Prediction of Drell-Yan nuclear modification factor at LHC using hybrid factorisation

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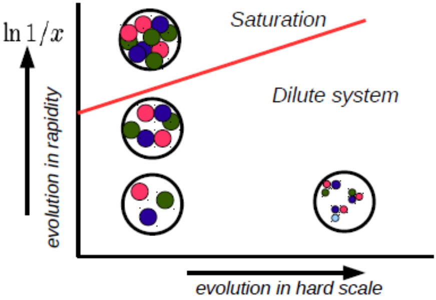
Introduction



- Large $\sqrt{s}$ at LHC → large range of Bjorken-x to probe,
- At small x and high parton density saturation effects expected ,
- not yet a clear smoking gun effect at LHC.

Drell-Yan as a saturation probe

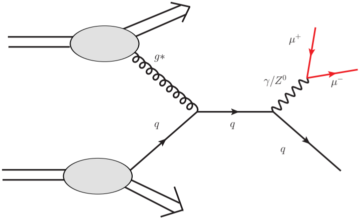


Figure: Example of DY diagram

- DY process clean to probe proton/nuclei structures, see [Motyka yesterday's talk]
- Clean signature experimentally (leptons)
- We are going to focus on forward DY
  $\Longrightarrow$ saturation effects are expected to be biggest there
- `[Schäfer,Szczurek,16]` has studied recently DY process in forward region using hybrid approach.
- They manadged to reproduce recent LHCb $p-p$ `[LHCb-CONF-2012-013, 12]` data well ($2 < \eta < 4.5$) **without saturation**.
- We will follow `[Schäfer,Szczurek,16]`'s approach, but look at p-Pb data!

Methodology

- We do Monte Carlo simulation in the hybrid factorization setting using `KaTie` MC tools

`[A. van Hameren, 16]`
`[see also Andreas's talk on Wednesday!]`.

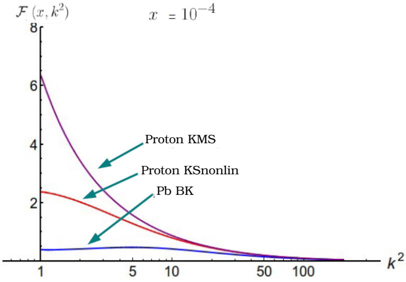
$$\sigma_{pp\to q\mu^+\mu^-} = \int d^2k_T dx_1 dx_2 \mathcal{F}(x_1, k_T, \mu) f(x_2, \mu) \sigma_{ab\to q\mu^+\mu^-}(x_1, x_2, k_T, \mu),$$

where:
$f(x_2, \mu)$ – is standard colinear PDF (quark)
$\mathcal{F}(x_1, k_T, \mu)$ – unintegrated parton distribution funtion (gluon),

as we expect the process in forward region be dominated by valence quarks interacting with low-x gluons.

- We use NLO MSTW2008 PDF set for $f(x_2, \mu)$.

Unintegrated Gluon Distributions



From K. Kutak

- We consider three unintegrated distributions $\mathcal{F}(x_1, k_T, \mu)$ from `[Kutak, Sapeta, 12]`:
    - KMS – from the solution of NLO BFKL equation + resummed corrections of higher orders,
    - KSnonlinear (KSnonlin) – from NLO BK equation + resummed corrections of higher orders,
    - Pb – from heavy ion version of KSnonlinear equation with saturation modified by greater radius $R = RA^{1/3}$.

Nuclear Modification Factor

- Our Pb gluon distribution is normalised to proton, so we can calculate Nuclear Modification Factors (NMF) straight forwards as:

$$NMF^{i}_{(KMS)} = \frac{\sigma^{i}_{(Pb)}}{\sigma^{i}_{(KMS)}}, \qquad NMF^{i}_{(KSnonlin)} = \frac{\sigma^{i}_{(Pb)}}{\sigma^{i}_{(KSnonlin)}},$$

  for signal bin i, where $\sigma^{i}_{(Pb)}$,$\sigma^{i}_{(KMS)}$ and $\sigma^{i}_{(KSnonlin)}$ are cross sections for the bin i obtained with Pb, KMS and KSnonlin gluon distribution respectively.

- We are going to calculate that for the dimuon-invariant mass.

Methodology 2 – Cuts

We follow analysis cuts from `[LHCb-CONF-2012-013]` which requires:

Analysis cuts

- a pair of (μ^+, μ^-),
- for both muons: $|p^\mu| > 10$ GeV, $|p_T^\mu| > 10$ GeV and $2 < \eta^\mu < 4.5$,
- $5 < M_{\mu\mu} < 9.25$ GeV or $10.5 < M_{\mu\mu} < 120$ GeV,
- if $M_{\mu\mu} > 40$ GeV then $P_T^\mu > 15$ GeV for both muons,

- Gap in $M_{\mu\mu}$ between $[9.25, 10.5]$ corresponds to Υ resonance.

Validation

- For validation purposes we are going to compare our results with events from `MadGraph_aMC@NLO [Alwall et. al, 2014]` (colinear MC).
- We generate LO and NLO samples with `MadGraph` which we then shower and hadronize with `Pythia8 [Sjöstrand, 2014]`

MC samples

- KMS – LO $pp \to \mu^+\mu^- + j$, `KaTie`
- KSnonlin – LO $pp \to \mu^+\mu^- + j$, `KaTie`
- Pb – LO $pPb \to \mu^+\mu^- + j$, `KaTie`
- MG-LO – LO $pp \to \mu^+\mu^-$, `MadGraph 5` & `Phythia 8`,
- MG-NLO – NLO $pp \to \mu^+\mu^-$, `MadGraph 5` & `Phythia 8`,

pp - Kinematic Distributions – DY invariant mass

- Both colinear and hybrid approaches reproduce data.
- KMS closer to data than KSnonlin (so we can confirm no suppression as in `[Schäfer,Szczurek,16]`)
- As one should expect, Pb production suppressed (by construction)

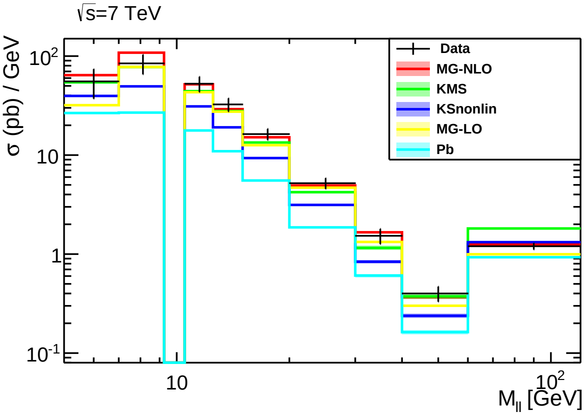
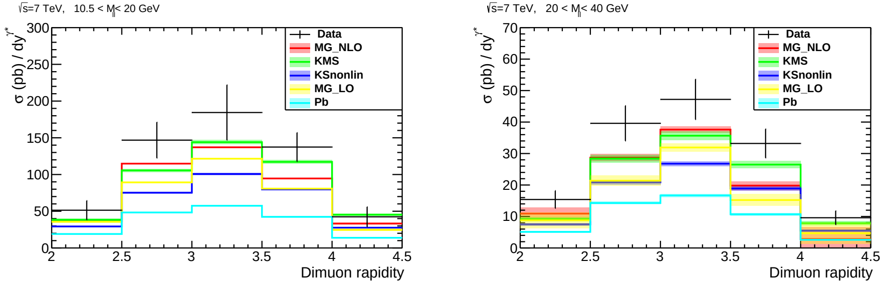


Figure: Distribution of the invariant mass $M_{\mu\mu}$ for different MC schemes compare to LHCb data.

pp - Rapidity Distributions

- LHCb provides also with the dimuon rapidity distributions,
- Ee seem to undershoot the distributions in all samples, however...,
- Numbers seem to not agree plots on the experimental side...,
- Overall consistency is good.



a) $10.5 < M_{\mu\mu} < 20$ GeV

b) $20 < M_{\mu\mu} < 40$ GeV

Figure: Distribution of dimuon system rapidity in a) $10.5 < M_{\mu\mu} < 20$ GeV , and b) $20 < M_{\mu\mu} < 40$ GeV invariant mass range.

Nuclear Modification Factor

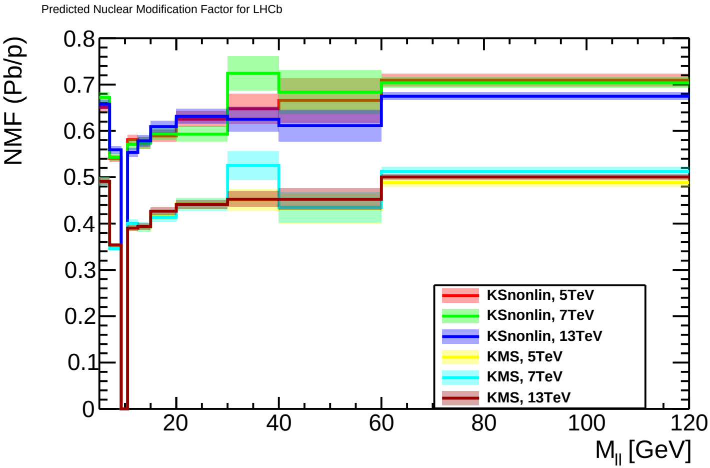
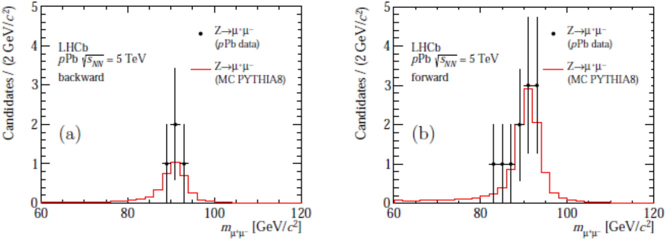


Figure: Prediction for NMFs for p-Pb at $5, 7$ and 13 TeV.

- Suppression from pPb and pp significantly below 1.
- KSnonlin being more suppressed gives higher nuclear factor.

Experimental Data



- Unfortunately no existing data on NMF calculated here so far,
- However, LHCb has published one proton-lead analysis of Z boson production at $\sqrt{s} = 5$ TeV [JHEP09 (2014) 030],
- They report:
  $\sigma^{LHCb}_{Z\to\mu^+\mu^-}(\text{fwd.}) = 13.5^{+5.4}_{-4.0}(stat.) \pm 1.2((syst.))$ nb
  $\sigma^{LHCb}_{Z\to\mu^+\mu^-}(\text{bwd.}) = 10.7^{+8.4}_{-5.1}(stat.) \pm 1.0((syst.))$ nb
- Our initial results seem to agree with that.
- Different and interesting modification factor (Forward-backward assymmetry):
  $R^{LHCb}_{FB}(2.5 < |y| < 4) = 0.094^{+0.104}_{-0.062}(\text{stat.}) \pm^{+0.004}_{-0.007}\ (\text{syst.})$ nb
- Cuts used there are different than used here.

Final words

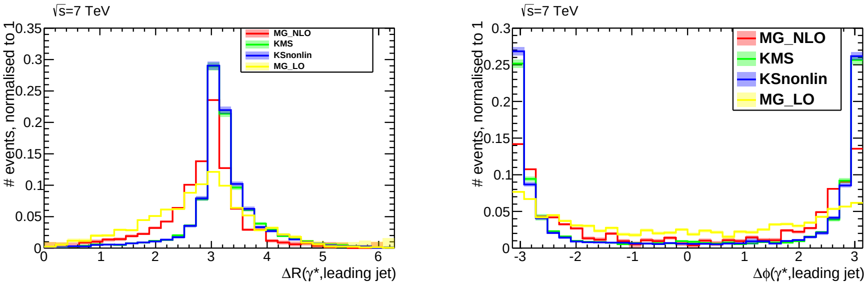
Conclusion

- We reproduce LHCb p-p data using hybrid factorisation MC,
- Predictions pased on linear evolution seems to fit data better,
- We calculate Nuclear Modification Factors for forward Z production,

Outlook

- We want to fully exploit existing LHCb data of Z production in pPb,
- We hope for more experimental results in those observables!

Probing k_T factorisation



a) $\Delta R(\gamma^*, j^{1st})$ **b)** $\Delta \phi(\gamma^*, j^{1st})$

Figure: Distribution of a) ΔR, b) $\Delta \phi$ between dimuon system momentum and the leading jet momentum.

NMF @ 5.02 TeV

M_{ll} bin	$\frac{Pb}{KMS}$ @ 5.02 TeV	$\frac{Pb}{KSnonlin}$ @ 5.02 TeV
$[5.0, 7.0]$	0.492 (0.009)	0.651 (0.011)
$[7.0, 9.25]$	0.347 (0.005)	0.541 (0.008)
$[9.25, 10.5]$	0.000 (0.000)	0.000 (0.000)
$[10.5, 12.5]$	0.392 (0.008)	0.581 (0.011)
$[12.5, 15.0]$	0.391 (0.009)	0.574 (0.012)
$[15.0, 20.0]$	0.418 (0.010)	0.589 (0.013)
$[20.0, 30.0]$	0.443 (0.013)	0.625 (0.017)
$[30.0, 40.0]$	0.451 (0.024)	0.648 (0.033)
$[40.0, 60.0]$	0.431 (0.033)	0.666 (0.048)
$[60.0, 120.0]$	0.488 (0.010)	0.709 (0.014)

Table: Nuclear modification factors for LHCb forward Z production at $\sqrt{s} = 5.02$ TeV. Error given is purely statistical, as explained in the text.

NMF @ 8.16 TeV

M_{ll} bin	$\frac{Pb}{KMS}$ @ 8.16 TeV	$\frac{Pb}{KSnonlin}$ @ 8.16 TeV
$[5.0, 7.0]$	0.512 (0.009)	0.654 (0.010)
$[7.0, 9.25]$	0.351 (0.005)	0.551 (0.008)
$[9.25, 10.5]$	0.000 (0.000)	0.000 (0.000)
$[10.5, 12.5]$	0.375 (0.007)	0.574 (0.011)
$[12.5, 15.0]$	0.403 (0.009)	0.586 (0.013)
$[15.0, 20.0]$	0.418 (0.009)	0.601 (0.013)
$[20.0, 30.0]$	0.425 (0.012)	0.597 (0.016)
$[30.0, 40.0]$	0.473 (0.023)	0.643 (0.030)
$[40.0, 60.0]$	0.494 (0.032)	0.707 (0.044)
$[60.0, 120.0]$	0.493 (0.008)	0.677 (0.010)

Table: Nuclear modification factors at 8.16 TeV. Error given is purely statistical.

NMF @ 13 TeV

M_{ll} bin	$\frac{Pb}{KMS}$ @ 13 TeV	$\frac{Pb}{KSnonlin}$ @ 13 TeV
$[5.0, 7.0]$	0.491 (0.007)	0.657 (0.010)
$[7.0, 9.25]$	0.354 (0.004)	0.559 (0.008)
$[9.25, 10.5]$	0.000 (0.000)	0.000 (0.000)
$[10.5, 12.5]$	0.390 (0.007)	0.553 (0.010)
$[12.5, 15.0]$	0.394 (0.007)	0.579 (0.012)
$[15.0, 20.0]$	0.427 (0.008)	0.609 (0.013)
$[20.0, 30.0]$	0.441 (0.010)	0.631 (0.016)
$[30.0, 40.0]$	0.453 (0.018)	0.625 (0.027)
$[40.0, 60.0]$	0.453 (0.023)	0.611 (0.034)
$[60.0, 120.0]$	0.501 (0.006)	0.675 (0.008)

Table: Nuclear modification factors at 13 TeV. Error given is purely statistical.