Experimental overview on: Electroweak probes in heavy-ion collisions

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Electroweak probes in URHI collisions

Electroweak probes are produced in different stages of the collision.

- **Hard EW probes:**
  - $W^\pm$, $Z$ and prompt $\gamma$
  - Produced in initial hard scattering
  - Production sensitive to initial conditions
  - Provide calibration for jet quenching

- **Soft EW probes:**
  - Thermal $\gamma$ and **dileptons**
  - Produced in different collision stages
  - Carry thermodynamical information
  - Test QED $\rightarrow$ UPC

**Remarks:**
- Electroweak probes do not carry colour charge $\rightarrow$ no coupling to strongly interacting matter

**References:**
- Yongsun Kim, June 16, PL-OTH 17:25
- Zaochen Ye, June 15, PL-BLK 15:35
OUTLINE

- Photons in HI:
  - Direct $\gamma$ in AuAu
  - Direct $\gamma$ in PbPb

- EW hard probes in HI:
  - $Z/\gamma^*$ boson
  - $W$ boson

- EW-tagged jets in PbPb:
  - $\gamma$-jets
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- EW-tagged jets in PbPb:
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Photons in HI

Sources of photons in HI:

- Direct photons
- Prompt photons
  - Pre-equilibrium photons
  - Thermal radiation
- Decay photons

- Prompt photons from hard scattering calculable with pQCD.
**Photons in HI**

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$dN/dp_T$ vs $p_T$ [GeV]

**Collision**  
**Pre-equilibrium**  
**QGP**  
**Hadronization**  
**Hadron Gas**  
**Hadronic Decay**  
**Time**
Photons in HI

Sources of photons in HI:

- Direct photons
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- Thermal γ sensitive to medium temperature and collective flow
- Spectra \( \sim e^{-E/Teff} \rightarrow Teff \) affected by blueshift due to expanding medium.
Sources of photons in HI:

- Direct photons
  - Prompt photons
  - Pre-equilibrium photons
  - Thermal radiation
- Decay photons

- Significant photon yield from hadronic decay ($\sim \pi^0, \eta$) → main background.
- Photon yield constrains initial conditions, sources, temperature and space-time evolution.
Low $p_T$ direct photon excess

- Significant excess at $p_T < 2$ GeV observed above $N_{\text{coll}}$-scaled pp by PHENIX.
  - Suggest large temperature ($T_{\text{eff}} \sim 240$ MeV) → earlier stage production
Low $p_T$ direct photon excess

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  - Suggest large temperature ($T_{\text{eff}} \sim 240$ MeV) $\rightarrow$ earlier stage production
- STAR also see an excess at $p_T < 3$ GeV but 3x lower than PHENIX.
• Significant excess at $p_T < 2$ GeV observed above $N_{\text{coll}}$-scaled pp by PHENIX.
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• STAR also see an excess at $p_T < 3$ GeV but 3x lower than PHENIX.
• Similar trend measured by ALICE at 2.76 TeV (excess $\sim 2.6\sigma$) → $T_{\text{eff}} \sim 297 \pm 43$ MeV.
Low $p_T$ direct photon excess

- Significant excess at $p_T < 2$ GeV observed above $N_{coll}$-scaled pp by **PHENIX**.
  - Suggest large temperature ($T_{eff} \sim 240$ MeV) $\rightarrow$ earlier stage production
- **STAR** also see an excess at $p_T < 3$ GeV but 3x lower than **PHENIX**.
- Similar trend measured by **ALICE** at 2.76 TeV (excess $\sim 2.6 \sigma$) $\rightarrow T_{eff} \sim 297 \pm 43$ MeV.
- Models describe **STAR** and **ALICE** data within unc., but underestimate **PHENIX** results at low $p_T$. 

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Andre Stahl - Electroweak probes in heavy-ion collisions

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Large direct photon flow

- Large direct $\gamma v_2$ ($\approx$ pion $v_2$) measured by PHENIX.
  - Since collective flow needs to build up $\rightarrow$ later stage production.
- Direct $\gamma v_2$ results from ALICE at 2.76 TeV compatible with PHENIX results at 200 GeV.
• Large direct $\gamma v_2$ (≈ pion $v_2$) measured by PHENIX.
  • Since collective flow needs to build up → later stage production.
• Direct $\gamma v_2$ results from ALICE at 2.76 TeV compatible with PHENIX results at 200 GeV.
• PHENIX large direct $\gamma v_2$ not reproduced by models.
  • Simultaneous description of yield and $v_2$ challenging → direct $\gamma$ puzzle.
Temperature from nonprompt photons

- Temperature extracted from fitting nonprompt $\gamma$ increases with $p_T$.
  - Suggests contributions from earlier time production beyond thermal radiation.
  - Dominant contribution from pre-equilibrium at $p_T > 3$ GeV in the model align well with data.
• New direct $\gamma$ results from ALICE in PbPb at 5.02 TeV.
Direct photon in PbPb @ 5.02 TeV

- New direct $\gamma$ results from ALICE in PbPb at 5.02 TeV.
- Fairly good agreement between latest theory and RHIC/LHC direct $\gamma$ yields.
- Improved understanding of photon production in HI over years.
Universal scaling of direct photon production

- Universal power-law scaling of direct $\gamma$ yield vs $N_{ch}$ seen for different systems and collision energies.
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No $p_T$ dependence of slope $\alpha$ observed contrary to expectations from different $\gamma$ contributions.
Universal scaling of direct photon production

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- No $p_T$ dependence of slope $\alpha$ observed contrary to expectations from different $\gamma$ contributions.
- Fitted slope lower than hydro calculations for thermal $\gamma$ ($\alpha > 1.5$) $\rightarrow$ impact from pre-equilibrium?
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EW boson lifetime $\sim$ QGP formation time in HI collisions

- Clean probes of the initial stage of the HI collision

**nPDF modification**

**Collision Geometry**

$\mu$
Probing nPDF in HI

- EW bosons probe flavour separation (u vs d quarks).
- Quark and gluons correlated by DGLAP at small $x$, high $Q^2$ → sensitive to gluon PDF.
- Large low-$x$ nPDF uncertainties → need data at forward $y$ or low Drell-Yan mass.
Drell-Yan in pPb

- Measured Drell-Yan over a wide mass range: $15 < M < 600$ GeV.
  - PDF model calculations underestimate data at low masses.
- Forward-backward ratios better described by nuclear PDFs compared to CT14 PDF.
**Forward Z boson in pPb**

- Measurements compatible with nPDF calculations.
- Results in forward region (small x) more precise than theory calculations.
- $R_{FB} < 1 \rightarrow$ slightly deviates from proton PDF calculations (CTEQ6.1).

New measurements are compared with predictions from various PDF sets (EPPS16, nCTEQ15, CT14+EPPS16) for the ratio $R_{pPb}$ and $R_{FB}$.

**Definitions:**
- $R_{pPb} = \frac{N_{pPb}}{N_{e+evt}} \langle T_{AA} \rangle \times \sigma_{pp}$
- $R_{FB} = \frac{d\sigma/dy |_{y>0}}{d\sigma/dy |_{y<0}}$
$y_{\text{cms}} < 0$ sensitive to antishadowing and EMC, while $y_{\text{cms}} > 0$ dominated by shadowing.
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- $W^+$ results described by nPDF models and deviates from CT14 by 3.5σ at largest $y$. 

\[ \frac{d\sigma}{dy_{\text{cms}}} = n\text{CTEQ15} \]

\[ \frac{d\sigma}{dy_{\text{cms}}} = n\text{NNPDF2} \]
- $y_{\text{cms}} < 0$ sensitive to antishadowing and EMC, while $y_{\text{cms}} > 0$ dominated by shadowing.
- $W^+$ results described by nPDF models and deviates from CT14 by $3.5\sigma$ at largest $y$.
- Tension between models and $W^-$ results at bins closest to midrapidity.
- ALICE results extend the trend observed in LHC data to larger rapidities.
- pPb: results at forward rapidity deviate from CT14 PDF and are more precise than EPPS16.
- ALICE results extend the trend observed in LHC data to larger rapidities.
- **pPb**: results at forward rapidity deviate from CT14 PDF and are more precise than EPPS16.
- **PbPb**: results are lower than PDF model (~2σ) → start to be sensitive to nuclear effects.
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- Good agreement with HG-PYTHIA, limited by precision at peripheral.
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• **CMS** Z boson data showed ‘suppression’ in peripheral events consistent with HG-PYTHIA.
**Experimental $T_{AA}$ from weak bosons**

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- Good agreement with HG-PYTHIA, limited by precision at peripheral.
- **CMS** Z boson data showed ‘suppression’ in peripheral events consistent with HG-PYTHIA.
- **ATLAS** EW boson vs centrality shows slight enhancement not described by HG-PYTHIA.
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EW-tagged jets vs inclusive jets can provide insights into color-charge dependent effects.

- EW-tagged jets
- Inclusive jets

EW bosons used to tag the initial state of the jet production.
• γ-tagged jet $R_{AA}$ > inclusive jet $R_{AA}$ in PbPb collisions.
  • Indicate gluon jets lose more energy than quark jets in medium.
• Results of γ-tagged jets higher than model but compatible with SCET calculations.
  • Possibility to constrain the color-charge dependence of jet energy loss.
Near Future HI upgrades at RHIC and LHC

- **LHC Run 3 + HL-LHC:**
  - Significant increase of luminosity and major detector upgrades.

- **STAR Forward Upgrade programme:**
  - Extend tracking and calo. to forward region (2.5 < $\eta$ < 4).

- **sPHENIX:**
  - New detector at RHIC, planning to take p-Au & Au-Au high statistics data.

- **Electro-Ion Collider at BNL:**
  - Collide e-ion beams at ~20-140 GeV at high luminosity.
Summary

✓ New RHIC/LHC direct $\gamma$ data in line with latest models + pre-eq. $\gamma$.

✓ Direct $\gamma$ flow and constant slope not yet fully understood.

✓ $W/Z$ bosons at forward $y$ in HI described by nPDF with smaller unc.

✓ Clear geometric bias vs Glauber in PbPb.

✓ $\gamma$+jet constrain color dependence of jet energy loss.
Thank you for your attention!
Probing nPDF in PbPb: W bosons

- Measurements well described by nPDF calculations.
Z-hadron correlations in PbPb

- Particle production enhanced at low $p_T$ in central PbPb compared to pp
- Excess in central PbPb seen vs $\Delta \Phi$, peaking at $\Delta \Phi \sim 2.5$.
- CoLBT and hybrid+wake model describes well the PbPb Z-tagged particle production