ILL upgrade experience

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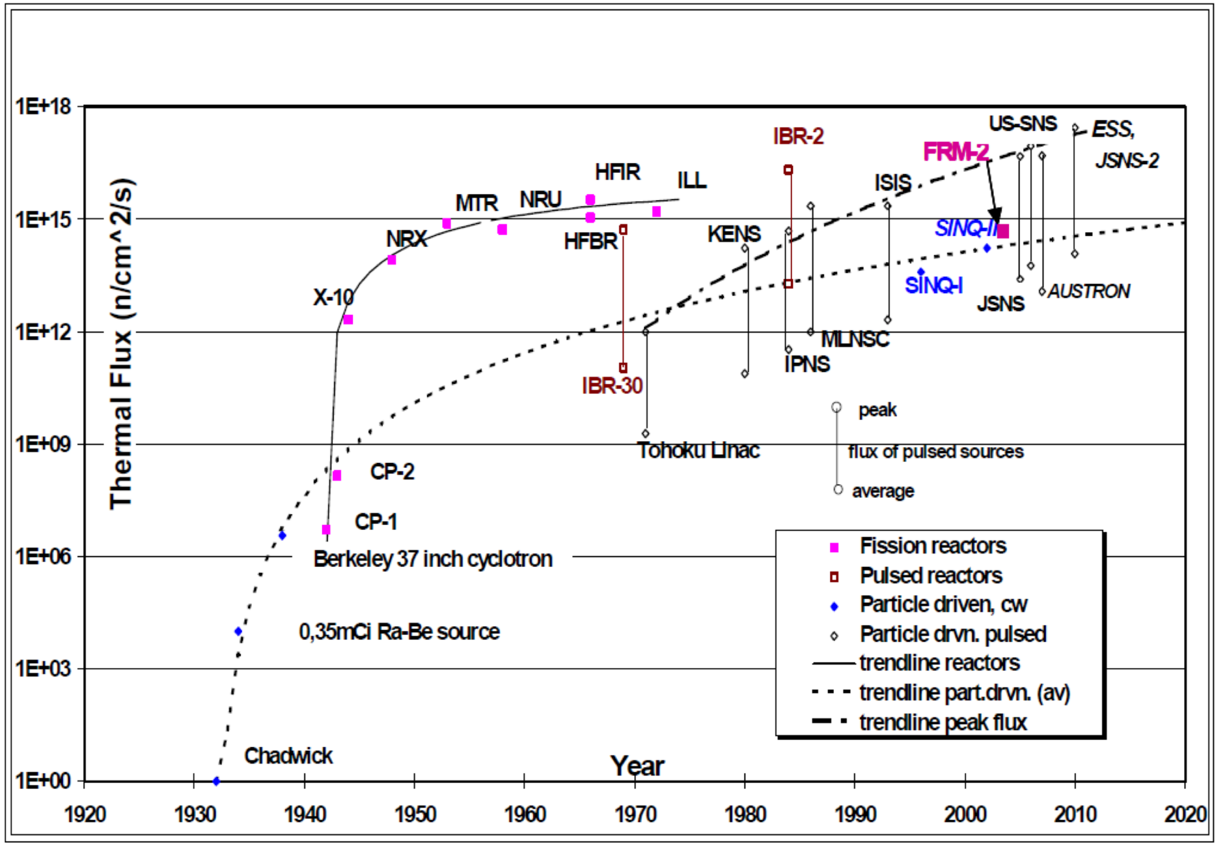
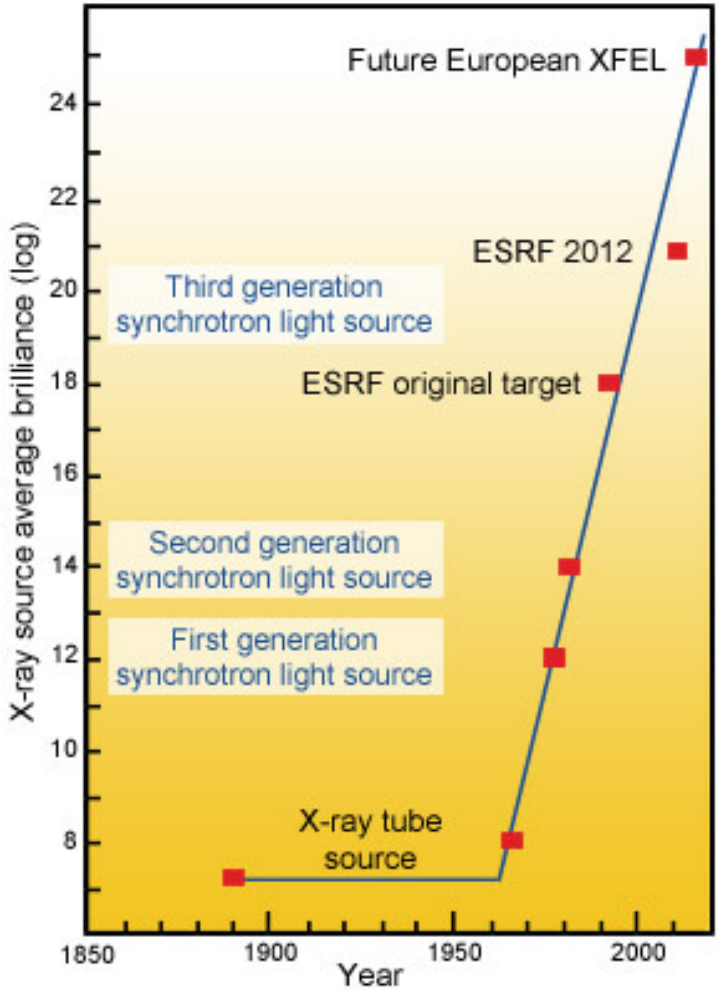
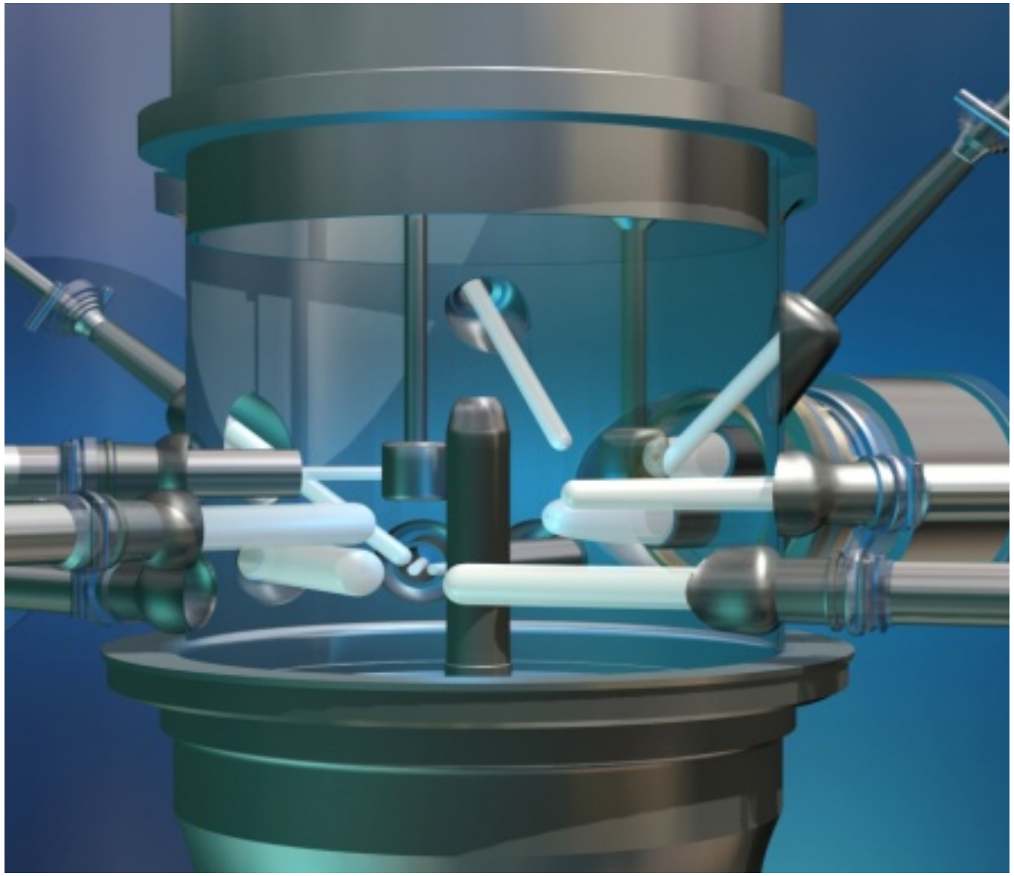
Neutron source flux





- **all known production reactions produce MeV neutrons**
- **moderation to <1ev is a diffusive and incoherent process**

Neutron source luminosity



ILL reactor:
peak flux density 3×10^{15} $cm^{-2}s^{-1}$ into 4π sterad

Neutron source (a beam tube):
surface ≈ 100 cm^2
luminous intensity 24×10^{15} s^{-1} $sterad^{-1}$ ≈ 6 Cd

Planck's constant $h = 6.626 \times 10^{-34}$ Js
1 Cd ≈ 4×10^{15} $s^{-1} sterad^{-1}$

Neutron facility efficiency

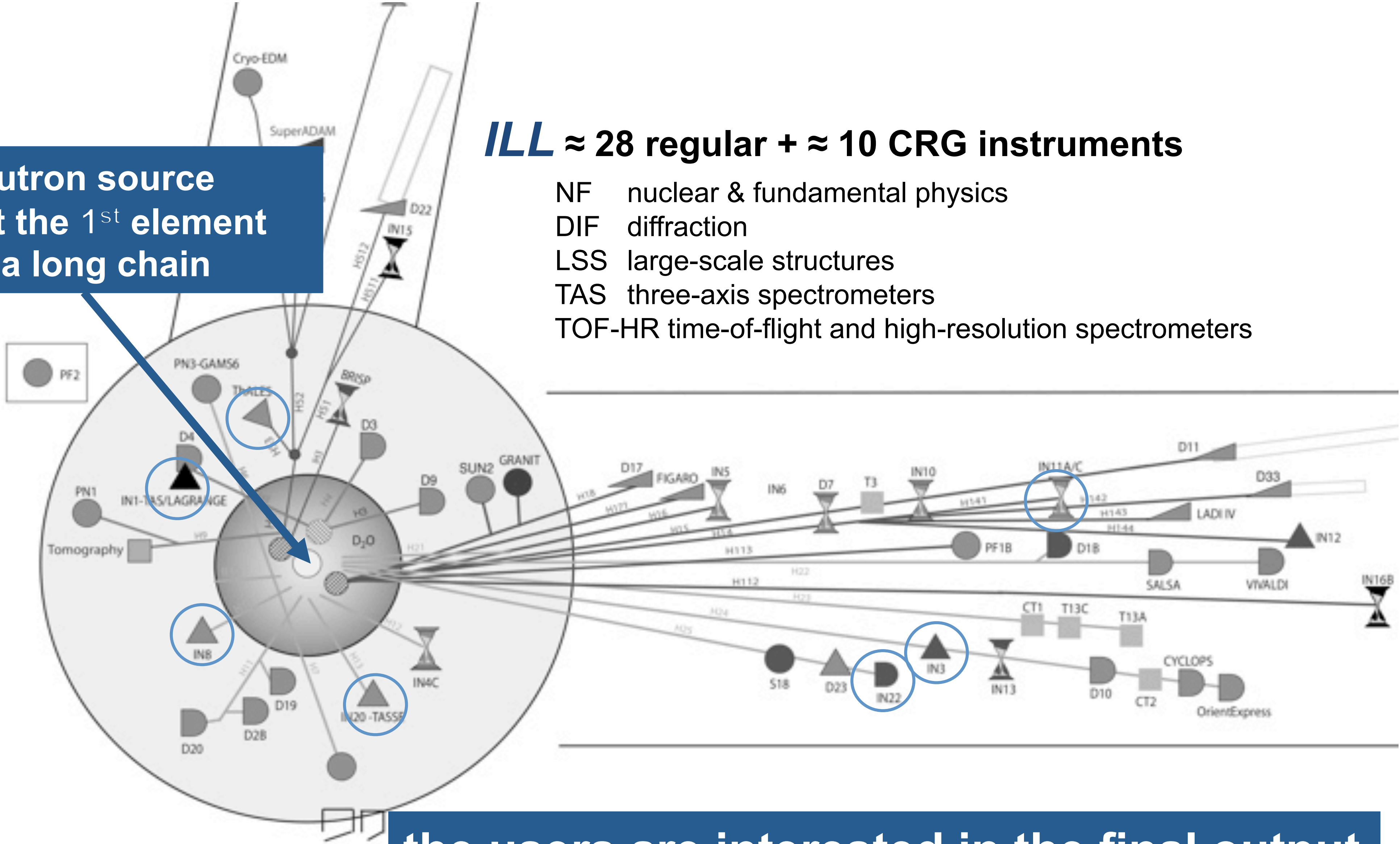
NEUTRONS FOR SOCIETY

Endurance
Setting the pace

ILL ≈ 28 regular + ≈ 10 CRG instruments

NF nuclear & fundamental physics
DIF diffraction
LSS large-scale structures
TAS three-axis spectrometers
TOF-HR time-of-flight and high-resolution spectrometers

neutron source is just the 1st element of a long chain



the users are interested in the final output

ILL upgrade programs

- **Deuxième souffle 1980 – 1988**
- **Troisième souffle (1991-1996) – abandoned**
- **Millenium 2000 - 2016 (2018)**
- **Endurance 2016 – (in progress)**

optimisation of neutron distribution (cold source, guides), instruments, sample environment & infrastructure

Millenium program

M-0:
13 instruments
+ neutron guides
+ sample environment

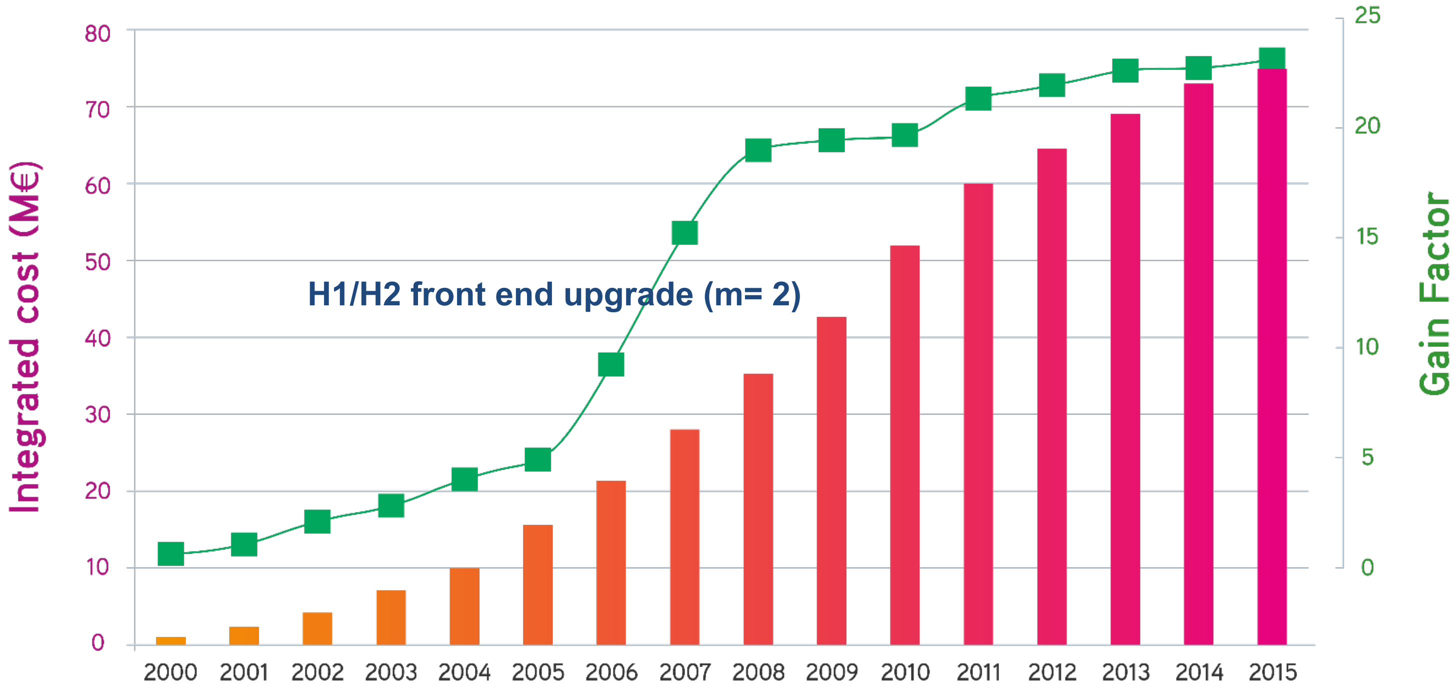
1x CRG

M-I:
8 instruments
+ neutron guides
+ sample environment

3x CRG

ILL Millenium program

2000 – 2015



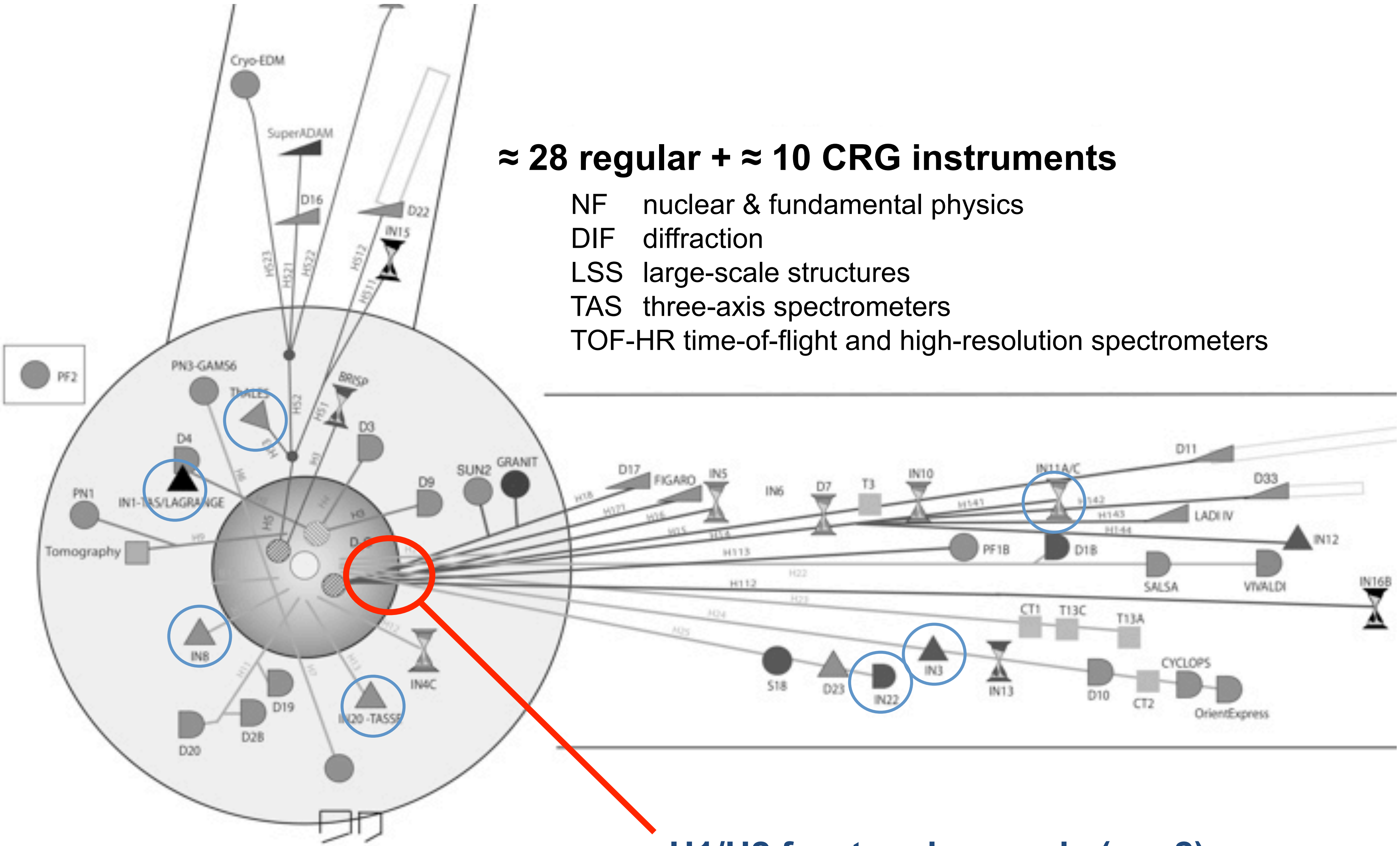
average neutron detection rate improved by a factor of ≈ 25

cost < 1 annual budget

ILL instruments

NEUTRONS FOR SOCIETY

Endurance
Setting the pace

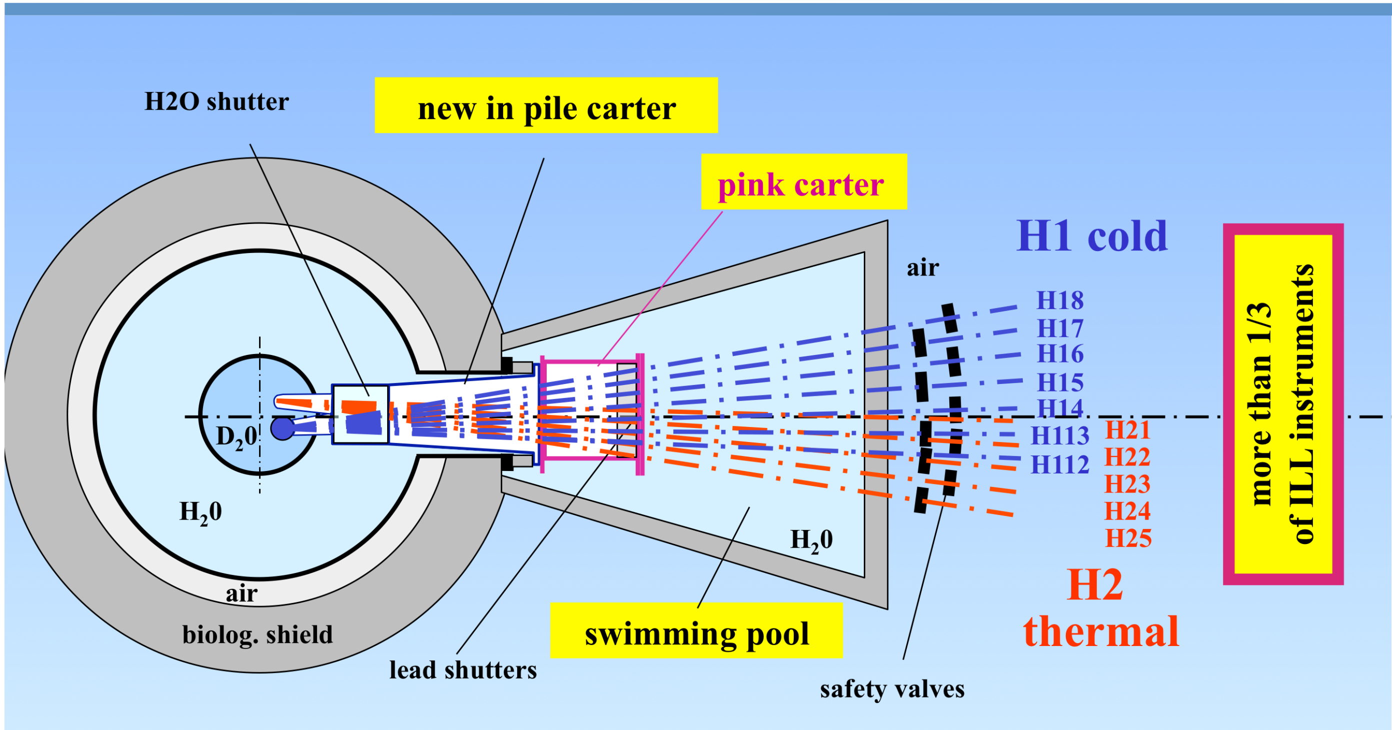


≈ 28 regular + ≈ 10 CRG instruments

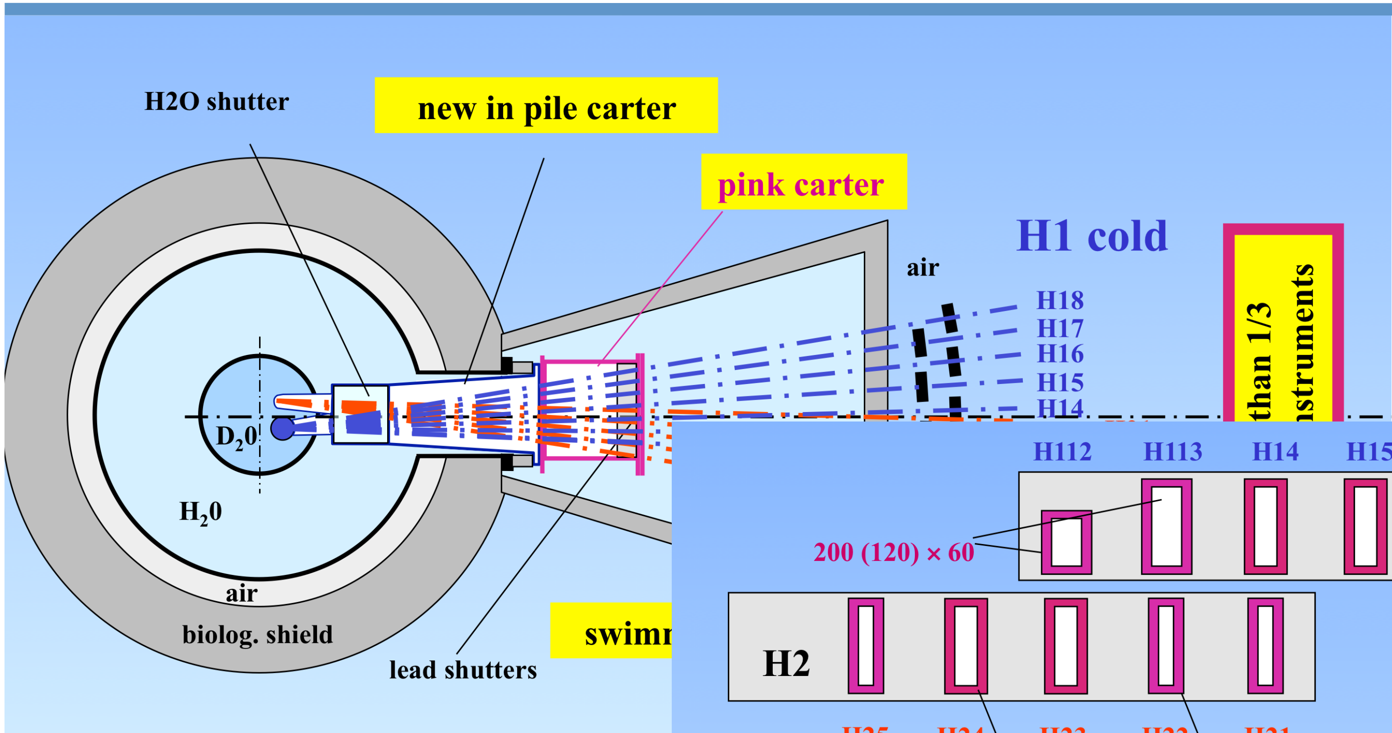
- NF nuclear & fundamental physics
- DIF diffraction
- LSS large-scale structures
- TAS three-axis spectrometers
- TOF-HR time-of-flight and high-resolution spectrometers

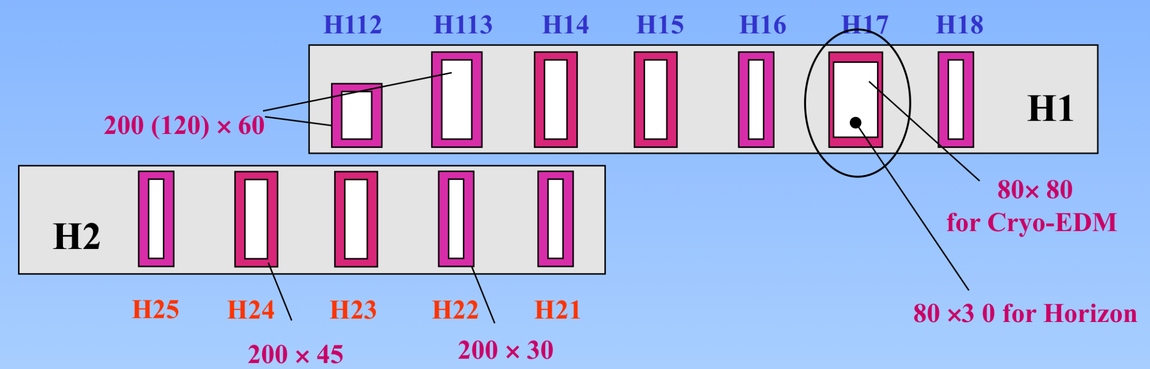
H1/H2 front end upgrade (m= 2)

H1/H2 front end upgrade



H1/H2 front end upgrade





→ALL THE GUIDES HAVE BEEN COATED WITH SUPERMIRRORS m=2 (EXCEPT THE VERTICAL FACES OF H18 : m=1).

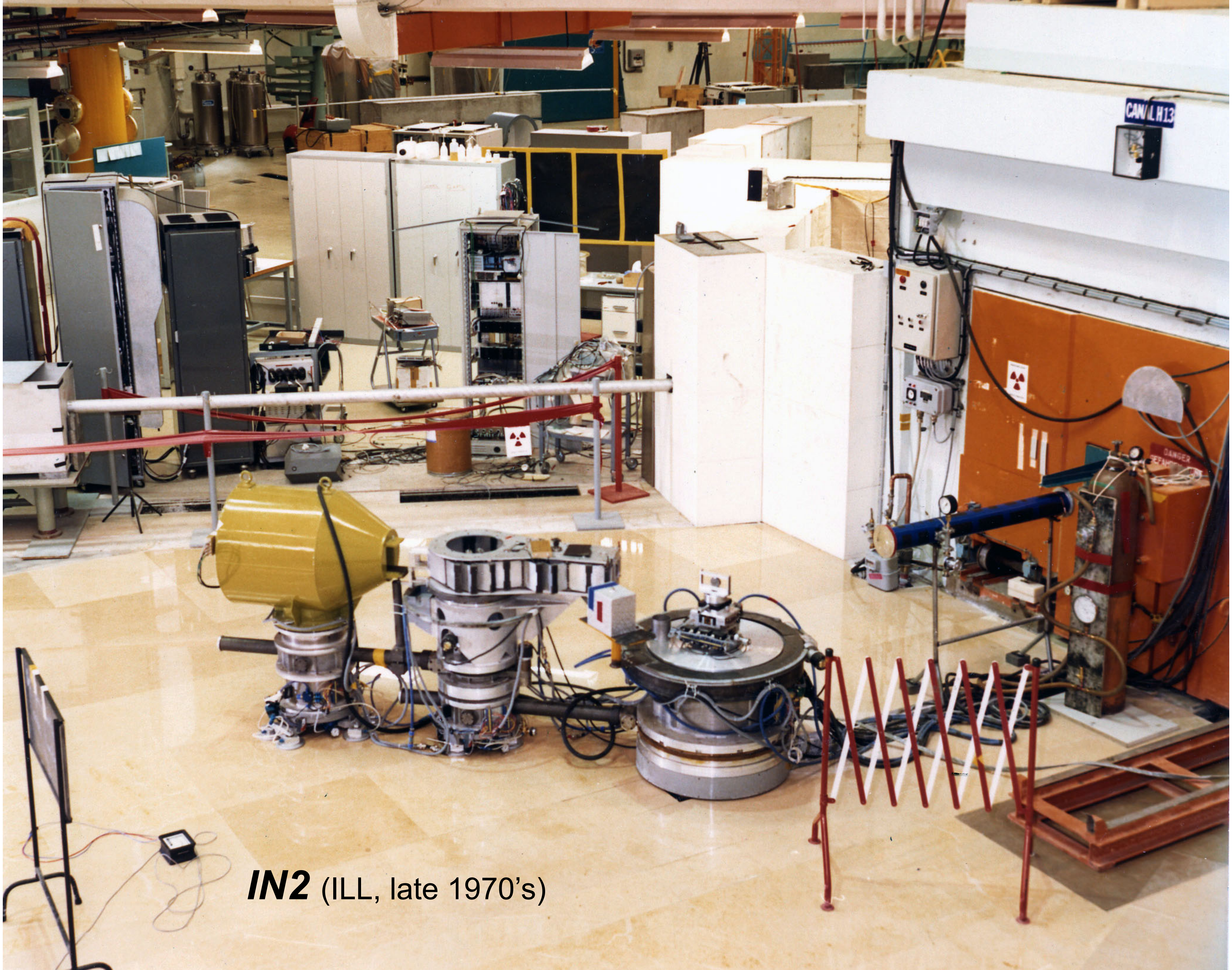
→ INTERNAL WIDTH OF H14, H15, H23, H24 HAS BEEN INCREASED FROM 30 mm TO 45 mm.

→ INTERNAL WIDTH OF H17 HAS BEEN INCREASED FROM 30 mm TO 80 mm (ONLY IN PILE PART).

→ H112 HAS BEEN PROLONGED TO THE END OF THE SWIMMING POOL WITH AN ANTI TRUMPET FORM (75 x 120 AT VS).

→NEW THERMAL GUIDES APPROACH : H2 GUIDES START MUCH CLOSER TO THE SOURCE PERMITTING FULL ILLUMINATION AT m = 2

courtessy R. Gähler (ILL)



IN2 (ILL, late 1970's)

Solid State Communications, Vol. 12, pp.537–540, 1973. Pergamon Press. Printed in Great Britain

SPIN WAVE MEASUREMENTS IN THE ONE-DIMENSIONAL FERROMAGNET $CsNiF_3$*

M. Steiner and B. Dorner†

Institut Max Von Laue–Paul Langevin, B.P. 156, 38042 Grenoble Cedex, France

(*Received* 20 *December* 1972 *by E.F. Bertaut*)

By inelastic neutron scattering from $CsNiF_3$ at 4.2K spin waves in a one-dimensional *ferromagnet* are found for the first time. The dispersion relation can be described by only nearest neighbour interaction and follows the relation $\nu = 0.09 + 0.98\ [1 - \cos(\pi q_c)]$ THz.

INTRODUCTION

WITH THE three-axis instrument IN2[1] at the High Flux Reactor in Grenoble, we performed an inelastic neutron scattering investigation on the one-dimensional ferromagnet $CsNiF_3$. Previous results[2–5] by quasielastic neutron scattering and by susceptibility measurements have shown that this system behaves like a one-dimensional *ferromagnet* above the three-dimensional antiferromagnetic transition temperature $T_N = 2.8$K. A one-dimensional system does not have long range order for $T > 0$. Correlations along the chains could be measured up to 20K. This one-dimensional behavior can be explained by the hexagonal

EXPERIMENT

We used two single crystals of a total volume of about 0.2cm^3. The two specimens were aligned parallel to each other with respect to the c-axis to within one degree (measured by the mosaic distribution). Mainly we worked with an incoming energy of 3.14THz (13.7meV) using flat Pyrolitic Graphite in the double monochromator and a bent one[9,10] in the analyzer. The higher order contamination was suppressed by the double monochromator and a pyrolitic Graphite filter[11] to 1.10^{-4} of the first order. Measurements were carried out at 4.2K.

$CsNiF_3$ @ IN2

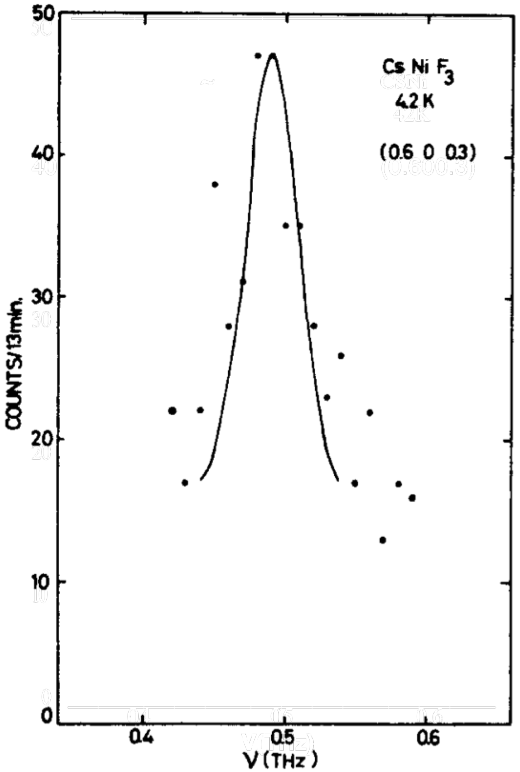


FIG. 2. Results of a const-Q scan, no background subtracted. The instrumental resolution is given by a Gaussian.

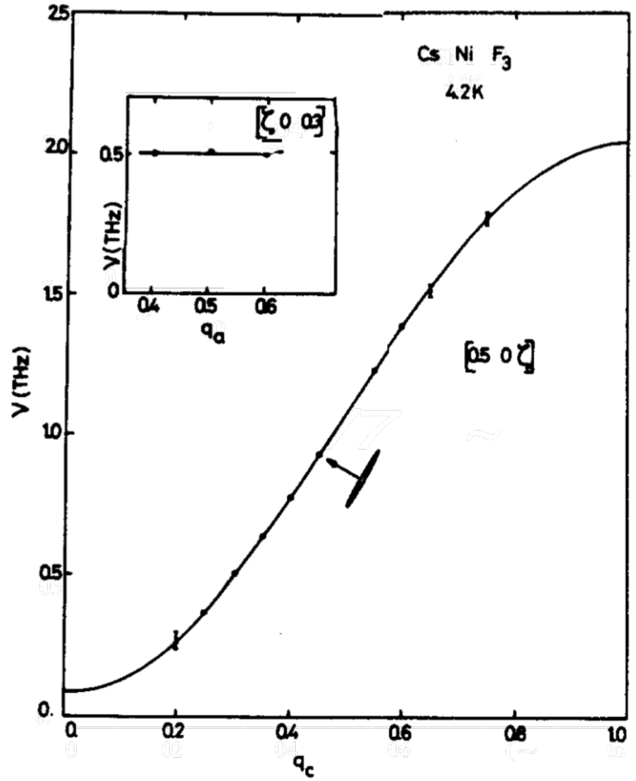
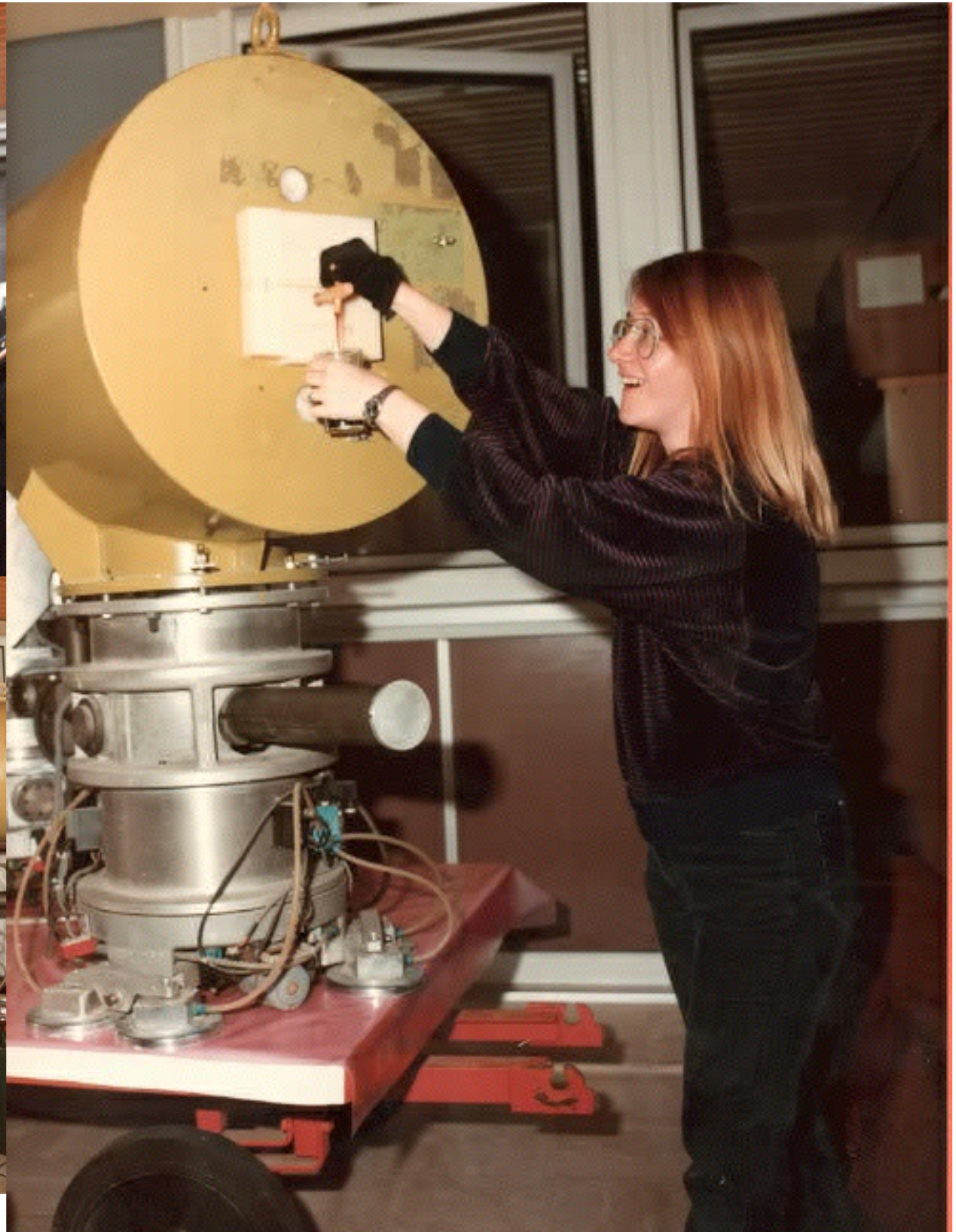


FIG. 3. Dispersion relation of the spinwaves along q_c and for different q_a in the insert. The solid line is the least squares fit of equation (1) to the data. The projected resolution is drawn as an ellipse.

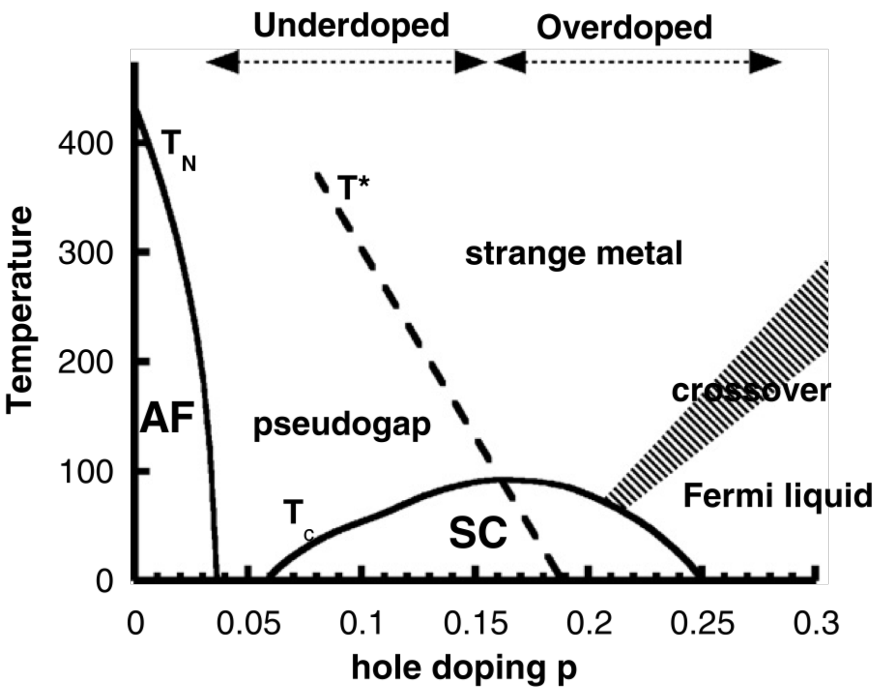
max. count-rate ≈ 3-4 cts/min




IN20 (1984)
DEMAG 50kg

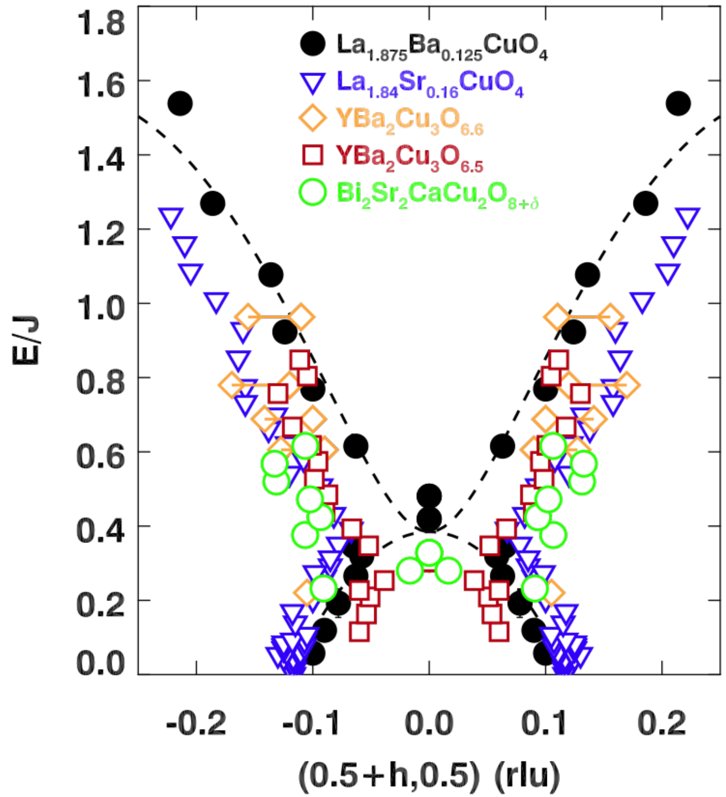
High-T_c cuprates

Phase diagram



P. Bourges, Y. Sidis, C.R. Physique 12 (2011) 461

Hourglass dispersion

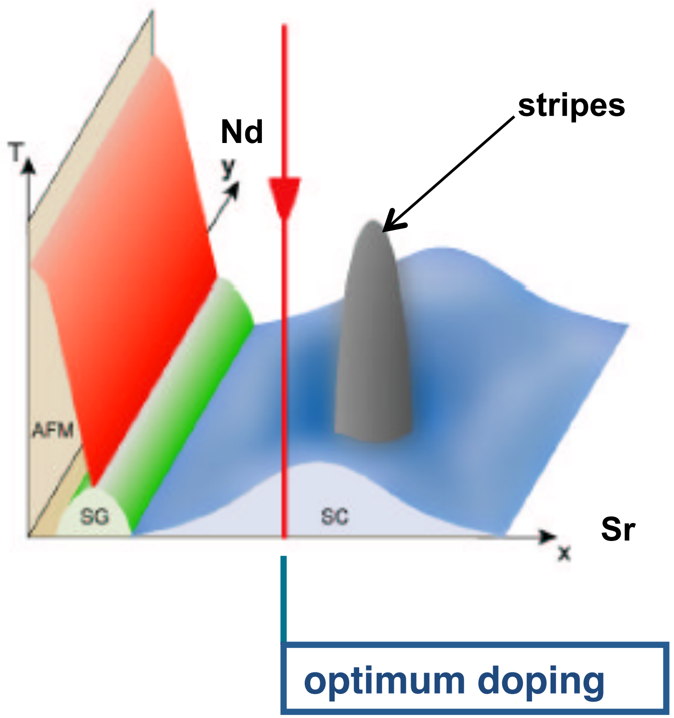


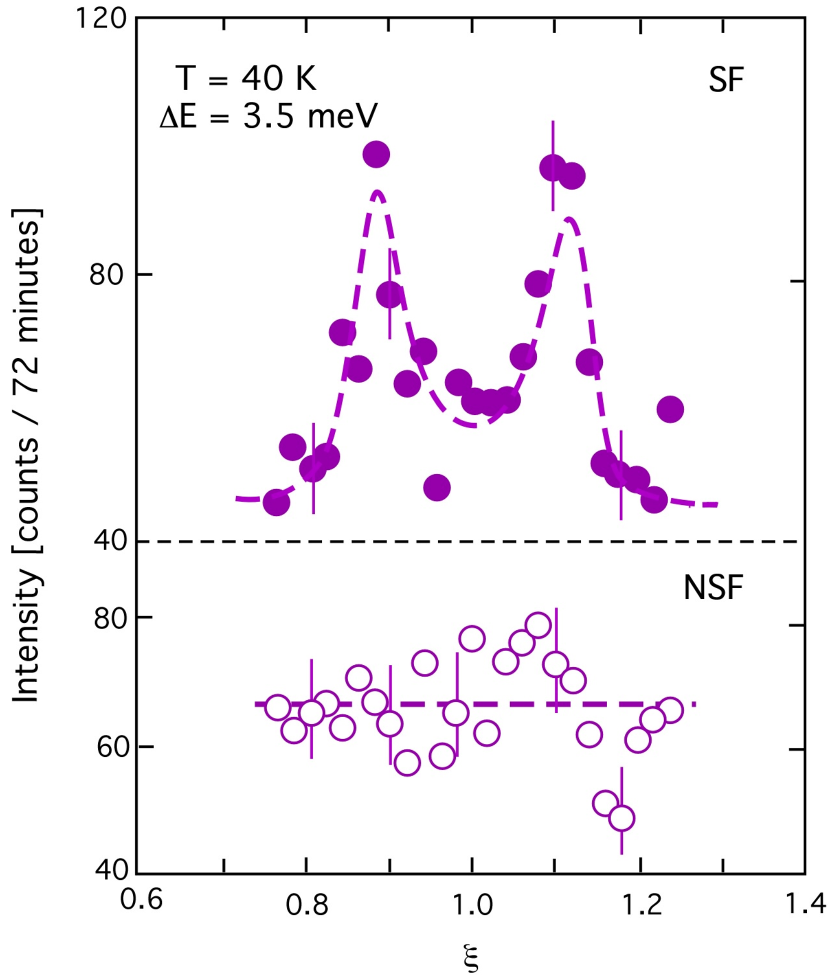
M. Matsuda *et al.*, J Phys Soc Japan **81**, 011007 (2012)

$2^{ème}$ souffle: *IN20* polarized TAS

what took days in 1996 ...

$La_{1.86}Sr_{0.14}CuO_4$ V = 5 cm³





G. Aeppli, T.E. Mason, S.M. Hayden. H.A. Mook, J. Kulda, Science 278 (1997) 1432

Millenium: *IN20B*

... is done in hours in 2003

- **partial intensities (polarized beam)**

$$I_x^{SF} \approx M_{\perp y}^2 + M_{\perp z}^2 + \frac{2}{3} I_{SI} + I_{BGR}$$

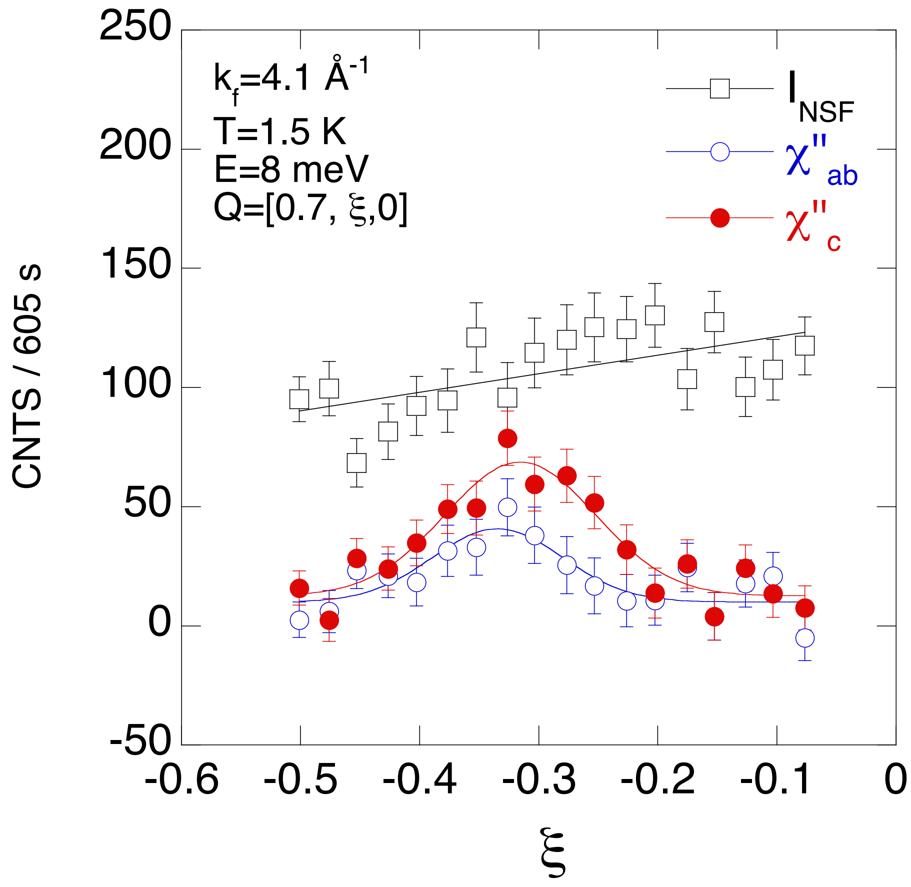
$$I_y^{SF} \approx M_{\perp z}^2 + \frac{2}{3} I_{SI} + I_{BGR}$$

$$I_z^{SF} \approx M_{\perp y}^2 + \frac{2}{3} I_{SI} + I_{BGR}$$

- **use difference signal to extract information:**

$$\chi_y'' \approx M_{\perp y}^2 \approx I_x^{SF} - I_y^{SF}$$

$$\chi_z'' \approx M_{\perp z}^2 \approx I_x^{SF} - I_z^{SF}$$

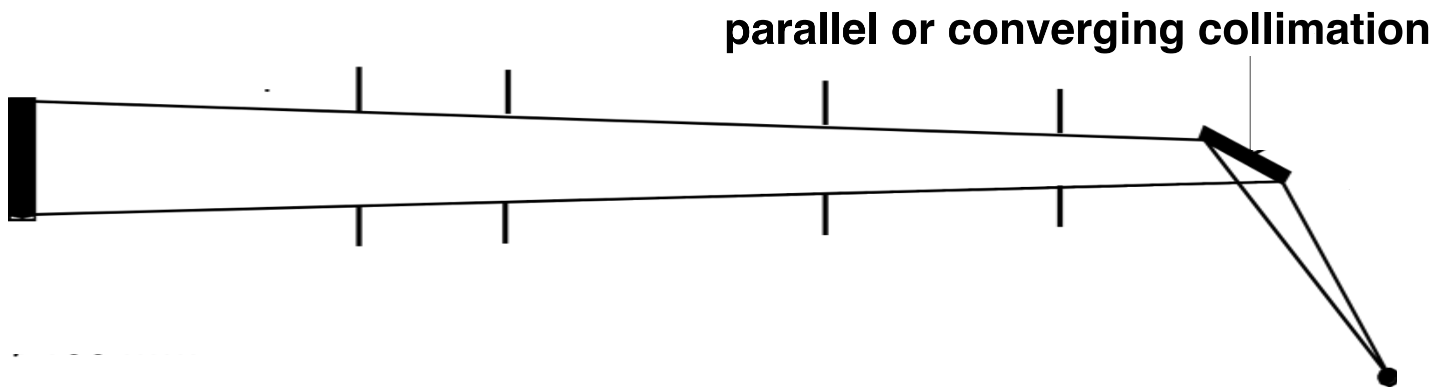


2003: Sr_2RuO_4 V < 1 cm^3

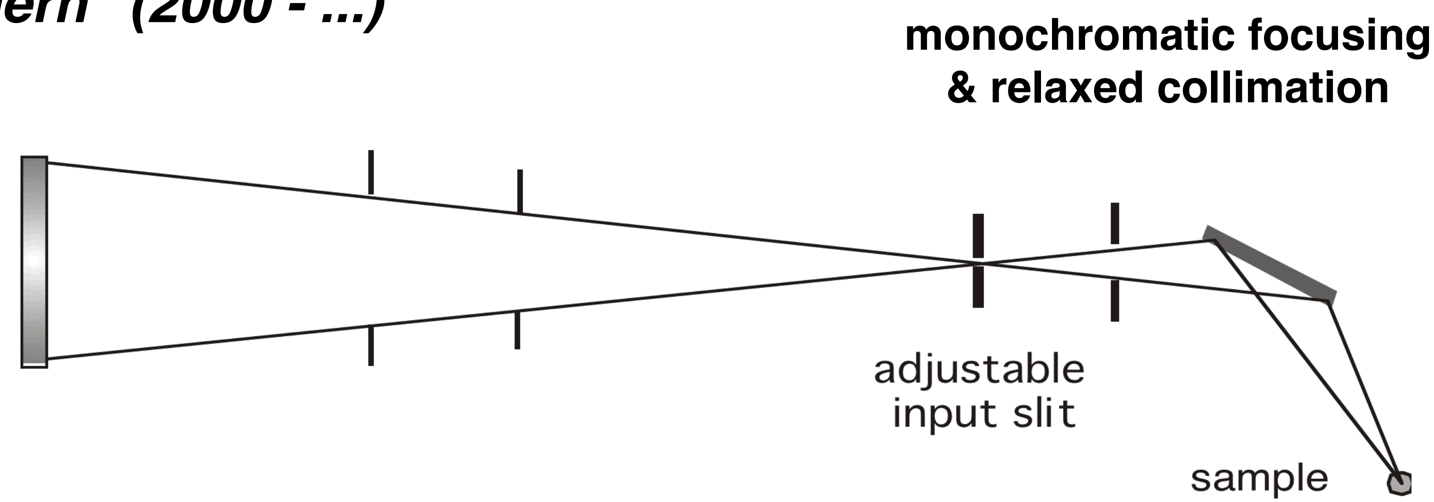
M. Braden et al., Phys. Rev. Lett. 92 (2004) 097402

TAS layout

”classic" (... – 2000)



"modern" (2000 - ...)



intensity gain ≈ 30x

sample size 1 – 2 cm3 ➔ 30 – 70 mm3

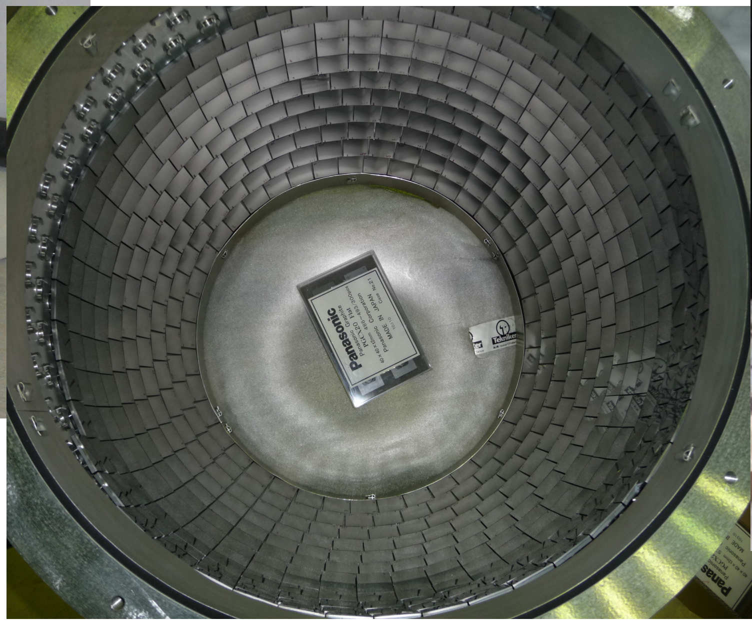
NEUTRONS
FOR SOCIETY

Monochromators & analyzers

Endurance
Setting the pace

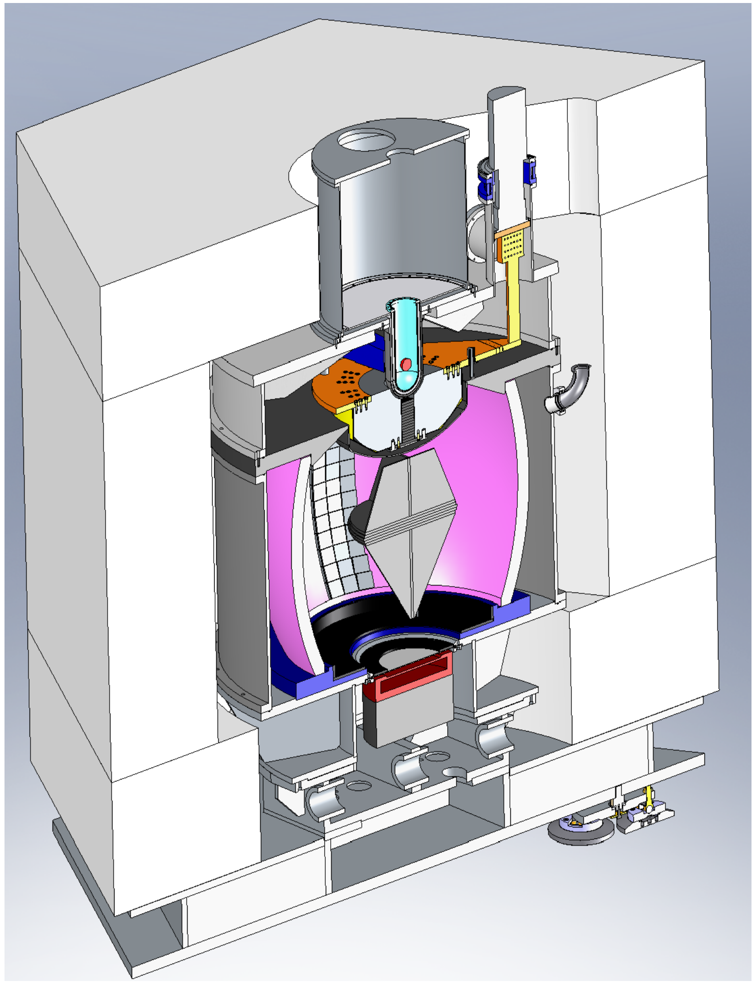
IN3 (1974)
Zn 002 analyzer
(1 big plate)

LAGRANGE (2012)
PG 002 analyzer (≈ 620 plates)



IN8 (2015)
monochromator
(4x 2D focusing face)

Millenium: *IN1 LAGRANGE*



ILL/Spain co-funding

A. Ivanov et al., ILL 2009-2011

IN1 *LAGRANGE*

Be-filter/PG-analyzer

ΔE < 1000 meV

	BeF	Lagrange
solid angle [sr]	0.06	2.5*
ΔE [meV]	3	0.75
transmission	0.7	0.5
background	1	1/30 – 1/10

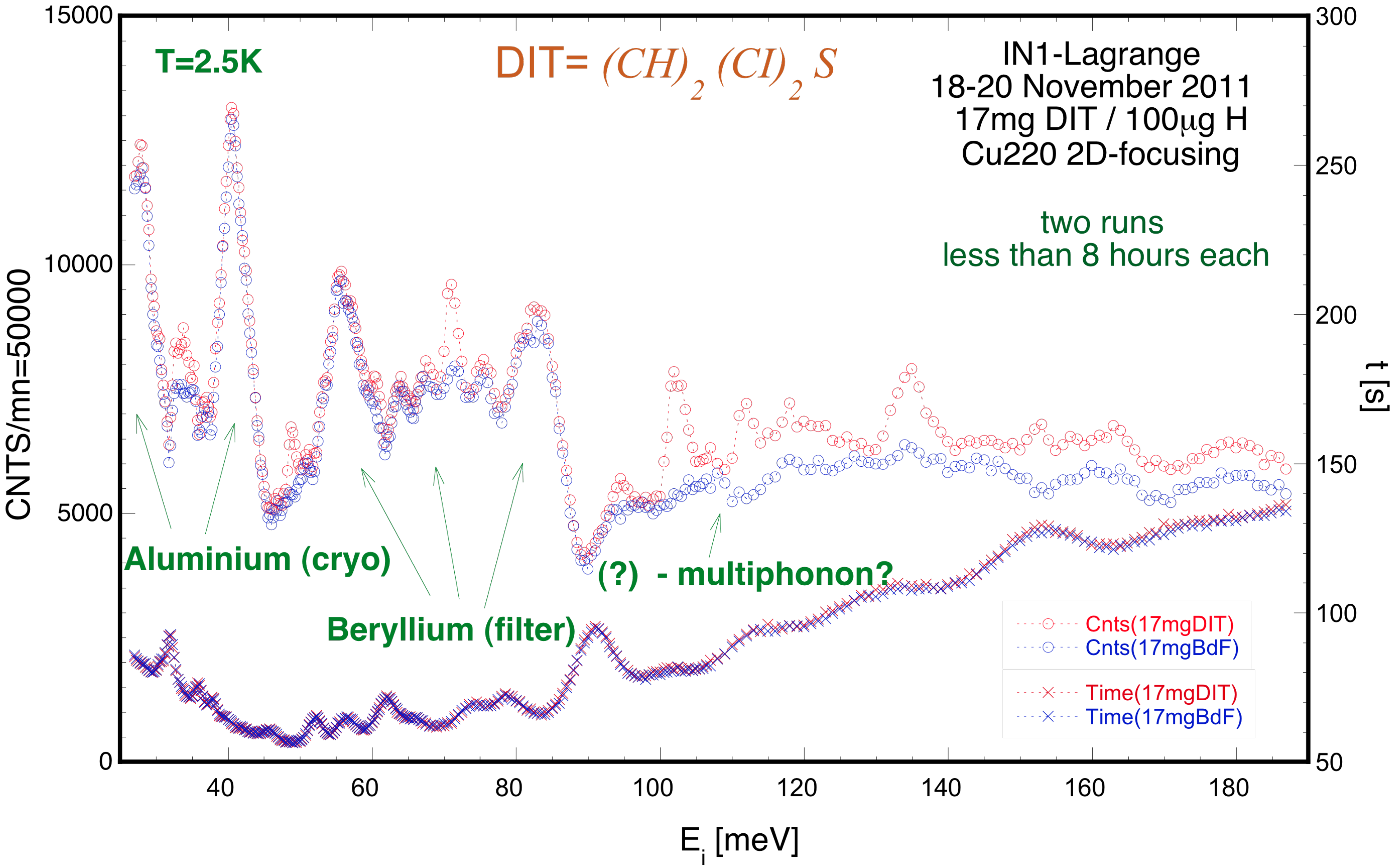
*) IN5 ≈ 1.8 sr

Samples down to
10 μg H
10 mg C

$^{1}H : \sigma_{inc} \approx 80$ barn

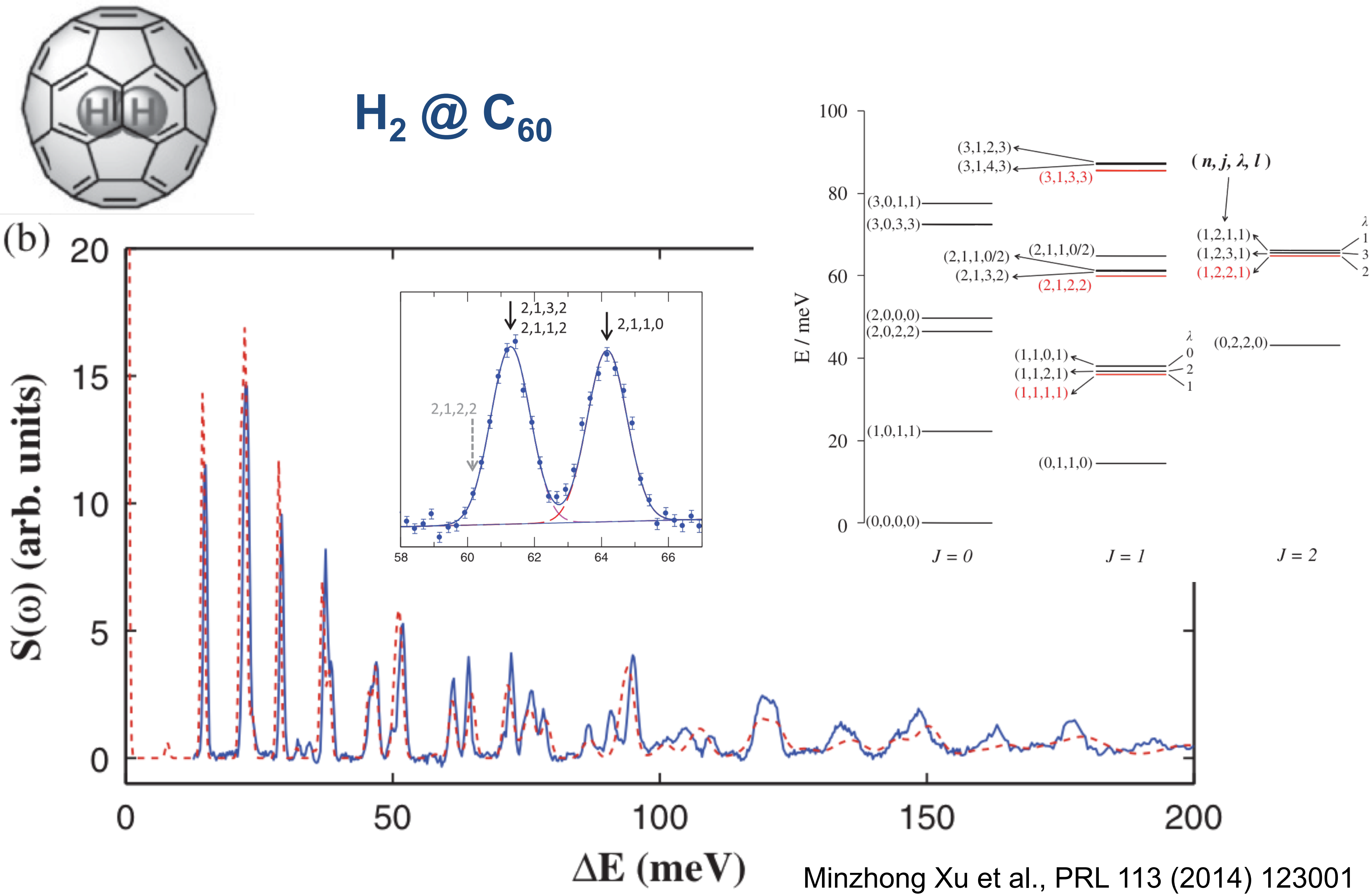
LAGRANGE sensitivity

DIT (2.5-diiodothiophene) ≈ 100 μg H



H2 in fullerene

H_2 @ C_{60}

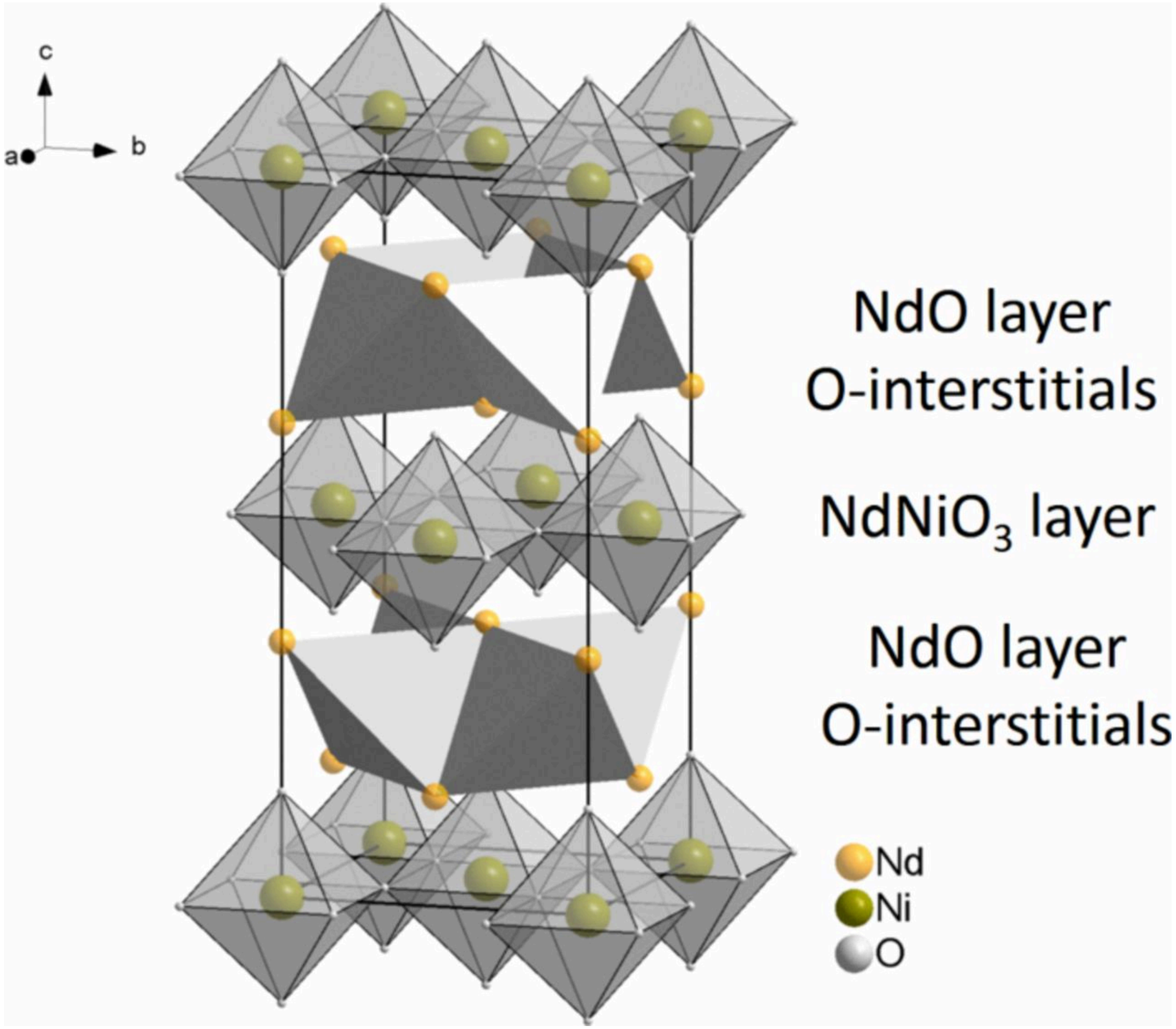


Minzhong Xu et al., PRL 113 (2014) 123001

Ionic conductivity

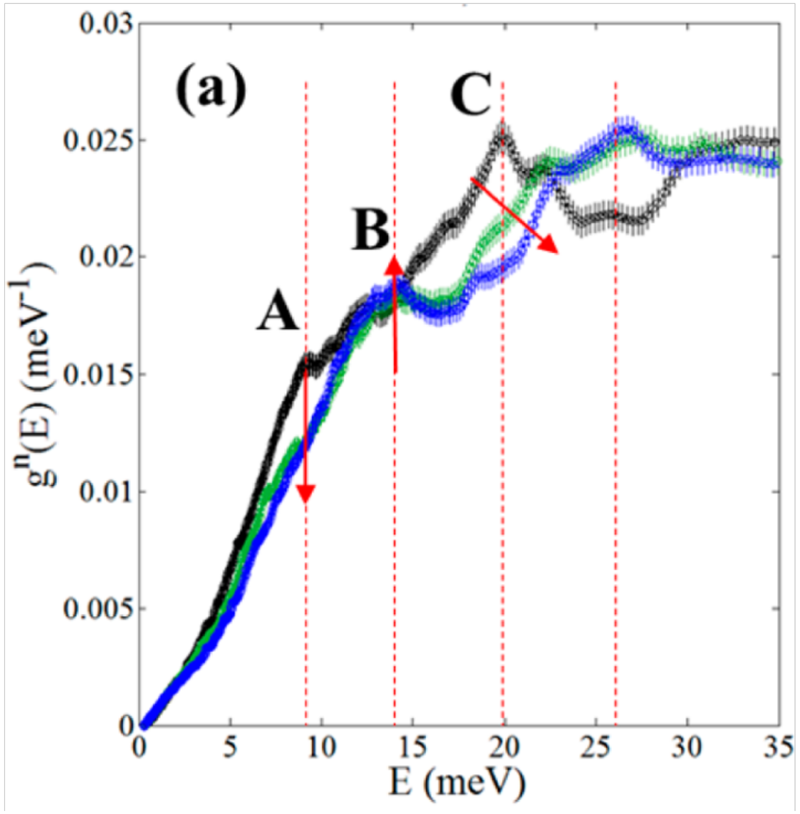
$Nd_2NiO_{4+\delta}$

layered perovskite

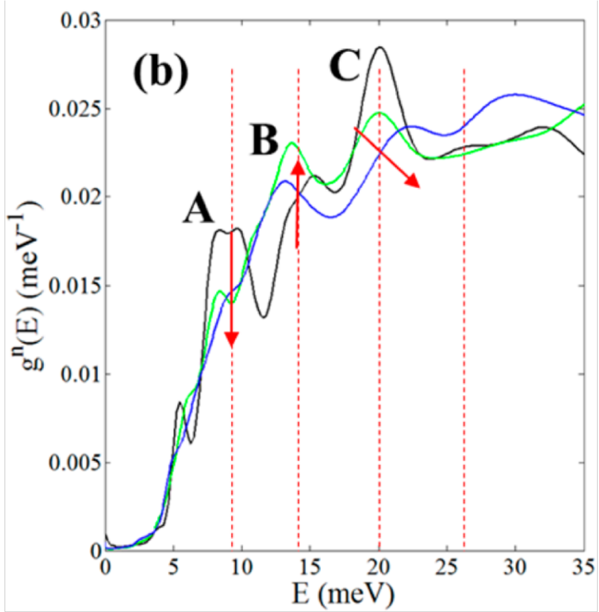


Ionic conductivity

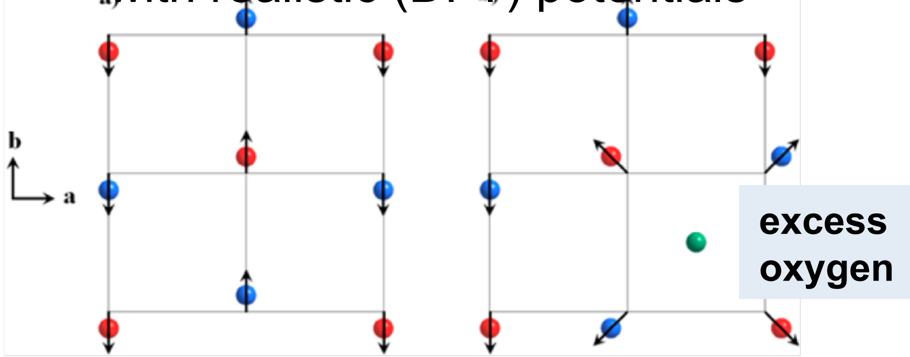
$Nd_2NiO_{4+\delta}$



generalized (neutron) phonon DOS



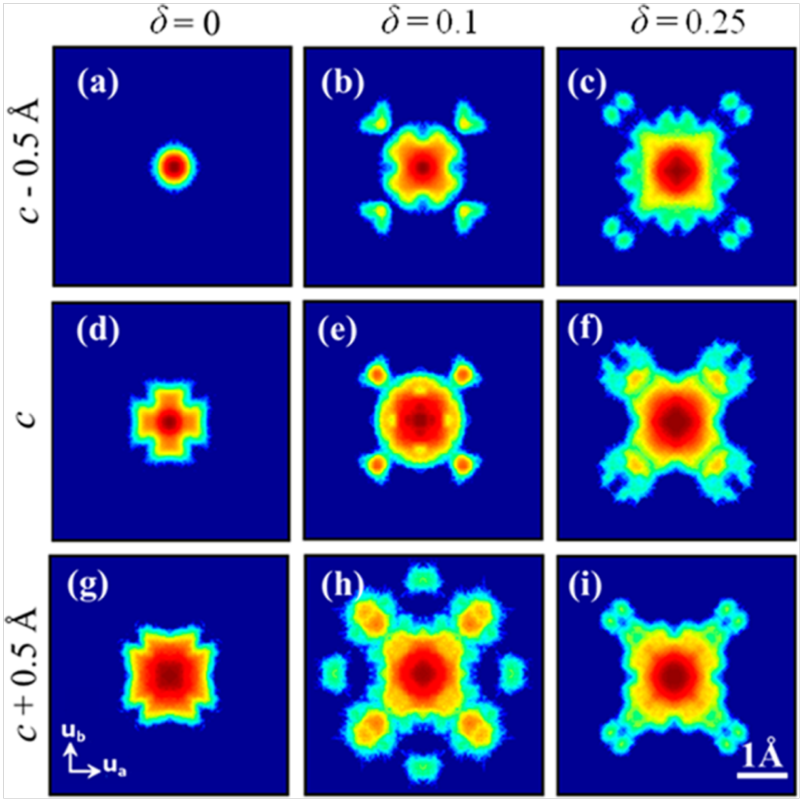
molecular dynamics
with realistic (DFT) potentials



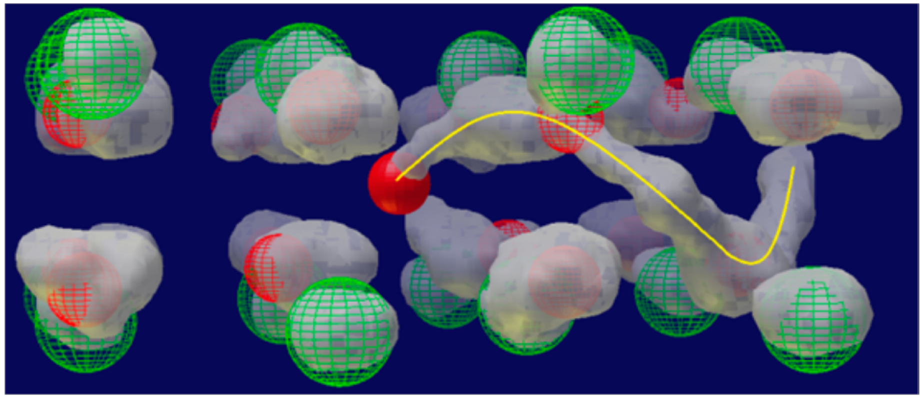
Perrichon A., Piovano A. et al., J. Phys. Chem C119 (2015) 1557

Ionic conductivity

$Nd_2NiO_{4+\delta}$



oxygen displacement correlations

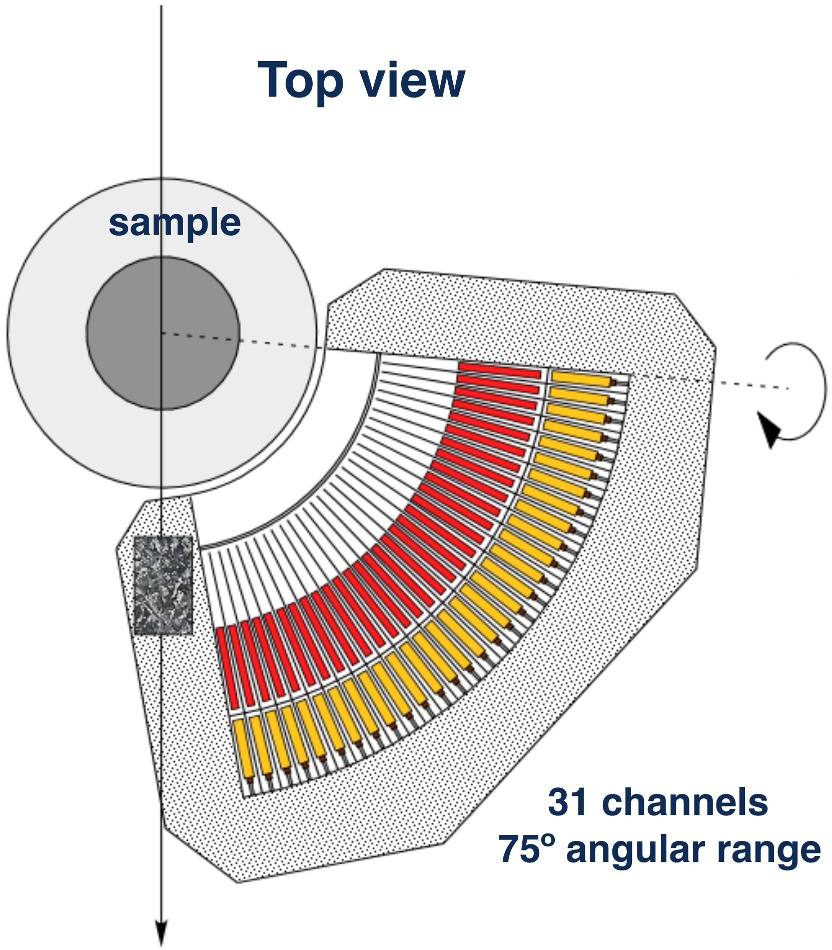


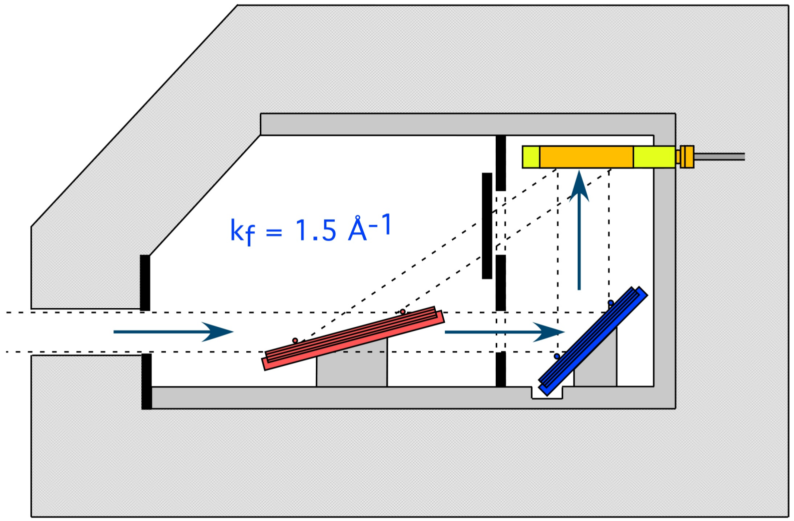
excess oxygen conduction path

Perrichon A., Piovano A. et al., J. Phys. Chem C119 (2015) 1557

Millenium: *FlatCone*

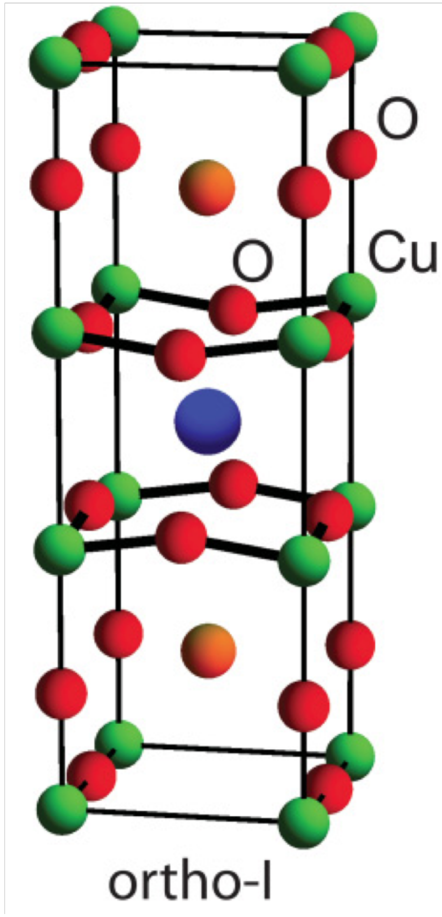
TAS multianalyzer

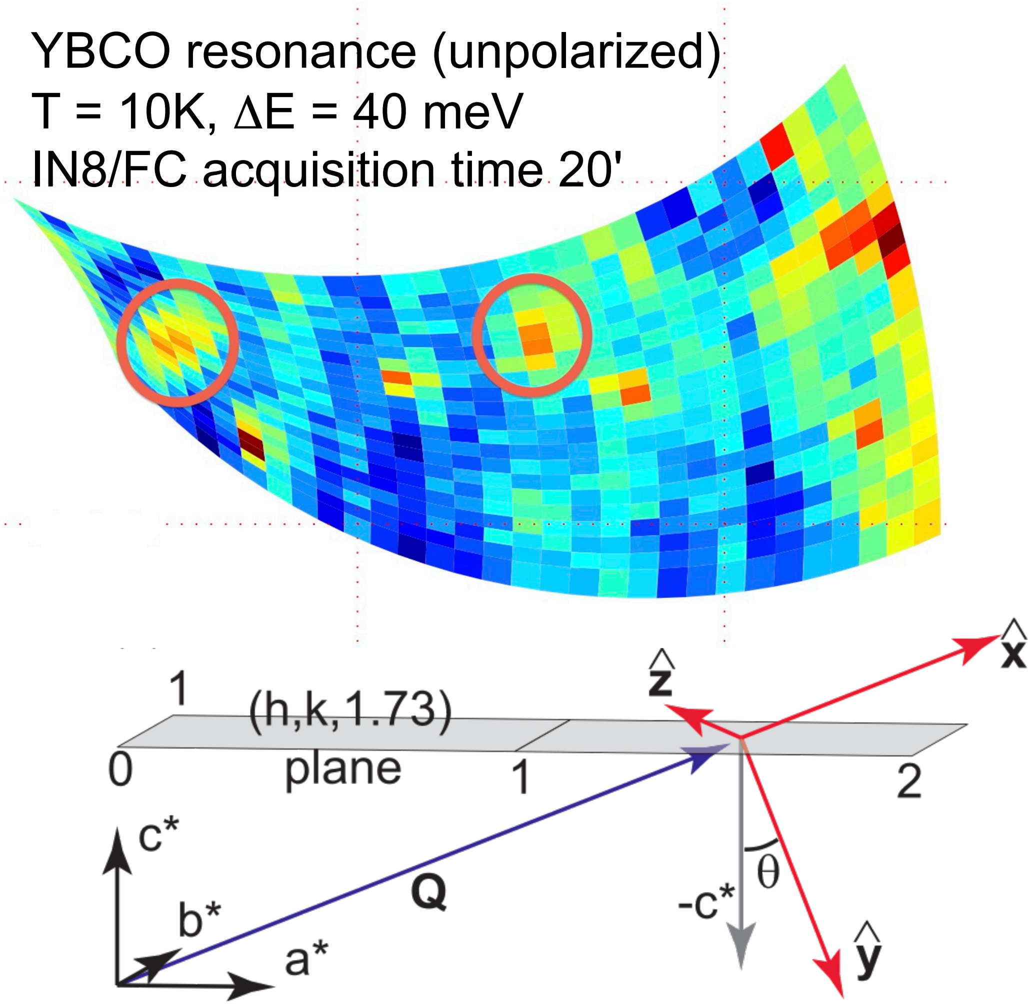




• angular coverage	75 deg
• pixel width [h / v]	1.3 / 4 deg
• no. of pixels	31
• SA distance	950 & 1200 mm
• analyzer crystals	Si 111
• cold neutrons	k_f = 1.4 Å^{-1}
	ΔE = 0 - 10 meV
• thermal neutrons	k_f = 3 Å^{-1}
	ΔE = 0 - 40 meV

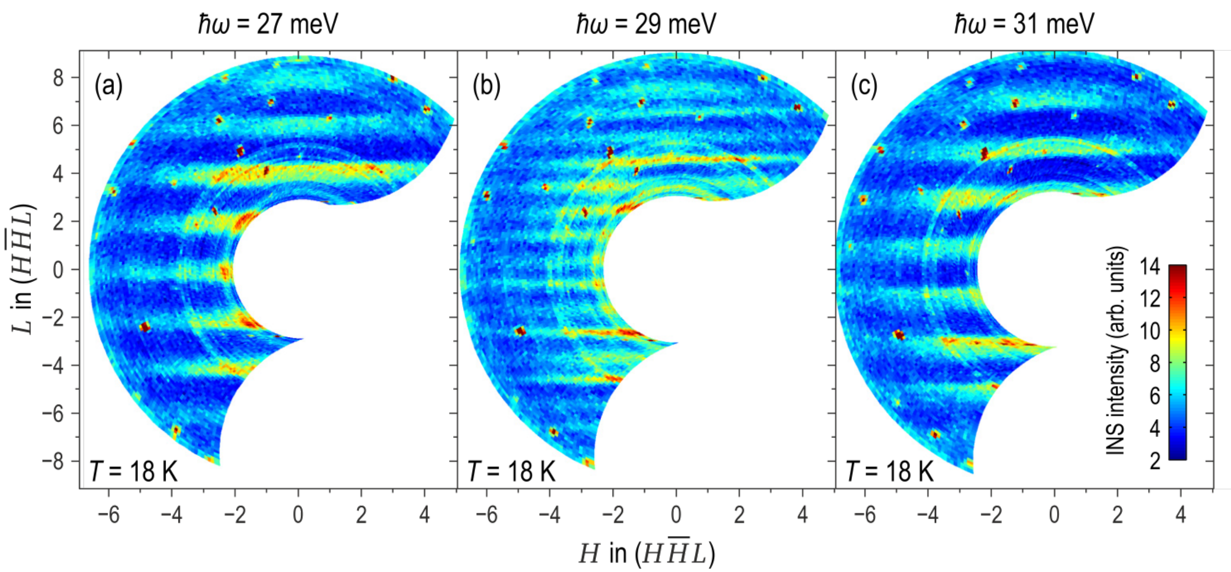
$YBa_2Cu_3O_{6.9}$

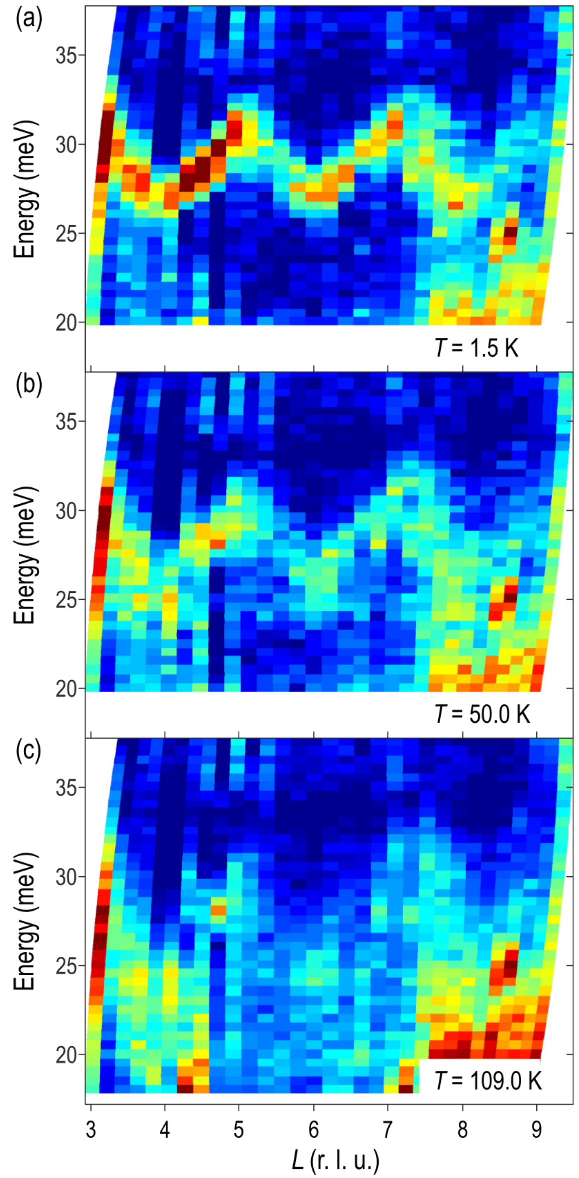




$YBa_2Cu_3O_{6.9}$
m = 32.5 g T_c = 93.0(2) K

FlatCone: $Ca_3Co_2O_6$

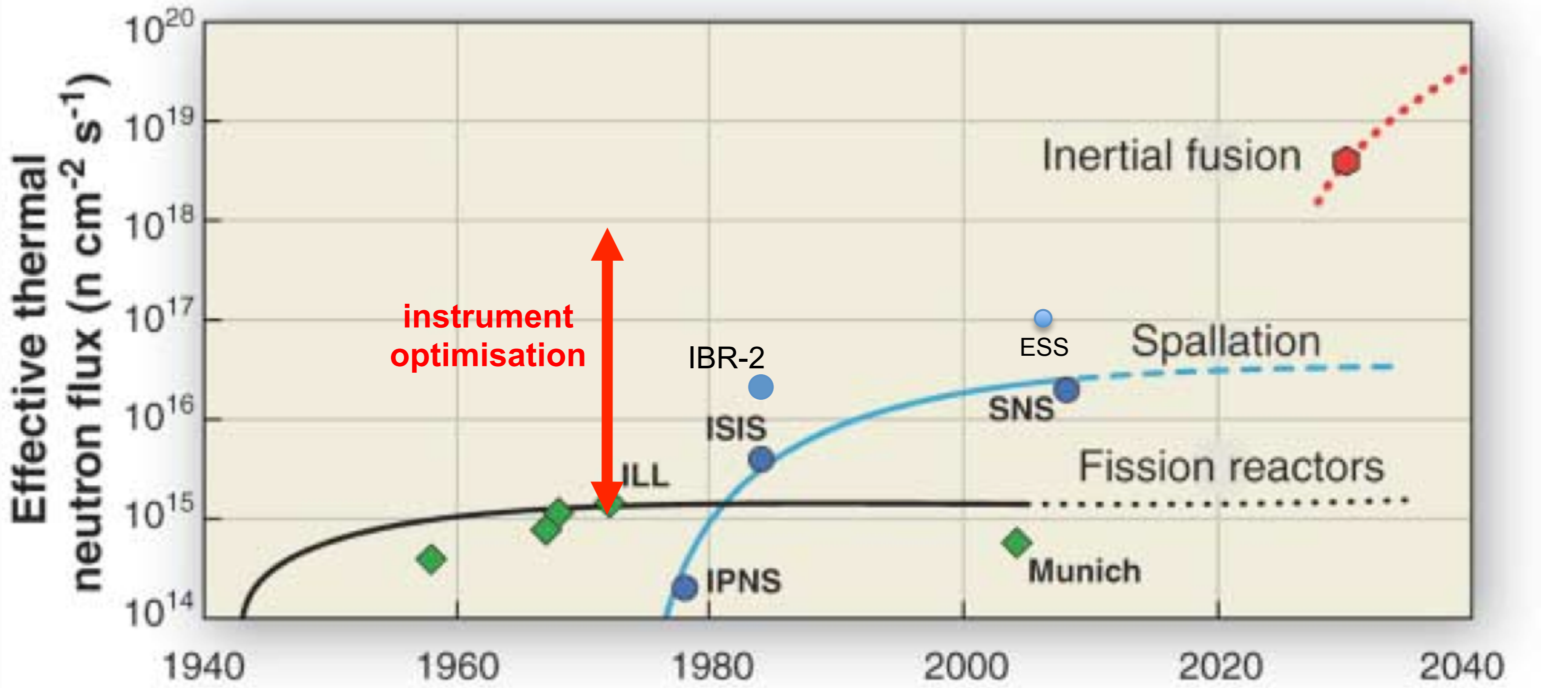




- frustrated triangular lattice (AFM below 24K)
- ferromagnetic chains
- large single ion anisotropy

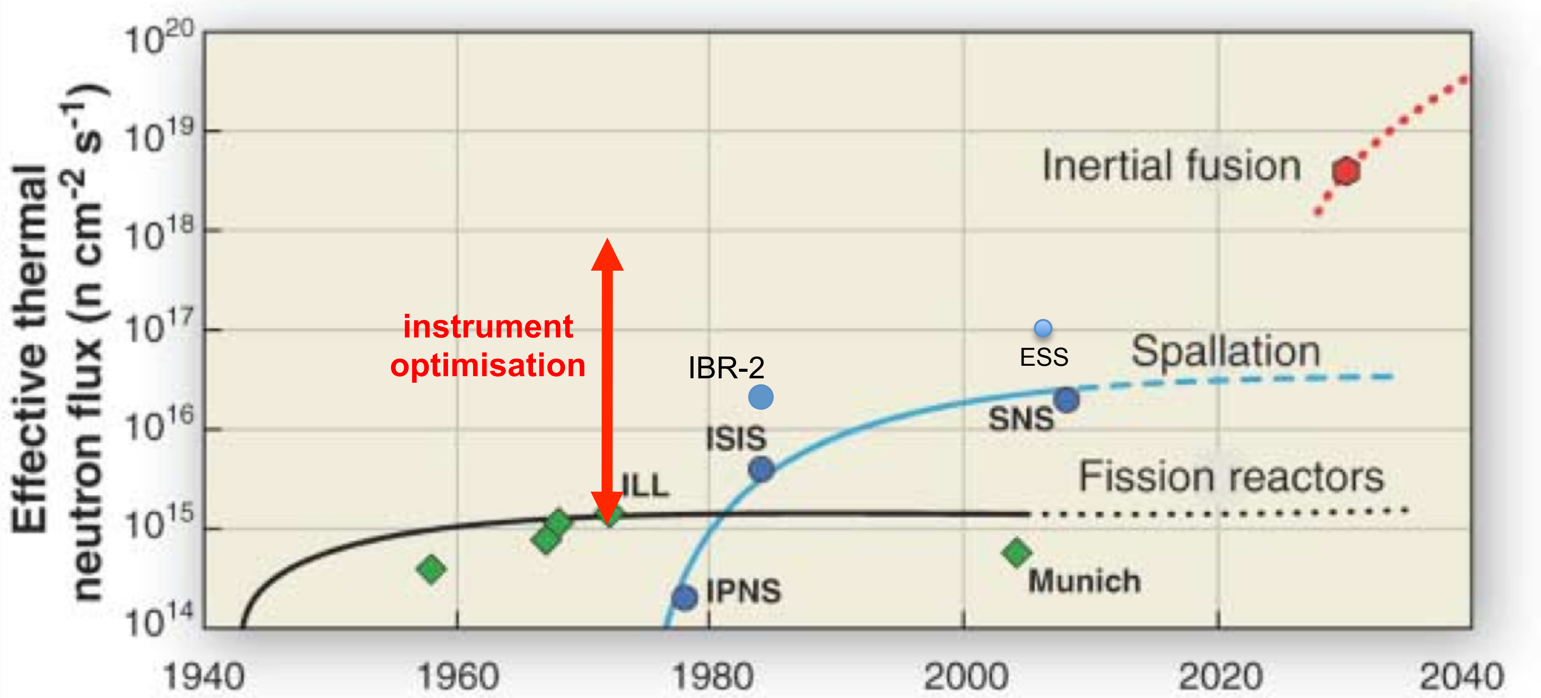
Inosov D.S. et al., PRB **88, 224403 (2013)**

Conclusions



- **40+ years of instrument development & infrastructure optimisation result in 2-3 orders of gain in experiment efficiency**
- **impact:**
  - **typical experiment duration reduced by factor 2-3**
  - **samples volumes reduced proportionately (eg. spectroscopy 10-50 mm^3, proteins 0.1 mm^3)**
  - **new science (frustrated magnetism, chemical kinetics, protein crystallography, ...)**

Conclusions



- really matters: useful flux on sample +
  - stability & regularity of operation
  - number & quality of output beams
  - upgradability
  - etc. ....
- instrument design, development & acquisition should go in parallel to a new source construction