T-REX

Time-of-flight Reciprocal space Explorer

A neutron spectrometer for ***magnetism****,*
material science *and* ***soft matter***
at ESS

A. Orecchini, A. Paciaroni, M. Zanatta,
L. Comez, G. Gubbiotti, C. Petrillo, F. Sacchetti

Dipartimento di Fisica e Geologia, Università degli Studi di Perugia
and Istituto Officina dei Materiali, Consiglio Nazionale delle Ricerche

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Summary

- Intro: Thermal Neutron Scattering
- The European Spallation Source
- T-REX and the Italian Contribution
- T-REX and its Science Cases

Thermal Neutrons

An excellent probe for condensed matter

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PROS

- Thermal (300 K) $\Rightarrow$ $\lambda \sim$ Å, $E \sim$ meV

  atomic structure & dynamics $\Rightarrow$ $S(Q,\omega)$

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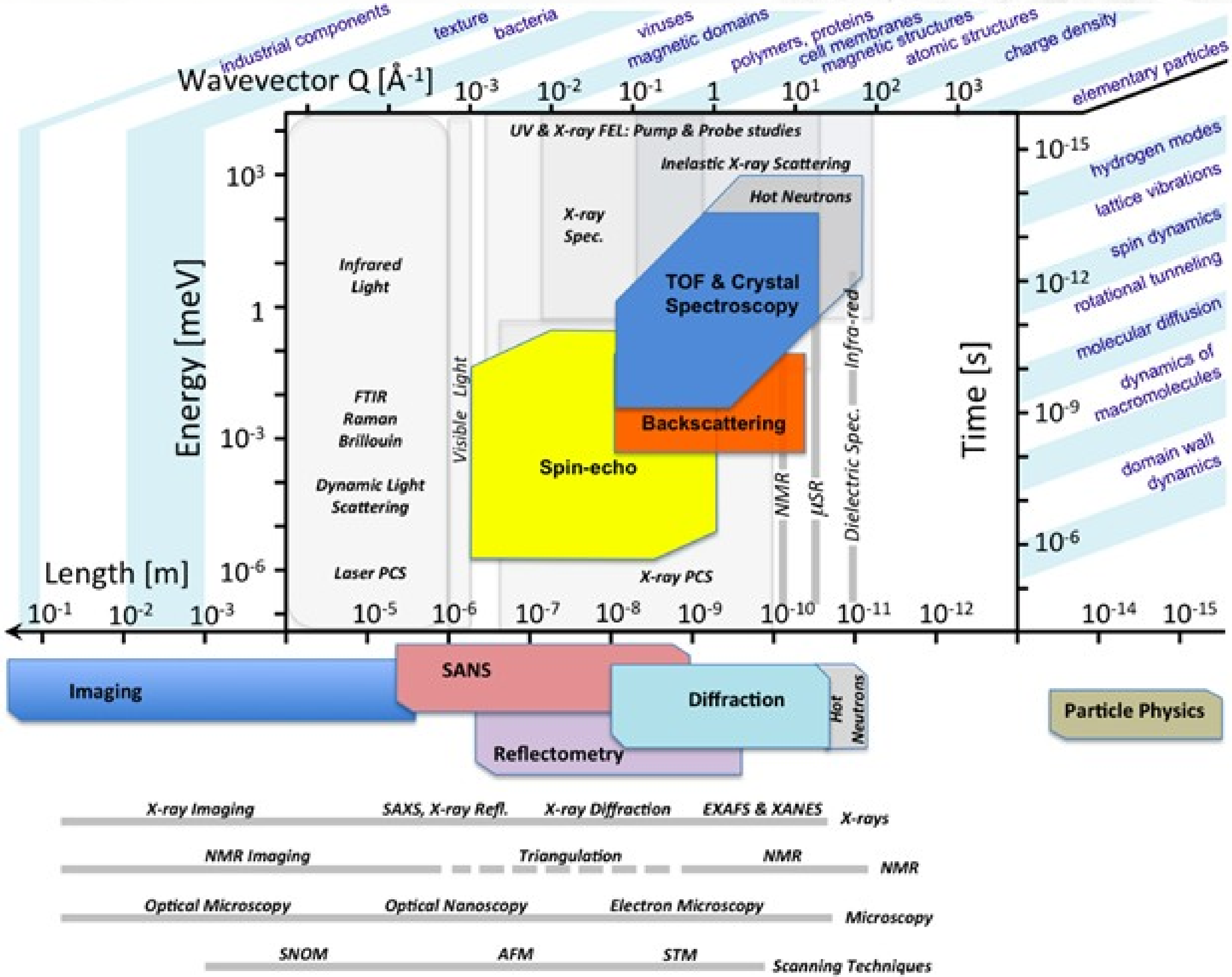
  atomic structure & dynamics
- Spin $\Rightarrow$ magnetic structure & dynamics $\Rightarrow$ $S_{mag}(Q,\omega)$

Thermal Neutrons



Thermal Neutrons

An excellent probe for condensed matter

PROS

- Thermal (300 K) $\Rightarrow$ $\lambda \sim$ Å, $E \sim$ meV
  atomic structure & dynamics
- Spin $\Rightarrow$ magnetic structure & dynamics
- No charge ("a gentle probe")
  $\Rightarrow$ weak coupling, linear response, bulk probe
- Coherent and incoherent scattering
  $\Rightarrow$ both collective and single-particle dynamics
- Isotope substitution $\Rightarrow$ atom selective investigations

CONS

- No charge $\Rightarrow$ bulk samples: big samples, no surface
- Need a Large Infrastructure for the SOURCE!!

Neutrons: a European Leadership

Neutrons: a European Leadership

- ILL Grenoble (France) *continua*
- ISIS Abingdon (United Kingdom) *pulsata*
- FRM2 Munich (Germany) *continua*
- PSI Villigen (Switzerland) *pulsata*

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- SNS Oak Ridge (US)
- J-PARC Tokai (Japan)
- Ansto Lucas Heights (Australia)
- CSNS Dongguan (China)

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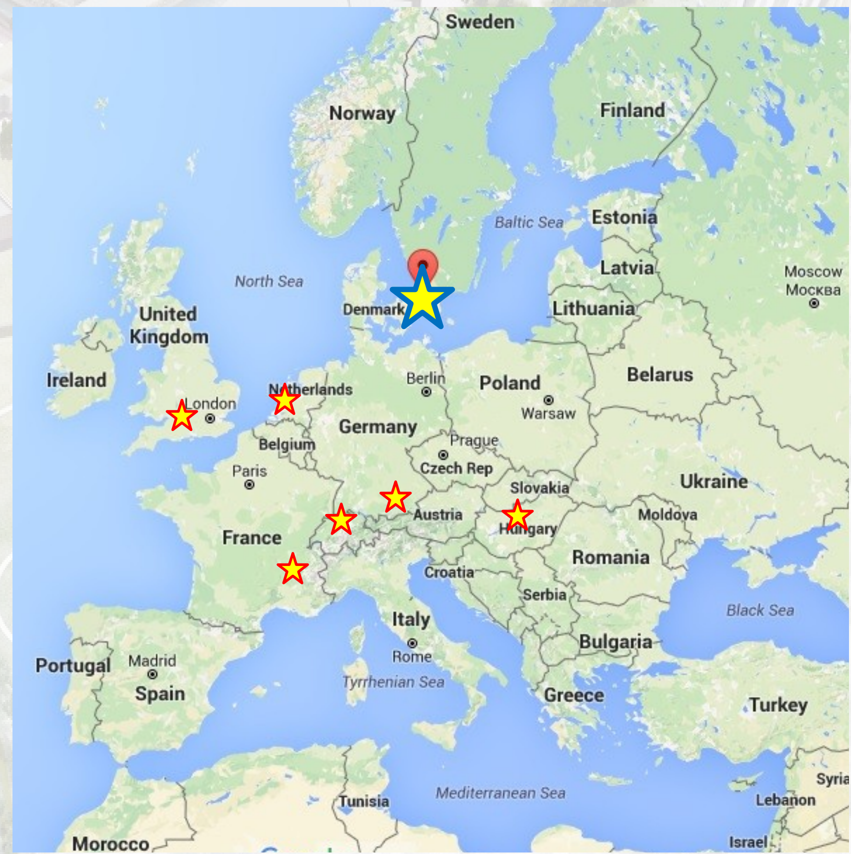
European Spallation Source ERIC

(*Lund*, Sweden)

- New-generation pulsed neutron source



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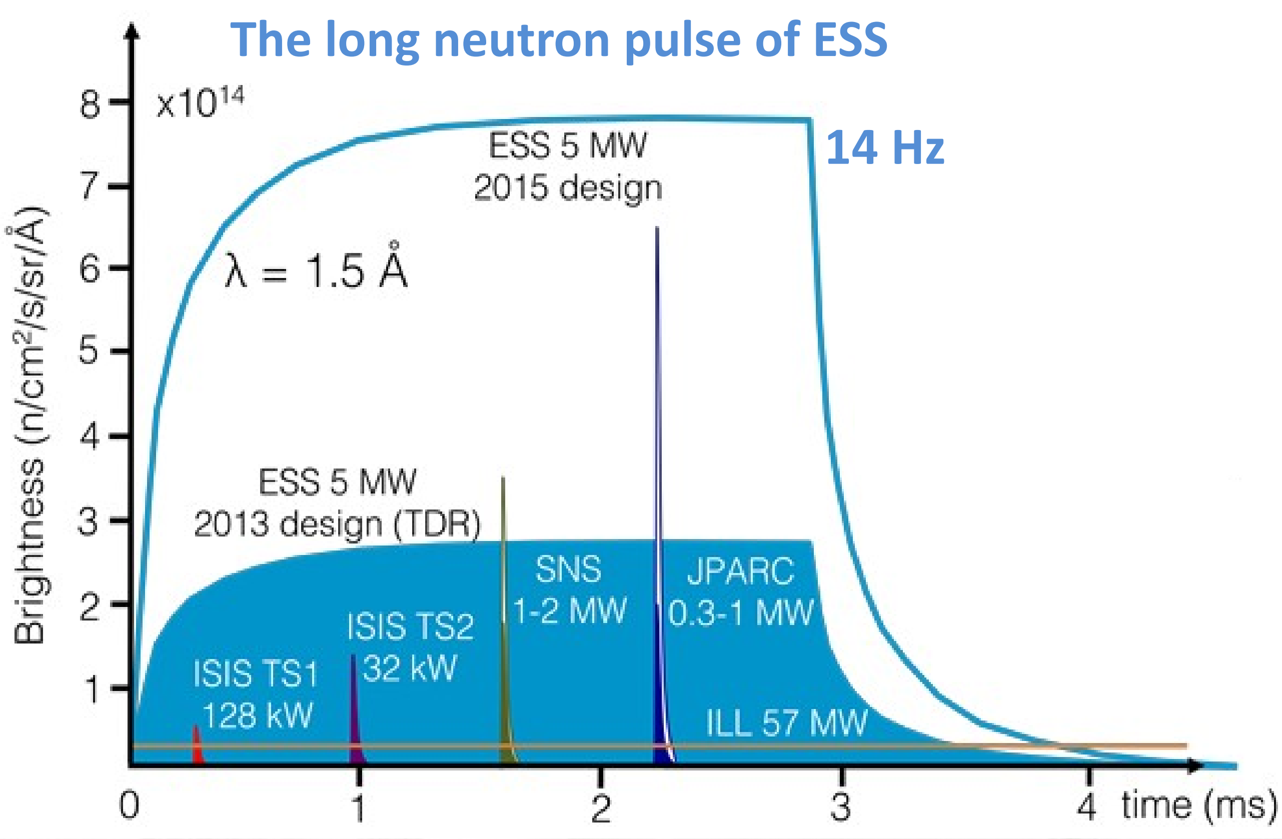
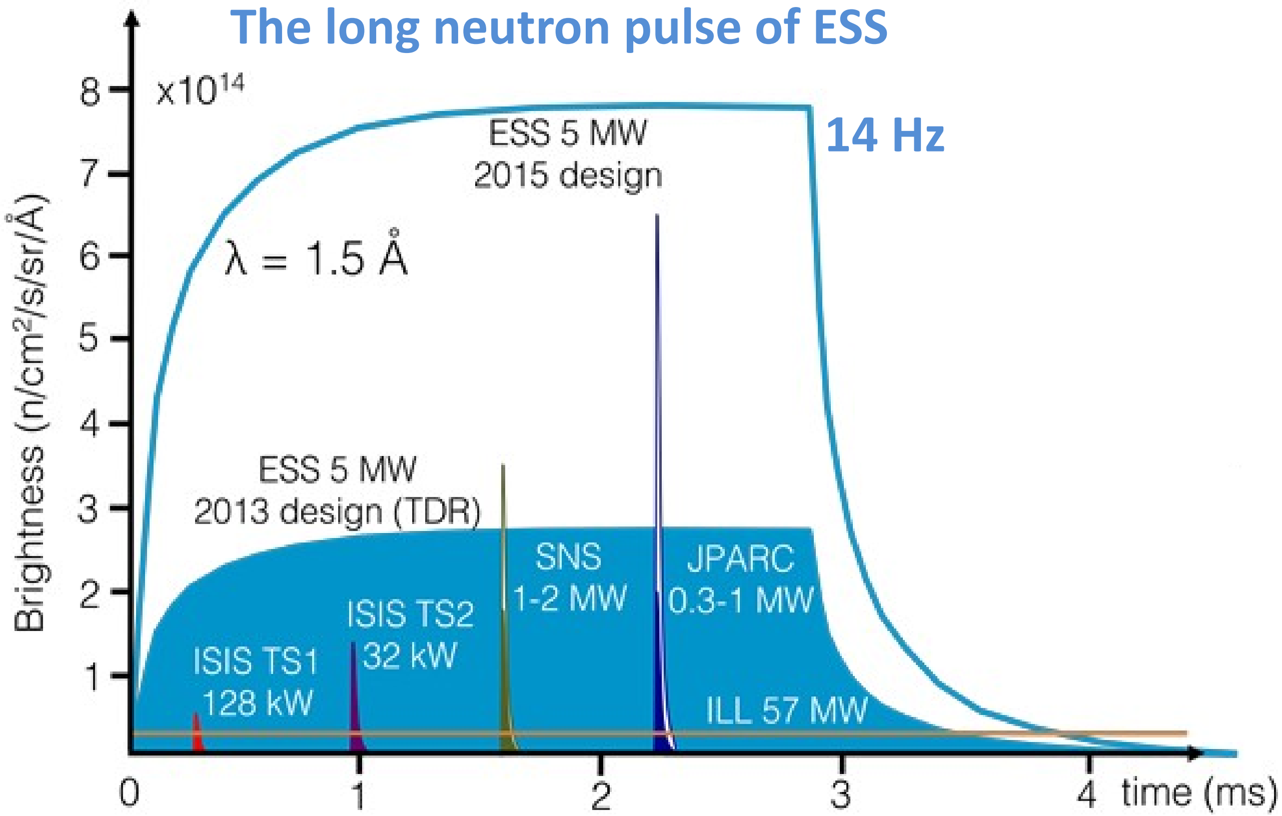


European Spallation Source ERIC

(*Lund*, Sweden)

- New-generation pulsed neutron source
- Higher brightness and longer pulse
- World-leading neutron facility

The long neutron pulse of ESS



European Spallation Source ERIC

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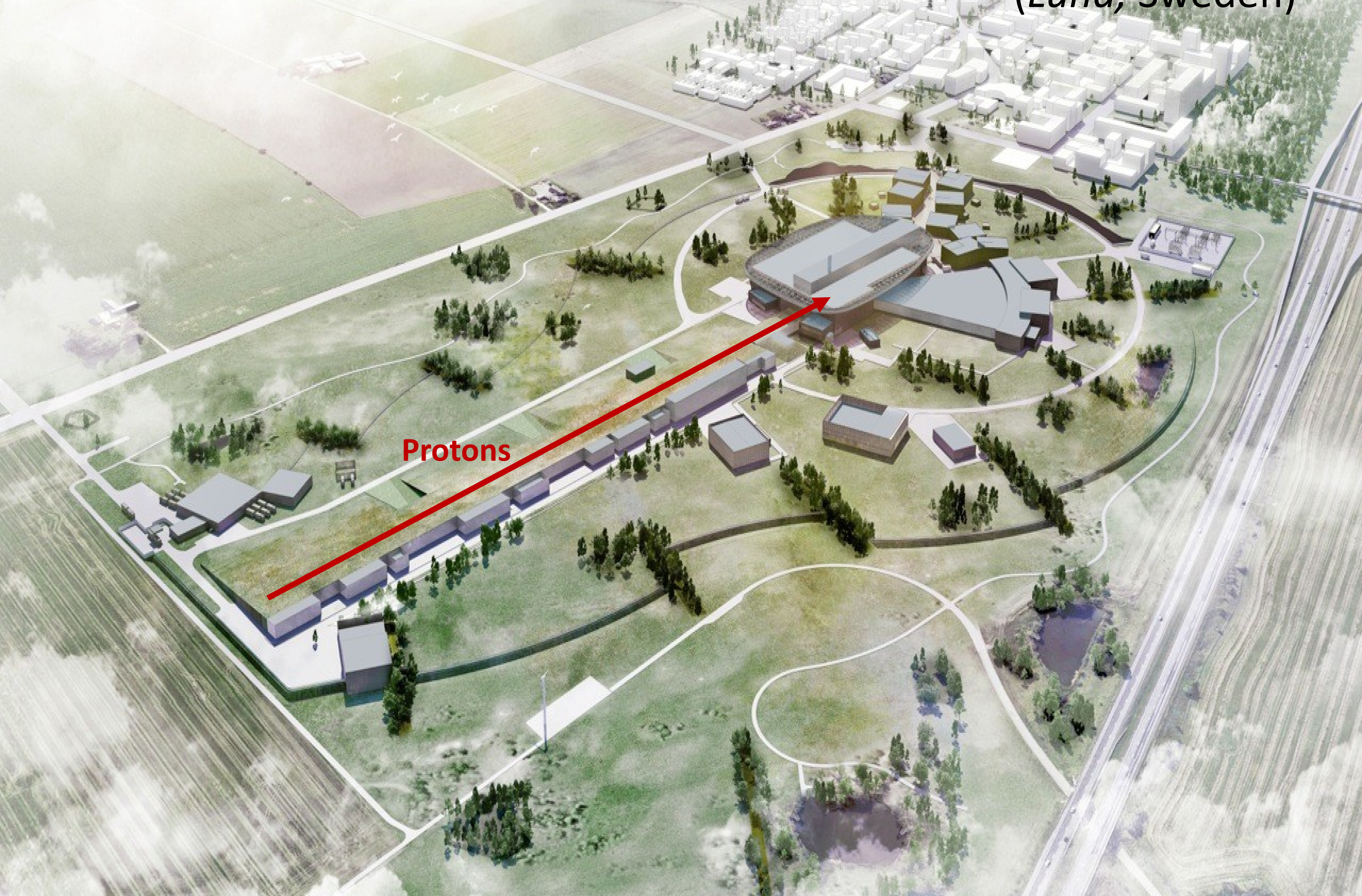

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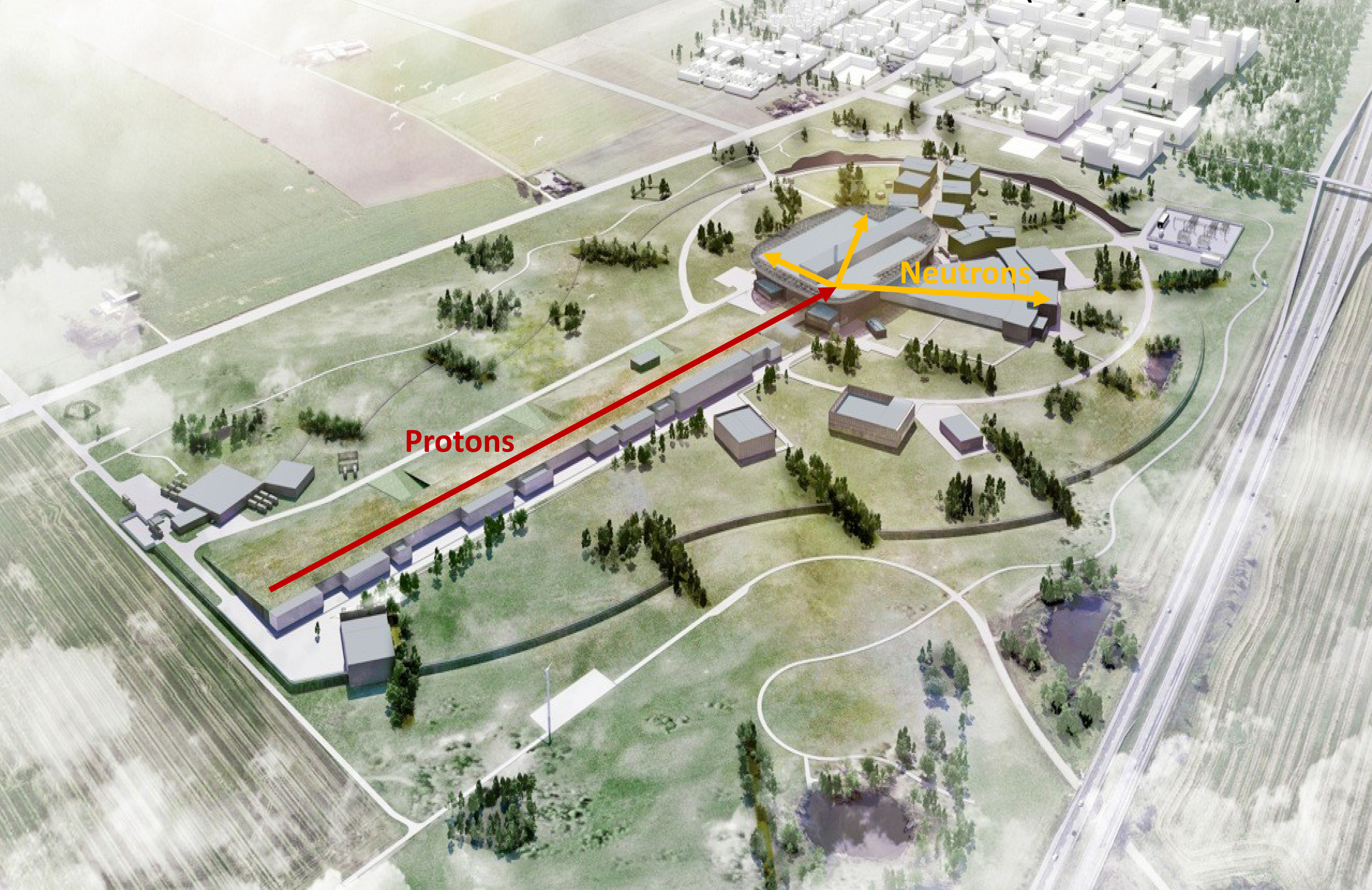

EUROPEAN SPALLATION SOURCE

The In-Kind Contribution process

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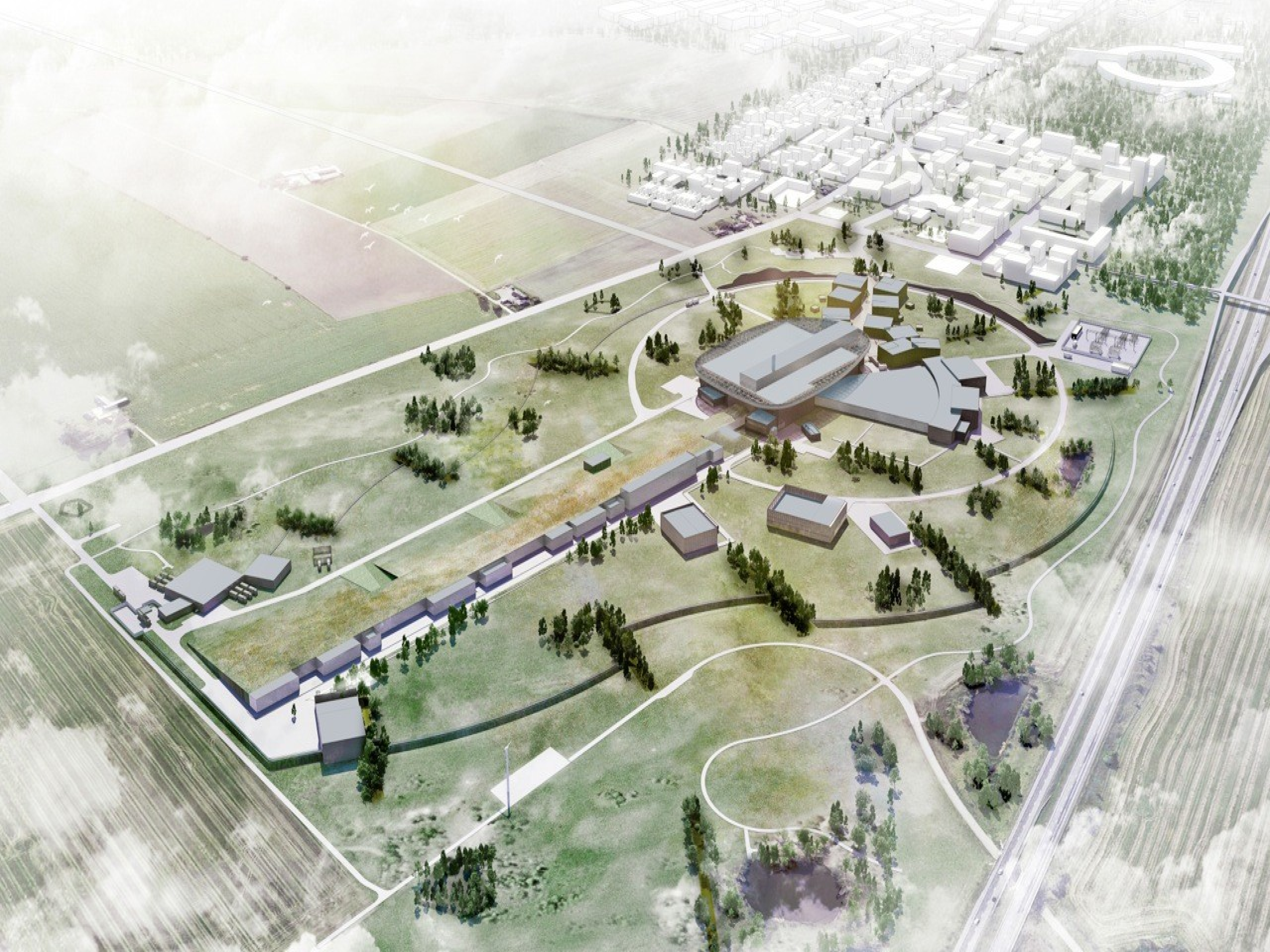
    - → **T-REX 16.85 M€ (2015)**

The In-Kind Contribution process

- Started in 2011
- 40 in-kind partner countries nowadays
- Call for in-kind proposals (2012)
- Collection of proposals from partner countries for:
  - Conventional facilities
  - Accelerator (INFN & Elettra)
  - Target
  - Neutron instruments (CNR)
- Thorough selection of proposals
  (still ongoing!)
- Progressive acceptance of proposals and in-kind values:
  - 15 out of 22 instruments
    - → **T-REX 16.85 M€ (2015)**
    - → **VESPA 12.00 M€ (2016)**




August 2017


August 2017
170 m


April 2019


January 2021


November 2021

2018 – Ion Source completed @INFN Catania

November 2018

Follow the #IonSourceAdventure from Sicily to Sweden

November 2018

November 2018.
High-level Swedish and Italian delegations, led by King Carl XVI Gustaf of Sweden and President Sergio Mattarella of Italy, came together to inaugurate the first major technical components to be commissioned at the European Spallation Source: the Accelerator’s Ion Source and LEBT.

T-REX

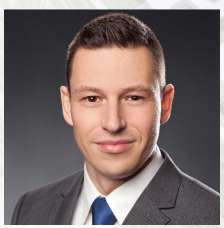
a German-Italian collaboration for ESS

Jülich Center for Neutron Science (Germany)


Thomas Brückel


Nicolò Violini


Jörg Voigt


Marcel Serwe

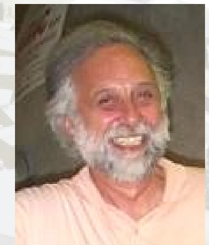

Tadeusz Kozielewski

Mario Könen
Achim Heynen

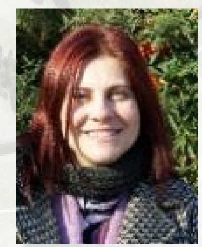
~75%

CNR - IOM & Università degli Studi di Perugia (Italy)


Andrea Orecchini

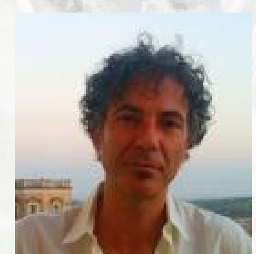

Francesco Sacchetti


Marco Zanatta


Lucia Comez


Pietro Tozzi

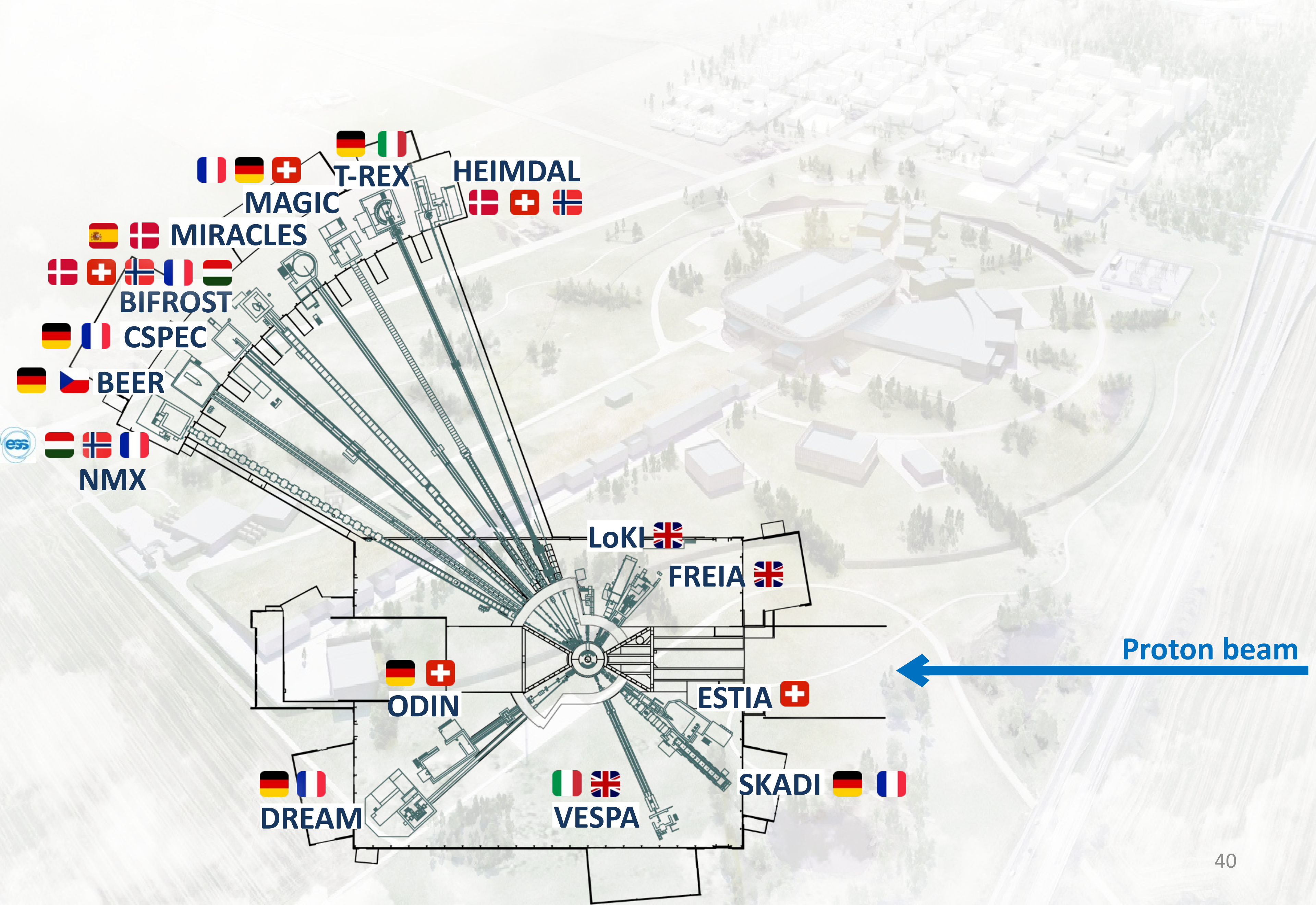

Gianluca Gubbiotti


Alessandro Paciaroni

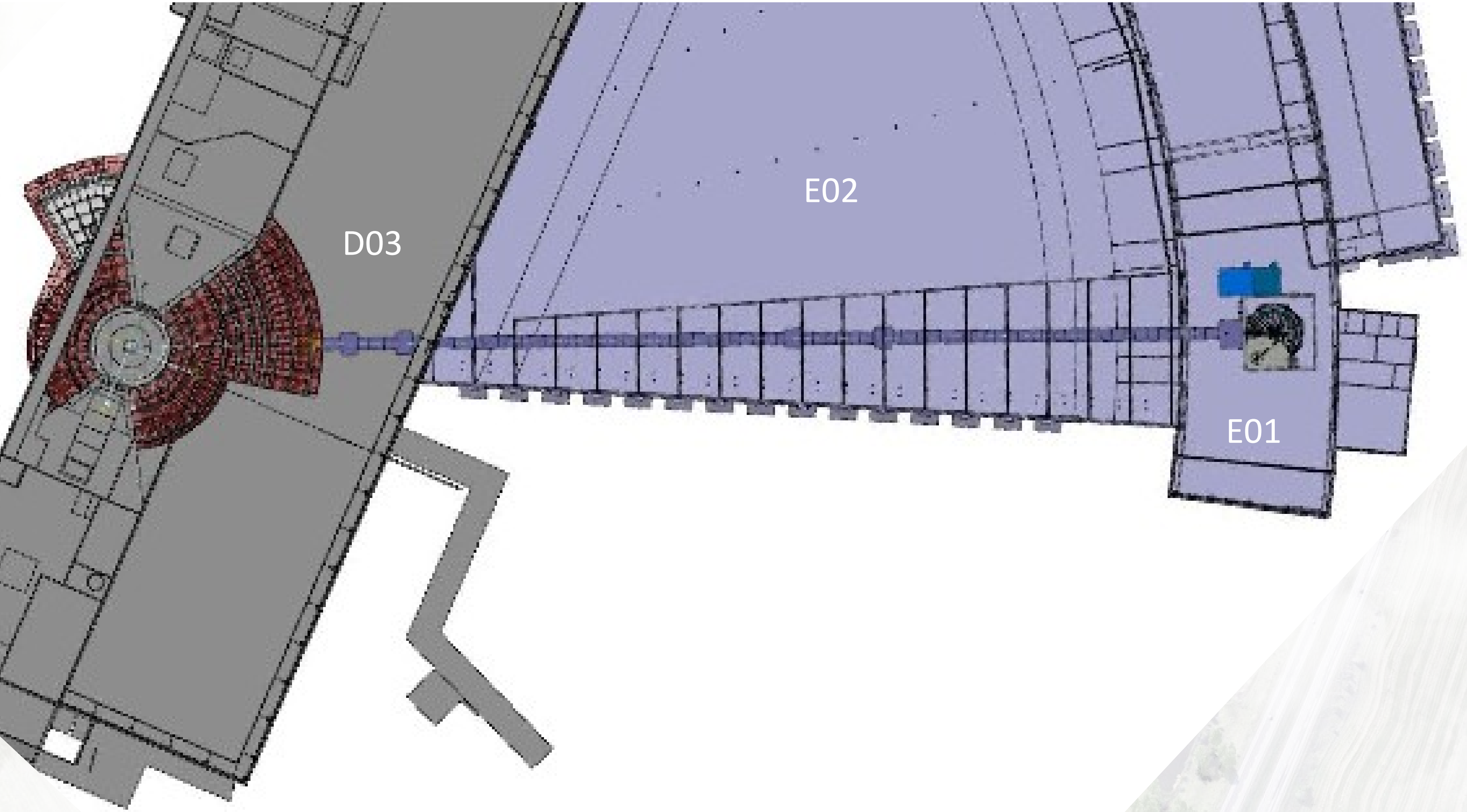
Gianluigi Piluso
Pietro Carmagnini

~25%

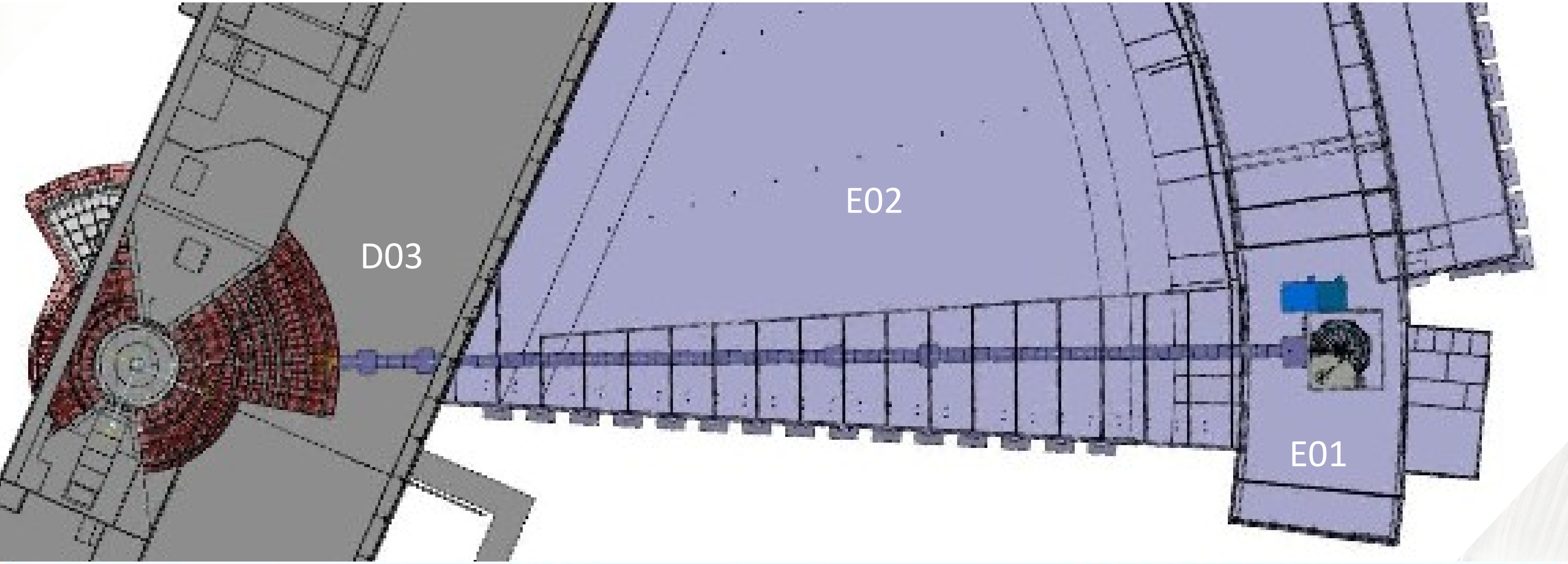
T-REX and the ESS instrument suite

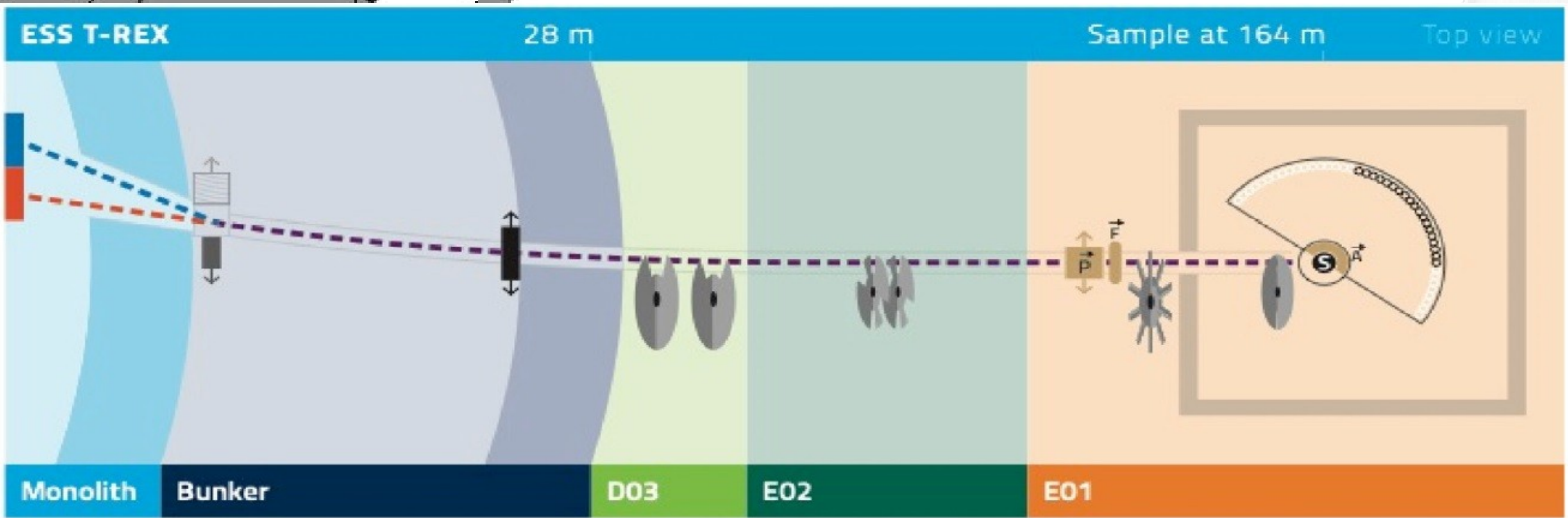


T-REX layout



T-REX layout


D03
E02
E01

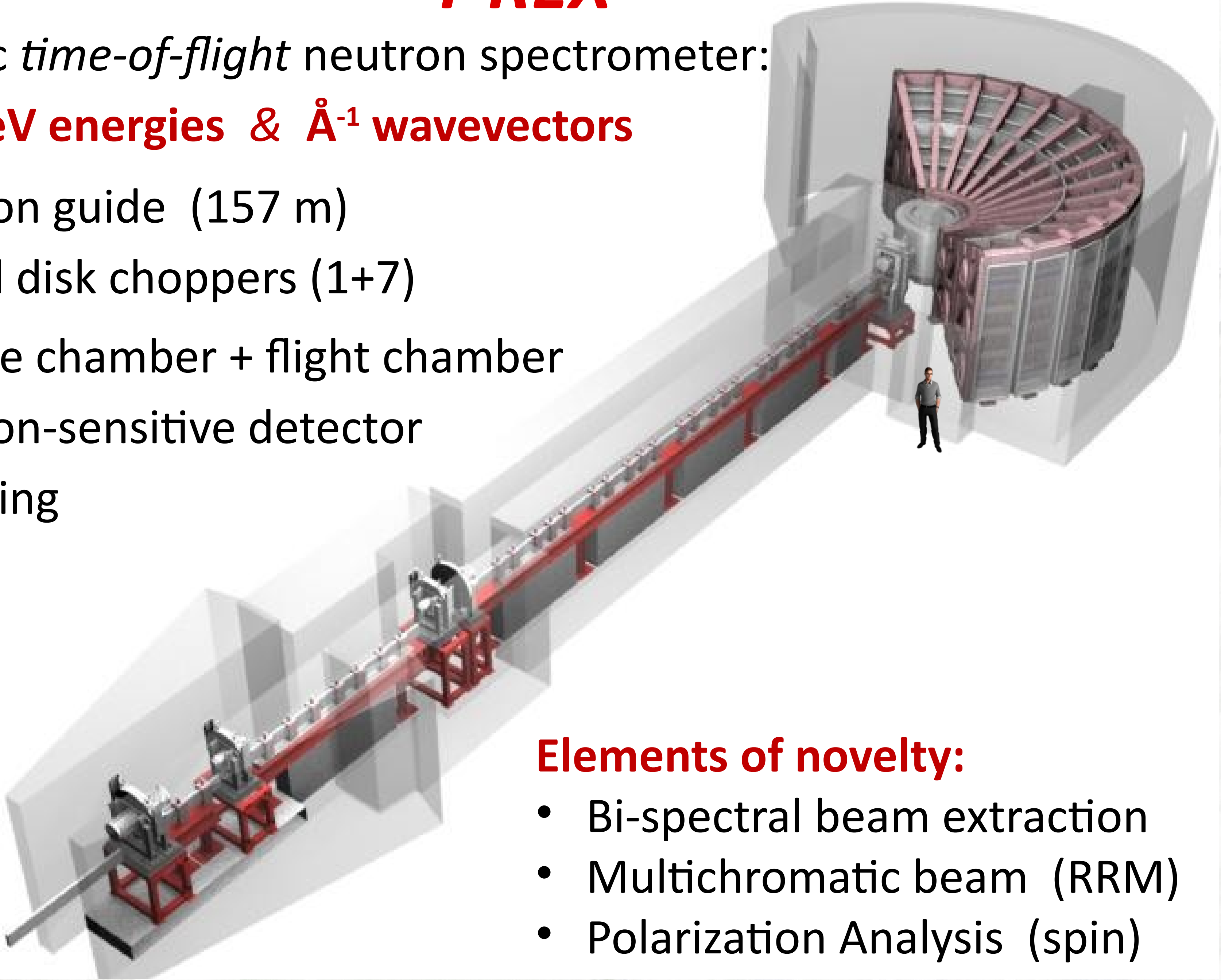

ESS T-REX
28 m
Sample at 164 m
Top view
Monolith
Bunker
D03
E02
E01

T-REX

A classic *time-of-flight* neutron spectrometer:

meV energies & Å^{-1} wavevectors

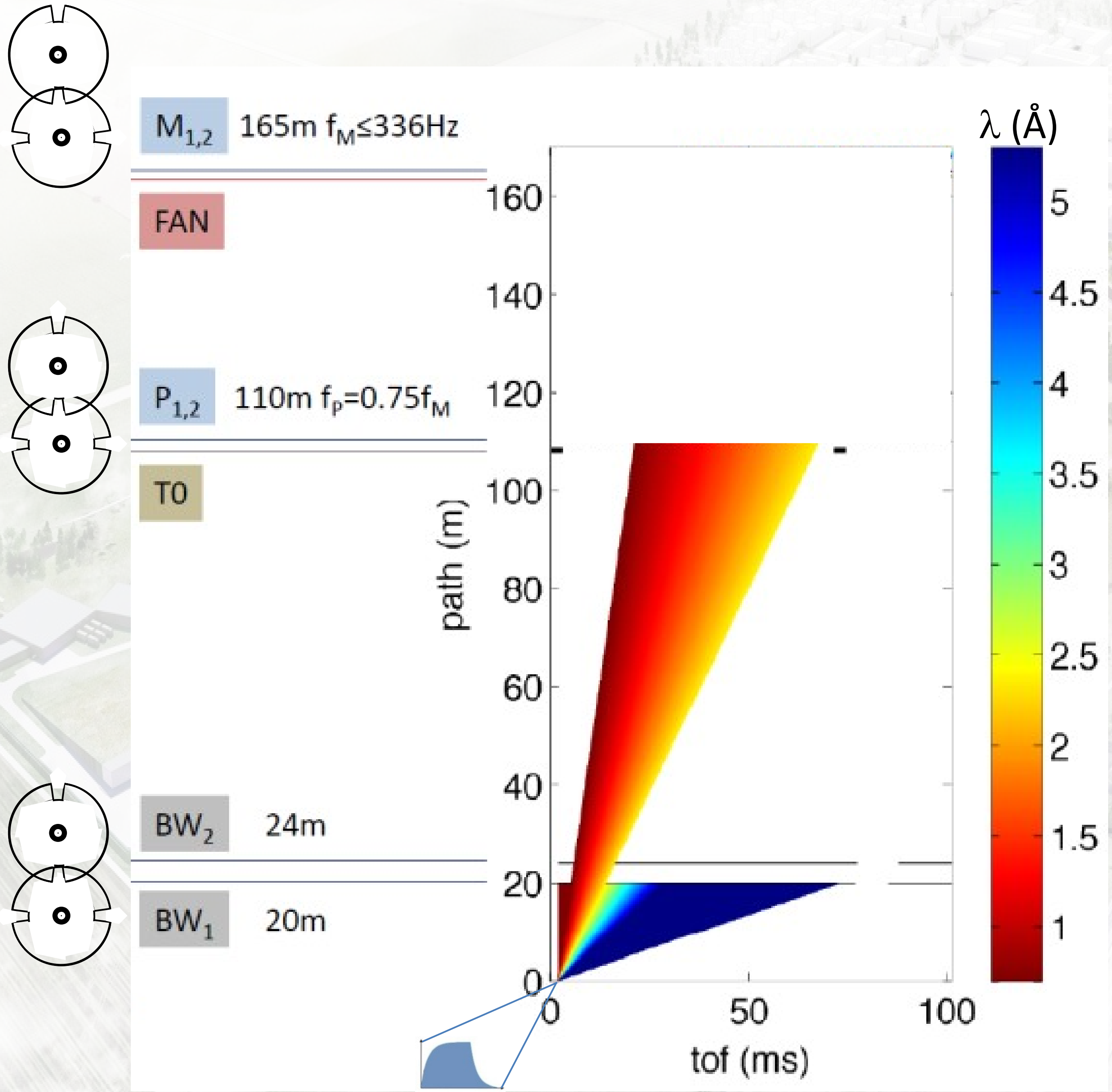
- neutron guide (157 m)
- T_0 and disk choppers (1+7)
- sample chamber + flight chamber
- position-sensitive detector
- shielding



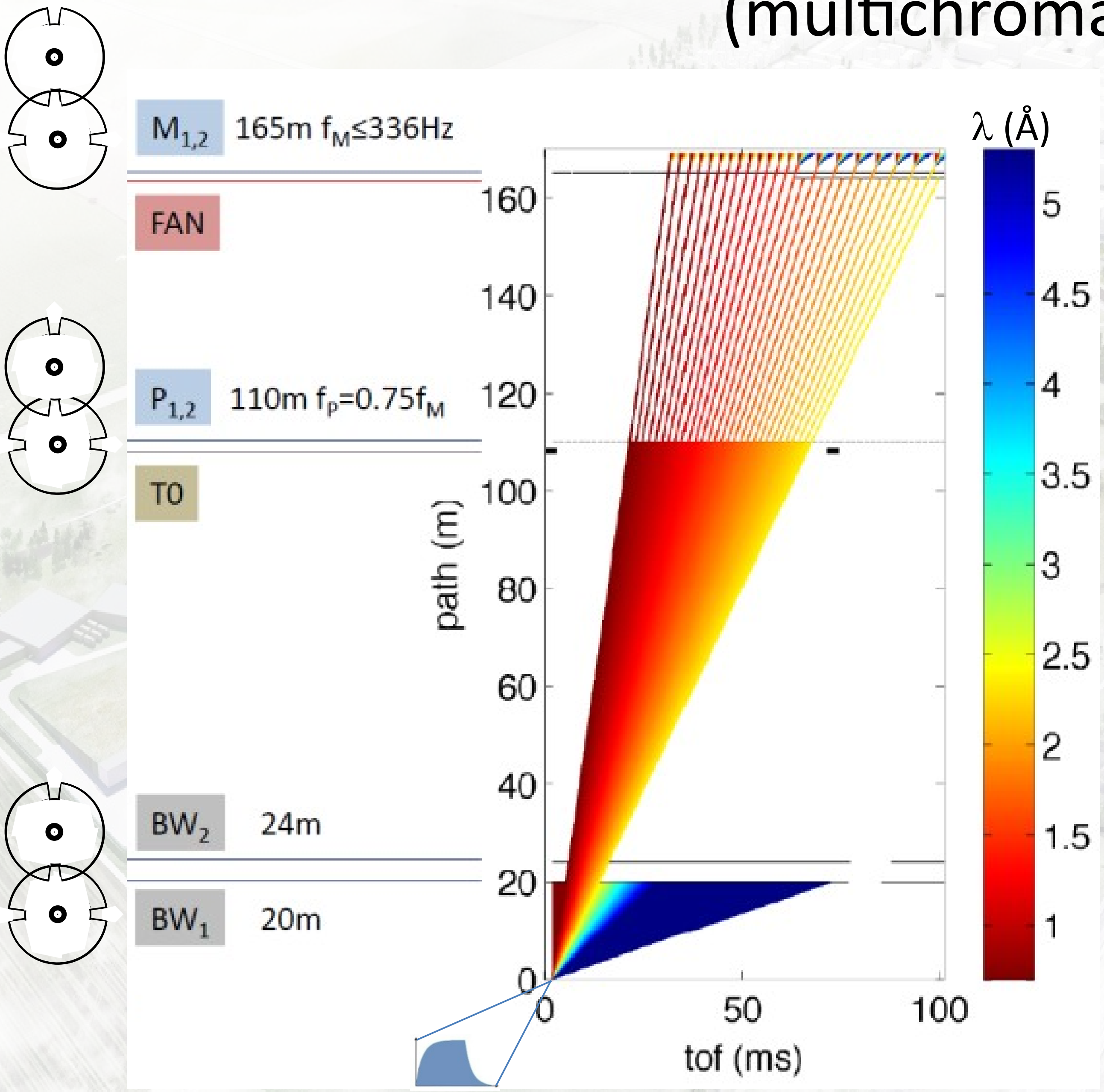
Elements of novelty:

- Bi-spectral beam extraction
- Multichromatic beam (RRM)
- Polarization Analysis (spin)

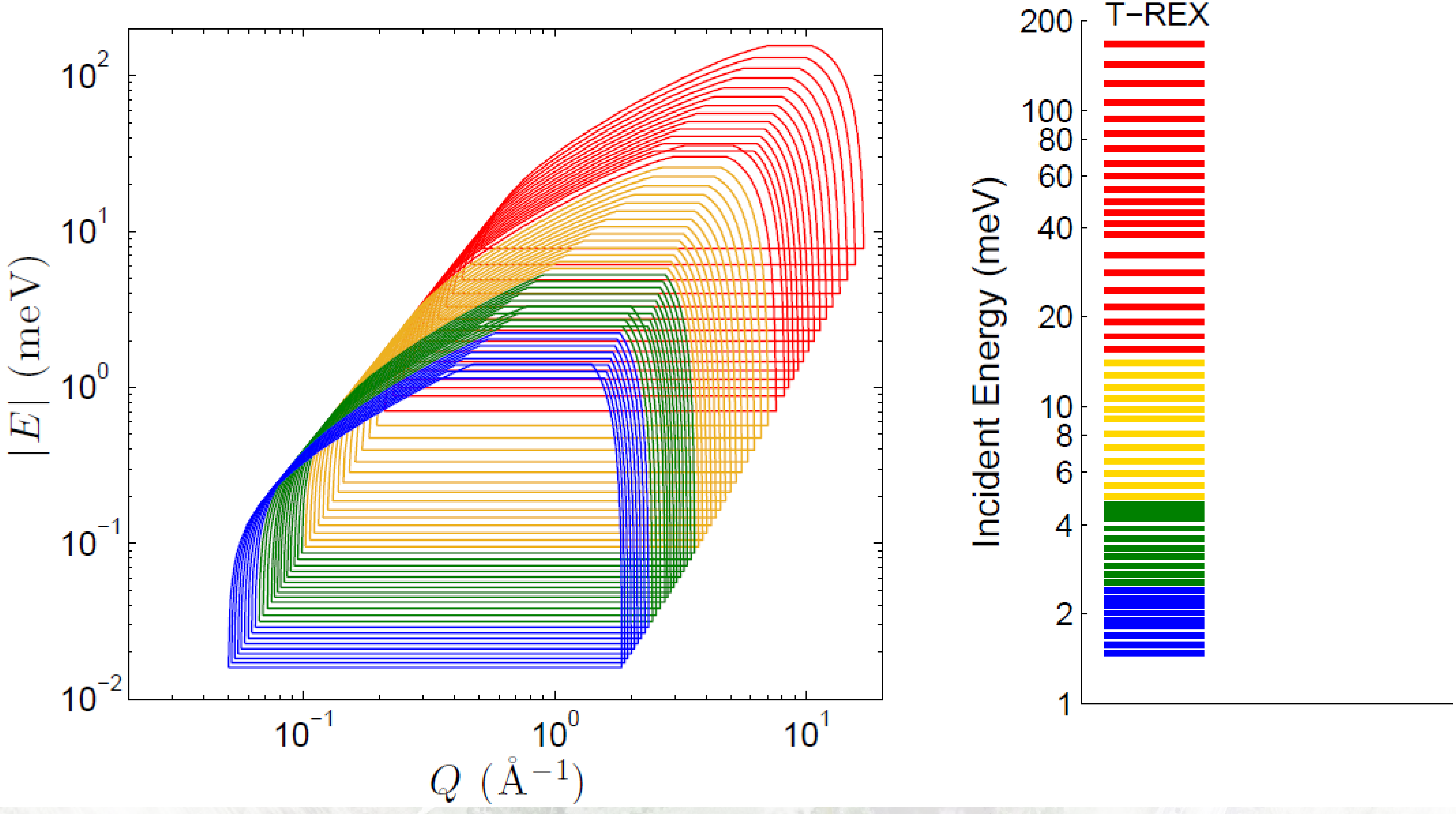
Time-Distance diagram



Time-Distance diagram (multichromatic beam)



Dynamical Range



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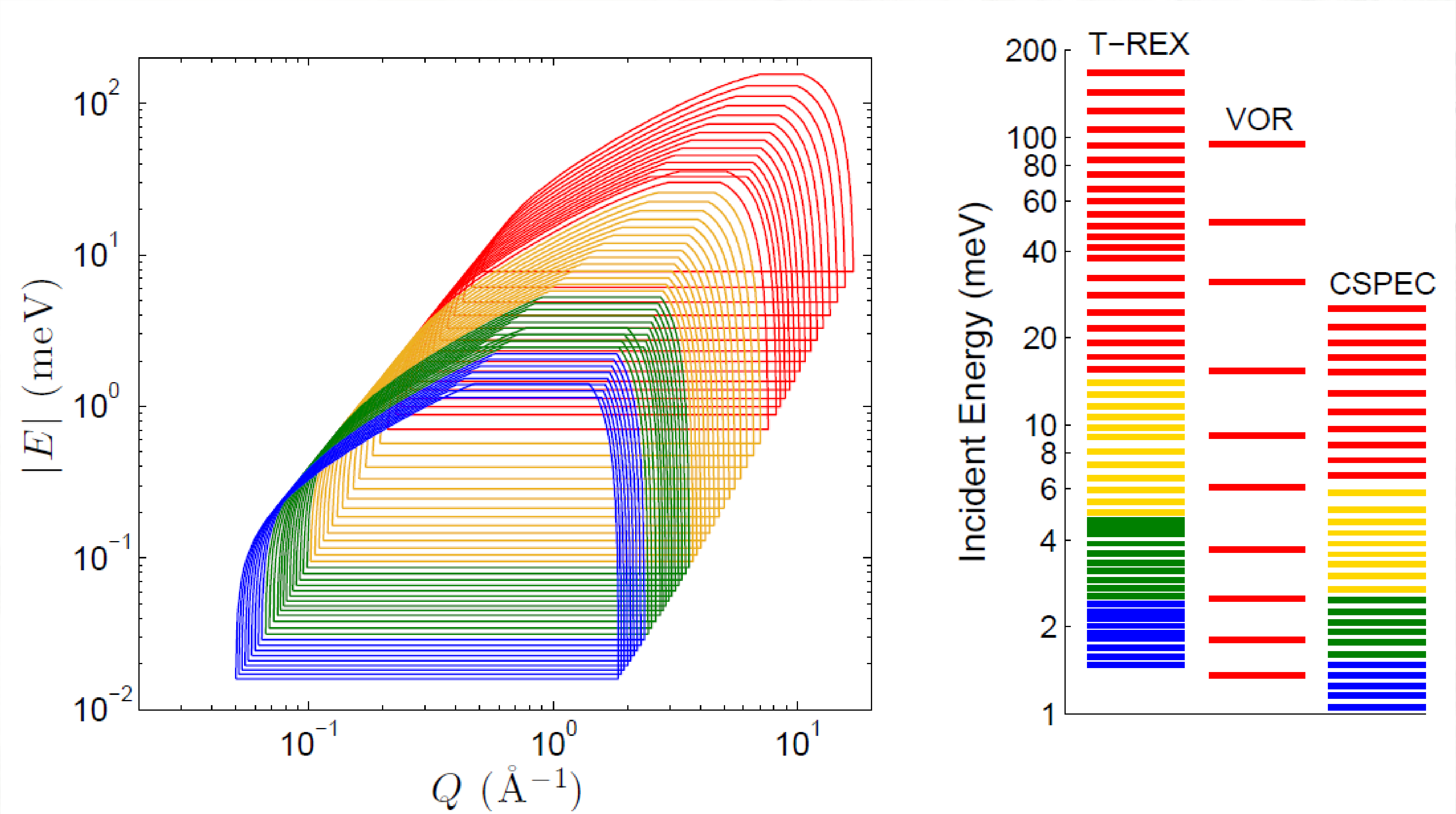


Main features

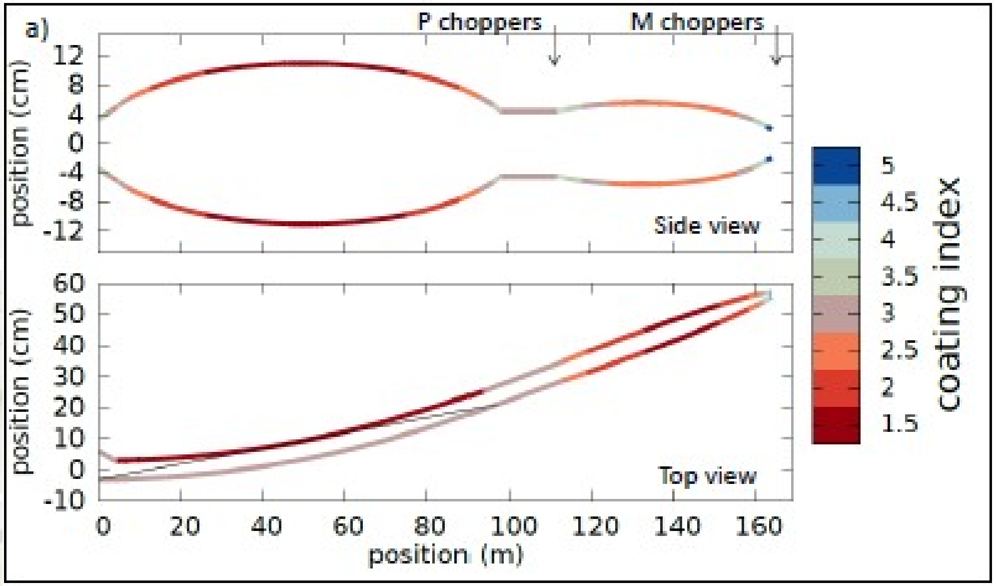
Incident energy	$2 < E < 160$ meV
Energy resolution	$0.02 < \Delta\hbar\omega < 10$ meV
Wavevector transfer range	$0.5 < Q < 170$ nm^{-1}
Wavevector transfer resolution	$0.1 < \Delta Q < 1$ nm^{-1}
Sample cross section	$\leq 10 \times 30$ mm^2
Main features	• Polarization analysis as a standard tool • Repetition rate multiplication • Four dimensional mapping capabilities • High intensity with low background • Adjustable resolution, for flexible trading of resolution for flux • Complex sample environment for *in-situ* and *in-operando* studies

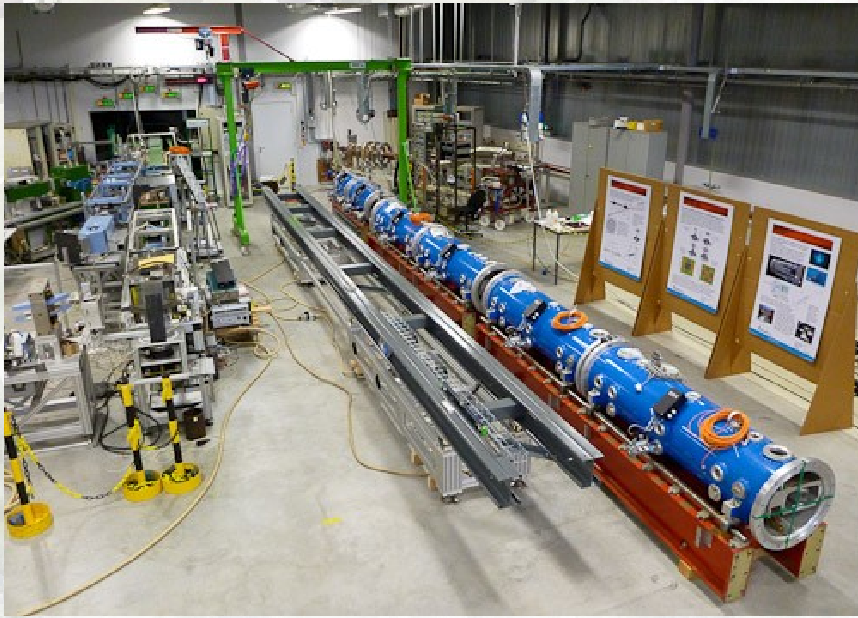
Gain factors

T-REX gain factor \ Instrument	LET	IN5	CNCS	4-SEASONS
Monochromatic gain factor	38	9	9	9
Gain factor at maximal RRM	90	100	140	45

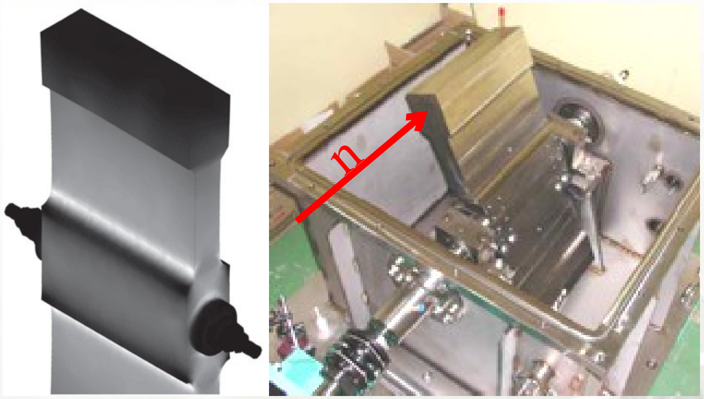
About ONE or TWO orders of MAGNITUDE

Neutron Guides

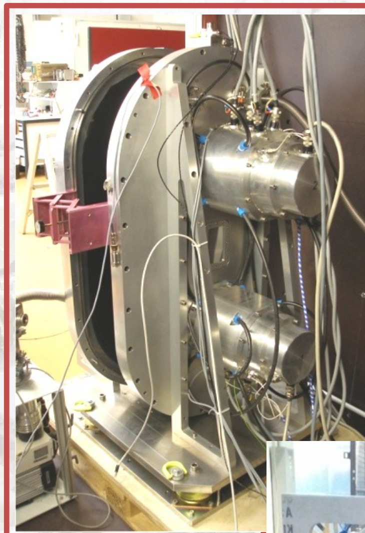




Choppers



T0 chopper
14 Hz



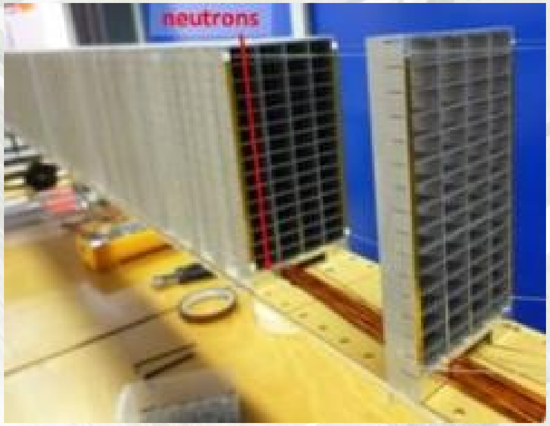
Monochromating double-disk chopper
< 336 Hz

Disk Choppers
14 Hz

Multi-GRID position-sensitive detectors

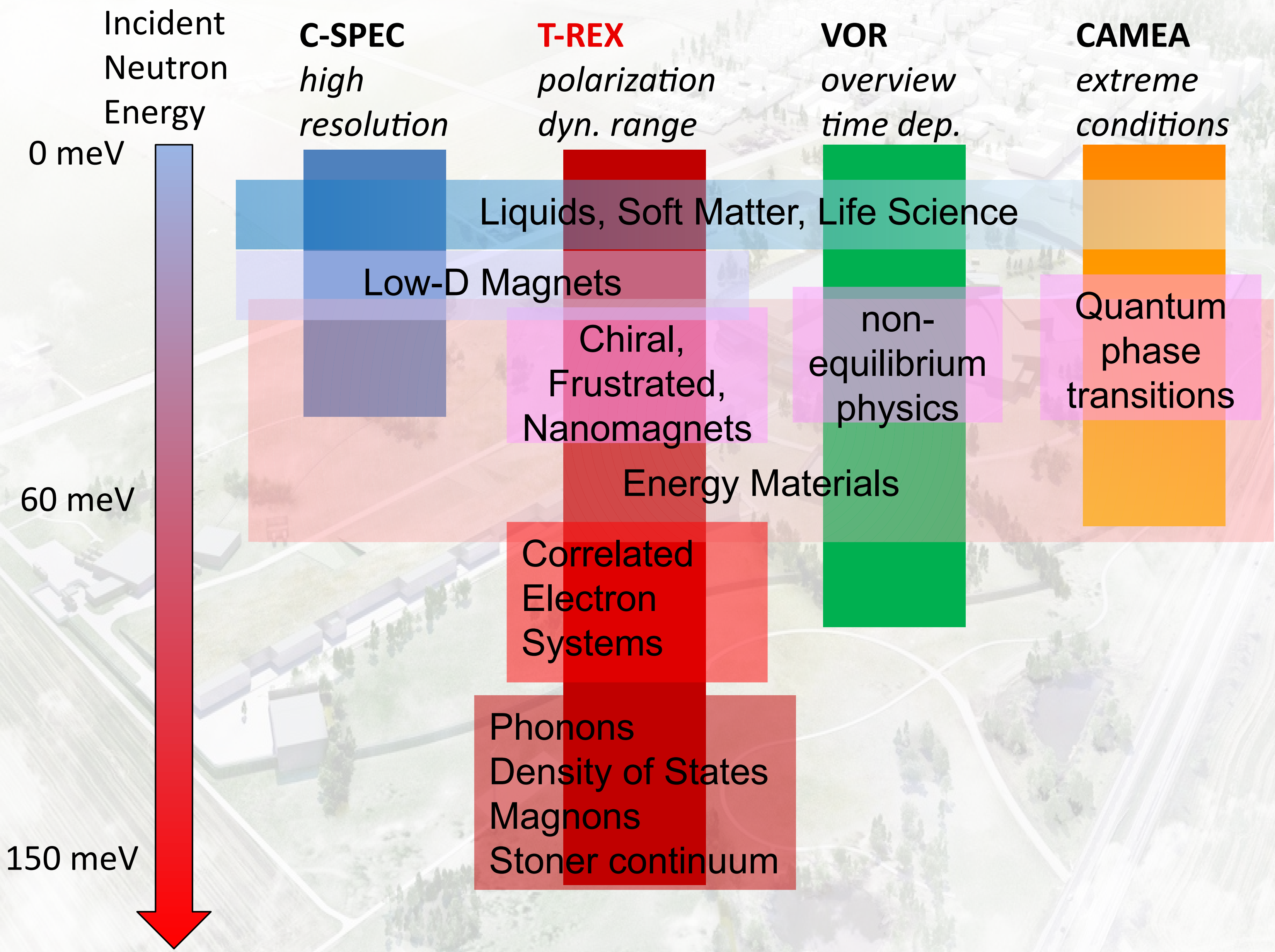
MG @ CNCS

- Size = half of "8-pack" module
- Installation June-July 2016
- Test at spectrometer
- Operation for 6+ months
- Side-by-side comparison to He3
- User experiments



Prototype under construction
20-24 $^{10}B_4C$ layers
6 x 1 µm, 10 x 1.25 µm, 4 x 2 µm
to reach 45-48% efficiency @ 1Å
Fairly compares to ^{3}He at 6 bar
Pure Al frames

Science Cases



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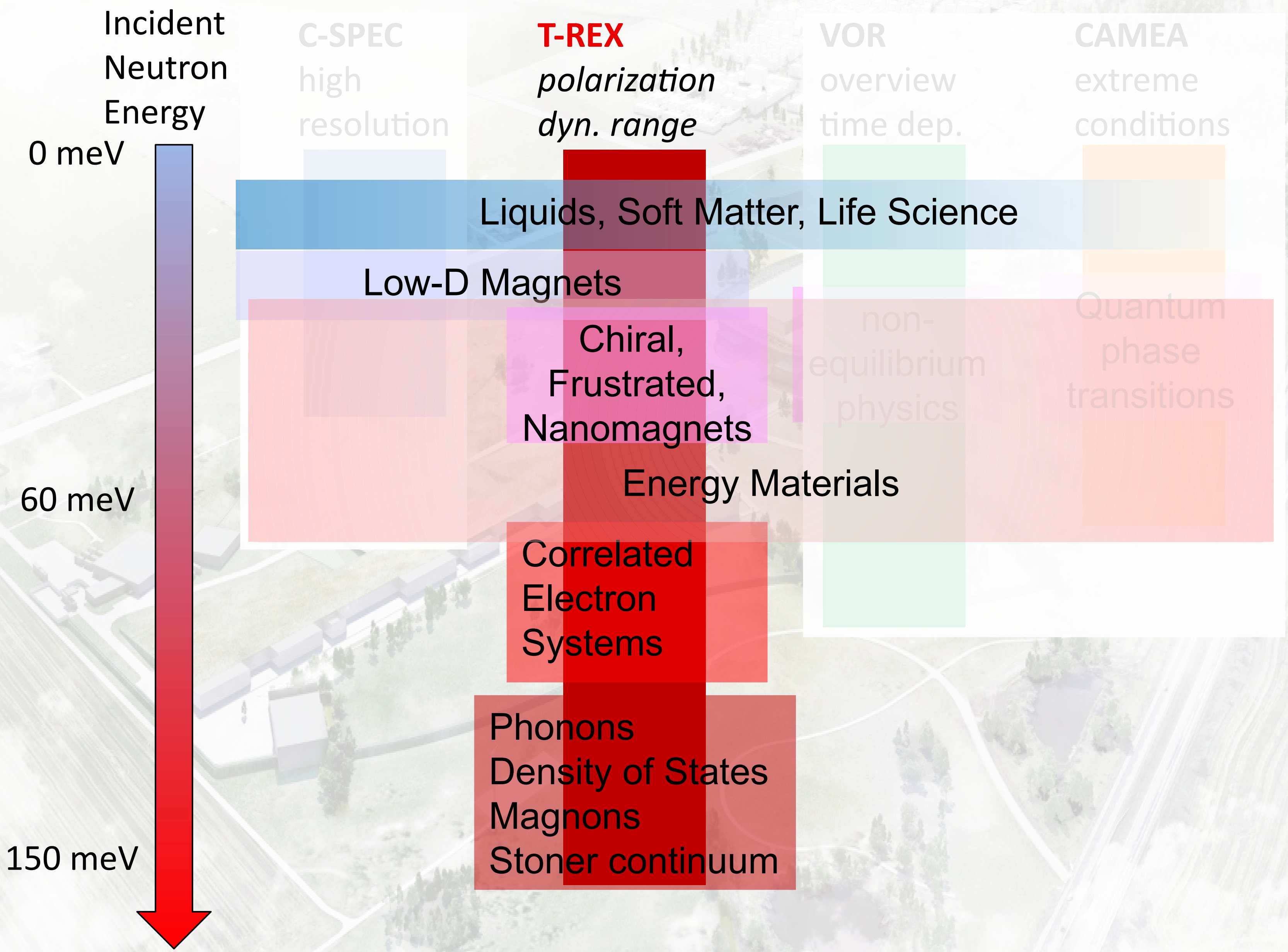
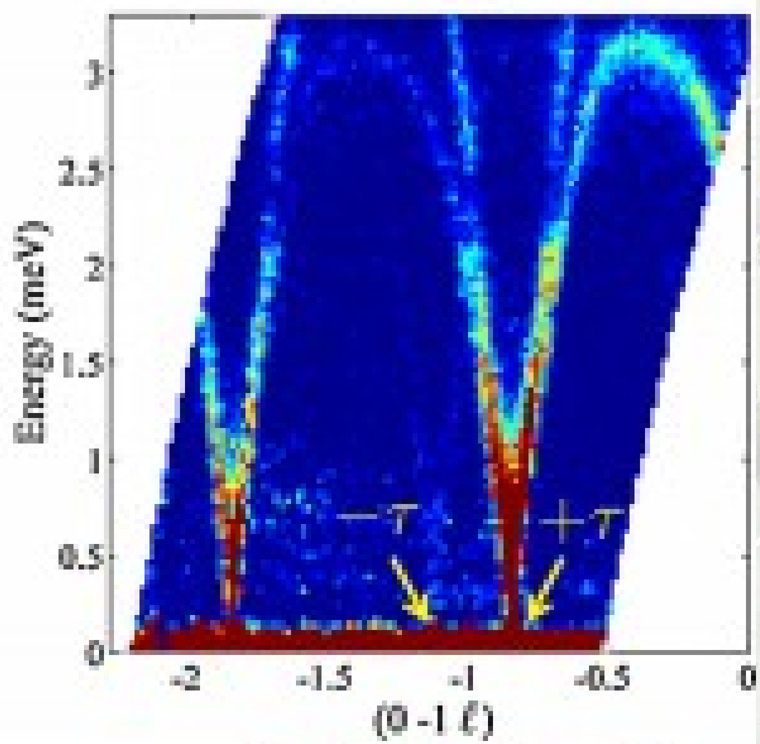


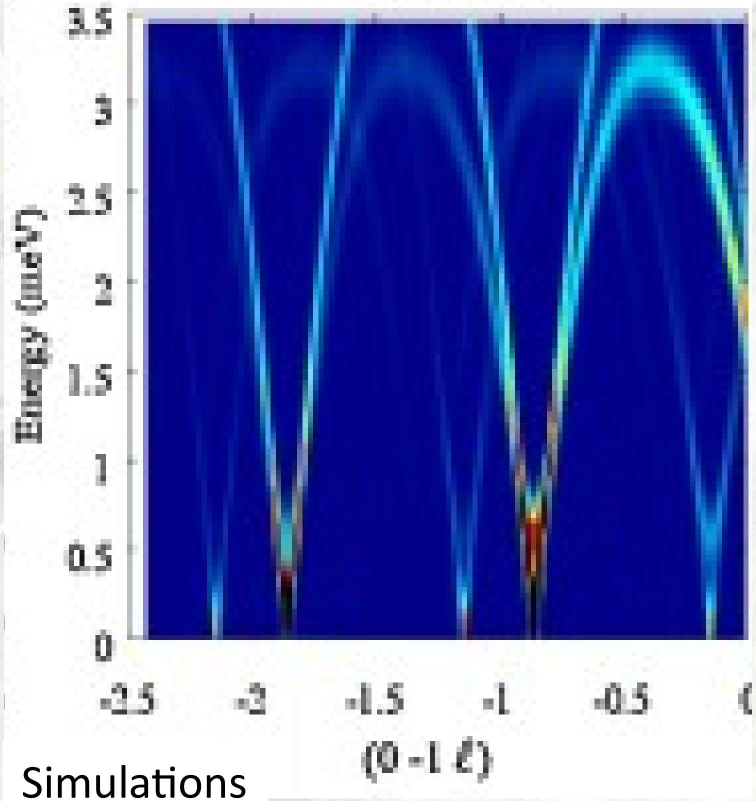
Spin waves in $Ba_3NbFe_3Si_2O_{14}$ single crystals

- Wide survey on IN5 (ToF) + Polarization Analysis on IN20 (TAS)

- Very good energy resolution
- Good ***Q*** resolution
- High flux



Expt. Data



Simulations

Loire *et al.*, PRL **106**, 207201 (2011)

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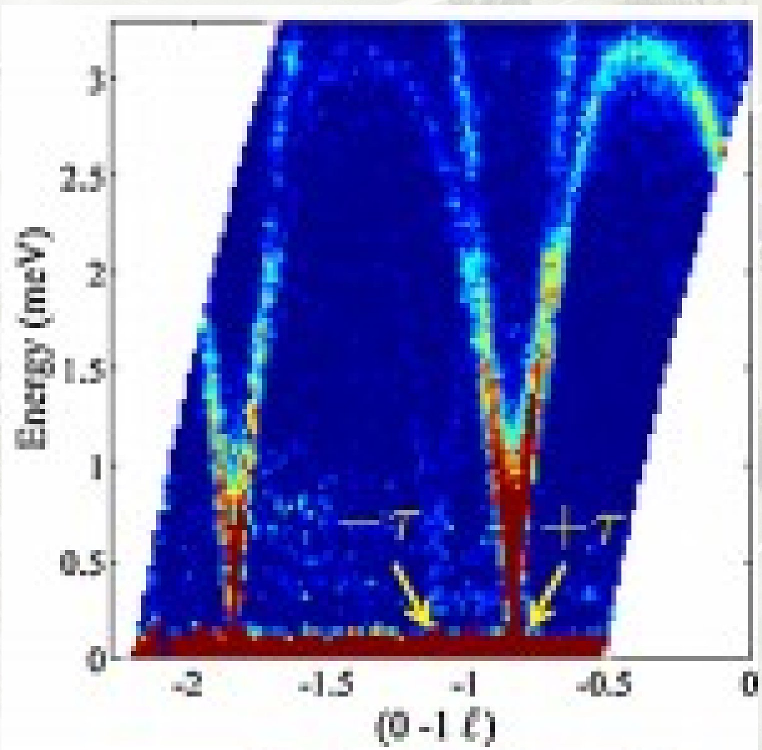

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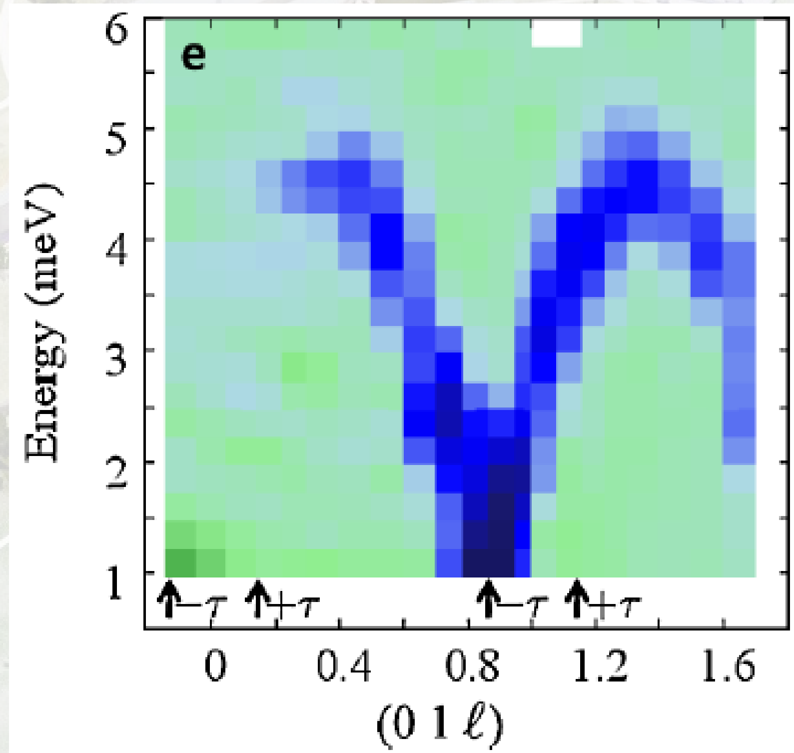
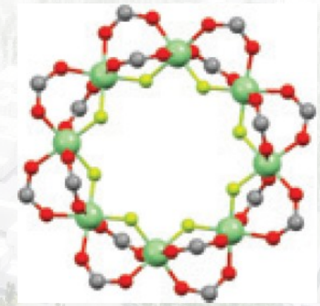


Expt. Data with Polarization Analysis

Loire *et al.*, PRL **106**, 207201 (2011)

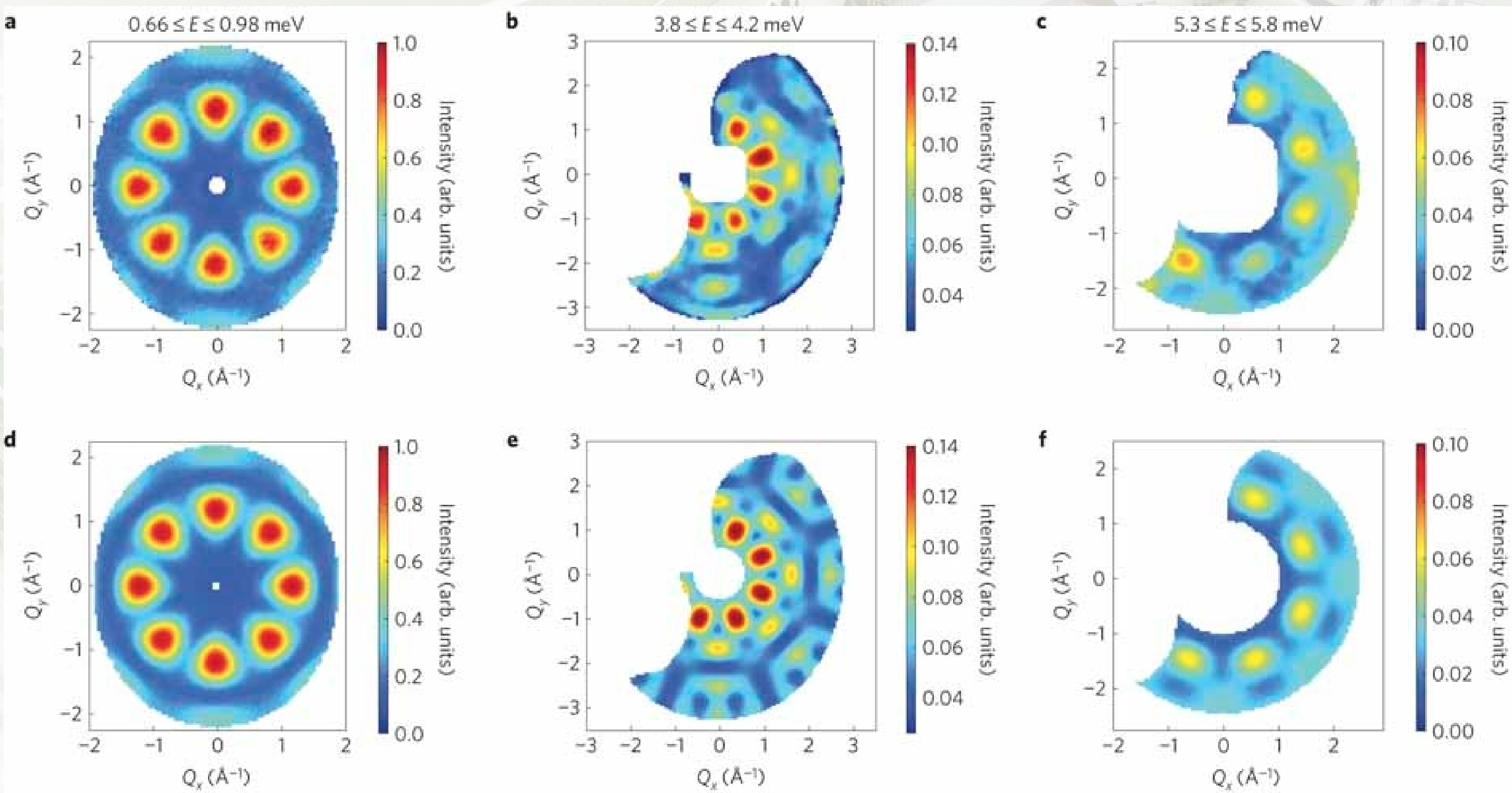
Spin dynamics of molecular nanomagnets

- Entangled spin states (quantum computing)
- Wide 4D mapping



data

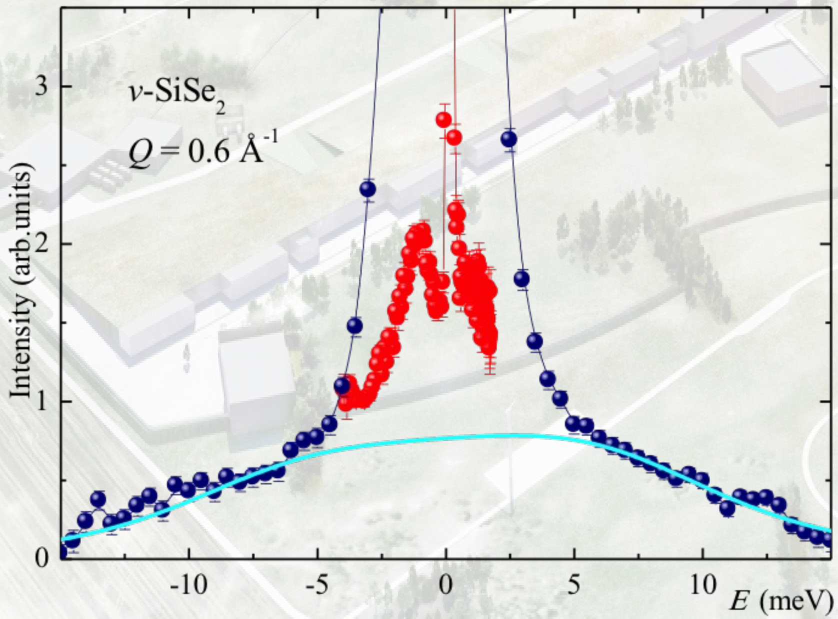
fit

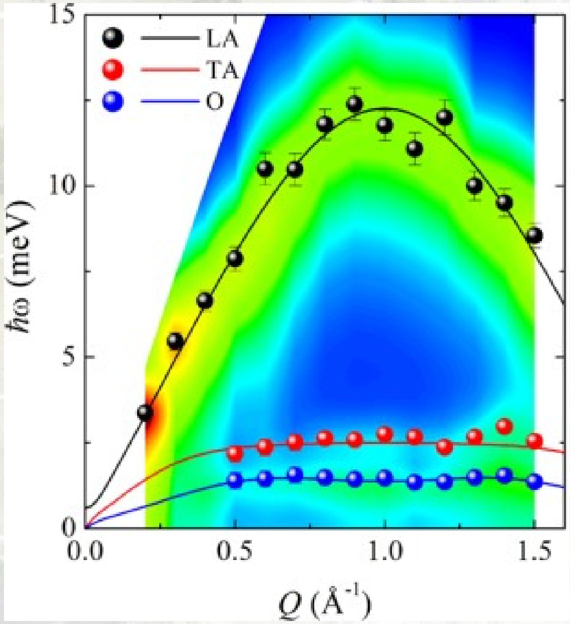


Baker et al. Nature Physics **8**, 906–911 (2012)

Short-wavelength collective excitations in disordered materials

- Complex multi-branched dispersion curves (2 instruments, variable resolution)
- Multichromatic beam!

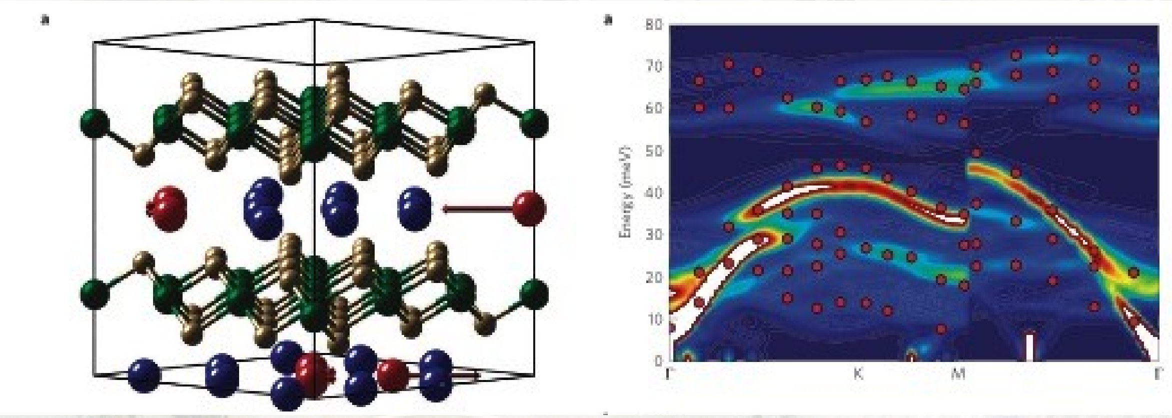




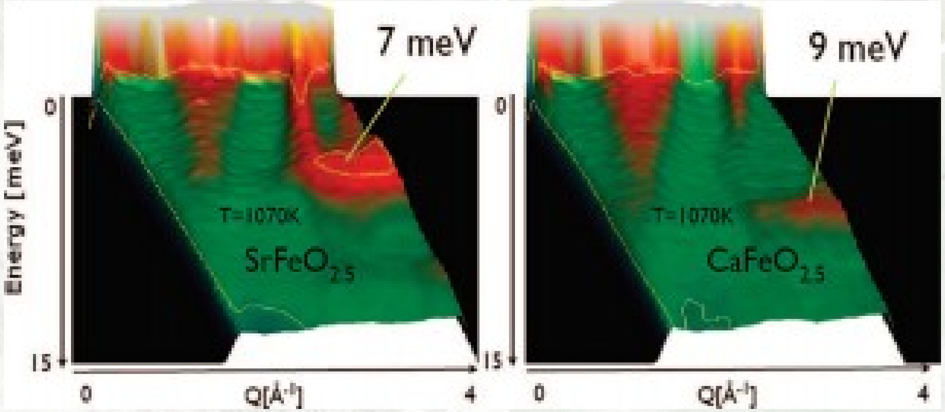
Zanatta *et al.*, J. Phys. Chem. Lett. **4**, 1143 (2013)

Materials for Energy

- Hydrogen storage
- Phonon assisted ionic conduction: from lattice dynamics to diffusive motion
  - Lattice dynamics: High excitation energy
  - Ionic Transport: tens of µeV resolution + large Q
  - Multi components: PA to separate coherent/incoherent scattering (not only H, but Li, Na, Cl,…)



Rattling in $Na_{0.8}CoO_2$
D. J. Voneshen *et al.*,
Nat. Mat. **12**, (2013) 1028



Phonon assisted oxygen mobility in SOFC
W. Paulus *et al*, JACS **130**, (2008), 16080

Blue-shift upon ligand binding in proteins (lysozyme)

- Small and anisotropic signal from functional vibrations (2 techniques)

- High flux
- 4D mapping

Niessen, Paciaroni, Orecchini et al., Biophys. J. 112, 933 (2017)

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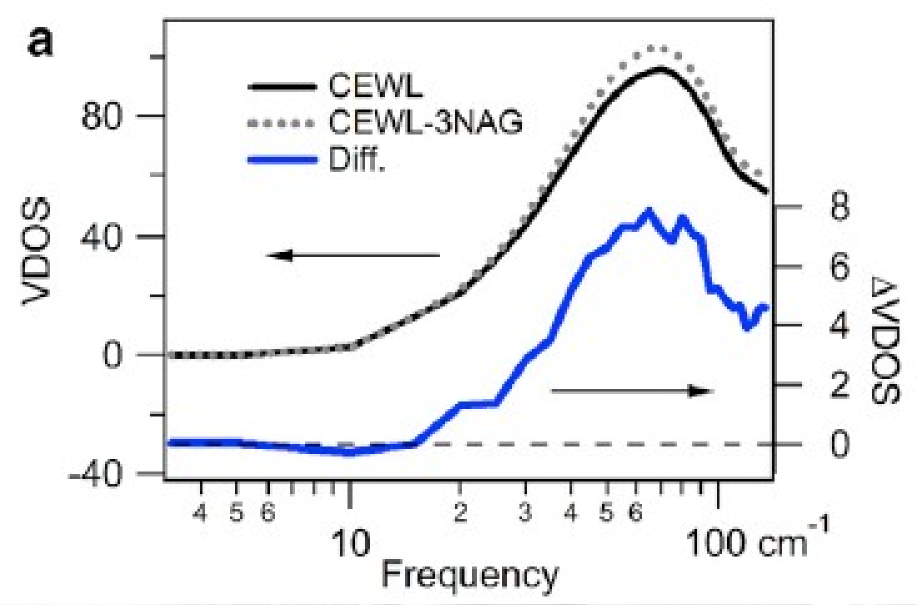

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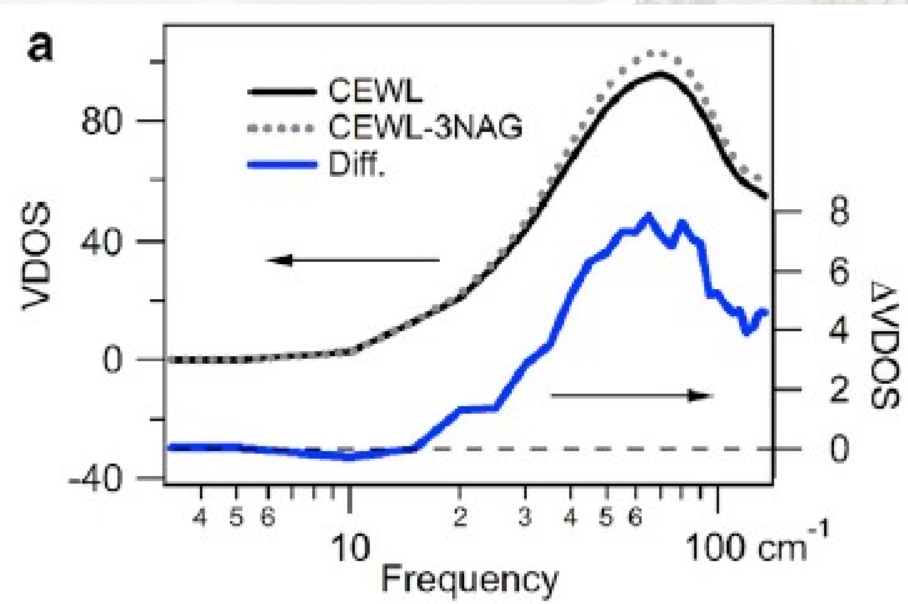

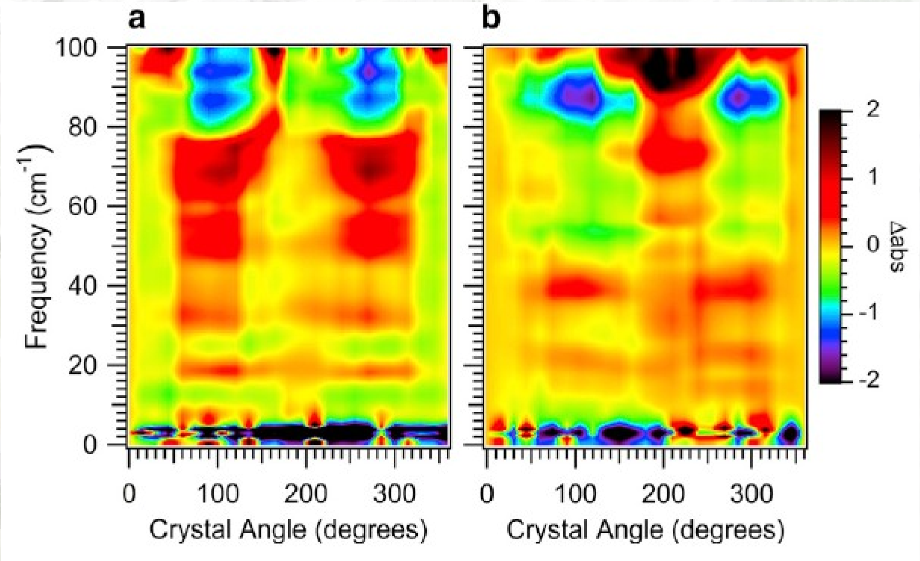

Niessen, Paciaroni, Orecchini et al., Biophys. J. 112, 933 (2017)

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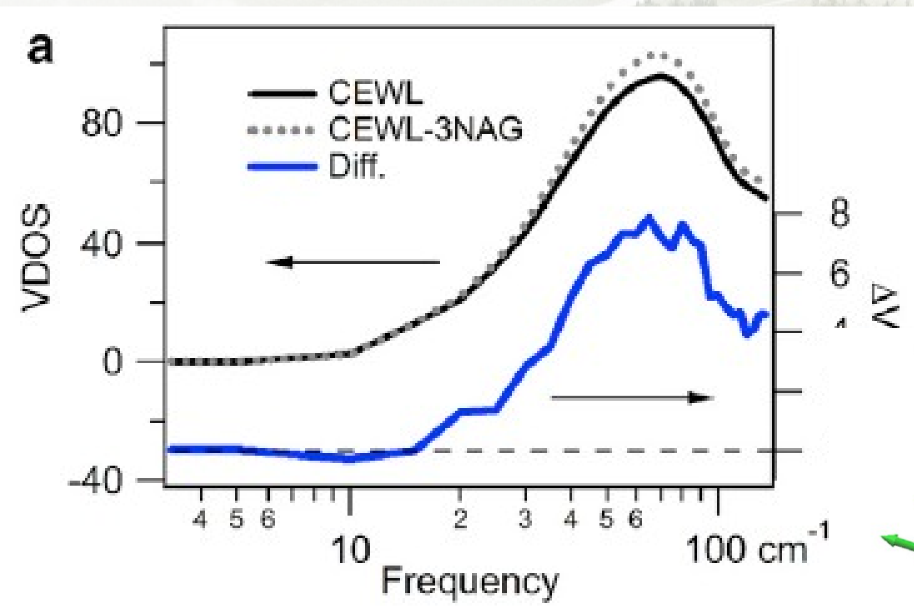
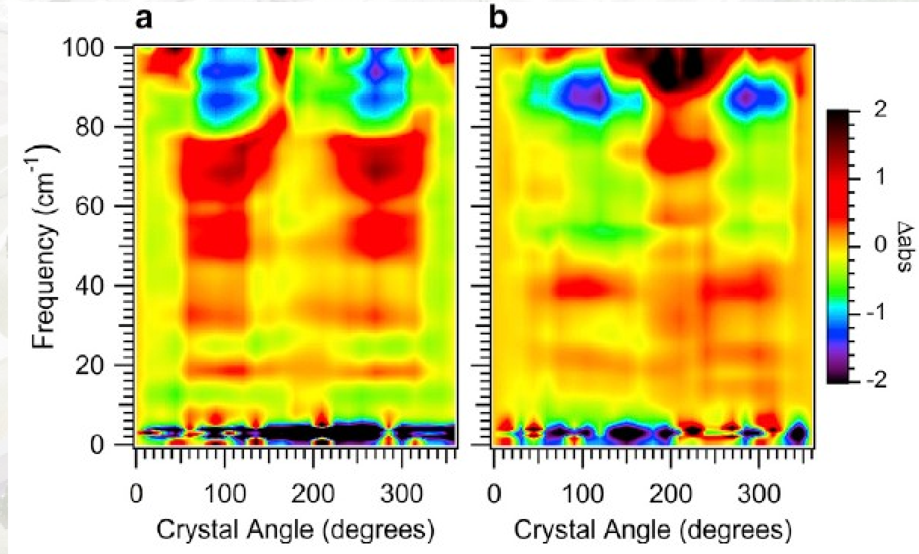
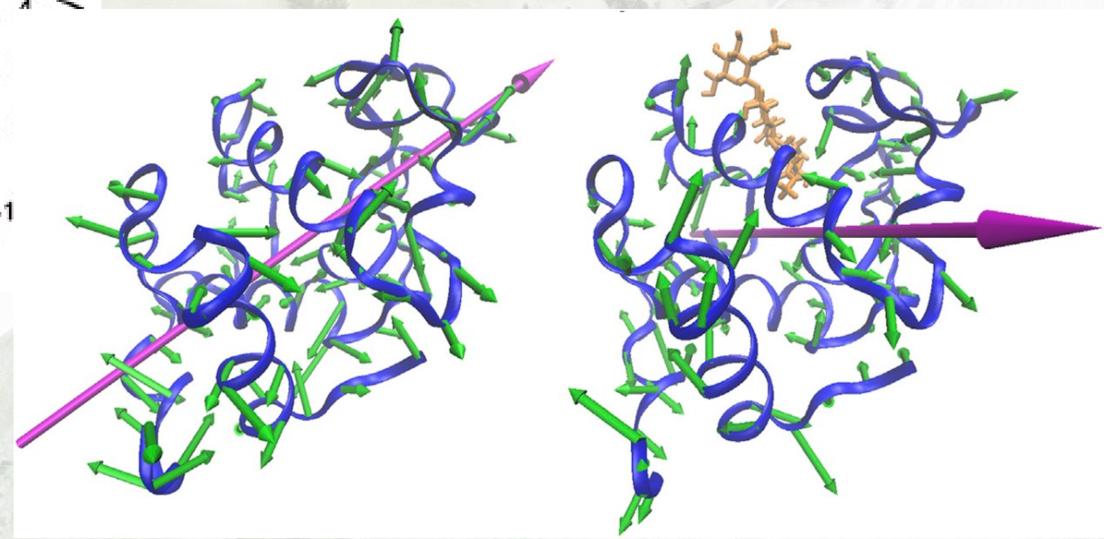
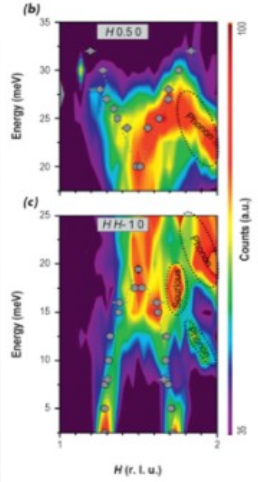
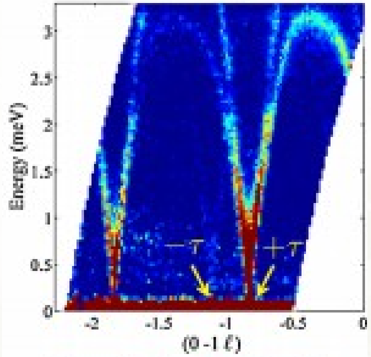


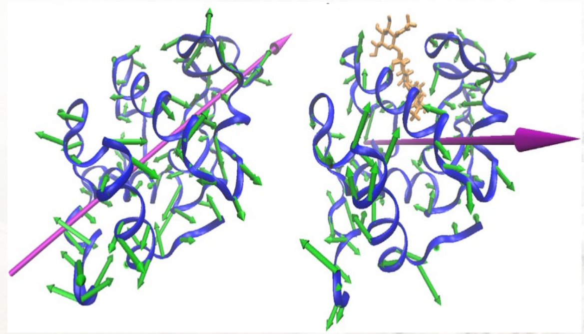


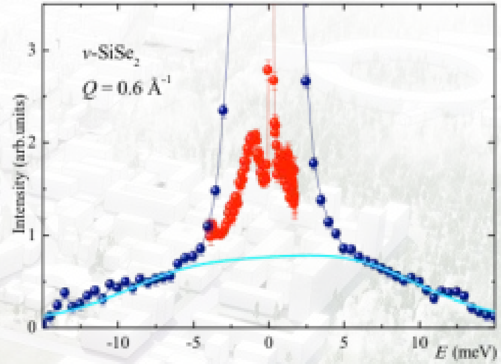


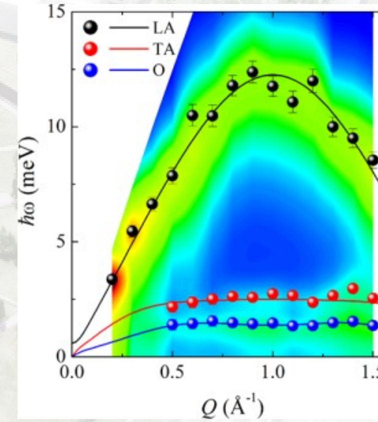
Niessen, Paciaroni, Orecchini et al., Biophys. J. 112, 933 (2017)



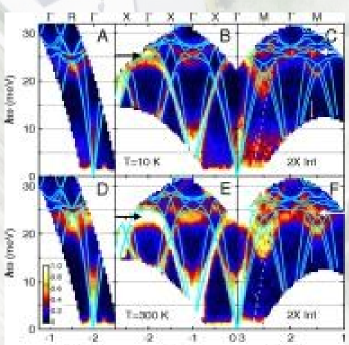


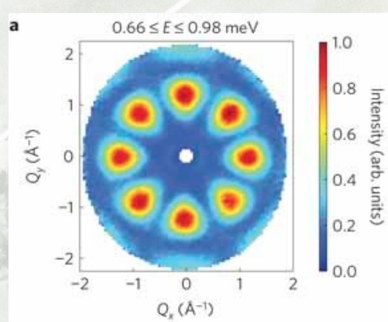


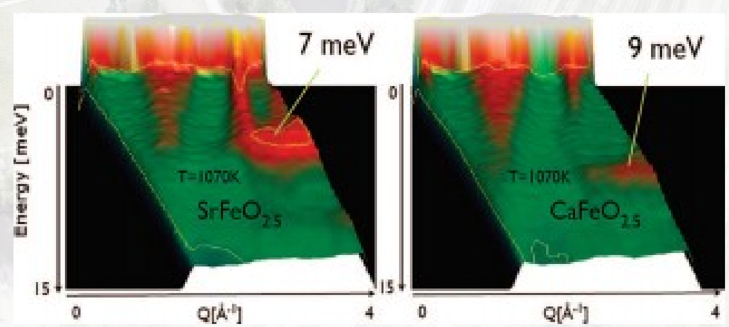


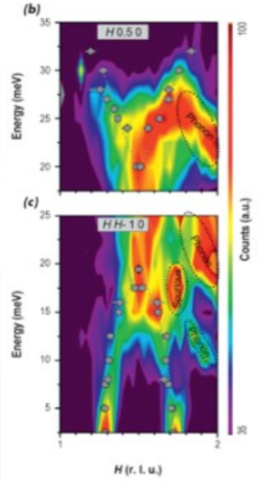


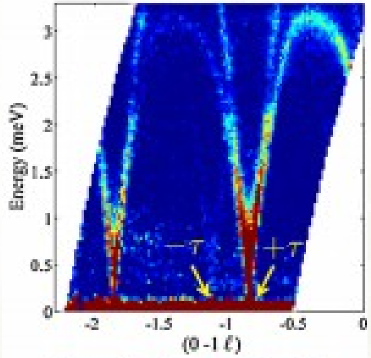
- **<u>Strong interdisciplinarity</u>**
- International partnerhip for world-class neutron science
- Contribution to the forthcoming **<u>C-Labs</u>**

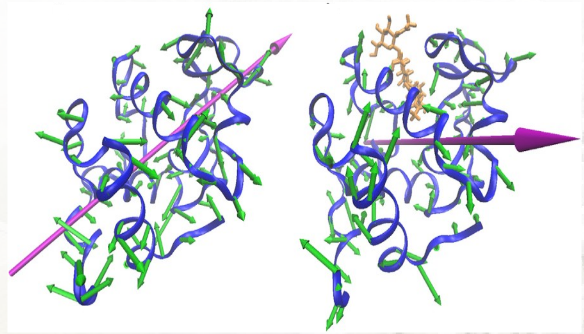


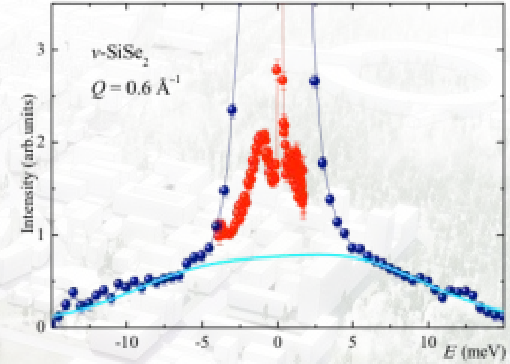




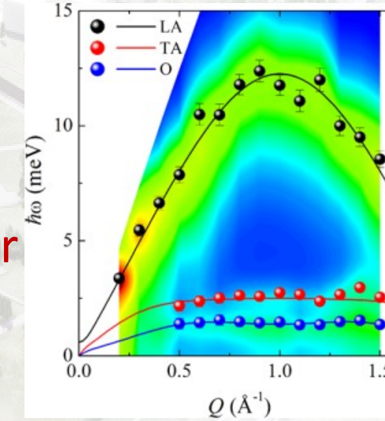




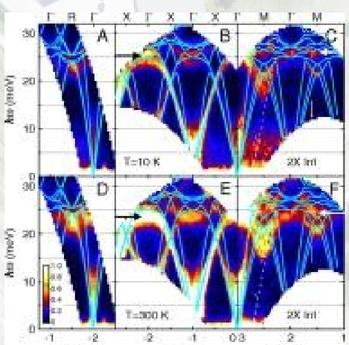


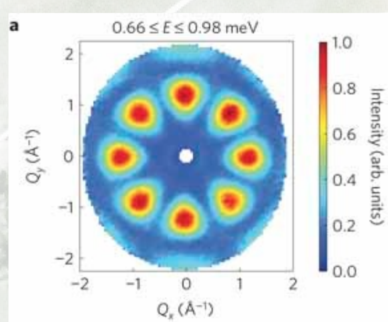


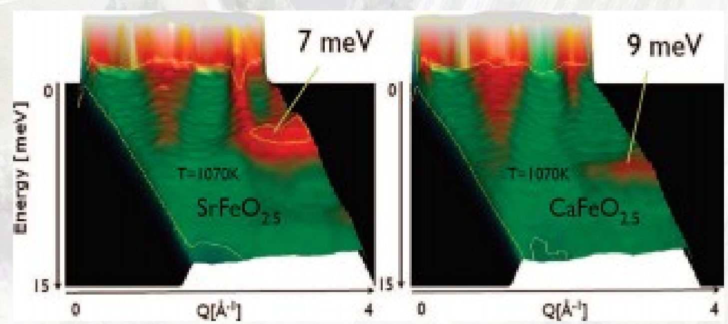
- <u>Piano Triennale</u>:
- Spettroscopia neutronica, di luce di sincrotrone e free electron laser



- <u>Azioni collaborative di Ateneo</u>:
- WP 1.1 - Ciclo della vita: processi naturali e patologici
- WP 1.3 - Sviluppo di prodotti e tecniche innovative diagnostiche e terapeutiche
- WP 4.2 - Nanoscienze e nanotecnologie
- WP 5.1 - Infrastrutture, sistemi energetici e produttivi a basso impatto ambientale







T-REX

Time-of-flight Reciprocal space Explorer

*A neutron spectrometer for **magnetism, material science** and soft **matter** at ESS*

The future of world-class neutron science

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L. Comez, G. Gubbiotti, C. Petrillo, F. Sacchetti

*Dipartimento di Fisica e Geologia, Università degli Studi di Perugia
and Istituto Officina dei Materiali, Consiglio Nazionale delle Ricerche*