Experimental summary:
What can we expect from theory for precision physics at the LHC? What should we not expect?

Many thanks to the organisers for having asked me to come and try to entertain you this morning with Kirill. I have long resisted giving summary talks at conferences but this was a topical conference where perhaps such a summary makes even sense. You will judge.

I will focus in this summary on trying to capture what we may or may not expect from our theory friends in the near future but without attempting to summarise really all what was said.

I will explain at the beginning why the DY process is so beautiful and pure in hadronic colliders. We have only begun to reap what it can teach us about EW and QCD at the LHC.

And I will (try to) entertain you further for 10 minutes at the end if there is time left with some historical memories from UA1/UA2.

Experimental summary:
what do we expect from theory for precision physics at the LHC?

At this conference, the word precision has different meanings in different areas (note that mass measurements are a special case):

- It means sub-percent precision in DY and in some aspects of flavour physics in LHCb
- It means a few percent at best still for top physics
- It means 10-40% for Higgs physics (eg couplings), at least for a while

It will not be a surprise therefore if I focus more on DY measurements in this summary.

In a nutshell, there are two key difficulties we are confronted with:

a) The lack of a MC generator tool for DY production which would include NNLO QCD calculations, perfectly matched and merged to PS, with a UE model reproducing the data

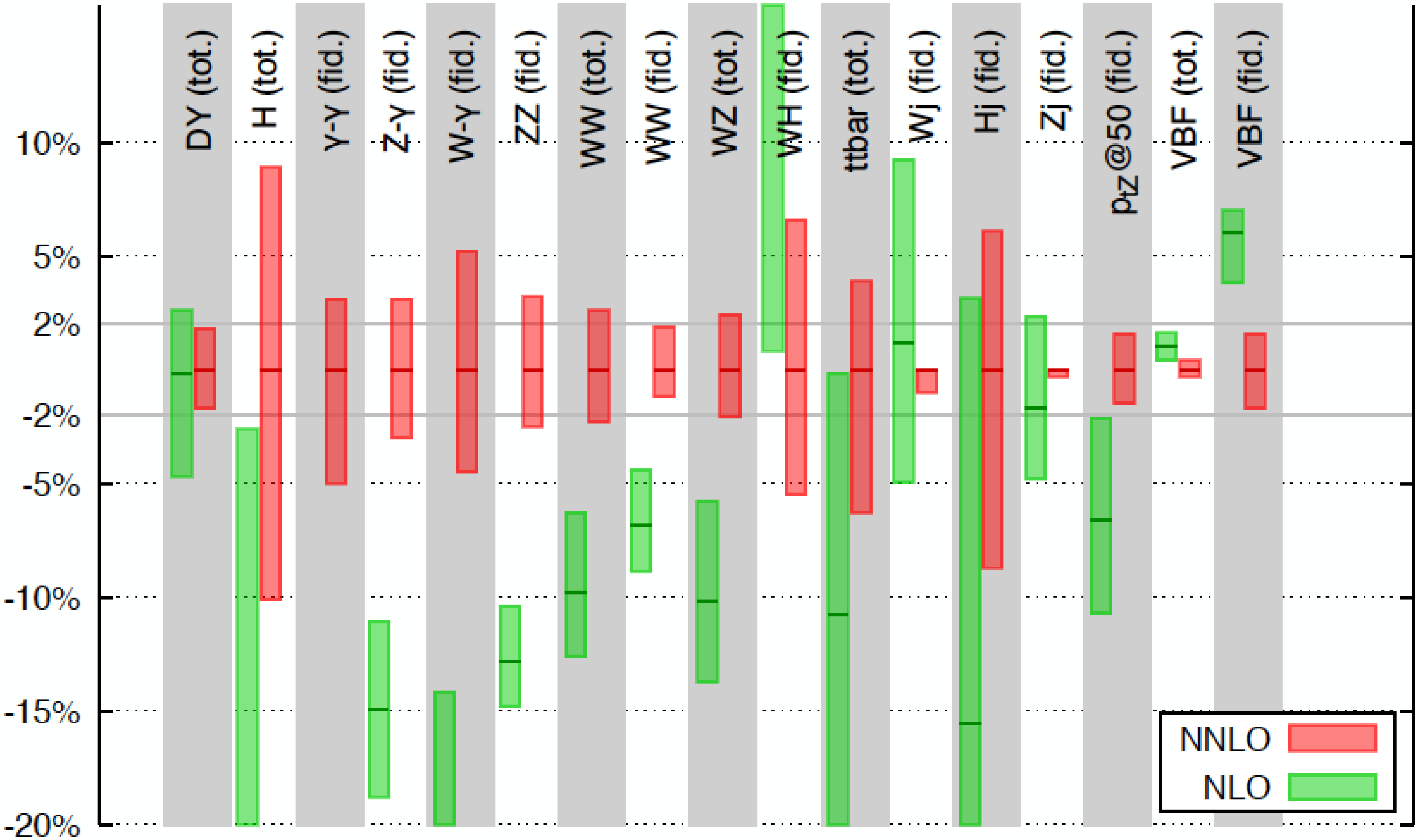
b) The complexity of dealing with a large number of sources of theoretical uncertainty which are not always reliable nor stable

Can we be reasonably certain that full calculation would fall within red bands below?

More importantly, how can we be sure that this would be the case after acceptance cuts, which eg for searches select only small fraction of events?

WHAT PRECISION AT NNLO?

G. Salam



Experimental summary: what do we expect from theory for precision physics at the LHC?

The world was not built in one day of course.

One can look at the situation today with optimism or with some concern about balance of effort in our community:

- We can be very optimistic seeing what has been achieved and the huge wealth of data we are accumulating now at 13 TeV

- The nagging concern is that of devoting enough effort in both communities to the rather small world of precision measurements. There are of course many people involved in searches in ATLAS and CMS and this is natural and there are many theorists building new physics models and worrying about … naturalness ☺

Some topics for SM discussion from conference here two years ago

Topic 1: 15'
Precision electroweak measurements at the LHC and beyond (mostly m_W and $\sin^2\theta_W$ but also m_Z)

Topic 2: 15'
Precision top mass and coupling measurements at the LHC and beyond

Topic 3: 15'
State-of-the-art MC tools and theory calculations

Topic 4: from yesterday's parallel session 15'
- Double-parton scattering, MPI and UE models, tunes
- Pile-up mitigation tools

LEP1 legacy: precision theoretical calculations were late.....

„The luminosity is determined by comparing the measured rate at low angle Bhabha scattering with the predicted SM cross-section"

With very first data (January 1990): exp. error 1.1%

But theor. error ~ 0.7% (no event generator available)

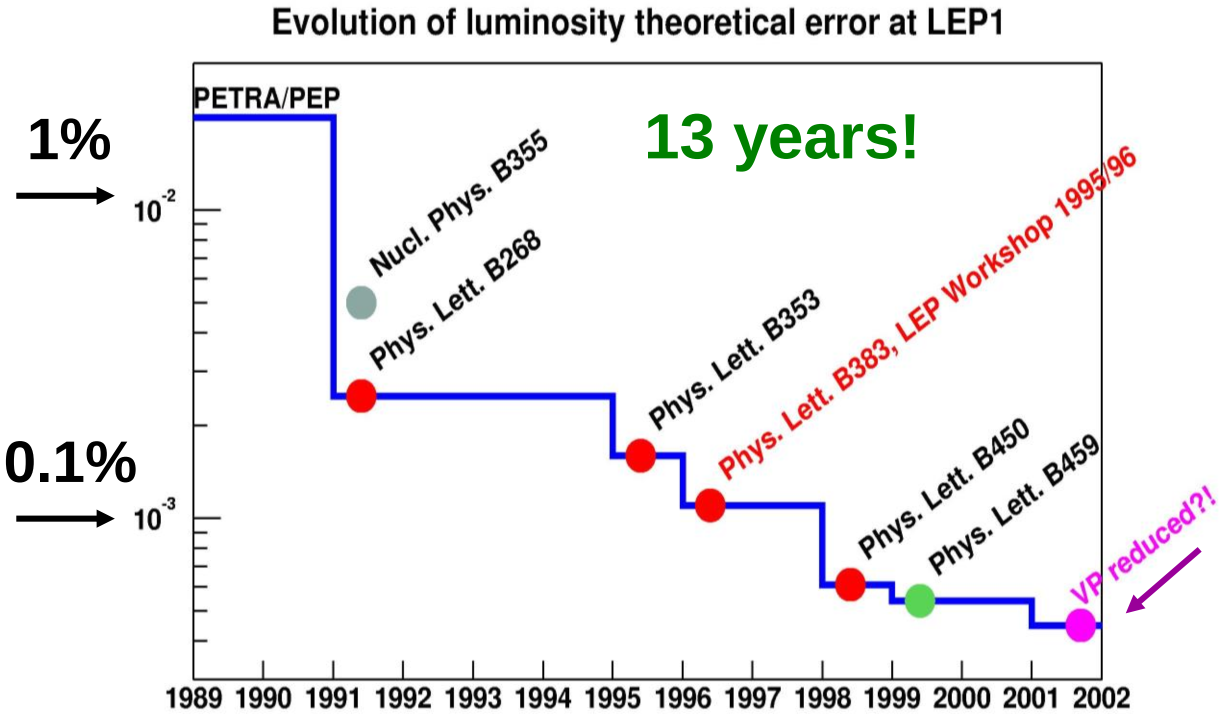
End of 1990: enormous progress, ALEPH going to 0.4%, still no event generator available
Published results (ALEPH, CERN-PPE/91-129, August 1991):
exp. error 0.6%
theor. error 0.3% (only LL O(α3) generator available + complicated procedure with anal. calc.)

LEP1 legacy: precision theoretical calculations were late.....

It was recognised very soon that the detector granularity was so good that theory had to care about photons with $E_\gamma < 1\% \; E_{beam}$.

Soft and collinear resummation was the key element, i.e. more important than expanding into finite higher orders!

S. Jadach, hep-ph/0306083



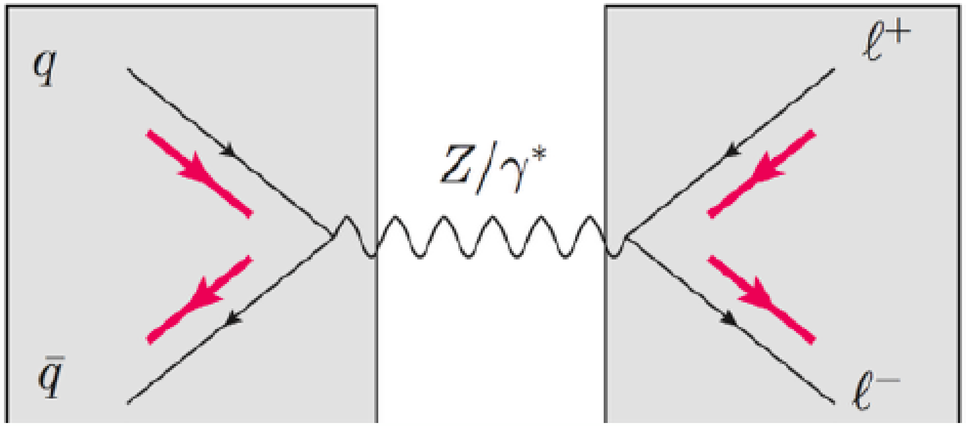
13 years!

End of LEP1 data-taking

Achieved with $O(\alpha^1$+h.o.LL) exp

0.045% was reached as final uncertainty of calculations

Measurement of angular coefficients in Z(W) decays to leptons



What is measured?

Primary: Eight Ai(p_T^Z) …

Secondary: Eight Ai(p_T^Z, y^Z) …

… Integrated over m^Z

- Angular distributions of leptons from Z-boson decays are a portal to its **production dynamics** via **polarisation**
- Exploit decomposition of cross-section into only nine terms at all orders in QCD
    - Angular dependence is fully analytical for 2 -> 2 process
    - Higher order effects absorbed into behavior of Ai coefficients
- These measurements…
    - Probe dynamics of QCD
    - Allow us to test and improve Monte Carlo implementations
    - Are a critical ingredient for future precision EW measurements

$$\frac{d^5\sigma}{\boxed{dp_T^Z\, dy^Z\, dm^Z}\, d\cos\theta\, d\phi} = \frac{3}{16\pi}\frac{d^3\sigma^{U+L}}{\boxed{dp_T^Z\, dy^Z\, dm^Z}} \times$$

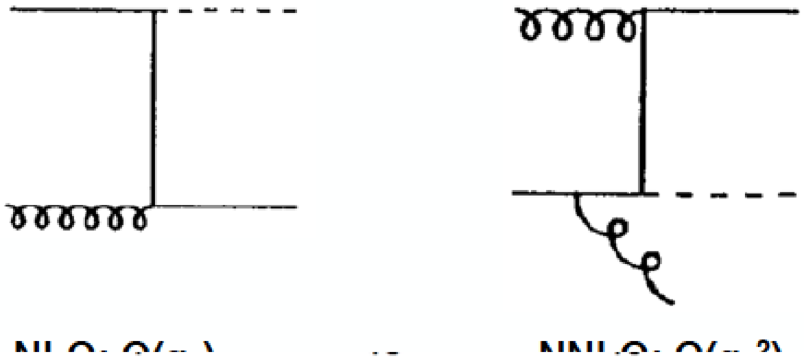
$$\{\boxed{(1+\cos^2\theta)} + 1/2\,\boxed{A_0}\boxed{(1-3\cos^2\theta)} + \boxed{A_1}\boxed{\sin 2\theta\ \cos\phi}$$

$$+1/2\,\boxed{A_2}\boxed{\sin^2\theta\ \cos 2\phi} + \boxed{A_3}\boxed{\sin\theta\ \cos\phi} + \boxed{A_4}\boxed{\cos\theta}$$

$$+\boxed{A_5}\boxed{\sin^2\theta\ \sin 2\phi} + \boxed{A_6}\boxed{\sin 2\theta\ \sin\phi} + \boxed{A_7}\boxed{\sin\theta\ \sin\phi}\}.$$

Measurement of angular coefficients in Z(W) decays to leptons

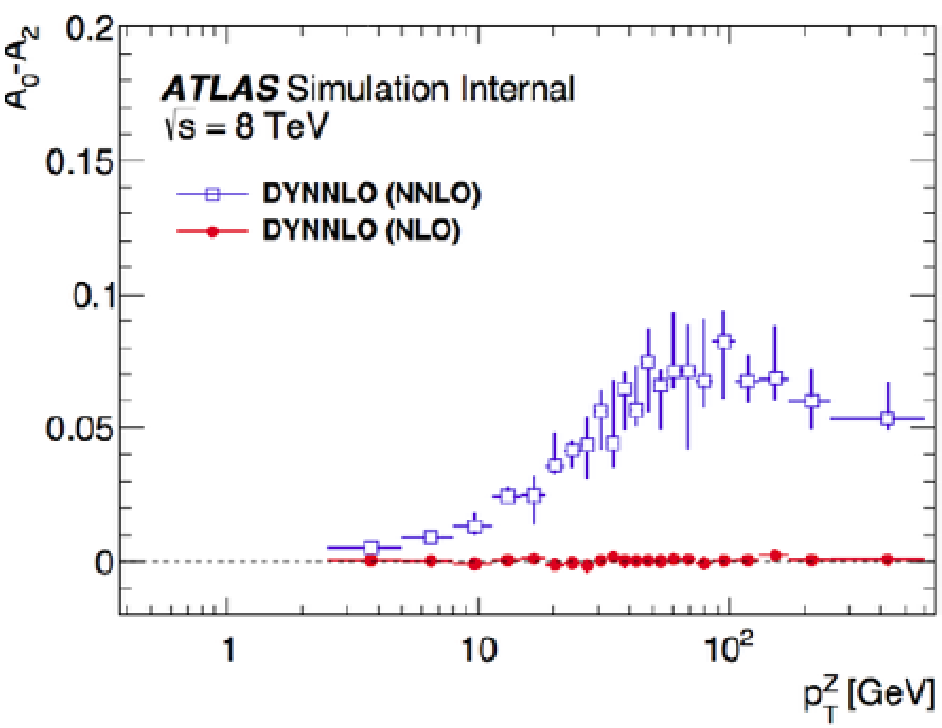
Theoretical predictions



- State-of-the-art fixed-order calculations obtained from DYNNLO
- Reference A_i implicit in calculations can be computed by exploiting the orthogonality between the harmonic polynomials
- The average value of the polynomials relates to

p_T^Z [GeV]

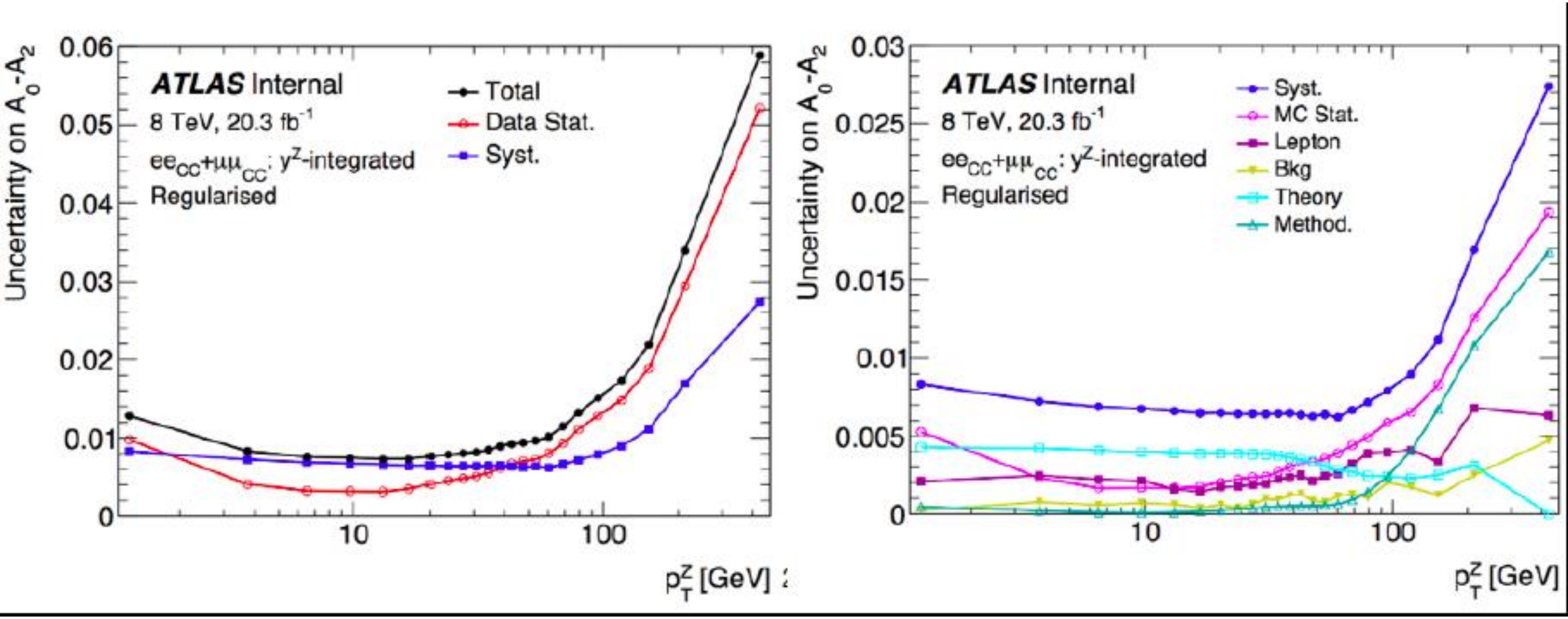
p_T^Z [GeV]



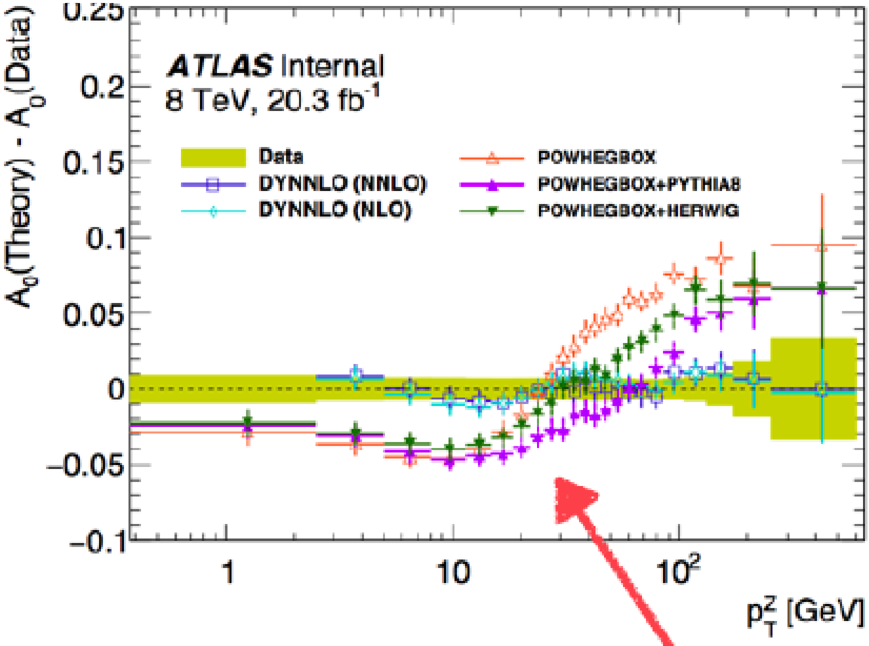
A_0 and A_2

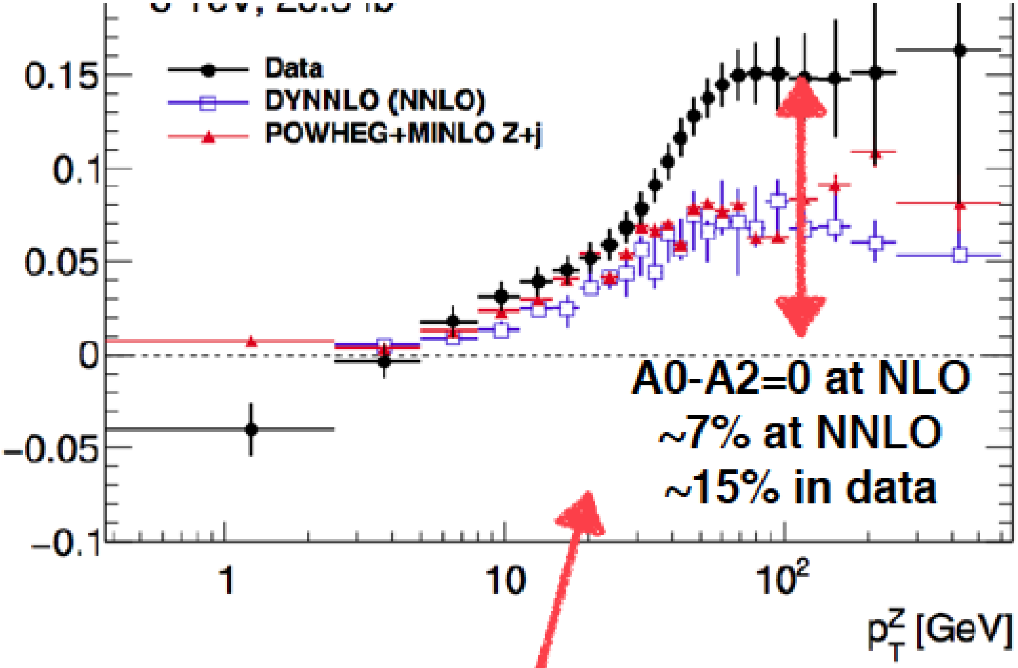
- A_0 and A_2 are fraction of transverse and longitudinal polarisations, respectively
- NLO: A_0=A_2 (aka Lam-Tung relationship)
  - Result of gluon being spin-1
- NNLO correction: A_0 > A_2

Measurement of angular coefficients in Z(W) decays to leptons



Measurement of angular coefficients in Z(W) decays to leptons





A0-A2=0 at NLO
~7% at NNLO
~15% in data

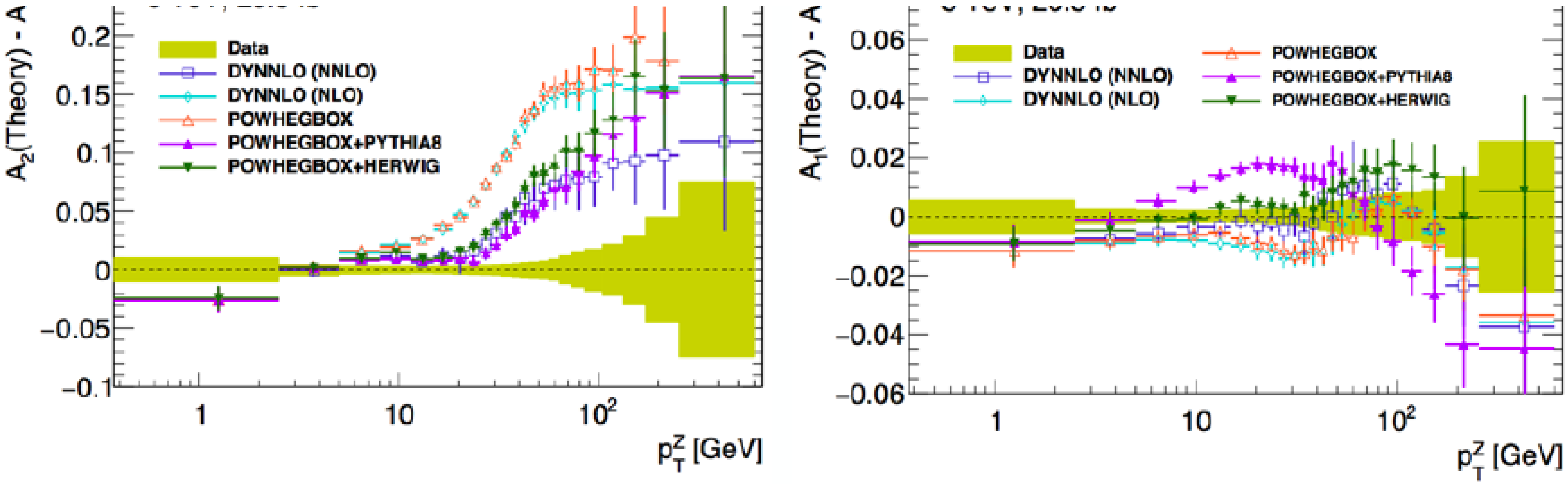
A_0, A_0-A_2

- Powheg completely mismodels A_0 (important for m_W discussion)
  - Related to implementation of Sudakov form factors and cutoffs in b-quark mass
  - Fixed in Powheg+MiNLO

A_0-A_2 (Lam-Tung) sensitive to higher order corrections

First ever observation of significant deviation from NNLO predictions

Measurement of angular coefficients in Z(W) decays to leptons

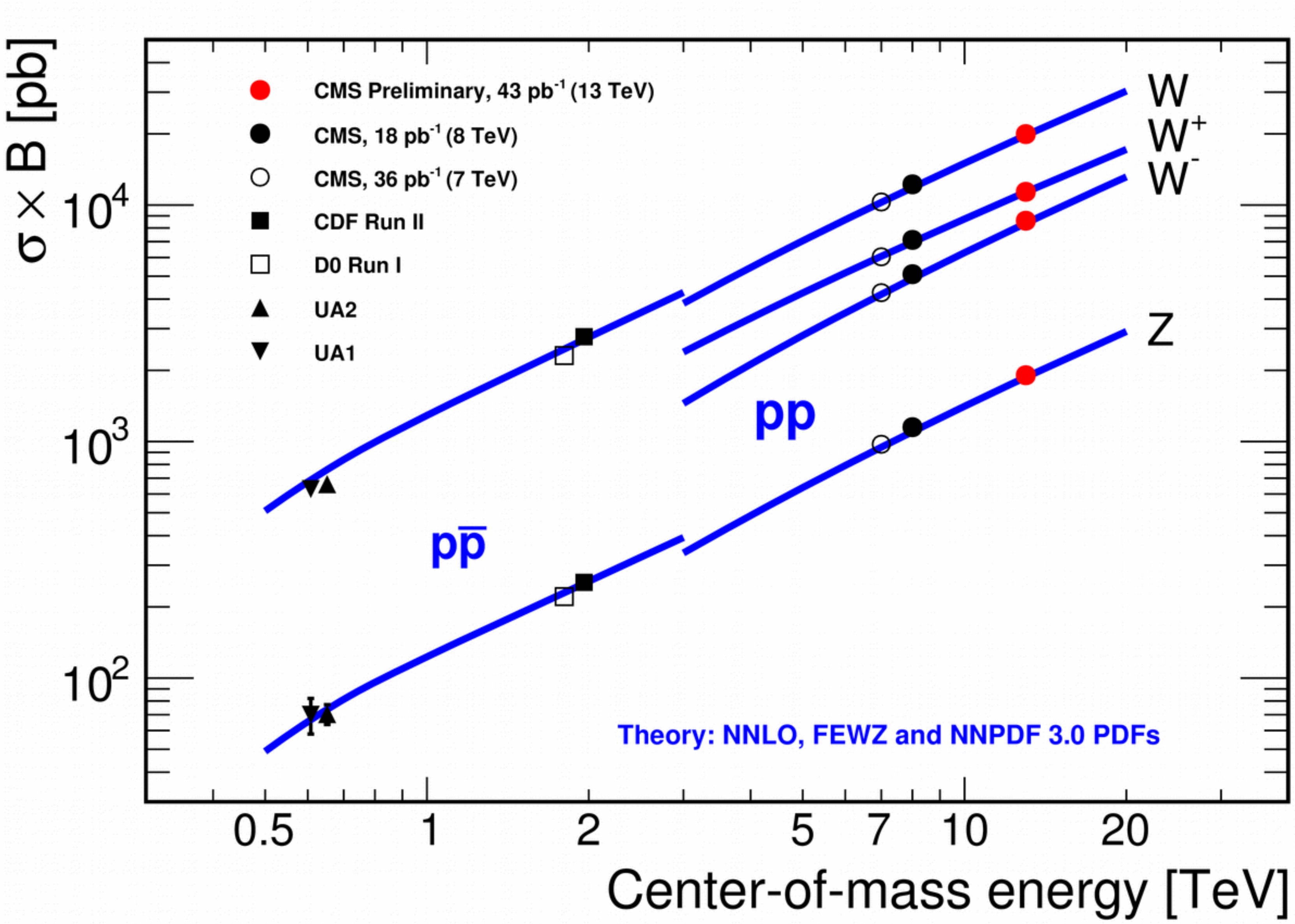


A_1, A_2 sensitive to parton shower

- A2:
  - Powheg Z w/out parton shower matches DYNNLO@NLO (formal accuracy of Powheg)
  - Powheg + PS closer to NNLO => PS emulates higher order effects
- A1:
  - Powheg Z w/out parton shower matches DYNNLO@NLO
  - Powheg+Herwig closer to NNLO for Z pT < ~100 GeV
  - Powheg+Pythia8 over and undershoots NNLO, crossing at Z pT ~ 60 GeV

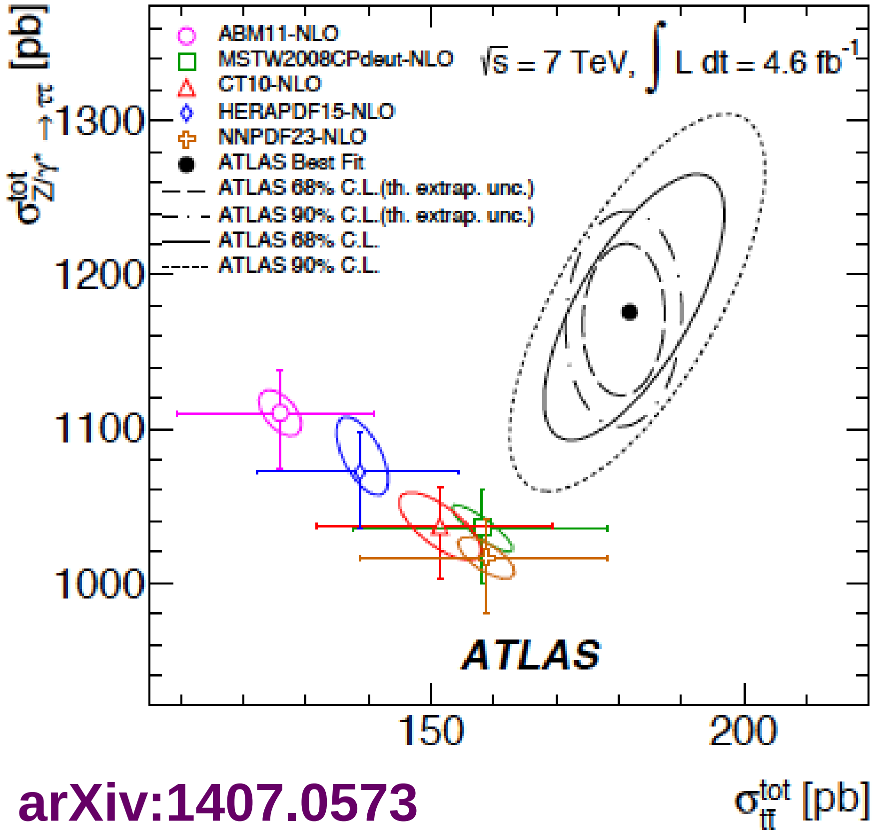
W/Z measurements

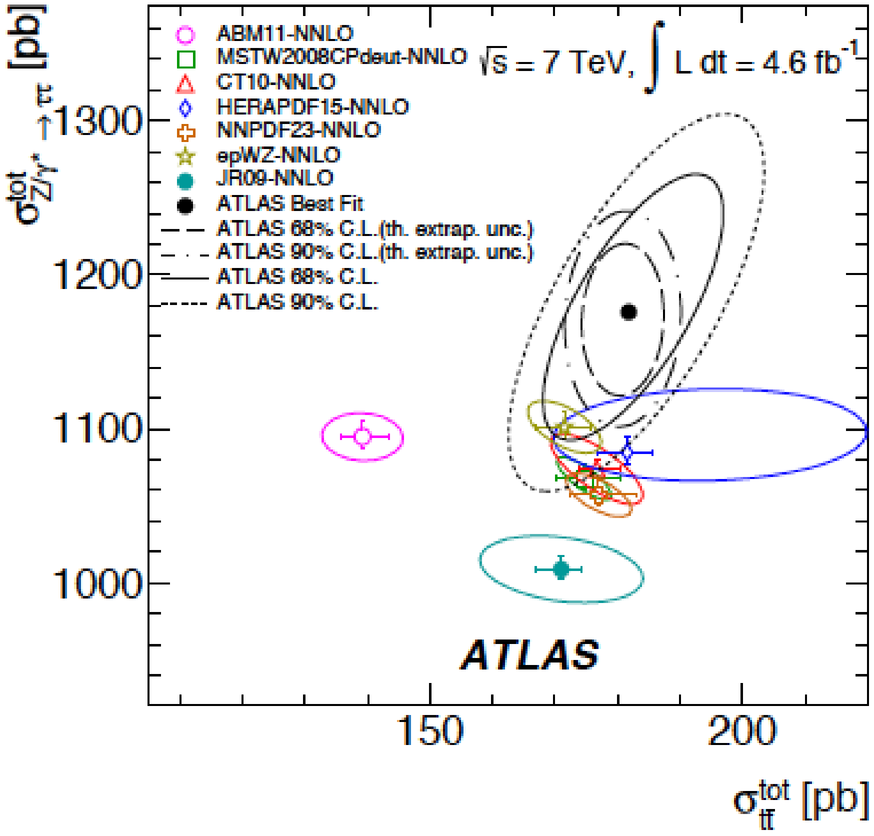
A wealth of measurements available already



NLO QCD is clearly insufficiently precise for SM, top (and even Higgs) measurements

- Fiducial cross sections can only be compared at NLO
- Until recently, total cross sections could be compared only between Z Drell-Yan and top pair production
- Note that ttbar NNLO calculation is > 3 years old now, still no NNLO differential MC available. Note also that Z to ⎮⎮ to e⌠ is not ok in MCFM





arXiv:1407.0573

W/Z fiducial/differential measurements

- Fiducial measurements provide already now a more precise test of QCD predictions, at least in terms of pdfs, than when they are corrected back to the total cross-sections
- Reducing the size of the error bars on the major axes of these ellipses is the challenge ATLAS/CMS have worked on very hard!

Note that the green ellipse is dominated by the uncertainty on the luminosity measurement which was 3.4%.

For 2011 data, down to 1.8%

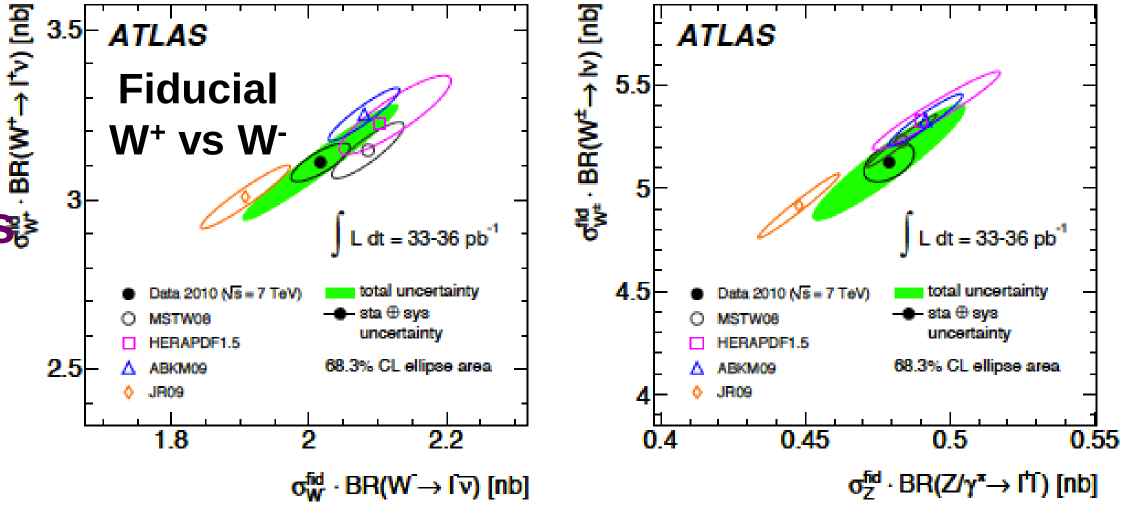


FIG. 15. *Measured and predicted fiducial cross sections times leptonic branching ratios,* σ_{W^+} *vs.* σ_{W^-} *(left) and* $(\sigma_{W^+}+\sigma_{W^-})$ *vs.* σ_{Z/γ^*} *(right). The ellipses illustrate the 68 % CL coverage for total uncertainties (full green) and excluding the luminosity uncertainty (open black). The uncertainties of the theoretical predictions are the PDF uncertainties only.*

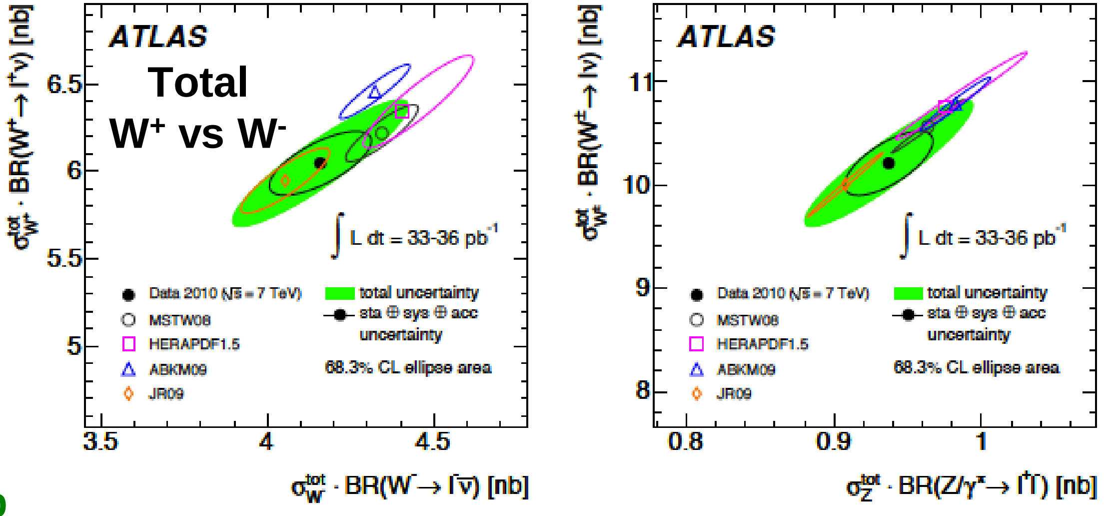


FIG. 16. *Measured and predicted total cross sections times leptonic branching ratios:* σ_{W^+} *vs.* σ_{W^-} *(left) and* $(\sigma_{W^+}+\sigma_{W^-})$ *vs.* σ_{Z/γ^*} *(right). The ellipses illustrate the 68 % CL coverage for total uncertainties (full green) and excluding the luminosity uncertainty (open black). The uncertainties of the theoretical predictions are the PDF uncertainties only.*

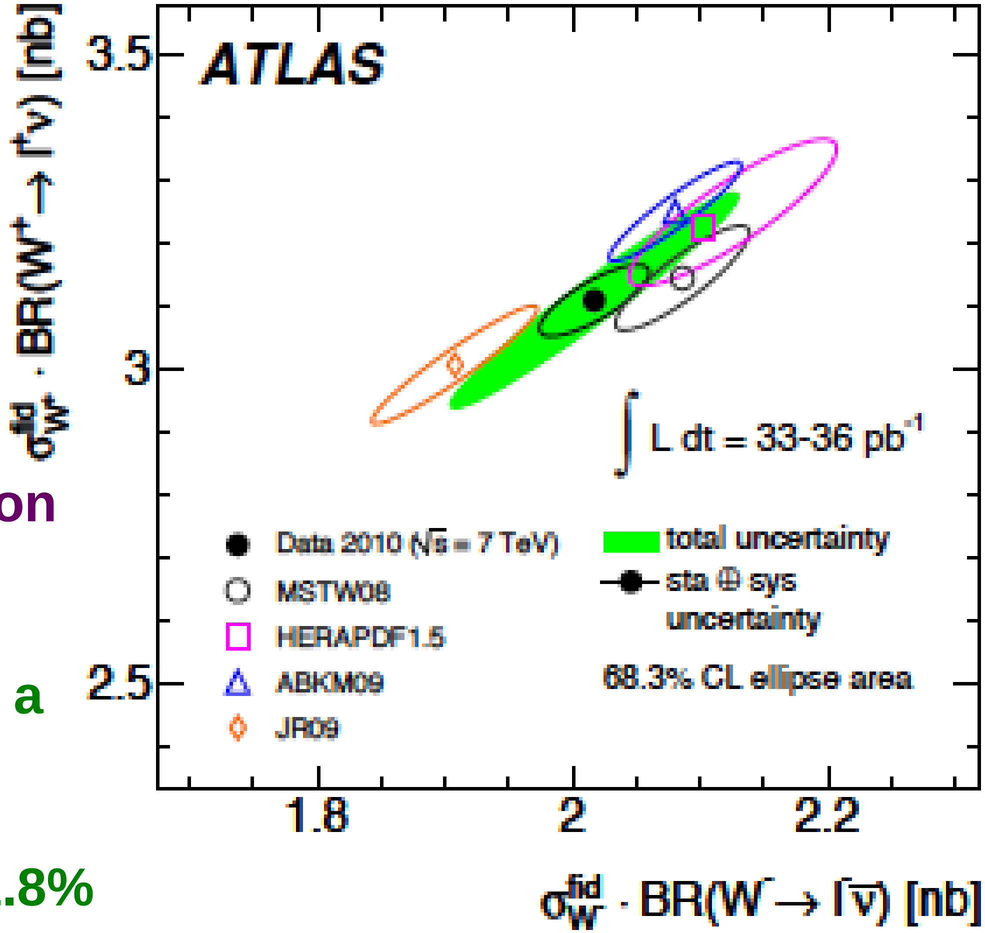
W/Z fiducial/differential measurements

- What is theory in this plot of integrated fiducial cross sections?

FEWZ (NNLO QCD differential MC, at parton level) with different NNLO PDF sets. Uncertainties on the theory ellipses are therefore purely QCD scale uncertainties i.e. they supposedly cover our lack of knowledge of higher-order corrections.

Can these be improved?

This is highly unlikely



- How to reach even better precision experimentally?

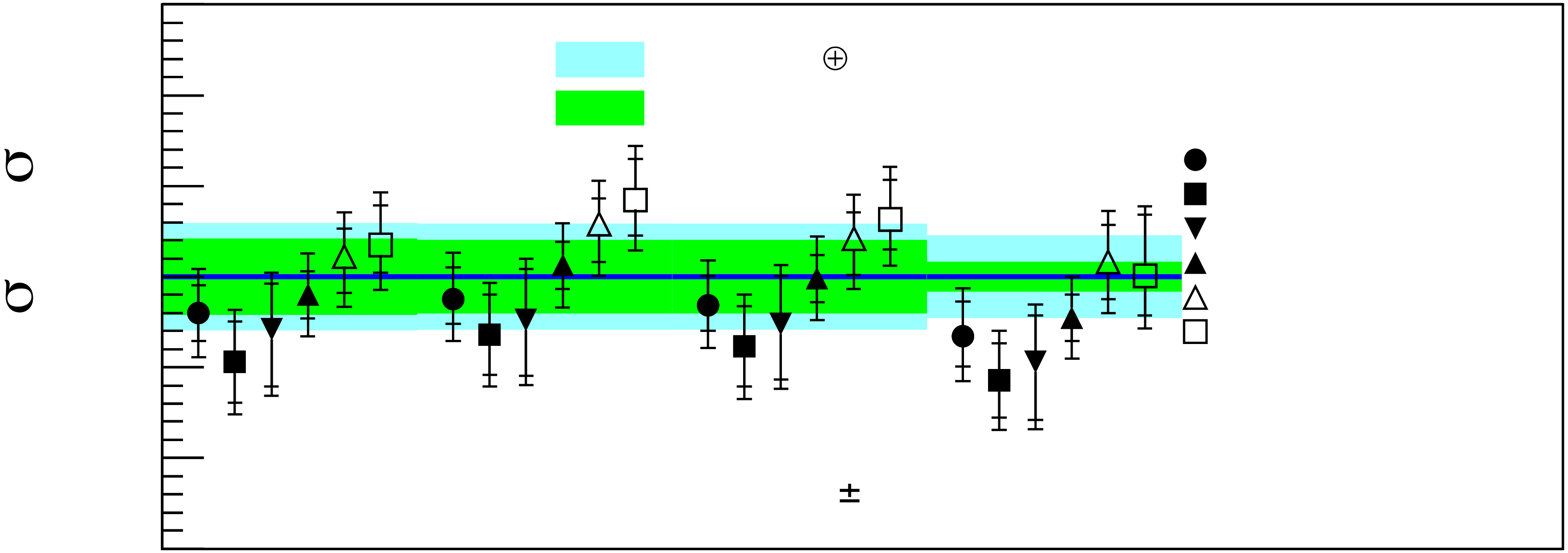
- Improve exp. syst. from few % to a total of ~ 0.5%

- Improve lumi syst from 3.4% to 1.8%

W/Z/ttbar fiducial/differential measurements

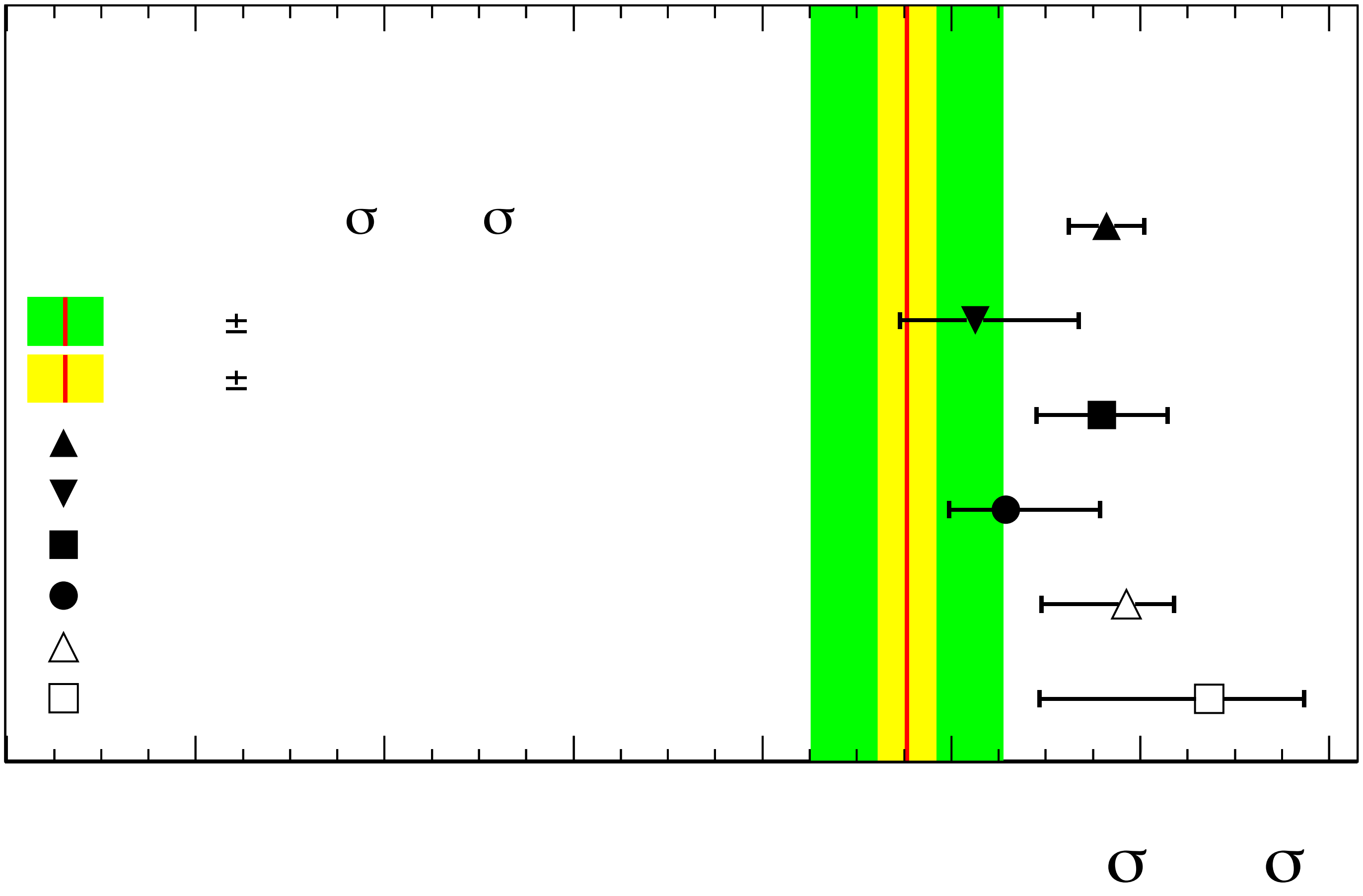
- The ratios of W to Z fiducial cross-sections have perhaps the highest potential for precision measurements in the future

- Even more promising are ratios of cross sections at different LHC energies and double ratios such as W/Z and ttbar/Z at different sqrts. Many cancellations to be expected, especially luminosity.



W/Z fiducial/differential measurements

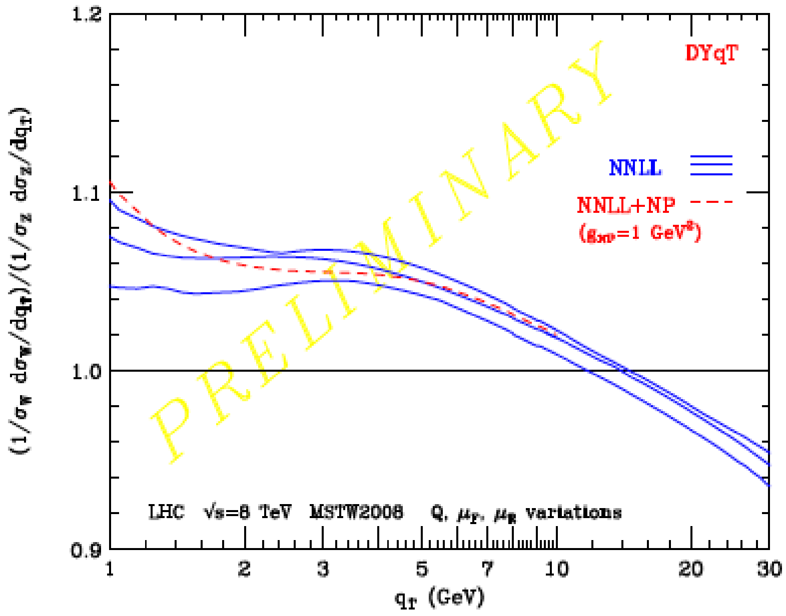
- The ratios of W to Z fiducial cross-sections have perhaps the highest potential for precision measurements in the future
- Here the scale uncertainties for the predictions are not plotted because there is no real guidance from theory on how to treat their possible correlations



Cancellation of uncertainties in ratios (?)

Beware! Plot below assumes all three scales (renorm., fact. and resummation) are fully correlated between W and Z.

W/Z ratio of observables: the q_T spectrum



DYqT resummed predictions for the ratio of W/Z normalized q_T spectra.

- The use of the W/Z ratio observables substantially reduces both the experimental and theoretical systematic uncertainties [Giele,Keller('97)].
- Resummed perturbative prediction for

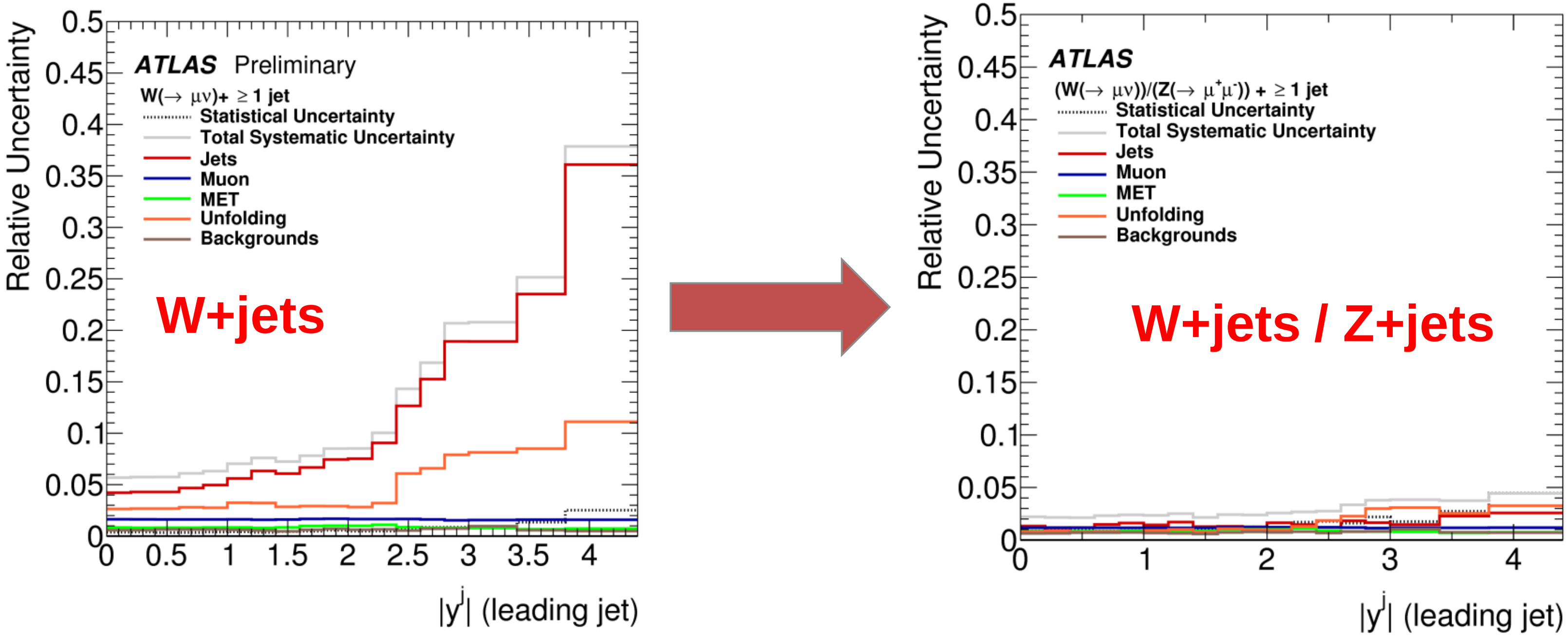
$$\frac{\frac{1}{\sigma_W}\frac{d\sigma_W}{dq_T}}{\frac{1}{\sigma_Z}\frac{d\sigma_Z}{dq_T}}(\mu_R, \mu_F, Q)$$

  with the customary scale variation.
- NNLL perturbative uncertainty band very small: 2-5% for $1 < q_T < 2\,\mathrm{GeV}$, 1.5-2% for $2 < q_T < 30\,\mathrm{GeV}$.
- Non perturbative effects within 1% for $1.5 < q_T < 5\,\mathrm{GeV}$ and negligible for $q_T > 5\,\mathrm{GeV}$.

DYRES: a tool to be used at the LHC?

Cancellation of uncertainties in ratios (?)

- ❑ **Ratio measurements allow for cancellations of uncertainties (exp. and theory)**
  - **Experimental: jet calibration uncertainties, lumi etc.**



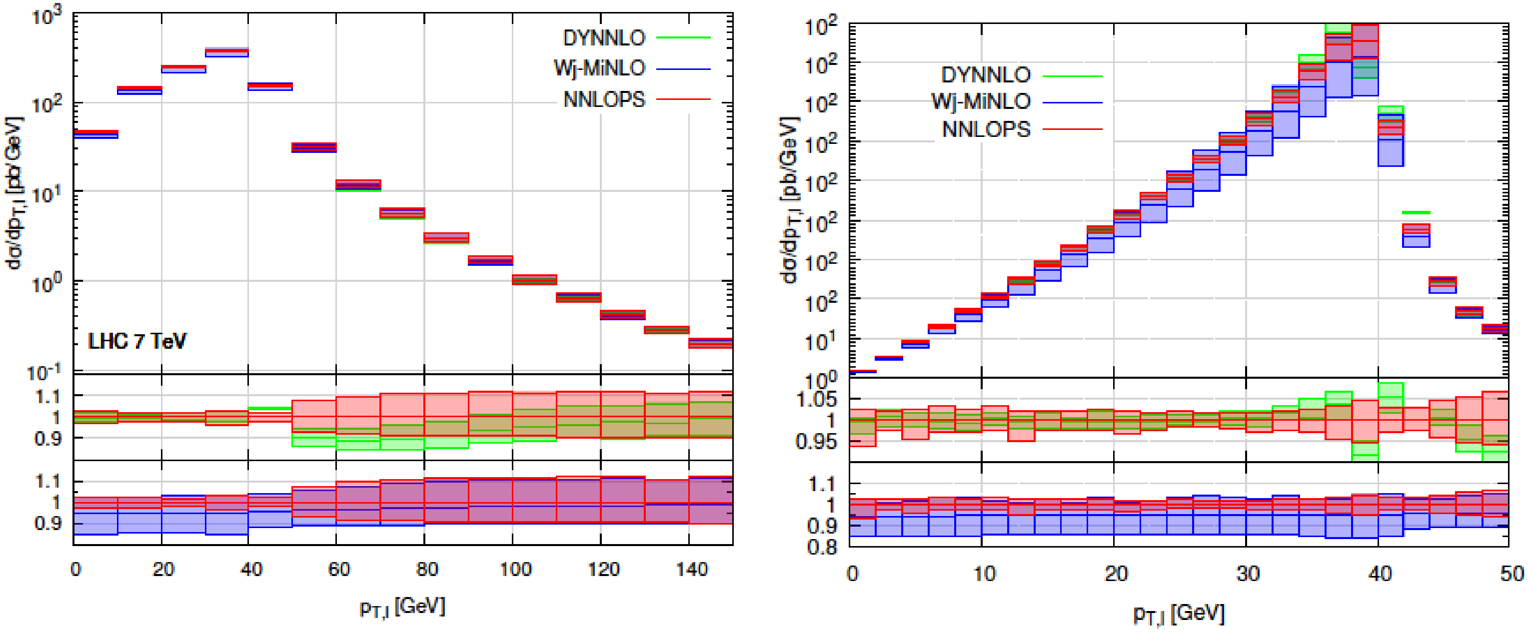
Theory: (if treated as correlated between numerator and denominator)

- ❑ **scale+PDF uncertainties: *20%* (W+1j) -> *2-4%* on W+1j/Z+1j at jet p_T=800 GeV**
- ❑ **Accurate test of SM predictions**
- ❑ **Important for Z(νν)+jets background estimation in searches**
- ❑ **Quasi model-independent searches for new physics**

Is Powheg+MiNLO formally NNLO accuracy?

Powheg+Minlo also pays attention to Z polarisation now!

W@NNLOPS, PS level



- not the observables we are using to do the NNLO reweighting
  - observe exactly what we expect: $p_{T,\ell}$ has NNLO uncertainty if $p_T < M_W/2$, NLO if $p_T > M_W/2$
  - smooth behaviour when close to Jacobian peak (also with small bins) (due to resummation of logs at small $p_{T,V}$)
- just above peak, `DYNNLO` uses $\mu = M_W$, `WJ-MiNLO` uses $\mu = p_{T,W}$
  - here $0 \lesssim p_{T,W} \lesssim M_W$ (so resummation region does contribute)

Experimental summary: the PDF saga

A number of important points were brought up concerning PDFs:

a) **Need to include theory uncertainties, i.e. QCD scales. Otherwise output of fits will be unreliable for certain data where these uncertainties are larger than the ones from the PDFs themselves.**

b) **Need to evaluate impact of parton shower on PDF fits**

c) **PDF fits should learn to use data provided at particle level (eg WD measurements of ATLAS and CMS)**

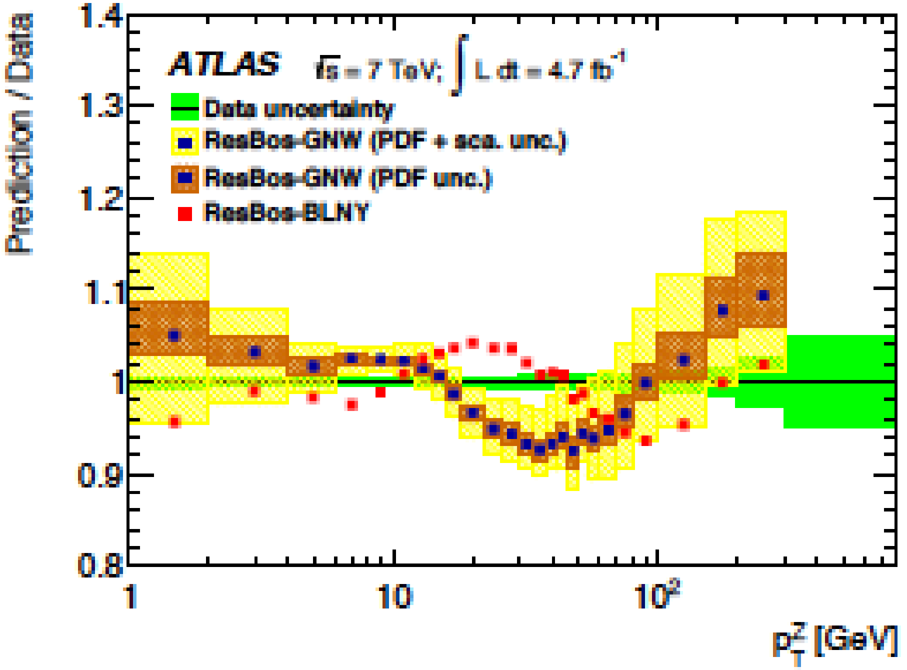
d) **XFITTER is a nice idea: it might be the seed to having one day a unified approach to PDF fits across the community**

e) **Finally, need to explore more vigorously the use of only DIS data above a certain Q2 threshold plus the available ATLAS and CMS data**

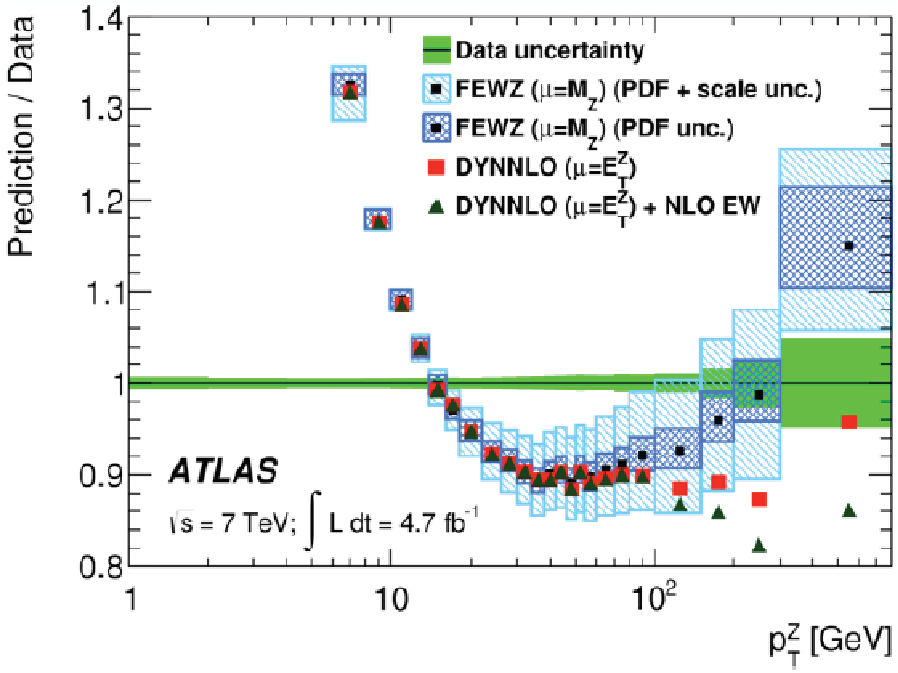
I have the impression that here the solution is <u>not</u> to have even more precise QCD calculations such as N3LO.

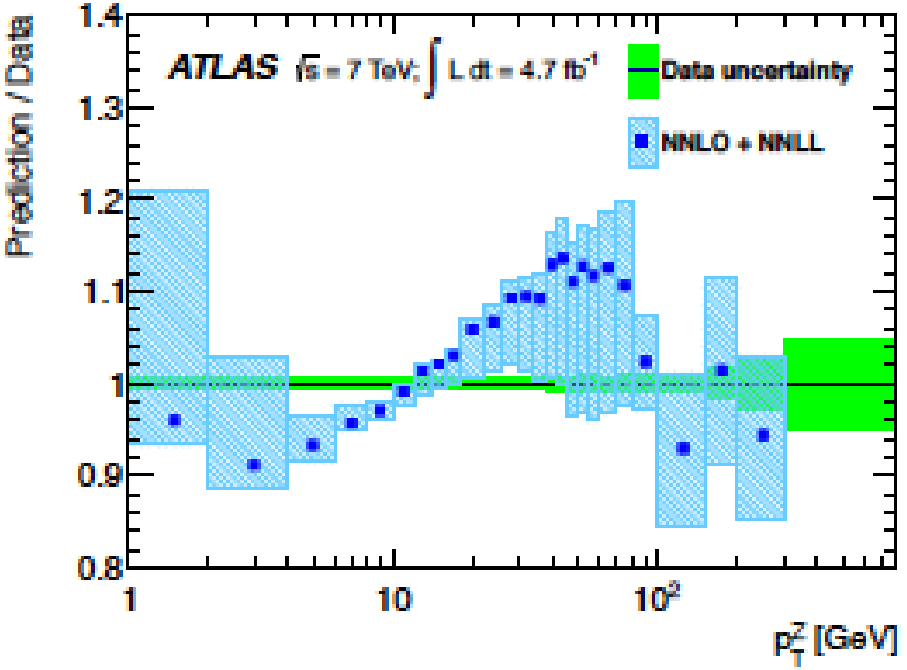
Very precise measurement of Z p_T poses problems to theory

- Shown also here are ResBos (top right) and resummation calculation by Banfi et al. (bottom right)
- Note: uncertainty on measurement at low p_T is ~ 0.5%, rising to 1.5% for p_T^Z ~ 150 GeV



ATLAS Z pT: NNLO / Data

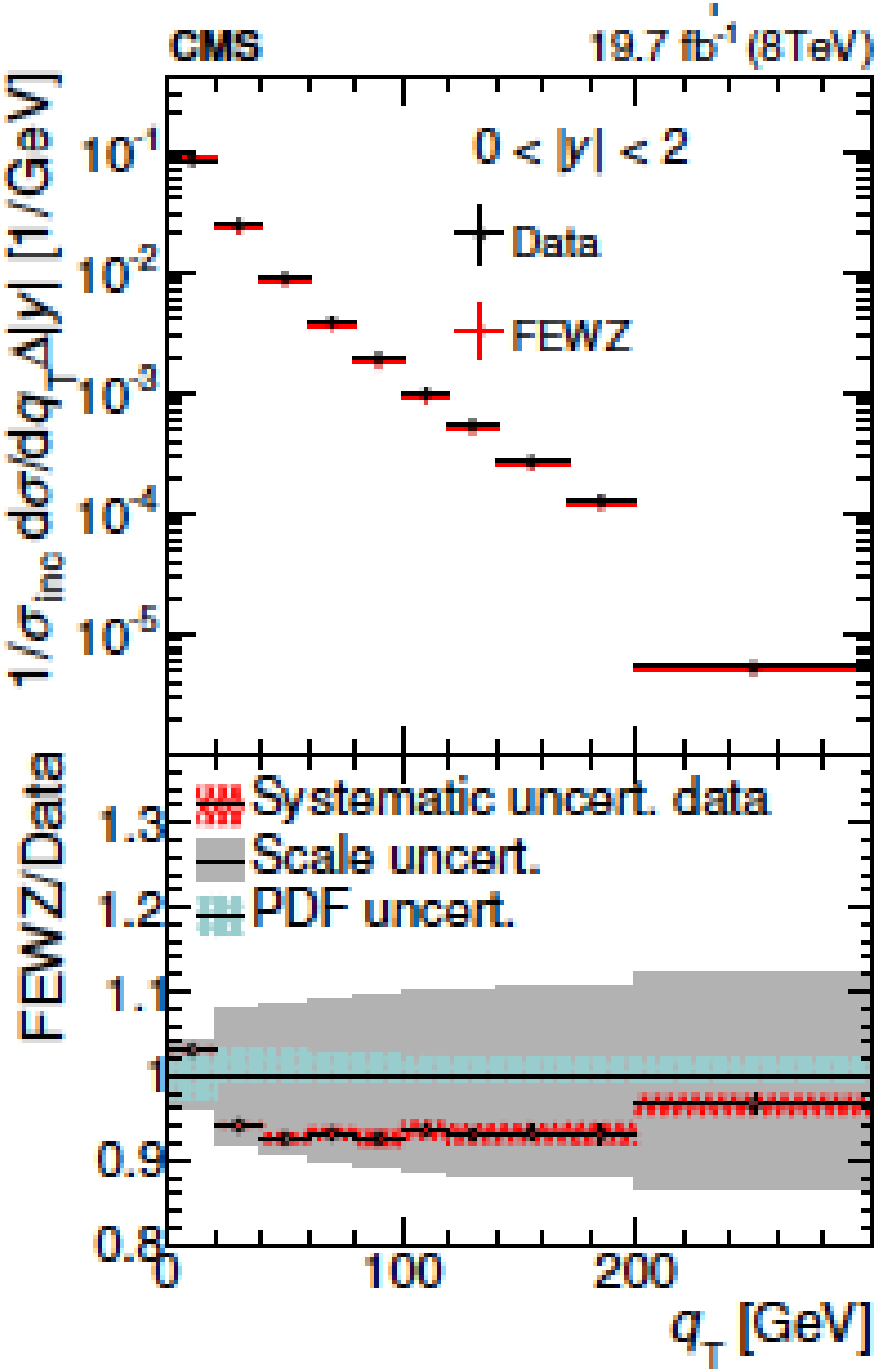




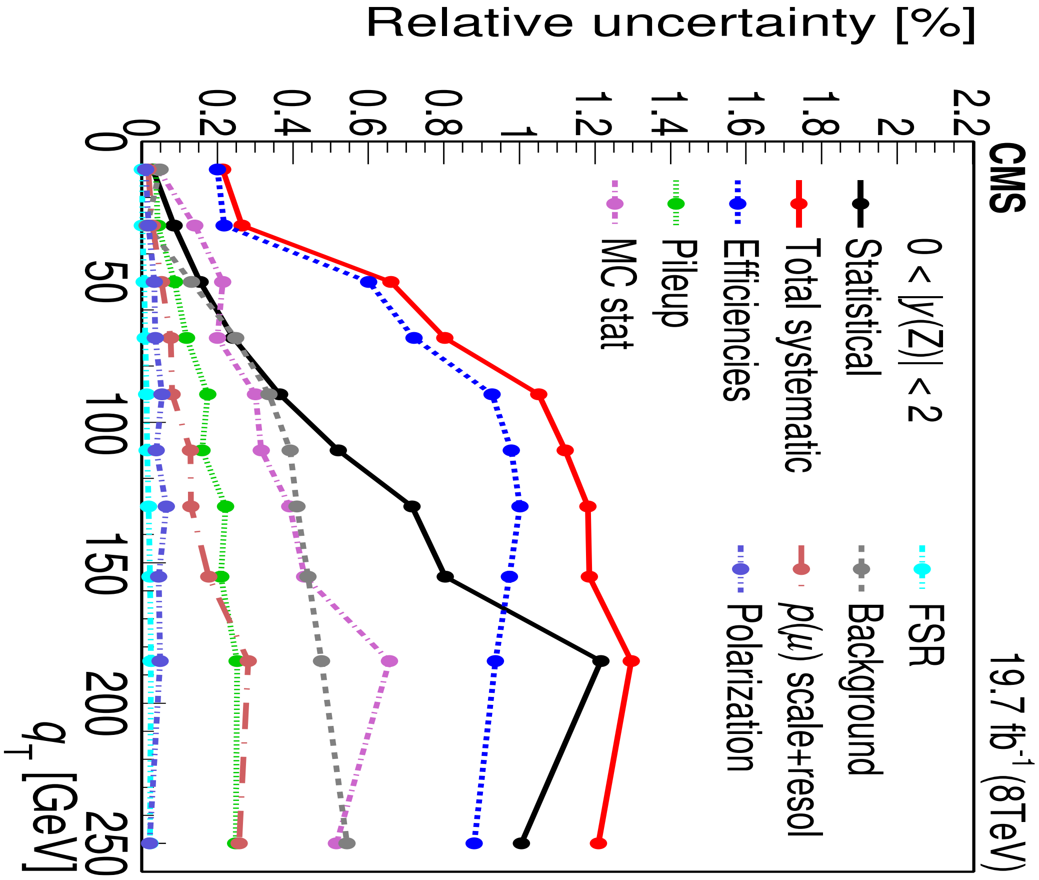
Very precise measurement of p_T^Z in terms of shape!

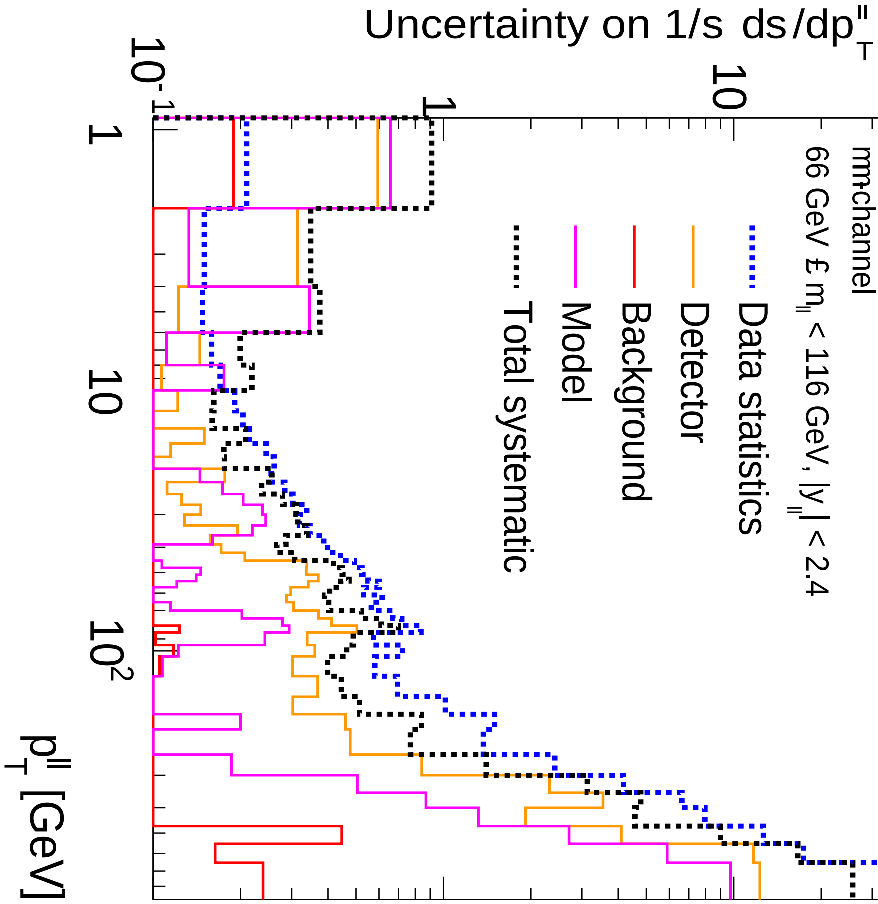
- Recent measurement published by CMS seems to indicate reasonable agreement between fixed-order calculations by FEWZ (NNLO) and measurements
- Measurements are much more precise than theory ($\int_{meas}$~1.5%)
- This measurement is very important for many reasons, one of them being m_W measurement

- But what does NNLO mean here?
- Actually, it means NNLO differential for any distribution which is defined for $p_T^Z = 0$ but only NLO for the others
- Non-trivial examples: cos⎝$_{CS}$ is NNLO but ⎞$_{CS}$ is only NLO



Very precise measurement of Z p_T sees agreement between ATLAS and CMS (but uncertainties seem surprisingly large in CMS measurements?)

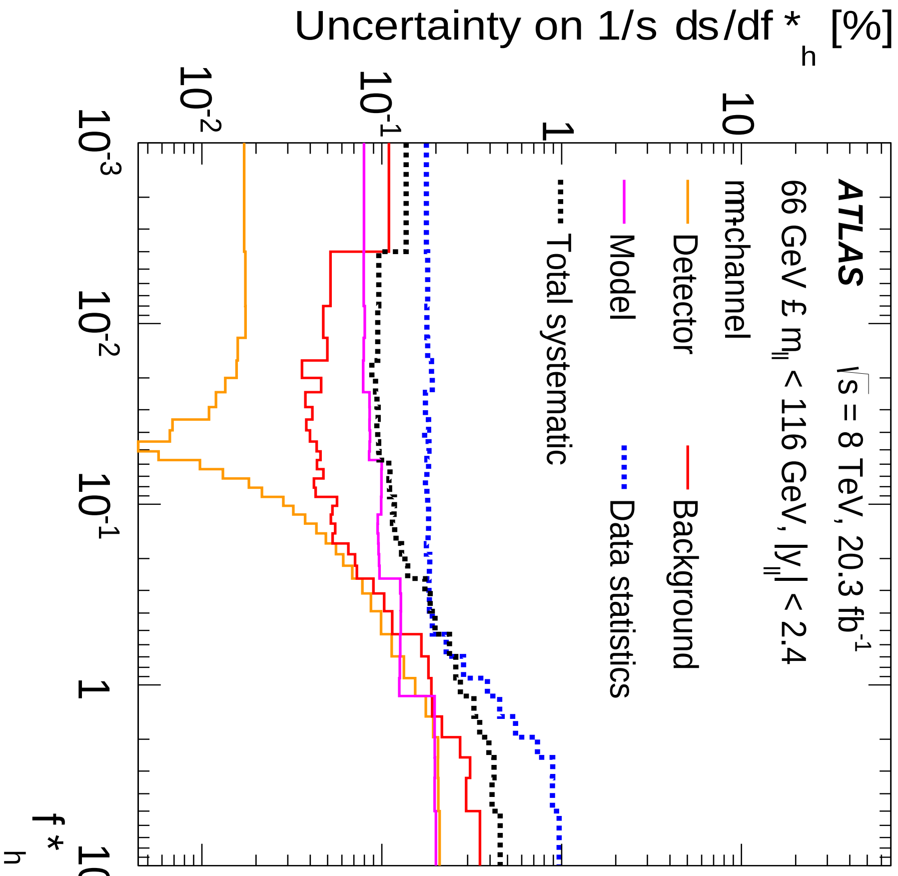


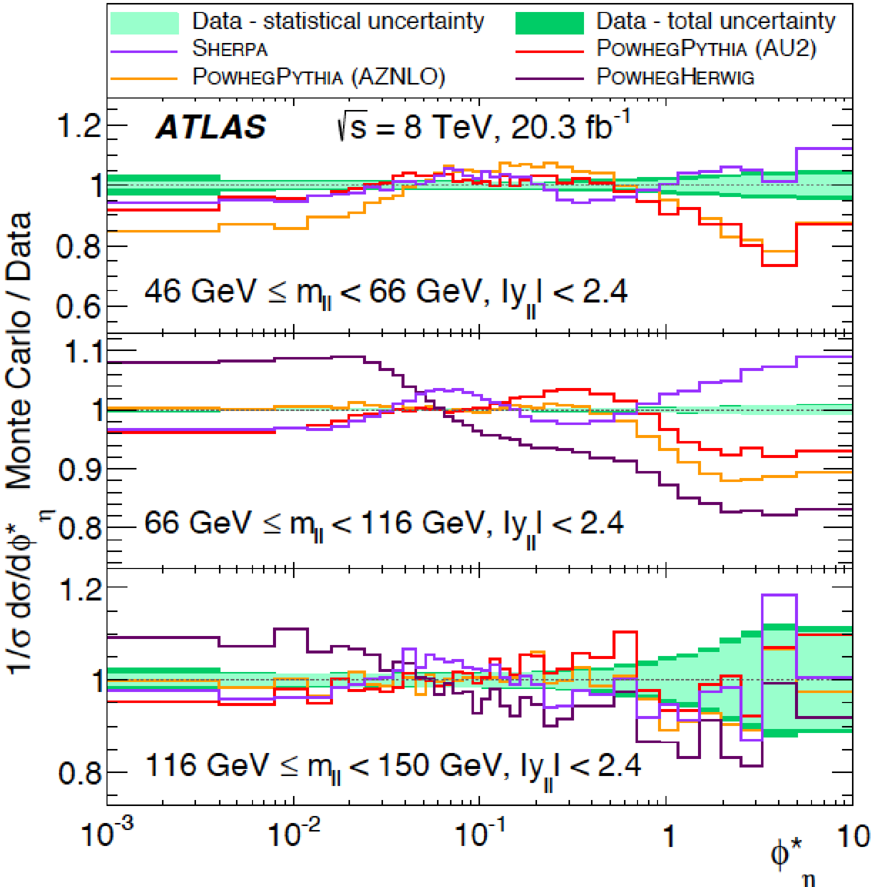


Choice of optimal variable reduces uncertainties a lot!

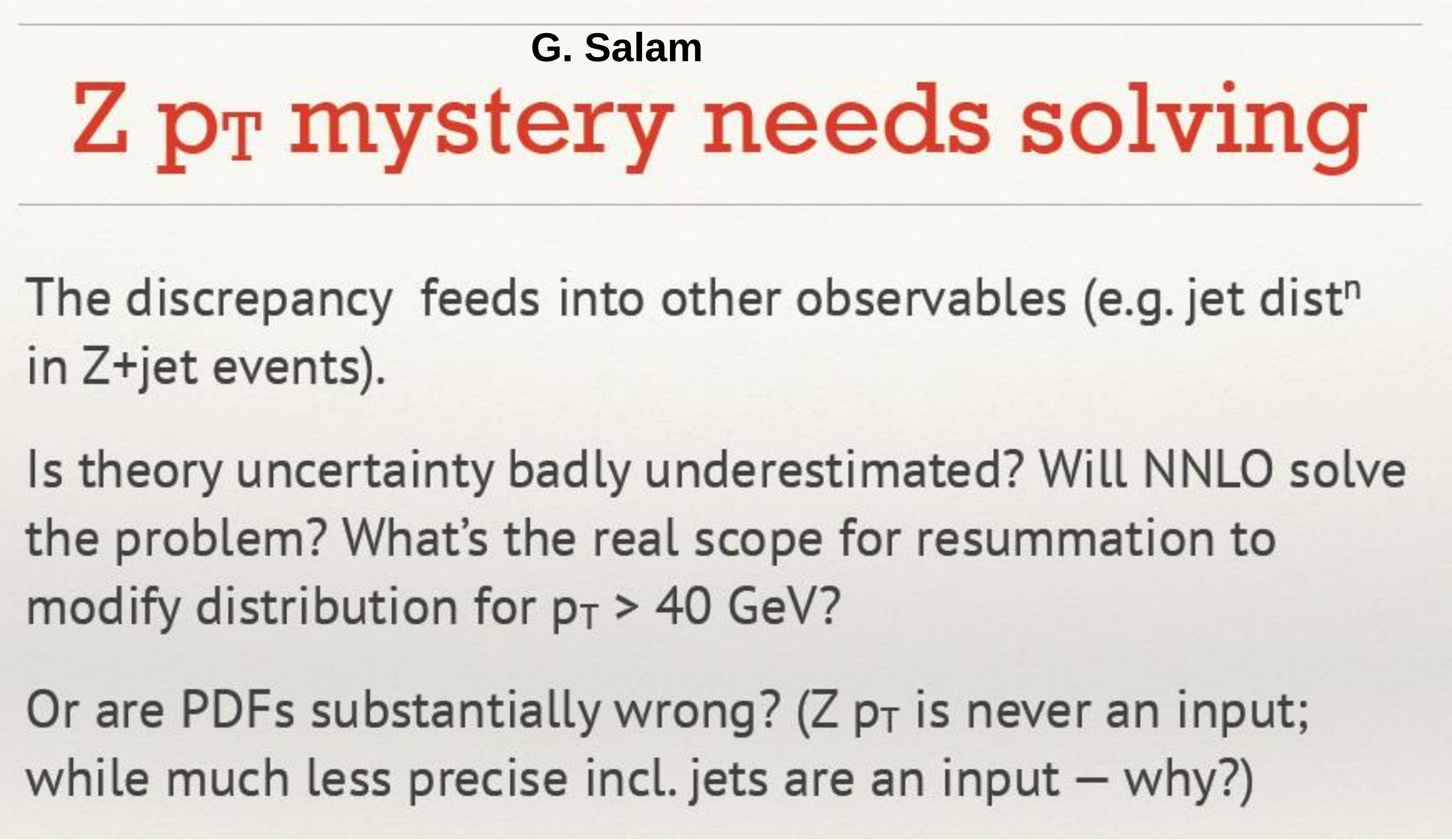
$$\phi^*_\eta = \tan\left(\frac{\pi - \Delta\phi}{2}\right) \cdot \sin(\theta^*_\eta) , \tag{1}$$

where $\Delta\phi$ is the azimuthal angle in radians between the two leptons. The angle θ^*_η is a measure of the scattering angle of the leptons with respect to the proton beam direction in the rest frame of the dilepton system and is defined by $\cos(\theta^*_\eta) = \tanh[(\eta^- - \eta^+)/2]$, where η^- and η^+ are the pseudorapidities of the negatively and positively charged lepton, respectively [21]. Therefore, ϕ^*_η depends exclusively on the





Very precise measurement of Z p_T poses problems to theory (and experiments)!



G. Salam

Z p_T mystery needs solving

The discrepancy feeds into other observables (e.g. jet dist^n in Z+jet events).

Is theory uncertainty badly underestimated? Will NNLO solve the problem? What's the real scope for resummation to modify distribution for $p_T > 40$ GeV?

Or are PDFs substantially wrong? (Z p_T is never an input; while much less precise incl. jets are an input – why?)

Experimental summary: « soft QCD » not discussed here!

One may think that this has little impact on precision measurements of DY, top or Higgs, but actually this is not necessarily true. We need more measurements in this area! A few illustrative examples can be quoted:

a) Precise measurement of underlying event in Z to ee and μμ
b) Colour reconnection in top mass measurement
c) UEPS (und. event and parton shower) uncertainties in VBF for Higgs measurements

In the end, « on n'est bien servi que par soi-même », i.e. for precision measurements of a given process, one should measure the underlying event in that process and not use MC with a possibly rando tune to mode it and worse use possible eigenvalues of the tune to estimate the uncertainties. So eventually for W mass, need to measure W underlying event, same for top and Higgs.

Precision meas. in the SM: pile-up and underlying event

- **Underlying event multiplicity in jet events and Z events precisely measured and hard to reproduce with MC models**

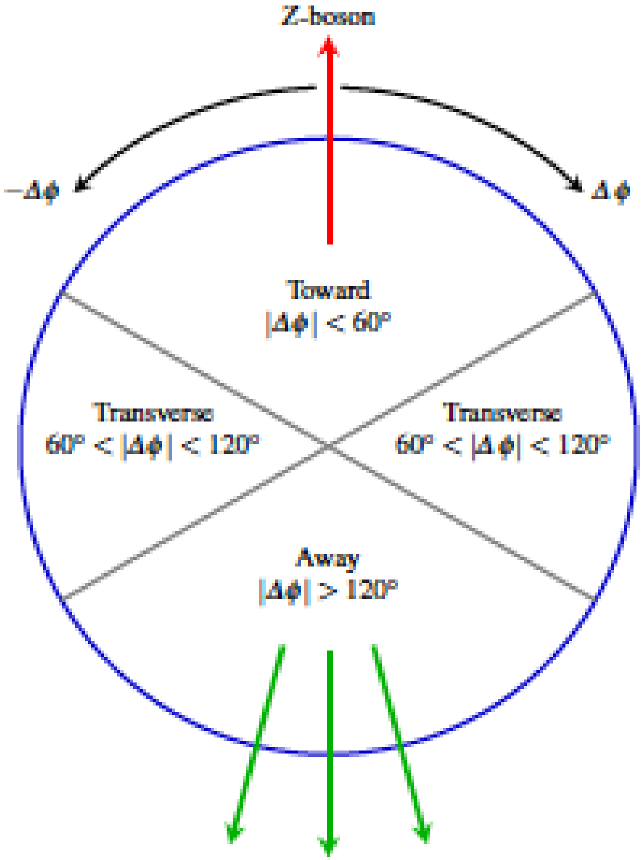
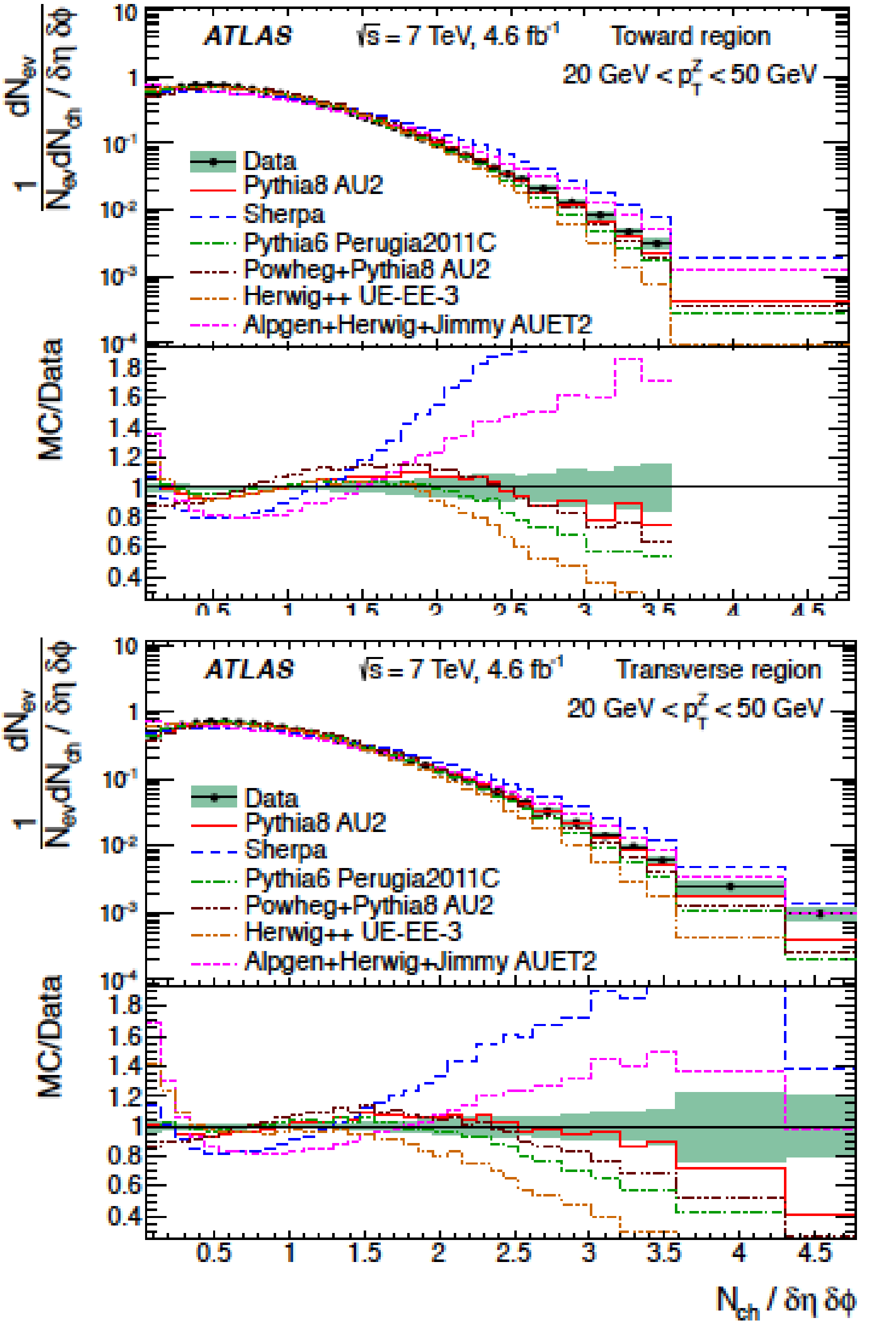
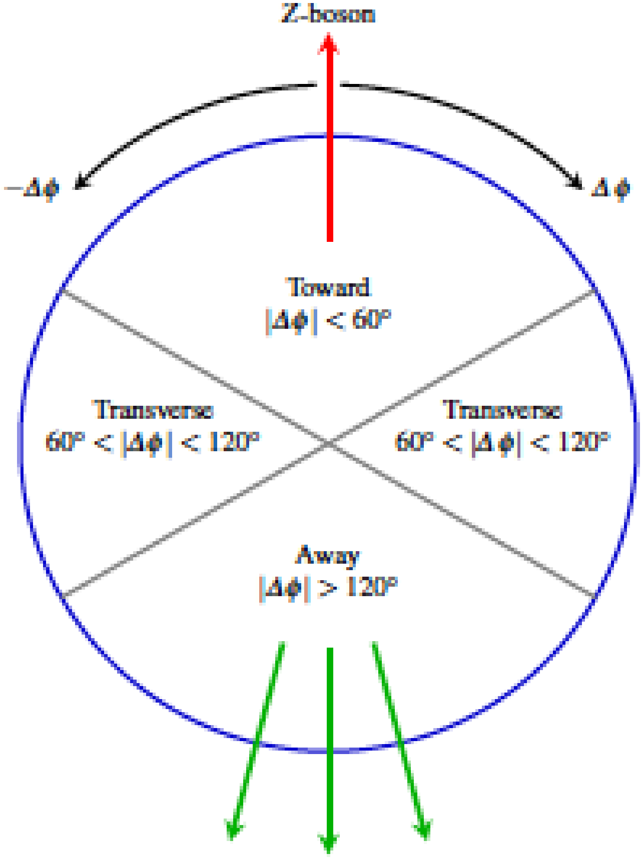


Fig. 1 Definition of UE regions as a function of the azimuthal angle with respect to the Z-boson.



Precision meas. in the SM: pile-up and underlying event

- Underlying event multiplicity in jet events and Z events precisely measured and hard to reproduce with MC models.
- Same is true for $<p_T>$ of ch. part.



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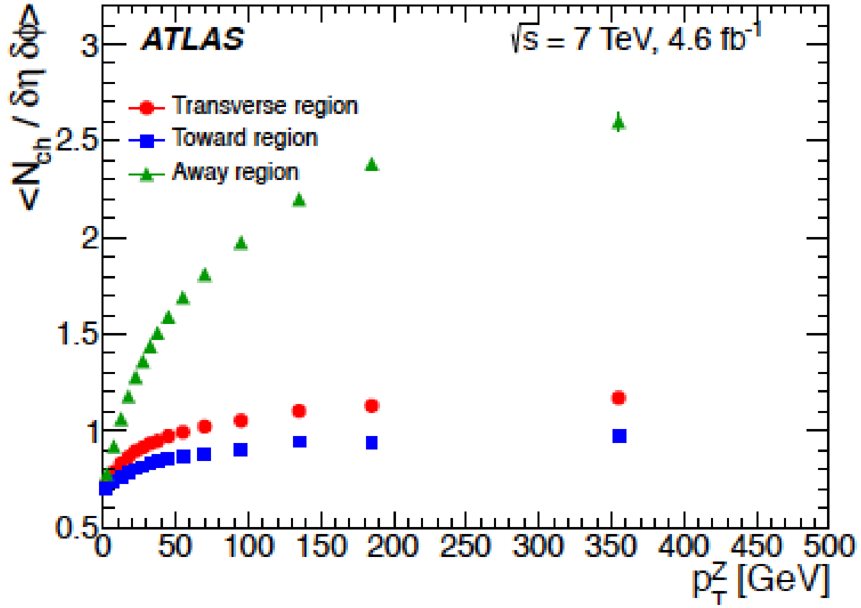
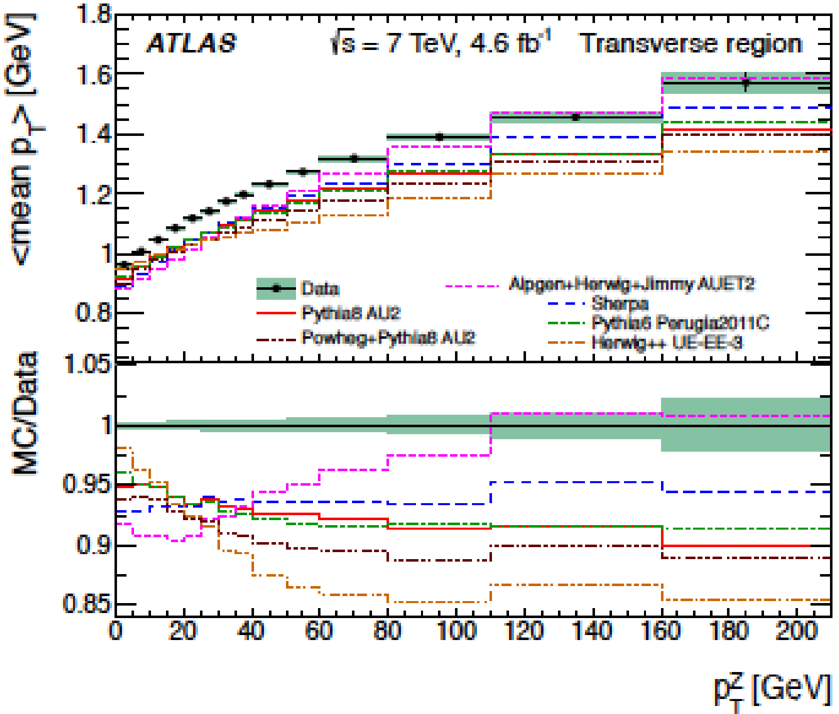




Precision meas. in the SM: pile-up and underlying event

- **Underlying event multiplicity in jet events and Z events precisely measured but difficult to compare on the same footing**

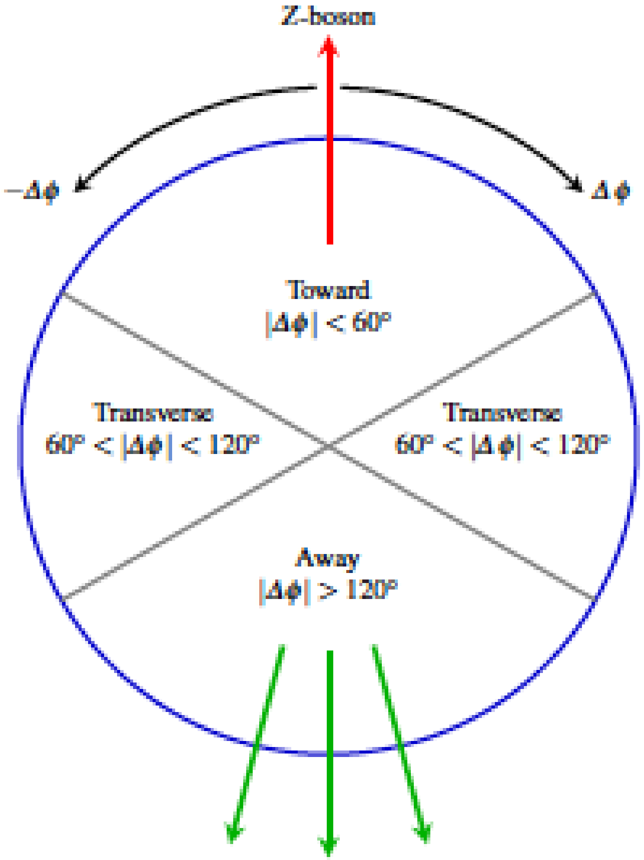
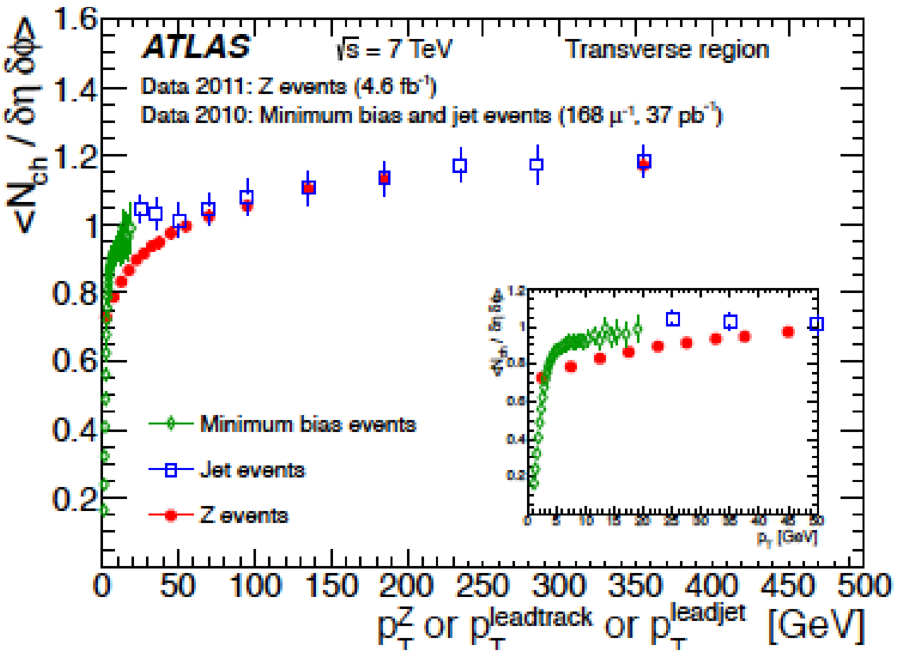
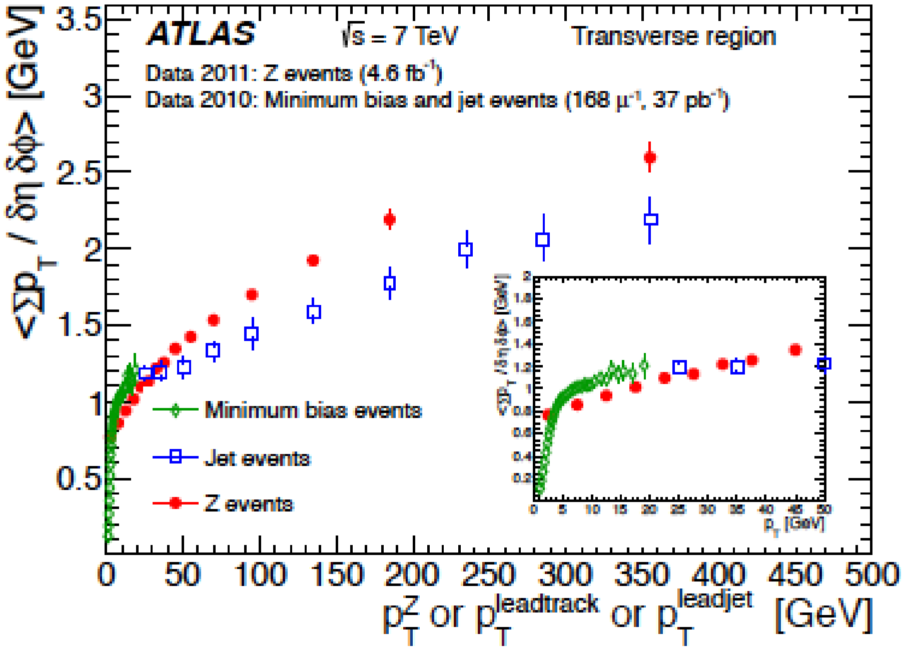


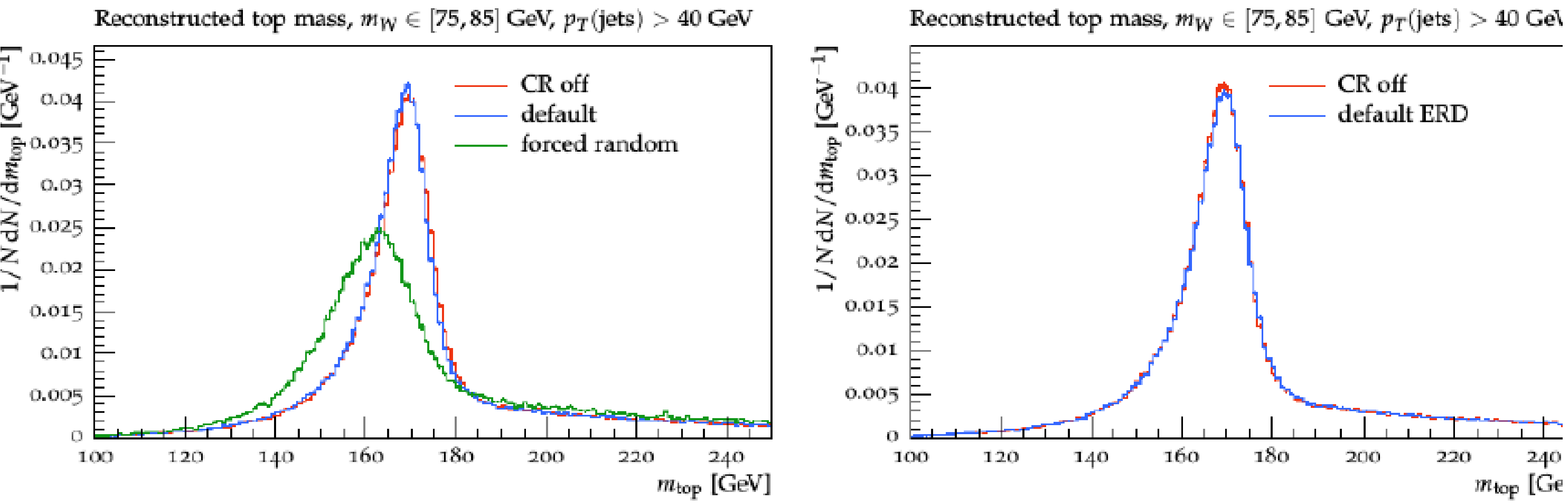
Fig. 1 Definition of UE regions as a function of the azimuthal angle with respect to the Z-boson.





Experimental summary: « soft QCD » not discussed here!

Colour reconnection before or after W decay changes top mass by 0.5 GeV!
On the other hand, switching it on or off, changes it by only 0.2 GeV!!
I have the feeling we need to bite the bullet and find observables (thrust, boosted top) which are not dependent on all these effects.



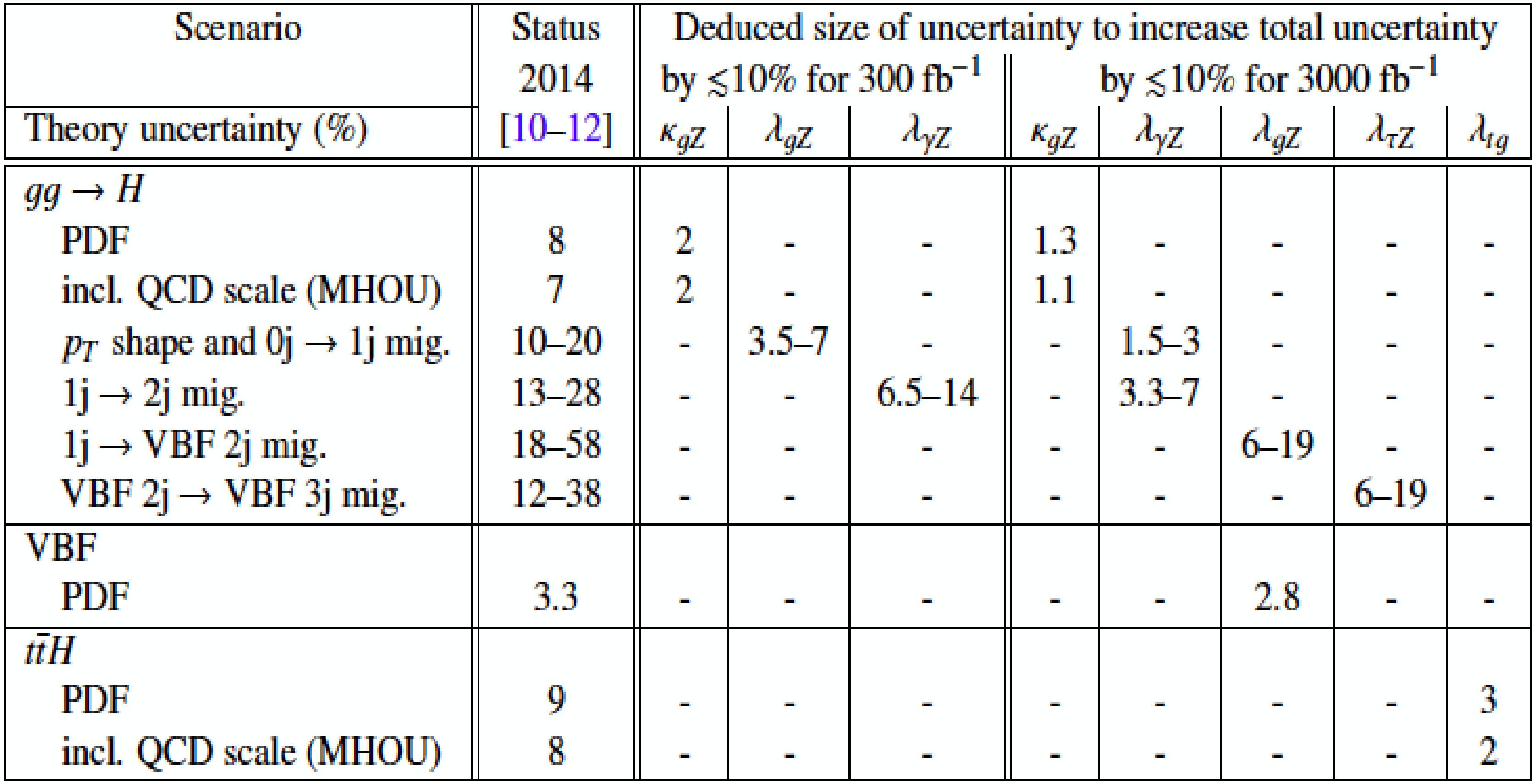
Colour reconnection changes the hadronic activity inside jets, leading to a different (b-)jet shapes ⇒ Uncertainty on m_t at $\mathcal{O}(500\text{ MeV})$ level.

Can be constrained by underlying event measurements, e.g. N_{ch} in cone around top direction (depleted w/o reconnection!)

Experimental summary: what about Higgs boson?

Theory uncertainties for Higgs signal

- What must be achieved for theory calculations in order to have a smaller than 10% contribution to the total uncertainty

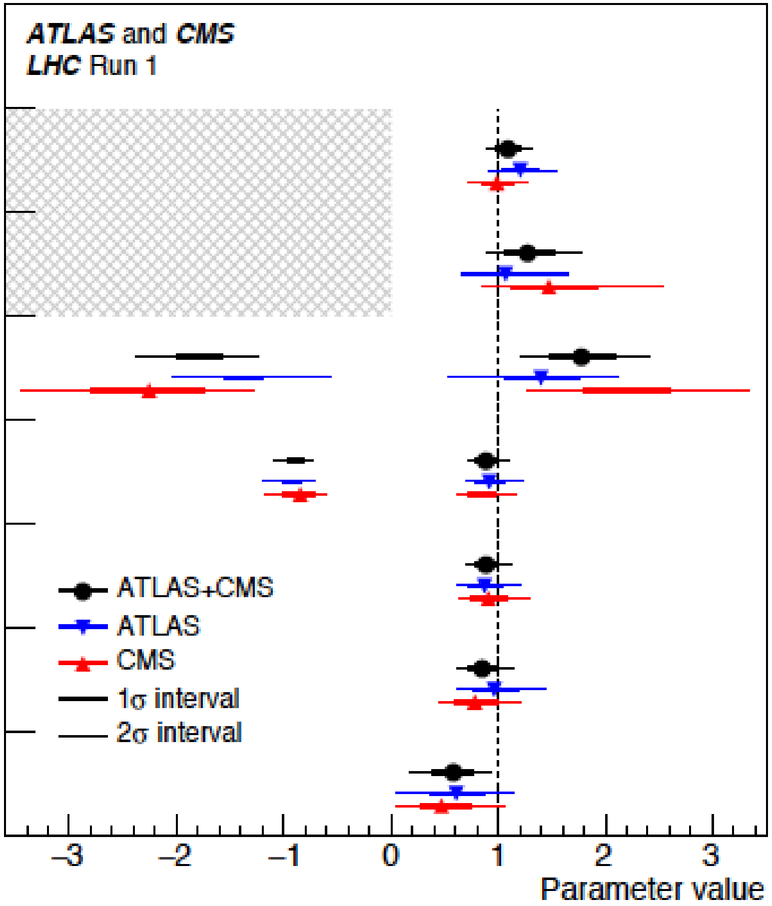


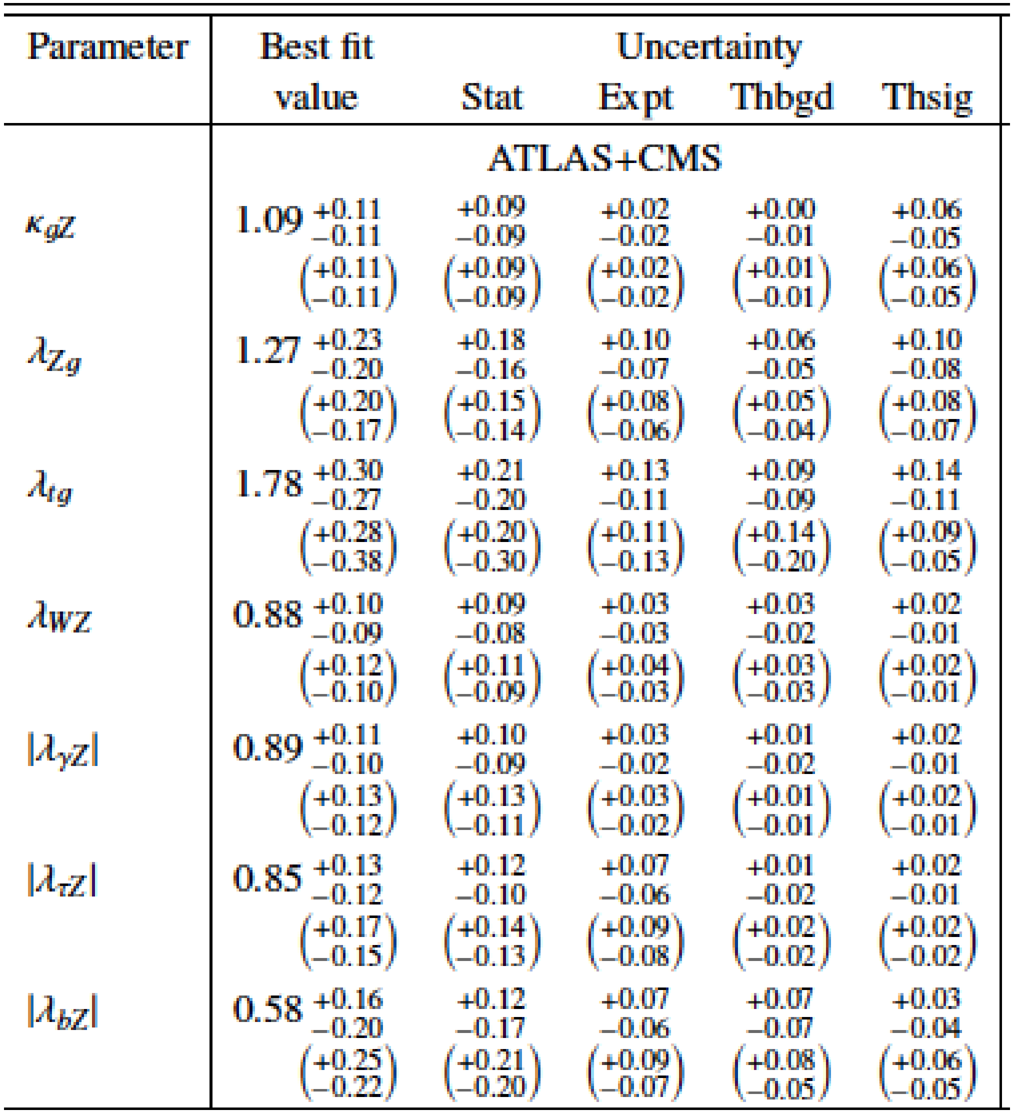
Scenario	Status	Deduced size of uncertainty to increase total uncertainty							
	2014	by $\lesssim$10% for 300 fb^{-1}			by $\lesssim$10% for 3000 fb^{-1}				
Theory uncertainty (%)	[10–12]	κ_{gZ}	λ_{gZ}	$\lambda_{\gamma Z}$	κ_{gZ}	$\lambda_{\gamma Z}$	λ_{gZ}	$\lambda_{\tau Z}$	λ_{tg}
$gg \to H$									
PDF	8	2	-	-	1.3	-	-	-	-
incl. QCD scale (MHOU)	7	2	-	-	1.1	-	-	-	-
p_T shape and 0j → 1j mig.	10–20	-	3.5–7	-	-	1.5–3	-	-	-
1j → 2j mig.	13–28	-	-	6.5–14	-	3.3–7	-	-	-
1j → VBF 2j mig.	18–58	-	-	-	-	-	6–19	-	-
VBF 2j → VBF 3j mig.	12–38	-	-	-	-	-	-	6–19	-
VBF									
PDF	3.3	-	-	-	-	-	2.8	-	-
$t\bar{t}H$									
PDF	9	-	-	-	-	-	-	-	3
incl. QCD scale (MHOU)	8	-	-	-	-	-	-	-	2

ATL-PHYS-PUB-2014-

Experimental summary: what about Higgs boson?

ATLAS and CMS have provided information from run 1 on the dominant uncertainties from theory on signal and background separately

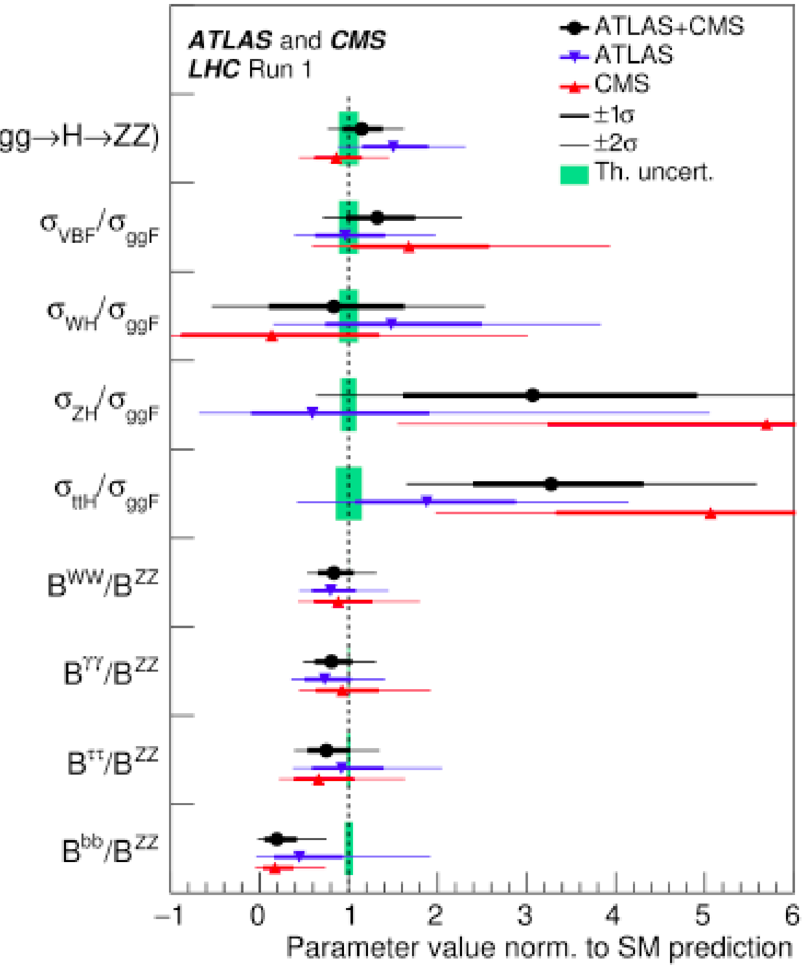


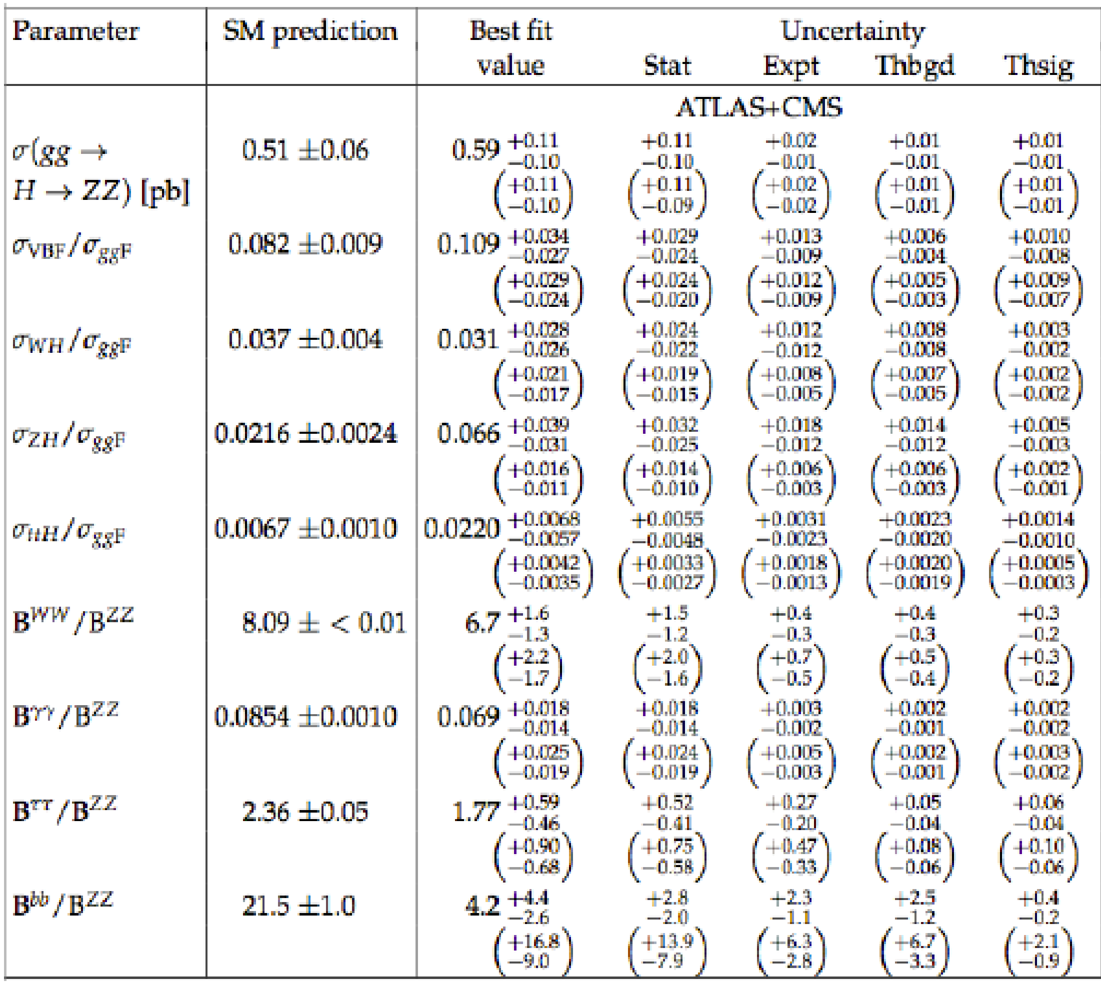


Parameter	Best fit value	Uncertainty Stat	Uncertainty Expt	Uncertainty Thbgd	Uncertainty Thsig
	ATLAS+CMS				
κ_{gZ}	$1.09^{+0.11}_{-0.11}$ $\left(^{+0.11}_{-0.11}\right)$	$^{+0.09}_{-0.09}$ $\left(^{+0.09}_{-0.09}\right)$	$^{+0.02}_{-0.02}$ $\left(^{+0.02}_{-0.02}\right)$	$^{+0.00}_{-0.01}$ $\left(^{+0.01}_{-0.01}\right)$	$^{+0.06}_{-0.05}$ $\left(^{+0.06}_{-0.05}\right)$
λ_{Zg}	$1.27^{+0.23}_{-0.20}$ $\left(^{+0.20}_{-0.17}\right)$	$^{+0.18}_{-0.16}$ $\left(^{+0.15}_{-0.14}\right)$	$^{+0.10}_{-0.07}$ $\left(^{+0.08}_{-0.06}\right)$	$^{+0.06}_{-0.05}$ $\left(^{+0.05}_{-0.04}\right)$	$^{+0.10}_{-0.08}$ $\left(^{+0.08}_{-0.07}\right)$
λ_{tg}	$1.78^{+0.30}_{-0.27}$ $\left(^{+0.28}_{-0.38}\right)$	$^{+0.21}_{-0.20}$ $\left(^{+0.20}_{-0.30}\right)$	$^{+0.13}_{-0.11}$ $\left(^{+0.11}_{-0.13}\right)$	$^{+0.09}_{-0.09}$ $\left(^{+0.14}_{-0.20}\right)$	$^{+0.14}_{-0.11}$ $\left(^{+0.09}_{-0.05}\right)$
λ_{WZ}	$0.88^{+0.10}_{-0.09}$ $\left(^{+0.12}_{-0.10}\right)$	$^{+0.09}_{-0.08}$ $\left(^{+0.11}_{-0.09}\right)$	$^{+0.03}_{-0.03}$ $\left(^{+0.04}_{-0.03}\right)$	$^{+0.03}_{-0.02}$ $\left(^{+0.03}_{-0.03}\right)$	$^{+0.02}_{-0.01}$ $\left(^{+0.02}_{-0.01}\right)$
$\lvert\lambda_{\gamma Z}\rvert$	$0.89^{+0.11}_{-0.10}$ $\left(^{+0.13}_{-0.12}\right)$	$^{+0.10}_{-0.09}$ $\left(^{+0.13}_{-0.11}\right)$	$^{+0.03}_{-0.02}$ $\left(^{+0.03}_{-0.02}\right)$	$^{+0.01}_{-0.02}$ $\left(^{+0.01}_{-0.01}\right)$	$^{+0.02}_{-0.01}$ $\left(^{+0.02}_{-0.01}\right)$
$\lvert\lambda_{\tau Z}\rvert$	$0.85^{+0.13}_{-0.12}$ $\left(^{+0.17}_{-0.15}\right)$	$^{+0.12}_{-0.10}$ $\left(^{+0.14}_{-0.13}\right)$	$^{+0.07}_{-0.06}$ $\left(^{+0.09}_{-0.08}\right)$	$^{+0.01}_{-0.02}$ $\left(^{+0.02}_{-0.02}\right)$	$^{+0.02}_{-0.01}$ $\left(^{+0.02}_{-0.02}\right)$
$\lvert\lambda_{bZ}\rvert$	$0.58^{+0.16}_{-0.20}$ $\left(^{+0.25}_{-0.22}\right)$	$^{+0.12}_{-0.17}$ $\left(^{+0.21}_{-0.20}\right)$	$^{+0.07}_{-0.06}$ $\left(^{+0.09}_{-0.07}\right)$	$^{+0.07}_{-0.07}$ $\left(^{+0.08}_{-0.05}\right)$	$^{+0.03}_{-0.04}$ $\left(^{+0.06}_{-0.05}\right)$

Experimental summary: what about Higgs boson?

ATLAS and CMS have provided information from run 1 on the dominant uncertainties from theory on signal and background separately





Parameter	SM prediction	Best fit value	Uncertainty			
			Stat	Expt	Thbgd	Thsig
		ATLAS+CMS				
$\sigma(gg \to H \to ZZ)$ [pb]	0.51 ± 0.06	$0.59^{+0.11}_{-0.10}$ $\left(^{+0.11}_{-0.10}\right)$	$^{+0.11}_{-0.10}$ $\left(^{+0.11}_{-0.09}\right)$	$^{+0.02}_{-0.01}$ $\left(^{+0.02}_{-0.02}\right)$	$^{+0.01}_{-0.01}$ $\left(^{+0.01}_{-0.01}\right)$	$^{+0.01}_{-0.01}$ $\left(^{+0.01}_{-0.01}\right)$
$\sigma_{\mathrm{VBF}}/\sigma_{gg\mathrm{F}}$	0.082 ± 0.009	$0.109^{+0.034}_{-0.027}$ $\left(^{+0.029}_{-0.024}\right)$	$^{+0.029}_{-0.024}$ $\left(^{+0.024}_{-0.020}\right)$	$^{+0.013}_{-0.009}$ $\left(^{+0.012}_{-0.009}\right)$	$^{+0.006}_{-0.004}$ $\left(^{+0.005}_{-0.003}\right)$	$^{+0.010}_{-0.008}$ $\left(^{+0.009}_{-0.007}\right)$
$\sigma_{WH}/\sigma_{gg\mathrm{F}}$	0.037 ± 0.004	$0.031^{+0.028}_{-0.026}$ $\left(^{+0.021}_{-0.017}\right)$	$^{+0.024}_{-0.022}$ $\left(^{+0.019}_{-0.015}\right)$	$^{+0.012}_{-0.012}$ $\left(^{+0.008}_{-0.005}\right)$	$^{+0.008}_{-0.008}$ $\left(^{+0.007}_{-0.005}\right)$	$^{+0.003}_{-0.002}$ $\left(^{+0.002}_{-0.002}\right)$
$\sigma_{ZH}/\sigma_{gg\mathrm{F}}$	0.0216 ± 0.0024	$0.066^{+0.039}_{-0.031}$ $\left(^{+0.016}_{-0.011}\right)$	$^{+0.032}_{-0.025}$ $\left(^{+0.014}_{-0.010}\right)$	$^{+0.018}_{-0.012}$ $\left(^{+0.006}_{-0.003}\right)$	$^{+0.014}_{-0.012}$ $\left(^{+0.006}_{-0.003}\right)$	$^{+0.005}_{-0.003}$ $\left(^{+0.002}_{-0.001}\right)$
$\sigma_{ttH}/\sigma_{gg\mathrm{F}}$	0.0067 ± 0.0010	$0.0220^{+0.0068}_{-0.0057}$ $\left(^{+0.0042}_{-0.0035}\right)$	$^{+0.0055}_{-0.0048}$ $\left(^{+0.0033}_{-0.0027}\right)$	$^{+0.0031}_{-0.0023}$ $\left(^{+0.0018}_{-0.0013}\right)$	$^{+0.0023}_{-0.0020}$ $\left(^{+0.0020}_{-0.0019}\right)$	$^{+0.0014}_{-0.0010}$ $\left(^{+0.0005}_{-0.0003}\right)$
$\mathrm{B}^{WW}/\mathrm{B}^{ZZ}$	$8.09 \pm < 0.01$	$6.7^{+1.6}_{-1.3}$ $\left(^{+2.2}_{-1.7}\right)$	$^{+1.5}_{-1.2}$ $\left(^{+2.0}_{-1.6}\right)$	$^{+0.4}_{-0.3}$ $\left(^{+0.7}_{-0.5}\right)$	$^{+0.4}_{-0.3}$ $\left(^{+0.5}_{-0.4}\right)$	$^{+0.3}_{-0.2}$ $\left(^{+0.3}_{-0.2}\right)$
$\mathrm{B}^{\gamma\gamma}/\mathrm{B}^{ZZ}$	0.0854 ± 0.0010	$0.069^{+0.018}_{-0.014}$ $\left(^{+0.025}_{-0.019}\right)$	$^{+0.018}_{-0.014}$ $\left(^{+0.024}_{-0.019}\right)$	$^{+0.003}_{-0.002}$ $\left(^{+0.005}_{-0.003}\right)$	$^{+0.002}_{-0.001}$ $\left(^{+0.002}_{-0.001}\right)$	$^{+0.002}_{-0.002}$ $\left(^{+0.003}_{-0.002}\right)$
$\mathrm{B}^{\tau\tau}/\mathrm{B}^{ZZ}$	2.36 ± 0.05	$1.77^{+0.59}_{-0.46}$ $\left(^{+0.90}_{-0.68}\right)$	$^{+0.52}_{-0.41}$ $\left(^{+0.75}_{-0.58}\right)$	$^{+0.27}_{-0.20}$ $\left(^{+0.47}_{-0.33}\right)$	$^{+0.05}_{-0.04}$ $\left(^{+0.08}_{-0.06}\right)$	$^{+0.06}_{-0.04}$ $\left(^{+0.10}_{-0.06}\right)$
$\mathrm{B}^{bb}/\mathrm{B}^{ZZ}$	21.5 ± 1.0	$4.2^{+4.4}_{-2.6}$ $\left(^{+16.8}_{-9.0}\right)$	$^{+2.8}_{-2.0}$ $\left(^{+13.9}_{-7.9}\right)$	$^{+2.3}_{-1.1}$ $\left(^{+6.3}_{-2.8}\right)$	$^{+2.5}_{-1.2}$ $\left(^{+6.7}_{-3.3}\right)$	$^{+0.4}_{-0.2}$ $\left(^{+2.1}_{-0.9}\right)$

Historical perspective: the 80's in UA1/UA2 at the SppS

From the beginning, with the observation of two-jet dominance and of 4 W → eν and 8 Z → e^+e^- decays

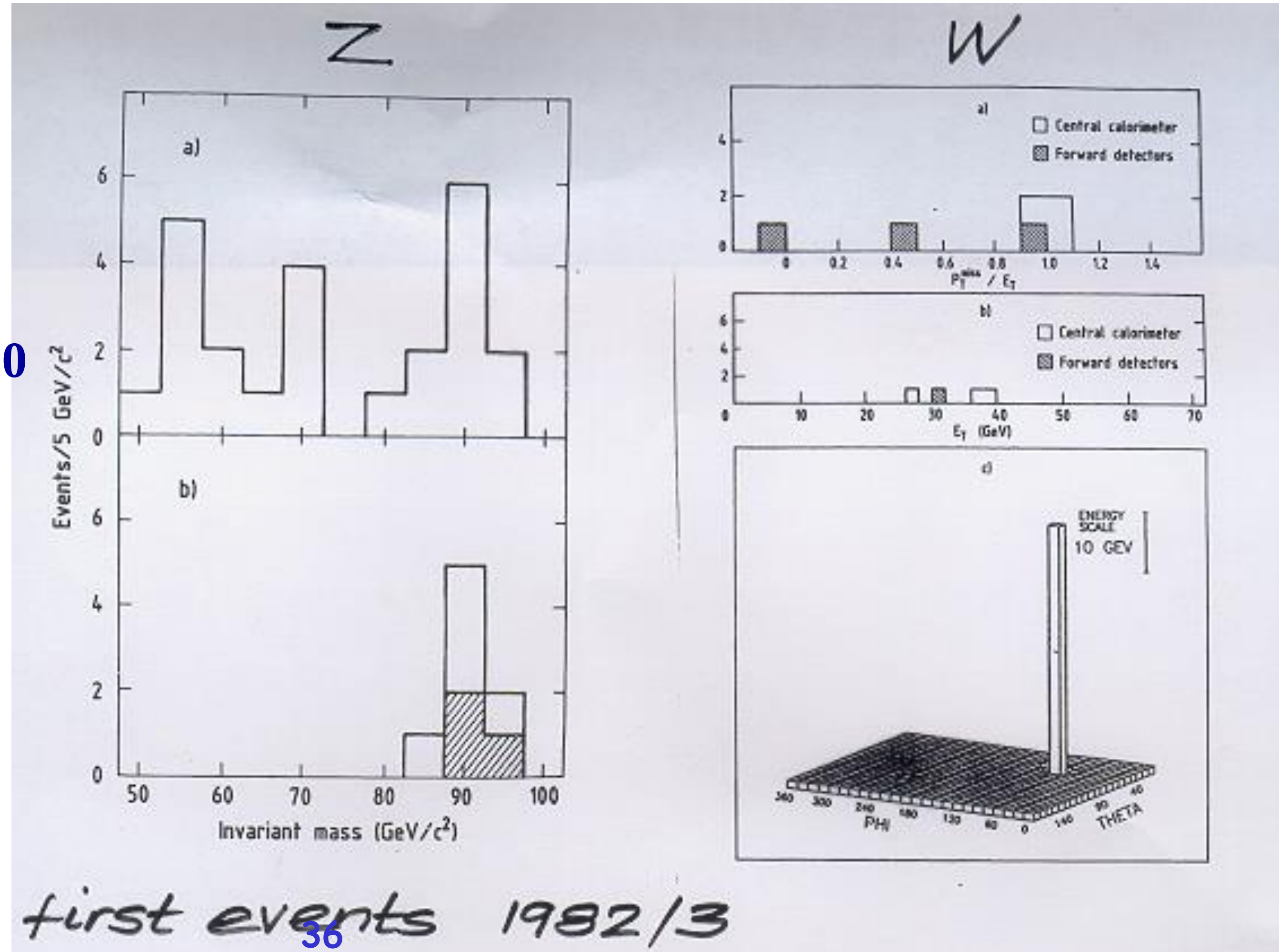
$\sqrt{s}$ = 546 GeV, L ~ 10^{29} $cm^{-2}s^{-1}$

UA2 was perceived as large at the time:

- ♥ 10-12 institutes
- ♥ from 50 to 100 authors
- ♥ cost ~ 10 MCHF
- ♥ duration 1980 to 1990

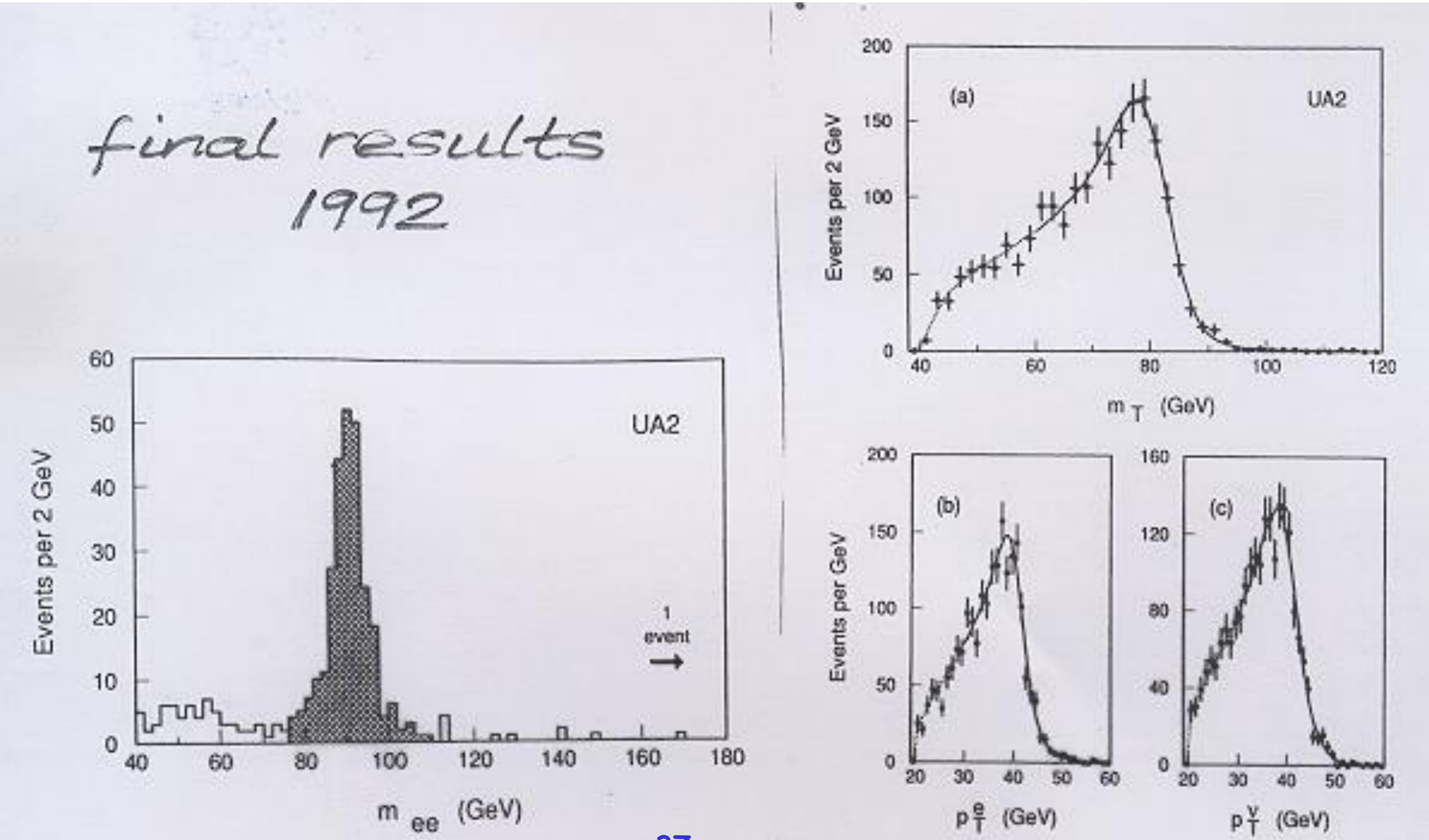
Physics analysis was organised in two groups:

- Electrons □ electroweak
- Jets □ QCD



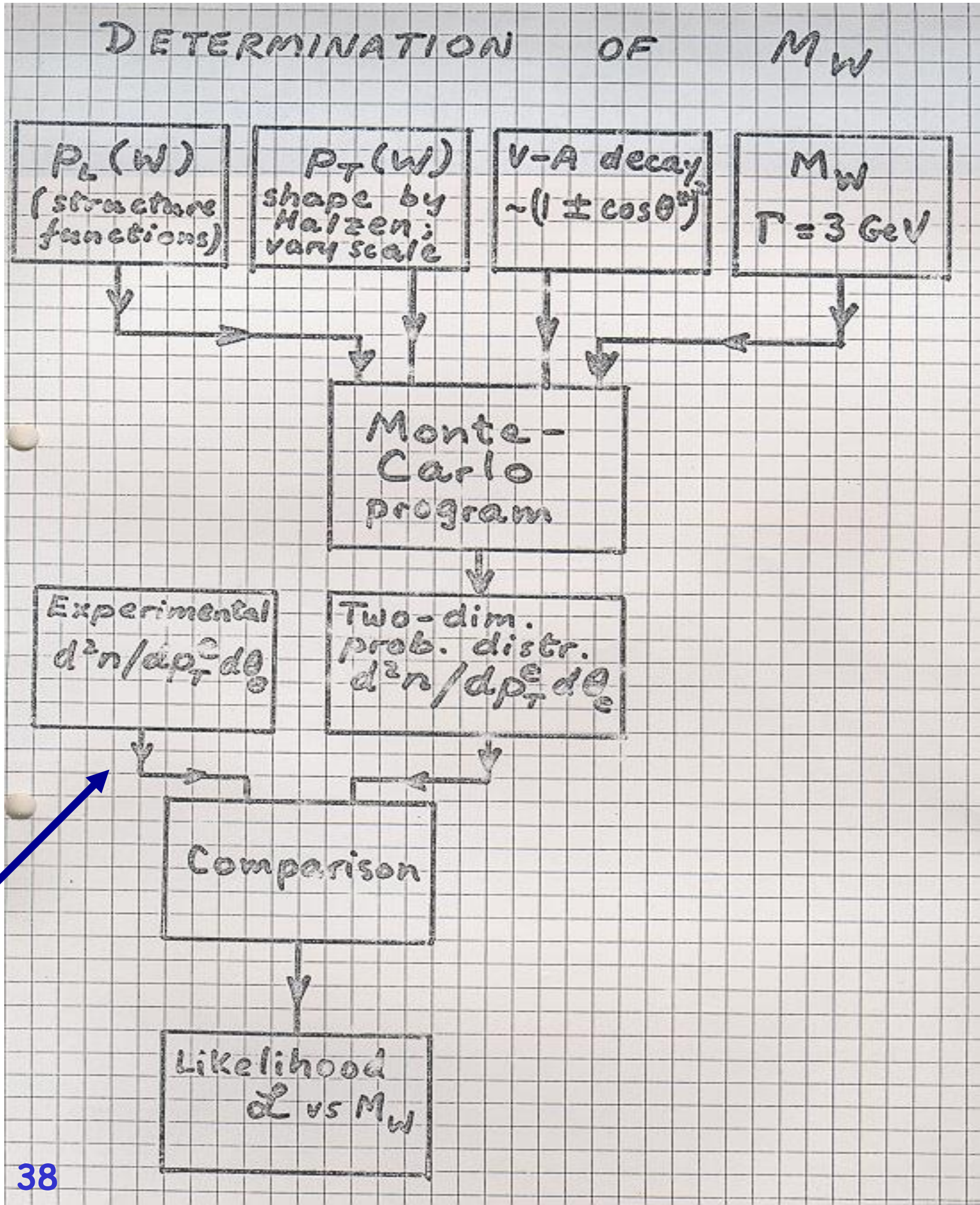
Historical perspective: the 80's in UA1/UA2 at the SppS

To the end, with first accurate measurements of the W/Z masses and the search for the top quark and for supersymmetry



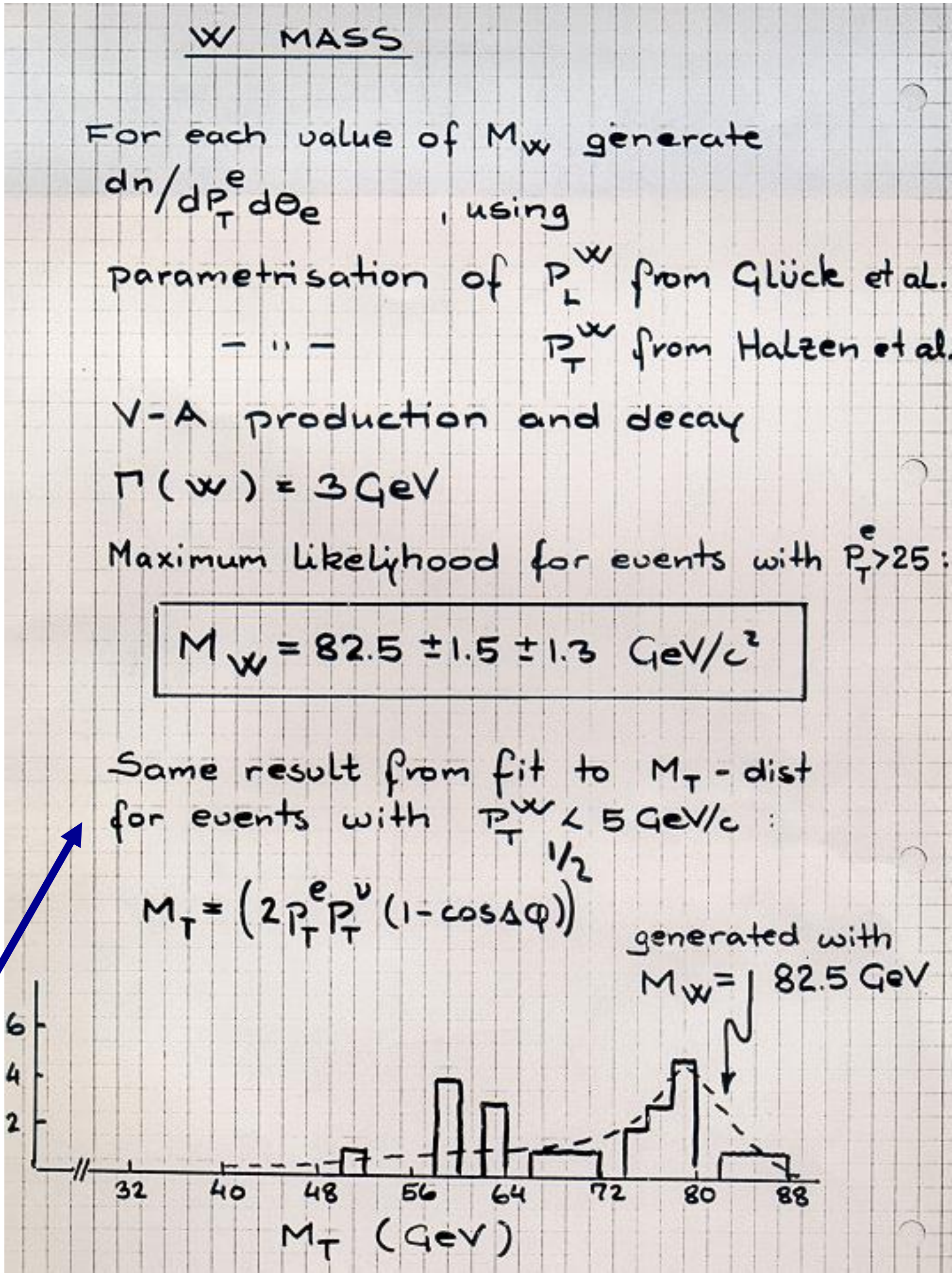
final results
1992

Historical perspective: the 80's in UA1/UA2 at the SppS



Software design in UA2

Historical perspective: the 80's in UA1/UA2 at the SppS



W MASS

For each value of M_W generate $dn/dp_T^e d\theta_e$, using

parametrisation of p_L^W from Glück et al.

— " — p_T^W from Halzen et al.

V-A production and decay

$\Gamma(W) = 3$ GeV

Maximum likelihood for events with $p_T^e > 25$:

$$\boxed{M_W = 82.5 \pm 1.5 \pm 1.3 \text{ GeV}/c^2}$$

Same result from fit to M_T - dist for events with $p_T^W < 5$ GeV/c :

$$M_T = \left(2 p_T^e p_T^\nu (1 - \cos\Delta\varphi)\right)^{1/2}$$

generated with $M_W = 82.5$ GeV

Software documentation in UA2

Historical perspective: the 80's in UA1/UA2 at the SppS

1984-1985 were exciting (and confusing) times!

Beware false positive signals!!

Over-abundance of Z → ee©events

Monojets

Dijets with missing E_T

High-p_T electrons with jets and missing E_T

Top quark "discovery"

Bumps in distributions
(jet-jet mass in UA2,
W decay electron spectrum in UA1)

P. Darriulat and students in a Youth Magazine

Tiềnphong

SỐ 313
THỨ SÁU
9/11/2007

www.tienphong.vn

CƠ QUAN TRUNG ƯƠNG CỦA ĐOÀN TNCS HỒ CHÍ MINH

CÔNG BỐ PHÁT HIỆN ĐỘT PHÁ VỀ TIA VŨ TRỤ

Nhóm Vật lý trẻ Việt Nam là đồng tác giả

Trang 4

Thăm vùng lũ, Thủ tướng Nguyễn Tấn Dũng:

Không được để dân đói

Xem tiếp trang 15

Đến "chân tường" mới tăng giá xăng dầu

Xem tiếp trang 3

Công bố chỉ số năng lực cạnh tranh cấp tỉnh 2007:

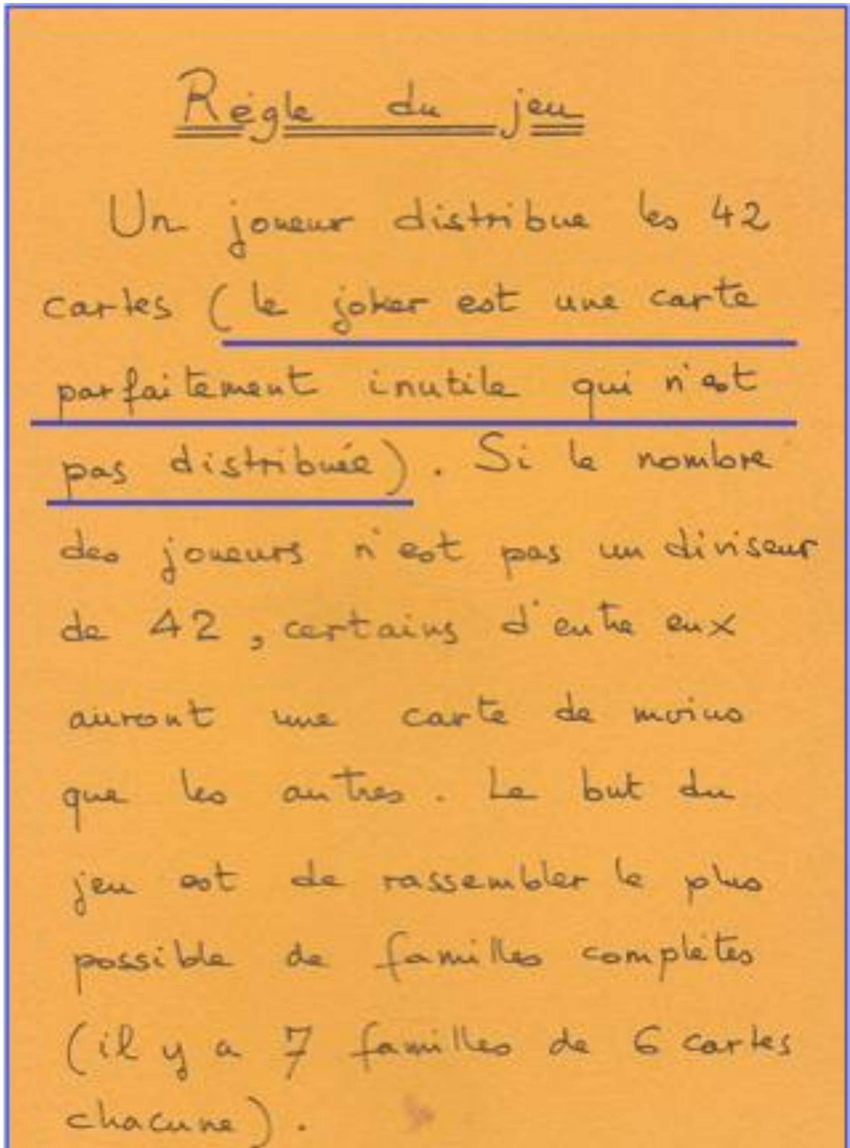
Bình Dương dẫn đầu, Hà Nội tụt hạng

Xem tiếp trang 3

General Giap received Pierre in the autumn and encouraged him to continue fighting for better Vietnamese universities.

One winter without snow, Pierre (who is exceptionally gifted at drawing) decided to put most of the UA2 collaboration (more or less from memory) into a deck of cards (seven family game).

I invite you to recognise who among the people below is present here!



Règle du jeu

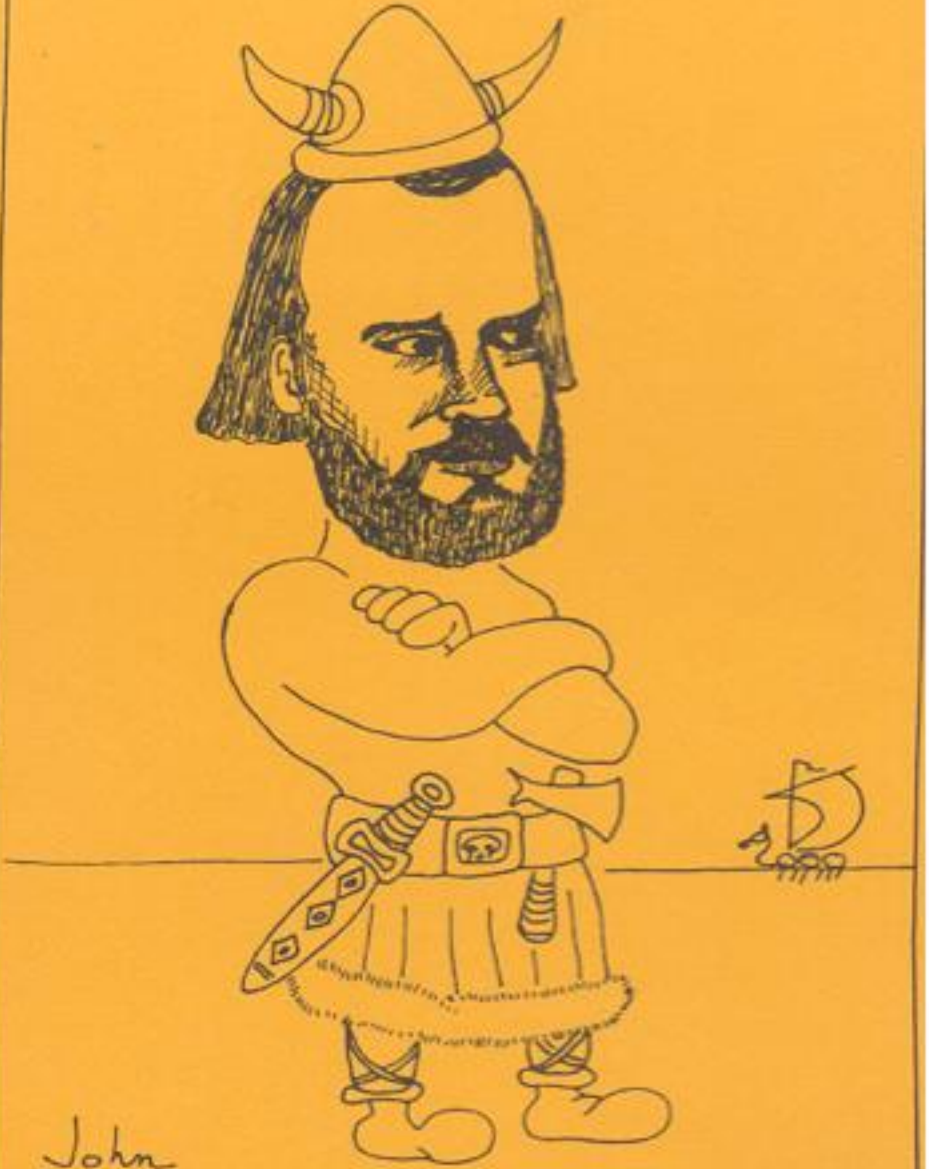
Un joueur distribue les 42 cartes (le joker est une carte parfaitement inutile qui n'est pas distribuée). Si le nombre des joueurs n'est pas un diviseur de 42, certains d'entre eux auront une carte de moins que les autres. Le but du jeu est de rassembler le plus possible de familles complètes (il y a 7 familles de 6 cartes chacune).

FAMILLE SAINT-QUANTÔME 6

FAMILLE JET 1

FAMILLE SAINT-QUANTÔME

1



John

FAMILLE JET

4

Peter

Bernard

FAMILLE NUTSNBOLTS

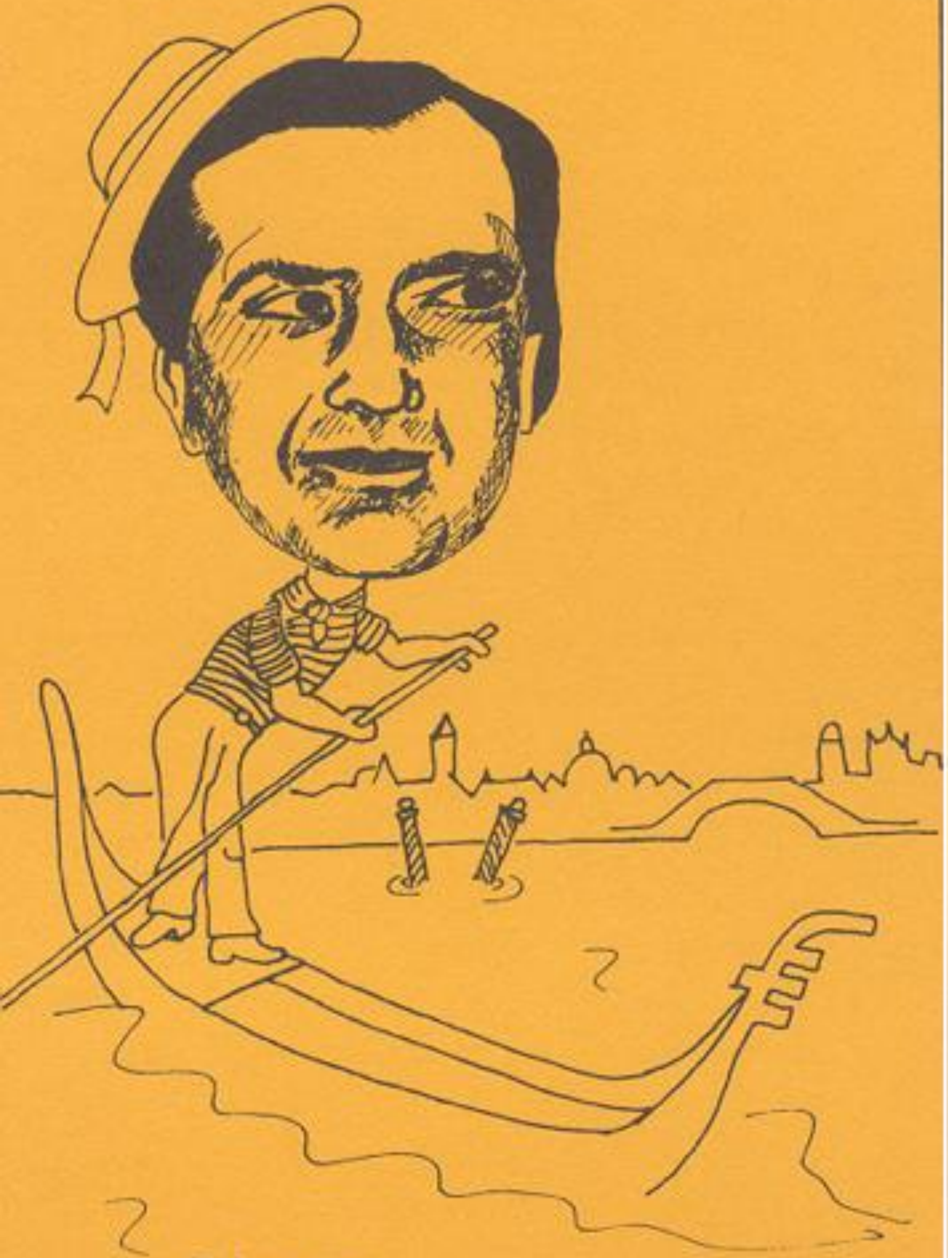
André

FAMILLE JET


FAMILLE TOURNEBANDE
3
Andy


6
FAMILLE JET
Tony

FAMILLE LOGGEDIN 3

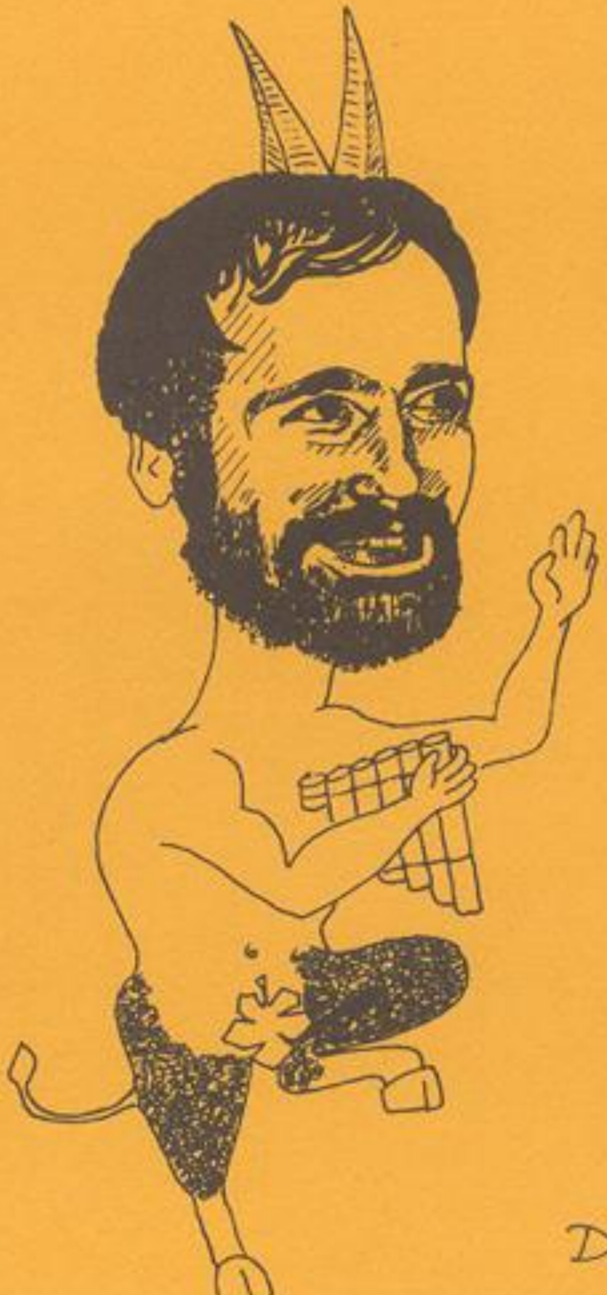


Claudio

FAMILLE LOGGEDIN 6

Patrizia

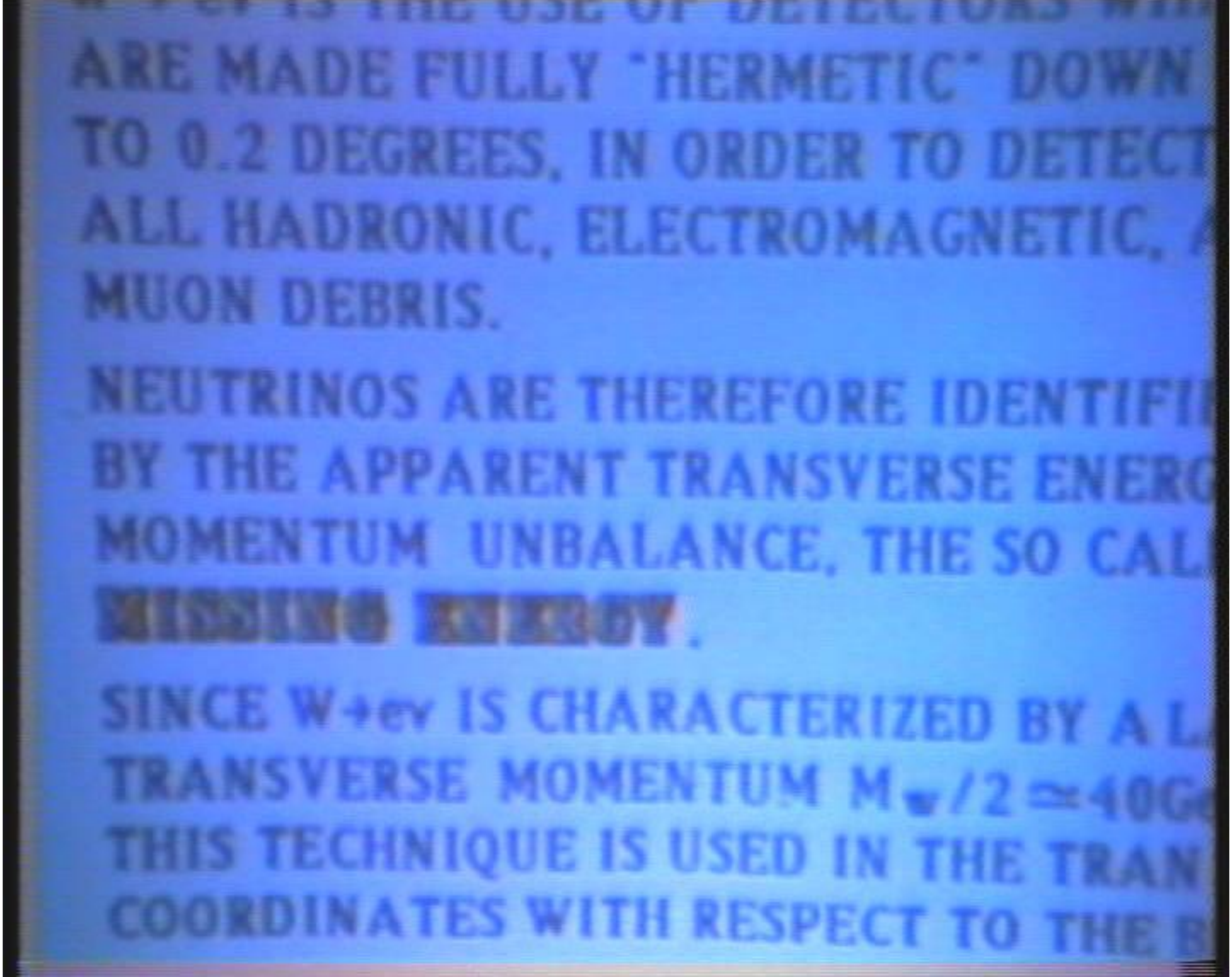
FAMILLE BOSON 5



Daniel

3 FAMILLE JET

Louis



IS THE USE OF DETECTORS WH
ARE MADE FULLY "HERMETIC" DOWN
TO 0.2 DEGREES, IN ORDER TO DETEC
ALL HADRONIC, ELECTROMAGNETIC, A
MUON DEBRIS.

NEUTRINOS ARE THEREFORE IDENTIFI
BY THE APPARENT TRANSVERSE ENERG
MOMENTUM UNBALANCE, THE SO CAL
MISSING ENERGY.

SINCE $W \to e\nu$ IS CHARACTERIZED BY A L
TRANSVERSE MOMENTUM $M_W/2 \simeq 40$G
THIS TECHNIQUE IS USED IN THE TRAN
COORDINATES WITH RESPECT TO THE B

AND $\Delta\phi > 60$

~ 700K triggers of each ty

Z^0 candidates were recognised
ine and fully reconstructed within
than one hour.

The whole data sample has been
reprocessed. Full event reconstruction
as been completed on a selected
ample to allow for speedy analysis.

MEER 1970

K HÜBNER et al 1972, 1973, 1974

$\mathcal{L} \lesssim$ a few 10^{25} $cm^{-2} s^{-1}$

ELECTRON COOLING

GI BUDKER 1966

A.S. DERBENEV & A. SKRINSKI 1968

STOCHASTIC COOLING

S VAN DER MEER 1972 (BETATRON)

L THORNDAHL 1975 (LONGITUDINAL)

W SCHNELL et al 1976 (ISR TESTS)

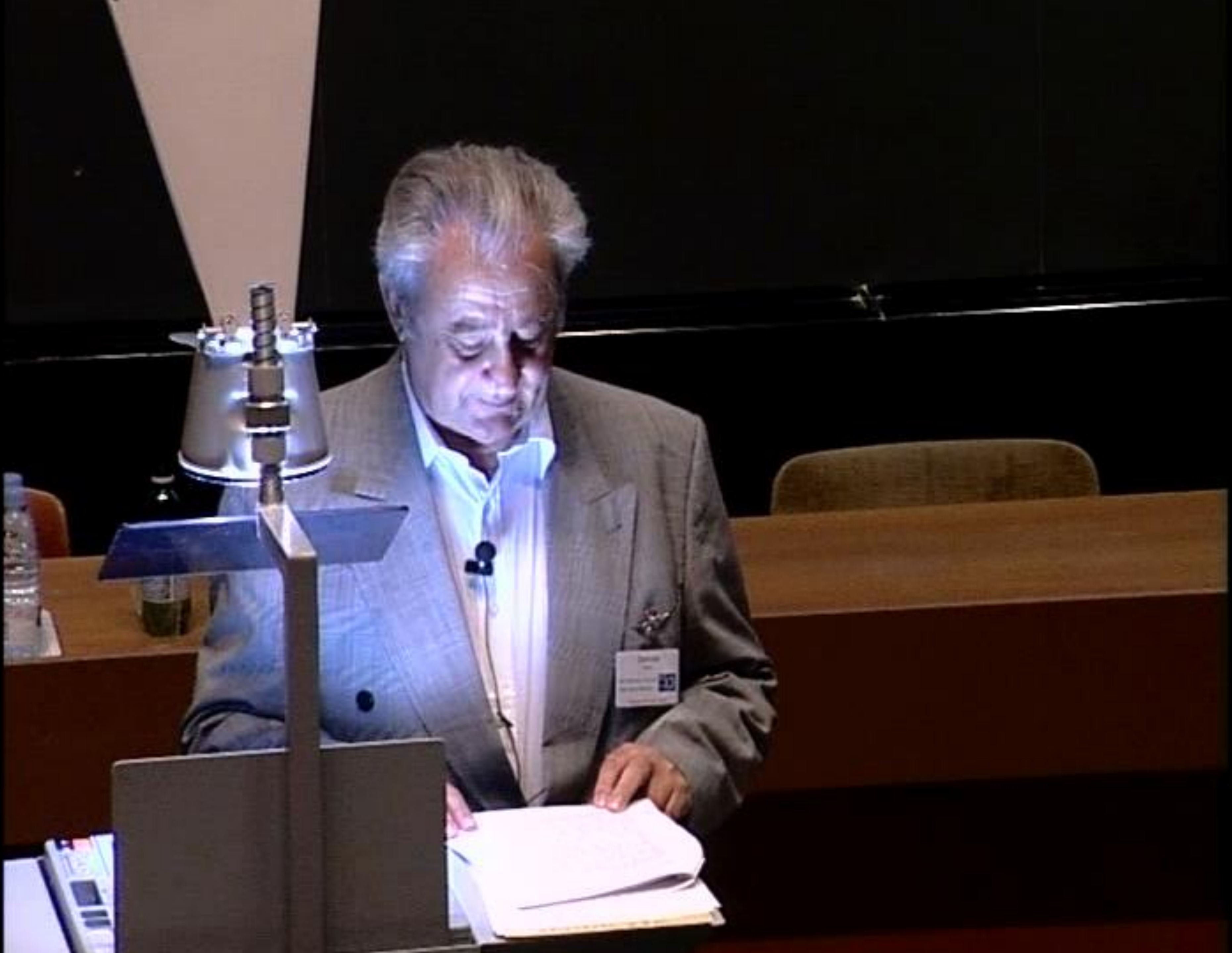
C. RUBBIA P. McINTYRE D. CLINE

1976

PRODUCING W/Z WITH EXISTING MACHINES

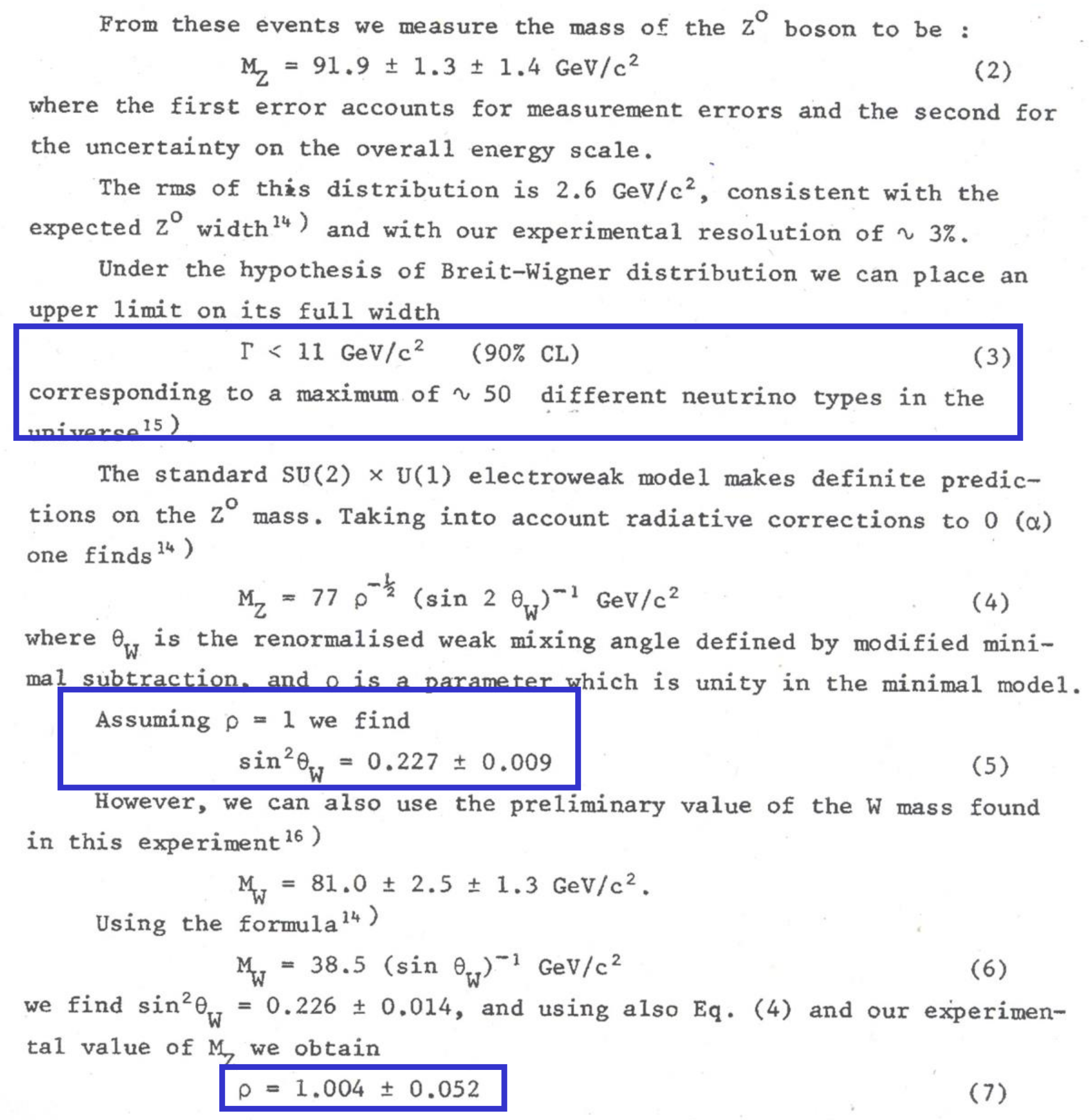
PROPOSALS TO CERN AND FERMILAB

1977 AT CERN



Historical perspective: the 80's in UA1/UA2 at the SppS

First ever EW fits in UA2 before LEP turned on



From these events we measure the mass of the Z^o boson to be :

$$M_Z = 91.9 \pm 1.3 \pm 1.4 \text{ GeV}/c^2 \qquad (2)$$

where the first error accounts for measurement errors and the second for the uncertainty on the overall energy scale.

The rms of this distribution is 2.6 GeV/c², consistent with the expected Z^o width[14]) and with our experimental resolution of ∿ 3%.

Under the hypothesis of Breit-Wigner distribution we can place an upper limit on its full width

$$\Gamma < 11 \text{ GeV}/c^2 \quad (90\% \text{ CL}) \qquad (3)$$

corresponding to a maximum of ∿ 50 different neutrino types in the universe[15])

The standard SU(2) × U(1) electroweak model makes definite predictions on the Z^o mass. Taking into account radiative corrections to 0 (α) one finds[14])

$$M_Z = 77\ \rho^{-\frac{1}{2}}\ (\sin 2\ \theta_W)^{-1} \text{ GeV}/c^2 \qquad (4)$$

where θ_W is the renormalised weak mixing angle defined by modified minimal subtraction, and ρ is a parameter which is unity in the minimal model.

Assuming ρ = 1 we find

$$\sin^2\theta_W = 0.227 \pm 0.009 \qquad (5)$$

However, we can also use the preliminary value of the W mass found in this experiment[16])

$$M_W = 81.0 \pm 2.5 \pm 1.3 \text{ GeV}/c^2.$$

Using the formula[14])

$$M_W = 38.5\ (\sin\ \theta_W)^{-1} \text{ GeV}/c^2 \qquad (6)$$

we find $\sin^2\theta_W = 0.226 \pm 0.014$, and using also Eq. (4) and our experimental value of M_Z we obtain

$$\rho = 1.004 \pm 0.052 \qquad (7)$$

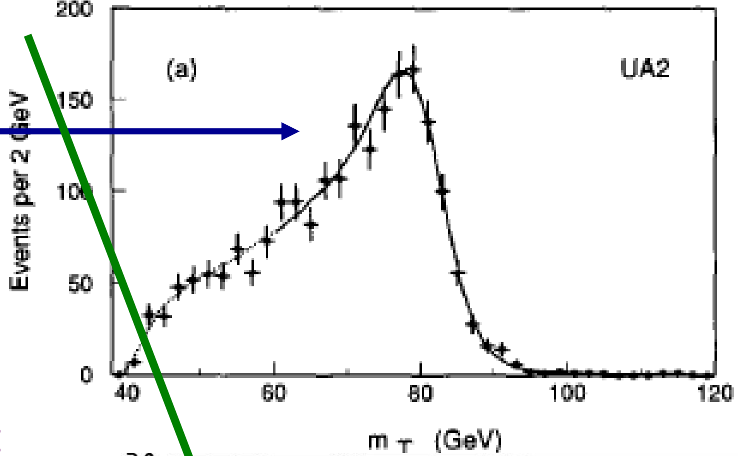
Historical perspective: the 80’s in UA1/UA2 at the SppS

Most important results from 1987-1990 campaign with UA2:

precise measurement of m_W/m_Z

and direct limit on top-quark mass (m_{top} < 60 GeV)

Transverse mass distribution for electron-neutrino pairs



$$\frac{m_W}{m_Z} = 0.8813 \pm 0.0036 \pm 0.0019$$

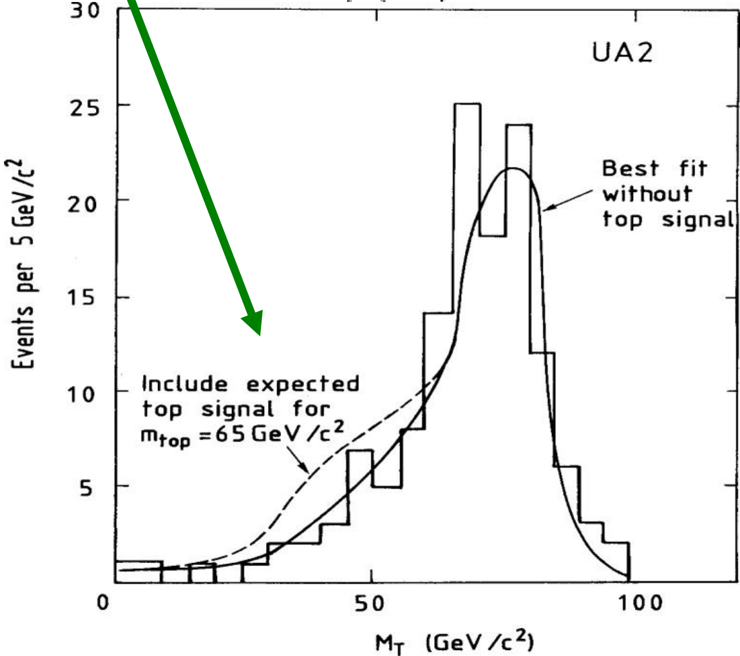
Using the precise measurement of m_Z (LEP):

$$m_W = 80.35 \pm 0.33 \pm 0.17 \text{ GeV}$$

Indirect limits on top-quark mass in the context of the Standard Model:

$$m_{top} = 160^{+50}_{-60} \text{ GeV}$$

(four years before the discovery of the top quark at Fermilab)



Backup

Some topics for SM discussion

This discussion session covers today's plenary session (except the small component from BSM, except if someone really wants to bring up something specific?) and yesterday's parallel session

We have about one hour for the discussion and many points of interest as the questions already illustrated.

These slides are just trying to organise the discussion into a few broad topics with a fixed time (roughly) allowed for each one of them and with the order not totally arbitrary (plenary session discussion points first and parallel session last)

Two caveats:

- despite the success of the LHC programme during run-1, we are still learning how to do precision measurements in ATLAS and CMS
- this is why we have not digested fully yet to the best of our understanding, neither our detector performance nor how well we can constrain the theoretical uncertainties (eg PDFs) from our own data. Le meilleur est encore à venir!

Some topics for SM discussion

Topic 1: 15’
Precision electroweak measurements at the LHC and beyond
(mostly m_W and $\sin^2\theta_W$ but also m_Z)

Topic 2: 15’
Precision top mass and coupling measurements at the LHC and beyond

Topic 3: 15’
State-of-the-art MC tools and theory calculations

Topic 4: from yesterday’s parallel session 15’
- Double-parton scattering, MPI and UE models, tunes
- Pile-up mitigation tools

Some topics for SM discussion

Precision EW measurements at the LHC and beyond

- **EW fits: shouldn’t these be more optimistic about the LHC potential, i.e. 5 MeV for m_W and inclusion of a reasonable expectation for $\sin^2\theta_W$? And shouldn’t they include the FEC much more precise expectations in such plots and predictions for the future? If not, why not?**
- **Methodology of m_W measurement at the LHC:**
  *** Should ATLAS and CMS do a measurement of m_Z (muon channel only) first as CDF has done with almost LEP accuracy (7 MeV!)?**
  *** Hadronic recoil: is the TeVatron RESBOS-only approach sustainable? Probably not, CDF and D0 might be both consistently off from the true m_W because of their reliance on the Z to W extrapolation. In pp collisions there are far more reasons to move away from this approach.**
  *** Is pile-up a limiting factor? Likely yes, since m_T is the least sensitive observable to theoretical uncertainties on pTW.**
  Should ATLAS and CMS ask for a low-lumi run dedicated to precision measurements? Would end of run-2 be the best time for this? What it means is ~ one year of data-taking with < 5 interactions per BX…

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Precision top measurements at the LHC and beyond

- EW fits: how will these deal with the by now discrepant measurements between CMS and D0 (about 3.3σ)?
- Is there a best-fit methodology for the top-quark mass? D0 claims they have demonstrated that the matrix-element method used for their best measurement is a clear improvement over other template methods.
- Should ATLAS and CMS use the same MC to have the same MC to pole-mass or MSbar-mass offset and uncertainty? If yes, which one?
- Is there any real reason from the theory side for measuring m_{top} to better than ~ 0.5 GeV accuracy? The vacuum stability argument is not a serious one (in my view!).
- What is likely to be the ultimate (end of run-2) precision from the theory on m_{top} for the Xsection-based measurement and for the direct mass measurements?

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MC tools and theoretical calculations

- Very complete and nice summary given today!
- Theoretical effort focuses often more on signals such as Higgs and SUSY which do not require the same accuracy as the SM precision measurements:
  * how soon could we have NNLO tools for diboson differential distributions?
  * how soon could be have NNLO tools for Wbb or ttbb production?
  * Etc, etc…
- Automatic tools at NLO in QCD can still be very inaccurate for various reasons: missing EW corrections, parton shower matching choice leading to distortion of basic distributions (excellent example is Z polarisation), choice of scale
- How can we improve recipes for scale uncertainties. One suggestion was made yesterday, others exist, but in any case we need more NNLO calculations to test the assumptions on systematics using the NLO to NNLO differences as one way to cross-check things.

Some topics for SM discussion

DPI cross-sections, MPI/UE/tunes

- only W+jj effective DPI cross-section has been measured by ATLAS and CMS and is ~ 15 mb
- this is most likely not a universal number (it depends on incoming partons for sure, but perhaps also on Q2-scale etc). Which other measurements should be done? Gluon-dominated versus quark-dominated? Same-sign W's? Photons + jets?
- MPI/UE/tunes is a different issue from DPI. The uncertainties derived here for eg Higgs measurements are usually based on fragile recipes (two-point one-sigma systematic derived from Pythia versus Herwig) or even worse (switch on and off MPI in UE as suggested in Higgs XS WG!). In this field, need to learn more about how to tune UE model depending on measurement itself.

Pile-up mitigation

- Highly successful and ever more sophisticated methods developed by ATLAS and CMS during run-1. Impact on systematics? UE subtraction? Which beam-spot size in z is optimal for the future?