

# AD/ELENA - ISOLDE - AWAKE - CLEAR => feedback from operation

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ACKNOWLEDGEMENT: F. Asvesta, M. Bergamaschi, S. Doebert, Y. Dutheil, S. J. Freeman, A. Gilardi, P. Korysko, B. Lefort, T. Prebibaj, E. Siesling, N. Soleri, S. Stegemann, J. Vollaire, S. Ulmer... the AD/ELENA, AWAKE, CLEAR, ISOLDE Operation++ teams, ...  
... and many more colleagues to whom I apologies

# Outline

- **Hadron-based facilities :**
  - AD/ELENA
  - ISOLDE
- **Electron-based facilities :**
  - AWAKE
  - CLEAR
- **Closing remarks**

## For each facility:

- *What is it ?*
- *2024 operation highlights*
- *Short-long term perspective*



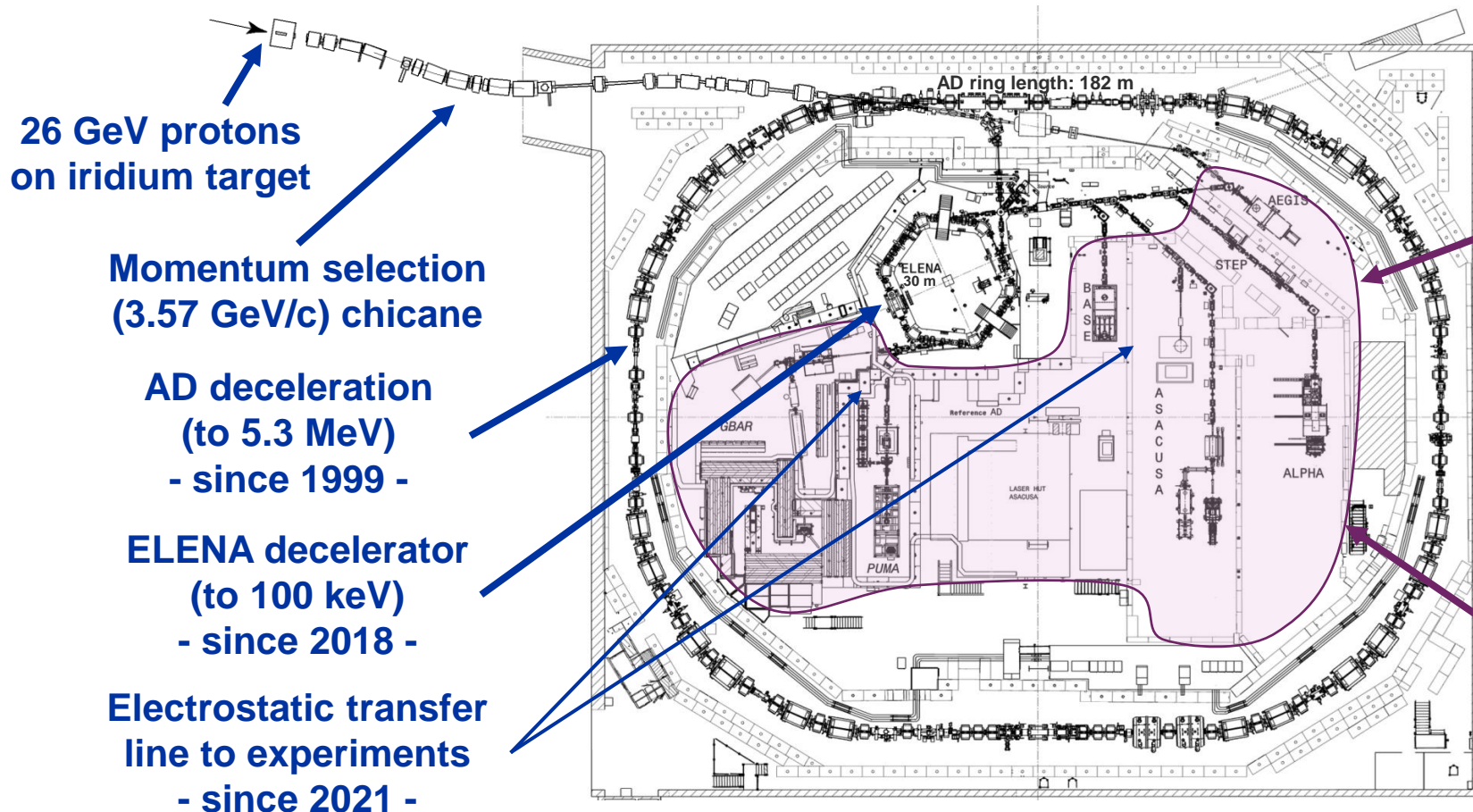
**AD/ELENA**





# AD/ELENA: a Unique pbar Facility!

- The only place in the world with low energy pbars in a synchrotron!
  - It seems unlikely to have similar capabilities elsewhere for the next 10-20 years
- Serving 60 Research Institutes/Universities – 350 Scientists – 6 Active Collaborations



**antiprotons**

**ASACUSA**  
Antiprotonic helium spectroscopy

**BASE, BASE-STEP**  
Fundamental properties of the proton/antiproton, tests of clock WEP / tests of exotic physics / antimatter-dark matter interaction, etc...

**PUMA**  
Antiproton/nuclei scattering to study neutron skins

**antihydrogen**

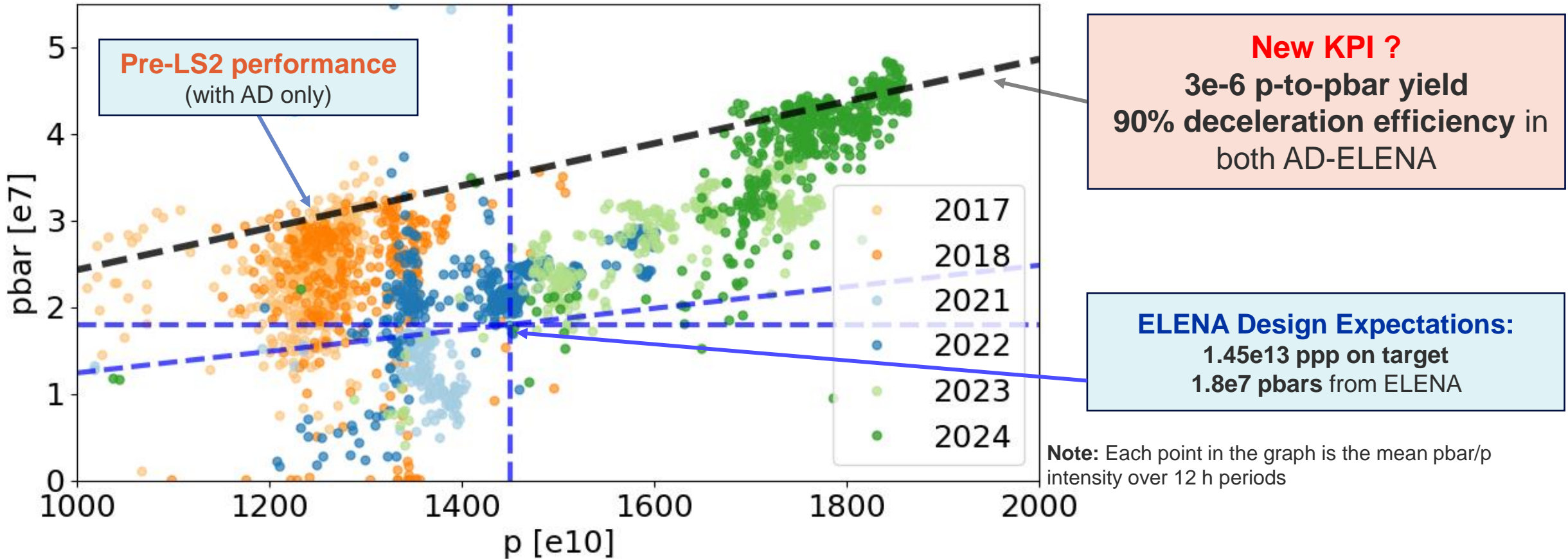
**ALPHA,**  
Spectroscopy of 1S-2S in antihydrogen

**ASACUSA, ALPHA**  
Spectroscopy of GS-HFS in antihydrogen

**ALPHA, AEGIS, GBAR**  
Test free fall weak equivalence principle with antihydrogen

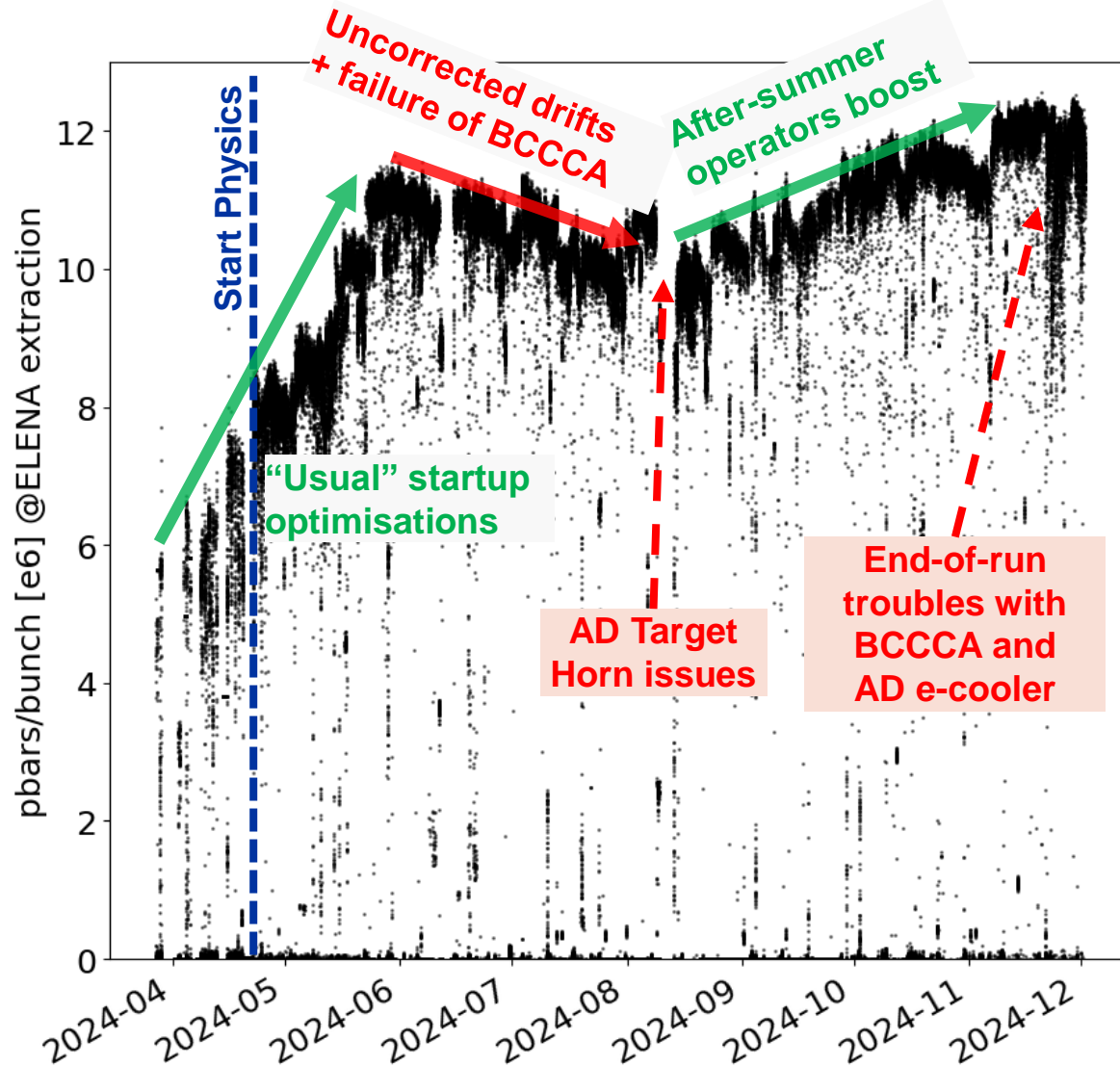
# Record performance of AD/ELENA Facility

- Enhancing reliability, operability, and overall pbar flux
  - Enabled by LIU upgrades (p intensity), and AD/ELENA investments (pbar yield and efficiency)



~2.7e18 p => ~6e12 pbars (10 pg of pbars!) in 1.5e5 shots => the highest integrated #pbars ever!

# AD/ELENA: Overview of the 2024 Run



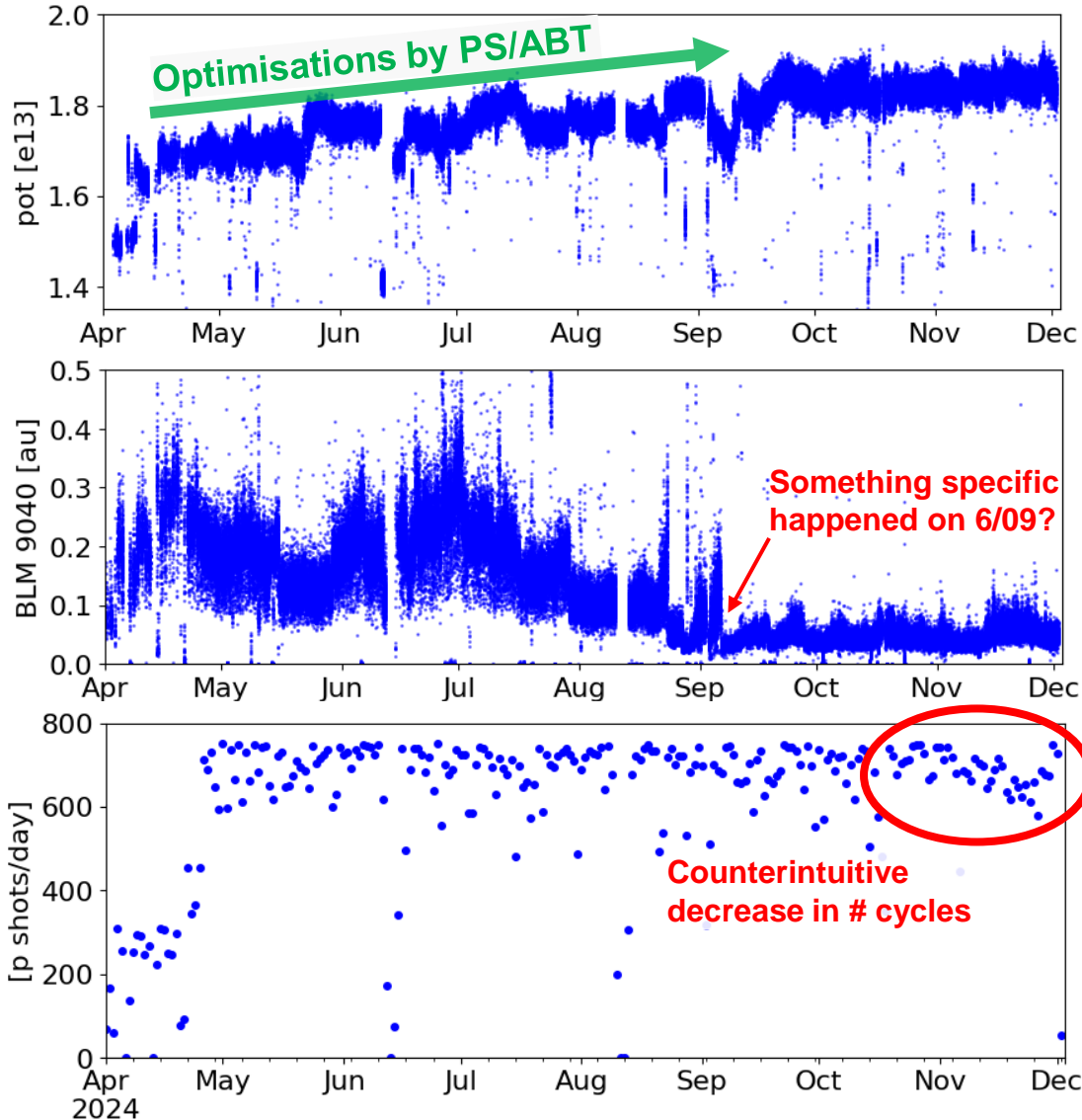
- Wrt 2023, no major performance increase were expected, but emittance reduction:
  - Expected **2023 peak performance**: **1e7 pbar/bunch** from ELENA
  - New working point in ELENA: **emittance reduction** for experiments⇒ Overall, **smooth restart** and **excellent performance quickly obtained**
- “Usual”(?) **critical items** (see [Jack’s talk](#)):
  - Failure of AD **BCCCA** int. monitor (see [Inaki’s talk](#))
    - **Partially blind** operation in AD
  - Issues with **AD Target Horn**
    - **Downtime, lower pbar yield** due to capped operation
  - **Instabilities** around **AD e-cooler**
    - **OP struggling** to keep peak performance



# Happy Users with Ambitious Goals: Stability Wanted!

- Most **technological challenges** and **ambitions** are **after the handover point!**
  - See talk by [S. Ulmer @IPP](#)
- **Present users are happy**
  - **No strong request for “better” or “more” beam**
    - Presently **profiting** of the **potential** and **flexibility** of **ELENA!**
  - **Request** for higher **shot-to-shot repeatability**, **beam availability** and **continuity**
    - Investment in **modern technologies/techniques** **crucial** for enhanced **beam stability** and **efficient operation** (this includes optics, control, instrumentation, ...)
    - **Paramount** to pursue **AD consolidation** efforts, while **intercepting upgrade needs**
    - Must ensure a **long term pbar-facility lifespan (20+ years)**
  - **Request** to maintain **full technical support** during **YETS/LS periods**, reserving **CALM periods for precision measurements** (>1 year old pbars are still in **BASE's trap, today**)
- **The AD/ELENA team strategy** is to **grasp peak (intensity) performance**, identify **limitations**, **solve** or **stabilise** them, profit of **ELENA's flexibility...**  
... **keep AD/ELENA an up to date facility**

# Proton production and delivery matters

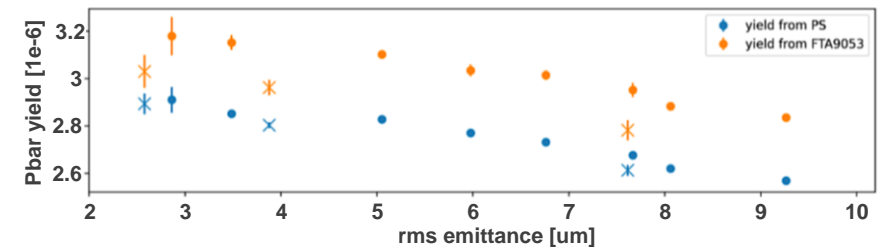
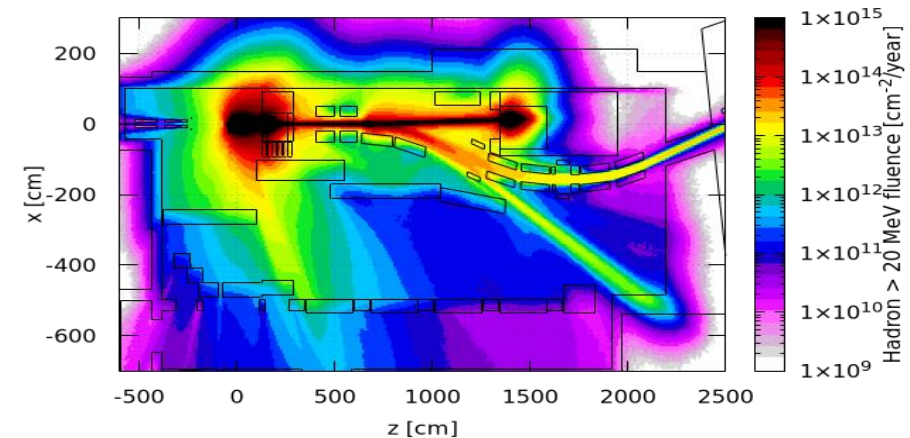
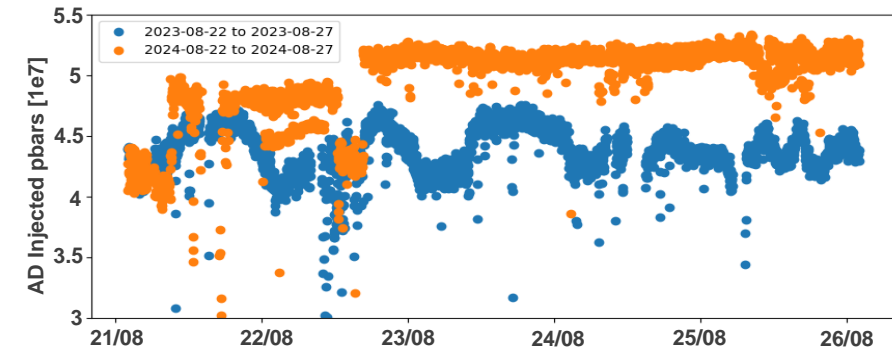


- **Pot intensity stability** is translated **one-to-one to pbar**
  - Invested on **PS hardware** (mainly LLRF) and **studies** (working point, emittance control, ...)
  - Started looking into “**de-bunched**” beam in PS
  - **TT2 trajectory** optimisation/**stabilisation**
- ⇒ **Improved transmission/p-on-target**, which seems to be confirmed by **less losses in TT2/FTA!**
  - **Goal for 2025: quantify and monitor evolution**
- Also, **identified possible aperture restriction** at AD target zone entrance caused by **pre-LS2 wrong p beam size estimate**
- **Rep. rate/number-of-cycles variation** remains a **source of “unhappiness”**
  - “**Non-linear impact**” on user’s physics reach
    - **Especially toward the end of the year!**
  - **shot-to-shot beam quality variation** difficult to quantify
  - **Looking forward for a dynamic scheduling after LS3?** (See *Denis’s talk*)

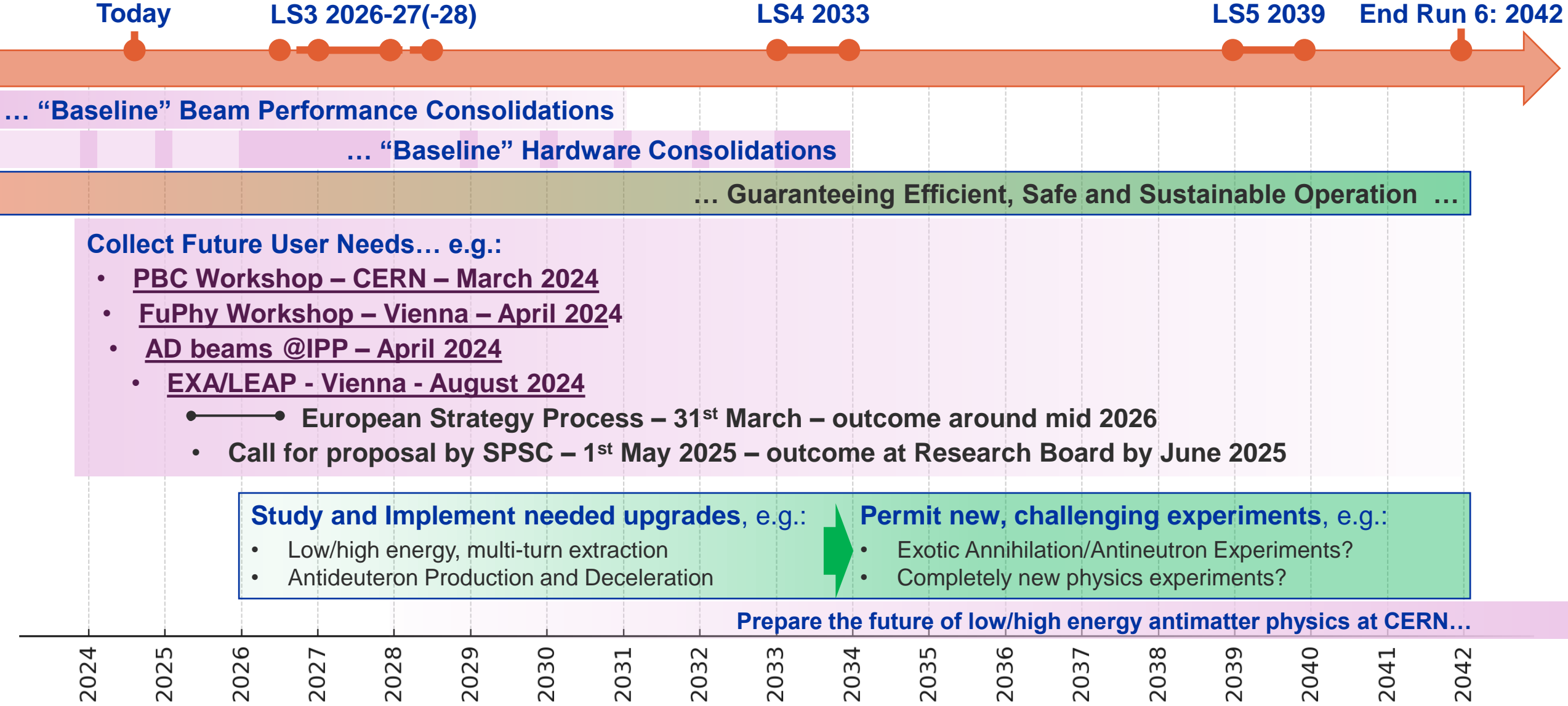


# Pbar yield and deceleration stability improvements

- **p beam position on target stabilisation**
  - UCAP feedback implemented using EPA framework (*thanks ABT!*)
    - **Warning! Initially fooled by BTV mirrors(?) moving with temperature(?!)**
      - Required custom ABT/BI procedure to stabilise the reading
      - A clear example of hardware-model-automation-operation challenge
- **Finally, refreshed efforts in FLUKA modelling of pbar yield** (*thanks ABT/STI!*)
  - Key ingredient to understand instrumentation along DI (*thanks BI!*)
  - Allows to make more sense of pbar-yield vs p-emittance observations (*thanks ABT!*)
    - (also, to start thinking about making antideuteron?!)
- **Impressive work on s-cooling setup automatization** (*thanks RF!*)
  - Already saved several hours of physics after issues!
- **Tackling several hardware-instability issues**
  - Horn exchange with initial design improvements (*thanks STI!*)
  - Identified instability in DI BHZ magnets (*thanks OP/ABT/EPC!*)
  - Solved long lasting instability issue with AD ejection septum (*thanks OP/ABT!*)
  - Identified and solved BBQ-induced orbit jitter at AD extraction (*thanks OP/BI!*)
  - Now looking at AD e-cooler-related orbit reproducibility ... (*thanks OP/BI!*)

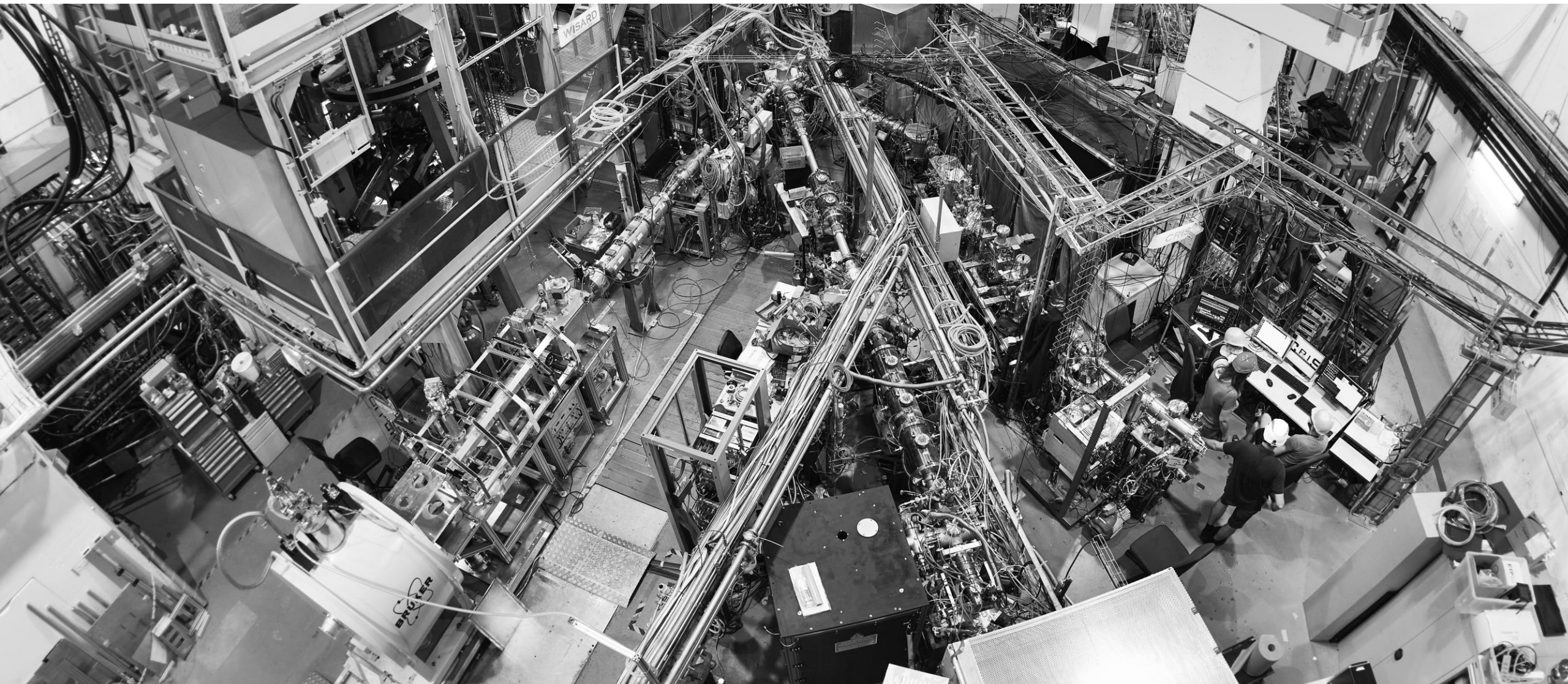


# Overall Long-Term Timeline for AD/ELENA (being discussed)





# ISOLDE

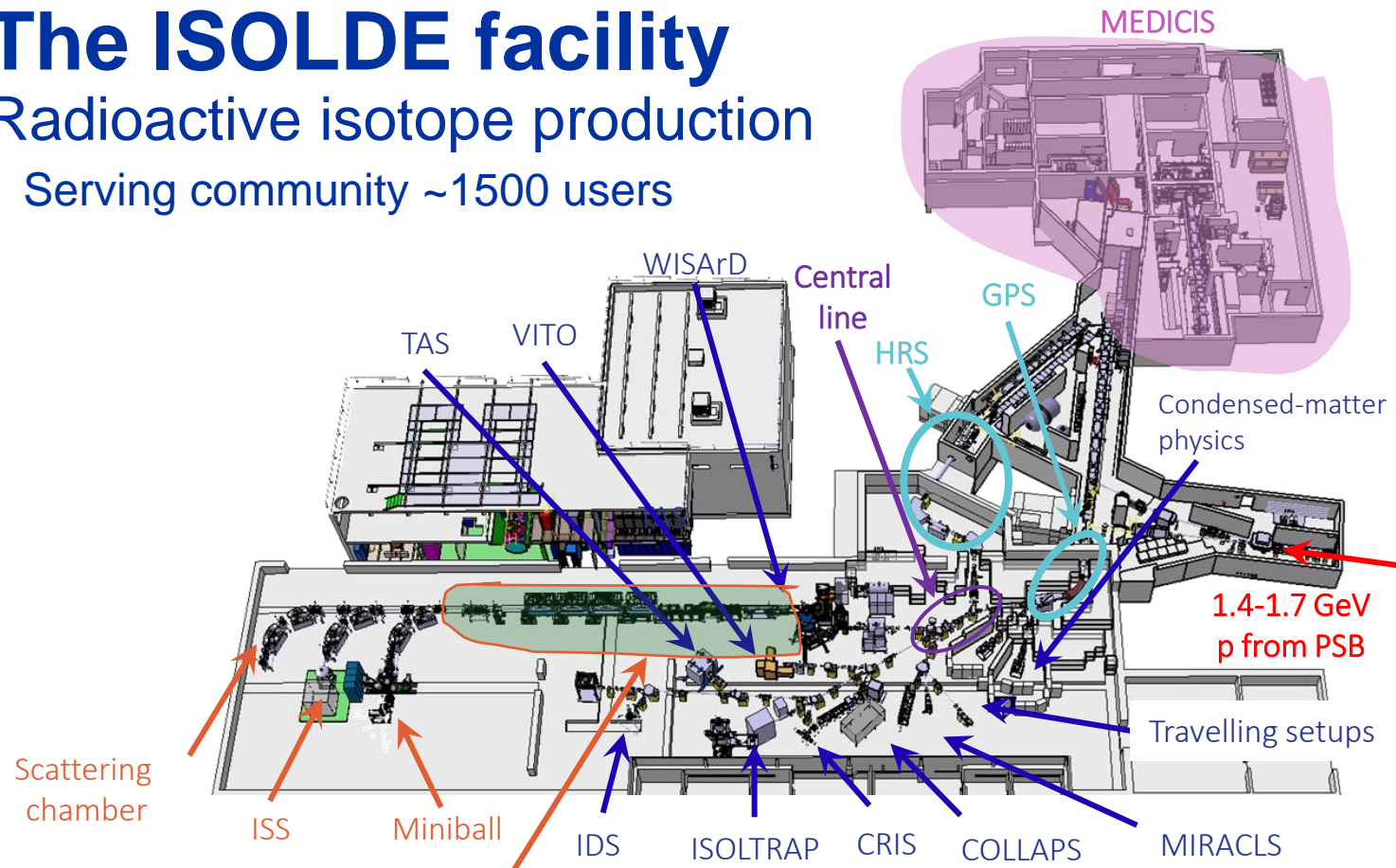




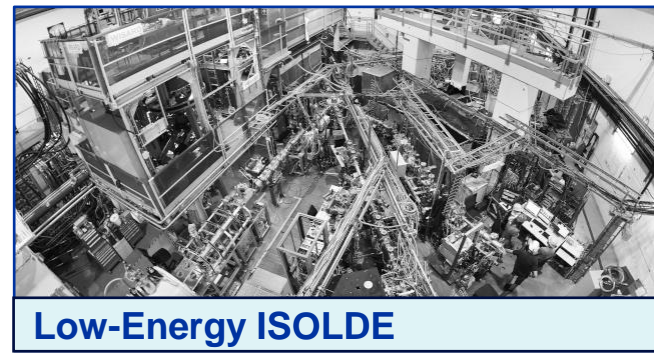
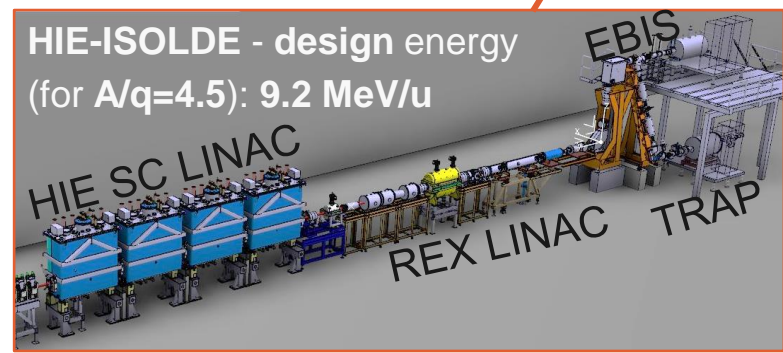
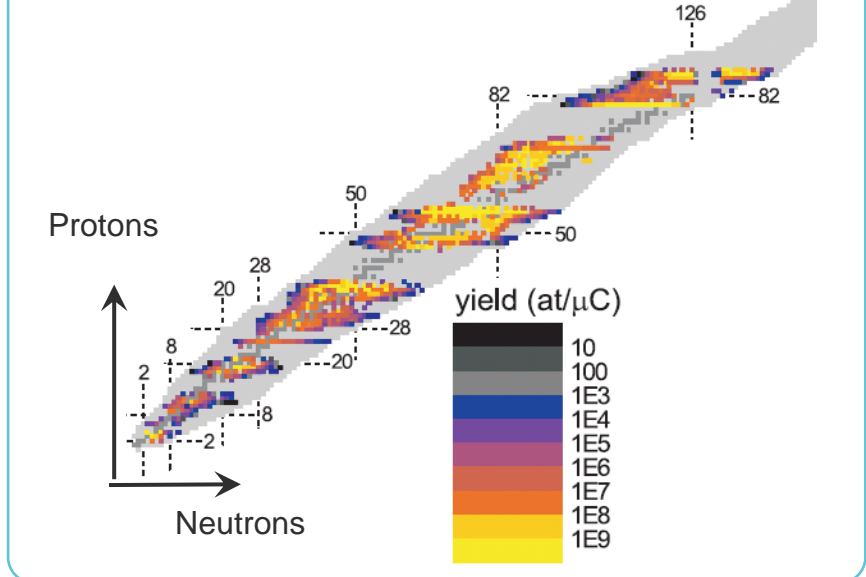
# The ISOLDE facility

## Radioactive isotope production

- Serving community ~1500 users



Variety of beams → breath of science  
 >1000 isotopes of 74 chemical elements

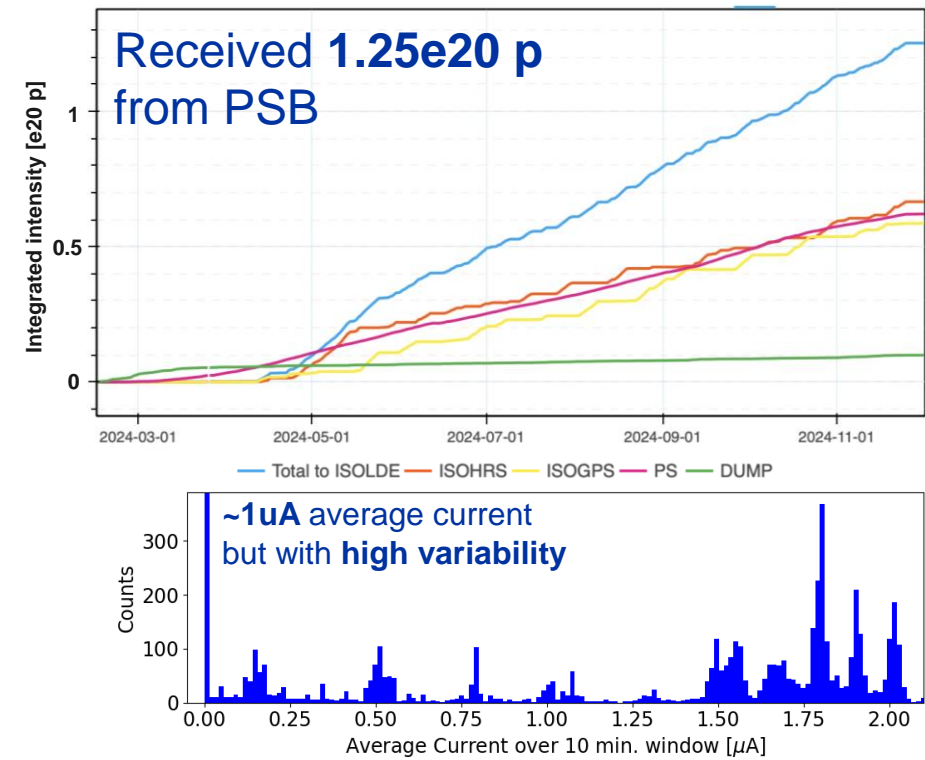


~15 experimental instruments  
 ~50 experiment/year

- Sequential scheduling (1 day - 1 week)
- Specific target + ion source unit per experiment
- Weekly target changes + “mini-commissioning”/machine set up

# ISOLDE 2024 Overview

- **Stable operation with ~50 experiments performed**
    - See [Dragoslav-Laza's talk](#) for user feedback
  - **Main (new) Issues**
    - **2 power cuts** (2nd Sep., 17th Oct.) during HIE-ISOLDE runs
      - several shifts needed for recovering good beam conditions
    - **Instabilities** experienced with **HRS cooler-buncher**
      - Only when used in “bunched” mode - **unclear reasons**
  - **Excellent work by SY-STI to increase the variety and purity of the RIBs:**
    - **New Laser-Ionisation schemes (RILIS)** (used by ~53% of experiments in 2024)
    - **New molecular beams production** for cleaner RIBs separation (used by ~20% of experiments in 2024)
- ⇒ **A prime example of maximising physics through modelling, hardware, and expertise!!**
- **Profiting of p-beam energy flexibility:**
    - **1.7 GeV** used for 2 experiment: e.g. **9Li experiment** given about a **factor of 2 more RIB intensity**



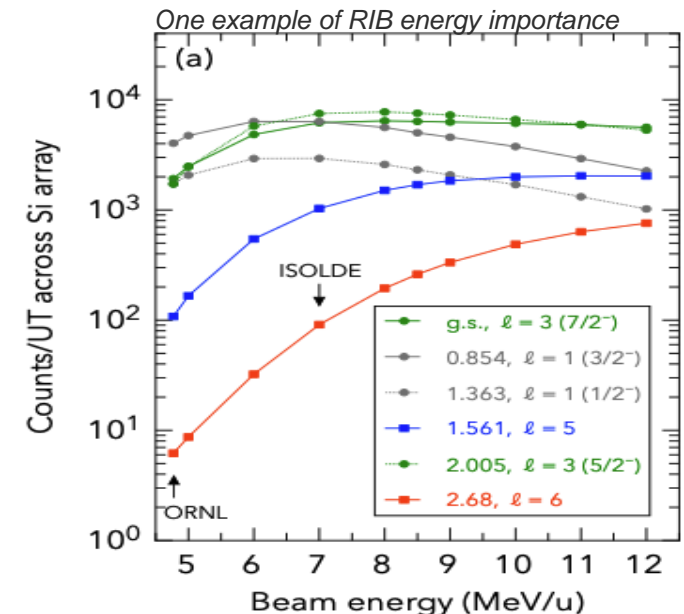
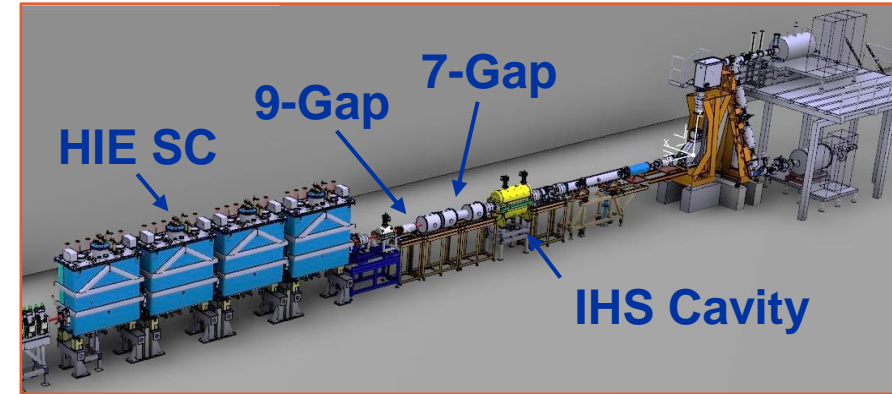
# ISOLDE wishes for 2025

- **Stable / Reliable operation to maximise physics**
  - **Remember:** ISOLDE is a research environment **experiment only last between 1 and 7 days**
  - **=> A stop/issue on the wrong day can cause an experiment to fail!**
- **Request for p beam flexibility** (energy, intensity, super-cycle composition, p-steering, ...)
  - **Remember:** several days of beam **re-commission after target exchange**, with **unpredictable challenges**
    - e.g. Requiring **different super-cycle composition** to optimise yield of interested species...
  - **Continue to profit of 1.7 GeV beam, possibly higher p intensities** (see [Pablo's talk](#))
  - Mind that ISOLDE will normally **start LS3 at the end of 2025!**
    - To be kept in mind for **prioritisation of protons**
- **Planned advancements in modelling and automation:**
  - **ISOLDE optics model** advancements (see [Pablo's talk](#))
  - Using an **ISOLDE beam signal** as parameter to **tune proton beam** delivery (see *Simon's slide in appendix*)
- **On the YETS scheduling side: special thanks to Cryo and RF colleagues!**
  - **Sequencing** of cooldown and RF reconditioning **optimised** thanks to experience gained over last years
  - **3 more weeks of physics** => Much appreciated by user community!



# Long-Lasting Limitation: Acceleration in HIE-ISOLDE

- HIE ISOLDE designed to reach 9.2 MeV/u for  $A/q=4.5$  and able to deliver 2 ms pulses at 50 Hz
- **IHS cavity phase and amplitude jumps**
  - **Detrimental for stable operation** and physics reach
  - Found procedure to quickly correct, but not always easy to quickly detect
    - Looking forward for LLRF consolidation in LS3 toward digital system for better diagnostics and automatic interventions
- **Continuous trip of 7-Gap cavities RF amplifiers** (reflected power)
  - Only possible to run them at lower power (70%), effectively **limiting  $A/q$  to 4.0**
  - Thought this could be **due to vibration**, but **no clear evidence**
  - **Strong limitation on physics reach** of the complex
- **Vacuum leak in the 9-Gap cavity vacuum leak issue**
  - Average RF power limited to 2 kW, effectively limiting **RF pulse duration to 1 ms**
  - **No development for now**. Also, **unsure**, if possible, to remove this limitation in LS3
- **HIE SC LINAC gradient limited to about 4.5 MV/m** (design 6 MV/m)
  - Effectively, limiting RIB's energy to **7.4 instead of 9.2 MeV/u**
    - **Major limitation for the physics reach (statistics and rigour/robustness) of the facility!**
    - **MTP request** to tackle this issue being submitted => **must be followed up!**
  - **On the positive side: model-based cavity phasing** to maximise acceleration for different configuration developed in 2024 (see [Birk Emil's talk](#))
    - => **much appreciated by Experiments!**



# Looking ahead, post LS3 expectations:

- Toward **design parameters** with necessary consolidations/improvements
  - **Must make sure** to reach **9.2 MeV/u** for **A/q=4.5** and able to deliver **2 ms** pulses at **50 Hz**
- Toward even **higher flexibility** to increase physics reach
  - **Varying p intensity** (1e13 to 5e13 ppp) from PSB
    - Note: **higher p flux** is, typically, **beneficial**
    - **Promising results** from 2024 MDs! (see [Pablo's talk](#))
    - Profiting of **mixed nTOF-ISOLDE cycles ?** (to be studied)
  - **Varying p energy** (from 1.4 to 2 GeV) from PSB
    - **Hardware upgrades** (dump, BTY, ...) underway
    - **PSB impedance limitations** being studied (see [Chiara's talk](#))
- Toward **model-based operation** (see [Pablo's talk](#))
  - **LSA deployed** in the LINAC in 2024
    - **Waiting for hardware consolidations** to fully profit it this
  - Ongoing effort for improving **general facility modelling**, **target integrity** and **yield studies** for increased intensity/energy, **BTY optics matching**, ... (thanks to all people involved!)

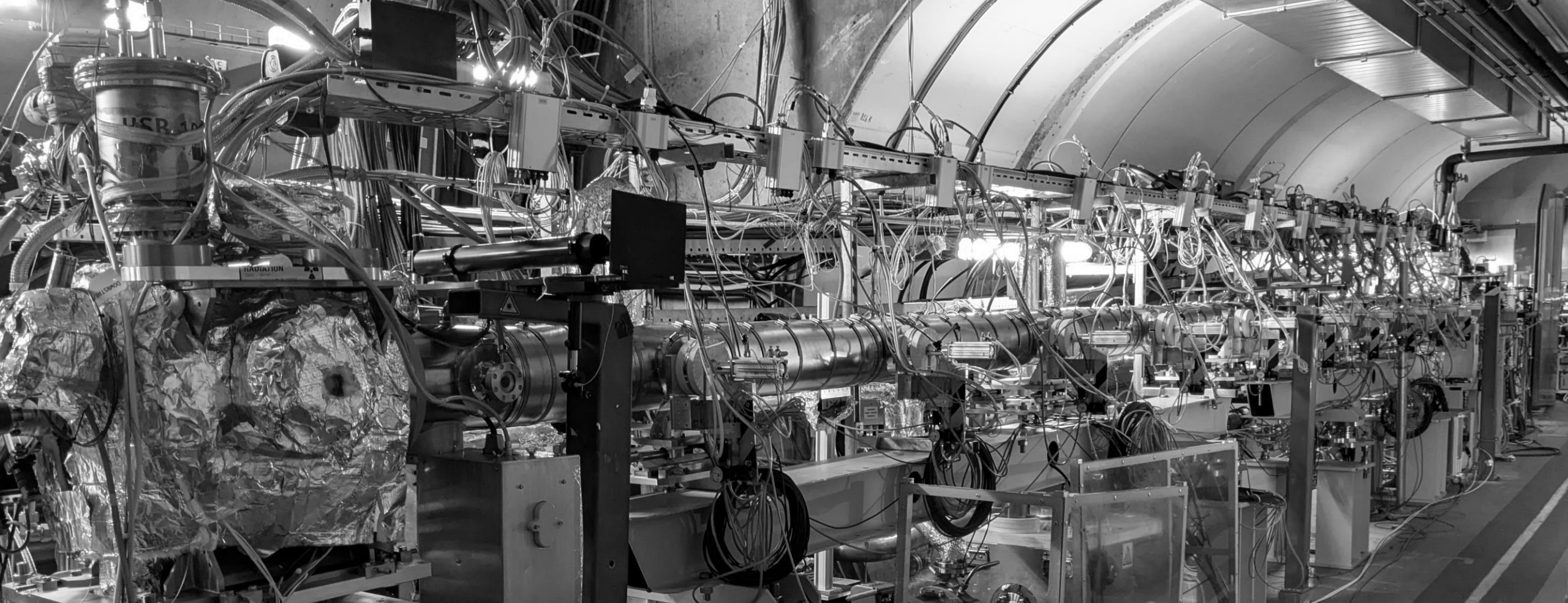
PSB Fixdisplay - W 47 20-Nov-2024 16:04:22

Comments (19-Nov-2024 11:05:33)  
 Coordinator : J.F. Comblin (168060)  
 Operator : CCC: 76671, 160357

BP	User	Pls	Ini.	Acc.	b.Ei.E10	Ei.E10	Dest.
8	ISOHRS_2024	19	●●●●	●●●●	3022	3057	ISOHRS
9	MD12563_ISOGPS	16	●●●●	●●●●	5065	5076	ISOGPS
10	---ZERO---	1	○●○●	○●○●	0.00	0.20	BDUMP
11	ISOHRS_2024	19	●●●●	●●●●	2993	2985	ISOHRS
12	ISOGPS_2024	18	●●●●	●●●●	1023	1044	ISOGPS
13	---ZERO---	1	○●○●	○●○●	0.00	0.31	BDUMP
14	ISOHRS_2024	19	●●●●	●●●●	3005	3002	ISOHRS
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18	ISOHRS_2024	19	●●●●	●●●●	3020	3025	ISOHRS
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	ISOGPS_2024						ISOGPS

20/62 No Message



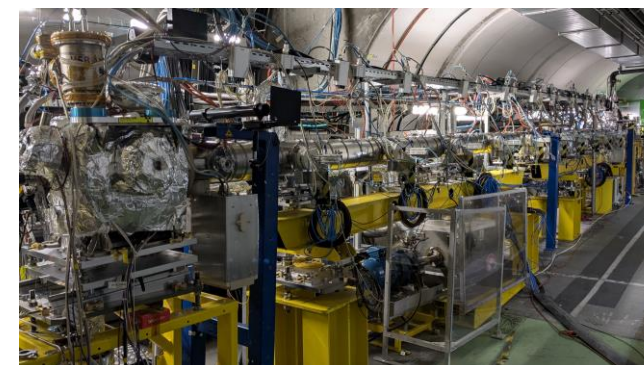
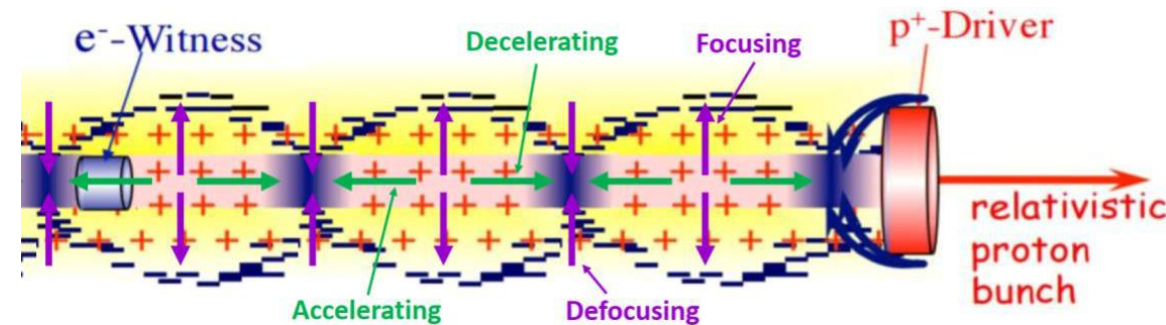
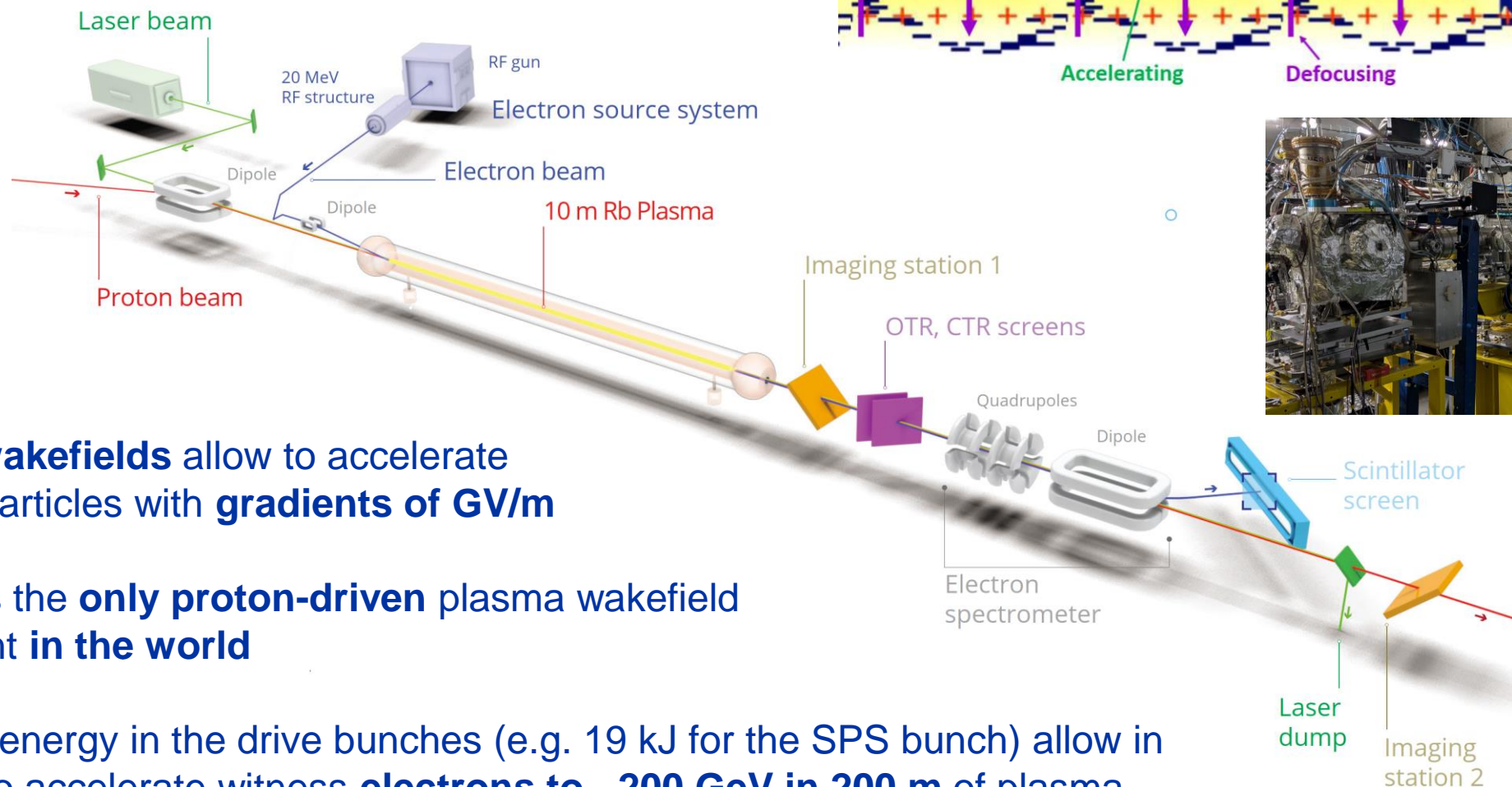


**AWAKE**





# AWAKE: Plasma Wakefield Acceleration R&D



- **Plasma wakefields** allow to accelerate charged particles with **gradients of GV/m**
- AWAKE is the **only proton-driven** plasma wakefield experiment **in the world**
- Very high energy in the drive bunches (e.g. 19 kJ for the SPS bunch) allow in principle to accelerate witness **electrons to ~200 GeV in 200 m** of plasma

# AWAKE 2024 highlights

- **A Productive Year with Significant Physics Results**

- Achieved the first clear observation of a **plasma density step** effect

- **Operation feedback: effective communication wanted!**

- AWAKE relies on a **stable and reproducible beam** for **multiple hours**
- e.g., **no interruptions** or parameter changes: p bunch length, timing...

- **Communication with machine operators is crucial!**

- e.g. alerts for **potential parameter changes** affecting AWAKE operations
- Operators **proactiveness is very much appreciated!** (*Thanks, SPS-OP!*)

- **Coordination with the LHC cycle/filling** to be improved:

- **Limitation: AWAKE is removed** from the super-cycle **during LHC fills** or **fill preparations**
  - **Example impact:** multi-hour-long measurements **must be repeated** if interrupted near completion
- **Mitigation: advance notice is essential** to allow proper planning of AWAKE measurements

- **Discrepancy between “SPS” and “AWAKE” availability metrics:**

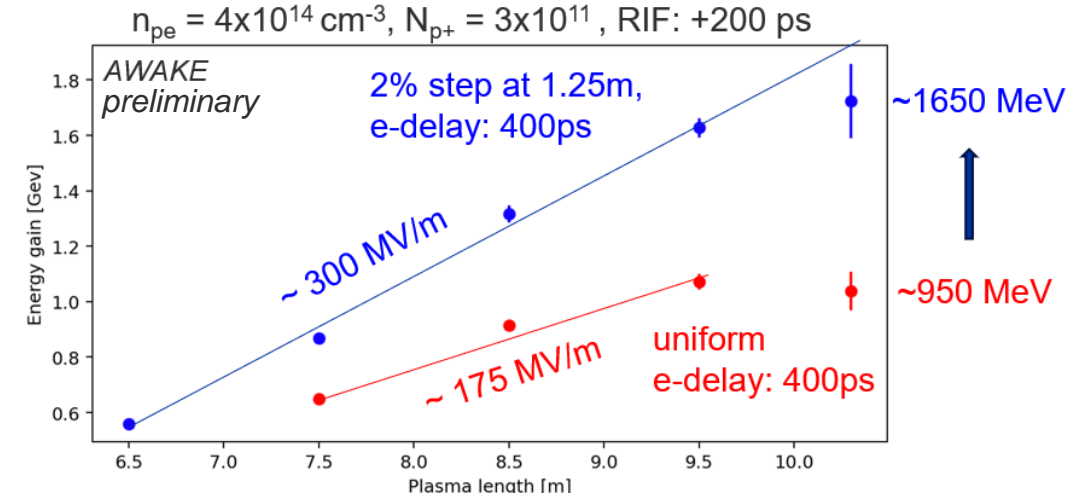
- **Remember:** only **one shift of personnel** conducting measurements in **AWAKE**

2024 average availability over one run period (MD days and LHC filling time not included)

	Run 1	Run 2	Run 3	Run 4	Run 5
SPS-AWAKE	96.9%	90%	95.1%	91.4%	98%
AWAKE exp.	64.3%	59.3%	52.5%	57.6%	57.6%

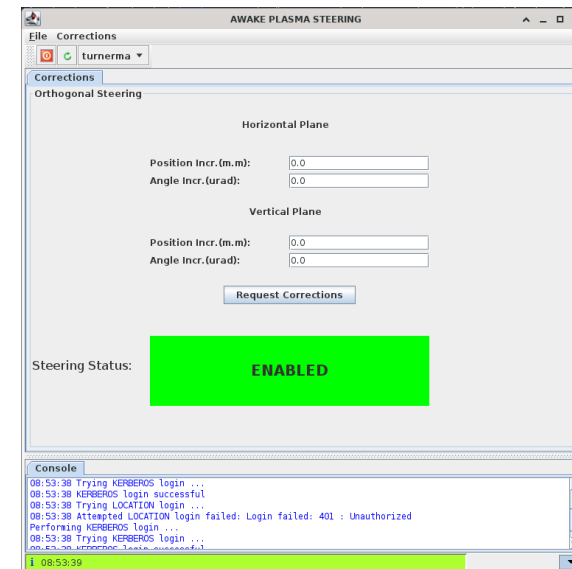
# extractions  
# extraction (ideal day\*)

\* On a non-MD day with uninterrupted delivery, scaled by the hours AWAKE was requesting beam



# AWAKE 2024 developments

- **Working on p bunch rotation and bunch characteristics** (*with I. Karpov*):
  - Produced RMS length of **~170 ps**, independent of bunch population (0.5, 1, 1.5, 2, 2.5, and  $3 \times 10^{11}$  protons/bunch)
  - Shorter bunches with RMS length of **~90 ps achieved** => **plan to use it in 2025** (not yet, for data consistency)
  - **Reduced** number of particles in the **bunch head**, with significant AWAKE measurement quality improvement
- **Correlation Between SPS Diagnostics and AWAKE:**
  - **AWAKE frequently spots SPS issues** due to its more sensitive streak camera diagnostics (though not always inserted)
    - **Critical for AWAKE** to be informed! **Better diagnostics/monitoring on the SPS side ?**
  - **SPS BQM attenuation settings** often remain unchanged when bunch intensity is modified (e.g. LHC <=> AWAKE settings)
    - **Could this process be automated ?**
- **Tools development for significant reduction of “CCC phone calls per day”:**
  - **Orthogonal steering tool** for the proton beamline (*thanks SPS Operation!*):
    - Tested successfully and **working effectively!**
  - **Strongly desired: beam inhibit extraction feature** (discussion ongoing):
    - **Currently handled manually** “over a phone call”
    - Would be **helpful for brief interruptions** (<5 cycles), e.g., when moving a screen ...
    - **Aim to have it ready before April 2025 proton run**



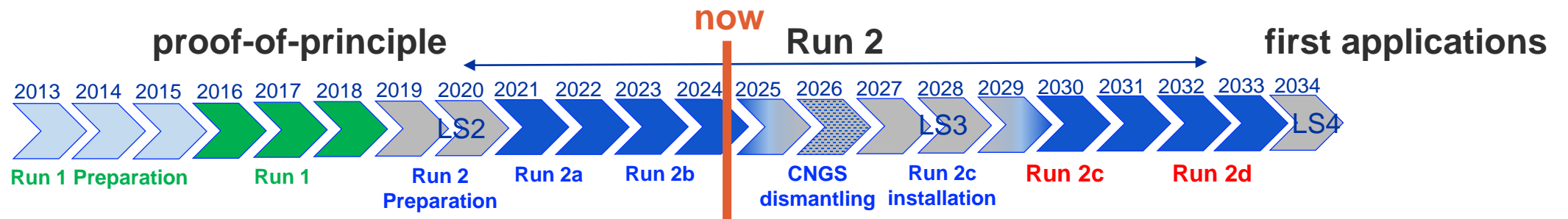


# AWAKE short- and long-term plans

Requested 5 weeks of proton run in April/May 2025

- **Goals:**
  - **Complete** the Run 2b datasets
  - **Explore** more in details parameters for Run 2c
- **Note:** **Last opportunity for physics before LS3** (proton beam back in 2029)

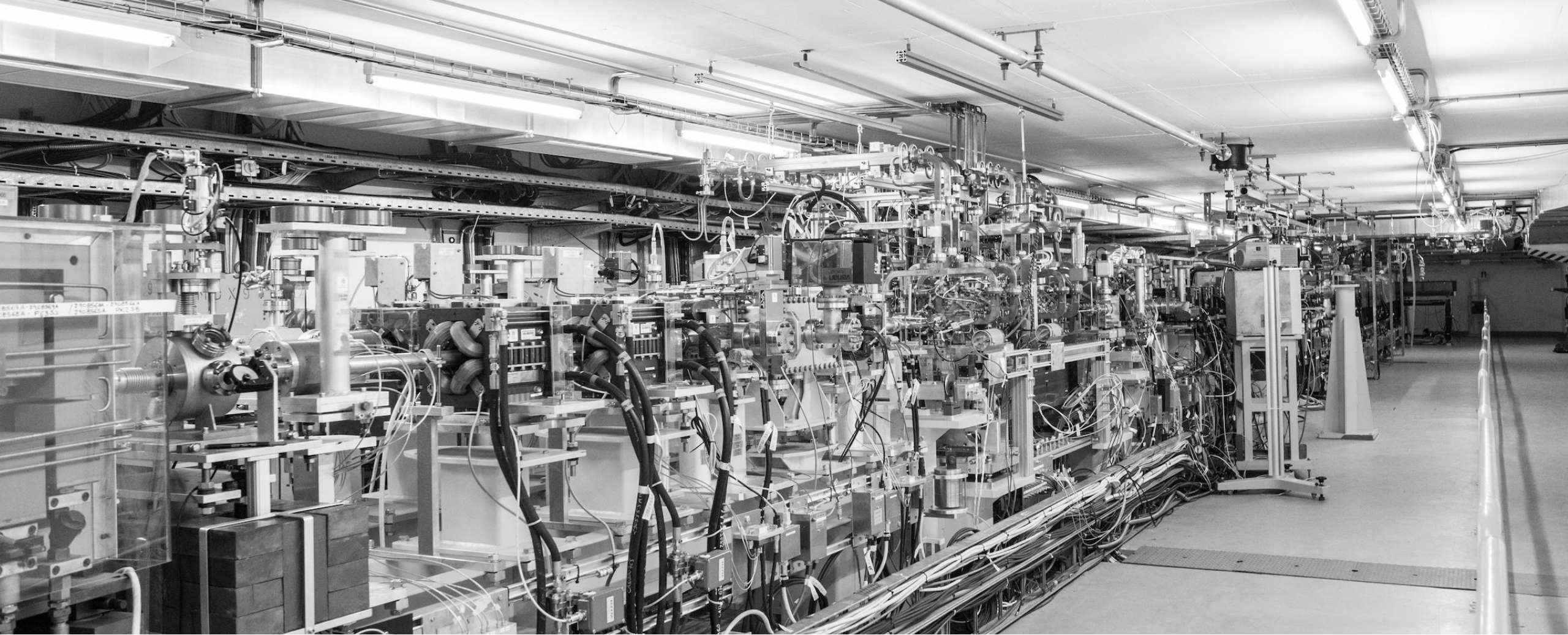
**AWAKE Run 2c/d approved by CERN in 2024 till LS4!**



**Run 2c:** Demonstrate electron acceleration and **emittance control** of externally injected electrons

**Run 2d:** Development of **scalable plasma sources** to 100s meters length with sub-% plasma density uniformity

→ **Toward first application proposals** for particle physics experiments with 50-200 GeV electron bunches

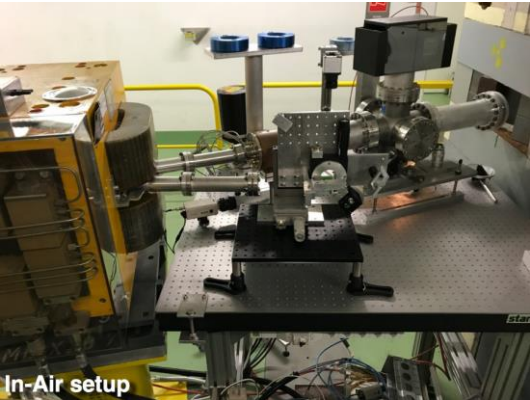


**CLEAR**





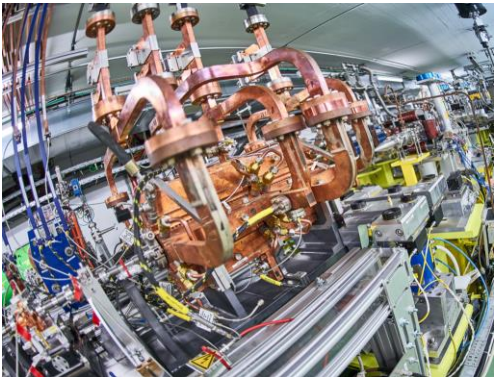
# CLEAR: e<sup>-</sup> for a large and varied range of experiments



**In-air test stand**

Testing ground for beam diagnostics R&D and THz radiation studies

**Irradiation for medical and other applications**

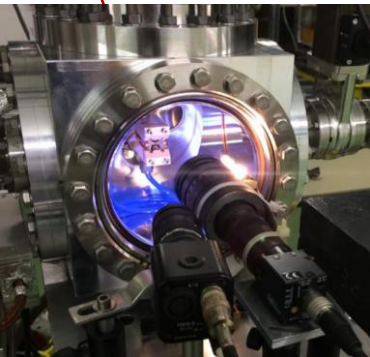
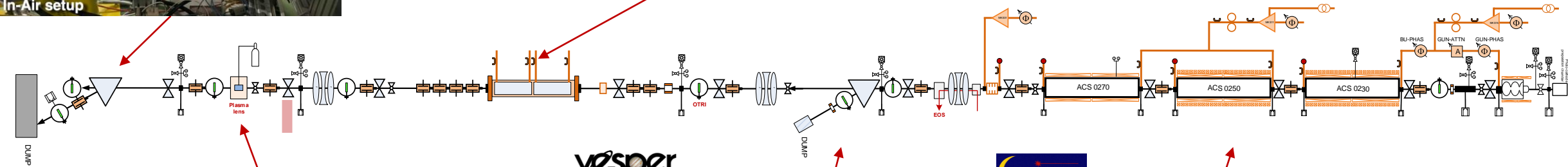


**CLIC Test-Stand**



**High-gradient and linear collider R&D**

+ *Beam instrumentation area*

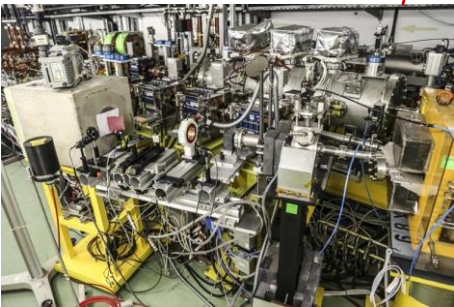


**The Plasma Lens Experiment**

Novel concepts of **plasma-based focusing** and acceleration



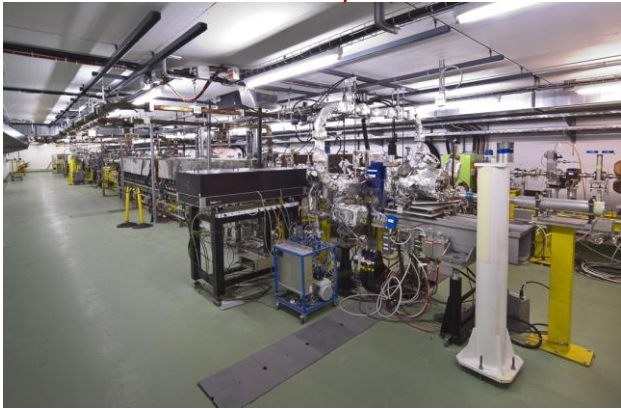
**vesper**



**VESPER**

**Beam irradiation facility** for studies on radiation damage of electronics

**CALIFES**



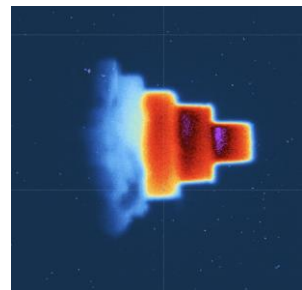
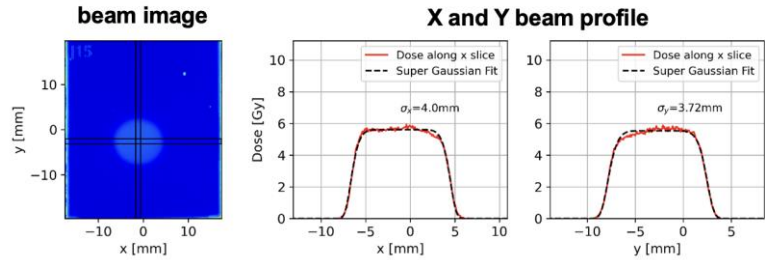
**CALIFES electron linac**

Flexible accelerator providing **200 MeV electron beams** to all CLEAR users



# CLEAR: a few 2024 Highlights

Double-scattering system for **uniform beam delivery** and real-time dosimetry system now fully operational (CERN/Oxford U.)

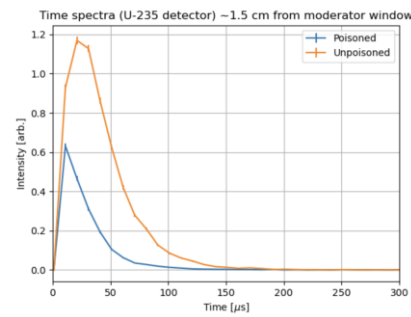
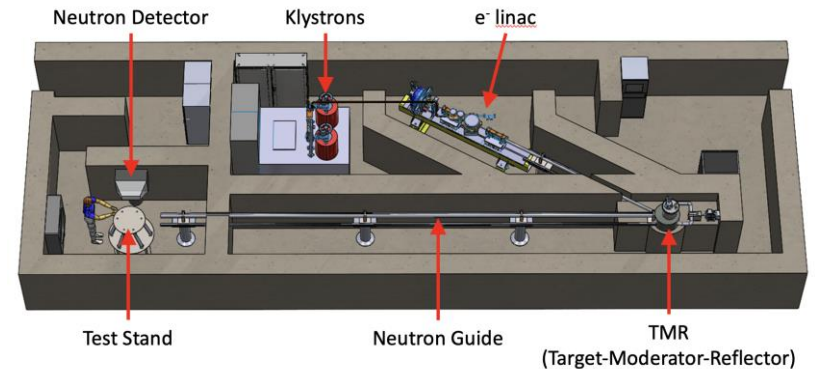


Beam-induced light in the scatterer

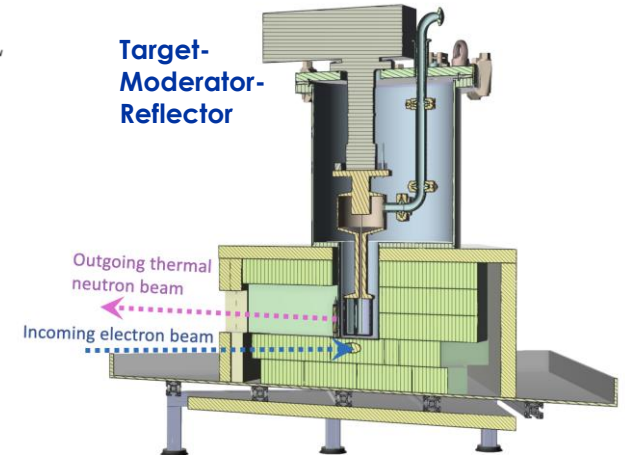
## In numbers:

- ~ 30 Experiments
- ~ 24 User groups internal/external
- > 20 external collaborating institutes
- 39 weeks of operation in total

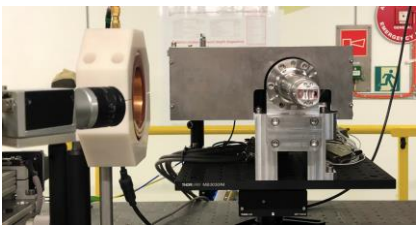
Experimental tests of the **neutron Target-Moderator-Reflector** for the **VULCAN project** (DAES/CERN-KT/CLEAR)



Neutron flux and time-of-flight measurements

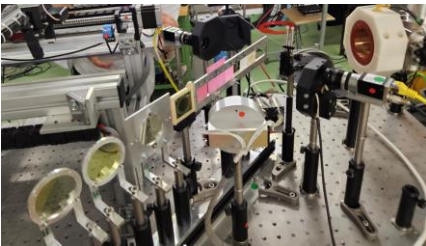


## Beam instrumentation R&D



Supporting FCC-ee R&D studies (e.g., EO longitudinal beam monitor, Karlsruhe)

Emittance measurements based on **digital micro-mirror and micro-lens array** (Liverpool U.)



Measurement of **scintillator screens response** (CERN/BI and Sheffield U.)

## First hands-on accelerator course, EURO-LABS

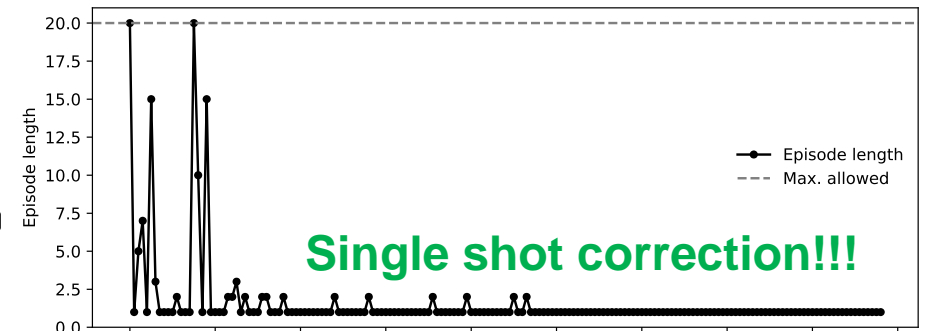
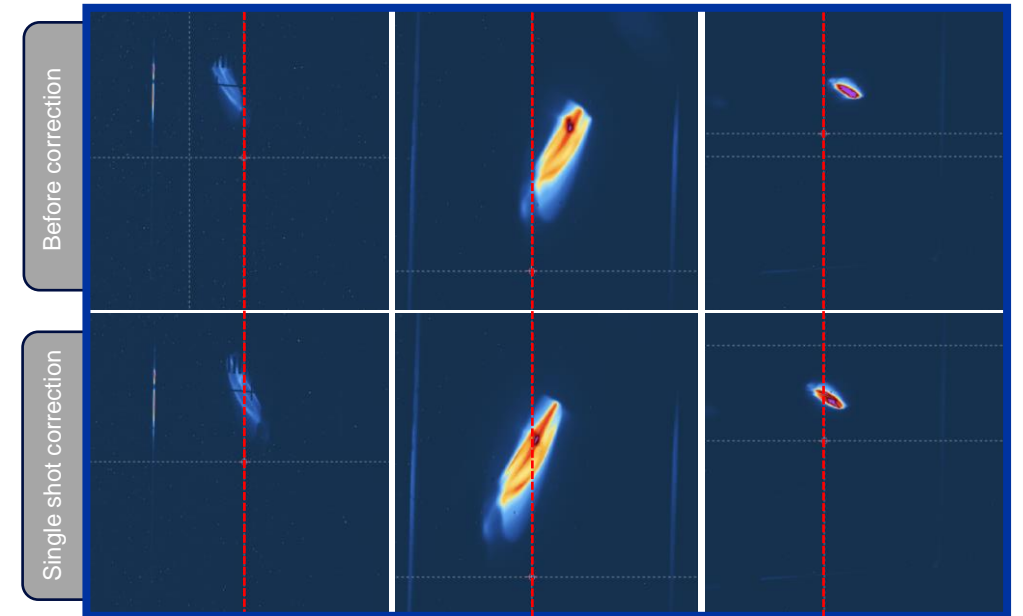
# EPA @CLEAR: Machine Learning for Accelerator Optimization

## Why CLEAR?

- **Availability:**
  - Can run **24/7**, also during **shutdown periods**
  - **High repetition rate** (from 0.83 to 10 Hz)
- **Flexibility:**
  - **Adjustable beam parameters** and components
- **Robustness:**
  - Relatively **simple** installation
  - **Limited risk** of breaking equipment with beam
  - Proven expertise in **recover quickly** from critical failures

## Example: Beam Trajectories Optimization

- **Approach:** autonomous control loop with **screen measurements** and **orbit corrections**
- **Result:** achieved **single-shot correction** after training!



Ready to host your next ML-based experiment! ... also during YETS/LS3...

# CLEAR – Extension of Operation & Improvements

- **Operation Extended Until 2030** ( running also during LS3 ):
  - Following a successful **review** in spring 2023, CLEAR's operation is extended with **strong scientific justification**: “CLEAR is a great asset to CERN, achieving excellent efficiency with **modest resources**.”

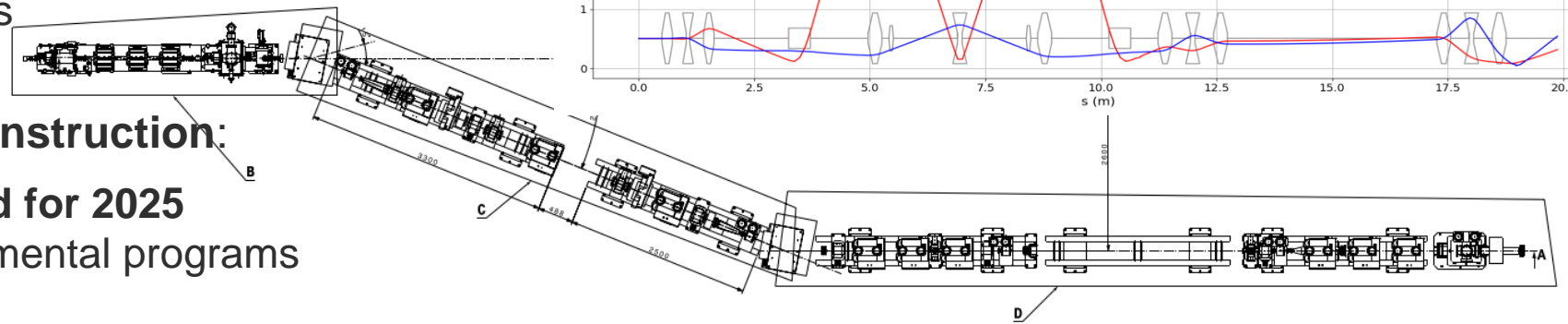
- **Ongoing Upgrades:**

1. **New EO Comb Laser Front-End:**

- **Ready in 2025**, enabling enhanced experimental capabilities

2. **New Beamline Under Construction:**

- Commissioning **planned for 2025** to support future experimental programs



- **Strategic Vision:**

- **Current Focus:** Expanding the experimental program with upgrades already in progress
- **Future Role:** Exploring CLEAR's potential **contribution to major CERN initiatives** (e.g., Higgs Factory)



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# FINAL REMARKS

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# Communication and Metrics Challenges

- **Lost Information in Communication:** *e.g.*
  - ELENA running H- before/after pbar physics **interfered with experiment plans** despite prior agreement
  - Operators **guessing beam availability** via other machine VSTARs
  - **Operator-dependent "hints"** highly appreciated but inconsistent
  - AWAKE seems to spend **way too much time over the phone** with the CCC

⇒ **Need: Smarter, streamlined communication without overloading forums/tools - could AI help?**
- **Data Link Between Users (GPN) and Operations (TN):**
  - Users resort to **ad-hoc solutions, typically inefficient** (and probably at the limit of security compliance)

⇒ **Could the use of DIP (or similar tools) be generalised?** (see [Pablo's talk](#))
- **Machine Availability vs User Perception:**
  - These facilities users have **short data-taking windows**, which **magnify impacts of downtime**
  - **Non-linear** relation between **beam downtime** and **experimental success**
  - **"Best effort support"** works for routine faults (typically solved by operators) but **fails during critical periods**

⇒ **Need: Shift availability metrics towards experiment-focused quantities - could AI help?**

# Conclusions

- **AD/ELENA keeps pushing peak performance to unprecedented pbar flux**
  - Happy users! and **more stability wanted!**
- **ISOLDE keeps expanding its nuclides reach**
  - Thanks to flexibility, flexibility, flexibility.... and even **more flexibility wanted!**
- **AWAKE pushes the high gradient limits**
- **CLEAR offers unique opportunity for testing (automation) concepts, even during LS3**  
⇒ Both AWAKE and CLEAR are **upgrading to align with future accelerator community needs**

- **Key Takeaways:**

- **Overall:** Facilities continue delivering unprecedented results, with **positive user feedback**
- **Challenge:** Small facilities relying on **individual commitments** and **limited support**
- **Progress:** **Performance dips** are being addressed by **resolving longstanding limitations** and **improving mutual understanding**
- **Key for success:** The future relies on the **collaboration among all of us !**



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# APPENDIX

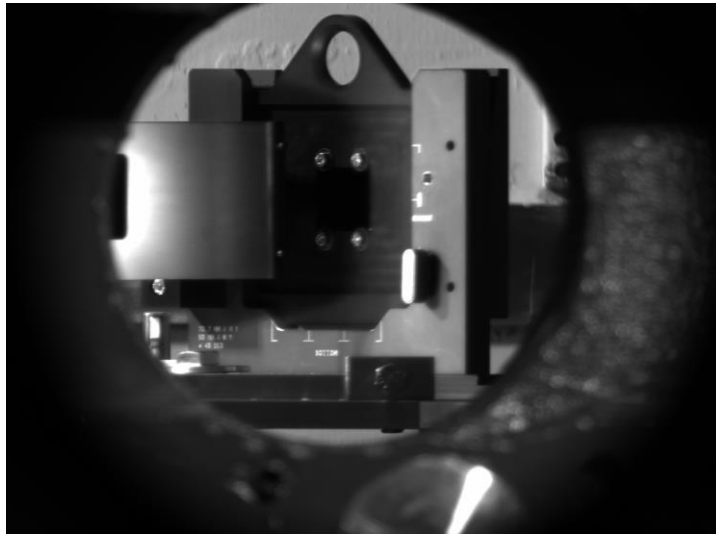
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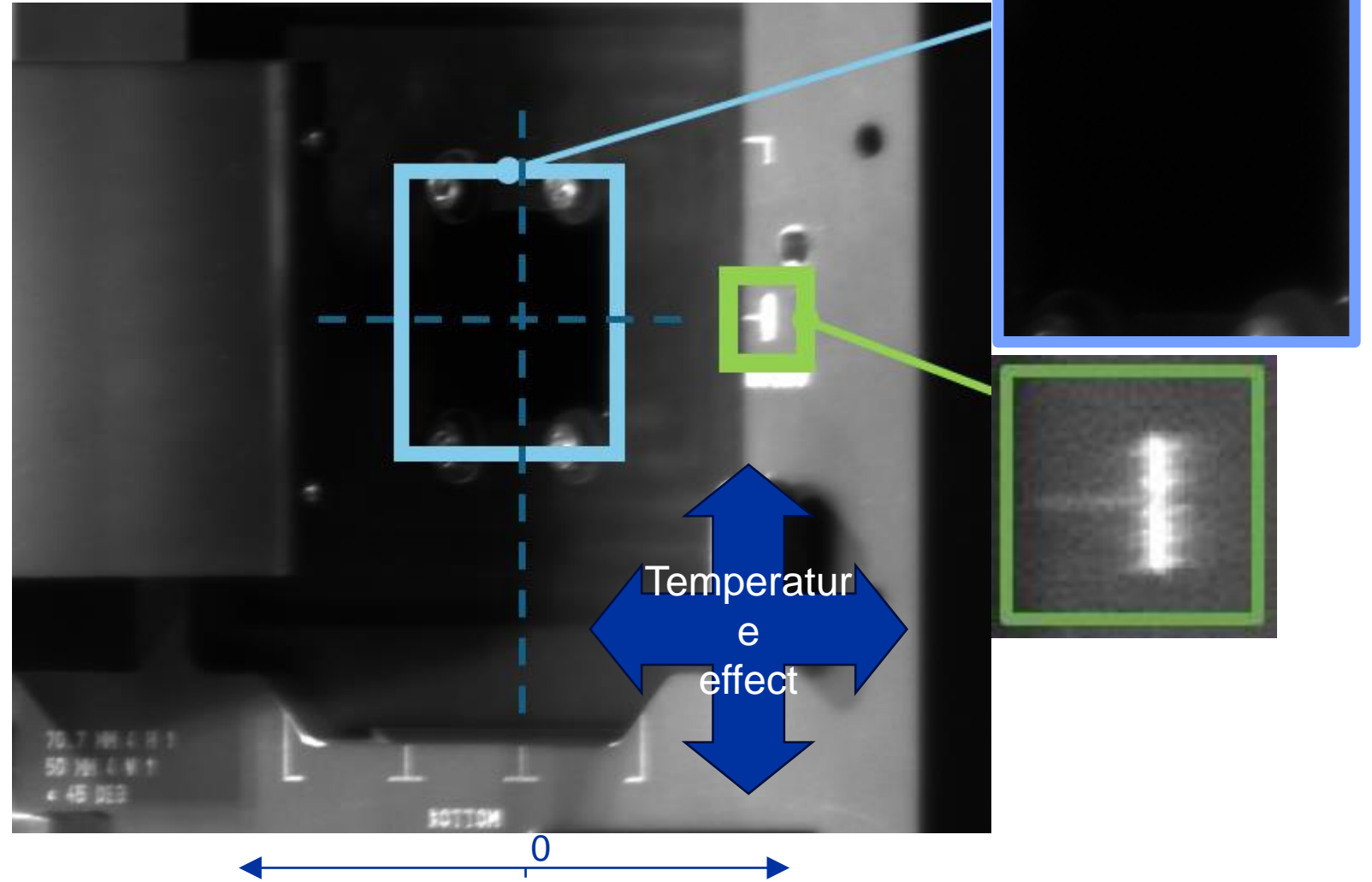
# AD/ELENA

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# AD Target BTV stability issue



*Calibration was fixed  
Image was 'moving' H & V  
→ Creates  $\Delta$ offset H & V while  
processing the position*

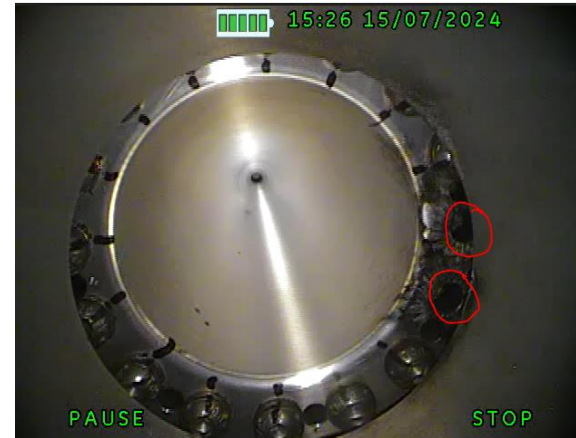


*Courtesy S.Burger, J.Martinez Samblas, M. Gonzalez-Berges, Y.Dutheil*



# Magnetic Horn July-August 2024 Failure and response

- **July-August 2024 failure timeline:**
  - Initial horn flashover in mid-July
  - Decrease from 7 to 5 kV resulting in a 5% decrease in antiproton yield
  - Final degradation on the 8<sup>th</sup> of August
  - Horn exchanged on 13<sup>th</sup> of August
- Failure mode: screws loosen before creating an electrical arc
- **Crisis response:** adapted a spare horn to include quick upgrades based on sensible electromechanical engineering practices:
  - Removal of interference areas
  - Implementation of improved anti-rotation devices
- **Challenge:**
  - Extremely complex system **demanding a fundamental understanding** for the development of a design that is reliable in the long term
  - Many solutions could be envisaged, also profiting from experience at other laboratories (FNAL, KEK) but they demand:
    - Development of reliable models
    - Thorough testing on surface test bench



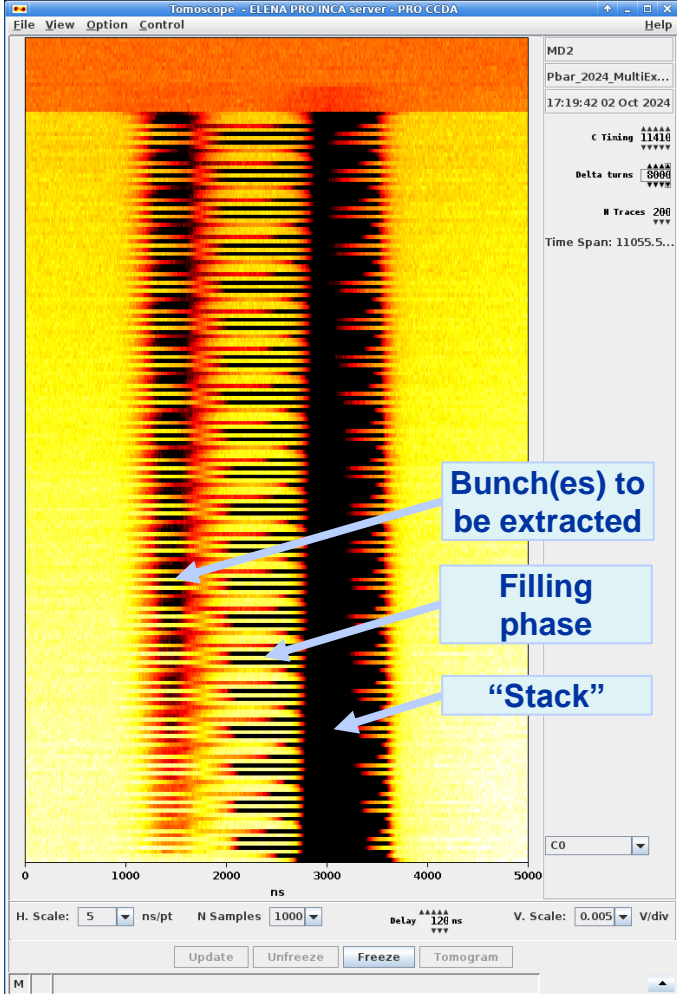
CONS request submitted

Courtesy of Nicola Solieri

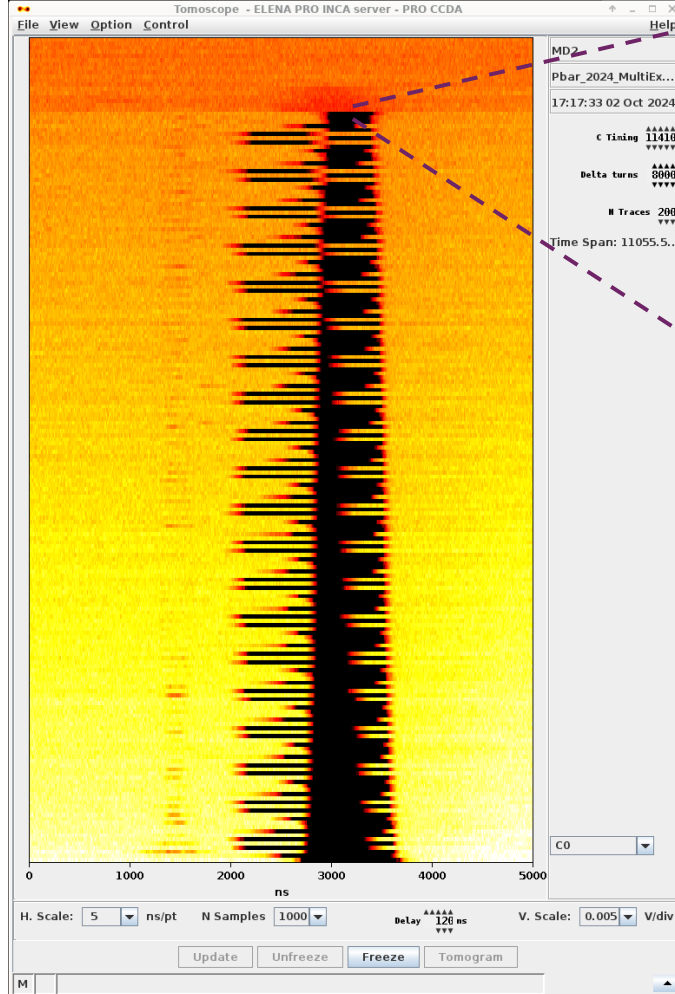
# Multi-Mini-Bunch Extraction (MMBE)

- Producing and extracting 100 pulses (one every 100 ms, for 10 s)

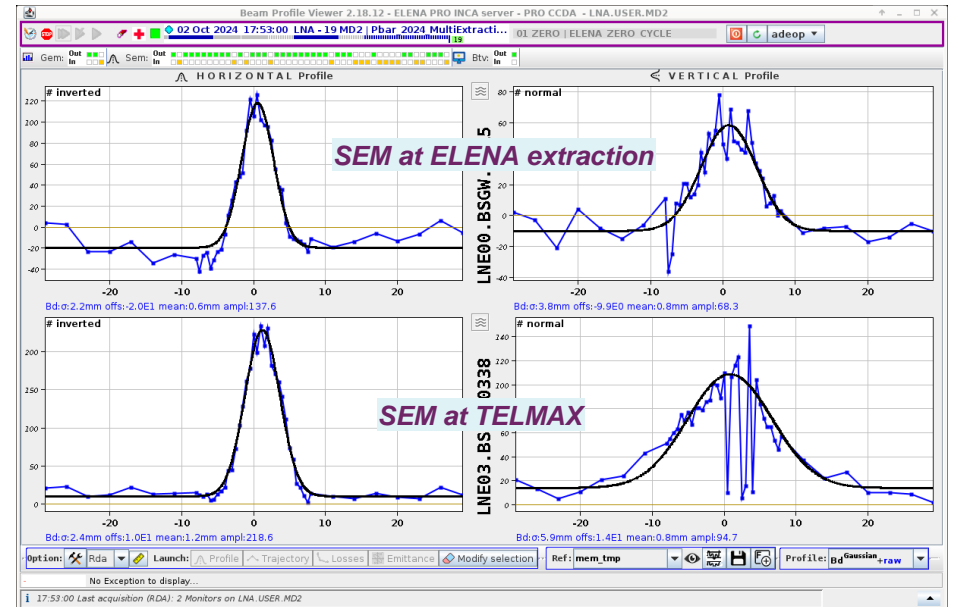
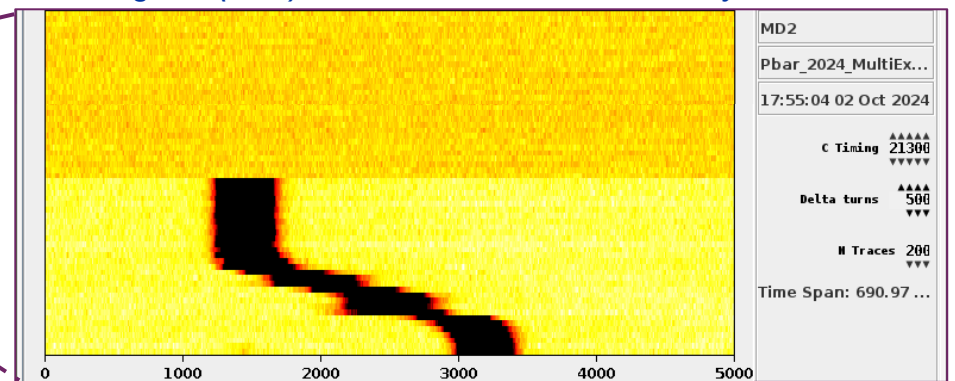
Repeat 100 times with pbars, no extraction



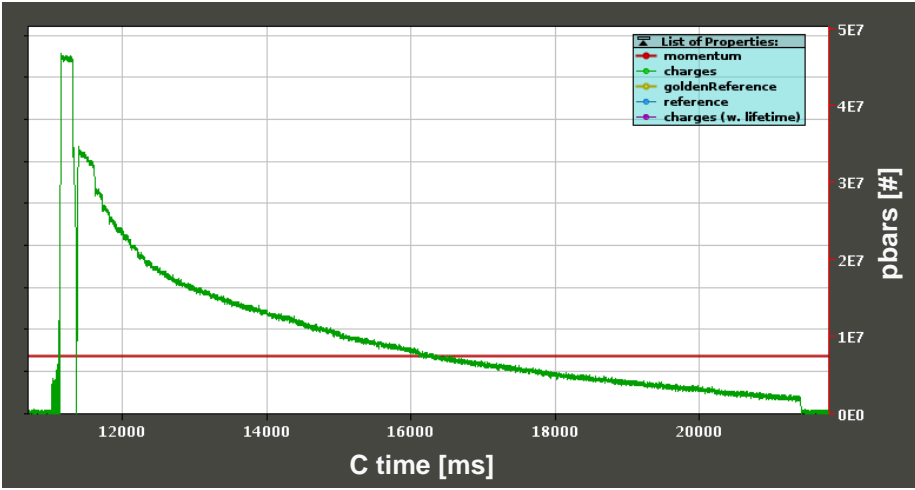
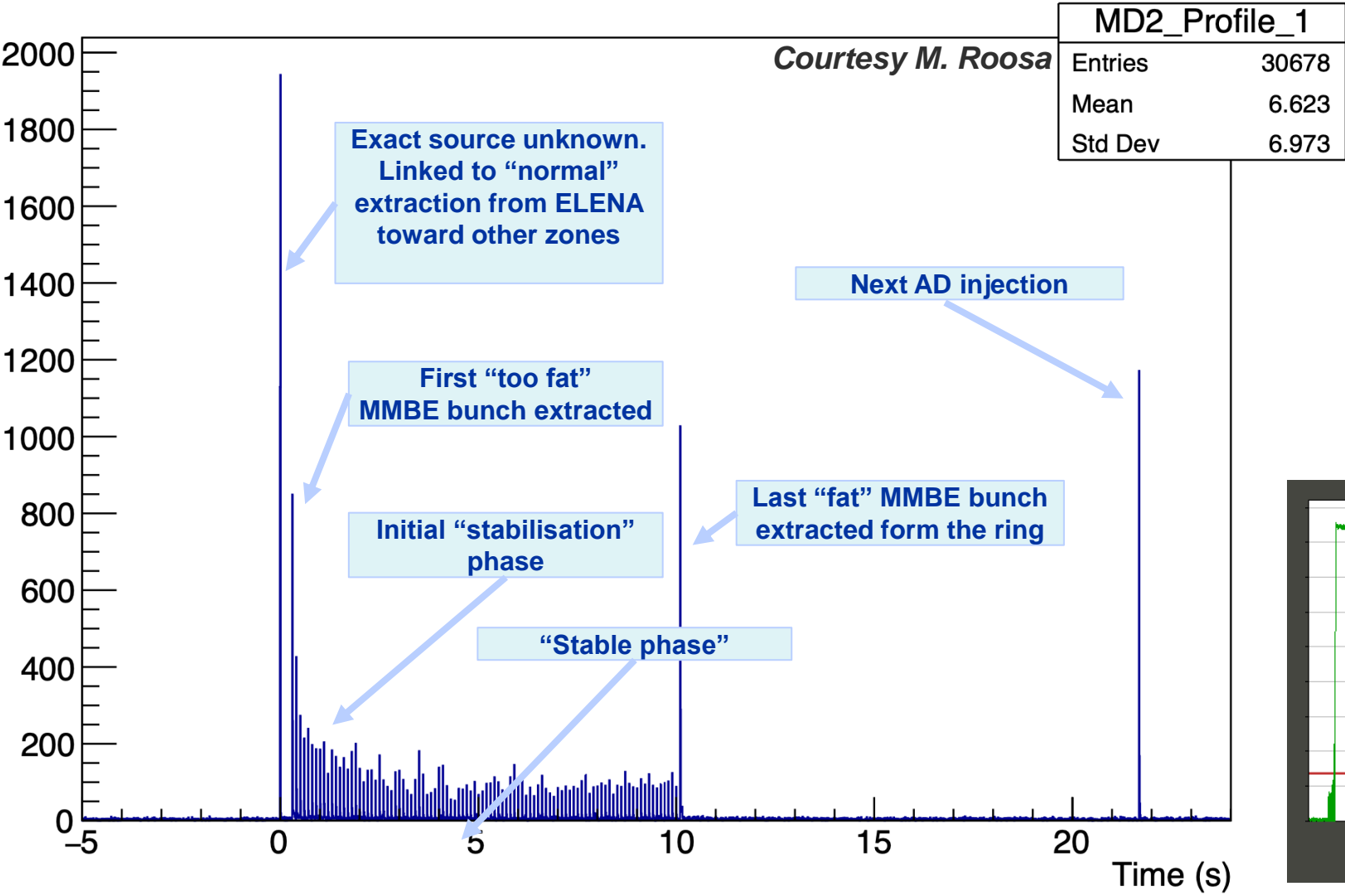
Extracting all 100 bunches



Extracting final (100<sup>th</sup>) bunch with full remanent intensity



# MMBE: what is seen by users in TELMAX





# AD/ELENA User Requirements

**Challenges:** most AD experiments face issues **after the handover point** due to ultra-precise, non-destructive investigations at sub p.p.t. levels

**Physics needs: stable pbar beam conditions** for antihydrogen and pbar-He experiments

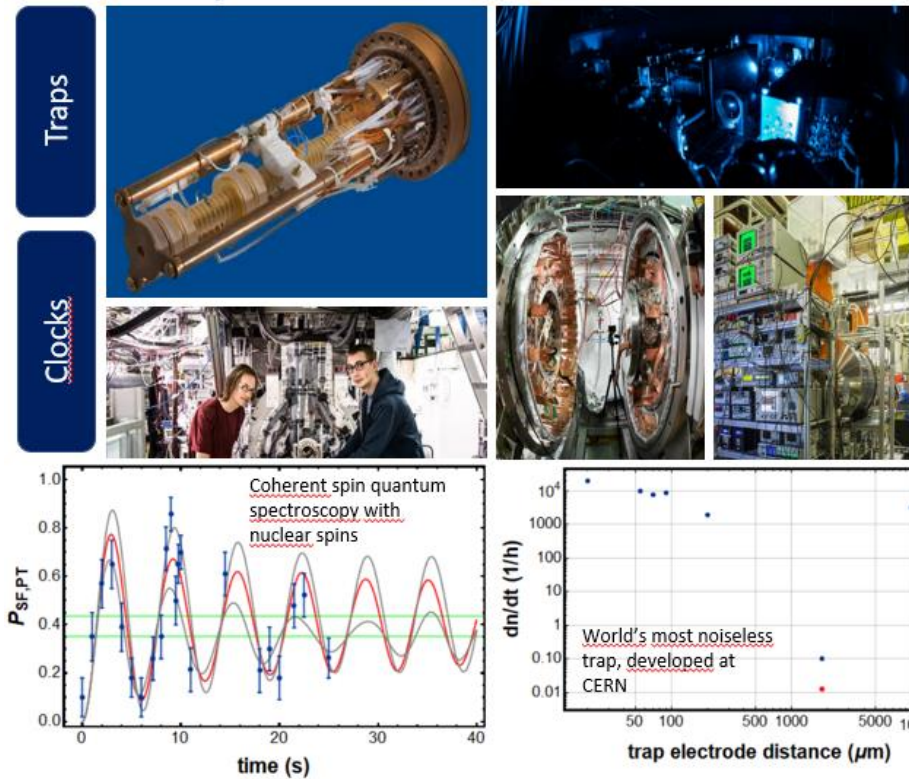
**Shutdown needs:** Some experiments require **CALM YETS periods**

**Support request:** Maintain offline operation and full technical support during LS-X periods, including ELENA H<sup>-</sup> operation in dedicated periods

## Future:

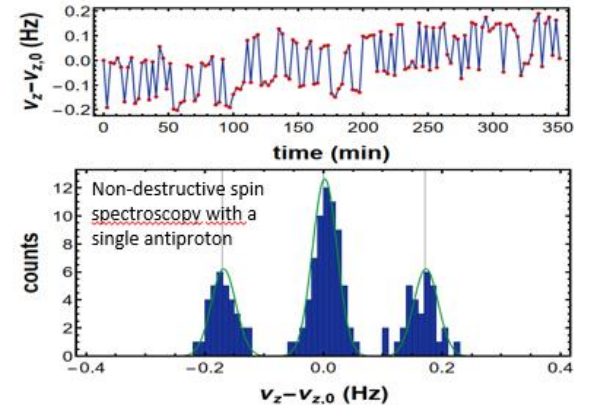
There is potential for **another 10 years** of meaningful physics experiments under the **current beam conditions**: potential of **ELENA is still being harvested!**

- To resolve some experimental results with even higher accuracy (p.p.t.), **some users** would find operation at **lower energy attractive** (e.g. 80 keV for GBAR and antiprotonic helium).
- In far future (>2035), there might be proposals that deal with **anti-deuterium** (NOT NOW).



## Innovation and Technology

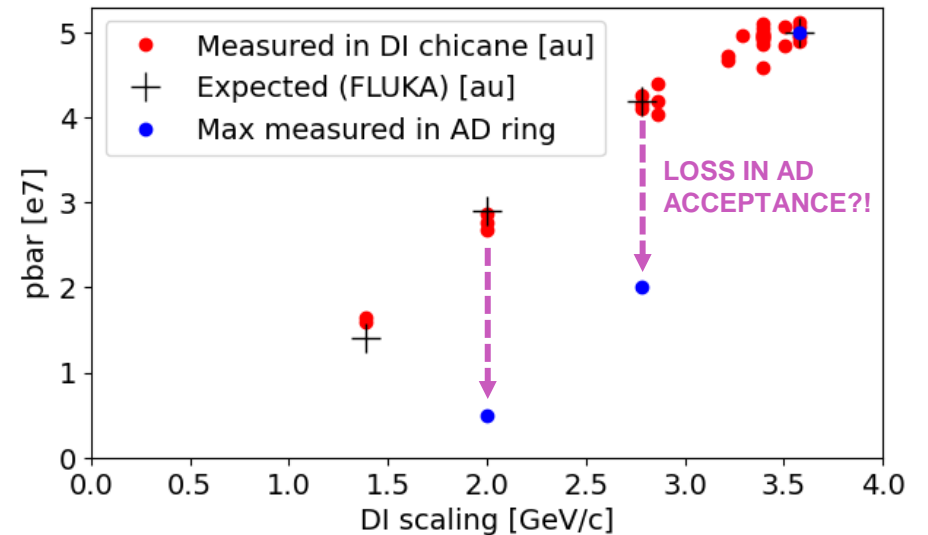
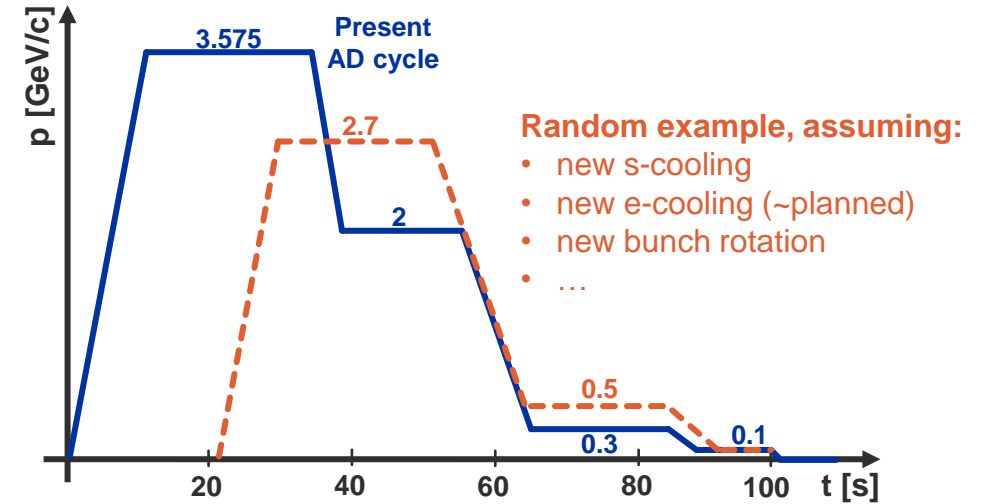
- Antihydrogen traps
- Advanced Multi Penning trap systems
- Ultra-stable ultra-high power lasers
- Transportable antimatter traps and reservoir traps
- Coherent, quantum limited spectroscopy schemes**
- Future: Quantum Logic Spectroscopy**



Courtesy S. Ulmer – ADUC Chair

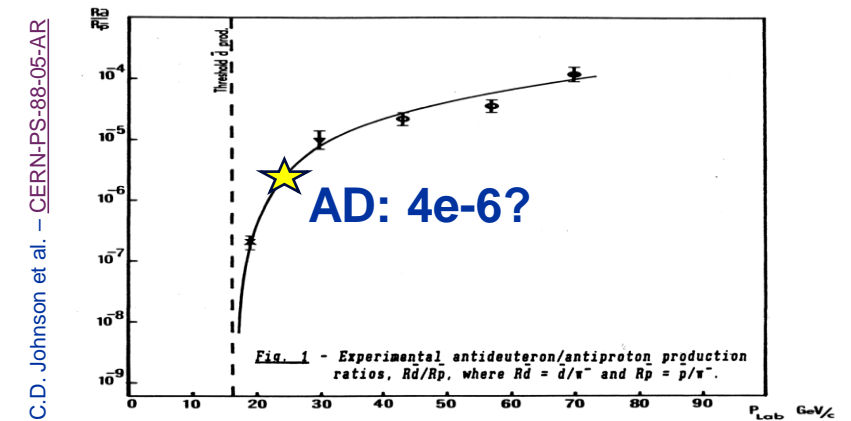
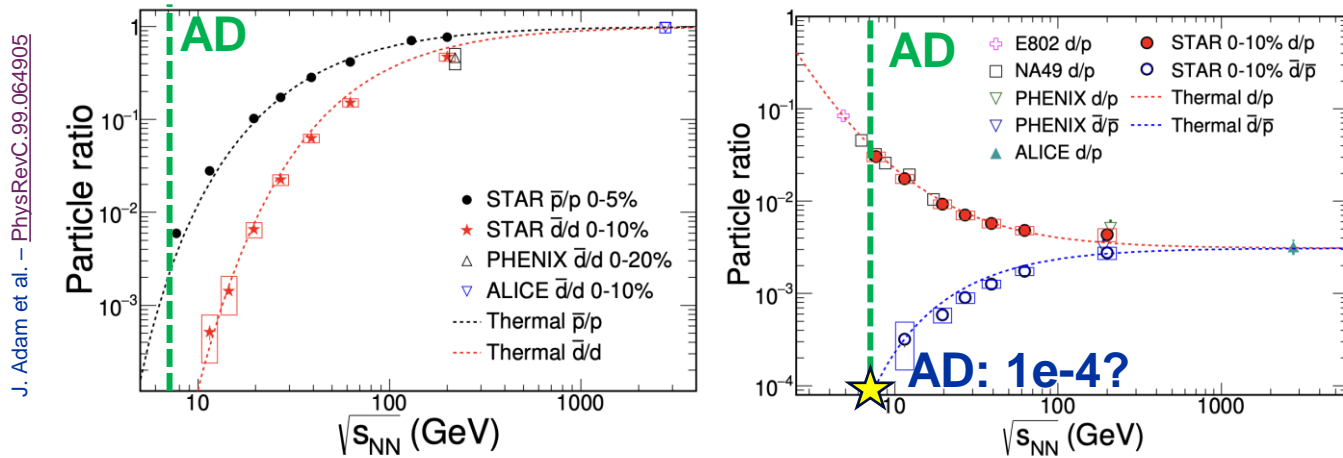
# Simpler/Shorter AD cycle for Fixed pbar Flux?

- 3.575 GeV/c was chosen to optimize accumulation at AA/AC times
- A new AD-like machine could be optimized differently with fix pbar flux, e.g.:
  - minimise energy use
  - simplify the cycle structure
  - ...
- **Significant impacts** on s-cooling, bunch-rotation, and RF systems.
  - However, it's a good opportunity to **profit of anyway necessary consolidations**
- Ongoing tests useful for:
  - Benchmarking AD target FLUKA models
  - Potential antideuteron search



# What about Antideuteron?

- Maybe possible to have ~10 to ~1000 antideuteron at AD injection already today ?!



- So far, not possible/being able to detect antideuteron in AD ...
  - Informally exploring the feasibility of a single-particle Resonant Schottky detector in AD ...
  - Still, assuming they could be decelerated/trapped, would those numbers be interesting?
    - **Note:** even if dbar found, s-cooling and RF systems will require key modifications to allow deceleration!
- **A new target and/or full facility might be required:**
  - A question that would need to be addressed to relevant strategic bodies beyond AD/ELENA ...



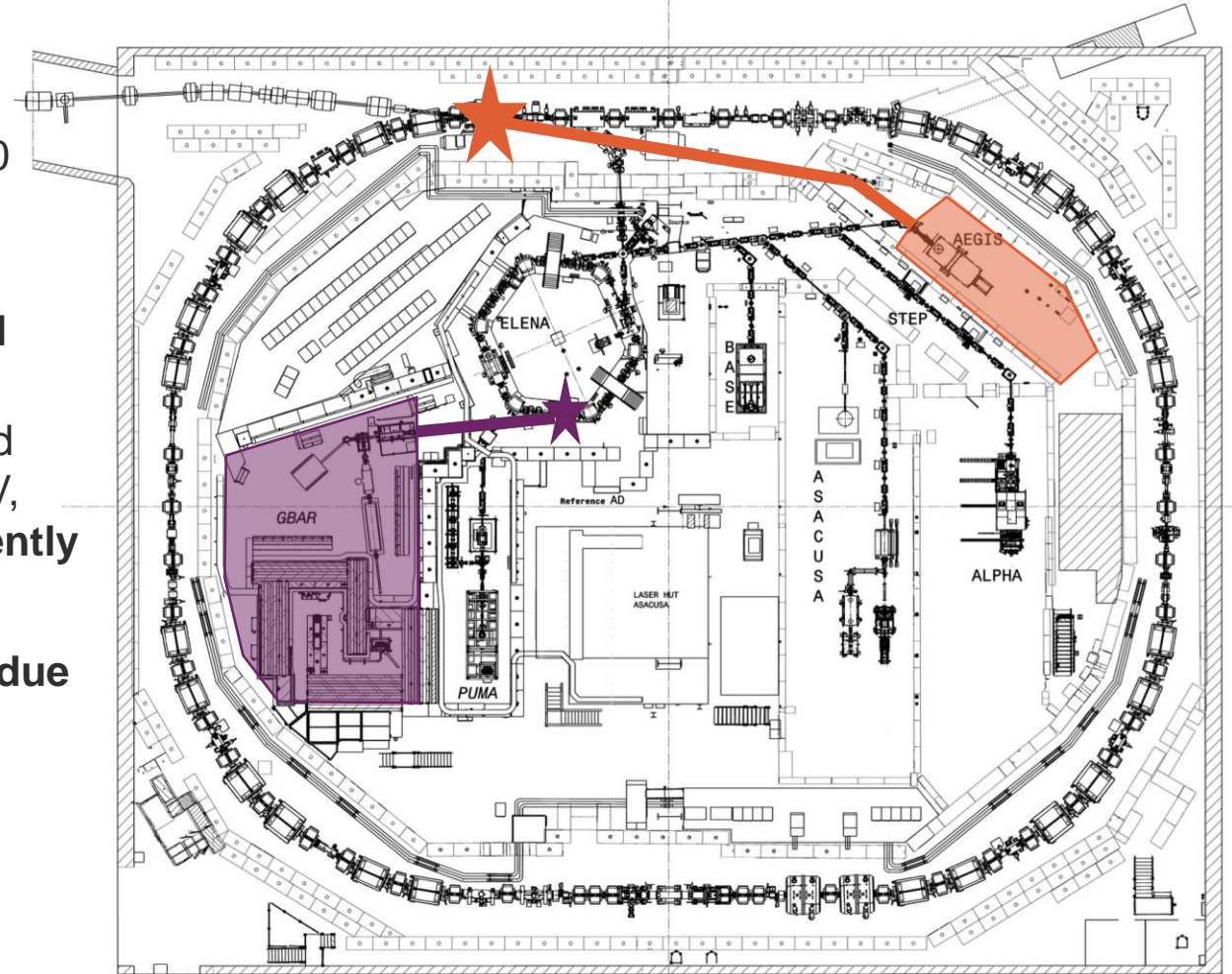
# Slow Extraction from ELENA and/or AD?

Courtesy Y. Dutheil et al. – CERN SY-ABT

- **Note:** In concert with experiment requests at the time, the **ELENA ring wasn't designed for slow extraction and no studies** were done for this
- **Presently bunched beam is fast extracted**
  - 500 mm long device with 400 mm plates provides ~ 40 kV.m integrated field to achieve 220 mrad deflection
- **Resonant slow extraction from ELENA** with an electrostatic septum blade to provide continuous spill from ~100 ms to >>1 s **might be possible**
  - Drop-in replacement of present extraction device could reach extraction **up to 450 keV** with a voltage of 10 kV, although **transport** to an experimental area is presently **limited to ~100 keV**
- **Slow extraction from the AD ring may be challenging** due to higher energy and limited space on the ring lattice

**Note 1: Activities need to reach CERN approval before significant resources can be allocated!**

**Note 2: Already done/planned within experiments at very low energy (a few 100 eV) ...**





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# ISOLDE

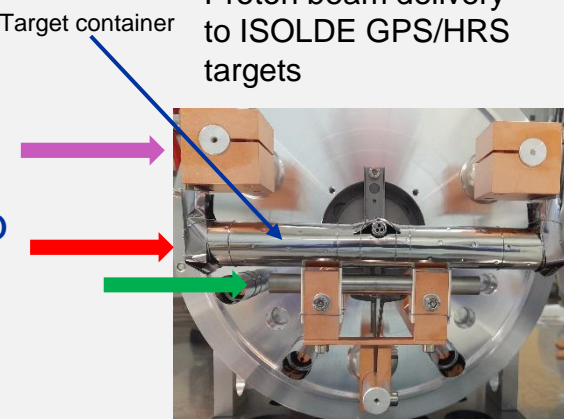
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# ISOLDE: proton beam optimizer using RIB signal

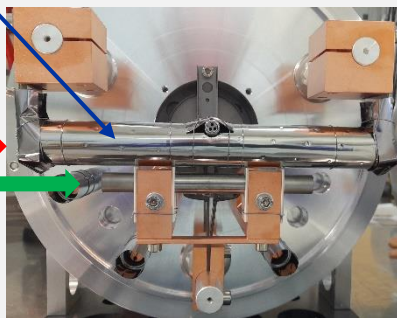
- Radioactive ion beam (RIB) production at ISOLDE strongly dependent on p-target interaction
- Conceptually, an interesting task for an optimiser – discussions ongoing

Target container

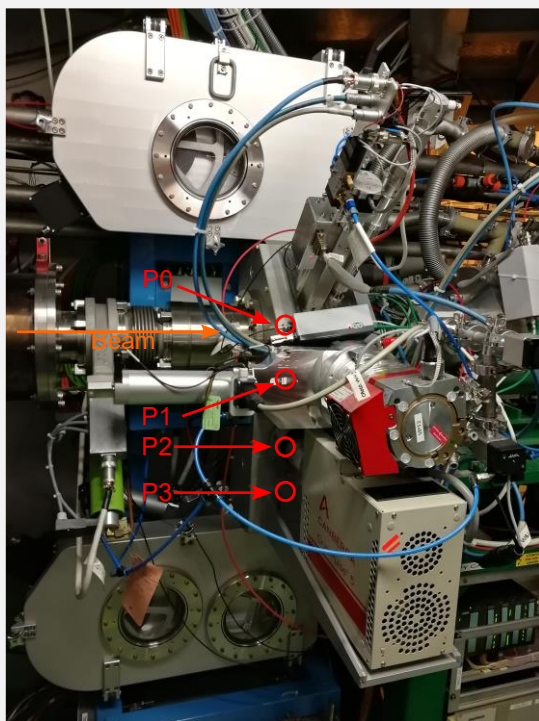
Proton beam delivery to ISOLDE GPS/HRS targets



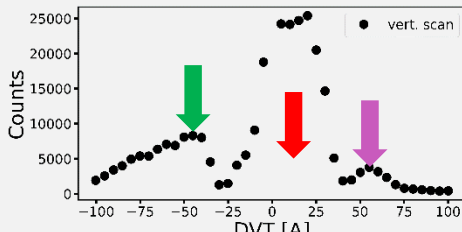
p



Fast tapestation: RIB-beam quality control via decay spectroscopy

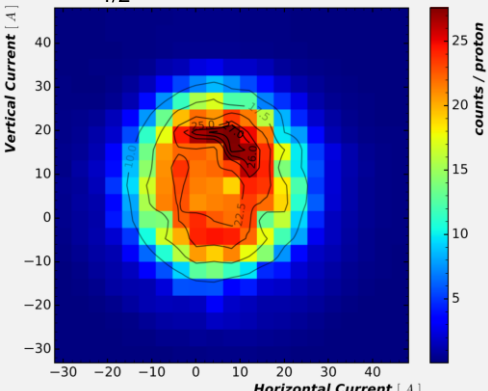


P-beam alignment on target

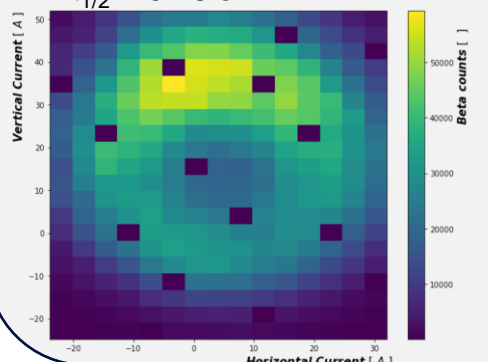


BTY.DVT214/324

$^{26}\text{Na}$  1.4 GeV 1E13 ppp  
 $t_{1/2} = 1.07$  s



$^{9}\text{Li}$  1.4 GeV 1E13 ppp  
 $t_{1/2} = 0.18$  s



- 2D proton scan on target container
- Different optima depending on isotope ( $t_{1/2}$ )
- Proton settings depending on isotopes?
- Use beam optimizer algorithms to tune both RIB- and p-beam-line?
- Use RIB signal as variable for beam steering?

Courtesy of Simon Stegemann on behalf of the SY-STL-RBS section

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# AWAKE

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# SPS-AWAKE Availability Metrics - details

## Operations/Remarks from July run

Week 24	M	T	W	Th	F	S	S
SPS extractions	140	234	e-beam	Par-MD	34	1155	396
Hours of beam to AWAKE	1.3	2.2	e-beam	Par-MD	0.4	6.9	2.6
Hours requested	1.3	3	MD	Par-MD	8	8	3

Week 25	M	T	W	Th	F	S	S
SPS extractions	240	1102	MD	Par-MD	781	264	543
Hours of beam to AWAKE	1.9	8.4	MD	Par-MD	6.5	1.7	3.3
Hours requested	8.5	9.5	MD	Par-MD	8	5	8.5

Week 26	M	T	W	Th	F	S	S
SPS extractions	851	1677	MD	165	532	1185	1264
Hours of beam to AWAKE	6.1	11.9	MD	2.4	3.9	7.2	7.7
Hours requested	12.5	13	MD	4	5.5	8	13

- W24: diag checks, failure of one heater of new plungers, cavity repair on SPS, power supply of new plunger rack broke
- W25: Injector down for emergency switch pressed in Meyrin, PLC reboot on plunger rack, SPS power convert fault required piquet, ventilation failure on TAG41
- W26: CV working on ventilation the morning, INAC4 stop long + fill + unstable beam, power supply of new plunger rack broke, fire alarm evacuation needed

### General remarks:

- LHC fill is a 1Hr down time to AWAKE



24/09/2024

Michele Bergamaschi





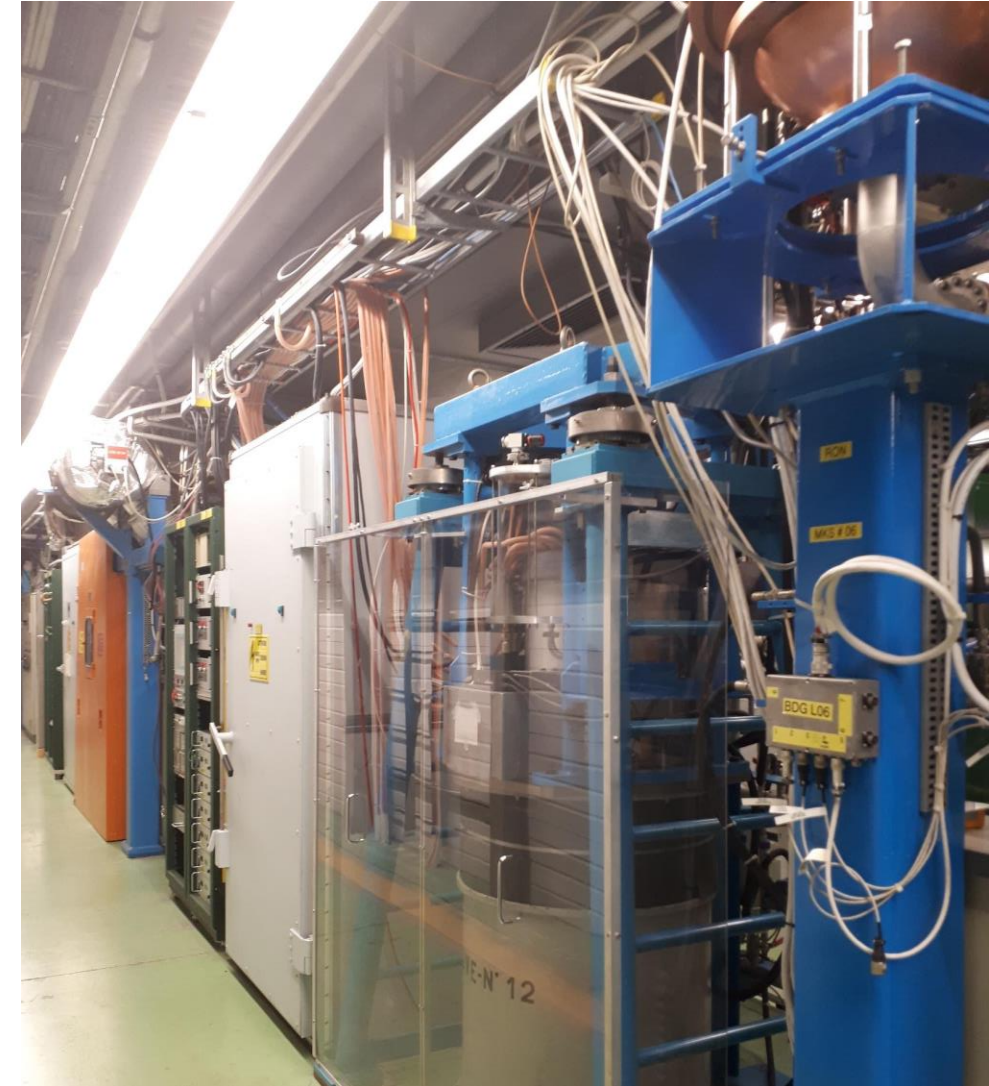
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# CLEAR

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# CLEAR: Hardware / Modelling Challenges

- **Mainly relying on old equipment from CTF3**
  - **Refurbishment** of old/spare magnets for building the new beamline
  - Reusing most of **CTF3 vacuum chambers/equipment**
  - Secured **power converters** and **cables** from CTF3
- **Main concerns with RF:**
  - **Outdated modulators** and **scarce availability of TH2100 klystrons** on the market and/or long delivery delays
    - Plans to refurbish old klystrons and maintain present modulators
  - **Outdated and fully-analogue LLRF system**
    - Still providing low jitter (ps level) triggering system
    - Exploring possibility for a digital system common to AWAKE
      - AWAKE prototype already at CERN ready for testing
- **Simple machine... for who knows it !**
  - Operation is for a large part covered by **temporary personnel**
  - Modelling/standardisation is **limited** mainly by **manpower**
  - **Efforts ongoing to implement automation, potentially using ML**



# Medical Applications

The potential use of very high-energy **electron (VHEE) beams (50-250 MeV)** for Radio Therapy (RT) recently gained interest, since electrons at these energies can travel deep into the patient.

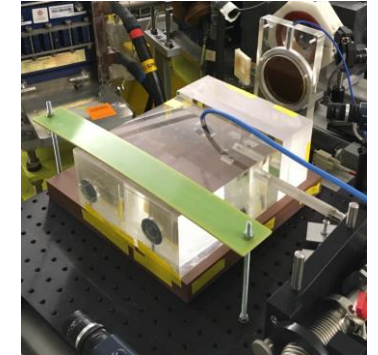
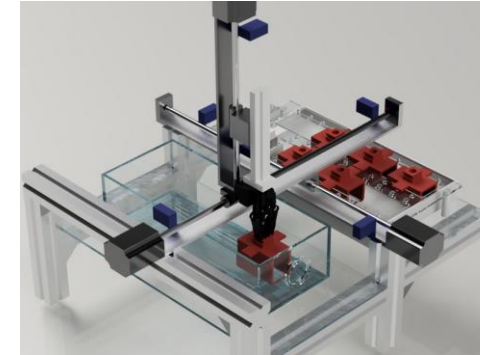
## Potential advantages of **VHEE RT**:

- Depth – dose profile for electrons better than X-rays
- Charged particles can be focused and steered (not possible with X-rays)
- Electron beams rather insensitive to tissue inhomogeneities
- Electron accelerators comparatively more compact, simpler and cheaper than proton/ion machines

This last advantage is now even more true given the recent advancements on **high-gradient acceleration (CLIC technology)**

Ultra-high dose rate (above **100 Gy/s**) radiation delivery (**FLASH**), showed normal tissue sparing, without compromising tumor control. Electron linacs can relatively easily reach **the high beam currents** needed for FLASH treatment of large fields.

More and more **existing electron linac facilities** are now being intensively used to investigate VHEE/FLASH RT



VHEE/FLASH RT studies at the CLEAR facility (CERN)

Facility	Applications
<b>ARES</b>	Accel. components, Diagnostics R&D Medical: <b>VHEE RT</b> , Electron CT Acceleration: ACHIP [29]
<b>CLARA</b>	Accel. components, Diagnostics R&D Medical: <b>VHEE RT</b> Acceleration: DWA, (P/L)WFA, THz
<b>CLEAR</b>	High gradient acceleration, plasma lens Radiation damage, Diagnostics R&D Medical: <b>VHEE &amp; FLASH RT</b>
<b>FLUTE</b>	Diagnostics R&D, THz Experiments Medical: <b>FLASH RT, Detectors</b> Machine Learning
<b>PITZ</b>	Min. beam emittance developments THz source development Medical: <b>FLASH RT &amp; dosimetry</b>
<b>SPARC_LAB</b>	Acceleration: PWFA, LWFA Radiation sources: FEL, THz, betatron

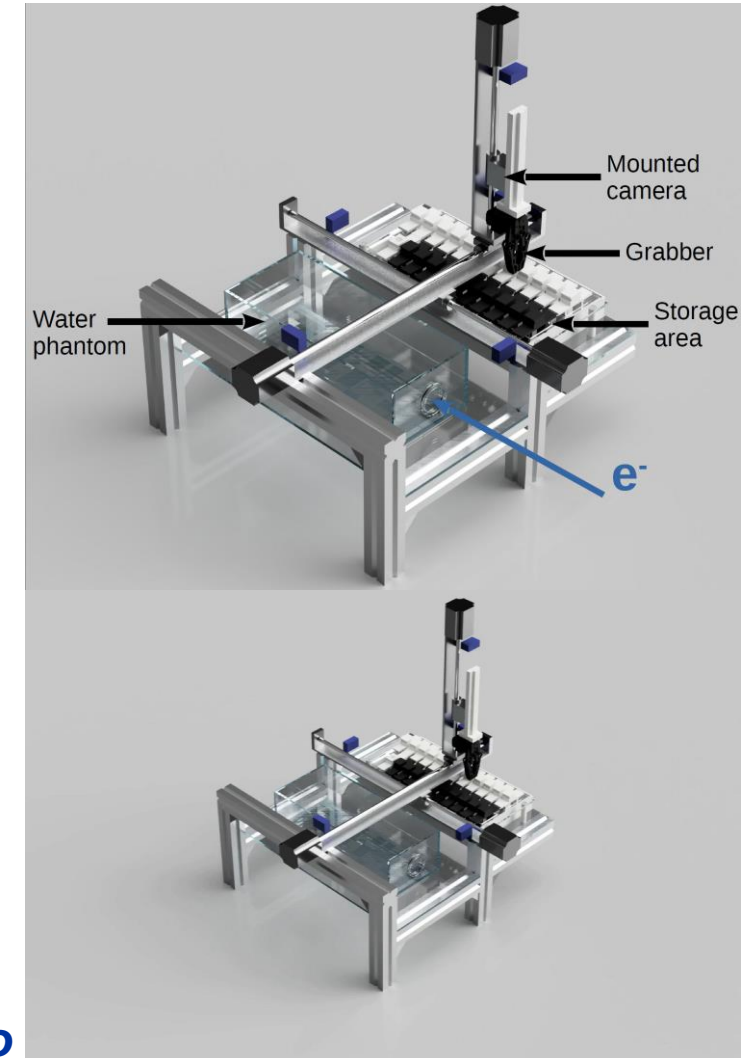
From: D. Angal-Kalinin et al., Electron beam test facilities for novel applications, Proc. IPAC '23



# C-Robot for irradiation studies



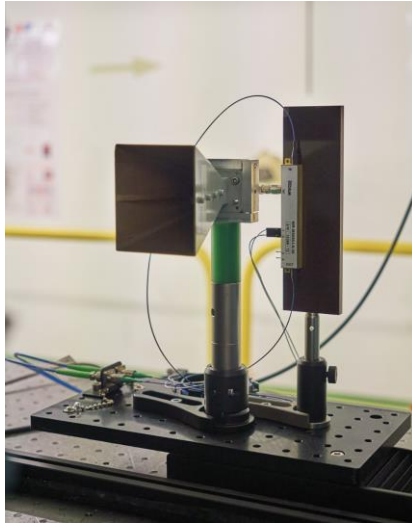
- In order to **facilitate** the **precise control** of **samples** for **multiple irradiations**, the CLEAR-Robot (**C-Robot**) was designed and built by members of the CLEAR Team
- It consists of **3 linear stages**, **6 limit switches**, a **3D-printed grabber**, **two water tanks** and an **Arduino board**.
  - It allows to have **up to 51 samples** to be irradiated
- It has a **precision in position** in 3 axis of **50  $\mu\text{m}$**
- It is **fully remotely controllable** from the **CERN Technical Network**
- Thanks to a **mounted camera**, it can also measure the **beam sizes** and **transverse positions** at the longitudinal position of the sample
- It is an **open-source project**: **pictures**, **3D renders**, **drawings** and all the **codes** for the **Arduino** and the **Graphical User Interface** can be found on:  
<https://pkorysko.web.cern.ch/C-Robot.html>
- Used for **100% of Medical Applications** in CLEAR in **2023**
- 3 similar robots are being built in **Germany** (PITZ), **Australia** (Australian Synchrotron) and **China** (IHEP)



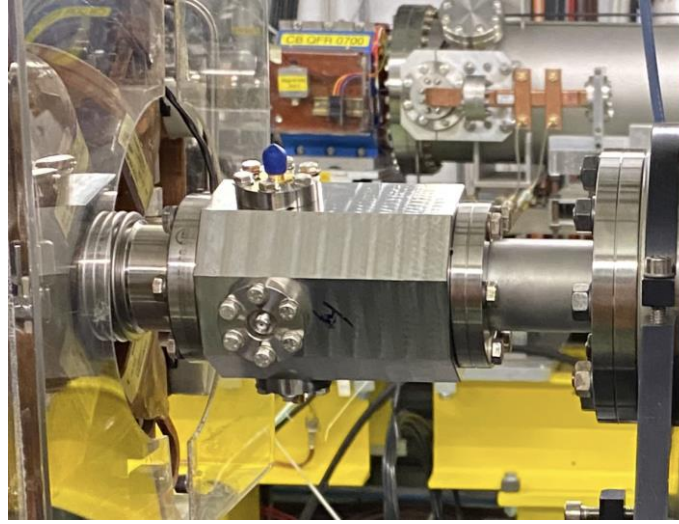
*Courtesy P. Korysko*

# Present contributions of CLEAR to FCC-ee

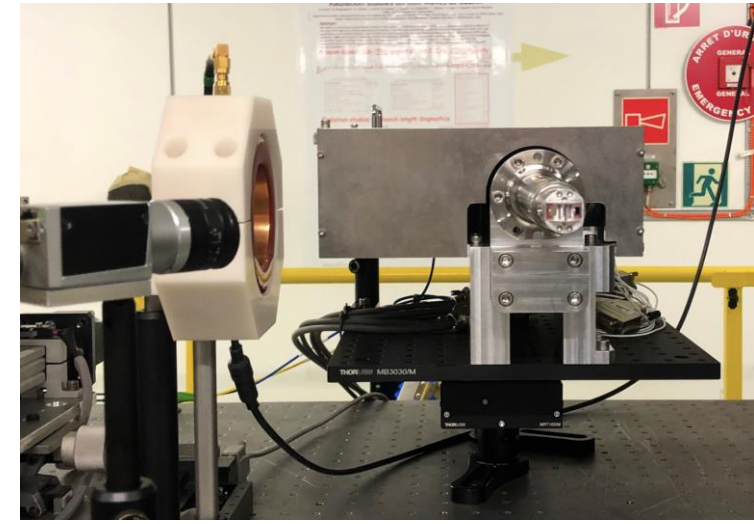
## Experiments in 2023:



Coherent Cherenkov diffraction radiation dielectric buttons (FCC-ee bunch length monitors)



Broadband Pick-up for the PSI Positron Production Project (P<sup>3</sup> - FCC-ee collaboration)



Bunch Profile Monitor for FCC-ee (KIT - Karlsruhe)

## Experiments in 2024:

- Electro-Optical Longitudinal Bunch Profile Monitor for FCC-ee (KIT)
- Coherent Cherenkov diffraction radiation dielectric buttons (CERN, BI)

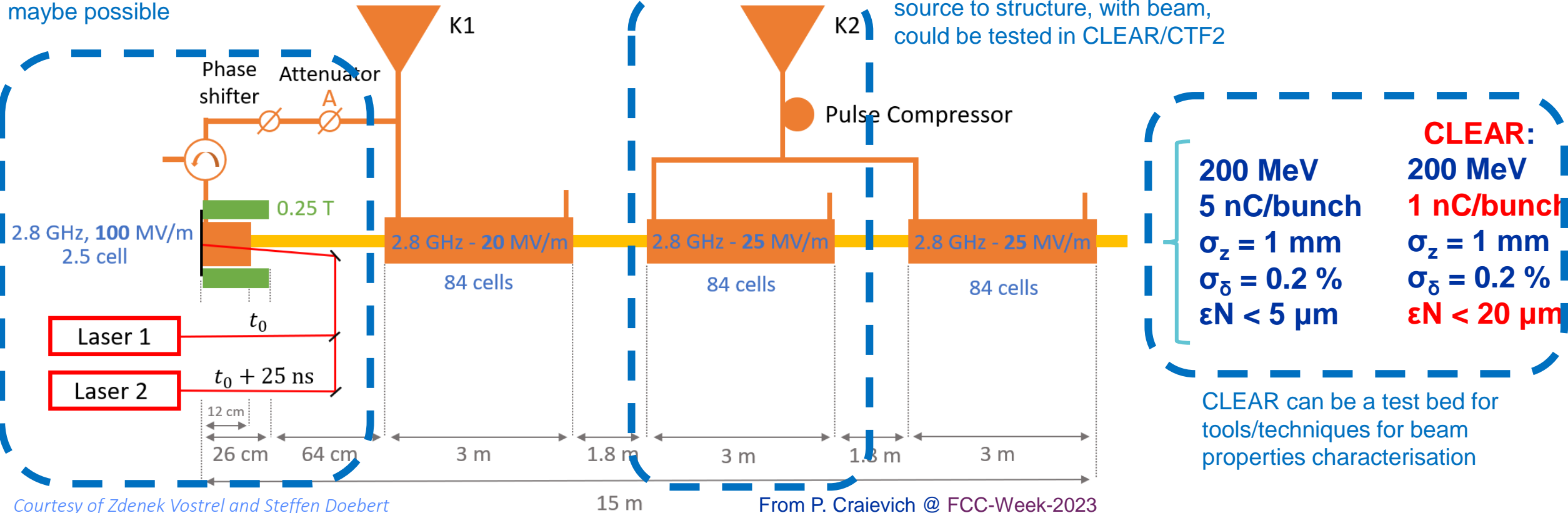
Posponed: Damage test of positron target materials (CERN, STI – M. Calviani, A. Perillo Marcone)  
⇒ discussion ongoing on future program, including positron detection, etc...

# FCC-ee Electron Source Frontend and CLEAR

- No surprise that FCC-ee front end not very different than CLEAR one
- CLEAR/CTF2 have expertise and space adapted to test prototypes of key components

2-bunches production as FCC-ee probably not possible at CLEAR, but “logics” test maybe possible

A prototype 2.8 GHz module from source to structure, with beam, could be tested in CLEAR/CTF2



Courtesy of Zdenek Vostrel and Steffen Doebert

From P. Craievich @ FCC-Week-2023