Multiboson measurements at CMS *(DPS WW production)*

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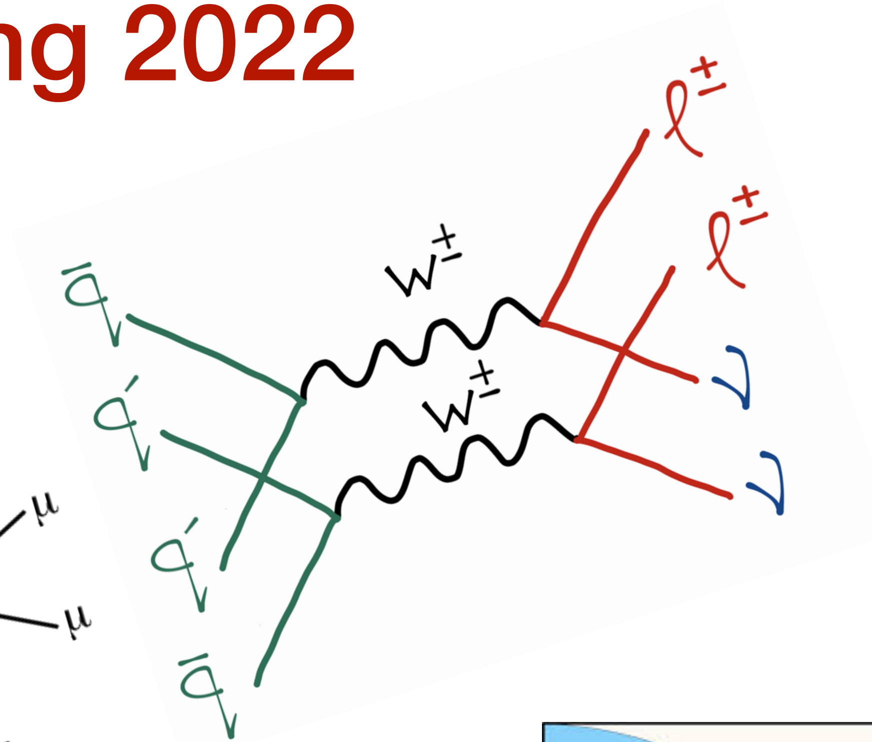
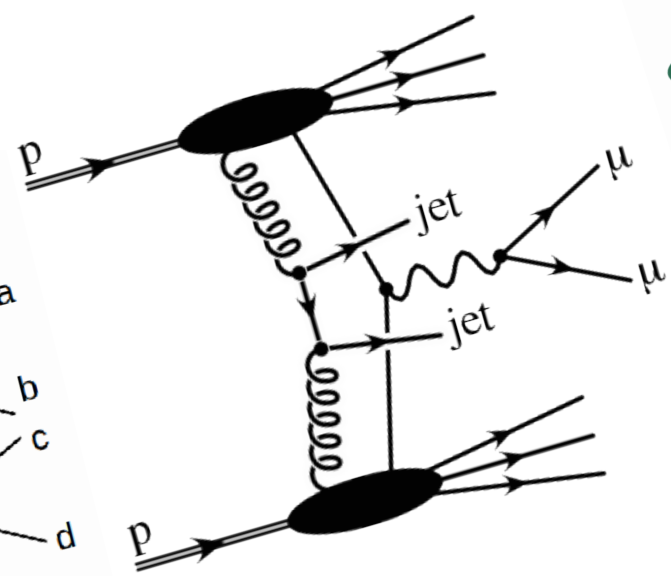
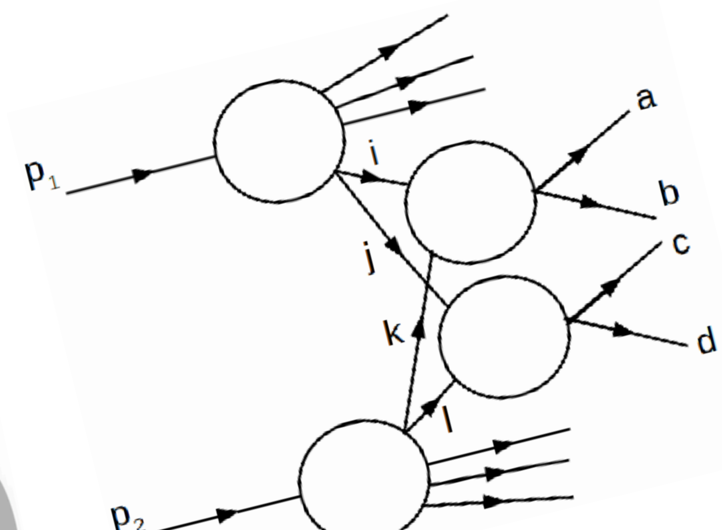
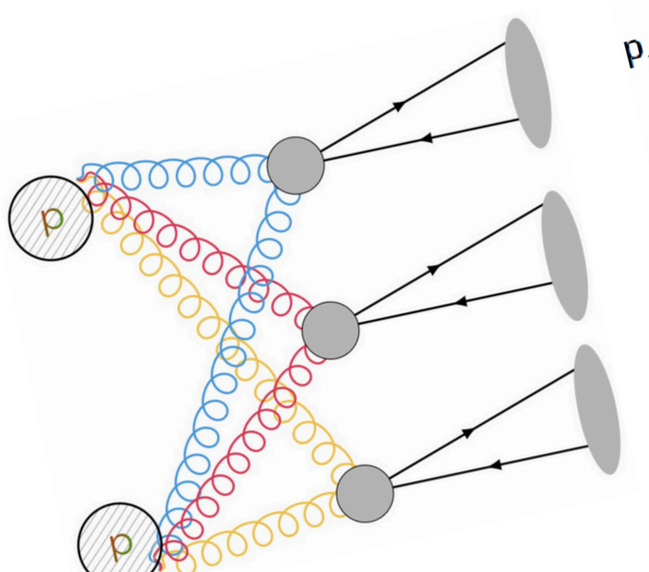
(on behalf of the CMS Collaboration)









Nov 26, 2022

Emmy Noether-Programm
DFG Deutsche Forschungsgemeinschaft

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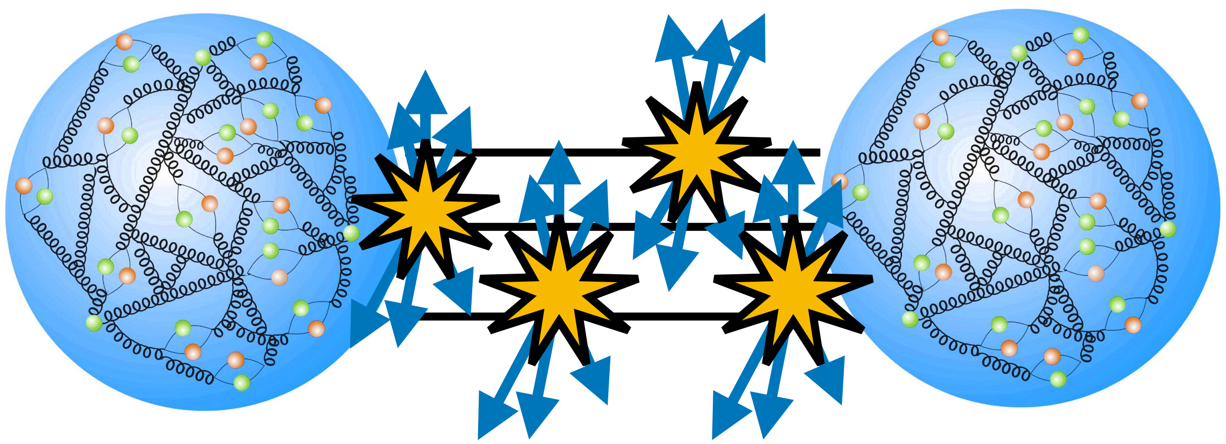
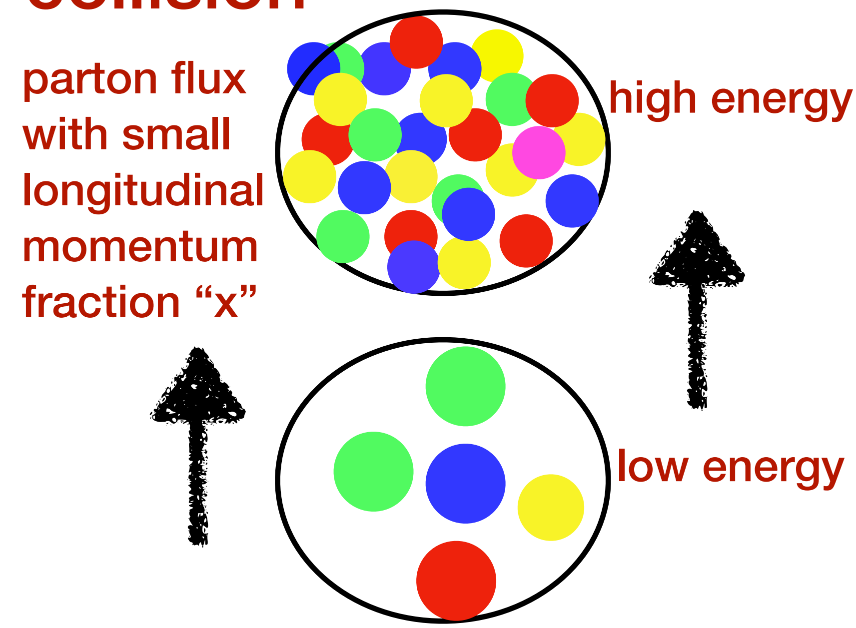
CMS Compact Muon Solenoid

Introduction

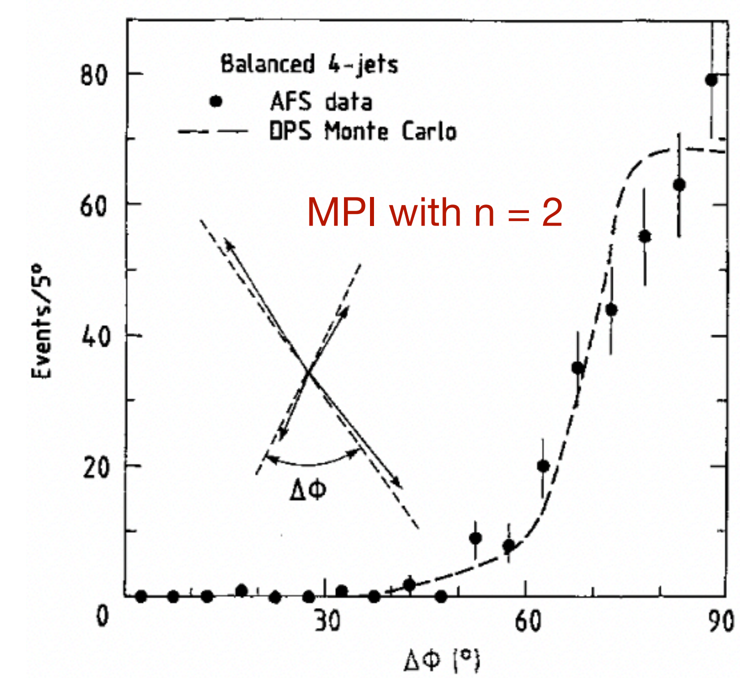
- **Hadrons are "composite" ⇢ possibility to have "n" multiple hard parton-parton interactions (MPI) in a single hadron-hadron collision**
- σ^{MPI} for a given interaction scale increases with $\sqrt{s}$





- First experimental evidence from CERN ISR
  - several measurements at Tevatron & LHC

Z. Phys.C- Particles and Fields 34,163(1987)

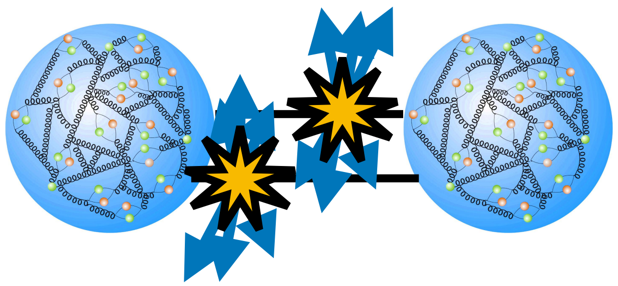


- MPI sensitive to interplay between non-perturbative & perturbative QCD effects ⇢ models need to be "tuned" using data

Hadron colliders such as LHC ideal to study MPI

Double parton scattering (DPS)

- Two distinct hard scatters in a single pp collision double parton scattering
- Cross section for a “nPS” process is suppressed as compared to SPS

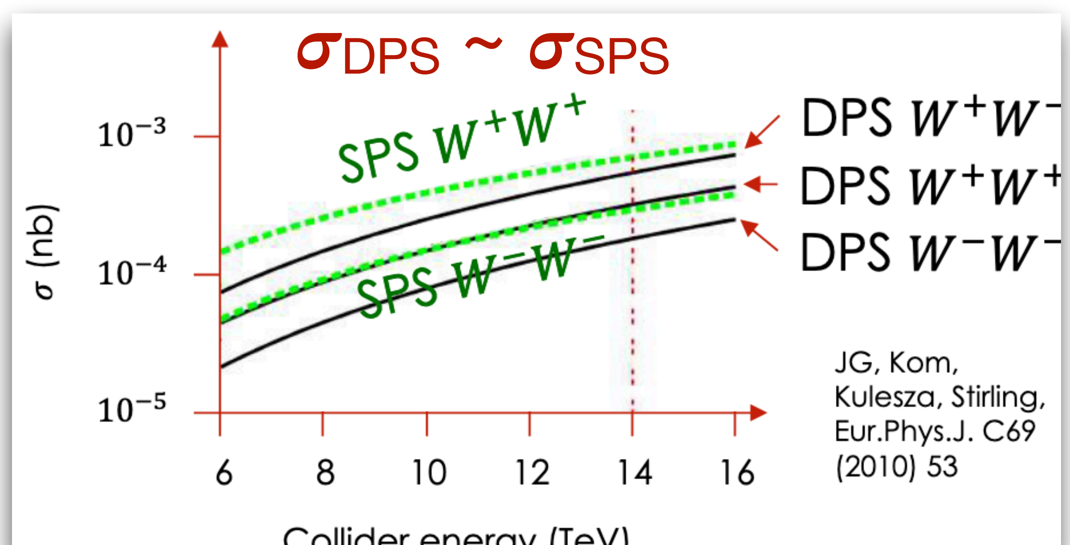


$$\frac{\sigma_{n\mathrm{PS}}}{\sigma_{\mathrm{SPS}}} \sim \left(\frac{\Lambda^2}{Q_h^2}\right)^{n-1}$$

Λ → hadronic scale ~1GeV

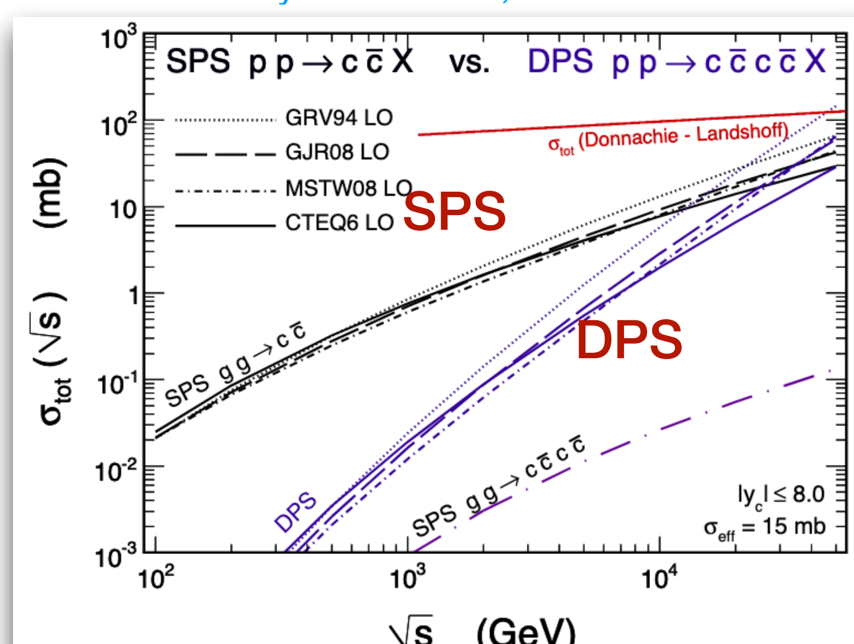
Q_h → hard interaction scale

In certain phase space regions contributions from DPS cannot be neglected

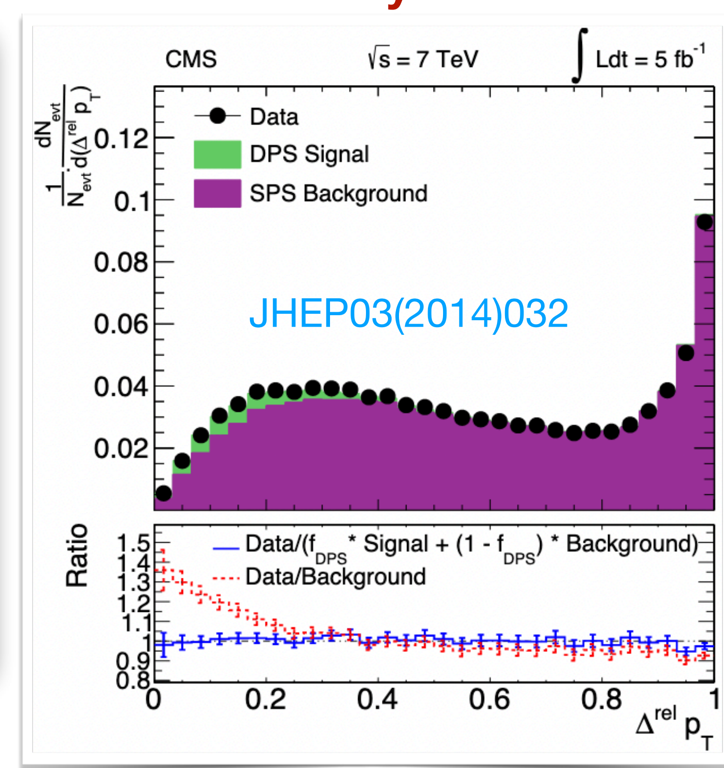


JG, Kom, Kulesza, Stirling, Eur.Phys.J. C69 (2010) 53

Phys. Rev. D79, 094034



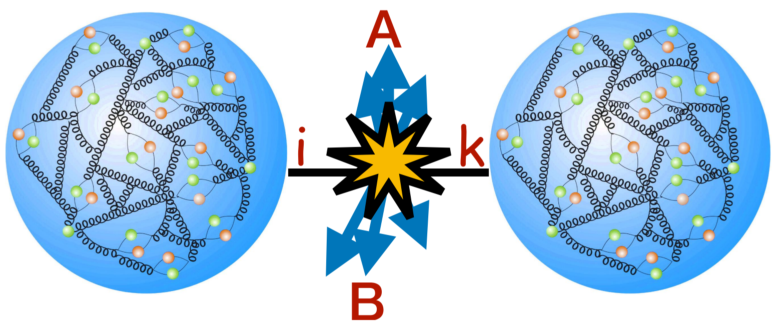
Populates phase space in a different way from SPS



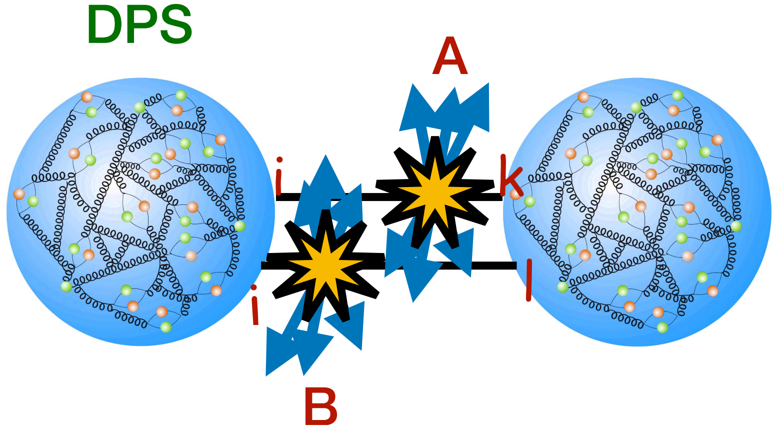
- Probes the internal structure of a proton
- Background for rare SM and new physics processes
- Provides input for the tuning of MC simulations

Cross section formula for DPS

SPS



DPS



PDFs partonic cross section

$$\sigma_{AB}^{\mathrm{SPS}} = \sum_{i,k} \int D^i(x_1; Q^2) D^k(x_1', Q^2) \times \hat{\sigma}_{AB}^{ik}(x_1, x_1', Q^2) dx_1 d' x_1$$

double PDFs partonic cross sections

$$\sigma_{AB}^{\mathrm{DPS}} = \frac{m}{2} \sum_{i,j,k,l} \int \Gamma^{ij}(x_1, x_2; b_1, b_2; Q_A^2, Q_B^2) \times \hat{\sigma}_A^{ij}(x_1, x_1', Q_A^2) \hat{\sigma}_B^{ij}(x_2, x_2', Q_B^2) \times \Gamma^{kl}(x_1', x_2'; b_1 - b, b_2 - b; Q_A^2, Q_B^2) dx_1 dx_2 dx_1' dx_2' d^2b_1 d^2b_2 d^2b$$

assuming longitudinal and transverse factorization of dPDFs

simplified expression for

σ_{DPS} ⇢ pocket formula

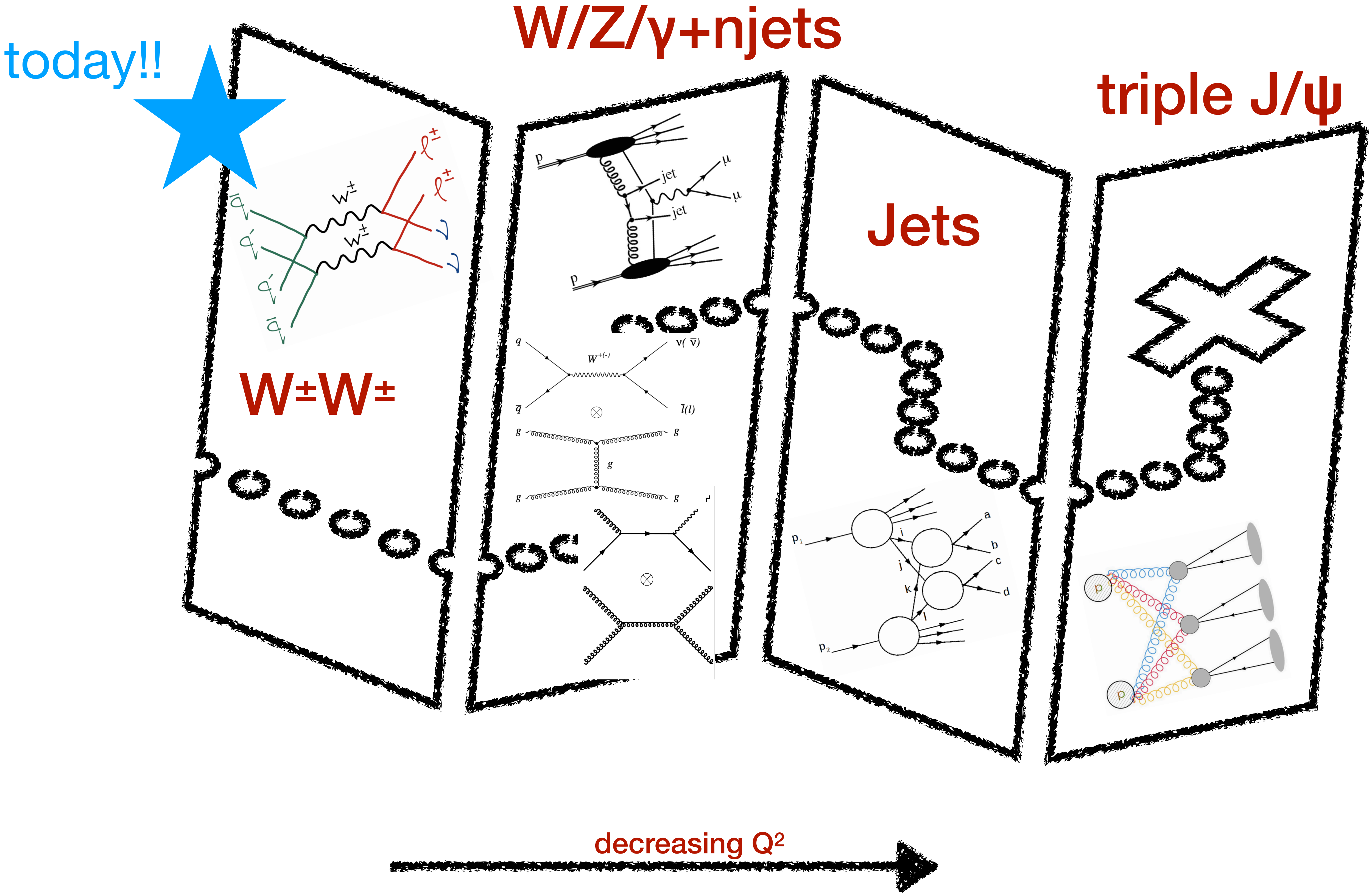
$$\boxed{\sigma_{AB}^{\mathrm{DPS}} = \frac{m}{2} \frac{\sigma_A \sigma_B}{\sigma_{\mathrm{eff}}} \quad \sigma_{\mathrm{eff}} = \left[\int d^2b\, t(b) \right]^{-1}}$$

σ_A, σ_B : SPS cross sections for two interactions

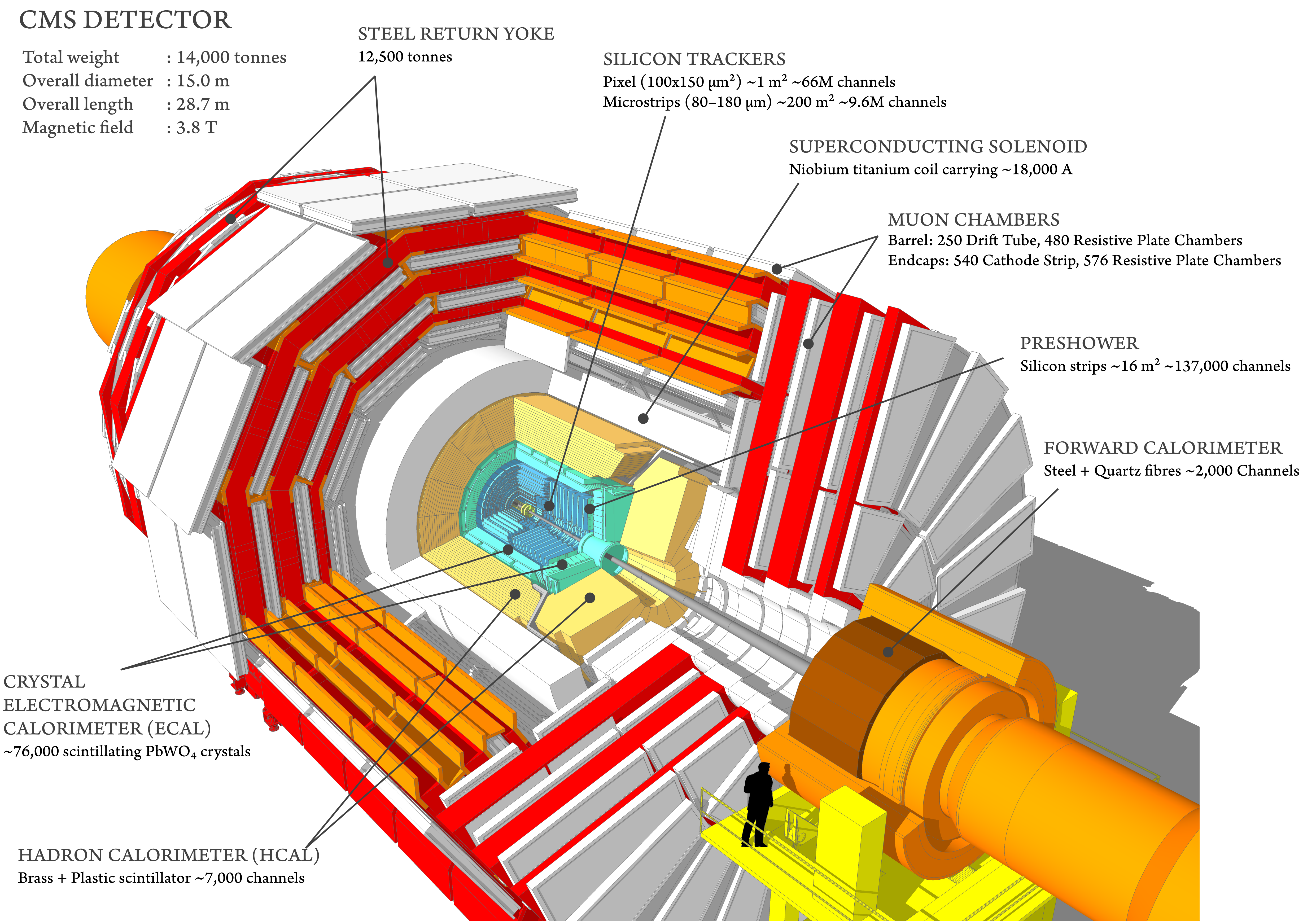
m : 1 if A = B else 2

σ_{eff} : effective cross section for DPS

DPS @CMS



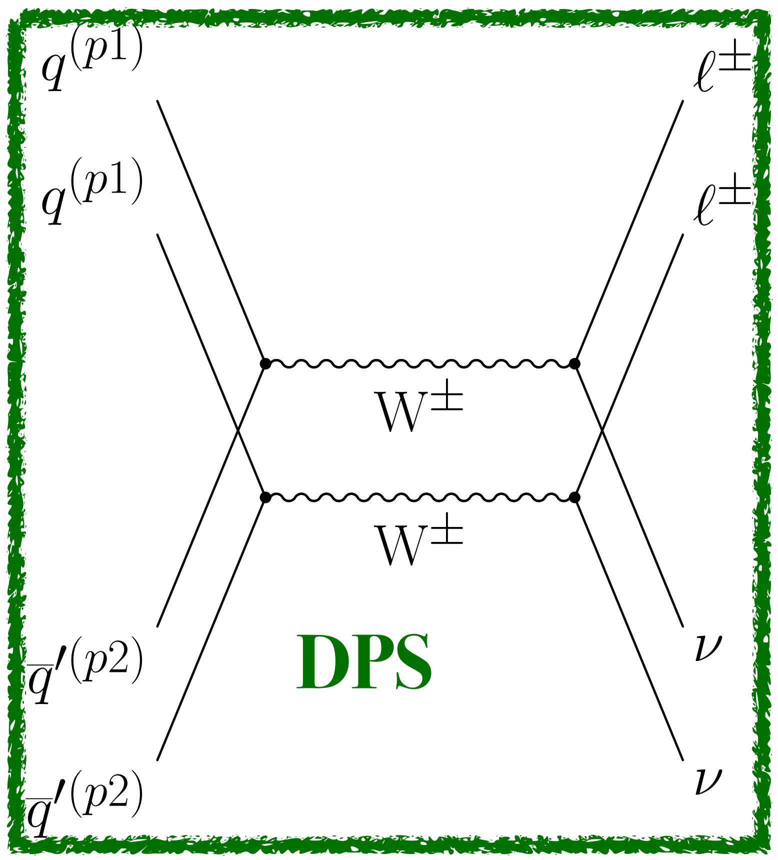
Compact Muon Solenoid (CMS)

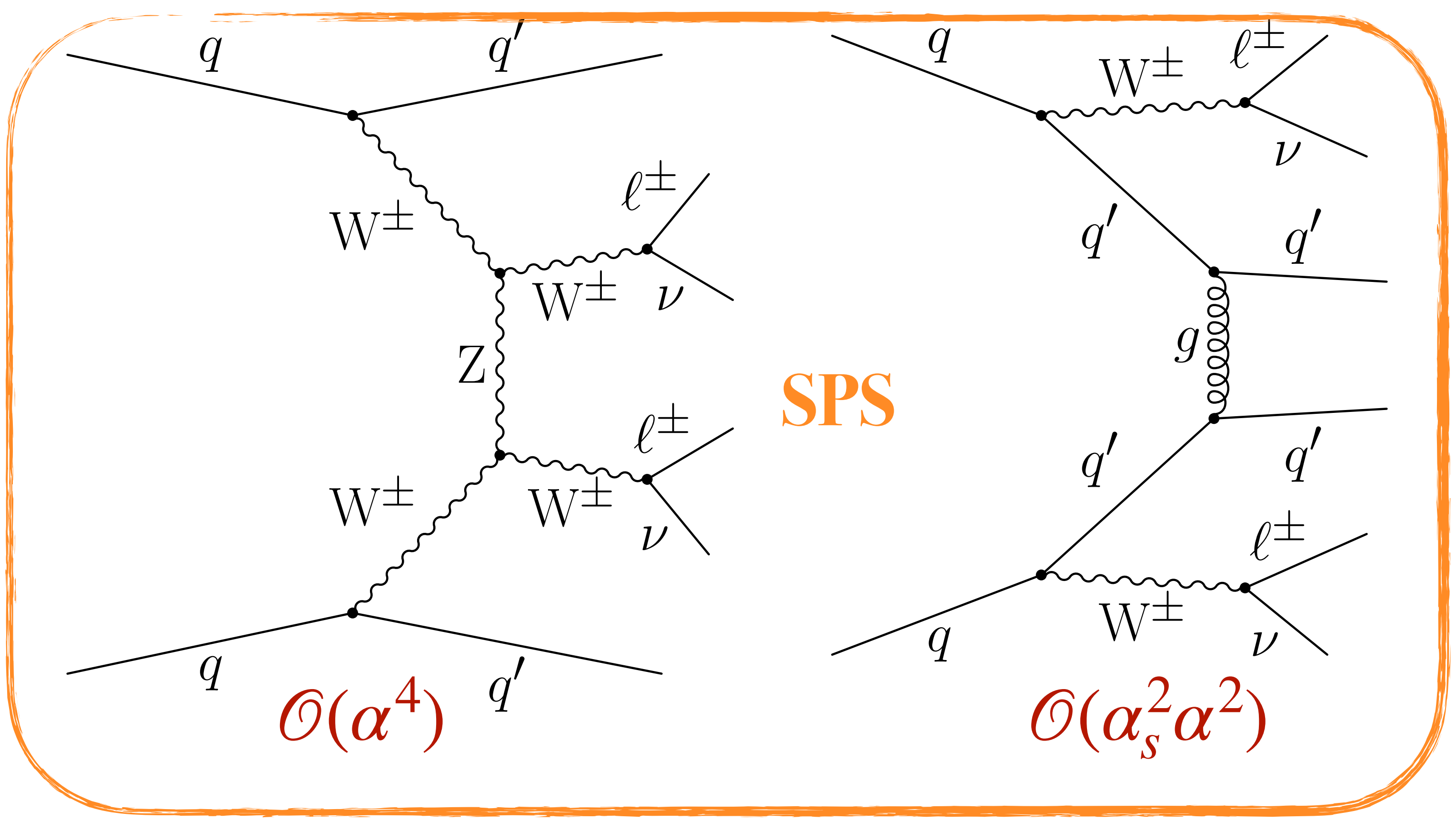


arXiv:2206.02681

DPS with W±W±

- Golden channel for DPS production since SPS W±W± production suppressed at matrix element level due to presence of (two) extra jets
- Pythia8 predicts cross section for WW ⇢ 2l2v = 0.18 pb ± 40% (tune) @13TeV





- Sensitive to inter-parton correlations
- Insensitive to pileup effects & clean final state with fully leptonic W decays

Analysis strategy

- Analysis performed using pp collisions data at 13TeV ⇢ 138 fb^{-1}
- Signal: $W^{\pm}W^{\pm}$ ⇢ eμ or μμ final states with moderate p_{T}^{miss} ⇢ modelled using Pythia8 & dShower with model uncertainties from Herwig

- Background contributions from prompt & nonprompt lepton productions
  - Prompt contributions ⇢ from MC simulations
  - Nonprompt contributions ⇢ estimated using data

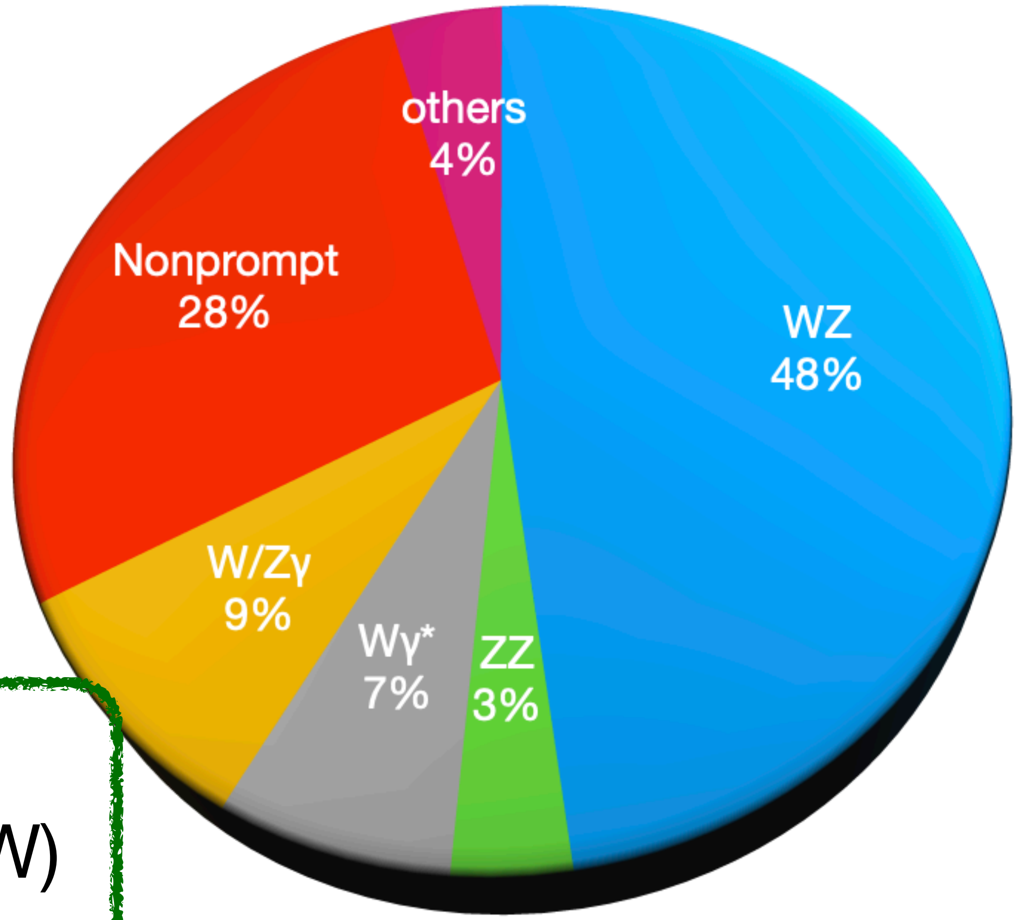
- Boosted decision trees (BDT) based signal & background discrimination

- Signal cross section extracted using binned maximum likelihood (ML) fit to the shape of the BDT classifier

event selection
two leptons $e^{\pm}\mu^{\pm}$ or $\mu^{\pm}\mu^{\pm}$
$p_T^{\ell_1} > 25$ GeV, $p_T^{\ell_2} > 20$ GeV
$\lvert\eta_e\rvert < 2.5$, $\lvert\eta_\mu\rvert < 2.4$
$p_T^{miss} > 15$ GeV
$m_{\ell\ell} > 12$ GeV
$N_{jets} < 2$
$N_{b\text{-}jets} == 0$
veto on additional leptons
veto on hadronic τ leptons
$p_T^{\ell\ell} > 20$ GeV for $e^{\pm}\mu^{\pm}$ channel

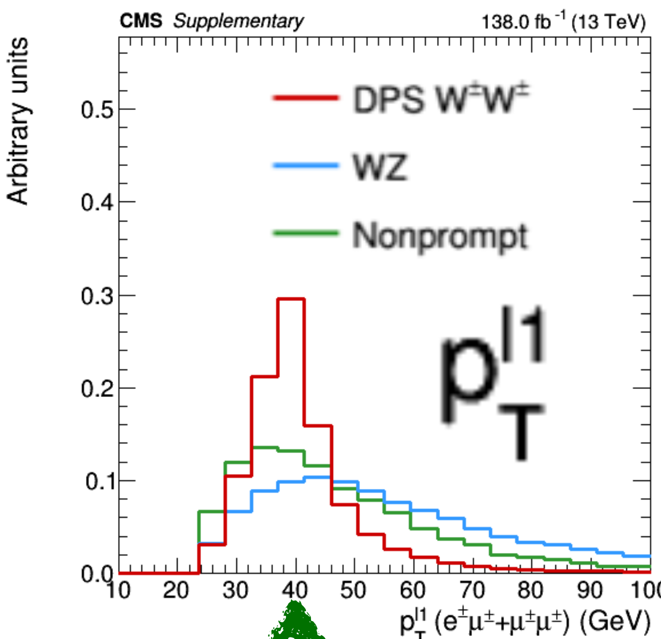
Backgrounds

- Dominant contribution from WZ ⇢ 3lν; one lepton from Z is lost
  - Kinematically very similar to the signal process
- Nonprompt lepton contributions (W+jets, QCD multijets, and semi-leptonic ttbar)
- Prompt lepton contributions also from:
  - Wγ*, ZZ, SPS W±W±, VVV, ttbarV
  - Photon conversions (W/Zγ) Only in eμ channel
  - Lepton charge misidentification (ttbar, DY, WW) (data-driven estimation)
- Negligible background contribution from pileup
- Two separate BDT classifiers for WZ & nonprompt

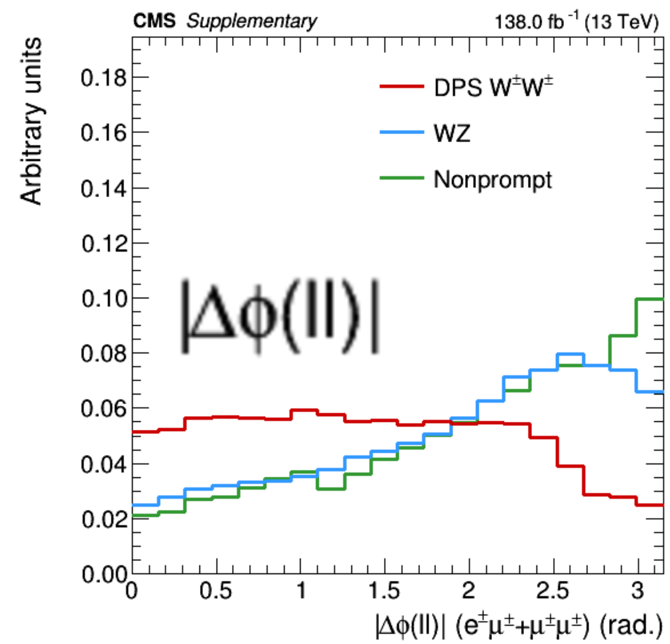


BDT classifiers

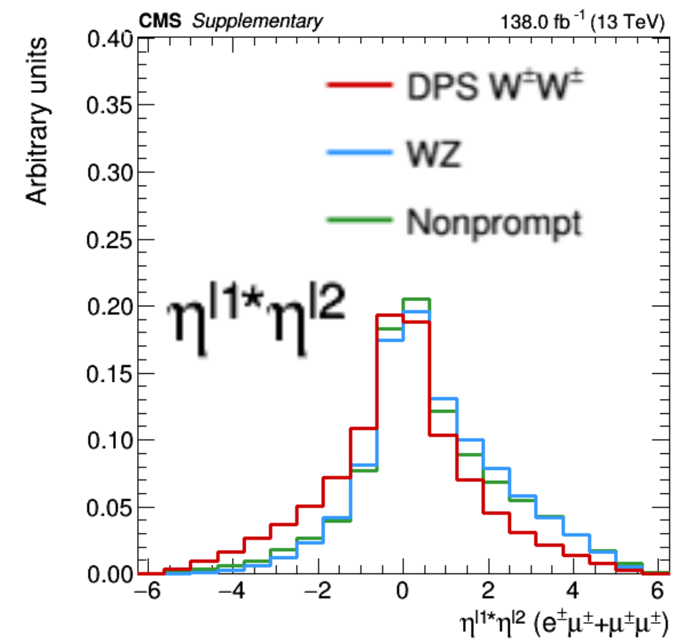
- Training variables ⇢ kinematic differences between (uncorrelated) signal & (correlated) backgrounds



mW/2



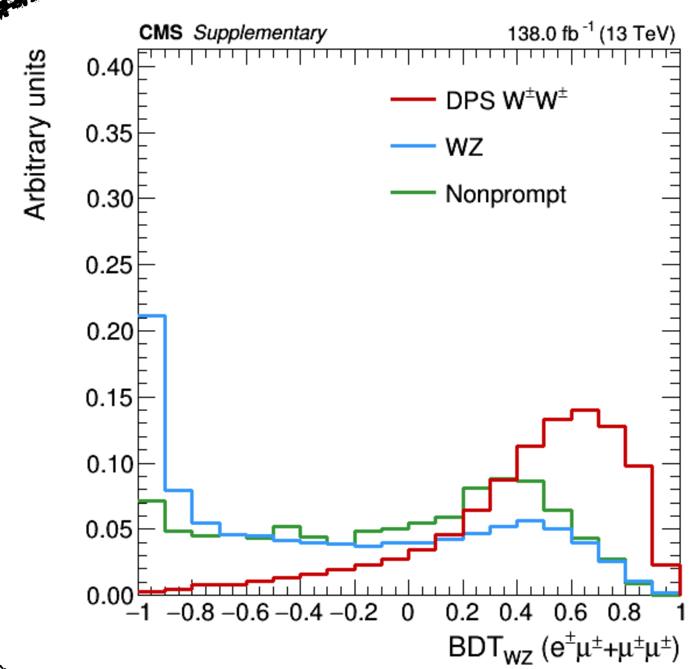
relatively flat signal

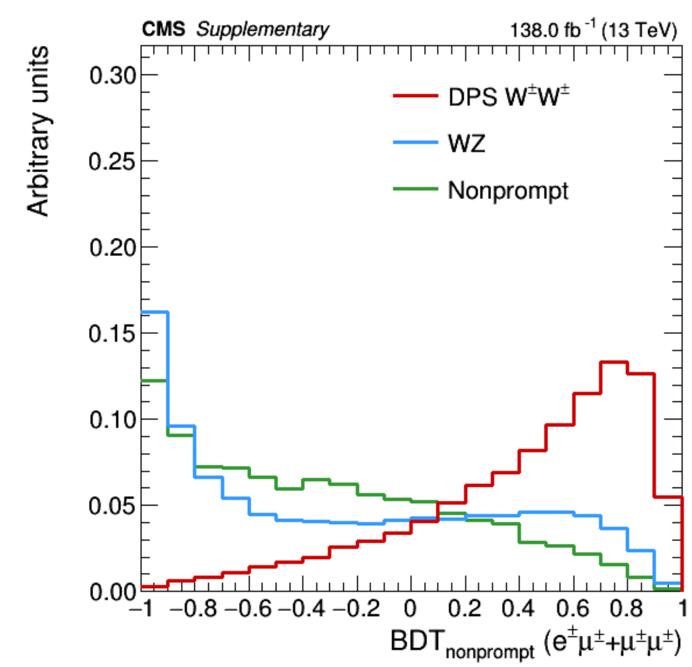


sensitive to correlations

training variables

$\mathrm{pT}_{l_{1,2}}$	$\mathrm{m_T}(\mathrm{l}_1, p_\mathrm{T}^\mathrm{miss})$
$p_\mathrm{T}^\mathrm{miss}$	$\mathrm{m_T}(\mathrm{l}_1, \mathrm{l}_2)$
$\mathrm{M}_\mathrm{T2}^\mathrm{ll}$	$\Delta\phi(l_1, l_2)$
$\eta_1 \times \eta_2$	$\Delta\phi(l_2, p_\mathrm{T}^\mathrm{miss})$
$\lvert\eta_1 + \eta_2\rvert$	$\Delta\phi(l_1 l_2, l_2)$



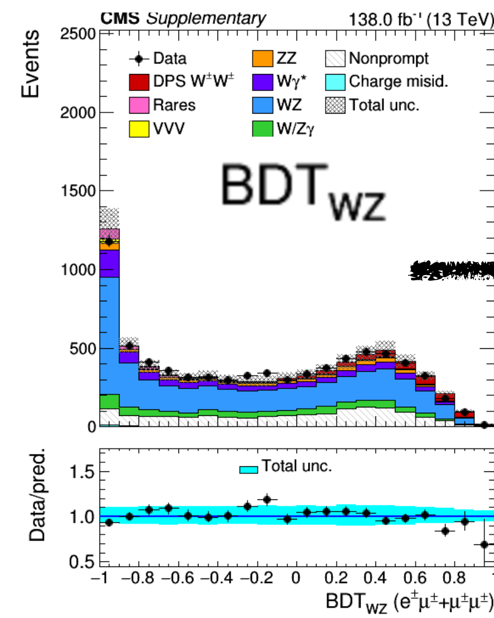


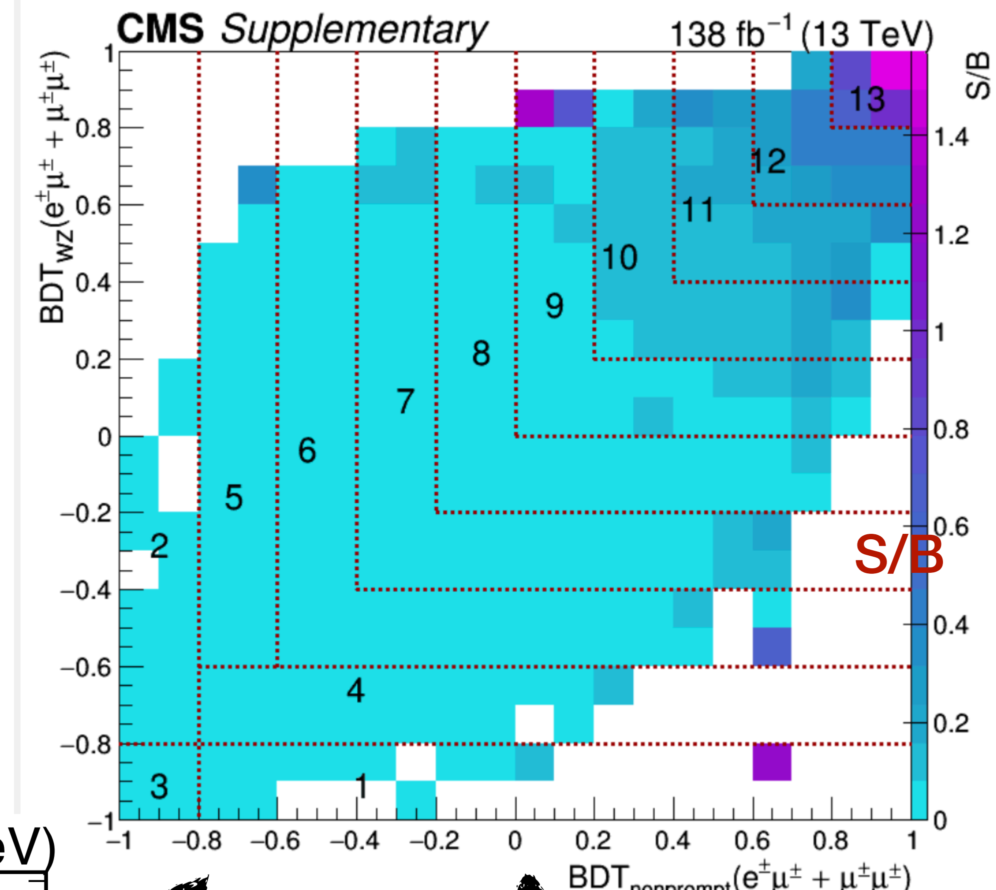
Statistical analysis

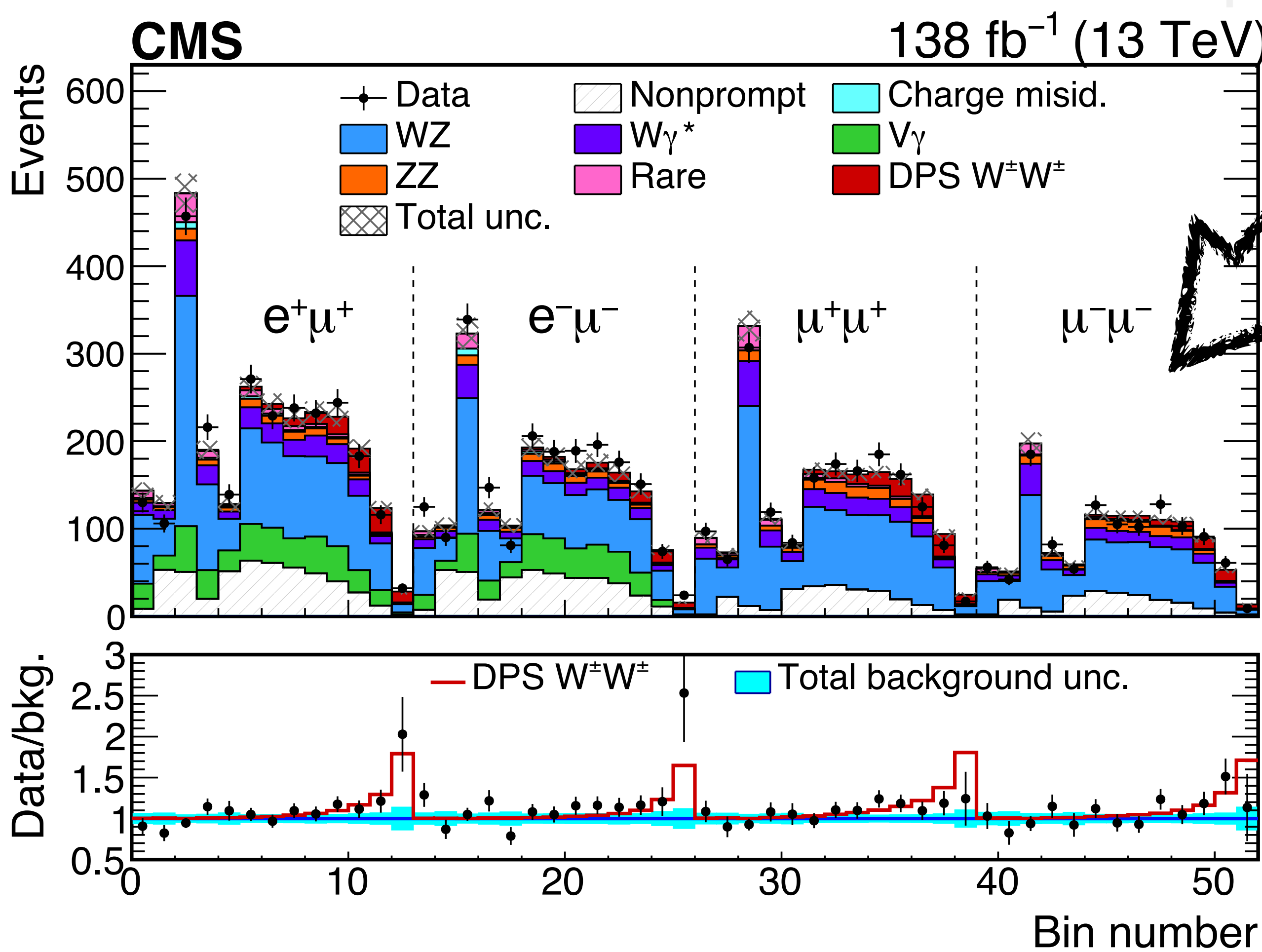
high purity bins

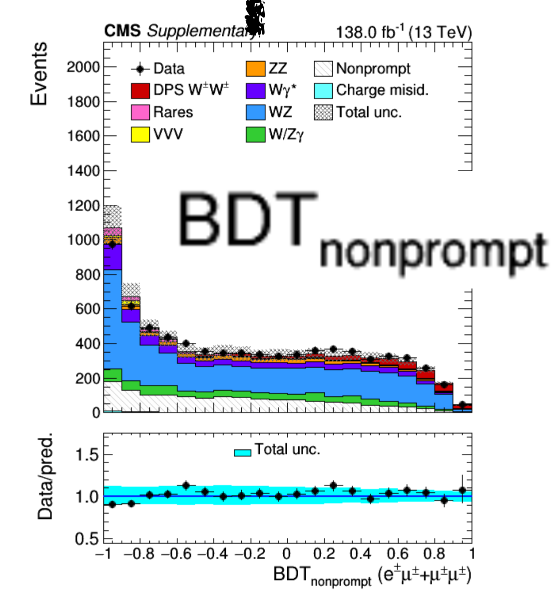
Two BDTs ⇢ 1D distribution

- Simultaneous ML fit to the shape of final BDT classifier in: **$e^+\mu^+$, $e^-\mu^-$, $\mu^+\mu^+$, $\mu^-\mu^-$**









signal visible in highest BDT bins

Results-i

Accepted for publications by PRL

Inclusive cross section

$$80.7 \pm 11.2\,(\text{stat})^{+9.5}_{-8.6}\,(\text{syst}) \pm 12.1\,(\text{model})\,\text{fb}$$

Fiducial cross section

$$6.28 \pm 0.81\,(\text{stat}) \pm 0.69\,(\text{syst}) \pm 0.37\,(\text{model})\,\text{fb}$$

First observation of W±W± via DPS with 6.2 s.d. (observed)

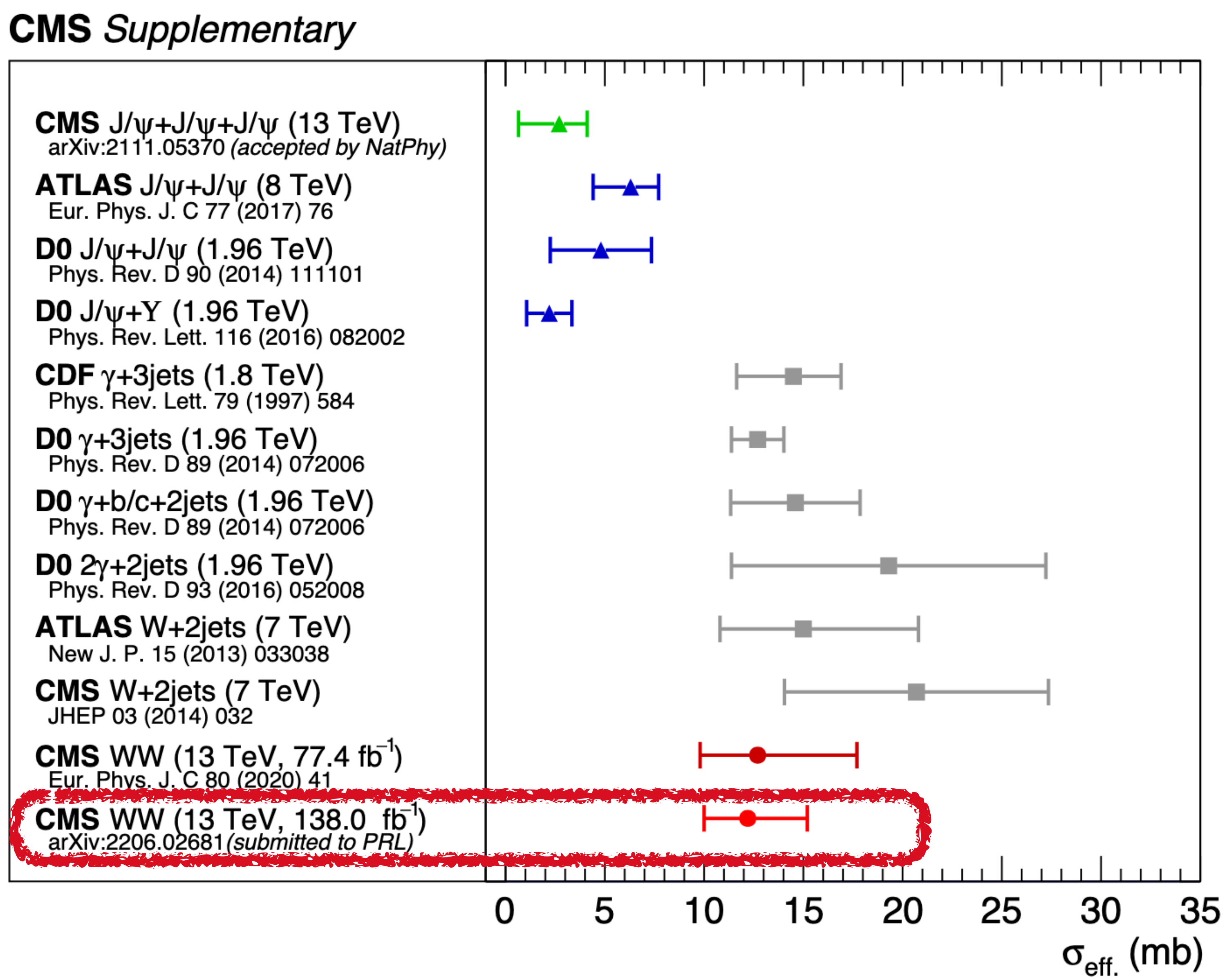
Fiducial region

exactly two dressed leptons $e^{\pm}\mu^{\pm}$ or $\mu^{\pm}\mu^{\pm}$
$p_T^{\ell_1} > 25$ GeV, $p_T^{\ell_2} > 20$ GeV
$\lvert\eta_e\rvert < 2.5$ (also vetoing the ECAL transition region), $\lvert\eta_\mu\rvert < 2.4$,
$m_{\ell\ell} > 12$ GeV
$p_T^{\ell\ell} > 20$ GeV for $e^{\pm}\mu^{\pm}$ channel

Using pocket formula

$$\sigma_{\text{eff}} = 12.2^{+2.9}_{-2.2}\,\text{mb}$$

Summary



- Consistent with previous measurement from the same channel & other measurements involving W bosons from ATLAS & CMS
  - Improved precision
  - Tensions with most gluon induced processes