Feedback from n_TOF & ISOLDE Experiments on 2022 Operation and Outlook

Joint Accelerator Performance Workshop, CERN, 05/12/2022

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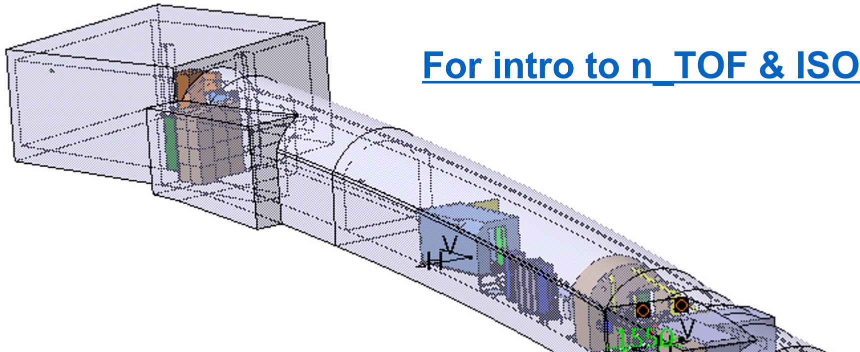
*ISOLDE slides thanks to Karl Johnston

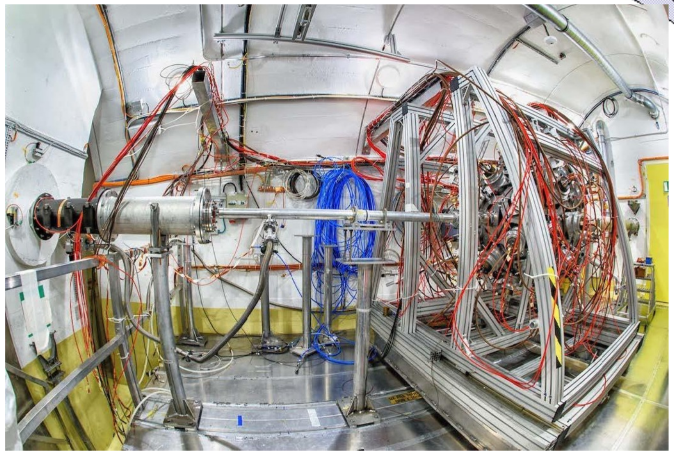
The n_TOF facility: EAR1 + EAR2 + NEAR

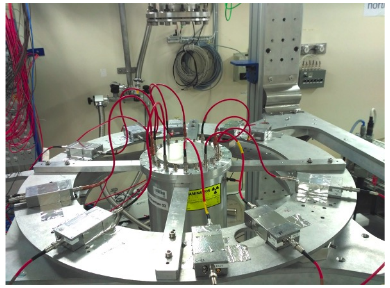


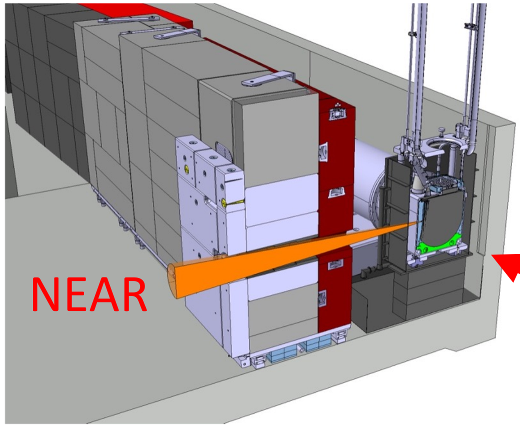
For intro to n_TOF & ISOLDE see Karl Johnston talk on IEF-2021

Three experimental areas (EAR)

- Horizontal flight path: EAR1 at 200 m
- Vertical flight-path: EAR2 at 20 m
- NEAR at 3m distance: activation measurements







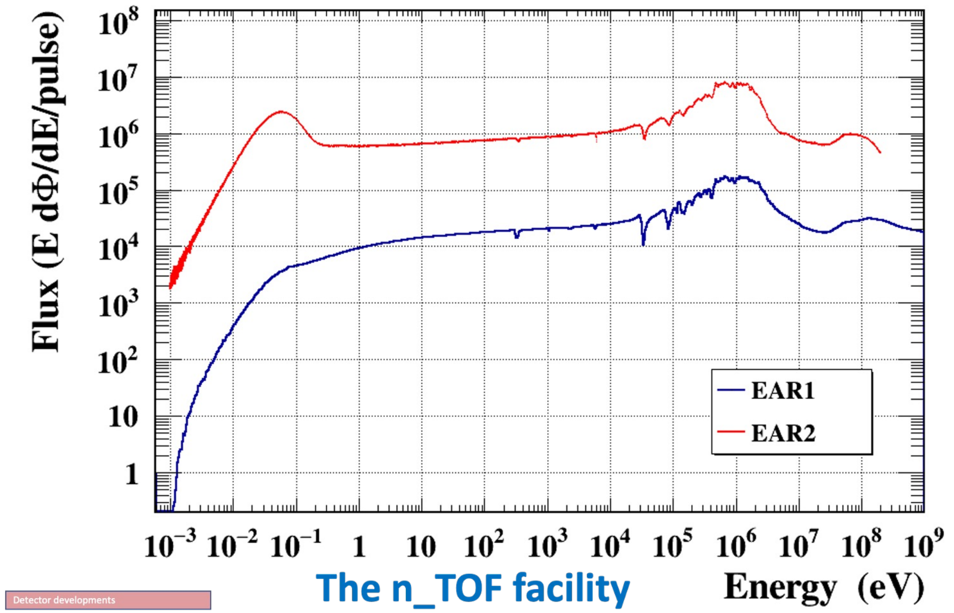
20 GeV proton beam from the PS

EAR1 & EAR2 beam lines with:

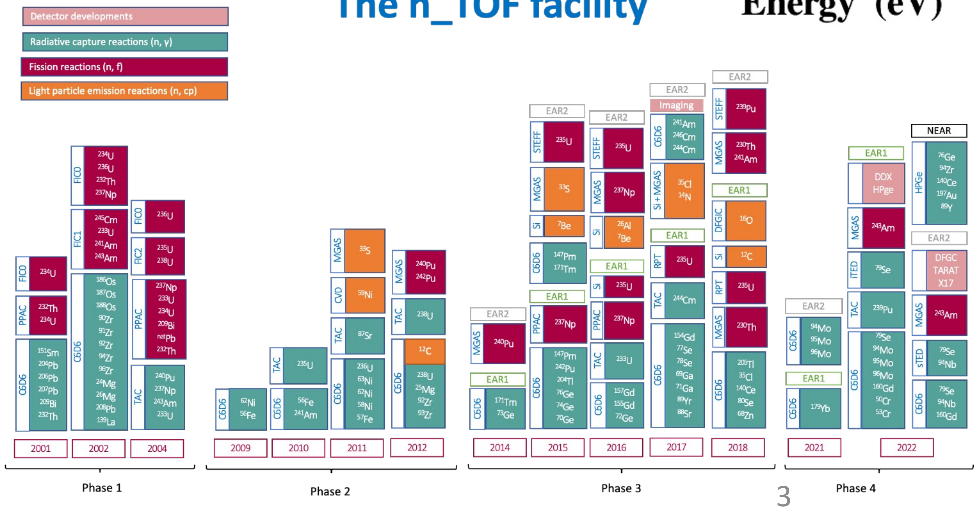
- 1st collimator
- halo cleaning, initial beam shaping
- Filter station
- Sweeping magnet
- 2nd collimator for beam shaping

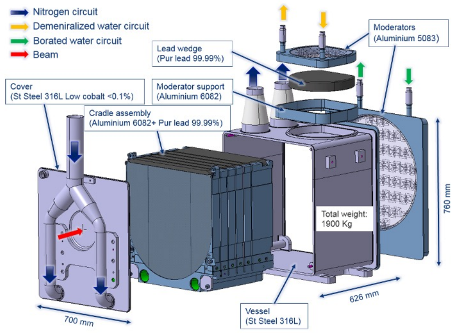
n_TOF: a unique neutron TOF facility

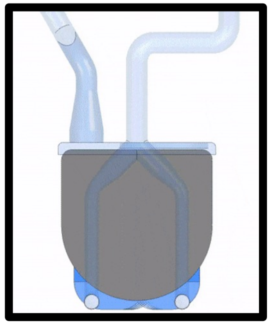
- **Excellent time/energy resolution**:
  - total pulse width 4σ = 28 ns
  - EAR1 0.03%@1 eV, 0.5%@1MeV
  - EAR2: 0.4%@1 eV, 4%@1MeV
- **Extended energy range** (experimental XS data for neutron energies covering 11 orders of magnitude): **meV to GeV**
- **High instantaneous flux**
  - EAR1 ~ 0.5E6 n/puse (18 mm aperture)
  - EAR2: ~1E7 n/pulse (23 mm aperture)
  - Excellent signal to background conditions
  - Measurements with samples of extreme specific radioactivity are feasible
- **Excellent (and stable) neutron production conditions thanks to our NEW G3 spallation target**

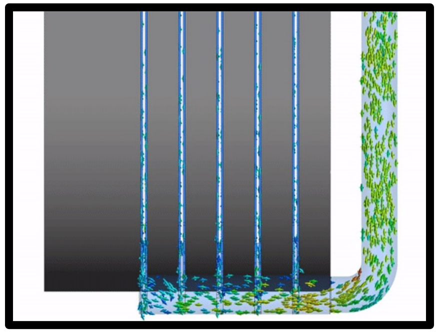


The n_TOF facility



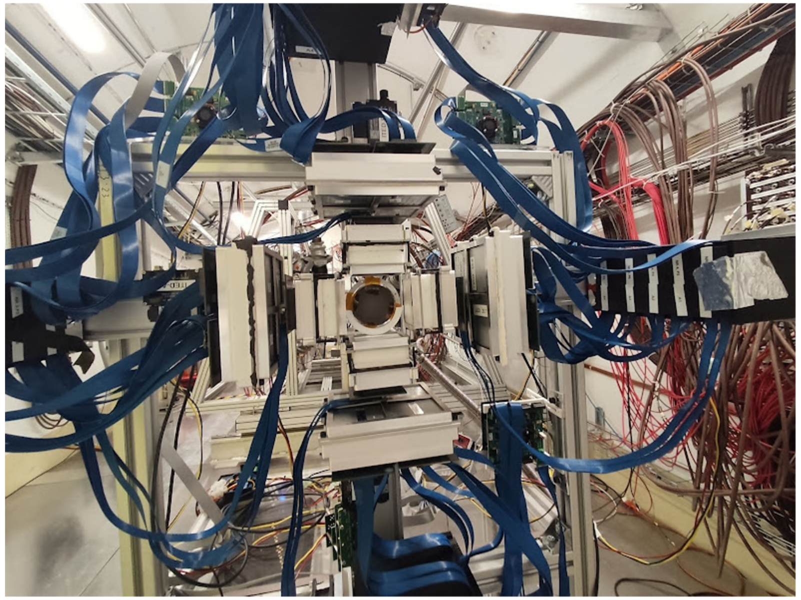


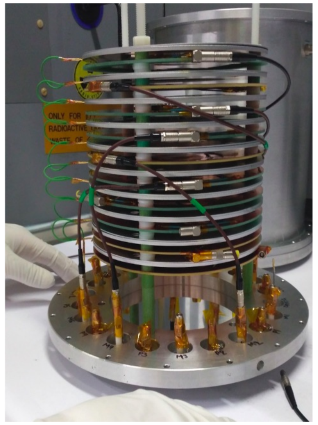


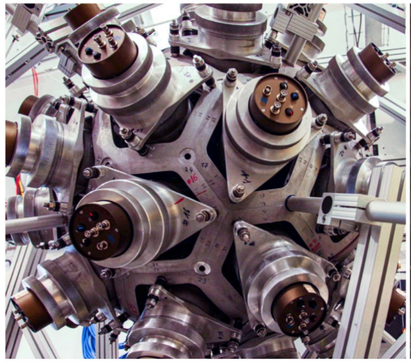


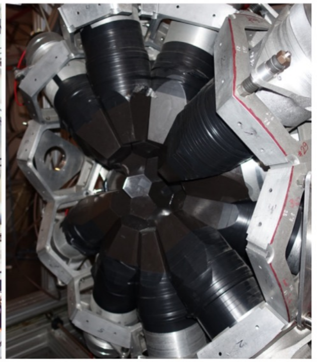
n_TOF: a unique neutron TOF facility

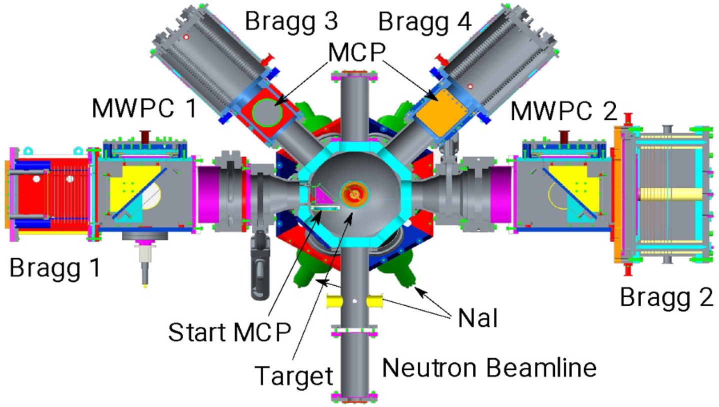
- **Low background** (Well defined/collimated neutron beams, optimized beam dump configurations, minimum scattered neutrons)
- **Pulse repetition rate excellent for TOF facility**
  - small enough to avoid pulse overlap
  - still high enough for a good duty cycle
- **Dedicated experimental setups** for each type of measurements
- **Unique type of measurements** (e.g fission tagging in neutron capture measurements, 2E-2u device STEFF)
- Just a few tens of meters away from **ISOLDE** (**synergies**, radioactive sample preparation)
- 130+ researchers, 30+ institutes, **10+ enthusiastic PhD students/year**

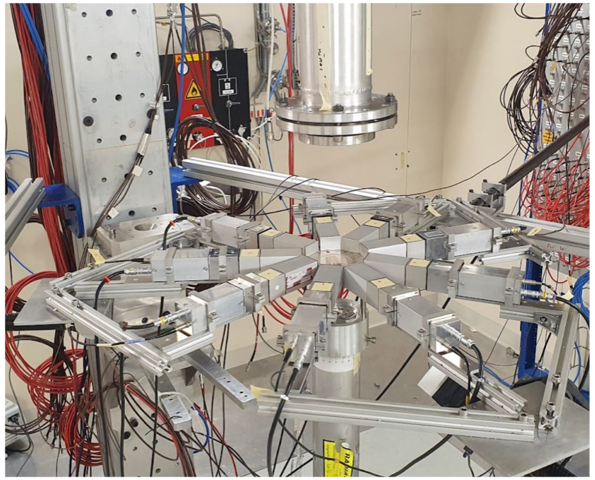






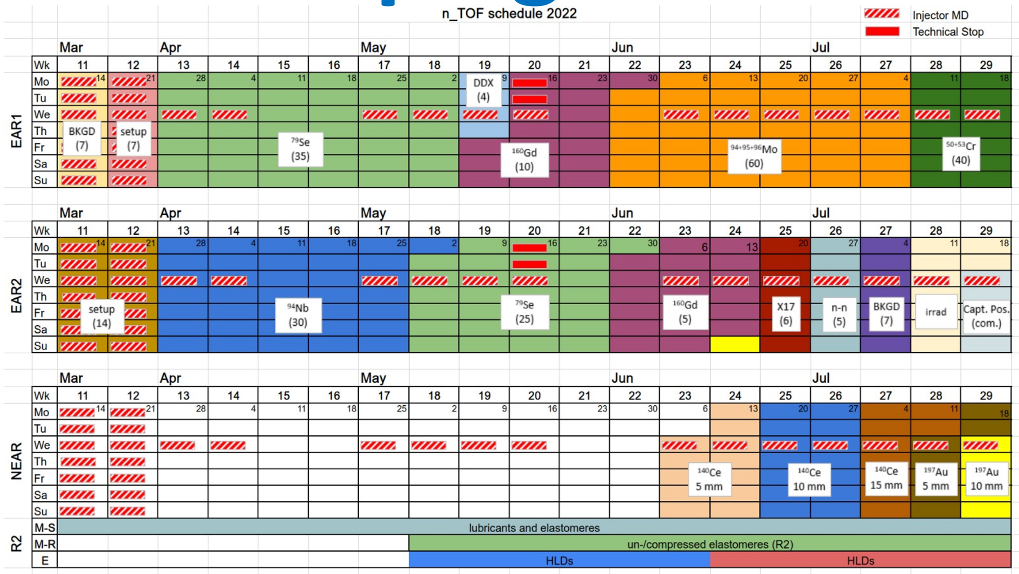


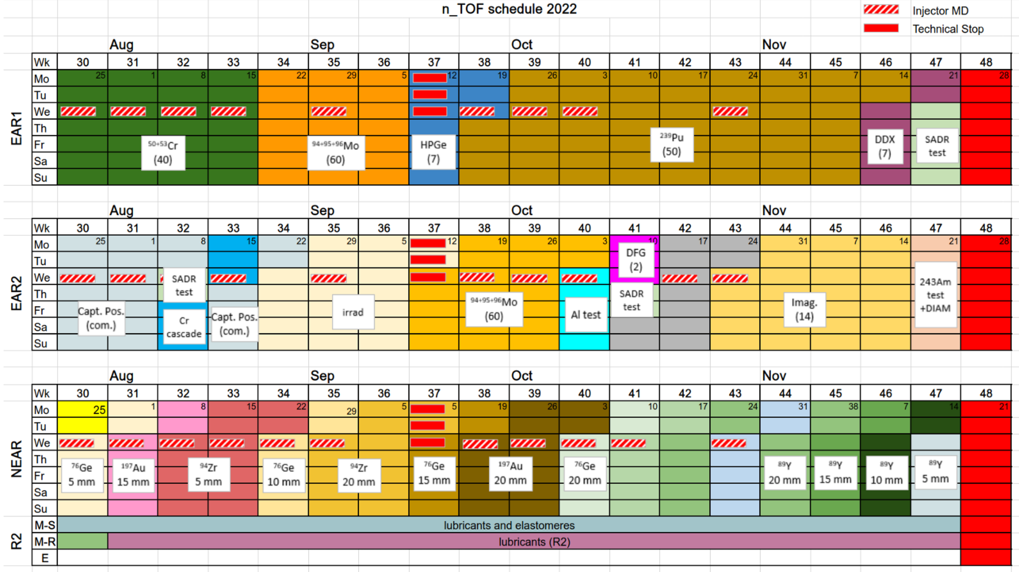




Highlights of the 2022 n_TOF campaign

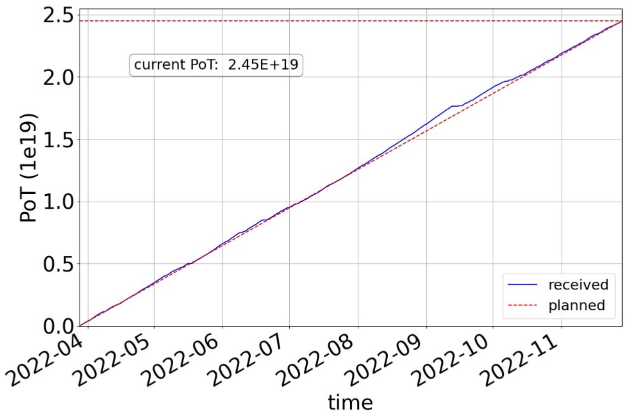
EAR1	EAR2	NEAR
• ^{79}Se(n,γ) • ^{160}Gd(n,γ) • ^{94,95,96}Mo(n,γ) • ^{50,53}Cr(n,γ) • ^{239}Pu(n,γ)(n,f)(a-ratio) • DDX det. dev. • HPGe test	• ^{79}Se(n,γ) • ^{94}Nb(n,γ) • ^{160}Gd(n,γ) • ^{94,95,96}Mo(n,γ) • X17 detector test • nn scattering det. test • neutron imaging • diamond det. test • BKG and other commissioning actions	• ^{197}Au(n,γ) • ^{140}Ce(n,γ) • ^{76}Ge(n,γ) • ^{94}Zr(n,γ) • ^{89}Y(n,γ)





- 9 neutron capture reactions have been studied (2 of the for the first time) at EAR1 & EAR2
- 5 detector development projects have been accomplished
- 1 fission tagging measurement has been performed
- 5 neutron capture reactions have been studied at NEAR with different filter configurations
- 2 new detector setups have been successfully applied for the first time

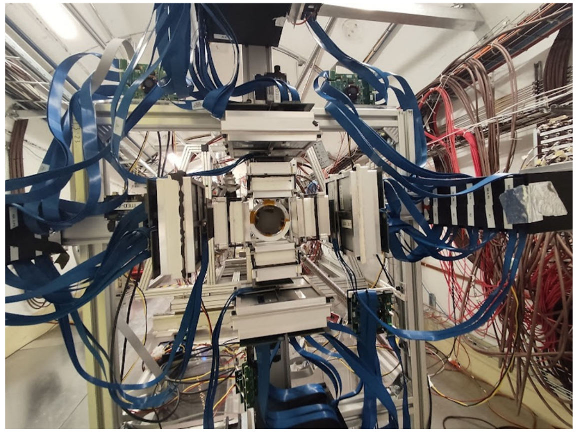
- protons expected:2.45eE19
- protons received: 2.45E19

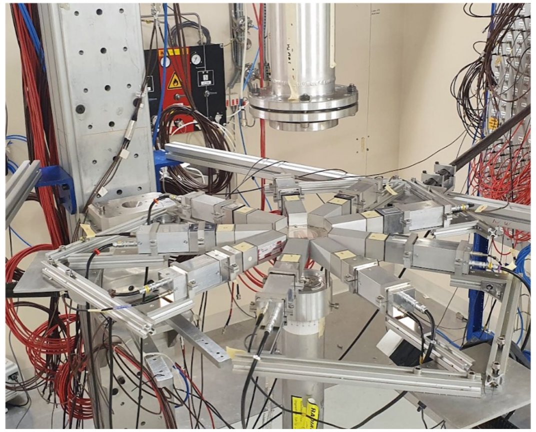


Highlights of the 2022 n_TOF campaign

^{79}Se(n,γ) and ^{94}Nb(n,γ) reaction studies:

- First experimental data
- Important branching points for s-process nucleosynthesis
- Nuclear waste transmutation ($T_{1/2}$(^{79}Se) = 3My, $T_{1/2}$(^{94}Nb) = 20ky)
- two innovative experimental setups were successfully used for the first time

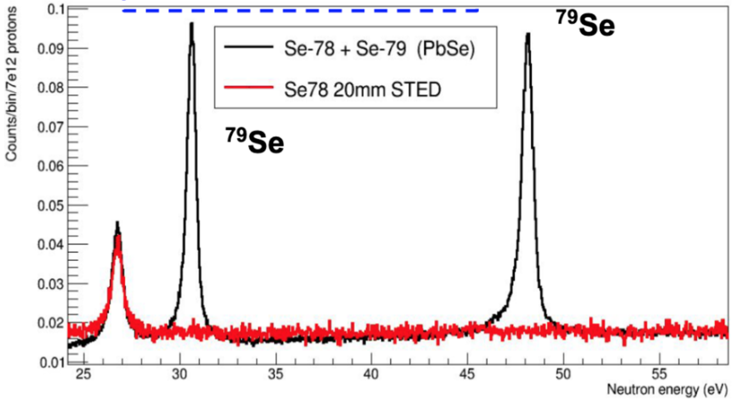


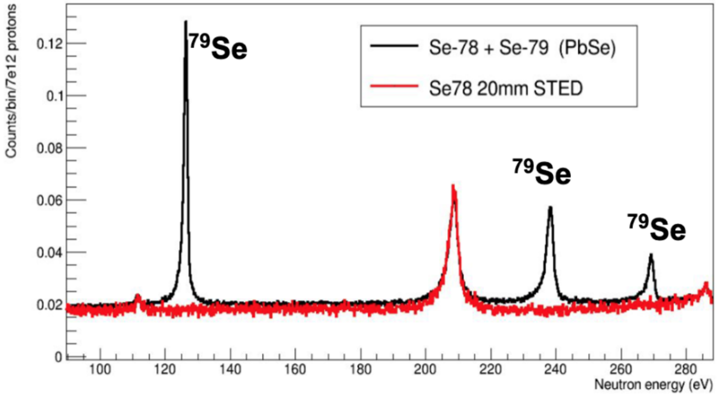


Resonances of Se-79 First ever measured!

Only dedicated :
~1.25e18p

- **Se-78 disc** vs **Se-79 (PbSe) sample**
- Sum of the STEDs is plotted



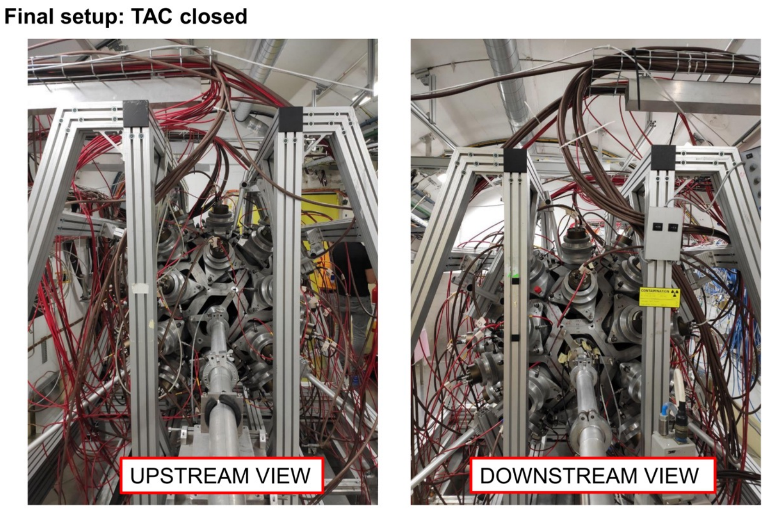


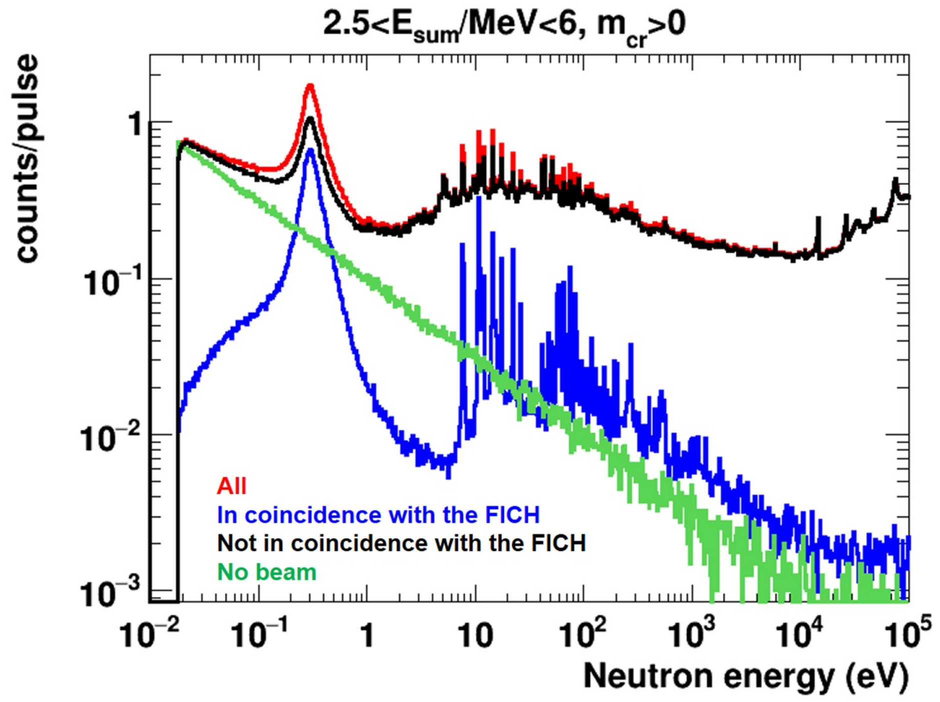
5 resonances below the first large resonance of Se-78 at 400 eV

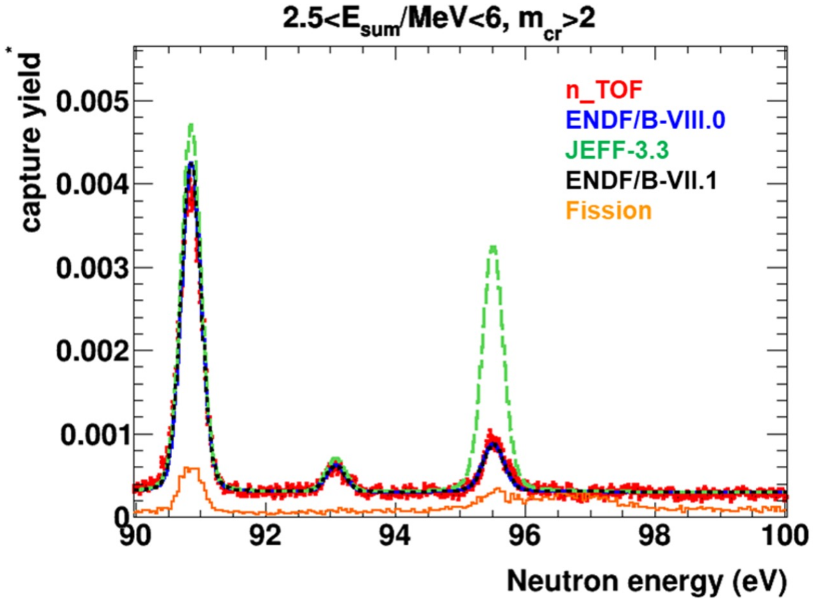
Highlights of the 2022 n_TOF campaign

^{239}Pu(n,γ) using fission tagging:

- Unique type of measurement
- Important data for energy applications
- Challenging: 330 MBq; 1TB/h

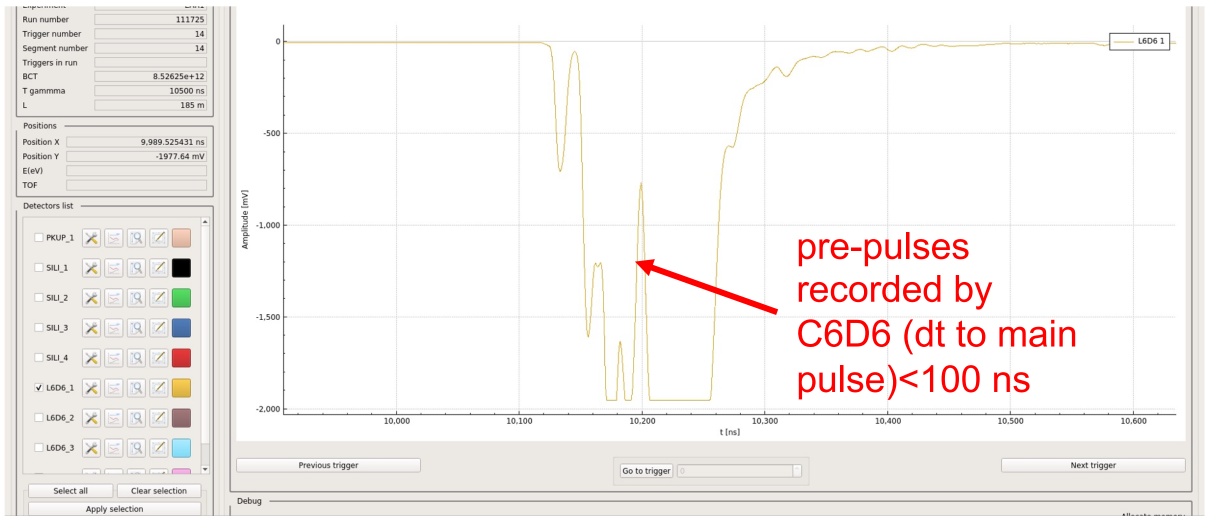


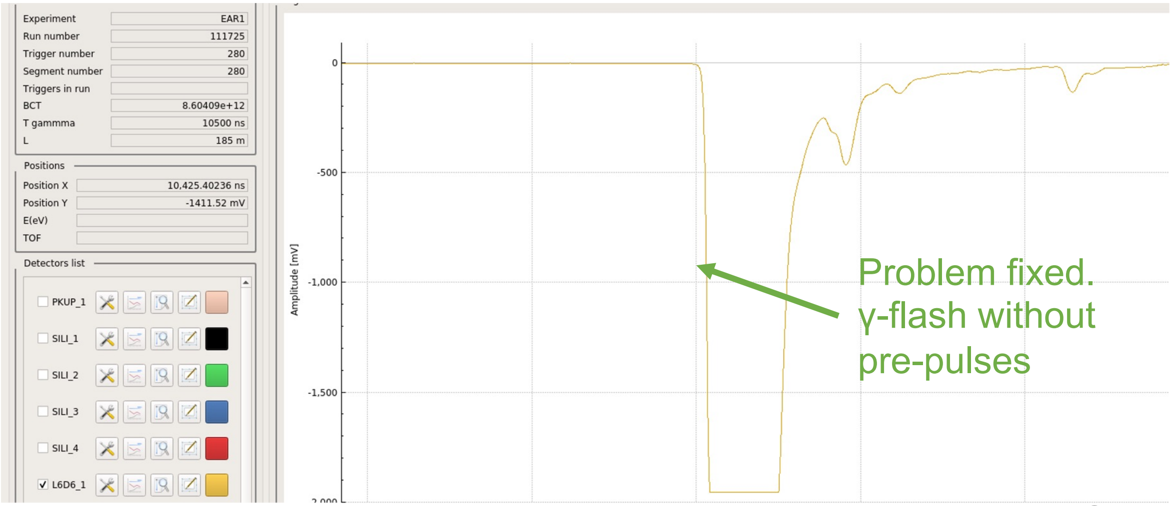




Issues during the 2022 campaign

- At the beginning of 2022 campaign some pre-pulses were recorded from our detectors. This complicates a lot the data analysis of our TOF data. Problem solved by adjusting the pulse rotation (at the cost of longer pulses)
- On n_TOF request the PS produced the cleanest beam ever wrt pre- and post tails of the TOF pulse at the cost of a slightly degraded pulse width (42 ns (2022) vs 28 ns (2018)). Ideal would be 7 ns (4σ=28 ns) with no tails.
- The neutron flux in EAR2 is changing with respect the vertical position of the beam centroid. That would be nice to have as stable beam spot as possible.
- For a few days (between 14.09.2022 - 18.09.2022) the proton counting was not correct (TIMBER data). This imposes difficulties in the quality checks of the data.





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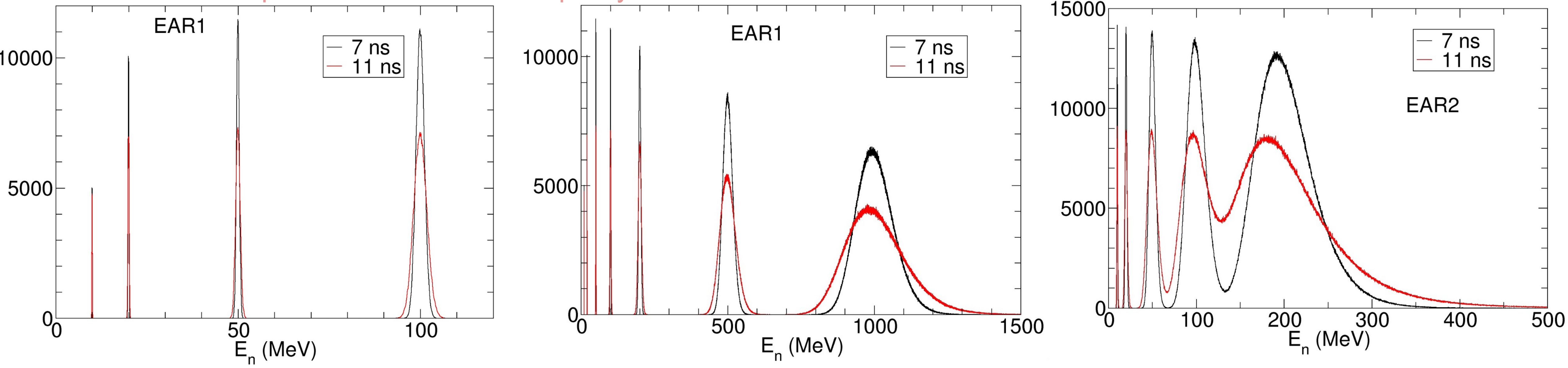

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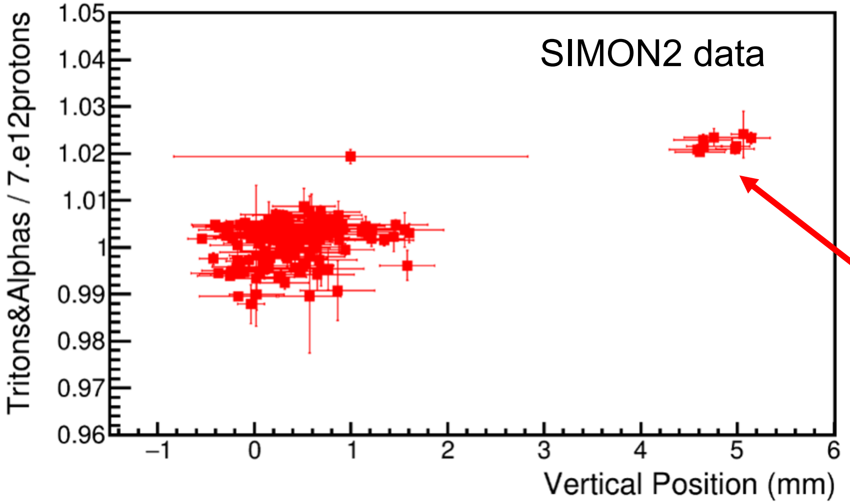
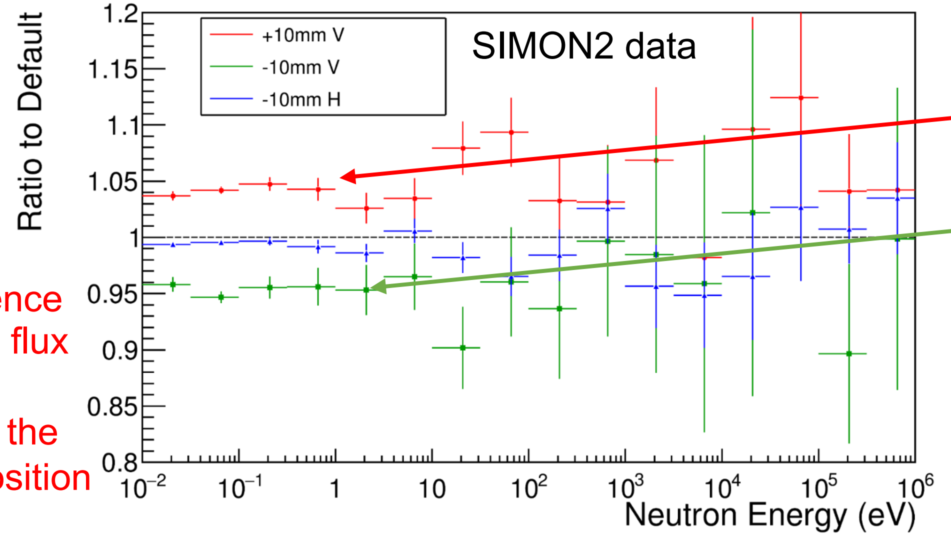


2% difference in neutron flux for 5mm change in the vertical position



±4% difference in neutron flux for ± 10 mm change in the vertical position

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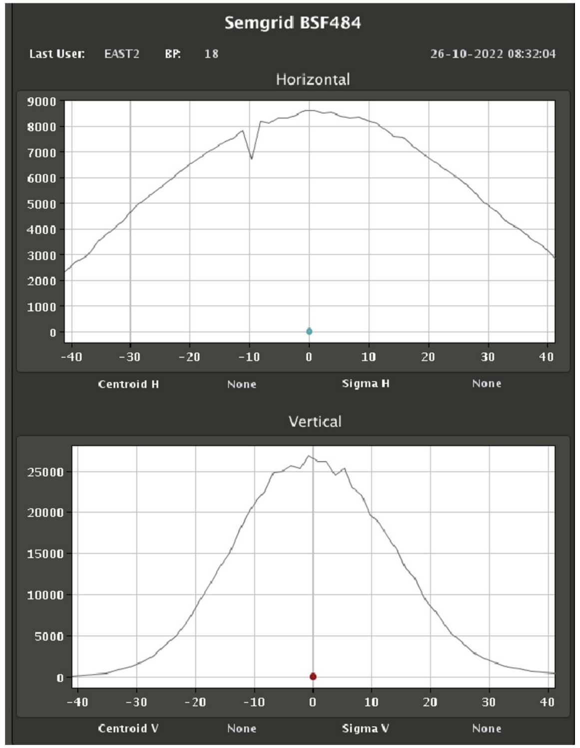
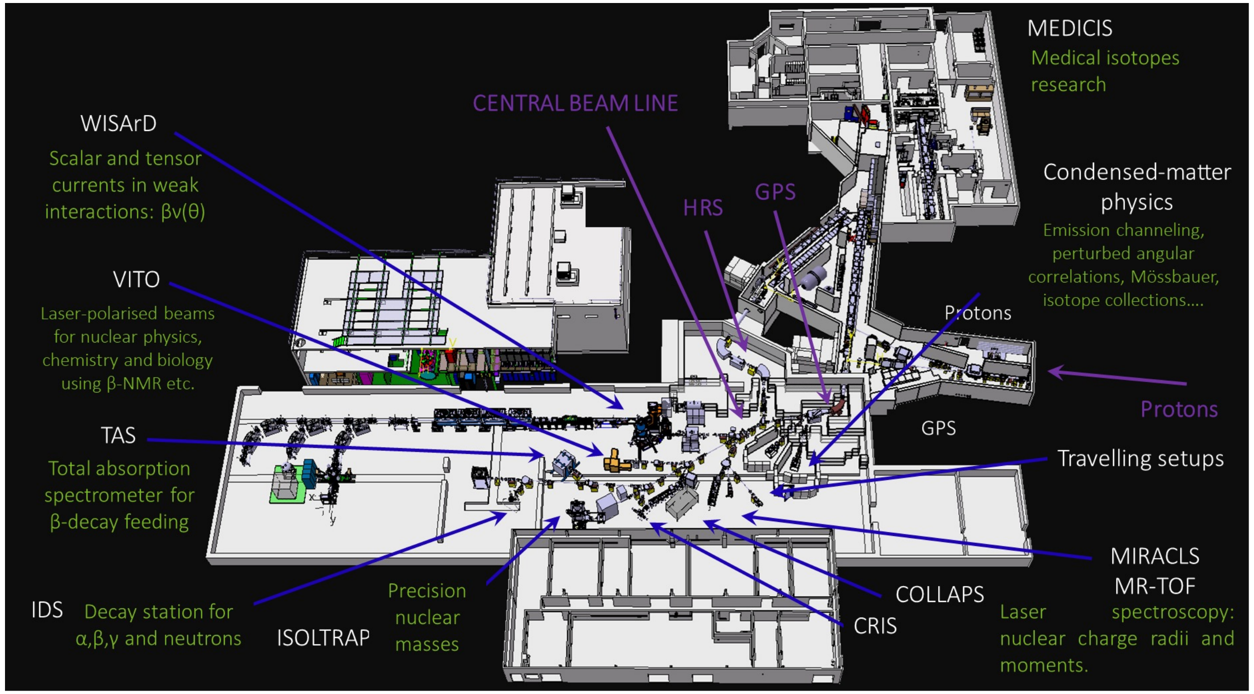
n_TOF desiderata for the 2023 operation

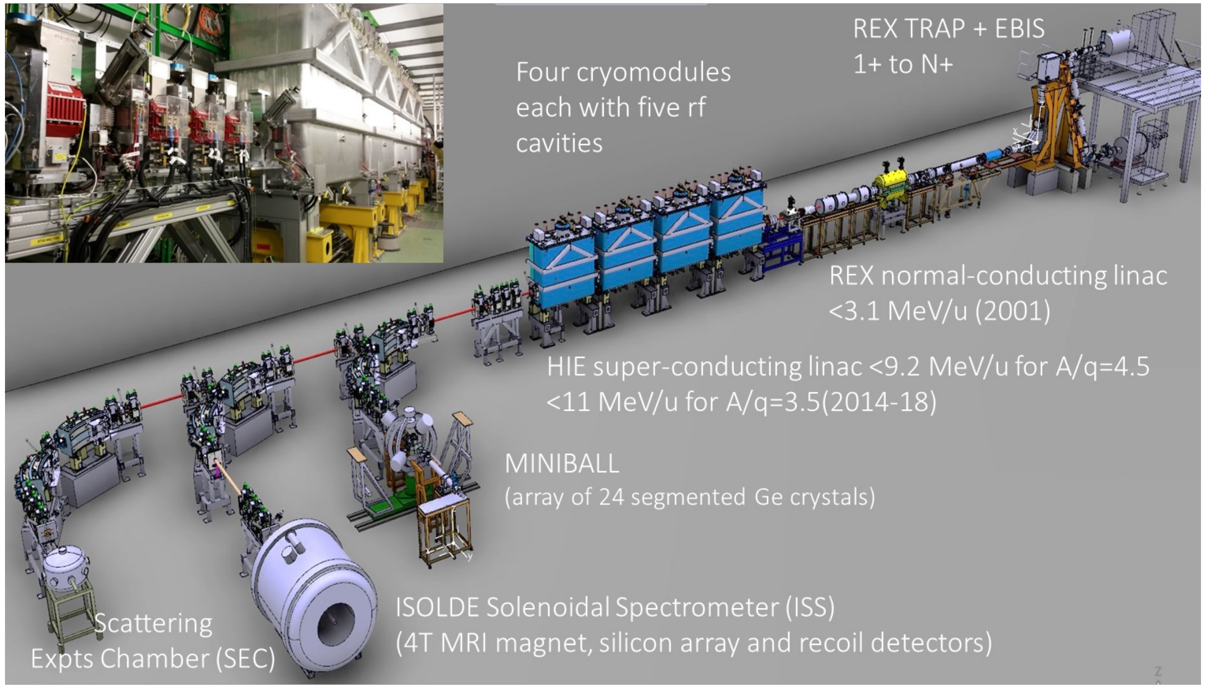
- **2023 Beam for n_TOF (our request: 210E17 or 1E17 protons/day)**
  - 03.04.2023 - for hardware commissioning (7days)
  - 10.04.2023 - Physics Start
  - 30.10.2023 - beam off (203 days of physics)
- **Pulses of different intensities**
  - High intensity (dedicated): 8.5E12 ppp
  - Low intensity (parasitic): 4.5E12 ppp
- **“Fixed” impact point on the lead target for both pulses**
  - ± 5 mm horizontal (centroid)
  - ± 3 mm vertical (centroid)
- **Same (as 2022) spatial profile dimensions of the beam**
- **Proton beam intensity: Raise interlock for avg. intensity from 167e10 p/s to 200-220e10 p/s is possible (still under investigation from SY-STI-TCD and HSE, from a technical standpoint as well as from RP)**
- **Pulse time length: back to 28 ns (σ ~ 7ns) without “tails” and pre-pulses**
- **For 2023 proton budget will be fully optimized, as every year, by running INTC approved experiments in parallel in three EARs**



- Worldwide leading Radioactive ion beam facility
- >1300 isotopes from 75 elements
- 17 (with CH joining in 2023) member countries in ISOLDE collaboration
- Large (and growing) user community from >45 countries: currently standing at around 1000 users.
- Extremely wide scientific programme: from nuclear structure to biochemistry to beyond standard model physics
- 2022 saw the 30th anniveserary of ISOLDE at the PSB



12 low energy beamlines: 30-60kV



3 High energy beamlines: <11MeV/u (depends on A/q)

- Worldwide leading Radioactive ion beam facility

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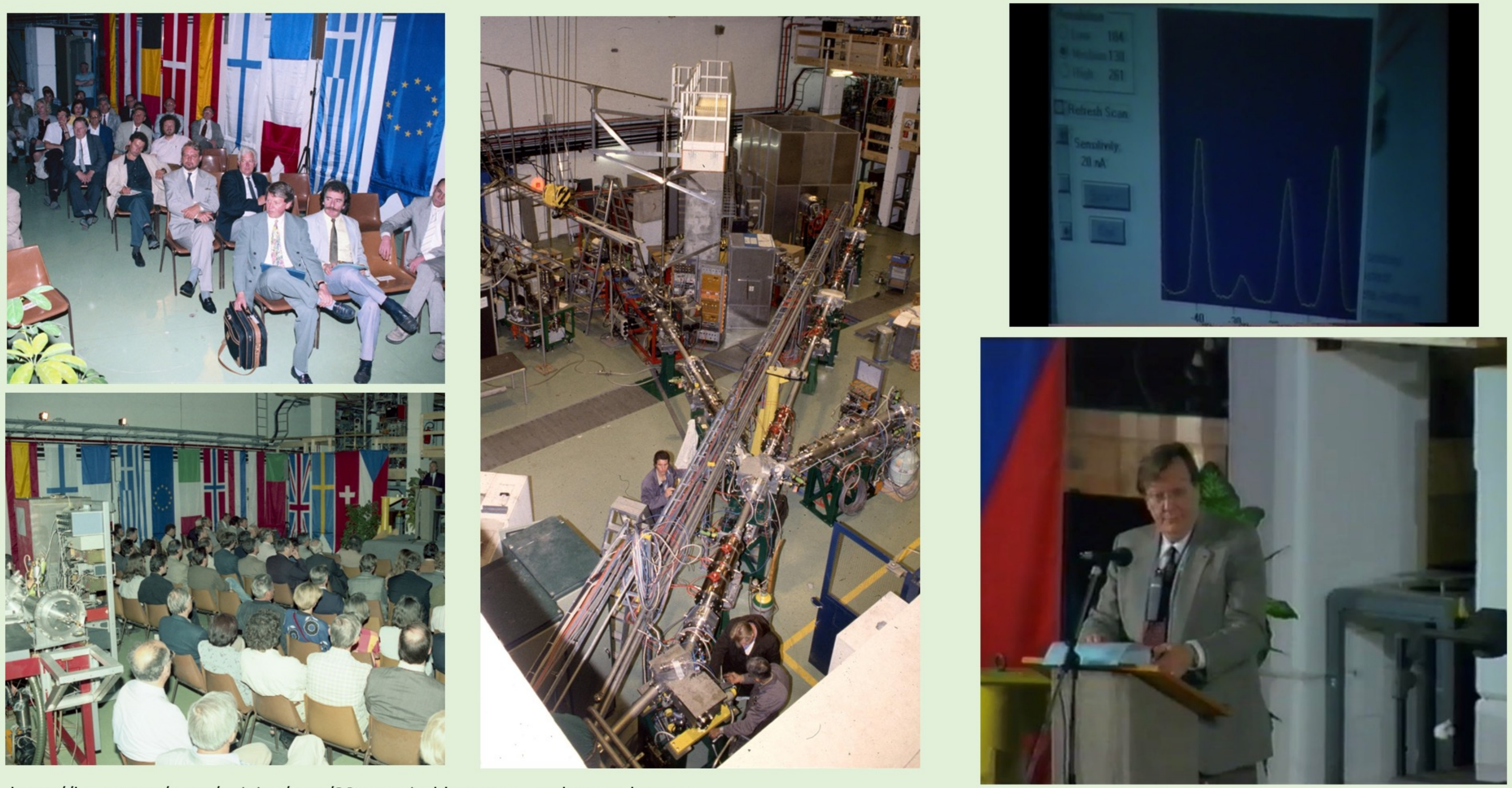
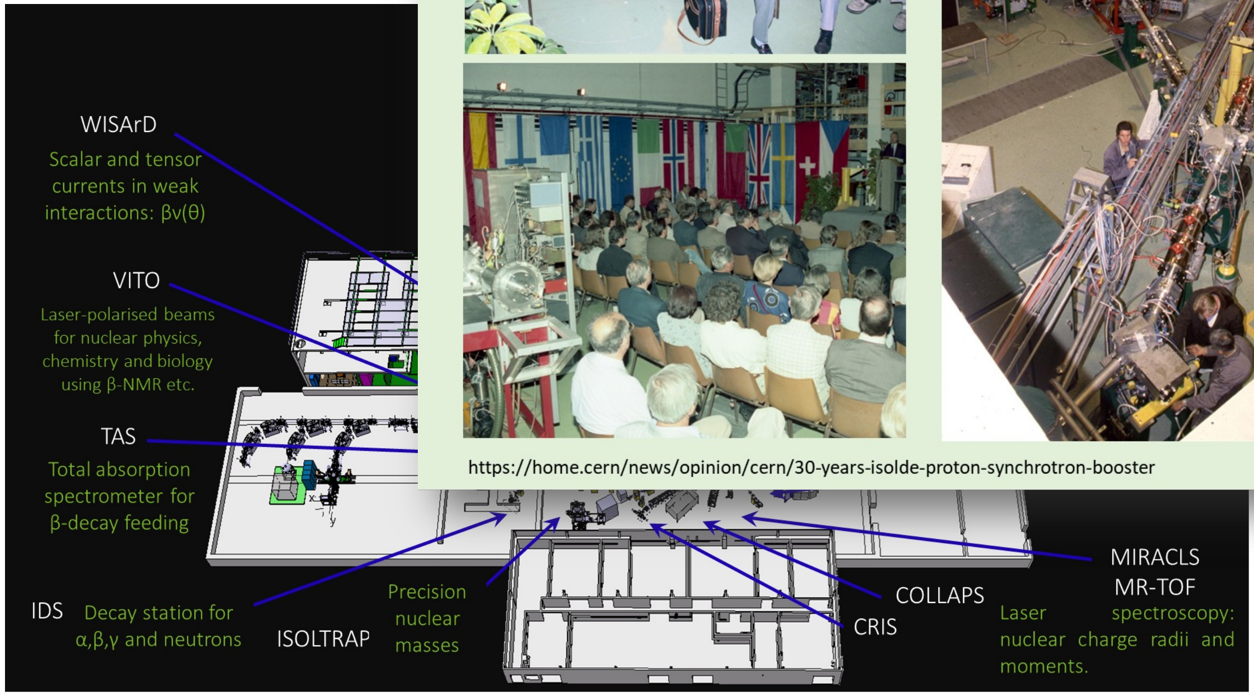
e to biochemistry to

26 May 2022: 30 years since the inauguration of ISOLDE at the PSB



https://home.cern/news/opinion/cern/30-years-isolde-proton-synchrotron-booster



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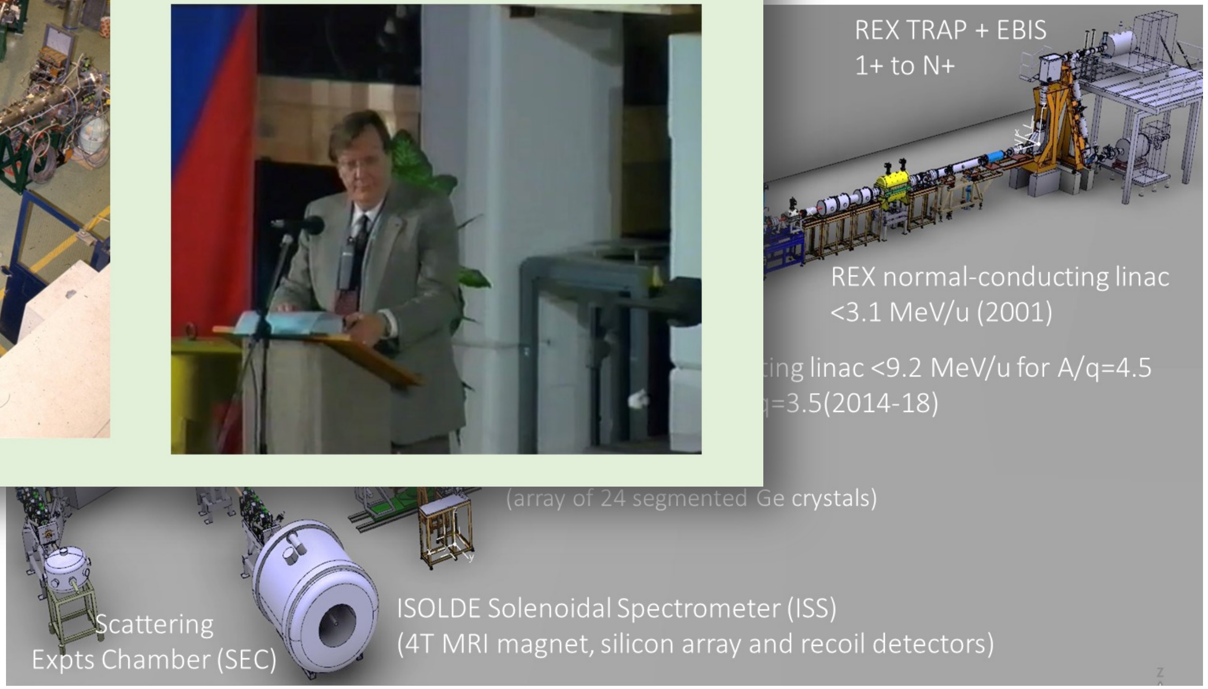
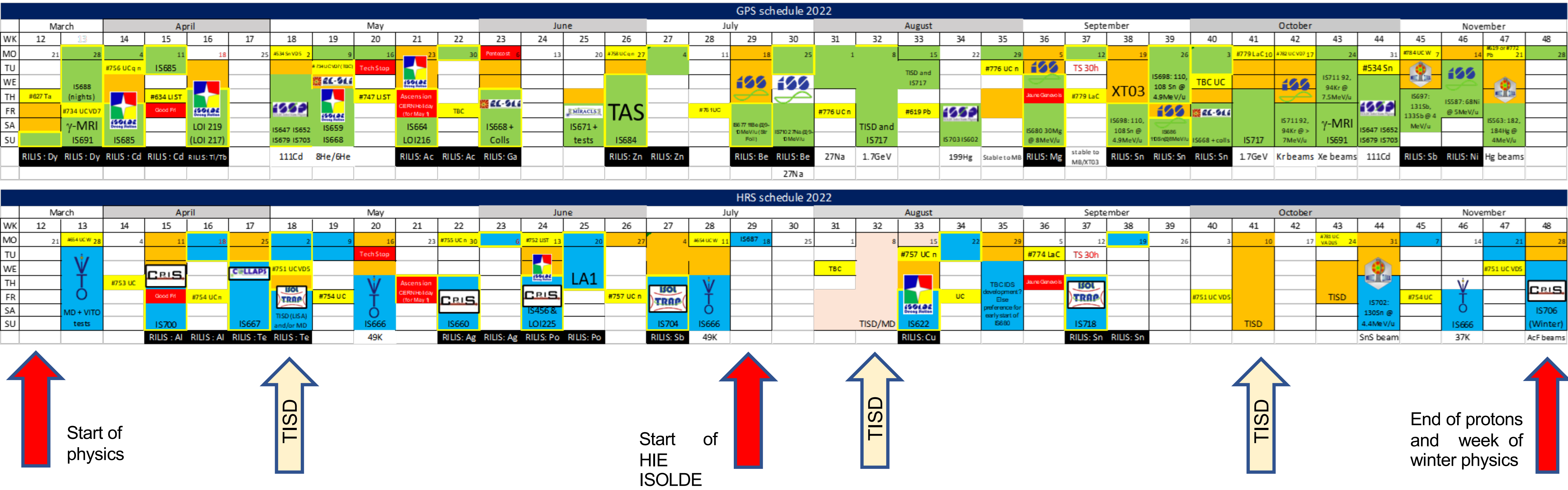


3 High energy beamlines: <11MeV/u (depends on A/q)

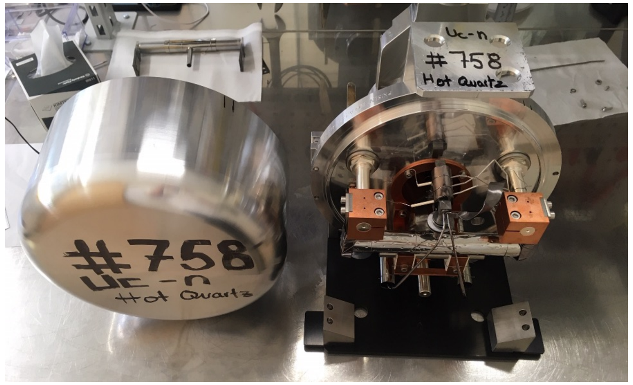
ISOLDE schedule 2022



- ISOLDE started low energy experiments on 28 March as planned
- HIE ISOLDE started on 20th July
- In total 52 experiments were performed, no runs cancelled. 252.33 days available for physics.
- Delivery of protons ended on 28th November
- One week of winter physics for laser spectroscopy of long-lived radioactive molecules. Finished this morning.
- New this year: «regular» blocks for machine development/Target development
- ~463 shifts delivered for physics/development.

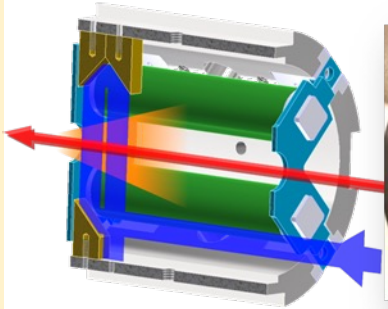
Feedback from the running period

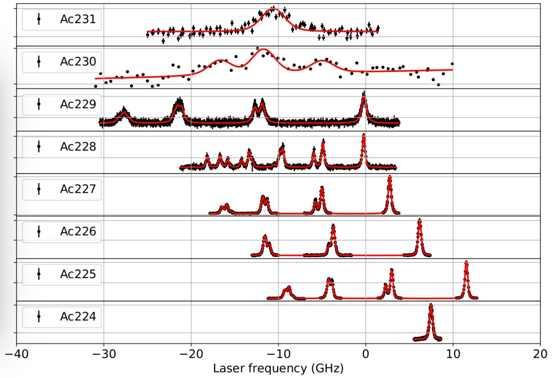
Targets:
- 24 new units
- Many complex units to meet physics requirements
- Mostly excellent performance, improvements in handling (nanolab) are being seen . Several yields exceeded expectations especially for HIE ISOLDE physics.
- 3 Online failures (leak and 2 ion sources), but reliability has been good.
- Reusing targets for less exotic isotopes is increasingly accepted, and successful



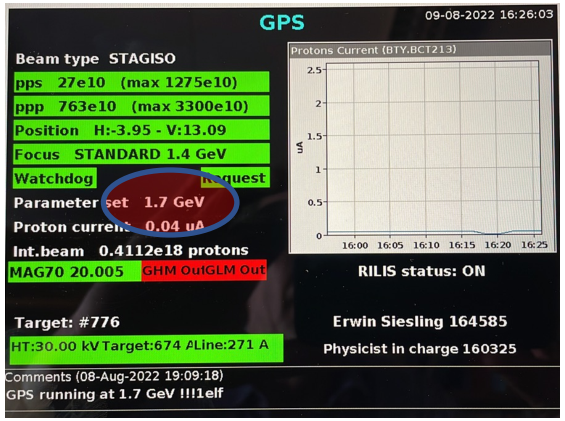
Target with «hot quartz» ion source: a complex ion source to suppress contaminants.

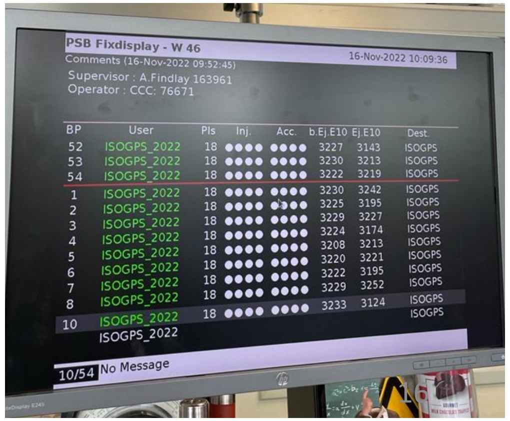
RILIS:
- Extremely busy year: 22 elements delivered for physics and development.
- Operated for 29 out of 36 weeks.
- Availability has been excellent, although support from Gatchina (RU) was missed.
- First year that LIST/PI List ran regularly for physics. Significant setting up time required, but very successful runs.





Protons:
- # of Protons on target is not a reliable guide for ISOLDE: proton request can run from 0.1 to 2uA. Depending on isotope requested, target unit etc.
- Capability of booster to adapt to ISOLDE requests is key.
- Availability and interactions with Booster team has been excellent throughout the year.
- 2022 saw many requests: NORMGPS/HRS; STAGISO_GPS/HRS; «stacked cycles»; Spaced cycles; and for first time 1.7GeV.
- Total number of protons delivered to ISOLDE ~10^{20}

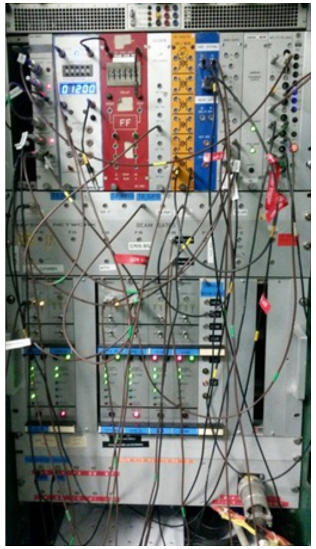




Issues encountered

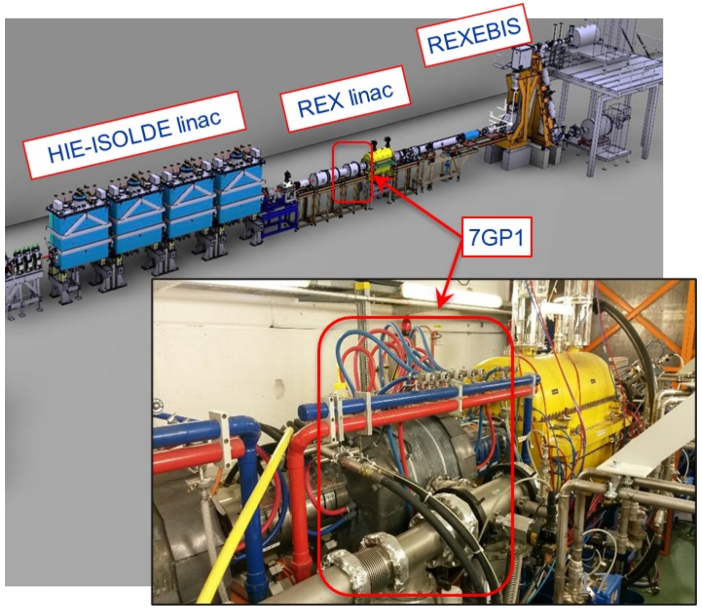
ISOLDE beam gates

- Key component of the machine.
- Several issues arose due to timing requirements for sensitive experiments. Workaround has been put in place (Erwin Siesling) but more robust solution is required, especially for the beamgate controls.
- Considerable down-time can be a consequence especially when an experiment starts with radioactive beam. (not seen while stable setup is taking place).
- Action for present YETS.



HIE ISOLDE I

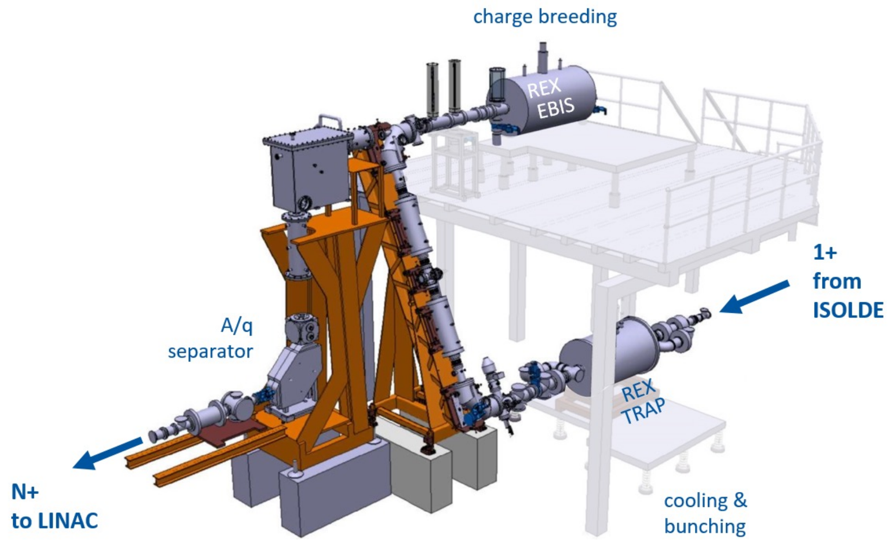
- Cooling in cryoplant was lost 3 times. Cavities required reconditioning delaying commissioning
- Beam commissioning was affected by instabilities in the REX accelerator. 7gap1 was especially problematic. Vibrations suspected and investigated. No cause of vibrations was identified, but problem disappeared in June.
- Early July, RF amplifiers were found to be increasing in temperature. Water pollution was found to be the cause.
- This led to an additional 2 weeks delay.
- Severely hampered the beam commissioning programme for HIE ISOLDE; essentially no time was available before physics.
- 7gap3 issue almost cost a physics run just before end of protons



HIE ISOLDE II: REX EBIS

- REX EBIS solenoid experienced rapid LHe boil-off in July.
- Numerous quenches in August and magnet is now operating at 1.5T instead of nominal 2T.
- Repair or replacement of this unit will take place in present YETS.

Fredrik Wenander IEFC 318



No physics runs lost: but we were very lucky!

RF instabilities and cryo plant went down after compressed air issue.

1st 2 HIE experiments

EBIS quenches

Main HIE ISOLDE campaign

7gap3 issue, solved on afternoon of final Friday to allow for physics run at Miniball

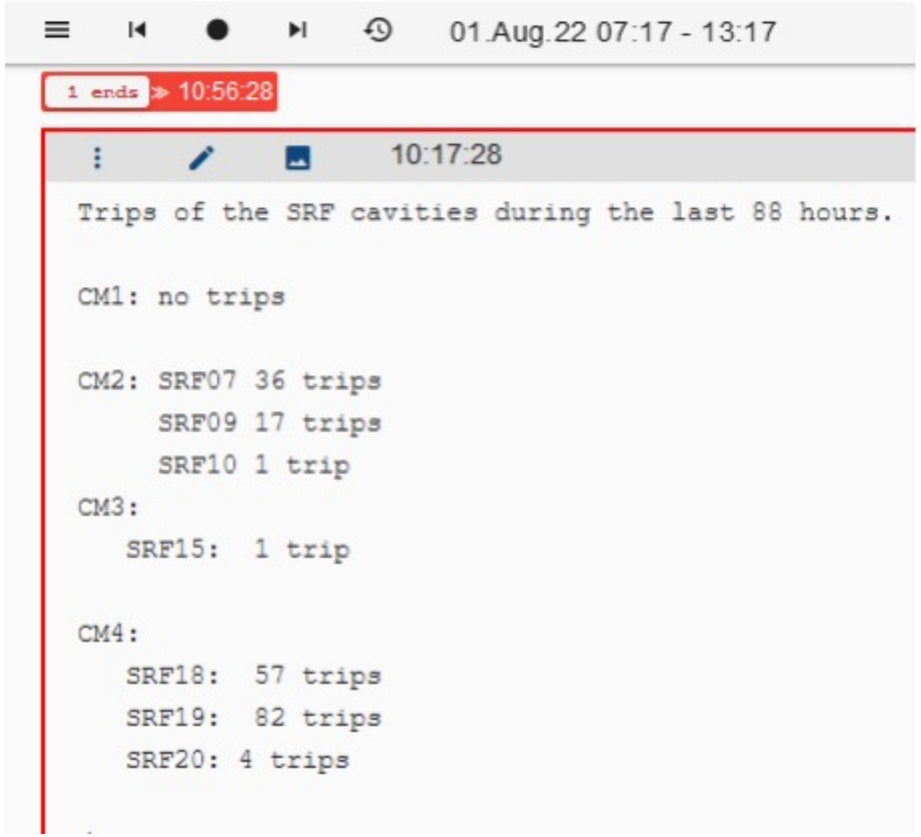
GPS schedule 2022

June				July				August					September				October					November			
23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Pentecost 6	13	20	#758 UCqn 27	4	11	18	25	1	8	15	22	29	5	12	19	26	3	#779 LaC 10	#782 UCV07 17	24	31	#784 UC W 7	14	#619 or #772 Pb 21	28
IS668 + Colls		IS671 + tests	TAS IS684		#761UC	IS677 11Be @9-10MeV/u (Str Foil)	IS710 27Na @9-10MeV/u	#776 UC n	TISD and IS717	TISD and IS717 #619 Pb	IS703 IS602	#776 UC n	Jaune Genevois IS680 30Mg @ 8MeV/u	TS 30h #779 LaC	XT03 IS698: 110, 108Sn @ 4.9MeV/u	IS698: 110, 108 Sn @ 4.9MeV/u IS686 110Sn@8MeV/u	TBC UC IS668 + colls	IS717	IS711 92, 94Kr @ > 7MeV/u	IS711 92, 94Kr @ 7.5MeV/u γ-MRI IS691	#534 Sn IS647 IS652 IS679 IS703	IS697: 131Sb, 133Sb @ 4 MeV/u	IS587: 68Ni @ 5MeV/u	IS563: 182, 184Hg @ 4MeV/u	
RILIS: Ga			RILIS: Zn	RILIS: Zn		RILIS: Be	RILIS: Be	27Na	1.7GeV		199Hg	Stable to MB	RILIS: Mg	stable to MB/XT03	RILIS: Sn	RILIS: Sn	RILIS: Sn	1.7GeV	Kr beams	Xe beams	111Cd	RILIS: Sb	RILIS: Ni	Hg beams	
							27Na																		

ISOLDE Superconducting LINAC

- Frequent SRF cavities trips (high sensitivity to vibrations, LHe pressure variations…) and loss of available accelerating gradient after the winter thermal cycle
- Issue being closely followed by RF expert in collaboration with TE-CRG (change in operating parameters of the cryo-plant)
- RF team optimized the cavity sequencer to restart the cavity faster after a trip to reduce downtime.
- Performance from September onwards was better, although some cavities were unusable and remained off.

Summary of trips from 1st run of HIE ISOLDE in July 2022



Partly because of various issues experienced this year and to coordinate the various proposed ISOLDE upgrades : a workshop was held in October to identify consolidation and upgrade strategy.

Mini-workshop on ISOLDE consolidation and improvement

Wednesday 19 Oct 2022, 09:00 → 17:30 Europe/Zurich

6/2-024 - BE Auditorium Meyrin (CERN)

Description The ISOLDE facility is one of the world leading facilities for the production, study and research using Radioactive Ion Beams. In June this year, the facility has celebrated its 30th years of operation using the protons from the Proton Synchrotron Booster (since 1967 ISOLDE had operated with the 600-MeV protons from the Synchrocyclotron). In order to ensure that the facility will remain at the forefront and continue to serve its growing users community for the next decades, we are organizing a workshop on the ISOLDE consolidation and improvement program.

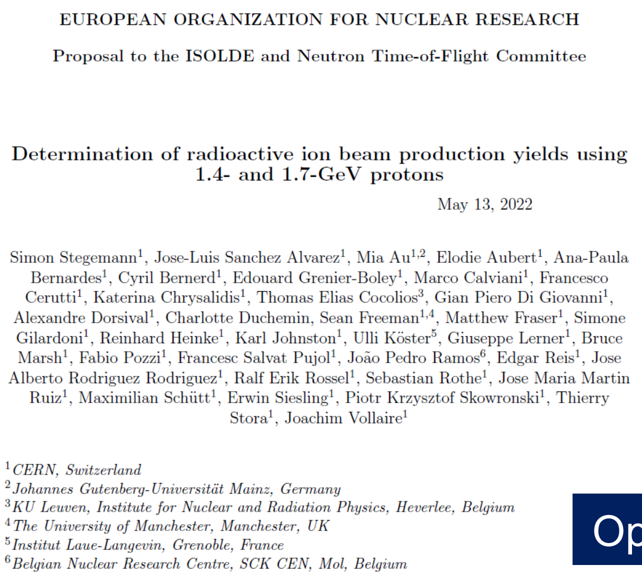
The purpose of the workshop is to identify critical aspects of the system or equipment that could jeopardize the facility availability and reliability and to review the planned and required consolidation plans. In addition, the users, operation and technical teams are asked to review any improvements to the facility that could further increase the physics outputs.

https://indico.cern.ch/event/1208149/

Staged approach awaiting approval

- **Urgent items (main items) : Now and LS3**
  - Consolidate REX solenoids
  - Reduce full thermal cycles of SC-Linac to protect cavities and reduce conditioning time
  - FIRIA
  - BTY PC consolidation (compatible with 2 GeV)
  - BTY Magnet consolidation (compatible with 2 GeV)
- **LS3 (main items)**
  - Dump replacement
  - Finishing 2 GeV
  - Delay FE replacement
- **Post LS3**
  - 5th SC cryomodule

Feedback from 1.7GeV tests (IS717)



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Determination of radioactive ion beam production yields using 1.4- and 1.7-GeV protons

May 13, 2022

Simon Stegemann[1], Jose-Luis Sanchez Alvarez[1], Mia Au[1,2], Elodie Aubert[1], Ana-Paula Bernardes[1], Cyril Bernerd[1], Edouard Grenier-Boley[1], Marco Calviani[1], Francesco Cerutti[1], Katerina Chrysalidis[1], Thomas Elias Cocolios[3], Gian Piero Di Giovanni[1], Alexandre Dorsival[1], Charlotte Duchemin, Sean Freeman[1,4], Matthew Fraser[1], Simone Gilardoni[1], Reinhard Heinke[1], Karl Johnston[1], Ulli Köster[5], Giuseppe Lerner[1], Bruce Marsh[1], Fabio Pozzi[1], Francesc Salvat Pujol[1], João Pedro Ramos[6], Edgar Reis[1], Jose Alberto Rodriguez Rodriguez[1], Ralf Erik Rossel[1], Sebastian Rothe[1], Jose Maria Martin Ruiz[1], Maximilian Schütt[1], Erwin Siesling[1], Piotr Krzysztof Skowronski[1], Thierry Stora[1], Joachim Vollaire[1]

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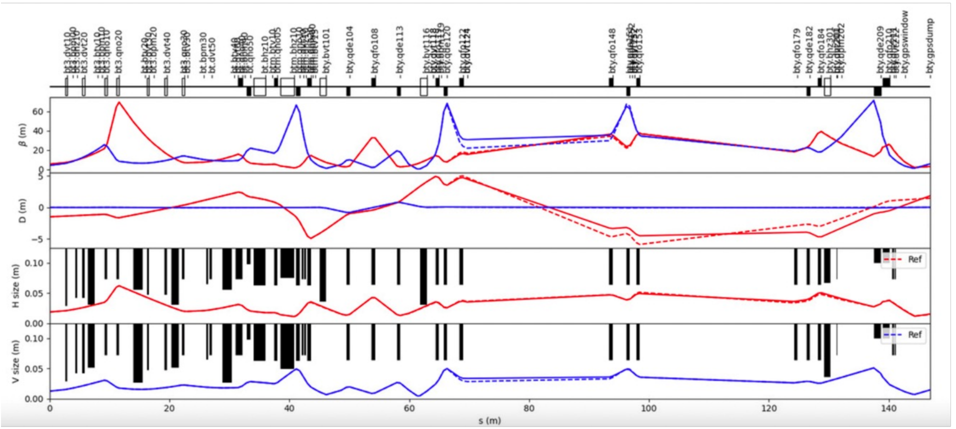
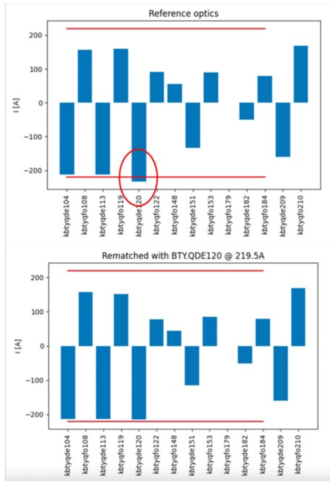
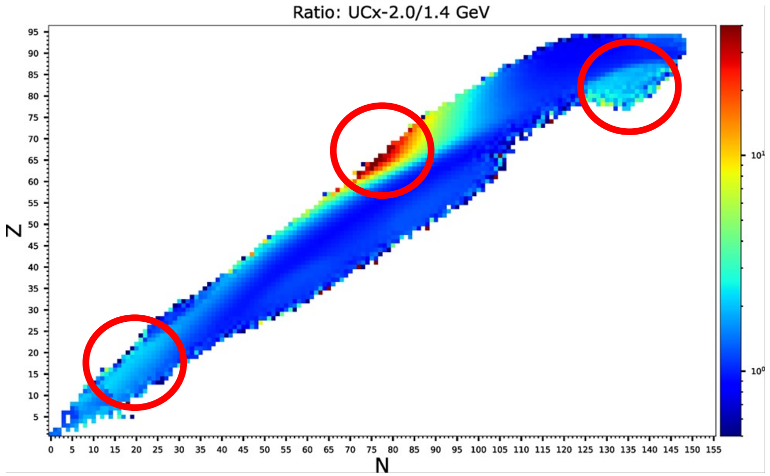
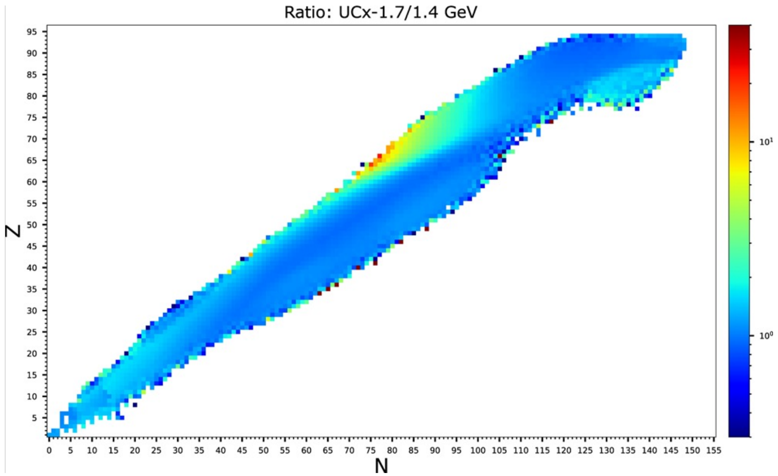




Optics model adapted for 1.7GeV. STAGISO beam: note higher energy, not yet full intensity



Fluka estimations



Benchmarked FLUKA yields

Clear increase in yield at 1.7GeV, verifying calculations. 2GeV protons will open new possibilities for physics.

Factors ≳ 2 important, **experiments done in shorter time**

Factors ≳5 important, allows **experiments with new isotopes**

2023 wishes/concerns

- For 2023, resolving the issues of 7gap1/3 and REX-EBIS are crucial before the campaign in the Summer.

- Degradation of the SRF cavities continues, now ~71% of design energy. Annual thermal cycling is affecting the performance of the cavities. At risk of compromising approved experiments with the gradients in their current state. Discussions ongoing with Cryo team about intermediate «LN2» solution.

- Due to instabilties at higher RF power, the machine is no longer capable of delivering beams with A/q = 4.5. In 2022, A/q~4.2-4.3 was possible but unstable. This leads to longer breeding times to reach the desired charge state and lower ionisation efficiencies.
  - Physics risks being compromised further if this situation degrades. Experiments with heavy isotopes at maximum energy are most at risk.

- In 2022 we have seen on the low energy beamlines the benefits of a dedicated commissioning programme and on the HIE ISOLDE side, the difficulties which arise when this is not possible. Especially important due to the short time available for HIE ISOLDE physics.

- In 2023 online physics will end on Oct 30th. Important that HIE ISOLDE is maintained for the winter physics period to allow long-lived isotopes to be post-accelerated.

Many thanks to all the technical teams for all their interventions, especially on HIE ISOLDE in 2022. Special thanks to Cristiano Gagliardi and Daniel Valuch for saving the day on more than one occasion.

Thank you!

Extra slide:

2023 n_TOF approved experiments

experiment	EAR1	EAR2	NEAR
MACS proof of principle			28
Diamonds			7
64Ni(n,g)		15	
Ta(n,g)	20		
135Cs(n,g)			40
12C(n,cp)	15	5	
243Am(n,f)	30	30	
40K(n,g)		50	
SADR	15	5	
HPGe	7		
Er	20		