Double Parton Scattering cross section limit from same-sign W bosons pair production in di-muon final state at LHC

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MPI@LHC2015, 23th Nov. 2015

Outline

DPS theory

- in the case of **two identical processes** with **no parton longitudinal correlation**:

$$\sigma^{incl}_{DPS}(s) = \frac{1}{2}\int d^2\beta\,(A(\beta))^2\,(\sigma^{incl})^2 \tag{1}$$

- all the unknown correlation of partons in transverse dimension are contained inside $\int d^2\beta\,(A(\beta))^2$ that is usually indicated as the inverse value of the effective cross section:

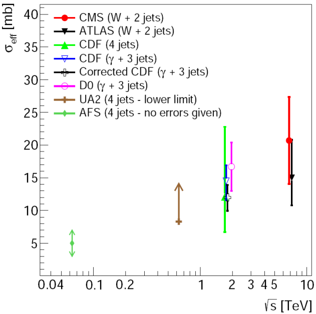
$$\sigma_{eff} = \frac{1}{2}\cdot\frac{(\sigma^{incl})^2}{\sigma^{incl}_{DPS}} \tag{2}$$

State of the art

Lack of angular and momentum correlations → DPS signature

State of the art for σ_{eff} measurements:

- 4 jets
- 3 jets+γ
- W + 2 jets



In all of these measurements the DPS contribution is extracted indirectly since SPS associated processes have a much higher cross section.

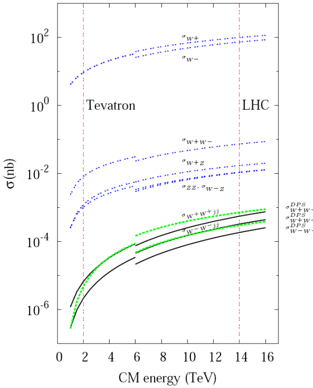
DPS in same sign WW

Pros

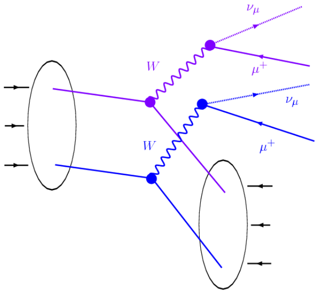
- the same sign muons final state presents a clean signature (better described than jets enviroments)
- the DPS cross section for such a final state is comparable to the SPS corresponding one.

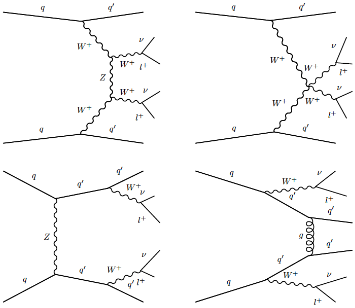
Cons

- expected cross section around 5 fb for a single flavour leptonic final state
- with 19.7 fb^{-1} we can realistically only put a limit



DPS in same sign WW



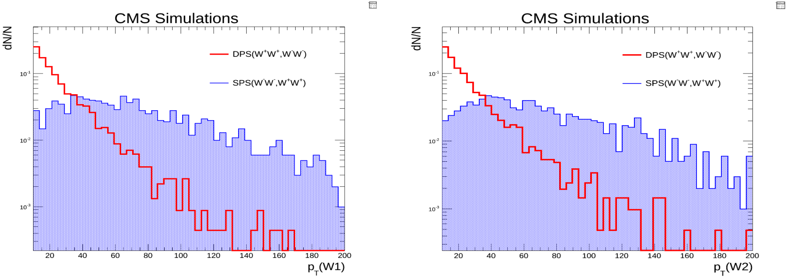


Signatures:

- absence of lepton angular and momentum correlation
- no direct production of jets

Gen Level studies

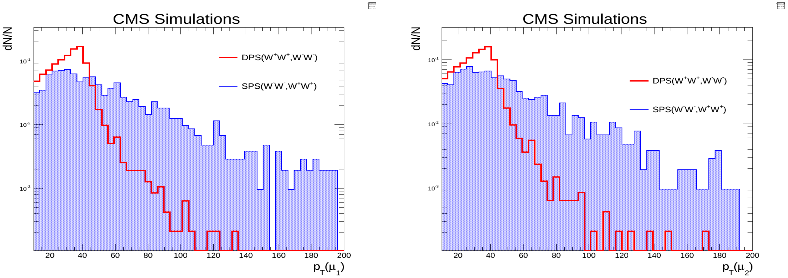
W and Muons Gen Level kinematic DPS vs SPS comparison



W bosons in SPS events are expected to be more boosted due to the necessity of balancing the energy of the associated jets.

Gen Level studies

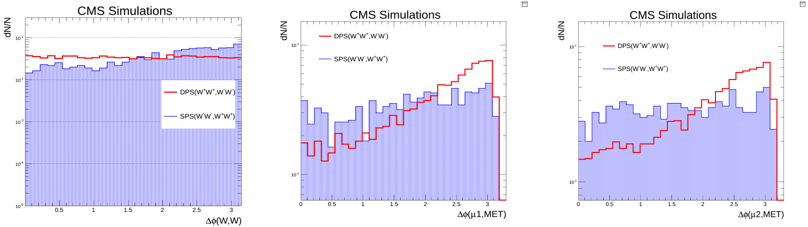
W and Muons Gen Level kinematic DPS vs SPS comparison



For the same reason we expected the p_{T} of the muons to be discriminant observable for DPS events.

Gen Level studies

W and Muons Gen Level topologic DPS vs SPS comparison



One can also think to use the SPS relative separation between W bosons that is expected to be different from the DPS one since the energy balance is not a constrain for DPS events.

Backgrounds

- **WZ, W γ and ZZ:**
  - one missed lepton needed in order to emulate ssWW
  - cross section higher than the DPS cross section by a factor of $\sim 10^2$
- **Drell-Yan, W + jets, QCD and $t\bar{t}$+jets:**
  - no direct production if same sign muons final state
  - huge cross section w.r.t. the DPS makes the contribution from misreconstructed muons (e.g. coming from jets) not negligible.

Datasets

DATA samples: Run2012 19.7 fb^{-1}.

Sample
DoubleMuRun2012A-22Jan2013-v1
DoubleMuParkedRun2012B-22Jan2013-v1AOD
DoubleMuParkedRun2012C-22Jan2013-v1AOD
DoubleMuParkedRun2012D-22Jan2013-v1AOD

MC samples: Summer12_DR53X-PU_S10_START53_V7A

Sample	Cross Section [pb]
WW_DoubleScattering_8TeV-pythia8	0.59 $\pm$ 0.02(LO)
Wp(m)Wp(m)qq_8TeV-madgraph	0.34 $\pm$ 0.03(LO)
WZ_TuneZ2star_8TeV_pythia6_tauola	33 $\pm$ 3(NLO)
WGstarToLNu2Mu_TuneZ2star_8TeV-madgraph-tauola	1.9 $\pm$ 0.2(LO)
ZZ_TuneZ2star_8TeV_pythia6_tauola	7.6 $\pm$ 0.3(NLO)
DYJetsToLL_M-50(10-50)_TuneZ2Star_8TeV-madgraph-tarball	18206 $\pm$ 100(NNLO)
TTJets_MassiveBinDECAY_TuneZ2star_8TeV-madgraph-tauola	234 $\pm$ 20(NNLO)
WJetsToLNu_TuneZ2Star_8TeV-madgraph-tarball	37509 $\pm$ 1300(NNLO)
QCD_Pt_20_MuEnrichedPt_15_TuneZ2star_8TeV_pythia6	134680 $\pm$ 100%(LO)

Strategy

- Define a base selection on the path of other WW analysis, keeping that as much loose as possible in order to save DPS statistics.
- Study the misidentified muons contribution in this selection
- Define a set of independent (as much as possible) sensitive variables to provide an input for a MVA (BDT in this case)
- Put a limit on DPS yield using the modified frequentist approach (CombineHiggs tool)

Selection

- **Trigger:** HLT_Mu17_TkMu8
- **Muons:** two tight muons (**standard working point**):
  - Normalized $\chi^2 < 10$.
  - The muon track reconstructed within the tracker volume, should have at least one valid pixel hit.
  - There should be hits registered in at least two muon stations by each of the muon tracks.
  - The number of valid hits in the muon chambers used in the global muon fit should be at least 1.
  - The transverse impact parameter, calculated w.r.t. beamspot position, should be less than 0.2 mm.
- **Missing energy**: MET Type0Type1 (PU) corrected and shift in xy plane corrected

Base selection

The most sensitive independent observables will be put as input for a MVA. Therefore we did not optimized the selection (as it would be for a cut based analysis).

Base selection summary

Muon object definition	POG Tight Muons Muons relative isolation: $I < 0.12$ Muons impact parameter: $d_{xy} < 0.02$ cm
Keeping the DPS efficiency as high as possible	At least two same sign muons Veto on third muon with $\mathrm{p_T} < 10\mathrm{GeV}$ $p_{\mathrm{T}\,\mu}^{leading} > 20\mathrm{GeV}$ $p_{\mathrm{T}\,\mu}^{subleading} > 10\mathrm{GeV}$
Reducing contribution from QCD multijet	$\lvert p_{\mathrm{T}\,\mu}^{leading}\rvert + \lvert p_{\mathrm{T}\,\mu}^{subleading}\rvert > 45\mathrm{GeV}$ $E_{\mathrm{T}}^{\mathrm{miss}} > 20\mathrm{GeV}$
Avoiding Z mass peak	$20 < M_{inv} < 75\mathrm{GeV}$ or $M_{inv} > 105\mathrm{GeV}$

Data driven: fake muons

A large part of background is expected to come from events in which one (or two) muons coming mainly from heavy-flavour decays are misidentified as coming from a *prompt* decay of W or Z boson.

Definitions:

- *fake* muons: any sources but W or Z decay
- *prompt* muons: coming from a W or Z boson decay

A data driven method has been studied in order to evaluate the contribution from fake muons mainly related to QCD and Wjets events, due to the lack of statistics and the not precise description of misidentified muons in MC.

Data driven: Strategy

1. Define a loose and a tight selection.
2. Select a fake/prompt muons enriched sample from data.
3. Evaluate respectively the fake/prompt ratios (tight/loose)
4. Subtract the contamination to the fake ratio coming from EWK processes
5. Use those ratios for weighting (based on p_T and η) data events passing different conditions: Tight-Loose, Loose-Loose and Tight-Tight
6. Use the sum of this weights to evaluate contribution from fake-fake and prompt-fake events

- *Fake ratio:* the ratio of the number of muon passing the tight selection over muons passing the loose one in the fake muon control sample
- *Prompt ratio:* it is defined as tight to loose ratio in a prompt lepton control sample obtained with a selection of Z boson production events

Data driven method

The total yield of events with one prompt and one fake muon can be evaluated by $\sum^i N^i_{pf}$, while the fake-fake events yield is obtained by $\sum^i N^i_{ff}$. (Details in backup)

Events	
N_{TT}	1539 ± 40
N_{TL}	4492 ± 67
N_{LL}	3974 ± 63
Evaluated prompt-fake yield	709 ± 7
Evaluated fake-fake yield	381 ± 4

BDT training

The idea is to use the BDT estimator to get a response shape with the highest possible DPS sensitivity.

- *signal* sample using opposite sign DPS MC events passing the offline base selection but with opposite sign request.
- *background* sample has been constructed mixing up the three main background in our base selection (properly reweighted): QCD, W + jets and WZ. For training QCD and W + jets sample, we used data-driven observables evaluated in an independent way.

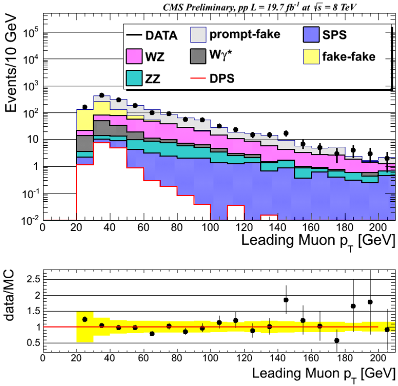
BDT input observables

- leading muon (μ_1) p_{T}
- subleading muon (μ_2) p_{T}
- $E_{\mathrm{T}}^{\mathrm{miss}}$
- $M_T(\mu_1, \mu_2)$ di-muon invariant transverse mass
- $\Delta\phi(\mu_1, \mu_2)$
- $\Delta\phi(\mu_1, E_{\mathrm{T}}^{\mathrm{miss}})$
- $\Delta\phi(\mu_2, E_{\mathrm{T}}^{\mathrm{miss}})$
- $\Delta\phi(\mu_1 + \mu_2, E_{\mathrm{T}}^{\mathrm{miss}})$: where $\mu_1 + \mu_2$ is the vector sum of muon four-momenta
- $m_T(W_{1/2}) = \sqrt{2 \cdot {p_{\mathrm{T}}}^{\mu_{1/2}} \cdot E_{\mathrm{T}}^{\mathrm{miss}} \cdot (1 - cos(\Delta\phi(\mu_{1/2}, E_{\mathrm{T}}^{\mathrm{miss}})))}$

BDT input observables

Yellow band shows the systematic uncertainty

- leading muon (μ_1) p_{T}
- subleading muon (μ_2) p_{T}
- $E_{\mathrm{T}}^{\mathrm{miss}}$
- $M_T(\mu_1, \mu_2)$ di-muon invariant transverse mass
- $\Delta\phi(\mu_1, \mu_2)$
- $\Delta\phi(\mu_1, E_{\mathrm{T}}^{\mathrm{miss}})$
- $\Delta\phi(\mu_2, E_{\mathrm{T}}^{\mathrm{miss}})$
- $\Delta\phi(\mu_1 + \mu_2, E_{\mathrm{T}}^{\mathrm{miss}})$
- $m_T(W_1)$
- $m_T(W_2)$



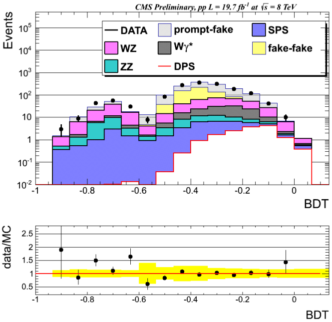
Systematics

Systematics summary

Source	DPS	SPS	WZ	ZZ	$W\gamma^*$	Fake-Fake	Prompt-Fake
Luminosity	2.5	2.5	2.5	2.5	2.5	-	-
PU re-weighting	0.5	0.3	0.5	0.1	0.7	-	-
Trigger and Muon id	0.1	0.1	0.1	0.1	0.1	-	-
MET	0.8	1.4	0.4	4.0	2.2	-	-
Fake-Fake normalization	-	-	-	-	-	60	-
Prompt-Fake normalization	-	-	-	-	-	-	30
MC normalization	4.0	10.0	10.0	4.0	10.0	-	-
Total	**4.8**	**10.4**	**10.3**	**6.2**	**10.6**	**60**	**30**

Result

Result for BDT observable and sample yields



Yellow band shows the systematic uncertainty

Sample	Events ± stat. ± syst.
DPS	15.0 ± 0.5 ± 0.7
SPS	30 ± 1 ± 3
WZ	263 ± 3 ± 30
ZZ	40 ± 1 ± 2
$W\gamma*$	86 ± 3 ± 9
Prompt-Fake	709 ± 7 ± 213
Fake-Fake	381 ± 4 ± 229
Total	1523 ± 9 ± 314
Data	1539

Limit setting

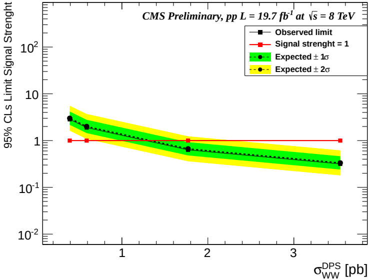
Statistical interpretation of the results is performed with the CL_s method, which is based on the modified frequentist approach
Limits are estimated by fitting BDT shape

95% CLs	**BDT**
Expected	r $<$ 2.001
Expected $\pm 1\sigma$	[1.443,2.778]
Expected $\pm 2\sigma$	[1.085,3.691]
Observed	r $<$ 1.897

Final result

The observed limit can be read as a limit on the DPS same sign W boson cross section of

$$\sigma_{WW}^{DPS} < r_{observed} \cdot \sigma_{WW}^{MC} = 1.897 \cdot 0.59\,\text{pb} = 1.12\,\text{pb}.$$



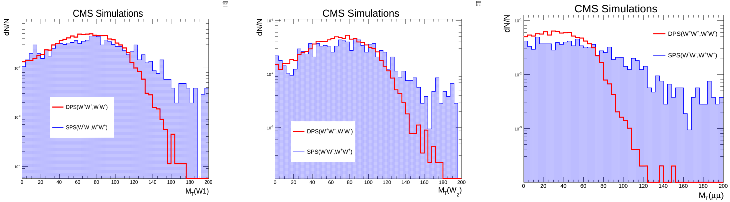
Summary

- A search for the same-sign W-pair DPS events in the di-muon final state is done using data with $\sqrt{s} = 8$ TeV and an integrated luminosity of 19.7 fb^{-1}
- BDT response shape gives the limit estimation, excluding at 95% CLs a signal strength $r > 1.897$ (28 DPS events), with an expected exclusion of $r > 2.01$ (30 DPS events), which means an upper limit on $\sigma_{WW}^{DPS} < 1.12$ pb at 95% of confidence level.
- Considering the two scattering to be independent and no correlation between interacting partons, one can put in relation the limit on σ_{WW}^{DPS} with the σ_{eff} using the factorization formula:

$$\sigma_{eff} > \frac{(\sigma_{W\to l\nu})^2}{2 \cdot (BR^2_{W\to l\nu}) \cdot \sigma_{WW}^{DPS}} = 5.91 \text{ mb.}$$

Thank you for your attention!

Other sensitive observable Gen Level comparison



Double Parton scattering in Pythia

In pythia 6/8 implementation:

$\sigma_{eff} = \sigma_{Non\text{-}Diffractive} / \langle f_{impact} \rangle$

$\langle f_{impact} \rangle$ is tune dependent

With soft MPI tune ↓

$\sigma_{eff} \approx 20 \div 30$ mb

Still 2 times higher than data

Moreover the two interactions are generated independently from each other.

Reco/Gen efficiency for the base selection

MC sample	Efficiency (%)
DPS	18 ± 0.7
SPS ++	26 ± 0.1
SPS –	27 ± 0.2
Drell-Yan	0.00020 ± 0.00007
WZ	2.64 ± 0.03
ZZ	0.48 ± 0.01
tt	0.044 ± 0.004
$W - \gamma^*$	3.1 ± 0.1
Wjets	0.06 ± 0.02
QCD	0.0006 ± 0.0006

Data driven method

- Tight selection: identical to the analysis selection
- Loose selection: same as above but I<0.4 and $d_{xy} < 0.2$ cm
- Fake and prompt muons enriched regions are needed for the evaluation of the fake and prompt ratio

Fake control sample	Prompt control sample
HLT_Mu17 or HLT_Mu8	HLT_Mu17_TkMu8
Only one POG tight muon	Only two opposite sign POG tight muon
${p_T}^{\mu} > 10$ GeV	${p_T}^{\mu 1} > 20$ GeV and ${p_T}^{\mu 2} > 10$ GeV
$E_T^{miss} < 20$ GeV	70 GeV $< M_{inv} <$ 110 GeV
$\sqrt{2 \cdot {p_T}^{\mu} \cdot E_T^{miss} \cdot (1 - cos(\Delta\phi(\mu, E_T^{miss})))} < 20$ GeV	only μ_2 studied for prompt ratio

We choose this fake region as it shows a good agreement with the isolation spectra expected for our fake muons (backup)

Data driven method

The prompt muon contamination fraction, electroweak (EWK) contamination, has been studied.

- tight selection $\rightarrow$ numerator of the fake ratio
- loose selection $\rightarrow$ denominator of the fake ratio

Correction based on MC has been applied.

Data driven method

Corrected fake ratio as function of p_T on the right and η on the left:

p_T range [GeV]	$0 < \eta < 1$	$1 < \eta < 1.4$	$1.4 < \eta < 2$	$2 < \eta < 2.4$
$10 < p_T < 15$	0.291±0.003	0.319±0.004	0.355±0.005	0.369±0.007
$15 < p_T < 20$	0.232±0.003	0.264±0.005	0.295±0.006	0.318±0.009
$20 < p_T < 25$	0.216±0.005	0.241±0.009	0.277±0.010	0.302±0.015
$25 < p_T < 35$	0.207±0.010	0.249±0.017	0.281±0.019	0.304±0.030
$p_T > 35$	0.204±0.020	0.234±0.033	0.281±0.034	0.274±0.054

Shape evaluation

Two different methods to evaluate the distributions from the fake-fake and prompt-fake events:

- **Method 1:** Depending upon the transverse momentum and pseudo-rapidity of the two muons, event by event weights (N^i_{ff} and N^i_{pf}) are applied using fake and prompt ratio
- **Method 2:** Expected number of prompt-fake and fake-fake events are calculated by summing over the event weights, whereas shapes are extracted using the events passing the selection by reversing the isolation cut, *i.e.*, $I > 0.12$.

Both methods have shown compatible (within uncertainties) results. Method 1 has been adopted to evaluate the final results, Method 2 has been used to get an independent sample for BDT training.

Opposite sign control region selection

Yellow band shows the systematic uncertainty

POG Tight Muons
At least two opposite sign muons
Veto on third muon with $p_\mathrm{T} < 10$ GeV
$p_\mathrm{T}{}_{\mu}^{leading} > 20$ GeV
$p_\mathrm{T}{}_{\mu}^{subleading} > 10$ GeV
$\lvert p_\mathrm{T}{}_{\mu}^{leading}\rvert + \lvert p_\mathrm{T}{}_{\mu}^{subleading}\rvert > 45$ GeV
$E_\mathrm{T}^\mathrm{miss} > 20$ GeV
20 GeV $< M_{inv} <$ 75 GeV or $M_{inv} >$ 105 GeV

- $p_{\mathrm{T}\mu_1}$
- $p_{\mathrm{T}\mu_2}$
- $E_\mathrm{T}^\mathrm{miss}$

Control regions

Same sign control region selection

Yellow band shows the systematic uncertainty

POG Tight Muons
At least two same sign muons
Veto on third muon with $p_T < 10$ GeV
$p_{T\mu}^{leading} > 20$ GeV
$p_{T\mu}^{subleading} > 10$ GeV
$\lvert p_{T\mu}^{leading}\rvert + \lvert p_{T\mu}^{subleading}\rvert < 45$ GeV
$E_T^{miss} > 20$ GeV
20 GeV $< M_{inv} <$ 75 GeV or $M_{inv} >$ 105 GeV

Sample	Events
DPS	-
SPS	1.000 ± 0.001
WZ	7.00 ± 0.03
ZZ	2.00 ± 0.01
WGstar	55 ± 1
Prompt-Fake	-
Fake-Fake	1116 ± 12
Total	1193 ± 13
Data	1272

Systematics

All the systematics uncertainties are applied as normalization factor to the BDT shapes used in this analysis, except for the BDT uncertainty for which we used a distribution uncertainty.

- **Luminosity (2.5%):** an uncertainty on the luminosity estimation of 2.5% is directly translated into an uncertainty on the yields for both signal sample and all background samples for which the yield is not determined from data.
- **MC pileup reweighting (0.1-0.7%):** The effects on MC distributions (signal and background) are evaluated varying event-by-event mean value of PU by ± 1.
- **Theoretical uncertainty (4-10%):** the respective cross sections are varied within their theoretical uncertainties.

Systematics

- **Muon reconstruction and identification (0.1%):** the uncertainty due to a different muon reconstruction and identification efficiency between data and Monte Carlo have been considered, varying the weight with a gaussian function with σ equal to the uncertainties.

Systematics

- **$E_{\mathrm{T}}^{\mathbf{miss}}$ uncertainties (0.4-2.2%):** the uncertainty related to $E_{\mathrm{T}}^{\mathrm{miss}}$ has different sources. In order to estimate those sources we compared the final yields for different $E_{\mathrm{T}}^{\mathrm{miss}}$ recontruction. The $E_{\mathrm{T}}^{\mathrm{miss}}$ components varied in that recontrustions follow the prescription of the $E_{\mathrm{T}}^{\mathrm{miss}}$ POG syst tools.

https://twiki.cern.ch/twiki/bin/view/CMSPublic/SWGuidePATTools#MET_Systematics_Tools

Systematics

- **Data-driven fake muon evaluation:**
  - difference in jet kinematic spectra between fake enriched control region and signal region may lead to a different fake muon scenario.
  - different quark content in W+jets and tt processes w.r.t. QCD one

Systematics

In order to face the first source prompt-fake and fake-fake muons yield evaluation with MC calculated along with jet p_{T} threshold of 25 GeV sample calculation as been compared to the one used and the one obtained by pure QCD MC ratios evaluation.

	Prompt-fake	Fake-fake
Simulated sample	586 ± 6	152 ± 2
Jet $p_{\mathrm{T}} >$25 GeV threshold sample	510 ± 5	161 ± 2
No jet threshold	709 ± 7	381 ± 4

Systematics

Using MC ratios from QCD samples: prompt-fake muons yield on W+jets simulated events compared to the simulation expectation.

Events	Prompt-fake
N_{TT}	125 ± 11
N_{TL}	404 ± 20
N_{LL}	48 ± 7
Evaluated yield	95 ± 6
Simulated yield	125

These systematic uncertainties are added in quadrature to give a total systematic uncertainty of 60% for fake+fake sample and of 30% for prompt+fake events.

Systematics

- **BDT uncertainty:** we varied, within the uncertainty, the muon p_{T} (considering the resolution less than 3%) and the $E_{\mathrm{T}}^{\mathrm{miss}}$ (with shapes used for systematics above) that are given as input to the BDT. This is the only background for which we took a shape systematics and not an overall normalization factor.

Prompt ratio:

p_{T} range [GeV]	$0 < \eta < 1.4$	$1.4 < \eta < 2.4$
$10 < p_{\mathrm{T}} < 15$	0.70 ± 0.01	0.75 ± 0.01
$15 < p_{\mathrm{T}} < 20$	0.757 ± 0.008	0.81 ± 0.01
$20 < p_{\mathrm{T}} < 25$	0.806 ± 0.006	0.86 ± 0.01
$25 < p_{\mathrm{T}} < 35$	0.899 ± 0.003	0.929 ± 0.005
$p_{\mathrm{T}} > 35$	0.97 ± 0.01	0.97 ± 0.02

For event i passing TT selection the corresponding weight are N^i_{pf} and N^i_{ff}:

$$N^i_{pf} = -\frac{1}{(p_1 - f_1) \cdot (p_2 - f_2)} \cdot [(1-p_2) \cdot (1-f_1) \cdot p_1 \cdot f_2 + (1-p_1) \cdot (1-f_2) \cdot p_2 \cdot f_1]$$

$$N^i_{ff} = \frac{1}{(p_1 - f_1) \cdot (p_2 - f_2)} \cdot f_1 \cdot f_2 \cdot (1 - p_1) \cdot (1 - p_2)$$

while case leading muon passing tight selection and subleading one passing only loose selection:

$$N^i_{pf} = \frac{1}{(p_1 - f_1) \cdot (p_2 - f_2)} \cdot [(1 - f_1) \cdot f_2 \cdot p_1 \cdot p_2 + (1 - p_1) \cdot f_1 \cdot f_2 \cdot p_2]$$

$$N^i_{ff} = \frac{1}{(p_1 - f_1) \cdot (p_2 - f_2)} \cdot p_2 \cdot (1 - p_1) \cdot f_2 \cdot f_1$$

for events with *loose* leading muons and *tight* subleading one, a simple substitution of p_1 in p_2 and f_1 in f_2 can provide the weights needed.
Finally, weights for events in which both muons are not passing tight requirements but succeed in passing the loose one are the following:

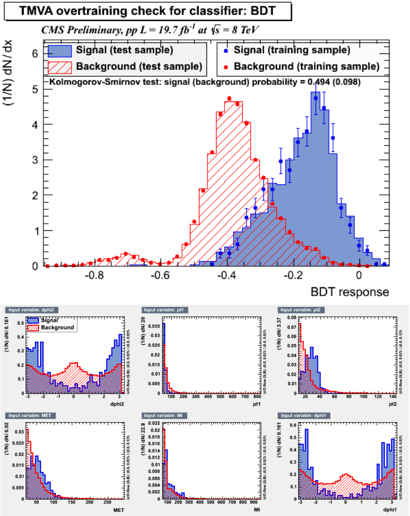
$$N^i_{pf} = -\frac{2}{(p_1 - f_1) \cdot (p_2 - f_2)} \cdot f_1 \cdot f_2 \cdot p_1 \cdot p_2$$

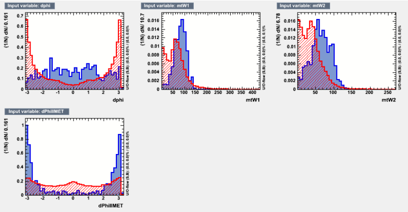
$$N^i_{ff} = \frac{1}{(p_1 - f_1) \cdot (p_2 - f_2)} \cdot f_1 \cdot f_2 \cdot p_1 \cdot p_2$$

Charge misidentification control region selection

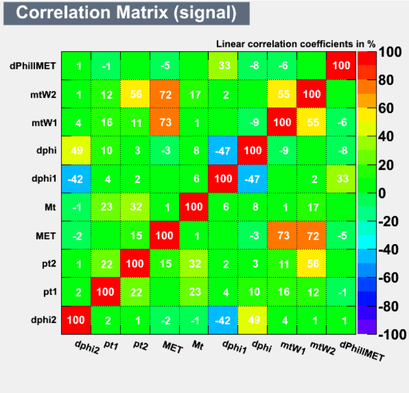
POG Tight Muons
At least two same sign muons
Veto on third muon with $p_{\mathrm{T}} < 10\,\mathrm{GeV}$
${p_{\mathrm{T}}}_{\mu}^{leading} > 20\,\mathrm{GeV}$
${p_{\mathrm{T}}}_{\mu}^{subleading} > 10\,\mathrm{GeV}$
$\lvert {p_{\mathrm{T}}}_{\mu}^{leading} \rvert + \lvert {p_{\mathrm{T}}}_{\mu}^{subleading} \rvert > 45\,\mathrm{GeV}$
$E_{\mathrm{T}}^{\mathrm{miss}} > 20\,\mathrm{GeV}$
$M_{inv} > 20\,\mathrm{GeV}$

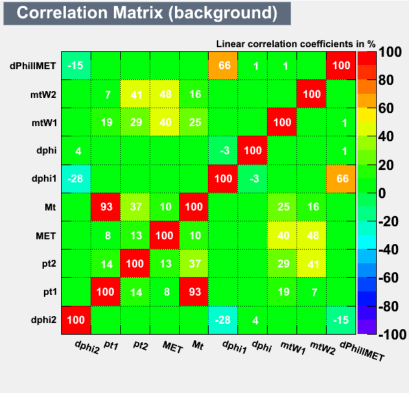
From MC matching studies in DY and tt samples, no contribution from charge misID


TMVA overtraining check for classifier: BDT
CMS Preliminary, pp L = 19.7 fb⁻¹ at √s = 8 TeV
Signal (test sample)
Background (test sample)
Signal (training sample)
Background (training sample)
Kolmogorov-Smirnov test: signal (background) probability = 0.494 (0.098)
(1/N) dN/ dx
BDT response
Input variable: dphi2
Input variable: pt1
Input variable: pt2
Input variable: MET
Input variable: Mt
Input variable: dphi1
Signal
Background
dphi2
pt1
pt2
MET
Mt
dphi1



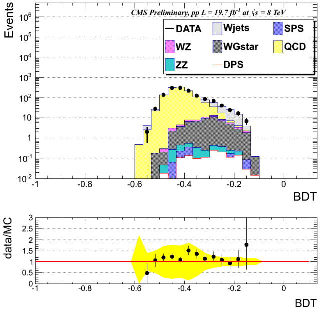
Input variable: dphi
(1/N) dN/ 0.161
dphi
Input variable: mtW1
(1/N) dN/ 10.7
mtW1
Input variable: mtW2
(1/N) dN/ 6.78
mtW2
Input variable: dPhillMET
(1/N) dN/ 0.161
dPhillMET


Correlation Matrix (signal)
Linear correlation coefficients in %
dPhillMET
mtW2
mtW1
dphi
dphi1
Mt
MET
pt2
pt1
dphi2
100
80
60
40
20
0
-20
-40
-60
-80
-100


Correlation Matrix (background)
Linear correlation coefficients in %
dPhillMET
mtW2
mtW1
dphi
dphi1
Mt
MET
pt2
pt1
dphi2
-15 66 1 1 100
7 41 48 16 100
19 29 40 25 100 1
4 -3 100 1
-28 100 -3 66
93 37 10 100 25 16
8 13 100 10 40 48
14 100 13 37 29 41
100 14 8 93 19 7
100 -28 4 -15
dphi2 pt1 pt2 MET Mt dphi1 dphi mtW1 mtW2 dPhillMET
100
80
60
40
20
0
-20
-40
-60
-80
-100

BDT response validation

BDT response in same sign control region



This additional cross check, in addition to the standard training checks (in backup), confirms a stable BDT response for a set of independent samples.

Systematic uncertainties summary (% variation on final total yield)

Source	Background syst. (%)	Signal syst. (%)
Luminosity	0.8	2.5
PU reweight	0.2	0.5
Muon reconstruction and ID	0.1	0.1
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.1	0.8
Fake Muons	27	-
MC normalization	3.2	4.0
Total	27.2	4.8

Parton correlation effect

	σ_{GS09}	σ_{MSTW_0}	σ_{MSTW_1}	σ_{MSTW_2}
W^+W^-	0.546	0.496	0.409	0.348
W^+W^+	0.321	0.338	0.269	0.223
W^-W^-	0.182	0.182	0.156	0.136
	R			
	0.784	1.00	1.00	1.00

J. R. Gaunt et al., *Same-sign W pair production as a probe of double parton scattering at the LHC*

MC driven reweight

MC normalization has been performed for the considered integrated luminosity, trigger and isolation.

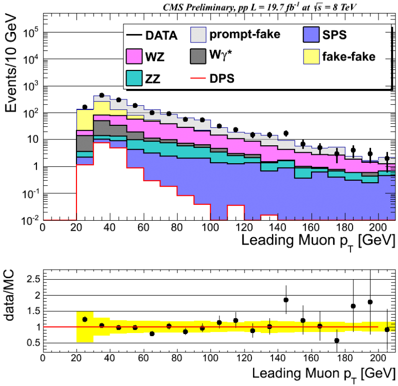
Sample	Weights
WW DPS	0.0138 ± 0.0008
WW SPS	0.056 ± 0.001
WZ	0.025 ± 0.002
Wγ^*	0.089 ± 0.006
ZZ	0.0165 ± 0.0008
Drell-Yan ($\rightarrow ll$)	2.0 ± 0.1 ($M_{inv} > 50$ GeV)
($M_{inv} > 10$ GeV)	8.0 ± 0.5 ($M_{inv} < 50$ GeV)
$t\bar{t}$	0.39 ± 0.03
W($\rightarrow l\nu$)	14 ± 1
QCD multijet	145 ± 5
($p_T > 20$GeV, $p_{T\mu} > 15$ GeV)	

- Drell-Yan and $t\bar{t}$ contribution from charge misidentification is negligible for muons and therefore they are not included in same sign distributions.
- **Due to the lack of statistics and the not precise description of misidentified muons in MC, W+jets, $t\bar{t}$ and QCD multijet contribution have been evaluated data-driven.**

BDT input observables

Yellow band shows the systematic uncertainty

- leading muon (μ_1) p_T
- subleading muon (μ_2) p_T
- E_T^{miss}
- $M_T(\mu_1, \mu_2)$ di-muon invariant transverse mass
- $\Delta\phi(\mu_1, \mu_2)$
- $\Delta\phi(\mu_1, E_T^{miss})$
- $\Delta\phi(\mu_2, E_T^{miss})$
- $\Delta\phi(\mu_1 + \mu_2, E_T^{miss})$
- $m_T(W_1)$
- $m_T(W_2)$



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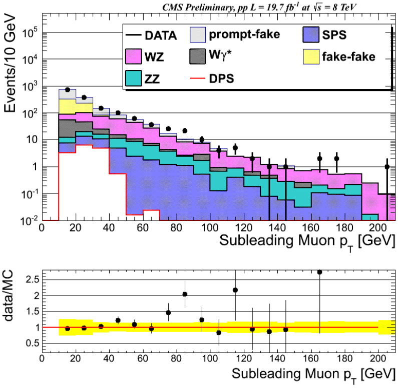

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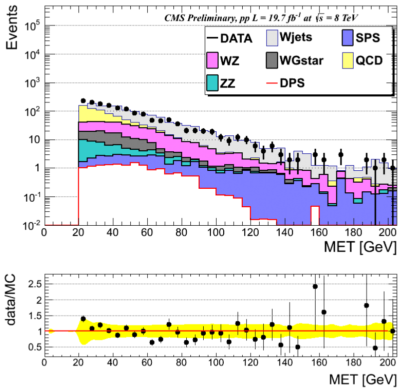

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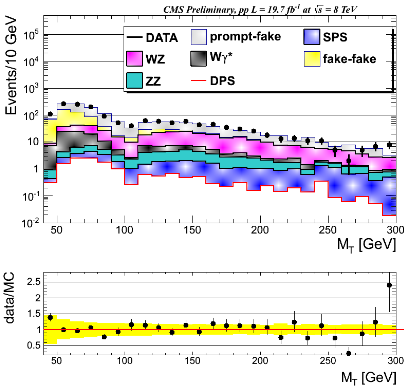

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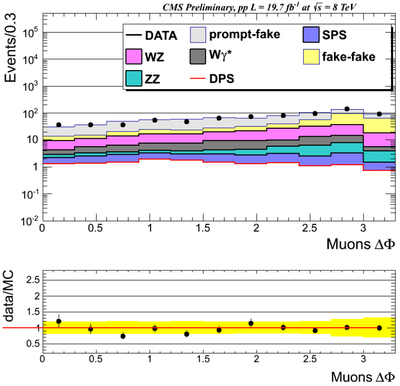

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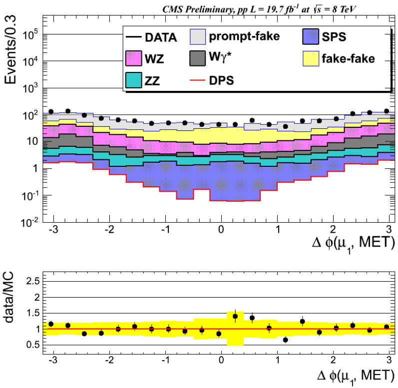

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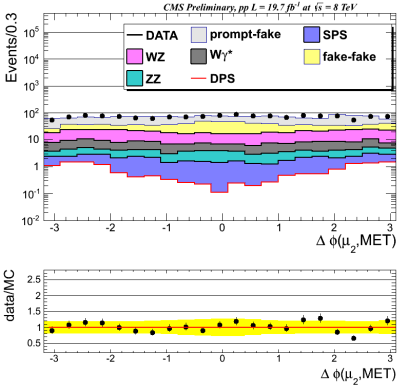

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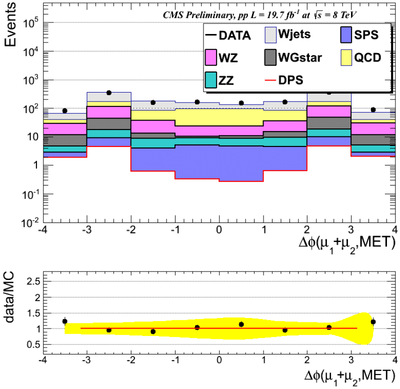

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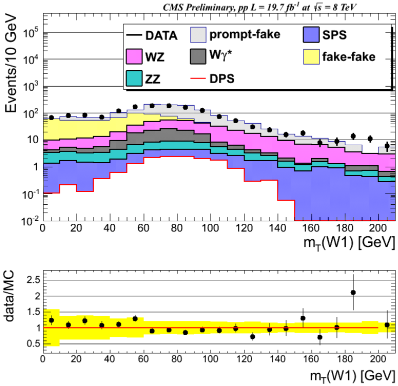

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