The BND

School,
Coffee,
And
Learning about
Excellence in scale variation with

CMS and
ATLAS
Folks
Entertainment group

Presents

Scale Variations as Theoretical Uncertainties

in the $t + \bar{t} → \ell\nu + \text{jets}$ process at CMS

What do we do?

- Look at top quark pair production
- Calculate theory predictions with matrix
- Study impact of different scales on the computation

  (eg. top mass, invariant mass of the top pair)
- Study impact of LO, NLO, NNLO
- Compare to CMS measurement

What are the scales anyway ?

- **2 important scales in hh colliders**
  - μ_F : the factorisation scale;
  - μ_R : the renormalisation scale.

The Holy Grail

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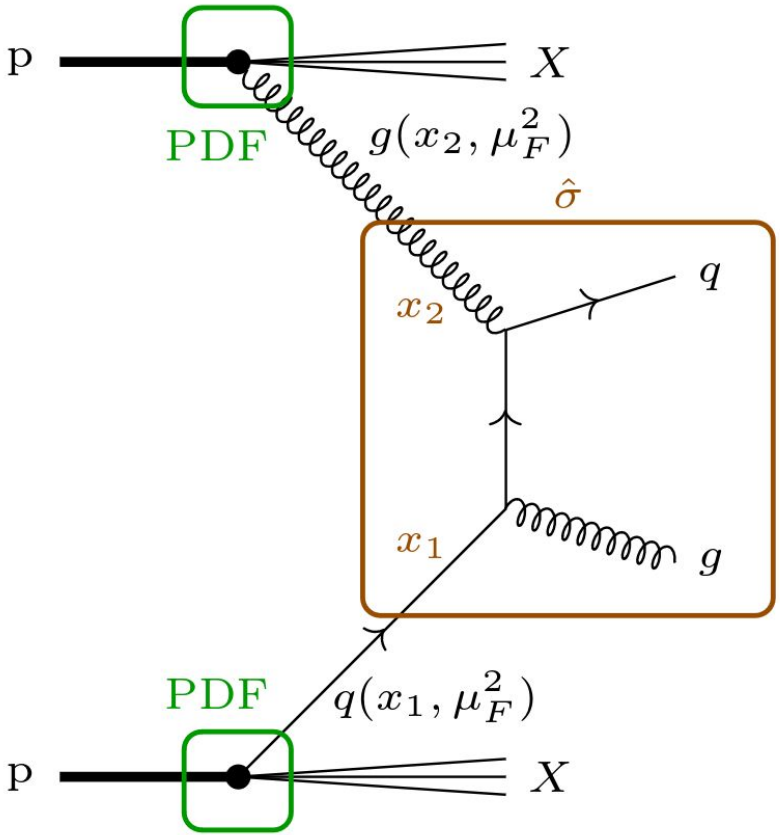

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Why Scale Variations?

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  - **In practice: results vary with scale**

Why Scale Variations?

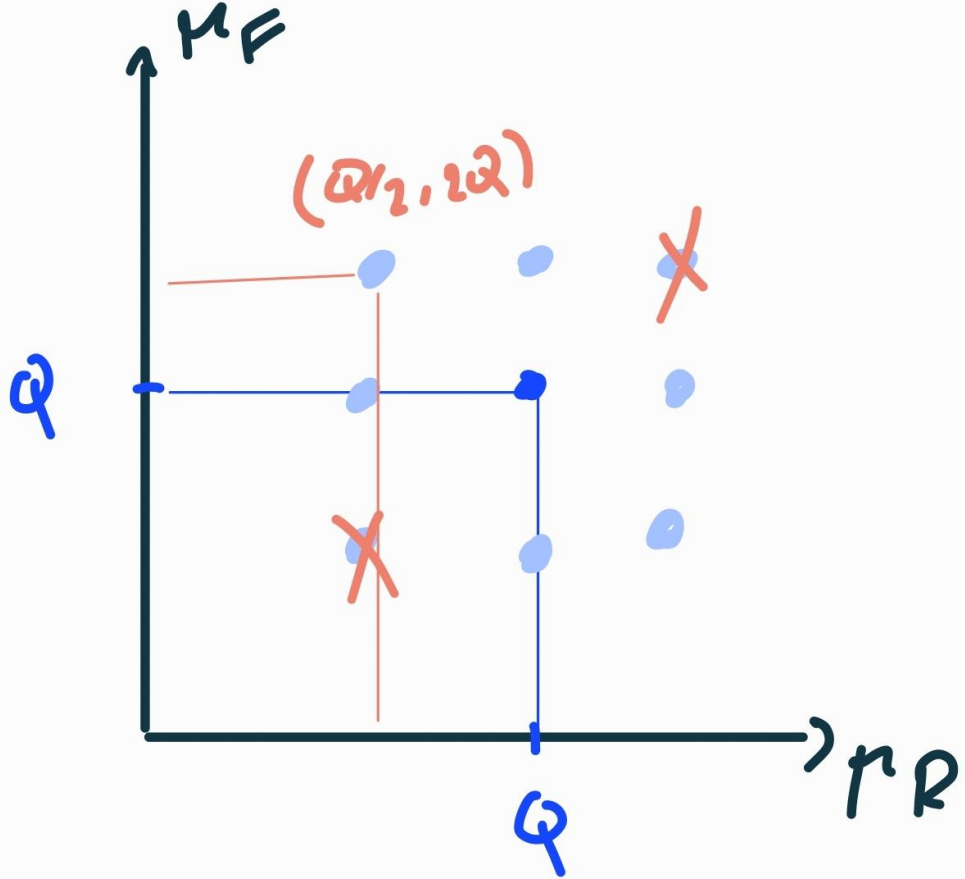
- Scale values are arbitrary
- Ideally, no dependence on scale choice
  - In practice: results vary with scale
- Determine influence of choice of different scale
  - Estimate of deviation from all-order calculation

Scale Variations

- **7-point scheme :**
  - **Choice of a scale : m_t, m_{tt}, H_T, etc.**

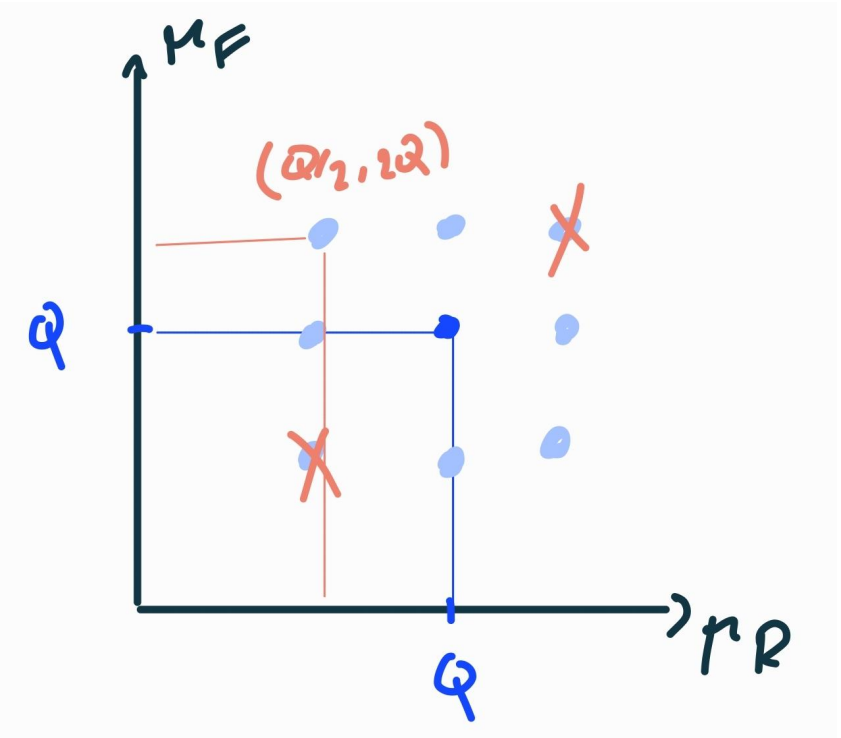
Scale Variations

- 7-point s
  - Ch



Scale Variations

- **7-point scheme :**
  - **Choice of a scale Q : m_t, m_{tt}, H_T, etc.**
  - **Vary the scales by factor 2**
    - excluding the 2 extremes
  - **Highest and lowest value of the cross-section ⇒ uncertainties**
    - Central value : (Q,Q).

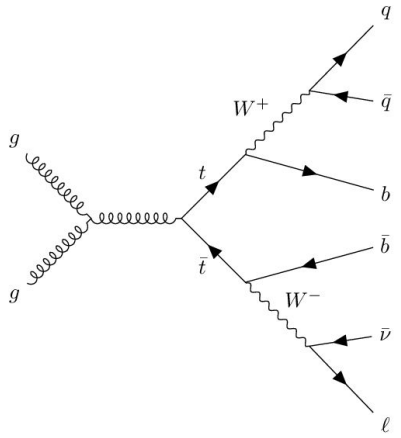


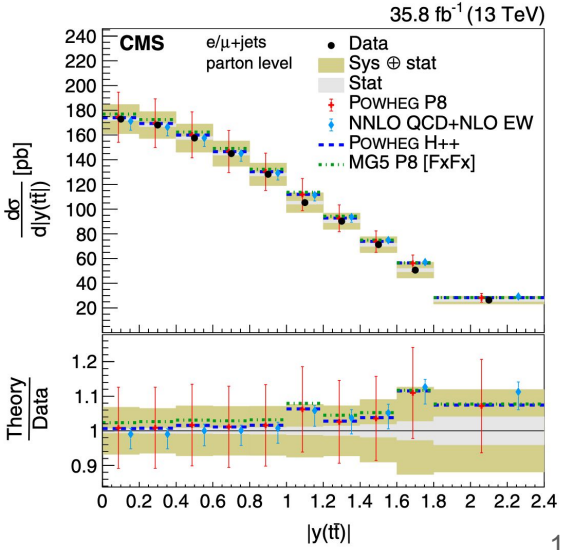
Results: Influence of Central Scale Choice

	up to 30%	below 15%
Central Scale Choice	Scale Uncertainty for LO	Scale Uncertainty for NLO
m_t	+29.7% -21.5%	+11.8% -11.9%
$m_t/2$	+32.5% -22.9%	+8.4% -10.5%
$m_{t\bar{t}}$	+25.9% -19.4%	+14.1% -12.7%
$m_{t\bar{t}}/2$	+28.0% -20.6%	+13.1% -12.4%
m_T	+25.9% -19.4%	+13.9% -12.6%
H_T	+26.5% -19.7%	+13.8% -12.6%
$H_T/2$	+28.7% -20.9%	+12.5% -12.2%
$H_T/4$	+30.9% -22.2%	+10.0% -11.1%

Differential cross-section measurement

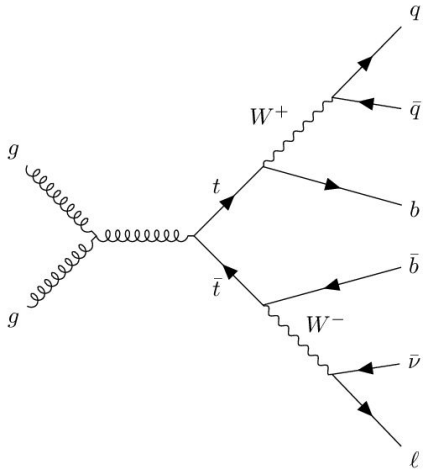
- Measurement of differential top pair production cross section
- Done by CMS with 35.8 fb^{-1} of LHC data
- Cross section measured as function of absolute rapidity and invariant mass
- Results can be compared to matrix-calculations
  ⇒ That's what we did



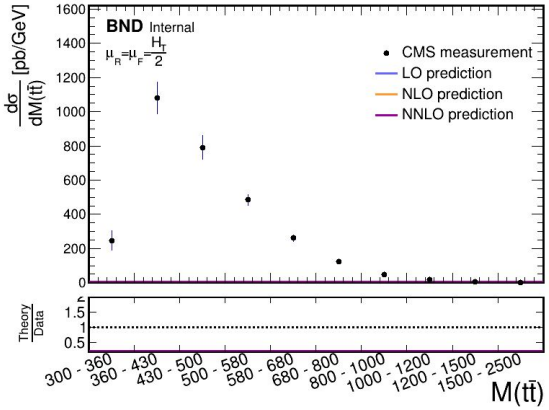


Phys. Rev. D, 97(11):112003, 2018

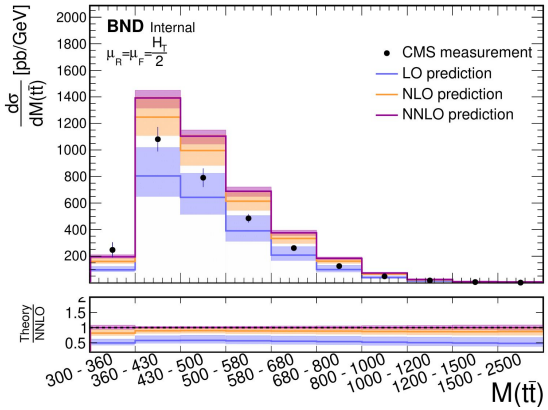
Some caveats for the comparison



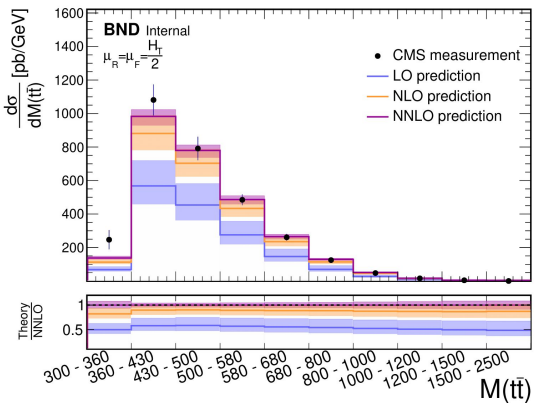
- **To make it work, one needs to:**
  - **check the units: Paper results are in pb, matrix results (occasionally) in fb**
  - **Take the W-decay branching ratio into account**



units ⇒

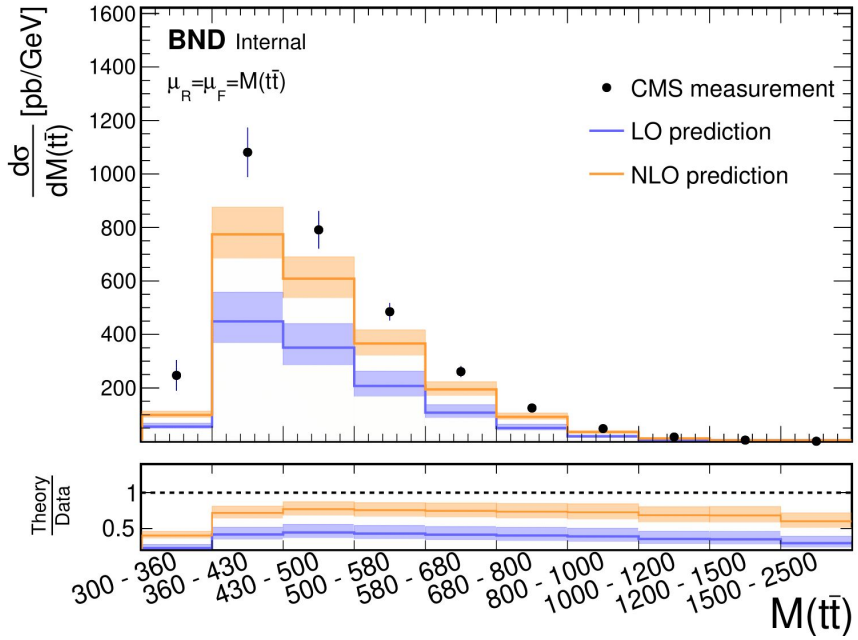


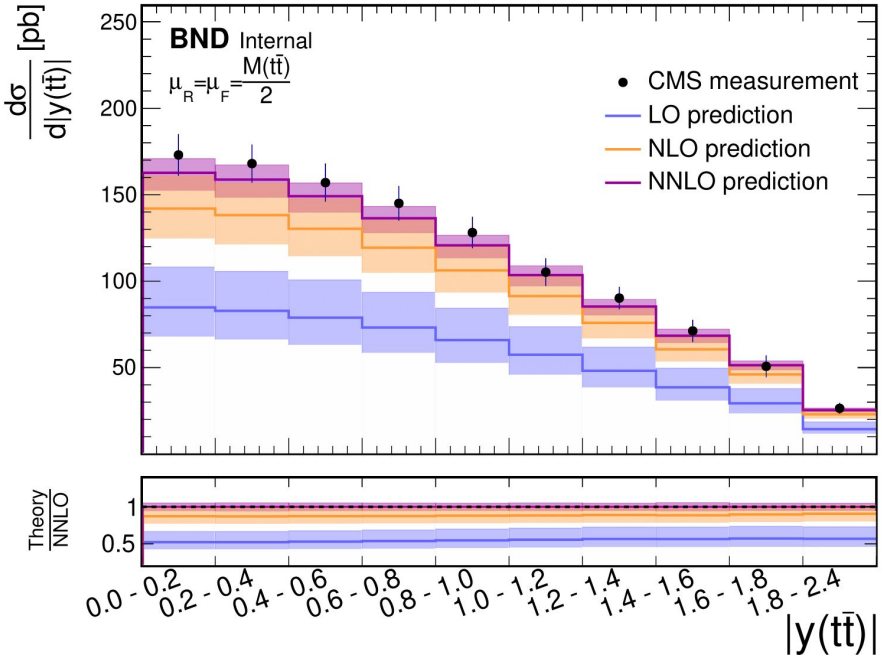
Branching ratio ⇒



What did we compare?

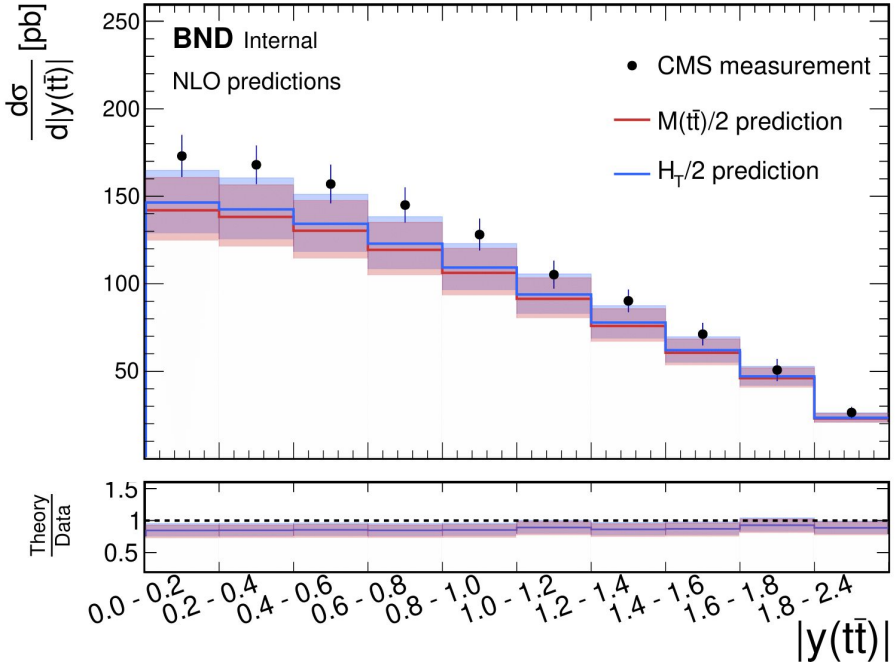
➢ **Different orders**

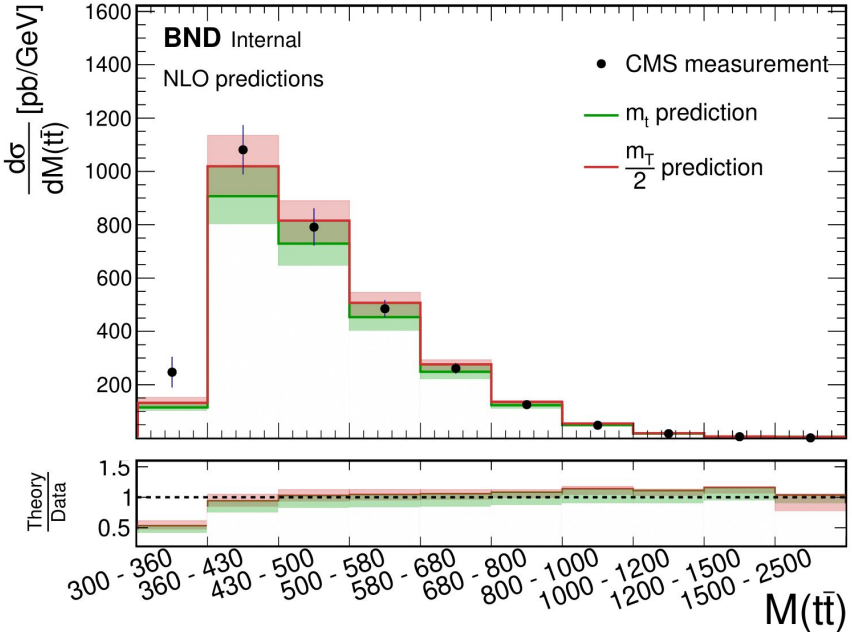




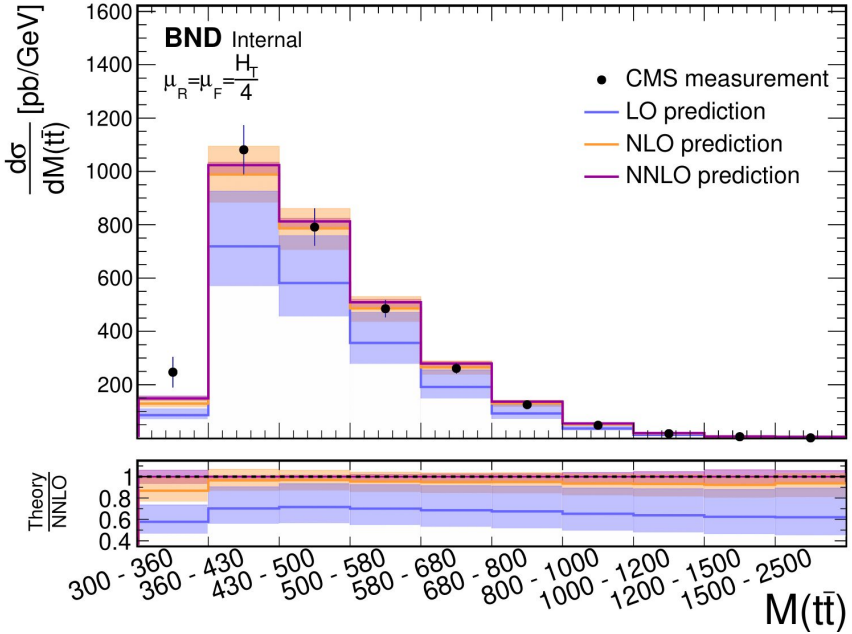
What did we compare?

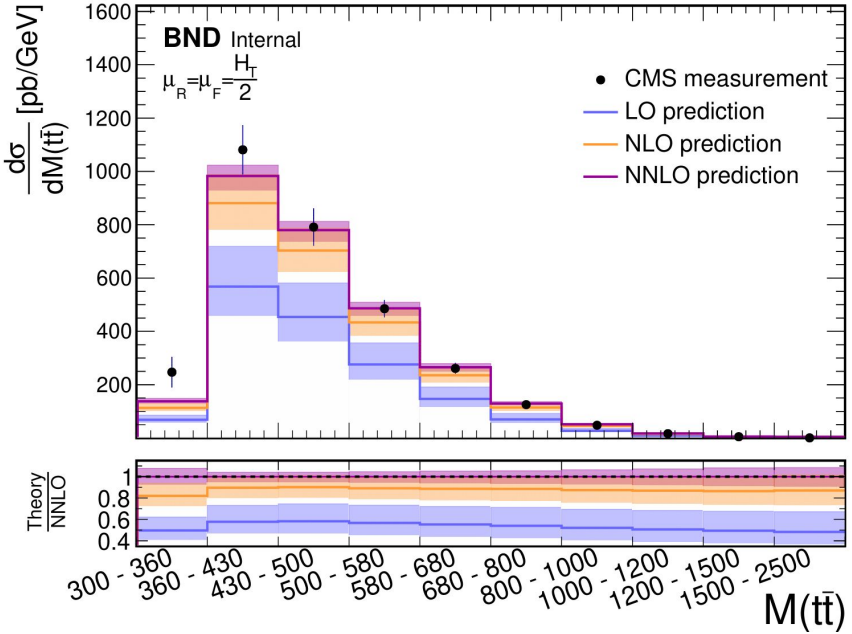
- **Different scales**





So which scale is the best?





- ✚ Smaller NNLO variations for HT/4
- ✚ Better agreement between orders for HT/4
- ▬ Asymmetric uncertainties for HT/4

What did we learn?

- **Theoretical uncertainties :**
  - **Patience:**
    - MC integrations ⇒ Takes (lots of) time
    - Orders of integration are limited
  - **Interpretation:**
    - Why do some scales work better?
    - Best choice is not absolute
  - **Scale variations ≠ uncertainties:**
    - Estimation of an uncertainty
  - **The power of teamwork is like a unicorn**
    - When in doubt, drink coffee