Physics at LHC (with ATLAS)

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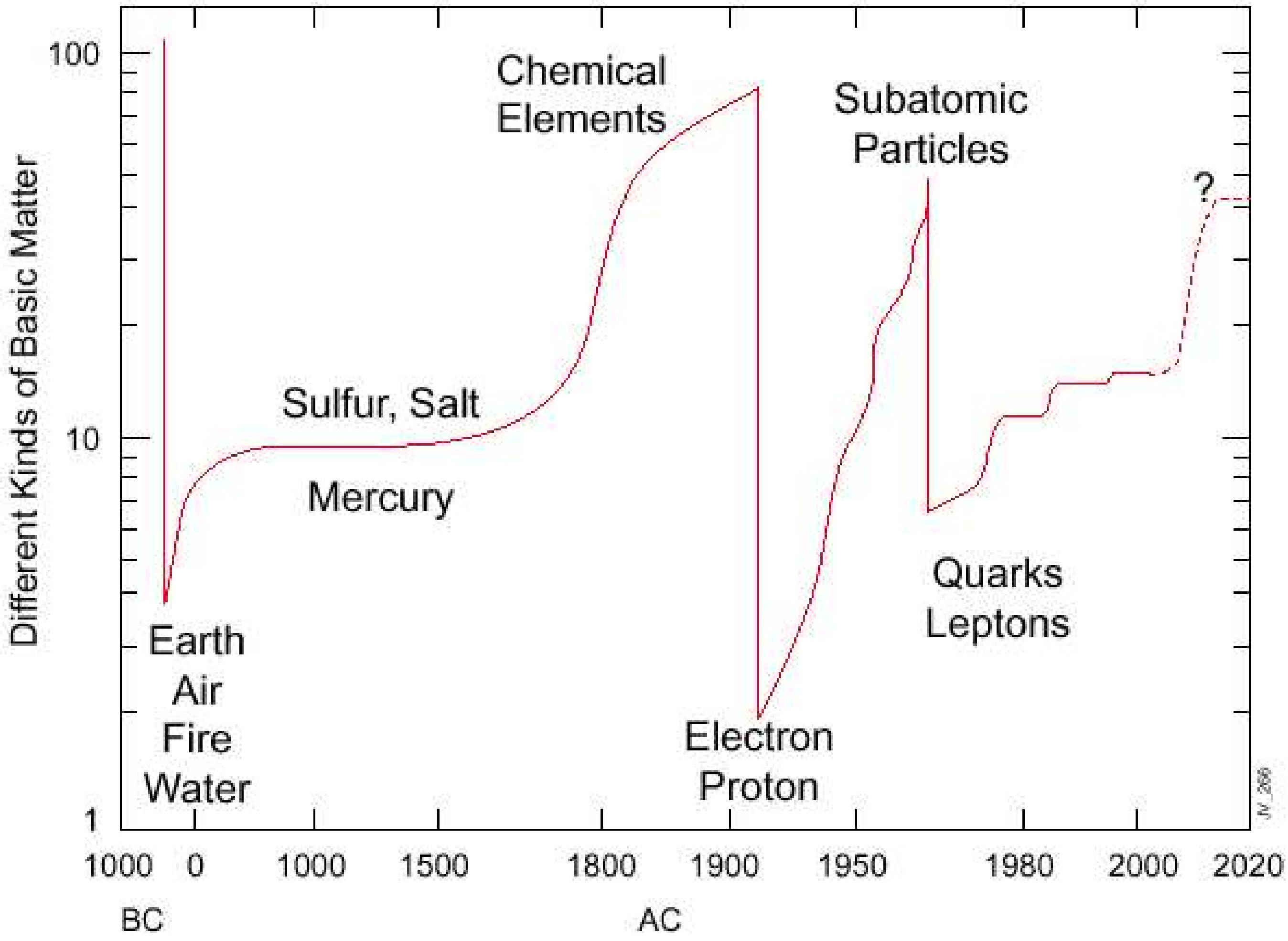
Outline

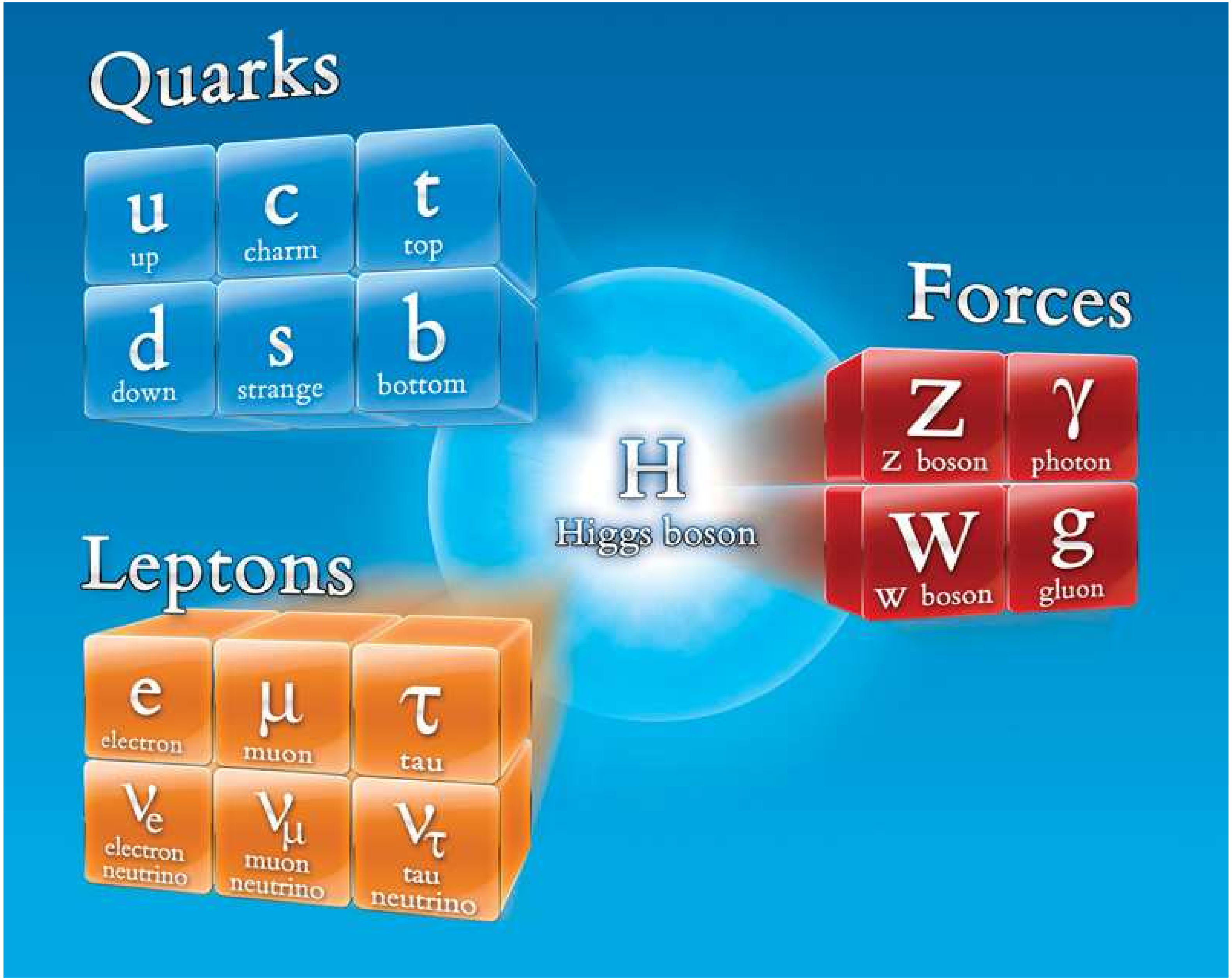
- The Standard Model (SM)
- Proton-proton collisions in terms of quarks and gluons
- Lepton pair production: $J/\psi, \Upsilon, Z, \ldots$
- Luminosity and Triggers
- Some measurements: J/ψ – prompt, non-prompt
- The first new particle discovered at LHC: $\chi_b(3P)$
- Other SM measurements: $t\bar{t}$, $W^{\pm}$, Z, ...
- Searches for Higgs, Supersymmetry, Exotics
- Summary and outlook

Constituents of Matter



From http://teachers.web.cern.ch/teachers/archiv/HST2002/webgroup/mcclean/Introduction to Particle Physics.ppt

Fundamental constituents of the Standard Model



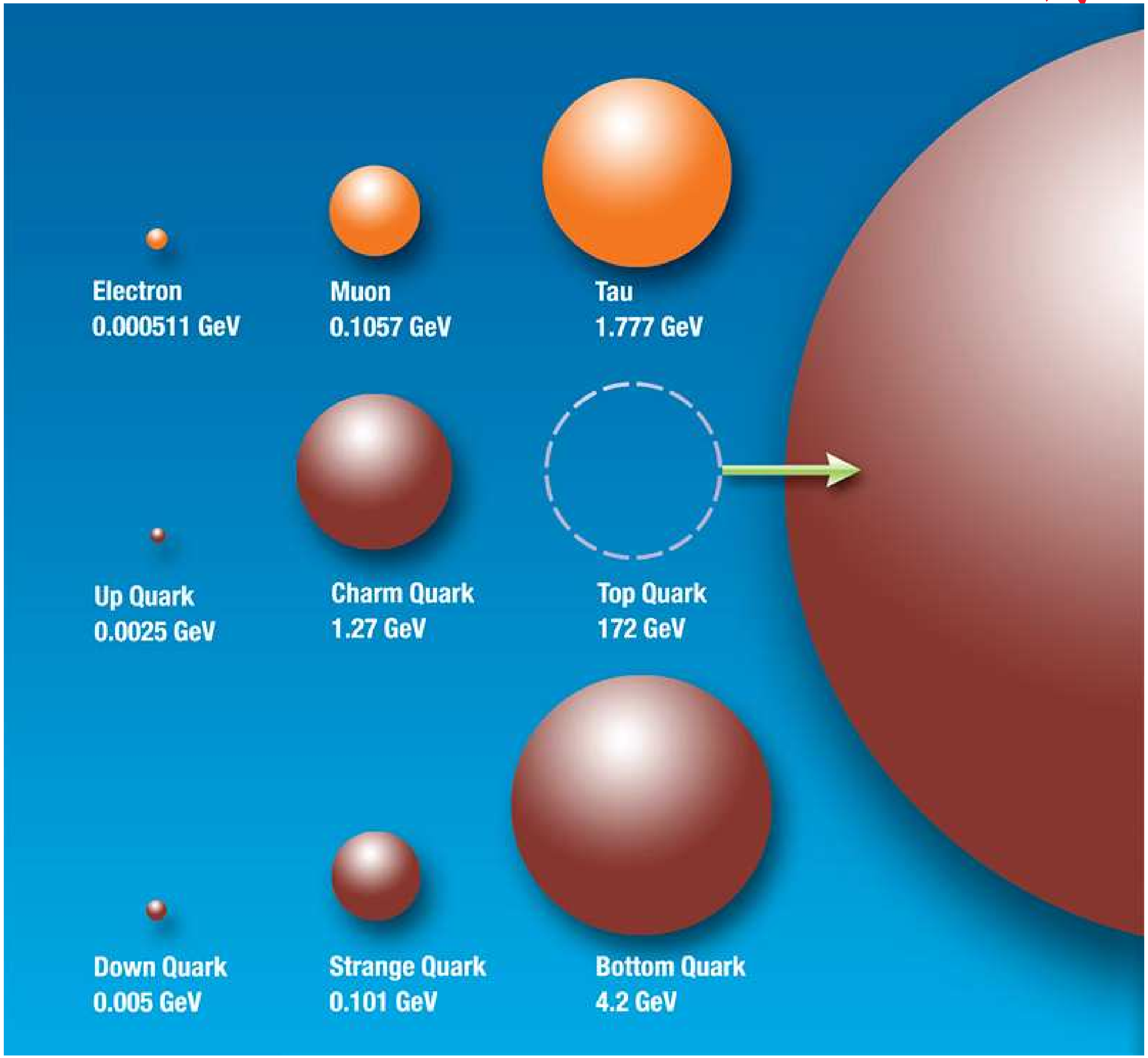
Generations and masses

Three "generations"

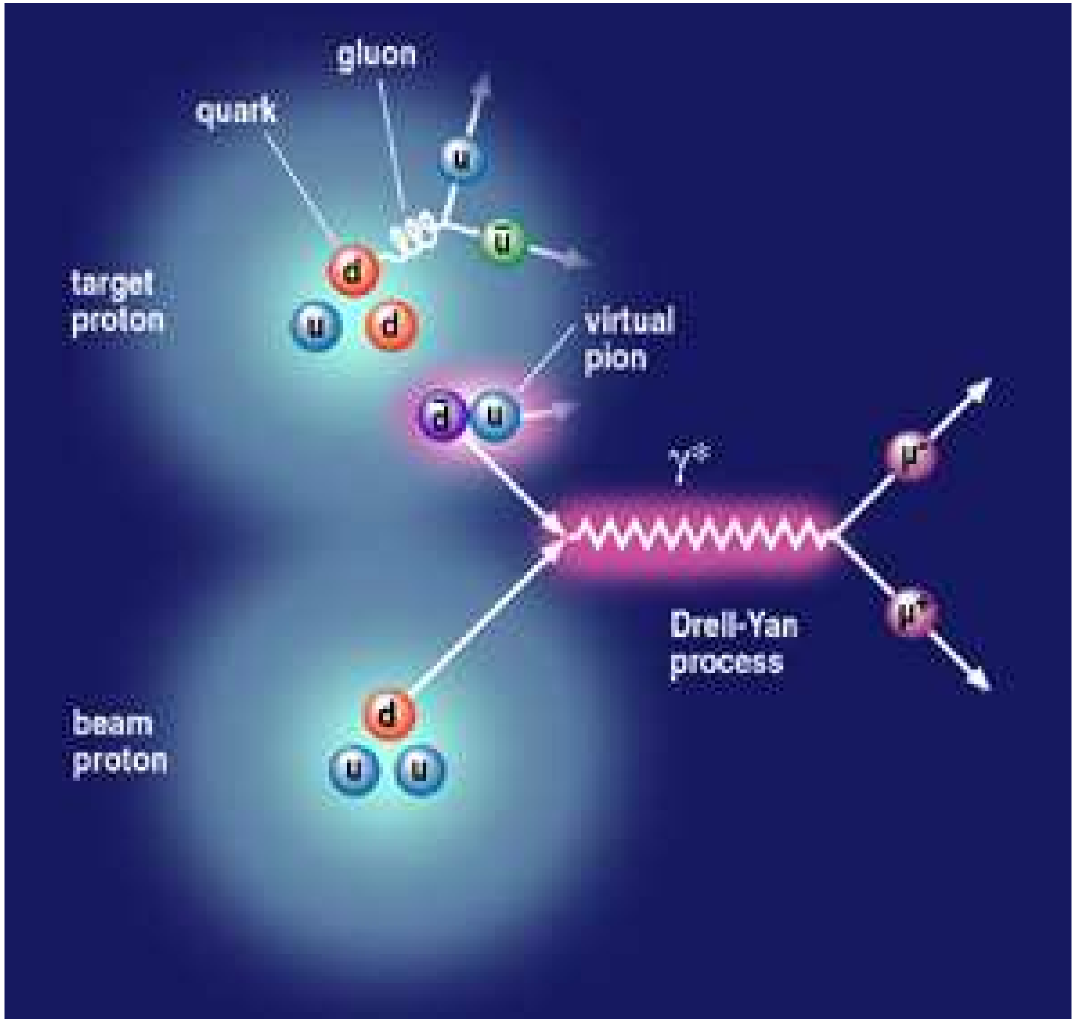
Getting heavier and heavier

Top quark especially heavy

No clue why. . .



Is LHC really a proton - proton collider?



High energy of constituents is needed to produce something new and interesting

A proton is a bunch of quarks and gluons, each carrying a fraction of energy

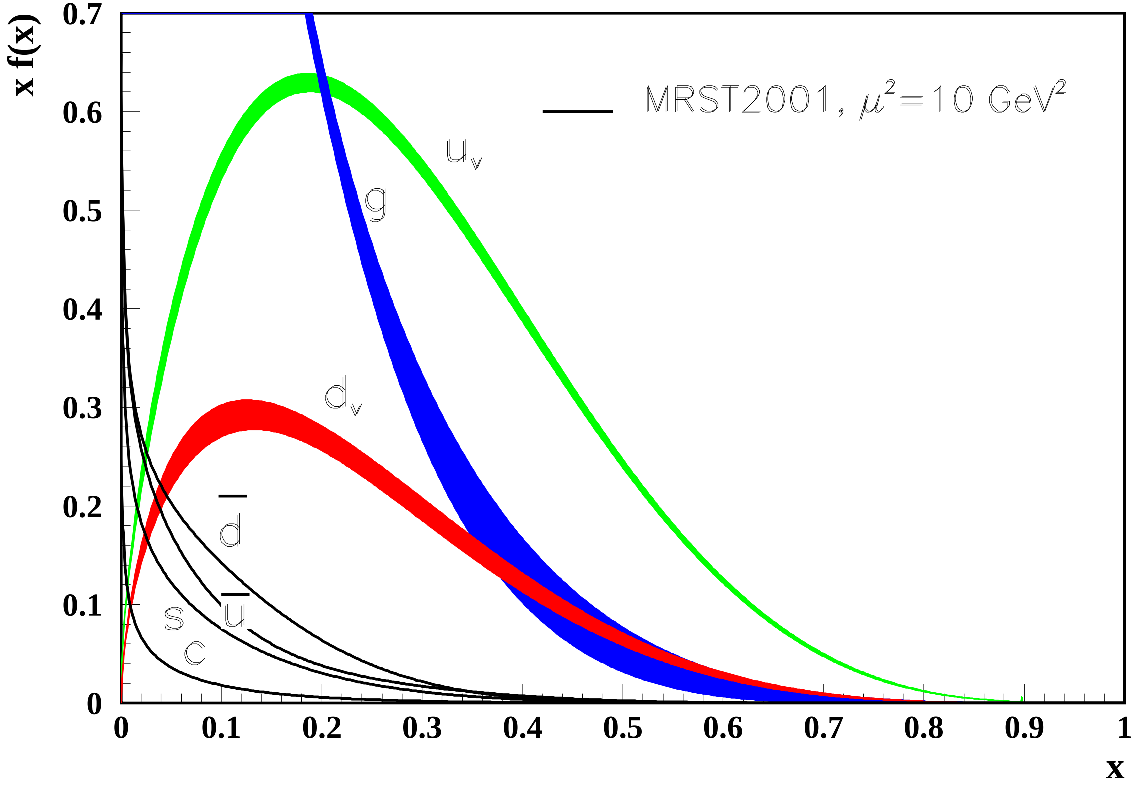
8 TeV of pp collision energy barely enough to produce a 1 TeV object. . .

Quark and gluon distributions in a proton

Only 30% of proton energy is carried by the three constituent uud quarks

Most of proton energy is carried by gluons

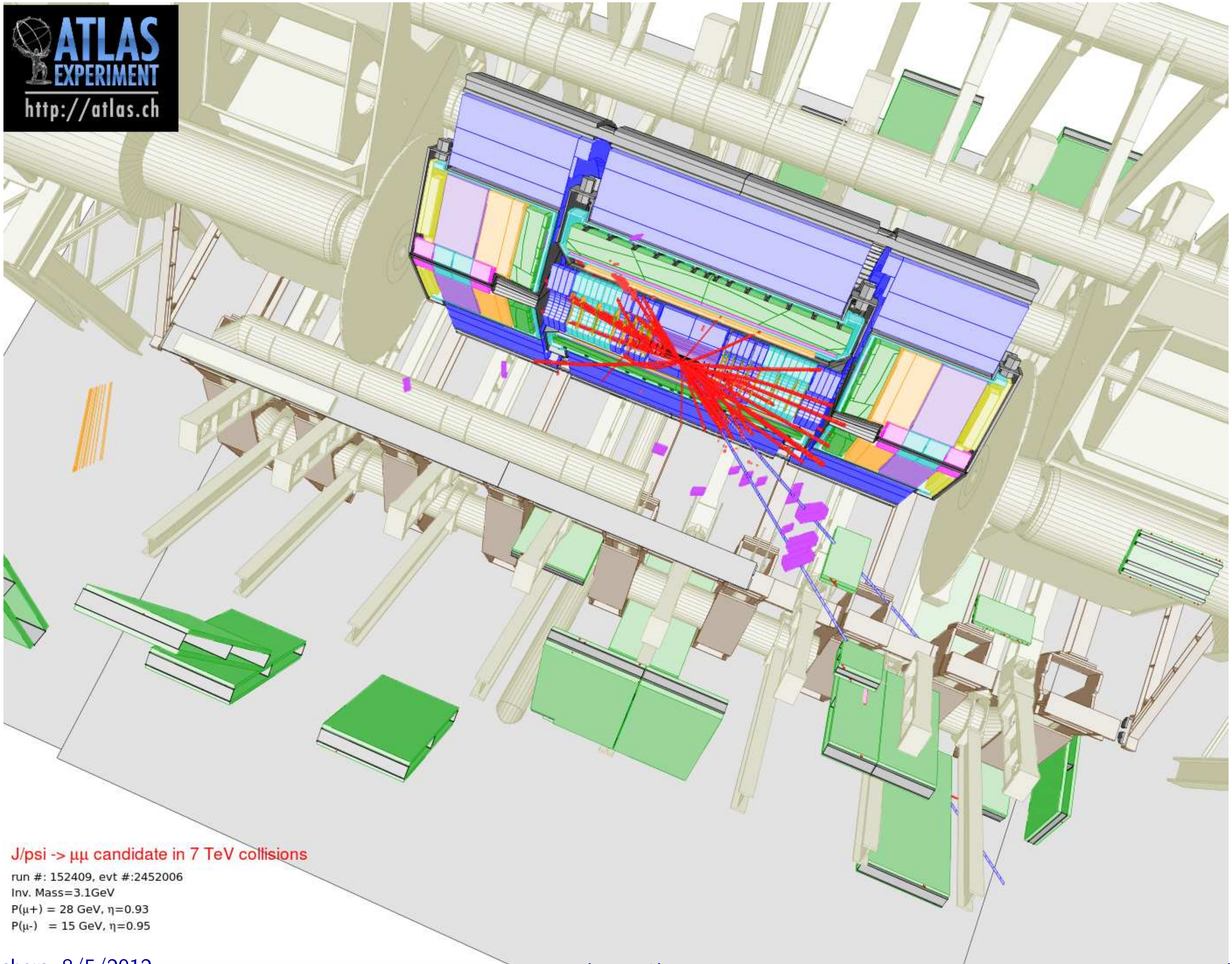
The "sea" of quark-antiquark pairs is also important



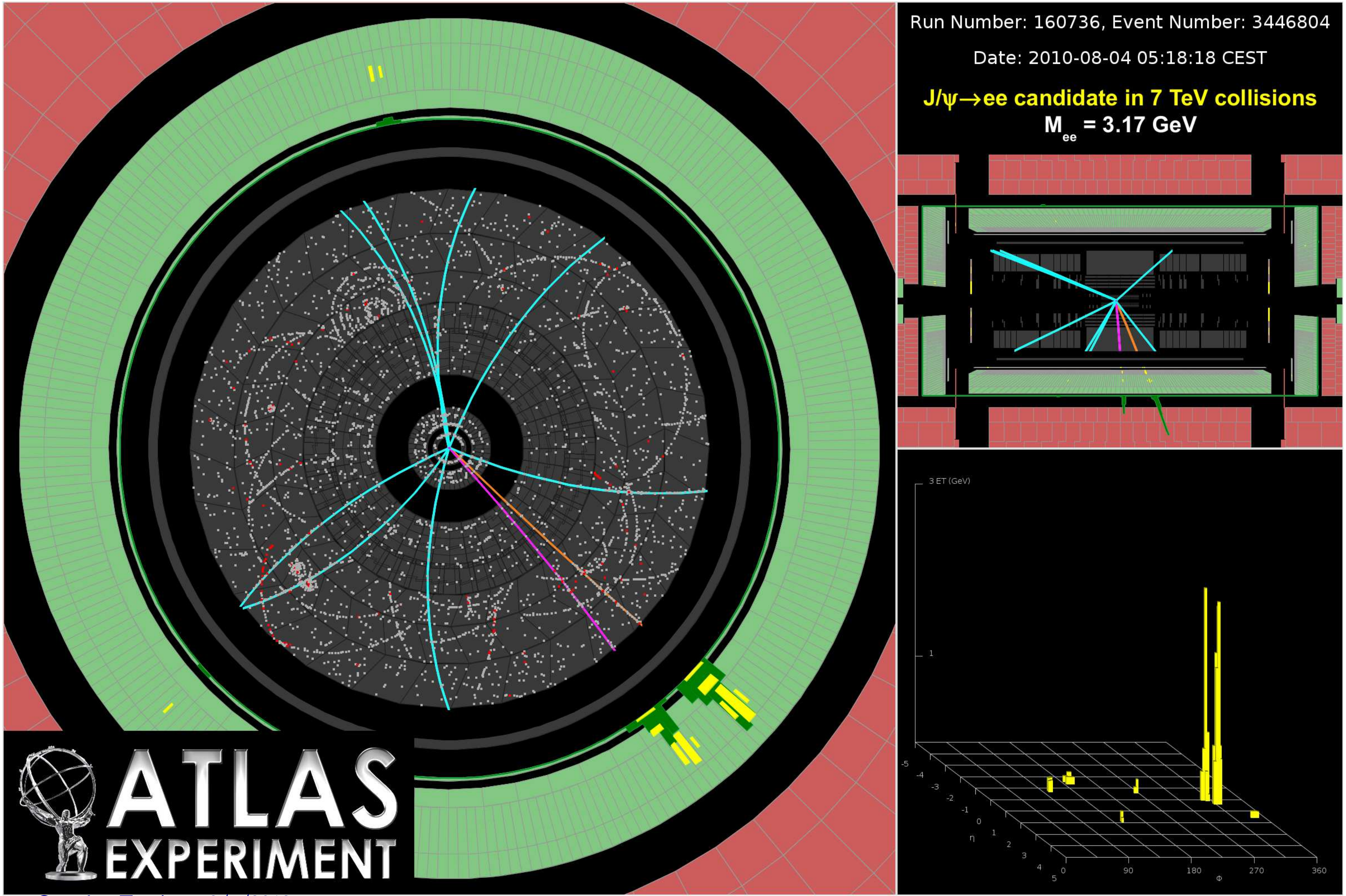
$$M^2 = x_1 \times x_2 \times (8\ TeV)^2$$

$$d\sigma \sim f_1(x_1) \times f_2(x_2) \times \hat{\sigma}(M^2)$$

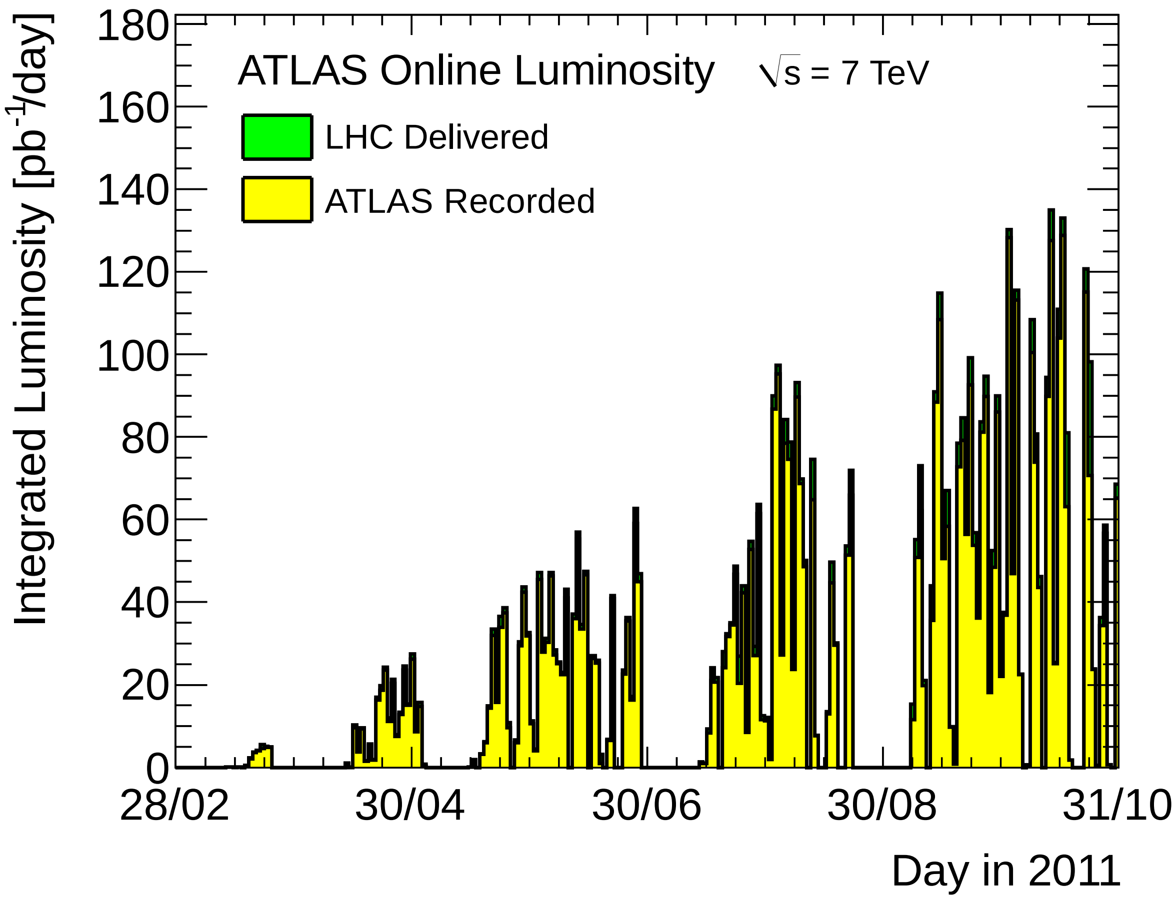
$pp \to J/\psi(\to \mu^+\mu^-) + X$



$$pp \to J/\psi(\to e^+e^-) + X$$



Luminosity



In early days of LHC:

100's of collisions / sec

Now:

many millions / sec

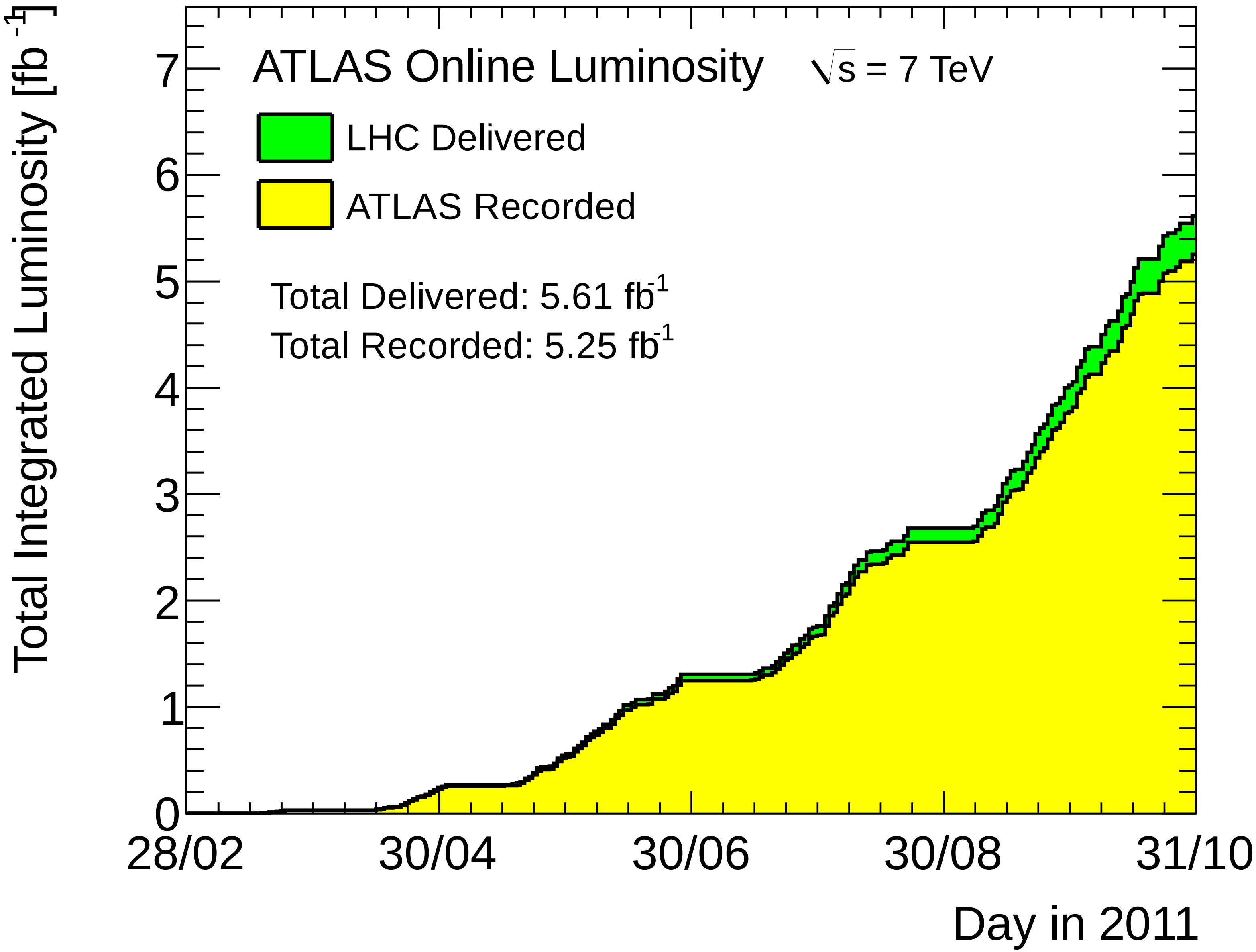
No time for viewing

events one-by one. . .

Full computing power of CERN only allows to reconstruct "just" a few hundred events per second

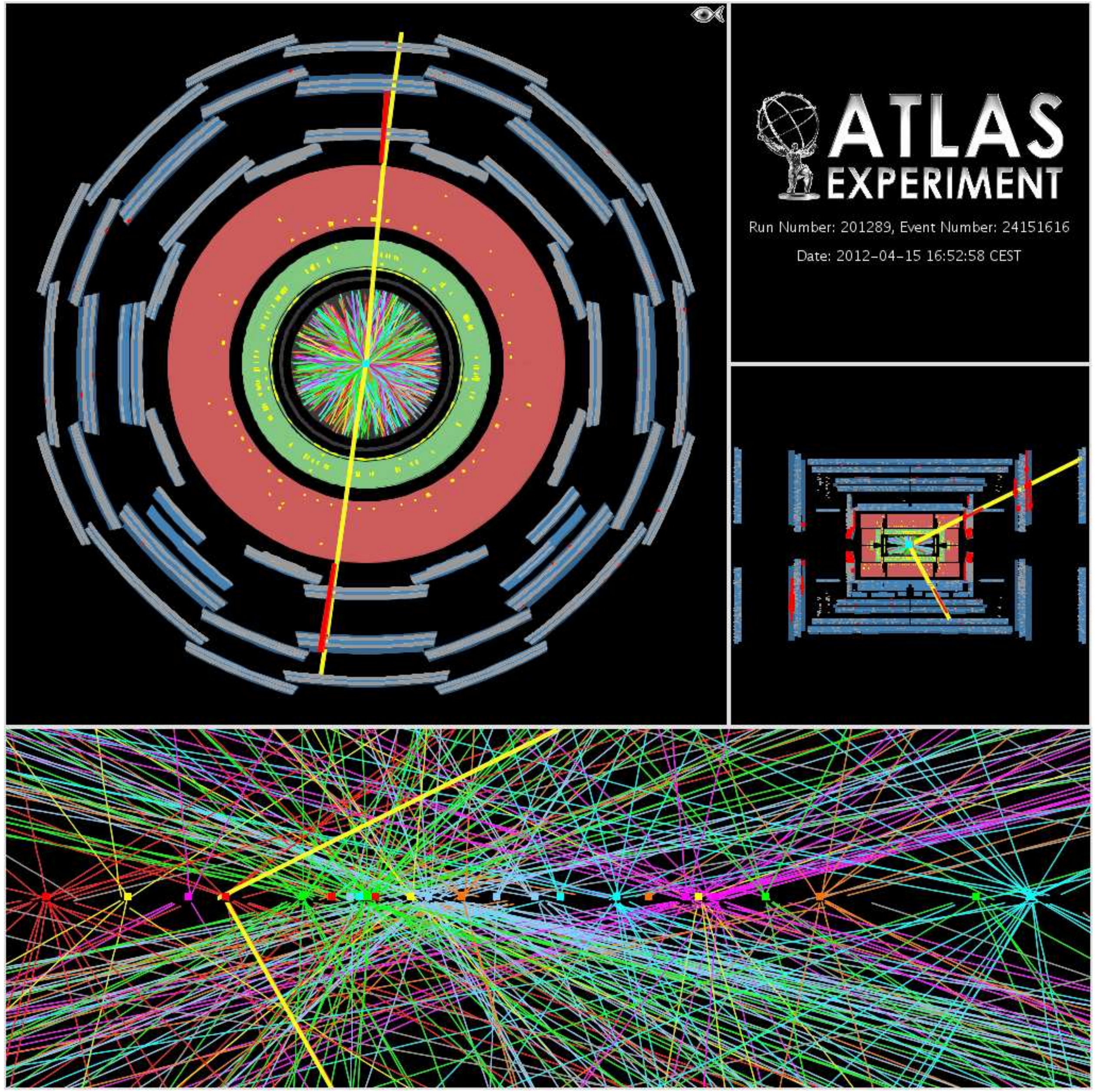
Very careful selection ("triggering") of potentially interesting events is required!

Integrated luminosity

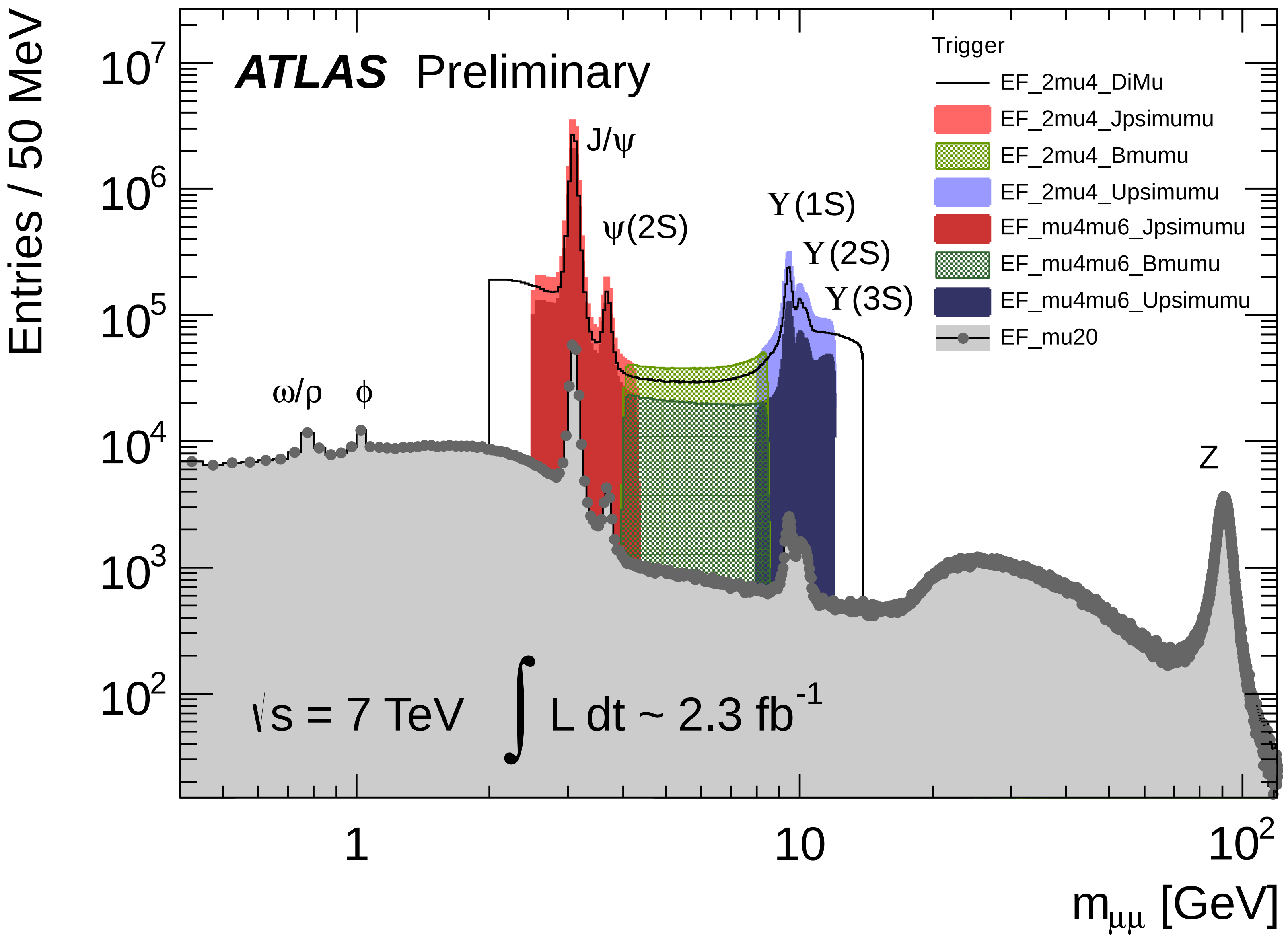


$Z \to \mu^+\mu^-$ candidate at high luminosity

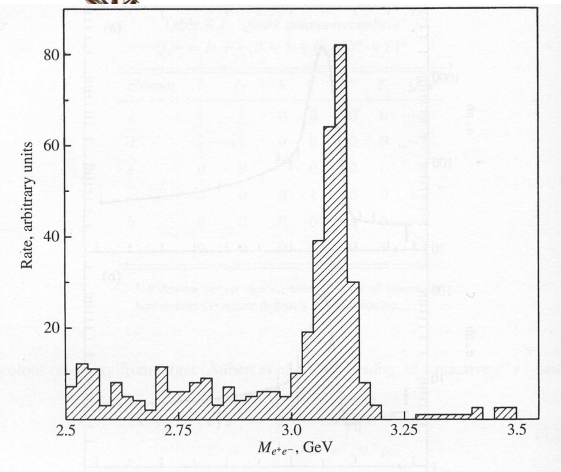
There are 20+ collisions
in one bunch crossing,
with a $Z \to \mu^+\mu^-$ candidate
produced in one of them.



History of 20th century Particle Physics in one plot



1974: discovery of J/ψ



$\Leftarrow$ **Discovery 1:** Ting's group

$$pN \to e^+e^-X$$

at $P_{\text{lab}} = 30$ GeV/c

[Aubert et al., PRL, 6/11/1974]

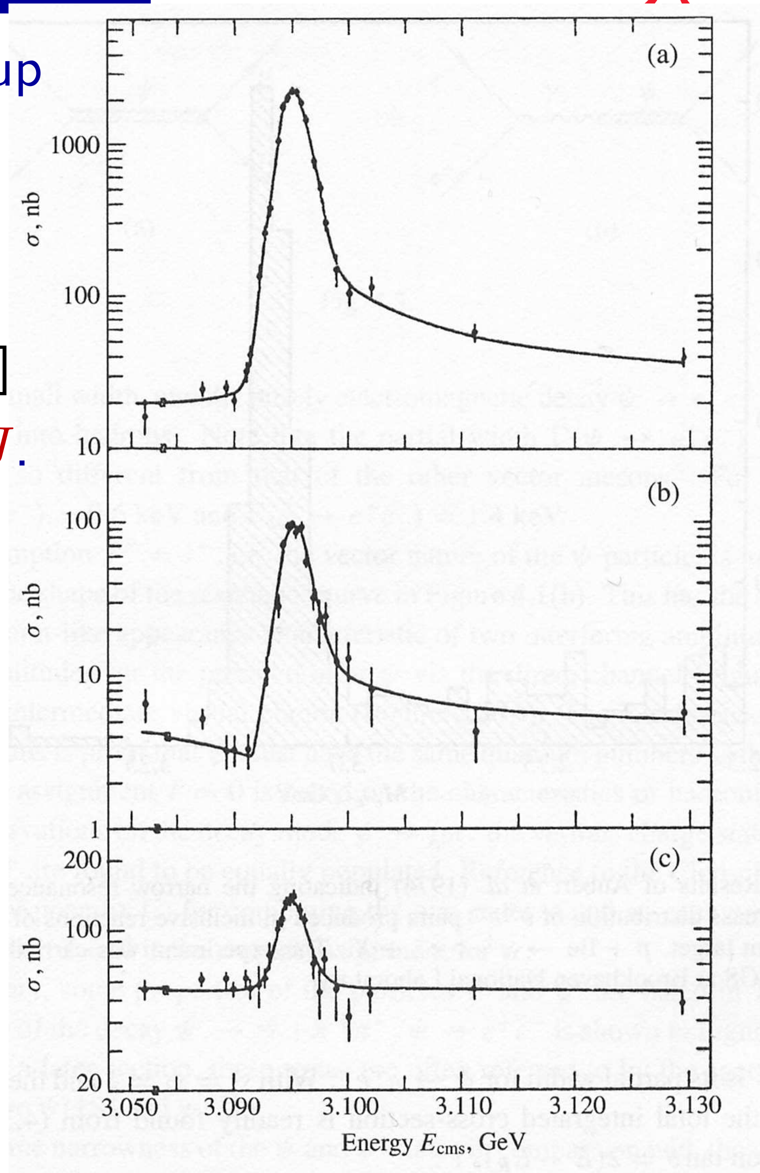
Found a peak in e^+e^- inv.mass at 3.1 GeV, called it J.

Discovery 2: Richter's group $\Rightarrow$

$$\begin{array}{lcl} (a)\ e^+e^- & \to & \text{hadrons} \\ (b)\ e^+e^- & \to & \mu^+\mu^- \\ (c)\ e^+e^- & \to & e^+e^- \end{array}$$

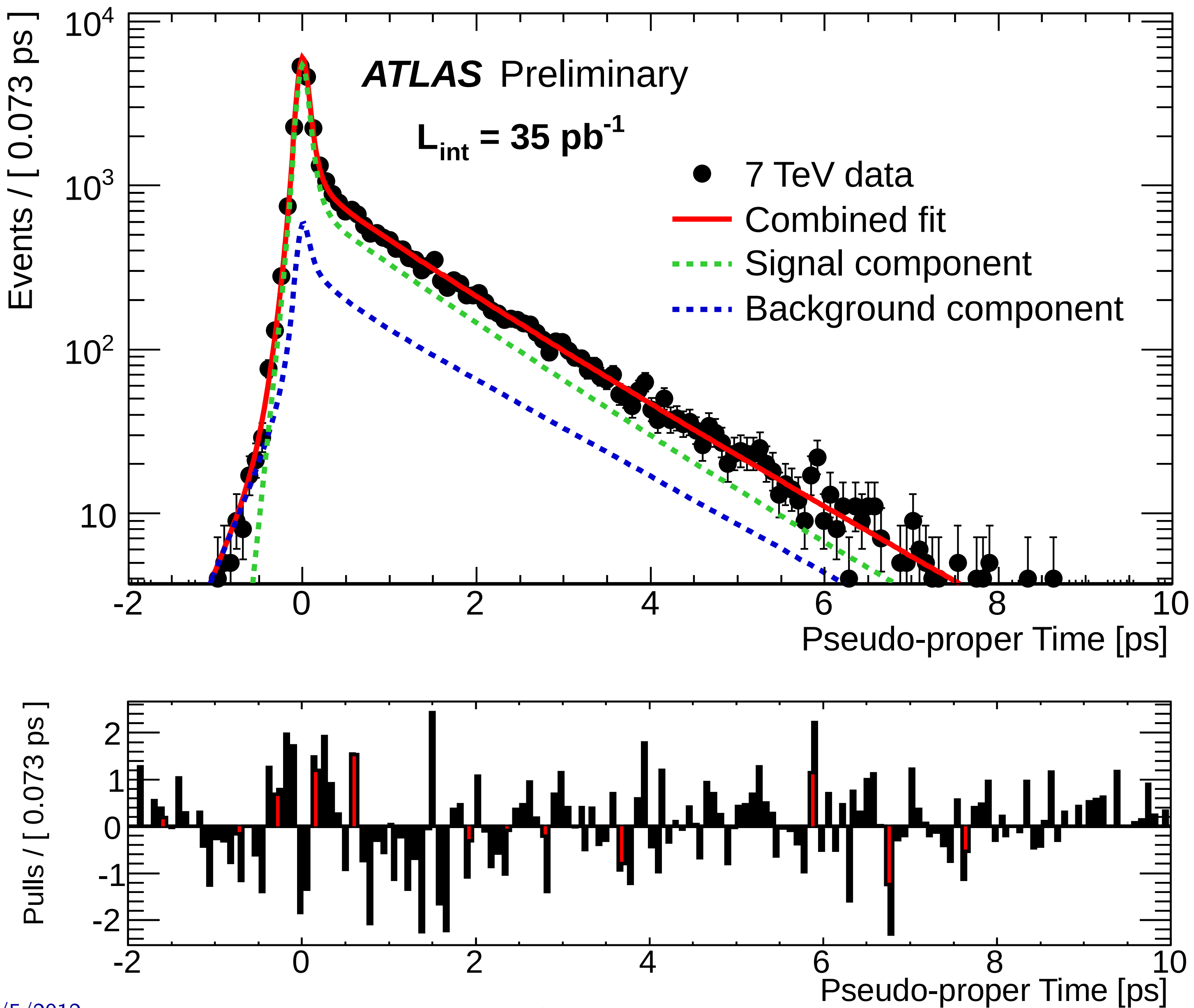
[Augustin et al., PRL, 7/11/1974]

Found a peak in all these three cross-sections, at the c.m.s. energy 3.1 GeV; called it ψ.

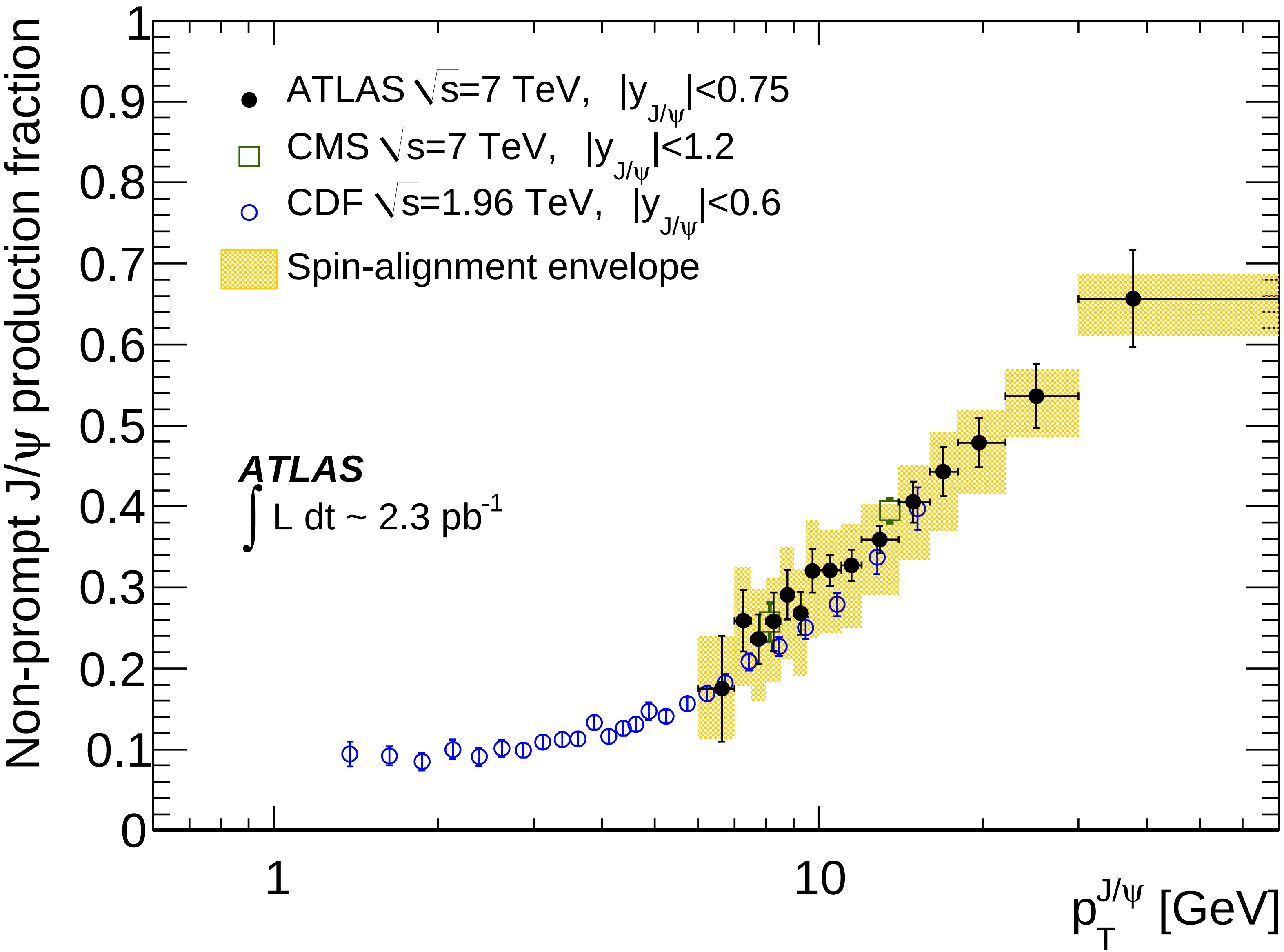


Now we know: J/ψ is a bound state of charm-anticharm, $c\bar{c}$.

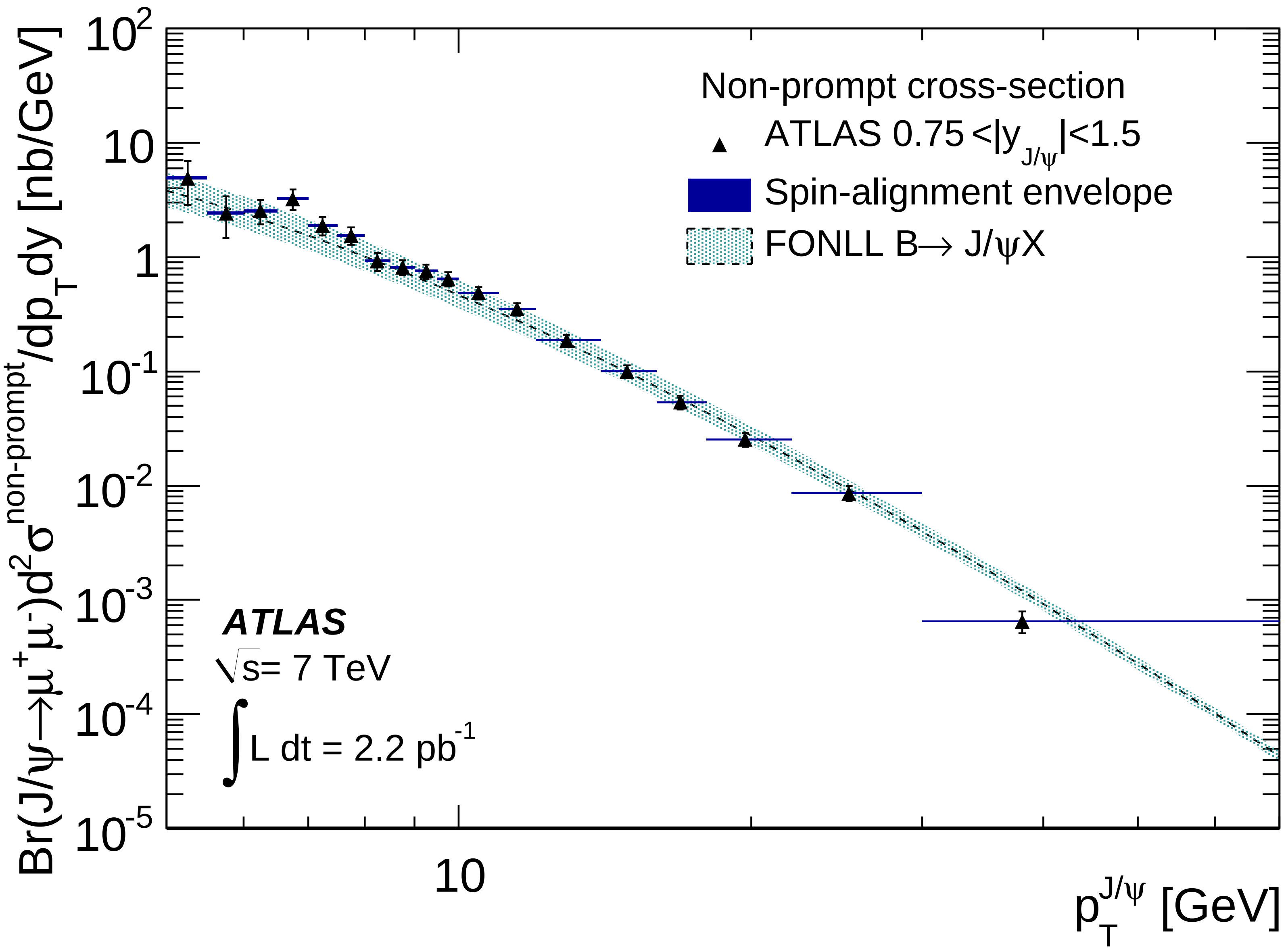
Proper Decay Time of the J/ψ vertex



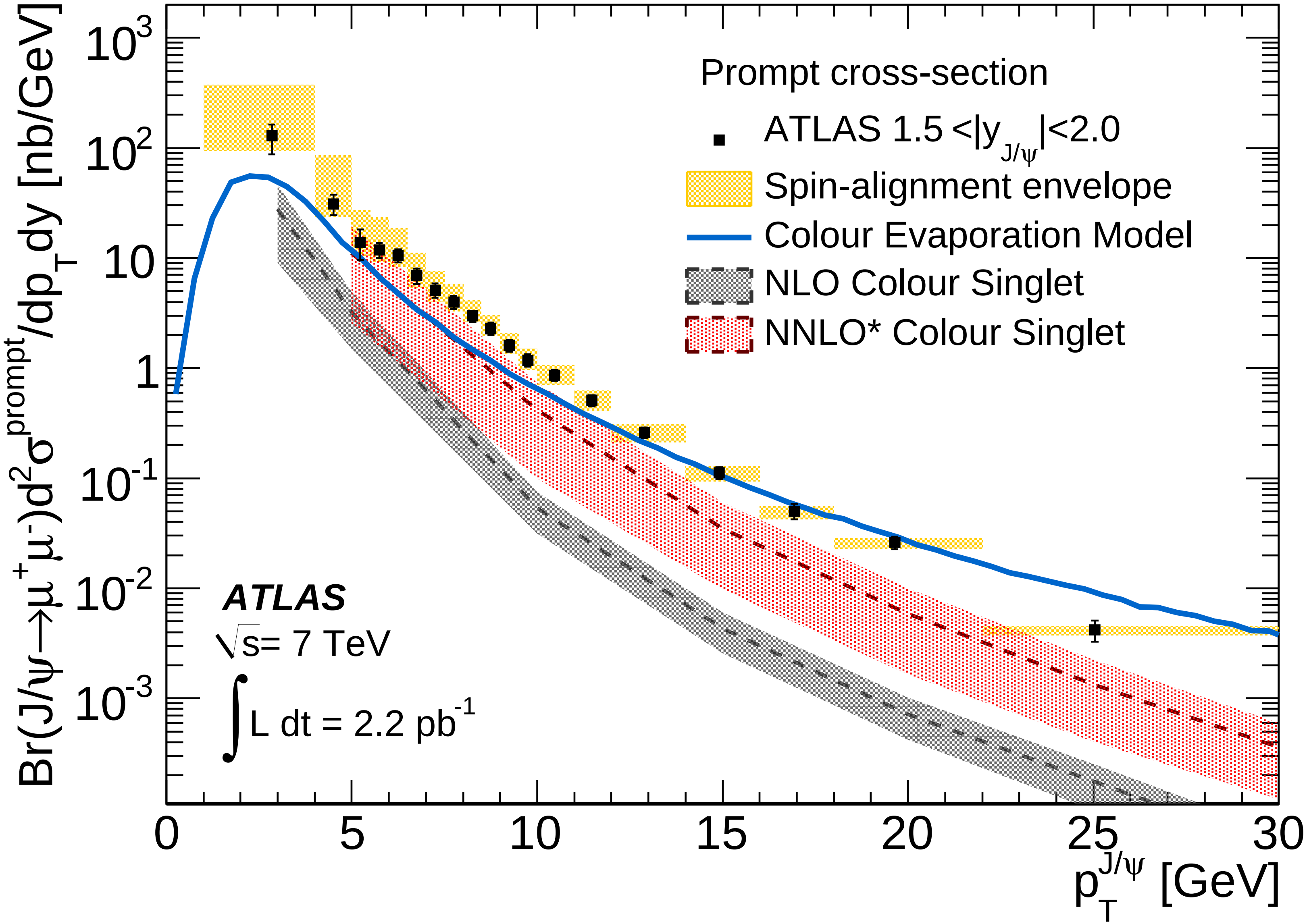
Fraction of non-promptly produced J/ψ



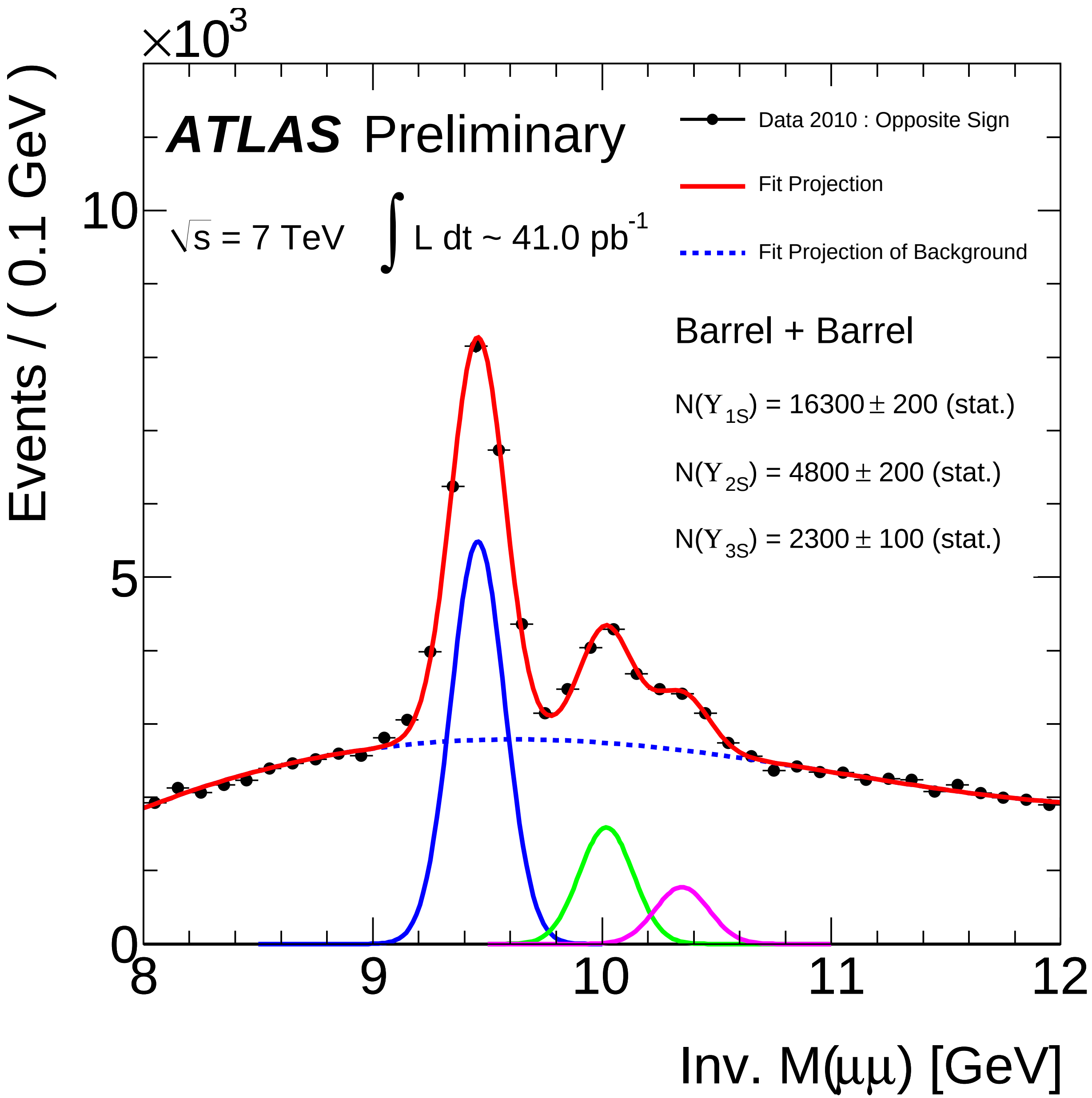
p_T dependence of non-prompt J/ψ



p_T dependence of prompt J/ψ



$b\bar{b}$ bound states: Υ system



Spectroscopy of $b\bar{b}$ mesons

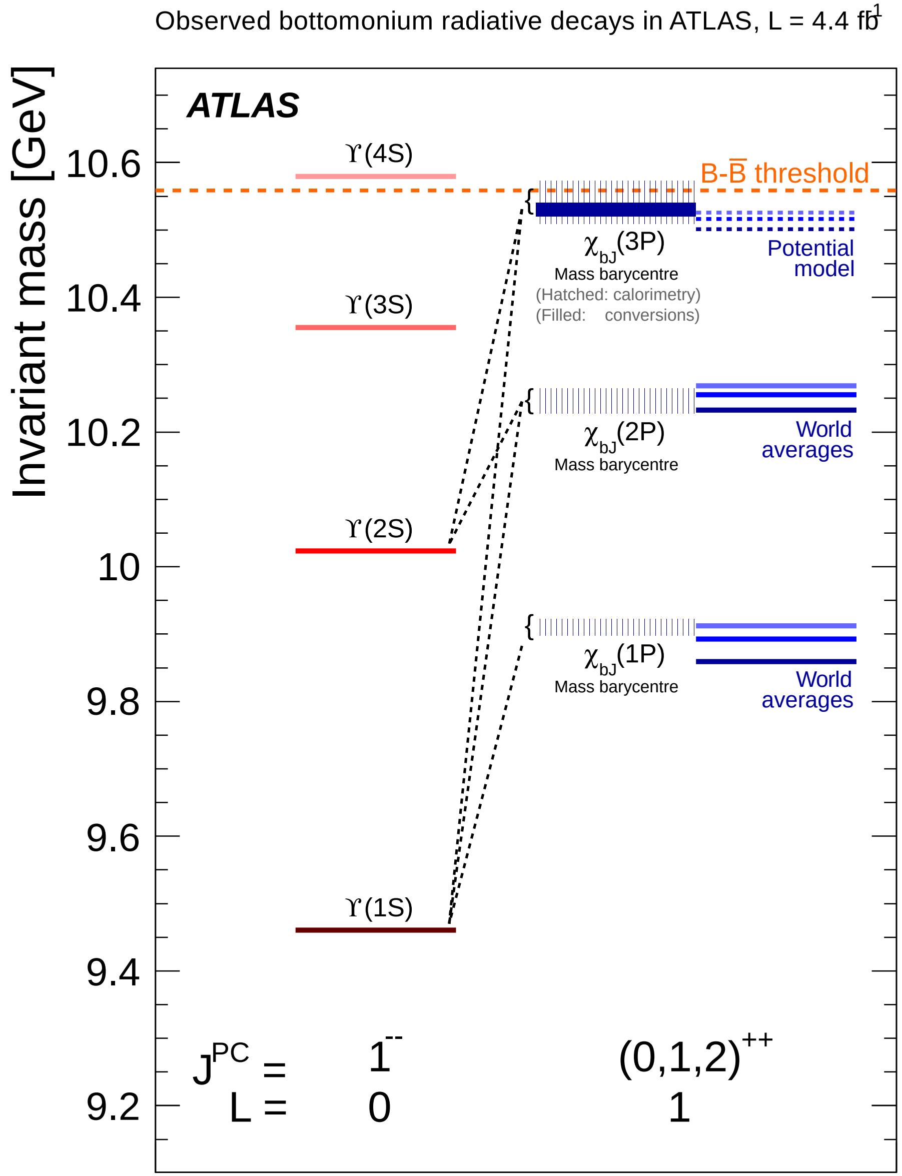
Spectroscopy similar to hydrogen atom

$\Upsilon(1S)$: ground state

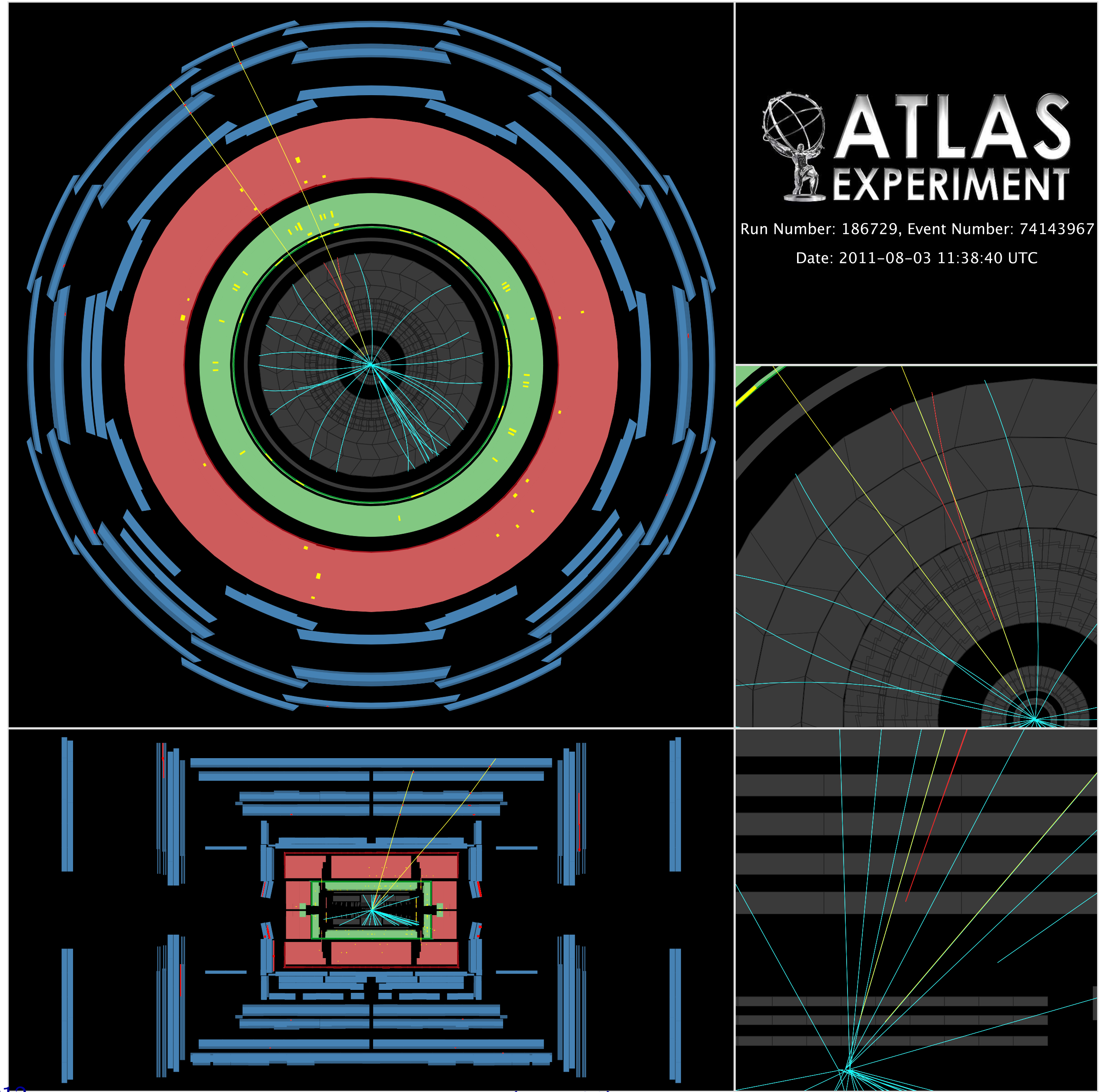
$\Upsilon(2S, 3S)$: radial excitations

Three families of χ_b:
orbital excitations, $L = 1$

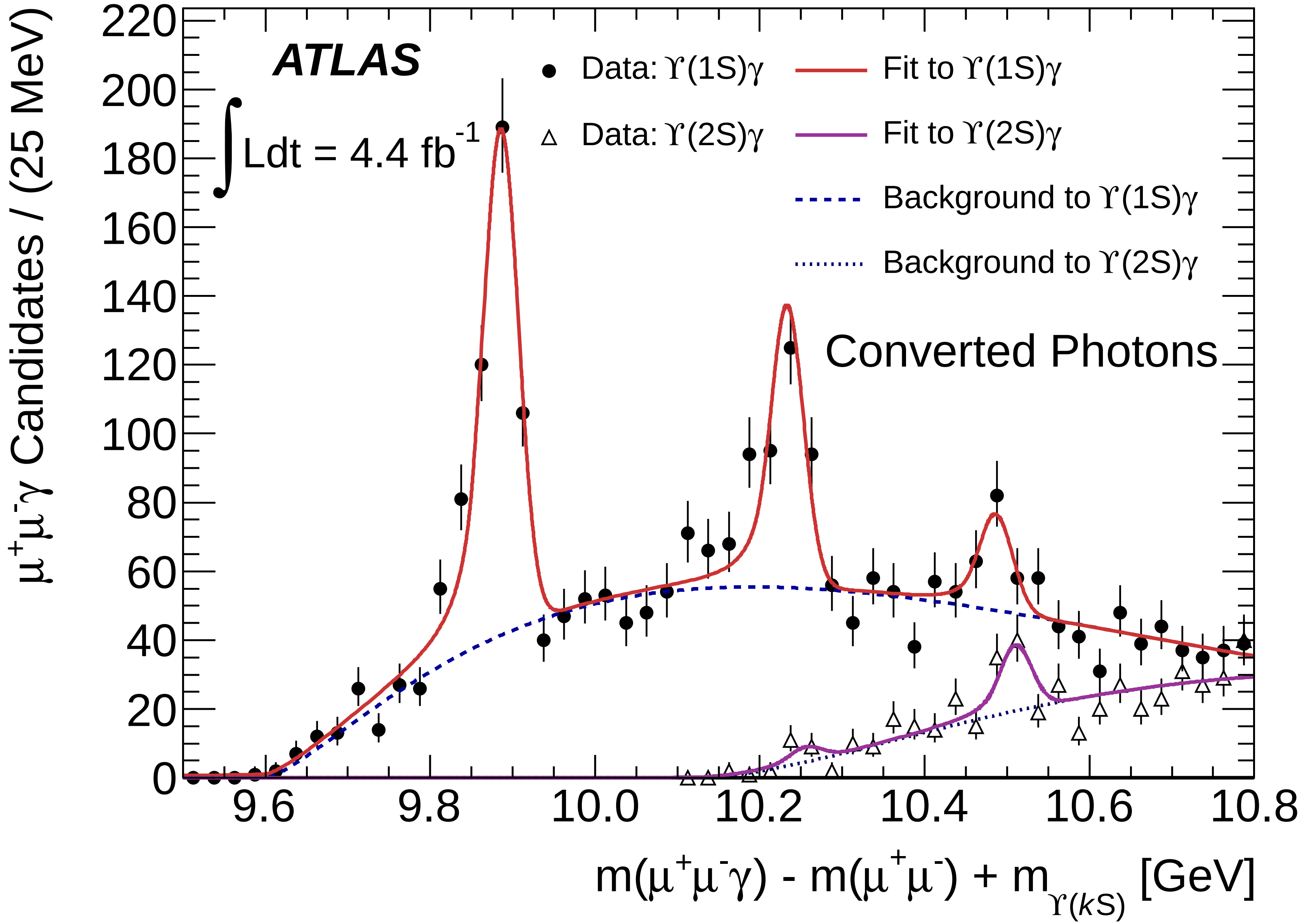
Until 22 December 2011, only
$\chi_b(1P)$ and $\chi_b(2P)$ were observed



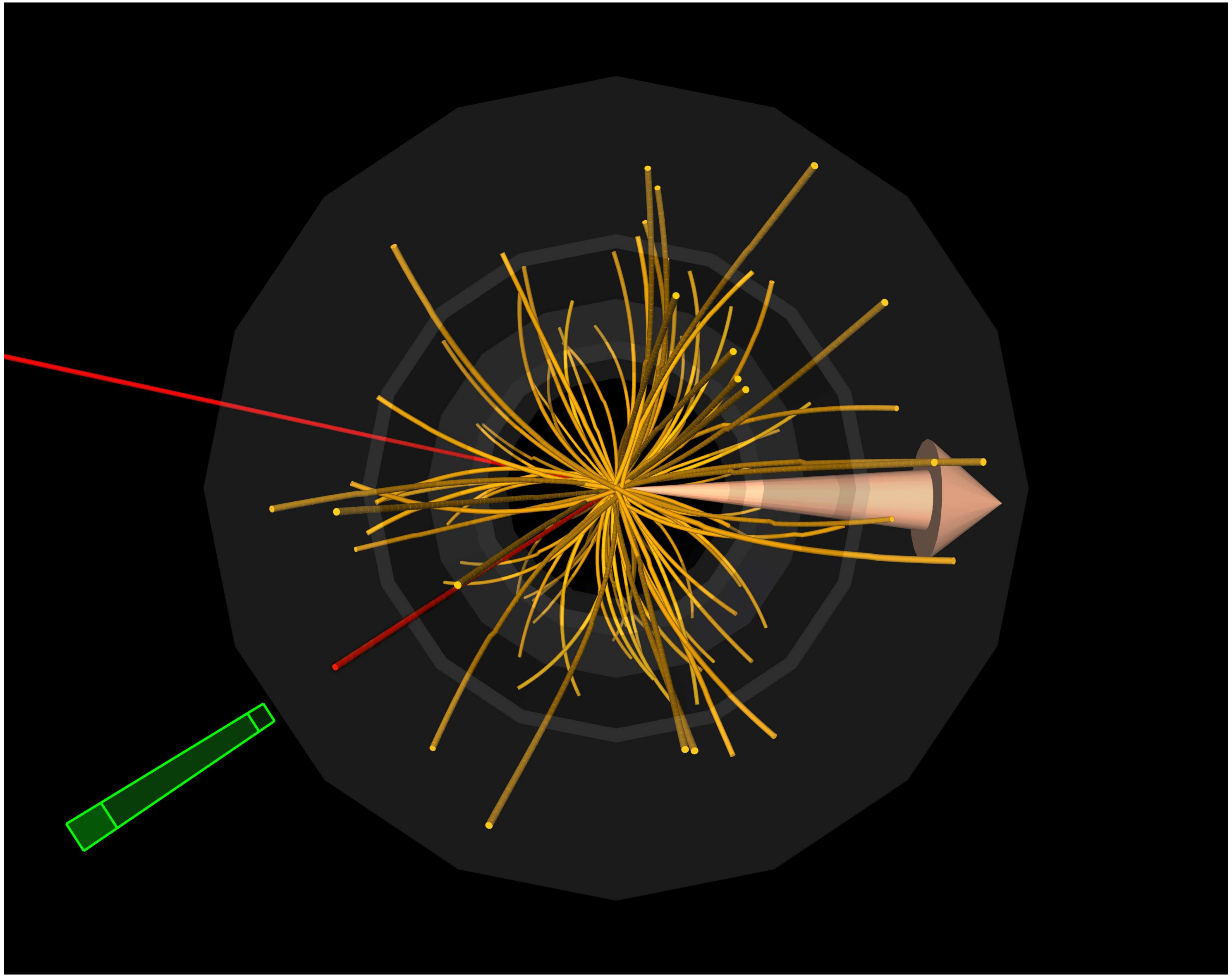
Event with $\chi_b(3P)$ candidate



All three χ_b peaks as seen by ATLAS



W^+W^- pair production



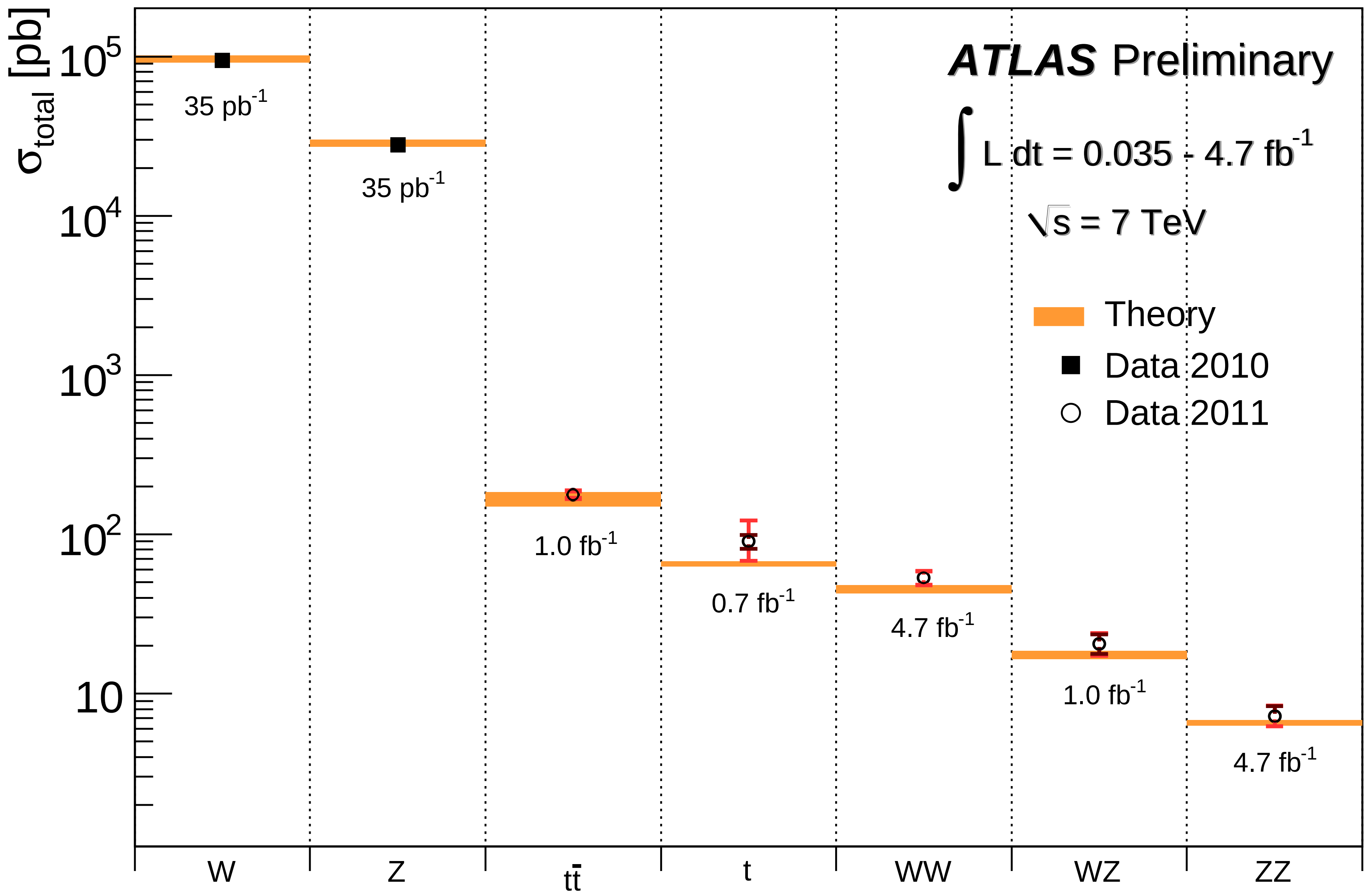
$W^+ \to \mu^+\nu_\mu$

$W^- \to e^-\bar{\nu}_e$

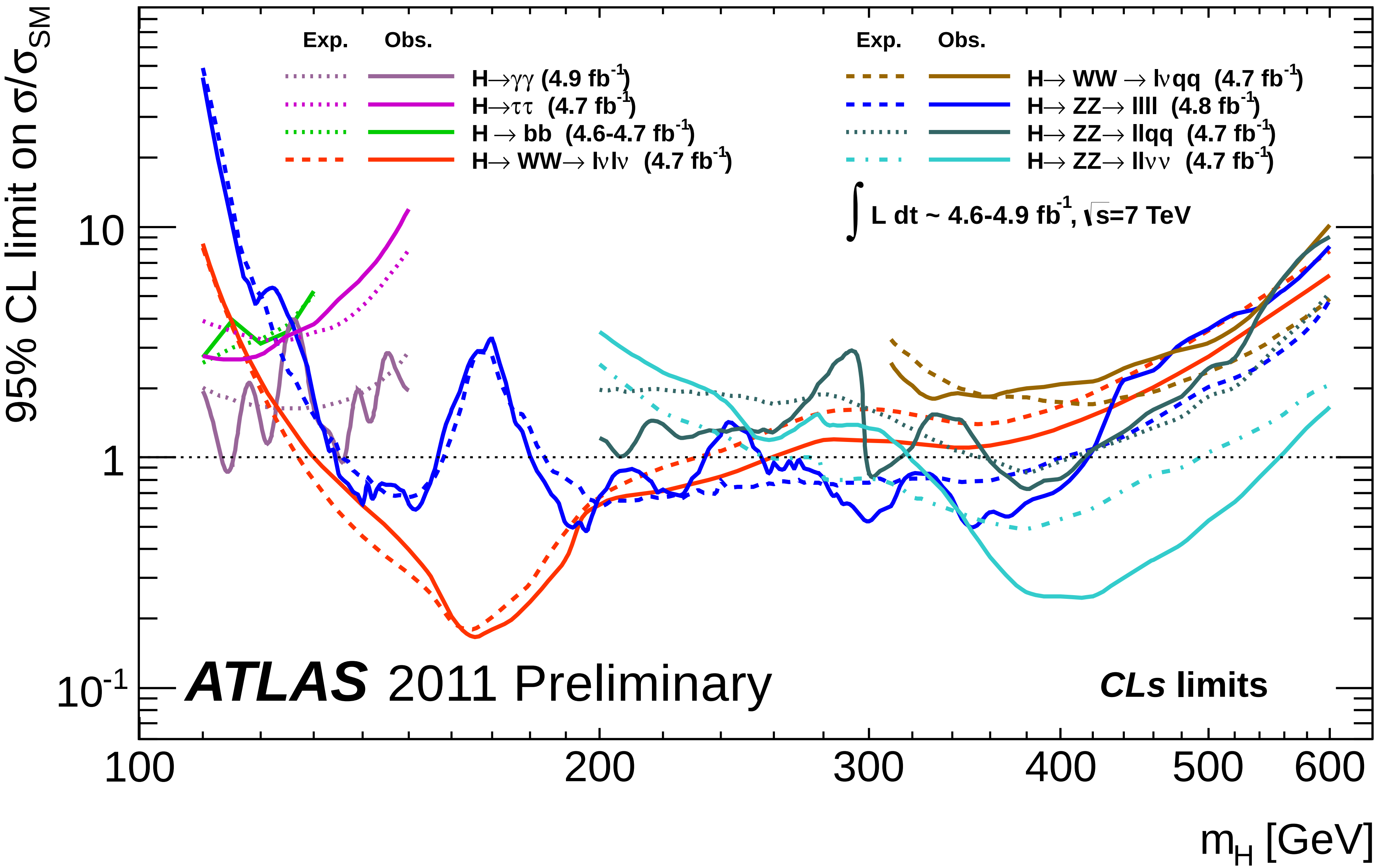
Neutrinos escape detection

$\Rightarrow$ missing P_T

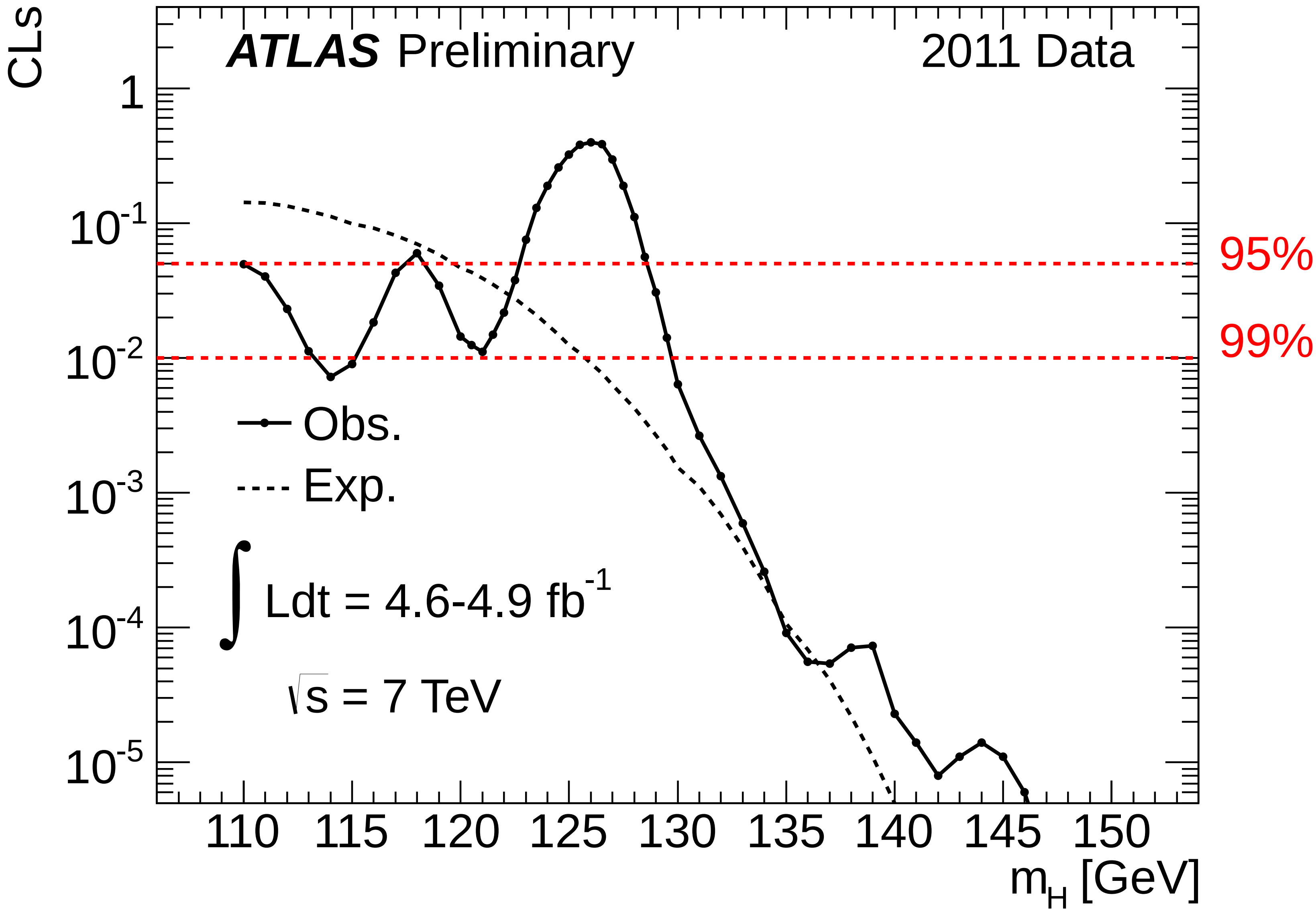
Standard Model cross sections vs theory



SM Higgs searches: separate decay modes



SM Higgs searches: summary



Questions to the Standard Model

The (gauge) symmetry group of the Standard Model is $SU(2) \times U(1) \times SU(3)$

Hence three types of interactions, and the variety of gauge bosons, the interaction carriers: $\gamma, W^{\pm}, Z^0, g$

- Why are these three types so different – and the fourth, gravity, even more so?
- Why three generations?
- Why fractional electric charges of quarks?
- Why are the fermion masses so different?
- What determines the mixing of various generations?

These and many more questions cannot be answered within SM.

We need a bigger theory. . .

Beyond the Standard Model

- Is there a bigger symmetry group, which will become visible at higher energies?
  $\Rightarrow$ Grand Unification

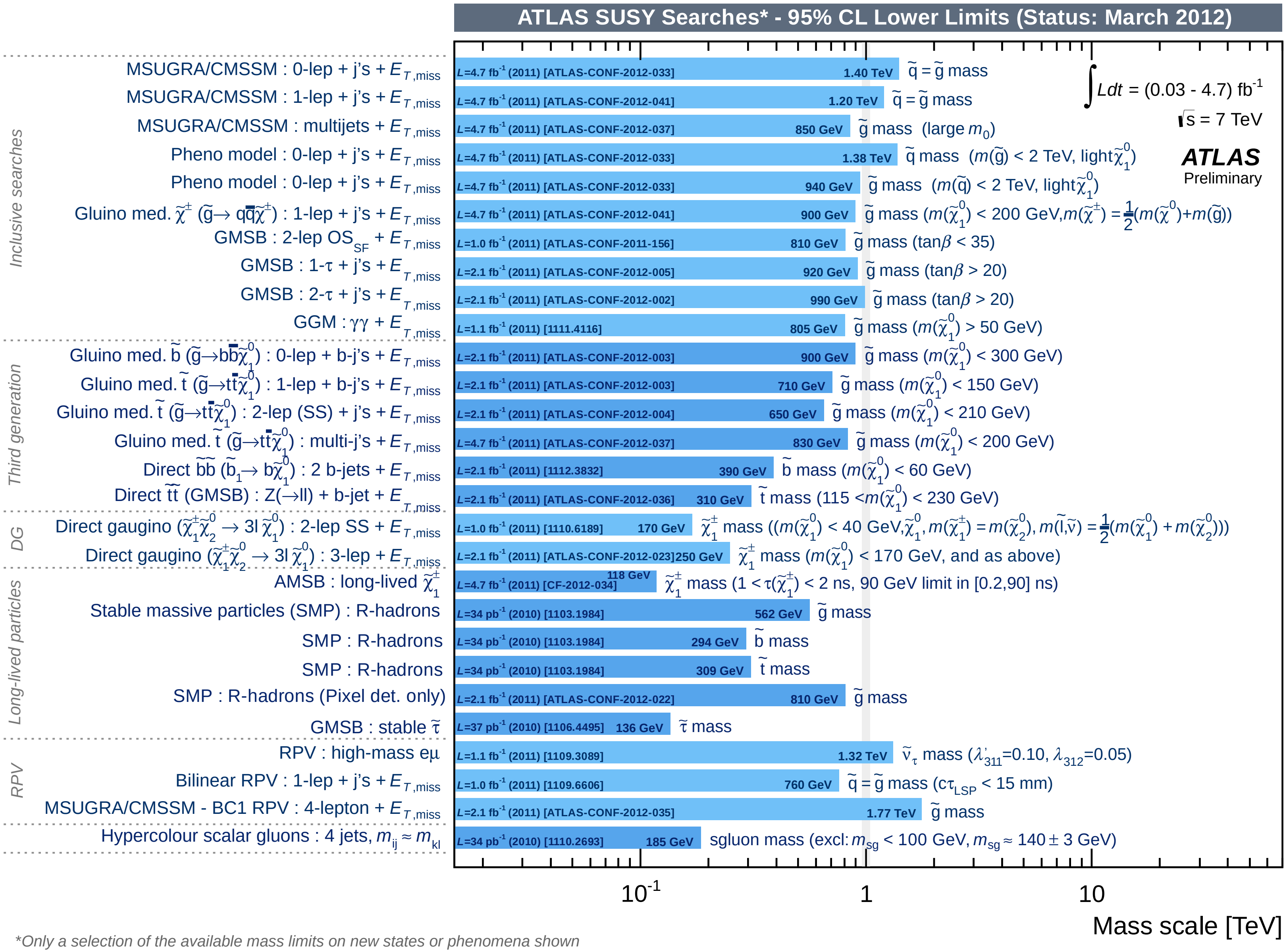
- Or maybe the Poincaré-Lorentz invariance group can be extended to include anticummutation relations?
  $\Rightarrow$ Supersymmetry

- Or maybe our space-time has more than 3+1 dimensions, some of which are "compactified" ?
  $\Rightarrow$ Large extra dimensions

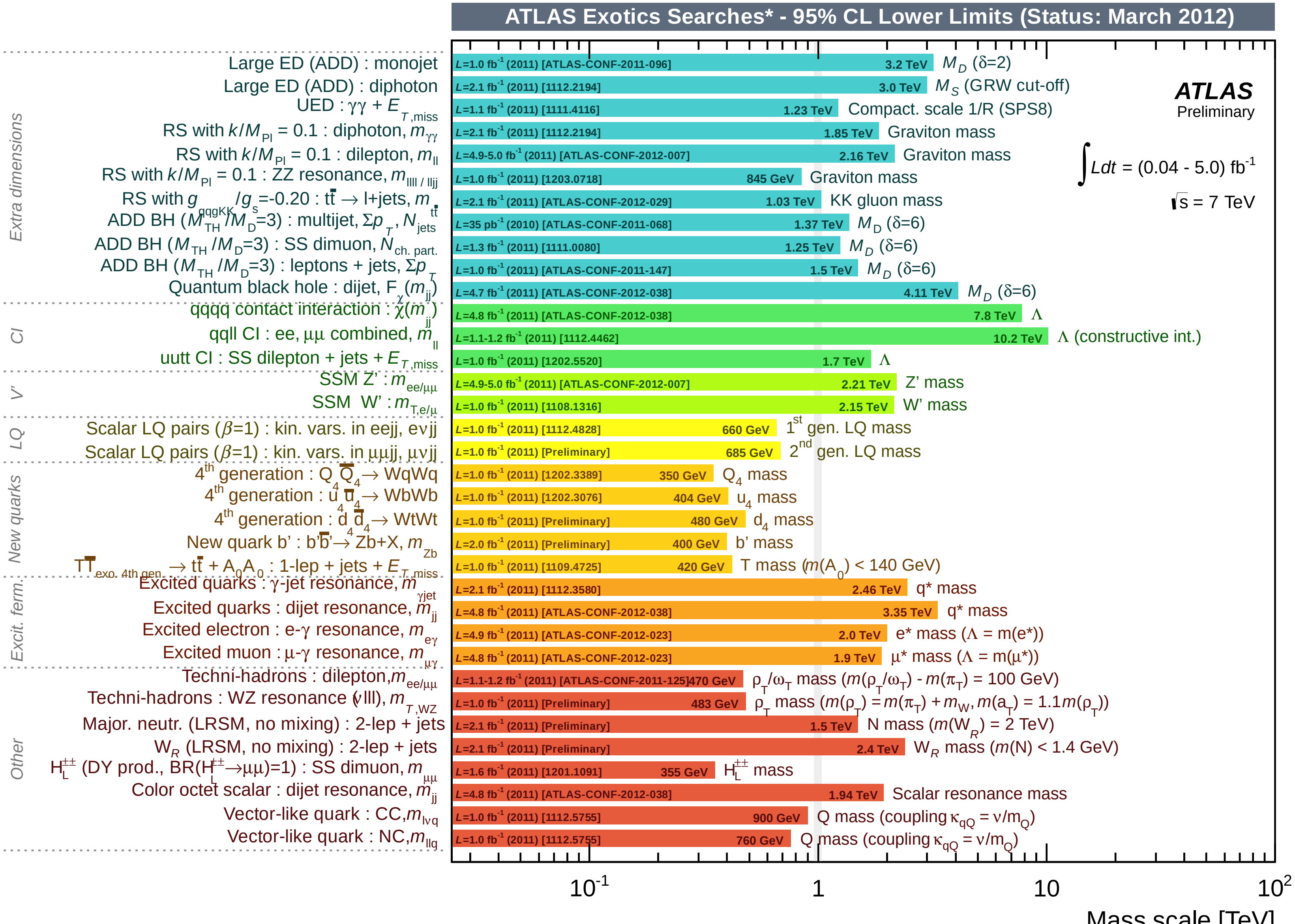
These, and many other, theories exist — and predict some observable effects.

Physicists are searching for them, in a hope to answer some of the questions...

Supersymmetry searches: lower limits



Exotics searches: lower limits



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

Summary and outlook

- Huge amount of work has been done by LHC experiments
- The first new state discovered: $\chi_b(3P)$
- No Higgs yet, but maybe later this year?
- The Standard Model is standing strong – no SUSY, no sign of any exotics either...
- A lot of data still to be analysed, and much more data is still to come
- Hoping for many fascinating discoveries in the near future!