Vorlesung 13:

Search for BSM Physics: Exotics

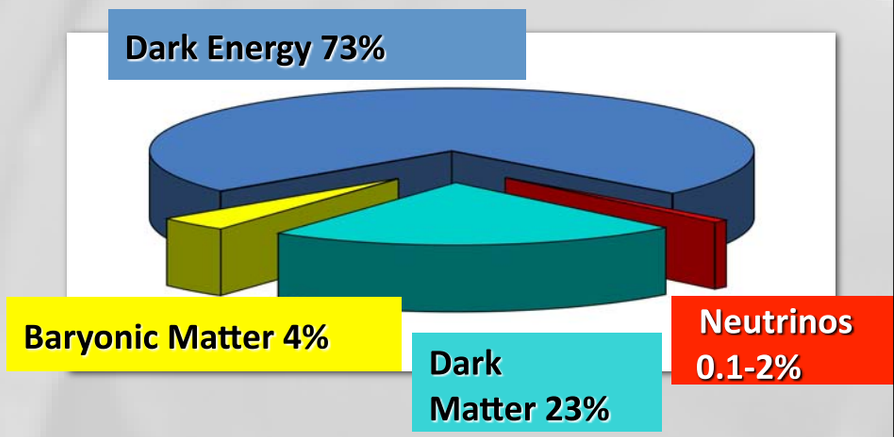
and

Future of LHC and other Collider Projects

- models / ideas for physics BSM
- some examples of LHC searches for physics BSM
- future plans: hadron colliders
  - 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:

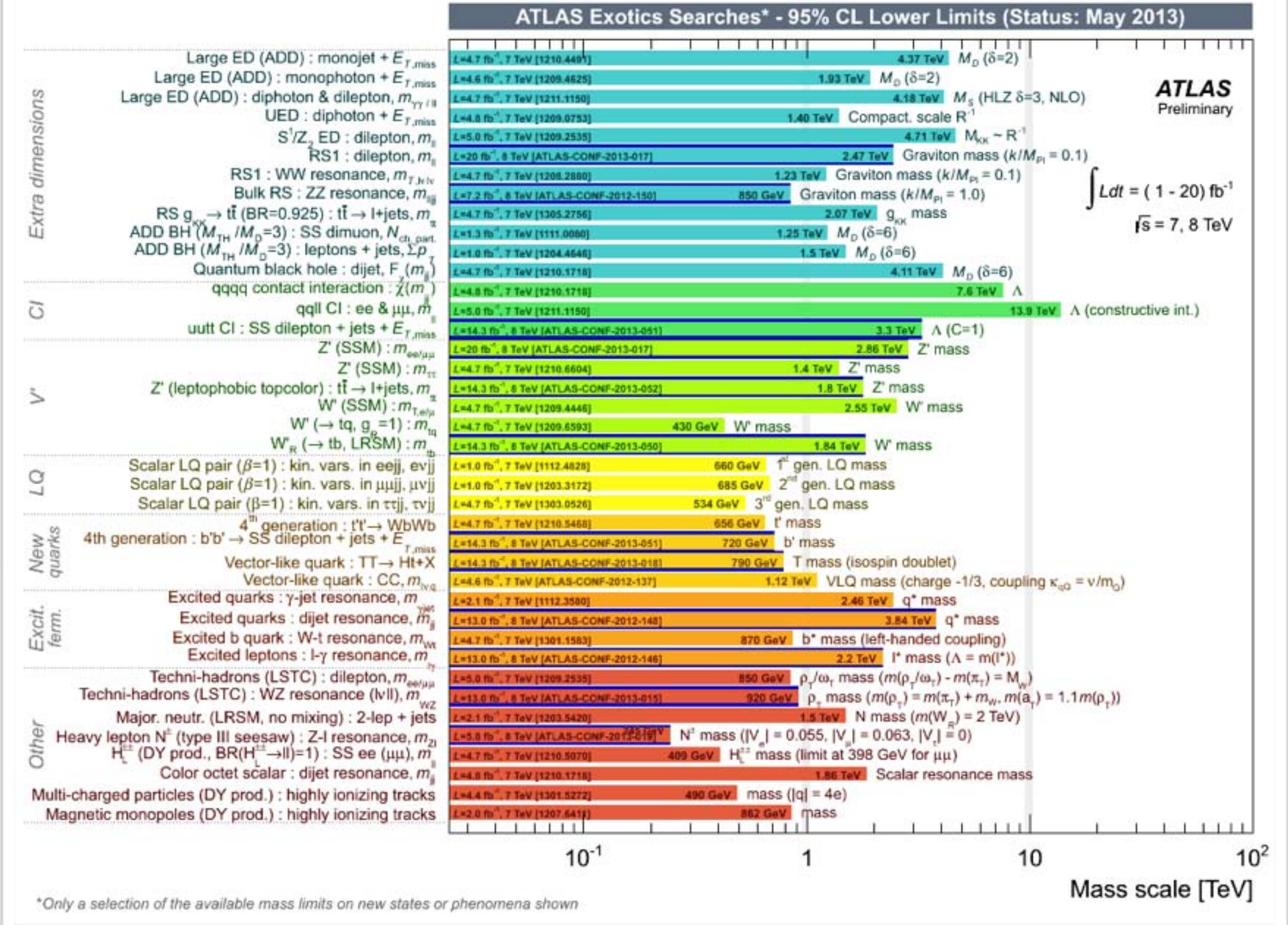
- Supersymmetry (SUSY) (see previous lecture)
- composite models (excited quarks & leptons)
- new symmetries (new heavy gauge bosons)
- large extra dimensions (micro black holes,…)
- technicolor models (composite Higgs)
- leptoquarks (GUT)
- …

exp. signatures of exotic BSM models:

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

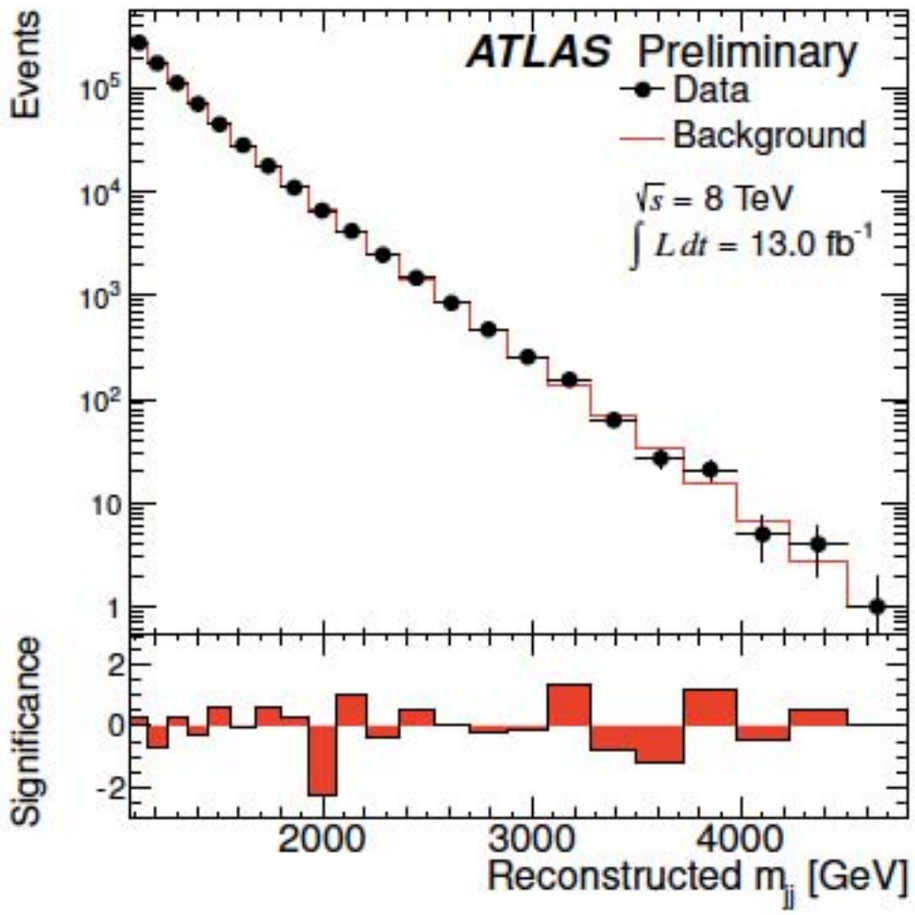
extensive searches so far have not shown any significant deviations from SM and thus, no compelling signature of any physics BSM

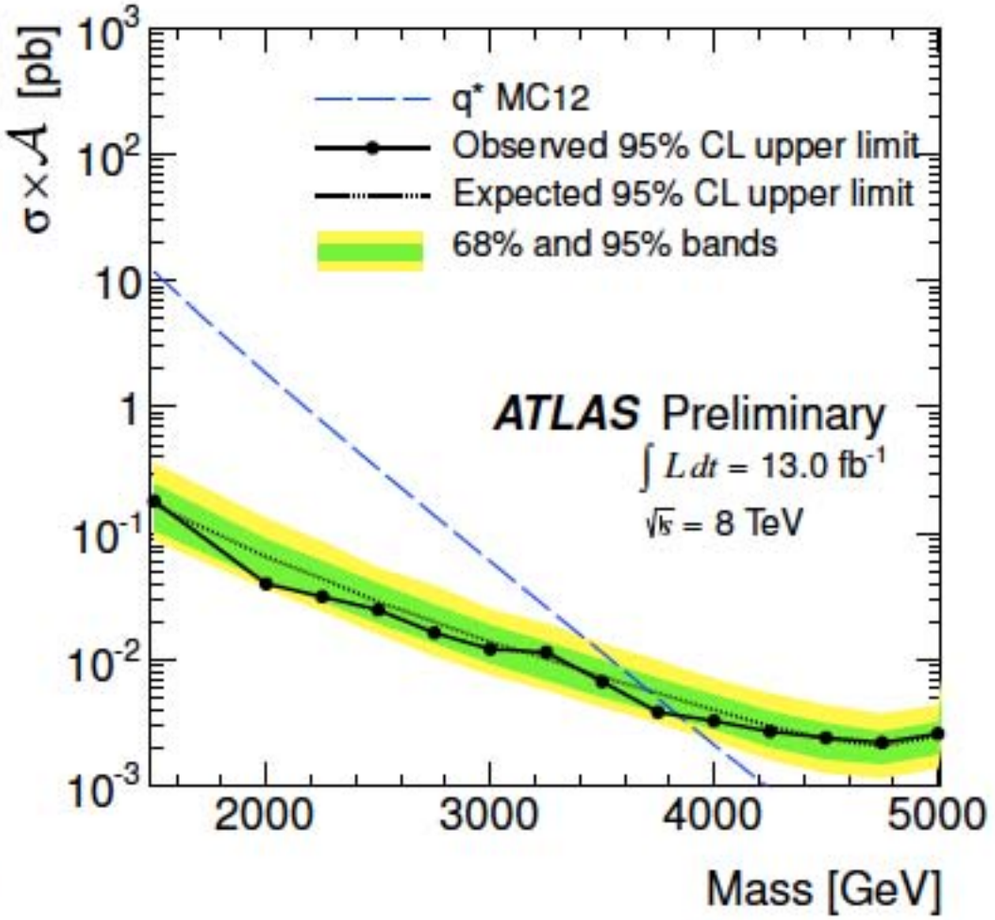
summary of (model dependent) exclusion limits:



compositeness / excited quarks:

dijet invariant mass distribution

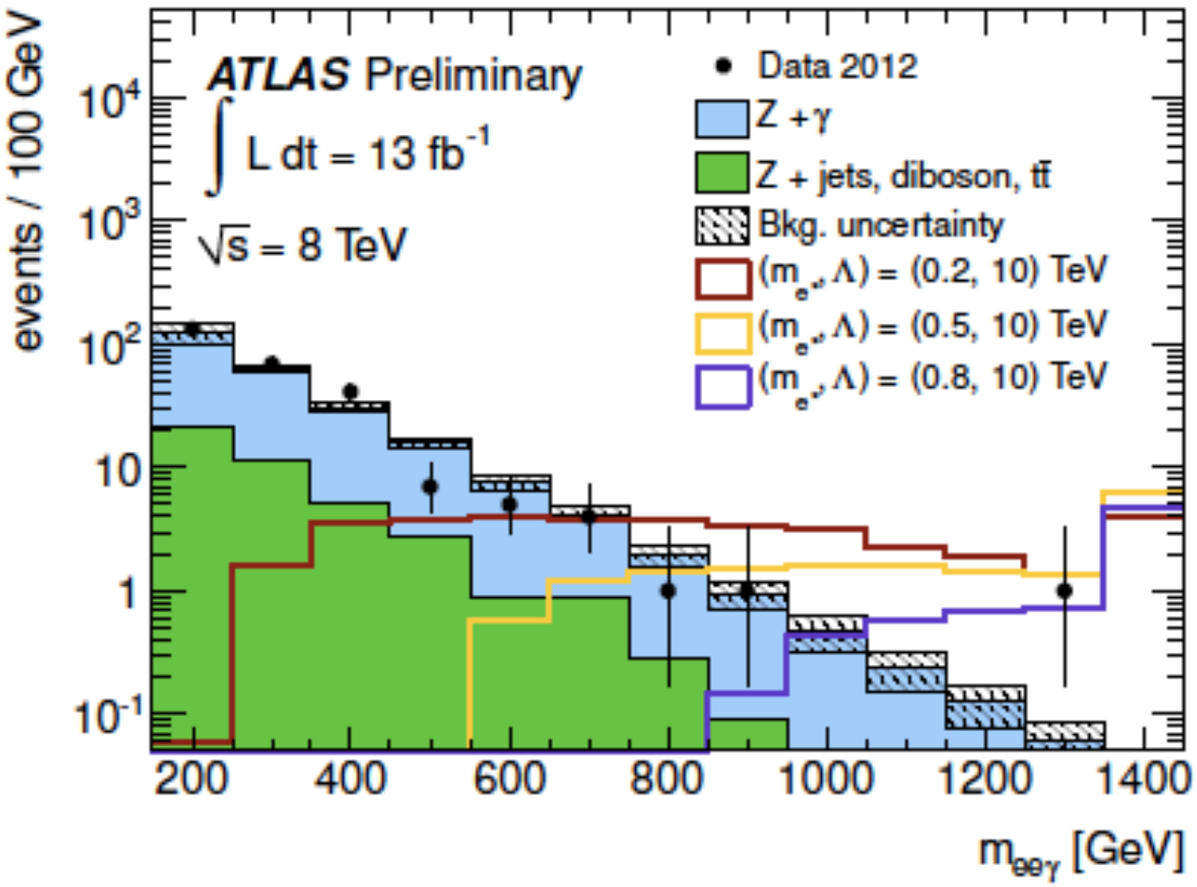


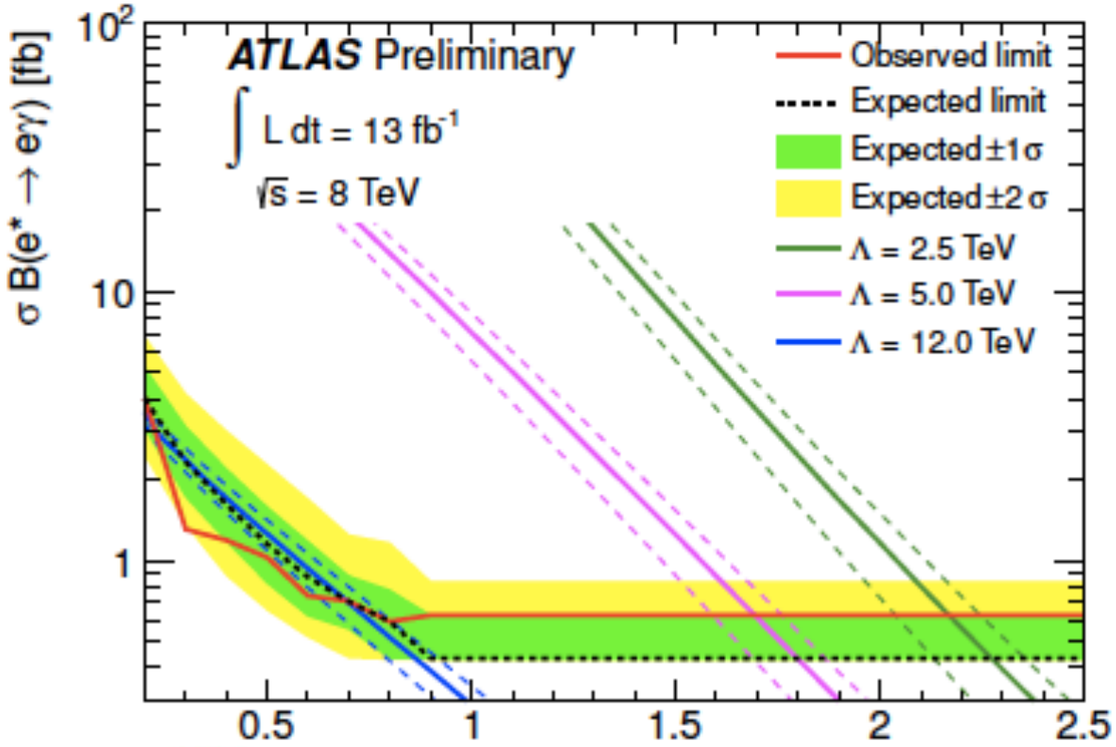


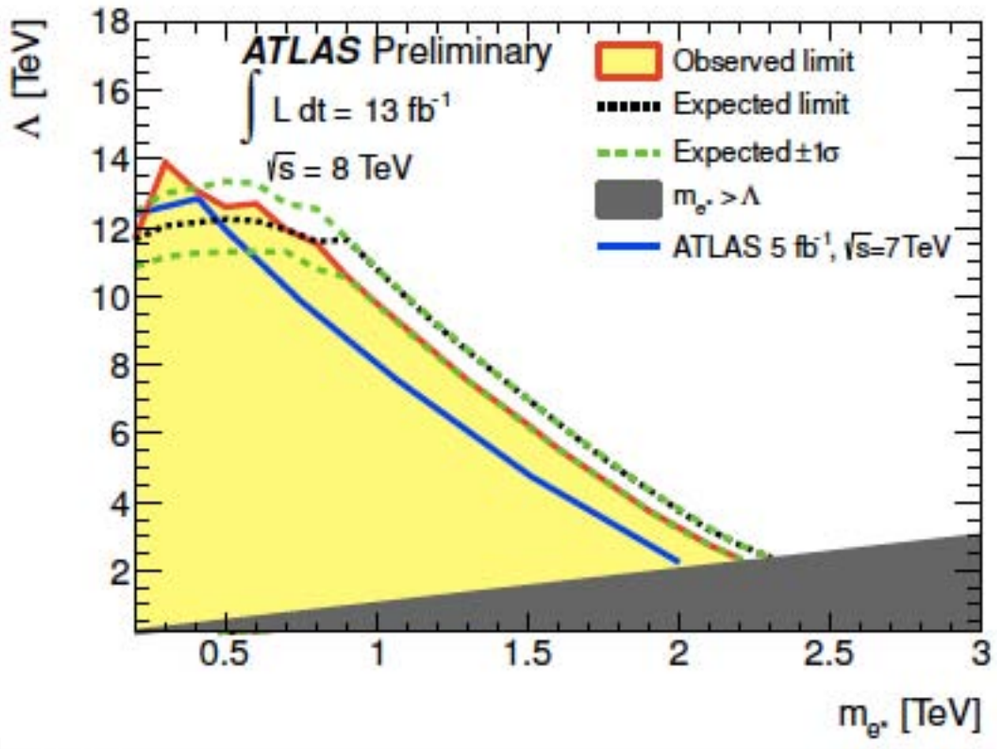
no excess (bump) above expected (smooth) background from SM observed –> lower limit of $M_{q^*} > 3.84$ TeV.

compositeness / excited leptons:

di-lepton-γ invariant mass distribution

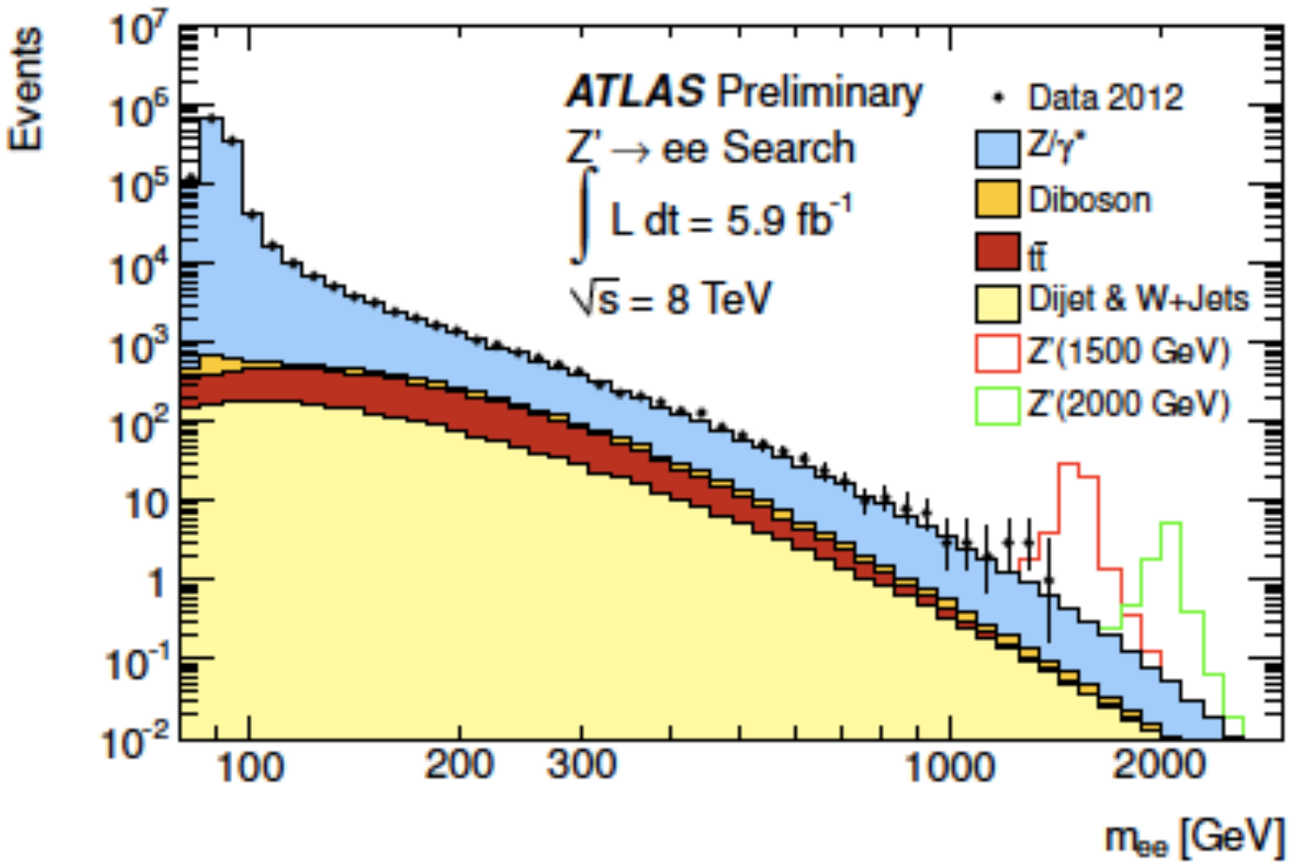


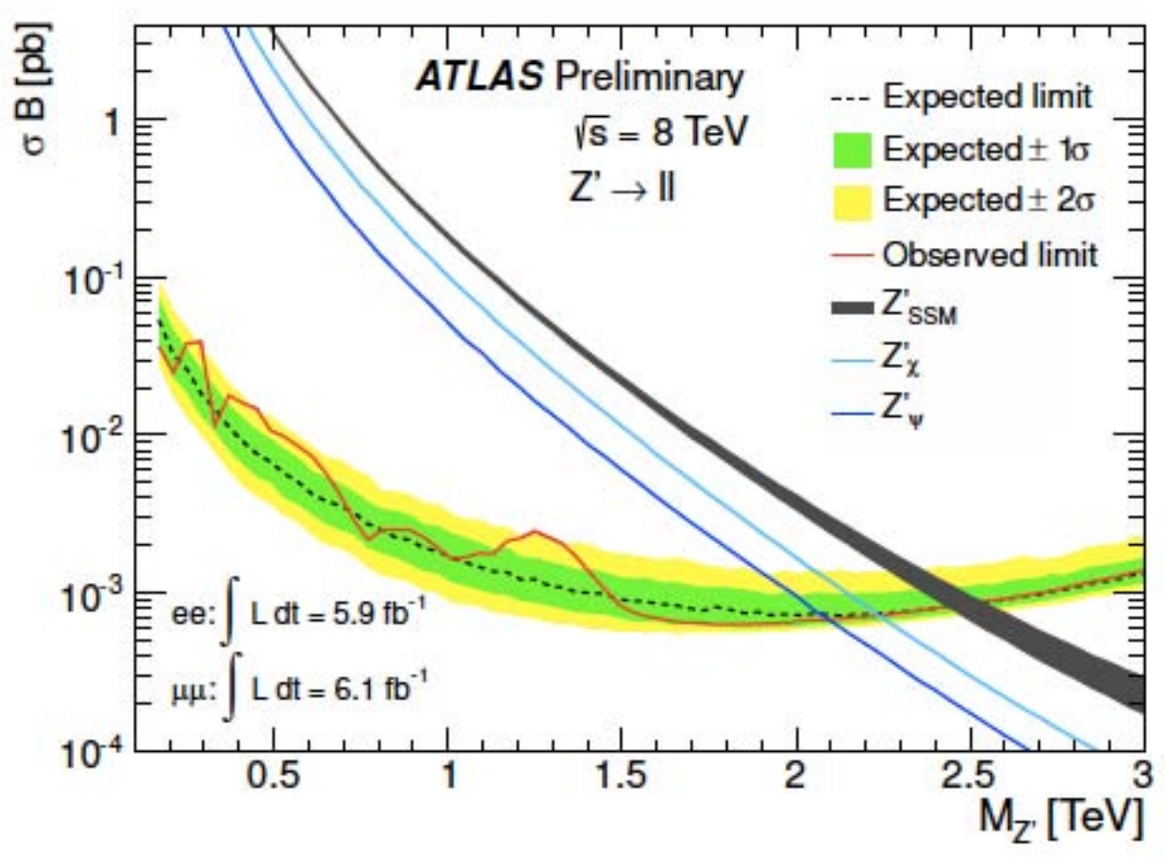




additional U(1)´ symmetry: new heavy Z

di-lepton invariant mass distribution

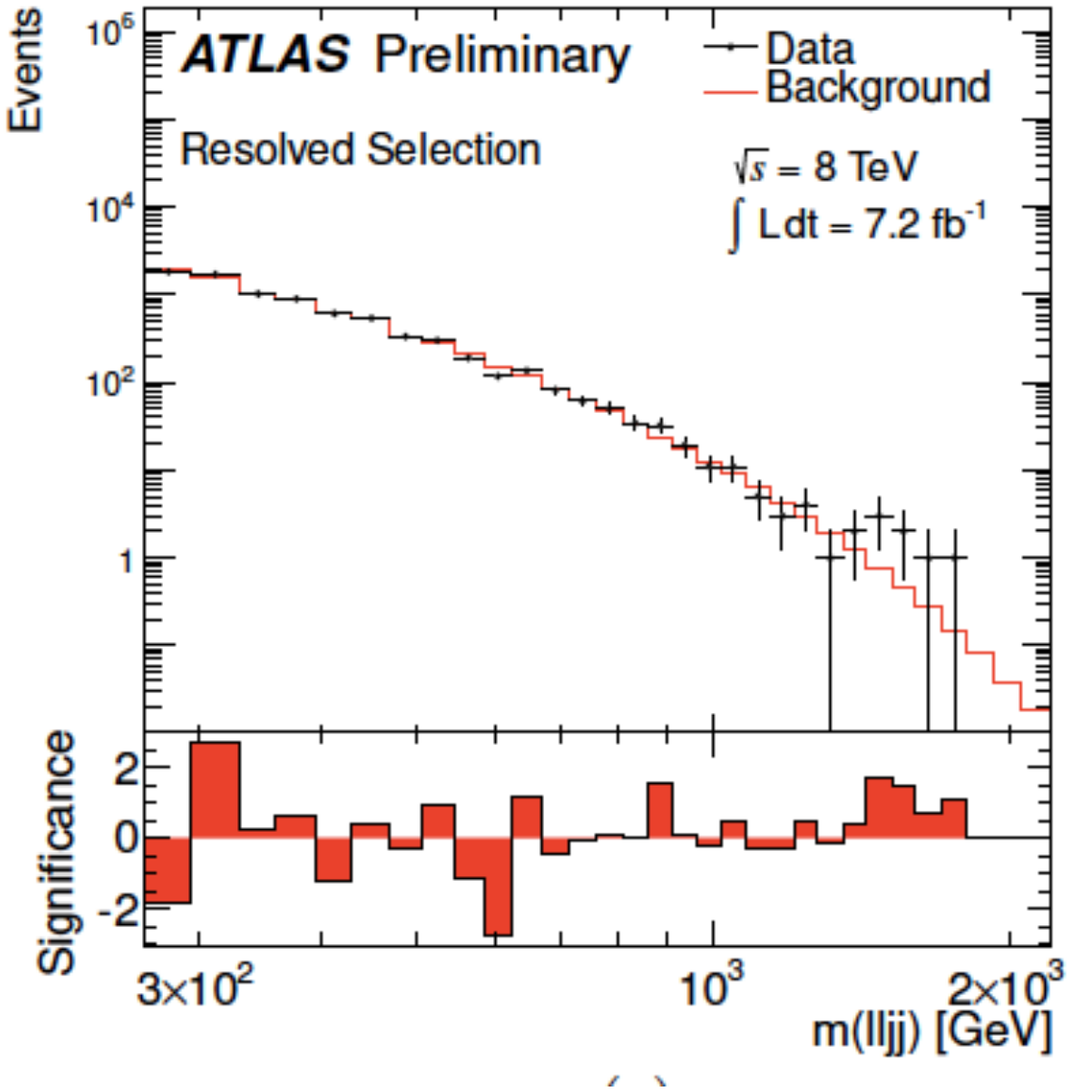


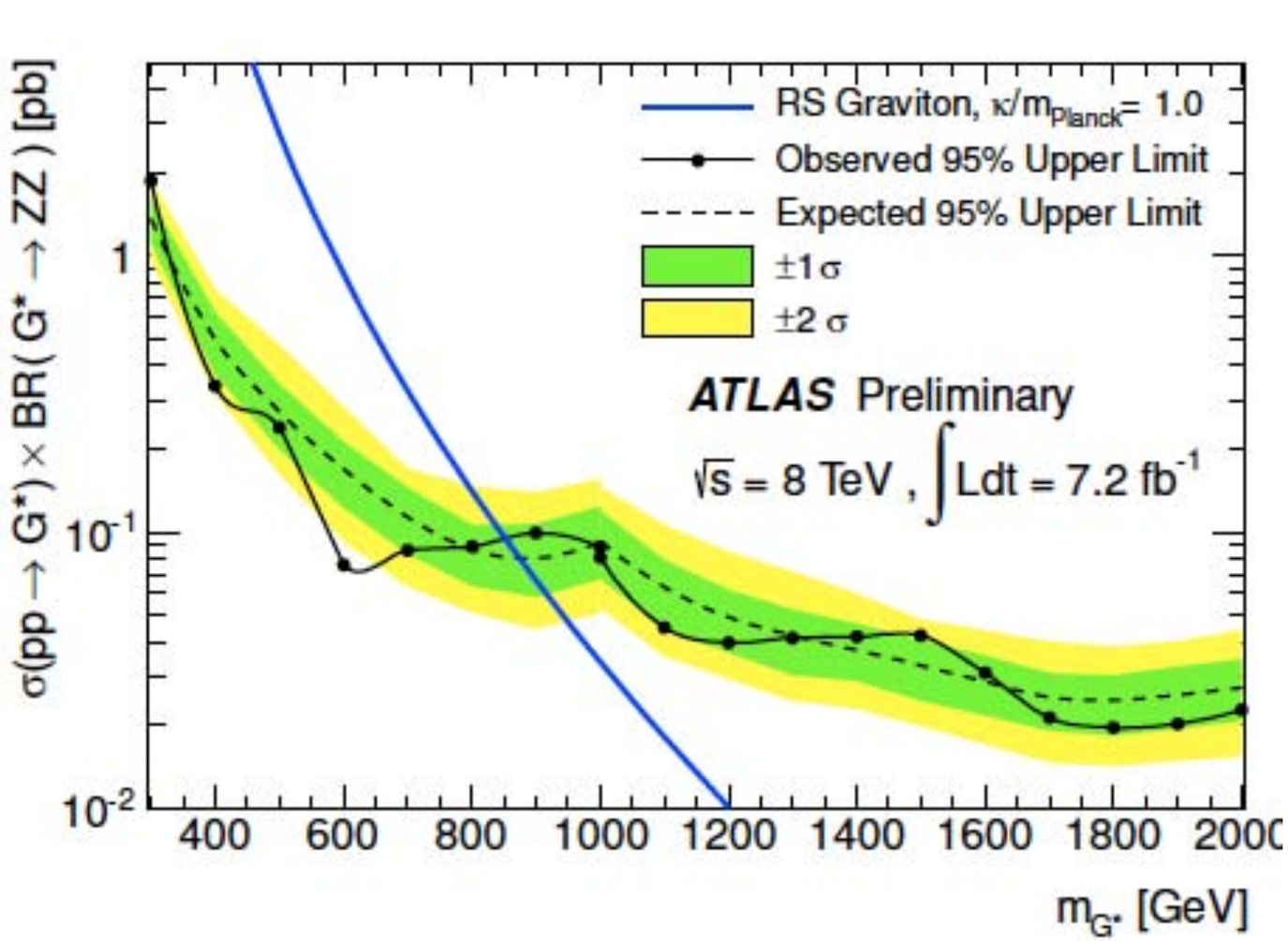


no excess (bump) above expected background from SM observed

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

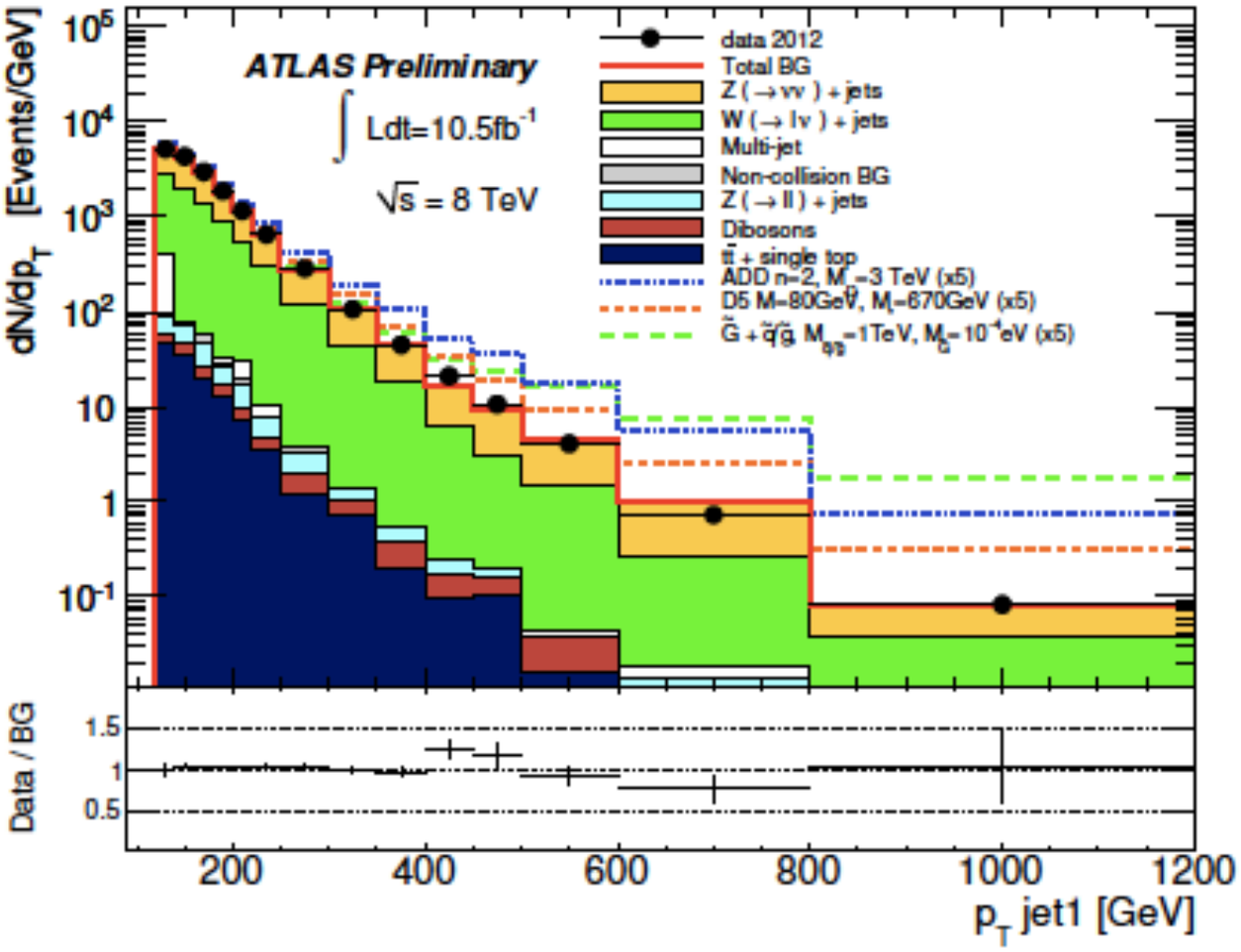
decay of spin-2 Randall-Sundrum(1) Graviton G*: resonant ZZ production

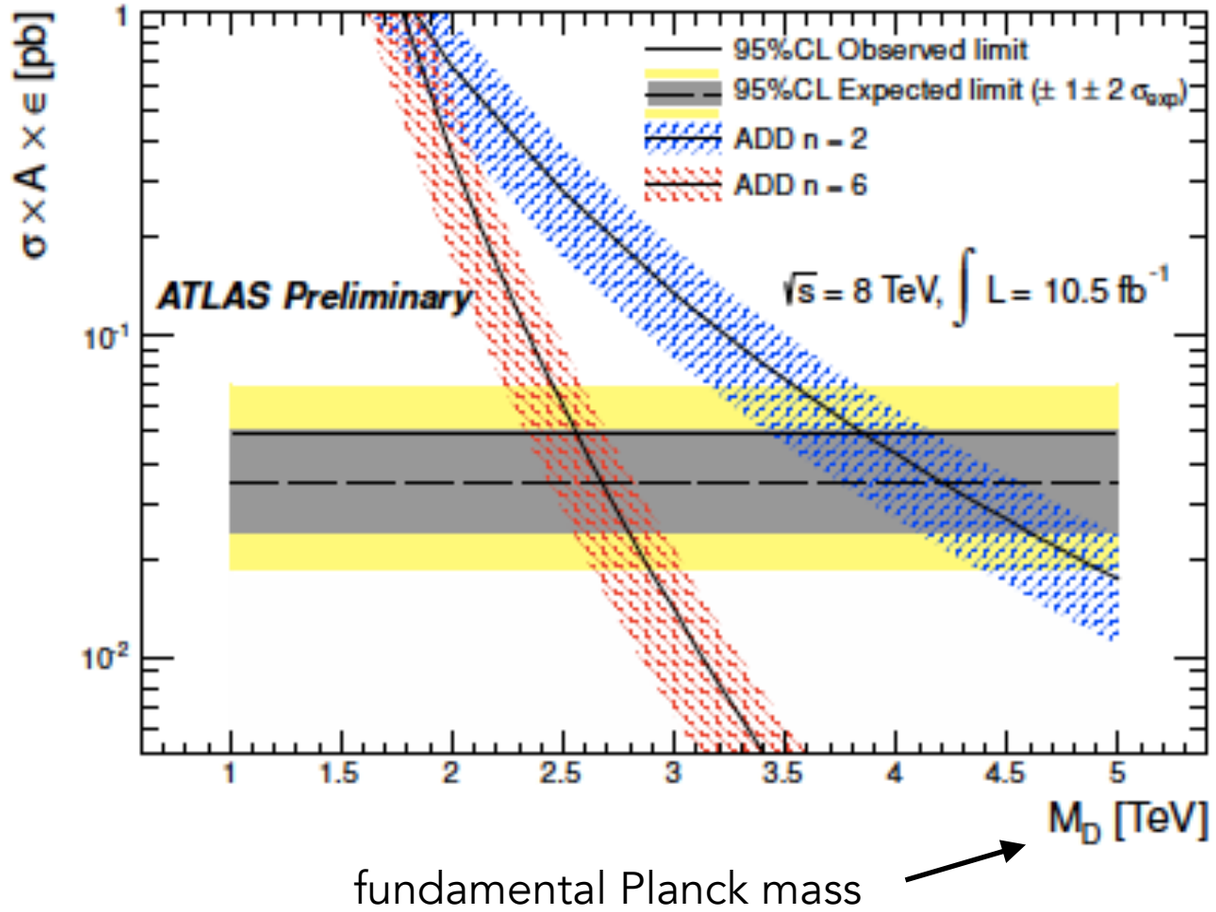




(1): model with one single warped extra dimension

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





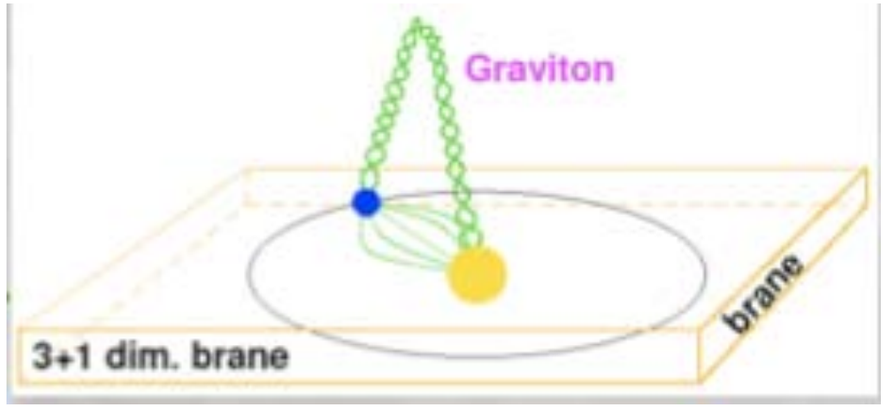
fundamental Planck mass

(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

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?) likely to (roughly) go along with this

– need an internationally agreed roadmap & timeline!

LHC schedule beyond LS1

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}

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

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

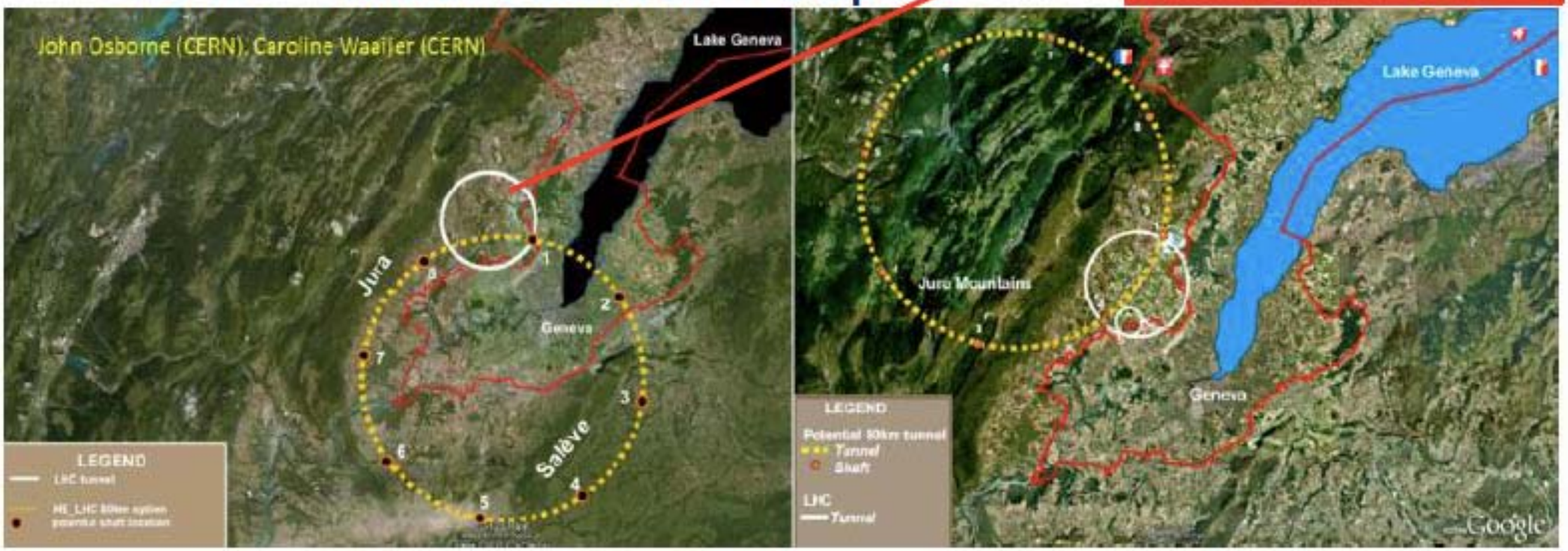
Future Accelerator Studies at CERN:

Exploratory studies for VHE-LHC

First studies on a new 80 km tunnel in the Geneva area

- 42 TeV with 8.3 T using present LHC dipoles
- 80 TeV with 16 T based on Nb_3Sn dipoles
- 100 TeV with 20 T based on HTS dipoles

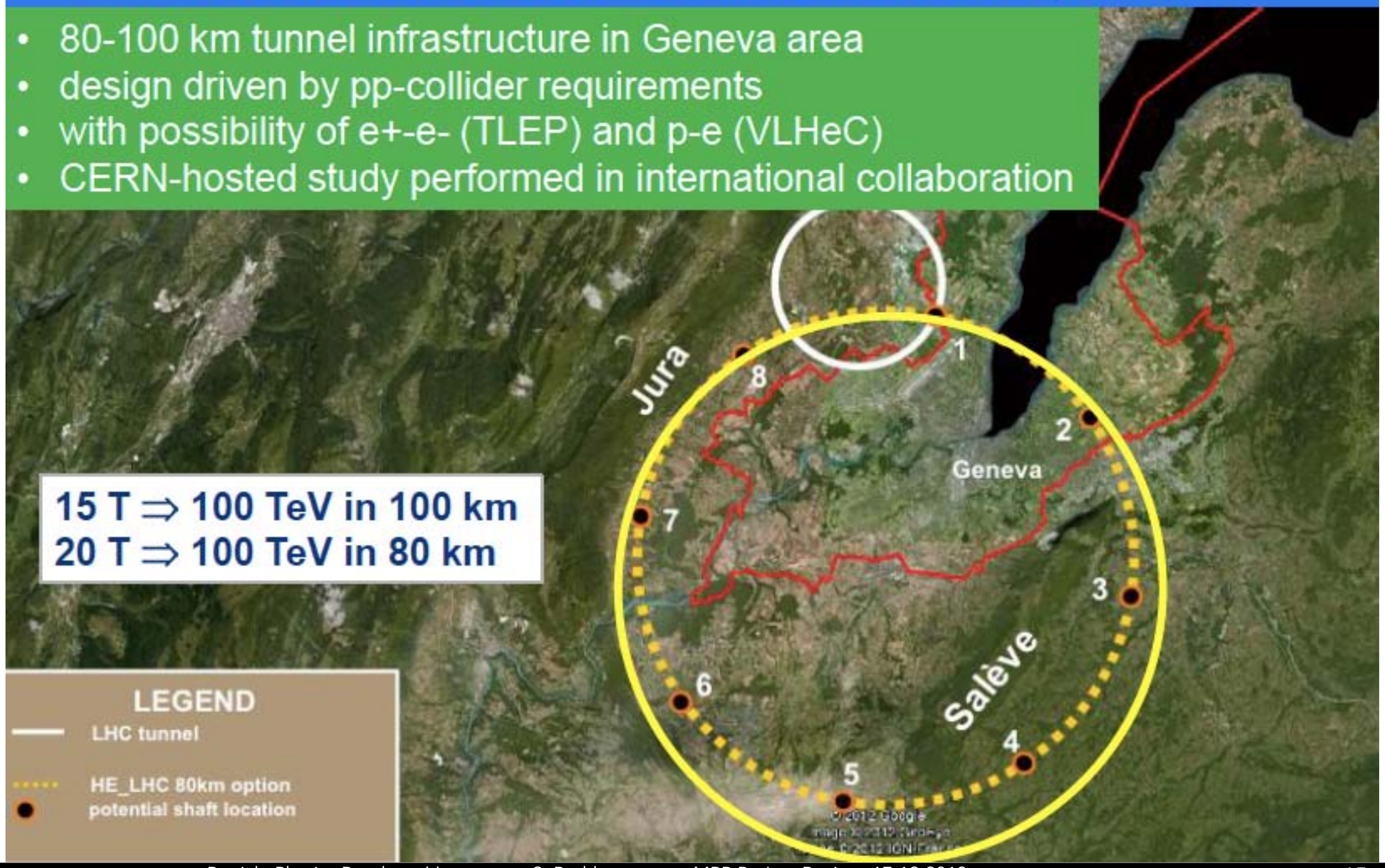
HE-LHC :33 TeV with 20T magnets



FCC Study (Future Circular Colliders)

CDR and cost review for the next ESU (2018)

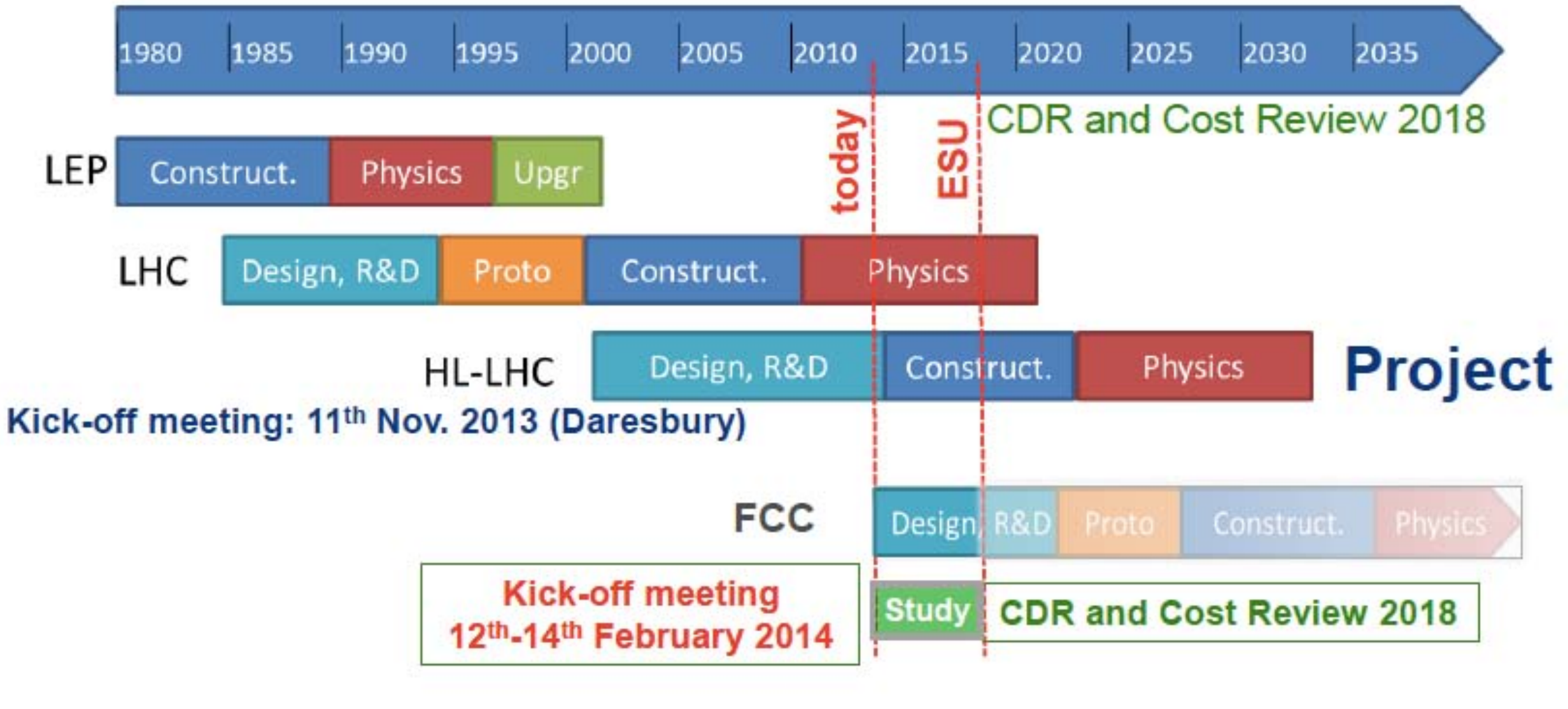
- 80-100 km tunnel infrastructure in Geneva area
- design driven by pp-collider requirements
- with possibility of e+-e- (TLEP) and p-e (VLHeC)
- CERN-hosted study performed in international collaboration



hadron collider parameters (comparison)

Facility	Ring (km)	Magnets (T)	√s (TeV)
(SSC)	87	6.6	40
LHC	27	8.3	14
HE-LHC	27	16-20	26-33
FHC	80	8.3	42
	80	20	100
	100	16	100

FCC study milestones



Summary of this lecture:

- similar as in case of SUSY searches, so far no indication for other searches for 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 prioritise the full exploitation of the LHC (incl. luminosity upgrade to hl-LHC)
- the next hadron collider planned is the FCC, with collision energies up to 100 TeV in a ring tunnel of 100 km length

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 scrutinised to the per-cent level, for many processes and signatures, for mass scales up to and exceeding 1 TeV
- the (a?) Higgs-Boson with a mass of 125 GeV was discovered
- 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

further reading for BSM searches:

- Y. Gershtein et al., “New Particles Working Group Report of Snowmass 2013”, arXiv:1311.0299
- M. Kaneda, “Exotic Searches in ATLAS”, Acta Physica Polonica B 44 (2013) 1495
- K. Romonowska-Rybinska, “Search for Exotic Physics with the CMS Detector at the LHC”, Acta Physica Polonica B44 (2013) 1569

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/