Electroweak Probes: Experimental Overview

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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?
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?

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

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

- 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)
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Di-Electron Continuum & Low $p_T \gamma$

• 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 $\rightarrow R_{\text{pPb}}$
  • ALICE soft di-electrons at 13 TeV pp
• Filling in pieces of the puzzle ...
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
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

- Cocktail describes ALICE pp data well, fits well with 7&13 TeV
- pPb data also well described by cocktail
Di-Electrons in pp & pPb @5 TeV

- 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

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

[Graph showing di-electron excess]
Di-Electron Excess pp @ 13 TeV

- 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!
Drell-Yan Measurement in pPb

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

- 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

**Table 2:**

<table>
<thead>
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<th>Observable</th>
<th>CT14</th>
<th>CT14+EPPS16</th>
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<tr>
<td>$\phi^*$ (60 &lt; $m_{\mu\mu}$ &lt; 120 GeV)</td>
<td>25</td>
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</table>
Forward W in pPb

- ALICE measured W boson in forward muon decays
- Precision data but low sensitivity to nPDF effects
Forward Z in pPb & PbPb

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

- 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

- Mid-rapidity $Z \rightarrow \text{ee}/\mu\mu$ 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)

- 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 $\sigma_{NN}$
- (Does this hold up?)
Forward W and PbPb Centrality

- ALICE Forward W bosons show clean $T_{AA}$ scaling
EW bosons and PbPb Centrality (CMS)

- 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)

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

Figure 5: Nuclear modification factors $R_{AA}$ as a function of the photon $E_T$ measured in the 0–10%, 10–30%, 30–50%, and 50–100% centrality ranges in PbPb. The symbols are placed at the center of the bin. The vertical bars associated with symbols indicate the statistical uncertainties and the horizontal bars reflect the bin width. The total systematic uncertainties without the $T_{AA}$ uncertainty are shown as the colored boxes. The $T_{AA}$ uncertainty, common to all points for a given centrality range, is indicated by the gray box centered at unity on the left side of each panel. The 2.3% integrated luminosity uncertainty for pp data is shown as the brown box at unity at the leftmost position.

The data are compared with the next-to-leading order perturbative quantum chromodynamics calculations using the generator JETPHOX with CT14 parton distribution functions (PDFs) for pp data and EPPS16 and nCTEQ15 nuclear PDFs for PbPb data. The predictions are found to be consistent with the cross sections for both pp and PbPb collisions. The current measurements significantly improve the precision compared to the previous CMS results at $p_T^{NN} = 2.76$ TeV and can be valuable inputs for global fits of nuclear PDFs.
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\(^{\pm}\) → e/μ
- 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 \(\sigma_{NN}\)]

### 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 \(\sigma_{NN}\)]
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 geometry 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 ...]