Precision measurements of Z and W boson properties at CMS

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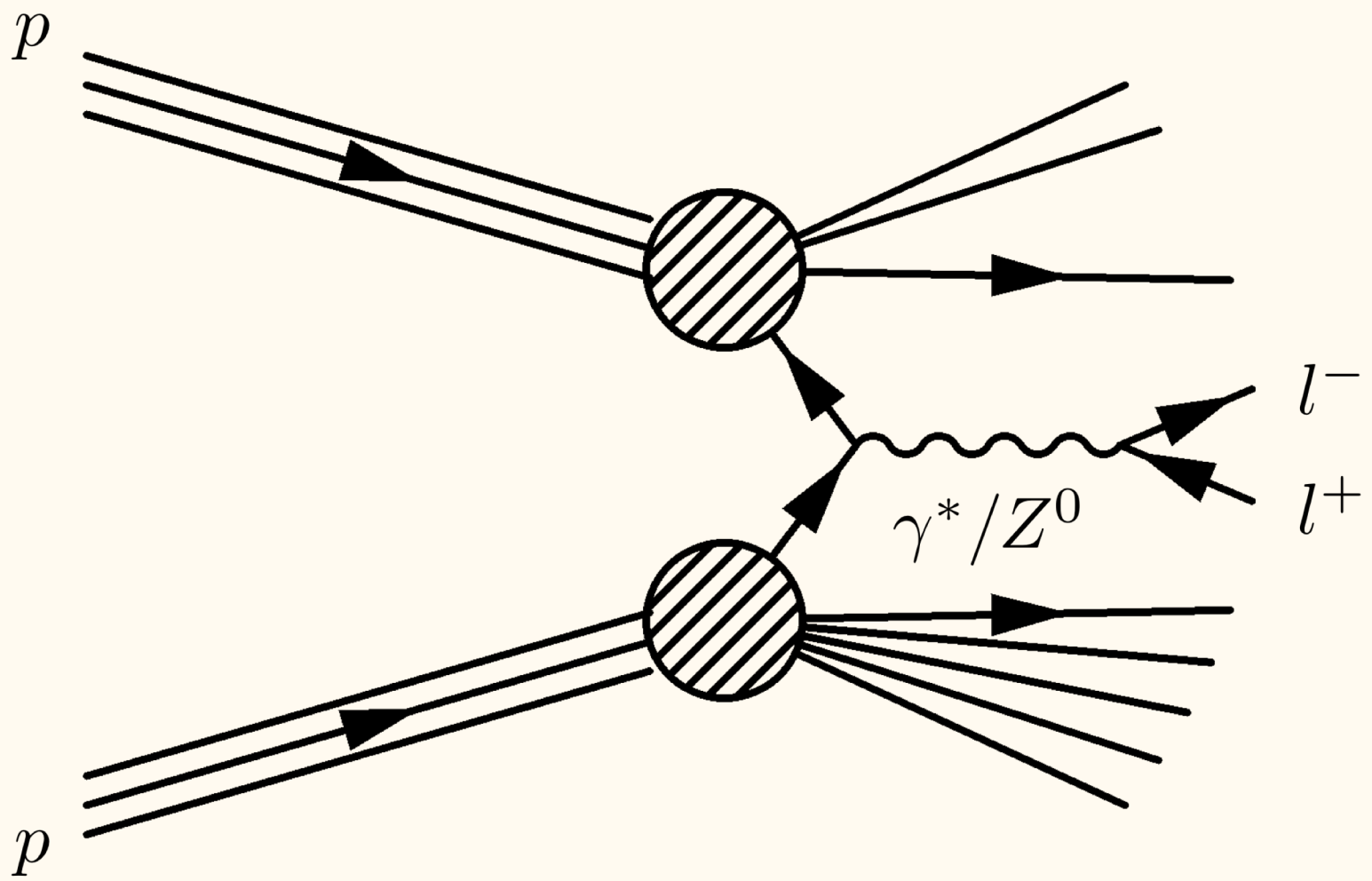
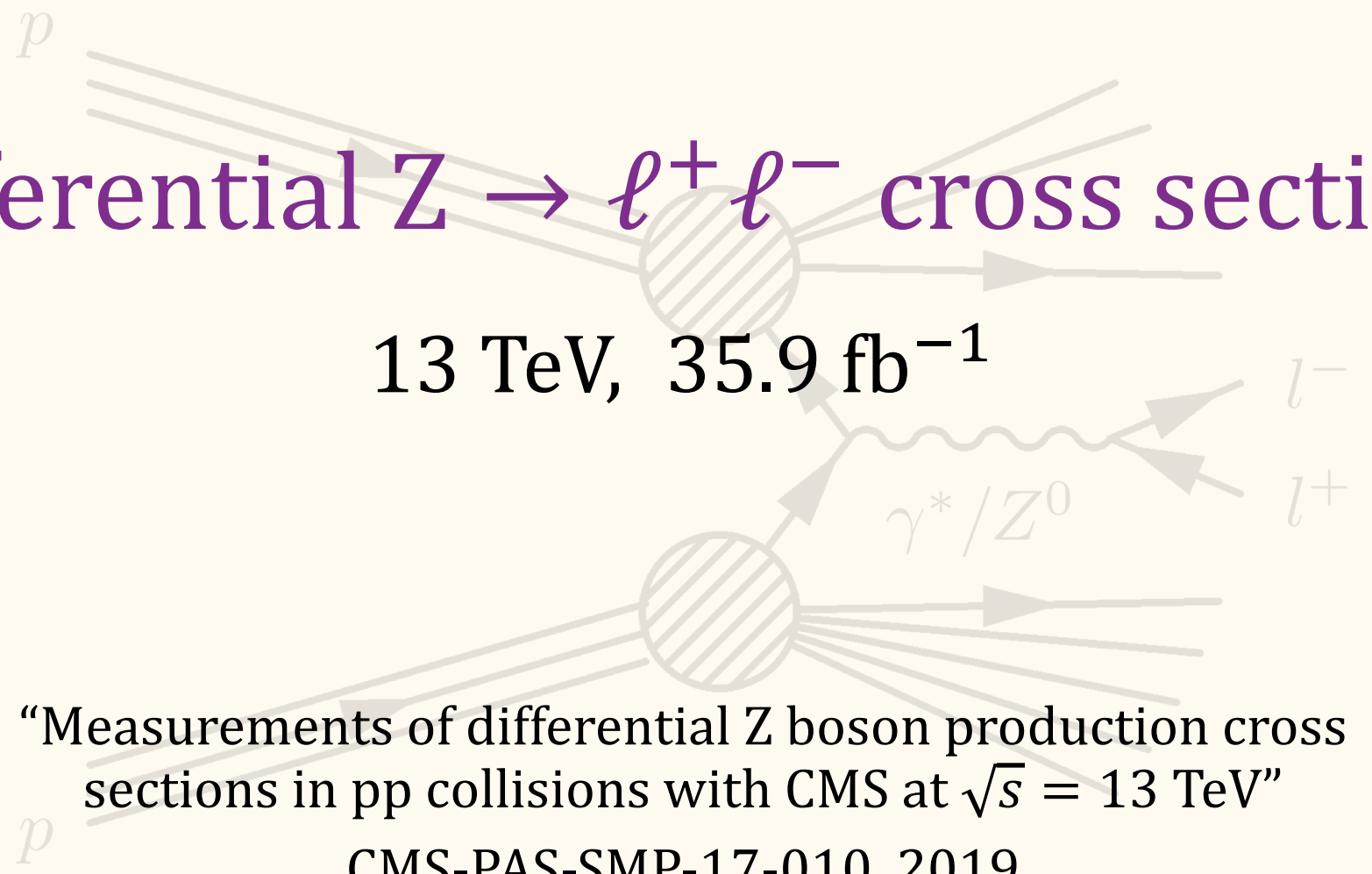
CMS Collaboration


p
p
γ^*/Z^0
l^-
l^+

Differential $Z \to \ell^+\ell^-$ cross sections



13 TeV, 35.9 fb^{-1}

"Measurements of differential Z boson production cross sections in pp collisions with CMS at $\sqrt{s} = 13$ TeV"

CMS-PAS-SMP-17-010, 2019

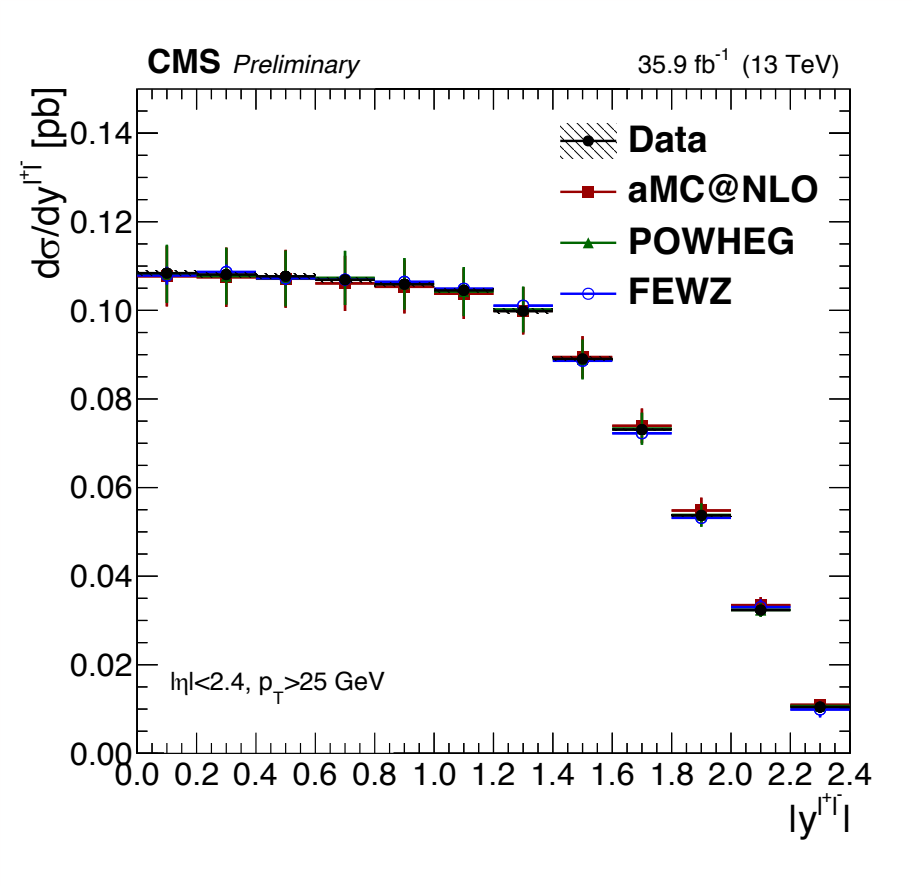
Source	$Z \to \mu\mu$ (%)	$Z \to$ ee (%)
Luminosity	2.5	2.5
Muon reconstruction efficiency	0.4	-
Muon selection efficiency	0.7	-
Muon momentum scale	0.1	-
Electron reconstruction efficiency	-	0.9
Electron selection efficiency	-	1.0
Electron momentum scale	-	0.2
Background estimation	< 0.1	< 0.1
Total (excluding luminosity)	0.8	1.4

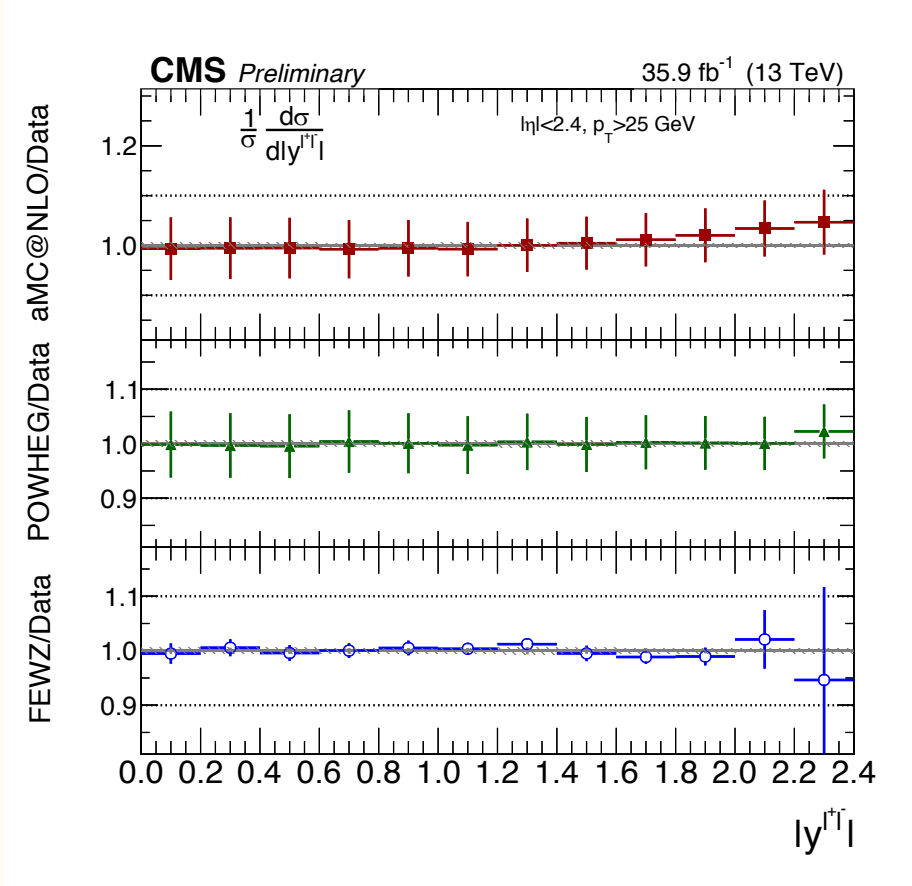
← normalize

combine →

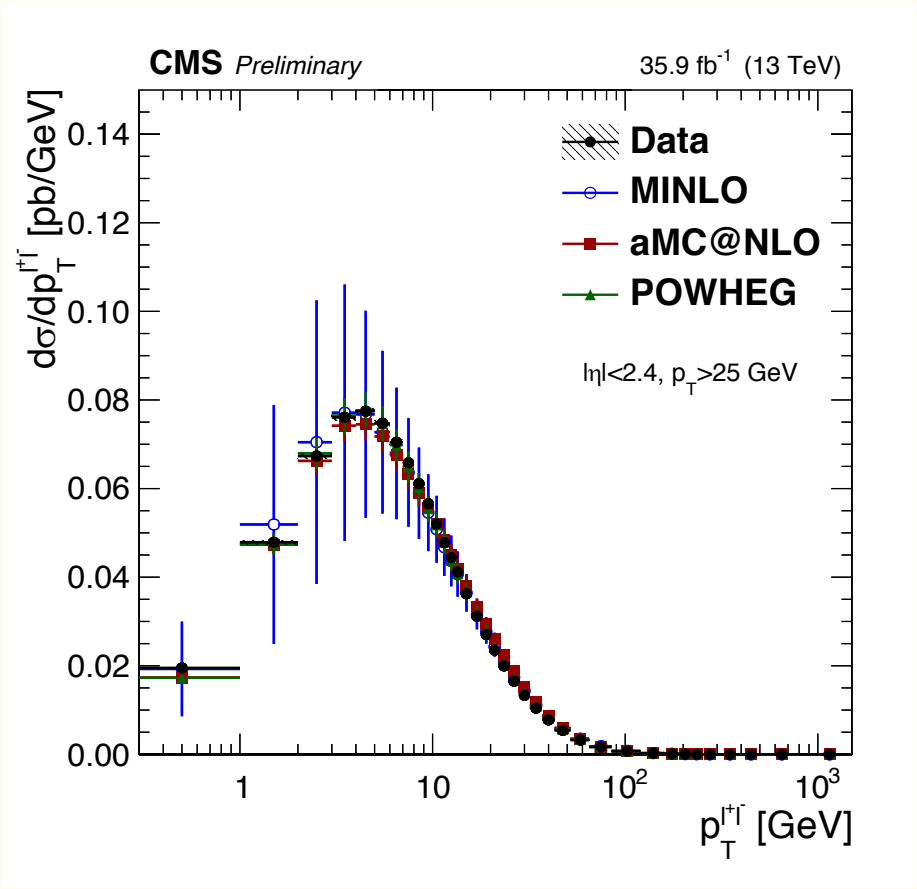
Cross section	$\sigma\,\mathcal{B}$ [pb]
$\sigma_{Z\to\mu\mu}$	$694 \pm 6\,(\text{syst}) \pm 17\,(\text{lumi})$
$\sigma_{Z\to ee}$	$712 \pm 10\,(\text{syst}) \pm 18\,(\text{lumi})$
$\sigma_{Z\to\ell\ell}$	$699 \pm 5\,(\text{syst}) \pm 17\,(\text{lumi})$

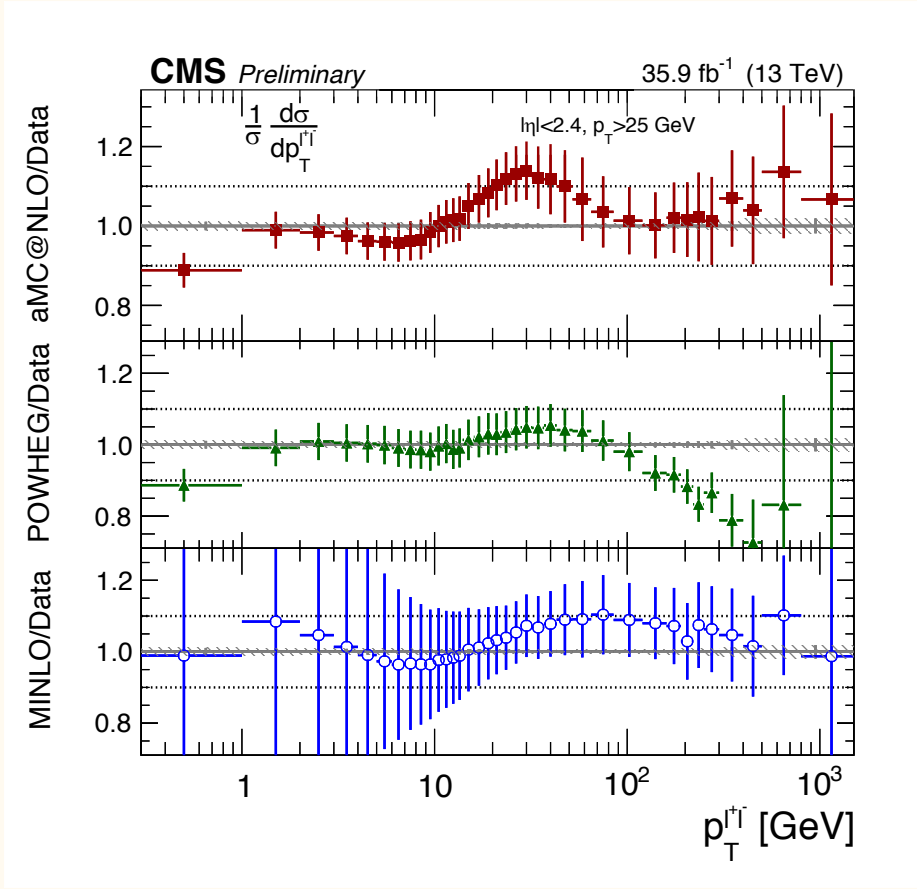
$|y|$


CMS Preliminary
35.9 fb-1 (13 TeV)
dσ/dy|l+l-| [pb]
Data
aMC@NLO
POWHEG
FEWZ
|η|<2.4, pT>25 GeV
|yl+l-|

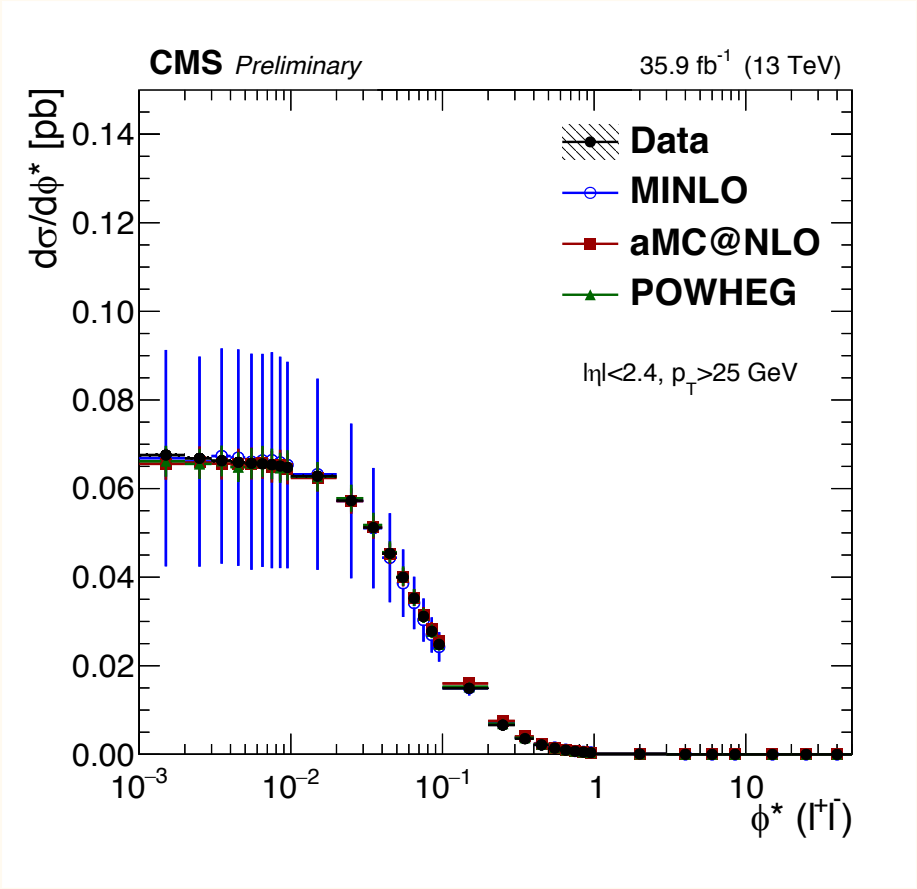

CMS Preliminary
35.9 fb-1 (13 TeV)
1/σ dσ/d|yl+l-|
|η|<2.4, pT>25 GeV
aMC@NLO/Data
POWHEG/Data
FEWZ/Data
|yl+l-|

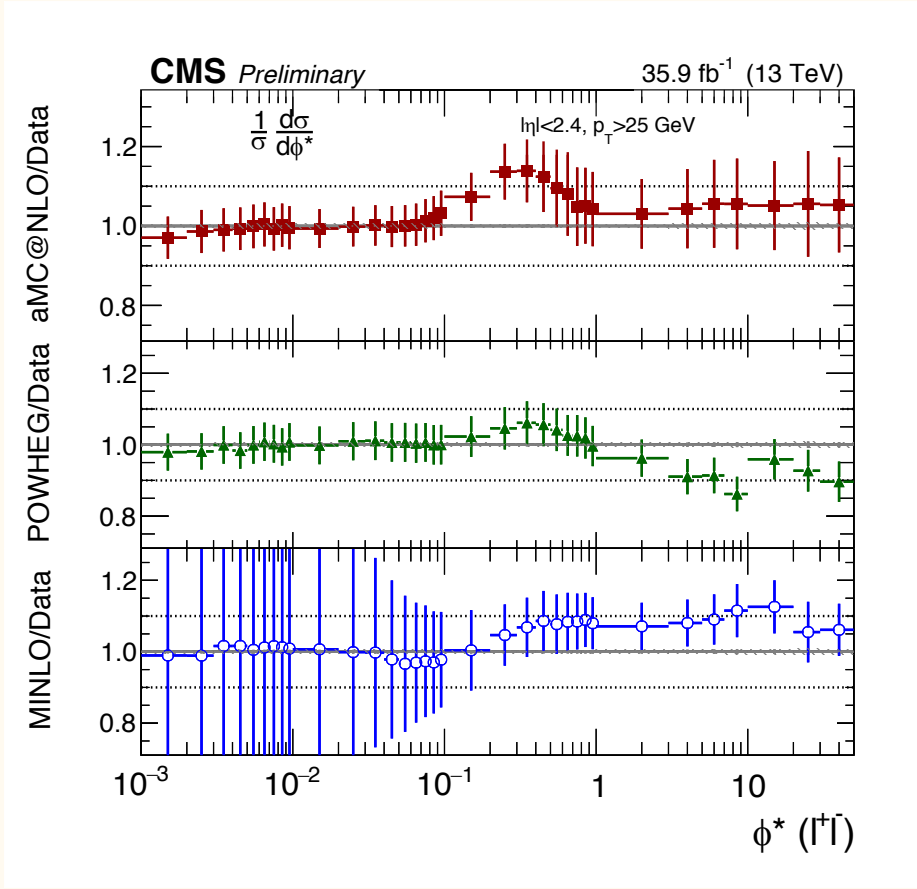
p_T

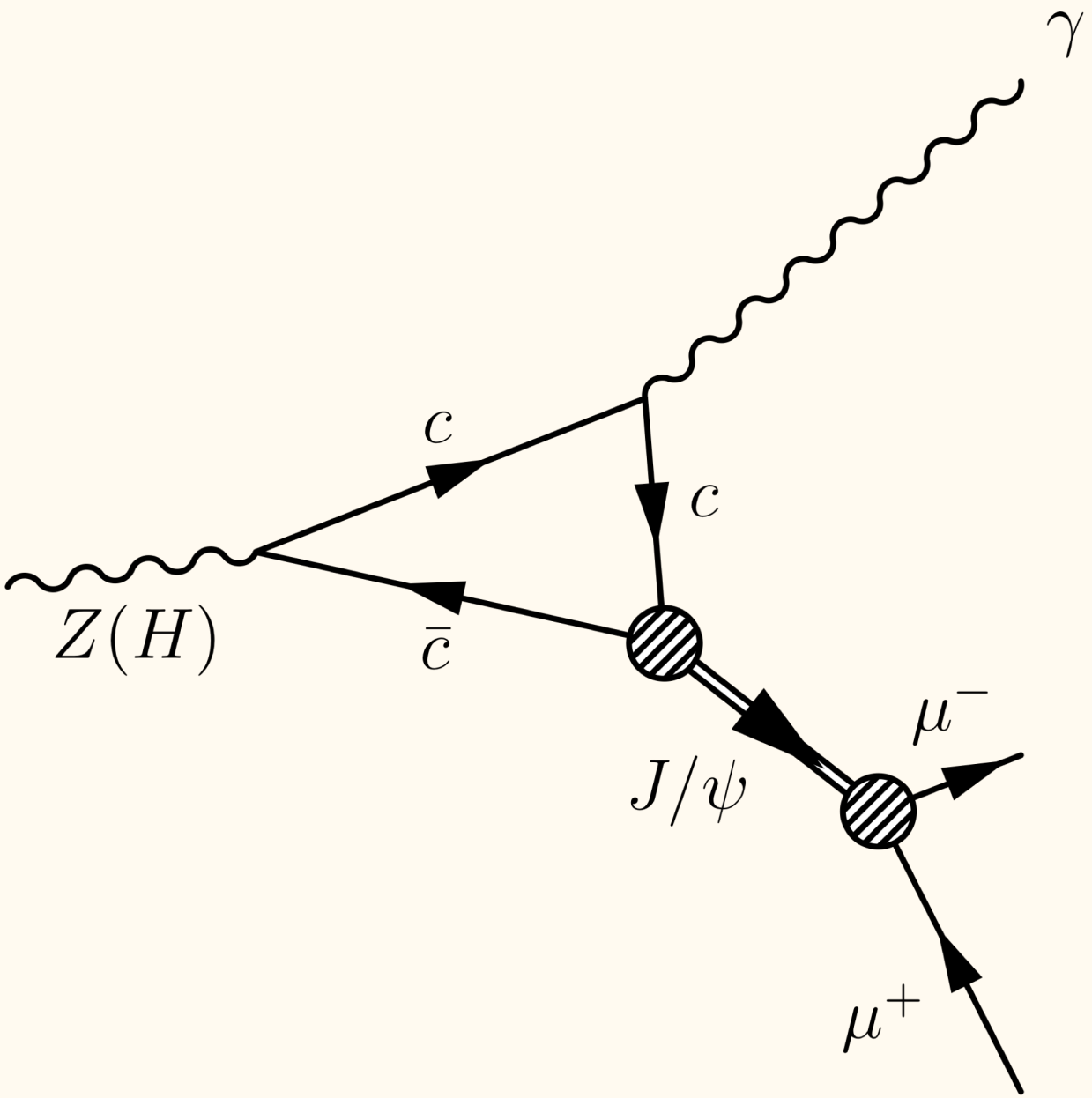

CMS Preliminary
35.9 fb-1 (13 TeV)
Data
MINLO
aMC@NLO
POWHEG
|η|<2.4, pT>25 GeV
dσ/dpT[l+l-] [pb/GeV]
pT[l+l-] [GeV]


CMS Preliminary
35.9 fb-1 (13 TeV)
1/σ dσ/dpT[l+l-]
|η|<2.4, pT>25 GeV
aMC@NLO/Data
POWHEG/Data
MINLO/Data
pT[l+l-] [GeV]

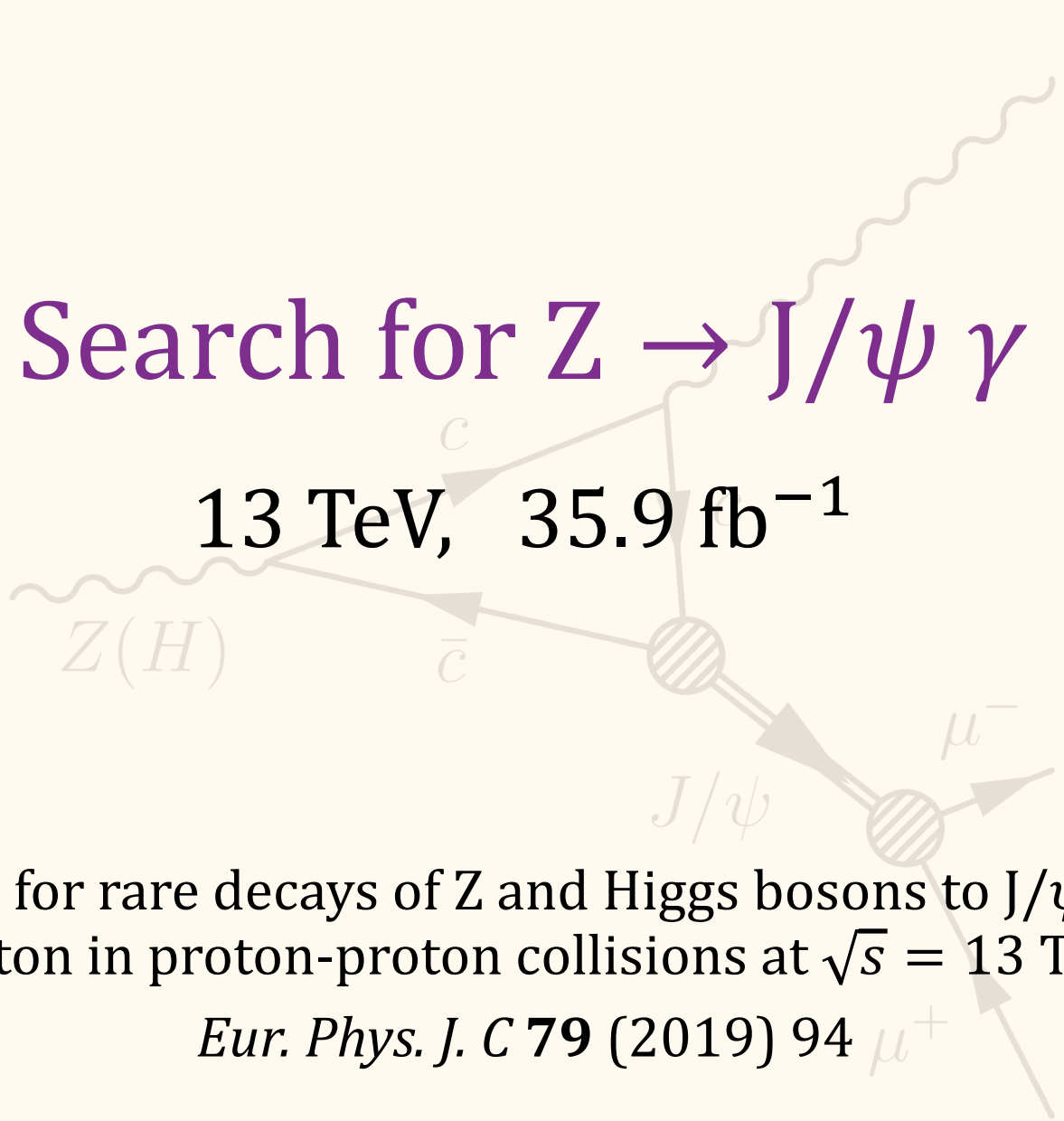
ϕ^*


CMS Preliminary
35.9 fb-1 (13 TeV)
dσ/dϕ* [pb]
Data
MINLO
aMC@NLO
POWHEG
|η|<2.4, pT>25 GeV
ϕ* (l+l-)


CMS Preliminary
35.9 fb-1 (13 TeV)
1/σ dσ/dϕ*
|η|<2.4, pT>25 GeV
aMC@NLO/Data
POWHEG/Data
MINLO/Data
ϕ* (l+l-)


γ
c
c
$Z(H)$
$\bar{c}$
μ^-
J/ψ
μ^+

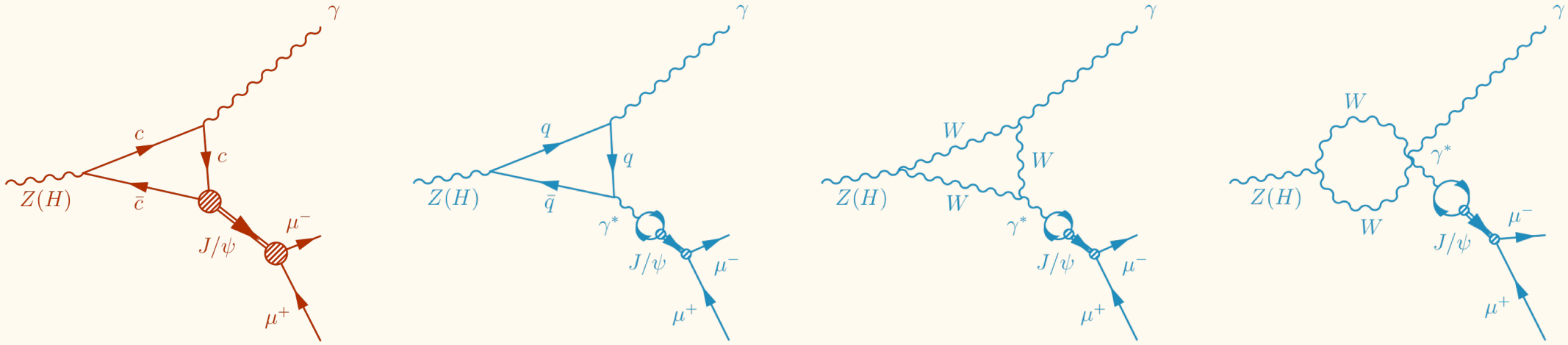
Search for $Z \to J/\psi\,\gamma$



13 TeV, 35.9 fb^{-1}

"Search for rare decays of Z and Higgs bosons to J/ψ and a photon in proton-proton collisions at $\sqrt{s} = 13$ TeV"

Eur. Phys. J. C **79** (2019) 94

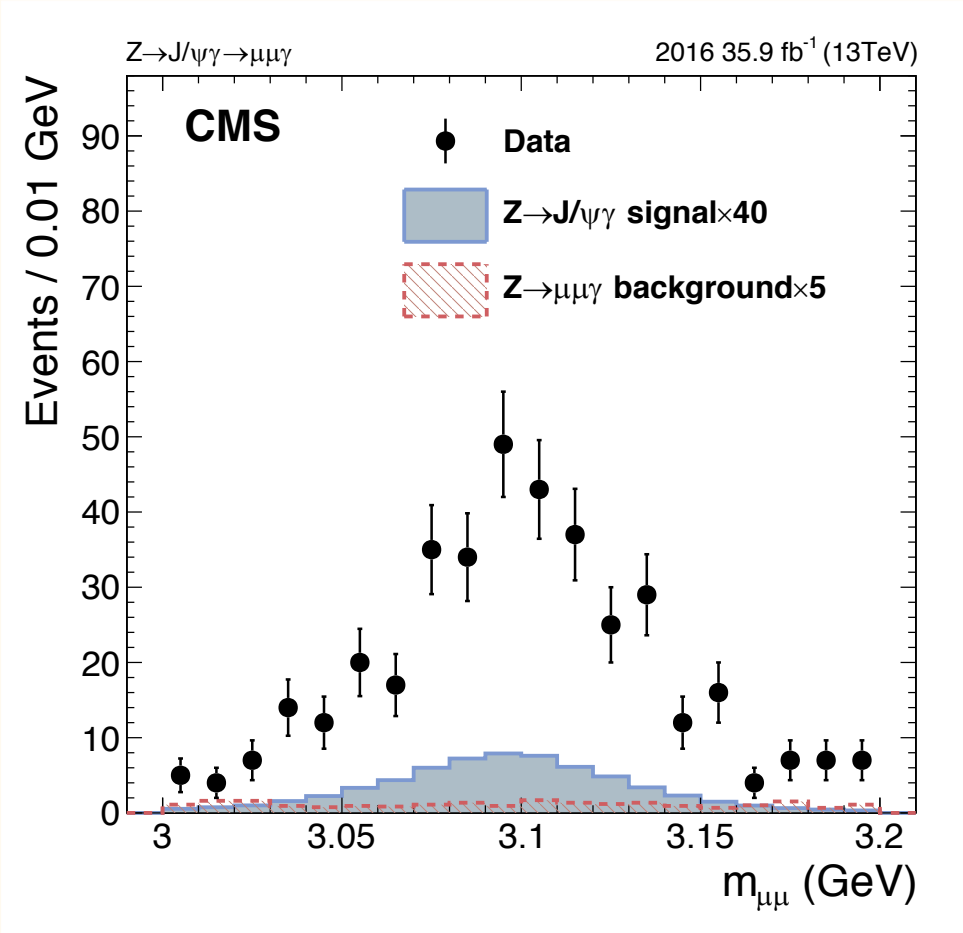


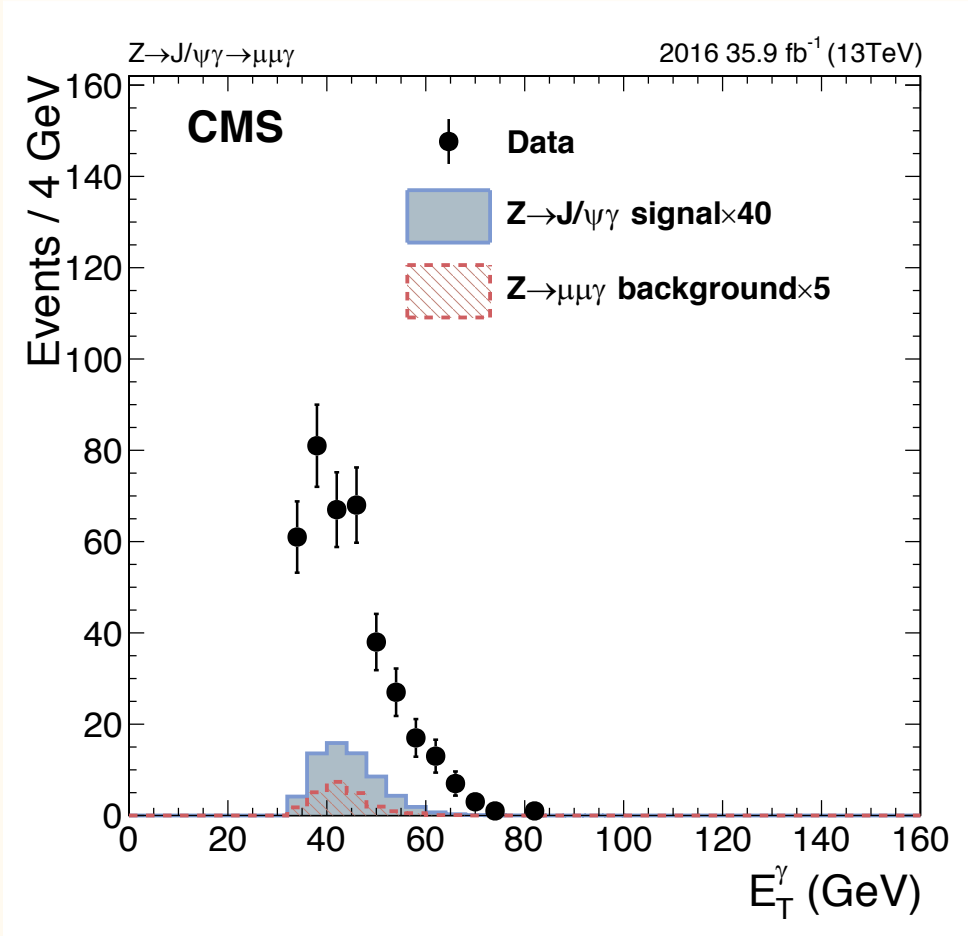
direct + indirect + higher order…

$$\mathcal{B}_{\mathrm{SM}}(\mathrm{Z} \to \mathrm{J}/\psi\,\gamma) \approx 9.0 \times 10^{-8}$$

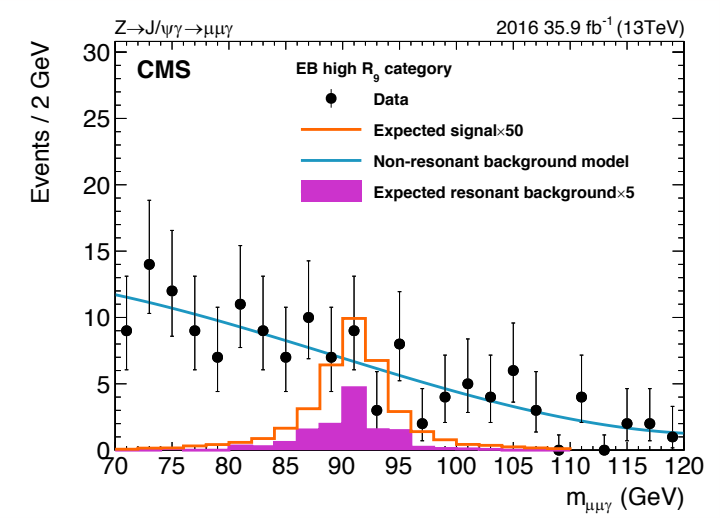
$J/\psi \rightarrow \mu^+\mu^-$

γ



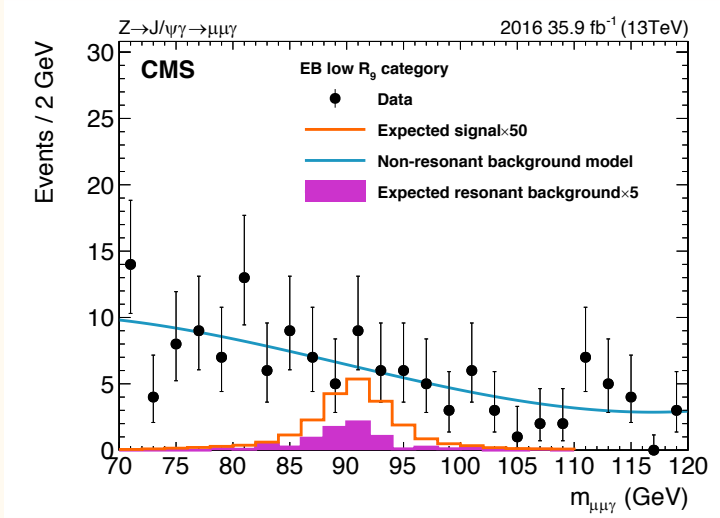


Barrel, high R_9



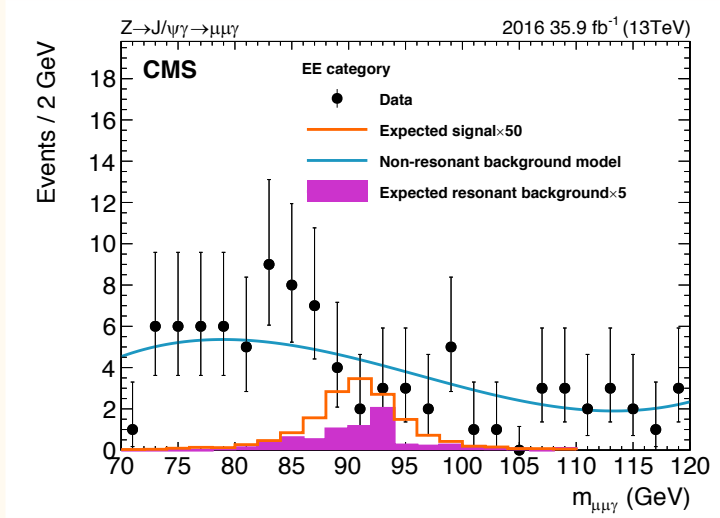
Purity: 0.99%

Barrel, low R_9



Purity: 0.65%

Endcaps



Purity: 0.68%

~2%

↓

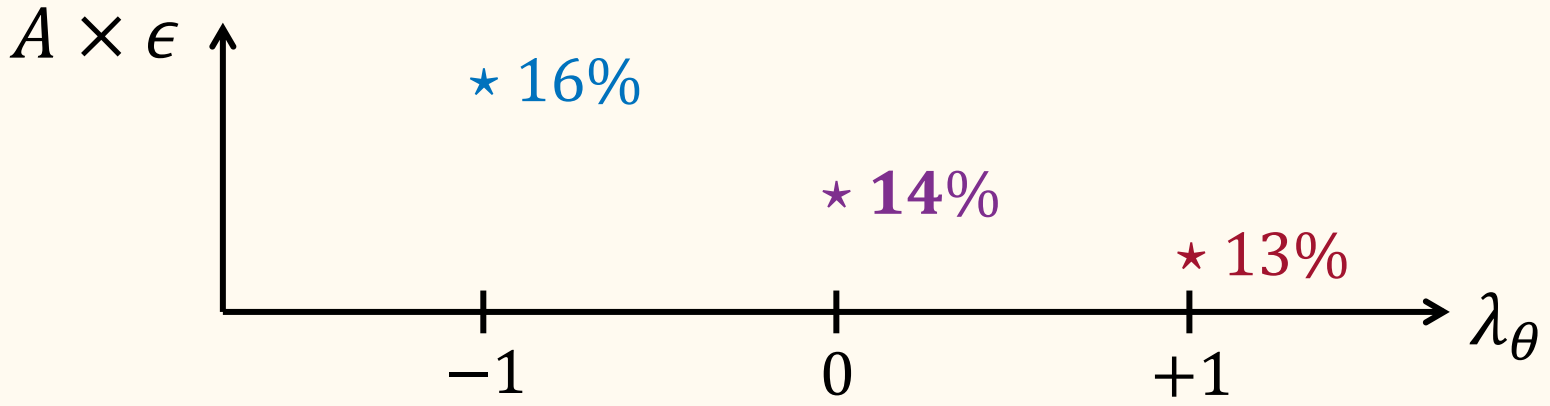
$Z \to J/\psi\gamma$ ($81 < m_{\mu\mu\gamma} < 101$ GeV)

Category	Observed data	Signal	Nonresonant background	Resonant background
EB high R_9	69	0.69	66.9±4.9	2.1
EB low R_9	67	0.42	62.6±4.6	1.2
EE	47	0.30	43.0±4.0	1.0

↑

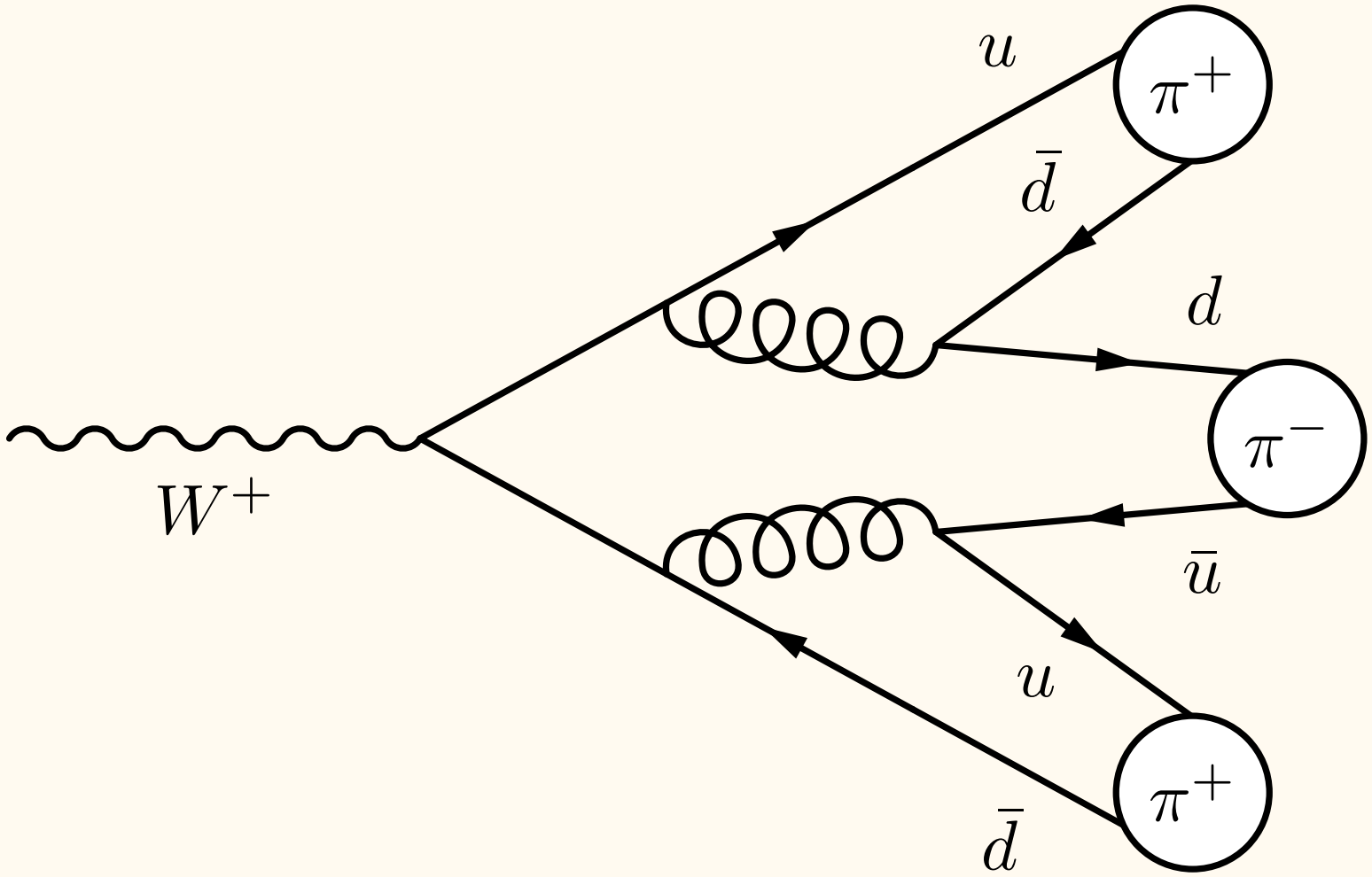
stat. only

Source	$Z \to J/\psi\gamma$ channel Signal	Resonant background
Integrated luminosity	2.5%	
Theoretical uncertainties		
Signal cross section (scale)	3.5%	5.0%
Signal cross section (PDF)	1.7%	5.0%
Branching fraction	—	5.0%
Detector simulation, reconstruction		
Pileup weight	0.8%	1.8%
Trigger	4.0%	4.0%
Muon ident./Isolation	3.0%	3.4%
Photon identification	1.1%	1.1%
Electron veto	1.1%	1.1%
Signal model		
$m_{\mu\mu\gamma}$ scale	0.06%	—
$m_{\mu\mu\gamma}$ resolution	1.0%	—



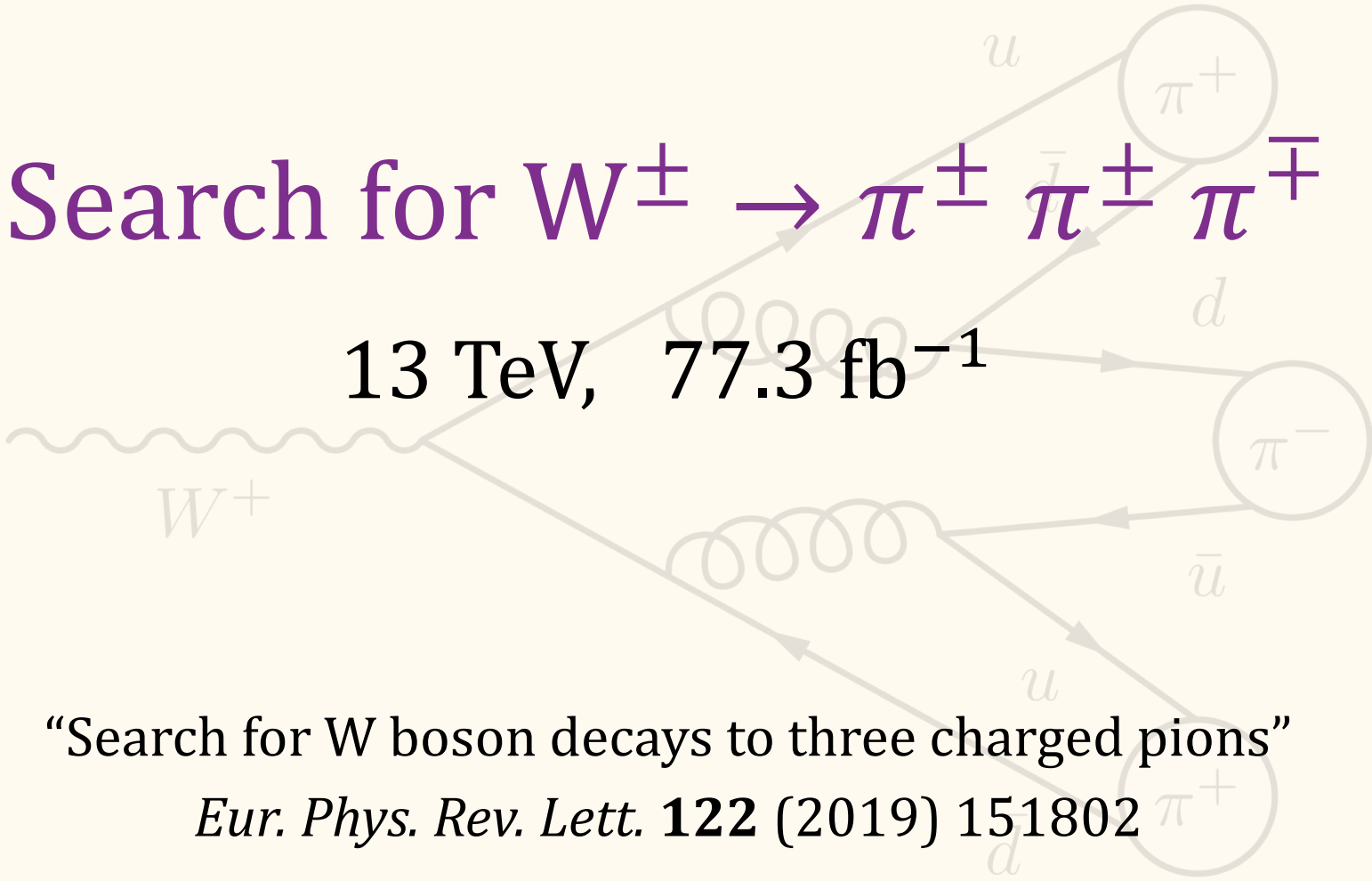
Channel	Polarization	σ (fb) at 95% CL	$\mathcal{B}(Z\ (H) \to J/\psi\gamma)$ at 95% CL	$\frac{\mathcal{B}(Z\ (H)\to J/\psi\gamma)}{\mathcal{B}_{SM}(Z\ (H)\to J/\psi\gamma)}$
$Z \to J/\psi\gamma$	Unpolarized	$4.6\ (5.3^{+2.3}_{-1.6})$	$1.4\ (1.6^{+0.7}_{-0.5}) \times 10^{-6}$	15 (18)
	Transverse	$5.0\ (5.9^{+2.5}_{-1.7})$	$1.5\ (1.7^{+0.7}_{-0.5}) \times 10^{-6}$	16 (19)
	Longitudinal	$3.9\ (4.6^{+2.0}_{-1.4})$	$1.2\ (1.4^{+0.6}_{-0.4}) \times 10^{-6}$	13 (15)

$$\mathcal{B}(Z \to J/\psi\,\gamma) < 1.4 \times 10^{-6}$$


u
π^+
$\bar{d}$
d
π^-
W^+
$\bar{u}$
u
π^+
$\bar{d}$

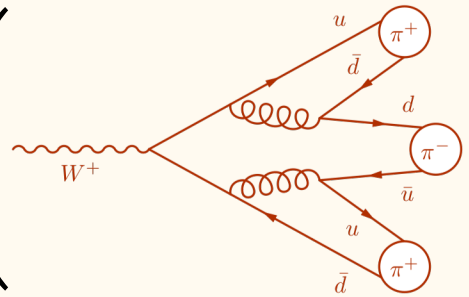
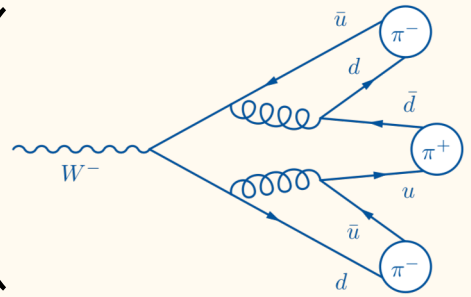
Search for $W^{\pm} \to \pi^{\pm} \pi^{\pm} \pi^{\mp}$

13 TeV, 77.3 fb^{-1}



"Search for W boson decays to three charged pions"

Eur. Phys. Rev. Lett. **122** (2019) 151802

$$\mathcal{B}_{\mathrm{SM}}\left(\ \text{  }\ + \cdots\right) = \mathcal{B}_{\mathrm{SM}}\left(\ \text{  }\ + \cdots\right)$$

$$= \textbf{?}$$

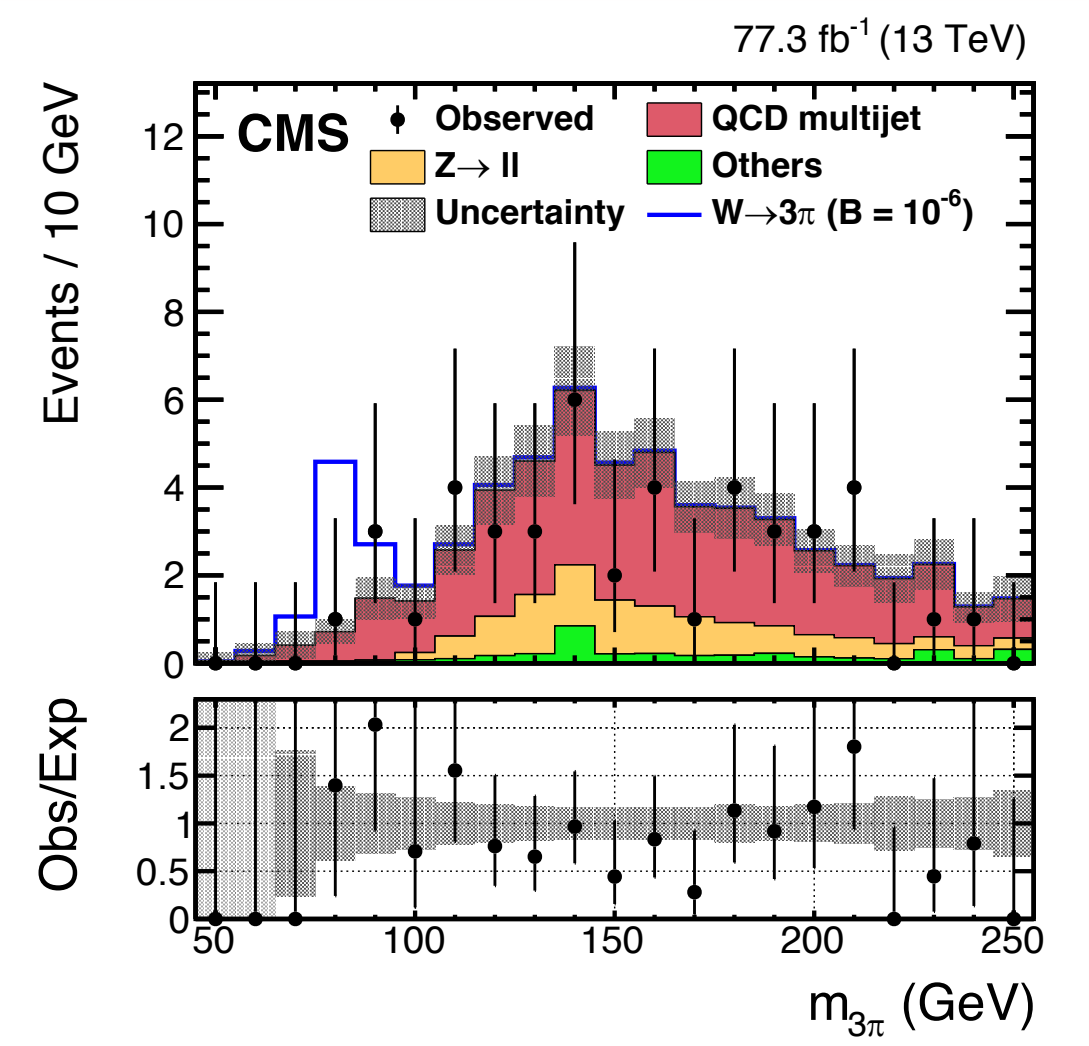
$$\mathcal{O}\left(\mathcal{B}_{\mathrm{SM}}(\mathrm{W} \to 3\pi)\right) \sim \mathcal{O}\left(\mathcal{B}_{\mathrm{SM}}(\mathrm{Z} \to 3\pi)\right)$$

$$\Downarrow$$

$$10^{-8} \lesssim \mathcal{B}_{\mathrm{SM}}(\mathrm{W} \to 3\pi) \lesssim 10^{-5}$$

$$\mathcal{B}(\tau^{\pm} \to \pi^{\pm} \upsilon_{\tau}) = 11\%$$

1. **Trigger on two τ_h** candidates with $p_{\mathrm{T}}^{\tau} > 35$ GeV
2. Reconstruct $\pi^{\pm}$ with **hadrons-plus-strips algorithm**
3. Estimate backgrounds using **three data-driven methods**



1. QCD multijet

   Invert isolation

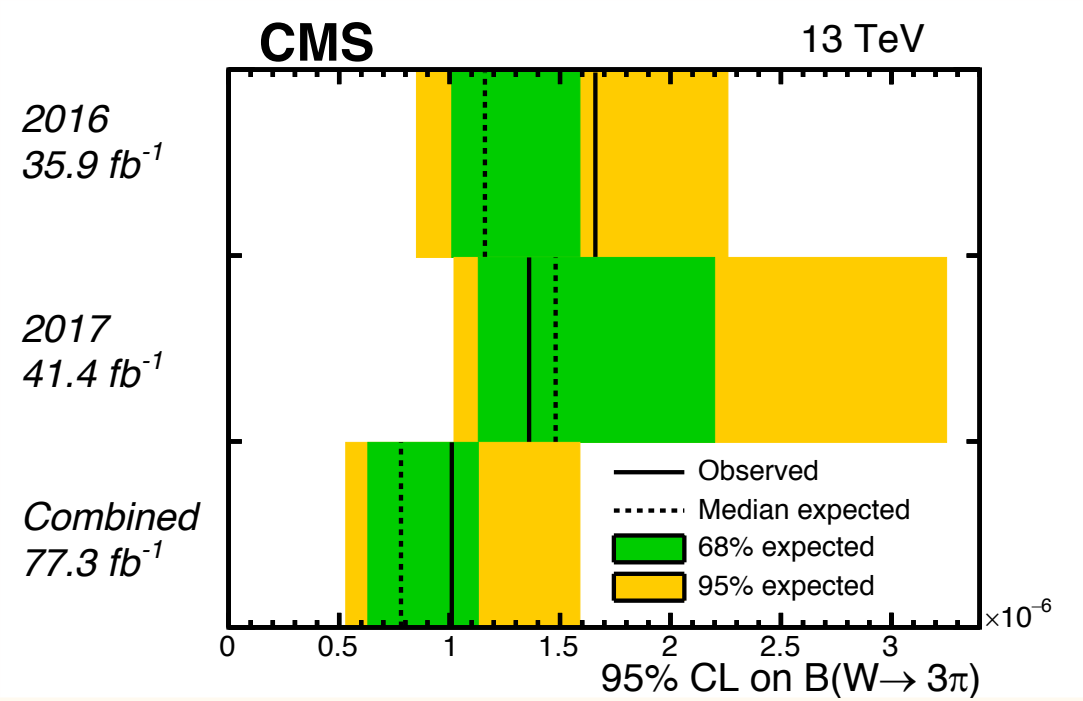
2. $Z \to \ell^+ \ell^-$ (shape)

   Invert $e^{\pm}$ discriminator

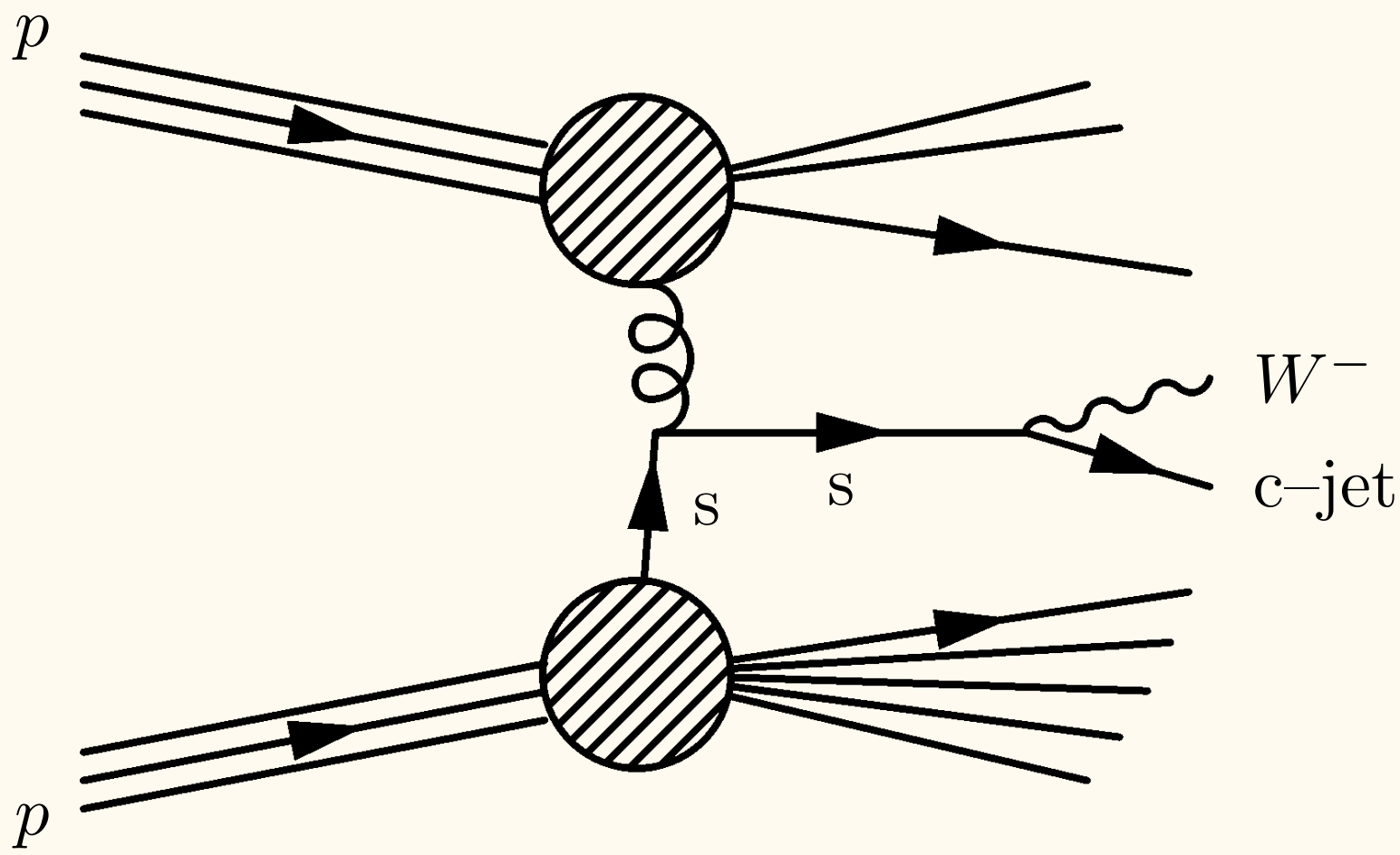
3. $t\bar{t}$ (shape)

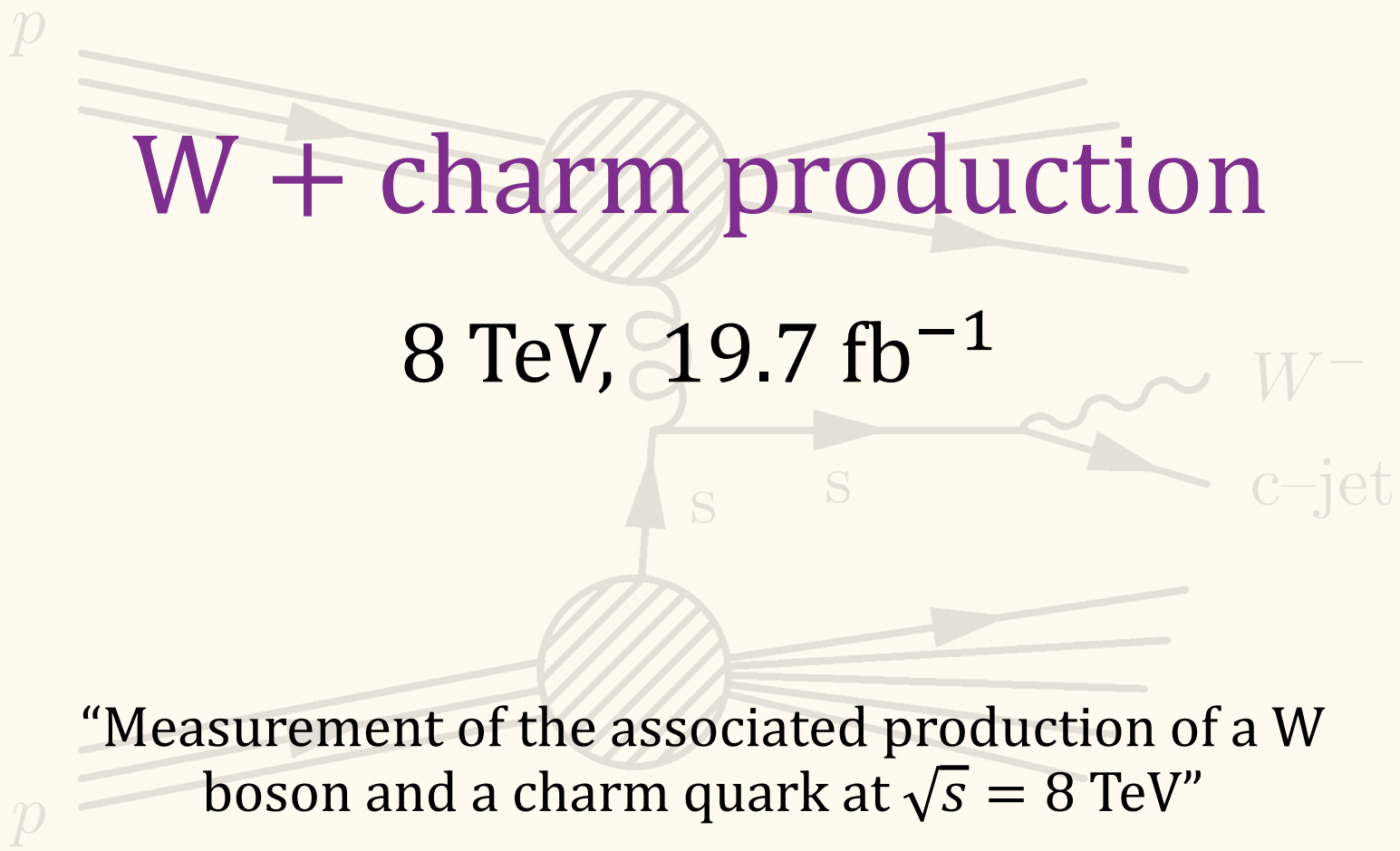
   Identify a b-jet

Source	Uncertainty
Luminosity	2.3–2.5%
Pion identification efficiency	15%
Trigger efficiency	7–17%
Pion energy scale	1.2%
Pion misidentification rate	1%
QCD background (estimation)	30%
$Z \to \ell^+\ell^-$ background (theory)	2%
W cross section (theory)	4%



$$\mathcal{B}(W \to 3\pi) < 1.01 \times 10^{-6}$$


p
p
s
s
W^-
c–jet



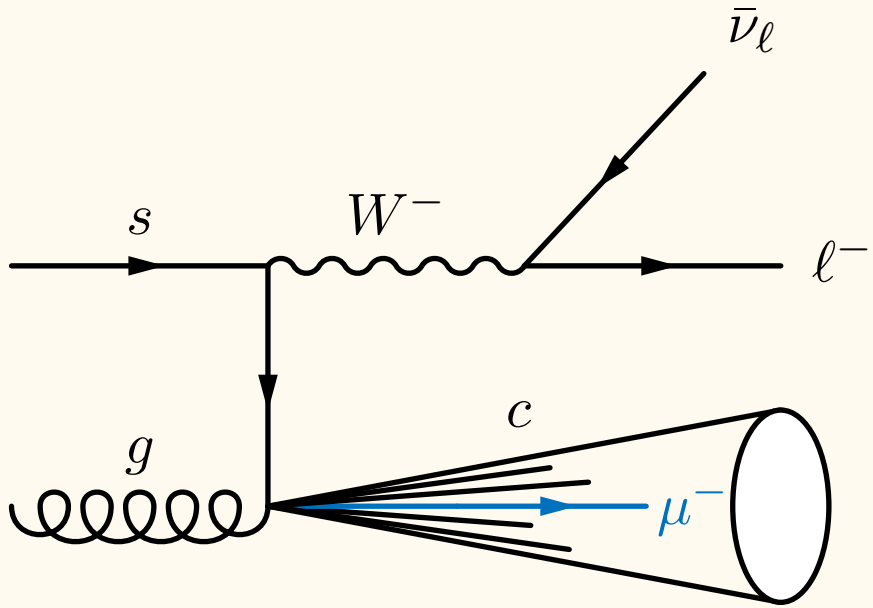
W + charm production

8 TeV, 19.7 fb^{-1}

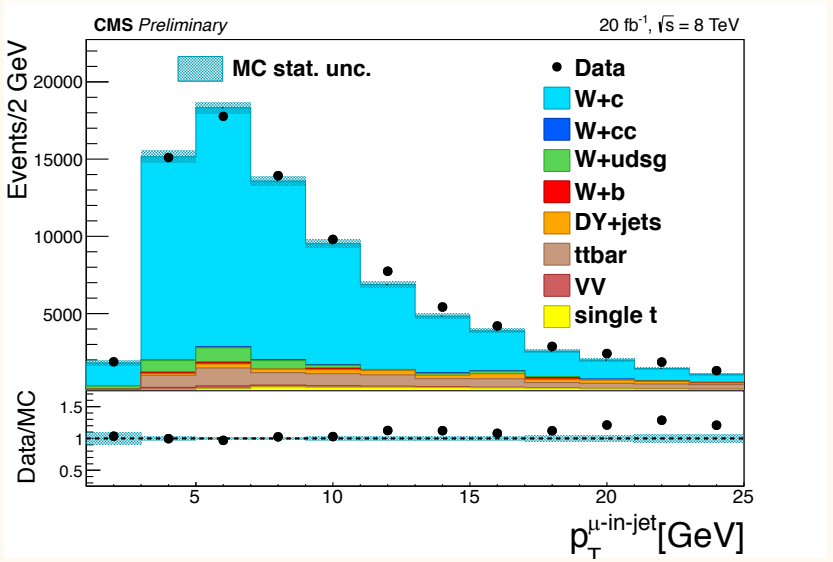
"Measurement of the associated production of a W boson and a charm quark at $\sqrt{s} = 8$ TeV"

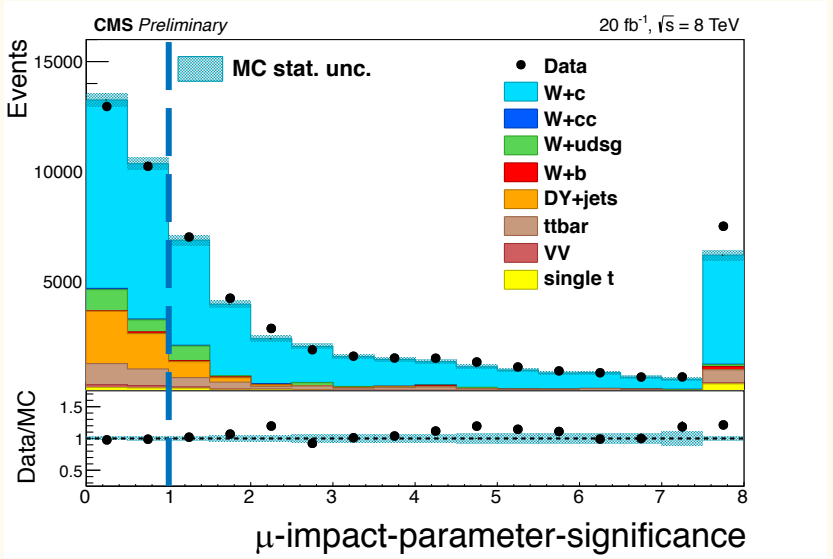
CMS-PAS-SMP-18-013, 2019

Semileptonic channel

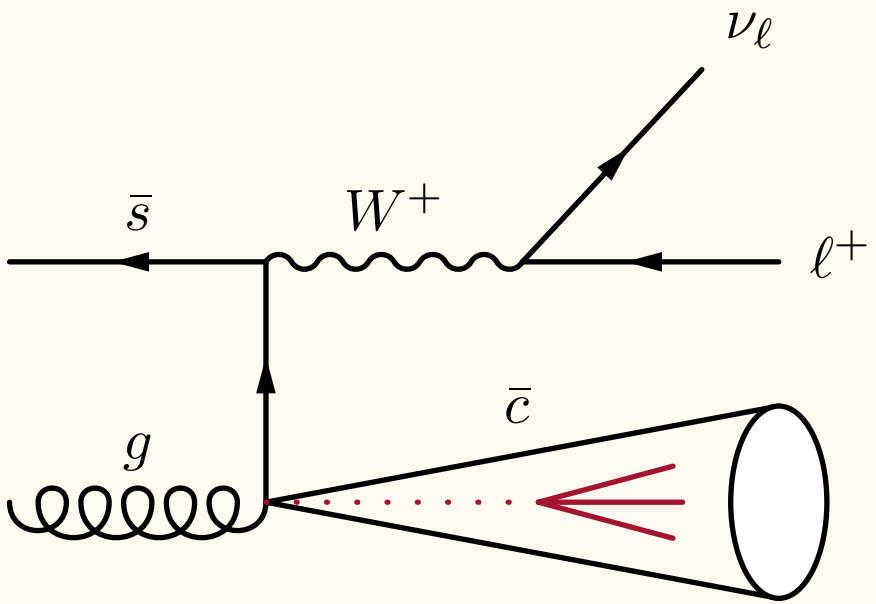


Purity: **~80%**

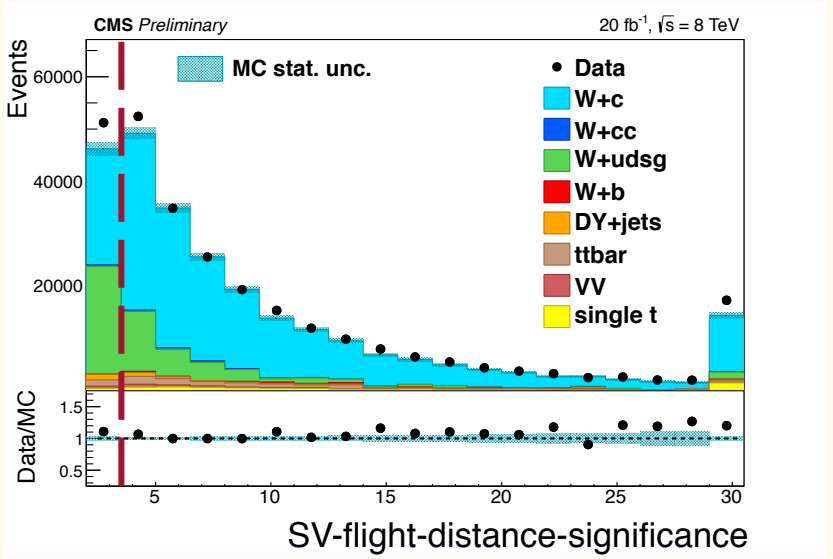


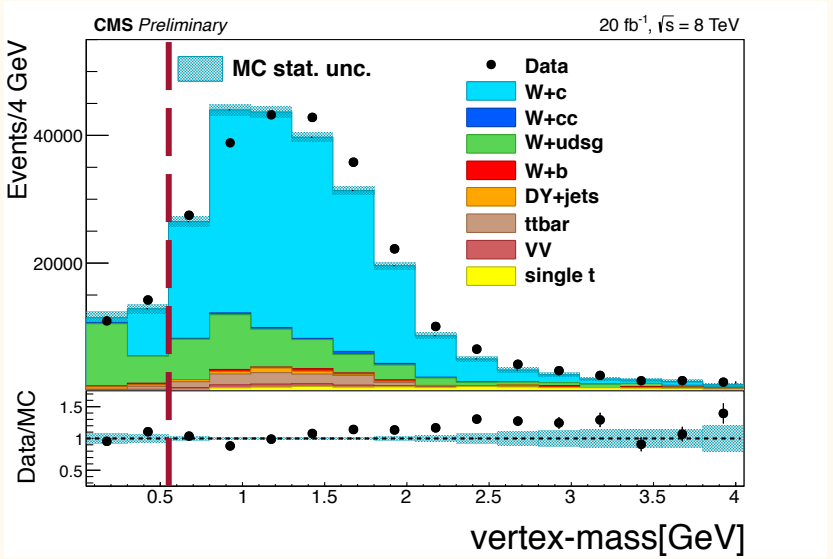


Secondary vertex channel



Purity: **~75%**



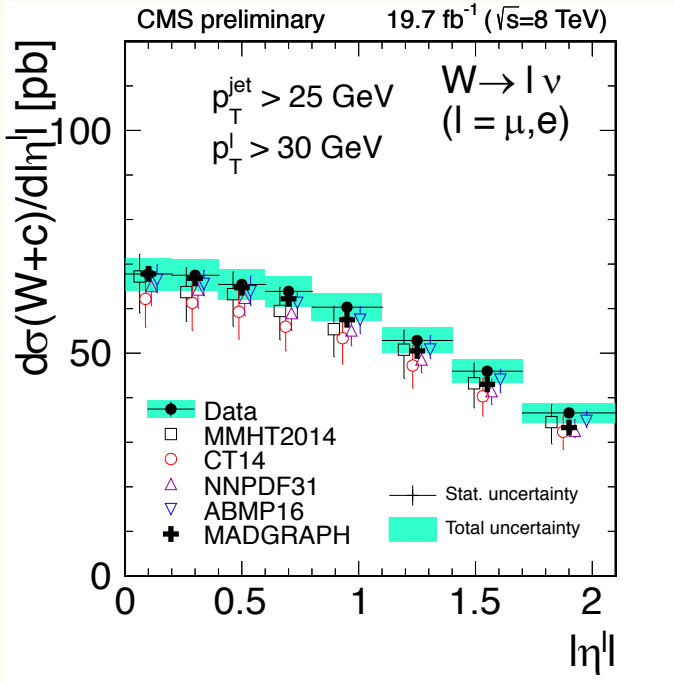


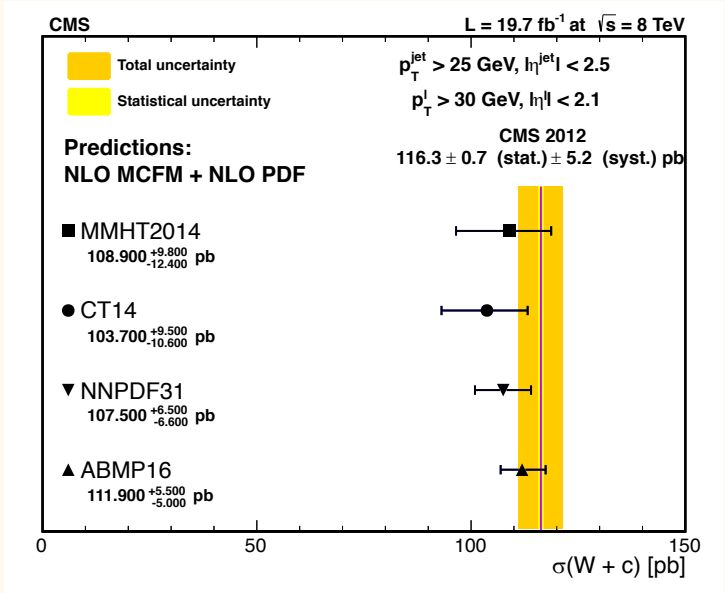
SL channel	
Channel	$N_{sel}(1 - f_{bkg})$
$W \to e\nu$	43128 ± 451
$W \to \mu\nu$	24858 ± 315

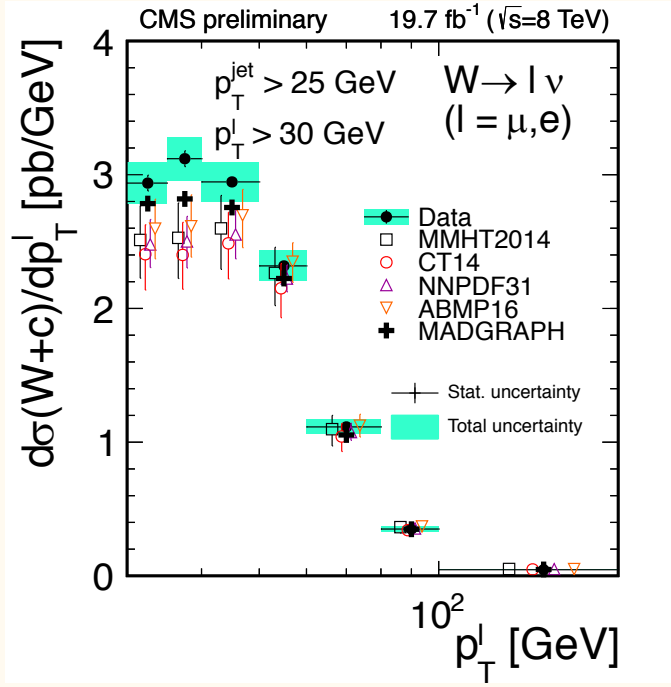
SV channel	
Channel	$N_{sel}(1 - f_{bkg})$
$W \to e\nu$	85555 ± 943
$W \to \mu\nu$	96782 ± 939

Source	Uncertainty [%]
Lepton efficiency	0.7
Jet energy correction	0.9
Pileup	0.6
SL μ in jet efficiency	0.8
SV charge determination	1.0
Fragmentation and branching ratio	1.7
SV efficiency	2.2
Background subtraction	0.6
Monte Carlo statistics	0.7
PDF	1.0
Luminosity	2.6
Total	4.5

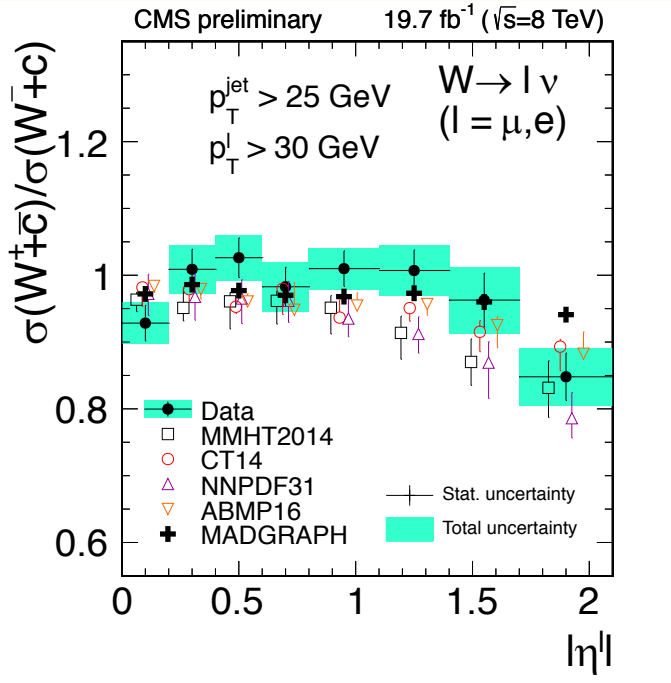
$$\sigma(\mathrm{W} + \mathrm{c} + \mathrm{X})\,\mathcal{B}(W \to \ell\upsilon) = 116.3 \pm 0.7(\mathrm{stat}) \pm 5.2(\mathrm{syst})\ \mathrm{pb}$$

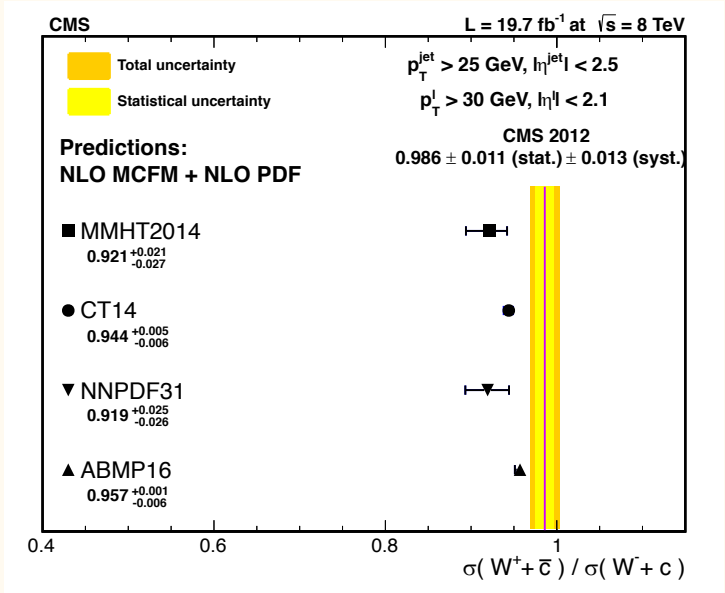


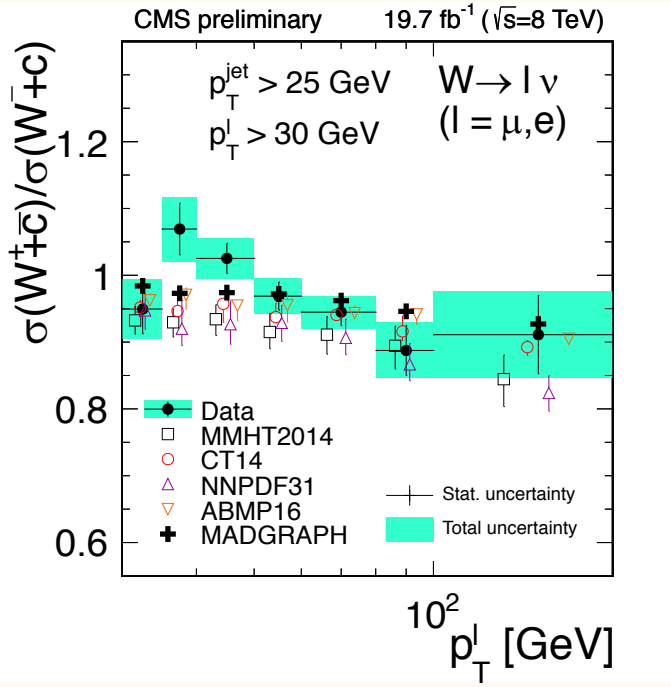




$$\frac{\sigma(W^+ + \bar{c})}{\sigma(W^- + c)} = 0.986 \pm 0.011(stat) \pm 0.013(syst)$$







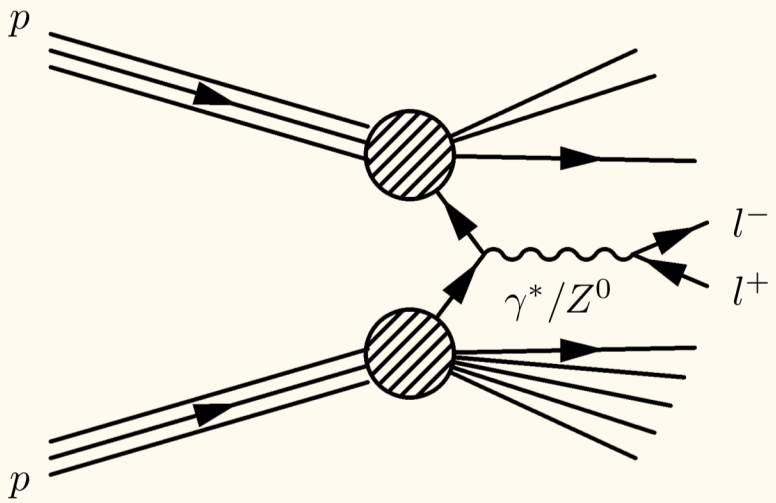
p
p
l^-
l^+
γ^*/Z^0

γ
c
c
$Z(H)$
$\bar{c}$
μ^-
J/ψ
μ^+

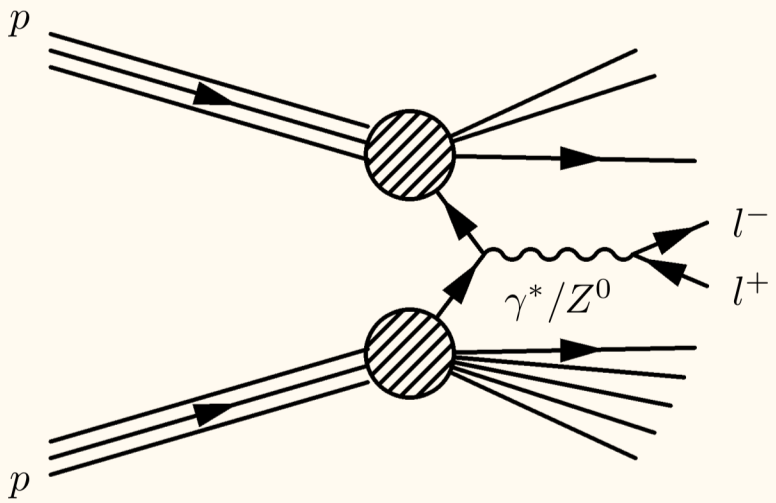
Summary

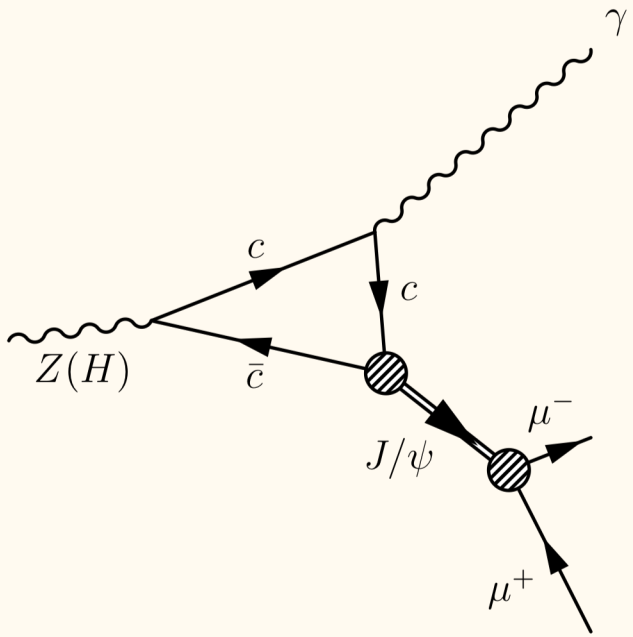
u
π^+
$\bar{d}$
d
W^+
π^-
$\bar{u}$
u
π^+
$\bar{d}$

p
W^-
s
s
c–jet
p



Summary


p
p
l^-
l^+
γ^*/Z^0

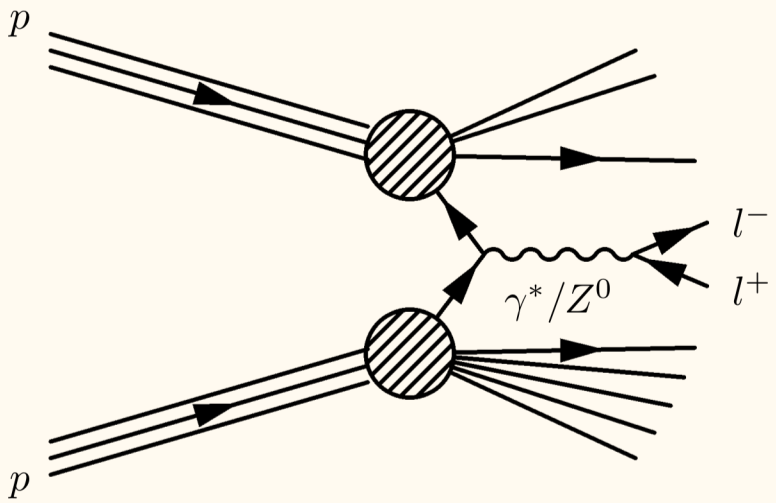

γ
c
c
$Z(H)$
$\bar{c}$
μ^-
J/ψ
μ^+

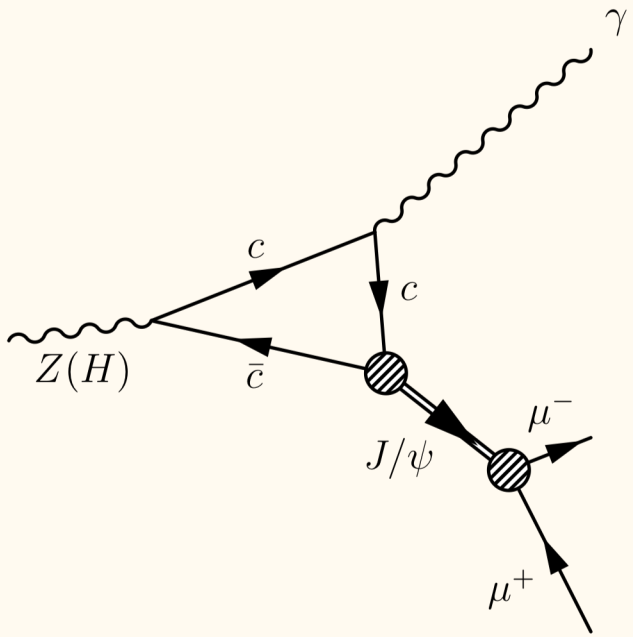
Summary

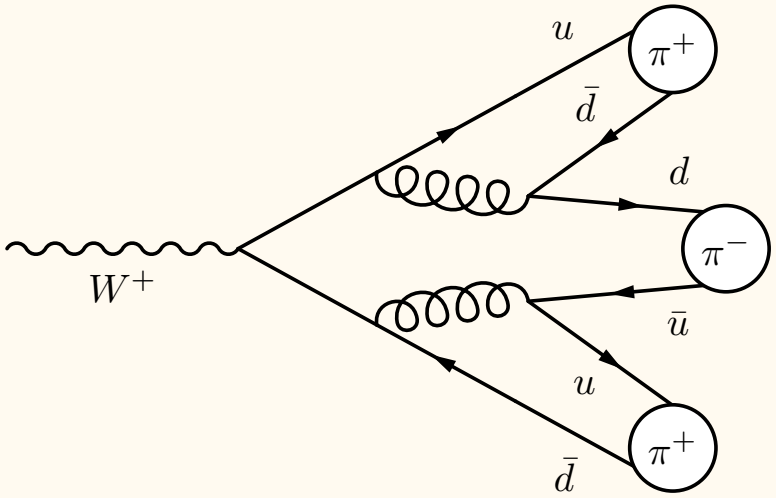
u
π^+
$\bar{d}$
d
W^+
π^-
$\bar{u}$
u
π^+
$\bar{d}$

p
W^-
s
s
c–jet
p

Summary

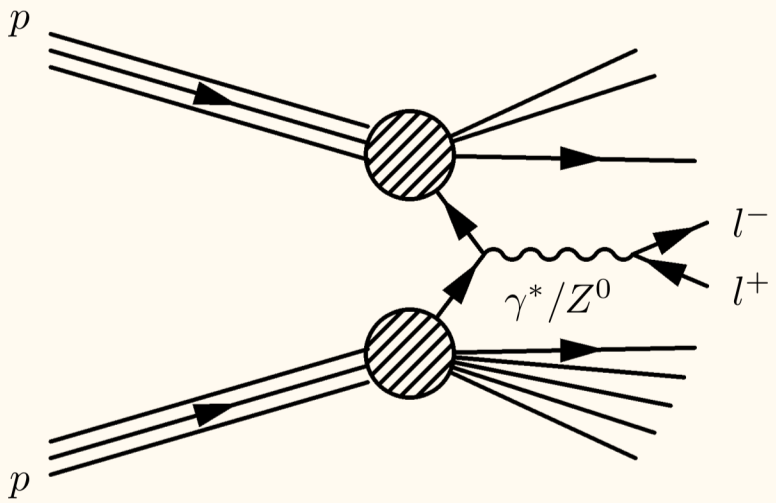

p
p
l^-
l^+
γ^*/Z^0

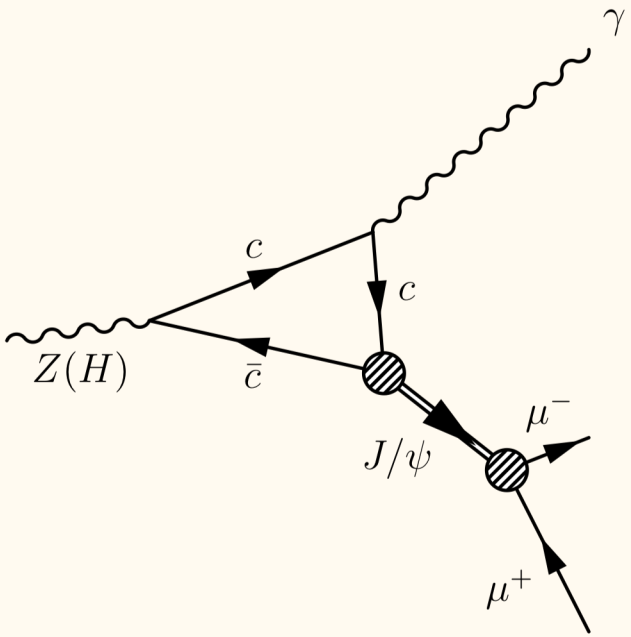

γ
c
c
$Z(H)$
$\bar{c}$
μ^-
J/ψ
μ^+

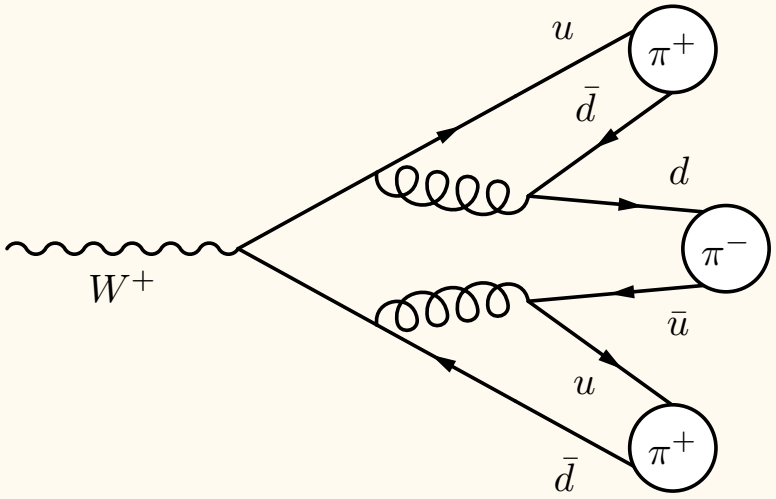

u
π^+
$\bar{d}$
d
π^-
W^+
$\bar{u}$
u
π^+
$\bar{d}$

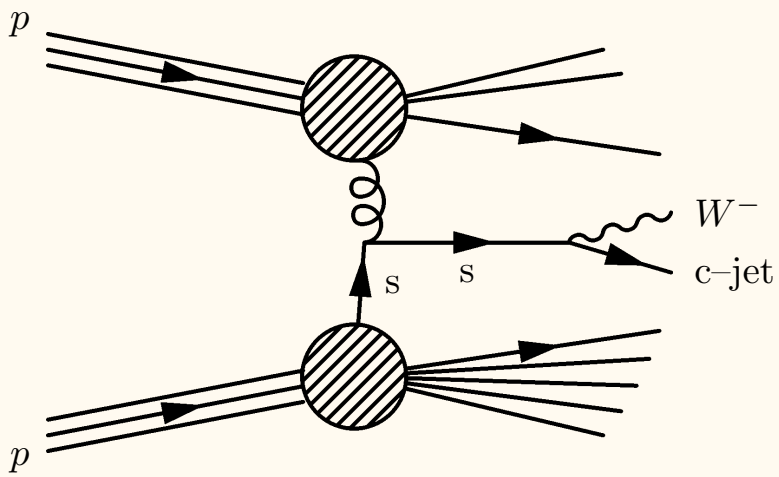
p
W^-
s
s
c–jet
p

Summary


p
p
l^-
l^+
γ^*/Z^0


γ
$Z(H)$
c
$\bar{c}$
c
J/ψ
μ^-
μ^+


W^+
u
$\bar{d}$
π^+
d
π^-
$\bar{u}$
u
$\bar{d}$
π^+


p
p
s
s
W^-
c–jet

References

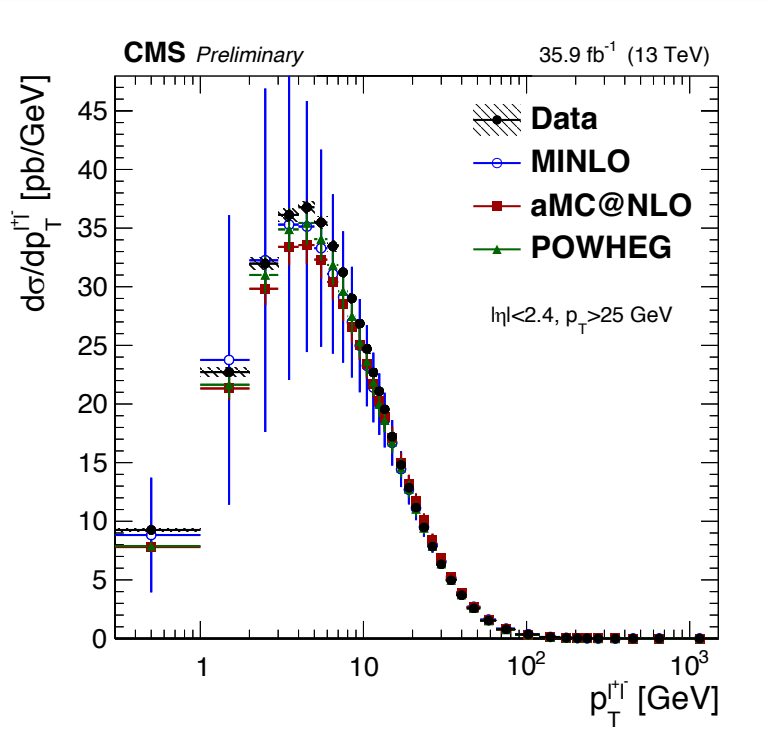
1. CMS Collaboration, "Measurements of differential Z boson production cross sections in pp collisions with CMS at $\sqrt{s} = 13$ TeV," CMS Physics Analysis Summary CMS-PAS-SMP-17-010, 2019.
2. CMS Collaboration, "Search for rare decays of Z and Higgs bosons to J/ψ and a photon in proton-proton collisions at $\sqrt{s} = 13$ TeV," *Eur. Phys. J. C* **79** (2019) 94 [arXiv:1810.10056].
3. CMS Collaboration, "Search for W boson decays to three charged pions," *Eur. Phys. Rev. Lett.* **122** (2019) 151802 [arXiv:1901.11201].
4. CMS Collaboration, "Measurement of the associated production of a W boson and a charm quark at $\sqrt{s} = 8$ TeV," CMS Physics Analysis Summary CMS-PAS-SMP-18-013, 2019.

Feynman diagrams for $Z \to \ell^+\ell^-$ and W + charm: Universität Zürich Physik-Institut
Feynman diagram and systematics table for $W \to 3\pi$; diagrams for W + charm: J. L. Rainbolt

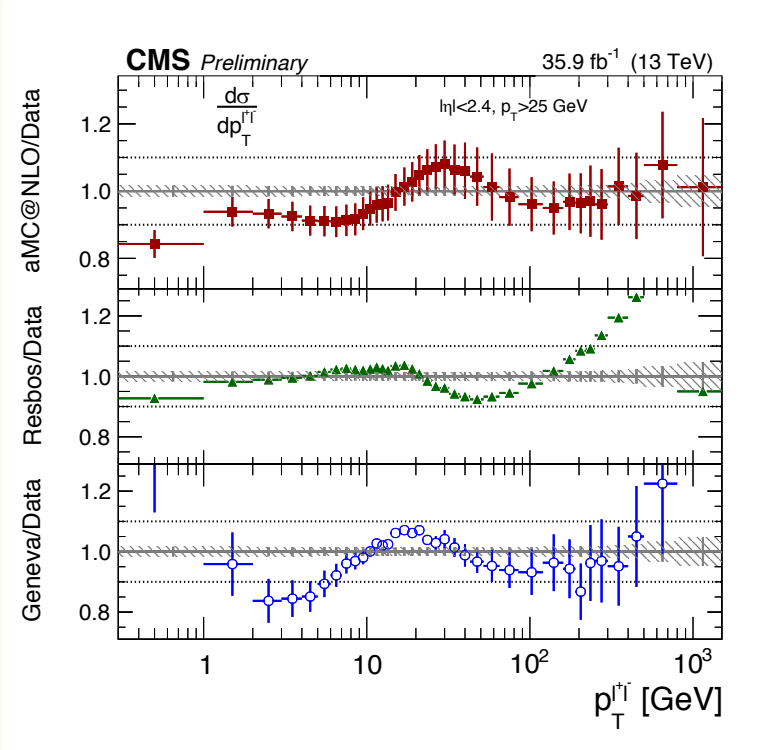
Backup slides

Differential $Z \to \ell^+\ell^-$ cross sections

Absolute

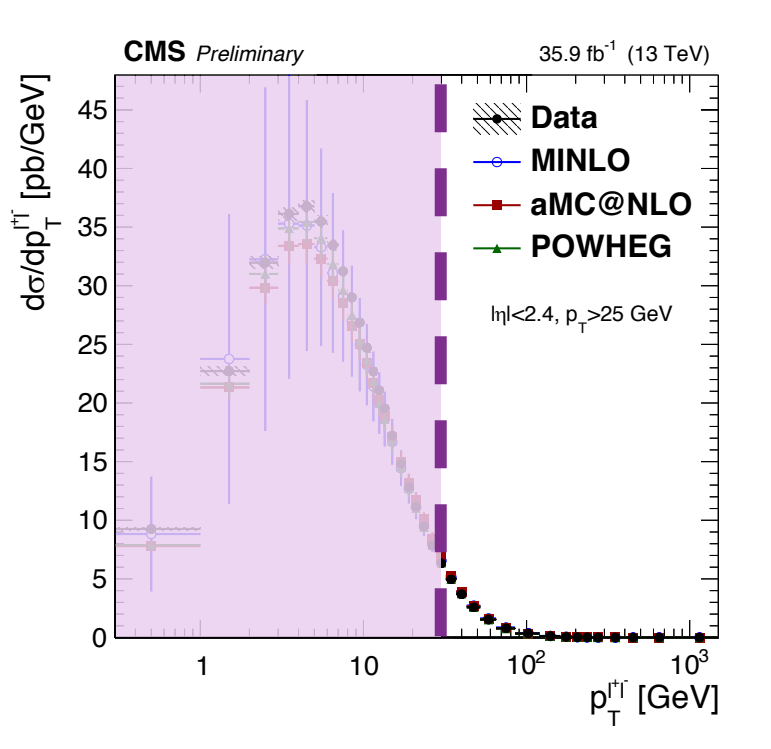


Resummed

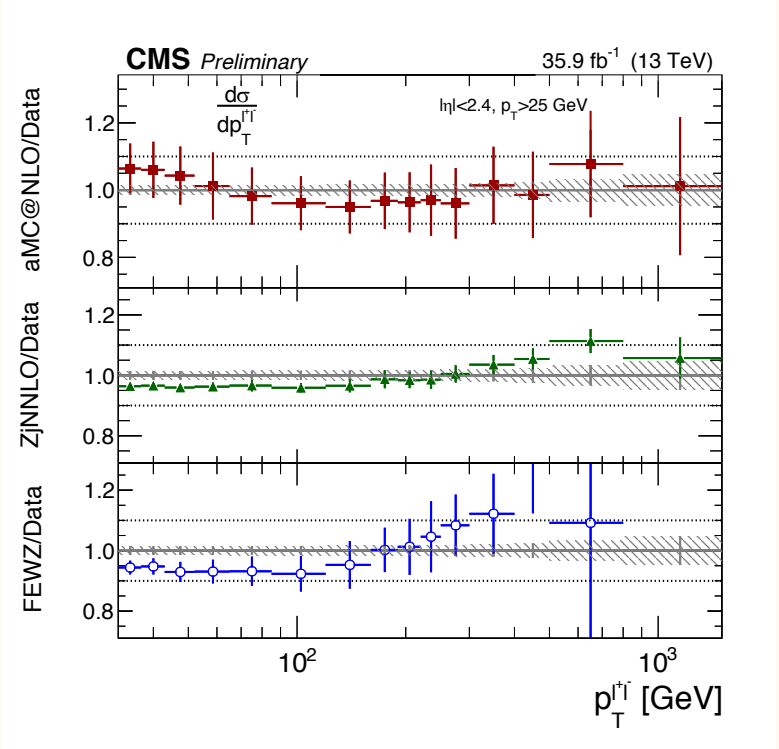


Differential $Z \to \ell^+\ell^-$ cross sections

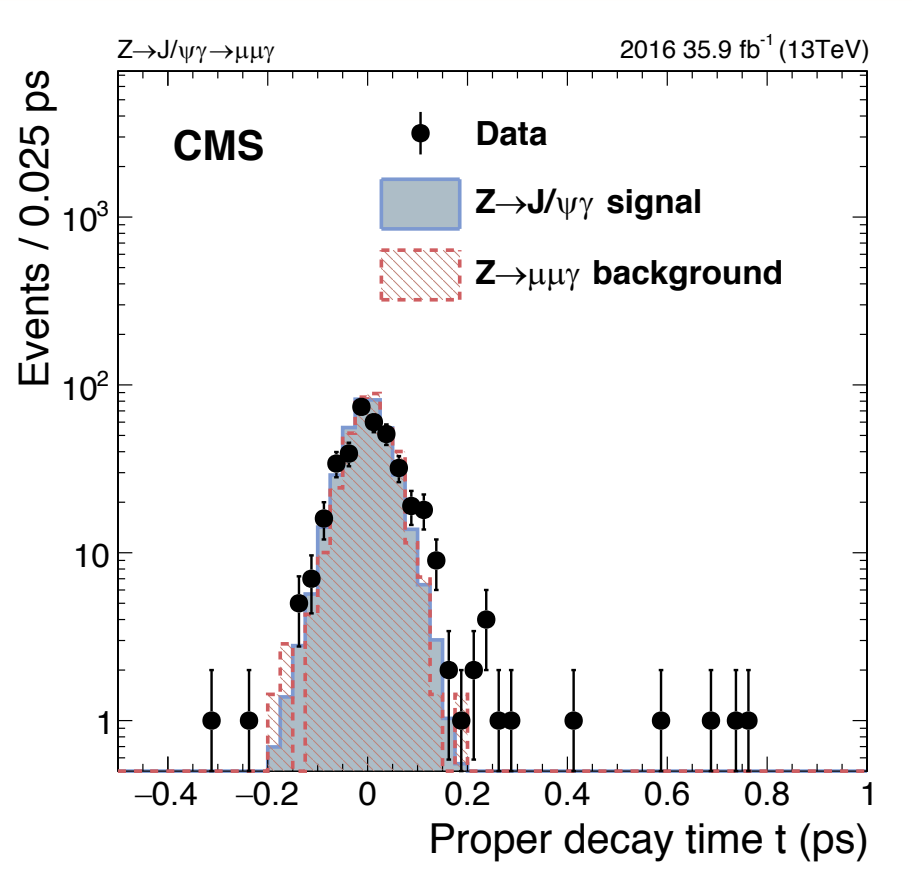
$p_T > 30$ GeV



Fixed order



Search for Z → J/ψ γ



W + charm production

SL channel	W + c	W + $c\bar{c}$	W + udsg	W + b	DY	$t\bar{t}$	single top	VV
W $\to$ eν	82.6%	0.2%	4.6%	0.4%	0.5%	8.4%	2.3%	1.0%
W $\to \mu\nu$	77.7%	0.4%	3.2%	0.6%	6.9%	7.8%	2.5%	0.9%

SV channel	W + c	W + $c\bar{c}$	W + udsg	W + b	DY	$t\bar{t}$	single top	VV
W $\to$ eν	73.8%	0.5%	15.1%	0.7%	1.9%	3.8%	3.2%	1.0%
W $\to \mu\nu$	74.5%	0.7%	16.0%	0.5%	0.6%	3.2%	3.5%	1.0%

SL channel			
Channel	$N_{sel}(1 - f_{bkg})$	$\mathcal{C}(\%)$	σ(W + c) [pb]
W $\to$ eν	43128 ± 451	1.916 ± 0.032	$114.3 \pm 1.2 \pm 8.1$
W $\to \mu\nu$	24858 ± 315	1.087 ± 0.024	$116.1 \pm 1.5 \pm 8.4$
SV channel			
Channel	$N_{sel}(1 - f_{bkg})$	$\mathcal{C}(\%)$	σ(W + c) [pb]
W $\to$ eν	85555 ± 943	3.681 ± 0.045	$118.0 \pm 1.3 \pm 5.9$
W $\to \mu\nu$	96782 ± 939	4.230 ± 0.047	$116.1 \pm 1.1 \pm 5.8$

W + charm production

SL channel			
Channel	$\sigma(W^+ + \bar{c})$ [pb]	$\sigma(W^- + c)$ [pb]	$\sigma(W^+ + \bar{c})/\sigma(W^- + c)$
$W \to e\nu$	$56.5 \pm 0.9 \pm 4.1$	$57.9 \pm 0.8 \pm 4.3$	$0.976 \pm 0.020 \pm 0.025$
$W \to \mu\nu$	$56.9 \pm 1.1 \pm 4.3$	$59.1 \pm 1.0 \pm 4.5$	$0.963 \pm 0.025 \pm 0.030$
SV channel			
Channel	$\sigma(W^+ + \bar{c})$ [pb]	$\sigma(W^- + c)$ [pb]	$\sigma(W^+ + \bar{c})/\sigma(W^- + c)$
$W \to e\nu$	$58.6 \pm 0.9 \pm 3.0$	$59.4 \pm 0.9 \pm 3.1$	$0.986 \pm 0.022 \pm 0.019$
$W \to \mu\nu$	$57.7 \pm 0.8 \pm 3.0$	$57.3 \pm 0.8 \pm 2.9$	$1.007 \pm 0.020 \pm 0.019$