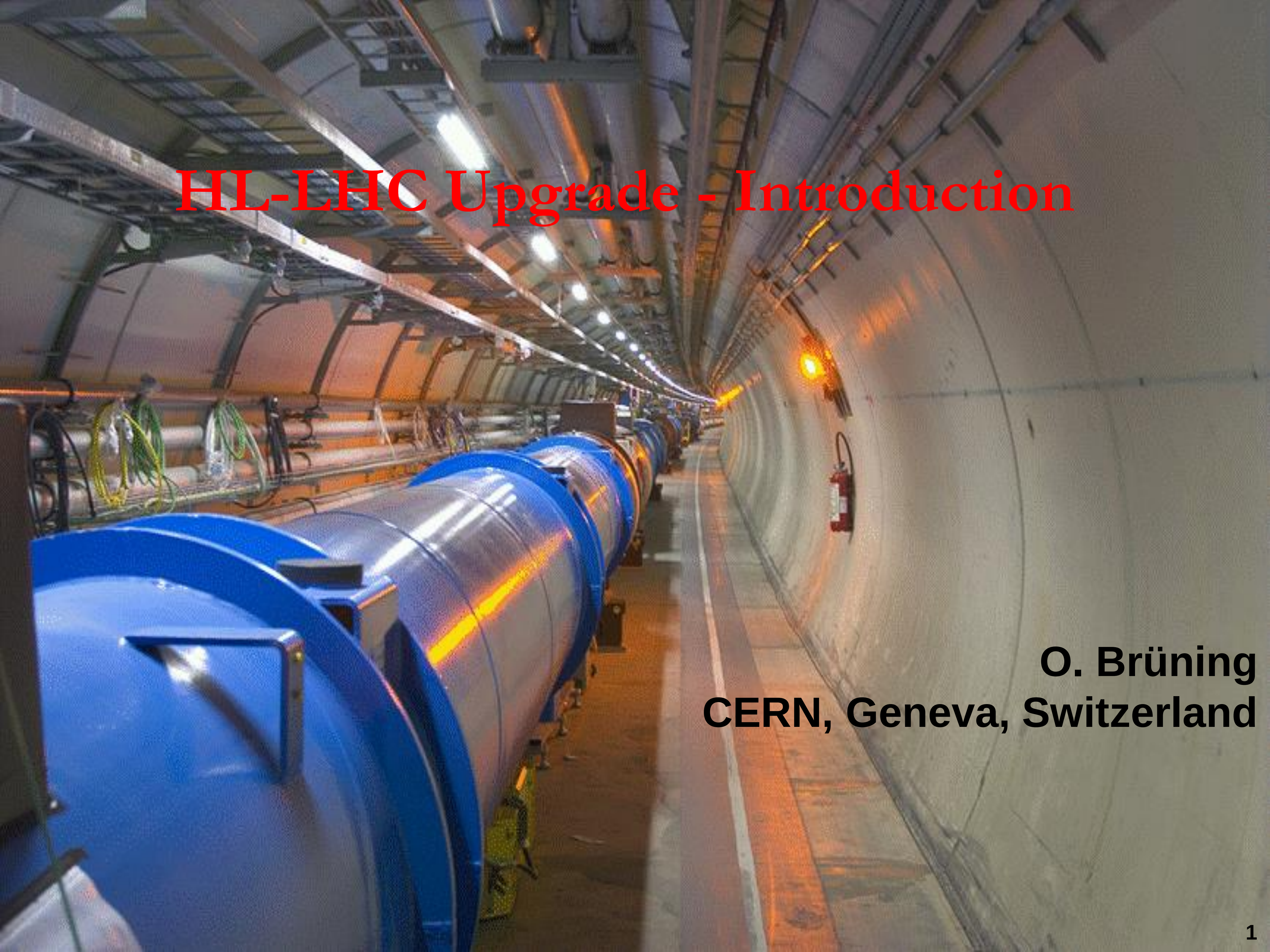


HL-LHC Upgrade - Introduction

O. Brüning
CERN, Geneva, Switzerland

Introduction: LHC Goals & Performance

- Collision energy: Higgs discovery requires $E_{CM} > 1$ TeV

  p collisions → $E_{beam} > 5$ TeV → LHC: E = 7 TeV

- Instantaneous luminosity: # events in detector $= L \times \sigma_{event}$

  rare events → $L > 10^{33} cm^{-2} sec^{-1}$ → $L = 10^{34} cm^{-2} sec^{-1}$

- Integrated luminosity: L $= \int L(t)\,dt$

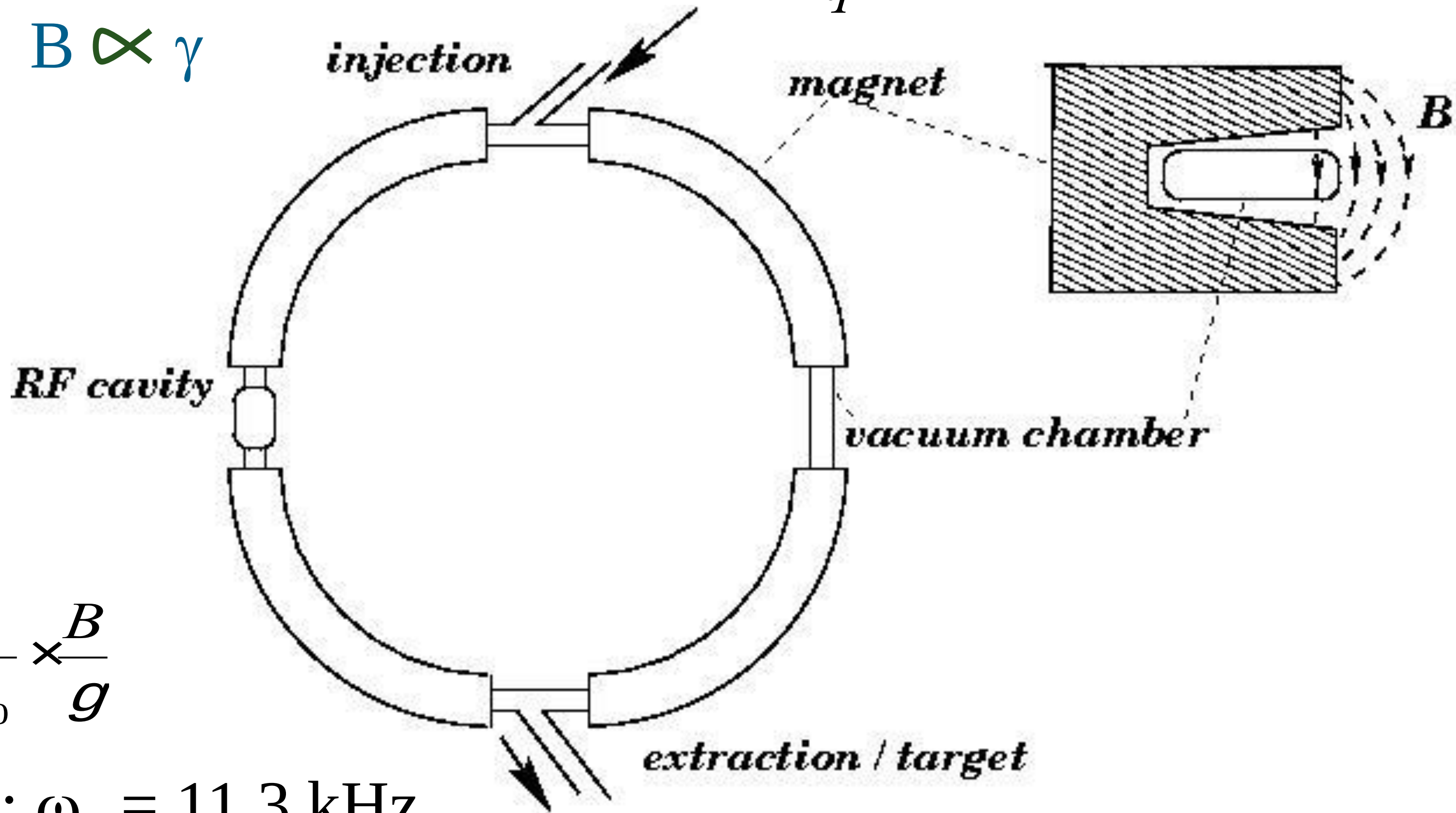
  depends on the beam lifetime, the LHC cycle and 'turn around' time and overall accelerator efficiency

Introduction: the LHC is a Synchrotron

R = constant:

$$r = \frac{m_0}{q} \times \frac{g}{B} \times v$$

v = c ➔ $B \propto \gamma$



$$w_0 = \frac{q}{m_0} \times \frac{B}{g}$$

LHC / LEP: ω_0 = 11.3 kHz

Introduction: the LHC is a Synchrotron

- physics goal: E = 7 TeV

- existing infrastructure: LEP tunnel: circ = 27 km (ca. 17mi)
  with 22 km arcs (ca. 14mi)

- assume 80% of arcs can be filled with dipole magnets: F = 0.8

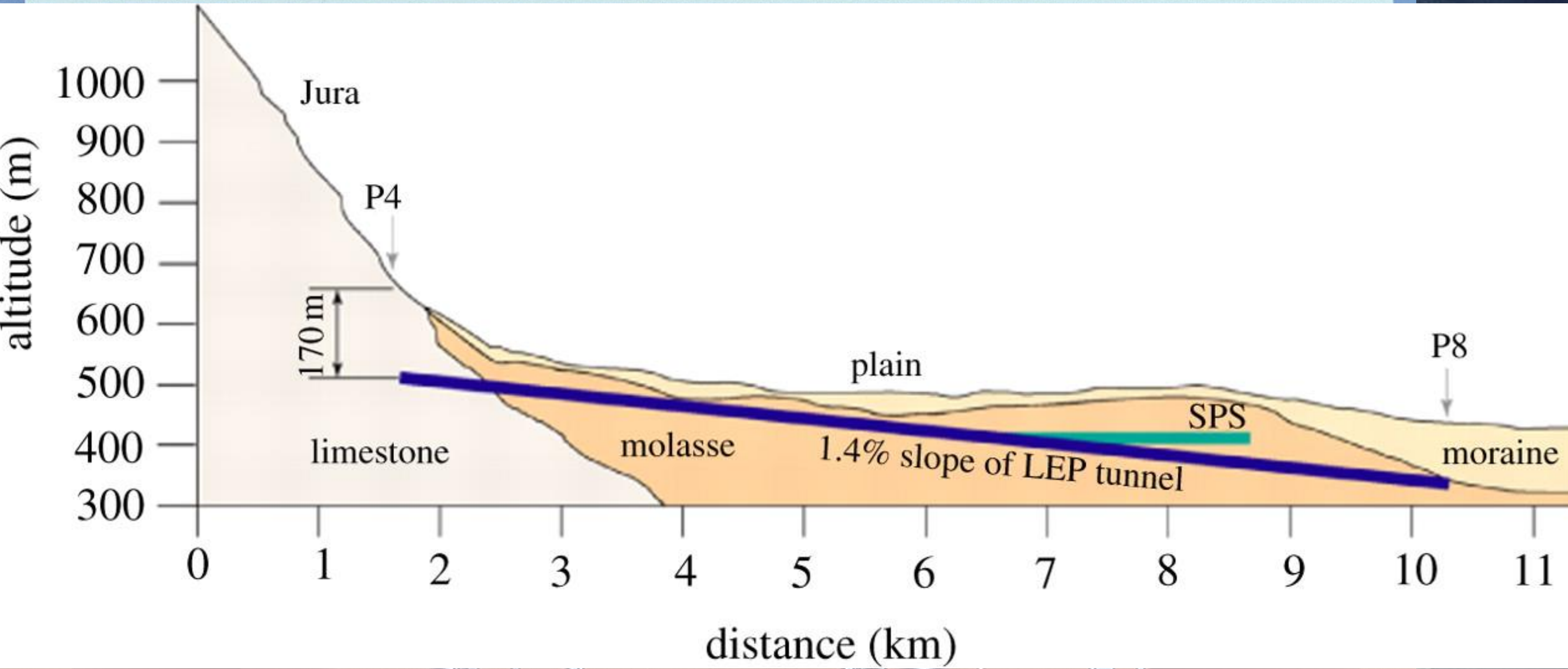
- required dipole field for the LHC:

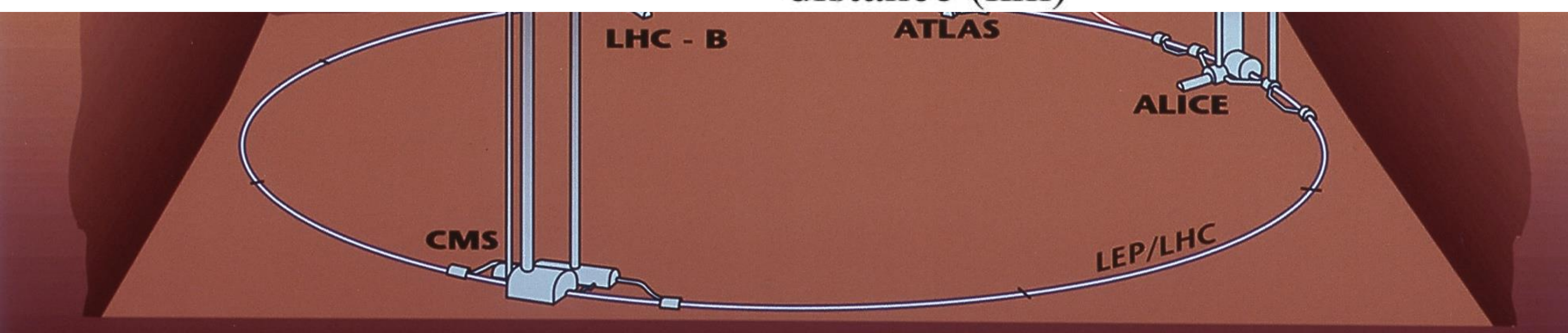
$$\frac{2\pi}{q} \times \frac{E/c}{circ \times F} = B$$

→ B = 8.38 T

(earth: 0.3 10^{-4} T)

Overall view of the LHC experiments.

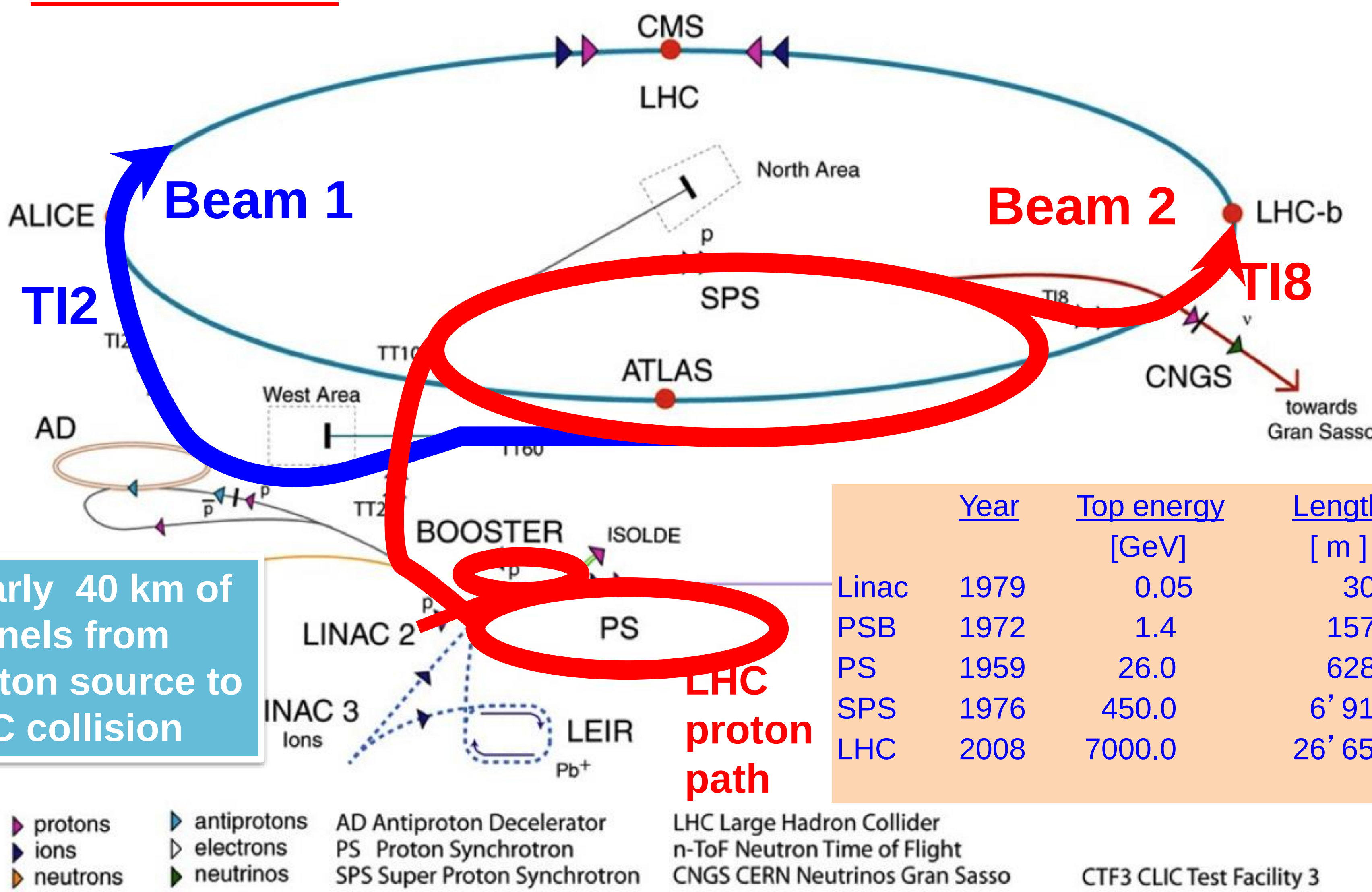




C!

.5 TeV

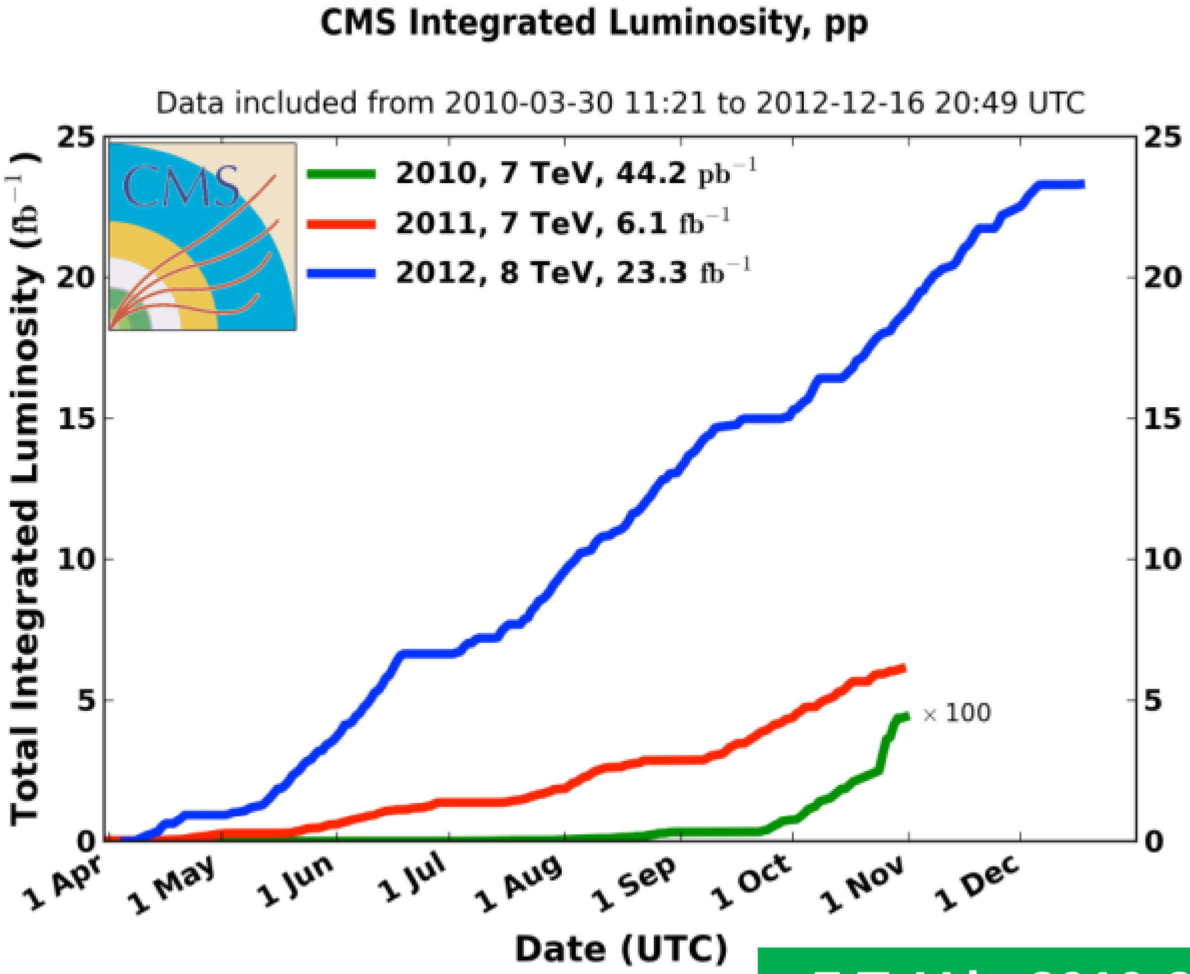
Introduction: LHC is NOT a Standalone Machine:



Nearly 40 km of tunnels from proton source to LHC collision

	Year	Top energy [GeV]	Length [m]
Linac	1979	0.05	30
PSB	1972	1.4	157
PS	1959	26.0	628
SPS	1976	450.0	6'911
LHC	2008	7000.0	26'657

LHC Performance during RunI: 2010-2012



Σ ~30 fb^{-1}

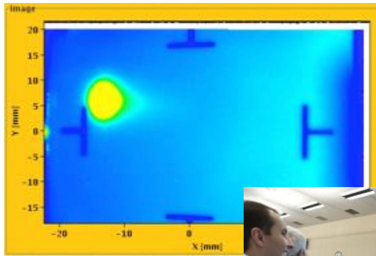
2010: **0.04 fb^{-1}**
7 TeV CoM
Commissioning

2011: **6.1 fb^{-1}**
7 TeV CoM
… exploring limits

2012: **23.3 fb^{-1}**
8 TeV CoM
… production

7 TeV in 2010-2011and 8 TeV in 2012

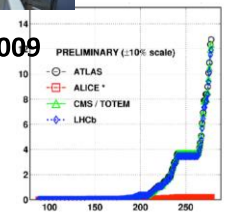
LHC RUN-I Timeline



August 2008
First injection test

September 10, 2008
First beams around

November 29, 2009
Beam back



April 2010
Squeeze to 3.5 m

October 14 2010
1e32
248 bunches

June 28 2011
1380 bunches (50ns)

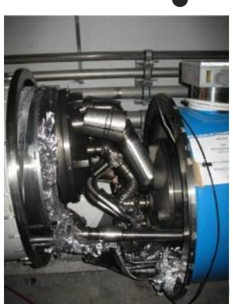
1380

6 June, 2012
6.8e33

4 July, 2012
Higgs discovery

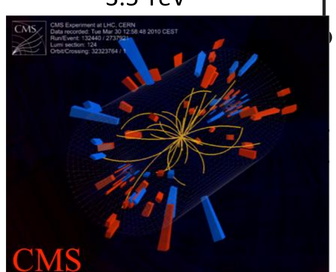
End of RunI
23.3fb^{-1}

2008	2009	2010	2011	2012

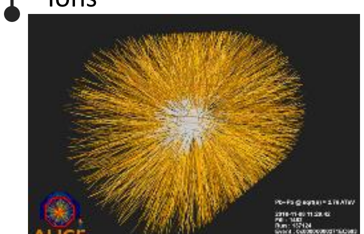


September 19, 2008
'Incident'
Accidental release of 600 MJ stored in one sector of LHC dipole magnets

March 30, 2010
First collisions at 3.5 TeV



November 2010
Ions

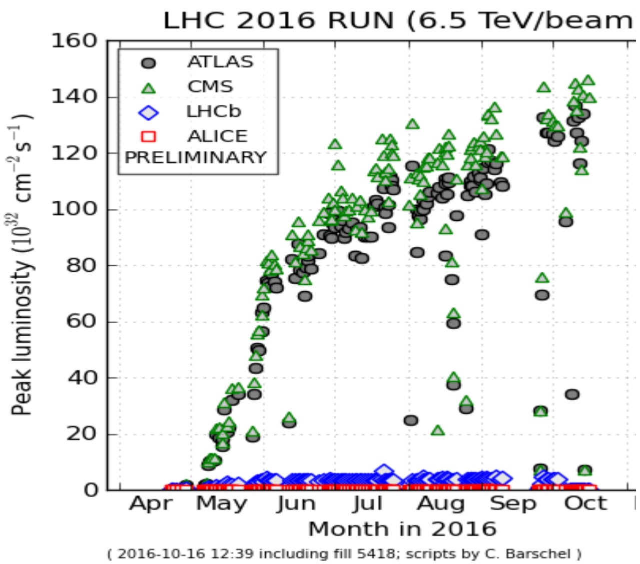


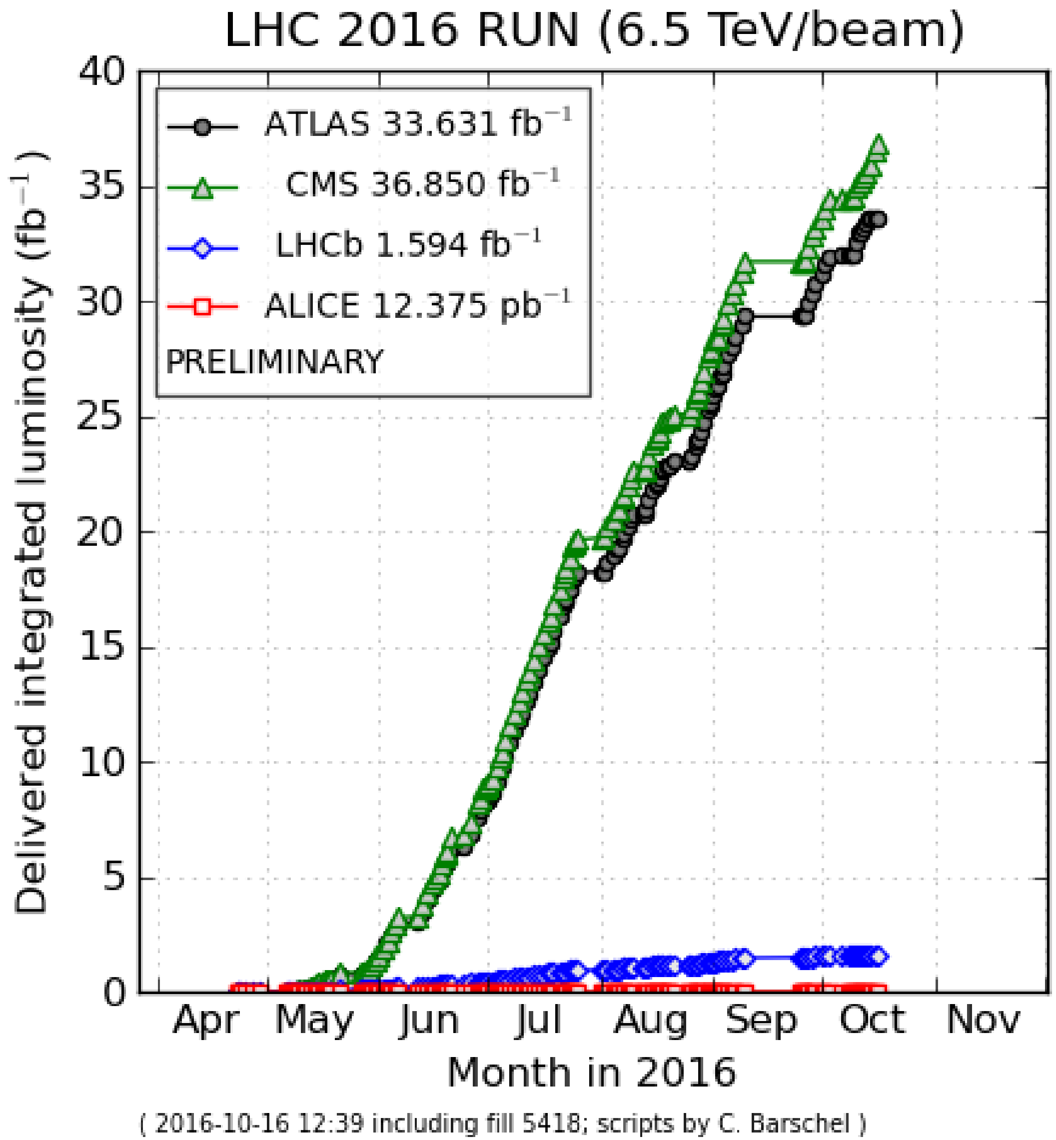
18 June, 2012
6.6 fb^{-1}
to ATLAS & CMS

LS1 Consolidation:

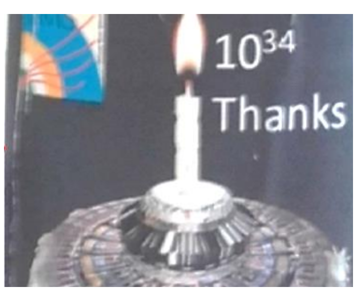
LHC Performance during RunII - 2016:

13 TeV after LS1

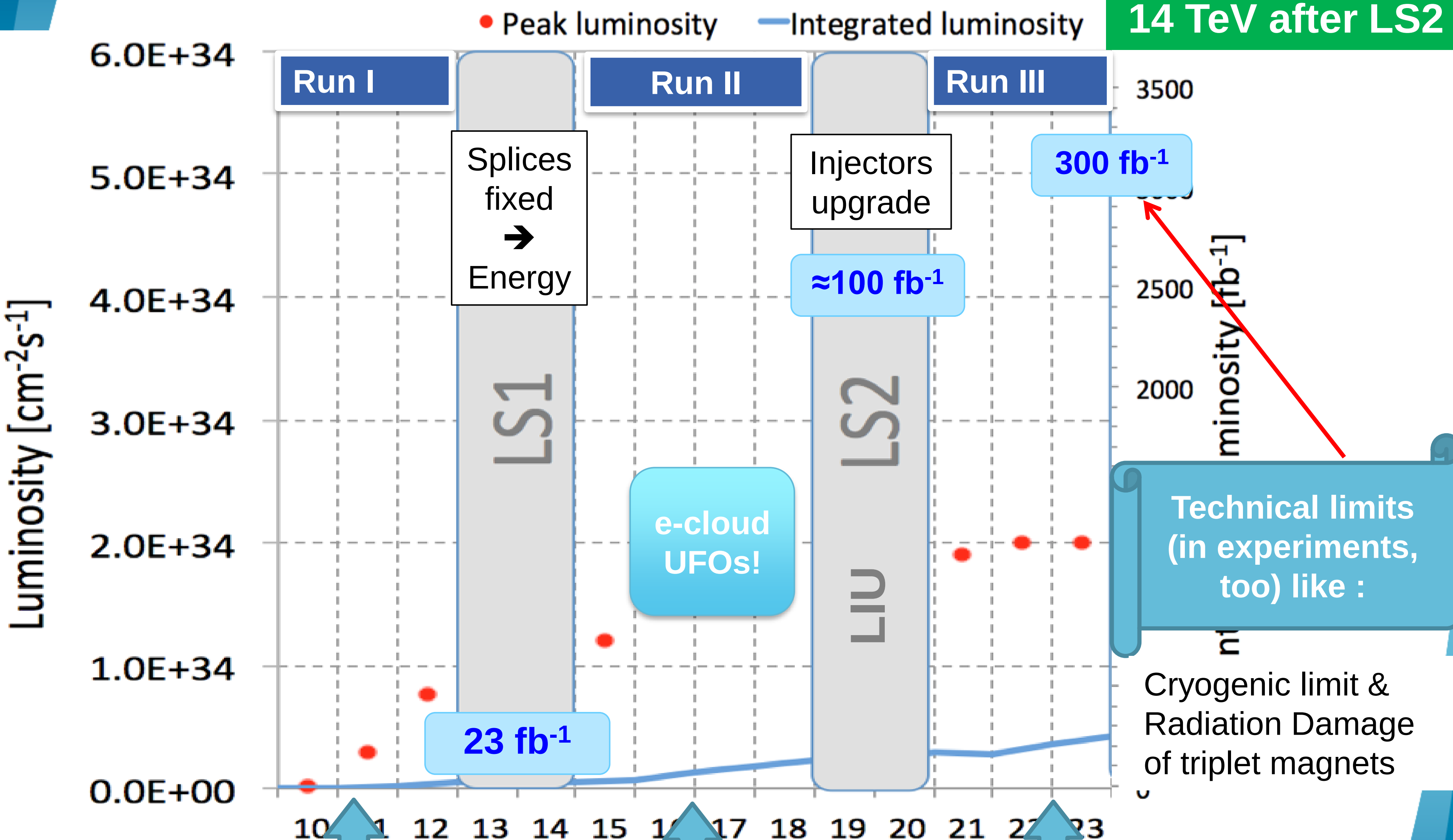




Design luminosity
> 10^{34} cm^{-2} s^{-1}



Performance Projections up to HL-LHC:



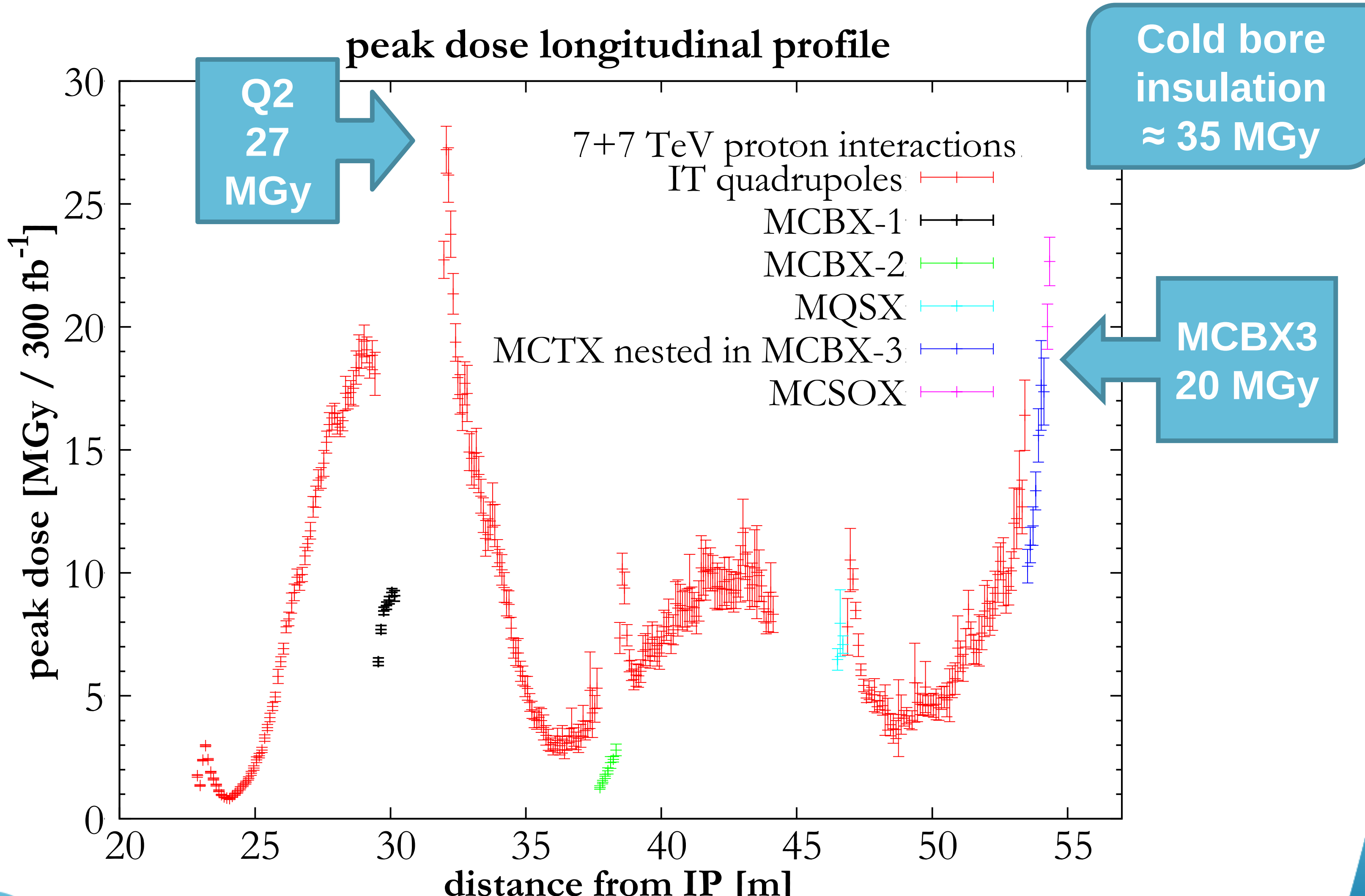
0.75 10^{34} $cm^{-2}s^{-1}$
50 ns bunch
high pile up ~40

1.5 10^{34} $cm^{-2}s^{-1}$
25 ns bunch
high pile up ~40

1.5 -2.2 10^{34} $cm^{-2}s^{-1}$
25 ns bunch
very high pile up > 60

HiLumi HL-LHC PROJECT

HL-LHC technical bottleneck: Radiation damage to triplet magnets at 300 fb^{-1}



LHC Upgrade Goals: Performance optimization

- Luminosity recipe (round beams):

$$L = \frac{n_b \cdot N_1 \cdot N_2 \cdot \gamma \cdot f_{rev}}{4\pi \cdot \beta^* \cdot \varepsilon_n} \cdot F(\phi, \beta^*, \varepsilon, \sigma_s)$$

→ 1) maximize bunch intensities → Injector complex

→ 2) minimize the beam emittance Upgrade LIU

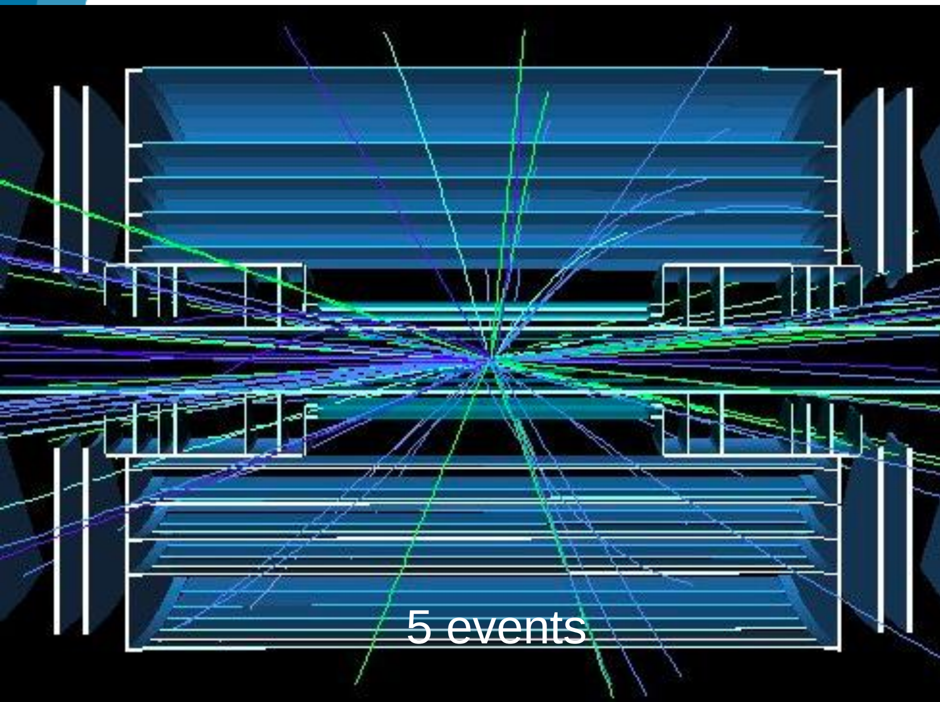
→ 3) minimize beam size (constant beam power); → triplet aperture

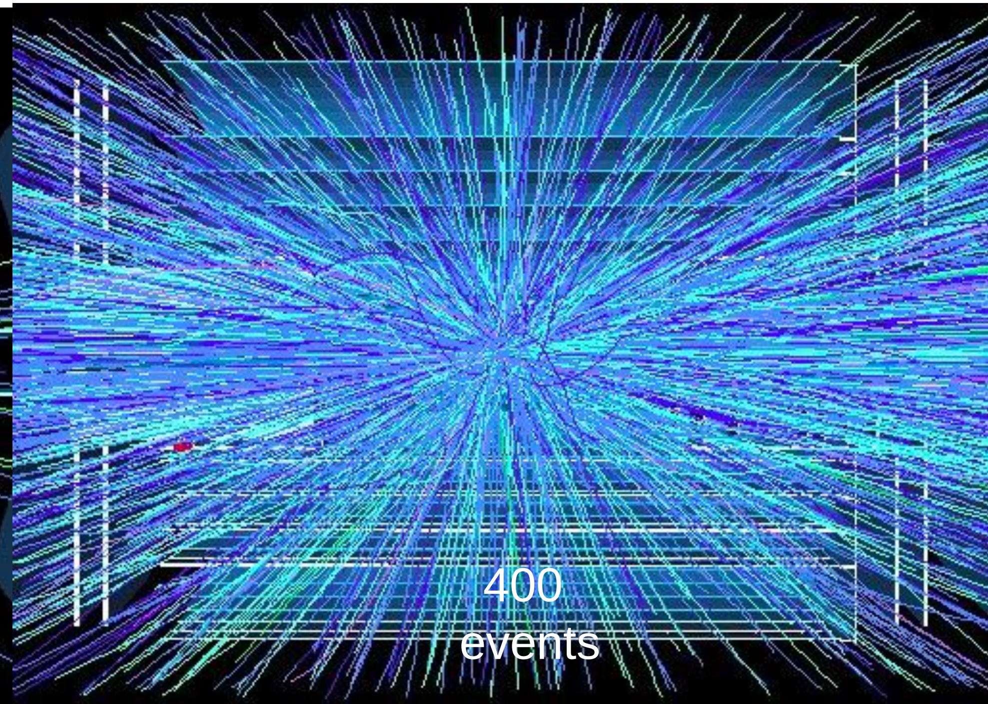
→ 4) maximize number of bunches (beam power); → 25ns

→ 5) compensate for 'F'; → Crab Cavities

→ 6) Improve machine 'Efficiency' → minimize number of unscheduled beam aborts

Goal of High Luminosity LHC (HL-LHC):





implying an integrated luminosity of **250 fb^{-1} per year**,

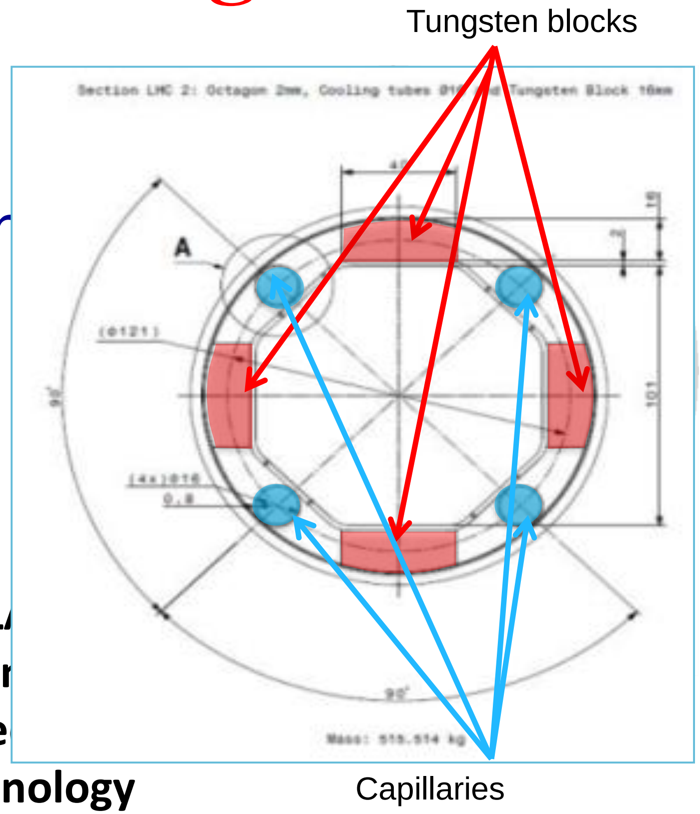
design oper. for μ δ **140** (➔ peak luminosity **5 10^{34} cm^{-2} s^{-1}**)

➔ Operation with levelled luminosity!

➔ 10x the luminosity reach of first 10 years of LHC operation!!

HL-LHC technical bottleneck: Radiation damage to triplet magnets

Need to replace existing triplet magnets with radiation hard system (shielding!) such that the new magnet coils receive a similar radiation dose @ 10 times higher integrated luminosity!!!!!



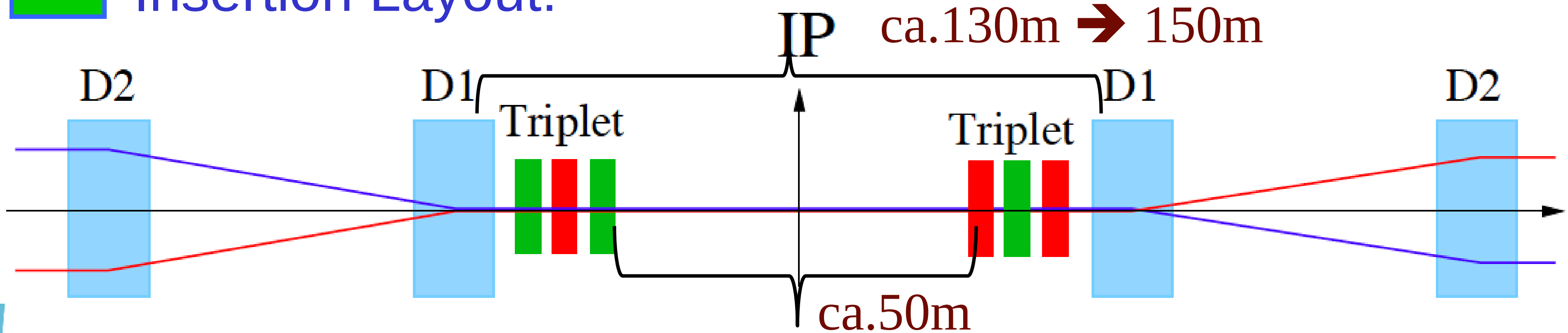
US-L
magn
Base
technology

- → Requires larger aperture!
- → New magnet technology
- → 70mm at 210 T/m ➔150mm diameter 140 T/m

  8T peak field at coils ➔ 12T field at coils (Nb_3Sn)!!!

HL-LHC Challenges: Crossing Angle

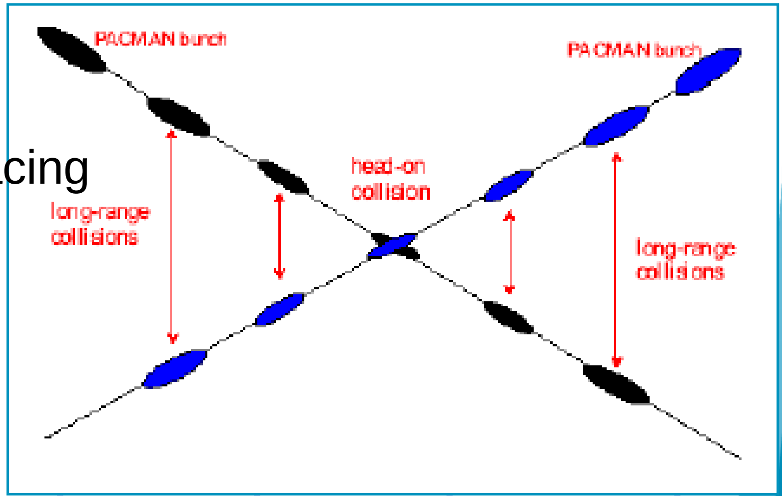
Insertion Layout:



Parasitic bunch encounters:

Operation with ca. 2800 bunches @ 25ns spacing
➔ approximately 30 unwanted collision per Interaction Region (IR).

➔ Operation requires crossing angle



non-linear fields from long-range beam-beam interaction:

efficient operation requires large beam separation at unwanted collision points ➔ Separation of 10 -12 σ ➔ large triplet apertures for HL-LHC!!

HL-LHC Upgrade Ingredients: Crab Cavities

Geometric Luminosity Reduction Factor:

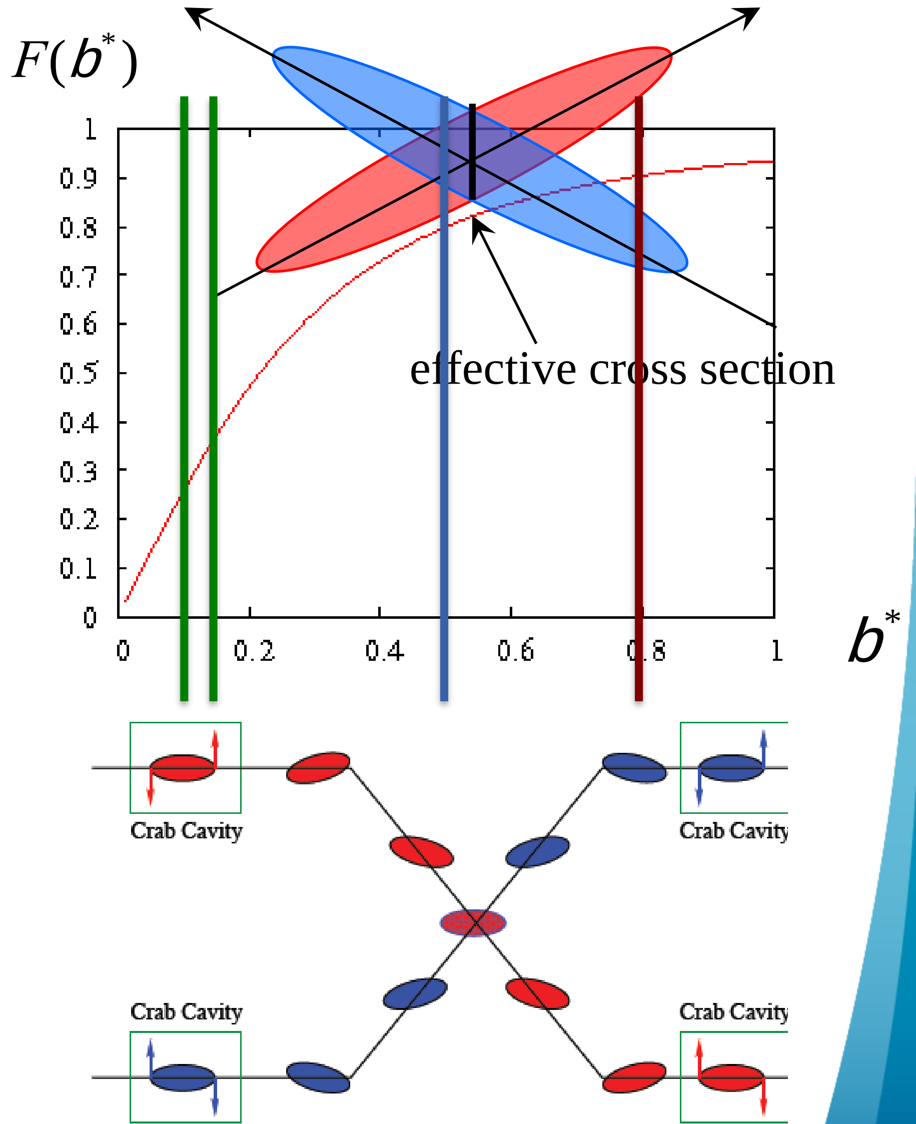
Crab Cavities:

- Reduces the effect of geometrical reduction factor
- Independent for each IP

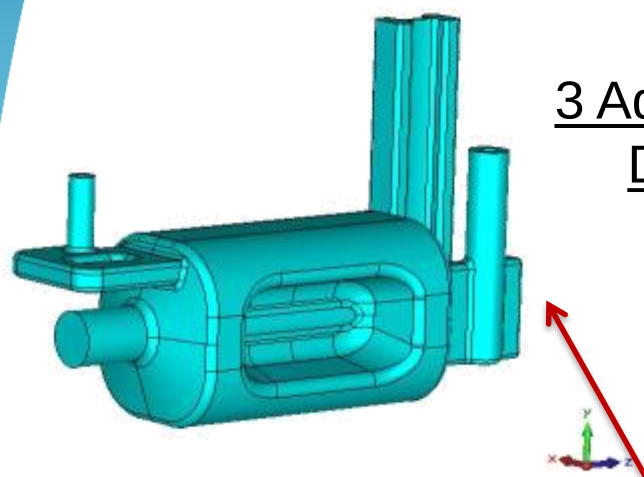
$$F = \frac{1}{\sqrt{1+\Phi^2}}; \quad \Phi \equiv \frac{\theta_c \sigma_z}{2\sigma_x}$$

- Noise from cavities to beam?!?
- Challenging space constraints:

  ➔ requires novel compact cavity design

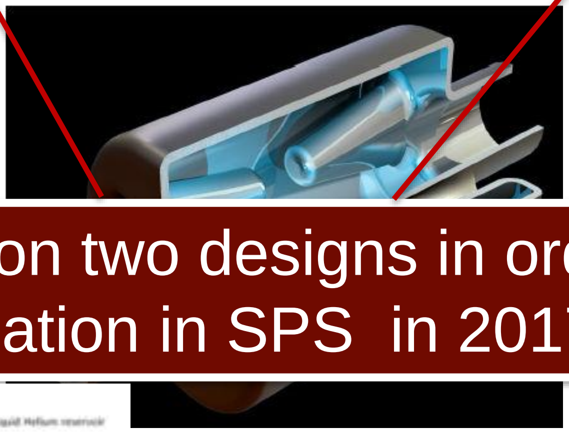


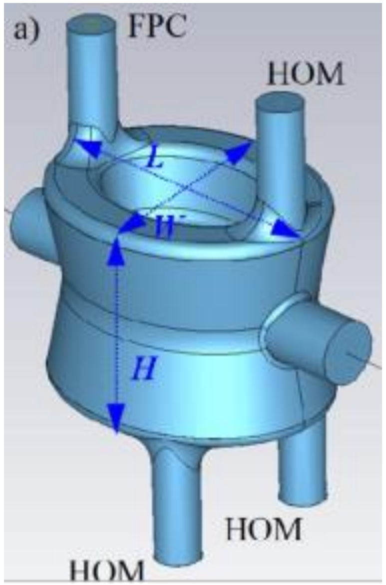
HL-LHC Crab Cavity Designs



RF Dipole: Waveguide or waveguide-coax couplers

3 Advanced Design Studies with Different Coupler concepts



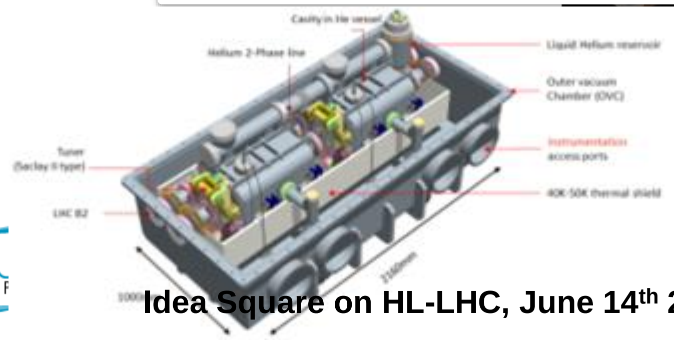


Double ¼-wave:

vith

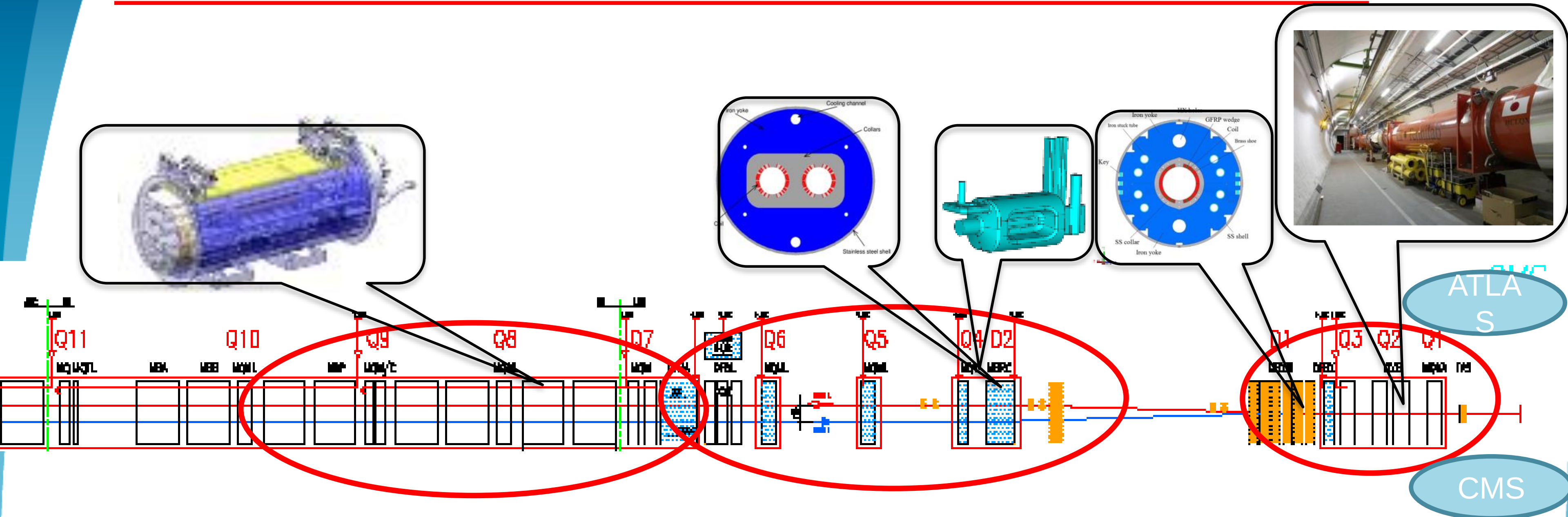
a

Concentrate on two designs in order to be ready for test installation in SPS in 2017/2018 TS



Present baseline: 4 cavity/cryomod
TEST in SPS under preparation for 2018

The critical zones around IP1 and IP5



3. For collimation we also need to change the DS in the continuous cryostat in IR7: 11T Nb_3Sn dipole

2. We also need to modify a large part of the matching section e.g. Crab Cavities & D1, D2

1. New triplet Nb_3Sn required due to:

-Radiation damage

-Need for more aperture

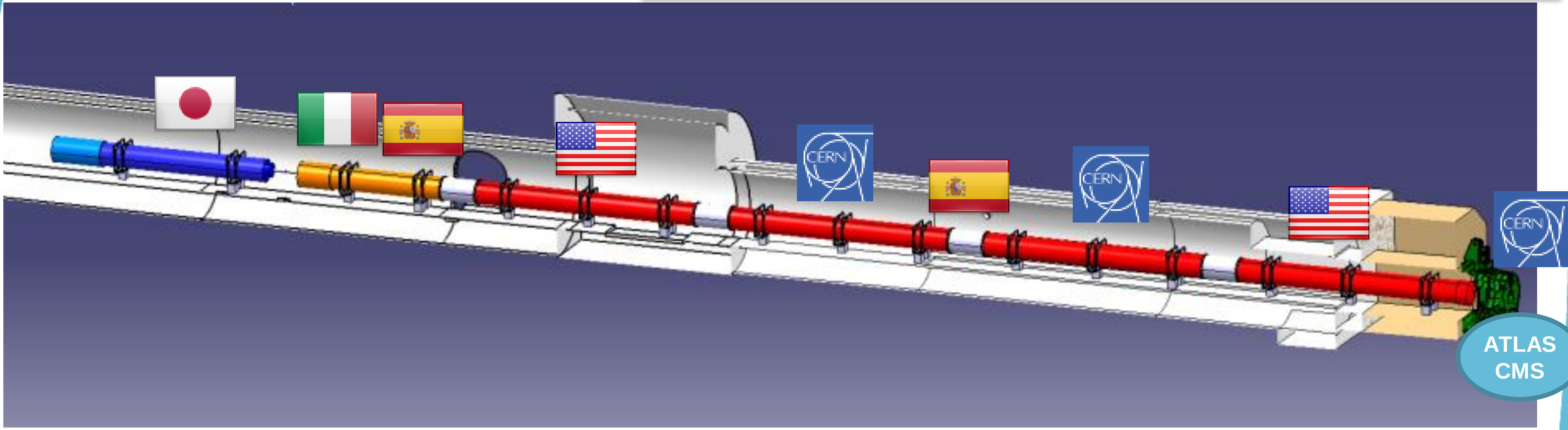
Changing the triplet region is not enough for reaching the HL-LHC goal!

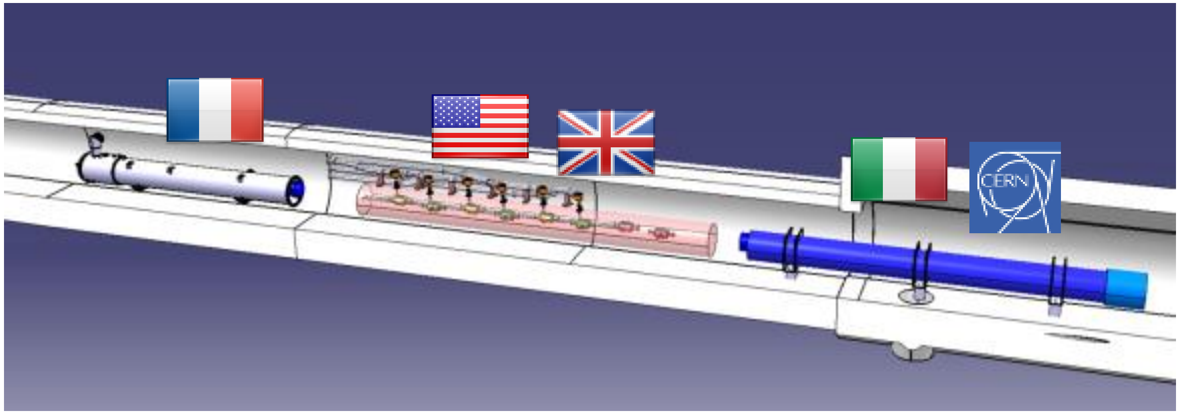
→ **More than 1.2 km of LHC !!**

→ **Plus technical infrastructure (e.g. Cryo and Powering)!!**

In-kind contributions and collaborations for design and prototypes

First approval as construction Project: Sept. 2013



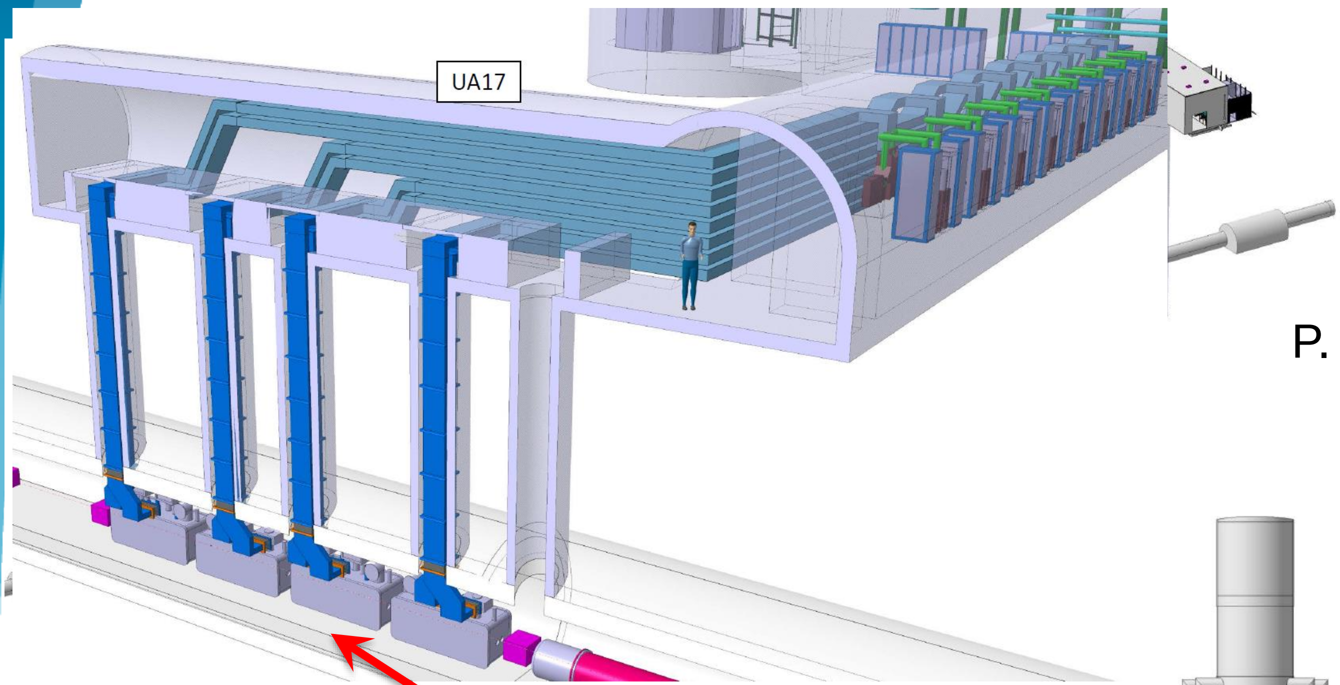


Q1-Q3 : R&D, Design, Prototypes and in-kind **USA**
D1 : R&D, Design, Prototypes and in-kind **JP**
D2: Design and Prototypes **IT**
MCBX : Design and Prototype **ES**
HO Correctors: Design and Prototypes **IT**
Q4 : Design and Prototype **FR**

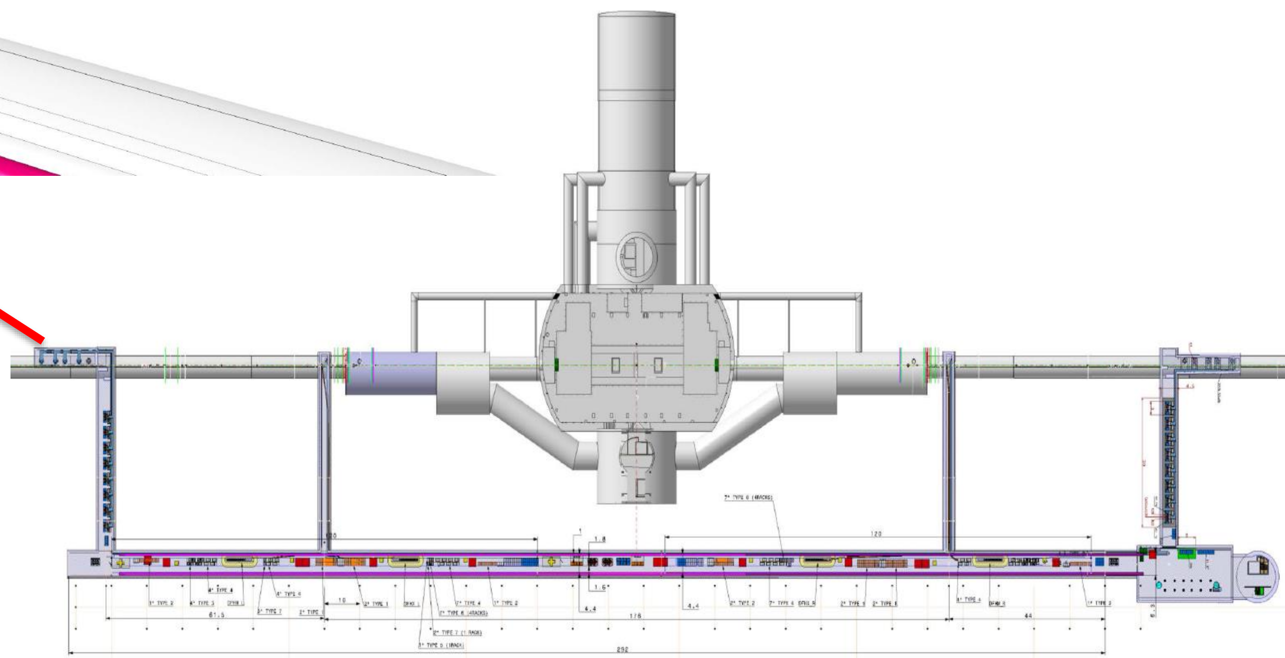
CC : R&D, Design and in-kind **USA**

CC : R&D and Design **UK**

IR1 & IR5 Underground Civil Engineering:



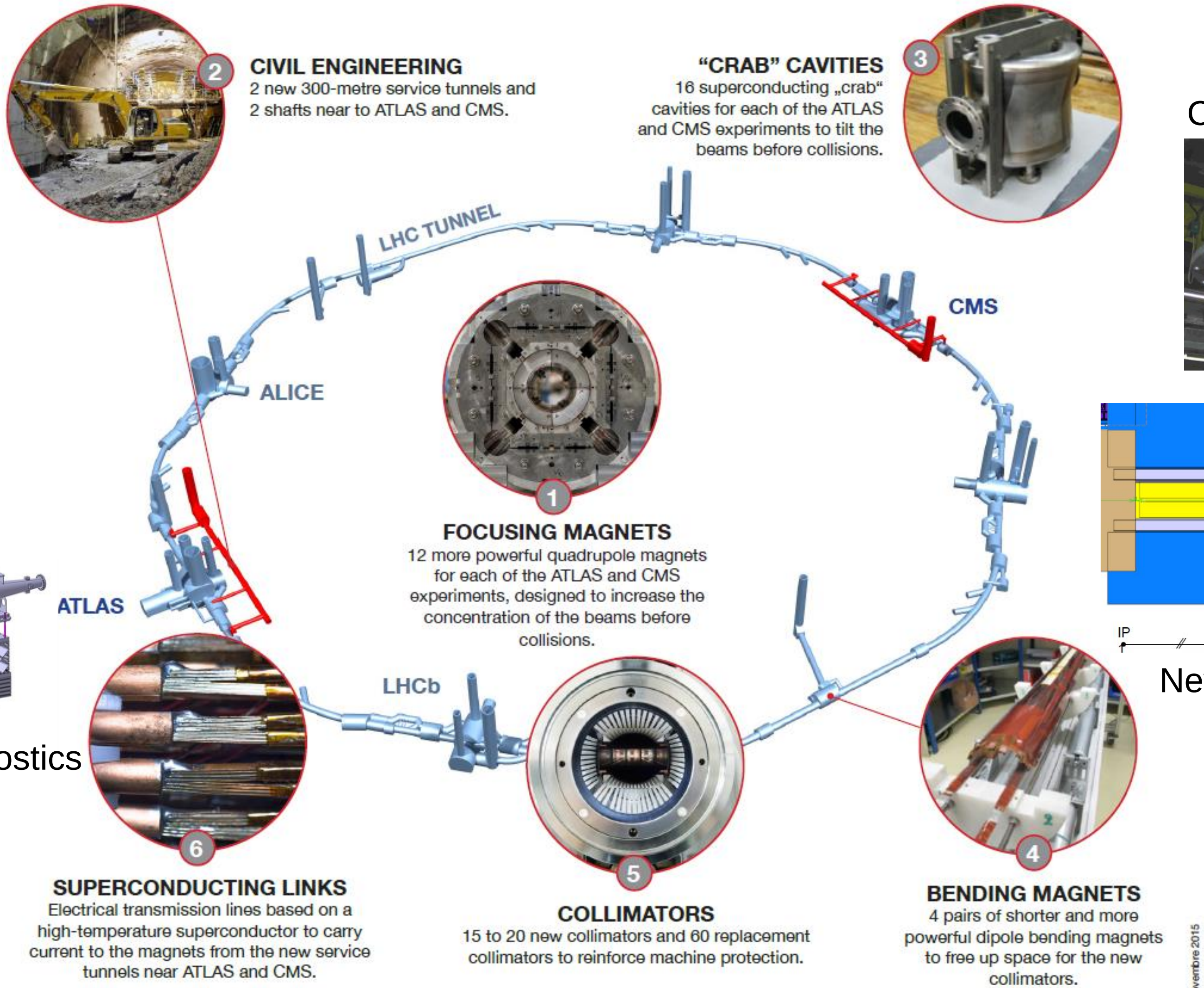
P. Fessia, HL-LHC TDR



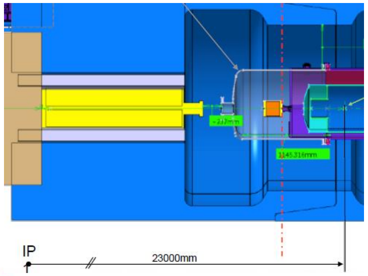
New Schedule: ➔ HL-LHC CE during LS2

HL-LHC: Project Corner Stones

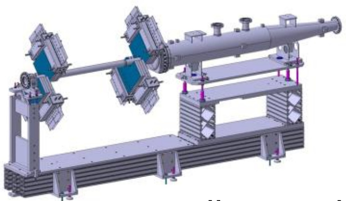
Cryo@P4



Cryo@P1-P5



New TAS and VCX



Beam diagnostics BGV

High Luminosity Work Packages after FP7 DS:

HL-LHC PROJECT MANAGEMENT

Project Leader: Lucio Rossi, CERN
Deputy Project Leader: Oliver Brüning, CERN
Project Office Manager: Laurent Tavian, CERN
Configuration, QA, Resource Manager: Isabel Bejar Alonso, CERN
Integration: Paolo Fessia, CERN
Collaborations (in-kind): Beniamino Di Girolamo, CERN
Budget Officer: Benoit Delille, CERN
Safety Officer: Thomas Otto, CERN
Communication: Isabel Bejar Alonso, CERN
Secretariat: Cécile Noels, CERN

WP2 Accelerator Physics
Gianluigi Arduini
Rogelio Tomas Garcia

WP3 IR Magnets
Ezio Todesco
Paolo Ferracin

WP4 Crab Cavities & RF
Rama Calaga
Ofelia Capatina

WP5 Collimation
Stefano Redaelli
Roderik Bruce

WP6A Cold Powering
Amalia Ballarino
Vittorio Parma

WP6B Warm Powering
Jean-Paul Burnet
Michele Martino

WP7 Machine Protection
Daniel Wollman
Reiner Denz

WP8 Collider-Experiment Interface
Helmut Burkhardt – F. Sanchez Galan
Sébastien Evrard

WP9 Cryogenics
Serge Claudet
Rob Van Weelderen

WP10 Energy Deposition & R2E
Markus Brugger – Francesco Cerutti

WP11 11 T Dipole
Frédéric Savary
Hervé Prin

WP12 Vacuum
Vincent Baglin
Roberto Kersevan

WP13 Beam Instrumentation
Rhodri Jones
Adriana Rossi

WP14 Beam Transfer
Chiara Bracco
Brennan Goddard

WP15 Integration & (De-)Installation
Paolo Fessia
Hélène Mainaud Durand (Survey)

WP16 IT String & Commissioning
Marta Bajko – Mirko Pojer

WP17 Infrastructure & Logistics
Laurent Tavian
Beniamino Di Girolamo

High Luminosity Project Office after FP7 DS:

Project Leader & Deputy
Project Definition & Strategy
Report to CERN Management and DHs
Report to Collaboration Board
Coordination technical WPs (2-14) & Collaborations

Safety officer

Budget Officer
Budget & its follow-up
Link to RC and to DAT

KT, Outreach and Communication

Project Office Manager
Coordination among officers, secretariat, interface with host states, General Planning Coordination, Safety follow up

Technical Infrastructure Officer

Civil Engineering
Impact & Environ. Studies
Electrical Distr. & CV
Access & Alarm
Logistics & link to Test Infra.
Consolidation & Operations

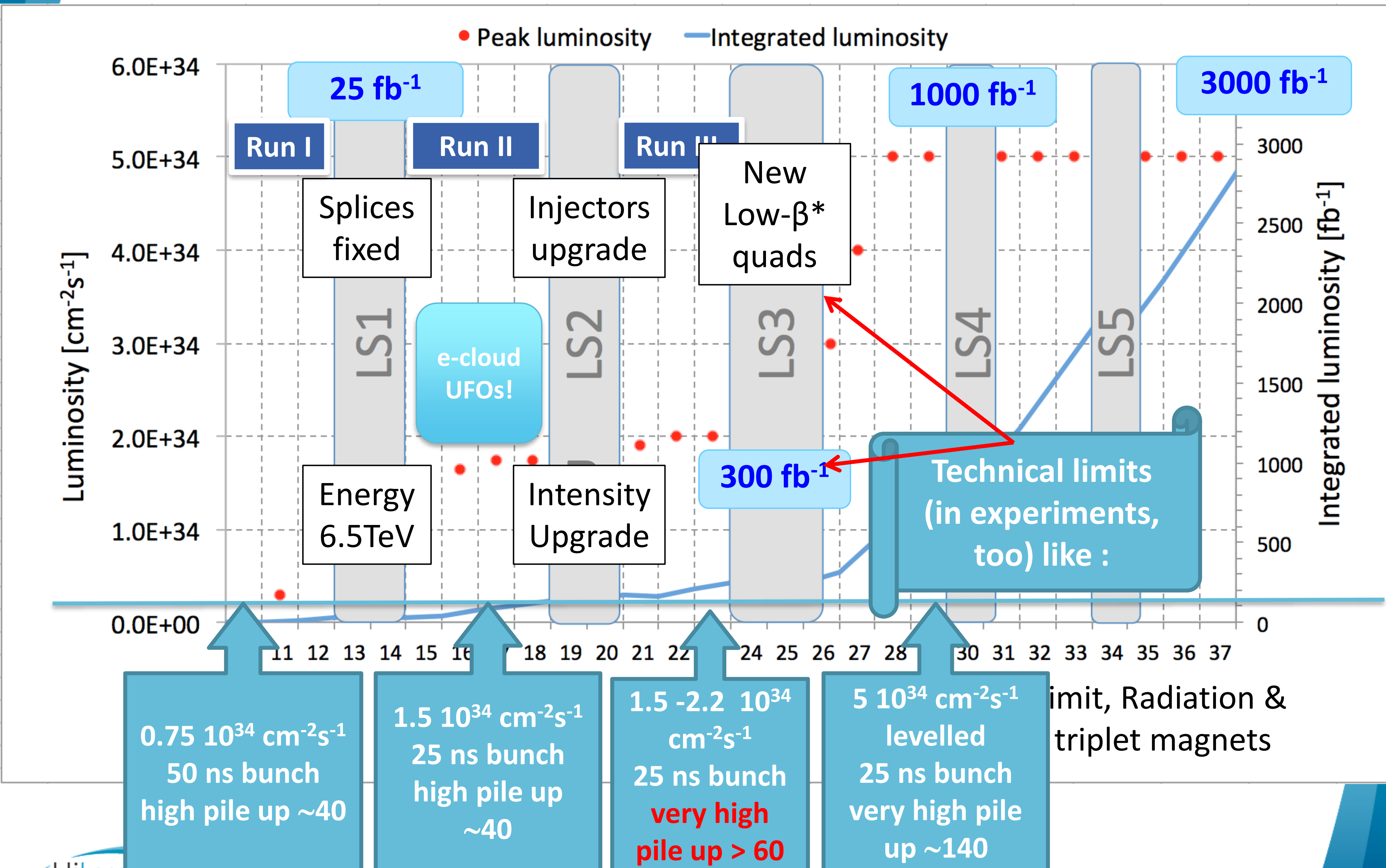
Configuration, Quality and Resource Officer

TDR Edition & Tech. Baseline
(PBS, interfaces, Tech. Specs,
Technical documentation & ECR)
Quality and Risk management
Resource & Purchase Plan

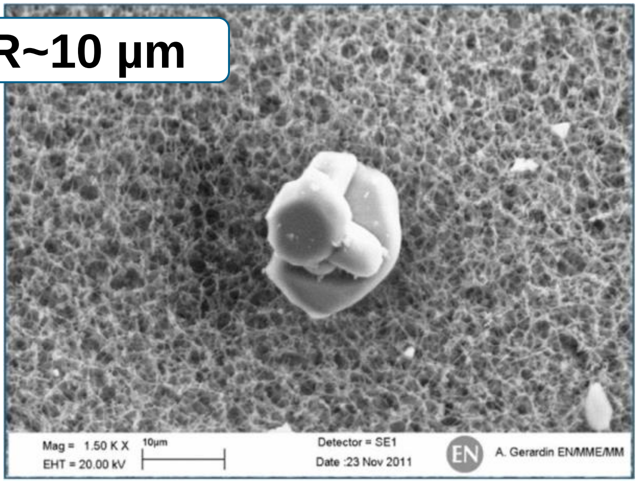
Integration and Installation Officer

Integration study and layout
Lead (de-) installation
Survey

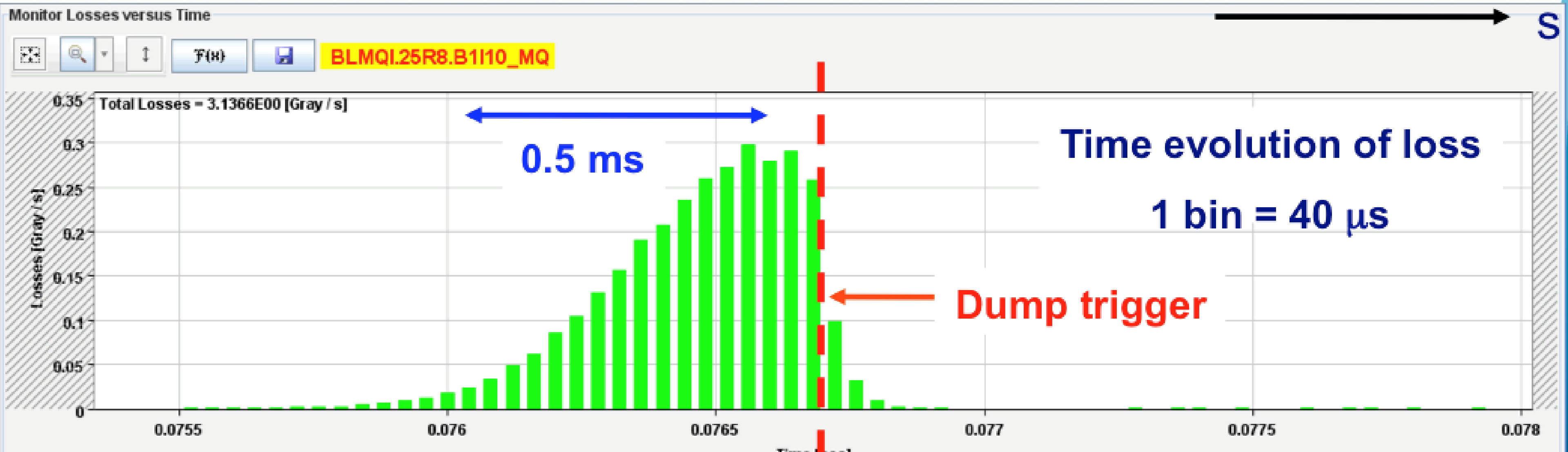
Performance Projections up to HL-LHC:



UFOs – Unidentified Falling Objects:

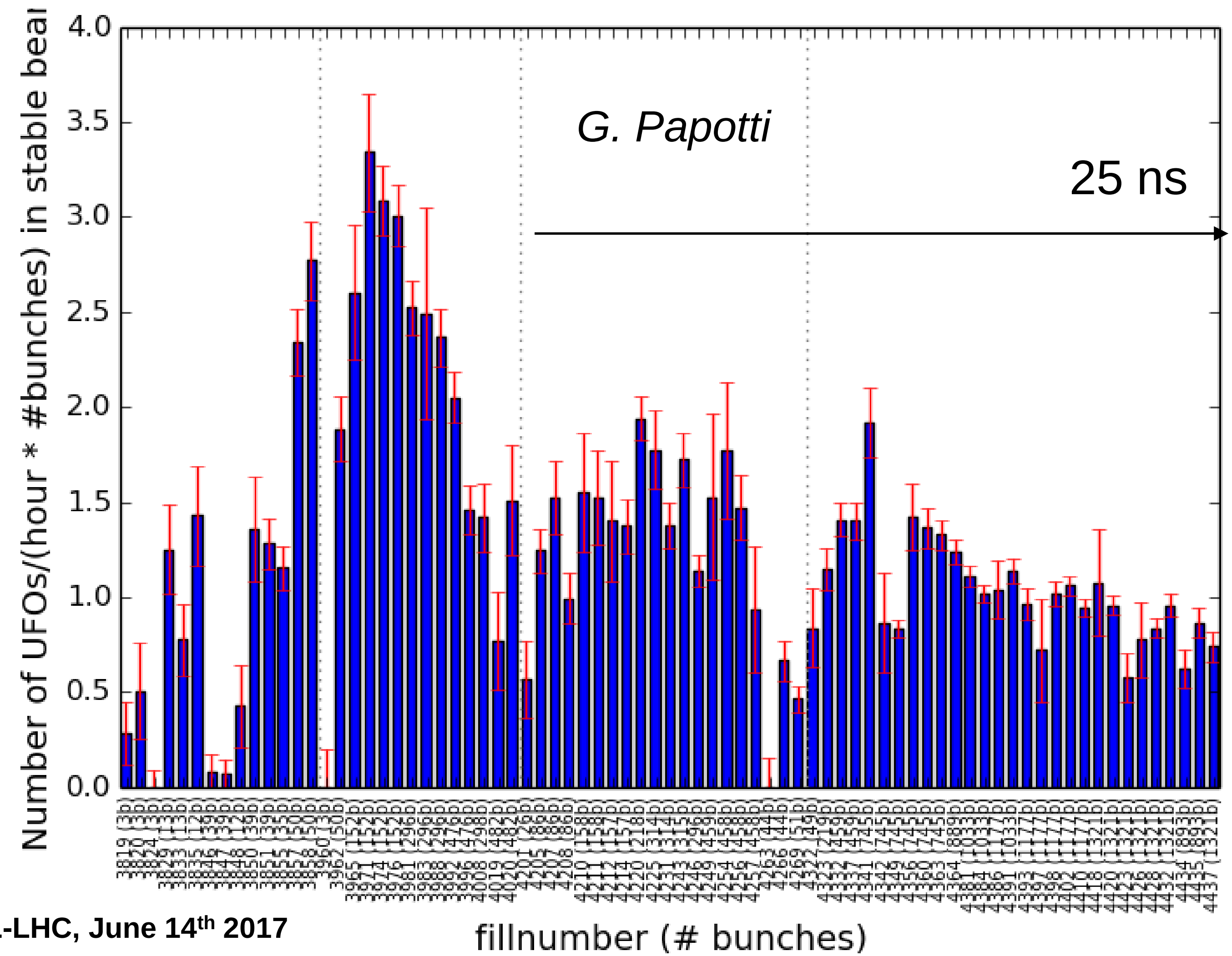


- Sudden local losses
- Rise time of the order of 1 ms.
- Potential explanation: dust particles falling into beam creating scatter losses and showers propagating downstream
- Distributed around the ring – arcs, inner triplets, IRs
- Even without quench, preventive dumps by QPS



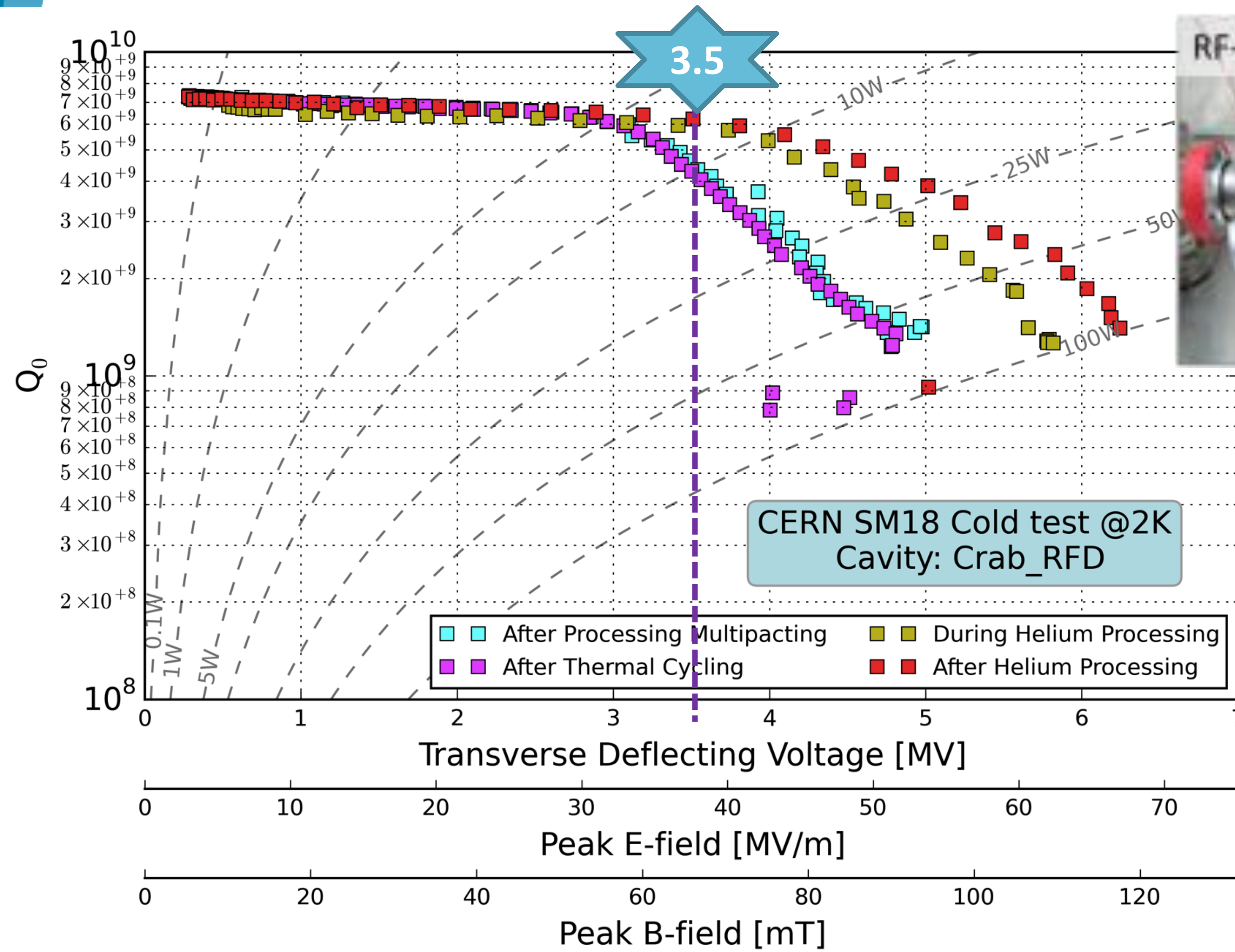
RunII Startup: UFO rates (September 2015)

- There are many UFOs, a significant number > 1% of threshold
- 0.07% of all UFOs actually dump the beam
- Slight signs of conditioning when normalizing rate by the total number of bunches



And excellent first results: RF Dipole

Results from Measurements @ CERN



Initial goal was 3.5 MV however ΔV > 5-6 MV would ease integration