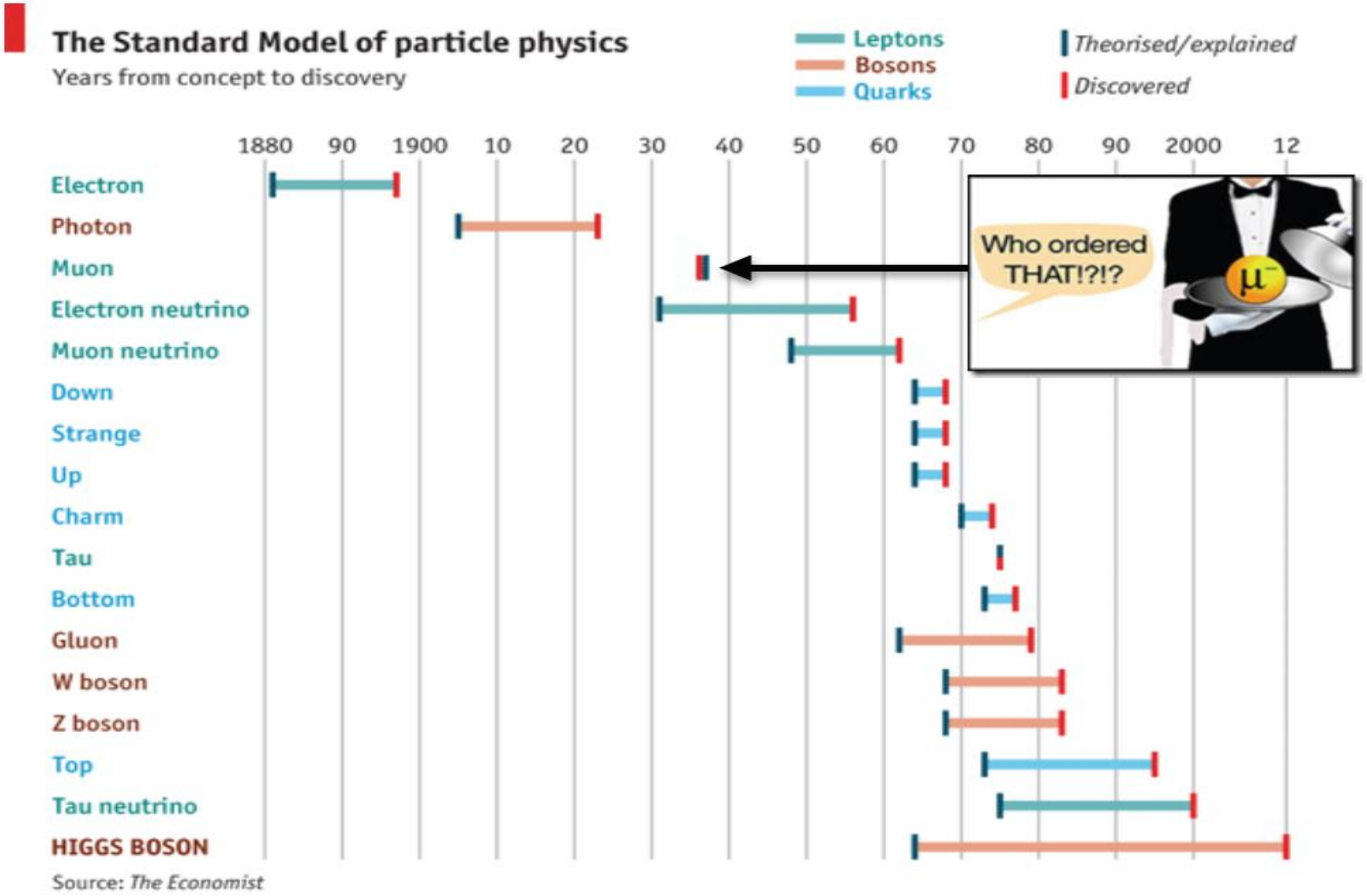
Introduction to particle physics: experimental part

Searches for New Physics

Results from Run II

Prof. dr hab. Elżbieta Richter-Wąs

Uncharted discoveries?

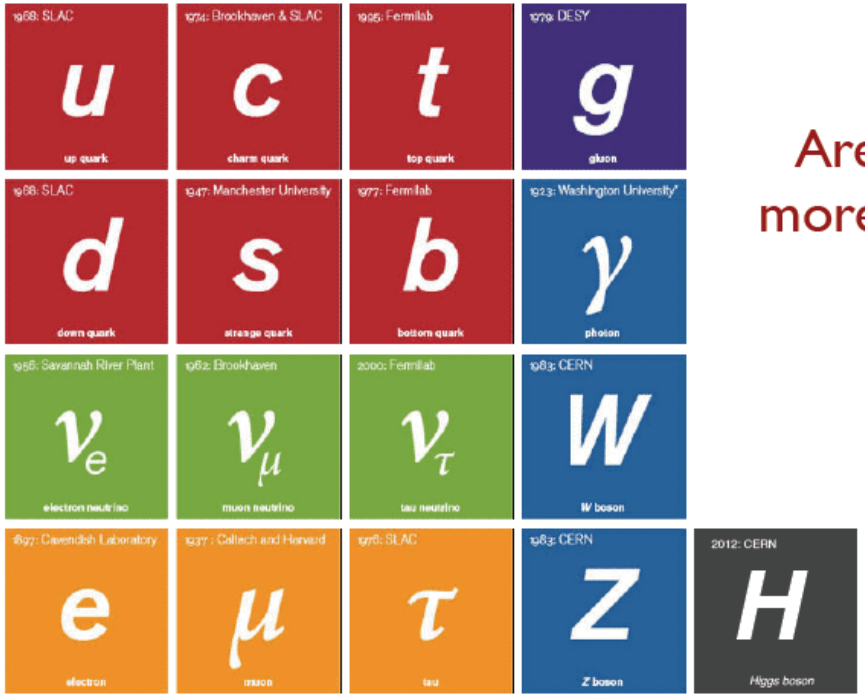


Many unanswered questions….

Why there are 3 families of particles? Are there more?

Why is the top quark so heavy?

Why there's more matter then anti-matter?



Are there more forces?

How do neutrinos get mass?

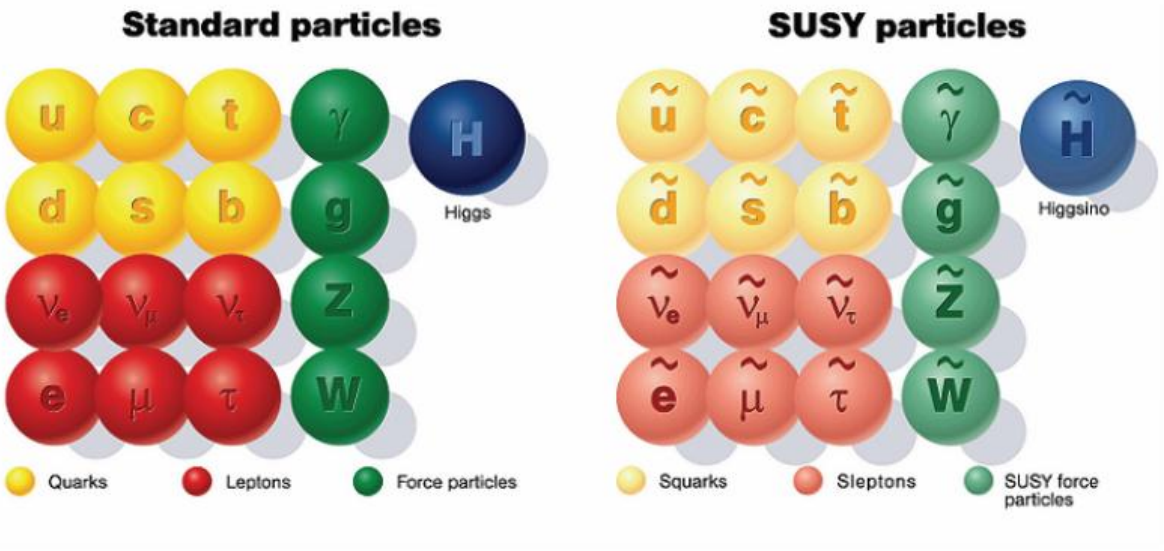
What keeps the Higgs mass so small?

How do we incorporate gravity?

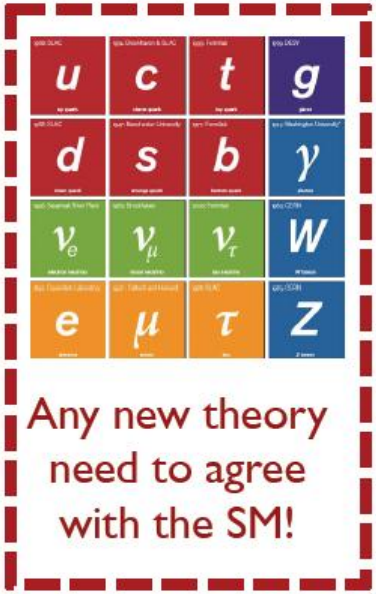
What is Dark Matter?

… as many possible answers to probe!

- Super-symmetry?



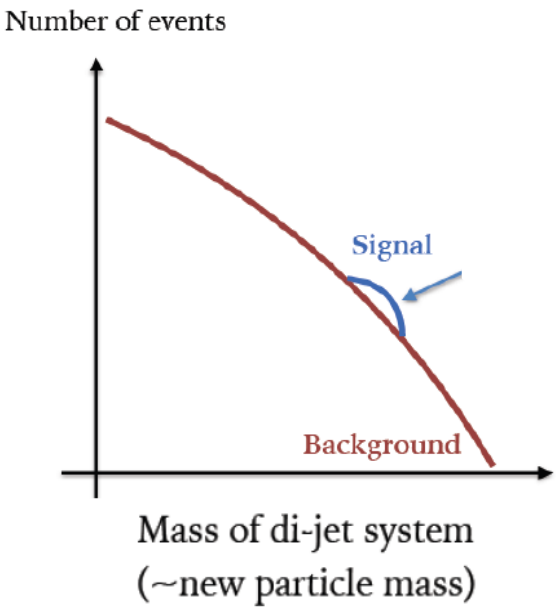
- Composite quark and/or leptons?
- New Heavy bosons?
- Gravitons?
- Dark Matter particles?
- …



How would new phenomena manifest?

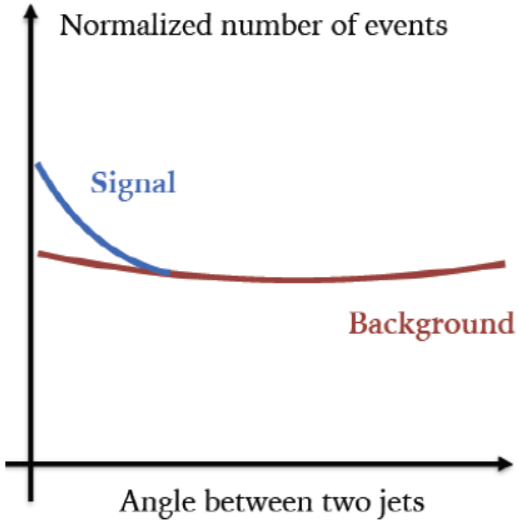
New particles:

resonant excess (bump) over Standard Model background



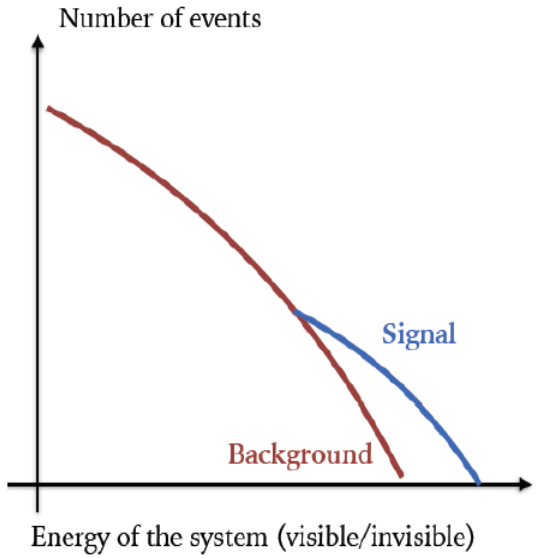
New interactions:

more central production (~Rutherford experiment)

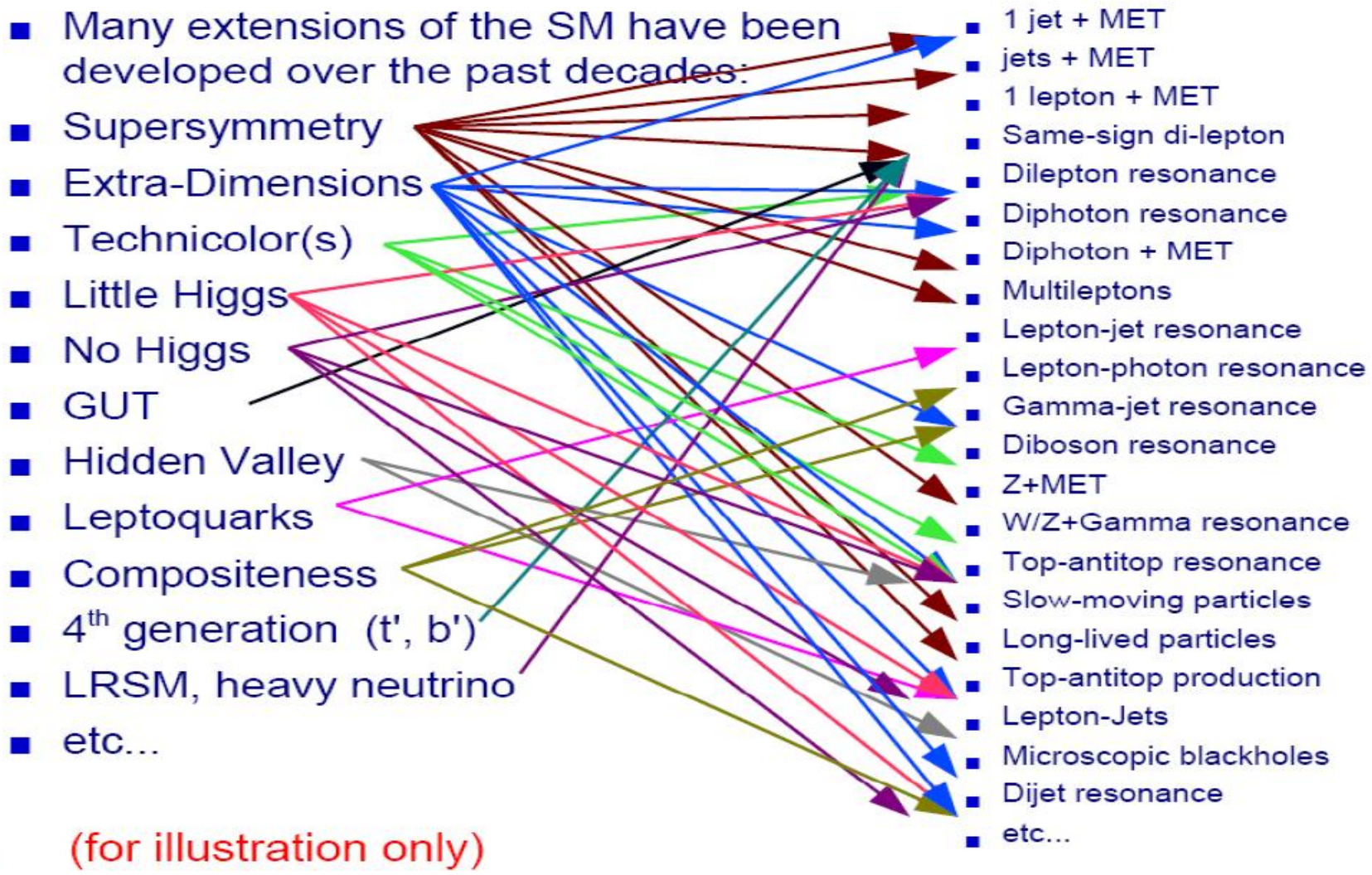


New particles and states:

larger multiplicity of objects at high masses

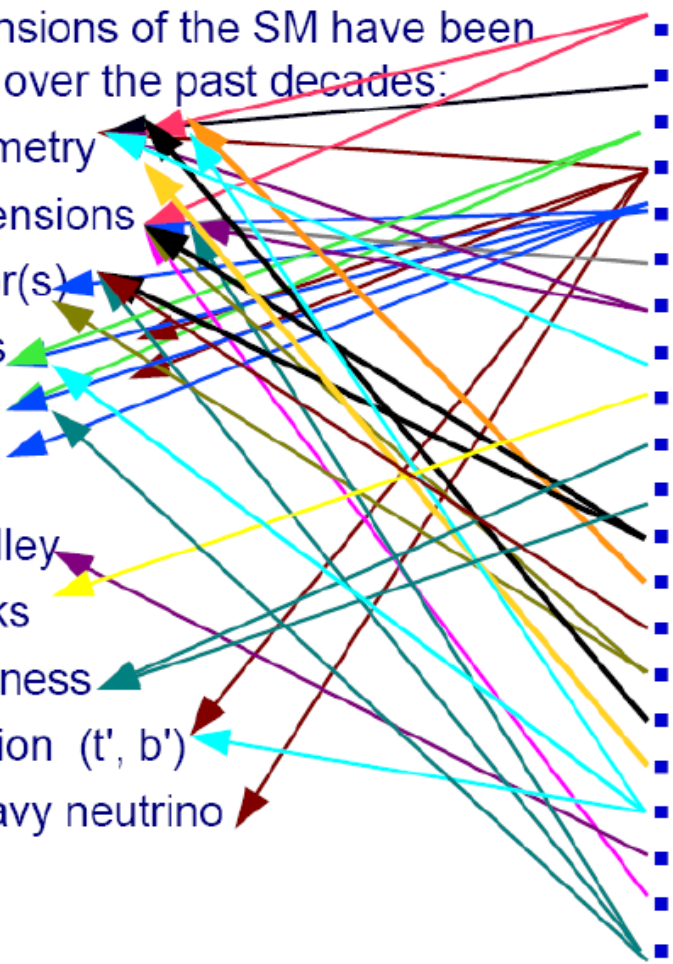


Long list of models and signatures



Long list of models and signatures

- Many extensions of the SM have been developed over the past decades:
- Supersymmetry
- Extra-Dimensions
- Technicolor(s)
- Little Higgs
- No Higgs
- GUT
- Hidden Valley
- Leptoquarks
- Compositeness
- 4th generation (t', b')
- LRSM, heavy neutrino
- etc...



- 1 jet + MET
- jets + MET
- 1 lepton + MET
- Same-sign di-lepton
- Dilepton resonance
- Diphoton resonance
- Diphoton + MET
- Multileptons
- Lepton-jet resonance
- Lepton-photon resonance
- Gamma-jet resonance
- Diboson resonance
- Z+MET
- W/Z+Gamma resonance
- Top-antitop resonance
- Slow-moving particles
- Long-lived particles
- Top-antitop production
- Lepton-Jets
- Microscopic blackholes
- Dijet resonance
- etc...

(for illustration only)

A complex 2D problem

Experimentally, a **signature standpoint** makes a lot of sense:

→ Practical

→ Less model-dependent

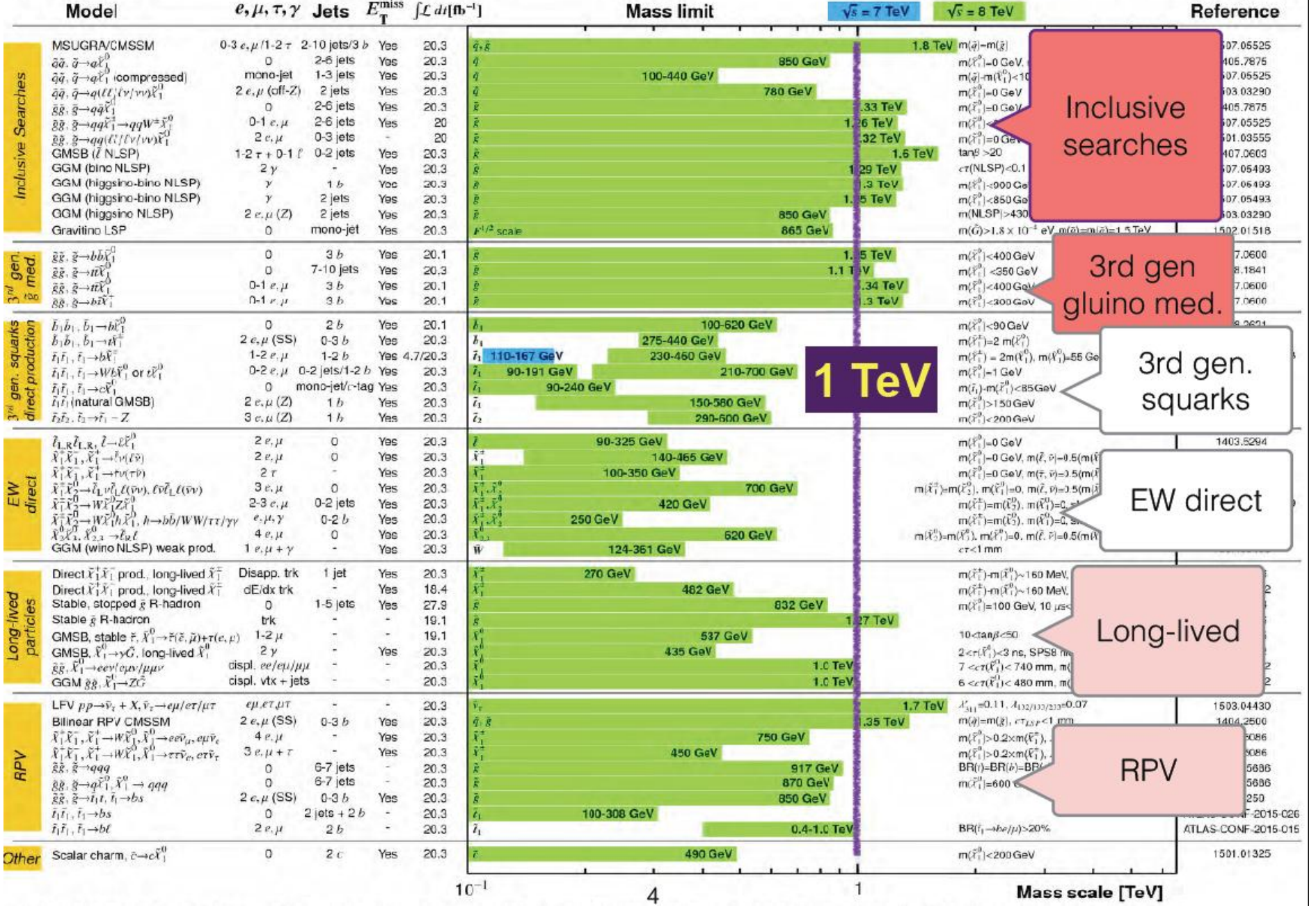
→ Important to cover every possible signature

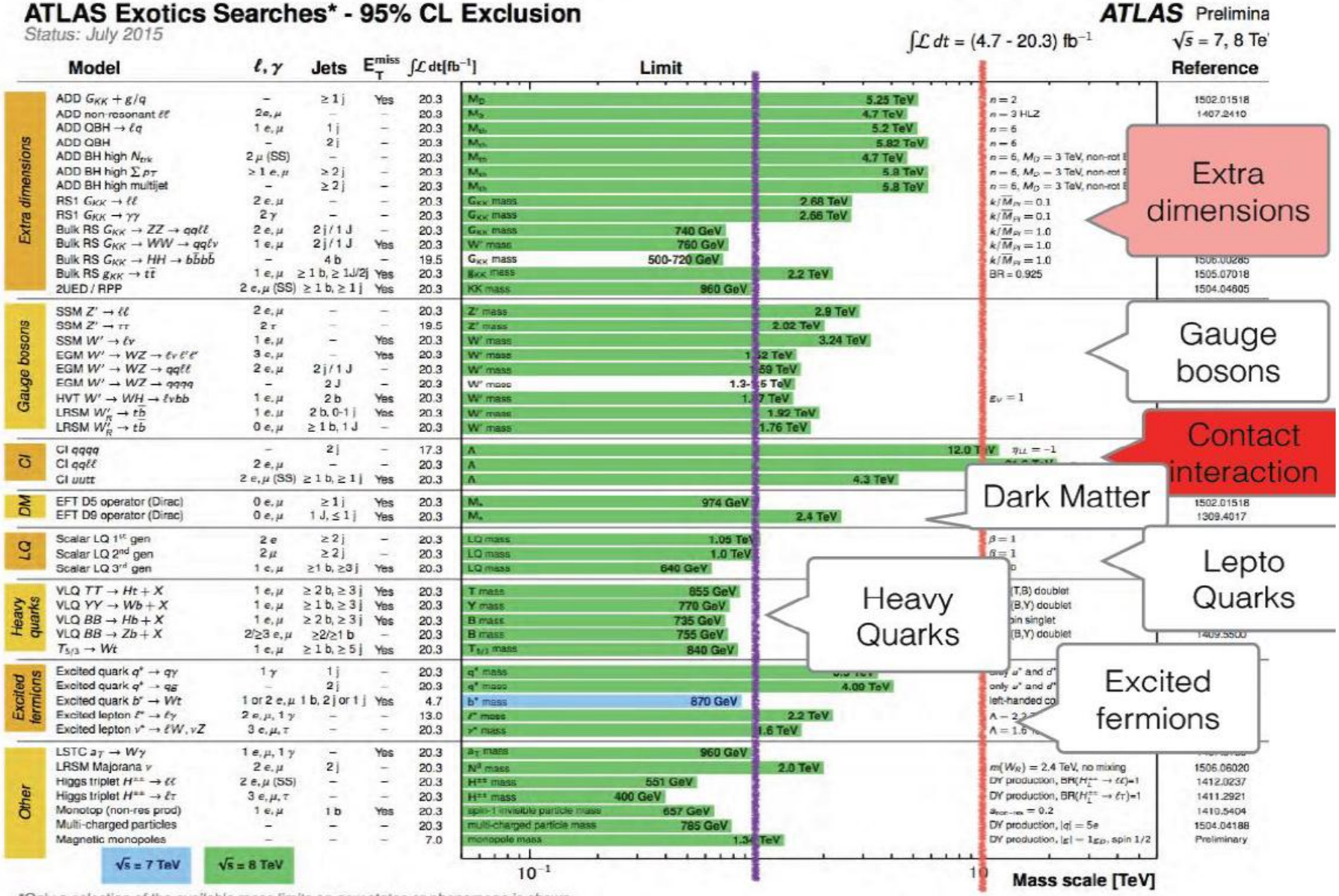
ATLAS SUSY Searches* - 95% CL Lower Limits

Status: July 2015

ATLAS Preliminary

$\sqrt{s}$ = 7, 8 TeV





16

1 TeV

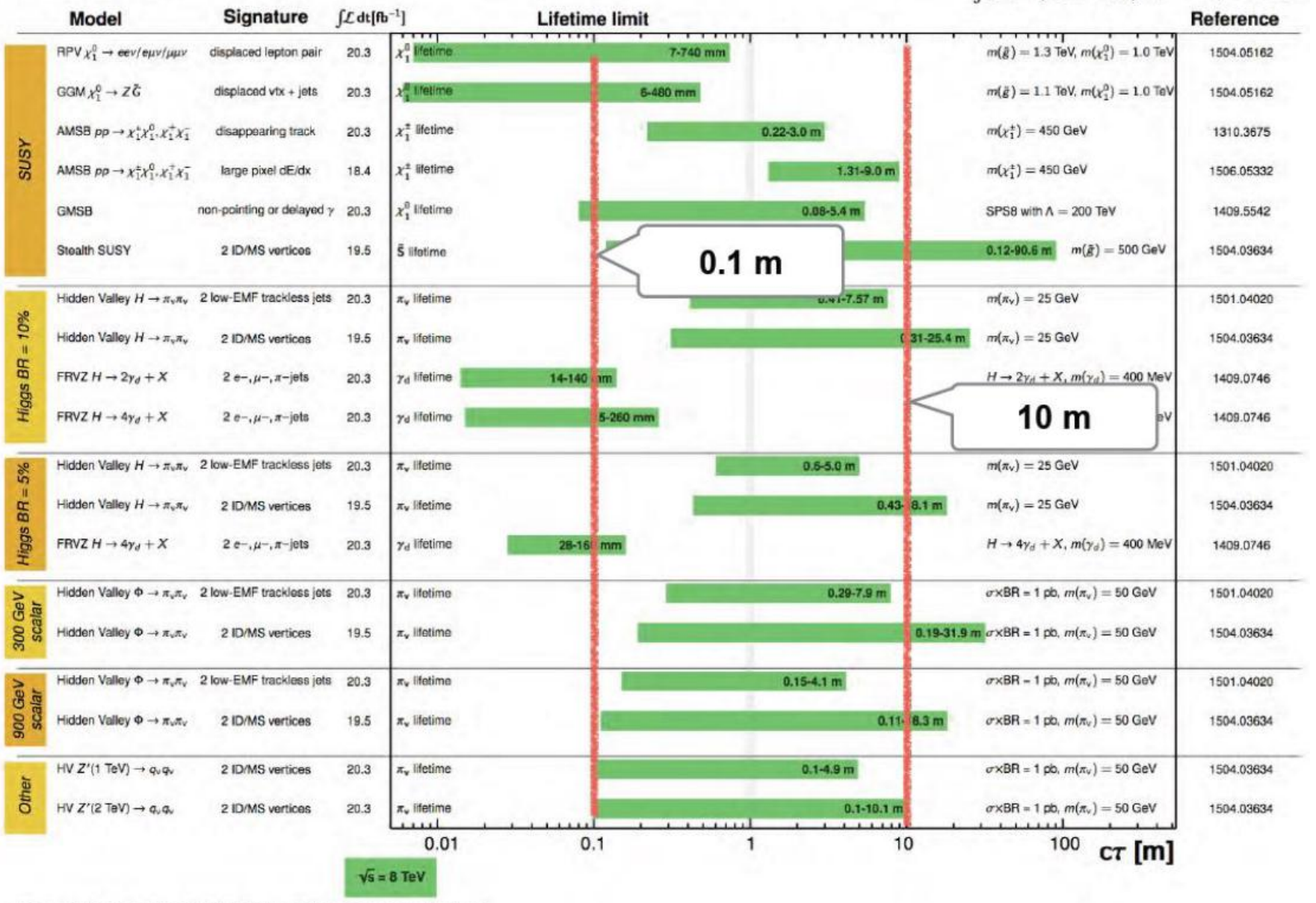
10 TeV

ATLAS Long-lived Particle Searches* - 95% CL Exclusion

Status: July 2015

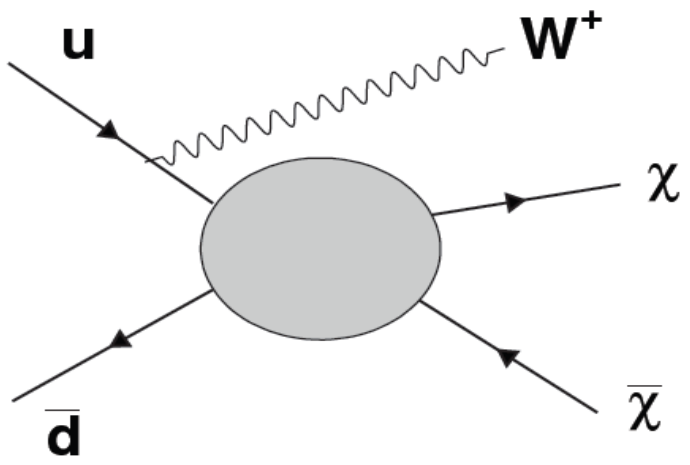
ATLAS Preliminary

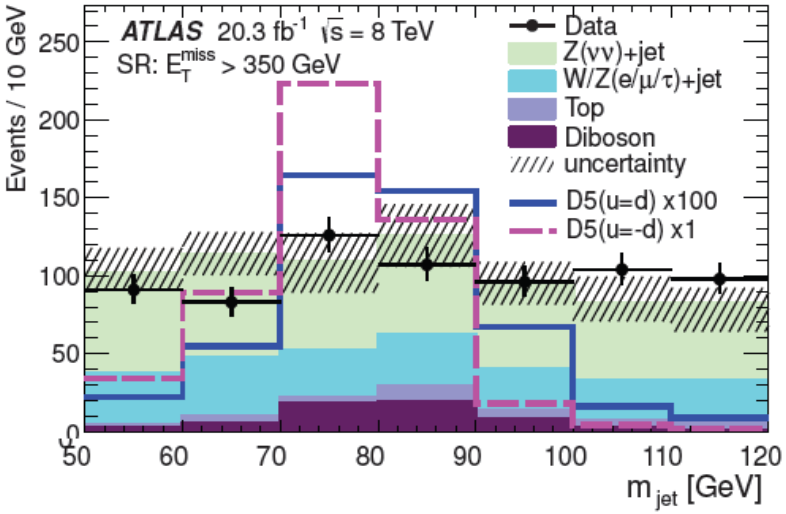
$\int \mathcal{L}\,dt$ = (18.4 - 20.3) fb^{-1} $\sqrt{s}$ = 8 TeV



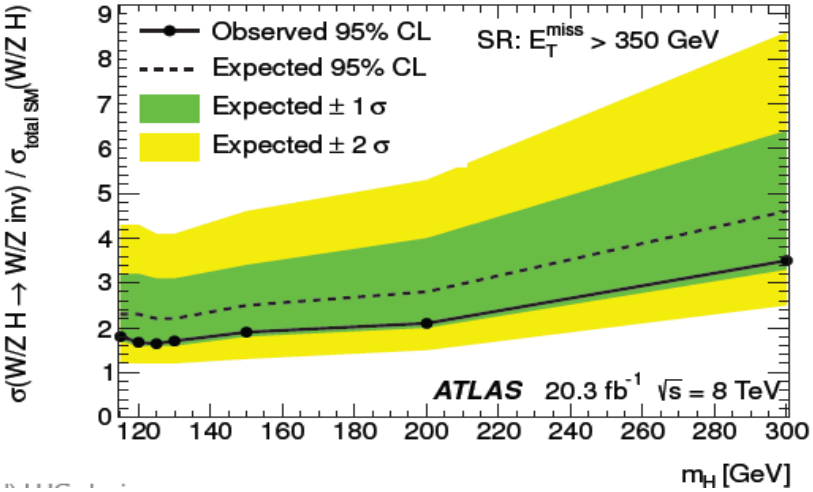
*Only a selection of the available lifetime limits on new states is shown.

ATLAS dark matter search





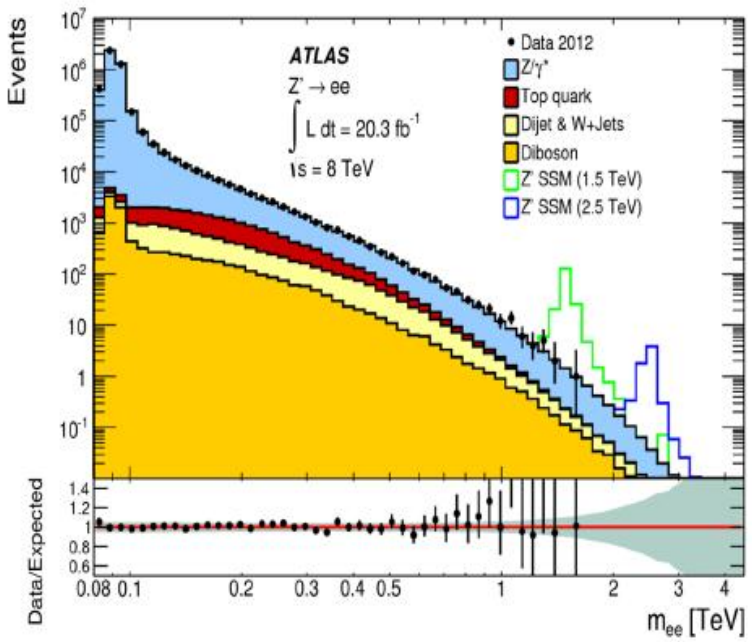
- Pair production of WIMPs plus W or Z bosons decaying and reconstructed as a single massive jet in association with large missing transverse momentum from the undetected WIMPS particles
- The interaction is unknown…
  - ✓ But this doesn't stop the search!



New heavy W and Z like particles

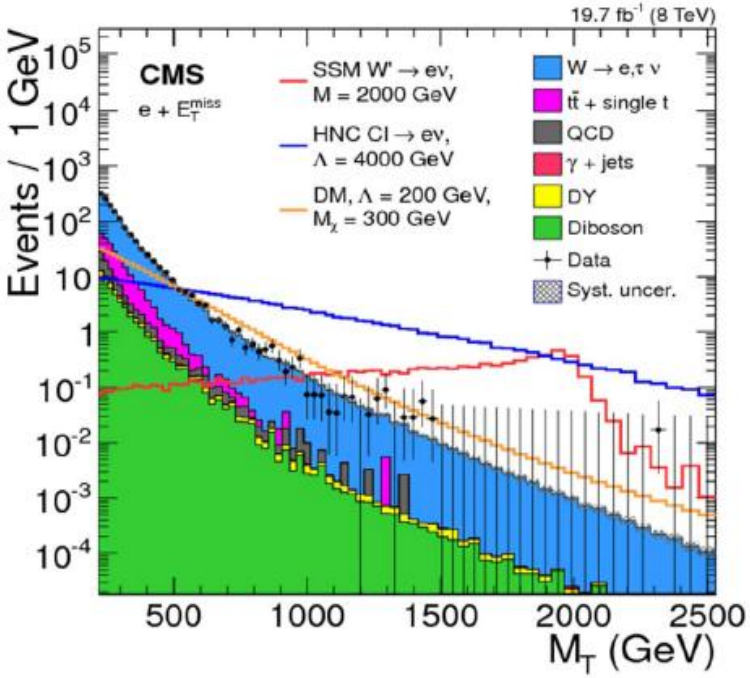
These searches are quite straight-forward, following basically the same analyses as for the familiar W and Z bosons

Z': Di-lepton pairs



Phys. Rev. D 90 (2014) 052005

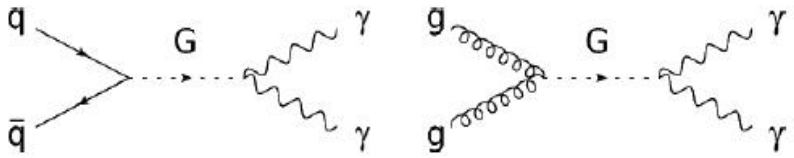
W': Lepton + ETmiss

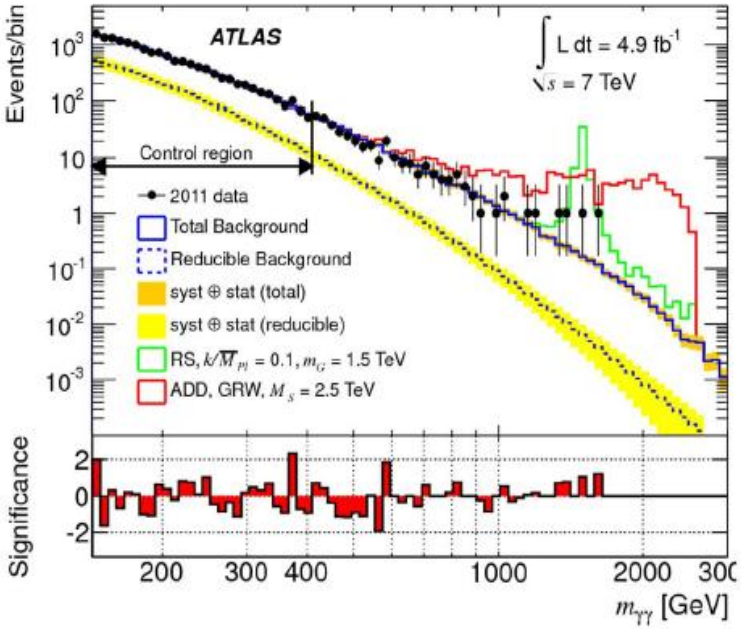


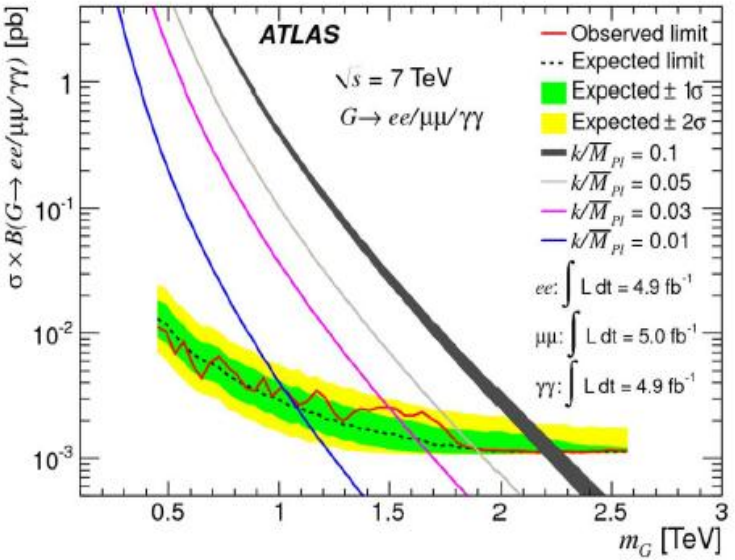
arXiv:1408.2745v1[hep-ex] sub. to Phys. Rev. D

New particles decaying into two photons

Example for a search of extra dimension signals (Kaluza-Klein Graviton in the Randall-Sundrum and Arkani-Hamed, Dimopoulos and Dvali models)





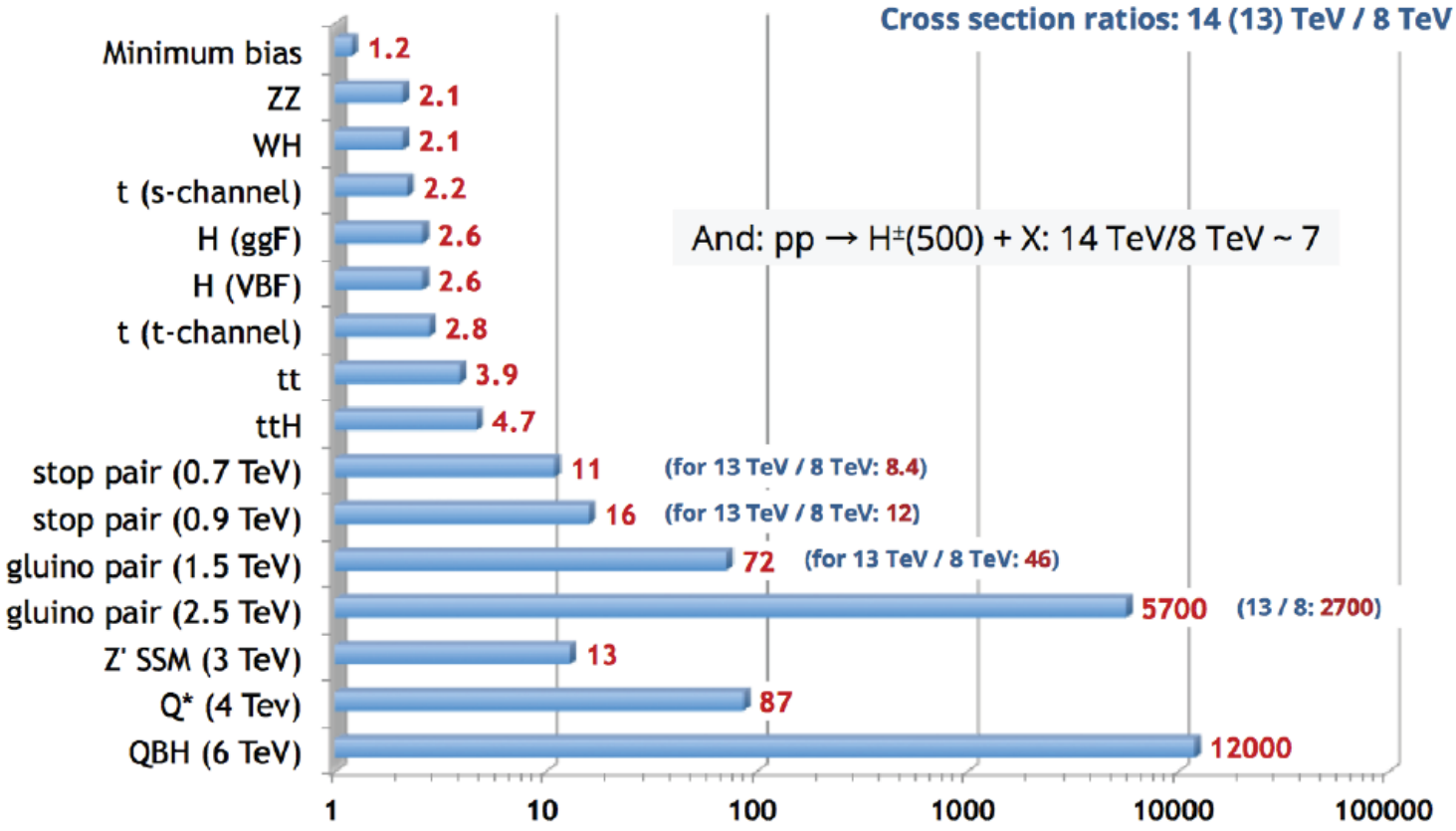


New J Phys 15 (2013) 043007

LHC Run 2

Hugely increased potential for discovery of heavy particles at 13 TeV

Perfect occasion for young motivated physicists: join the search!

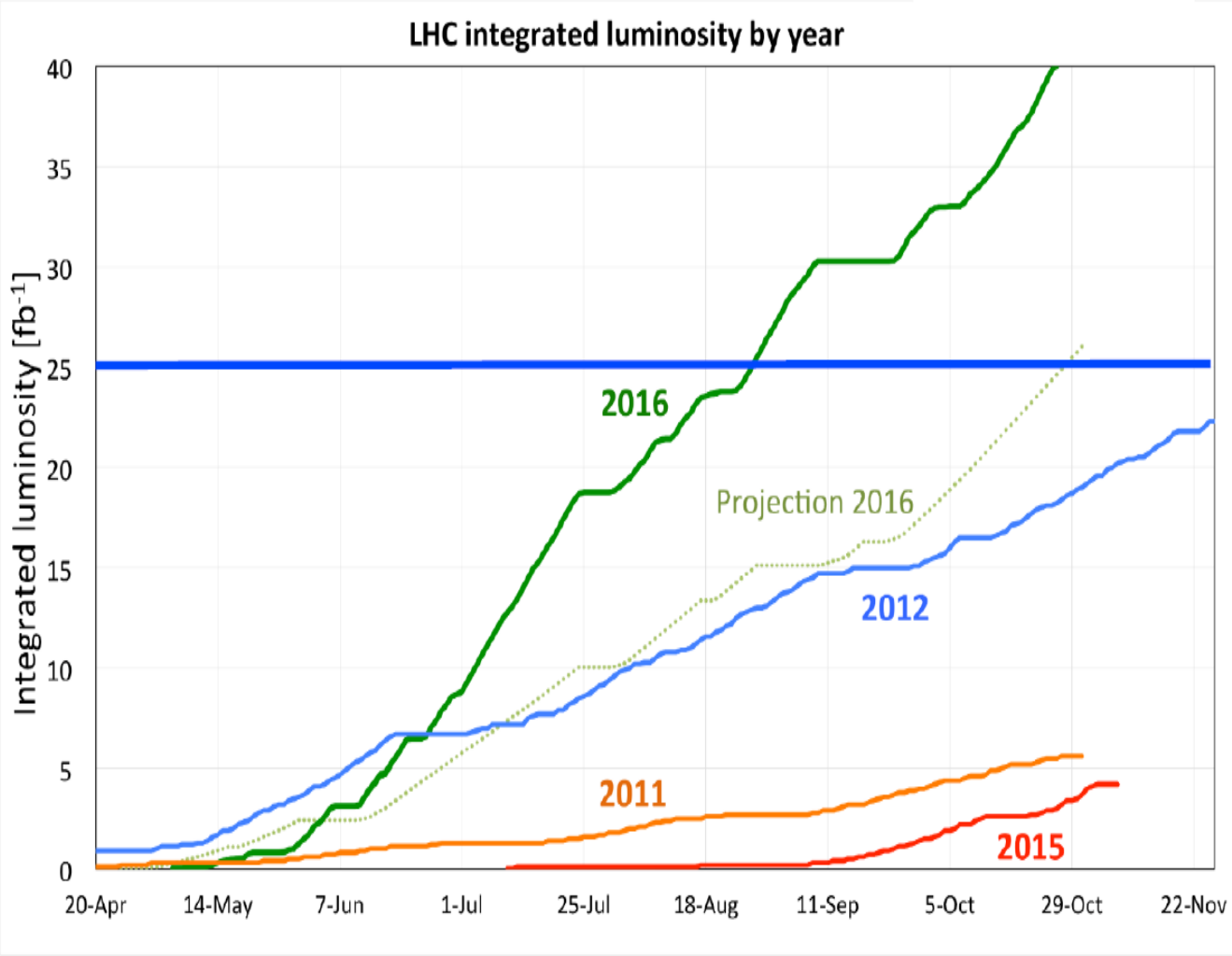


The very successfull 2016

2011: 3.5 TeV
2012: 4 TeV
2015/16: 6.5 TeV

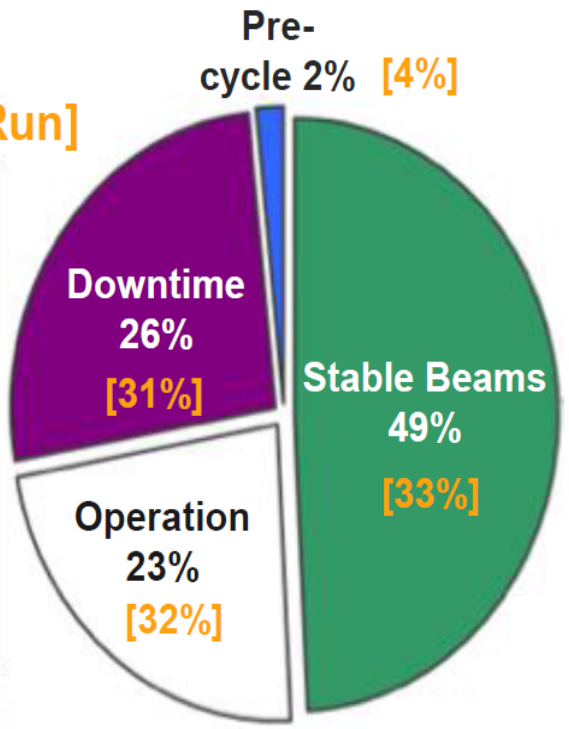
Peak luminosity > $1.35 \times 10^{34}\ cm^{-2}s^{-1}$

about 40 fb^{-1} in both ATLAS and CMS ☺



Availability in 2016

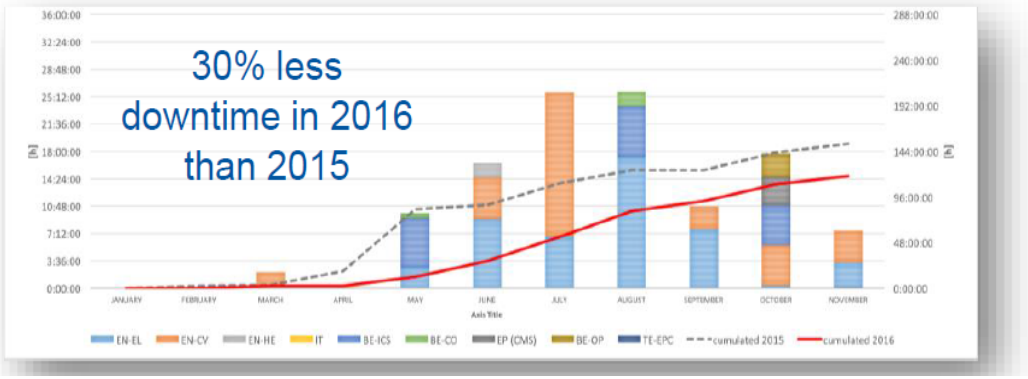
[2015 - 25 ns Run]



Remarkable availability:

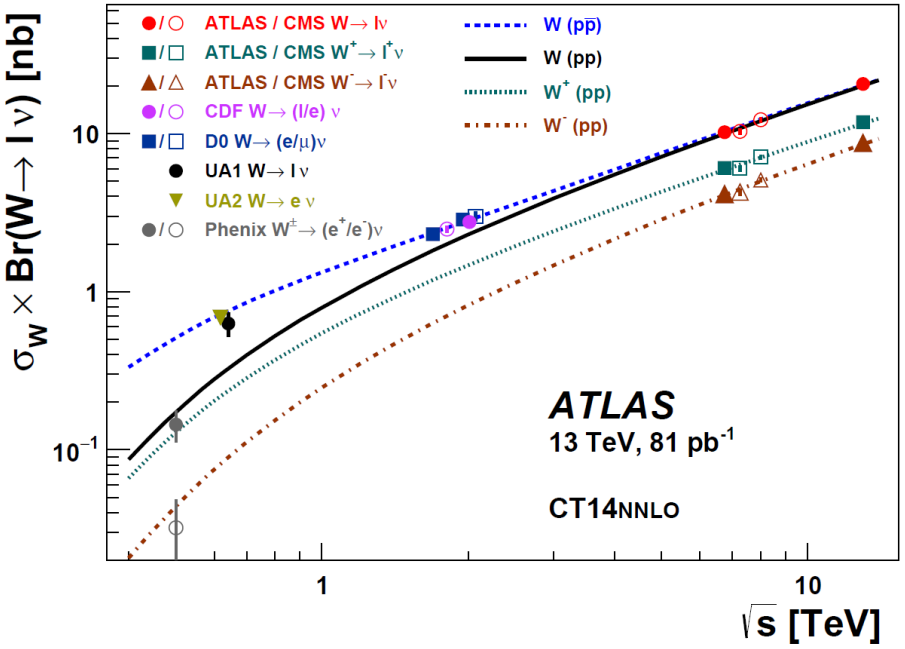
- **Increased** operational efficiency
- **Enhanced** system availability
- **New** pre-cycle strategy

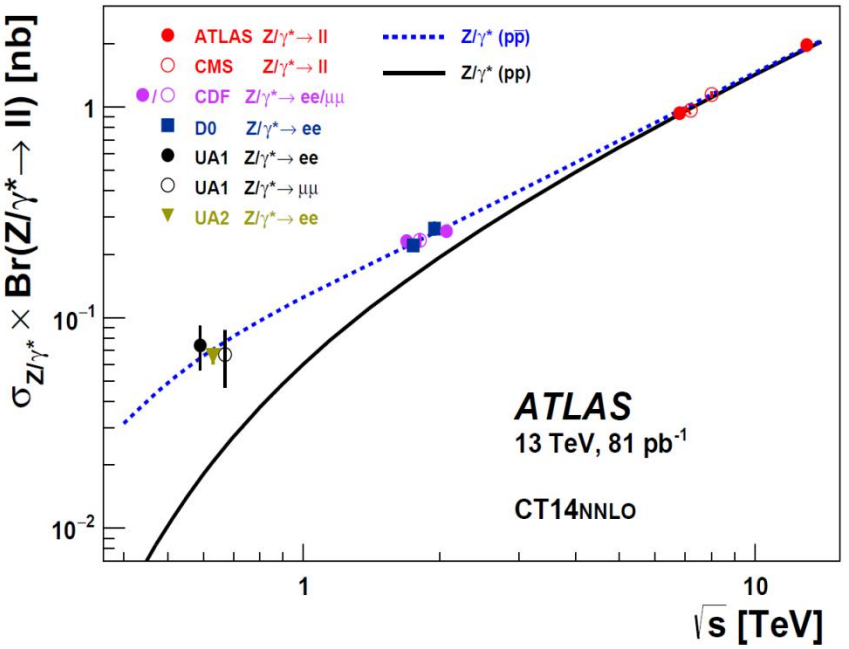
Downtime of technical infrastructures

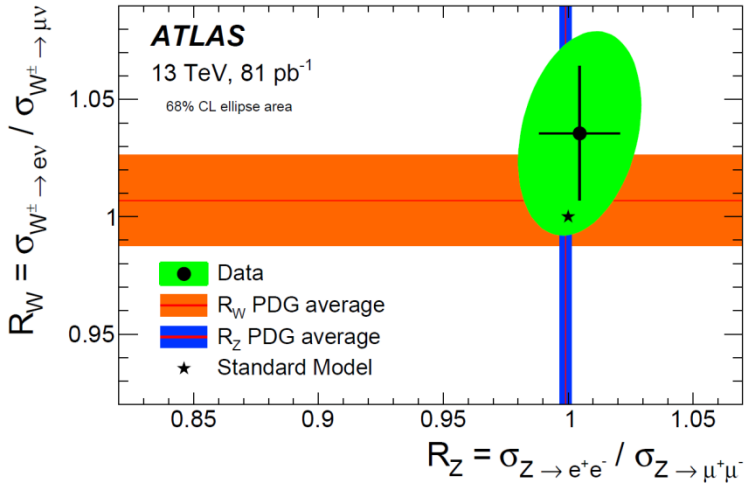


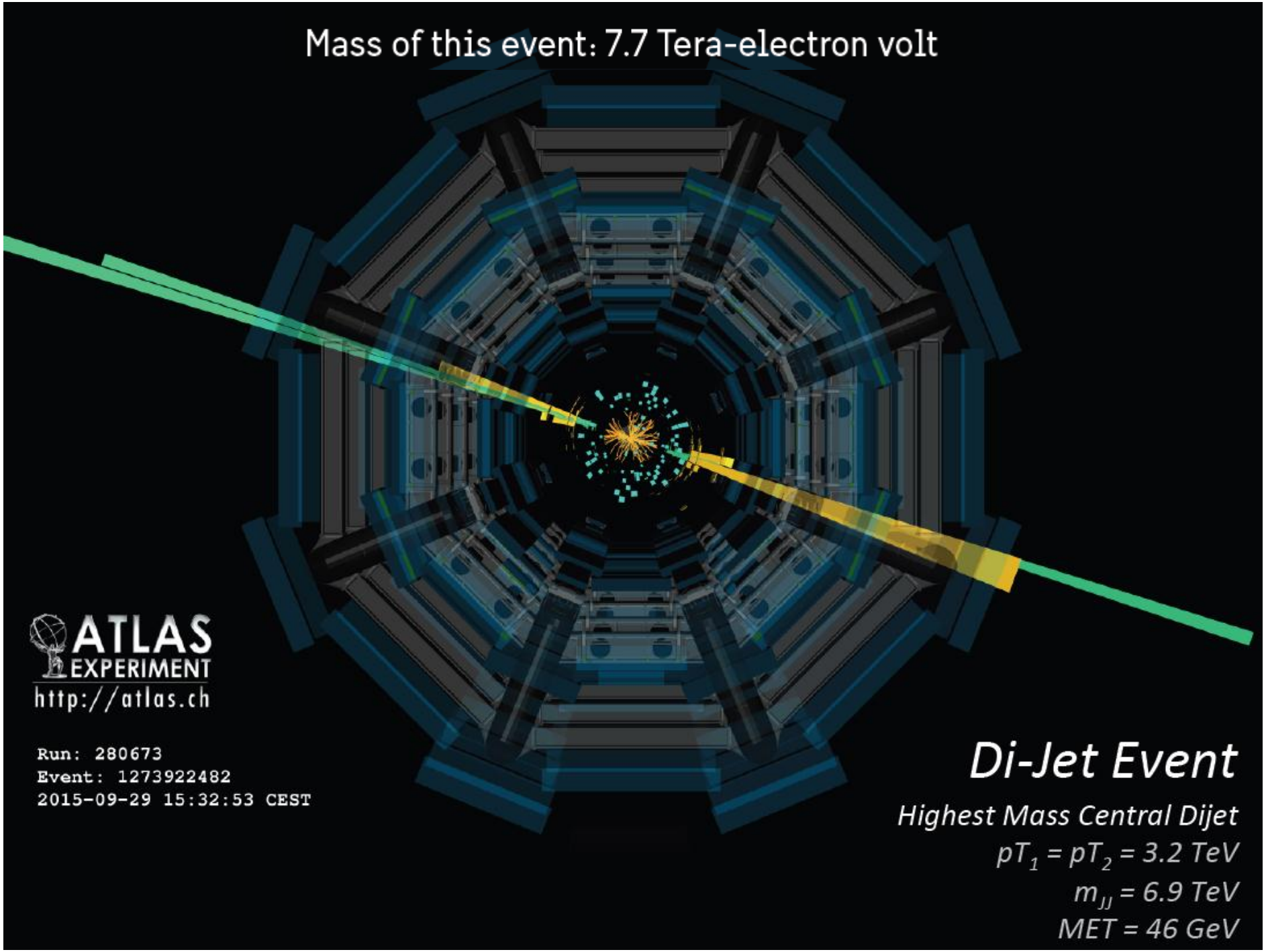
Non-availability of beams from the injector complex is the largest source of LHC downtime

W, Z cross-section at 13 TeV








Mass of this event: 7.7 Tera-electron volt
ATLAS
EXPERIMENT
http://atlas.ch
Run: 280673
Event: 1273922482
2015-09-29 15:32:53 CEST
Di-Jet Event
Highest Mass Central Dijet
$pT_1 = pT_2 = 3.2$ TeV
$m_{JJ} = 6.9$ TeV
MET = 46 GeV

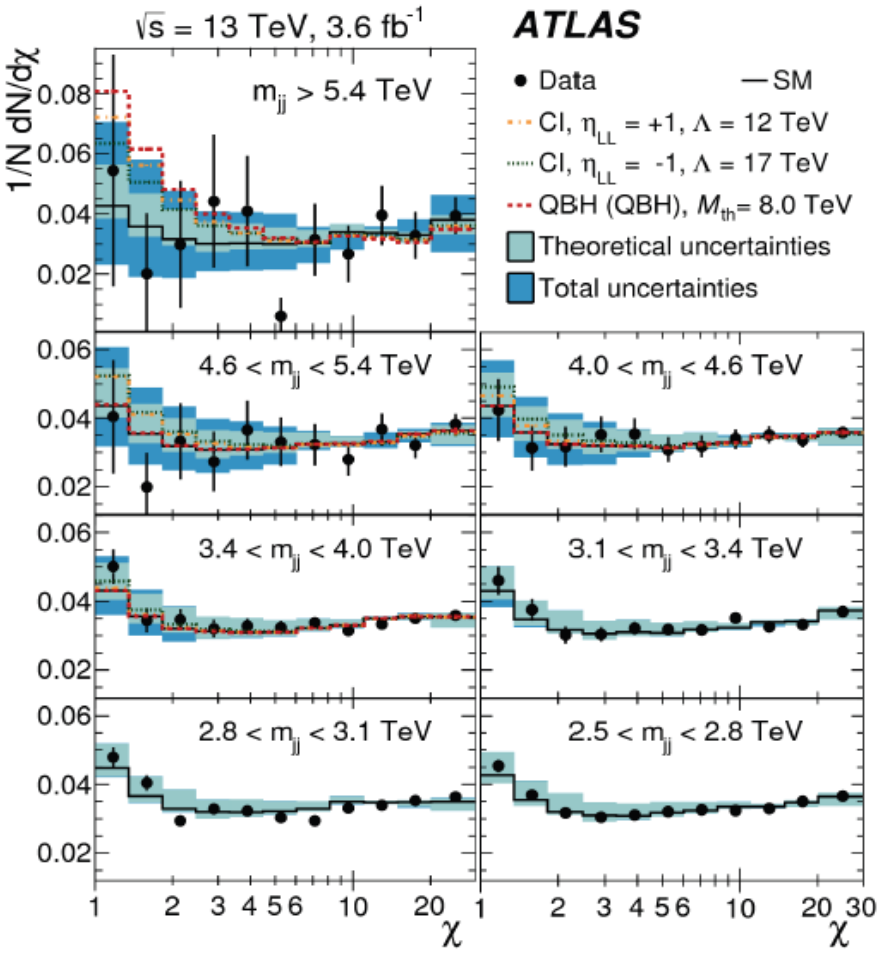
Dijet Angular Searches

Search in dijet mass bins using angular distribution

$$\chi = e^{2|y^*|} \sim \frac{1+\cos\theta^*}{1-\cos\theta^*}$$

1512.01530

Search for distortions of the dijet angular distribution from Contact Interactions of particles at much higher masses O(Λ) with color-singlet left-handed chiral couplings (in 4-fermion effective field theory)



No deviations observed, limits set at 12 TeV on Λ (for η_{LL} = 1)

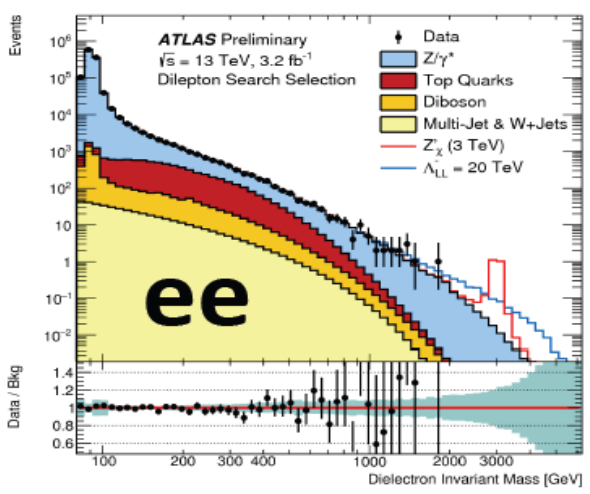
Dilepton Resonances (LFC and LFV)

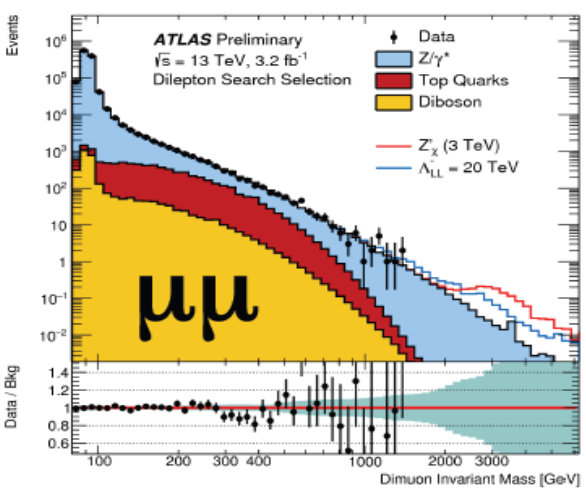
Search for Z' in dilepton (LFC) and (LFV) *(in eμ decays)*

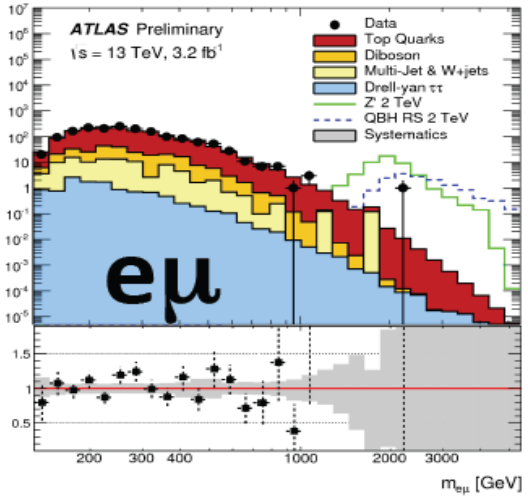
ATLAS-CONF-2015-070

ATLAS-CONF-2015-072

- Main background DY is taken from MC
- Top and diboson extrapolated at very high masses using a functional form
- Background from MC except for MJ in dielectron uses Matrix method (based on electron ID)







Highest di-electron mass event at 1.8 TeV

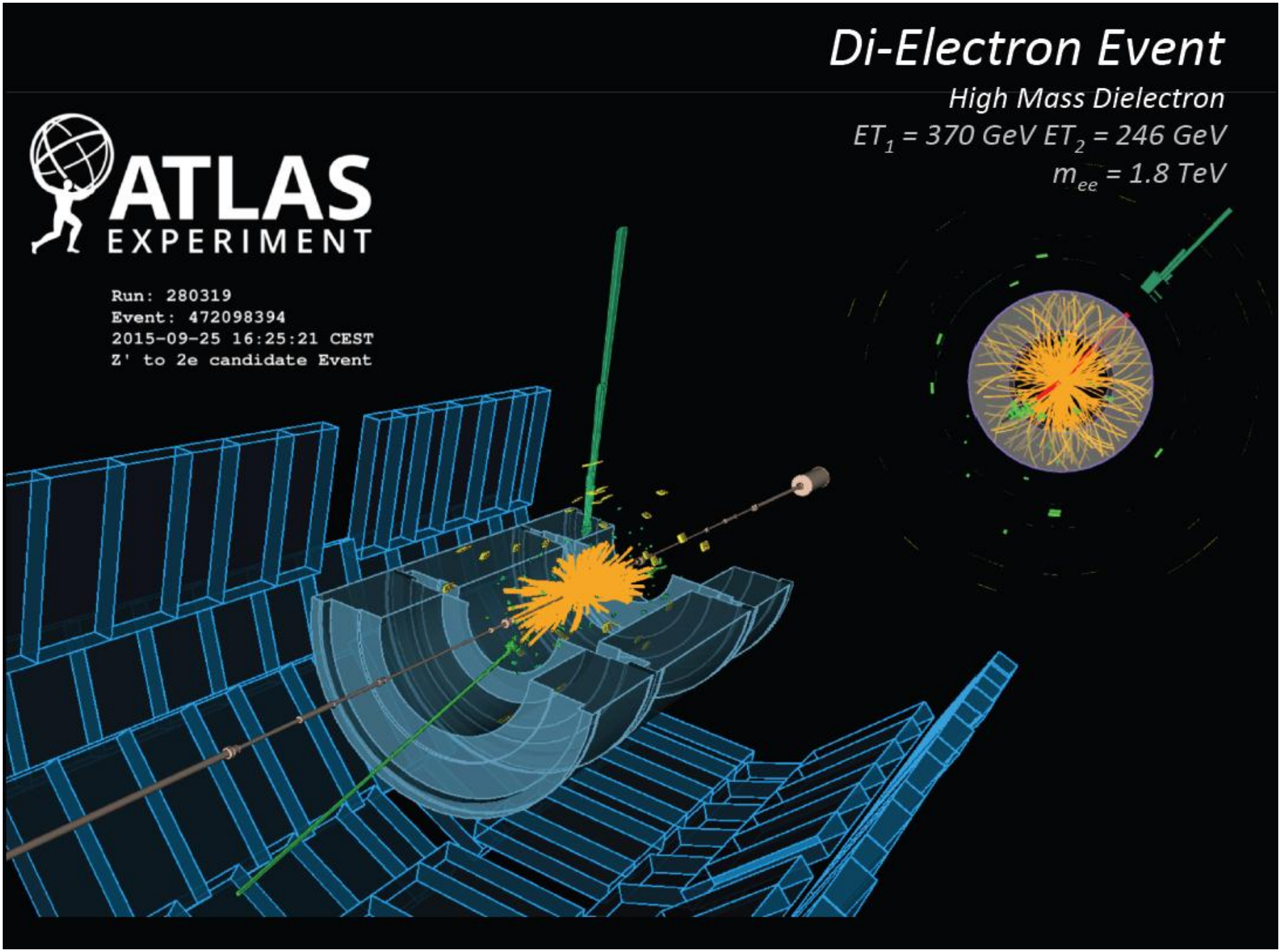
Highest di-muon mass event at 1.4 TeV

Highest eμ mass event at 2.1 TeV

No Excess found !

95% CL Limit on SSM Z' at 3.4 TeV (2.9 TeV from Run-1)

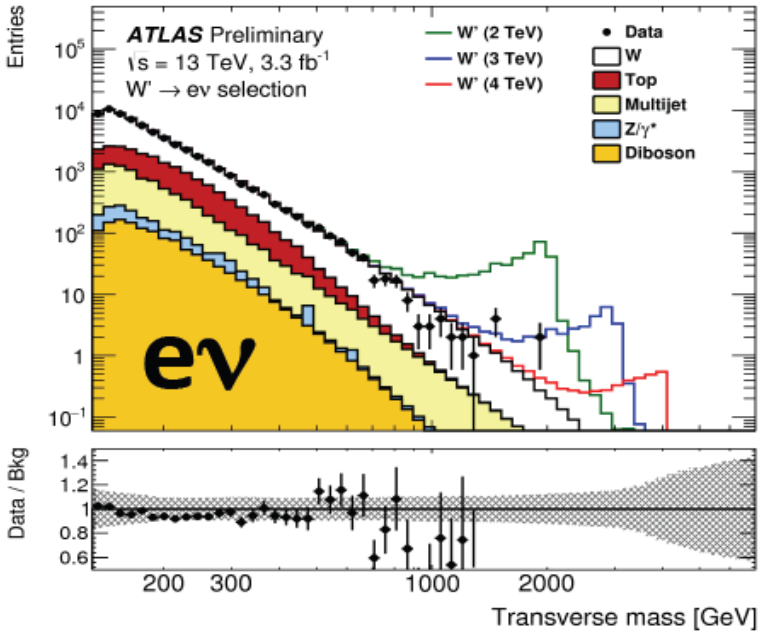
95% CL Limit on SSM LFV Z' at 3.0 TeV (2.5 TeV from Run-1)

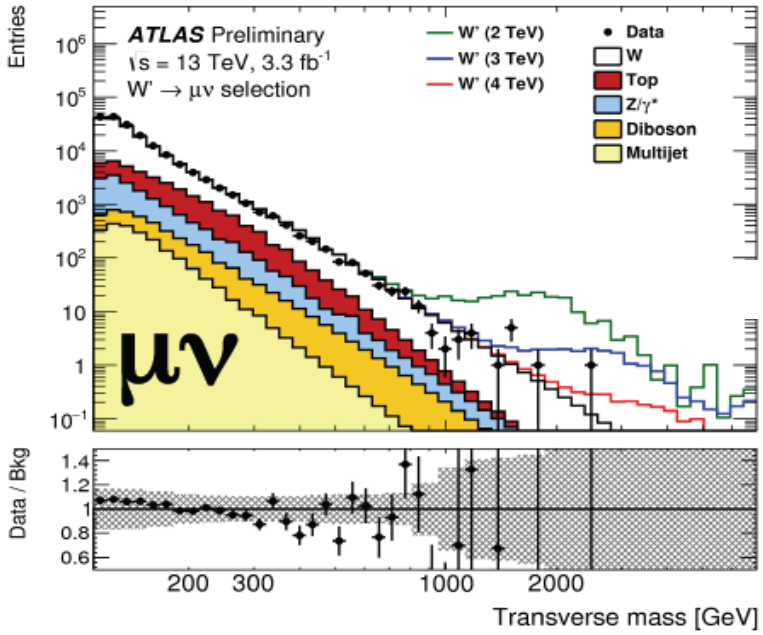

Di-Electron Event
High Mass Dielectron
ET_1 = 370 GeV ET_2 = 246 GeV
m_{ee} = 1.8 TeV
ATLAS
EXPERIMENT
Run: 280319
Event: 472098394
2015-09-25 16:25:21 CEST
Z' to 2e candidate Event

Search for Resonant Lepton-MET

- Search for W' in lepton-MET final states

ATLAS-CONF-2015-063





Highest electron-MET mass event at 1.95 TeV

Highest muon-MET mass event at 2.2 TeV

No Excess found !

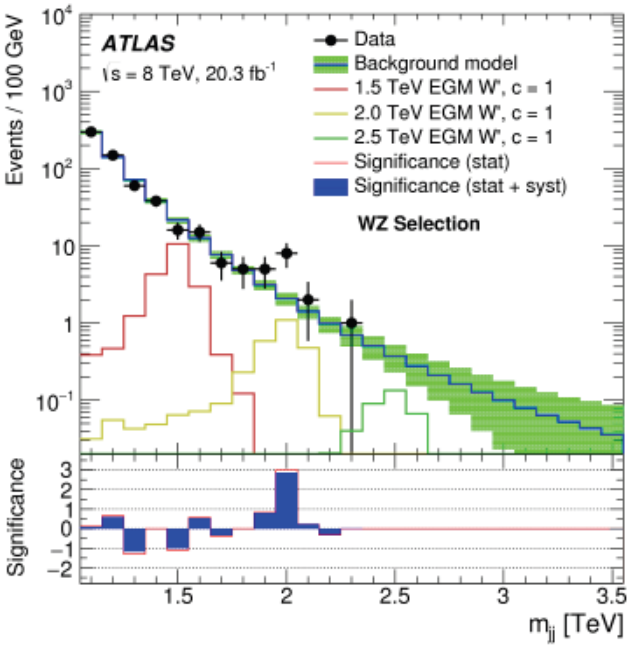
95%CL Limit on SSM W' at 4.1 TeV (3.2 TeV at Run-1)

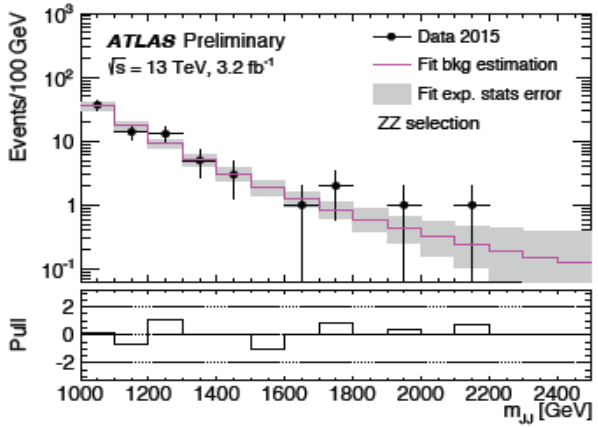
Fully hadronic JJ Diboson Searches

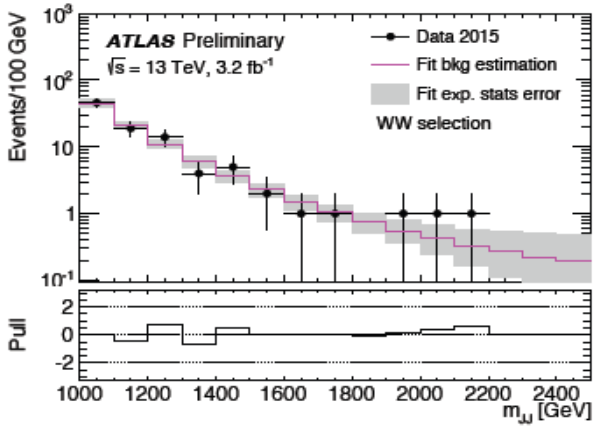
ATLAS-CONF-2015-073

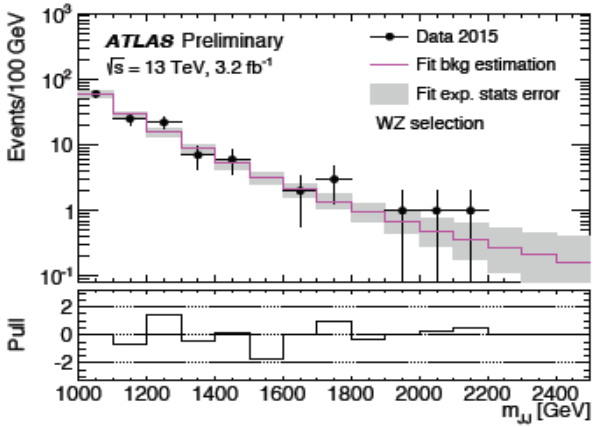
Run-1

- **Modest excess at Run-1:** **3.4σ** local / **2.5σ global**
- **Analysis very similar to Run 1**, with functional fit of the background
- **No significant excess is observed**
  however sensitivity not high enough for conclusive probe of the Run 1 excess

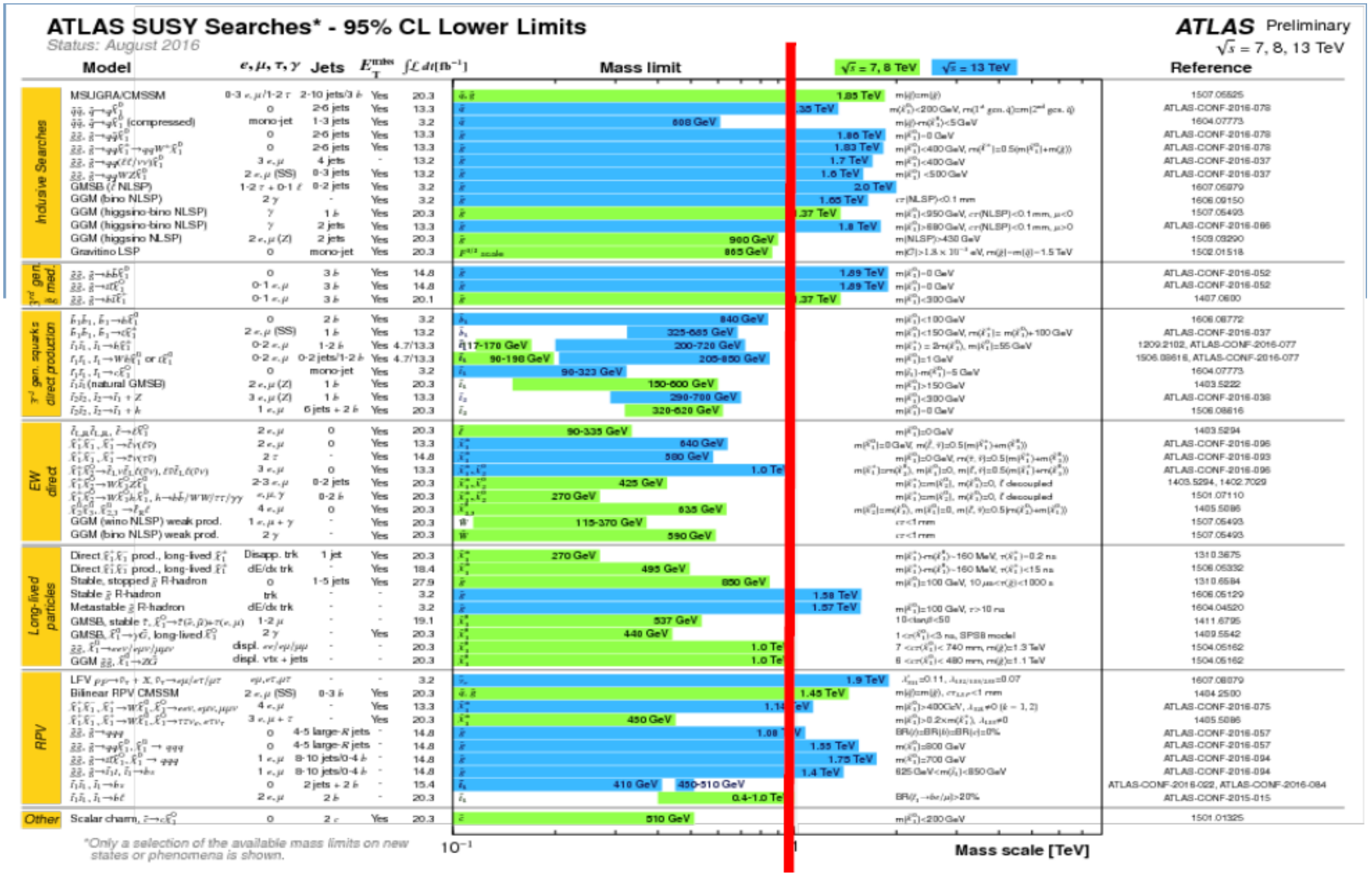








SUSY searches

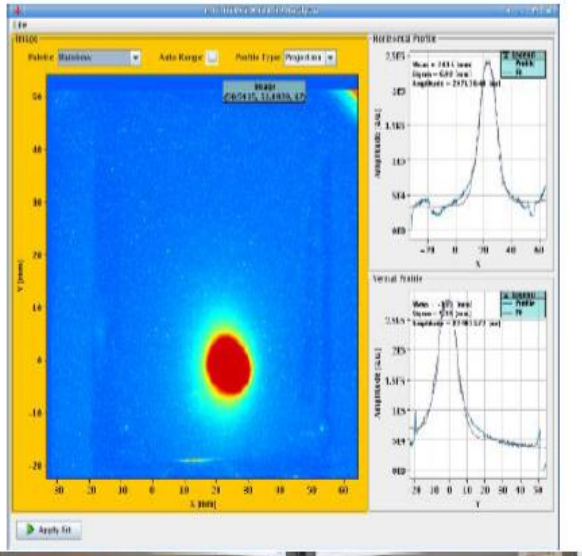


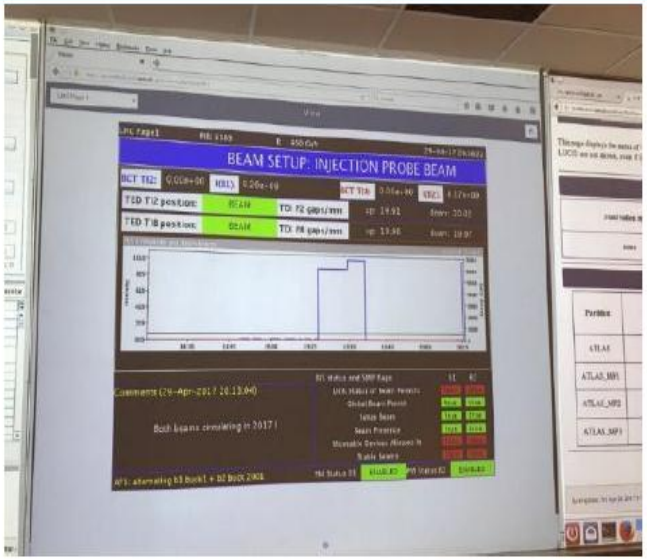
Looking forward to more

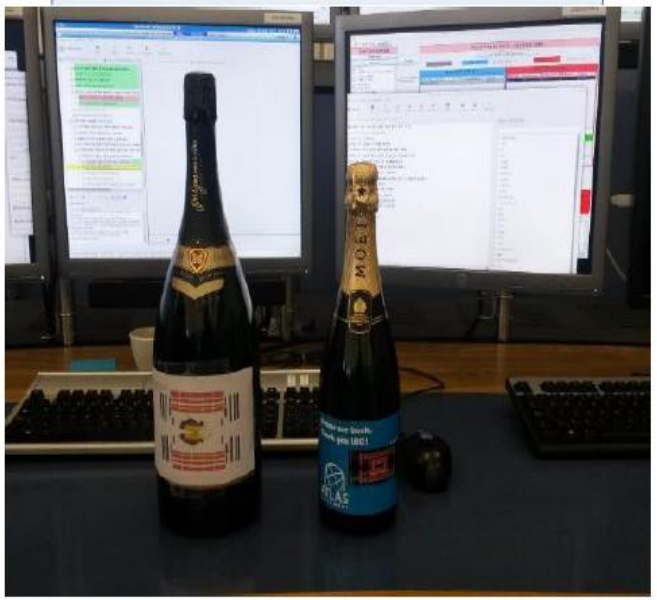
38 countries
182 institutions
>1000 students

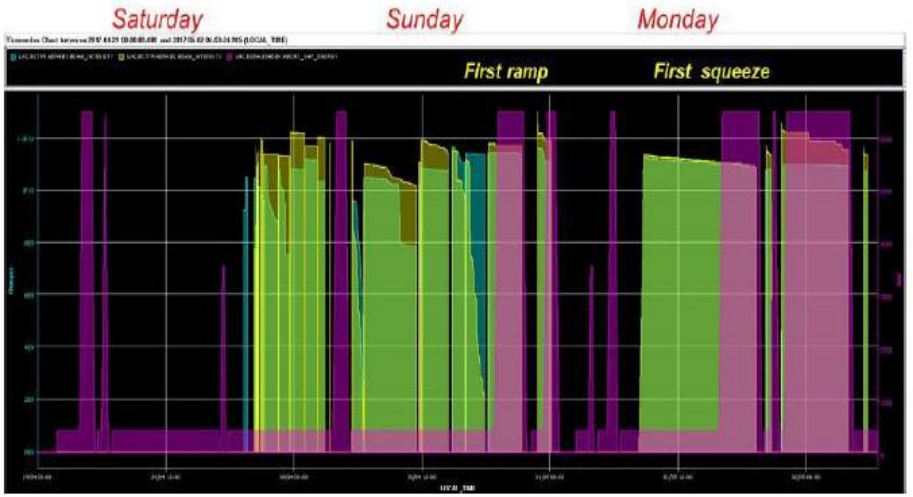
ERW

2017: beams are back in LHC from Friday 29th April









2017 scenarios

	Nominal	BCMS	BCMS+
Beta* (1/5) [cm]	40	40	33
Half crossing angle [urad]	185	150	170
No. of colliding bunches	2748	2544	2544
Proton per bunch	1.1e11	1.2e11	1.2e11
Emittance into SB [um]	~3.2	~2.3	~2.3
Bunch length [ns]	1.05	1.05	1.05
Peak luminosity [$cm^{-2}s^{-1}$]	~1.1e34	~1.7e34	~1.8e34
Peak pile-up	~28	~48	~52
Luminosity lifetime [h]	~24	~15	~14

2017 plans: **45fb^{-1}**

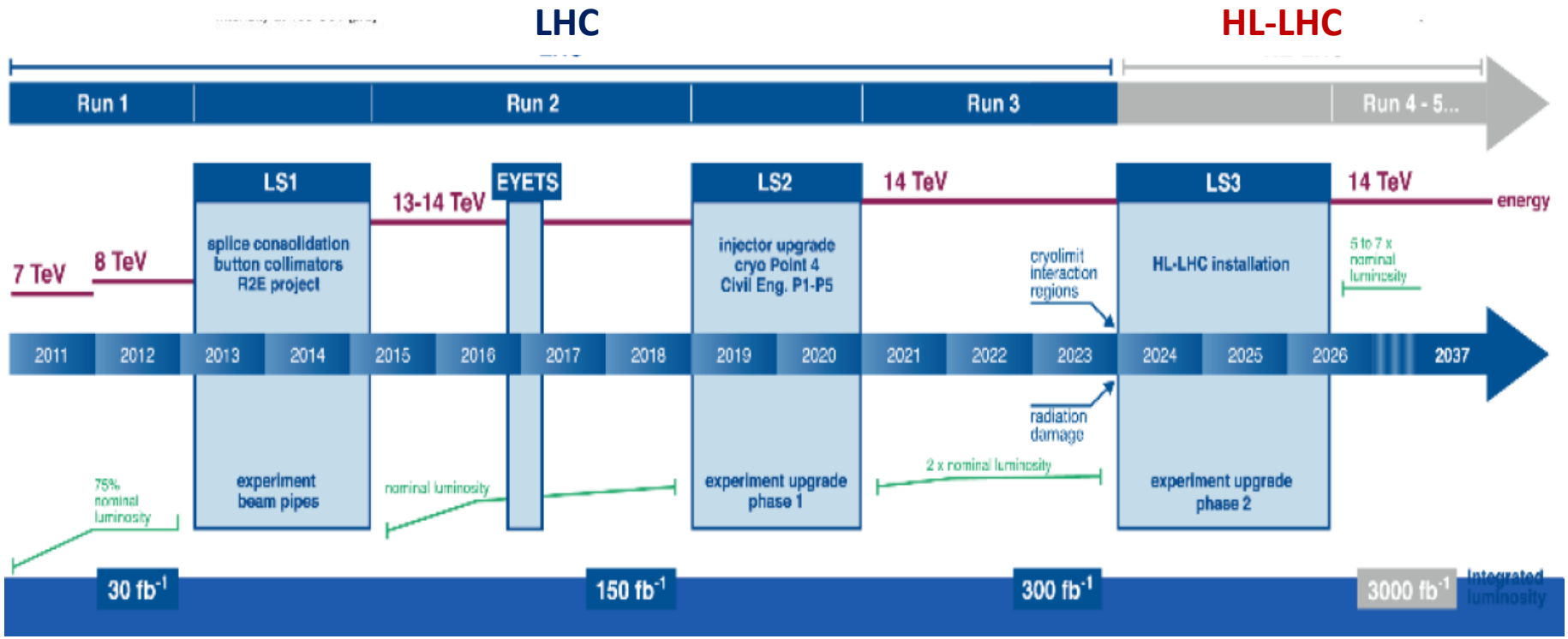
Run 2 @ 13 TeV c.m.

Large Hadron Collider will operate till 2035

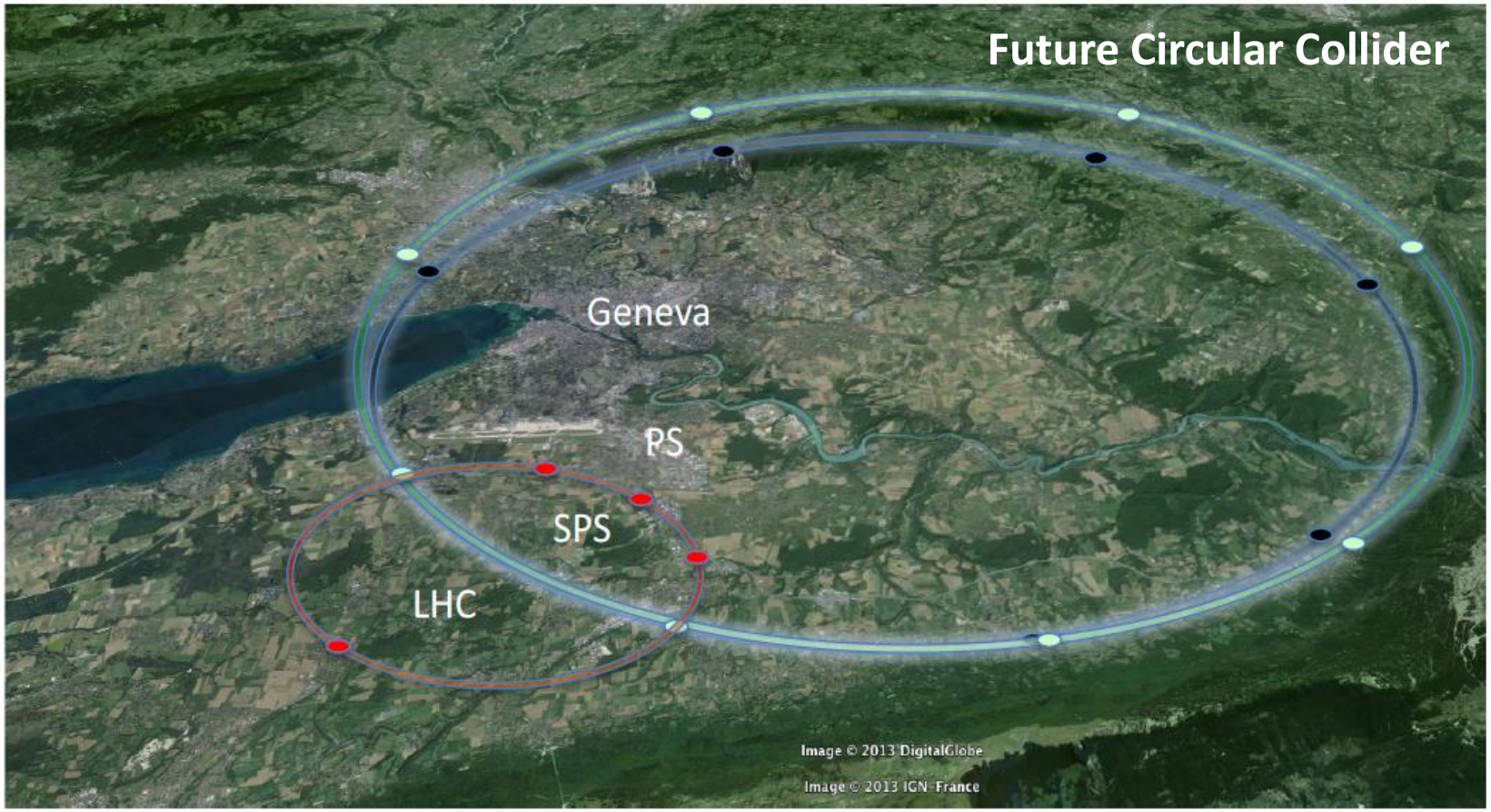
More than 1400 papers published 2010-2016 by 4 LHC experiments.

We are on the route to UNKNOWN …!

Only 2% of complete LHC/HL-LHC has been delivered to date.



ECFA report 2016 (European Committee for Future Accelerators)



LHC	HE-LHC	FCC-hh	FCC-hh
27 km, 8.33 T	27 km, **20 T**	80 km, **20 T**	100 km, **16 T**
14 TeV (c.o.m.)	33 TeV (c.o.m.)	100 TeV (c.o.m.)	100 TeV (c.o.m.)