DPS characterization with same sign W boson pair production

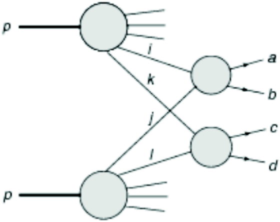
Diego Ciangottini

MPI workshop
Perugia, 24th Oct. 2016

Outline

DPS: how to measure

Theoretical estimations of σ_{eff} oscillate between 10 and 60 mb.

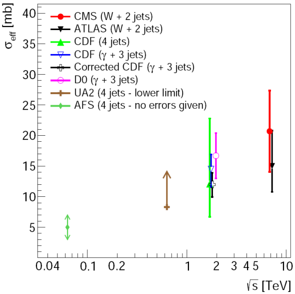


Lack of angular and momentum correlations are the only way so far

DPS: state of the art

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

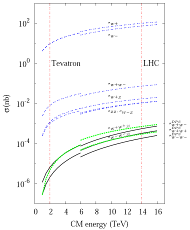
Pros

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

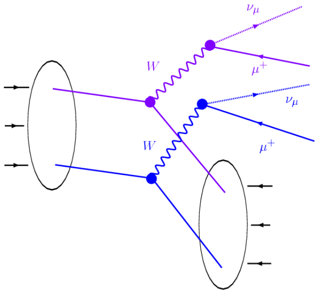
Eur.Phys.J. C69 (2010) 53-65

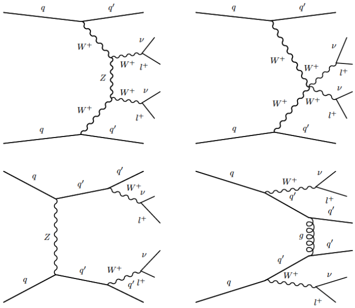


	σ_{GS09}	σ_{MSTW_0}	σ_{MSTW_1}	σ_{MSTW_2}
W^+W^-	0.546	0.496	0.409	0.348
W^+W^+	0.321	0.338	0.269	0.223
W^-W^-	0.182	0.182	0.156	0.136
		R		
	0.784	1.00	1.00	1.00

Table 2. DPS WW total cross sections (in pb) for pp collisions at $\sqrt{s} = 14$ TeV evaluated using different dPDFs sets. The values are obtained by first calculating the leptonic cross sections, before dividing by the corresponding branching ratios.

DPS in same sign WW: di-muon final state





Signatures:

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

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.

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)

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

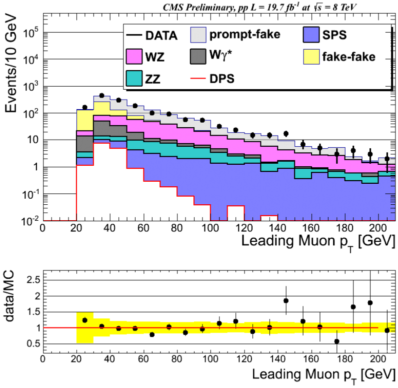
BDT input observables

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

BDT input observables

Yellow band shows the systematic uncertainty

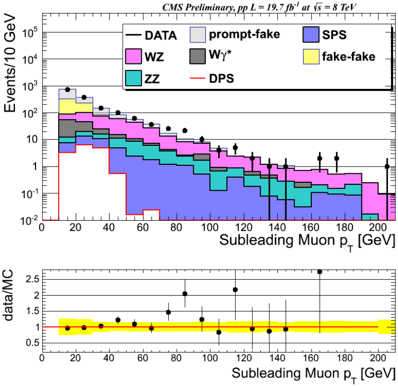
- leading muon (μ_1) p_T
- subleading muon (μ_2) p_T
- E_T^{miss}
- $M_T(\mu_1, \mu_2)$ di-muon invariant transverse mass
- $\Delta\phi(\mu_1, \mu_2)$
- $\Delta\phi(\mu_1, E_T^{miss})$
- $\Delta\phi(\mu_2, E_T^{miss})$
- $\Delta\phi(\mu_1 + \mu_2, E_T^{miss})$
- $m_T(W_1)$
- $m_T(W_2)$



BDT input observables

Yellow band shows the systematic uncertainty

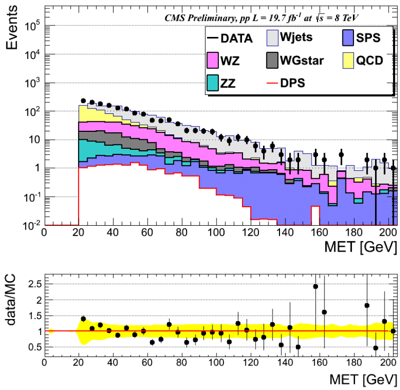
- leading muon (μ_1) p_T
- subleading muon (μ_2) p_T
- E_T^{miss}
- $M_T(\mu_1, \mu_2)$ di-muon invariant transverse mass
- $\Delta\phi(\mu_1, \mu_2)$
- $\Delta\phi(\mu_1, E_T^{miss})$
- $\Delta\phi(\mu_2, E_T^{miss})$
- $\Delta\phi(\mu_1 + \mu_2, E_T^{miss})$
- $m_T(W_1)$
- $m_T(W_2)$



BDT input observables

Yellow band shows the systematic uncertainty

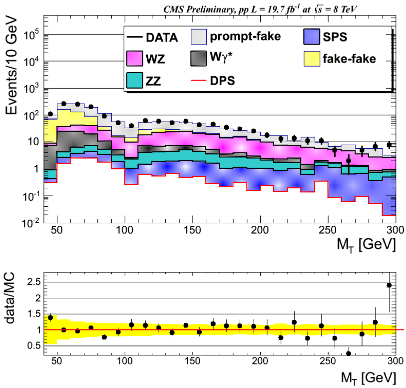
- leading muon (μ_1) p_T
- subleading muon (μ_2) p_T
- E_T^{miss}
- $M_T(\mu_1, \mu_2)$ di-muon invariant transverse mass
- $\Delta\phi(\mu_1, \mu_2)$
- $\Delta\phi(\mu_1, E_T^{miss})$
- $\Delta\phi(\mu_2, E_T^{miss})$
- $\Delta\phi(\mu_1 + \mu_2, E_T^{miss})$
- $m_T(W_1)$
- $m_T(W_2)$



BDT input observables

Yellow band shows the systematic uncertainty

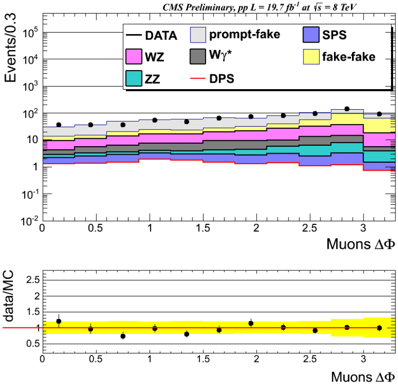
- leading muon (μ_1) p_T
- subleading muon (μ_2) p_T
- E_T^{miss}
- $M_T(\mu_1, \mu_2)$ di-muon invariant transverse mass
- $\Delta\phi(\mu_1, \mu_2)$
- $\Delta\phi(\mu_1, E_T^{miss})$
- $\Delta\phi(\mu_2, E_T^{miss})$
- $\Delta\phi(\mu_1 + \mu_2, E_T^{miss})$
- $m_T(W_1)$
- $m_T(W_2)$



BDT input observables

Yellow band shows the systematic uncertainty

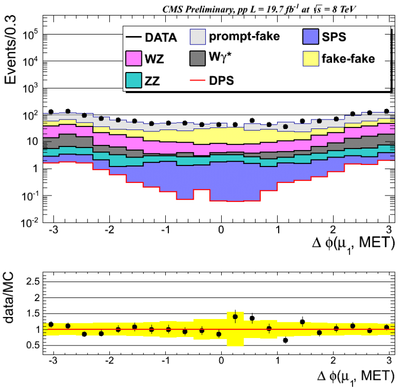
- leading muon (μ_1) p_T
- subleading muon (μ_2) p_T
- E_T^{miss}
- $M_T(\mu_1, \mu_2)$ di-muon invariant transverse mass
- $\Delta\phi(\mu_1, \mu_2)$
- $\Delta\phi(\mu_1, E_T^{miss})$
- $\Delta\phi(\mu_2, E_T^{miss})$
- $\Delta\phi(\mu_1 + \mu_2, E_T^{miss})$
- $m_T(W_1)$
- $m_T(W_2)$



BDT input observables

Yellow band shows the systematic uncertainty

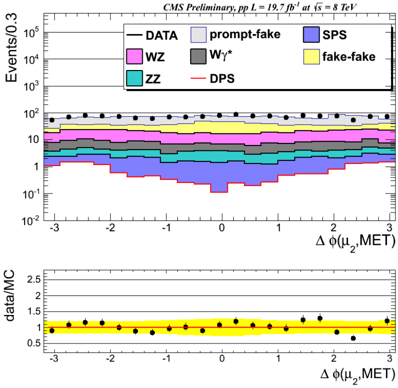
- leading muon (μ_1) p_T
- subleading muon (μ_2) p_T
- E_T^{miss}
- $M_T(\mu_1, \mu_2)$ di-muon invariant transverse mass
- $\Delta\phi(\mu_1, \mu_2)$
- $\Delta\phi(\mu_1, E_T^{miss})$
- $\Delta\phi(\mu_2, E_T^{miss})$
- $\Delta\phi(\mu_1 + \mu_2, E_T^{miss})$
- $m_T(W_1)$
- $m_T(W_2)$



BDT input observables

Yellow band shows the systematic uncertainty

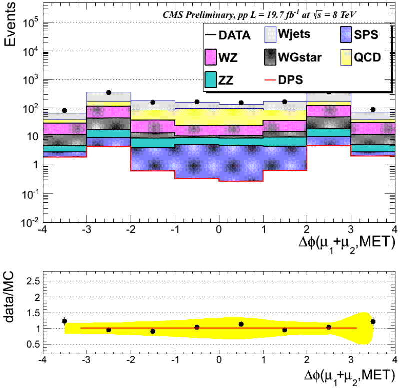
- leading muon (μ_1) p_T
- subleading muon (μ_2) p_T
- E_T^{miss}
- $M_T(\mu_1, \mu_2)$ di-muon invariant transverse mass
- $\Delta\phi(\mu_1, \mu_2)$
- $\Delta\phi(\mu_1, E_T^{miss})$
- $\Delta\phi(\mu_2, E_T^{miss})$
- $\Delta\phi(\mu_1 + \mu_2, E_T^{miss})$
- $m_T(W_1)$
- $m_T(W_2)$



BDT input observables

Yellow band shows the systematic uncertainty

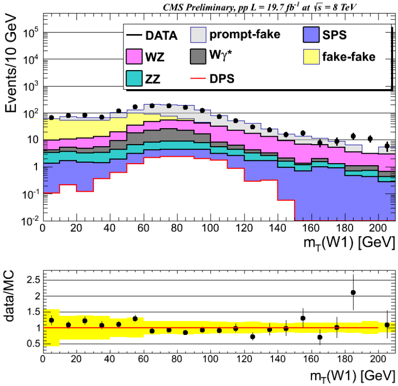
- leading muon (μ_1) p_T
- subleading muon (μ_2) p_T
- E_T^{miss}
- $M_T(\mu_1, \mu_2)$ di-muon invariant transverse mass
- $\Delta\phi(\mu_1, \mu_2)$
- $\Delta\phi(\mu_1, E_T^{miss})$
- $\Delta\phi(\mu_2, E_T^{miss})$
- $\Delta\phi(\mu_1 + \mu_2, E_T^{miss})$
- $m_T(W_1)$
- $m_T(W_2)$



BDT input observables

Yellow band shows the systematic uncertainty

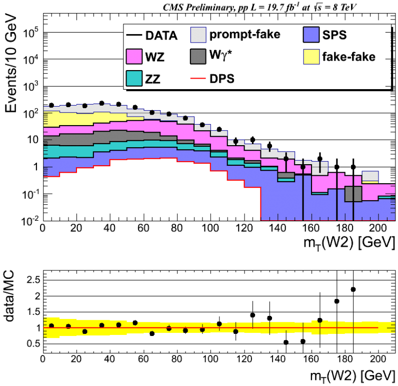
- leading muon (μ_1) p_T
- subleading muon (μ_2) p_T
- E_T^{miss}
- $M_T(\mu_1, \mu_2)$ di-muon invariant transverse mass
- $\Delta\phi(\mu_1, \mu_2)$
- $\Delta\phi(\mu_1, E_T^{miss})$
- $\Delta\phi(\mu_2, E_T^{miss})$
- $\Delta\phi(\mu_1 + \mu_2, E_T^{miss})$
- $m_T(W_1)$
- $m_T(W_2)$



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
- $\Delta\phi(\mu_1, \mu_2)$
- $\Delta\phi(\mu_1, E_T^{miss})$
- $\Delta\phi(\mu_2, E_T^{miss})$
- $\Delta\phi(\mu_1 + \mu_2, E_T^{miss})$
- $m_T(W_1)$
- $m_T(W_2)$



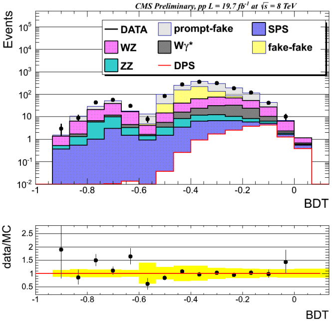
Systematics

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

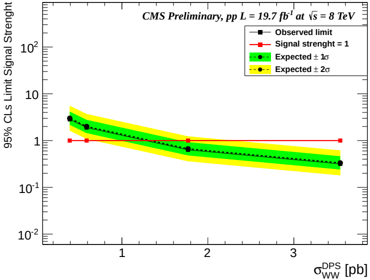
95% CLs	**BDT**
Expected	r $<$ 2.001
Expected $\pm 1\sigma$	[1.443,2.778]
Expected $\pm 2\sigma$	[1.085,3.691]
Observed	r $<$ 1.897

r = *signal strength* = # observed / # expected

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 $\sqrt{s} = 8\,\text{TeV}$ 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:

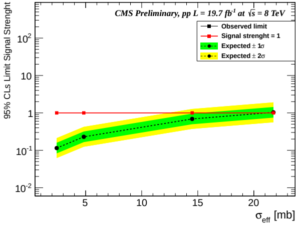
$$\sigma_{eff} > \frac{(\sigma_{W\to l\nu})^2}{2 \cdot (BR^2_{W\to l\nu}) \cdot \sigma_{WW}^{DPS}} = 5.91\,\text{mb}(@95\%CL).$$

Plans for DPS at 13 TeV

- In around 2 years from now LHC plans to collect 10 times more statistics than in 2012...
- This amount of data (also xsec S/B improvement?) would allow the direct measurement of same sign WW DPS processes cross section.

Considerations

- Some improvements in the analysis flow still doable, but I don't think they are worth on the current statistics (e.g. better muon isolation, and b jets veto).
- The DPS process in ZZ will be also open for an investigation as well next.



Studies on e-mu and e-e final states are ongoing but less sensitive due to top contribution and higher charge mis-id

Thank you for your attention!

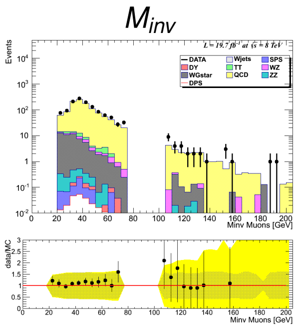
Control regions

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 $p_{\mathrm{T}} < 10$ GeV
$p_{\mathrm{T}}{}_{\mu}^{leading} > 20$ GeV
$p_{\mathrm{T}}{}_{\mu}^{subleading} > 10$ GeV
$|p_{\mathrm{T}}{}_{\mu}^{leading}| + |p_{\mathrm{T}}{}_{\mu}^{subleading}| < 45$ GeV
$E_{\mathrm{T}}^{\mathrm{miss}} > 20$ 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



Control regions

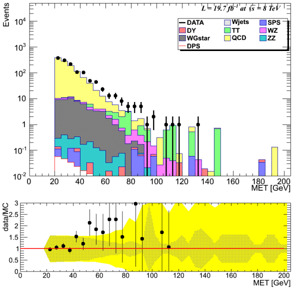
Same sign control region selection

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
$|p_{T\,\mu}^{leading}| + |p_{T\,\mu}^{subleading}| < 45$ GeV
$E_T^{miss} > 20$ GeV
$20\text{ GeV} < M_{inv} < 75\text{ GeV}$ or $M_{inv} > 105$ GeV

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

E_T^{miss}



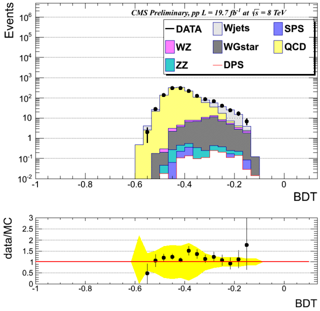
BDT training

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 with *Method 2*

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.