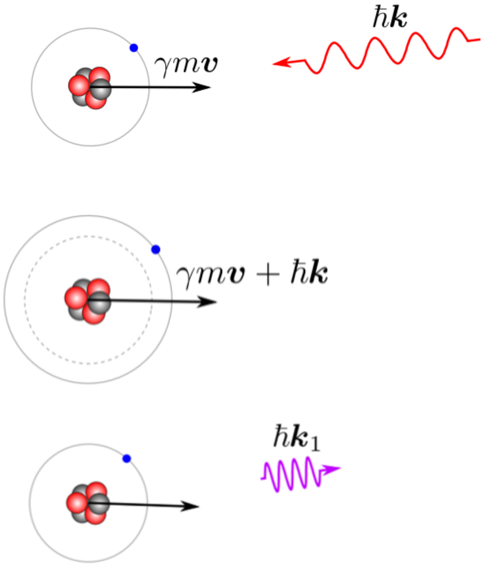
CERN

Gamma Factory SPS PoP: Status

Y. Dutheil on behalf of the PBC Gamma Factory SPS PoP Working Group

Gamma factory principle



- Excitation of partially stripped ion at high energy
  - In the ion referential the photon gets a ~2γ boost
  - The change in momentum of the ion is very small

- The excited state is very short lived
  - A photon is spontaneously emitted, isotropically in the referential of the ion
  - The boost back to the rest frame provides another ~2γ boost to forward photons

For instance

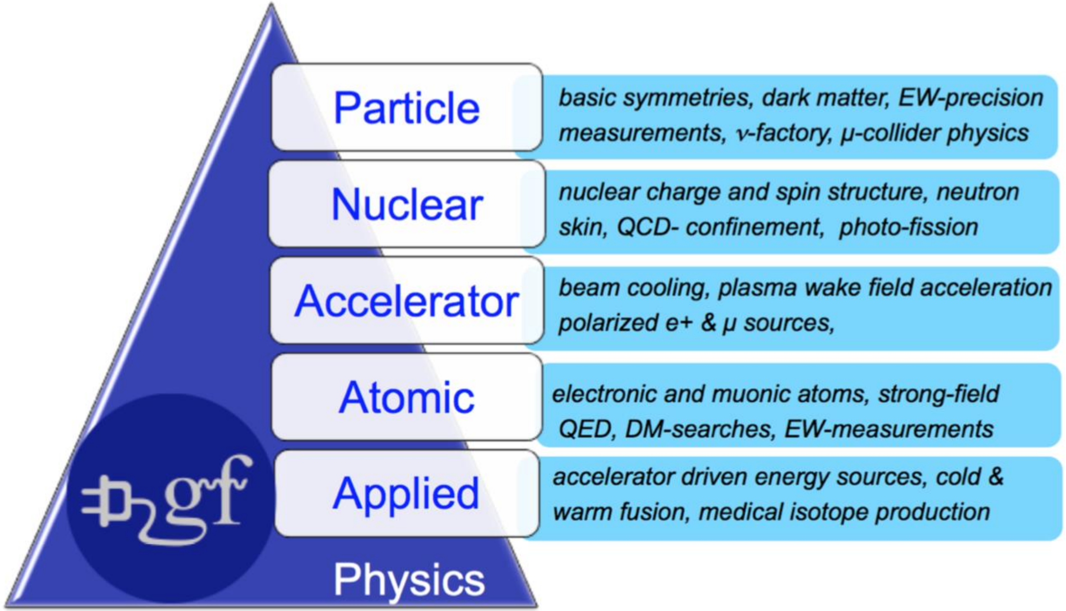
$\boxed{\text{Energy upshifting by a factor } 4\gamma^2}$

H-like Xenon at LHC (γ=3000) → 180 MeV

Li-like Calcium at SPS (γ=130) → 80 keV

Gamma context

- Wide physics prospects
- Example this afternoon with “**Gamma Factory driven subcritical reactor**” by W. Krasny



PoP objectives

- Demonstrate integration and operation of a laser and a Fabry-Perot cavity in a hadron storage ring
  - Laser commercially available but limited experience in hadron ring
  - Operation compatible with other ring users
- Benchmark simulations of atomic excitation rates
  - Modelling of laser-ion collisions requires new numerical tools
- Control of ion and photon bunches
  - Control of spatial, time and spectral overlap
- Demonstrate laser cooling of relativistic beams and investigate different approaches
  - Models show different cooling regimes depending on collision scheme
- Investigate feasibility of relativistic atomic physics measurements
  - Accurate and absolute measurement of deep electronic transition energies are highly relevant to fundamental physics

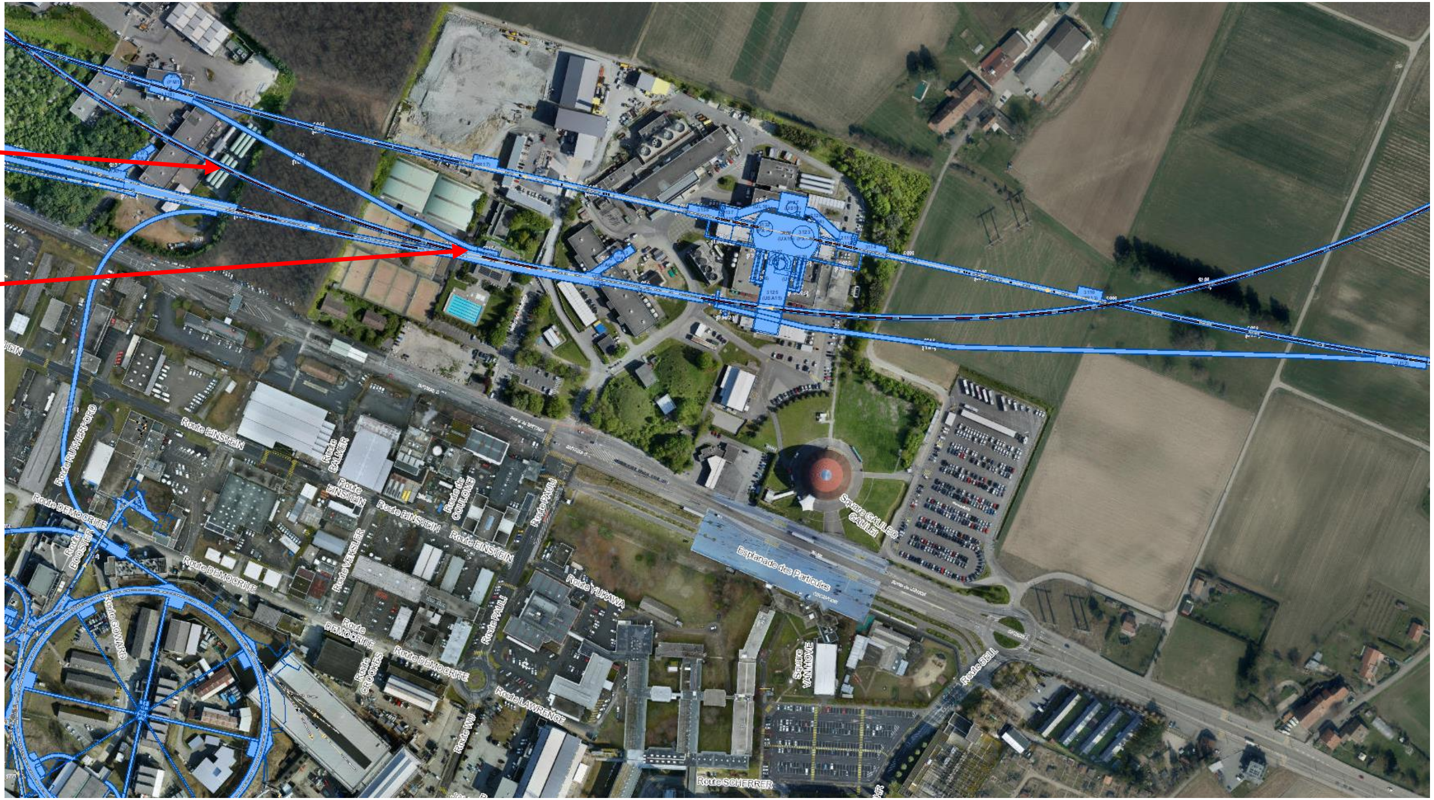
Breakthrough in accelerator physics

Unique measurement in atomic physics

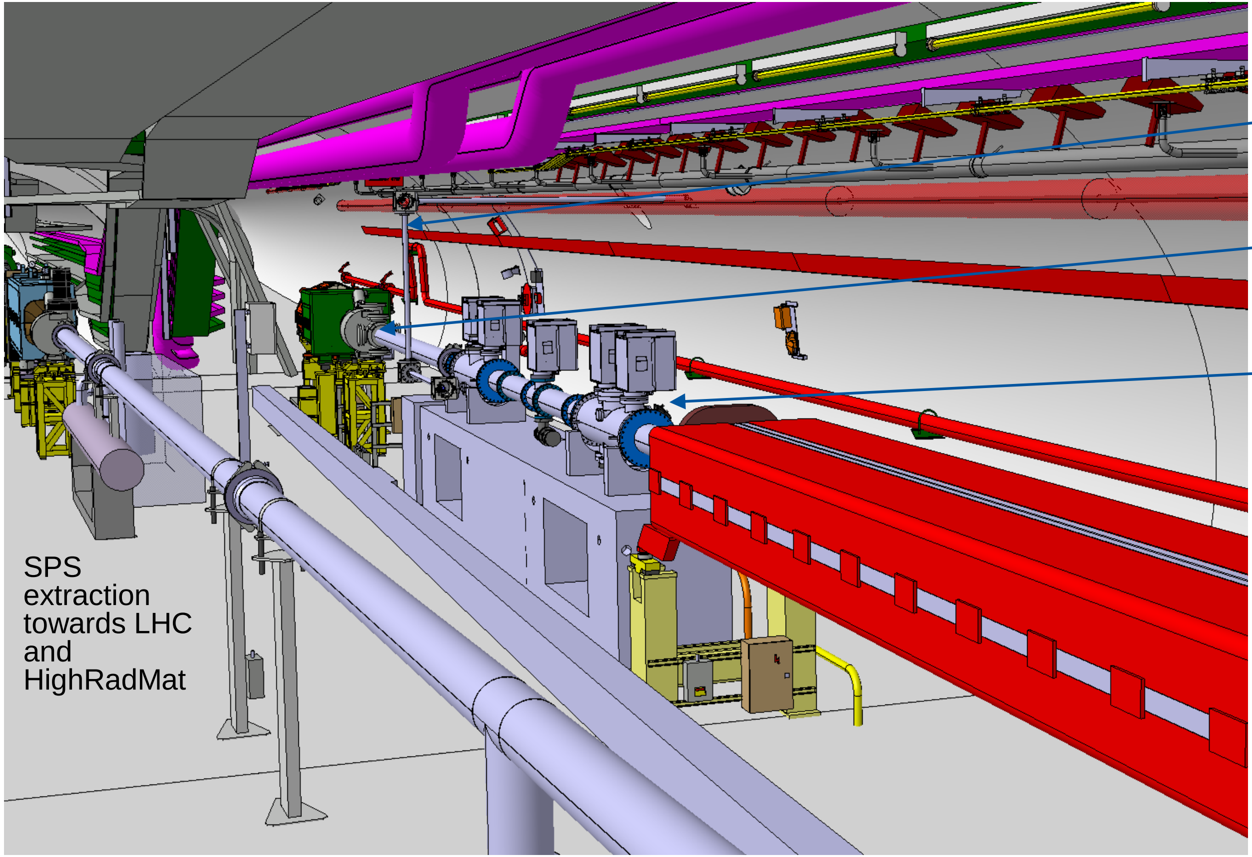
Interaction region location

SPS

PoP location



Integration in the tunnel



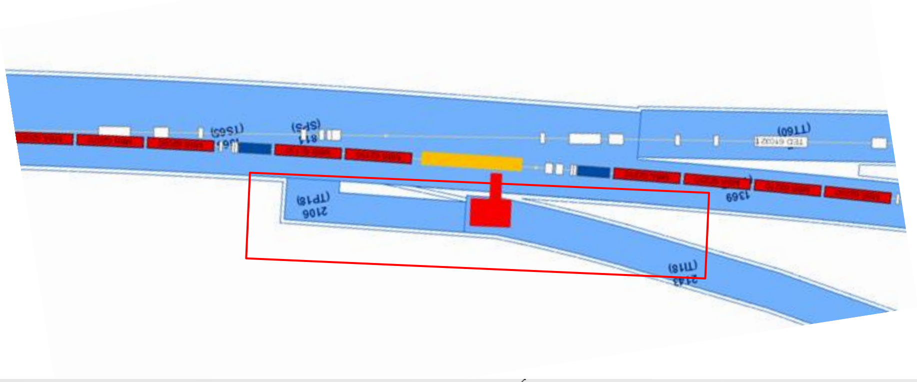
Laser transport line

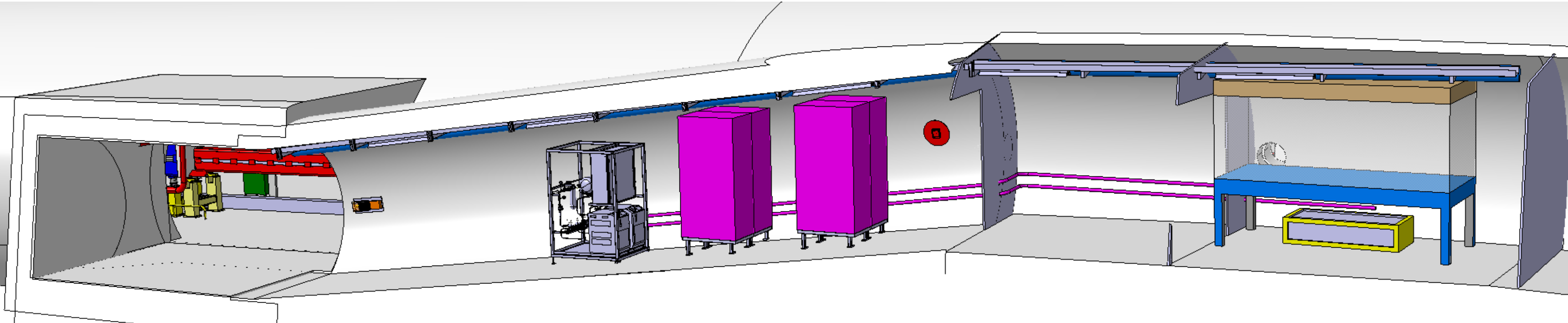
X-rays detector

Laser cavity

Upstream dipole

Integration in the SPS tunnel



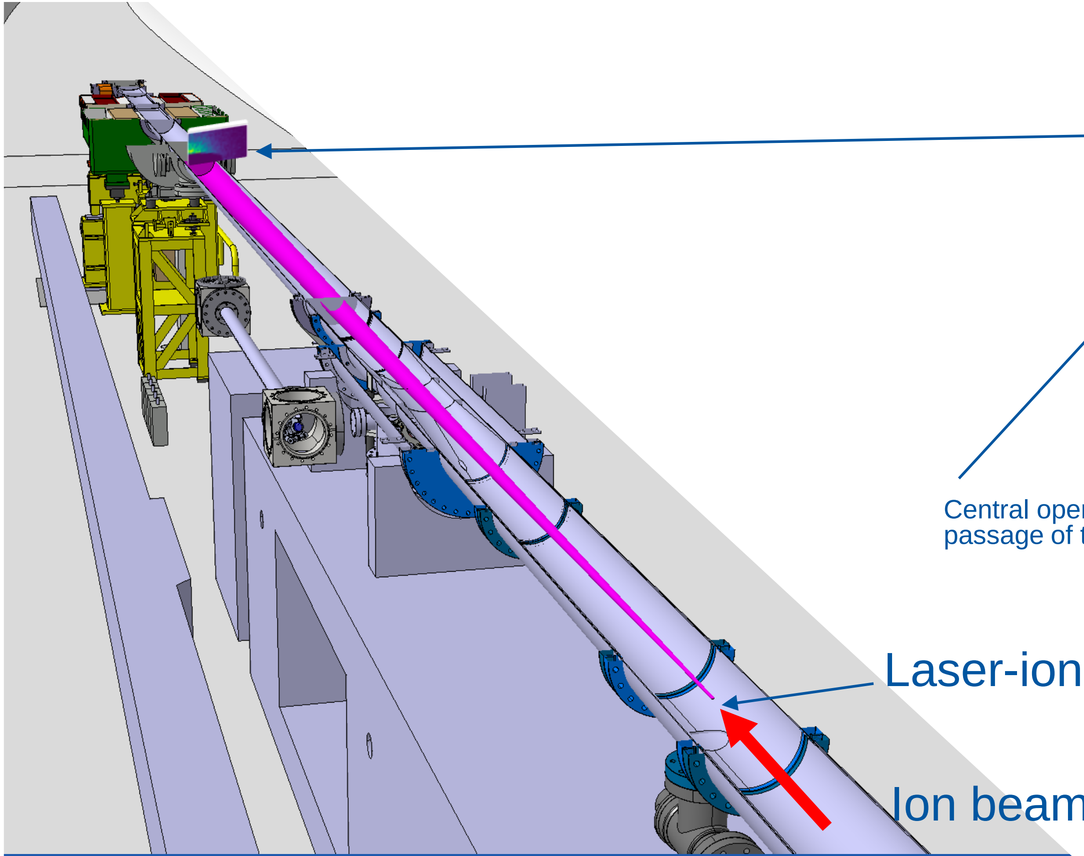


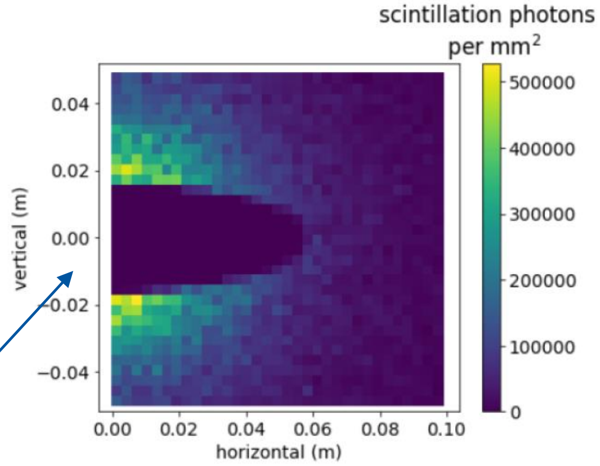
Electronics and access

Changing room

Laser room

Main goal 1: observation of Xray photons





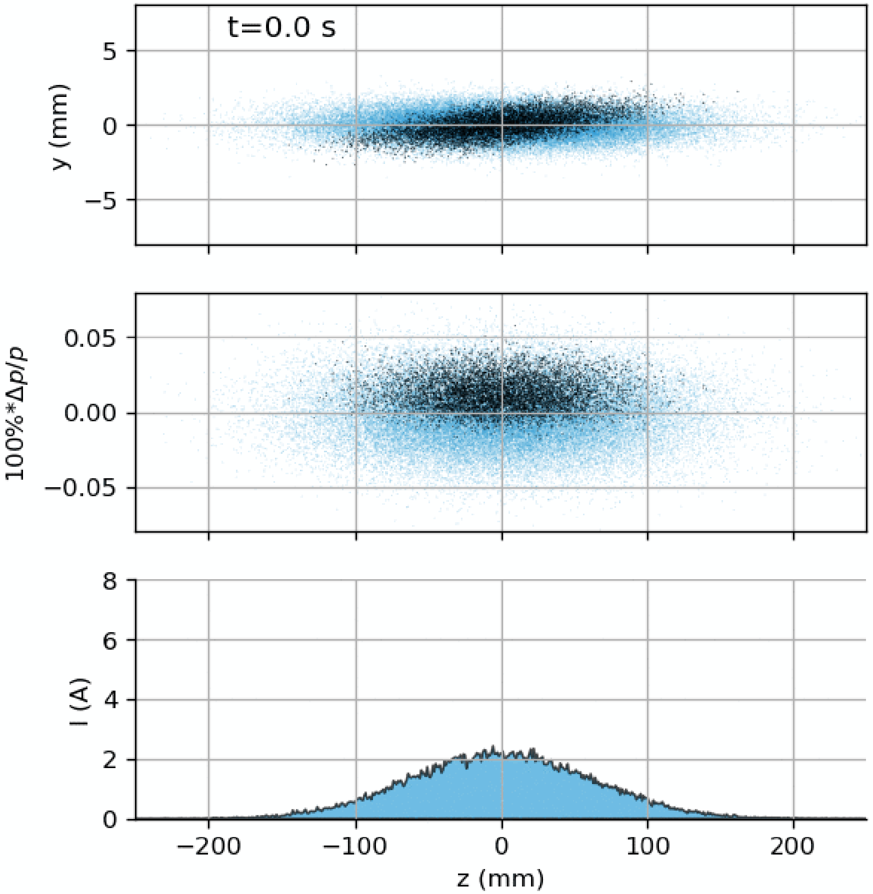
Central opening for the passage of the ion beam

Laser-ion interaction point

Ion beam direction

Main goal 2: observation of fast longitudinal cooling

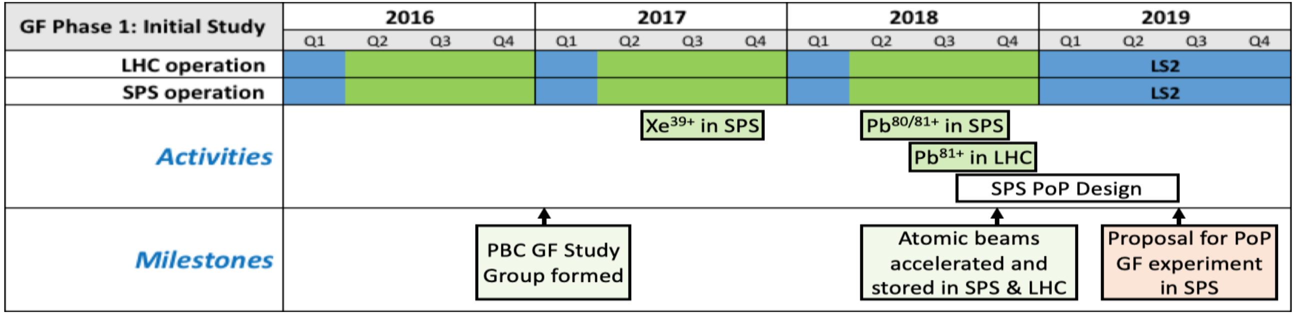
- Requires the control of the resonant conditions over long durations ~10s
  - Fast cooling is achieved when the laser only excites ions with higher energy than the reference particle
- Observed with fast increase in peak current
- Further scheme of fast transverse cooling is under investigation

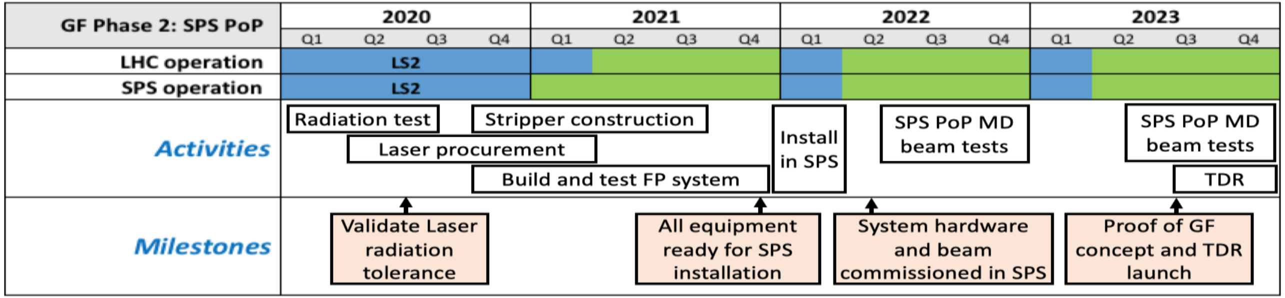


Simulation details.

Timeline plans in 2019

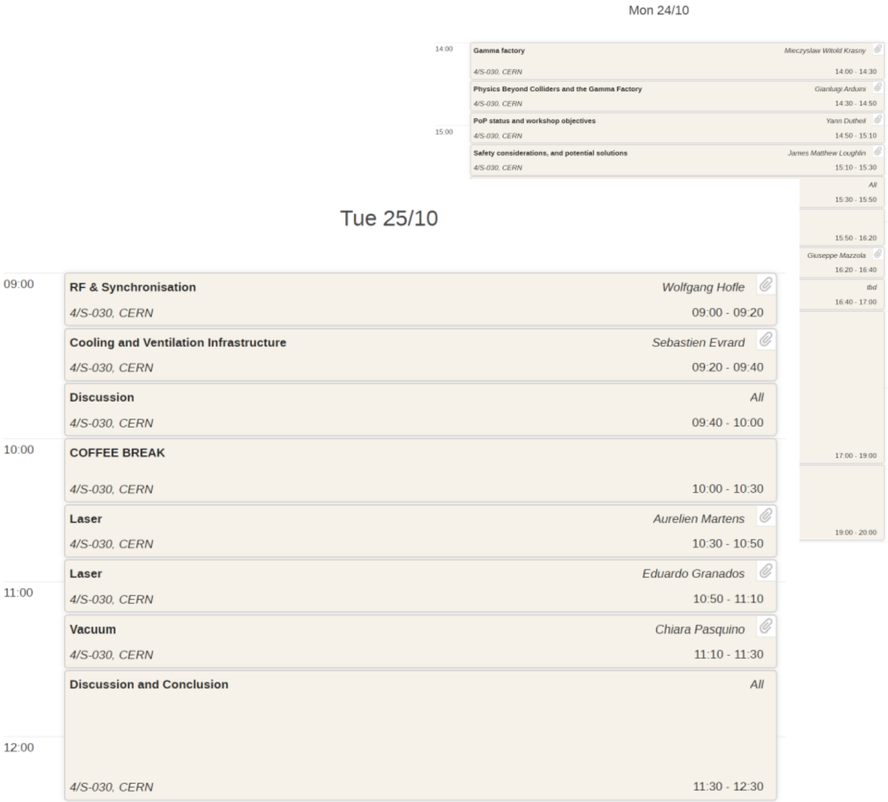
- Plans established in 2019
- LoI submitted in September 2019 to the SPSC
- Reviewed by the SPSC in October 2020





Status of the project

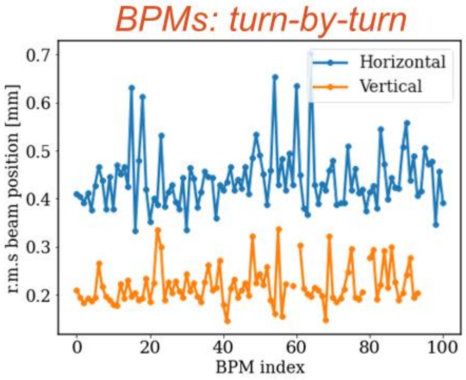
- The LoI submitted in 2019 remains our proposal but a review of the resources and timeline is needed
- Technical review of the compatibility and coherence of the different systems and associated CERN groups responsability
- Workshop held 2 weeks ago focused on the technical groups of CERN to produce a coherent implementation timeline around the LS3



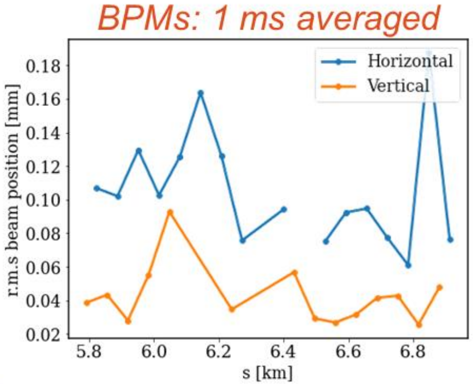
SPS MD5044 on machine stability for GF PoP

- Led by R. Ramjiawan (SY-ABT)
- Investigate the SPS beam stability and demonstrate control over the beam position at the proposed GF IP.
- Aims achieved:
  - Establishing the SPS cycle, with acceleration and 10s flat-top at 787.53 T.m (equivalent to 236 GeV for protons)
  - Study the SPS beam stability at the GF IP location on the millisecond-to-second time-scale.
  - Perform scans of the revolution frequency and, thus, the orbit radius using radial steering (±0.8 mm).
  - Perform scans of the horizontal and vertical position at the GF IP using an orbit bump (±1 mm).
  - Take data with different super-cycle configurations to compare for hysteresis effects.
- PoP requirements validated

BEAM JITTER AT GF IP
two BPM modes



r.m.s:
x ≈450 µm
y≈ 250 µm



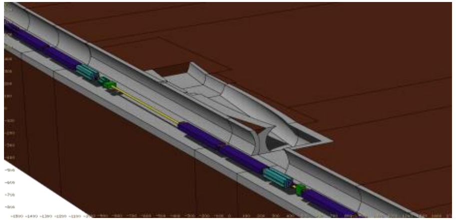
r.m.s:
x ≈100 µm
y≈ 40 µm

GF-PoP – R2E evaluations

Beam-gas interaction based source term to assess the effects of radiation to electronics during **proton run**

- The model is used to represent **conservatively** the radiation environment in LSS6 and ARC6 of SPS despite the **beam-gas interaction is not the main process** of proton losses in the studied section

- **Different detectors available** in the considered periods → The radiation profile obtained from the source assumption using different proton energies (14GeV/c and 400GeV/c) can be adapted

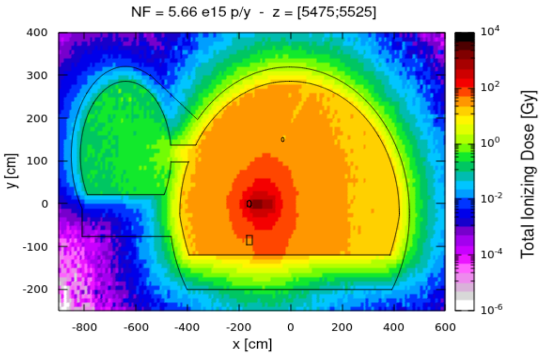


R2E quantities evaluated in the **worst case** analyzed - 400GeV/c proton - and **rescaled** through measurements fit

- **Limits of radiation-safe area for electronic system:**
  → $3e6\ High\ Energy\ Hadrons/cm2/year$
  → $3e7\ Thermal\ neutron/cm2/year$
  → Above these levels, Single Event Effect are a threat for the successful operation
  → Relevant limits for the Partially Stripped Ion run

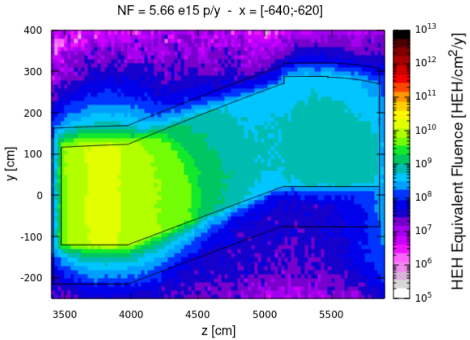
- **Cumulative radiation effects are significant at dose level above ~10Gy**
  → Relevant during the proton run where electronics non-operational or unbiased

TID in side tunnel – Hole for laser included



Total ionizing dose (TID)

HEH eq. fluence in side tunnel – Effect of holes visible



High Energy Hadrons Equivalent fluence (HEH)

Specific electronic requirements needed for more detailed analyses

GF-PoP – R2E Conclusion/Next Steps

- **Conclusions**:
  - With the assumption of beam-gas as source, using the normalization factor fitted with the measurements and in the case of 400GeV/c proton losses, **R2E results in SPS and service tunnel are above the limits defined for a radiation-safe area during the proton run**

    → If operative electronic installed close to beam-line during proton run, it needs to be checked and eventually protected
  - In the same conditions, **cumulative radiation effects are acceptable in service tunnel**

    → Possibility to install non-operational electronics in service tunnel during proton run previously the PSI run

- **Next steps:**
  - **Deployment of new detectors** (RPLs and BatMONs) **in the side tunnel**

    More precise estimation of R2E quantities in the service tunnel could be computed with the additional information given by the detectors' measurements → request to R2E

  - **Simulation with Partially Stripped Ions for R2E studies**

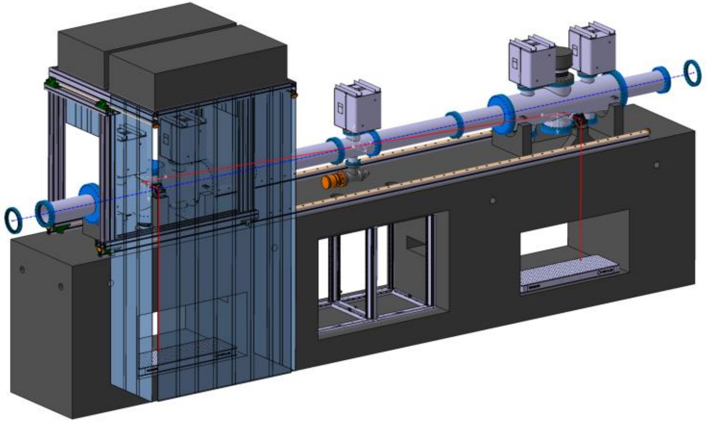
    → beam-gas interaction is expected to be the main source of losses

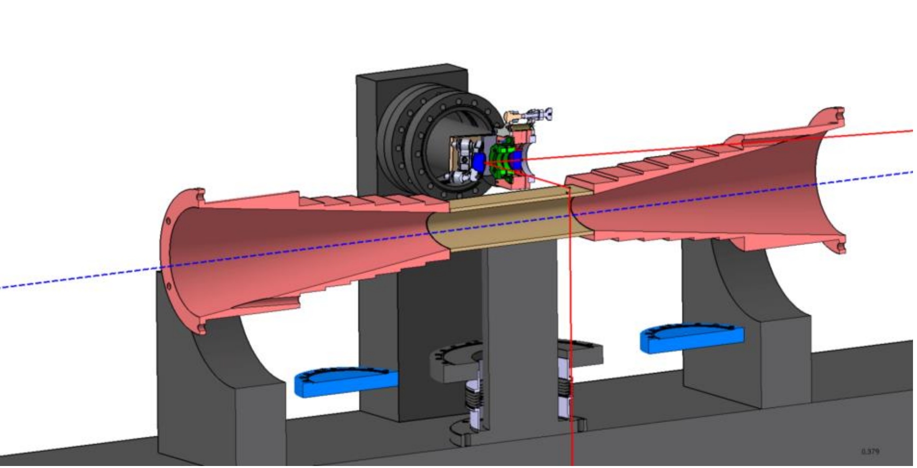
    → electronics in position and operative

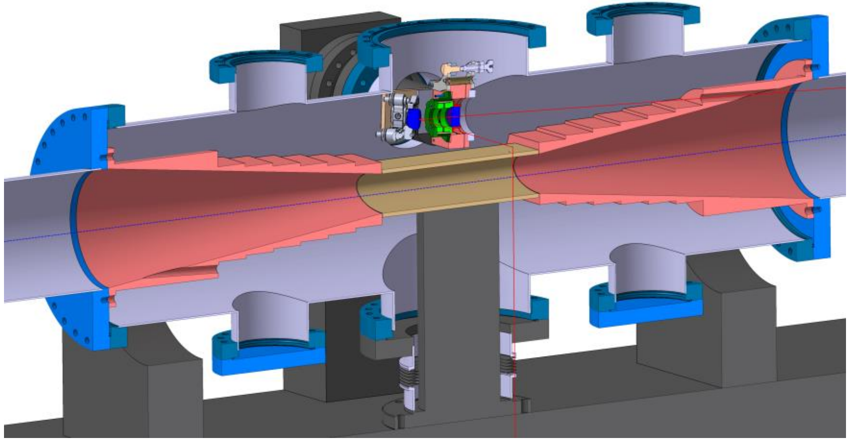
    → need to estimate the radiation environment

Fabry Perot Cavity

- Reviewed design of the mirror holding system with direct contact with the marble table
- Discussion with CERN groups to detail the responsibilities of the different elements (chamber, mirrors, etc …)

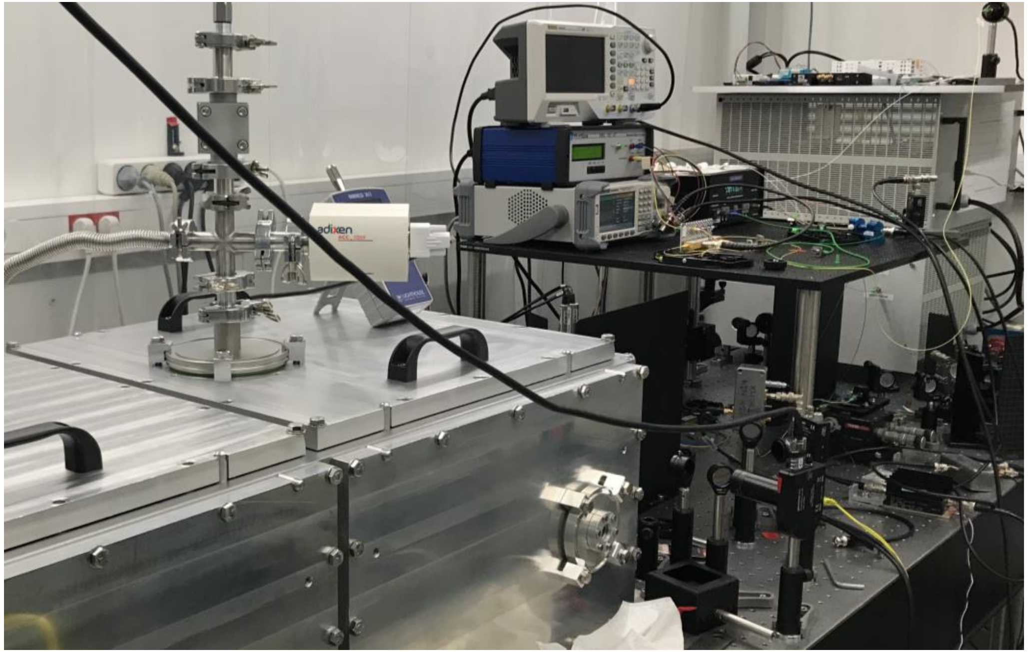






Laser system tests (ICJLab-Orsay, July 2022)

- tests at ICJLab-Orsay in July 2022
- Critical milestone reached with the characterization of a suitable laser provider with a 160MHz system and validated through with a pulse picking system at the PoP repetition rate of 40MHz
- Next steps
  - Update of the cavity design to add BPMs and the possibility to quickly remove it from the SPS ring in case of problems
  - Establish responsibilities and timeline with CERN groups



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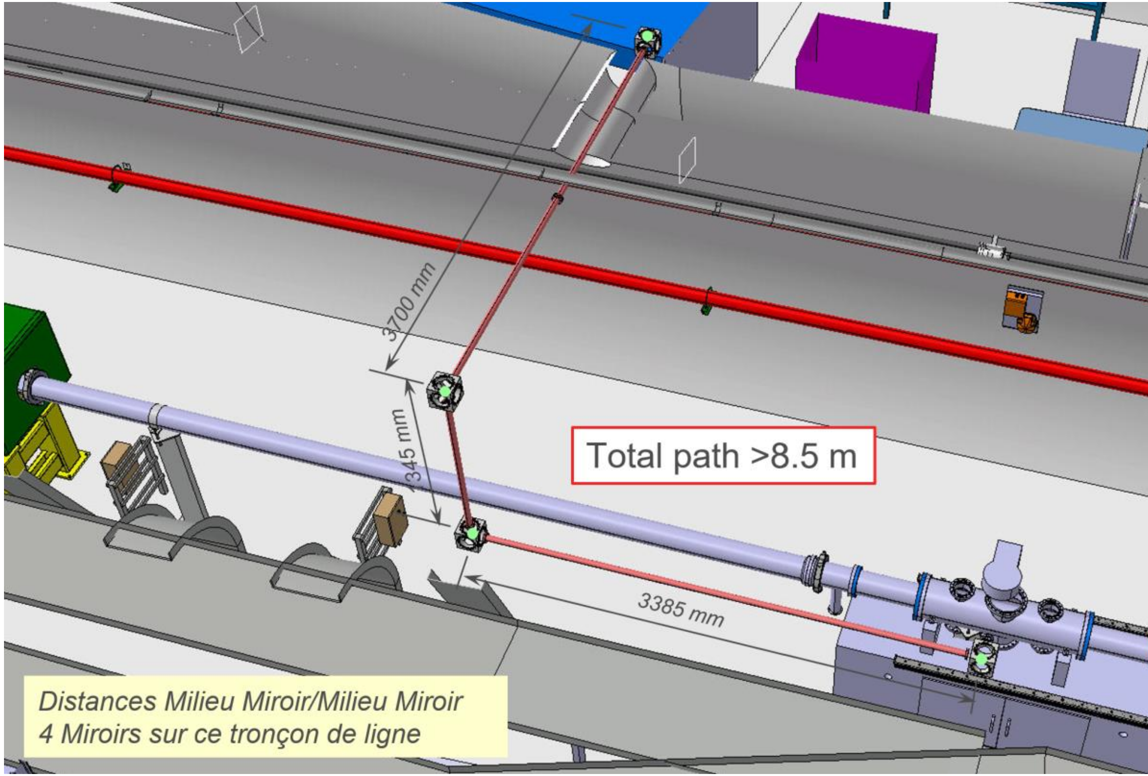
Design of the optical system for the gamma factory proof of principle experiment at the CERN Super Proton Synchrotron

Aurélien Martens, Kevin Cassou, Ronic Chiche, Kevin Dupraz, Daniele Nutarelli, Yann Peinaud, Fabian Zomer, Yann Dutheil, Brennan Goddard, Mieczyslaw Witold Krasny, Thibaut Lefevre, and Francesco Maria Velotti

Phys. Rev. Accel. Beams **25**, 101601 – Published 7 October 2022

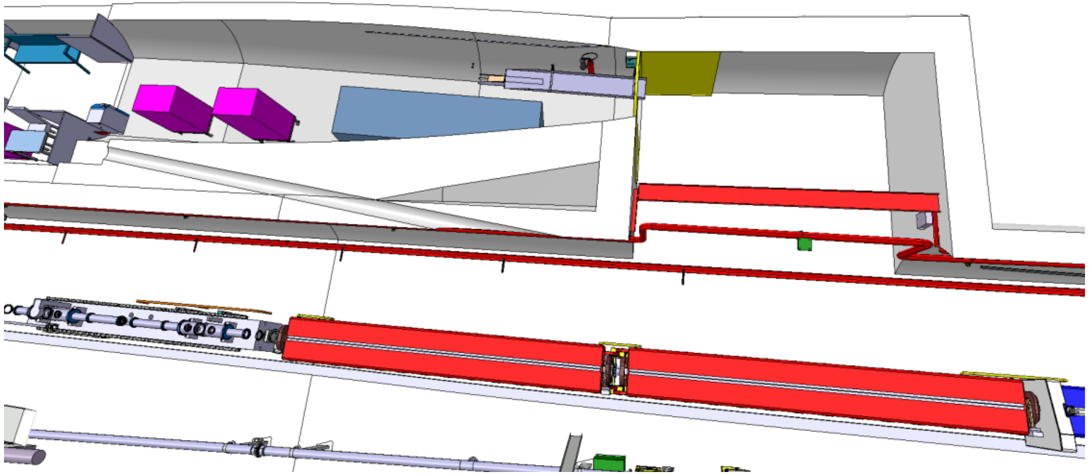
Laser transport line

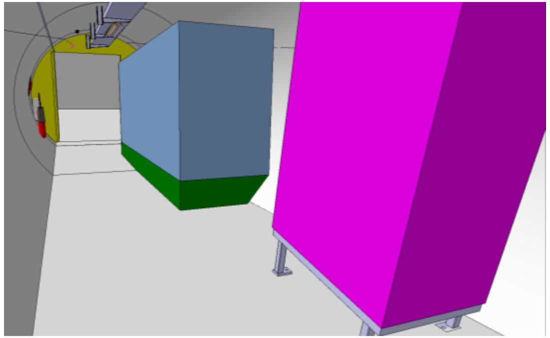
- Transport of the primary laser pulse to the cavity
- Critical stability and feedback pointing system discussed
- Order of magnitude costing established by SY-STI
- Next steps
  - Investigate a new generic design of mirror boxes with diagnostics
  - Clearly establish the responsibilities and interfaces between CERN and ICJLab
  - Formalise a schedule and a review of the estimated cost

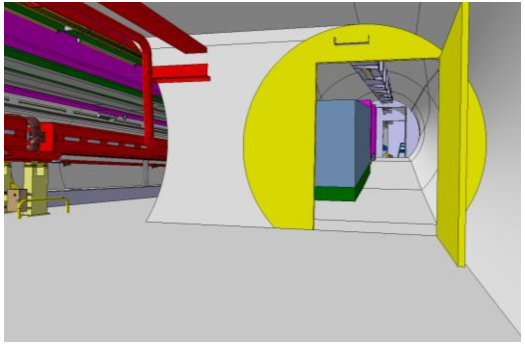


Cooling and ventilation

- Technical solution identified
- Space reservation established
- Costing completed based on 2022 prices
- Next steps
  - Review of the solution with expected radiation levels
  - Integration of the cooling unit and related ducts
  - On-site visit to confirm the environmental conditions of the tunnel

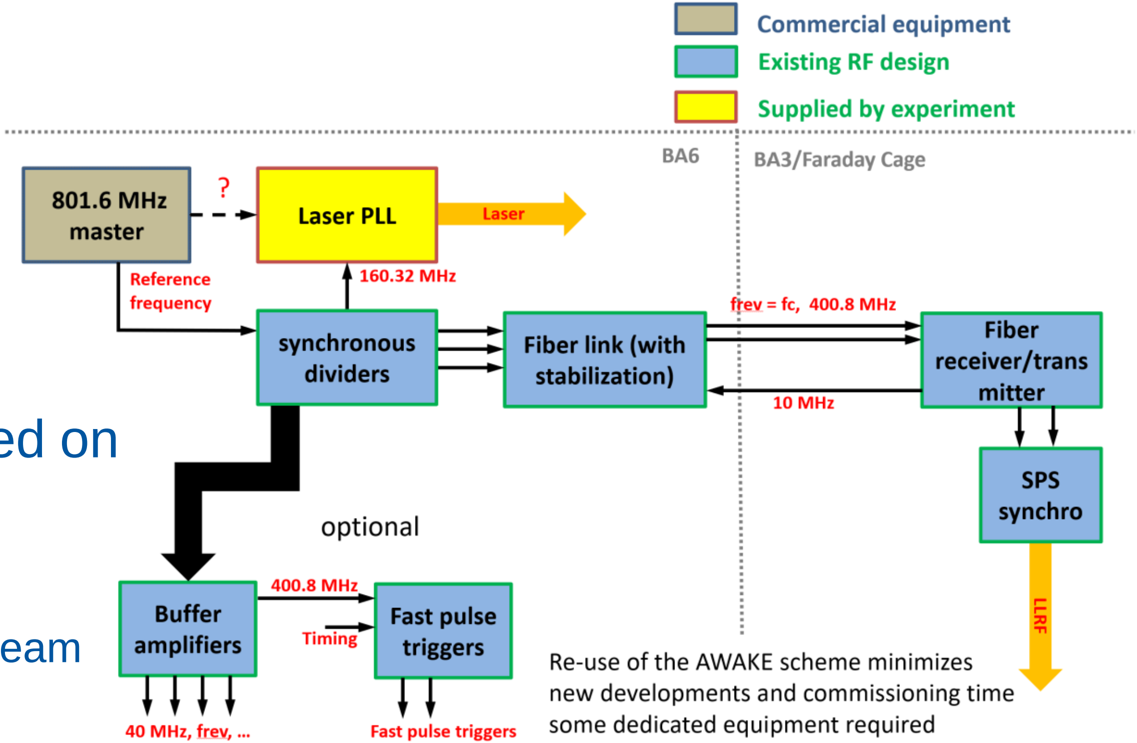






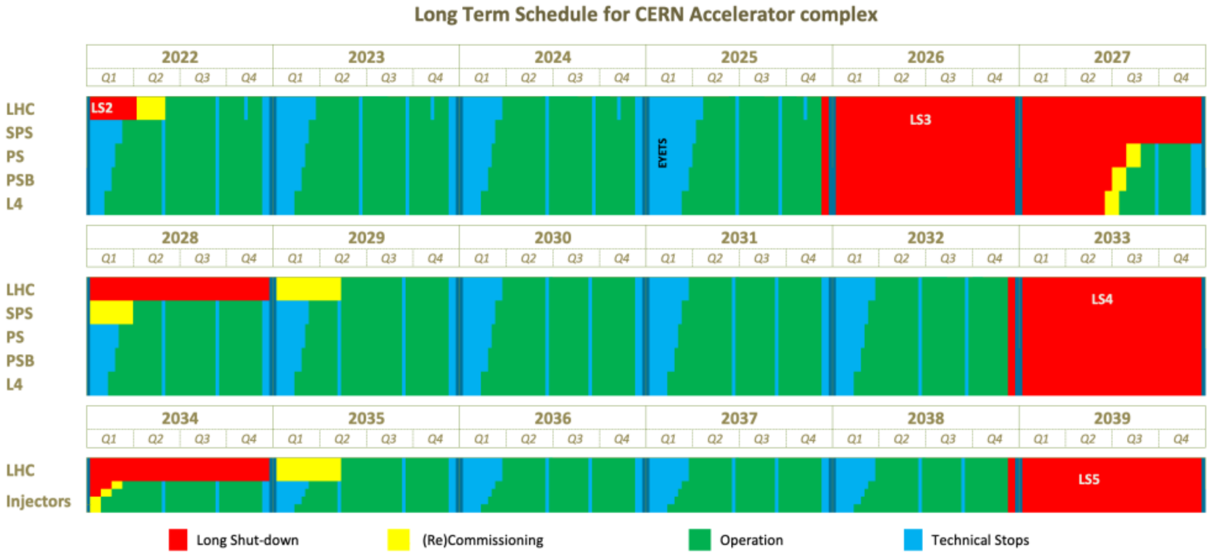
RF synchronisation

- Precise operation frequency established
- Synchronisation scheme based on the existing AWAKE system
- Next steps
  - Estimation of the duration of the beam synchronisation during the cycle
  - Study the possibility of remote controls and diagnostics
  - Obtain more precise cost estimate for cabling and rack systems



Ressources and timeline

- The review of the costing is ongoing and not all inputs have been included but estimates remain close to the 2019 LoI (~2.5 MCHF)
- The new timeline is centered around LS3 with an operation in 2028
  - Work in the tunnel before LS3 is considered due to the high work load of CERN groups during the long shutdown



CERN long term schedule from 06/2022

Collaboration and funding

- MoU signed between CERN and 2 institutions
  - IN2P3 in France for ICJLab in Orsay
  - Jagiellonian University in Krakow, Poland
- Collaboration with ICJLab is strong and an addendum on the laser activities is under preparation
- Outside funding sourcing is being actively investigated and a submission to an EU grant, with CERN support, is considered for early 2024
- An enlargement of the collaboration is needed and new signatories of the MoU sought, in particular in Europe

Conclusion

- The support of PBC is essential to development of the proposal, both for its framework and its resources
- Critical milestone in the laser system were usefully passed and a strong collaboration between ICJLab and SY-STI-LP section is ongoing to design, install and operate it in the SPS tunnel
- Resources and costing
  - The compilation of resources is ongoing after a dedicated meeting 2 weeks ago
  - A review and summary should be completed in early 2023
- Collaboration and funding
  - An extension of the collaboration to other institutes is needed
  - Possible use of highly cooled light ions beam for the LHC is investigated
  - The strengthening of atomic physics case of the PoP is ongoing
  - The application to EU INFRA-DEV grant in early 2024 is the most promising financing option

Thank you