Future of heavy flavor physics at ATLAS and CMS

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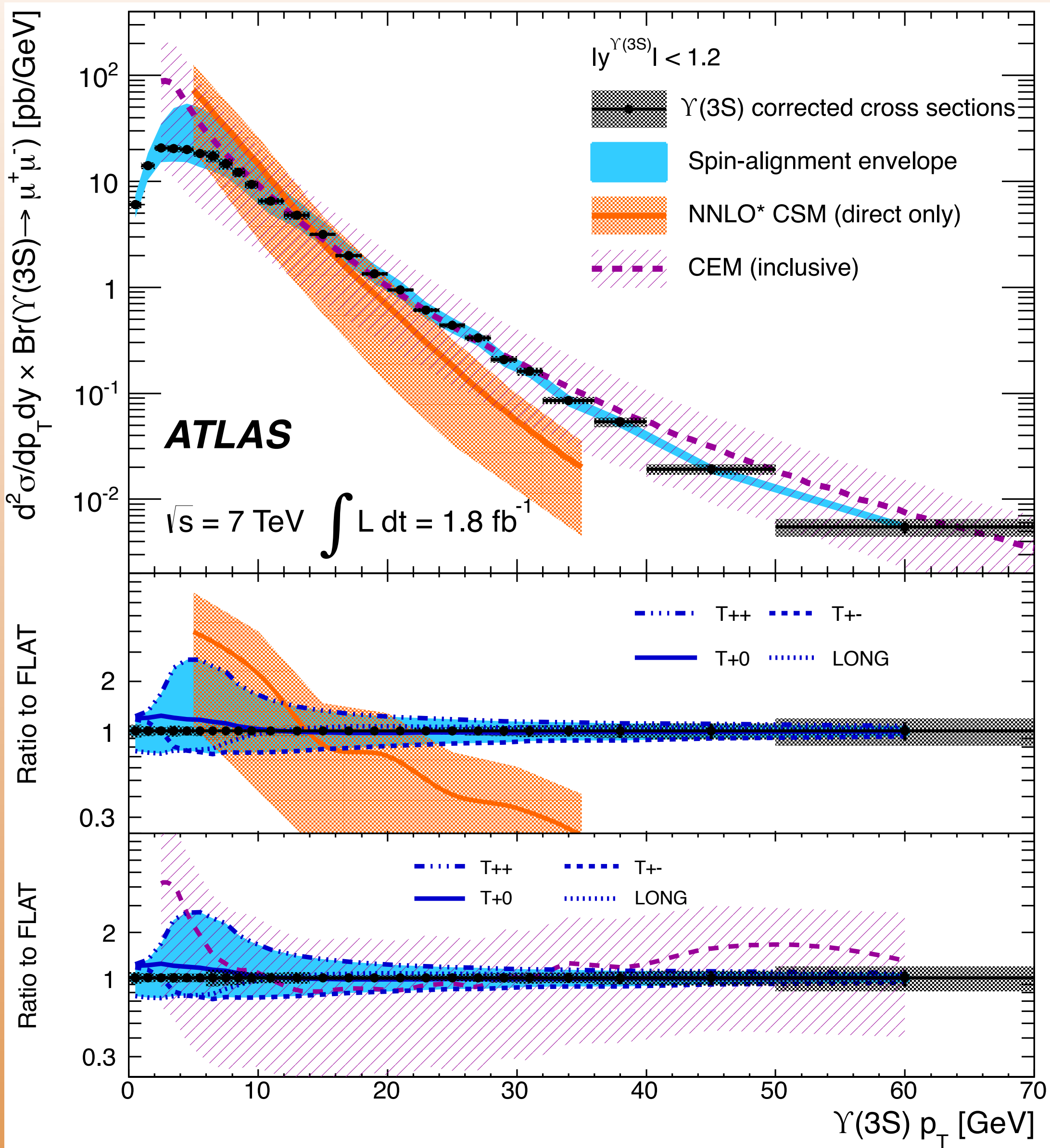
Results shown are public. Predictions made are my own and are not endorsed by ATLAS or CMS. Terminology and details from CMS but I believe similar considerations apply to ATLAS.

Perspective on heavy flavor physics

- Heavy flavor production measurements:
  - p_T and η spectra of open b and c hadrons, quarkonium (including prompt and nonprompt charmonium), and exotic states (X, Y, Z).
  - Polarization of integer spin (quarkonia) and half-integer spin particles (baryons)
- Search for new particles:
  - Excited b baryons
  - Double or triple heavy flavor baryons
  - New $b\bar{b}$ quarkonia and exotic states like X, Y, Z
- Measurements of decays
  - Branching fractions (including new decay channels)
  - Angular analysis of decays
  - CP violation parameters
  - Lifetime and mass
- Some links: twiki.cern.ch/twiki/bin/view/AtlasPublic/BPhysPublicResults
  twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH
  CMS HF doc for 2011 IF workshop: cds.cern.ch/record/1406826

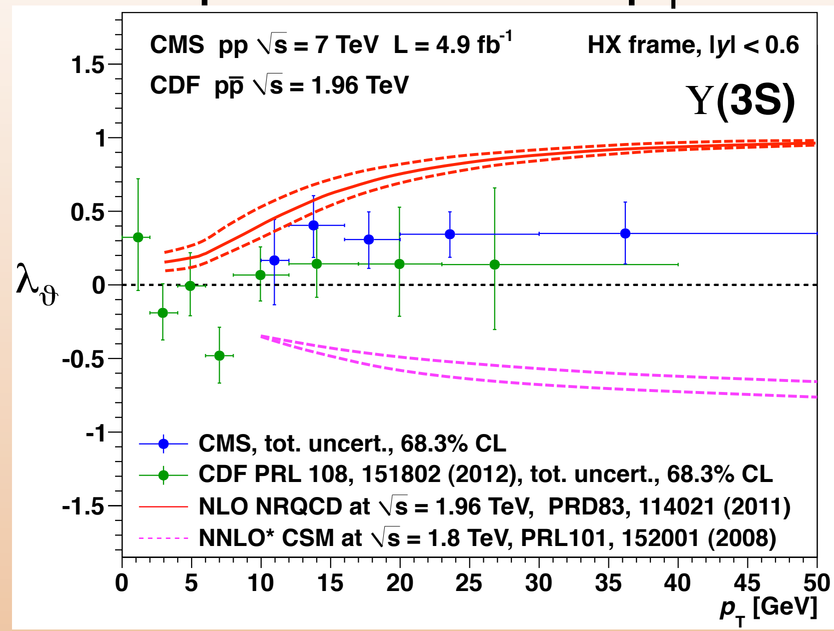
Production measurements by ATLAS/CMS

Υ differential cross section.



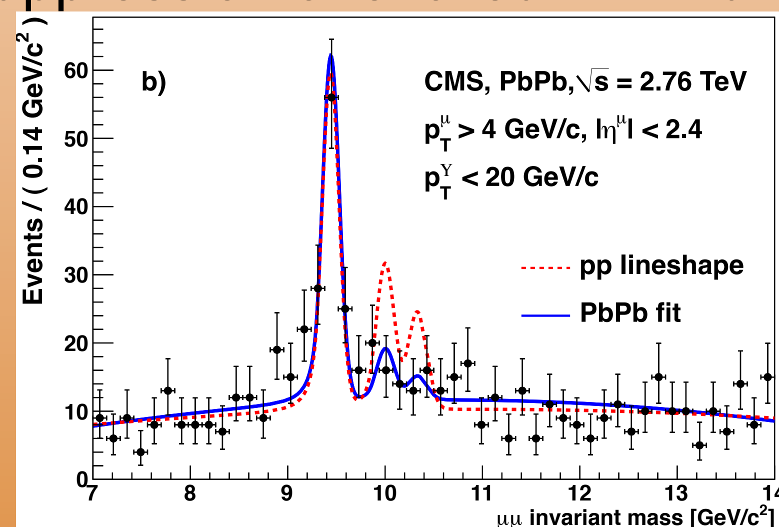
PRD87 (2013) 052004

Υ polarization vs p_T



PRL 110 (2013) 081802

Suppression of excited Υ in PbPb

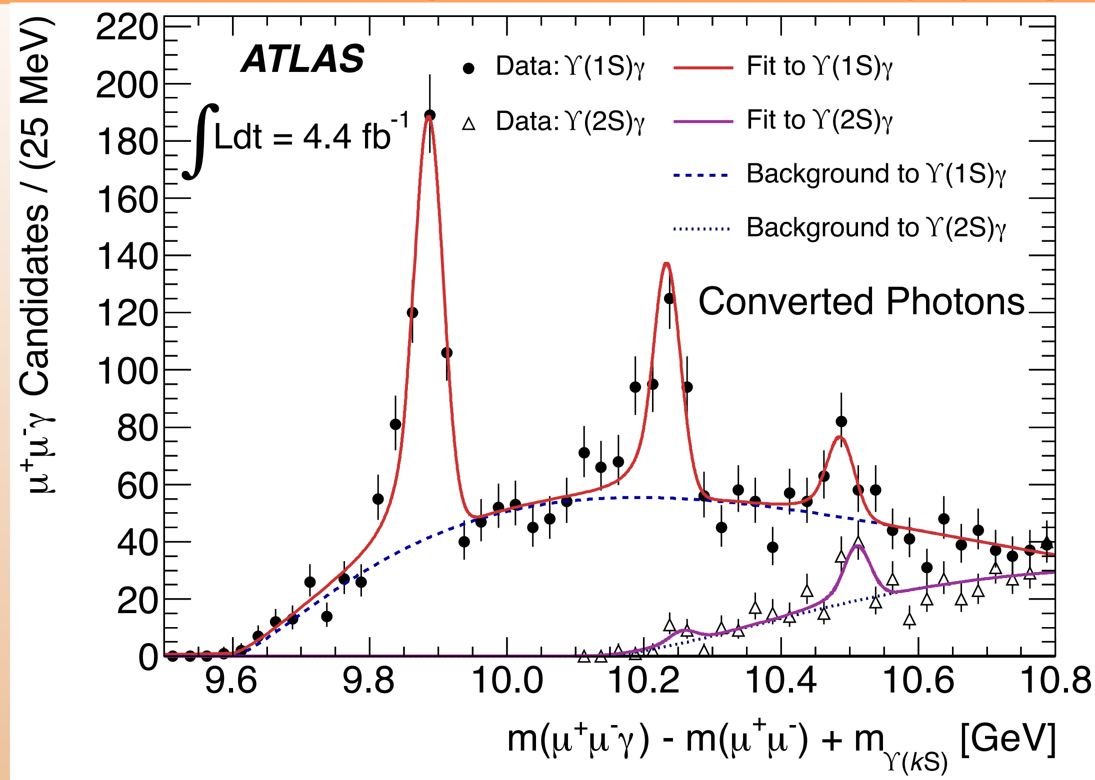


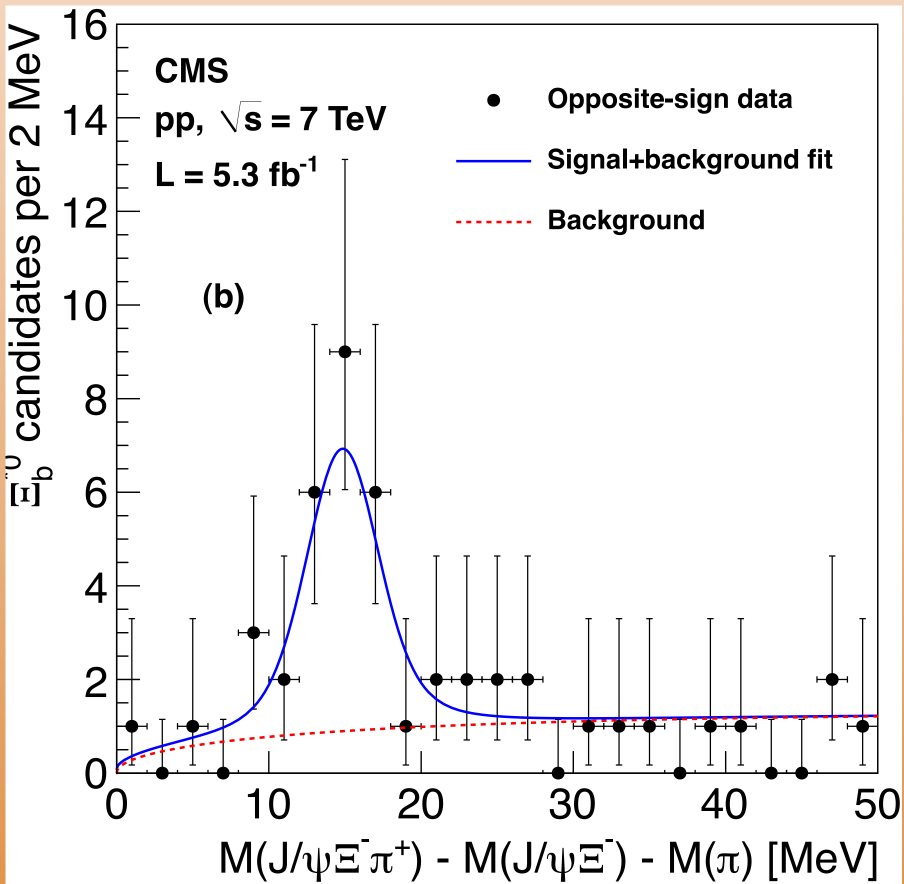
PRL 107 (2011) 052302

New particles from ATLAS/CMS (besides Higgs)

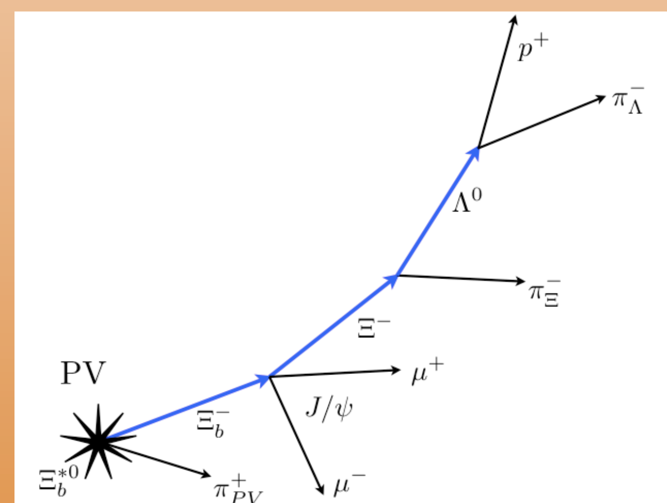
PRL 108 (2012) 152001

Reconstruct χ_b(1P,2P,3P)→Υ(1S,2S)γ with Υ→μμ and γ→ee. Discovery of χ_b(3P).





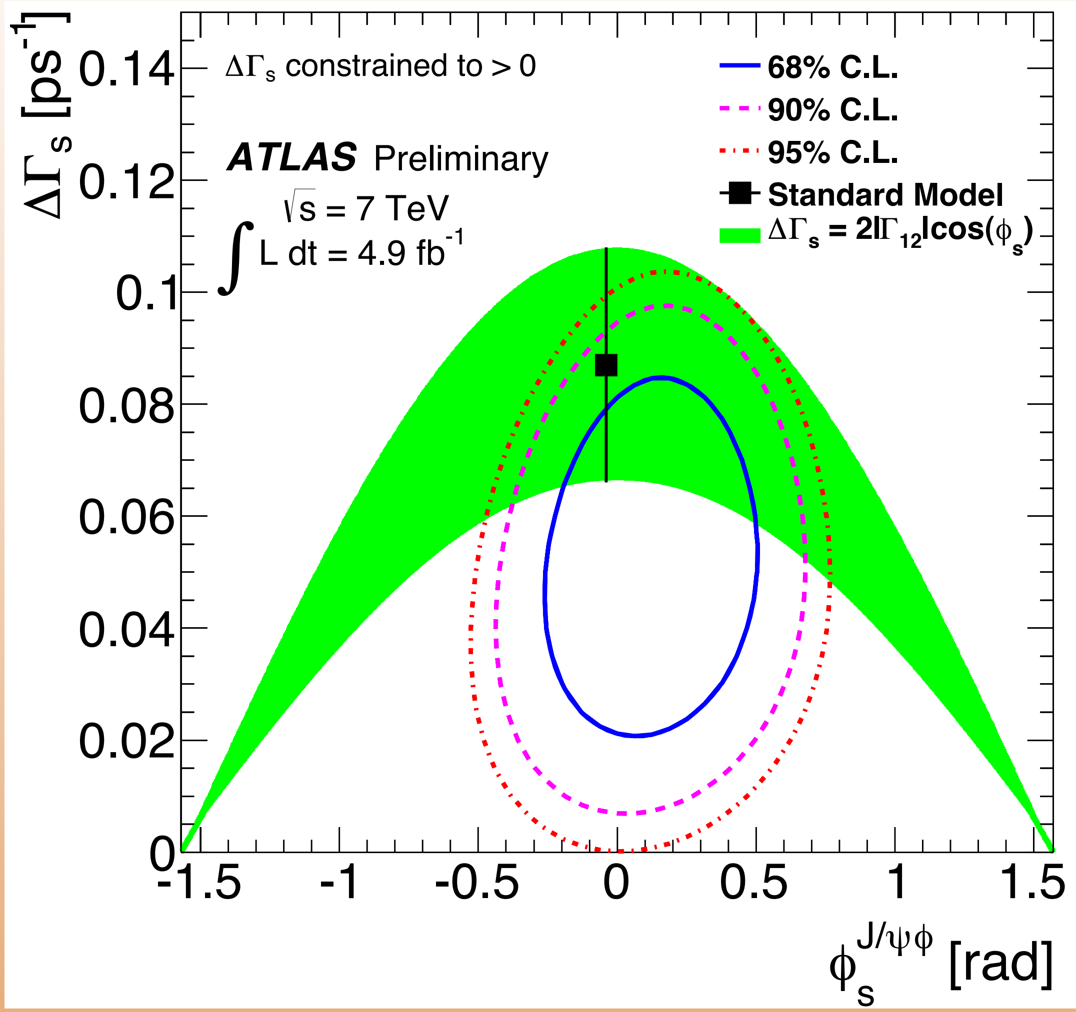
Discovery of Ξ_b^{*0} using decay chain $\Xi_b^{*0} \to \Xi_b^- \pi^+$ with $\Xi_b^- \to J/\psi \Xi^-$ and $J/\psi \to \mu\mu$, $\Xi^- \to \Lambda\pi^-$ and $\Lambda \to p\pi^-$.

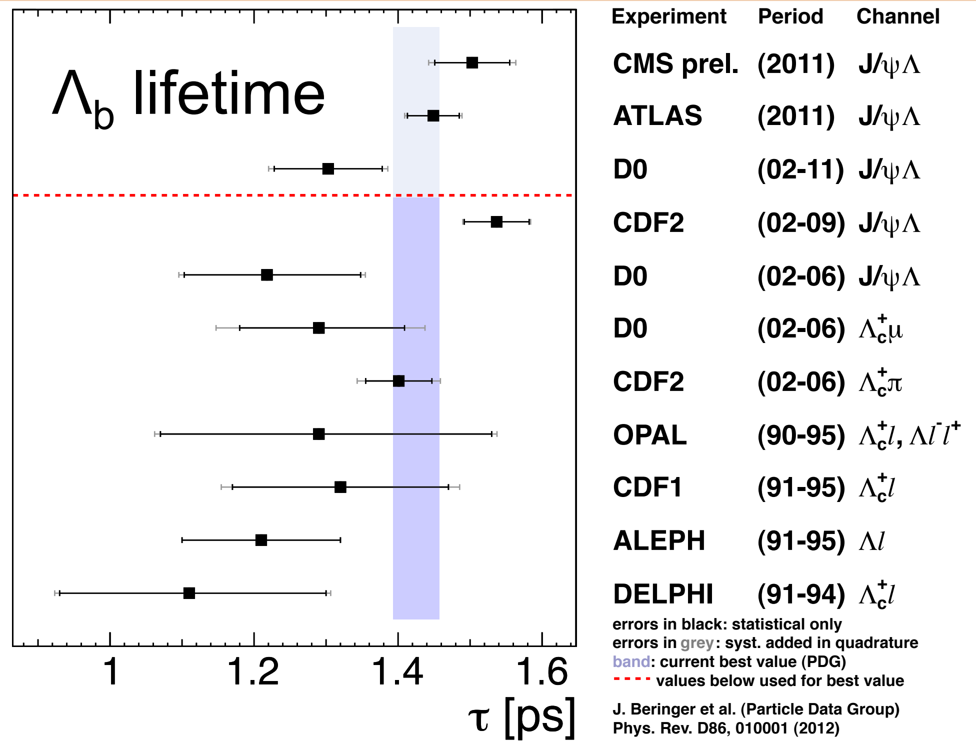


PRL 108 (2012) 252002

Decay measurements by ATLAS/CMS

ATLAS measured $\Delta\Gamma_s$ vs φ_s in $B_s \to J/\psi\varphi$ using time-dependence to distinguish CP states and flavor tagging to separate flavor states: ATLAS-CONF-2013-039

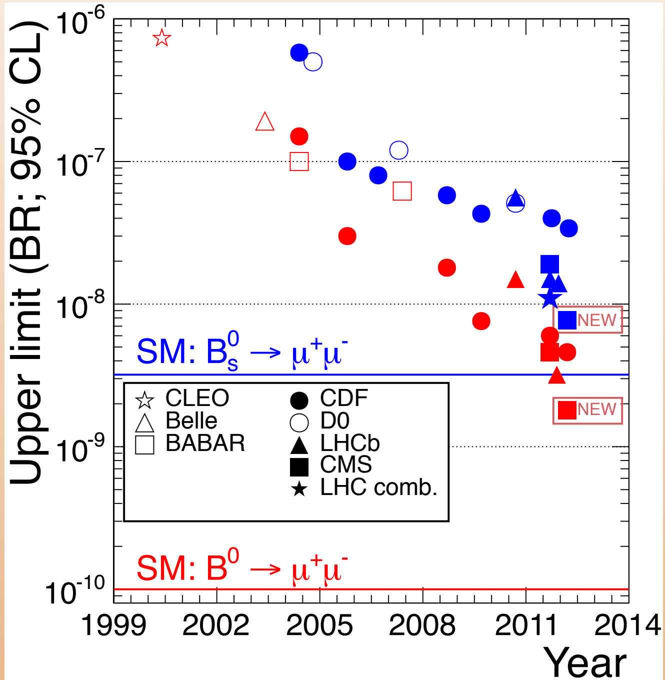




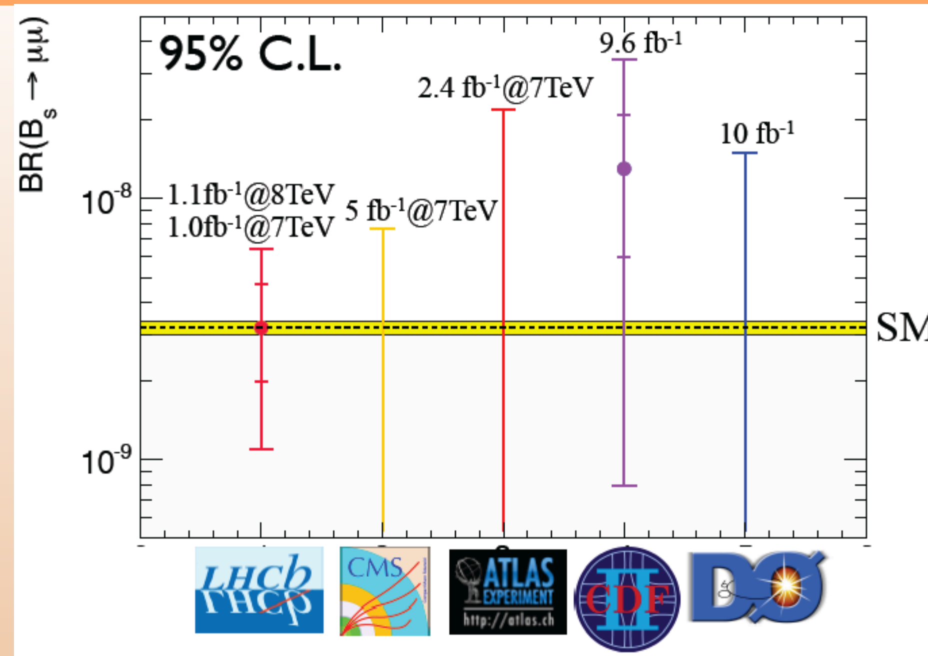
ATLAS (PRD 87 (2013) 032002) and CMS (preliminary) precision measurements of Λ_b lifetime.

Rare decays at ATLAS/CMS

For ~1 week in winter 2012, CMS had best limits on $B_{s,d} \to \mu\mu$

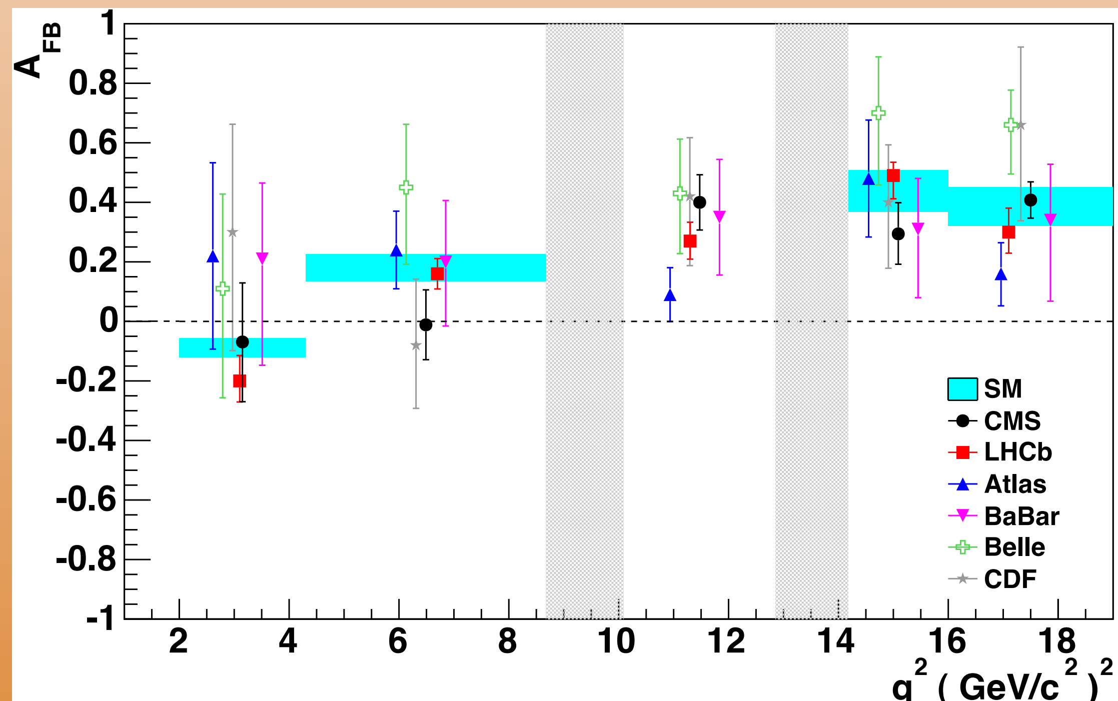


Since then, LHCb has executed better and has the best results. But don't count out ATLAS and CMS yet.



From Takuya Nobe talk at Beauty2013

At Beauty2013, ATLAS, CMS, and LHCb showed new results (2011 data only) on $B^0 \to K^{*0}\mu\mu$ including measurements of new physics sensitive variable A_{FB} vs q^2. 3-4 times more data in 2012.



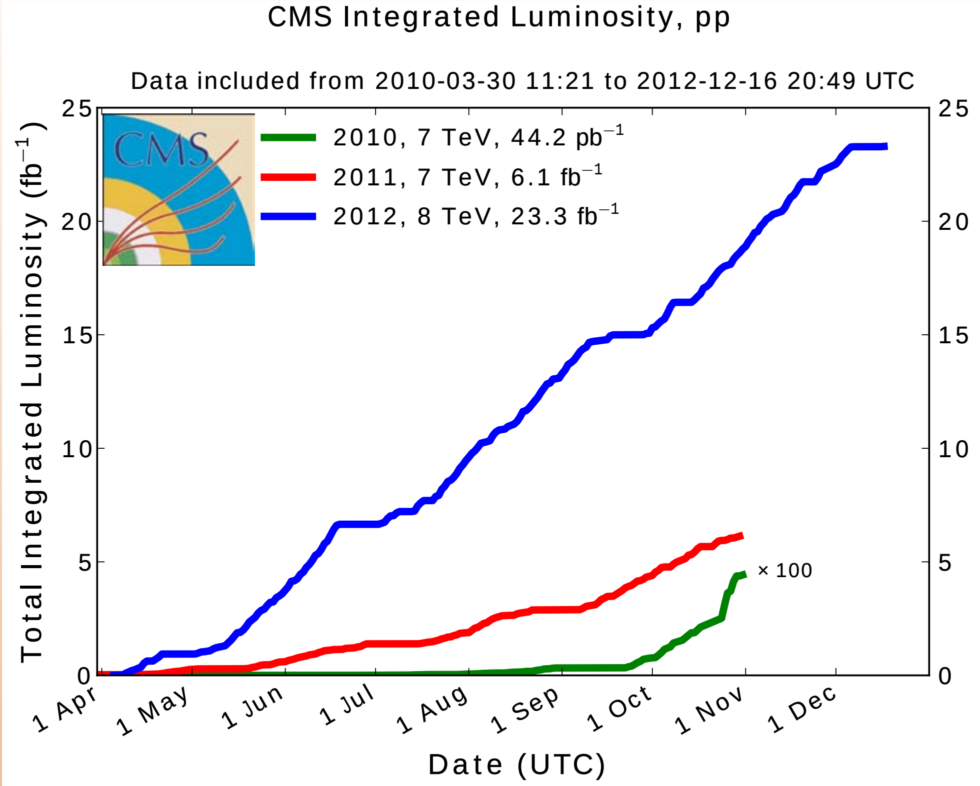
Challenge for ATLAS and CMS

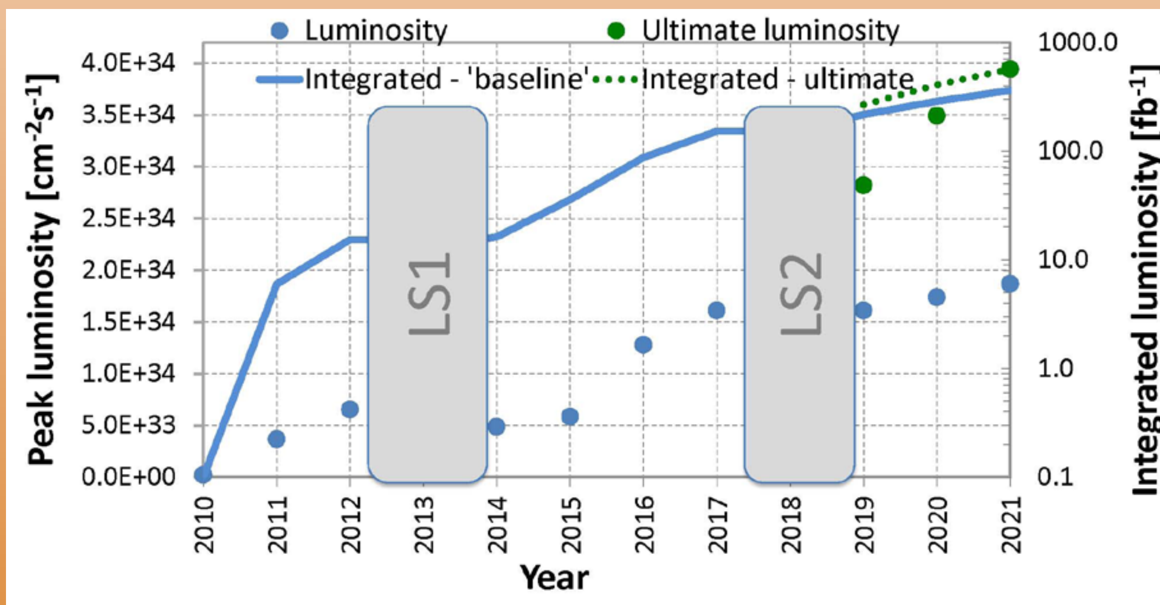
Most of trigger bandwidth is for high p_T physics so only a small slice of heavy flavor cross section is collected.

- Use muon triggers rather than electron triggers since the benefit of electron triggers is statistics but they have higher backgrounds so it is counterproductive.
- Muons at level 1 (L1) followed by additional requirements at high level trigger (HLT) where muons are connected to tracks: mass cuts, vertexing cuts, displacement cuts, etc.
- For production analyses, prescale the common low p_T events, allowing full collection of the rare high p_T events.
- Possible to require high p_T single displaced muon to identify semileptonic b-decay in order to get unbiased b-hadron on opposite side. But signal-to-background is very low.
- b-tagging triggers for other purposes can be used for some production studies.
- Offline b-physics analysis is ~immune to pileup because muon detectors have low occupancy and tracking is sufficiently granular to discriminate. Very little use of missing energy, jet energy, etc.

Future b-physics at ATLAS/CMS

- Two solutions to trigger problem:
  - Take lots of data and analyze offline where things are ~easy
  - Move analysis to the trigger level and collect small amount of data (only solution for ATLAS/CMS in the future).
- Current results generally based on ~5 fb^{-1} of data from 2011 (analyzing 20 fb^{-1} from 2012).
- Up to ~100 fb^{-1}/year by 2021
  - Data with ~same detector (some upgrades like pixel detector)
  - Need to reduce trigger rate by factor of ~20 compared to 2011
- HL-LHC: ~250 fb^{-1}/year after 2023. Many upgrades.





Future of triggers for ATLAS/CMS

- Production studies of high statistics decays like ψ,Y → μμ will simply need to use smart prescales to collect events out to high p_T.
- Production and decay studies of more complicated decays like $\chi_{b,c}$ → γ + Y,ψ, X(3872)→J/ψ$\pi^+\pi^-$, Λ_b→J/ψΛ, Λ_b→Λμμ, B_s→J/ψφ, or $B_{s,d}$→μμ will need to continue moving offline work to the trigger in order to keep L1 and HLT trigger rates under control:
  - Move muon-track association from HLT to L1 for better resolution (not much can be done before 2022).
  - Move dimuon vertexing and invariant mass calculation from HLT to L1 (only crude mass before 2022).
  - Move searches for photons, V^0s, and tracks with vertexing and invariant mass cuts from offline to HLT (possible ~now with smart algorithms and sufficient computing).
- Upgraded tracker for HL-LHC (in 2022) will have tracking very early in trigger (likely seeded by muon, EM cluster, or jet) to get better resolution, background rejection, and pileup rejection.

Summary and outlook for ATLAS/CMS

- ATLAS and CMS continue to produce high-quality, world-class b-physics results (although not with the breadth of LHCb).
- Production physics (including differential cross sections, polarization measurements, jet content, etc.) will continue to be provided with increasing p_T reach in a region inaccessible to LHCb.
- Studies of rare decays ($B_{s,d} \rightarrow \mu\mu$, $b \rightarrow s\mu\mu$ and maybe $D^0 \rightarrow \mu\mu$, $\tau \rightarrow \mu\mu\mu$), measurement of CP violation (especially $B_s \rightarrow J/\psi\varphi$), and searches for new particles (with two muons in decay chain) are statistics limited. Assuming we can pack enough intelligence into the trigger, should scale with square root of integrated luminosity and will be competitive with and perhaps better than LHCb.
- Given the big improvements in tracking at the trigger level expected in the HL-LHC era (>2022), this may allow better b-physics than the high pileup, radiation damaged years between LS2 and LS3 (2019-2021).