Measurement in four mass regions in the dimuon channel using $10.4 \ fb^{-1}$ data at the DØ experiment

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arxiv:1410.8052 [hep-ex]

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Overview of the talk

1. The $\phi^*_\eta$ variable
2. Motivations
3. Event selection and data decomposition
4. Comparison with theoretical prediction
5. Summary
6. Back up
The $\phi_\eta^*$ variable [Eur. Phys. J. C71 1600(2011)]

- $\phi_\eta^* = \tan(\phi_{acop}/2) \sin(\theta^*)$
- $\phi_\eta^*$ probes the same physics as $Q_T$
- $\phi_\eta^*$ is less sensitive to effects of detector resolution and efficiency
Motivations

1. Low mass region \((30 < M_{\mu\mu} < 60 \text{ GeV})\)
   - sensitive to small-\(x\) effects
     \(x_{1,2} = \frac{M}{\sqrt{s}} e^{\pm y}\)

2. High mass region \((160 < M_{\mu\mu} < 300 \cup 300 < M_{\mu\mu} < 500 \text{ GeV})\)
   - constrain ISR uncertainty with systems with high final state masses.

3. Peak region \((70 < M_{\mu\mu} < 110 \text{ GeV})\)
   - more statistics, \(\int L dt\) increased from 7.3 fb\(^{-1}\) to 10.4 fb\(^{-1}\).
Results in the peak region using 7.3 fb$^{-1}$ data [ PRL 106, 122001 (2011)]

\[ \frac{\chi^2_{(ee,\mu\mu)}}{\text{Data}} = 25/24 \]

\[ \frac{\chi^2_{(ee,\mu\mu)}}{\text{Data}} = 27/24 \]

\[ 70 < M_{\mu\mu} < 110 \text{ GeV} \]
“Tuning” ResBos [arXiv: 1309.1393]

The $ee$ data was from 2011 DØ paper shown in previous slide [PRL 106, 122001 (2011)]

[Graph showing data and theory predictions for $\phi_\eta^*$ in four mass regions at DØ]
Event selection and data decomposition

1. Event selection
   - \( p_T > 15 \text{ GeV}, |\eta| < 2, \) isolated and tightly identified muon pairs

2. Bin-by-bin corrections
   - Data is corrected back to the particle level with the same kinematic cuts above

Table: Decomposition of the full event sample.

<table>
<thead>
<tr>
<th>Mass region</th>
<th>(30, 60) GeV</th>
<th>(160, 300) GeV</th>
<th>(300, 500) GeV</th>
<th>(70, 110) GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Events</td>
<td>74k</td>
<td>1.7k</td>
<td>0.3k</td>
<td>645k</td>
</tr>
<tr>
<td>DY signal fraction</td>
<td>90%</td>
<td>73%</td>
<td>57%</td>
<td>99.84%</td>
</tr>
</tbody>
</table>

Note that the off-peak region suffers from mass migration in Drell Yan process due to the mismeasurement in \( M_{\mu\mu} \).
Comparison with the “tuned” ResBos prediction [arXiv:1309.1393]

Comparison for $70 < M_{\mu\mu} < 110$ GeV

Ratio in $1/\sigma(d\sigma/d\phi_\eta^*)$ of $|y| < 1$ to $1 < |y| < 2$.

A Large decrease in theoretical uncertainty due to cancellations!
Comparison to theoretical prediction in the low-mass region

Comparison to the ResBos prediction in $30 < M_{\mu\mu} < 60$ GeV

Comparison to a NNLL+NLO prediction [JHEP01 (2012) 044]

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Dimuon $\phi_{\eta}^*$ in four mass regions at DØ
width in terms of dimuon invariant mass

(a) $|y| < 1$
(b) $1 < |y| < 2$

Comparison to ResBos in the high mass region

$160 < M_{\mu\mu} < 300$ GeV

$300 < M_{\mu\mu} < 500$ GeV

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Summary

- **The peak region (645k events)**
  - The transverse momentum can be determined with unprecedented precision.
  - The tuned ResBos prediction is in excellent agreement with data.
  - Ratio in \((1/d\sigma)(d\sigma/d\phi^*)\) of \(|y| < 1\) to \(1 < |y| < 2\) provides further stringent test of the prediction with reduced theoretical uncertainty!

- **The low-mass region results (74k events)**
  - The ResBos prediction is in reasonable agreement with data.

- **High-mass region (2k events)**
  - The ResBos prediction is in reasonable agreement with data but no detailed comparison can be made due to limited statistics.

- **The NLO+NNLL QCD prediction**
  - is in excellent agreement with data within assigned theoretical uncertainty in both on-peak region and low mass region.
Comparison with a NLO+NNLL QCD prediction in the peak region [ JHEP01 (2012) 044]

![Graphs showing comparison between data and theoretical predictions](image)

- (a) $|y| < 1$
- (b) $1 < |y| < 2$

Data/NNLL+NLO

- (a) $|y| < 1$
  - DØ 10.4 fb$^{-1}$
  - $70 \text{ GeV} < M_{\mu\mu} < 110 \text{ GeV}$
  - $\mu\mu$ data
  - All scales
  - $\mu_Q = M_{\mu\mu}$

- (b) $1 < |y| < 2$
  - DØ 10.4 fb$^{-1}$
  - $70 \text{ GeV} < M_{\mu\mu} < 110 \text{ GeV}$
  - $\mu\mu$ data
  - All scales
  - $\mu_Q = M_{\mu\mu}$
Ratio of \( (1/\sigma)(d\sigma/d\phi^*_\eta) \) in rapidity bins in the peak region

The motivation for this comparison is that the ratio in \( (1/\sigma)(d\sigma/d\phi^*_\eta) \) of central rapidity region to that of forward rapidity region can reduce the uncertainty band from QCD scales to percent level due to cancellations. It suggests the possibility of a new variable that is less sensitive to theoretical uncertainty.
Comparison to ResBos in low-mass region

\( |y| < 1 \)  

\( 1 < |y| < 2 \)  

DØ 10.4 fb^{-1}  

30 GeV < \( M_{\mu\mu} \) < 60 GeV

\( \Delta \mu\mu \text{ data} \)

\( \text{ResBos} \)

\((e)\, M_{\mu\mu} \in (30, 60)\)
Comparison with ResBos prediction in high mass region

Data/ResBos

(a) 160 GeV < M_{ll} < 300 GeV
DØ 10.4 fb^{-1}

(b) 300 GeV < M_{ll} < 500 GeV
DØ 10.4 fb^{-1}

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$\phi_{\text{mod}}$ distribution in the peak region

$\phi_{\text{mod}} = |\text{mod}(8\phi/\pi, 1) - 0.5|$  Octant gap: $\phi_{\text{mod}} > 0.45$

Data
Signal
WW
$Z \rightarrow \tau^+\tau^-$
t t
Multijets

N=645 k, $\chi^2=49.0/19$
\( M_{\text{pseudo}} \) distribution in the low-mass region

Migration background is defined as \( M_{Z}^{true} > 70 \text{ GeV} \) including **FSR**.

\[
M_{\text{pseudo}} = \sqrt{2 \times p_{T}^{0} \times p_{T}^{0} \times (\cosh(\eta_{1} - \eta_{2}) - \cos(\phi_{1} - \phi_{2}))}, \]
where \( p_{T}^{0} \) is the transverse momentum of the leading muon.
$M_{\mu\mu}$ distribution in the high-mass region

Mismeasured background is defined as events with $M_Z^{true}$ at generator level outside the defined mass bin at detector level.

$(m) \quad M_{\mu\mu} \in (160, 300)$
Systematic uncertainty in the peak region

The systematic error is smaller than the statistical error in all bins of $\phi^*_{\eta}$ in the peak region.

Figure: $70 < M_{\mu\mu} < 110$ GeV region.
Systematic uncertainty in the low-mass region

The systematic error is smaller than the statistical error in all bins of $\phi_\eta^*$ in the low-mass region.

Figure: $30 < M_{\mu\mu} < 60 \text{ GeV}$ region.
Systematic uncertainty in the high-mass region

The systematic error is much smaller than the statistical error in all bins of $\phi^{*}_{\eta}$ in the high-mass region.

(a) $160 < M_{\mu\mu} < 300$

(b) $300 < M_{\mu\mu} < 500$