Heavy Flavours Summary

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First off, thanks to the speakers!

- Joaquim Matias, Greig Cowan, Sergey Yaschenko
- Jan Winter, Matteo Negrini, Shannon Crucy, Stefano Frixione, Maria Merola, Gregor Kasieczka, Celine Deterre

Outline

1) B physics: outlook for the future and LCHb / Belle II complementarity

2) Top physics: key measurements, comments, and outlook

3) Questions for discussion

LHCb (upgrade) versus Belle-II

Some discussions following session on how LHCb (with the upgrade) compare to Belle-II

Core data taking periods

LHCb	2011-2018
LHCb upgrade	2020-2026
BELLE-II	2018-2022

Two key areas emphasised here that illustrates how many different measurements is what could allow New Physics to be identified beyond doubt

EFT – the language of B physics

Generally

$$\mathcal{L} = \mathcal{L}^{\rm SM} + \frac{1}{\Lambda^2} \sum c_i O_i + \dots$$

In B physics we integrate out all particles with $M \gg m_b$ and construct effective weak Hamiltonian.

E.g., for $B \to K^* \mu^+ \mu^-$: $\mathcal{L}^{b\to s} = -\frac{4 G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_i C_i Q_i$

$$Q_7 = \frac{e}{(4\pi)^2}\, m_b\, (\bar{s}\, \sigma^{\mu\nu} P_R\, b)\; F_{\mu\nu}\,, \quad Q_9 = \frac{e^2}{(4\pi)^2}\, (\bar{s}\, \gamma^\mu P_L\, b)\, (\bar{\ell}\, \gamma_\mu\, \ell)\,, \text{ etc}$$

- goal: deduce or put bounds on new interactions by measuring $C_i = C_i^{\rm SM} + C_i^{\rm NP}$

Electroweak penguin measurements

An extensive laboratory for searching for New Physics as seen in session

QCD uncertainties controlled by forming ratios

Inclusive and exclusive measurements

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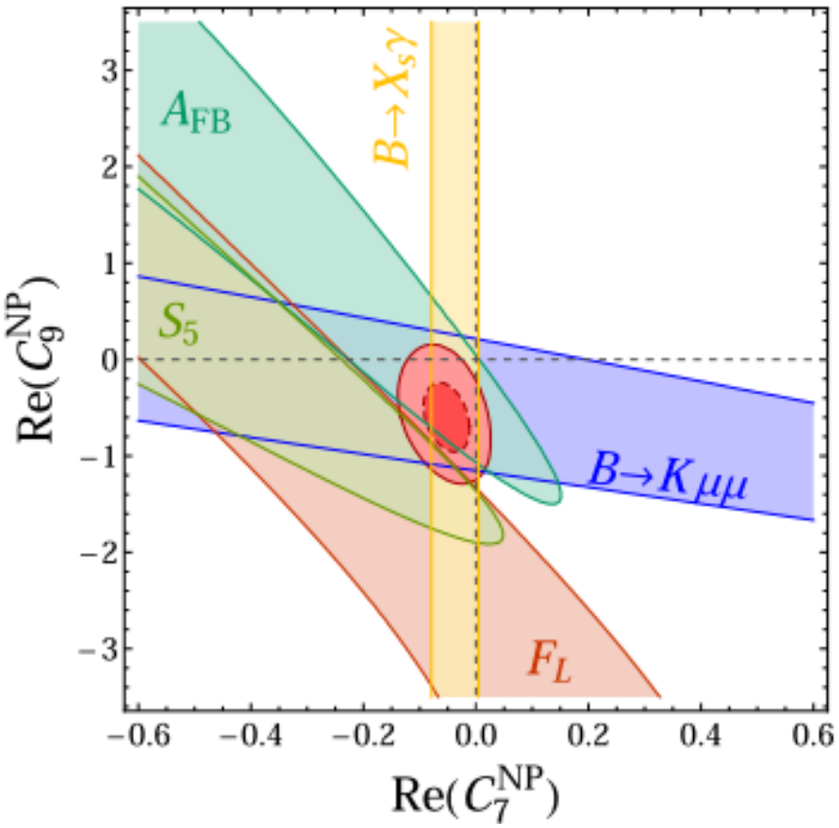
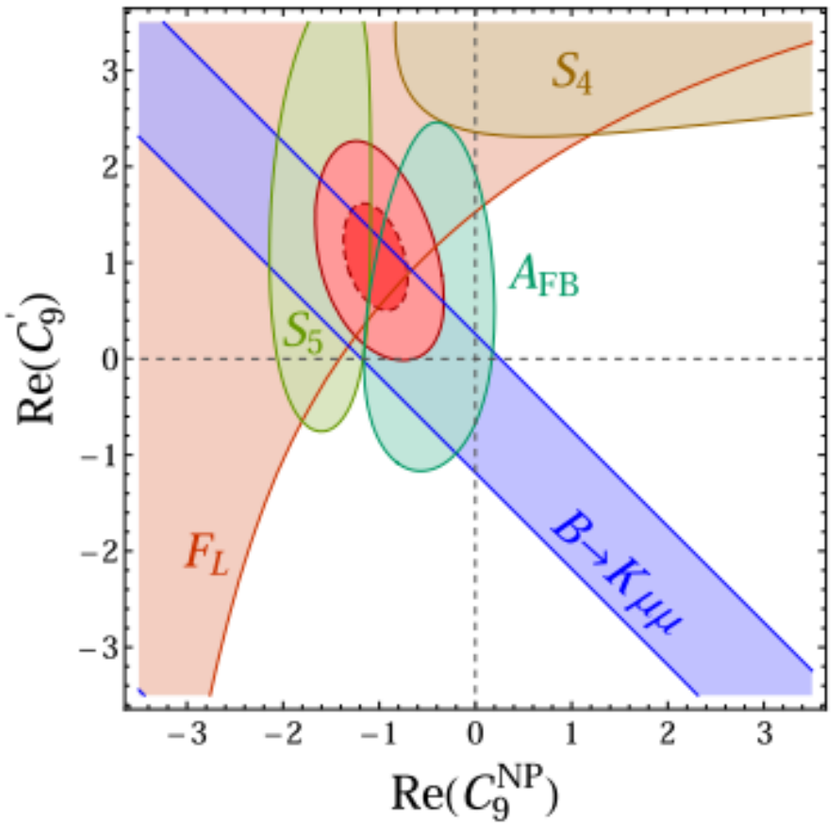
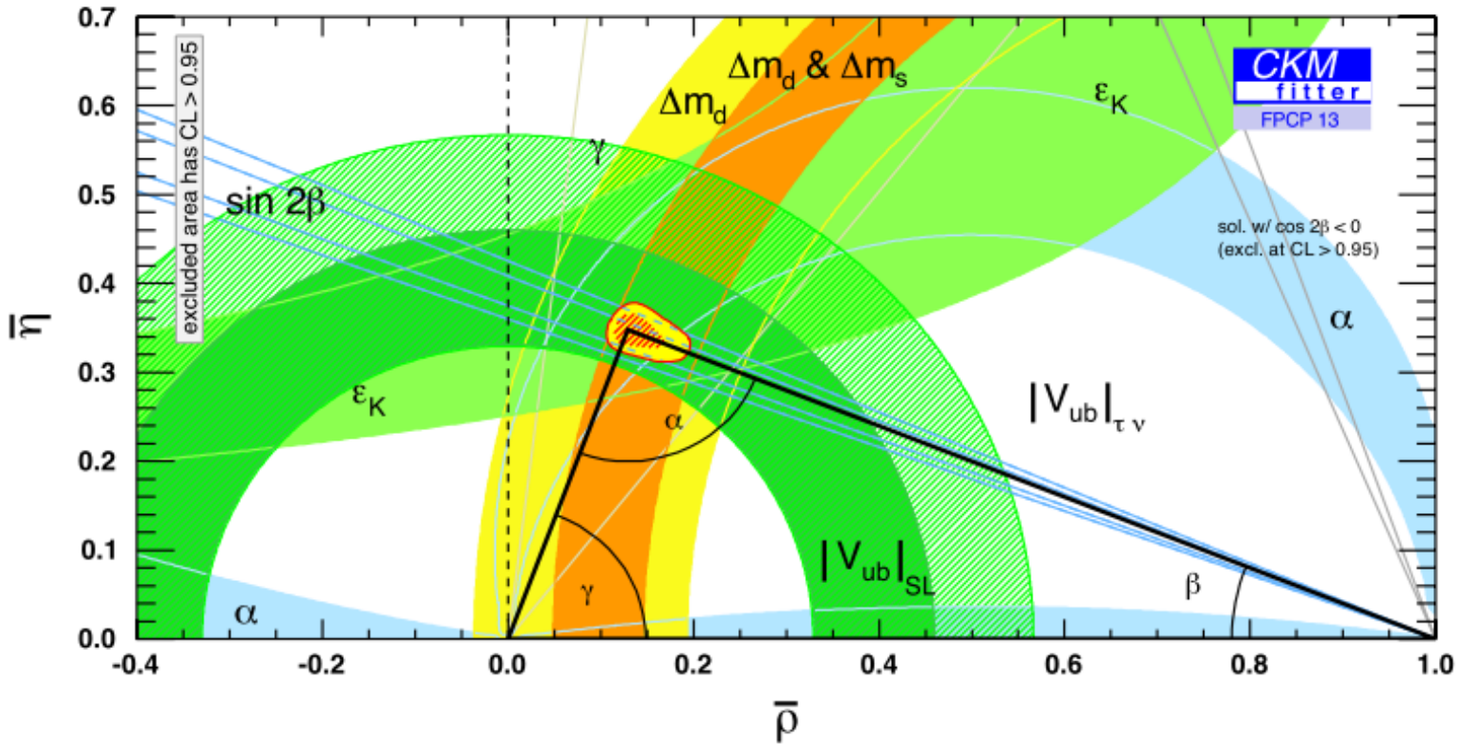




CP violation measurements

New Physics not expected to have SM CKM phases

- QCD uncertainties are for many measurements insignificant
- CKM matrix elements should be measured ever more precise as way to look for inconsistency



Improving $|V_{ub}|$ and and γ is the key to progress

LHCb (upgrade) versus Belle-II

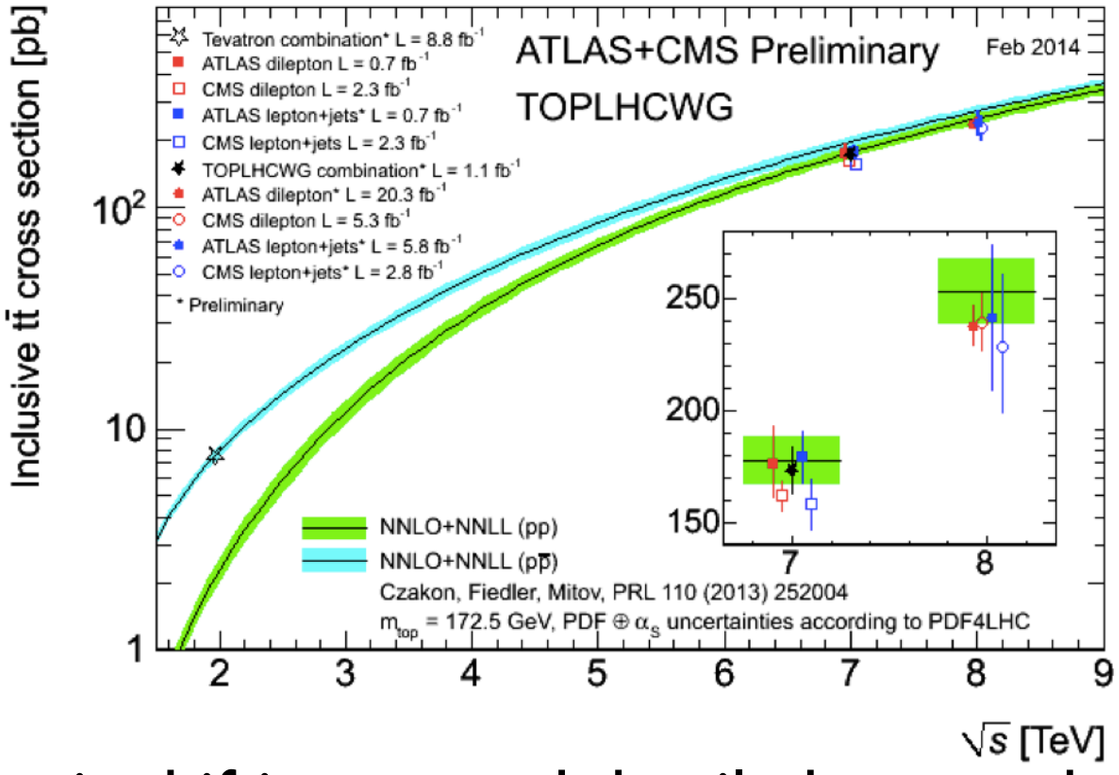
Look at measurements with minimal theoretical error

	LHCb	BELLE-II	LHCb-Upgrd	ATLAS/CMS
$\|V_{ub}\|$	✔✔	✔✔✔	✔✔	
CP angle γ	✔	✔✔	✔✔✔	
CPV in penguins	✔	✔✔	✔✔✔	
Charm CPV	✔✔	✔✔	✔✔✔	
$B \to K^{(*)}ll$	✔✔	✔	✔✔✔	✔
$B \to K^{(*)}\upsilon\upsilon$		✔✔✔		
$B^0 \to \mu\mu$	✔	✔	✔✔✔	✔✔✔
$B^+ \to \tau\upsilon$		✔✔✔		

A healthy combination of complementarity and competition

$t\bar{t}$ production

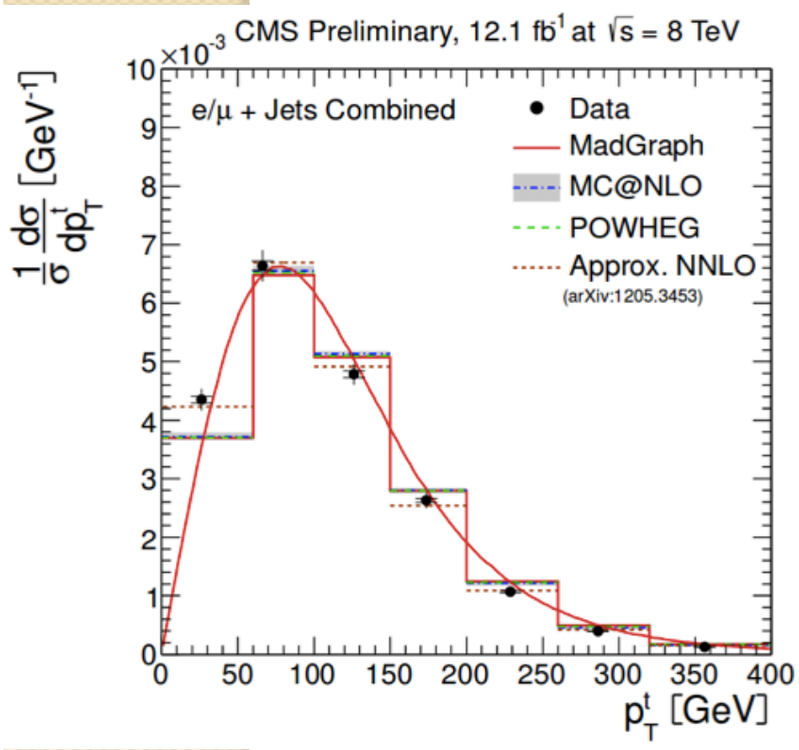
- Inclusive cross section entered the precision regime
- Tevatron combination ~5%, ATLAS, CMS: ~4%@7 TeV, 5%@8 TeV

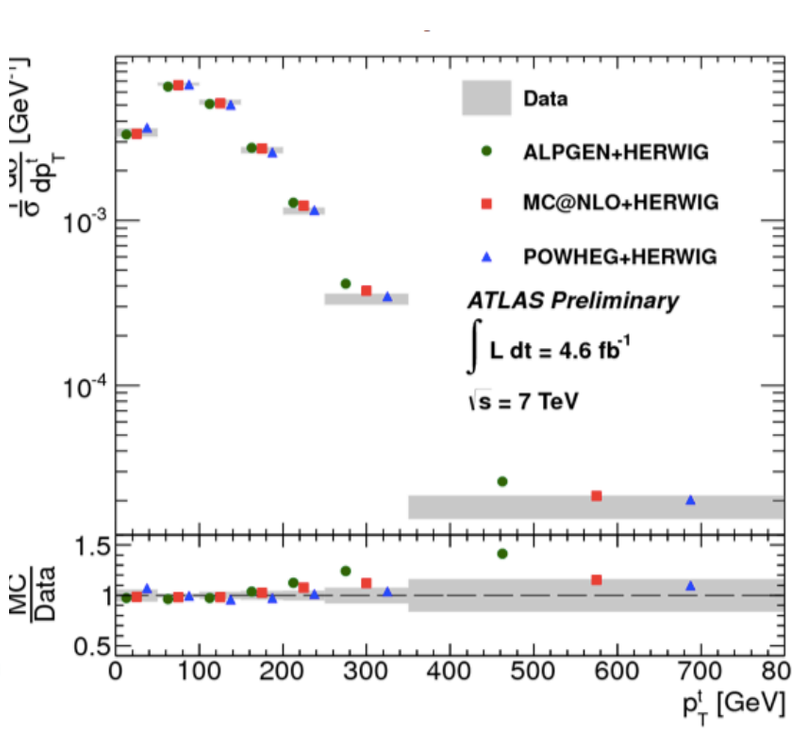


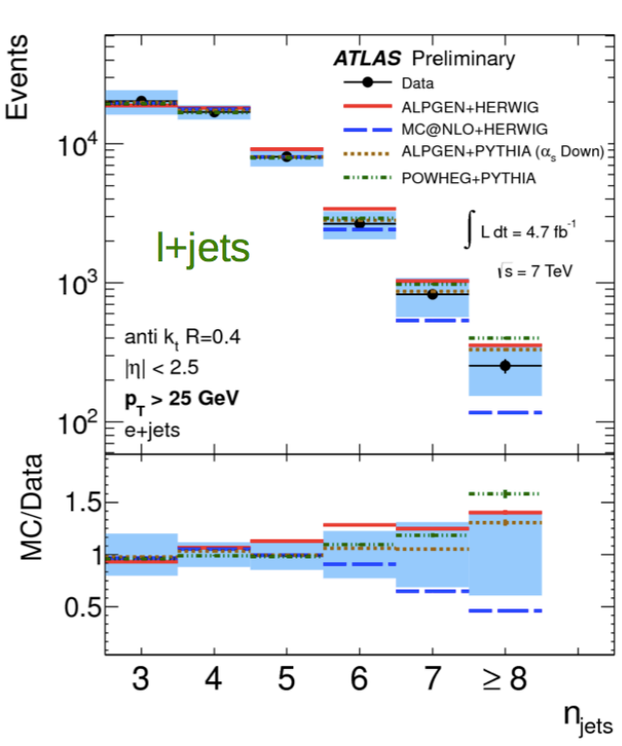
- Emphasis shifting toward detailed comprehension of the production mechanism → differential cross sections

$t\bar{t}$ differential

- In general, overall good agreement, but hints of discrepancies found, e.g.: in $p_T(t)$, jet multiplicity
  - How much is important the MC tune?
  - Does all comparisons make sense? *"If MC@NLO or other gens predicts the jet multiplicity it's by chance"* (S.Frixione)
  - Are we looking at the right observables?

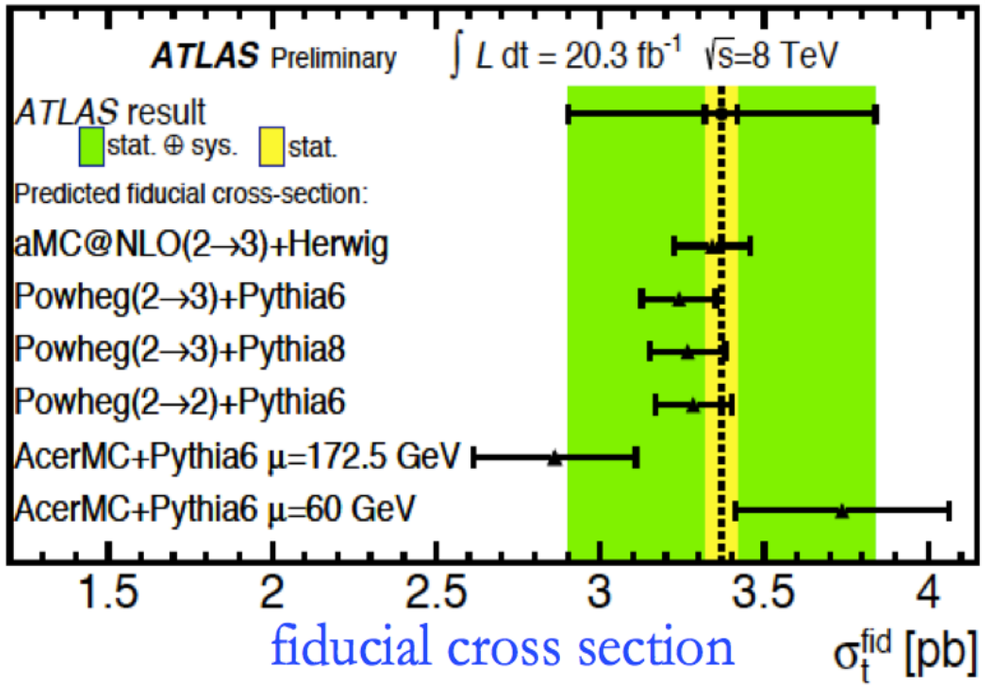


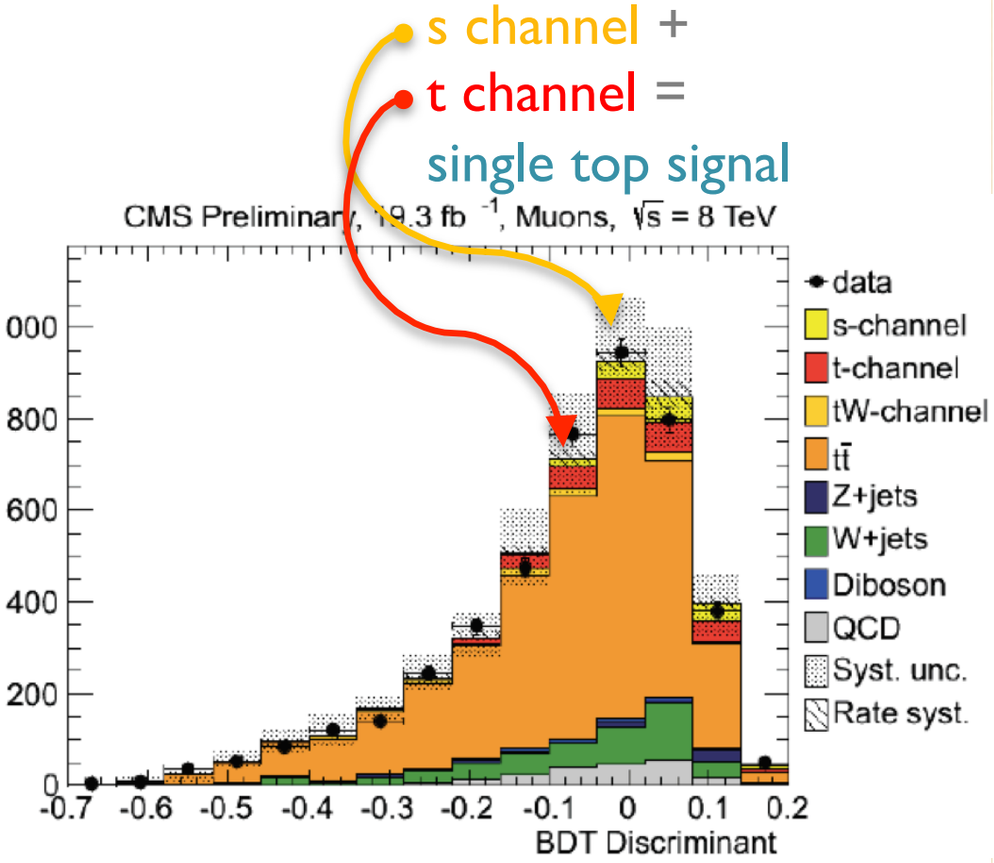




Single top

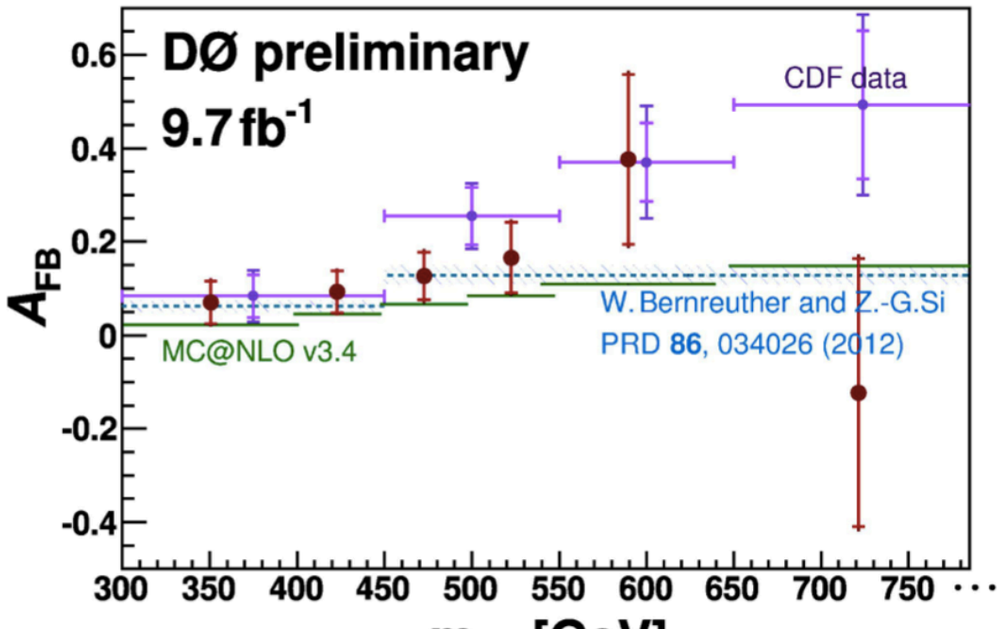
- Updated measurements at 8 TeV of t channel by ATLAS and CMS
- ATLAS focused on fiducial-volume measurement, may be the trend for future rounds of updates
- s channel is very hard at LHC, dominated by large uncertainties on $t\bar{t}$ background (can improve w/ NLO MC)
- But t and s channel should not be treated separately, conceptually
- Move from two separate measurements (t and s channel) to a single-top measurement in two different fiducial volumes?

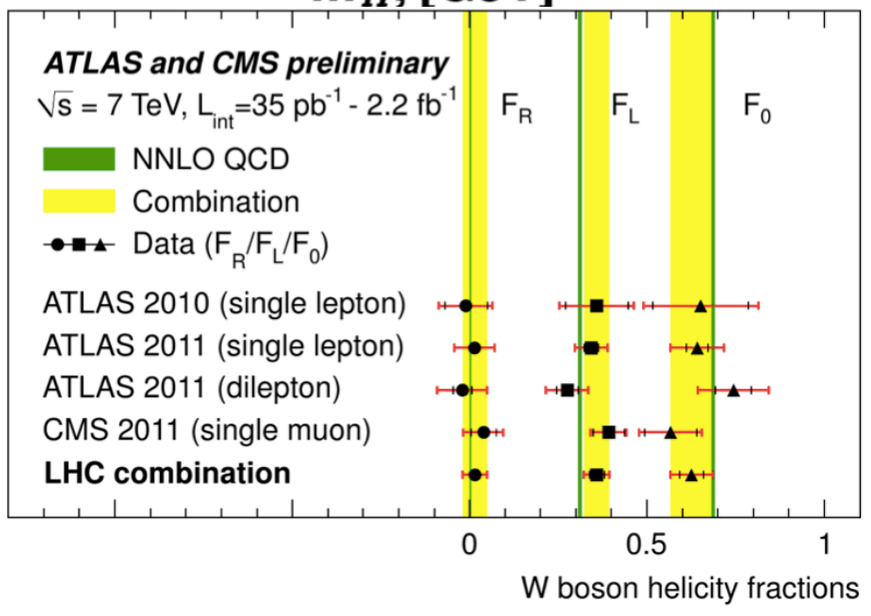




Top properties

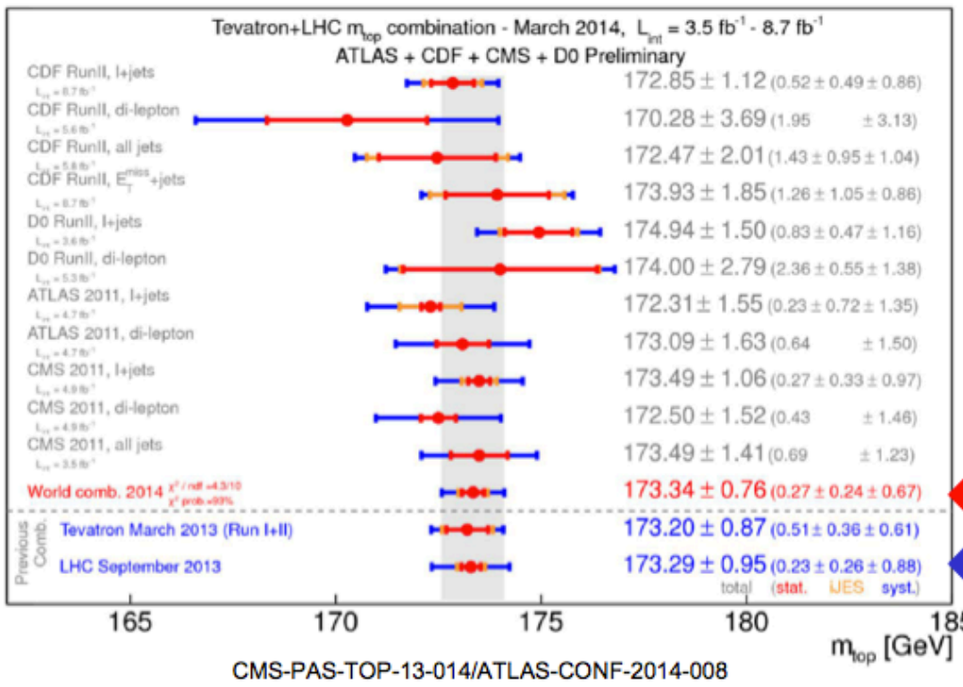
- Tevatron statement on A_{FB} asymmetry not as strong as before (not confirmed by D0)
  - LHC can probe charge asymmetry, hard to probe A_{FB} with pp collisions
- Increasing precision on W polarization measurement, enhanced by ATLAS +CMS combination. But no surprise spotted so far





Top mass measurements – precision and problems

LHC and World Combination



- First LHC+Tevatron result!
- Total uncertainty on top quark mass <1 GeV for combinations.

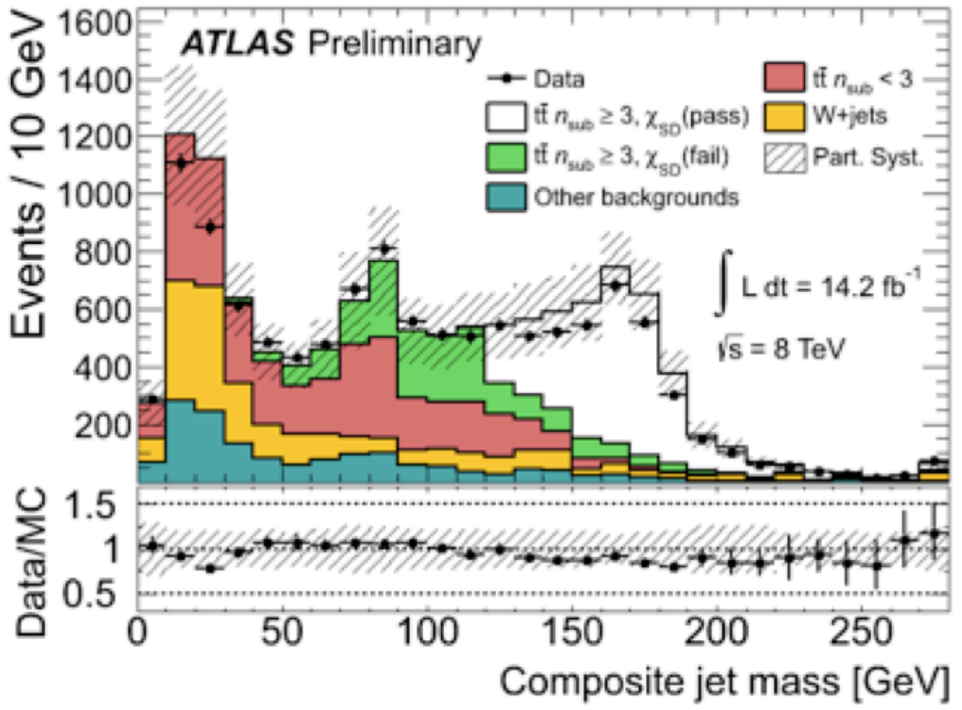
m_t=173.34±0.27(stat.)±0.71(syst.) GeV

m_t=173.29±0.23(stat.)±0.92(syst.) GeV

- nagging issue: $m_t = m_t^{\rm exp} \pm \mathcal{O}(1GeV)$ (mass scheme ambiguity)
- "monte-carlo mass" $\sim m_t^{\rm pole}$ but even that has renormalon ambiguity)
- can extract running mass from cross section (Moch, Uwer), etc, but important open issue

Outlook and expectations at 14 TeV

- Top quarks will be tools for BSM searches at 14 TeV
- With the very first data, inclusive tt^- cross section and differential studies (e.g.: vs m_{tt}) will be possible and could give first hints of new physics, e.g.: in the presence of a high-mass resonance
- Highly boosted top quarks will be more and more important at 14 TeV, not only for BSM searches, but also for SM measurements in high p_T pase-space regions



- Single top: s channel may still be very hard, at least until large integrated luminosity is collected

Some theory issues (Jan Winter)

Summary

- Top quark physics has seen great progress over the course of one year (since Freiburg conference), owing to many automated NLO computations.
- Monte Carlos for top physics: standard nowadays is NLO+PS for single top quark, top quark pair and associated production.
  - PowhegBox (and interface to showers). [Nason et al.]
  - MC@NLO and aMC@NLO (and interface to showers). [Frixione et al.]
  - Sherpa with virtual corrections from BlackHat/GoSam/OpenLoops/NJet etc. [Krauss et al.]
  - MatchBox in Herwig++ [Gieseke, Plätzer et al.]
  - UNLOPS in Pythia 8 [Lönnblad, Prestel]
- NLO matrix-element plus parton shower merging produces remarkable results.
- My apologies for being selective. No discussion of
  - single-top production ($\rightarrow$ S. Frixione's talk)
  - resummed calculations
  - top quark polarization and spin correlations
  - treatment of decays and boosted top quarks
  - theoretical issues regarding top quark mass definition
  - etc.

  in the context of top quark physics.

Discussion

Goal of sessions was dialogue between theorists and experimentalists.
Succeeded!

Interesting points raised, to think about

- single top (what to measure and how to call it)
- top mass definitions (how to settle this and quote a reasonable error)
- when should experiment correct back to (differential) cross sections for on-shell tops and when not?
- EW corrections – irrelevant for total cross section but important for boosted top. How to get make sure they get included consistently?
- what are most exciting measurements at LHC14?
- any gripes: experimentalists to theorists or vice versa?
- questions on B physics and the direction it's heading in?
- anything else?