Vorlesung 13:

Search for BSM Physics: Exotics

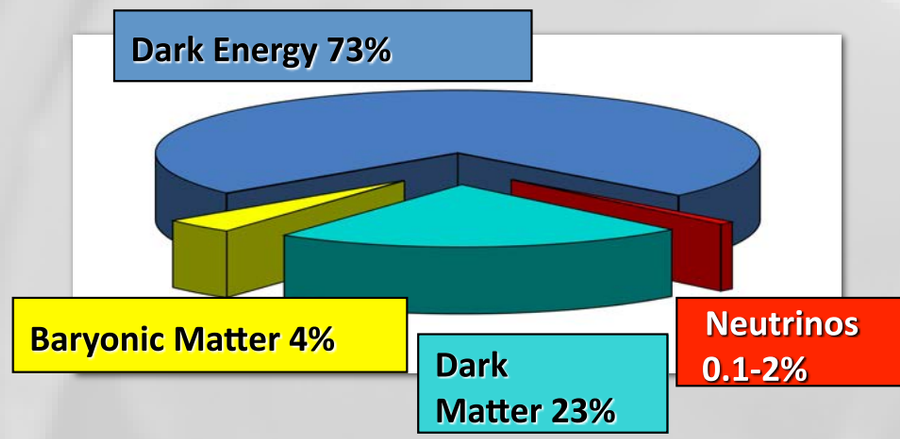
and

Future of LHC and other Collider Projects

- models / ideas for physics BSM
- some examples of LHC searches for physics BSM
- LHC future plans
  - LHC
  - hl-LHC
  - VL-LHC / FCC

today, there are few but significant signals for BSM physics:

- neutrinos are not massless
- 95% of the mass/energy budget of the universe cannot be explained by SM particles and forces:
  - Dark Matter (23%)
  - Dark Energy (73%)



some en vogue models of BSM:

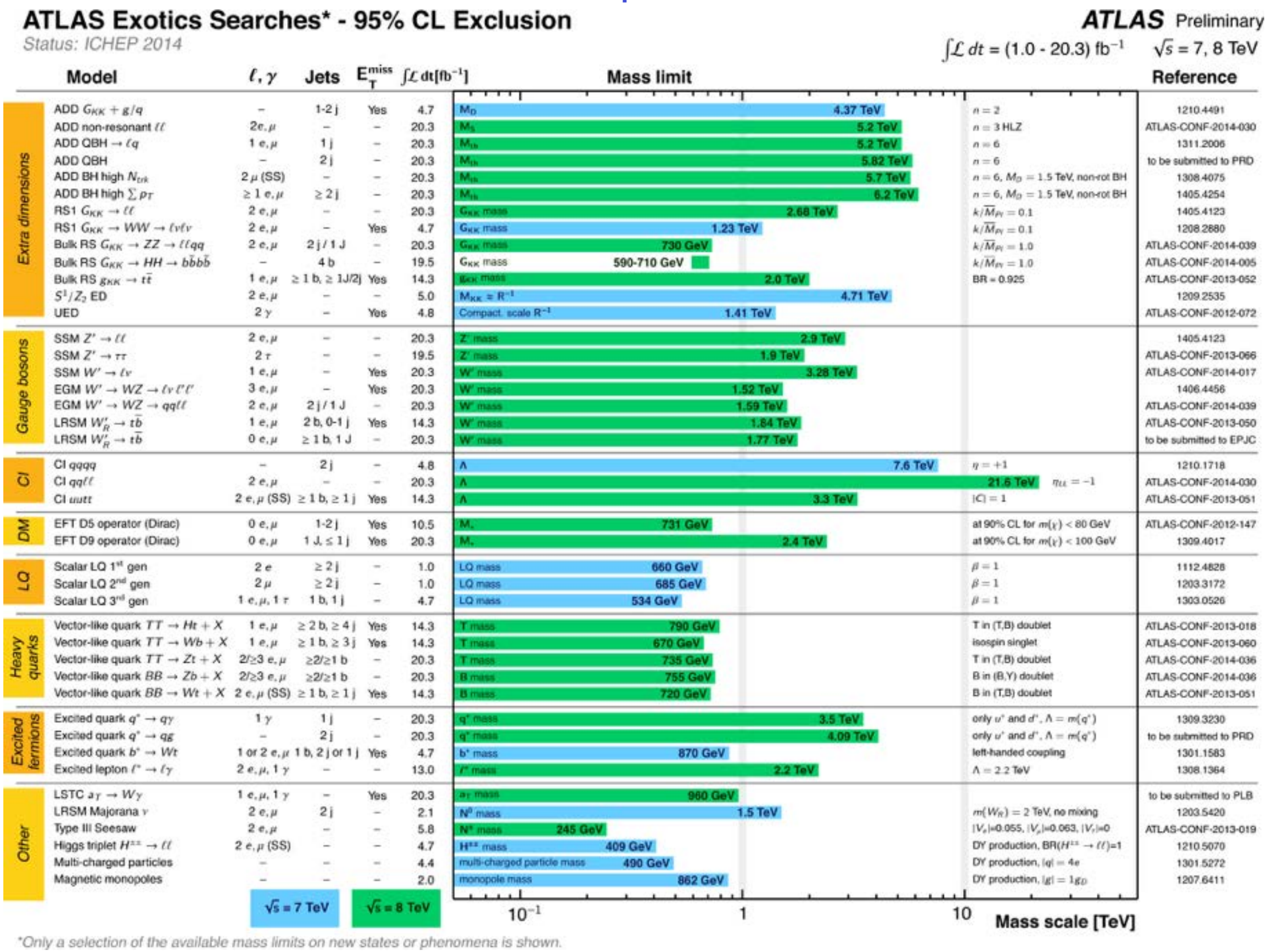
- Supersymmetry (SUSY) (see previous lecture)
- composite models (excited quarks & leptons)
- new symmetries (new heavy gauge bosons)
- large extra dimensions (micro black holes,…)
- technicolor models (composite Higgs)
- leptoquarks (GUT)
- …

exp. signatures of exotic BSM models:

- high-mass resonances decaying into jets, leptons, bosons
- large missing energies; mono jets; …

extensive searches so far have not shown any significant deviations from SM and thus, no compelling signature of any physics BSM

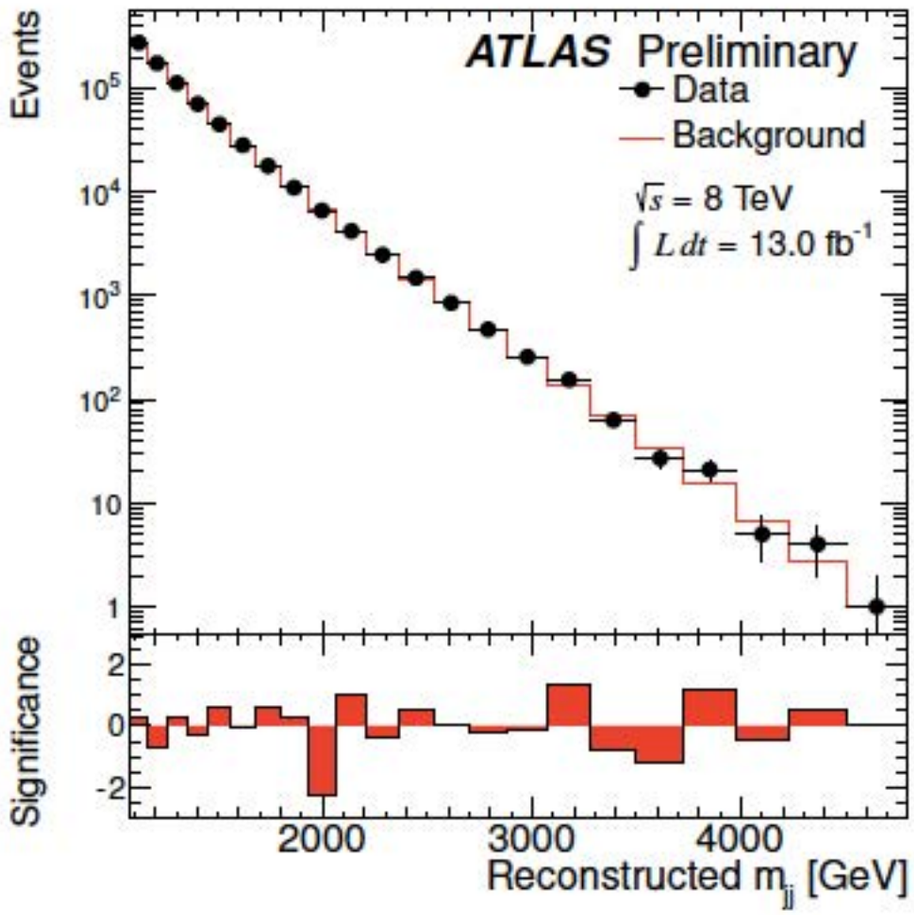
summary of (model dependent) exclusion limits:

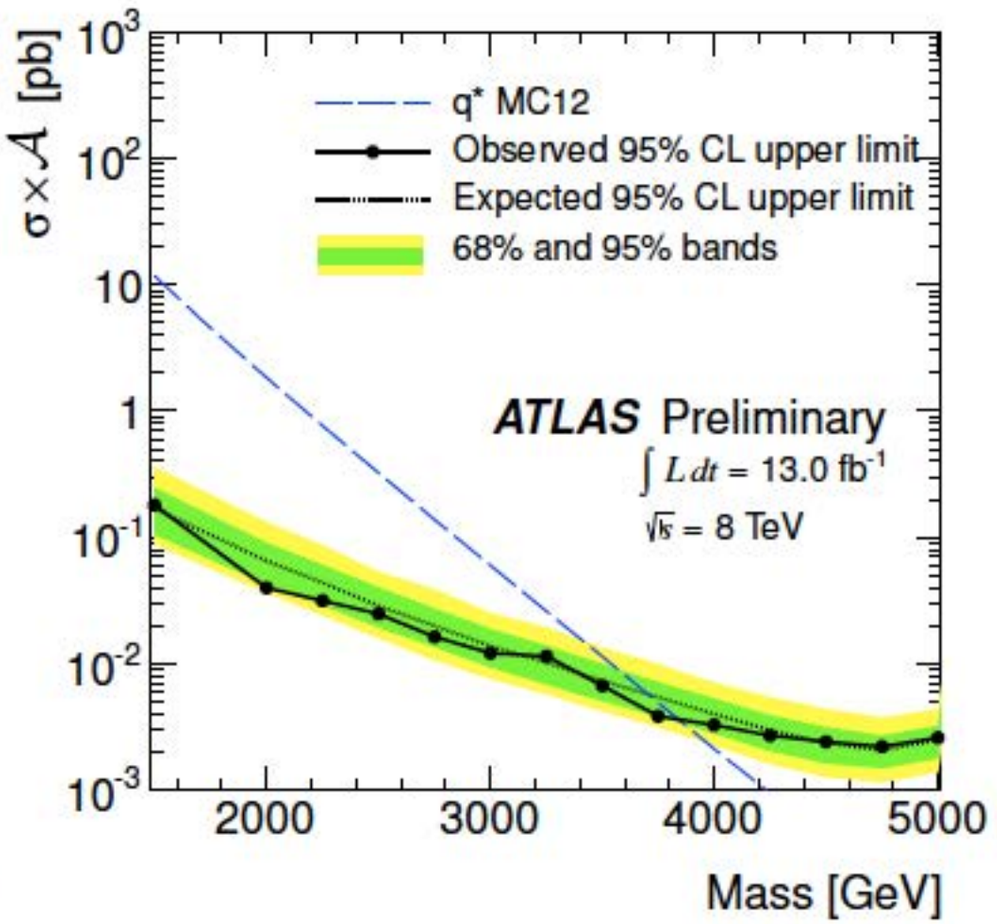


*Only a selection of the available mass limits on new states or phenomena is shown.

compositeness / excited quarks:

dijet invariant mass distribution

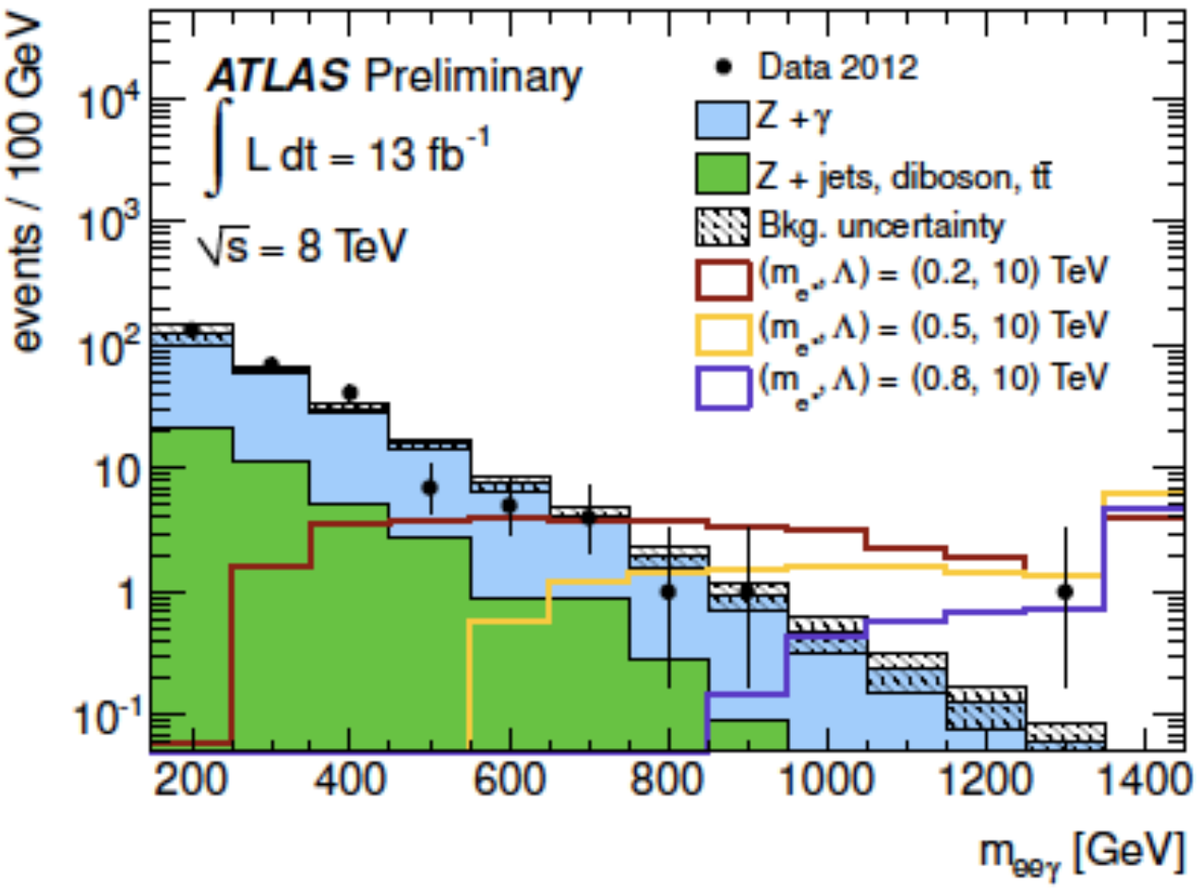


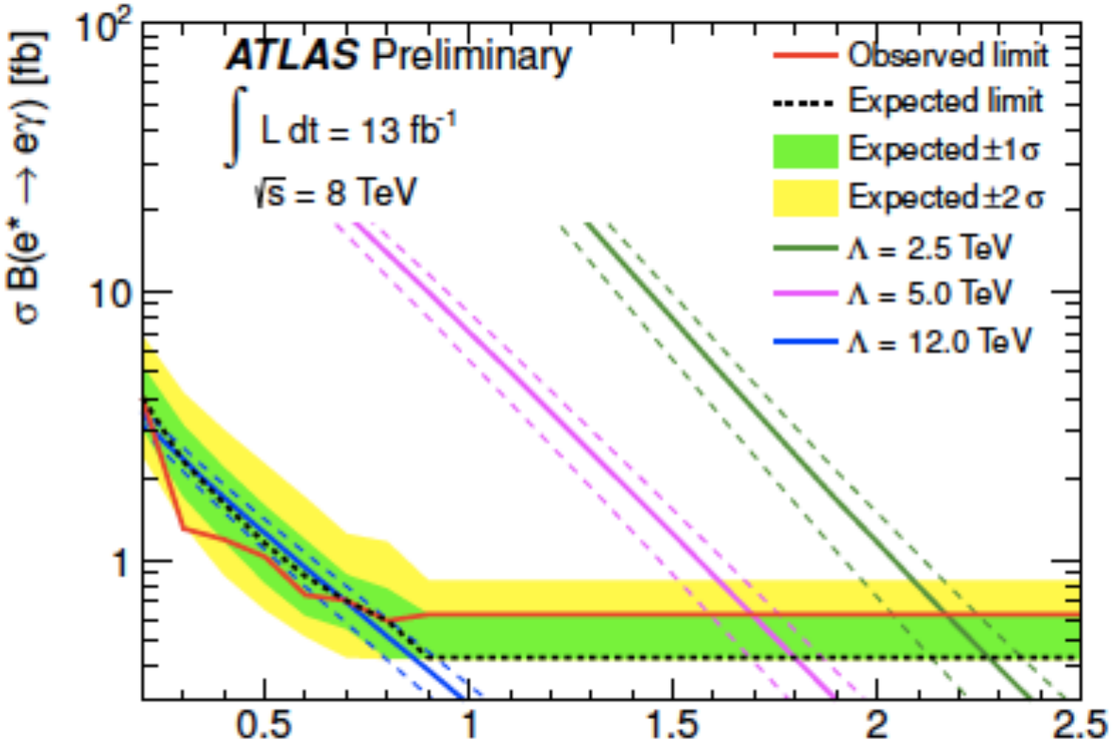


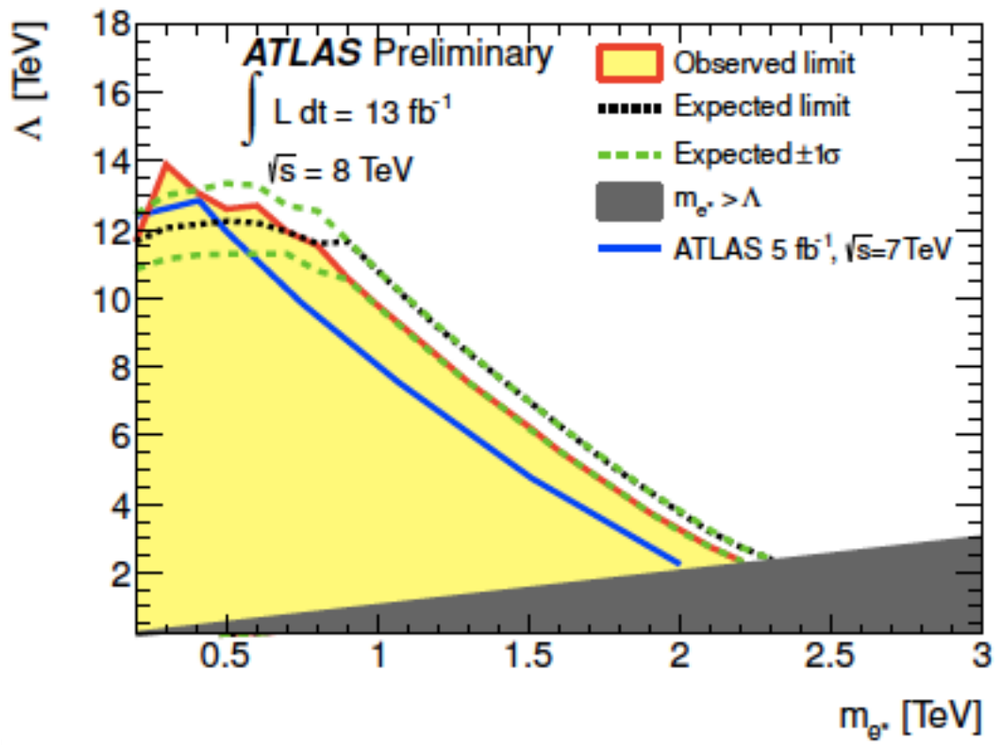
no excess (bump) above expected (smooth) background from SM observed –> lower limit of $M_{q^*} > 3.84$ TeV.

compositeness / excited leptons:

di-lepton-γ invariant mass distribution

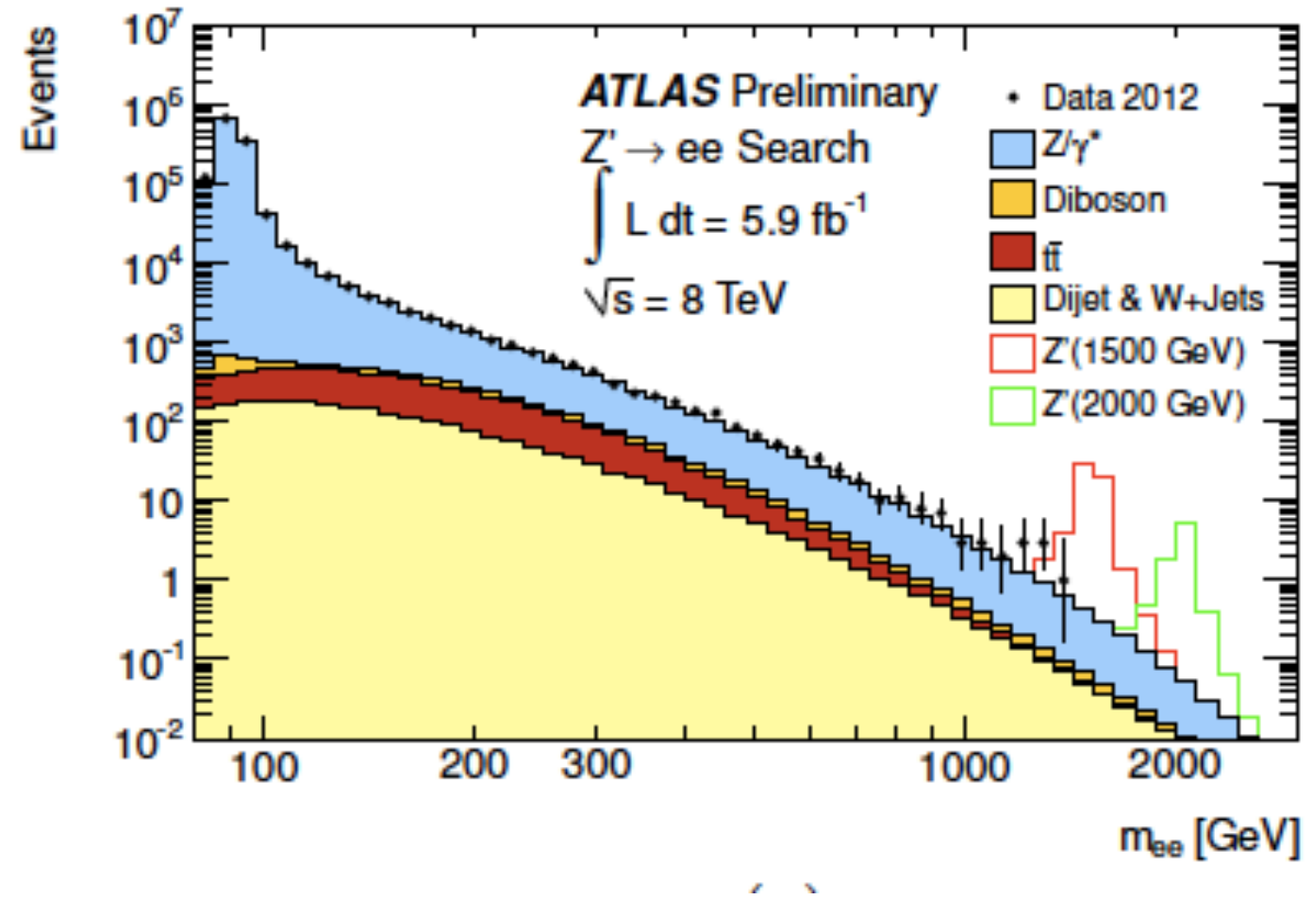


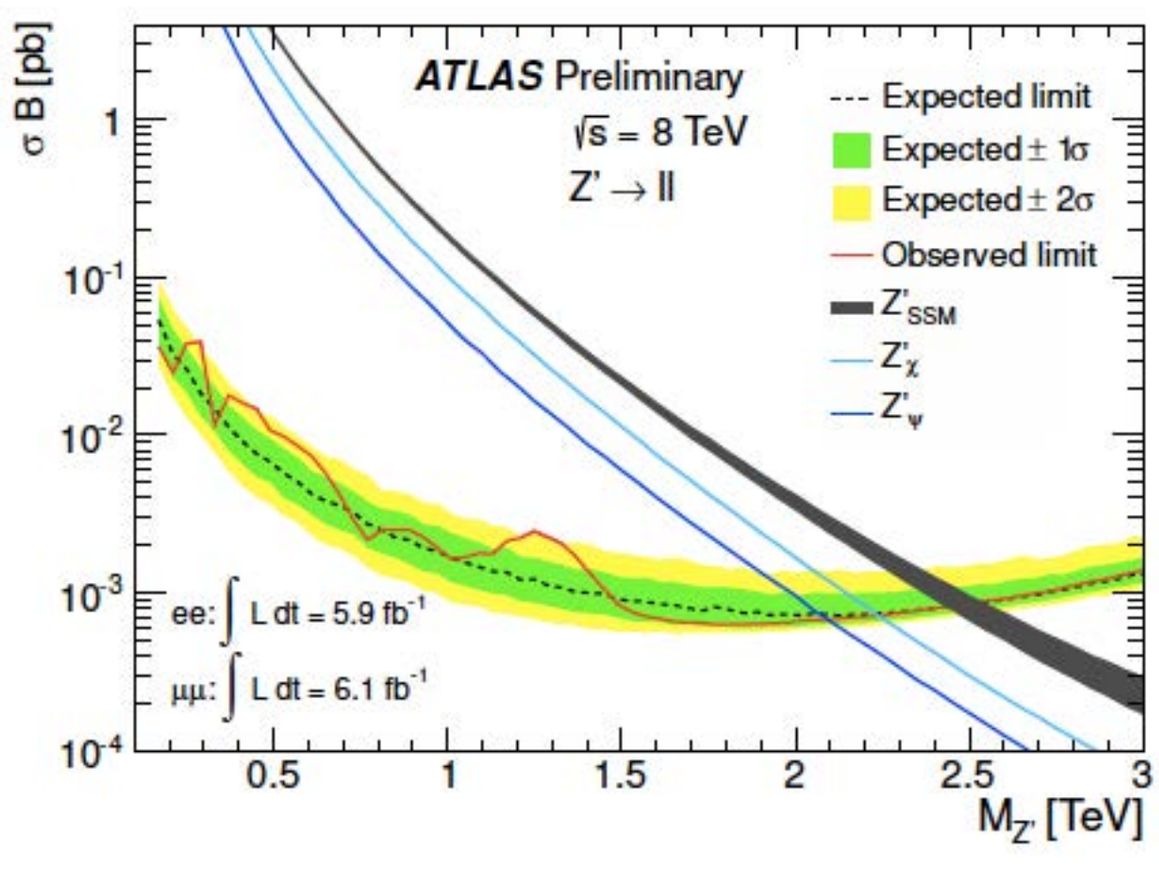




additional U(1)´ symmetry: new heavy Z

di-lepton invariant mass distribution

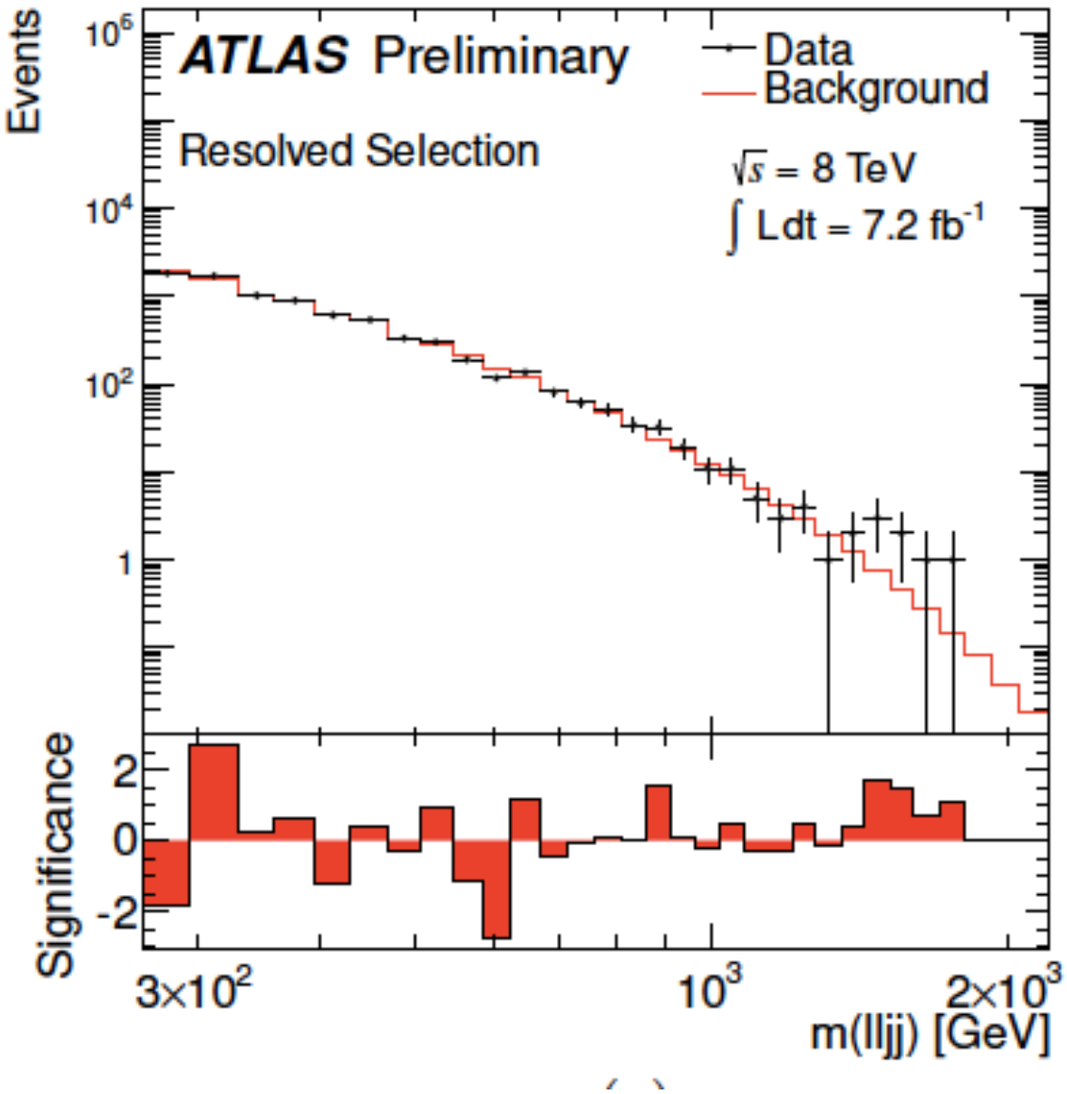


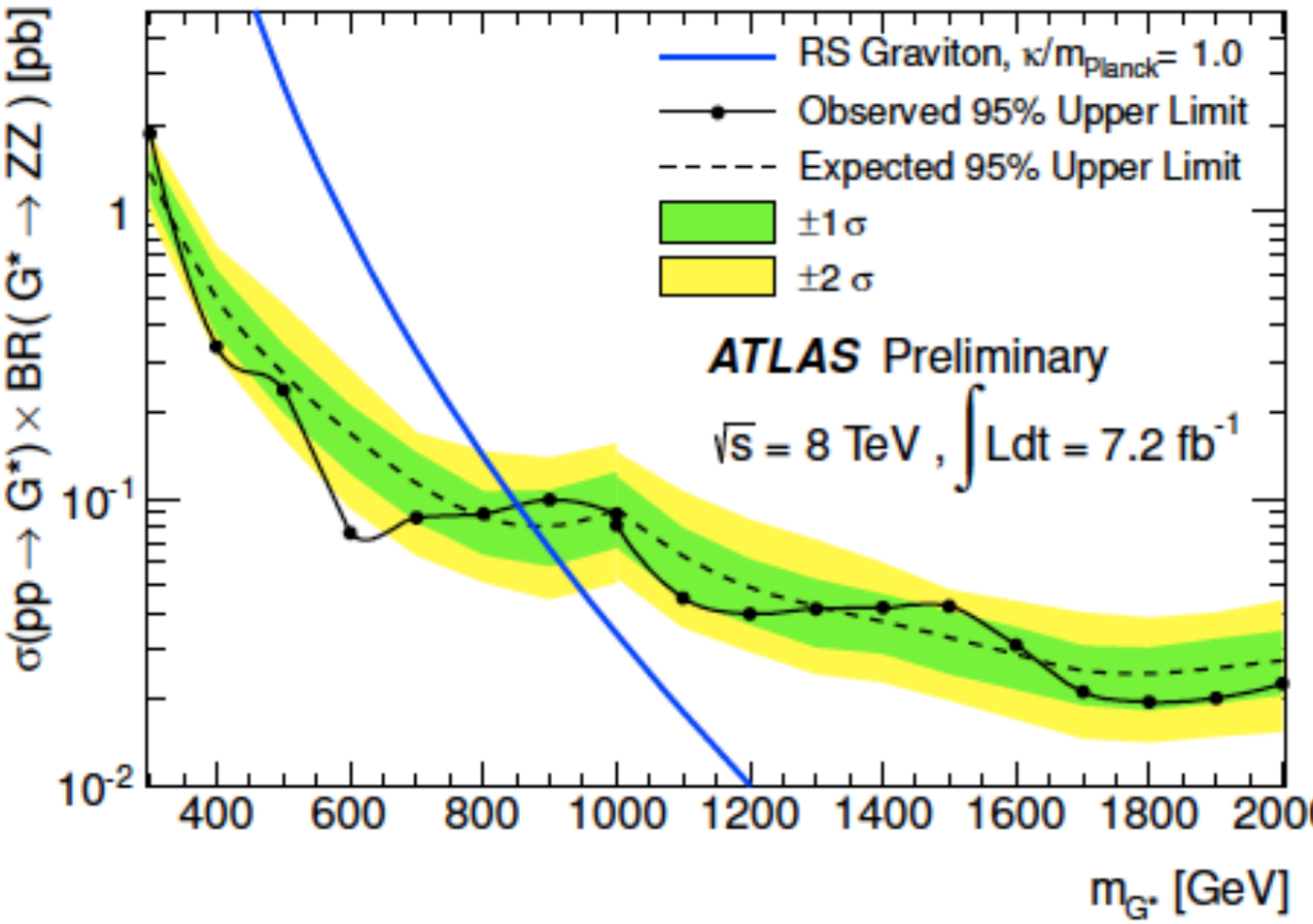


no excess (bump) above expected background from SM observed

–> model dependent lower limits of $M_{Z'} > 2 \ldots 2.5$ TeV.

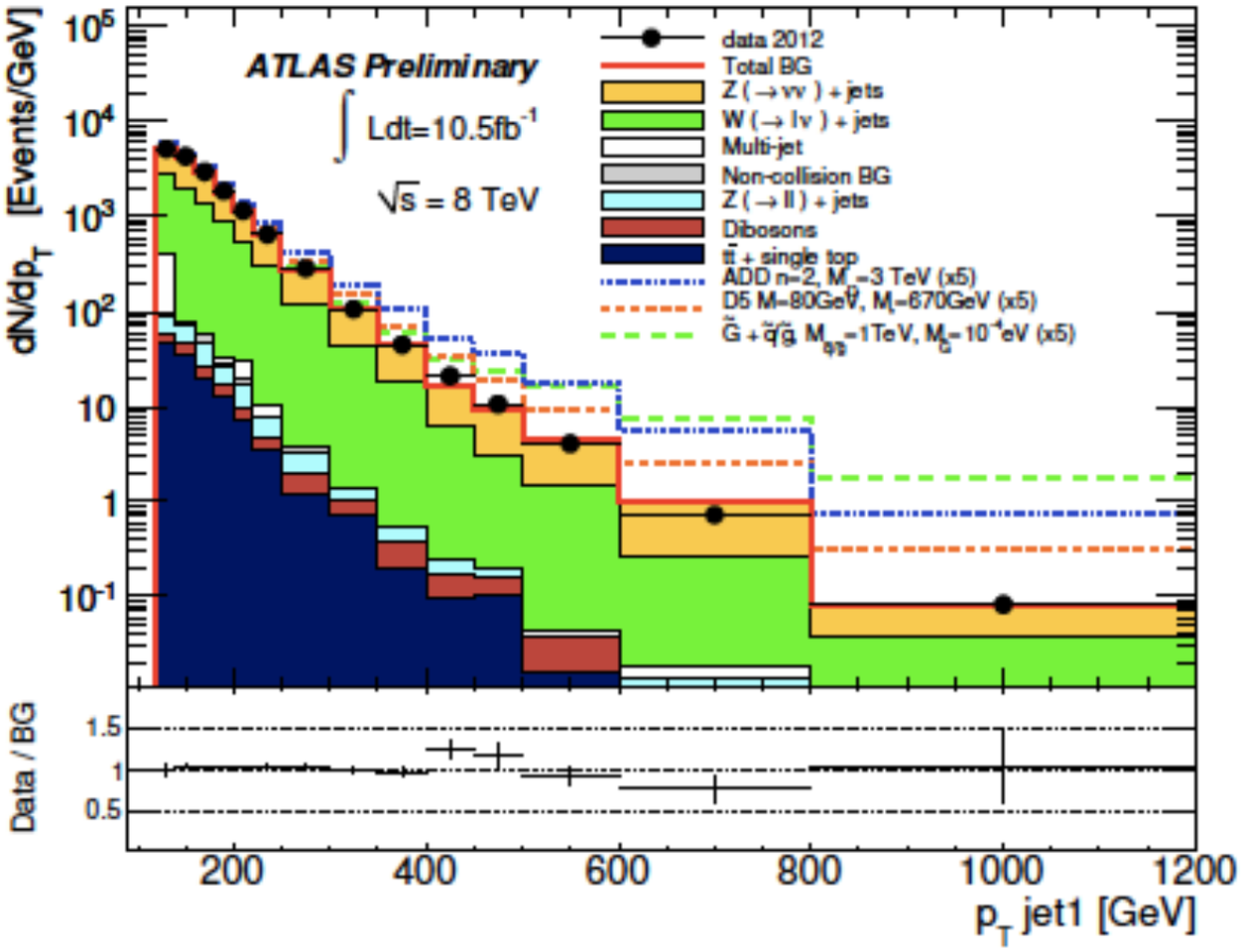
decay of spin-2 Randall-Sundrum(1) Graviton G*: resonant ZZ production

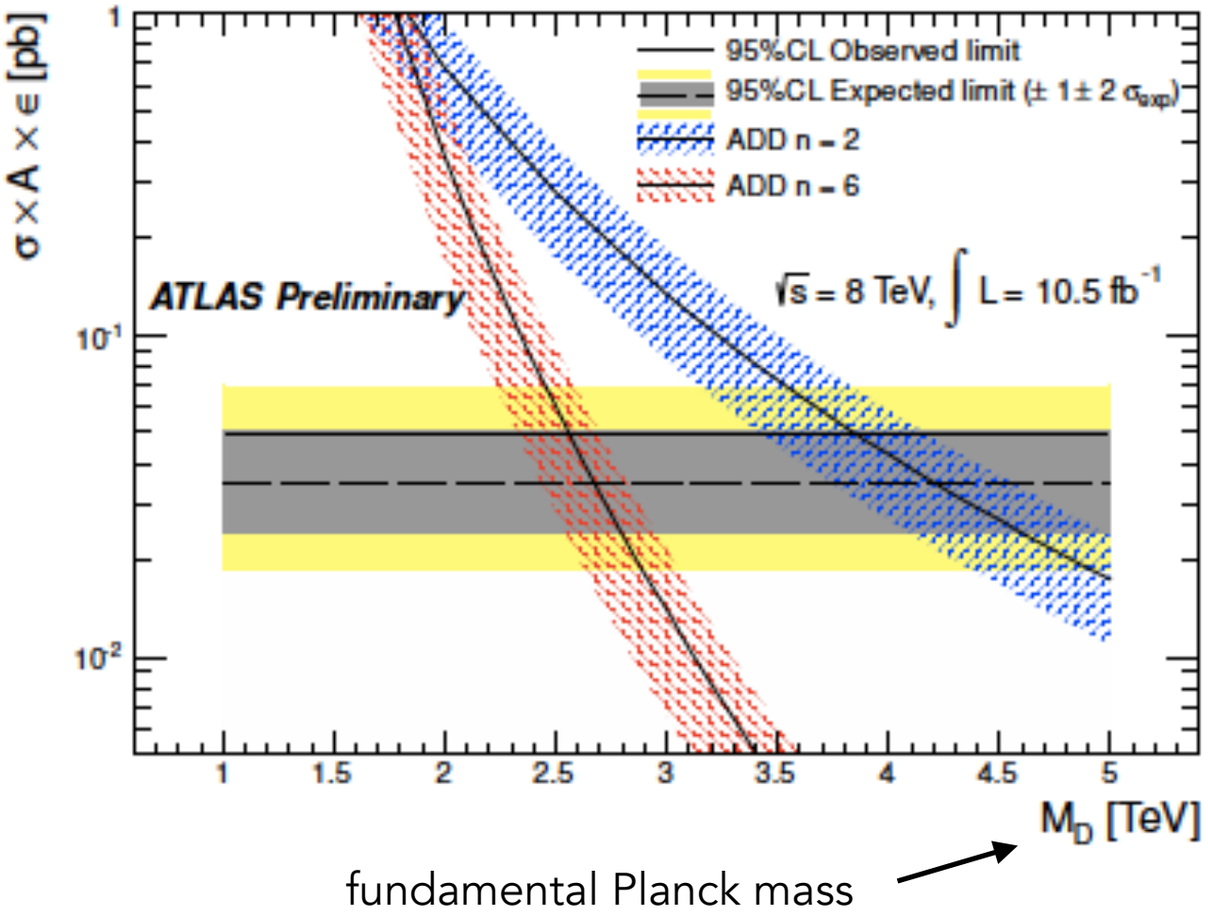




(1): model with one single warped extra dimension

decay of ADD(1) Graviton G* and/or WIMPS(2): mono-jet plus E_T^{miss} production





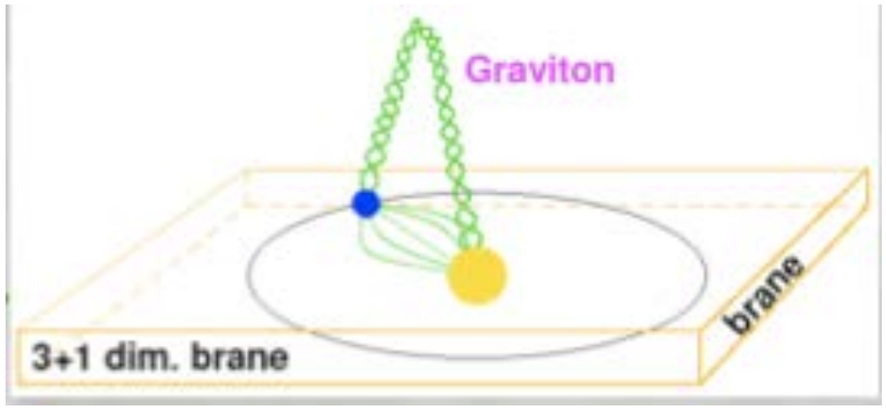
fundamental Planck mass

(1): Arkani-Hamed / Dimopoulos / Dvali: large extra dimensions (n)

(2): Weakly Interacting Massive Particles

ADD model of large extra dimensions:

- fields of SM are confined to 3+1-dimensional membrane



- gravity propagates to n additional spatial extra dimensions

- extra dimensions are compactified on an n-dimensional torus / sphere of radius *R*

- Planck-mass in 4+n dimensions : $M_D^{n+2} \sim M_{Pl}^2 R^{-n}$ may approach TeV scale for large n

“Absence of evidence is not evidence of absence”

meaning:

no sign of physics BSM so far,
but unexplored phase space still large.

Future prospects:

- higher luminosity
- higher energies
- future colliders

Future (hadron) collider projects

– the European strategy update 2013 recommended:

1. LHC, hl-LHC (high luminosity LHC; E=14 TeV; L~5 $10^{34}cm^{-2}s^{-1}$)
2. future accelerator & detector R&D
3. Japanese ILC (intern. linear e+e- collider; E=250 / 500 / 1000 GeV)

… (b-factory; ν long baseline; …)

– USA, Japan (Asia) (roughly) go along with this

– need an internationally agreed roadmap & timeline!

– approved project: high luminosity upgrade of LHC (hl-LHC)

LHC - future planning:

2013 / 2014 / 2015:

- ~20 months shut-down (installation of final safety systems for highest magnet currents to reach design-energy of 14 TeV)

2015 - 2022:

- full energy (14 TeV) and luminosity (10^{34} cm^{-2} s^{-1})

expect ~10 times more data than available today

from ~2025 - 2035:

- upgraded LHC and detectors (hl-LHC; luminosity x 5))

expect ~100 times more data than available today

>~ 2035:

- Future Circular Collider (FCC)? 100 km circ., 100 TeV

LHC schedule beyond LS1

LS1: Long Shutdown 1; 2013-2015)

Only EYETS (19 weeks) (no Linac4 connection during Run2)

LS2 starting in 2018 (July) 18 months + 3months BC (Beam Commissioning)

LS3 LHC: starting in 2023 => 30 months + 3 BC

injectors: in 2024 => 13 months + 3 BC

CERN

LHC schedule approved by CERN management and LHC experiments spokespersons and technical coordinators
Monday 2nd December 2013

Run I: E = 7 / 8 TeV; intL ~ 25 fb^{-1} (2009 - 2013)

Run II / III: E = 14 TeV; intL ~ 300 fb^{-1} (2015 - 2022)

Run IV - VI: E = 14 TeV; intL ~3000 fb^{-1} (2025 - 2035)

Summary of this lecture:

- similar as in case of SUSY searches, so far no indication for other physics BSM were found
- exclusion limits for excited leptons and quarks, for new heavy gauge bosons, for the effects of extra spacial dimensions and other effects range up to mass scales of several 100 GeV to TeV
- The discovery potential of LHC so far explored is only at the percent level of the planned overall LHC program

- European and international road maps of particle physics prioritize the full exploitation of the LHC (incl. luminosity upgrade to hl-LHC)

- plans of future colliders beyond LHC: see next lecture

Summary of this lecture series:

- the LHC successfully completed its first run period (2010-2012) at energies of 7 and 8 TeV c.m., with ~30 pb-1 of data collected per experiment in p-p collider mode
- the validity of the Standard Model was scrutinized to the per-cent level, for many processes and signatures, for mass scales up to and exceeding 1 TeV
- a new Boson with a mass of 125 GeV was discovered; initial determinations of its properties (spin, couplings) are compatible with those expected for the SM Higgs boson, but also with the lightest SUSY Higgs boson
- intense searches for signals of physics beyond the SM, like SUSY, large extra dimensions, compositeness, did not uncover any new effects, but posed exclusion limits up to mass scales of several TeV
- after 2 years of intense refurbishments and repairs, LHC will continue to run in spring 2015, at 14 TeV c.m. design energy and 10^{34} cm^{-2} s^{-1} luminosity
- the LHC program is planned to commence, incl. upgrades, until about 2035, with the ultimate goal to collect 3000 pb^{-1} of data
- with 100times more data at (almost) double the energy of today, prospects and hopes for discovering new physics BSM are still very high

further reading for BSM searches:

- R. Pöttgen, “Exotic Searches at ATLAS”, arXiv:1411.4292.
- S. Maruyama, “Searches for Exotic Phenomena at ATLAS and CMS”, arXiv:1411.0204.

… and references therein

further reading for future collider plans:

- M. Krammer, “The update of the European strategy for particle physics”, Physica Scripta 2013 014019, http://iopscience.iop.org/1402-4896/2013/T158/014019/