Outlook/first results for Run-3 in CMS:

Measurement of $\sigma_{t\bar{t}}$ at $\sqrt{s} = 13.6$ TeV with the CMS detector

TOP 2022, Durham

→ as seen in poster by Laurids Jeppe

Evan Altair Ranken

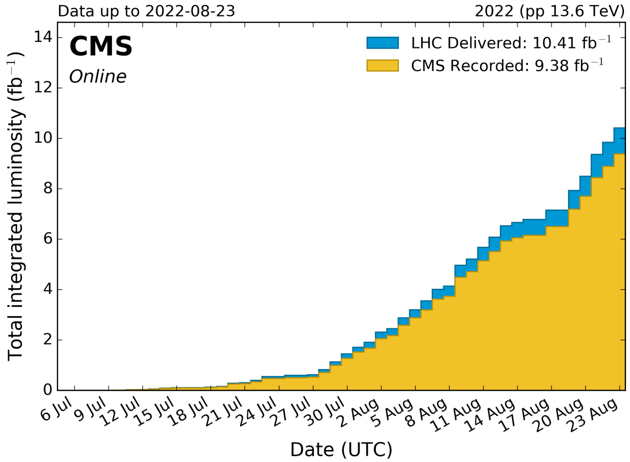
on behalf of the CMS Collaboration

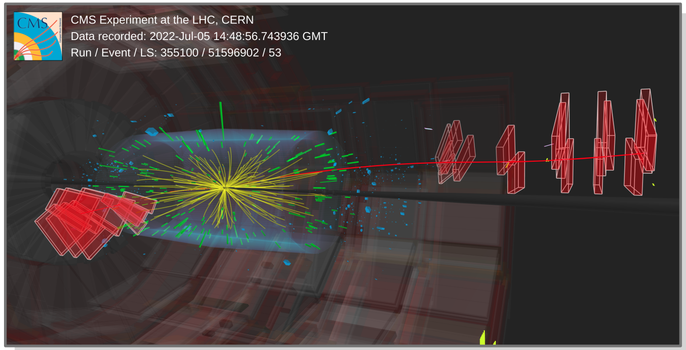
08.09.2022

Introduction

Run-3 has begun!

About 10 fb^{-1} collected by CMS at $\sqrt{s} = 13.6$ TeV





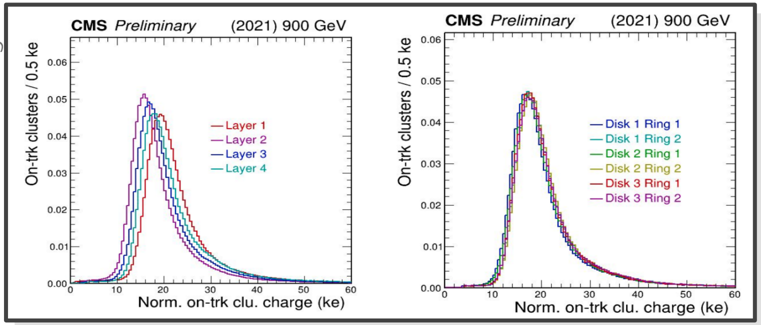
CMS-PHO-EVENTS-2022-030-8

Run-3: an upgraded endeavor

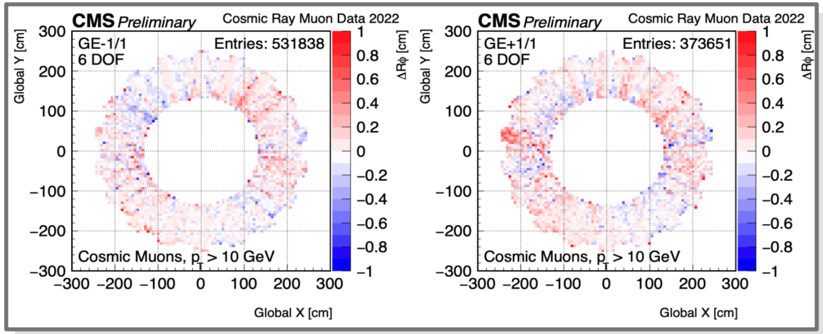
- Numerous upgrades during LHC long shutdown 2

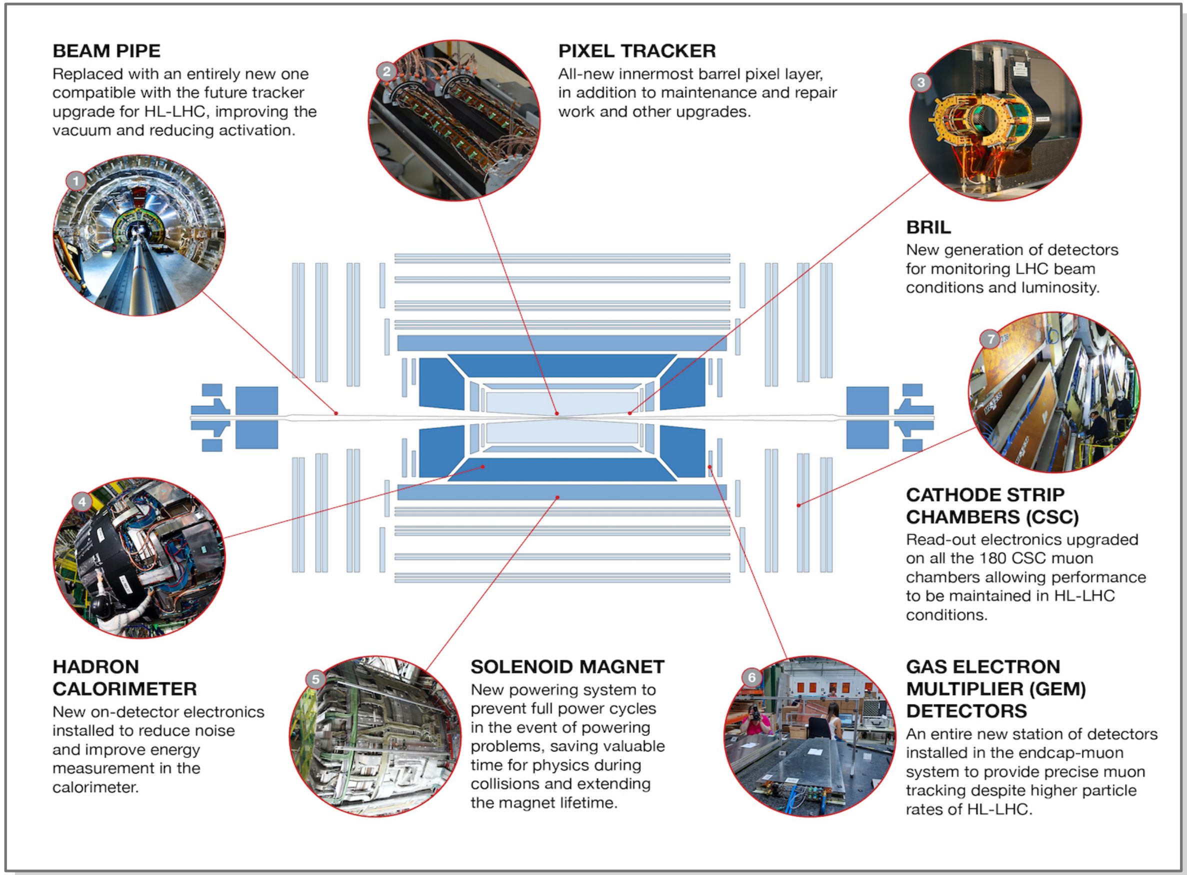
  → preparations for HL-LHC underway!

CMS-DP-2022-026
Tracker cluster charge



CMS-DP-2022-028

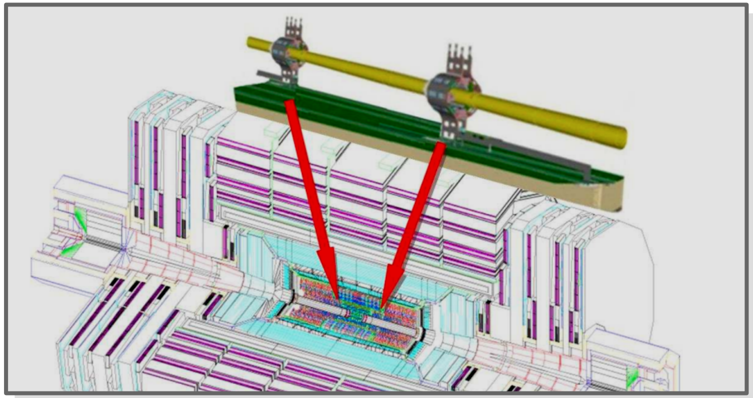




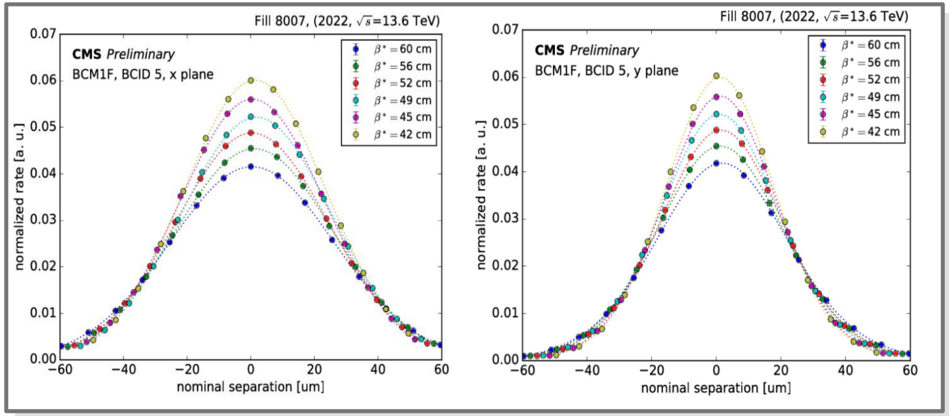
CERN-GRAPHICS-2022-007

Run-3: upgrades continued

- Luminometers: 3 separate inst. lumi measurements
  - BCM1F: more channels, silicon diodes for Run-3

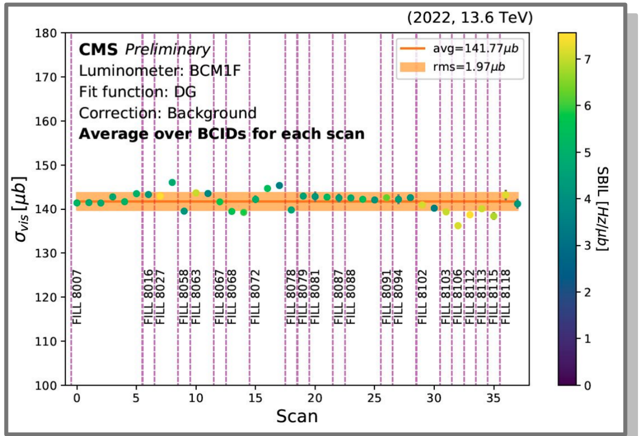


BCM1F beam profile

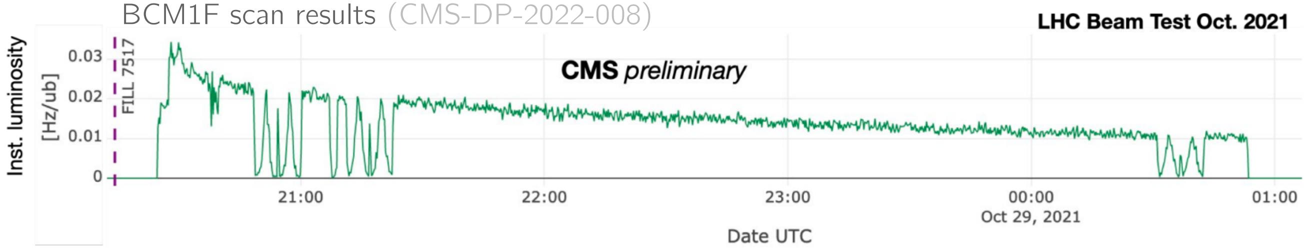


More Run-3 plots on the way!

BCM1F calibration constant measurement



BCM1F scan results (CMS-DP-2022-008)

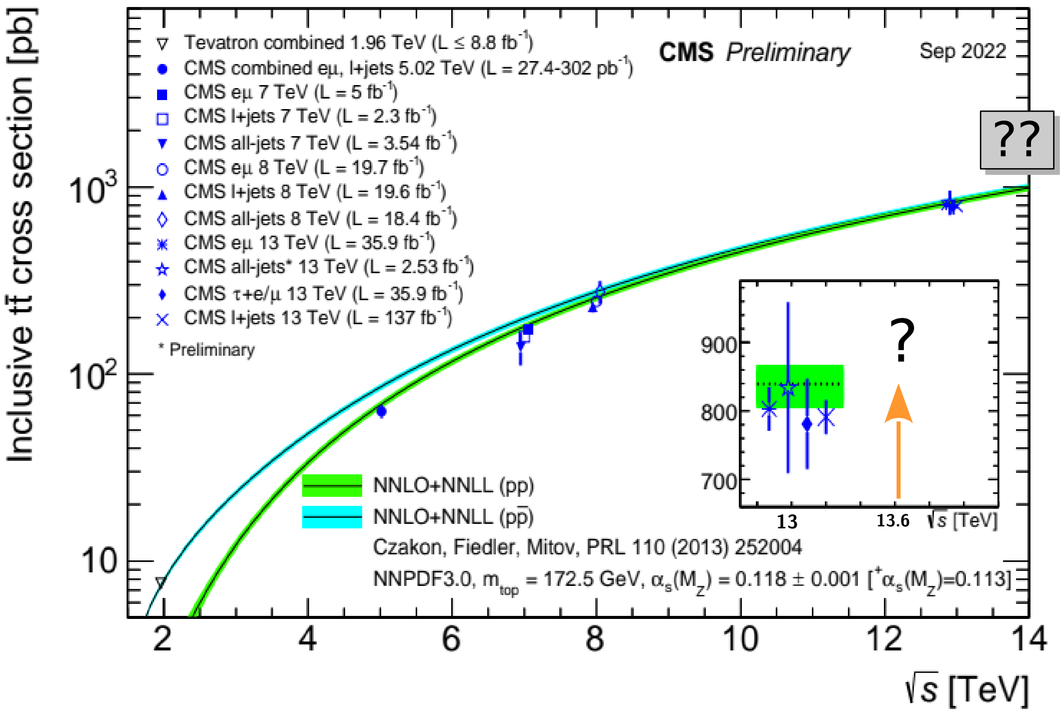


Top pair production in Run-3

σ_{tt} rises to **921 pb** at $\sqrt{s} = 13.6$ TeV

(from 834 pb in LHC Run-2)

Early opportunity to distinguish physics at the new energy frontier



Strategy & dataset

CMS presents a measurement of σ_{tt} using a new technique, specifically designed for early data

- Channel combination constrains lepton ID & b tag efficiencies *in situ:*

  ee, μμ, eμ, e+jets, μ+jets

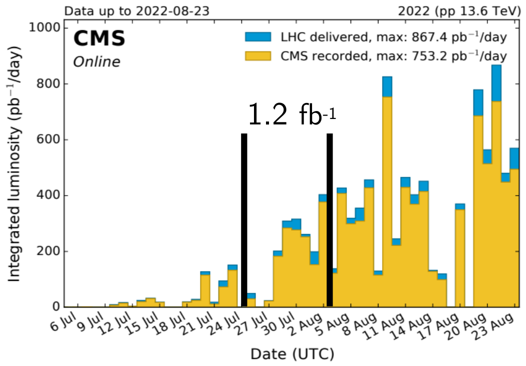
- Avoids the need for some general-purpose calibrations
- Can be adapted to future precision measurements

Dataset

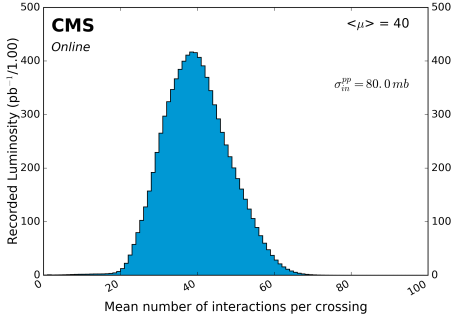
- 1.20 fb^{-1} +/- 6% of certified data

  collected from 27 July to 3 August

- Value & uncertainty come from emittance scans cross-checked by new Z-boson counting method



Expected pileup from measured lumi & LHC default σ_{in}



Lepton selection

- ID scale factors (SF) depend on lepton kinematics, but these variables are not needed for a simple cross section measurement
- Synchronize object selection between channels so that lepton offline efficiencies ϵ_μ and ϵ_e factorize, e.g.

– ee yield $\sim \epsilon_e^2$	– e+jets yield $\sim \epsilon_e$
– eμ yield $\sim \epsilon_e \epsilon_\mu$	– μ+jets yield $\sim \epsilon_\mu$
– μμ yield $\sim \epsilon_\mu^2$	

- Channel combination distinguishes the effect of lepton ID efficiencies from σ_{tt}
- Fit analysis-specific scale factors in situ, without general-purpose ID efficiency studies

Object selection

- **Lepton selection:**
  - $p_T > 35$ GeV
  - Tight cut-based IDs (70% signal efficiency) ported from Run-2
- **Jet selection:** AK4 jets
  - $p_T > 30$ GeV
  - b tagging: Deepjet algorithm
  - Bin content follows binomial distribution in tagging efficiency

$$\epsilon_b^{N_{\mathrm{b-tag}}} (1-\epsilon_b)^{N_{\mathrm{b-jet}} - N_{\mathrm{b-tag}}}$$

- **Dilepton:** at least 1 jet

ee, μμ: at least 1 b-jet

eμ: no b-tag requirement

- **Lepton+jets**

at least 3 jets

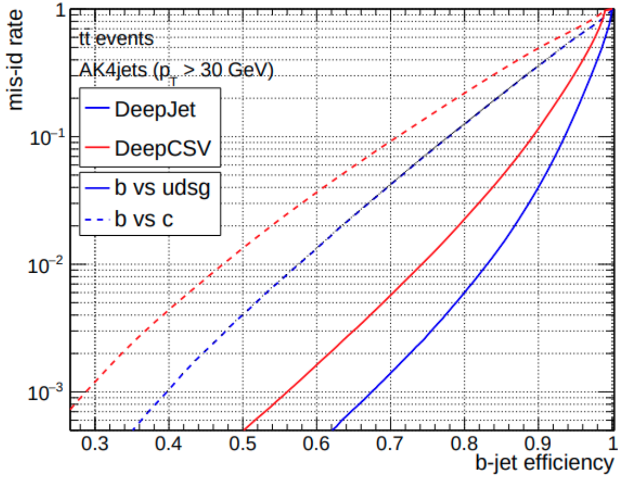
at least 1 b-tagged jet

- Lepton+jets channel:

define hadronic W with 2 highest p_T non-b-tagged jets

→ use for coarse jet energy calibration (JEC)

(sensitive to large discrepancies in data/MC)



ArXiv:2008.10519 (@ 13 TeV)

Other corrections and backgrounds

Pileup

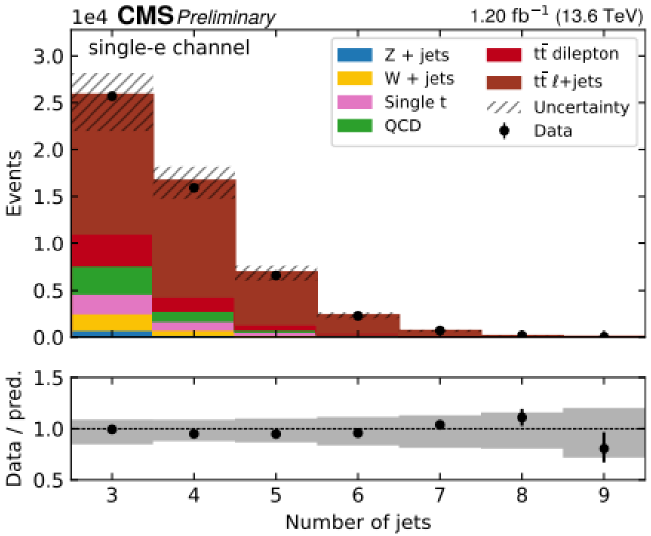
- Reweight based on 3 pileup-related variables:
  - N_{vertex}
  - Tracker energy flux
  - Calorimeter energy flux

Drell Yan normalization

- Background content depends on b-jet multiplicity
- Check against data-driven estimate:
  ratio of Z events inside/outside Z-peak sideband
- Consistent with unity

Non-prompt lepton background (QCD)

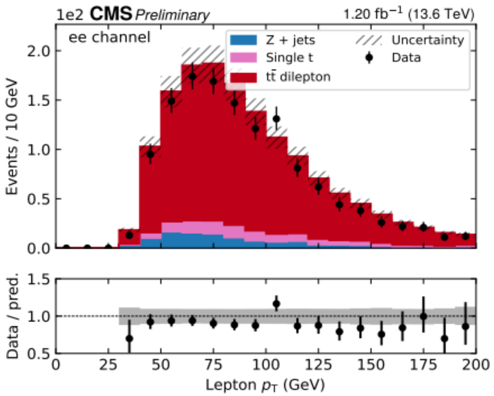
- data-driven estimation
- Use lepton isolation sideband, 1-jet sideband

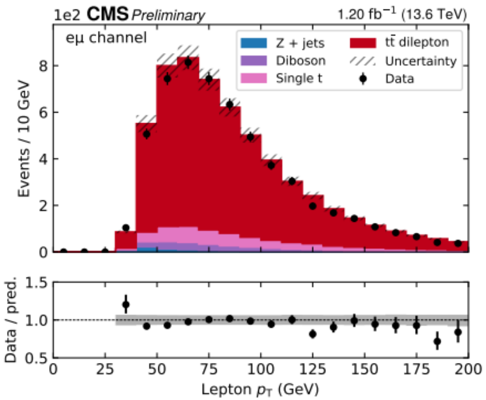


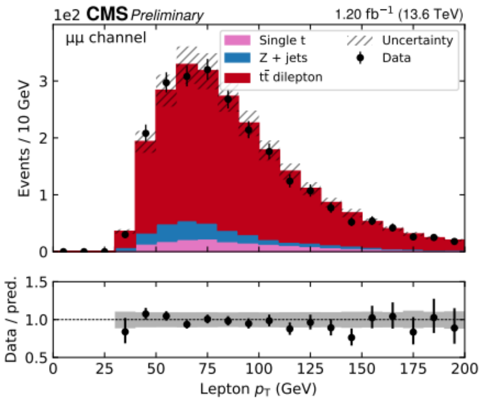
Control plots: dilepton

ee | eμ | μμ

leading lepton p_T







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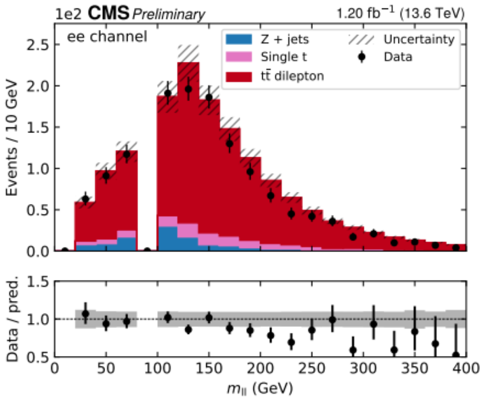
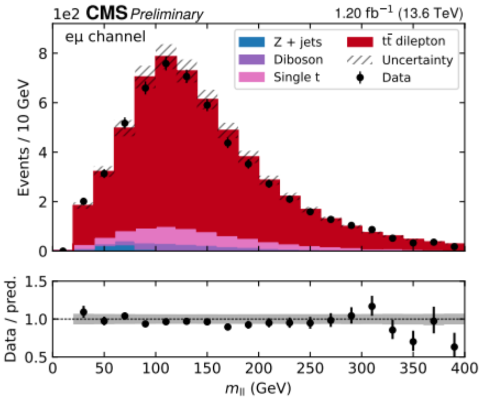
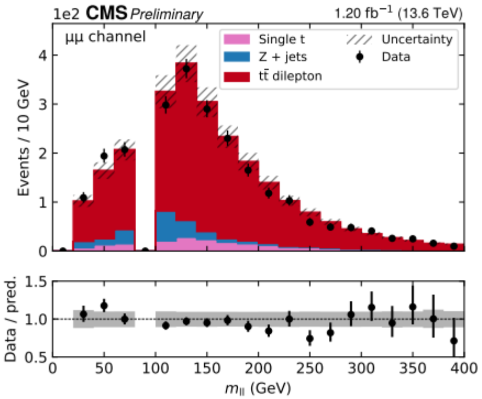






Uncertainty bands not including

Lepton ID SF

(floating parameter)

Post-fit lepton ID SF applied

Not all distributions need precise calibration

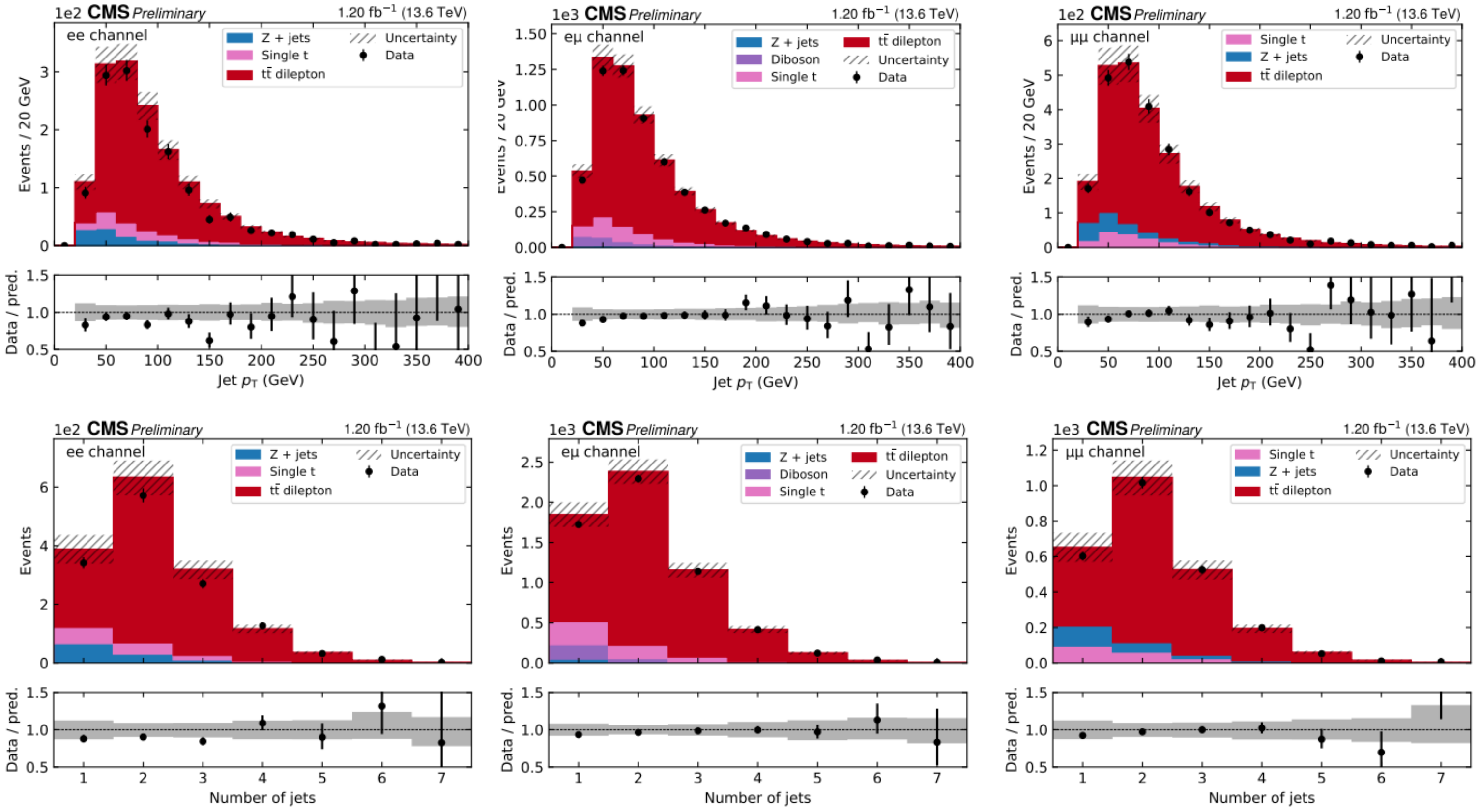
We are looking for slopes, any major mismodeling

Control plots: dilepton

ee | eμ | μμ

leading jet p_T

N (jets)



Uncertainty bands not including

Lepton ID SF

(floating parameter)

Post-fit lepton ID SF applied

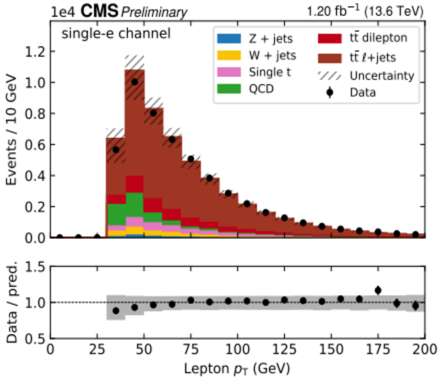
Not all distributions need precise calibration

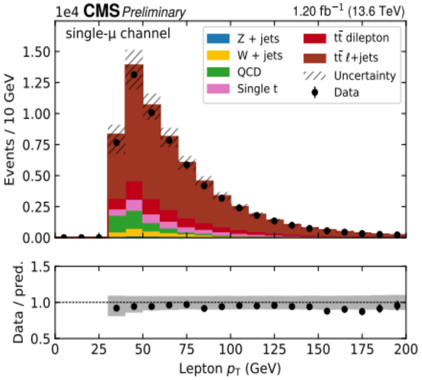
We are looking for slopes, any major mismodeling

Control plots: lepton+jets

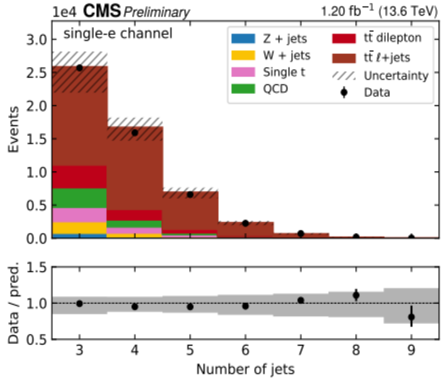
e+jets | μ+jets | e+jets | μ+jets

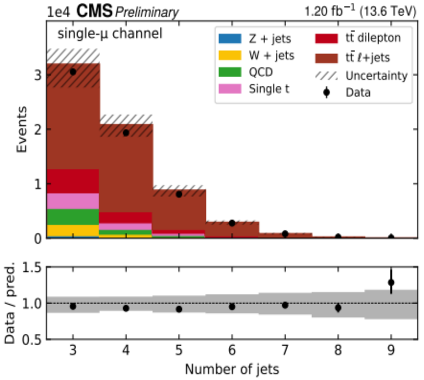
lepton p_T



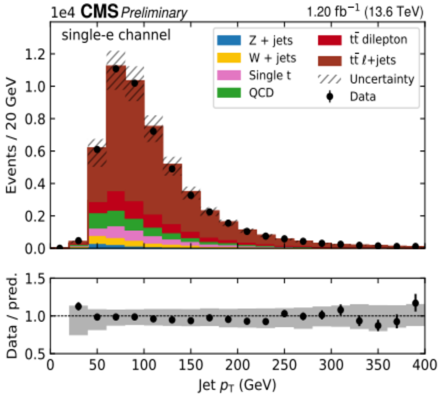


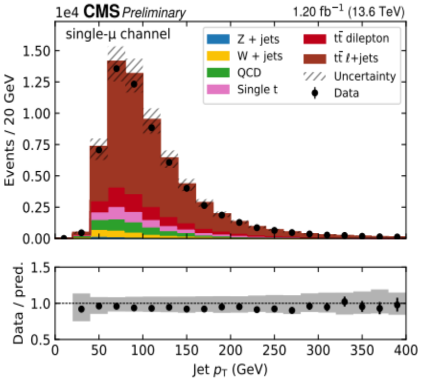
N (jets)



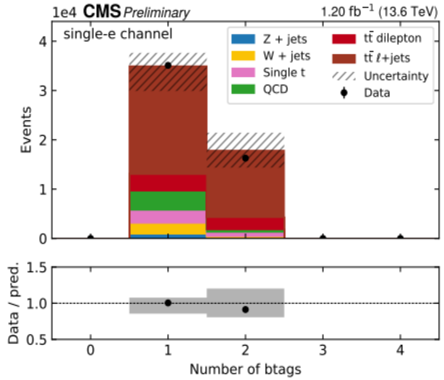


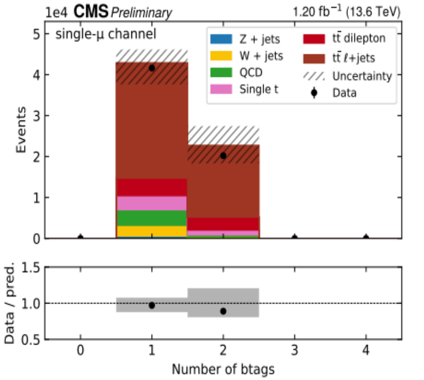
Jet p_T





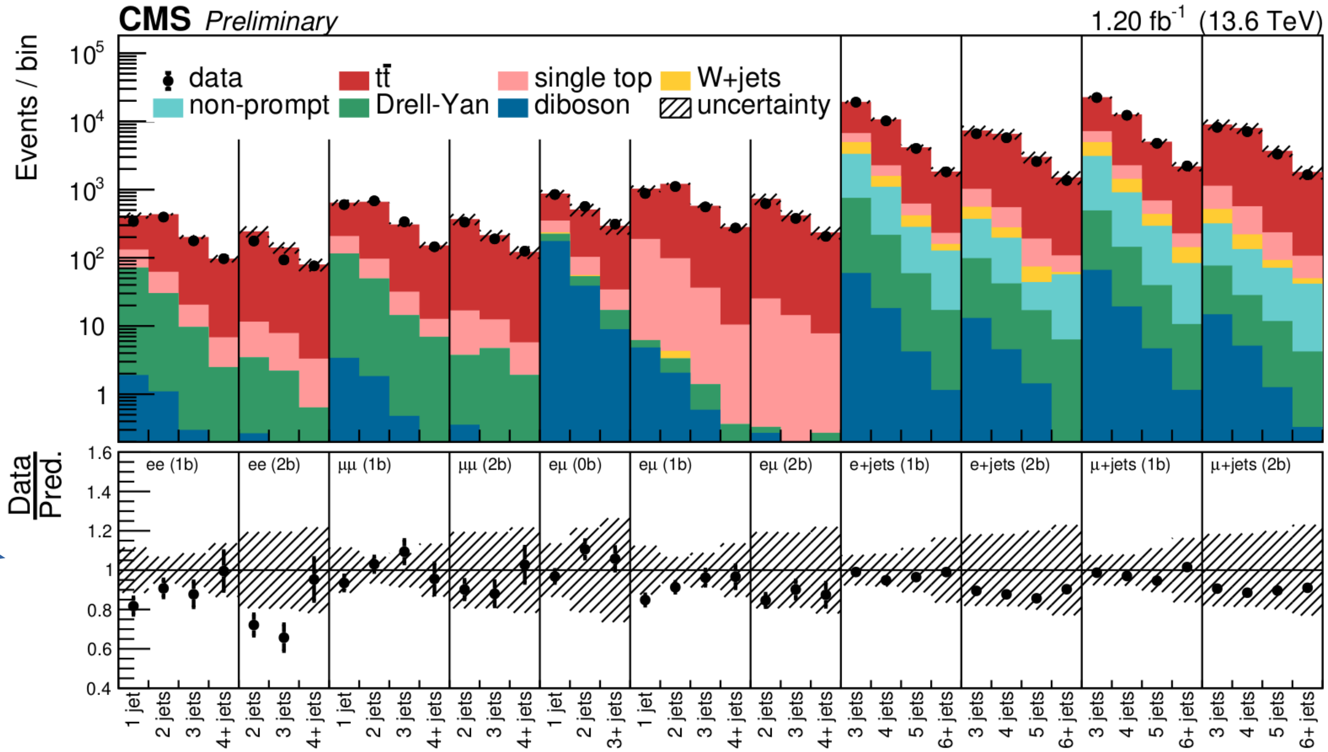
N (b jets)





Analysis binning

- Channels defined by lepton content
  - → further separated by b jet content
  - → coarsely binned in N_{jet}
- **Final binning** (pre-fit)
- Note:
  No lepton SF applied,
  No associated unc.



Statistical methods

- Maximum likelihood (ML) fit: $\mathcal{L} = \prod_{\text{bin}} \mathcal{L}_{\text{bin}}$, $\mathcal{L}_{\text{bin}} = \Gamma\left[n_{\text{obs}}^{\text{bin}} \middle| r\, s^{\text{bin}}(\{\theta_i\}) + b^{\text{bin}}(\{\theta_i\}) \right] \times \prod_i p_i(\theta_i)$

  - Statistical fluctuations:
    → Poisson distribution
  - Normalization uncertainties:
    → log-normal distribution
  - Binned shape effects:
    → template morphing
  - Lepton scale factors:
    → floating parameters (flat pdf)

$$\Gamma[n|\lambda] = \frac{\lambda^n e^{-\lambda}}{n!}$$

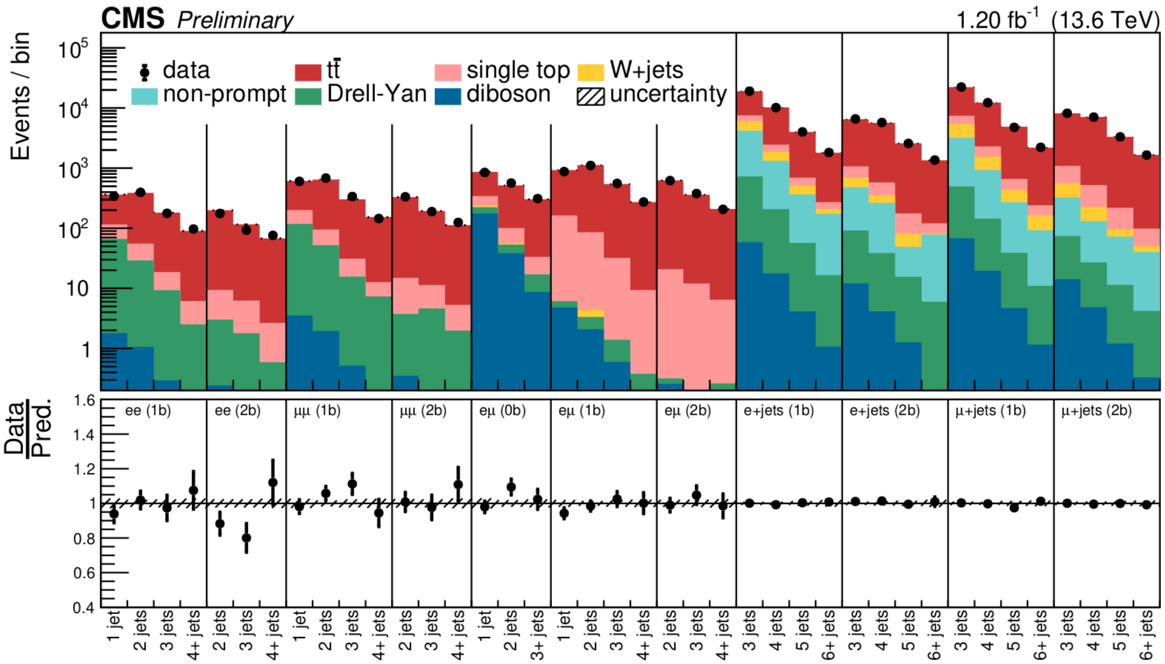
$$\begin{aligned} s &= \text{signal} \\ b &= \text{background} \\ \{\theta_i\} &= \text{nuisances} \\ p_i(\theta_i) &= \text{penalties} \end{aligned}$$

Jet calibrations:

- Only preliminary calibrations available for 2022 data
- We use a coarse calibration based on hadronic W mass for the nominal case (+ standard uncs.)
- Difference with preliminary calibrations taken as an externalized uncertainty

Result

$$\sigma_{t\bar{t}} = 887^{+43}_{-41}(\text{stat} + \text{sys}) \pm 53(\text{lumi})\,\text{pb}$$



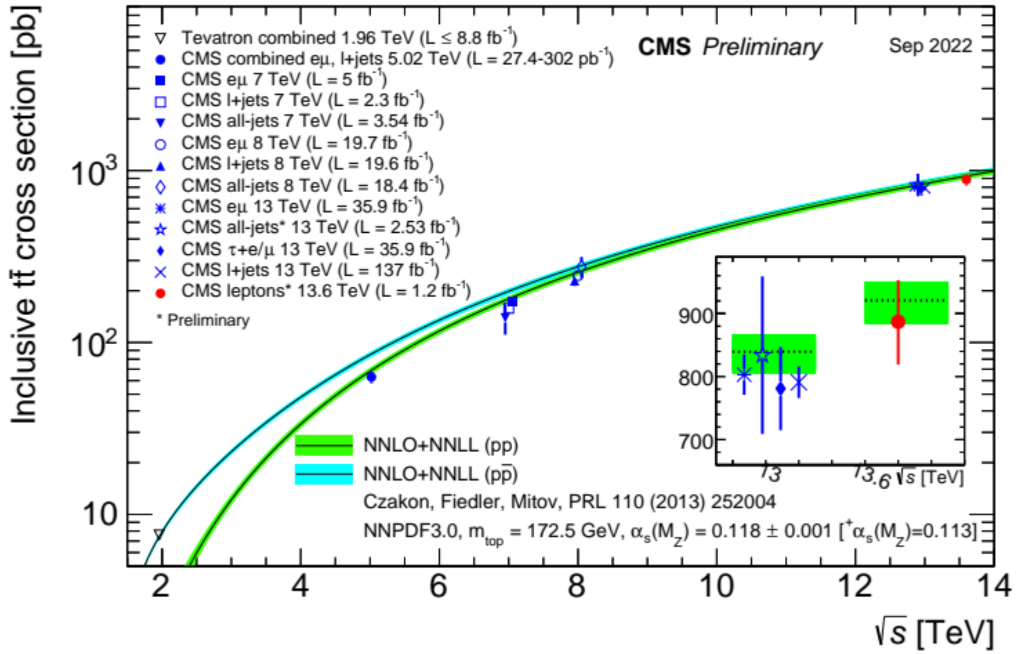
Dominant uncertainties:

Source	Uncertainty (%)
Lepton ID SF	3.4
Jet energy scale	1.6
b tagging SF	1.5
ME/PS matching	1.1
Drell-Yan background	0.9
Pileup	0.7
combined likelihood fit	4
Jet calibration (external)	2
luminosity (external)	6

$$\sigma_{t\bar{t}} = 887^{+68}_{-67}\,\text{pb}$$

Conclusion

- We are excited to kick off the study of top quark physics at a new energy frontier!
- CMS data taking has begun, and data is rapidly becoming available for analysis
- We present a novel early measurement which uses multiple channels to constrain efficiencies *in situ*
- **Top quark physics has arrived @ LHC Run-3!**



First measurement of top quark production by CMS at $\sqrt{s}$ = 13.6 TeV!

$$\sigma_{t\bar{t}} = 887^{+43}_{-41}(\text{stat} + \text{sys}) \pm 53(\text{lumi})\,\text{pb}$$

CMS-PAS-TOP-22-012
(online very soon!)