Particle Physics with Neutrons at the ESS

- ESS – a long-pulse spallation source
- Particle physics proposals
- A cold beam line:
  - Interest of pulsed beams
  - Design criteria
- Summary

Torsten Soldner
Institut Laue Langevin

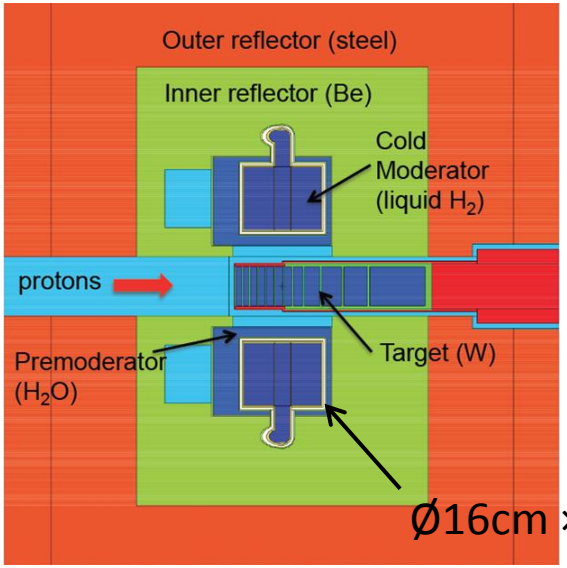
ESS – A long-pulse spallation source

	SNS	ESS
Average po		
Proton puls		
Energy per		
Pulse repet		

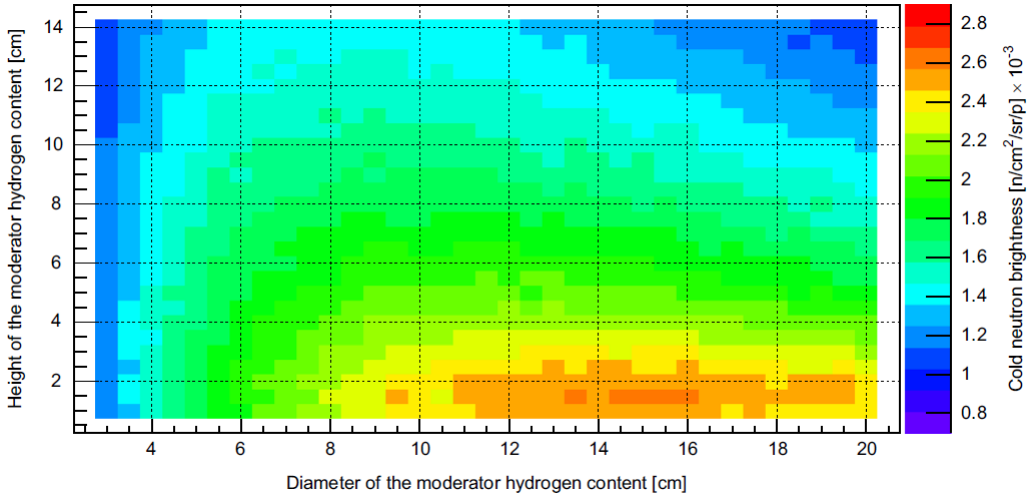
nt:
nstant ~100 µs

Time-averaged brightness: ESS ~ ILL
Peak brightness: ESS ~ 30 × ILL

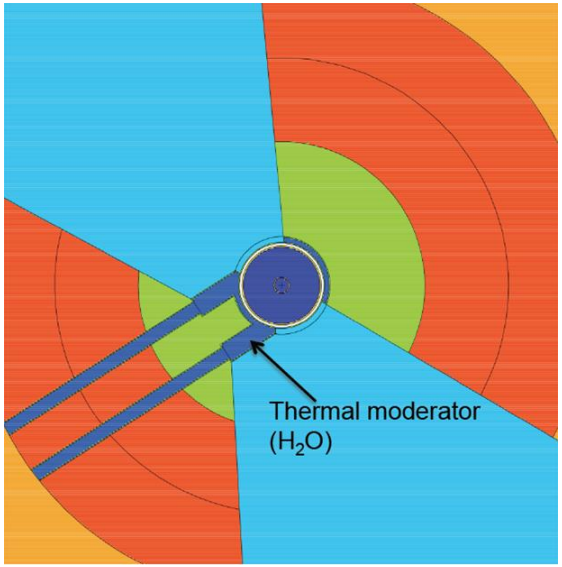
ESS moderators

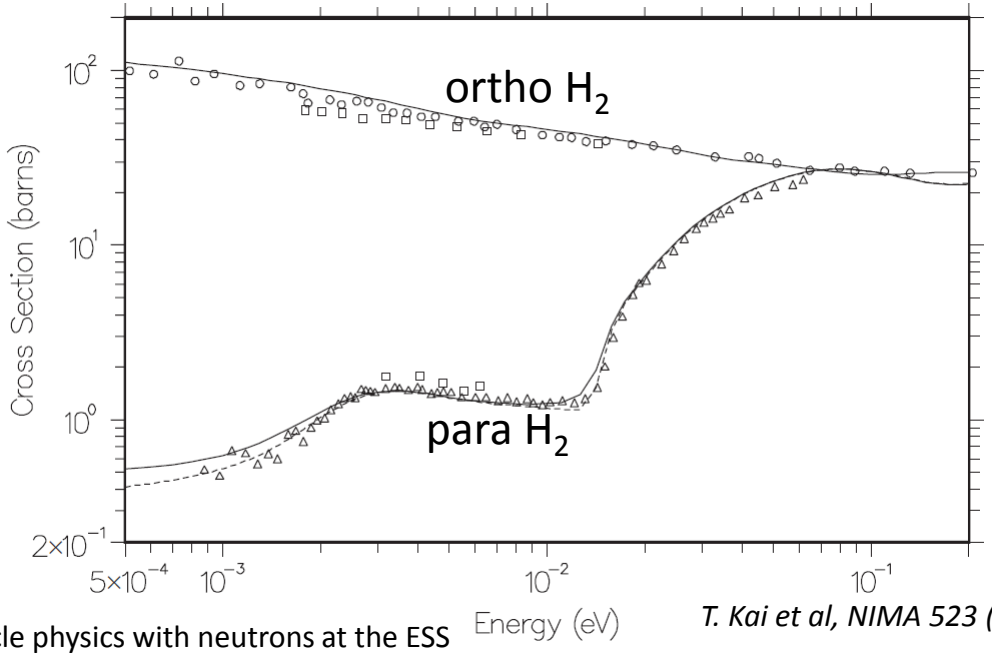


Ø16cm × 12cm



K. Batkov et al, NIMA 729 (2013) 500

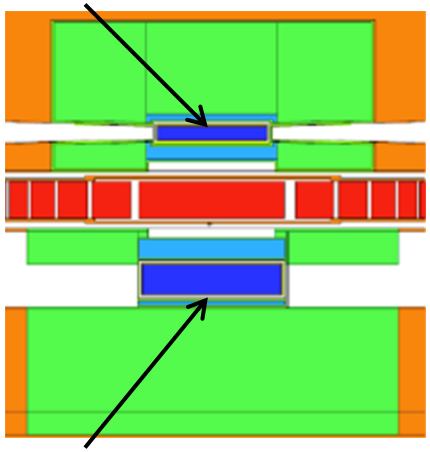




T. Kai et al, NIMA 523 (2004) 398

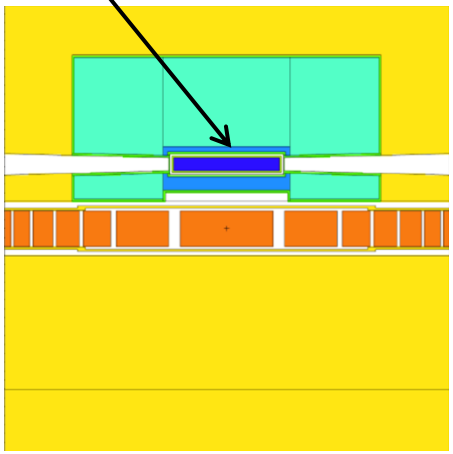
ESS moderators

Ø22cm × 3cm



Ø22cm × 6cm

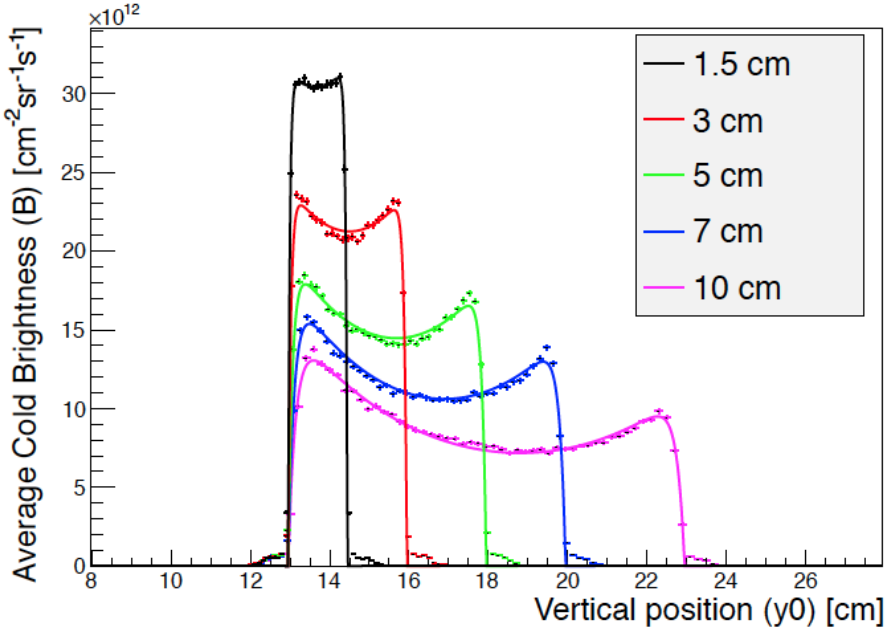
Ø22cm × 3cm



Preferred: One flat (3 cm), one intermediate (6 cm)

Small perturbation for flat moderator: 2×120° extraction possible

6 cm only for instruments that need larger moderator



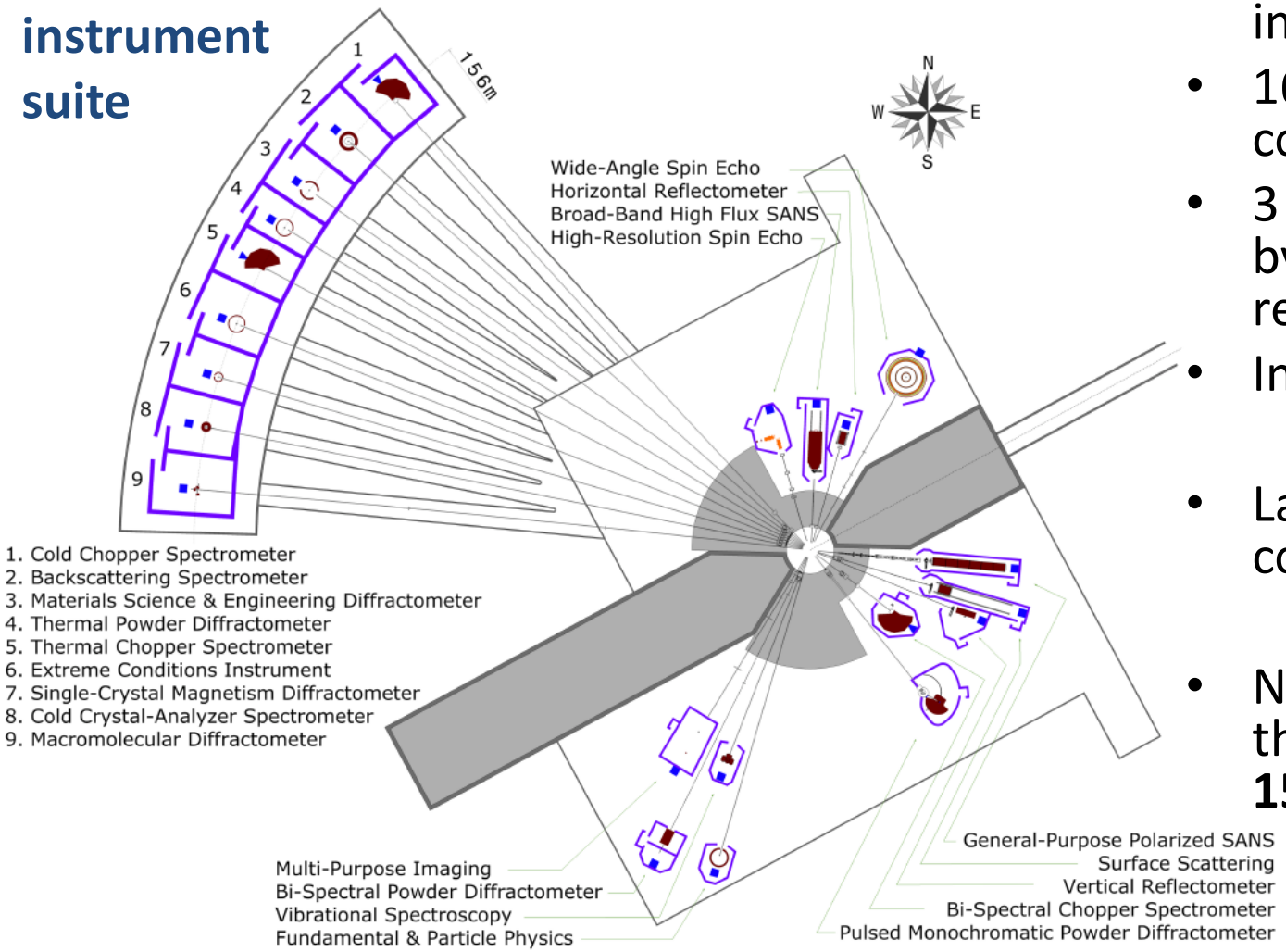
6 cm moderator: 70% of integral brightness of TDR moderator

Luca Zanini (ESS)

Fallback: Only one flat

ESS instruments

Reference instrument suite



- 22 publicly funded instruments
- 16 instruments in construction budget
- 3 proposals approved by STC + 9 recommended by SAC
- Instrument: 10-20 M€
- Labs from partner countries can propose
- Next deadline (last for the 16 first): **15 Jan 2015**

Neutron particle physics at the ESS

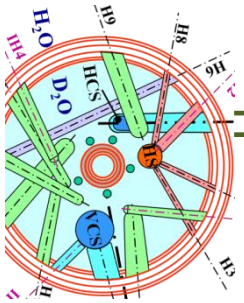
Advantages:

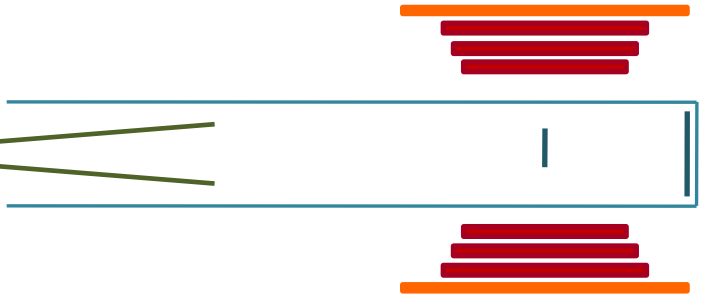
1. Same time average flux as ILL ***and*** pulsed
2. Not yet built: Optimisation at/of green-field facility (if we are fast)

Presently discussed proposals:

- Search for neutron-antineutron oscillations (2)
- Beam UCN source (2, 1)
- Cold neutron beam line (1)

nnbar at ILL





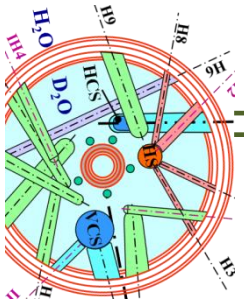
^{58}Ni guide

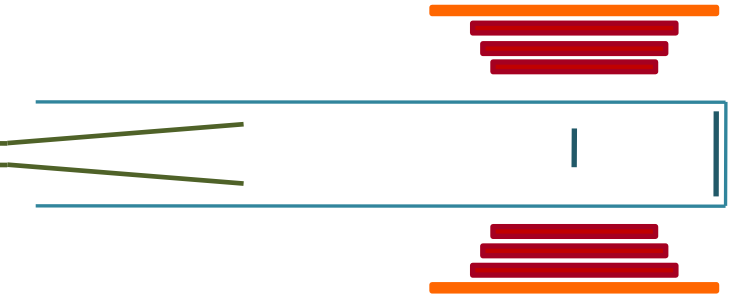
~ 80 m free flight

1 year running

Replacement of reactor vessel

nnbar at ESS?





^{58}Ni guide

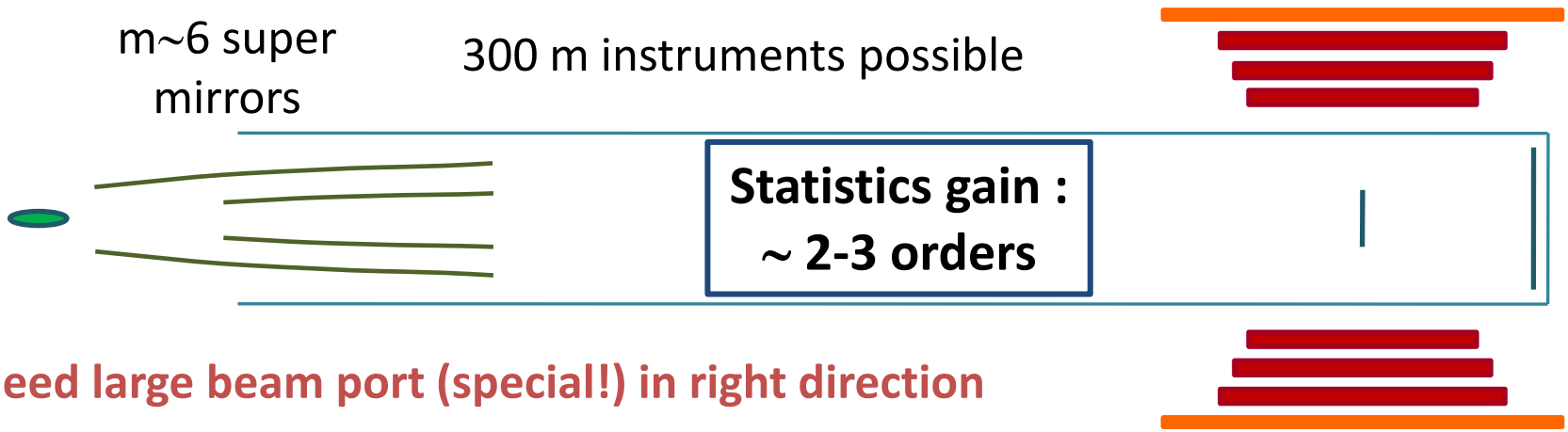
~ 80 m free flight

1 year running

Replacement of reactor vessel

m~6 super mirrors

300 m instruments possible



Statistics gain : ~ 2-3 orders

Need large beam port (special!) in right direction

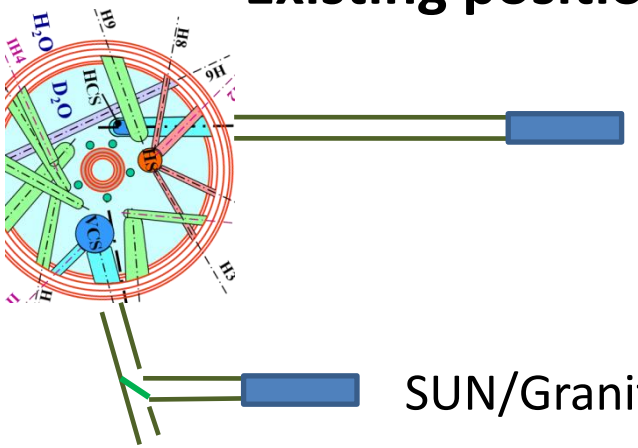
nnbar @ ESS – Status

- Would be outside the standard ESS instrument suite (costs and scope)
- Enthusiasm @ ESS. However, limited time window for design optimisation.

- Attempts to form a collaboration (G. Brooijmans et al.):
  - Workshop at CERN (June 2014)
  - Strong interest from US nnbar, engagement in neutronics simulations (Y. Kamyshkov et al.)
  - Small interest in European neutron community

UCN source at ESS

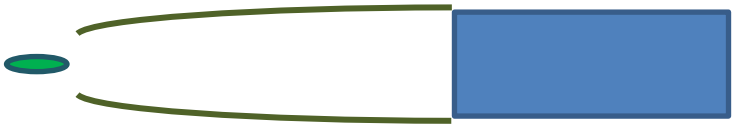
Existing positions @ ILL: Compromises



CryoEDM position: m = 1.2 x 2 guide

SUN/Granit positions: m = 2 guide + monochromator

ESS: Full optimisation starting from cold moderator



Highest production rate

Need large beam port & high-m extraction

Highest density

Statistics gain : ~ 1-2 orders

Monochromatisation by choppers for low background experiments

UCN source at ESS – Physics programme

- Gravitational spectroscopy
- Cryogenic EDM experiment
- Neutron beta decay

Proposers to ESS:

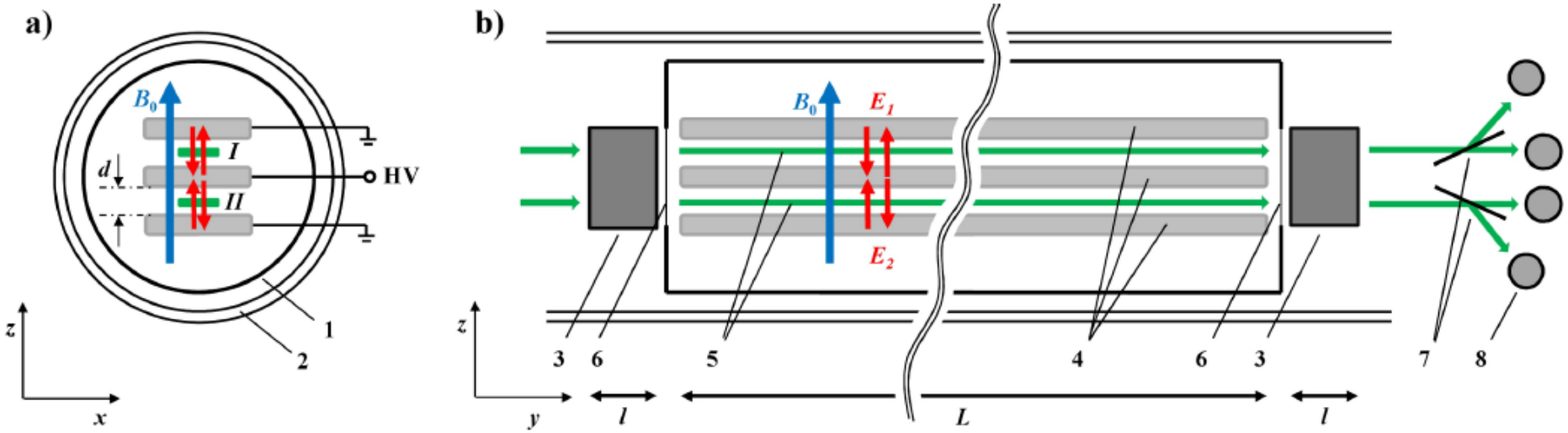
- H. Abele, P. Fierlinger, O. Zimmer

Pulsed neutron beams

- λ Wavelength information without statistics loss
  - Velocity dependence of signal and systematics
  - Loss-free monochromatisation
- τ Time localisation of neutron pulse
  - Signal/background
  - Suppression of background with different time constant
- ξ Spatial localisation of neutron pulse
  - Separation of beam-related background
  - Separation of undefined spectrometer response

NEDM with a cold beam

F. Piegsa, ETH



Different velocity dependence of signal and systematics – separation for free

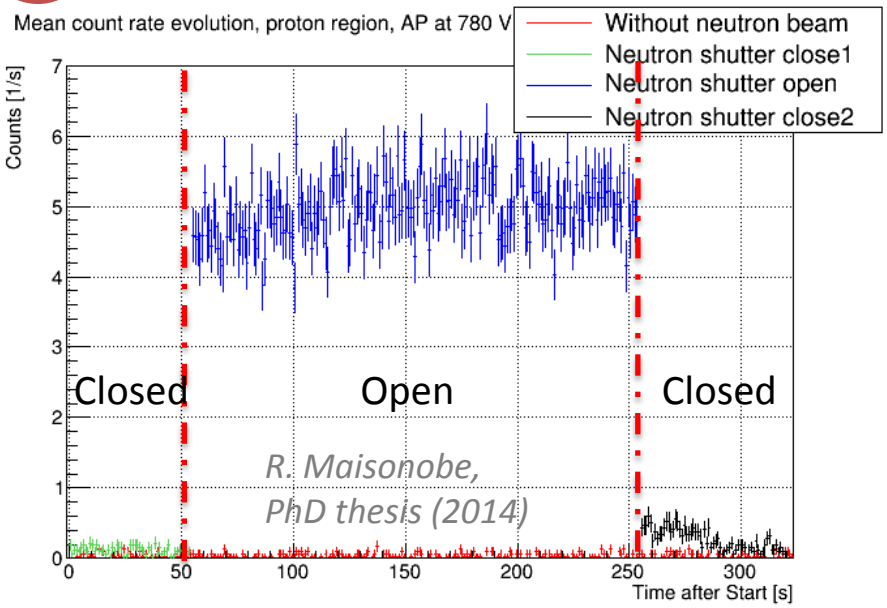
- Main systematics $\propto v$
- Signal $\propto 1/v$

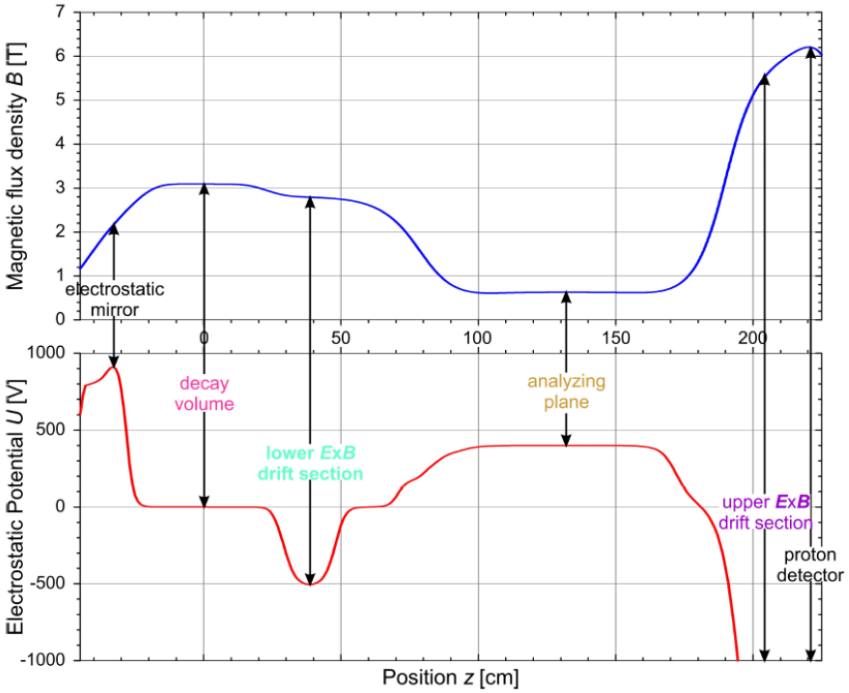
→Gain in systematics re-enables beam experiments

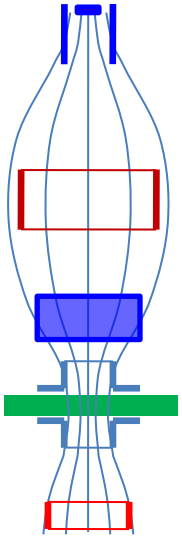
L = 50 m
Source-detectors 75 m
Neutrons 6-10 Å (660-400 m/s)
Sensitivity: $5 \cdot 10^{-28}$ *e*cm

F. Piegsa, Phys Rev C 88 (2013) 045502

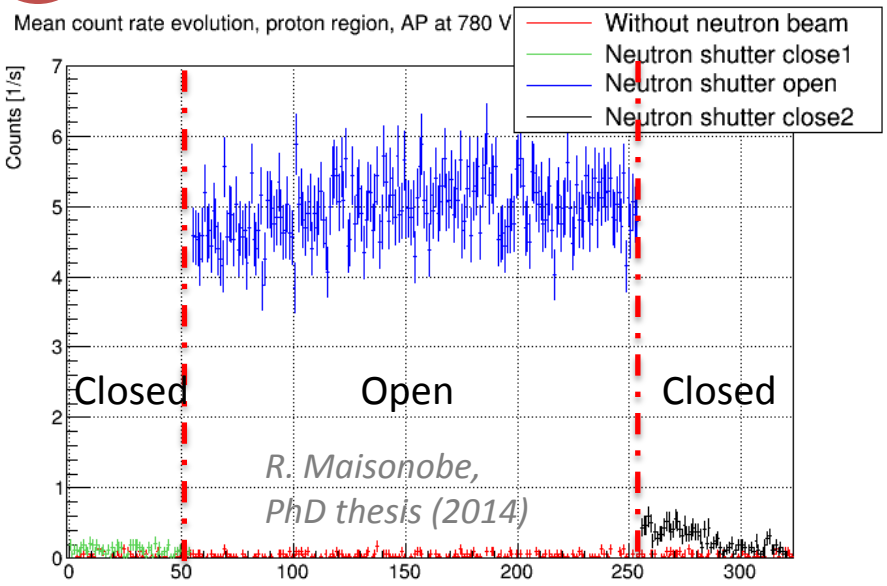
Proton spectrum with *a*SPECT: Background

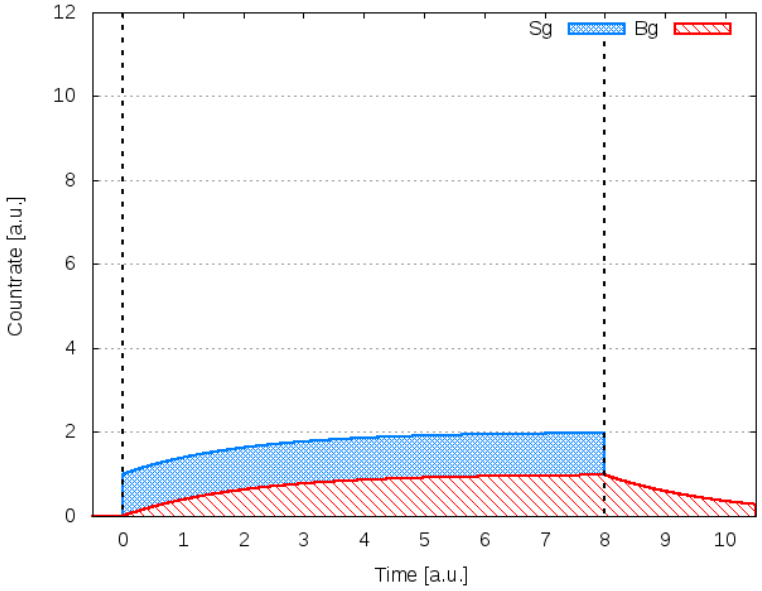


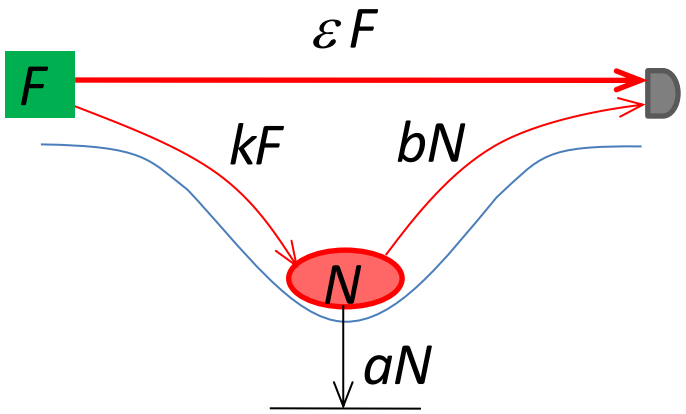




Background from Traps





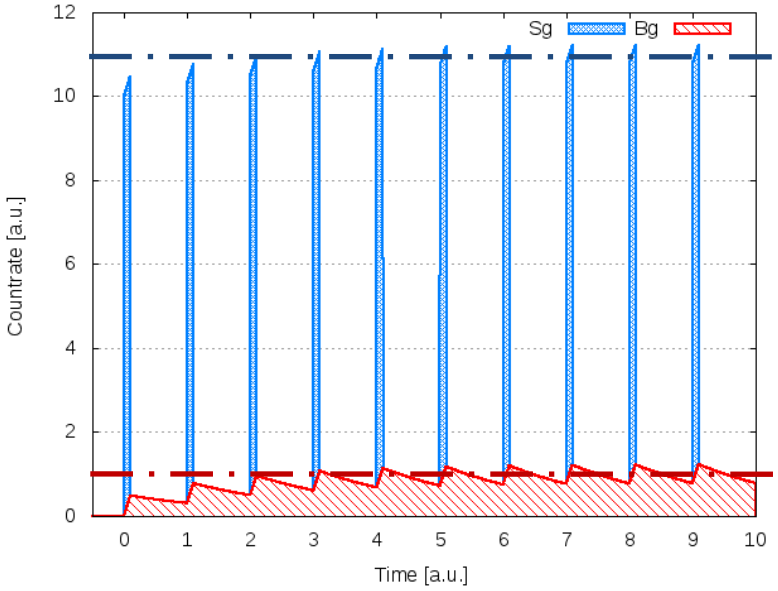


$$\frac{dN}{dt} = kF - \frac{N}{\tau} \qquad \frac{1}{\tau} \equiv a + b$$

$$F > 0: \quad N(t) = \left(N_0 - kF\tau\right) e^{-\frac{t}{\tau}} + kF\tau$$

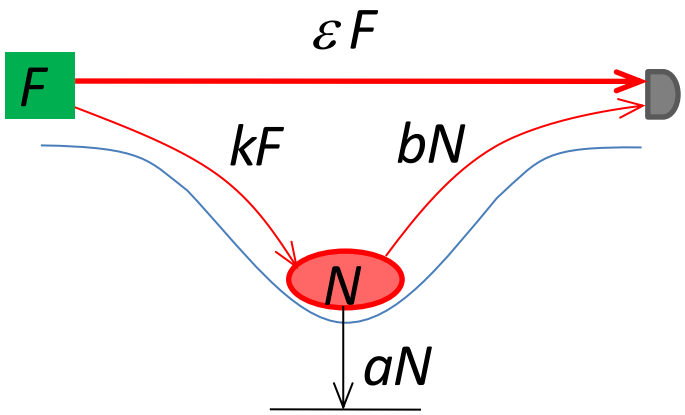
$$F = 0: \quad N(t) = N_0 \, e^{-\frac{t}{\tau}}$$

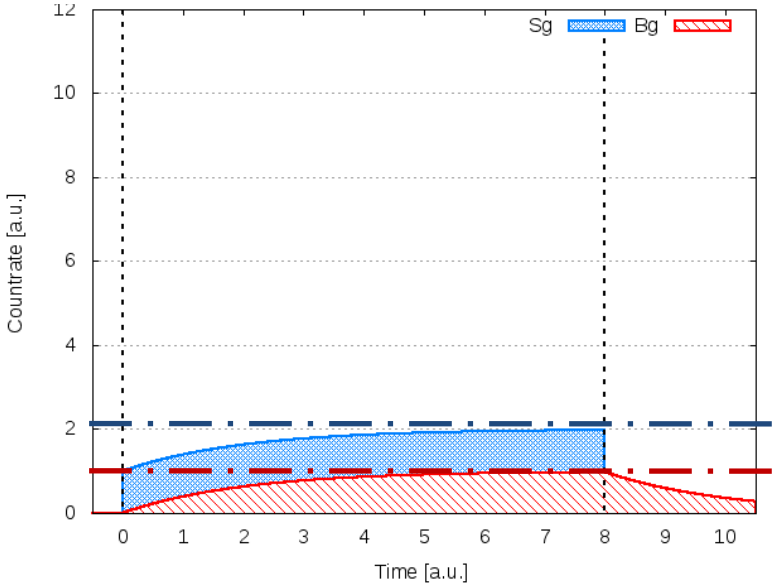
Background from Traps at ESS



$\varepsilon F_{\text{Peak}}$

$k\langle F\rangle\tau$





εF

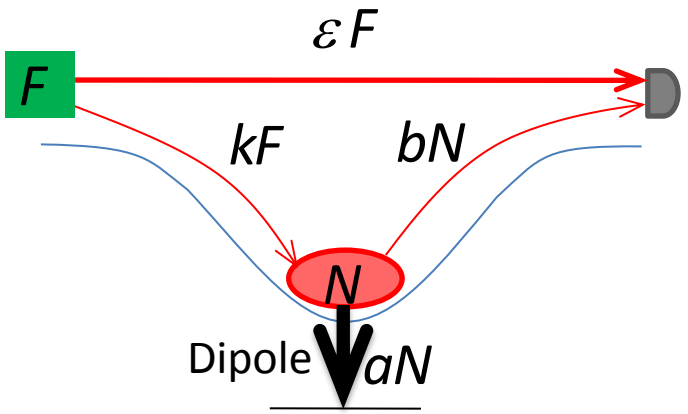
$kF\tau$

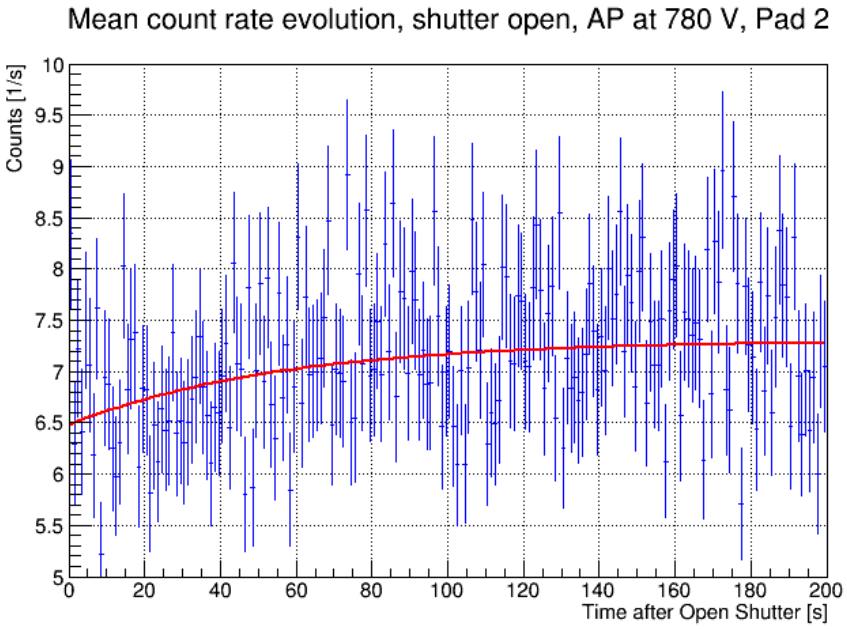
Pulsed source (ESS):

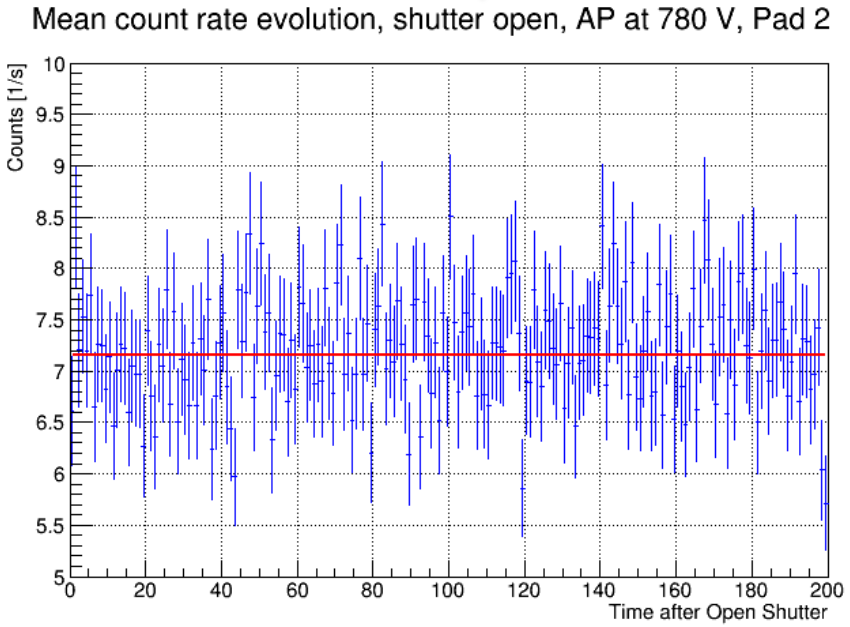
$$\left(\frac{\text{Sg}}{\text{Bg}}\right)_{\text{Pulsed}} = \frac{F_{\text{peak}}}{\langle F\rangle}\left(\frac{\text{Sg}}{\text{Bg}}\right)_{\text{Cont}}$$

$$\text{non trivial since } \text{Bg} \propto F$$

Don’t worry for aSPECT 2013...







R. Maisonobe, PhD thesis (2014)

Perkeo II *A* – Background

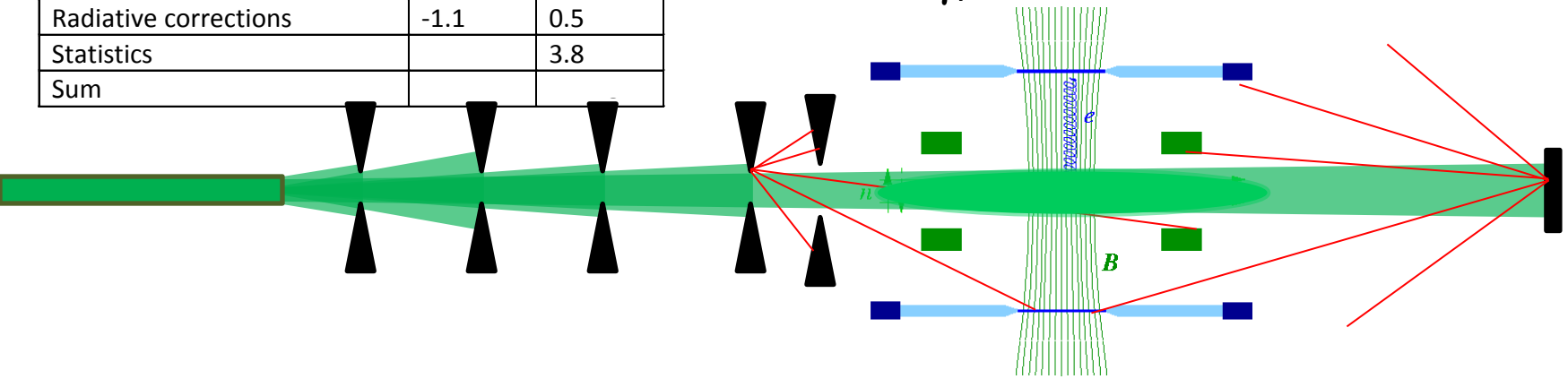
Effect	Cor [10^{-3}]	Err [10^{-3}]
Polarisation analysis Polarisation efficiency Flipper efficiency	3	1 1
Detector response		2.5
Solid angle (mirror + edge)	-1.6+0.6	+0.8-0.5
Dead time	-1.2	0.1
Radiative corrections	-1.1	0.5
Statistics		3.8
Sum		

Background

Best materials:

→ Scattering: ~10^{-3}

→ γ, fast *n*: ~10^{-4}



Decay

Lifetime 900 s

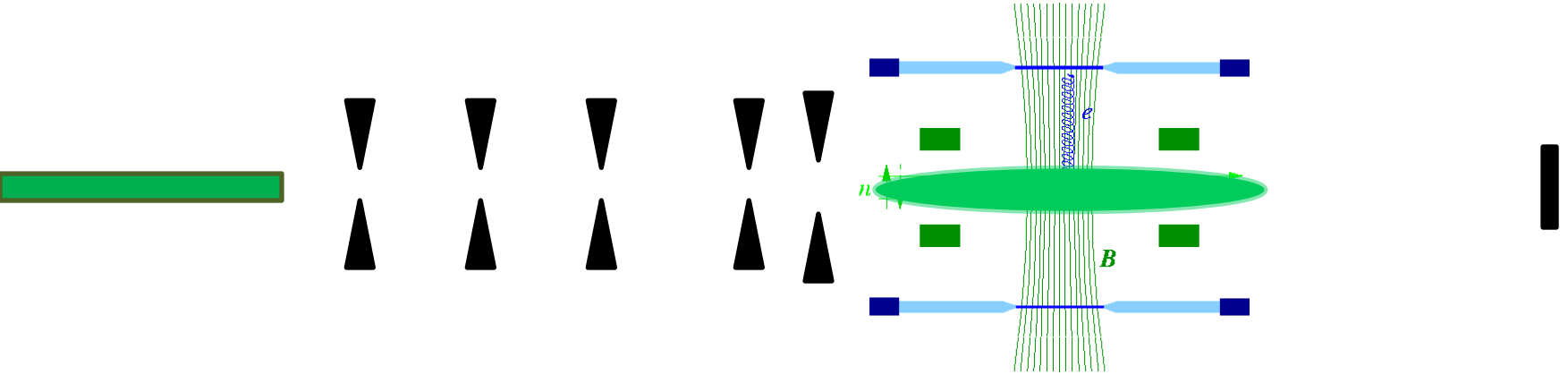
Velocity 800 m/s

→ Decay probability 10^{-7}

$A = -0.11972^{+53}_{-65}$

D. Mund et al, PRL 110 (2013) 172502

But: Statistics too low



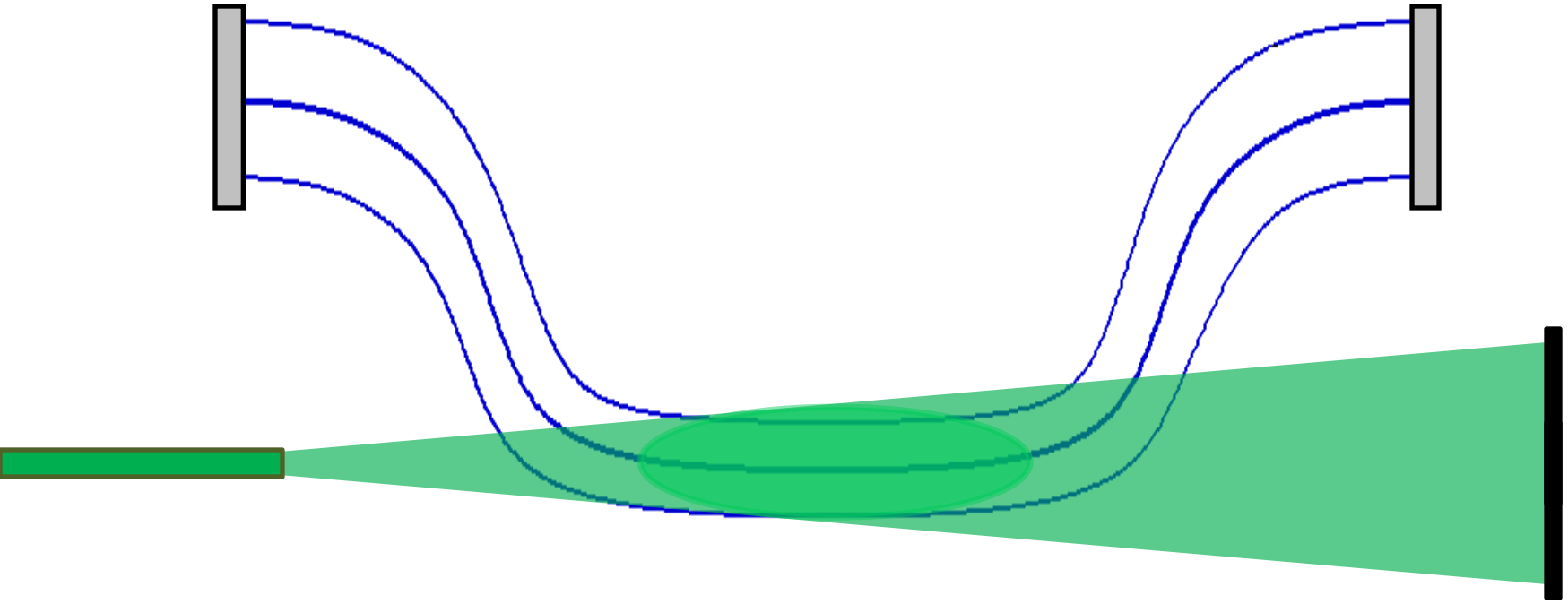
10^6 /s m

10^5 /s m polarised

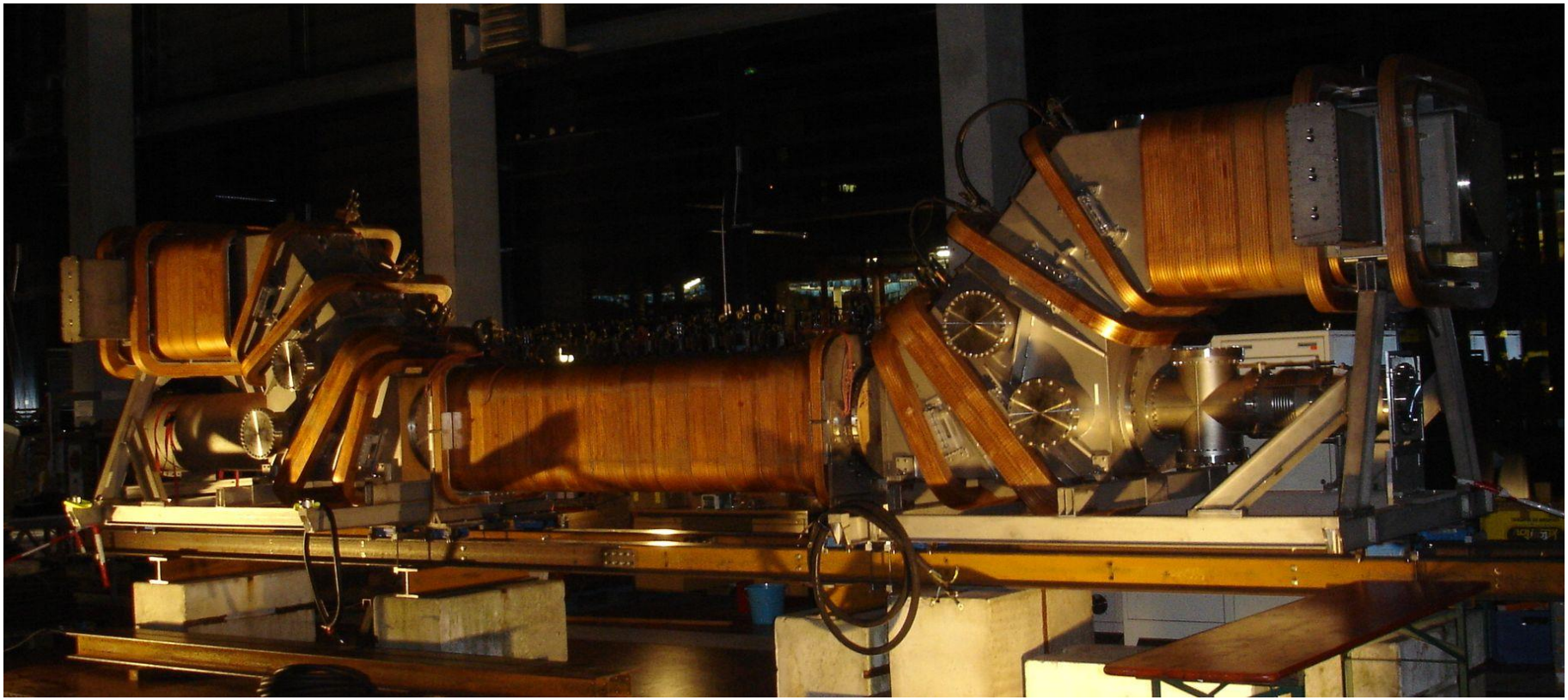
10^3 /s m
Monochromatisation
100 s/m
Chopper
~10 /s m

Better at pulsed source

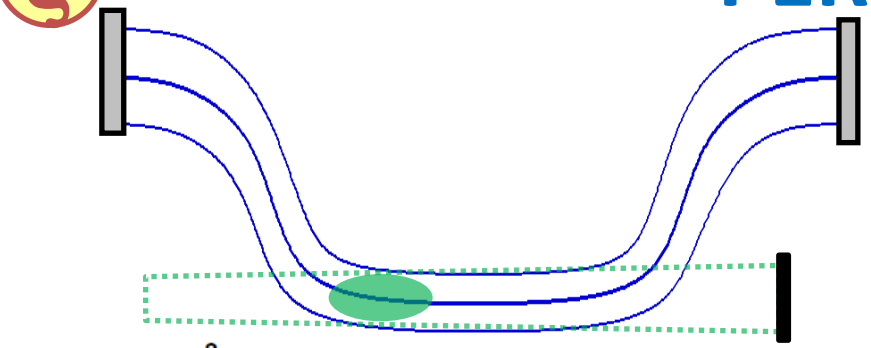
Solution – Improve acceptance – Perkeo III

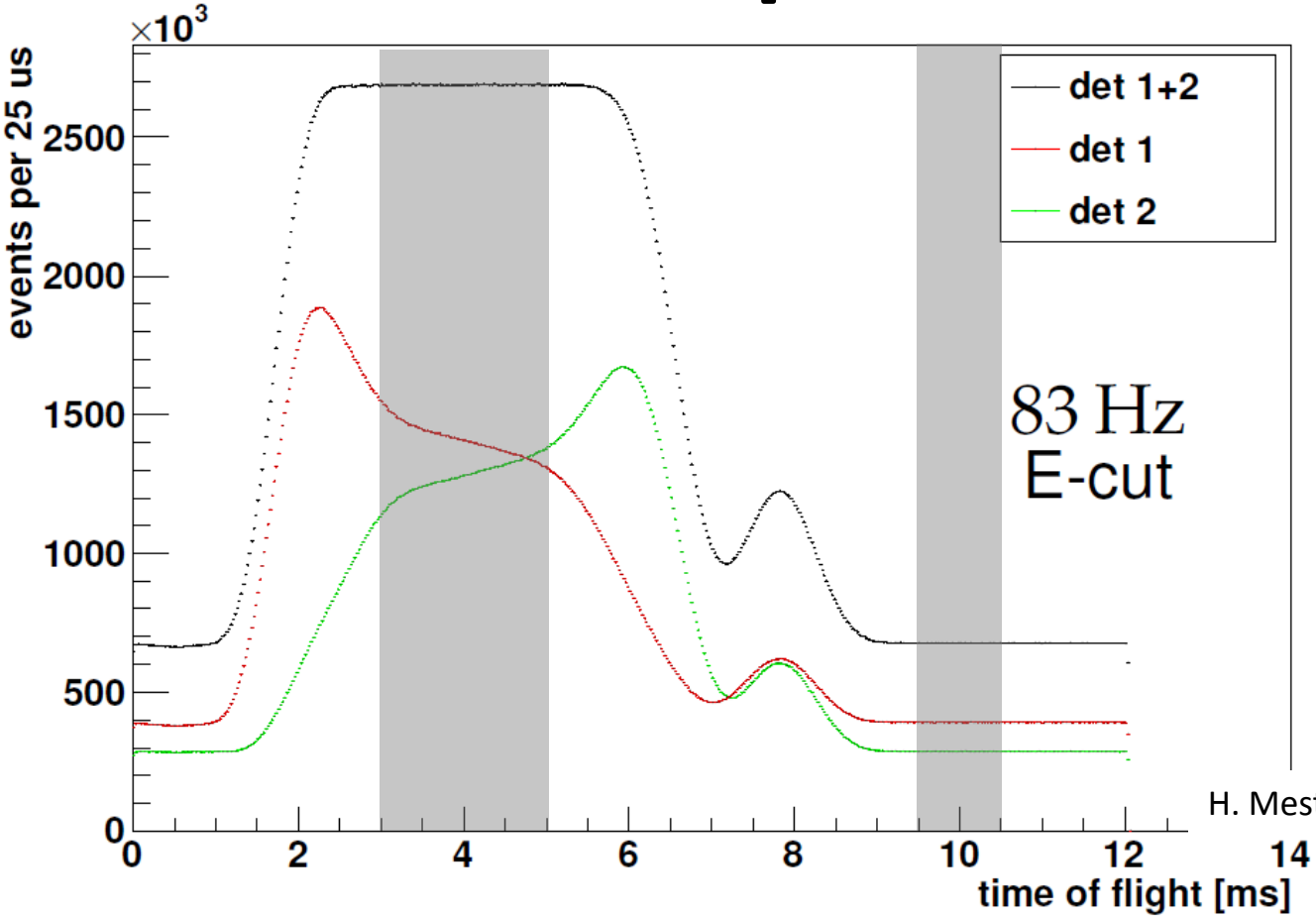


PERKEO III



PERKEO III





Spatial localisation of pulsed beam:

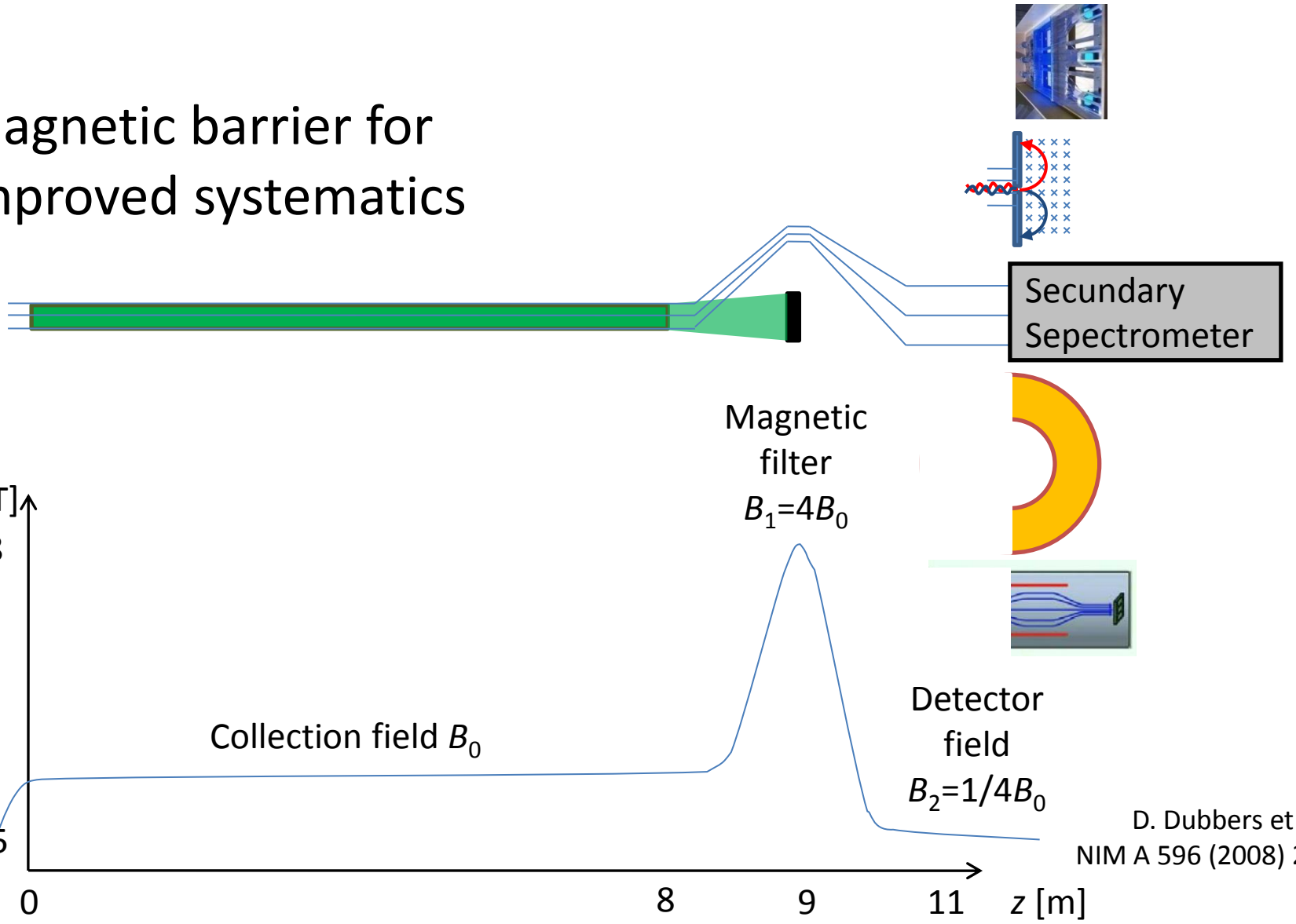
- ✓Background
- ✓"Solid angle"
  - ✓Magnetic mirror
  - ✓Edge effects

But: Acceptance of diluted beam
→Large detectors
Solution: PERC

H. Mest, PhD thesis, Uni Heidelberg 2011

Keep neutron density – PERC

Magnetic barrier for improved systematics



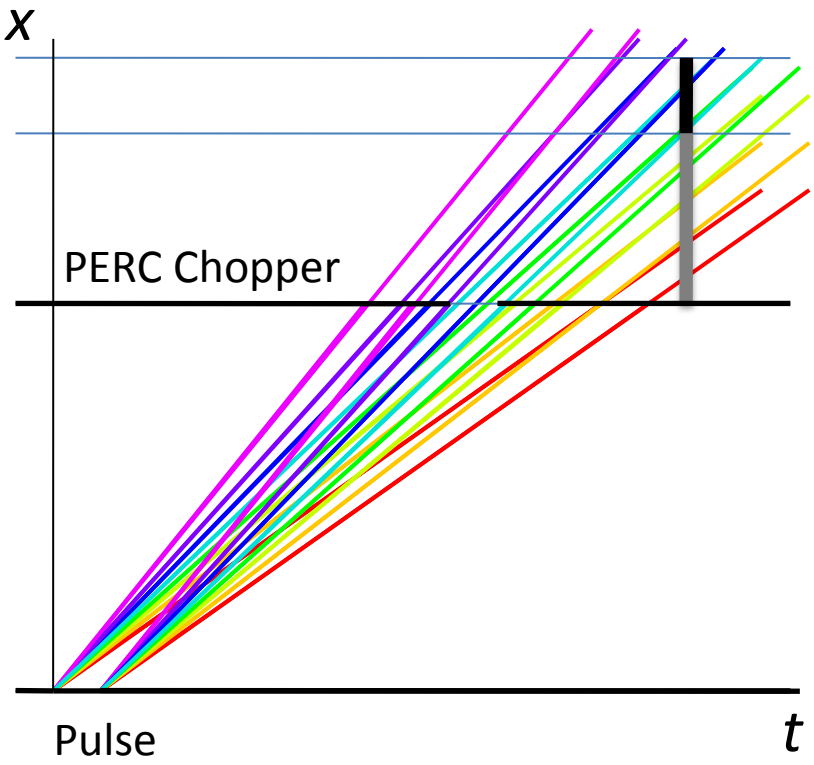
D. Dubbers et al., NIM A 596 (2008) 238

PERC@ESS

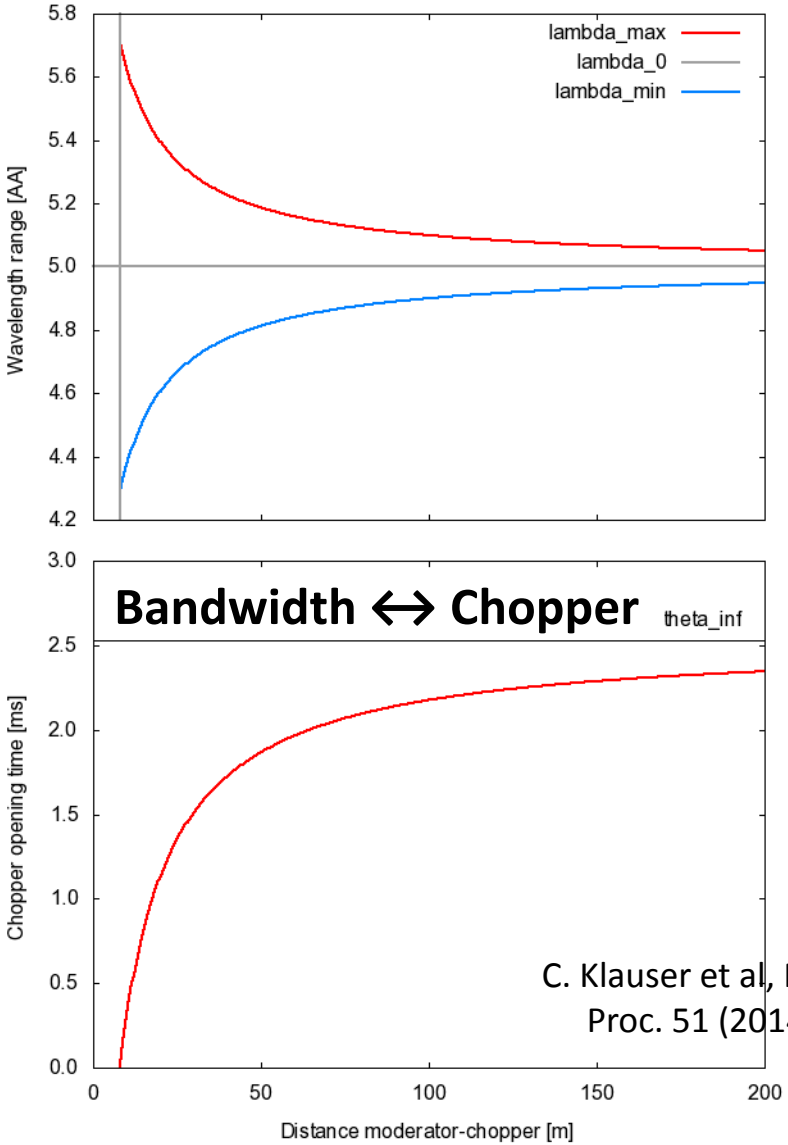
Requirement 1

Pulse length *p* at PERC exit

→ Chopper open time

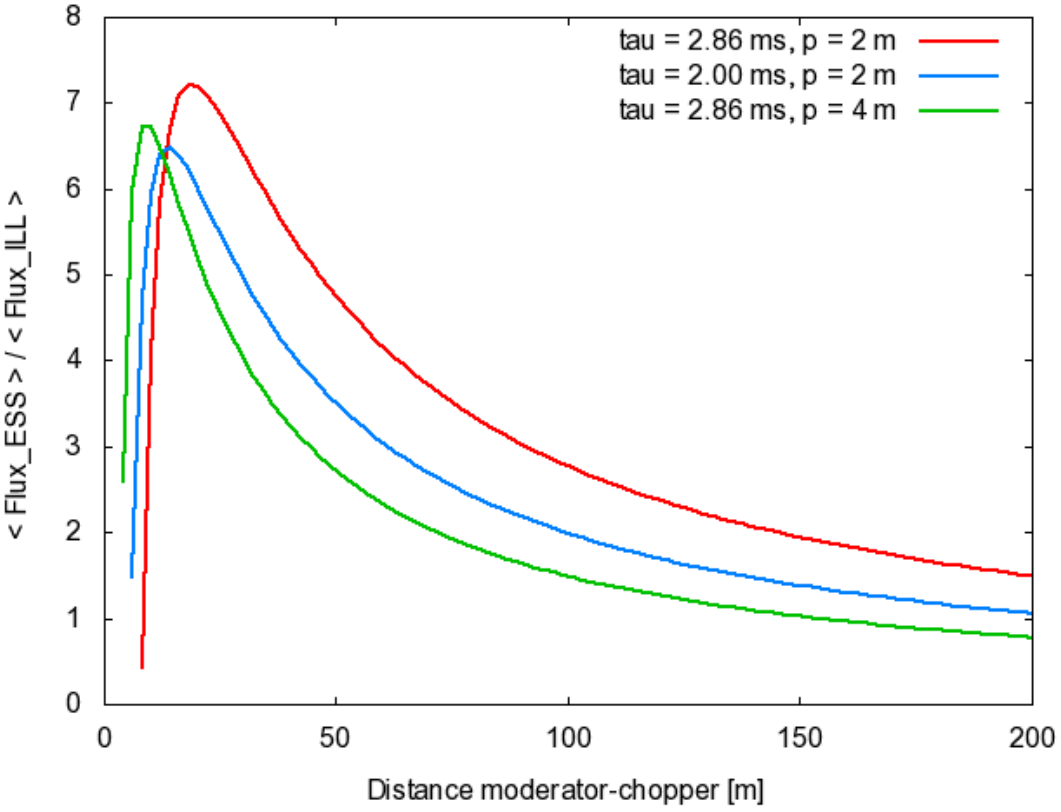


Distance ↔ Bandwidth



C. Klauser et al, Phys. Proc. 51 (2014) 46

PERC@ESS – almost ideal time structure



Requirement 2

Only one pulse in PERC

→ Optimum chopper frequency (70 Hz)

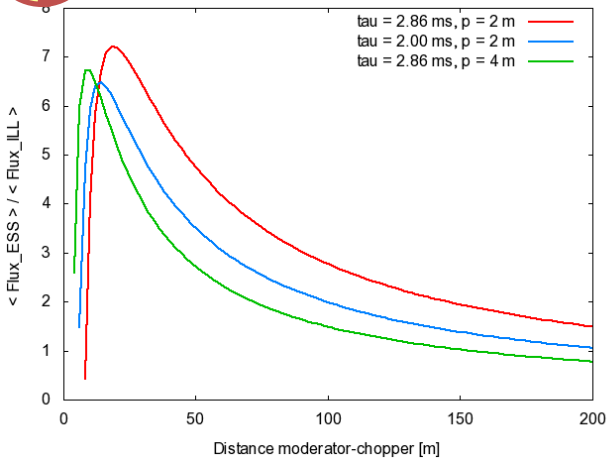
Fixed at ESS to 14 Hz

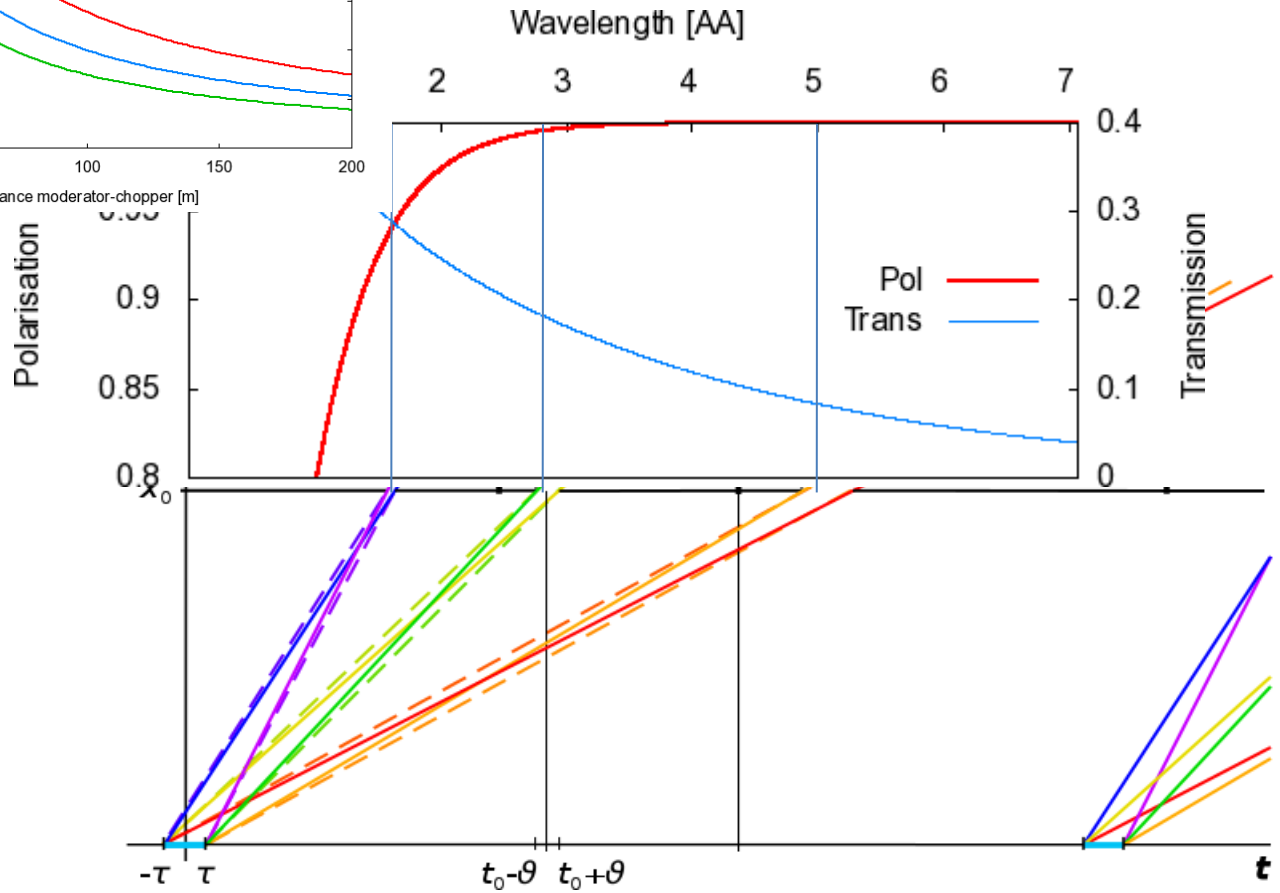
Advantage reactor

→ Substantial gain in intensity possible

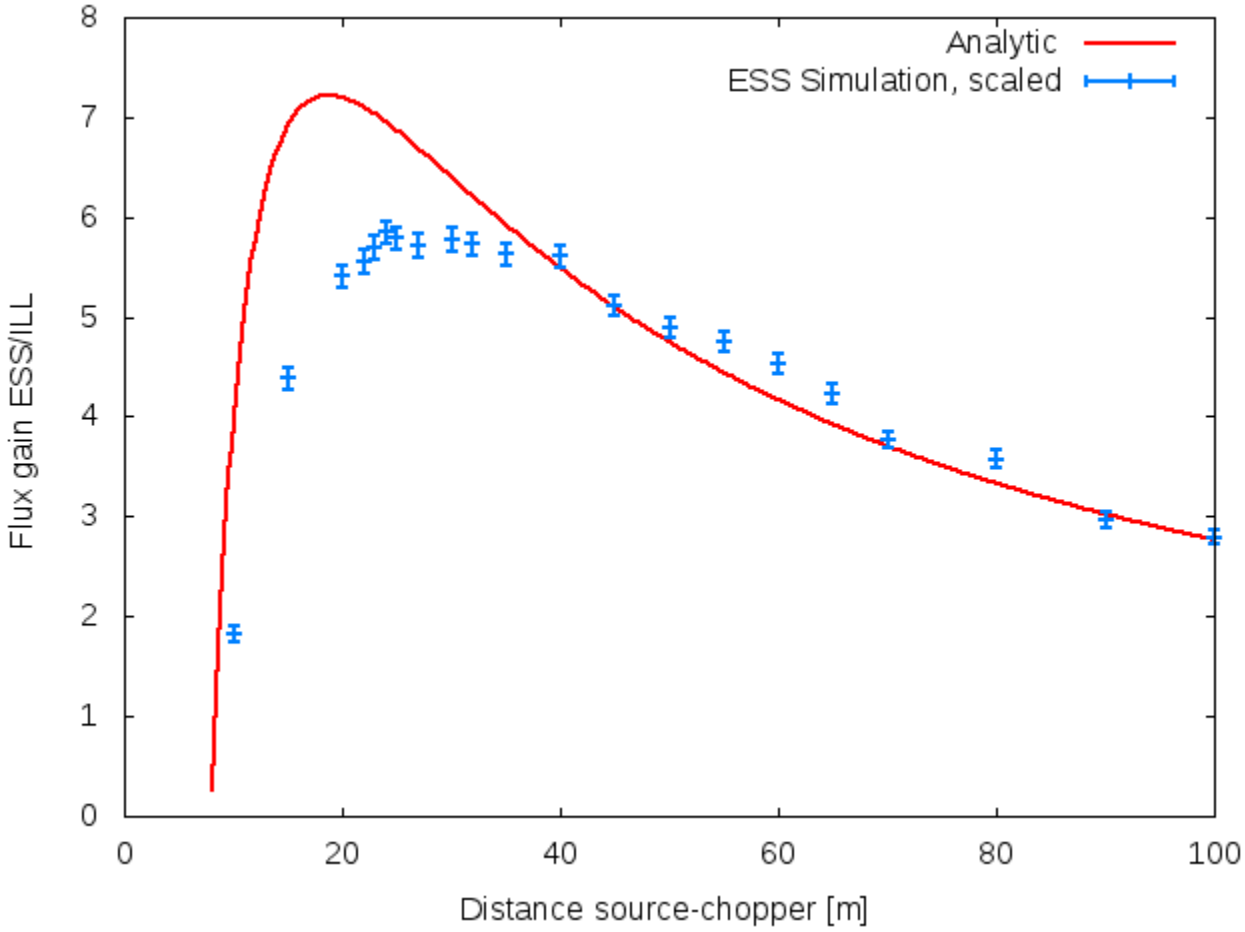
C. Klauser et al, Phys. Proc. 51 (2014) 46

PERC@ESS – Wavelength Frame Multiplication





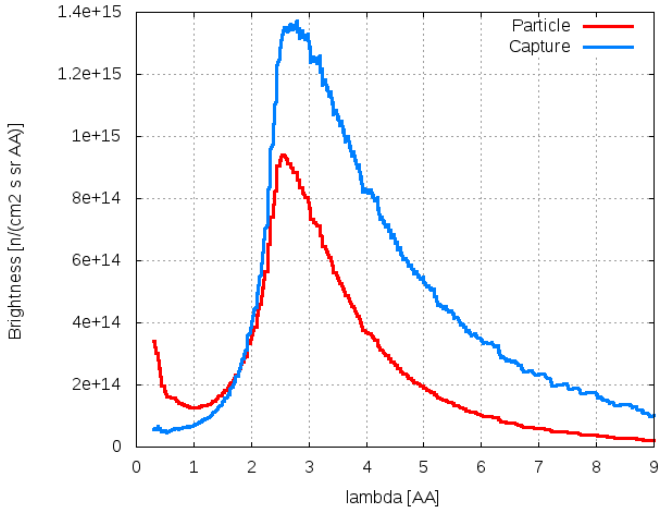
Status – First MC simulations

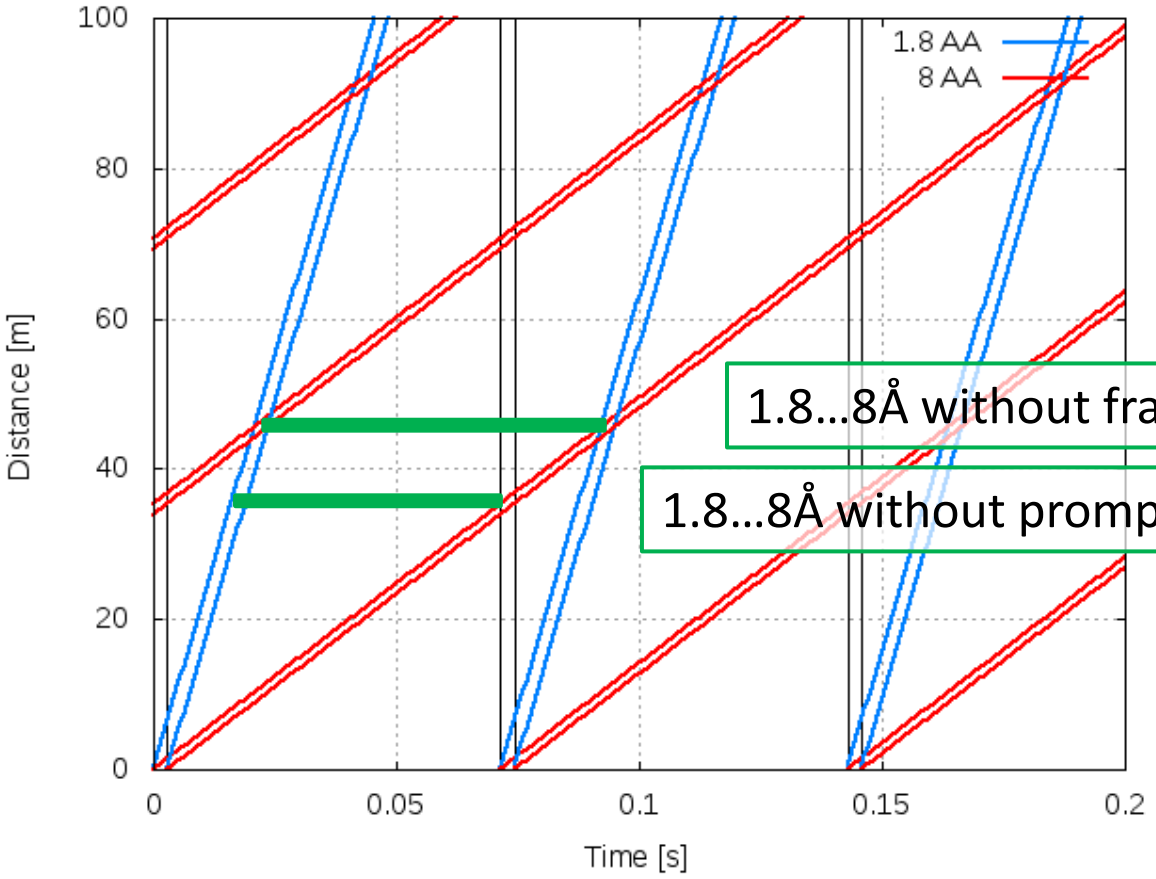


C. Theroine et al, Beamline proposal, in preparation

Beamline design – requirement 1

Maximum time-averaged flux with wavelength information





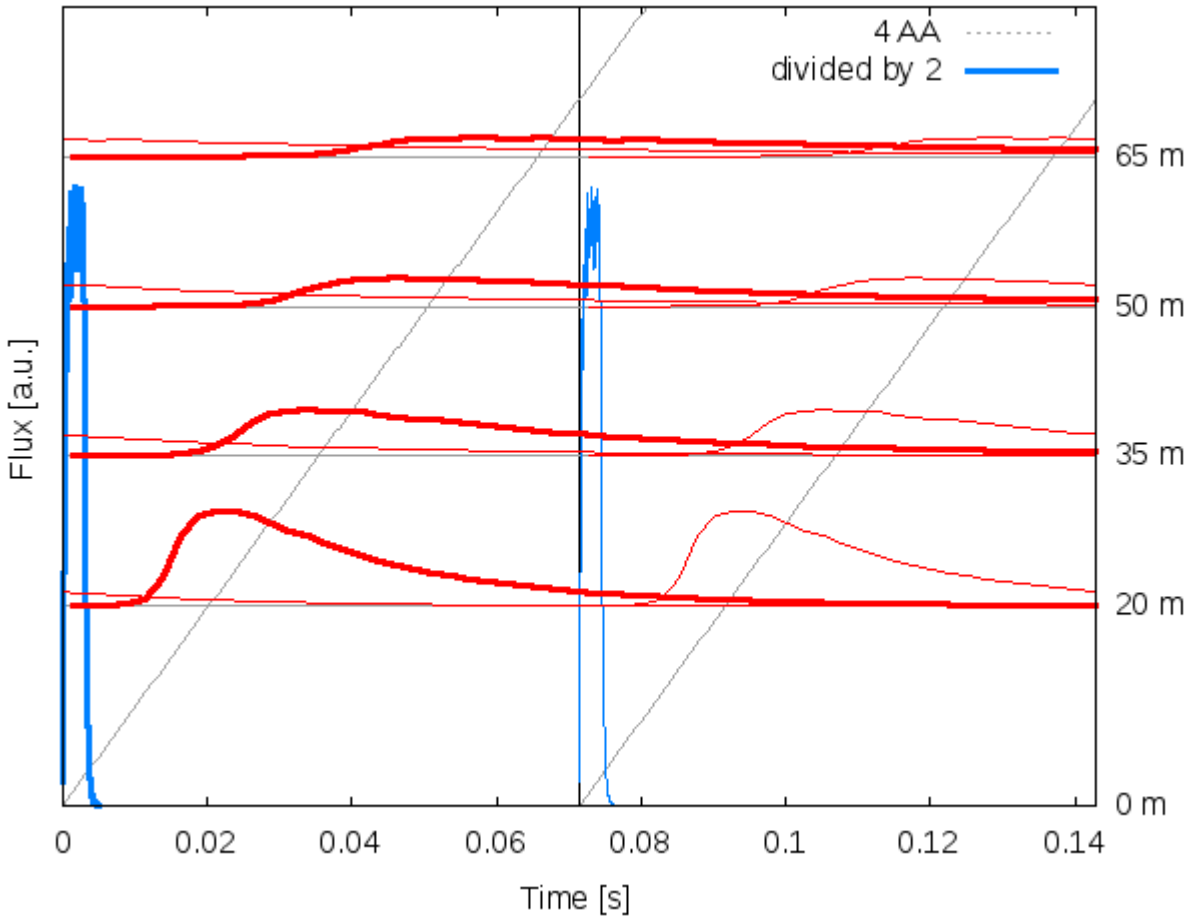
1.8…8Å without frame overlap → 45 m

1.8…8Å without prompt pulse → 35 m

Note: This is distance to "detector"

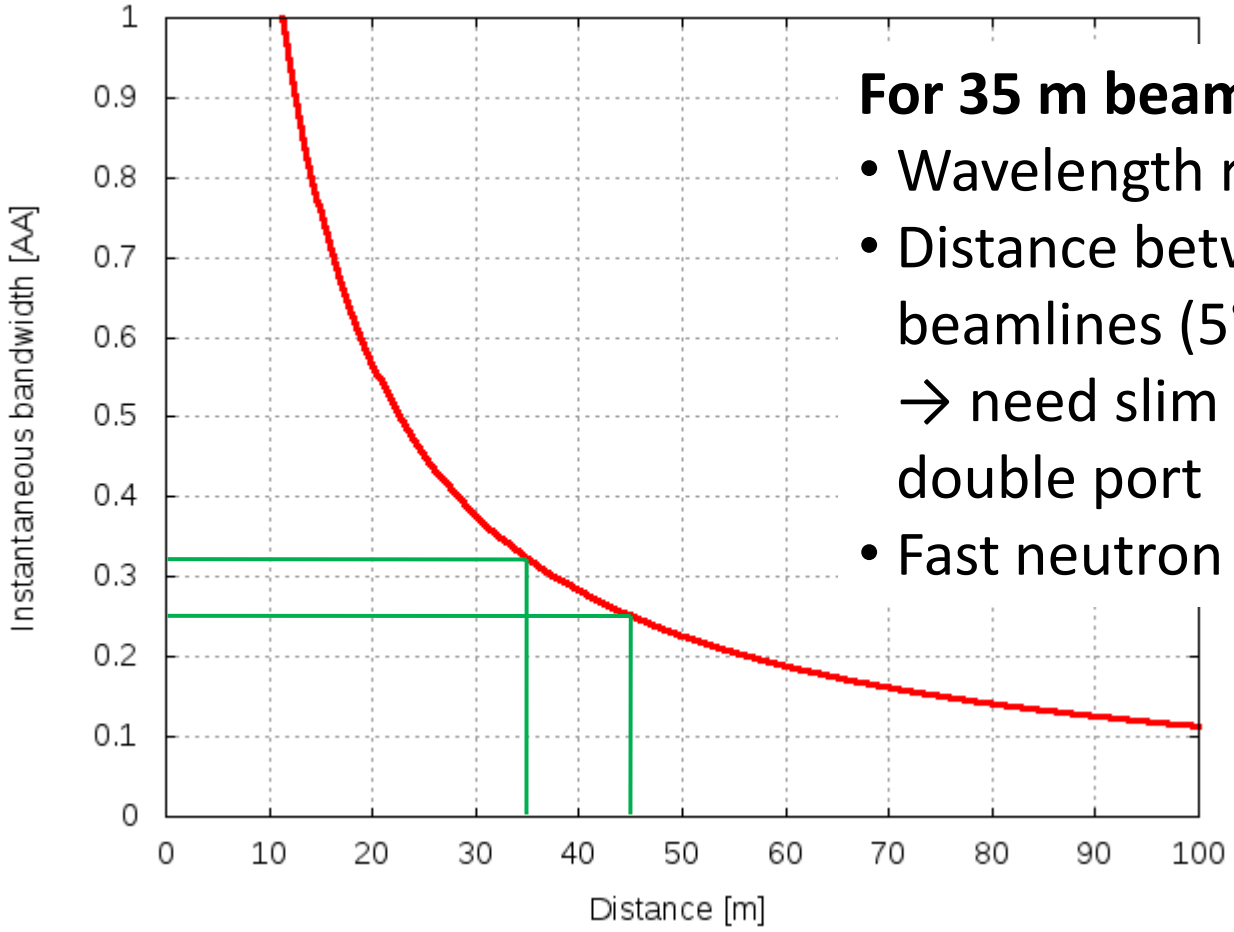
Beamline design – requirement 2

Well-pronounced pulse structure (see aSPECT)



Beamline design – requirement 3

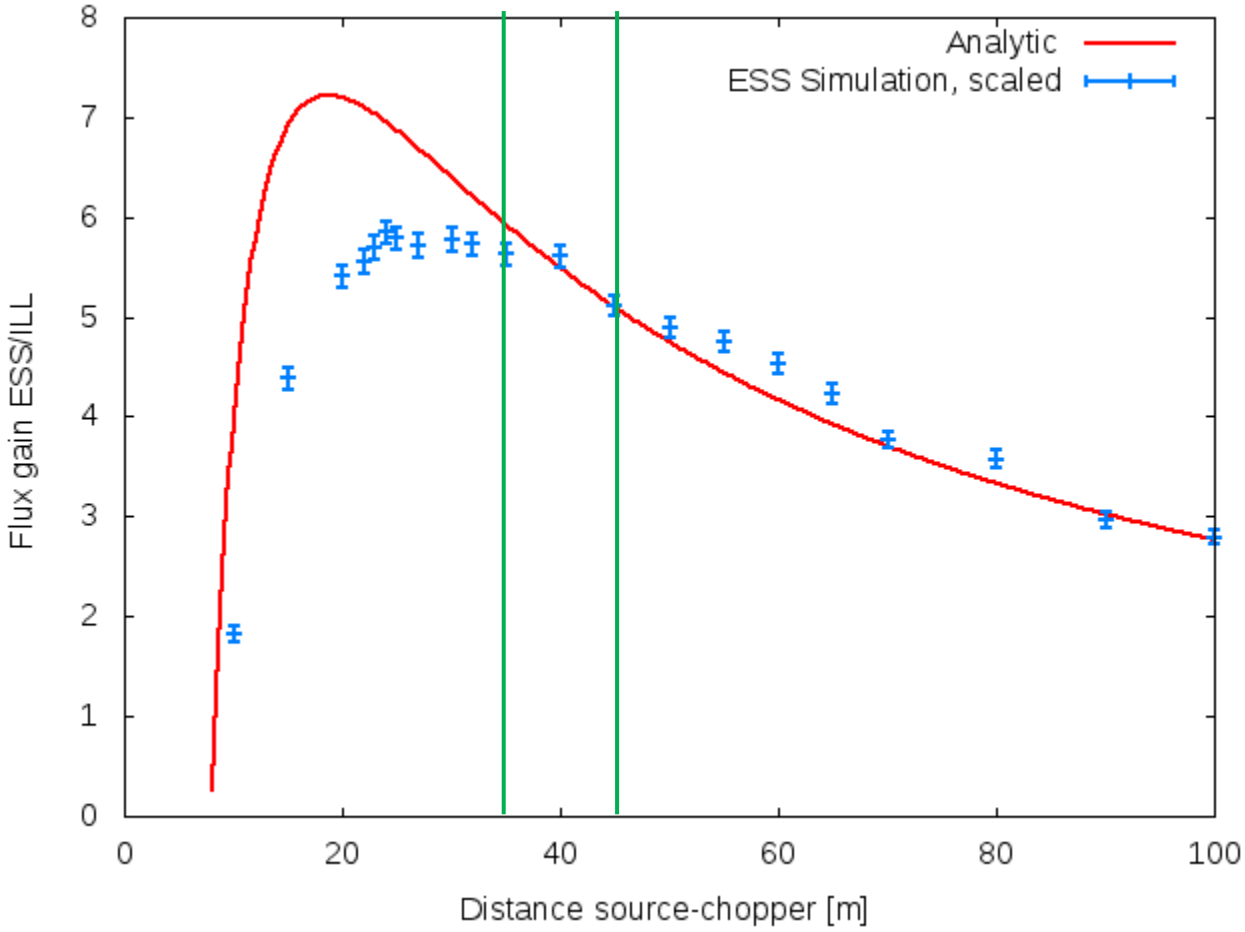
Reasonable wavelength resolution (instantaneous bandwidth)



For 35 m beamline:

- Wavelength resolution 0.3 Å
- Distance between beamlines (5°): 3 m
  → need slim neigbours or double port
- Fast neutron background?

Fits well for PERC



Without wavelength frame multiplication

Guide optimisation

Long instruments (PERC) best for long-pulse source

→ Use moderator brilliance to parallelize beam?

Q: Best guide height?

Focussing option for high flux and large divergence : npdγ, aSPECT

Looks similar to UCN cold guide design but:

- UCN source should reach larger acceptance
- UCN: No reason for short cold guide – better gain in background & space

Physics case

- No European strategy (in contrast to the US)
- Strong groups & projects in cold neutron decay – Strong physics programme with PERC
- This workshop?

Benchmark experiments:

- ξ PERC (guide)
- τ aSPECT (large diverg.)
- ξ PERKEO II (low divergence)
- λ npdγ (target)

Summary

- The ESS is going to be! First pulsed source with same time-averaged flux as ILL!
- Particle physics can profit from
  - –Green-field features (still)
  - –Pulse structure:
    - Wavelength information for free
    - Time and spatial localisation of pulse
    - →Cleaner systematics
- Proposals in next round:
  - –Beam UCN source with optimised cold neutron extraction
  - –Cold beamline of about 35 m length
- You are welcome to join!