Interview for the Chung-Yao Chao Fellowship

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2021.06.05

ATLAS EXPERIMENT

上海交通大學
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Resume

Education and work experiences

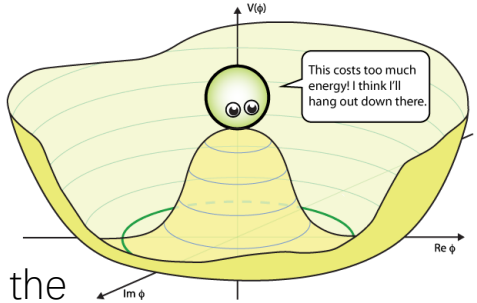
- 2010.09 ~ 2014.06 ***Lanzhou University***
  Bachelor in nuclear science and technology
- 2014.09 ~ 2021.03 ***University of Science and Technology of China***
  PhD in particle and nuclear physics
- 2021.03 ~ now ***Shanghai Jiao Tong University***
  Postdoc. in School of Physics and Astronomy
  working with **Haijun Yang and Shu Li**

Research experiences

- 2015.09 ~ now Member of ATLAS Collaboration
- Observation of vector boson scattering ZZ with the ATLAS detector
  1st observation at LHC
- Study of ATLAS NSW detector hits modelling and simulation
- Determination and characterisations of low p_T di-muon trigger efficiencies

Electroweak Symmetry Breaking

- The nature of EWSB is still a mystery.
- In the SM, the Higgs mechanism tries to explain this.



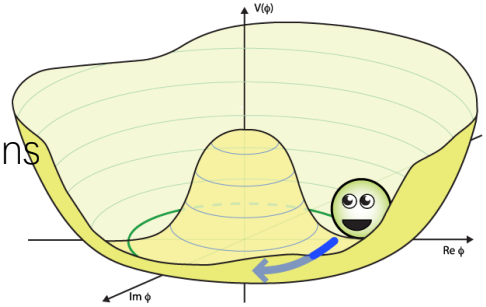
4 massless vector bosons($W^{1,2,3}, B$)

4 degrees of freedom for the Higgs sector

$$4\times 2 + 4$$

2 transverse modes

1 Higgs boson and 3 massless Goldstone bosons



The Higgs mechanism $\Rightarrow$ $W^{1,2,3}, B \Rightarrow W^{+}, W^{-}, Z^{0}, \gamma$

3 massive bosons (W^{+}, W^{-}, Z^{0}) Massless γ The Higgs boson

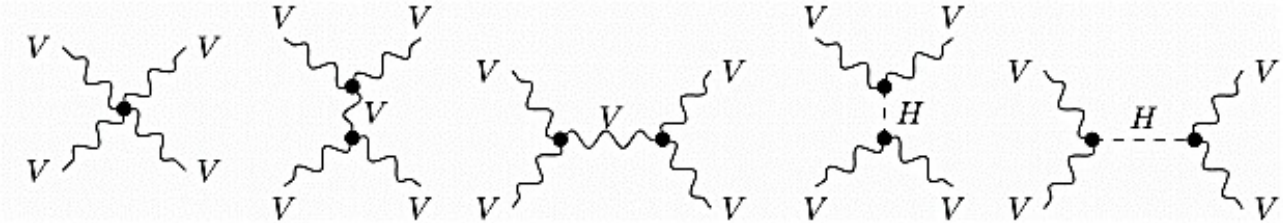
$$3\times 3 + 2 + 1$$

2 transverse modes + 1 longitudinal mode

- Understanding the nature of EWSB could give us more clues for new physics!

Vector Boson Scattering

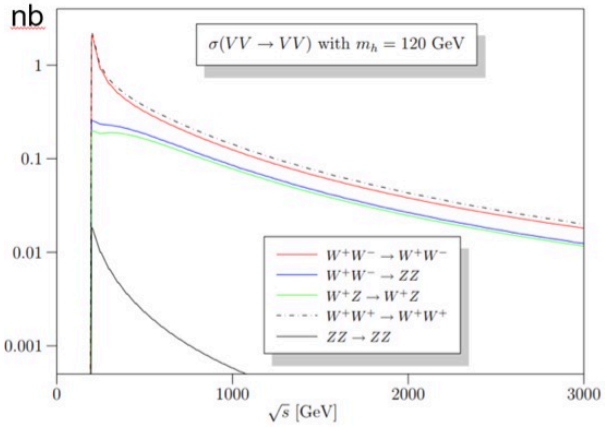
- ***VBS*** measurements offers an important way to probe ***electroweak symmetry breaking***.



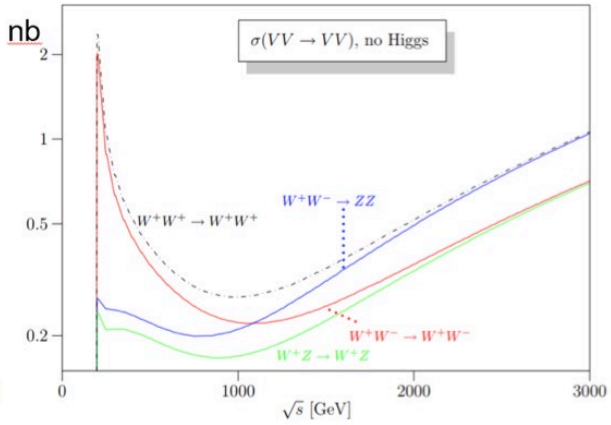
- The presence of the Higgs boson prevents the VBS amplitudes from violating ***unitarity*** at the TeV scale.

- Sensitive to anomalous quartic coupling: ***probe aQGC, test SM, search for new physics.***

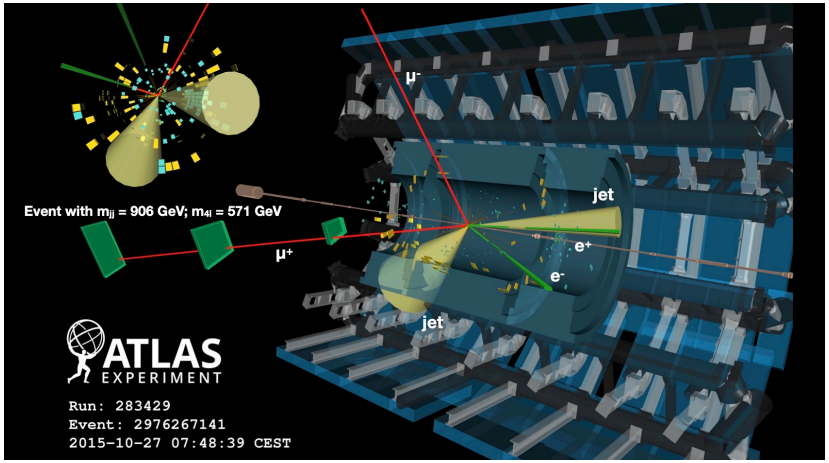
SM VV scattering process with low mass Higgs (120GeV)

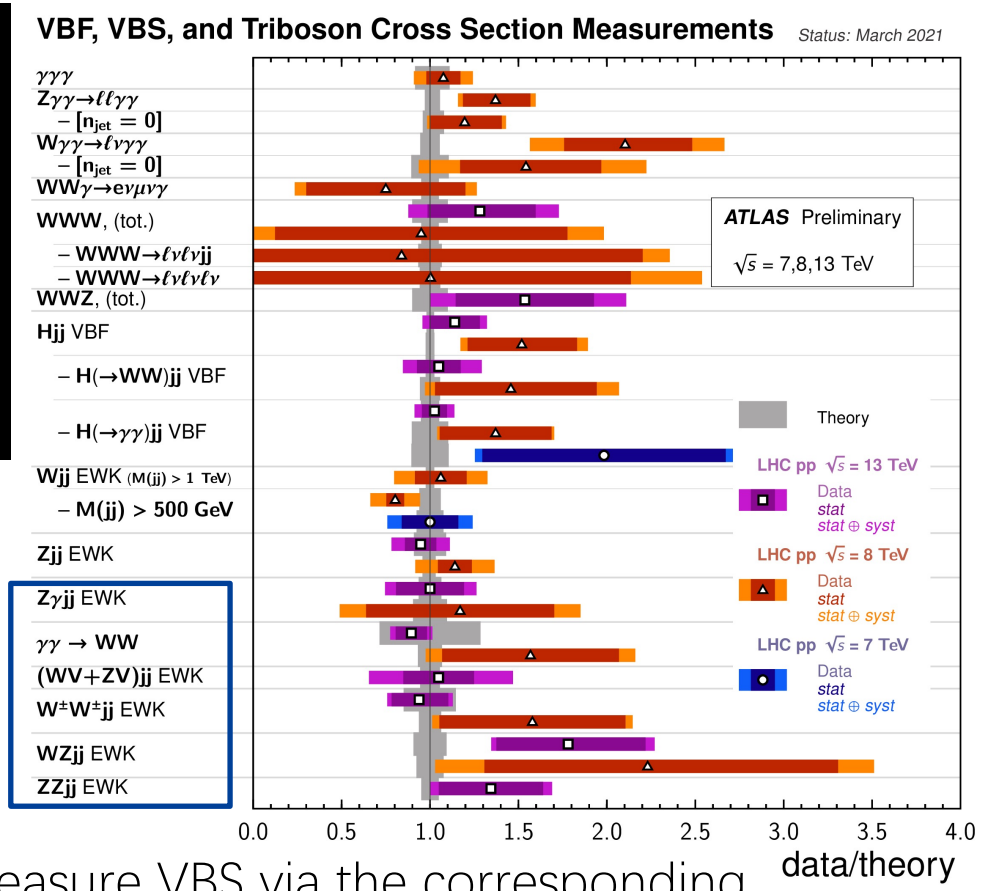


SM VV scattering process w/o a Higgs boson



EW VVjj Production





- VBS topology:
  - Two hard forward jets with large m_{jj} and large $\Delta\eta_{jj}$

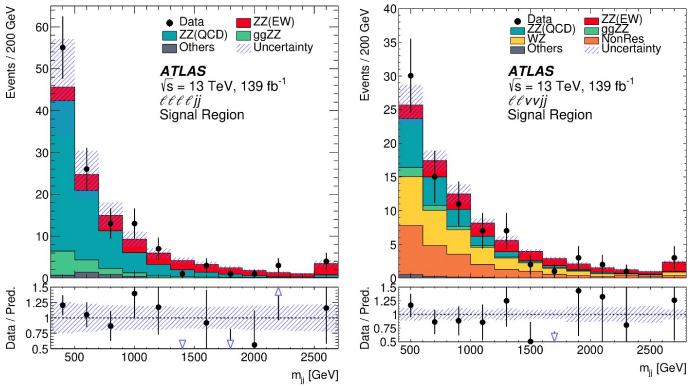
    Sensitive variables

Two channels: $lllljj$ and $llvvjj$

- Measure VBS via the corresponding EW productions.
- EW-ZZjj: smallest cross-section in massive VVjj + not observed before

EW ZZjj Production at 13 TeV

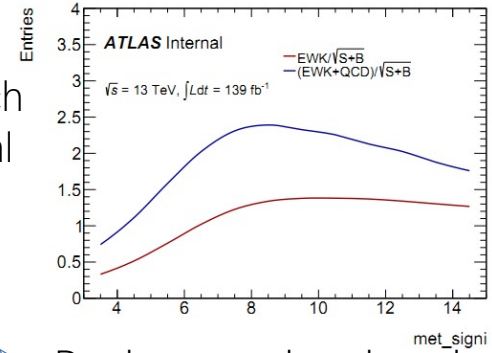
- Interference between EW and QCD
  - Interference/EW is around **6.8% (2.3%)** in the $lllljj$ ($llvvjj$) channel.
  - Treat the interference contribution as an additional systematic uncertainty.
- EW-ZZjj component extraction

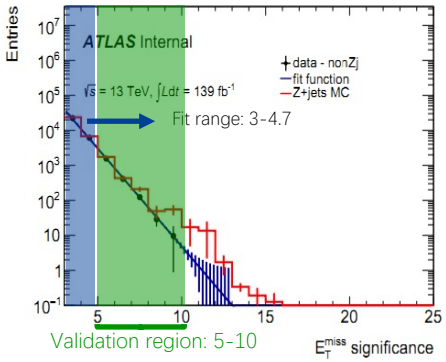


  - To distinguish the EW and other components, a **profile likelihood fit** is performed on **Gradient Boosted Decision Tree.**
  - **Simultaneous fit** SR & QCD CR. Extract QCD normalization factor.

$lllljj$:

- Event selection optimization
  - Scan sensitive variables to search for the best signal region selection.





- Background estimation
  - Data-driven methods are used.

$llvvjj$:

Signal: ZZ(EW)

Irreducible background: $qq \to ZZjj$ and $gg \to ZZjj$

Others background: Background due to misidentified lepton ($t\bar{t}, Z+jets, \ldots$); Triboson (WWZ ...)

Irreducible background: $qq \to ZZjj$ and $gg \to ZZjj$

WZ background

Non-Resonant background: $t\bar{t}$, WW, Wt, Z→ $\tau\tau$, single top

Others background: $Z+jets$ and other ($ZZ \to llll, VVV, ttV, ttVV$)

EW ZZjj Production at 13 TeV

- Fiducial cross-sections for inclusive production of the EW and QCD processes:
  - $\sigma_{meas.}^{lllljj} = 1.27 \pm 0.14\ fb$
  - $\sigma_{meas.}^{llvvjj} = 1.22 \pm 0.35\ fb$
- Significance: 5.5σ

Observation!

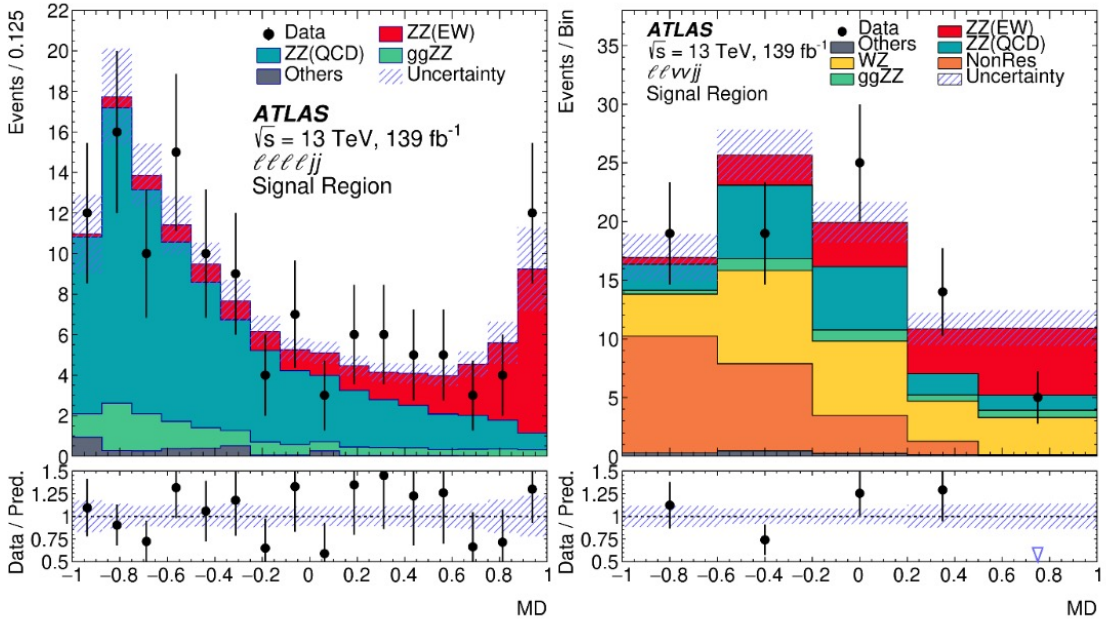
New milestone reached in the study of EW-VVjj production.

Approval Presentation

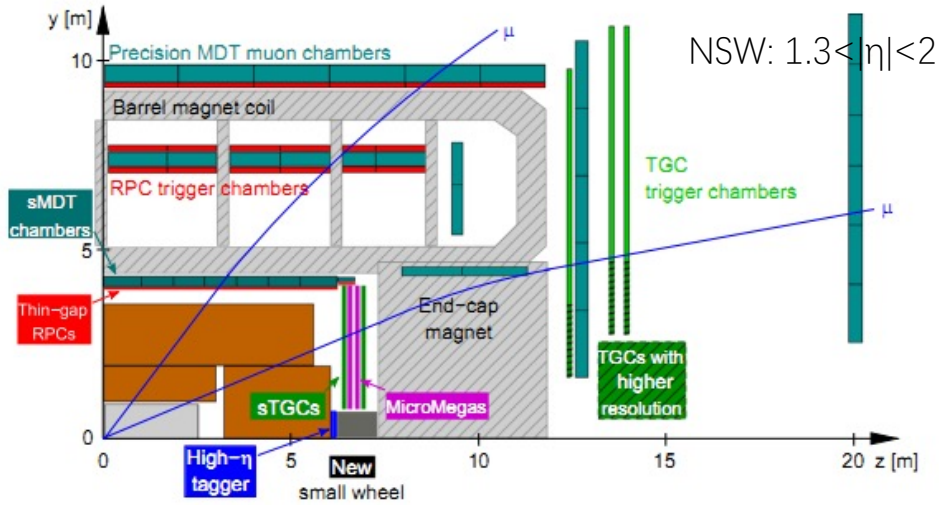
Approved by ATLAS and submitted to *Nature Physics!*

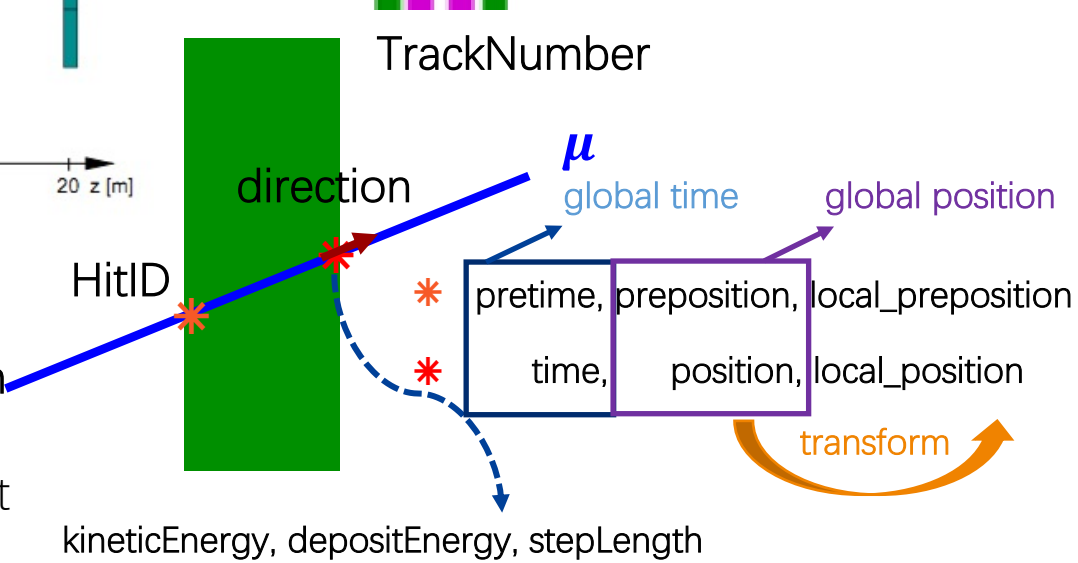
arXiv:2004.10612

- The EW-ZZjj cross-section
  - Combing two channels
  - The measured fiducial cross-section over the SM prediction for EW-ZZjj production: $\mu_{EW} = 1.35 \pm 0.34$
  - $\sigma_{EW}^{FV} = 0.82 \pm 0.21\ fb$



NSW Hit EDM



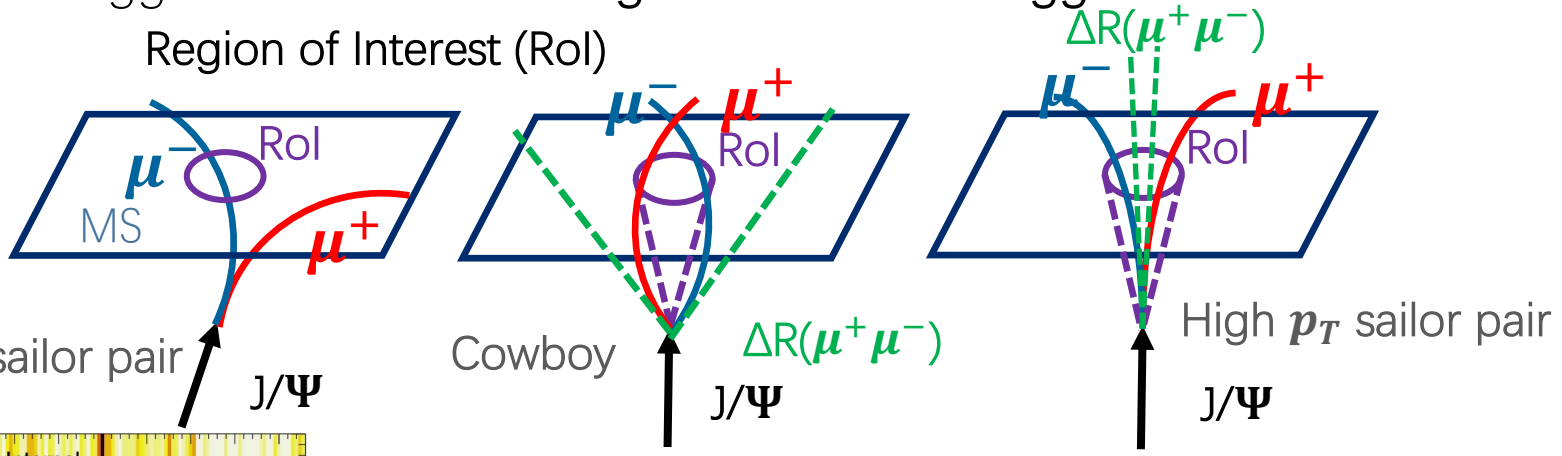


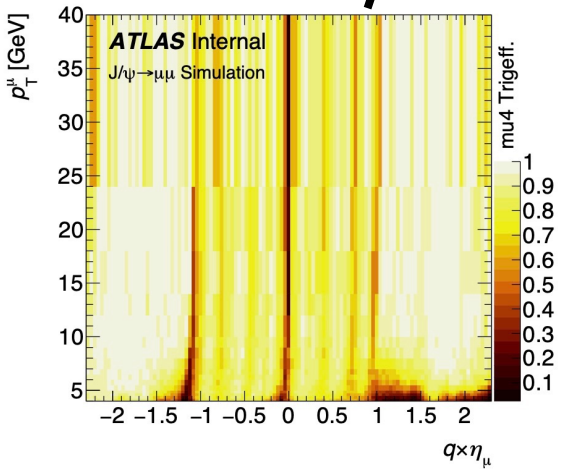
- NSW hit event data model (EDM) contains quite some **redundant information**, which might **overwhelm the simulation** in the case of **high pile-up/lumi.** Improvement of the hit EDM is a necessary step.
- Apply new EDM: Hit Size/Evt decreased ~ 41.1%(MM); 44.1%(sTGC)

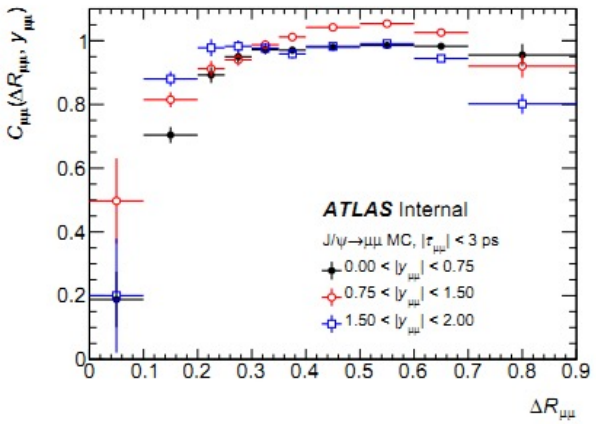
- stepLenght: The distance to an interaction in the current materia
- HitID: link to StationName, PhiSector, Zsector, MultiLayer, Layer, Side

Low p_T Muon Trigger Efficiency

- The key to the B-physics program is muons that can be identified cleanly at early stages of the trigger.
- The B-triggers are based on **single and dimuon triggers**.







Paper public presentation

- Results were applied to charmonium and bottomonium cross section measurements at 5TeV.

Eur. Phys. J. C 78 (2018) 171

Publications

- Observation of electroweak production of two jets and a Z-boson pair with the ATLAS detector at the LHC, https://arxiv.org/abs/2004.10612 (Submitted to *Nature Physics*)
- Measurement of the production cross-section of J/ψ and ψ (2S) mesons at high transverse momentum in pp collisions at $\sqrt{s}$=13 TeV with the ATLAS detector, ATLAS-CONF-2019-047
- Observation of electroweak production of two jets in association with a Z-boson pair in pp collisions at $\sqrt{s}$ =13 TeV with the ATLAS detector, ATLAS-CONF-2019-033
- Measurement of quarkonium production in proton-lead and proton-proton collisions at 5.02 TeV with the ATLAS detector, Eur. Phys. J. C 78 (2018) 171
- Recent heavy-flavour results from ATLAS, EPJ Web of Conferences 171, 01006 (2018)
- Study of J/ψ and ψ (2S) production in $\sqrt{s_{NN}}$=5.02 TeV pPb and $\sqrt{s}$ =2.76 TeV pp collisions with the ATLAS detector, ATLAS-CONF-2015-023

Talks

Nov. 2020 Seminar in Shanghai Jiao Tong University, Shanghai
-- Observation of electroweak production of ZZjj with the ATLAS detector
-- https://indico-tdli.sjtu.edu.cn/event/334/

May.2020 2020 Phenomenology Symposium, virtual meeting
-- Recent observation and measurements of vector-boson fusion and scattering with ATLAS
-- https://indico.cern.ch/event/858682/contributions/3837122/

Oct.2019 The 5th China LHC Physics Workshop, Dalian
-- Observation of vector boson scattering ZZjj process with the ATLAS detector
-- https://indico.ihep.ac.cn/event/9805/session/12/contribution/72

Jun.2019 Approval Presentation, CERN
-- VBS ZZjj Analysis at 13 TeV
-- https://indico.cern.ch/event/828725/contributions/3469048/attachments/1865272/3067661/unblindingClosureMeeting_Jun.192019.pdf

21st Particles and Nuclei International Conference 2017, Beijing
-- Production of b and c hadrons with the ATLAS detector
-- https://indico.ihep.ac.cn/event/6329/session/8/contribution/264

Talks

Jul.2017 17th Strangeness in Quark Matter, Utrecht
-- Recent heavy-flavour results from ATLAS
-- https://indico.cern.ch/event/576735/contributions/2566850/

Feb.2017 Quark Matter 2017, Chicago
-- Measurement of bottomonuim production in p+Pb and pp collisions at 5 TeV with ATLAS detector (Poster)
-- http://qm2017.phy.uic.edu/files/PosterSession_final.pdf

Jan.2017 Paper public presentation in ATLAS weekly meeting, CERN
-- Measurement of quarkonium production in proton-lead and proton-proton collisions at 5.02 TeV with the ATLAS detector
-- https://indico.cern.ch/event/598990/

Dec.2016 The Second China LHC Physics Workshop, Beijing
-- J/ψ and ψ(2S) production in pp and PbPb collisions at 5.02 TeV with ATLAS
-- https://indico.ihep.ac.cn/event/6062/session/2/contribution/137

Aug.2016 High Energy Physics conference of Chinese Physical Society, Hefei
-- ATLAS Quarkonium Production Measurements
-- https://indico.ihep.ac.cn/event/5600/session/124/contribution/436

Working Plans

- ATLAS experiment
  - 1st observation of electroweak production of $W\gamma jj$ process with the ATLAS detector
  - 1st attempt to search for triHiggs process
  - Probe the EW phase transition via VBS heavy majorana neutrino search
- Calorimeter R&D for future experiment

Thanks !

Longitudinal Vector Boson Scattering

- The discovery of a Higgs boson does not totally validate the Higgs mechanism, a few other theories also predict the existence of a Higgs boson.

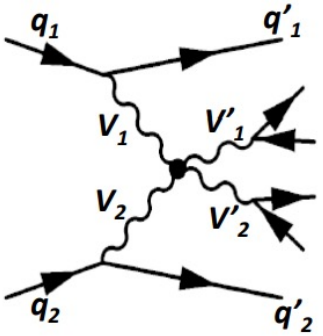
- The higgs mechanism:

the Goldstone bosons after the EWSB are "eaten" by masselsss W/Z bosons and become their longitudinal modes

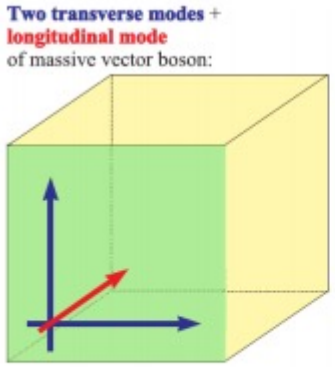
3 massive bosons (W^+, W^-, Z) Massless γ the Higgs boson

$$3 \times 3 + 2 + 1$$

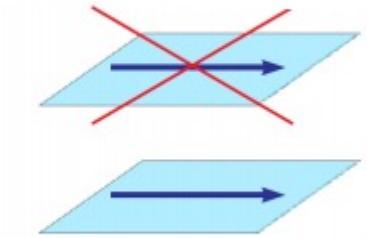
2 transverse modes +
1 longitudinal mode



$V_1V_2 \rightarrow V_1V_2$ (V_1, V_2 = W, Z) scattering



Massive vector boson



Higgs boson

- Need to observe VV→VV first and then study $V_L V_L \rightarrow V_L V_L$

EW ZZjj production at 13 TeV

- Cross-sections:

$VVjj$	final states	$\sigma(VVjj\text{-EW})$ / fb	$\sigma(VVjj\text{-QCD})$ / fb
$W^{\pm}W^{\pm}$	$\ell\nu\ell\nu jj$	4.28 ± 0.01	1.69 ± 0.02
$W^{+}W^{-}$	$\ell\nu\ell\nu jj$	15.57 ± 0.08	35.24 ± 0.13
ZZ	$\ell\ell\nu\nu jj$	0.39 ± 0.01	0.55 ± 0.01
ZV	$\ell\ell jjjj$	0.98 ± 0.07	3.13 ± 0.22
$Z\gamma$	$\ell\ell\gamma jj$	9.24 ± 0.02	71.28 ± 0.33
WZ	$\ell\nu\ell\ell jj$	2.36 ± 0.01	7.19 ± 0.01
ZZ	$\ell\ell\ell\ell jj$	0.12 ± 0.01	0.21 ± 0.01

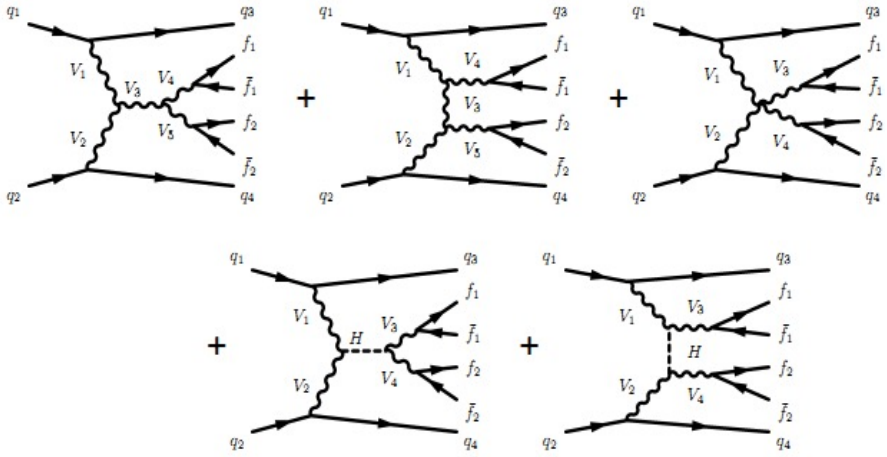
- Production cross-section for EW and QCD VVjj production:
  - All results are obtained from SHERPA
  - Pre-VBS cuts applied

- EW-ZZjj: smallest cross-section in massive VVjj + not observed before

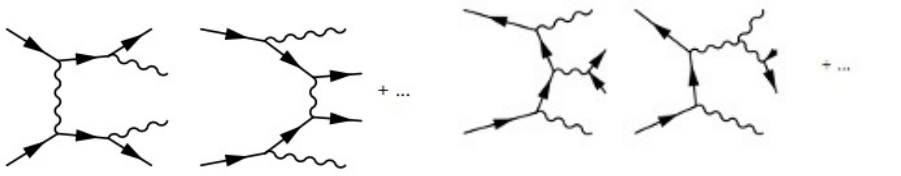
VVjj production at the LHC

EW-VVjj

VBS process:

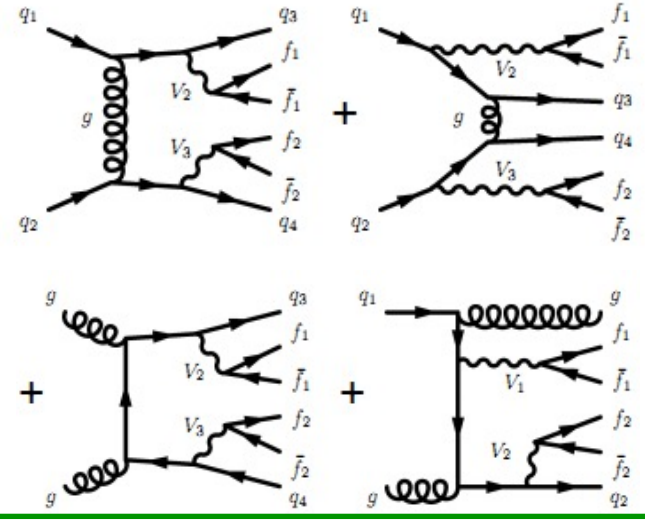


Non-VBS process:



VVV with one hadronically decaying gauge boson

QCD-VVjj

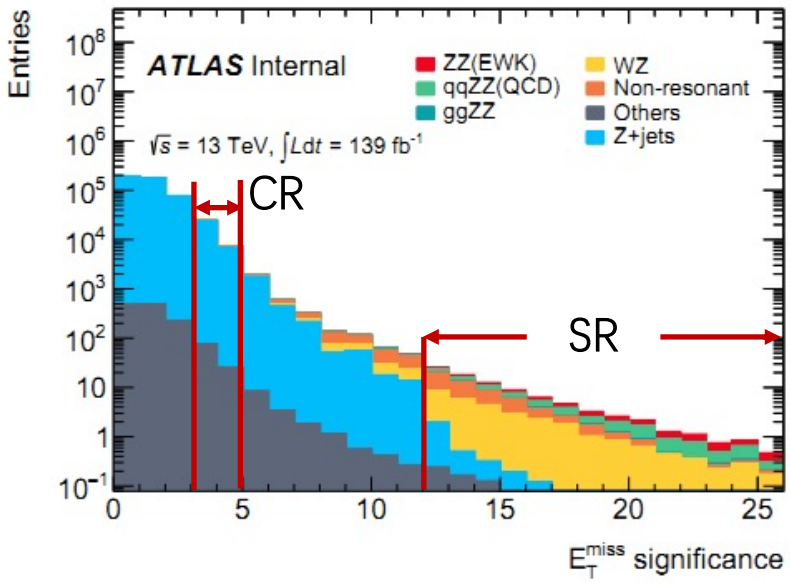


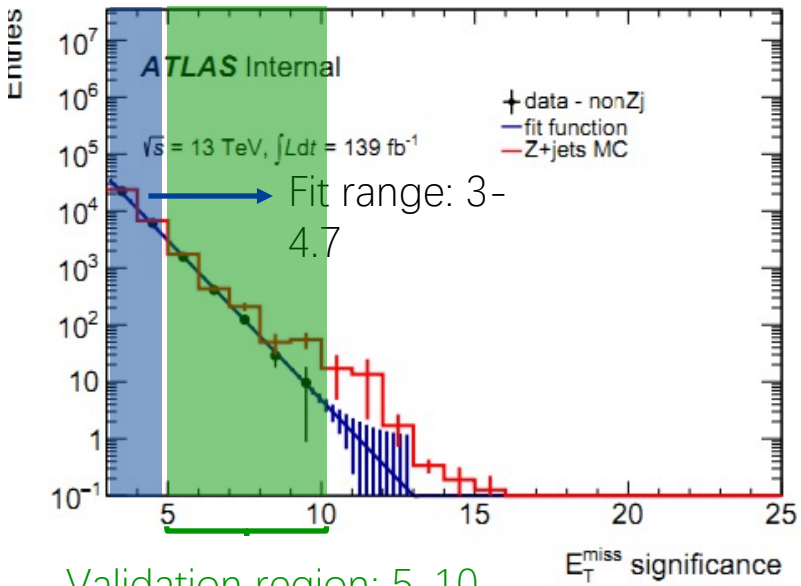
- VVjj category:
  - EW-VVjj (including VBS)
  - QCD-VVjj

VBS and non-VBS processes cannot separate due to gauge invariance requirement.

$llvvjj$ Background: Others

- Z+jets background: highly suppressed by E_T^{miss} significance.
  - Use SR MC to estimate Z+jets shape.
  - Choose low E_T^{miss} significance region as CR.
  - Z+jets yield in SR: $0.28^{+1.50}_{-0.28}$
  - Fit CR data – nonZjMC. Extrapolate fit result to SR to derive SR Z+jets event yield.
  - Systematics: variations in the fit function (100%), fit parameter (21.4%) and fit range (42.9%); differences between MC prediction and data-driven estimation (a factor of 5).





- ZZ → $\mathbf{llll}$,VVV, ttV, ttVV backgrounds: MC

Event Yields & Uncertainties

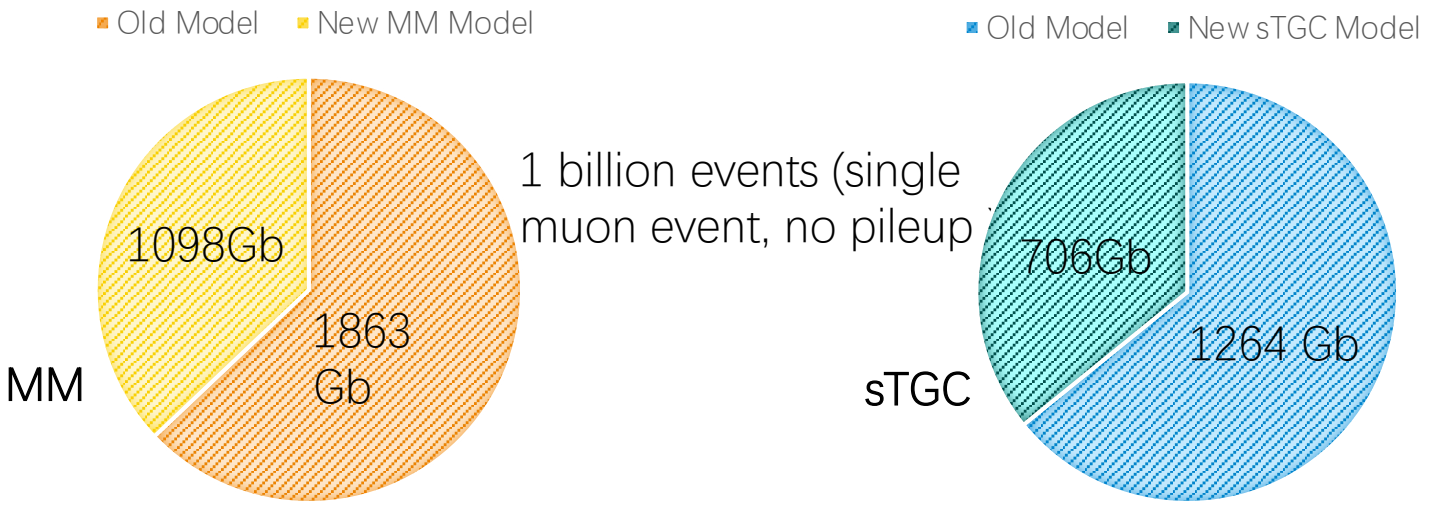
- Event yields:
  - Uncertainties: stat.+syst.
  - Minor backgrounds are summed together as 'Others'.
- Theoretical uncertainties:
  - PDF, QCD scale, α_s, parton showering (PS).
  - Interference effect between the EW and QCD processes is 6.8%(2.3%) in $lllljj$($llvvjj$) channel. Treat as an extra uncertainty in the EW signal predictions.

Process	$lllljj$	$llvvjj$
EW $ZZjj$	20.6 ± 2.5	12.3 ± 0.7
QCD $ZZjj$	77.4 ± 25.0	17.2 ± 3.5
QCD $ggZZjj$	13.1 ± 4.4	3.5 ± 1.1
Non-resonant	-	21.4 ± 4.8
WZ	-	22.8 ± 1.1
Others	3.2 ± 2.1	1.2 ± 0.9
Total	114.3 ± 25.6	78.4 ± 6.2
Data	127	82

- Generator modelling uncertainty: estimated by comparing Sherpa with MadGraph5_aMC@NLO 2.6.1 predictions at particle level.

- Experimental uncertainties:
  - luminosity: 1.7%.
  - The momentum scale and resolution of leptons and jets, lepton reconstruction and selection efficiencies, trigger selection efficiency, the calculation of the E_T^{miss} soft-term, the pile-up correction, and the b-jet identification efficiency: 5-10%.
  - Jet pile-up uncertainty.

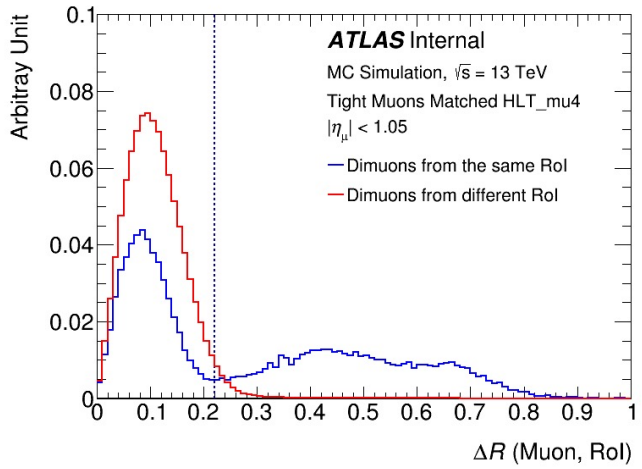
Hit Size



- New hit model has been built:
  Hit Size/Evt decreased ~ **41.1%(44.1%)** in MM(sTGC).

- Regular sTGC/MM digitization package has been modified: new digits can be produced from new hit.

Trigger efficiency



- Signal muon trigger efficiency
  - High $\boldsymbol{p_T}$ sailor pair and cowboy will increase the single muon trigger efficiency.
  - The high $\boldsymbol{p_T}$ sailor can be corrected by ΔR cuts.
  - Cowboy can be corrected by $\Delta R(Muon, RoI)$

$\epsilon_{trigger}(p_T, q, \eta_\mu)$ close ⇦ L1 cut to the genuine one.

- Dimuon trigger efficiency

$$\epsilon_{dimuon} = \epsilon_{trigger}(P_T^1, q, \eta_\mu^1) \cdot \epsilon_{trigger}(P_T^2, q, \eta_\mu^2) \cdot C(\Delta R_{\mu\mu}, y^{\mu\mu}, \tau)$$

$\epsilon_{trigger}$: Single muon trigger efficiency.

$C(\Delta R_{\mu\mu}, y^{\mu\mu}, \tau)$: Correct dimuon trigger inefficiency when two muons are in the same RoI.

$$N(reco\ \&match\ dimuon\ trigger) = N(reco) \times \epsilon(mu4; \mu^+) \cdot \epsilon(mu4; \mu^-) \cdot C(\Delta R_{\mu\mu}, y^{\mu\mu}, \tau)$$

$$C(\Delta R_{\mu\mu}, y^{\mu\mu}, \tau) = \frac{N(reco\&matched\ with\ dimuon\ trigger)}{N(reco\&\ \mu^+\ or\ \mu^-\ matched\ mu4) \cdot \omega}$$

Publications & Talks

Publications

- Observation of electroweak production of two jets and a Z-boson pair with the ATLAS detector at the LHC, https://arxiv.org/abs/2004.10612 (Submitted to *Nature Physics*)
- Measurement of quarkonium production in proton-lead and proton-proton collisions at 5.02 TeV with the ATLAS detector, Eur. Phys. J. C 78 (2018) 171
- Recent heavy-flavour results from ATLAS, EPJ Web of Conferences 171, 01006 (2018)

Talks

- Recent observation and measurements of vector-boson fusion and scattering with ATLAS — 2020 Phenomenology Symposium
- Observation of vector boson scattering ZZjj process with the ATLAS detector — The 5th China LHC Physics Workshop
- Production of b and c hadrons with the ATLAS detector — 21st Particles and Nuclei International Conference 2017
- Recent heavy-flavour results from ATLAS — 17th Strangeness in Quark Matter
- J/ψ and ψ(2S) production in pp and PbPb collisions at 5.02 TeV with ATLAS — The Second China LHC Physics Workshop