Introduction to the review for needs of a hollow e-lens for the HL-LHC

S. Redaelli

on behalf of the collimation team

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

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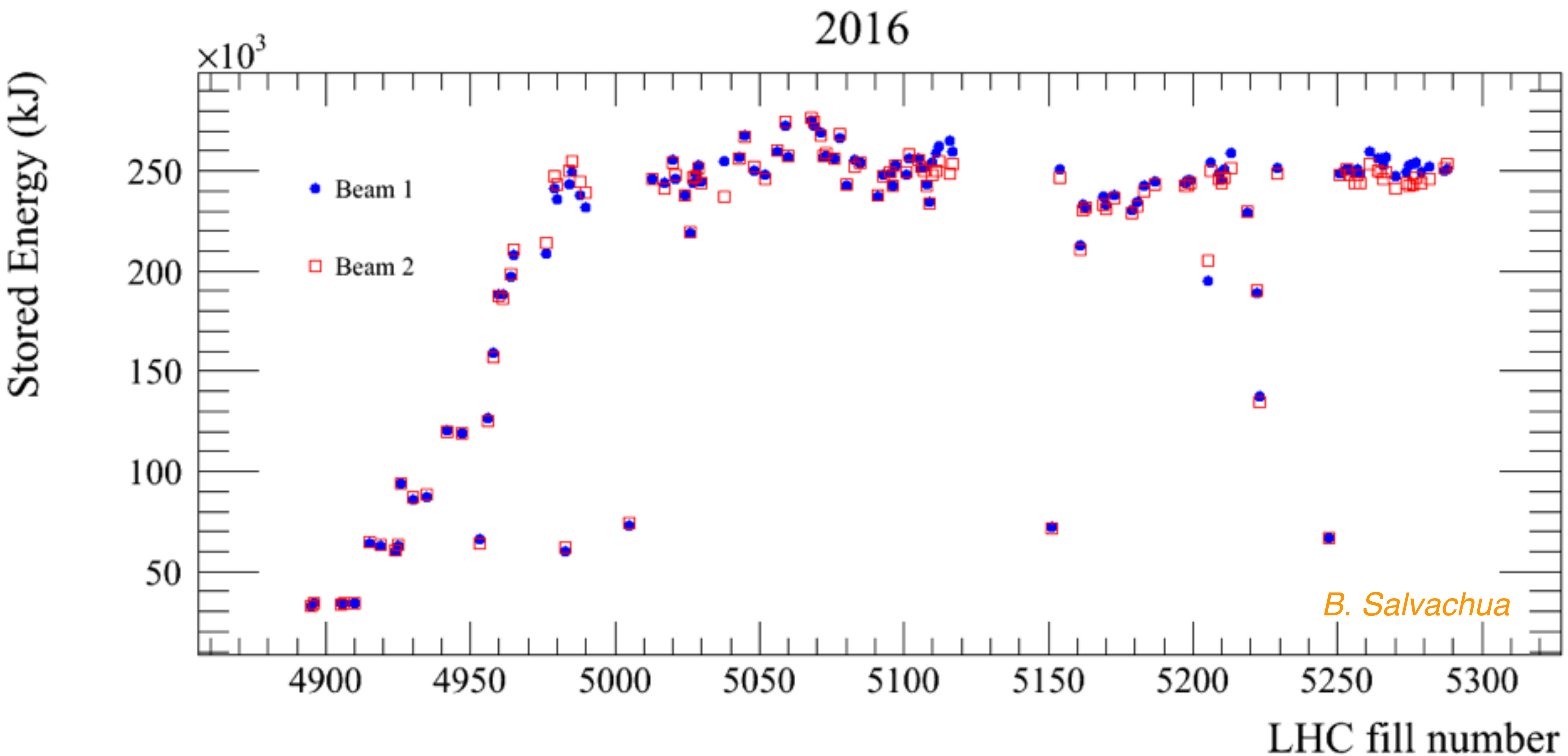


LHC Run II: good performance stored beam energy above 250MJ

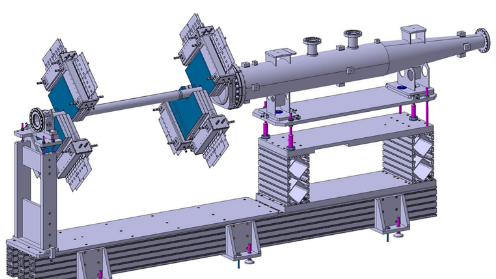
Beam energy = **6.5 TeV** (design = 7 TeV)

***β^** = 40cm** (30% lower than design of 55 cm)

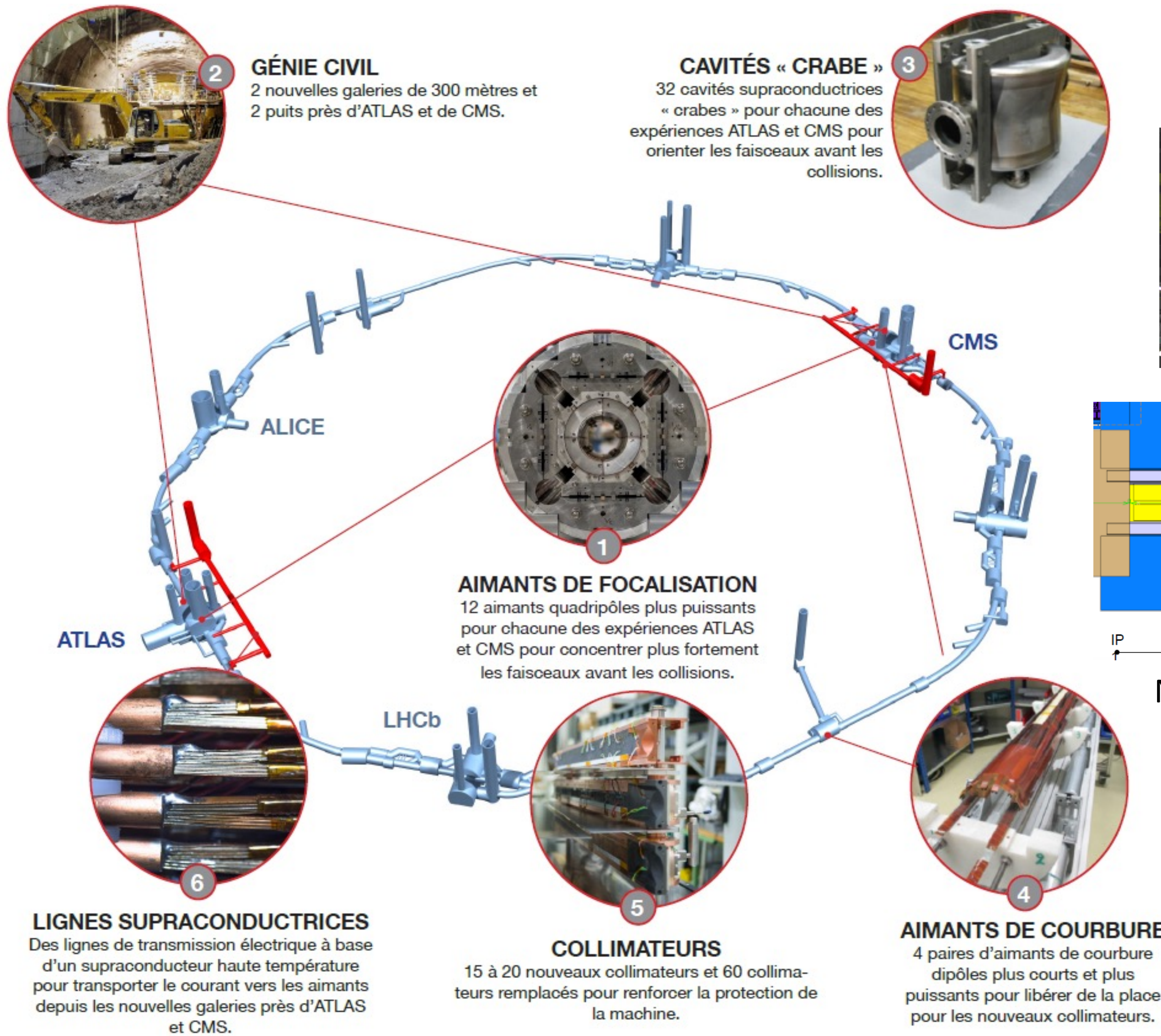
2016: Lower intensities, limited by injection kickers and SPS dump.

Main upgrades of HL-LHC

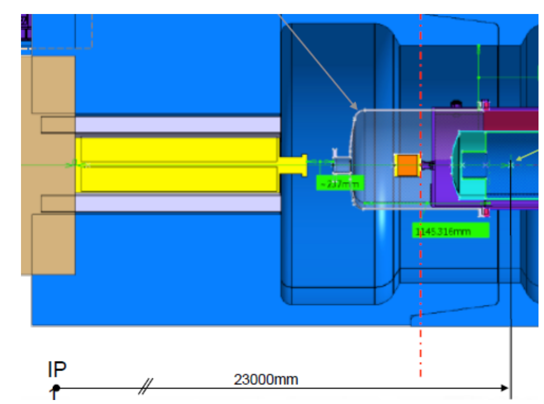
Cryo@P4



Beam diagnostics
BGV



Cryo@P1-P5



New TAS and VCX

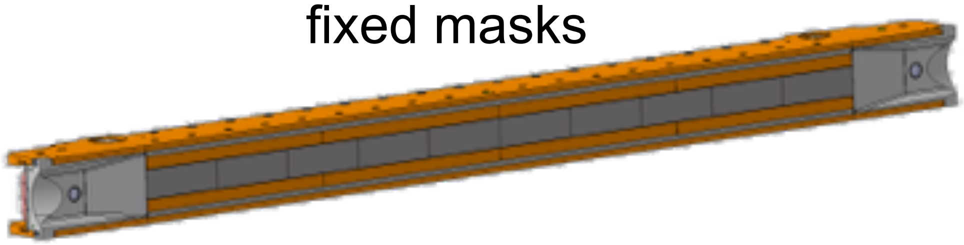
Challenges for collimation

- Increased beam stored energy: 362MJ → 700MJ at 7 TeV
  - ***Collimation cleaning*** *versus quench limits of superconducting magnets.*
  - *Machine protection constraints from* ***beam tail*** *population*
    (7 MJ above 3 sigmas even for perfect Gaussian tails!).
- Larger bunch intensity (Ib=2.3x10^{11}p) in smaller emittance (2.0 µm)
  - ***Collimation impedance*** *versus beam stability.*
  - ***Collimator robustness*** *against regular and abnormal beam losses*
    at injection as well as top energy.
- Larger p-p luminosity (1.0 x 10^{34}cm^{-2}s^{-1} → 5.0-7.5 x 10^{34}cm^{-2}s^{-1})
  - *More challenging* ***collimation of physics debris****.*
  - *Overall upgrade of the* ***collimation layouts*** *in the insertion regions.*
- Much smaller β^* in the collision points (55 cm → 15 cm)
  - *Cleaning and protection of high-luminosity insertions and physics background.*
  - *Concerns from ground motion and cultural noise with betas of ~20km*
- Operational efficiency is a must for HL-LHC!
  - *Collimators: high precision devices that must work in high radiation environment*
- Upgraded ion performan

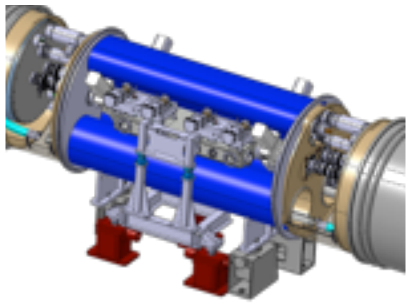
Operation with crab-cavities adds new scenarios for fast failures the call for controls of halo population.

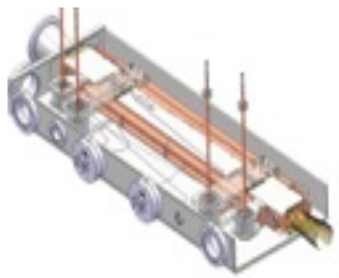
Collimation upgrade baseline

Completely new layouts
Novel materials: TCTs in CuCD
IR1+IR5, <u>per beam</u>:
- 4 tertiary collimators
- 3 physics debris collimators
- fixed masks

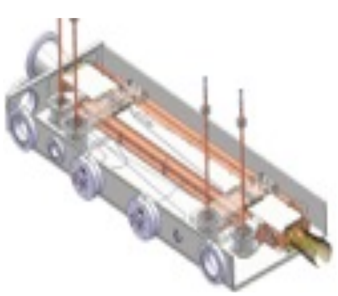


Cleaning: DS coll. + 11T dipoles, 1 unit per beam

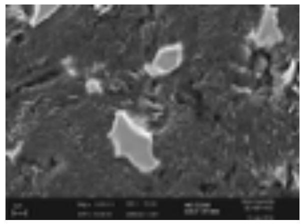


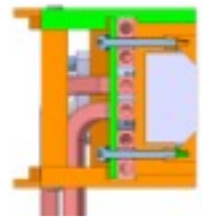


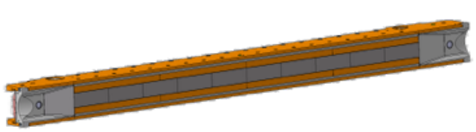
Ion physics debris: DS collimation

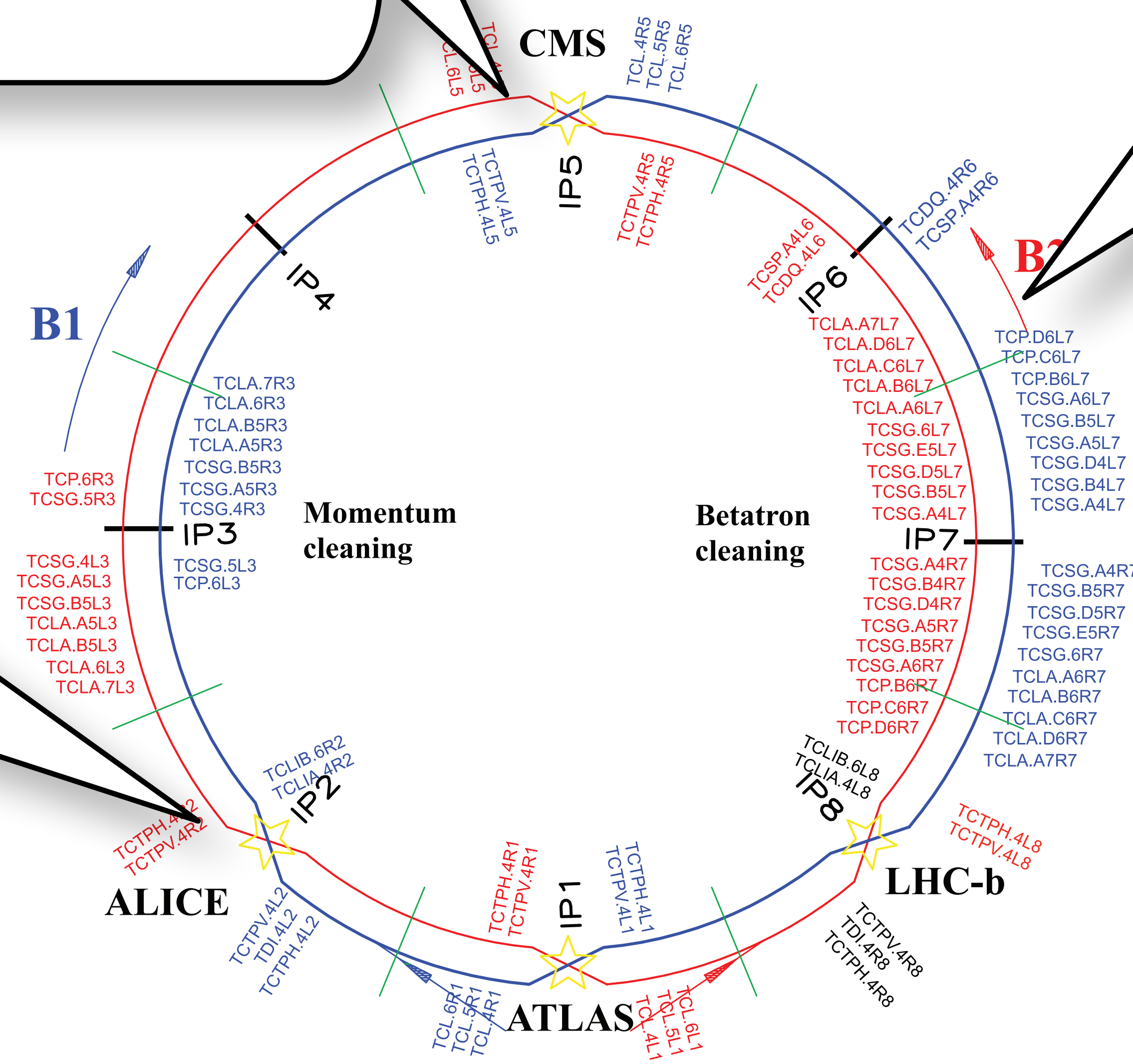


Low-impedance, high robustness secondary collimators: coated MoGr









Open questions

- **The present collimation upgrade baseline is solid**

  "Historical" concerns on collimation cleaning, impedance, robustness and operational efficiency (alignment) are addressed.

- **The success of HL-LHC relies on unexplored regimes**
  - Double bunch intensity in smaller emittance

    How halo population and beam lifetime scale?
  - Operation with crab cavities

    No experience with proton beams. Implications for machine protection?
  - Luminosity levelling

    Must ensure a loss-free operation while levelling at $5x10^{34}cm^{-2}s^{-1}$

- **Re-baselining of June 2016 added some uncertainties**

  See introduction by Oliver.

- **Recent concerns from ground motion** — dedicated talk

- **Recap.: 3 quench tests in 2015 at 6.5TeV**

  - Still no quench for protons (~600kW losses)

  - Quench for ion debris with <15mW steady losses in DS

  - Quench with ions in IR7 with 15kW beam losses

  Scaling to 7 TeV still entails uncertainties.

Why a hollow e-lens review now

Sufficient operational experience at 6.5TeV

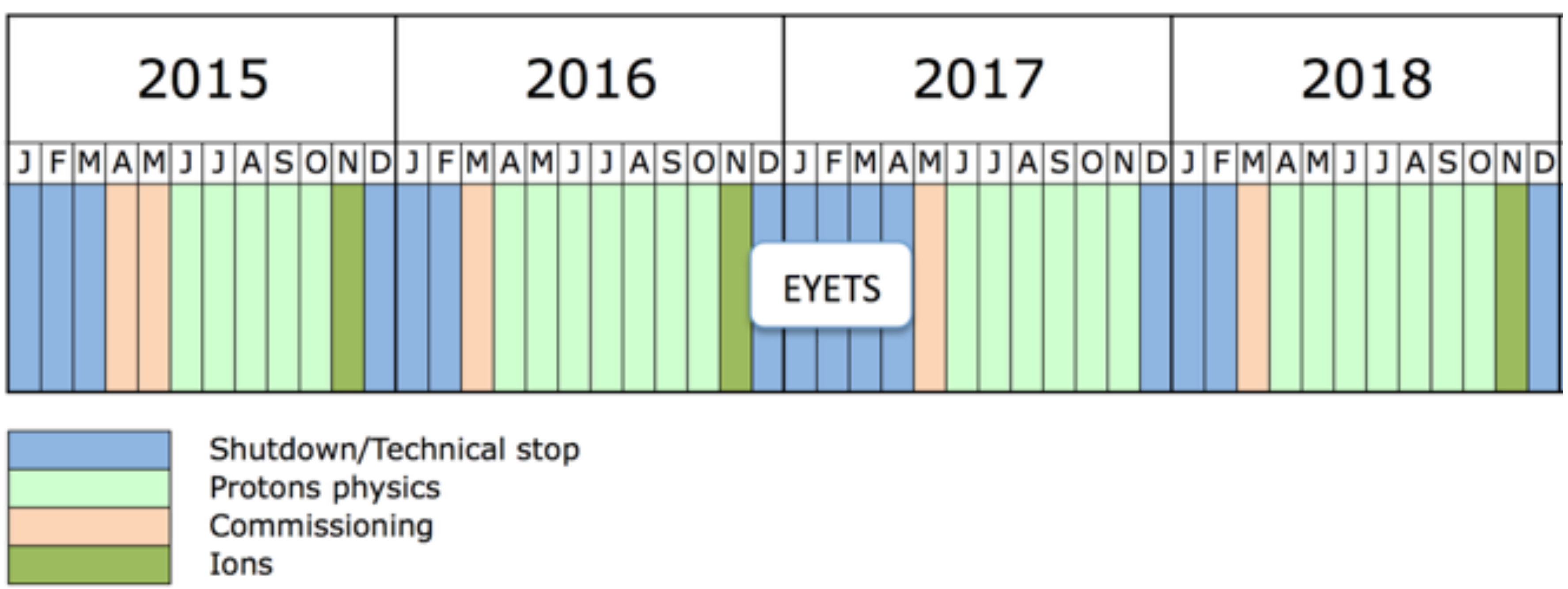
2017 run starts late — after EYETS — would set us back to fall 2017
One caveat: not seen e-cloud limitations this year because of intensity limitation

(CERN) timeline for construction of hollow e-lenses

End of 2017 estimated as latest date to comfortably produce 2 units in LS2
Require another year of technical design and studies before final TDR.

LARP collaboration for production as in-kind contribution

Must have by January 2017 a statement on baseline status for HEL



Collimation reviews and losses — i

Collimation project review 2004

"The assumption of a minimally tolerable beam lifetime of 0.2 hours over a short period seems reasonable based on experiences made at the TEVATRON, HERA and RHIC. However, a wide spectrum of combinations between enhanced loss rates and their durations exists and fast loss mechanisms were insufficiently considered."

Collimation project review 2009

"Another potentially very beneficial proposal consists in the application of a hollow electron beam that effectively functions as a beam scraper for the LHC proton beam. This hollow e-beam scraper might be an excellent solution to relax the sensitivity of the collimator loss rates with respect to small beam jitter, as it was observed at HERA or the TEVATRON."

Review 2011 on needs for dispersion suppressors

"Since no material must be placed close to the beam, there exists no damage risk with this scheme. Beyond a certain betatron amplitude the hollow e-beam would generate high diffusion rates for the protons. It can be expected that this mechanism also smoothens out spiky loss rates in time. With high intensity and primary collimators placed close to the beam, such non-uniformly distributed loss rates can be an operational problem."

Collimation reviews and losses — ii

Review 2013 on needs for dispersion suppressors

"…Ideas of scraping off halo particles with other methods and an improved understanding of halo formation are being discussed. One option is to use hollow electron beams as it has been demonstrated at FNAL. Other alternatives should be explored, such as tune modulation, crystal collimation etc. The committee considers studies on halo cleaning with different methods for controlling beam losses and for machine protection as very interesting. … In HERA the operation suffered from spiky loss patterns. … If such a scenario becomes an issue at LHC, direct control of halo diffusion and the temporal distribution of losses could become important. The hollow electron beam option can be a solution for these issues."

HL-LHC cost&schedule review 2015

"The HEB collimation concept could become very important for high intensity operation, especially to control time wise uneven loss patterns. A fast diffusion speed beyond a certain betatron amplitude could reduce the sensitivity of the losses to orbit jitter from ground motion."

CMAC 2016

"Recommendation: Utilize
tighter settings at the bea

Consistent concerns from experience at other machines that loss spikes can be an issue. Acknowledgement that HEL are a viable solution!

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Loss and lifetime observations during nominal operation and their extrapolation to HL-LHC parameters.	*Belen Maria Salvachua Ferrando*	
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Discussion		
30-7-018 - Kjell Johnsen Auditorium, CERN		10:15 - 10:30
What did we learn about HALO population during LRBB studies and MDs?	*Yannis Papaphilippou*	
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CERN		11:00 - 11:30
What did we learn about HALO population during MDs and regular operation?	*Gianluca Valentino*	
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Observations and measurements on the impact of earthquakes and cultural noise on the LHC operation and their extrapolation to HL-LHC parameters.	*Michaela Schaumann*	
30-7-018 - Kjell Johnsen Auditorium, CERN		12:00 - 12:30
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Session / Location	Speaker / Time
Operational experience from HERA and their extrapolation to the HL-LHC	*Mike Seidel*
30-7-018 - Kjell Johnsen Auditorium, CERN	14:15 - 14:35
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Operational experience of RHIC electron lenses and their effect on collimation and halo populations	*Wolfram Fischer*
30-7-018 - Kjell Johnsen Auditorium, CERN	14:45 - 15:05
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Operational experience from Tevatron and relevance for HL-LHC	*Alexander Valishev et al.*
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Expectations (extrapolated from LHC operation) for the beam lifetime and halo population based on scaling from the LHC observations for radiation damping and IBS excitation.	*Fanouria Antoniou*
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RF overview of the Crab Cavity system for HL-LHC with presentation on potential failure modes and summary of the KEK operation experience.	*Rama Calaga*
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30-7-018 - Kjell Johnsen Auditorium, CERN	17:35 - 17:50
Potential failure scenarios in the HL-LHC machine that can lead to very fast orbit changes (e.g. missing beam-beam kicks, damper failure scenarios, Crab cavity failure scenarios etc) and the resulting machine protection requirements for HL-LHC operation (with input from collimation team).	*Daniel Wollmann*
Discussion	
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Operational experience from HERA and their extrapolation to the HL-LHC — *Mike Seidel*
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Operational experience of RHIC electron lenses and their effect on collimation and halo populations — *Wolfram Fischer*
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Coffee break
CERN

Expectations (extrapolated fro
scaling from the LHC observa

Discussion
30-7-018 - Kjell Johnsen Auditor

Measured effects of depleted halo population with hollow e-lens and relevance for HL-LHC — *Giulio Stancari*
30-7-018 - Kjell Johnsen Auditorium, CERN — 09:00 - 09:20

Discussion
30-7-018 - Kjell Johnsen Auditorium, CERN — 09:20 - 09:30

Alternative methods for halo depletion (damper and tune modulation [and wire]), long range beam-beam and comparison of their performance / reliability to that of a hollow electron lens. — *Roderik Bruce*
30-7-018 - Kjell Johnsen Auditorium, CERN — 09:30 - 10:00

Discussion
30-7-018 - Kjell Johnsen Auditorium, CERN — 10:00 - 10:15

Potential performance reach for the HL-LHC in case of a depleted beam halo — *Gianluigi Arduini*
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Basic idea for halo control

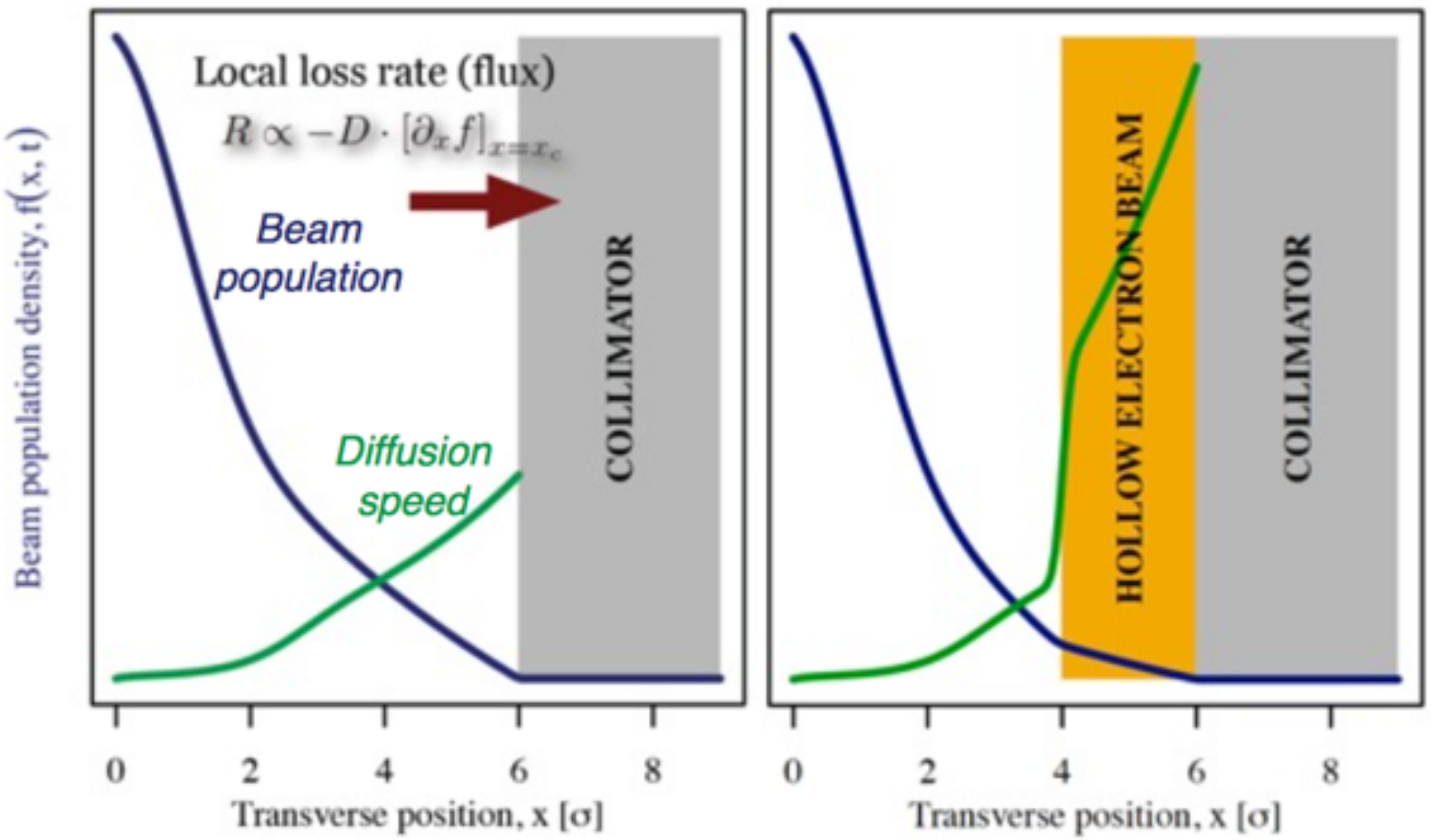
Controlling rate of halo diffusion creates a region of depleted halo.

Driving motivations:

- Control actively <u>when</u> loss occur;
- Mitigation of loss spikes, e.g. in case of orbit jitters;
- Reduced risk of damage with highly populated halos.

Key requirements:

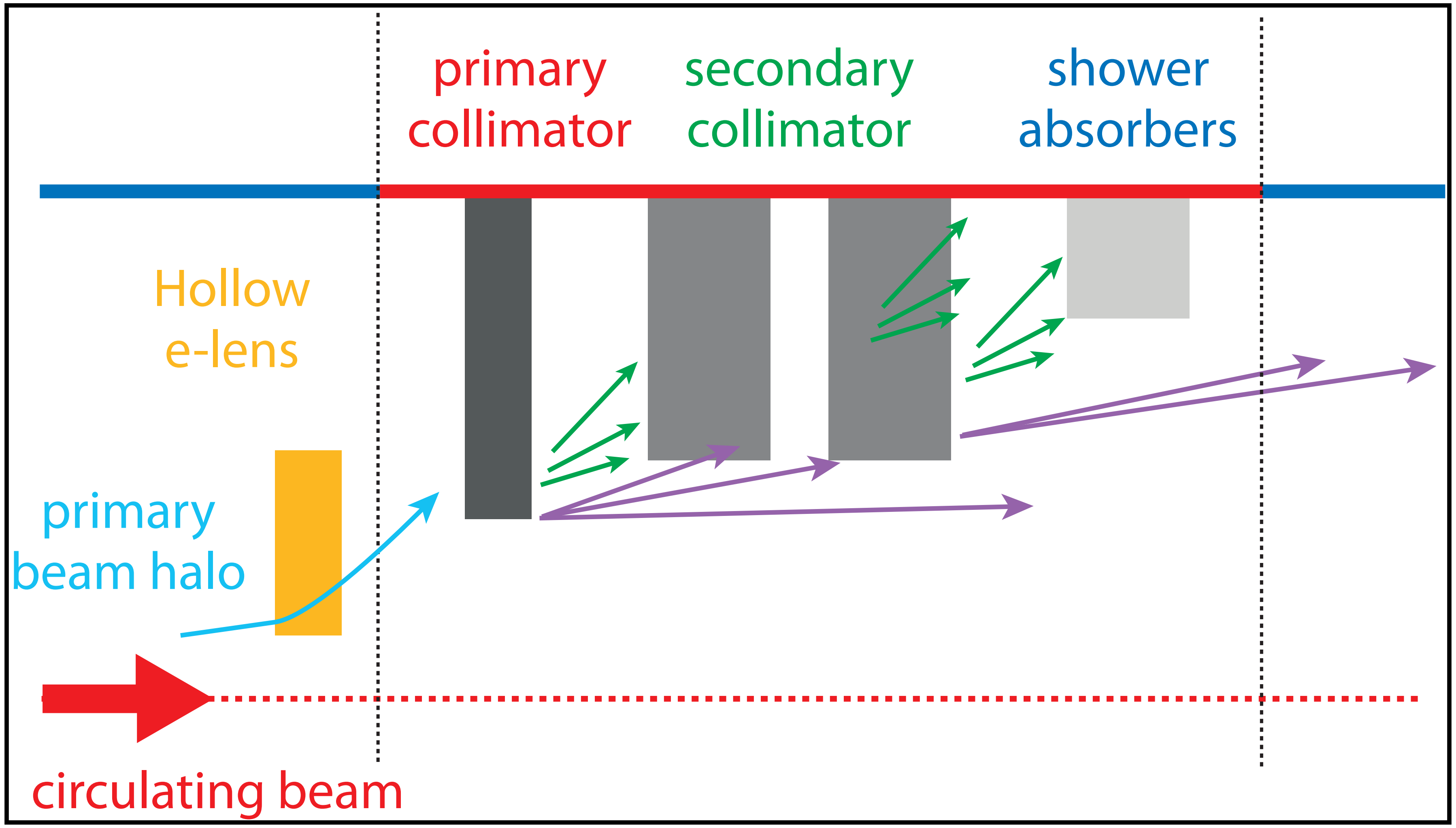
- Need to be able to select particles by transverse amplitudes;
- Adjust depletion rates in time ranges that depend on OP scenarii;
- Effect on the core must be negligible.



Talk by G. Stancari — will see how this worked at the Tevatron with hollow e-lens.

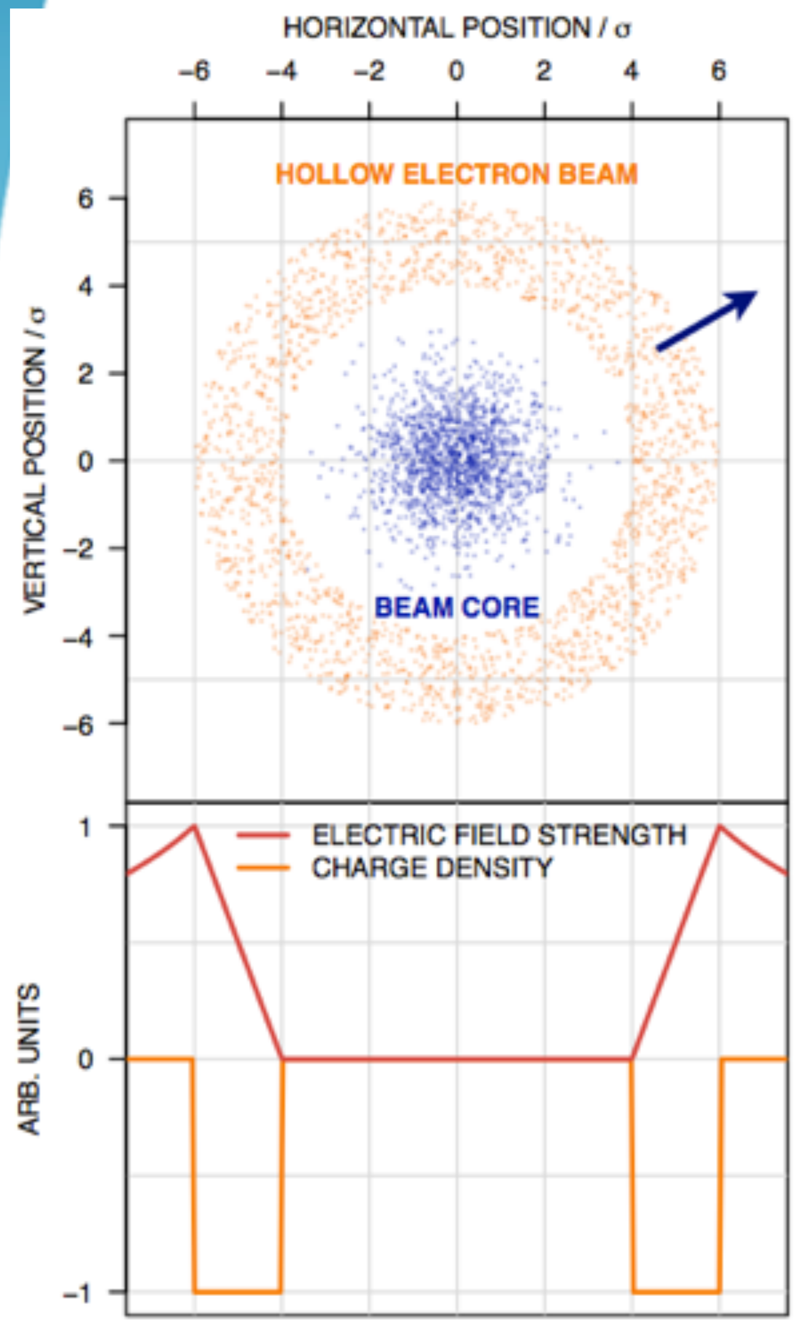
Illustrative plot by G. Stancari

Integration in the collimation



“Non-material” scraper — adds scraping functionality but particles are disposed of by the present collimation system.
Can be installed in other points than IR7, because kicks per turn are small.
Same conceptual implementation of other methods.

Hollow election beams



Hollow electron beams runs co-axial to proton beam:

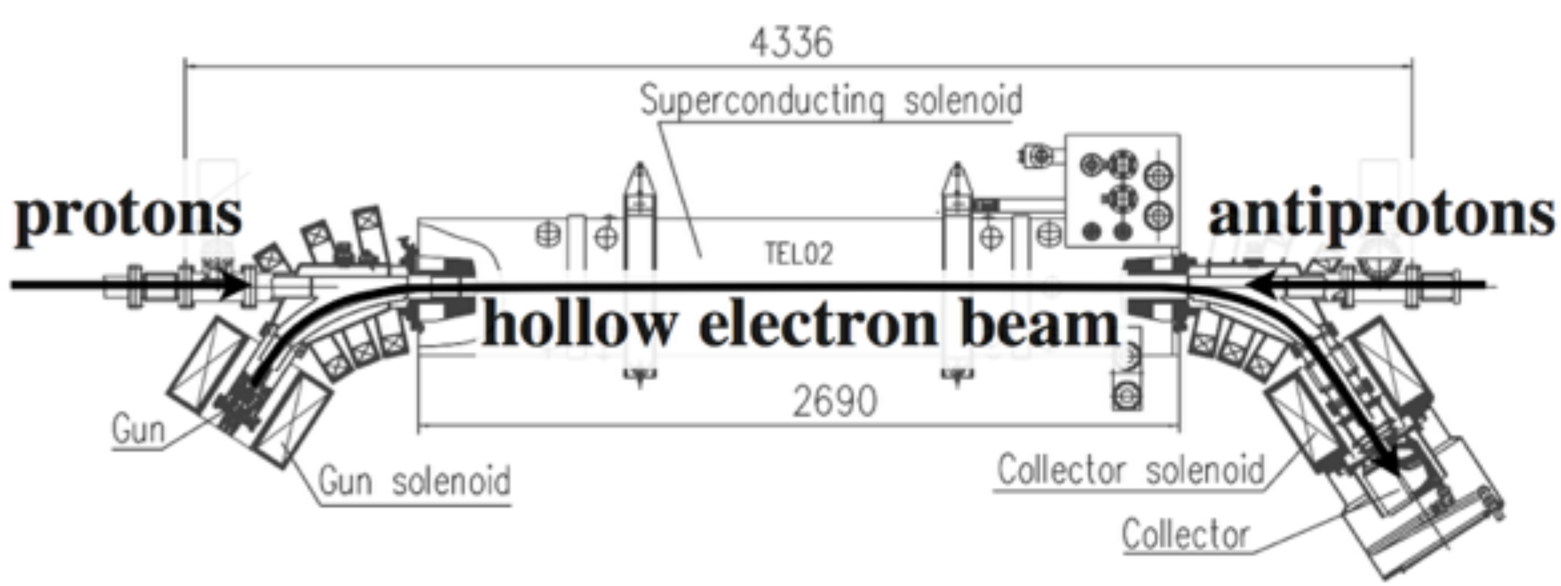
- Zero field in the core
- Selection of affected particles by transverse amplitudes at the HEL location

Length of a few meters (depends on e-beam current)

E-beam is disposable and can be pulsed at high rates (DC vs AC excitation)

Highly tuneable — e-beam current, radius, pulsing modes.

Well-established technique used in accelerators.



Alternative methods under study

- **Narrow-band excitation with transverse damper (ADT)**
  Tested in MDs at the LHC in 2015 and 2016
  Allows bunch-by-bunch excitations.
- **Resonance excitations with tune ripple**
  Used in HERA.
  Preliminary MDs at the LHC 3 weeks ago.
  No bunch-by-bunch.
- **Resonant excitation with crab cavities.**
  Recent proposal by Themis M. Similar to ADT method.
  Try to address this in MD5.

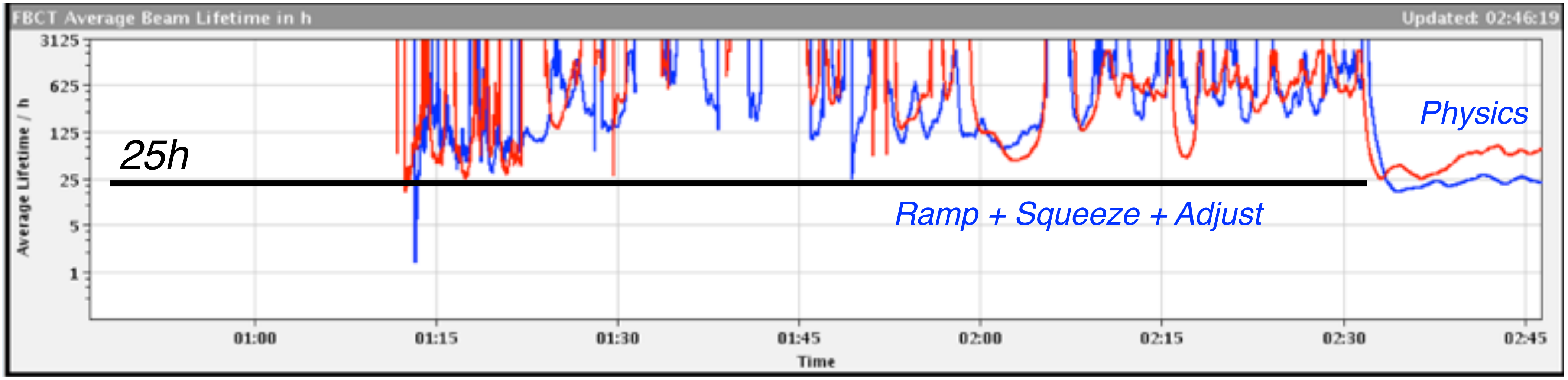
Talk by R. Bruce

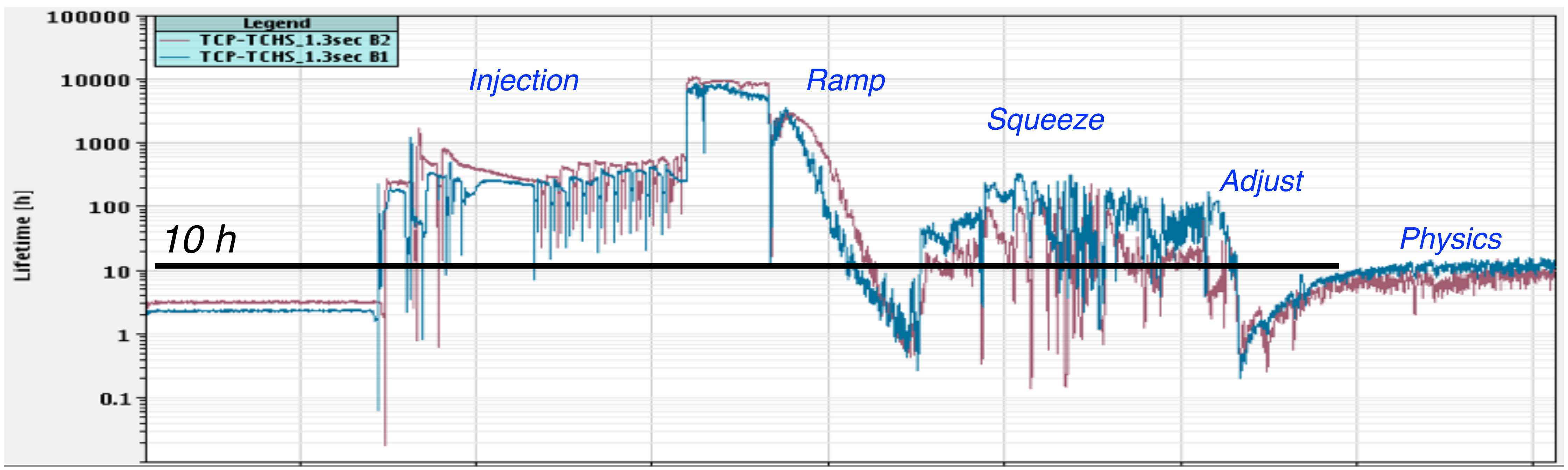
Do not act in transverse (x,y) plan but rely on detuning with amplitudes and (for some) on precise tune knowledge bunch-by-bunch. Effect on core: concern!

Studied with high priority in Run II — only viable solution in case of problems with halos in Run III.

Operational scenarios

*Couple of **illustrative** examples from 2011/12*





A) Loss mitigation during cycle setup:
  - end of ramp, squeeze, collision setup. Time scale: ~min

B) Static control of tails during long stores in physics
  - Time scale: continuous depletion for hours.

C) New for HL-LHC — betastar levelling

Possible benefits from HEL

Main functionalities (asking feedback to the review panel!)

- Loss spike mitigation
- Halo population controls for fast failure of 700 MJ beams

Provides several nice additional "bonus" features:

- Enhanced collimation: smoothing/reduction of total losses through halo loss control (for given cleaning)
- Adds scraping functionality at tight amplitude, no materials constraints (recap. recent Roman pot run with scraping at 2 sigmas)
- Control of impact parameters on collimators, useful for ions
  Improve ion cleaning with 1 dispersion suppressor collimator
  Complementary to crystal collimation.
- Specific for e-lens: allow new AP studies by changing the gun (Gaussian or flat distributions)
- Specific for e-lens: Provides complementary halo measurements

Talk by G. Stancari

Potential ways to boost performance (also in light of recent re-baselining)

- Allow tighter IR7 hierarchy for larger beta* reach
- Operation at smaller crossing, if limited in adjust by loss spikes.

Talk by G. Arduini

Possible drawbacks of HEL

New — complex — device that needs to be commissioned

↦ See talks on operational experience at Tevatron and RHIC

Possible concerns if it does not work as designed?

↦ In the worst case, keep it OFF. No detrimental effects for the beam if aperture well designed.

Halo "too clean" to detect early on losses, for machine protection

↦ Depletion rates are smoothly tuneable

↦ Batch-by-batch to leave "witness" batches with populated halos

Loose Landau damping is tails are removed

↦ Present specs have inner radius of >5 real beam sigma

↦ Compression factors of e-beam can be tuned with solenoide field

Perturbations of beam from residual fields and imperfections

↦ Nothing in DC mode (preferred operation mode)

↦ Propose an 'S' shape design to self-compensate edge effects

Outline

- Introduction
- HL-LHC and collimation upgrades
- Halo control needs
- **Status of HE design**
- Conclusions

Conceptual design for LHC lenses

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN – ACCELERATORS AND TECHNOLOGY SECTOR

CERN-ACC-2014-0248

FERMILAB-TM-2572-APC

Conceptual design of hollow electron lenses for beam halo control in the Large Hadron Collider*

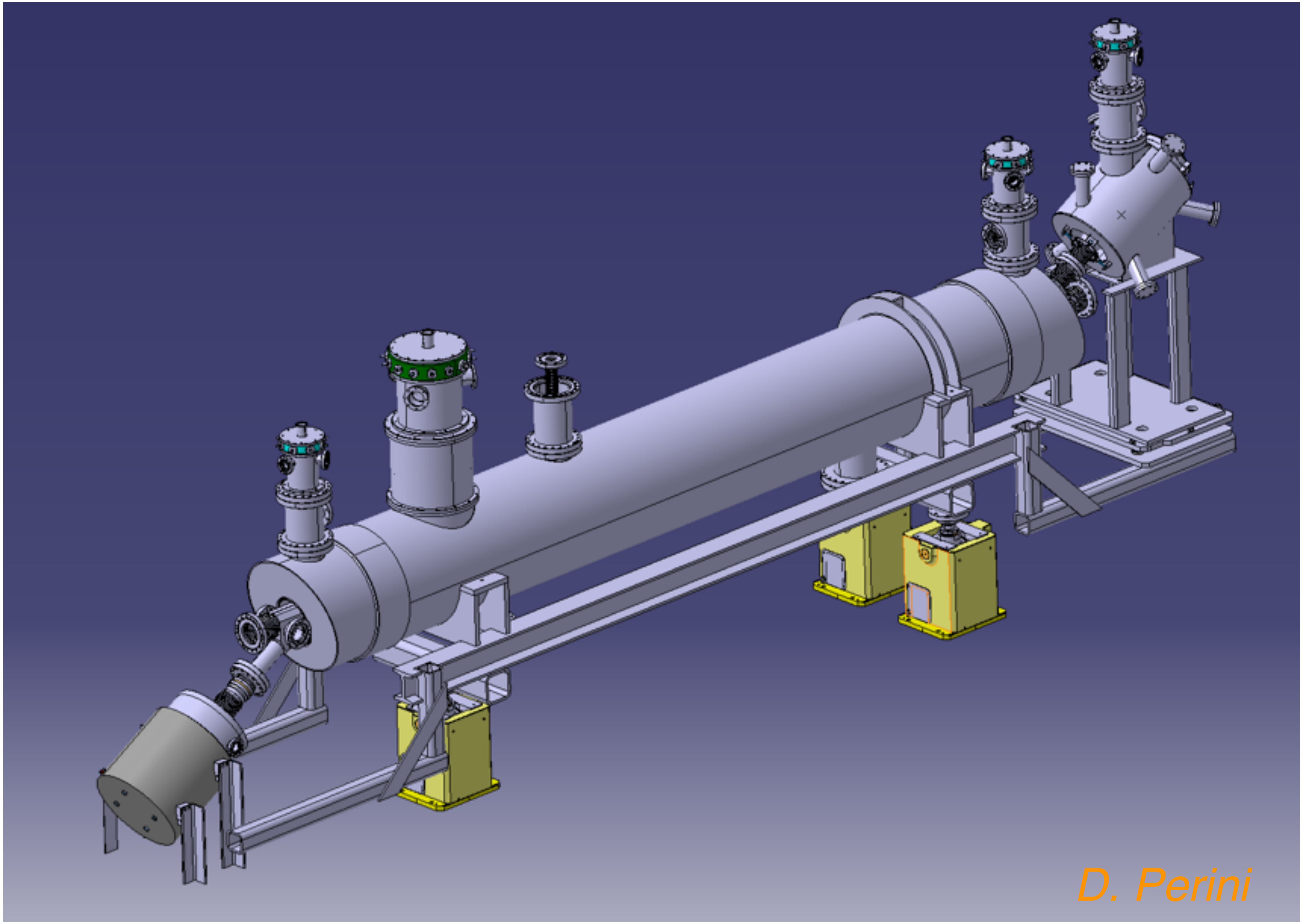
G. Stancari, V. Previtali, and A. Valishev
Fermi National Accelerator Laboratory, PO Box 500, Batavia, Illinois 60510, USA

R. Bruce, S. Redaelli, A. Rossi, and B. Salvachua Ferrando
CERN, CH-1211 Geneva 23, Switzerland
(Dated: October 30, 2014)

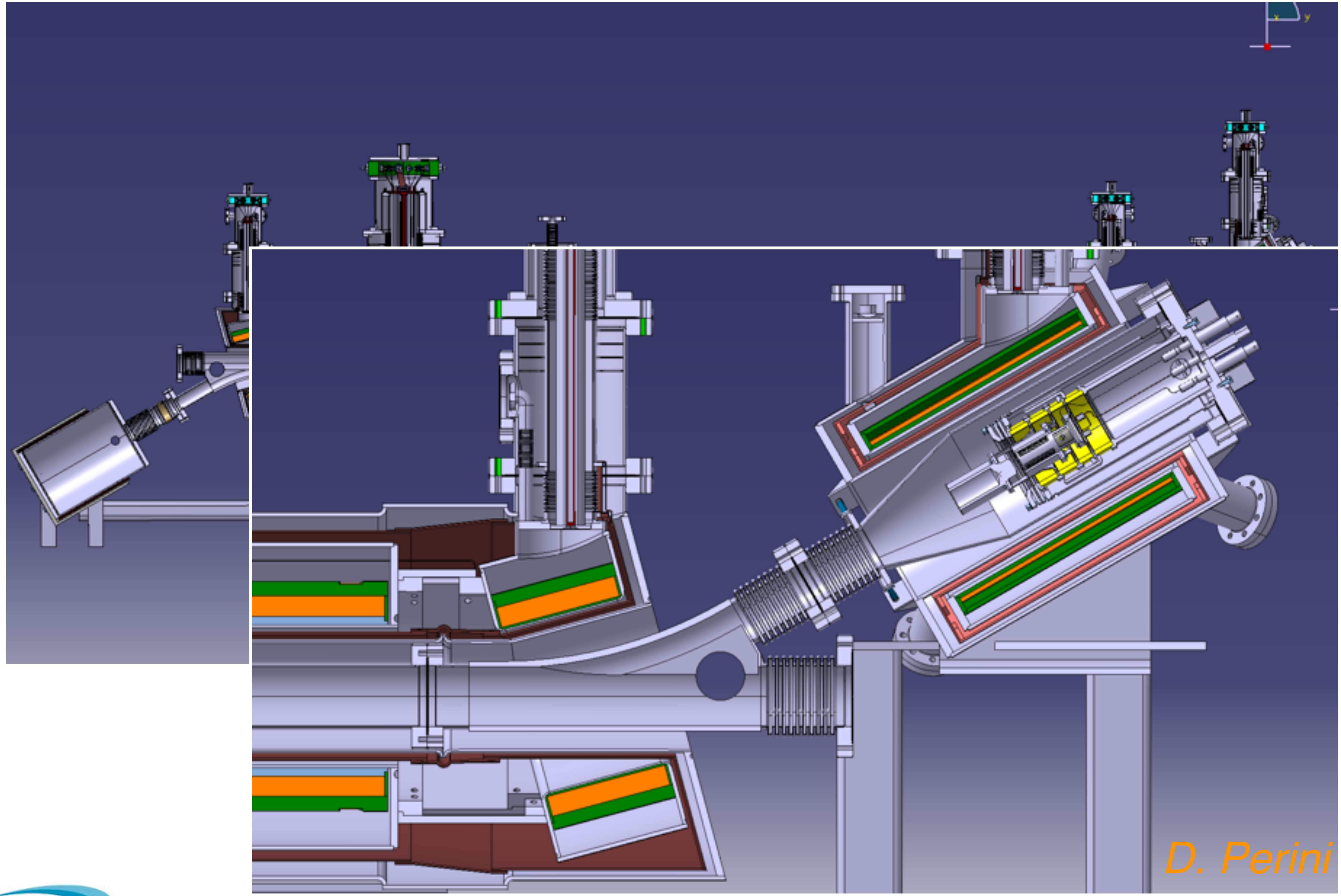
Present conceptual design based on achieved parameters

- Range of sigmas — 4-8 (emittance of 3.5 microns)
- Halo depletion time — < a few minutes
- Electron beam current — up to 5 A
- Time structure — rise time of 200ns (batch-by-batch)
- Main solenoid field — 6 T

LHC HEL design



Detailed component design



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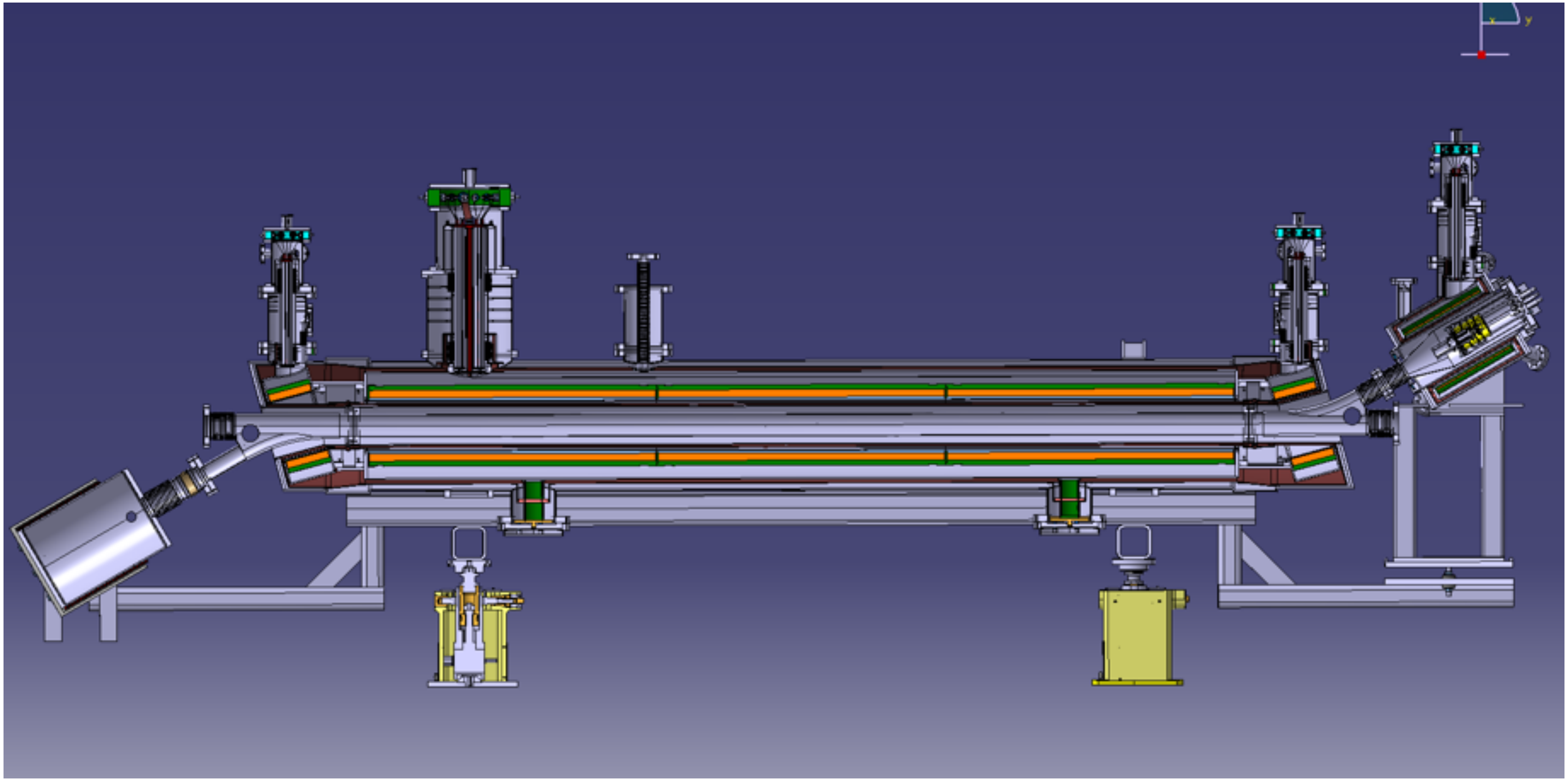
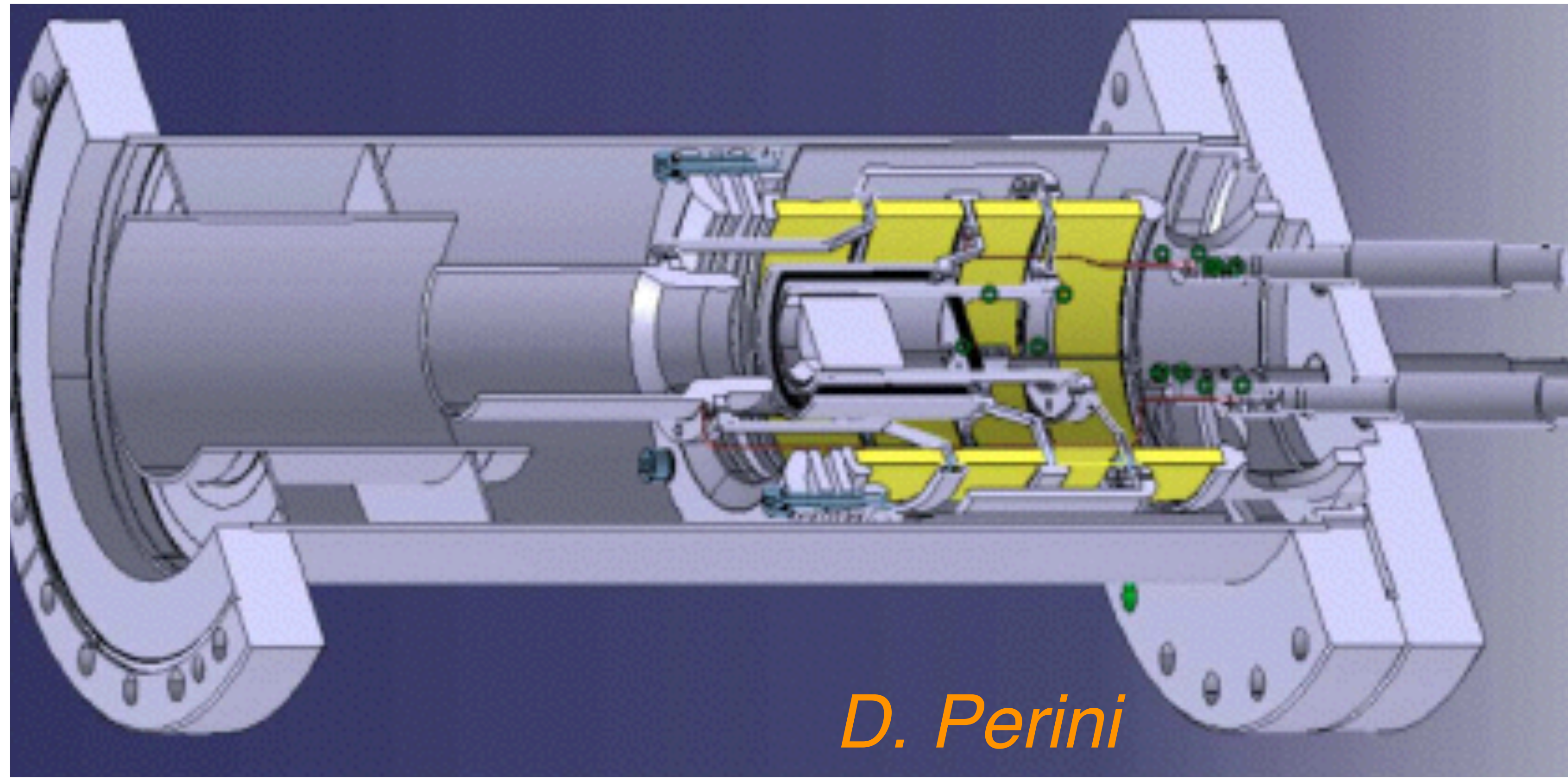
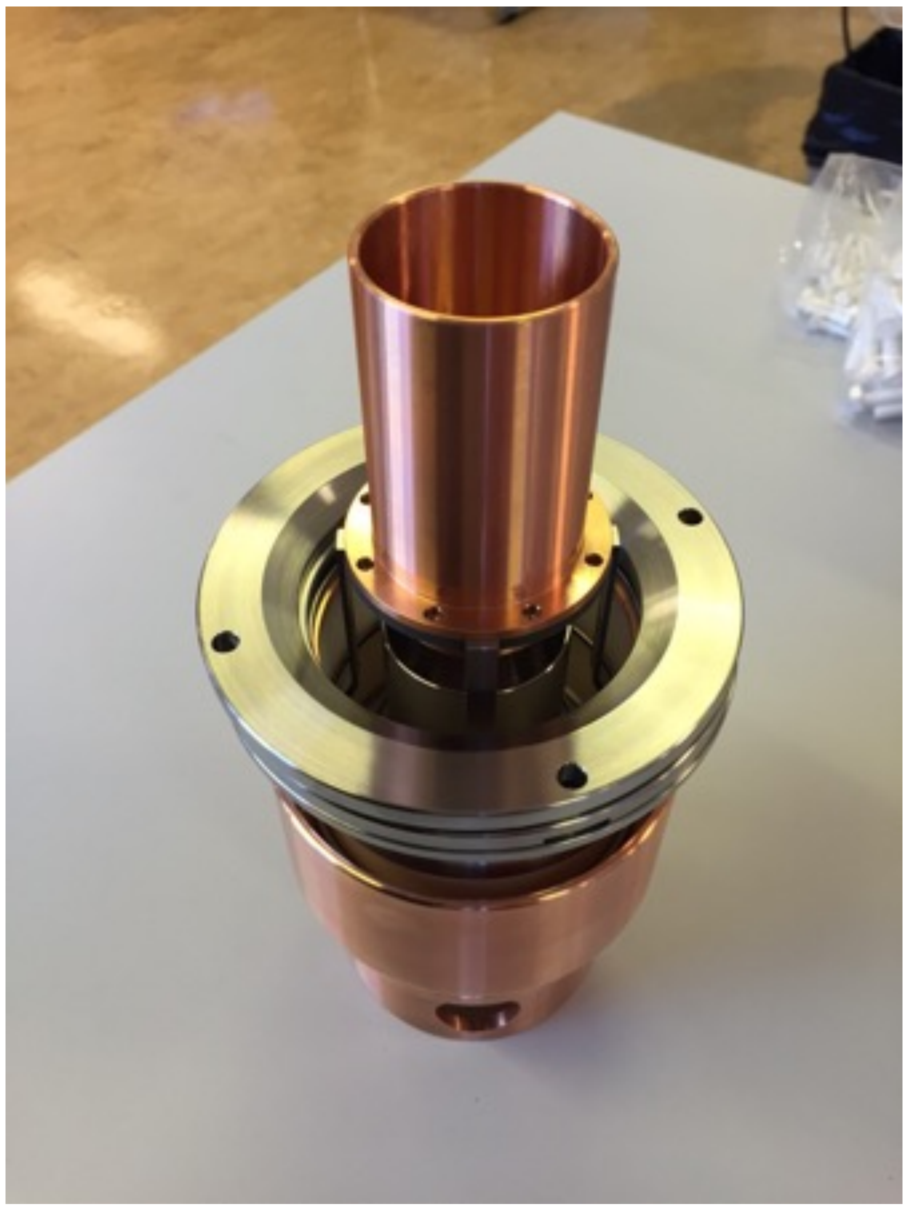


D. Perini

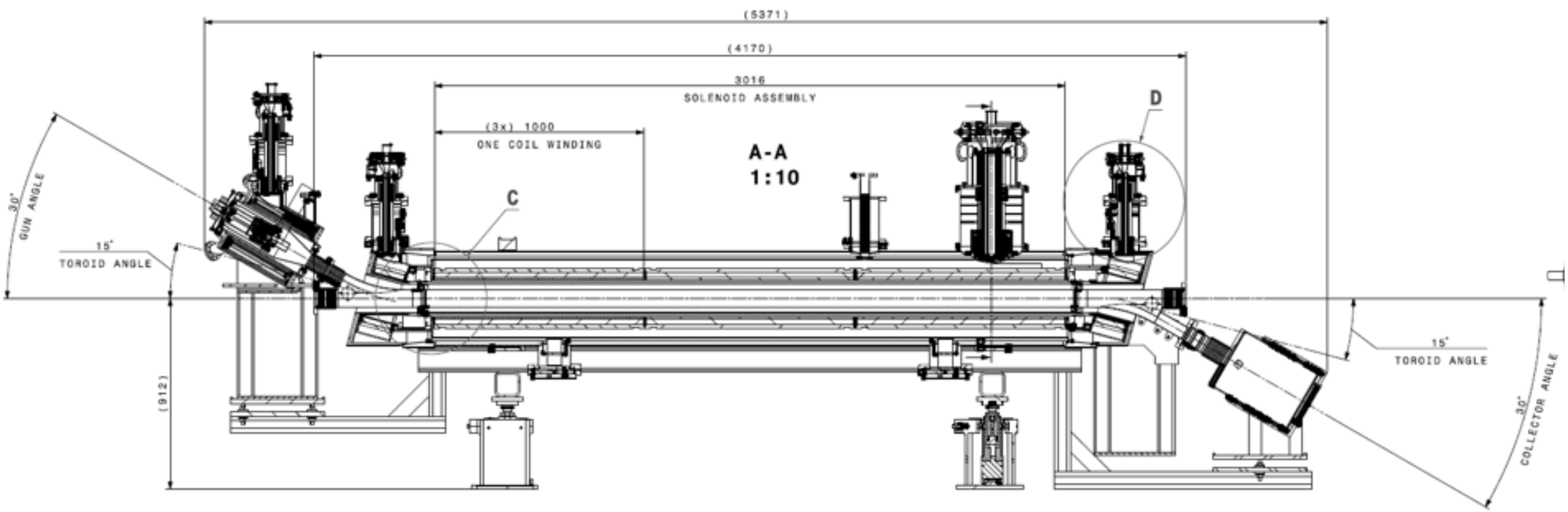
Gun





First CERN gun will soon be tested at the FNAL electron beam test stand!

Location and infrastructure



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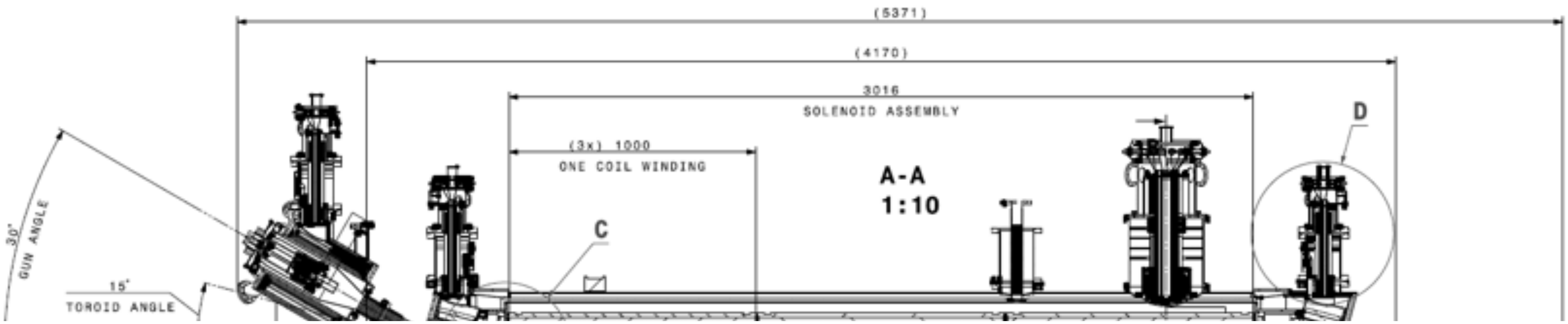
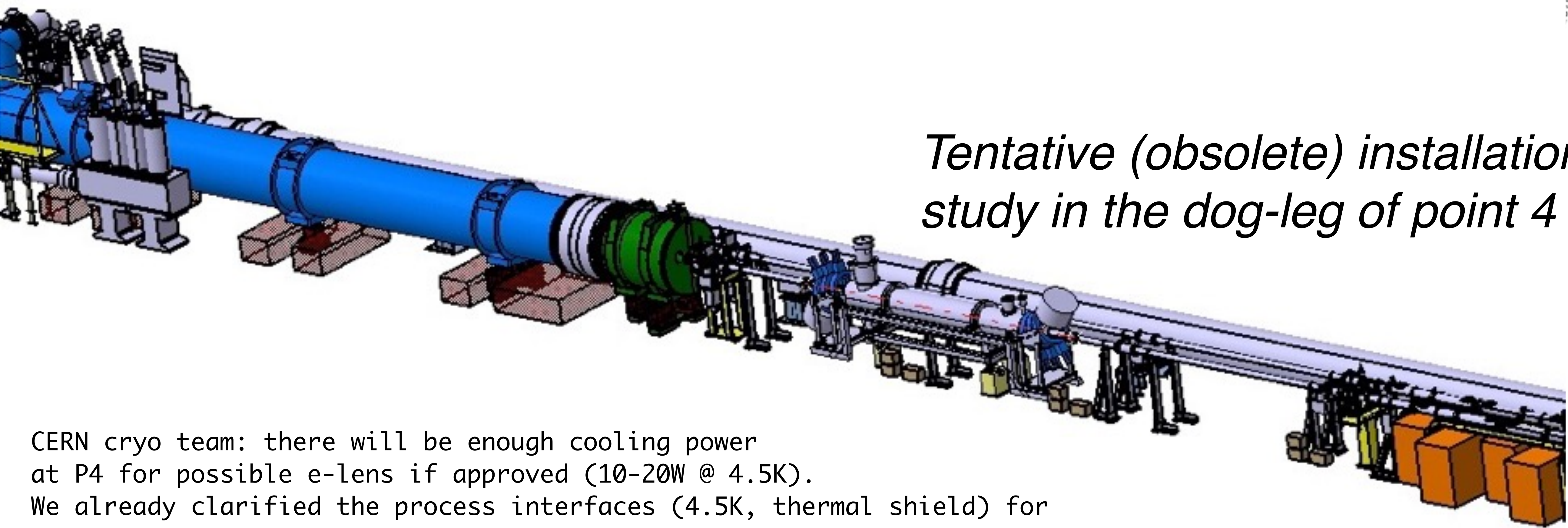


A. Rossi & integration team



Tentative (obsolete) installation study in the dog-leg of point 4

```
CERN cryo team: there will be enough cooling power
at P4 for possible e-lens if approved (10-20W @ 4.5K).
We already clarified the process interfaces (4.5K, thermal shield) for
pressure and temperature, and position is so far open but could be
managed with connections to be installed during a LS.
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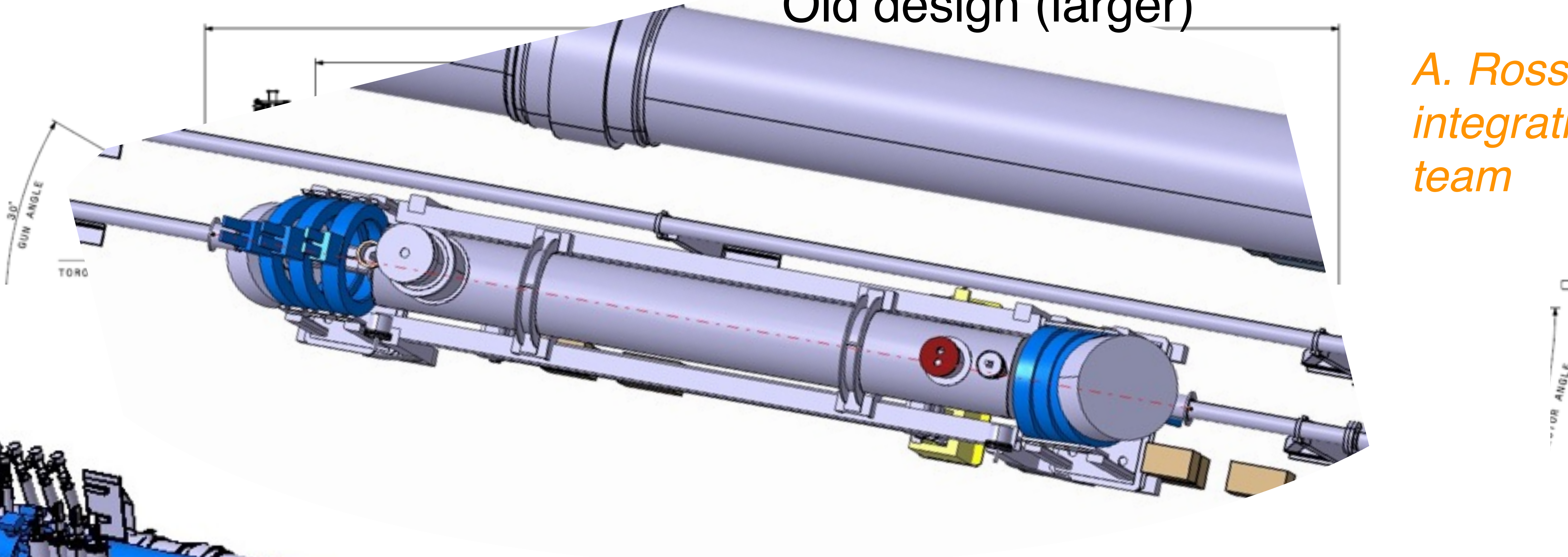
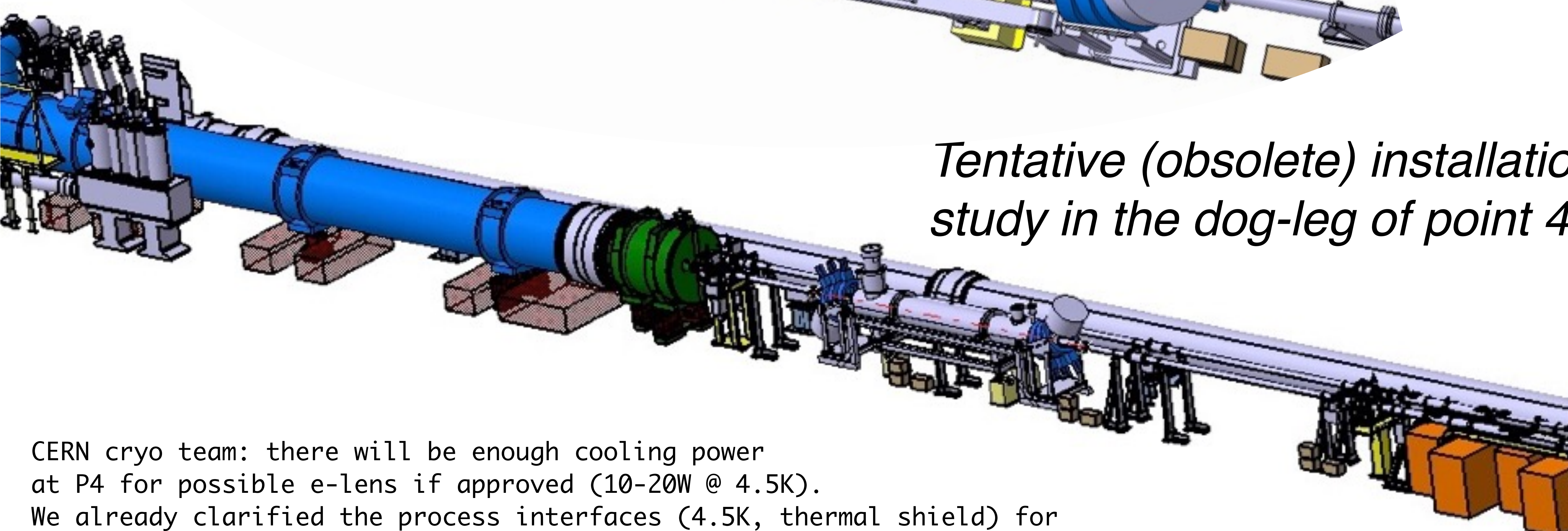
Location and infrastructure

Old design (larger)



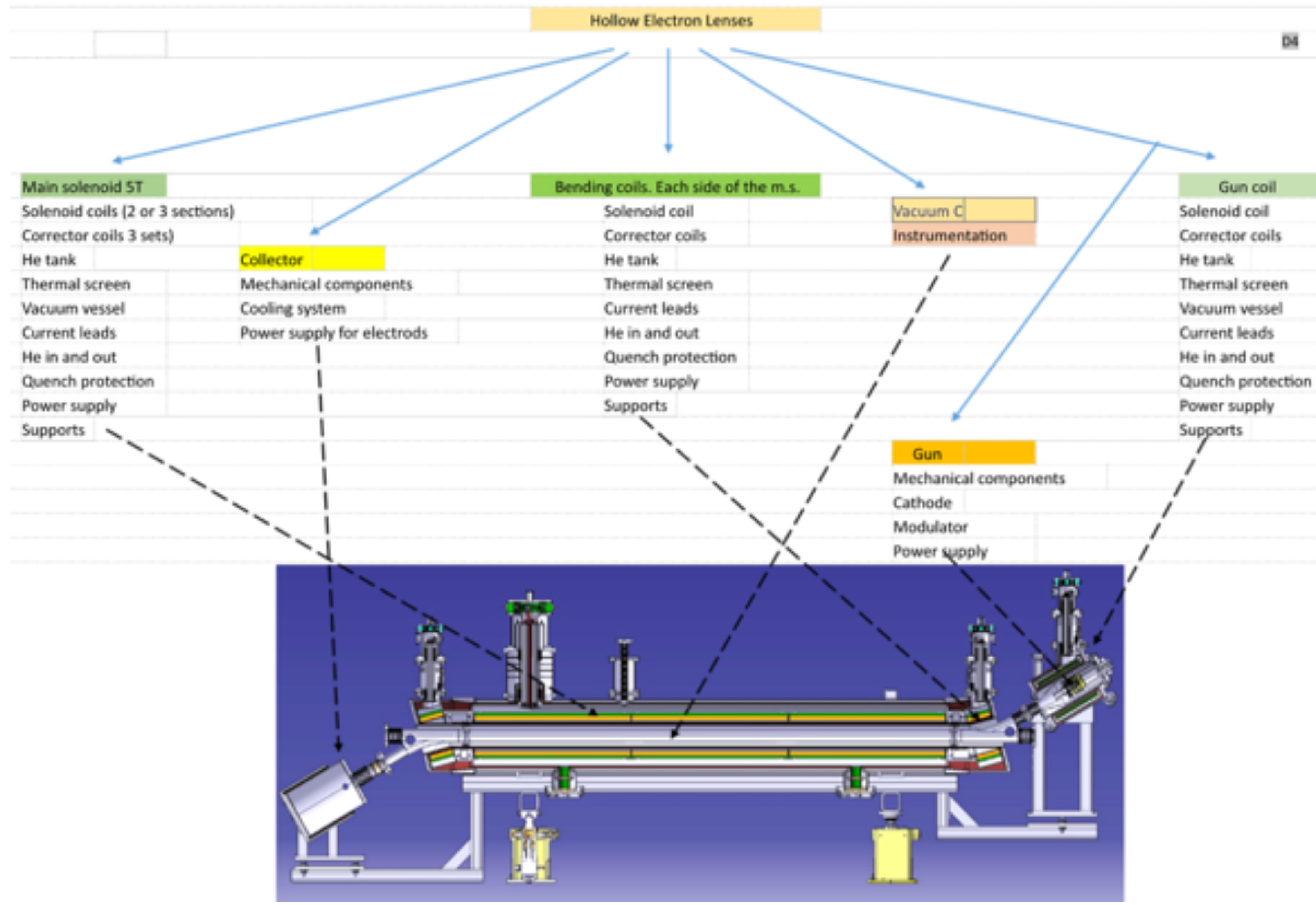
A. Rossi & integration team

Tentative (obsolete) installation study in the dog-leg of point 4



CERN cryo team: there will be enough cooling power
at P4 for possible e-lens if approved (10-20W @ 4.5K).
We already clarified the process interfaces (4.5K, thermal shield) for
pressure and temperature, and position is so far open but could be
managed with connections to be installed during a LS.

Cost estimates



Detailed work by D. Perini (CERN) and L. Valerio (FNAL)

Included all key hardware components, for 2 units:

CERN	↦	5 MCHF
FNAL	↦	12.8 M$

Magnet configuration not fully equivalent.

Not included: cabling, infrastructure, power supplies, modulators, halo monitoring (in WP13)

Conclusions

- **Introduced the topics of halo controls for the HL-LHC**
  - *Topic recognised as critical consistently in collimation reviews that warned us about possible concerns from loss spikes.*
  - *Needs were clearer in Run I, losses have got quieter at 6.5 TeV.*
- **We have worked actively on designing a hollow lens for HL**
  - *Very advanced design status that followed a CDR produced with FNAL.*
  - *Design in nearly complete, could be finalised in less than 1 year:*
    - *Still many details can be improved, but no showstopper.*
  - *Interest by US-LARP and other partners to contribute to construction.*
- **Alternative techniques for halo control studied**
  - *Dedicate talk will address the limitations that we think they have.*
- **It is now time to decide if this shall be made part of the collimation upgrade baseline**
  - *Far enough into run II at 6.5TeV.*
- **We are looking forward to getting feedback from this review!**