Recent W/Z precision measurements @LHCb

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LHCb前沿物理研讨会

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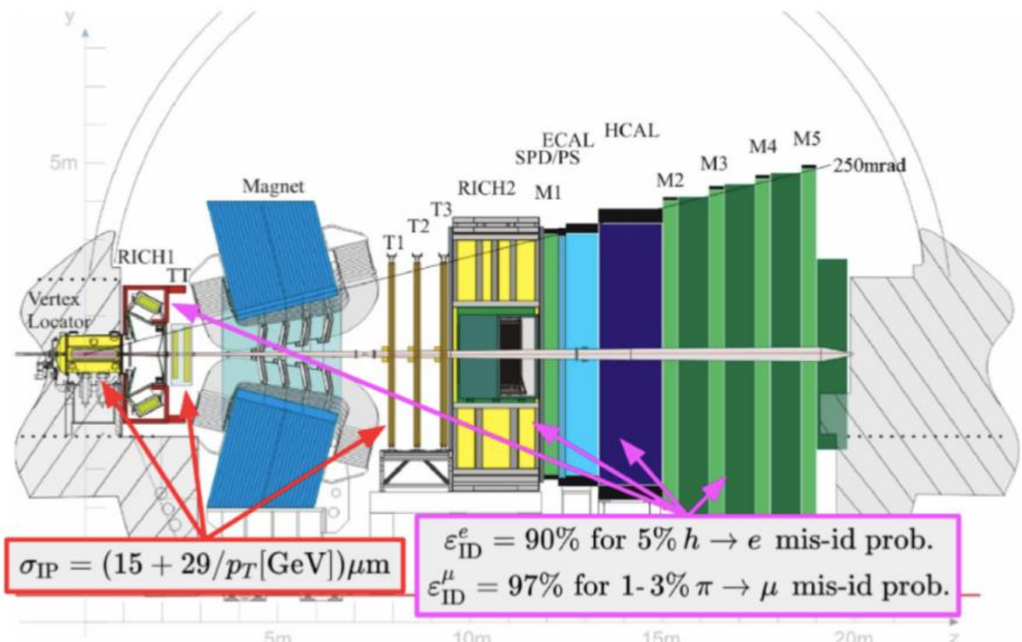
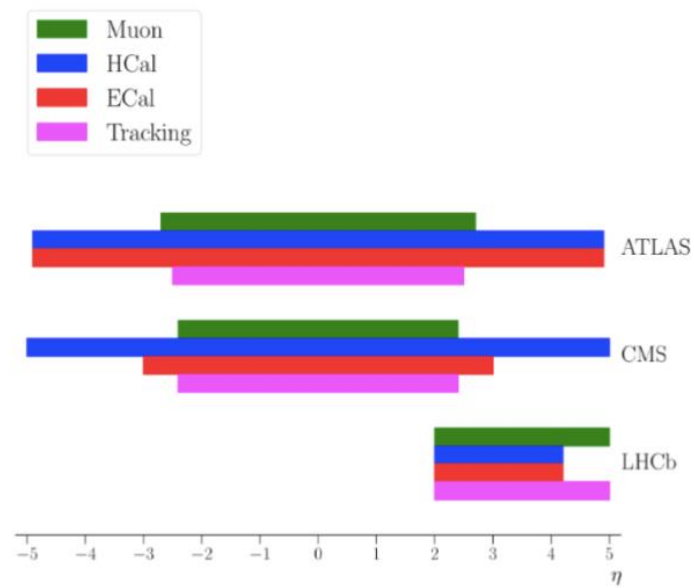
LHCb detector

Single-arm forward spectrometer with 2 < η < 5; coverage is complementary to ATLAS and CMS; extended to EW measurements: excellent performance tracking and muon detector



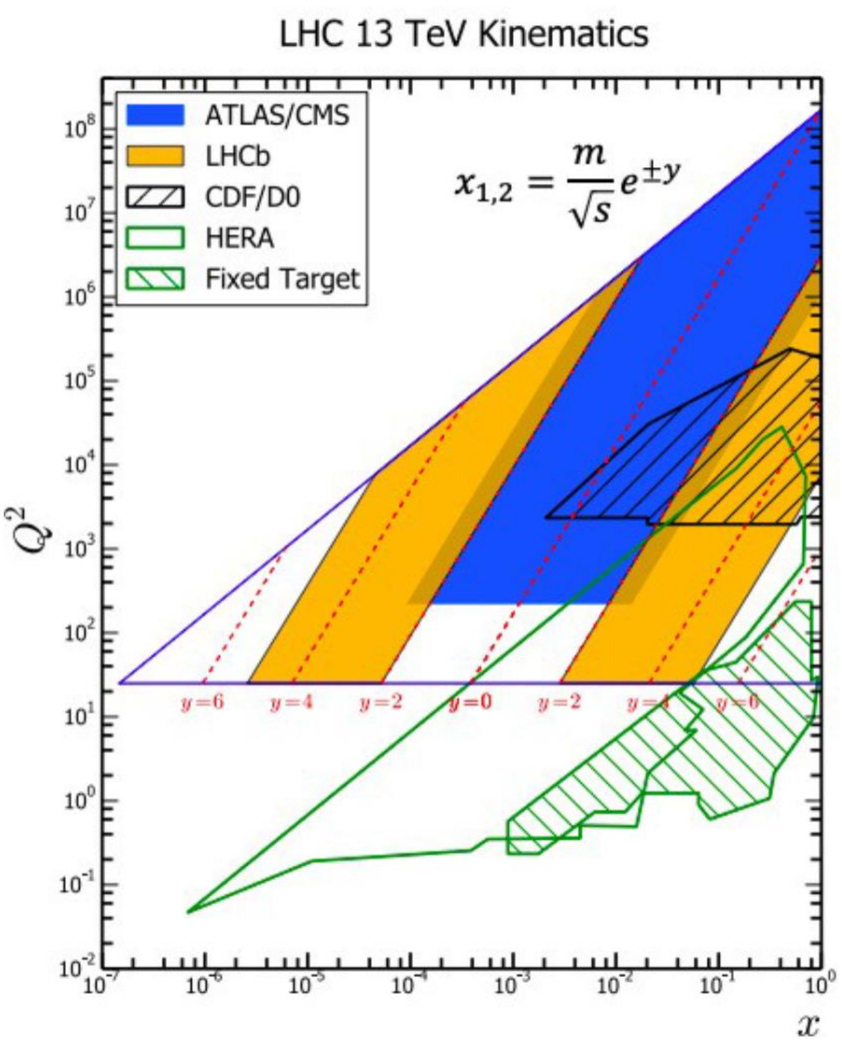


JIST 3 (2008) S08005
Int. J. Mod. Phys. A 30. 1530022 (2015)

W/Z physics at LHCb

LHCb has already delivered a strong program of physics with W and Z boson mainly probing QCD, measuring weak mixing angle and W boson mass.

LHCb detector provides access to high and low Bjorken-x region PDFs, has not been probed directly at electroweak energy scales before



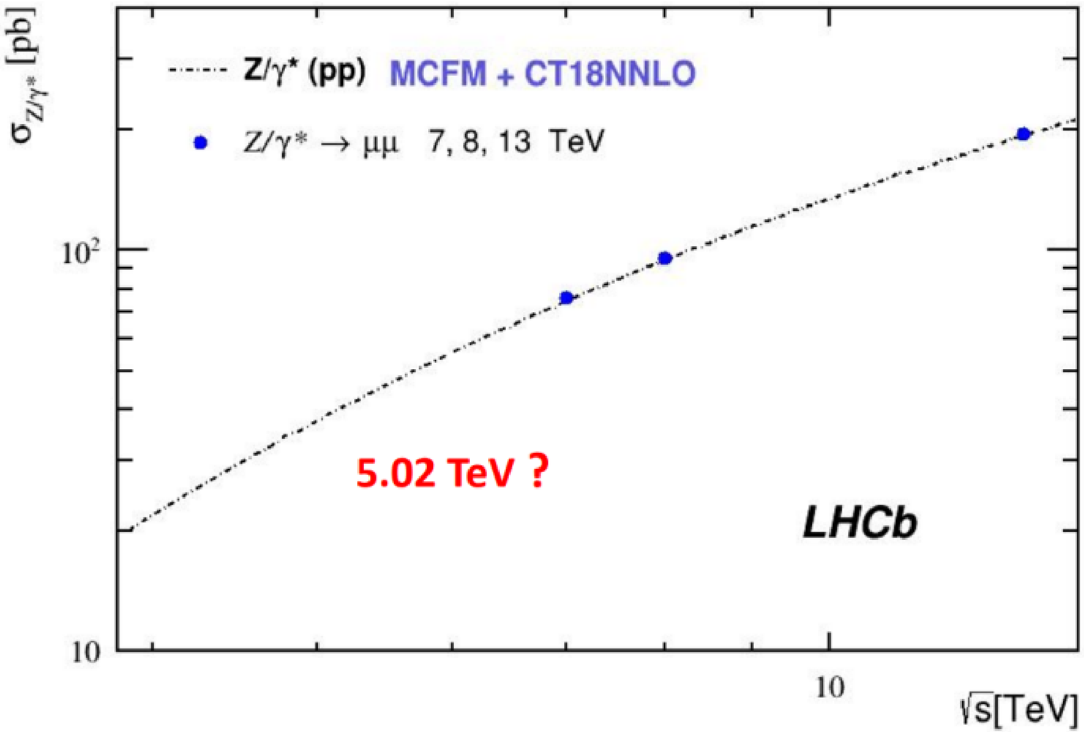
Z cross section 5 TeV-Introduction

· Provide important test of the QCD and the EW sector of SM at LHC energies

· Constrain the uncertainty of PDF @ 5.02 TeV

· Data: 2017, 99.86 pb^{-1}

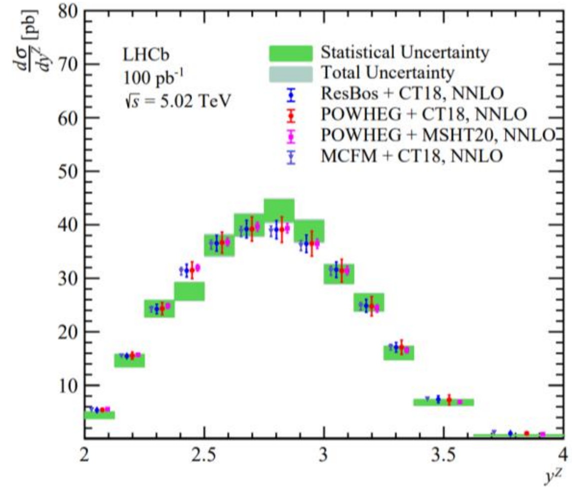
· Selection requirements: P_T^{μ}> 20 GeV, 2 < η_{μ} < 4.5, $\frac{\sigma_P^{\mu}}{P}$ < 0.1, 60 < $M_{\mu\mu}$ < 120 GeV

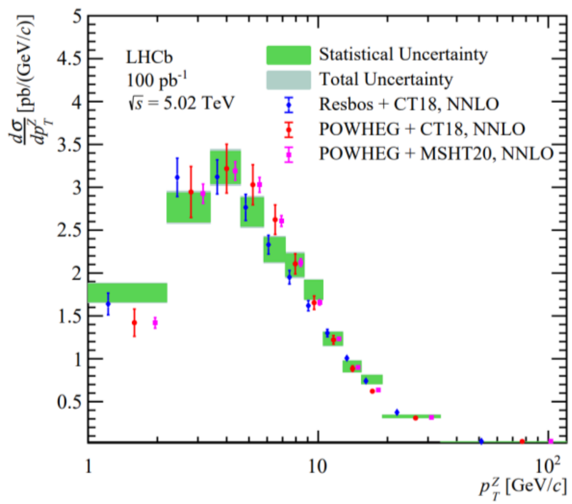


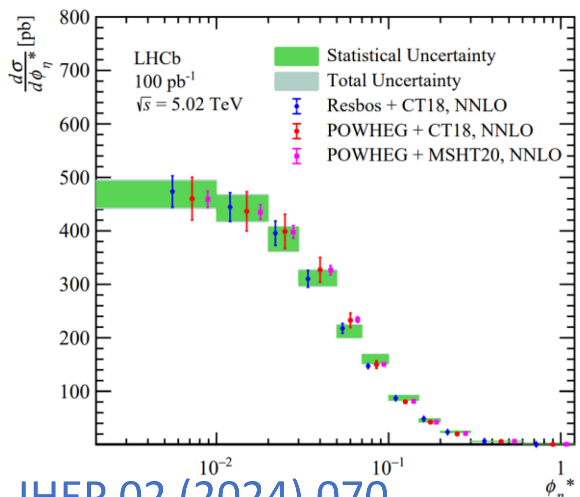
Z cross section 5 TeV-Differential cross

Reasonable agreements between data and predictions, the uncertainty is dominant by statistical uncertainty

Source	$\Delta\sigma$ [pb]	$\Delta\sigma/\sigma$ [%]
Luminosity	0.79	2.00
Statistical	0.70	1.77
Tracking	0.40	1.01
Efficiency Closure	0.24	0.61
Trigger	0.21	0.54
Background	0.19	0.48
Identification	0.10	0.25
FSR	0.07	0.18
Calibration	$< 4.0 \times 10^{-3}$	< 0.01
Total Systematic (excl. lumi.)	0.56	1.42



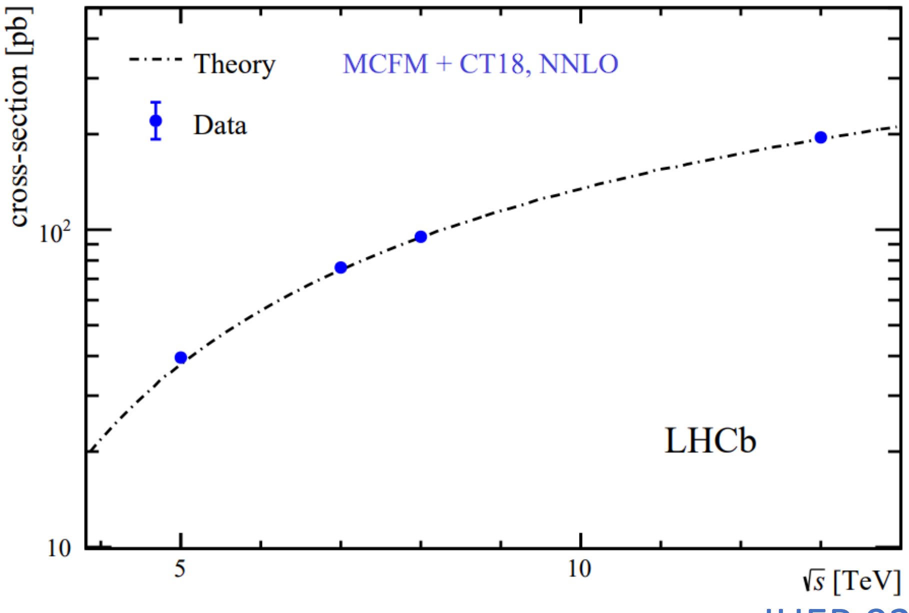


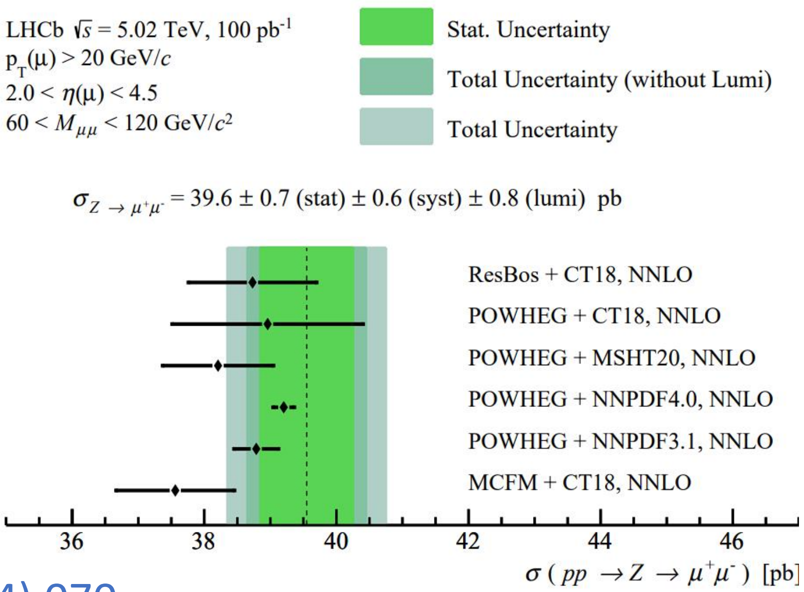


JHEP 02 (2024) 070

Z cross section 5 TeV-Result

For total cross section, there are also reasonable agreements between data and predictions



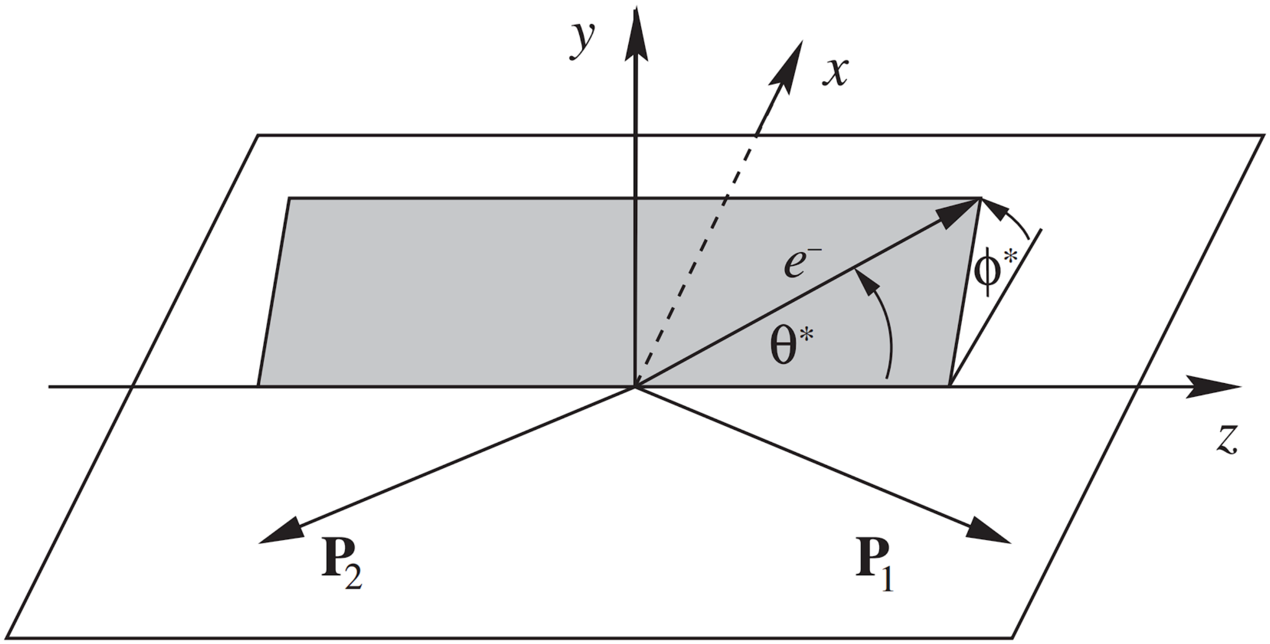


JHEP 02 (2024) 070

Z angular coefficient-introduction

· The kinematic distribution of the final-state leptons provides a direct probe of the polarization of the intermediate gauge boson

· Differential cross section of the lepton decay angle ($\cos\theta$, ϕ) in Collins-Soper frame



Phys.Rev.D 84 (2011) 012007

Z angular coefficient-introduction

A_0 A_1 A_2 A_3 ΔA_4 and A_0 - A_2 are measured

$$\frac{d\sigma}{dP_T^2\,dy\,d\cos\theta\,d\phi} \propto (1+\cos^2\theta)$$ → LO term

$$+\ \frac{1}{2}A_0(1-3\cos^2\theta)$$ → $\cos^2\theta$: higher order term

$$+\ A_1\sin 2\theta\cos\phi + \frac{1}{2}A_2\sin^2\theta\cos 2\phi + A_3\sin\theta\cos\phi$$ → (θ, ϕ) terms

$$+\ A_4\cos\theta$$ → LO term : determine A_{fb}

$$+\ A_5\sin^2\theta\sin 2\phi + A_6\sin 2\theta\sin\phi + A_7\sin\theta\sin\phi$$ → very small terms

Dateset: 2016 2017 2018

Selection requirements:

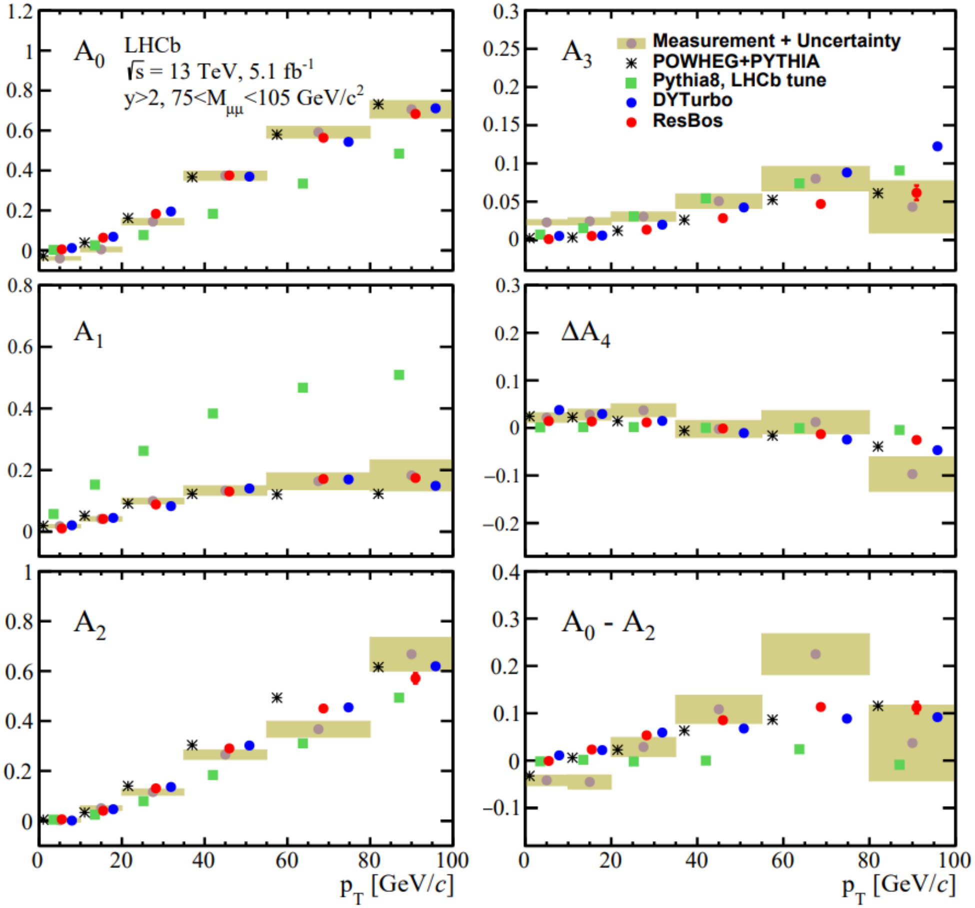
Particle	Selections
Z	50<Mass<150GeV
Z	$\chi^2_{vtx}/ndf < 9$
All tracks	$2.0 < \eta < 4.5$
All tracks	$P_T > 20\text{GeV}$
All tracks	$\frac{\sigma_p}{p} < 0.1$
All tracks	$\frac{p_T^\mu}{p_T^\mu + p_T^{\mu-cone}} > 0.85$

Z angular coefficient- p_T dependent results

The uncertainty is dominated by statistical uncertainty, Measurements are at Born level

In order to investigate its variation across the kinematic range, ΔA_4 is measured

ΔA_4 is the difference between this bin value and 5 bins average value

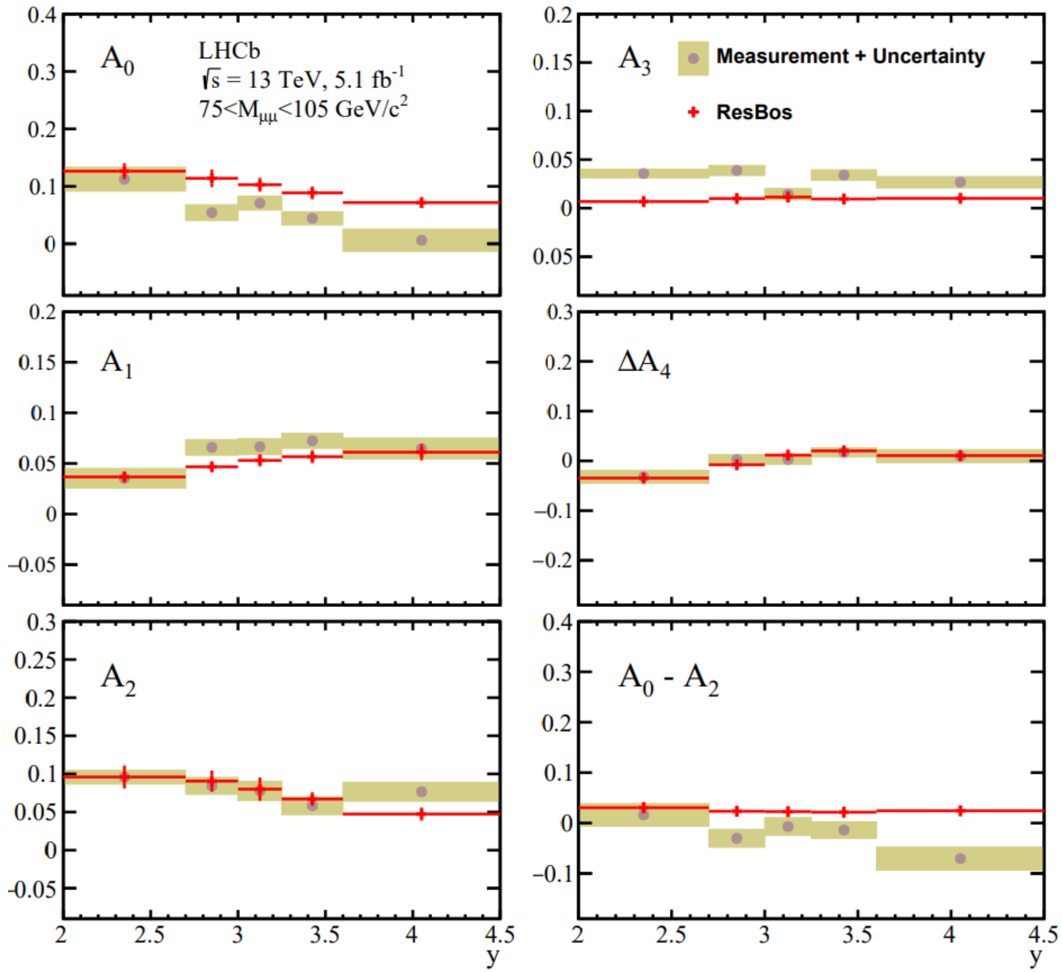


PRL 129 (2022) 091801

Z angular coefficient- y dependent results

$A_0 - A_2$: differences between measurements and predictions, especially in the highest y region

A y dependence in the QCD resummation or high-order effects



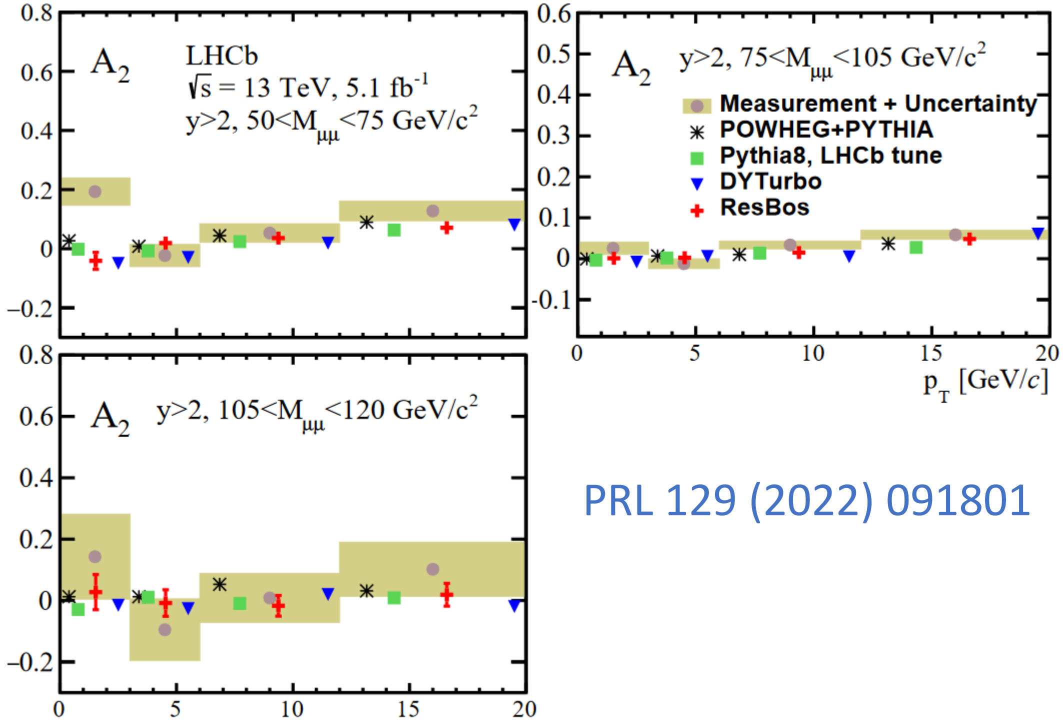
PRL 129 (2022) 091801

Z angular coefficient-Boer-Mulders TMD

· A_2 is sensitive to the Boer-Mulder transverse momentum dependent PDFs

· The measured A_2 values deviate significantly from all predictions in the lowest P_T region for the low-mass region

· None of the predictions include nonperturbative spin-momentum correlations



PRL 129 (2022) 091801

Weak Mixing Angle-introduction

- Introduction

A key parameter in the SM, describing the vector and axial-vector components of the coupling of the boson

$$sin^2\theta_W = (1 - \frac{m_W^2}{m_Z^2})$$

$$sin^2\theta_{eff}^{lept} = k_f sin^2\theta_W$$

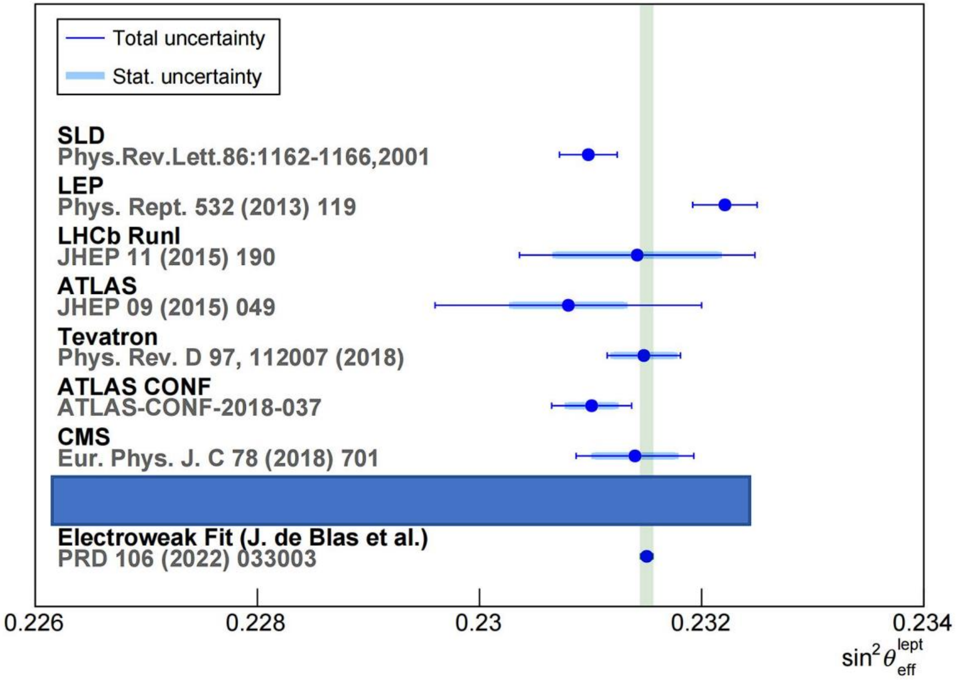
- Dataset

Blinded procedure based on 2016, 2017 and 2018

- Selection requirements:

$66 < M_{\mu\mu} < 116$ GeV,

$P_T^{\mu} > 20$GeV, $2.0 < \eta_{\mu} < 4.5$

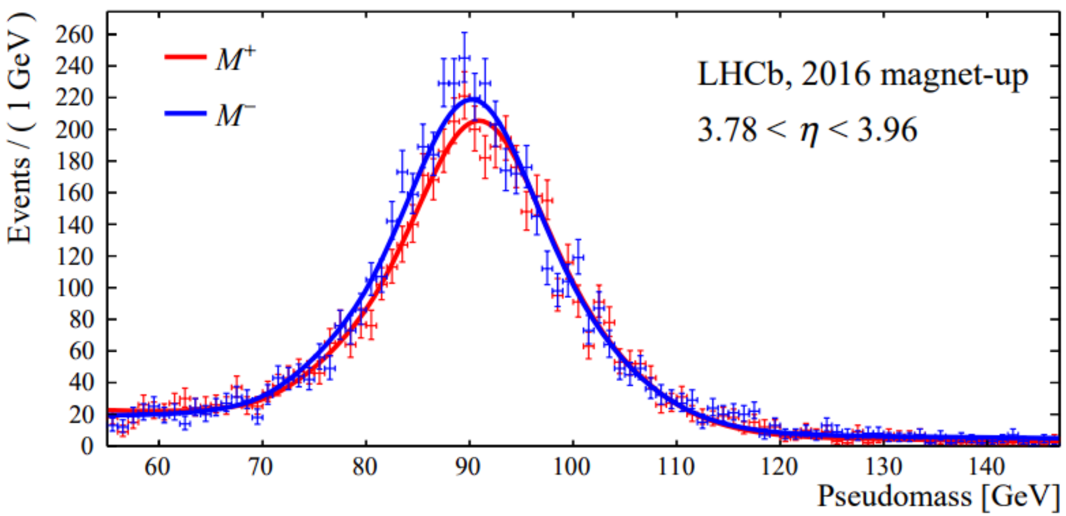


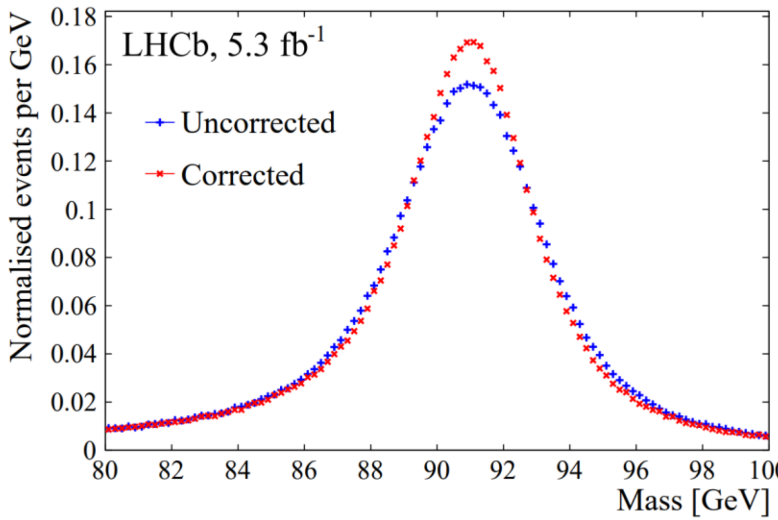
Weak Mixing Angle-pseudomass

Muons from Z tend to have very small curvature values, are sensitive to the alignment of the tracking system

Pseudomass can be used to determine the curvature values

$$\mathcal{M}^{\pm} = \sqrt{2p^{\pm}p_T^{\pm}\frac{P^{\mp}}{p_T^{\mp}}(1 - \cos\theta)}$$





JINST 19 P03010

Weak Mixing Angle-A_{FB}

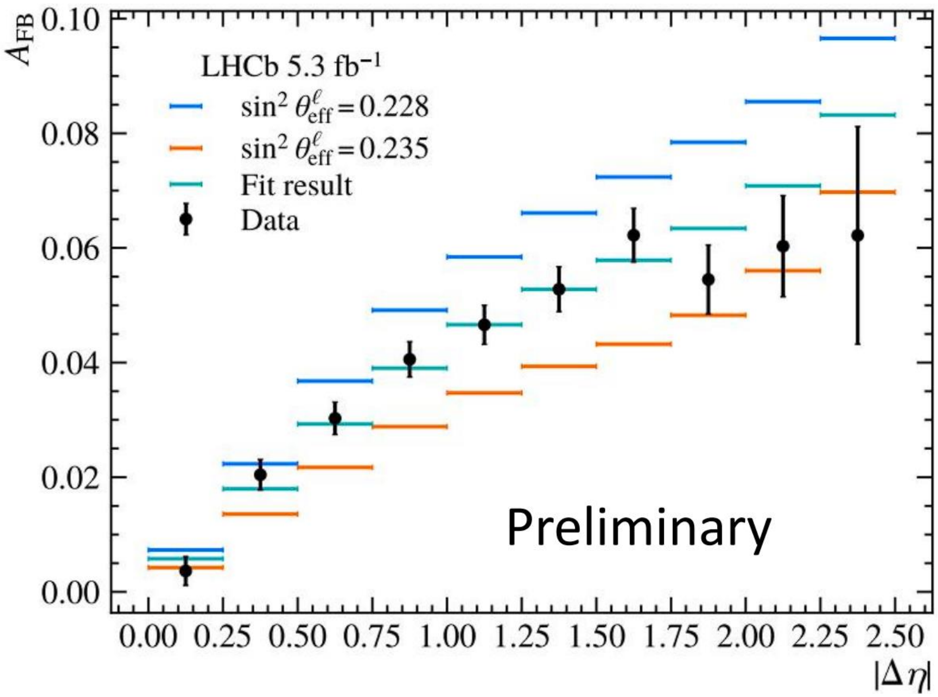
$sin^2\theta_{eff}^{lept}$ can be determined from A_{FB} in $pp \to Z/\gamma^* \to l^+l^-$

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

σ_F: cross-sections integrated over forward range, 0 < cosθ^* < 1

σ_B: cross-sections integrated over forward range, -1 < cosθ^* < 0

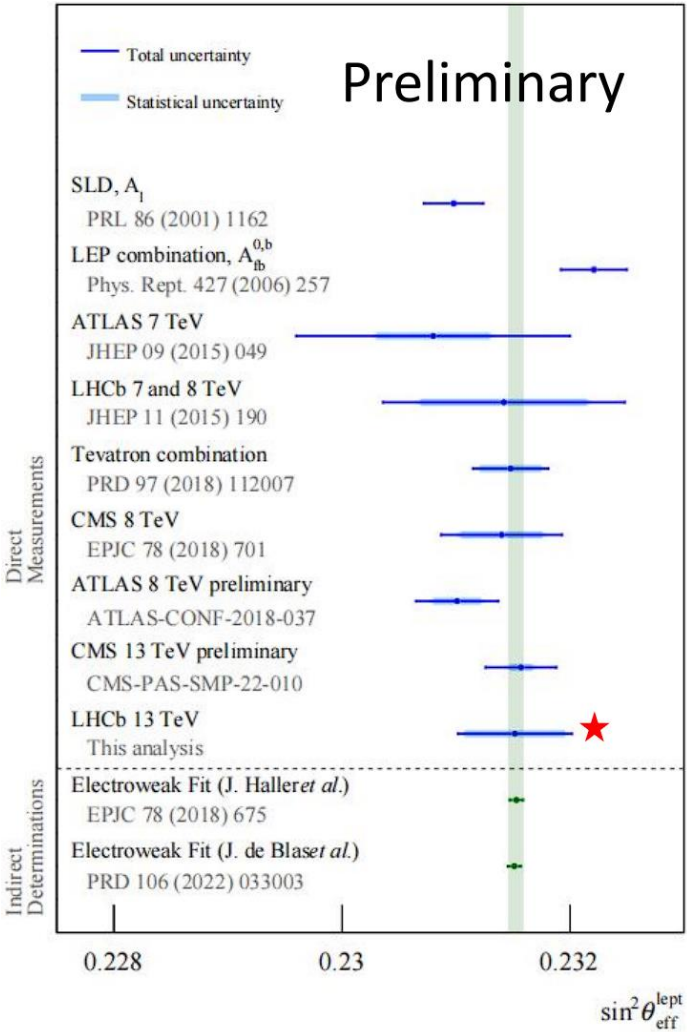
θ^*: the polar angle in Collins-Soper frame



$$\Delta\eta = \eta_{\mu^+} - \eta_{\mu^-}$$

measure A_{FB} in ten intervals of $|\Delta\eta|$ up to $|\Delta\eta|$ = 2.5 using $Z \to \mu^+\mu^-$ decays

Weak Mixing Angle-Result



Applying the relevant shifts and including the theoretical uncertainties, the final result is

$$0.231512 \pm 0.00044(\text{stat.}) \pm 0.00005(\text{syst.}) \pm 0.00022(\text{theory})$$

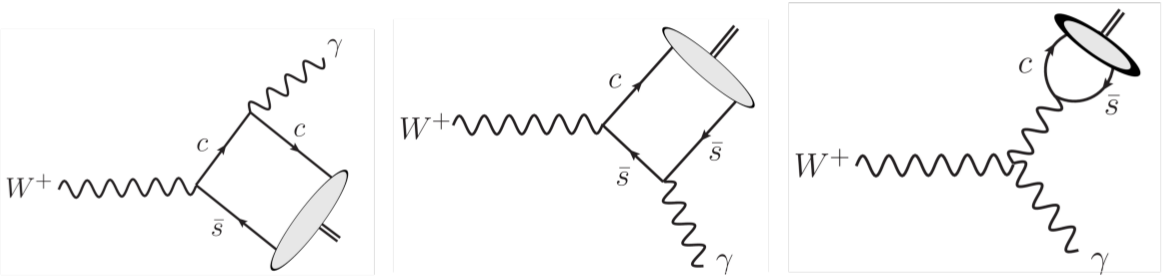
· relevant shifts: non-linearity shift and PDF average shift(NNPDF3.1, CT18, MSHT20)

· theory uncertainty include PDF uncertainty, QCD and EW uncertainty

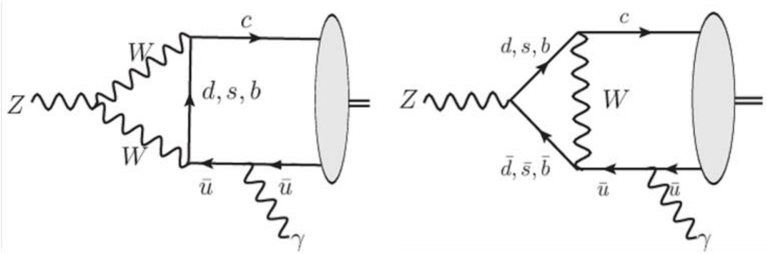
WZ Rare Decay-introduction

· Limited knowledge on W/Z boson rare decay

· The upper limit on the relative branching fraction of the $W^{\pm} \rightarrow D_s^{\pm}\gamma$ is determined to 1.2×10^{-2} (CDF, PRD 58 (1998) 091101)



· $\mathrm{Z} \rightarrow D^0\gamma$ has not been searched, theory prediction branch fraction [$10^{-12} \sim 10^{-6}$]



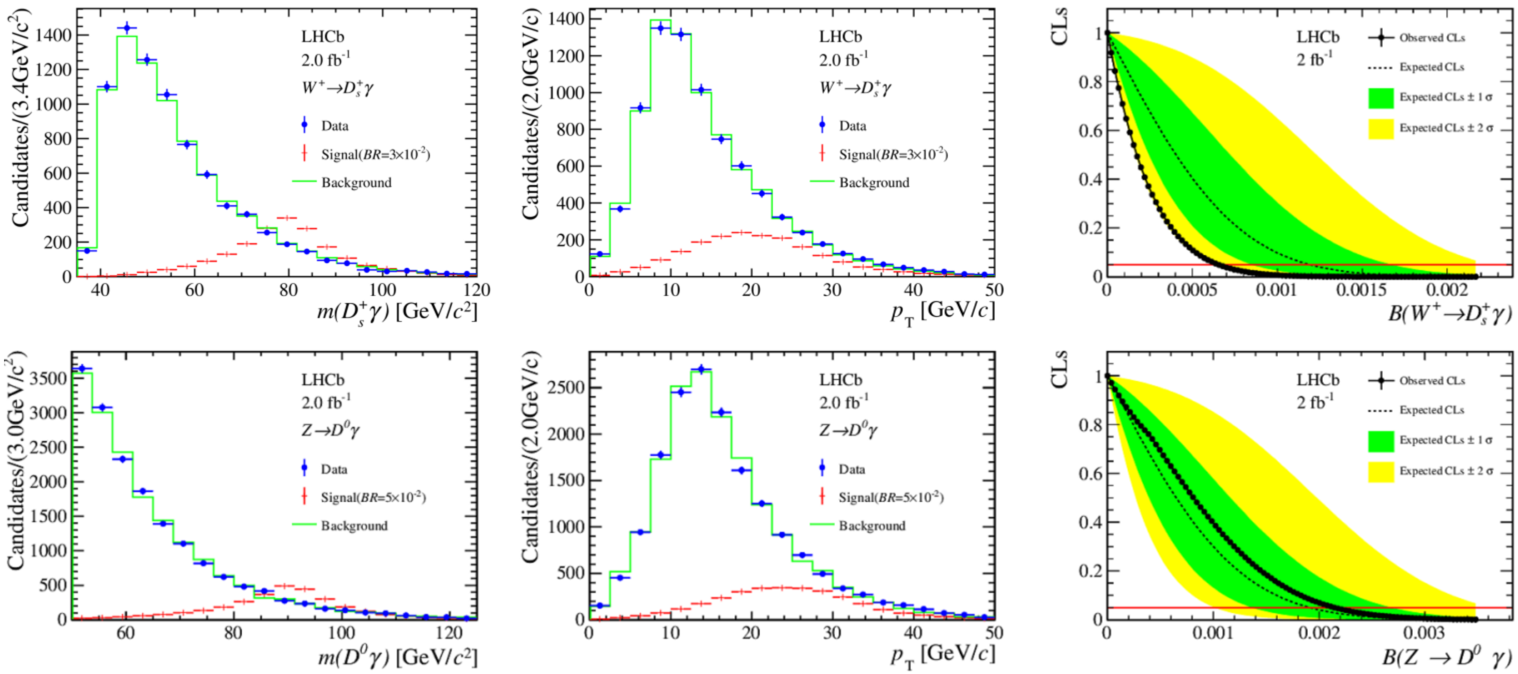
Chinese Phys. C 47 093002

WZ Rare Decay-CLs method

· We use LHCb 2018 data and there is no visible signal

· The CLs method is used to set upper limit for these rare decay searches

· X axis variable for left column plots is pseudo mass



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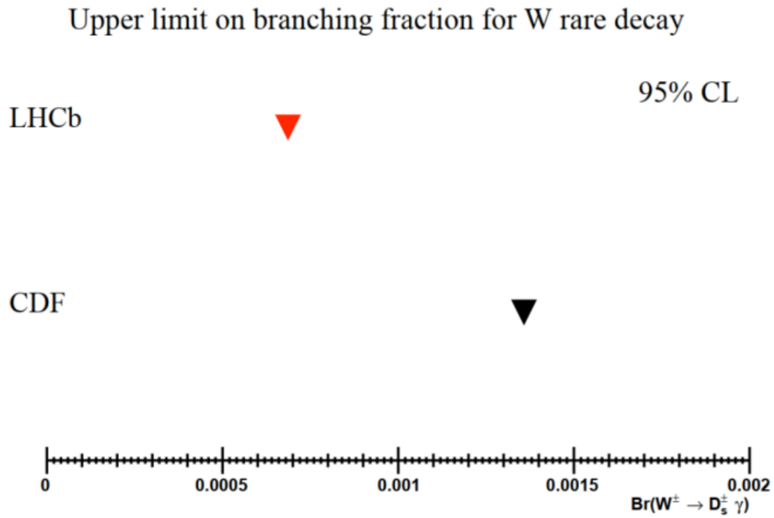
WZ Rare Decay-Result

- The upper limit of $W^{\pm} \to D_s^{\pm}\gamma$ is set at 6.5×10^{-4} and for $Z \to D^0\gamma$ is 2.1×10^{-3}

Source	$Z \to D^0\gamma$ (%)	$W^+ \to D_s^+\gamma$ (%)
Meson BF	0.76	1.86
Normalization	0.96	3.08
Dalitz	-	0.24
MC sample size	0.11	0.09
PID	0.09	0.17
Photon ID	2.32	0.95
Calorimeter saturation	3.00	3.10
Background	0.08	0.36
Acceptance	0.57	0.82
PV association	0.57	0.29
Resolution	0.20	0.09
Total	4.07	4.94



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- First upper limit on the exclusive $Z \to D^0\gamma$ decay

Summary

The LHCb detector has proved its capability to do high-precision measurements of EW observables

The first measurement of the Z production cross-section in the forward region @ 5 TeV

The first measurement of the angular coefficients of Drell-Yan ($\mu^+ \mu^-$) pairs in the forward region of pp collisions @ 13 TeV

The precision measurement of weaking mixing angle

To Do List

W boson production cross-section and lepton charge asymmetry @13TeV @5TeV

W boson mass measurement @13 TeV

Angular coefficients of Drell-Yan ($\mu^+ \mu^-$) pairs in the forward region of pp collisions @ 7 TeV @ 8 TeV

ttbar production cross-section @13 TeV

Low mass Drell-Yan production cross-section @13 TeV

End

Thank you for your listening!

Backup

Uncertainties of Z angular coefficient:

	$y^Z \in [2, 2.7]$						$y^Z \in [2.7, 3]$					
Coefficient	A_0	A_1	A_2	A_3	ΔA_4	$A_0 - A2$	A_0	A_1	A_2	A_3	ΔA_4	$A_0 - A2$
Total	0.1124	0.0354	0.0958	0.0357	-0.0321	0.0162	0.0543	0.0659	0.0843	0.0388	0.0026	-0.0302
Stat	0.0180	0.0085	0.0078	0.0039	0.0103	0.0197	0.0119	0.0067	0.0096	0.0046	0.0077	0.0153
Syst	0.0102	0.0046	0.0044	0.0022	0.0062	0.0112	0.0068	0.0038	0.0055	0.0024	0.0041	0.0088
MC Stat	0.0102	0.0044	0.0043	0.0022	0.0062	0.0111	0.0067	0.0035	0.0054	0.0024	0.0041	0.0086
FSR	0.0006	0.0013	0.0004	0.0001	0.0001	0.0007	0.0006	0.0013	0.0005	0.0002	-	0.0008
Eff	0.0005	0.0002	0.0001	-	-	0.0005	0.0002	-	-	-	-	0.0002
Bkg	0.0003	-	0.0001	-	-	0.0003	0.0001	-	-	-	-	0.0001
Smear	-	-	-	-	-	-	-	-	-	-	-	-
PDF	0.0001	0.0003	0.0004	0.0001	0.0004	0.0004	0.0007	0.0010	0.0011	0.0003	0.0004	0.0017
Extraction	0.0011	0.0002	0.0004	-	0.0004	0.0012	0.0006	0.0001	0.0003	0.0001	0.0003	0.0007

	$y^Z \in [3, 3.25]$						$y^Z \in [3.25, 3.6]$					
Coefficient	A_0	A_1	A_2	A_3	ΔA_4	$A_0 - A2$	A_0	A_1	A_2	A_3	ΔA_4	$A_0 - A2$
Total	0.0708	0.0665	0.0778	0.0144	0.0029	-0.0070	0.0443	0.0723	0.0583	0.0341	0.0171	-0.0139
Stat	0.0107	0.0068	0.0110	0.0051	0.0075	0.0154	0.0102	0.0065	0.0102	0.0047	0.0072	0.0145
Syst	0.0058	0.0039	0.0064	0.0028	0.0040	0.0087	0.0053	0.0036	0.0059	0.0026	0.0037	0.0078
MC Stat	0.0057	0.0036	0.0063	0.0027	0.0040	0.0085	0.0052	0.0031	0.0057	0.0026	0.0037	0.0077
FSR	0.0009	0.0015	0.0007	0.0003	-	0.0012	0.0007	0.0015	0.0006	0.0002	-	0.0010
Eff	0.0001	-	0.0001	-	-	0.0002	0.0001	-	-	-	-	0.0002
Bkg	-	-	0.0001	-	-	0.0002	-	-	-	-	-	-
Smear	-	-	-	-	-	-	-	-	-	-	-	-
PDF	0.0005	0.0004	0.0006	0.0006	0.0004	0.0009	0.0006	0.0008	0.0008	0.0004	0.0003	0.0005
Extraction	0.0002	0.0001	0.0007	-	0.0002	0.0007	0.0004	0.0001	0.0006	0.0001	0.0002	0.0007