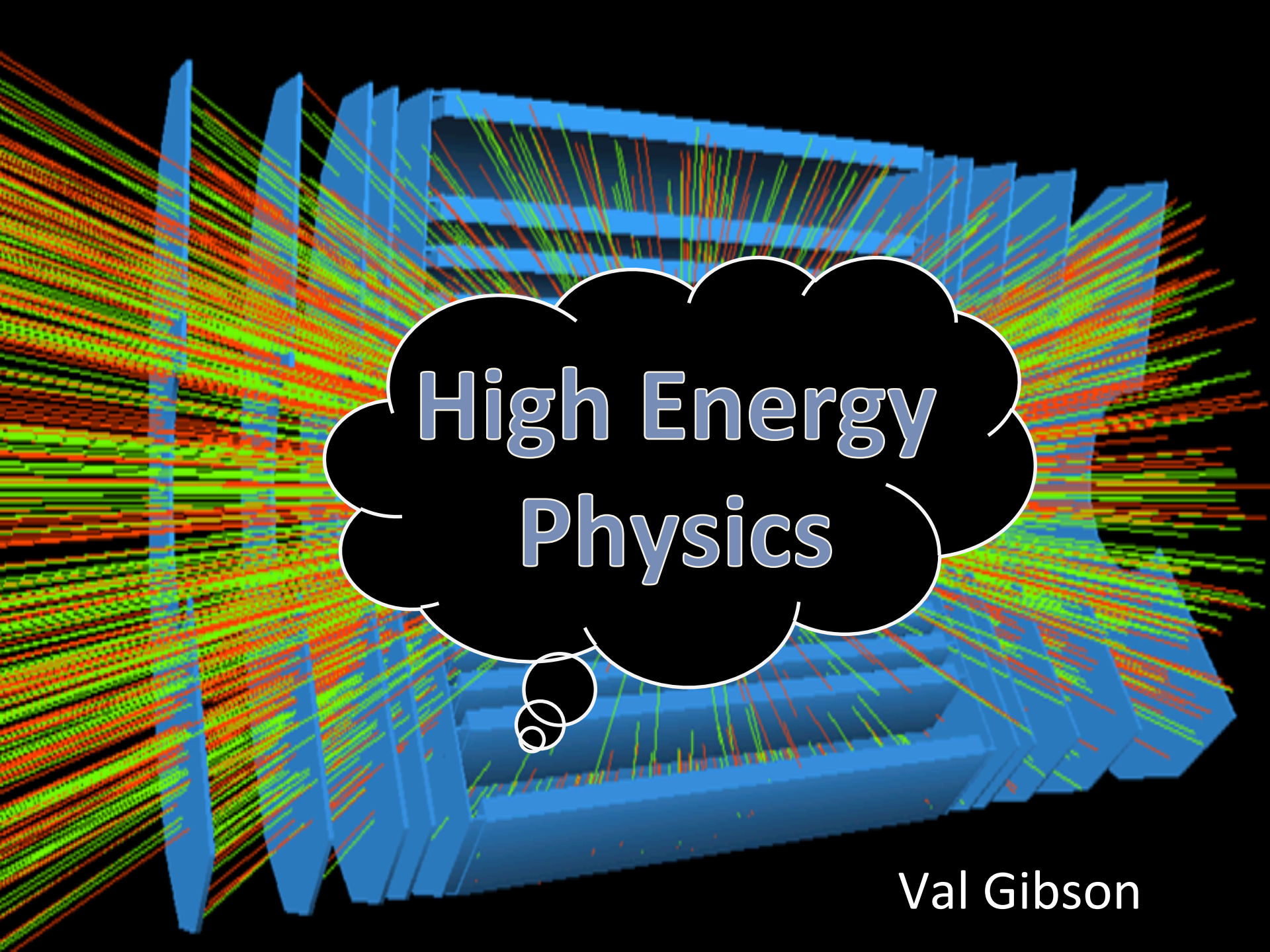
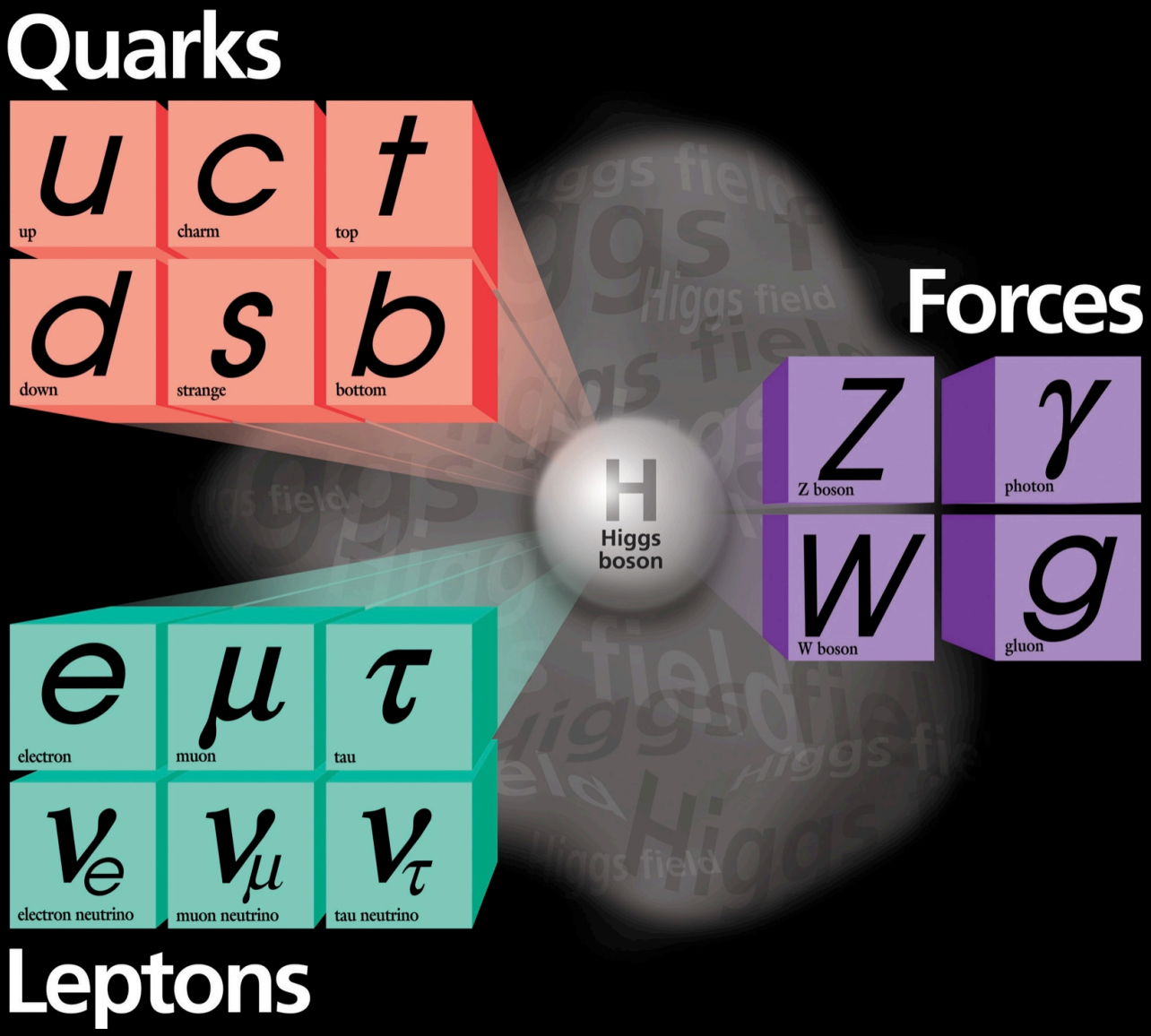


Val Gibson

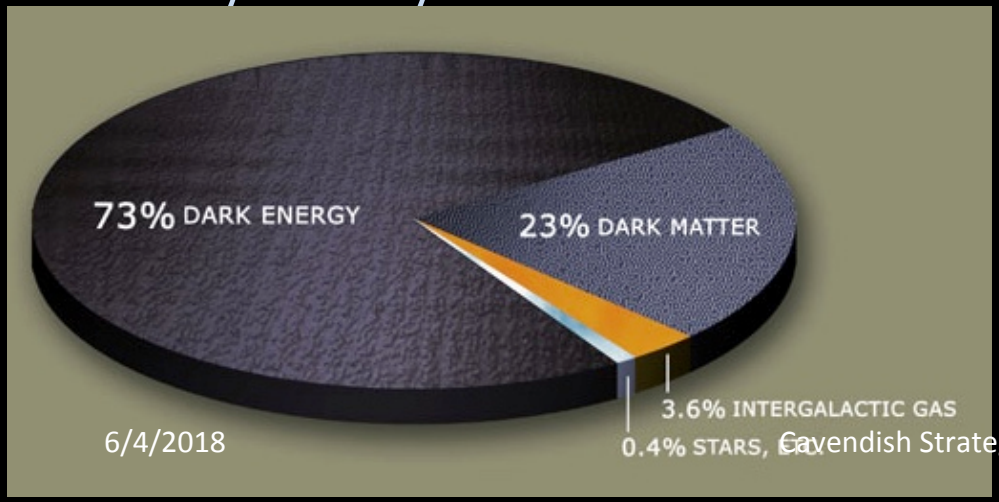
The Standard Model

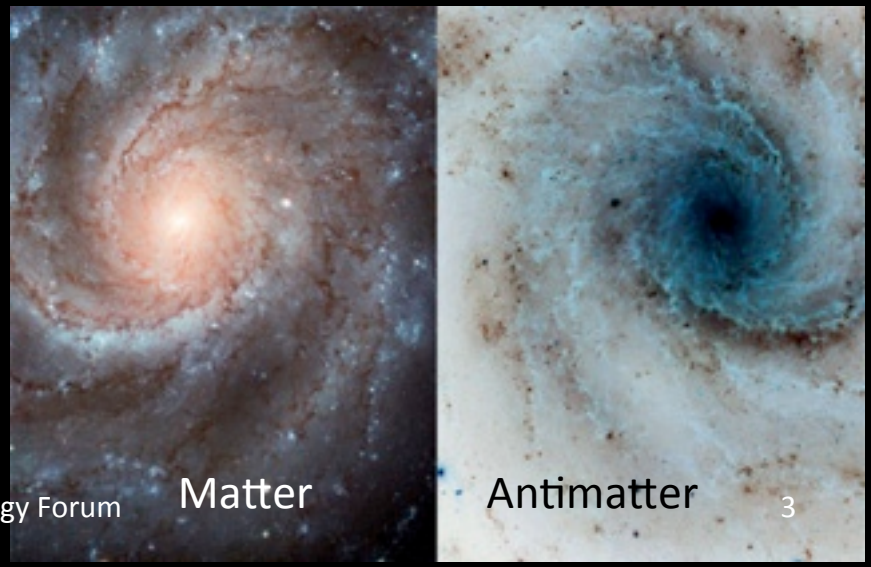


Beyond the Standard Model

Standard Model is an approximate theory

- Higgs sector is "unnatural" (hierarchy problem)
- Neutrino mass is not explained
- Too many free parameters (20 out of a total of 25 from the flavour sector)
- No unification of 4 forces
- No explanation of dark matter, dark energy
- There must be more "CP violation" for observed matter-antimatter asymmetry





HEP Priorities

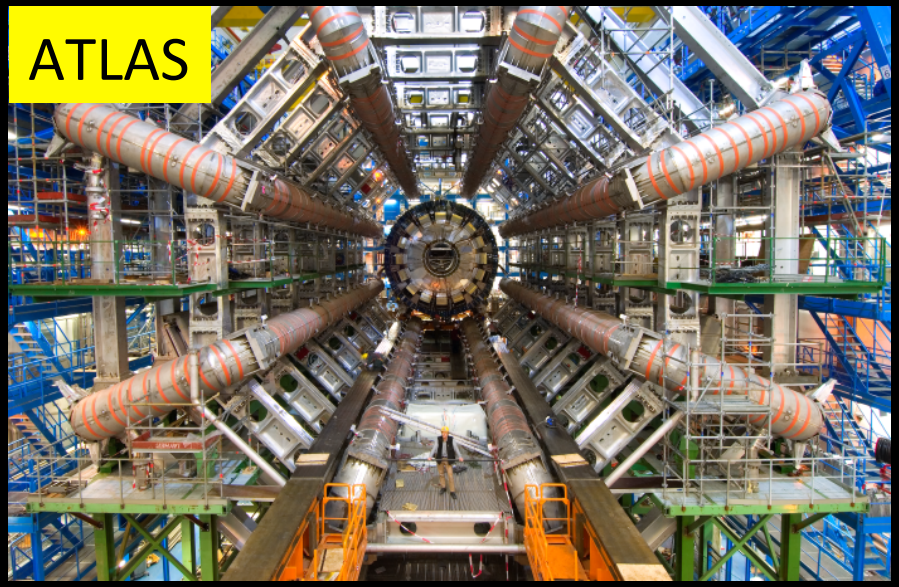
Scientific priorities follow the 4 recommendations from the "European Strategy for Particle Physics" (2013) for accelerator-based activities (& STFC).

- Exploitation of the full-potential of the LHC.
- Major participation in a long base-line neutrino programme.
- High-energy frontier, post-LHC, CERN accelerator.
- International Linear Collider for high-precision studies.

"European Strategy for Particle Physics" Update May 2020

Overview of HEP Projects

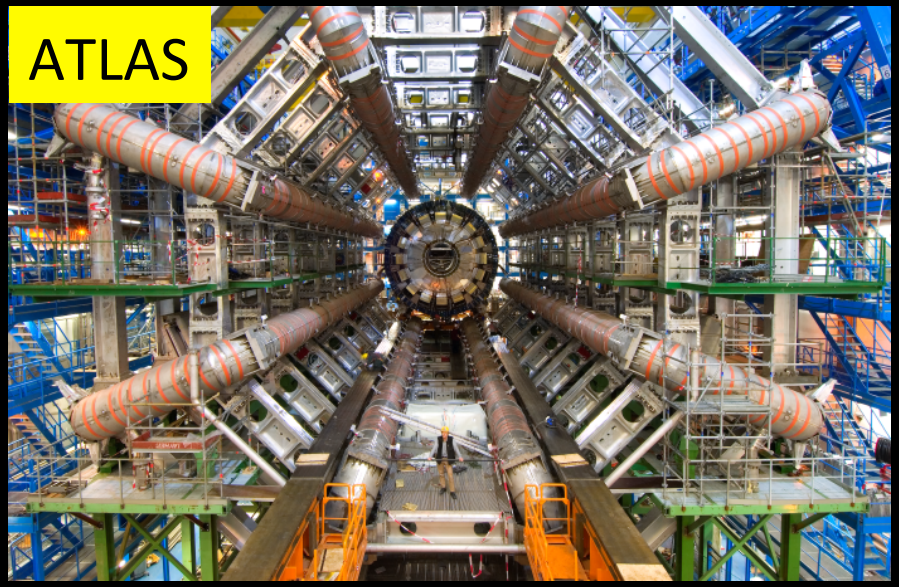
ATLAS



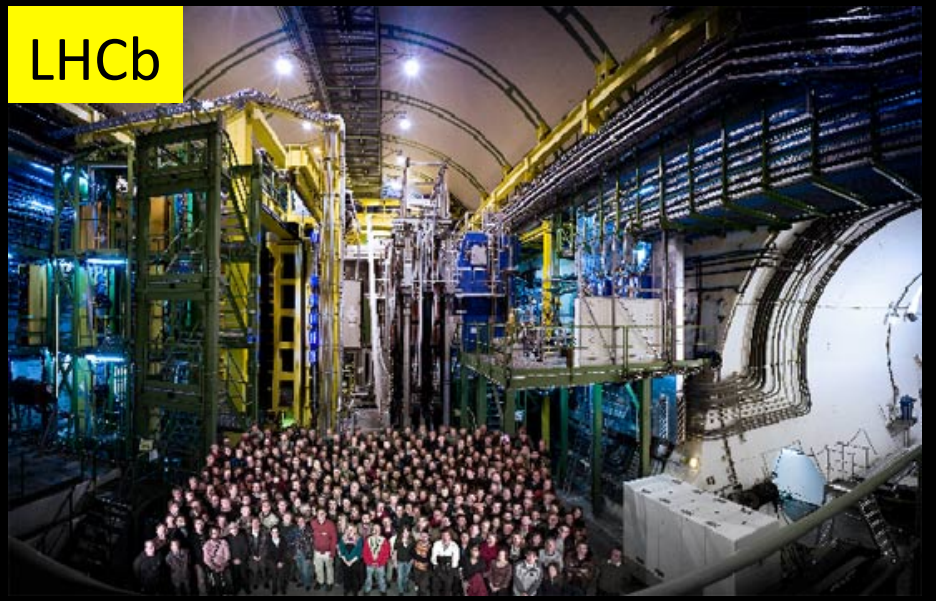
LHCb

Overview of HEP Projects

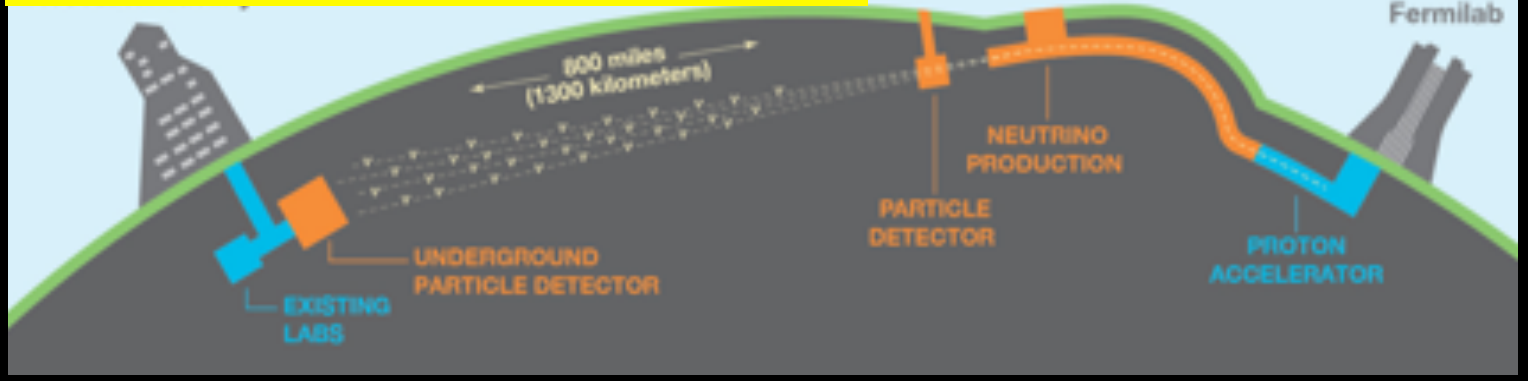
ATLAS



LHCb

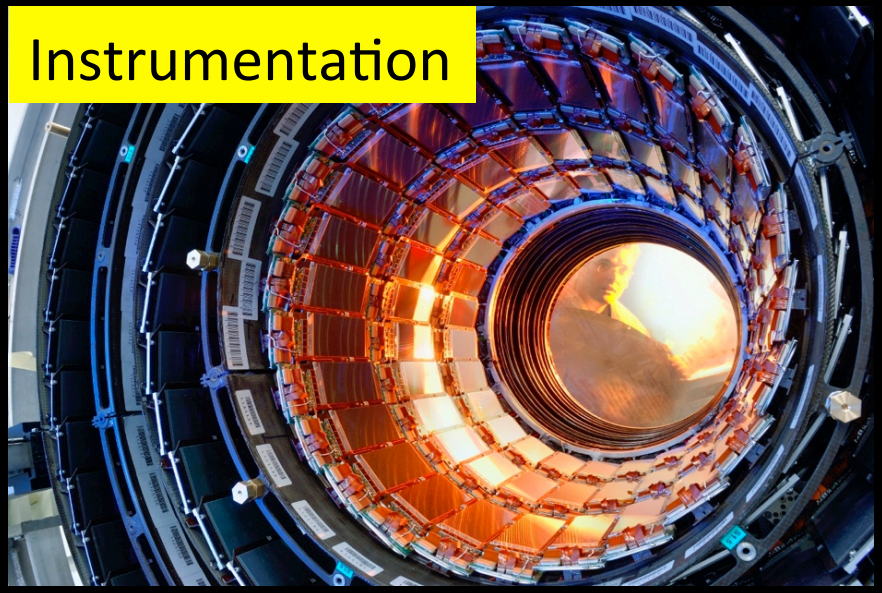


Neutrinos (MicroBooNE/DUNE)

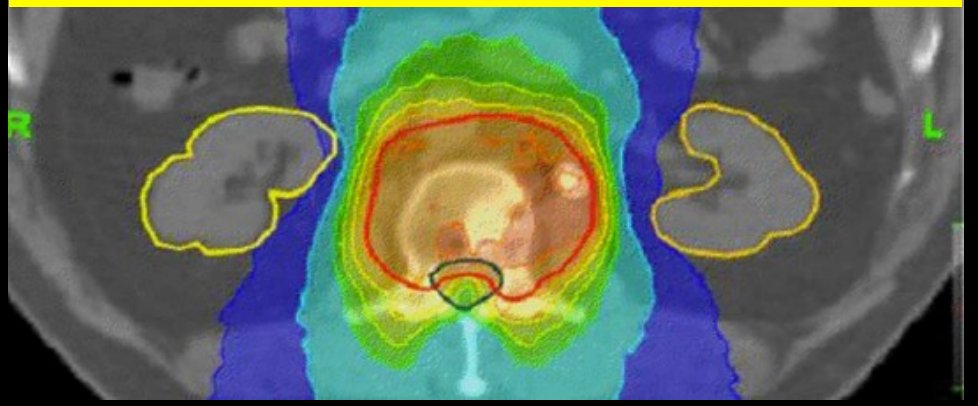


Overview of HEP Projects

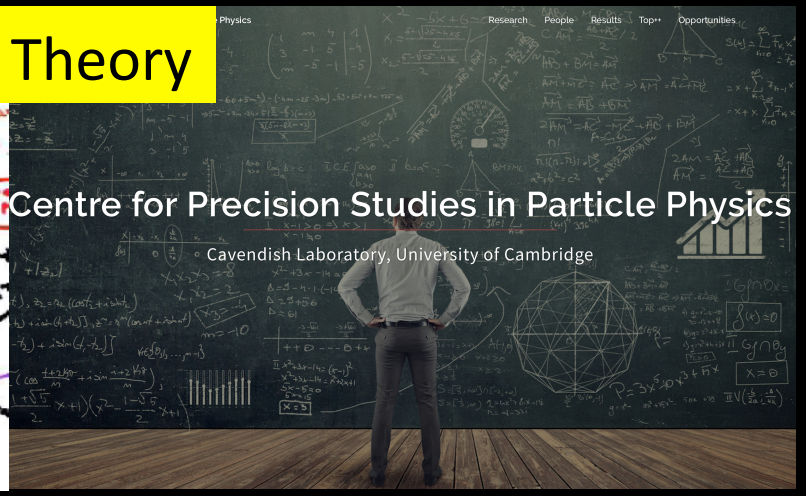
Instrumentation



Impact: outreach, comp radiotherapy, security



HEP Theory



Overview of HEP Projects

ATLAS

Richard Batley
Chris Lester
Andy Parker
Tina Potter (ECL)
+1 Lecturer

John Chapman
Will Fawcett
John Hill
Pat Ward

Sarah Williams
5 PhD, 2 MPhil students

LHCb

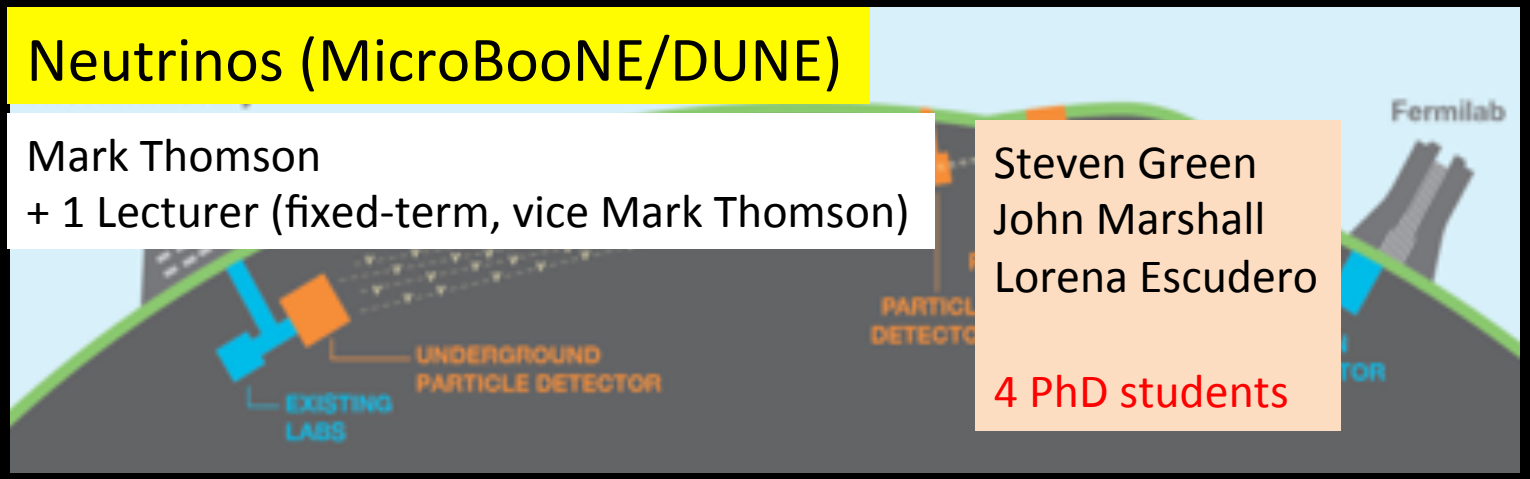
Val Gibson
Marc-Olivier Bettler

Jordi Garra Tico
Chris Jones

Susan Haines
Harry Cliff
Matt Kenzie

7 PhD students

Neutrinos (MicroBooNE/DUNE)



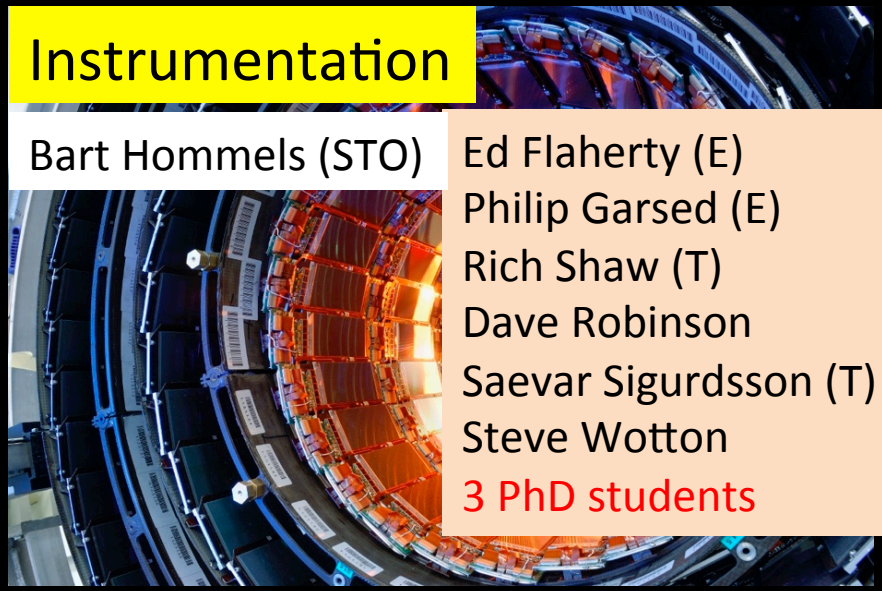
Mark Thomson
+ 1 Lecturer (fixed-term, vice Mark Thomson)

Steven Green
John Marshall
Lorena Escudero

4 PhD students

Overview of HEP Projects

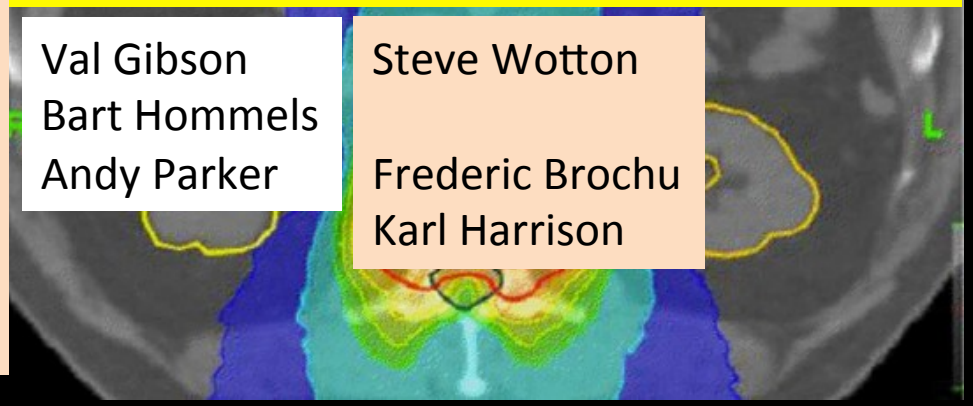
Instrumentation



Bart Hommels (STO)

Ed Flaherty (E)
Philip Garsed (E)
Rich Shaw (T)
Dave Robinson
Saevar Sigurdsson (T)
Steve Wotton
3 PhD students

Impact: outreach, comp radiotherapy, security



Val Gibson
Bart Hommels
Andy Parker

Steve Wotton

Frederic Brochu
Karl Harrison

HEP Theory

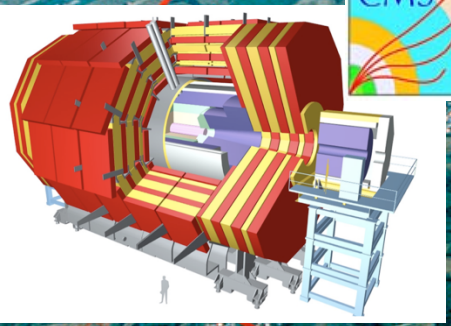
Ben Gripaios
Alex Mitov

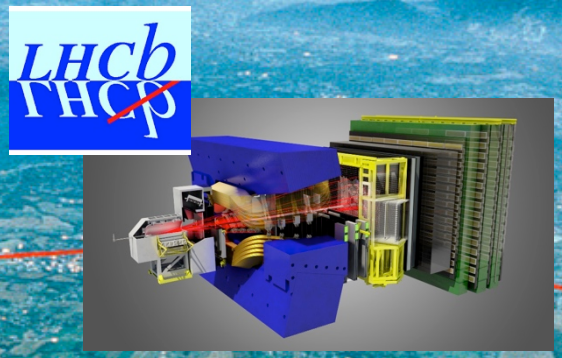
Stefano Boselli
Zahari Kassabov
Andrew Papanastasiou

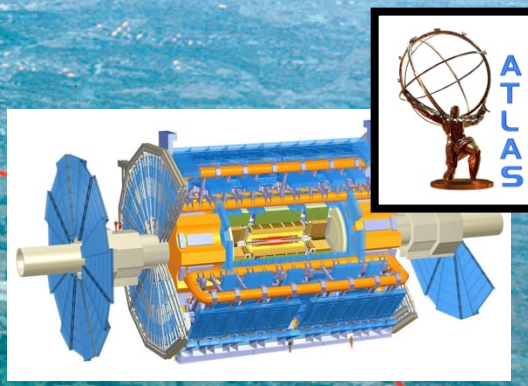
Maria Ubiali
Tevong You

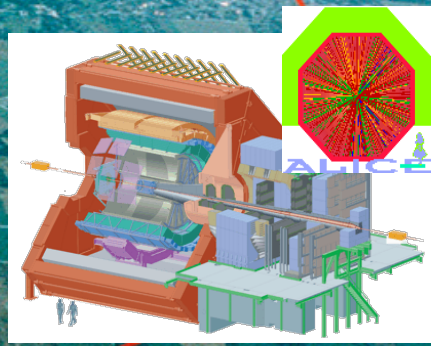
4 PhD students

The Large Hadron Collider

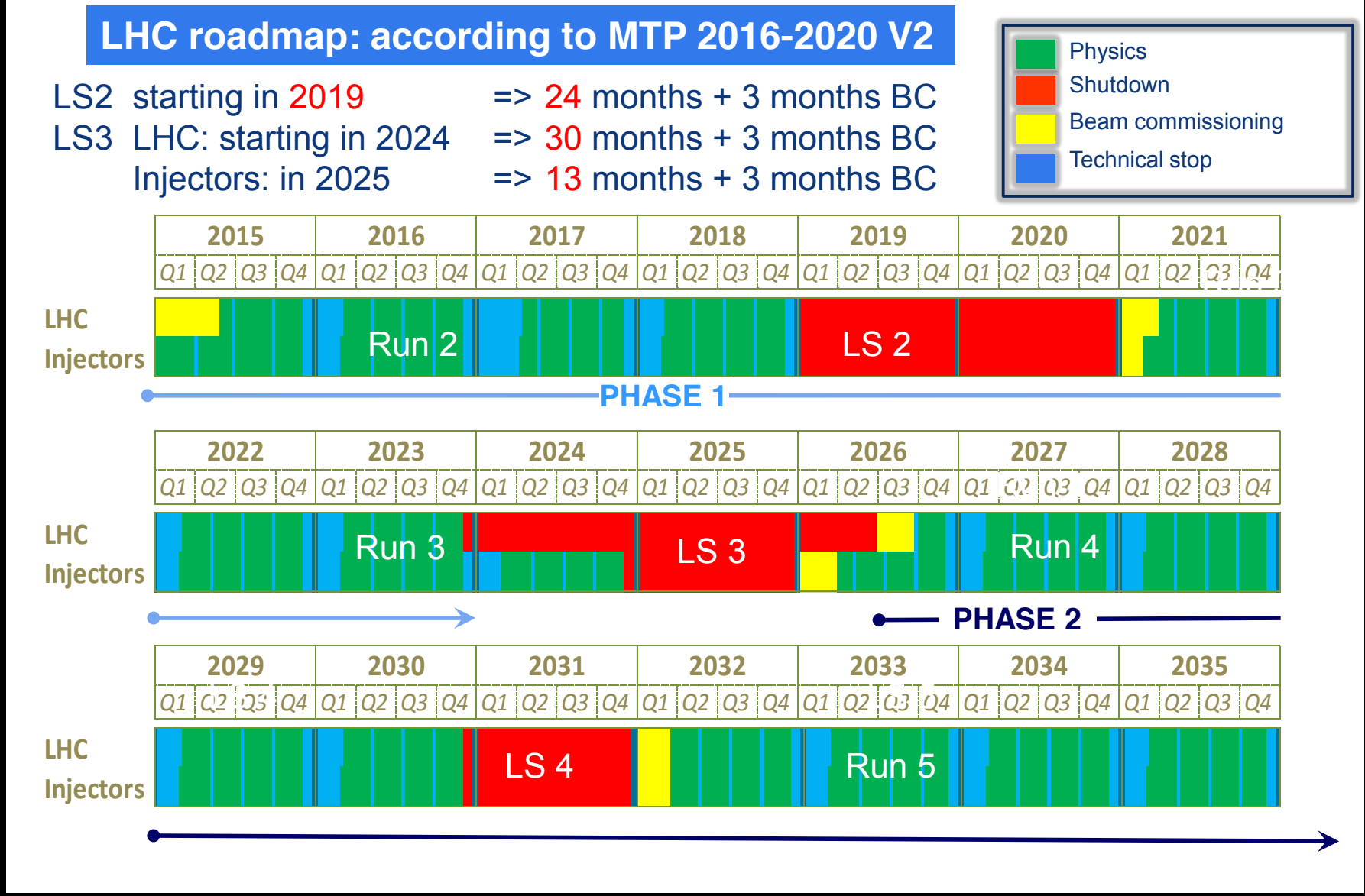








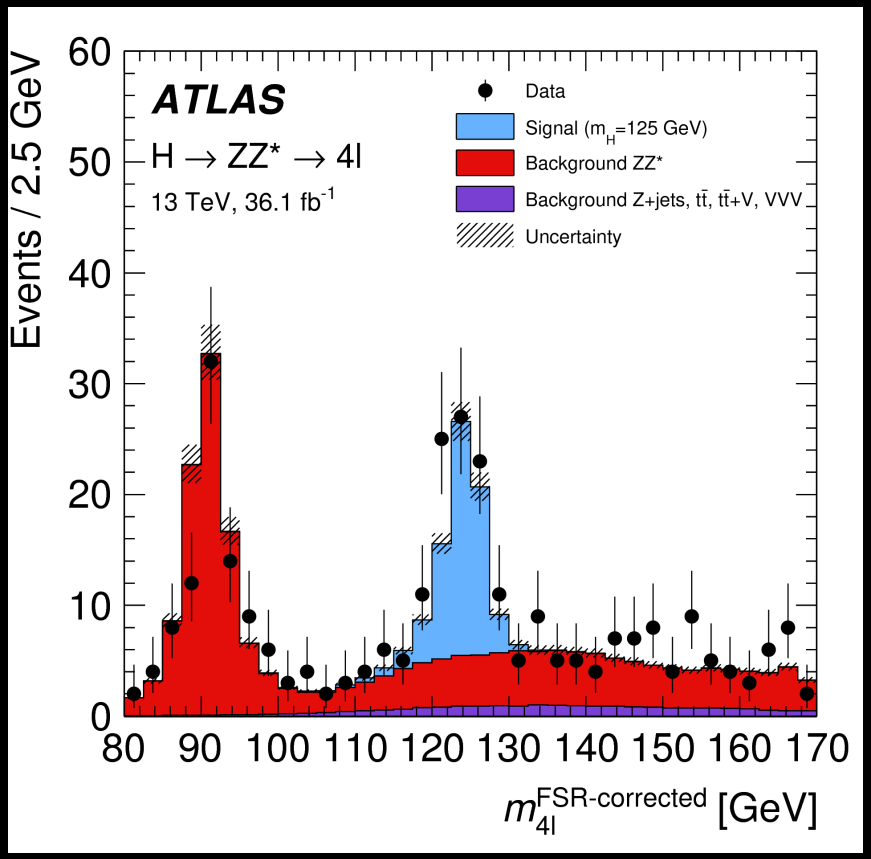
Large Hadron Collider

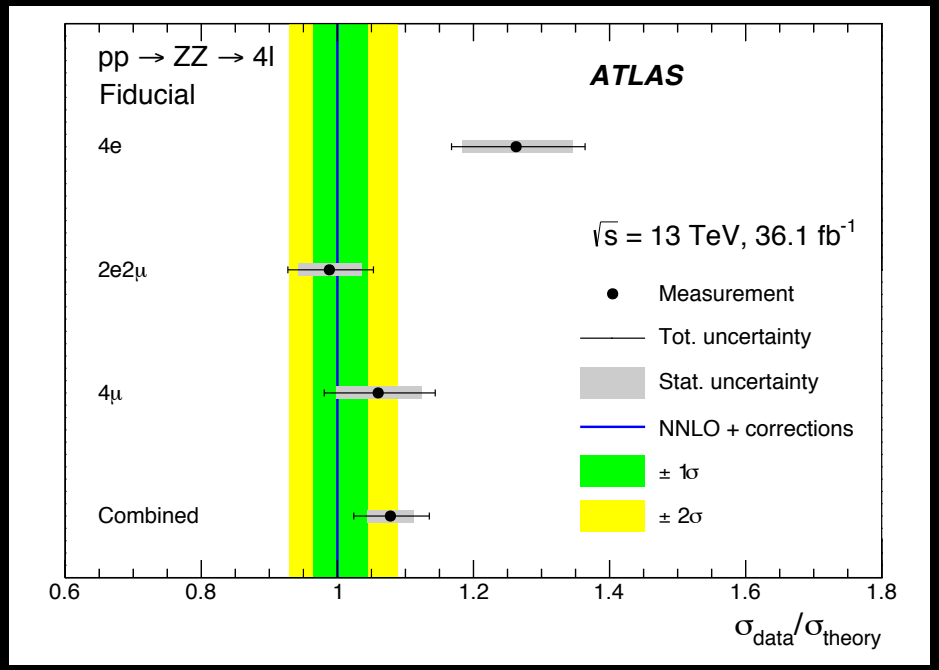


ATLAS: Standard Model

Batley et al

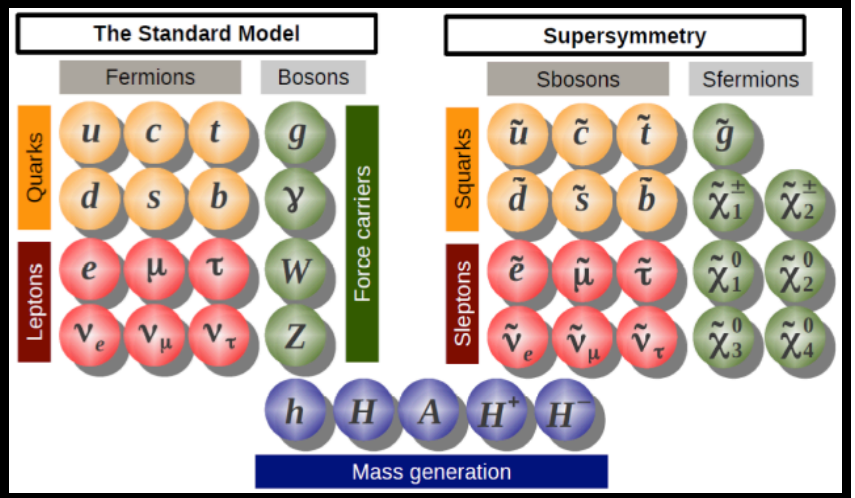
Precision measurements of the Standard Model Higgs and others…. no surprises

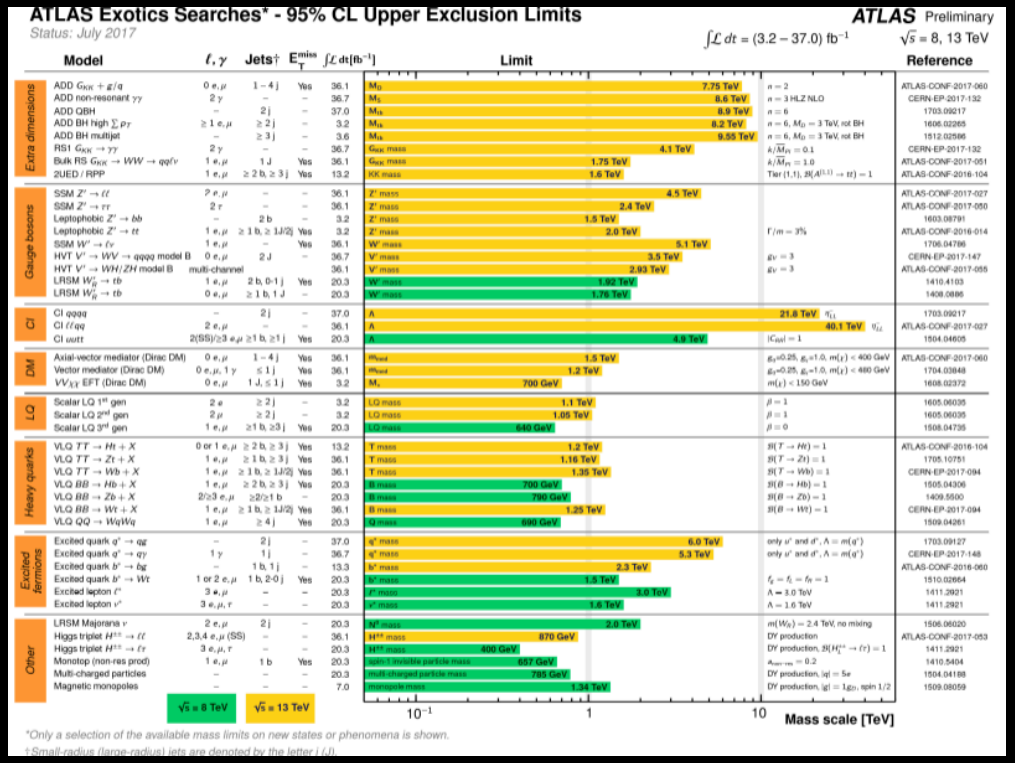




ATLAS BSM Lester, Parker, Potter et al

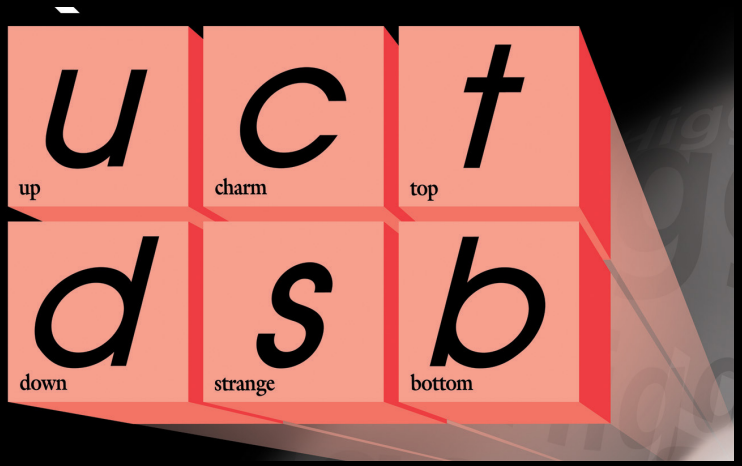
SUSY, extra dimensions… as LHC runs continue, we push to improve sensitivity to difficult/rare/high mass scenarios (compressed mass spectra, low cross-section, SM-like…).

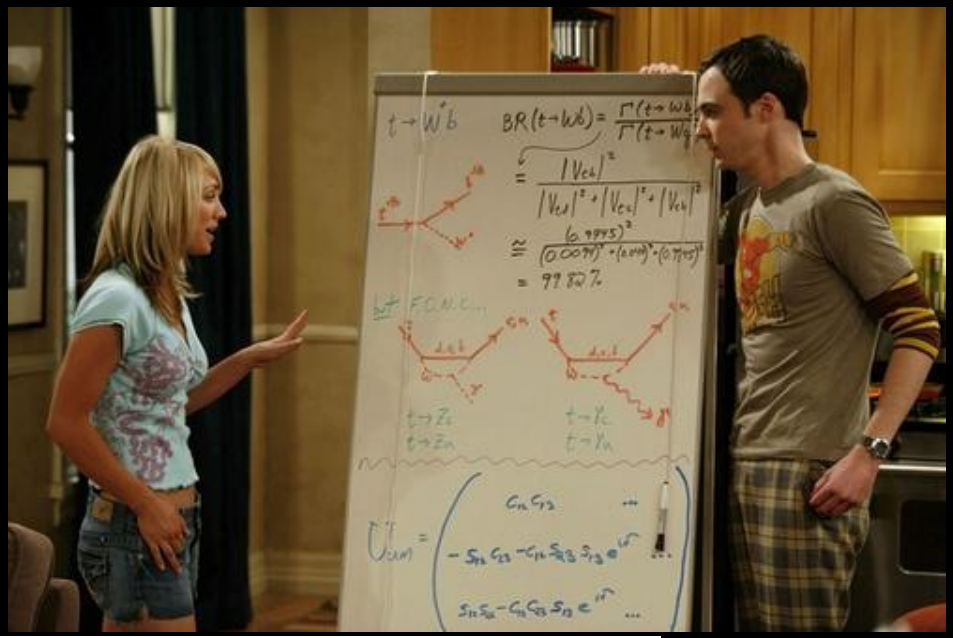


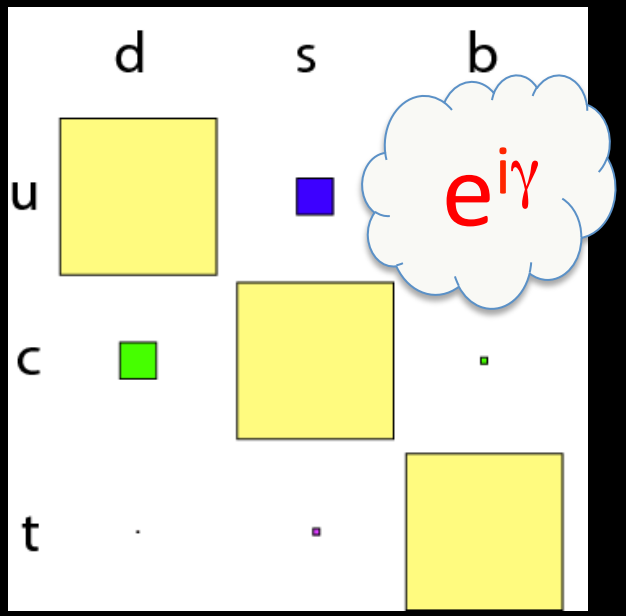


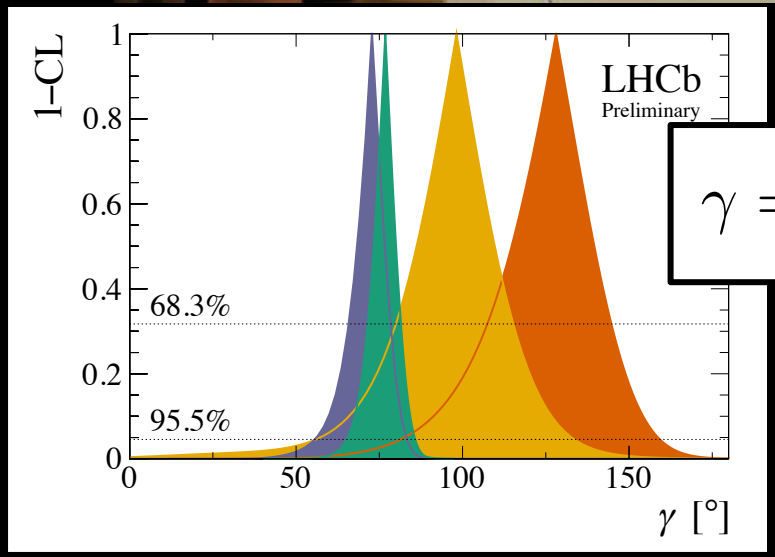
LHCb: CP Violation

Gibson et al









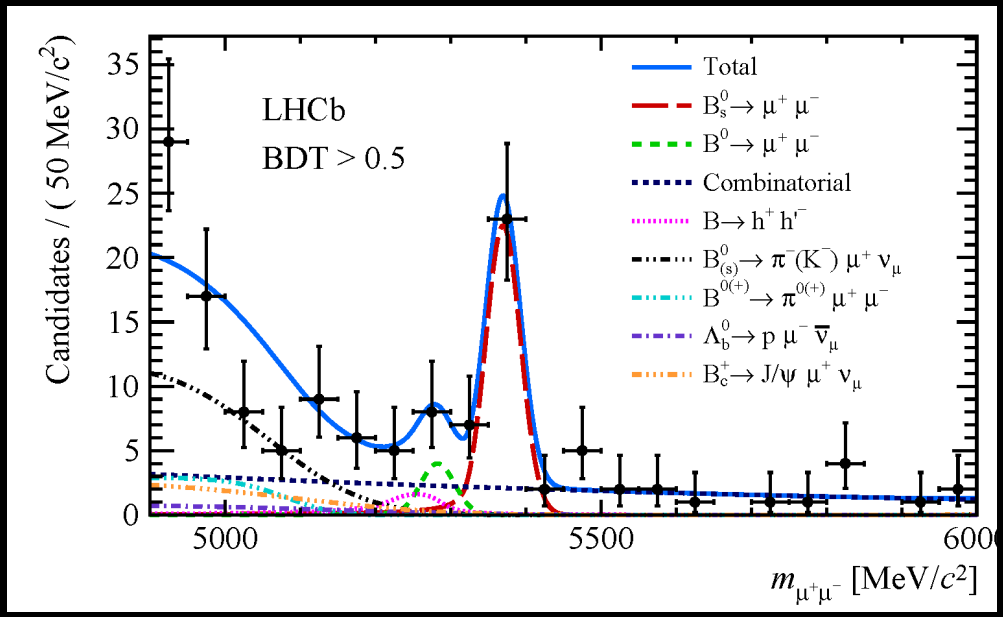
$$\gamma = (76.8\,^{+5.1}_{-5.7})^\circ$$

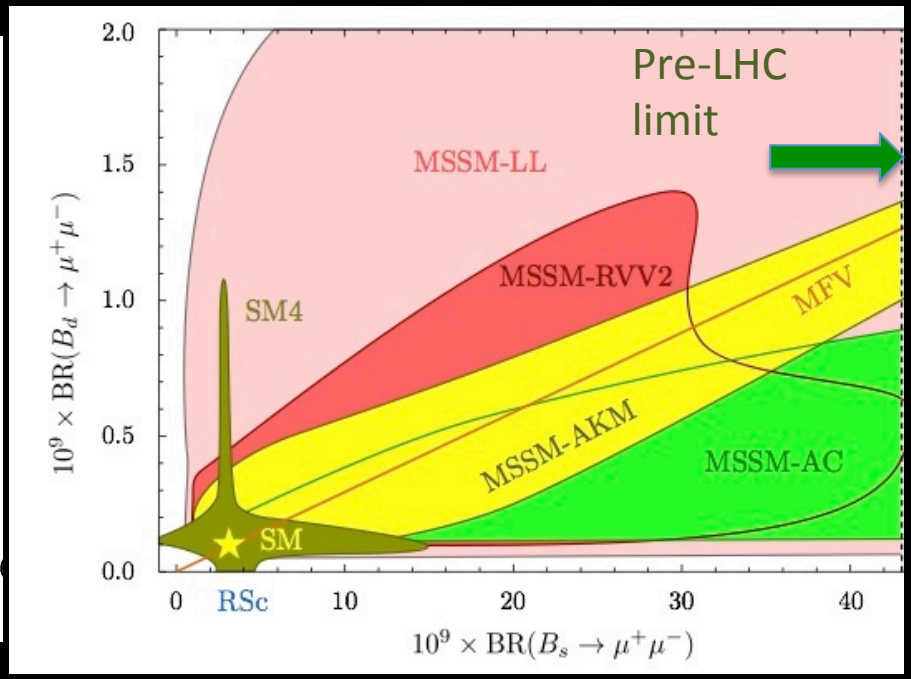
LHCb: Rare B Decays

Bettler, Gibson et al

$B_s \to \mu^+\mu^-$ is a golden place to search for New Physics!

Expect one B_s to decay into 2 muons once every 3.7 billion decays (1 every 2 trillion pp collisions at LHCb).





$$B(B_s \to \mu^+\mu^-) = (3.0 \pm 0.6\,^{+0.3}_{-0.2}) \times 10^{-9}$$

7.8σ

LHCb: Rare B Decays

Bettler, Gibson et al

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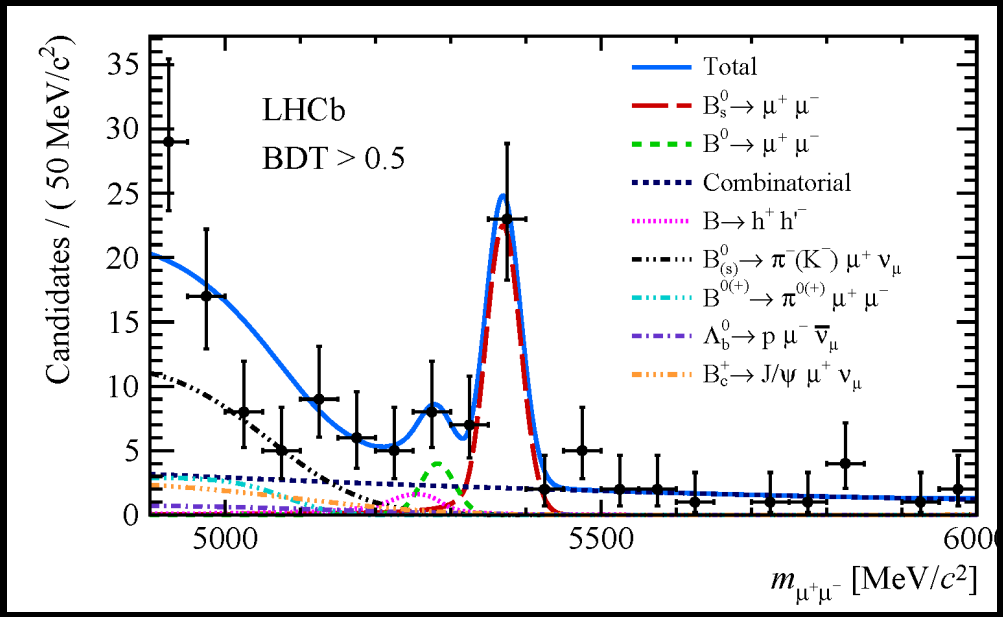
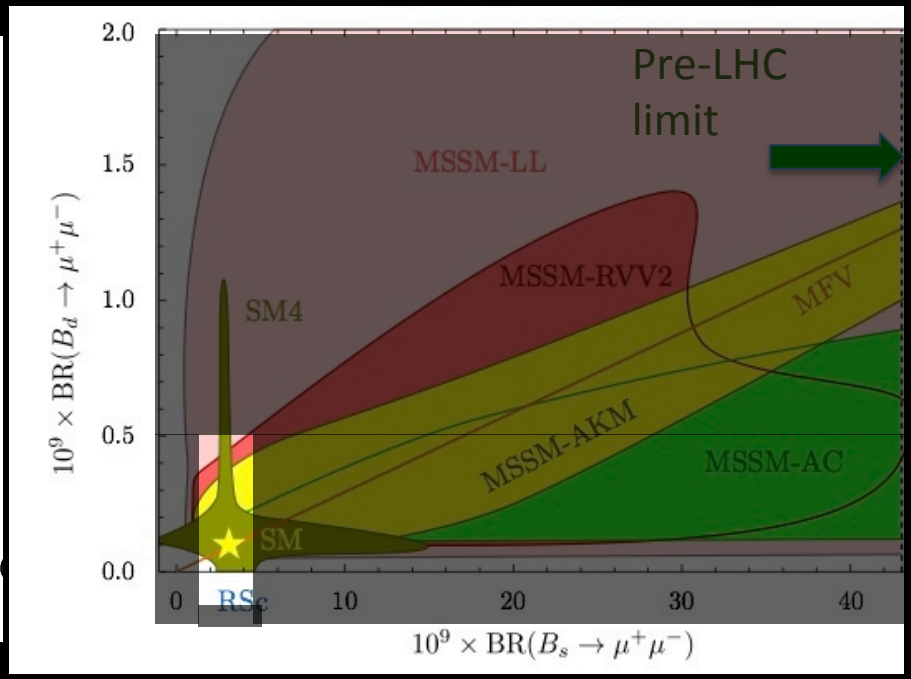




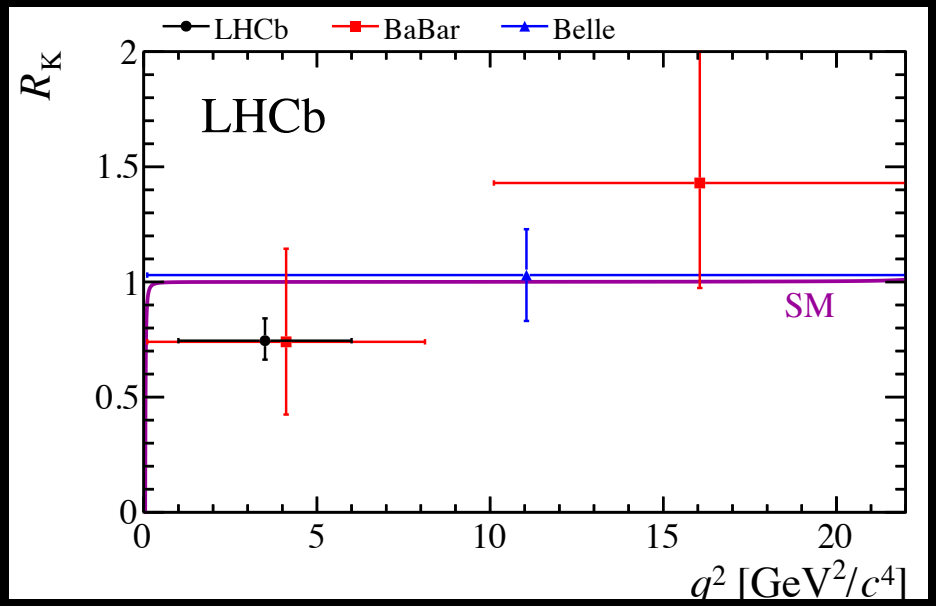
$$B\left(B_s \to \mu^+\mu^-\right) = \left(3.0 \pm 0.6\,^{+0.3}_{-0.2}\right) \times 10^{-9}$$

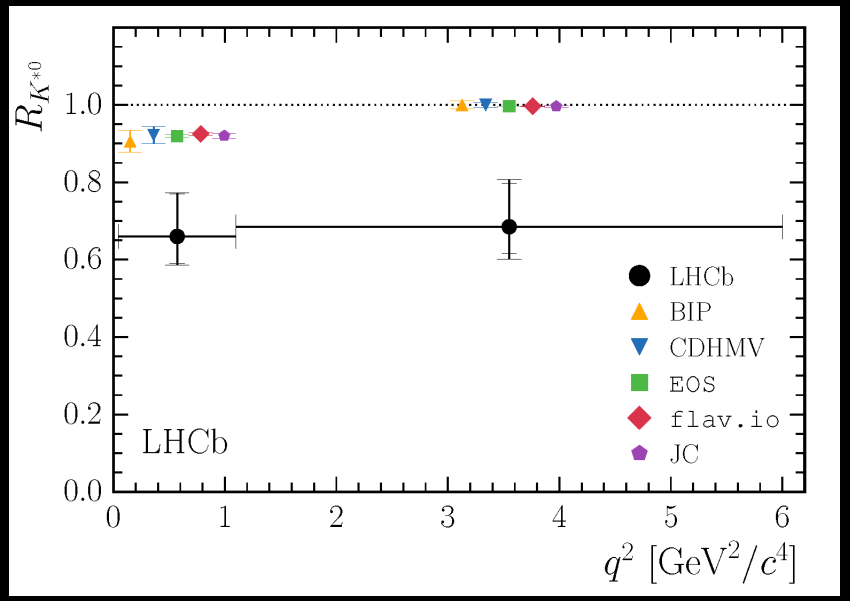
7.8σ

LHCb: Intriguing Anomalies

Bettler, Gibson et al

SM predicts that the W boson should interact with electrons, muons and tau leptons the same (lepton universality).



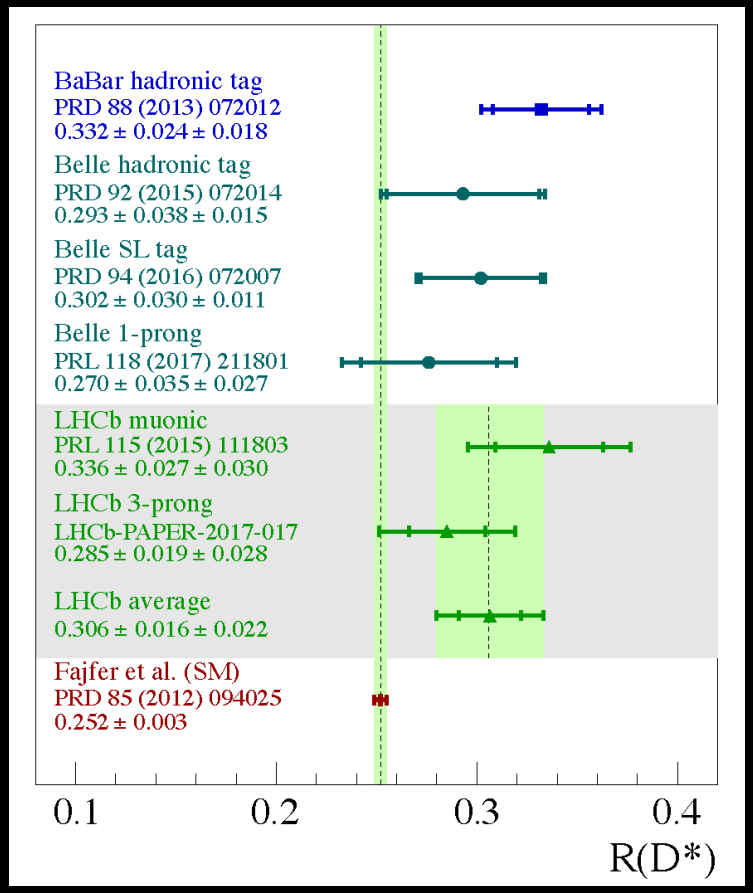


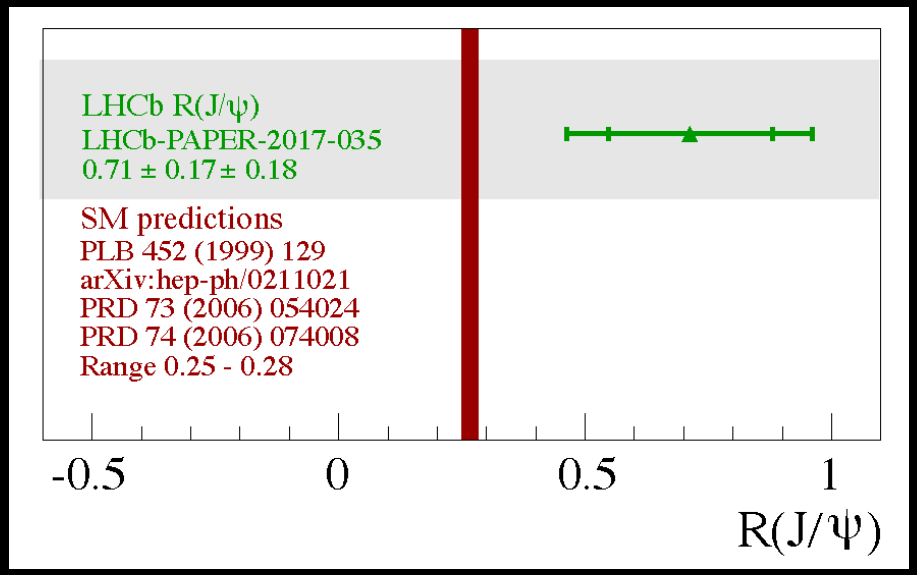
$$R(K) = \frac{B\left(B^+ \to K^+ \mu^+ \mu^-\right)}{B\left(B^+ \to K^+ e^+ e^-\right)}$$

$$R(K^*) = \frac{B\left(B^0 \to K^{*0} \mu^+ \mu^-\right)}{B\left(B^0 \to K^{*0} e^+ e^-\right)}$$

e–μ Lepton Non-Universality ??

LHCb: Intriguing Anomalies





$$R(J/\psi) = \frac{B(B_c^+ \to J/\psi \tau^+ \nu_\tau)}{B(B_c^+ \to J/\psi \mu^+ \nu_\mu)}$$

$$R(D^*) = \frac{B(B^0 \to D^{*-} \tau^+ \nu_\tau)}{B(B^0 \to D^{*-} \mu^+ \nu_\mu)}$$

μ–τ Lepton Non-Universality ??

HEP Theory

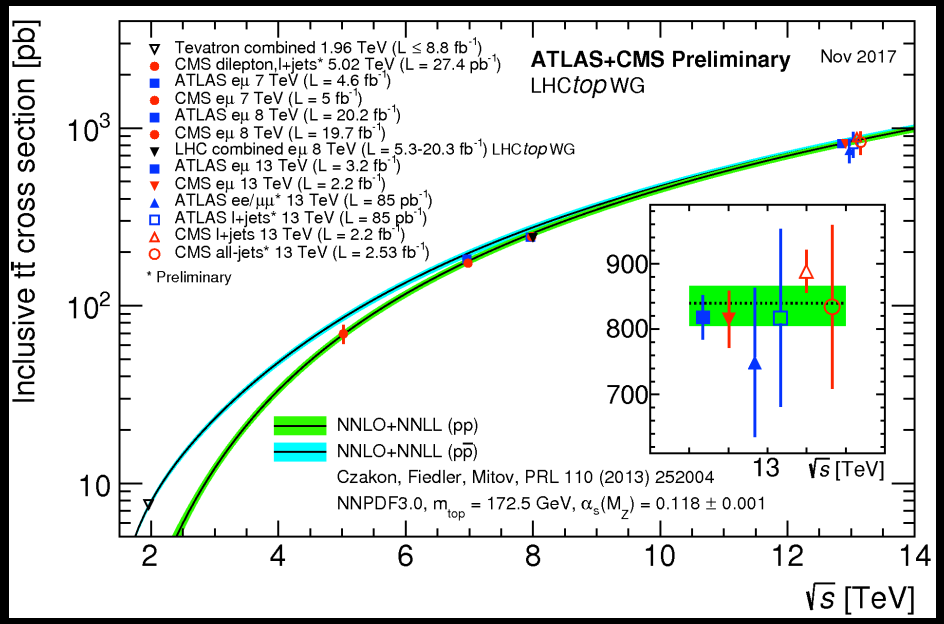
Centre for Precision Studies: Alex Mitov

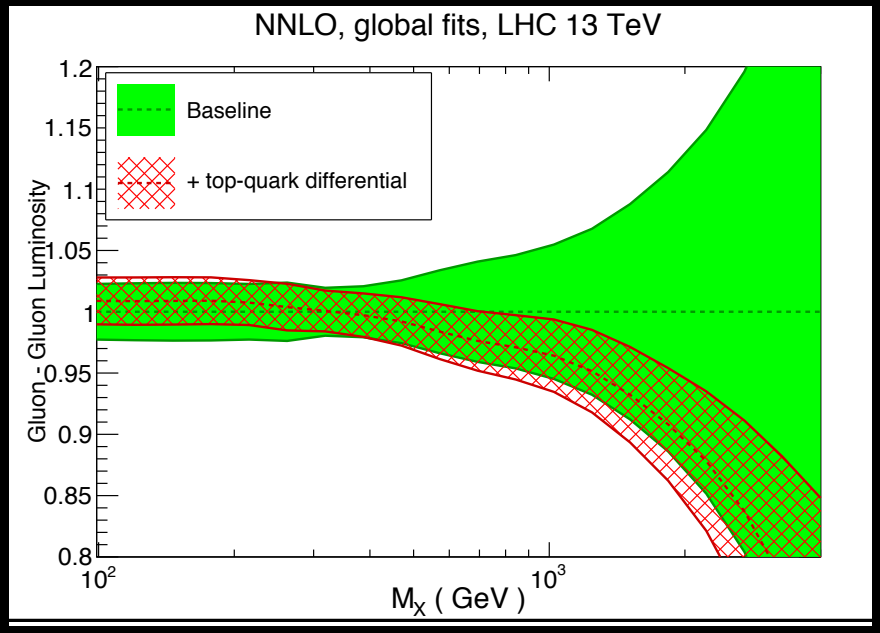
- Focus on top quark production

HEP Theory

Centre for Precision Studies: Alex Mitov

- Focus on top quark production





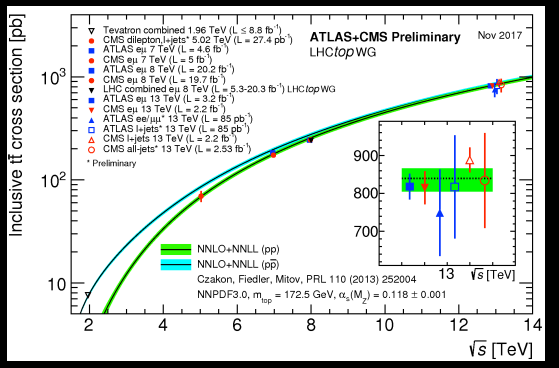
Most precise calculation of top pair production

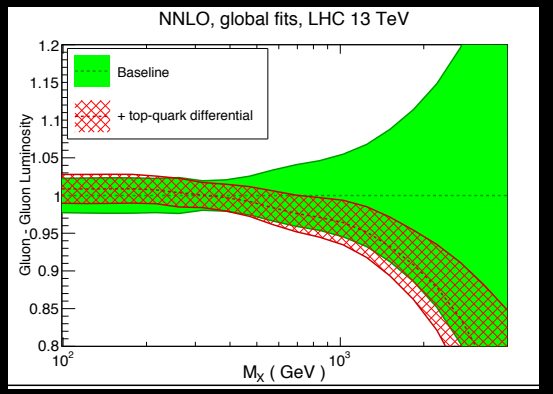
Uncertainty on gluon parton distribution function

HEP Theory

Centre for Precision Studies: Alex Mitov

- Focus on top quark production





Beyond Standard Model: Ben Gripaios

- Motivations as strong as ever
- LHC legacy: what will next-generation theorists wish had been measured?
- Lepton Flavour Universality & B-decay anomalies
- What is dark matter (underground/overground, gravity waves, thermal relic ν, hidden sector)?

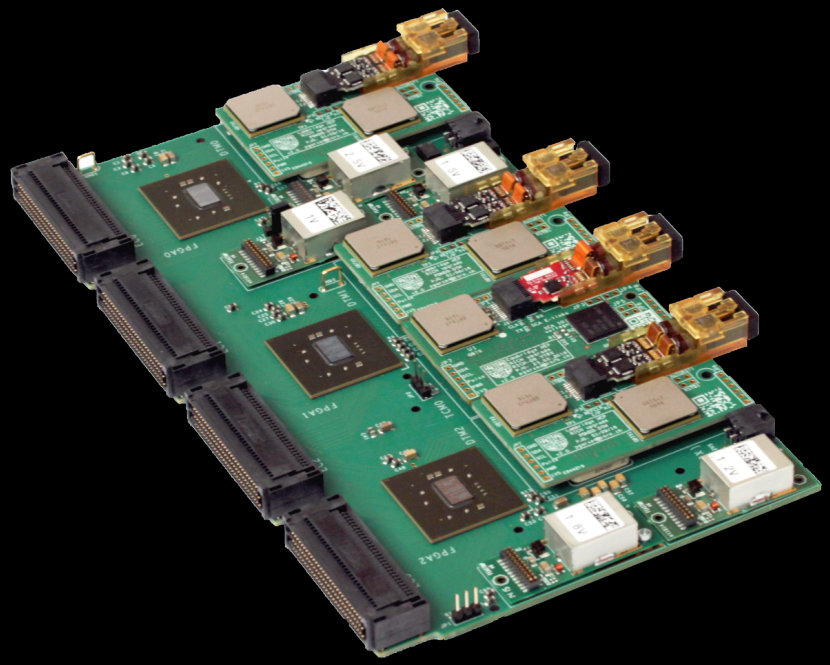
Unique collaboration of HEP experiment-theory (Cavendish + DAMTP): Cambridge SUSY Working Group.

Instrumentation

Lester, Gibson, Wotton et al

Fast readout electronics & DAQ

- ATLAS and LHCb off-detector electronics modules.
- ATLAS upgrade: Level-1 ECAL trigger electronics LS2 (2019)
- LHCb upgrade: RICH on-detector electronics LS2 (2019)

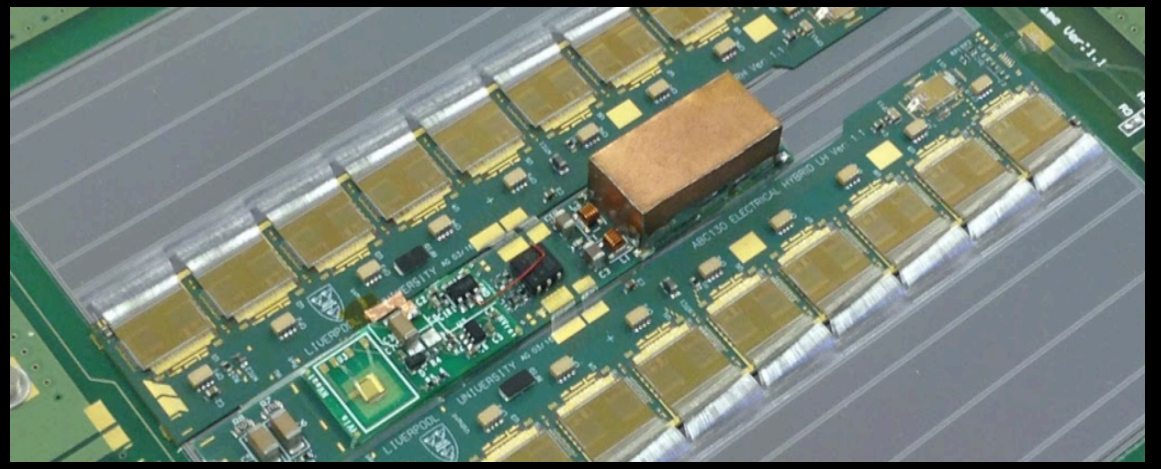


Instrumentation

Hommels, Robinson et al

Silicon strip detectors

- ATLAS SCT modules.
- ATLAS upgrade - ITk: Si module building and QA LS3 (2024)



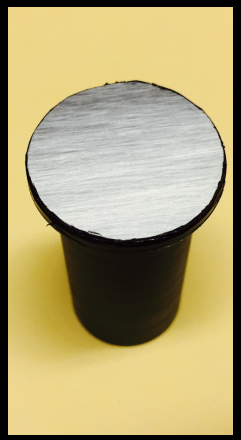
Need build >1000 10cm x 10xm silicon modules for ATLAS ITk and test sensors.

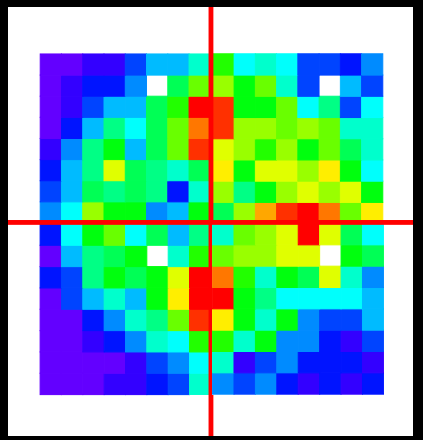
Instrumentation (future)

- Fast Readout Electronics & DAQ
  - Fast digital readout of large arrays.
  - Timing in RICH detectors.

LS3/4 LHCb Upgrade 1b/II

- Silicon Detectors
  - CMOS technology (requires CMOS engineer)
  - Build-up niche capabilities e.g. radiation effects on silicon sensors, power delivery systems (silicon carbide)
- Generic Detector R&D
  - Novel detector technology e.g. Photonic crystals to detect Cherenkov radiation





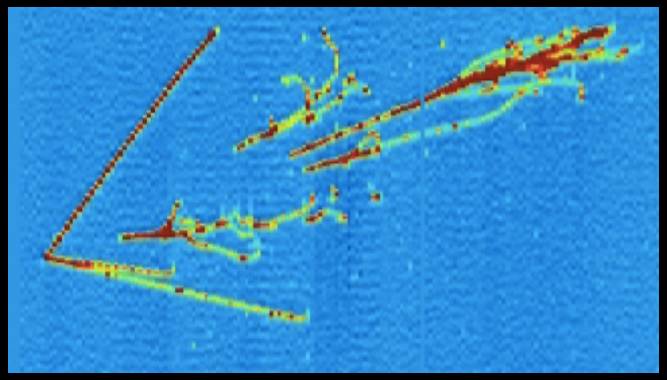
Neutrinos

Thomson et al

Neutrino masses are currently the only firm evidence of BSM physics

- Rich experimental programme utilizing LAr-TPCs

Cambridge at forefront of development of image recognition and pattern recognition for global neutrino programme



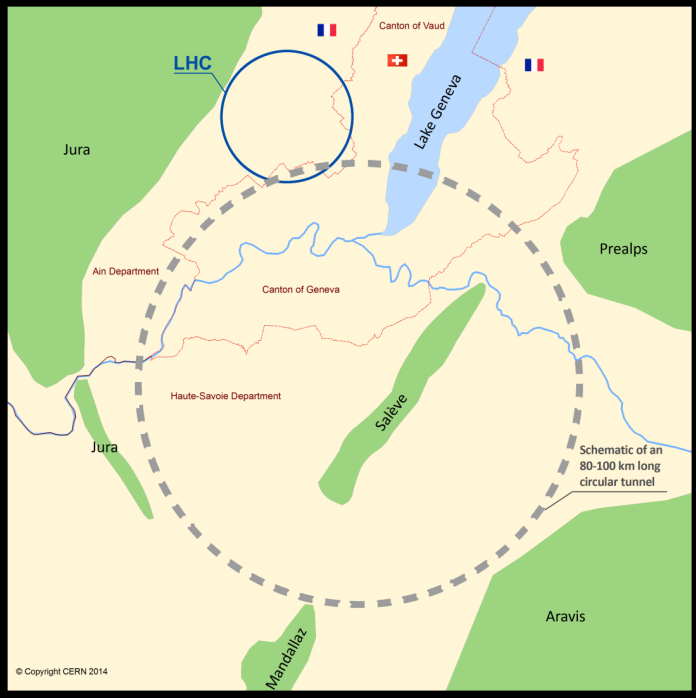
- MicroBooNE (2015 – 2021?)
  - Search for sterile neutrinos – MiniBooNE anomaly
- ProtoDUNE (2018-2020?)
  - Massive LAr-TPC prototypes for DUNE at CERN
- DUNE (2026-2040)
  - The world's first mega-science neutrino project
  - Until recently, Cambridge leadership

Future Opportunities

Parker, Thomson et al

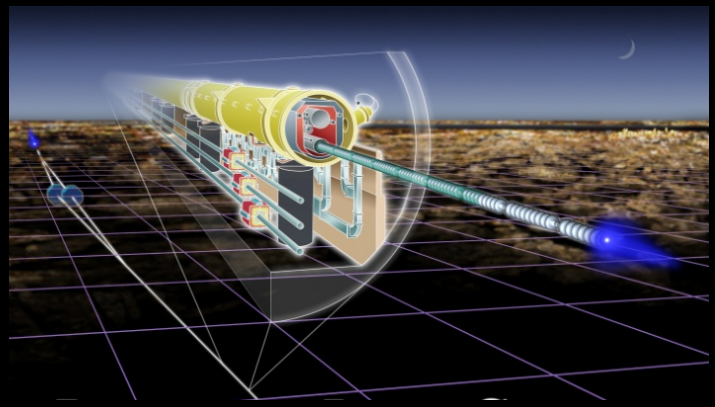
Future Circular Collider (CERN)

- 100 TeV, 80-100 km pp (ee or ep)
- Low Higgs mass – "unnatural" – need to fully explore EWSB.
- Regular International meetings (e.g. FCC).



International Linear Collider (Japan)

- 250/500 TeV Higgs factory (ee)
- Detector & physics studies (CALICE)
- Opportunity for Si-based ECAL using CMOS technology



HEP Strategic View

- Full exploitation of LHC (ATLAS & LHCb and upgrades) now → 2035
- Neutrinos (DUNE) 2019 → 2040
  - £65M investment from UK government
  - UK will construct major parts of the DUNE detector and associated neutrino beam, first data 2026
  - Cambridge is in a strong position to tap into this opportunity
  - Potential for a strategic investment

HEP Strategic View

- Full exploitation of LHC (ATLAS & LHCb and upgrades) now → 2035
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  - £65M investment from UK government
  - UK will construct major parts of the DUNE detector and associated neutrino beam, first data 2026
  - Cambridge is in a strong position to tap into this opportunity
  - Potential for a strategic investment
- Centre for Instrumentation (Cavendish III) 2022 →
- Enhance HEP theory in-line with experiment
- Dark Matter (accelerator vs direct dark matter detection: Xenon1T, Darkside etc)
- Particle Astrophysics projects (LSST, CTA etc).

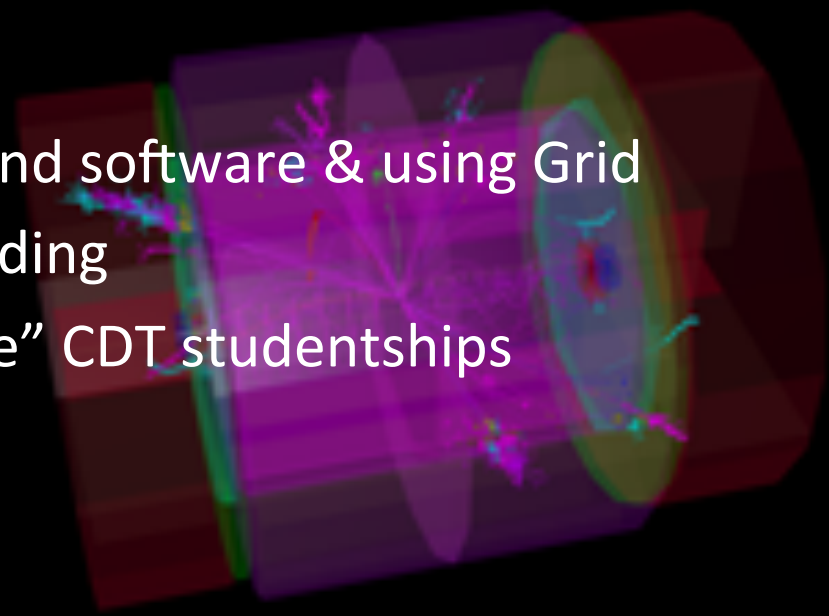
General considerations

Instrumentation

- Attractive career path for key engineers independent from grant income
- Centre for Instrumentation (Cavendish III)

Computing and Software

- Expertise in BigData computing and software & using Grid
- RICH pat rec, particle flow, jet finding
- Attractive “Data Intensive Science” CDT studentships



Summary

The HEP experiment and theory research group has a world-class (& high-priority STFC) science programme, with an innovative and collaborative vision for the future.

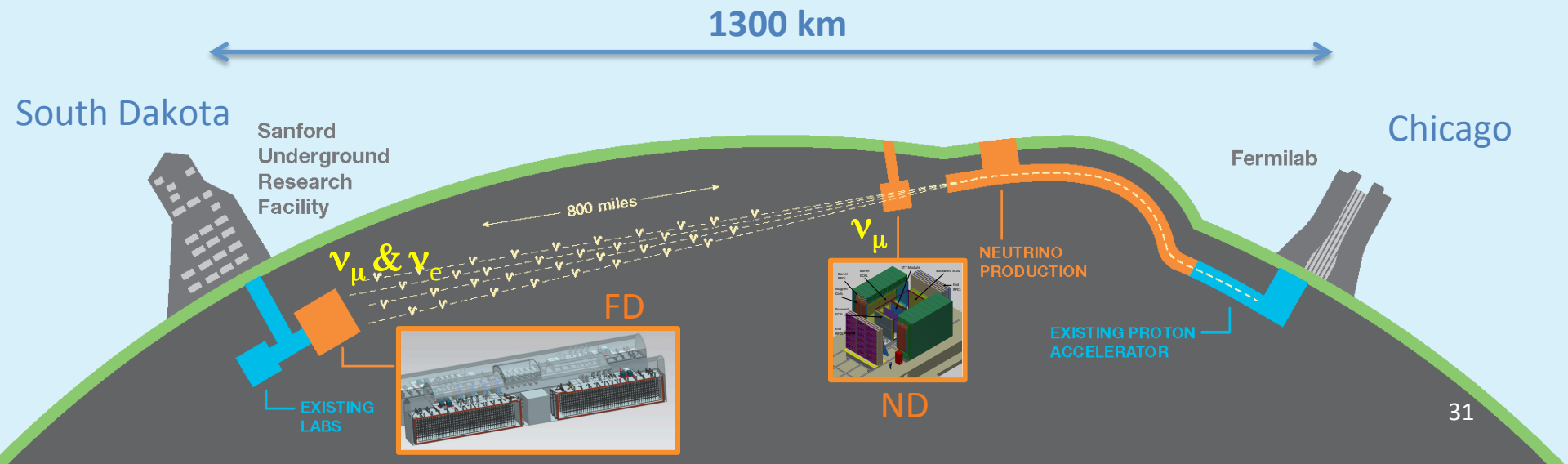
Major opportunities with new appointments:

- LHC exploitation — Lecturer
- Neutrinos (DUNE) detector readout software & DAQ — Lecturer
- Dark Matter (direct detection) initiative — Senior strategic appointment
- CMOS Engineer — STO or equiv.

The Deep Underground Neutrino Experiment

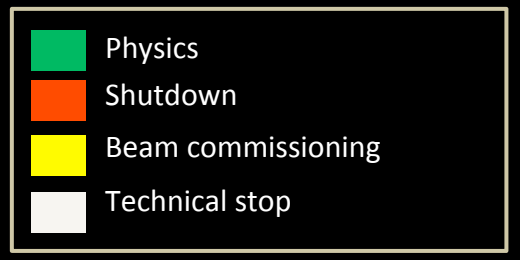
DUNE:

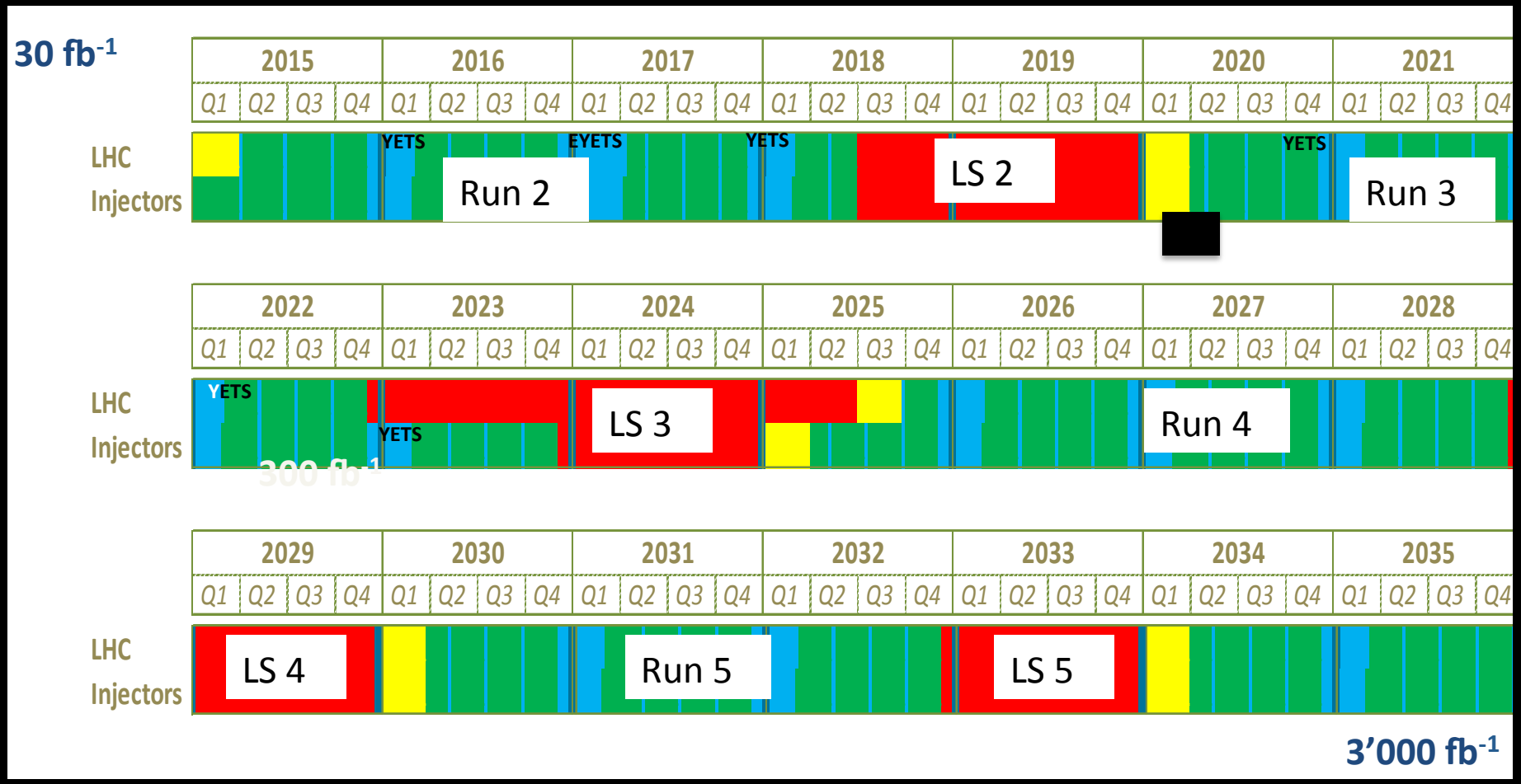
- Large underground Liquid Argon Time Projection Chamber
  Four 17,000 ton LAr-TPCs, one mile underground
- Fire neutrinos 800 miles from Fermilab to South Dakota
- Aiming for first beam in 2026
- Targeting major discoveries: leptonic CPV, proton decay, SN νs



LHC schedule beyond LS1

LS2 starting in 2018 (July) => 18 months + 3 months BC
LS3 LHC: starting in 2023 => 30 months + 3 months BC
Injectors: in 2024 => 13 months + 3 months BC





LHC schedule approved by CERN management and LHC experiments spokespersons and technical coordinators (December 2013)

LHCb Experiment

Discovery of tetraquarks, pentaquarks