Overview of activities at CERN

Manfred Krammer

CERN

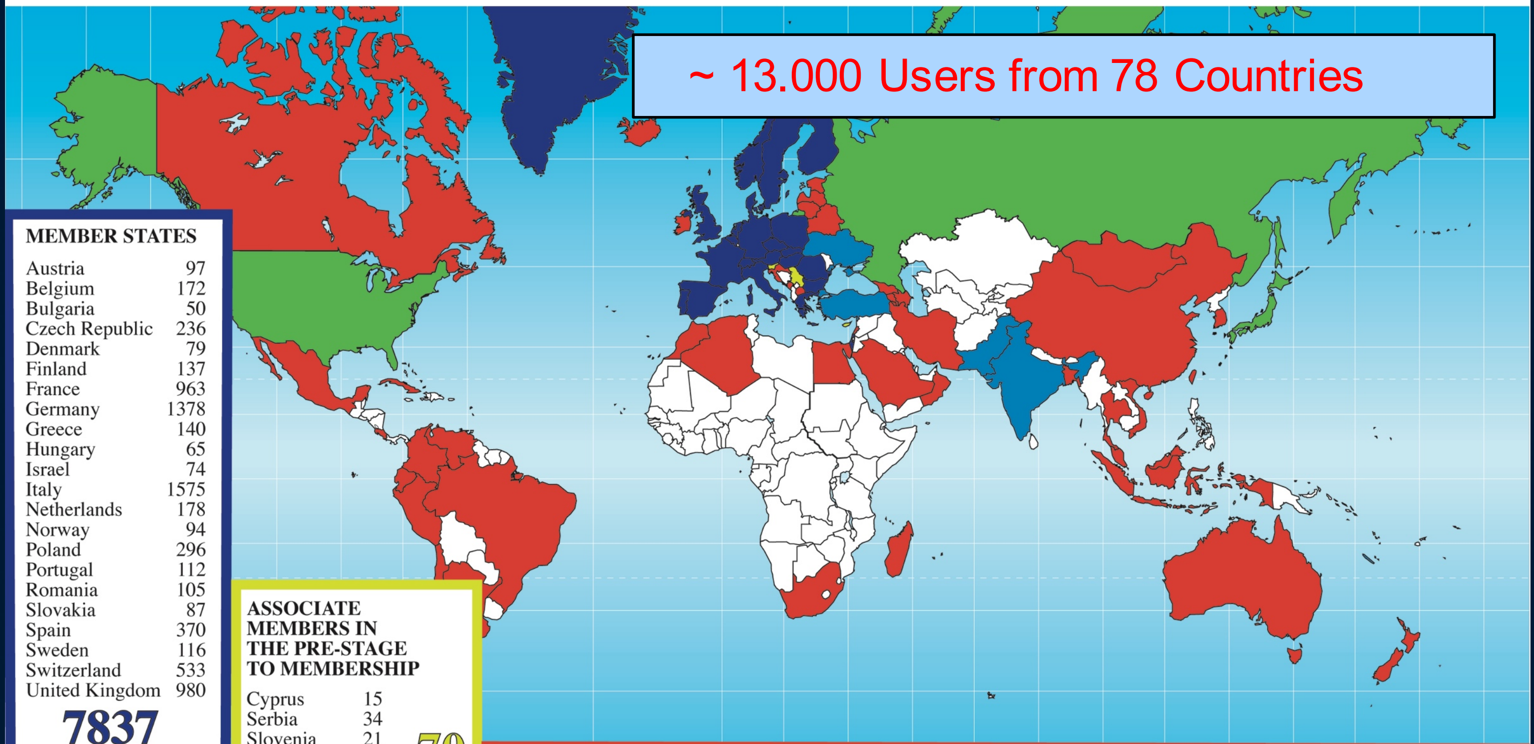
XIV ICFA School on Instrumentation in Elementary Particle Physics

27 November 2017, La Habana, Cuba


CERN was founded 1954: 12 European States
"Science for Peace"
Today: 22 Member States
~ 2500 staff
~ 2300 other paid personnel
~ 13000 scientific users
Member States: Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Spain, Sweden, Switzerland and the United Kingdom
Associate Member: Croatia, Cyprus, India, Pakistan, Serbia, Slovenia, Turkey, Ukraine
Applicant States for Membership or Associate Membership: Brazil, Lithuania, Russia
Observers to Council: Japan, Russia, United States of America; JINR, European Commission and UNESCO
July 2017

Science at CERN is done by scientists from all over the world

Distribution of All CERN Users by Location of Institute on 5 July 2017



MEMBER STATES

Austria	97
Belgium	172
Bulgaria	50
Czech Republic	236
Denmark	79
Finland	137
France	963
Germany	1378
Greece	140
Hungary	65
Israel	74
Italy	1575
Netherlands	178
Norway	94
Poland	296
Portugal	112
Romania	105
Slovakia	87
Spain	370
Sweden	116
Switzerland	533
United Kingdom	980

7837

ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP

Cyprus	15
Serbia	34
Slovenia	21

70

ASSOCIATE MEMBERS

India	233
Pakistan	36
Turkey	131
Ukraine	37

437

OBSERVERS

Japan	263
Russia	1068
USA	2152

3483

OTHERS

Algeria	1
Argentina	23
Armenia	19
Australia	37
Azerbaijan	4
Bangladesh	4
Belarus	24
Brazil	136
Canada	191
Chile	24
China	243
Colombia	28
Costa Rica	1
Croatia	27
Cuba	3
Ecuador	2
Egypt	27
Estonia	19
Georgia	28
Hong Kong	26
Iceland	5
Indonesia	7
Iran	28
Ireland	9
Korea	160
Latvia	1
Lebanon	8
Lithuania	26
Madagascar	3
Malaysia	8
Malta	6
Mexico	68
Mongolia	2
Montenegro	4
Morocco	11
New Zealand	8
Oman	10
Peru	2
Saudi Arabia	1
Singapore	4
South Africa	60
Taiwan	74
Thailand	19
TFYROM	2
Venezuela	1
Viet Nam	1

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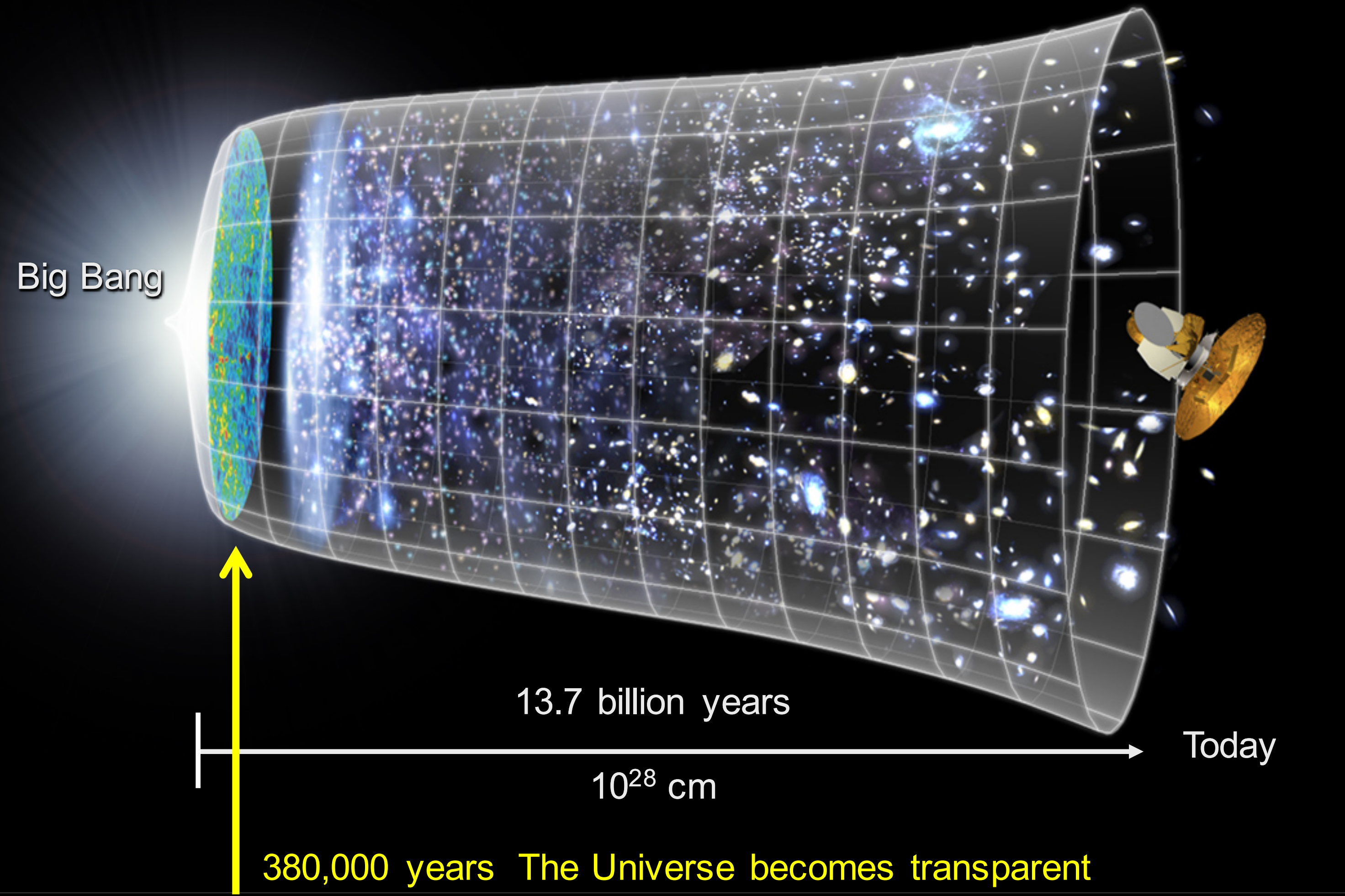
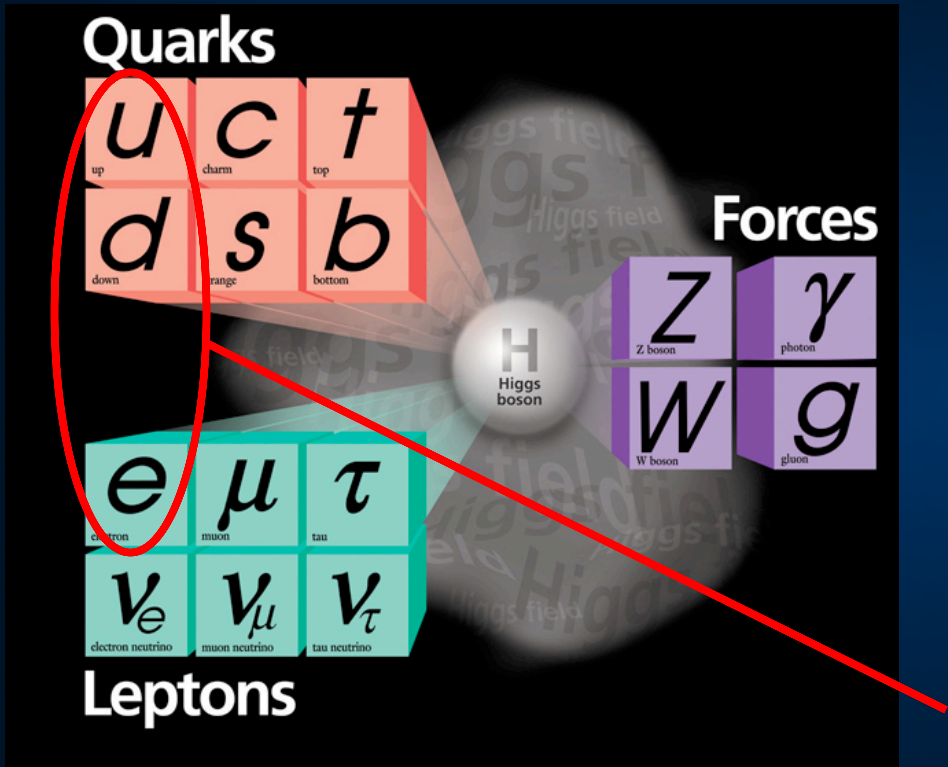
Physics at CERN: Understanding the Universe



The Standard Model of Particle Physics



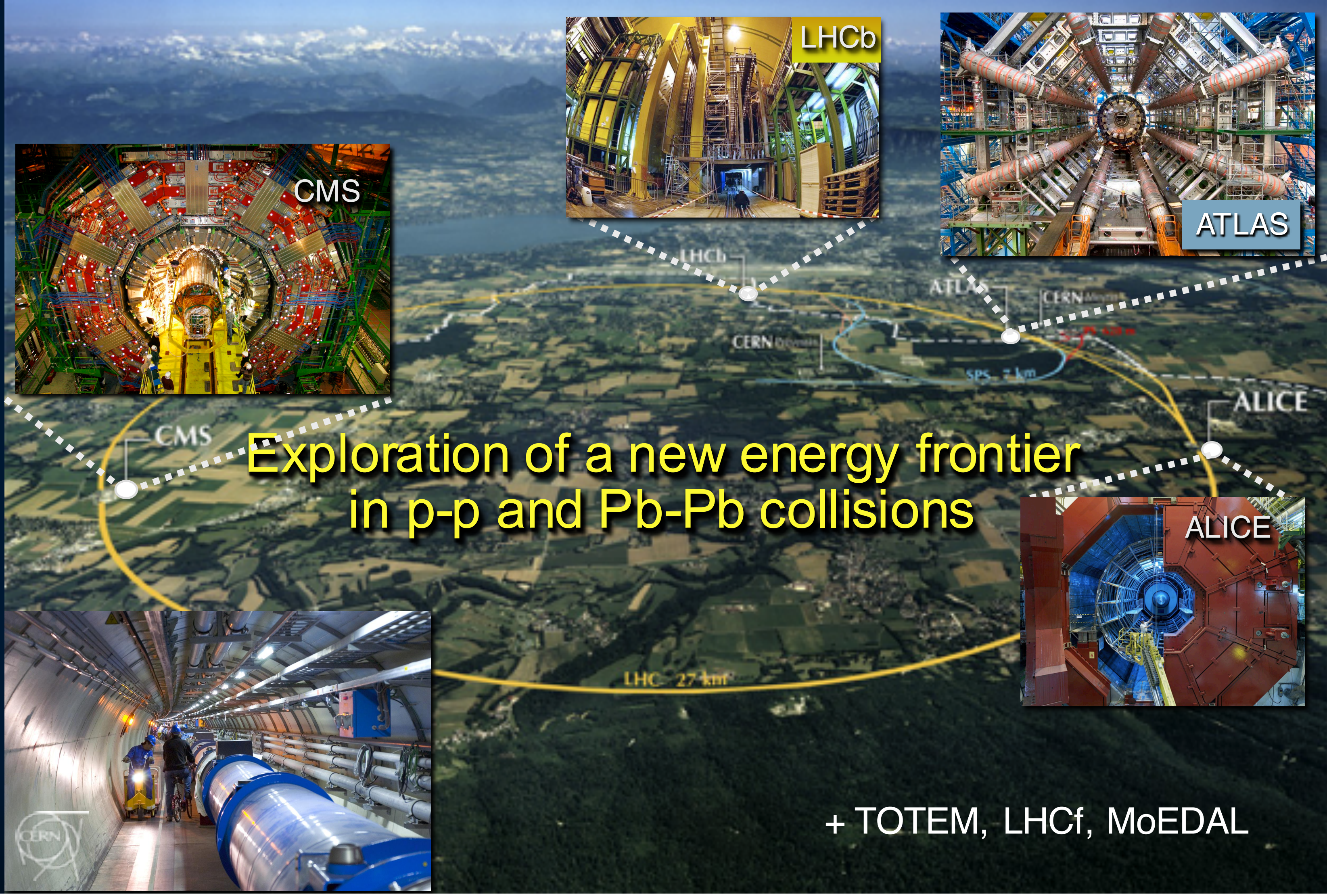
Several observations and mysteries point to the fact that the SM is not the final theory:

- Dark Matter
- Mass of the neutrinos
- Matter Antimatter asymmetry
- Strong CP problem
-
- And finally, inclusion of Gravity in the final theory

Sufficient to explain baryonic matter around us!

Complete, after the discovery of the Higgs Boson in 2012.

LHC the Flagship Project of CERN



Exploration of a new energy frontier
in p-p and Pb-Pb collisions

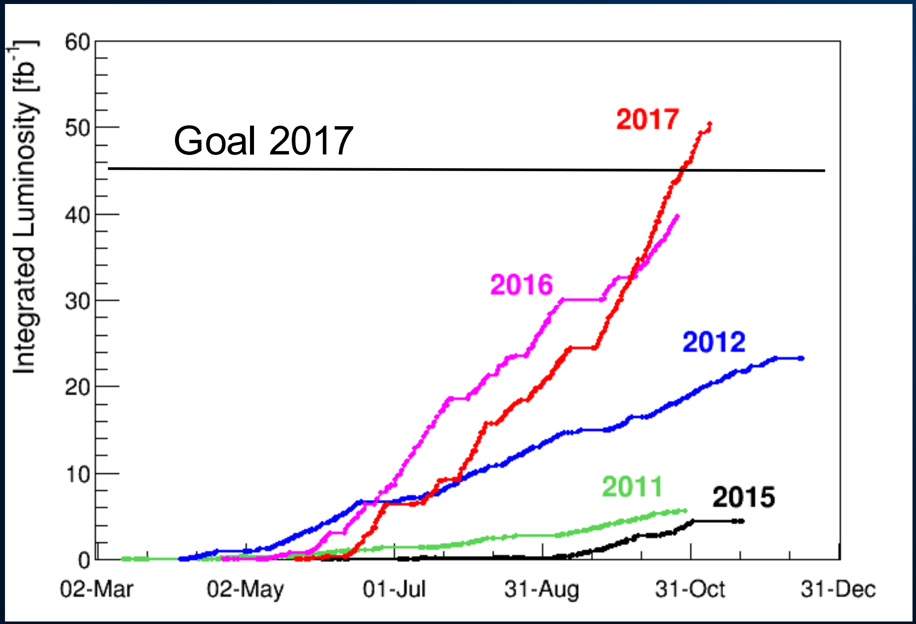
+ TOTEM, LHCf, MoEDAL

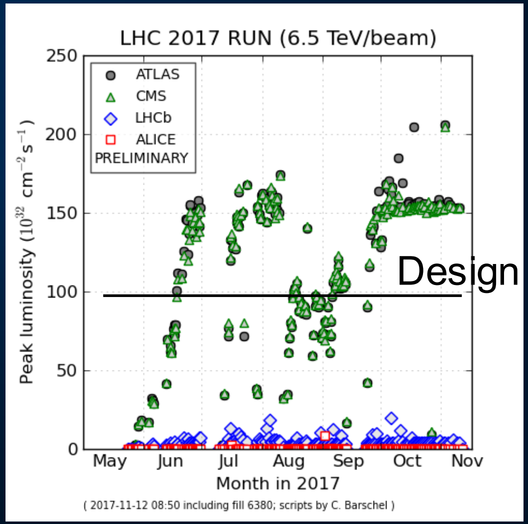
Performance of the LHC Machine in 2017

2017 another record year for the LHC!
13 TeV High intensity pp run stopped Nov. 10 (Goal 45 fb^{-1} achieved 50 fb^{-1})
Continue with special runs (5 TeV pp reference, low energy high β)
Technical stop (YETS) starts Dec. 4

2018: restart March, goal 18 weeks physics to physics

Peak luminosity achieved
2.2 10^{34} cm^{-2} s^{-1}
With luminosity levelling at LHC operated at 1.5 10^{34} cm^{-2} s^{-1}





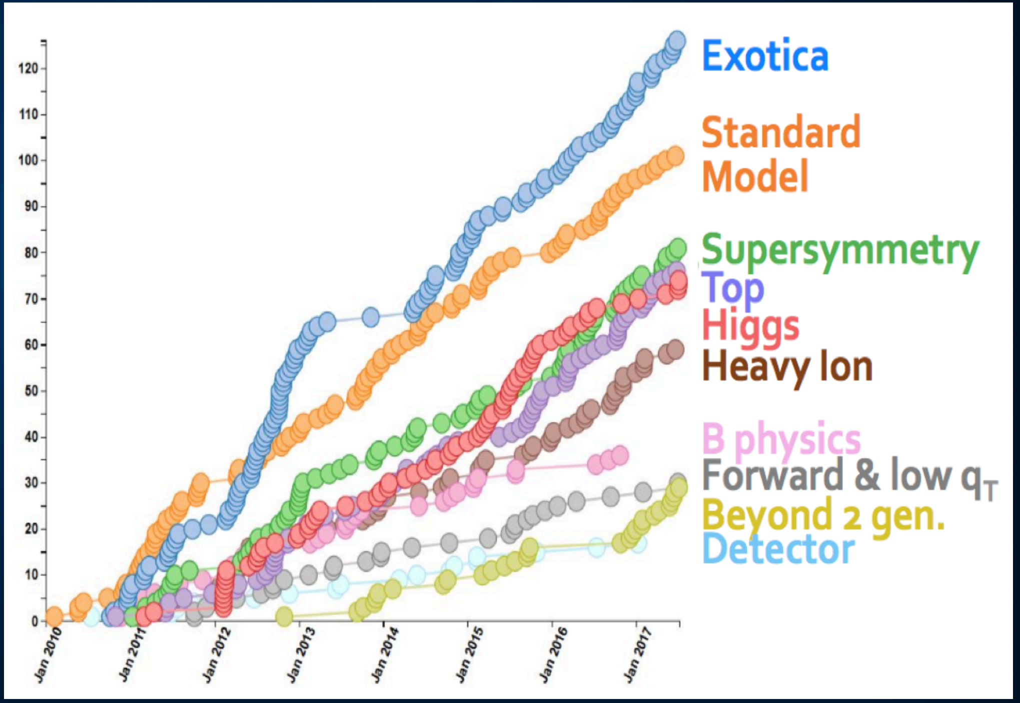
LHC Physics - Overview

Very wide spectrum of physics

- Study of the standard model particles and processes
- Search for hints of physics beyond the standard model "new physics"
- Search for exotic particles
- Heavy ion physics
- And, of course, the study of the Higgs!

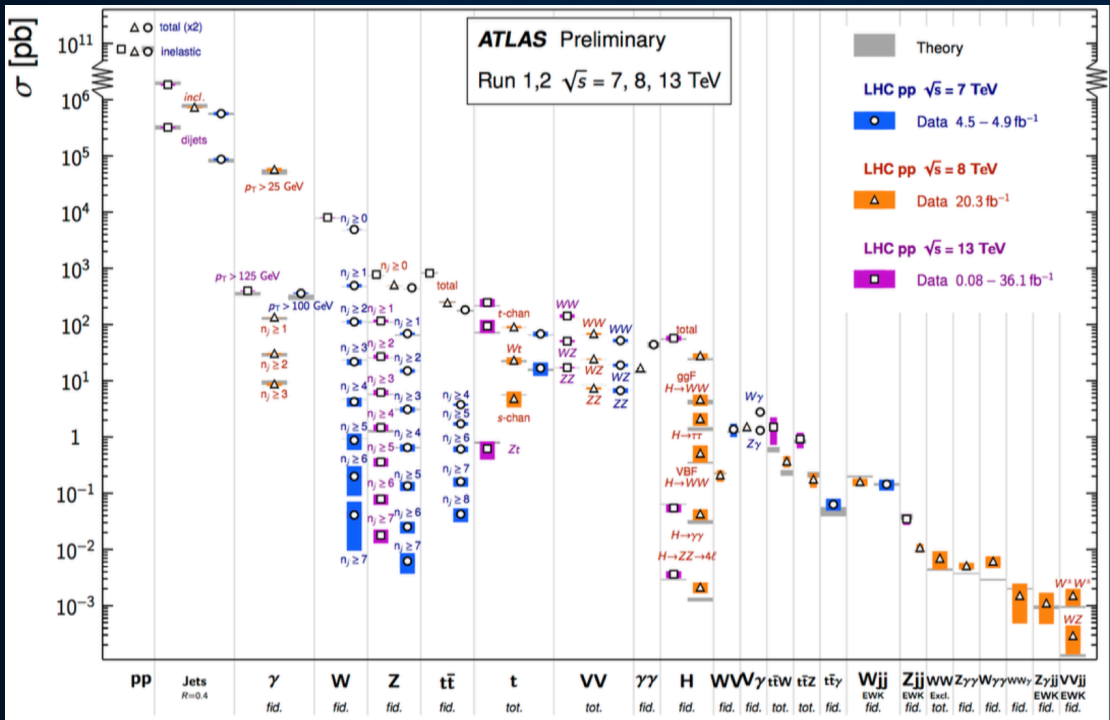
A few examples on the following slides.

E.g. Scientific output of CMS:
628 physics paper submitted as of July 2017



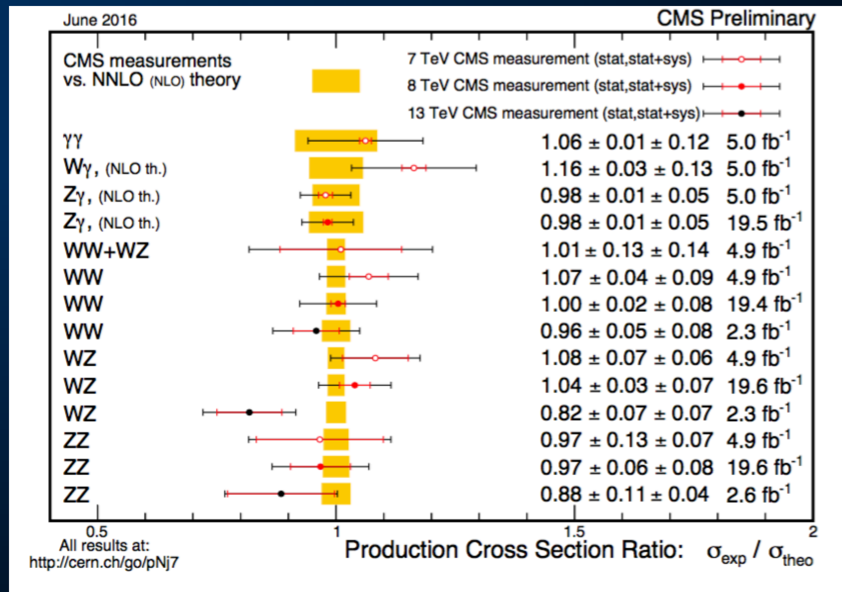
LHC Physics – SM Physics

SM cross sections measured over more than 14 orders of magnitude - comparison with theory.



Low cross section for high mass objects such as W and Z

Integrated luminosity delivered by LHC and very high trigger selectivity by the experiments allow precision measurements.



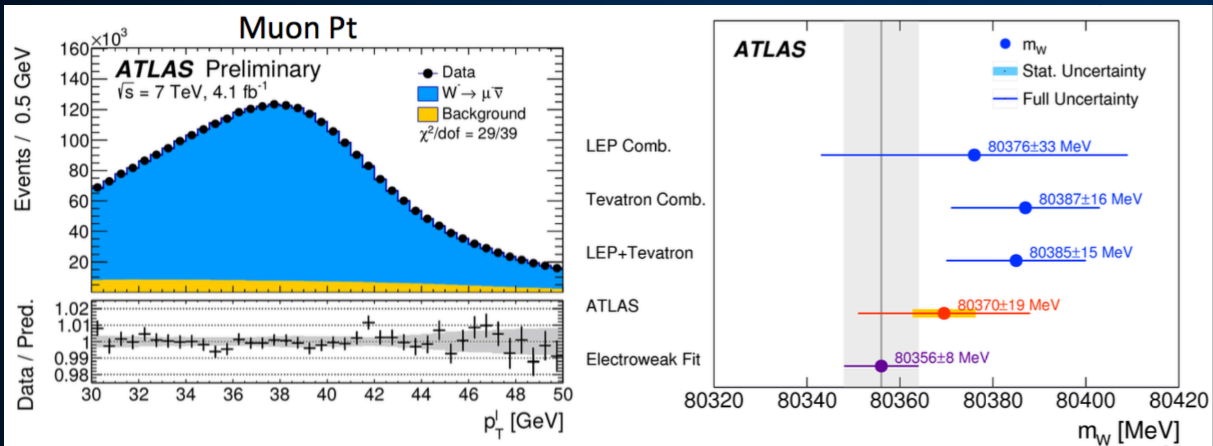
W Boson Mass

Precision measurement of W mass

Huge effort to understand detector response and modelling of kinematic quantities (e.g. lepton p_T, E_T^{miss})

Run 1, 7 TeV data only (low pile up, 4.6 fb^{-1}), similar precison reached as for current best measurement.

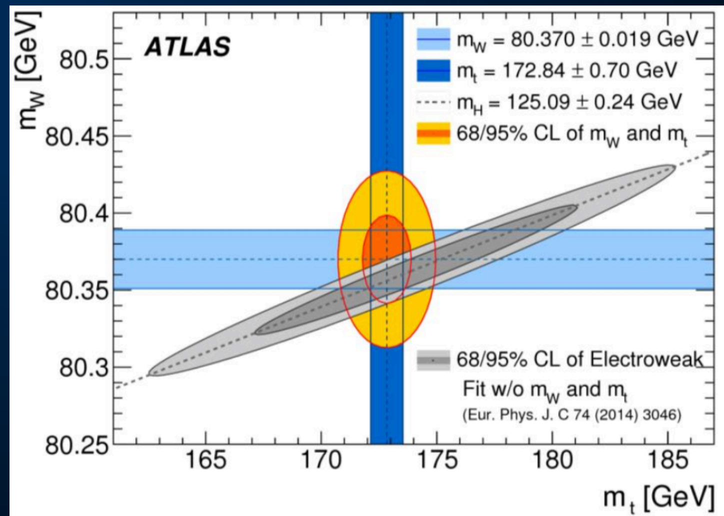
Muon p_T distribution from $W \rightarrow \mu\nu$ decays.



arXiv:1701.07240

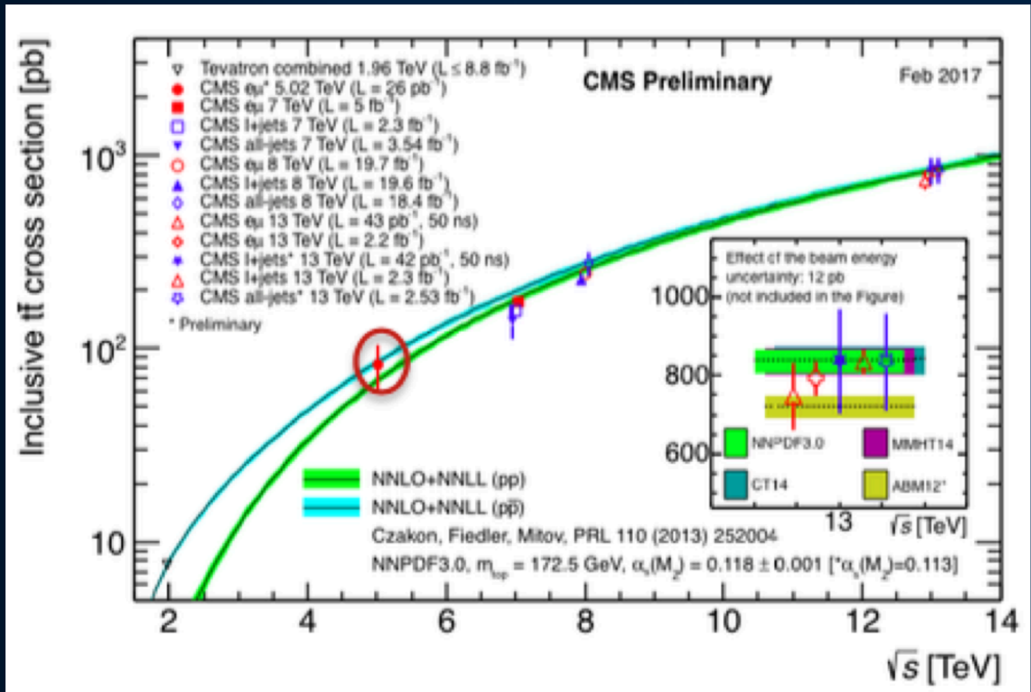
M_W = 80.370 ± 0.019 GeV

Result consistent with SM prediction:



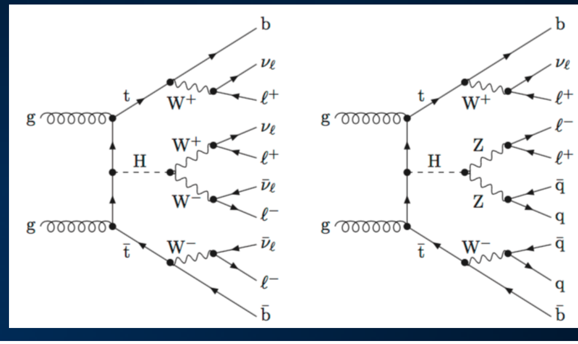
LHC Physics - Top

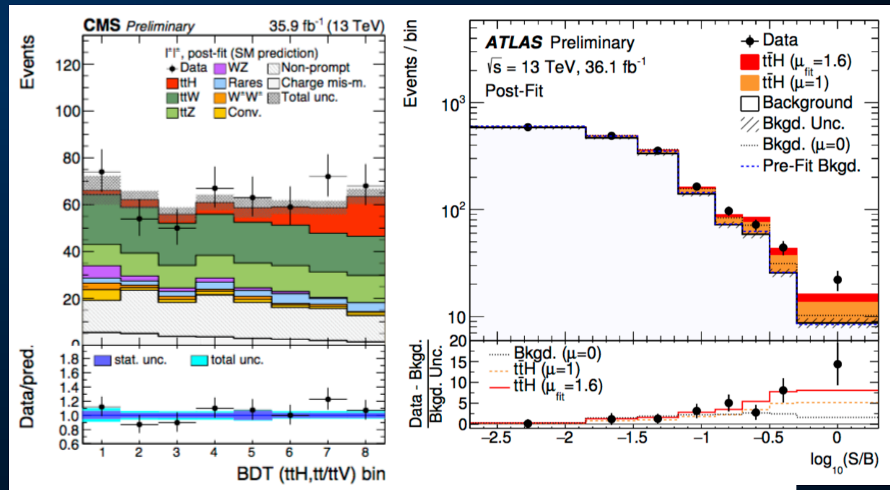
LHC as Top factory: Top pair production rate is > 10 Hz



Inclusive tt(bar) cross section: 835±33 pb (CMS)
Compared to theory 816±42 pb

Many channels beeing investigated
e.g. evidence for tt(bar)H:



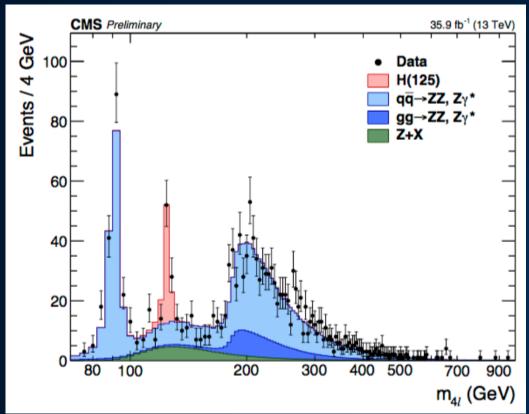


CMS PAS HIG-17-004, ATLAS-CONF-2017-077

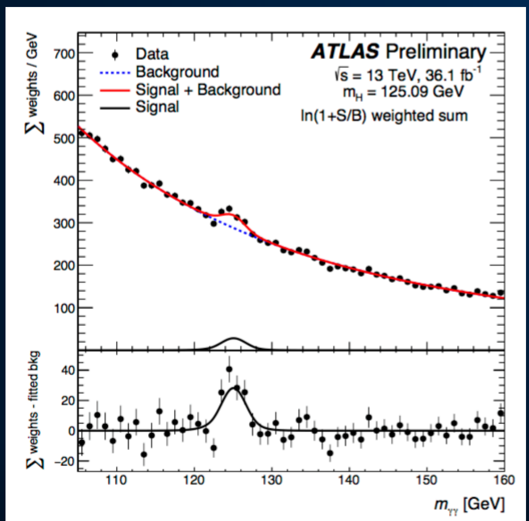
LHC Physics - Higgs

5 years after the discovery – start seeing Higgs like other SM particles

CMS PAS HIG-16-041



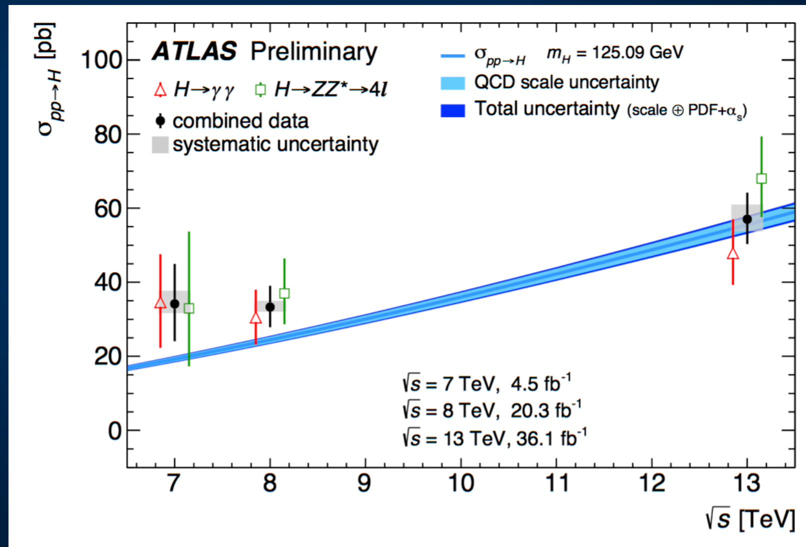
ATLAS-CONF-2017-045



Higgs Boson mass

CMS: m_H=125.26±0.20(stat.)±0.08(sys.) GeV *arXiv:1706.09936*

ATLAS: m_H=124.98±0.19(stat.)±0.21(sys.) GeV *ATLAS-CONF-2017-046*



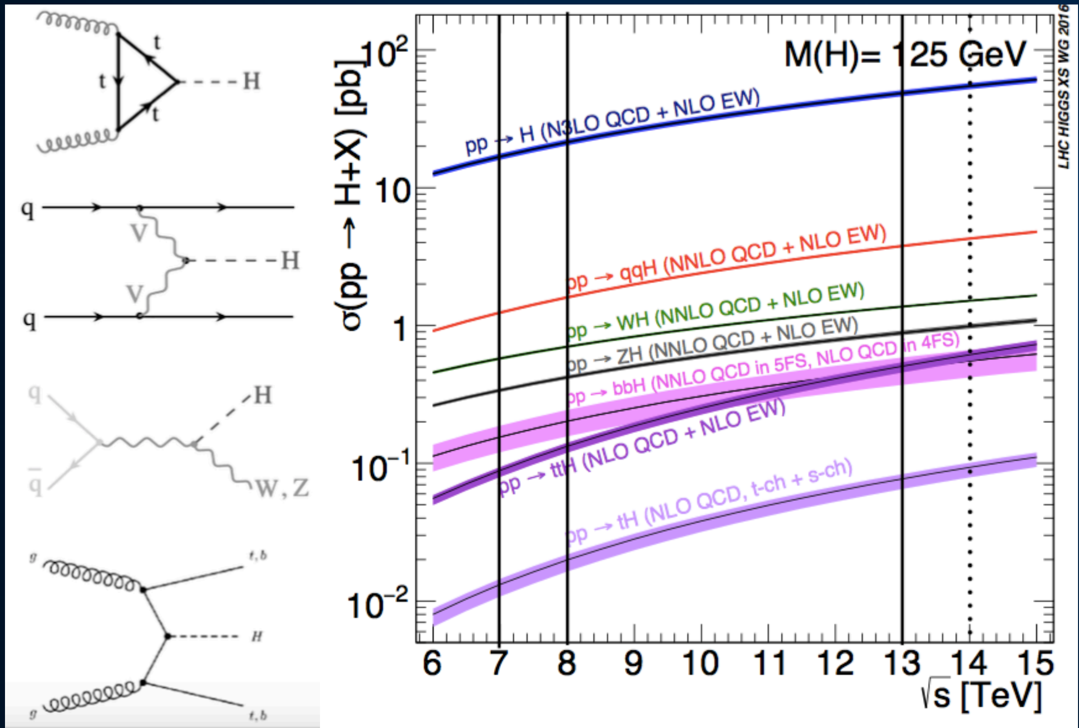
ATLAS-CONF-2017-047

First measurements of differential cross-sections, e.g. as function of Higgs Boson kinematics.

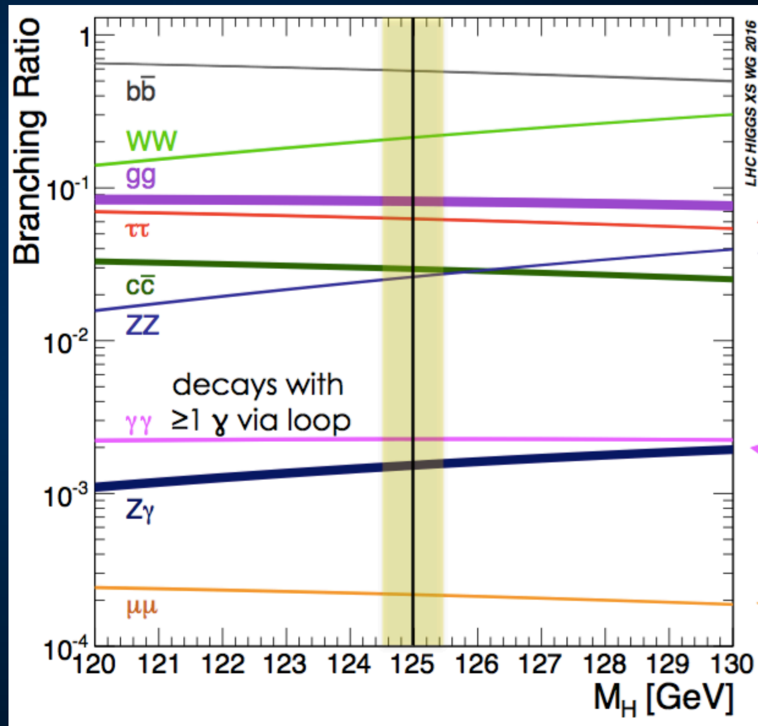
LHC Physics - Higgs

LHC an excellent machine to study Higgs in great details – lot of information extractable.

Higgs production mechanism



Higgs decay modes

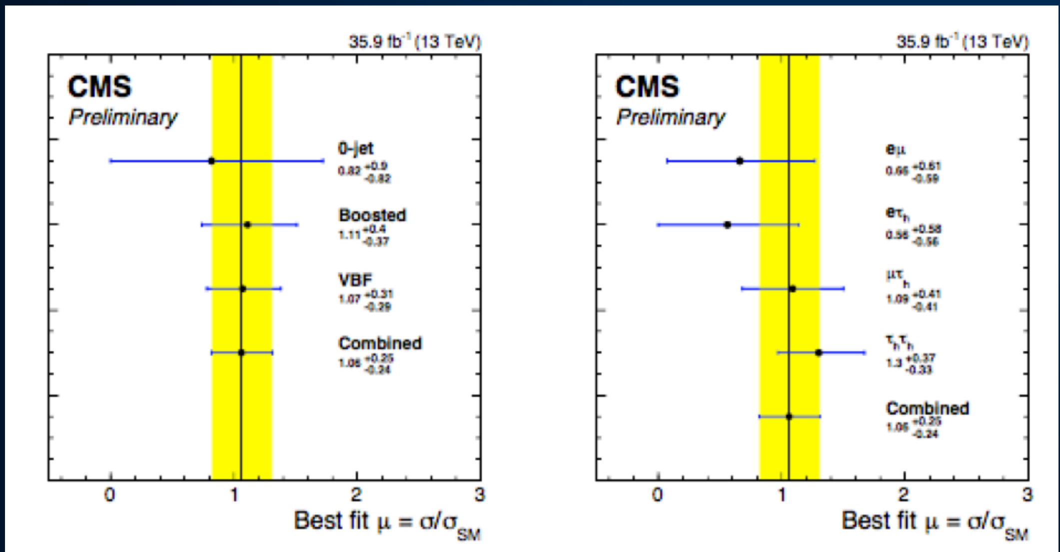


LHC Physics - Higgs

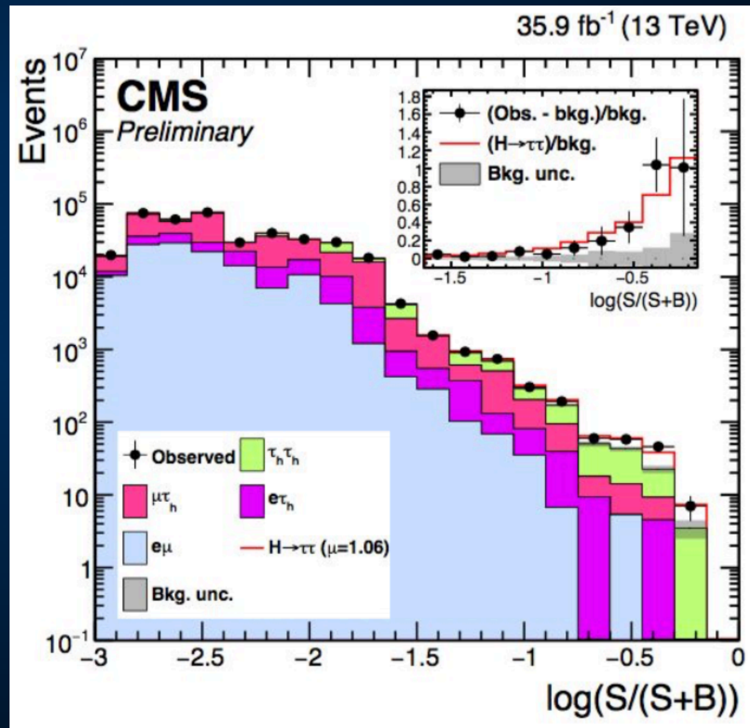
Observation of Higgs decaying to τ pairs (by single experiment)

First direct observation of Higgs coupling to leptons

- Three production modes: gluon-gluon fusion, Vector Boson fusion, boosted di-taus
- Four decay topologies: $e\mu$, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$
- Irreducible background from W+jets, Drell Yang → *ll*, $\tau\tau$, *t-tbar*



CMS PAS HIG-16-043



Combined best-fit signal strength $\mu = \frac{\sigma}{\sigma_{SM}}$ = 1.06 ±0.25

Significance 5.9 sigma

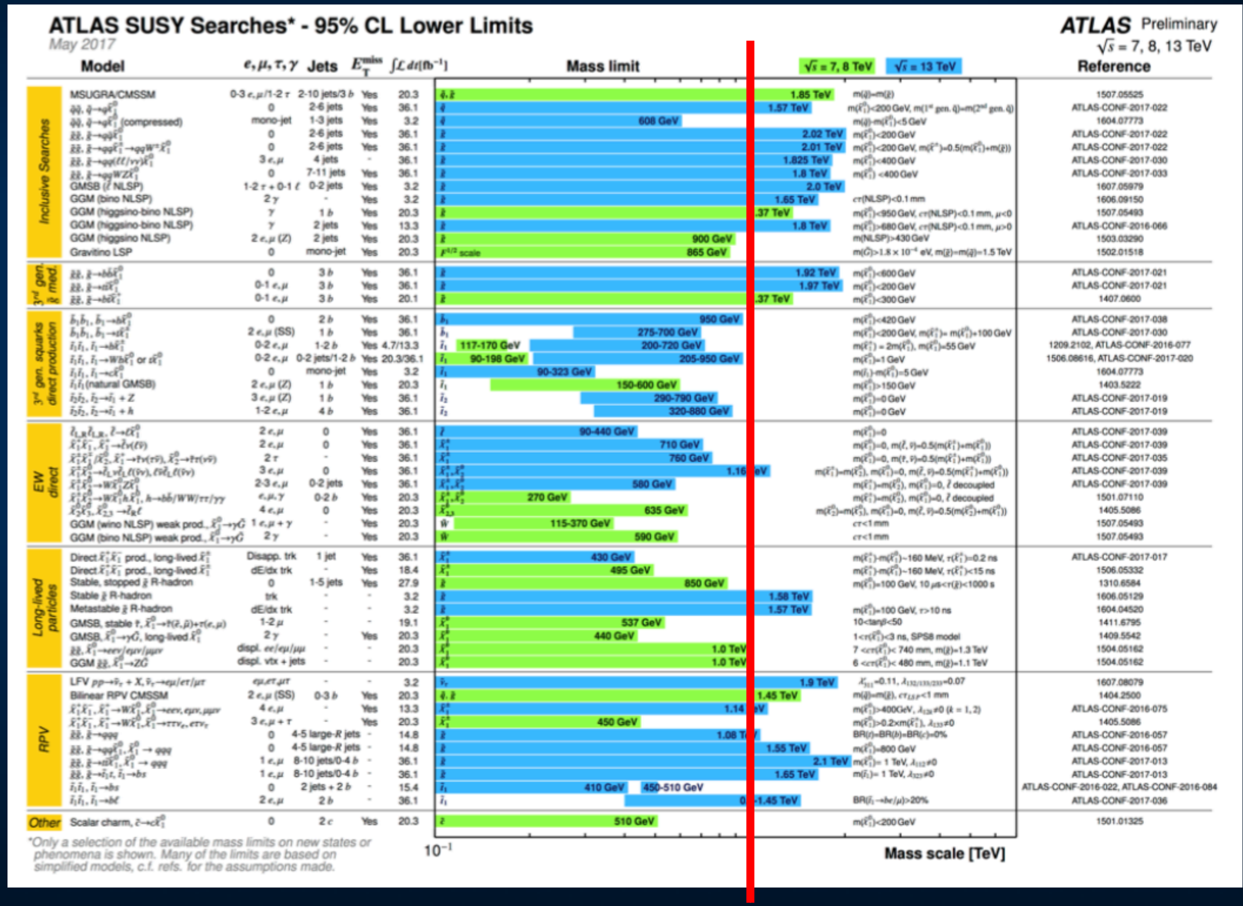
LHC Physics – Search for Supersymmetry

Where is SUSY? Too good to be true – would solve Hierarchy Problem, Dark Matter, Unification!

Many search channels, probing different models and final states.

No signal seen so far

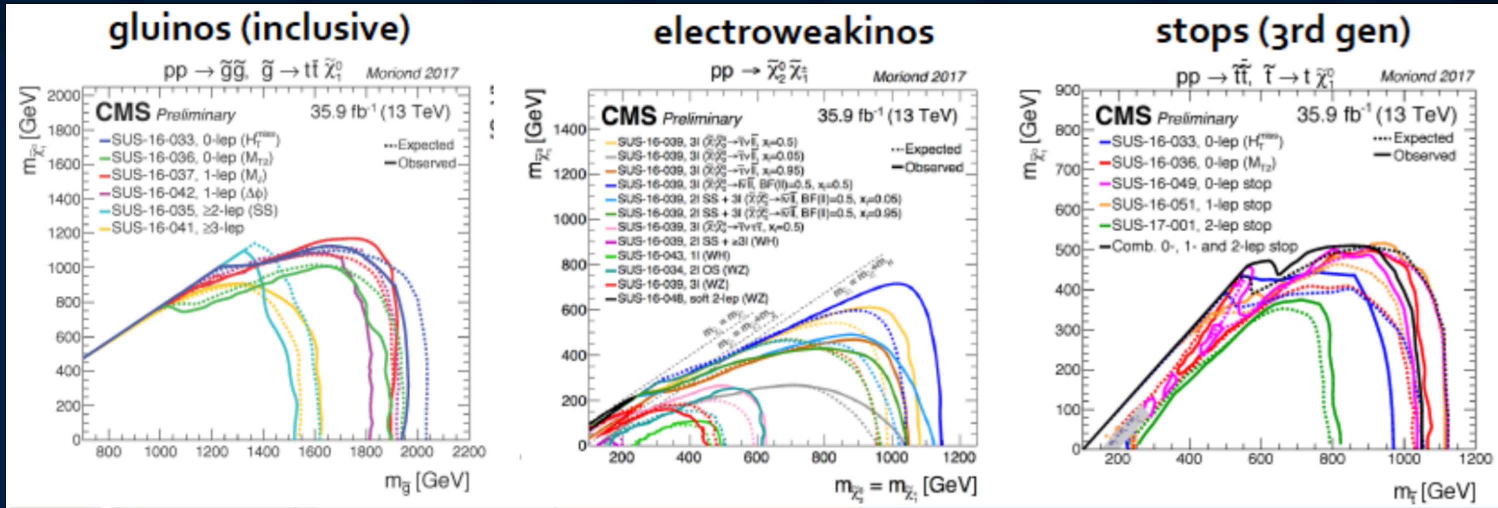
In many channels the limit reached is 1 TeV and beyond for specific channels



1 TeV

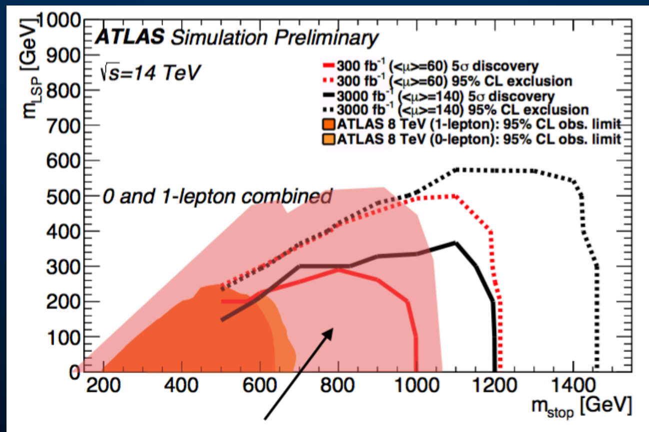
LHC Physics – Search for Supersymmetry

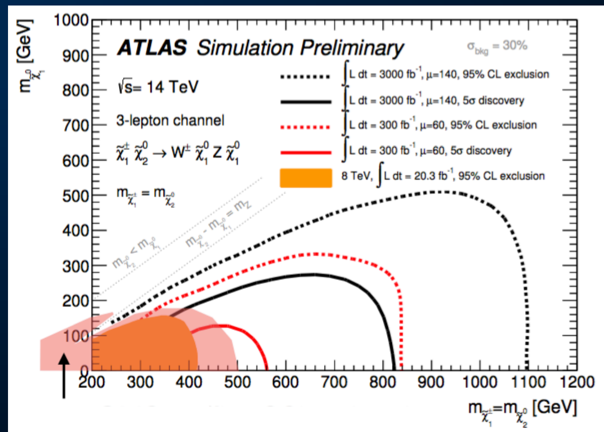
SUSY searches, a few examples:



Remaining discovery potential depending on channel

- QCD charged states, e.g. stops
- Electroweak super partners



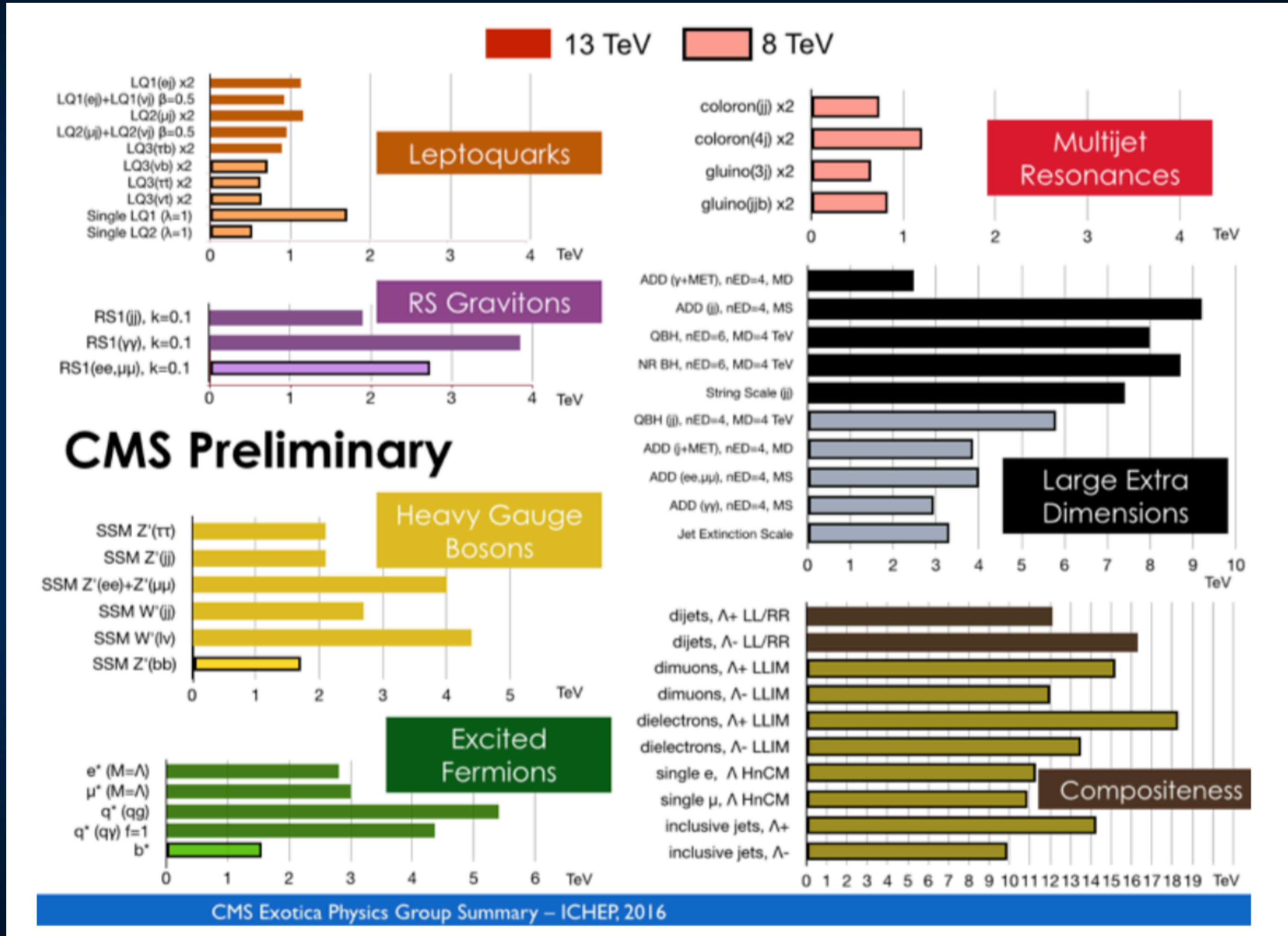


LHC Physics – General (Exotica) Searches

Leave no stone unturned!

Searches ongoing for

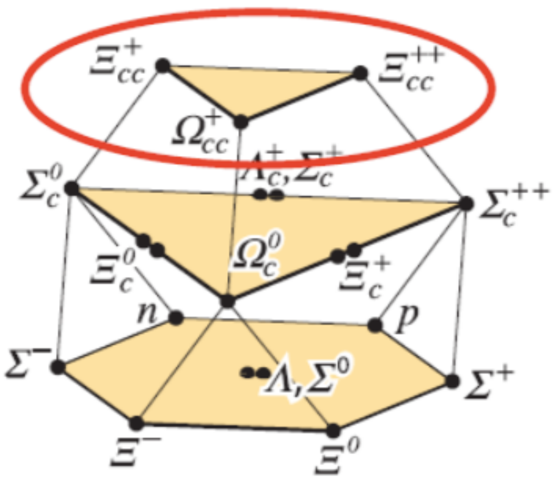
- Leptoquarks
- Gravitons
- Heavy Gauge Bosons
- Excited Fermions
- Extra Dimensions
- Compositeness
- Long lived stable particles
- .....



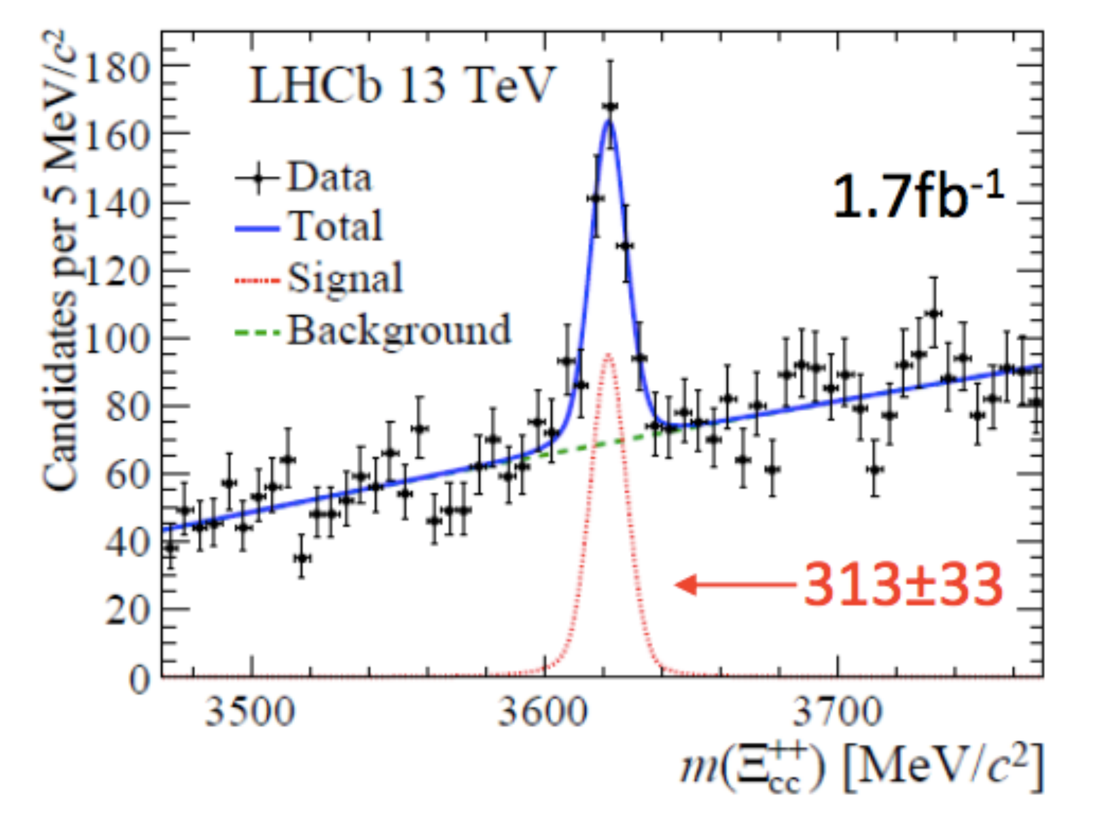
LHC Physics – Heavy Flavour

Latest discovery by LHCb: First observation of Ξ_{cc}^{++}

First Baryon with two heavy quarks.



SU(4) flavor multiplets, PDG Review of Particle Physics, Phys.Rev. D86, 010001.

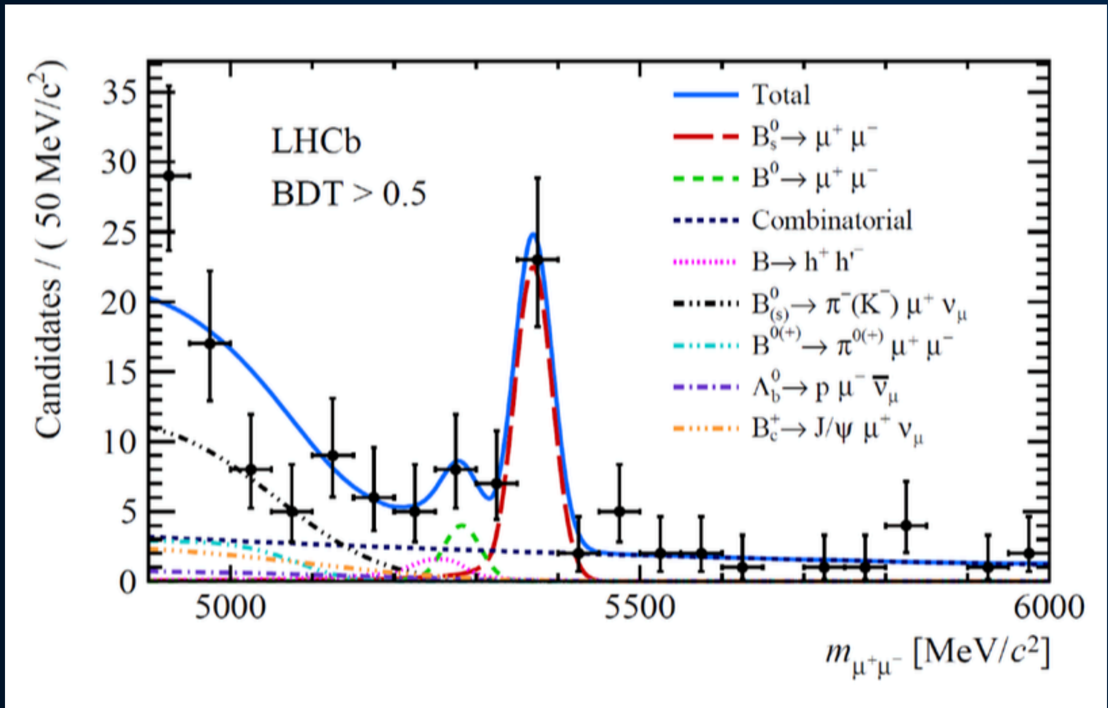


Interesting in view of tests of QCD

arXiv:1707.01621

LHC Physics – Heavy Flavour

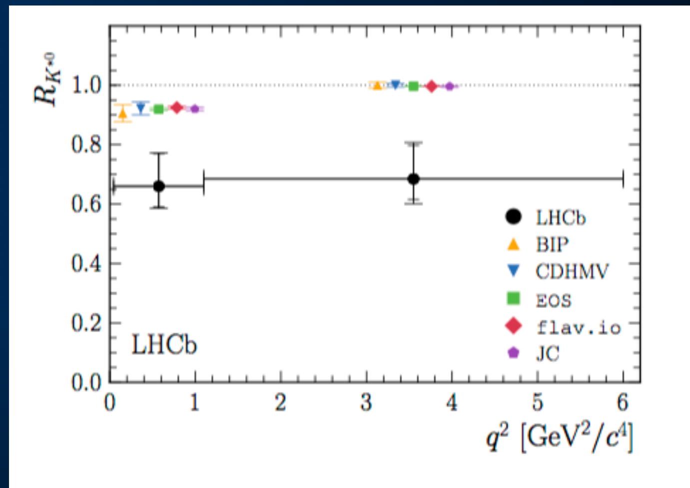
Very rare decays, e.g. $B^0_s \to \mu^+\mu^-$ (BR~3 x10^{-9})
and search for $B^0_d \to \mu^+\mu^-$ (BR<3.4x10^{-10})



PRL 118 (2017) 191801

Lepton flavour universality $R_{K^{*0}}$
Decays of $b \to s l^+ l^-$

$$R_{K^{*0}} = \frac{\mathcal{B}(B^0 \to K^{*0}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{*0}J/\psi(\to \mu^+\mu^-))} \Big/ \frac{\mathcal{B}(B^0 \to K^{*0}e^+e^-)}{\mathcal{B}(B^0 \to K^{*0}J/\psi(\to e^+e^-))}$$



ArXiv:1705.05802

Is this a smoking gun for BSM physics?
More statistics will tell soon.

Heavy Ion Programme at the LHC

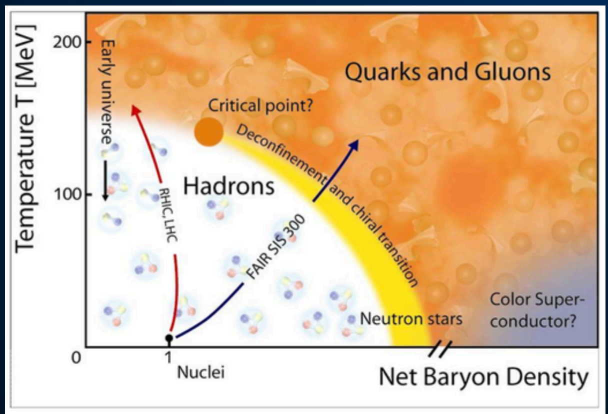
Typically 1 month every year (not in 2017) fully ionized ^{208}Pb nuclei are accelerated in the LHC for Pb-Pb collisions and p-Pb, Pb-p collisions.

Energies: Pb-Pb: $\sqrt{s_{NN}}$=2.76, 5.02 TeV, p-Pb: $\sqrt{s_{NN}}$=5.02, 8.16 TeV

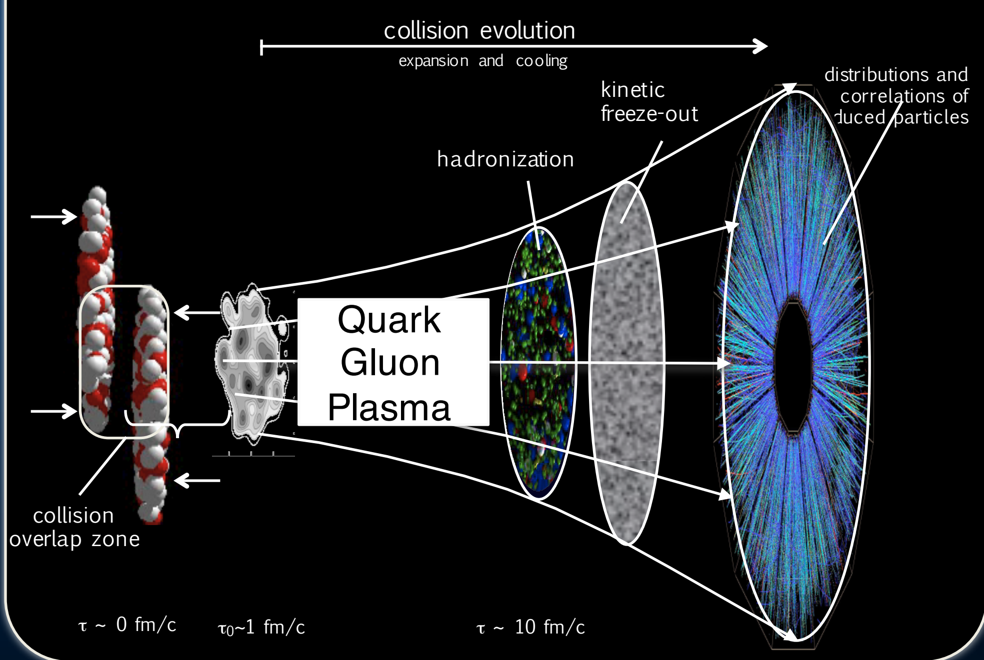
ALICE specialized experiment for heavy ions physics. All four LHC experiments participate in the program.

Large energy density in the collisions of heavy ions allows the study of deconfined QCD:

- Quark gluon plasma – a state of matter formed just after the big bang
- Characterization of QGP
- Test of QCD under extreme conditions



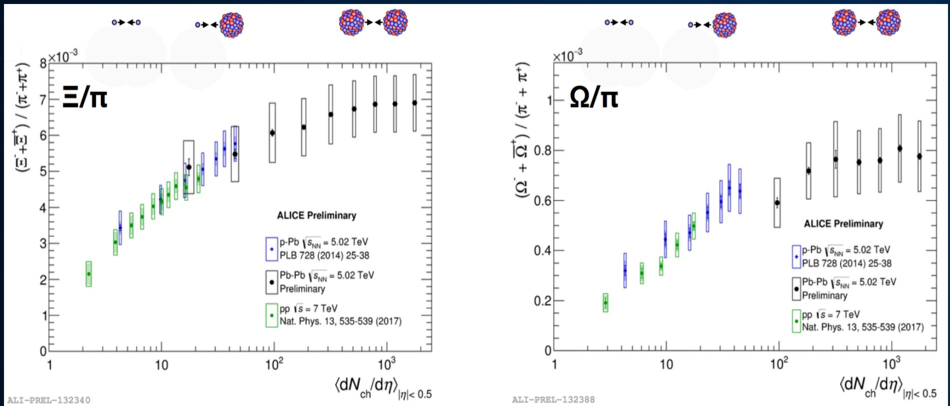
M. Weber, ALICE Introduction



LHC Physics – Heavy Ion

Strangeness enhancement – a sign for QGP

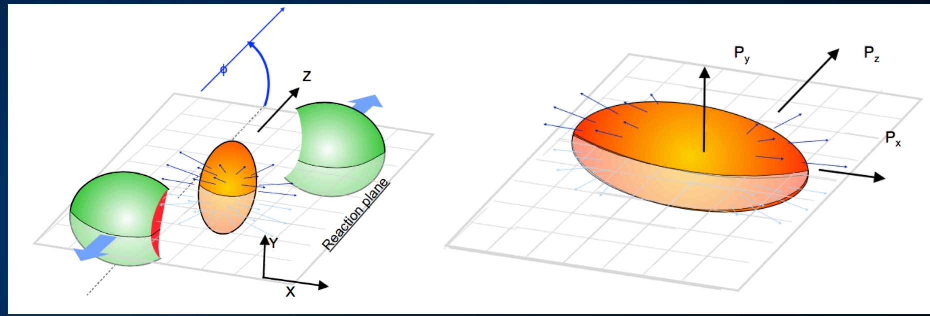
Now seen also in p-Pb and p-p collisions as smooth evolution with particle multiplicity



Not reproduced by traditional soft QCD models (e.g. Pythia)

Anisotropic Flow

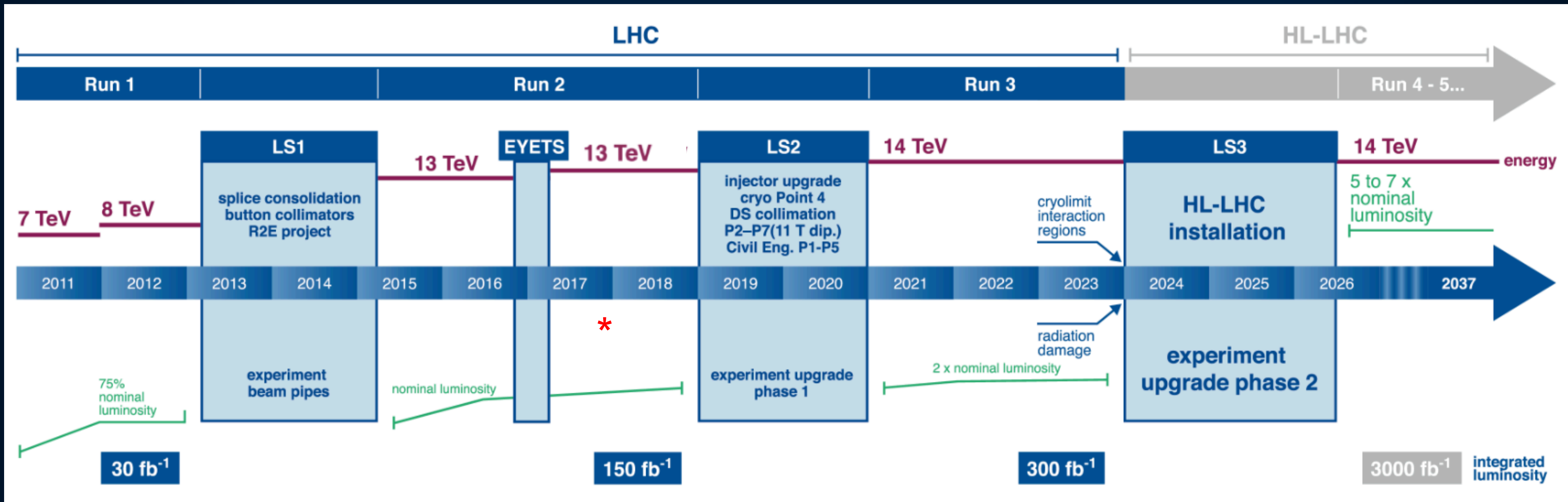
Spatial deformation at collision results in azimuthal pressure gradients and anisotropic particle density



Analysis result: QGP behaves like an almost perfect liquid (very little viscosity)

LHC and HL-LHC

Present planning: operation at 13 TeV during run 2, increase energy to 14 TeV for run 3



HL-LHC project officially approved by CERN Council in June 2016

Operation of the LHC foreseen until 2037

Until now only ~4% of LHC/HL-LHC data taken – a lot to come!

High Luminosity - LHC

Increase luminosity of the LHC up to $5 \times 10^{34}\ cm^{-2}s^{-1}$ levelled (5x design) to achieve 3000 fb^{-1} collected data until ~2037

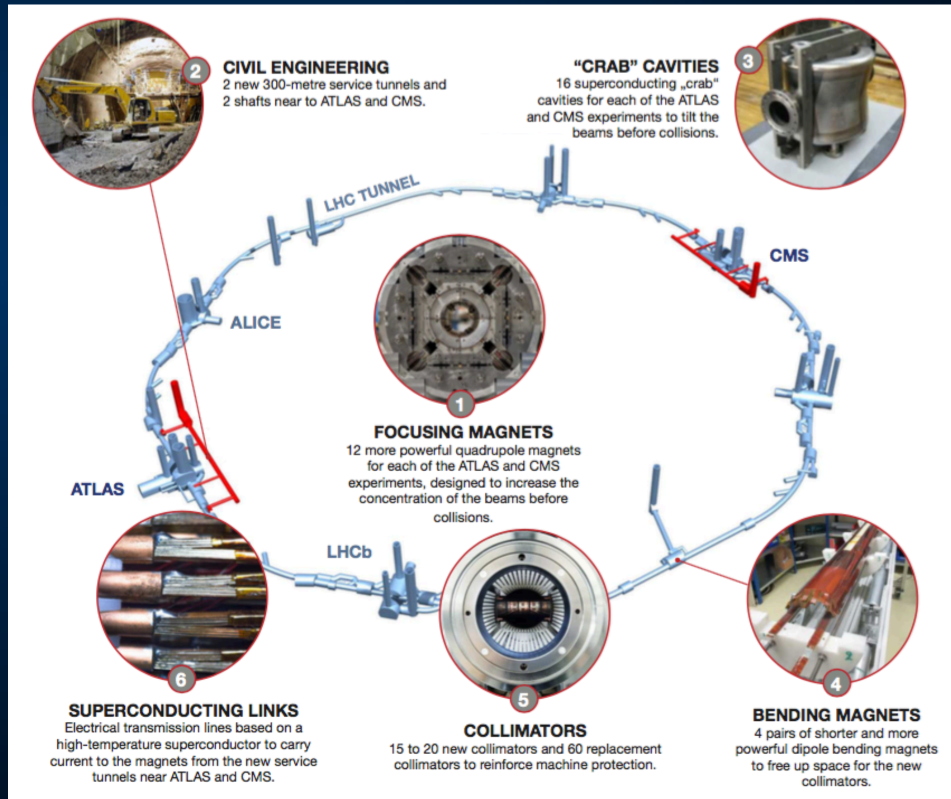
Rich physics programme: precision measurement of Higgs couplings, second generation couplings $H \rightarrow \mu\mu$, increase of discovery potential, many precision measurement, etc.

Upgrades for HL-LHC, interventions on 1.2 km of the machine:

- Civil engineering for service tunnels and shafts
- New Nb_3Sn magnets (11 T)
- Crab cavities
- Oct 2016 new LINAC4 reached nominal energy of 160 MeV

Major upgrades planned for the 4 LHC experiments:

- New detectors, e.g. Trackers, Muon chambers, Calorimeter
- Almost complete exchange of electronics
- New trigger systems



CERN is not only LHC

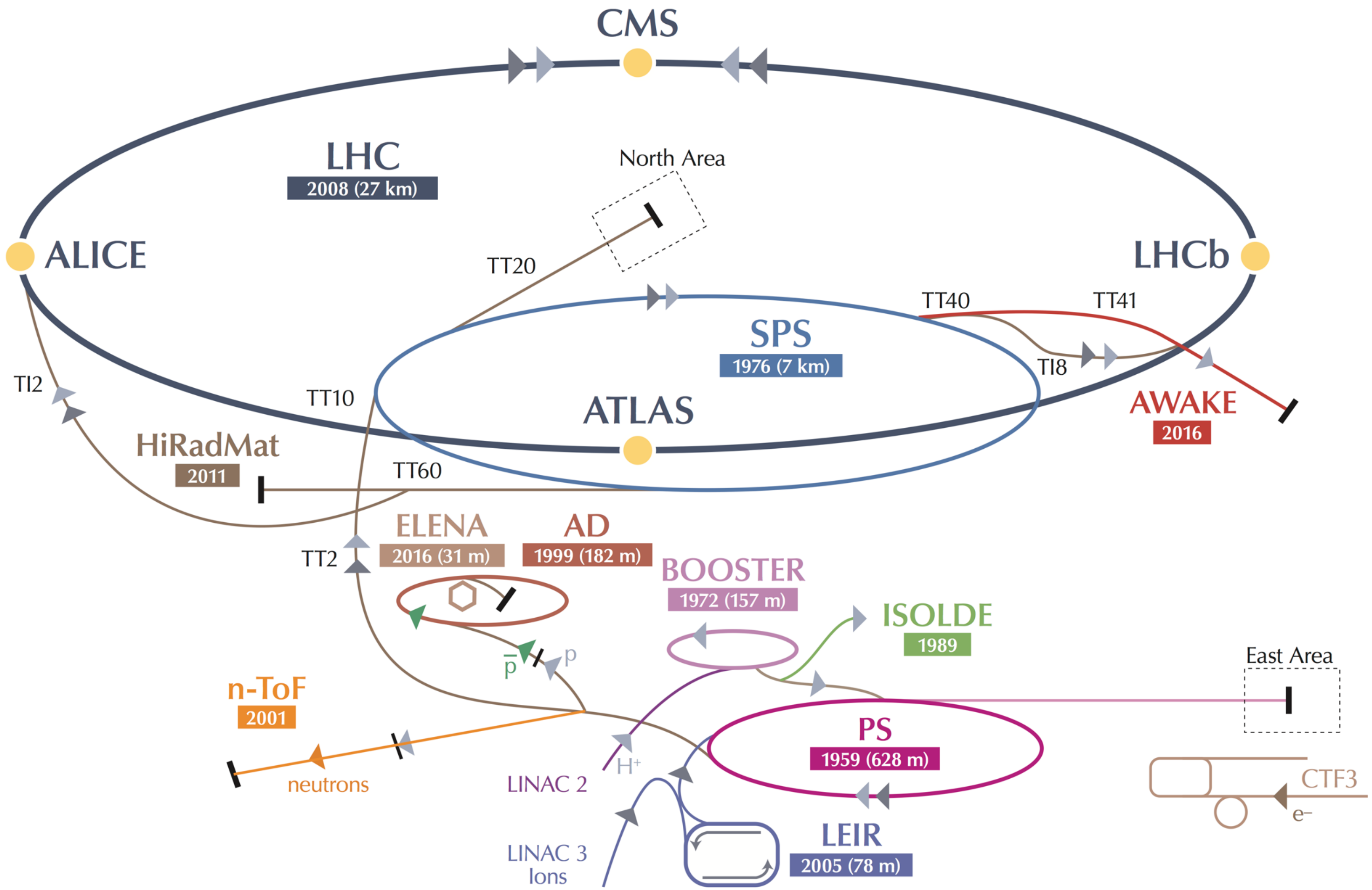
3 main pillars of the scientific strategy of CERN:

- Full exploitation of the LHC including upgrades and HL-LHC

- A scientific diversity programme
  Experiments exploiting the accelerator complex at CERN
  Non-Accelerator experiments (CAST, OSQAR)
  Participation in accelerator-based neutrino projects outside Europe

- Preparing CERN's future
  Studies for future accelerators: CLIC, FCC
  Studies for CERNs future diversity programme: "Physics beyond colliders"
  R&D on accelerator and experimental techniques

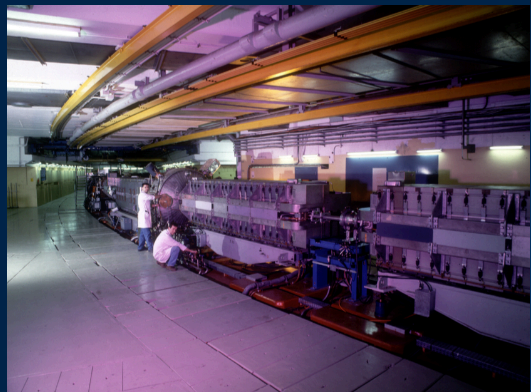
CERN Accelerator Complex



Fixed Target Physics

Lower energy experiments using the injector accelerators PS or SPS (in 1-100 GeV range)
Allow precision measurements and comparison with theory

Proton Synchrotron (1959)
14 – 26 GeV, max. 1.4×10^{13} protons per pulse



Super Proton Synchrotron (1976)
Protons up to 400 GeV, max. 9.5×10^{9} p per bunch

Fixed target experiments:

- NA58 (COMPASS): muon spin physics, hadron spectroscopy
- NA61 (SHINE): strong interaction, quark gluon plasma, neutrino and cosmic ray program
- NA62: rare K decays BR($K^+ \rightarrow \pi^+ \nu \bar{\nu}$)
- NA63: electromagnetic processes in strong crystalline fields
- NA64: search for dark photons in missing energy events

CERN

Fixed Target Physics

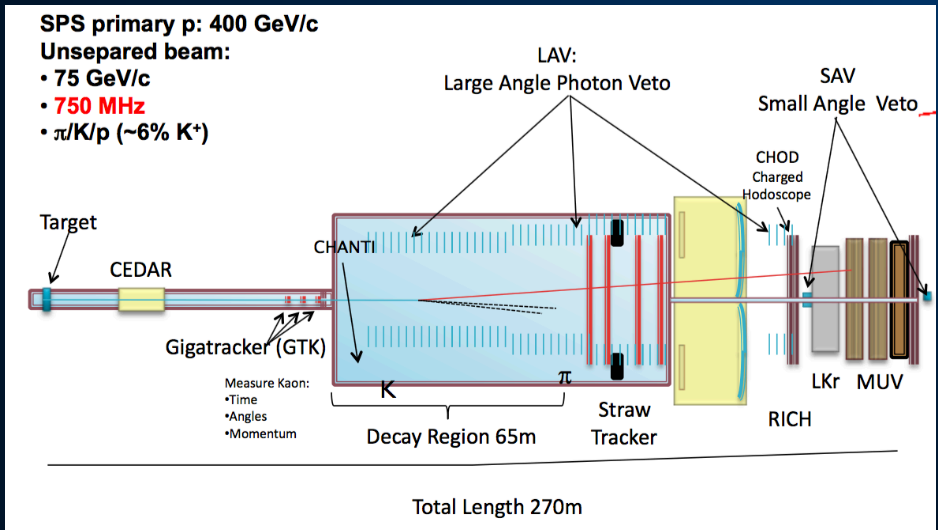
NA62

Search for very rare decays: BR($K^+ \rightarrow \pi^+ \nu\bar{\nu}$) predicted by theory to be (8±1)x10^{-11} (Buras et al. 2015)

And much more, e.g. Precision measurements of dominant Kaon BRs

- Precision test of lepton universality $R_K = \Gamma(K \rightarrow e\nu(\gamma))/\Gamma(K \rightarrow \mu\nu(\gamma))$
- Searches for lepton flavour or number violation $K^+ \rightarrow \pi^+\mu e, K^+ \rightarrow \pi^-\mu^+e^+, K^+ \rightarrow \pi^- l^+ l^+$
- Searches for heavy neutrinos $K^+ \rightarrow l^+\nu_h$
- Searches for long-lived dark sector particles: dark photons, axion like particles produced in target
- π^0 decays $\pi^0 \rightarrow invisible, 3\gamma, 4\gamma$

First data with completed detector in 2016, 3x10^{12} K^+ collected in 2017

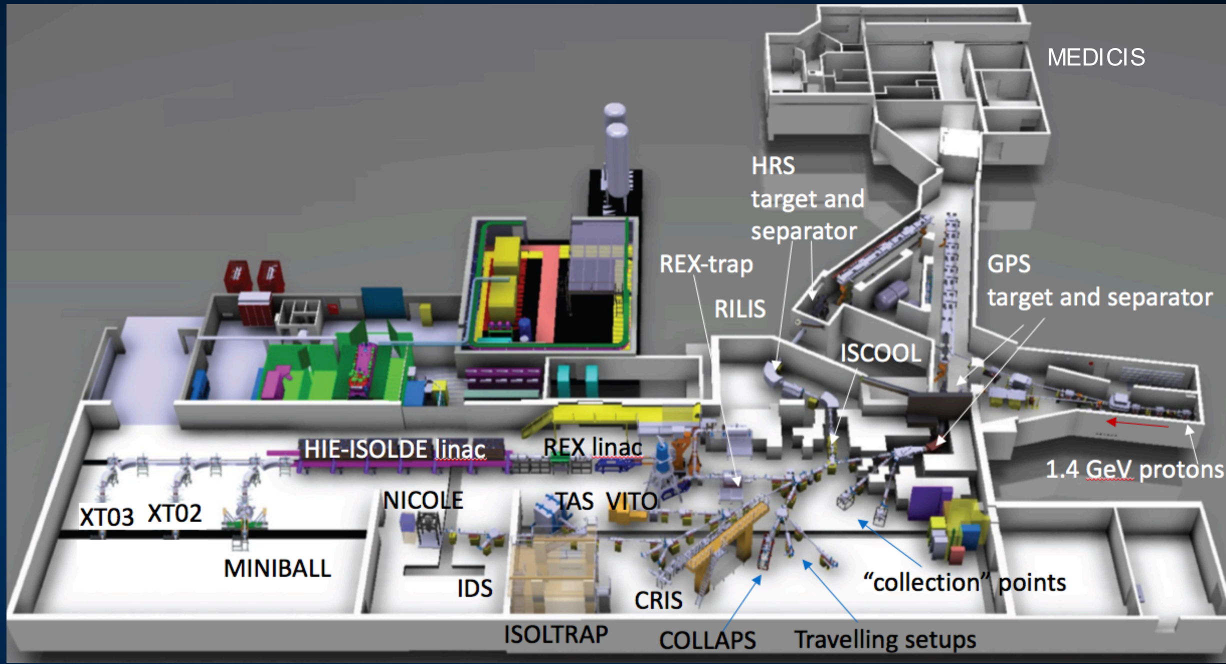


(60 m long)

Nuclear Physics: ISOLDE

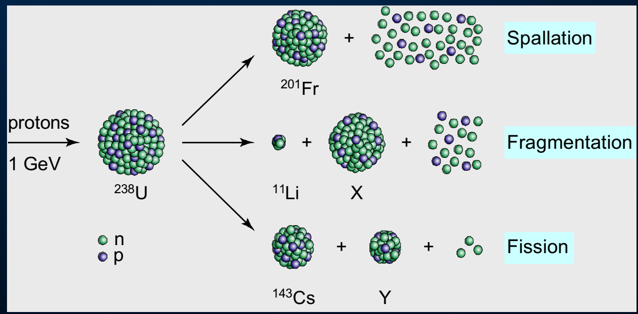
ISOLDE: radioactive ion beams

- Nuclear and Atomic physics
- Nuclear Astrophysics
- Material Science
- Life Sciences
- Fundamental interactions



HIE-ISOLDE (post acceleration up to 7,5 MeV/nucleon, 10 MeV/nucleon in 2018)

Over 20 Target materials:
carbides, oxides, solid metals, molten metals and molten salts (U, Ta, Zr, Y, Ti, Si, ...)



3 types of ion sources: surface, plasma, laser

Charge breader for post acceleration

➢ 1000 isotopes of 75 chemical elements produced

Nuclear Physics: ISOLDE

ISOLDE: radioactive ion beams
- Nuclear and Atomic physics
- Nuclear Astrophysics
- Material Science
- Life Sciences
- Fundamental interactions

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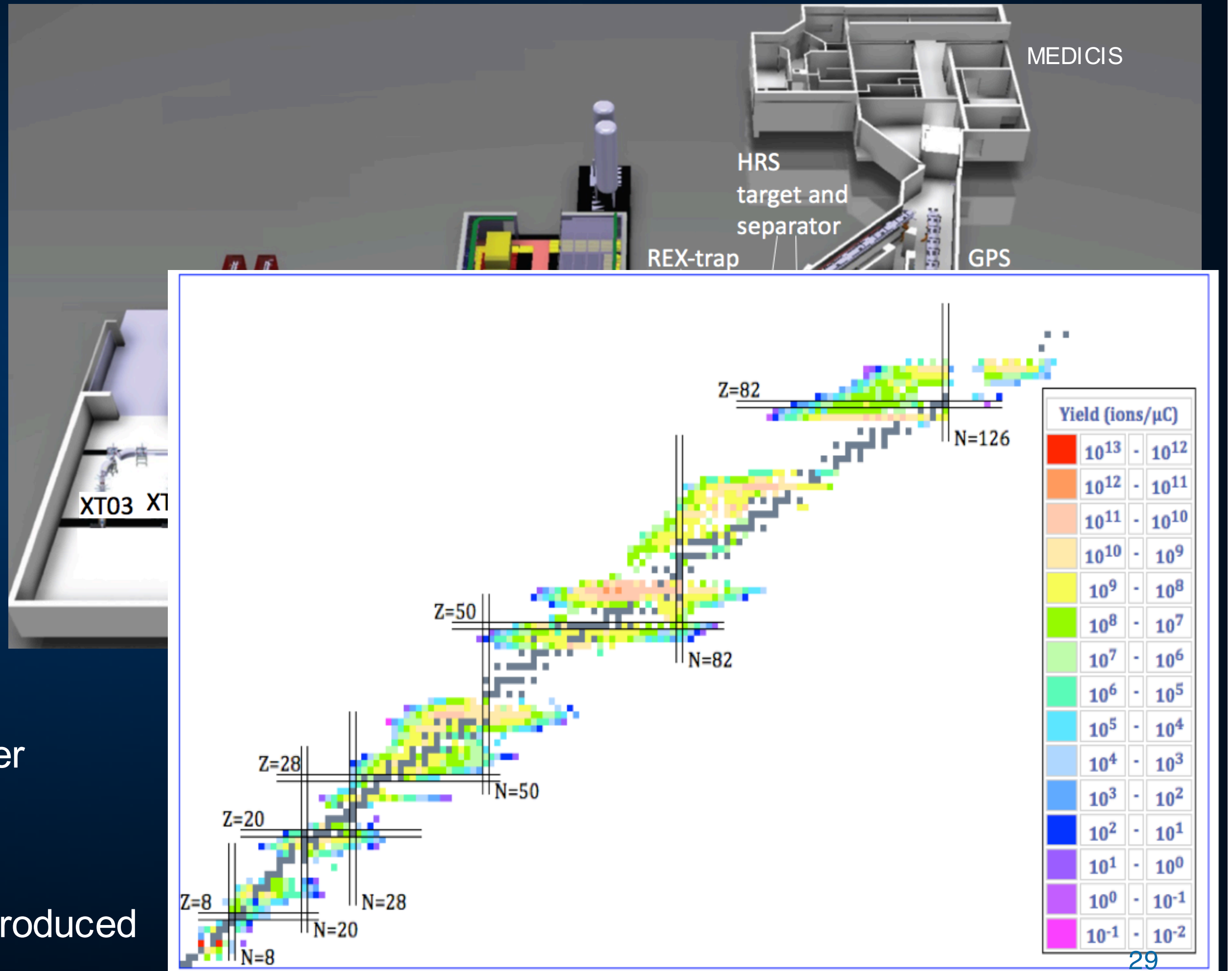


Nuclear Physics: ISOLDE

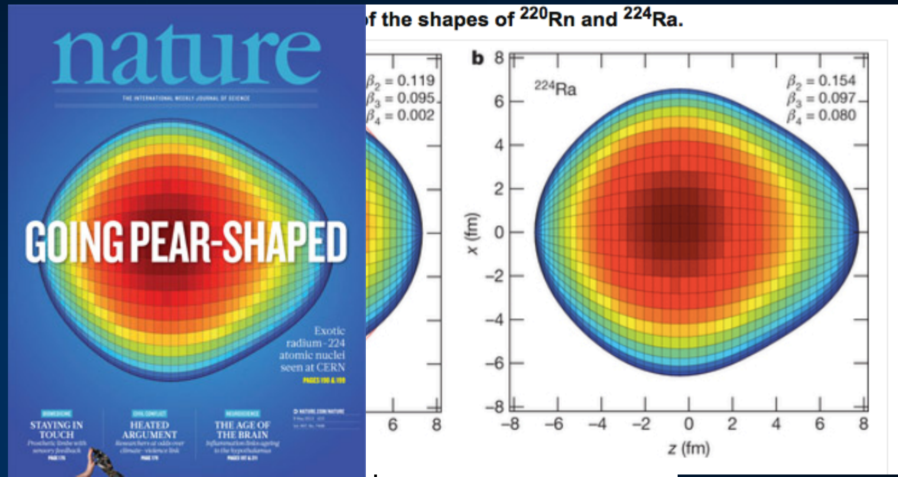
About 50 experiments every year using the ISOLDE facility

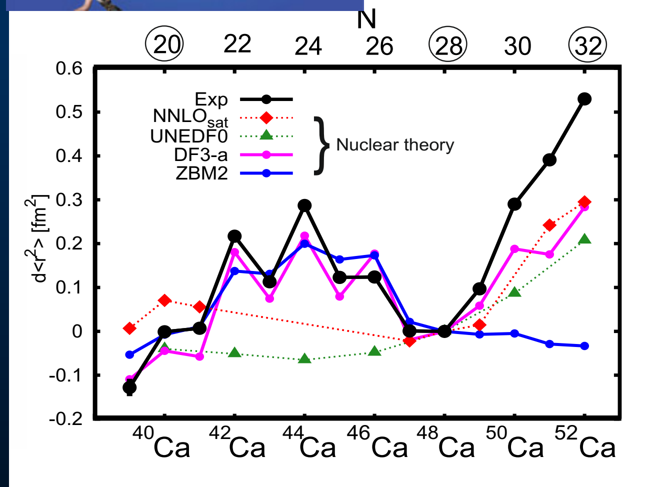
A few examples:

- Determination of the ionization potential of Astatine (At)
  Rarest naturally occurring element in the earth crust
  IP(At) = 9.31751(8) eV *Nature Com. 14May2013 DOI 10.1038*

- Studies of pear-shaped nuclei by Coulomb excitation *L. P. Gaffney, et al. (2013). Nature, 497(7448)*

- Investigation of emerging new magic numbers far from stability (N=32, N=34) by the determination of the masses of $^{51-54}Ca$
  R. F Garcia Ruiz et al., 8 Feb 2016, Nature Physics 12 (2016) 594





Nuclear Physics: nTOF

nTOF (neutron time-of-flight) a spallation source using 20 GeV/c protons from the PS

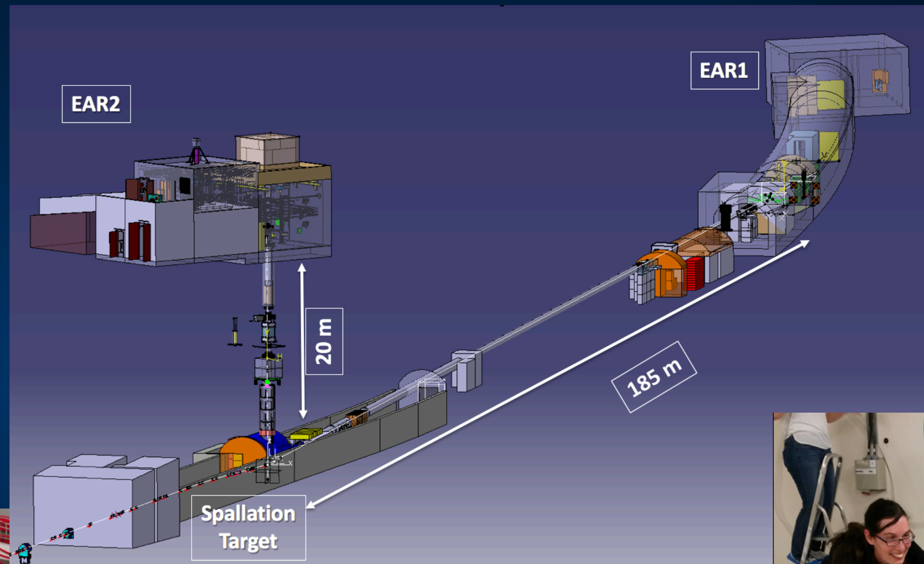
Neutron cross-section measurements

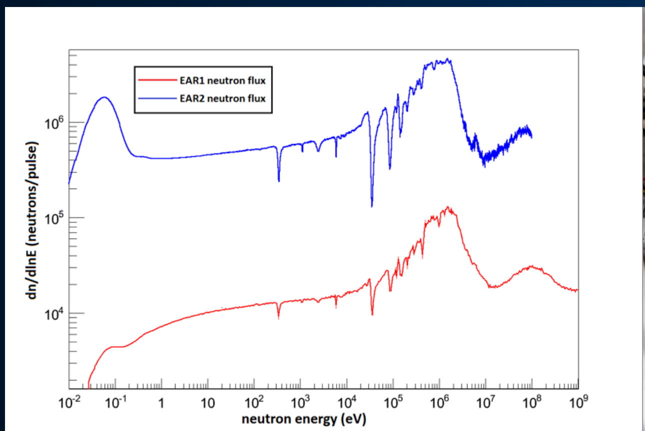
- Astrophysics
- Nuclear Physics
- Medical Applications
- Nuclear Waste Transmutation

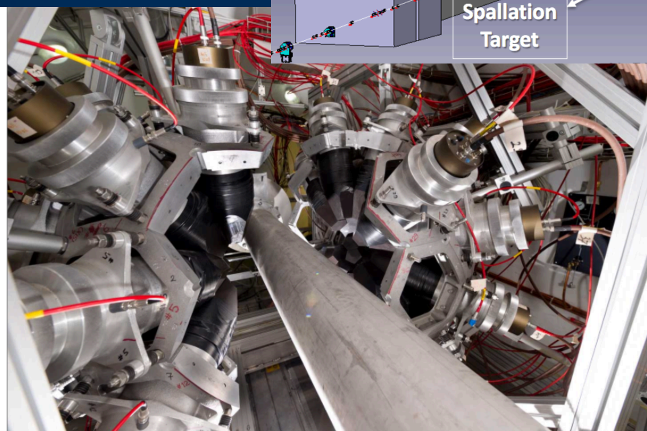
2 experimental areas EAR1 and EAR2

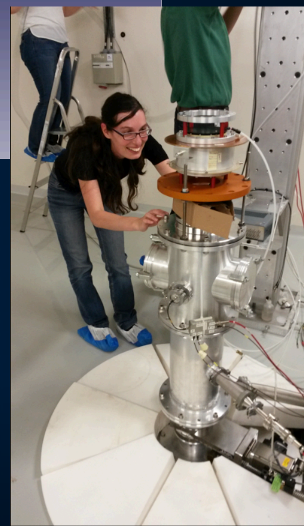
High instantaneous neutron flux (10^5/cm^2/pulse)

Large energy range (25 meV – 1 GeV)









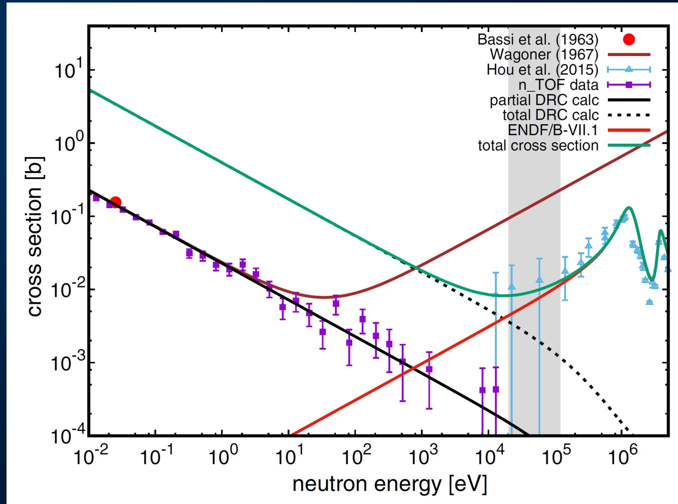
Nuclear Physics: nTOF

Example: Tracing the cosmological Lithium problem

Theory of Big Bang Nucleosynthesis predicts the abundance of primordial elements (H, He, Li)
Predictions agree with observations, except for ^{7}Li (factor 2-3 lower measured)

- 95% of primordial ^{7}Li produced by electron capture decay of ^{7}Be ($T_{1/2}$=53,2 days)
- Does a higher destruction rate of ^{7}Be explains the ^{7}Li deficit
- Neutron cross section measurements difficult due to lifetime of radioisotope and small sample mass

Measurements done at nTOF in 2015: ^{7}Be(n,a)^{4}He
And in 2016: ^{7}Be(n,p)^{7}Li



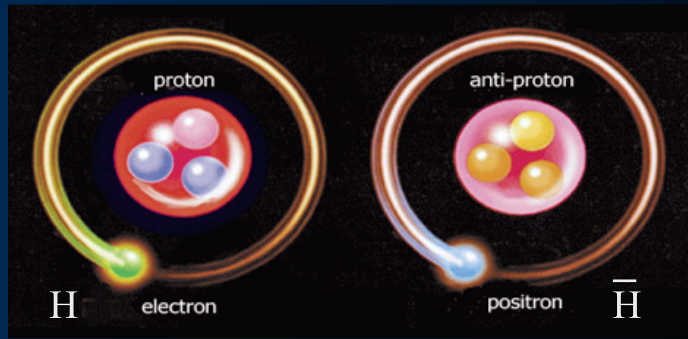
The ^{7}Be(n,a)^{4}He result makes the problem even worse: no explanation

M. Barbagallo et al., Physical Review Letters 117, 152701, 2016

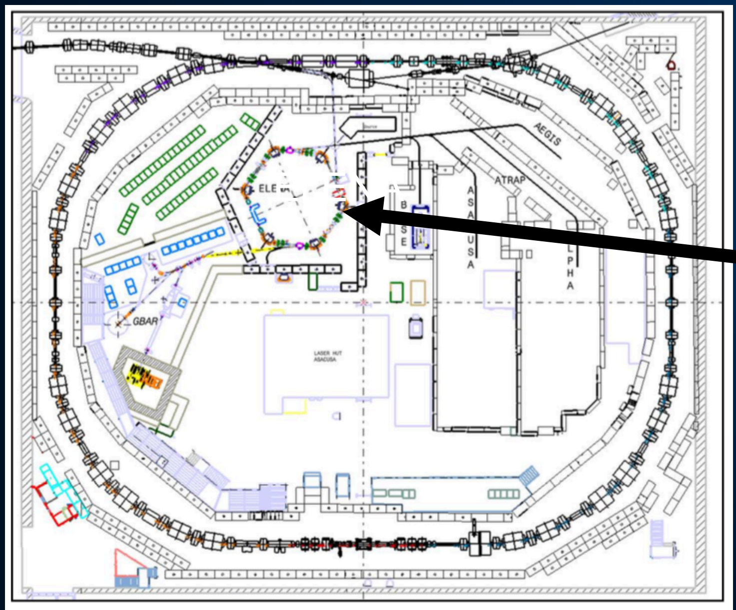
Antiproton & Antihydrogen Physics

Matter-Antimatter comparison

- Test CPT invariance, the most fundamental Symmetry in relativistic quantum field theory
- Test of the Weak Equivalence Principle by measuring the gravitaional behavior of antimatter
- Measurements of “antihydrogen”-like systems: antiprotonic helium, positronium, protonium



The Antiproton Decelerator (AD): antiprotons at 5.3 MeV



In commissioning ELENA
Extra Low Energy Antiprotons
at 100 keV
→10-100 x larger trapping efficiency
→ Parallel running of experiments

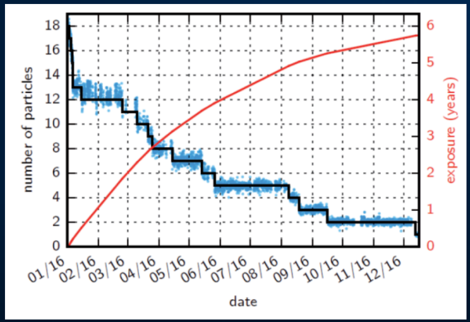
Antiproton & Antihydrogen Physics

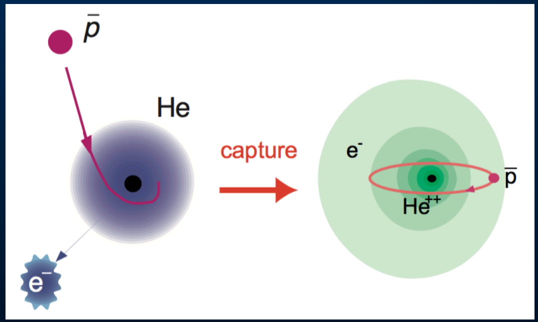
6 experiments connected to the AD/ELENA:

ATRAP spectroscopy and magnetic moment of the antiproton
With a single trapped antiproton: $\mu_{p(bar)} / \mu_p$=-1.000000+-5 x 10^{-6} *Phys. Rev. Lett. 110, 130801 (2013)*

BASE magnetic moment of the antiproton
Trapped antiprotons and stored them for >400 days
Improvement of precision by a factor of 350: $\mu_{p(bar)}$ = -2.7928473441 (42) μ_N *Nature 550, 371 (2017)*

ASACUSA spectroscopy of exotic atoms
antiprotonic Helium p(bar)He^+, H(bar) ground state hyperfine splitting
Measurement of the ratio of $M_{p(bar)}$ / m_e , agrees to measured M_p / m_e within 8 x 10^{-10}
Science Vol. 354, Issue 6312, pp. 610-614 (2016)





Antiproton & Antihydrogen Physics

ALPHA/ALPHA-g spectroscopy and gravity

1st measurement of 1s – 2s transition in anti-H to 10^{-10}

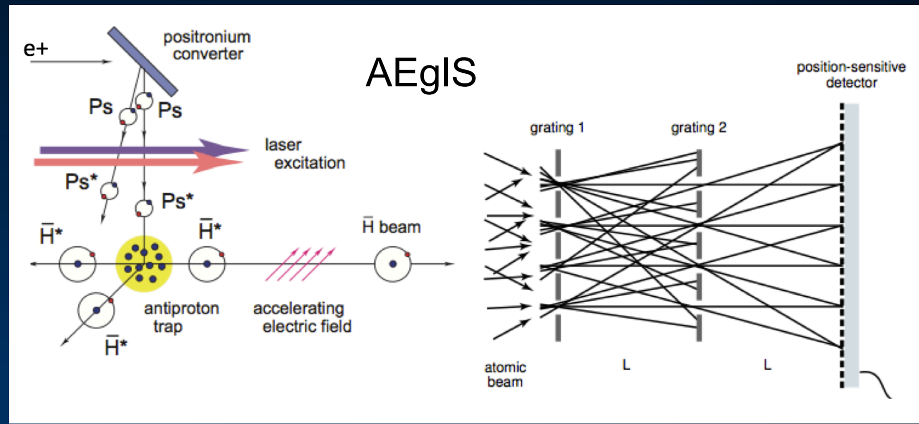
Nature 541, 506-510 (2017)

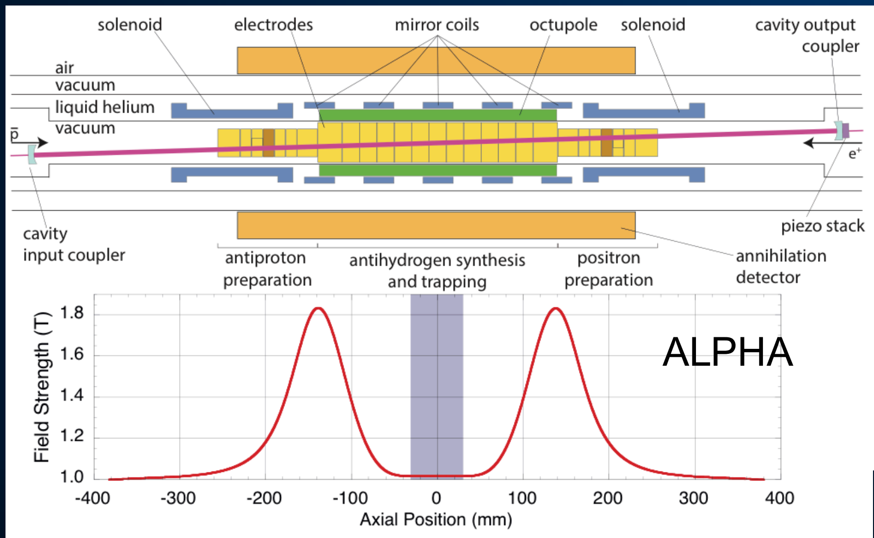
1st observation of the hyperfine spectrum of anti-H

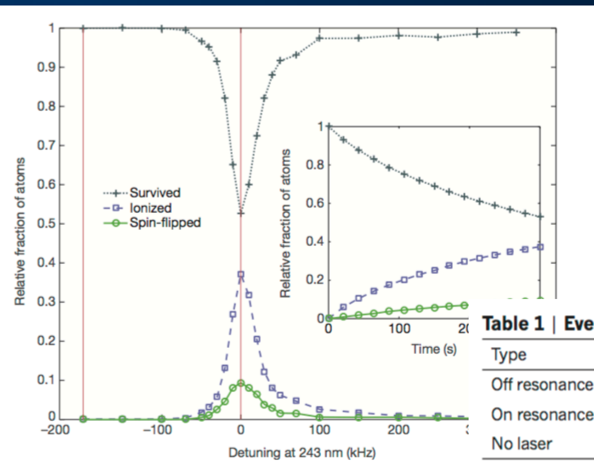
Nature 548, 66-70 (2017)

AEgIS spectroscopy, antimatter gravity experiment

GBAR (will start in 2017 connected to ELENA)
antimatter gravity experiment







H̄ excited to 2s state, ioinzed by the laser and removed from the trap.

Table 1 | Events during the 1.5-s ramp down of the trap magnets

Type	Number of detected events	Background	Uncertainty
Off resonance	159	0.7	13
On resonance	67	0.7	8.2
No laser	142	0.7	12

Environmental Physics

CLOUD - Study effect of cosmic rays on cloud formation

Clouds created in a large climatic chamber

Study influence of natural and man made aerosols on the development of clouds, cosmic rays “simulated” by PS beam.

Ultra clean, can simulate temperature conditions anywhere in the atmosphere, equipped with a wide range of instruments for monitoring and analysis.

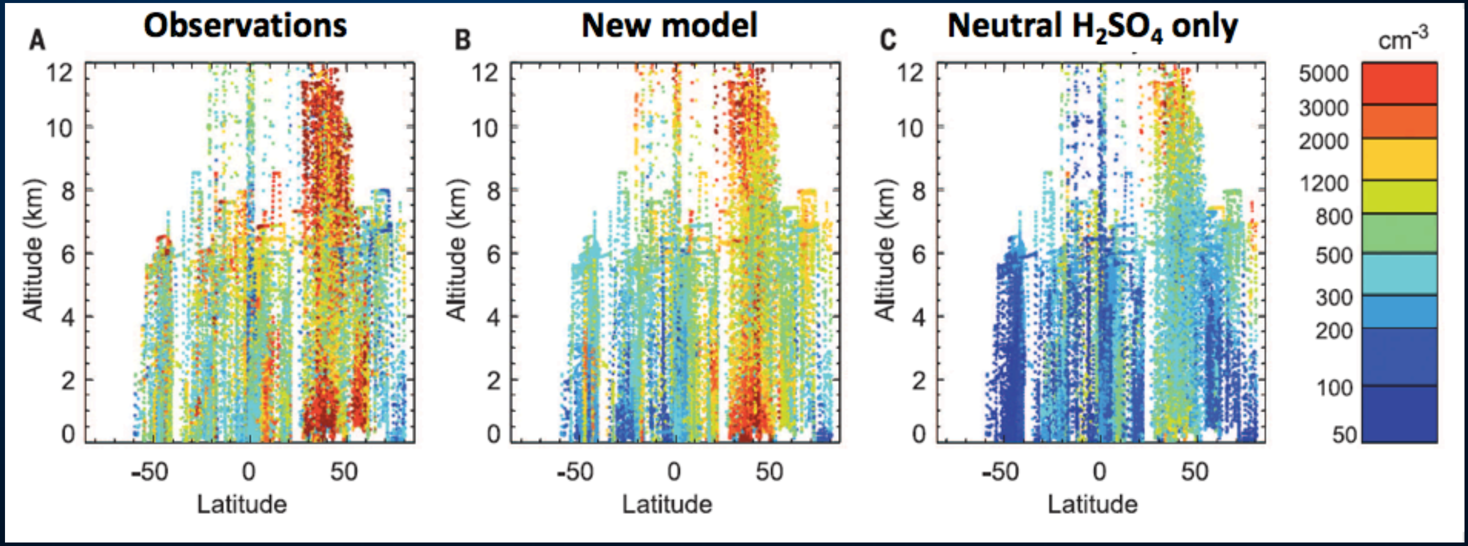
Environmental Physics

Global climate models have large uncertainties in particular what concerns the understanding of aerosols in the atmosphere and their effect on cloud formation.

The CLOUD experiment has gathered experimental data to model aerosol production solely based on laboratory measurements.

Science 10.1126/science.aaf2649 (2016)

Cloud formation was higher than expected in pre-industrial times due to pure biogenic nucleation and influenced by cosmic rays. Result important to reduce uncertainties in current climate model.



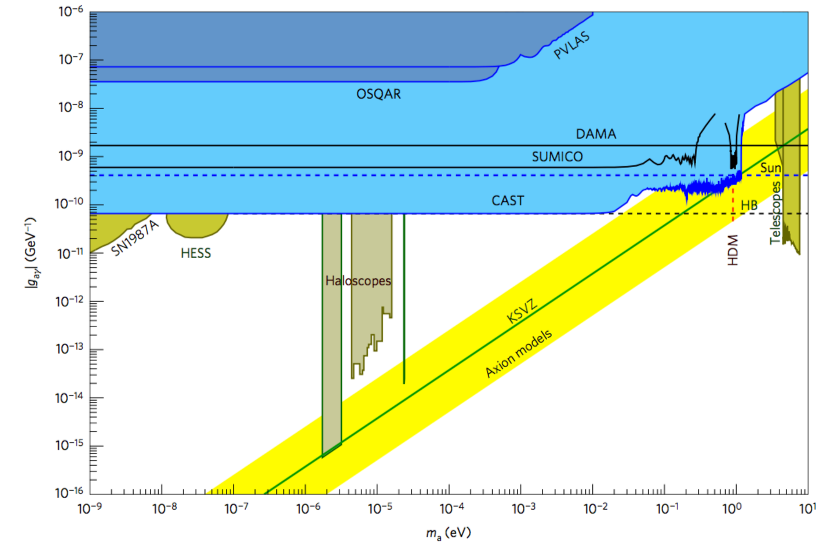
Nature 533, 527-531 (26 May 2016)

Non Accelerator Experiments

CAST: The CERN Axion Solar Telescope (using a LHC test magnet)

- Search for solar axions
- New search for dark matter axions
- New search for solar chameleons

Constraints on Axion-Photon coupling:



Nature Physics 13, 584-590 (2017)

OSQAR: Search for Axions through "Light shining through wall experiments" and search for Chameleons "inverse Primakoff conversion – afterglow" Using LHC prototype dipol magnet

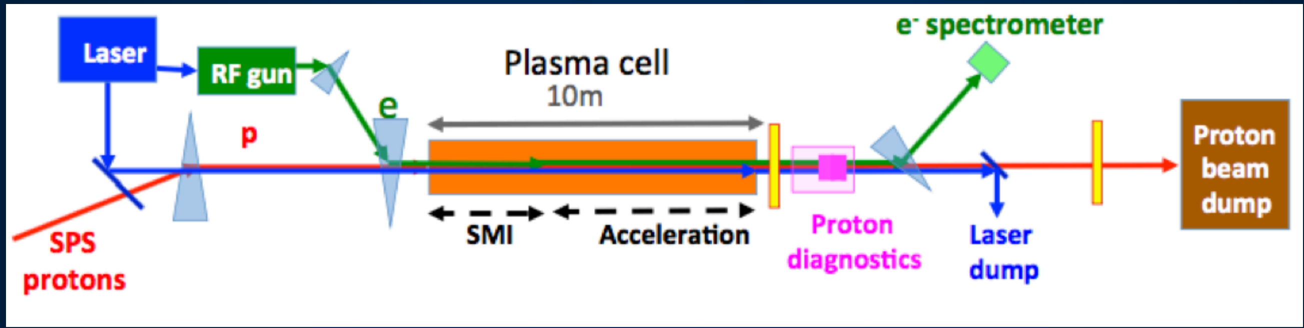
AWAKE

Advanced Proton Driven Plasma Wakefield Accelerator Experiment

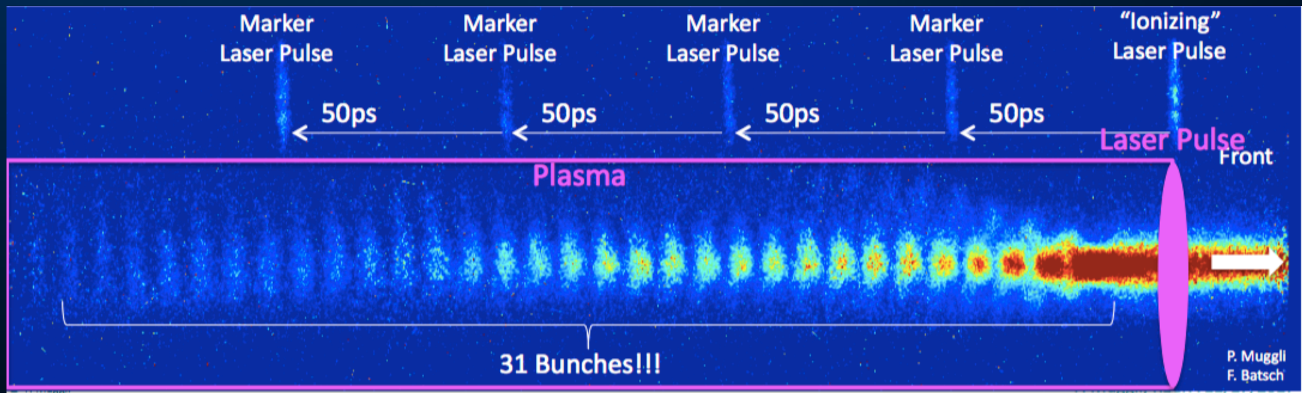
R&D experiment to demonstrate novel accelerator technique:

400 GeV proton beam generates strong electromagnetic field in plasma,

e^- beam to be accelerated in the wake of the p beam – aim for accelerator gradients of ~GeV/m

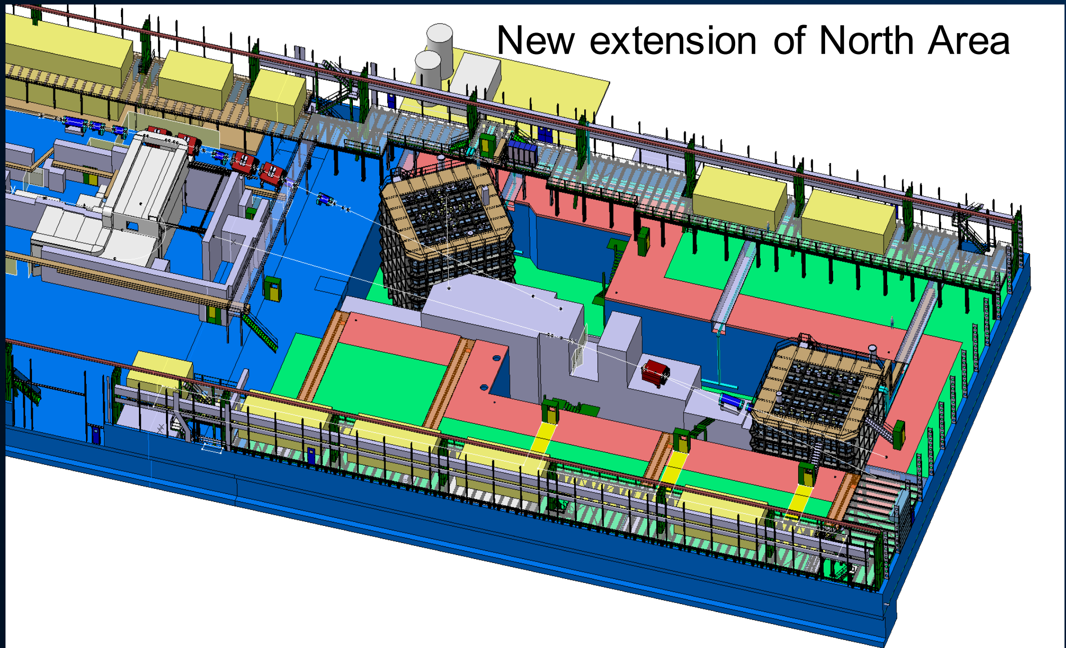


Observation of beam induced self modulated instabilities



Neutrino Physics

Following the 2013 European Strategy Update CERN established the Neutrino Platform at CERN:
Support for the European Neutrino Community, test area with charged beams for neutrino detectors (e.g. R&D for large liquid argon detectors)



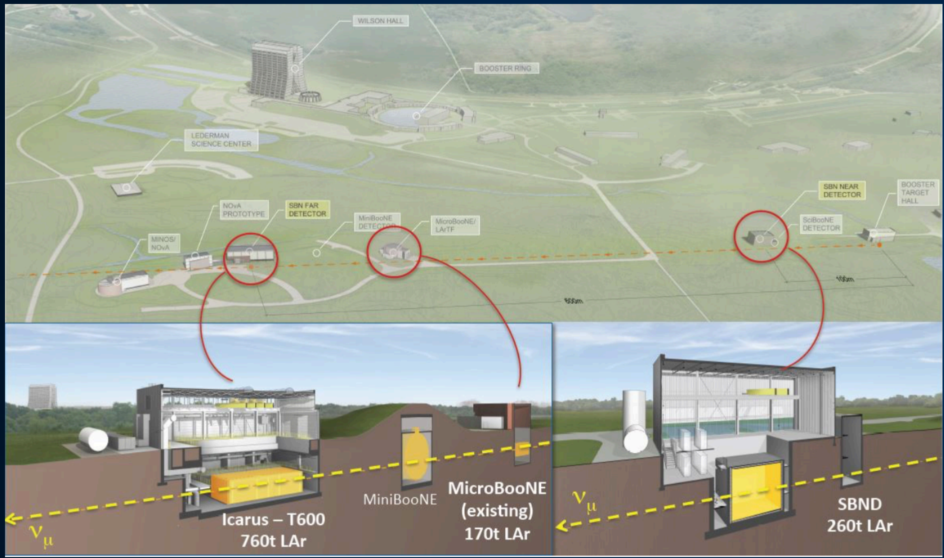
At present 5 projects/activities part of the platform:

- Refurbishment of ICARUS, a short base line detector – done
- Construction of two large LAr Prototypes for DUNE (Single phase and double phase). Test with charged beams planned for end of 2018.
- Baby MIND a magnetized iron spectrometer for a JPARC experiment
- PLAFOND framework for generic R&D

Neutrino Physics

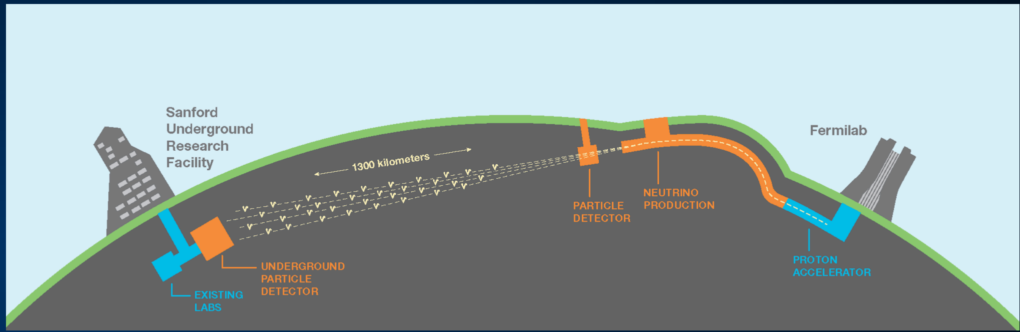
Participation of CERN in two experiments connected to FERMILAB in the US:

Short base line experiment ICARUS



A multi-detector programme addressing unexplained anomalies (sterile Neutrinos?). ICARUS 600 m from target. Plan to start physics operation in 2018.

Long base line experiment DUNE



Wide band neutrino beam from FNAL (60-120 GeV, 1.2-2.3 MW) to Homestake mine (South Dakota)
Baseline 1300 km (800 miles)
~1500 m underground
4 detectors with 17400 tons of LAr each
Neutrino beam in 2026

Neutrino Physics

Neutrino oscillation physics with DUNE:

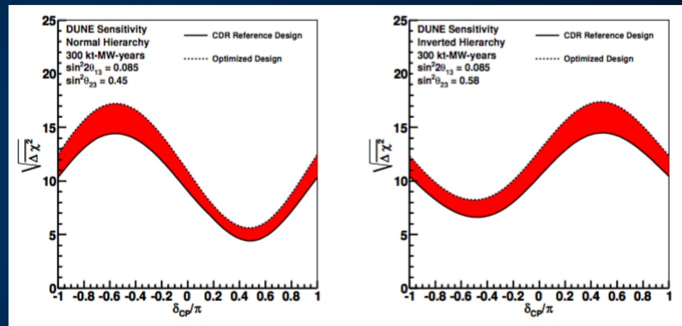
- Mass hierarchy
- CP violation

Plus much more:

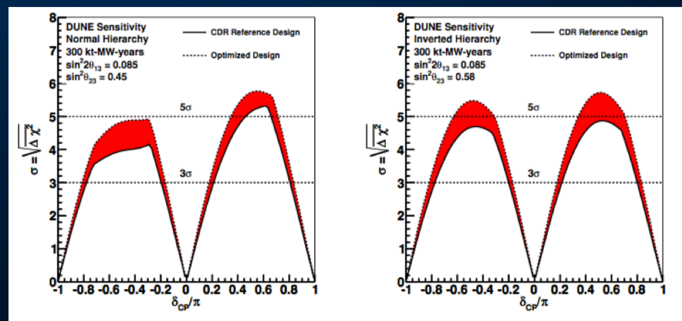
- Proton decay (specific decays, e.g. $p \rightarrow K^{+}\nu$(bar)
- Atmospheric neutrinos
- Neutrinos from supernova (ν_e component giving insight into early stage of the core collapse)
- Near detector provides precision measurements of neutrino interactions (EW physics, nucleon structure, search for new particles, e.g. heavy sterile neutrinos, dark matter particles

DUNE physics performance:
Assuming 7 years of operation, 40kt detector, 1.08 MW 80 GeV proton beam

Sensitivity mass hierarchy



Sensitivity CP violation



DUNE CDR arXiv:1512.06148

Studies for Future Facilities

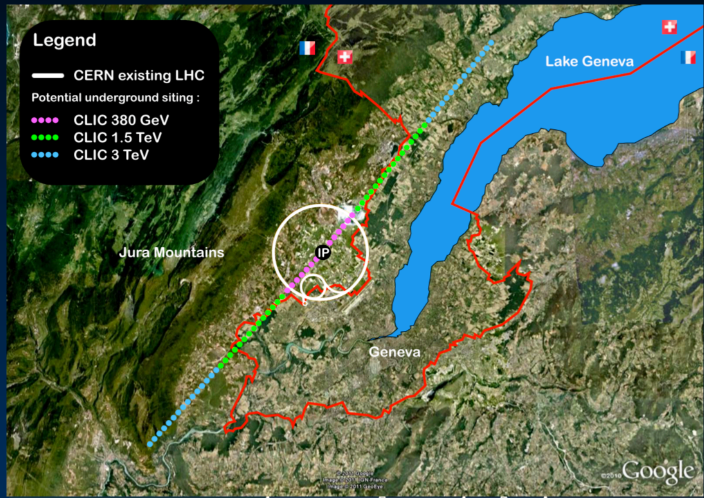
LHC, and its upgrade to higher luminosity, is central to CERN program for next decade(s)
But Europe need to prepare for what will come after, so future accelerators and experiments are under study

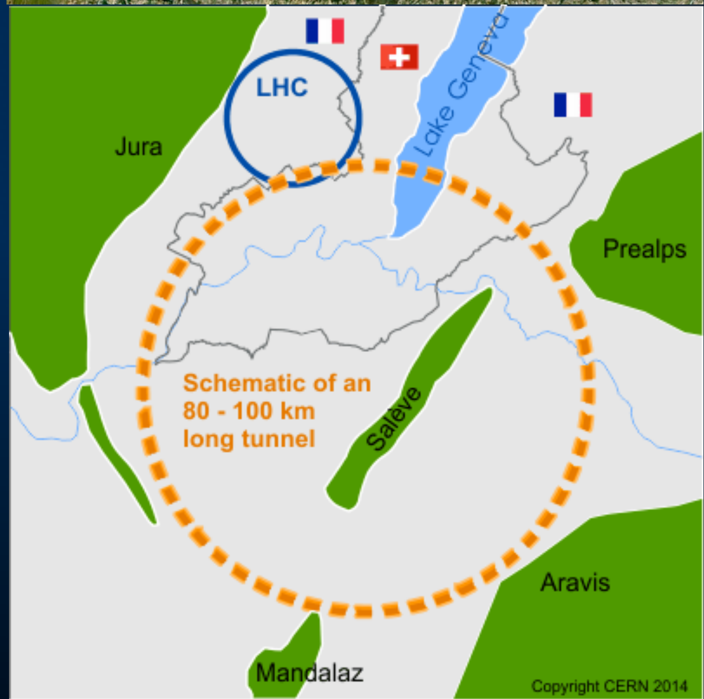
- CLIC – Compact Linear Collider
  Study of the design for a possible future e^+e^- linear collider up to 3 TeV, starting at 380 GeV

- FCC – Future Circular Collider
  Study of a 100 km circumference machine for pp collisions at 100 TeV, as well as e^+e^-, option for ep

- Physics beyond Colliders
  Study to explore possibilities using the non-collider part of the CERN accelerator complex

Time schedule for next update of the European Strategy defined: Conclusion in May 2020.





R&D on Experimental Technologies

New physics requires new experimental technologies!

R&D within the CERN EP department

Detector technology

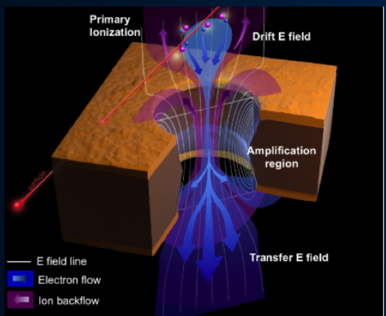
- Radiation tolerant silicon detectors (RD50)
- Gaseous detectors (RD51)
- Scintillating fibre detectors
- Novel on-detector cooling
- Micro-systems engineering

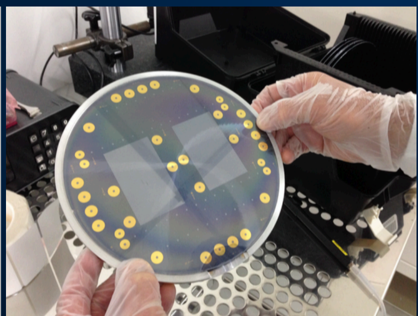
Electronics

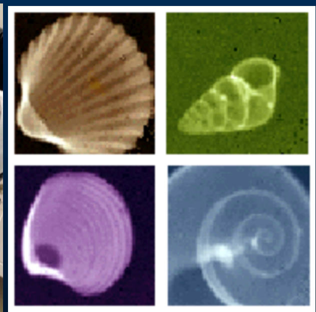
- Radiation hard ASICs
- Fast, low power optical links
- Radiation hard DC-DC converters
- Readout electronic for pixel detectors (RD53)
- Pixel X-ray imaging chip, Medipix

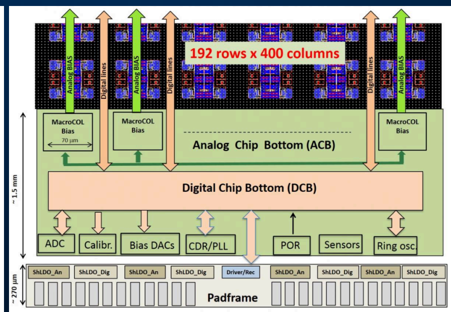
Software

- Simulation (Geant4, GeantV, Fluka, Garfield)
- Analysis (ROOT)
- Virtual Software Appliance (CernVM, CernVM-FS)
- Data models
- Framework and infrastructure, (GAUDI)
- Reconstruction







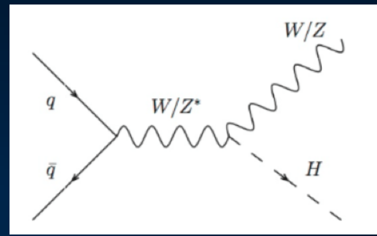


Thank you for your attention !

LHC Physics - Higgs

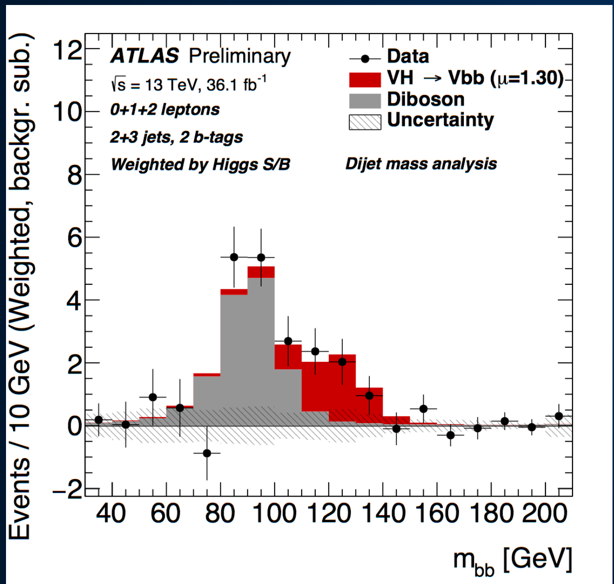
Evidence for Higgs decaying to b-quarks

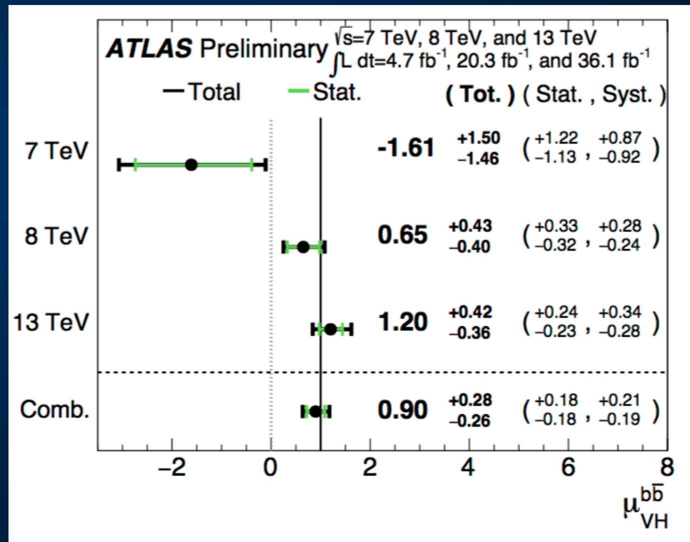
H→bb decay is dominating (BR~58%)
Combined Tevatron significance for this channel was 2.8 σ



ATLAS combined analysis for Z and W final states ($Z\rightarrow ll$, $Z\rightarrow \nu\nu$, $W\rightarrow l\nu$)

ATLAS-CONF-2017-041





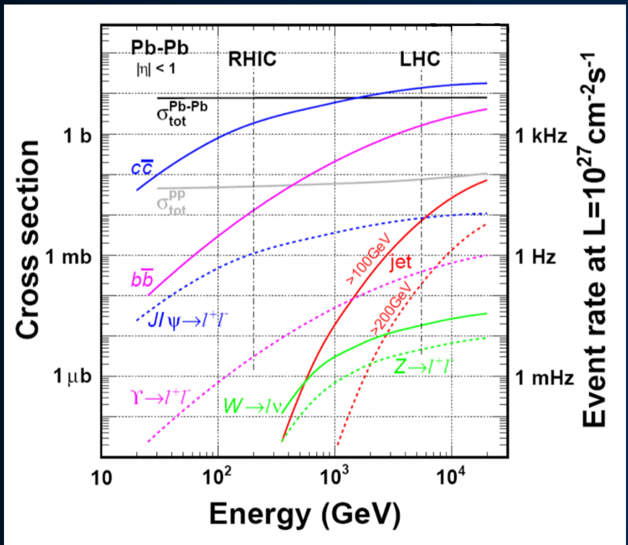
Significance 3.5 σ (expected 3.0 σ)

Signal strength $\mu = \frac{\sigma}{\sigma_{SM}}$ = 0.90$\pm$0.18 (stat.) $^{+0.21}_{-0.19}$ (syst.)

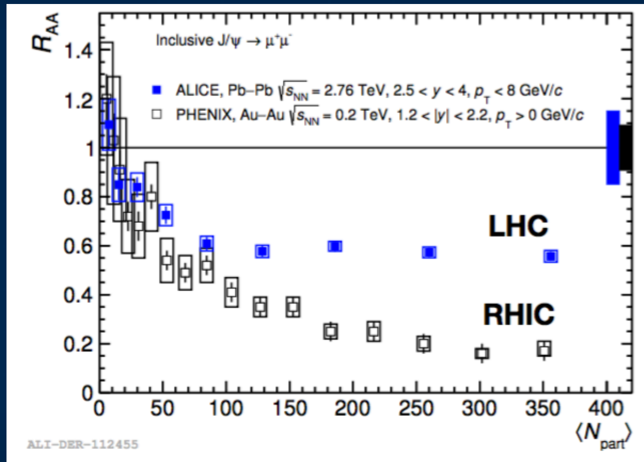
LHC Physics – Heavy Ion

Large cross section for hard probes, e.g. heavy quarks, traversing the QQP

High momentum partons lose energy while propagating through the QGP → Jet quenching



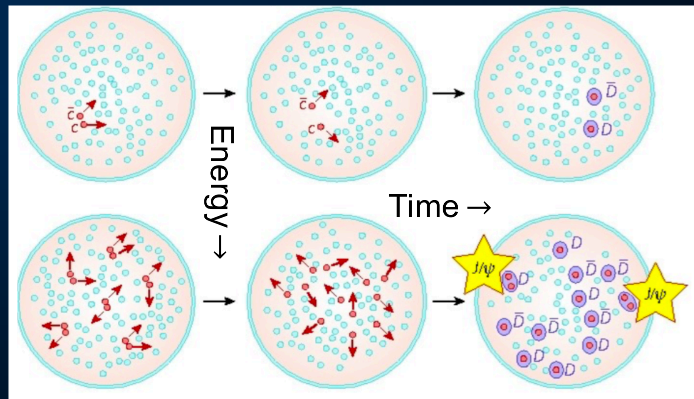
J/ψ suppression and quark (re)combination



M. Floris, EPS2017

At lower energy (RHIC) colour screening in QGP sēparates cc pairs → J/ψ suppression.

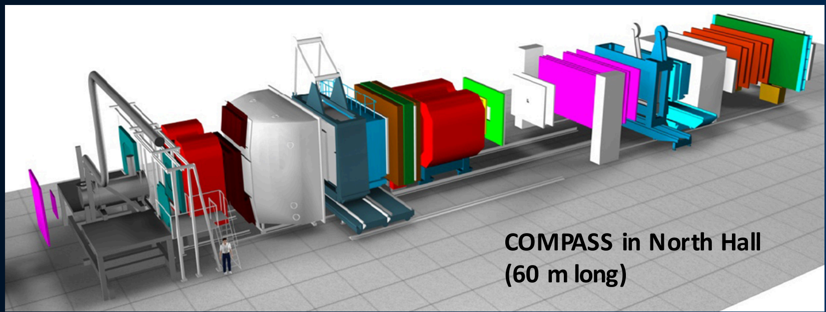
At higher energies re-generation from unrelated c quarks → J/ψ suppression suppressed.



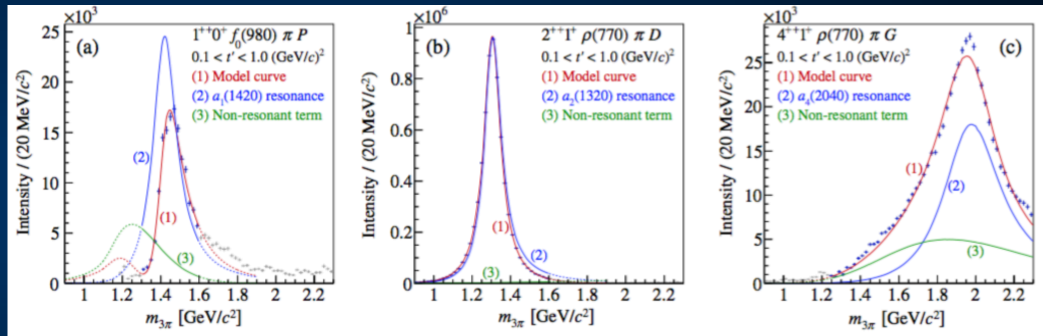
Fixed Target Physics

NA58 COMPASS

Study of hadron structure and hadron spectroscopy with high intensity muon and hadron beams on different (polarized) targets.



E.g. Partial Wave Analysis of measured spectrum, diffractive dissociation of π into $\pi^-\pi^-\pi^+$



Phys. Rev. Lett. 115, 082001 (2015)

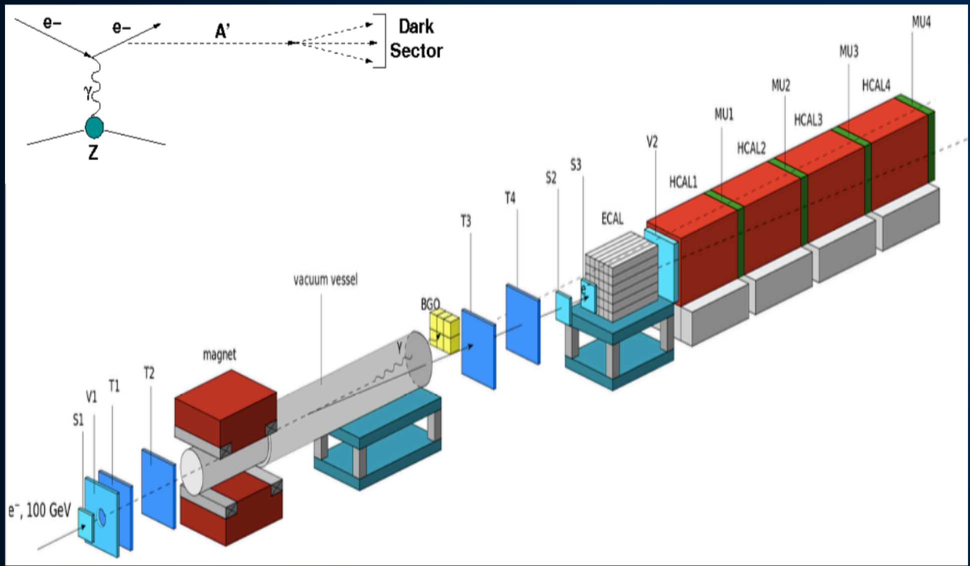
→ Discovery of a narrow Axial-Vector Meson $a_1(1420)$ - Exotic, not predicted by Lattice QCD

→ First polarised Drell-Yan measurement results

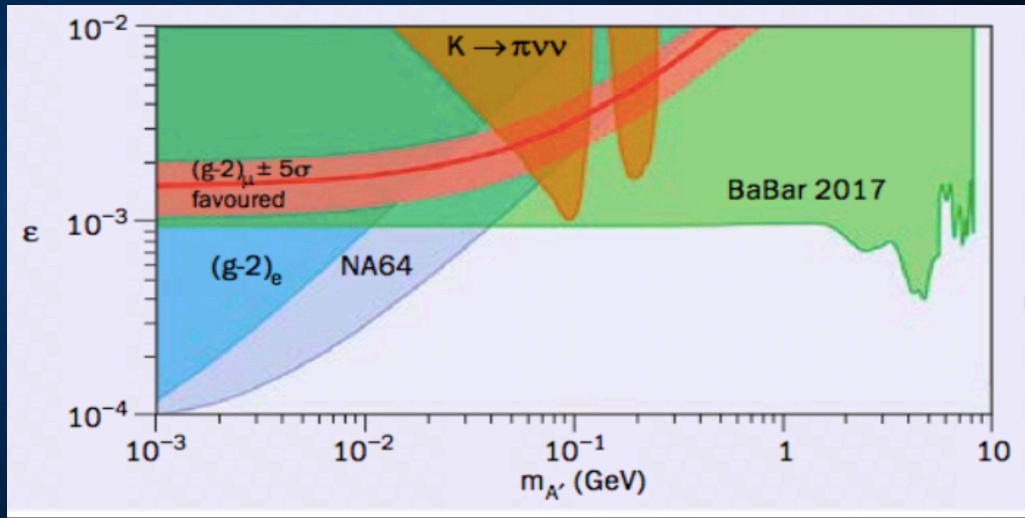
Fixed Target Physics

NA64

Search for new, in particular Dark Sector particles in missing energy events. Run in 2016/2017 with 100 GeV electrons.



NA64 excludes dark photons as explanation for g-2 anomaly



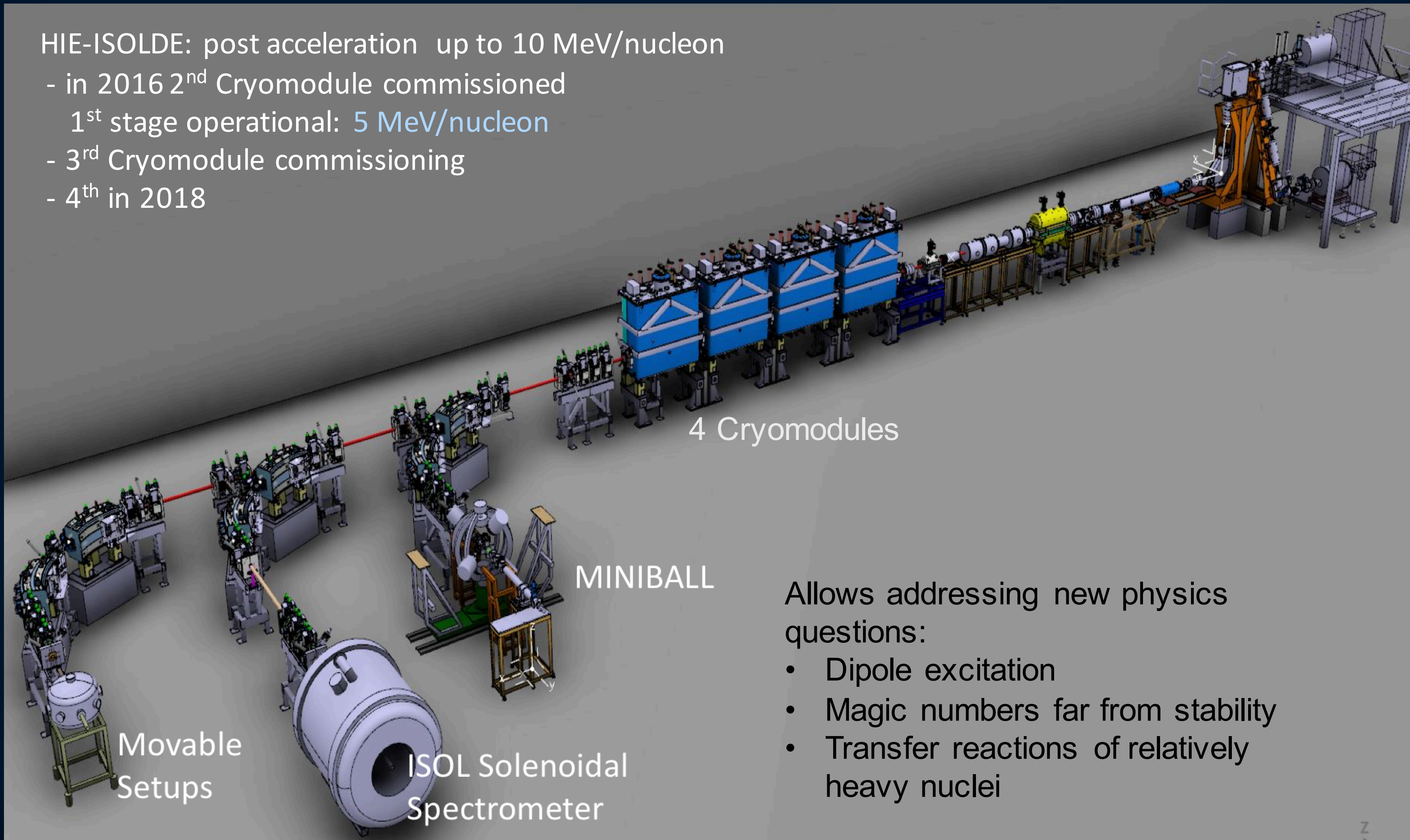
Phys. Rev. Lett. 118 011802

Aditional programme: search for light X Boson with visible decay to e^+e^- (motivated by excess of events in transition from excited ^{8}Be at 16.7 MeV)

HIE-ISOLDE

HIE-ISOLDE: post acceleration up to 10 MeV/nucleon

- in 2016 2nd Cryomodule commissioned
  1st stage operational: 5 MeV/nucleon
- 3rd Cryomodule commissioning
- 4th in 2018



Allows addressing new physics questions:

- Dipole excitation
- Magic numbers far from stability
- Transfer reactions of relatively heavy nuclei

Nuclear Physics: ISOLDE

About 50 experiments every year using the ISOLDE facility

Another example:

- Quadrupol Moment of ^{219}Fr
  Laser spectroscopy probing the hyperfine structure
  Spherical up to N=126 → Sudden deformation for $^{219-225}Fr$
  R.P. de Groote et al., Phys. Rev. Lett. ***115*** *132501 (2015)*