ATLAS measurements of vector boson production

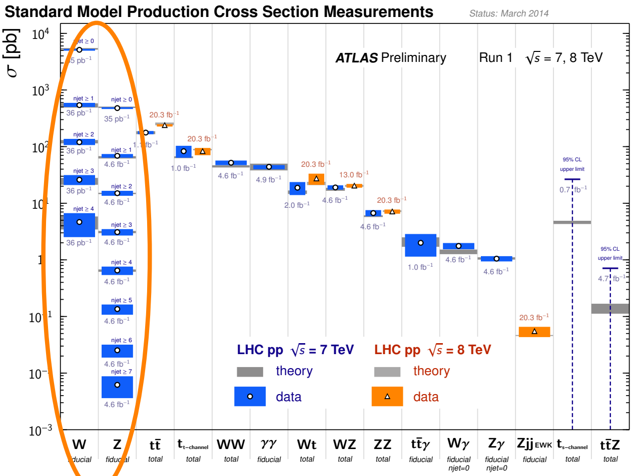
Christian Gütschow

University College London

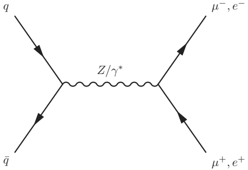
PHENO 2014, Pittsburgh, 05–07 May

Overview

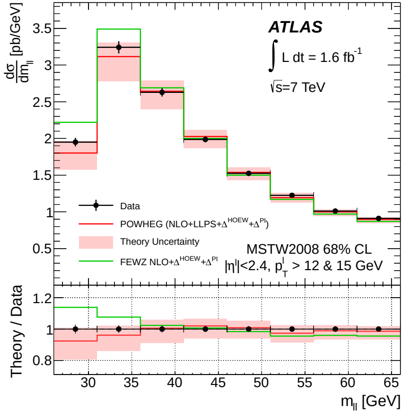
- High precision measurements of W/Z production are crucial to improve our understanding of the Standard Model
- Test of state-of-the-art theoretical predictions in perturbative QCD
- Use data to constrain parton distribution functions (PDFs)
- Important backgrounds in many LHC new physics searches

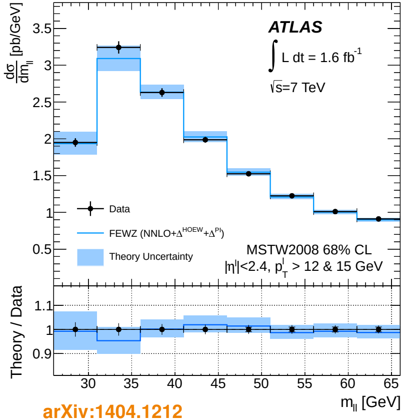


Low mass Drell-Yan production



- Data compared to predictions from FEWZ at (N)NLO and Powheg (NLO matched to LL parton shower) with electroweak corrections and MSTW2008(N)NLO PDF sets
- Good description of data, except for unmatched NLO prediction

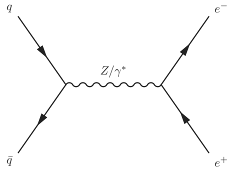


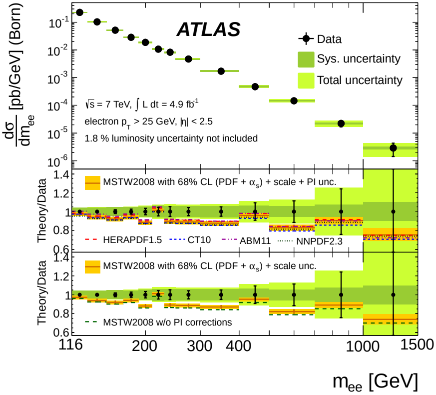


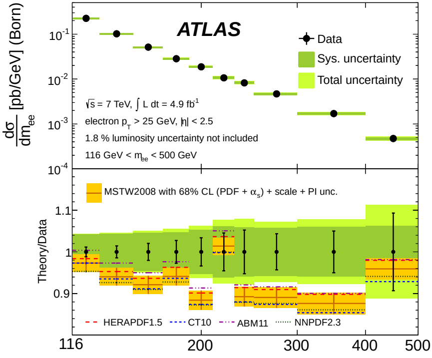
arXiv:1404.1212

High mass Drell-Yan production

- Data compared to NNLO prediction from FEWZ with electroweak corrections and various NNLO PDFs
- Some tension in systematics-limited region ($m_{ee} < 400$ GeV), but theory still compatible ($\chi^2/N_{df} < 1.5$) with data
- Potential to constrain PDF predictions



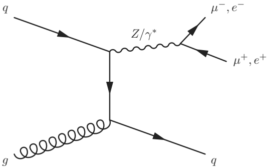




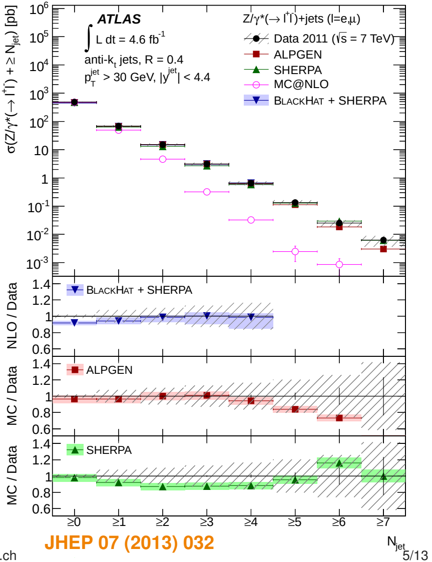
m_ee [GeV]

PLB 725 (2013) pp. 223–242

Z + jets



- Unfolded data compared to predictions from
  - BlackHat+Sherpa (fixed-order NLO)
  - Alpgen+Herwig+Jimmy ($Z+\leq 5$ partons at ME level, AUET2 tune, CTEQ6L PDF)
  - Sherpa (MENloPS, $Z+\leq 5$ partons at ME level, CT10 PDF)
  - MC@NLO+Herwig (AUET2 tune, CT10 PDF)
- ME+PS predictions work well after normalising to inclusive NNLO inclusive cross section
- Good agreement with BlackHat+Sherpa fixed order NLO calculation
- MC@NLO+Herwig fails to predict jet multiplicities
- Dominant experimental uncertainty due to jet energy scale, between 7 % ($\geq$ 1 jet) and 17 % ($\geq$ 4 jets), but up to 30 % for forward jets



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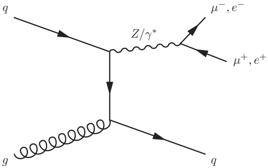
$Z + $ jets



- Unfolded data compared to predictions from
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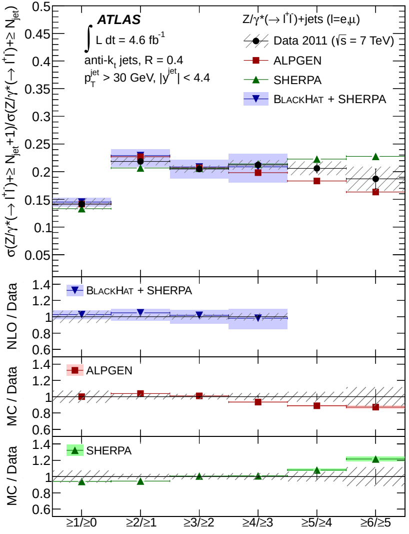
  - Alpgen+Herwig+Jimmy ($Z+ \leq 5$ partons at ME level, AUET2 tune, CTEQ6L PDF)
  - Sherpa (MENloPS, $Z+ \leq 5$ partons at ME level, CT10 PDF)
- Cross section ratio for successive multiplicities reduces jet energy scale uncertainty: 3–4 %
- Precision test of Standard Model predictions



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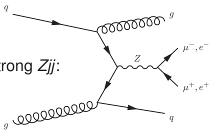
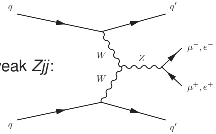
Zjj production

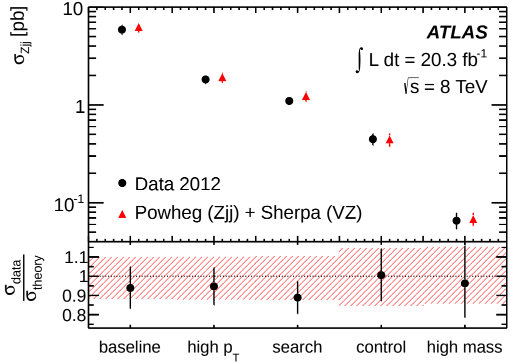
- Measured in five fiducial regions with varying sensitivity to electroweak component:
  - baseline: Z candidate and at least 2 jets with $p_T^{j_{1(2)}} > 55(45)$ GeV
  - high-p_T: baseline selection with $p_T^{j_{1(2)}} > 85(75)$ GeV
  - search: baseline and veto on interval jets with $p_T > 25$ GeV
  - control: baseline and at least one interval jet with $p_T > 25$ GeV
  - high-mass: baseline with $m_{jj} > 1$ TeV
- Unfolded data compared to Powheg (NLO matched to LL Pythia 6, Perugia 2011 tune, including MiNlo feature for strong *Zjj*)
- Excellent agreement with Standard Model predictions

strong *Zjj*:



electroweak *Zjj*:





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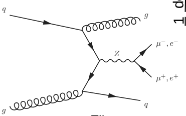
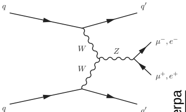
Zjj production

- Sherpa LO for $Z + 2, 3, 4$ jets using CT10 PDF, Powheg NLO for $Z + 2j$, LO for $Z + 3j$ and LL for $Z + 4j$
- Sherpa predicts too large a cross section for variables sensitive to dijet kinematics (e.g. left), does slightly better than Powheg for variables sensitive to *t*-channel colour flow (e.g. right)

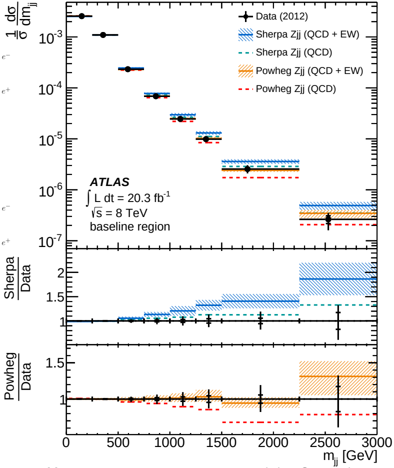


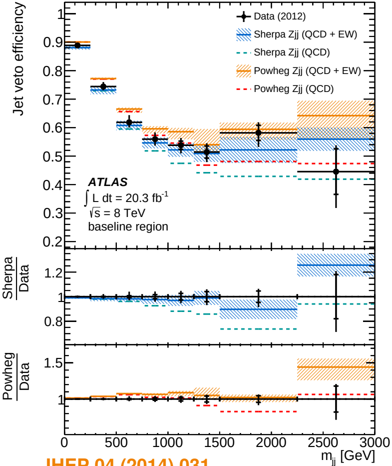
strong *Zjj*



electroweak *Zjj*

See Haolu Feng's talk for details on extraction and observation of EW component!





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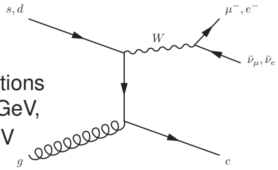
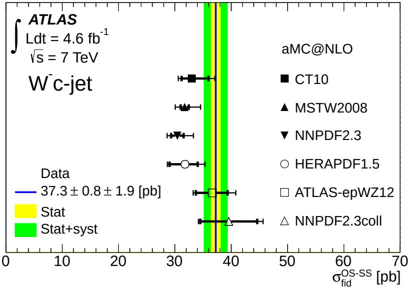
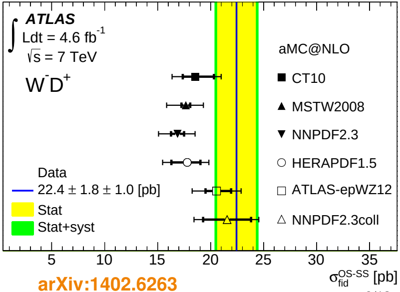
$W + c$ production

- Potential to constrain s-quark PDF at $x \sim 0.01$



- Particle-level cross sections measured for $p_{\mathrm{T}}^{\ell} > 20\,\mathrm{GeV}$, $|\eta^\ell| < 2.5$, $p_{\mathrm{T}}^{\nu} > 25\,\mathrm{GeV}$ and $m_{\mathrm{T}}^{W} > 40\,\mathrm{GeV}$
- Separate analyses for $W + c$-jet and $W + D^{(*)}$-mesons (sensitive to lower c-momenta)
- Opposite/same-sign charge subtraction suppresses $W + c\bar{c}$
- Unfolded data compared to aMC@NLO with various (N)NLO PDF predictions
- Data prefers PDF sets with unsuppressed s-quark density (ATLAS-epWZ12, NNPDF2.3coll)
- Experimental uncertainties: 5–6 % for $W + c$-jet and 4–5 % for $W + D^{(*)}$-meson

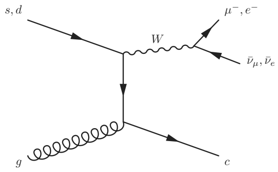


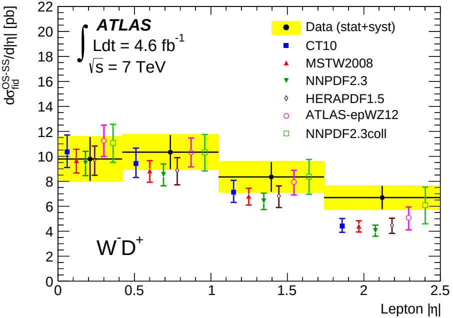


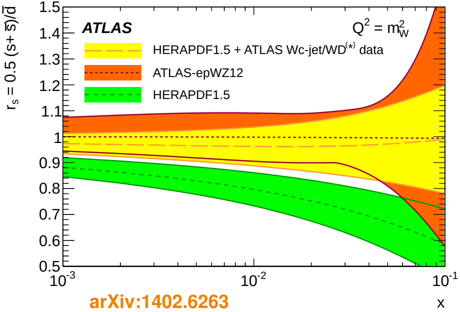
arXiv:1402.6263

$W + c$ production

- Cross section also measured differentially as a function of lepton pseudorapidity (left)
- $W + c$ data used to fit ratio of strange-to-down sea quark distributions (right)
    - favours hypothesis of SU(3)-symmetric light-quark sea







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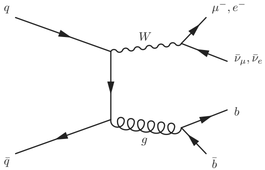
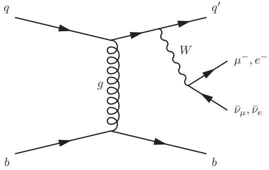
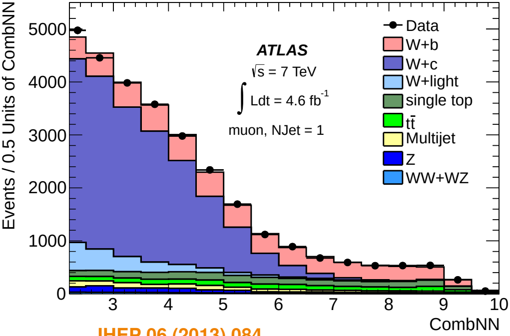
$W + b$-jets





- Important background to $WH(\to b\bar{b})$
- Test of different approximations:
  - 4- vs 5-flavour number scheme
  - massless vs massive b-quarks
- Particle-level selection:
  - W-candidate with $p_T^\ell > 25\,\text{GeV}$, $|\eta^\ell| < 2.5$, $p_T^\nu > 25\,\text{GeV}$ and $m_T^W > 60\,\text{GeV}$
  - one or two central ($|y^j| < 2.1$) jets with $p_T^j > 25\,\text{GeV}$
  - either or both jets matched ($\Delta R \leq 0.3$) to b-hadron with $p_T > 5\,\text{GeV}$ (require exactly 1 b-tagged jet at detector level)
  - jet-lepton separation ($\Delta R > 0.5$)
- Neural network discriminant (CombNN) used to enhance b-jet contribution and to discriminate between flavours within enriched sample
  - $\sim 20\,\%$ signal fraction



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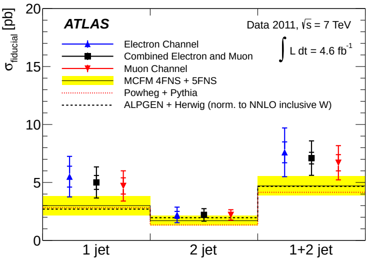
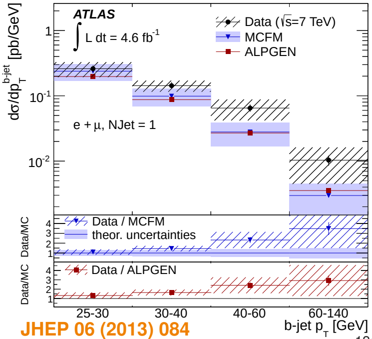
$W + b$-jets

- Unfolded data compared to
  - Alpgen+Herwig+Jimmy (LO 4FNS with CTEQ6L1 PDF, scaled to NNLO inclusive W)
  - MCFM (NLO 4+5FNS with NLO MSTW2008 PDF and correction for both underlying event and double parton interactions)
  - Powheg+Pythia (NLO 4FNS matched to LL PS using AUET2B tune, with NLO MSTW2008 PDF and correction for double parton interactions)
- 1-jet category: measured cross section underestimated at large b-jet p_T, but NLO calculations still consistent to within 1.5σ
- Good agreement in 2-jet category (with smallest uncertainty)
- Also measured without single top subtraction





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Summary

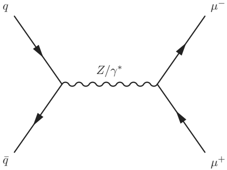
- Measurements of V production test pQCD calculations at energies and in regions of phase space that have never before been probed
- Data fully corrected for detector effects and compared to ME+PS predictions as well as to (N)NLO calculations (corrected for non-perturbative effects) with various PDF sets

low mass DY:	**arXiv:1404.1212**
high mass DY:	**PLB 725 (2013) pp. 223–242**
Z + **jets:**	**JHEP 07 (2013) 032**
Zjj**:**	**JHEP 04 (2014) 031**
$W + c$**:**	**arXiv:1402.6263**
$W + b$**:**	**JHEP 06 (2013) 084**

- Standard Model predictions consistent with measurement, but some discrepancies between data and calculations highlighted in different analyses

Backup

Extended low mass Drell-Yan production



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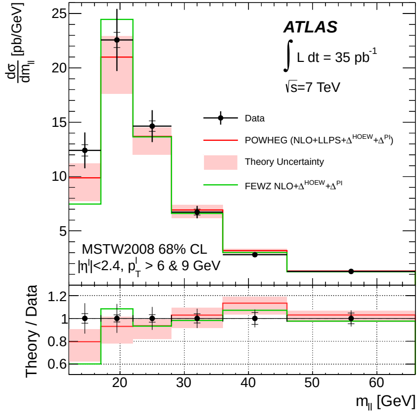
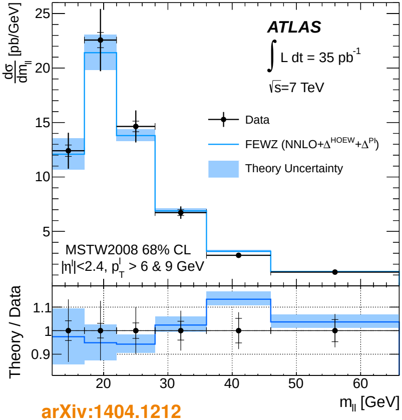
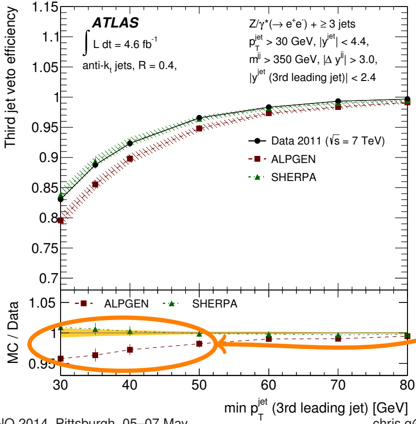


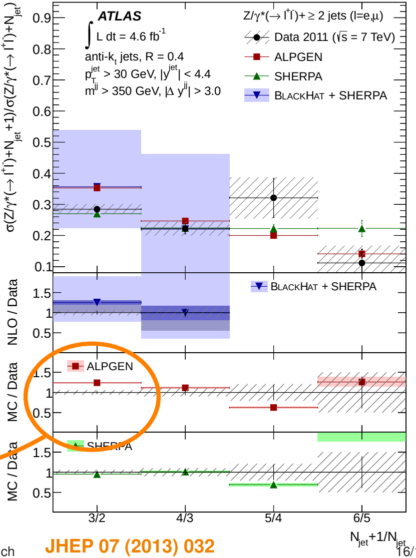


arXiv:1404.1212

$Z+$ jets

- Alpgen overpredicts 3-to-2-jet ratio after basic VBF-like preselection
- Therefore Alpgen underestimates jet veto efficiency:





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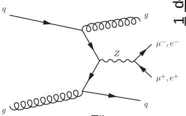
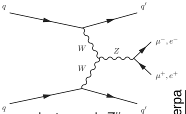


strong *Zjj*



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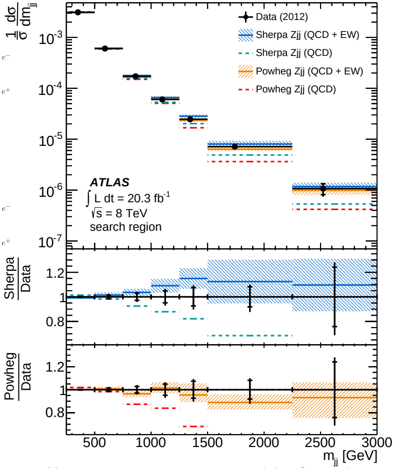

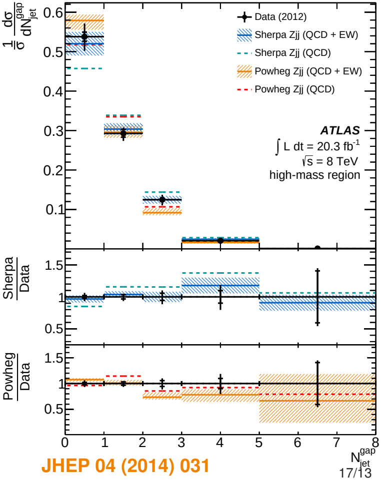

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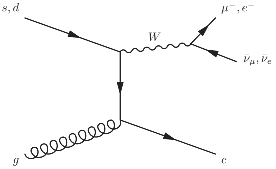
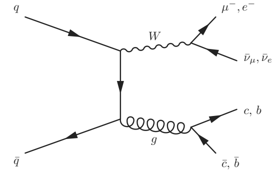
W + *c* production

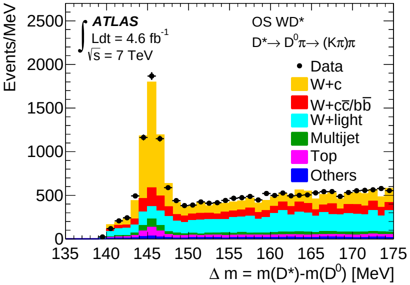
- *W* always accompanied by *c*-quark of opposite sign:

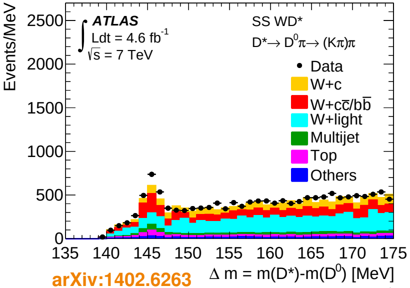


- Most background evenly distributed between opposite-sign (OS) and same-sign (SS) events:



- Measure difference to select signal with very high purity





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