בס"ד

Electroweak Probes: Experimental Overview

Zvi Citron

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HP 2020, 2 June

Overview

- Results from $\gamma\gamma$ to di-lepton, a “new” QGP observable?
  - Can we find a new EM probe of the QGP? New observable for fundamental properties of QGP?
- Di-lepton continuum, an “old” QGP observable
  - Can we refine a thermal probe of QGP?
- EW bosons for nPDF and centrality studies
  - Can we learn everything we need to know ‘before’ the QGP?

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Di-Lepton Production from Photon Interactions (in QGP ?)

- ATLAS & STAR have measured di-lepton production from photon interactions in hadronic collisions complementing UPC
- Question remains,
  - Can we learn about the QGP itself, EM degrees of freedom (?), from these observables?
  - Is QED sufficient to explain observables?

    [PRL 122 (2019) 132301, PRC99 (2019) 044901, PLB 800 (2020) 135089]

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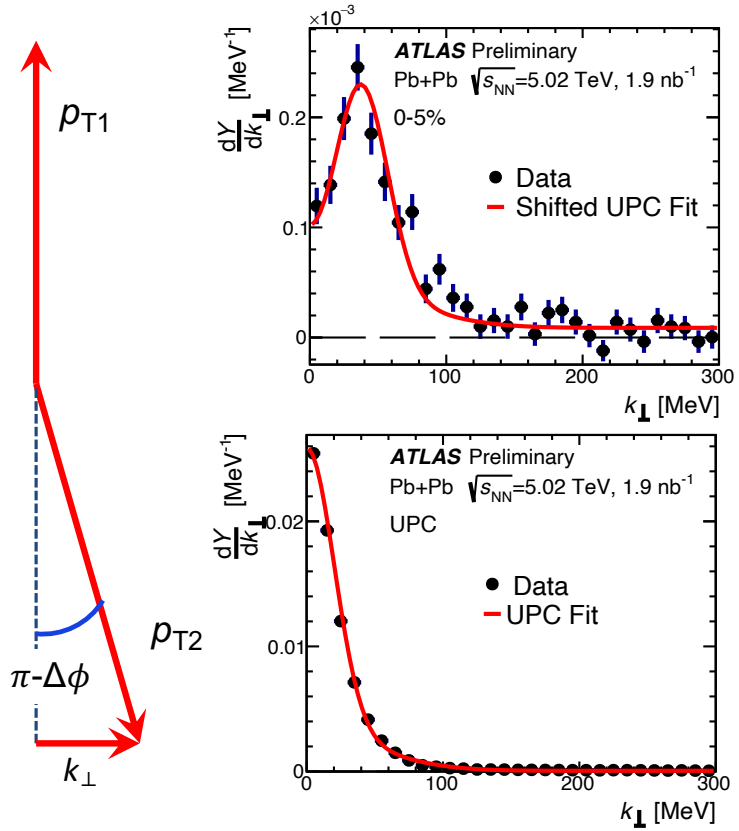
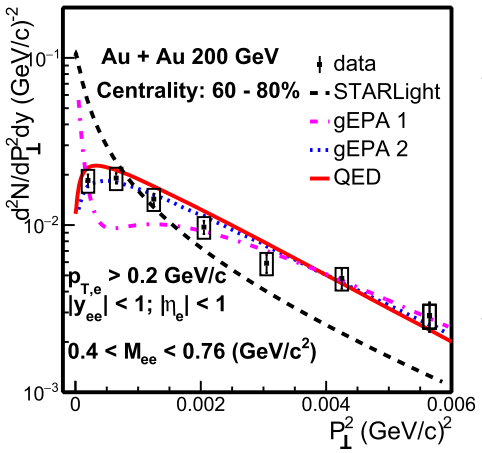
Di-Lepton Production from Photon Interactions (in QGP ?)

ATLAS-CONF-2019-051



STAR, PRL. 121 (2018) 132301
[W. Zha et al. PLB 800 (2020) 135089]



- Identify $\gamma\gamma \rightarrow ll$ in hadronic collisions
- Momentum broadening observed
- Centrality dependence of broadening observed
- QED calculations seem to reproduce effect (at least qualitatively)

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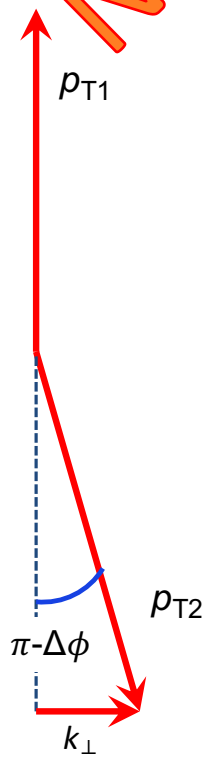
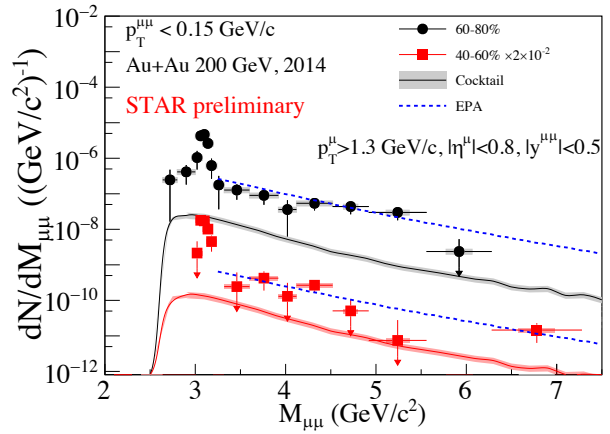
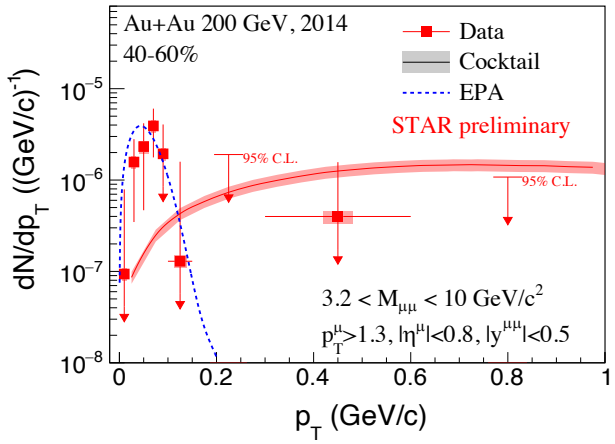
Di-Lepton Production from Photon Interactions (in QGP ?)

Brand New!

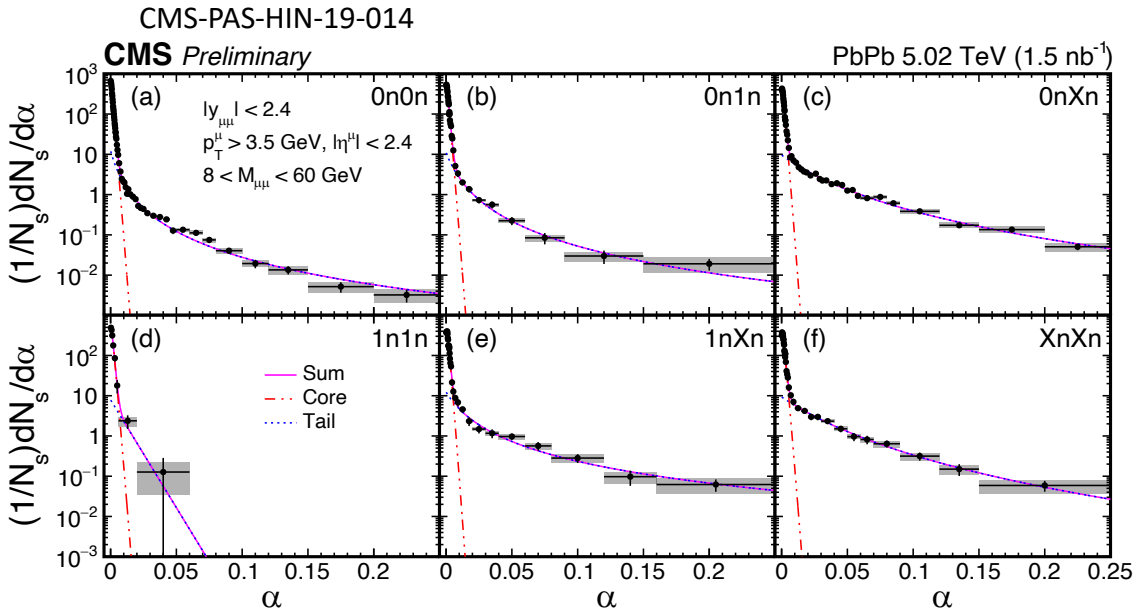






- Identify $\gamma\gamma \rightarrow ll$ in hadronic collisions
- Momentum broadening observed
- Centrality dependence of broadening observed
- QED calculations seem to reproduce effect (at least qualitatively)
- First $\gamma\gamma \rightarrow \mu\mu$ results from STAR
  - Consistent with hadronic interaction cocktail for p_T>0.15 GeV
  - Qualitative agreement with $\gamma\gamma$ QED calculations for p_T<0.15

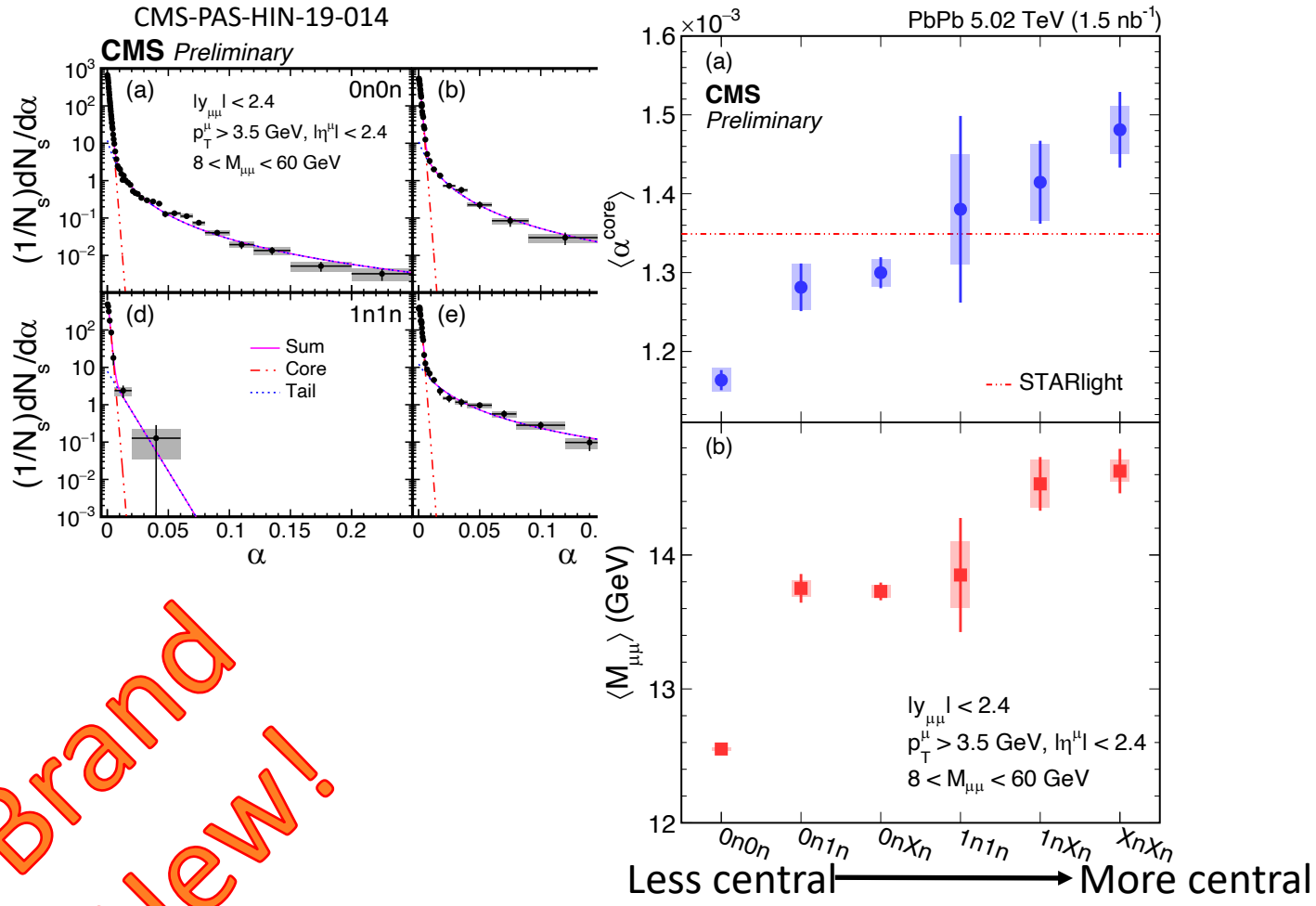
Di-Lepton Production from Photon Interactions (in QGP ?)



- CMS measurement of EM b dependence using forward n multiplicity
- Characterize ‘core’ pairs aco-planarity of di-muons as f(#n)

Brand New!

Di-Lepton Production from Photon Interactions (in QGP ?)



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Di-Electron Continuum & Low p_T γ

- Program of study dating back ~40 years
- Ultimate goal to connect back to parton deconfinement and chiral symmetry
- Active directions (with new results):
  - Direct photons
  - STAR Beam energy scan
  - ALICE pp & pPb at 5 TeV → R_{pPb}
  - ALICE soft di-electrons at 13 TeV pp
- Filling in pieces of the puzzle …

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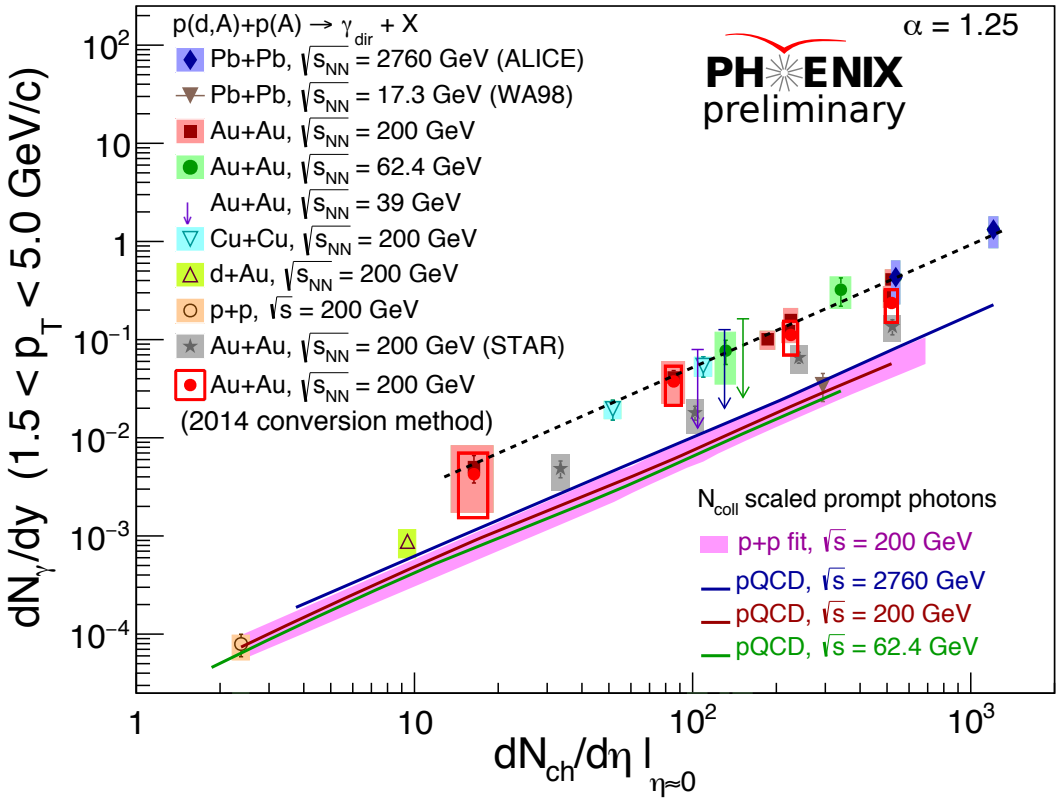
Direct Photon Scaling



- Low p_T photons may be probing thermodynamics
- PHENIX observes scaling across energy/system size with only two parameters
- Photon production same in all these systems?
  →Suggestive of *some* commonality

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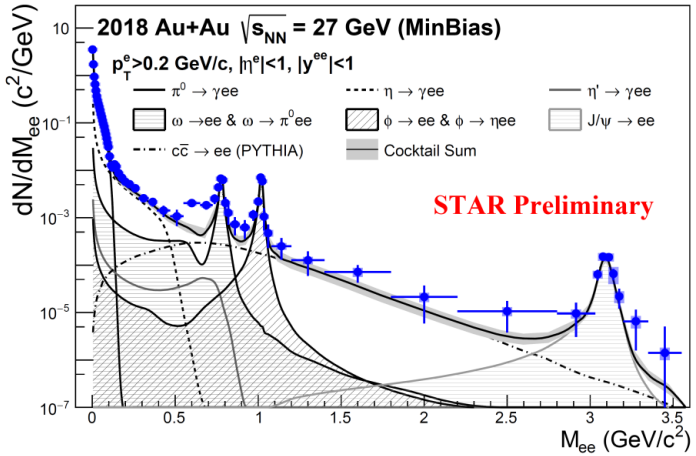
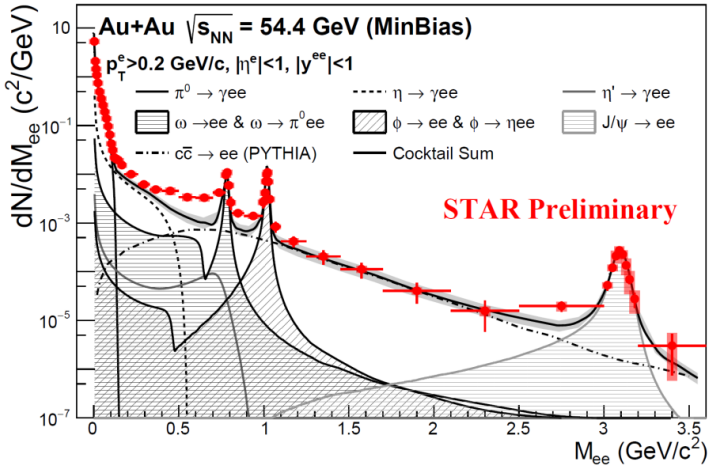
Di-Electrons Results w/BES





- STAR is filling in the ‘map’ of the di-electron continuum as a function of energy
- Higher statistics and precision even at low energies will allow differential measurements

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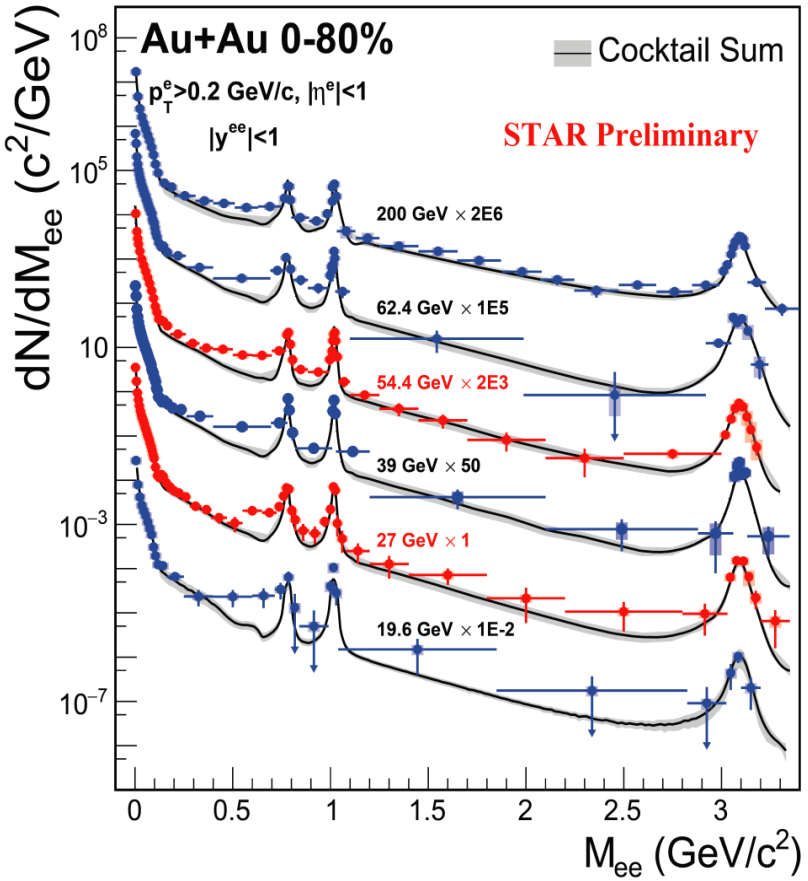
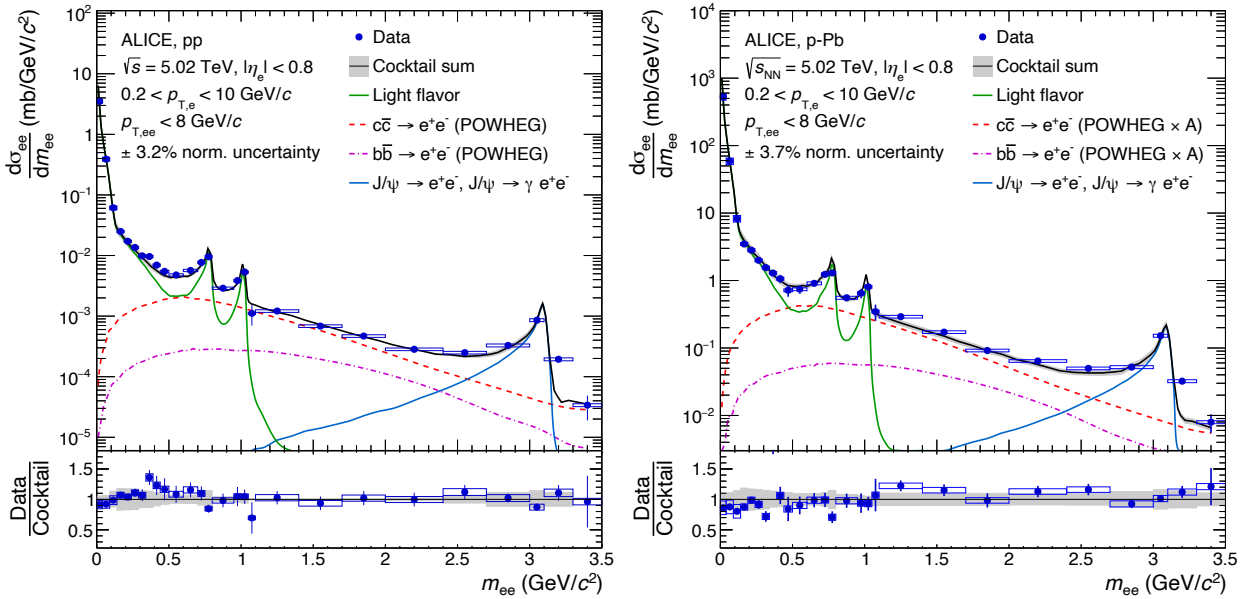


- STAR is filling in the 'map' of the di-electron continuum as a function of energy
- Higher statistics and precision even at low energies will allow differential measurements
  → Moving towards a complete picture

Di-Electrons in pp & pPb @5 TeV

New!



- Cocktail describes ALICE pp data well, fits well with 7&13 TeV
- pPb data also well described by cocktail

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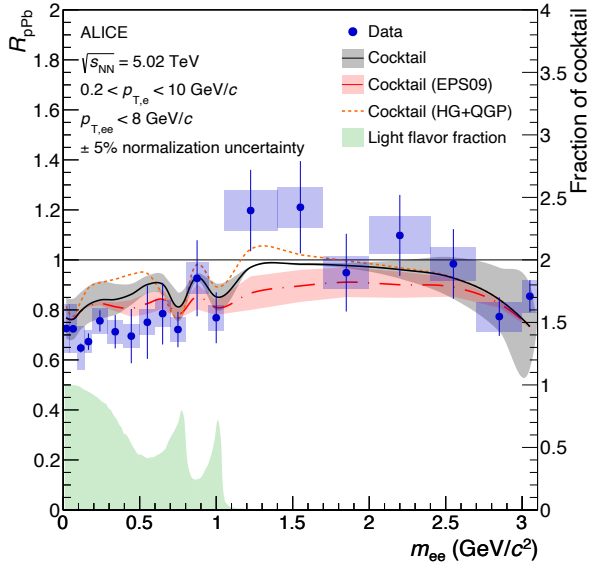
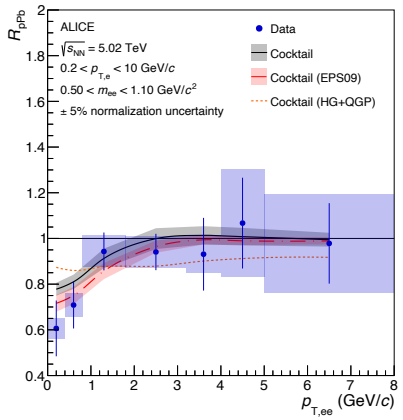
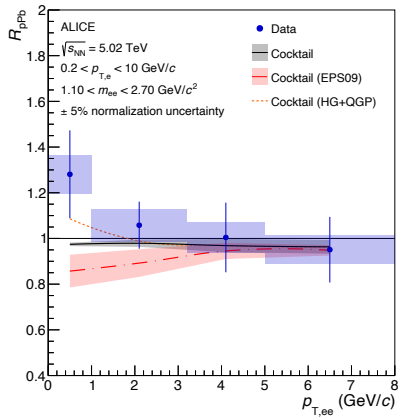


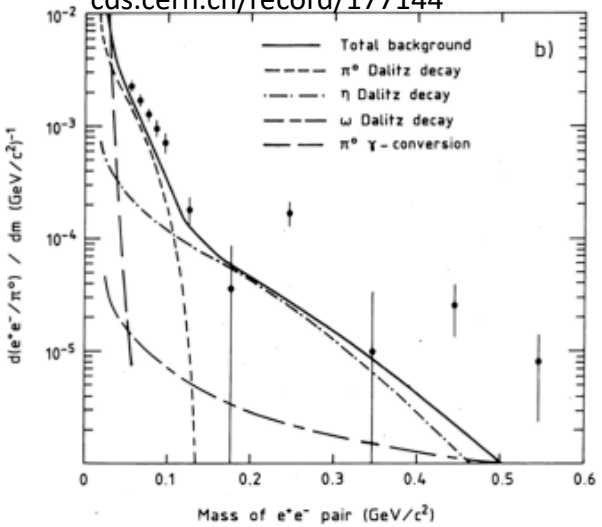




- Cocktail describes ALICE pp data well, fits well with 7&13 TeV
- pPb data also well described by cocktail
- R_{pPb} emphasizes that there are many ingredients at play that still need to be sorted out (CNM vs thermal, and heavy flavor contributions are still an issue)

Di-Electron Excess pp @ 13 TeV

cds.cern.ch/record/177144



- 30 year old di-electron excess @ISR
- Inspired special low field ALICE run @ 13 TeV

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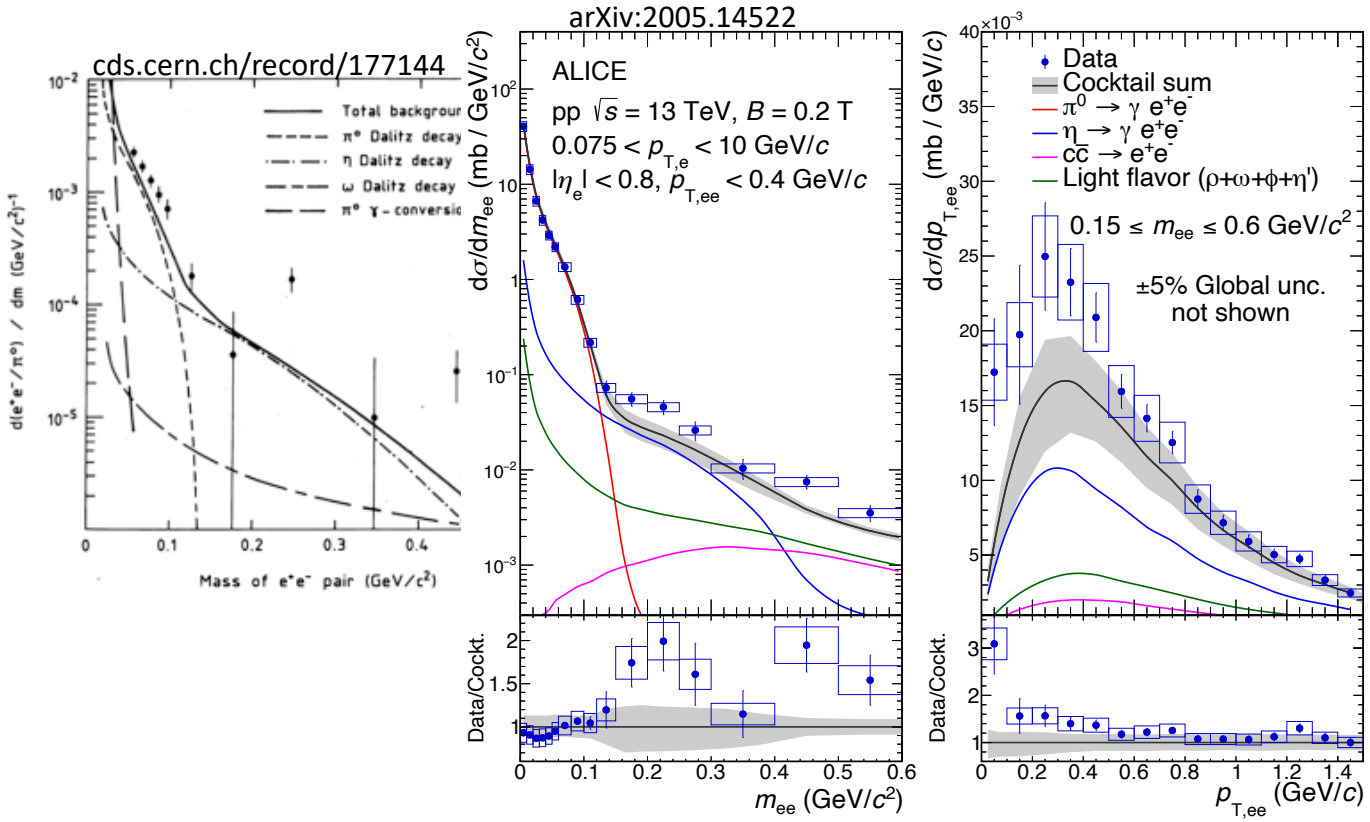
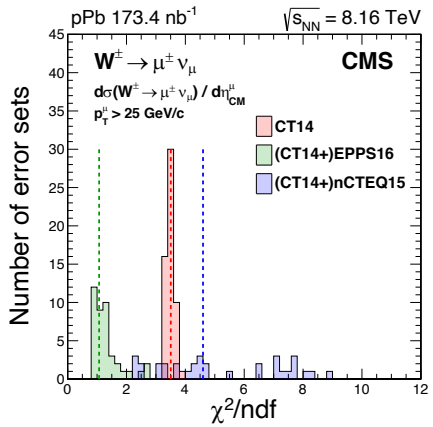


- 30 year old di-electron excess @ISR
- Inspired special low field ALICE run @ 13 TeV
- Excess observed at 1.6 sigma level
  - The story continues with ALICE upgrades …

EW Bosons and nPDF

- What do we need to understand *before* a QGP?
  - Initial state
  - Collision geometry
- EW bosons are our built in control for hard scattering processes
- Especially in pPb among the best probes of nPDF modification @LHC
  - Preponderance of evidence favoring modification

New!



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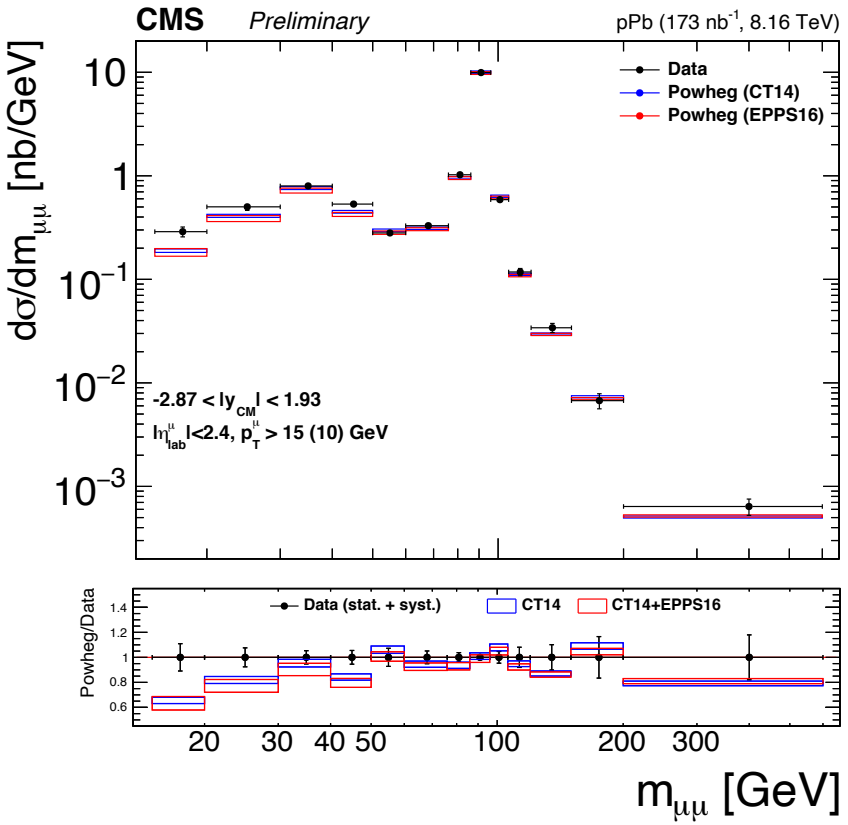
Drell-Yan Measurement in pPb

Brand New!

CMS-PAS-HIN-18-003



- CMS made first measurement of Drell-Yan in pPb!
- Overall reasonable agreement with pQCD calculations

Drell-Yan Measurement in pPb

Brand New!

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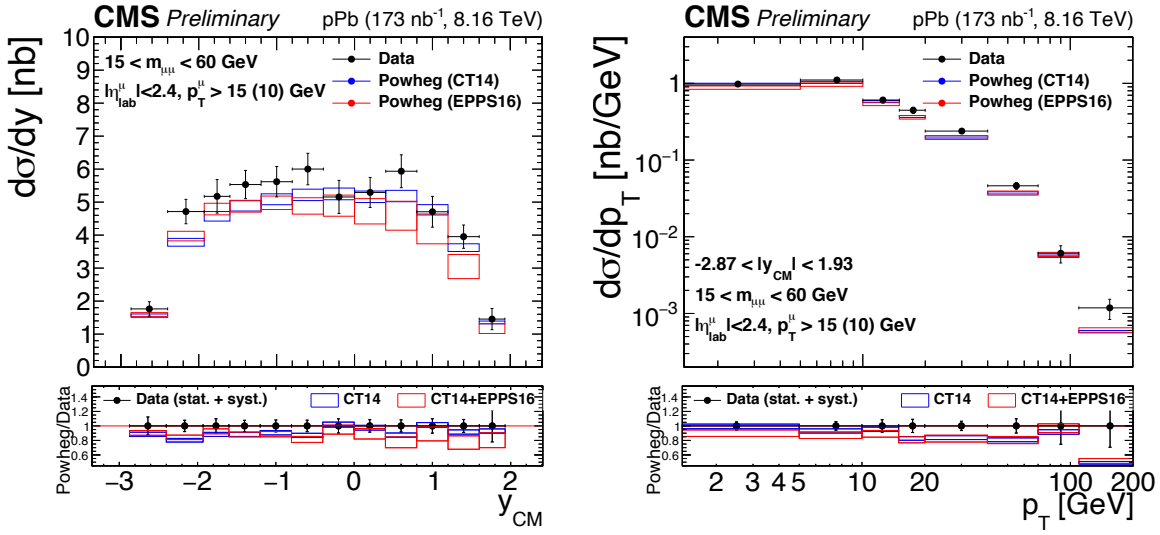
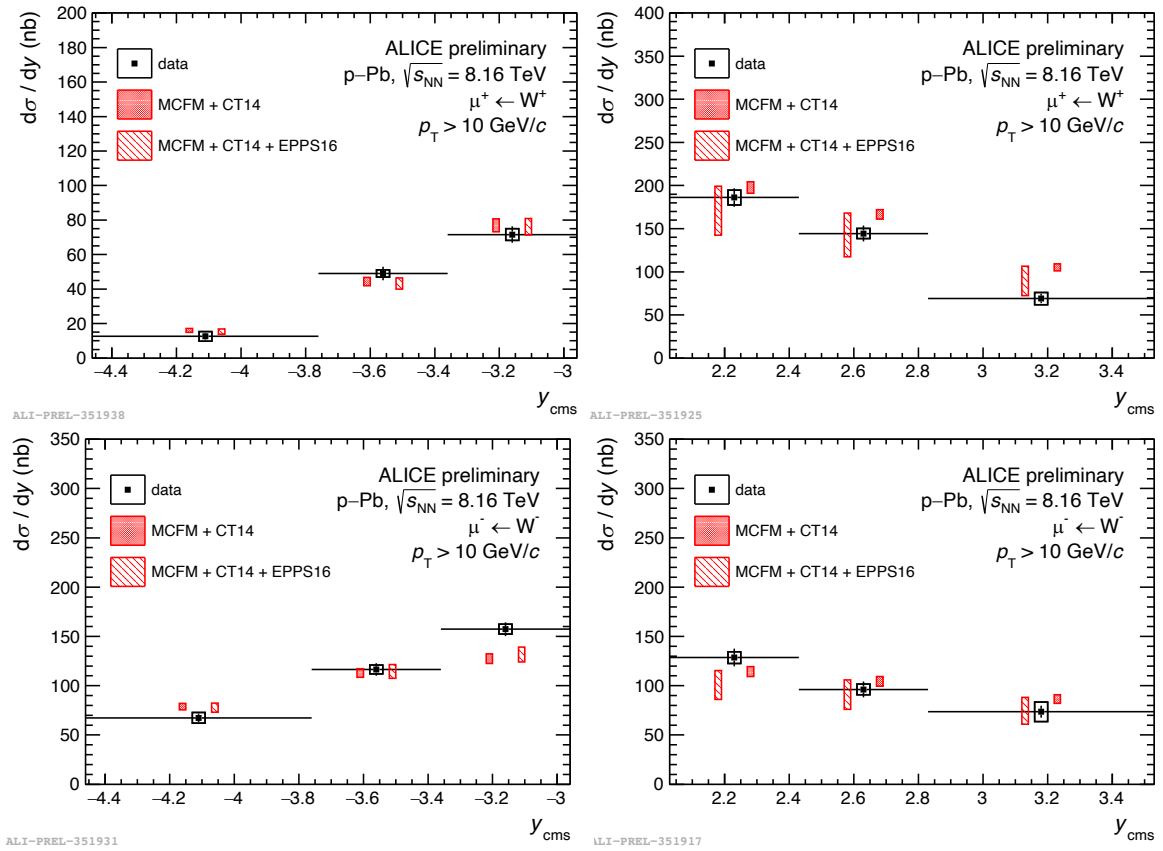


Observable	CT14			CT14+EPPS16		
	χ^2	dof	Prob. [%]	χ^2	dof	Prob. [%]
$m_{\mu\mu}$ (GeV)	27	13	1.1	25	13	2.2
y_{CM} $(15 < m_{\mu\mu} < 60\,\mathrm{GeV})$	6.3	12	90	5.7	12	93
p_{T} (GeV) $(15 < m_{\mu\mu} < 60\,\mathrm{GeV})$	13	8	13	7.6	8	47
ϕ^* $(15 < m_{\mu\mu} < 60\,\mathrm{GeV})$	7.4	9	59	8.3	9	51
y_{CM} $(60 < m_{\mu\mu} < 120\,\mathrm{GeV})$	51	24	0.11	33	24	9.7
p_{T} (GeV) $(60 < m_{\mu\mu} < 120\,\mathrm{GeV})$	29	17	3.5	53	17	0.002
ϕ^* $(60 < m_{\mu\mu} < 120\,\mathrm{GeV})$	25	17	9.1	44	17	0.03

- CMS made first measurement of Drell-Yan in pPb!
- Overall reasonable agreement with pQCD calculations
- Close look seems to indicate some room for improvement on possible mismodeling

Forward W in pPb

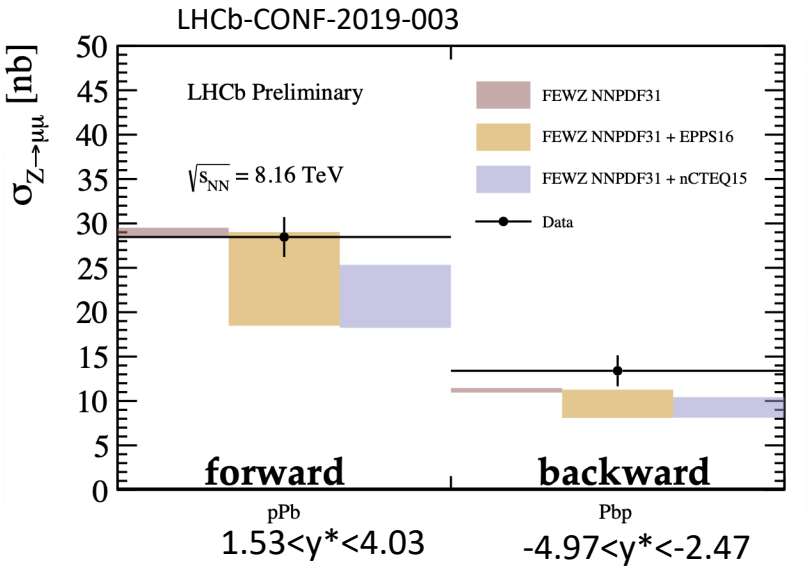


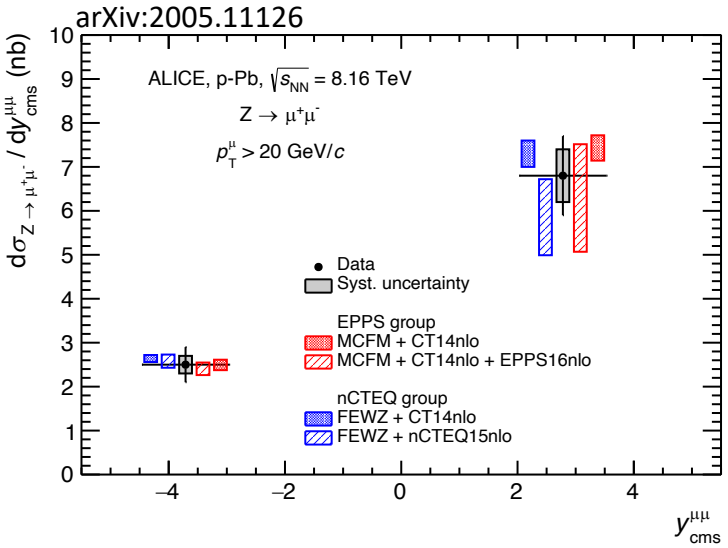
Brand New!

- ALICE measured W boson in forward muon decays
- Precision data but low sensitivity to nPDF effects

Forward Z in pPb & PbPb

New!



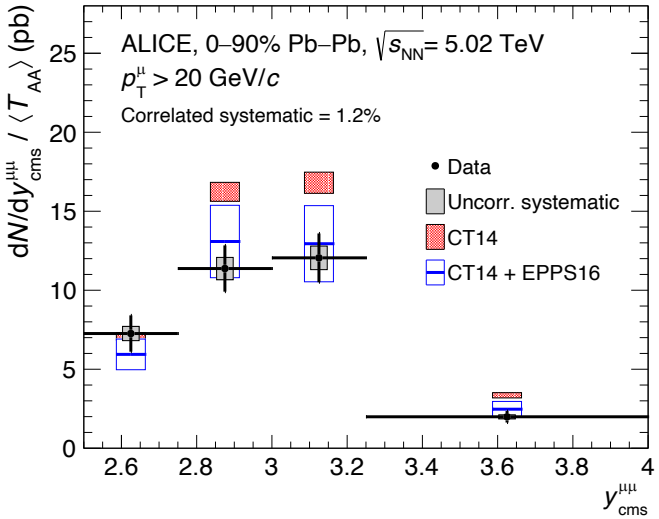


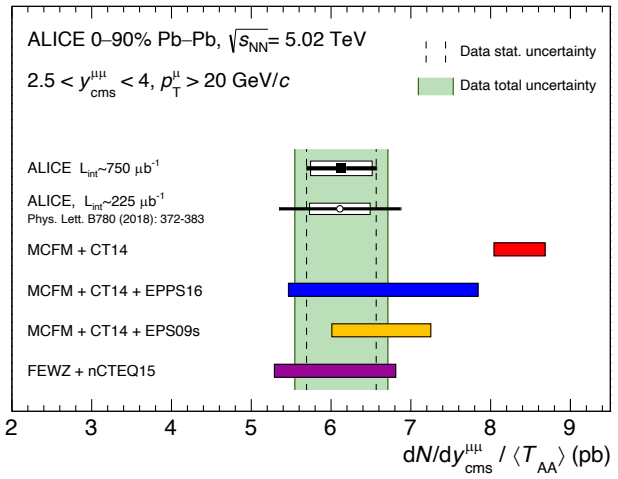
- Z boson measured in forward muon decays by ALICE & LHCb
- Precision pPb data but low sensitivity to nPDF differences

Forward Z in pPb & PbPb

New!

arXiv:2005.11126



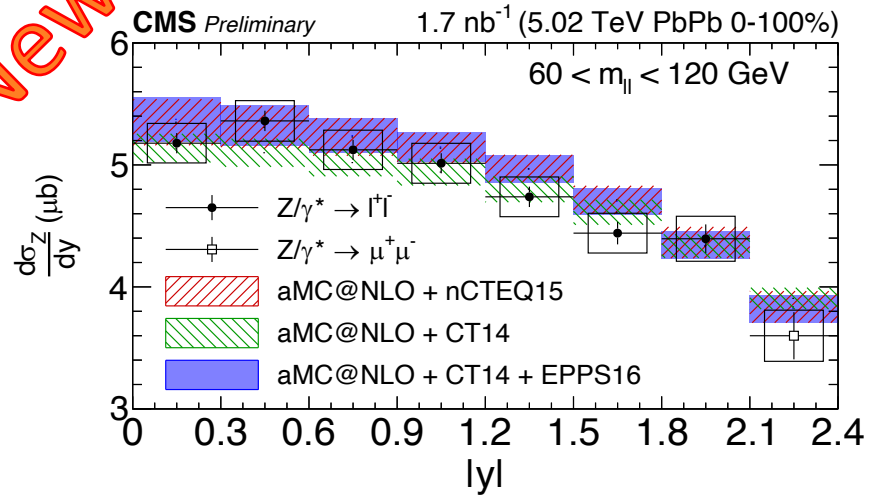


- Z boson measured in forward muon decays by ALICE & LHCb
- Precision pPb data but low sensitivity to nPDF differences
- PbPb data clearly favor modification of free PDF

Midrapidity Z in PbPb

Brand New!

CMS-PAS-19-003



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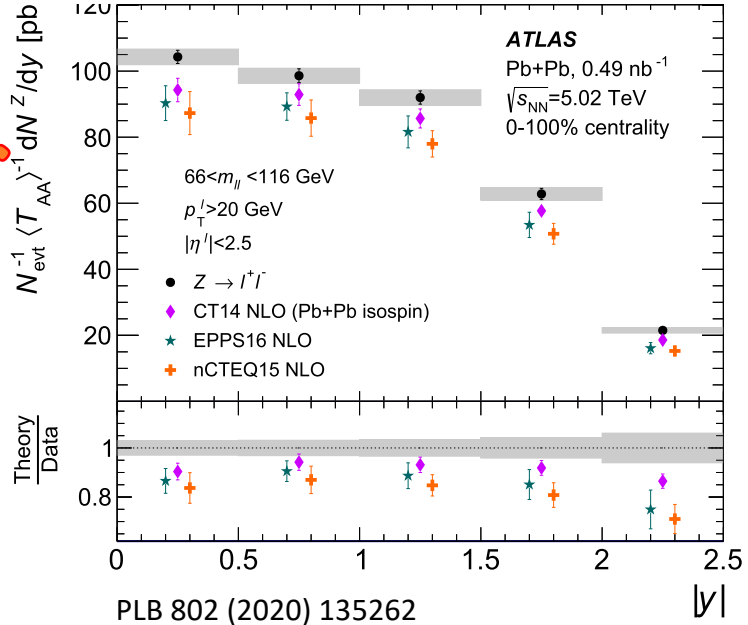


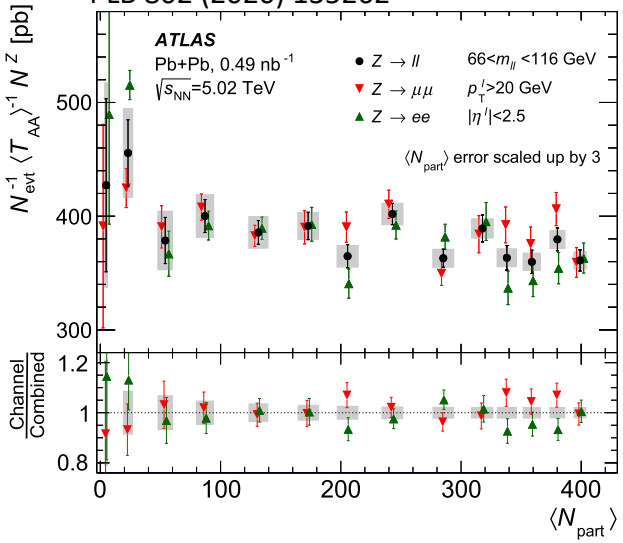
PLB 802 (2020) 135262

- Mid-rapidity Z → ee/μμ measured by ATLAS and CMS
- Largely insensitive to nPDF vs PDF
- If anything ATLAS data seems to slightly disfavor nPDF

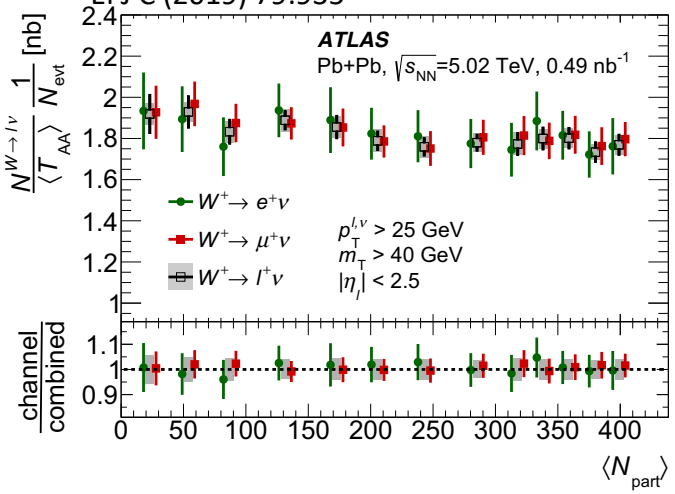
EW bosons and PbPb Centrality (ATLAS)

New!

PLB 802 (2020) 135262

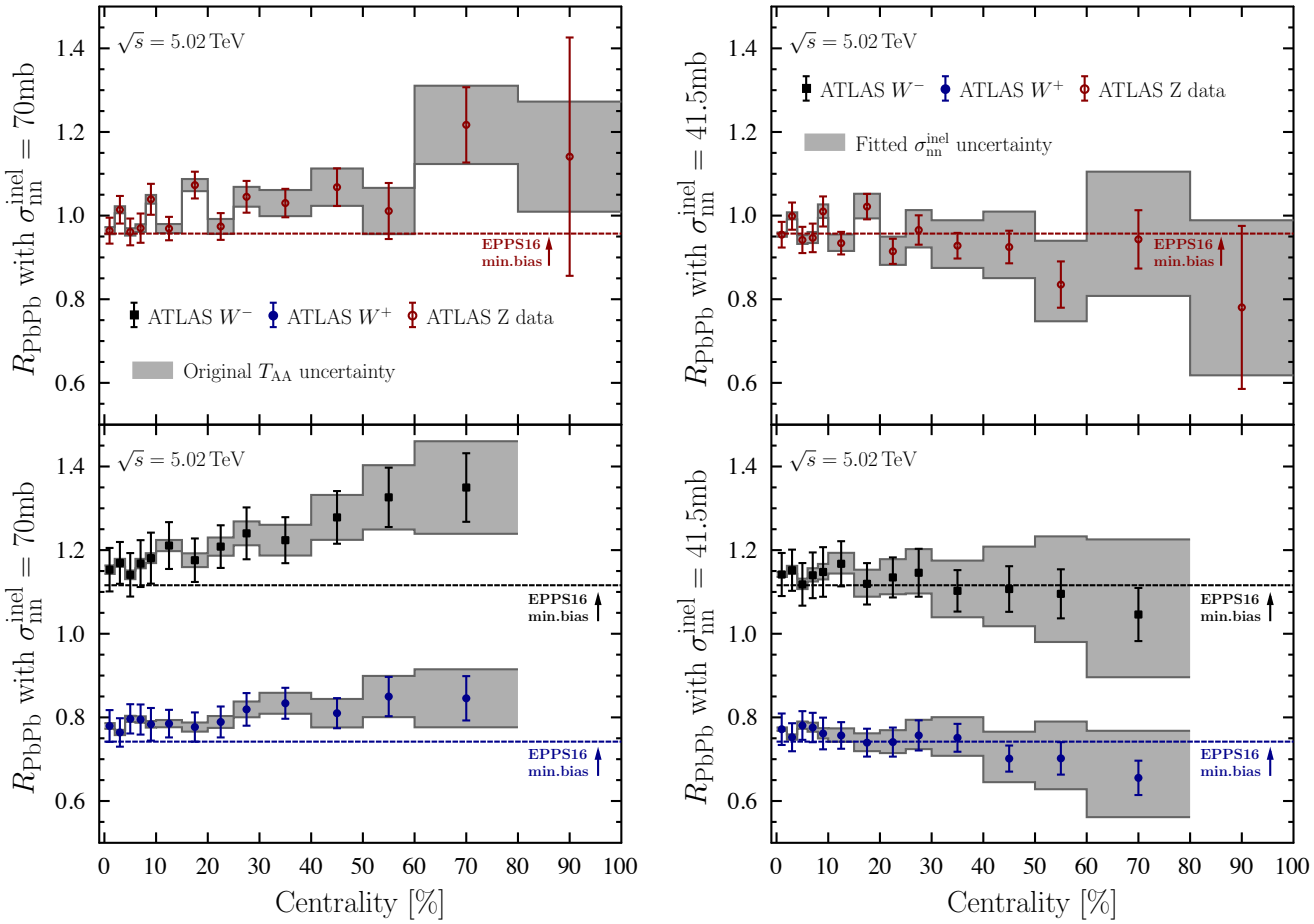


EPJ C (2019) 79:935



- Are nPDF actually (slightly) disfavored?
- Rapidity distribution is fairly compatible, normalization is off
- Check integrated yield vs centrality and ask if there is “Shadowing in inelastic nucleon-nucleon cross section?” (arXiv:2003.11856)

EW bosons and PbPb Centrality



- Are nPDF actually (slightly) disfavored?
- Rapidity distribution is fairly compatible, normalization is off
- Check integrated yield vs centrality and ask if there is “Shadowing in inelastic nucleon-nucleon cross section?” (arXiv:2003.11856)
- Take the yields rather than Glauber model as start, and fit for σ_{NN}
- (Does this hold up?)

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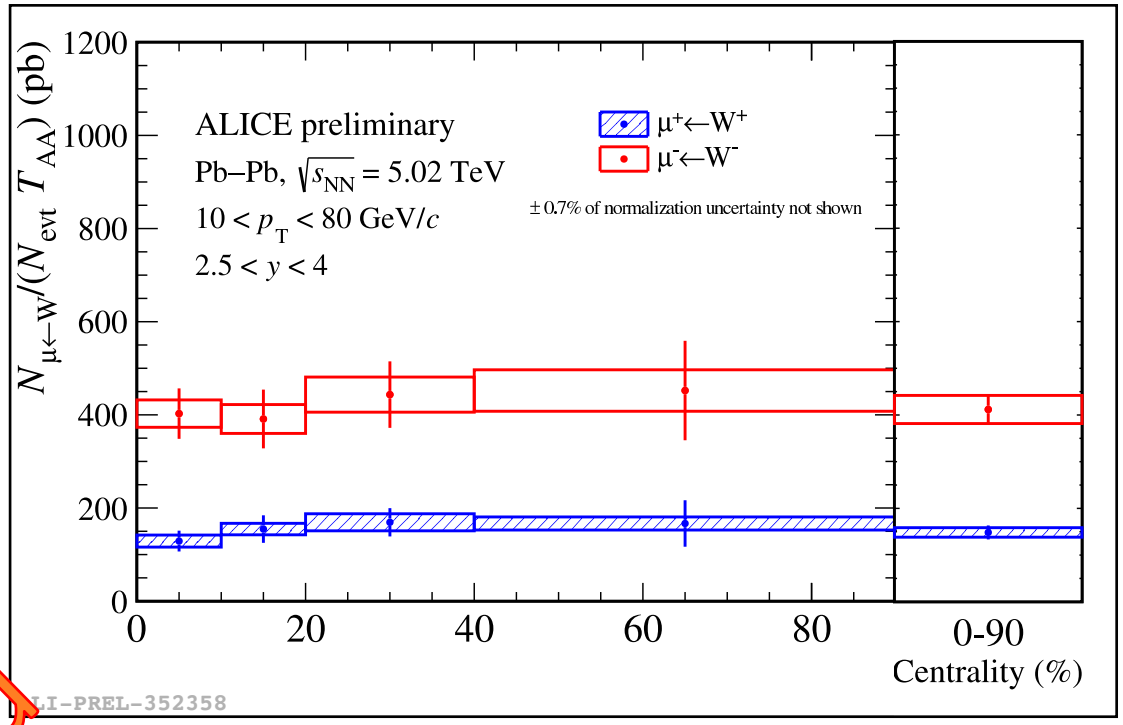
Forward W and PbPb Centrality



Brand New!

- ALICE Forward W bosons show clean T_{AA} scaling

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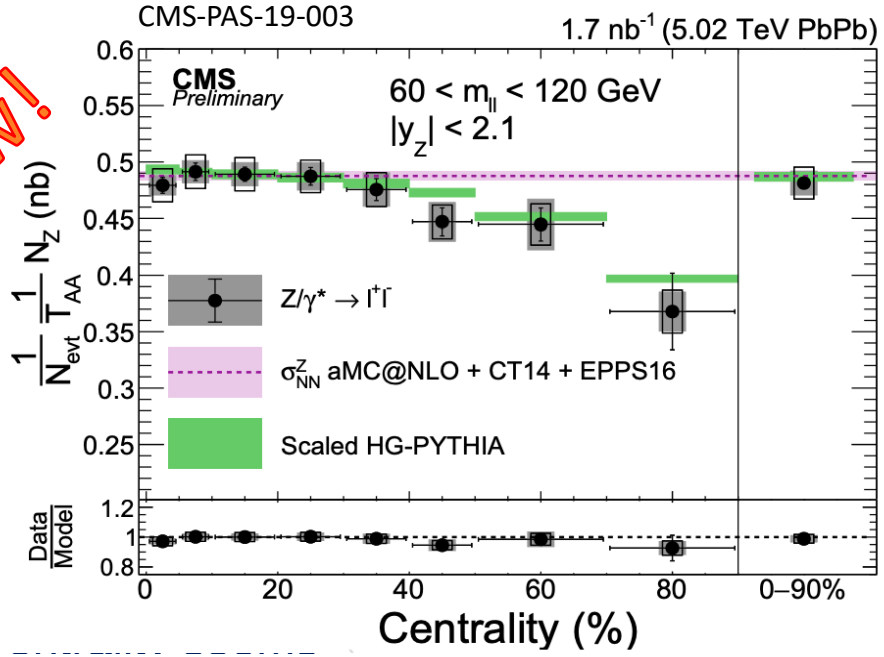
EW bosons and PbPb Centrality (CMS)

Brand New!



- Z boson data shows clear ‘suppression’ in peripheral events
- Consistent with HG-Pythia, but at odds with ATLAS data

EW bosons and PbPb Centrality (CMS)

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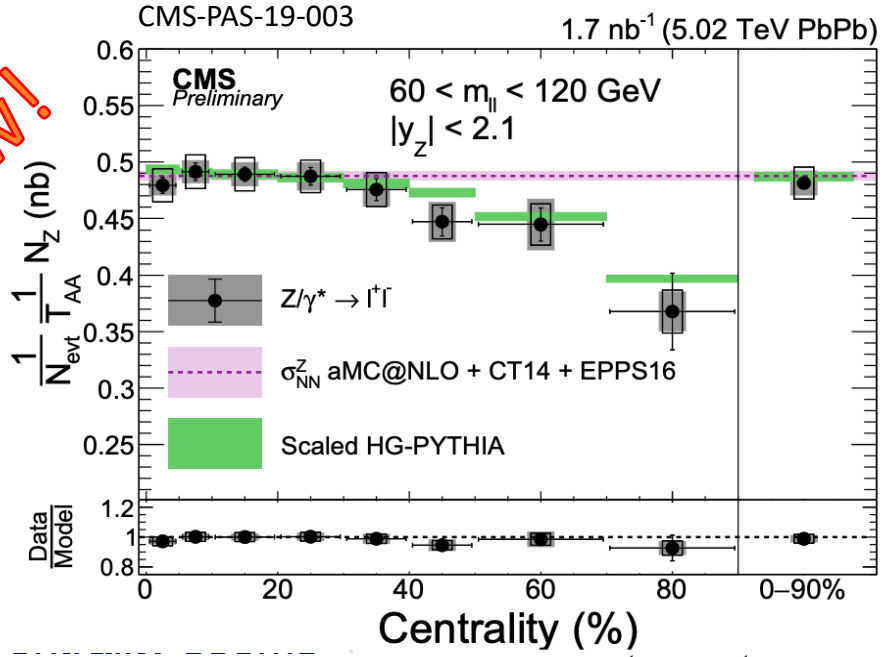

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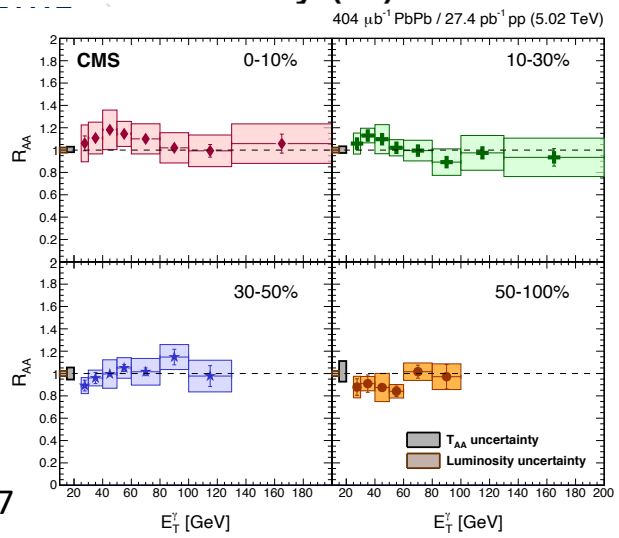

- Z boson data shows clear ‘suppression’ in peripheral events
- Consistent with HG-Pythia, but at odds with ATLAS data
- Photons look similar

arXiv:2003.12797

So about those Zs…

- **There is *clear tension* between ATLAS and CMS Z bosons yields in peripheral PbPb collisions @5.02 TeV**
  - (It's not easy to quantify brand new preliminary data in slightly different binning but) eyeballing it looks to be ≈ 3 sigma
  - Each result is really two measurements e/μ
  - Is this a Z boson issue or a centrality issue?

Peripheral Yield/T_{AA} Doesn't Drop

- ATLAS Z data is supported by ATLAS W data
  - x8 $W^{\pm} \rightarrow e/\mu$
- ALICE W data
  - x2, $W^{\pm}$, but precision not as high
- →HG-Pythia model is not the whole story or is wrong
- [→Slight tick *upwards* impetus for shadowing in σ_{NN}]

Peripheral Yield/T_{AA} Drops

- CMS Z data is supported by CMS photon measurement
  - Only mild sensitivity in one 50-100% bin
- →Strong confirmation of HG-Pythia model
- [→Presumably disfavors shadowing in σ_{NN}]

Summary

- Electroweak probes are a crucial part of the field as:
  - Intrinsically interesting probes
    - Where does the di-electron excess come from and how does it map to the parameters we know?
    - What can we say about the initial nuclear state from our EW boson measurements?
    - Are there EM signatures of the QGP hiding in di-lepton pairs?
  - Key to understanding other measurements
    - Can we prove or even improve our understanding of collision geometery based on EW measurements?
- High-quality results from RHIC & LHC experiments are answering questions and raising new ones
- There seems to be a significant discrepancy between ATLAS and CMS on Z boson yields with implications for above questions
- Many great results that I didn't get to:
  - EW boson + jet – Control the parton scattering with EW selection
  - Z tagged & photonuclear event v_2 – Control the collision with EW selection
  - Light by light scattering studies – QED (and BSM…) studies
- [NA60+ hoping to make measurements @SPS in Run 4 …]