W mass in CMS: status and prospects

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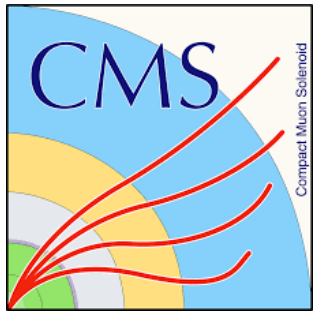

The experimental program in **PRIN 2017F28R78**

- **WP1: Muon scale calibration**
  - Local tracker calibration
  - Momentum calibration
  - FSR in J/Ψ
- **WP2: Differential Drell-Yan**
  - q_T, $|y|$, A_i in CC Drell-Yan
  - q_T, $|y|$, Q in NC Drell-Yan
- **WP3: *W* mass**
  - Framework
  - Fit optimization
  - Systematics

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Preliminary results presented by Suvankar at ICHEP2020
Part of the new calibration?

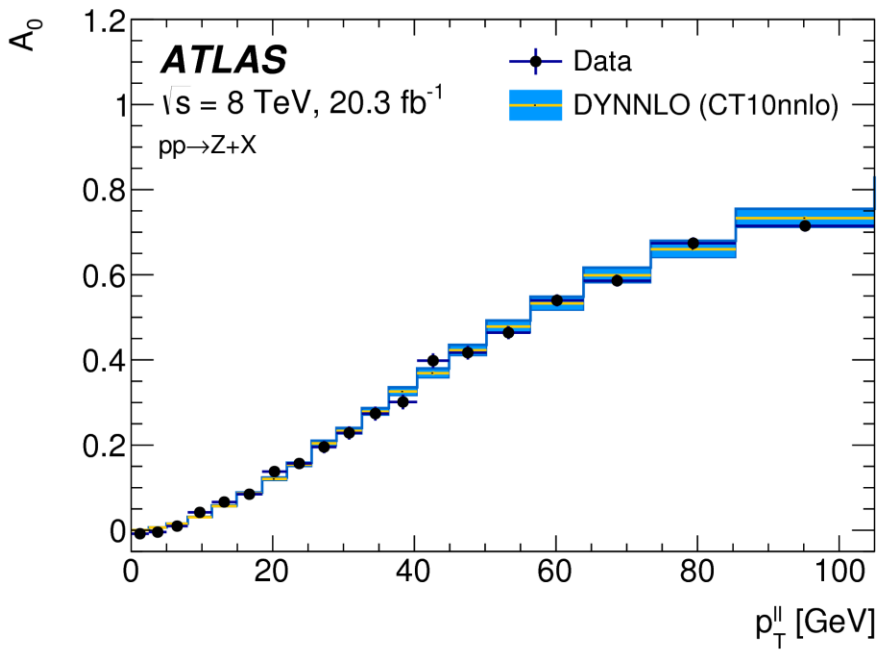
In tandem

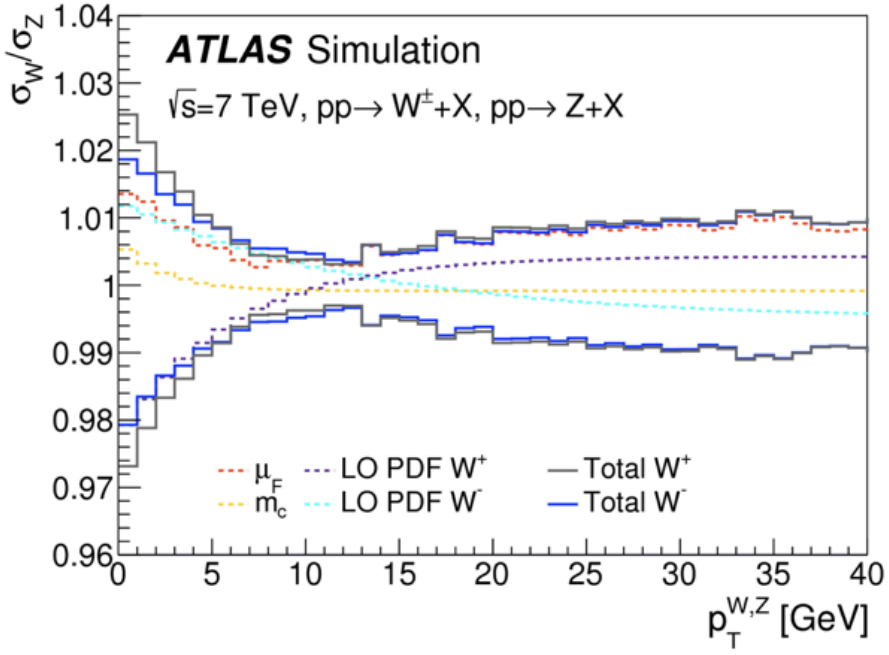
Not by us directly
- $d\sigma/dQ$ → JHEP12(2019)059
- $d\sigma/dq_T$ → JHEP12(2019)061
- $d^2\sigma/dQdq_T$ → SMP-20-003 to be submitted soon

To be finalized

Preamble: *W* mass in CMS

- CMS guidelines: avoid treatment of theory uncert. *a' la* ATLAS
  - *Z*-to-*W* porting w/ tuned PYTHIA8 resulted in aggressive QCD uncertainty
    - And in tension with resumed calculations and other collider data (→ PRD 103 (2021) 012003)



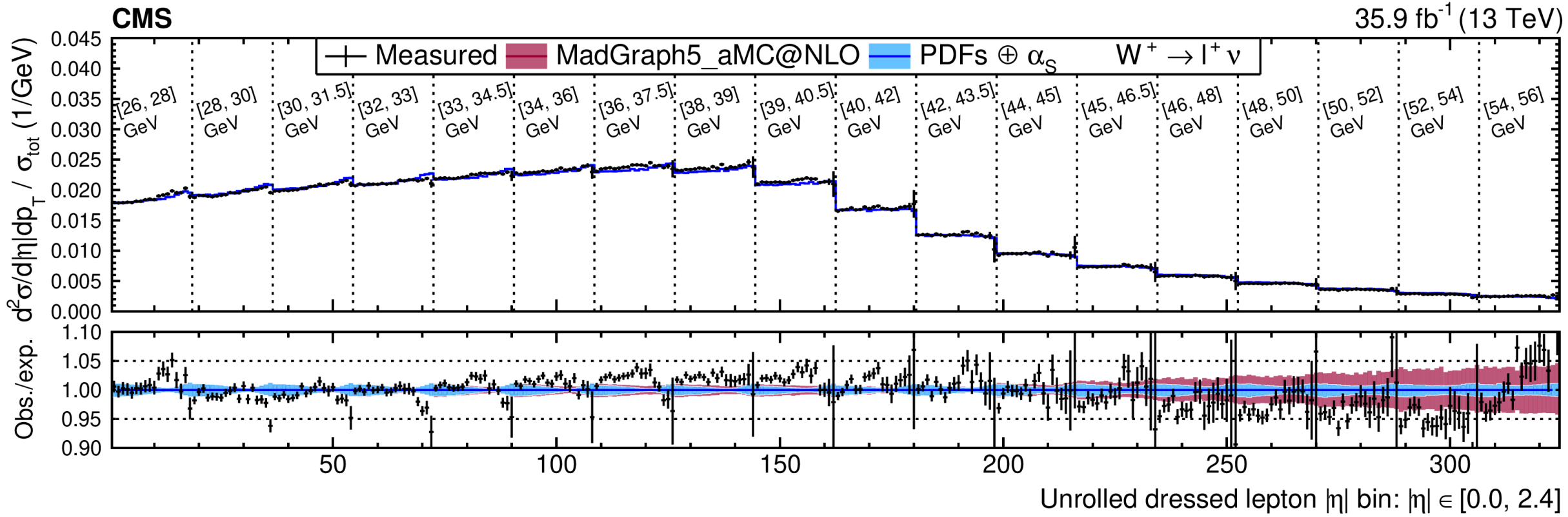


Preamble: *W* mass in CMS

Two roads have been thus pursued by CMS:

- Perform **ancillary measurements** to constrain model parameters
  - e.g.: charge asymmetry measurement → more precise PDFs → smaller Δ_{PDF}
- Use **state-of-the-art calculations** taken with their native uncertainties
  - NLO_{PS} → $NNLO_{PS}$
  - $(N^2)LL$ → N^3LL
  - NNPDF3.0 → NNPDF3.1

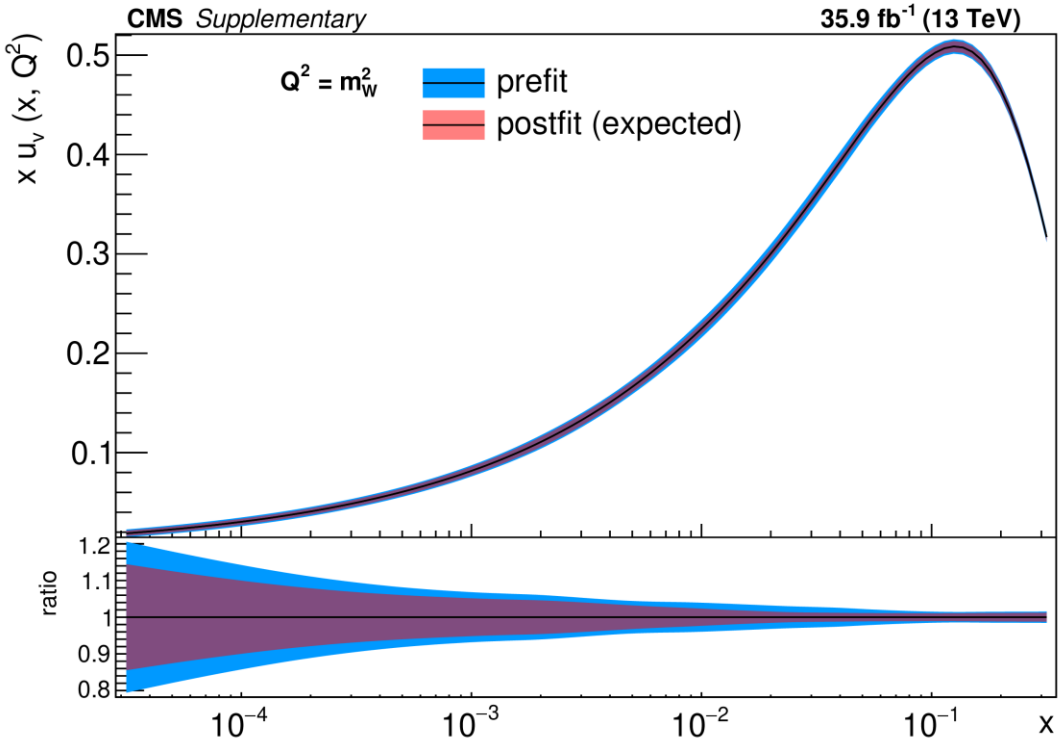
Rapidity, helicity, 2D x-sections, and charge asymmetry

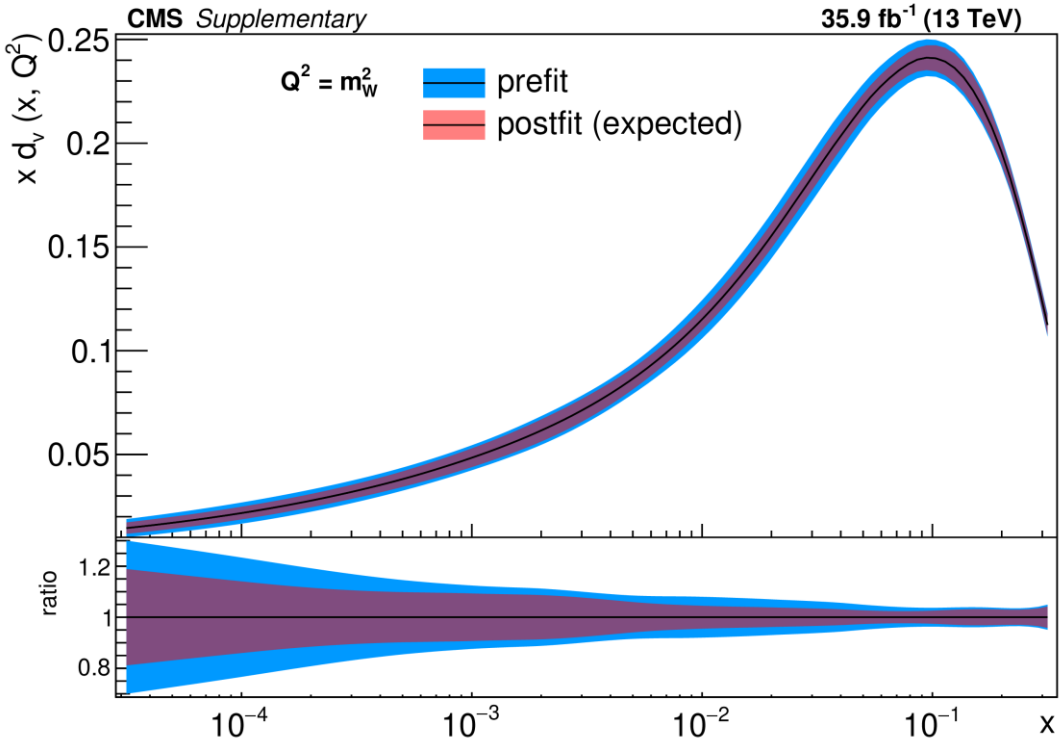


PRD 102 (2020) 092012

Rapidity, helicity, 2D x-sections, and charge asymmetry

- High-precision and granularity 2D measurement constrains the PDFs
  - Though not a rigorous PDF fit, constraining power is evident





http://cms-results.web.cern.ch/cms-results/public-results/publications/SMP-18-012/

Known limitations

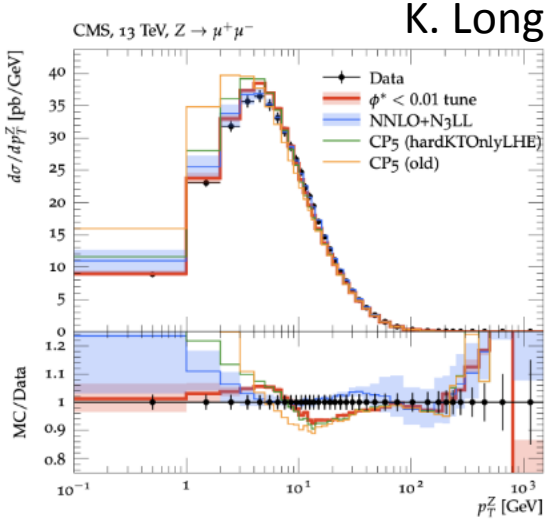
- Reference MC for *W*-helicity: MG5_aMC@NLO + Pythia8
  - Small statistic (→ L_{eq} = 5/fb)
  - Large ren./fact. scale uncertainties and only LL-accurate at low q_T
  - Poor treatment of QED (LL-accurate)
- Using best muon calibration at that moment (→ EPJC 72 (2012) 2194)
  - Mostly a benchmark for HZZ4l
  - Precision not sufficient for M_W
- Some further descoping needed before moving to next steps:
  - Drop electron channel
  - No transverse mass fit
  - Restrict to well understood sub-sample of Run 2 data

https://indico.cern.ch/event/1018618/#1-w-mass-measurement

Highlights on the new MC

- Generation of dedicated **MiNNLO$_{PS}$ + Pythia (QCD) + Photos (QED FSR)** samples has been a major achievement
  - L_{eq}~ 30/fb with 9% of negative events for both for CC and NC Drell-Yan → ~1B events in full simulation
- Several iterations required before…
  - attaining formal NNLO accuracy (→ MiNNLO issue)
  - get all needed weights (→ CMSSW issues)
- *Ad hoc* Pythia tune was made to match this MC to published CMS Z q_T and ϕ^* data at 13 TeV
  - Providing a better pre-fit modeling

K. Long

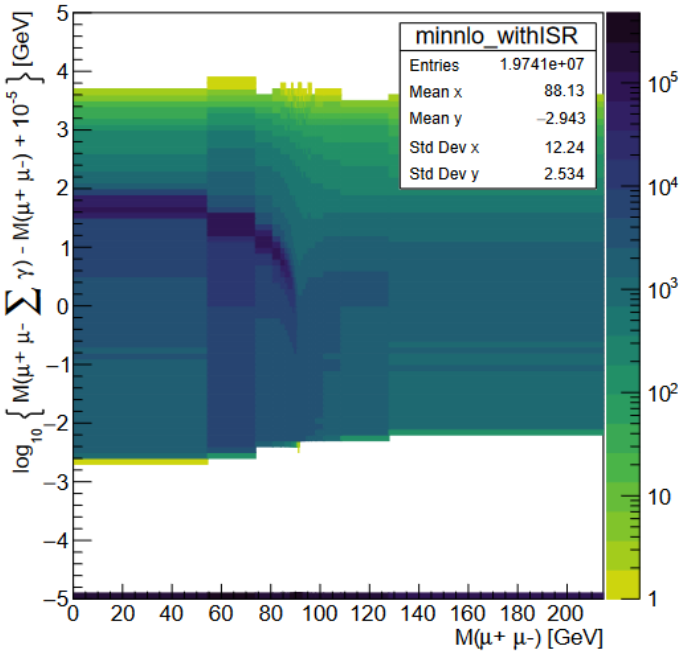


SMP-17-010 data
Best tune for MiNNLO+Pythia
CP5 tune with/without fix

Highlights on the new MC

- QED FSR now handled by Photos
  - Reweighting to **Horace 'new exp'** (→ matched O(α) EW and h.o. QED) in 2D-space m_{ll} *vs* $\log(m_{ll(\Sigma\gamma)} - m_{ll} + \varepsilon)$
    - Check impact of QED ISR unaccounted for by Photos
    - Reduced uncertainty from EW m.h.o
- Reweighting of $d\sigma/dq_T$ to SCETlib (→ N^{3}LL matched to NNLO)
  - Preferred over others due to shorter execution time

M. Seidel



- Strategy to marginalize the ren./fact. scales within the fit to be finalized
  - Likely, a combination of log-normal priors decorrelated in bins of q_T and $|y|$ of sizes:

    $\sigma(\mu_R\uparrow, \mu_F)/\sigma(\mu_R,\mu_F)$

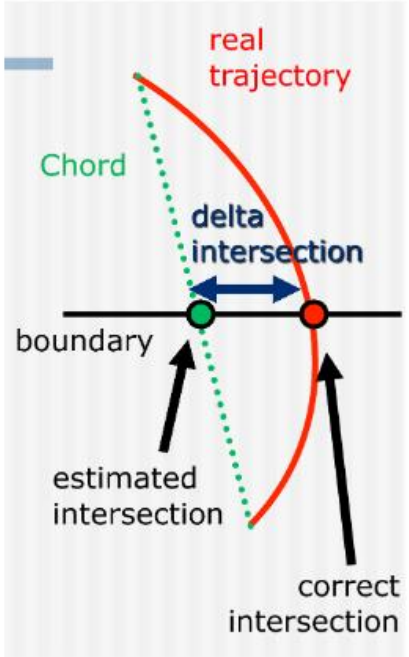
    $\sigma(\mu_R, \mu_F\uparrow)/\sigma(\mu_R,\mu_F)$

    $\sigma(\mu_R\uparrow, \mu_F\uparrow)/\sigma(\mu_R,\mu_F)$

Muon scale calibration

- Original plan was to use analytical model to parametrize curvature biases
  - Large non-closure was spotted long ago by Elisabetta and Gigi
  - Among others: issue in Geant Surface Interection Precision, bias in smoothing step of KF-based fit (KF → GBL refit), …

- Scale calibration has undergone a deep refurbishment
  - Now resembling a complete re-alignment algorithm
  - Analytical method then possible on top or re-calibrated tracks



See Elisabetta's talk !!!

Framework

- A number of additional unexpected experimental bugs/issues were found
  - Muon pre-firing inefficiency (1-3% effect)
  - Dynamical hit inefficiencies in Si strips (first half of 2016 data affected, ~1% effect)
  - Various bugs in MC generation

  ➔ Many re-processing of our lightweight analysis ntuples needed
- Analysis framework now able to handle large number of histograms exploiting multi-threading (RDataFrame)
  - Extensive use of a dedicated **AMD EPYC™ 7742** server with up to **256 threads**
- Statistical analysis (fit) now using a custom TensorFlow-based minimizer developed by CERN colleagues

See Suvankar's talk !!!

A few more thoughts

- With the profiling of PDFs and/or the advent of new PDF fits (→ NNPDF4.0), Δ_{PDF} will likely become sub-leading
- Uncertainty on q_T still remains
  - Reweighting to N^{3}LL will improve, but:
    - How much?
    - Which correlation scheme?
    - NP corrections?
  - Opportunity of including low-PU data (200/pb) under study, but likely not enough to make a real impact
- We are thus pursuing a third approach
  - M_W and model parameters in a single pass → **agnostic fit**

The agnostic fit

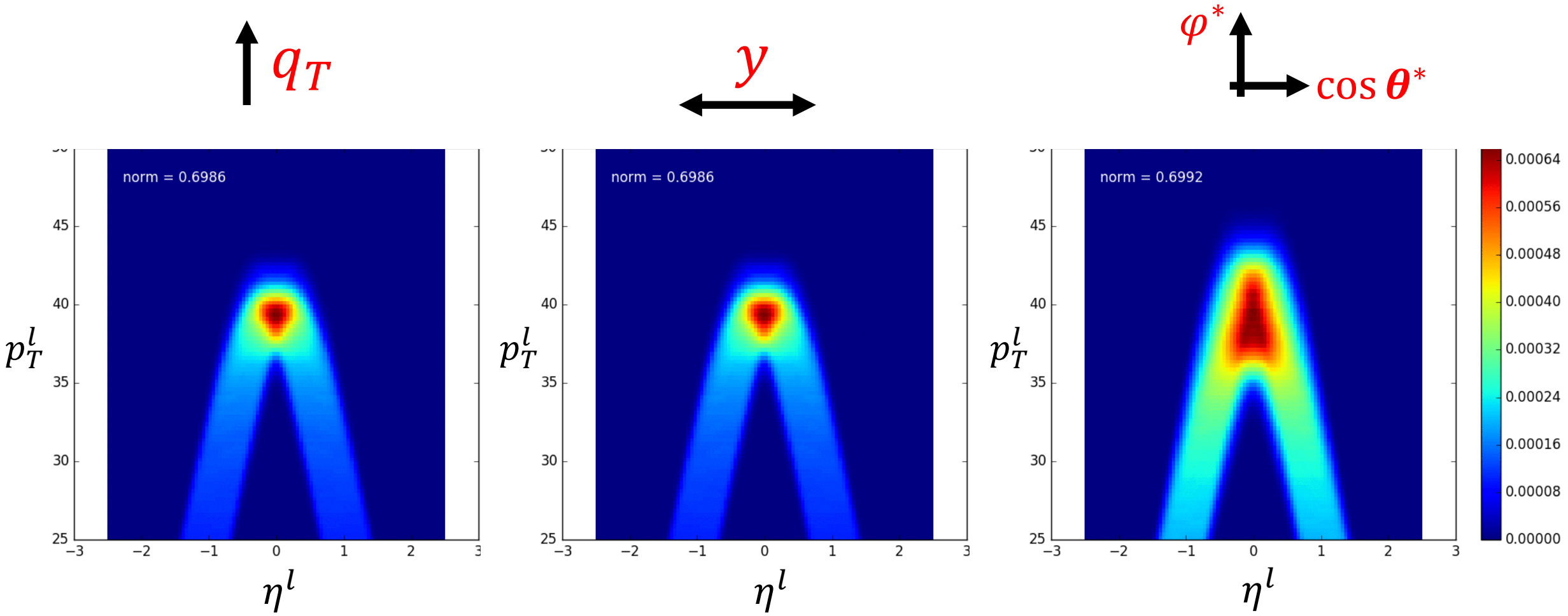
- Express the joint p.d.f. (p_T^l, η^l) as a linear combination of a set of templates:

$$\frac{\Delta^2\sigma}{\Delta p_T^l\,\Delta\eta^l} = \sum_{\Delta q_T,\Delta|y|} \frac{\Delta^2\boldsymbol{\sigma_{-1}}}{\Delta\boldsymbol{q_T}\,\Delta|\boldsymbol{y}|}\left(\boldsymbol{T_{-1}}(p_T,\eta\mid\boldsymbol{M_W}) + \sum_{i=0\ldots4} \boldsymbol{A_{i,\Delta q_T,\Delta|y|}} \times \boldsymbol{T_i}(p_T,\eta\mid\boldsymbol{M_W})\right)$$

- Unpolarized cross sections $\boldsymbol{\Delta^2\sigma_{-1}/\Delta q_T\,\Delta|y|}$ and angular coefficients $\boldsymbol{A_{i,\Delta q_T,\Delta|y|}}$ parametrize the *W* production & decay dynamics

- **Templates $\boldsymbol{T_i}$** are independent from any QCD
  - depend parametrically on $\boldsymbol{M_W}$

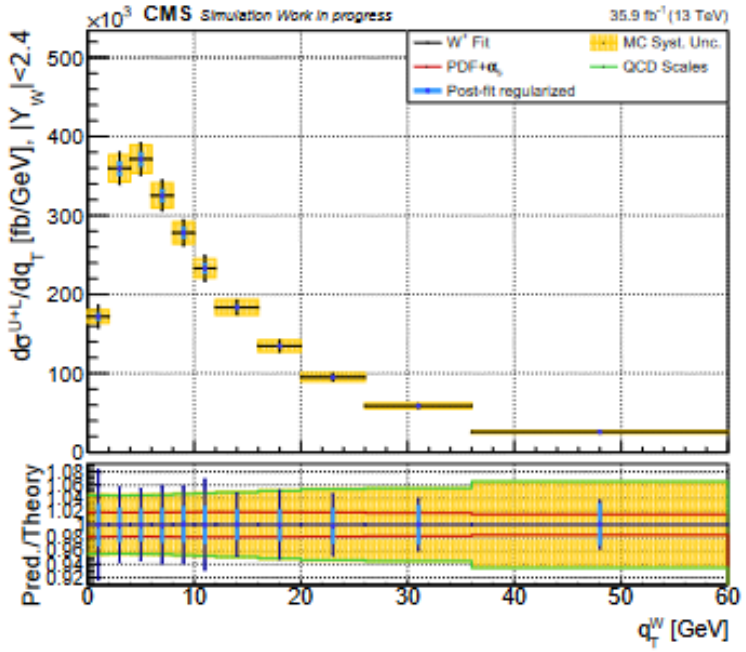
Templates in (p_T^l, η^l)

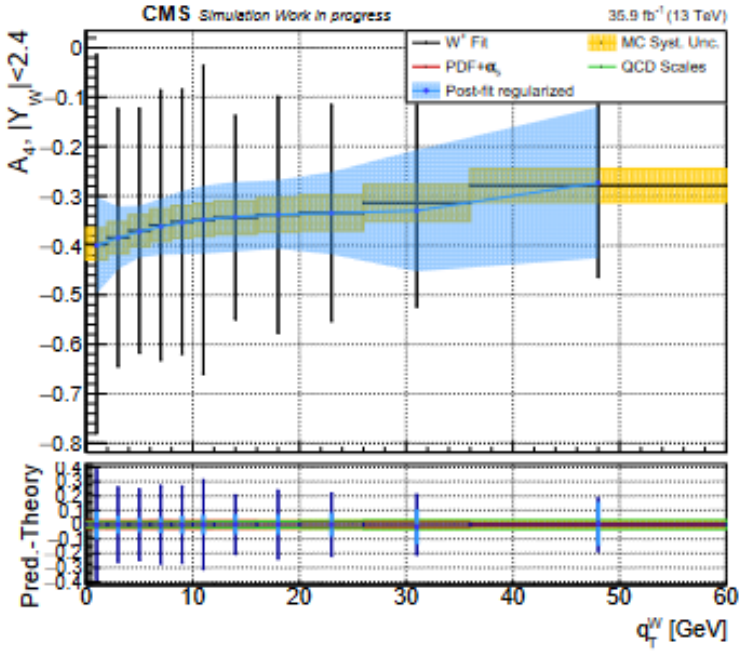


First results

- First round of agnostic fit deployed on 2016 data
  - Limited by finite size of aMC@NLO sample available at that time

Results are encouraging and cry out for a continuation of this analysis!





See Valerio's talk !!!
http://cds.cern.ch/record/2776894/files/?ln=it

Agnostic fit w/ new MC in Elisabetta's thesis → targeting first CMS paper on *W* mass

Looking ahead

- The agnostic approach benefits the most from statistics
  - Not necessarily better than a MC-driven approach on small data samples
  - Extension to full Run2 is a big challenge

- Thanks to new fundings from ERC (→ "ASYMOW" project) we can continue this effort towards a full Run2+Run3 result
  - The work done so far with the PRIN has been fundamental

    SPECIAL THANKS TO THE YOUNGEST!
  - Many challenges remain open:
    - Large-scale MC production of full simulation
    - Detector stability over three (+three) years of data taking
    - Dealing with a complicated fit model

Conclusions

- Even if in an extraordinarily troubled period, many steps forward have been achieved since our last meeting in Pisa:
  - https://indico.sns.it/event/18/

- We are confident that the first CMS *W* mass result is behind the corner. **Financial support from the PRIN has been very important**

- Many new opportunities are coming soon!

Finally… Thanks a lot, Alessandro, for organizing this meeting!