# Annual report first year of PhD course

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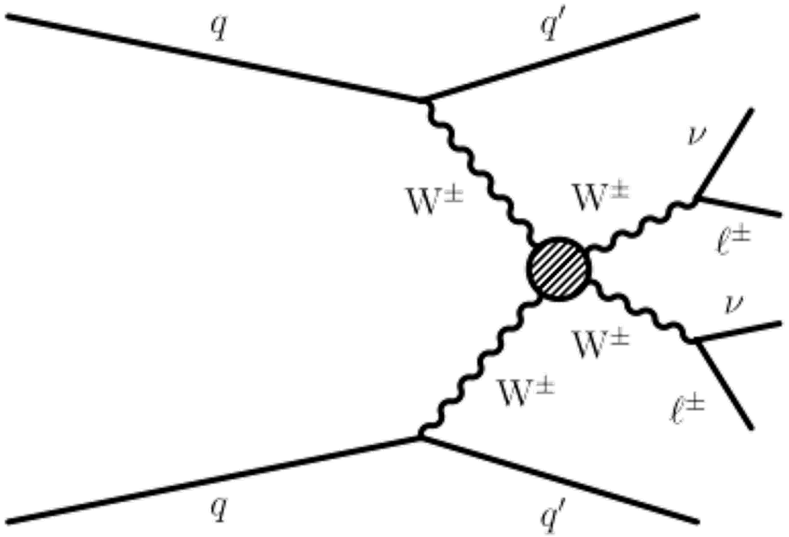
# Overview

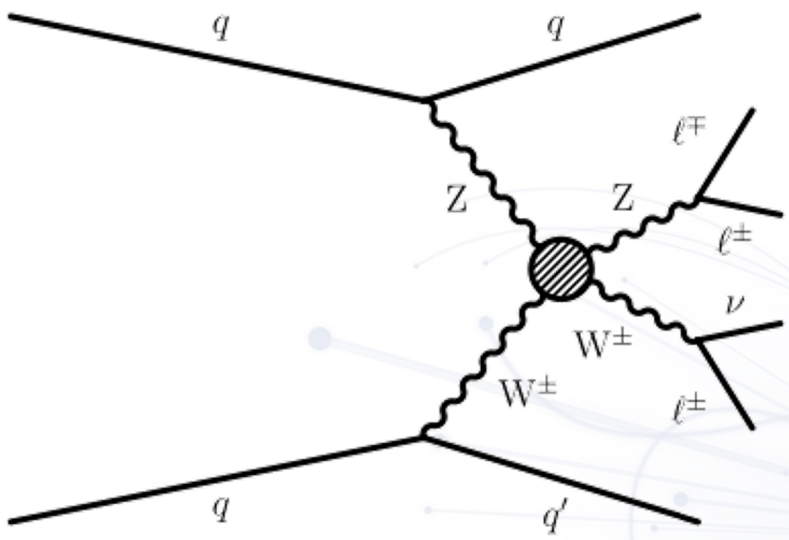
- Vector Boson Scattering with hadronic decay of τ lepton in the final state
  - Overview about VBS
  - Status of the analysis
- CMS outer tracker for High Luminosity
  - Assembly of modules in Perugia
  - Collaboration with MUonE experiment

# VBS with hadronic decay of $\tau$ lepton

# What is vector boson scattering?

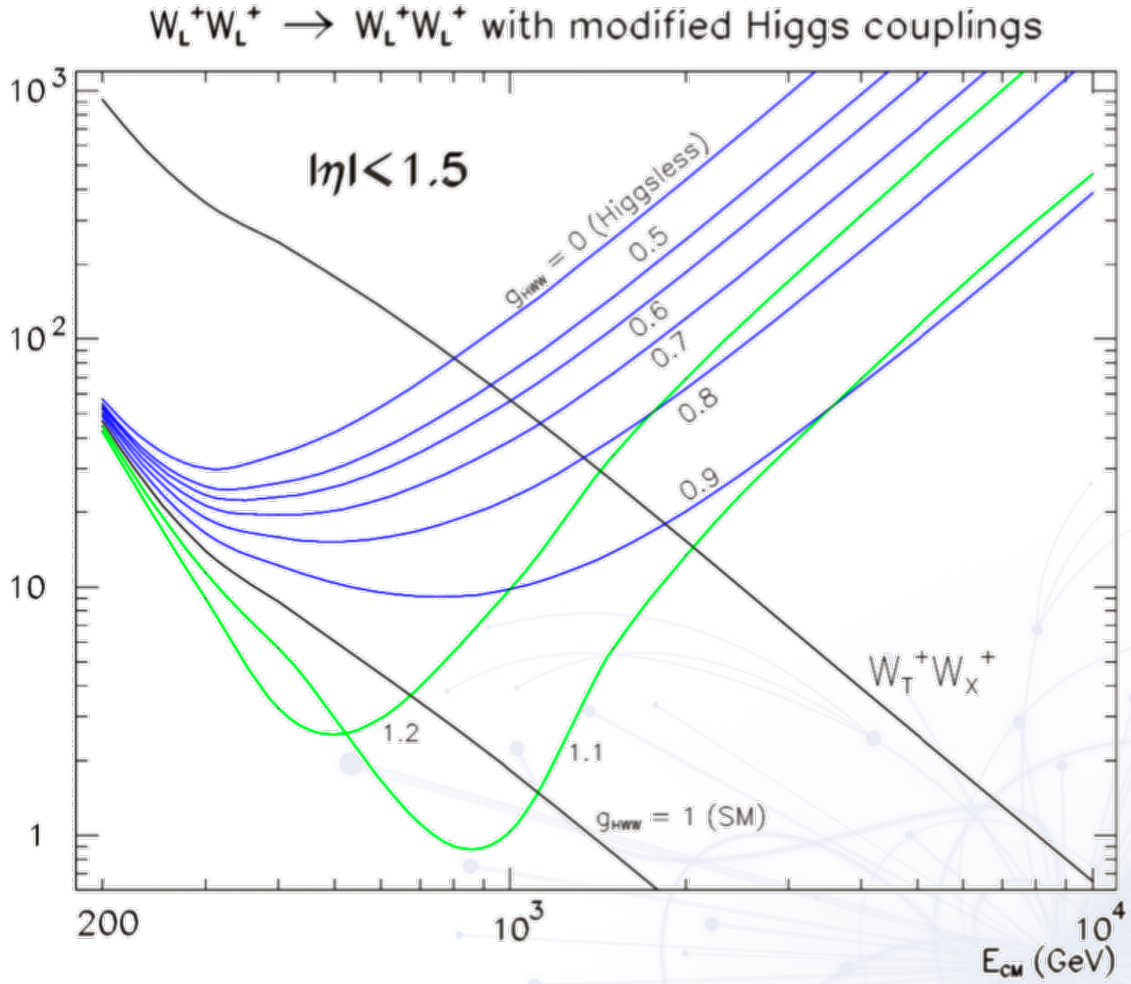
- Vector Boson Scattering (VBS): VV → VV process (V=W, Z)
- @ LHC → **final state with two jets + V decays**
  - qq → 2 V radiation → V decay
- Part of diboson + 2 jets production



# Why is VBS interesting?

- Higgs discovery → vector bosons acquire mass through Brout – Englert – Higgs mechanism, but modifications in the Higgs sector have effect on the vector bosons masses
- Changes in the Higgs sector → scattering of longitudinally polarized vector bosons **diverges with energy for couplings different than SM** → VBS is a powerful probe for anomalies in the EWSB process
- My research project → scattering between two same sign Ws (**ssWW VBS**)

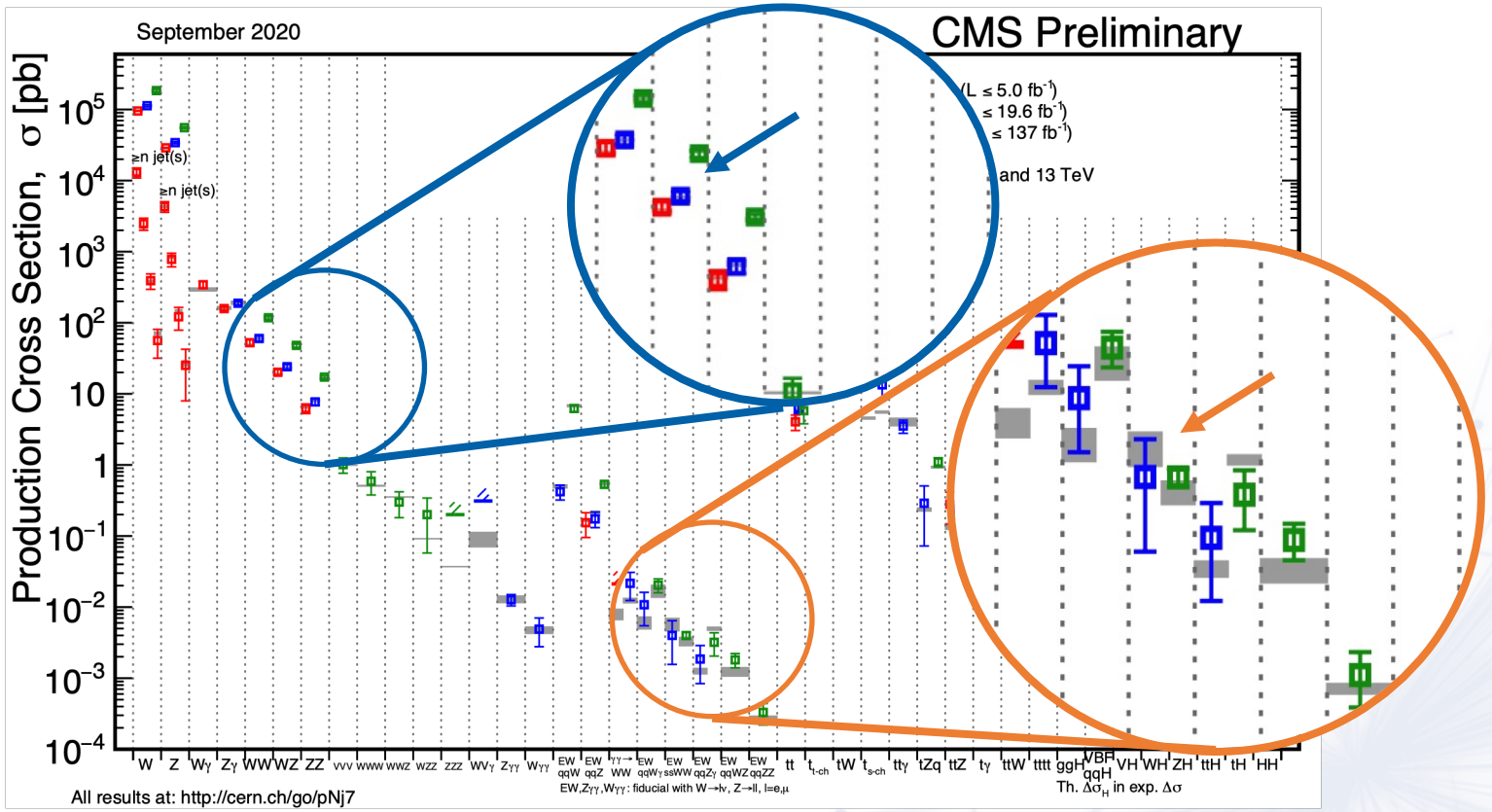


# Why ssWW?

- Highest $\frac{\sigma_{EWK}}{\sigma_{QCD}} \sim 1$ (e.g. opposite sign production → $\frac{\sigma_{QCD}}{\sigma_{EWK}} \sim 50$)
- Final state with leptonic decay of the W «easy» to find

$$qq \to qqW^{\pm}W^{\pm} \to \ell^{\pm}\ell^{\pm}\nu_{\ell}\nu_{\ell}jj \quad (\ell = e, \mu)$$

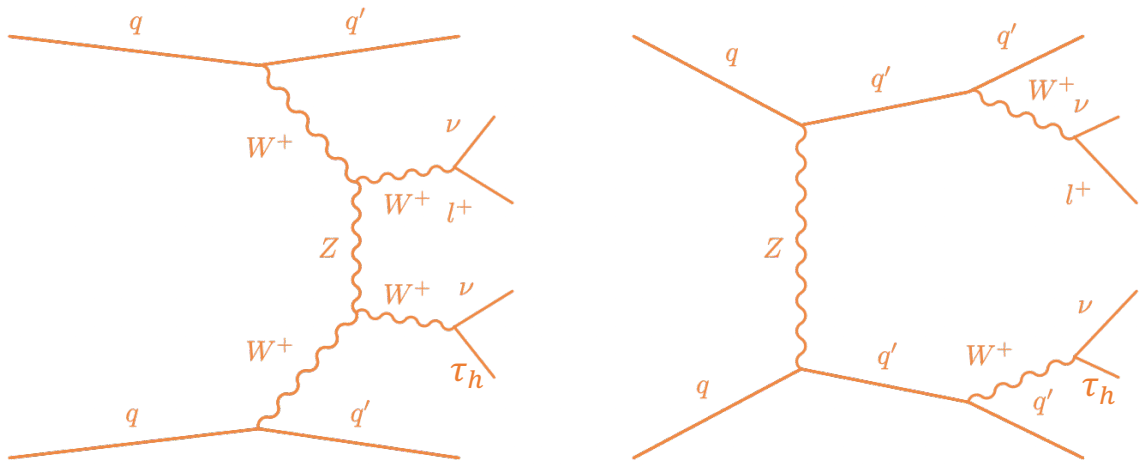
- Compromise between **cross section and final state purity**

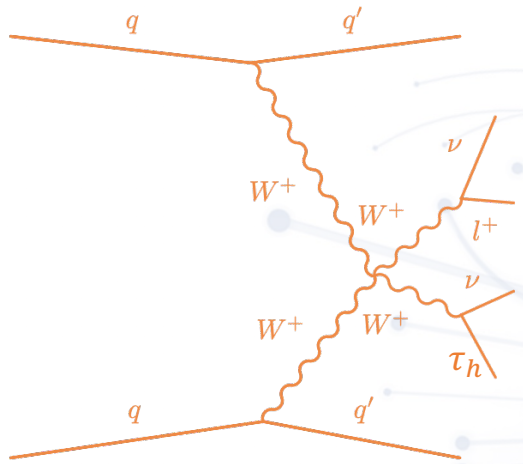


# VBS: two same sign Ws with $\tau_h$

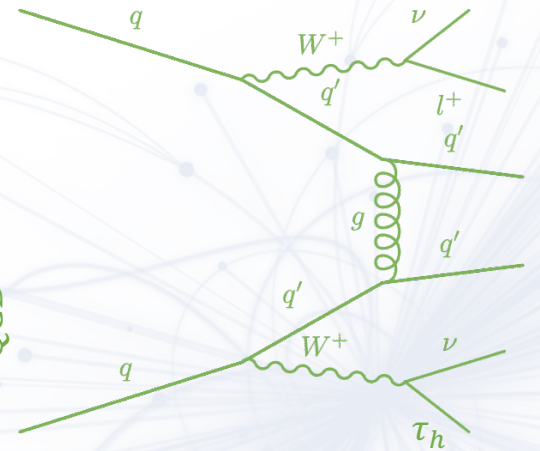
- 4 LO diagrams for VBS ssWW processes:
  - EWK ssWW: **signal**
  - QCD ssWW: **background**
- Final state considered in the analysis: $\ell^{\pm}\tau_h^{\pm}jj\nu_\ell\nu_\tau(\ell = e, \mu)$
  - $\tau$ high mass → possible enhancement of BSM effect wrt light leptons
- **First study for CMS collaboration with this final state** in this channel

$\sigma_{EWK} \simeq 26.15$ fb

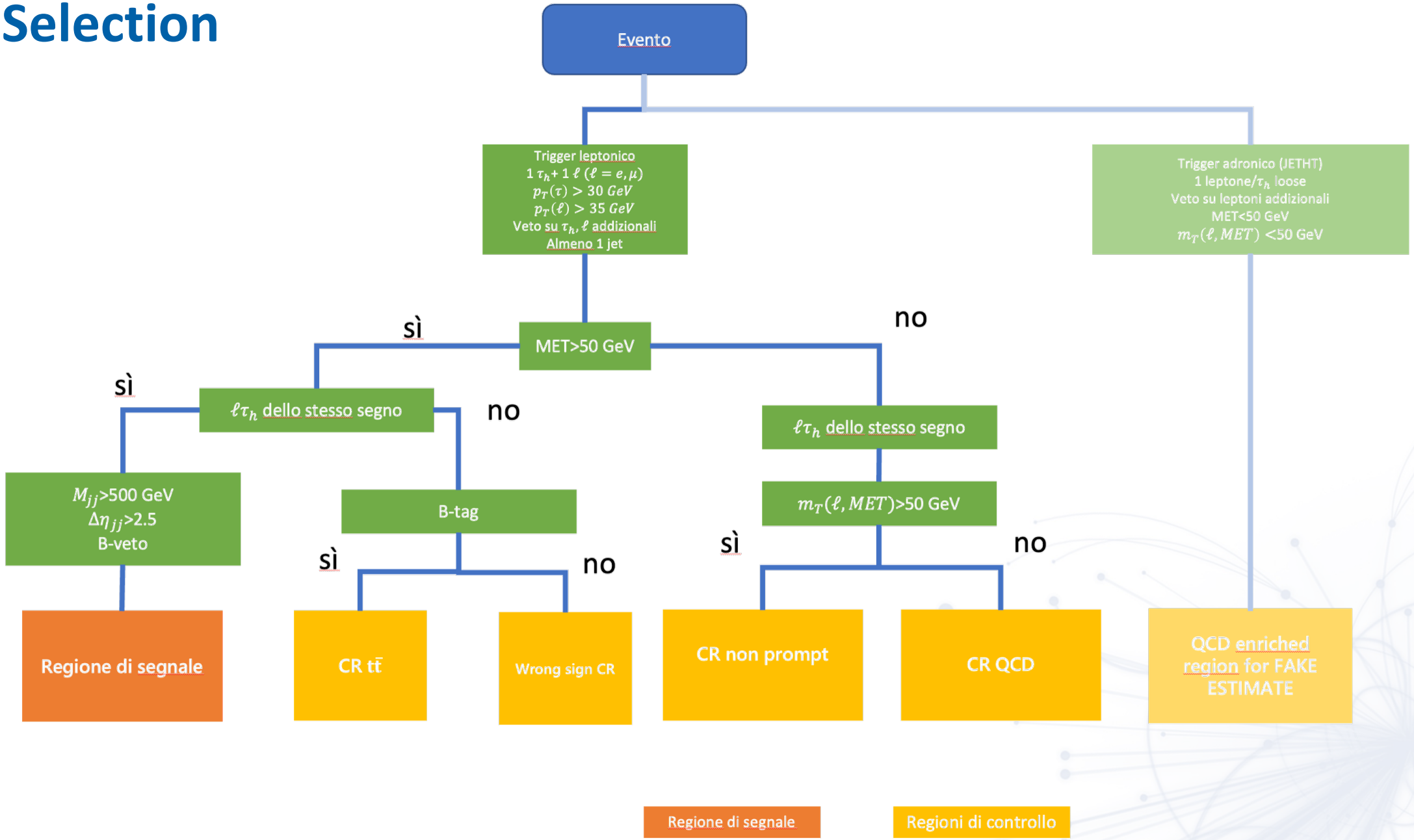



$\sigma_{QCD} \simeq 26.96$ fb

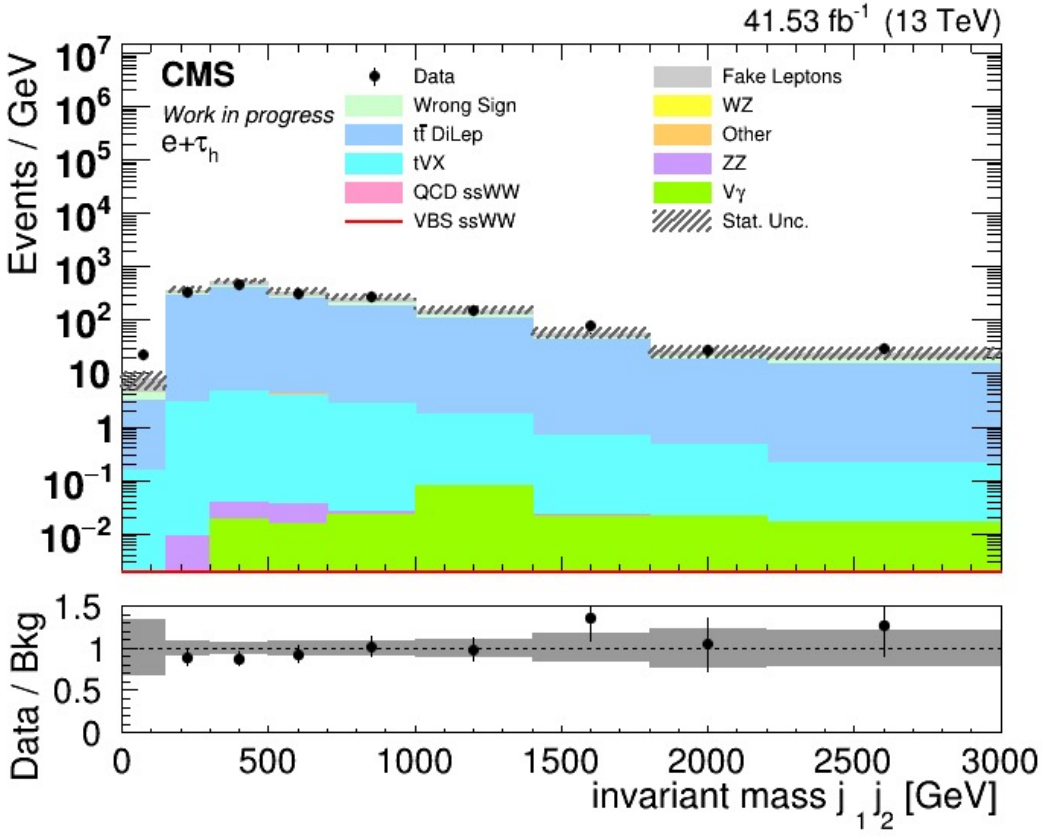


# Selection

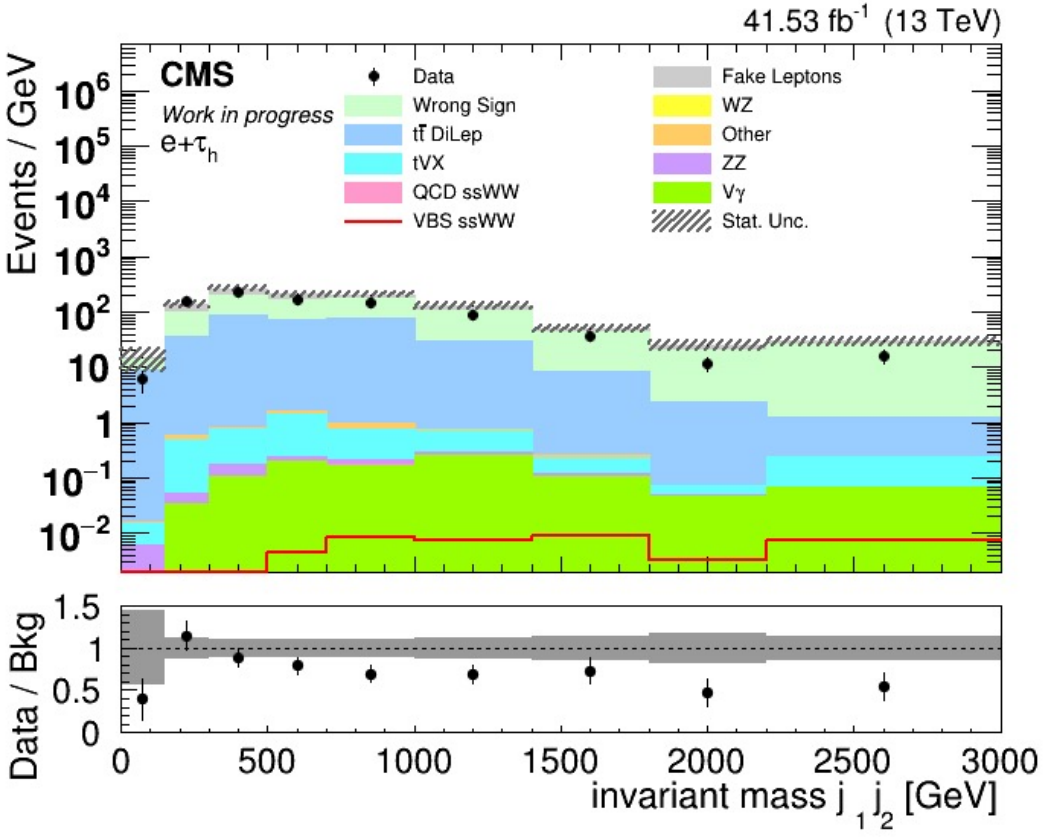

Evento
Trigger leptonico
$1\,\tau_h + 1\,\ell\ (\ell = e, \mu)$
$p_T(\tau) > 30\ GeV$
$p_T(\ell) > 35\ GeV$
Veto su $\tau_h$, $\ell$ addizionali
Almeno 1 jet
Trigger adronico (JETHT)
1 leptone/$\tau_h$ loose
Veto su leptoni addizionali
MET<50 GeV
$m_T(\ell, MET)$ <50 GeV
sì
MET>50 GeV
no
sì
$\ell\tau_h$ dello stesso segno
no
$\ell\tau_h$ dello stesso segno
$M_{jj}$>500 GeV
$\Delta\eta_{jj}$>2.5
B-veto
B-tag
$m_T(\ell, MET)$>50 GeV
sì
no
sì
no
Regione di segnale
CR $t\bar{t}$
Wrong sign CR
CR non prompt
CR QCD
QCD enriched region for FAKE ESTIMATE
Regione di segnale
Regioni di controllo

# Control regions

## $t\bar{t}$ CR

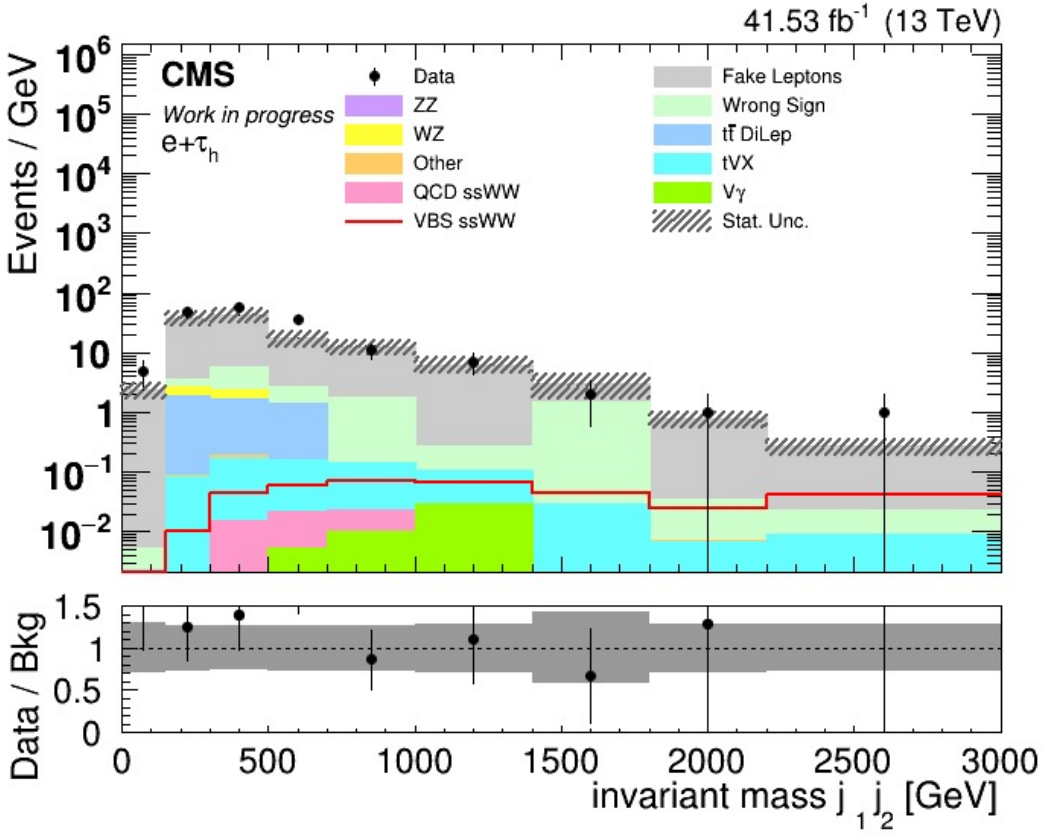



## Wrong sign CR

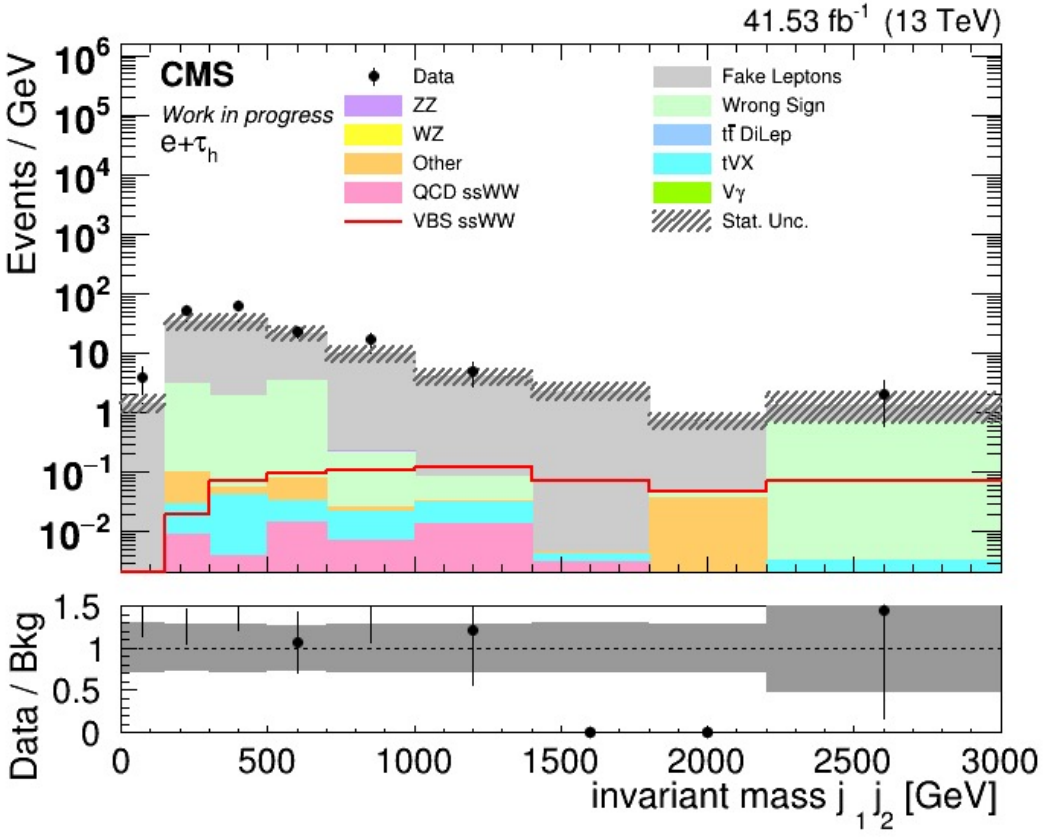


# Control regions

## QCD CR

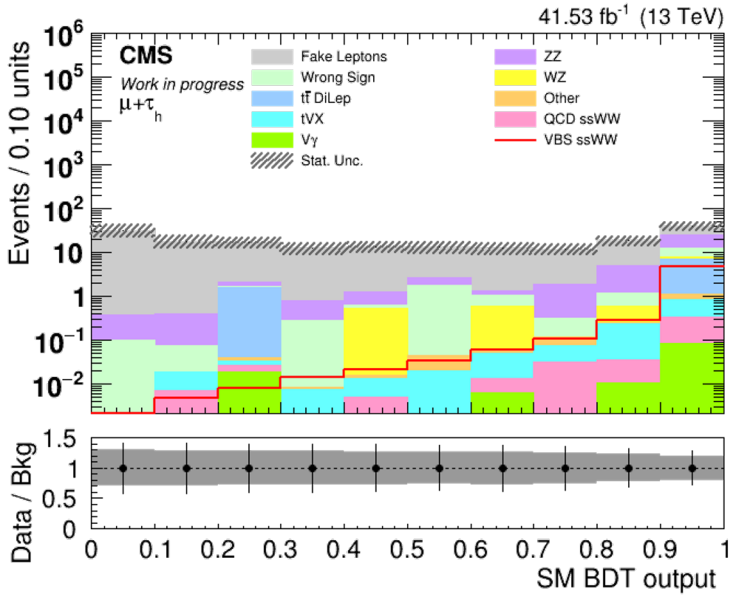


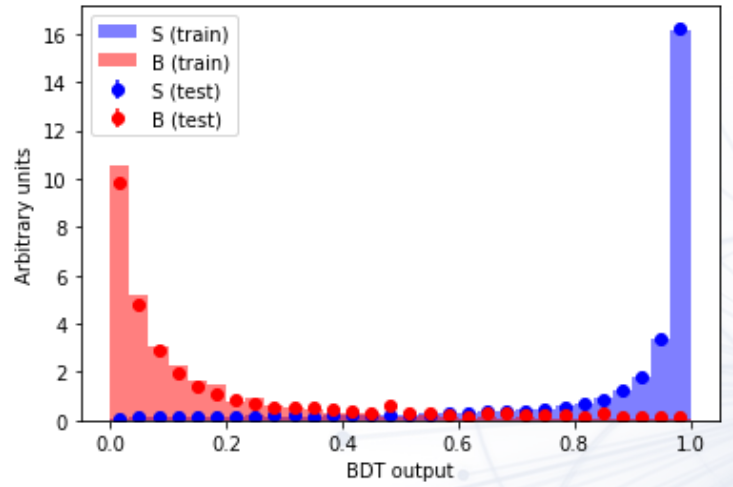

## W+jets CR



# Preliminary studies on the SM process sensitivity for 2017 CMS data

- Luminosity considered: RunII - 2017 CMS data → 41.5 $fb^{-1}$
- BDT trained for discriminating signal (VBS SSWW SM) vs major backgrounds (W+jets + $t\bar{t}$) → good signal-background discrimination
- **Significance study on the blinded signal region** → fit with Combine tool over the signal + control regions
- Variable fitted: BDT output → obtained **significance ~ 0.548**



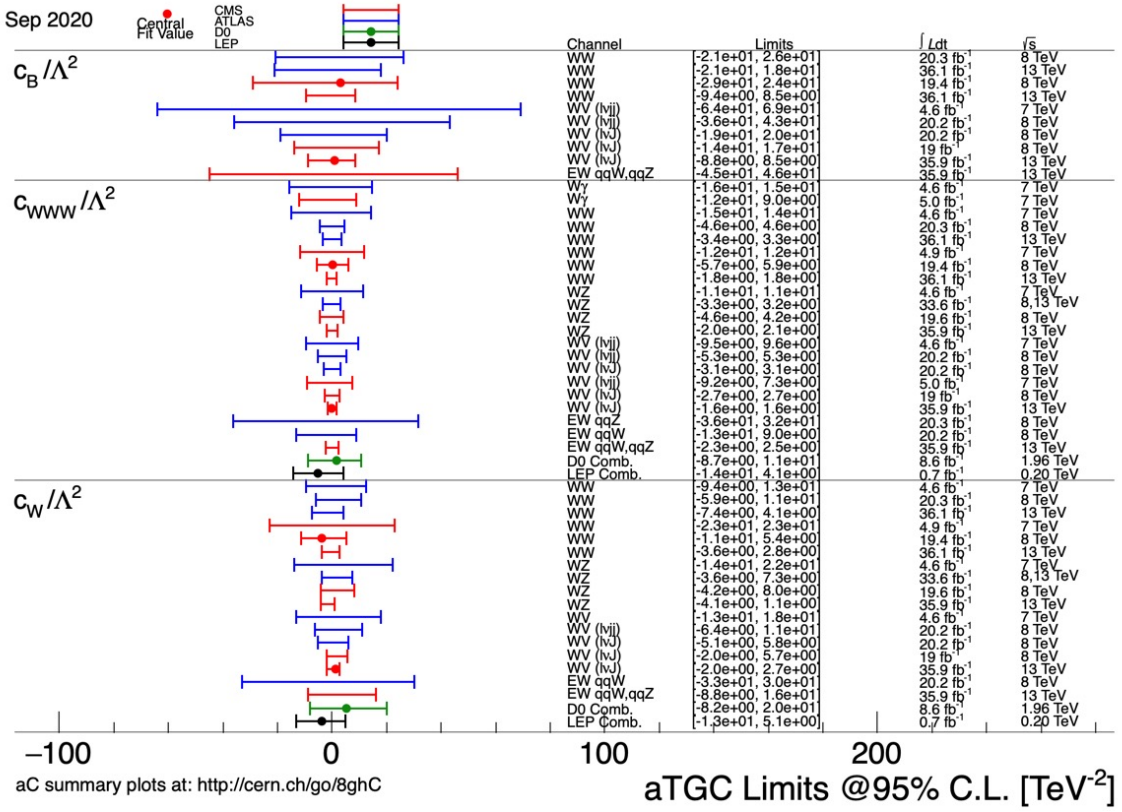
# BSM searches – Effective Field Theory approach

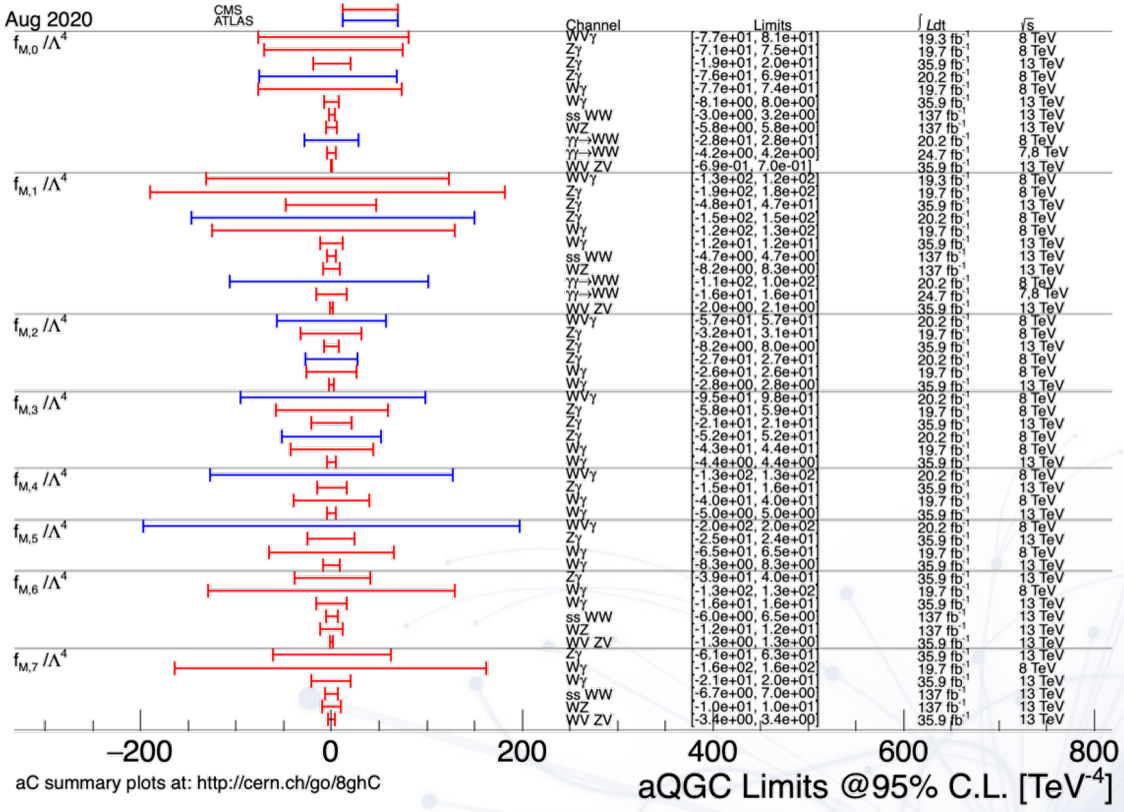
- SM as low energy effect of a more general UV complete theory
- Standard Model Effective Field Theory (SMEFT) → **expansion over the scale at wich new physics should appear ($\Lambda$)**

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \Sigma_i c_i^{(6)} \vartheta_i^{(6)} + \Sigma_i c_i^{(8)} \vartheta_i^{(8)} + \cdots$$

- VBS → upper and lower limits on Wilson coefficients for SMEFT operator with dimension > 4
- 2499 independent parameters for dim(6) ≪ dim(8) → impossible to fit all of them together
- Fitting just the CP preserving operators
- Historically, VBS is used to put constraints on dim(8) operator coefficients

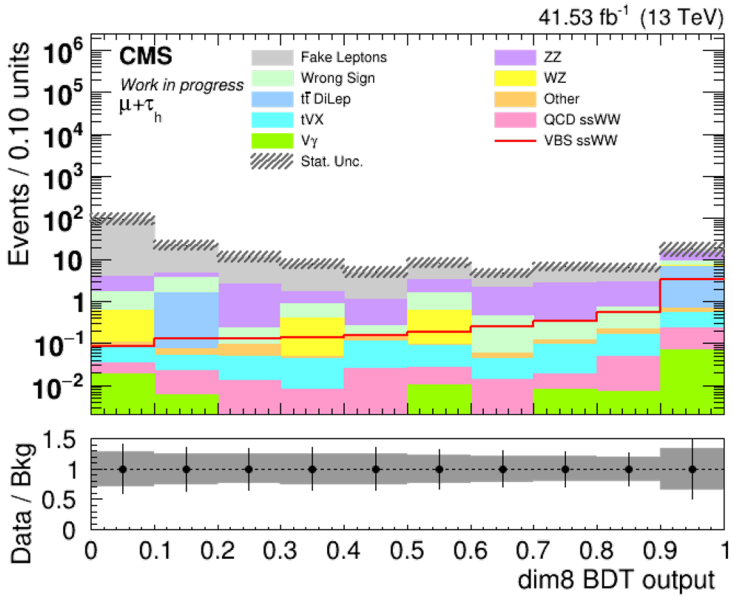
# Effective Field Theory coefficient now

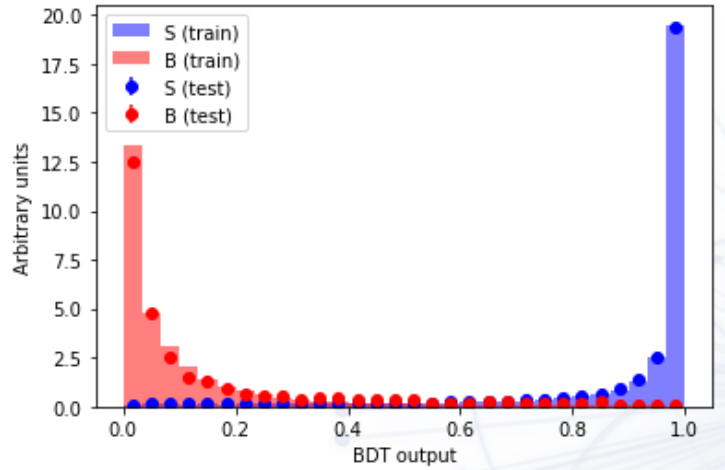


# BSM – preliminary studies on anomalous couplings

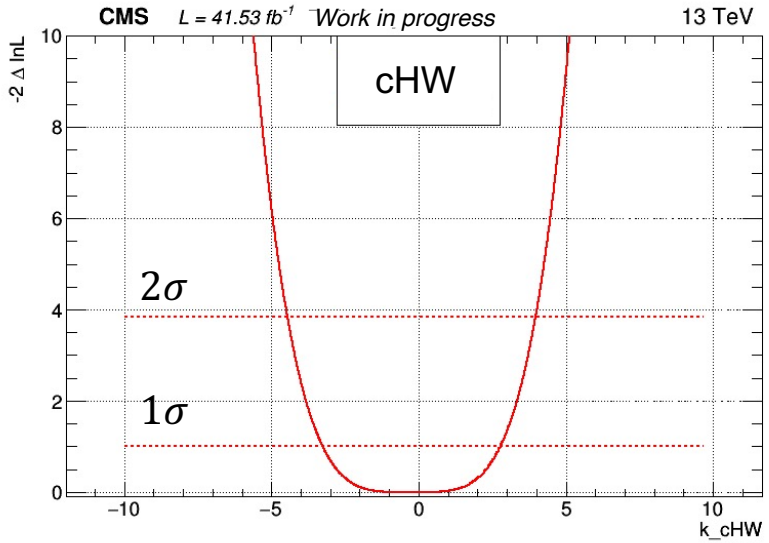
- Luminosity considered: RunII - 2017 CMS data → 41.5 $fb^{-1}$
- BDT trained for discriminating signal (VBS SSWW SM + operators with dim>4) vs major backgrounds (W+jets + $t\bar{t}$) → good signal-background discrimination
- BDT output used for profiled likelihood fit with Combine tool, to **extract limits on the coefficients**

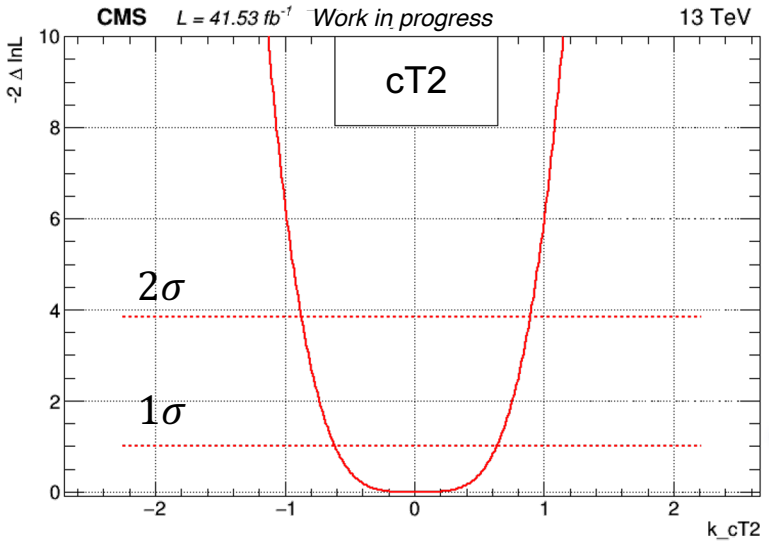


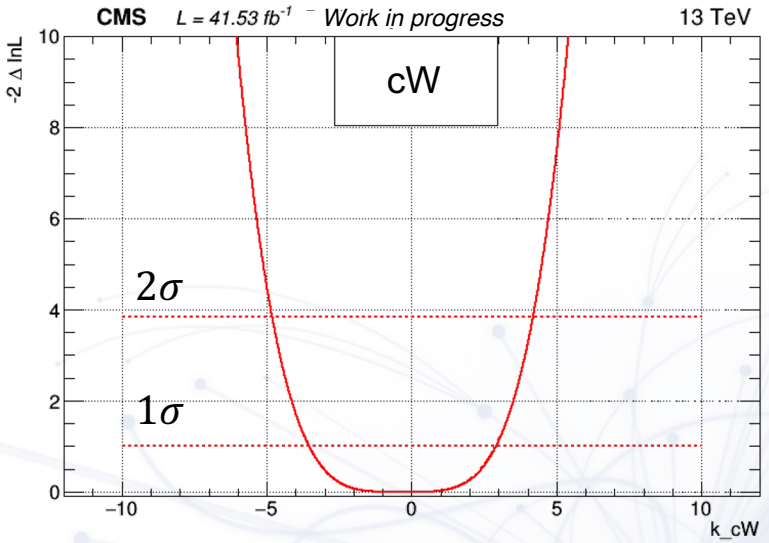



# Limits on anomalous gauge couplings

- Perliminary estimated limits → **results comparable with ones by "classic" analysis** with light leptons in the final state



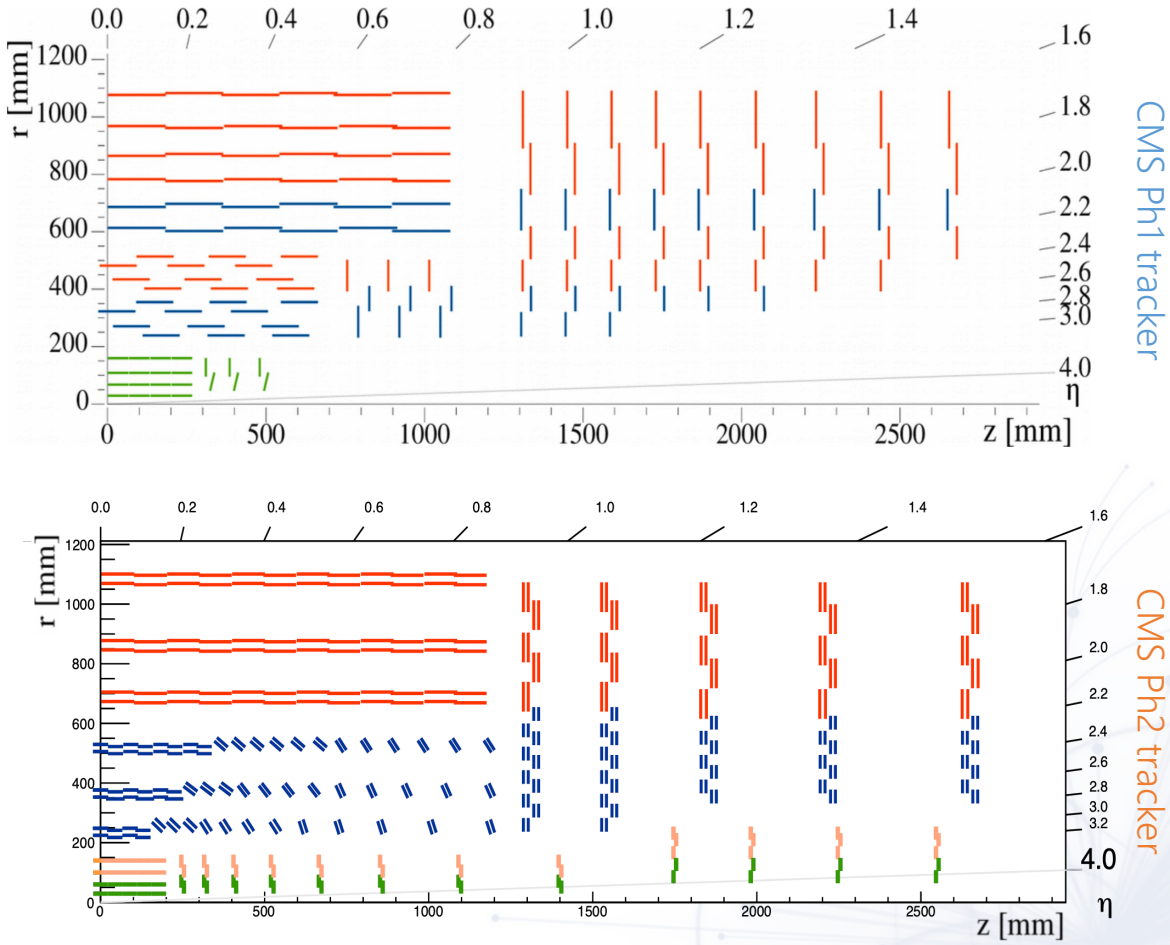



# CMS outer tracker

# CMS outer tracker

- Hi-Lumi upgrade of LHC after LS3 (~2026)
  - Peak Luminosity ~$7.5 \times 10^{34} cm^{-2} s^{-1}$
  - Expected Pile-up ~200
  - Higher rates and radiation dose wrt Run3
  - New Magnets (11T)
  - Etc..
- Necessary upgrade of current tracker:
  - leakage current or full depletion voltage limitations → big **part of current tracker will be inoperational**
  - Higher **radiation level** → upgraded tracker target: integrated luminosity of 3000 $fb^{-1}$
  - Efficient tracking + Higher pileup → **Increase of granularity needed**
  - Contribution to **level-1 trigger** → selection of interesting physics at the first trigger stage is extremely challenging at high luminosity

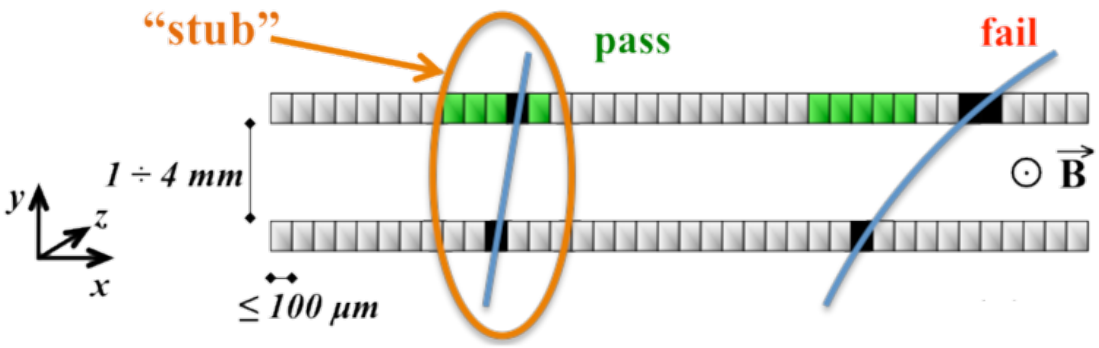


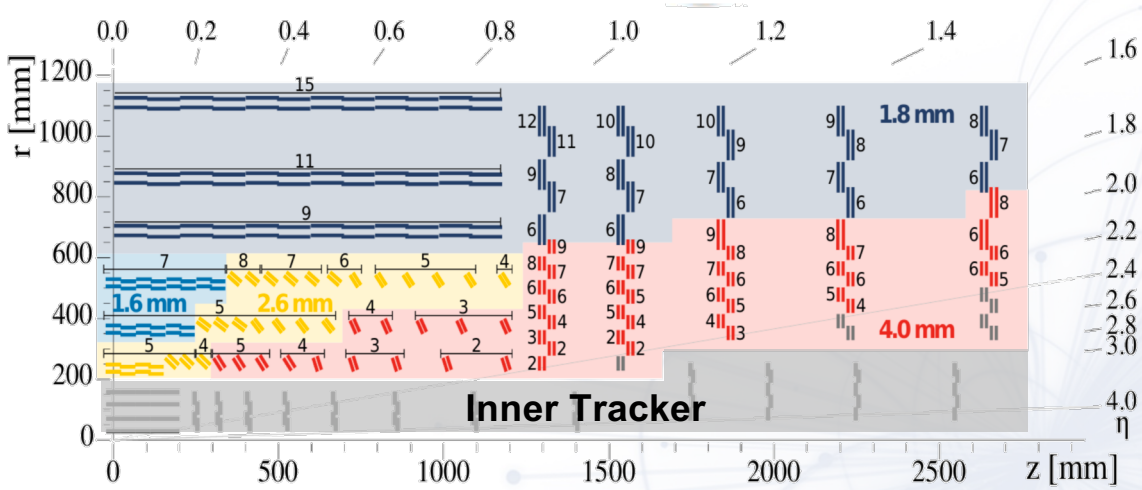
# CMS outer tracker

- HL-LHC → higher collision rate→ Most of charged particles have low $p_T$ → $p_T$ selection at readout level in order to reduce the L1 tracking input data size

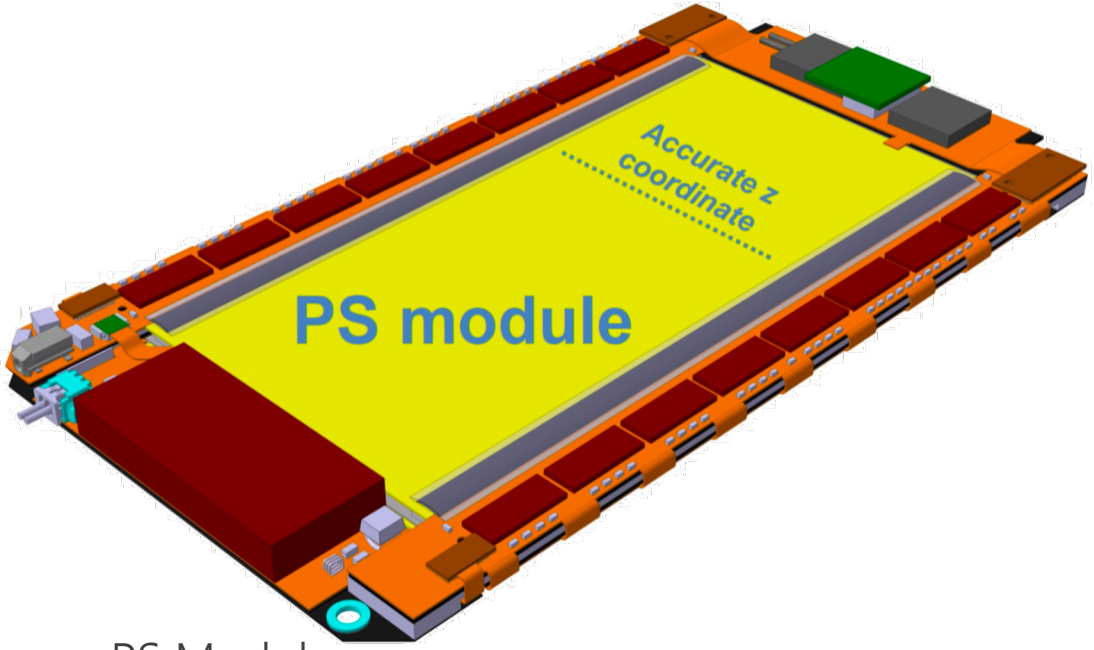
pT modules

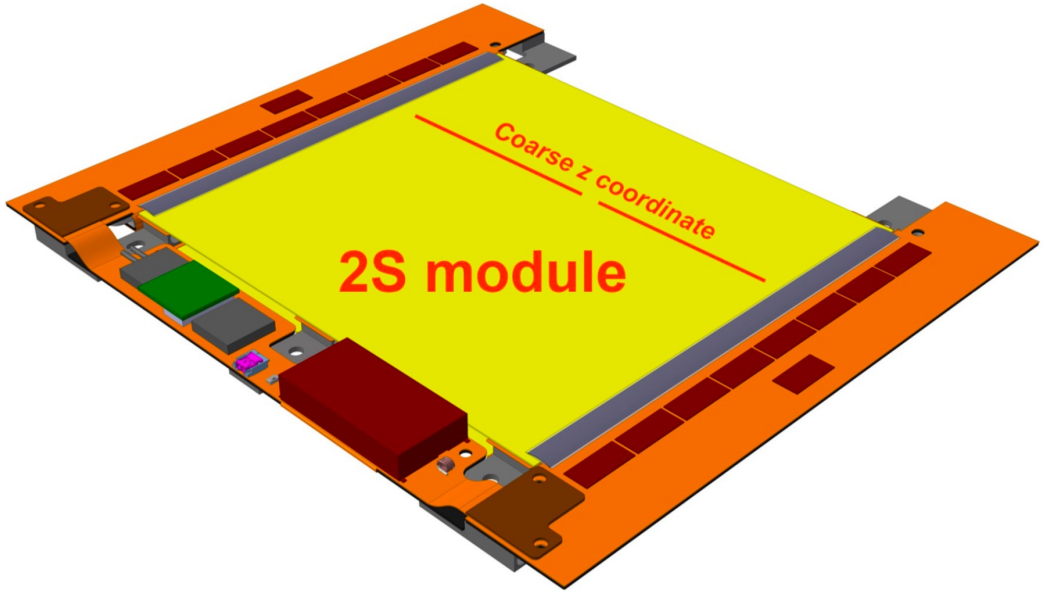
- Two silicon sensors with small spacing in a module
- Flex hybrid in order to get data from both sensors to one ASIC → Select track «stubs»
- Different sensor spacing for different detector region
- Tunable correlation windows



# CMS outer tracker



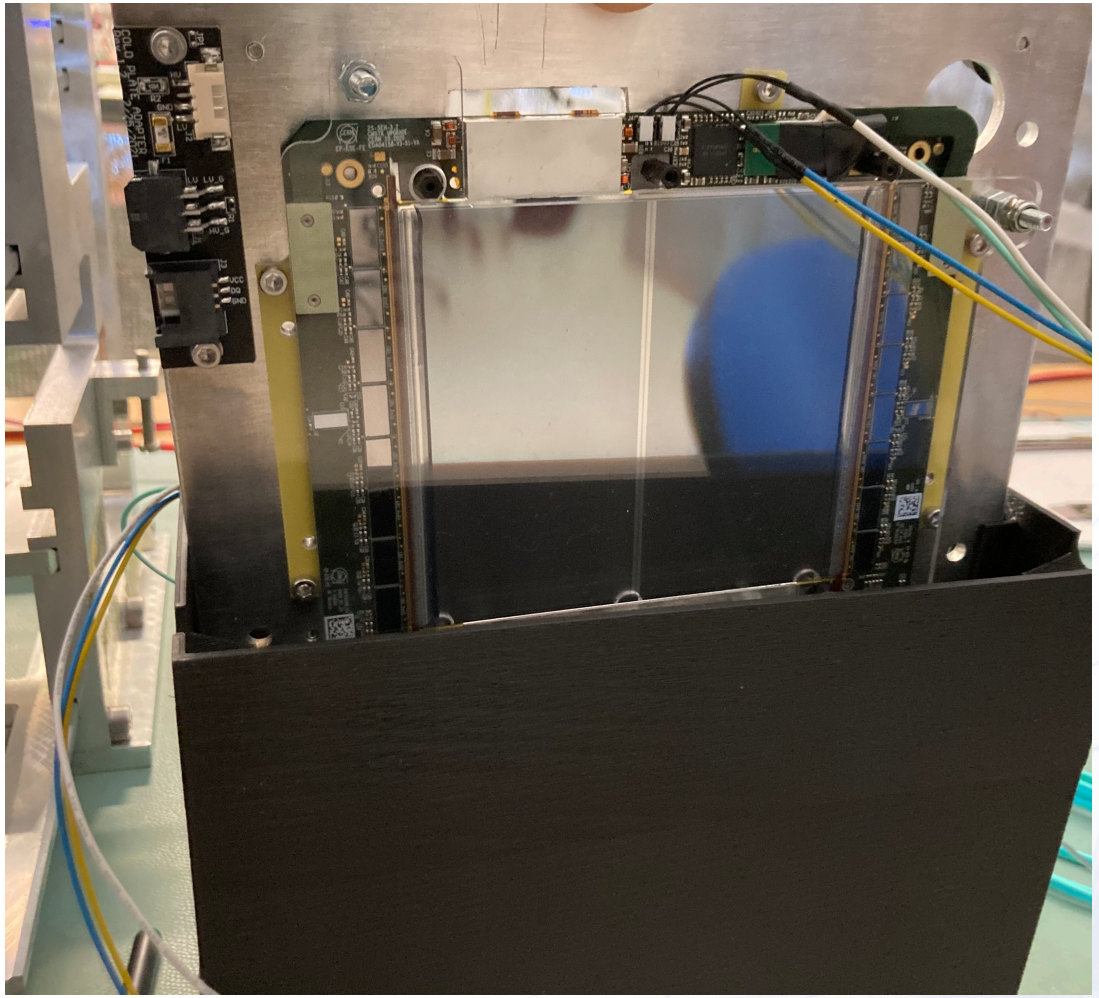




- PS Modules
  - 3 different spacing : 1.6mm & 2.6mm & 4mm
  - One strip sensor: 2.5cm x 100µm strips
  - One macro Pixel sensor : 1.5mm x 100µm pixels
  - Sensor dimension  5cm x 10 cm
    - two column of 960 strips
    - 32x960 pixels

- 2S Modules
  - 2 different spacing : 1.8mm & 4mm
  - 2 micro strip sensors with 5cm x 90µm strips
  - Sensor dimension are 10cm x 10cm
    - two column of 1016 strips

# CMS outer tracker – 2S modules and MUonE

- First 2S functional module from Perugia delivered @ CERN three weeks ago
- Other 2 + 1 (arriving today from Perugia) here at CERN
- Working with DAQ experts @ CERN for **characterization of the modules** → today started the MUonE + CMS test beam for the modules, which will be my main work in the next three weeks
- Atm also working for the development of a **semi-online DQM tool for MUonE** (git here)



# The next future

- Follow **beam test for MUonE + CMS modules** – starting today! → first test of the DAQ system for CMS modules
- Ongoing training for CMS tracker modules DAQ – I'll be at CERN until Christmas
- Contributing to the work for MUonE → writing code for semi-online data quality monitoring
- Finalization and **starting the approval procedure for VBS ssWW analysis**

# Educational activities

Courses for the first year

- **Effective Field Theory**
  - Theoretical introduction to EFT – *D. Buttazzo*
  - Effective gauge theory in Spintronics – *G. Tatara*
  - Effective Field Theory studies at the LHC – *P. Govoni, I. Brivio*
- **Probability and Uncertainty** – *G. d'Agostini*
- **Nanosystems and advanced materials**
  - Nanostructured materials and their characterization by synchrotron radiation - *M. Pedio*
  - Raman spectroscopy on lowdimensional materials - *P. Postorino*
  - Molecular Nanomagnets - *E. Garlatti, A. Chiesa*
- **Introduction to Atmospheric Physics, Climate and COPERNICUS DATA STORE (CDS)** - *P. Bongioannini Cerlini*
- **Multimessenger Astrophysics (from em multifrequency to gravitational waves)** - *G. Greco, S. Germani, M. Punturo, G. Tosti*
- **Teaching and Learning Physics at University** - *G. Organtini*
- **Physics @ LHC** – *M. Gallinaro*

Seminars

- Present and future of multi-messender astronomy including gravitational-wave – M. Branchesi
- Searching for life in the universe: how, where and why? – A. Balbi
- The black hole guide to the quantum theories of gravity – R. Emparan
- SAFIR: A fast pre-clinical PET insert – G. Dissertori
- B-physics anomalies ant the flavour problem – G. Isidori
- Neutrons for Magnetism in Spin Chain Materials – B. Grenier

Schools

- 4th CMS Tracker Upgrade DAQ school – Online
- Advanced VBS training school – Milano Bicocca

Conferences:

- 107° Congresso Nazionale Società italiana di Fisica - Scattering di bosoni vettoriali con due W dello stesso segno e decadimento adronico del · nello stato finale in CMS

# Papers published with CMS collaboration - 1

- Search for new particles in events with energetic jets and large missing transverse momentum in proton-proton collisions at $\sqrt{s} = $ 13 TeV, CMS Collaboration, e-Print: 2107.13021 [hep-ex]
- Measurement of the inclusive and differential Higgs boson production cross sections in the decay mode to a pair of $\tau$ leptons in pp collisions at $\sqrt{s} = $ 13 TeV, CMS Collaboration, e-Print: 2107.11486 [hep-ex]
- Combined searches for the production of supersymmetric top quark partners in proton-proton collisions at $\sqrt{s} =$ 13 TeV, CMS Collaboration, e-Print: 2107.10892 [hep-ex]
- Search for long-lived particles decaying in the CMS endcap muon detectors in proton-proton collisions at $\sqrt{s} = $ 13 TeV, CMS Collaboration, e-Print: 2107.04838 [hep-ex]
- Measurement of the inclusive and differential $\mathrm{t\overline{t}}\gamma$ cross sections in the single-lepton channel and EFT interpretation at $\sqrt{s}$ = 13 TeV, CMS Collaboration, e-Print: 2107.01508 [hep-ex]
- Measurements of the electroweak diboson production cross sections in proton-proton collisions at $\sqrt{s} =$ 5.02 TeV using leptonic decays, CMS Collaboration, e-Print: 2107.01137 [hep-ex]
- Search for electroweak production of charginos and neutralinos in proton-proton collisions at $\sqrt{s} = $ 13 TeV, CMS Collaboration,e Print: 2106.14246 [hep-ex]
- Search for lepton-flavor violating decays of the Higgs boson in the $\mu\tau$ and e$\tau$ final states in proton-proton collisions at $\sqrt{s}$ = 13 TeV, CMS Collaboration, e-Print: 2105.03007 [hep-ex]
- Constraints on anomalous Higgs boson couplings to vector bosons and fermions in its production and decay using the four-lepton final state, CMS Collaboration, e-Print: 2104.12152 [hep-ex]
- Search for charged Higgs bosons produced in vector boson fusion processes and decaying into vector boson pairs in protonâ€"proton collisions at $\sqrt{s} = 13\,{\text {TeV}} $, CMS Collaboration, e-Print: 2104.04762 [hep-ex]
- Measurements of Higgs boson production cross sections and couplings in the diphoton decay channel at $ \sqrt{\mathrm{s}} $ = 13 TeV, CMS Collaboration, e-Print: 2103.06956 [hep-ex]

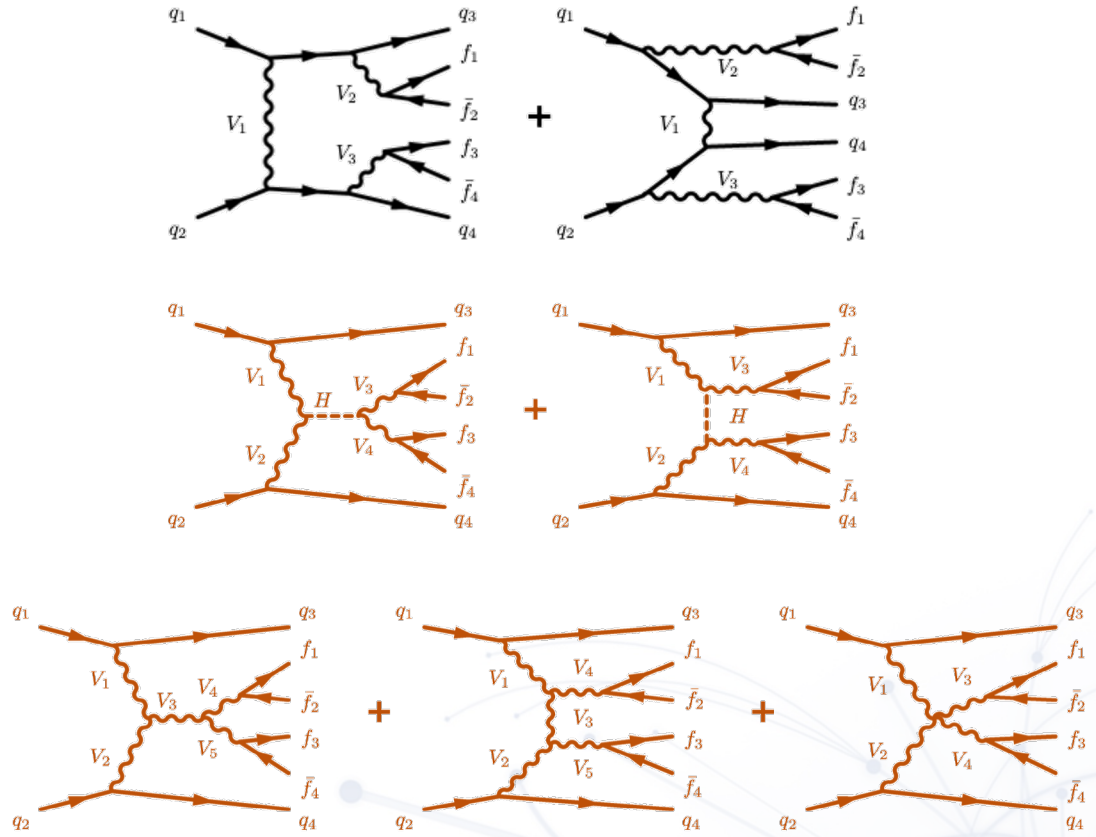
# Papers published with CMS collaboration - 2

- Search for long-lived particles decaying to leptons with large impact parameter in proton-proton collisions at $\sqrt{s}$ = 13 TeV, CMS Collaboration, e-Print: 2110.04809
- Analysis of the CP structure of the Yukawa coupling between the Higgs boson and $\tau$ leptons in proton-proton collisions at $\sqrt{s}$ = 13 TeV, CMS Collaboration, e-Print: 2110.04836 [hep-ex]
- Measurement of double-parton scattering in inclusive production of four jets with low transverse momentum in proton-proton collisions at $\sqrt{s}$ = 13 TeV, CMS Collaboration, e-Print: 2109.13822 [hep-ex]
- Search for heavy resonances decaying to Z($\nu\bar{\nu}$)V(q$\bar{q}$') in proton-proton collisions at $\sqrt{s}$ = 13 TeV, CMS Collaboration, e-Print: 2109.08268 [hep-ex]
- Search for heavy resonances decaying to WW, WZ, or WH boson pairs in the lepton plus merged jet final state in proton-proton collisions at $\sqrt{s}$ = 13 TeV, CMS Collaboration, e-Print: 2109.06055 [hep-ex]
- Study of quark and gluon jet substructure in Z+jet and dijet events from pp collisions, CMS Collaboration, e-Print: 2109.03340 [hep-ex]
- Observation of tW production in the single-lepton channel in pp collisions at $\sqrt{s}$ = 13 TeV, CMS Collaboration, e-Print: 2109.01706 [hep-ex]
- Measurement of the top quark mass using events with a single reconstructed top quark in pp collisions at $\sqrt{s}$ = 13 TeV, CMS Collaboration, e-Print: 2108.10407 [hep-ex]
- Measurement of differential $\text{t}\overline{\text{t}}$ production cross sections in the full kinematic range using lepton+jets events from proton-proton collisions at $\sqrt{s} = $ 13 TeV,CMS Collaboration, e-Print: 2108.02803 [hep-ex]
- Probing effective field theory operators in the associated production of top quarks with a Z boson in multilepton final states at $\sqrt{s} = $ 13 TeV, CMS Collaboration, e-Print: 2107.13896 [hep-ex]
- Search for chargino-neutralino production in events with Higgs and W bosons using 137 fb$^{-1}$ of proton-proton collisions at $\sqrt{s} =$ 13 TeV, CMS Collaboration, e-Print: 2107.12553 [hep-ex]

# Backup

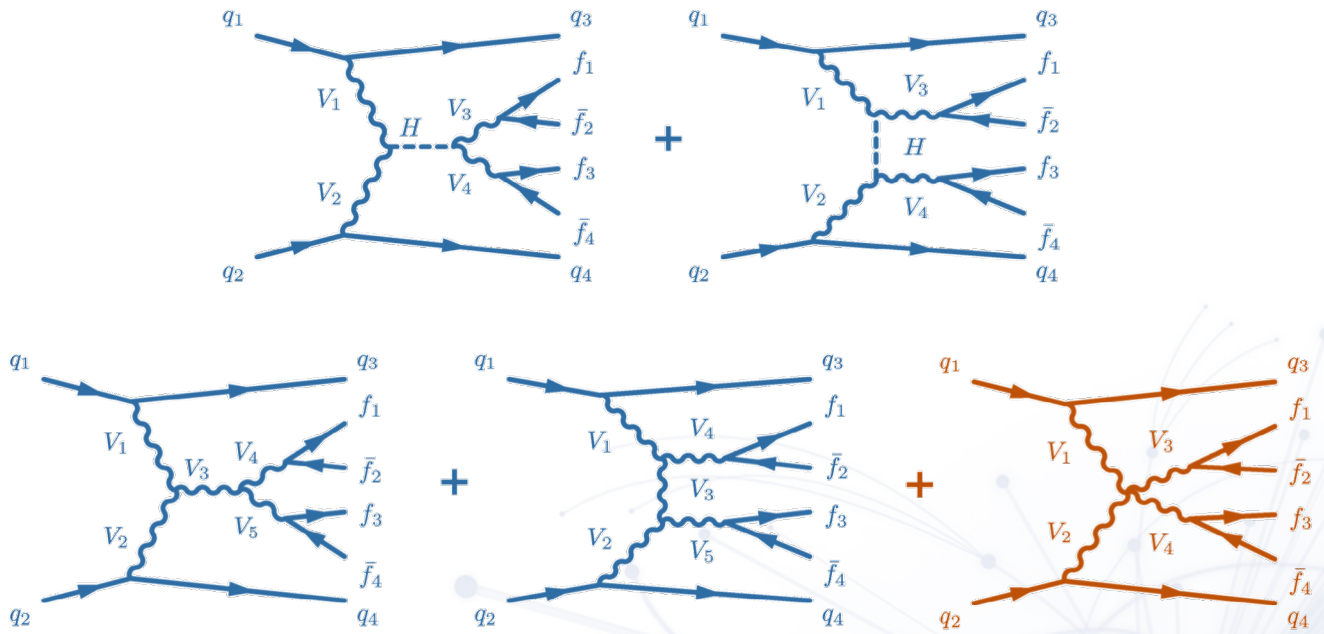
# Vector Boson Scattering - LO

- VBS @ LO categorized by the number and nature of vertexes
- "EWK production" $\vartheta(\alpha^4)$
  - Non VBS → no vector boson self coupling vertexes
  - VBS
- Impossible to decouple the two production in a gauge invariant way



# Vector Boson Scattering - LO

- VBS production
  - VBF channel → triple vertex w interaction between vector bosons/Higgs
  - Quartic vertexes



# Vector Boson Scattering - Tree level

- "QCD production" $\vartheta(\alpha^2\alpha_s^2)$
- No self V interaction
  → not useful for the EWSB studies
  → usually bkg for the VBS region
- Usually large xSec →$\sigma_{QCD}$ up to $100\times\sigma_{EWK}$