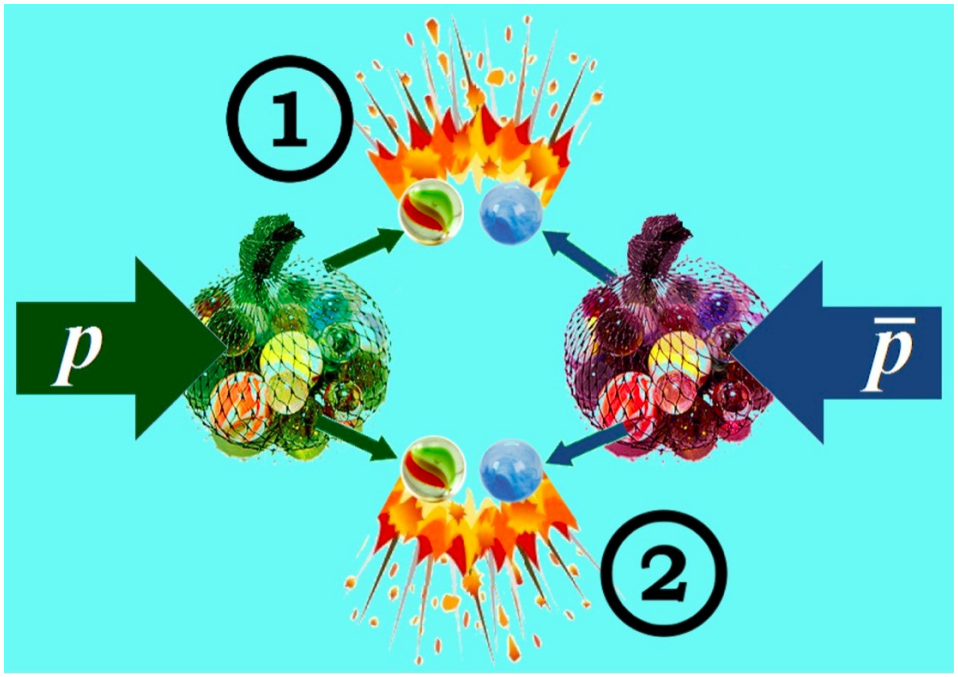
Double parton scattering measurements at CMS



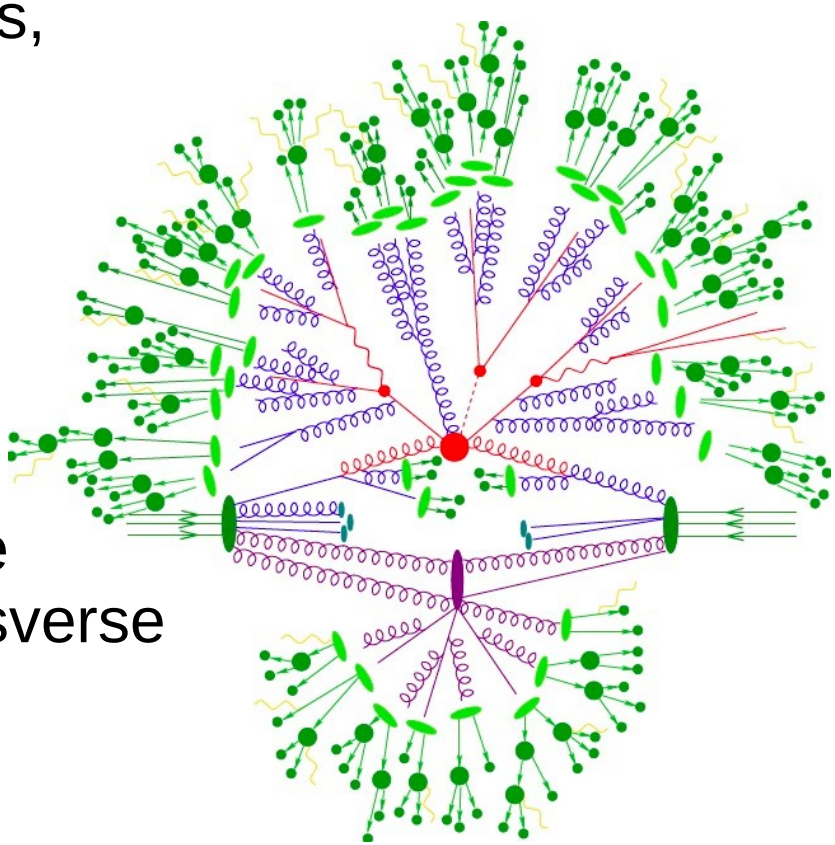
Gábor Veres

DIS 2018 Kobe, Japan, 17th April, 2018

Eötvös Loránd University Budapest
MTA-ELTE Lendület CMS Particle and Nuclear Physics Group

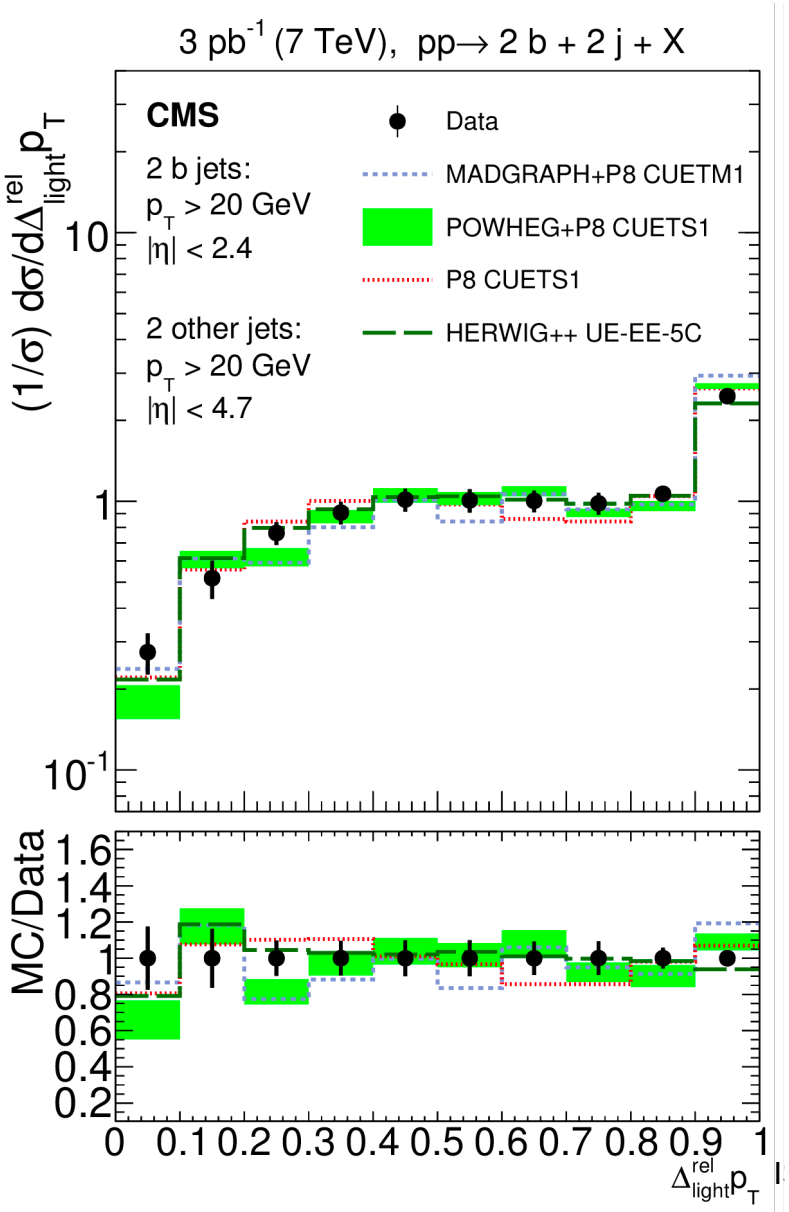
Multiple parton interactions

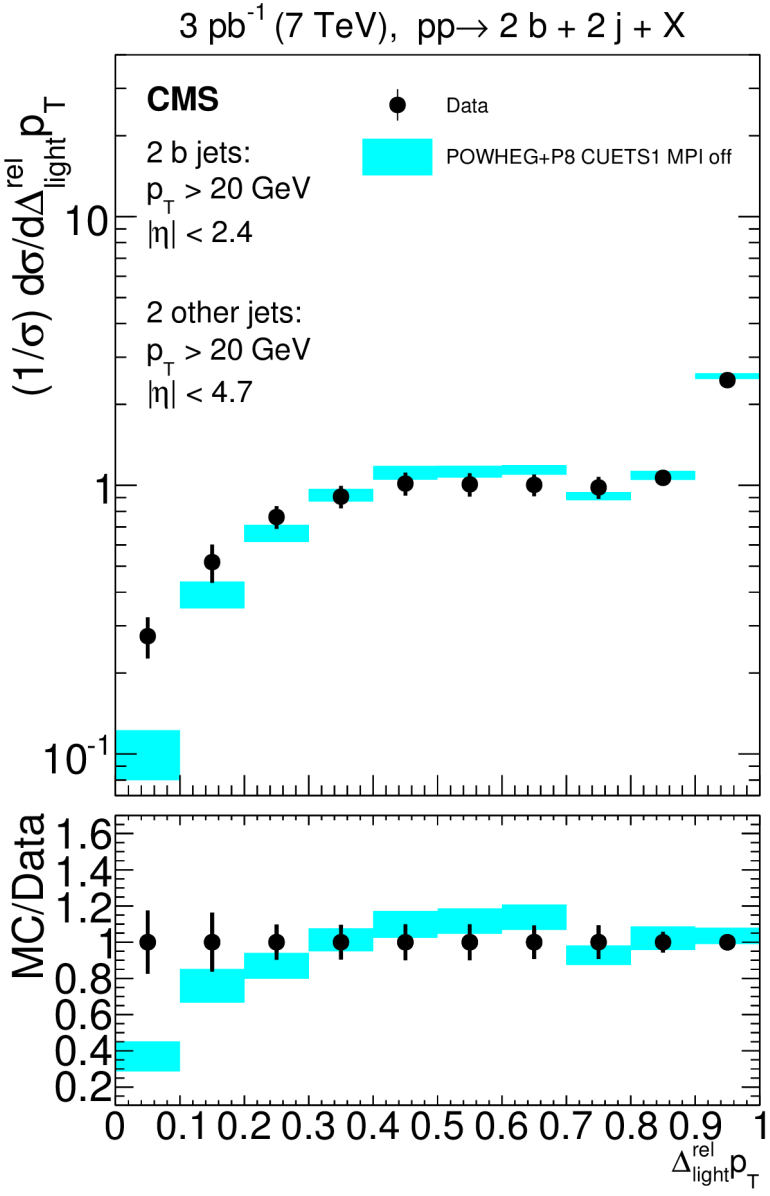
- Theoretical idea dates back to the parton model
- Double parton scattering signatures: 4 jets, 2 jets and W, 3 jets and photon, etc...
- LHC is especially abundant in MPI
  - high energy final states
- Complicated correlation effects are still unexplored
- The effective cross section: overlap of the spatial distributions of partons in the transverse plane
- Experimental challenges:
  - DPS final states can also be produced by SPS
  - Sometimes complicated multivariate analyses



2 jets + 2 b-jets in pp collisions at 7 TeV

- Kinematical distributions between 2 b-jets and 2 light jets
- Data well described by pQCD @NLO with PS and MPI
- Jet correlations do not agree with no-MPI models

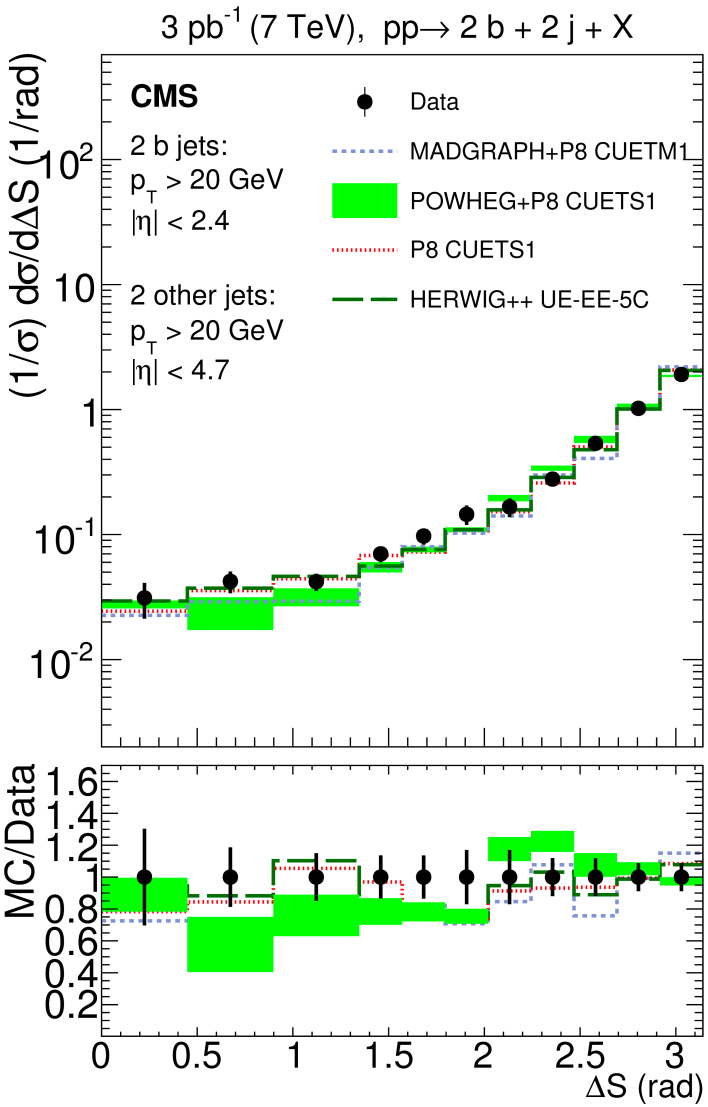


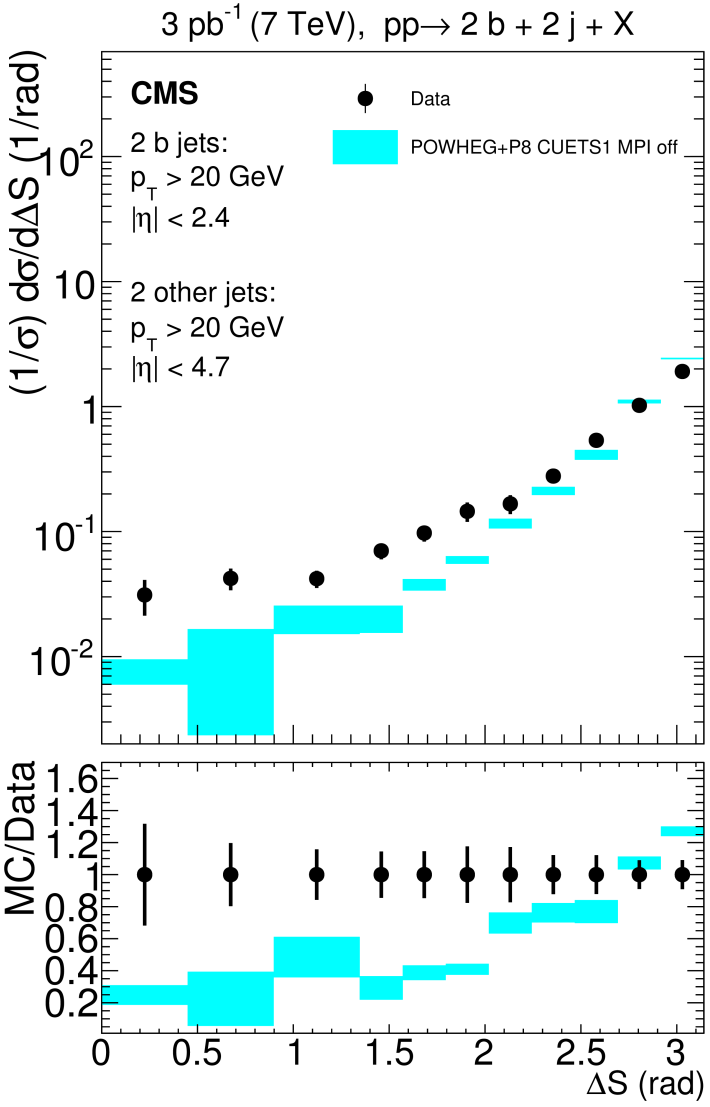


PRD 94 (2016) 112005
CMS-FSQ-13-010

2 jets + 2 b-jets in pp collisions at 7 TeV

- $\sigma(pp \rightarrow bb+jj+X)=69\pm3(st)\pm24(sy)nb$ for $p_T>20$ GeV and $|\eta_{b(j)}|<2.4(4.7)$
- ΔS: azimuthal angle between two dijet pairs

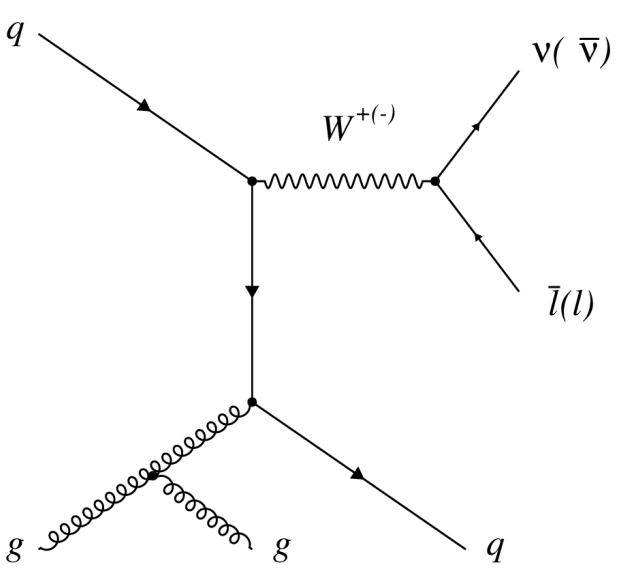


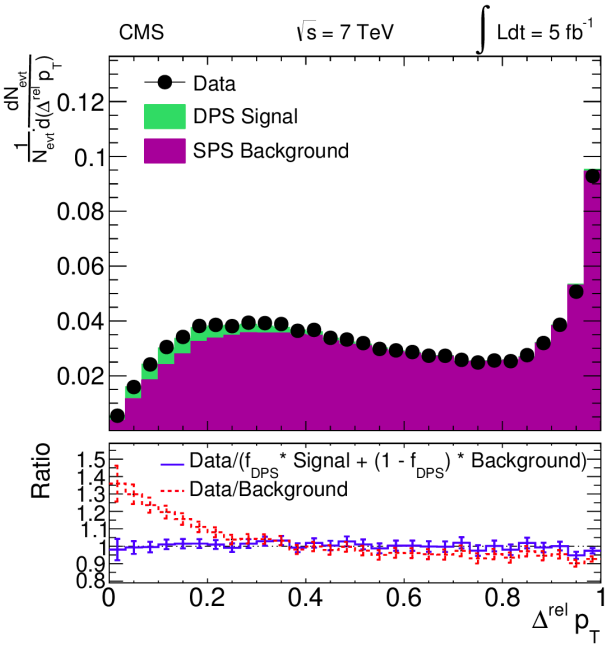


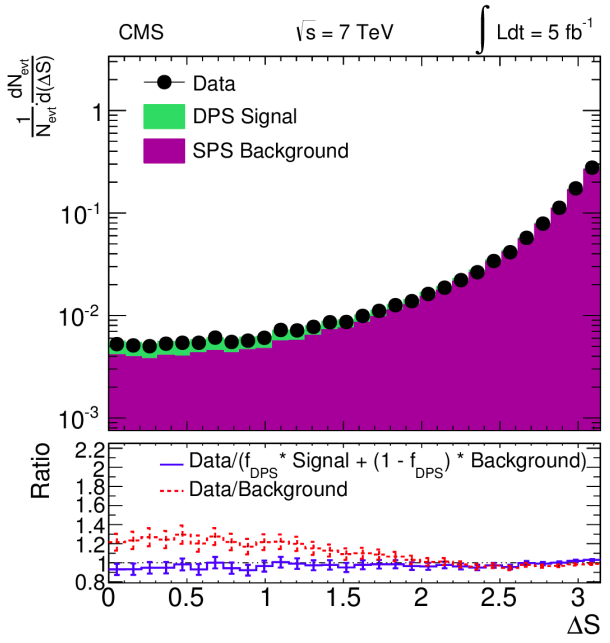
PRD 94 (2016) 112005
CMS-FSQ-13-010

DPS in W+2jets in pp collisions at 7 TeV

- $W \rightarrow \mu\nu$ deay with two associated jets, 5 fb^{-1} data, template fit
- Fraction of W from DPS: 0.055 $\pm$ 0.002 (stat) $\pm$ 0.014 (syst)
- MadGraph5+PYTHIA8 and POWHEG2 + PYTHIA6: MPI is needed
- From that, σ_{eff} = 20.7 $\pm$ 0.8 (stat) $\pm$ 6.6 (syst) mb



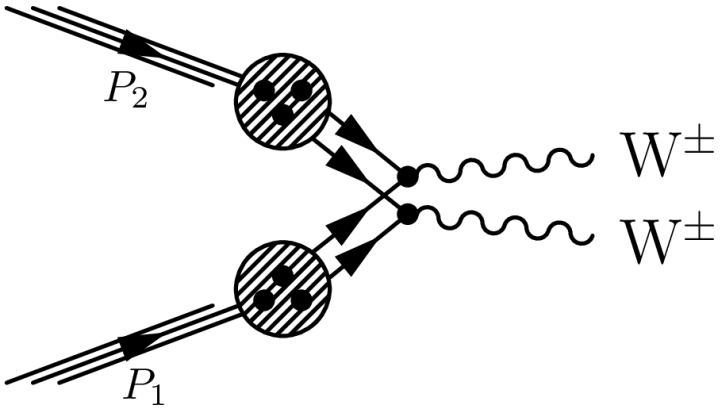




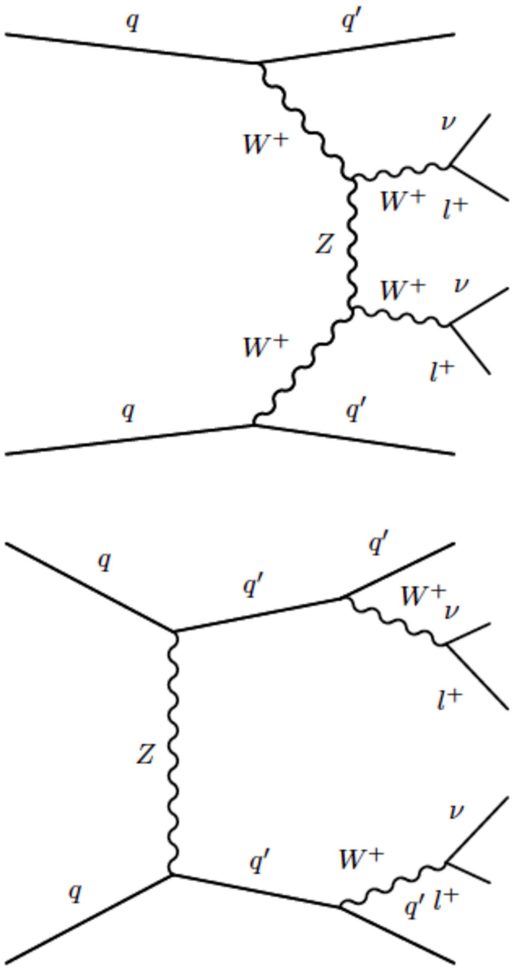
JHEP 1403 (2014) 032
CMS-FSQ-12-028

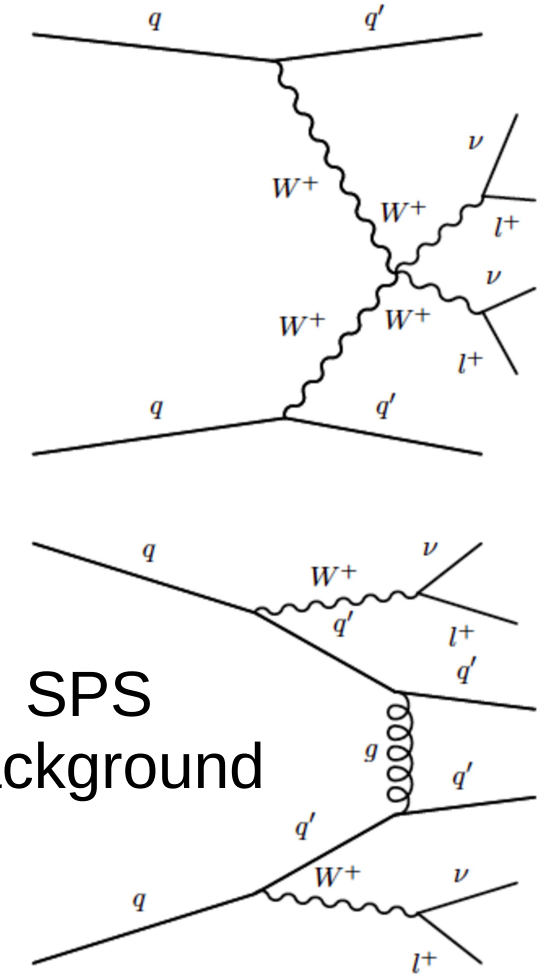
DPS in same-sign WW events at 13 TeV

- $W^{\pm}W^{\pm}$ studied in the $\mu^{\pm}\mu^{\pm}$ and $e^{\pm}\mu^{\pm}$ final states. 2016 data
- Single parton scattering (SPS): 2 jets in the final state!



DPS signal





SPS background

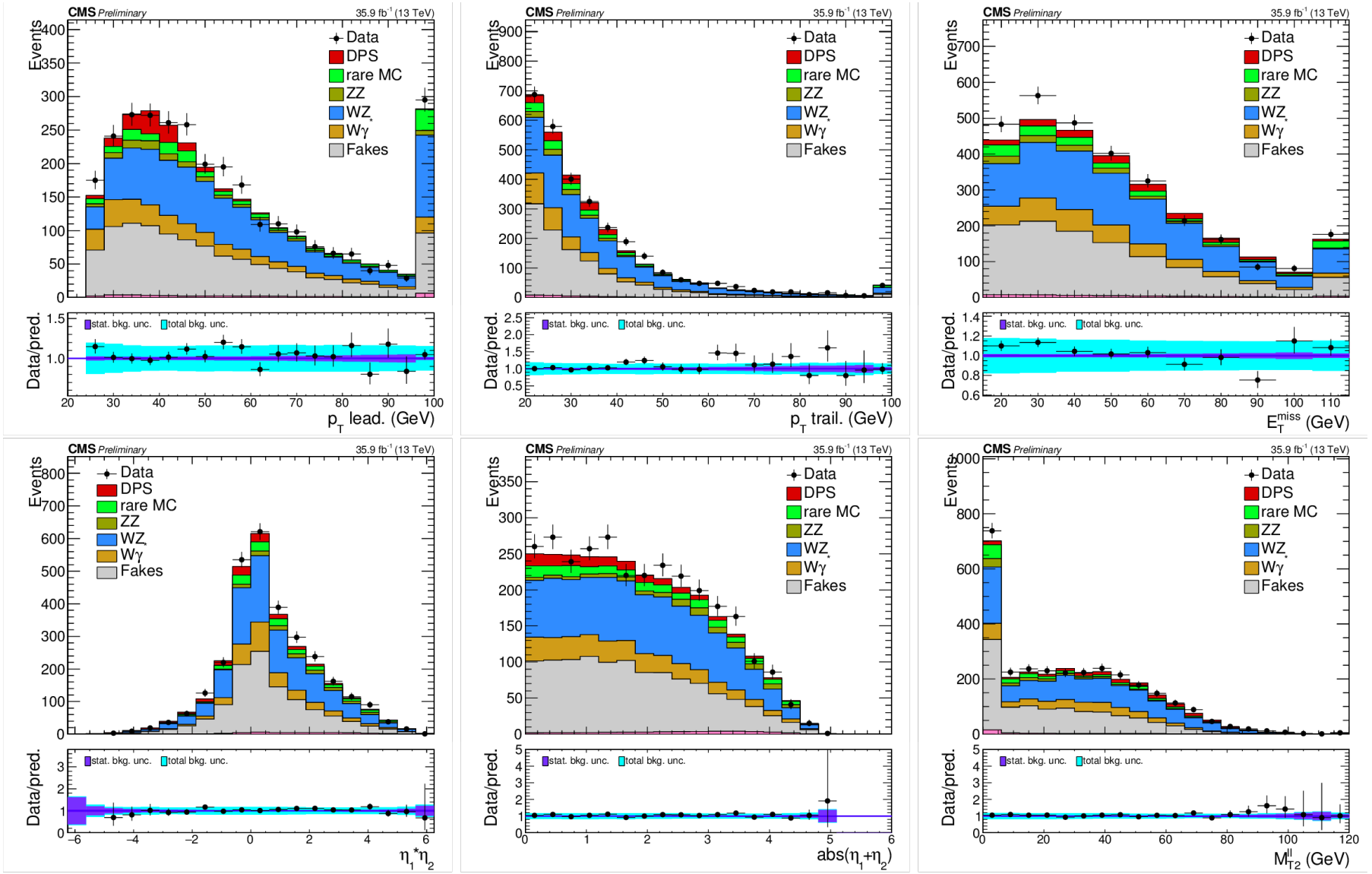
DPS in same-sign WW events at 13 TeV

- W±W± studied in the μ±μ± and e±μ± final states. 2016 data
- Single parton scattering (SPS): 2 jets in the final state!
- Therefore, the event selection uses a jet veto:

$$
\begin{gathered}
\text{two leptons: } e^{\pm}\mu^{\pm} \text{ or } \mu^{\pm}\mu^{\pm} \\
p_T^{\ell 1} > 25\,\text{GeV}\ ,\ p_T^{\ell 2} > 20\,\text{GeV} \\
|\eta_e| < 2.5,\ |\eta_\mu| < 2.4 \\
E_{\text{T}}^{\text{miss}} > 15\,\text{GeV} \\
N_{\text{jets}} < 2\ (p_{\text{T}} > 30\,\text{GeV}) \\
N_{\text{b-jets}} = 0\ (p_{\text{T}} > 25\,\text{GeV}) \\
\text{veto on additional leptons} \\
\text{veto on hadronic } \tau \text{ lepton decays}
\end{gathered}
$$

DPS in same-sign WW events at 13 TeV

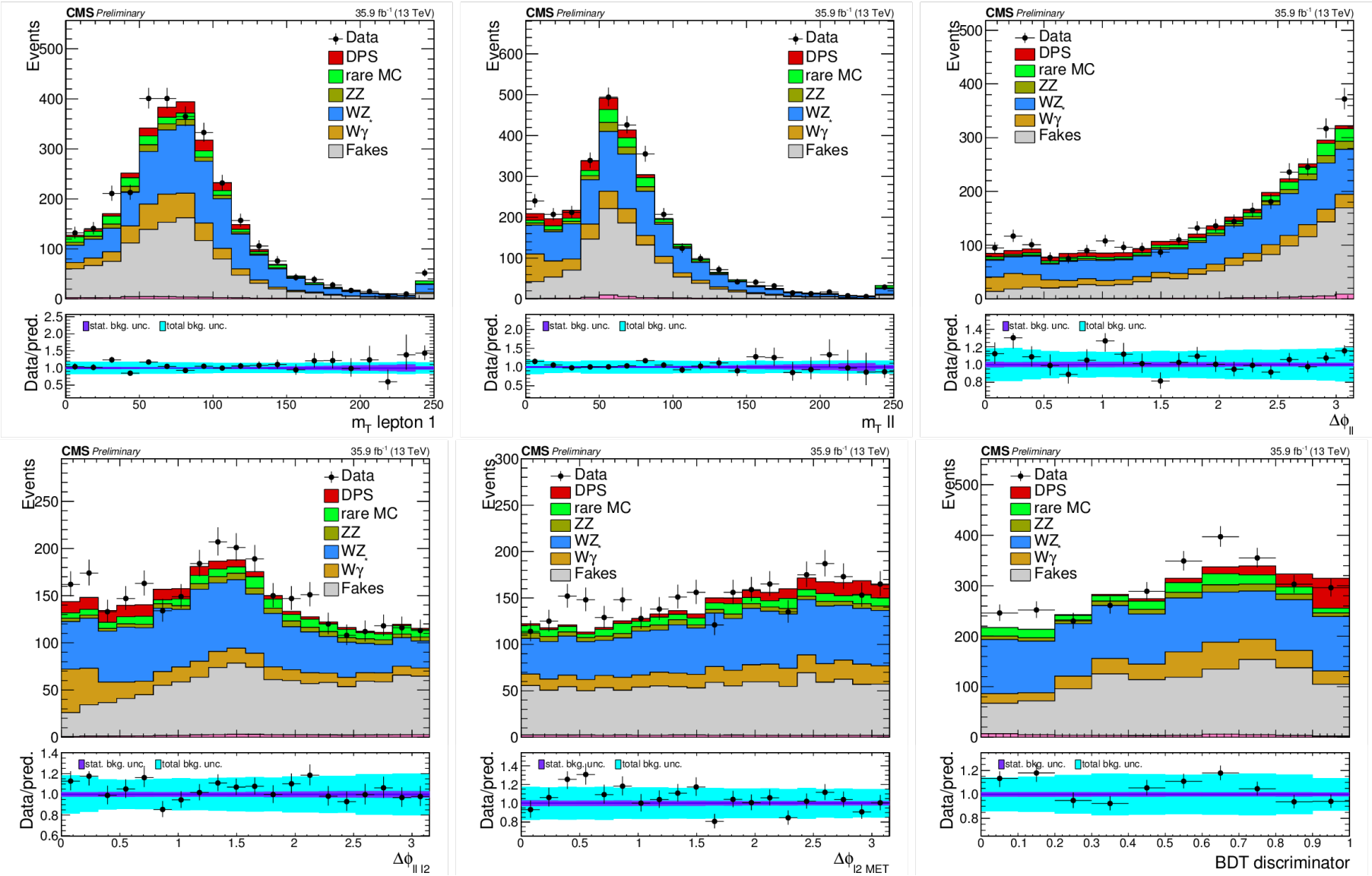
- A multivariate classifier is used to distinguish signal and bkgd



CMS-PAS-FSQ-16-009

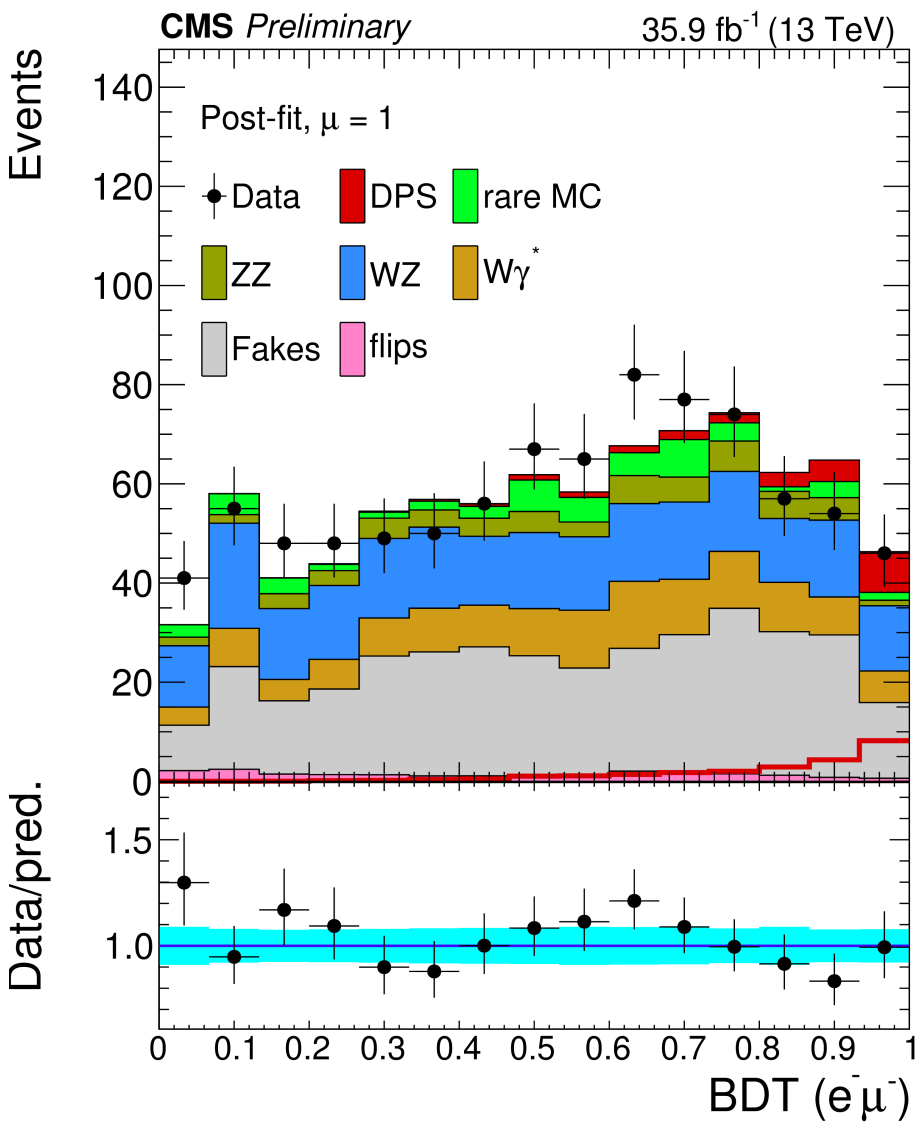
DPS in same-sign WW events at 13 TeV

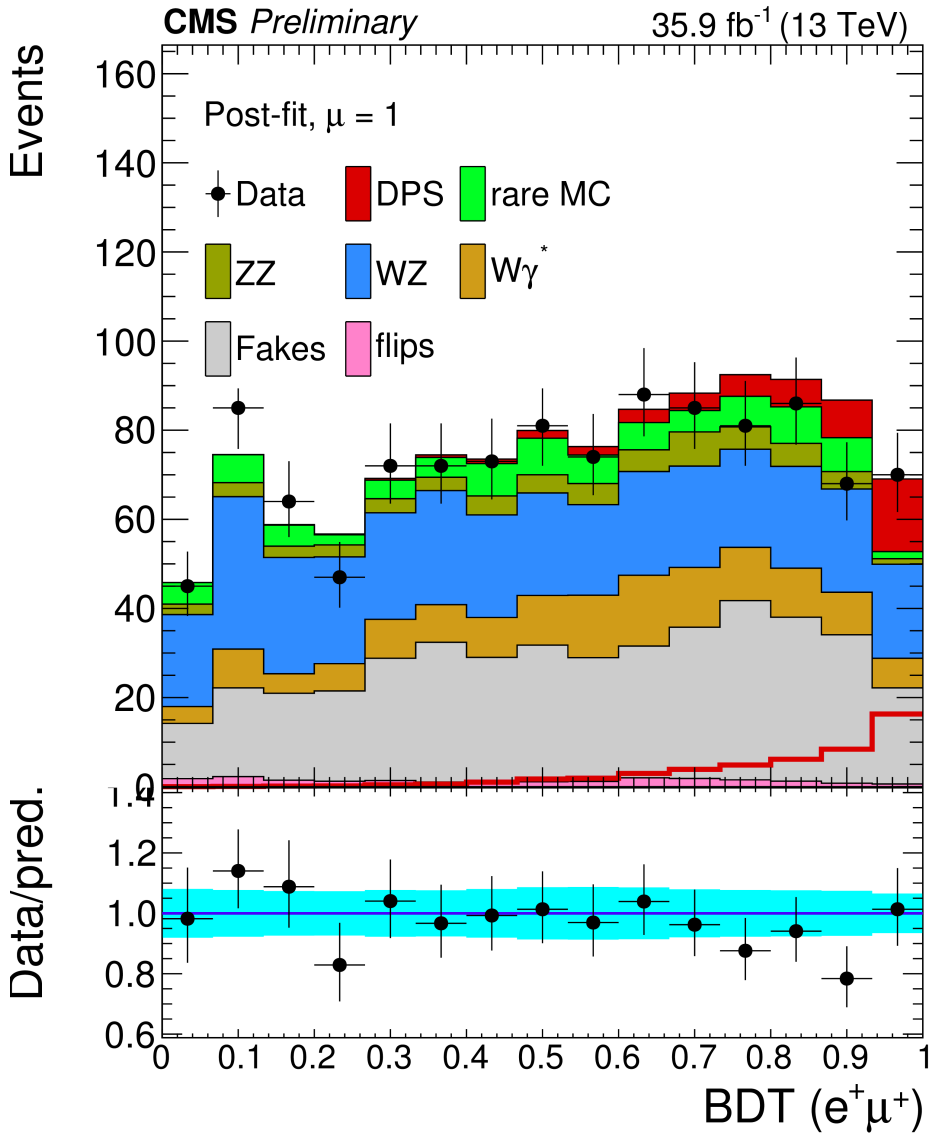
- A multivariate classifier is used to distinguish signal and bkgd



DPS in same-sign WW events at 13 TeV

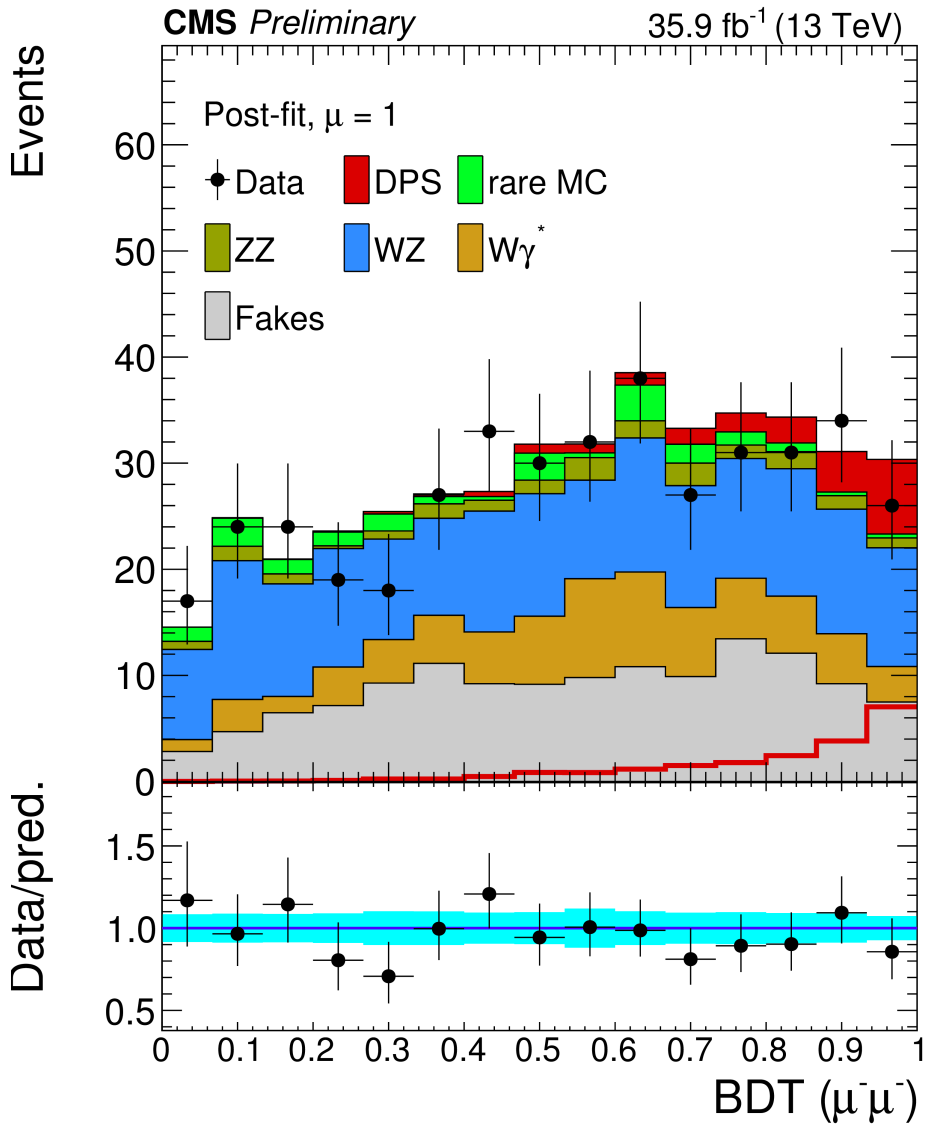
- BDT classifier output for $e^-\mu^-$ and $e^+\mu^+$

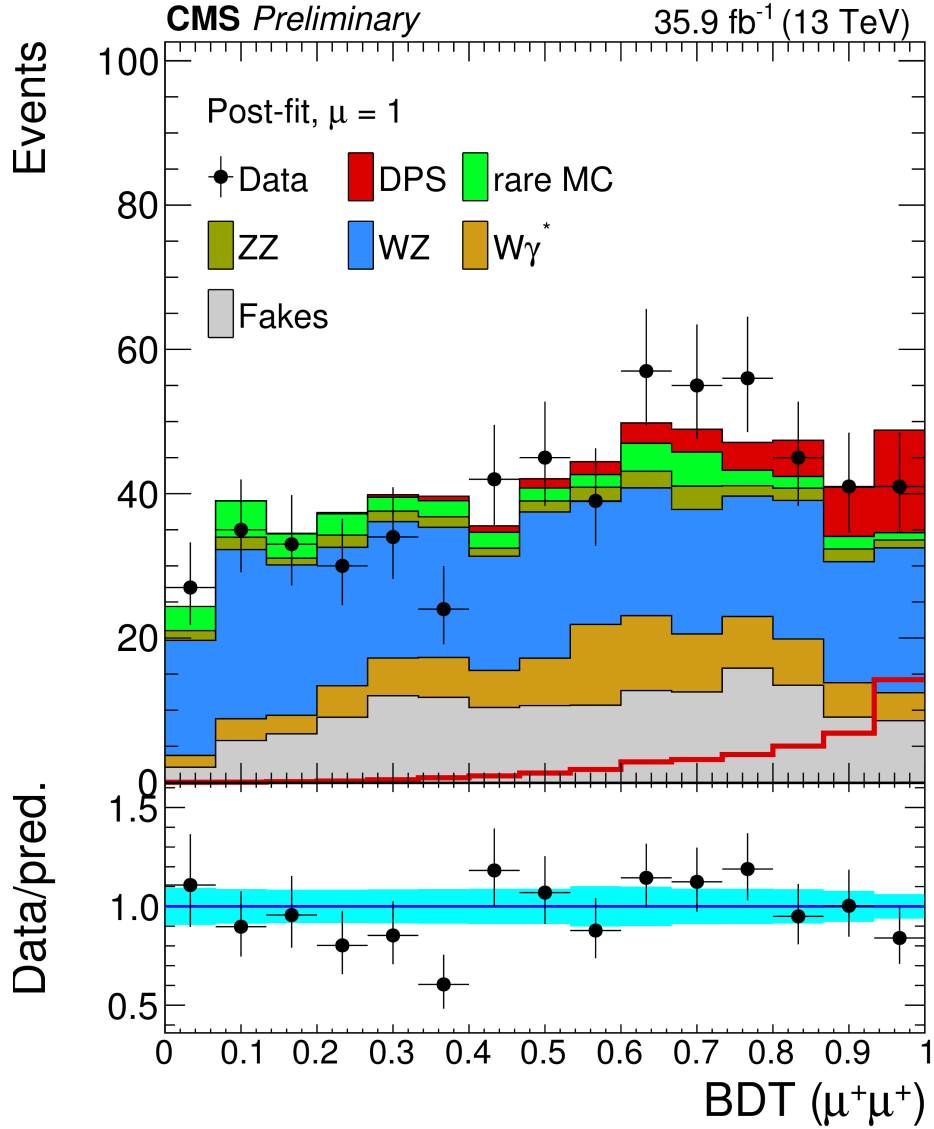




DPS in same-sign WW events at 13 TeV

- BDT classifier output for $\mu^-\mu^-$ and $\mu^+\mu^+$





DPS in same-sign WW events at 13 TeV

- Expected background and signal yields, and observed number of data events in 35.9 fb^{-1}:

	$\mu^+\mu^+$	$\mu^-\mu^-$	$e^+\mu^+$	$e^-\mu^-$
fakes	151.1 ± 26.6	132.7 ± 23.4	412.7 ± 47.2	341.4 ± 39.0
WZ	277.2 ± 28.1	164.5 ± 16.7	355.9 ± 36.1	228.1 ± 23.2
ZZ	24.8 ± 7.0	18.7 ± 5.3	57.8 ± 16.4	55.8 ± 15.8
$W\gamma*$	85.9 ± 27.5	73.1 ± 23.4	142.8 ± 45.7	127.7 ± 40.9
other rare	39.7 ± 15.0	20.2 ± 7.7	83.7 ± 31.7	49.4 ± 18.8
charge flips	—	—	20.4 ± 0.0	21.5 ± 0.0
background	578.6 ± 50.3	409.2 ± 38.2	1073.3 ± 83.0	824.0 ± 65.8
DPS WW	41.1 ± 1.0	20.6 ± 0.5	48.7 ± 1.2	24.1 ± 0.6
observed	604	411	1091	869

DPS in same-sign WW events at 13 TeV

- Fit to the constrained BDT classifier
- Result: $1.09^{+0.50}_{-0.49}$ pb (2.23σ), PYTHIA 8 prediction: 1.64 pb

	expected	observed
$\sigma^{\text{pythia}}_{\text{DPSWW}}$	1.64 pb	$1.09^{+0.50}_{-0.49}$ pb
$\sigma^{\text{factorized}}_{\text{DPSWW}}$	0.87 pb	
significance for $\sigma^{\text{pythia}}_{\text{DPSWW}}$	$3.27\,\sigma$	$2.23\,\sigma$
significance for $\sigma^{\text{factorized}}_{\text{DPSWW}}$	$1.81\,\sigma$	
UL in the absence of signal	< 0.97 pb	< 1.94 pb

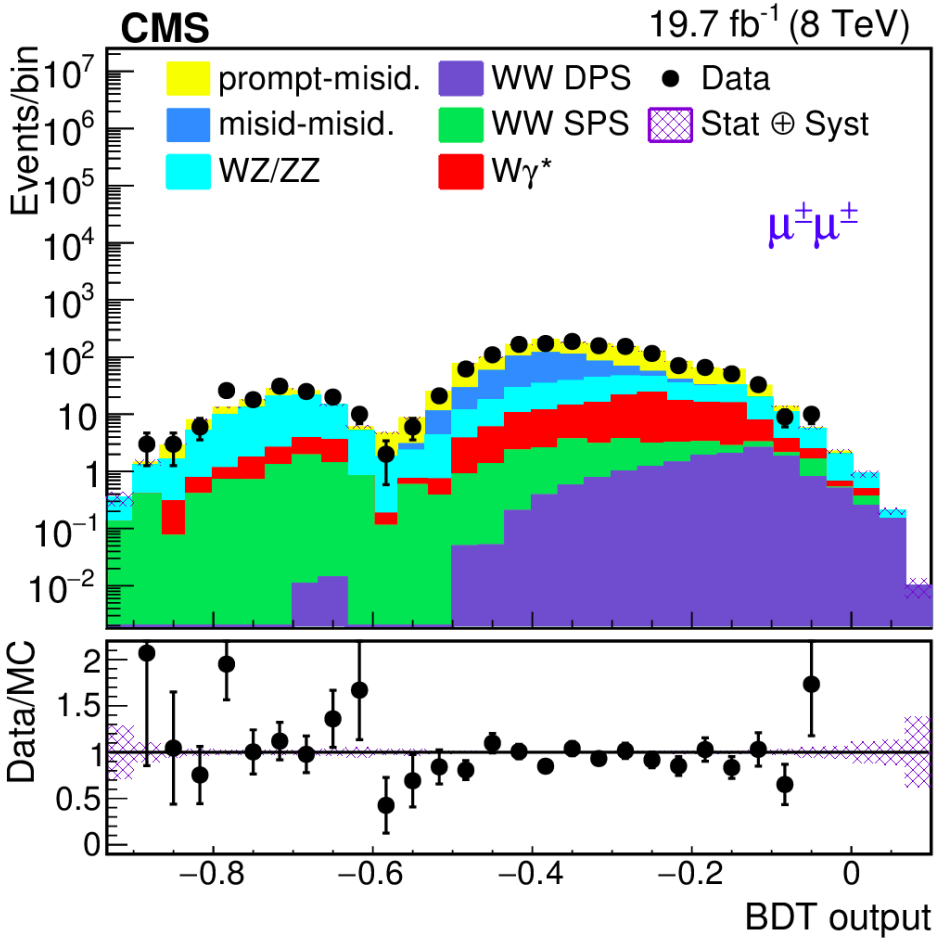
DPS in same-sign WW events at 8 TeV

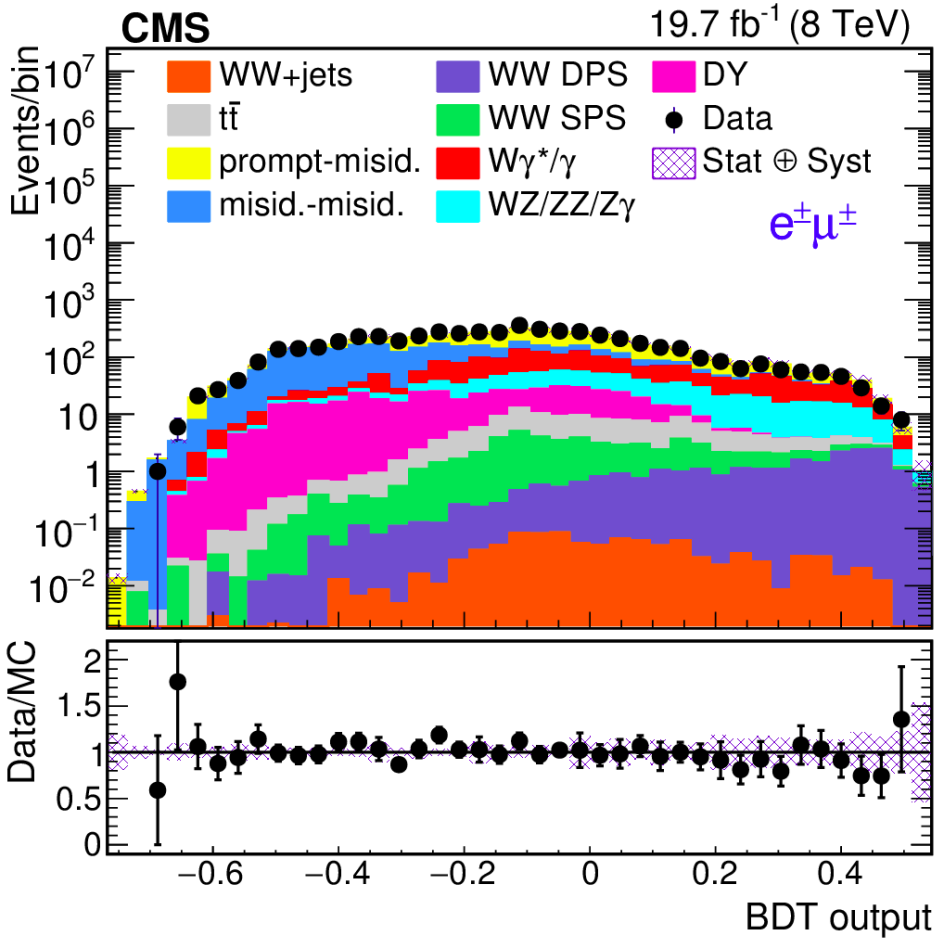
- $W^{\pm}W^{\pm}$ events in 19.7 fb^{-1} of data at 8 TeV
- Our first search for same-sign WW production via DPS
- Event selection:

Dimuon channel	Electron-muon channel
Pair of same-sign leptons	
Leading lepton $p_{\mathrm{T}} > 20\,\mathrm{GeV}$	
Subleading lepton $p_{\mathrm{T}} > 10\,\mathrm{GeV}$	
No third isolated and identified lepton with $p_{\mathrm{T}} > 10\,\mathrm{GeV}$	
$p_{\mathrm{T}}^{\mathrm{miss}} > 20\,\mathrm{GeV}$	
$m_{\ell\ell} > 20\,\mathrm{GeV}$	
$m_{\ell\ell} \notin [75, 105]\,\mathrm{GeV}$	—
$\lvert p_{\mathrm{T}_{\mu_1}} \rvert + \lvert p_{\mathrm{T}_{\mu_2}} \rvert > 45\,\mathrm{GeV}$	—
—	No b-tagged jet with $p_{\mathrm{T}} > 30\,\mathrm{GeV}$ and $\lvert\eta\rvert < 2.1$

DPS in same-sign WW events at 8 TeV

- Distribution of the BDT discriminant in the $\mu^{\pm}\mu^{\pm}$ and $e^{\pm}e^{\pm}$ events

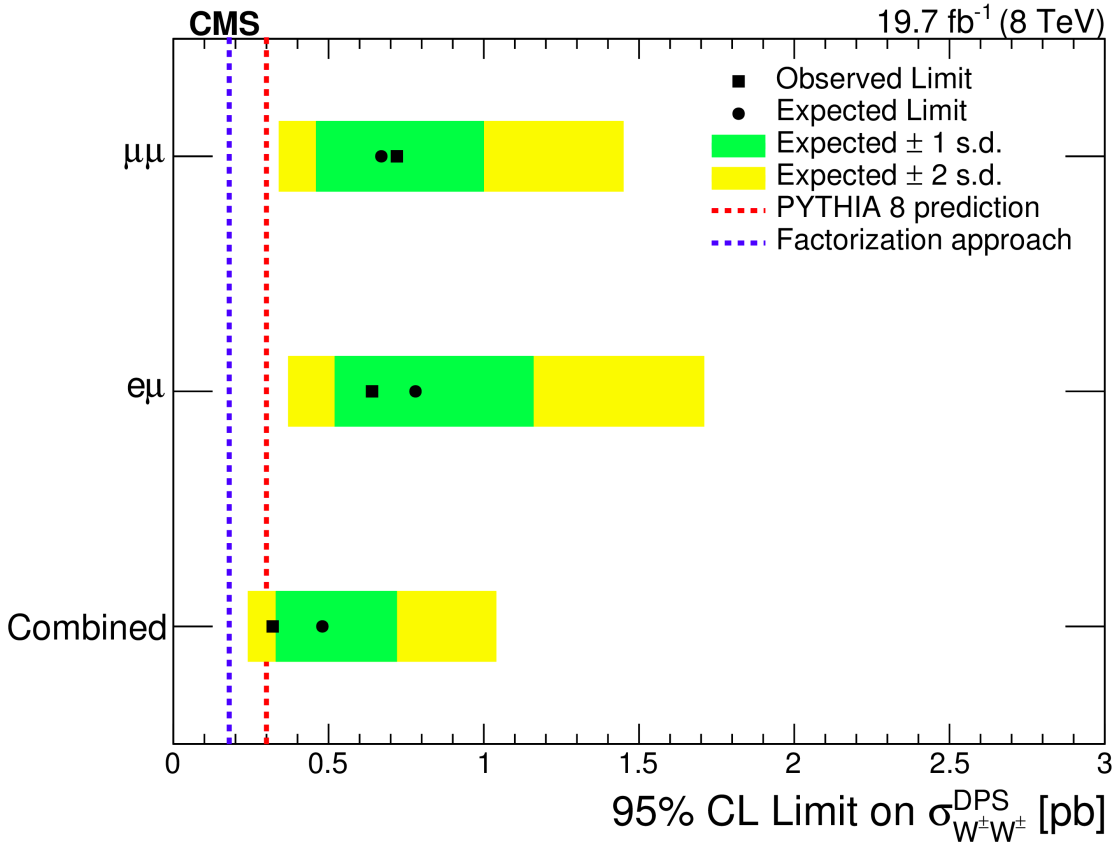




JHEP 1802 (2018) 032
CMS-PAS-FSQ-16-005

DPS in same-sign WW events at 8 TeV

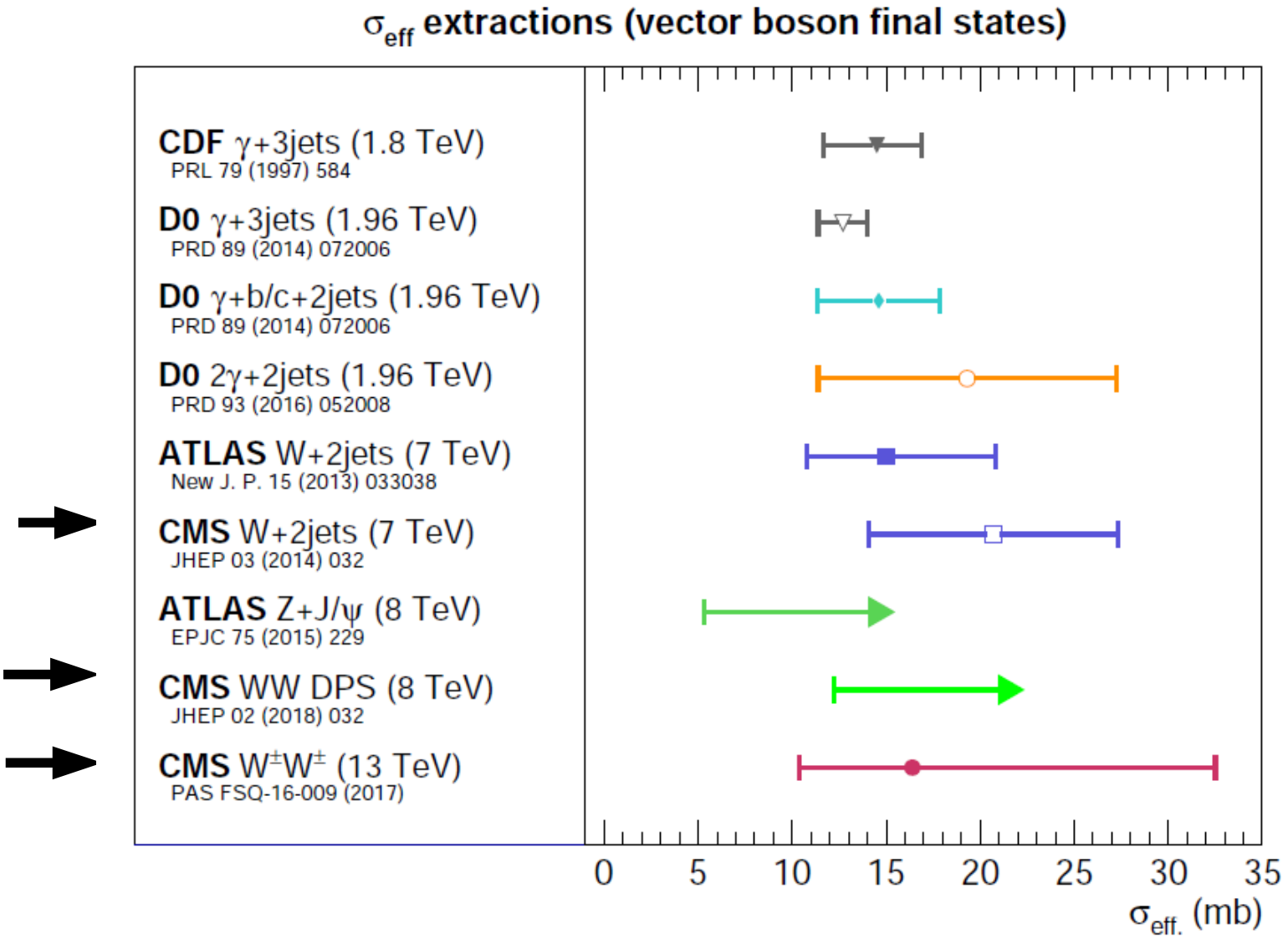
- No significant excess observed above the SPS process
- 0.32 pb is the upper limit (95% CL) for DPS
- Therefore a **lower limit of 12.2 mb** is set for the effective DPS cross section parameter (95% CL)



JHEP 1802 (2018) 032
CMS-PAS-FSQ-16-005

Effective cross section compilation

- Summary of the effective DPS cross section measurements



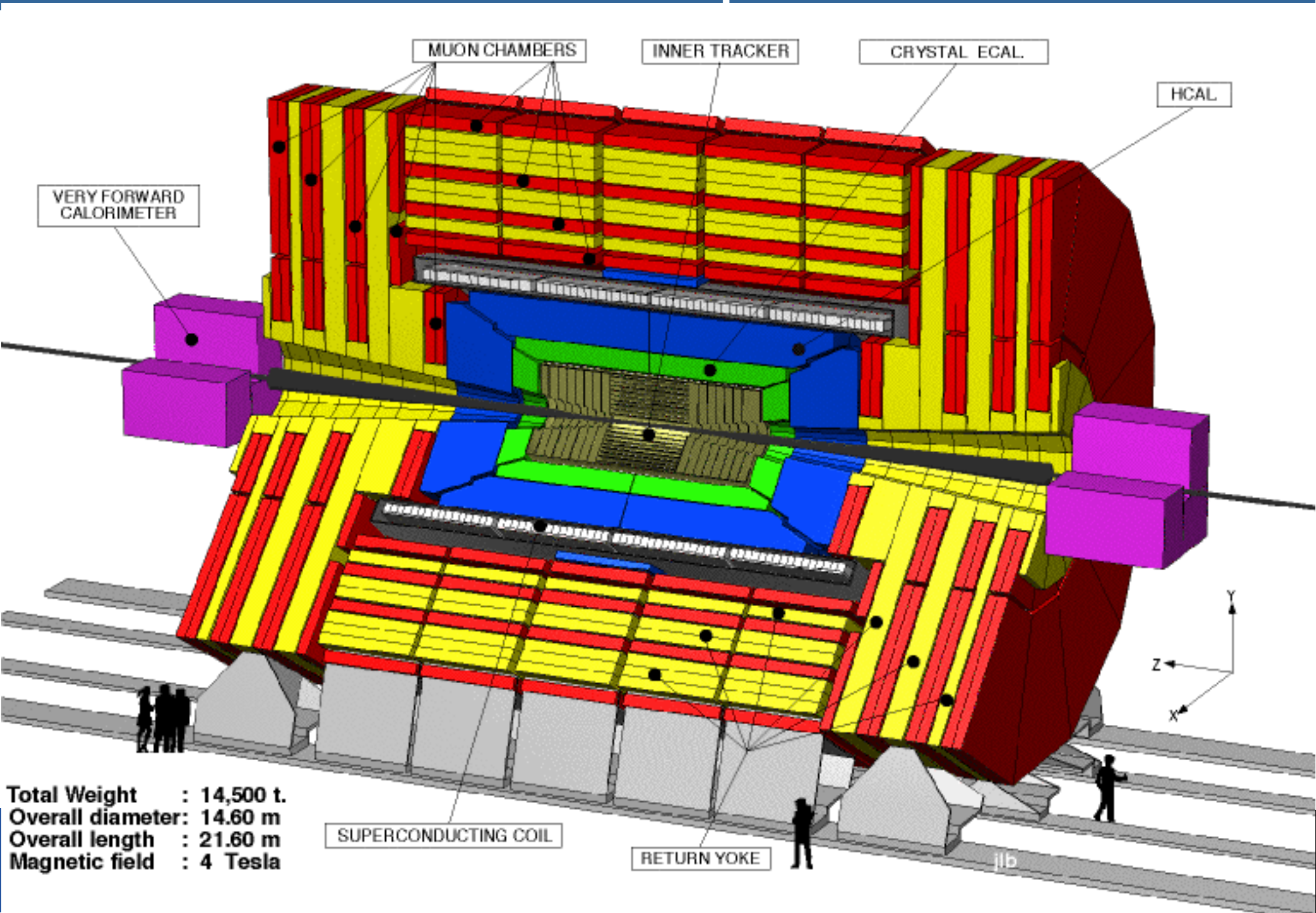
Summary

- Multi Parton Interactions can be studied in many ways, in various channels
  - Multiple jets
  - Vector bosons and multijets
  - vector boson pairs...
- Challenges:
  - Complicated **multivariate** analysis methods
  - Finding appropriate and sensitive **observables** is nontrivial
  - High **luminosity** is often essential
- Very active field and important new observations:
  - Tiny cross sections, extreme **tests** of the Standard Model,...

With more date collected, new opportunities!

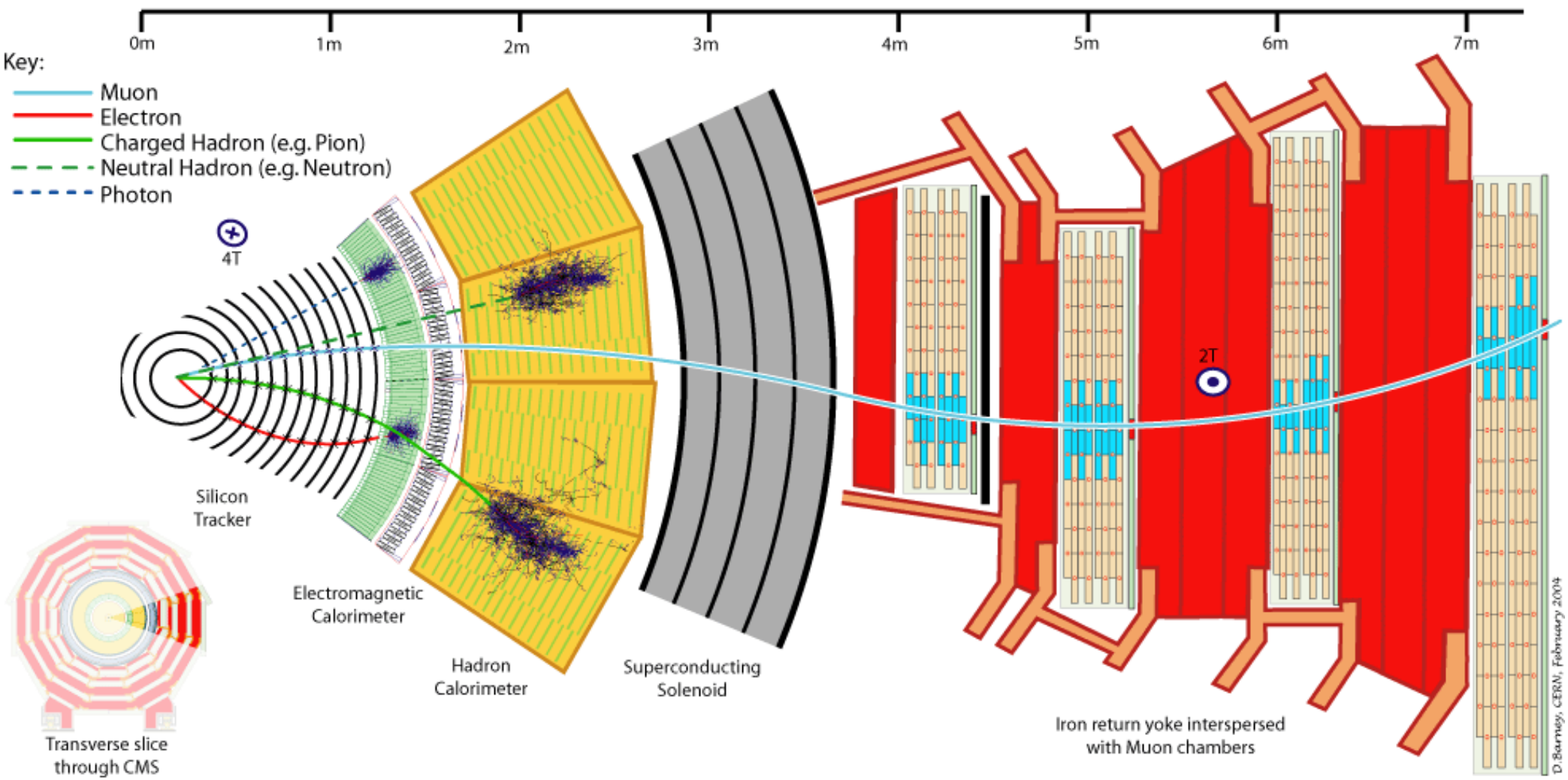
BACKUP

The CMS experiment



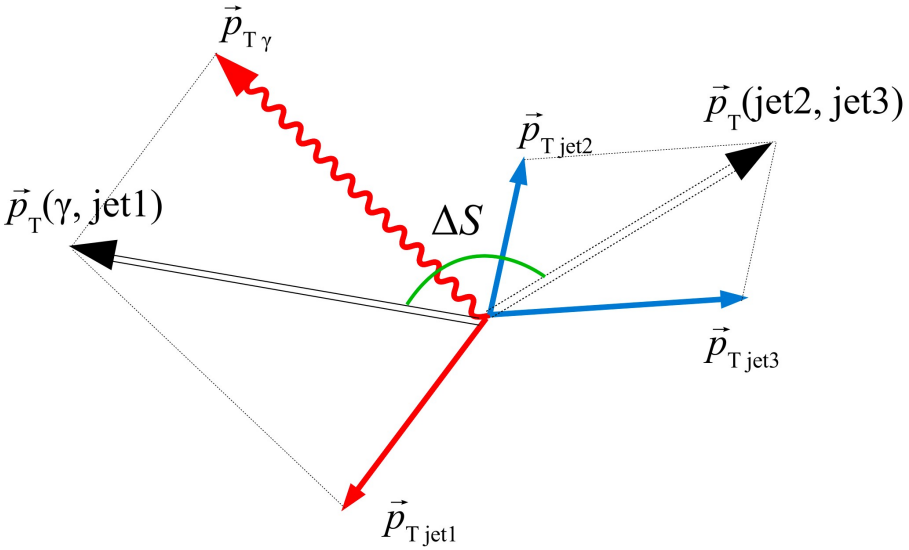
Total Weight : 14,500 t.
Overall diameter: 14.60 m
Overall length : 21.60 m
Magnetic field : 4 Tesla

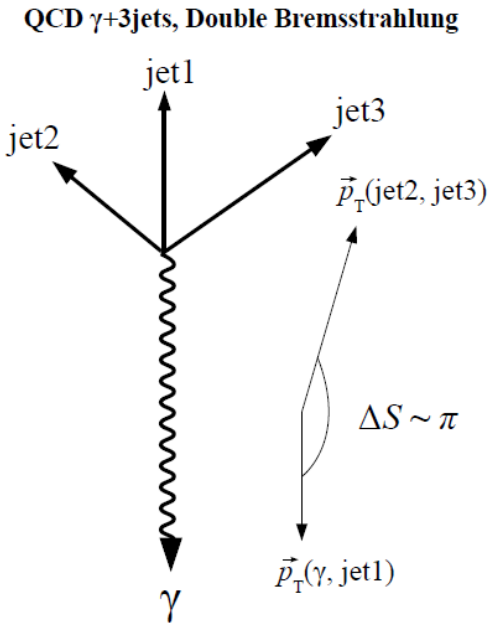
The CMS Experiment

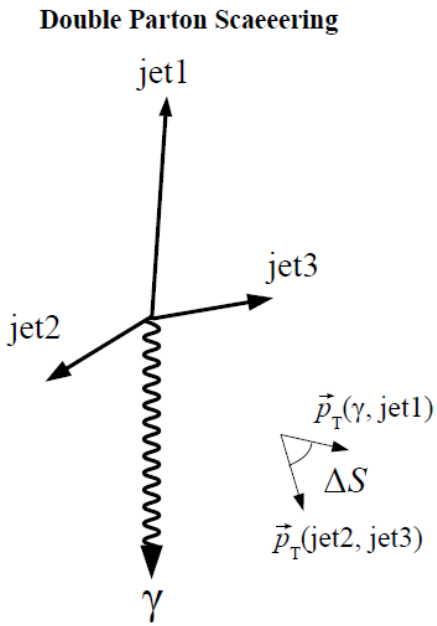


DPS in γ+3 jets in pp collisions at 7 TeV

- 36 pb^{-1} of data in 2010
- The photon and the leading jet are required to have p_T>75 GeV
- Two other jets are in the p_T>20 GeV range



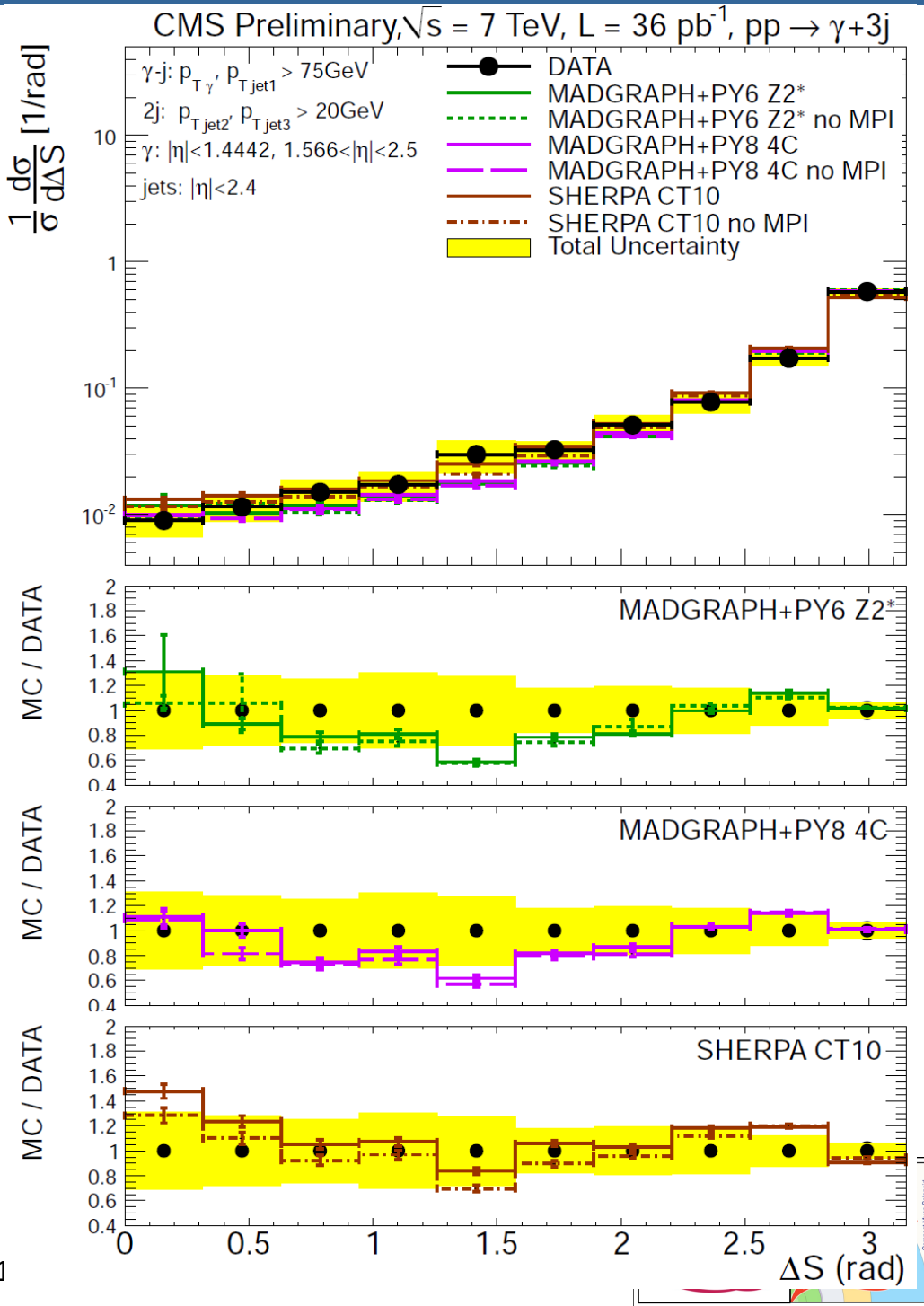




DPS in γ+3 jets in pp collisions at 7 TeV

- Many kinematical distributions are compared to MC predictions
- For example, ΔS distributions are sensitive to DPS in the low ΔS region
- Higher order, parton showers affect the SPS contributions
- MC with and without MPI do not differ significantly
- Conclusion on DPS component is not possible within this given precision

- Let us look at other observables!



CMS-FSQ-12-017