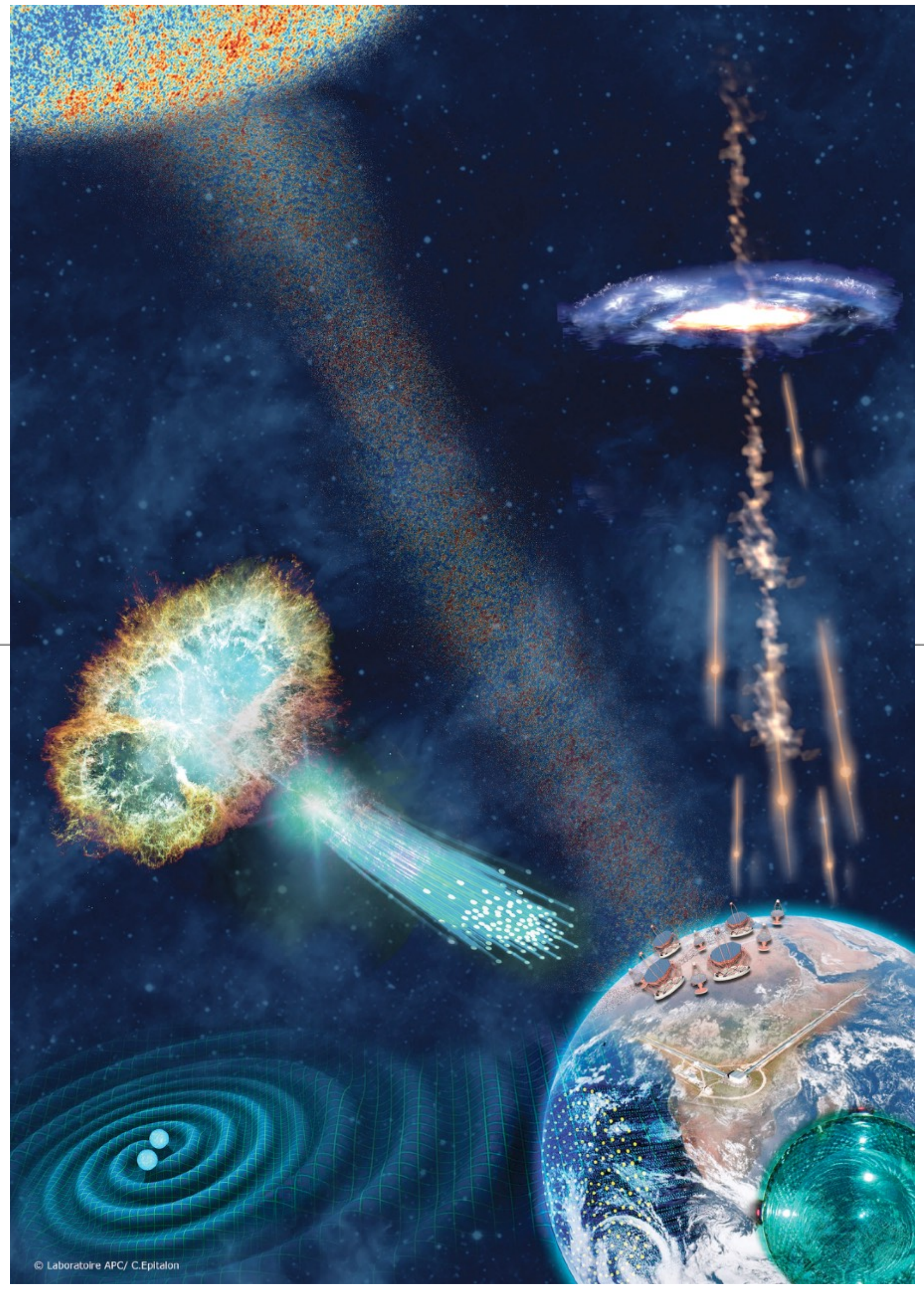
CERN and Astroparticle Physics



Eckhard Elsen

Director Research and Computing

CERN

Launch of European Astroparticle Physics Strategy, Residence Palace, Brussels, 9th Jan 2018


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

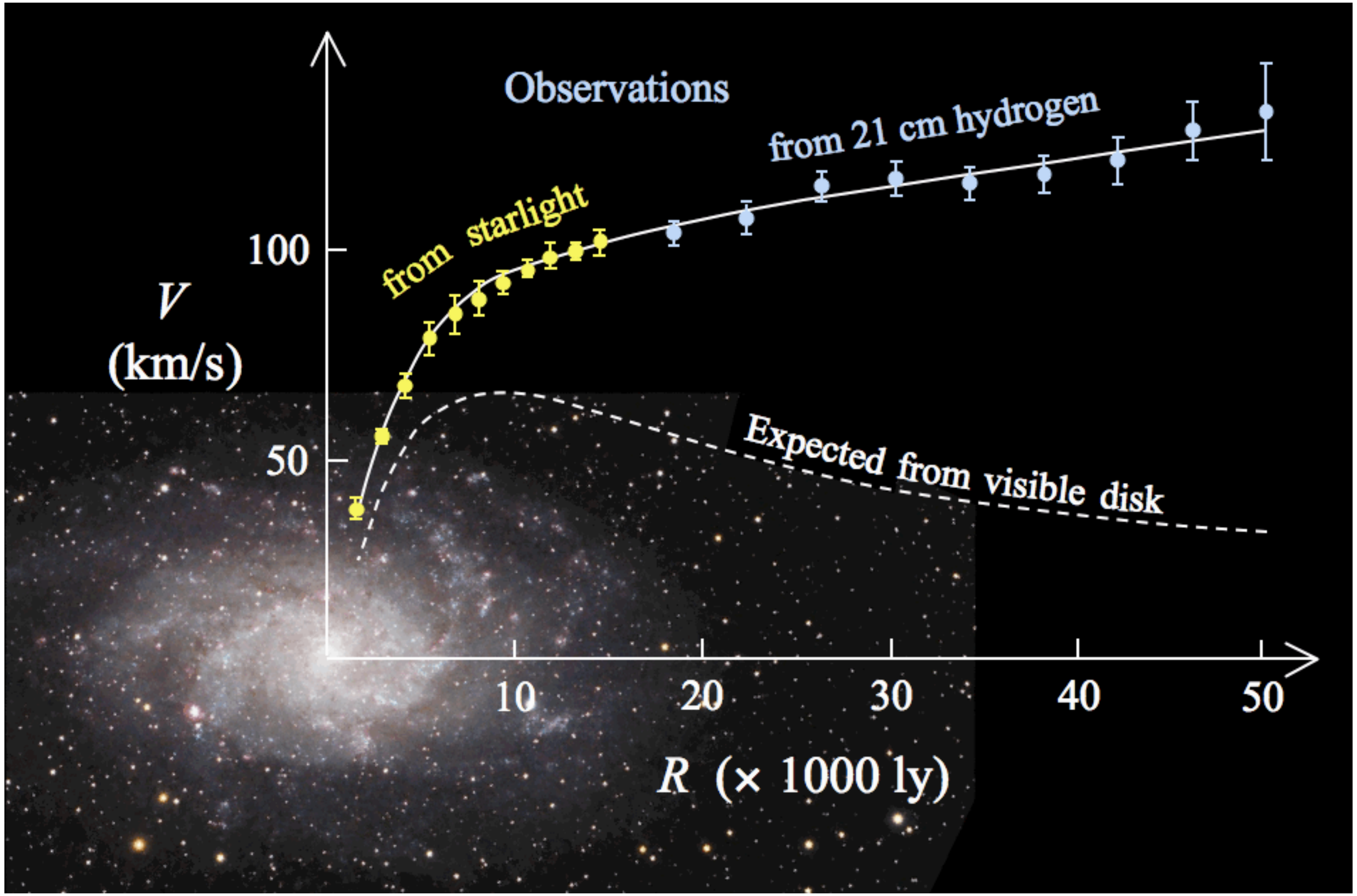
Astroparticle Physics and Particle Physics

- Astroparticle Physics looks at objects of cosmic accelerators over a wide spectrum of energies
  - Gamma rays
  - Protons and electrons
  - Heavy ions
  - Neutrinos

Particle Physics employs controlled accelerators at fixed energies

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

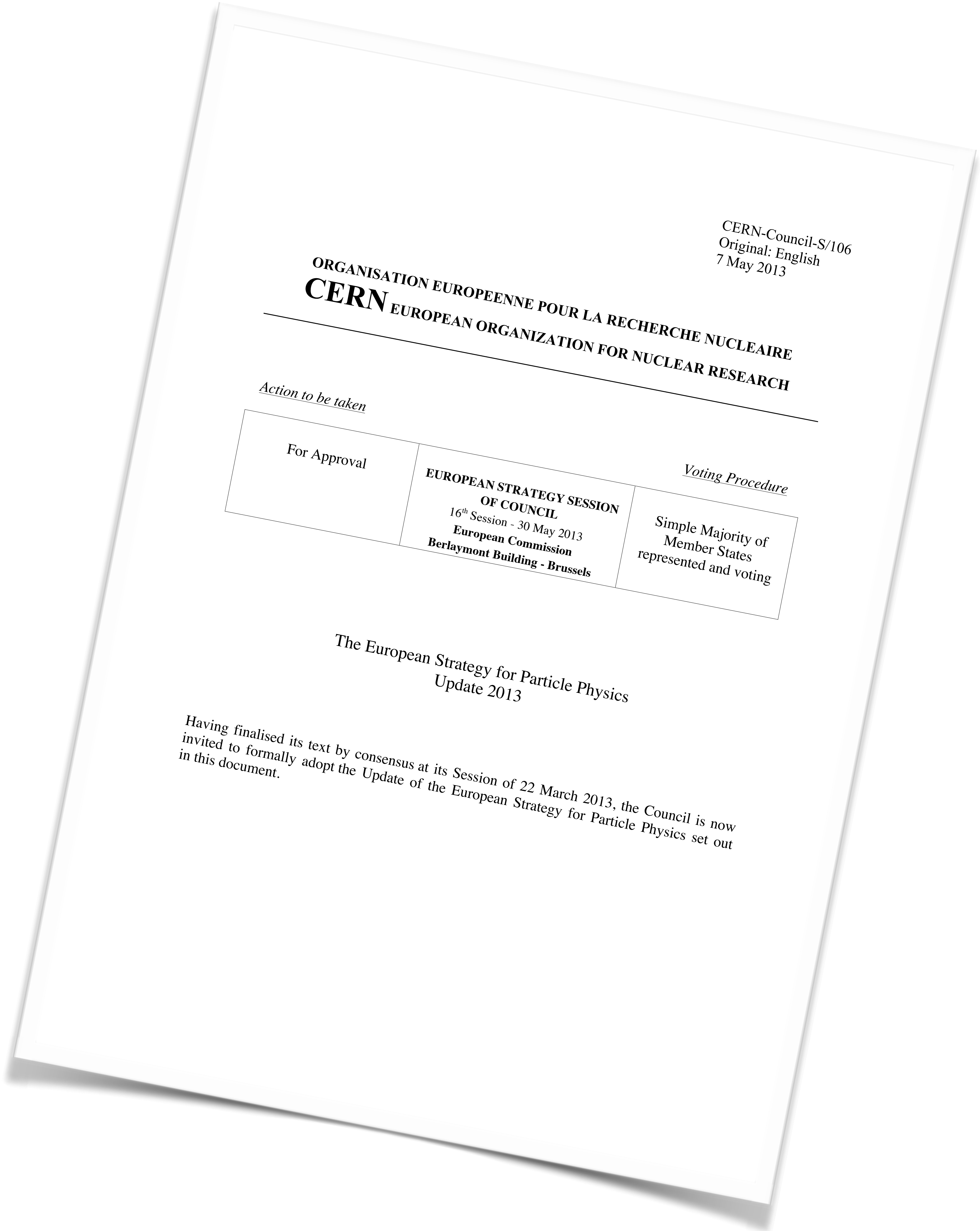


Dark Matter

Currently executing the ongoing European Strategy for Particle Physics (ESPP)

…

preparing the Update of the ESPP in 2020



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

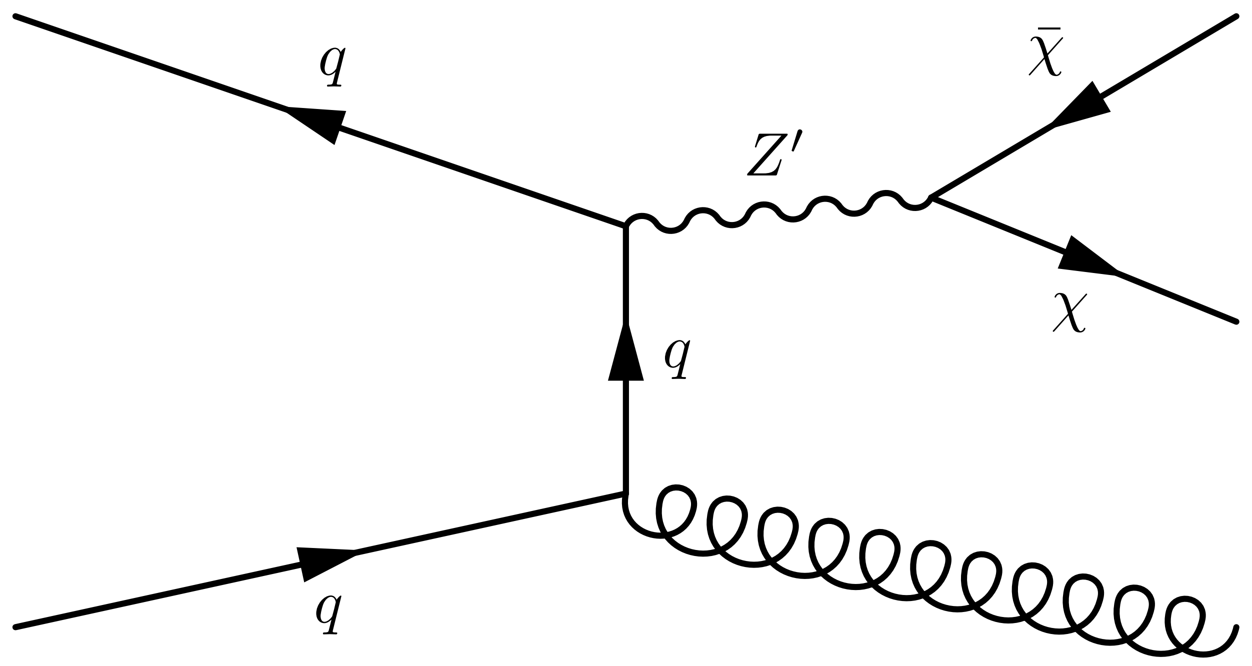
The European Strategy for Particle Physics
Update 2013

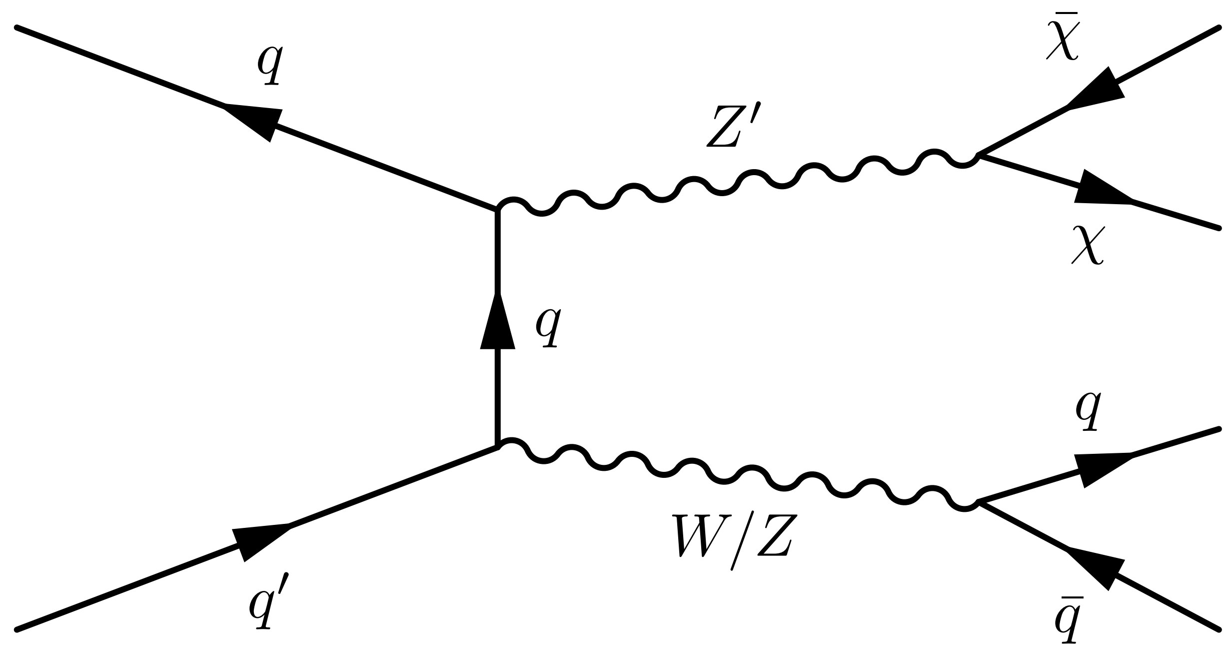
Having finalised its text by consensus at its Session of 22 March 2013, the Council is now invited to formally adopt the Update of the European Strategy for Particle Physics set out in this document.

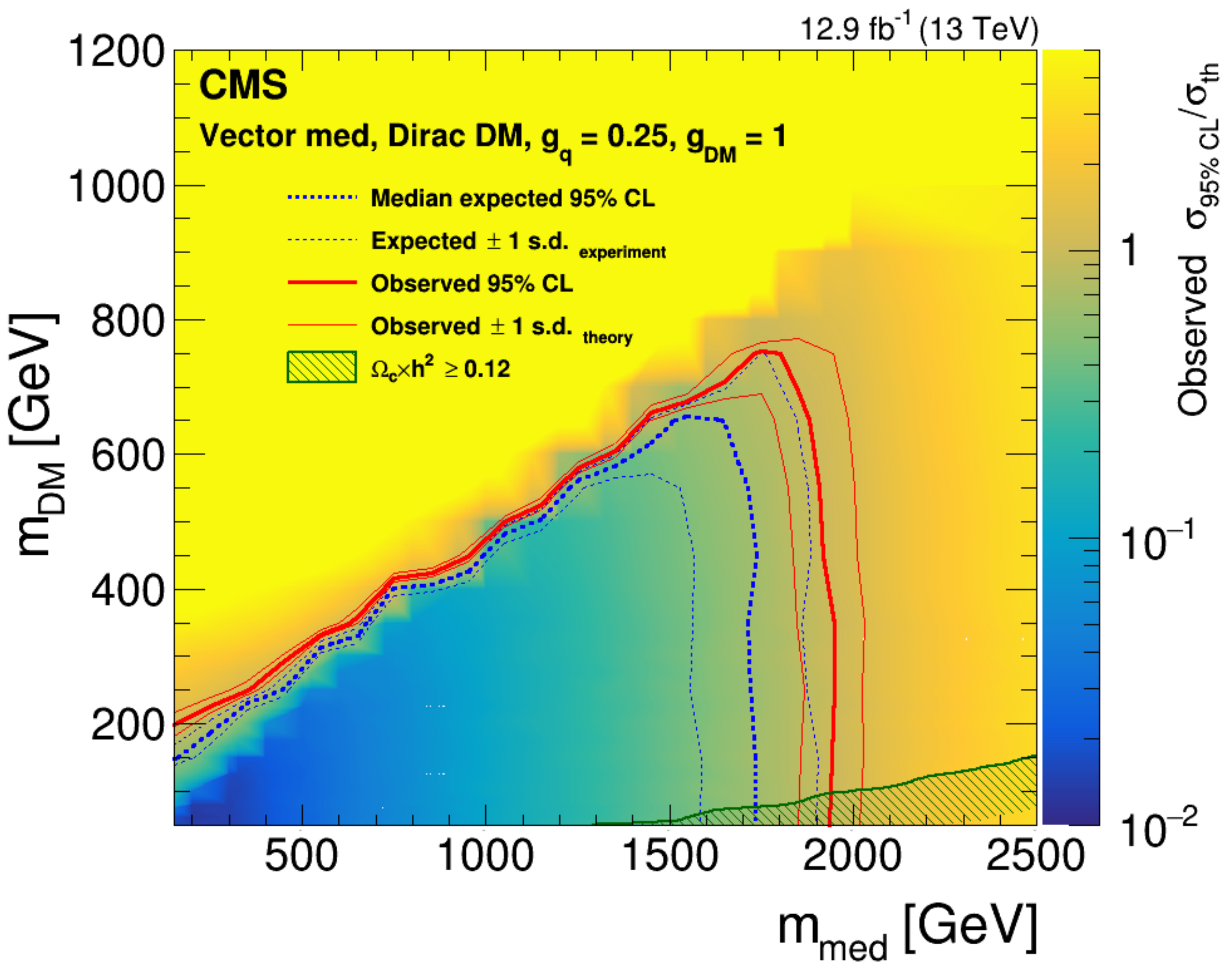
LHC as #1 tool…

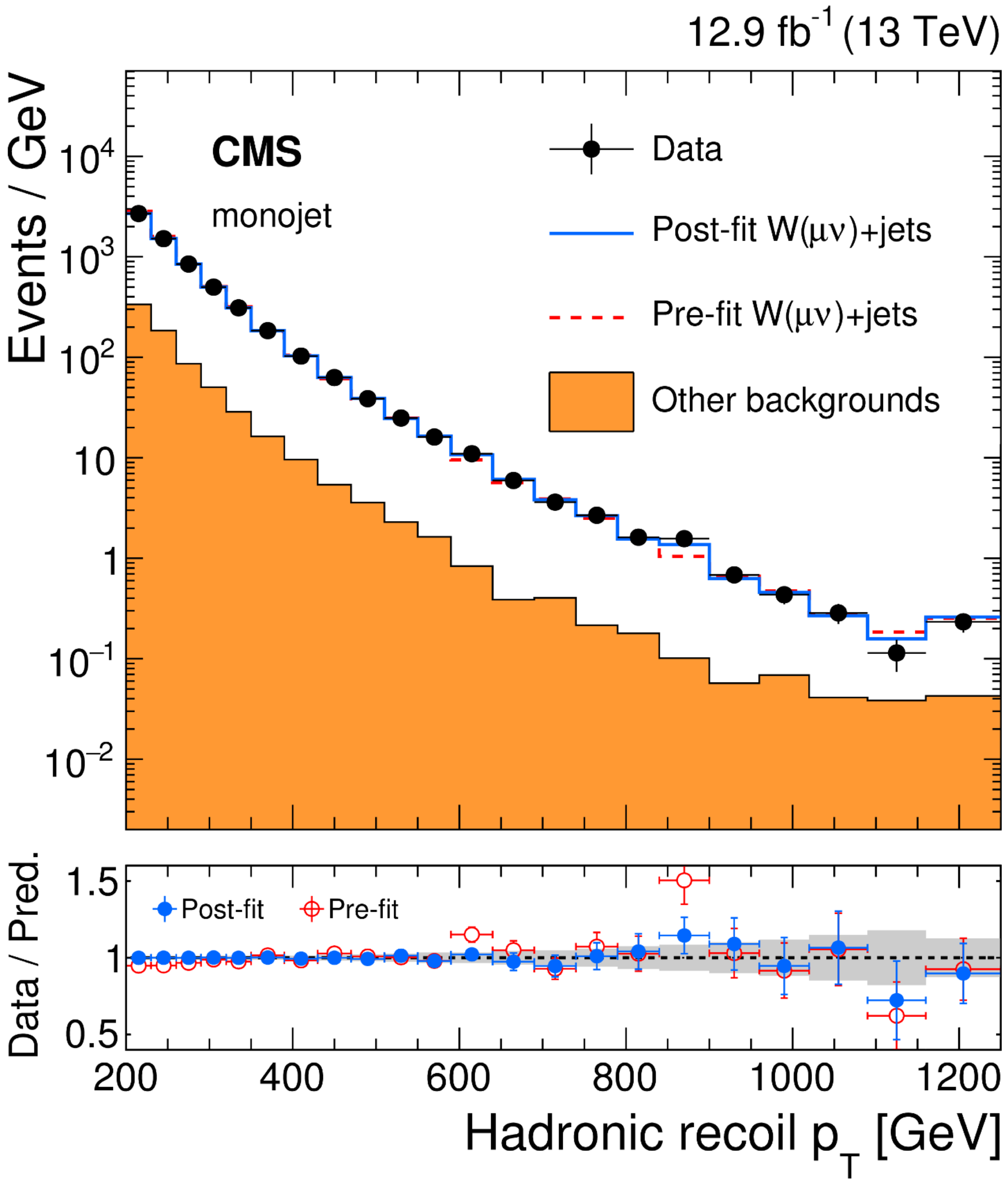

LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
CMS
ALICE
LHC 27 km

Example of Dark Matter Search at the LHC



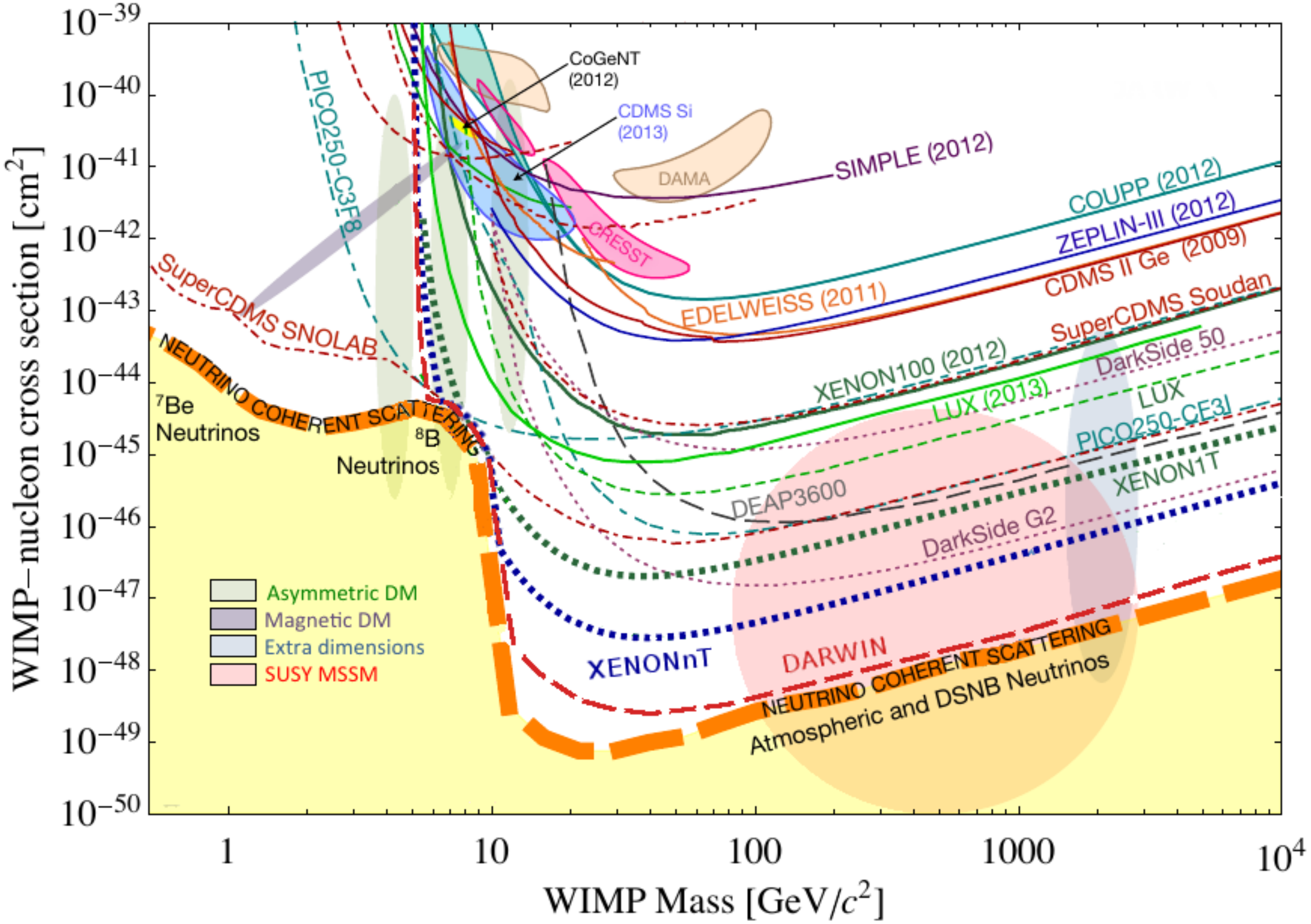






Search for Exotic Compact Objects

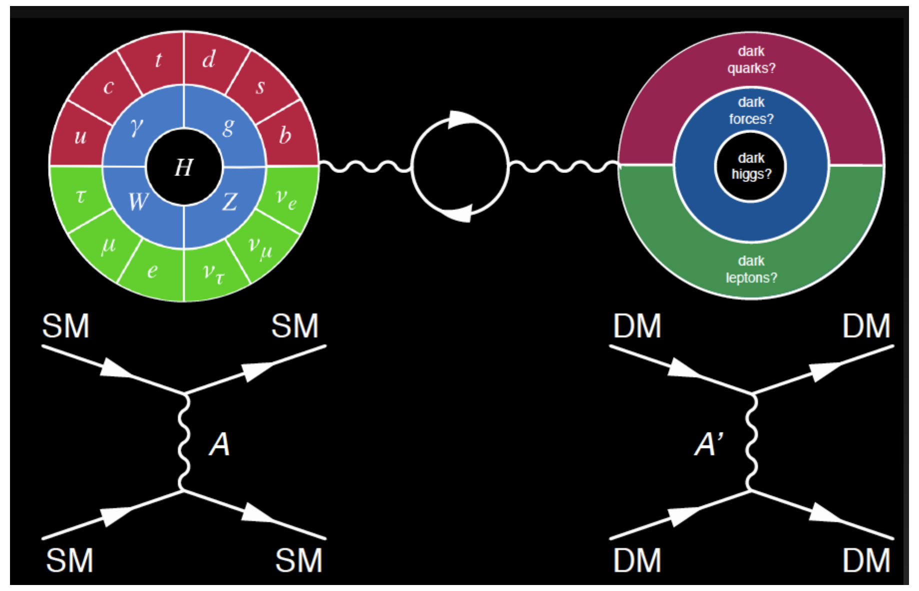
- WIMP miracle
  - dark matter as a weakly-interacting particle with mass ≈100 GeV
  - flurry of experiments with sensitivities in the region >10 GeV



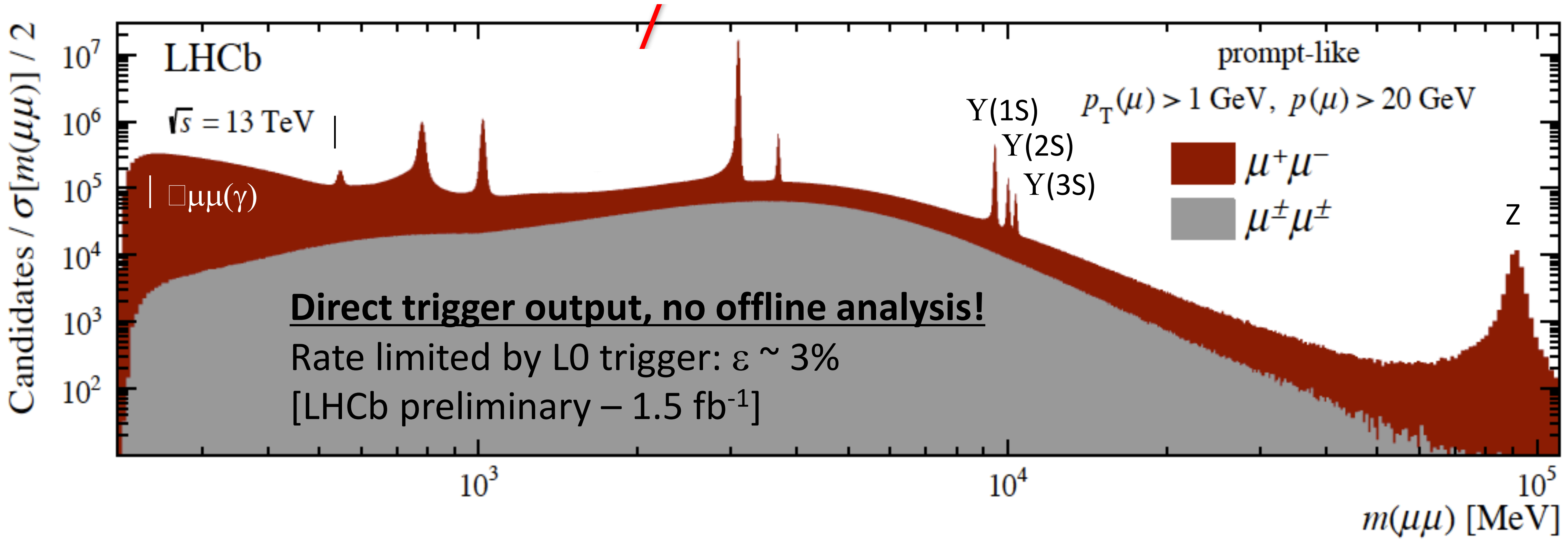
LHCb

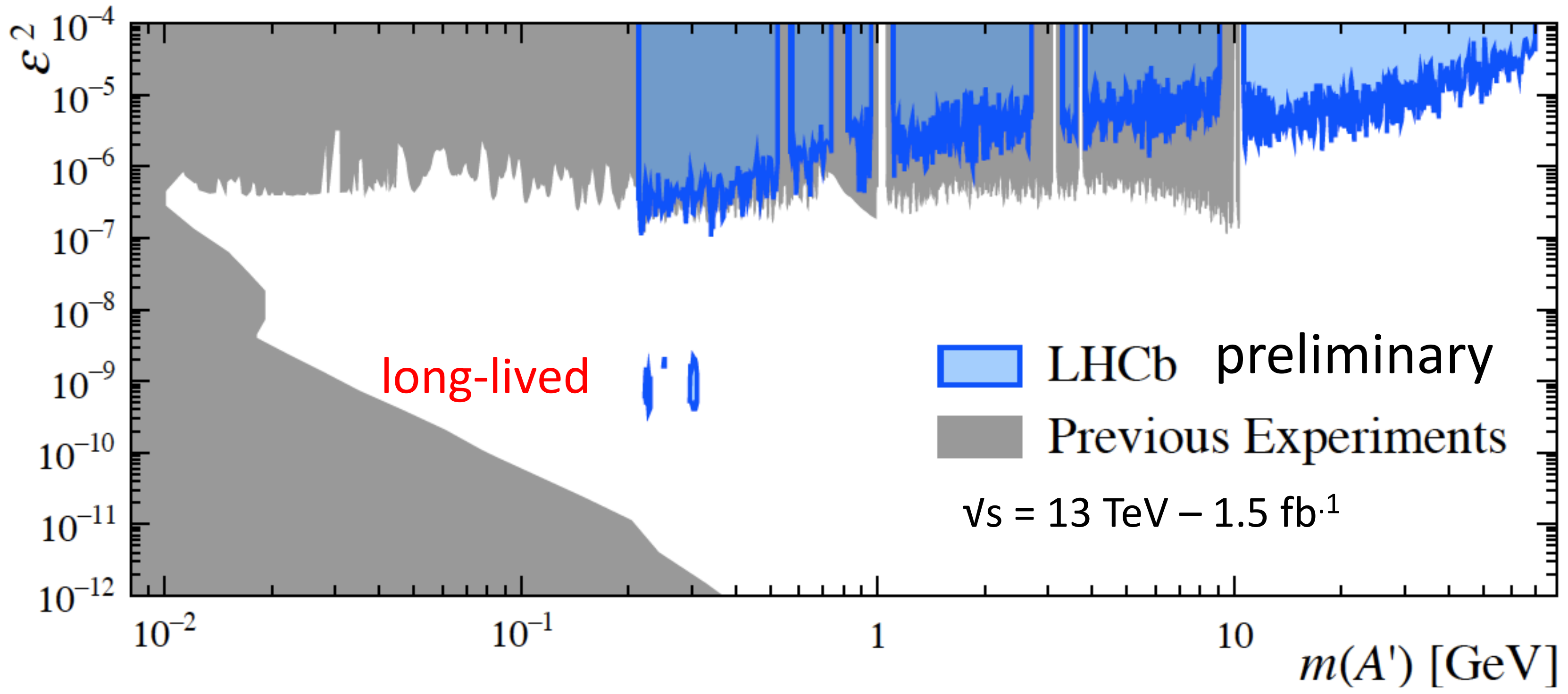
Search for dark photons

- 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



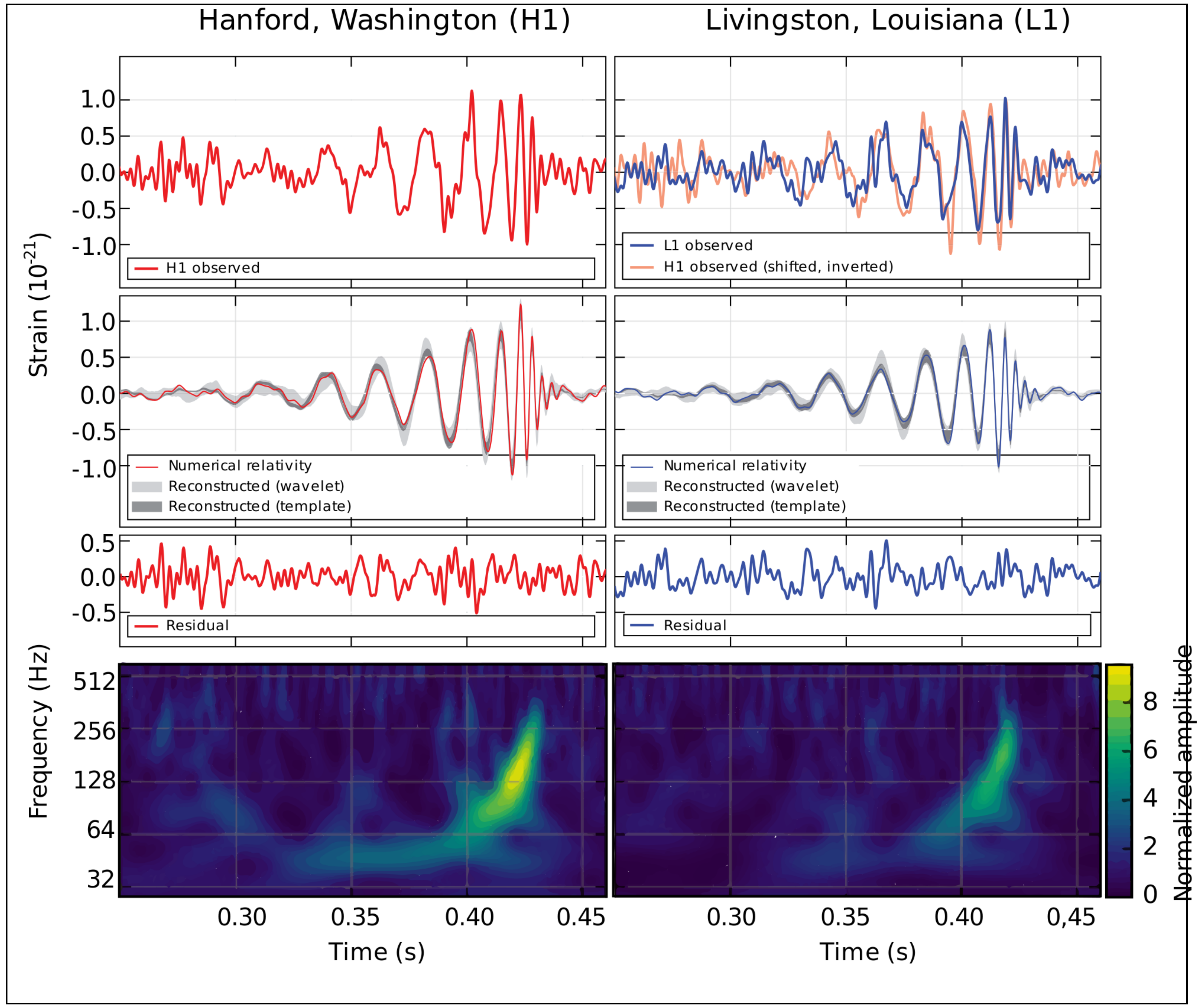


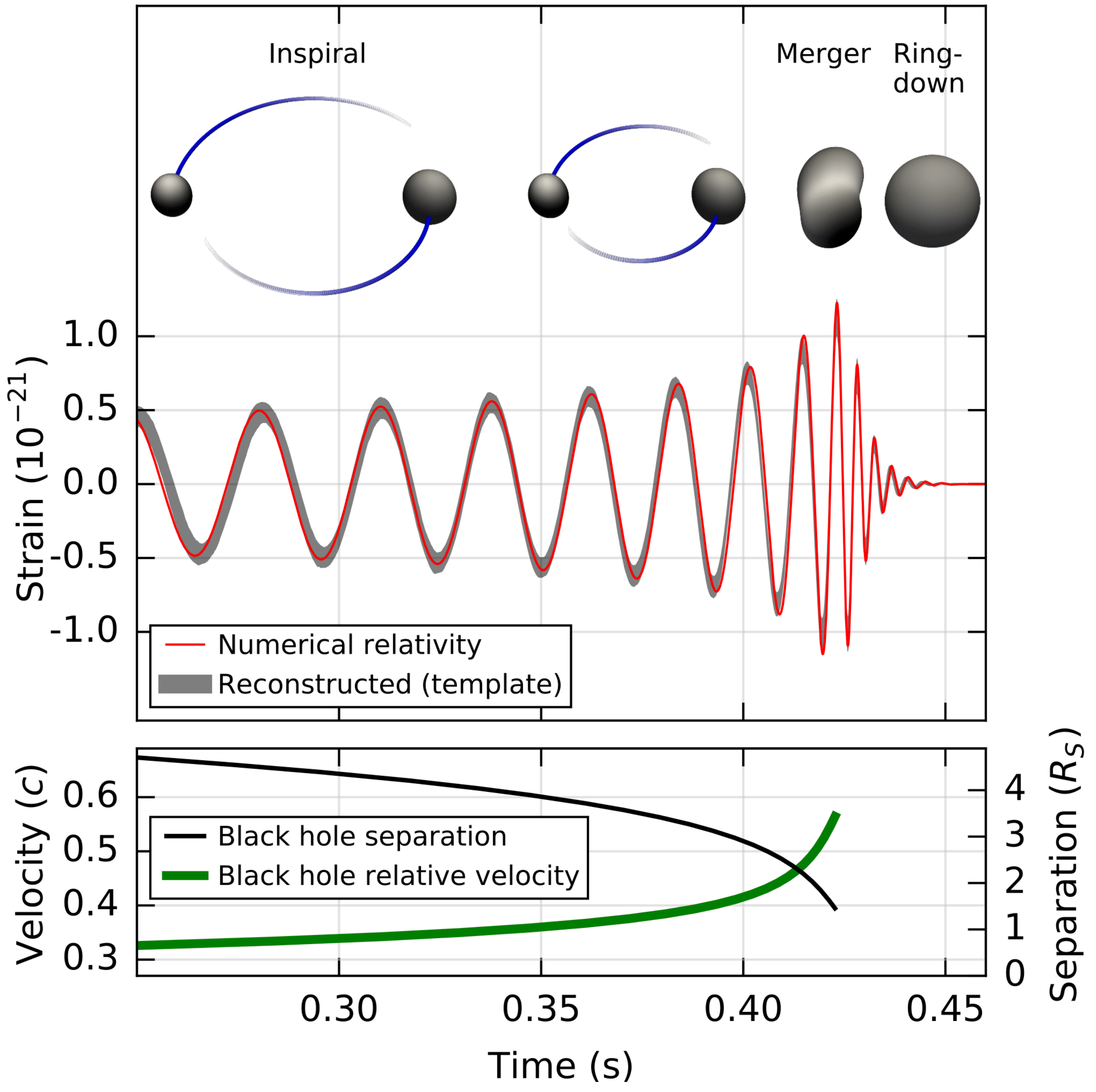
Astroparticle Physics and Particle Physics

- Astroparticle Physics looks at objects of cosmic accelerators over a wide spectrum of energies
  - Gamma rays
  - Protons and electrons
  - Heavy ions
  - Neutrinos
  - **Graviton**

Particle Physics employs controlled accelerators at fixed energies

Observation of Gravitational Waves





Nobel Prize Gravitational Waves 2017

While mostly using its accelerators for research CERN establishes formal contacts to neighbouring fields…

CERN Recognized Experiments

- Recognized experiments must have substantial participation of physicists from several CERN Member States.
- Recognized experiments must already be approved by relevant agencies and be reasonably funded.
- Whenever an experiment requests this status the case will be handled by the Recognized Experiments Committee, where the requirements will be defined and discussed. The Committee will present to the Research Board the recommendation for granting RE status.
  The Research Board will judge whether recognition by CERN is appropriate, in which case this should not be taken to imply that CERN has in any sense approved the experiment.
- …

Number	Experiment	First Recognized	valid until
RE 1	AMS	1997	31-DEC-2019
RE 2b	Pamela	1999	31-DEC-2018
RE 3	Auger	1998	31-DEC-2018
RE 6	Antares	1999	31-DEC-2019
RE 7	Fermi (former	2000	31-DEC-2018
RE 8	LISA-PF	2000	31-DEC-2018
RE 10	IceCube	2005	31-DEC-2018
RE 11	MICE	2005	31-DEC-2018
RE 12	MEG	2005	31-DEC-2018
RE 13	T2K	2006	31-DEC-2018
RE 14	Katrin	2007	31-DEC-2019
RE 17	Magic	2008	31-DEC-2017
RE 18	ArDM	2008	31-DEC-2017
RE 19	CREAM	2010	31-DEC-2018
RE 20	Belle II	2011	31-DEC-2019
RE 21	CBM	2011	31-DEC-2019
RE 22	Panda	2011	31-DEC-2019
RE 23	CTA-PP	2011	31-DEC-2017
RE 25	CALET	2012	31-DEC-2017
RE 26	Borexino	2012	31-DEC-2017
RE 27	NEXT	2013	31-DEC-2018
RE 28	Advanced Virgo	2013	31-DEC-2018
RE 29	DAMPE	2014	31-DEC-2019
RE 30	KM3NeT Phase 1	2014	31-DEC-2019
RE 31	Euclid	2015	31-DEC-2018
RE 33	LIGO	2016	31-DEC-2018
RE 34	JUNO	2017	31-DEC-2019
RE 35	SNO+	2017	31-DEC-2019

CERN Recognized Experiments mentioned in APPEC Strategy

- 18 of 28 currently listed Recognized Experiments are mentioned in the new APPEC Strategy
  - Charged particles
  - Neutrinos
  - Dark matter
  - Gravitational Waves

Number	Experiment	First Recognized	valid until
RE 1	AMS	1997	31-DEC-2019
RE 2b	Pamela	1999	31-DEC-2018
RE 3	Auger	1998	31-DEC-2018
RE 6	Antares	1999	31-DEC-2019
RE 7	Fermi (former GLAST)	2000	31-DEC-2018
RE 8	LISA-PF	2000	31-DEC-2018
RE 10	IceCube	2005	31-DEC-2018
RE 14	Katrin	2007	31-DEC-2019
RE 17	Magic	2008	31-DEC-2017
RE 18	ArDM	2008	31-DEC-2017
RE 23	CTA-PP	2011	31-DEC-2017
RE 26	Borexino	2012	31-DEC-2017
RE 27	NEXT	2013	31-DEC-2018
RE 28	Advanced Virgo	2013	31-DEC-2018
RE 30	KM3NeT Phase 1	2014	31-DEC-2019
RE 31	Euclid	2015	31-DEC-2018
RE 33	LIGO	2016	31-DEC-2018
RE 34	JUNO	2017	31-DEC-2019

Higgs Particle

- Higgs is the fundmental scalar of particle physics
- Higgs particle couples to mass
  - Portal to new physics

H → fermions

$H \to \tau\tau$

$H \to b\bar{b}$

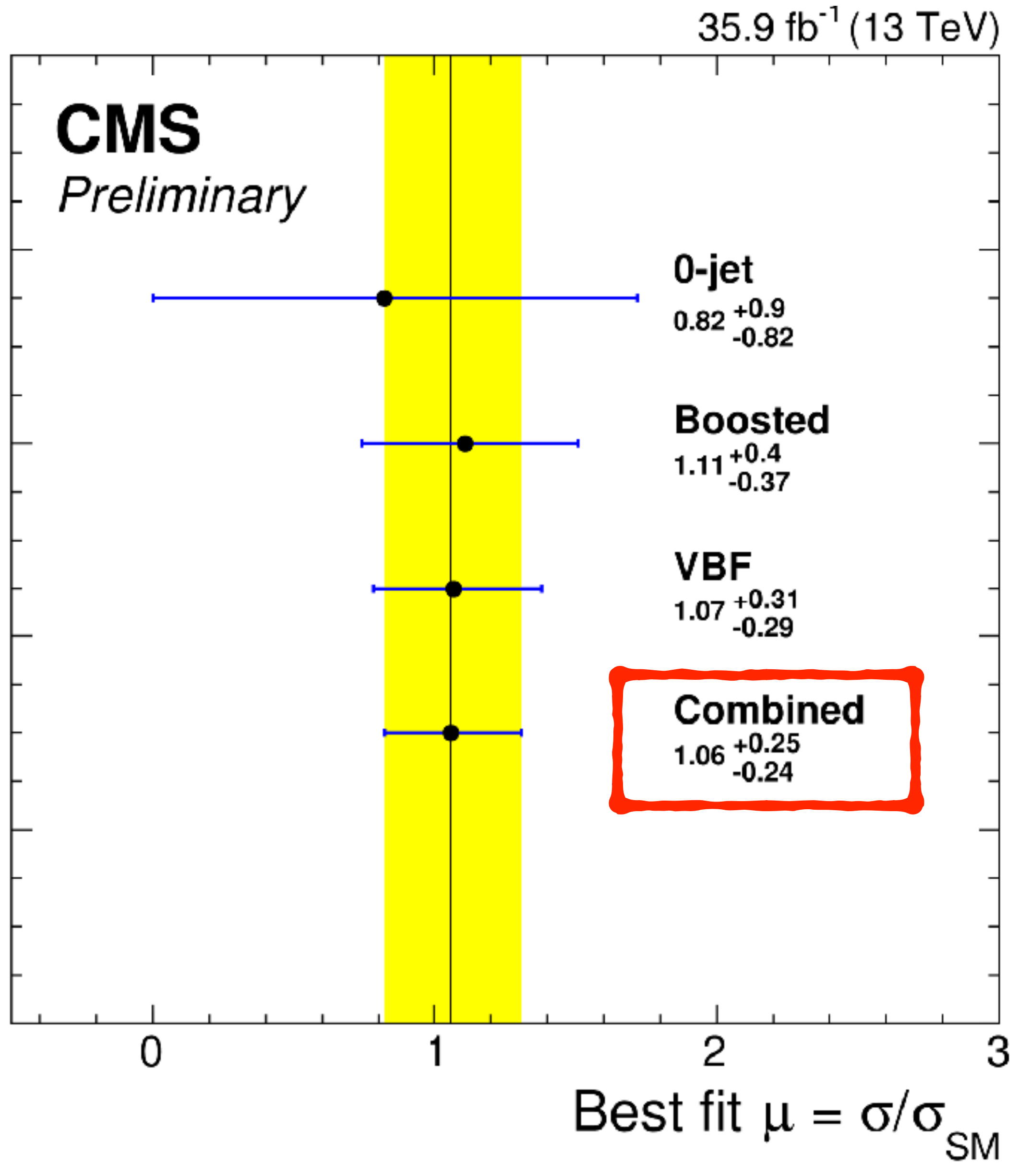
Using

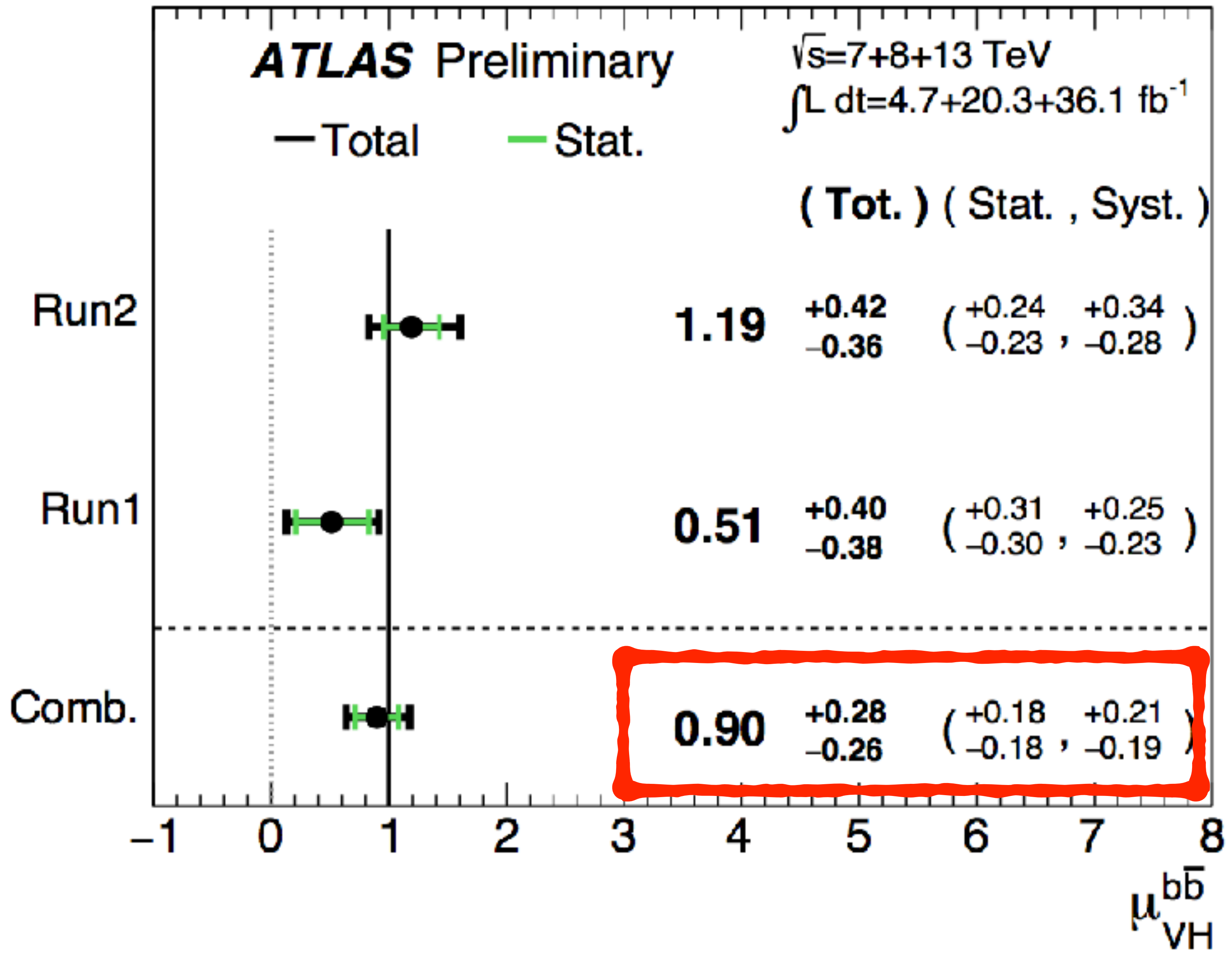
$\tau_h\tau_h$

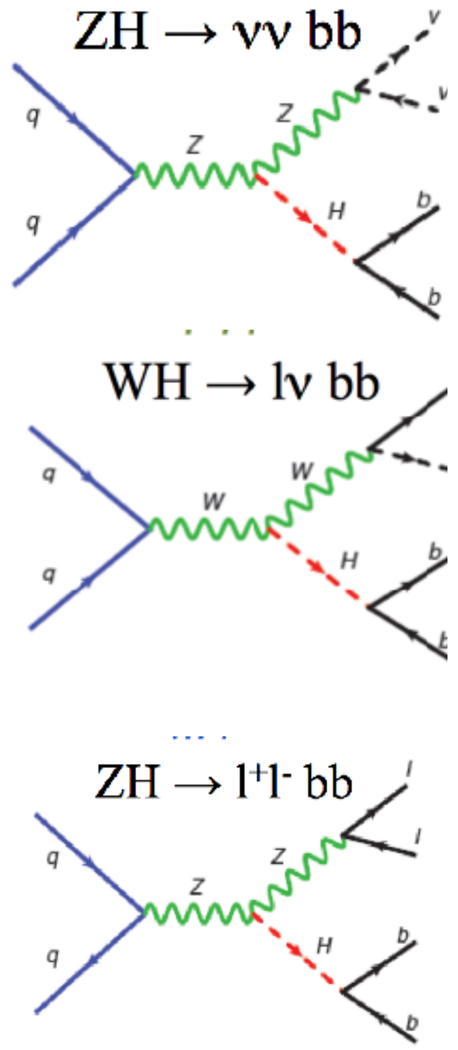
$e\tau_h$

$\mu\tau_h$

$e\mu$





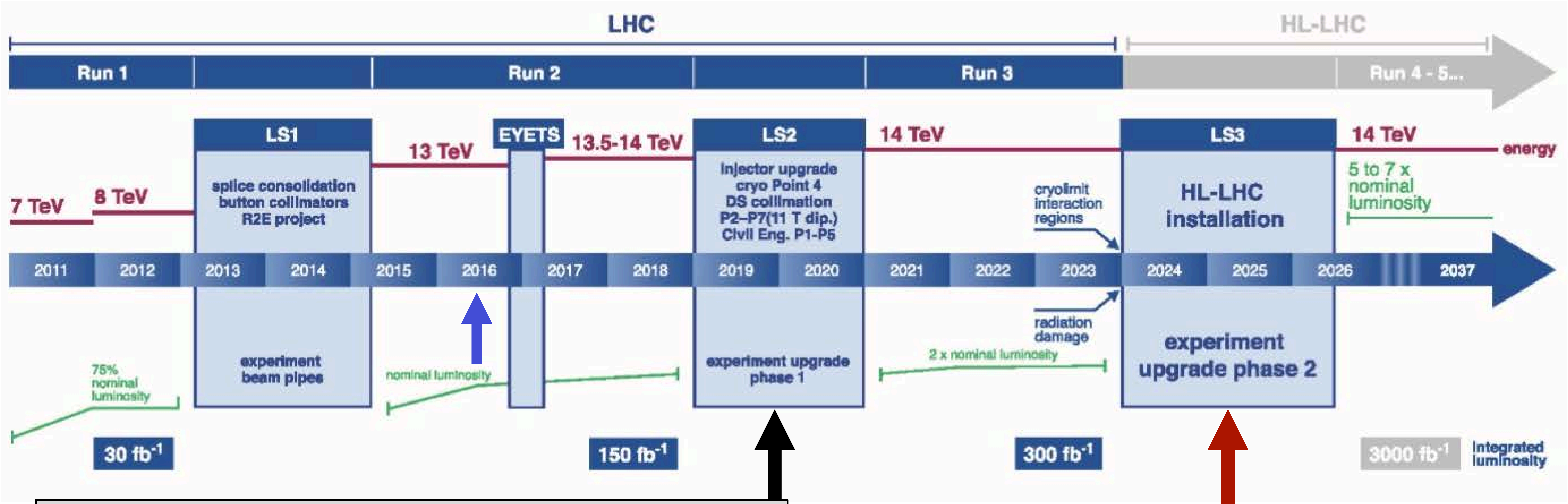


4.9 σ

from run 2

3.5 σ

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

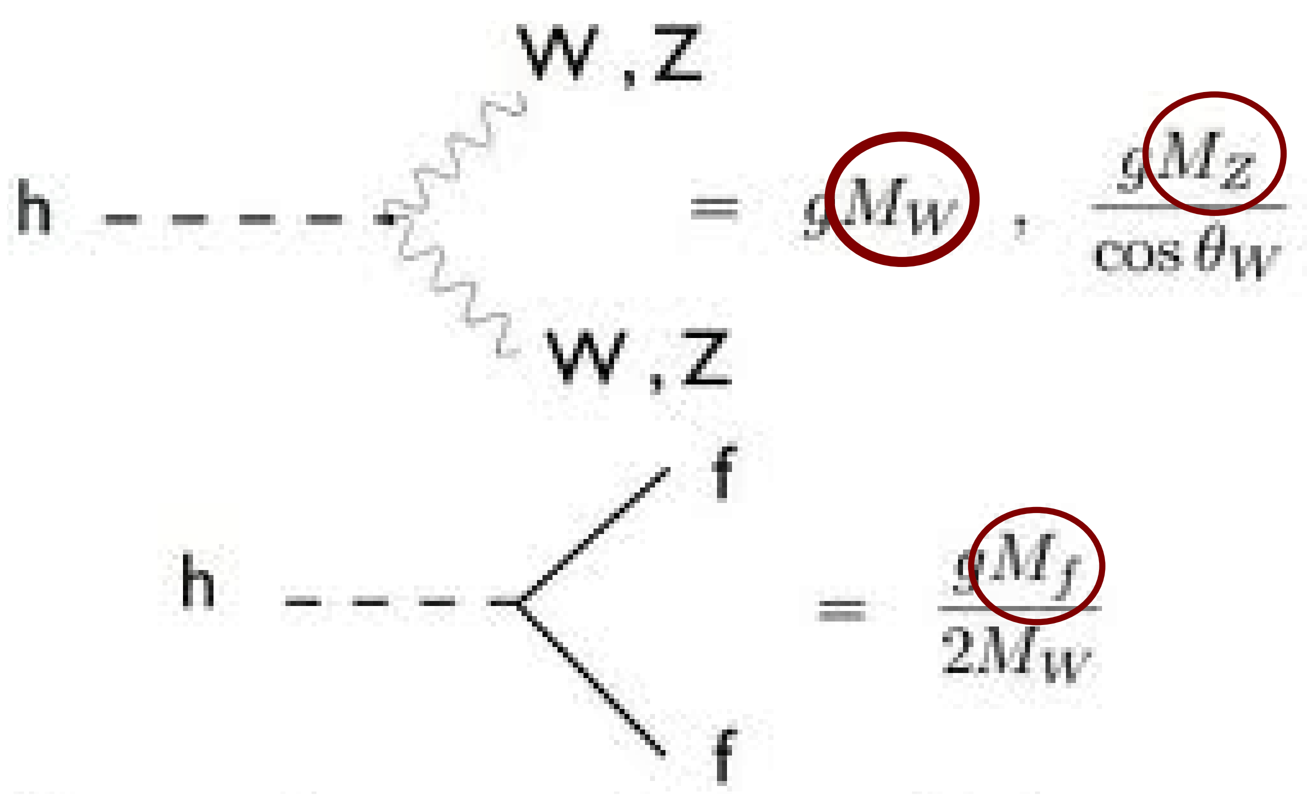
LS3 (2024-2026):

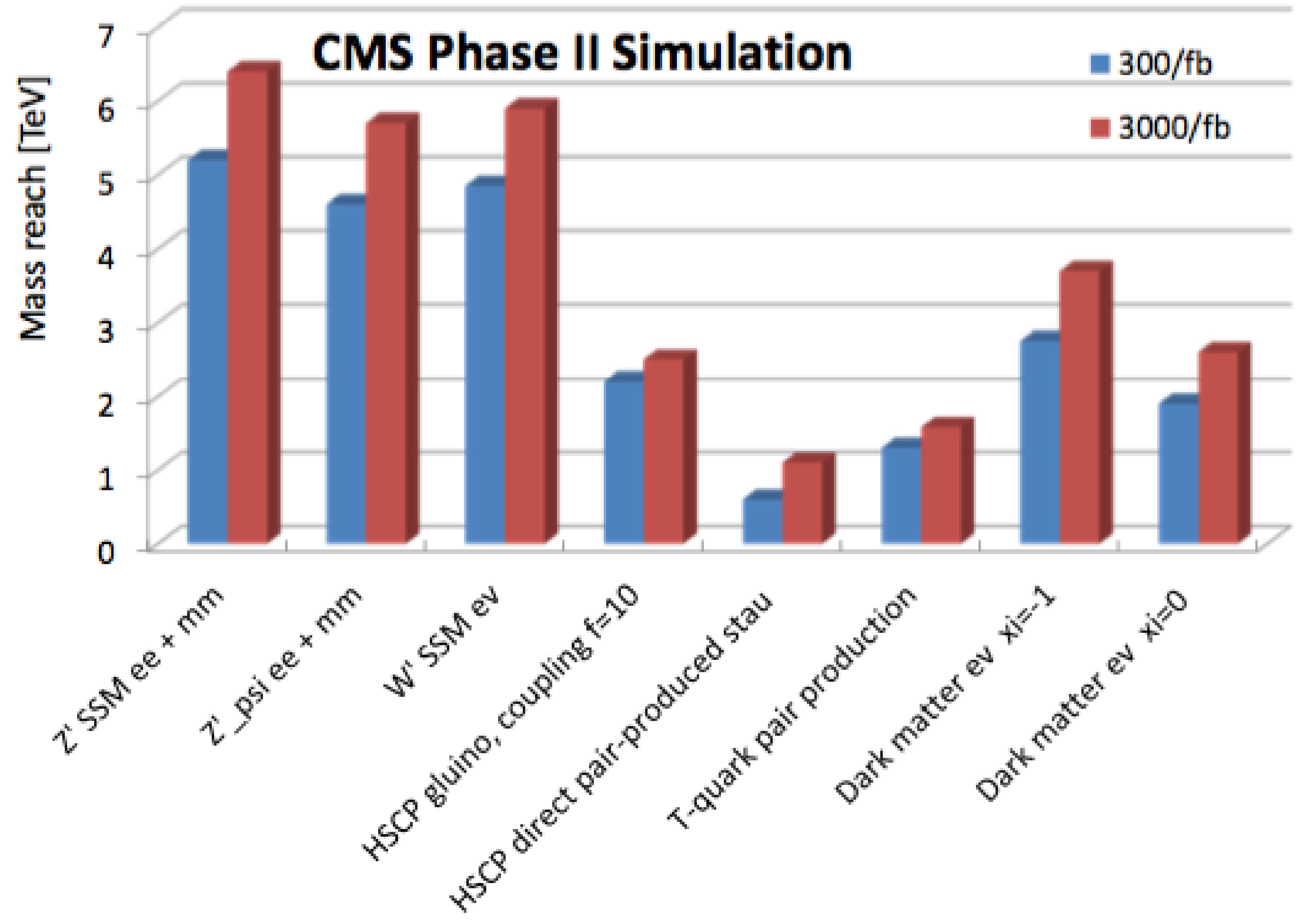
- ❑ **HL-LHC installation**
- ❑ Phase-2 upgrade of ATLAS and CMS

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

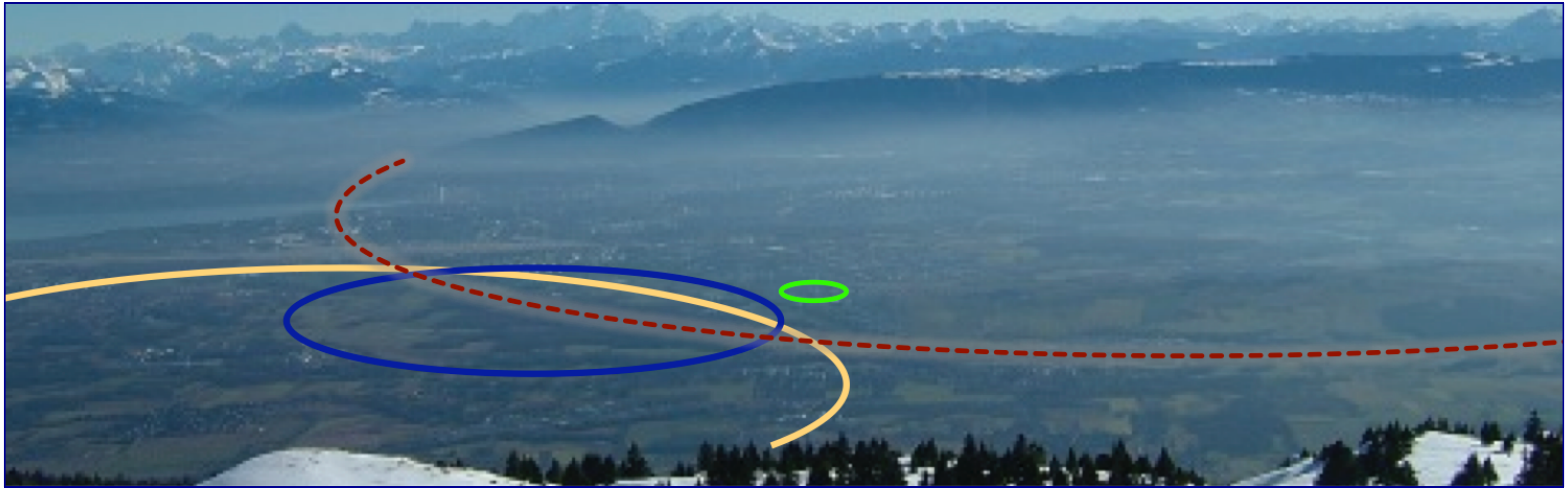
A few physics example for HL-LHC

- 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





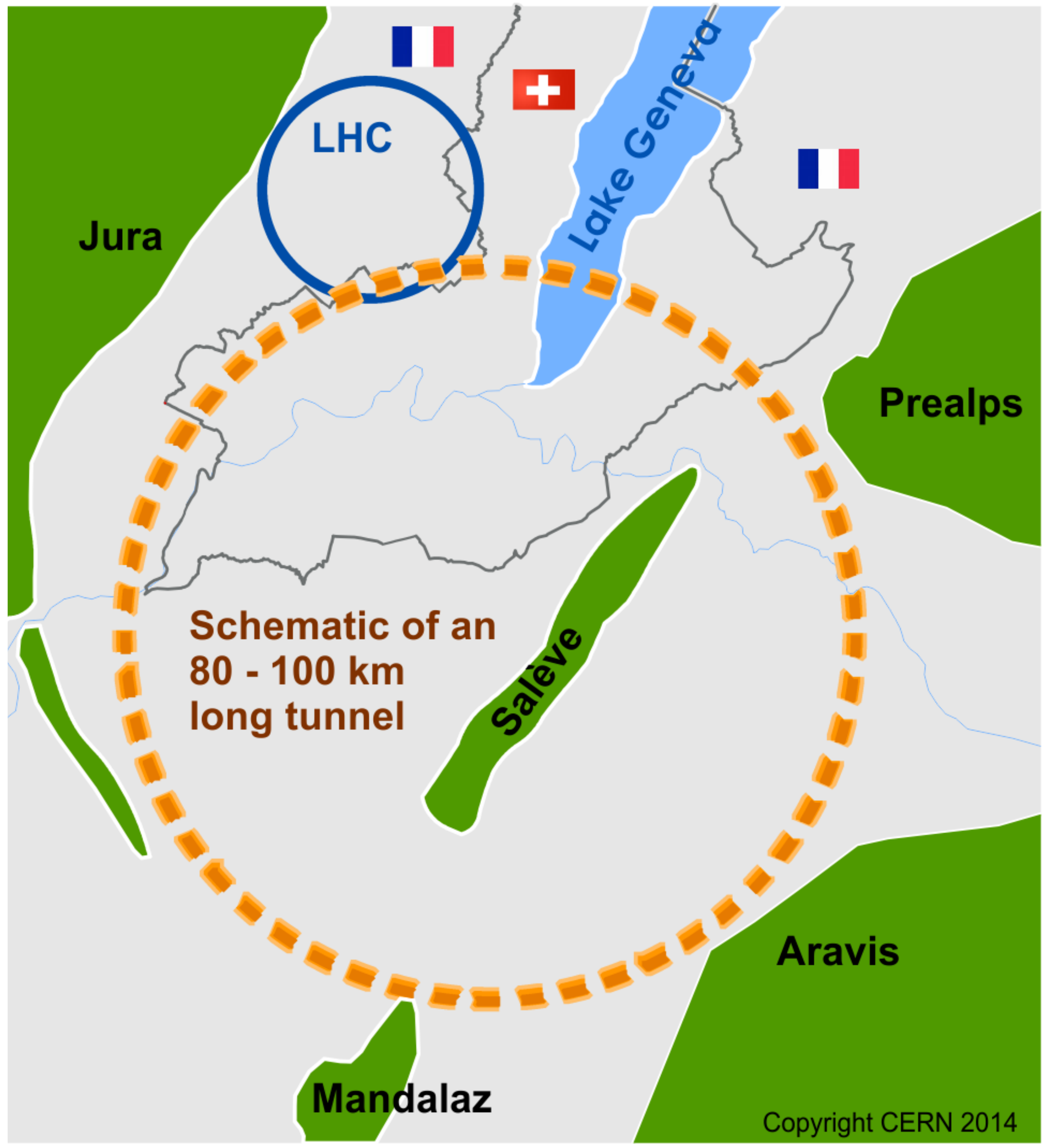
Future Circular Collider FCC



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

FCC Conceptual Design Report by end 2018

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



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

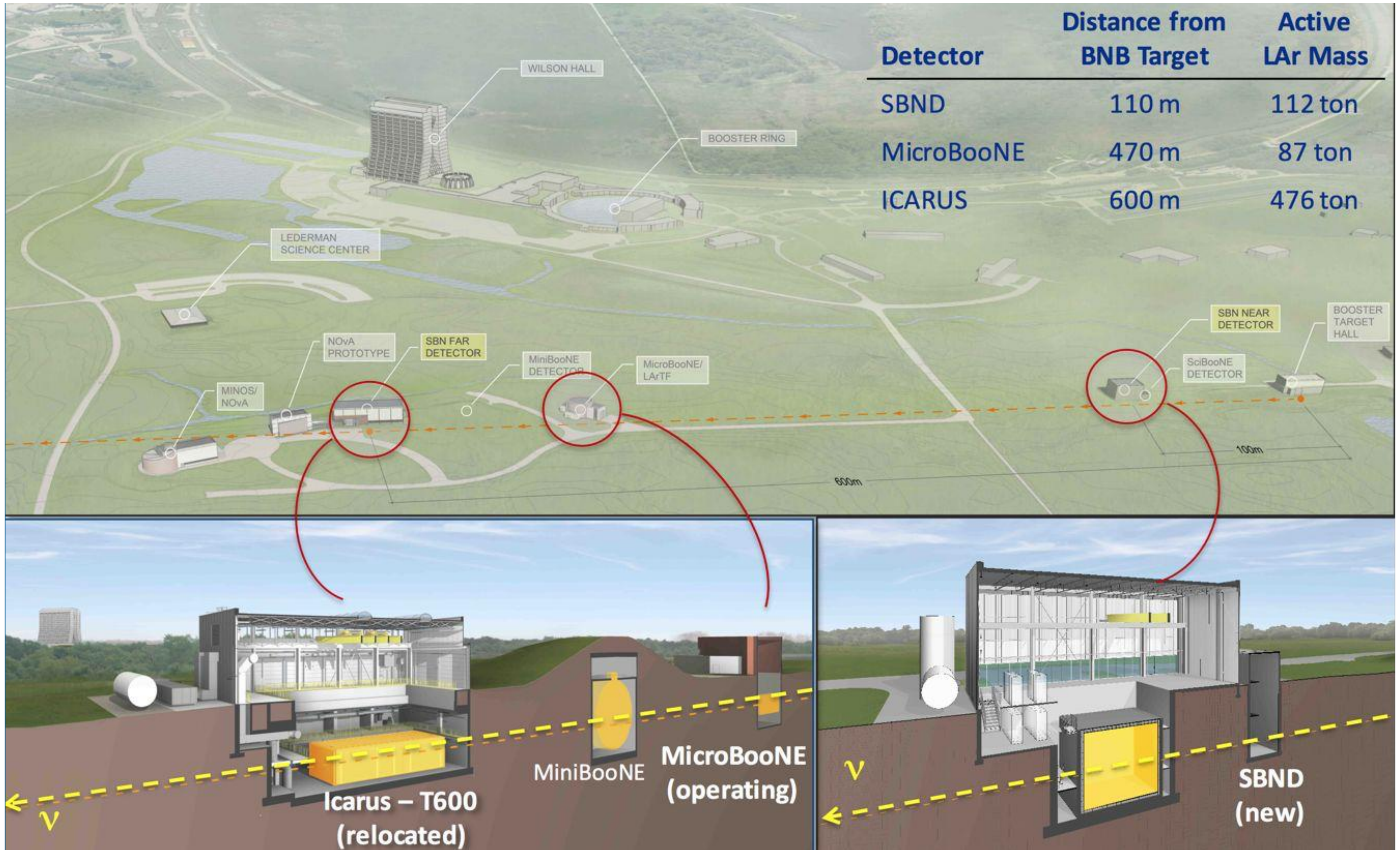
  - Detector development (initial emphasis on Lar TPC)

  - Extension of EHN1 hall

Charged particles from SPS available

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



J-PARC at Neutrino Platform

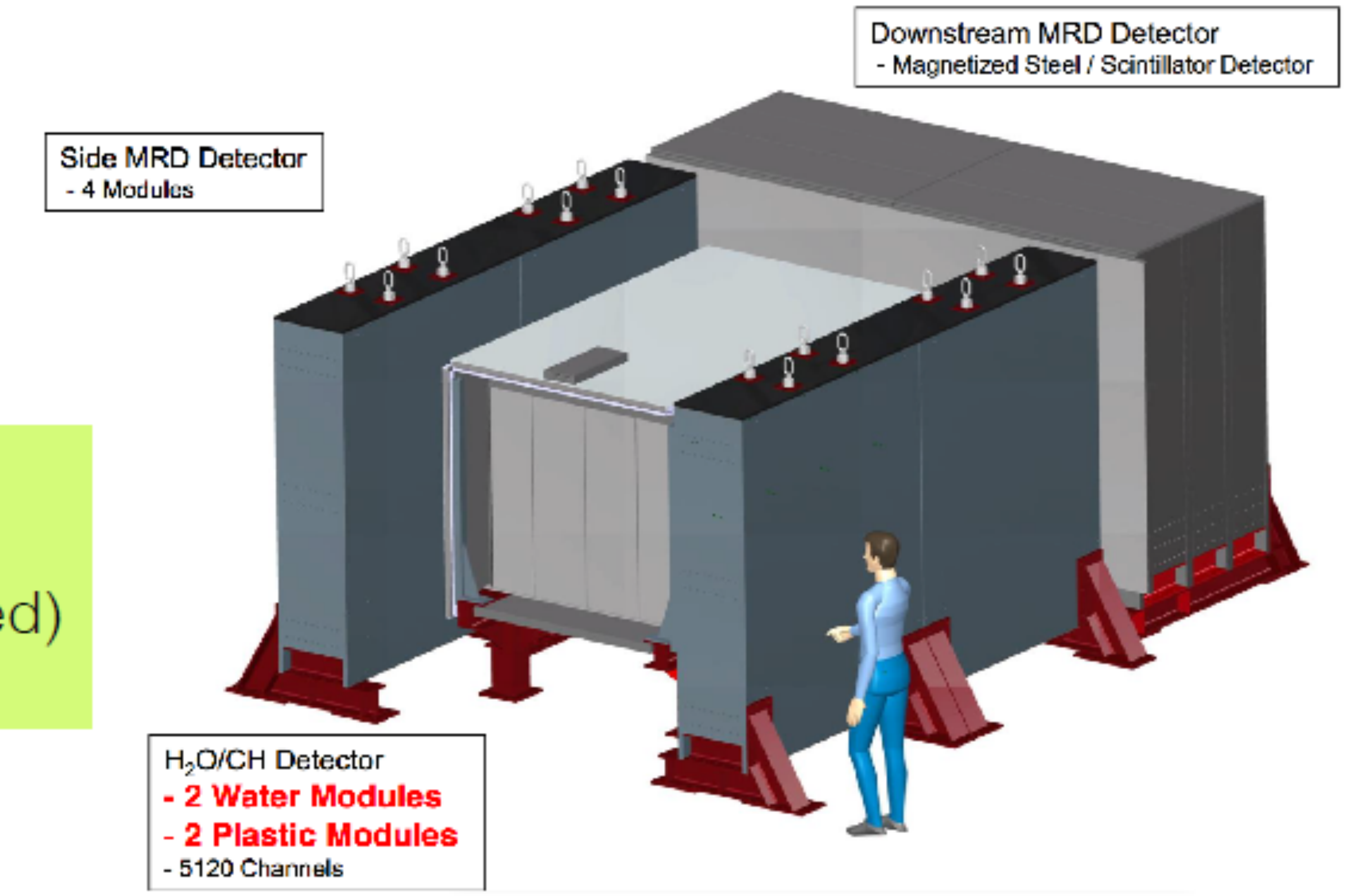
- 3% precision H_2O/C_nH_n cross-section ratio
- Study of ν_μ energy reconstruction
- wide angle θ coverage
- complementary to ND280

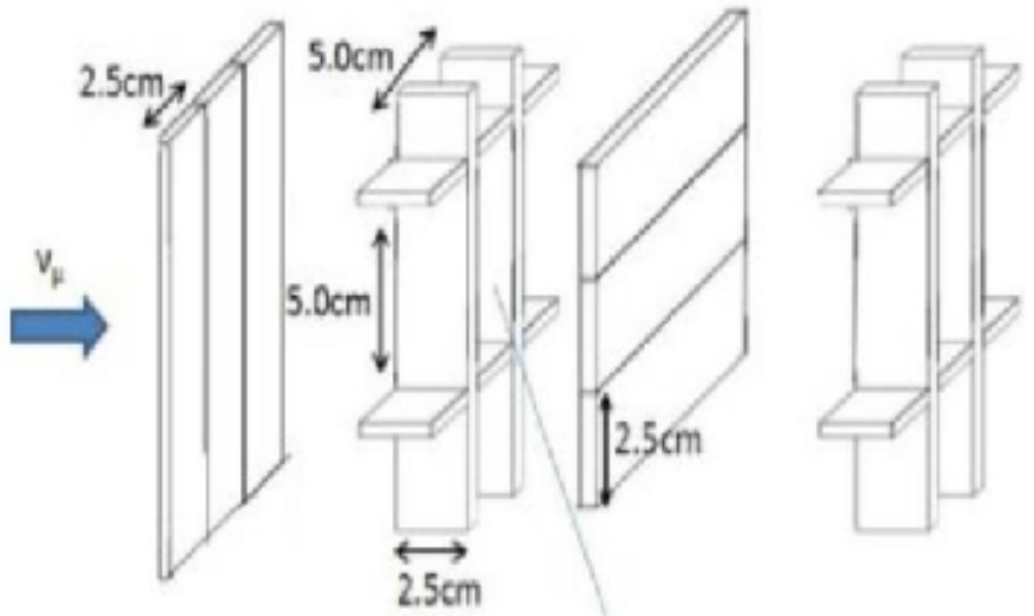
3% precision H_2O / CH x-section ratio

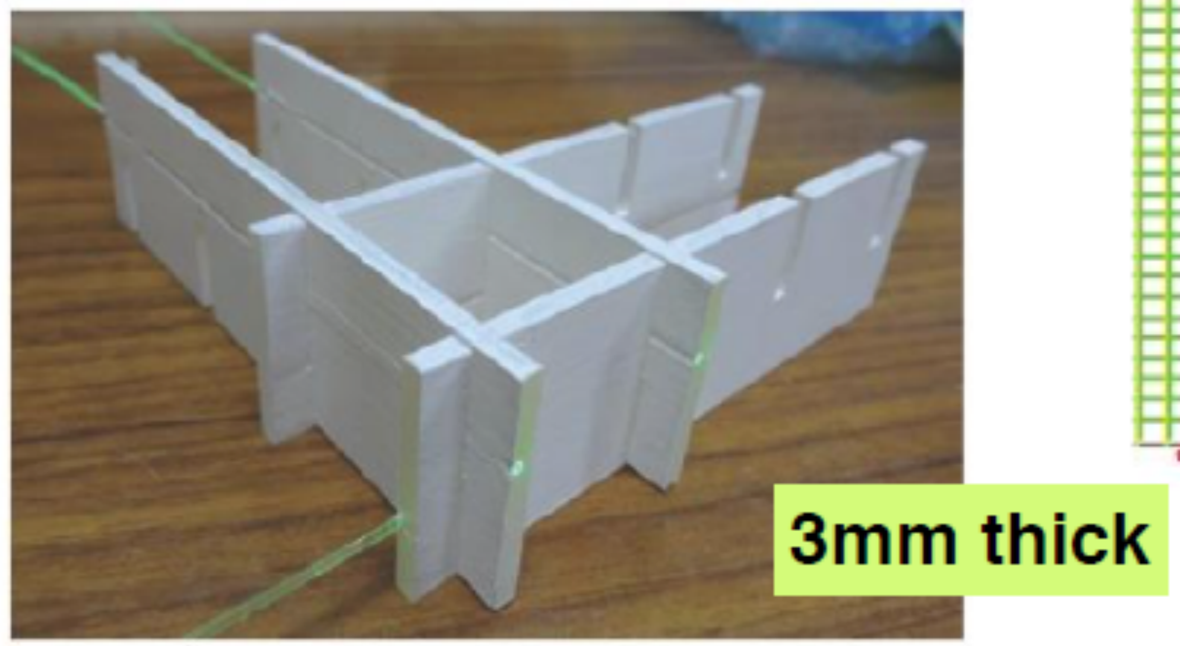
Wagasci

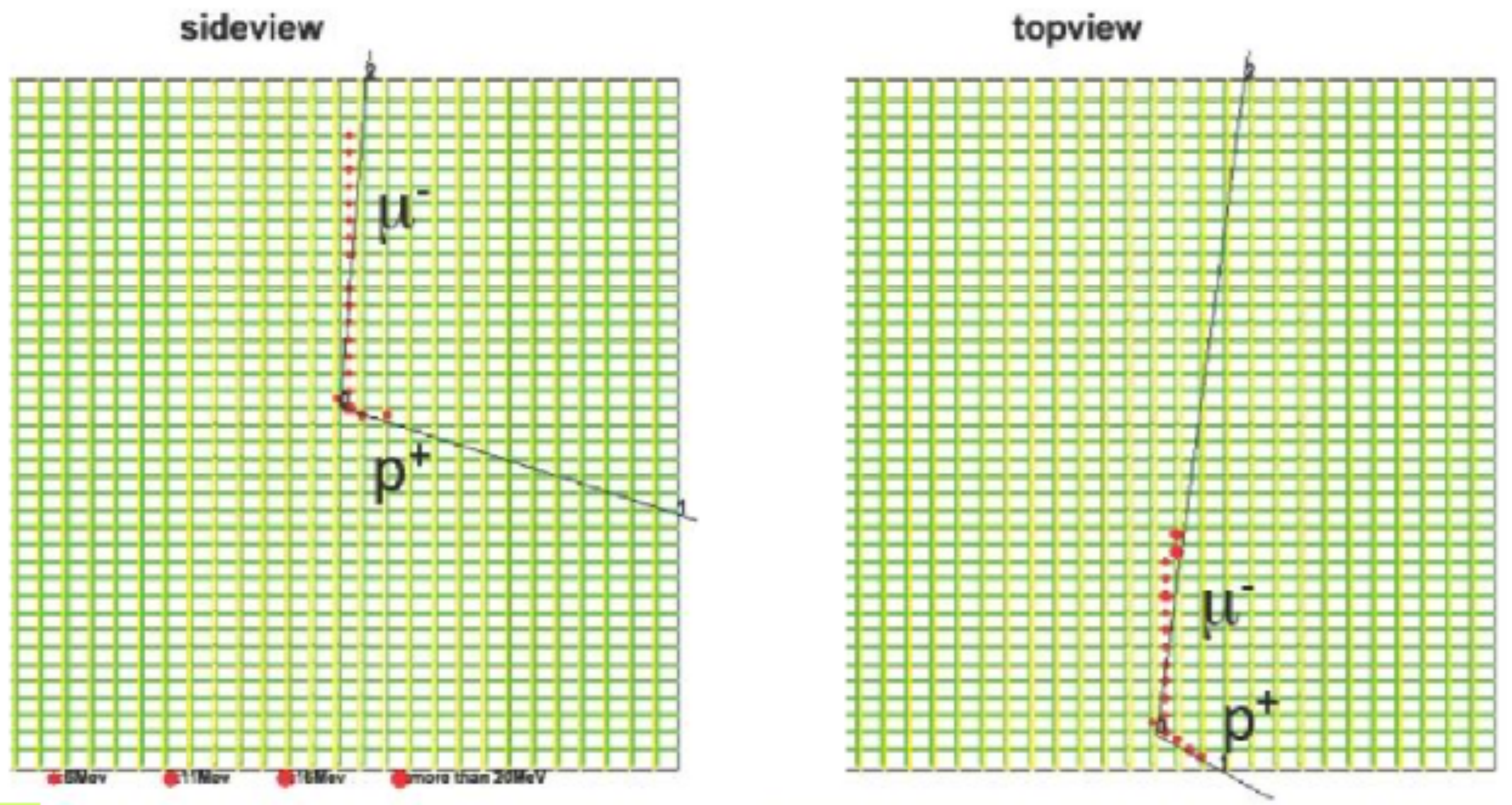
Wagasci collaboration

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







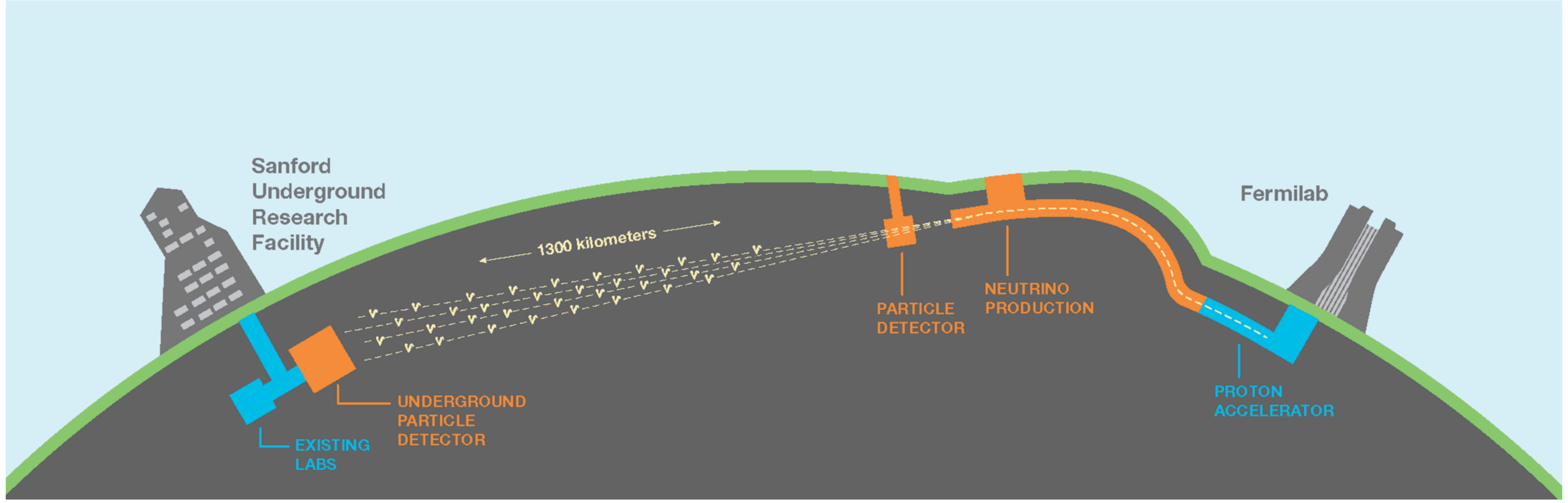


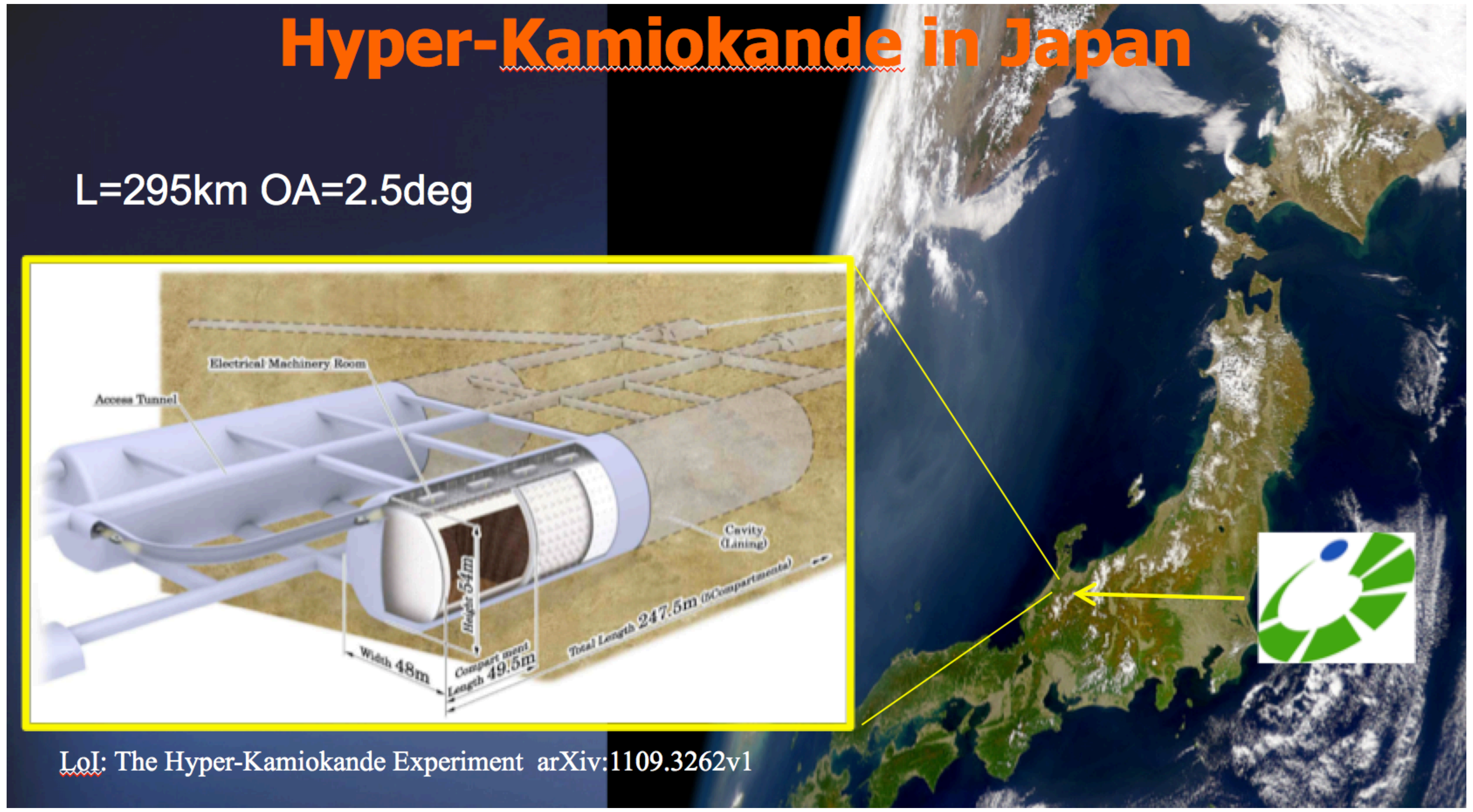
Long baseline neutrino programmes

- 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, …

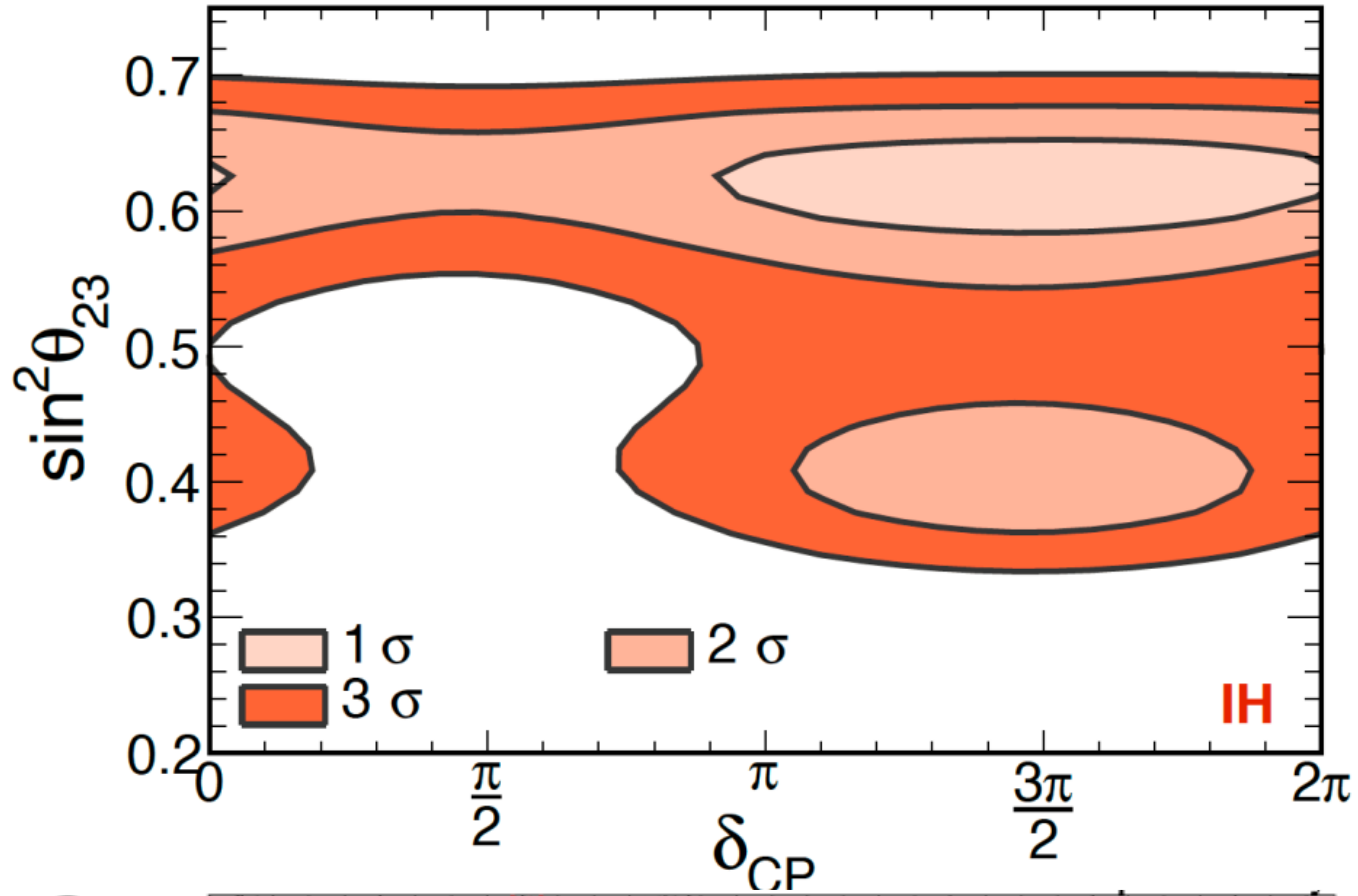




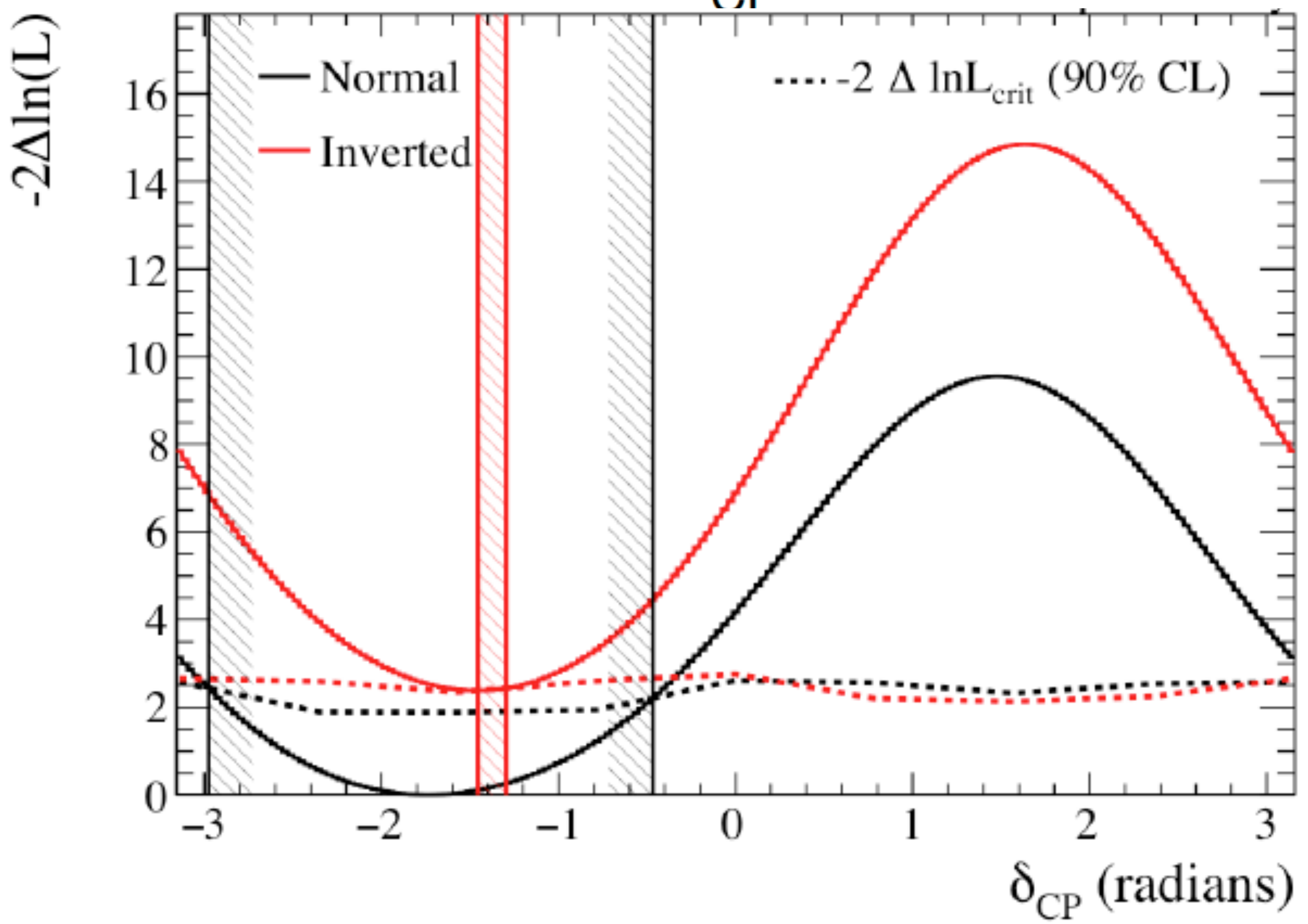
CP violation

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

Nova

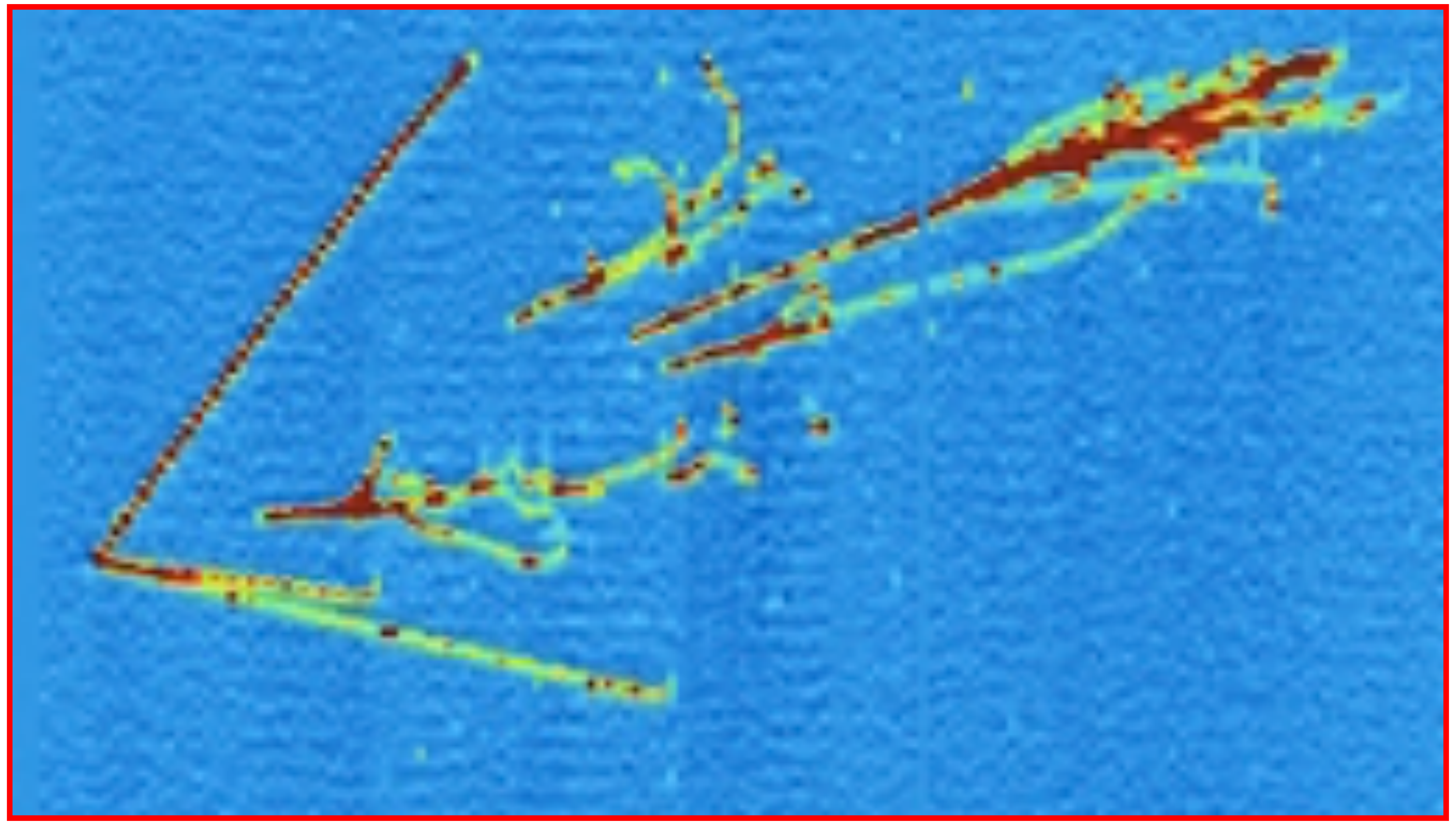


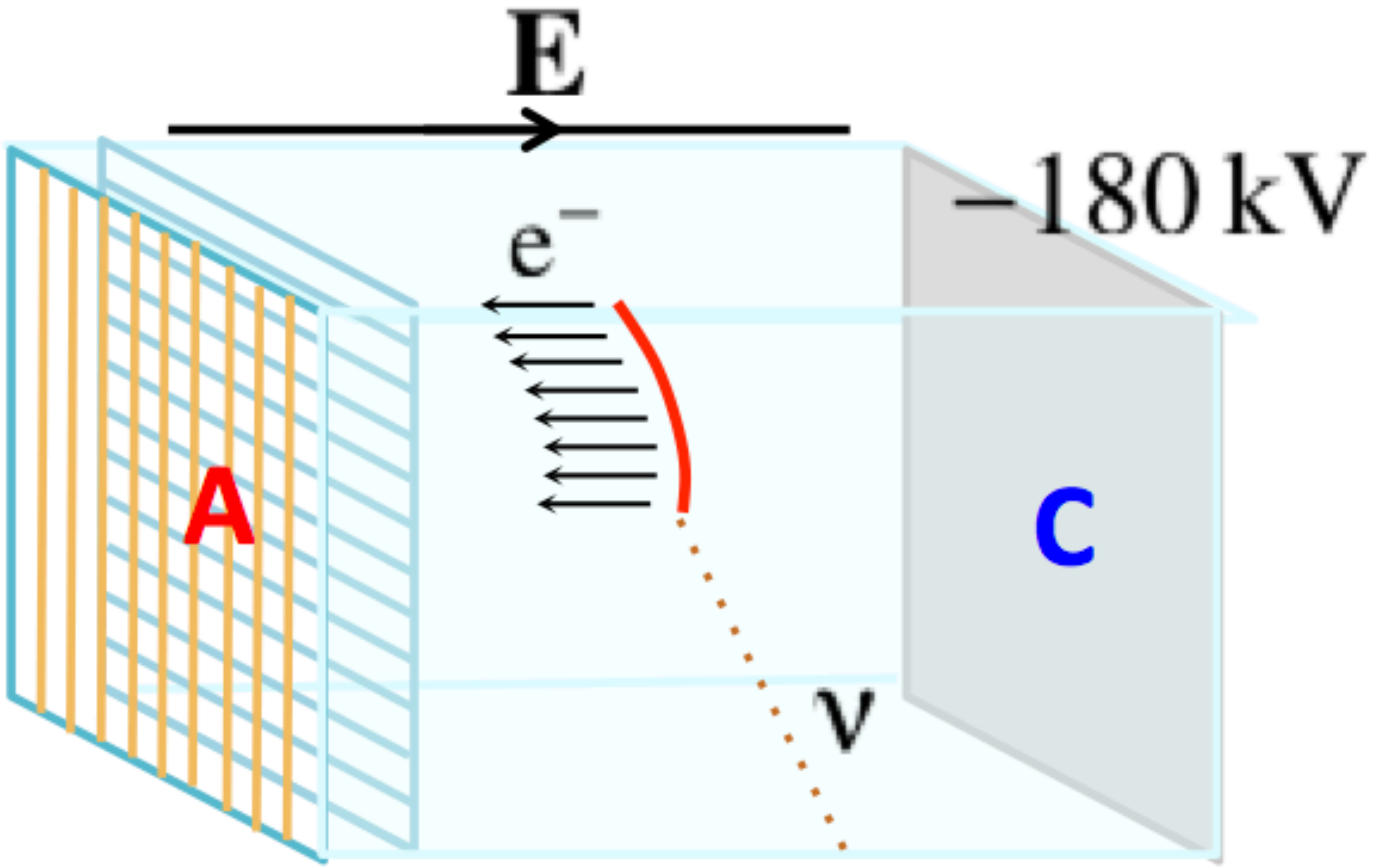
T2K



LAr Technology

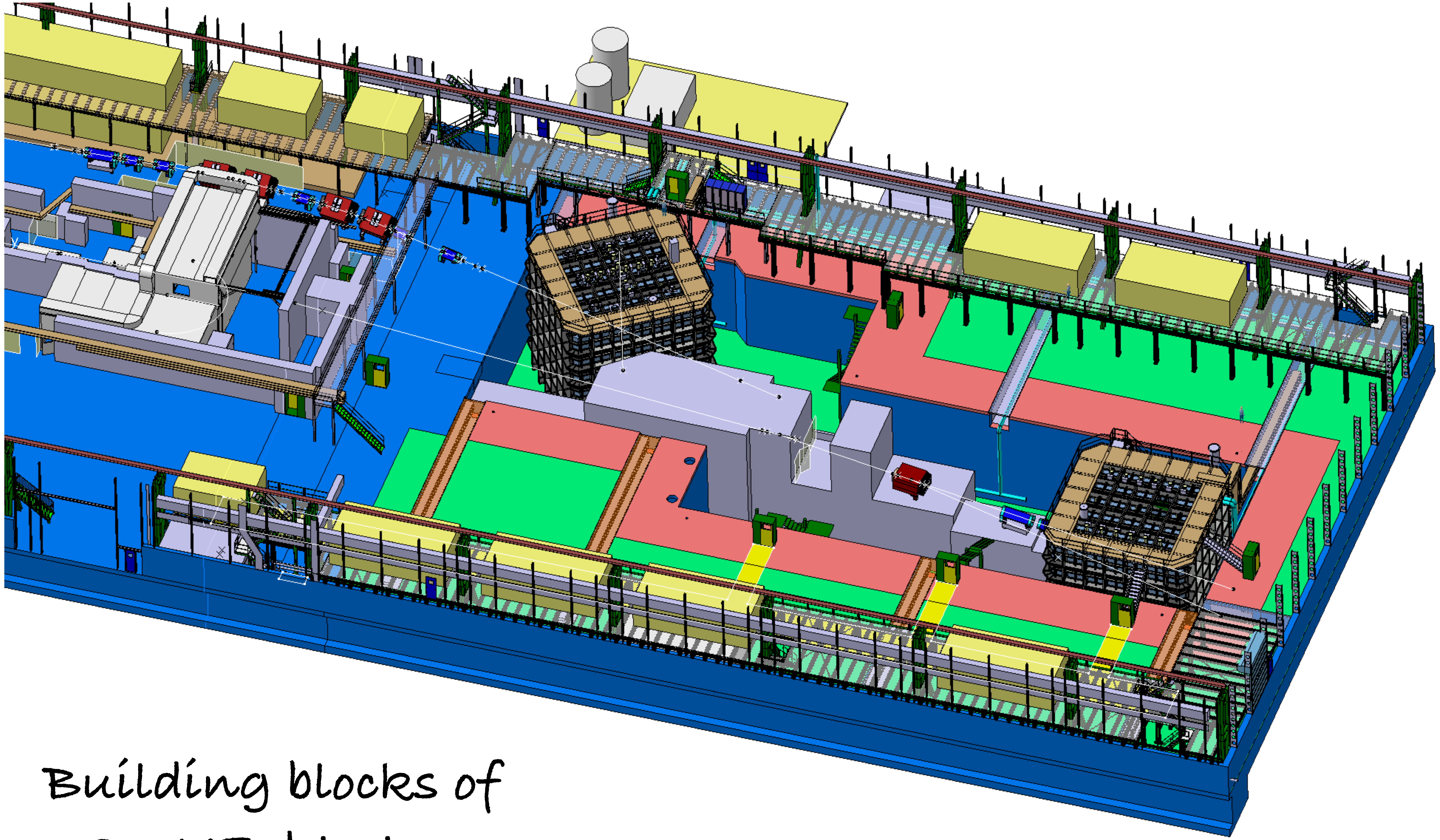
- LarTPC large scale active detectors
    - few mm precision
    - good energy resolution





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

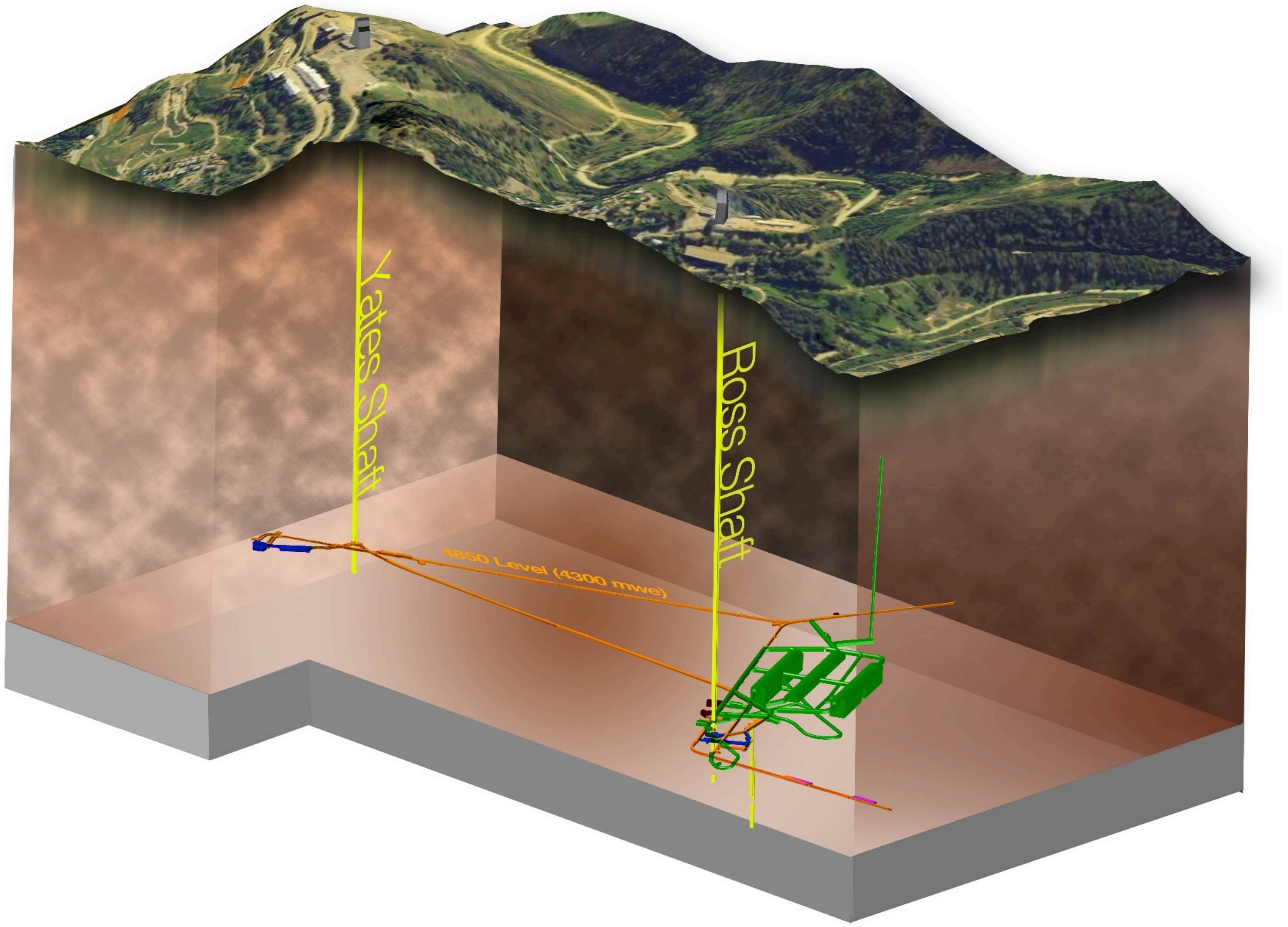
preparing the cryostat inner structures

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)



Summary

- Astroparticle Physics and Particle Physics share many concepts
  - Experimental techniques
    - precision particle spectra
  - Observation of high energy gamma rays and neutrinos spurs additional interest in cosmic accelerators
  - Consistent description of the evolution of the Universe from quantum phase to large scale structures
- Detection of gravitational waves establishes a new observational discipline; multi-messenger identification of neutron star merger is an experimental triumph
  - Graviton is a new particle