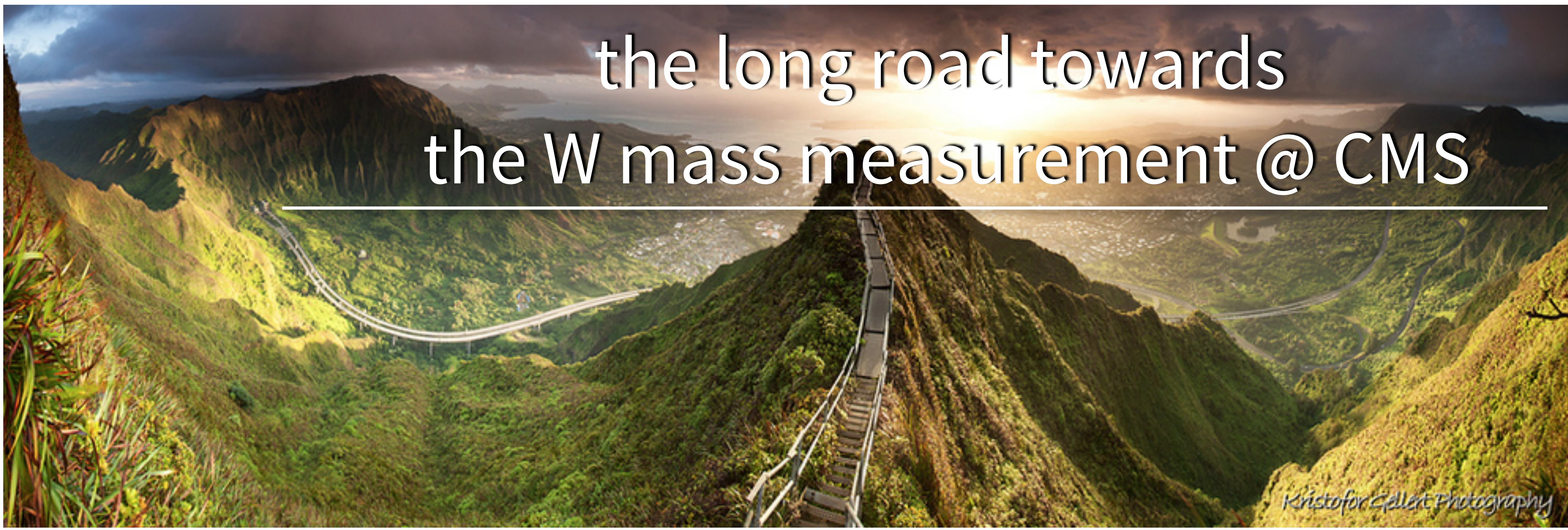
the long road towards the W mass measurement @ CMS

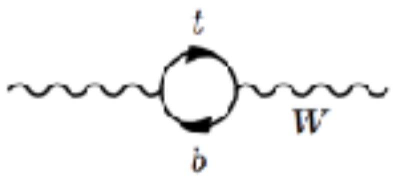


Elisabetta Manca
Scuola Normale Superiore and INFN Pisa
on behalf of the CMS W mass group

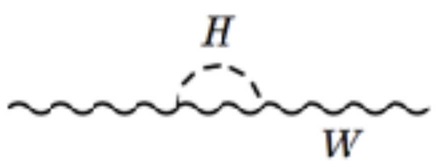
CMS Italia 2017 - Piacenza

image: “Stairway to Heaven”,
island of O‘ahu, Hawaii

why a precise measurement of the W mass?



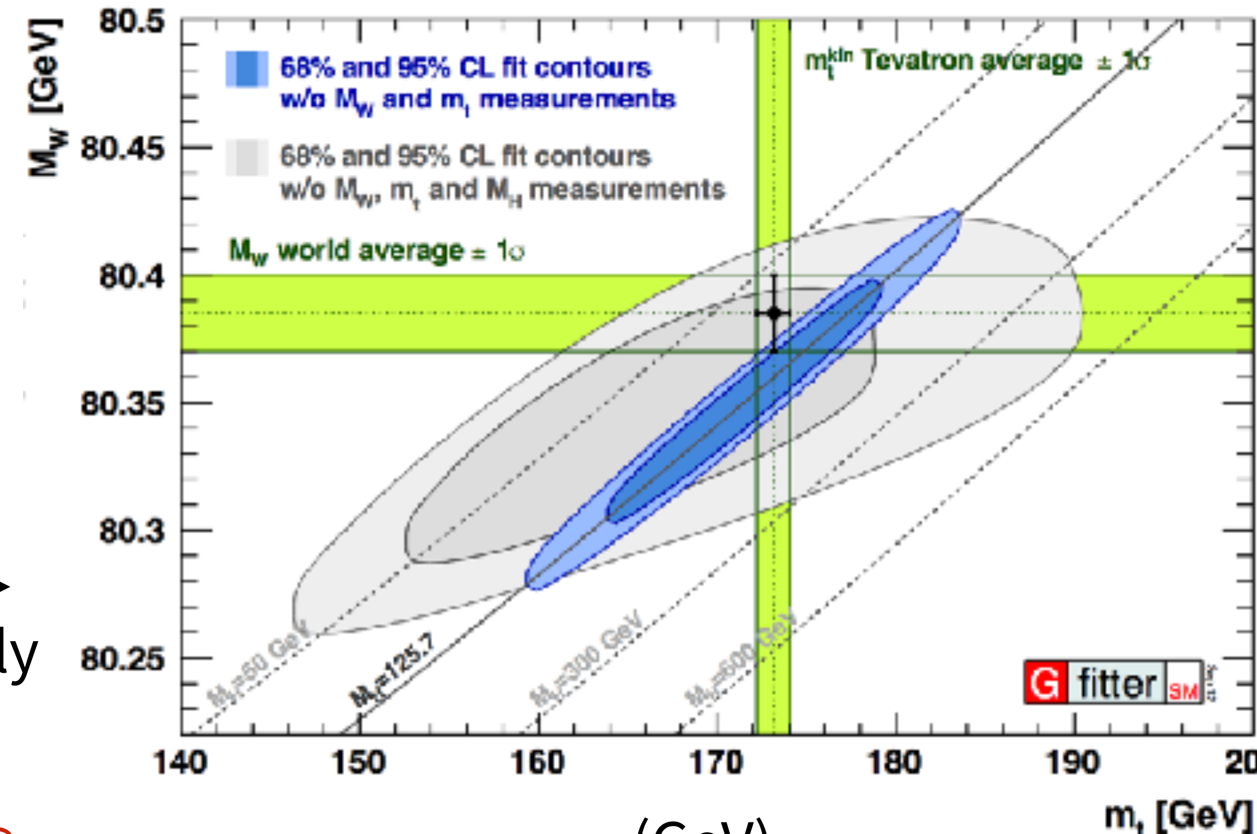
$\sim (M_{top}/M_W)^2$



$\sim \log(M_H/M_W)$

radiative corrections in SM induce relations among M_W, M_H and M_{top}

check → experimentally



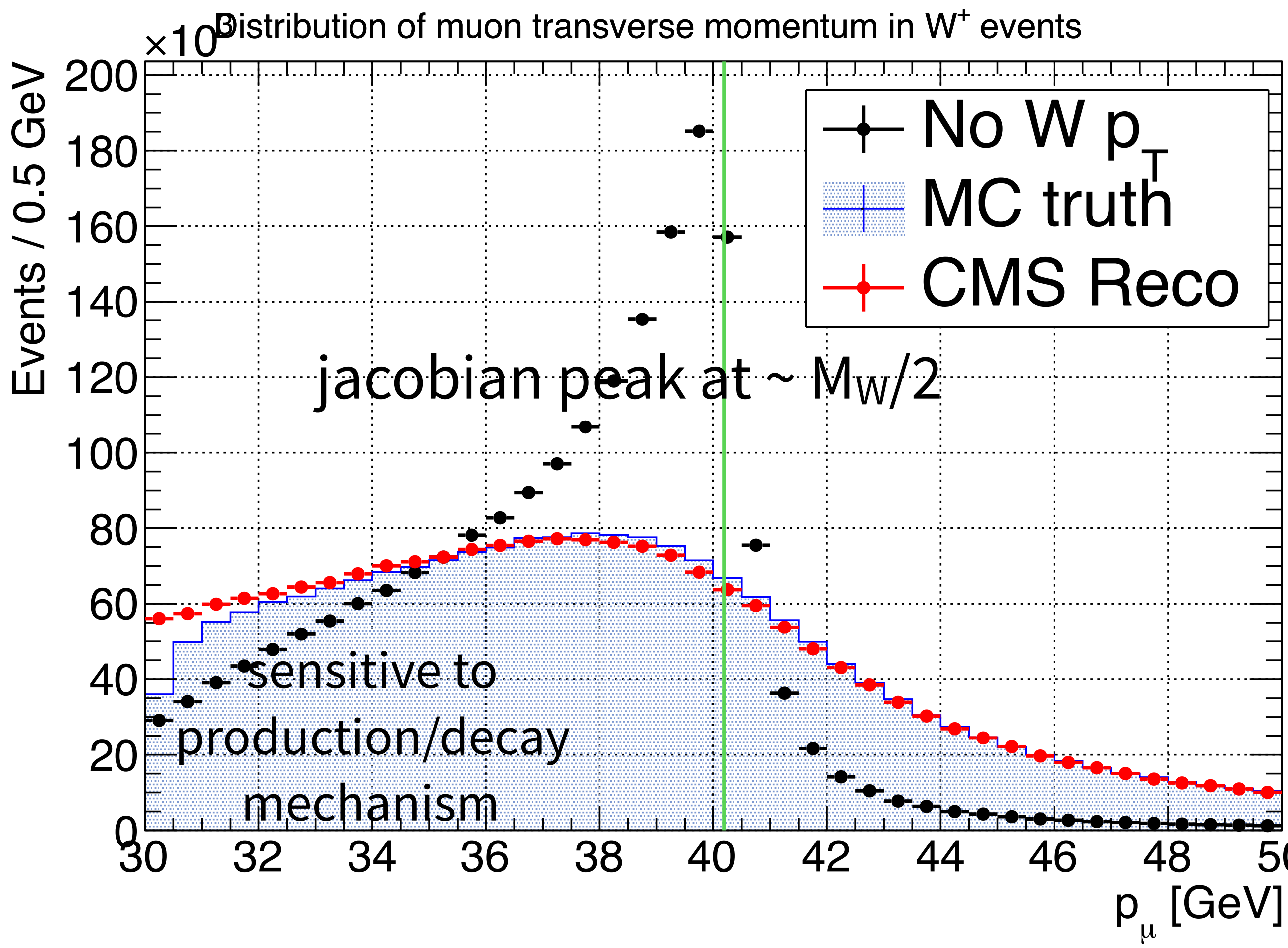
(GeV)

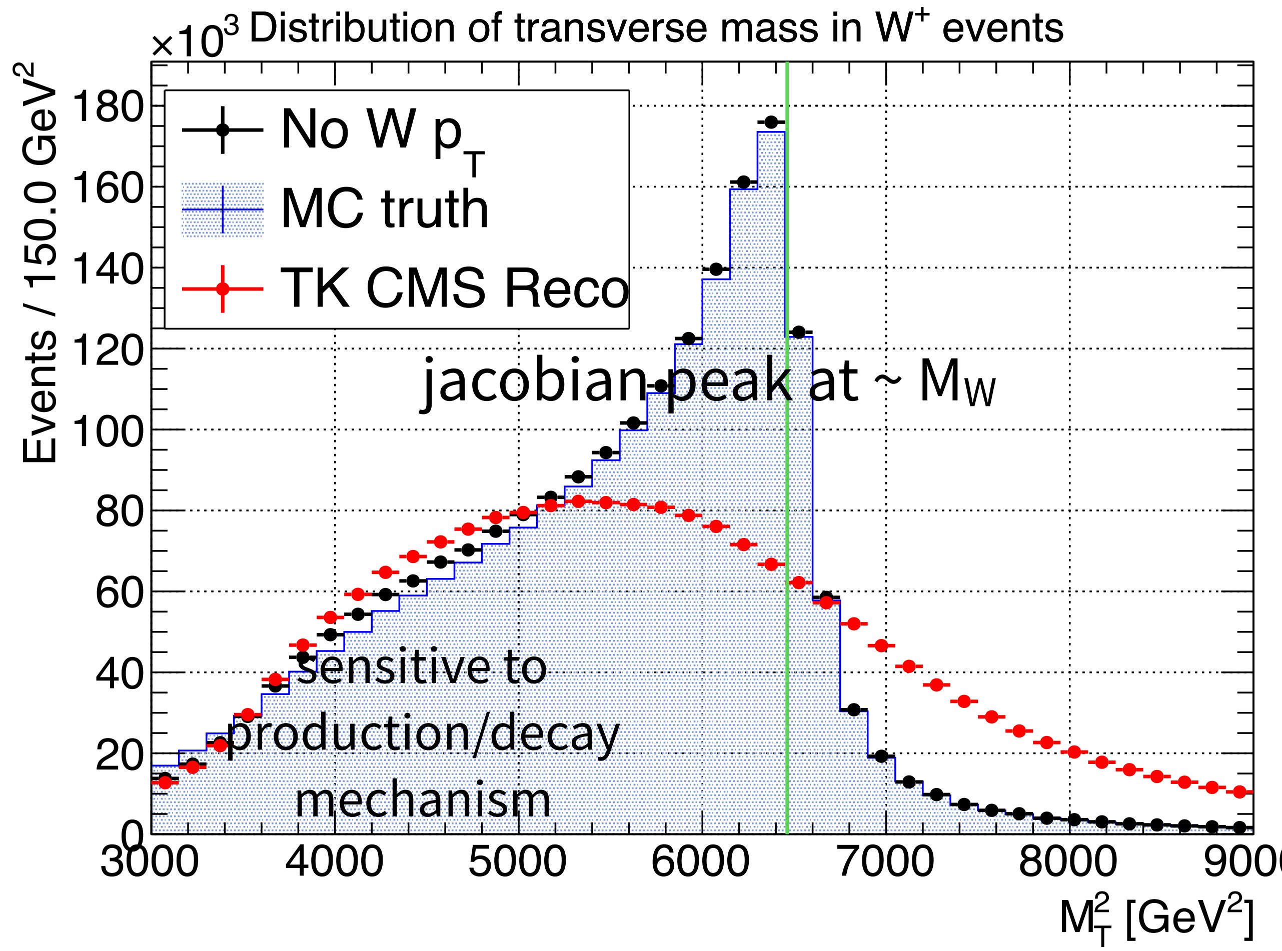
	measurement	posterior	SM prediction
m_H	125.09 ± 0.24	125.09 ± 0.24	102.8 ± 26.3
m_{top}	173.34 ± 0.76	173.61 ± 0.63	176.6 ± 2.5
m_W	80.385 ± 0.015	80.3644 ± 0.0061	80.3604 ± 0.0066

arXiv:1608.01509

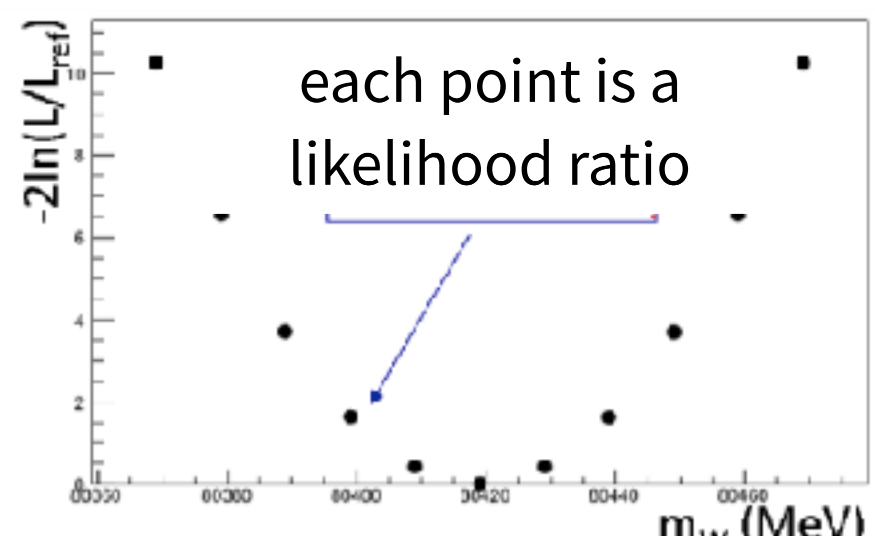
A measurement of M_W at 10^{-4} level could shed new light to our knowledge of the SM

the “traditional way”





extract M_W from these distributions through a template fit for different M_W hypothesis



Distributions in data and MC must agree at 10^{-4} level not to bias the fit

our first milestone - the Z *W-like* mass measurement

crucial for understanding in depth the experimental calibrations

	$M_Z^{W_{\rm like}+}$			$M_Z^{W_{\rm like}-}$		
Sources of uncertainty	p_T	m_T	$\not{E}_T$	p_T	m_T	$\not{E}_T$
Lepton efficiencies	1	1	1	1	1	1
Lepton calibration	14	13	14	12	15	14
Recoil calibration	0	9	13	0	9	14
Total experimental syst. uncertainties	14	17	19	12	18	19

more details in backup

NB: Z W-like mass measurement has been performed with **muons** only

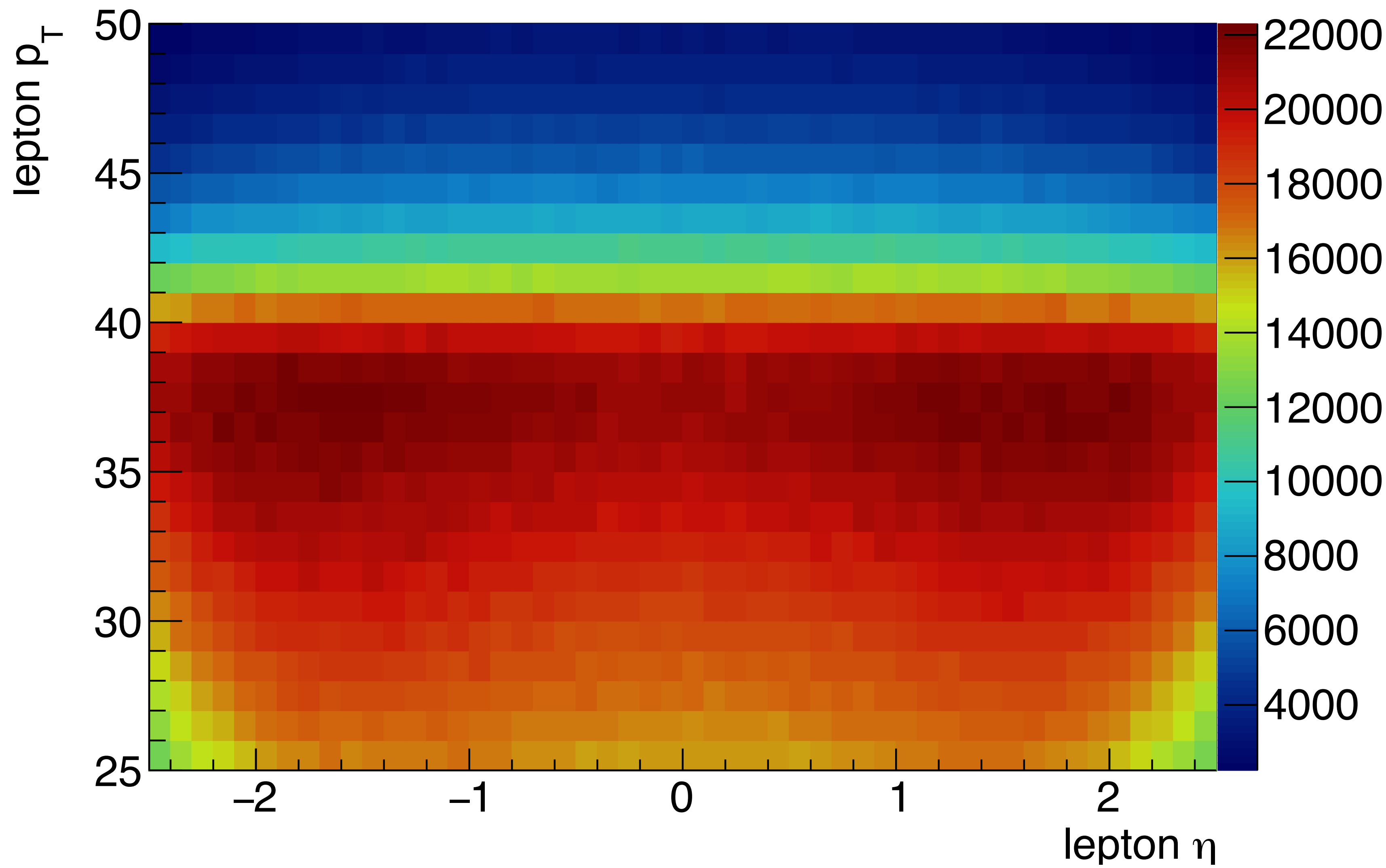
Now **electrons** are included in the analysis thanks to the efforts of the Roma group

group	Pisa	Roma	CERN	Saclay	ETH	UCLA	FTE
manpower students	2+2	2+1	3	2	1	1	~ 5

profiting of the **huge amount of statistics** and the **outstanding control of our detector**, we are currently developing **new** tools and strategies to face:

- *PDF uncertainty*
- *Wp_T modelling*
- *recoil modelling*

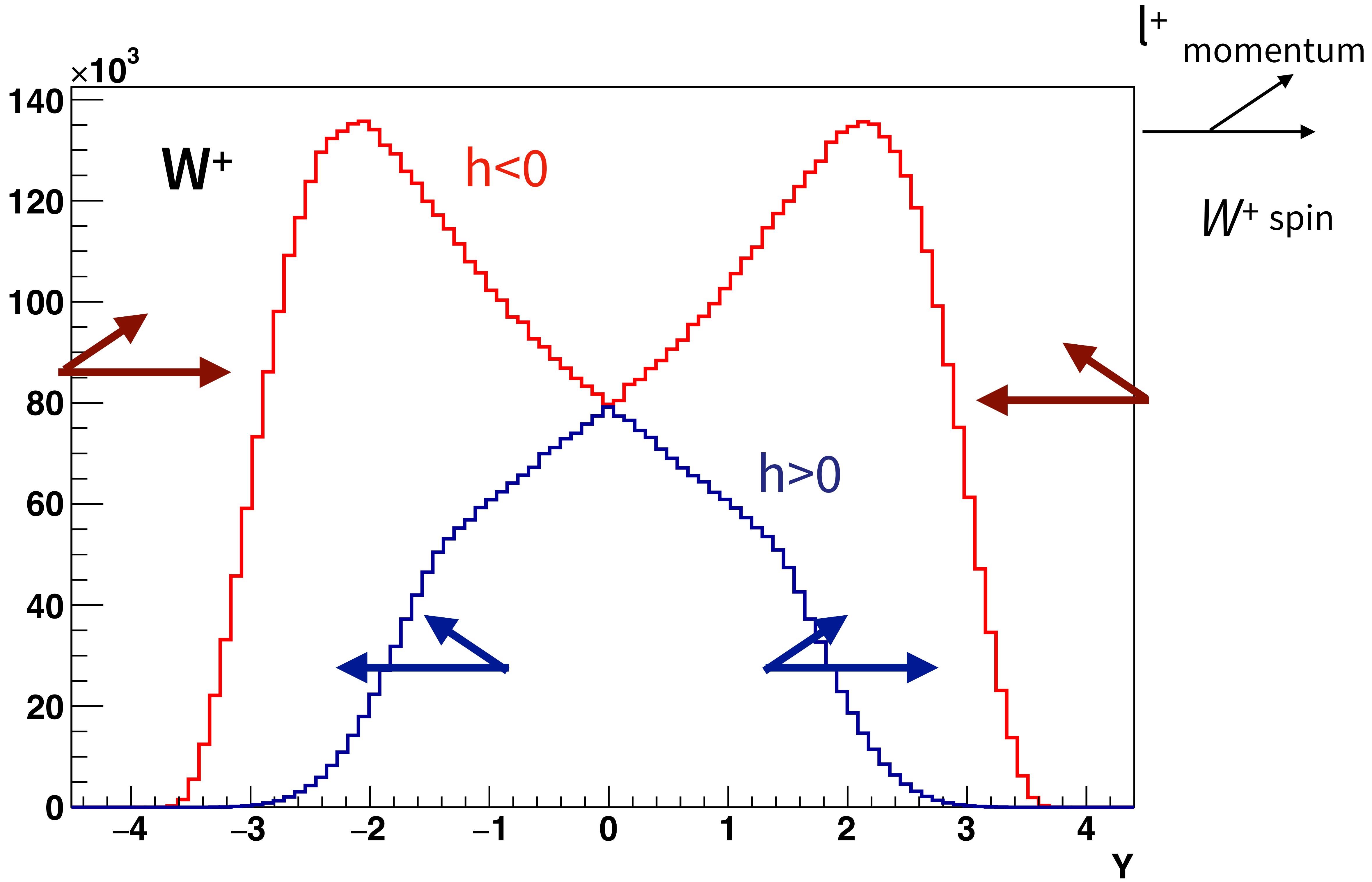
the Power of Simplicity



lepton p_T and η carry information about the unknown rapidity/helicity of W boson

can we unfold this 2D distribution and reconstruct rapidity/helicity distributions?

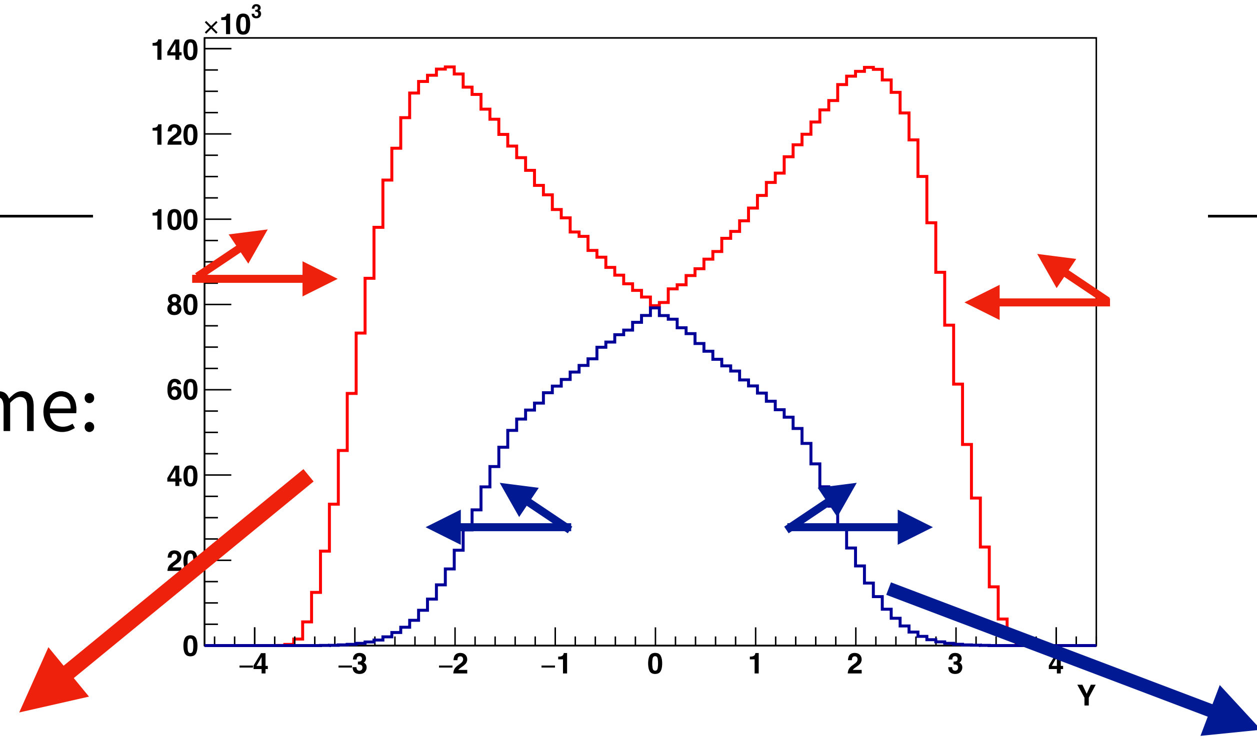
the W decay has a strong spin analysing power

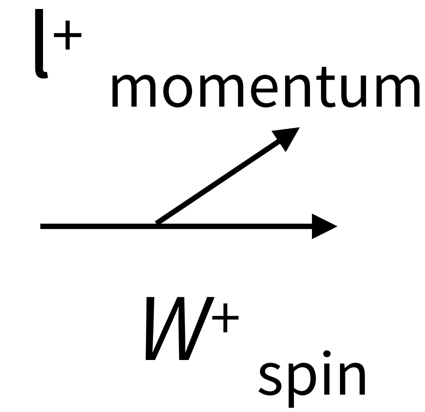


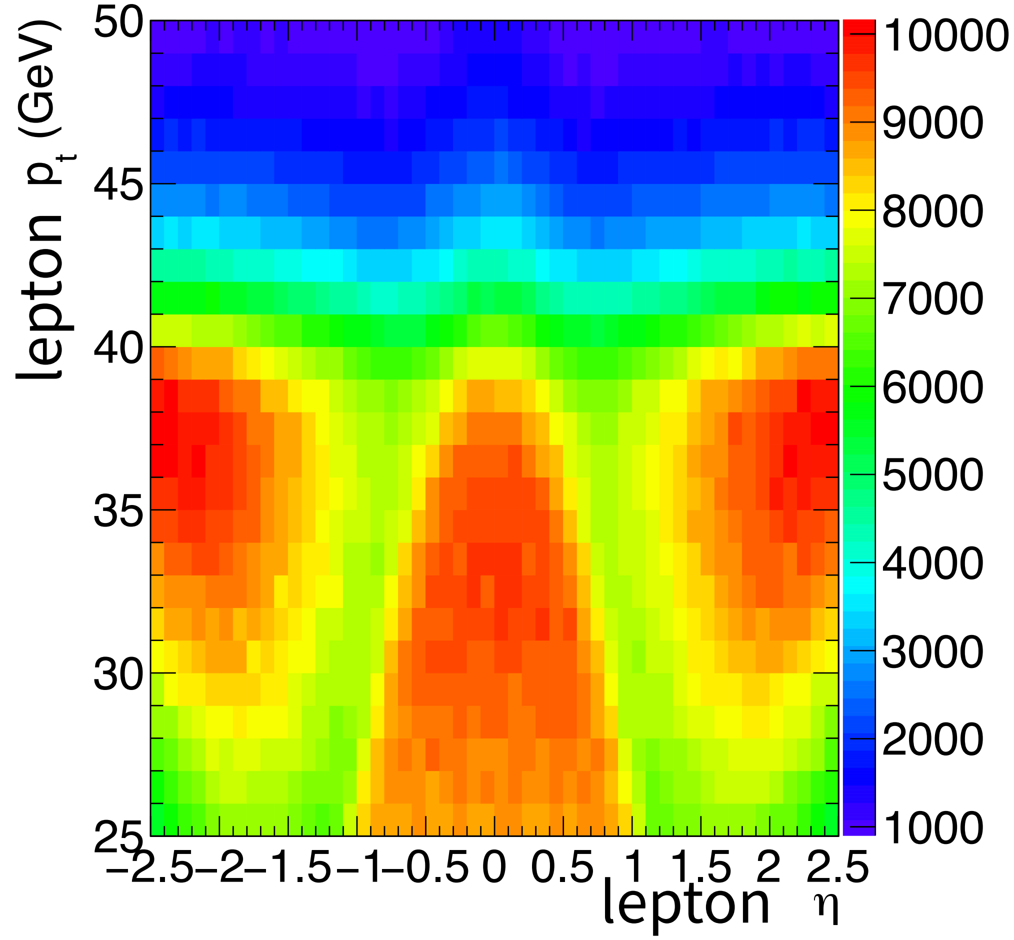
boost to lab frame:

$\eta_{LAB} = \eta_{CM} + Y$

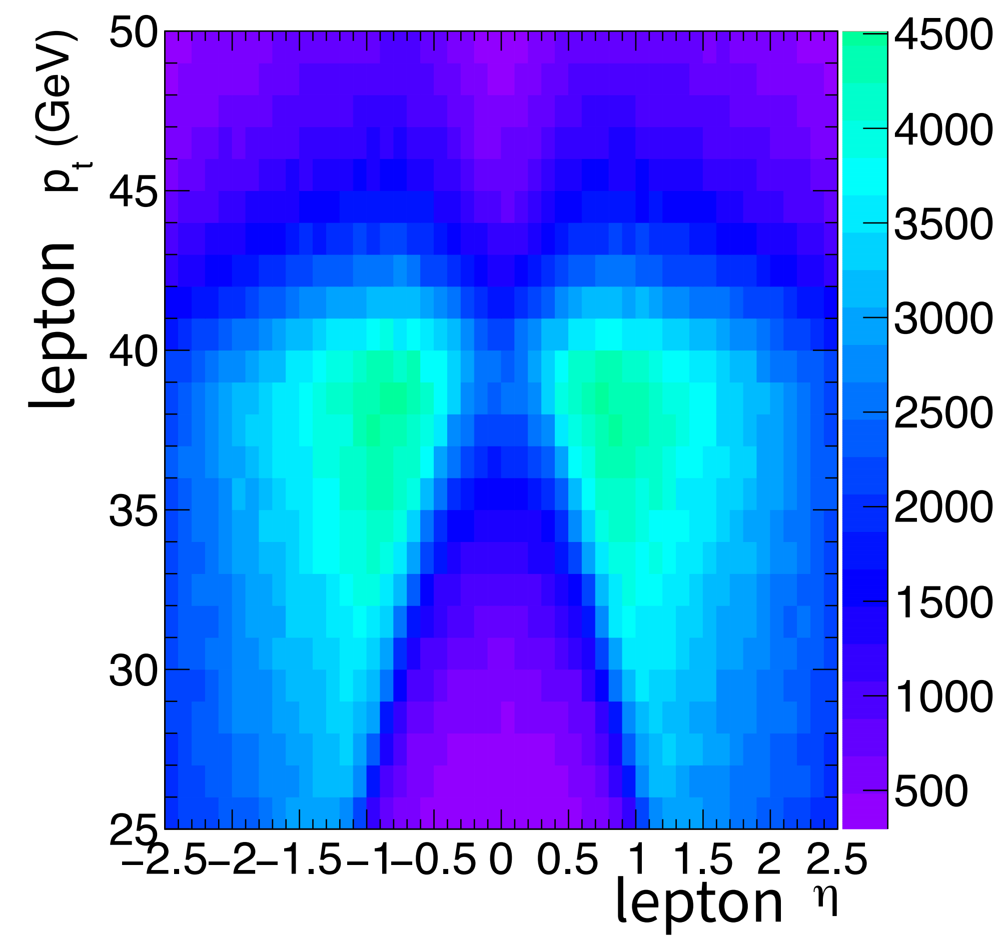
$\eta_{cm} \sim \pm 0.5$







h<0



h>0

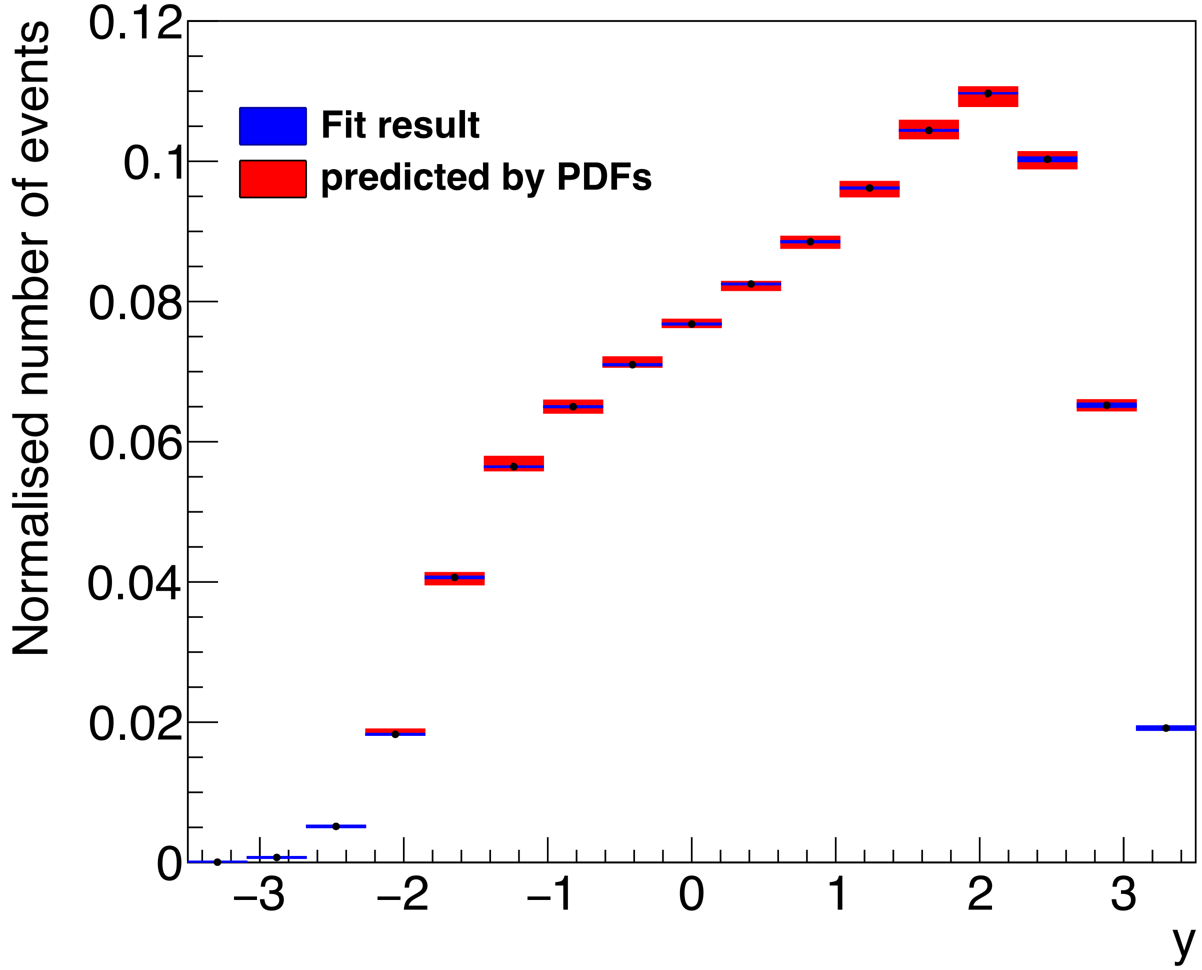
this simple observation opens the possibility of measuring the W rapidity spectrum for each helicity

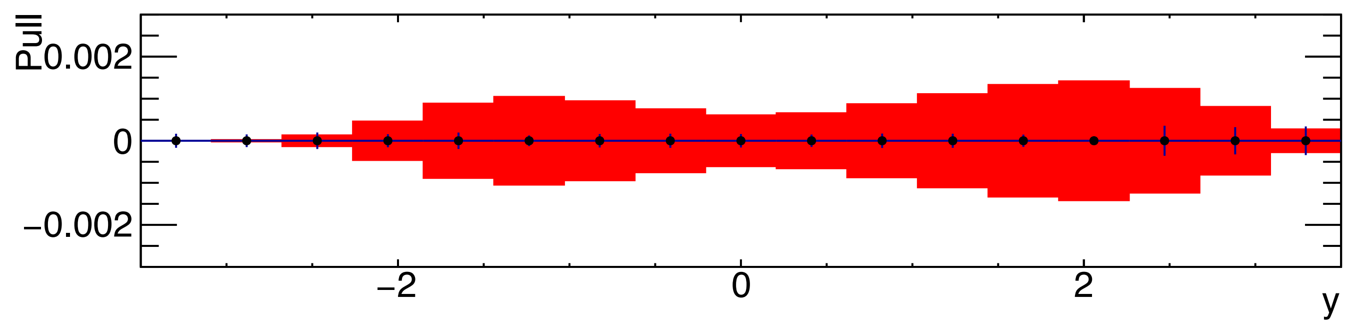
arXiv:1707.09344

About the rapidity and helicity distributions of the W bosons produced at LHC

E.M., O.Cerri, N.Foppiani, G.Rolandi

rapidity distributions of W^+ bosons with spin pointing to negative z





tiny statistical error bars with respect to the uncertainty of the newest NNPDF3.1

18M of W+ in the fit
(61M in CMS 8 TeV statistics)

such a measurement

- is interesting per se since it has never been done
- will constrain the bulk of the PDF uncertainty in the W mass measurement

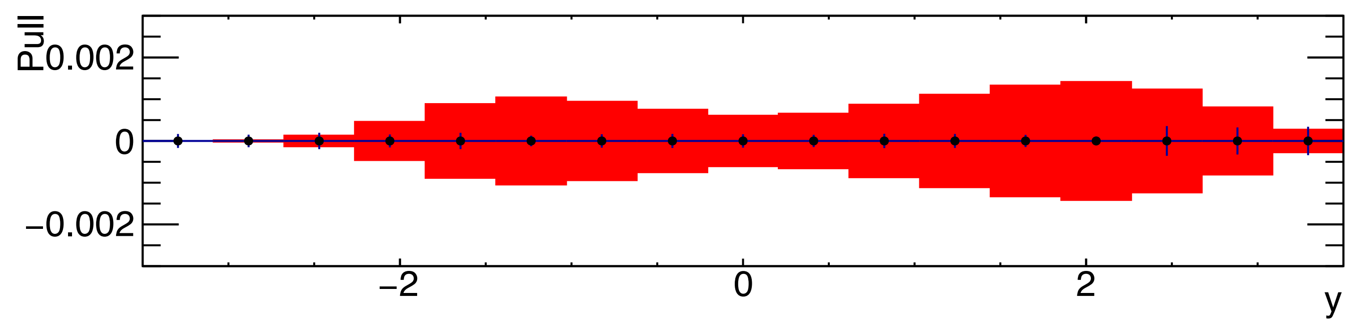
effort started in CMS since this summer using muons and electrons

we are analysing 13 TeV data (technically much easier)

- evaluating the QCD background in muon and electron samples
- producing the templates for the fit (solving some subtle theoretical problems)
- implementing the fit

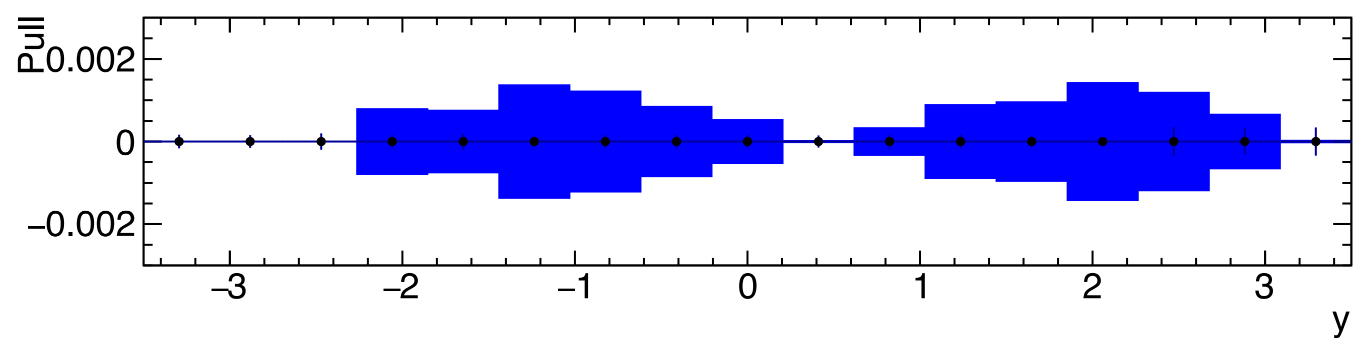
PDF vs systematics in W pT

PDF variations



fit is sensitive to W pT variations: systematic uncertainty comparable to PDF variations

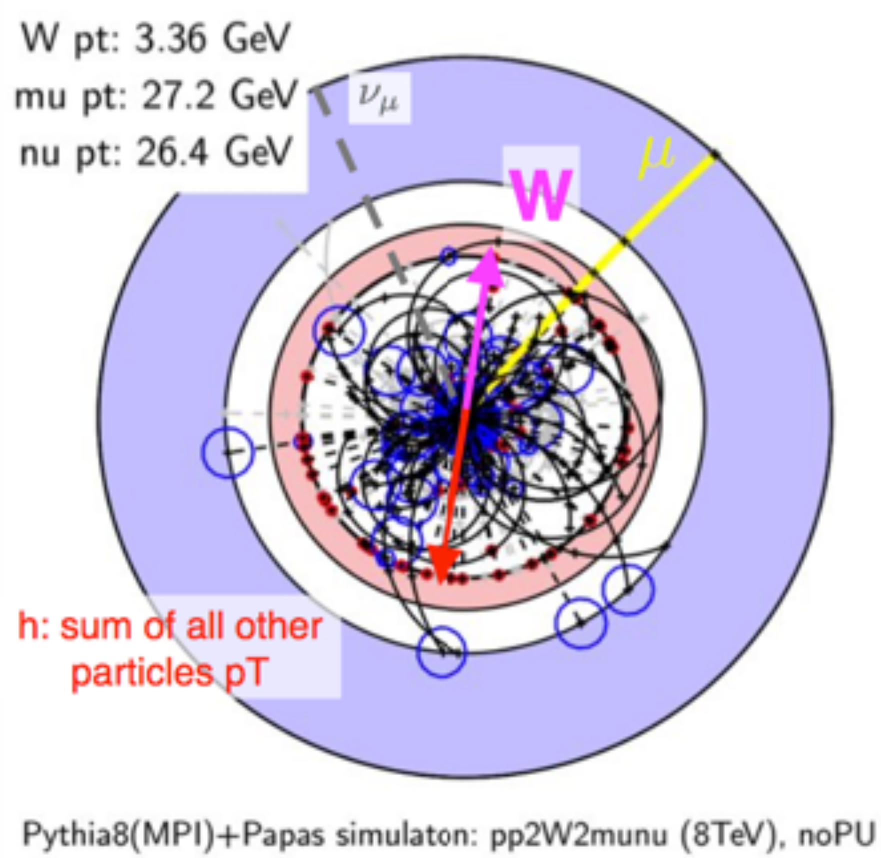
W pT variations



can we use this sensitivity to fit the W double differential phase space in pT and Y?
still trying to assess the feasibility

essential point: 13 TeV statistics is a factor 50 wrt to the plots above

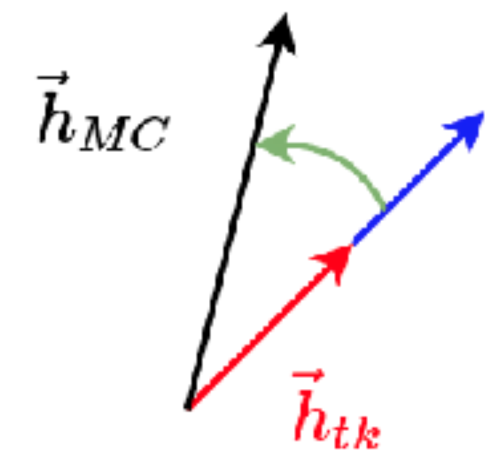
measuring the W p_T from recoil information



recoil equals W pt event by event

but mismeasured due to:

- particles out of acceptance
- pile up



set up a regression in order to get the PDF of the true recoil on an event by event basis

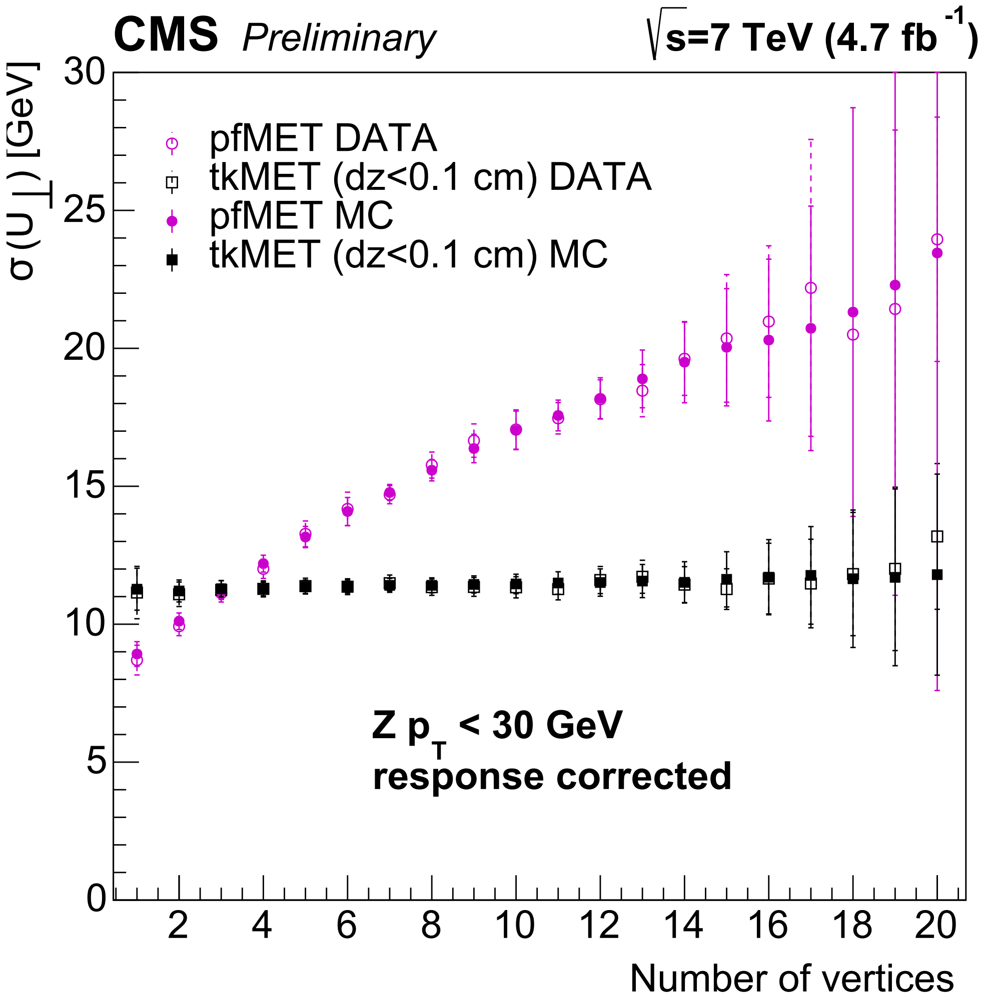
topic deeply studied in:

CERN-THESIS-2017-157 *Olmo Cerri*
CERN-THESIS-2017-125 *Nicolo' Foppiani*

SCUOLA NORMALE SUPERIORE

measuring the W p_T from recoil information

we start from what we know



kill pile up using charged tracks

regression

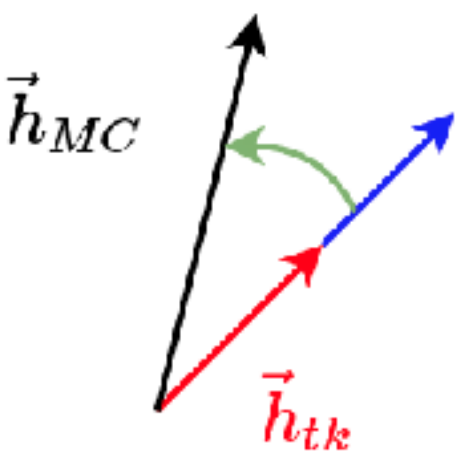
x

"correlated observables"

- tracks multiplicity
- highest track momentum
- sphericity
- neutrals
- number of pileup vertices ....

$$e1_{tk}^{MC} = h_{MC}/h_{tk}$$

$$e_2 = \Delta\phi$$

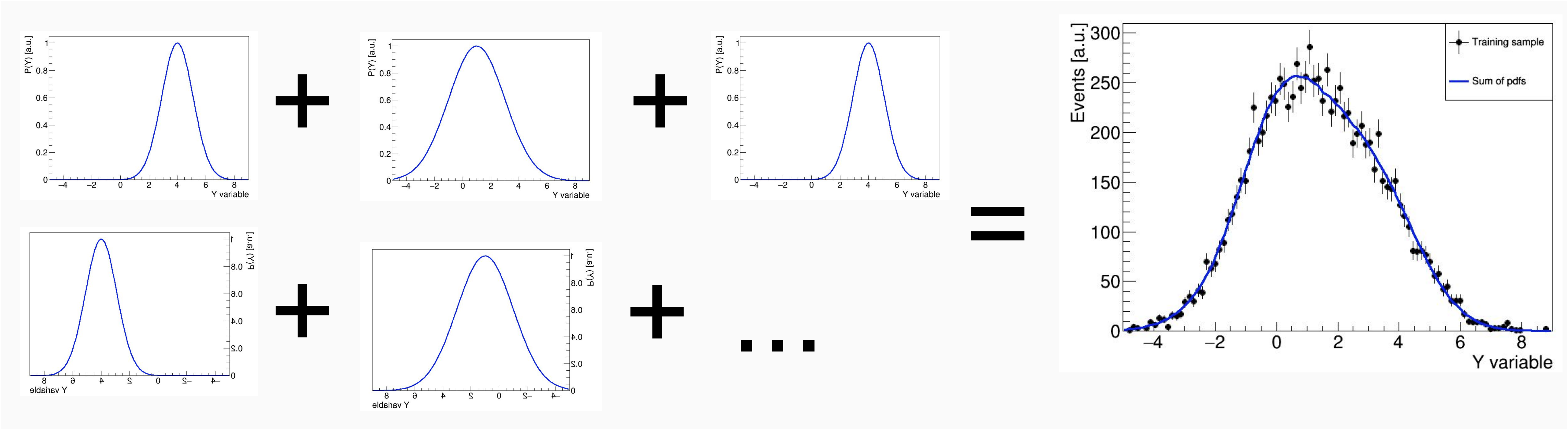


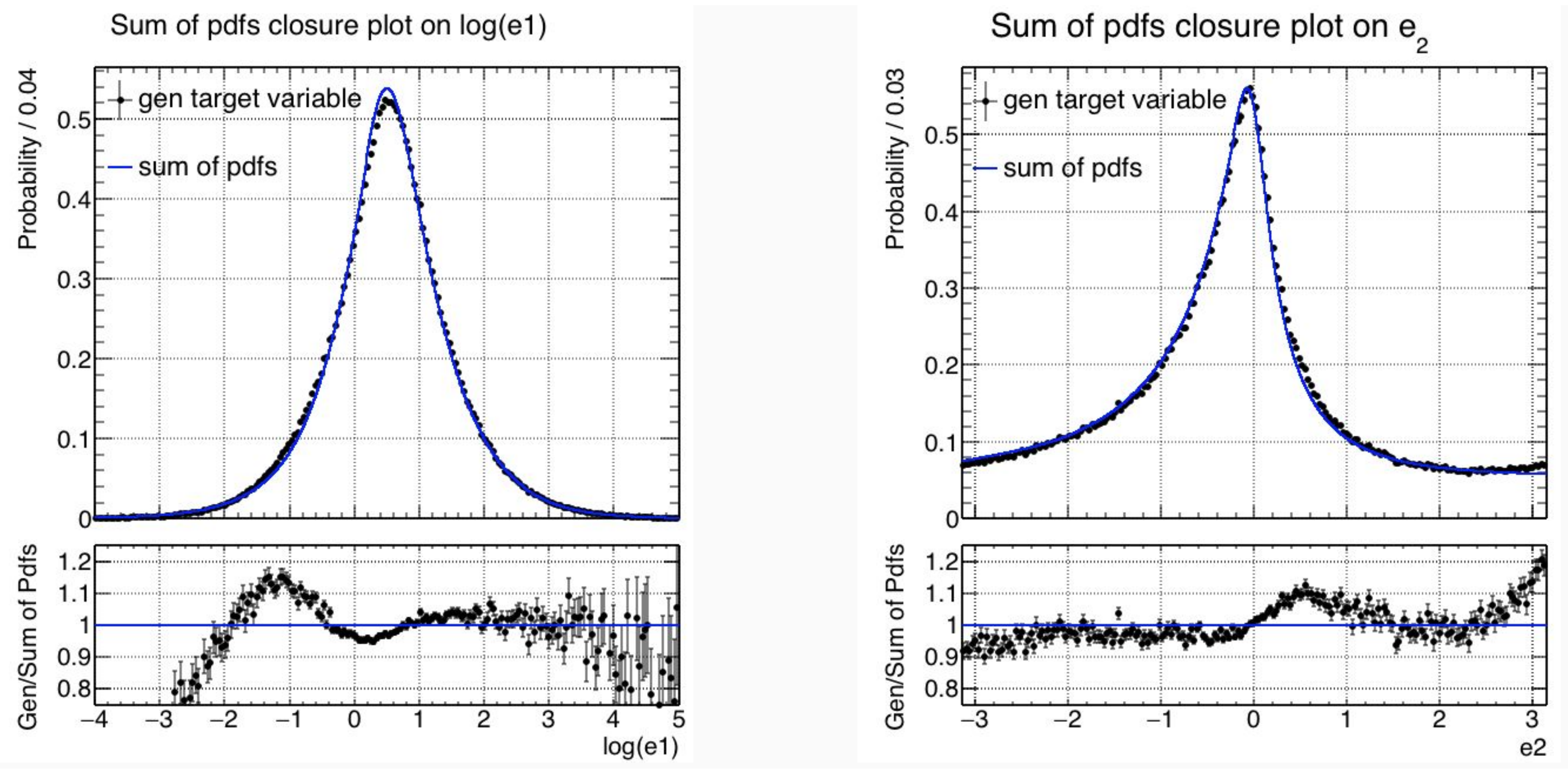
P(y|x)

of scale (**e1**) and angle (**e2**) of the recoil

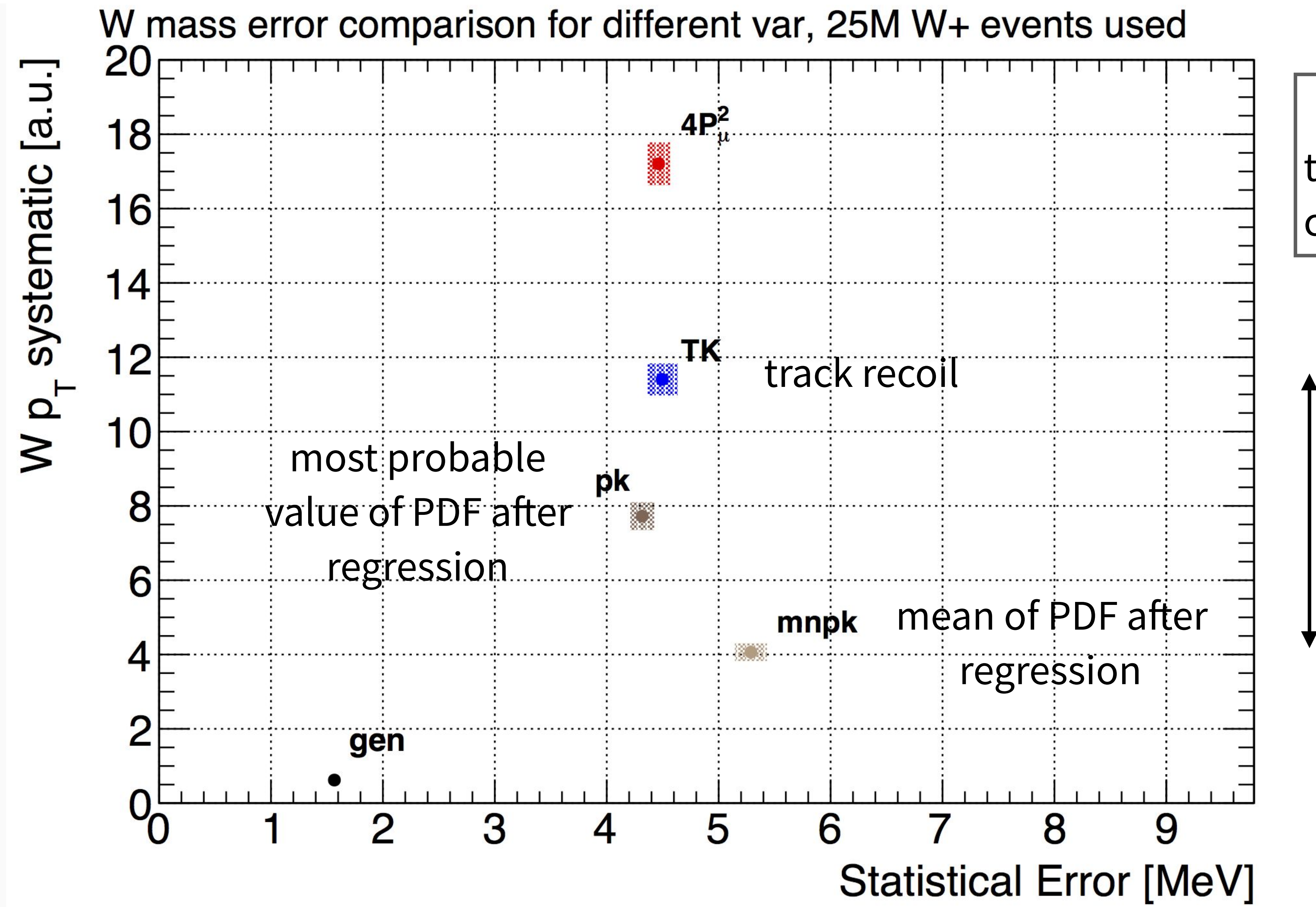
closure test

reobtain the original spectrum by summing up all the PDFs





systematics on the W mass measurement



caveat:
this assumes a perfectly calibrated detector

how do we calibrate the detector for this measurement?

$$f(M_T) = J \times \int f_l(p_T^l, \Delta\phi_{l,W}|z) f_h(p_T^h, \Delta\phi_{h,W}|z) f_W(z) dz$$

- J: Jacobian of M_T^2
- f_l: lepton pdf given W kinematics
- f_h: recoil pdf given W kinematics
- f_W: pdf of W kinematics
- z: W kinematics: 4-vectors

this is a crucial formula: given the W kinematics, recoil and lepton are uncorrelated

$y = \{p_T^h, \Delta\Phi_{h,W}\}$, $z = \{p_T^W, p_L^W\}$ ⟶ let's concentrate on the recoil

problem:

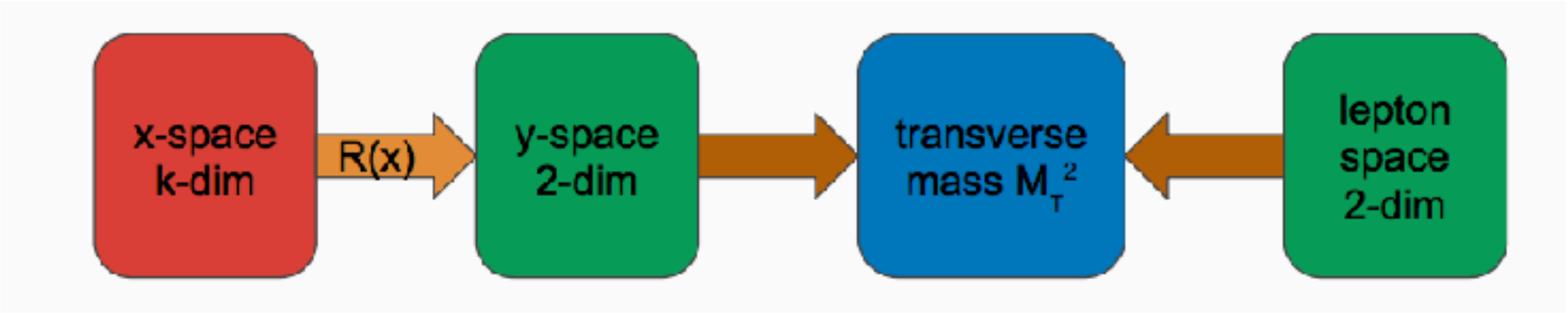
$f(y|z)_{DATA} \neq f(y|z)_{MC}$ implies a systematic uncertainty on the fit that we have to calibrate out

morphing MC to data

The correct procedure should be to equalise all the variables given as input in data and MC in a correlated way

this is not straightforward in such a high number of dimensions (typically 10-12)

let's calibrate f(y|z) instead of f(x|z)

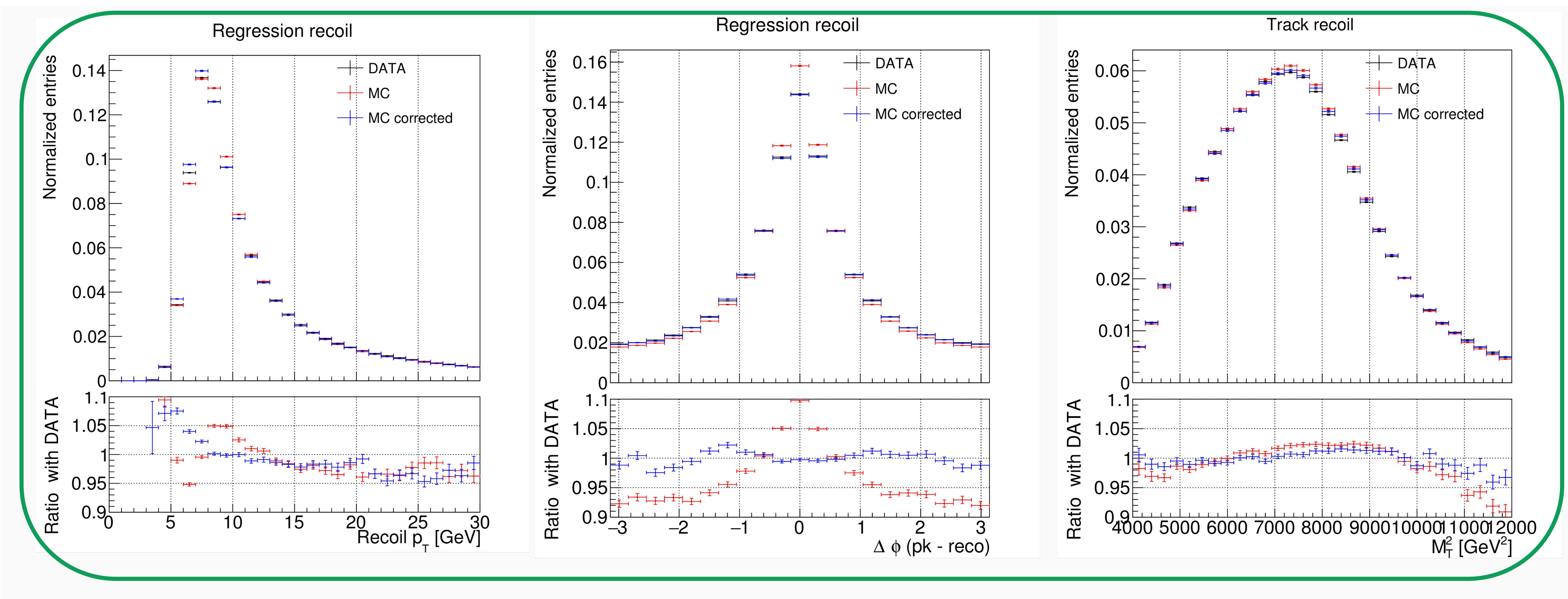


this way we have reduced the problem to 2 dimensions only

quantile morphing 2D on Z events

a tool to perform 2D quantile morphing is in place

limited by MC statistics



check the residual bias:	before	after
track recoil	28 ± 11	-14 ± 8
regression	140 ±14	-11 ± 10

still biased! work in progress

conclusions

we are working on many fronts and we have new ideas to attack the main systematics

as usual, manpower is our main problem

. . . the top is still far, but we'll get there!

backup

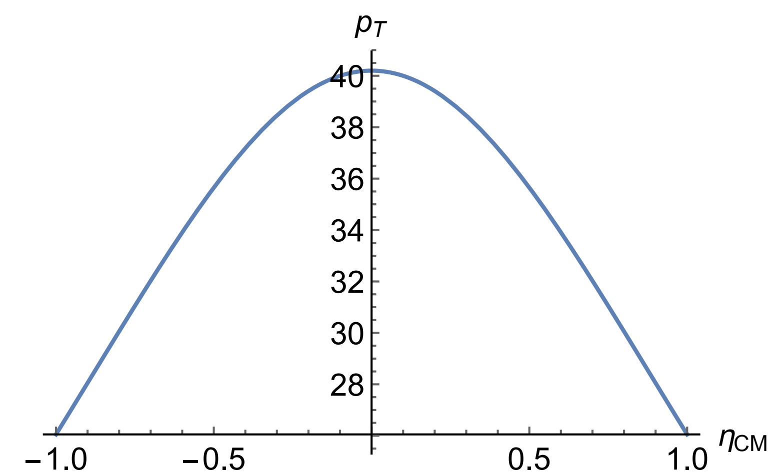
where does “PDF uncertainty” come from?

boost to lab frame:

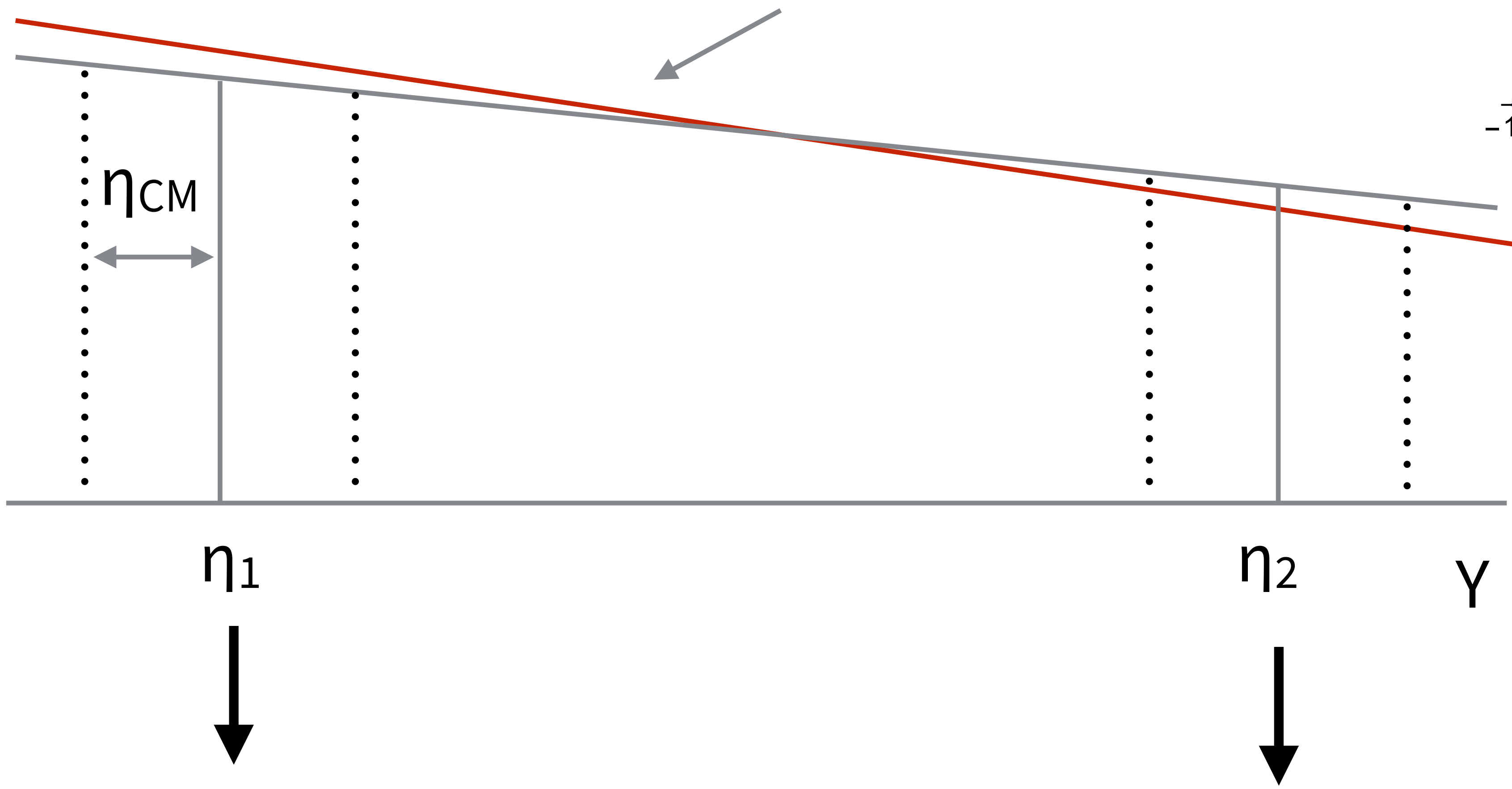
$\eta_{LAB} = \eta_{CM} + Y$

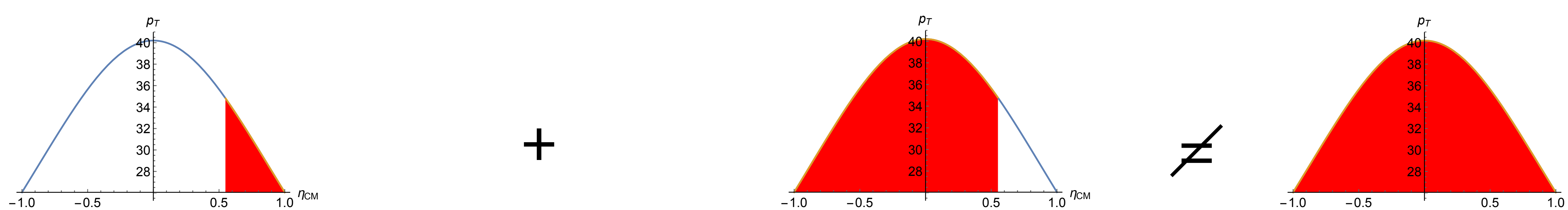
uncertainty on

Y shape due to PDFs

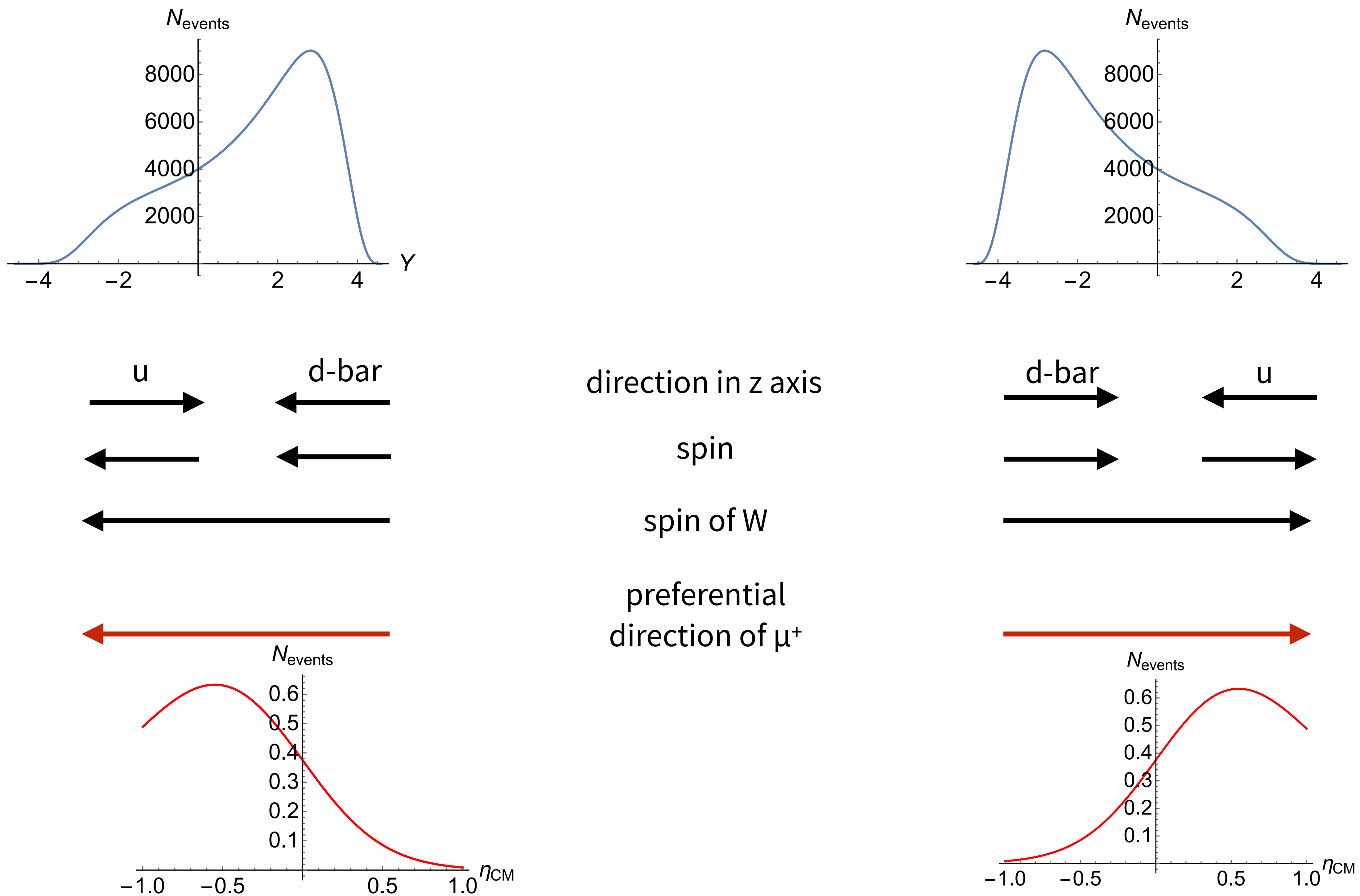


neglecting W p_T





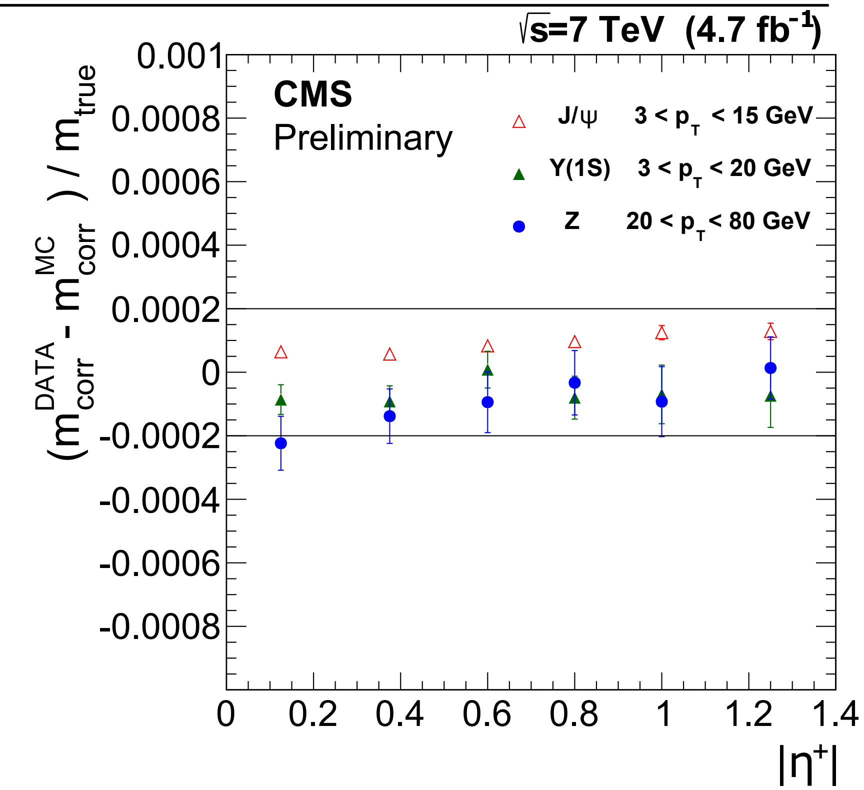
in addition, *W* polarisation…



status of the muon momentum scale calibration

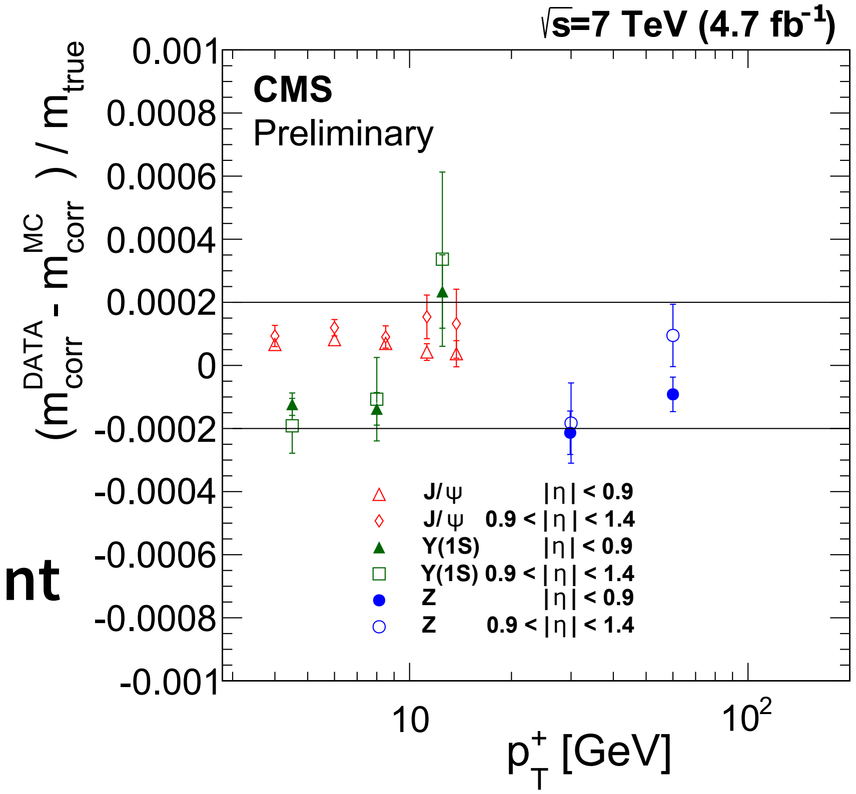
Calibration performed fitting the bias in muon p_T due to:

- mismodelling of magnetic field
- mismodelling of the material budget of the tracker
- residual misalignment of the tracker modules



1. extract corrections coefficient fitting the peak position of the invariant mass distribution in dimuon JPsi and Upsilon events

2. check the validity of the procedure using dimuon Z events



currently at the level of 2 10-4 but a lot of room for improvement