Recent EWK precision measurements in CMS

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on behalf of the CMS collaboration

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EWK precision measurements

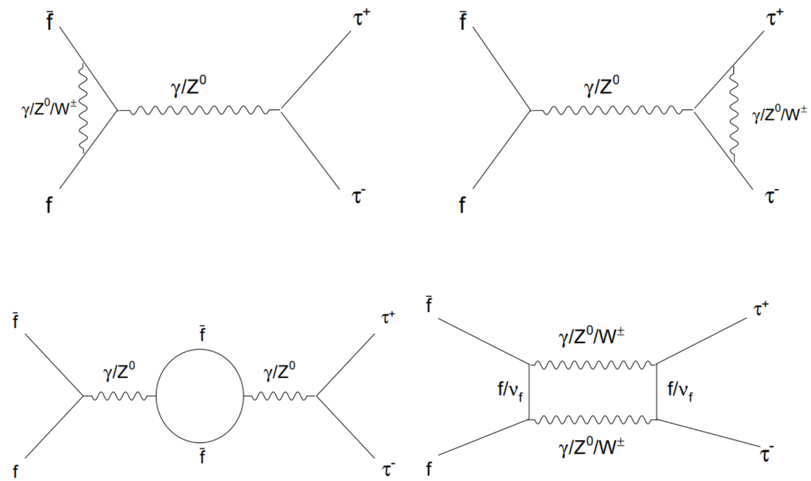
- Electroweak precision observables

$$\alpha_{em}, m_W, m_Z, G_F, \sin^2\theta_W, m_H$$

- Why one would want to measure something precisely?

The possible NP is certainly a very small effect and is hiding in higher orders

$$M_W^2 = \frac{\pi\alpha}{\sqrt{2}}\frac{1}{G_F s_W^2}(1+\Delta r)$$

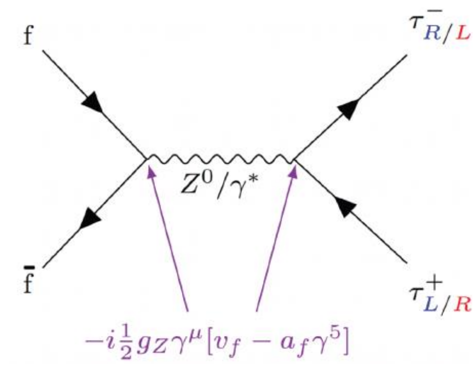


Focus in this talk

- Weak mixing angle in $Z \rightarrow \tau\tau$
- Z boson invisible width
- $W \rightarrow \tau\nu$ decay branching fraction

τ-lepton polarization in Z-boson decays

CMS-PAS-SMP-18-010



- Z boson couplings are different for left and right-handed fermions.

- Tau lepton is a brilliant tool → one can measure its spin in the detector.

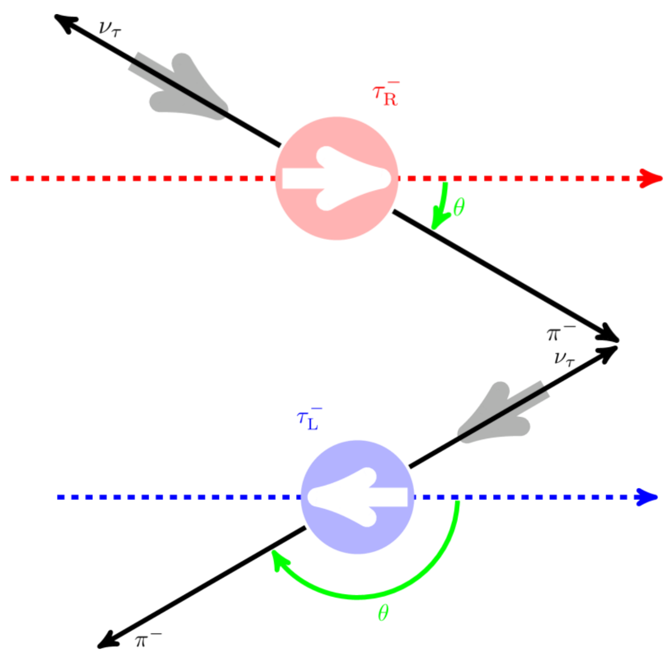
- The τ-lepton polarization asymmetry:

$$P_\tau = \frac{\sigma(\tau_R^-) - \sigma(\tau_L^-)}{\sigma_{total}}$$

- At Z-pole proportional to τ weak couplings

$$P_\tau = -A_\tau = -\frac{2v_\tau a_\tau}{v_\tau^2 + a_\tau^2} \approx -2 \cdot \frac{v_\tau}{a_\tau} = -2(1 - 4\sin^2\theta_W^{\text{eff}})$$

- The τ helicity state determined from the angular distributions of decay products (wrt to τ and/or wrt to each other)



τ-lepton polarization in Z-boson decays

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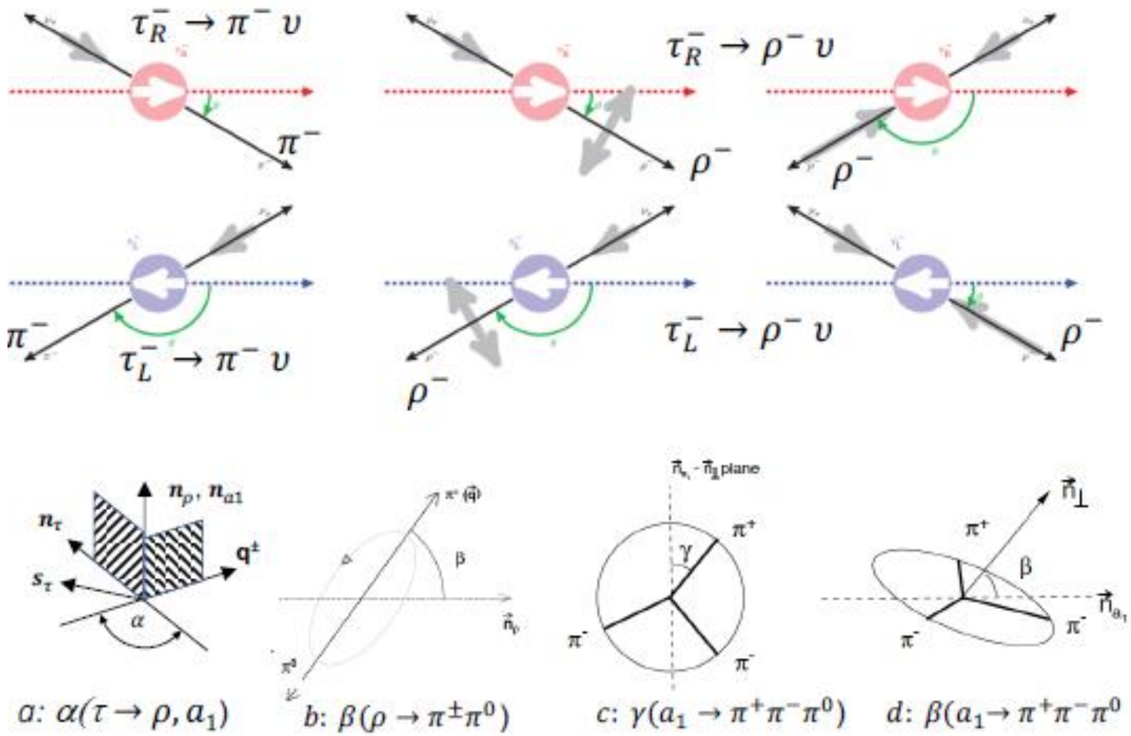

- A sensitive observable for each tau decay
- If several observables -> combine into one-dimensional
- Reconstruct the polarimetric vector where possible (maximum sensitivity)
- Helicity states of both taus are 100% anti-correlated

τ-lepton polarization in Z-boson decays

- Cover all possible τ decays
- When more than one spin-sensitive observable → combined into one (accounting for τ-leptons spin correlation)

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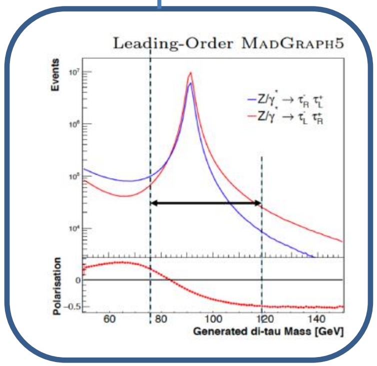
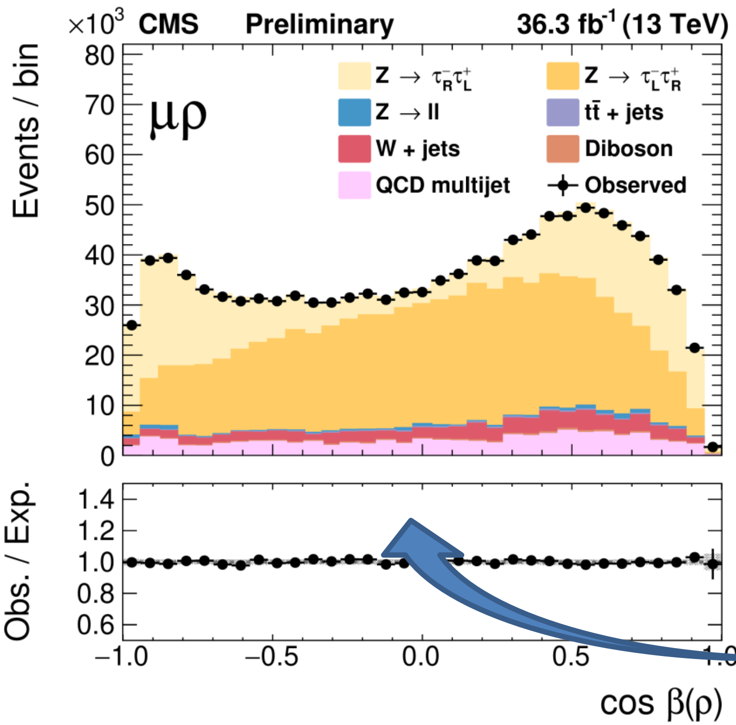
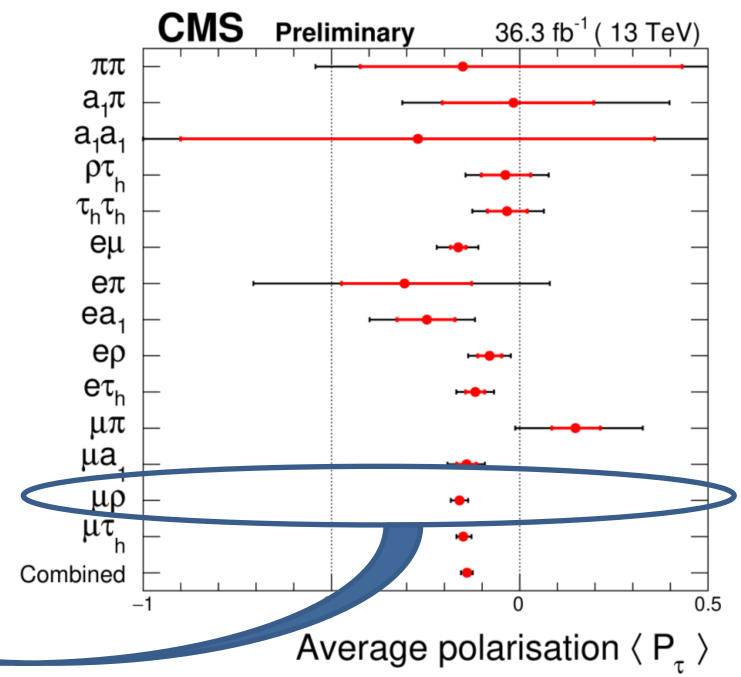
- Measured polarization asymmetry is an average over the Z line shape.







τ-lepton polarization in Z-boson decays

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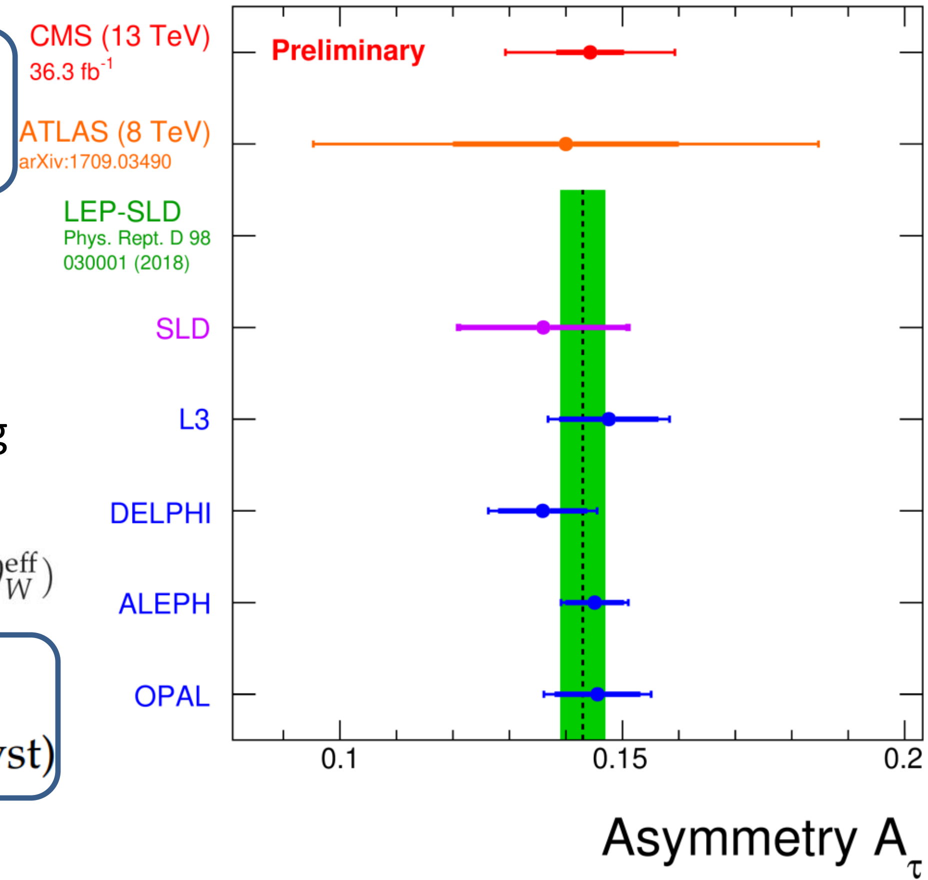
- Average polarization corrected to the Z pole can be compared to LEP

$$\mathcal{P}_\tau(Z^0) = -0.144 \pm 0.015$$
$$= -0.144 \pm 0.006\,(\text{stat}) \pm 0.014\,(\text{syst})$$

- CMS precision (2016 data) is comparable to SLD measurement.



At Z-pole is directly related to the weak mixing angle:

$$P_\tau = -A_\tau = -\frac{2v_\tau a_\tau}{v_\tau^2 + a_\tau^2} \approx -2 \cdot \frac{v_\tau}{a_\tau} = -2(1 - 4\sin^2\theta_W^{\text{eff}})$$

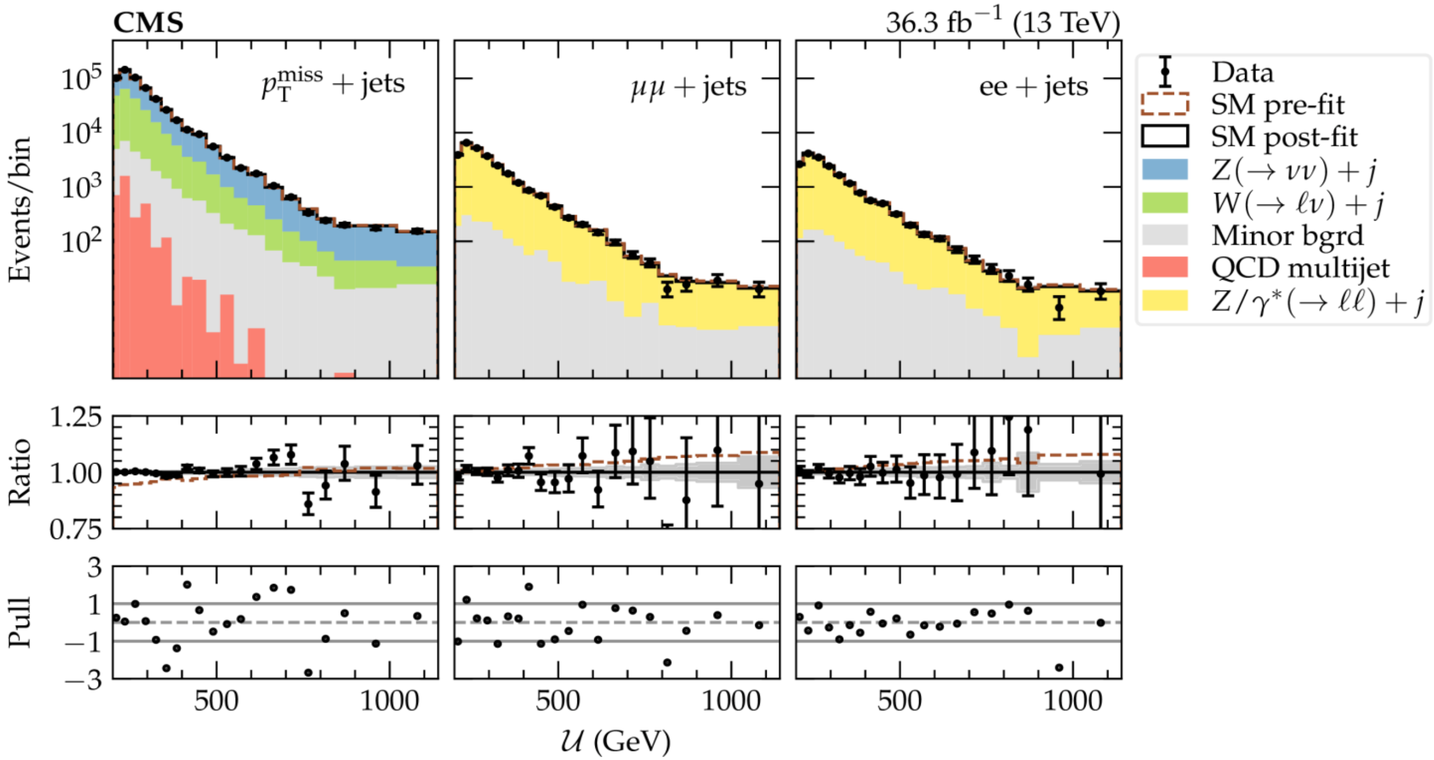
$$\sin^2\theta_W^{\text{eff}} = 0.2319 \pm 0.0019$$
$$= 0.2319 \pm 0.0008\,(\text{stat}) \pm 0.0018\,(\text{syst})$$

Complementary to the weak mixing angle measured in $Z \to \mu\mu$ and $Z \to ee$.

Z boson invisible width

arXiv:2206.07110
Accepted by PLB

- Constraint on the number of neutrino types
- Look for very energetic jet accompanied by a large missing transverse momentum
- Z boson is transversely boosted
- Simultaneous fit in signal and $Z/\gamma^* \rightarrow \mu\mu\ (ee)$ + jets categories



Z boson invisible width

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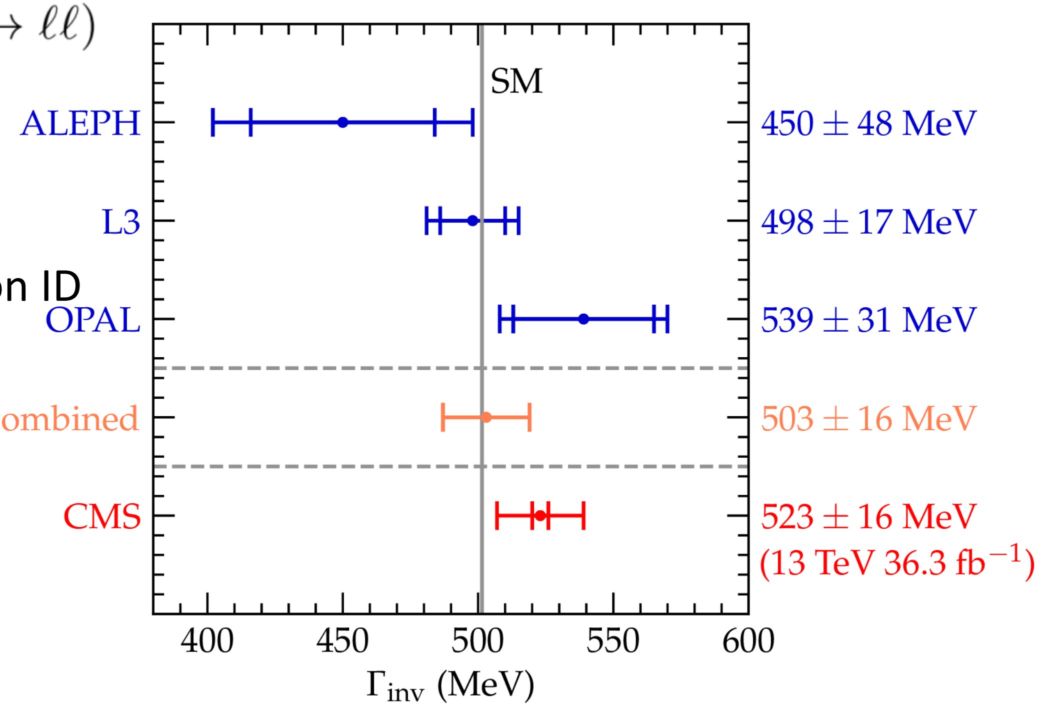
The width is determined as:

$$\Gamma(Z \to \nu\bar{\nu}) = \frac{\sigma(Z\text{+jets})\mathcal{B}(Z \to \nu\bar{\nu})}{\sigma(Z\text{+jets})\mathcal{B}(Z \to \ell\ell)}\Gamma(Z \to \ell\ell)$$

$$\Gamma_{\text{inv}} = 523 \pm 3\,(\text{stat}) \pm 16\,(\text{syst})\,\text{MeV}$$

Muon and electron ID efficiency



- The single most precise direct measurement!
- Competitive to combined LEP value and compatible with expected in SM.

$W \rightarrow \tau\nu$ decay branching fraction

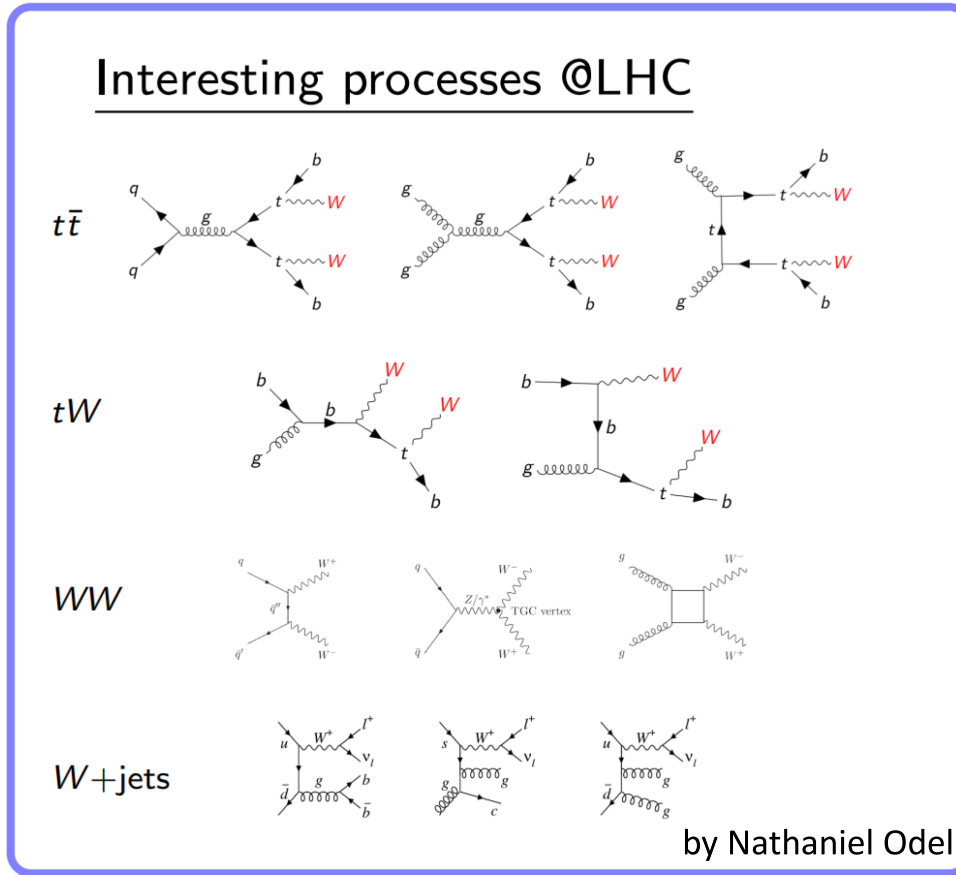
[Phys. Rev. D 105, 072008](#)

- Test of Lepton Universality

- The LEP combination indicated 2.6 deviation from W decay to electron and muon.

$$\frac{2B(W \rightarrow \tau\nu_\tau)}{B(W \rightarrow e\nu_e) + B(W \rightarrow \mu\nu_\mu)} = 1.066 \pm 0.025$$

$$\frac{\mathcal{B}(\mathrm{W} \rightarrow \mathrm{h})}{1 - \mathcal{B}(\mathrm{W} \rightarrow \mathrm{h})} = \left(1 + \frac{\alpha_S(m_W^2)}{\pi}\right) \sum_{\substack{i=(u,c),\\ j=(d,s,b)}} |V_{ij}{}^2|$$

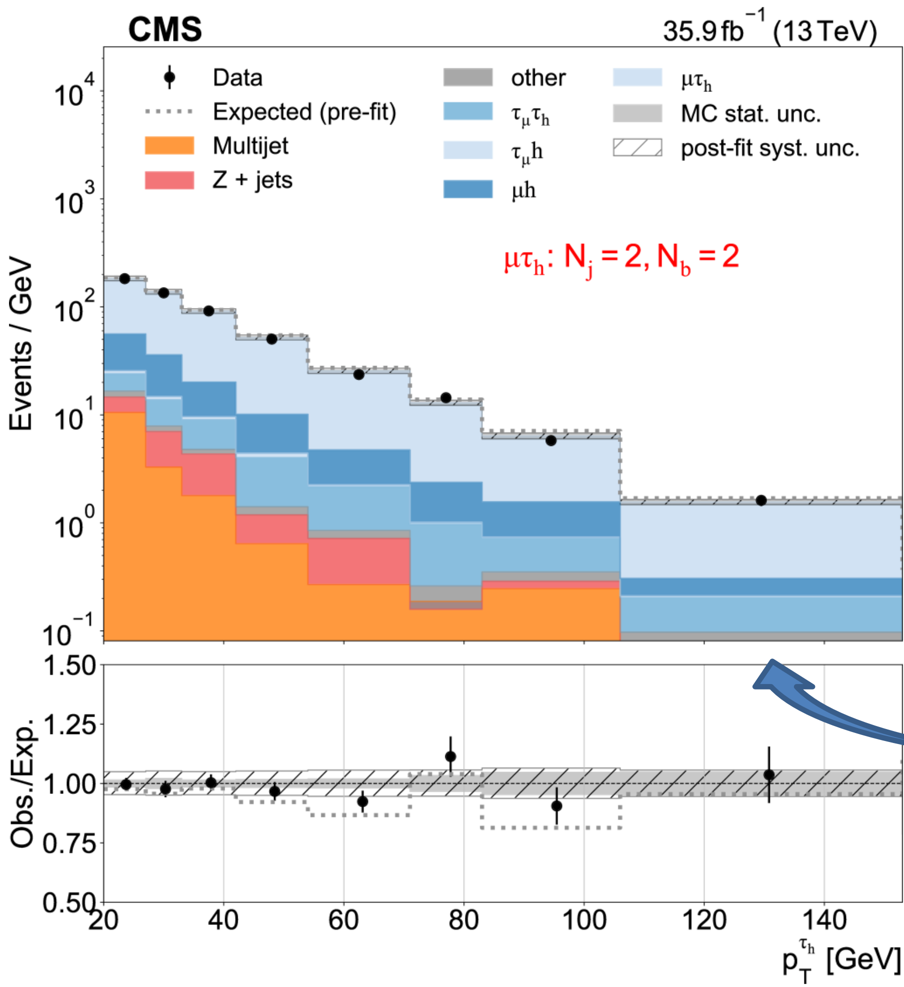


Advantage of LHC is huge W production rate

- $t\bar{t}$ as a main source, clean signature (jet multiplicity, b-tagging)
- Also consider other W sources: $tW, WW, W + jets$

$W \to \tau\nu$ decay branching fraction

Phys. Rev. D 105, 072008



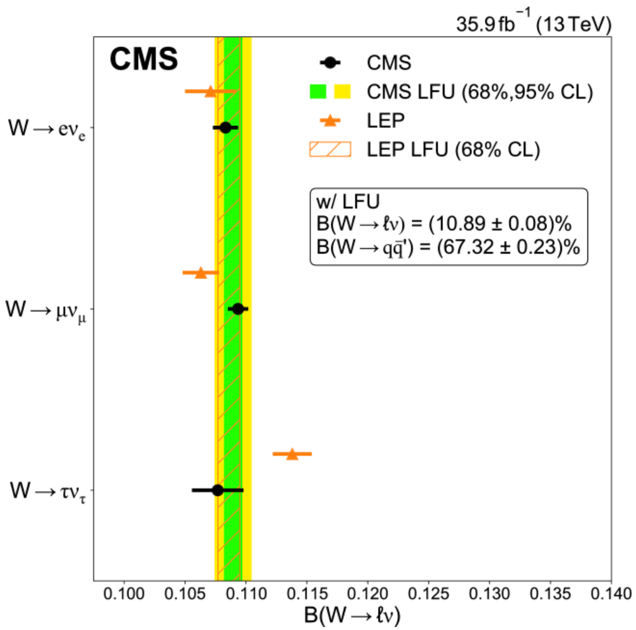
- Categorize events by jets and b-tag multiplicities
- Exploit pT to discriminate prompt leptons from W and leptons mediated by τ lepton

	$N_j = 0$	$N_j = 1$	$N_j = 2$	$N_j = 3$	$N_j \geq 4$
$N_b = 0$	$e\tau, \mu\tau, e\mu$	$e\tau, \mu\tau, e\mu$	$e\tau, \mu\tau$; $ee, \mu\mu, e\mu$		
$N_b = 1$		$e\tau, \mu\tau, e\mu$	$e\tau, \mu\tau$	$e\tau, \mu\tau$	
			$ee, \mu\mu, e\mu$		
					$eh, \mu h$
$N_b \geq 2$			$e\tau, \mu\tau$	$e\tau, \mu\tau$	
			$ee, \mu\mu, e\mu$		
					$eh, \mu h$

Fit to
- ll - subleading lepton pT
- $l\tau$ - hadronic τ pT
- lh - lepton pT

$W \to \tau\nu$ decay branching fraction

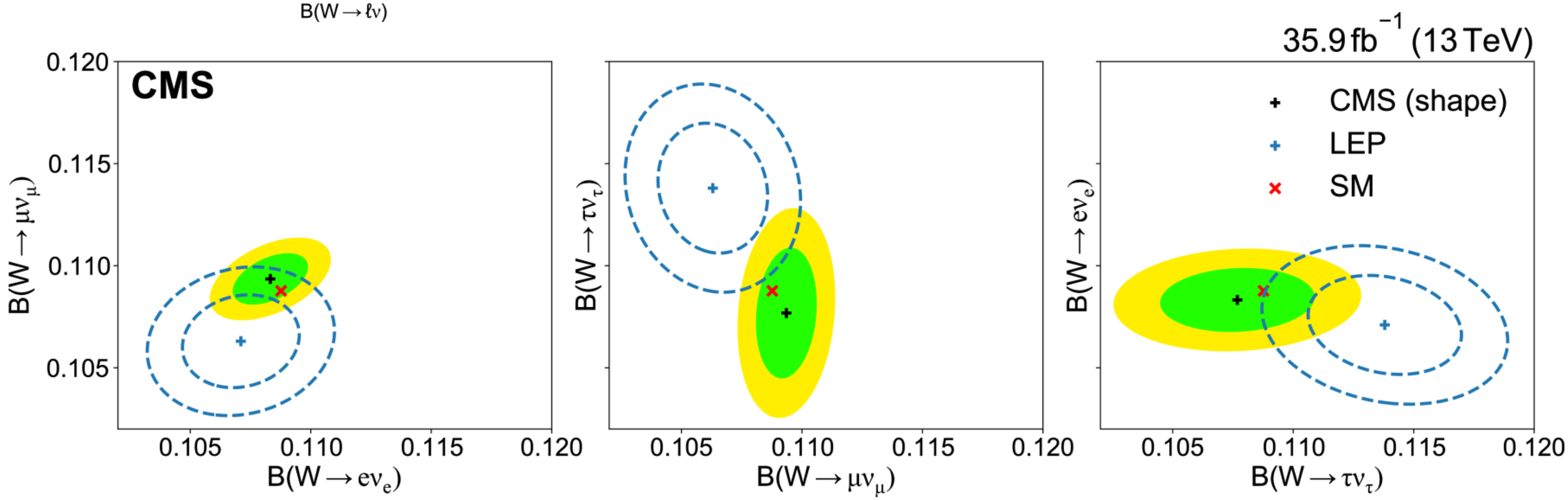
[Phys. Rev. D 105, 072008]



	CMS	LEP	ATLAS	LHCb	CDF	D0
$R_{\mu/e}$	1.009 ± 0.009	0.993 ± 0.019	1.003 ± 0.010	0.980 ± 0.012	0.991 ± 0.012	0.886 ± 0.121
$R_{\tau/e}$	0.994 ± 0.021	1.063 ± 0.027	—	—	—	—
$R_{\tau/\mu}$	0.985 ± 0.020	1.070 ± 0.026	0.992 ± 0.013	—	—	—
$R_{\tau/\ell}$	1.002 ± 0.019	1.066 ± 0.025	—	—	—	—

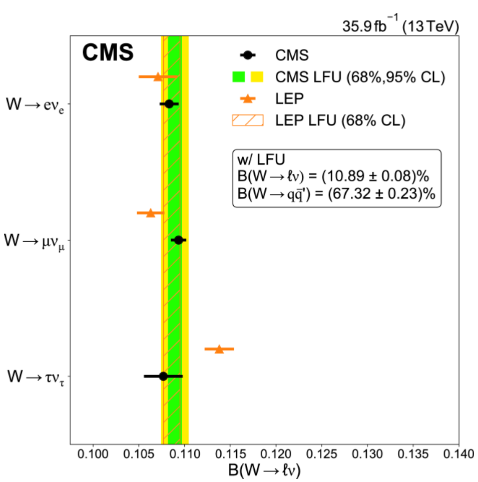
- Precision exceeds the one achieved by LEP, but
- The result is consistent with LFU hypothesis …
- Extract Vcs and $\alpha_s(m^2{}_W)$

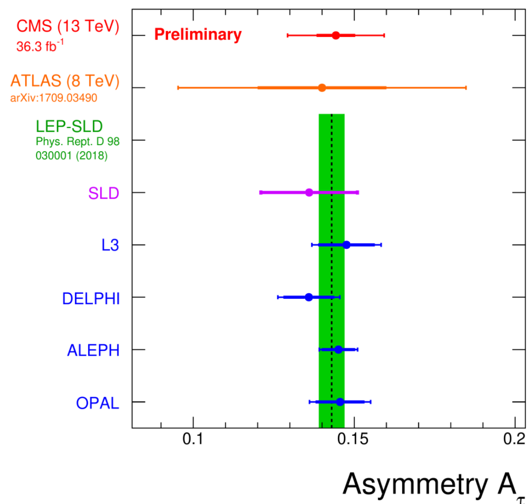
$$|V_{cs}| = 0.969 \pm 0.011$$
$$\alpha_S(m_W^2) = 0.094 \pm 0.033$$

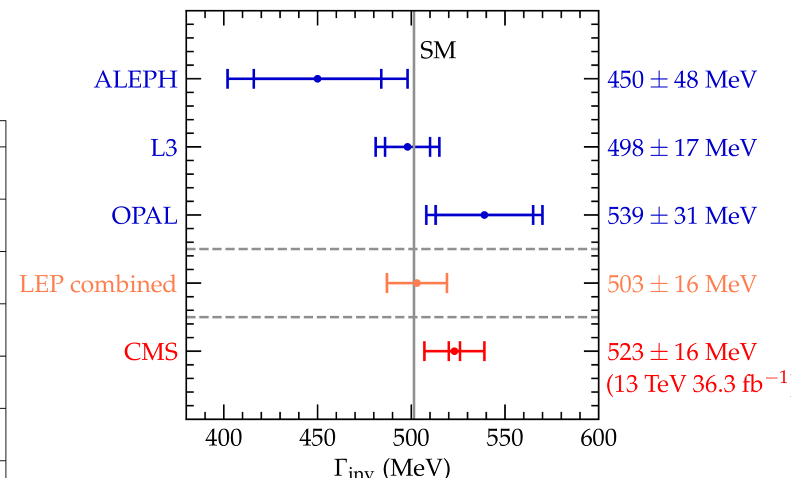


Summary

- In many areas CMS approaching or already exceeding the LEP precision
- Increasing accuracy is not easy, but every step forward becomes intriguing!







Additional material

Additional material

Source of uncertainty	Prefit uncertainty per channel			
	$\tau_h\tau_h$	$\tau_\mu\tau_h$	$\tau_e\tau_h$	$\tau_e\tau_\mu$
$e \to \tau_h$ fake rate	10%	$< 40\%$	10%	-
$\mu \to \tau_h$ fake rate		$< 40\%$		-
jet $\to \tau_h$ fake rate	p_T-dependent $\approx 20\% \times p_T^{jet}/100\text{GeV}$			
Tau identification efficiency	p_T MVA-DM			-
Tau trigger efficiency	p_T MVA-DM		-	-
Electron trigger efficiency	-	-	p_T MVA-DM	
Muon trigger efficiency	-	p_T η	-	p_T MVA-DM
Hadronic tau energy scale	p_T MVA-DM $< 2\%$			-
Neutral, charged hadrons energy	2%	2%	2%	-
Muon energy scale	-	0.4–2.7%	-	0.4–2.7 %
Muon to tau fake energy scale	-	1%	-	-
Electron energy scale	-	-	Event-dependent	
Electron to tau fake energy scale	-	-	0.8–6.6%	-
Misidentified $\tau_h \to h^\pm$	2.8%	2.8%	2.8%	-
Misidentified $\tau_h \to h^\pm\pi^0$	3.2%	3.2%	3.2%	-
Misidentified $\tau_h \to h^\pm h^\pm h^\pm$	3.7%	3.7%	3.7%	-
Parton re-weighting	100% for all channels			
Drell-Yan MC re-weighting	100% for all channels			
Top p_T re-weighting	100% for all channels			
MC comparison for signal	100% for all channels			
p_T^{miss} unclustered scale	Event-dependent, but negligible			
p_T^{miss} recoil correction	Event-dependent, but negligible			
Limited MC statistics	Bin by bin fluctuations			

Additional material

Source of systematic uncertainty	Uncertainty (%)
Muon identification efficiency (syst.)	2.1
Jet energy scale	1.8–1.9
Electron identification efficiency (syst.)	1.6
Electron identification efficiency (stat.)	1.0
Pileup	0.9–1.0
Electron trigger efficiency	0.7
τ_h veto efficiency	0.6–0.7
p_T^{miss} trigger efficiency (jets plus p_T^{miss} region)	0.7
p_T^{miss} trigger efficiency ($Z/\gamma^* \rightarrow \mu\mu$ region)	0.6
Boson p_T dependence of QCD corrections	0.5
Jet energy resolution	0.3–0.5
p_T^{miss} trigger efficiency (μ+jets region)	0.4
Muon identification efficiency (stat.)	0.3
Electron reconstruction efficiency (syst.)	0.3
Boson p_T dependence of EW corrections	0.3
PDFs	0.2
Renormalization/factorization scale	0.2
Electron reconstruction efficiency (stat.)	0.2
Overall	3.2