A NEW METHOD TO FIND OUT THE OPTIMAL NEUTRON MODERATOR SIZE BASED ON NEUTRON SCATTERING INSTRUMENT PARAMETERS

Peter Konik[1,*], Alexander Ioffe[2]

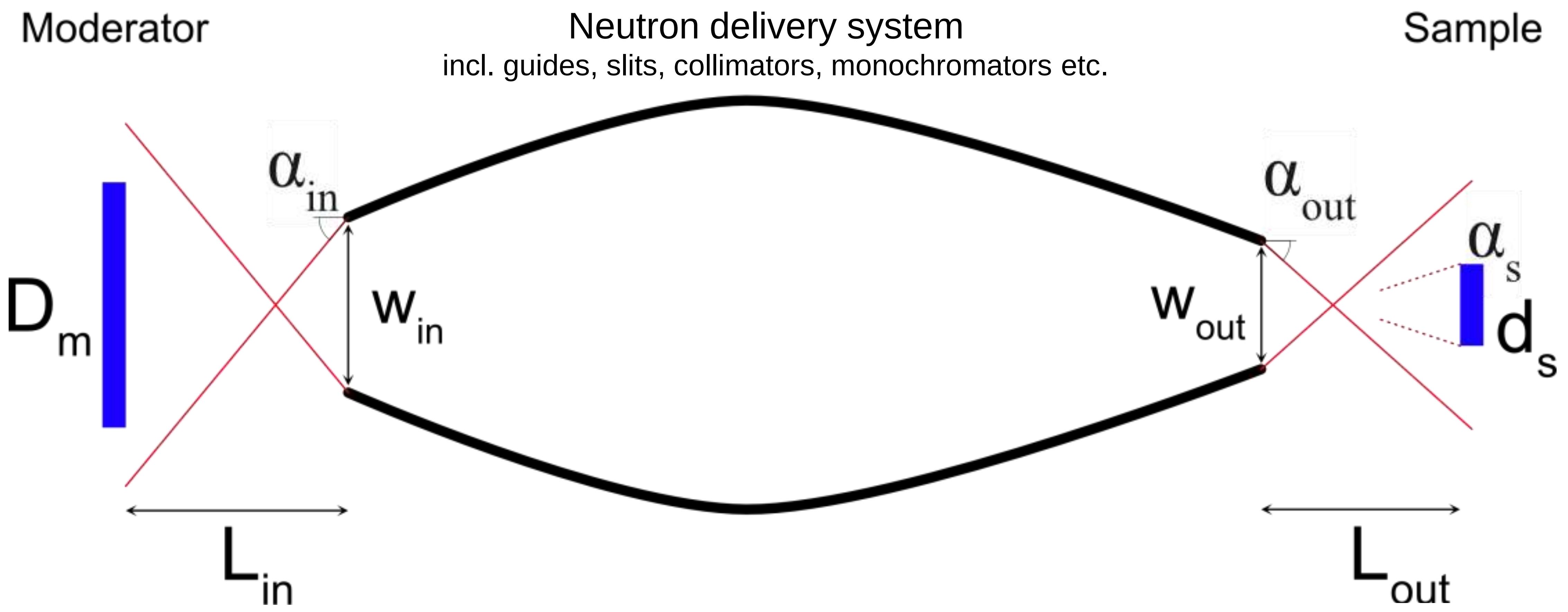
[1]Neutron Spectroscopy Laboratory, HUN-REN Centre for Energy Research, Budapest, Hungary
[2]Jülich Centre for Neutron Science (JCNS) at Heinz Maier-Leibnitz Zentrum (MLZ)
Forschungszentrum Jülich GmbH, Germany

ICANS XXIV meeting

** Previous address: Jülich Centre for Neutron Science (JCNS) at Heinz Maier-Leibnitz Zentrum (MLZ), Forschungszentrum Jülich GmbH, Germany*

LET'S BUILD A NEW INSTRUMENT

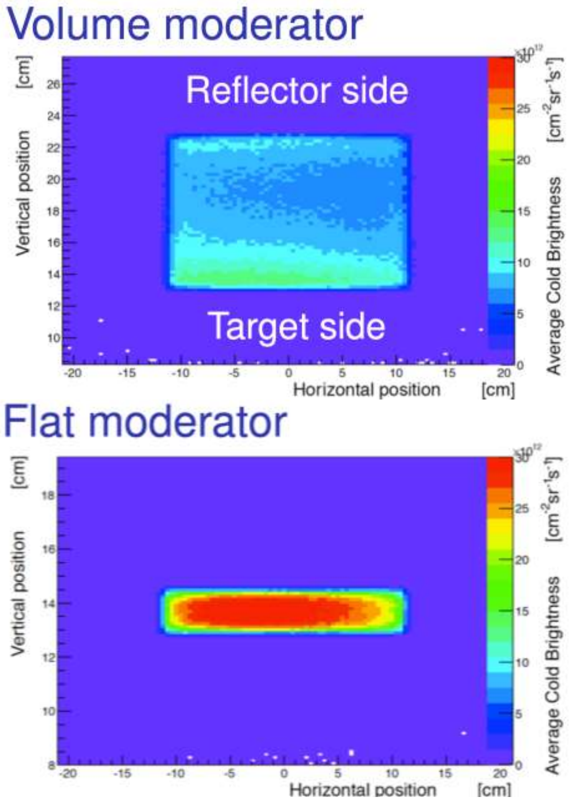
- Given are sample size d_s and angular resolution $\boldsymbol{\alpha}_s$
- L_{in} and L_{out} are constraints
- No preliminary information about guide shape or coating ($\boldsymbol{\alpha}_{\text{in}}$, $\boldsymbol{\alpha}_{\text{out}}$, w_{in}, w_{out} are free parameters)



CHOICE OF MODERATOR

Why smaller moderator?

- Better target coupling
- Less absorption
- Increased briliance for pH2

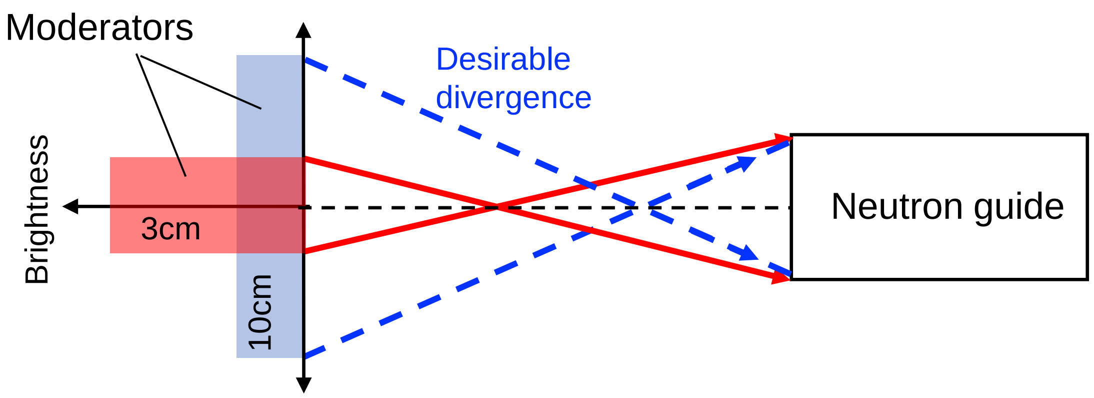


K. Batkov, A. Takibayev, L. Zanini, F. Mezei NIM A729 (2013) 500.

Why larger moderator?

- Better thermalization
- Better guide entrance illumination

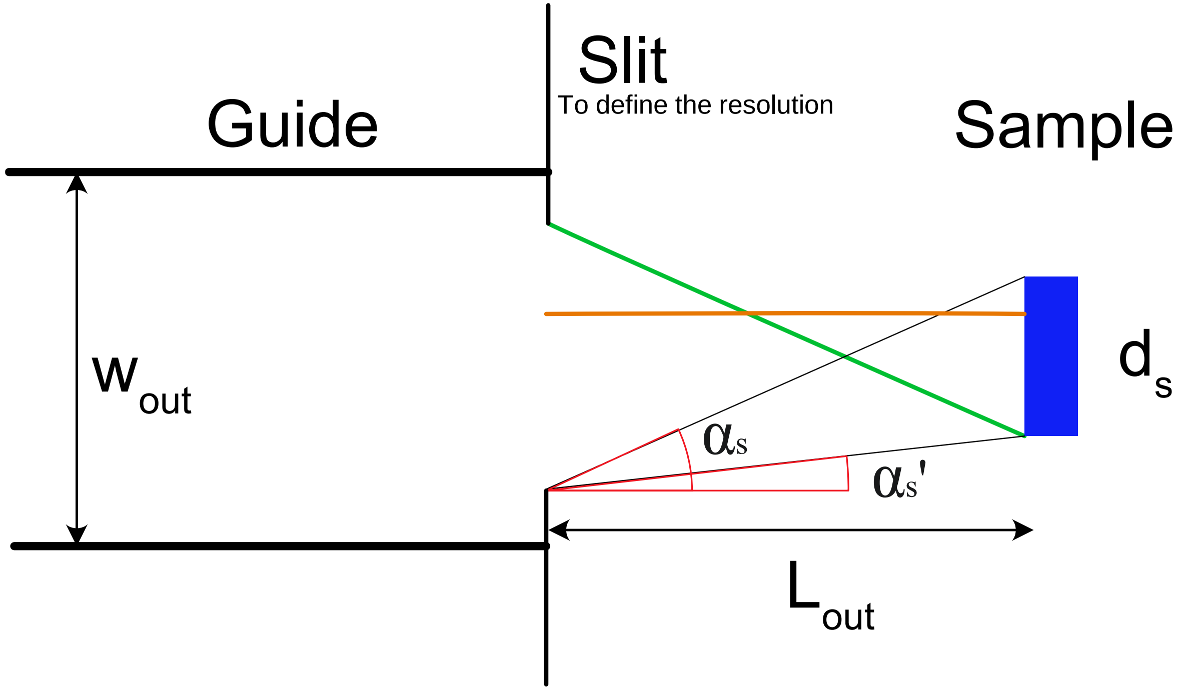
(but we don’t know entrance size or required divergence)



One needs to determine the moderator size providing highest brilliance, full sample illumination and minimal background (over-illumination) at the sample

INSTRUMENT REQUIREMENTS

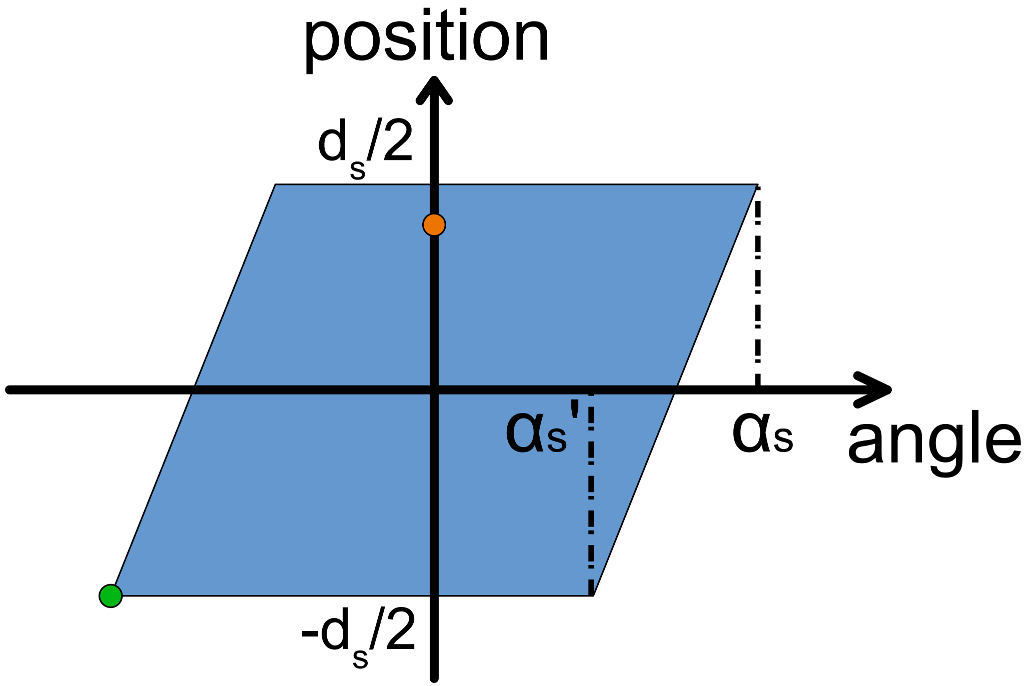
Real space



Phase space (PS)

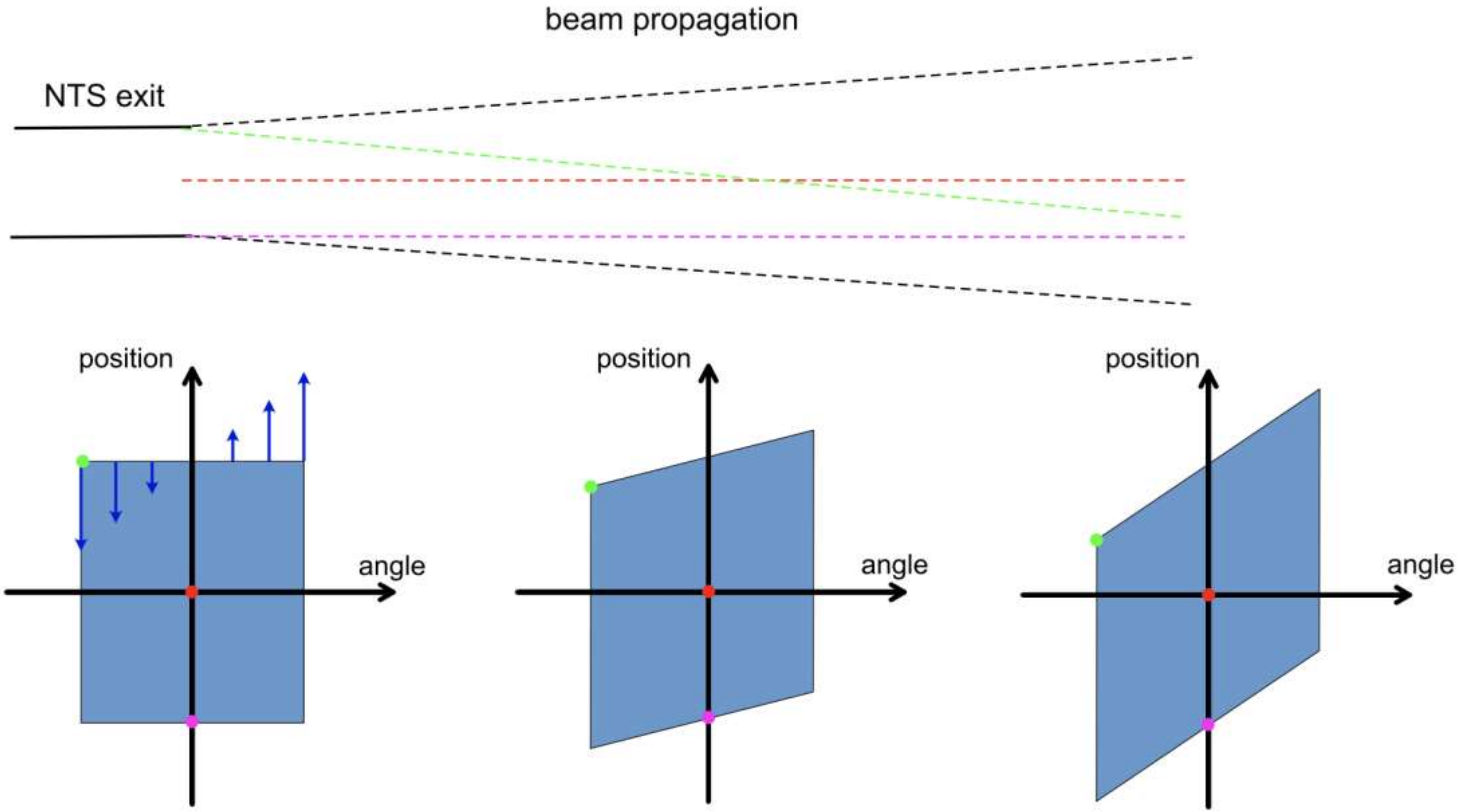
Each point = one trajectory

Method developed by JRD Copley, M Bertelsen



$$V_S = d_S(\alpha_S + \alpha_S')$$

BEAM PROPAGATION



PHASE SPACE (PS) FOCUSING AT GUIDE EXIT

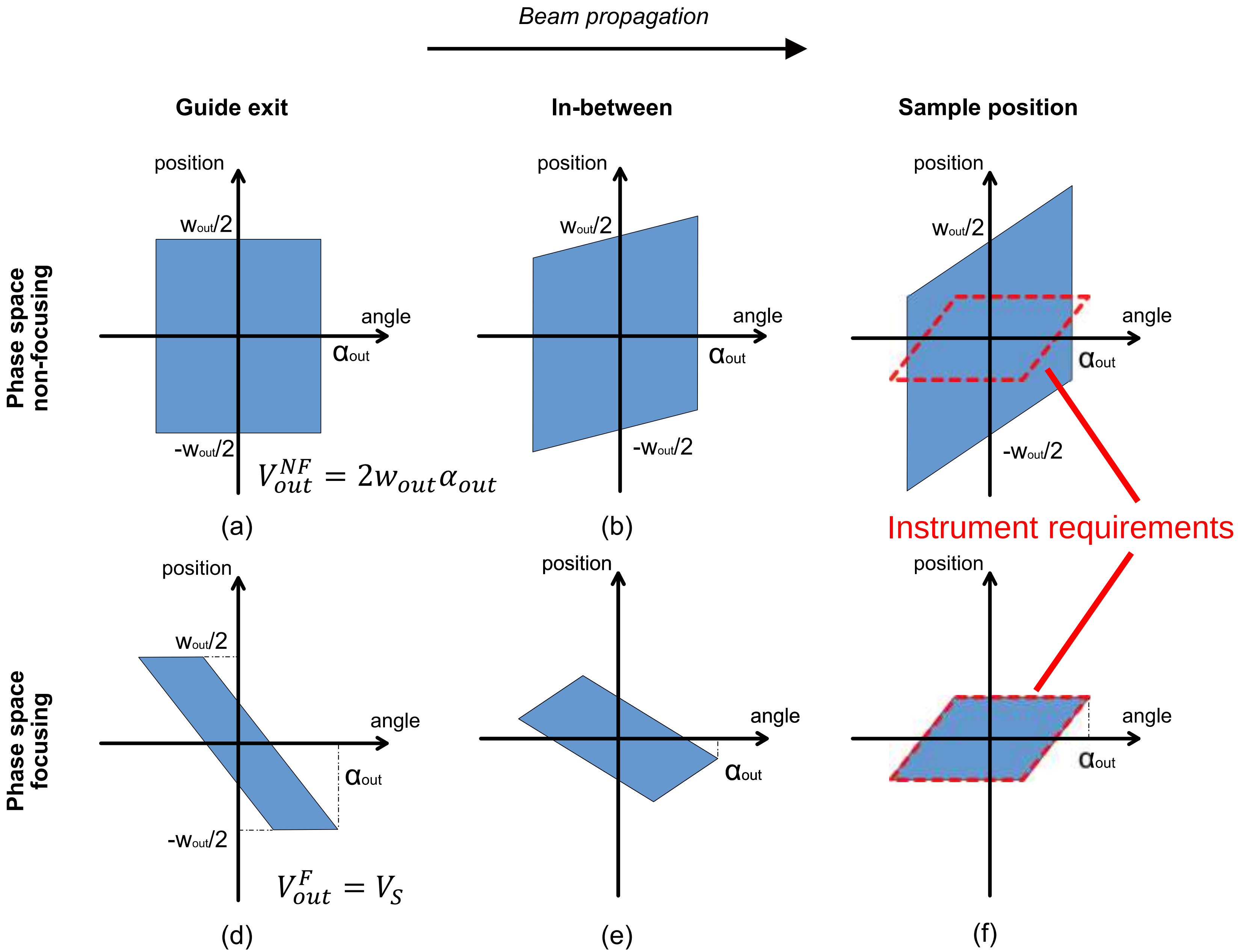
PS focusing ≠ real space focusing

PS-non focusing (PS-NF) – no angle-position correlations

e.g. straight guide

PS-focusing (PS-F) – specific beam correlations, leading to exact phase volume shape at given distance

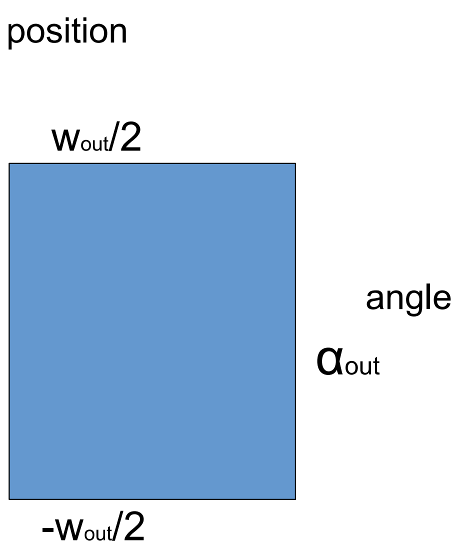
May be e.g. elliptic focusing nose, but not necessarily



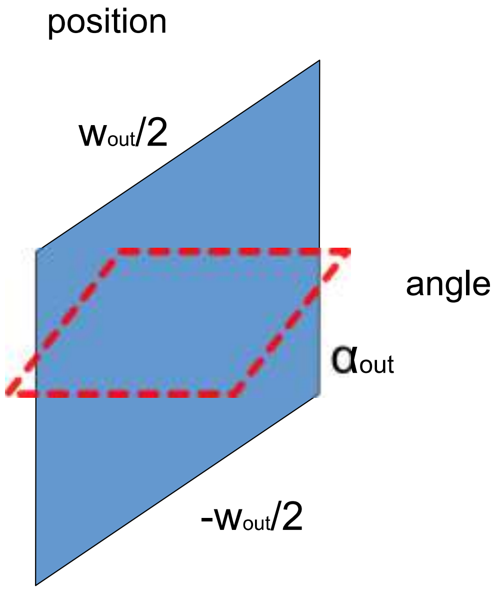
BEAM AFTER GUIDE EXIT

Phase space non-focusing guide

Guide exit



Sample



Ideal illumination conditions:

- Full sample illumination (max flux)

$$\alpha_{out} = \alpha_S$$

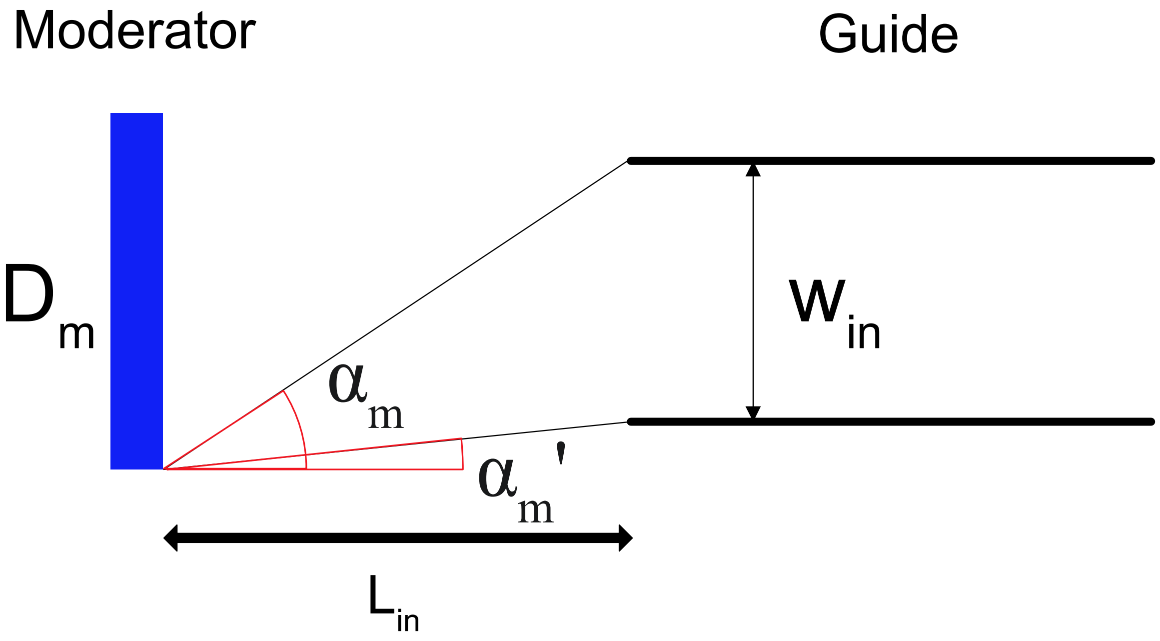
- Minimal over-illumination (min BG)

$$w_{out} = 2L_{out} \tan \alpha_S - d_s$$

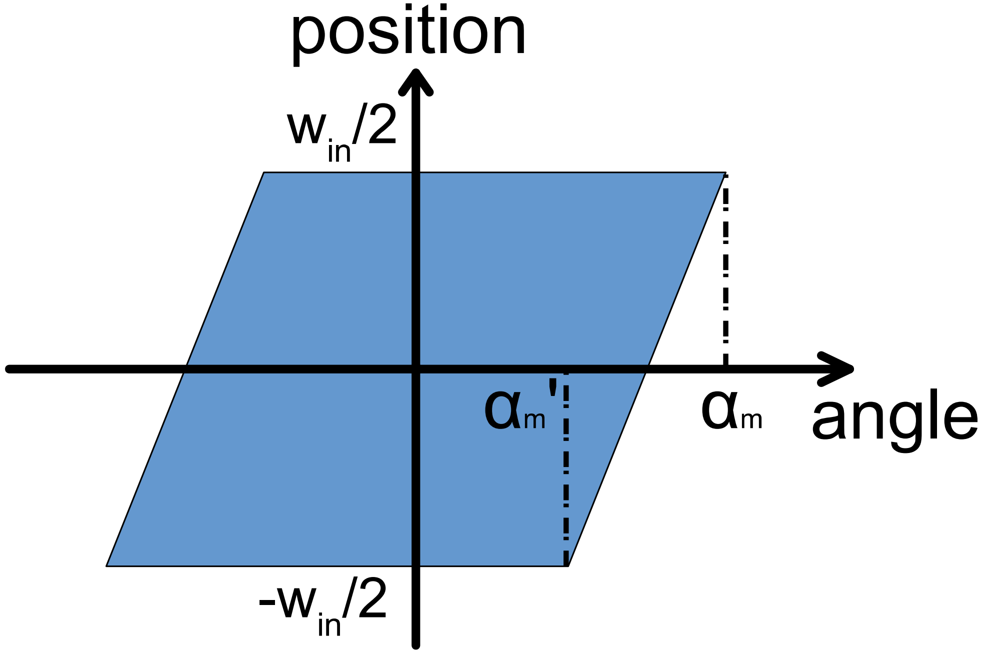
Conditions are also true for PS-F case

GUIDE ENTRANCE

Real space



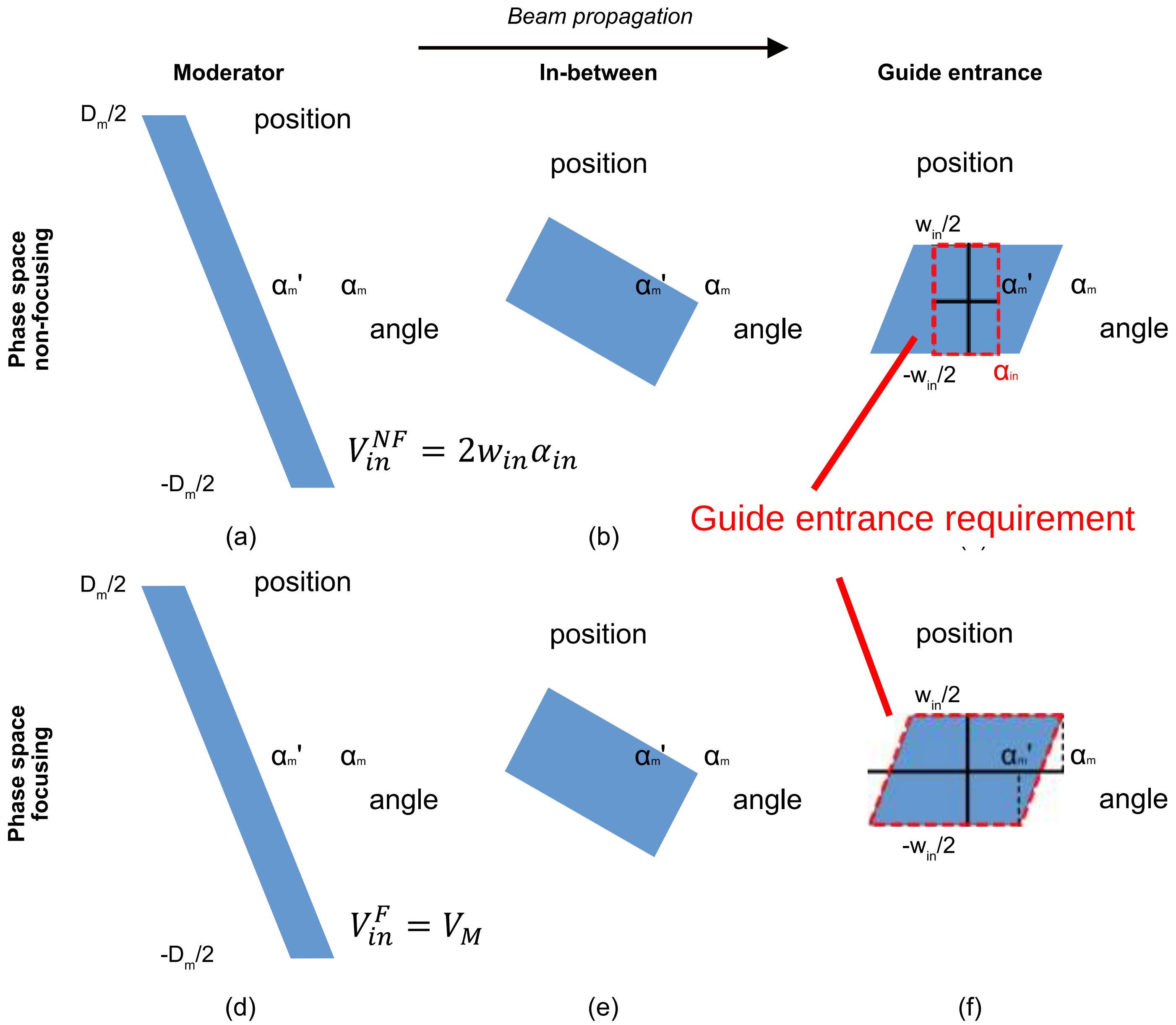
Phase space (PS)



$$V_M = w_{in}(\alpha_M + \alpha'_M) =$$

$$w_{in}\left(arc\tan\frac{D_m + w_{in}}{2L_{in}} + arc\tan\frac{D_m - w_{in}}{2L_{in}}\right)$$

PS FOCUSING AT GUIDE ENTRANCE



PS-NF – accepted (= transported to guide exit) beam has no correlation

Almost any guide

PS-F – accepted beam has specific correlation, allowing to capture all neutrons from moderator

May be lens or Selene guide, but not necessarily

CURVES OF OPTIMAL AND FULL SAMPLE ILLUMINATION (COFSI)

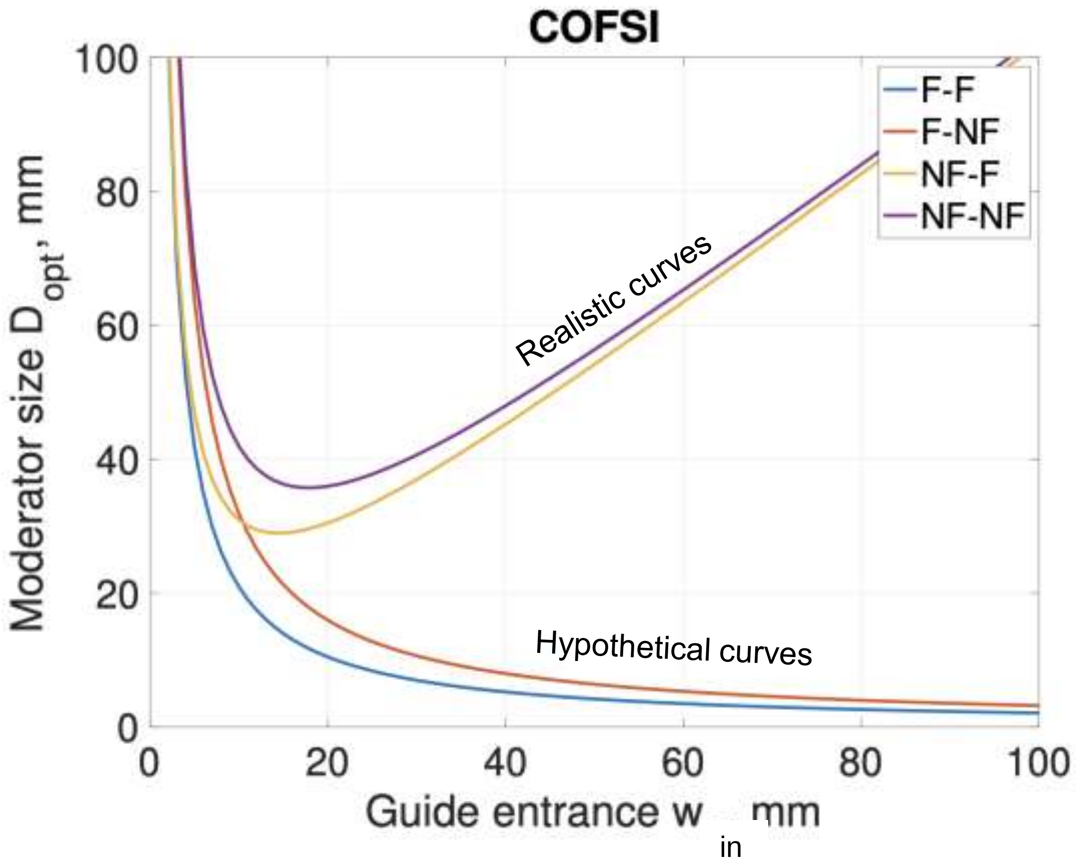
If 3 conditions are fulfilled simultaneously:

1. Guide natural divergence equals the instrument resolution
2. Guide exit provides perfect sample illumination
3. Moderator provides just enough neutrons

+ we assume ideal transport $V_{in}=V_{out}$ (Liouville theorem)

=> we can calculate D_{opt}

$D_{opt} =$		*NTS entrance* F	*NTS entrance* NF
NTS exit	F	$\frac{2d_s\alpha_s L_{in}}{w_{in}}$	$\frac{2d_s\alpha_s L_{in}}{w_{in}} + w_{in}$
NTS exit	NF double-slit	$\frac{2d_s\alpha_s L_{in}}{w_{in}} \cdot \frac{n}{n-1}$	$\frac{2d_s\alpha_s L_{in}}{w_{in}} \cdot \frac{n}{n-1} + w_{in}$
NTS exit	NF Soller or natural	$\frac{2d_s\alpha_s L_{in}}{w_{in}} + \frac{4\alpha_s^2 L_{in} L_{out}}{w_{in}}$	$\frac{2d_s\alpha_s L_{in}}{w_{in}} + \frac{4\alpha_s^2 L_{in} L_{out}}{w_{in}} + w_{in}$



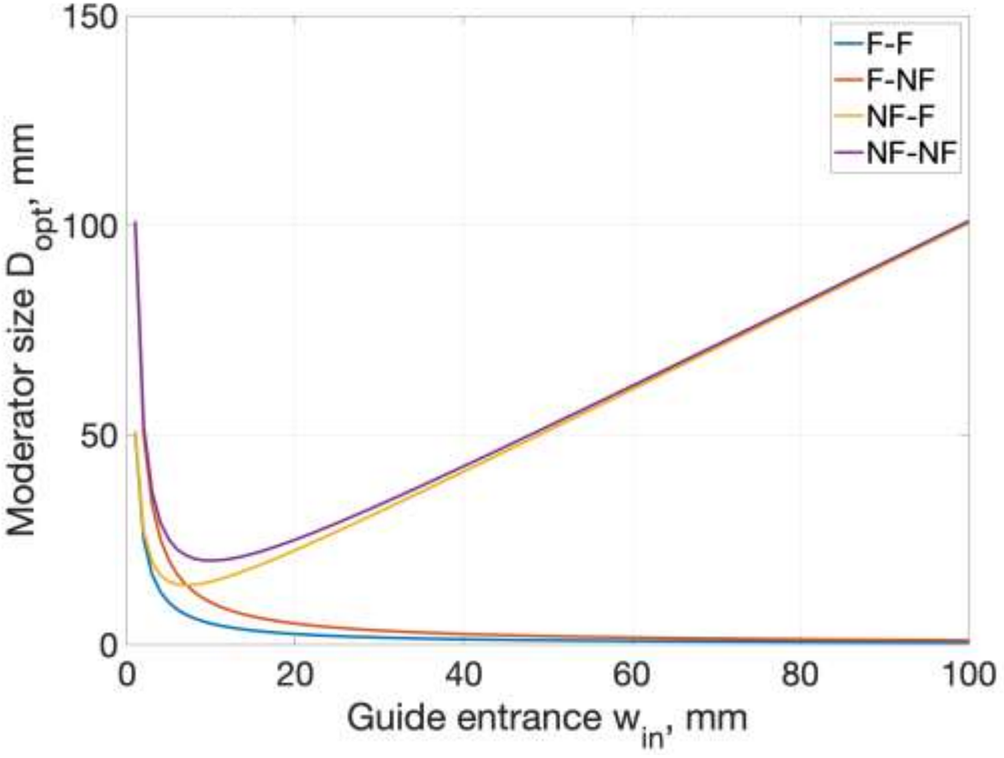
COFSI is defined by only 4 parameters (sample size, resolution, distances)

COFSI EXAMPLES (I)

Brilliance-hungry instrument

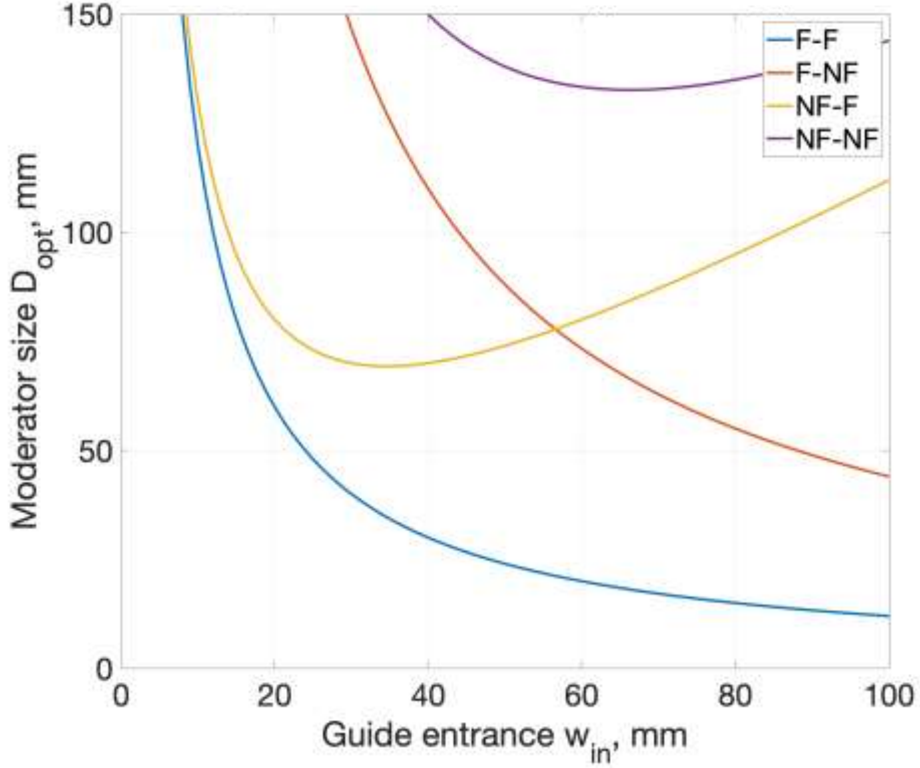
Flux-hungry instrument

Reflectometer



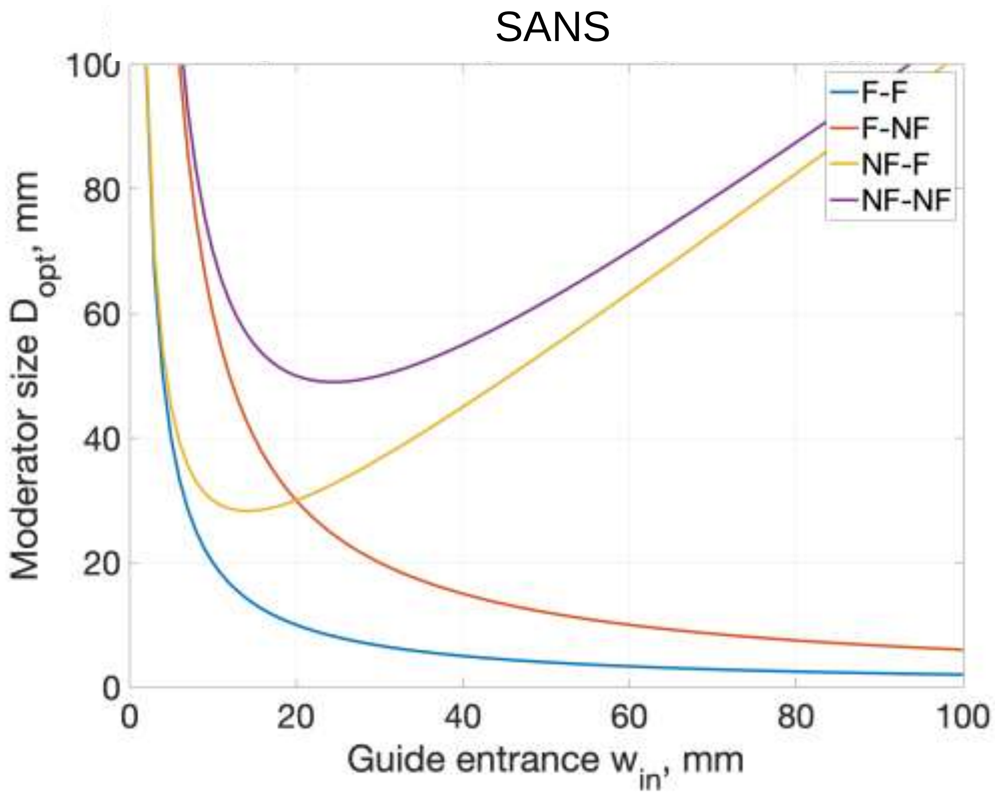
10 mm	d_s	30 mm
0.14°	α_s	0.8°
2 m	L_{in}	2 m
4 m	L_{out}	4 m

Spin-echo



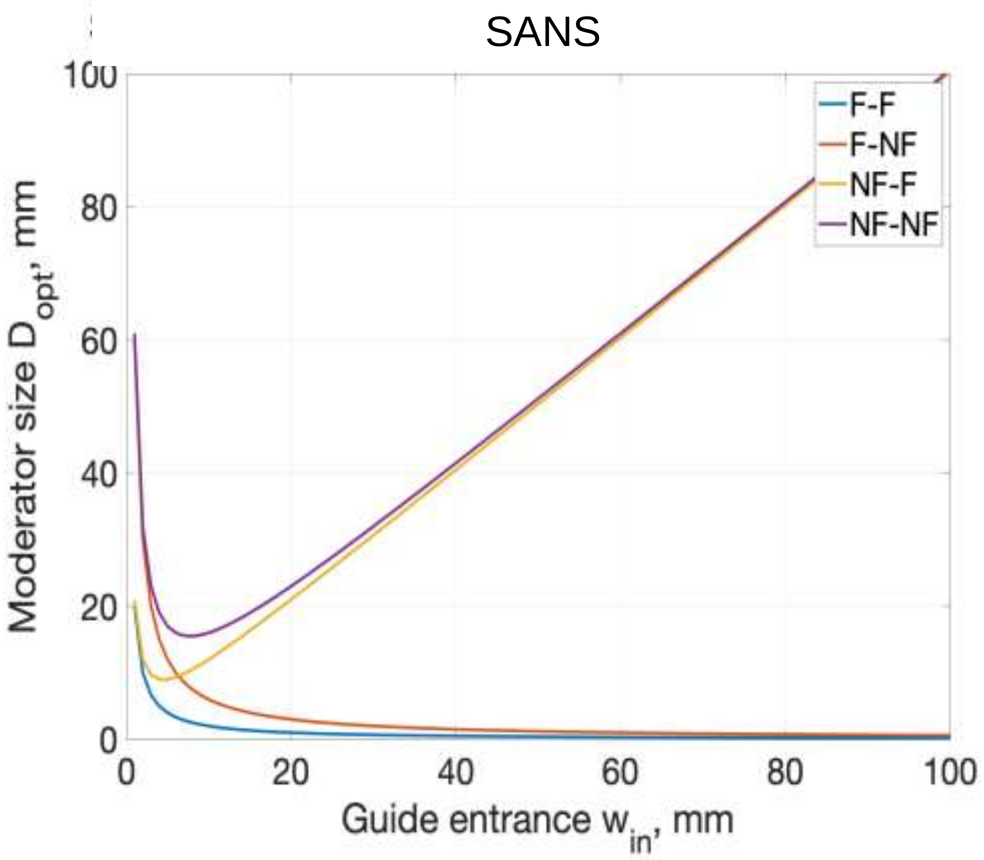
COFSI EXAMPLES (II)

High-Q mode



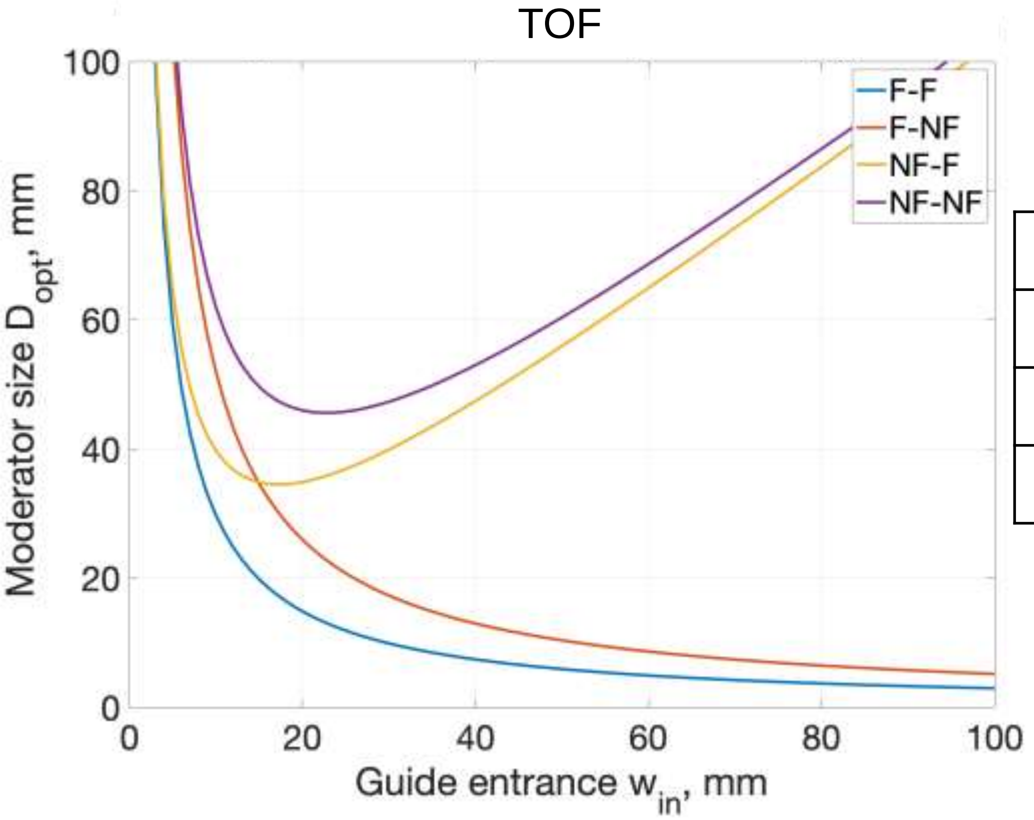
10 mm	d_s	10 mm
0.40º	α_s	0.04º
2 m	L_{in}	2 m
2 m	L_{out}	20 m

Low-Q mode



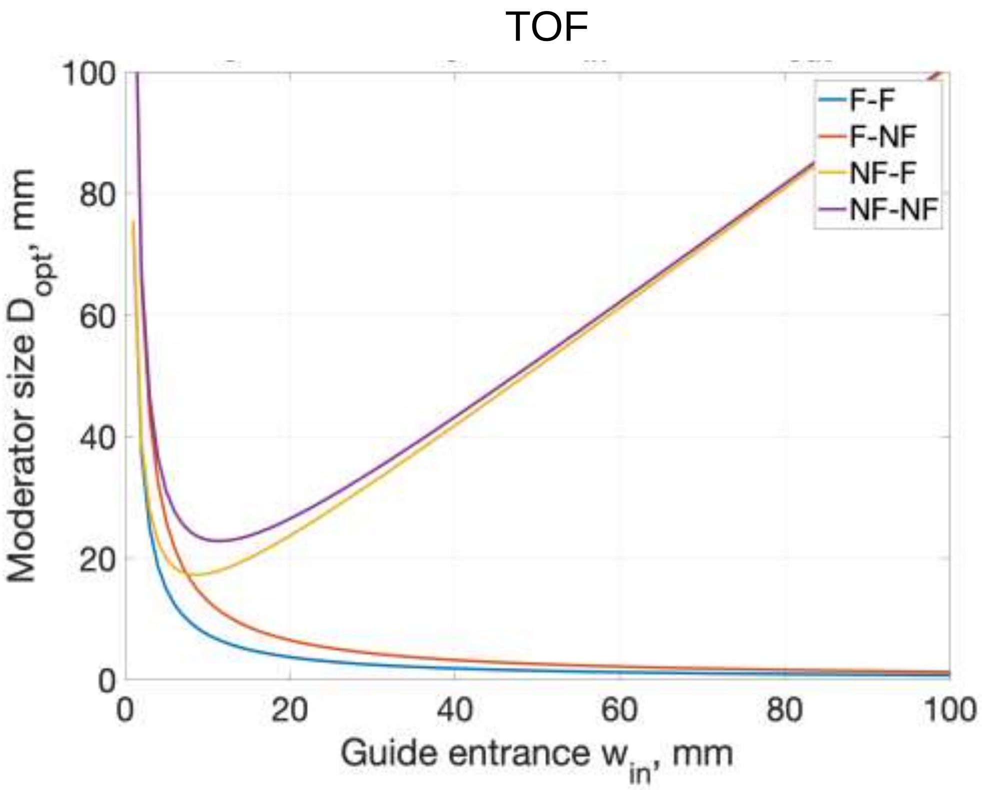
COFSI EXAMPLES (III)

Traditional source



10 mm	d_s	10 mm
1°	α_s	1°
2 m	L_{in}	0.5 m
0.5 m	L_{out}	0.5 m

Compact source

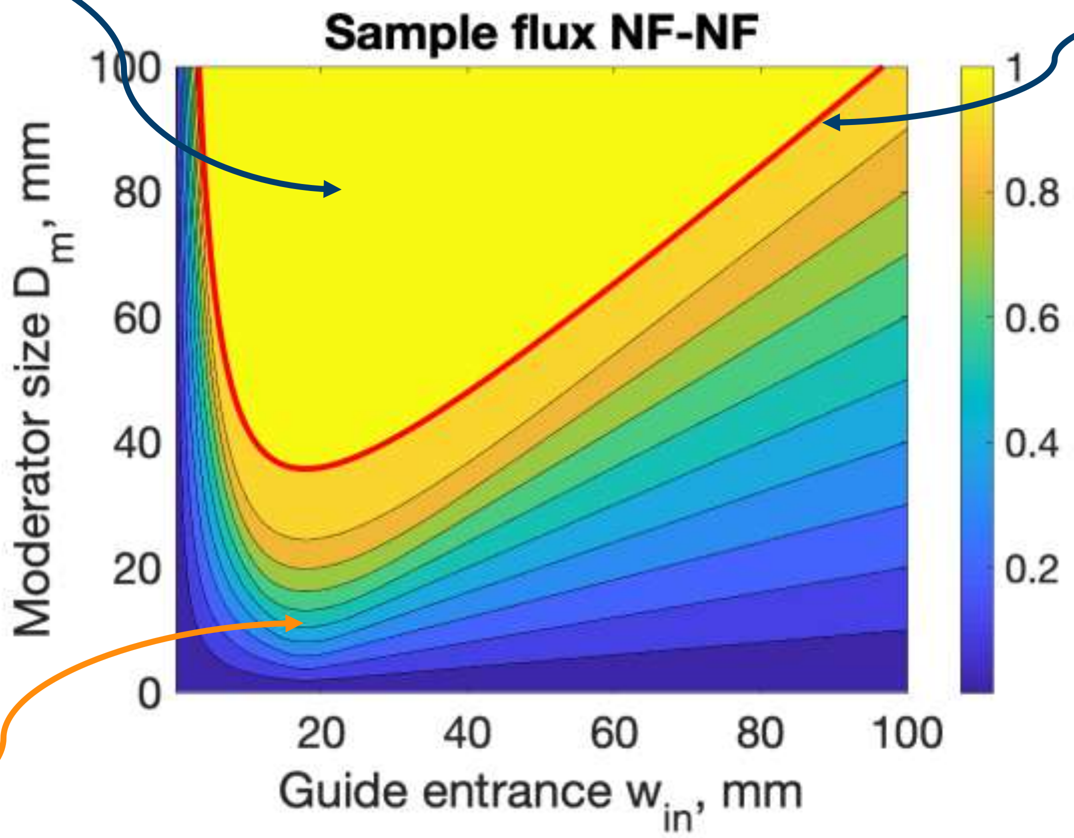


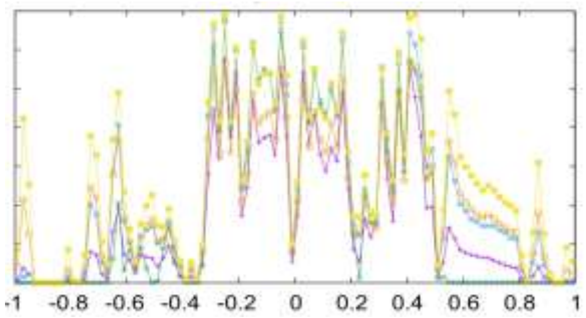
WHAT HAPPENS WHEN ONE DEVIATES FROM COFSI?

Sample illumination conditions are still true

Moderator over-illuminates guide entrance
Excessive neutrons are absorbed along the guide

COFSI: sample is fully illuminated
Minimal number of useless neutrons at sample

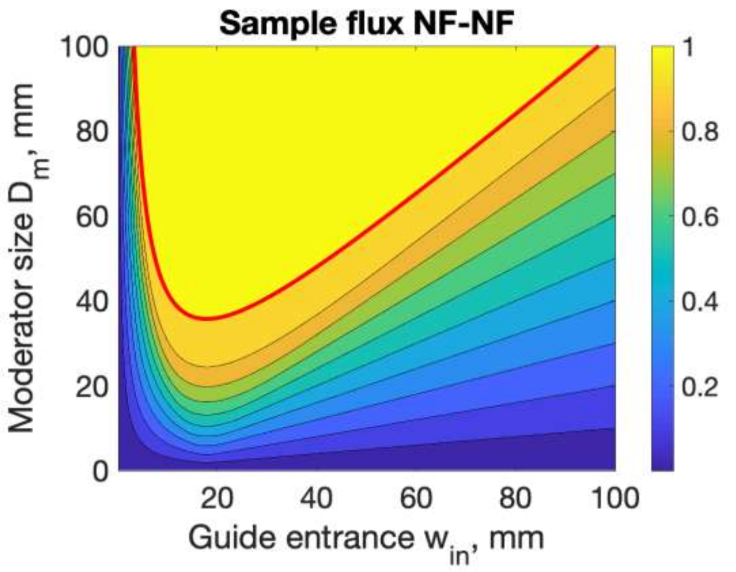




Moderator under-illuminates guide entrance
Useful sample flux reduced
“Gothic-like structure” of divergence

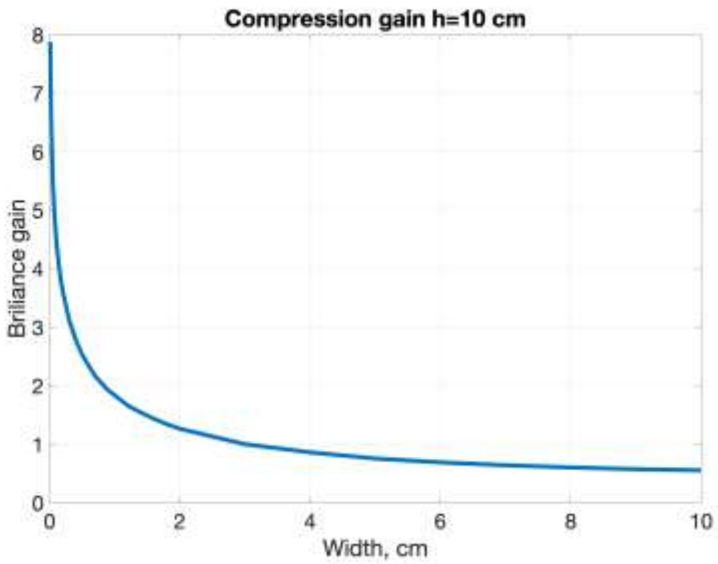
DEPENDENCE OF BRILLIANCE FROM THE SOURCE SIZE

Size-independent brilliance

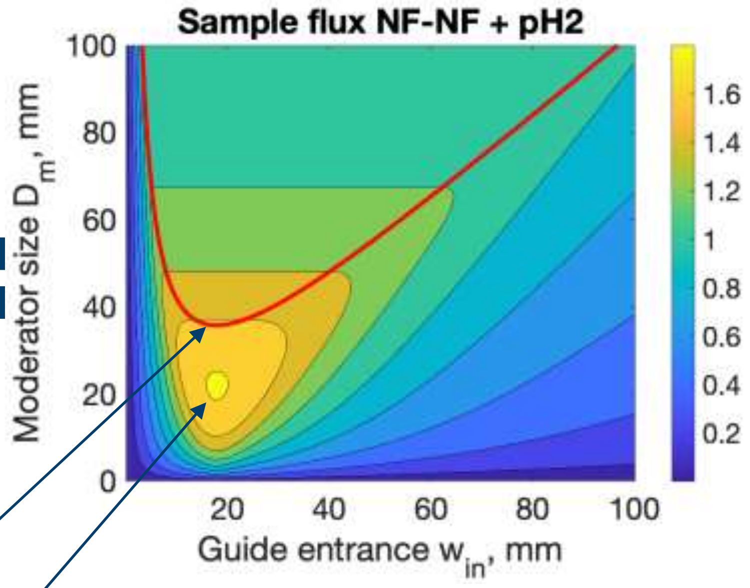


Size dependence for pH_2 flat moderator

(see Monday talk by A. Ioffe)



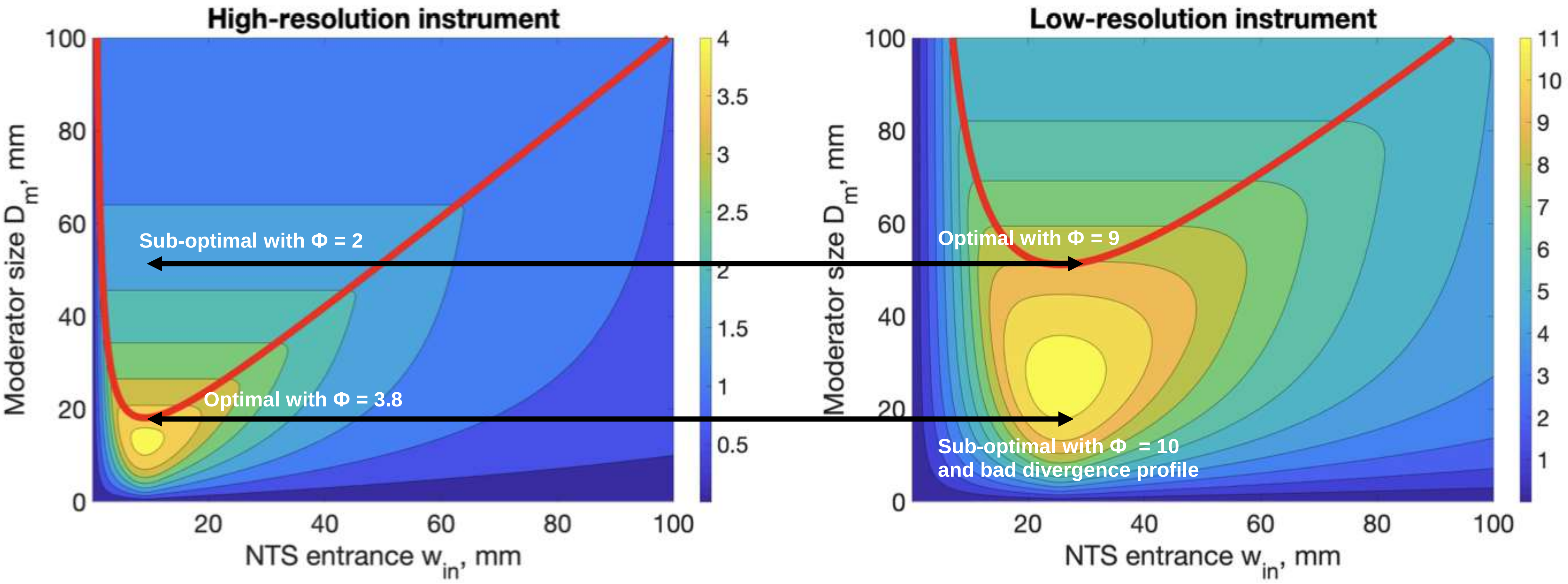
Size-dependent brilliance



High flux + ideal sample illumination

Higher flux + “gothic” divergence profile

OPTIMIZATION EXAMPLE FOR TWO INSTRUMENTS AT PH_2 MODERATOR



Best solution is probably close to D_{opt}=18 mm:

- HR instrument reaches best performance
- LR instrument gets very high (not maximum) flux
- LR instrument sample under-illumination probably does not compromise its operation
- LR instrument guide entrance is larger than that of HR instrument

CONCLUSION

- Moderator and guide entrance sizes both play key role in instrument design
- A method has been developed to find their optimal combination based only on 4 instrument parameters
  - Very fast and easy to use
  - MC calculations could be employed for better determination of guide PS type and to account for guide losses

- Hypothetical PS F-F guides potentially open possibility to use very small moderators with very high brilliance <u>for all instruments</u>

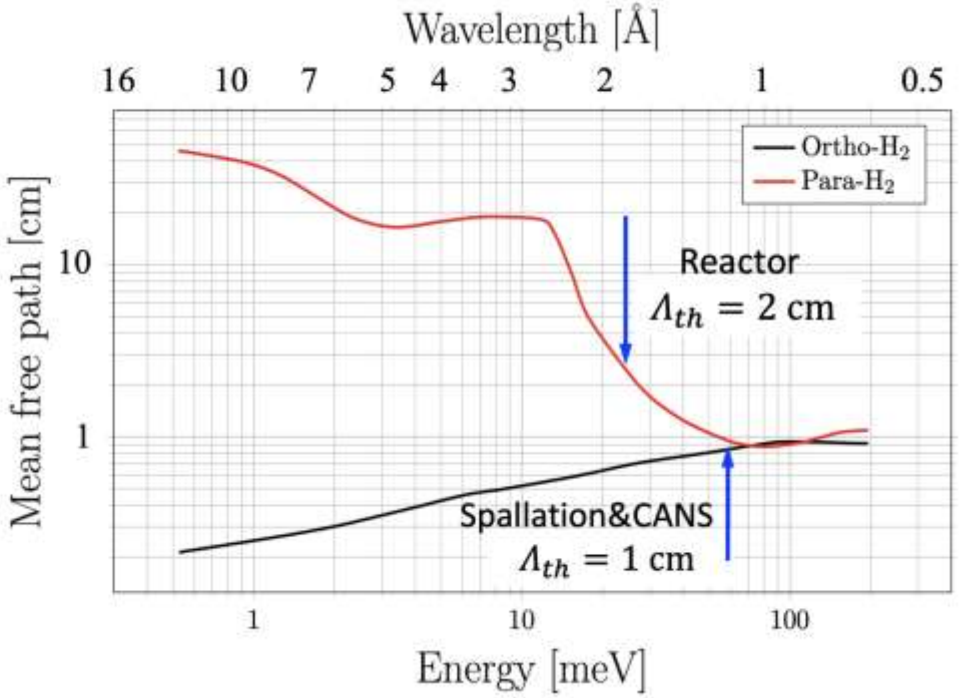
Konik, P., & Ioffe, A. (2023). A new method to find out the optimal neutron moderator size based on neutron scattering instrument parameters. *NIM A 1056, 168643*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 871072

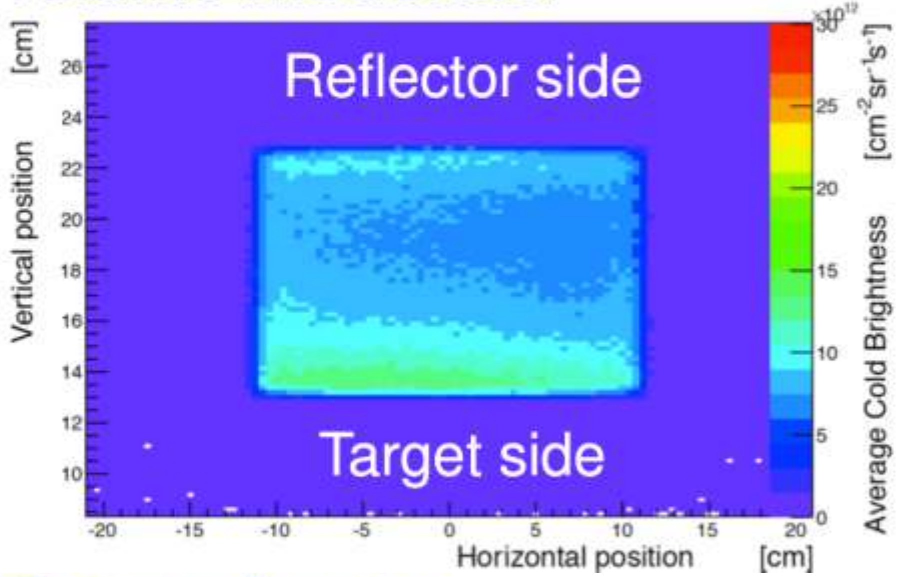
THANK YOU FOR ATTENTION!

HUN REN

PARA-H_2 MODERATORS



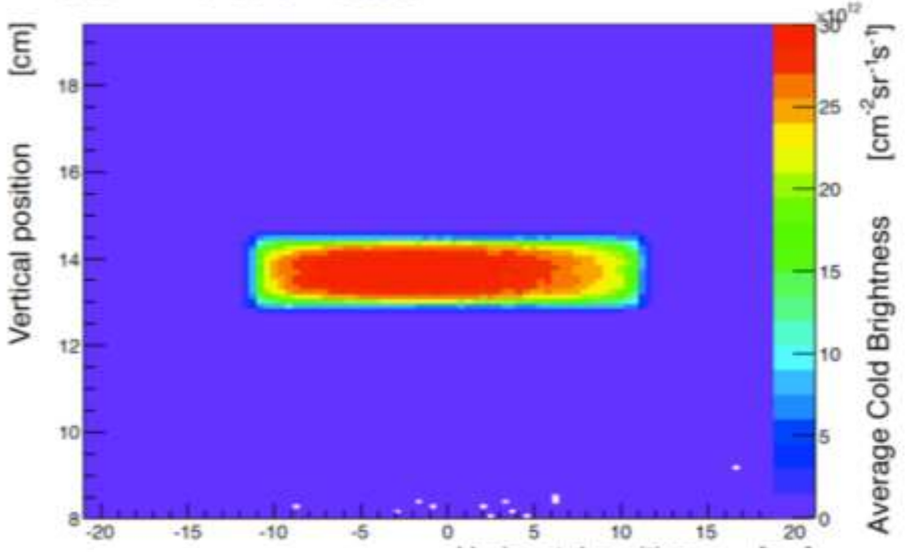
Volume moderator



- Low-dimensional para-H_2 moderators provide strong brilliance

- Studies from first sketches to conceptual designs for ESS and SNS STS, reactors and compact sources

Flat moderator



K. Batkov, A. Takibayev, L. Zanini, F. Mezei
NIM A729 (2013) 500.

BRILLIANCE AND FLUX

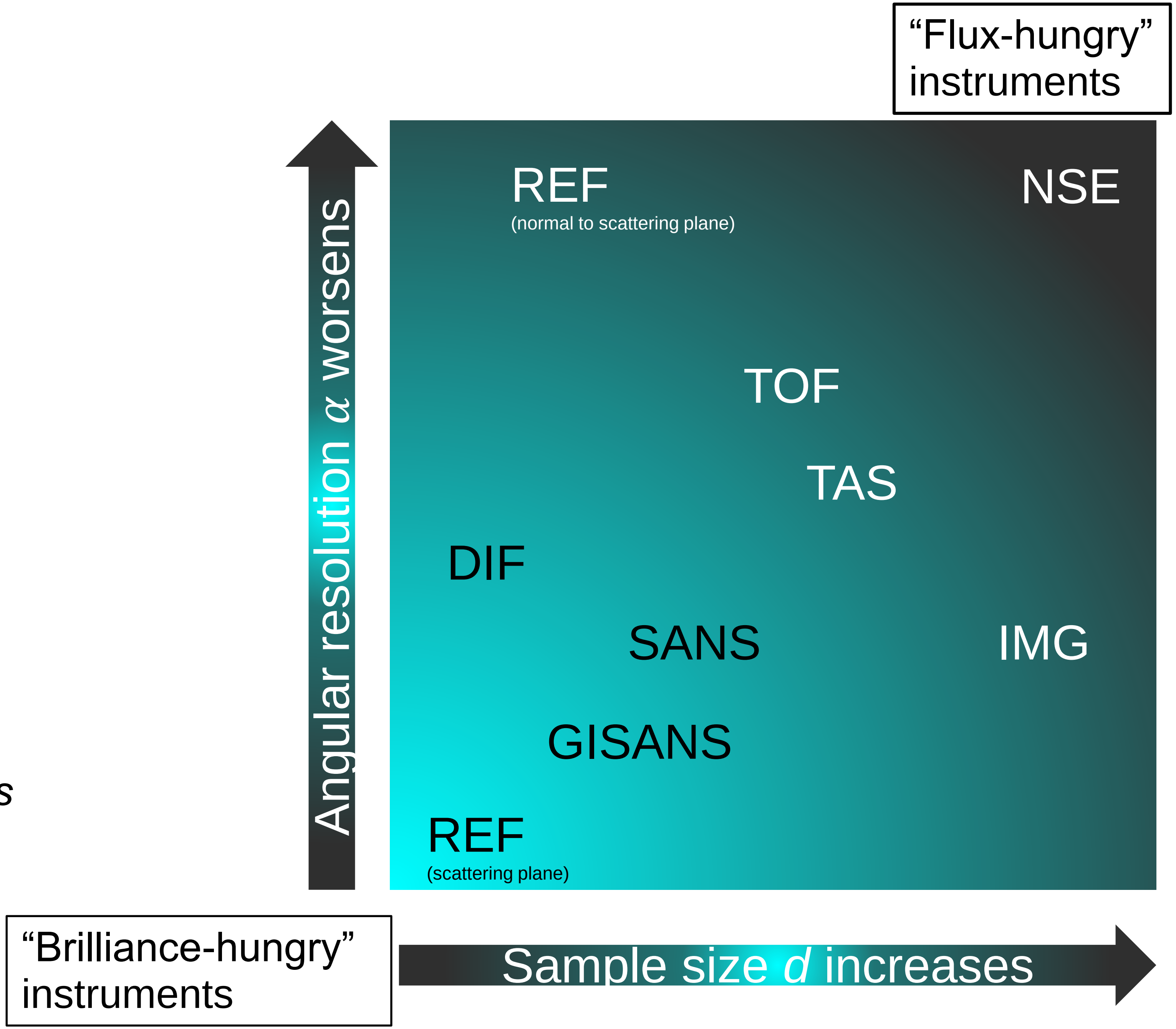
Brilliance

B – how many neutrons the source emits from defined area in defined solid angle

Flux at sample position

$$\Phi_S = \int_{0}^{d} \int_{-\alpha}^{\alpha} B_s(D, w_0)\, d\alpha\, dd$$

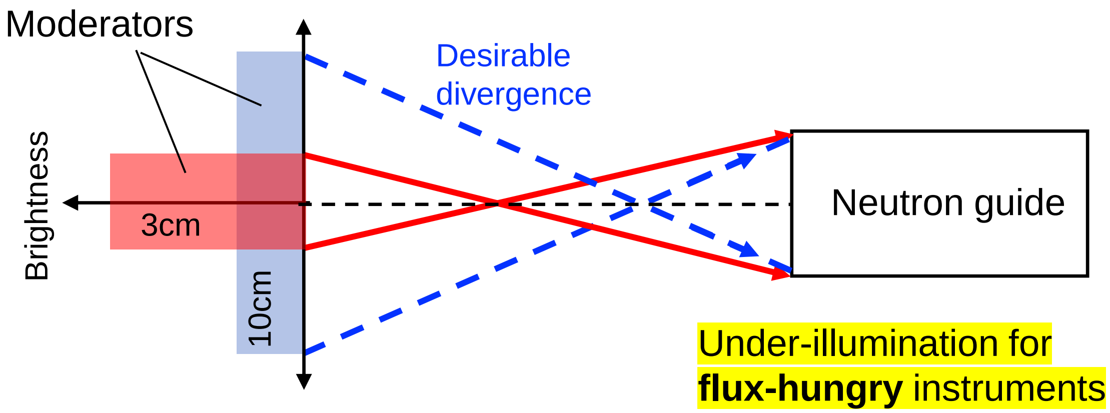
It's all about instrument requirements (integration limits)!



BRILLIANCE AND FLUX TRADE-OFF

High-brilliance cold moderators:

- Gain in flux on sample for **brilliance-hungry** instruments requiring highly collimated beams and small samples (reflectometer, SANS, …)
- Not so advantageous for **flux-hungry** instruments with relaxed Q-resolution and larger samples (NSE, fundamental physics,…)



One needs to determine the moderator size providing highest brilliance, full sample illumination and minimal background (over-illumination) at the sample