Article: Measurement of angular correlations in Drell-Yan lepton pairs to probe Z/γ^* boson transverse momentum at $\sqrt{s} = 7$ TeV with the ATLAS detector.

Seminar presentation for the HASCO Summer School 2013

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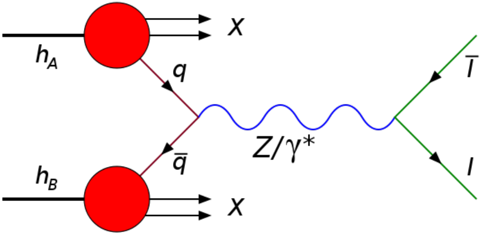
Introduction

the 'Drell-Yan' process

- First suggested by Sidney Drell and Tung-Mow Yan in 1970.
- High energy hadron-hadron scattering:
  $h_A(p_A) + h_B(p_B) \to V(M, p_T) + X \to \ell + \bar{\ell} + X$
- In this case: $h_A(p_A) + h_B(p_B) \to Z/\gamma^* + X \to e^+/\mu^+ + e^-/\mu^- + X$



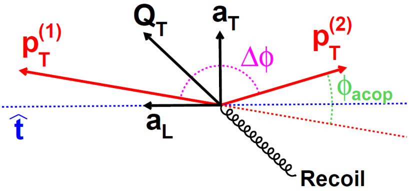
Why study this process?

- The process provides valuable information about the parton distribution functions.
- Frequently produced $\Rightarrow$important for background analysis.
- Good for calibration tests.
- Heavier neutral gauge boson Z'(if it exists) $\Rightarrow$ beyond SM physics.

Kinematics

- Measure the p_T for the Z/γ^* - limited by experimental resolution and uncertainties.
- Therefore switching to the related variable ϕ^*_η (def. in two slides).
- Related to the quantity $\frac{p_T^Z}{m_{\ell\ell}}$.

Geometry and definitions



- $\Delta\phi$ - azimuthal opening angle.
- Q_T - corresponds to the transverse momentum of p_T^Z .
- $\hat{t}$ - the 'thrust axis'(defined by the leptons transverse momentum).
- a_T - component of Q_T that is transverse to the thrust axis (important variable!)
- $\phi_{acop} = \pi - \Delta\phi$ - introduced for convenience.

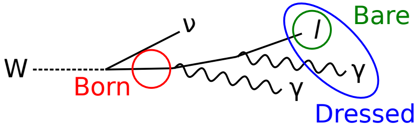
Putting the kinematics and geometry together

'Gluing' together the pieces of the kinematics and the geometry one arrives at

$$\phi^*_\eta = \tan(\tfrac{\phi_{acop}}{2})\sin(\theta^*_\eta).$$

- Why did an η subscript appear all the sudden..? And what is θ^*_η?
- Use pseudorapidities to define the angle $\theta^*_\eta \Rightarrow$ scattering angle.
- ϕ^*_η exclusively depends on the lepton pair track directions.

Born, Bare and Dressed leptons



- True dilepton mass $m_{\ell\ell}$ and ϕ^*_η defined by three distinct reference points:
- 1. 'Born' - lepton right after decay (primary vertex), QED FSR[1] corrections
- 2. 'Dressed' - lepton that emitted a photon (some QED FSR corrections) and with the cone restriction $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.1$
- 3. 'Bare' - lepton after QED FSR , no corrections for QED FSR

[1]final state radiation

QCD Predictions

- Non-zero p_T^Z is mainly generated through the emission of partons in the initial state.
- In high p_T^Z region: primarily hard parton emission.

$\Rightarrow$ Fixed order pertubative approach (which breaks down at $p_T^Z \ll m_Z$ because of powers of large logarithmic terms).

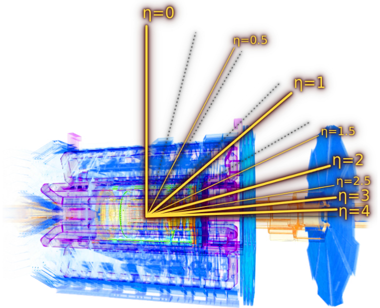
- RESBOS uses next-to-next-to-leading logarithms and result matching to fixed order calculation at $\mathcal{O}(\alpha_s)$. Then correction to $\mathcal{O}(\alpha_s^2)$ by using a factor $k\left(p_T^Z, y_z\right)$. Additionally: non-pertubative form factor determined by measurements.
- SHERPA and ALPGEN use tree-level matrix elements for generating multiple hard partons together with weak boson. Then matching to parton shower algorithms to avoid double counting of QCD emissions from matrix and parton shower.
- MC@NLO and POWHEG use next-to-leading order QCD matrix elements together with a parton shower algorithm.

Event Simulation

- Use MC simulations to calculate efficiencies and acceptances for $Z/\gamma^* \to \ell^+\ell^-$ and to unfold measured ϕ_η^* spectrum for detector effects and different levels of QED FSR.
- Simulate BG[2] by MC generators (different ones for different BGs) interfaced to PHOTOS for QED FSR (except for SHERPA: it linked up to an YFS-algorithm).
- Account for pile-up by overlaying events.
- Re-weight the MC events to match observed ATLAS detector luminocity.
- Model response of the detector with GEANT4. Fully simulated events are passed through the same reconstruction chain as the data.
- Correct the simulated events for differences with respect to the data in trigger efficiences, lepton reconstruction/identification and energy/momentum scale and resolution.

[2]background

Event reconstruction selection



Source: edited from www.atlas.ch/multimedia/#di-jet-event

For e^+e^-:

- electron candidate (shower shape, track quality) with > 20 GeV p_T (later > 22 GeV with incr. luminocity)
- other, opposely charged, electron (same criteria) with > 25 GeV p_T
- $|\eta| < 2.4$ with $1.37 < |\eta| < 1.52$ excluded

For $\mu^+\mu^-$:

- isolated muon with > 18 GeV p_T
- other, opposely charged, muon (also isolated) with > 20 GeV p_T
- $|\eta| < 2.4$, impact parameter less than 10 mm to prim. vertex (to reduce cosmic rays)

Event reconstruction selection

Additional criteria:

- stable beam
- good data-quality
- > 1 primary vertex reconstructed from > 2 tracks
- invariant mass $66\,\mathrm{GeV} < m_{\ell\ell} < 116\,\mathrm{GeV}$

Results

After fulfilling all selection criteria, $1.22 \cdot 10^6$ candidate di-electron events and $1.69 \cdot 10^6$ candidate di-muon events are left.

Background estimation

- Main BG from $Z/\gamma^* \to \tau^+\tau^-$, $W \to \ell\nu$, production of $t\bar{t}$ and di-bosons is estimated by MC-simulations.
- At high ϕ^*_η: domination of $t\bar{t}$ and di-boson productions.
- At low ϕ^*_η: domination of multijet production (with a jet falsely identified as a primary e or μ).

$\Rightarrow$ use a sample with a lot of falsely identified e/μ (by using data not fullfilling the e identification criteria / non-isolated μ).

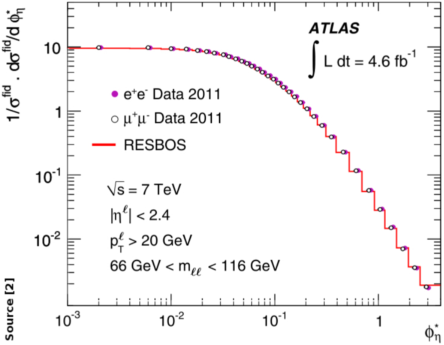
- Another irreduceable BG from $\gamma\gamma \to \ell^+\ell^-$ plays almost no role (about 0.1% of total BG).

Results

Total fraction of BG events is $0.61 \pm 0.28\%$ for e and $0.56 \pm 0.28\%$ for μ. About 50% of the BG is from multi-jet production.

Cross-section measurements

- Get the crossection by splitting the data into bins of ϕ^*_η (or of ϕ^*_η and y_z[3]) and substracting the BG.
- Correct for detector acceptance, inefficiencies and QED FSR using bin-by-bin correlations.



- Correction factors from signal MC events.
- Purity (fraction of simulated events with generator level same ϕ^*_η that end up in the same ϕ^*_η bin in the graph) is always more than 83% and goes up to 98%.
- Normalize the data in each bin to the cross-section.

[3] rapidity of the Z^*

Systematic uncertainties

systematic uncertainties uncorrelated between bins

error	for e^+e^-	for $\mu^+\mu^-$
uncertainties in bin-by-bin correction factors from MC sample statistics	0.2% at low ϕ^*_η 0.9% at high ϕ^*_η	0.13% at low ϕ^*_η 0.6% at high ϕ^*_η
local biases in angular measurements (ϕ, η) by tracking detectors	0.1%	0.1%
conservative systematic uncertainty from ϕ^*_η-dependent modelling of QED FSR	0.3%	0.3%

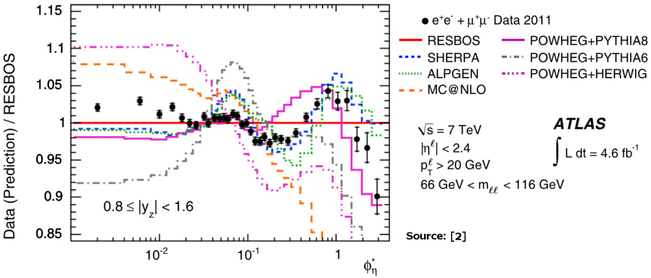
All systematic uncertainties are given as percent of the normalized differential cross-section. They are added up in quadrature for each data-point.

Systematic uncertainties

systematic uncertainties correlated between bins

error	for e^+e^-	for $\mu^+\mu^-$
number of BG events	$\leq 0.3\%$	$\leq 0.3\%$
mis-modelling of angular resolution of tracking detectors	$\leq 0.3\%$	$\leq 0.2\%$
dependence of bin-by-bin correction factors on the shape of assumed ϕ^*_η-distribution	$< 0.1\%$	$< 0.1\%$
weak dependence of ϕ^*_η on uncertainties in ℓ energy/momentum scale	$< 0.1\%$	$< 0.03\%$
mis-modeling of ℓ identification efficiencies / trigger efficiencies in simulation	0.05% / 0.04%	0.03% / 0.02%
pile-up	$\leq 0.05\%$	$\leq 0.05\%$

Results



Source: [2]

- Graphs for other y_z-Regions look similar.
- Combined analysis for e^+e^- and $\mu^+\mu^-$ to reduce correlated uncertainties (down to 0.5...0.8%).
- Accuracy is slightly worse in the upper/lower region than the best generators (2...5% vs. 2%).
- Overall performance is better than most other generators.
- Finer details are not captured very well by any generator.

Sources

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