nPDF studies with electroweak bosons in pPb at 8.16 TeV with the CMS experiment

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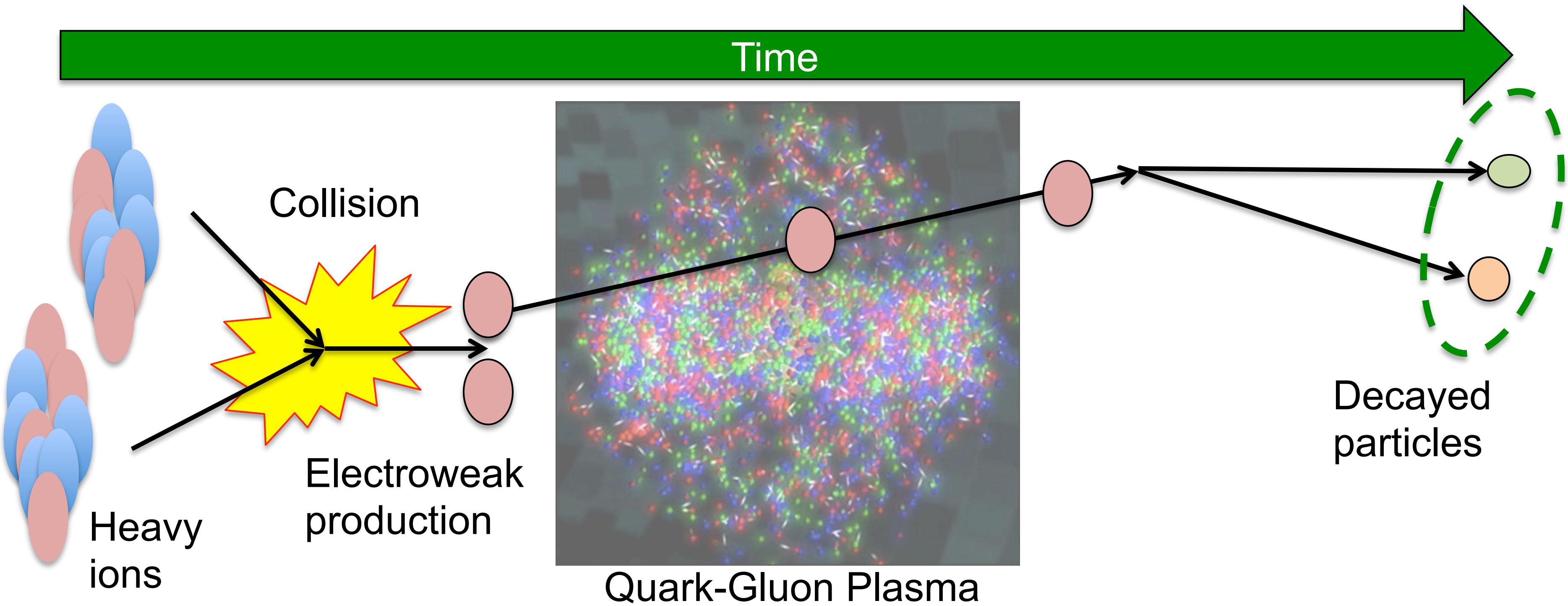
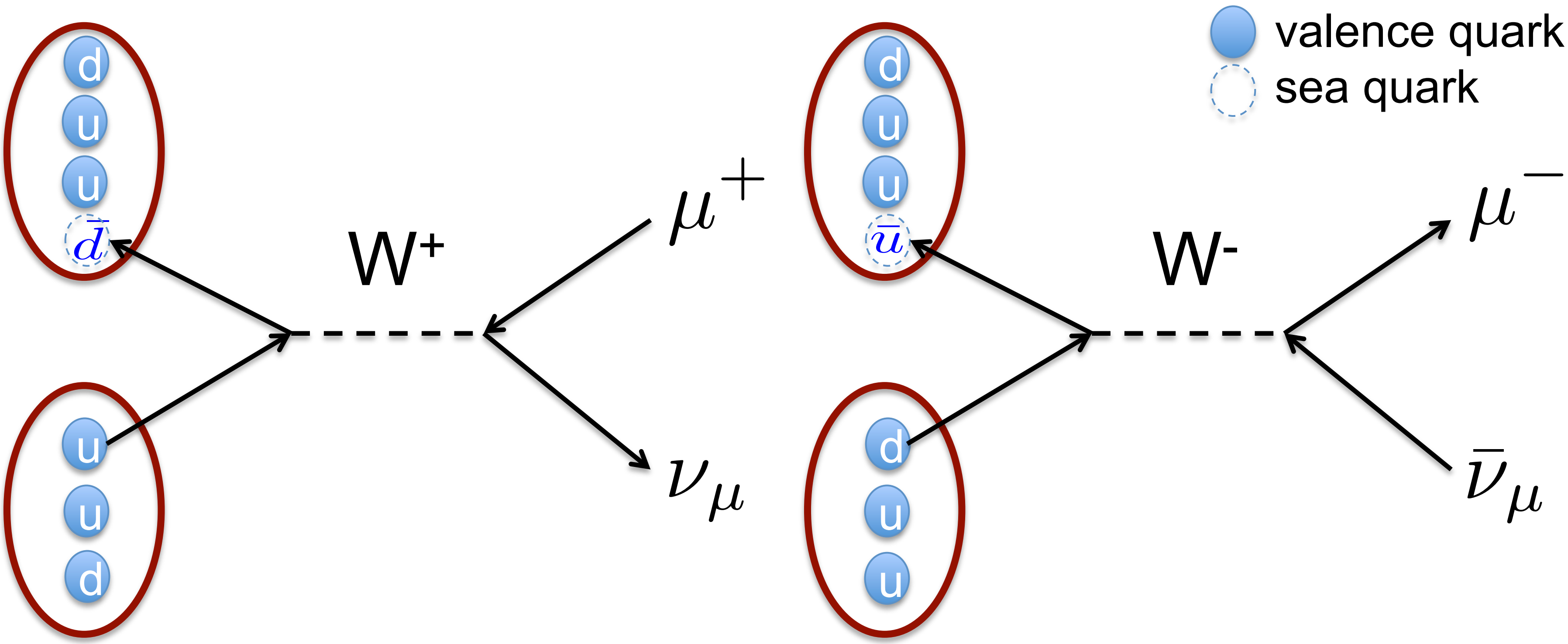
Motivation of electroweak analysis

- **Electroweak bosons are created in the early stages of the heavy ion collisions**
- **No interaction with QCD matter, keep the information of the initial condition**
  - good probe for nuclear parton distribution functions (nPDFs)



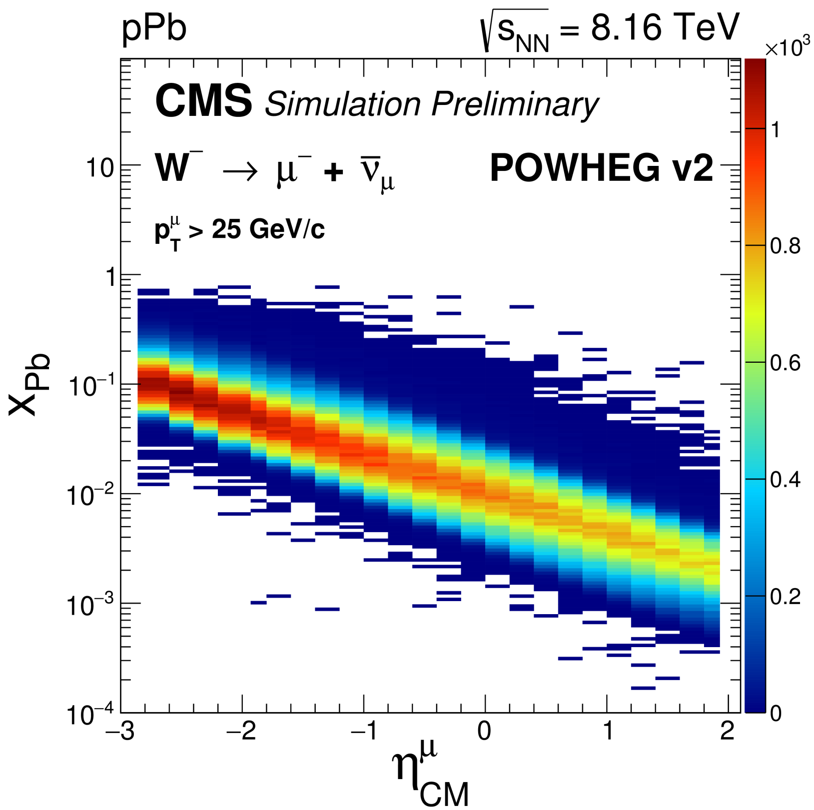
Production and decay of W boson

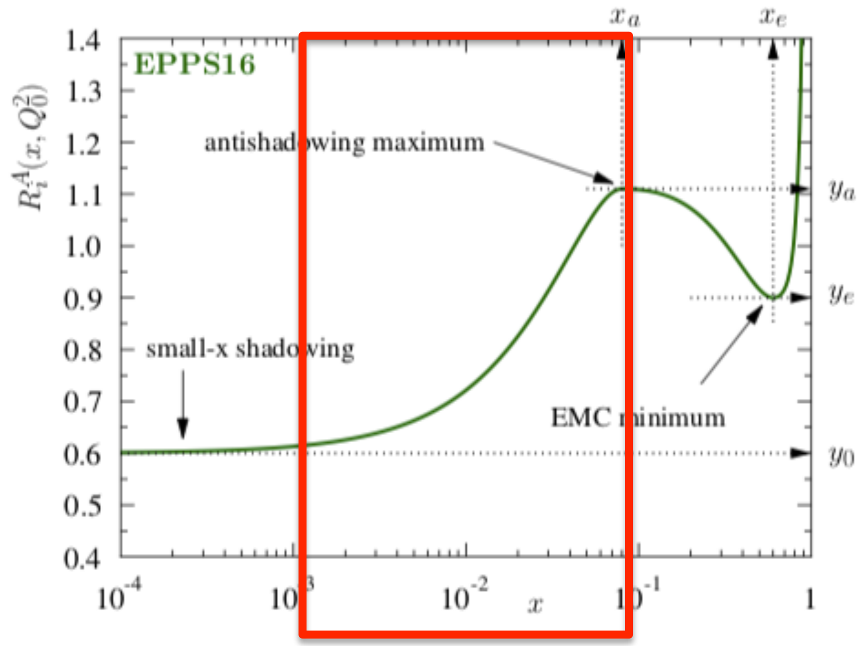


- **one valence quark + one anti-quark from sea quark -> production of W boson**
- **W boson is sensitive to isospin effects**
  - *p*+Pb ⬄ [0.67*u*+0.33*d*] + [0.46*u*+0.54*d*]

Sasha Milov,
HP18 student lecture

x range by W boson





x range by W boson
in 8.16 TeV pPb

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- **W production in pPb at 8.16 TeV probe the quark nPDFs in $10^{-3} < x < 10^{-1}$ at high Q^2**

CMS Event selection

- **Dataset**

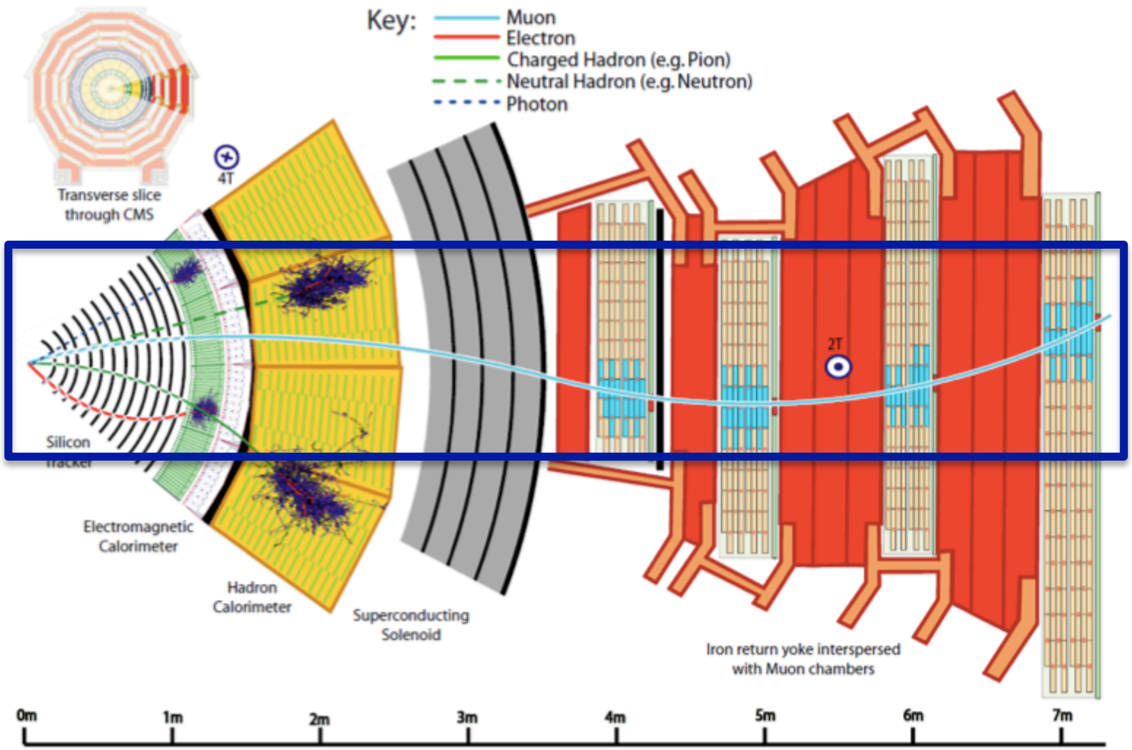
	Year	Collision energy	Integrated luminosity
pPb	2016	8.16 TeV	173.4 nb^{-1}

  - Integrated luminosity is about 5 times larger than previous 5.02 TeV pPb dataset

- **Event selection**
  - Trigger : at least one muon candidate of p_T > 12 GeV/c
  - Veto Z->$\mu^+\mu^-$: reject events with $\mu^+\mu^-$ pairs, each muon's p_T>15 GeV

Muon reconstruction and selection (1)

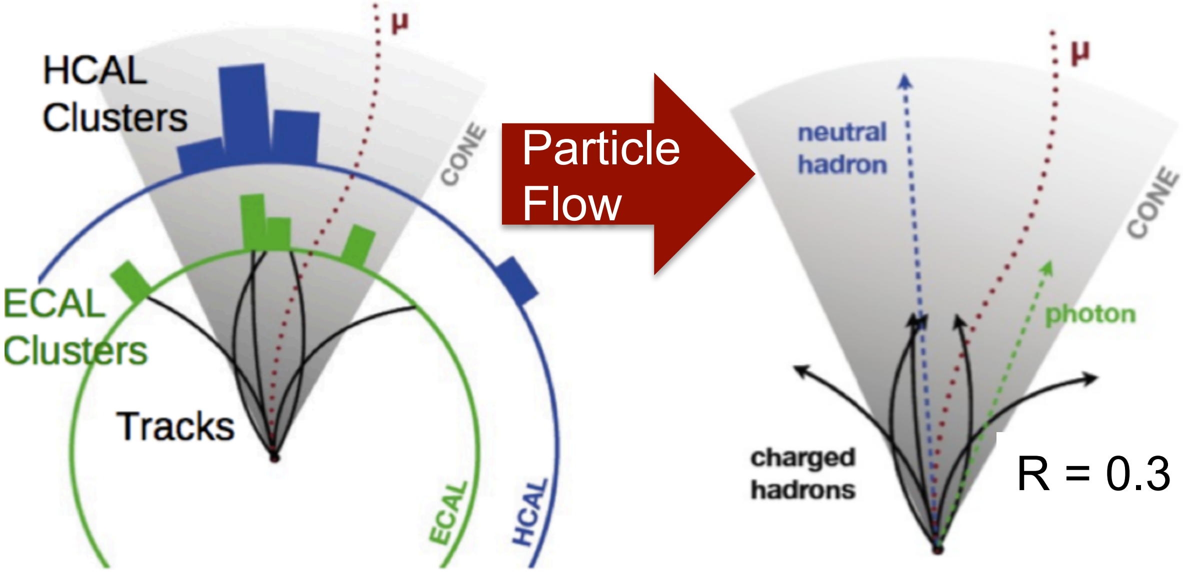
- Muon p_T > 25 GeV/c with $|\eta_{lab}(\mu)| < 2.4$
- Combines the information from the muon system and inner tracker



- Quality cuts applied such as number of hits in pixel detector

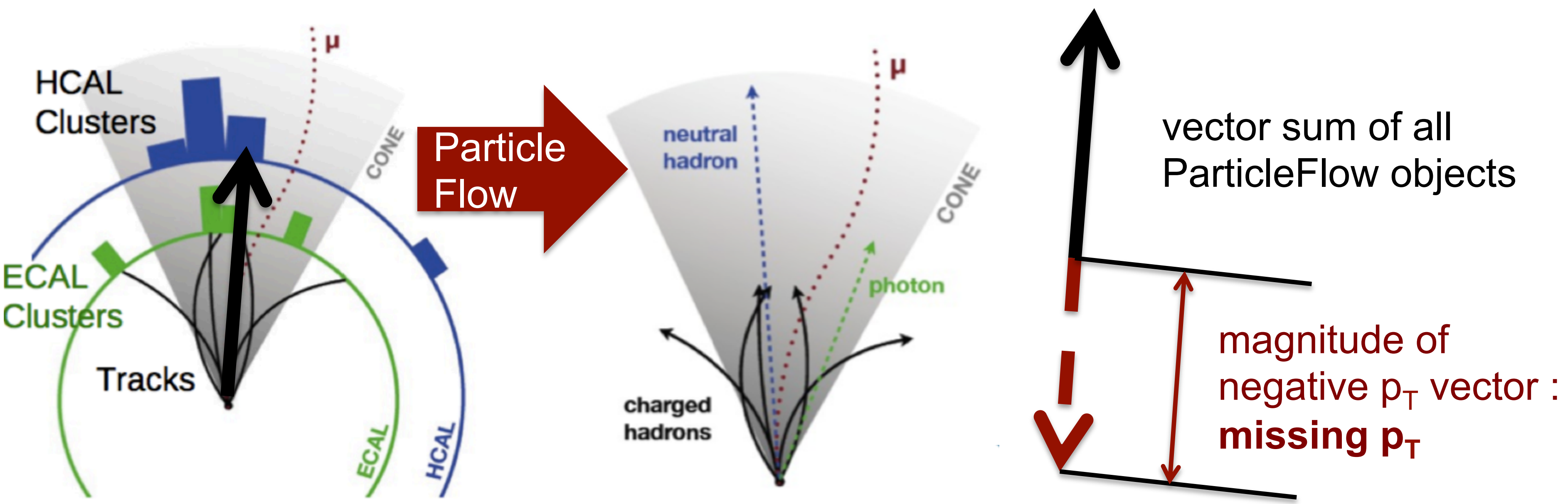
Muon reconstruction and selection (2)

- **Muon isolation from nearby hadronic activity is required to reduce the jet background**
  - Use the charged hadrons, neutral hadrons and photons reconstructed by calorimeters (ECAL, HCAL) - ParticleFlow
  - Calculate sum of p_T of those(S) in a cone of radius R = 0.3
  - If S / muon's p_T < 0.15, considered as isolated muons



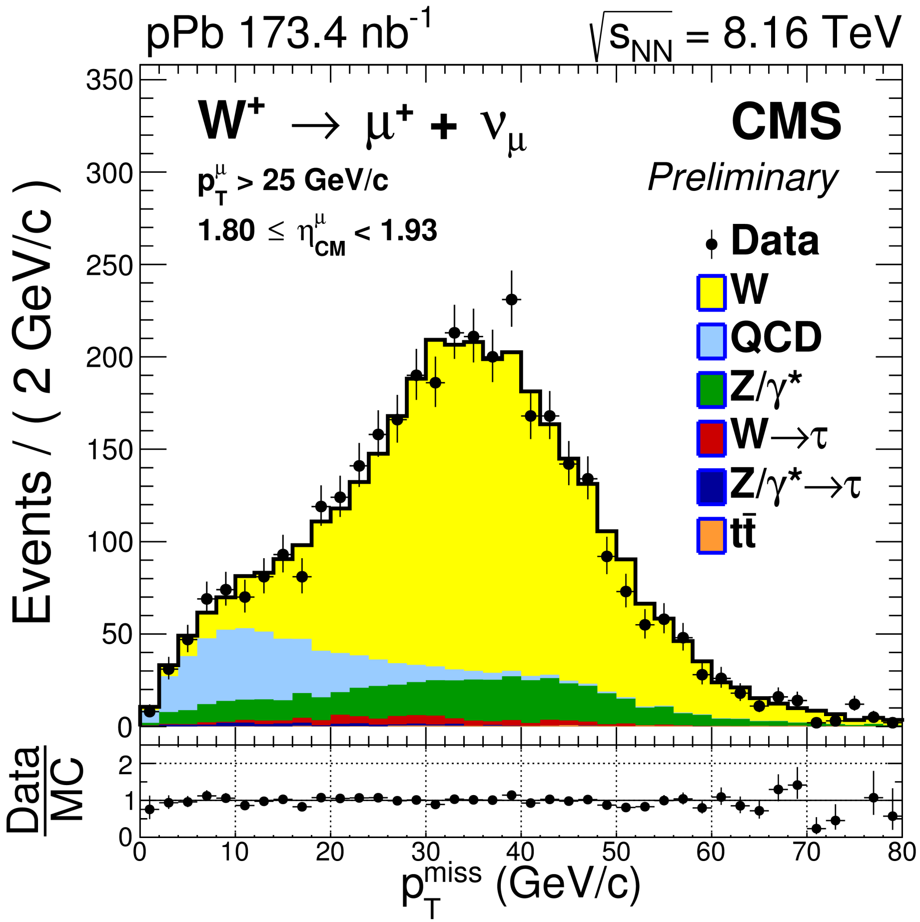
Missing p_T distributions (1)

- Neutrino (from W decay) does not interact with the detector
- Neutrino's presence is inferred from the overall momentum imbalance in the transverse plane (missing p_T)
- missing p_T : magnitude of the negative p_T vector of all reconstructed ParticleFlow objects in an event



Missing p_T distributions (2)

- **W yields extracted from fits of the missing p_T distribution in 24 bins of muon η_{CM}**



- Except QCD multijet backgrounds, all the signal and backgrounds are simulated from MC template
  - pPb NLO POWHEG v2 with CT14+EPPS16 nPDF
- QCD multijet background is derived from data

Summary of the used nPDFs

	EPPS16	EPS09	nCTEQ15	DSSZ12	HKN07	KA15
FT e-DIS	✓	✓	✓	✓	✓	✓
FT ν-DIS	✓	✗	✗#	✓	✗	✗
FT Drell-Yan	✓	✓	✓	✓	✓	✓
RHIC π^0	✓	✓	✓	✗	✗	✗
LHC W/Z	✓	✗	✗*	✗	✗	✗
LHC dijet	✓	✗	✗	✗	✗	✗
QCD order	NLO	LO & NLO	NLO	NLO	LO & NLO	NNLO
Kinematic cuts	$Q > 1.3$GeV	$Q > 1.3$GeV	$Q > 2$GeV $W > 3.5$GeV	$Q > 1$GeV	$Q > 1$GeV	$Q > 1$GeV
No data points	1811	929	740	1579	1241	1479
No free param.	20	15	16	25	12	16
χ^2/dof	1.00	0.79	0.81	0.99	1.21	1.15
Error analysis	Hessian	Hessian	Hessian	Hessian	Hessian	Hessian
Tolerance $\Delta\chi^2$	52	50	35	30	13.7	1?
Proton baseline	CT14NLO	CTEQ6.1	CTEQ6.1-like	MSTW2008	MRST1998	JR09
Heavy-quark eff.	✓	✗	✓	✓	✗	✗
Flavour sep.	✓	✗	✓ (val.)	✗	✗	✗
Reference	[1612.05741]	[0902.4154]	[1509.00792]	[1112.6324]	[0709.3038]	[1601.00939]

In a separate dedicated analysis [PRL106, 122301, (2011), 1012.0286; PRD80, 094004, (2009), 0907.2357]

* See a reweighting study [EPJC77, 488 (2017), 1610.02925]

- **EPPS16 use the LHC data**

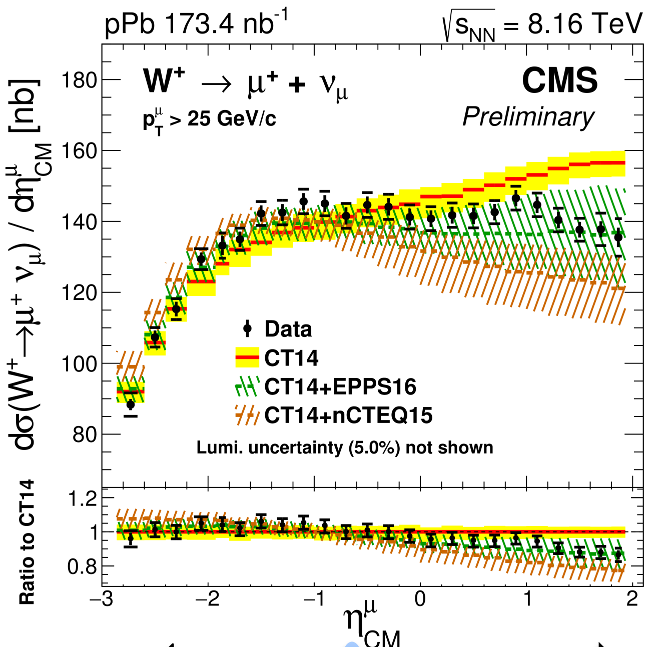
Alexander Kusina,
HP18 student lecture

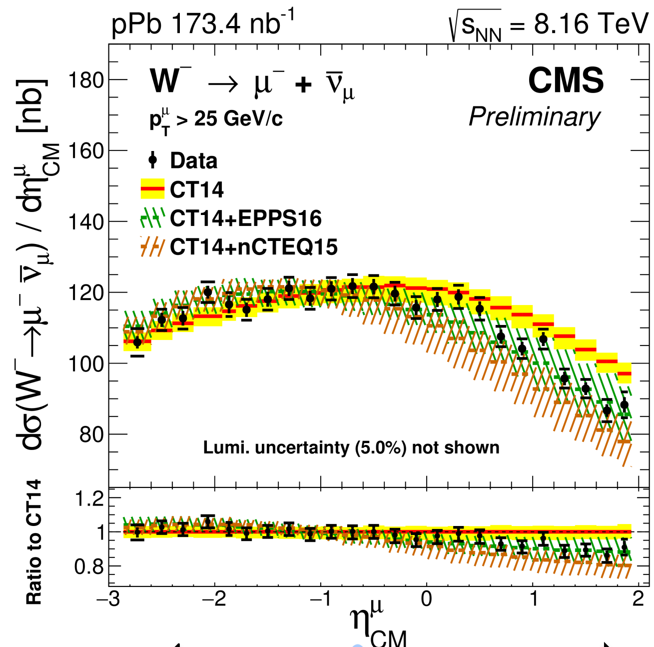
Differential cross sections

$$\frac{d\sigma(W \rightarrow \mu\nu_{\mu})}{d\eta^{\mu}_{\mathrm{CM}}}(\eta^{\mu}_{\mathrm{CM}}) = \frac{N_{\mu}(\eta^{\mu}_{\mathrm{CM}})}{\mathcal{L}\Delta\eta^{\mu}_{\mathrm{CM}}}$$

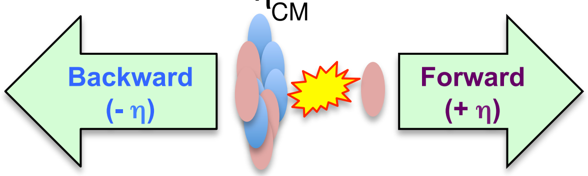
- CT14 (only proton PDF)
- CT14+EPPS16 (nPDF) w/ LHC data
- CT14+nCTEQ15 (nPDF)

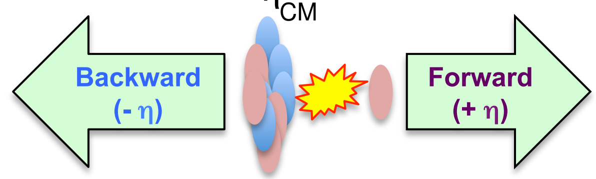
W+





W-





- **Backward region (no/small nuclear effects)**
  - agreement with PDF and nPDF calculations
- **Forward region (nuclear effects)**
  - nPDFs favored

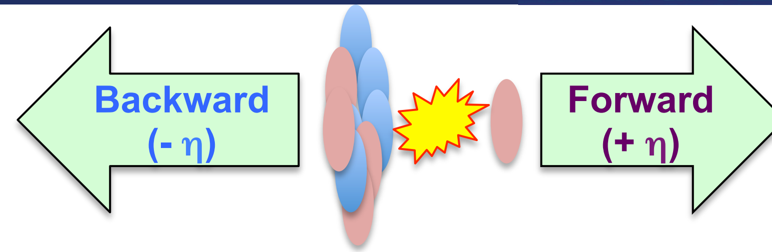
CT14 : Phys. Rev. D93 (2016), no. 3, 033006
EPPS16 : Eur. Phys. J. C77 (2017), no. 3, 163
nCTEQ15 : Phys. Rev. D93 (2016), no. 8, 085037

Forward-backward ratio (R_{FB})

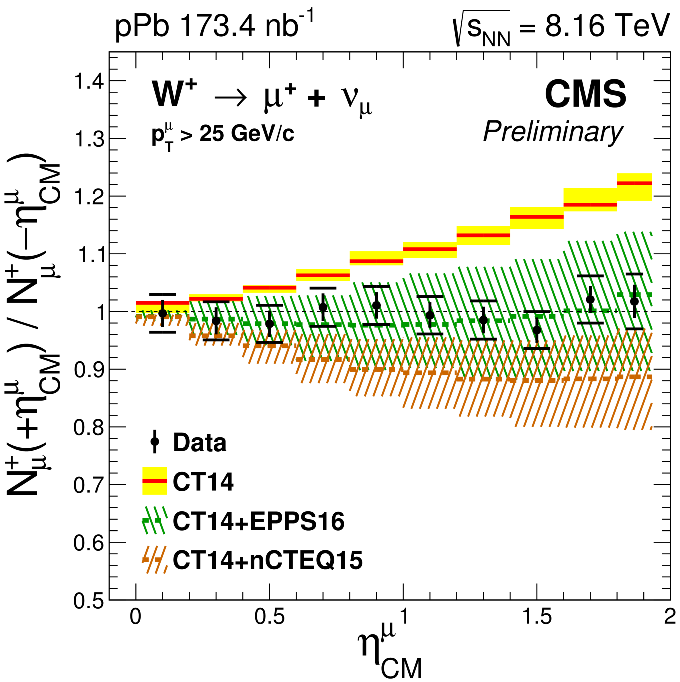
$$\frac{N_\mu(+\eta^\mu_{\mathrm{CM}})}{N_\mu(-\eta^\mu_{\mathrm{CM}})}$$

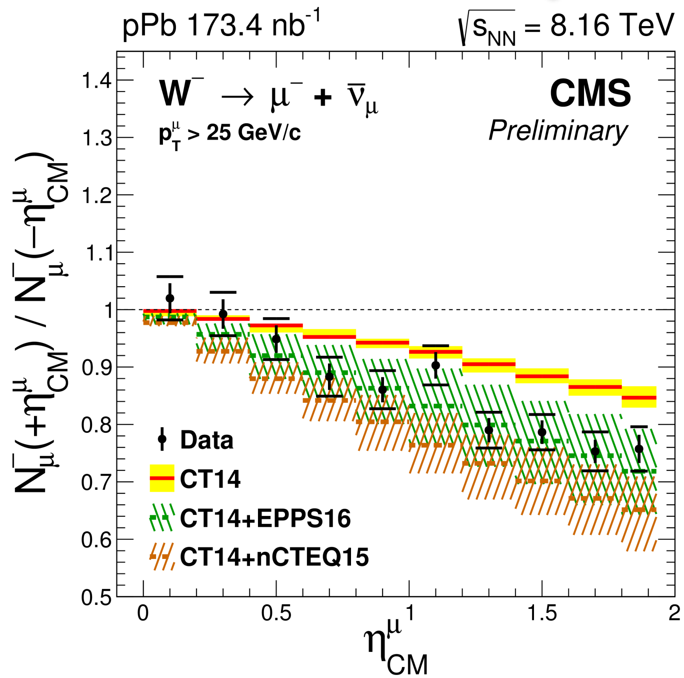
Forward

Backward



W+



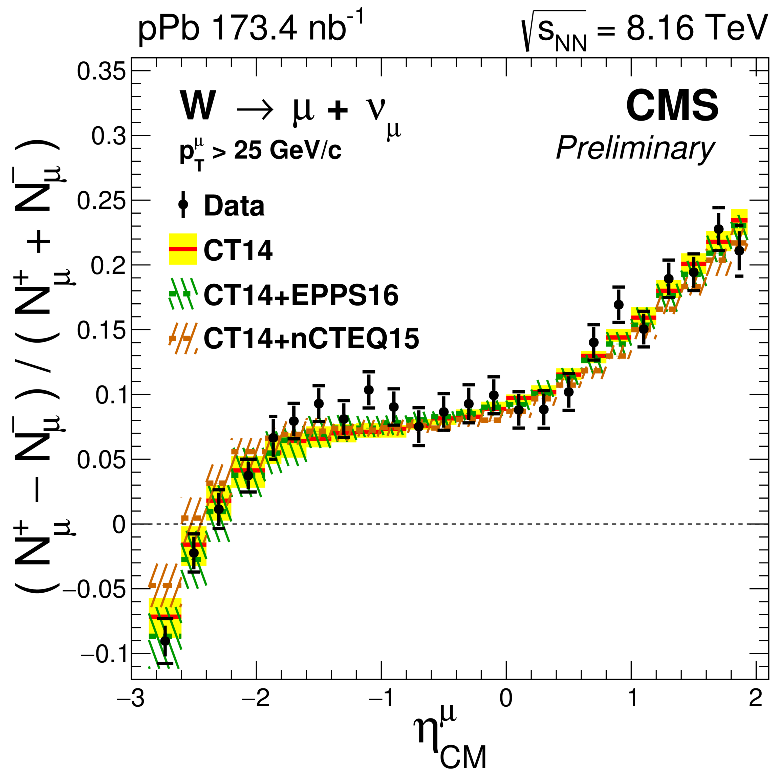


W-

- **The nPDFs calculations are favored over the CT14 PDF**
- **Experimental uncertainties are smaller than model uncertainties**
  - Data can be used to constrain models

Muon charge asymmetry

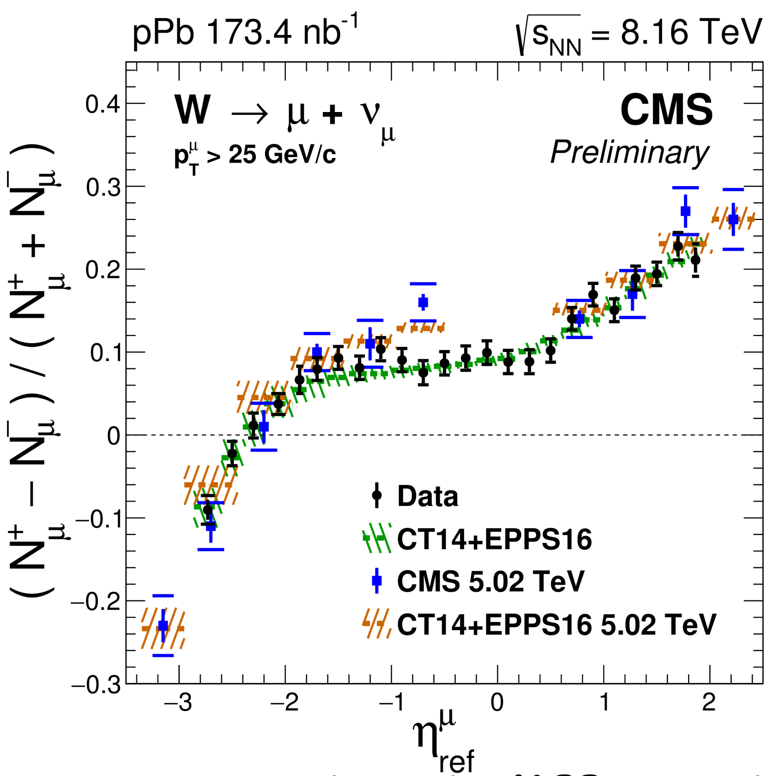
$$\mathcal{A} \equiv \frac{(N_\mu^+ - N_\mu^-)}{(N_\mu^+ + N_\mu^-)}$$



- **PDF and nPDFs reproduce the measurements**

Muon charge asymmetry

$$\mathcal{A} \equiv \frac{(N_\mu^+ - N_\mu^-)}{(N_\mu^+ + N_\mu^-)}$$



5TeV pPb :
Phys. Lett. B 750 (2015) 565-586

- **Measurements at different collision energies agree**

$$\eta^\mu_{\mathrm{ref}} = \eta^\mu_{\mathrm{CM}} \pm \ln(8.16\ \mathrm{TeV}/\sqrt{s_{\mathrm{NN}}})$$

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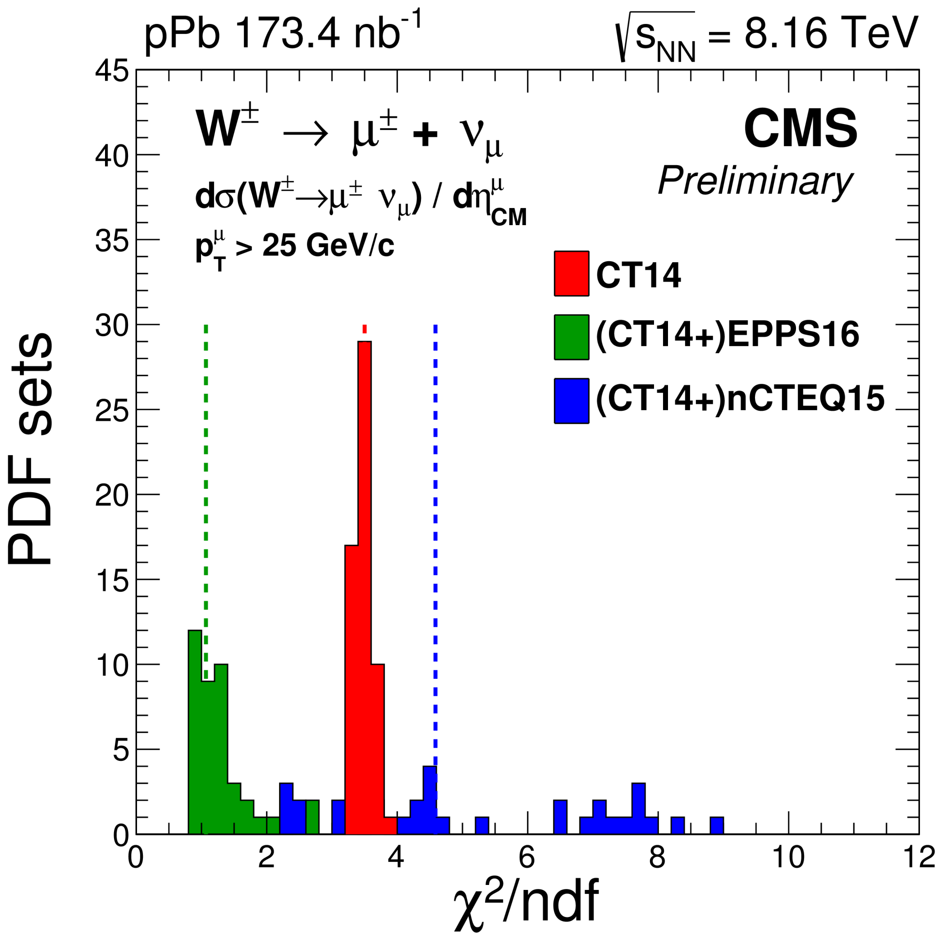
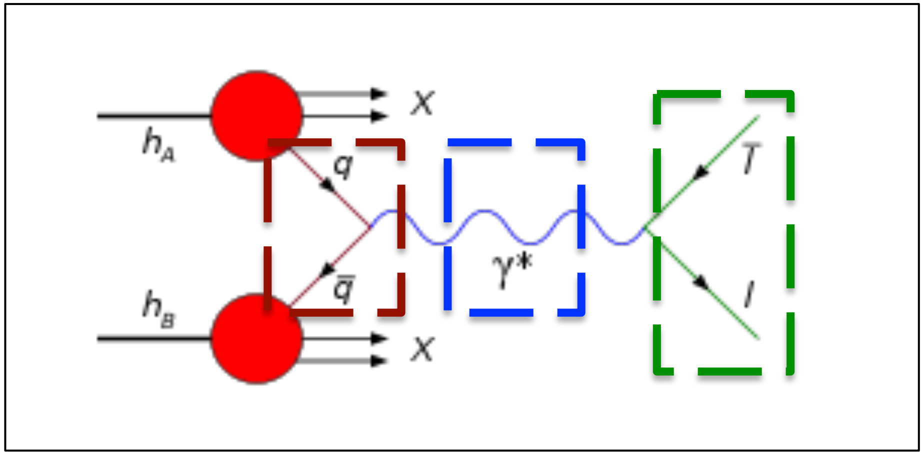
Distribution of the χ^2 / ndf values



- The vertical dashed lines represent the prediction corresponding to the central set of CT14, nCTEQ15, and EPPS16
- Most of the EPPS16 individual sets show good agreement with data than CT14 with nCTEQ15 and CT14 only

Prospect of Drell-Yan analysis (1)

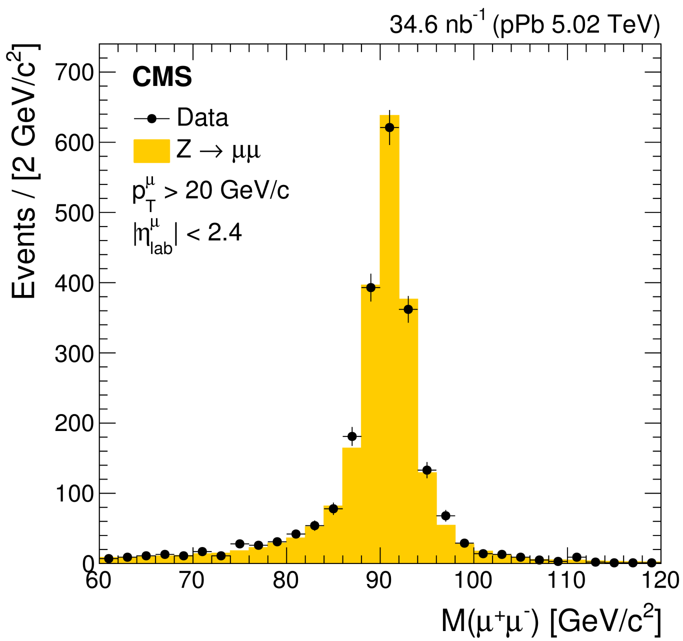


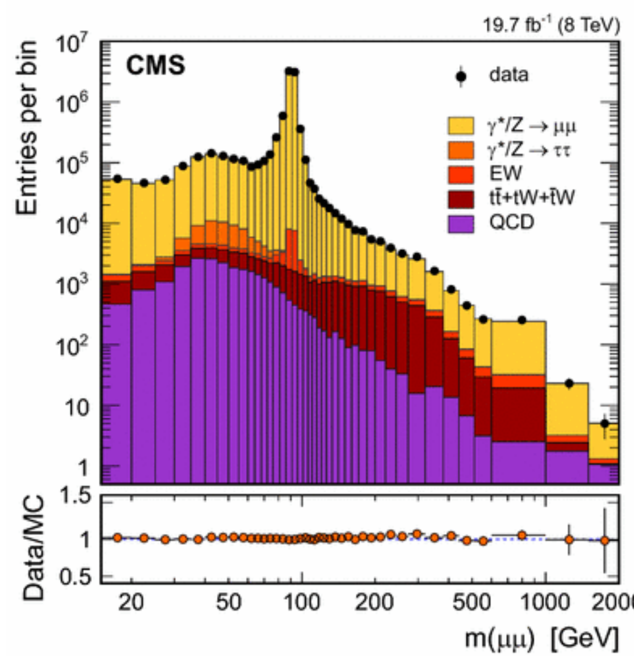
- Drell-Yan process
  - annihilate quark-antiquark pair from hadron-hadron scattering
  - via virtual gamma or Z boson
  - decayed into a pair of oppositely-charged leptons(muon, electron) channel

- **Drell-Yan process could give good constraints for PDF and nPDF**

Prospect of Drell-Yan analysis (2)

pPb 5.02 TeV **pp 8 TeV** **pPb 8.16 TeV**





Phys. Lett. B 759 (2016) 36

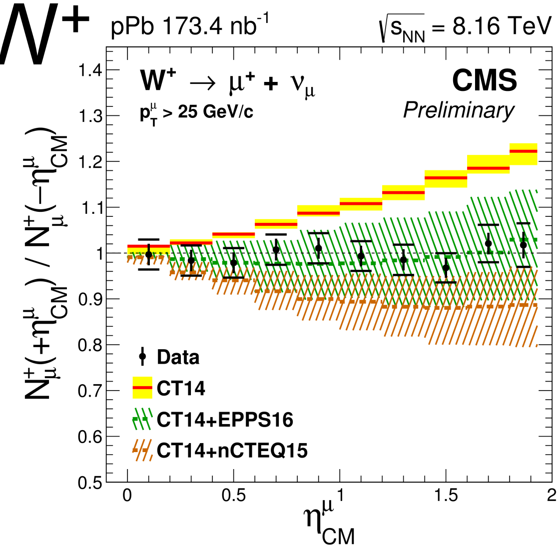
Eur. Phys. J C75 (2015)147

- **CMS has measured Z boson in pPb collisions**
- **Ongoing to measure Drell-Yan process in 8.16 TeV pPb collisions**

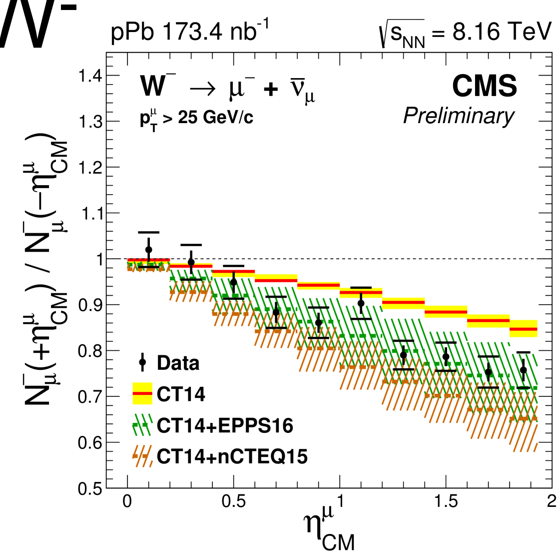
Summary

- **CMS has measured W boson production in pPb collisions at 8.16 TeV**
- **The measurement shows good agreement with nPDF sets, not only proton PDF**
- **The small experimental uncertainties can be used to constrain present models**
- **Measurement of Drell-Yan process at 8.16 TeV pPb collision will be shown soon**

W^+



W^-

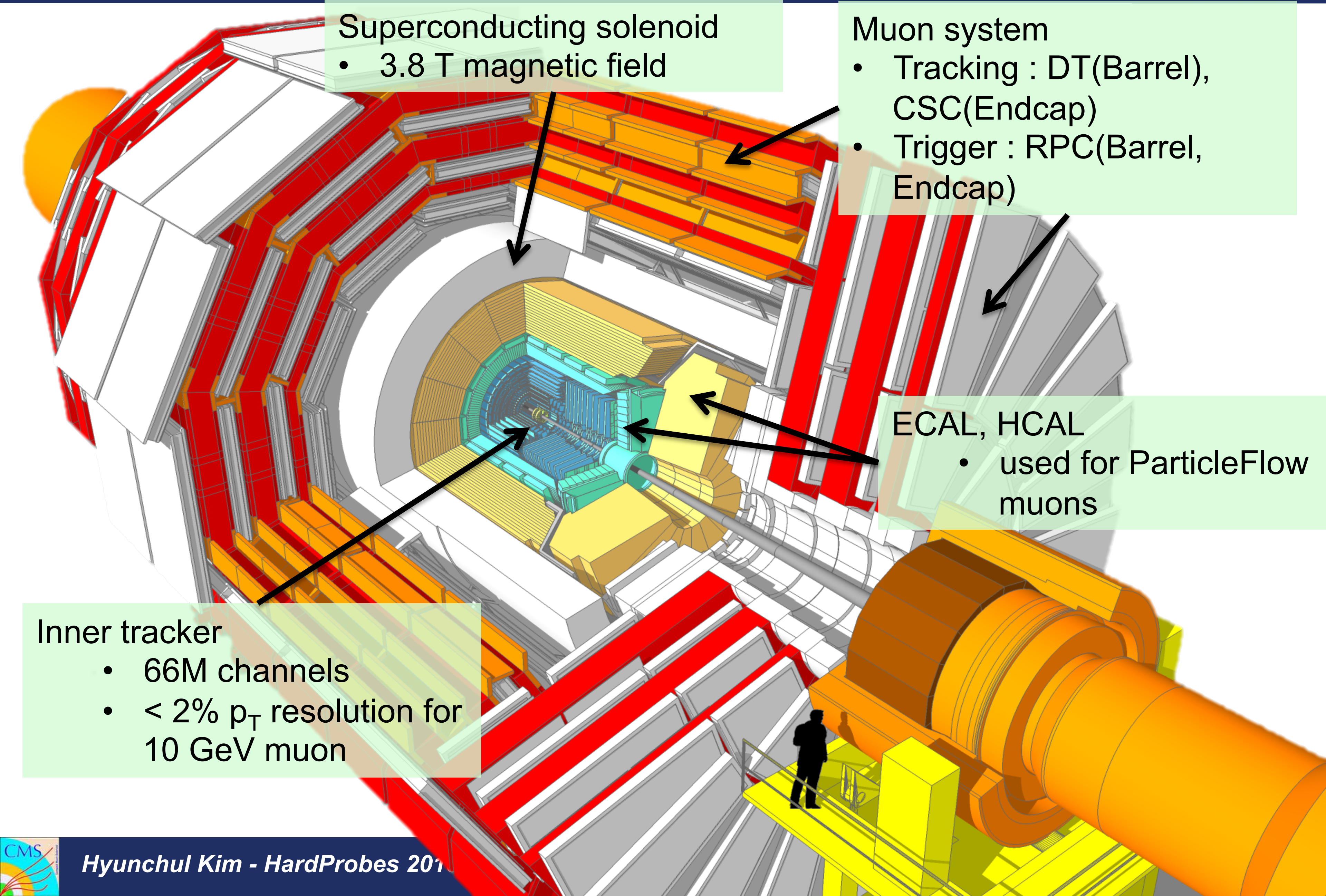


Thank you for your attention

Probing nPDF with CMS:
see also Yeonju Go''s talk (11:05-) - dijets

Backup

Structure of the CMS detector



Standard tight muon ID selection

- The candidate is reconstructed as a Global Muon
- Particle-Flow muon ID is needed
- χ^2 / ndf of the global-muon track fit < 10
- At least one muon-chamber hit included in the global-muon track fit
- Muon segments in at least two muon stations
- The transverse distance of the tracker track w.r.t. the primary vertex is dxy < 2 mm
- The longitudinal distance of the tracker track w.r.t. the primary vertex is dz < 5 mm
- Number of pixel hits > 0
- Cut on number of tracker layers with hits > 5

Example of EPPS16 nPDFs

Free proton baseline (CT14NLO)

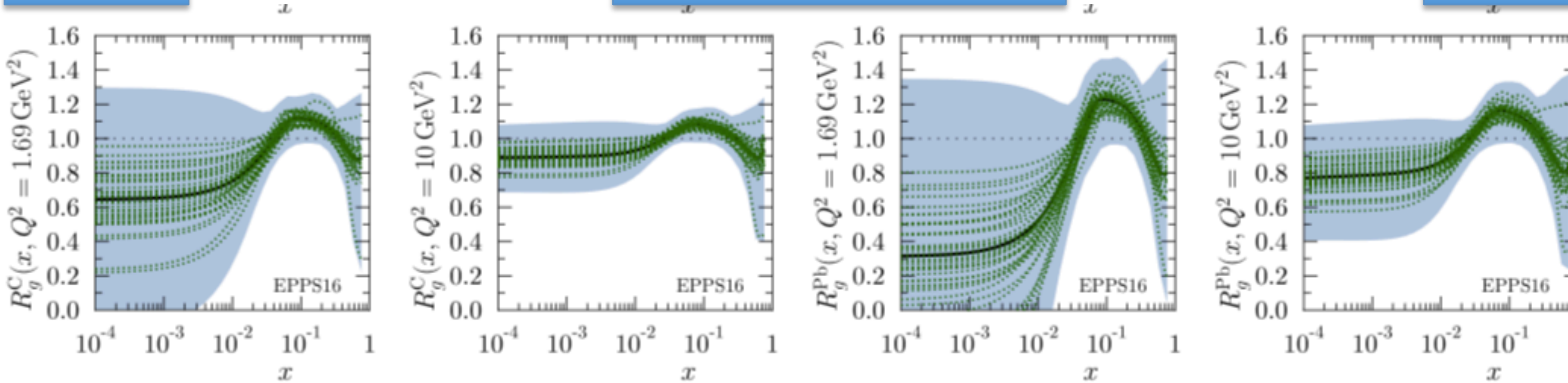
For EPPS16 nPDF

$$f_i^{\mathrm{p}/A}(x,Q^2) \equiv R_i^A(x,Q^2)\, f_i^{\mathrm{p}}(x,Q^2)$$

Carbon

Nuclear modification

Pb



EPJC March 2017, 77:163

Maximum uncertainties of the measured observables

Category	$W^{-} d\sigma/d\eta_{CM}$ [%]	$W^{+} d\sigma/d\eta_{CM}$ [%]	$W^{-} R_{FB}$	$W^{+} R_{FB}$	$W R_{FB}$	$(N_{\mu}^{+} - N_{\mu}^{-})/(N_{\mu}^{+} + N_{\mu}^{-})$
Boson p_{T} reweighing	0.5	0.4	0.001	0.001	0.001	0.001
EWK background	0.4	0.3	0.002	0.001	0.001	0.000
POWHEG EWK correction	0.9	0.5	0.007	0.004	0.006	0.003
Efficiency	3.0	3.2	0.026	0.037	0.030	0.011
Event activity reweighing	0.6	0.4	0.002	0.002	0.001	0.002
MET template binning	0.1	0.1	0.002	0.001	0.001	0.001
QCD background	1.2	0.7	0.016	0.007	0.009	0.006
Hadronic recoil correction	0.2	0.3	0.002	0.004	0.002	0.002
Total systematic uncertainty	3.3	3.3	0.030	0.038	0.031	0.013
Statistical uncertainy	2.4	2.0	0.026	0.029	0.019	0.015

Results of the χ^2 test between the measurements and the theory calculations

Observable	CT14			CT14+EPPS16			CT14+nCTEQ15		
	χ^2	ndf	Prob.(%)	χ^2	ndf	Prob.(%)	χ^2	ndf	Prob.(%)
$d\sigma(W \to \mu\nu_\mu)/d\eta^{\mu}_{CM}$	135	48	3×10^{-8}	32	48	96	40	48	79
$(N_\mu^+ - N_\mu^-)/(N_\mu^+ + N_\mu^-)$	23	24	54	18	24	80	29	24	23
$N_\mu^\pm(+\eta^\mu_{CM})/N_\mu^\pm(-\eta^\mu_{CM})$	98	20	3×10^{-10}	11	20	95	14	20	83
$N_\mu(+\eta^\mu_{CM})/N_\mu(-\eta^\mu_{CM})$	87	10	2×10^{-12}	3	10	99	5	10	90