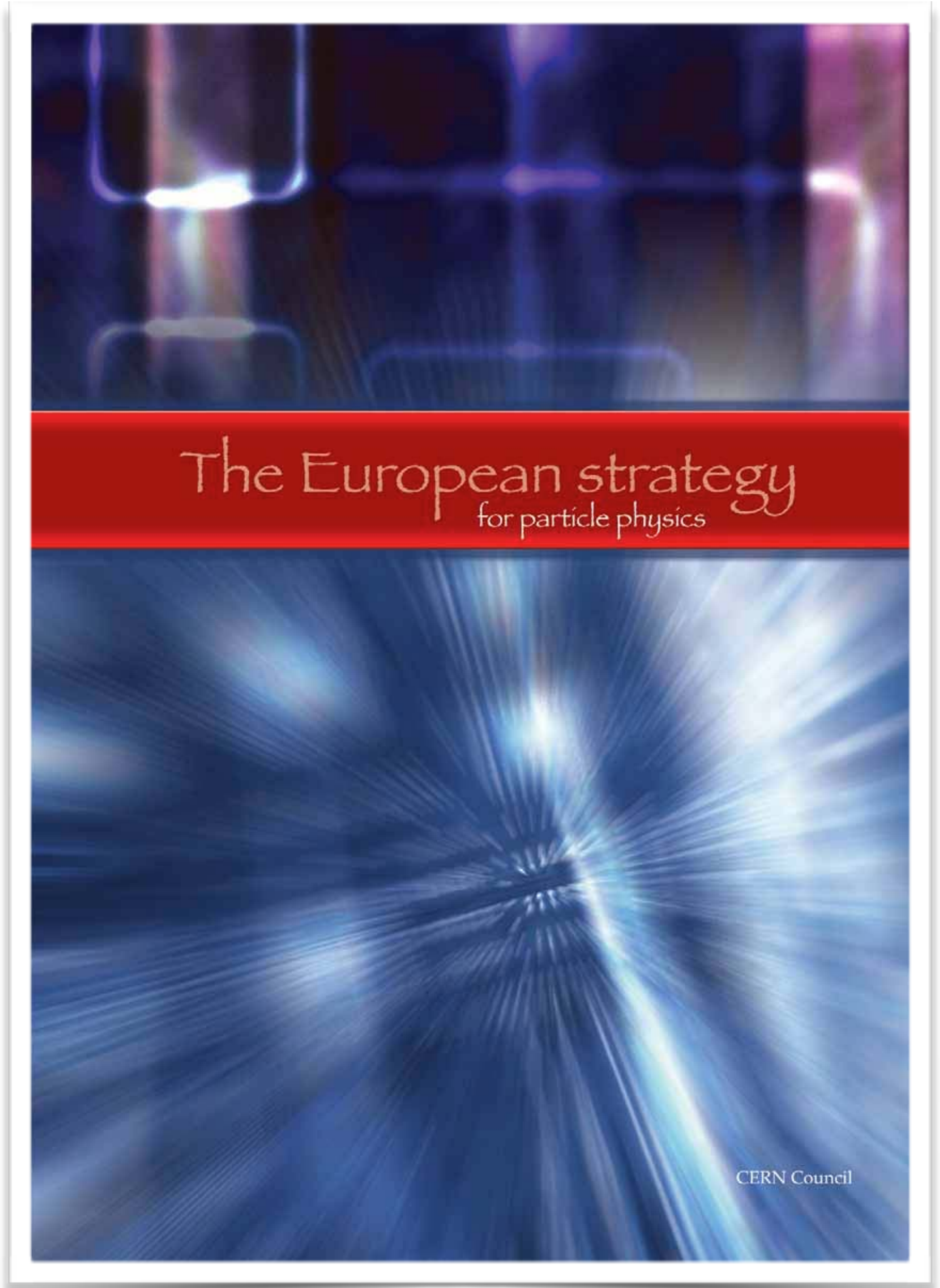
Implementation of the European Strategy for Particle Physics

E.Elsen

European Strategy for Particle Physics and updates



2006

2013

~2019

full impact of run 2

European Strategy for Particle Physics Update 2013

- Full exploitation of the LHC (and its luminosity upgrade)
- Future energy frontier machines
- e^+e^- linear collider in Japan
- ν–physics
- diverse physics programme
- …

Energy Frontier

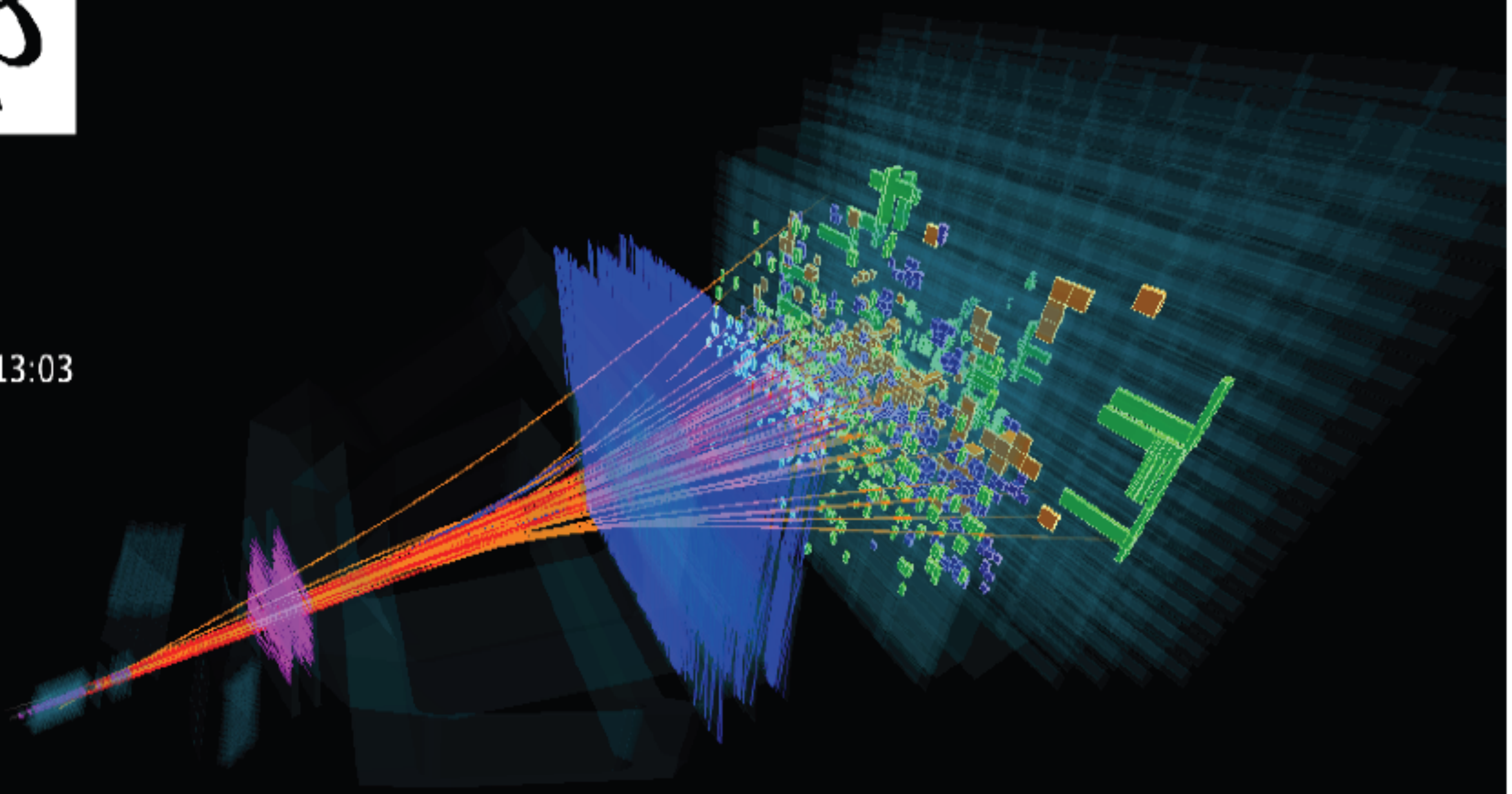
- The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme.

  Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.


LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
ALICE
CMS
LHC 27 km

PbPb collisions

Event 250756
Run 168821
Sun, 29 Nov 2015 21:13:03

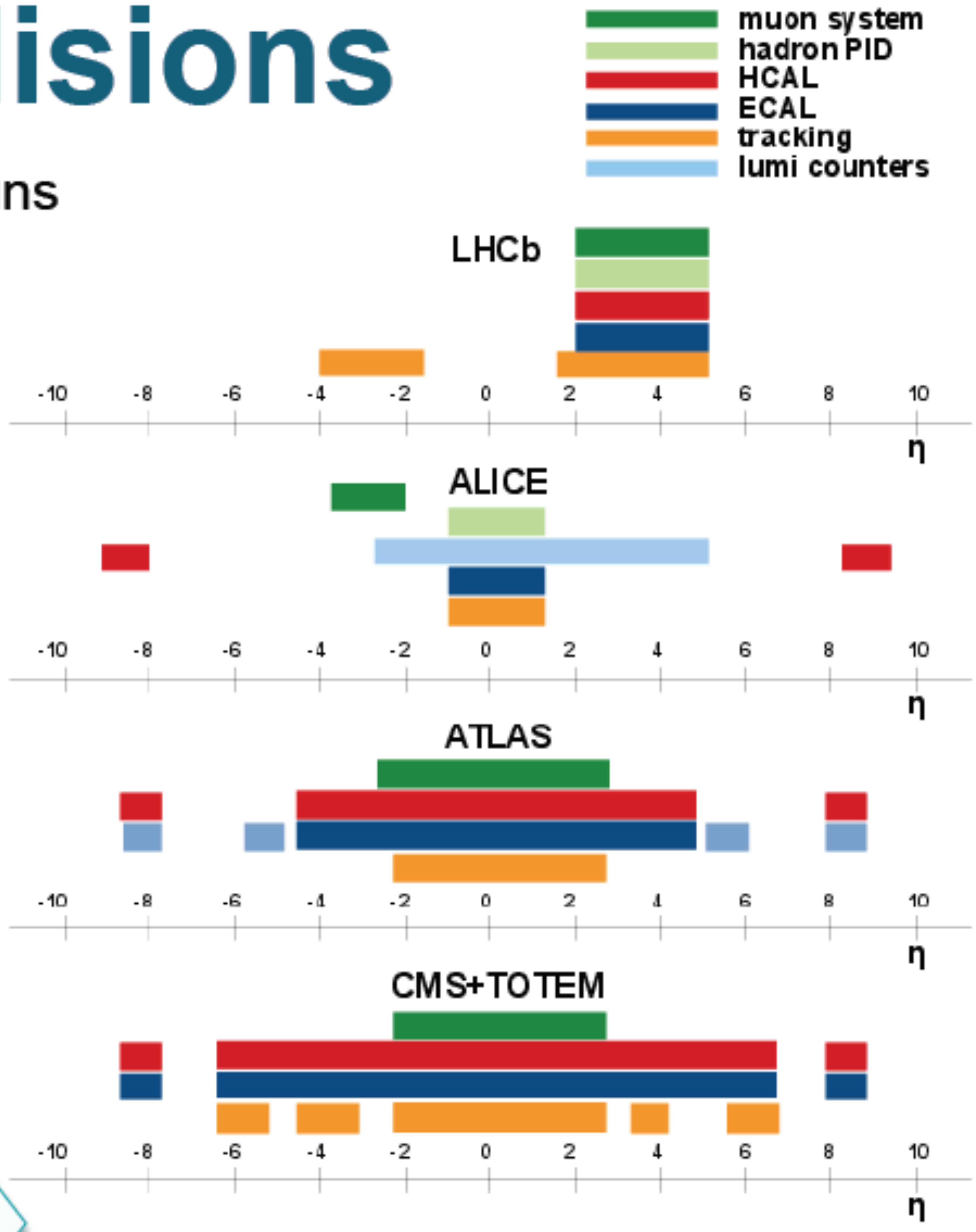


PbPb collisions

- LHCb is participating in Pb-Pb collision runs
- Unique fully instrumented experiment in the forward region
- Physics motivations:
  - Probe colour screening and quark gluon plasma (QGP) temperature through sequential melting of quarkonium states
  - Structure of nucleons, hadronisation, central exclusive production, …
  - Focus on peripheral collisions in Pb-Pb, with a centrality up to 50%

	Date	Data sample
PbPb	25 Nov.-….	
PbAr	27 Nov.-…	

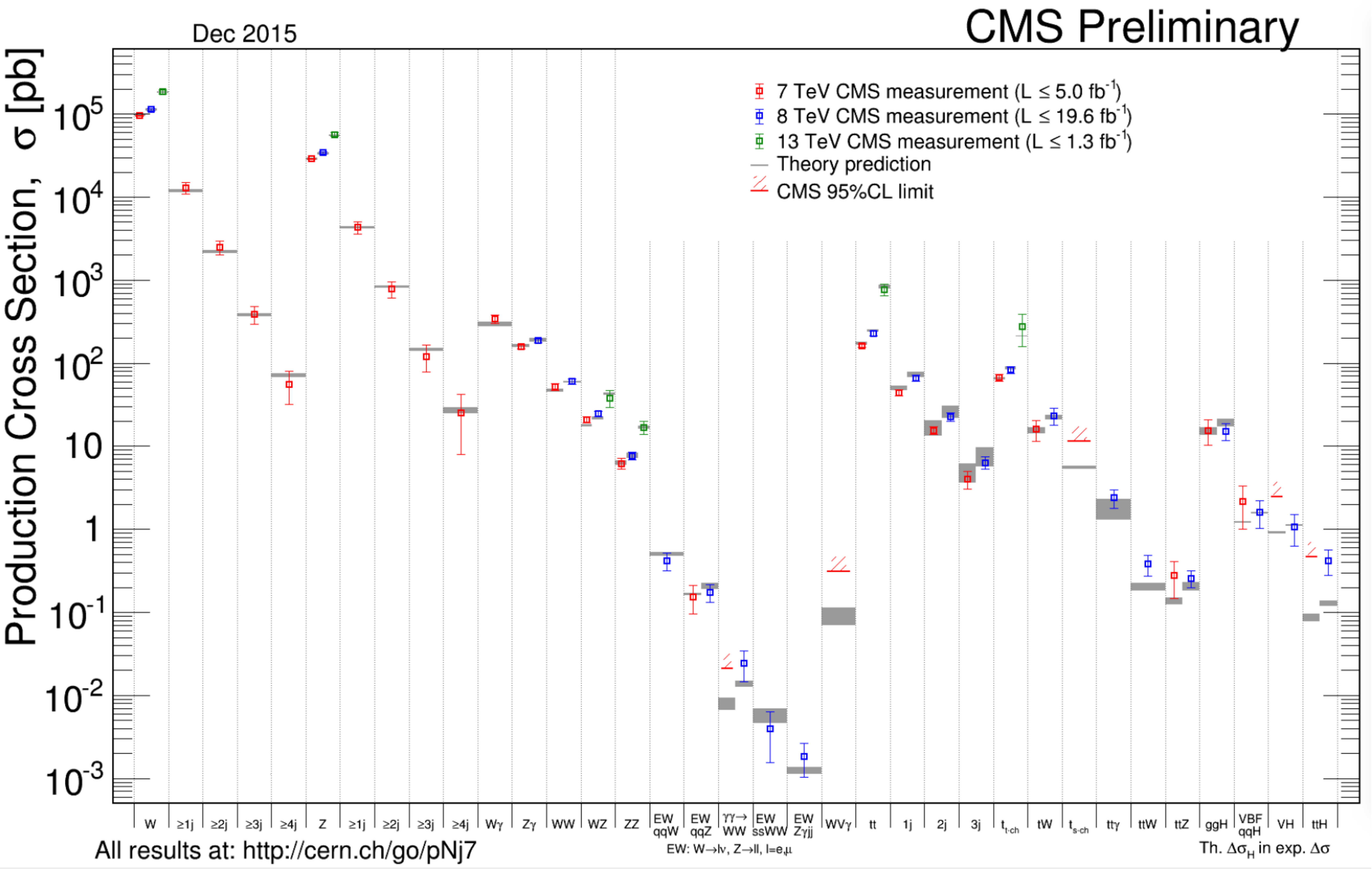
Data taking ongoing



Measurement of Standard Model cross sections

CMS

- Pilot run in 2015 opened a new energy range
- Standard Model cross sections, incl. 13 TeV data
- relevant cross sections vary over 8 orders of magnitude

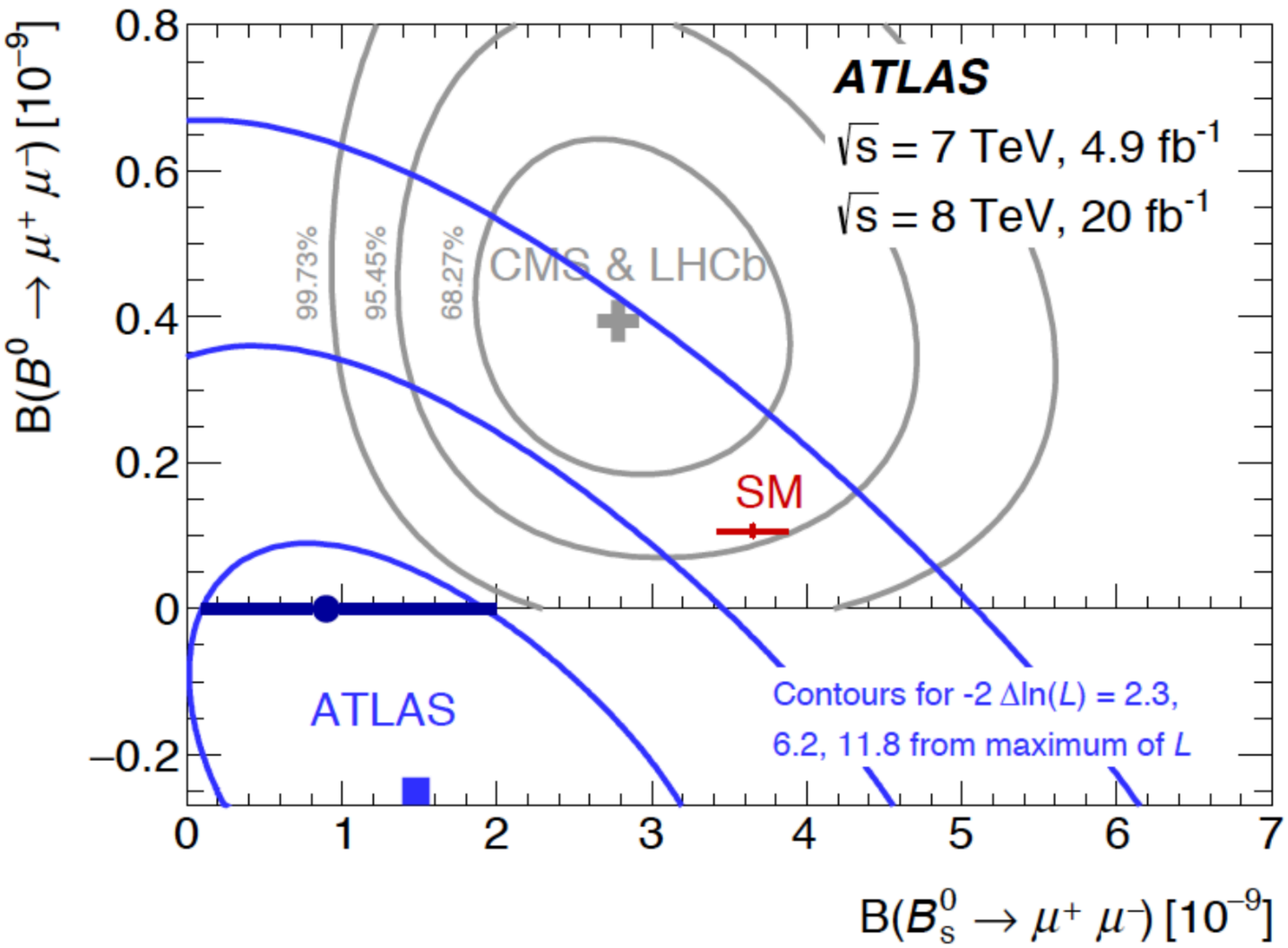


ATLAS measurement of $B_{d,s} \to \mu^+\mu^-$

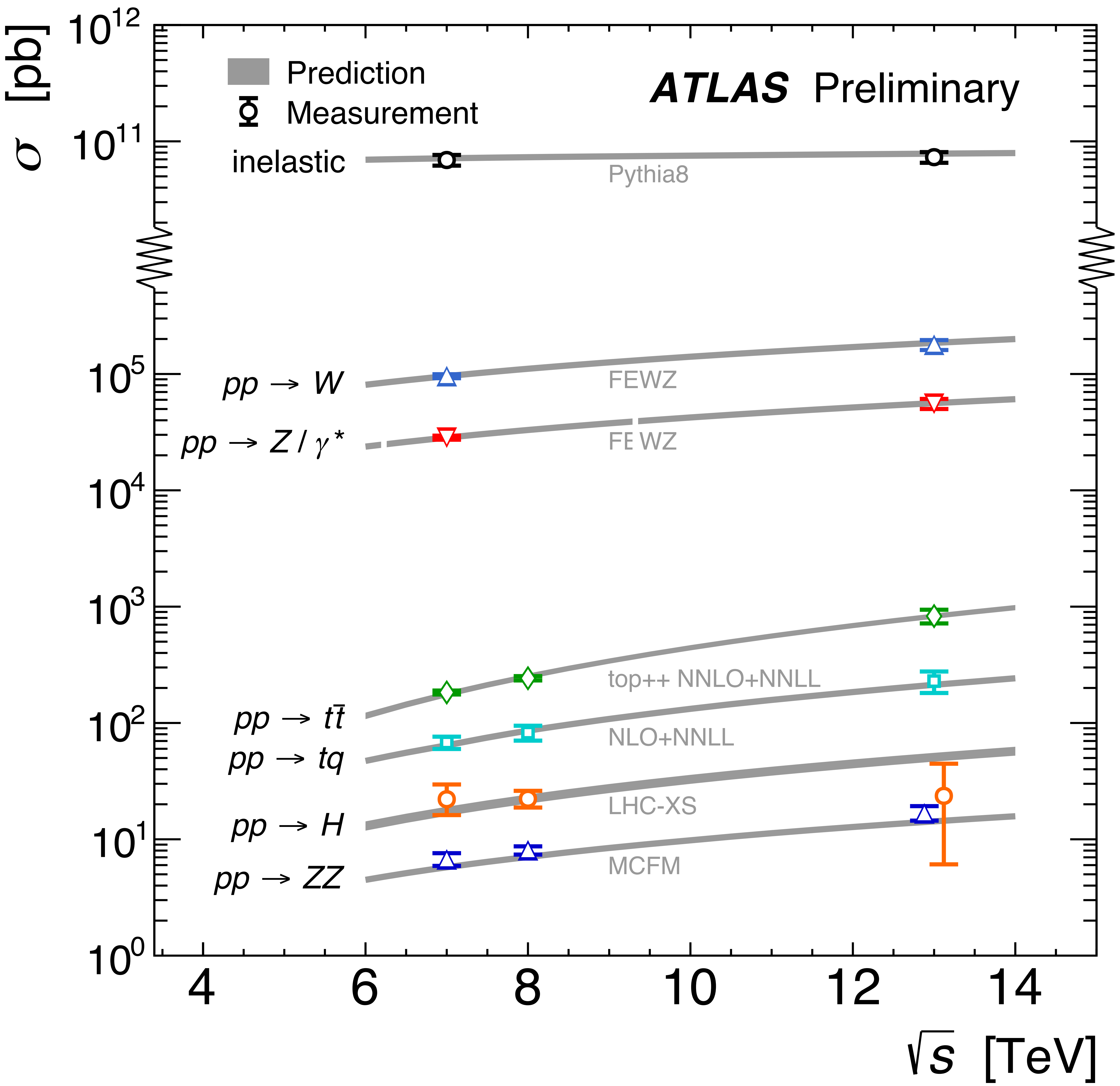
- Complementing results of LHCb and CMS
  - based on 25 fb^{-1} of run 1 at 7 and 8 TeV
  - some tension

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left(0.9^{+1.1}_{-0.8}\right) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 4.2 \times 10^{-10}$$

at 95% CL



Cross Sections as a function of √s



inelastic
7 TeV, 20 μb^-1, Nat. Commun. 2, 463 (2011)
13 TeV, 63 μb^-1, ATLAS-CONF-2015-038

pp → W
7 TeV, 36 pb^-1, PRD 85, 072004 (2012)
13 TeV, 85 pb^-1, ATLAS-CONF-2015-039

pp → Z / γ*
7 TeV, 36 pb^-1, PRD 85, 072004 (2012)
13 TeV, 85 pb^-1, ATLAS-CONF-2015-039

pp → tt̄
7 TeV, 4.6 fb^-1, Eur. Phys. J. C 74:3109 (2014)
8 TeV, 20.3 fb^-1, Eur. Phys. J. C 74:3109 (2014)
13 TeV, 78 pb^-1, ATLAS-CONF-2015-049

pp → tq
7 TeV, 4.6 fb^-1, PRD 90, 112006 (2014)
8 TeV, 20.3 fb^-1, ATLAS-CONF-2014-007
13 TeV, 3.2 fb^-1, ATLAS-CONF-2015-079

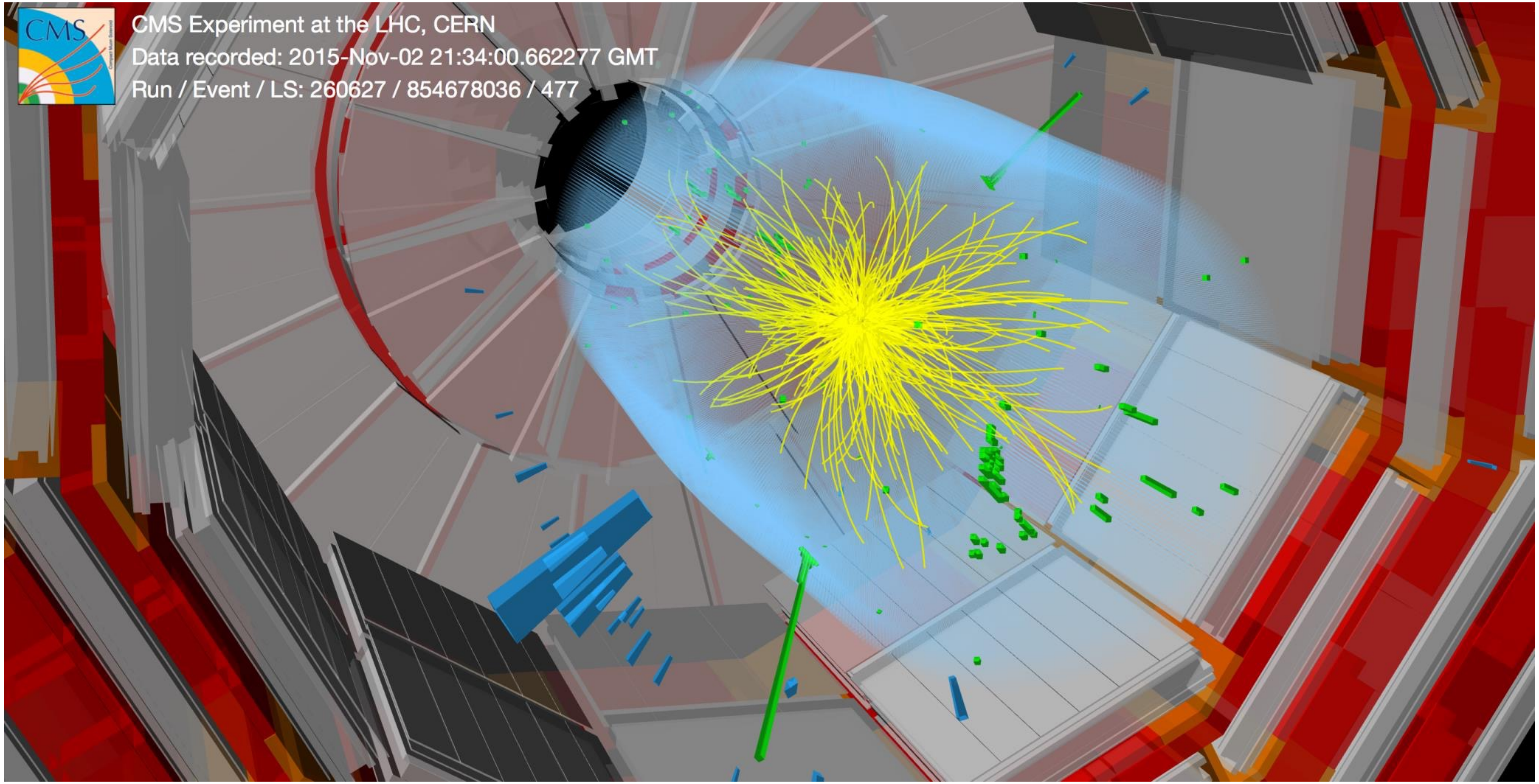
pp → H
7 TeV, 4.5 fb^-1, arXiv:1507.04548
8 TeV, 20.3 fb^-1, arXiv:1507.04548
13 TeV, 3.2 fb^-1, ATLAS-CONF-2015-069

pp → ZZ
7 TeV, 4.6 fb^-1, JHEP 03, 128 (2013)
8 TeV, 20.3 fb^-1, ATLAS-CONF-2013-020
13 TeV, 3.2 fb^-1, STDM-2015-13

Search for Diphoton resonances

CMS

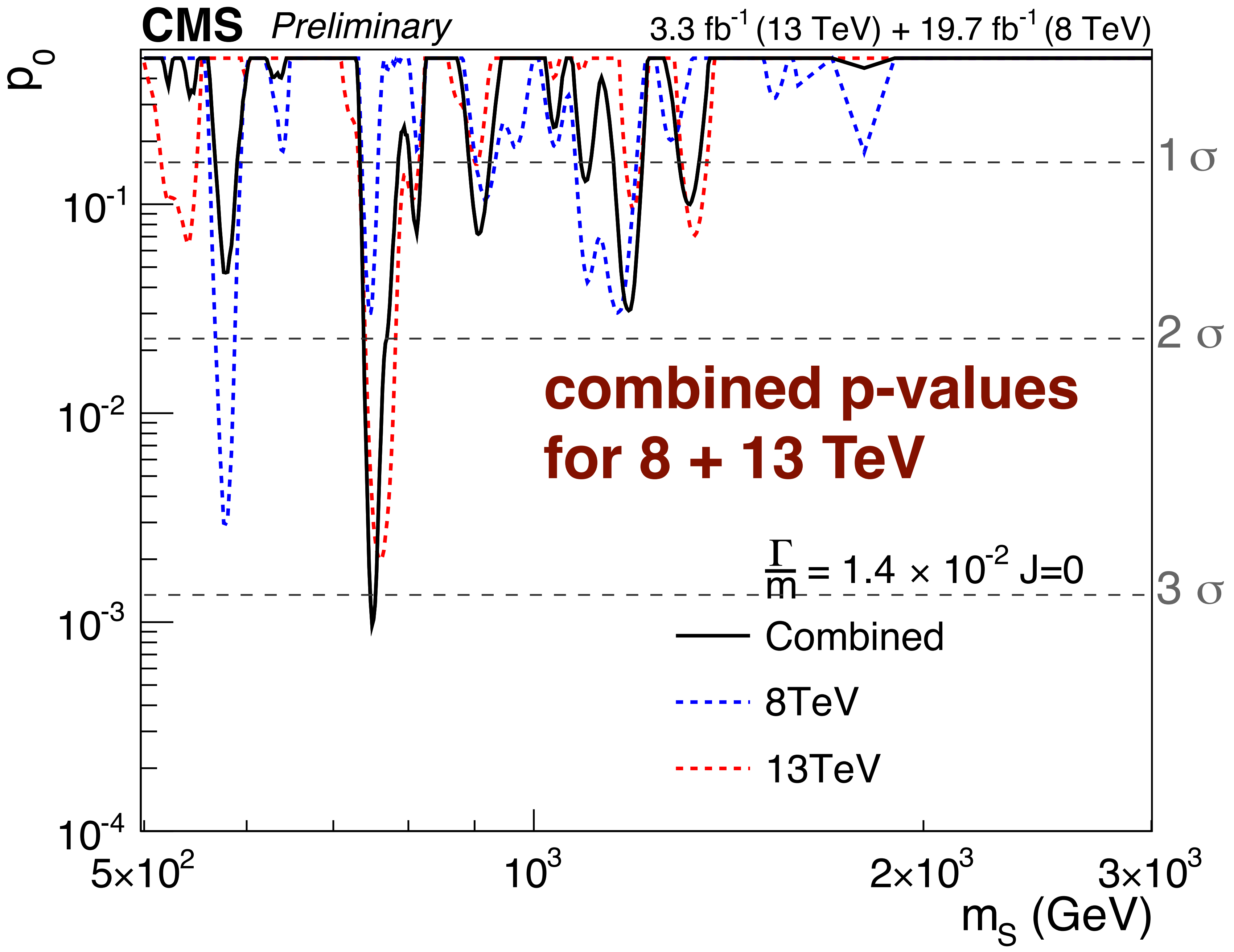
$m_{\gamma\gamma}$=745 GeV

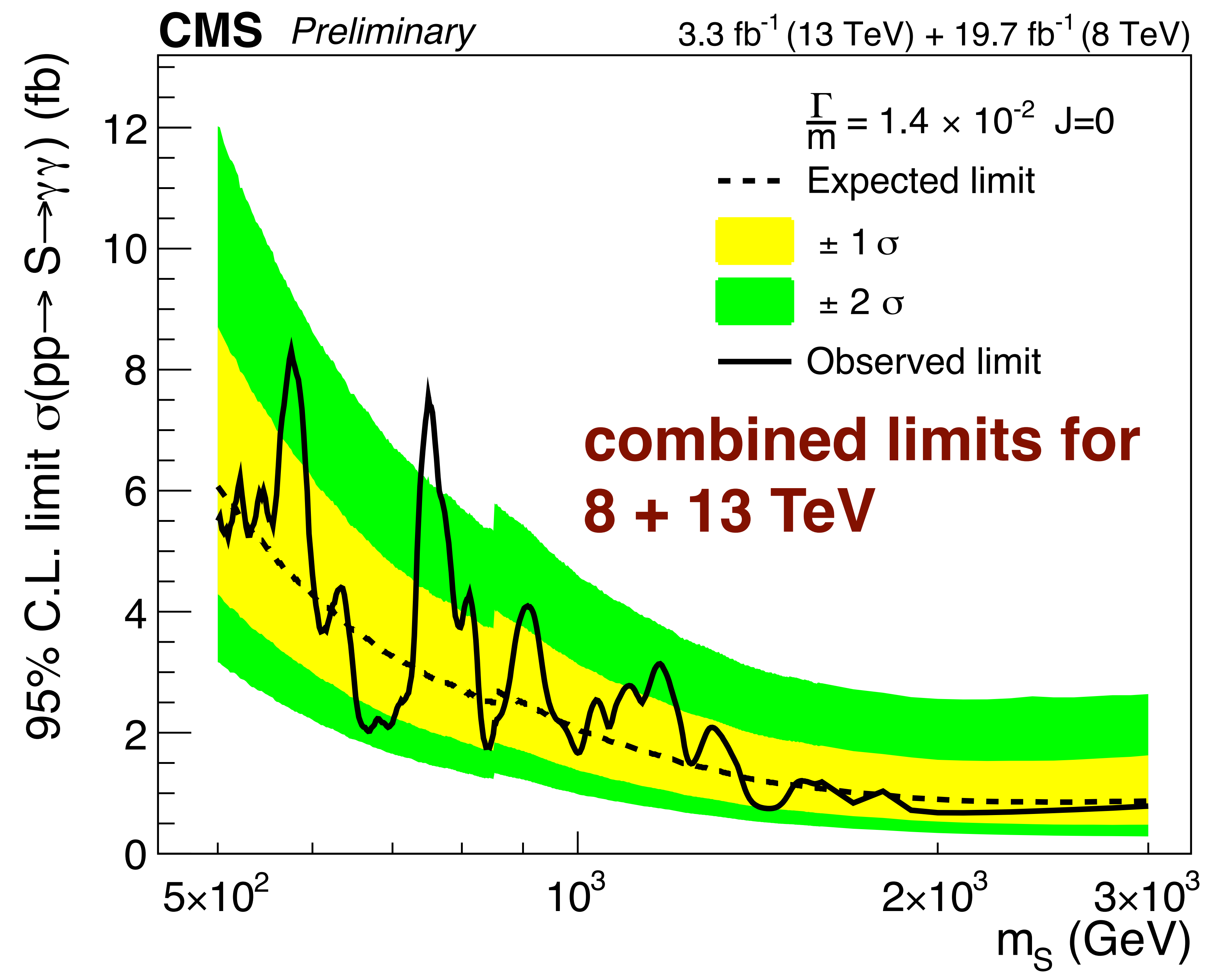


Diphoton Resonances

[EXO-16-018]

- Combined 8 TeV + 13 TeV results
  - Largest excess is observed for **750 GeV, spin-0, narrow width**
    - local significance of 3.4σ, 1.6σ after look-elsewhere effect





- Dec ’15 result: largest excess at 760 GeV for $\Gamma/M=1.4\times10^{-2}$
  - local significance of ~3σ, <1.7σ after look-elsewhere effect

Di-photons: search for spin-0 resonance

ATLAS

ATLAS-CONF-2016-xxx

Selection optimised for Higgs-like signal:

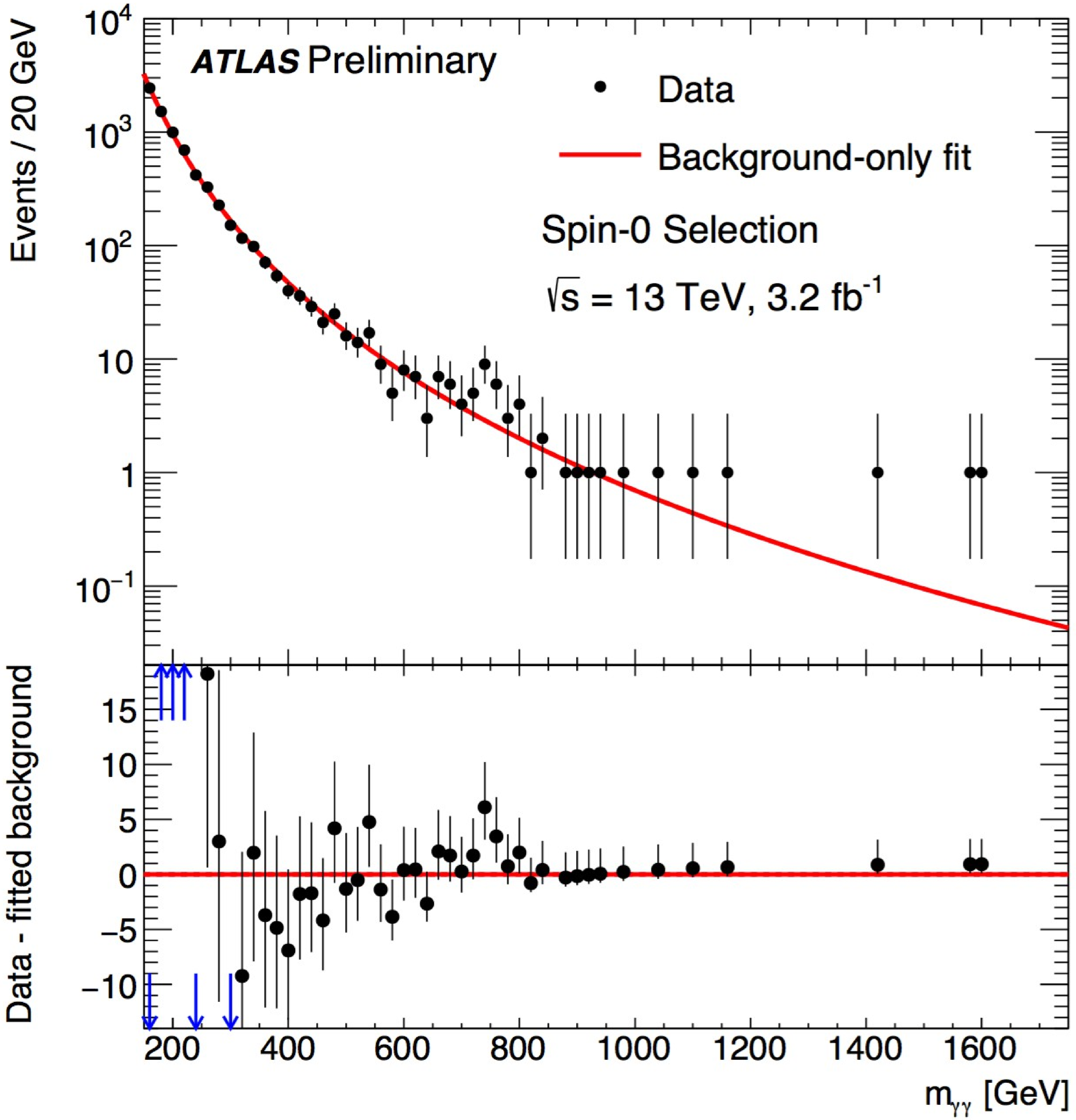
- two Photons (tight identification)
- photons required to be isolated
- Photon transverse energies:

  $E_T(\gamma_1) > 0.4\ m_{\gamma\gamma}$

  $E_T(\gamma_2) > 0.3\ m_{\gamma\gamma}$

  (effectively depletes forward regions)

Background modelled using fit to functional form

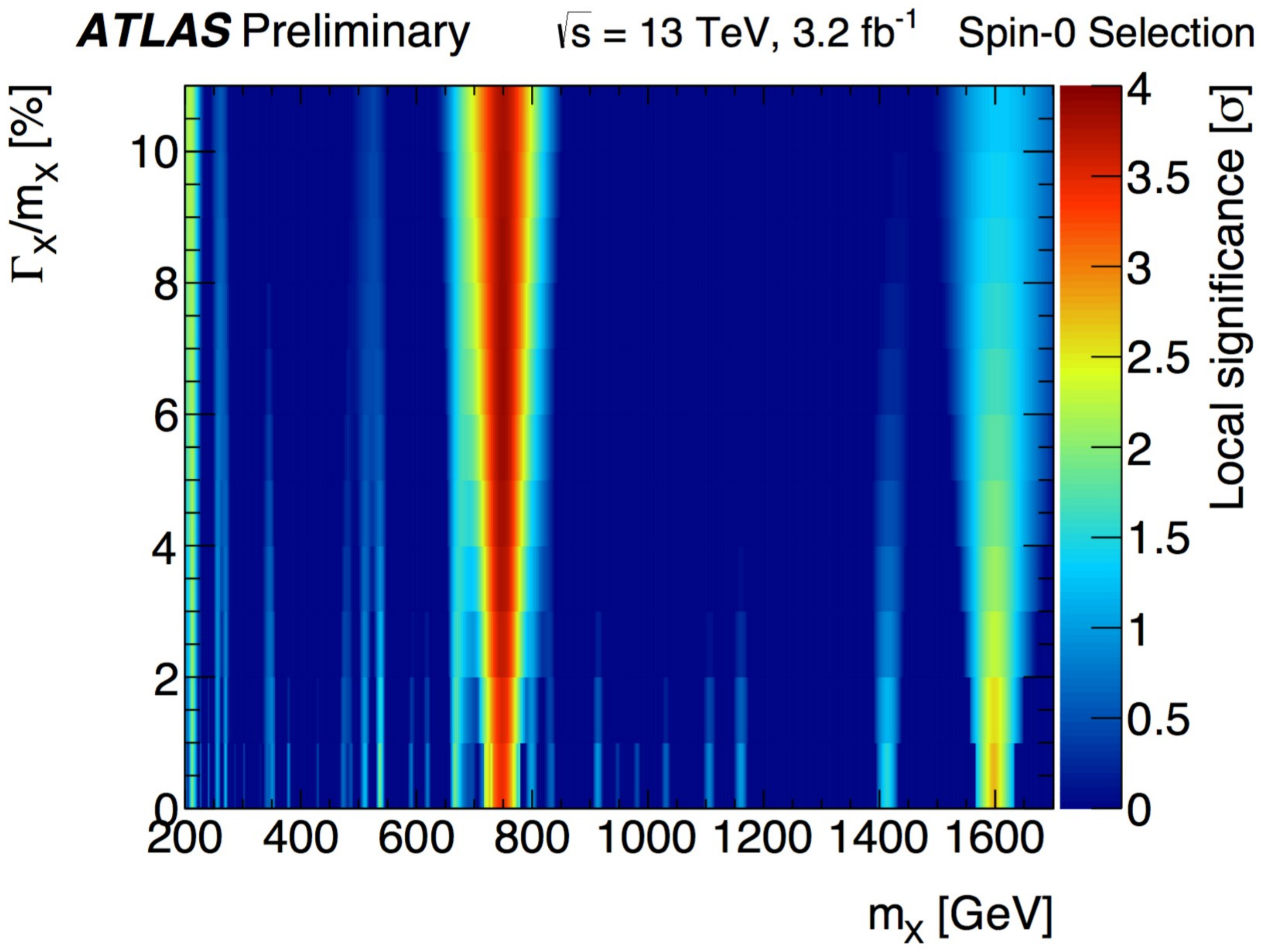


Di-photons: search for spin-0 resonance

Perform 2D p_0 scan (as function of mass and width of the hypothetical resonance).

Largest deviation from background-only hypothesis:
near 750 GeV
width ≈ 45 GeV (i.e. 6%)

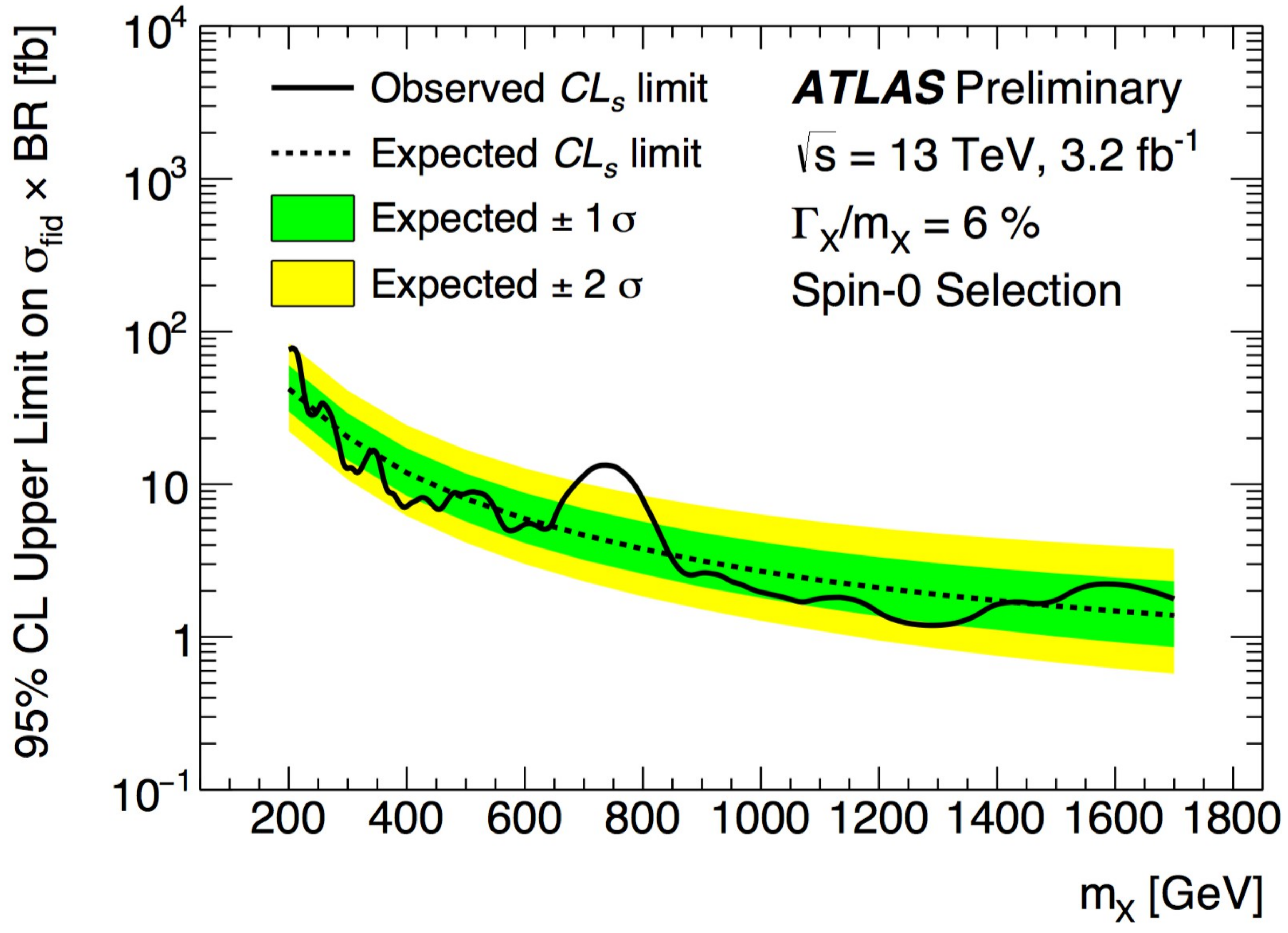
Local significance: 3.9σ
Global significance: 2.0σ



ATLAS-CONF-2016-xxx

Report limits on fiducial cross section as a function of mass hypothesis, for several width hypotheses.

Example shown here: width of 6%



Compatibility with the $\sqrt{s}$ = 8 TeV data

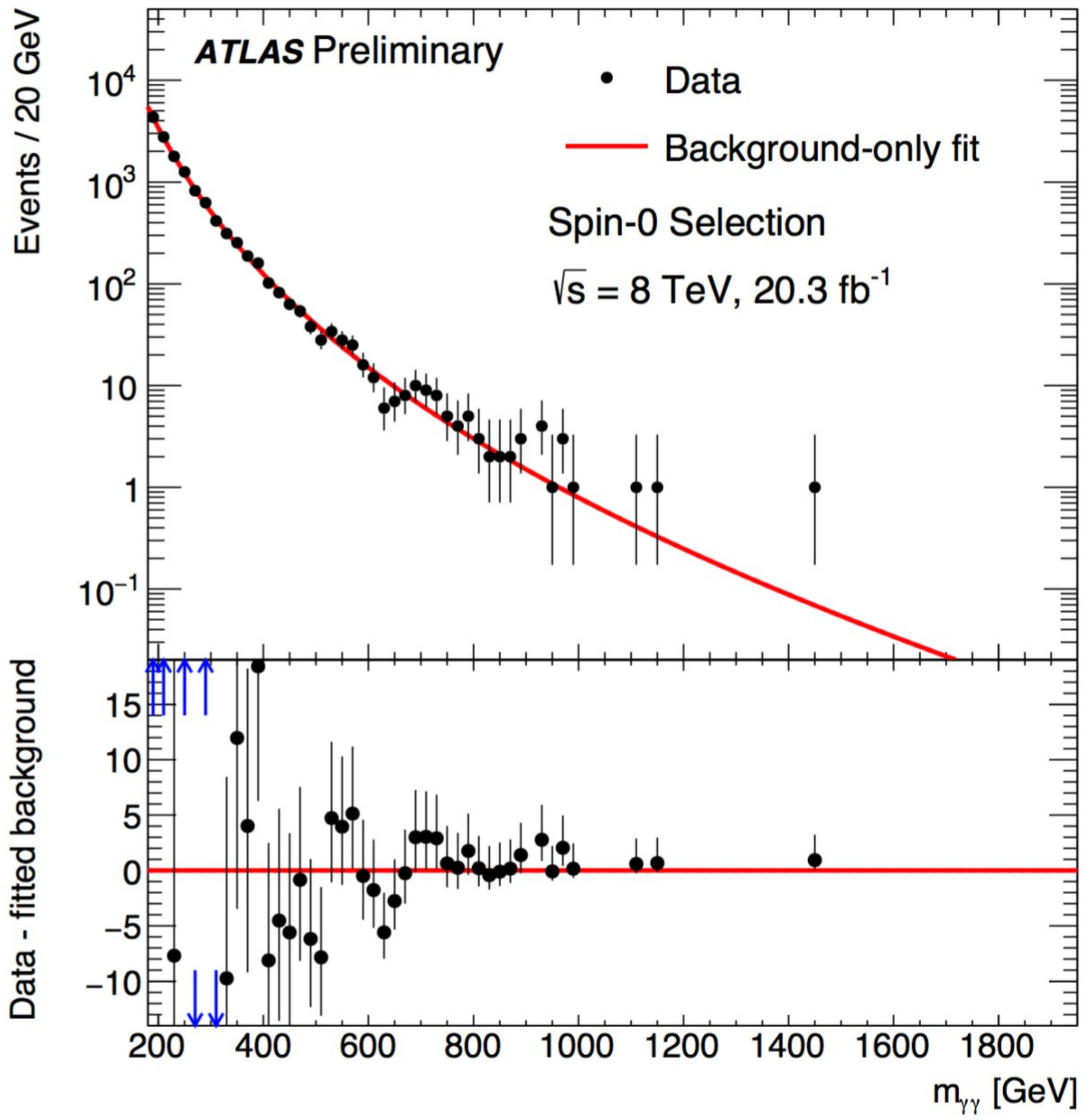
ATLAS

ATLAS-CONF-2016-xxx

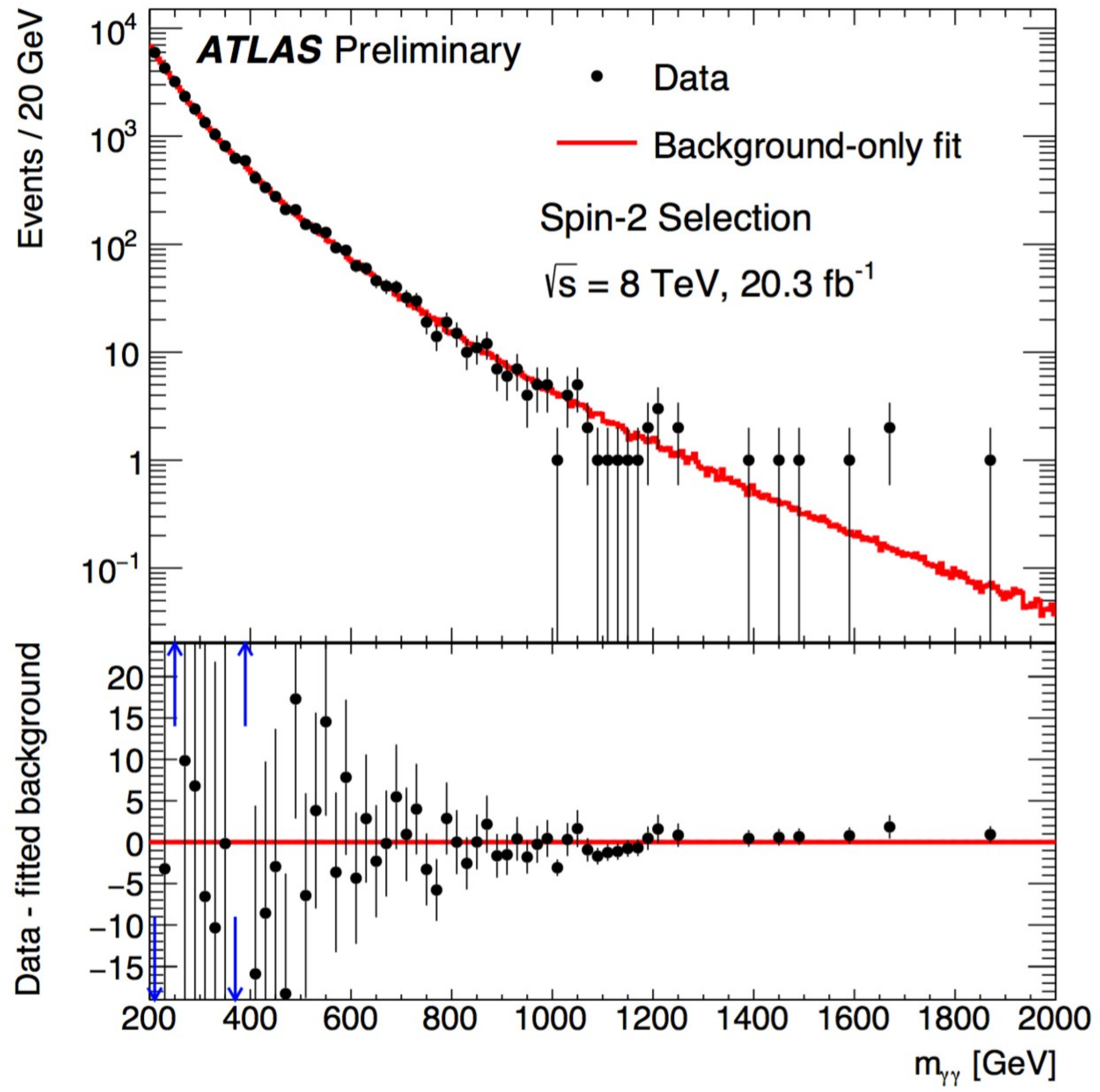
Spin 0	Spin 2
8 TeV data: 1.9σ deviation from B-only hypothesis at m_x = 750 GeV, Γ_x/m_x = 6%	8 TeV data: no excess in the region of interest

Assuming common signal model; production cross-section scales like Parton luminosities
- gg s-channel = 4.7
- qq s-channel = 2.7

Compatibility 8 TeV ↔ 13 TeV (gg hypothesis): 1.2σ
Compatibility 8 TeV ↔ 13 TeV (qq hypothesis): 2.1σ



Compatibility 8 TeV ↔ 13 TeV (gg hypothesis): 2.7σ
Compatibility 8 TeV ↔ 13 TeV (qq hypothesis): 3.6σ

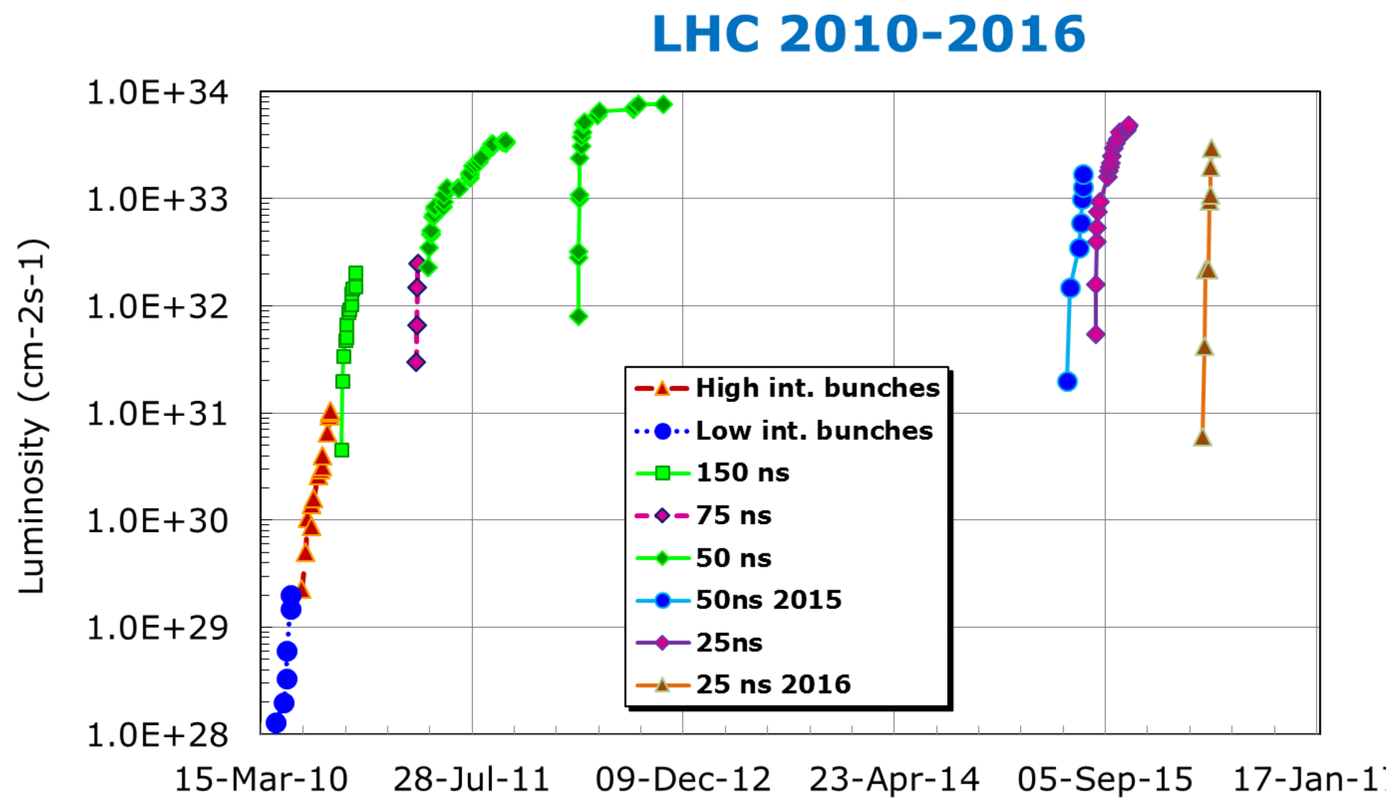


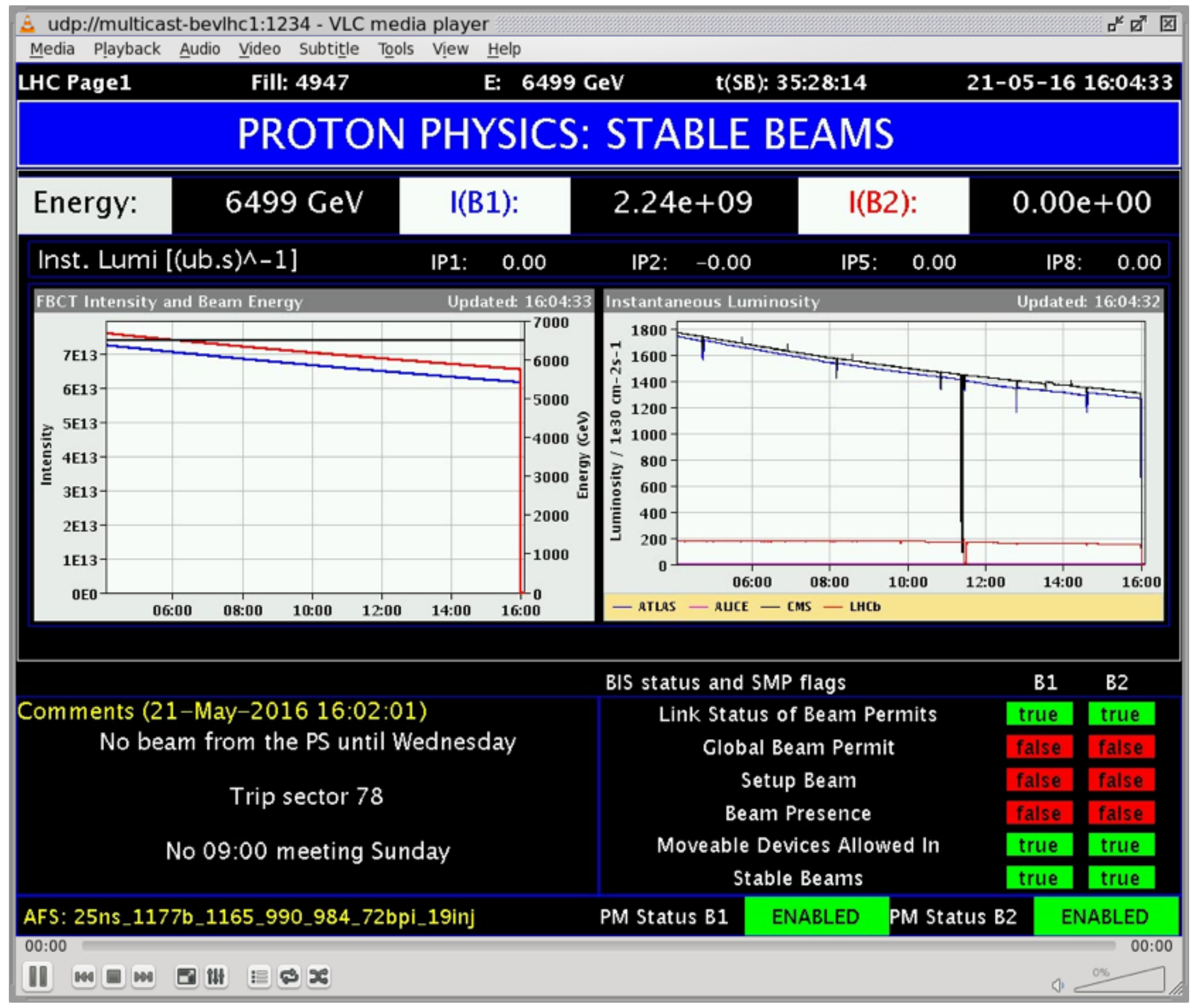
Di-Photon analysis – the bump

- Intriguing hints at ATLAS and CMS
  - spurred many theoretical investigations
  - analyses of 2015 data are being documented which are soon to appear
  - **calls for more luminosity**
- Expect experimental conclusion on existence of a signal with 2016 data…

Startup 2016 – LHC in good shape…

- LHC already well conditioned
  - 25 ns operation commissioned
  - e-cloud: vacuum well maintained over shutdown; remaining scrubbing will be done during physics runs
- LHC reliable
  - record fill 21.5.2016 with almost 36 h duration



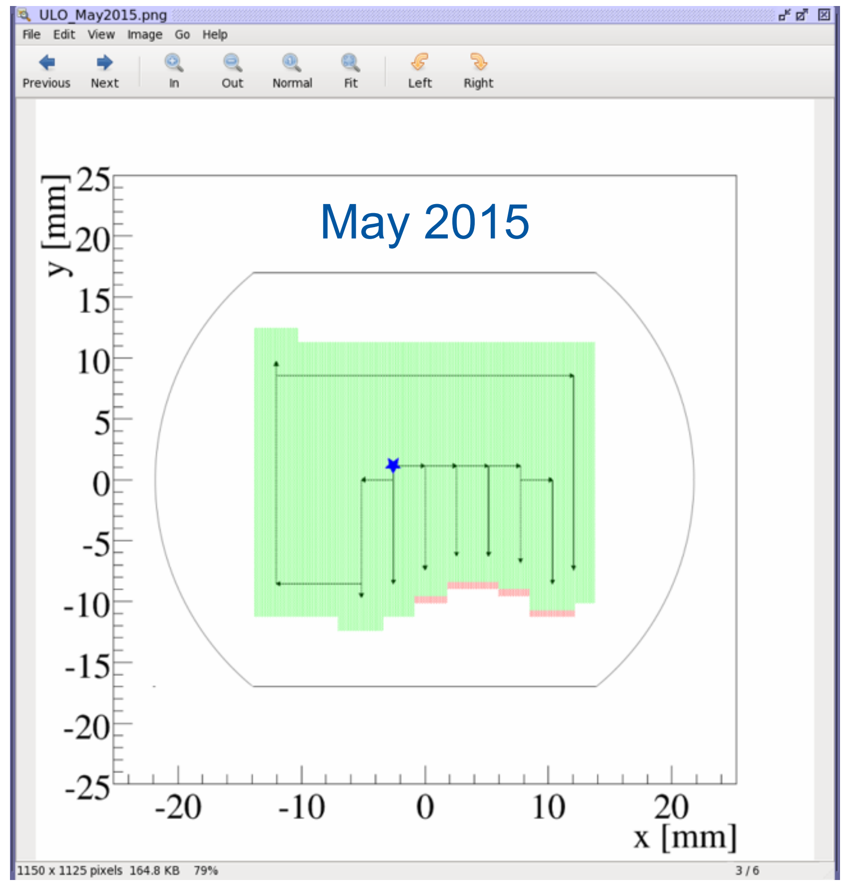


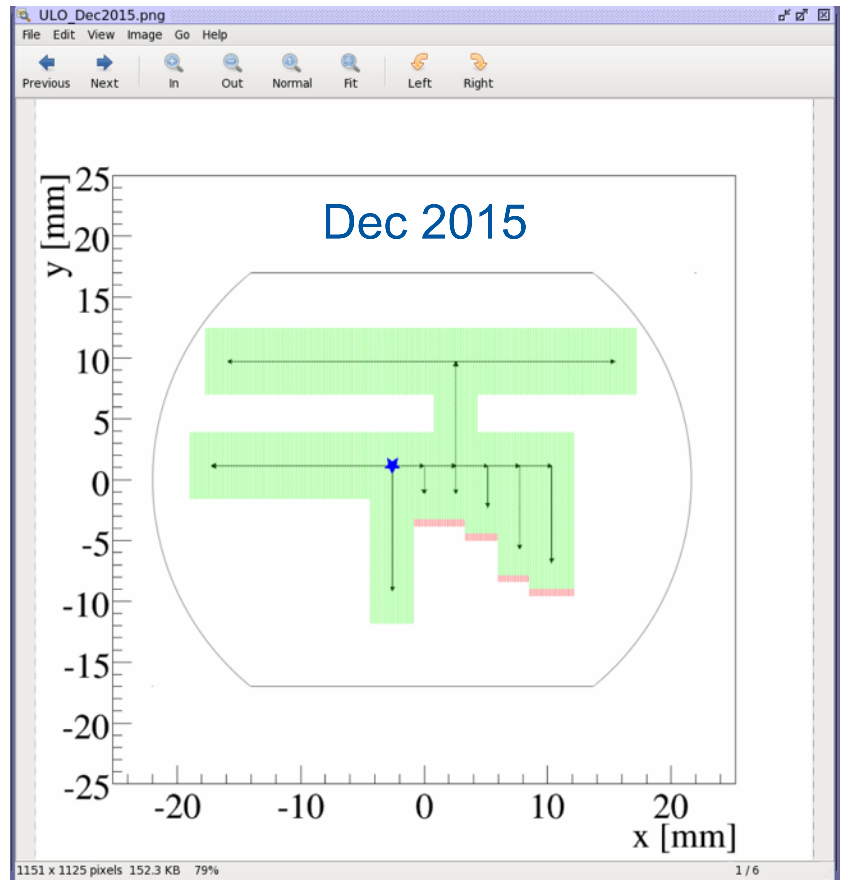
35h28m stable beams - integrated luminosity ~270 pb^{-1} !

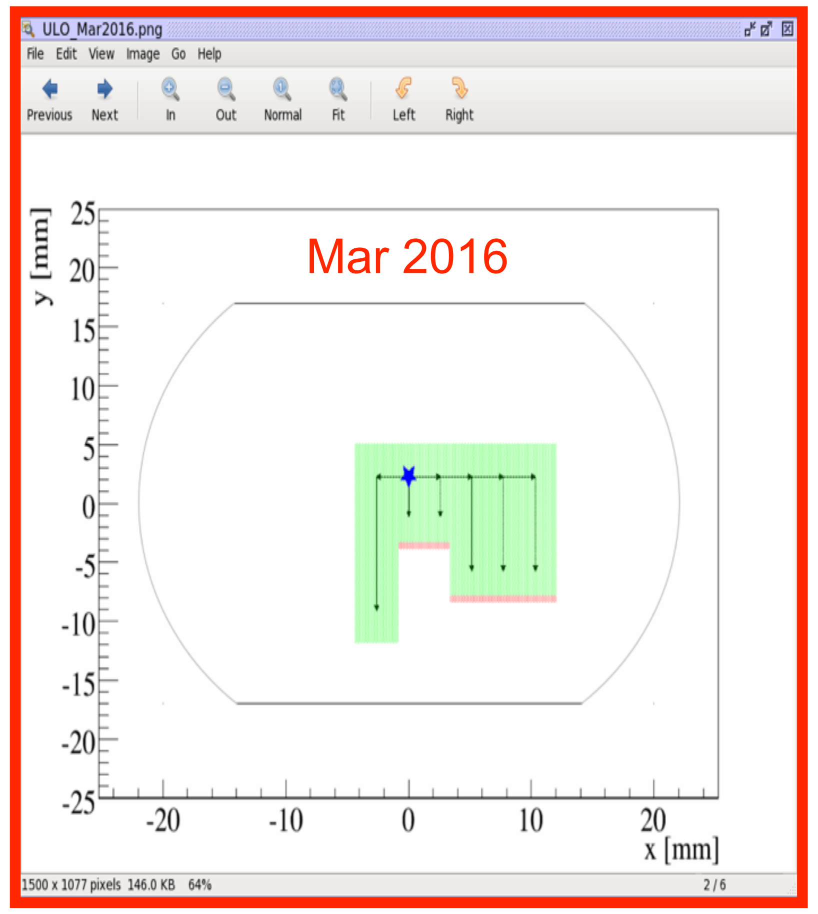
ULO has not moved

- A yet Unidentified Lying Object (ULO) is suspected to cause an aperture limitation in sector 15 R8
  - position has not changed
  - can be circumvented by orbit bump

Result of scans in 2015 and 2016





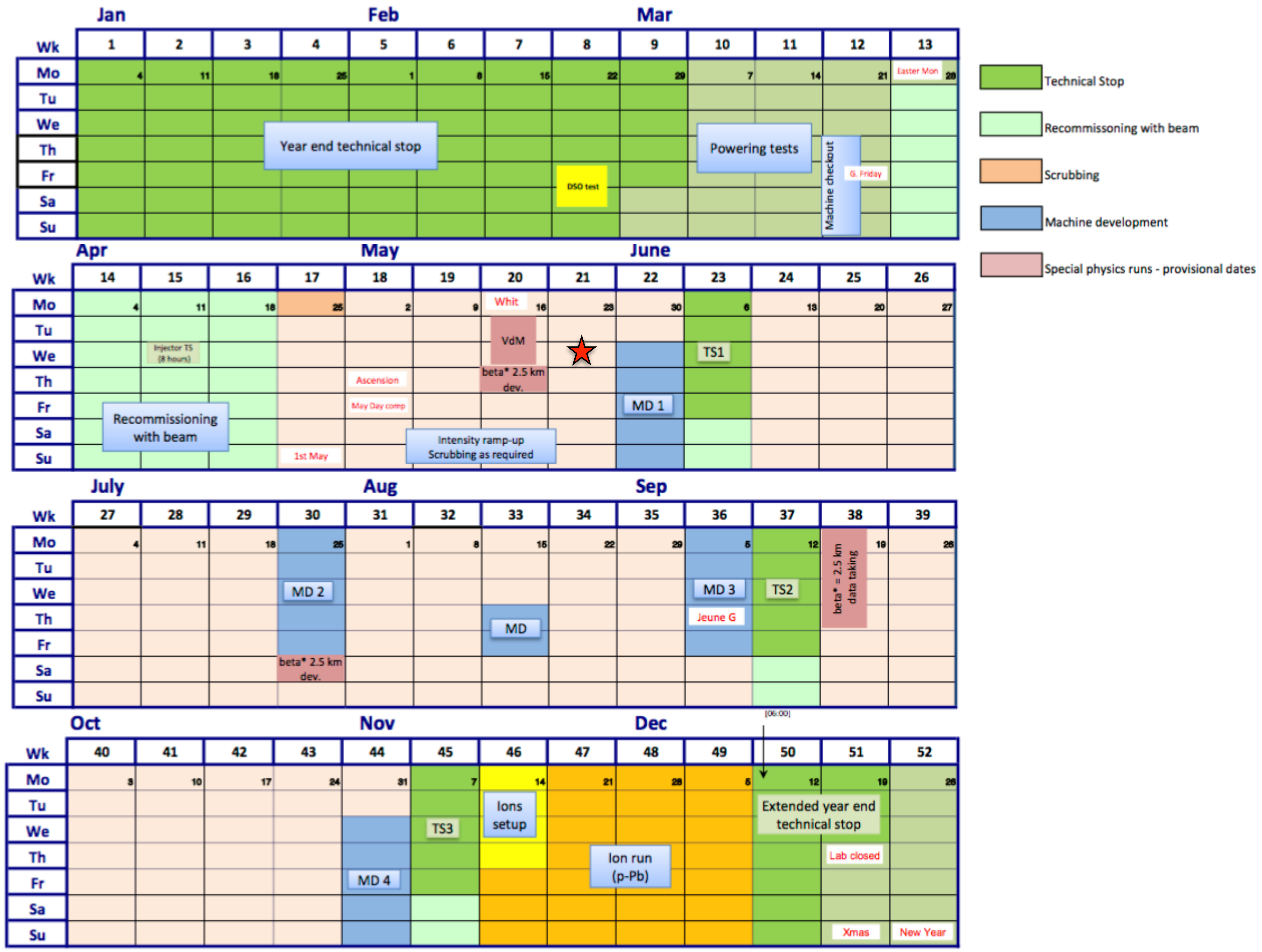


LHC Schedule 2016

- 150 d
  pp-collisions

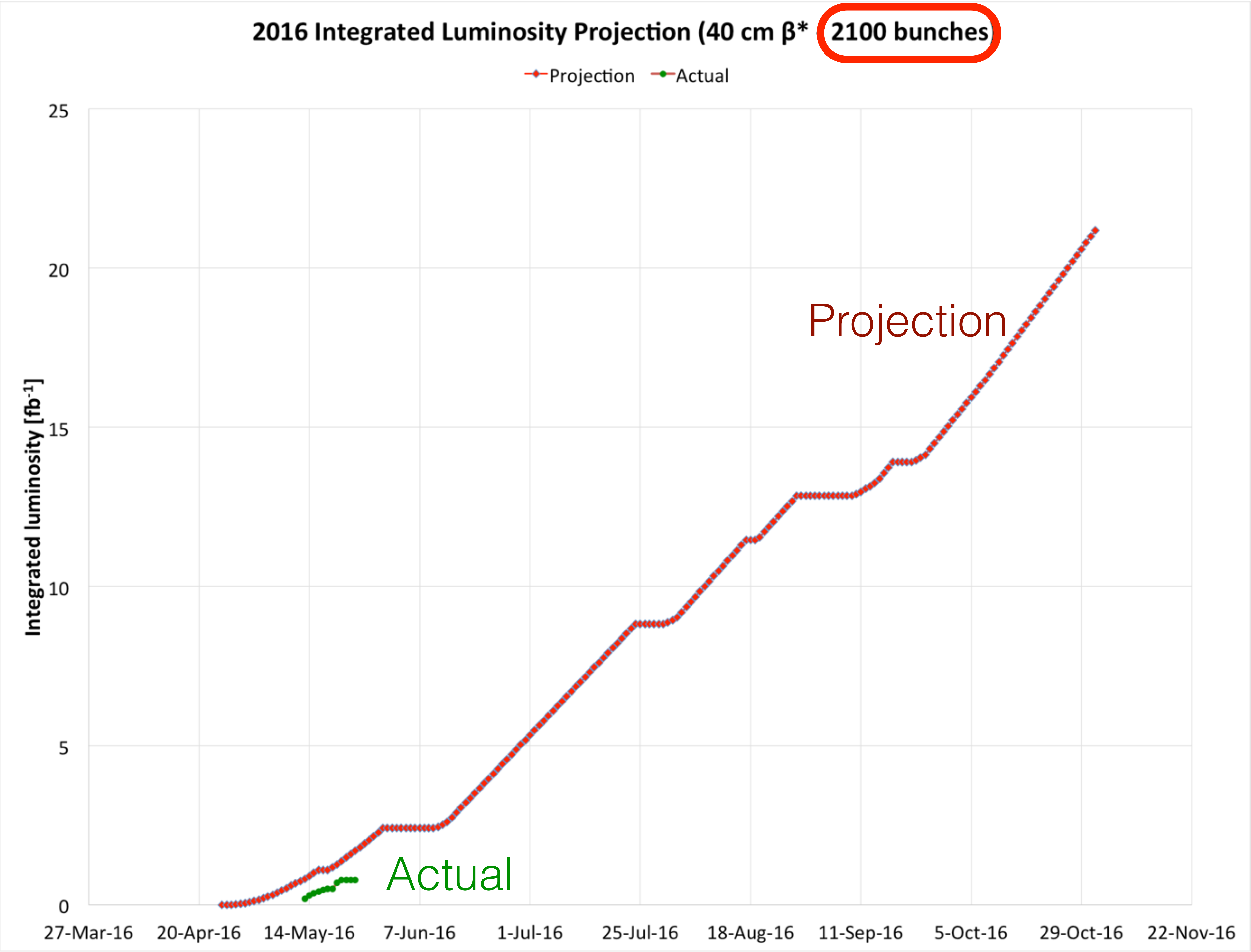
- 24 d
  p-Pb collisions

- 8 d
  special physics runs at large β*



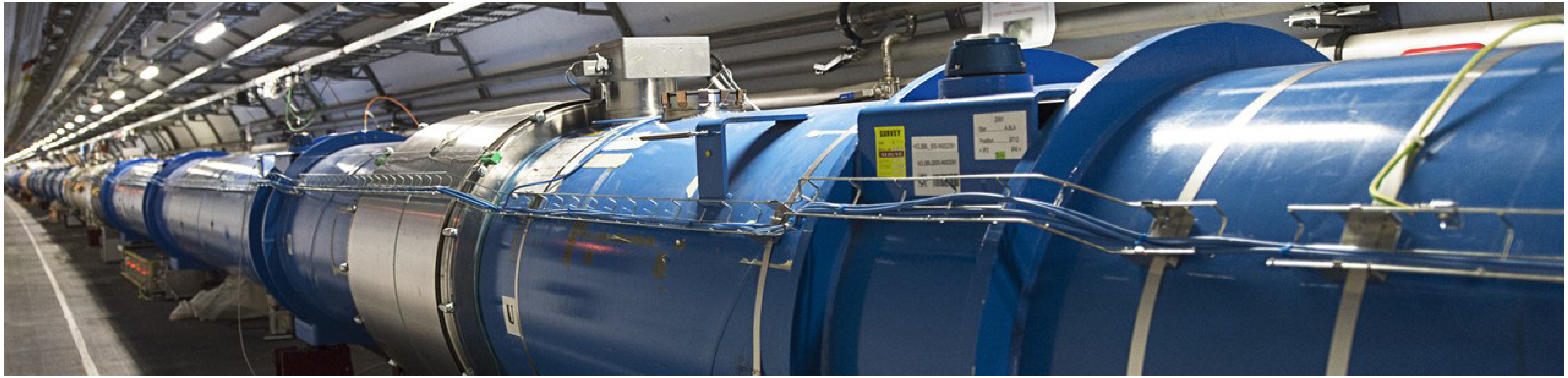
LHC Luminosity Projection 2016

- Operation with 25 ns bunch separation and β*=40 cm
- Have experienced limitations from injectors
  - SPS internal dump exhibits vacuum leak → power limitation/ precaution
  - 66 kV power supply
  - PS backup power supply failed

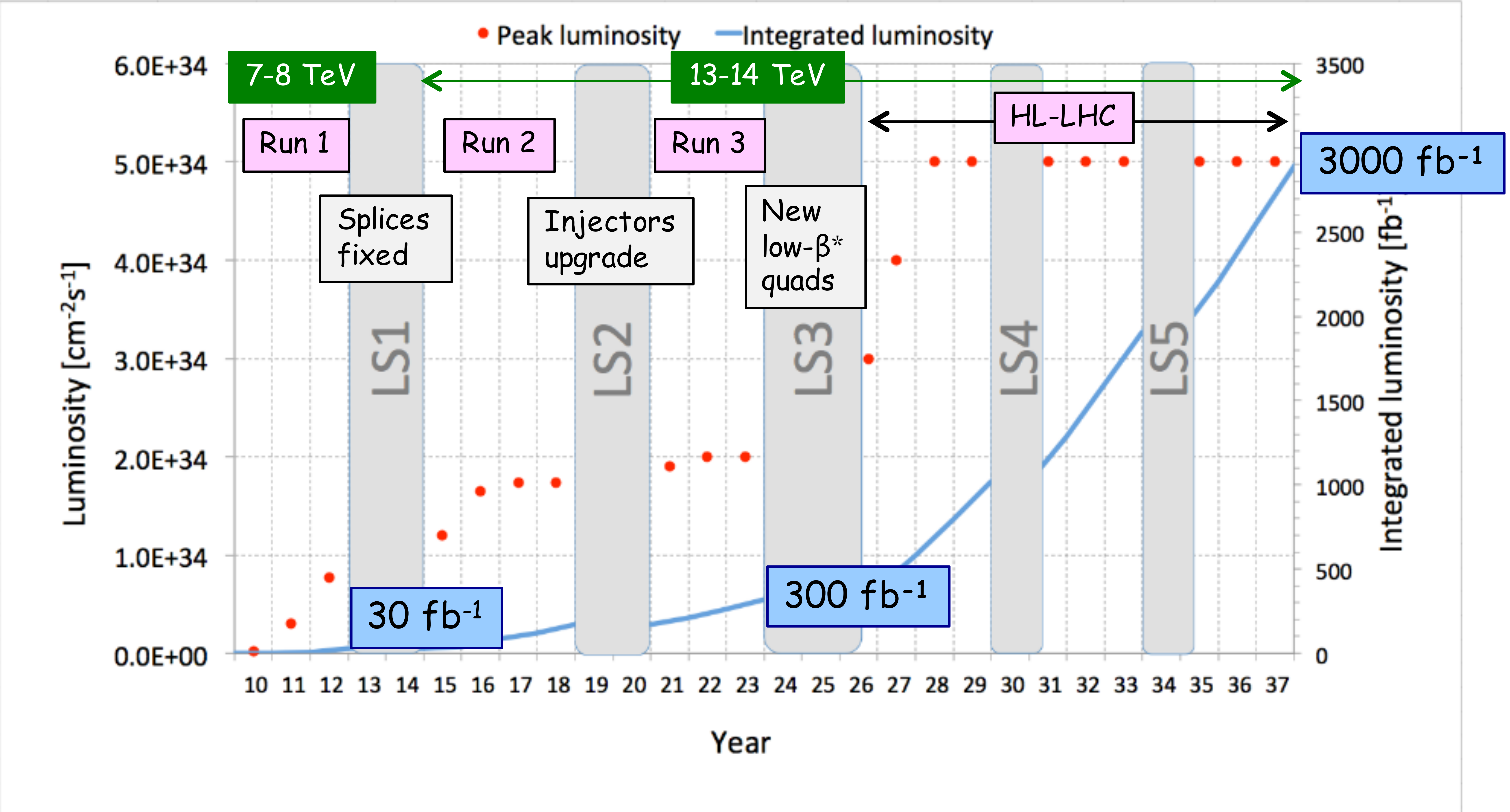


High Lumi LHC (HL-LHC)

- FP7 Design Study completed in 2015
  - first (short) 11 Tesla magnet operational
- HL-LHC now underway as a **project** at CERN
  - and recognised as a landmark on the ESFRI list 2016



The present and near/medium-term future: LHC and HL-LHC



F.Gianotti
EPS 2015

LHC is highest-E, highest-L operational collider → full exploitation ($\sqrt{s}$ ~ 14 TeV, 3000/fb) is mandatory:

- ❑ If new physics discovered in Run 2-3:
  → first detailed exploration of new physics with well understood machine and experiments
- ❑ If no new physics in Run 2-3:
  → extend direct discovery potential by ~ 20-30% (up to m ~ 8 TeV)

In either case: measure H couplings to few percent (including 2nd generation: Hμμ)

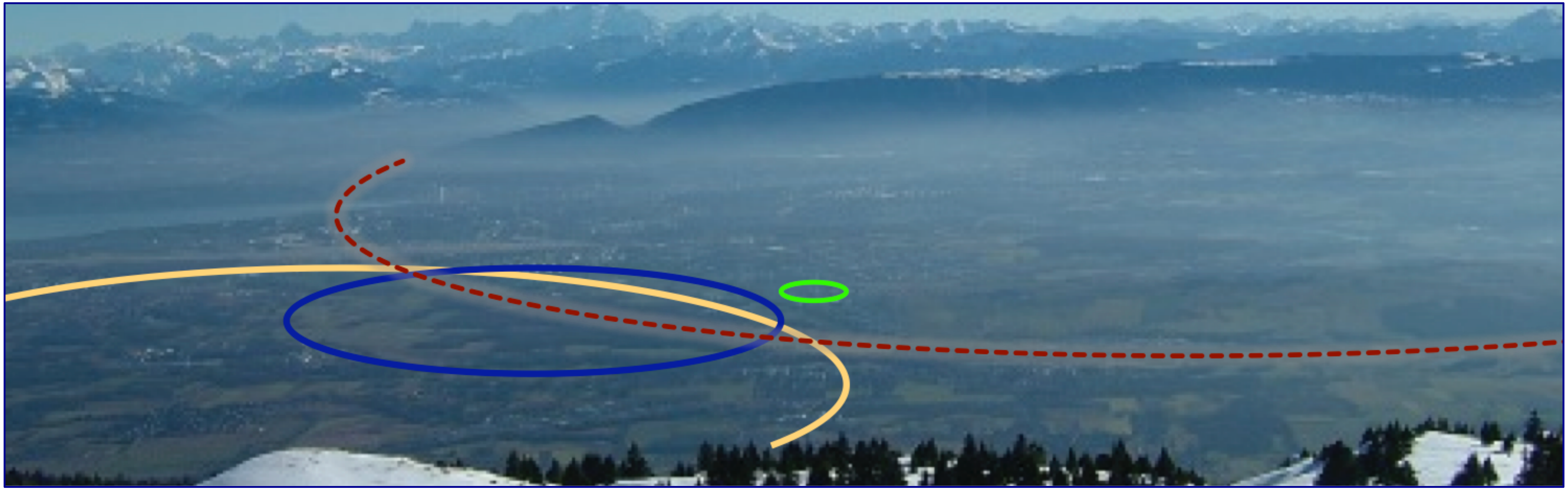
Energy Frontier

- To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available.

  CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron- positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide.

Highest energy hadron colliders

Future Circular Collider FCC



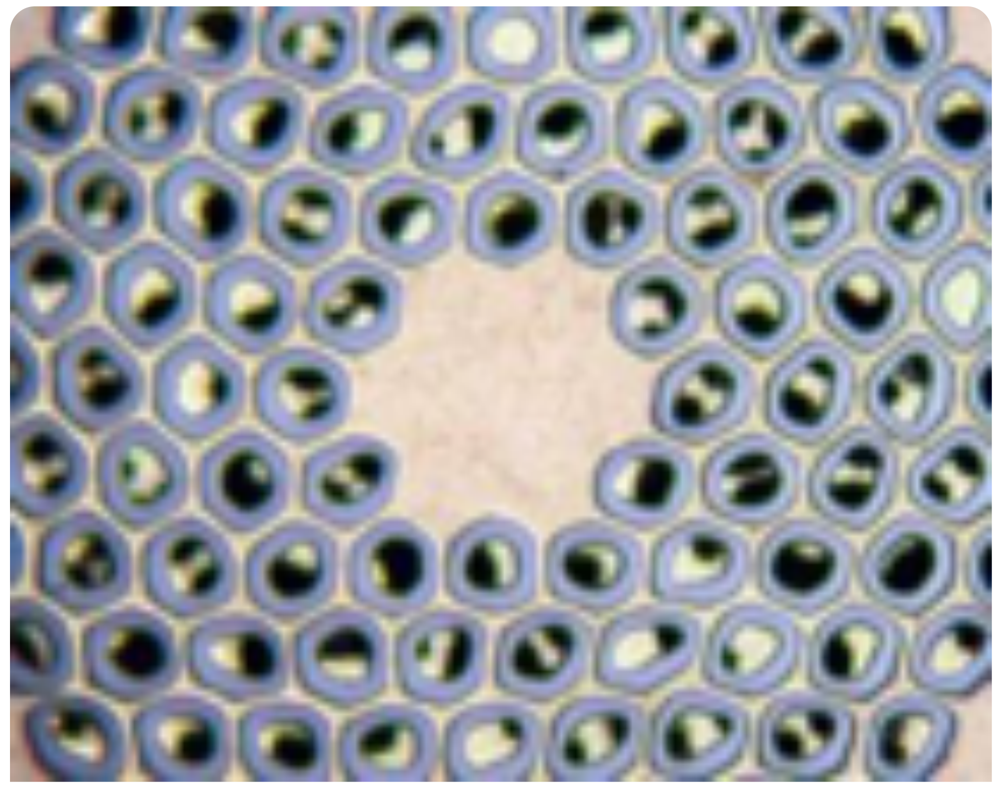
- European Design Study
- ~100 TeV pp in a ~100 km ring

High-field magnets

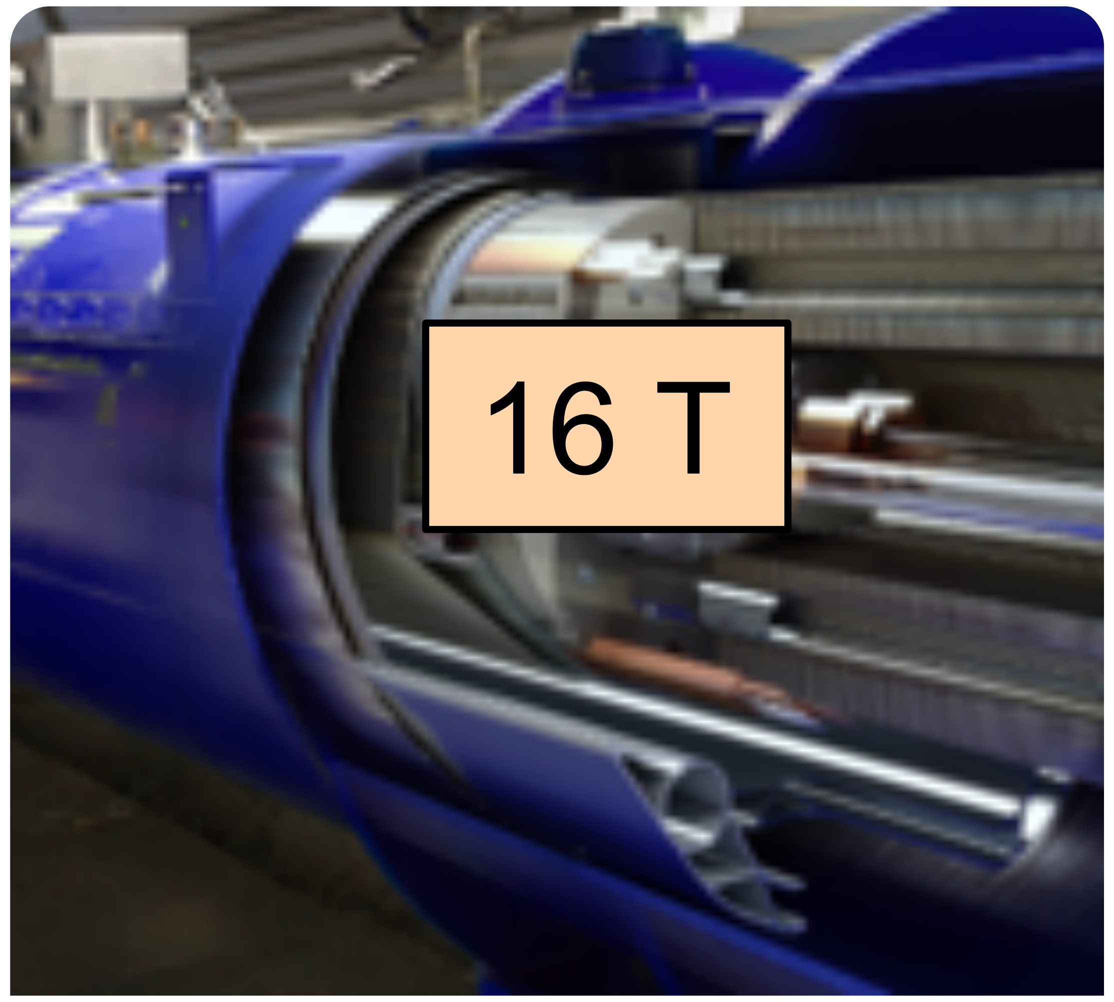
- Key to high energies
  - FCC and
  - HE-LHC = use of high field magnets in existing LHC ring
  - Nb_3Sn may lead to ~16 T magnets
    - HL-LHC magnets provide a ~1.2 km test of the technology
  - an insert of HTS may increase field to 20 T

Magnet R&D

LHC: nominal 8.3 T; exercise 9 T (being studied)
HL-LHC:
- 11 T dipoles in dispersion suppression collimators
- 12-13 T low-β quadrupoles ATLAS and CMS IR's



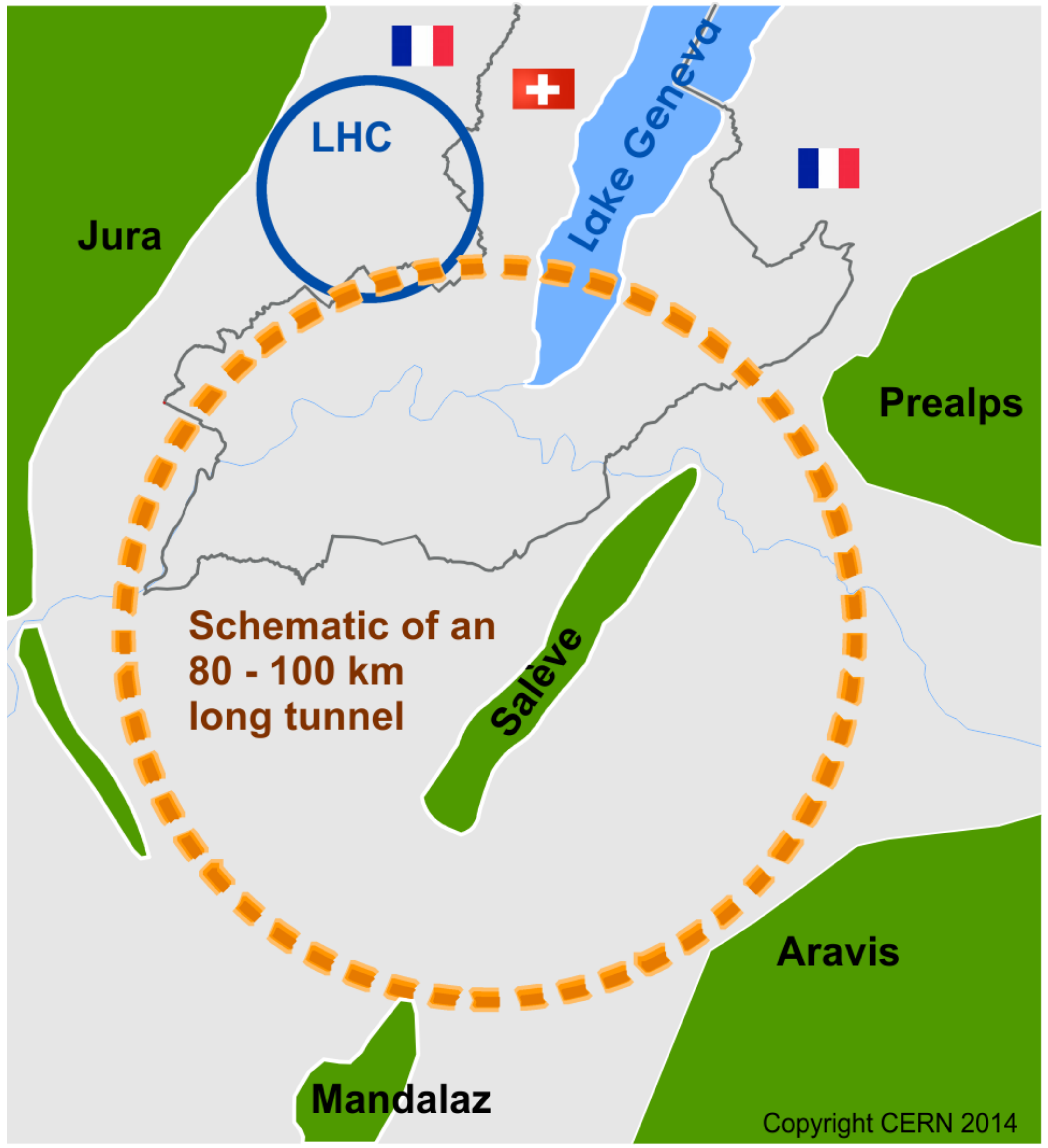
Nb_3Sn matrix



Dec 2015: 2 in 1 dipole of 1.8 m length reaches nominal 11.3 T.

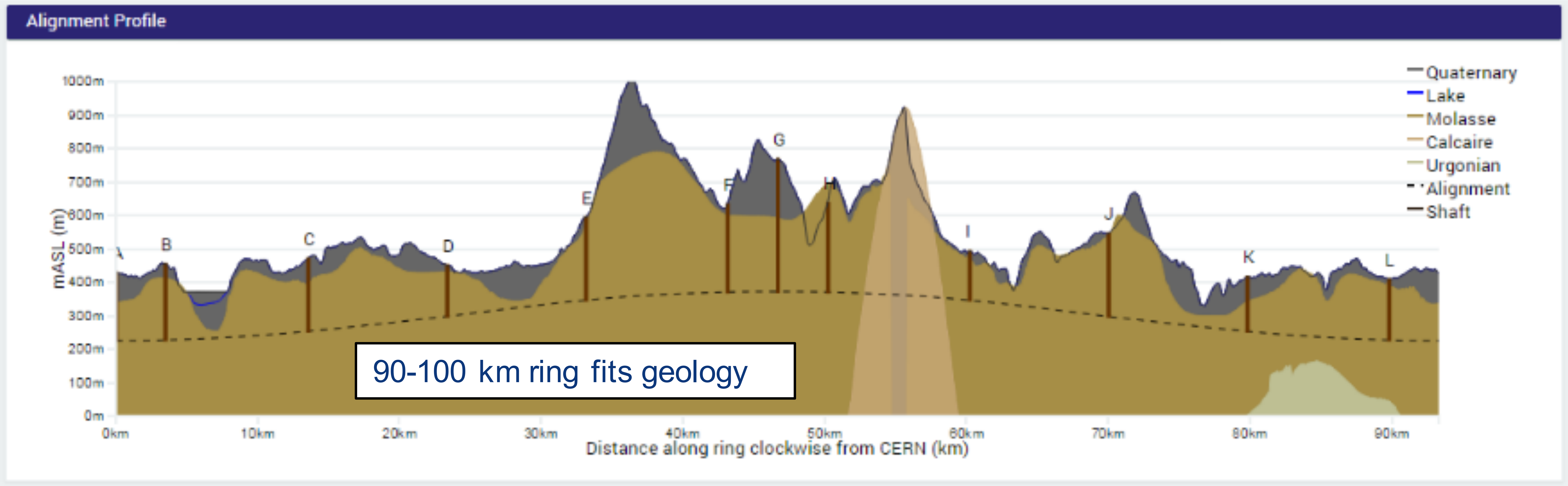
Conceptual Design Report by end 2018

- **pp-Collider (FCC-hh) – sets the boundary conditions**
  - **100 km ring, $\sqrt{s}$=100 TeV, L~2x10^{35}**
  - **HE-LHC is included (~28 TeV)**
- e^+e^--Collider as a possible first step
  - $\sqrt{s}$= 90 - 350 GeV,
    L~1.3x10^{34} at high E
- eh-Collider as an option
  - $\sqrt{s}$=3.5 TeV, L~10^{34}

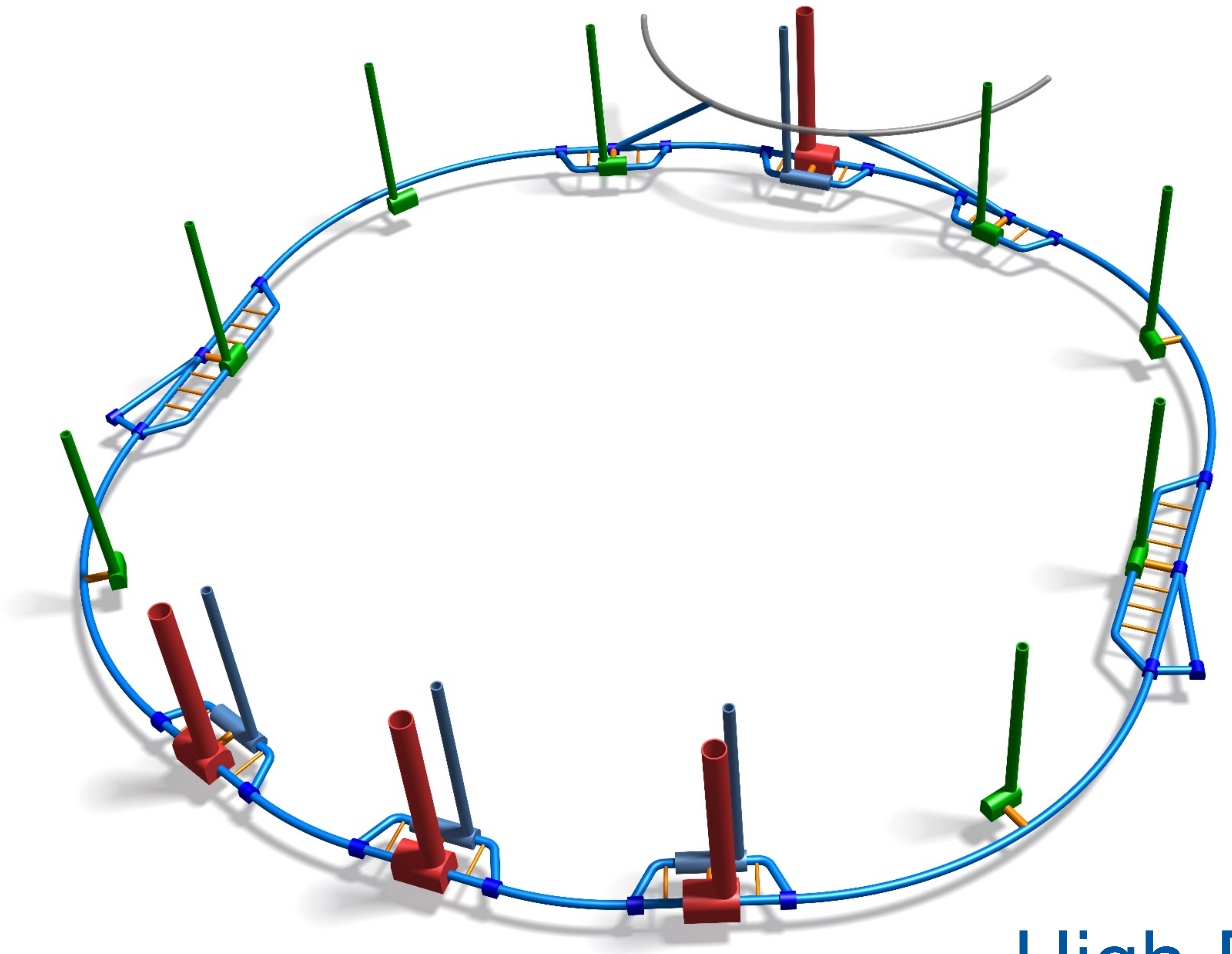


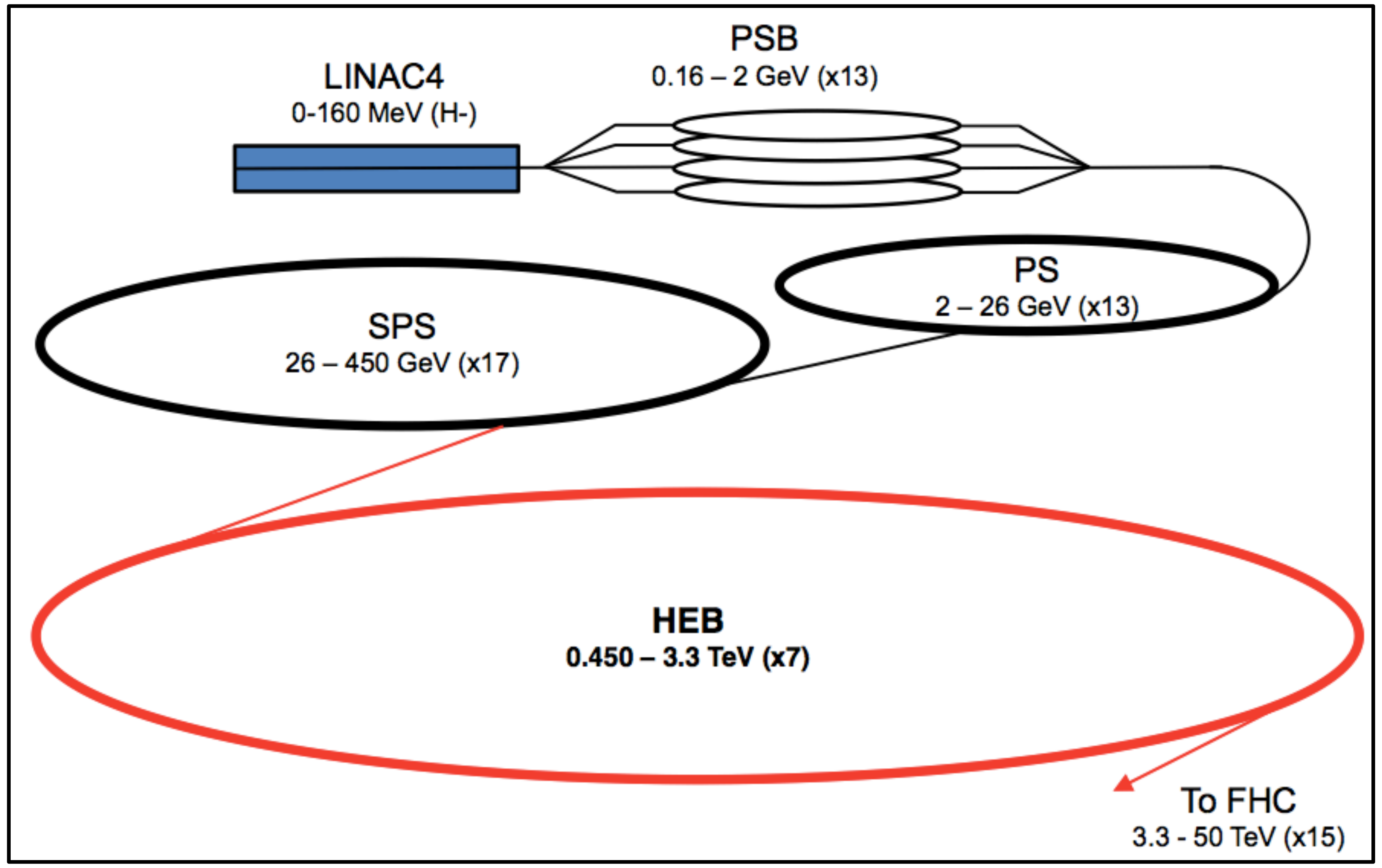
Site investigations @ CERN

- Studies are site independent. – FCC@CERN benefits from existing infrastructure.



3-D Model and Injectors @ CERN





High-Energy Booster (HEB) is “refurbished” LHC

– New power converters to achieve fast ramp (50 A/s)

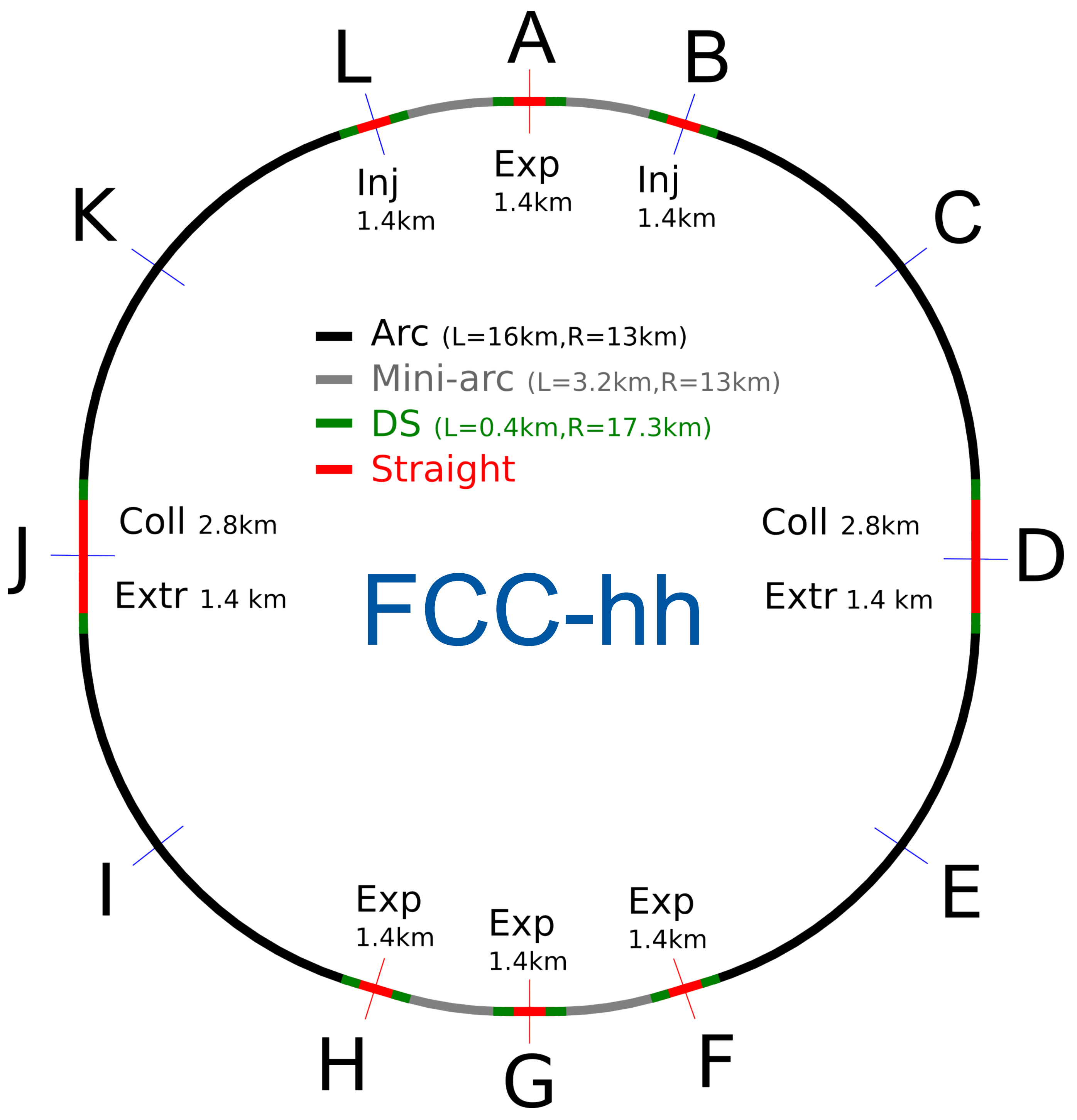
– Resulting filling time 30 mins

FCC-hh Parameters

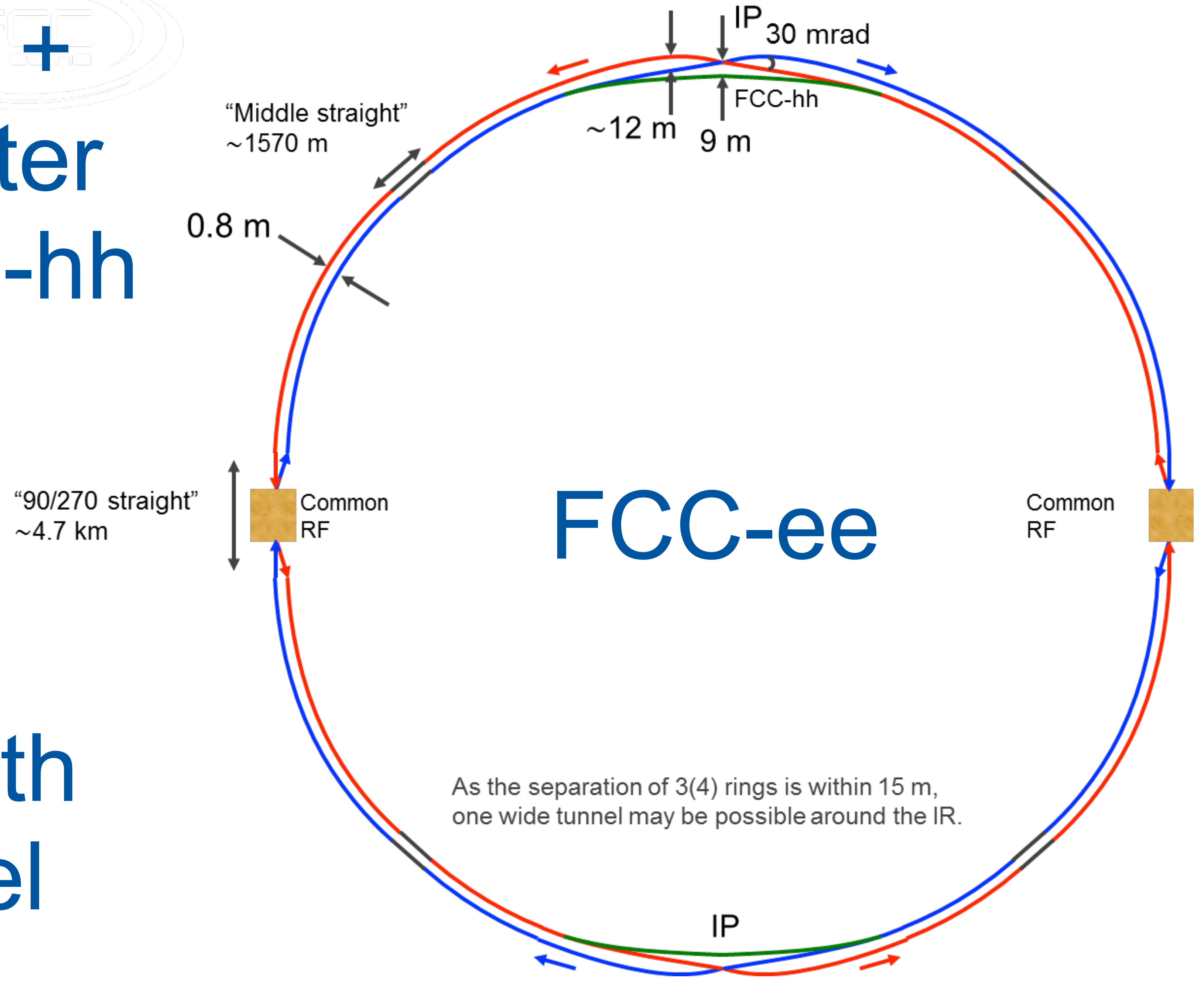
Parameter	FCC-hh		SppC	LHC	HL LHC
collision energy cms [TeV]	100		71.2	14	
dipole field [T]	16		20	8.3	
# IP	2 main + 2		2	2 main + 2	
bunch intensity [10^{11}]	1	1 (0.2)	2	1.1	2.2
bunch spacing [ns]	25	25 (5)	25	25	25
luminosity/Ip [10^{34} $cm^{-2}s^{-1}$]	5	~25	12	1	5
events/bunch crossing	170	~850 (170)	400	27	135
stored energy/beam [GJ]	8.4		6.6	0.36	0.7
E-loss/turn synchrotron radiation/beam	5 MeV 3 MW		2 MeV 5.8 MW	7 keV 5.4 kW	7 keV 9.5 kW

Layout of FCC-hh and FCC-ee

- Closed orbit solution now available for both machines.



2 rings + 1 booster in FCC-hh tunnel



FCC-ee compatible with **FCC-pp** tunnel layout

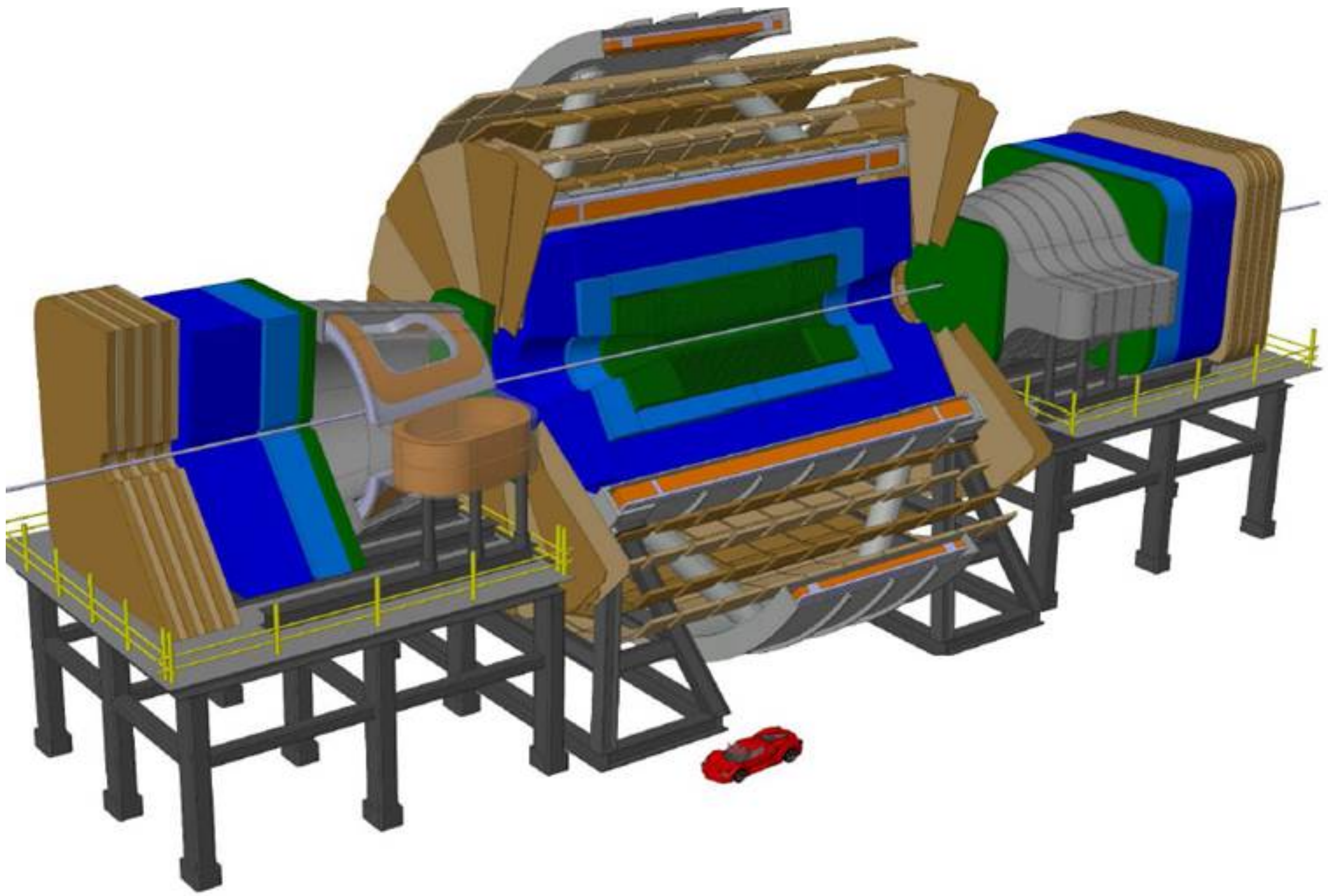
Circular Lepton Colliders

parameter	FCC-ee			CepC	LEP2
energy/beam [GeV]	**45**	**120**	**175**	**120**	105
bunches/beam	90000	770	78	50	4
beam current [mA]	1450	30	6.6	16.6	3
luminosity/IP x 10^{34} $cm^{-2}s^{-1}$	**70**	**5**	**1.3**	**2.0**	0.0012
energy loss/turn [GeV]	0.03	1.67	7.55	3.1	3.34
synchrotron power [MW]	**100**			**103**	22
RF voltage [GV]	0.08	3.0	10	6.9	3.5

FCC-ee
- 2 rings
- 2 IP with crab waist

CepC (China)
– 1 ring with possible double ring sections

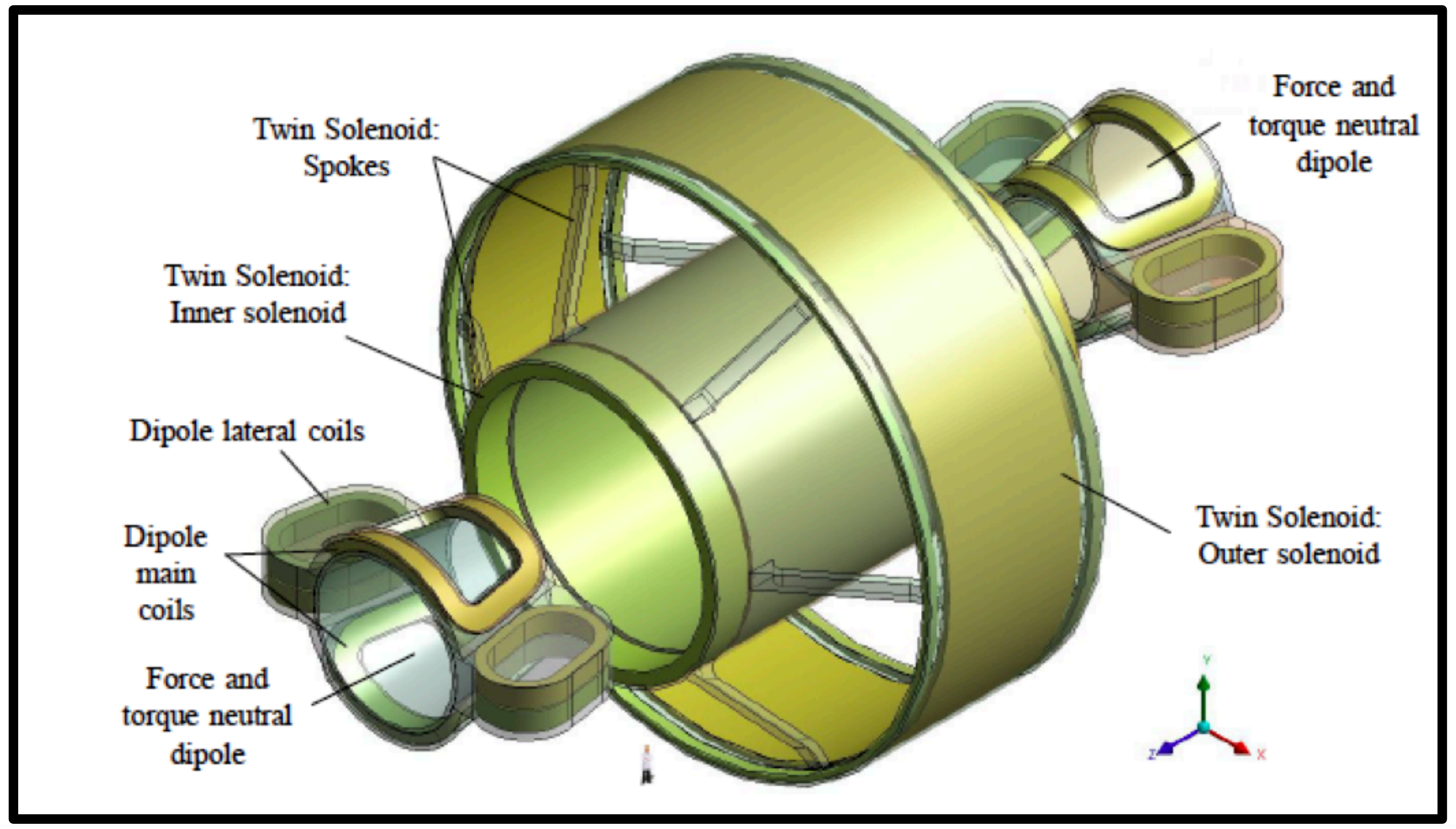
FCC detector concepts for 100 TeV



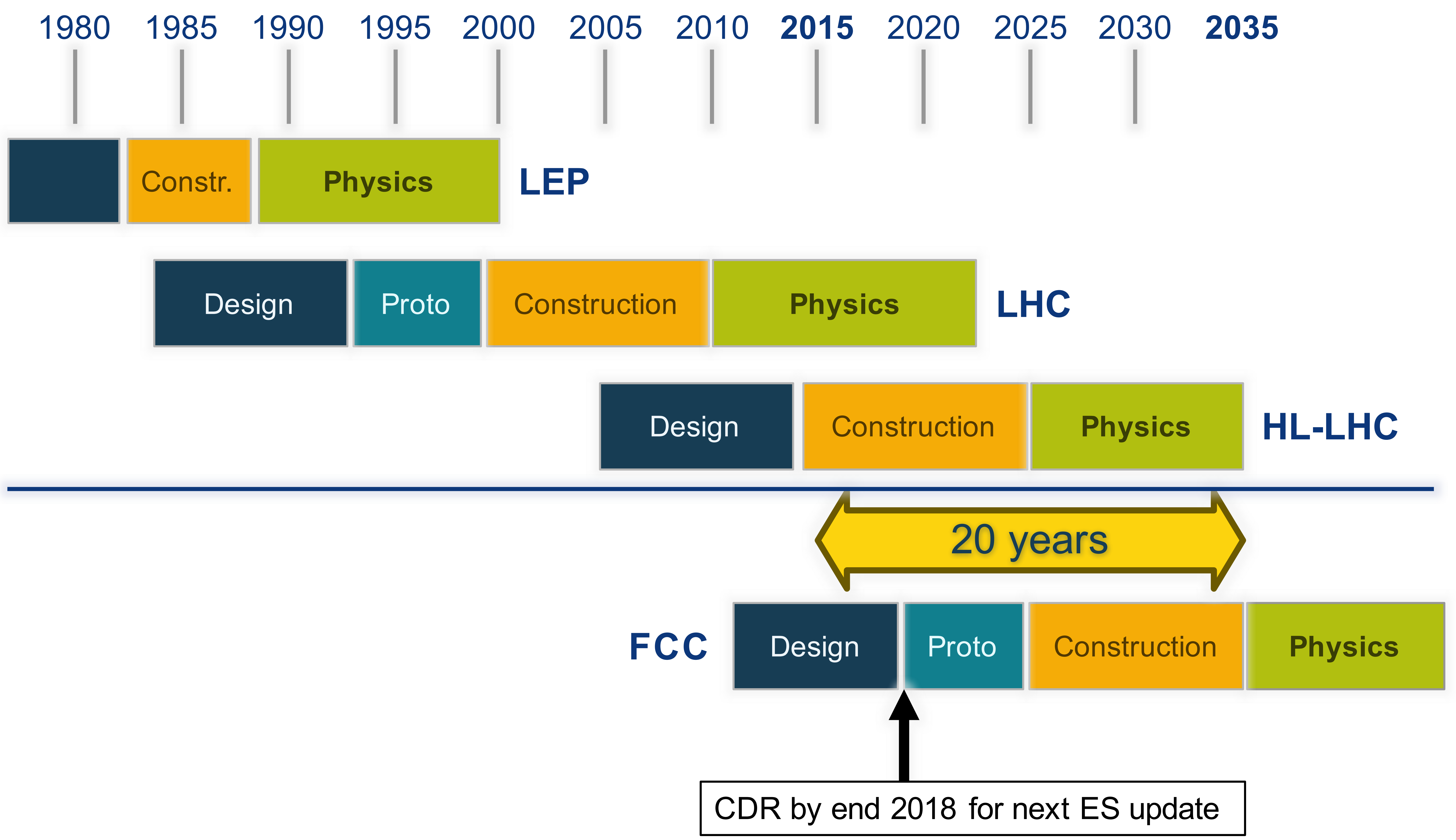
Driving requirements:

BL^2 ~10 x ATLAS/CMS for 10% muon momentum resolution at 10-20 TeV. Requires 1μm resolution

- large-bore, high-field solenoid
- return flux captured by twin solenoid
- Coverage with tracking and precise calorimetry up to $|\eta|$~5 for light particles
- forward dipole à la LHCb: B~10 Tm



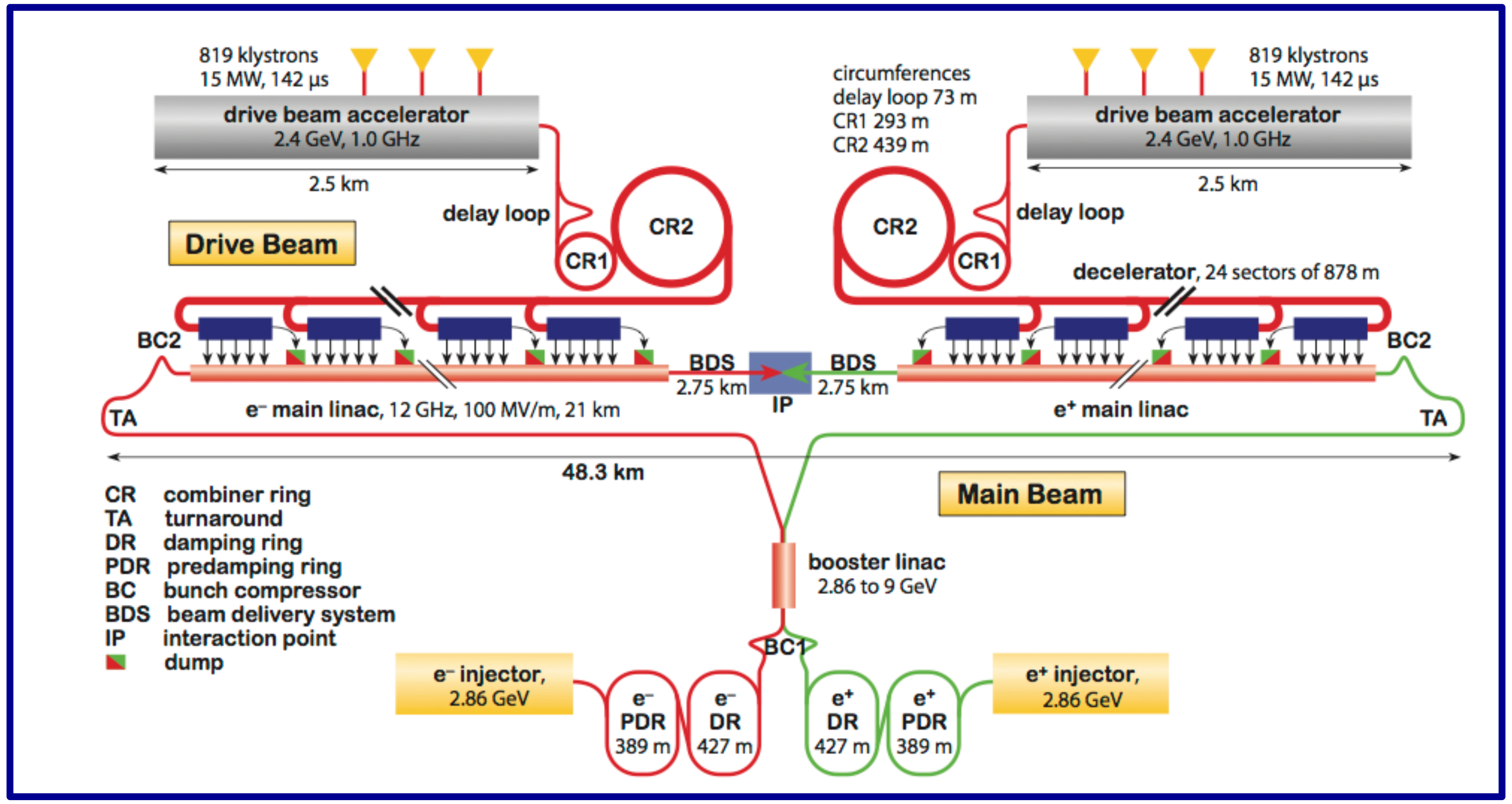
Possible Timeline



Highest energy in lepton colliders

Compact Linear Collider CLIC

- e^+e^- collider 1-3 TeV
- currently only option for the TeV region
- exploring 380 GeV operation (klystrons?)



- CDR 2013
- CTF3 has provided key results (end 2016)
- ready for a demonstrator

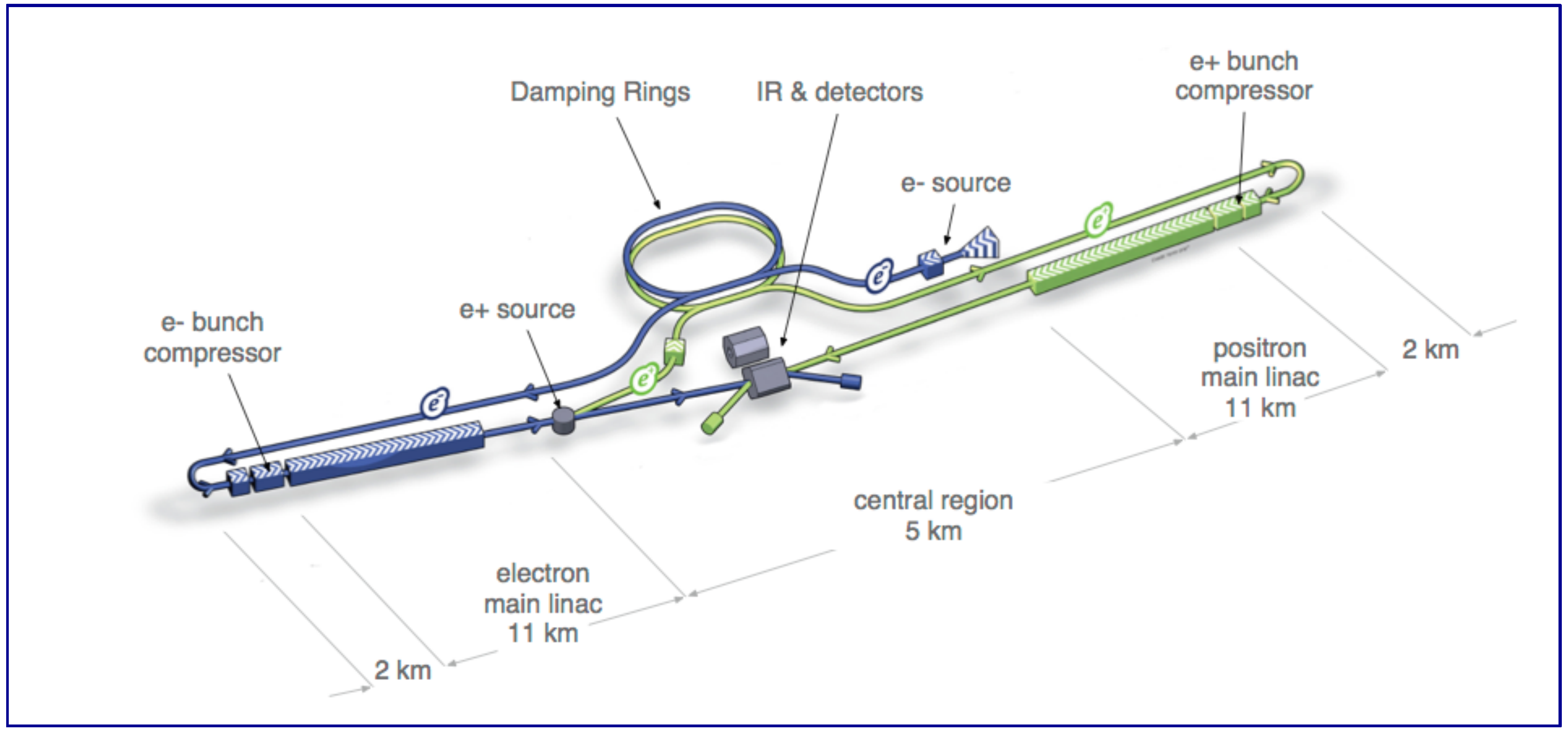
e^+e^- collider

- There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded. The Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate.

  Europe looks forward to a proposal from Japan to discuss a possible participation.

International Linear Collider ILC

- e^+e^- collider $\sqrt{s}$ = 0.5 TeV (upgradeable to 1 TeV)
- precision Higgs and Top programme and beyond



- Project is mature (TDR 2012)
- hosting evaluated by Japanese government
- international project (without host laboratory)

International Linear Collider

- Ministry MEXT continues to evaluate the implications of hosting ILC in Japan
  - cost, manpower (skills)
- ICFA decided to prolong the mandate of the Linear Collider Board (LCB) for two years

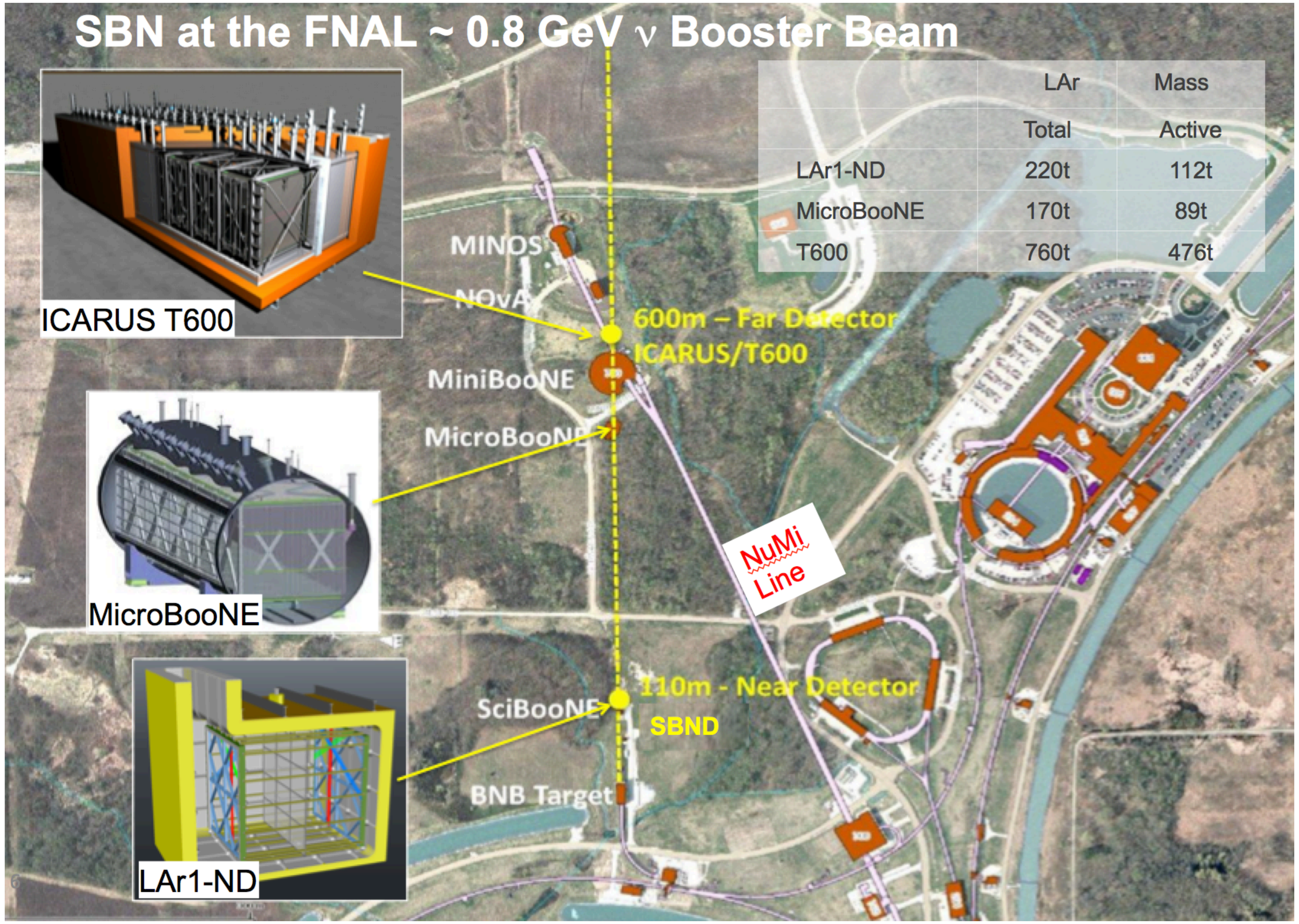
ν-physics

- Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments.

  Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.

Short baseline programme at Fermilab

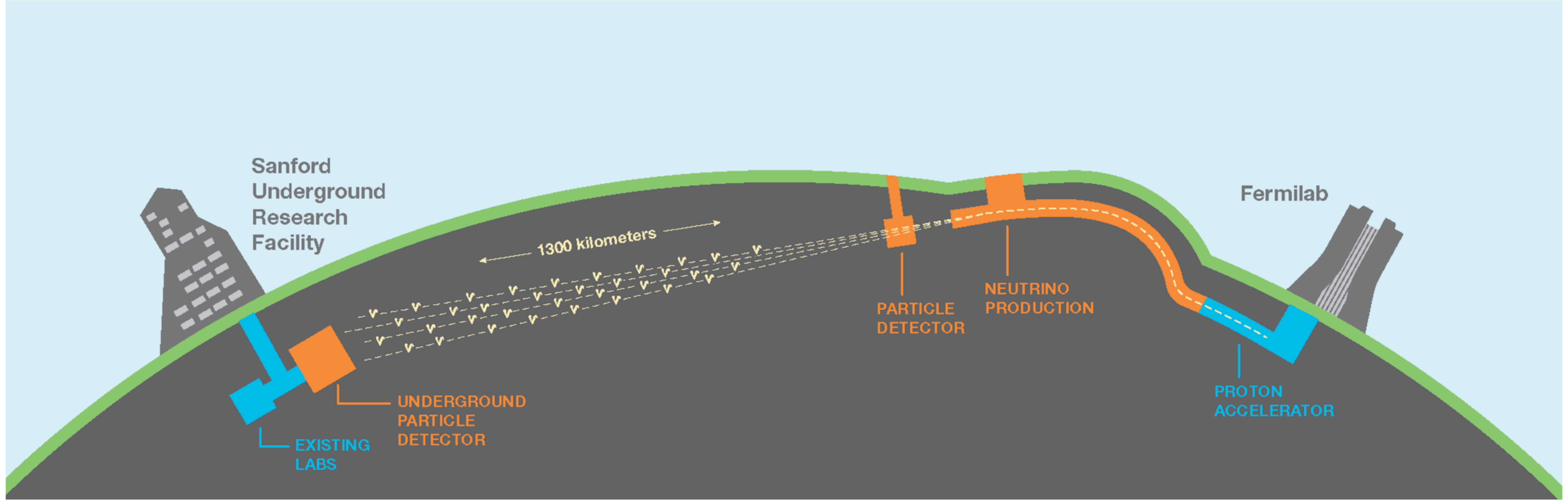
- To resolve experimental inconsistencies in the measured ν-spectrum
- Using
  - LAr-ND (near detector)
  - MicroBooNE
  - refurbished ICARUS



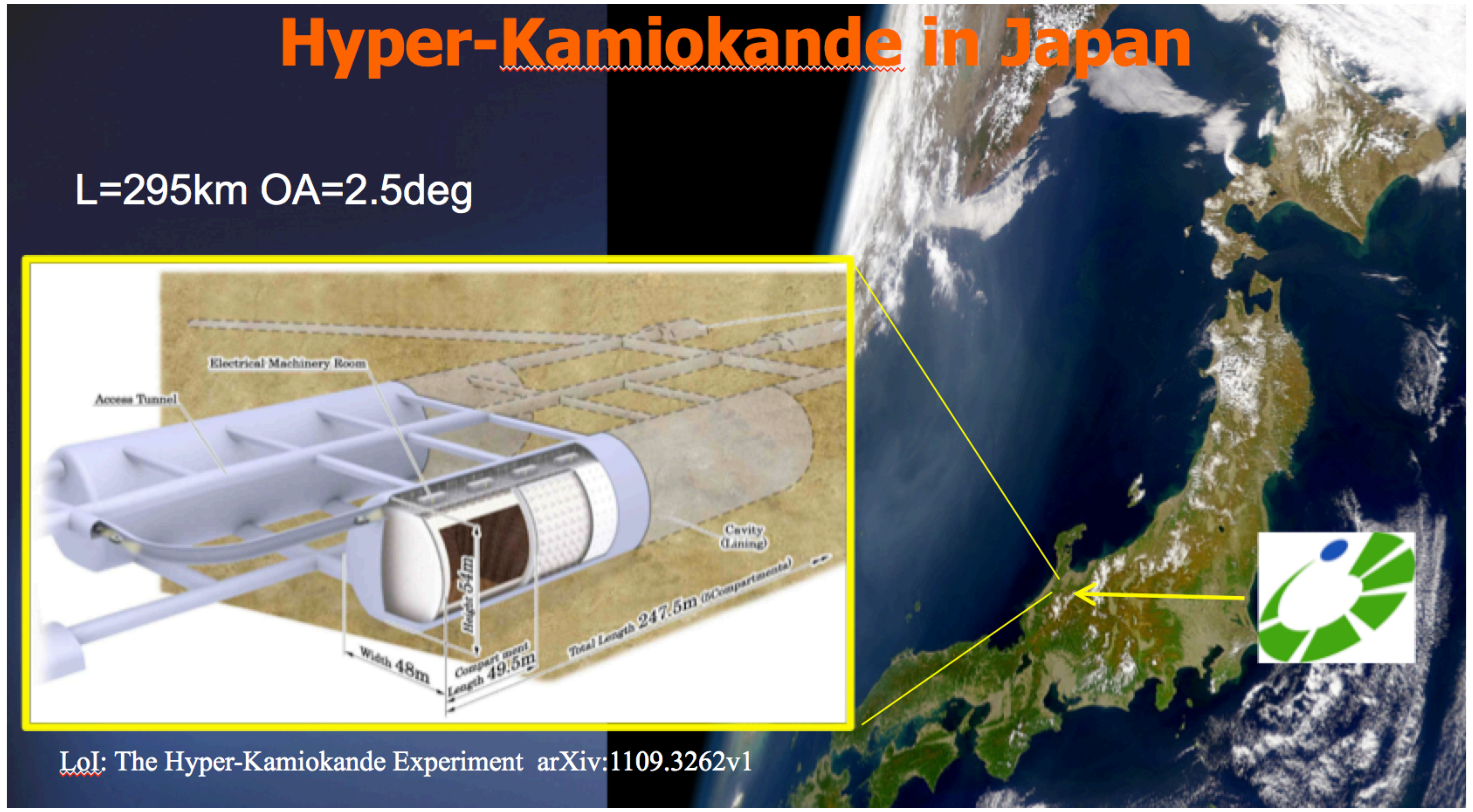
	LAr Total	Mass Active
LAr1-ND	220t	112t
MicroBooNE	170t	89t
T600	760t	476t

Long baseline neutrino programmes

- Fermilab is planning a long baseline neutrino facility (LBNF), a wide band neutrino beam to the DUNE experiment (LArTPC) in South Dakota



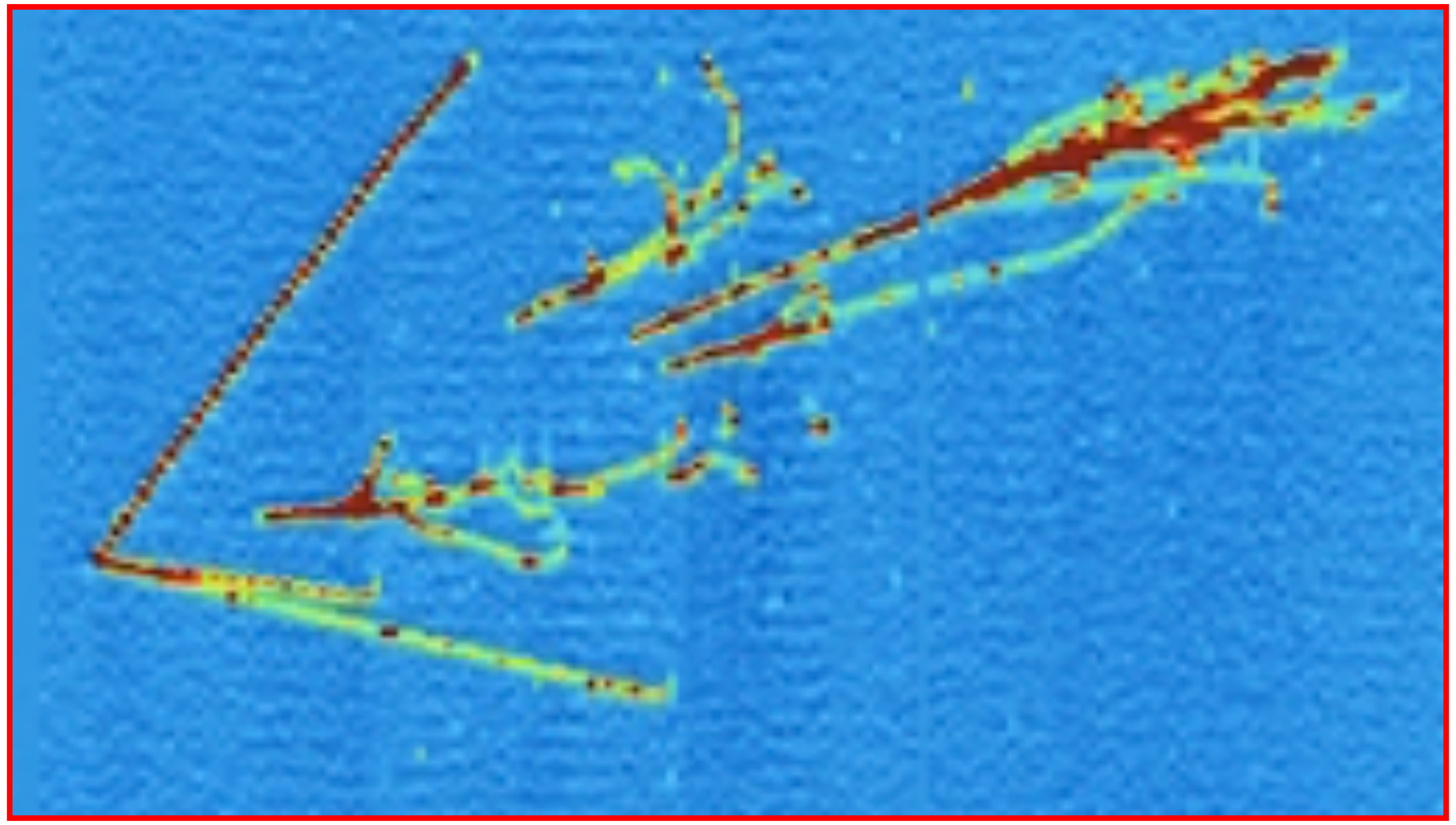
- KEK is considering Hyper-K (water Cherenkov detector) at Kamioka

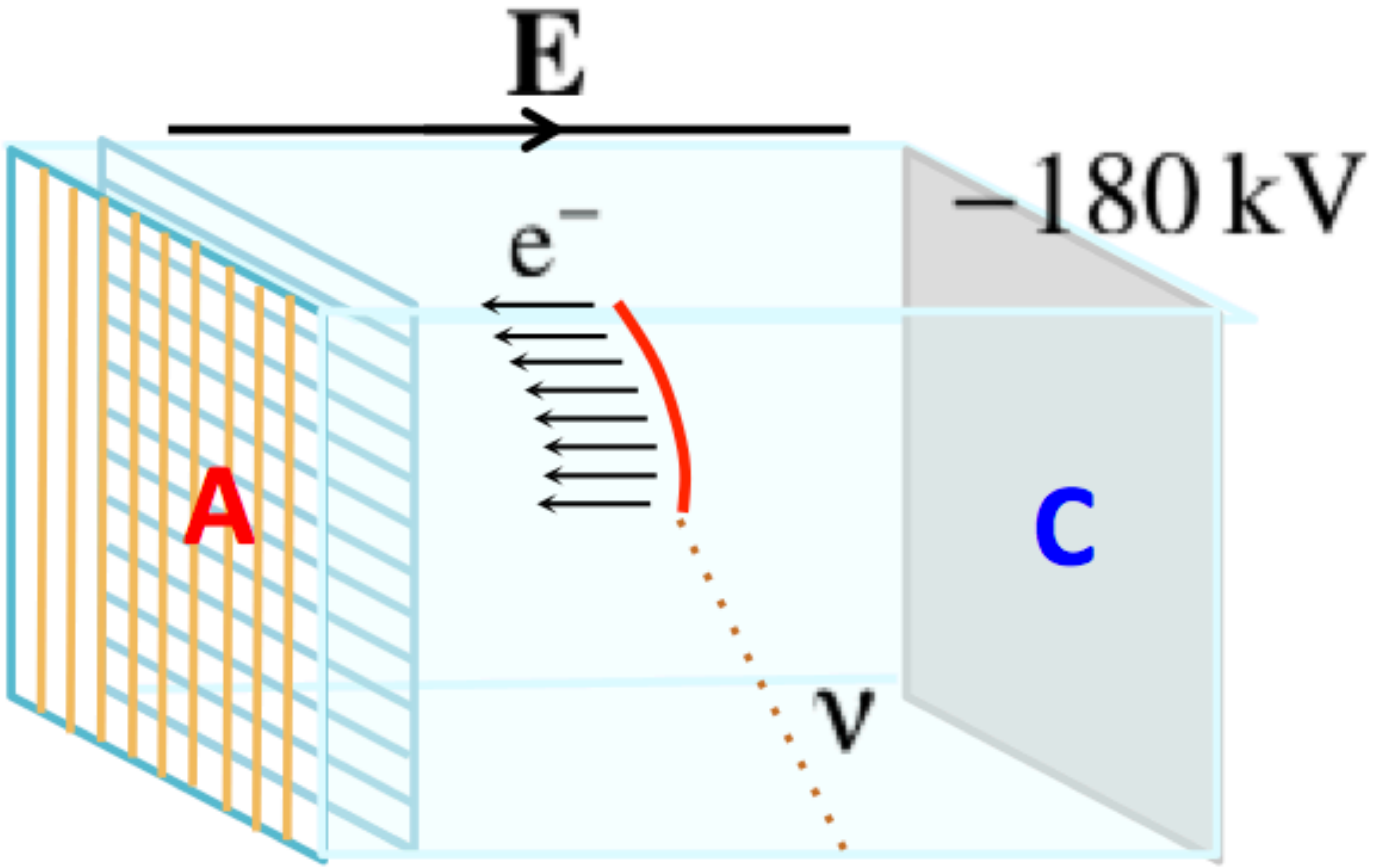


- Goals: neutrino-oscillation parameters, mass hierarchy and CP-violation

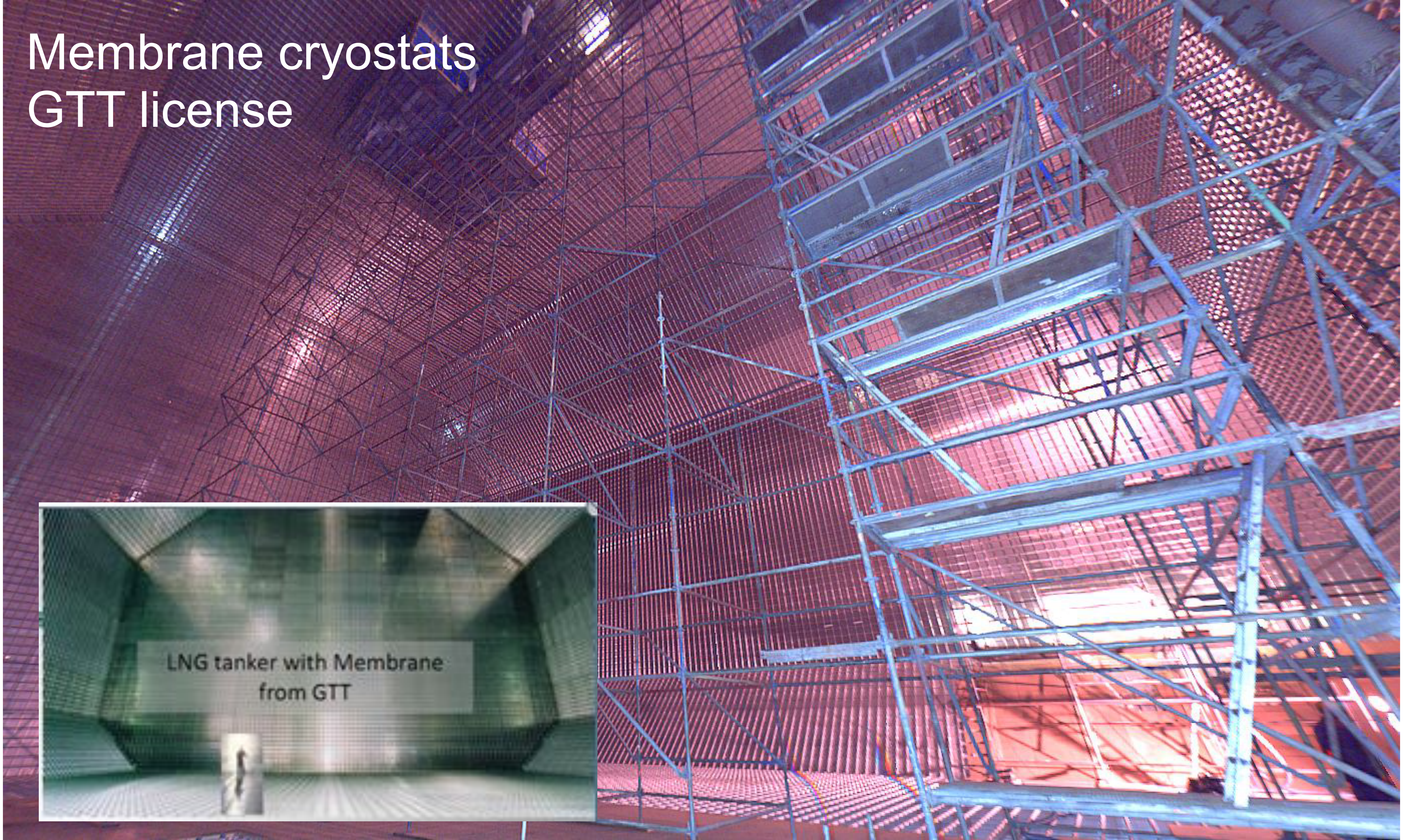
LAr Technology

- LarTPC large scale active detectors
    - few mm precision
    - good energy resolution



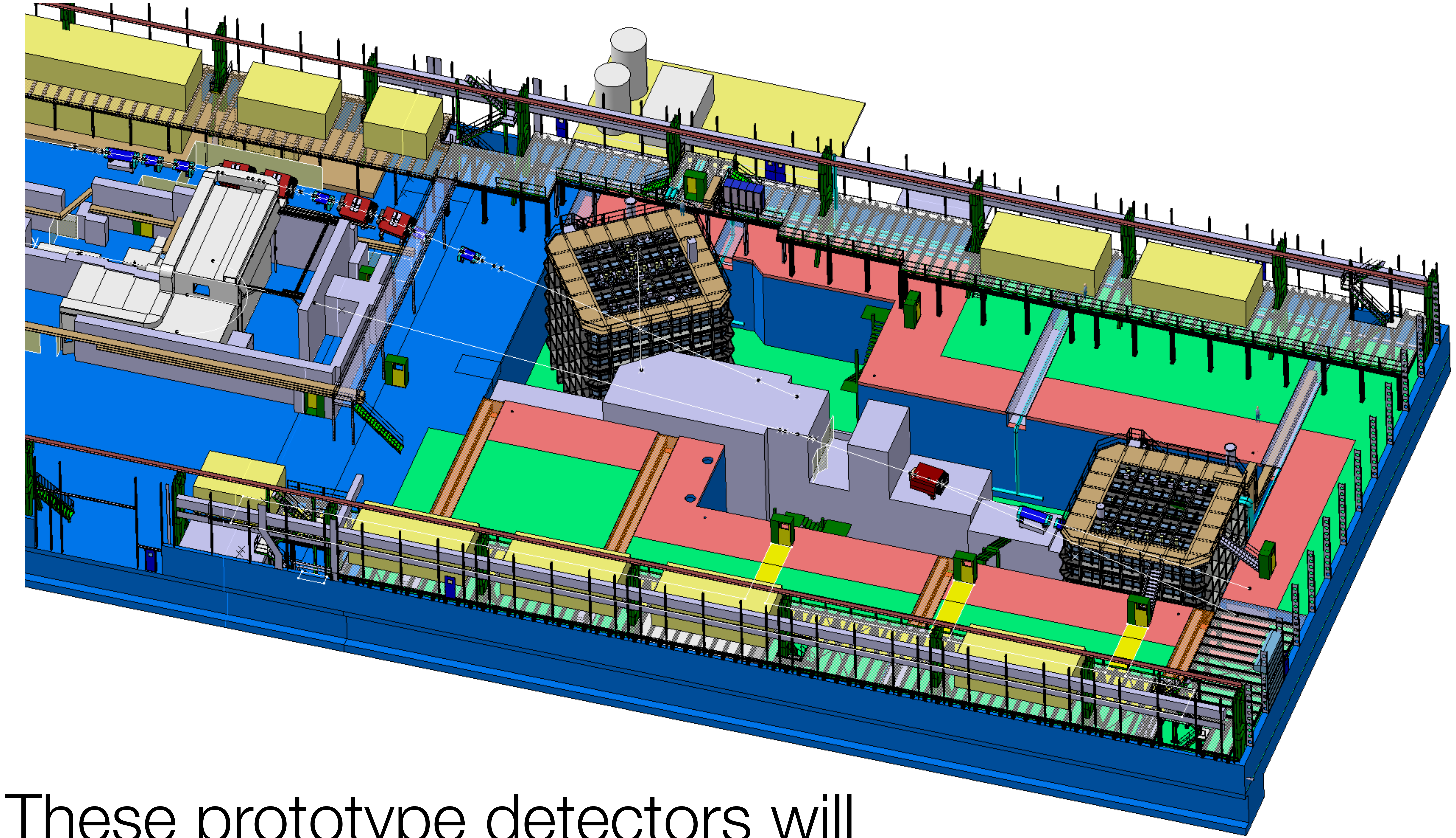


Membrane cryostats
GTT license



Neutrino Platform at CERN

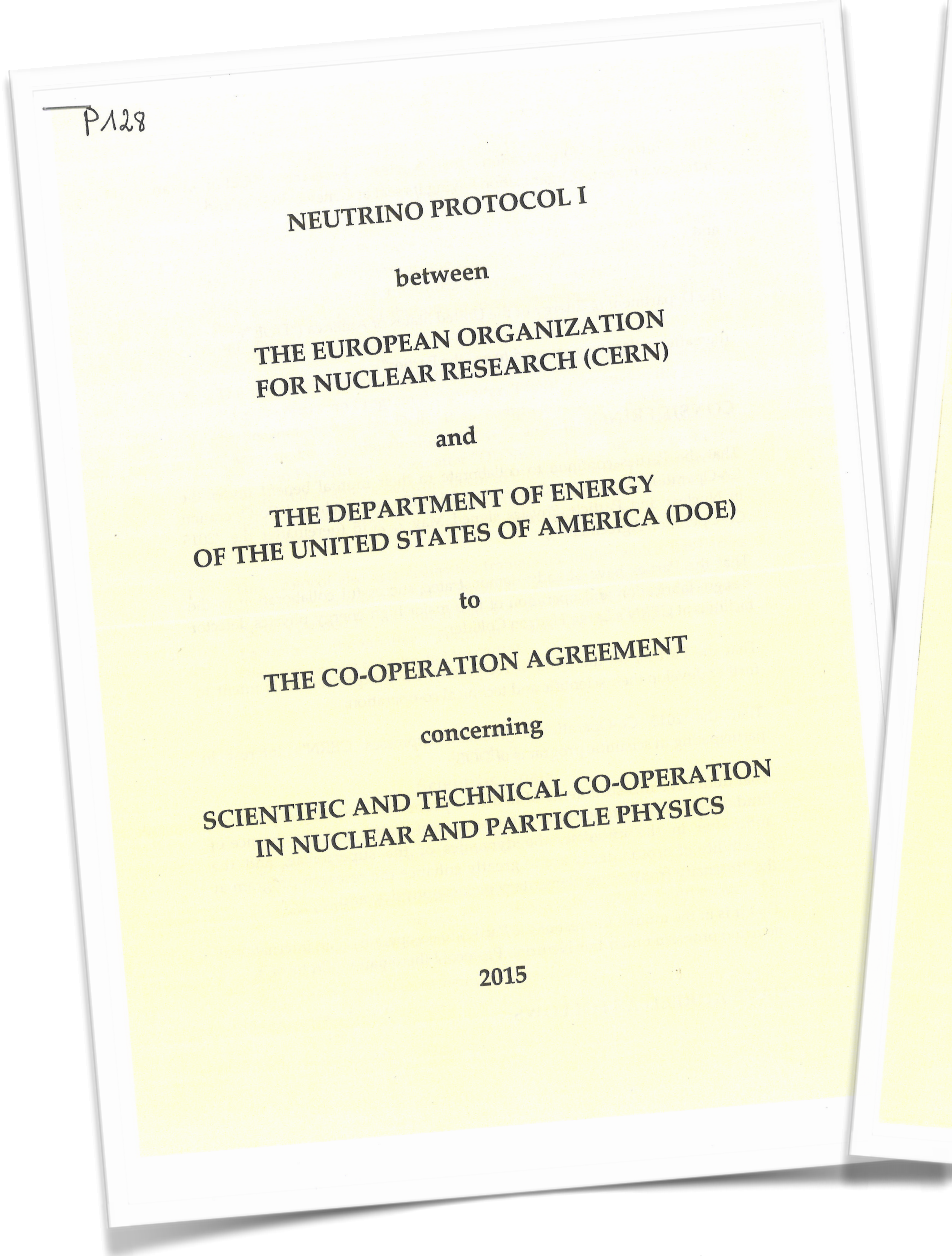
To develop experimental techniques, e.g. protoDUNE
– single phase
– double phase



These prototype detectors will generate a data stream comparable to that of ALICE in Heavy Iron Running

International Framework of Neutrino Programme

- no ν-beams at CERN
- foster European engagement in short- and long-baseline neutrino programmes
- Memoranda of Understanding have been concluded end of 2015
  - being supplemented by addenda on work programme


P128

NEUTRINO PROTOCOL I

between

THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

and

THE DEPARTMENT OF ENERGY OF THE UNITED STATES OF AMERICA (DOE)

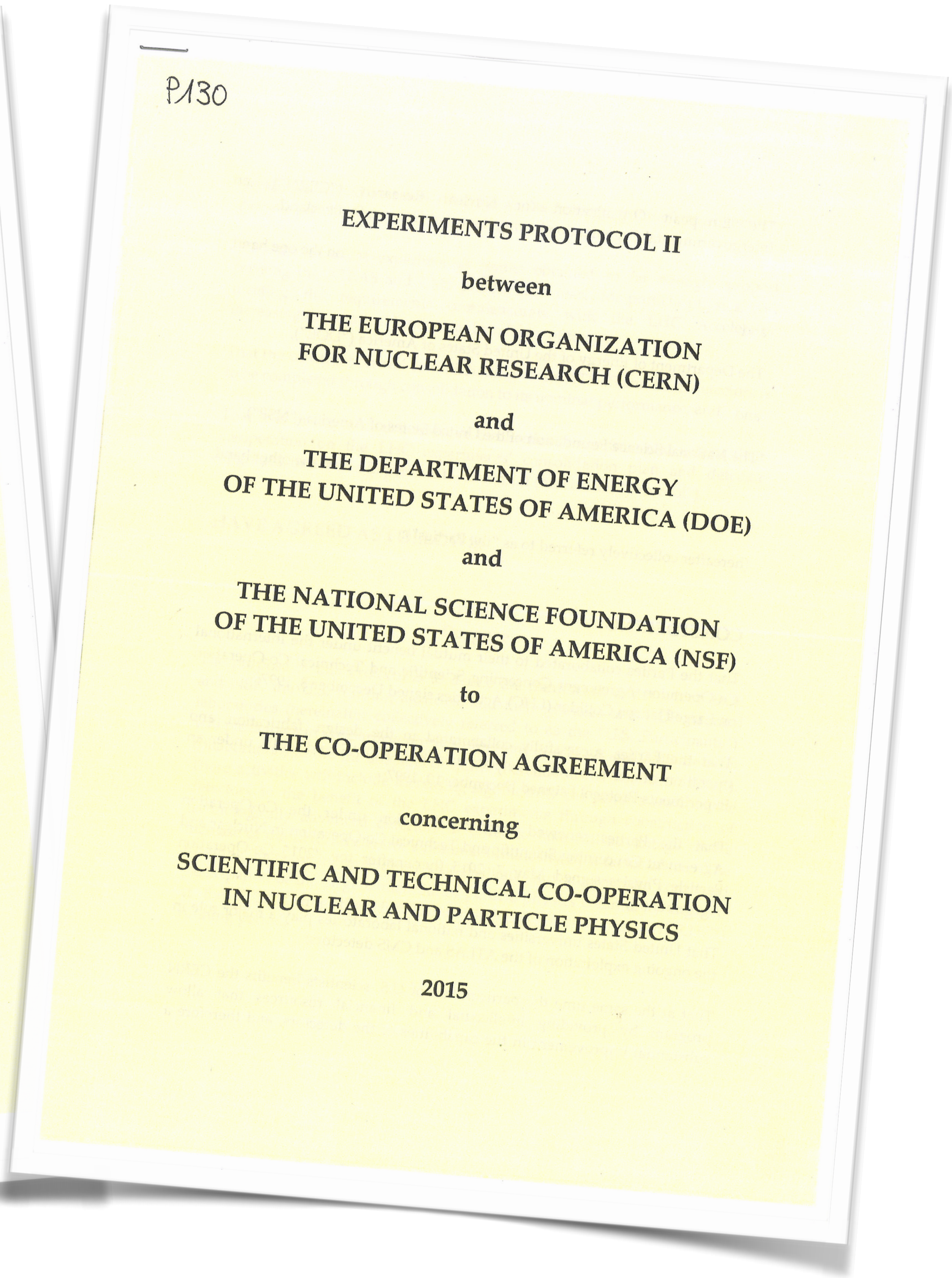
to

THE CO-OPERATION AGREEMENT

concerning

SCIENTIFIC AND TECHNICAL CO-OPERATION IN NUCLEAR AND PARTICLE PHYSICS

2015


P130

EXPERIMENTS PROTOCOL II

between

THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

and

THE DEPARTMENT OF ENERGY OF THE UNITED STATES OF AMERICA (DOE)

and

THE NATIONAL SCIENCE FOUNDATION OF THE UNITED STATES OF AMERICA (NSF)

to

THE CO-OPERATION AGREEMENT

concerning

SCIENTIFIC AND TECHNICAL CO-OPERATION IN NUCLEAR AND PARTICLE PHYSICS

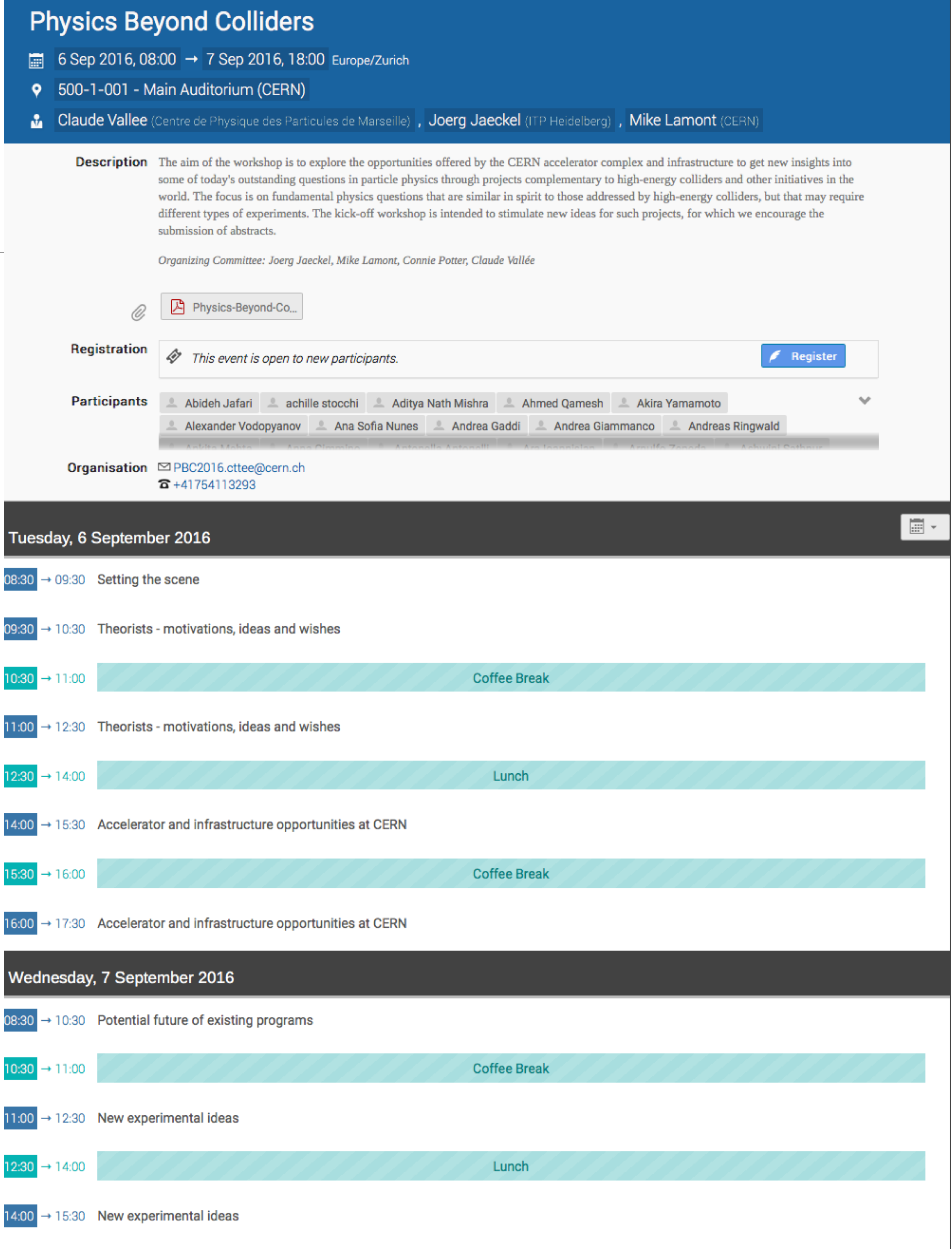
2015

CERN engages in external projects

Beyond flagship projects – at CERN

Physics-Beyond-Colliders Study Group

- Workshop announced for early September 2016
- Convened by
  - C Vallee
  - J Jäckel
  - M Lamont
- Will contribute to ESPP update



Physics Beyond Colliders

6 Sep 2016, 08:00 → 7 Sep 2016, 18:00 Europe/Zurich

500-1-001 - Main Auditorium (CERN)

Claude Vallee (Centre de Physique des Particules de Marseille), Joerg Jaeckel (ITP Heidelberg), Mike Lamont (CERN)

Description The aim of the workshop is to explore the opportunities offered by the CERN accelerator complex and infrastructure to get new insights into some of today's outstanding questions in particle physics through projects complementary to high-energy colliders and other initiatives in the world. The focus is on fundamental physics questions that are similar in spirit to those addressed by high-energy colliders, but that may require different types of experiments. The kick-off workshop is intended to stimulate new ideas for such projects, for which we encourage the submission of abstracts.

Organizing Committee: Joerg Jaeckel, Mike Lamont, Connie Potter, Claude Vallée

Physics-Beyond-Co...

Registration *This event is open to new participants.* Register

Participants Abideh Jafari, achille stocchi, Aditya Nath Mishra, Ahmed Qamesh, Akira Yamamoto, Alexander Vodopyanov, Ana Sofia Nunes, Andrea Gaddi, Andrea Giammanco, Andreas Ringwald

Organisation PBC2016.cttee@cern.ch
+41754113293

Tuesday, 6 September 2016

08:30 → 09:30	Setting the scene
09:30 → 10:30	Theorists - motivations, ideas and wishes
10:30 → 11:00	Coffee Break
11:00 → 12:30	Theorists - motivations, ideas and wishes
12:30 → 14:00	Lunch
14:00 → 15:30	Accelerator and infrastructure opportunities at CERN
15:30 → 16:00	Coffee Break
16:00 → 17:30	Accelerator and infrastructure opportunities at CERN

Wednesday, 7 September 2016

08:30 → 10:30	Potential future of existing programs
10:30 → 11:00	Coffee Break
11:00 → 12:30	New experimental ideas
12:30 → 14:00	Lunch
14:00 → 15:30	New experimental ideas

Status of Implementation of ESPP

	LHC/HL-LHC	FCC/CLIC	ILC	ν
Study	√ / √	ongoing / √	√	√
Readiness	√ / prep	– / CDR	TDR	Rigorous CD_i CD3a SURF
International Agreement	√ / √	preparing for next ESPP		√
Completion	running / 2025	after HL-LHC		LBNF/Dune (or Hyper-K)

Conclusion

- Internationally balanced strategies have proven to be powerful means of
    - setting priorities among physicists and
    - ascertaining financial support for the large infrastructures of our field
- Given the long lead times it is important that they be carried out in the respective timeframe
- Strategies need to be updated and adjusted every 5-8 years, i.e. whenever an important implementation step has been made or nature has given new guidance