Experimental Particle Physics - Future Perspectives

Eckhard Elsen

Director Research and Computing

Max Planck Institute for Physics: 100 Year Anniversary, Munich 10-12.10.2017

Two centennial events

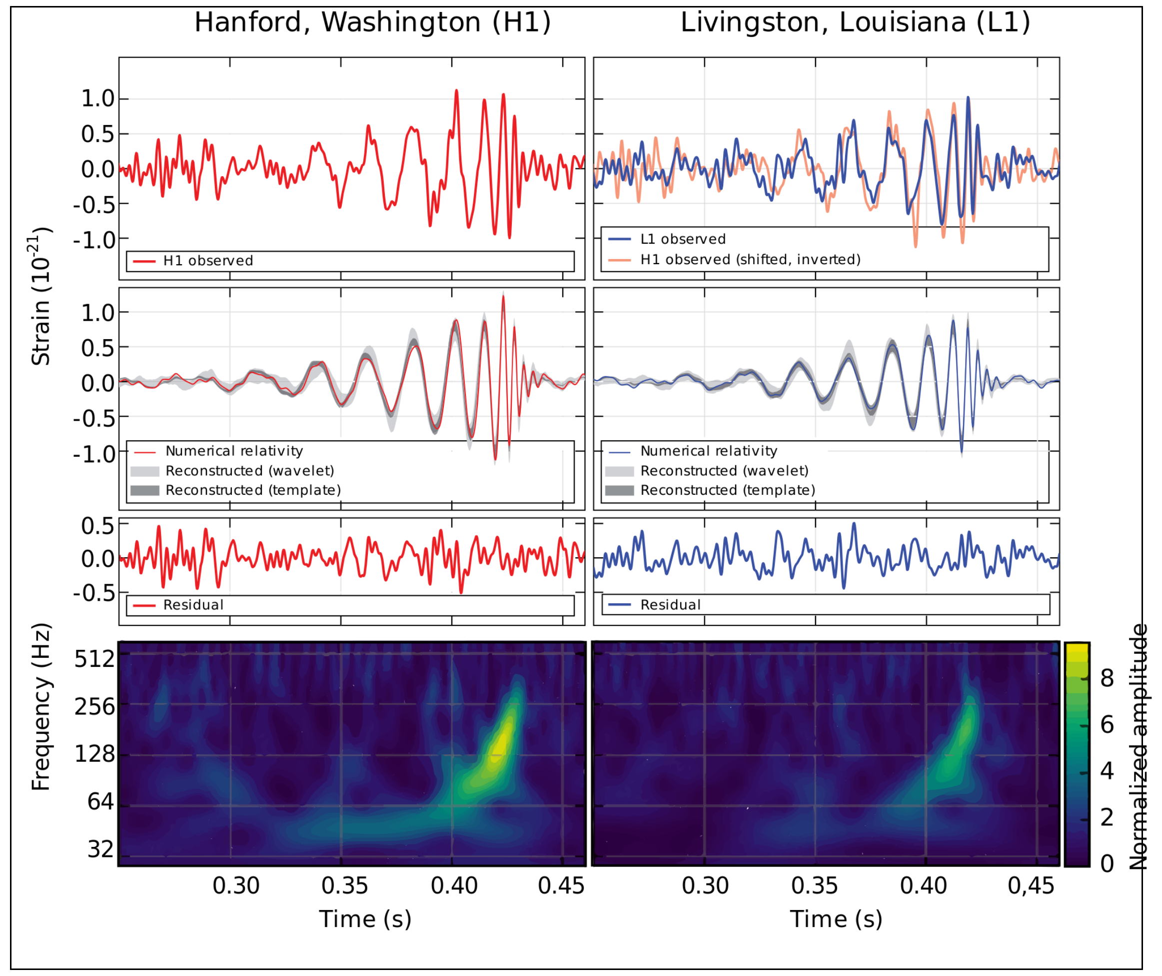
Kaiser-Wilhelm-Institut für Physik

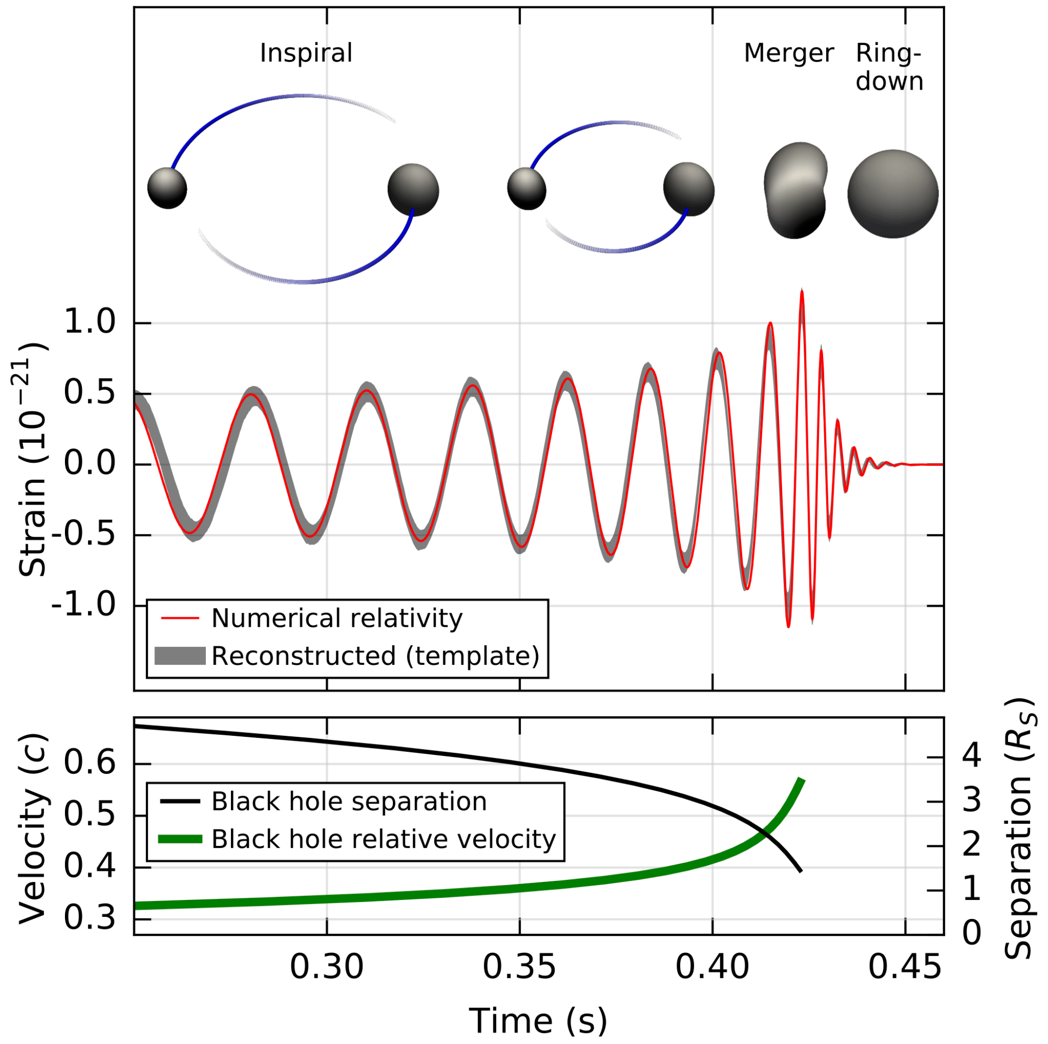
General Relativity

Research Programme 2017

1958

Nobel Prize Gravitational Waves 2017

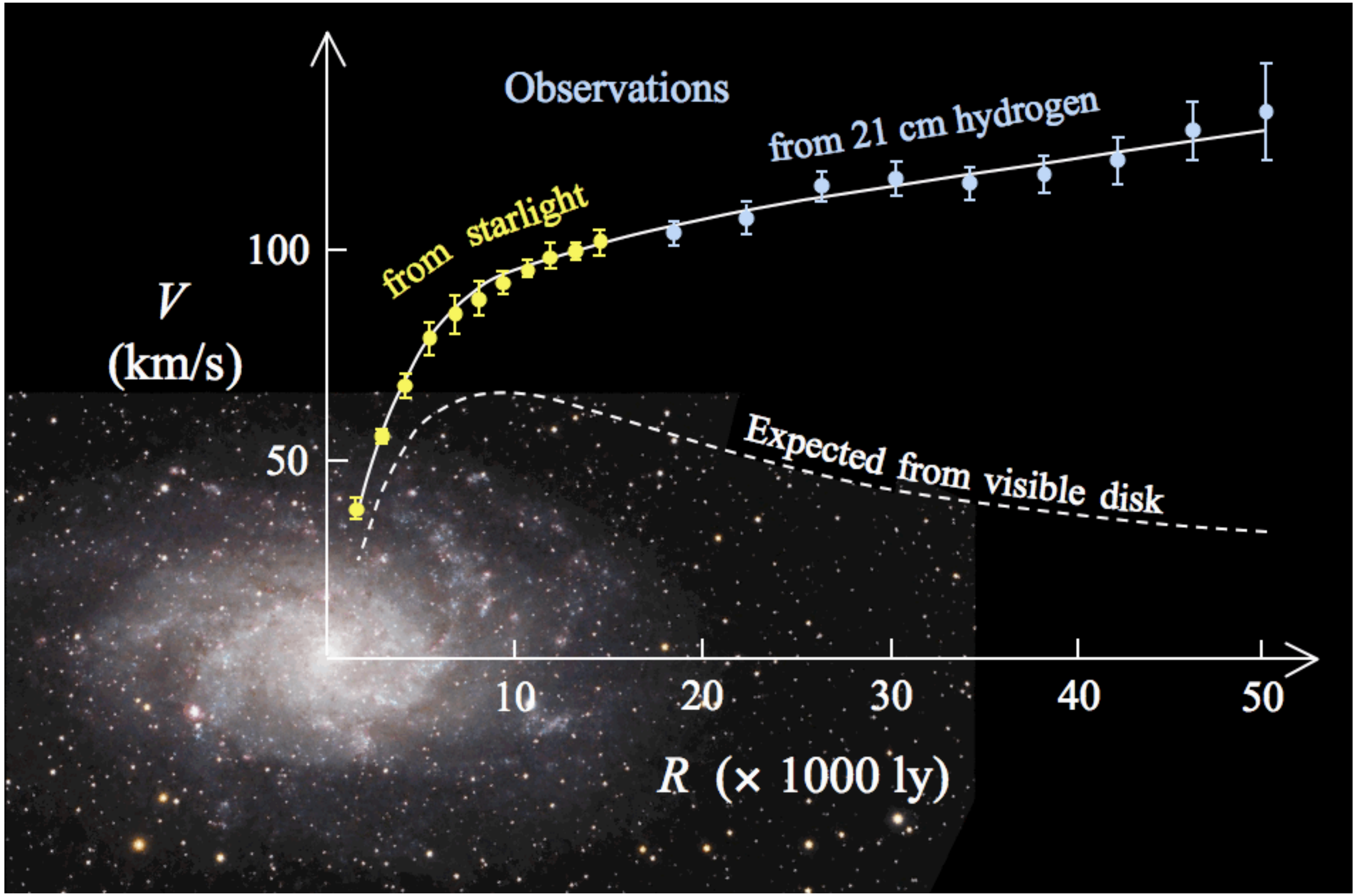





Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
380,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
PLANCK
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years
today

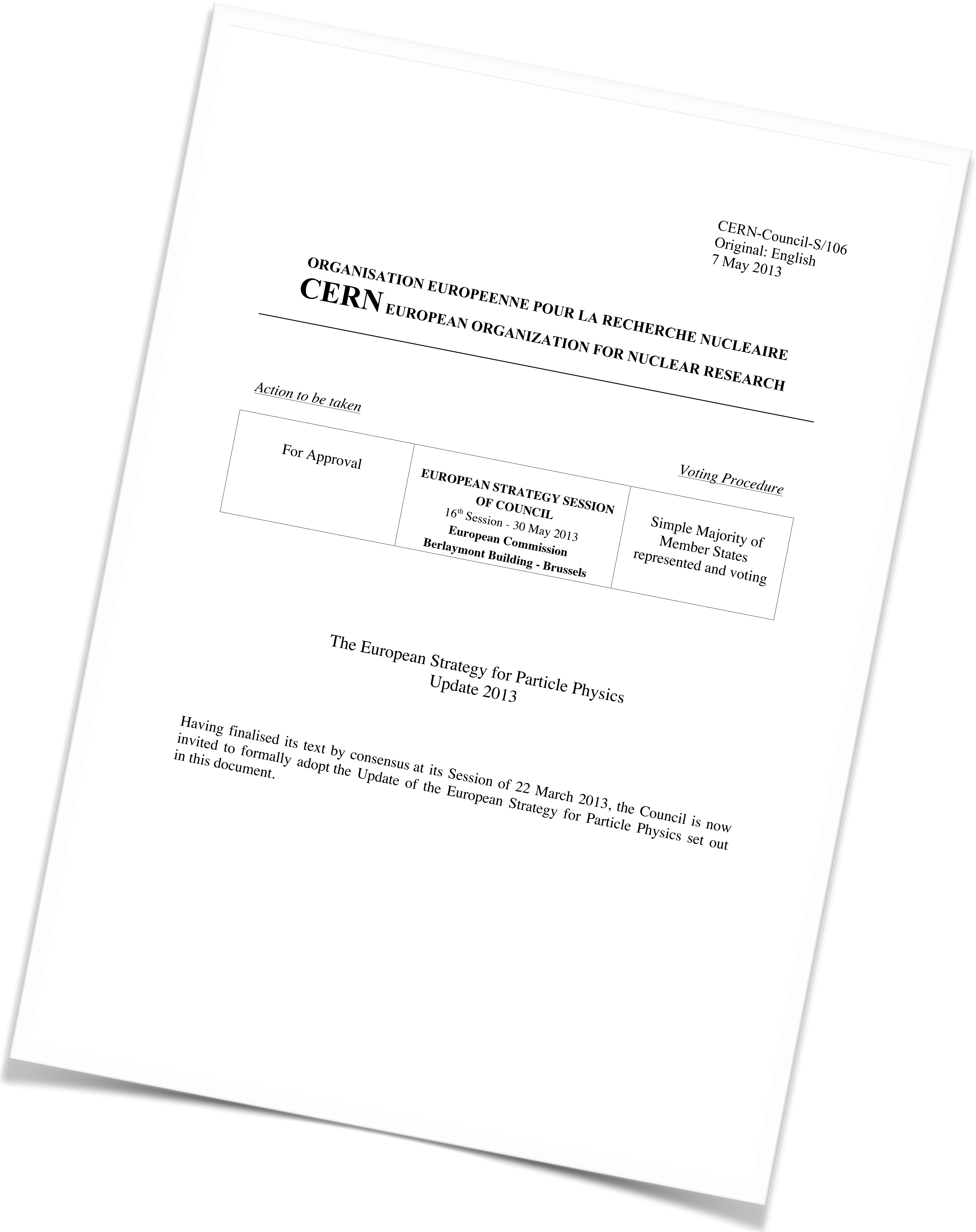
Rotational Curves of Galaxies

- Outer rim of galaxies is seen to rotate faster than expected from Newtonian mechanics
  - there is more mass than is seen interacting



Dark Matter

…executing the ongoing European Strategy for Particle Physics


CERN-Council-S/106
Original: English
7 May 2013

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Action to be taken

		Voting Procedure
For Approval	**EUROPEAN STRATEGY SESSION OF COUNCIL** 16th Session - 30 May 2013 **European Commission** **Berlaymont Building - Brussels**	Simple Majority of Member States represented and voting

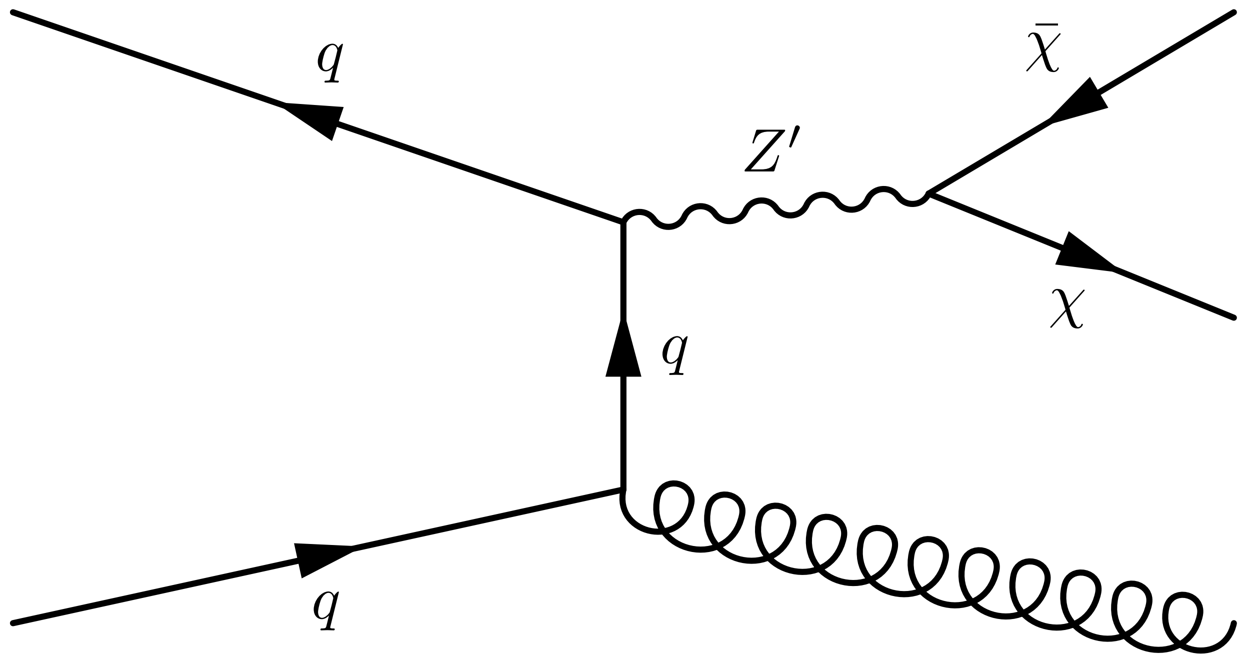
The European Strategy for Particle Physics
Update 2013

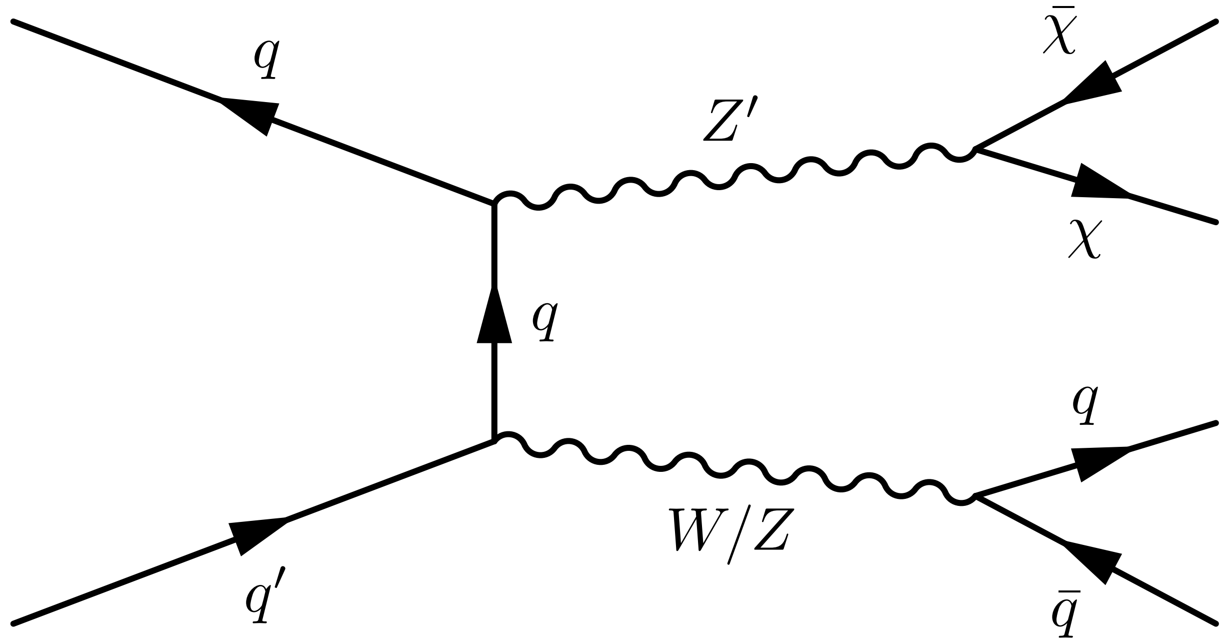
Having finalised its text by consensus at its Session of 22 March 2013, the Council is now invited to formally adopt the Update of the European Strategy for Particle Physics set out in this document.

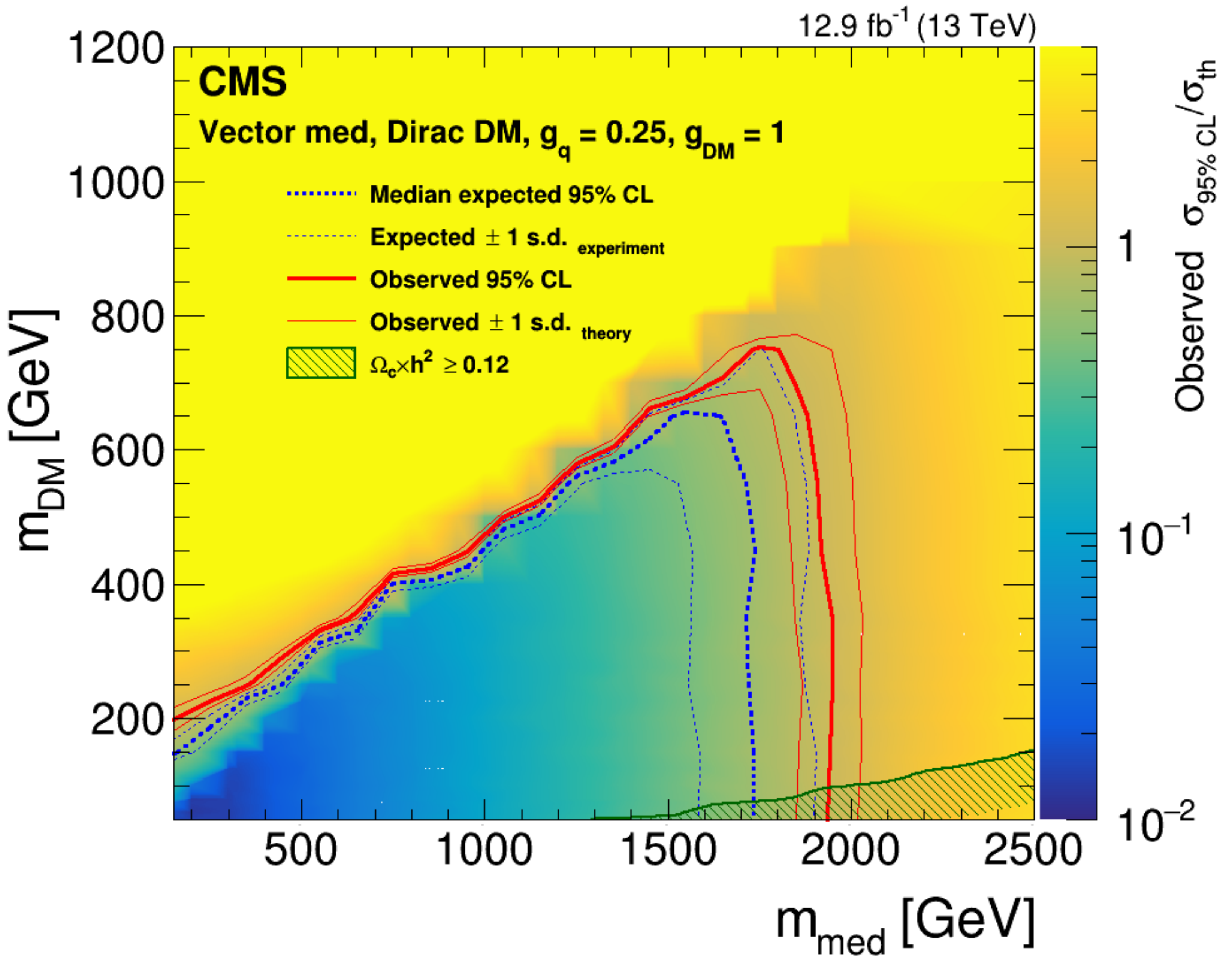
LHC as #1 tool…

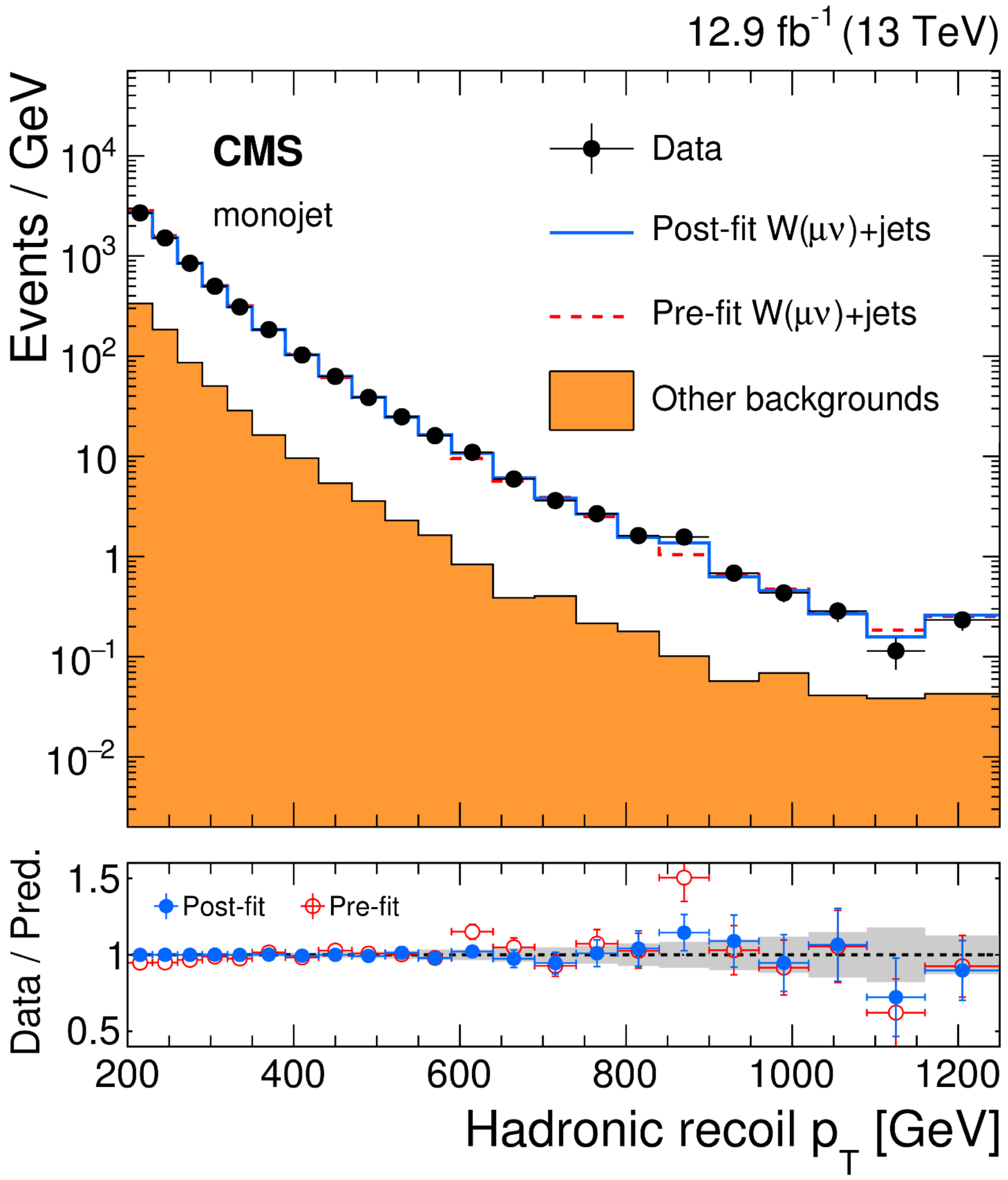

LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
CMS
ALICE
LHC 27 km

Example of Dark Matter Search at the LHC









Goal of LHC – Identify the Physics beyond the Standard Model

- Explore an energy regime that has not been chartered before
    - have entered 13 TeV regime in *production* mode

↓ Luminosity need in both cases

- 14 TeV *after* Long Shutdown 2 and possibly 15 TeV (study group)

direct search

- Look for small deviations (small couplings) from the Standard Model
    - Precision measurements of (rare) processes
    - Higgs particle as a portal

indirect search

H → fermions

Using

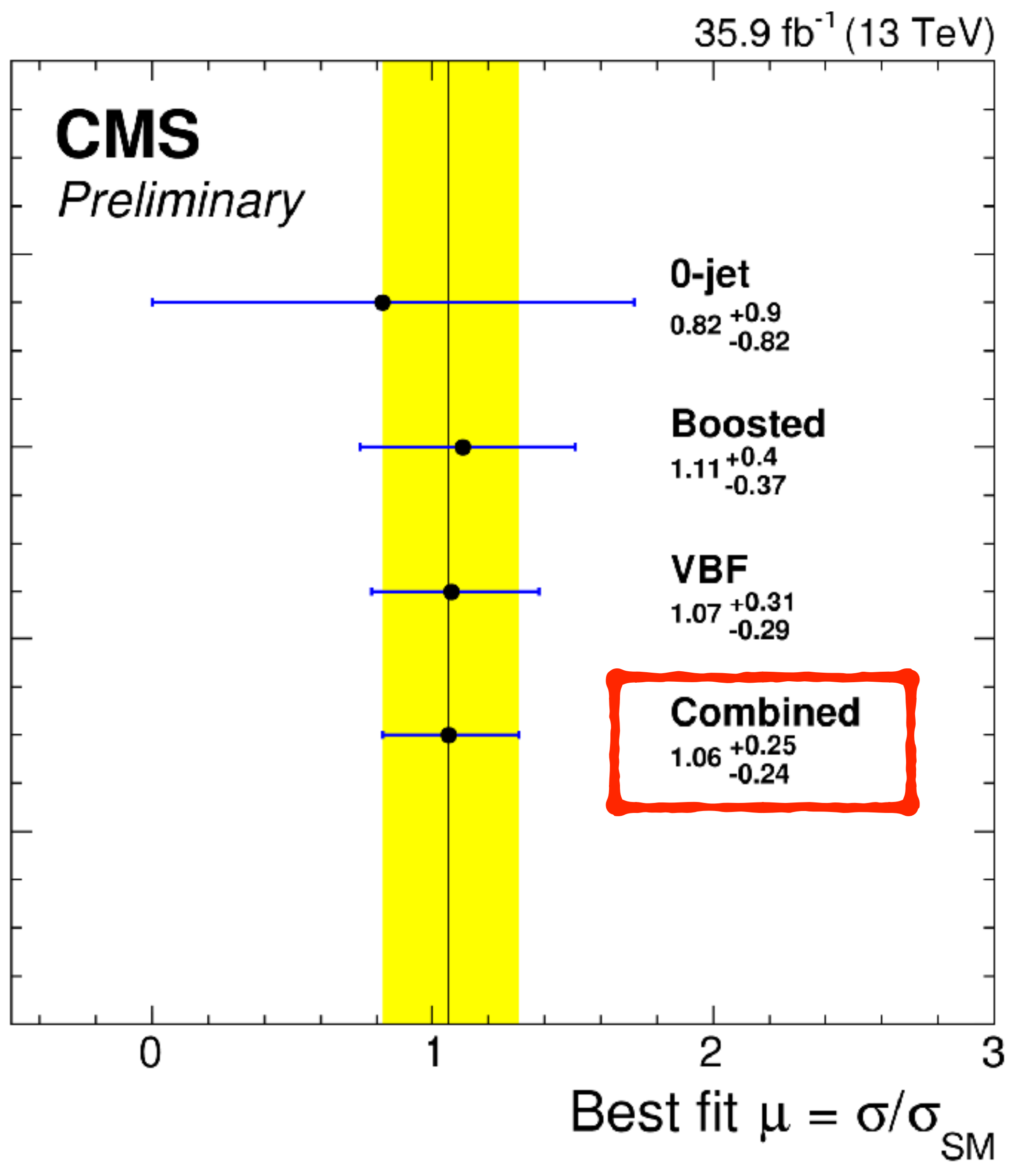
$\tau_h \tau_h$

$e\,\tau_h$

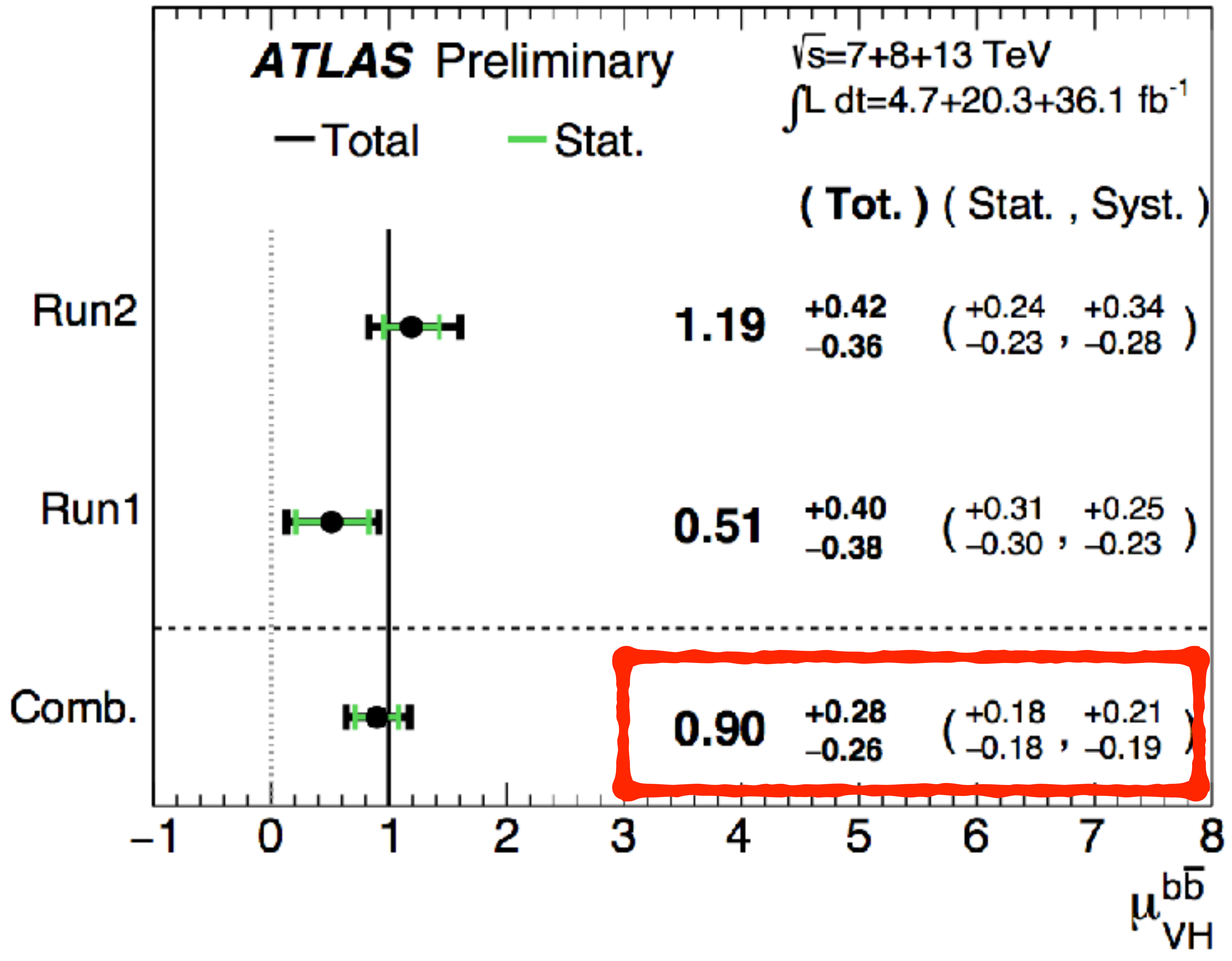
$\mu\,\tau_h$

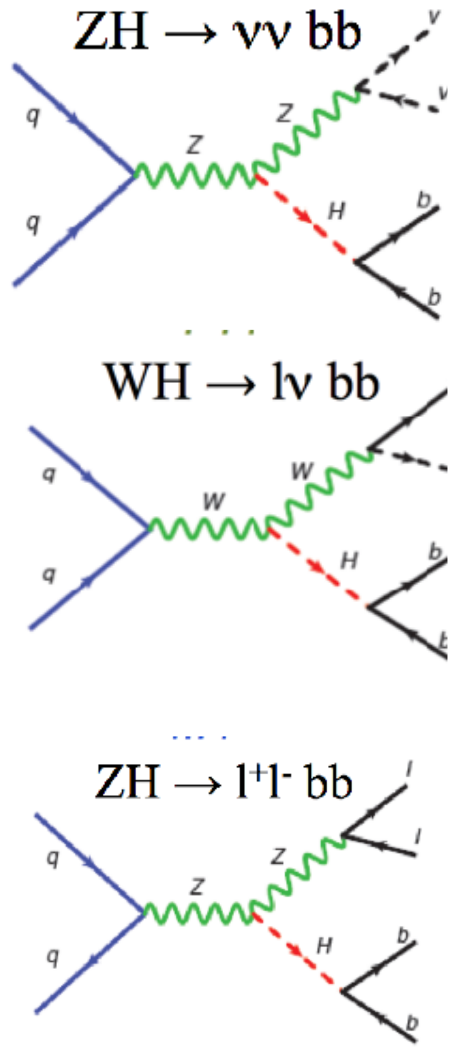
$e\mu$

$H \to \tau\tau$



$H \to b\bar{b}$





4.9 σ

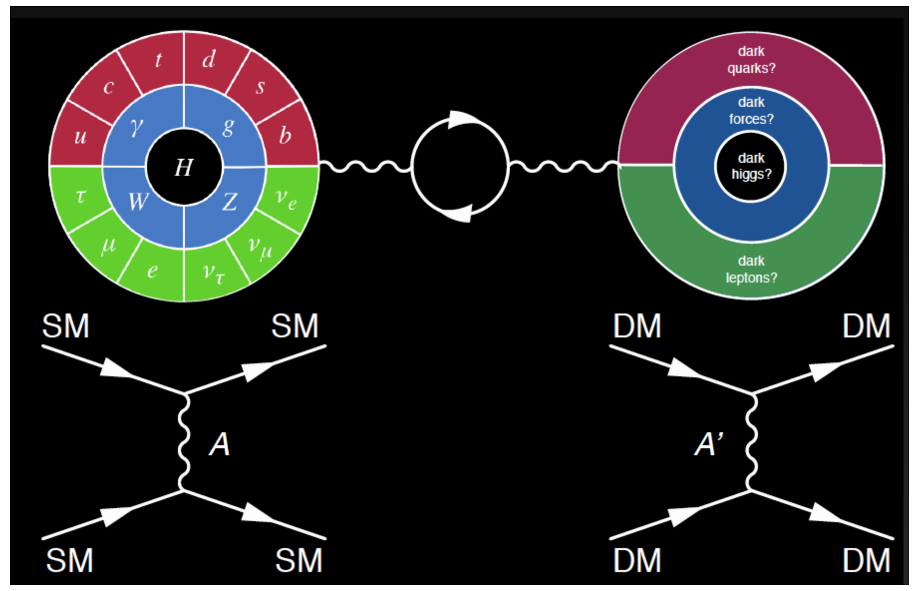
from run 2

3.5 σ

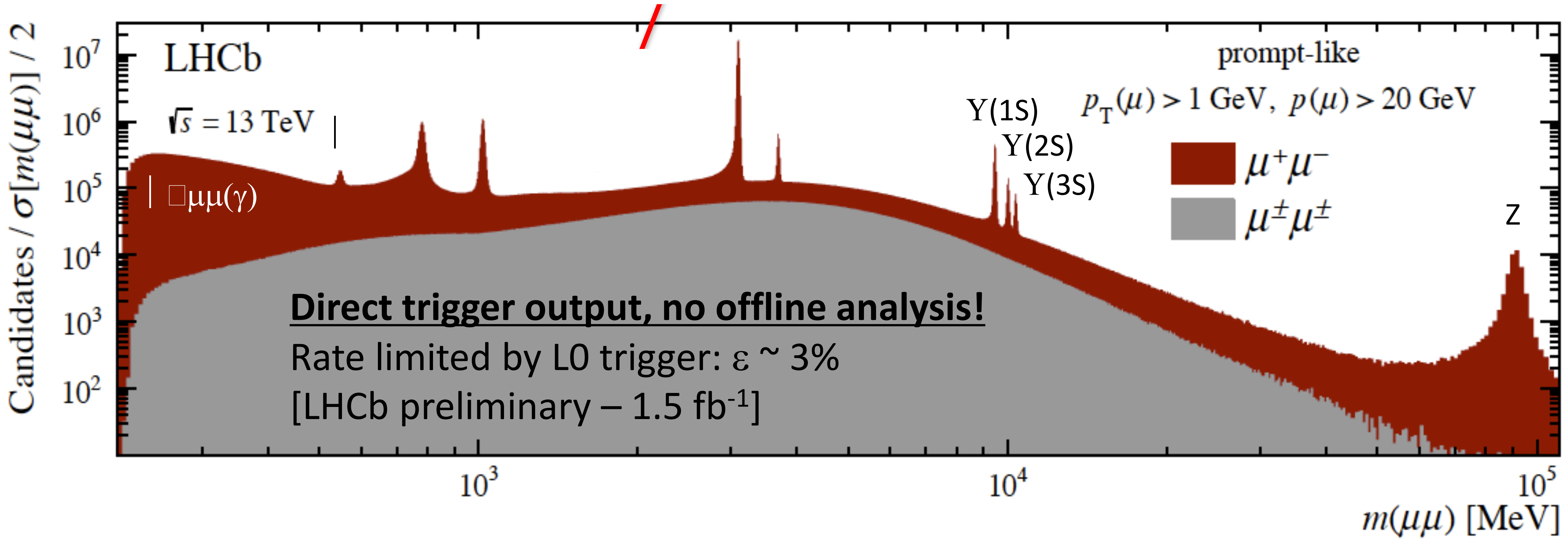
LHCb

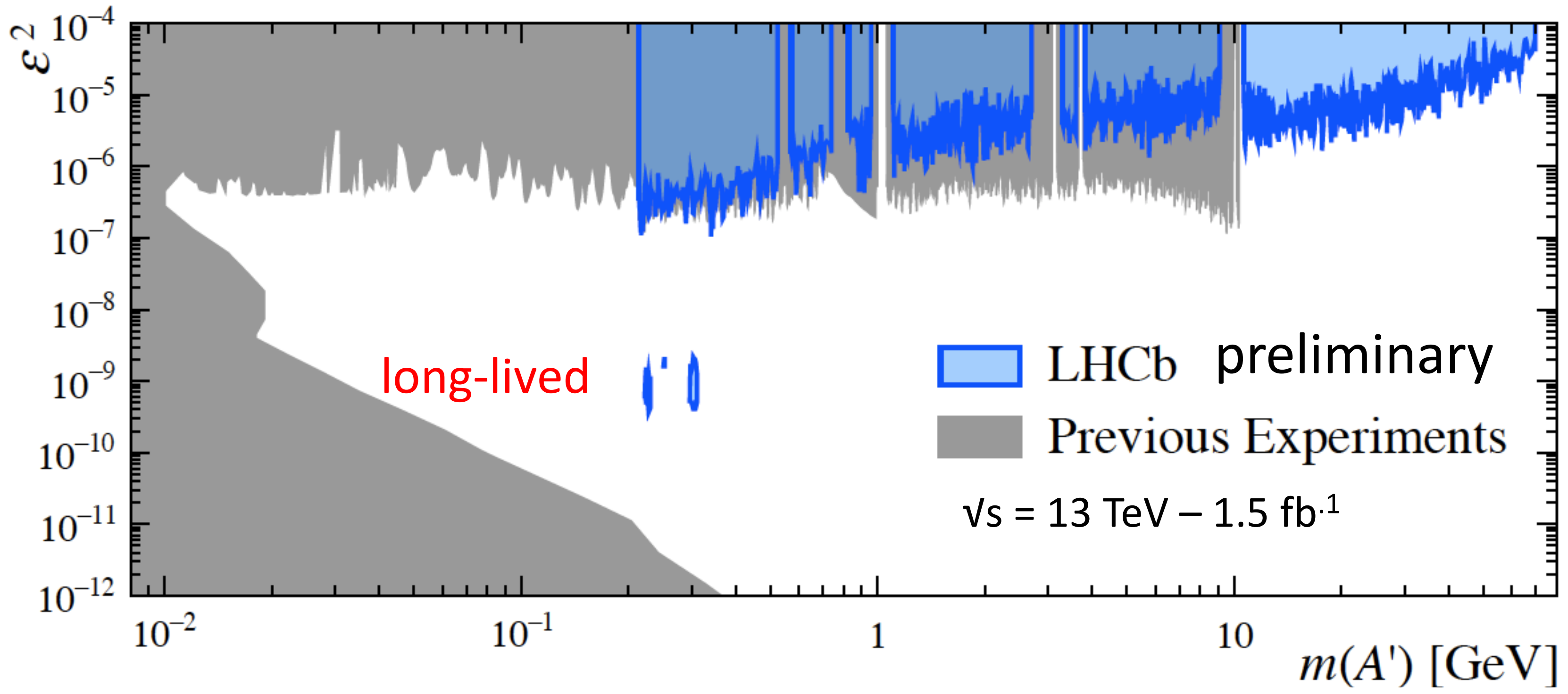
Search for dark photons

- Hypothesis: Dark sector not directly interacting with SM fields
- Coupling through kinetic term with mixing ε
- Dark photons A' couple with strength $10^{-6}<\varepsilon<10^{-2}$ and would open a portal for searches
- LHCb searches (online) in μμ mode

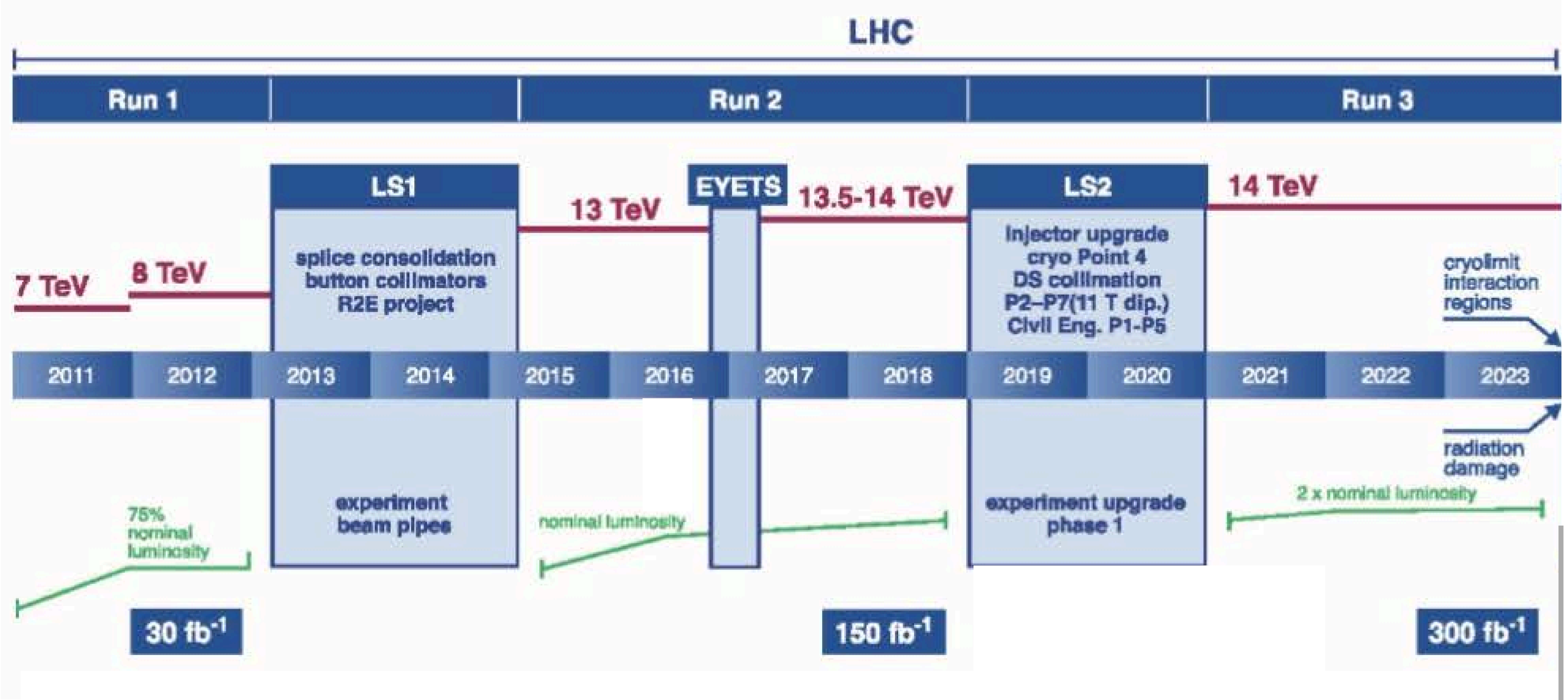


coupling eε





LHC schedule

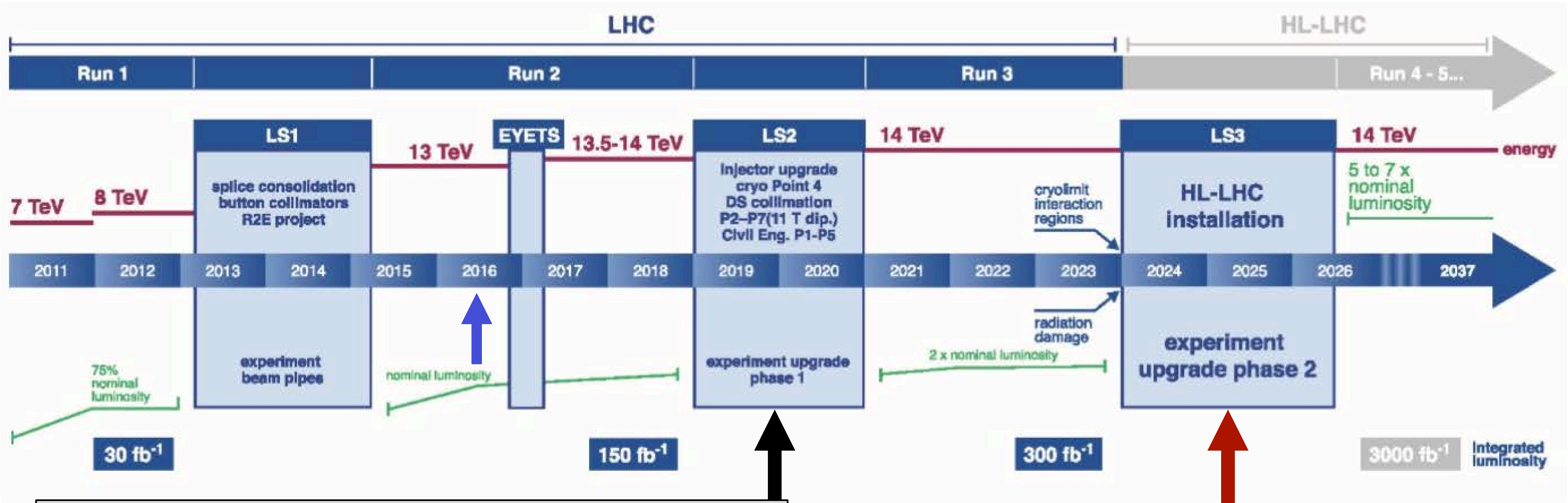


HL-LHC
High
Luminosity
Phase of LHC

Substantial upgrades for ALICE and LHCb; preparatory upgrades for ATLAS and CMS including civil construction

end of original LHC

HL-LHC schedule



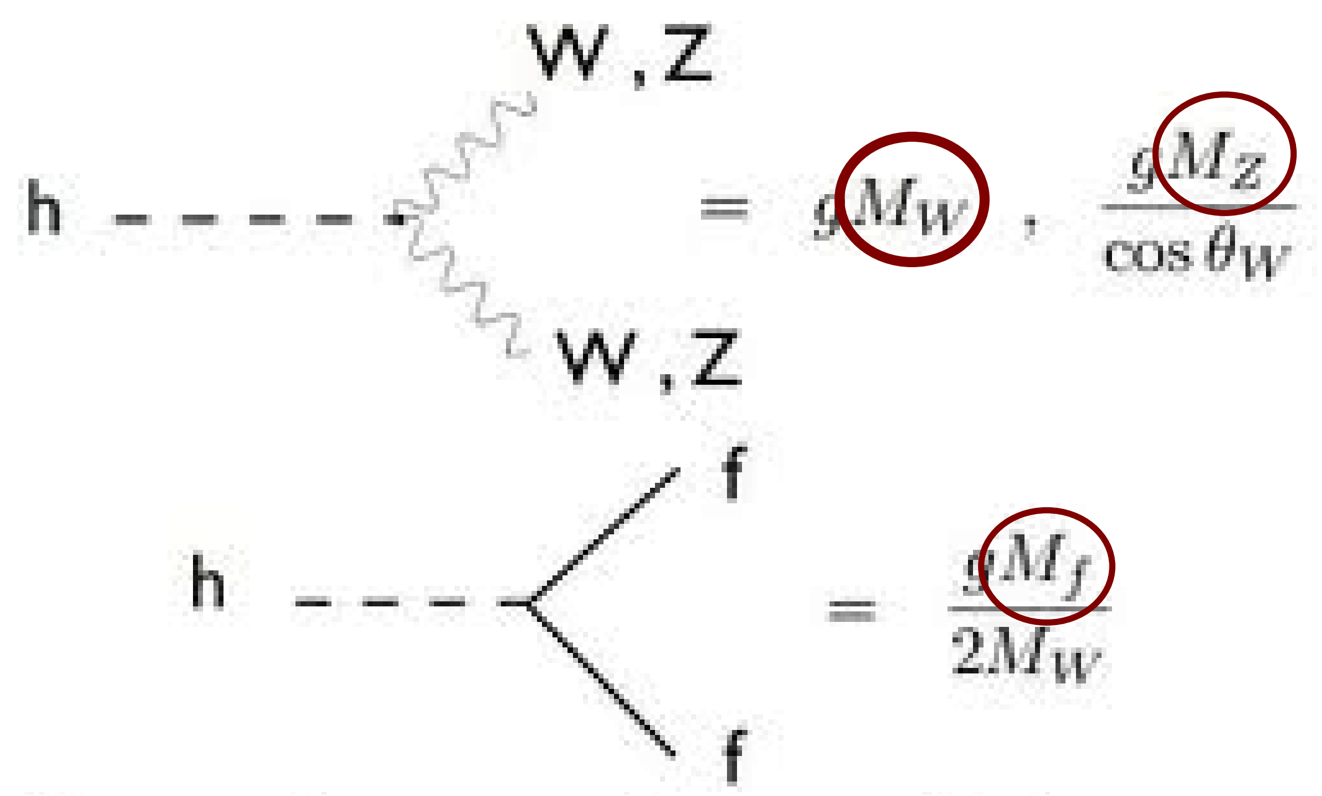
LS2 (2019-2020):
- ❑ LHC Injectors Upgrade (LIU)
- ❑ Civil engineering for HL-LHC equipment P1,P5
- ❑ First 11 T dipoles P7; cryogenics in P4
- ❑ Phase-1 upgrade of LHC experiments

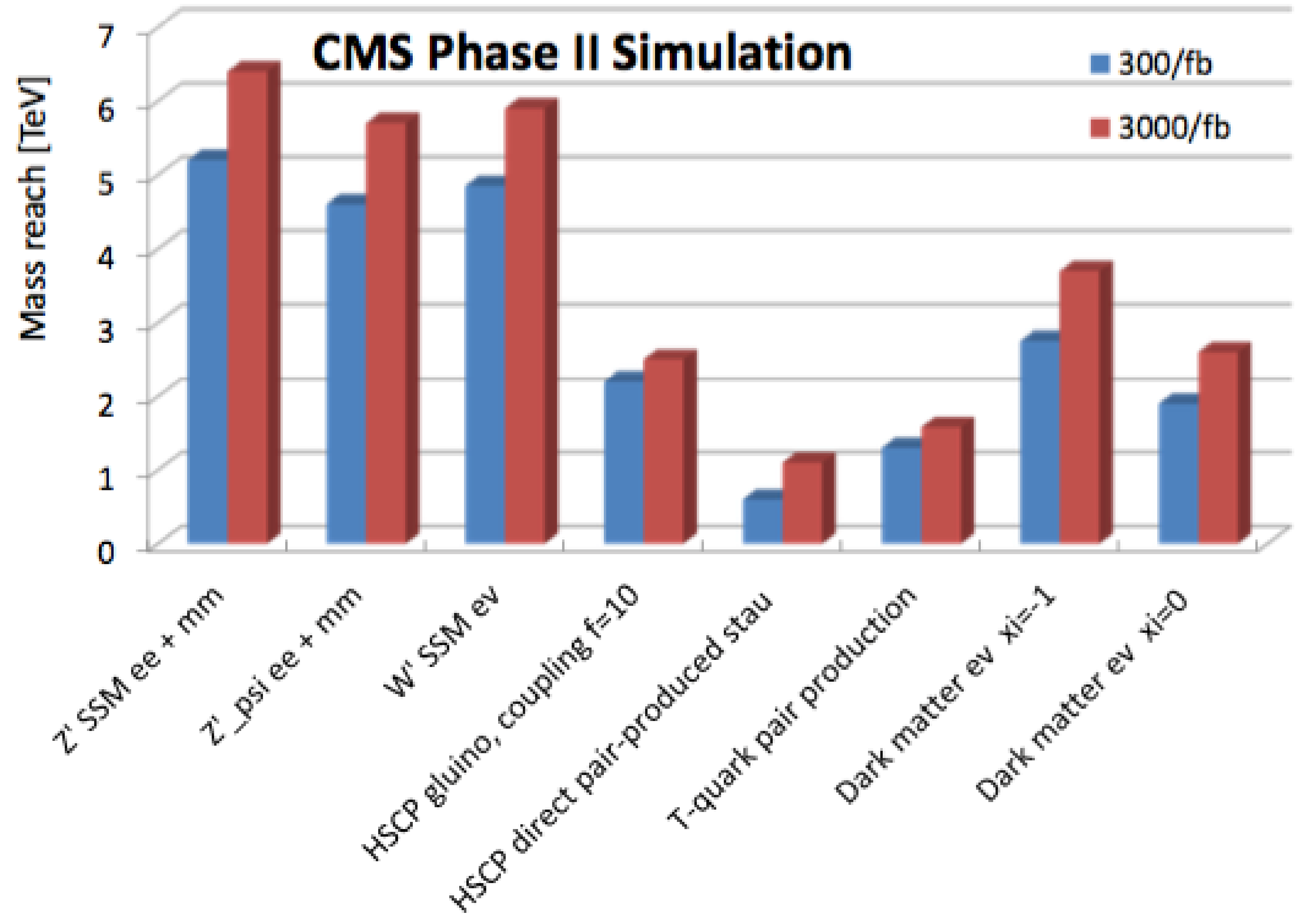
LS3 (2024-2026):
- ❑ **HL-LHC installation**
- ❑ Phase-2 upgrade of ATLAS and CMS

Schedule driven by radiation damage to inner triplet (eol: 2023)

A few physics example for HL-LHC

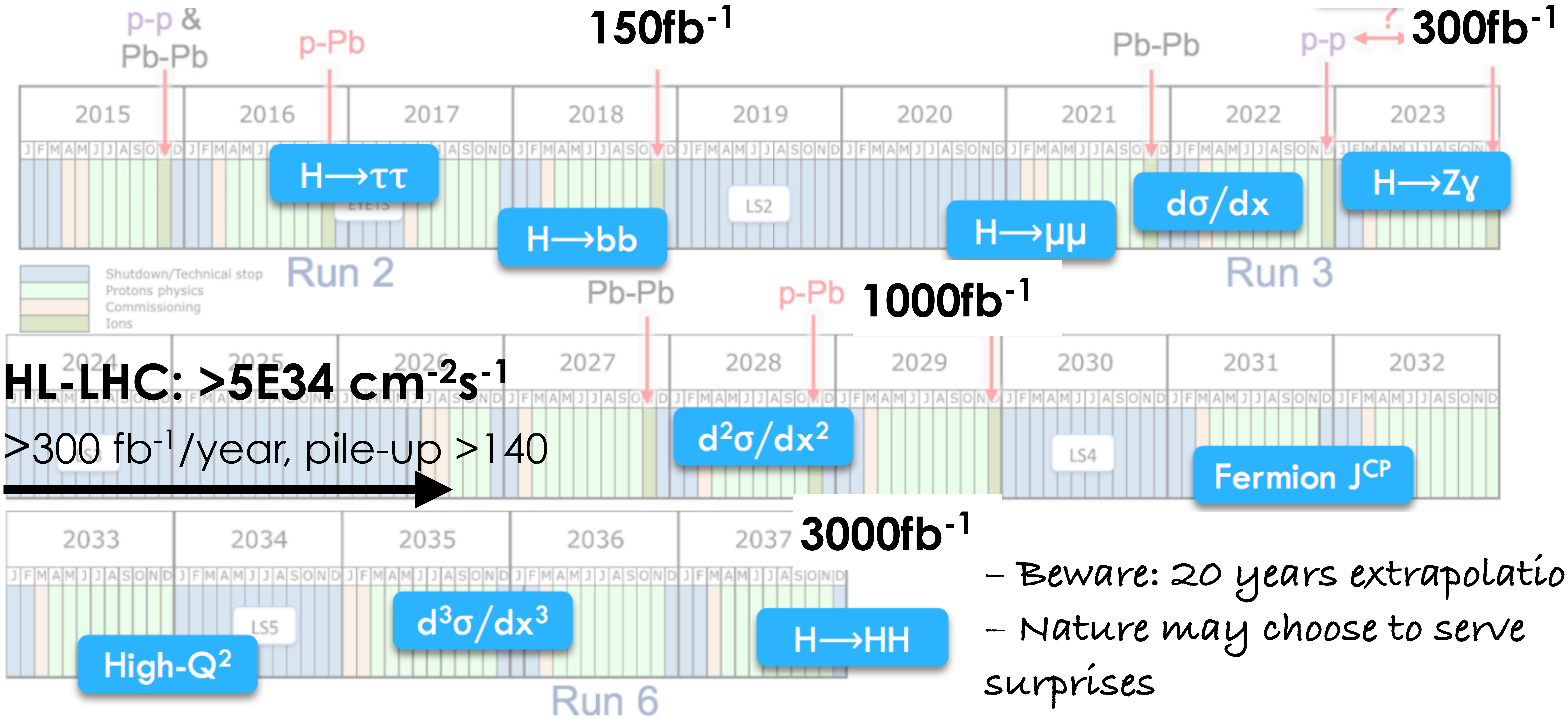
- measurement of Higgs couplings
  - deviations may be at the few %-level
  - access to second generation couplings H→μμ
- 20-30% larger discovery potential (8 TeV)
  - precision measurements





SM Physics Menu on the LHC and HL-LHC Running Schedule

Credits: A. David @ GRC 2017



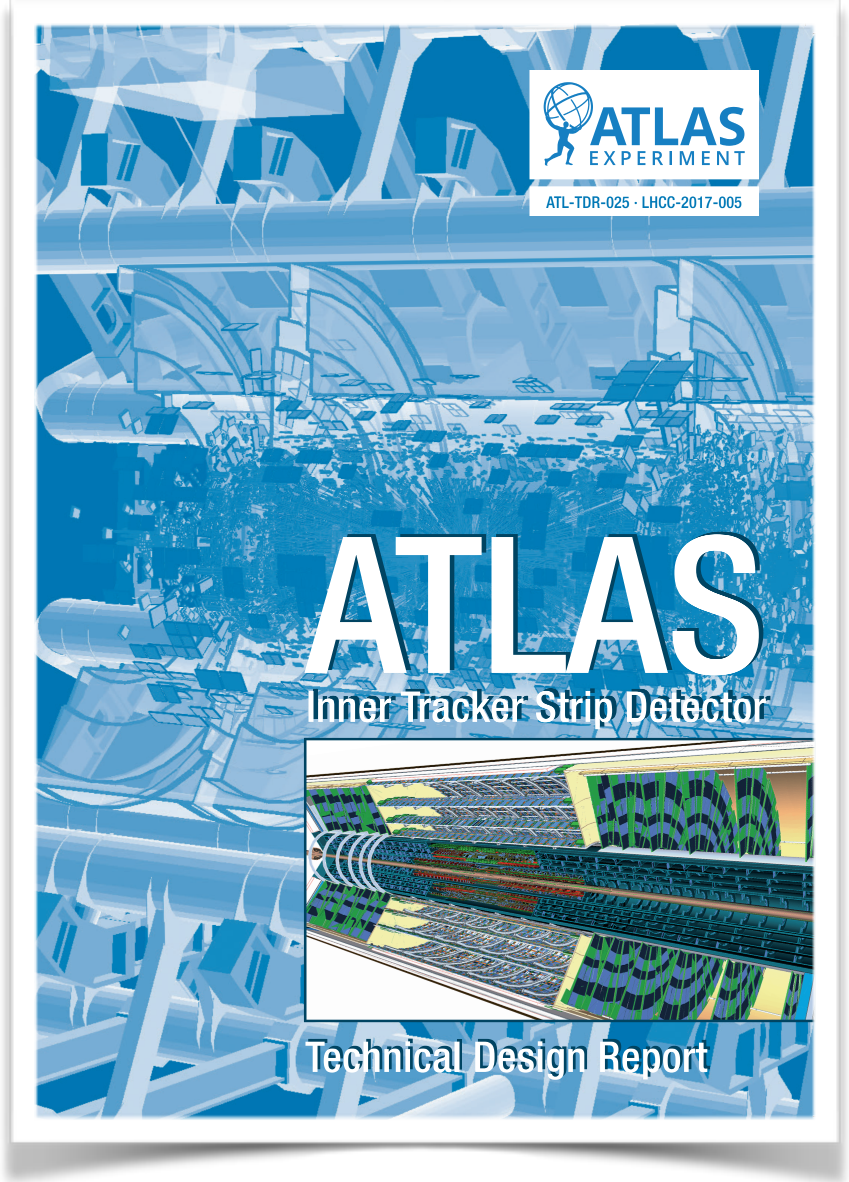
- Beware: 20 years extrapolation
- Nature may choose to serve surprises

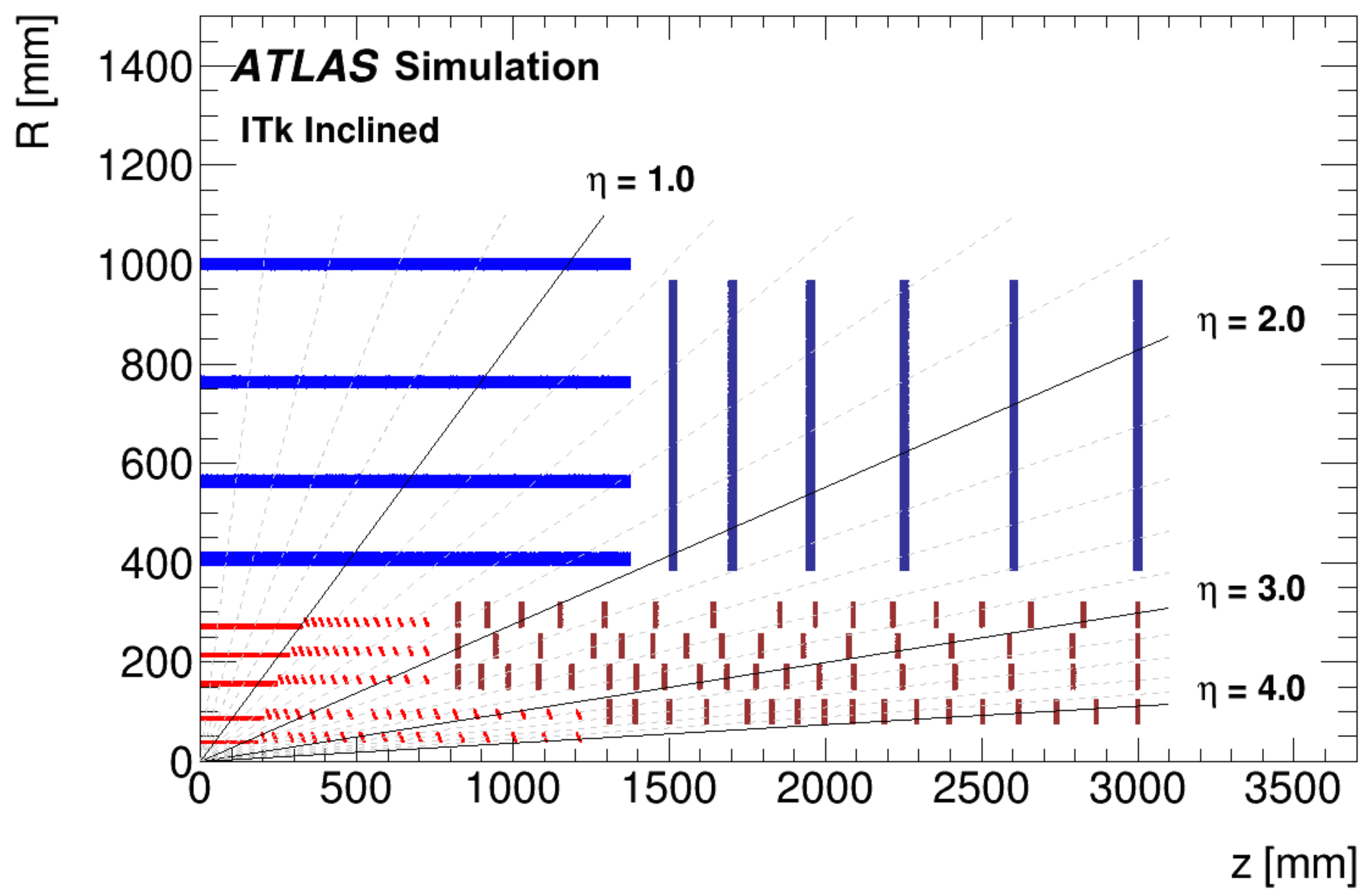
Phase II Detector upgrades

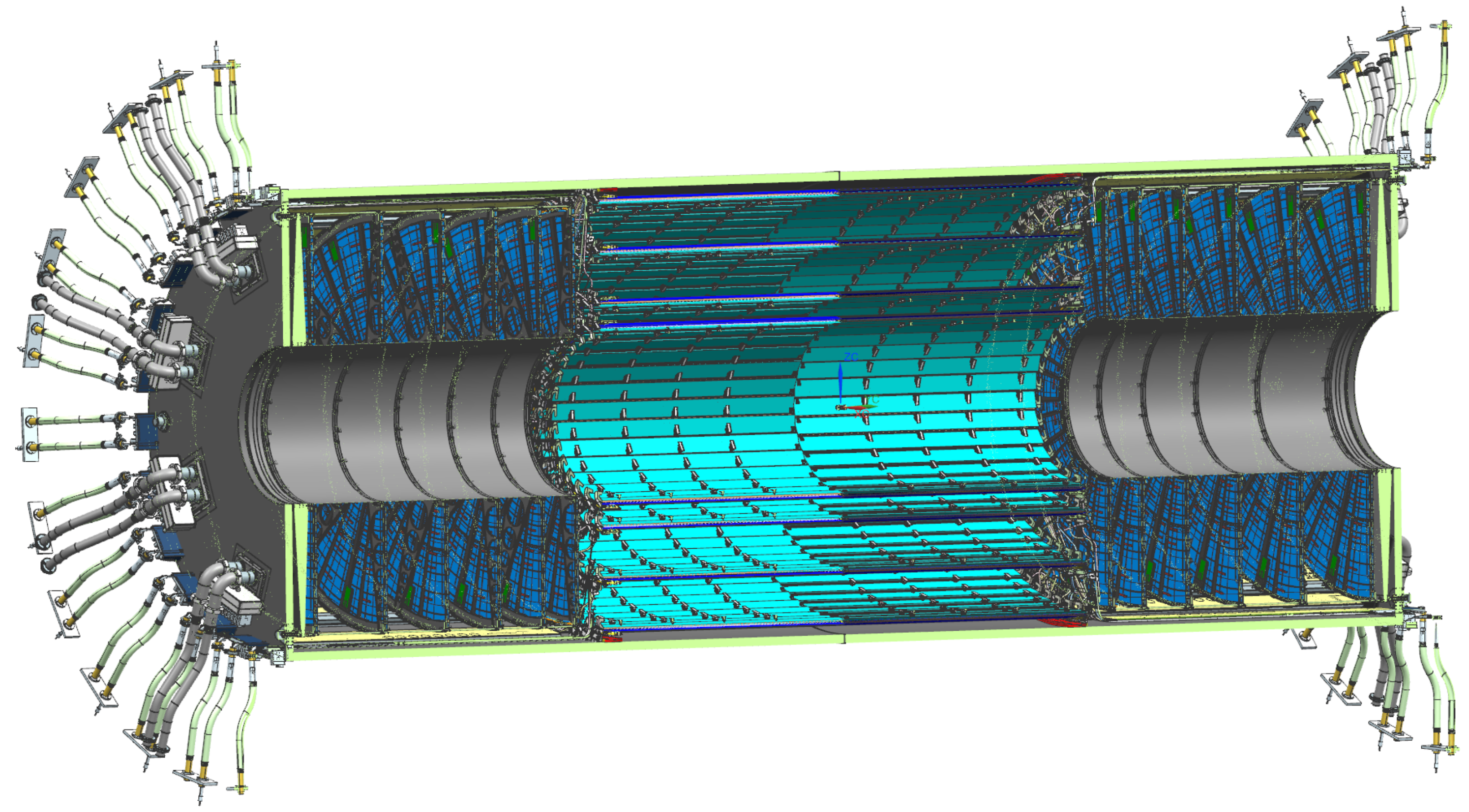
- replace radiation-damaged components
- enable detectors to withstand the rates at phase I performance

ATLAS ITk strips TDR (Phase II Upgrade)

- Settled on 5 pixel + 4 strips system
- Only the strips are evaluated in TDR – although status of pixel mentioned
- The pixel TDR will follow at the end of 2017
- Large document (>500 pages)





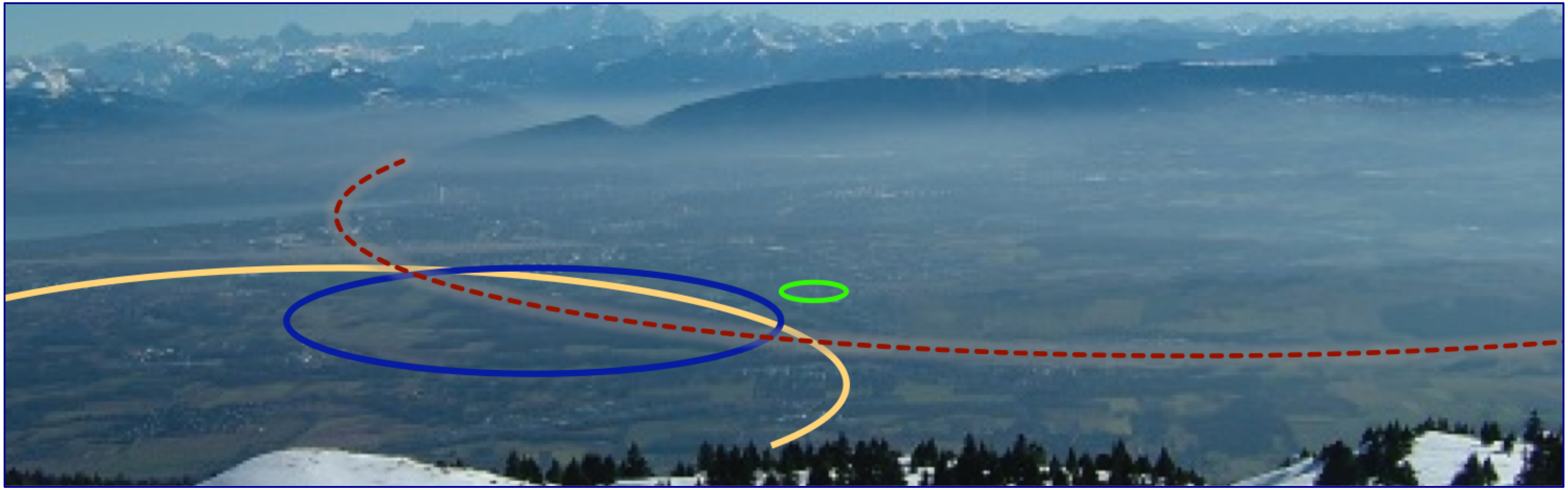


Highest energy hadron colliders

From European Strategy of Particle Physics

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.

Future Circular Collider FCC



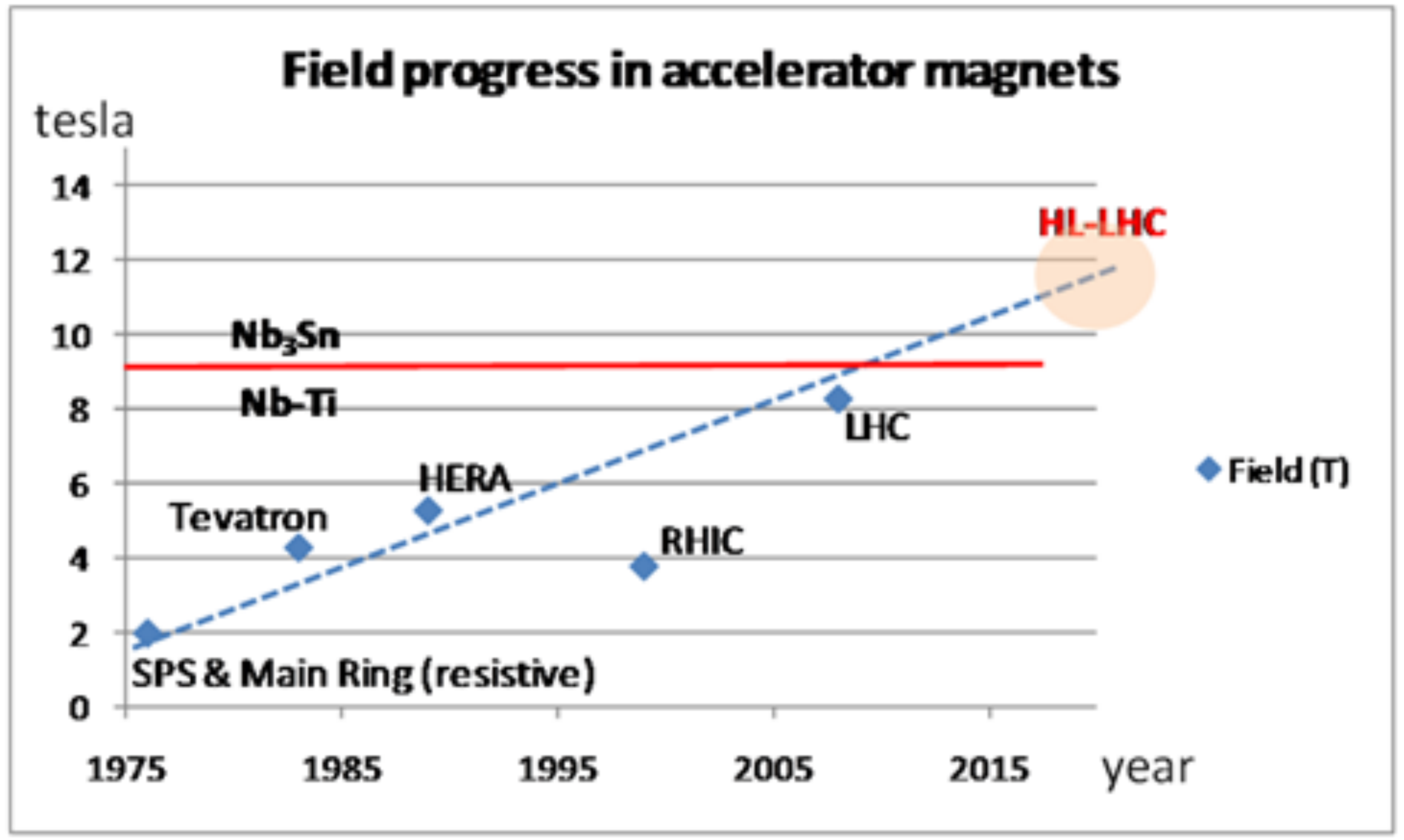
- Study for A 100 km ring providing collisions at 100 TeV cm
    - employs injector chain of CERN

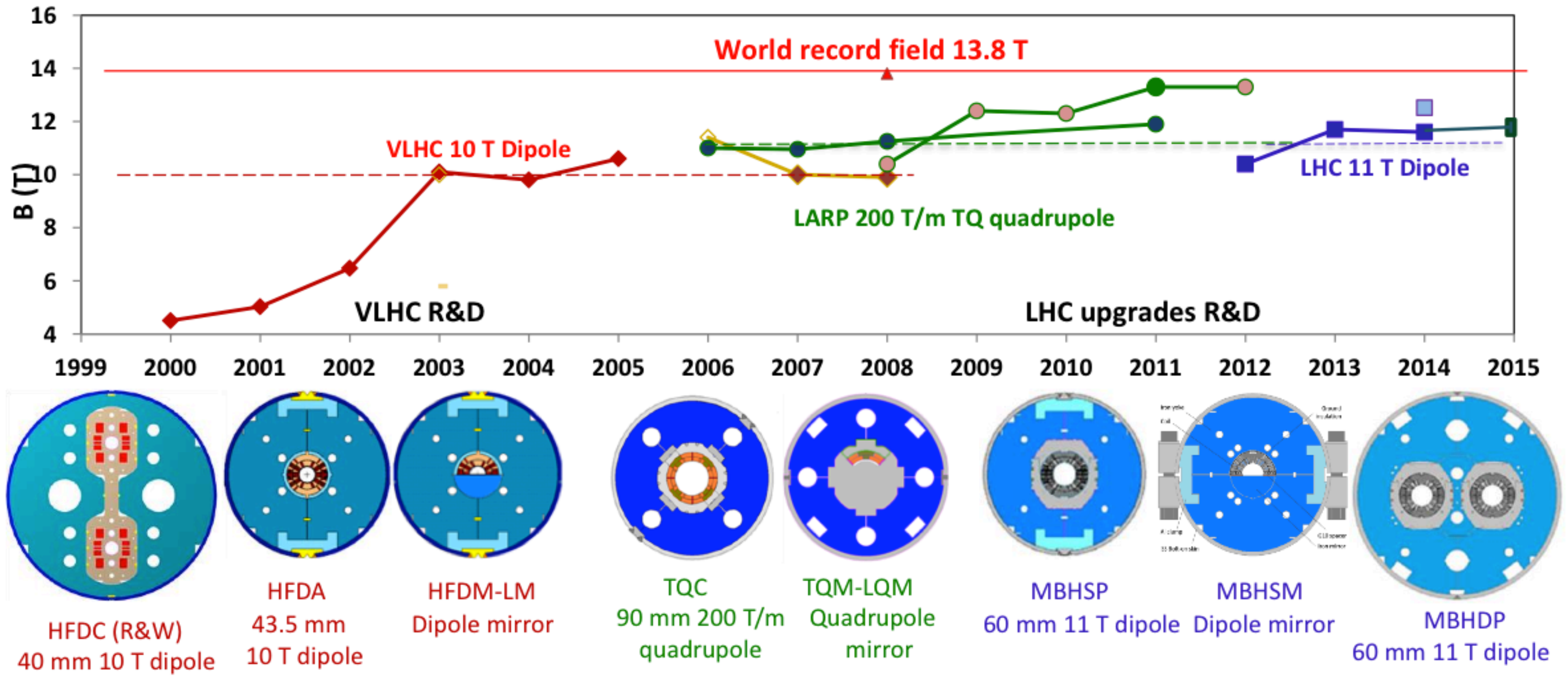
High-field magnets

- Key to high energies
  - FCC and
  - HE-LHC = use of high field magnets in existing LHC ring
- Technology
  - Nb_3Sn allows ~16 T magnets that need to be developed (size, cost, industry…)
    - HL-LHC magnets provide a ~1.2 km test of the technology (11 T magnets)
  - an insert of HTS may increase field to 20 T (requires considerable research)

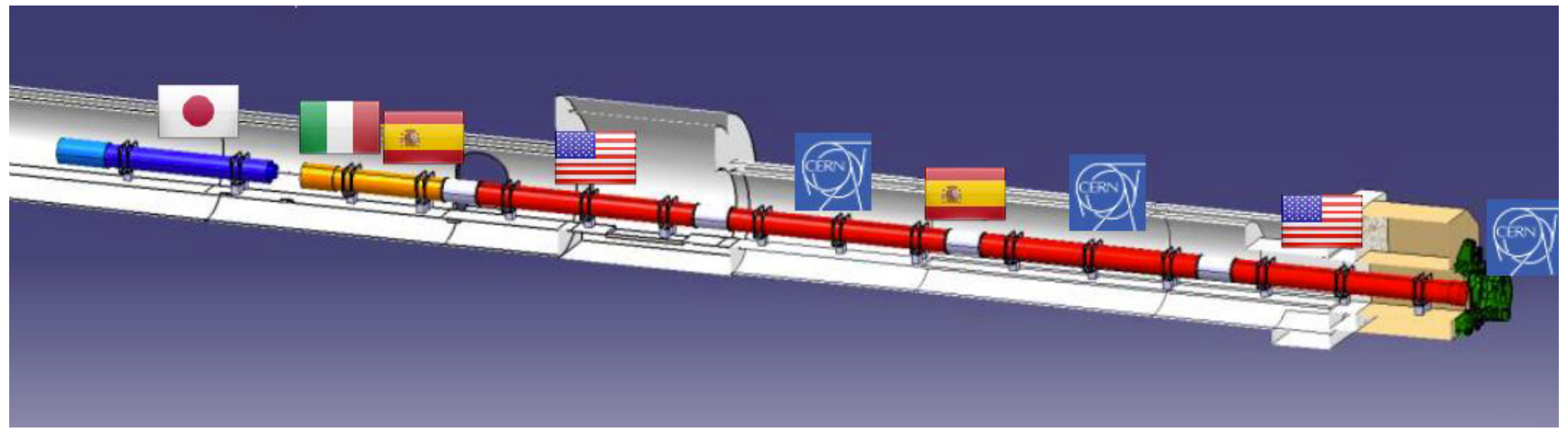
International Collaboration on Magnet Development

- Nb_3Sn magnets: international R&D programme
  - several European countries and US LARP programme and its successor



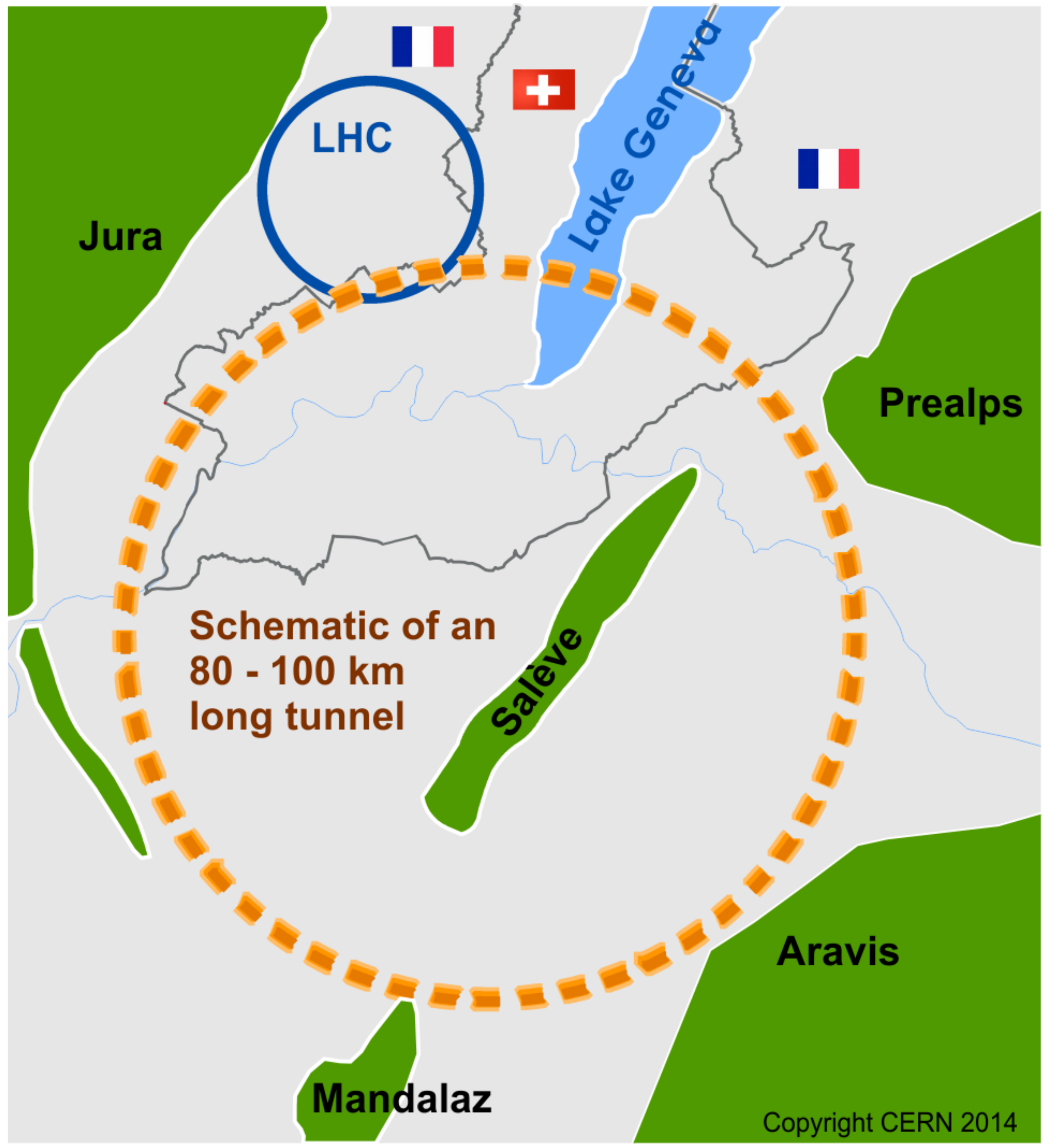


1.2KM of LHC modified



FCC Conceptual Design Report by end 2018

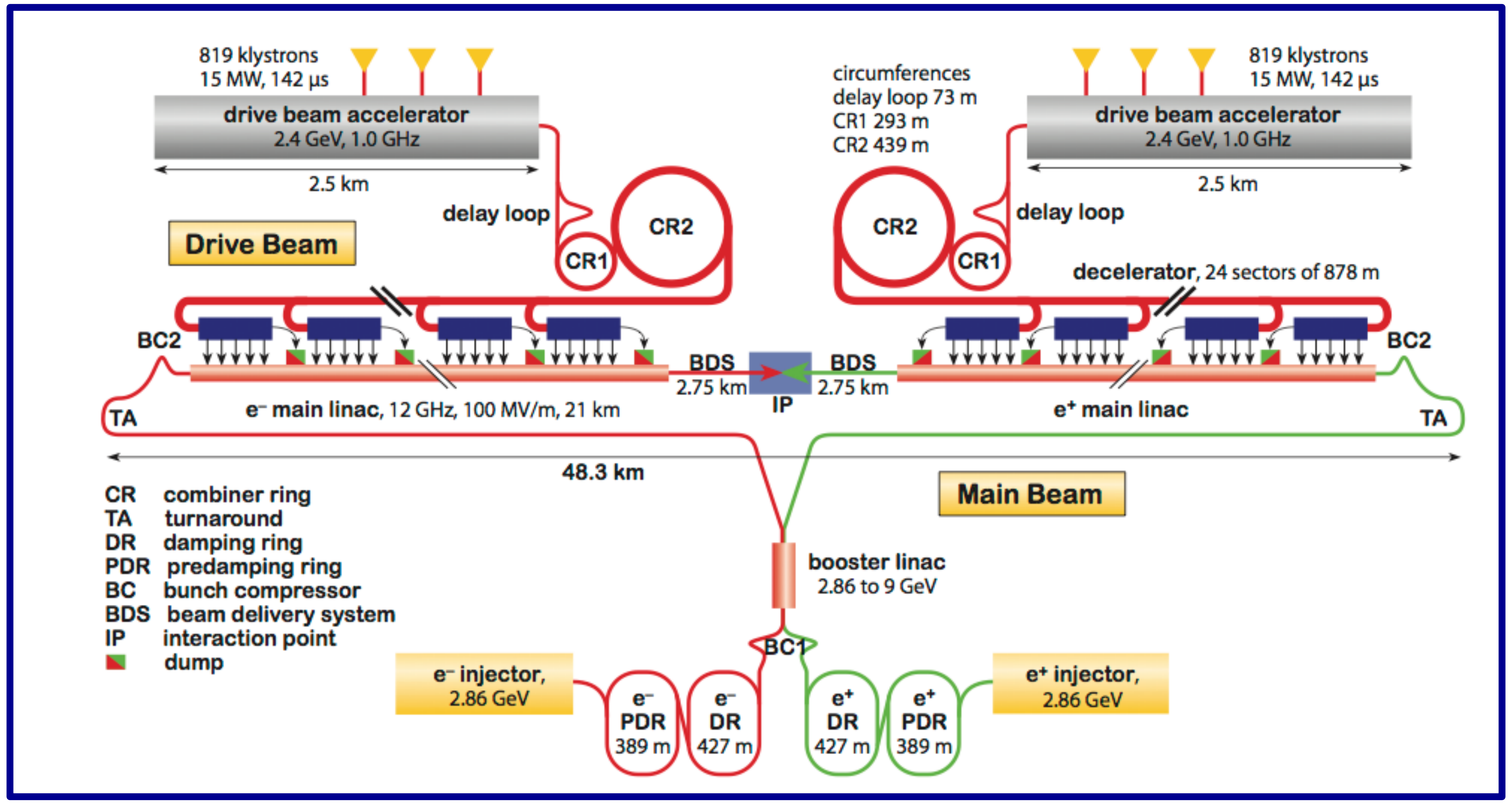
- **pp-Collider (FCC-hh) – sets the boundary conditions**
  - **100 km ring, $\sqrt{s}$=100 TeV, L~2x10^{35}**
  - **HE-LHC is included (~28 TeV)**
- e^+e^--Collider as a possible first step
  - $\sqrt{s}$= 90 - 350 GeV,
    L~1.3x10^{34} at high E
- eh-Collider as an option
  - $\sqrt{s}$=3.5 TeV, L~10^{34}



Highest energy with lepton colliders

Compact Linear Collider CLIC

- e^+e^- collider 1-3 TeV
- currently only option for the TeV region
- 380 GeV study has been completed both for 2-beam and klystrons approach; now explore 250 GeV
- decisive input to next update of European Strategy for Particle Physics

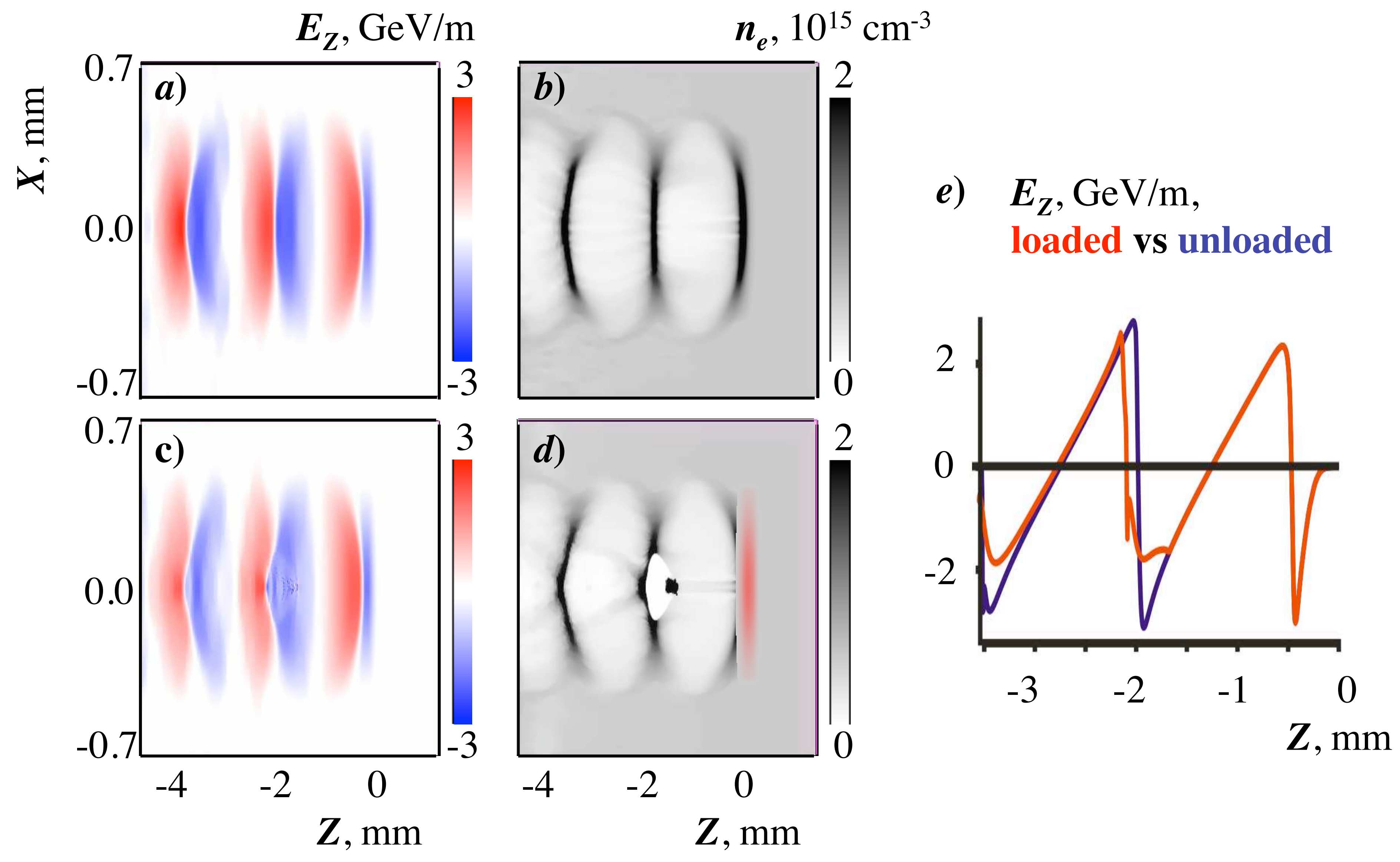


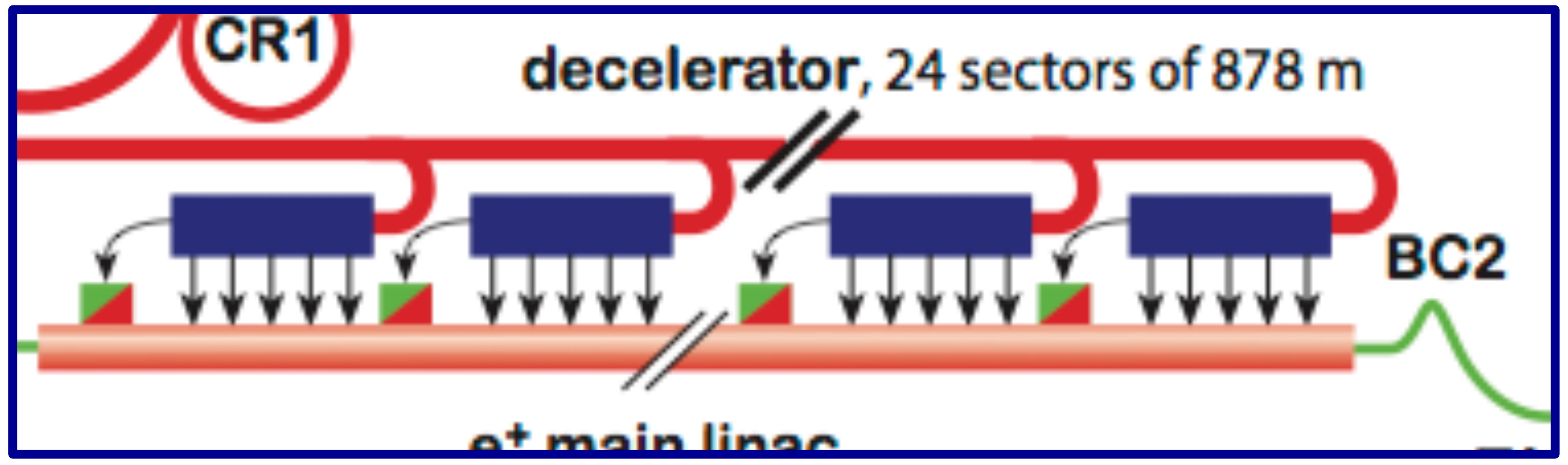
- CDR 2013
- CTF3 has provided key results
  - experimental programme ended 2016
- ready for a demonstrator

Beyond current technologies

AWAKE – proton driven plasma wakefield acceleration

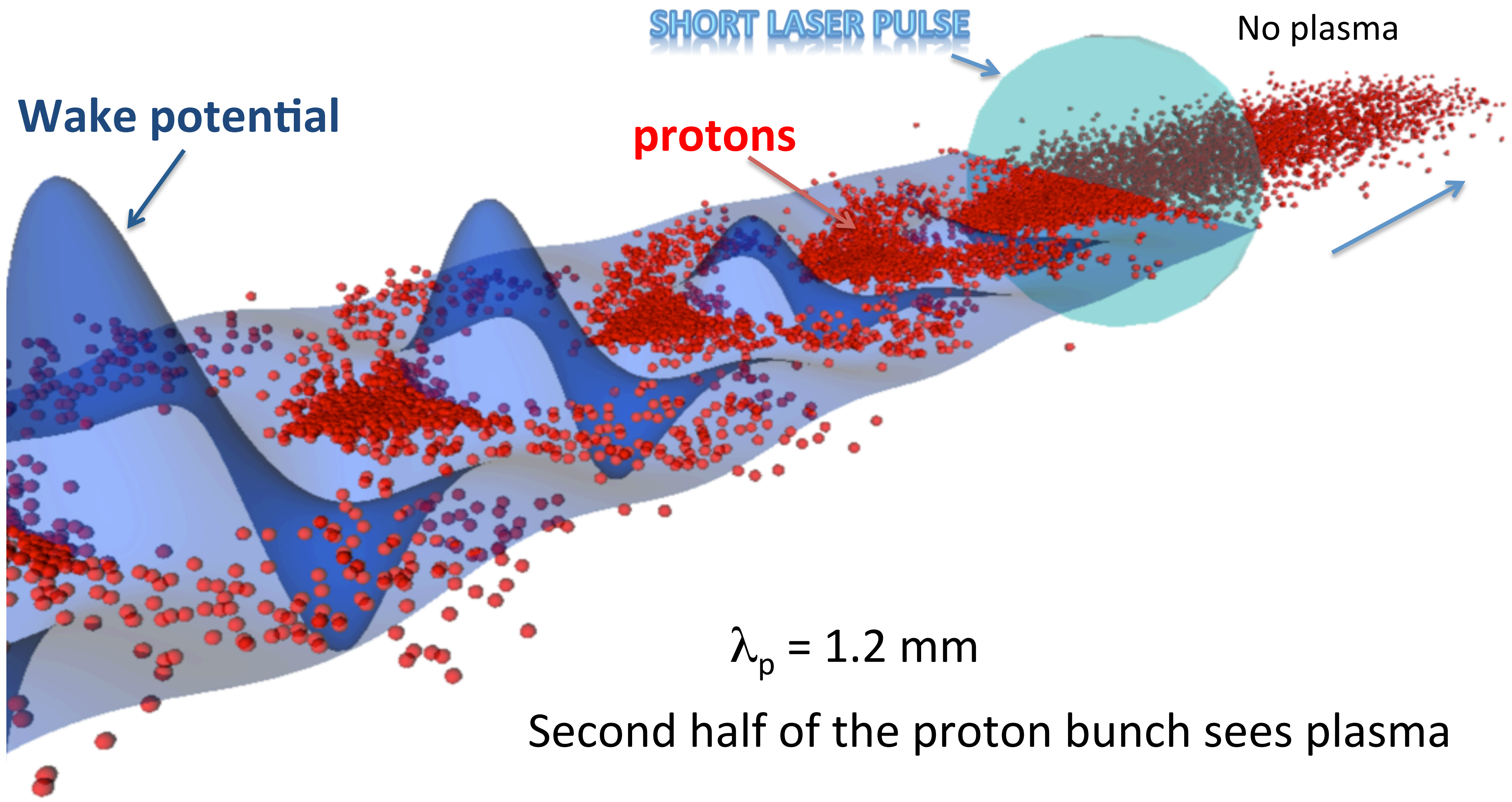
- Single stage acceleration to high energy
  - plasma allows few GeV/m acceleration
  - exhaust the 20 kJ energy per bunch at the SPS and transfer the energy to the witness bunch
  - Idea: *generate the field where and when you need it*
    - CLIC analogy with metallic structures

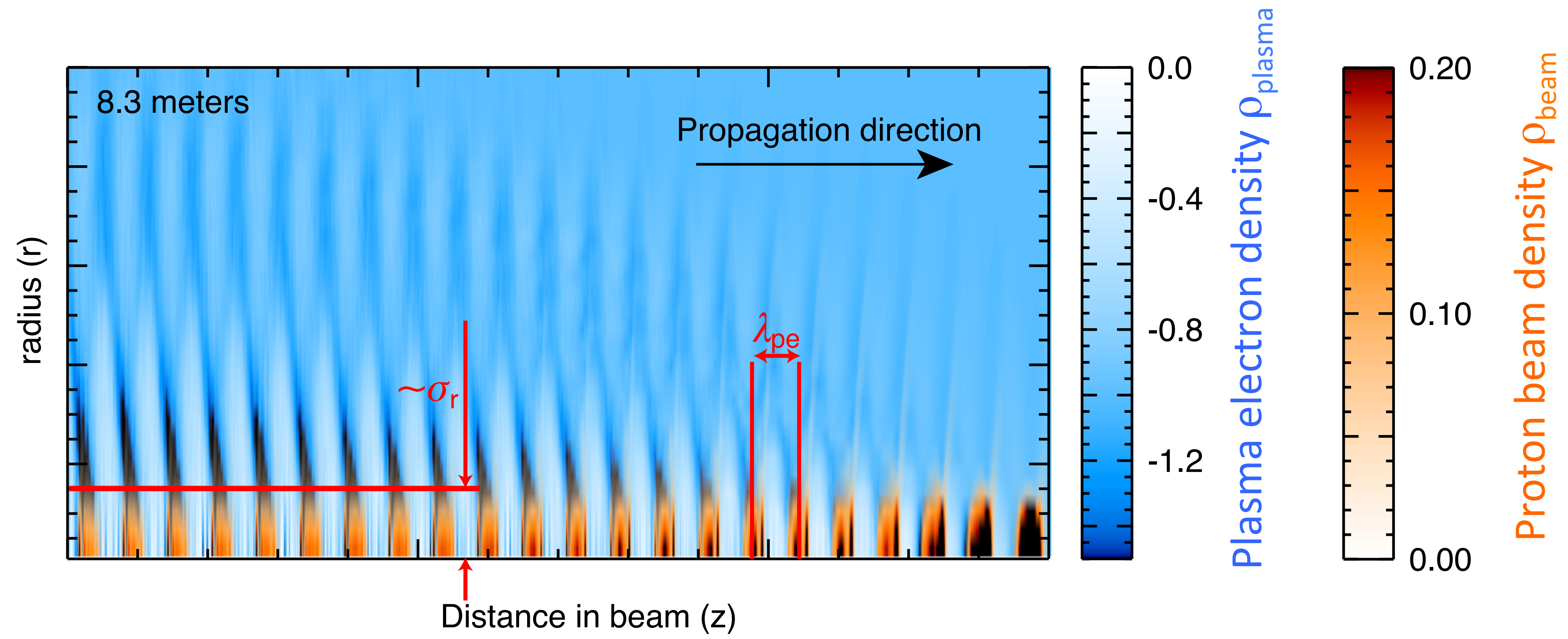




AWAKE

- Charge fluctuations in the bunch (or external laser pulse) starts to seed a plasma at the characteristic wavelength
    - self-modulates the charge density of the proton bunch
    - electrons injected into the plasma would then be accelerated

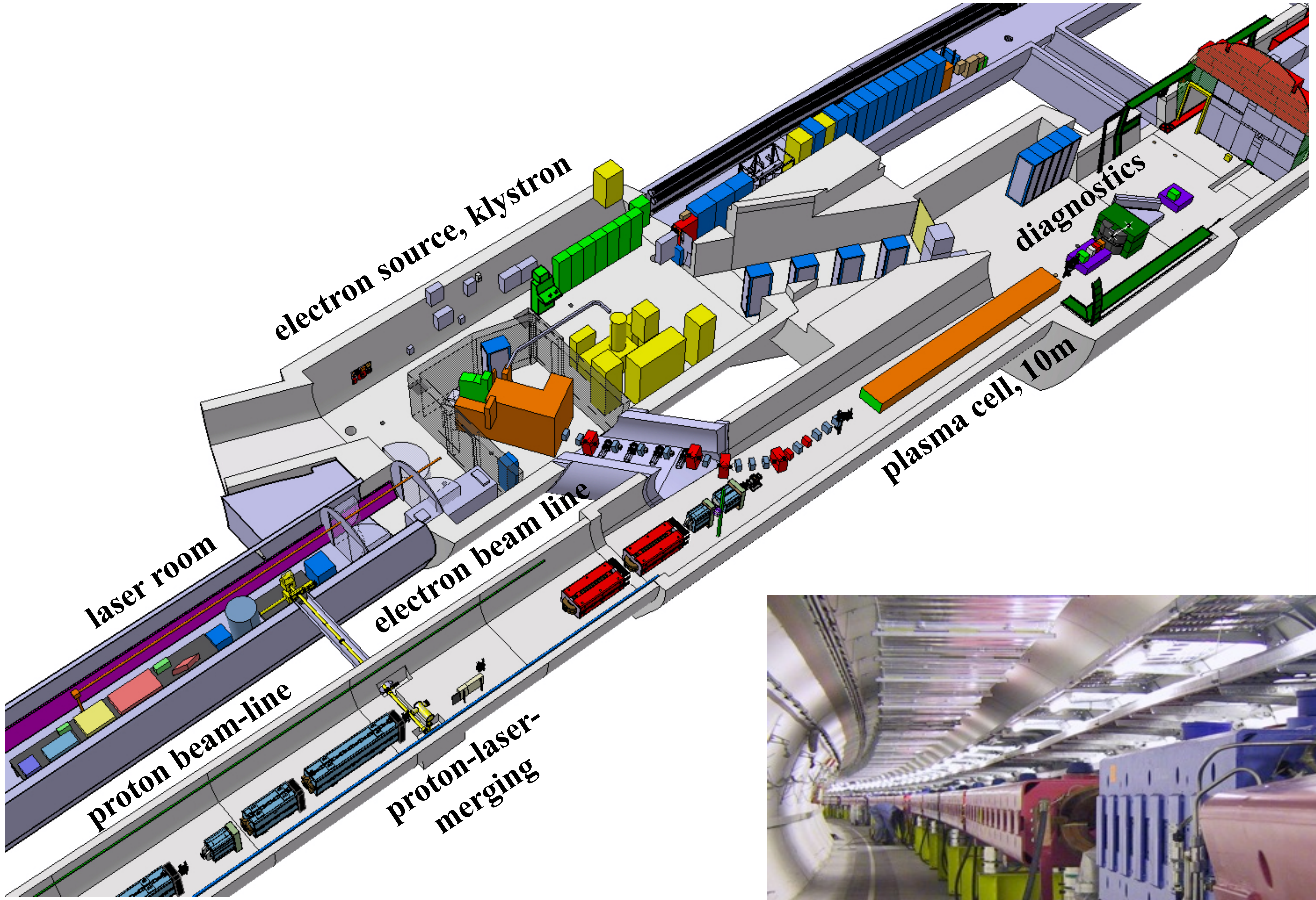




AWAKE Set-up

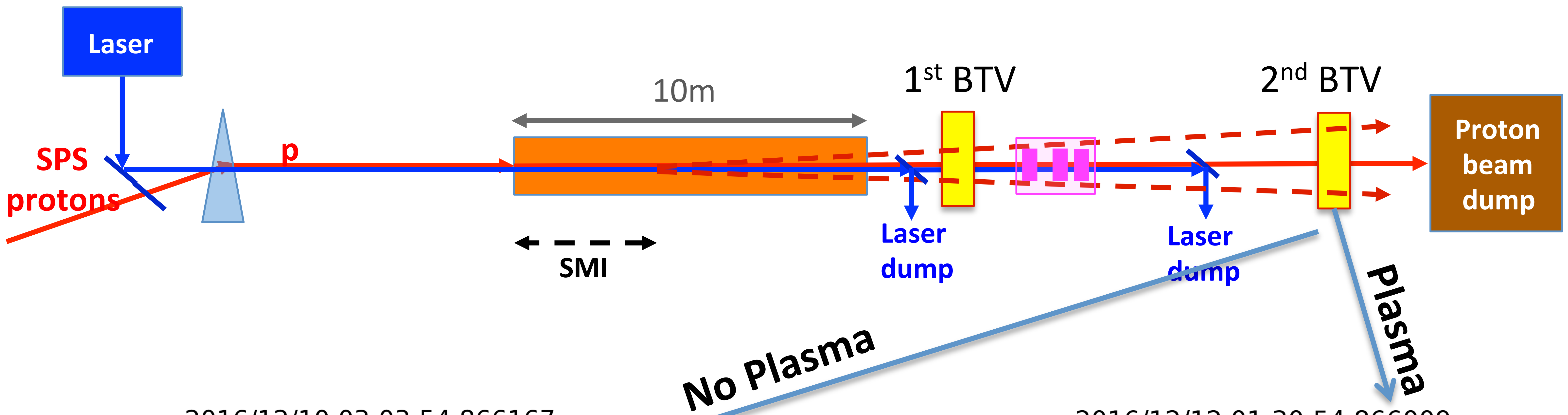
- Installation at former proton beam line for neutrinos to Gran Sasso

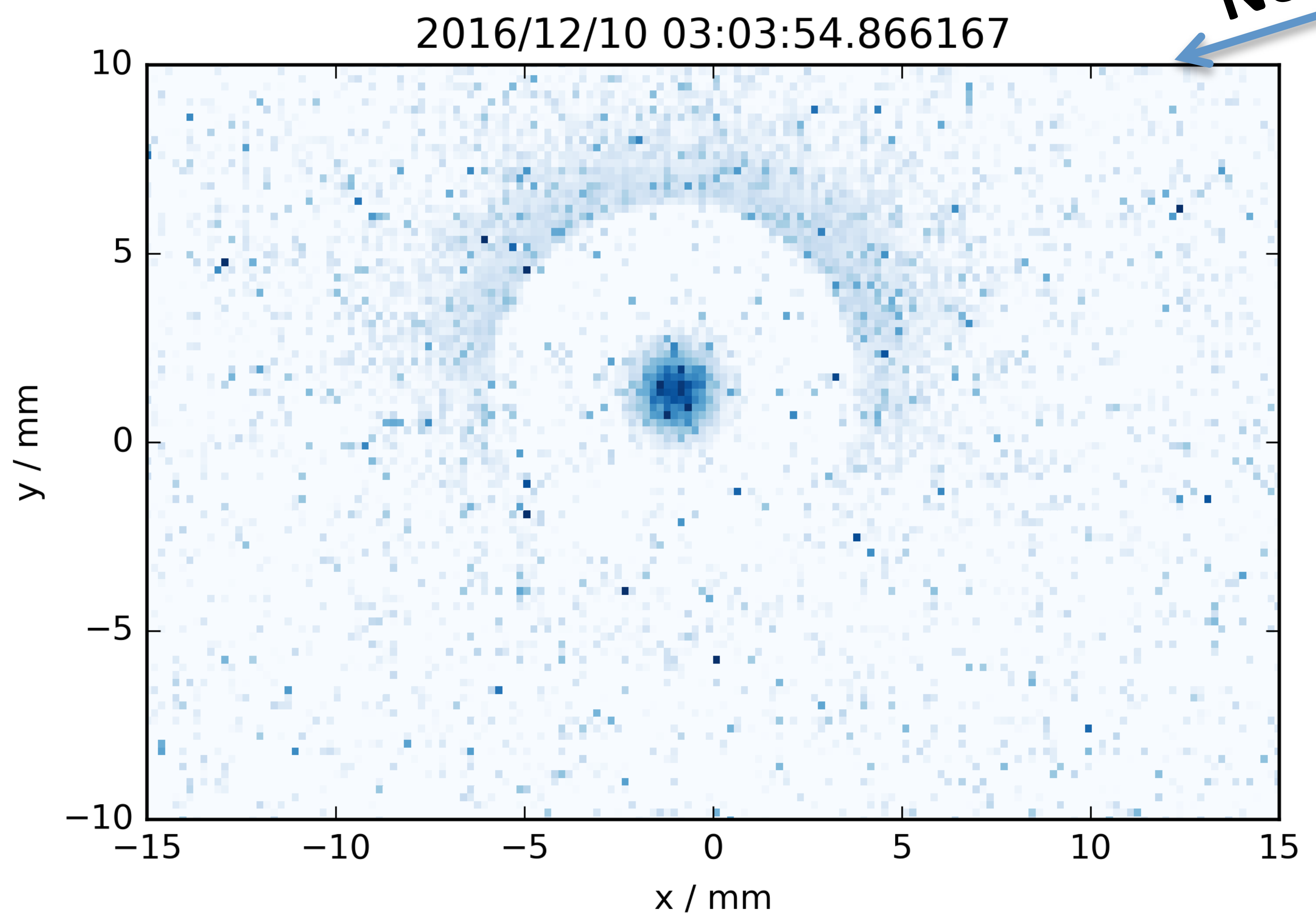
- experimental area for plasma cell and electron injector

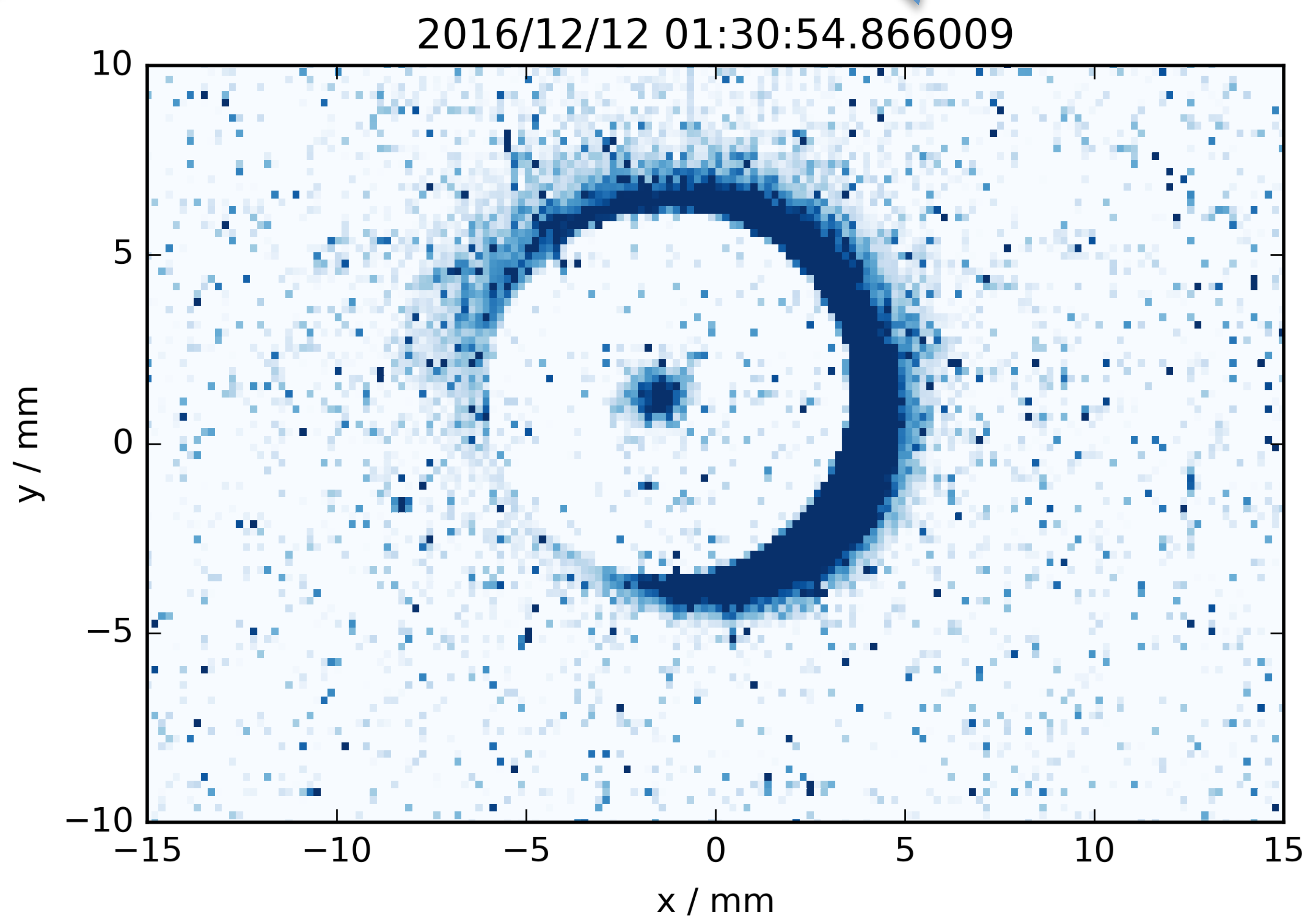


Observation of Transverse Blow-up of beam

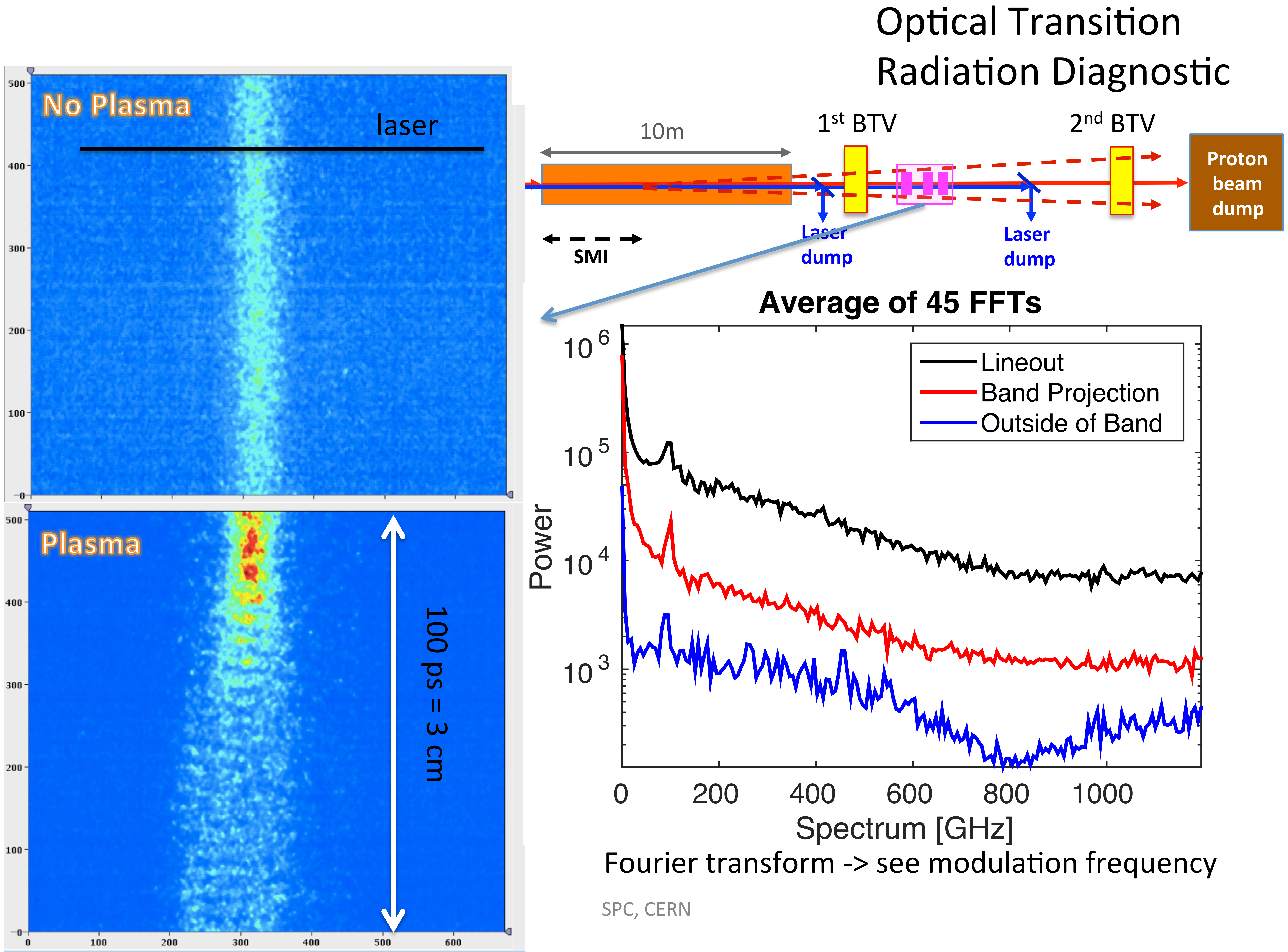
- Considerable transverse blow-up of beam
  - only possible in the presence of large electrical fields







AWAKE: First observation of self-modulation



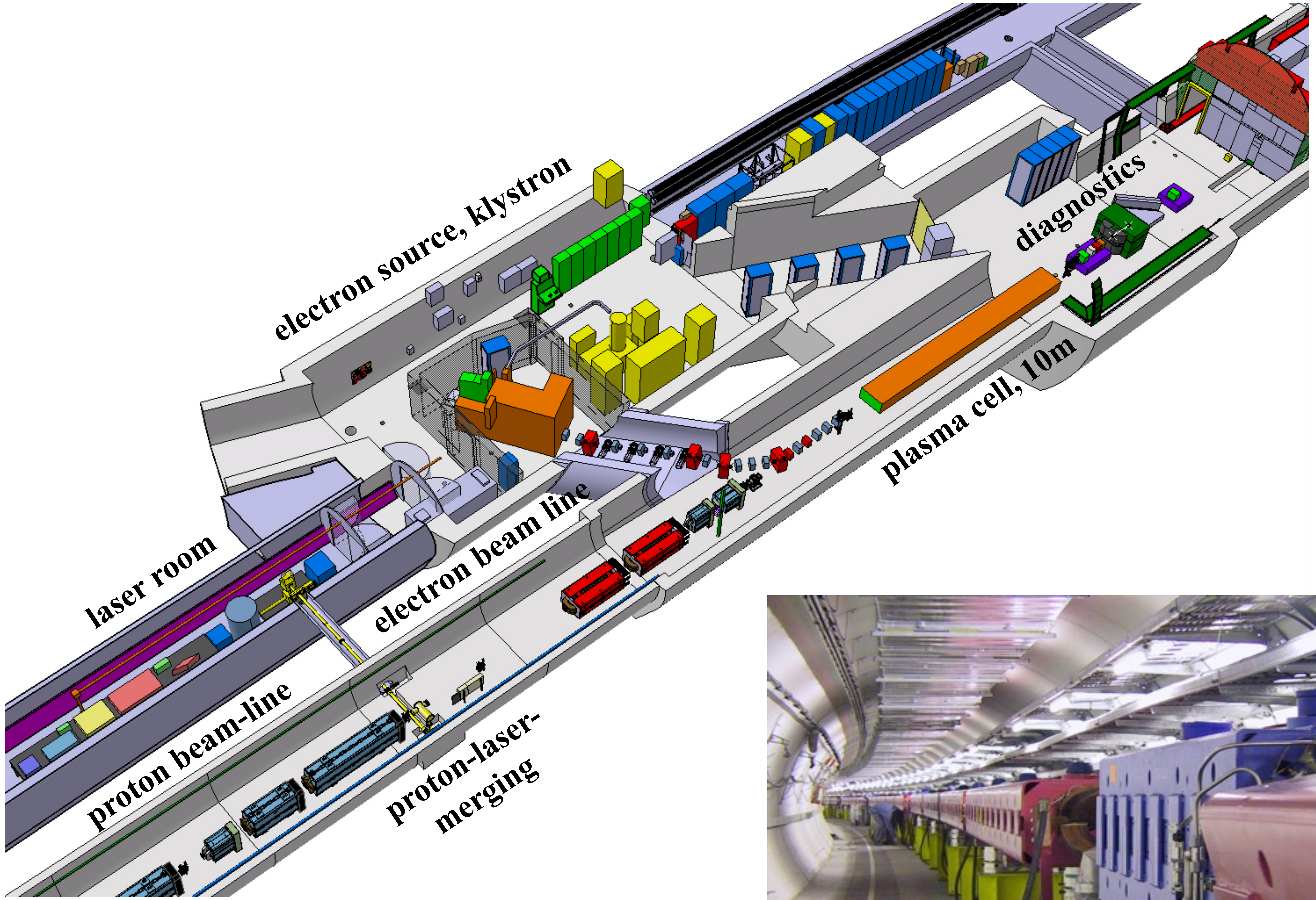
Fourier transform -> see modulation frequency

SPC, CERN

AWAKE Overview

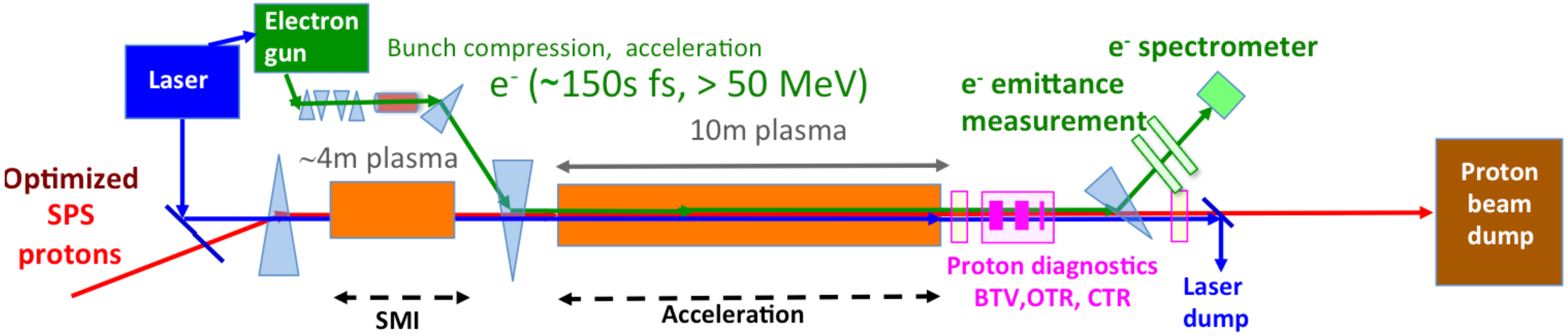
- Understand the physics of self-modulation instability

- Probe the accelerating wakefields with externally injected electrons



AWAKE: Run II

Goals:
- stable acceleration of bunch of electrons with high gradients over long distances
- ‘good’ electron bunch emittance at plasma exit



Require:
- Compressed proton beam in SPS
- Short electron bunch with higher energy for loading wakefield
- Density step in plasma for freezing modulation
- Alternative plasma cell developments

Preliminary Run 2 electron beam parameters

Parameter	Value
Acc. gradient	>0.5 GV/m
Energy gain	10 GeV
Injection energy	$\gtrsim$ 50 MeV
Bunch length, rms	40–60 μm (120–180 fs)
Peak current	200–400 A
Bunch charge	67–200 pC
Final energy spread, rms	few %
Final emittance	$\lesssim$ 10 μm

e^+e^- collider

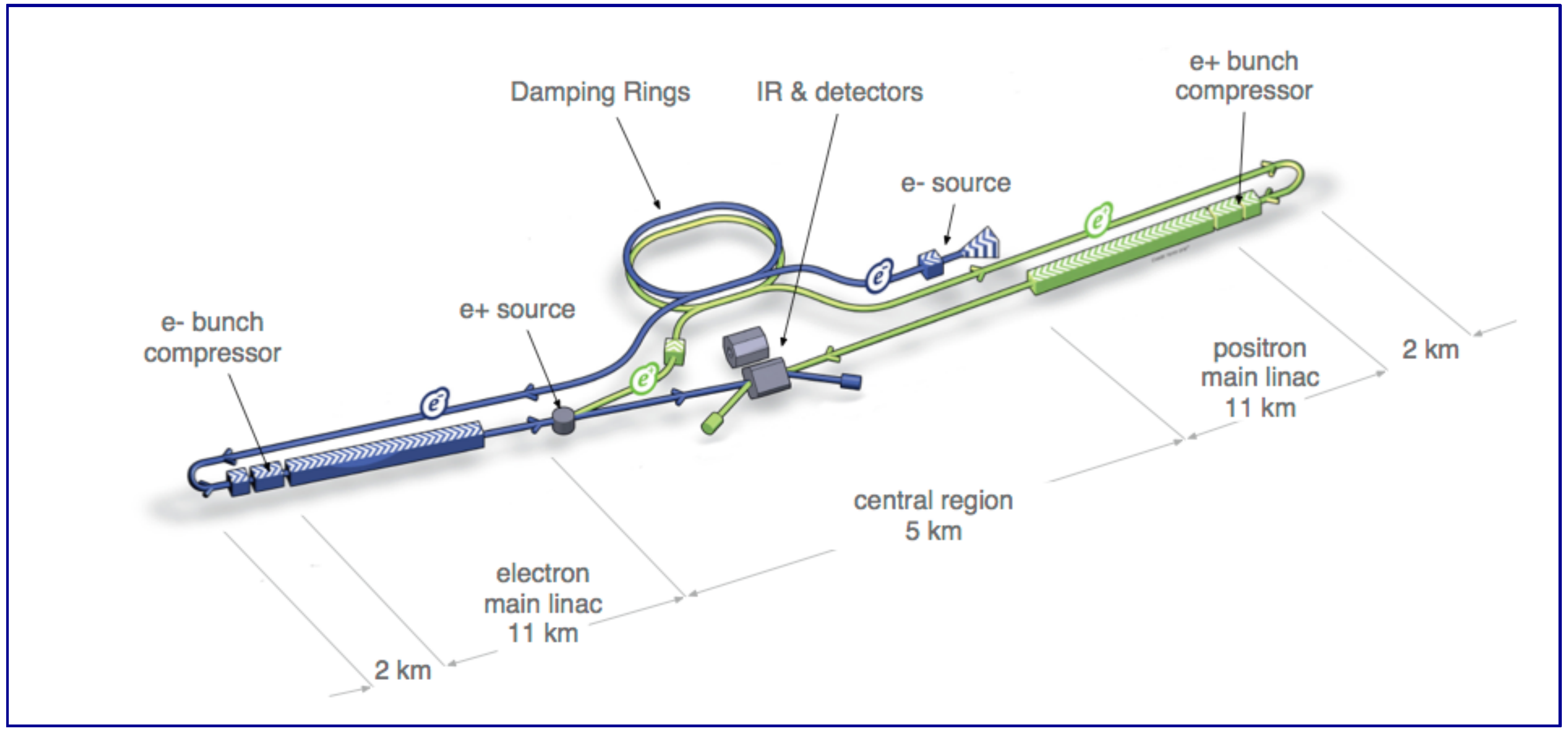
From European Strategy of Particle Physics

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
- Ministry MEXT continues to evaluate the implications of hosting ILC in Japan w.r.t. cost, manpower (skills)



- Project is mature (TDR 2012)
- hosting evaluated by Japanese government
- expect (some) statement by the end of 2018

Japanese developments since release of TDR

ILC Advisory Panel

- Setup by MEXT in May 2014
- Activities in the first year (May 2014-June 2015)
  - Elementary particle and nuclear physics WG, TDR-validation WG
  - 1st Nomura Research Institute survey (Spin-off and research trend)
  - Summary of the ILC advisory panel's discussions to date
- Activities in the second year (June 2015-July 2016)
  - Human resource securing and developing WG
  - Report on measures to secure and develop human resources for the ILC
  - 2nd Nomura Research Institute survey (technology issues)
- Activities in the third year (July 2016-July 2017)
  - Management and organizational structure WG, 3rd survey on large international projects
  - Report on ILC management and organizational structure (English translation being prepared)
- The Panel activity will continue.

Various country visits to explore regional interest

MEXT-DOE discussion group

1st meeting in May 2016 in Washington, A meeting in August 2016 during ICHEP 2016
2nd meeting in October 2016, decided to start US-Japan cooperative R&Ds for ILC cost reduction.
Discussion group meetings will continue.

US-Japan discussion first

Slide from Y.Okada

ILC – Technical Developments

- Recent Proposal to start with 250 GeV cm
  - Higgs precision studies complementing LHC
    - contrast with HL-LHC results and theory assumptions
  - Upgrade option needs to be preserved to tackle top threshold
- TDR cost of ~8 bn ILCU* can be reduced by ~40% for 250 GeV machine
  - Japanese hosting discussion reinvigorated

* 1 ILCU = 1 $US in 2012

ILC Project Phases

2017 – 2018 Pre - preparation phase

- The ongoing activities with relevance to the ILC in Europe are reviewed.

2019 – 2022: Preparation phase

- This period needs to be initiated by a positive statement from the Japanese government about hosting the ILC, followed by a European strategy update that ranks European participation in the ILC as a high-priority item. The preparation phase focuses on preparation for construction and agreement on the definition of deliverables and their allocation to regions.

2023 and beyond: Construction phase

- The construction phase will start after the ILC laboratory has been established and intergovernmental agreements are in place. At the current stage, only the existing capabilities of the European groups relevant for this phase can be described.

S Stapnes at Sep 2017 Council Session

Pre-preparation phase – current focus areas (2017-2018)

Item/topic	Brief description	CERN	France CEA	Germany DESY	Time line
SCRF	Cavity fabrication including forming and EBW technology,	✓			2017-18
	Cavity surface process: High-Q &–G with N-infusion to be demonstrated with statics, using High-G cavities available (# > 10) and fundamental surface research		✓	✓	2017-18
	Power input-coupler: plug compatible coupler with new ceramic window requiring no-coating	✓			2017-19
	Tuner: Cost-effective tuner w/ lever-arm tuner design	✓	✓		2017-19
	Cavity-string assembly: clean robotic-work for QA/QC.		✓		2017-19
Cryogenics	Design study: optimum layout, emergency/failure mode analysis, He inventory, and cryogenics safety management.	✓			2017-18
HLRF	Klystron: high-efficiency in both RF power and solenoid using HTS	✓			2017- (longer)
CFS	Civil engineering and layout optimization, including Tunnel Optimization Tool (TOT) development, and general safety management.	✓			2017-18
Beam dump	18 MW main beam dump: design study and R&D to seek for an optimum and reliable system including robotic work	✓			2017- (longer)
Positron source	Targetry simulation through undulator driven approach			✓	2017-19
Rad. safety	Radiation safety and control reflected to the tunnel/wall design	✓			2017 – (longer)

Focused R&D on some key areas (cost, power, technically critical)

S Stapnes at Sep 2017 Council Session

Pre-preparation phase – European XFEL and ESS

	Germany	France		Italy	Poland			Russia	Spain
	DESY	CEA Saclay	LAL	INFN Milan	IFJ PAN	WUT	NCBJ	BINP	CIEMAT
Linac									
Cryomodules	✓	✓		✓					
SCRF Cavities	✓			✓					
Power Couplers	✓		✓						
HOM Couplers							✓		
Frequency Tuners	✓								
Cold Vacuum	✓							✓	
Cavity String Assembly	✓	✓							
SC Magnets	✓				✓				✓
Infrastructure									
AMTF	✓				✓	✓		✓	
Cryogenics	✓								
Sites & Buildings									
AMTF hall	✓								

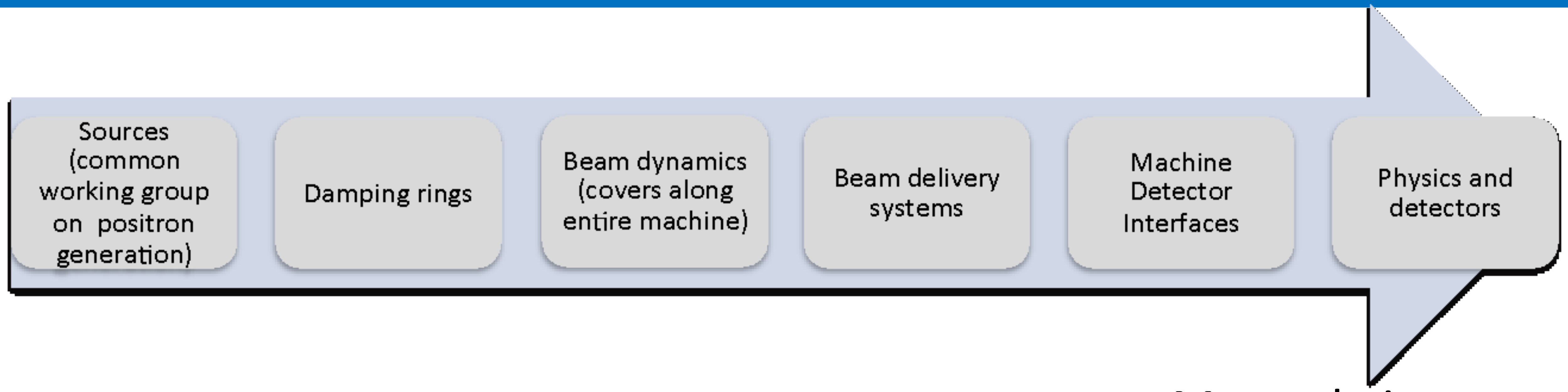
- Expertise across all essential parts of ILC
- Facilities set up in Europe
- Industrial capacity in Europe
- E-XFEL: ~7% of a 250 GeV ILC (~100 modules)

- ESS cryo-module production next
- Expertise/facilities being maintained and developed

	Germany	France		Italy		Poland	Spain	Sweden		UK
	DESY	CEA	IPNO	Elettra	INFN-LASA	IFJ-PAN	ESS Bilbao	ESS	Uppsala	STFC
RF systems				✓			✓	✓		
LLRF									✓	
Cryomodules		✓	✓							
SCRF Cavities		✓	✓		✓					✓
Power Couplers		✓	✓							
HOM couplers										
Frequency Tuners		✓	✓							
Cold Vacuum		✓	✓					✓		
Cavity String Assembly		✓	✓							
RF Tests (Cavites)	✓									✓
RF Tests (Cryomodules)		✓	✓			✓		✓	✓	

S Stapnes at Sep 2017 Council Session

Pre-preparation phase – Common studies w/CLIC, ATF2 KEK



Many obvious common areas for ILC/CLIC, beyond RF technologies:

- Common WGs on Beam-dynamics, Sources, MDI, DRs, RTML, BDS (yearly LC workshops built around these WGs/topics – all with CLIC co-conveners)
- Cost and power studies and comparison

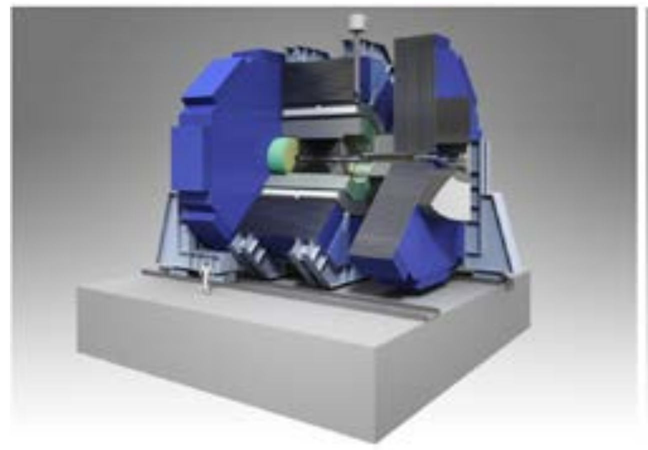
ATF2: International collaboration with many European groups:

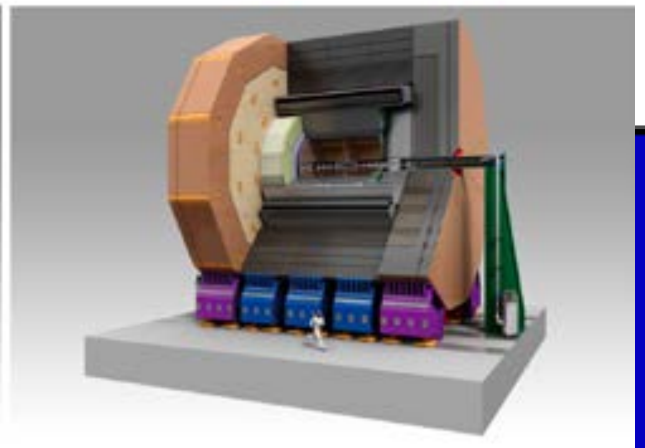
- Final focus studies (crucial for LC luminosities)
- Extensively used for Ph.D training

	CERN	France		Germany	Spain	UK	
		LAL	LAPP	DESY	IFIC	Oxford	RHUL
Goal 1							
Very-low β	✓						
Ultra-low β	✓						
Halo control		✓			✓		
Wakefield/Intensity	✓				✓		✓
Instrumentation	✓	✓			✓		✓
Ground motion	✓		✓				
Background				✓			✓
Goal 2							
Stabilisation/Feedback		✓				✓	

Pre-preparation phase – Detector studies and final overview

S Stapnes at Sep 2017 Council Session





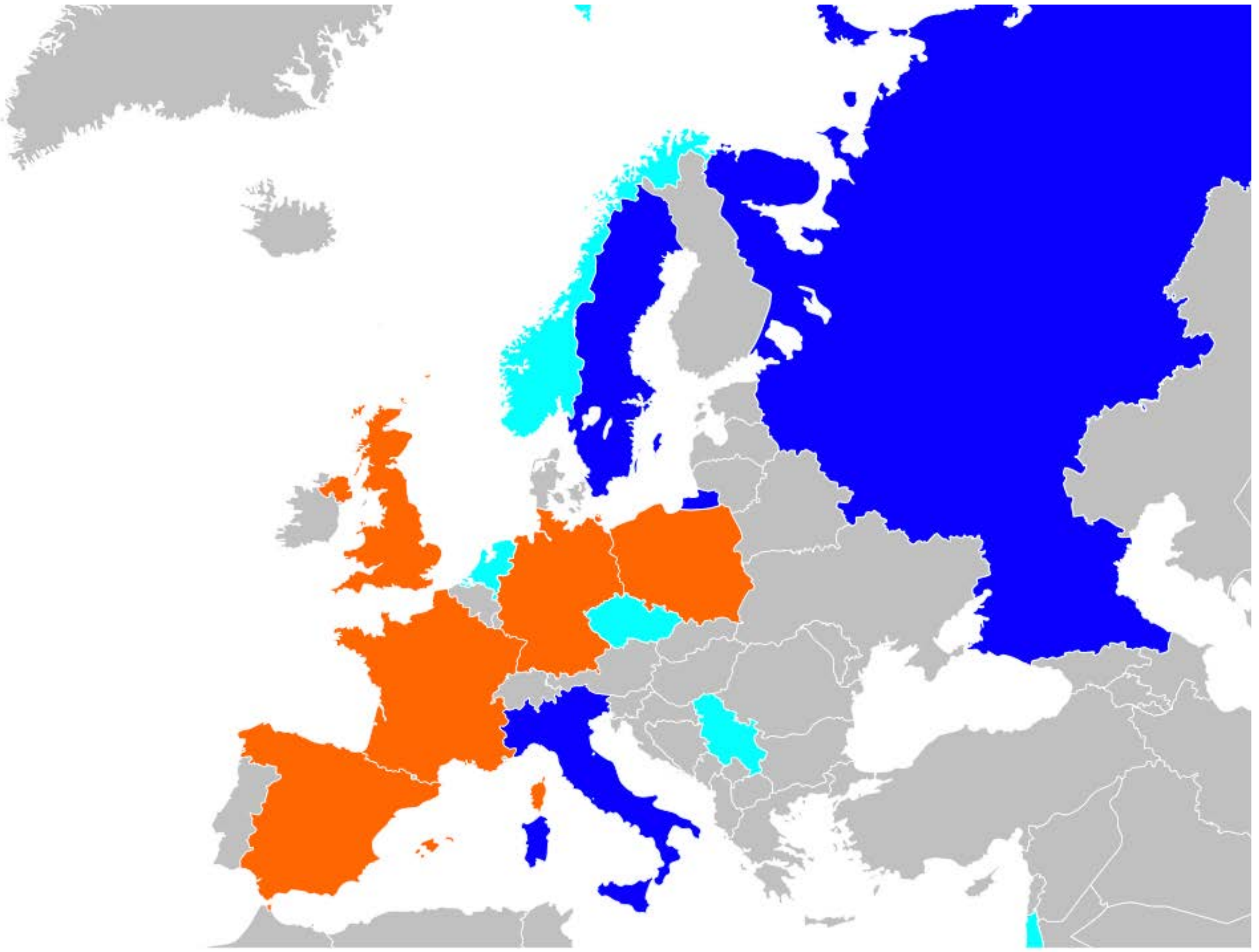
	CERN	DESY	Czech Republic	France	Germany	Israel	Netherlands	Norway	Poland	Serbia	Spain	UK
Vertexing	✓	✓	✓	✓	✓				✓		✓	✓
Tracking	✓	✓		✓	✓		✓				✓	✓
Calorimetry	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
MDI	✓	✓						✓				✓
System Integration	✓	✓		✓							✓	

Pre-preparation summary:

Europe has played – and continues to play – a central role in development of the ILC project

Large European projects are being implemented where the ILC/SCRF technology is being put to use and is being validated

European Industry is well prepared to construct parts for ILC



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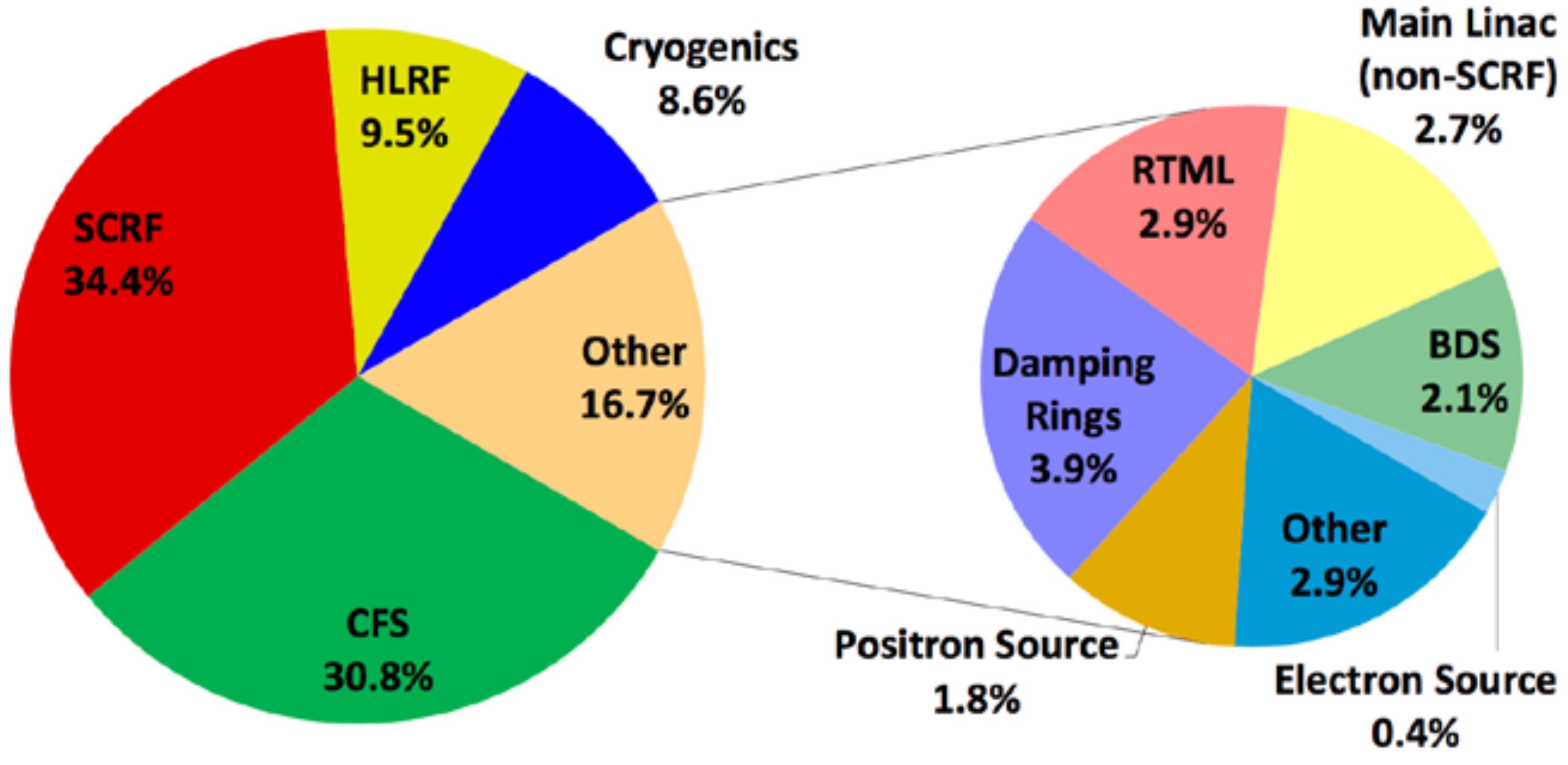
Construction phase 2023 and beyond

The construction phase will start after the ILC laboratory has been established and inter-governmental agreements are in place. At the current stage, only the existing capabilities of the European groups relevant for this phase can be described.



As mentioned above, the detailed contributions will have to be defined during the preparation phase and formalized by inter-governmental agreements. Some contributions from Europe are imperative for the project - most prominently superconducting RF modules.

So premature to plan in detail, however some comments can be made:

- Focus on technical items for ILC (not CE and infrastructure)
- E-XFEL ~7% of a 250 GeV ILC – and more than 10% of the cryo-modules needed
- Detector construction expected to follow LHC detector model
- Spending significantly above the levels mentioned on previous page only by ~2025-26

Preparation Phase 2019-22: Key activities

S Stapnes at Sep 2017 Council Session

This period needs to be initiated by a positive statement from the Japanese government about hosting the ILC, followed by a European strategy update that ranks European participation in the ILC as a high-priority item. The preparation phase focuses on preparation for construction and agreement on the definition of deliverables and their allocation to regions.

- The European groups will concentrate on preparation for their deliverables, including European industry.
- Europe and European scientists, as part of an international project team, will also participate in the overall finalization of the design, while in parallel contributing to the work of setting up the overall structure and governance of the ILC project and of the associated laboratory.

Key activities in Europe	More details
SCRF activities	
	Cavity fabrication and preparation, Power Couplers, Automation of assembly, E-XEL -> ILC
High efficiency klystron R&D	
Cryogenics system	LHC system similar in size to ILC
Accelerator Domain Issues	
	Positron source, Damping Rings, Beam Delivery Systems, Low emittance beam transport, Beam dumps, Positron source
Detector and Physics	
	Design optimization, MDI, Technical prototypes, TDR, physics studies
Documentation system	Experience from E-FEL
"Regional" Design office	Naturally at CERN, linking to other European National Labs

ν-physics

From European Strategy of Particle Physics

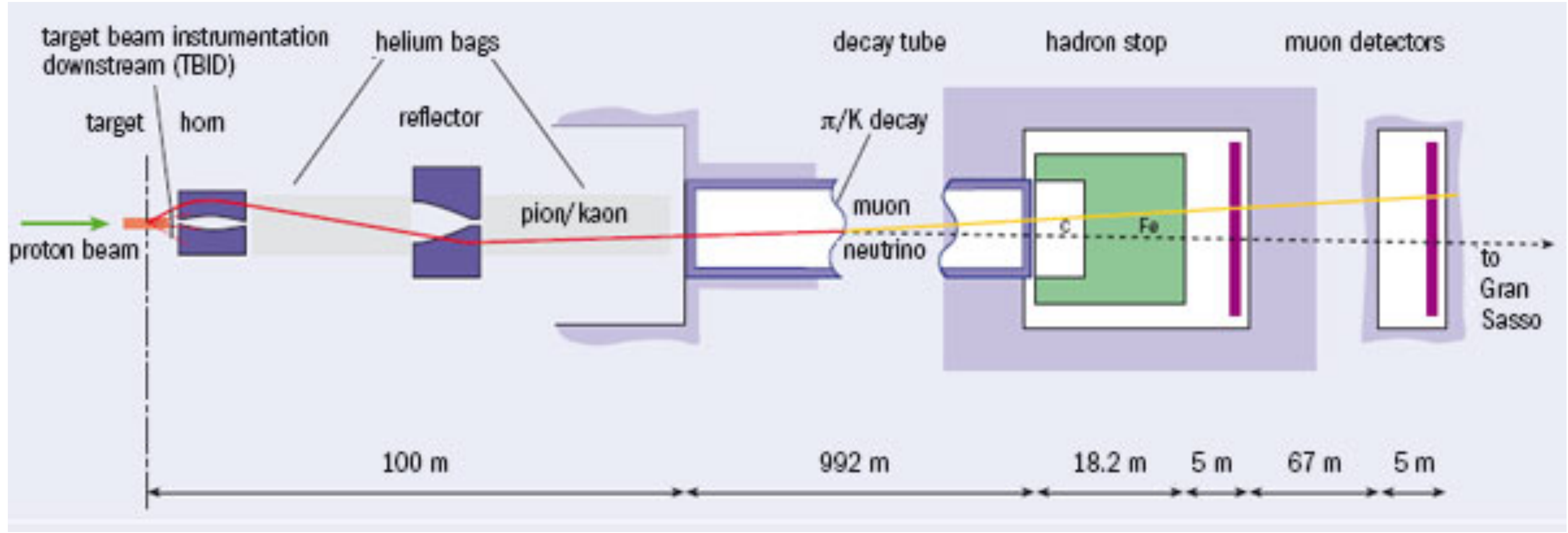
Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.

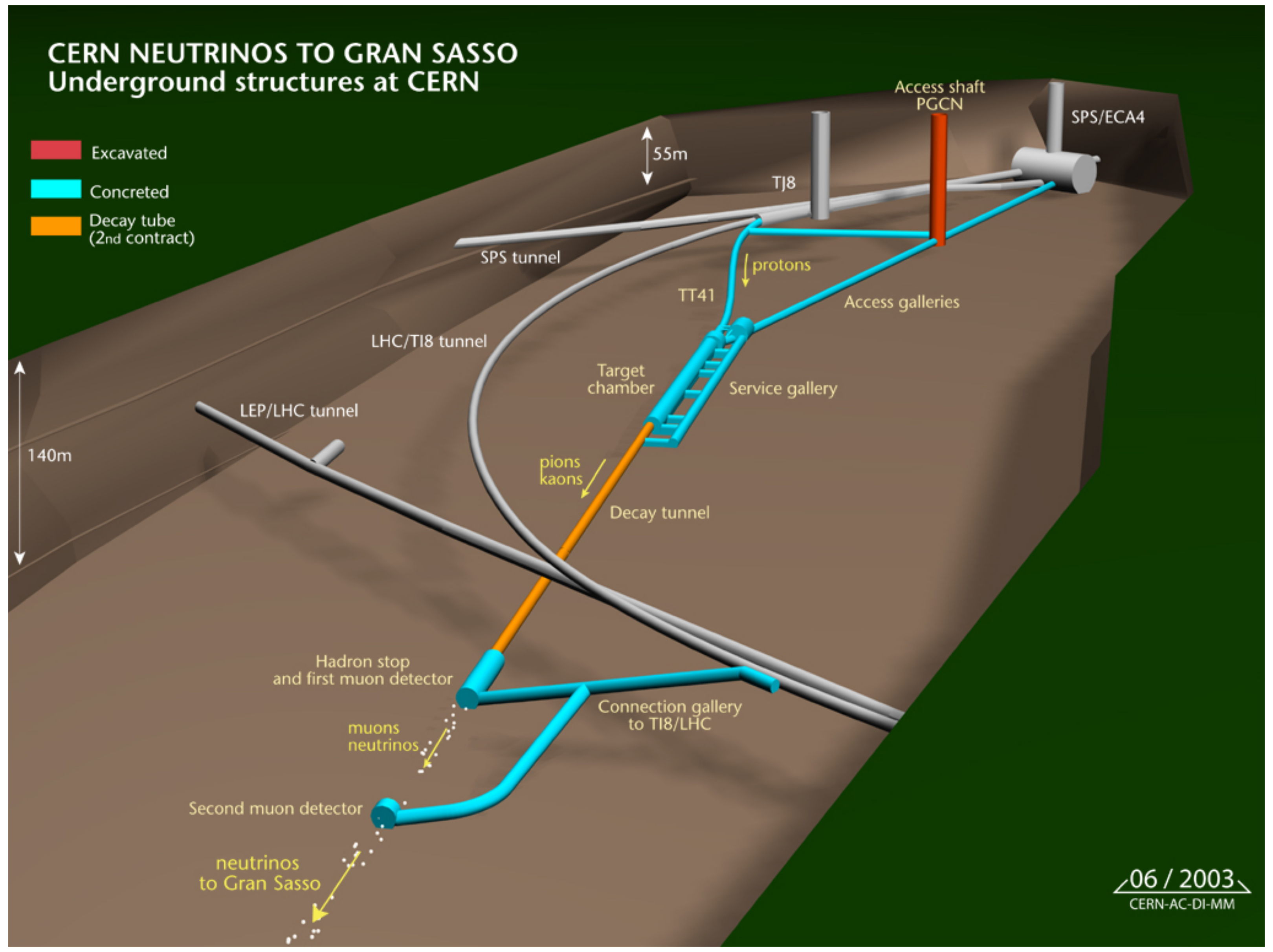
Neutrinos at CERN

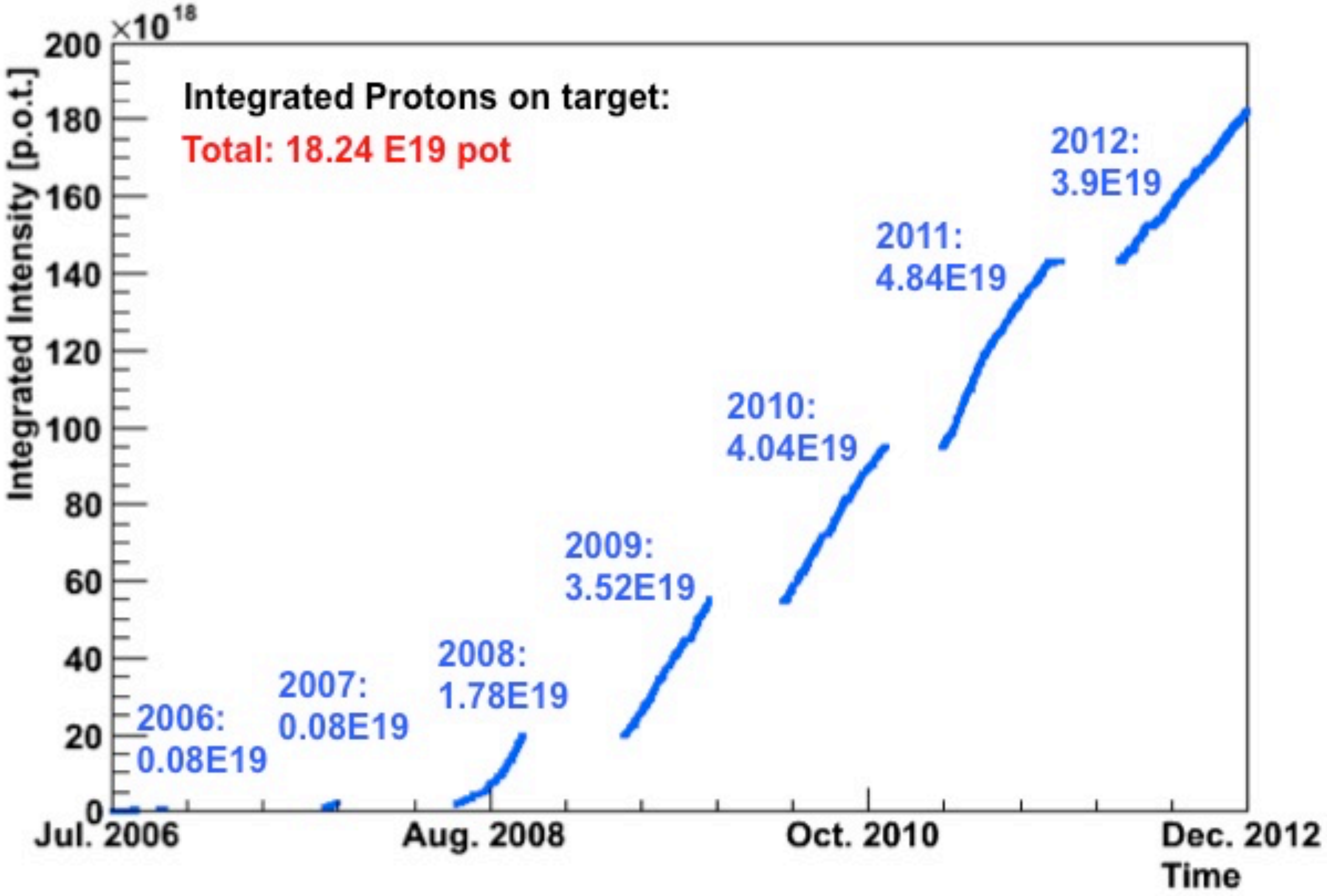
- Long tradition
  - detection of neutral currents at Gargamelle in 1973
  - CDHS and CHARM…
- More recently
  - CNGS
    - sending neutrinos from CERN to Gran Sasso

CNGS 2006 - 2012

- CERN ν-beam to Gran Sasso



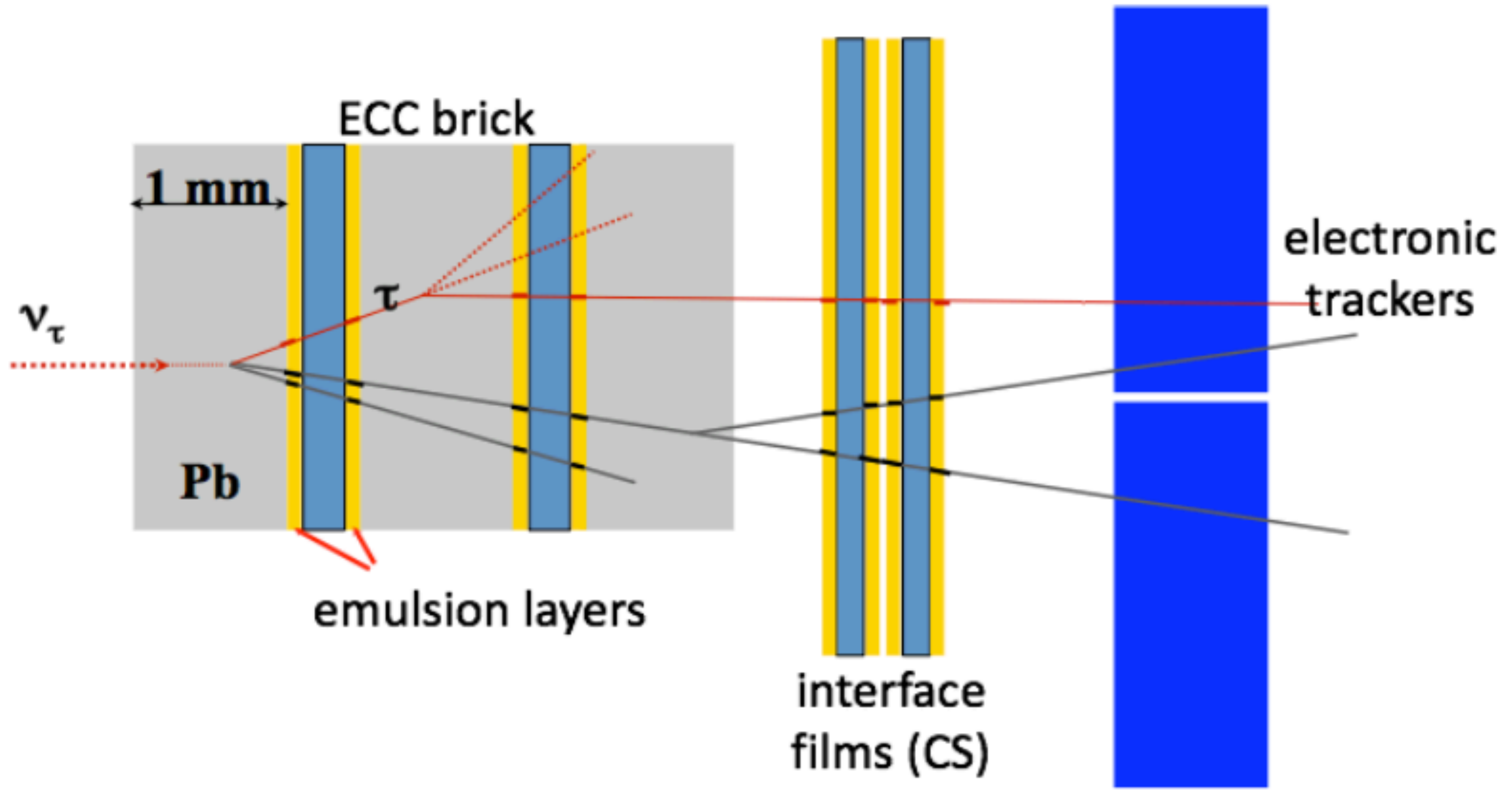


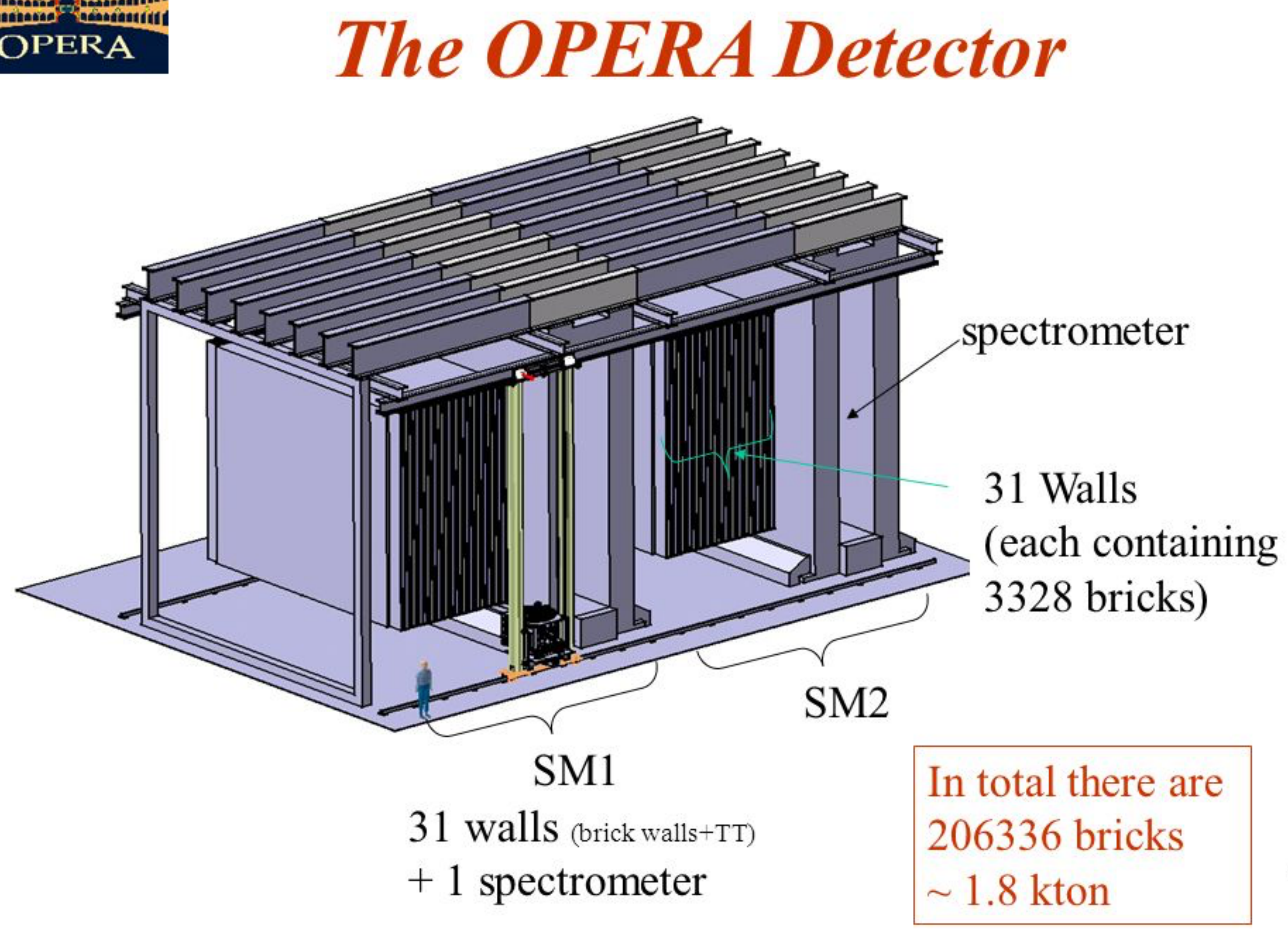


1.8×10^{20} p.o.t.

OPERA

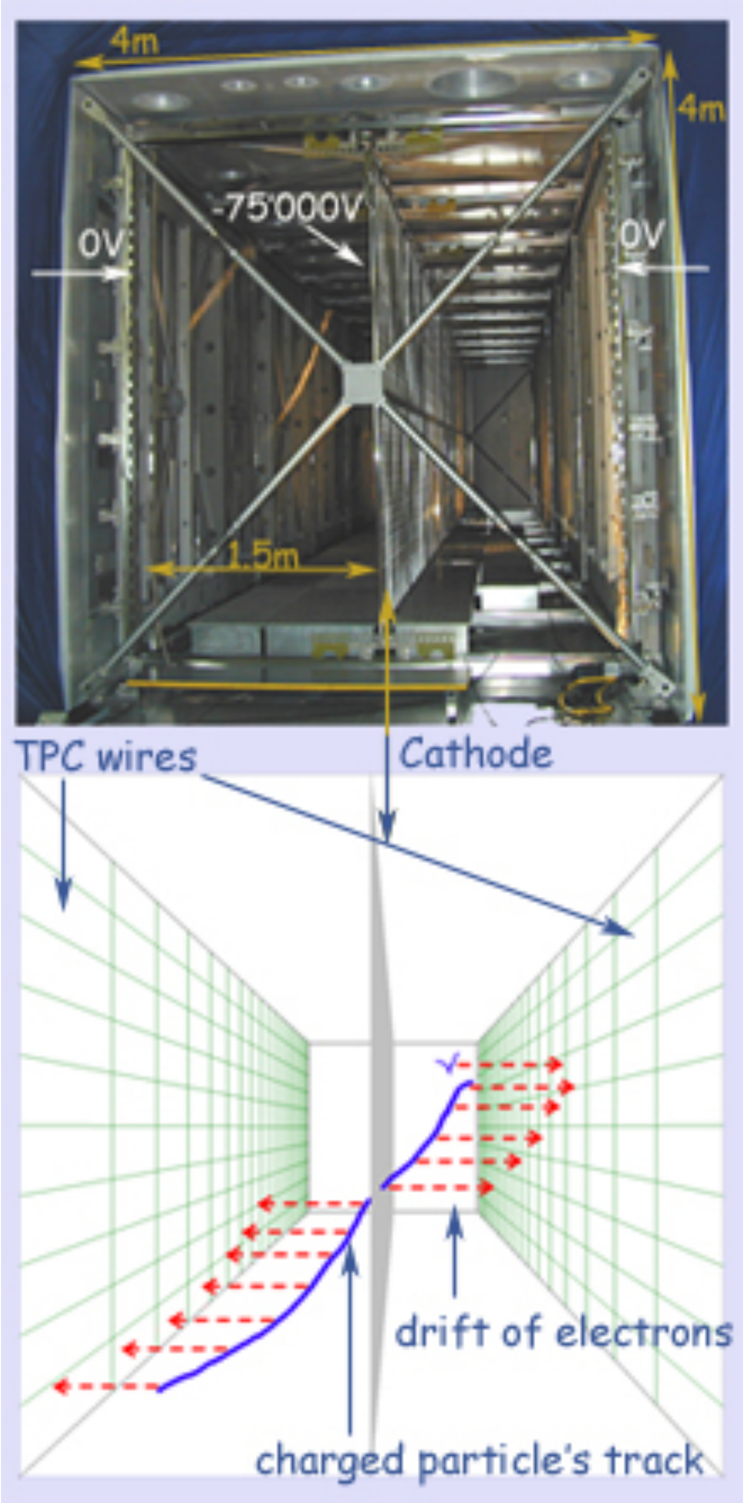
- 5 ν_τ were detected in emulsion detector
  - Detection of $\nu_\mu \rightarrow \nu_\tau$ oscillations

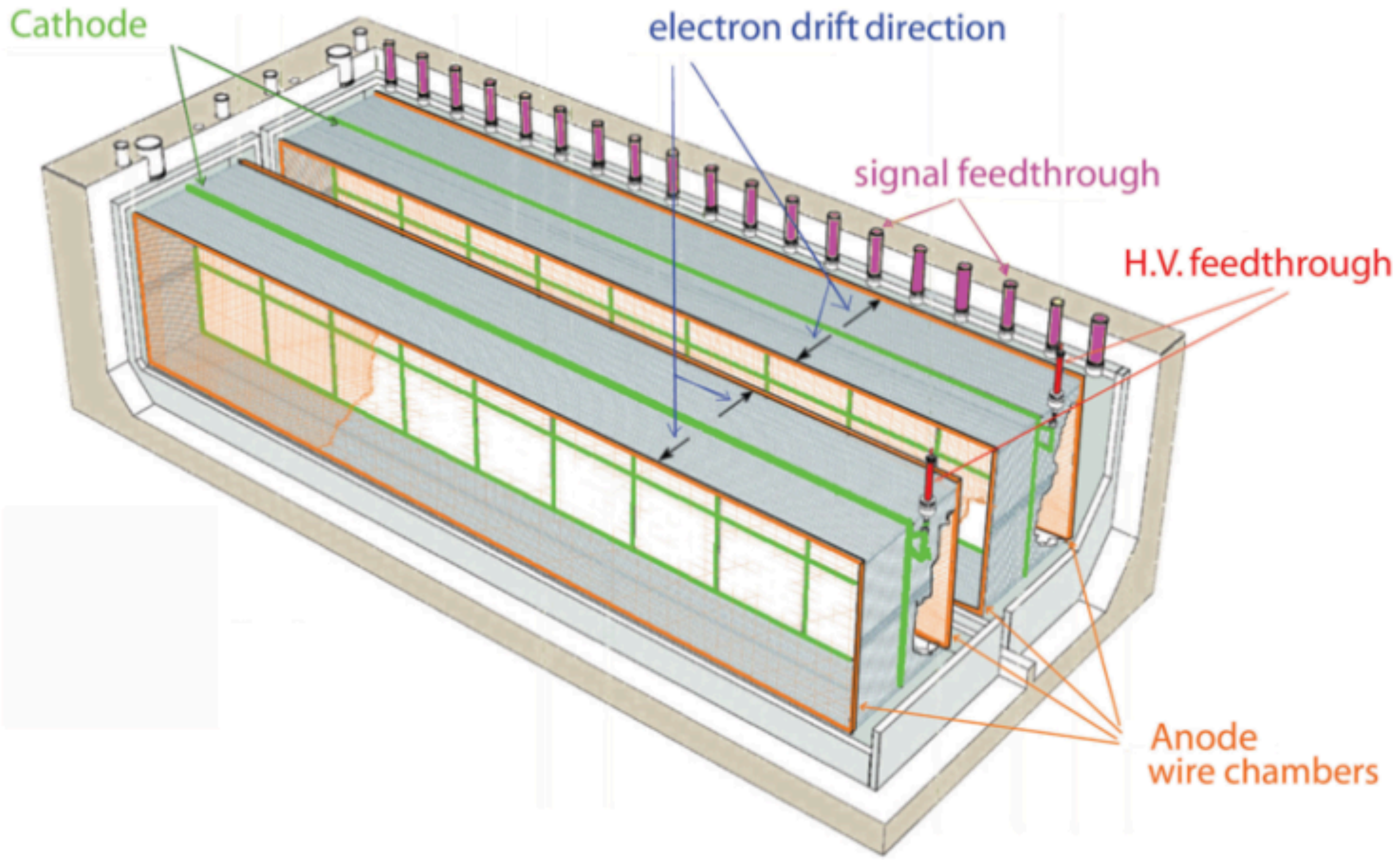




ICARUS at Gran Sasso

- LArTPC
  - search for $\nu_\mu \rightarrow \nu_e$ oscillations and LSND effect
    - $P_{\nu\mu \rightarrow \nu e} \leq 5.4 \times 10^{-3}$ @ 90%CL
  - search for $\nu_\mu \rightarrow \nu_\tau$ oscillations





Neutrino Physics at CERN in the LHC era

- with the ESPP of 2012…
  …decision to end CNGS in 2012
- Establishment of a Neutrino Platform at CERN
  - as a springboard for European Physicists to engage in accelerator based neutrino physics in the US and in Japan
  - Detector development (initial emphasis on Lar TPC)
  - Extension of EHN1 hall

Charged particles from SPS available

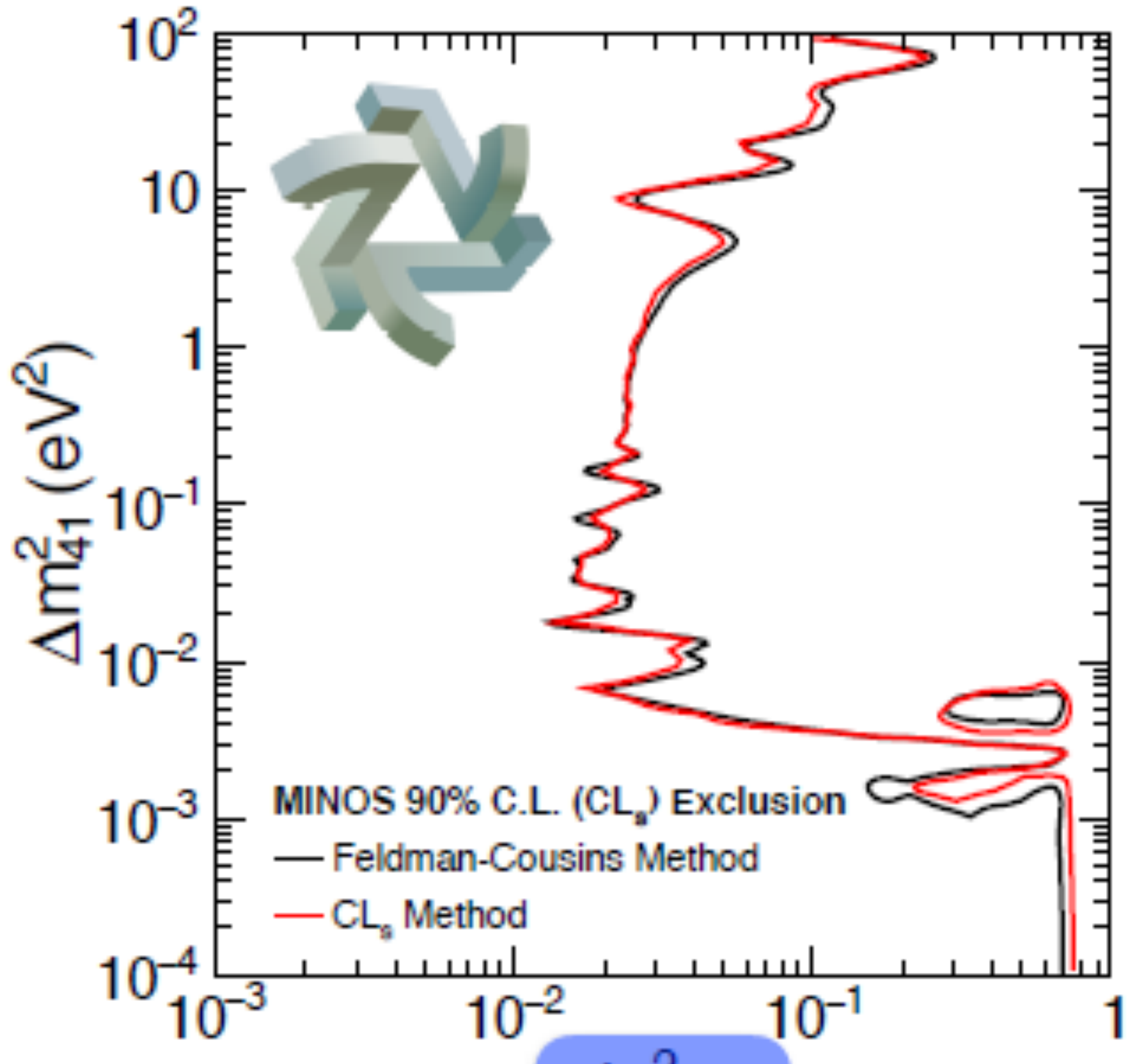
Fast entry into Short Baseline Programme at Fermilab

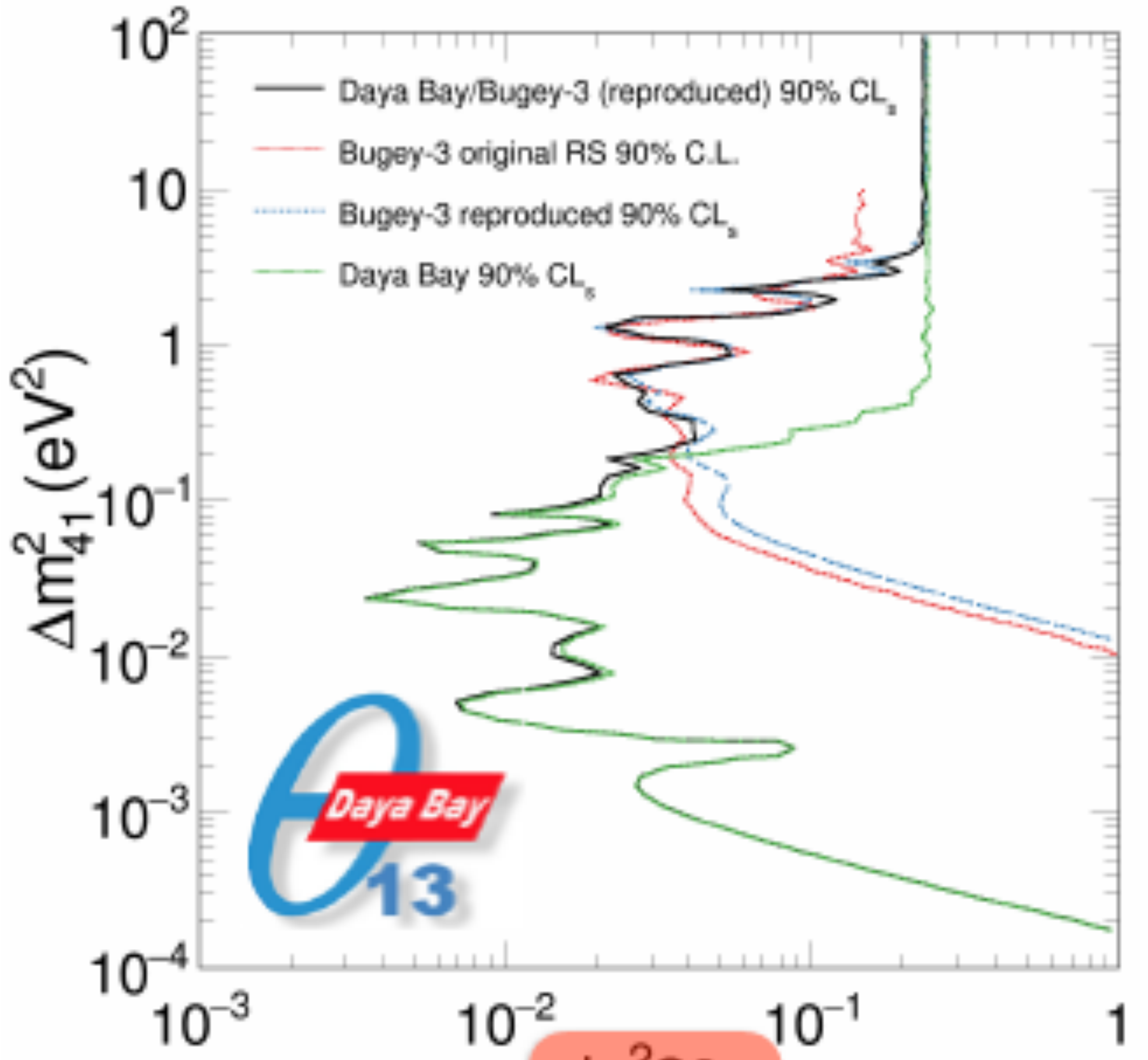
- ICARUS
  - ended data taking at LNGS
  - pioneered LarTPC technology
  - space at LNGS had to be cleared

ICARUS overhaul at CERN (WA104 - NP01)

- Detector upgrade
  - more PMTs
  - new cathode, inner cabling
  - new electronics
- Scintillator layer (cosmic tagger)
- New cryostat and cryogenic plant
- Reassembly of the 2 T300 modules inside cryostats and shipment to Fermilab

Sterile neutrino search

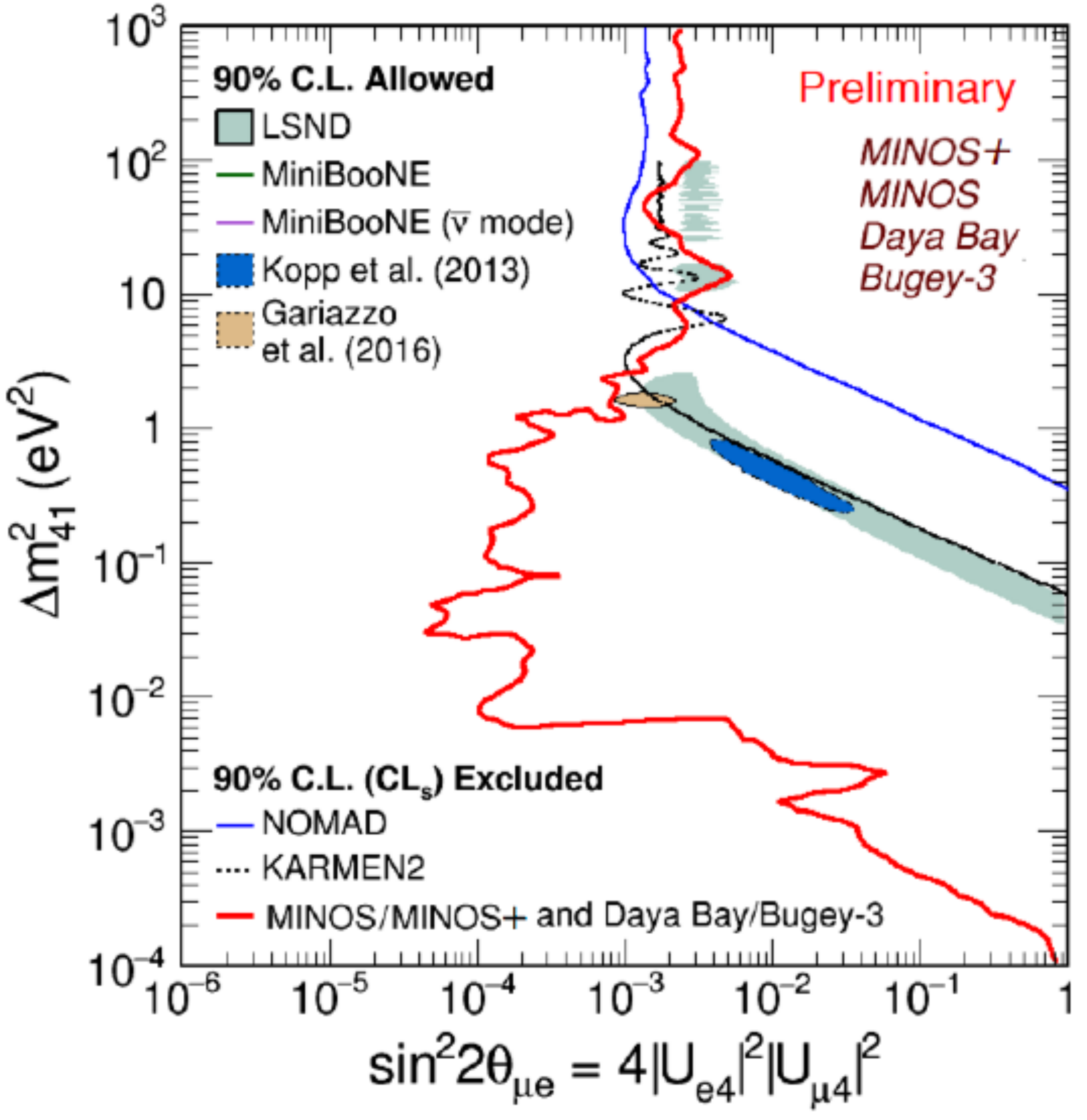




$\sin^2\theta_{24}$ $\sin^2 2\theta_{14}$

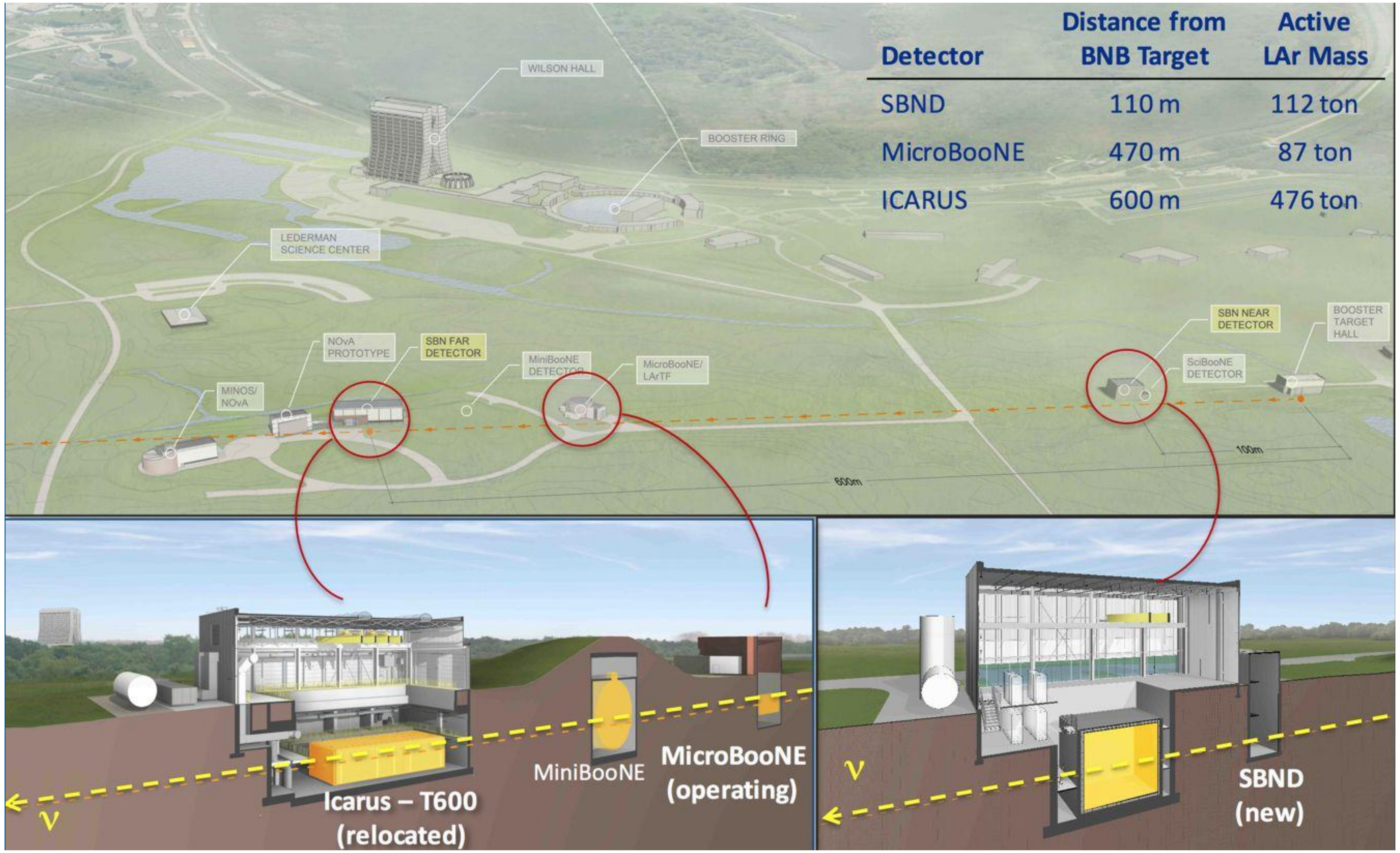
LSND & MiniBooNE

$$4|U_{e4}|^2|U_{\mu 4}|^2 = \sin^2\theta_{24}\sin^2 2\theta_{14} \equiv \sin^2 2\theta_{\mu e}$$



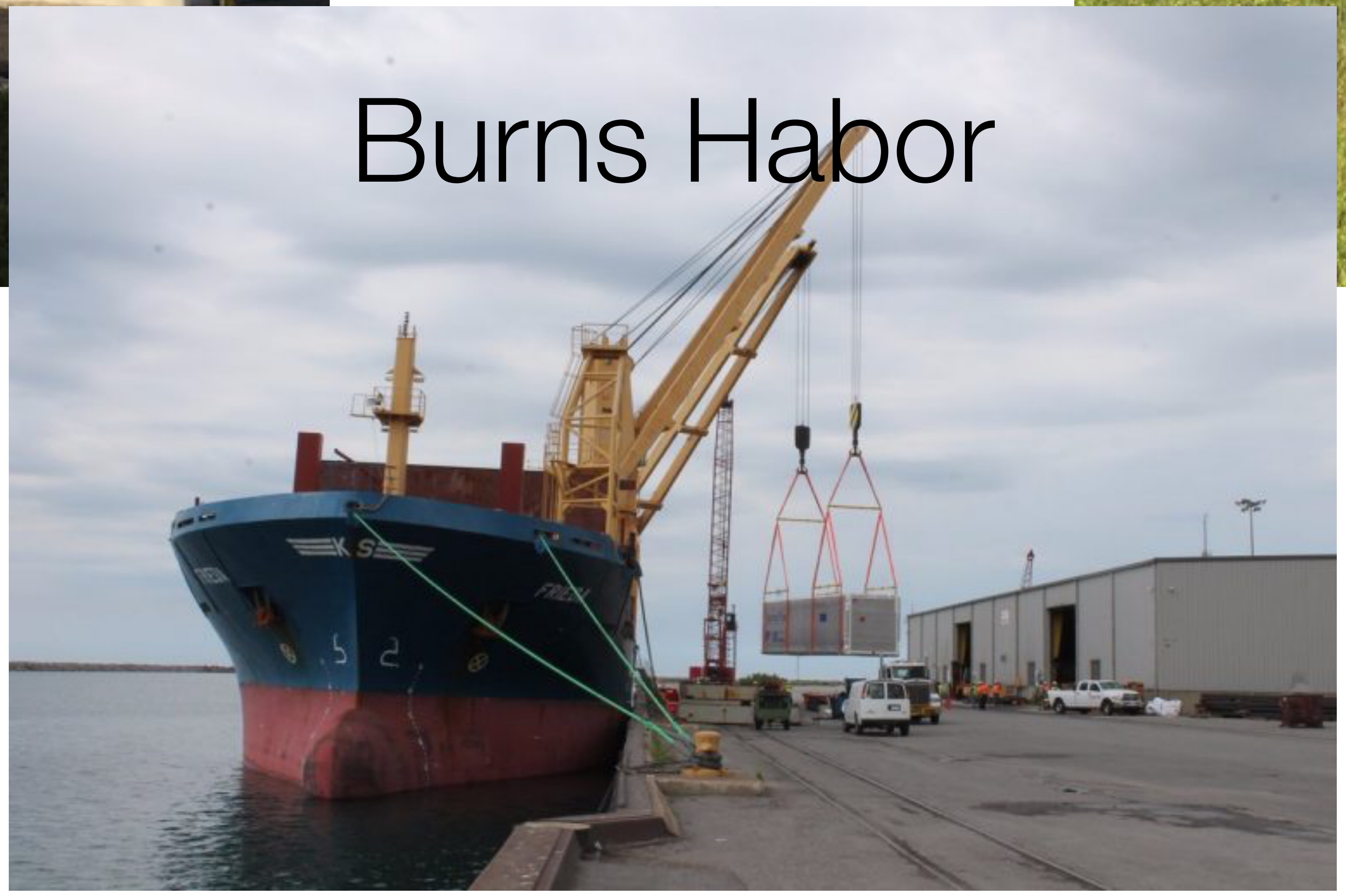
Short baseline programme at Fermilab

- To resolve experimental inconsistencies in the measured ν-spectrum
  - SBND (near detector)
  - MicroBooNE (operating)
  - MiniBooNE
  - refurbished ICARUS arrived at Fermilab



ICARUS Trip

CERN



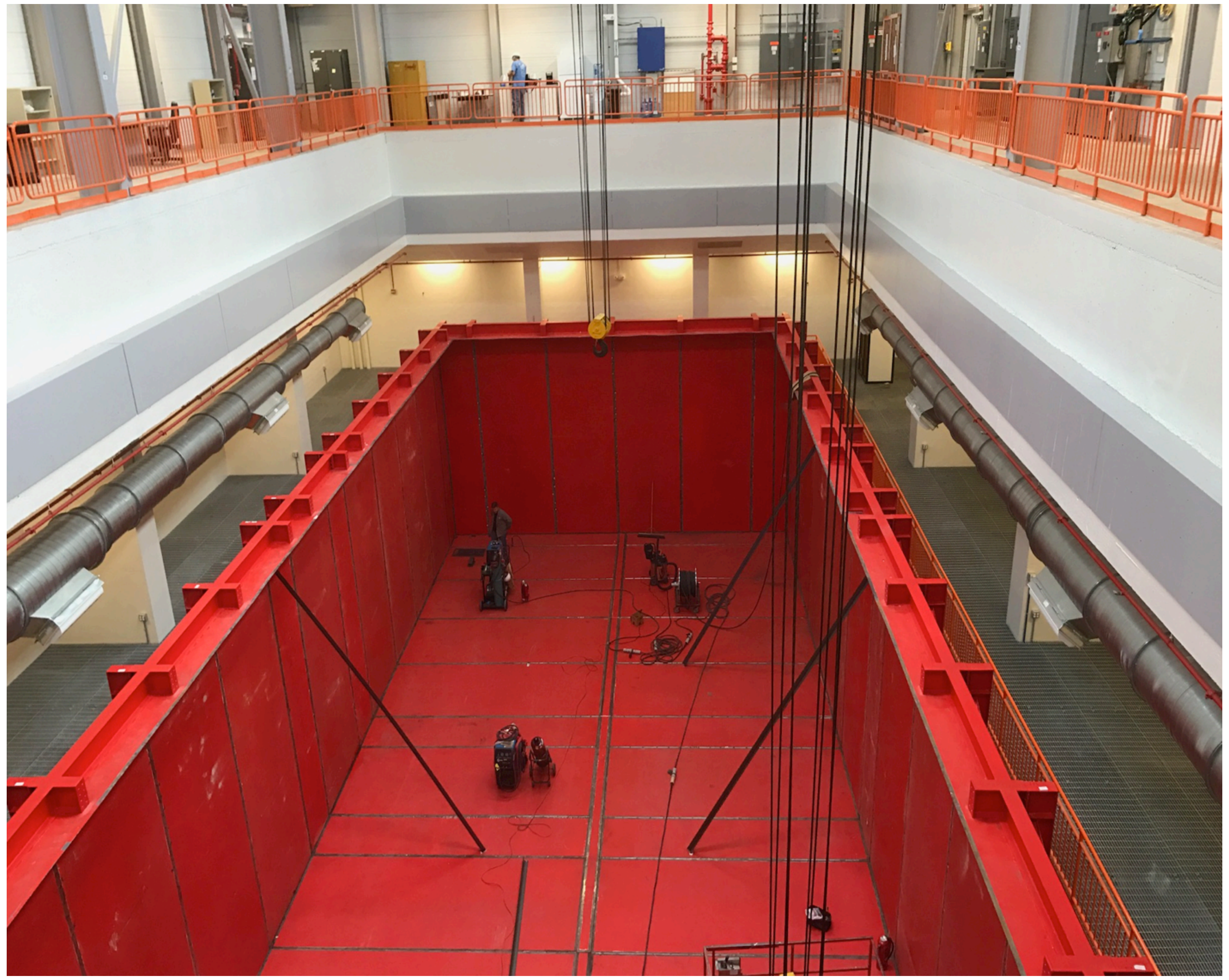
Burns Habor

Fermilab

ICARUS arrival at Fermilab

- Novel cryostat technology for ICARUS
  - based on GTT technology well established for vessels carrying liquid gases
  - much more demanding on stability

Route Planning	Route Schedule
Dep. CERN	12 June 2017
↓ truck	
Arr. Basel (CH)	14 June 2017
Dep. Basel (CH)	15 or 16 June 2017
↓ barge	
Arr. Antwerp (NL)	21 June 2017
Dep. Antwerp (NL)	earliest/latest on 23/30 June 2017
↓ ship	
Arr. Burns Arbor (USA, IN)	appr. 23-24 days after departure from Antwerp
↓ truck	
FERMILAB	appr. 2 days after dep. from Burns Arbor



J-PARC at Neutrino Platform

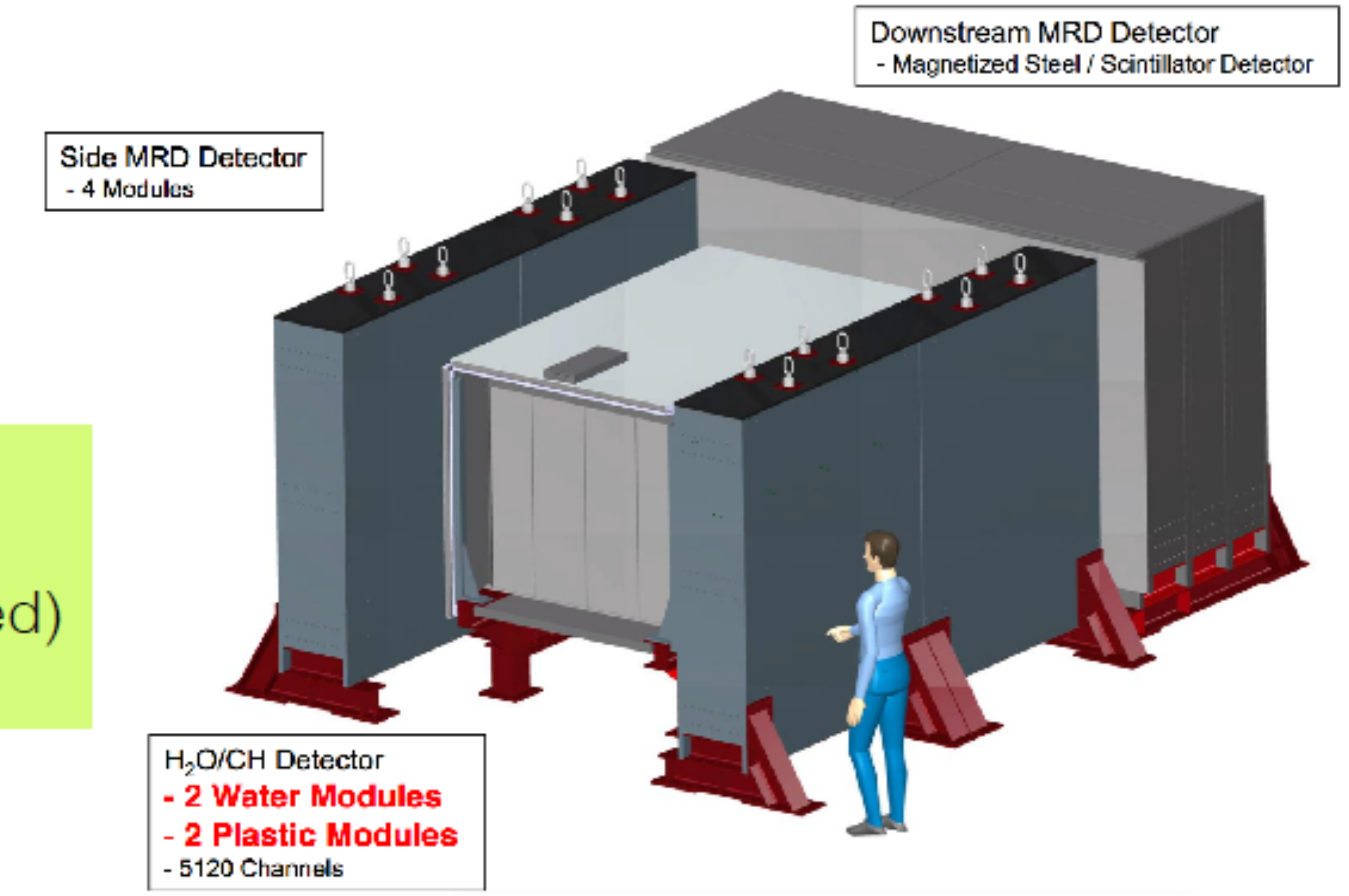
- 3% precision H_2O/C_nH_n cross-section ratio
- Study of ν_μ energy reconstruction
- wide angle θ coverage
- complementary to ND280

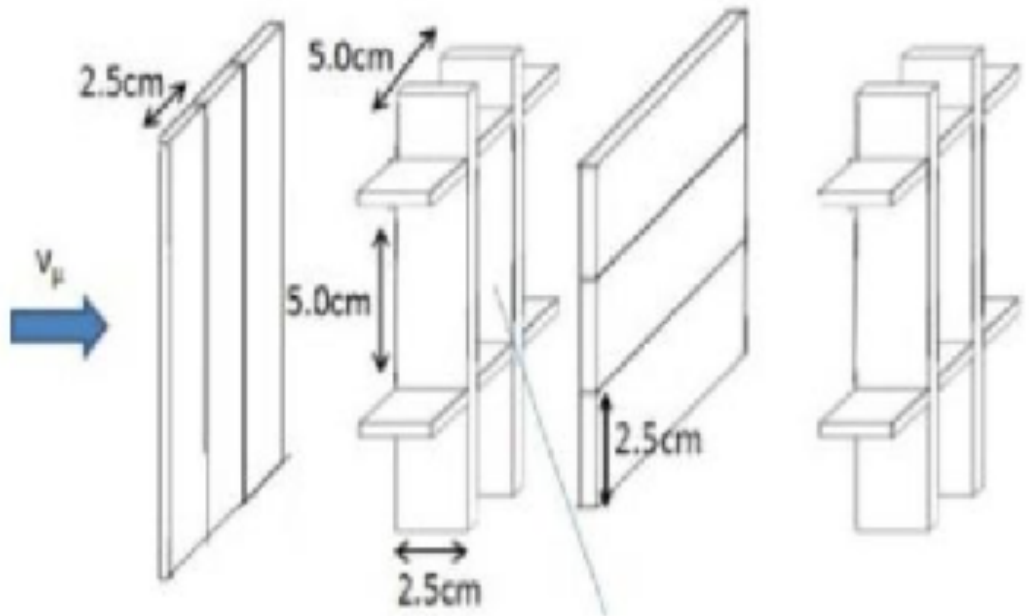
3% precision H_2O / CH x-section ratio

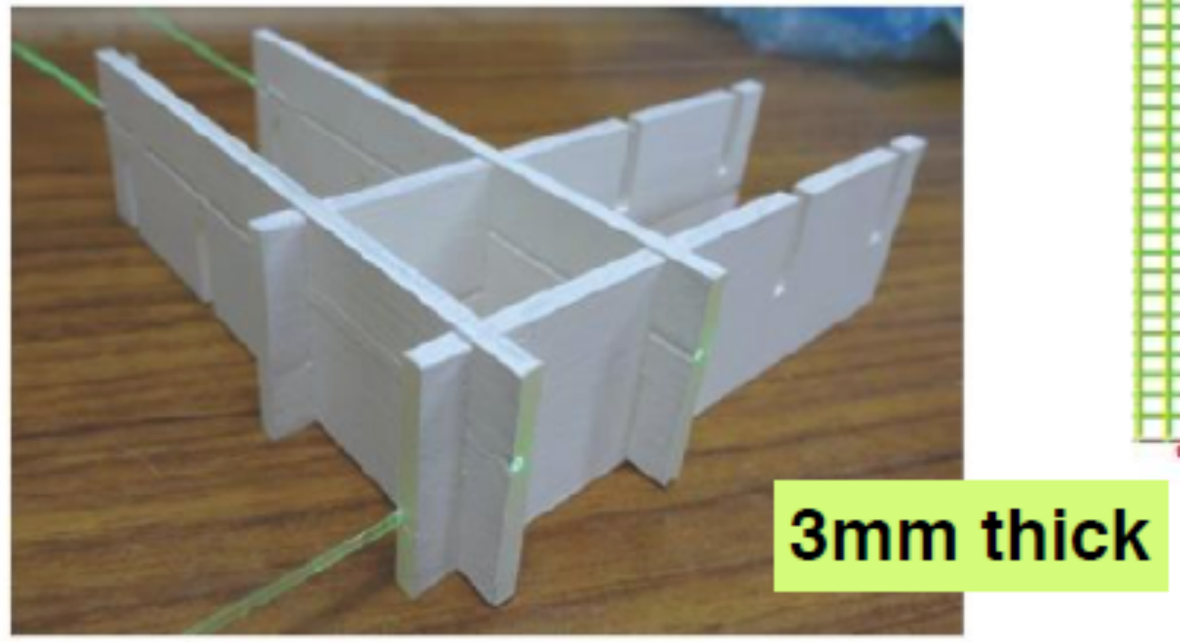
Wagasci

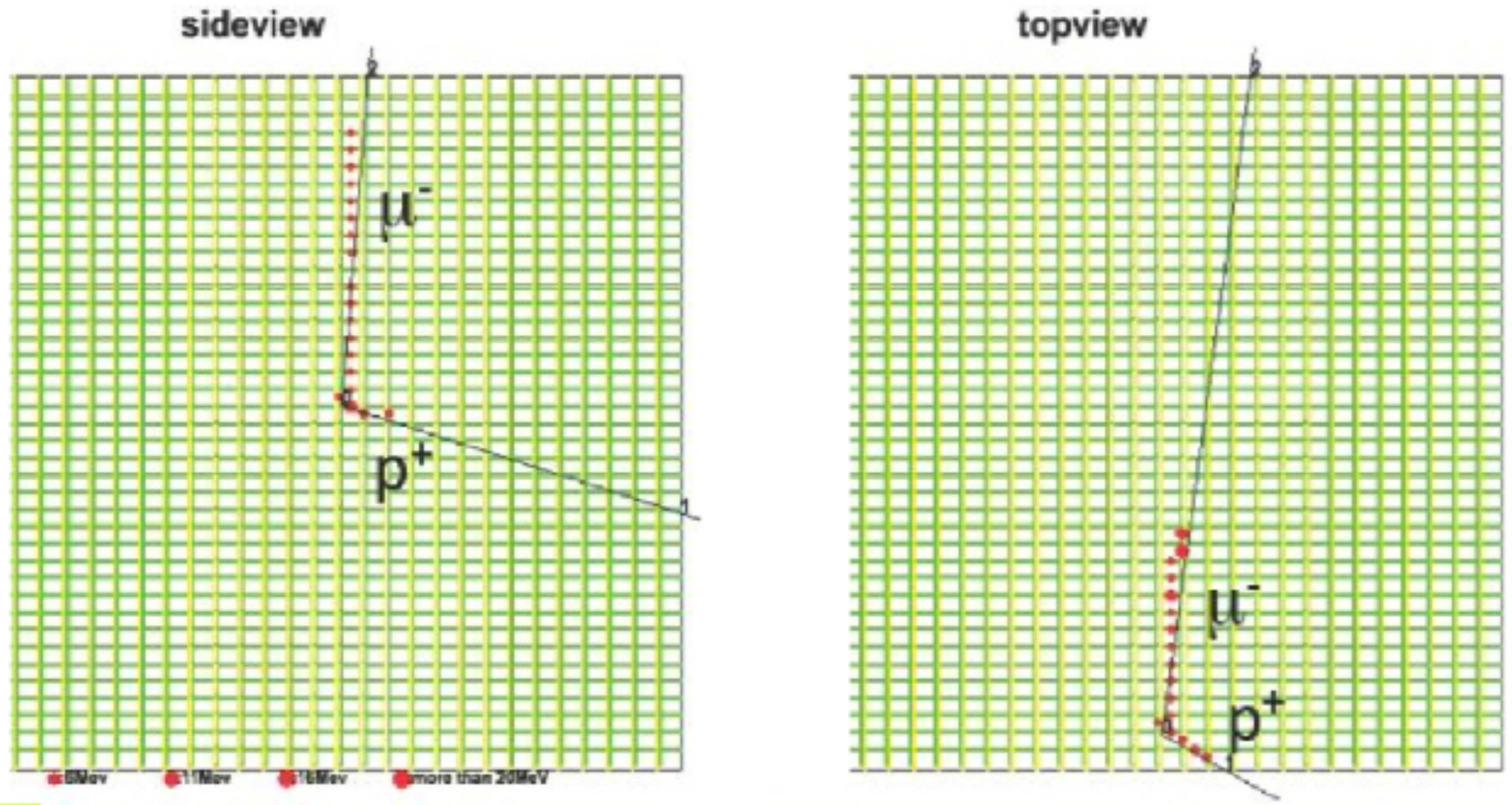
Wagasci collaboration

'The B2 experiment'
- 3D scintillator grid filled with water
- Side MRDs and end MRD (magnetized)
- Excellent phase space coverage



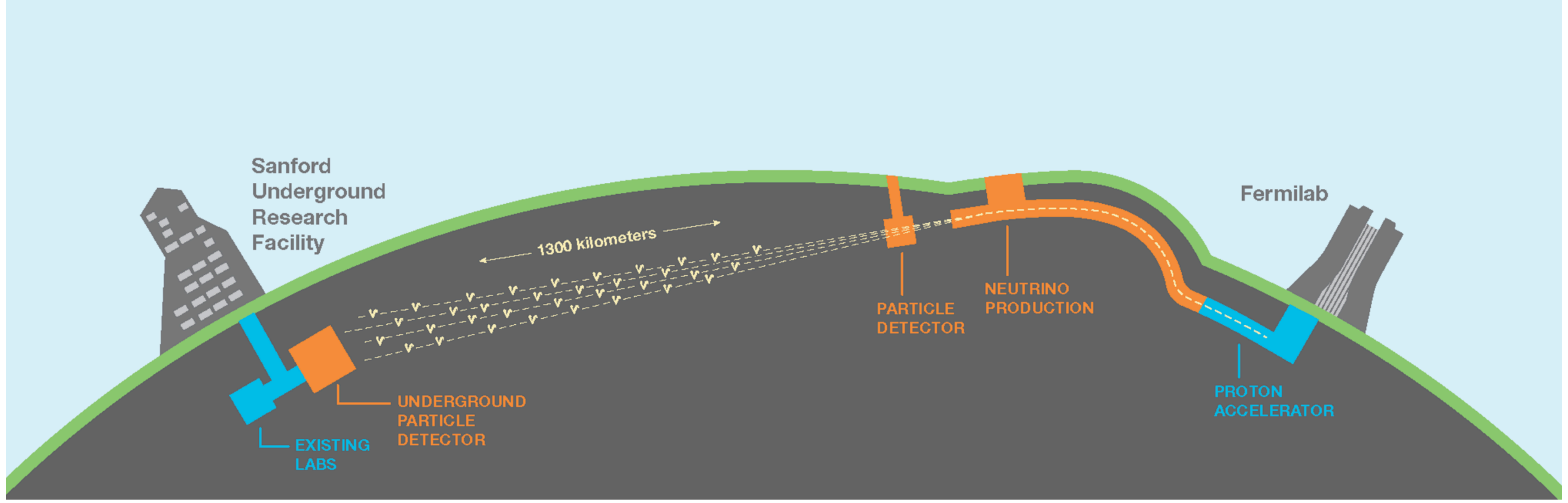


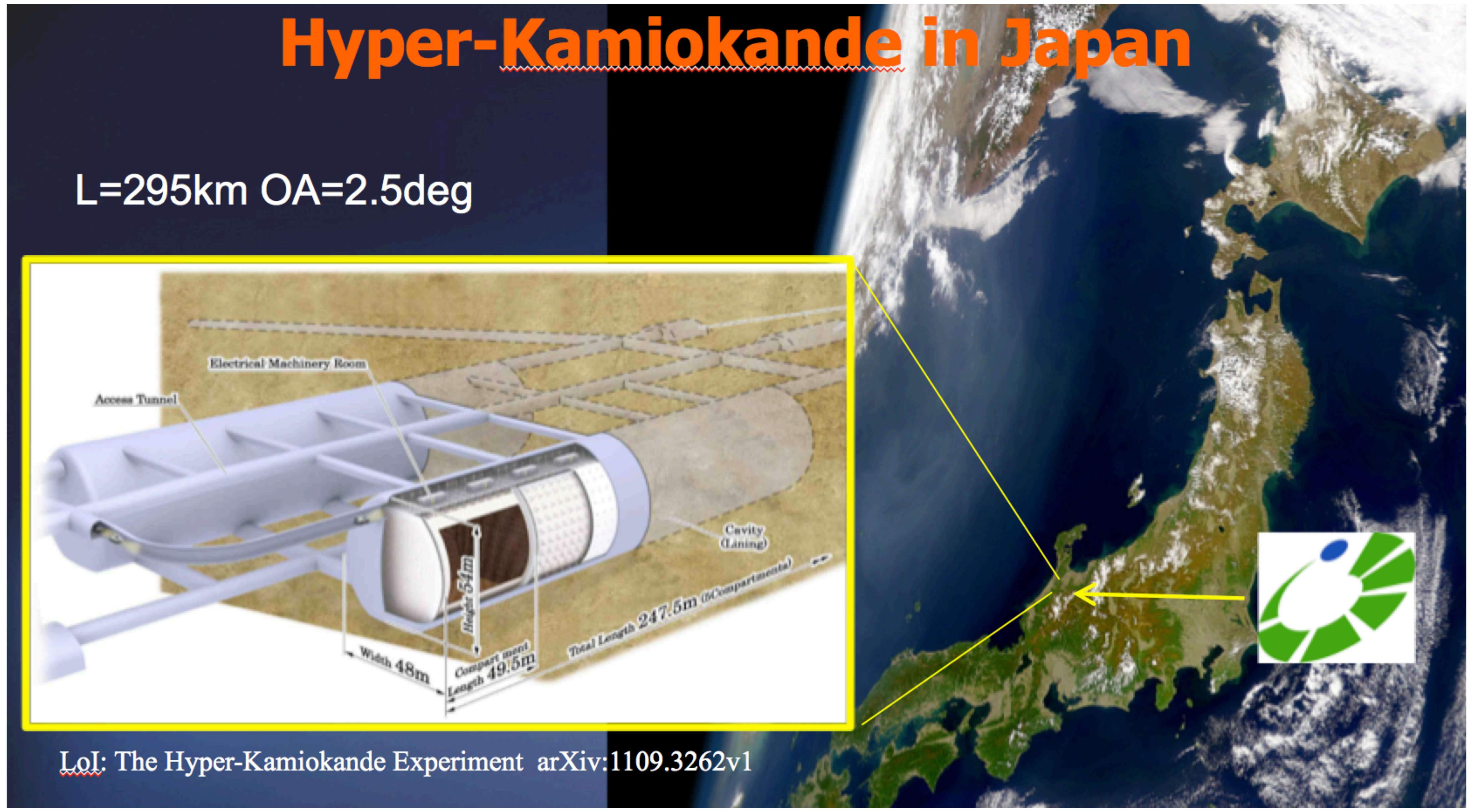




Long baseline neutrino programmes

- Fermilab is constructing a long baseline neutrino facility (LBNF), a wide band neutrino beam to the DUNE experiment (40 kt LArTPC) in South Dakota
- Tokyo is considering Hyper-K (water Cherenkov detector) at Kamioka
- Goals: neutrino-oscillation parameters, mass hierarchy and CP-violation, …

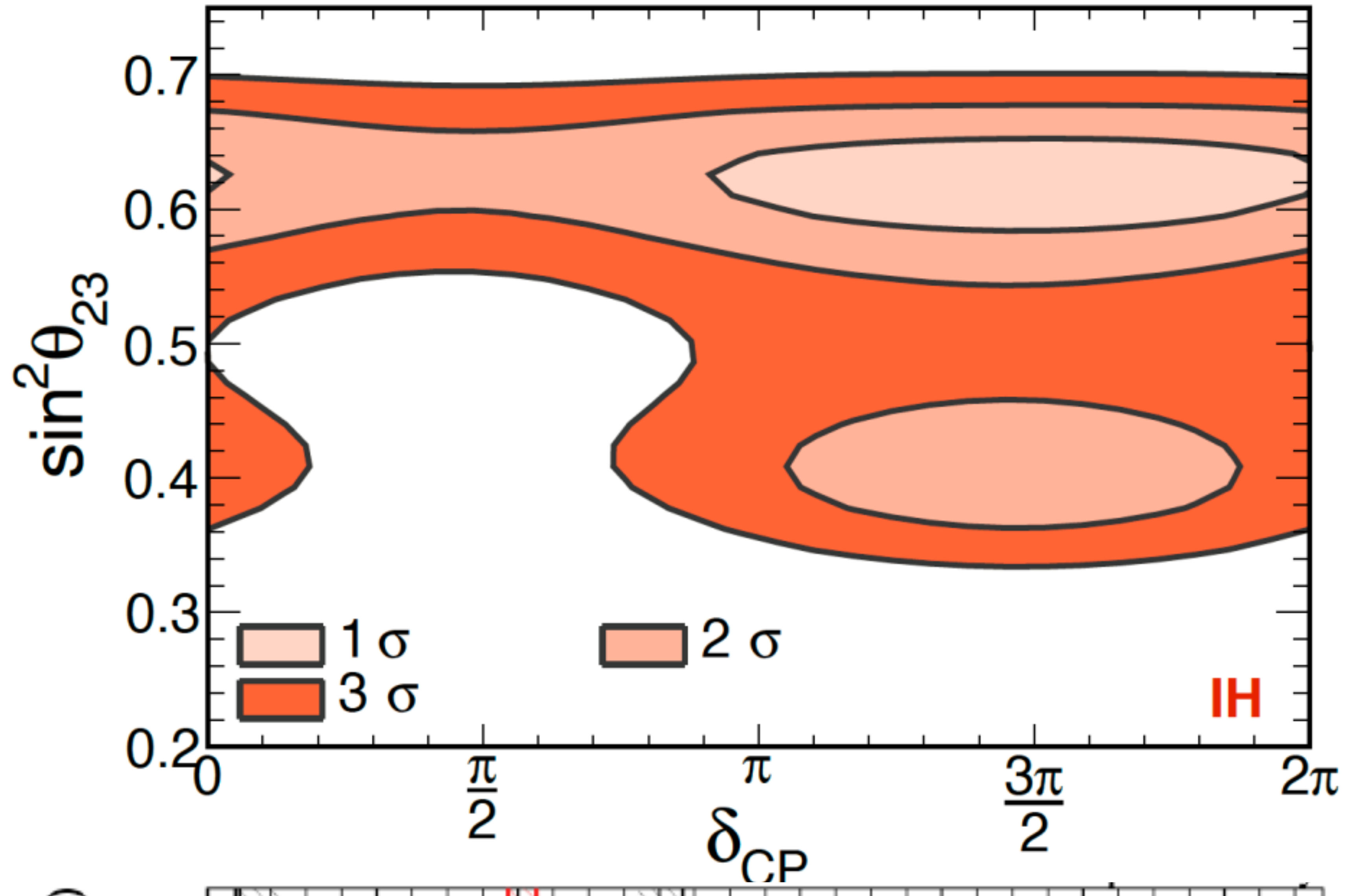




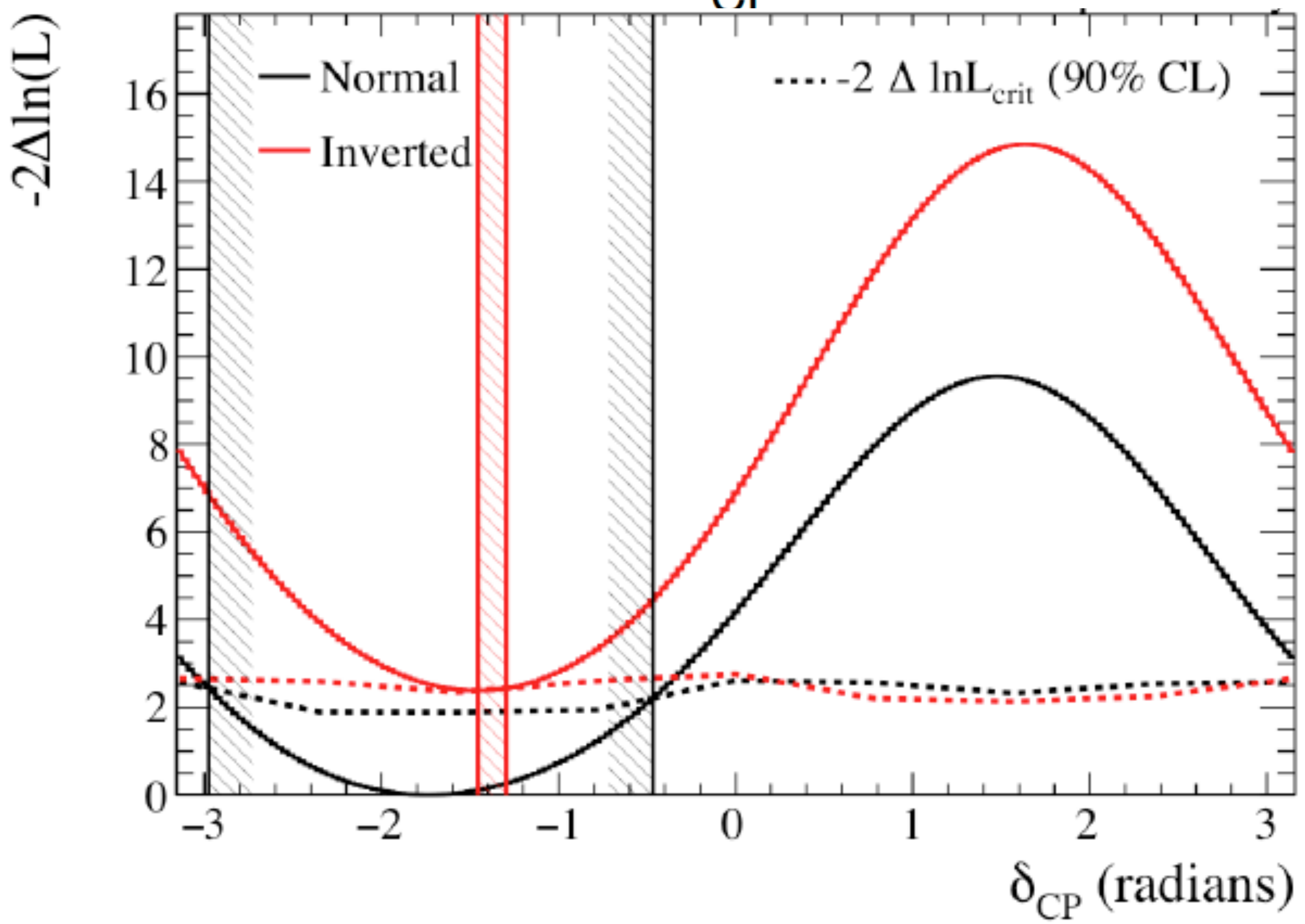
CP violation

- Both Nova and T2K see slight preference for CP violation in neutrino sector
  - angle around 270°
  - good prospects for large mass detectors

Nova

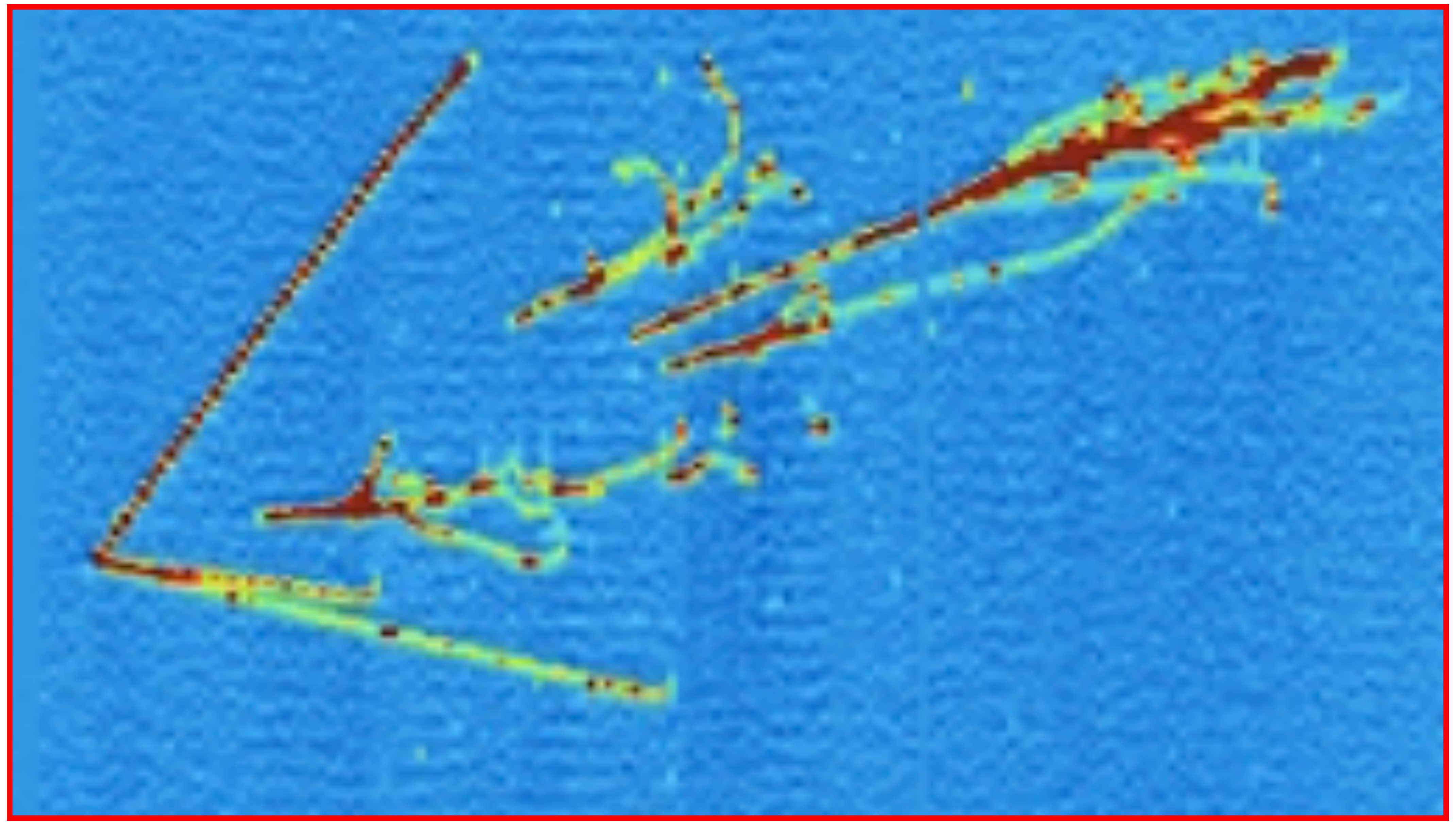


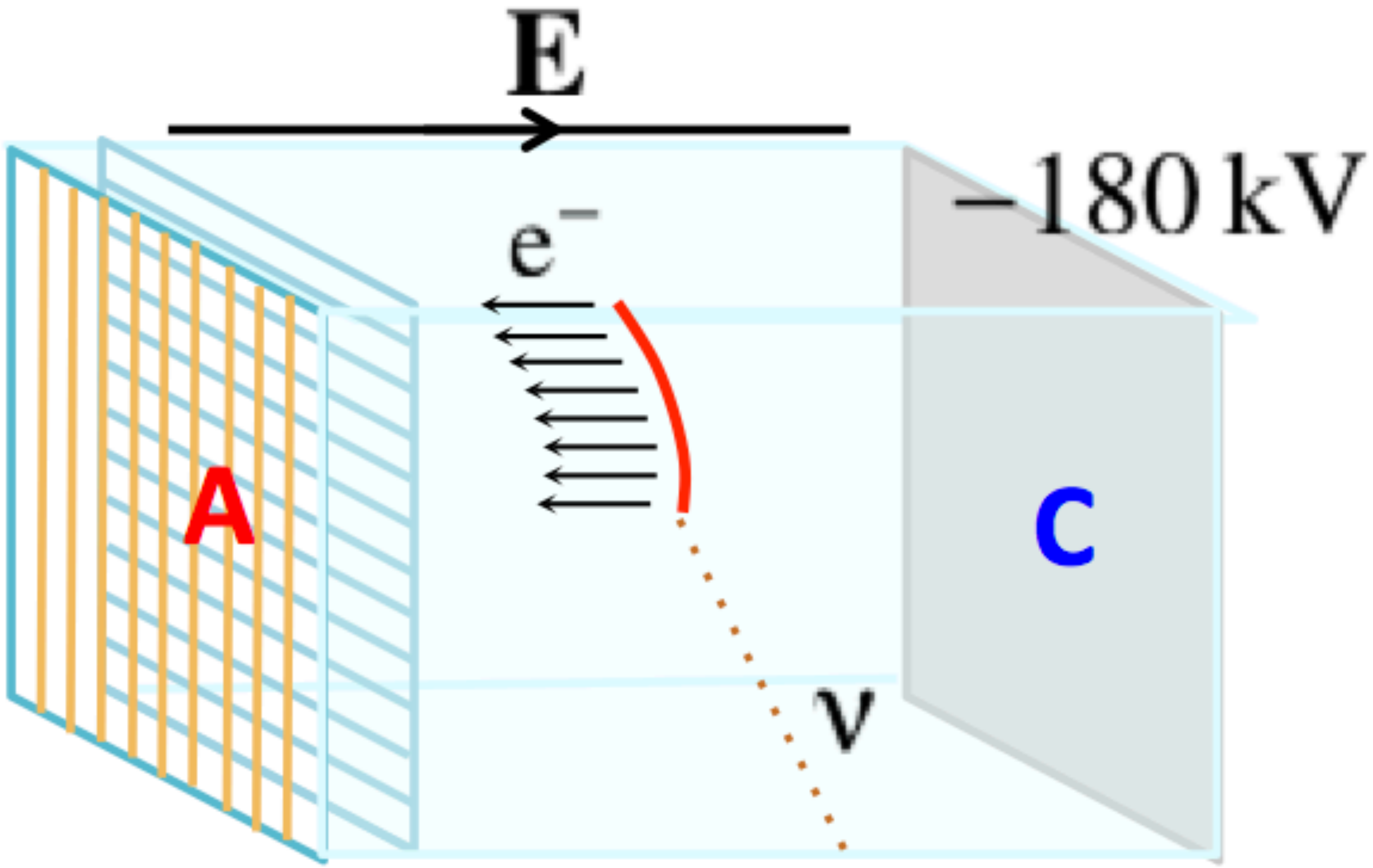
T2K



LAr Technology

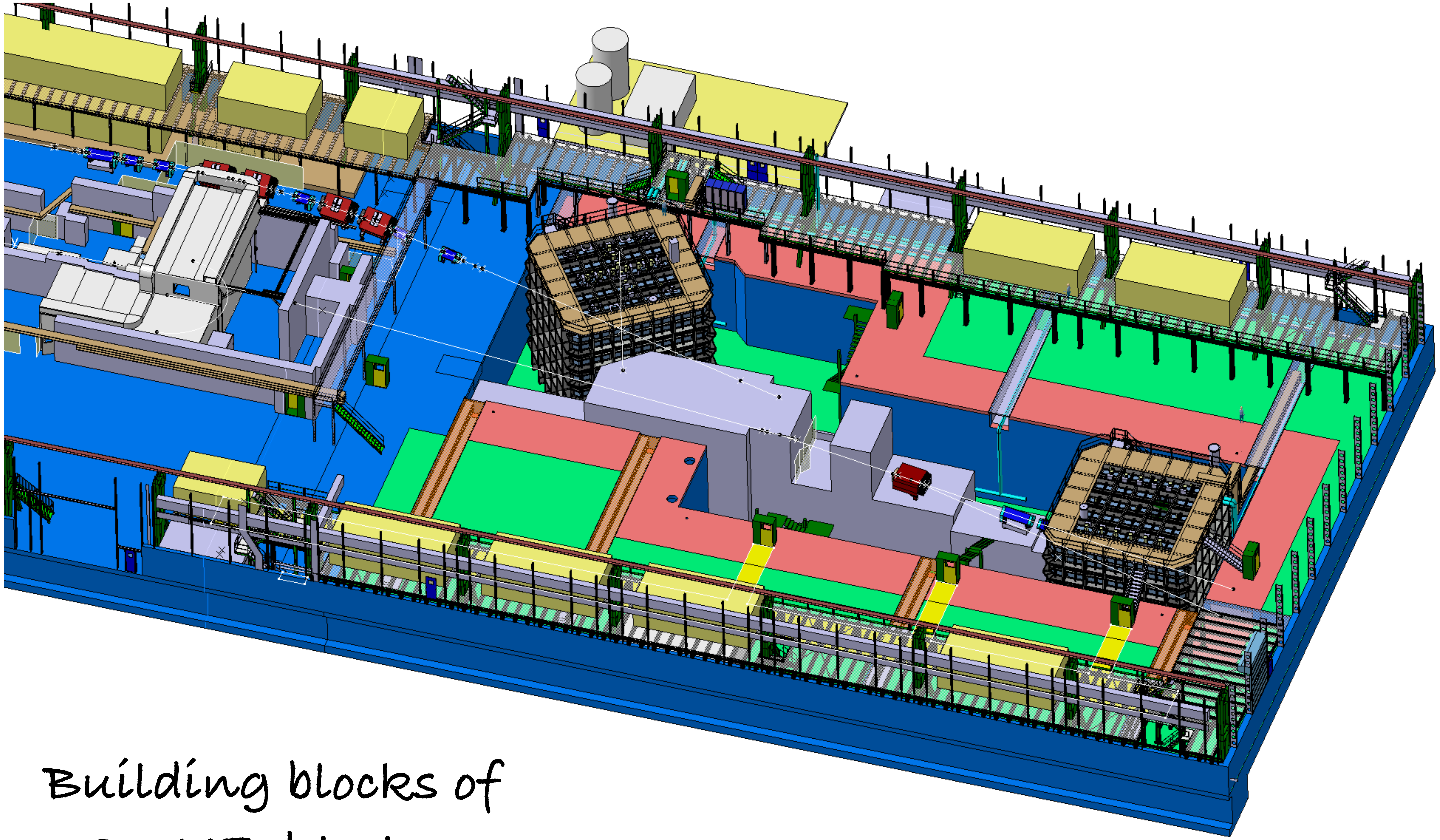
- LarTPC large scale active detectors
  - few mm precision
  - good energy resolution





Neutrino Platform at CERN

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



Building blocks of DUNE detector

Preparing the protoDUNE cryostat structures at CERN

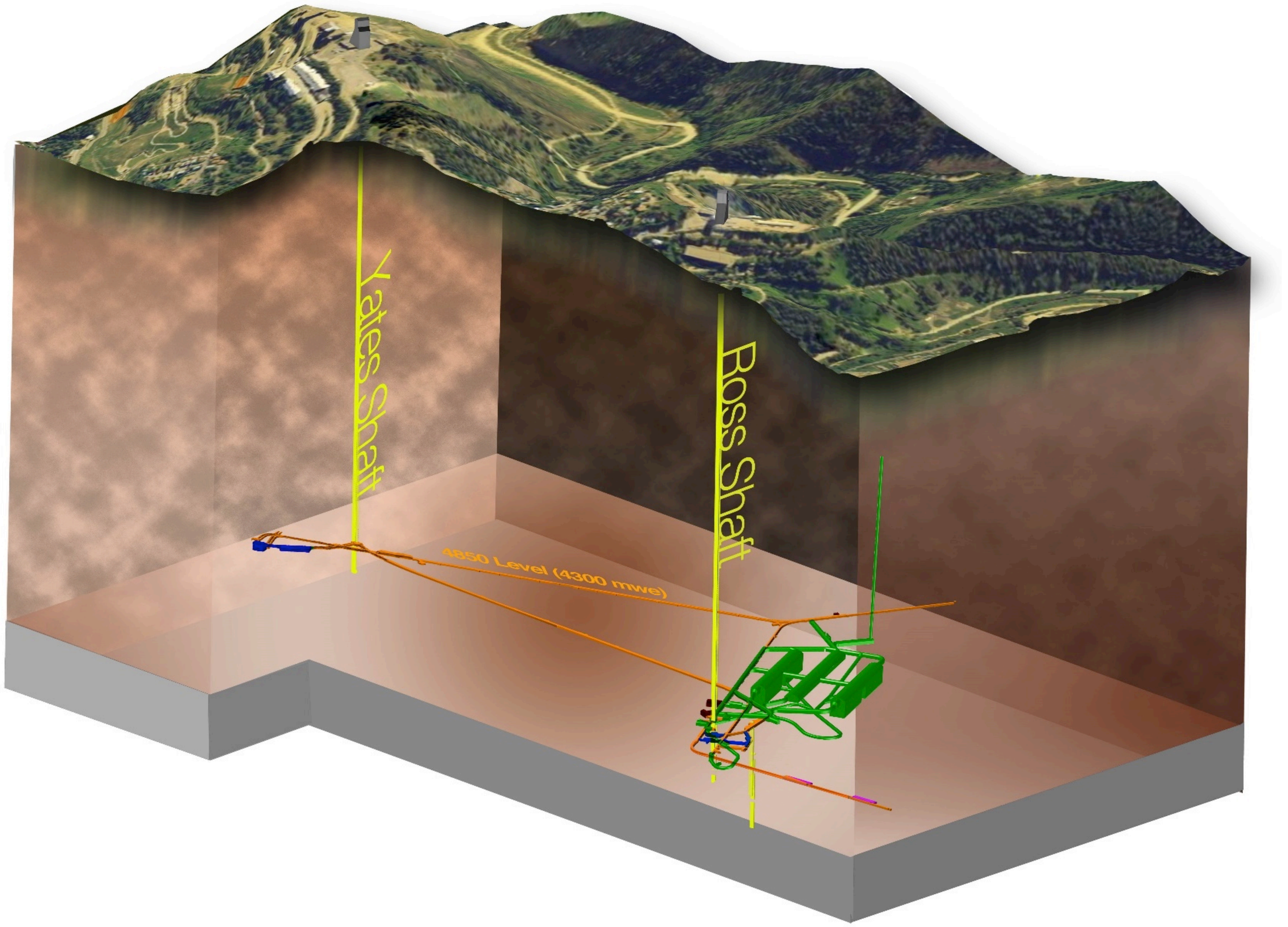
preparing the cryostat inner structures

active volume 6x6x6 m^3

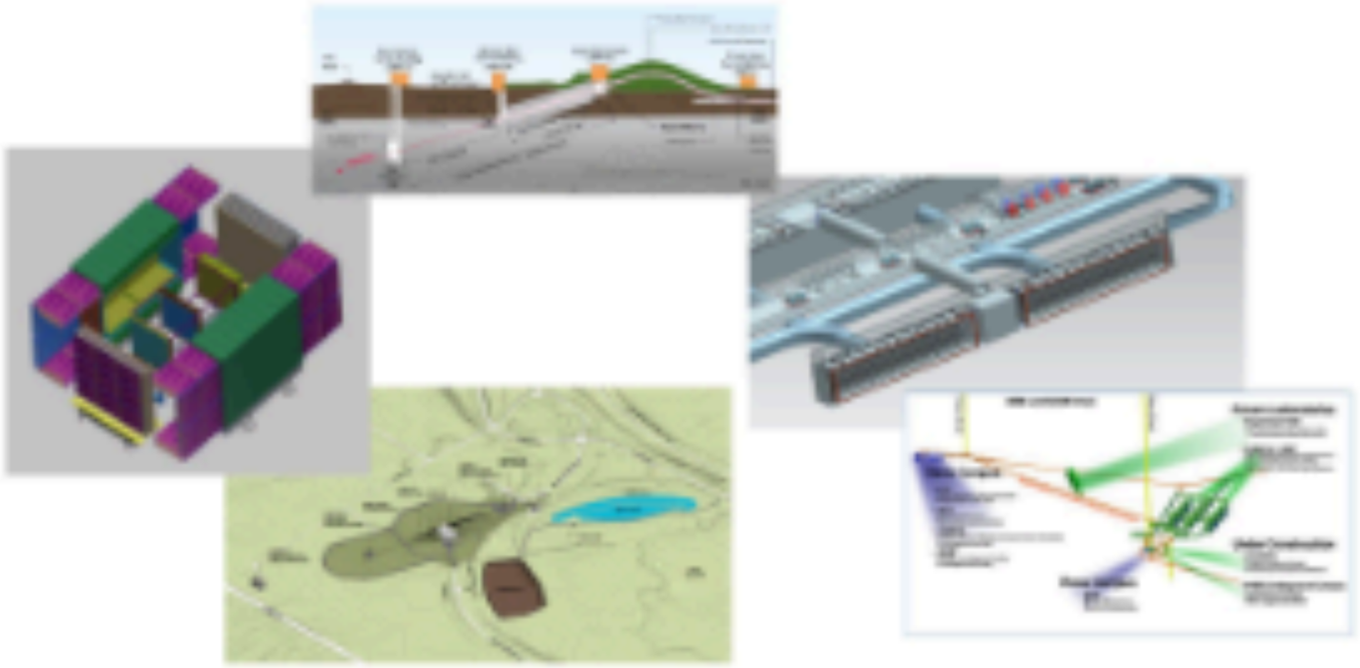
at the neutrino platform

LBNF / DUNE - far detector

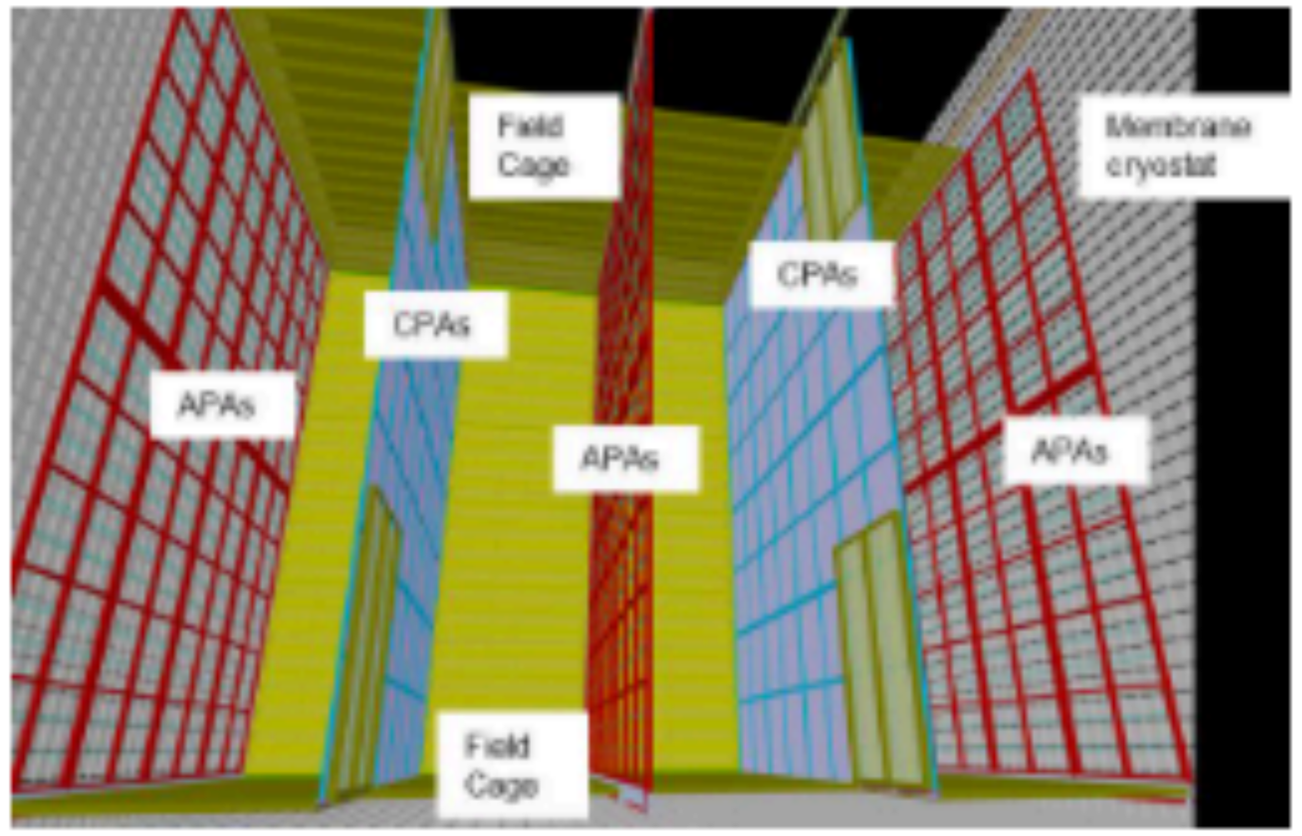
- Sanford Lab Reliability FY16 – 18 (~30M$)
  - Ross shaft rehab; Hoist motor rebuild…
- Pre-Exc Construction FY17 – 18 (~15M$)
  - Rock disposal systems
  - Ross headframe upgrade, more…
- Excavation & Surface Construction FY19 – 22 (~300M$)
- Cryostats/Cryogenic Systems FY20 – 25 (In kind)



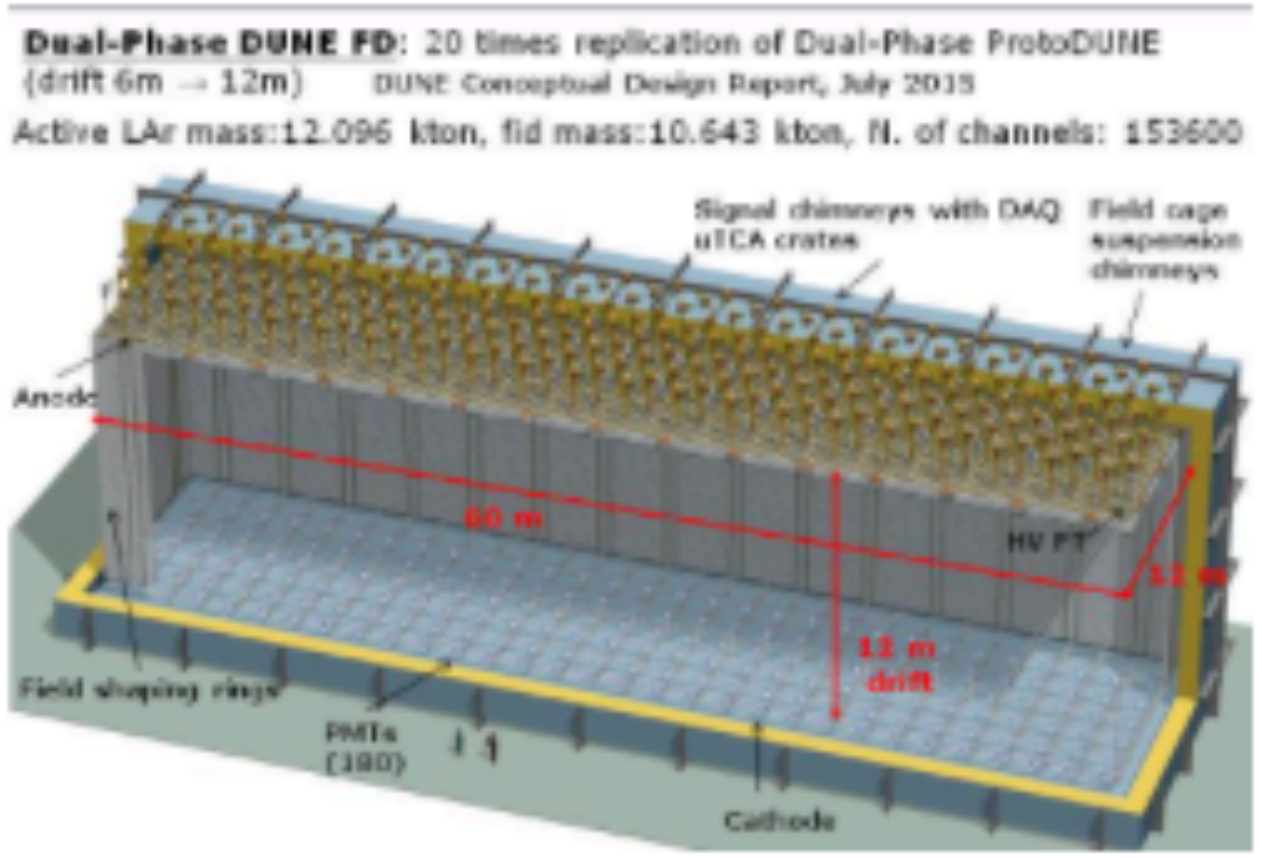
International DUNE Project



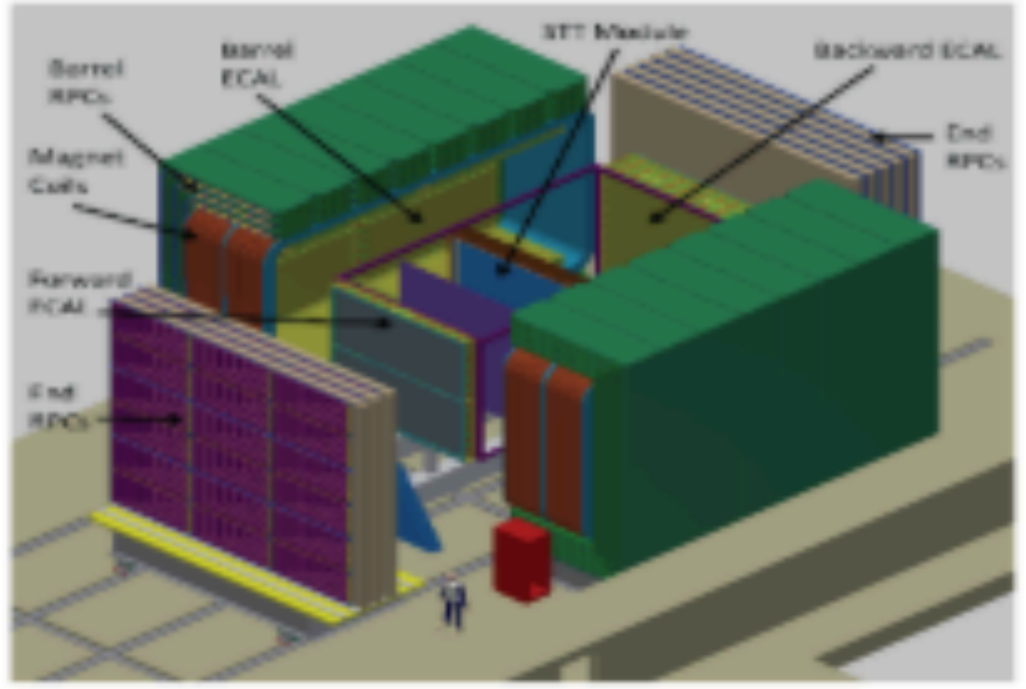
DUNE project Office
Installation and Integration



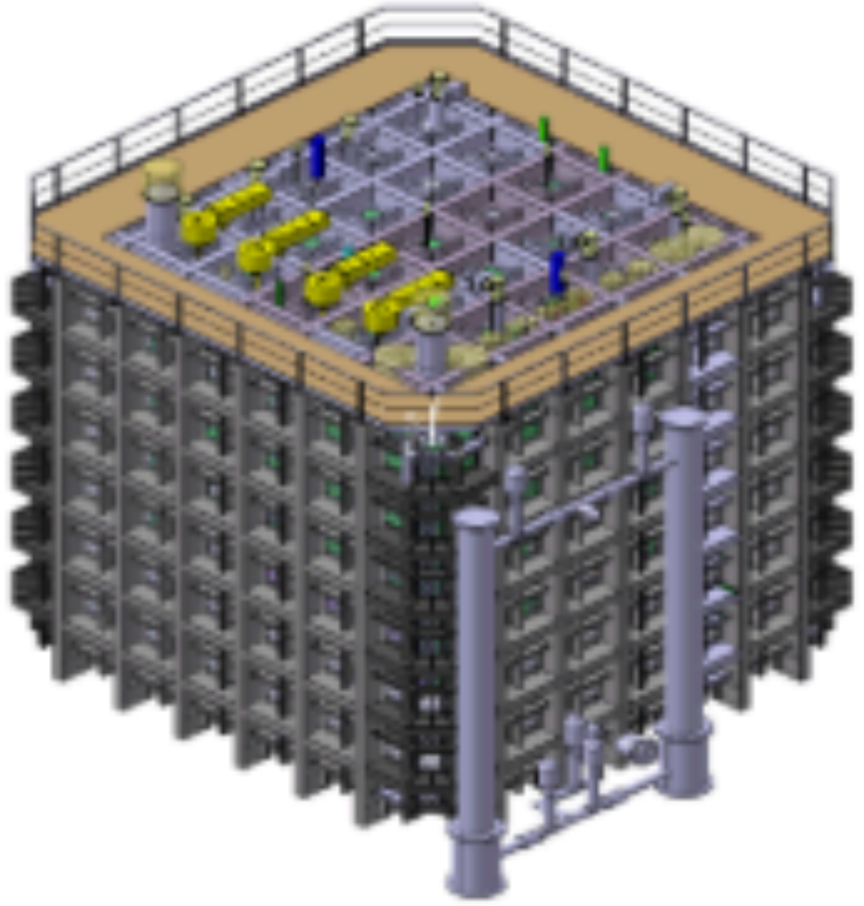
FAR DETECTOR - Single Phase



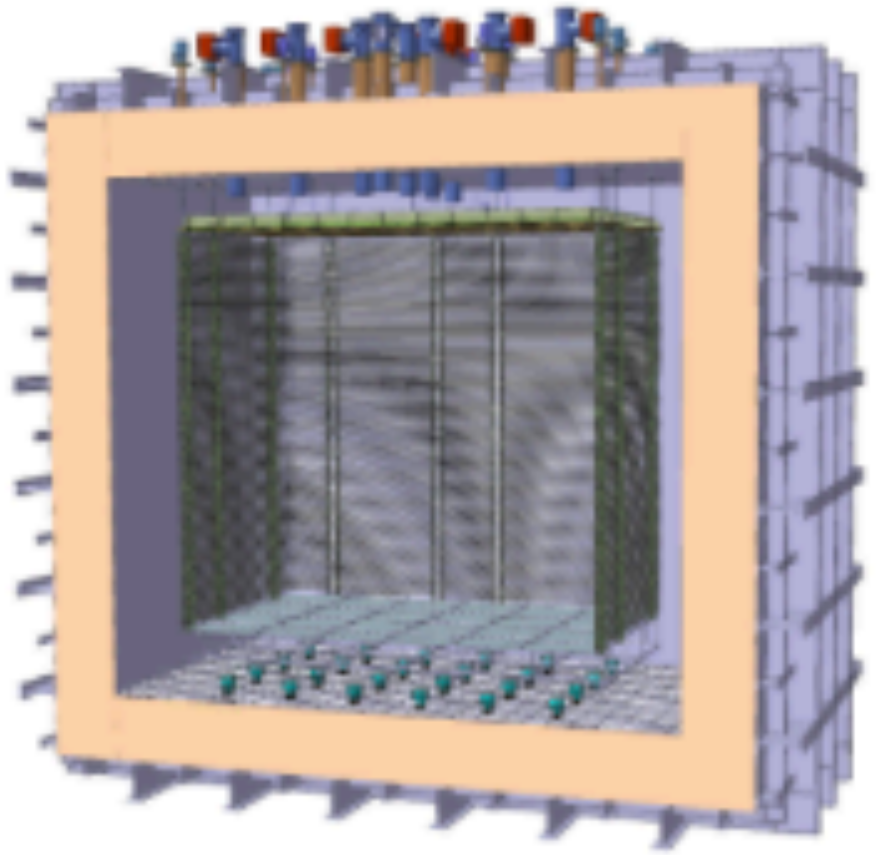
FAR DETECTOR - Dual Phase



NEAR DETECTOR



ProtoDUNE-SP
CERN Twiki, CENF, FNAL Wiki, BNL Wiki



ProtoDUNE-DP

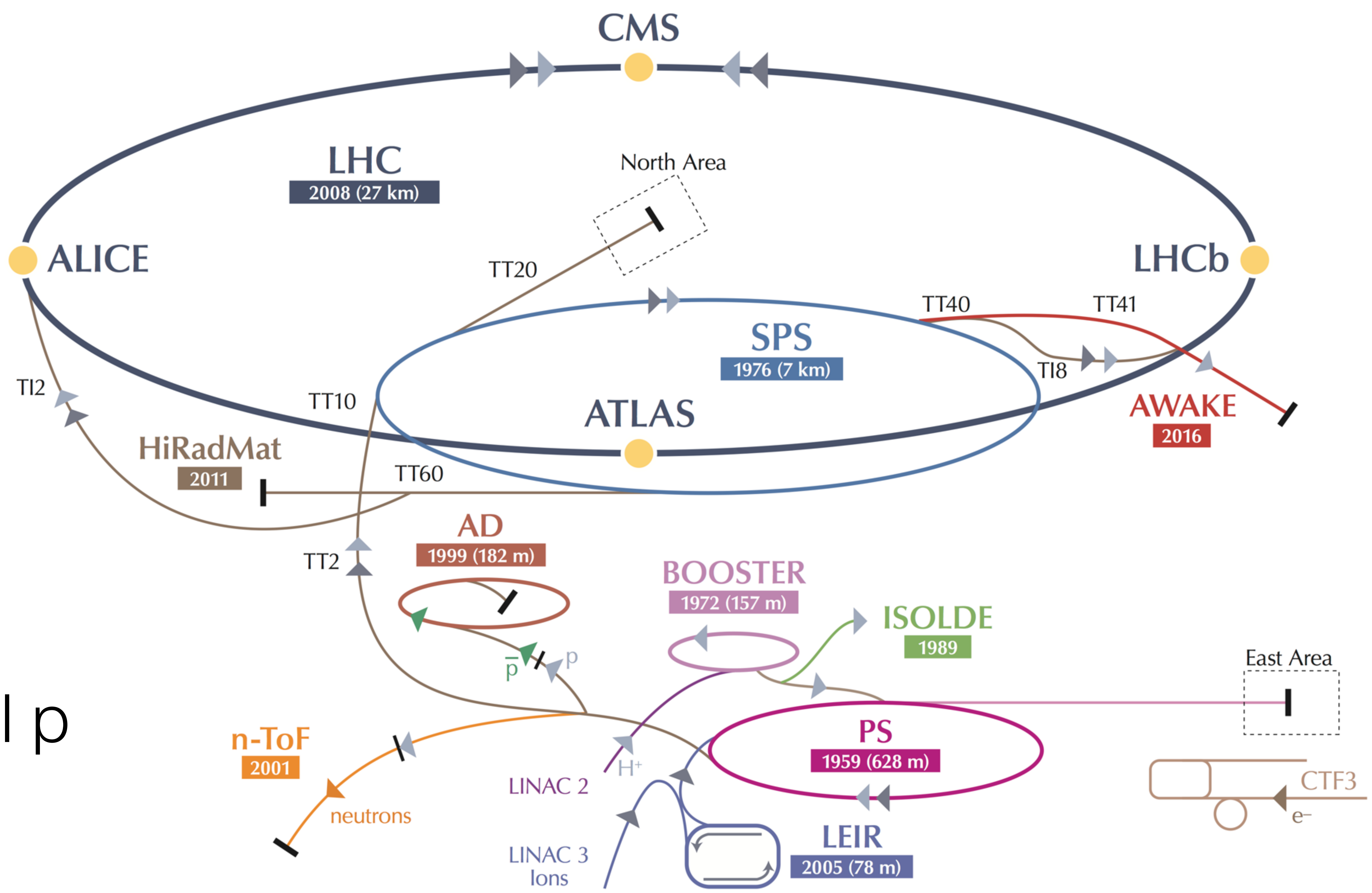
Towards 2020 Update of European Strategy for Particle Physics

– LHC and HL-LHC exploitation (√)
– Prepare for the next step at the energy frontier
– Rich diversity programme…

LHC and its injector chain used for physics

- LHC
  - ongoing Run 2 @ 13 TeV
- Injectors supporting
  - Fixed target programme
  - ISOLDE (isotopes)
  - n-ToF
  - AD-programme

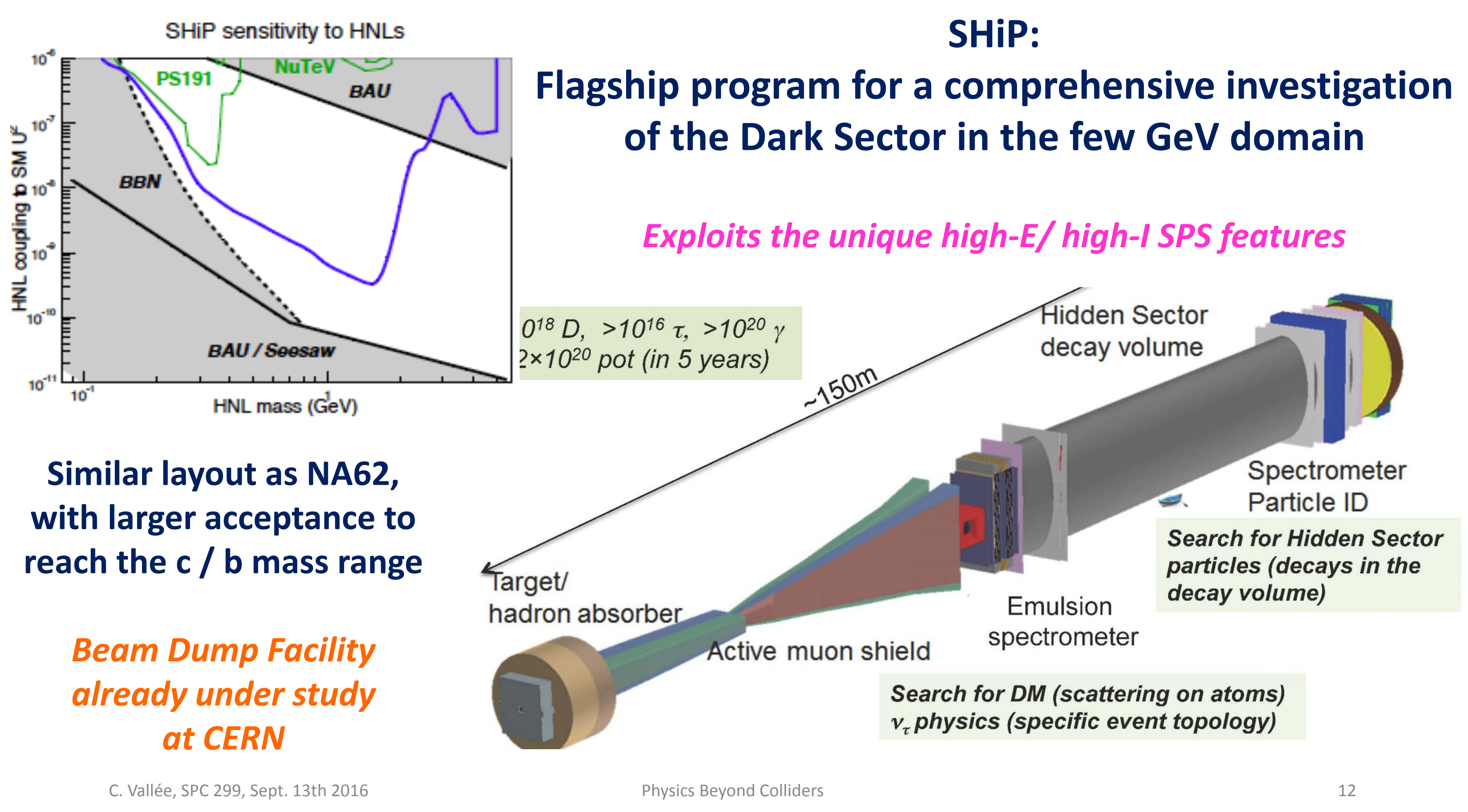
} 75% of all p

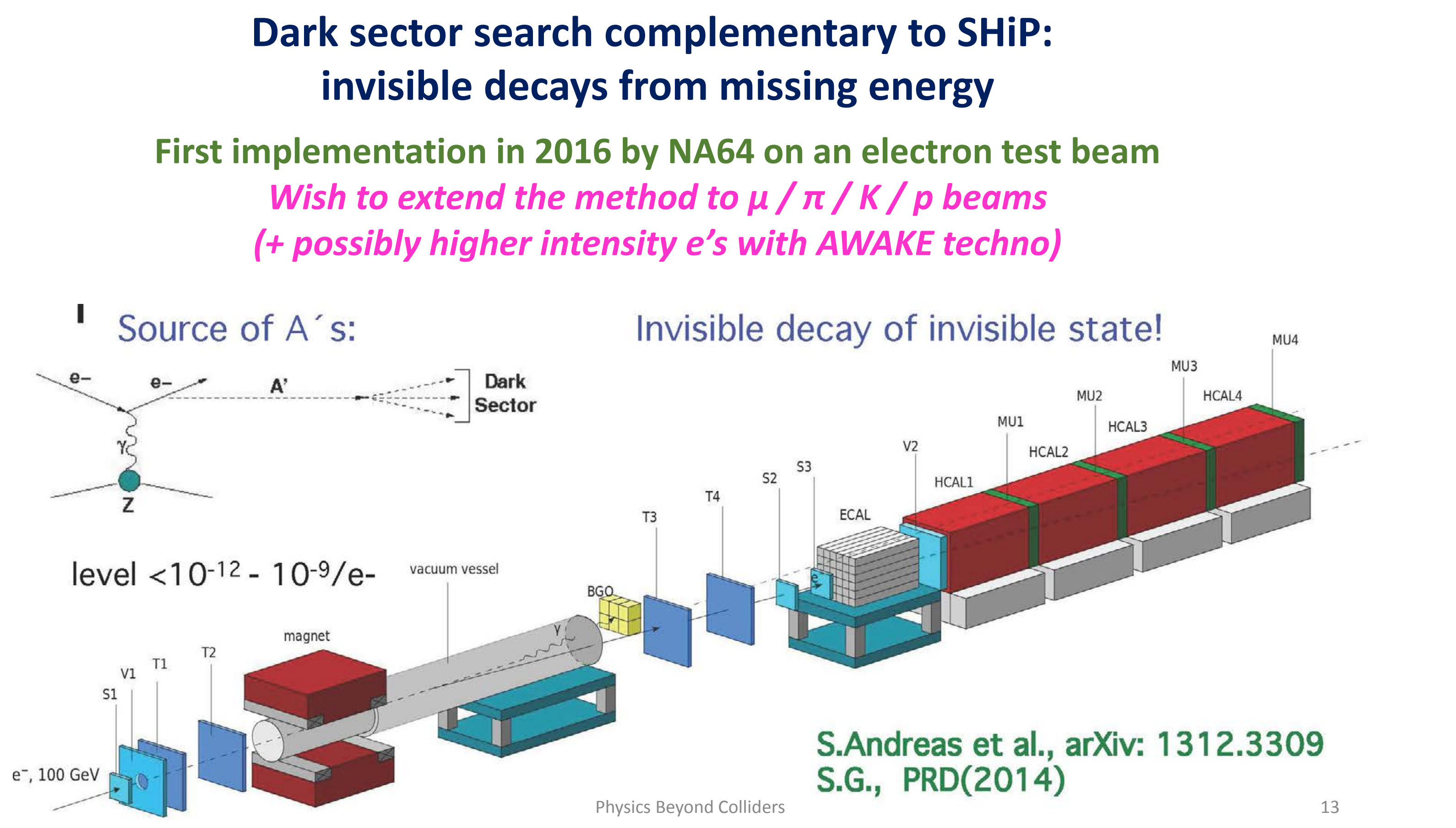


Physics Beyond Collider Study

- Kickoff meeting held in September 2016
  Follow-up in November 2017

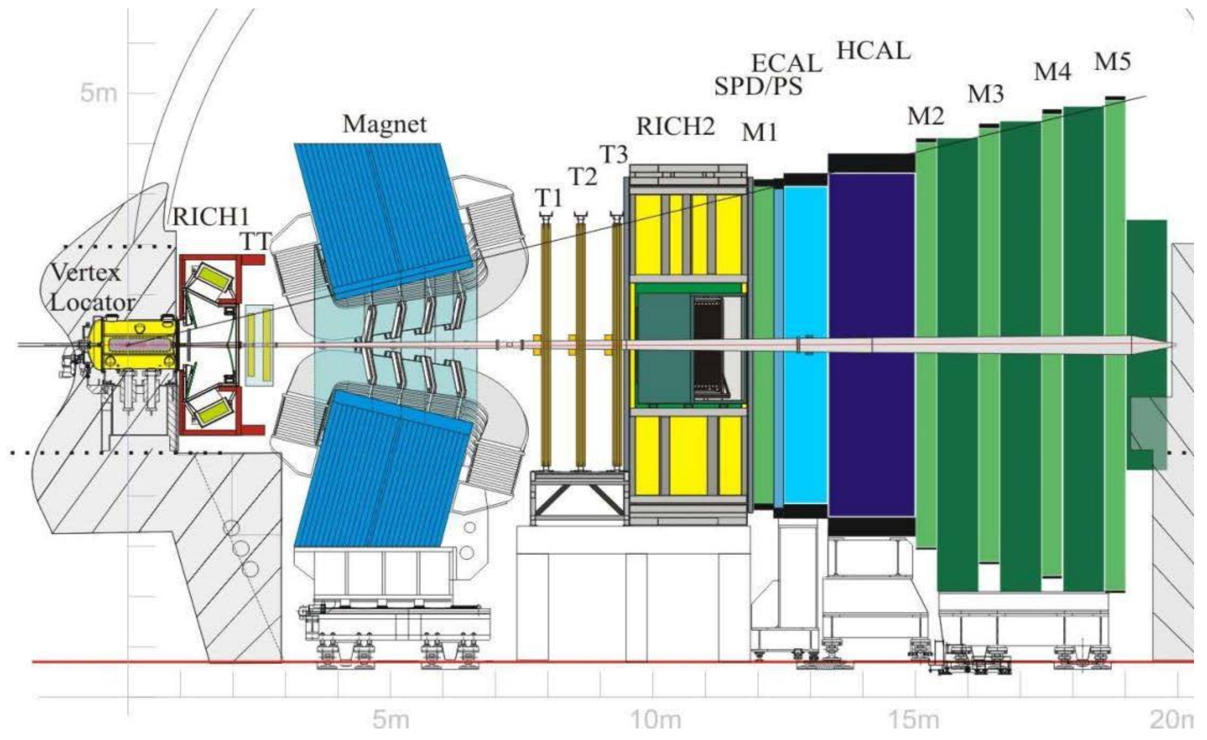
  - Study of fixed target programme



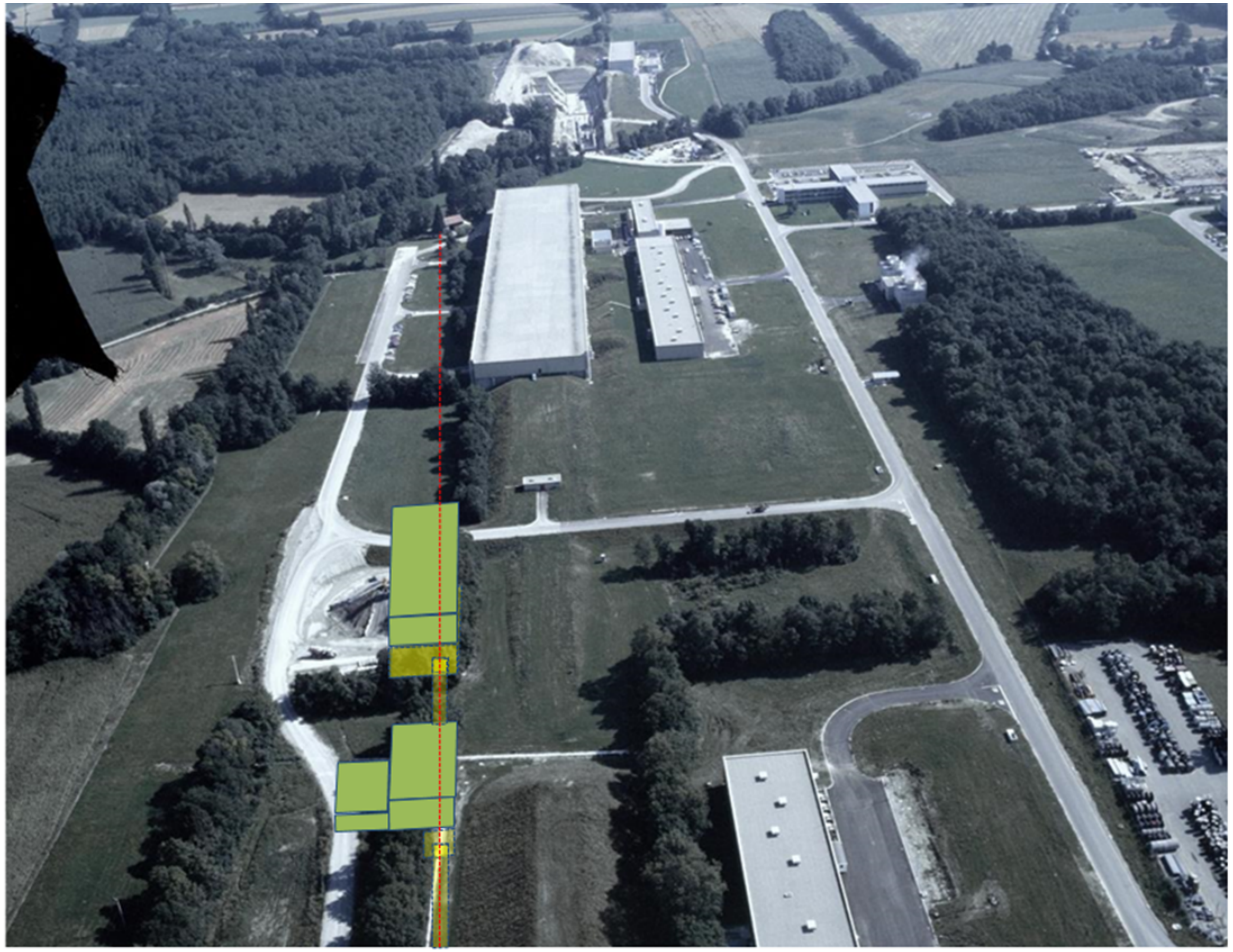


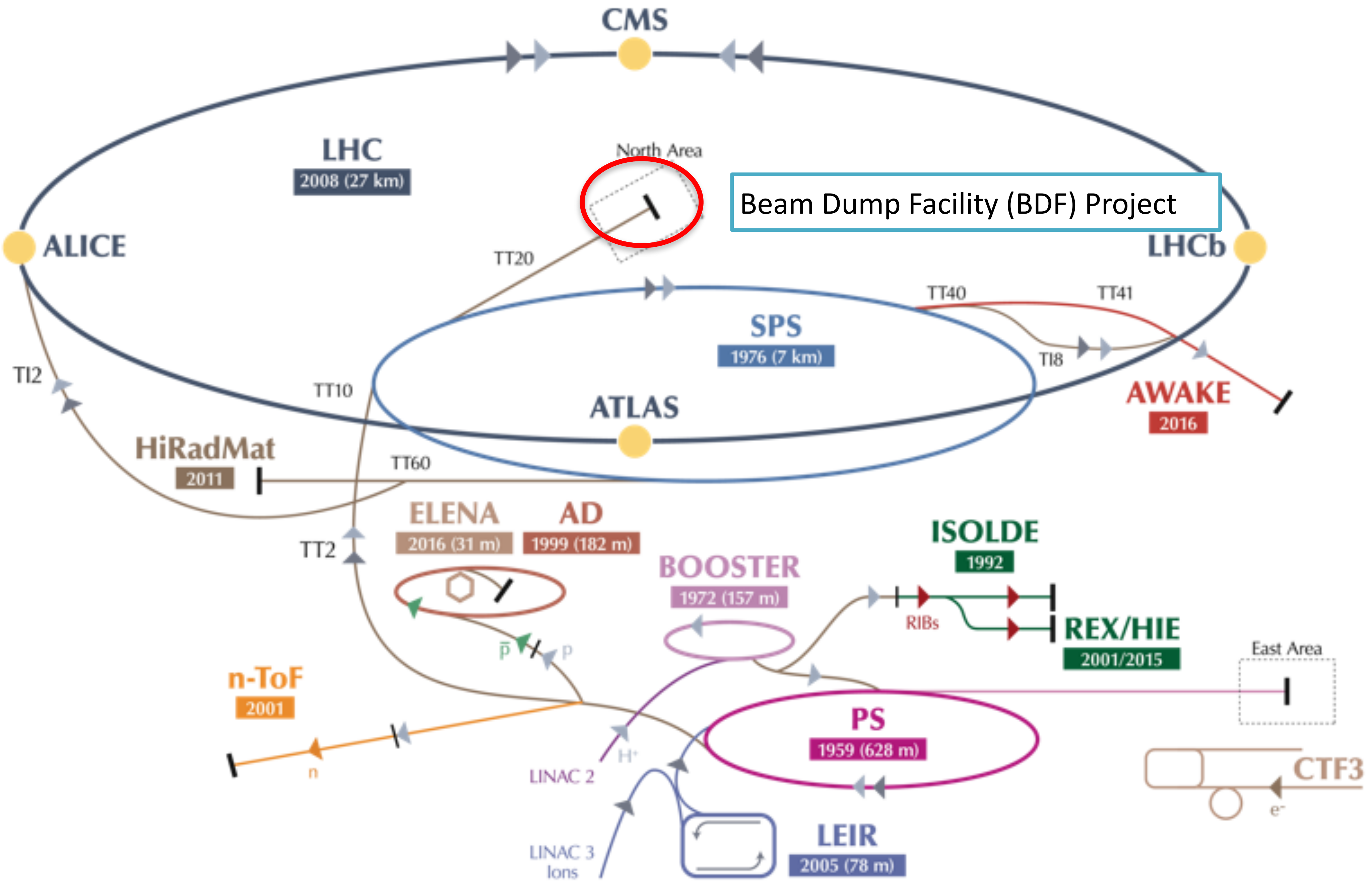
…even with LHC beams

SMOG



PBC Study cont'd: Beam Dump Facility (BDF)

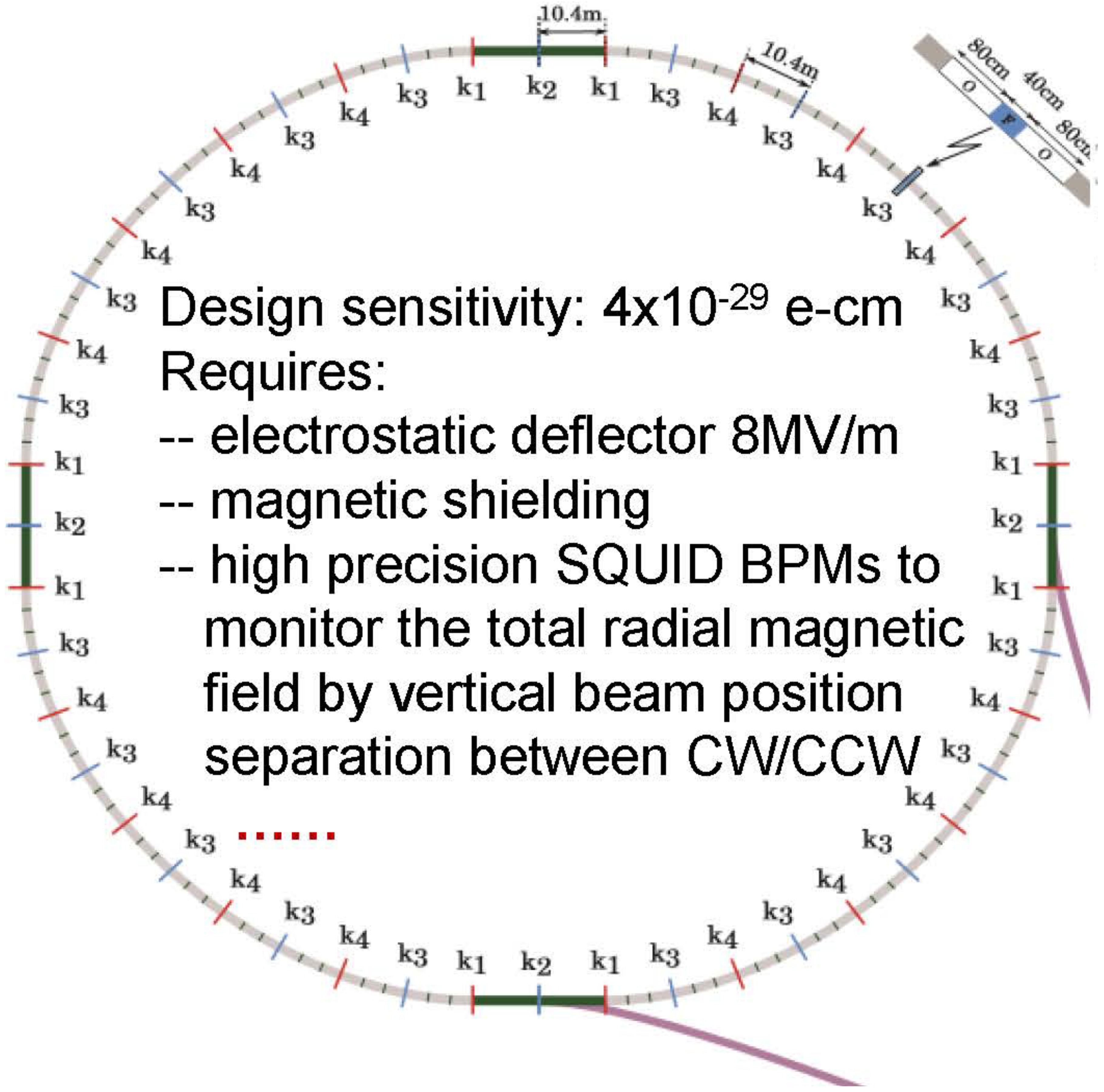




Joint operation of North Area and BDF

PBC Study cont'd: Proton EDM

Study of an all-electrostatic storage ring



Design sensitivity: 4×10^{-29} e-cm

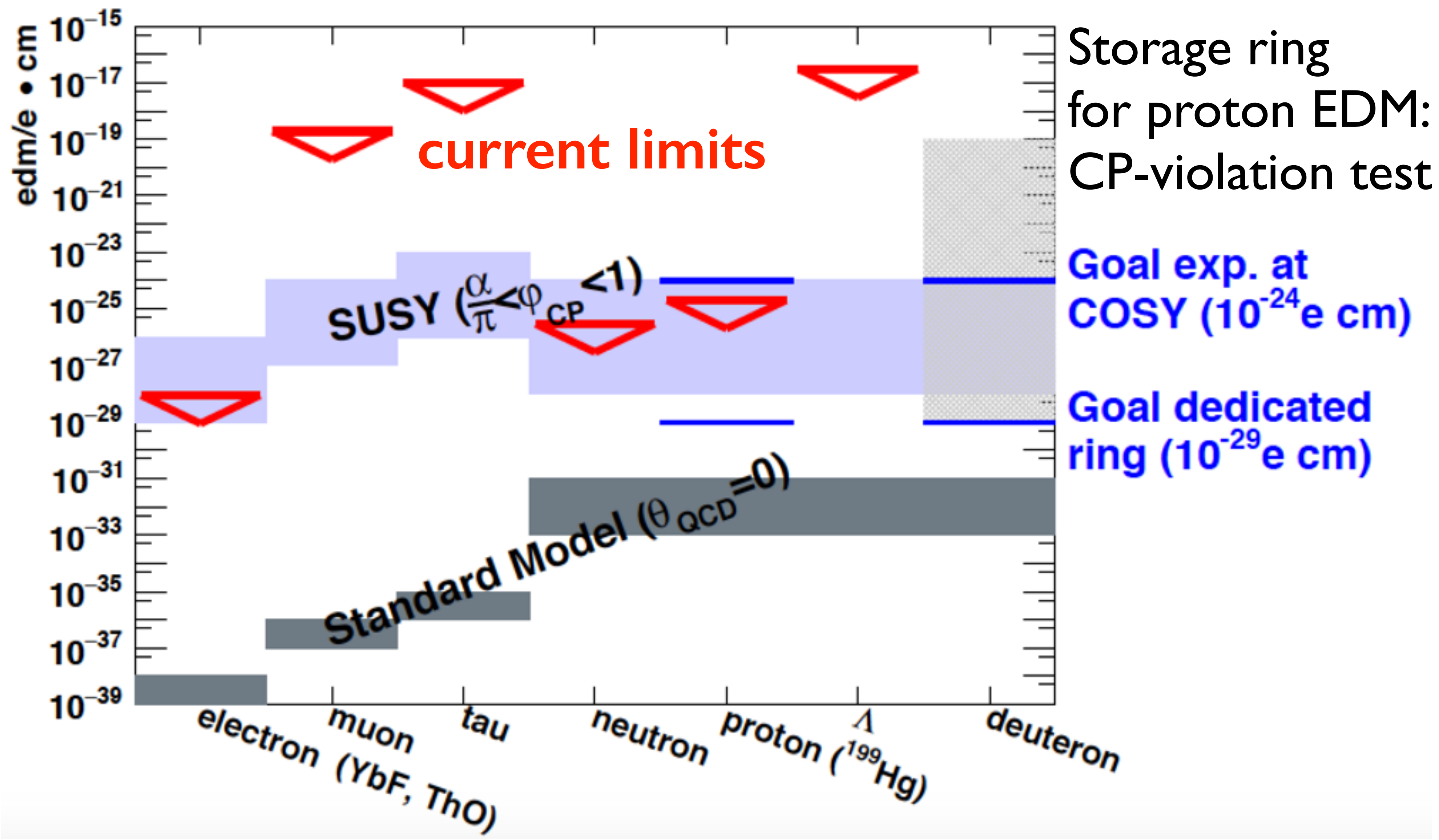
Requires:

-- electrostatic deflector 8MV/m

-- magnetic shielding

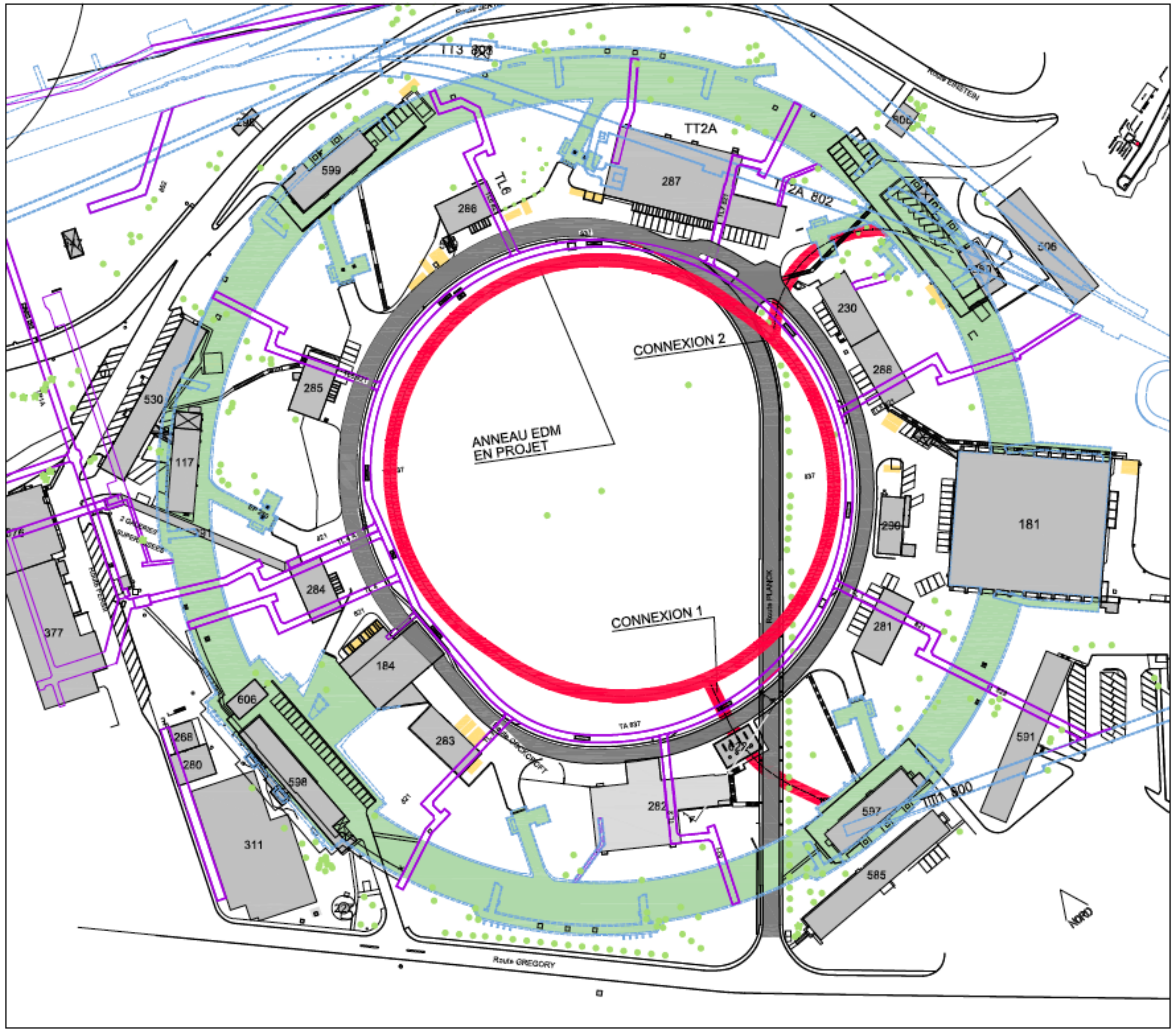
-- high precision SQUID BPMs to monitor the total radial magnetic field by vertical beam position separation between CW/CCW

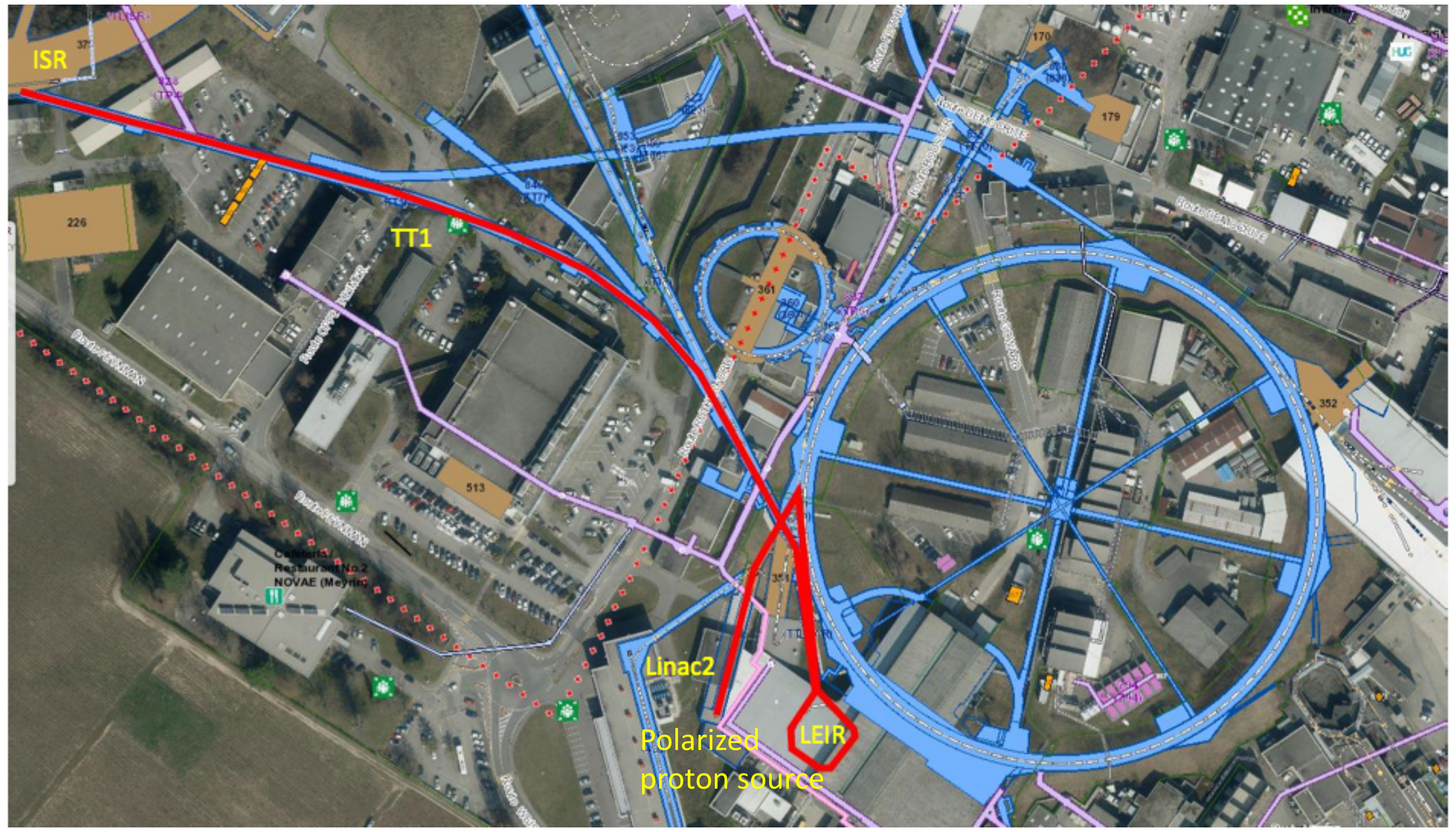
......



Sensitivity of 10^{-29} e-cm corresponds to 100 TeV for new physics scale

Possible realisation at CERN in ISR building





Polarized protons with
p = 0.7 GeV/c, v/c = 0.6

Summary

- Experimental Programme of LHC extremely rich; long range experimental programme guarantees physics return
    - by exploring the highest energies
    - by searching for violations of the SM in (highly sensitive) rare decays
- Preparing Update of the European Strategy for Particle Physics
  - LHC and HL-LHC
  - Energy Frontier (FCC / CLIC) and R&D beyond
  - Accelerator based neutrino programme (US & Japan) via neutrino platform
  - Vibrant physics programme Beyond Colliders

2018 (end): reports on Physics
2019: community discussion
with input from other regions