Open bottom production at NNLO+NNLL

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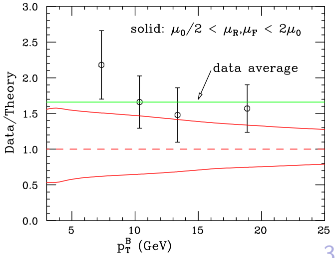
Open bottom production

- A wealth of data from the Tevatron and S$p\bar{p}$S on open bottom production
- Processes considered:
  $p\,\bar{p} \longrightarrow b + X$
  $(\Lsh B \,/\, \mu \,/\, J/\psi \,/\, \psi(2S))$
  $p\,\bar{p} \longrightarrow 2b + X$
  $(\Lsh 2B \,/\, 2\mu)$
- Previous comparisons to theory: NLO(+NLL)
  Cacciari, Greco, Nason (1998)
- Consistently found data/theory $\approx 1.5 - 2$
  (initially data/theory ≈ 3 before theory improvements)
- We can do better: NNLO+NNLL!
- Calculations were performed using C++ library STRIPPER

Addressing the Tevatron ‘excess’

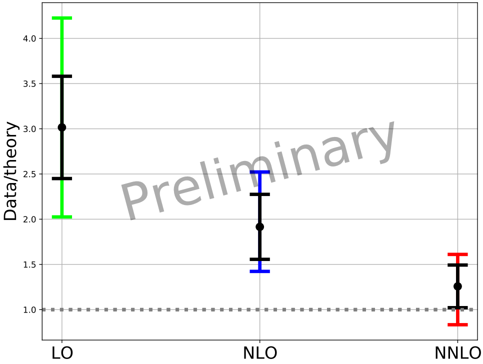
- Many measurements find ratio data/theory > 1
- Not always clear from individual measurements, but pattern appears when considering many measurements
- Idea: ‘average’ many measurements
- Rigorous combination not feasible (by us)
- But: rough estimate sufficient for our purposes
- ⇒ Simple weighted average with conservative error estimate

Figure taken from *Is There a Significant Excess in Bottom Hadroproduction at the Tevatron?* (Cacciari and Nason, 2002)



Addressing the Tevatron ‘excess’

- Average of 10 measurements
- Data published at *b*-quark level
- Fiducial cross sections with p_T cuts from 5 GeV to 54 GeV
- Ratio shows no (statistically significant) p_T-dependence

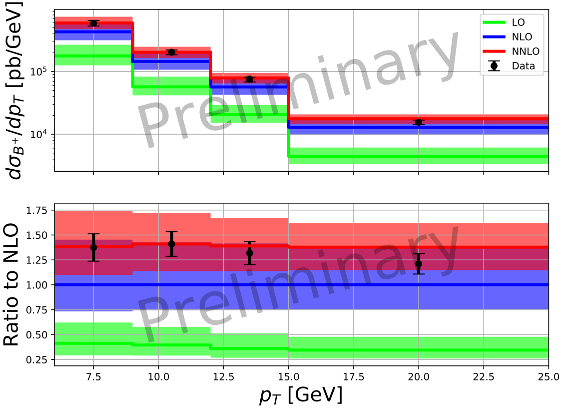


$$\text{NLO: } 1.92 \pm 0.36(\text{exp.})^{+0.61}_{-0.49}(\text{th.})$$
$$\text{NNLO: } 1.26 \pm 0.24(\text{exp.})^{+0.35}_{-0.42}(\text{th.})$$

Much better agreement at NNLO!

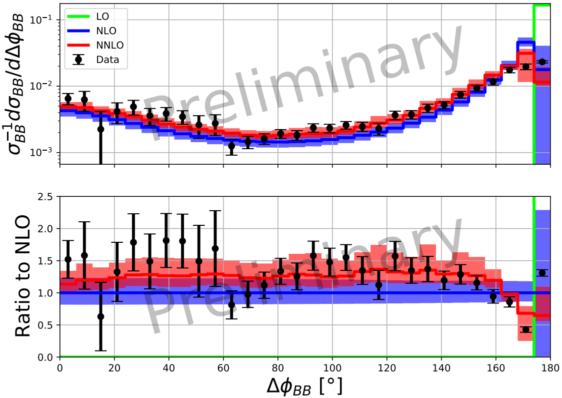
Differential measurement: B-hadron p_T

- CDF measurement of B^+ p_T spectrum Phys.Rev.D 75 (2007) 012010
- Large NNLO corrections
- Uncertainties reduced, but still quite large
- $\alpha_s(m_b) \approx 0.2$
  $\Rightarrow$ slow convergence



Differential measurement: BB angular correlation

- CDF measurement of BB azimuthal distribution Phys.Rev.D 71 (2005) 092001
- Significantly improved agreement at NNLO
- (Expected) slow convergence of last two bins
- NNLO nevertheless major improvement over NLO even here



What about resummation?

- All results so far involve fixed-order massive $b\bar{b}$ production
- Nothing new: b-quark-level NNLO predictions available for a while
  Catani, Devoto, Grazzini, Kallweit, Mazzitelli (2020)
- Also B-hadron-level NNLO using parton shower
  Mazzitelli, Ratti, Wiesemann, Zanderighi (2023)
- Real novelty of this talk: NNLL resummation
- Specifically: resummation of $\ln(p_{T,b}^2/m_b^2)$ at high p_T
- Essentially a straightforward extension of FONLL

The muon p_T spectrum through NNLO+NNLL

- Study muons from B-hadron decays at 630 GeV S$p\bar{p}$S

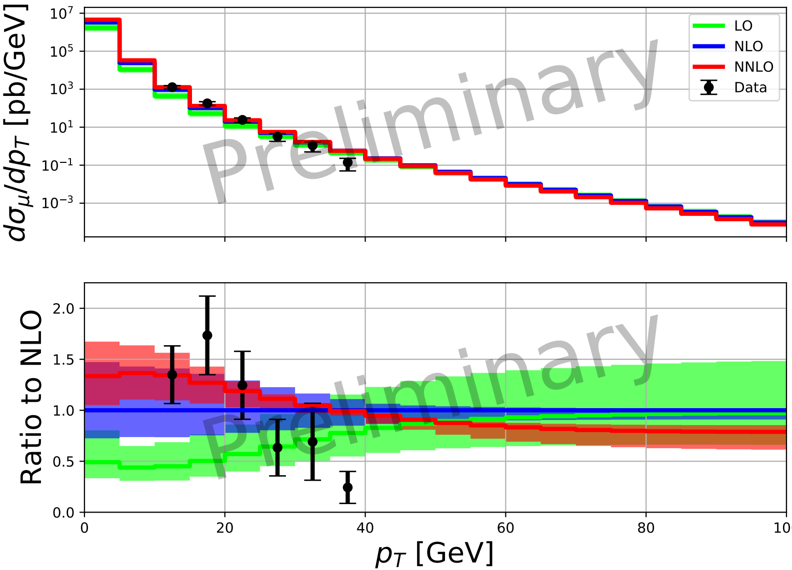
  Phys.Lett.B 256 (1991) 121

- Probes muons up to 40 GeV $\leftrightarrow$ b-quarks up to $\sim$ 80 GeV

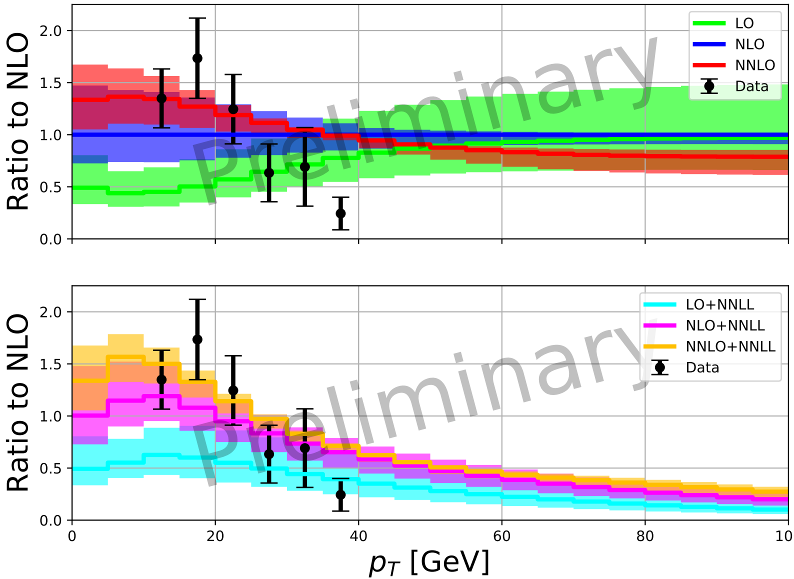
- $\Rightarrow \ln(p_{T,b}^2/m_b^2) \sim 6$

- Resummation effects expected to be large

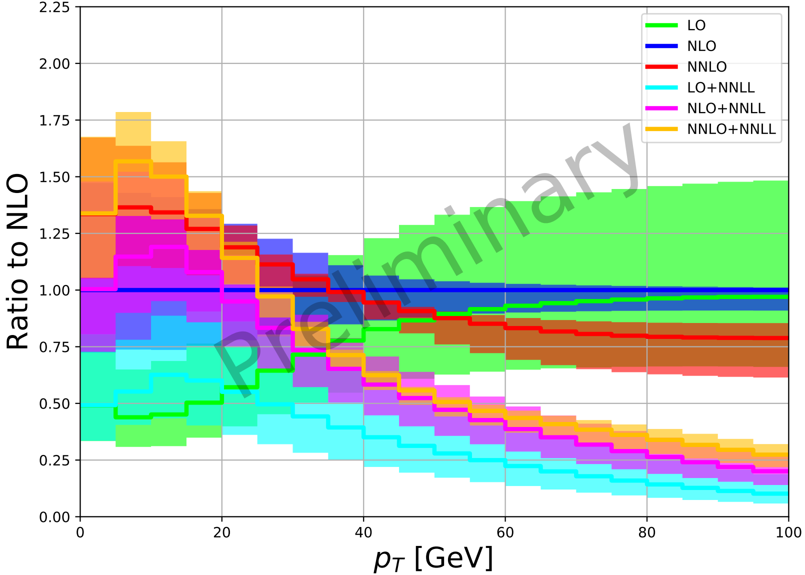
The muon p_T spectrum through NNLO+NNLL



The muon p_T spectrum through NNLO+NNLL



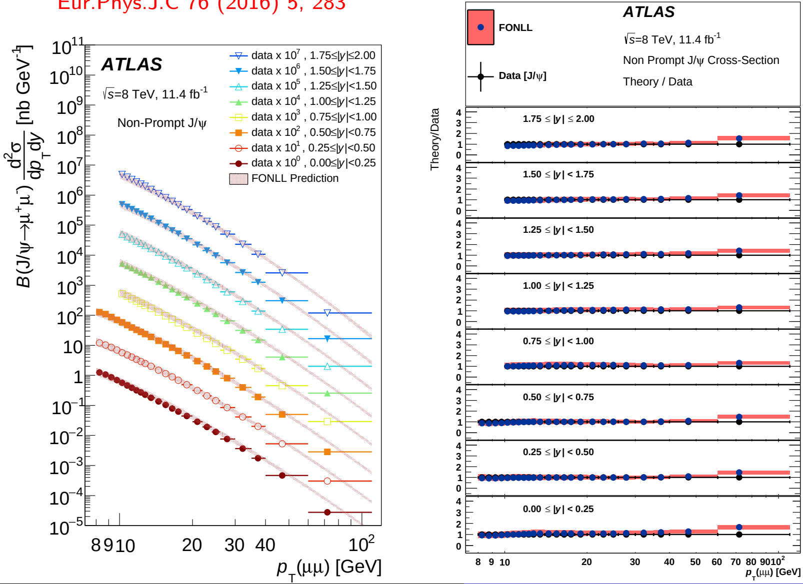
The muon p_T spectrum through NNLO+NNLL



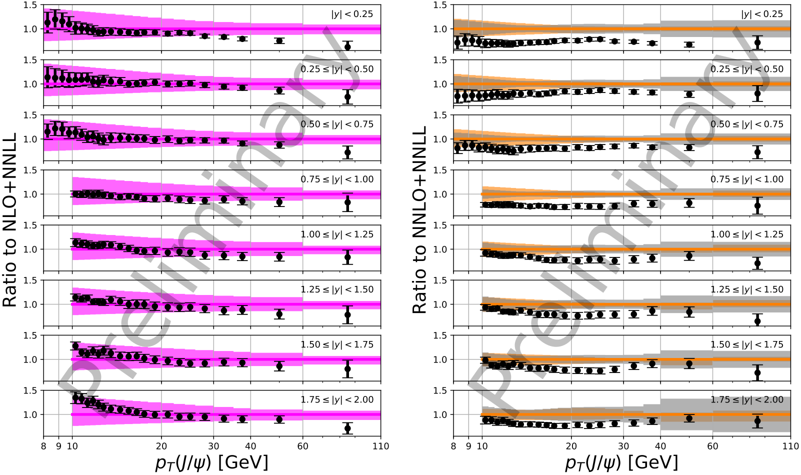
But what about the LHC?

ATLAS study: J/ψ's from B-hadron decays

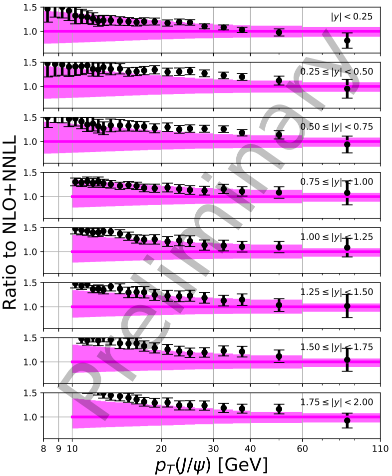
Eur.Phys.J.C 76 (2016) 5, 283

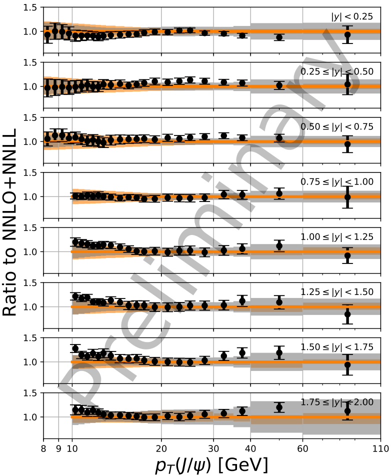


J/ψ's from B-hadron decays: not well described



Possible fix: reduce overall normalisation





J/ψ's from B-hadron decays: possible fix

- Reducing the overall normalisation by a factor ~ 1.3 reproduces data perfectly
- Possible explanation: $\mathrm{BR}(B \to J/\psi + X)$ should be ~ 1.3 times smaller than world average
- PDG value has $\sim 10\%$ uncertainty $\Rightarrow 2.5 - 3\sigma$
- Use data-theory comparison to 'measure' $\mathrm{BR}(B \to J/\psi + X)$? Stay tuned!
- Note: deviation previously hidden by large NLO uncertainties!

Conclusion & outlook

- First NNLO+NNLL calculation of open bottom at hadron colliders
- NNLO corrections essentially get rid of the old Tevatron 'excess'
- NNLO+NNLL improves agreement with Tevatron, S$p\bar{p}$S and LHC data
- Much smaller uncertainties than at NLO+NLL
- LHC prediction shown just an early example: many interesting measurements made over the years. More results to come!