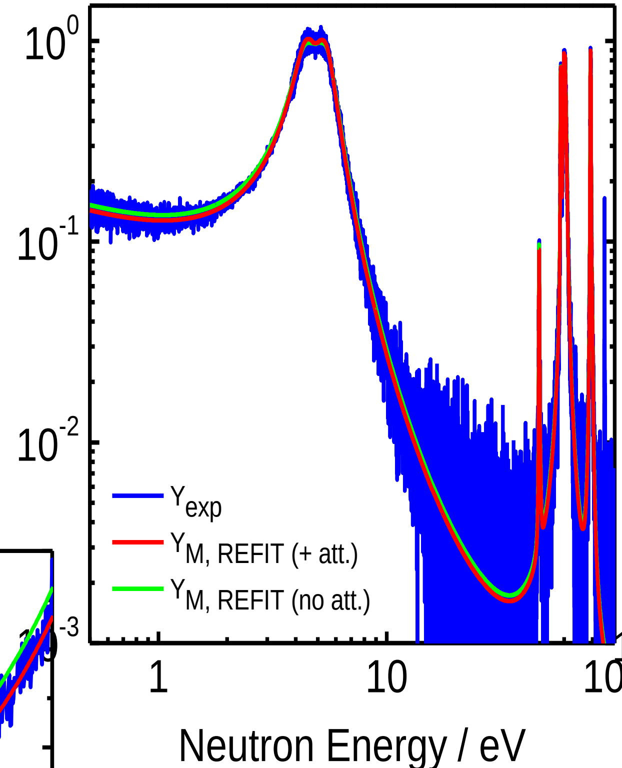
Effect depends on thickness : difference of 10% between 0.1 and 1mm sample for 4.9 eV resonance in Au

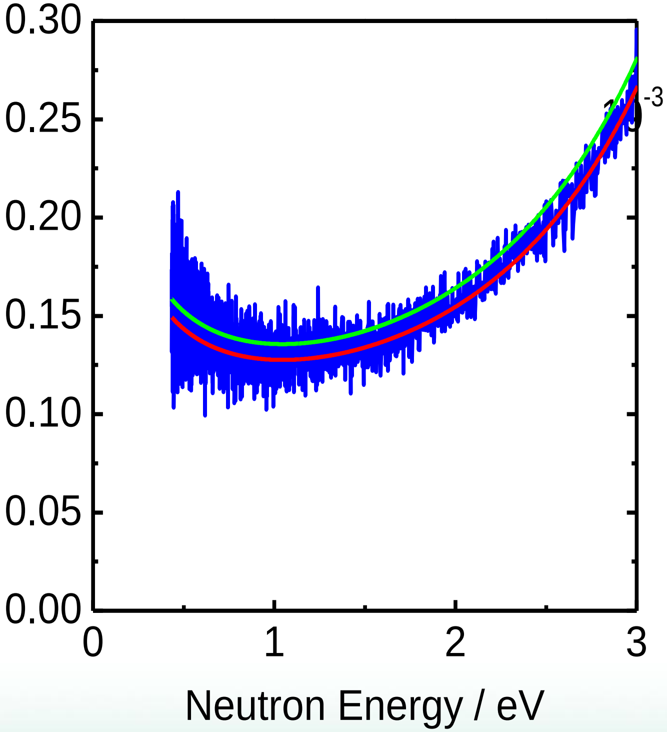


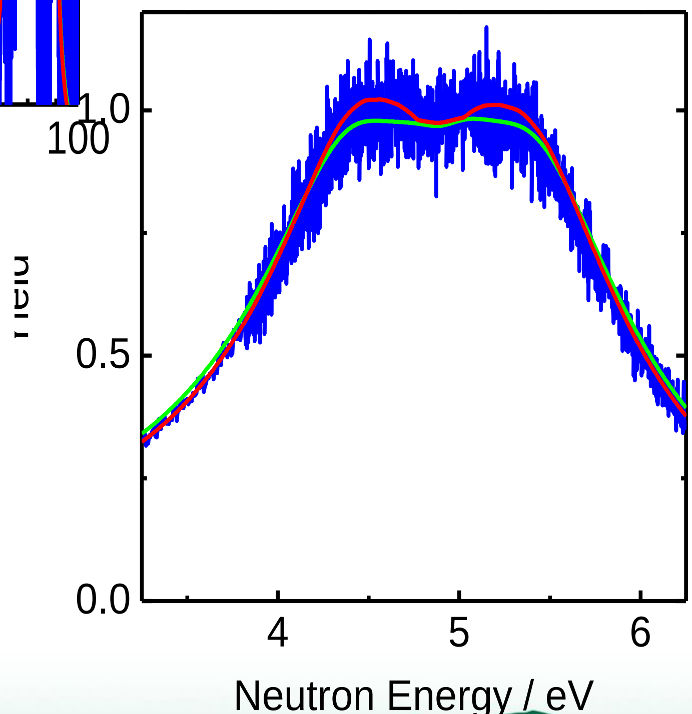
$$\boxed{K_c(n\sigma_t) = \frac{< WF_1 >}{< WF_2 >}}$$

Borella et al., NIMA 577 (2007) 626

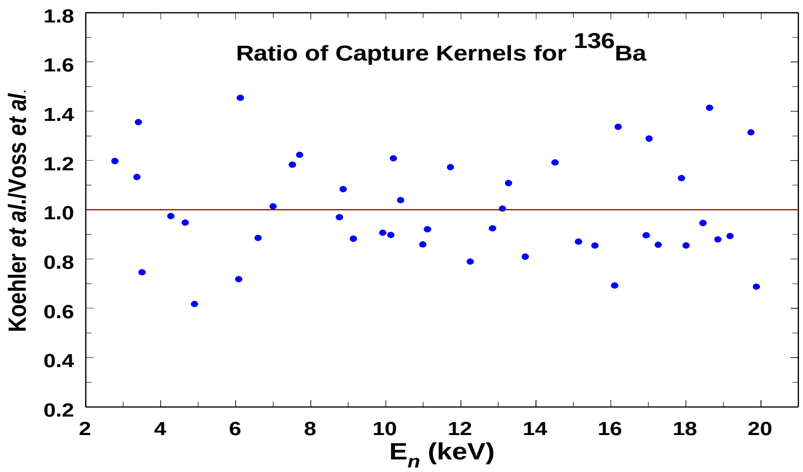
WF depending on σ_{tot},
WONDER 2006
Borella et al., NIMA 577 (2007) 626

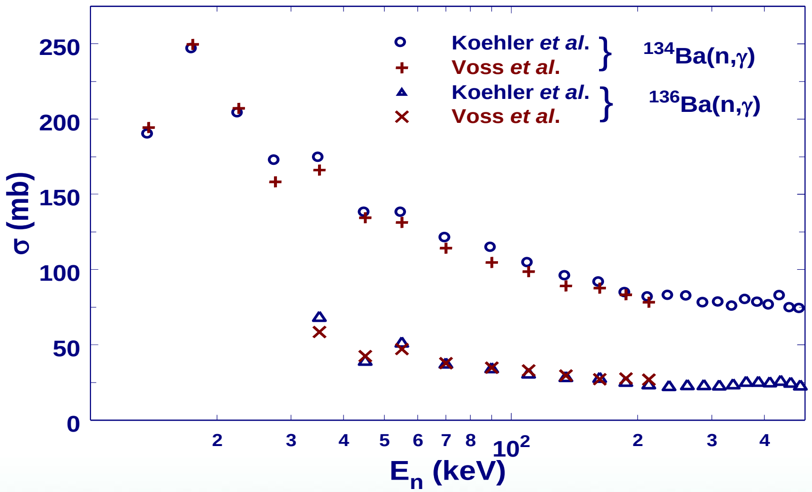






New ORELA Weighting Functions Demonstrated to be Accurate to Better Than 3%



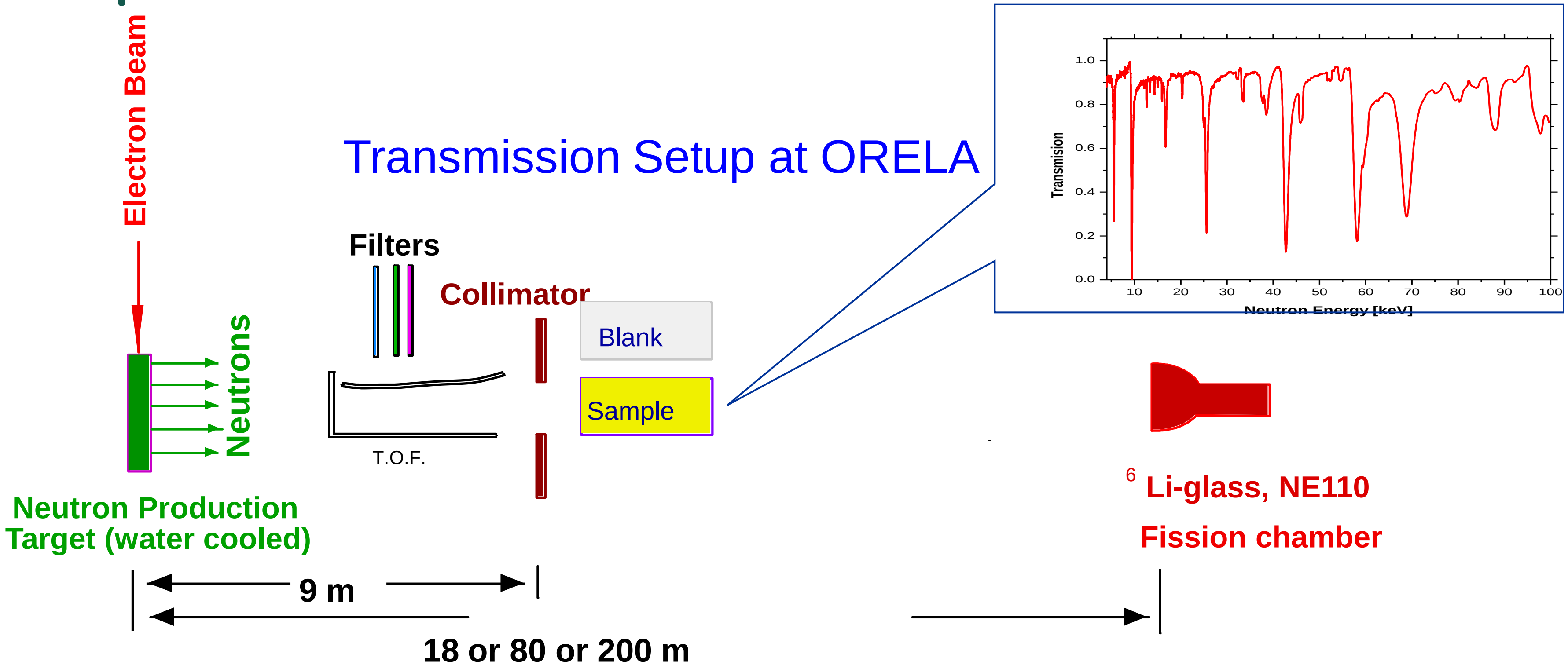


Excellent agreement between ORELA C_6D_6 (Koehler *et al.*) and FZK BaF_2 (Voss *et al.*) $^{134,136}Ba(n,\gamma)$ measurements.

Hardness of cascade varies considerably from resonance-to-resonance, but no systematic difference between capture kernels observed.

Excellent (<3%) agreement for average cross sections.

Simplified schematic of neutron transmission



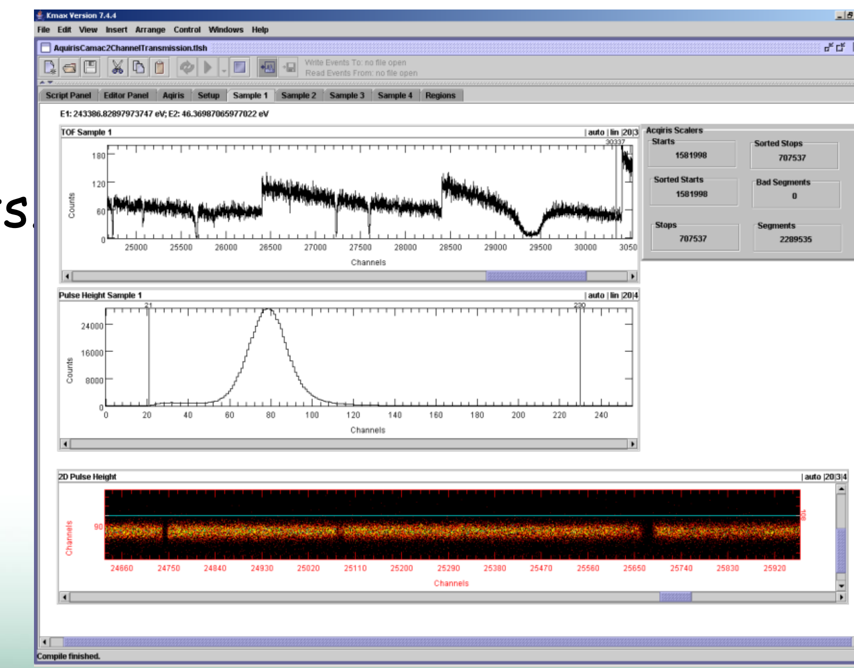
- For transmission, separate measurements of sample in and sample out

$$T = e^{-N\sigma_T d}$$

$$\boxed{T_{exp} = N \frac{C'_{in} - B'_{in}}{C'_{out} - B'_{out}}}$$

New & Improved ORELA Transmission Apparatus

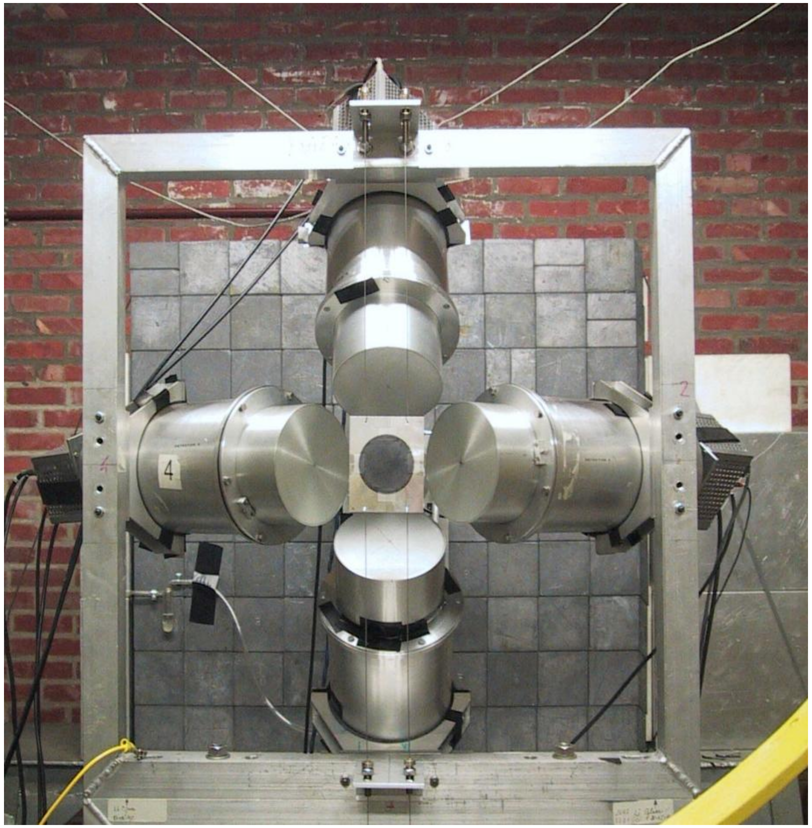
- Transient digitizer (Acqiris DC-270) replaced old CAMAC TDC and several NIM modules.
- Allows simultaneous measurement of time of flight and pulse height.
- Unlimited stops per start
  Previous system limited to 8 stops/start (LeCroy 4208 TDC)
- Fewer NIM and CAMAC modules
  Simpler and more reliable
- Filters for background measurements.



Capture cross section measurements at GELINA

L = 10 m, 30 m and 60 m

- C_6D_6 liquid scintillators
  - 125^o
  - PHWT
- Flux measurements (IC)
  - $^{10}B(n,\alpha)$
  - $^{235}U(n,f)$



- Normalize to standard (Au, Fe or other saturated resonance)

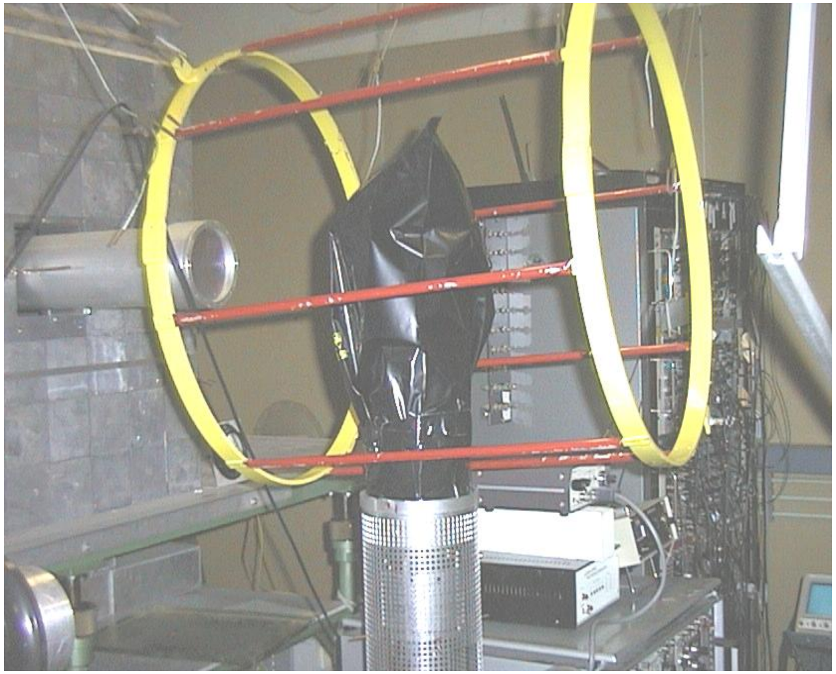
$$\boxed{Y_{exp} = \sigma_\varphi \frac{C_w - B_w}{C_\varphi - B_\varphi}}$$

$$C_w(T_n) = \int C_c(T_n, E_d)\, WF(E_d)\, dE_d$$

GELINA Transmission Measurements

Sample & Background Filters

Detector



Detector stations
Moderated : L = 30 m, 50 m, (100 m, 200 m)
Fast : L = 400 m

Low energy : ^{6}Li(n,t)α Li-glass

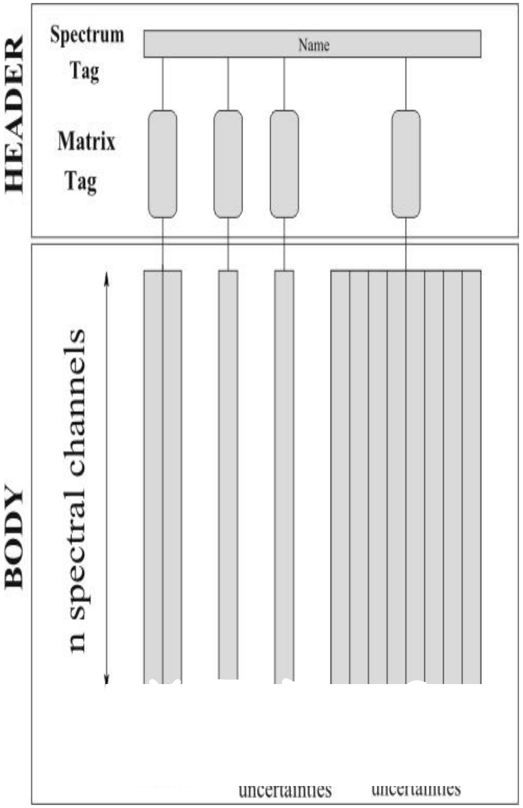
High energy : H(n,n)H Plastic scintillator

$$T = \frac{C_{in}}{C_{out}} \cong e^{-n\sigma_{tot}}$$

Data reduction with full covariance information

Analysis of Generic tof_Spectra (AGS)

- Transform count rate spectra into observables (transmission factors, partial reaction yields)
- Full propagation of uncertainties starting from counting statistics
- Output: complete covariance matrix
- Special format for covariance matrix
- Due to the special format used in AGS:
  - **Reduce space for data storage (EXFOR)**
  - **Verify and document the sources of uncertainties in each step of the reduction process**



Observable Z (dim. n) with k sources of correlated uncertainties $\Rightarrow$

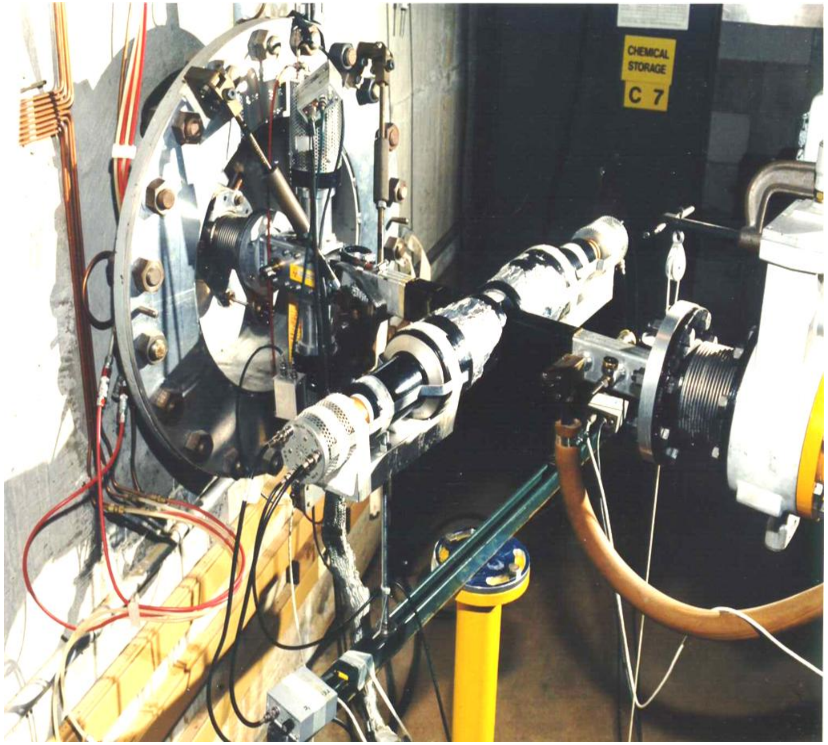
D_Z : uncorrelated part
n values

S_Z : correlated part
dim. (n x k)

$$\boxed{C_Z = D_Z + S_Z\, S_Z^{\,T}}$$

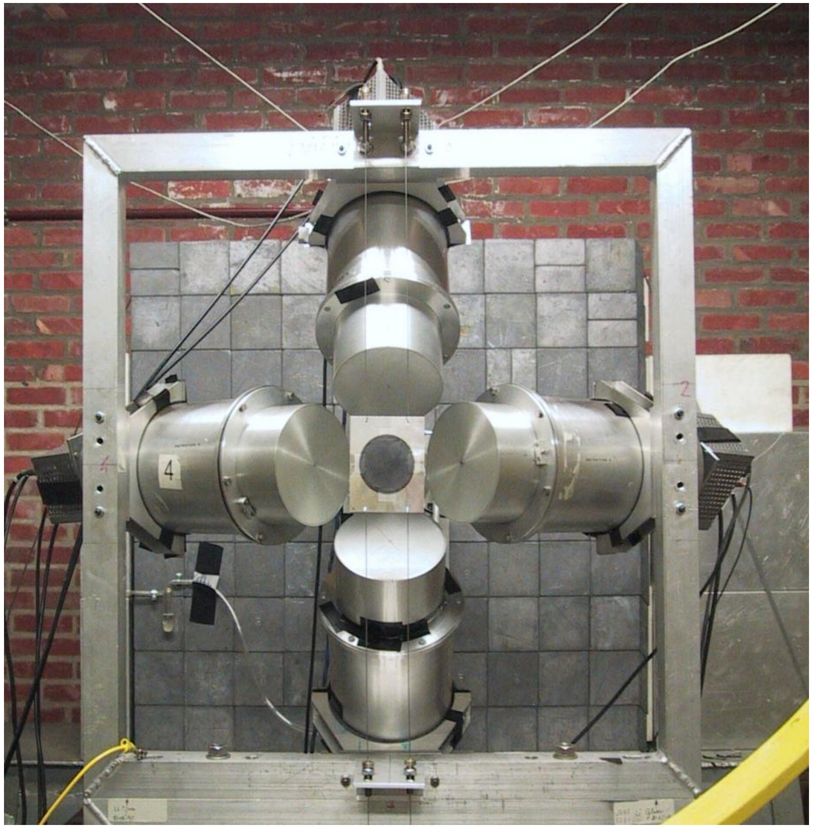
Bastian et al., PHYSOR 2006

System. Uncertainties ORELA (n,γ) set up



- PHWF known to 2%
- Normalization to Au 1.5-2%
- Others: n-flux monitor, dead-time, sample, γ-ray attenuation in sample, gain-shift : 1.2%
- Others? Sample scattered neutron correction, … , …
- Optimistic total systematic uncertainty: ~3%

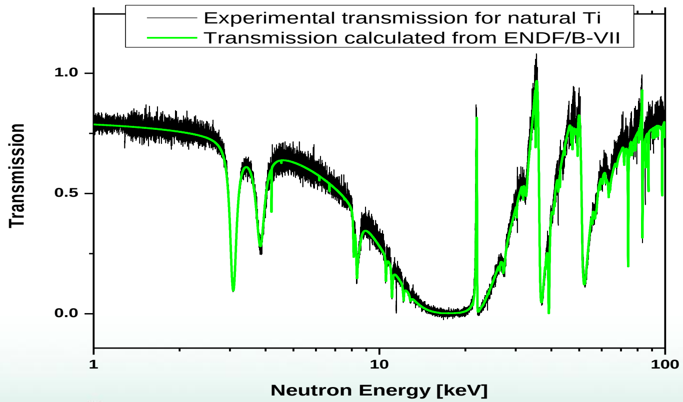
System. Uncertainties GELINA (n,γ) set up

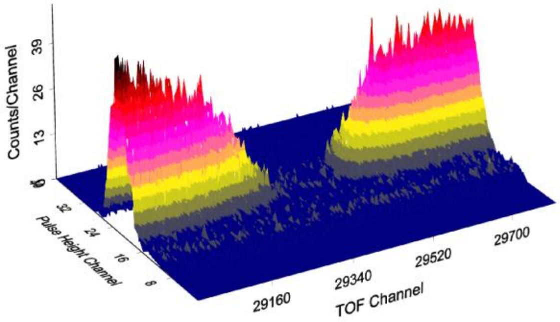


- PHWF known to 2%, less with internal normalization
- Normalization to Au or others: 1.5-2%
- Others: n-flux monitor, dead-time, sample, γ-ray attenuation in sample, gain-shift : 1-2% (with reservations)
- Others?
- Optimistic total systematic uncertainty: ~3%

Transmission at ORELA

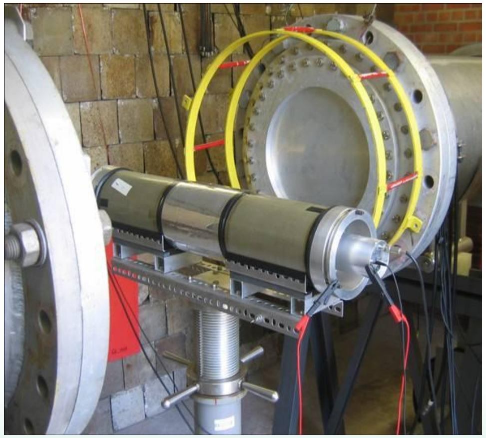
- Can achieve signal to background ratio of up to 0.1%.
- Background corrections: ambient, overlap, and (n,γ) on H. Are only fraction of counts compared to counting statistics (~4% on a 1% correction).
- Normalizations problem are circumvented by cycling the samples every 10 minutes. Consistency check on scalers.
- Sample condition is the biggest systematic uncertainty.
- Others: dead time, γ-ray attenuation in sample, gain-shift : ~1%





Transmission at GELINA

- Can achieve signal to background ratio of up to 1%
- Background corrections fitted to black resonances over broad neutron energy range. (2% on a 1% correction)
- Normalizations problem are circumvented by cycling the samples. Consistency check on scalers.
- Sample condition is the biggest systematic uncertainty.
- Others: dead time, attenuation in sample, gain-shift : ~1%?



Other facilities

- n_TOF, PHW detectors:
  - Biggest problem poor statistics of data.
  - No simultaneous flux measurement, only control; use evaluated flux.
  - Backgrounds due to high energy particles, γ-flash (no Pb filter)
  - Resolution: new target design Pb cylinder with 40cm dia., 60cm long, with 5 cm of water
  - 4π BaF_2
- DANCE at LANSCE, 4π BaF_2
- RPI

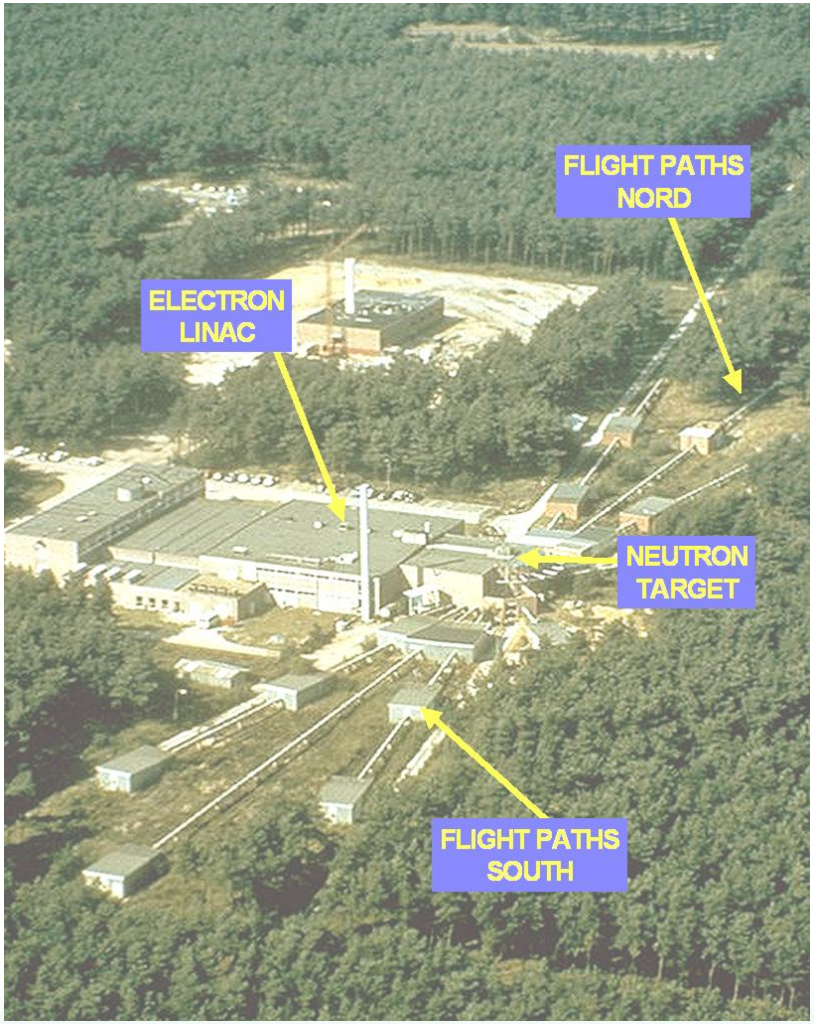
Conclusion

- Statistical uncertainties: measure longer.
- Optimistic uncertainties for GELINA and ORELA (n,γ) set up: ~3%
- Pessimistic/Realistic? 3-5% depends also on sample.

- (n,γ) systematic uncertainties of 1% can be achieved but require great effort, i.e. time and manpower.
- Transmission better than 1% can be achieved.

- What about correction of experimental effects? Self-Shielding , Multiple Scattering, Resolution,….

GELINA

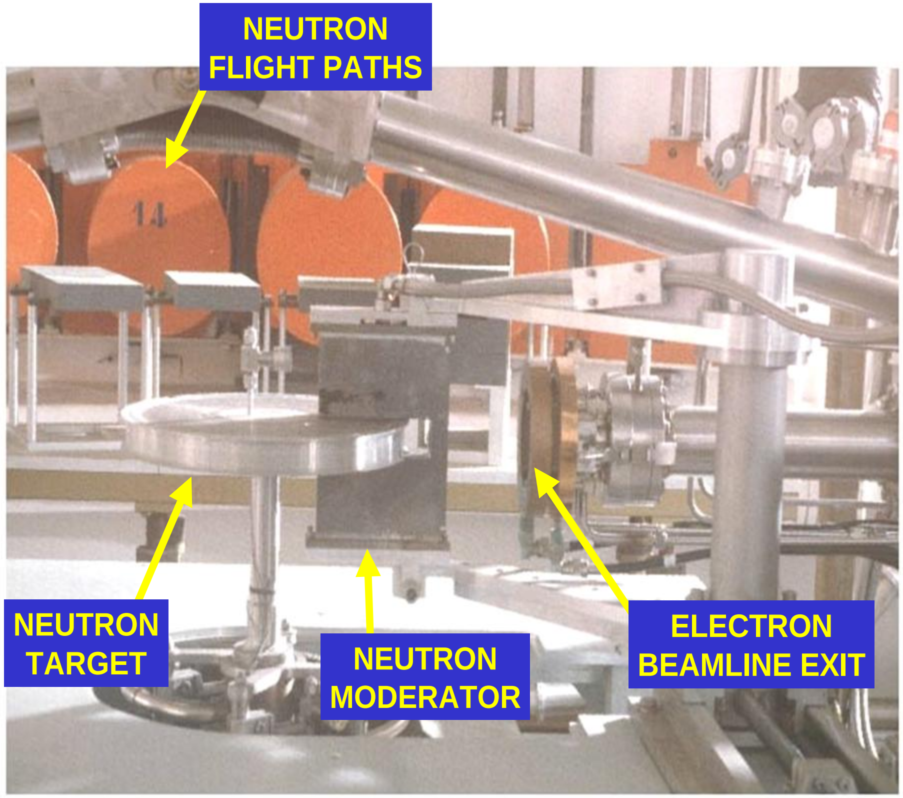


- Time-of-flight facility
- Pulsed white neutron source

  (10 meV < E_n < 20 MeV)
- Multi-user facility with 10 flight paths (10 m - 400 m)
- The measurement stations have special equipment to perform:
  - Total cross section measurements
  - Partial cross section measurements

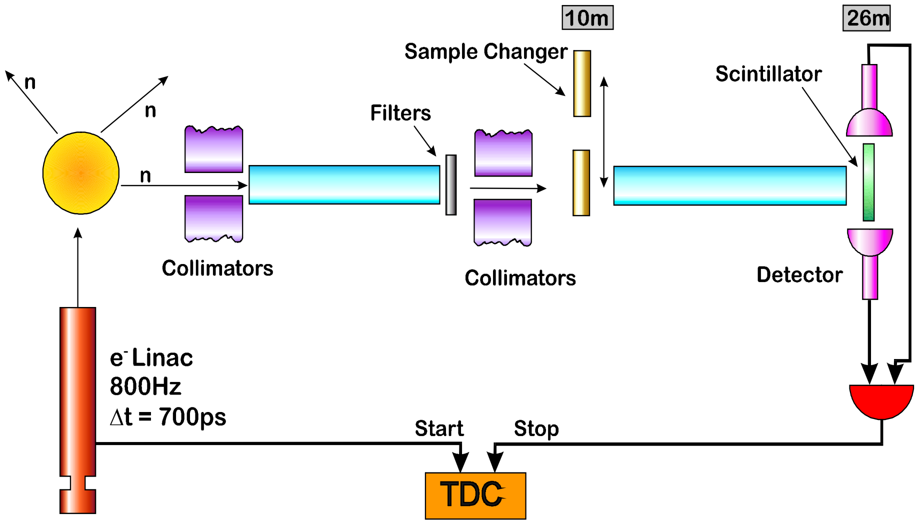
Pulse Width	: 1ns		
Frequency	: 40 Hz	–	800 Hz
Average Current	: 4.7 μA	–	75 μA
Neutron intensity	: 1.6 10^{12} n/s	–	2.5 10^{13} n/s

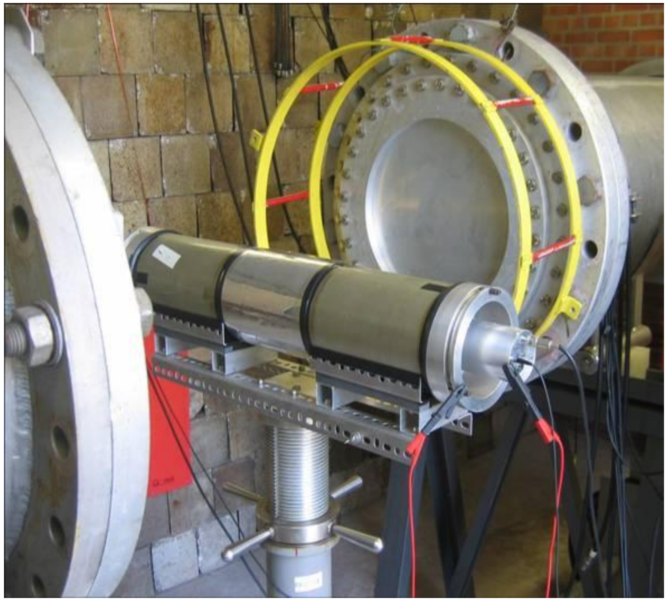
Neutron Production



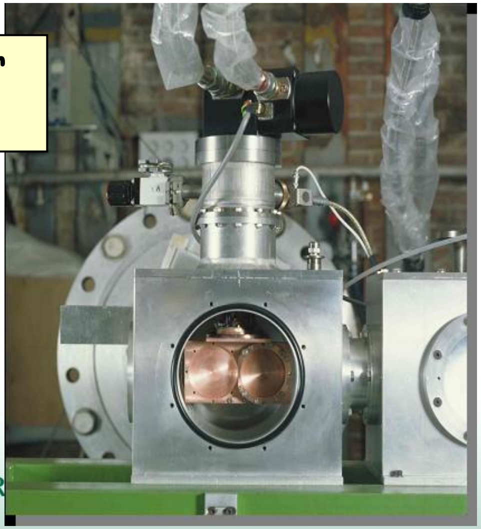
- e^- accelerated to $E_{e-,max} \approx$ 140 MeV
- (e^-, γ) Bremsstrahlung in U-target (rotating & cooled with liquied Hg)
- (γ,n) , (γ ,f) in U-target
- Low energy neutrons by water moderator in Be-canning

Transmission Setup @25m





cryostat sample changer
temp. range 10K - 350K



^{6}Li glass (NE912)
diam.: 10cm
thickness 1cm
2 * 5" PM tube

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