CMS Overview

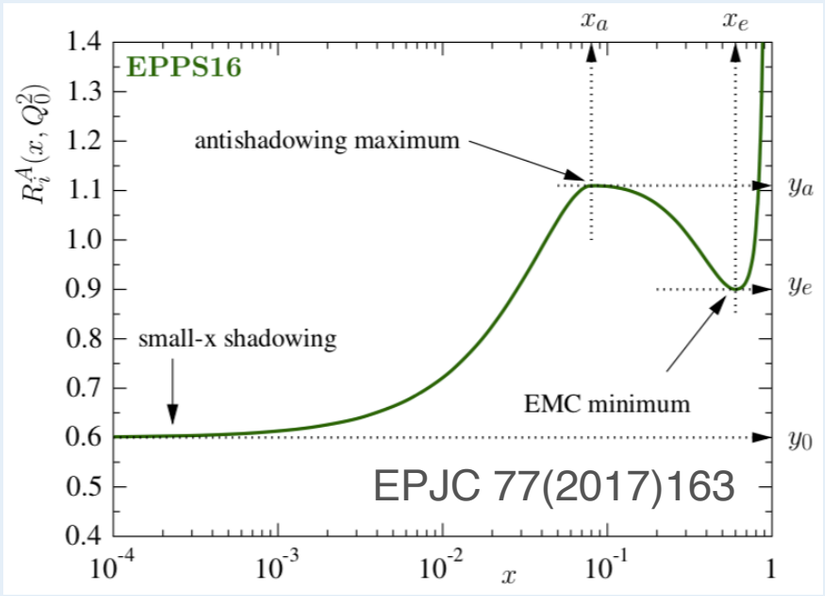
Jing Wang (MIT)
on behalf of the CMS Collaboration

5th International Conference on the Initial Stages in High-Energy Nuclear Collisions
24 - 28 June 2019
Columbia University, New York, NY (US)

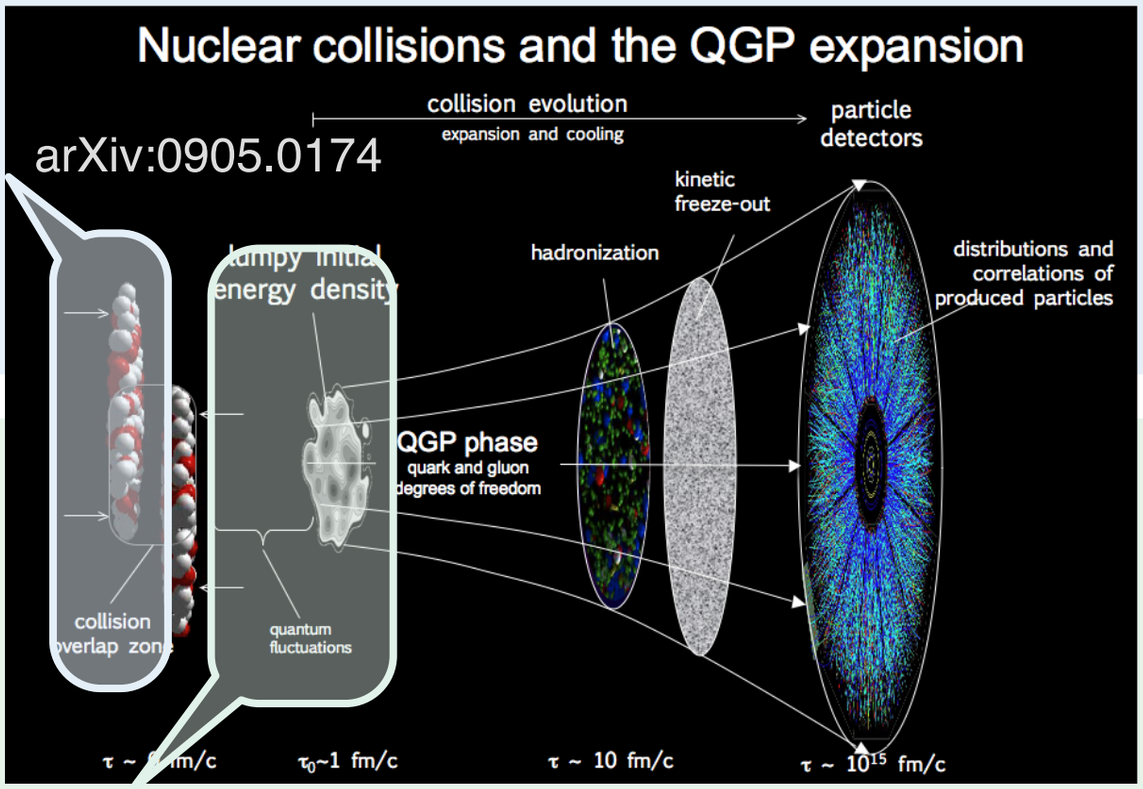
Why the Physics Interest in the Initial Stages?

Motivation

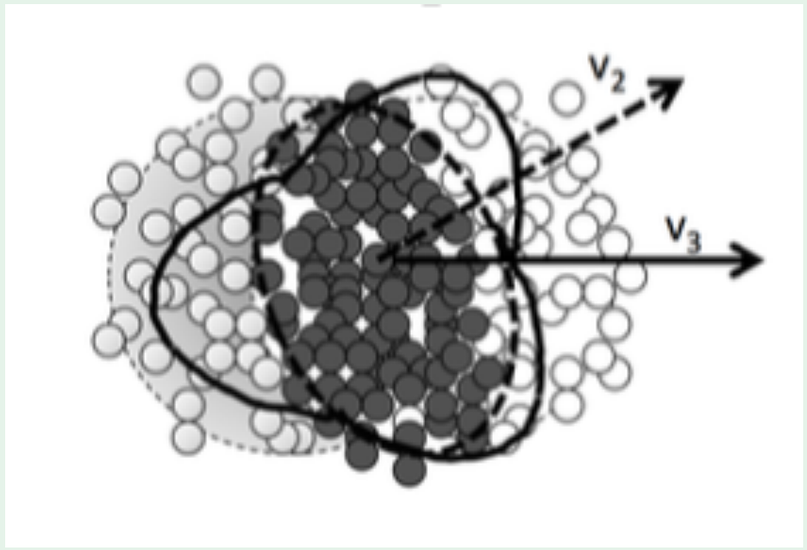
Constrain nPDF



- PDFs in bound nucleons modified compared to free protons
- Crucial input for QCD calculation in heavy-ion collisions



Initial Geometric Fluctuations



- Poor knowledge of how the system evolves towards thermalization

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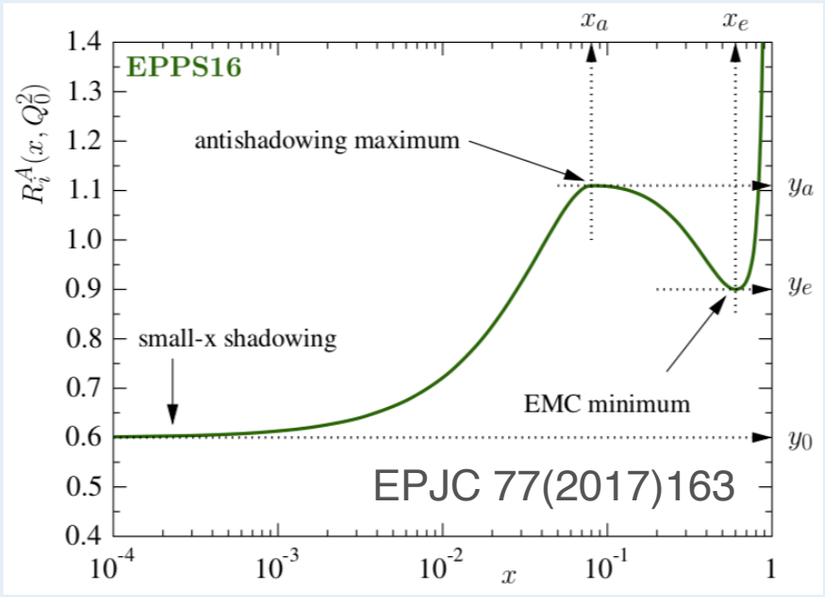

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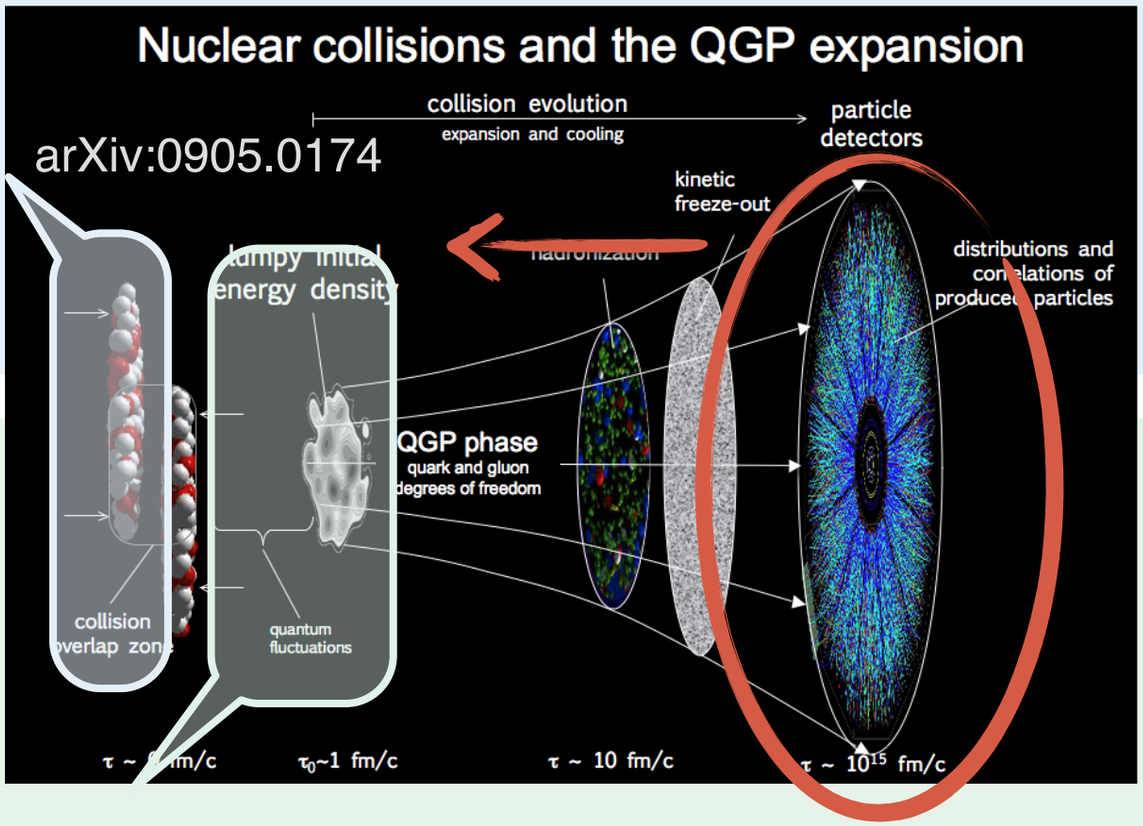

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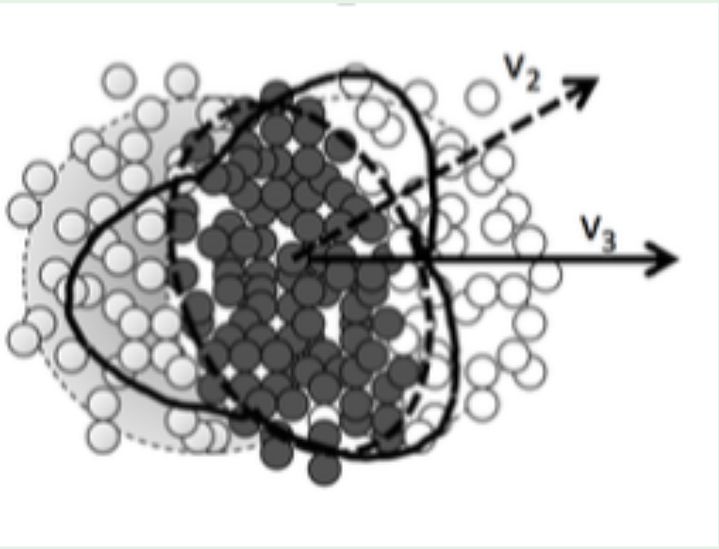


- Poor knowledge of how the system evolves towards thermalization

How to do that in experiments?

Initial Stage Studies in Experiments

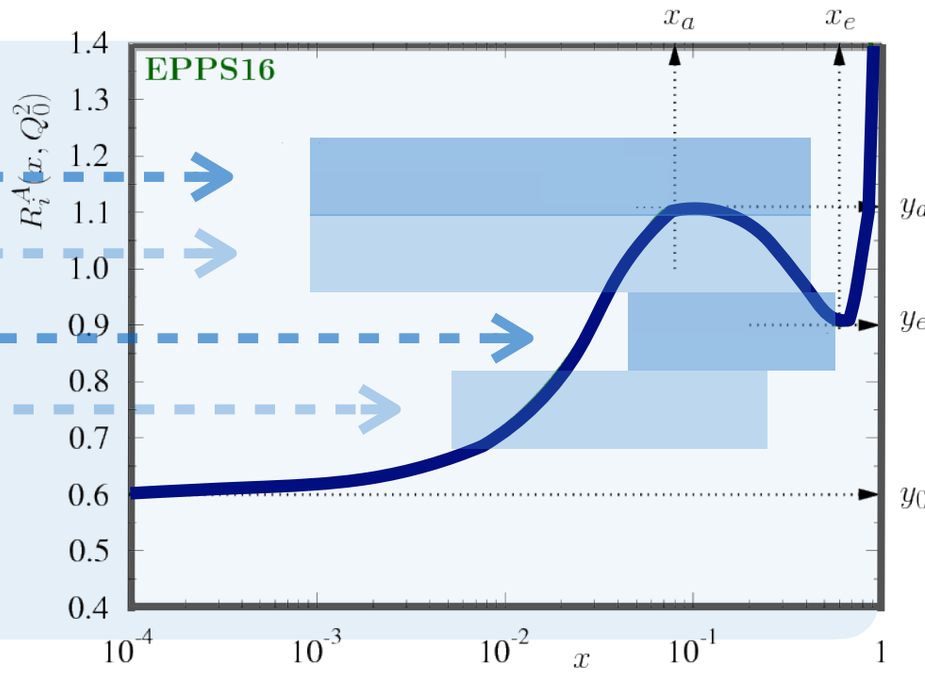
Motivation

Constrain nPDF

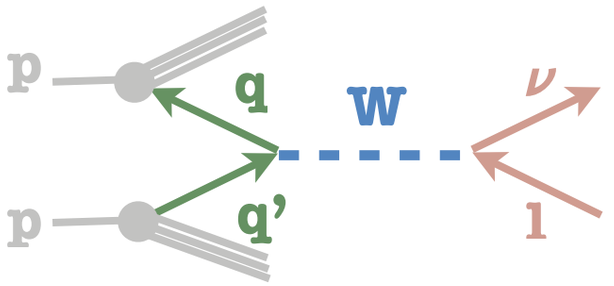
- x: 10^{-3}-10^{-1}, $Q^2 \sim M^2_{W/Z}$
- x: 10^{-3}-10^{-1}
- high x, $Q^2 \sim M^2_t$
- x: 10^{-2}-10^{-1}

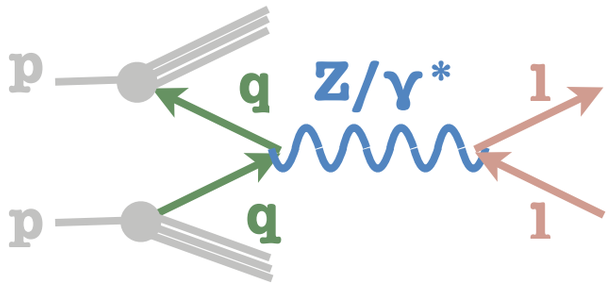
Probes + Observables

- Electroweak boson in pA
- Isolated photon in pA(AA)
- Top production in pA
- Dijet in pA



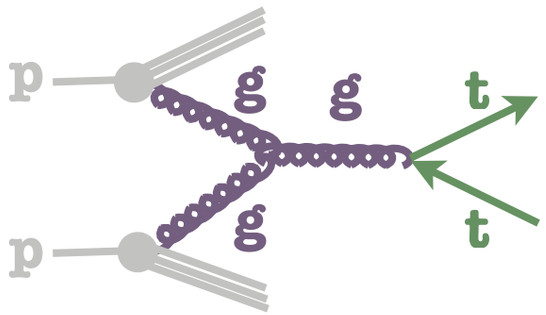
- **Electroweak boson (quark nPDF)**
  - ➡ Rapidity distribution sensitive to nPDF
  - ➡ high-Q regime





- **Dijet (gluon nPDF)**
  - ➡ Rapidity distribution sensitive to nPDF

- **Top quark (gluon nPDF)**
  - ➡ Decay before interacting with the medium
  - ➡ high-x, high-Q region ⇒ EMC



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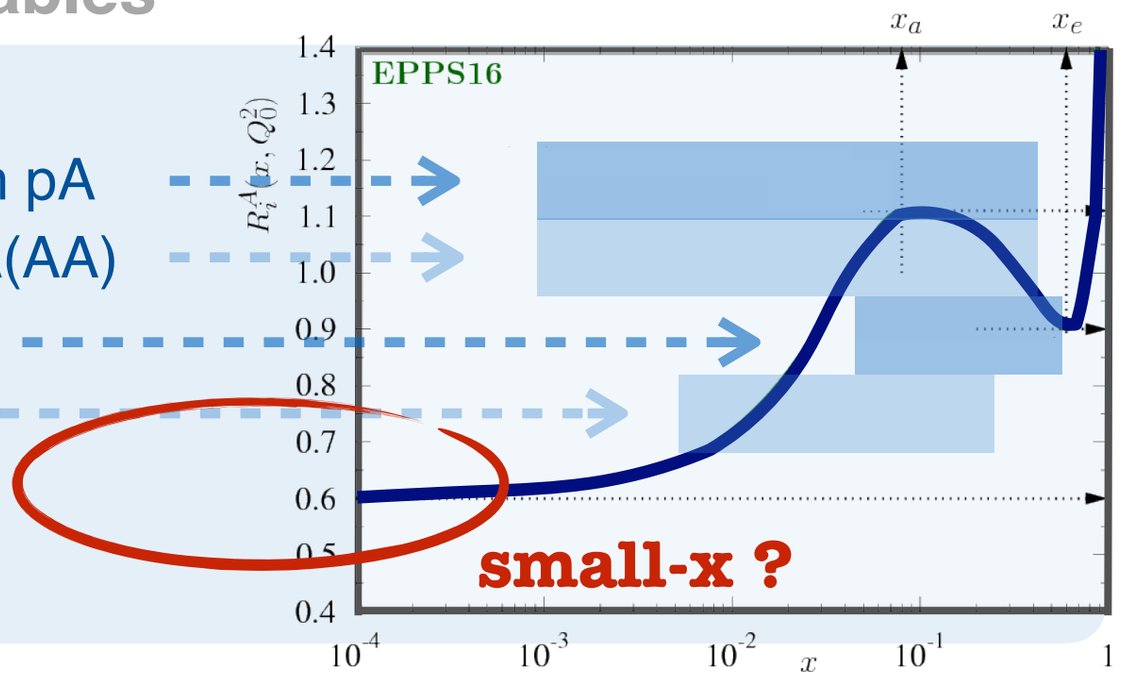

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▸ x: ~10^{-6}	• Forward jets
Small-x QCD (UPC)	
▸ $W_{\gamma p}$: 10-10^3 GeV	• Photo-production J/ψ,ϒ in UPC
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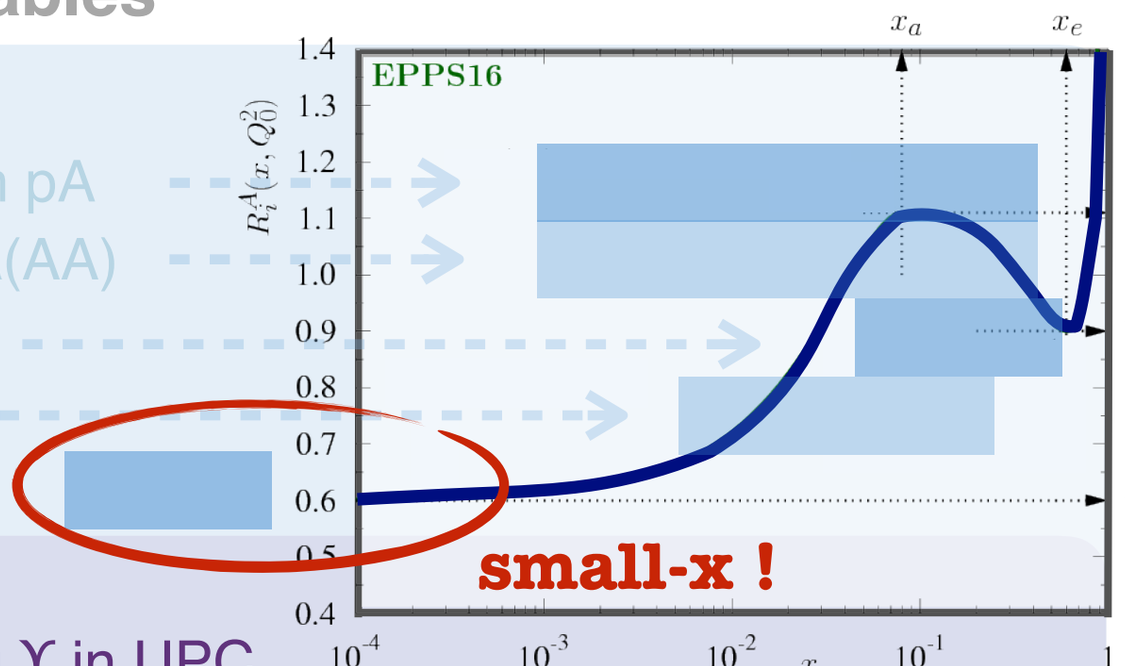
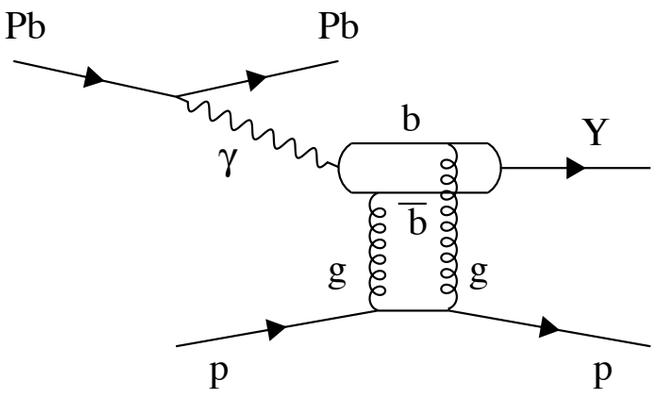


- Forward ⇔ Small x

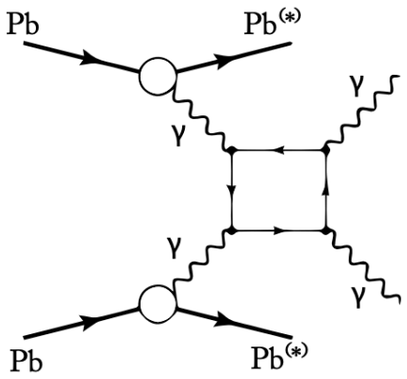
$$x \approx \frac{p_T}{\sqrt{s}} e^{\pm\eta}$$

- Rare processes only studied in UPC
- Large EM field
  - ➡ Equivalent photon flux

Photo-production



Light-by-light scattering



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	• Multi-particle correlations in small system
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Probe Full Evolution with Heavy Quarks	
▸ Produced in early stages	• Open and hidden heavy flavor hadronization
	• Correlations in pp, pA, AA

CMS Talks in IS2019

▸ *Emilien Chapon*	• Electroweak boson in pPb	**Tues. 14:40 [329]**
	• Isolated photon in pA(AA)	
▸ *Cole Leon Lindsey*	• Top production in pPb	**Poster**
	• Dijet in pPb	
▸ *Alexandr Bylinkin*	• Forward jets in pPb	**Tues. 17:20 [329]**
	• Photo-production J/ψ,ϒ in UPC	
▸ *Marek Bohdan Walczak*	• Photo-production ρ in UPC	**Tues. 17:40 [329]**
	• Forward rapidity gap	
	• Light-by-light scatterings	
	• Higher-order flow harmonics	
▸ *Shengquan Tuo*	• Multi-particle correlations in pPb	**Wed. 16:30 [301]**
	• Symmetric Cumulant	
▸ *Yongsun Kim*	• ϒ Production in pp, pPb, PbPb	**Wed. 14:20 [329]**
	• Open and hidden heavy flavor	

Heavy-ion data collection in CMS

	Collision System	Energy	LHC Delivered	CMS Recorded
		Run 1		
2011	Pb-Pb	2.76 TeV	184.1 μb^{-1}	174.3 μb^{-1}
2013	p-Pb	5.02 TeV	36.1 nb^{-1}	35.5 nb^{-1}
		Run2		
2015	p-p	5.02 TeV	28.8 pb^{-1}	28.1 pb^{-1}
2015	Pb-Pb	5.02 TeV	0.60 nb^{-1}	0.55 nb^{-1}
2016	p-Pb	8.16 TeV	188.3 nb^{-1}	180.2 nb^{-1}
2017	Xe+Xe	5.44 TeV	6.3 μb^{-1}	6.0 μb^{-1}
2017	p-p	5.02 TeV	334.3 pb^{-1}	316.3 pb^{-1}
2018	Pb-Pb	5.02 TeV	1.80 nb^{-1}	1.71 nb^{-1}

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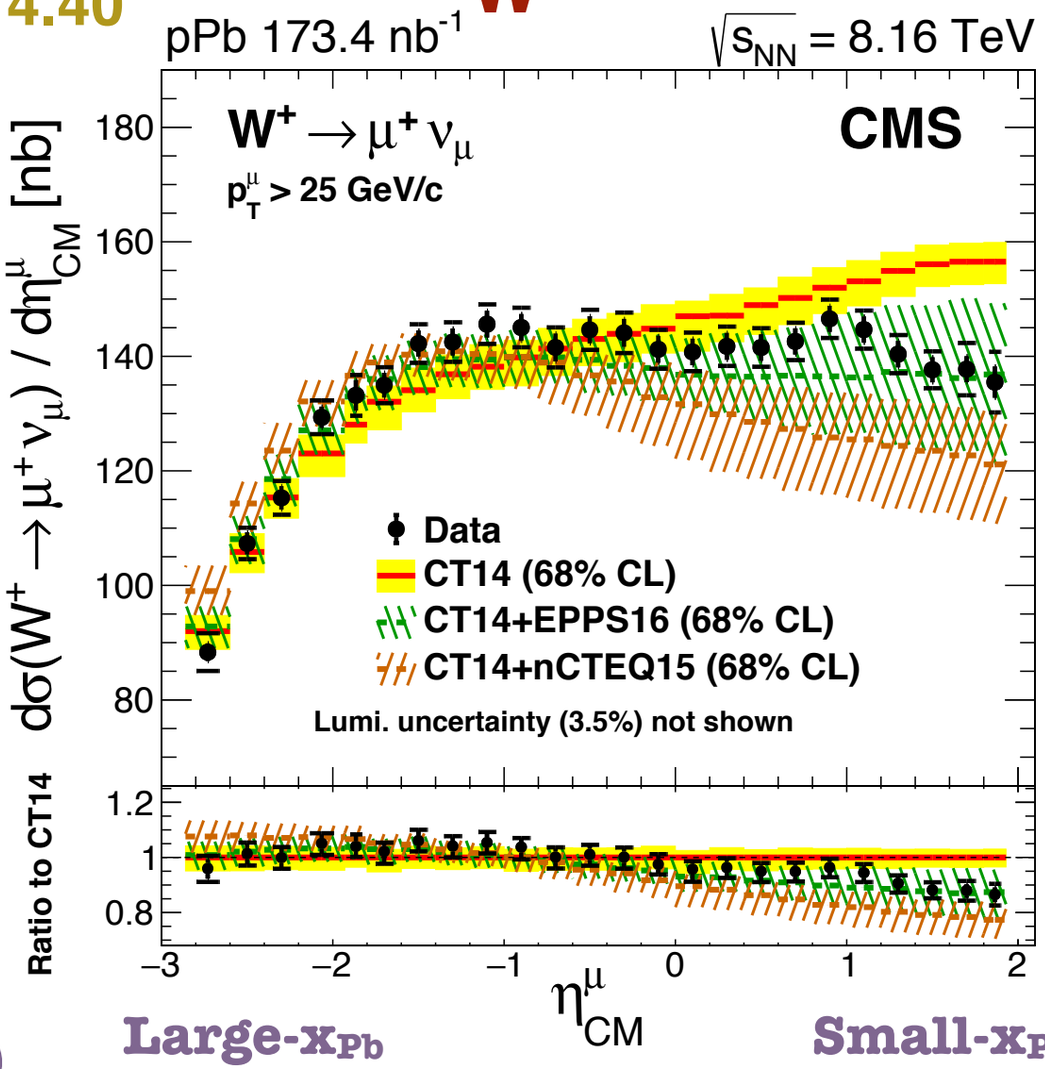
nPDF: W production in pPb@8.16TeV

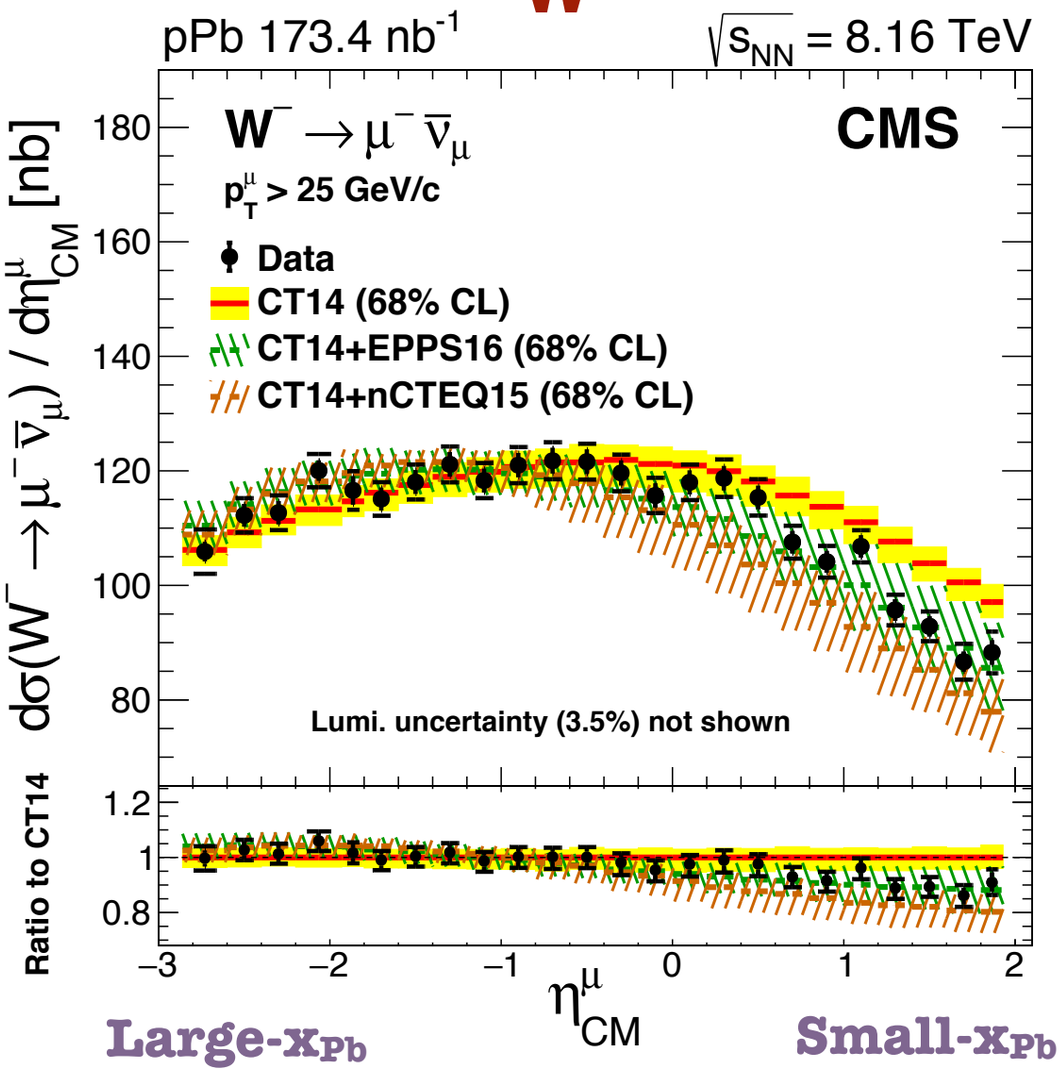
Emilien Chapon
Tues. 14.40

arXiv:1905.01486

W+



W-



Large-x_{Pb} ← **Pb-going** | **p-going** → **Small-x_{Pb}**

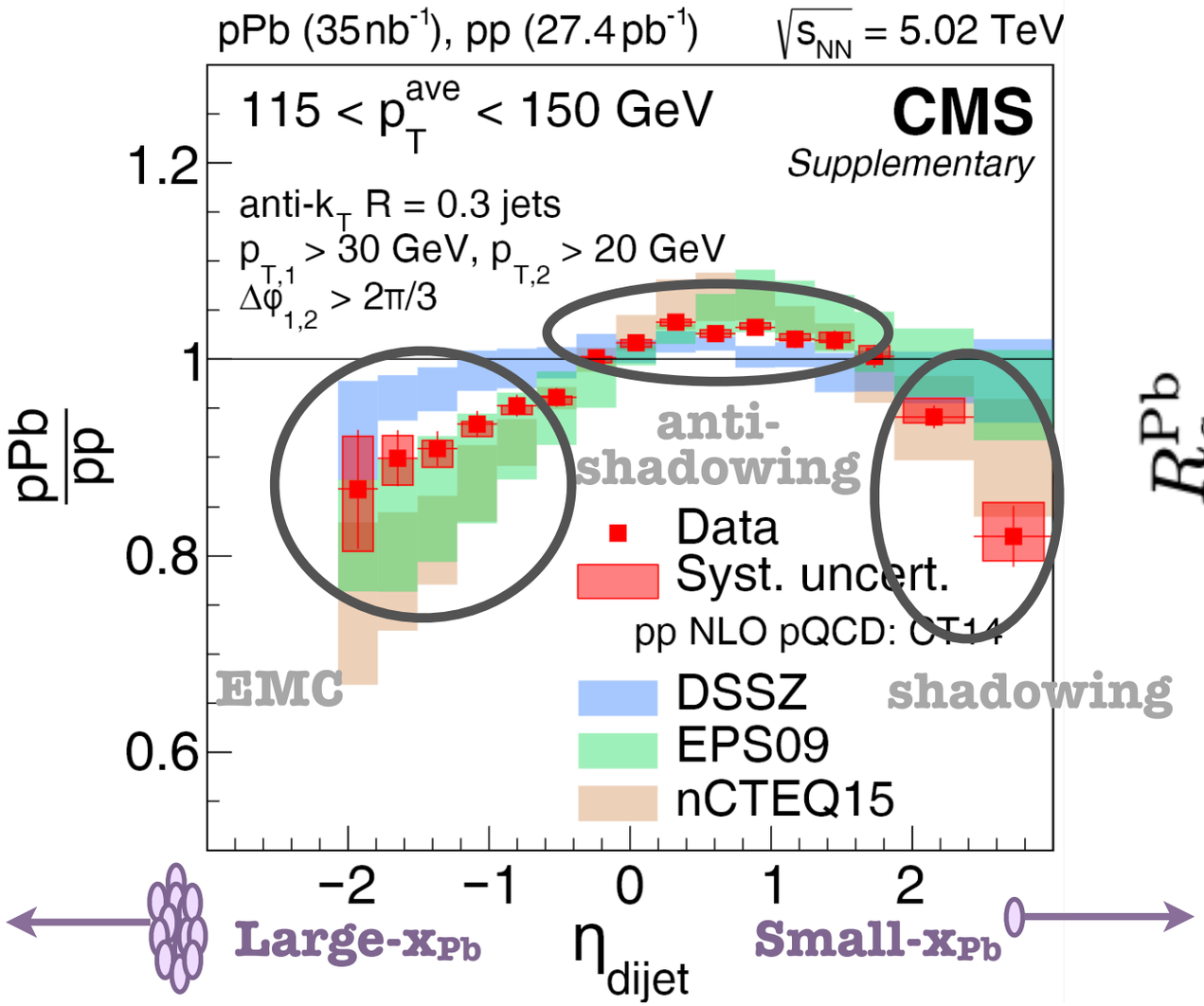
- W is sensitive to isospin effects
- $\eta_{CM} < 0$ (Pb-going, **large x_{Pb}**): Data agrees with **PDF and nPDF**
  - ➡ slight anti-shadowing at $x \sim 10^{-1}$
- $\eta_{CM} > 0$ (p-going, **small x_{Pb}**): Data favors **nPDF**
  - ➡ significant shadowing at $x \sim 10^{-3}$
  - ➡ **Consistent with EPPS16, exclude ~~CT14 (nucleon PDF)~~**

nPDF: Dijet vs. η_{dijet} in pPb@5.02TeV

Alexandr Bylinkin, Tues. 17.20

PRL 121 (2018) 062002

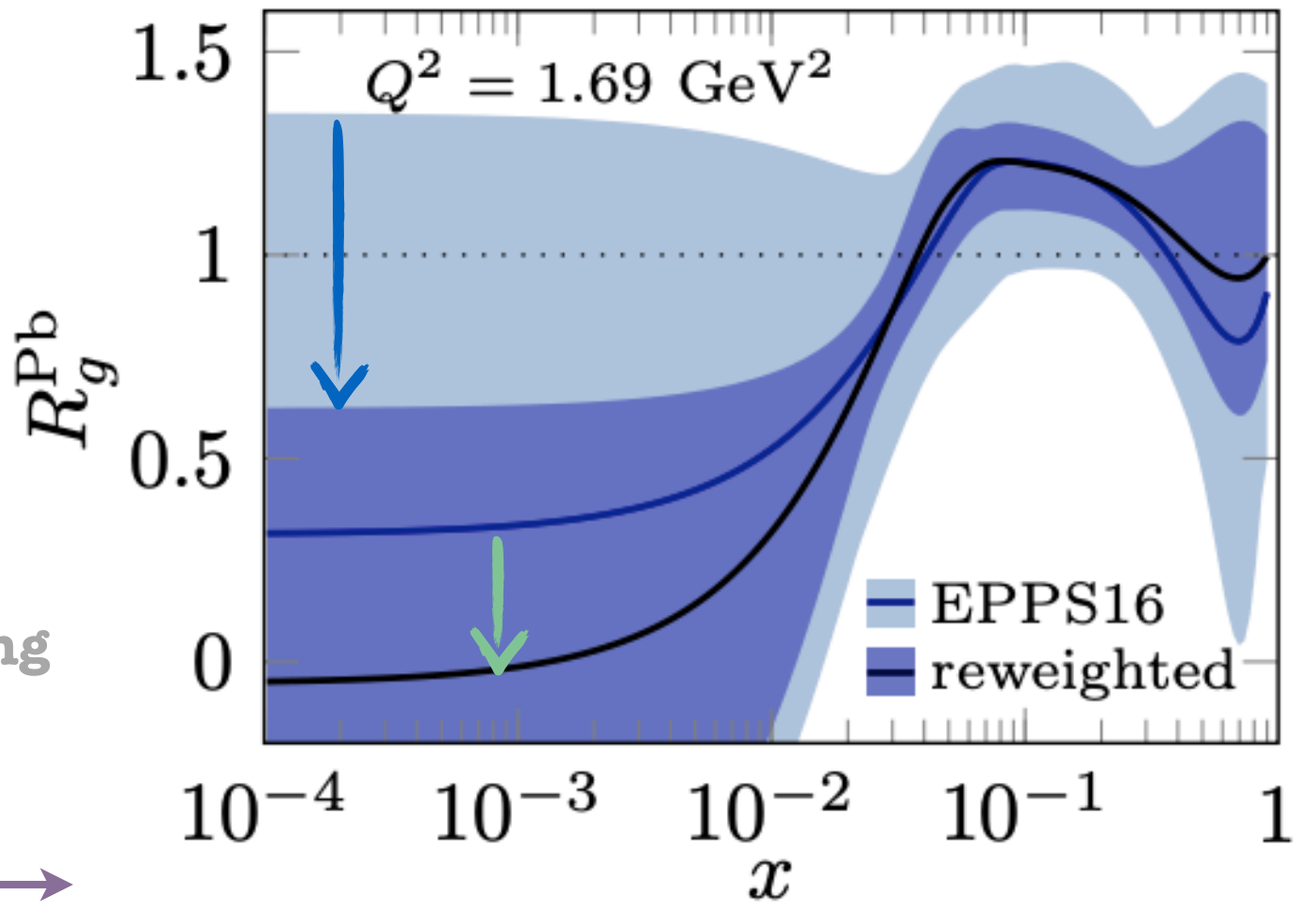
CMS result vs. Models



- pPb/pp deviates significantly from unity
- Evidence of gluon anti-shadowing
- Agrees with **EPS09**
- Disagree with **DSSZ** and **nCTEQ15**

Impact on EPPS16 nPDF

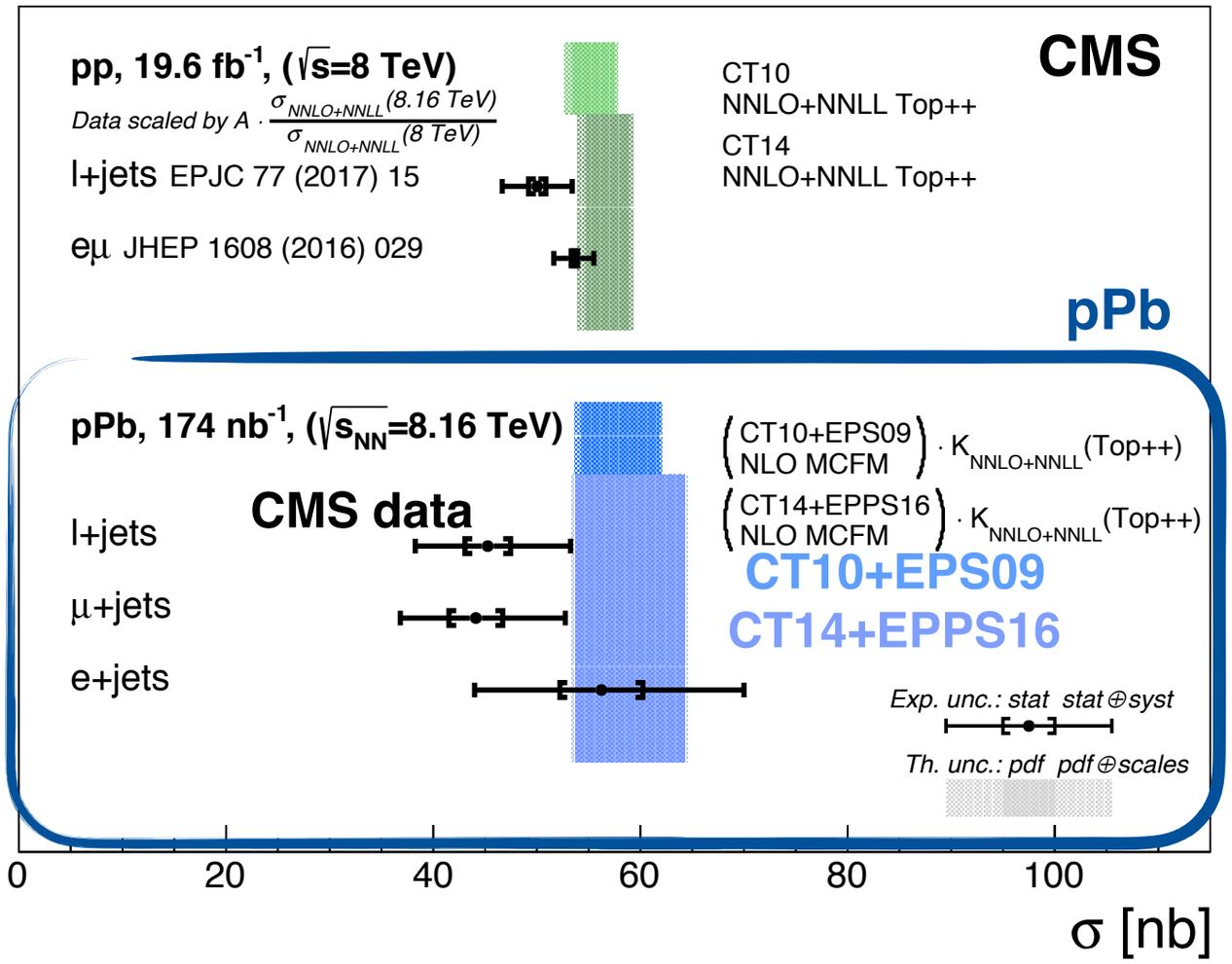
arXiv: 1812.05438

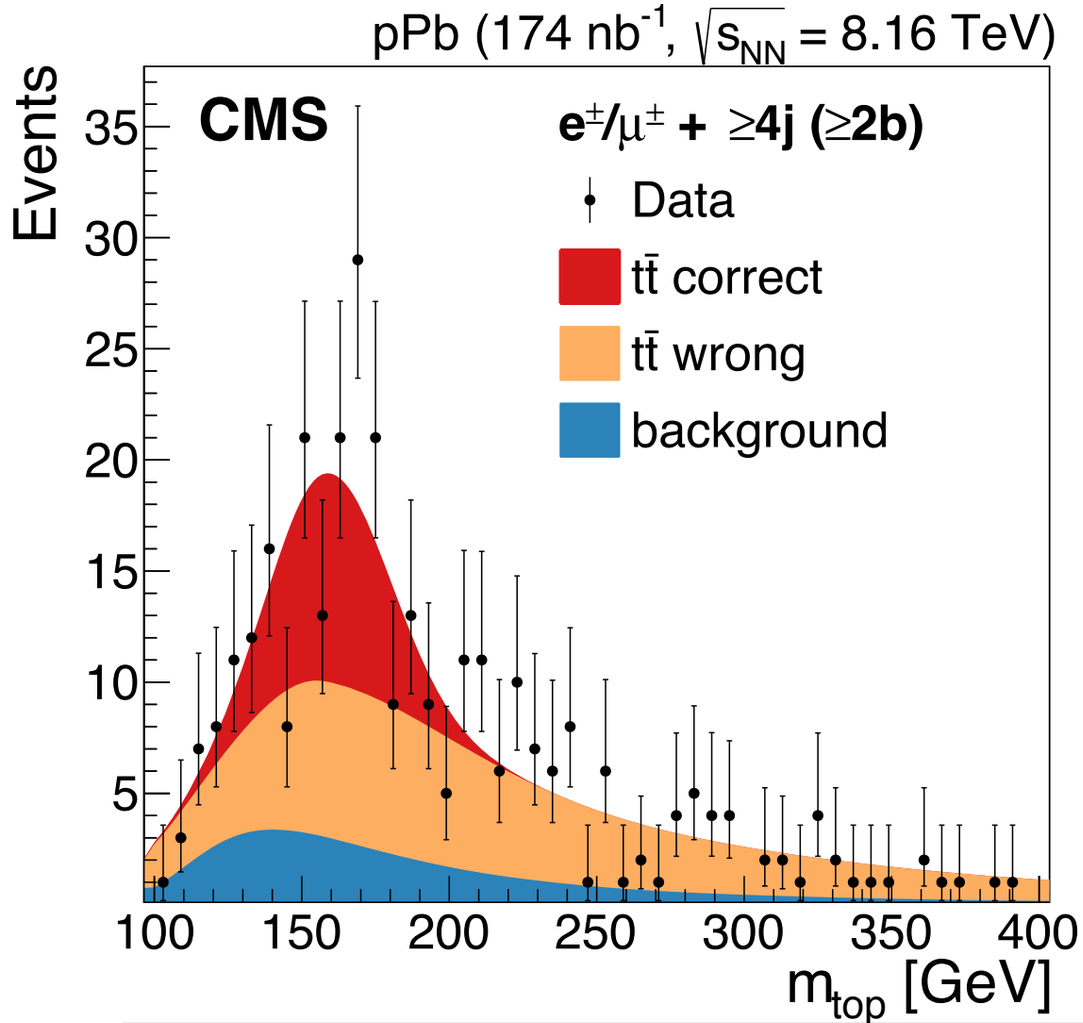


- **EPPS16 uncertainties dramatically reduced with CMS dijet pPb results**
- Downward pull in the shadowing region

nPDF: Top Production in pPb@8.16TeV

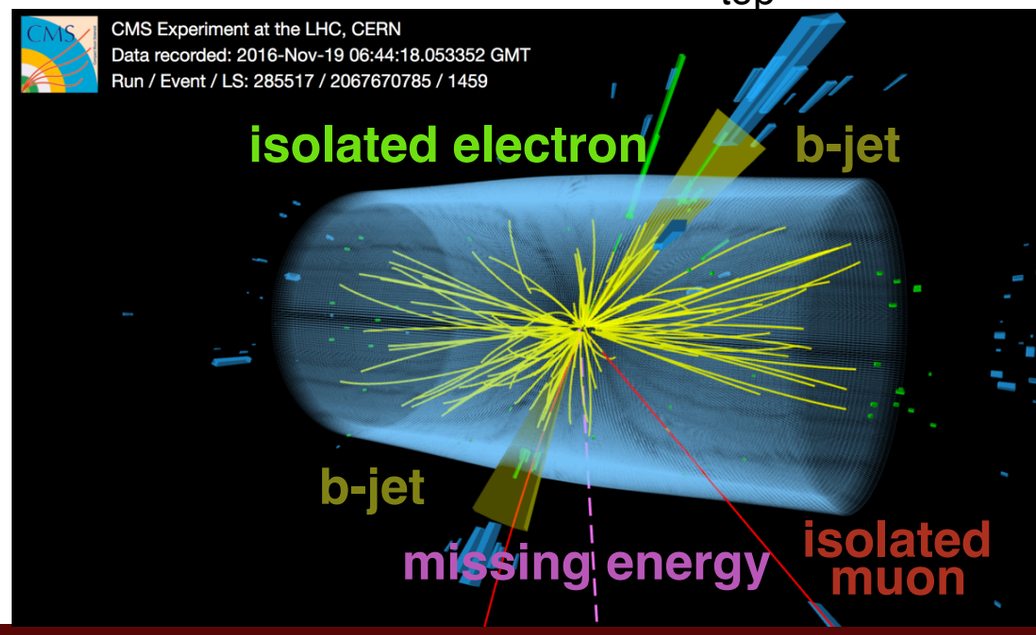
Cole Leon Lindsey, Poster





- First observation of top quark production in **pPb**!
- New constraint to gluon PDF at large x
- Inclusive cross section (45 ± 8 nb) agrees with NNLO pQCD + nPDF calculations

PRL 119 (2017) 242001

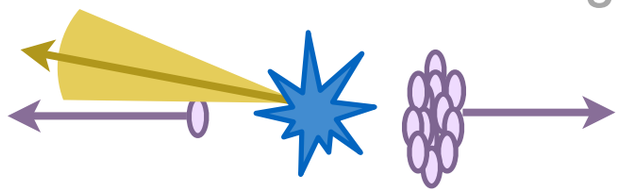


nPDF: Forward jets in pPb@5.02 TeV

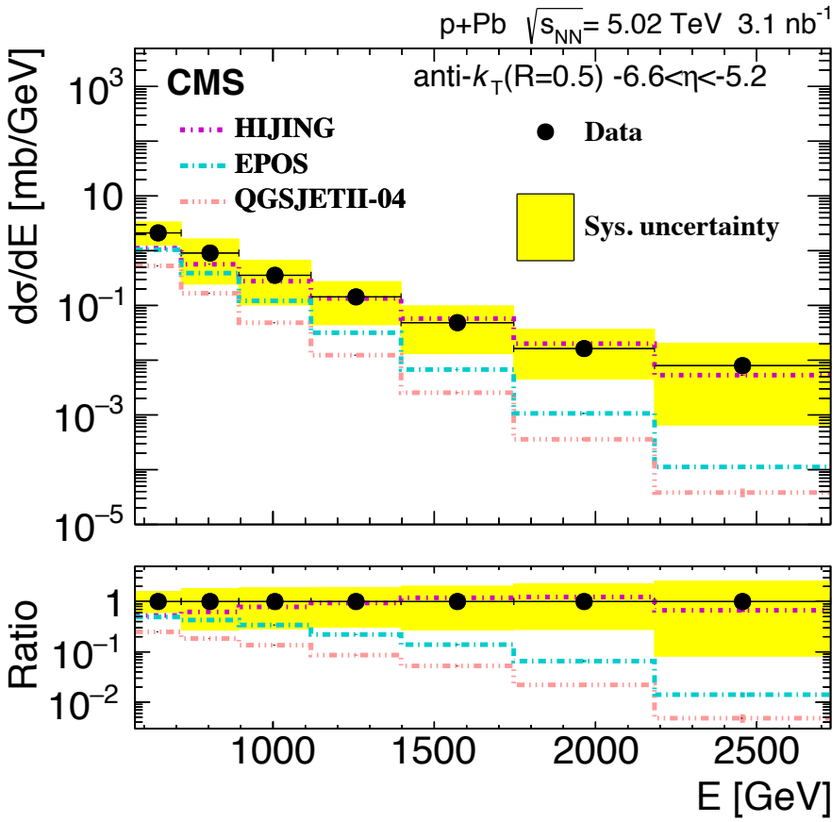
Alexandr Bylinkin
Tues. 17.20

JHEP 05 (2019) 043

forward: $-6.6 < \eta < -5.2$
$x_{Pb} \sim 10^{-6}$

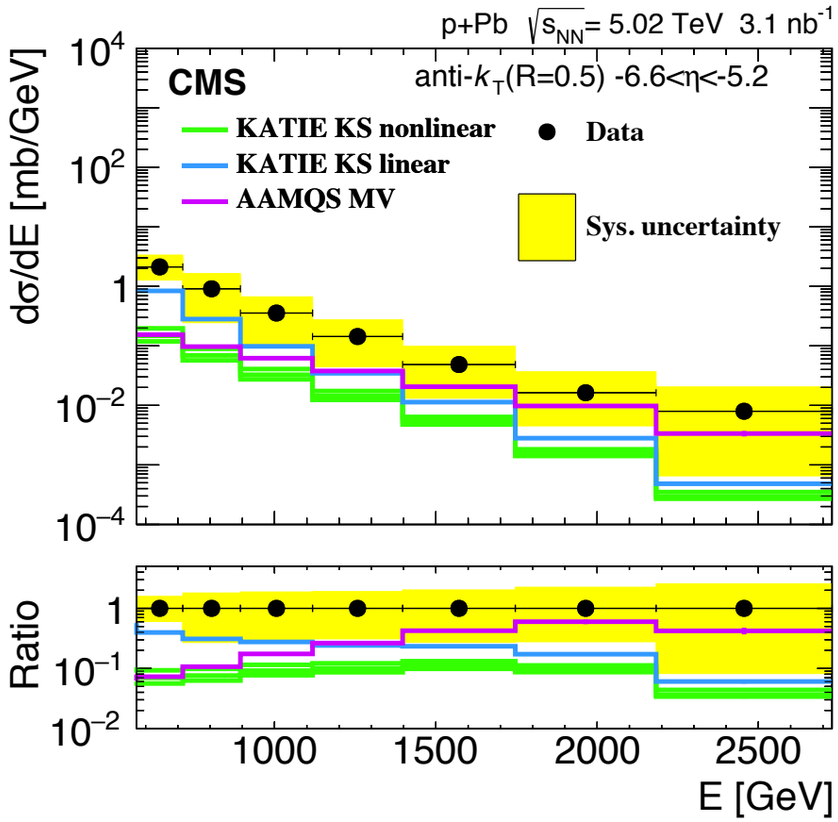


vs. MC generators



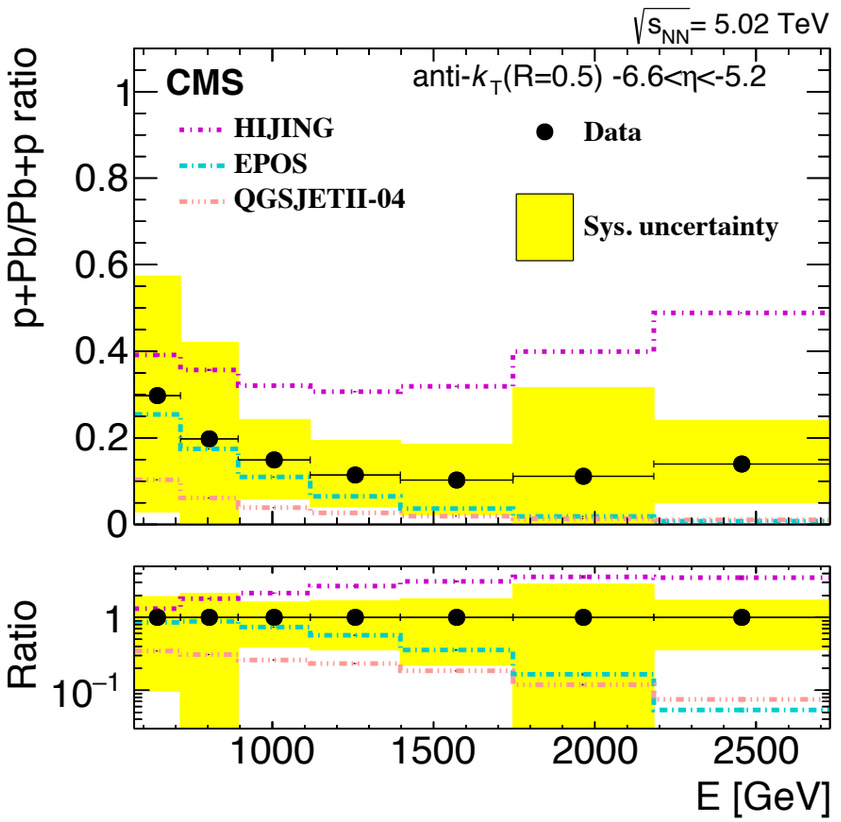
- Agrees with **HIJING**
- **EPOS-LHC** and **QGSJETII-04** are too soft

vs. saturation models



- Saturation models do not describe the data

pPb/Pbp



- None of the models describe pPb/Pbp well
- Data provide constraints to parton saturation models

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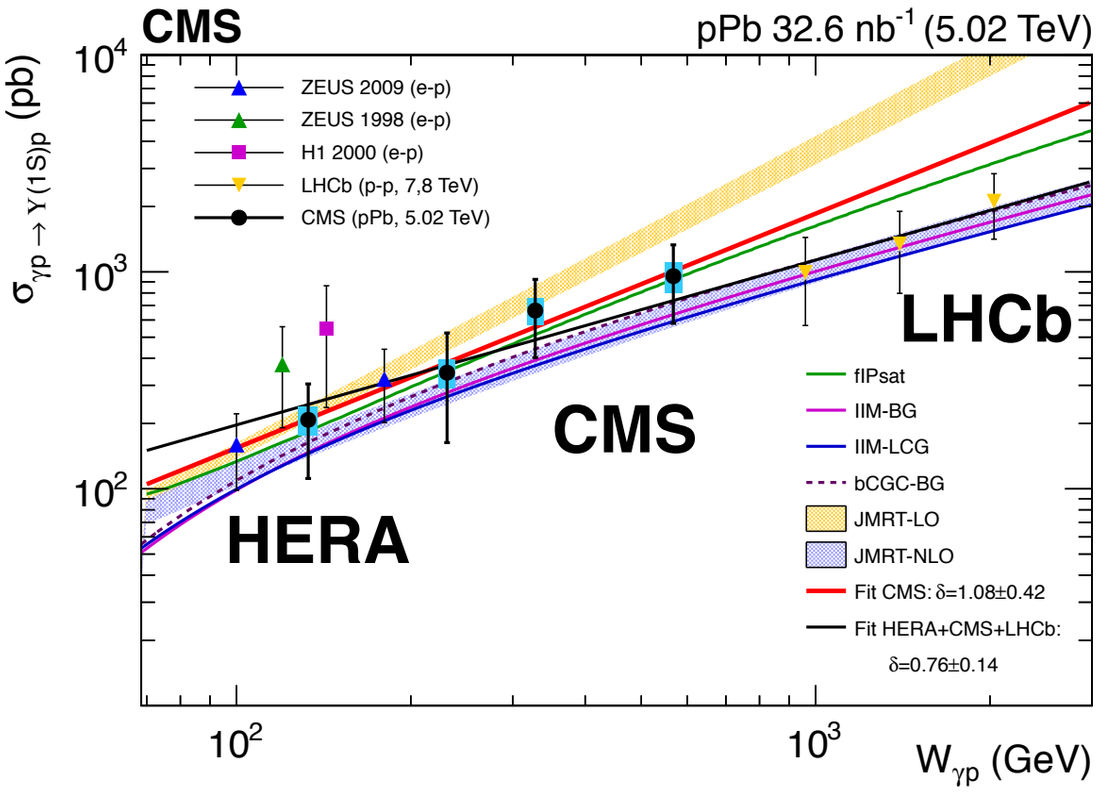
UPC Photo-production: ϒ in pPb@5.02TeV

Marek Bohdan Walczak, Tues. 17.40

EPJC 79 (2019) 277

ϒ(1S) cross-section vs. $W_{\gamma p}$



- Unexplored region of $W_{\gamma p}$

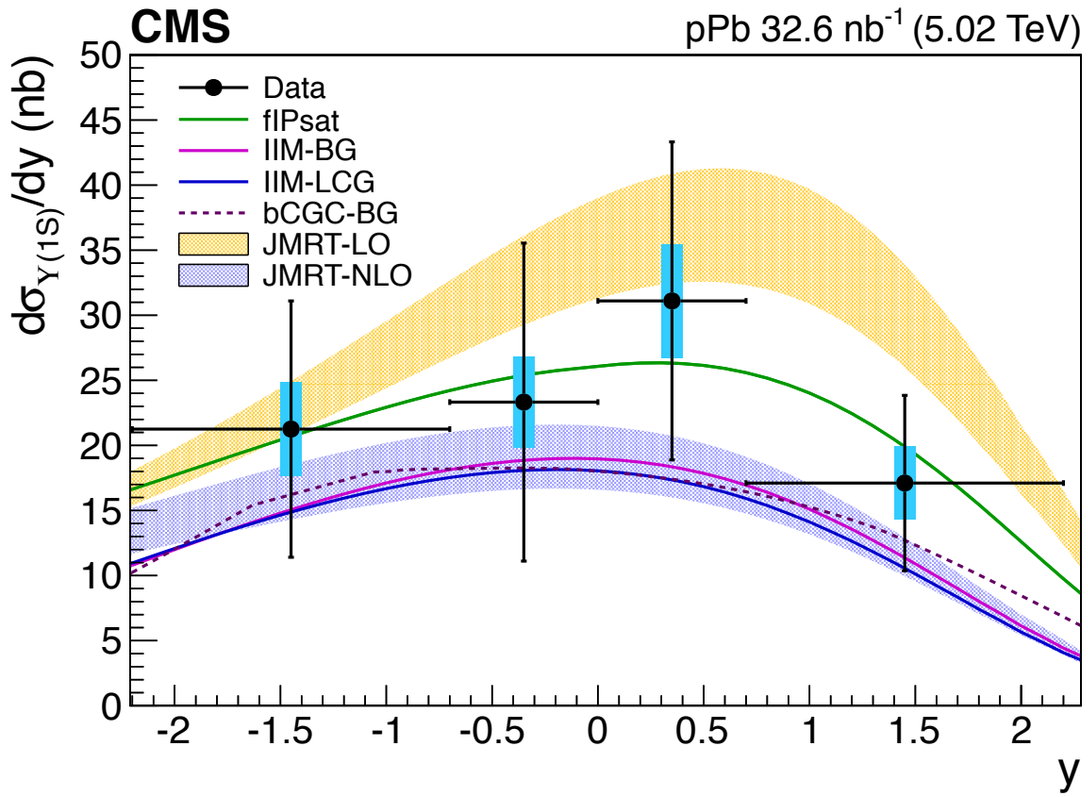
$$W^2_{\gamma p} = 2E_p M_\Upsilon e^{\pm y} (91-826 GeV)$$

- Sensitive to gluon density at small x_p

$$x = m^2_\Upsilon \Big/ W^2_{\gamma p} \; (10^{-4} - 10^{-2})$$

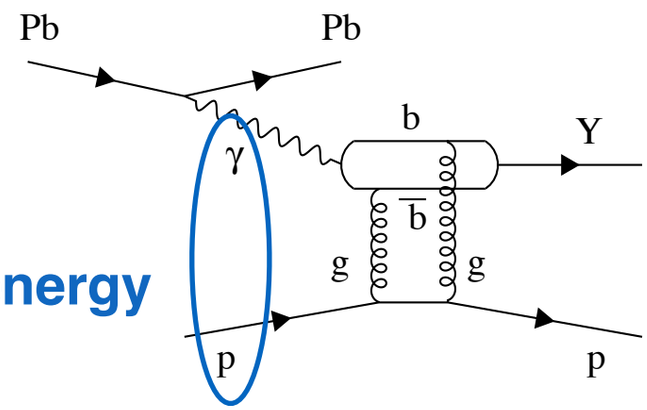
- Y(1S) x-section follows power law
  - ➡ $\sigma_\Upsilon(W_{\gamma p}) = \alpha W^\delta$
  - ➡ δ consistent with HERA

ϒ(1S) rapidity distribution



- y distribution consistent with various theoretical models

$W_{\gamma p}$: γp CoM energy

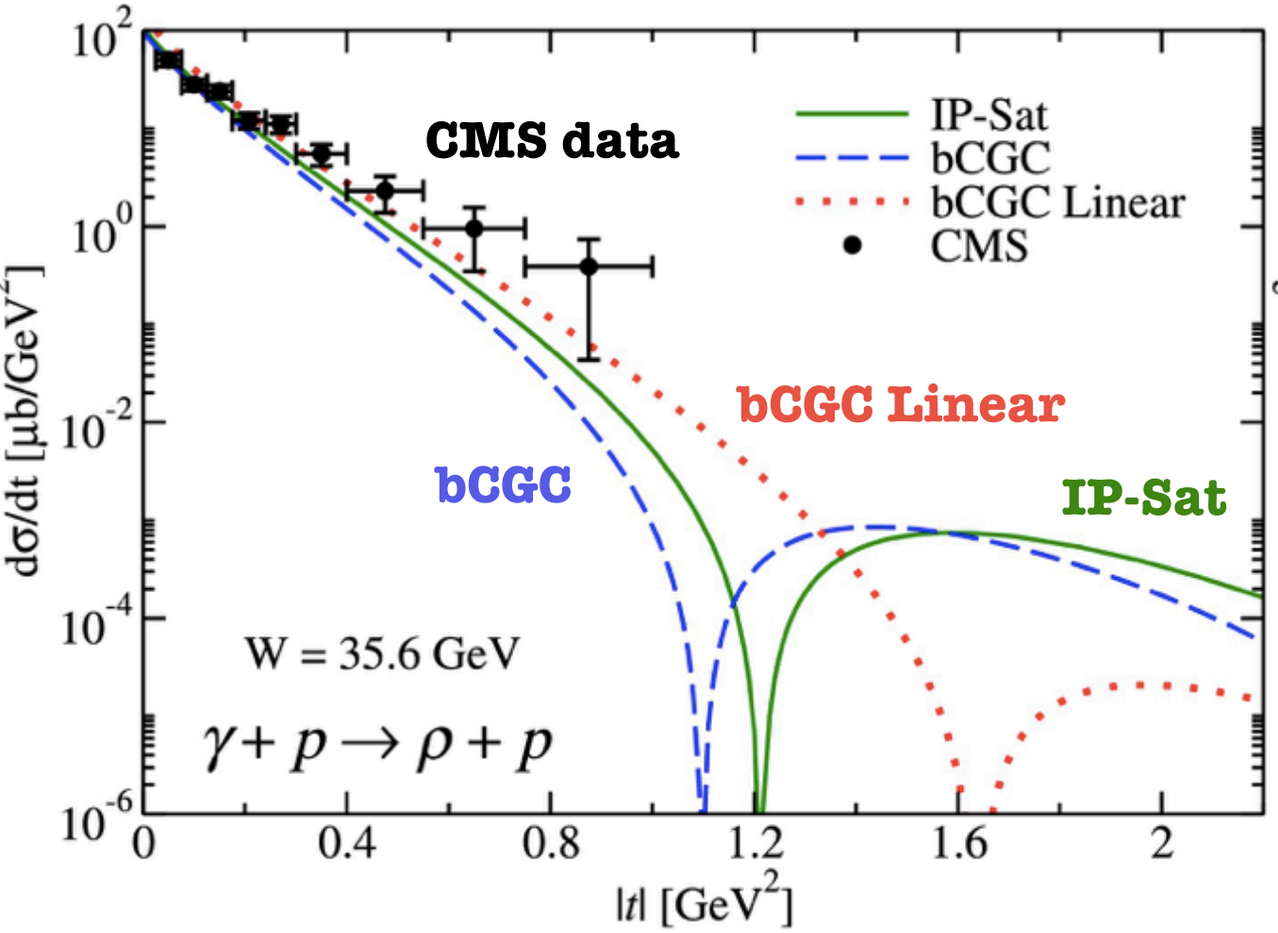


UPC Photo-production: $\rho(770)^0$ in pPb@5.02TeV

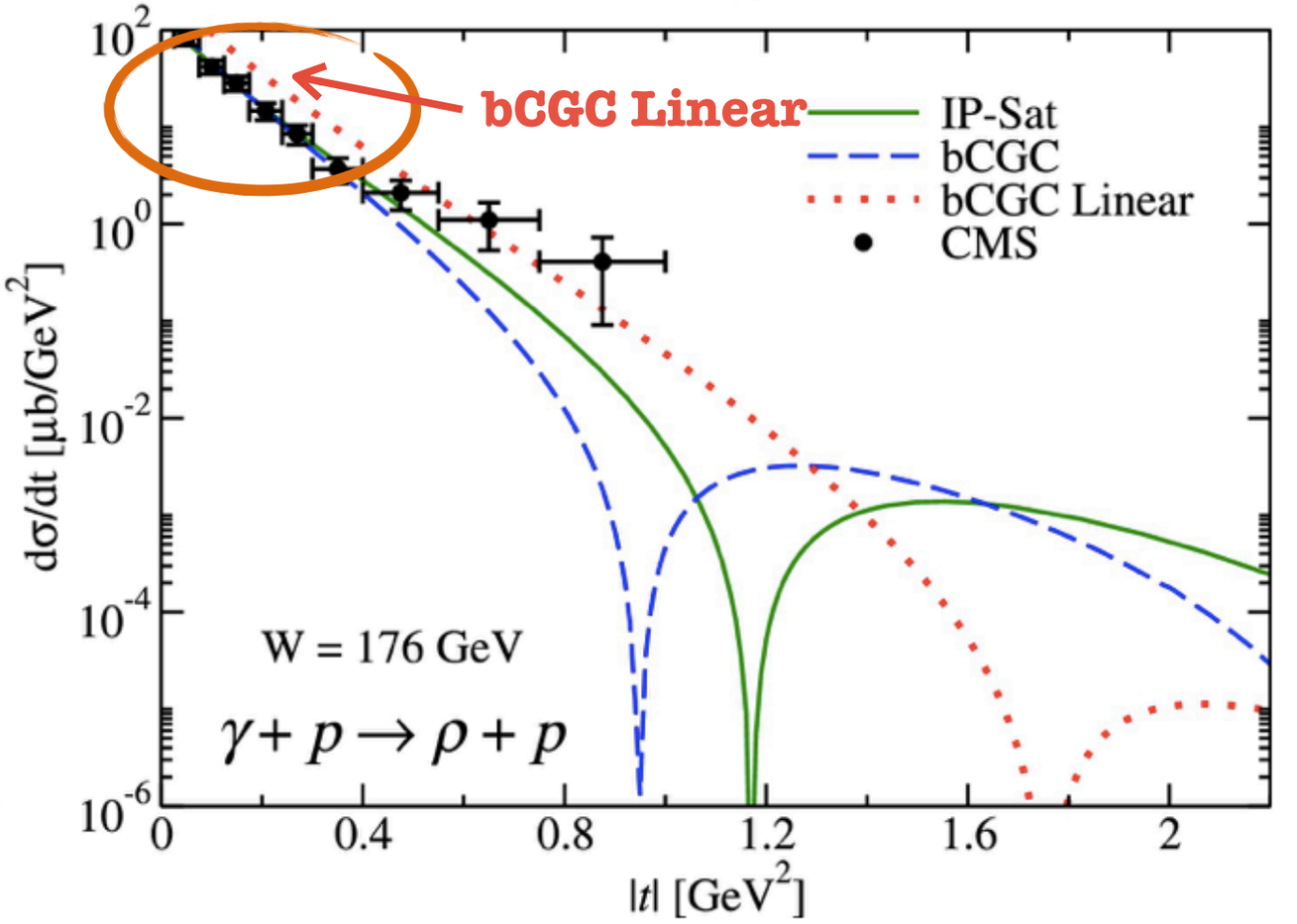
Marek Bohdan Walczak, Tues. 17.40

arXiv:1902.01339, PLB 791(2019)299

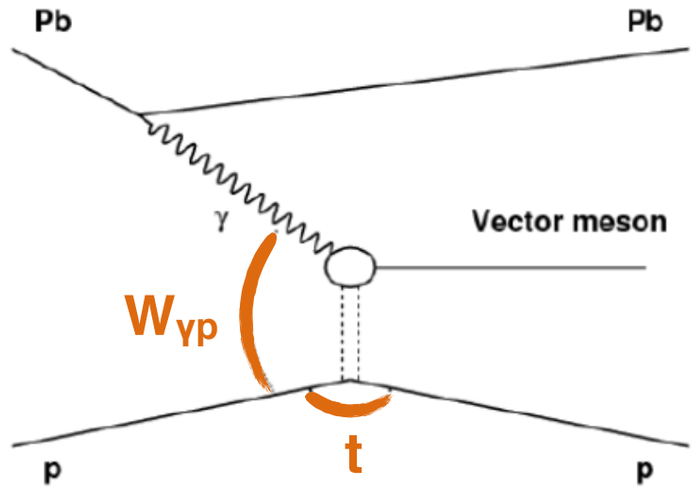
$\rho(770)^0$ vs. t, $W_{\gamma p}$ = 35.6 GeV



$\rho(770)^0$ vs. t, $W_{\gamma p}$ = 176 GeV

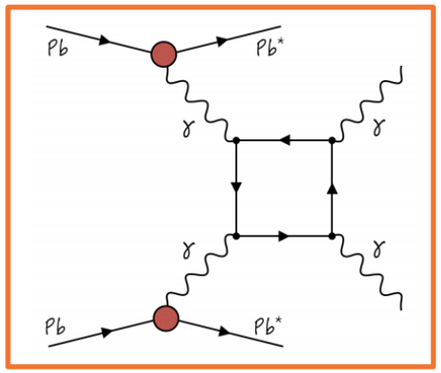


- First measurement of the energy-dependent dσ/dt!
  - ➡ 4 energy points
- The energy dependence of the low-t values for UPC $\rho(770)^0$ is sensitive to the onset of gluon saturation
  - ➡ |t| < 0.5: data gets closer to calculations with nonlinear components (saturation) at high energy

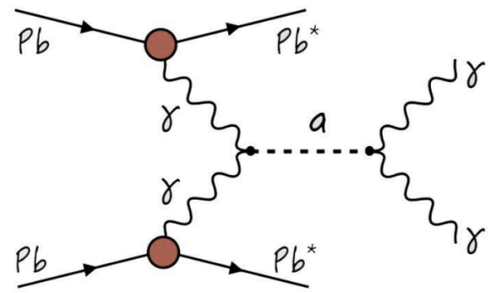


UPC: Search for Axion in PbPb@5.02TeV

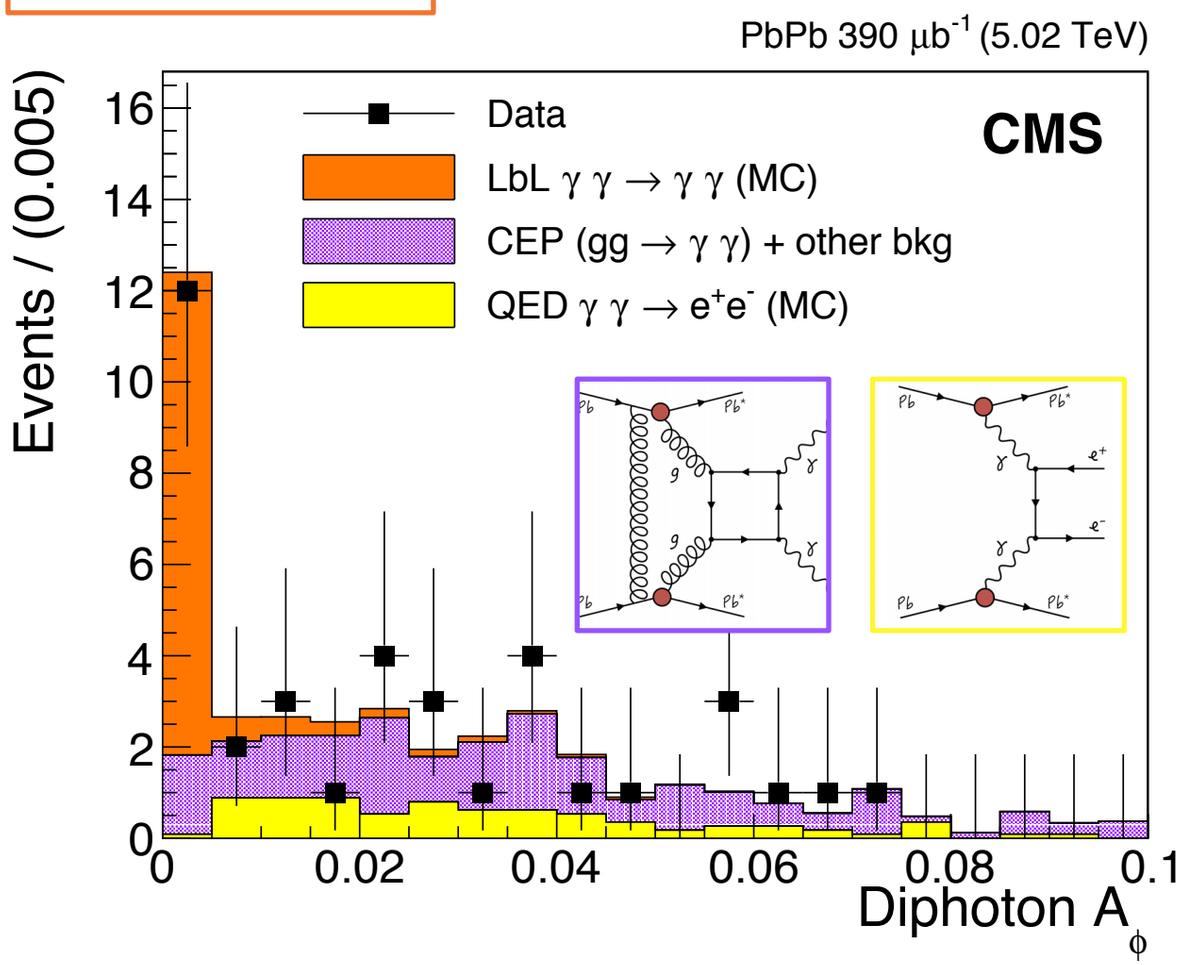
arXiv:1810.04602

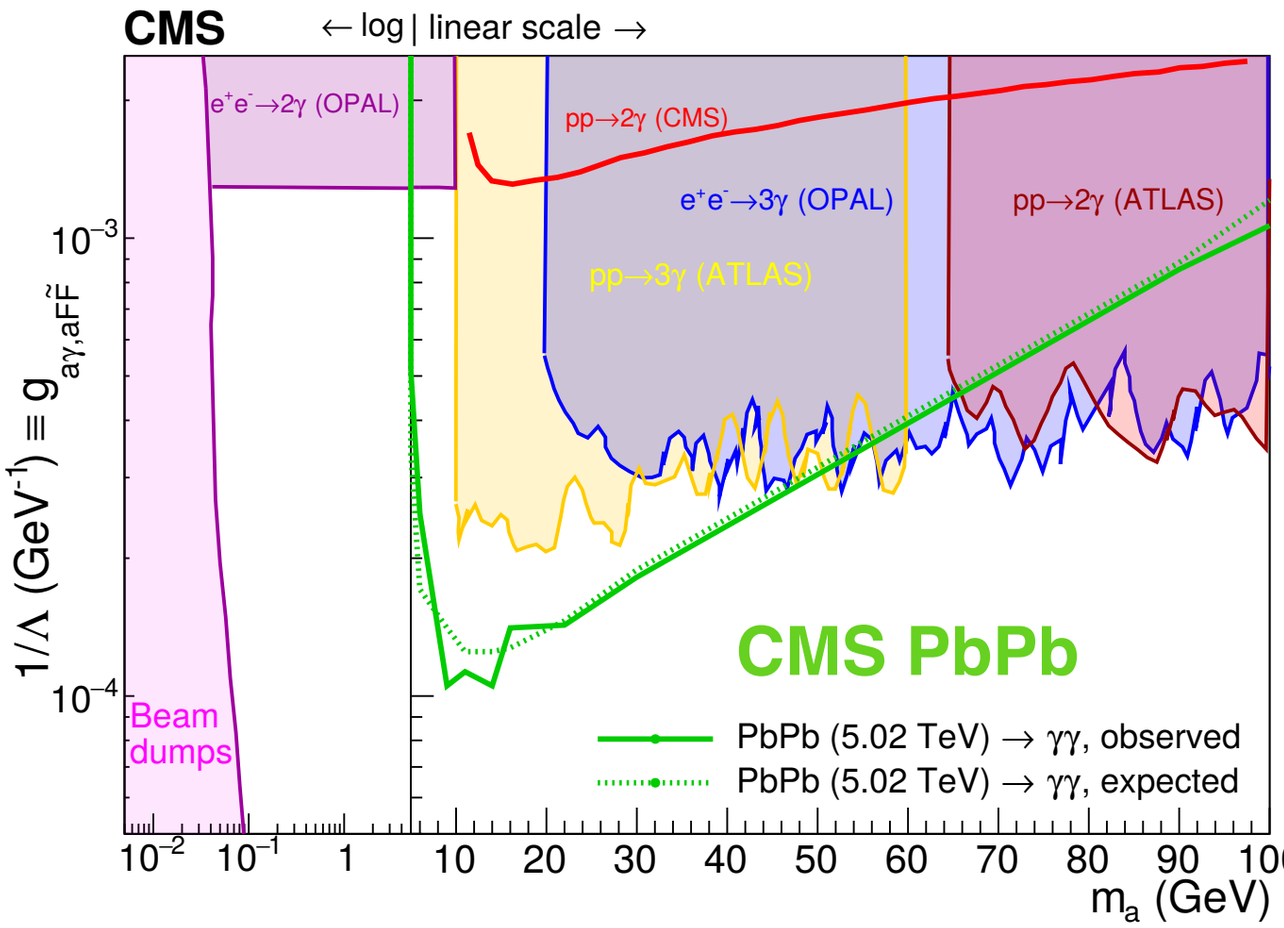


Direct observation of light-by-light scatterings



New limits on axion-like particles





- Strong EM field between Pb-Pb provides a large photon flux
- Observed 14 light-by-light events (4.1σ)
- New limits on axion-like particles over m_a = 5-50 GeV

Chapter 3

Constrain nPDF

- x: 10^{-3}-10^{-1}, $Q^2 \sim M^2_{W/Z}$ • Electroweak boson in pA
- x: 10^{-3}-10^{-1} • Isolated photon in pA(AA)
- high x, $Q^2 \sim M^2_t$ • Top production in pA
- x: 10^{-2}-10^{-1} • Dijet in pA
- x: $\sim 10^{-6}$ • Forward jets

Small-x QCD (UPC)

- $W_{\gamma p}$: 10-10^3 GeV • Photo-production J/ψ,ϒ in UPC
- $W_{\gamma p}$: 10-10^2 GeV • Photo-production ρ in UPC
- Diffraction • Forward rapidity gap
- Search axion • Light-by-light scatterings

Initial Fluctuations + Correlations in Small Syst

- Higher-order flow harmonics
- Multi-particle correlations in small system
- Symmetric Cumulant

Probe Full Evolution with Heavy Quarks

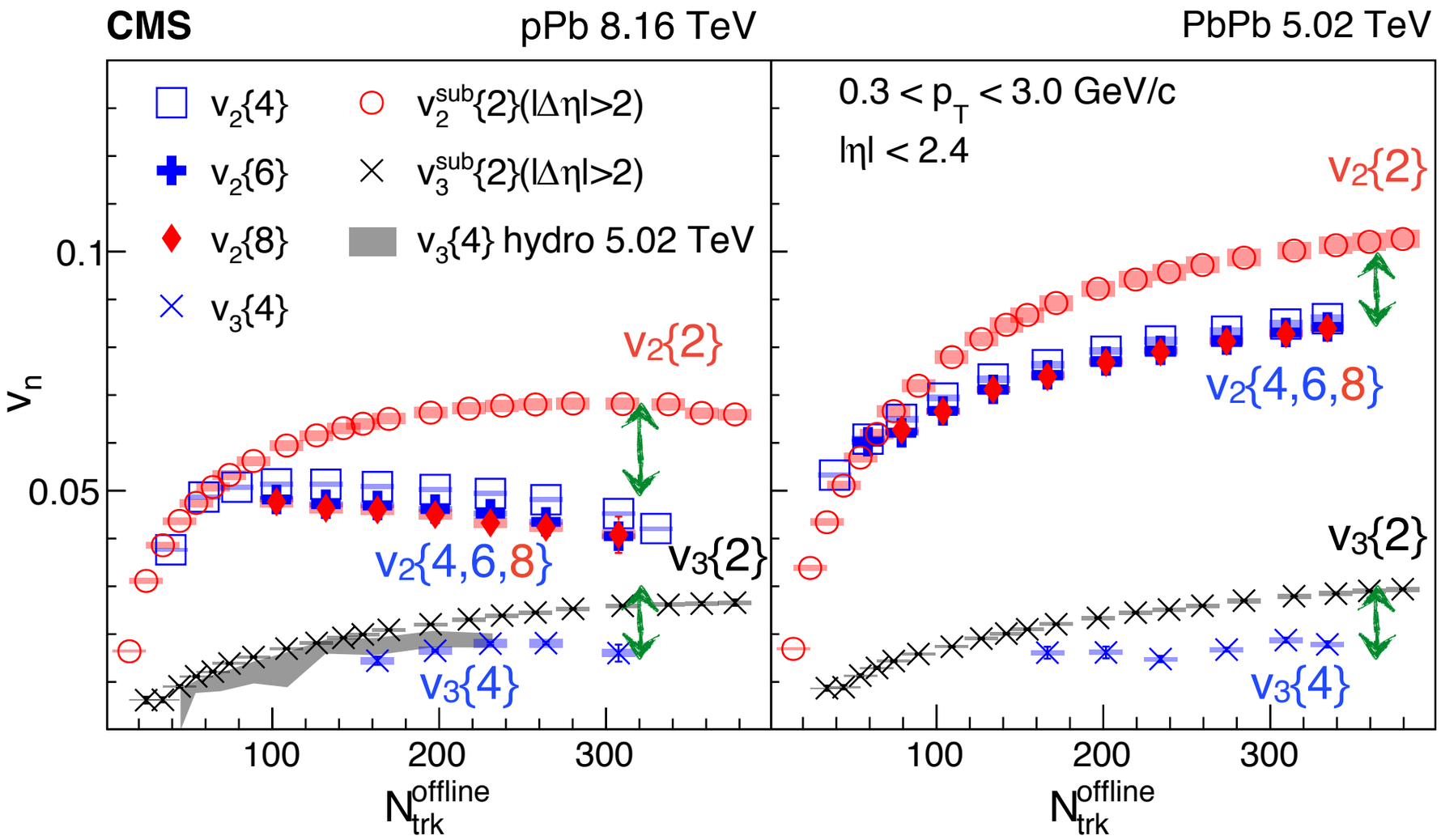
- Produced in early stages
- Open and hidden heavy flavor hadronization
- Correlations in pp, pA, AA

Multi-particle Correlation in pPb@8.16TeV+PbPb@5.02 TeV

Shengquan Tuo
Wed. 16.30

arXiv:1904.11519

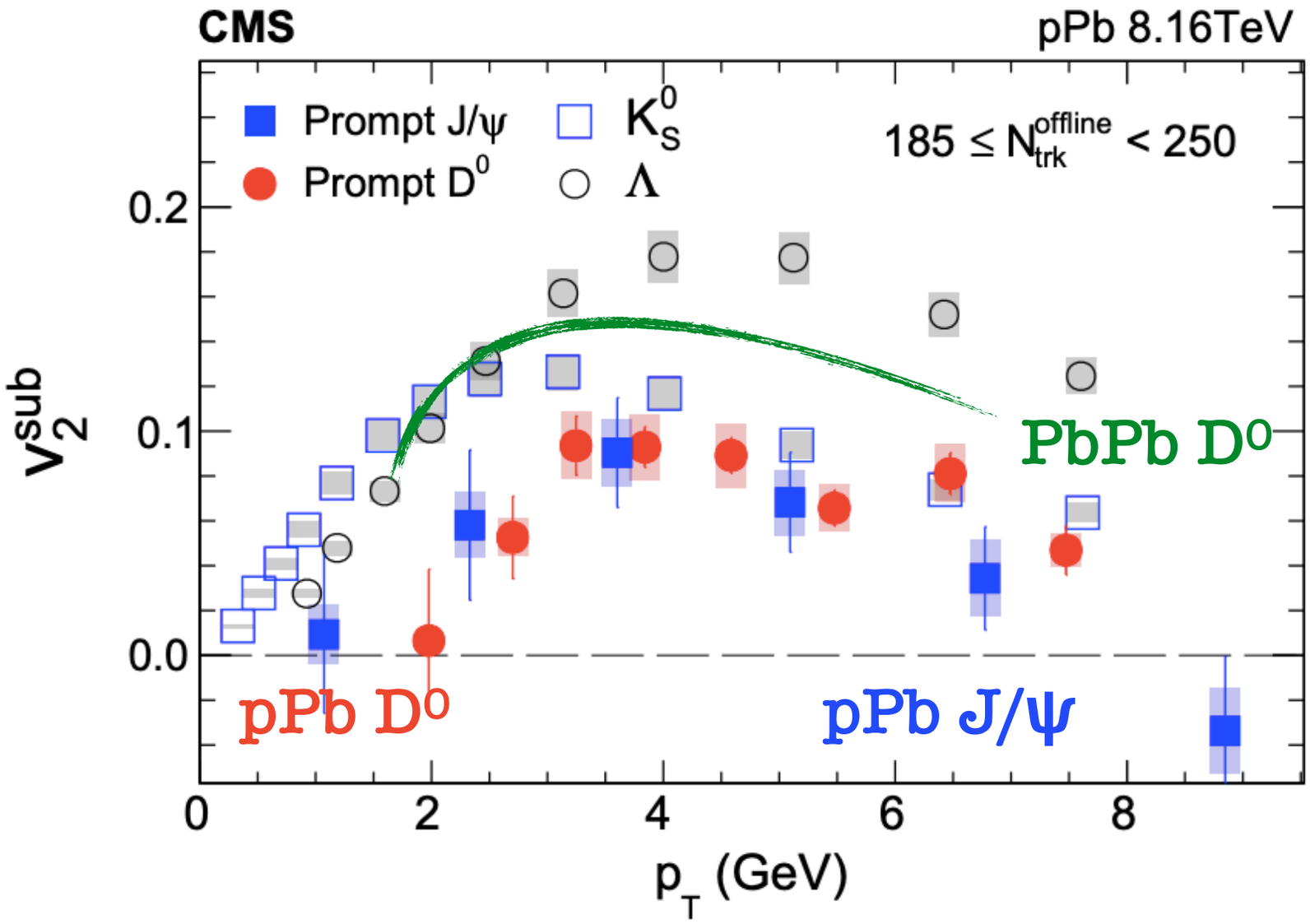
pPb **PbPb**



- v_2(PbPb) > v_2(pPb) ⇒ v_2(PbPb) dominated by global geometry (in hydrodynamic picture)
- v_3(pPb) ≈ v_3(PbPb) ⇒ v_3 driven by initial fluctuations
- First $v_3\{4\}$ measurement in pPb collisions
- $v_n\{2\} > v_n\{4,(6,8)\}$ for both pPb and PbPb ⇒ significant fluctuation components
- pPb has real $v_2\{4\} \approx v_2\{6\} \approx v_2\{8\}$ ⇒ collective behavior in pPb

Prompt D^0 and prompt J/ψ v_2 in pPb@8.16TeV

PRL 121 (2018) 082301
PLB 791 (2019) 172



- Significant **positive prompt D^0** and **J/ψ v_2** in high-mult **pPb**
  - ➡ Direct evidence of charm quark v_2 in pPb
  - ➡ v_2 (prompt D^0) ≈ v_2 (prompt J/ψ)
- D^0 v_2 (pPb) < D^0 v_2 (PbPb) at given p_T

Chapter 4

Constrain nPDF

- x: 10^{-3}-10^{-1}, $Q^2 \sim M^2_{W/Z}$ • Electroweak boson in pA
- x: 10^{-3}-10^{-1} • Isolated photon in pA(AA)
- high x, $Q^2 \sim M^2_t$ • Top production in pA
- x: 10^{-2}-10^{-1} • Dijet in pA
- x: $\sim 10^{-6}$ • Forward jets

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Probe Full Evolution with Heavy Quarks

- Produced in early stages
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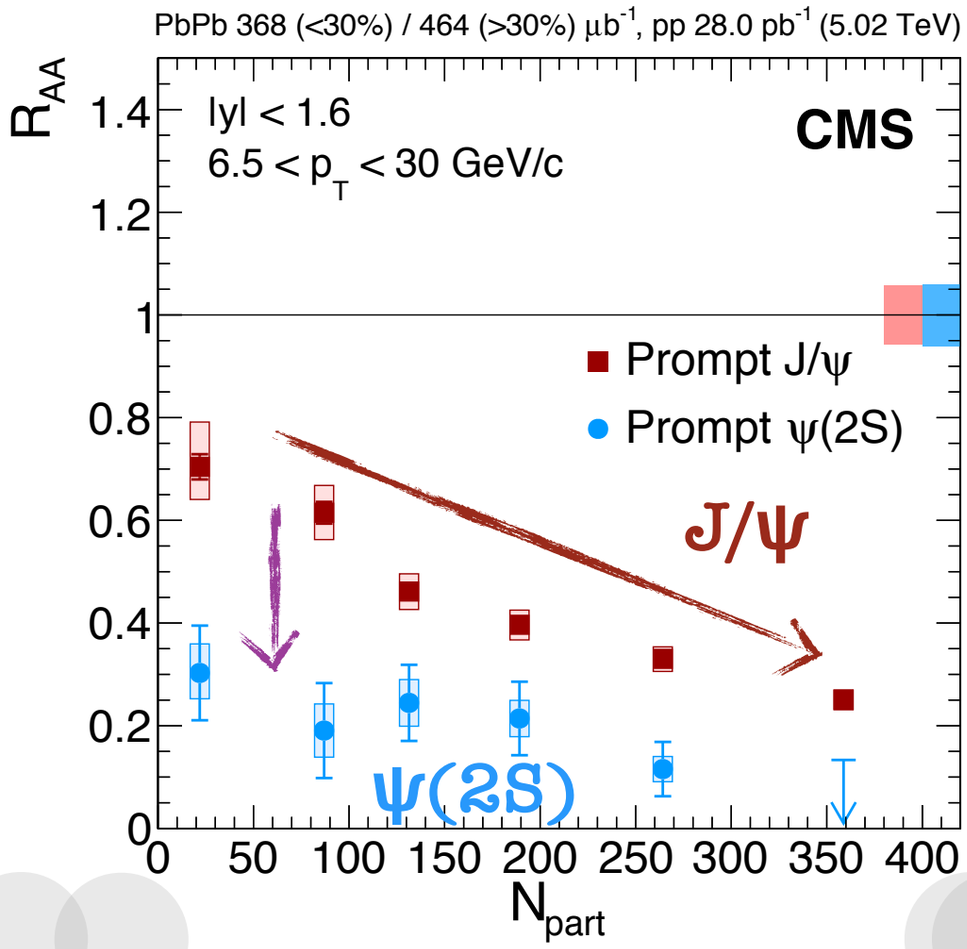
- Correlations in pp, pA, AA

Charmonia Production in PbPb + pPb @5.02TeV

EPJC 78 (2018) 509

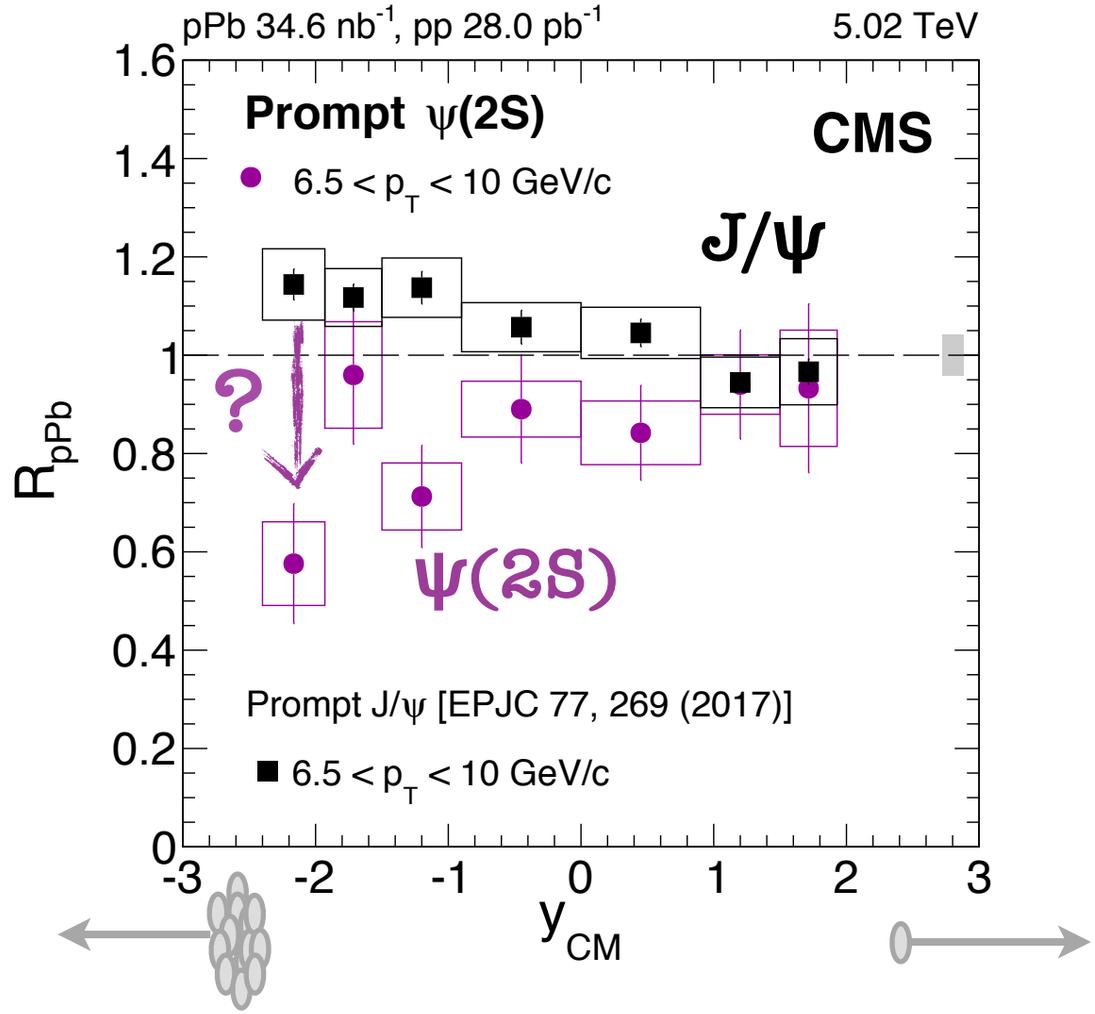
PLB 790 (2019) 509

PbPb (2015)



- Strong suppression for ψ(2S) and J/ψ
- **ψ(2S) R_{AA} < J/ψ R_{AA}** in **PbPb**

pPb



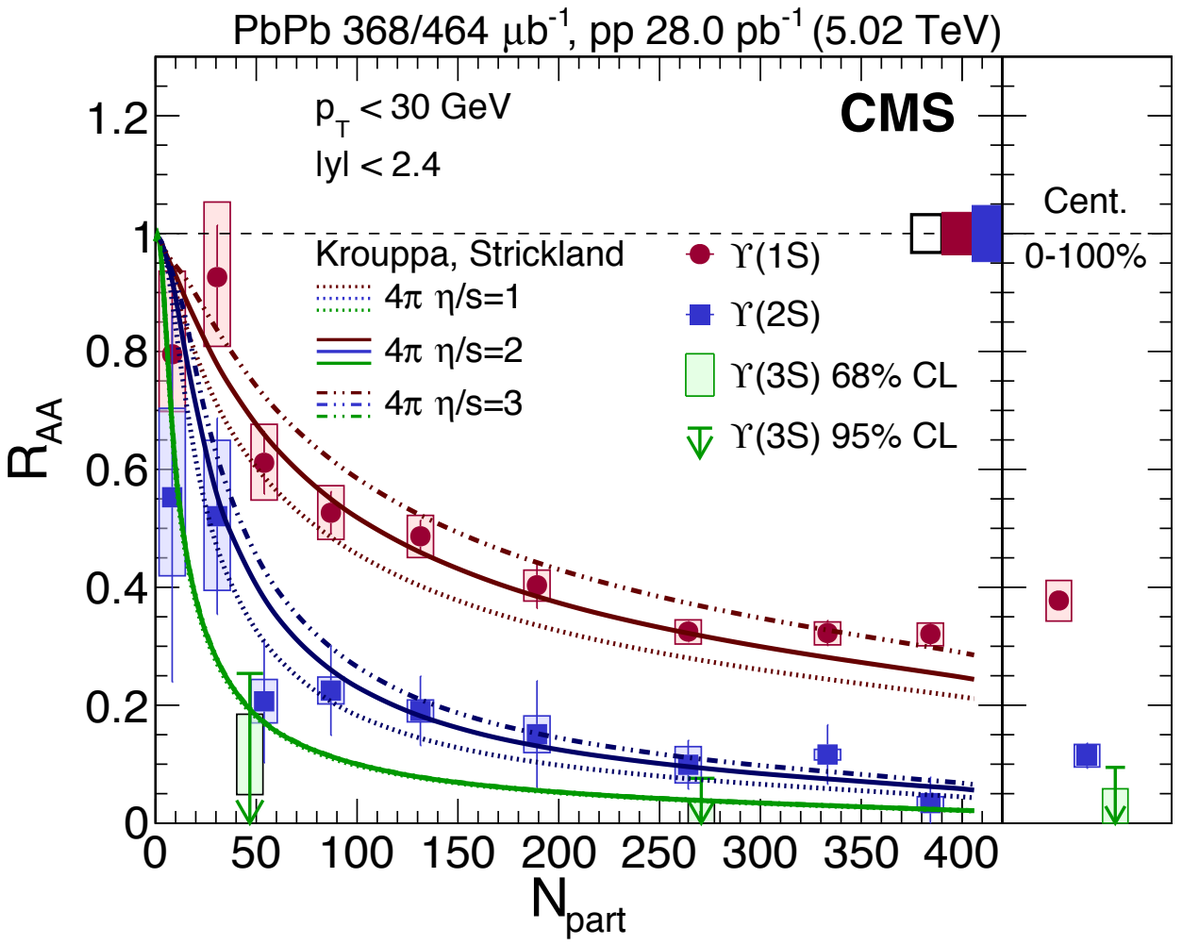
- Constrain CNM effects
- **ψ(2S) R_{pA} < J/ψ R_{pA}** in **pPb**
  - ➡ Cannot be explained by nPDF or coherent energy loss

ϒ Sequential Suppression in PbPb@5.02TeV

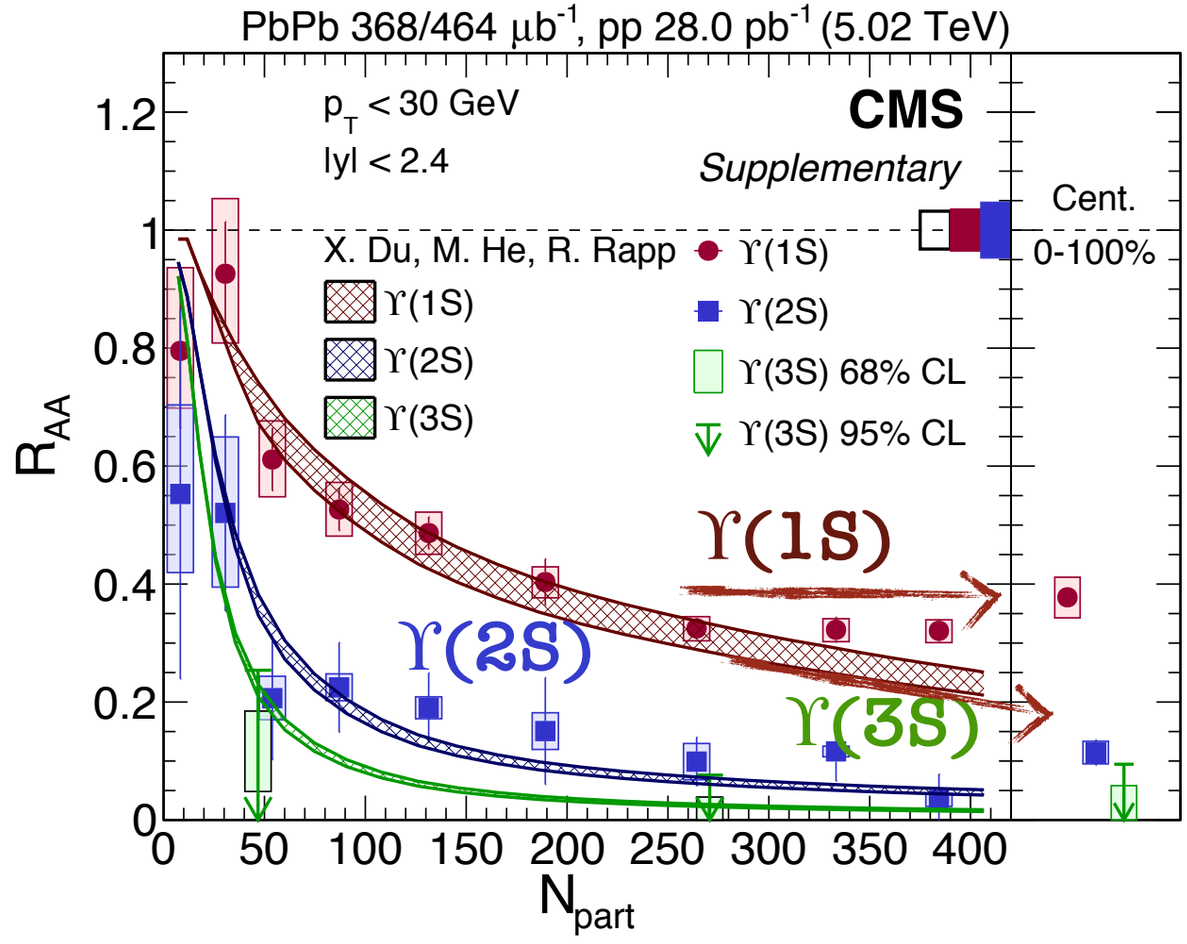
Yongsun Kim
Wed. 14.20

PLB 790 (2019) 270

R_{AA} vs. model w/o ϒ regeneration

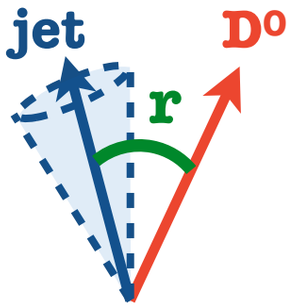


R_{AA} vs. model w/ ϒ regeneration

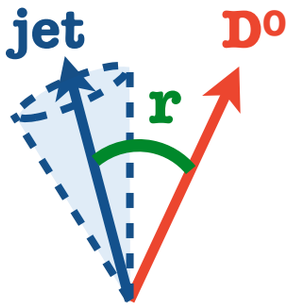


- No sign of ϒ(3S) in PbPb data (2015) ⇒ 2018 has 5x more!
- Agree with models with **melting + with or without** ϒ regenerations
- Deviation between data and theory at most central events?
- At most central and most peripheral events larger η/s agrees better

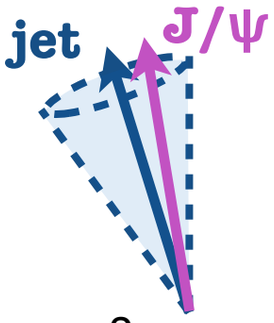
Heavy Flavor in Jets in pp + PbPb @5.02TeV



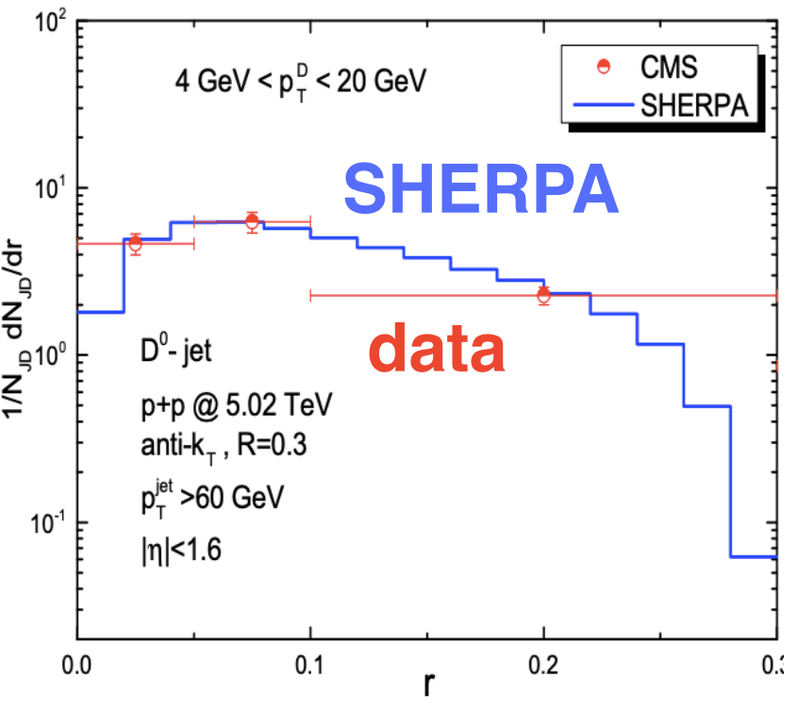
D⁰ in pp

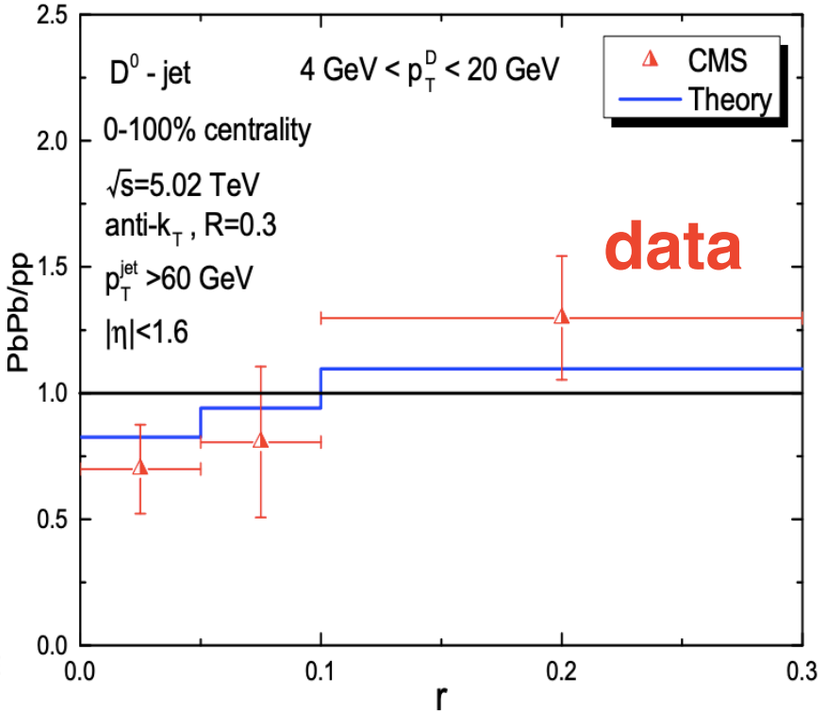


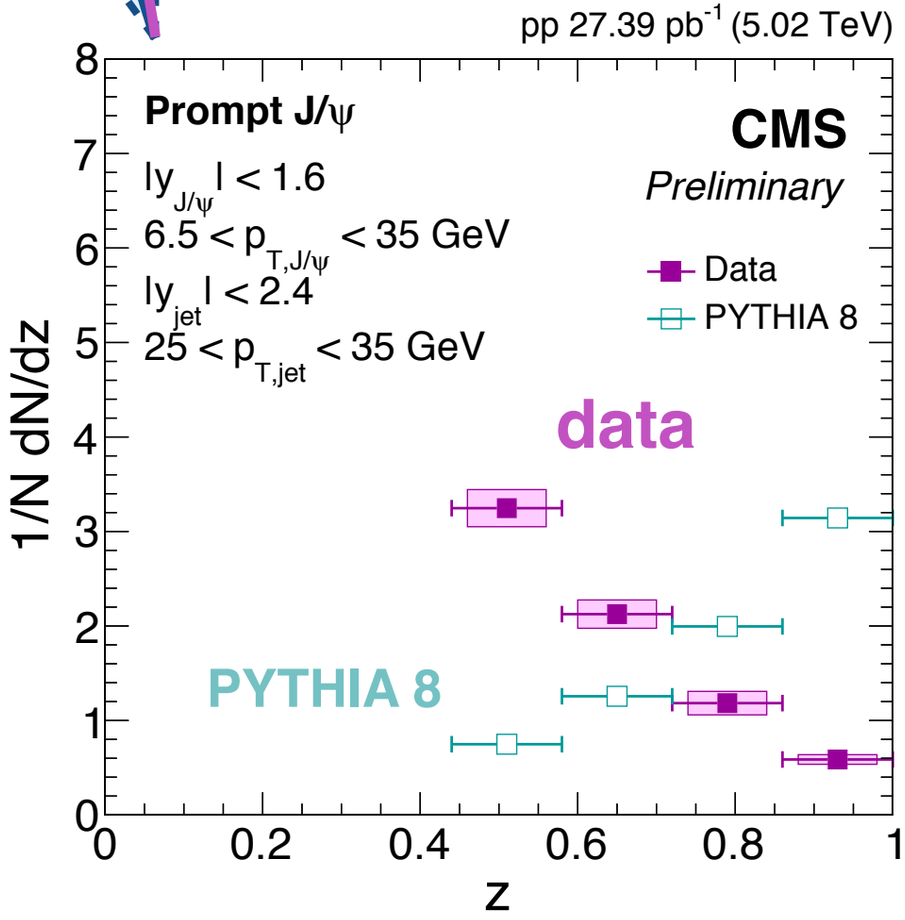
D⁰ in PbPb



prompt J/ψ in pp







- pp: agrees with SHERPA calculations
- PbPb/pp: increases as a function of r
  - ➡ Hint that D⁰ are further from jet axis in PbPb than pp
  - ➡ Consistent with theoretical models inside jet cone

- Prompt J/ψ not described by PYTHIA8
  - ➡ PYTHIA 8 too much harder
- Similar as observed by LHCb in different kinematics

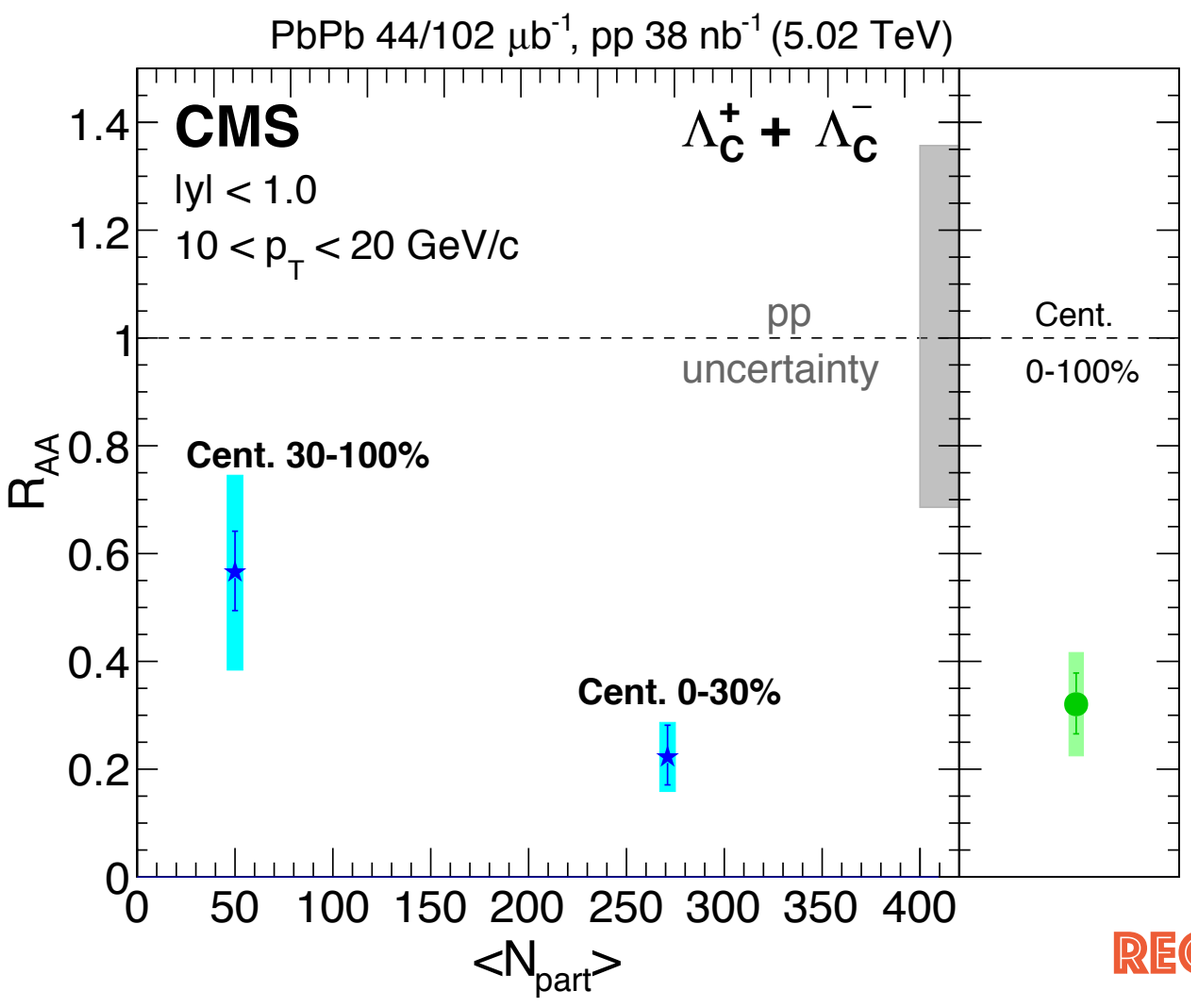
arXiv:1906.01499
CMS-PAS-HIN-18-007

CMS-PAS-HIN-18-012

Charm Hadronization: Λ_c in PbPb@5.02TeV

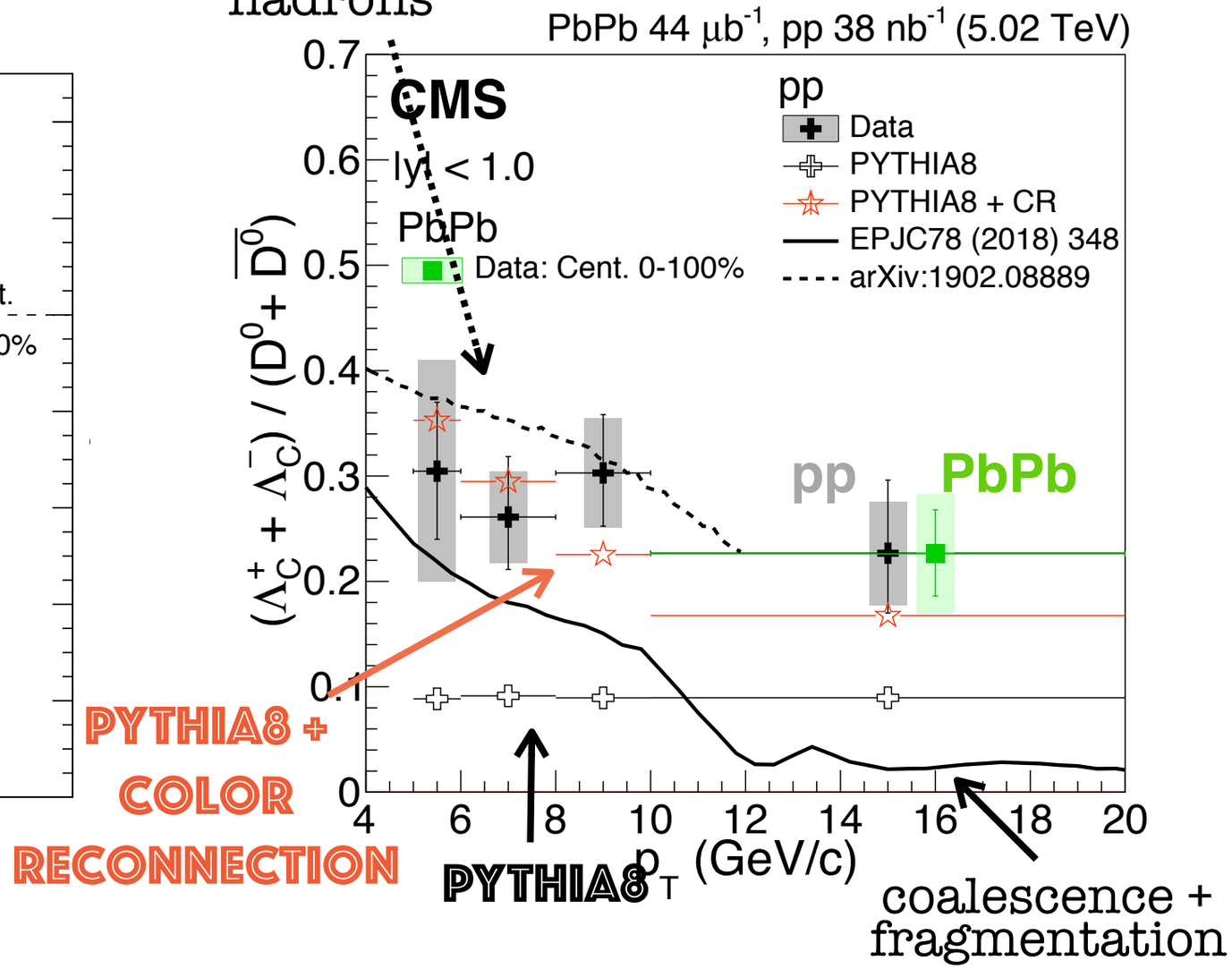
arXiv:1906.03322

R_{AA}



Λ_c/D^0

Feed down from excited charm hadrons

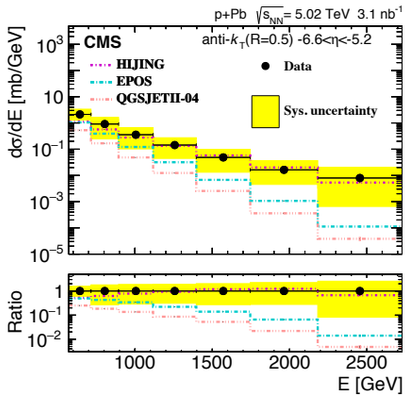


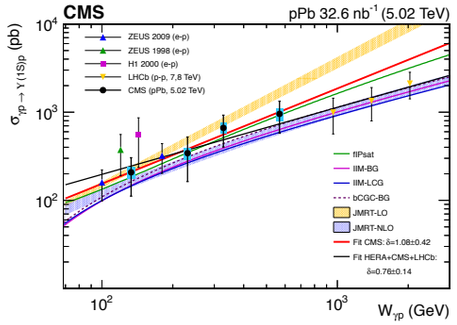
- pp Λ_c to D^0 ratio is ~3x higher than PYTHIA8
- Agreement with PYTHIA8 + color reconnection mechanism
- Similar ratio of Λ_c to D^0 in $10 < p_T < 20$ GeV/c in pp and PbPb within large uncertainties

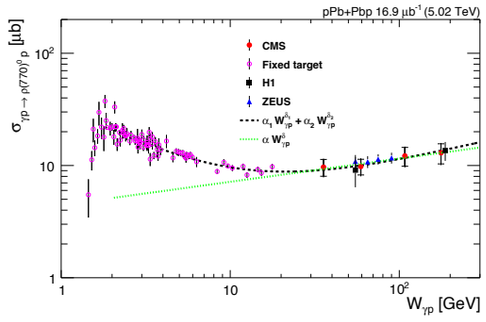
Summary

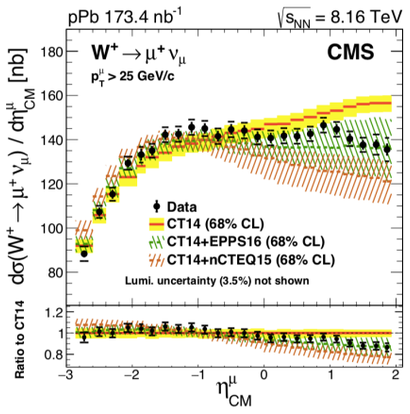
Various studies on IS from CMS in different systems!

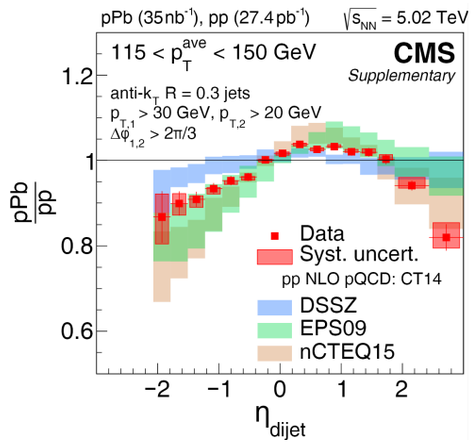
pPb

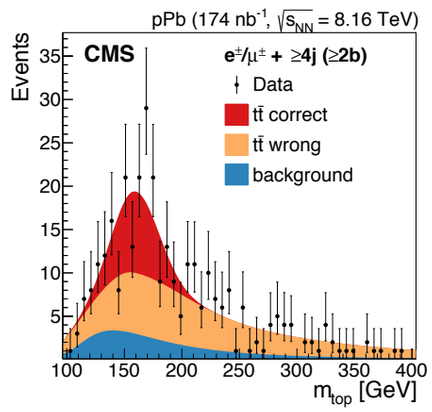


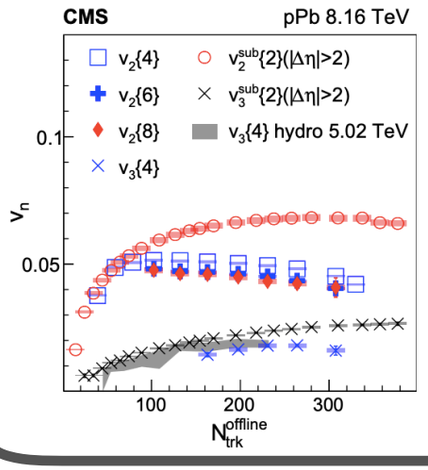


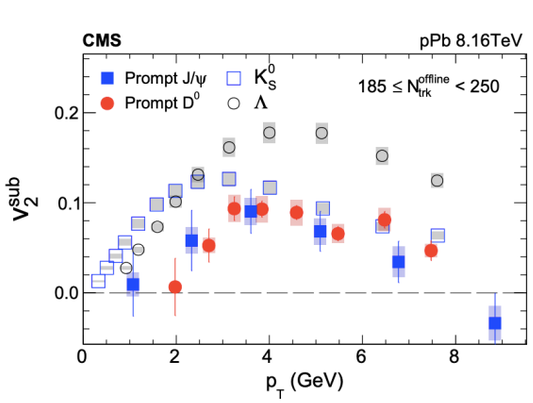


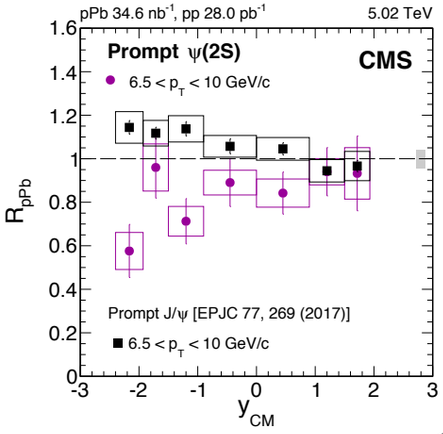




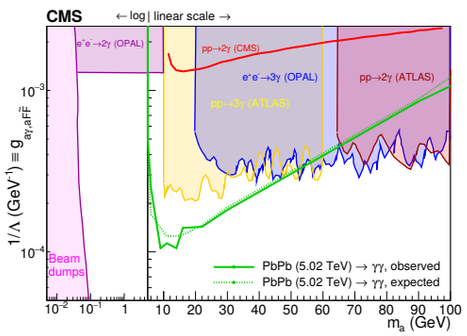


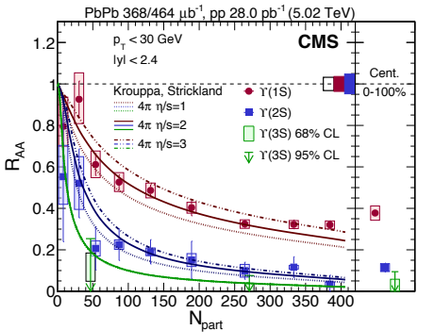


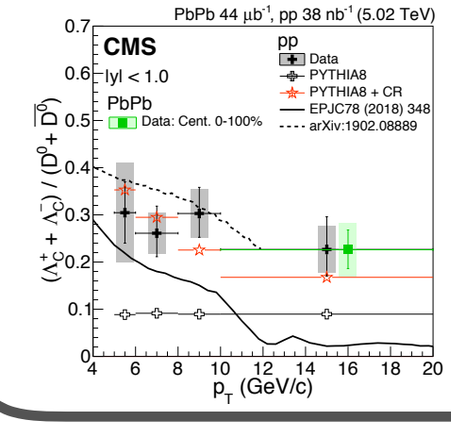


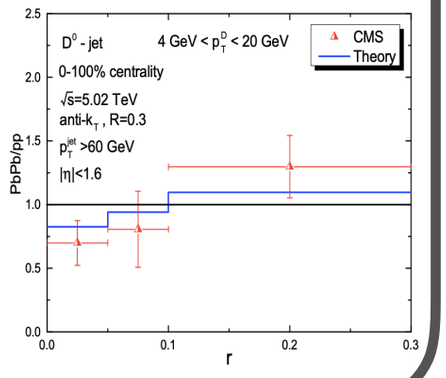


PbPb

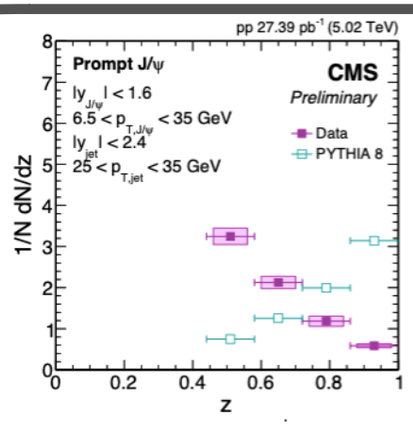








pp



The MIT RHIG's work was supported by US DOE-NP

Summary

Various physics messages on initial stages from CMS!

- Observation of light-by-light scattering, new limit of axion-like particles
- Photo-production ρ t-distribution sensitive to the onset of saturation
- Small x_{Pb}~10^{-6} probed with forward jets
- ϒ photo-production in unexplored W region
- Evidence of quark shadowing, gluon (anti-)shadowing and EMC effects in Pb
- L_c production much higher than PYTHIA8
- Strong constrain to gluon nPDF by dijet η result
- J/ψ much less isolated than PYTHIA8
- Observation of top production in pPb
- Smaller ψ(2S) R_{pA} than J/ψ in the Pb-going direction
- Large v_2 of D^0 and J/ψ in pPb
- Fluctuations studied with multi-particle correlations
- ϒ(nS) sequential suppression in PbPb

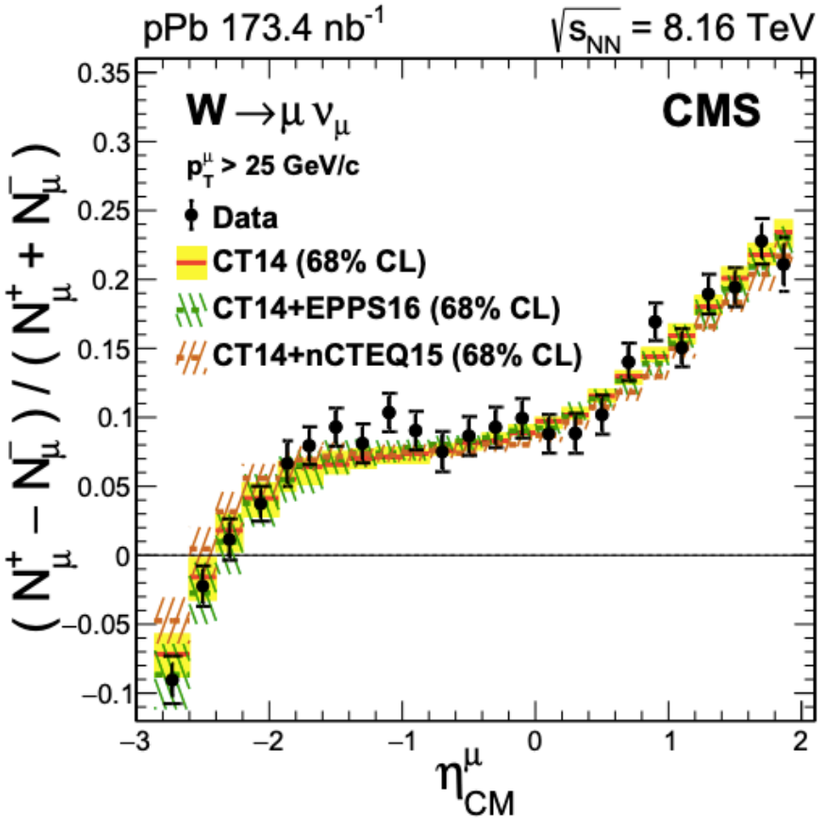
The MIT RHIG's work was supported by US DOE-NP

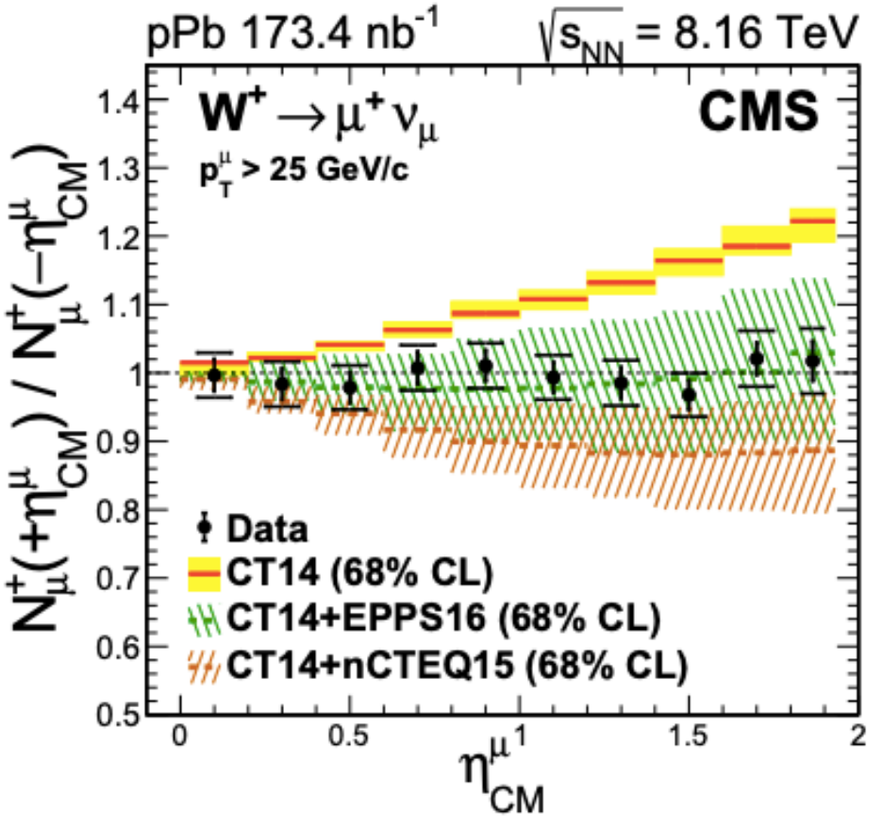
Back up

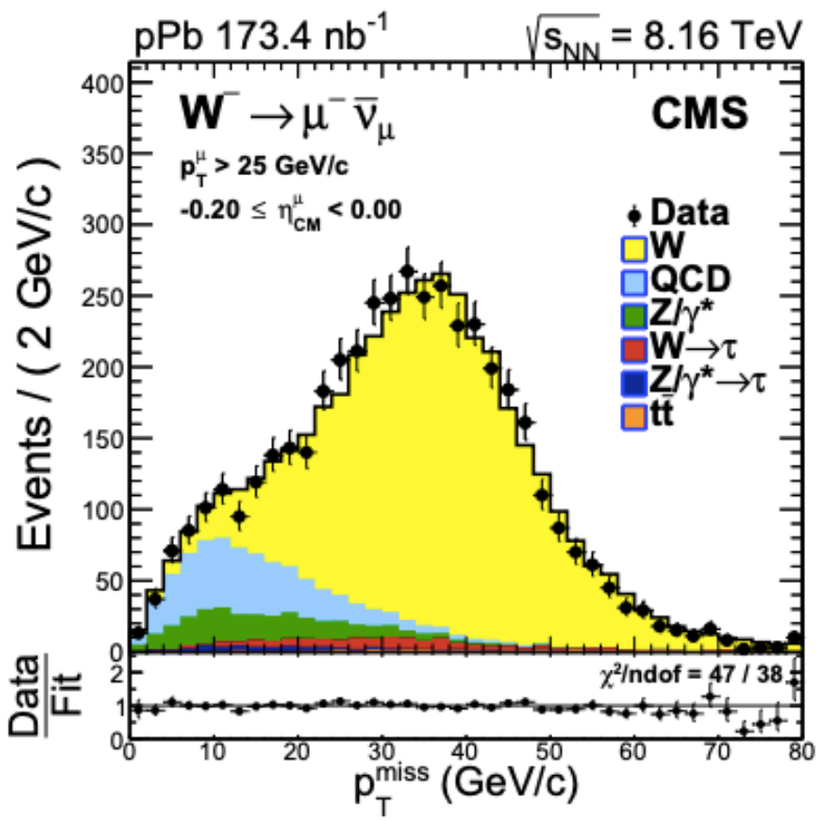
Thanks for your attention!

Cheat sheet: W production in pPb

- **$W \rightarrow \mu\nu$**
- **2016 pPb+Pbp @8.16TeV** (6.5TeV+2.56TeV), $\eta_{lab} = \eta_{CM}$-0.465
- **Trigger**: at least one μ $p_T > 12$GeV
- **Evt sel (EM cont)**: interaction vertex(N_{trk}>1), HF leading tower > 3 GeV (< 0.2% loss)
- **Offline μ**: $p_T > 25$ GeV, $|\eta| < 2.4$, isolated $I < 0.15$
- **Background**: DY(remove events with >=2 isolated μ), QCD multijet(data-driven, nonisolated muon), others (MC)
- **Signal ext**: fit on missing pT(from PF obj), 97971±332 μ+, 81147±301 μ-
- **Leading syst**: TnP







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- **Background**: DY(remove events with >=2 isolated μ), QCD multijet(data-driven, nonisolated muon), others (MC)
- **Signal ext**: fit on missing pT(from PF obj), 97971±332 μ+, 81147±301 μ-
- **Leading syst**: TnP
- Account for bin-to-bin correlations of uncertainties (experimental and theoretical)

Observable	CT14			CT14+EPPS16			CT14+nCTEQ15		
	χ^2	dof	Prob. [%]	χ^2	dof	Prob. [%]	χ^2	dof	Prob. [%]
$d\sigma^{W^\pm \to \mu^\pm \nu_\mu}(\eta^\mu_{CM})/d\eta^\mu_{CM}$	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
$N^\pm_\mu(+\eta^\mu_{CM})/N^\pm_\mu(-\eta^\mu_{CM})$	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

Cheat sheet: Dijet in pPb

- **2013 pPb+Pbp @5.02TeV** (4TeV+1.58TeV), $\eta_{lab} = \eta_{CM}$-0.465
- No significance dijet imbanlance in pPb compared with pp
- **Trigger**: Single jet > 40, 60, 80 GeV
- **Evt sel (EM cont)**: interaction vertex(N_{trk}>1), HF coincidence > 3 GeV for +&&-, PU filter
- **Offline jet**: anti-kT PF 0.3, l η_{lab}l < 3, $p_{T,1}$ > 30 GeV, $p_{T,2}$ > 20 GeV, $\Delta\phi > 2\pi/3$
- $p_T^{ave} = (p_{T,1}+p_{T,2})/2 \sim Q$, 55 => 400 GeV
- **Leading syst**: JES
- **p value**: EPS09 (0.19), DSSZ (<10^{-8}), nCTEQ15(<10^{-8}) for one p_T^{ave}

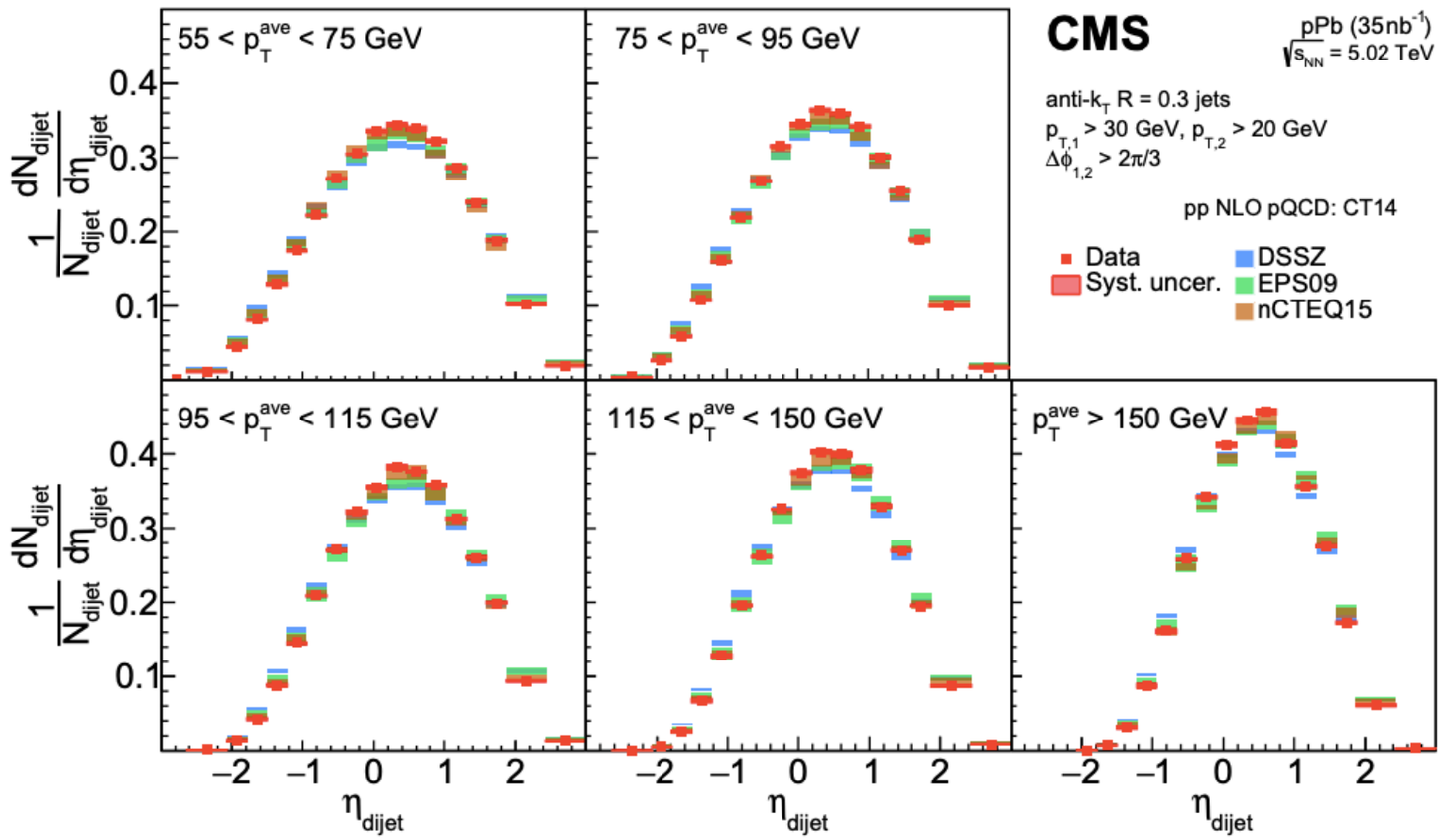
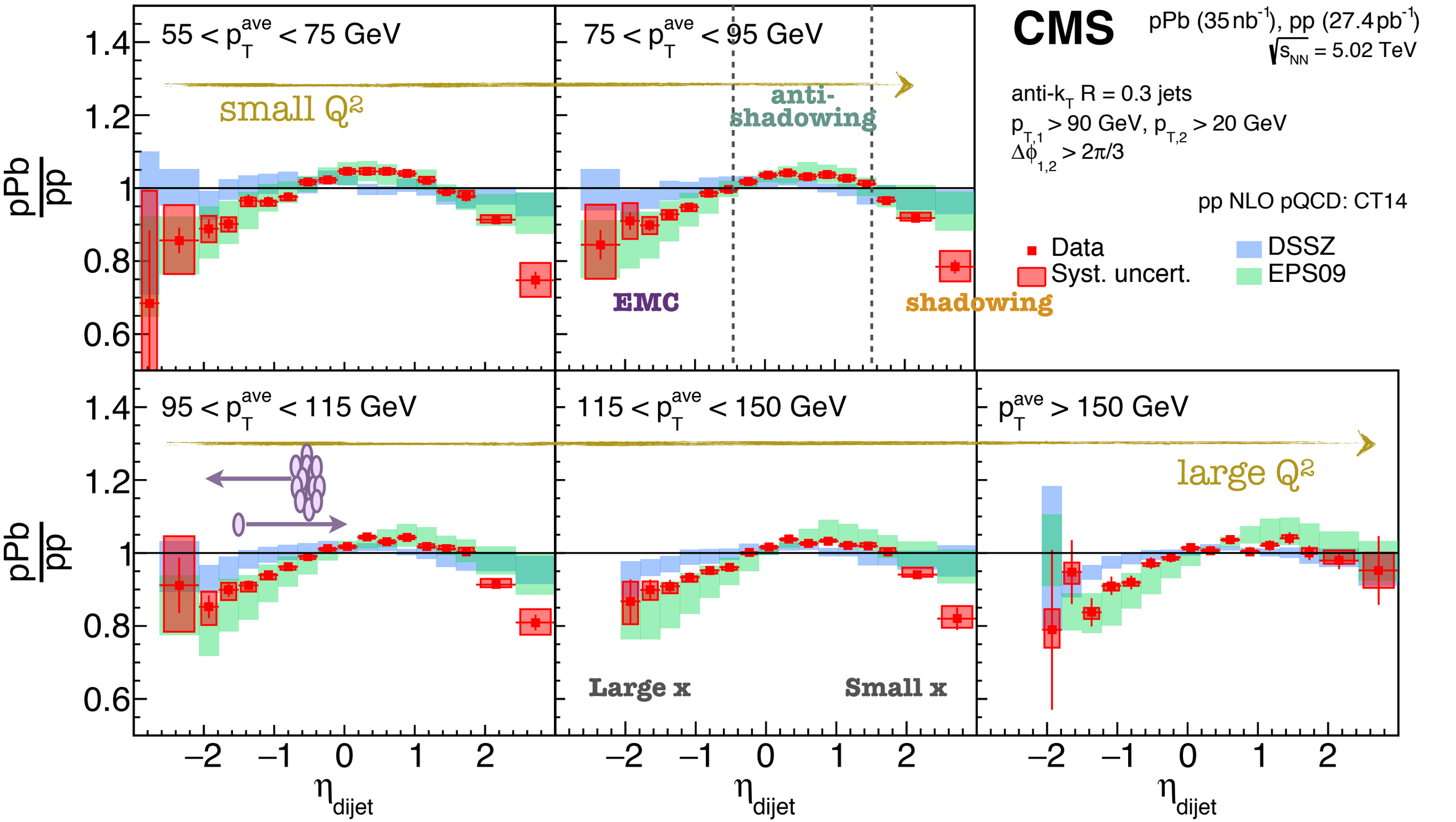


FIG. 2. The measured pPb dijet pseudorapidity spectra in bins of p_T^{ave}, overlaid with the NLO pQCD calculations of DSSZ [3], EPS09 [4], and nCTEQ15 [5] nPDFs, using the CT14 [1] as the baseline PDF. The red boxes indicate systematic uncertainties in data and the height of the NLO pQCD calculation boxes represent the nPDF uncertainties.

Cheat sheet: Dijet in pPb

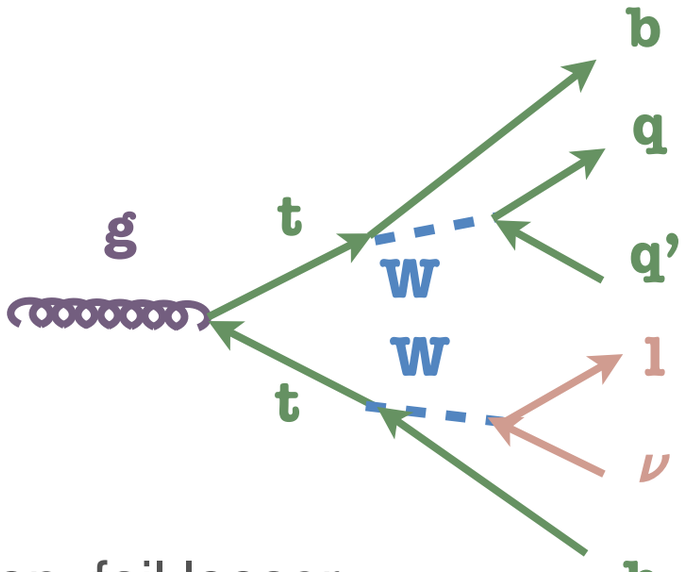
pPb 5.02 TeV

PRL 121 (2018) 062002



Cheat sheet: Top production in pPb

- **tt→WbWb→μνbjj'b** (large BR~34%, only one missing p_T)
- **2016 pPb+Pbp @8.16TeV** (6.5TeV+2.56TeV), $\eta_{lab} = \eta_{CM}$-0.465
- **Trigger**: at least one μ(e) $p_T > 12$GeV($E_T > 20$GeV)
- **Evt sel**: interaction vertex(N_{trk}>1), HF leading tower > 3 GeV,
- **Offline μ/e**: exactly one μ(e) $p_T > 30$ GeV, $|\eta| < 2.1$, isolated
- **b-tagging**: ~70% efficiency, 0.1% misidentification
- **jets**: chose two jets smallest separation
- **Background**: W+jets, QCD multijet (data-driven: opposite isolation, fail looser identification)



- 710 signals in total
- **Leading syst**: b-tagging efficiency
- A net overall anti shadowing effect increases the total to quark pair cross section by only 4% for both EPPS16 and EPS09 sets in pPb relative to pp collisions

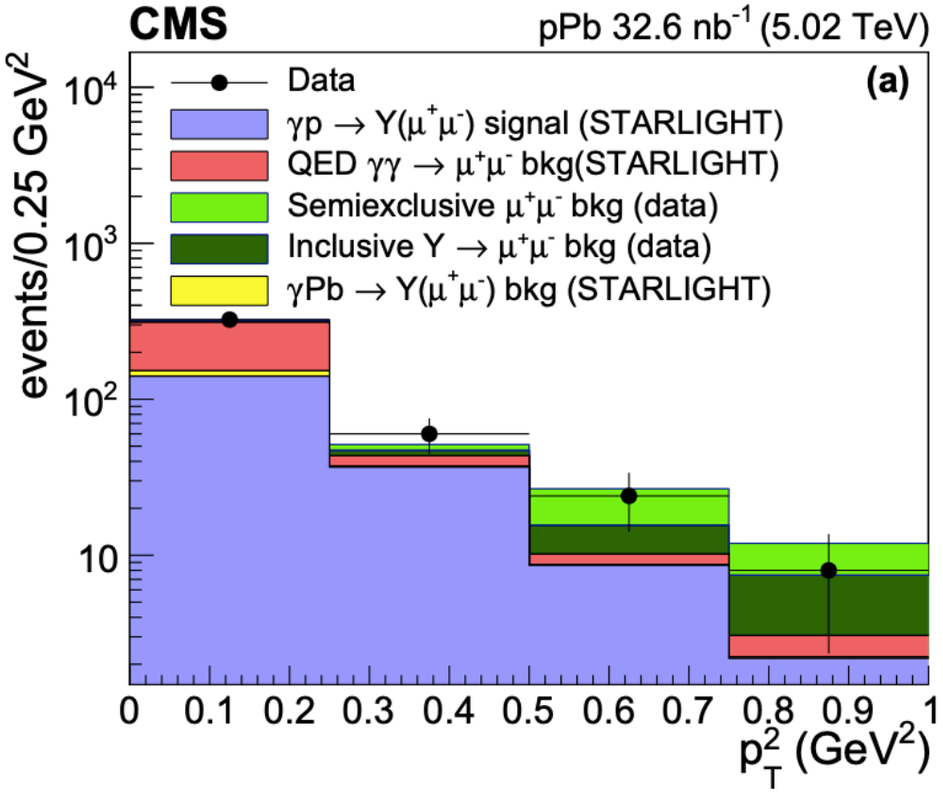
Cheat sheet: Forward jets in pPb

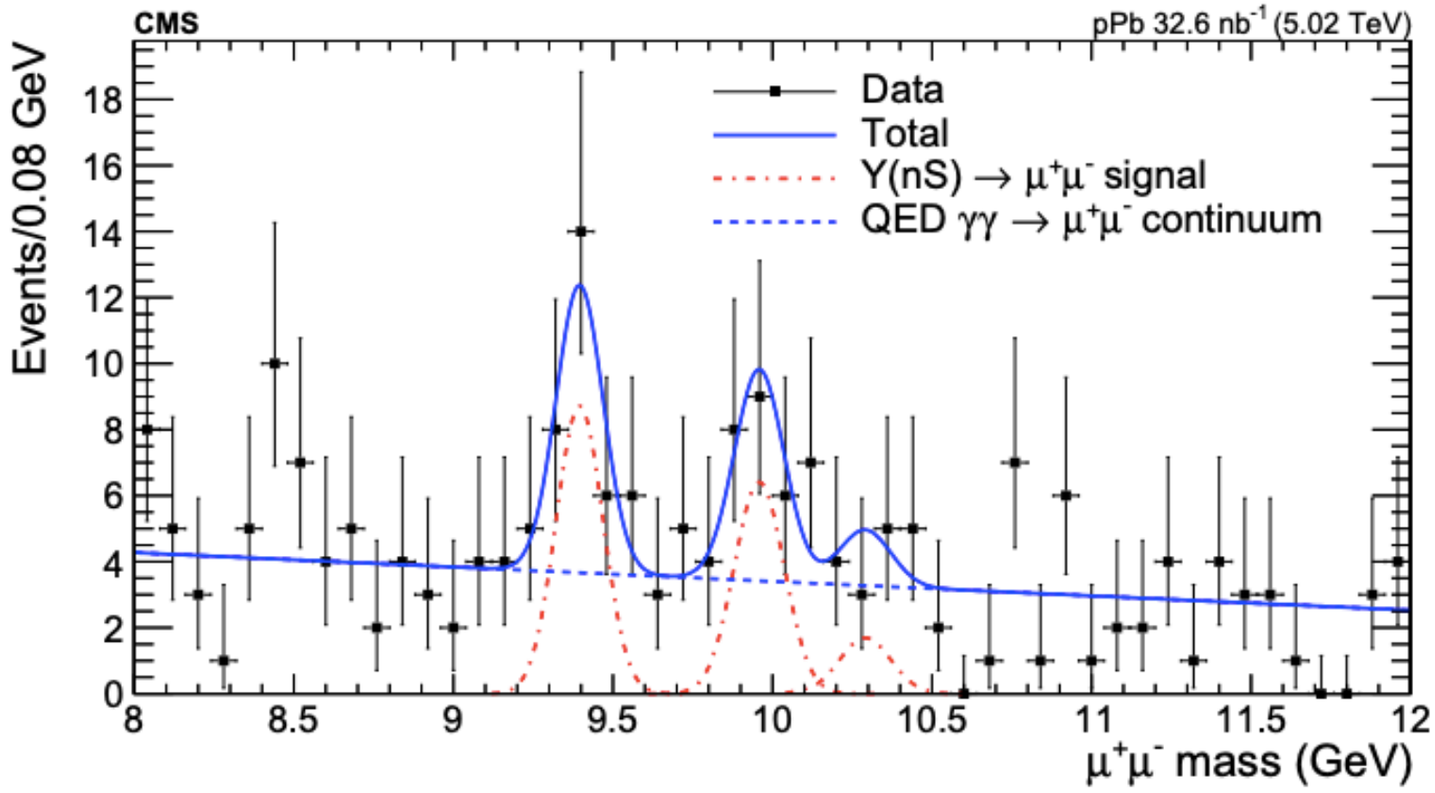
- **2013 pPb+Pbp @5.02TeV** (4TeV+1.58TeV), $\eta_{lab} = \eta_{CM}$-0.465, L=9.84 nb-1, <PU>=0.0763
- **Trigger**: MinBias + 1 pixel track
- **Evt sel**: interaction vertex(N_{trk}>1), HF coincidence > 4 GeV for +&&-, PU filter (suppress diffractive + photon-induced)
- **Offline jet**: anti-kT Calo 0.5, E > 550 GeV => p_T ~ 3 GeV (opt for missed and fake jets)
- $p_T^{ave} = (p_{T,1}+p_{T,2})/2$ ~ Q, 55 => 400 GeV
- **Leading syst**: JES + Model dependence (unfolding)
- Pbp significant contribution from ion remnants

pp figure

Cheat sheet: UPC Upsilon in pPb

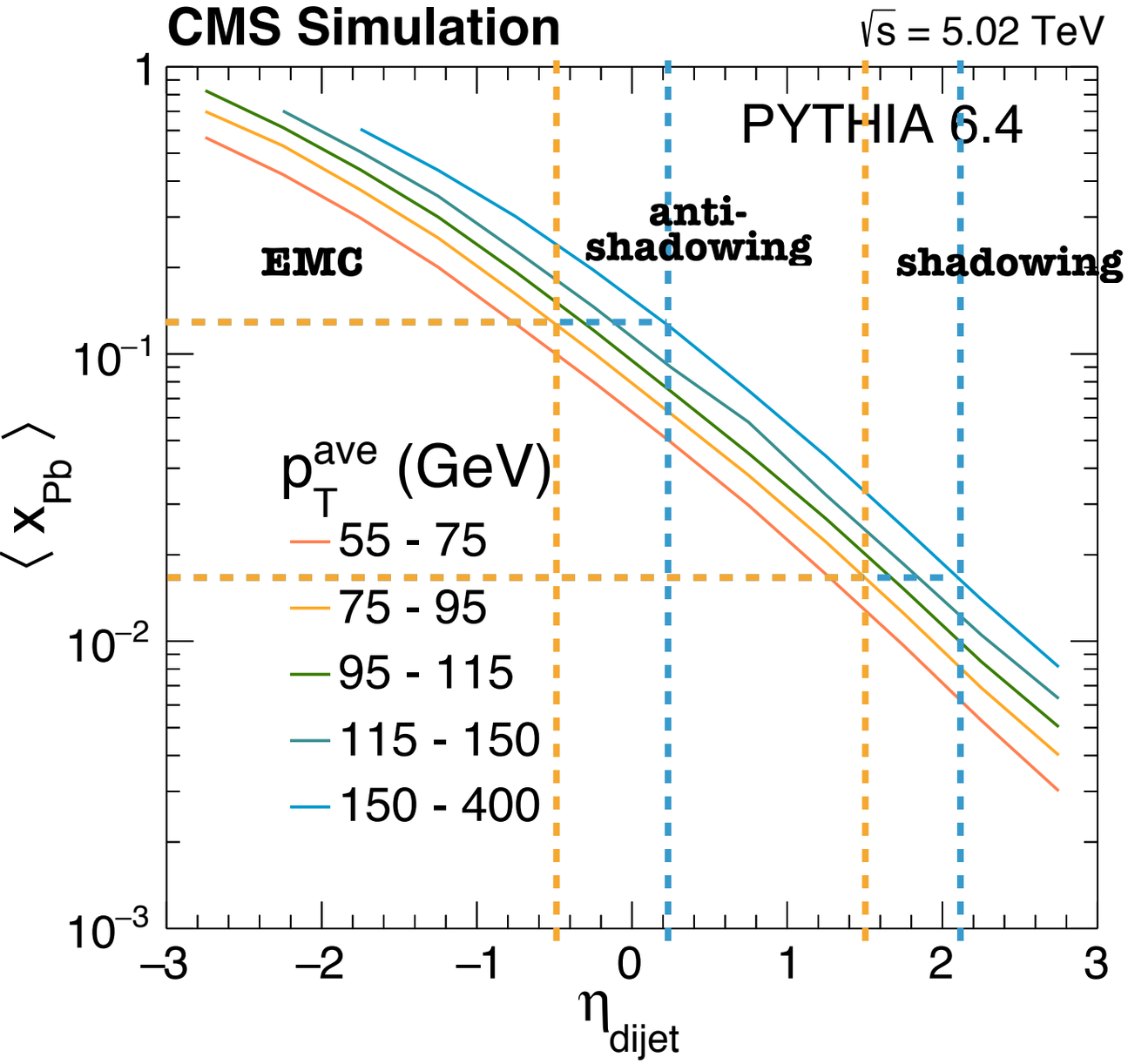
- **2013 pPb+Pbp @5.02TeV** (4TeV+1.58TeV), $\eta_{lab} = \eta_{CM}$-0.465
- W range <= |y| < 2.2
- only photon-p signal, reject photon-Pb
- **Trigger**: at least one μ + at least one but not more than six tracks
- **Evt sel**: no energy deposit in HF (< 5 GeV)
- **Offline μ**: $p_T > 3.3$ GeV, $|\eta| < 2.2$
- Offline ϒ: ϒ vertex no extra charged particle with $p_T > 0.1$ GeV, $0.1 < p_T < 1$ GeV
- **Leading syst**: TnP



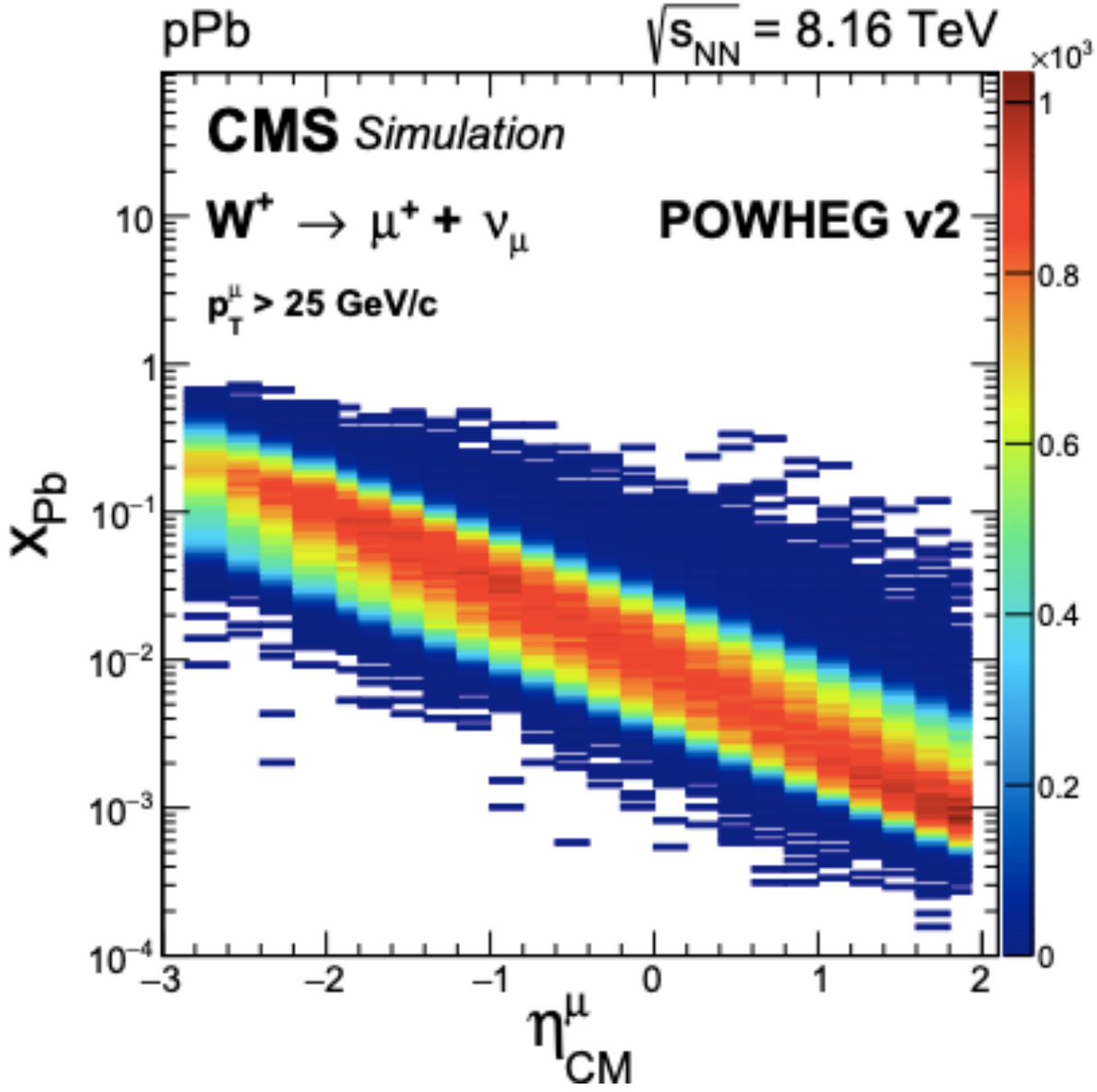


nPDF Backup

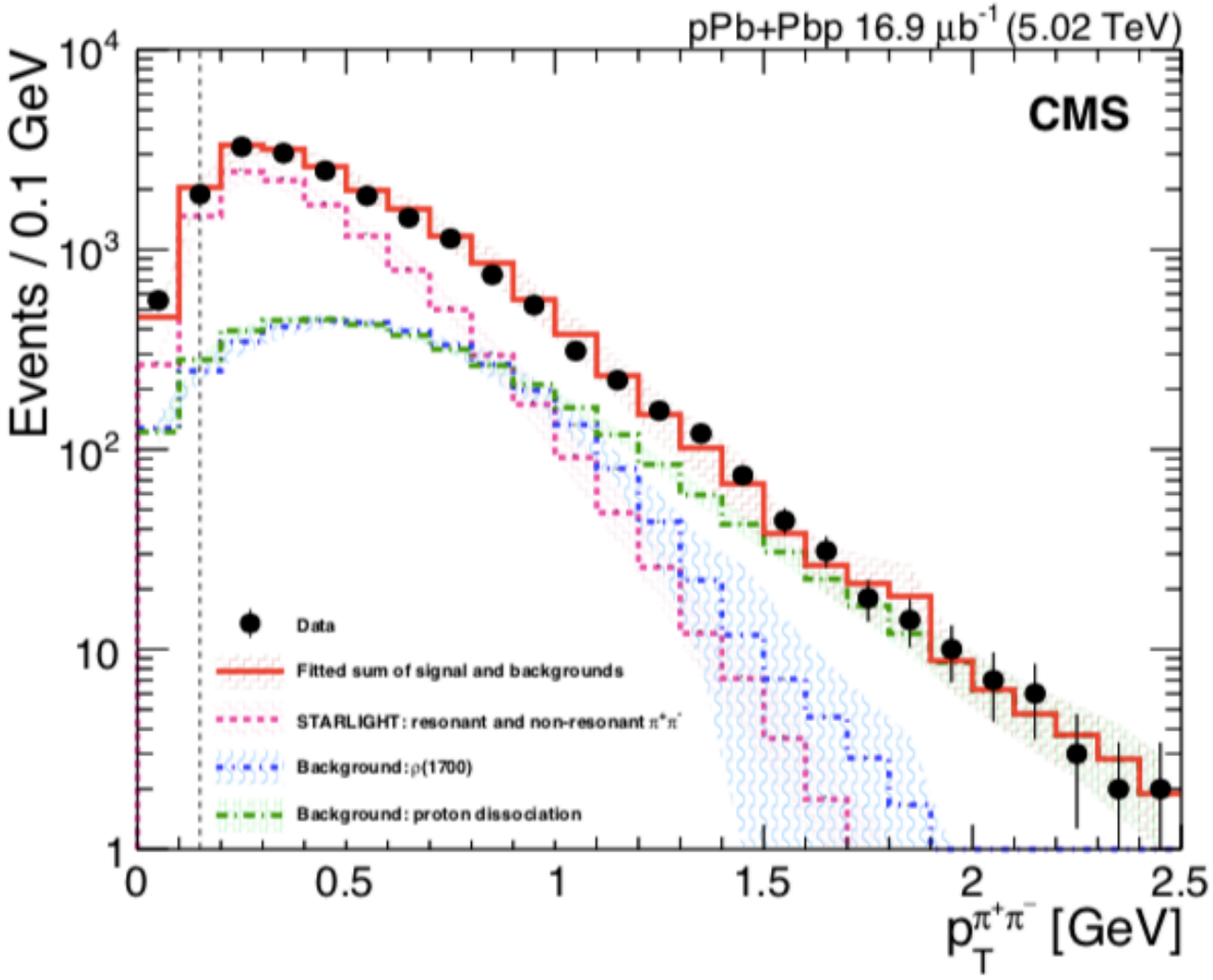
dijet

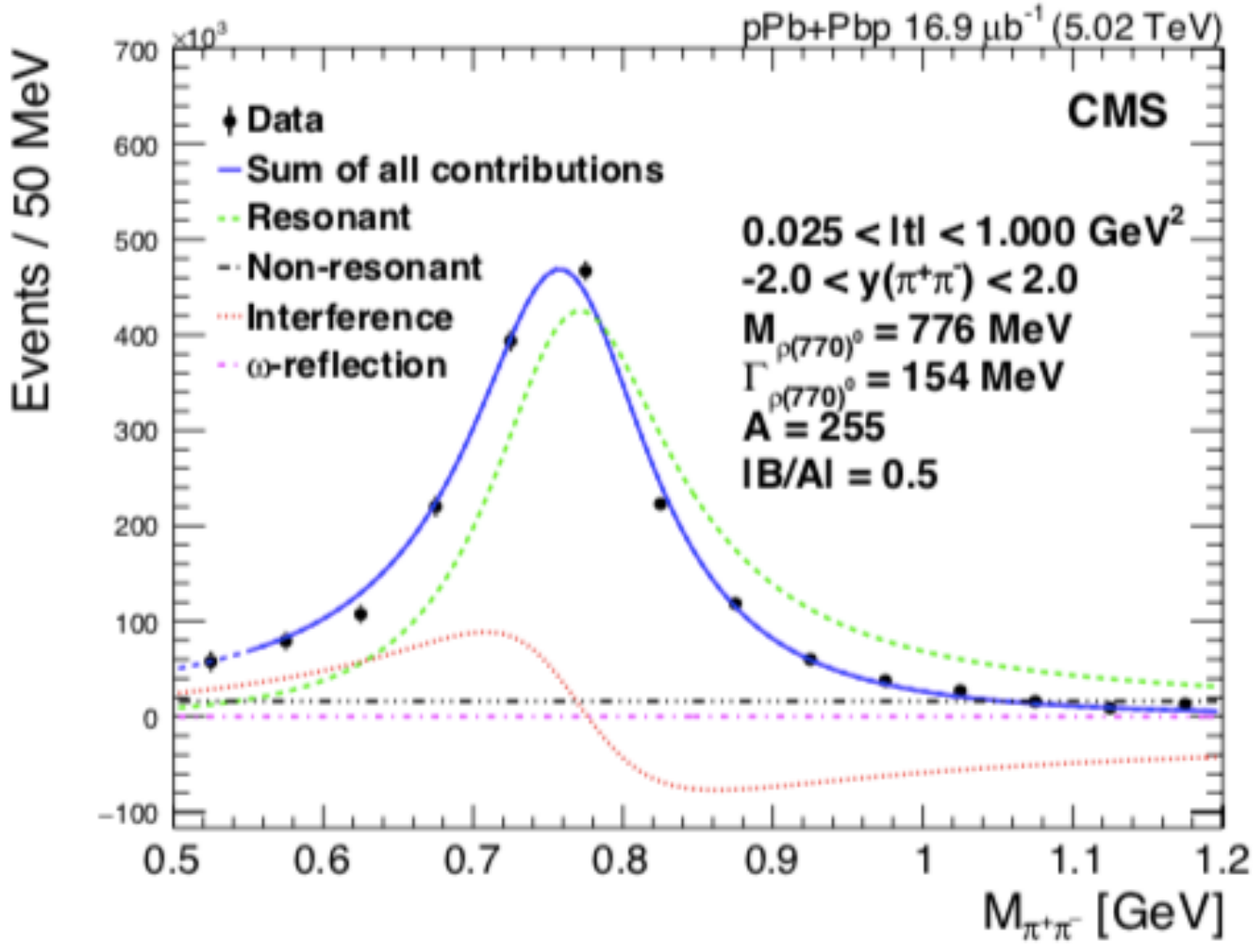


W boson

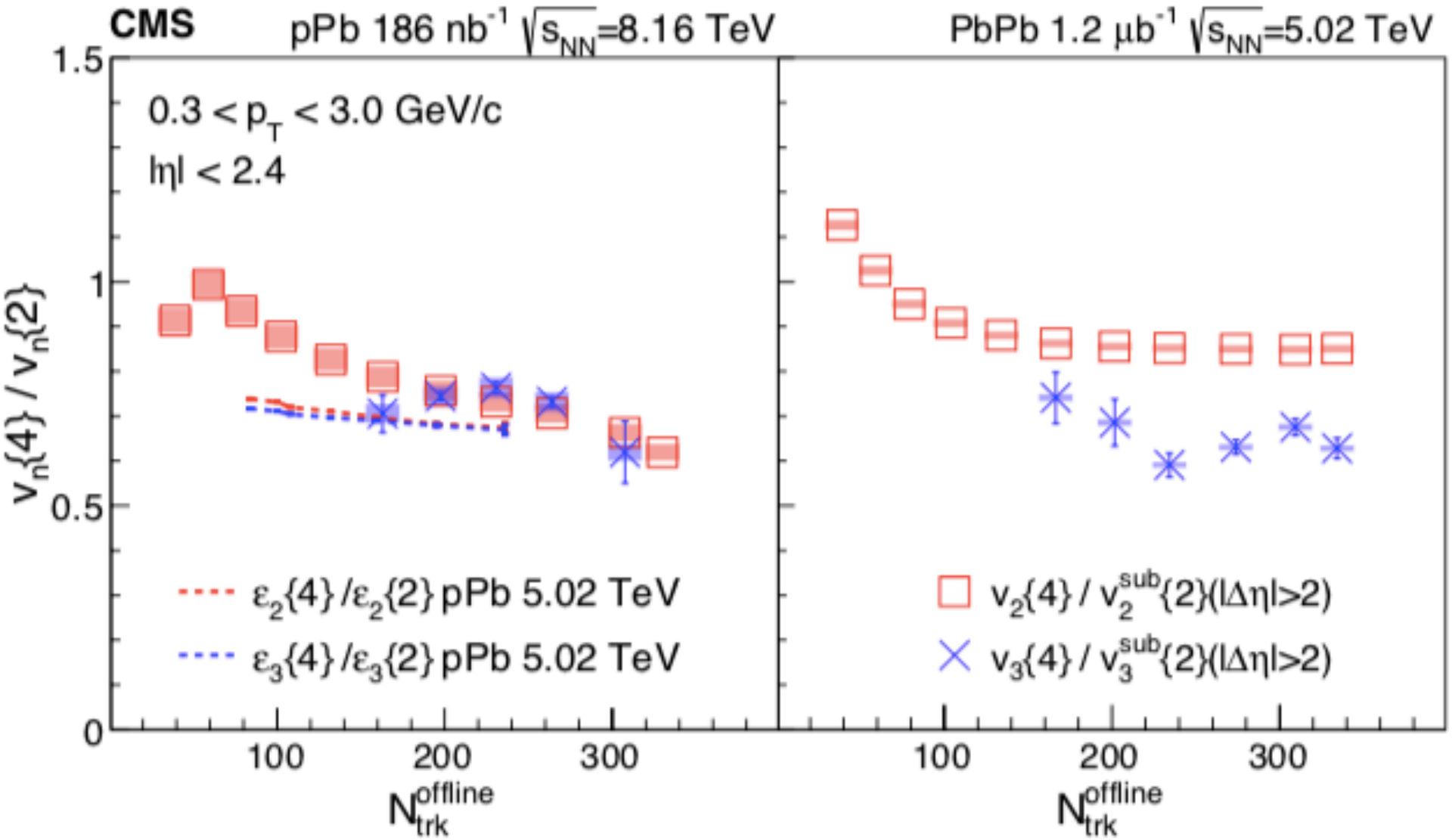


rho

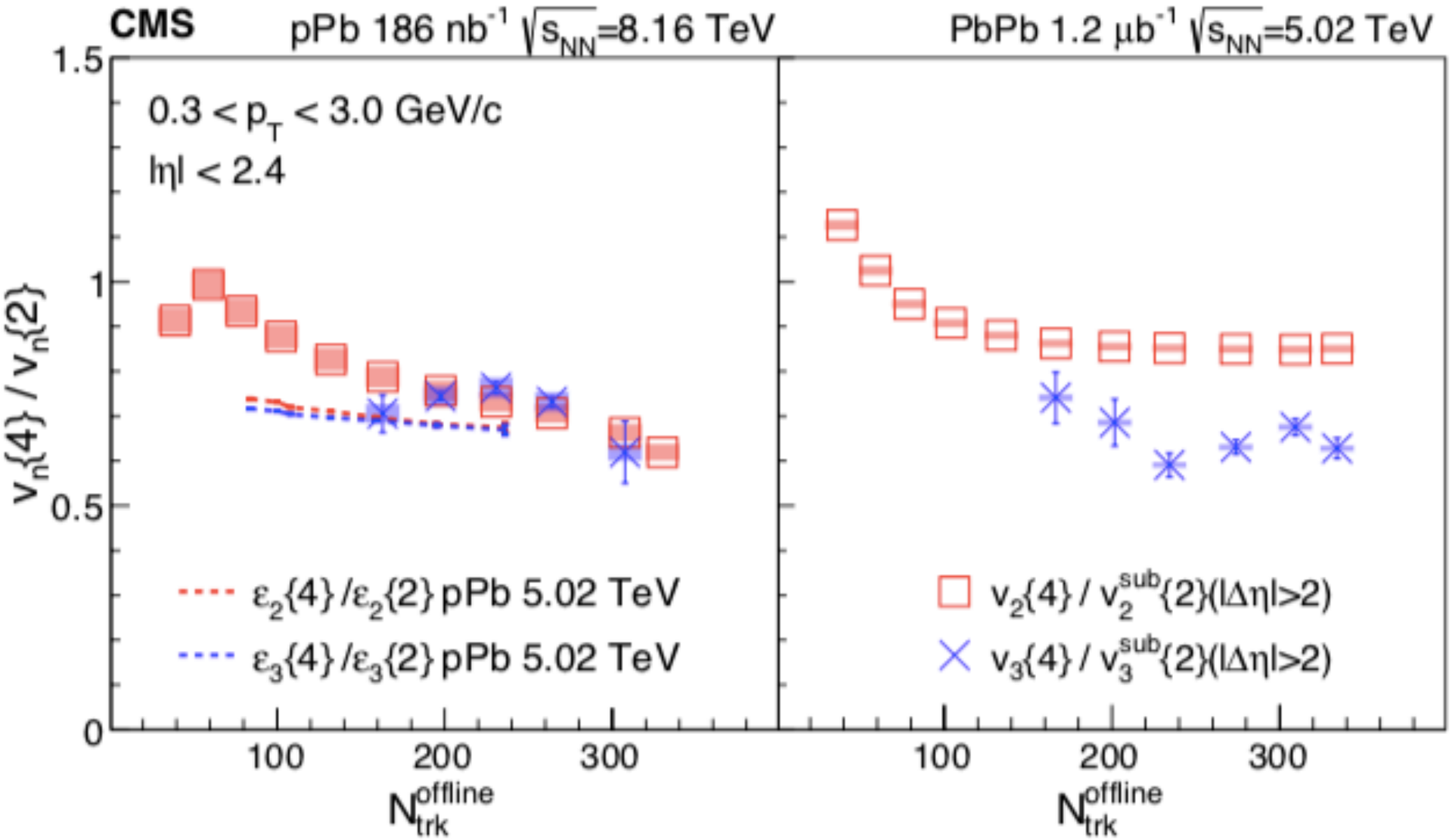

pPb+Pbp 16.9 μb^{-1} (5.02 TeV)
CMS
Events / 0.1 GeV
Data
Fitted sum of signal and backgrounds
STARLIGHT: resonant and non-resonant π⁺π⁻
Background: ρ(1700)
Background: proton dissociation
$p_T^{\pi^+\pi^-}$ [GeV]


pPb+Pbp 16.9 μb^{-1} (5.02 TeV)
CMS
Events / 50 MeV
Data
Sum of all contributions
Resonant
Non-resonant
Interference
ω-reflection
0.025 < |t| < 1.000 GeV²
-2.0 < y(π⁺π⁻) < 2.0
$M_{\rho(770)^0}$ = 776 MeV
$\Gamma_{\rho(770)^0}$ = 154 MeV
A = 255
|B/A| = 0.5
$M_{\pi^+\pi^-}$ [GeV]

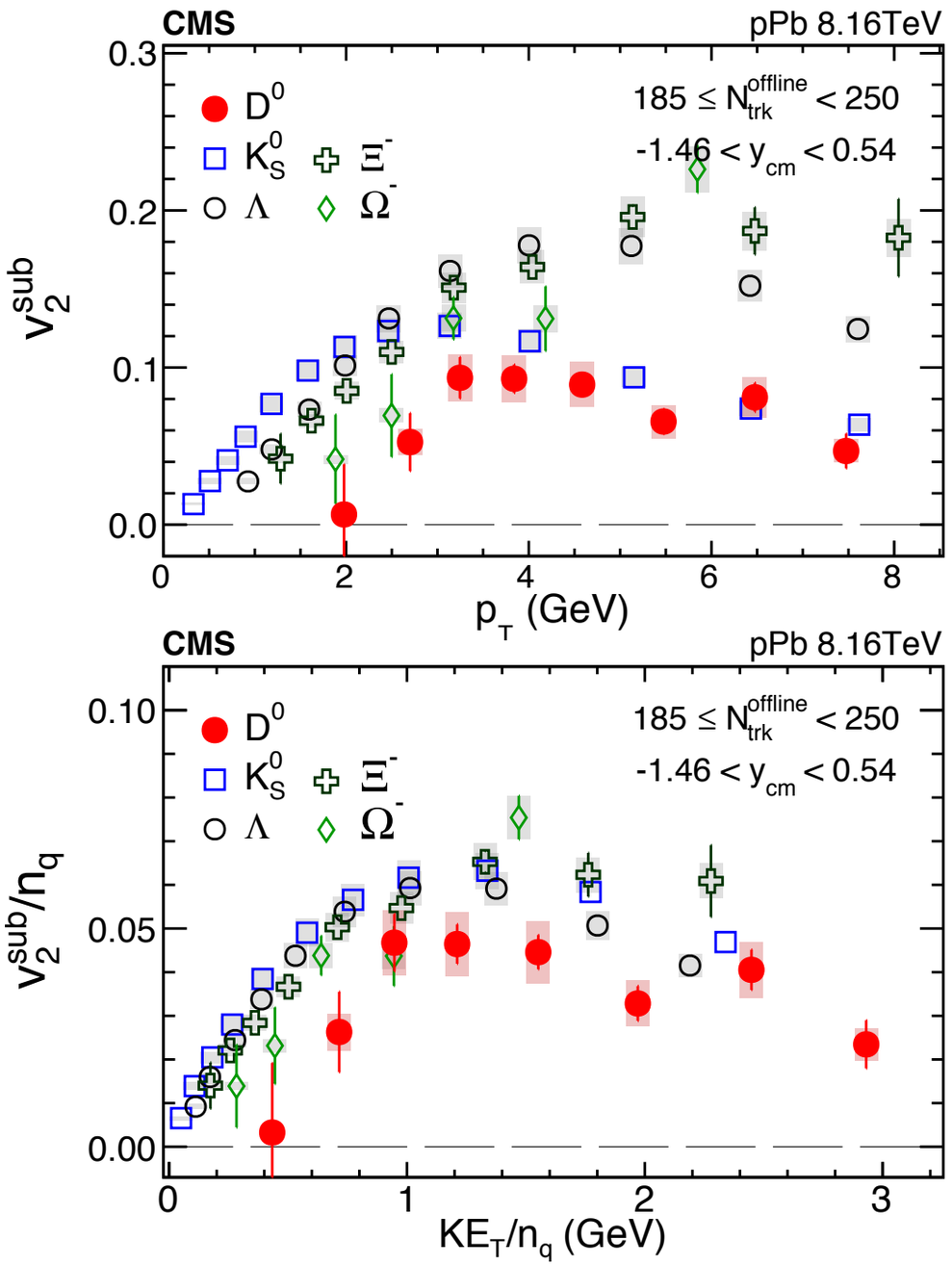
Multi-particle correlation

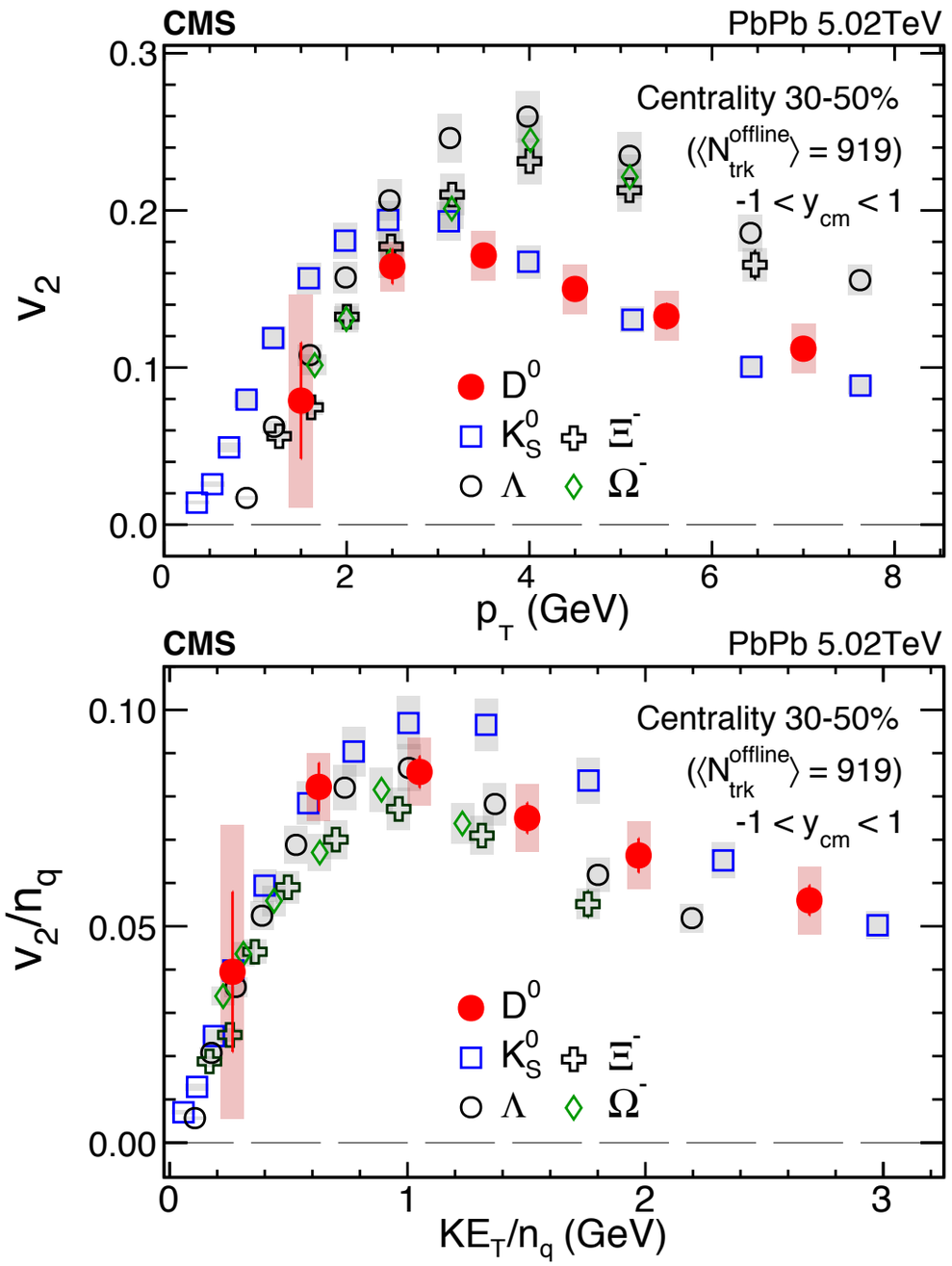


Multi-particle correlation



Collectivity in small system



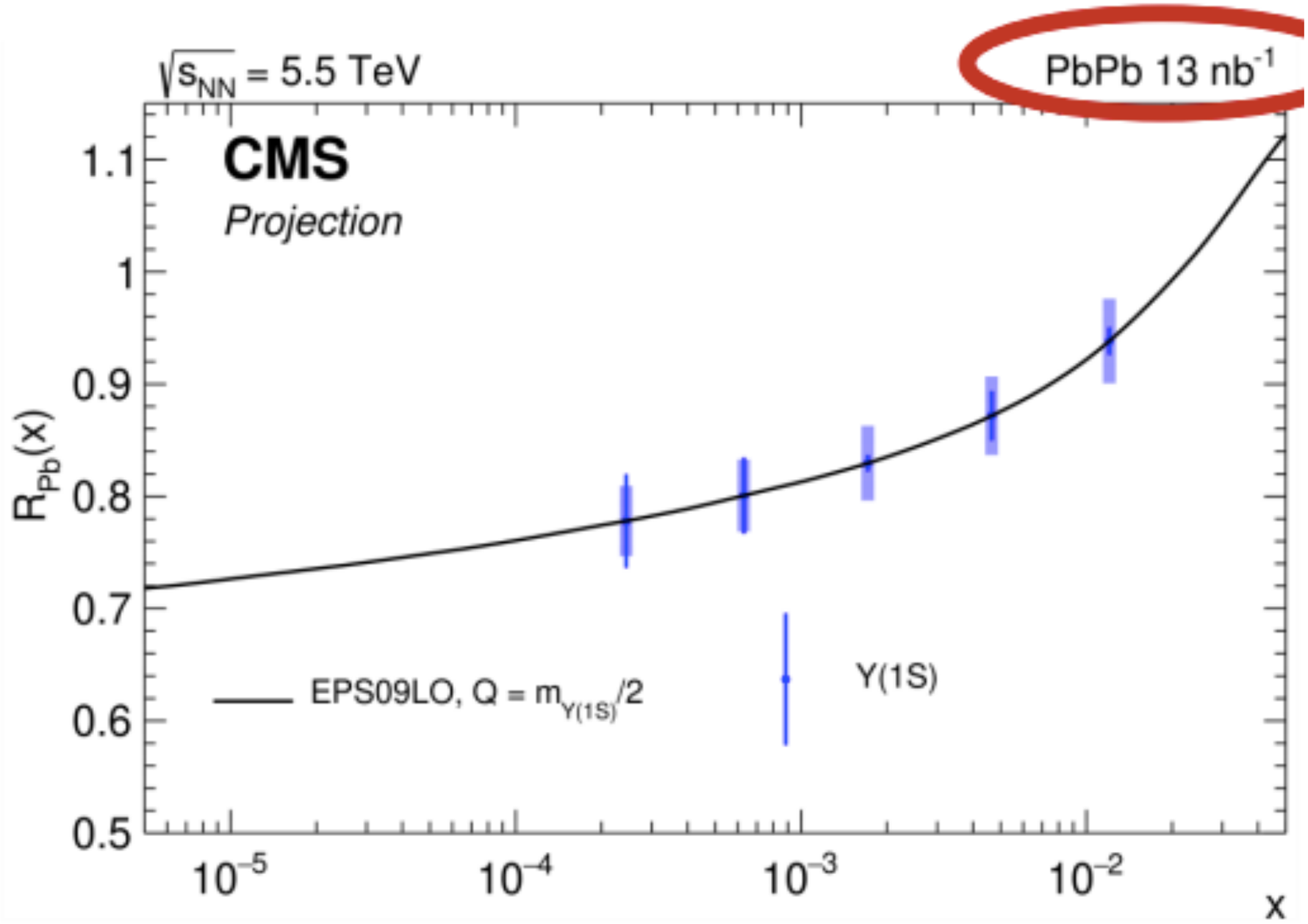


Future

From the WG5 Yellow Report (https://arxiv.org/abs/1812.06772)

Year	Systems, $\sqrt{s_{\mathrm{NN}}}$	Time	L_{int}
2021	Pb–Pb 5.5 TeV	3 weeks	2.3 nb^{-1}
	pp 5.5 TeV	1 week	3 pb^{-1} (ALICE), 300 pb^{-1} (ATLAS, CMS), 25 pb^{-1} (LHCb)
2022	Pb–Pb 5.5 TeV	5 weeks	3.9 nb^{-1}
	O–O, p–O	1 week	500 $\mu\mathrm{b}^{-1}$ and 200 $\mu\mathrm{b}^{-1}$
2023	p–Pb 8.8 TeV	3 weeks	0.6 pb^{-1} (ATLAS, CMS), 0.3 pb^{-1} (ALICE, LHCb)
	pp 8.8 TeV	few days	1.5 pb^{-1} (ALICE), 100 pb^{-1} (ATLAS, CMS, LHCb)
2027	Pb–Pb 5.5 TeV	5 weeks	3.8 nb^{-1}
	pp 5.5 TeV	1 week	3 pb^{-1} (ALICE), 300 pb^{-1} (ATLAS, CMS), 25 pb^{-1} (LHCb)
2028	p–Pb 8.8 TeV	3 weeks	0.6 pb^{-1} (ATLAS, CMS), 0.3 pb^{-1} (ALICE, LHCb)
	pp 8.8 TeV	few days	1.5 pb^{-1} (ALICE), 100 pb^{-1} (ATLAS, CMS, LHCb)
2029	Pb–Pb 5.5 TeV	4 weeks	3 nb^{-1}
Run-5	Intermediate AA	11 weeks	e.g. Ar–Ar 3–9 pb^{-1} (optimal species to be defined)
	pp reference	1 week	

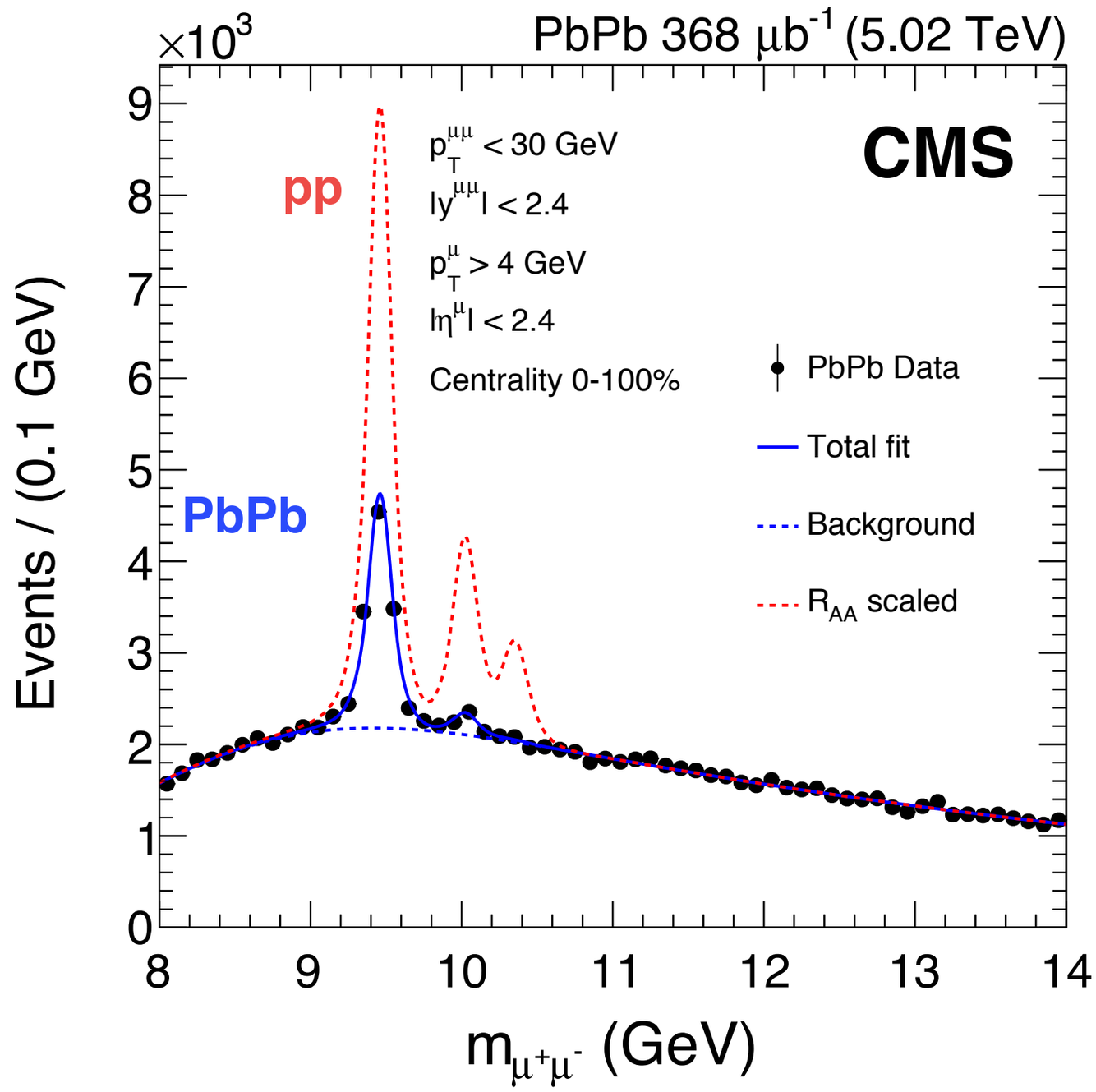
Future


$\sqrt{s_{NN}}$ = 5.5 TeV
PbPb 13 nb^{-1}
CMS
Projection
$R_{Pb}(x)$
1.1
1
0.9
0.8
0.7
0.6
0.5
EPS09LO, Q = $m_{Y(1S)}/2$
Y(1S)
10^{-5}
10^{-4}
10^{-3}
10^{-2}
x

Upsilon Sequential Suppression in PbPb

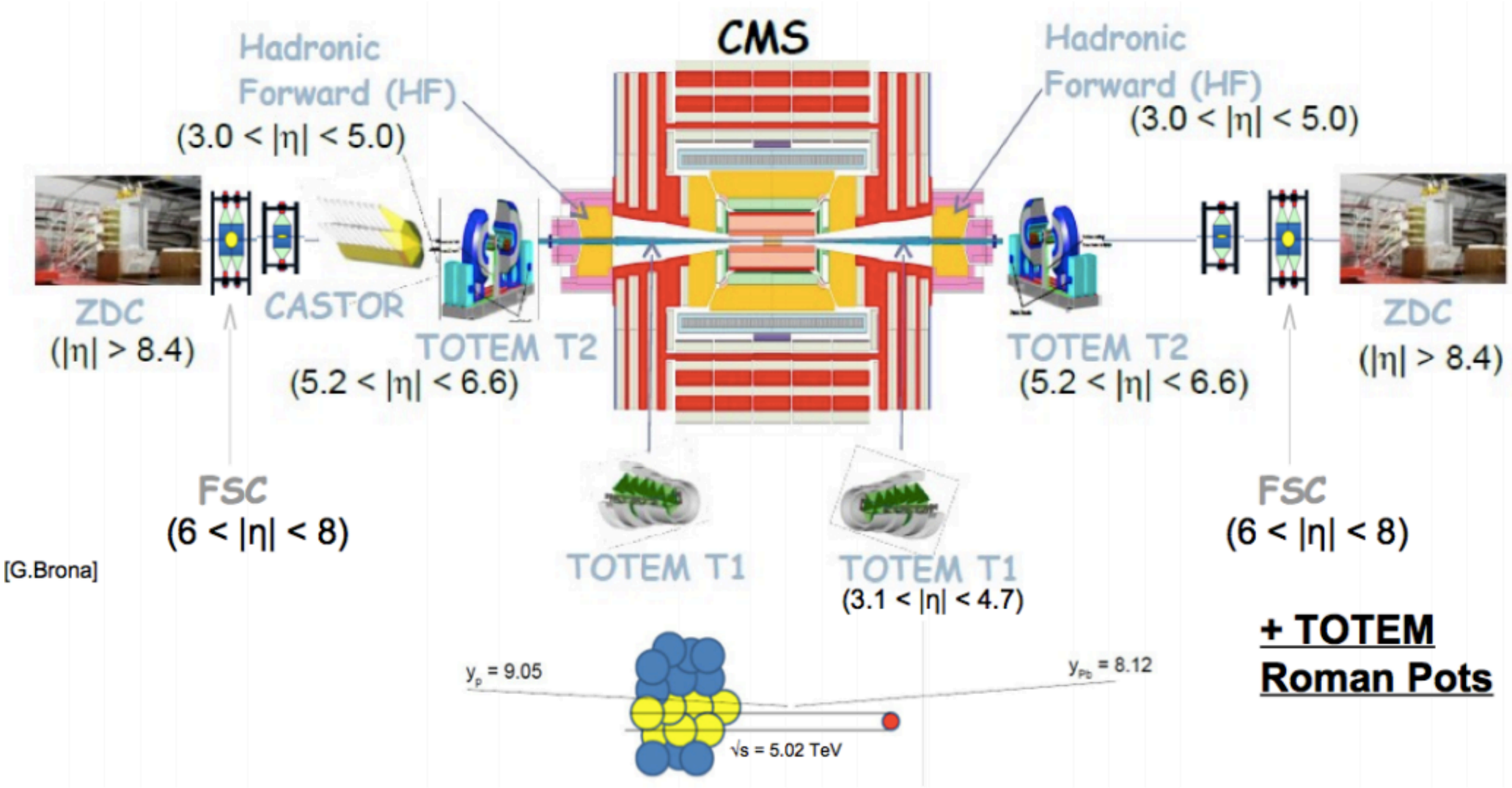
Yongsun Kim
Wed. 14.20

PLB 790 (2019) 270



UPC Upsilon

UPCs at CMS



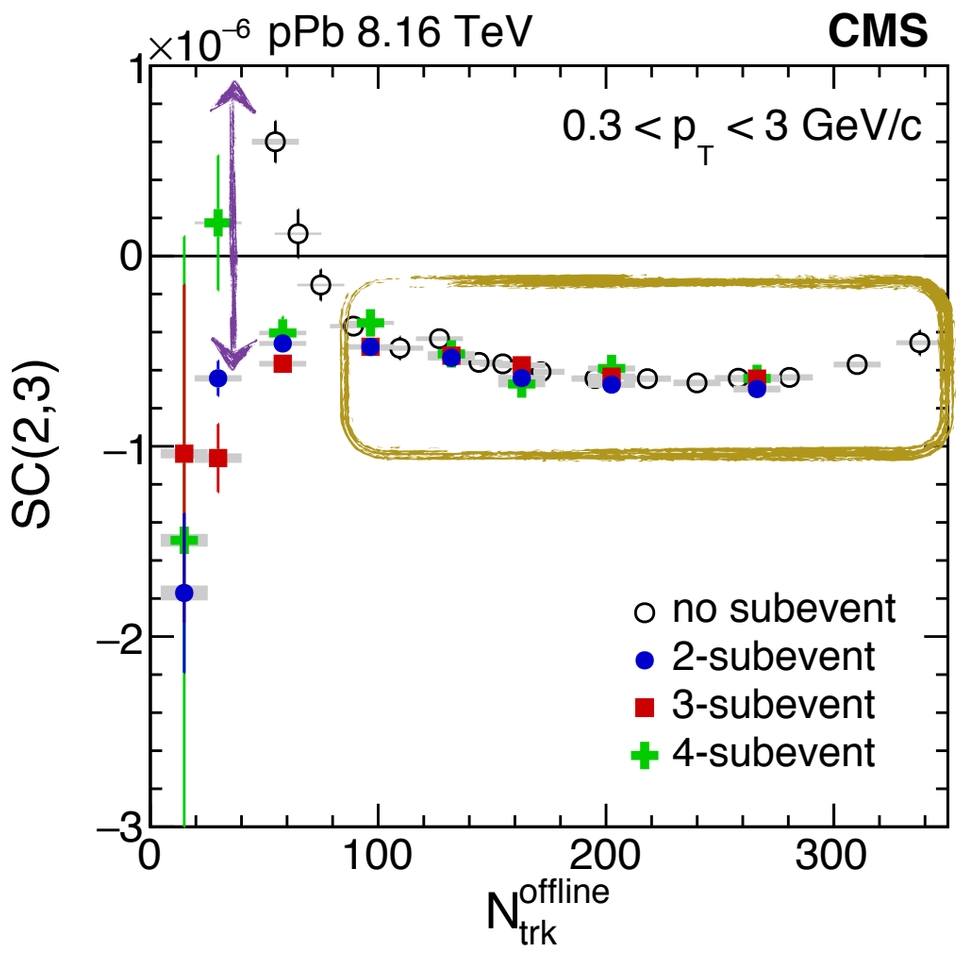
[G.Brona]

+ TOTEM Roman Pots

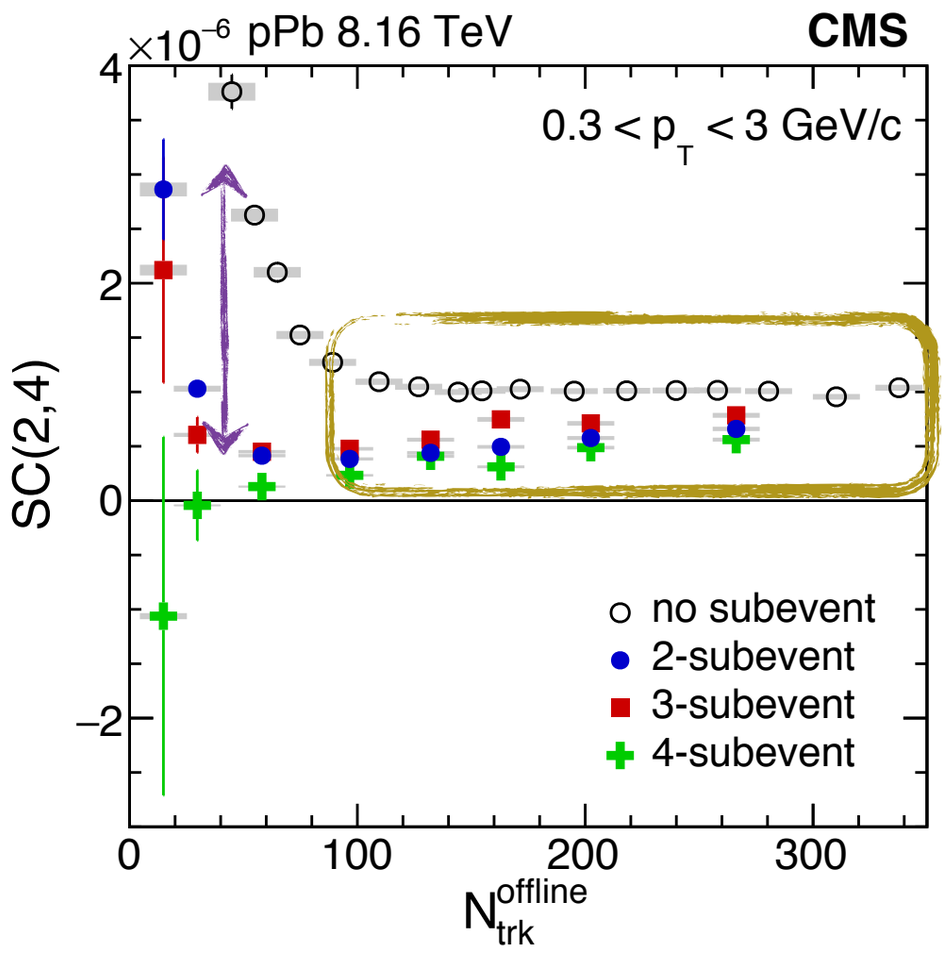
Symmetric Cumulants with Subevents in pPb

arXiv:1905.09935

SC(2,3)



SC(2,4)



Suppressing non-flow contribution with subevents (More subevent, more suppression)

Low-multiplicity ($N_{trk} < 80$): Non-flow contribution is suppressed

High-multiplicity ($N_{trk} > 80$)

- SC(2,3): Non-flow component negligible
- v_2 and v_3 anti-correlated

- SC(2,4): Hierarchy of subevent number
- v_2 and v_4 correlated?