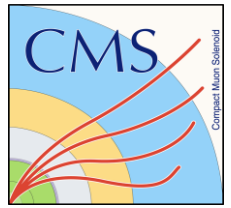
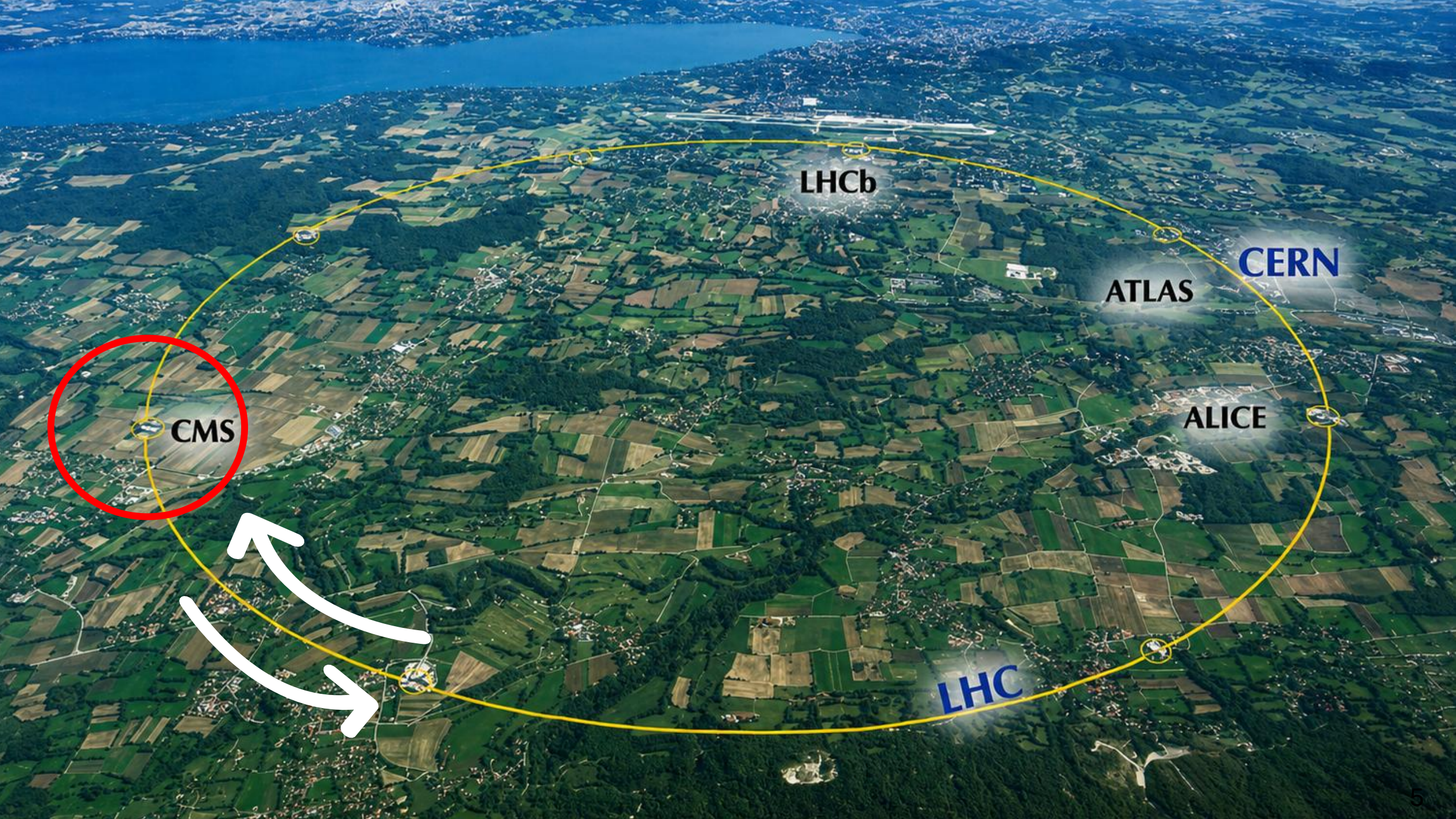
UNIVERSITÀ DI PAVIA
Department of Physics
"Alessandro Volta"

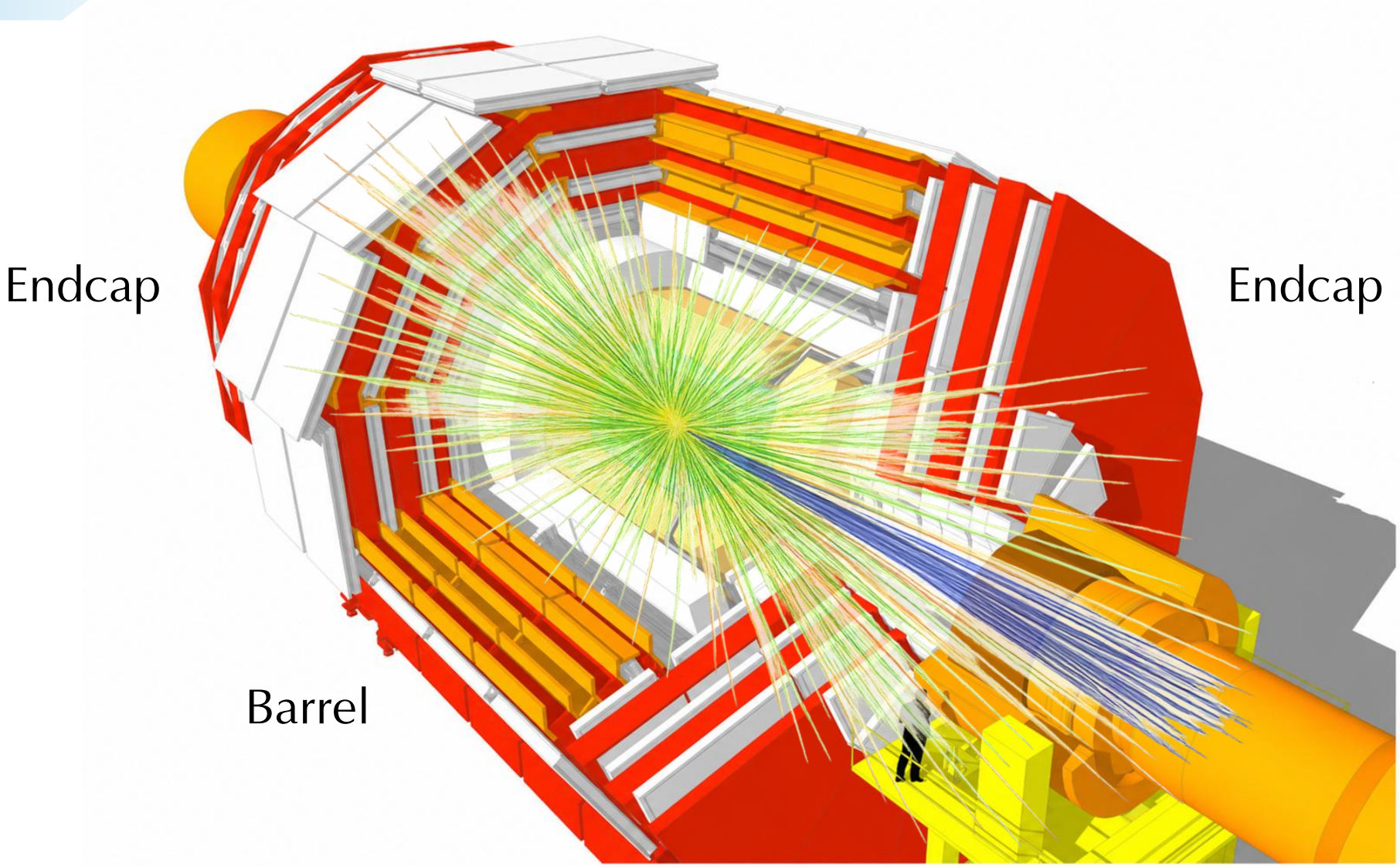


Discovery of ZZ Vector Boson Scattering at the CMS experiment

Alessandro Tamigio
1° year PhD
End of the Year seminar, 16/09/26


LHCb
CERN
ATLAS
CMS
ALICE
LHC

Compact Muon Solenoid (CMS) experiment

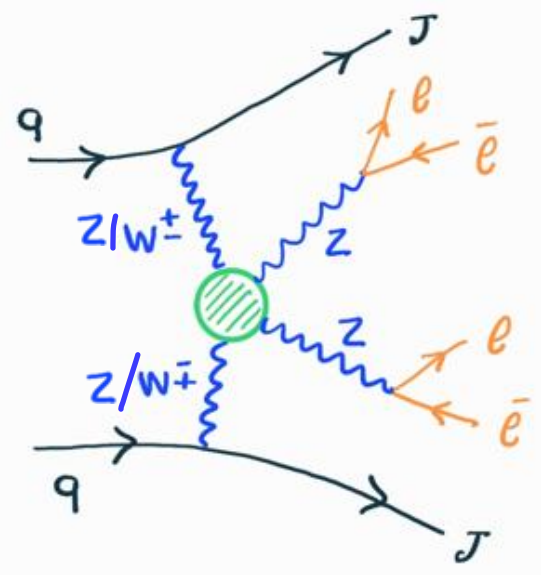


Vector Boson Scattering (VBS) process

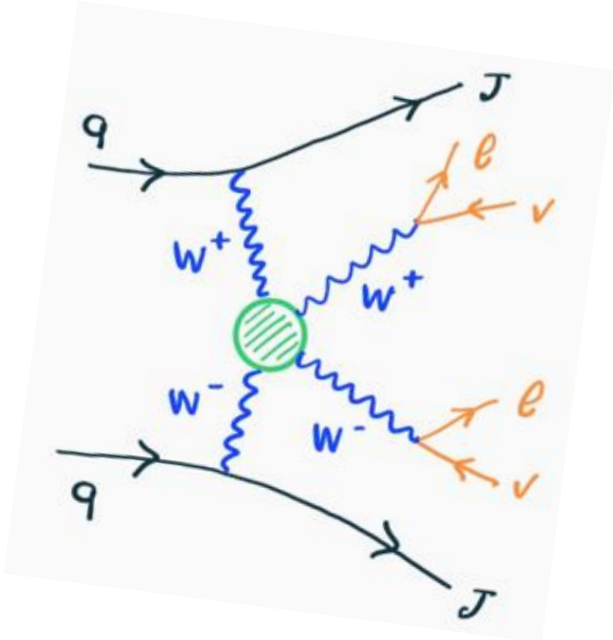
What VBS is

Quarks emit bosons (W and Z) which interact with each other giving different possible final states

$qq \rightarrow ZZjj \rightarrow l\bar{l}l\bar{l}jj$

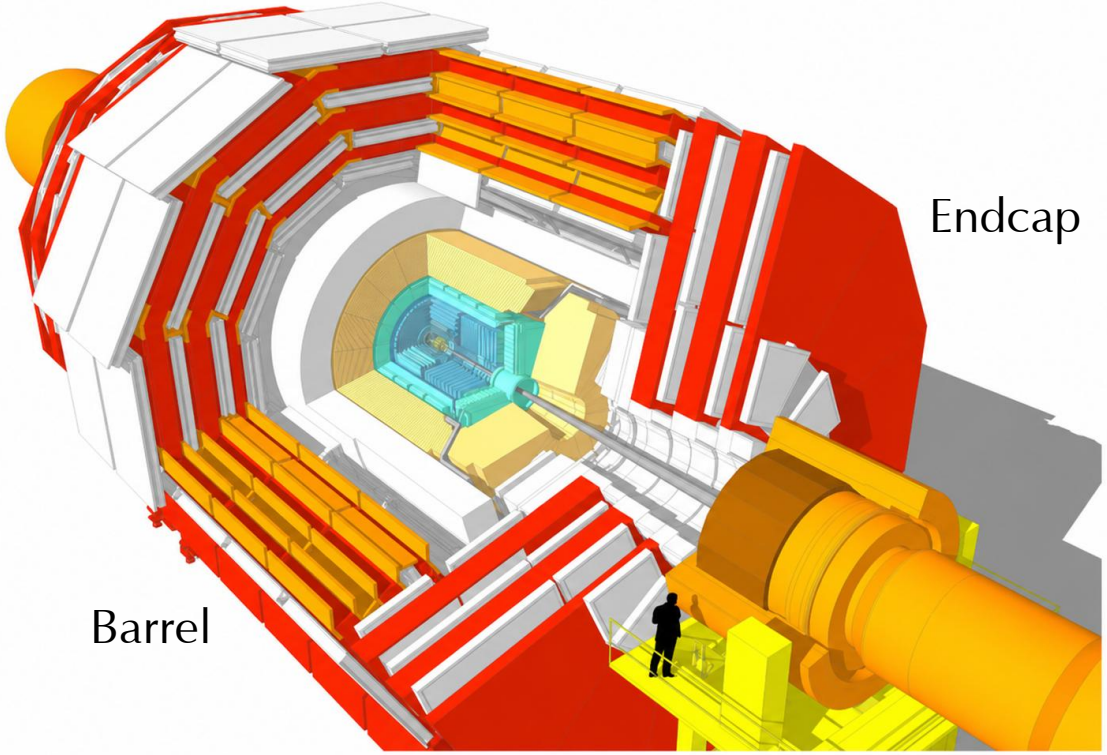


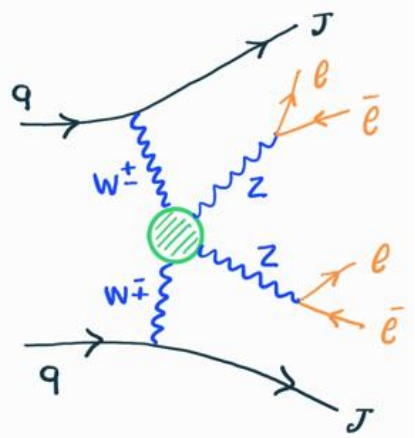
$qq \rightarrow W^+W^-jj \rightarrow lvlvjj$

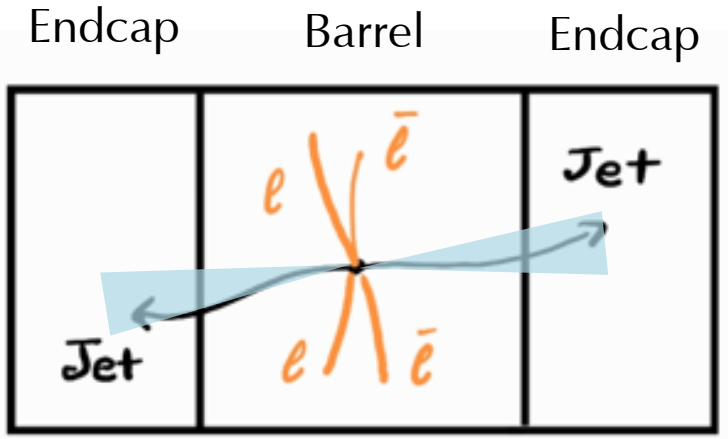


Vector Boson Scattering (VBS) process

Where



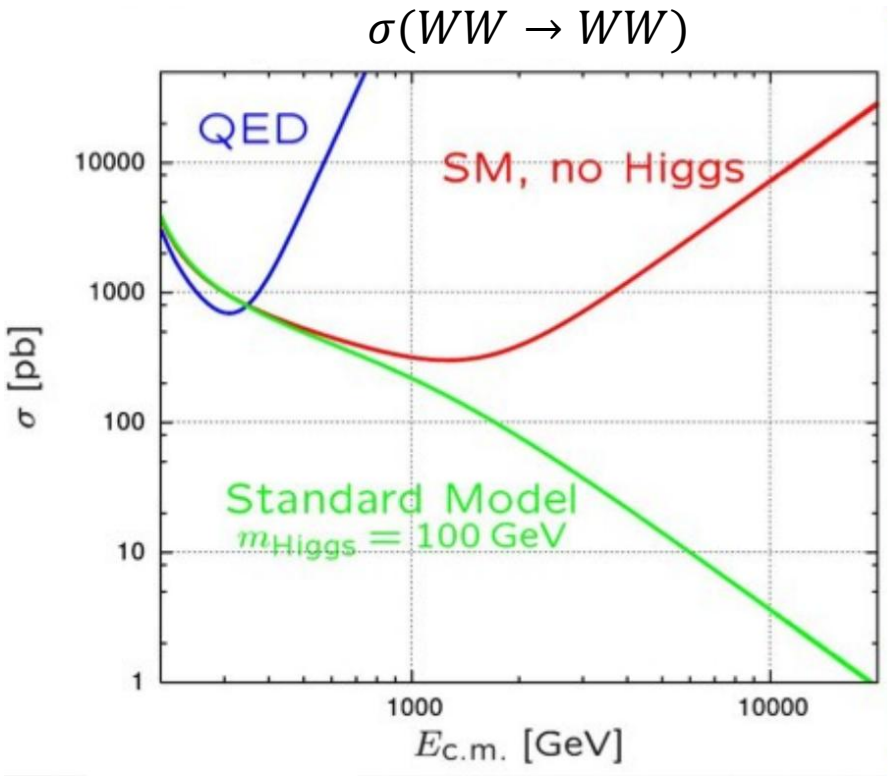


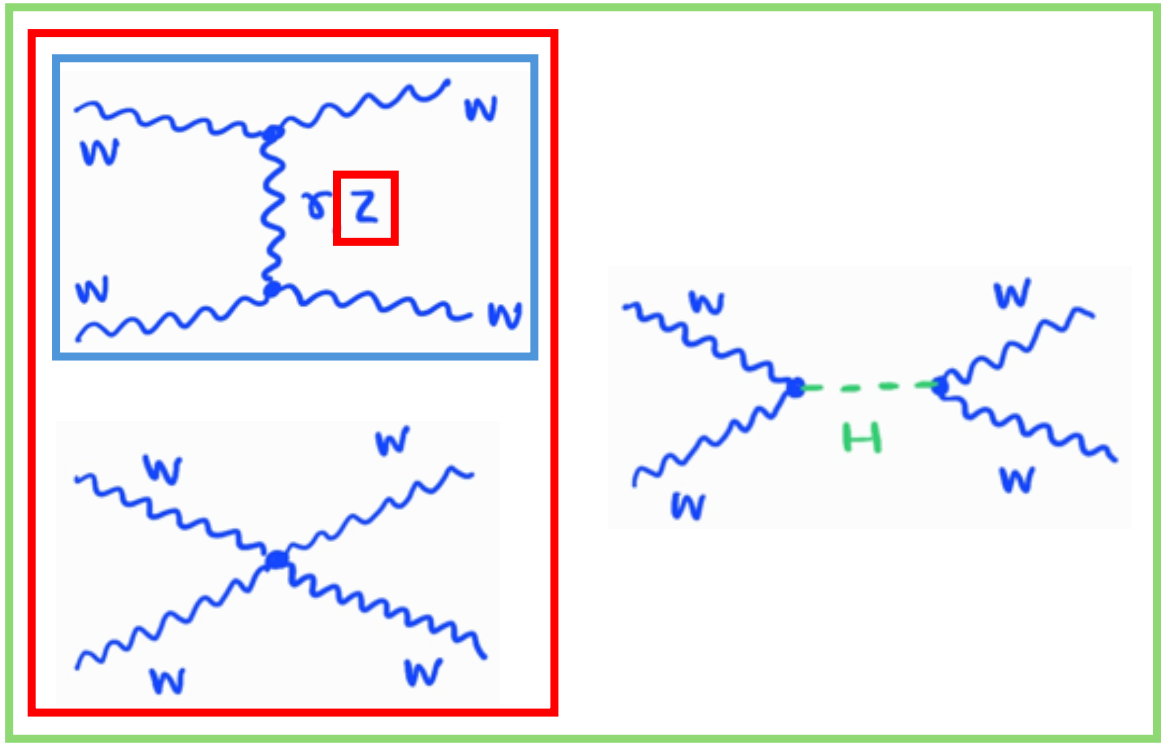


Vector Boson Scattering (VBS) process

Why

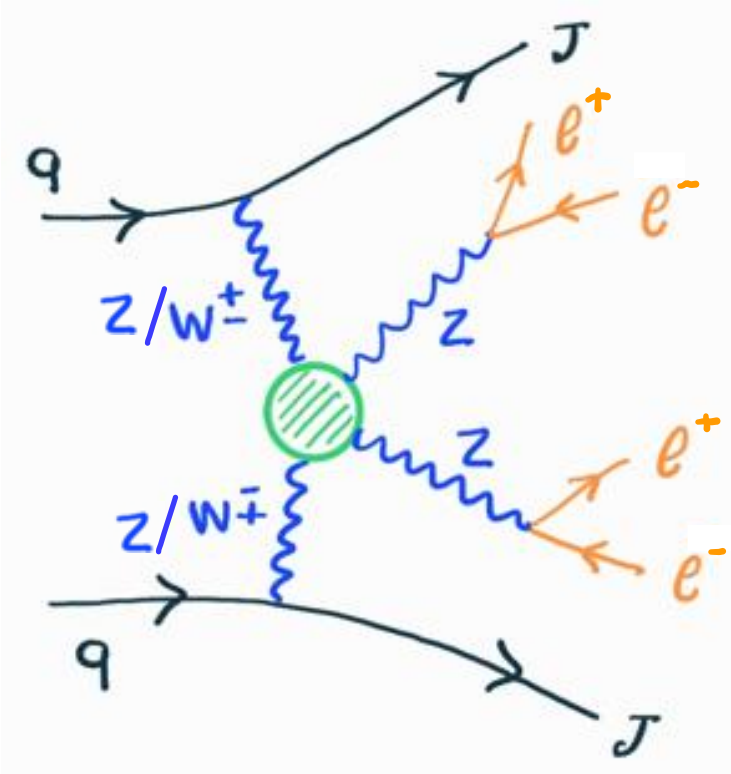
Investigate EW structure and the role of the Higgs boson in the Standard Model





Fully leptonic ZZ VBS channel: final states

High purity

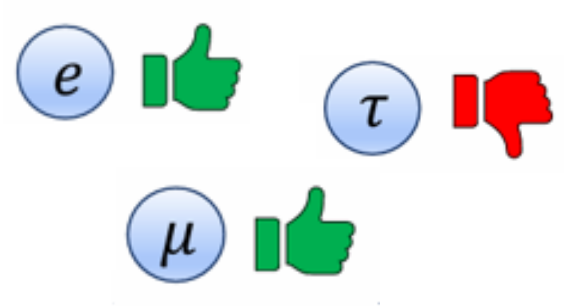


Low statistics

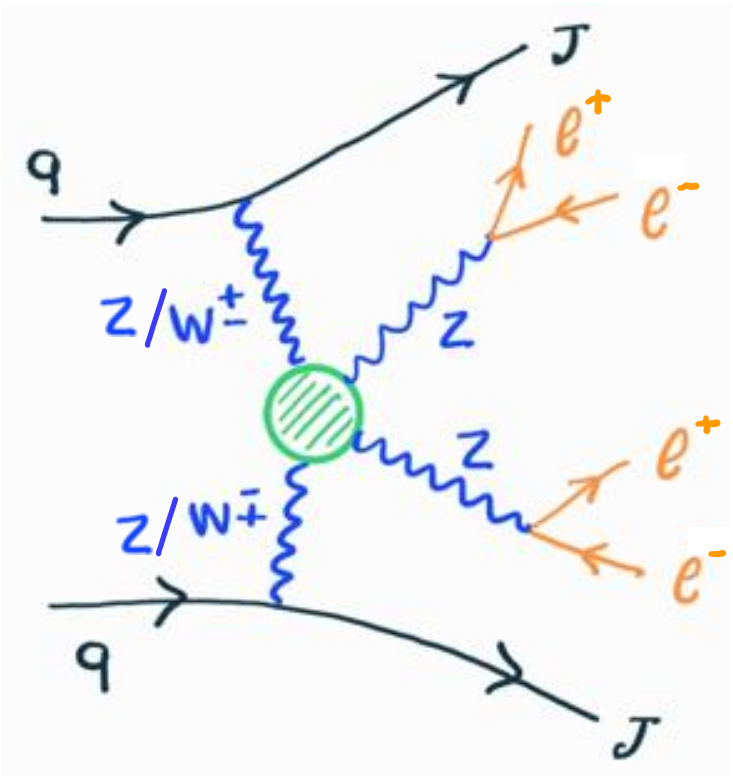
Fully leptonic ZZ VBS channel: final states

High purity

Final states

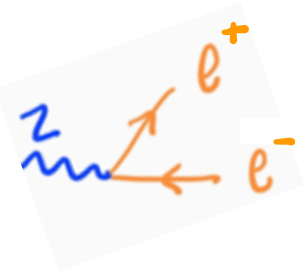


4μ $2e2\mu$ $4e$



Extremely rare decay

$BR(Z \to l\bar{l}) \simeq 3\%$



Low statistics

Fully leptonic ZZ VBS channel: selections

Datasets

	Years	Luminosity (/fb)
Run 2	2016 - 2018	137
Run 3	2022 - 2026	312

Run 2: published analysis
Run 3: my Phd project

Fully leptonic ZZ VBS channel: selections

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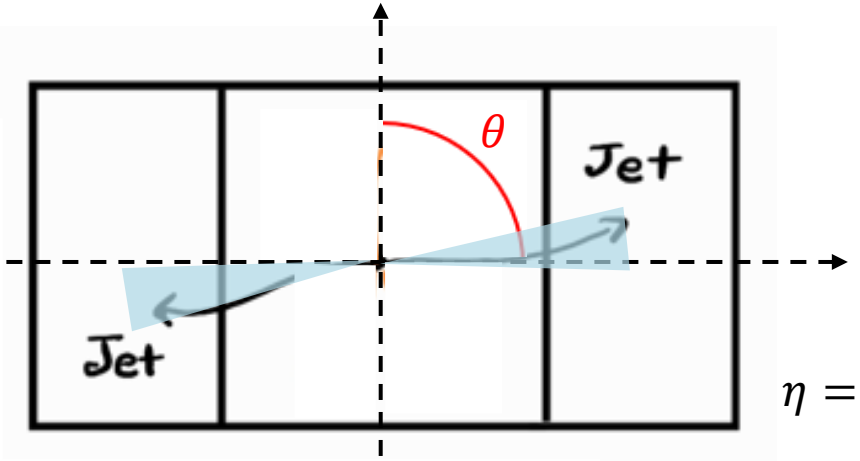
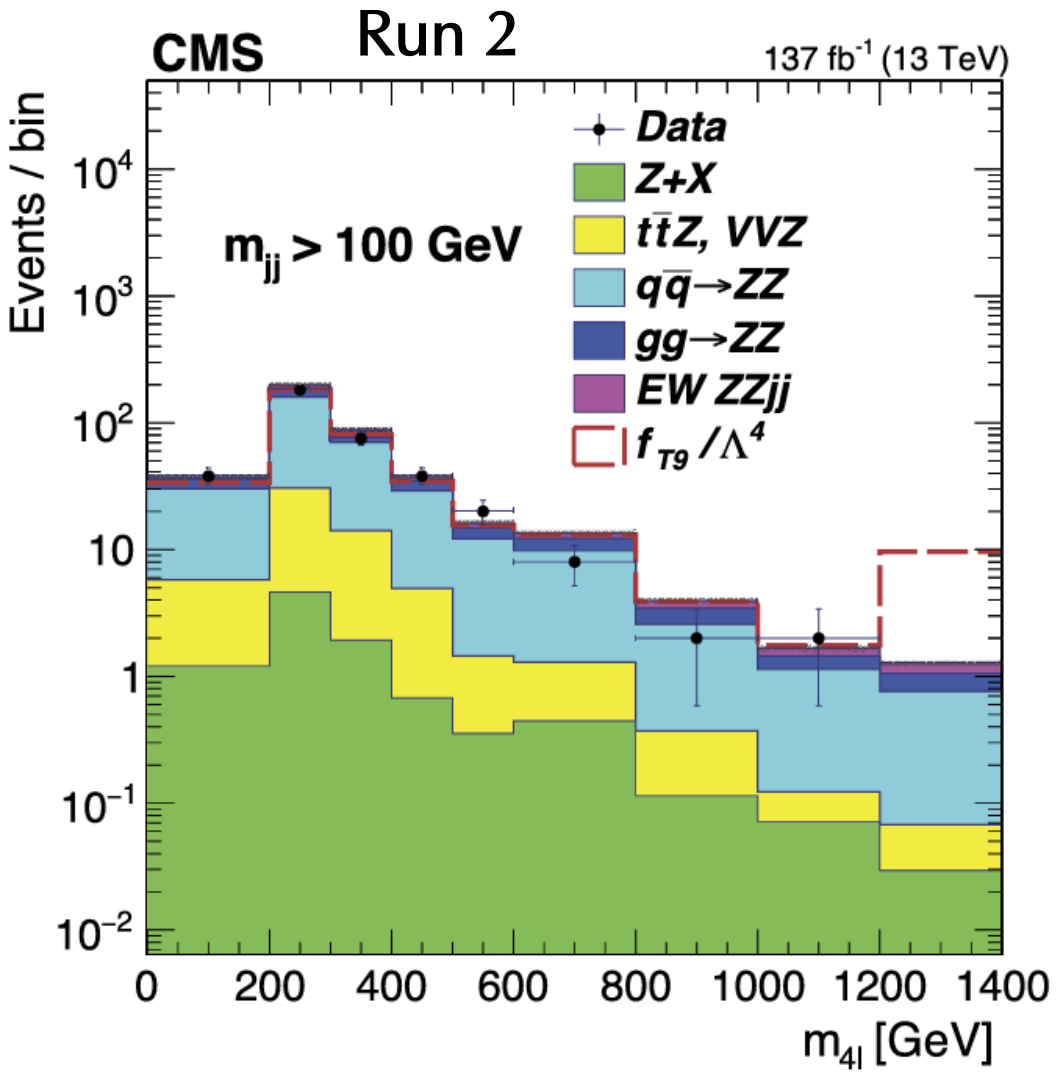


$$\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$$

Run 2 selections

Particle type	Selection
	$ZZjj$ inclusive
Leptons	$p_{\mathrm{T}}(\ell_1) > 20\,\mathrm{GeV}$
	$p_{\mathrm{T}}(\ell_2) > 10\,\mathrm{GeV}$
	$p_{\mathrm{T}}(\ell) > 5\,\mathrm{GeV}$
Z and ZZ	$60 < m(\ell\ell) < 120\,\mathrm{GeV}$
Jets	at least 2
	$p_{\mathrm{T}}(\mathrm{j}) > 30\,\mathrm{GeV}$
	$\lvert\eta(\mathrm{j})\rvert < 4.7$

State of the art



Signal

$EW\ ZZjj$

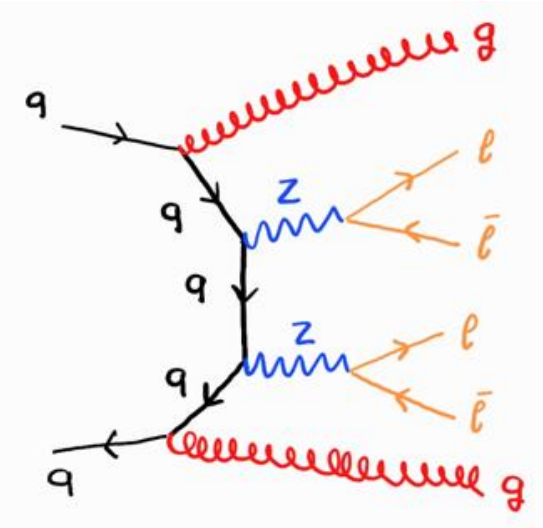
Backgrounds

$qq \to ZZ$

$gg \to ZZ$

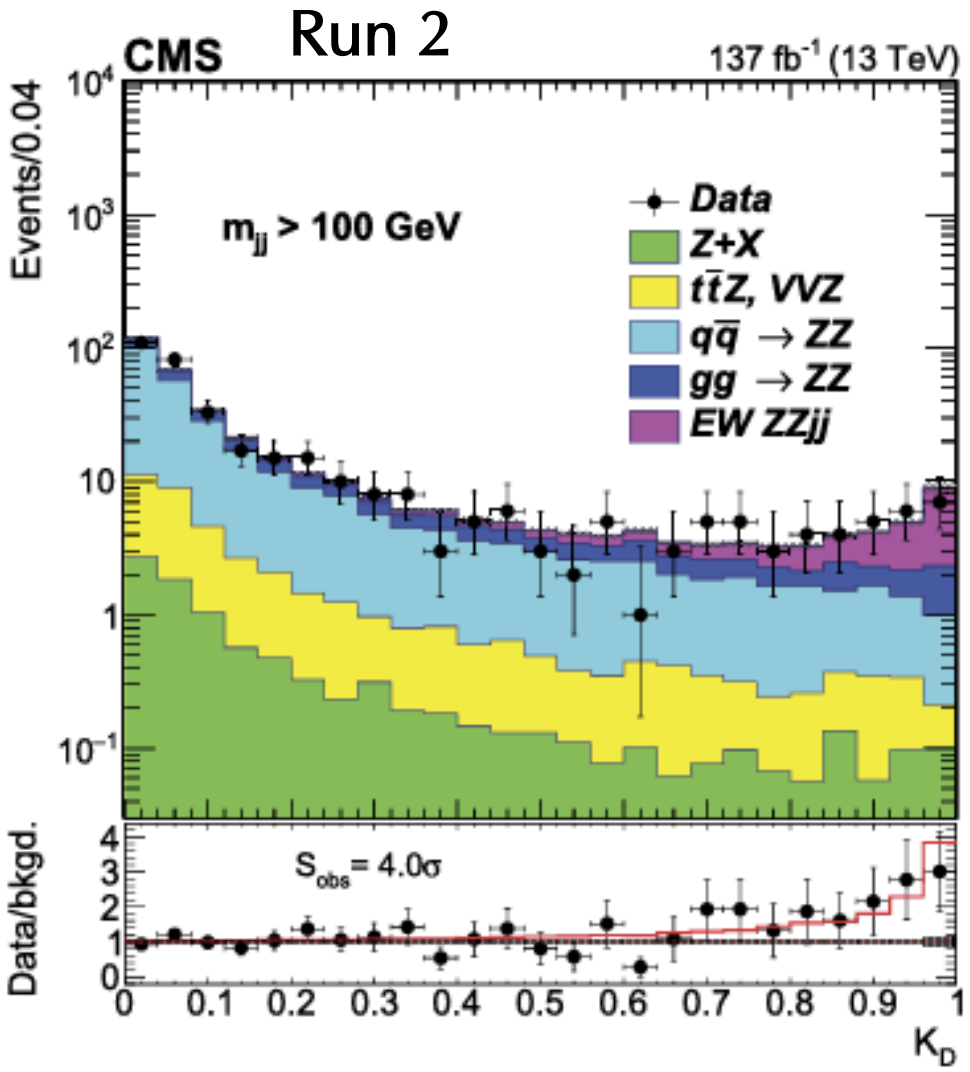
$Z + jets$

$pp \to t\bar{t}Z + jets$
$pp \to VVZ + jets$



CMS Collaboration, 'Evidence for electroweak production of four charged leptons and two jets in proton-proton collisions at $\sqrt{S} = 13\ TeV$'. Physics Letters B 812 (2021) 135992

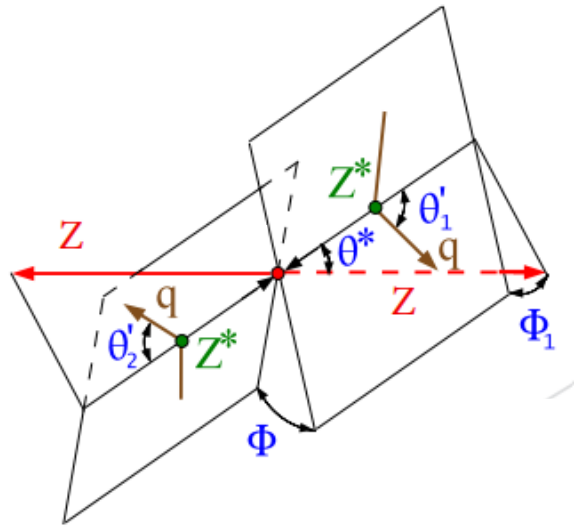
State of the art



Signal

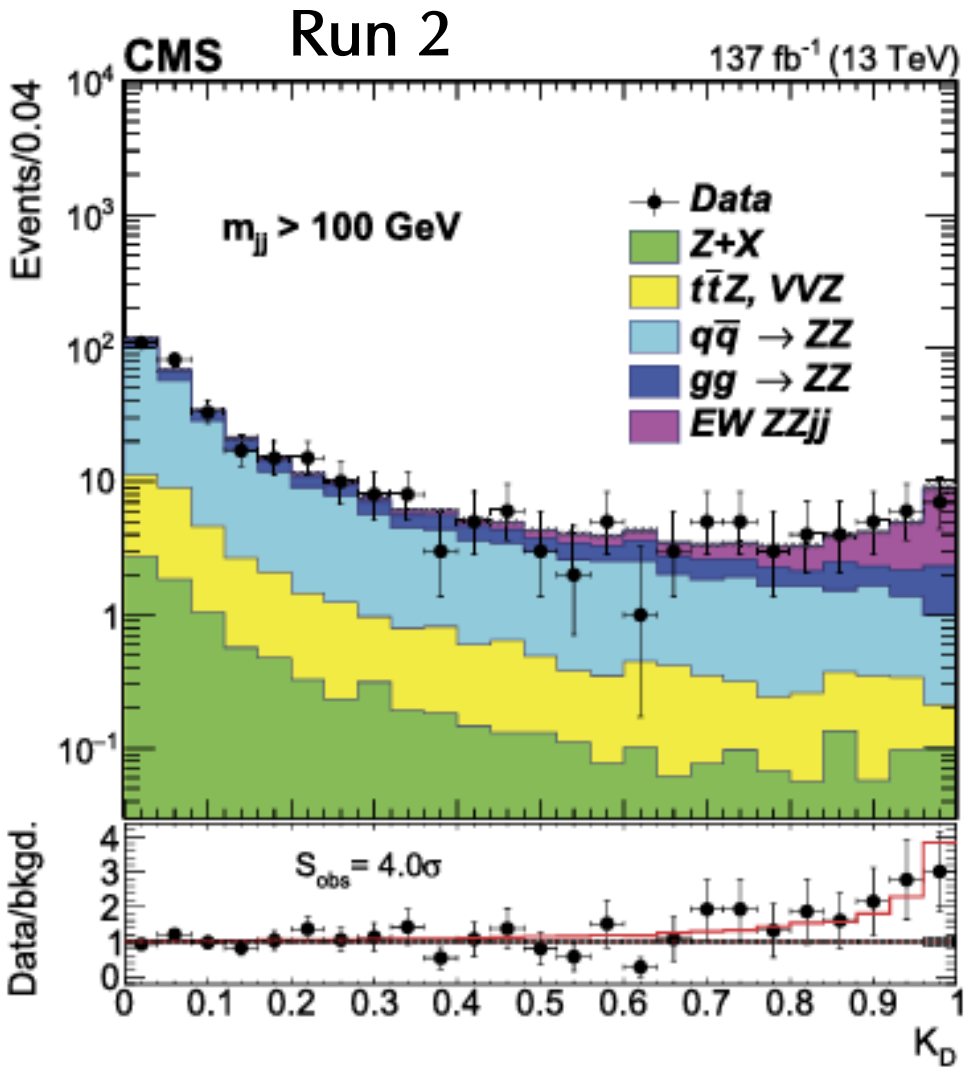
$EW\ ZZjj$

$$K_D = \frac{P_{EWK}}{P_{EWK} + P_{QCD}}$$



CMS Collaboration, 'Evidence for electroweak production of four charged leptons and two jets in proton-proton collisions at $\sqrt{S} = 13\ TeV$'. Physics Letters B 812 (2021) 135992

State of the art: cross section and significance



Cross section measured

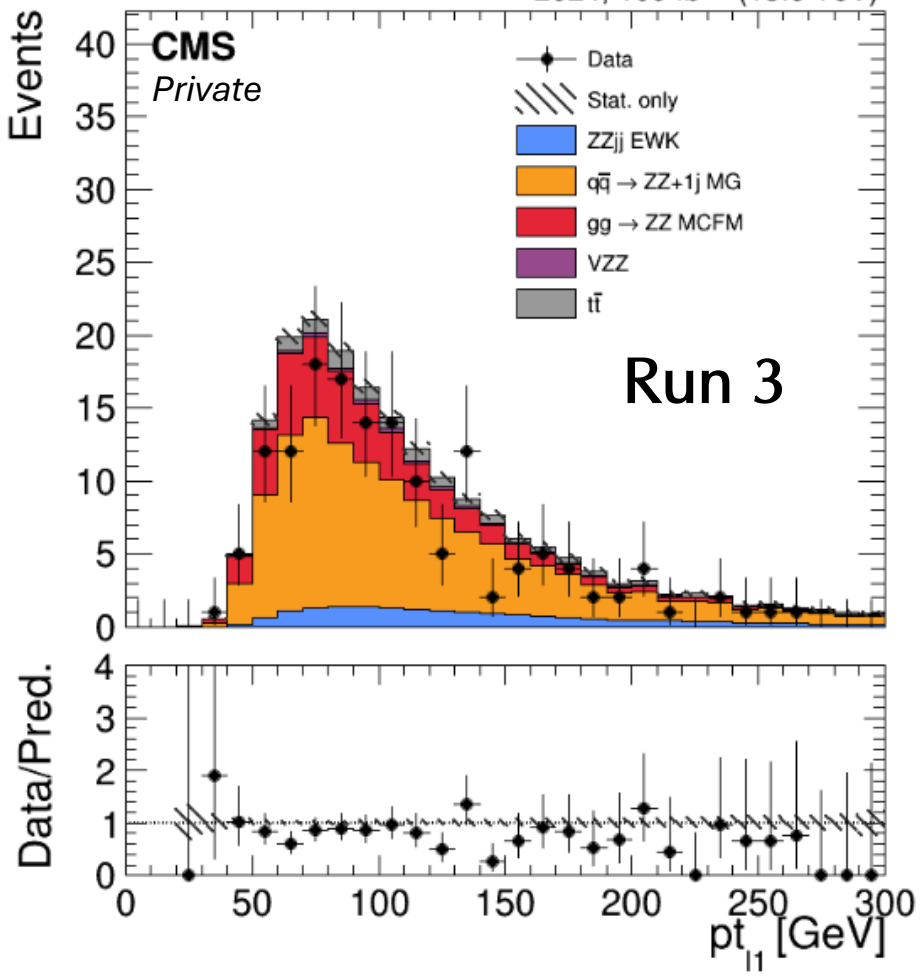
$$\sigma_{EW} = 0.33^{+0.11}_{-0.10}(stat)^{+0.04}_{-0.03}(sist)\ fb$$

Significance $\sim \frac{S}{\sqrt{B}} \cong 4\sigma$

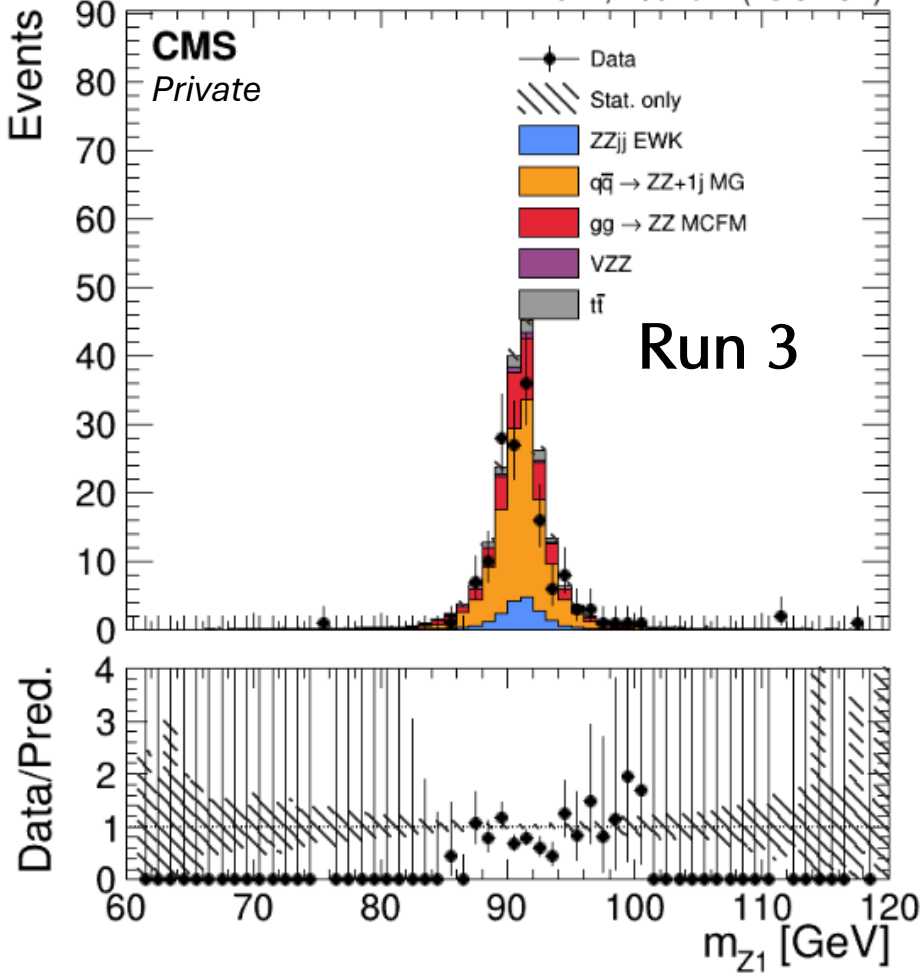
CMS Collaboration, 'Evidence for electroweak production of four charged leptons and two jets in proton-proton collisions at $\sqrt{S} = 13\ TeV$'. Physics Letters B 812 (2021) 135992

My work with Run 3

$p_T(l_1)$



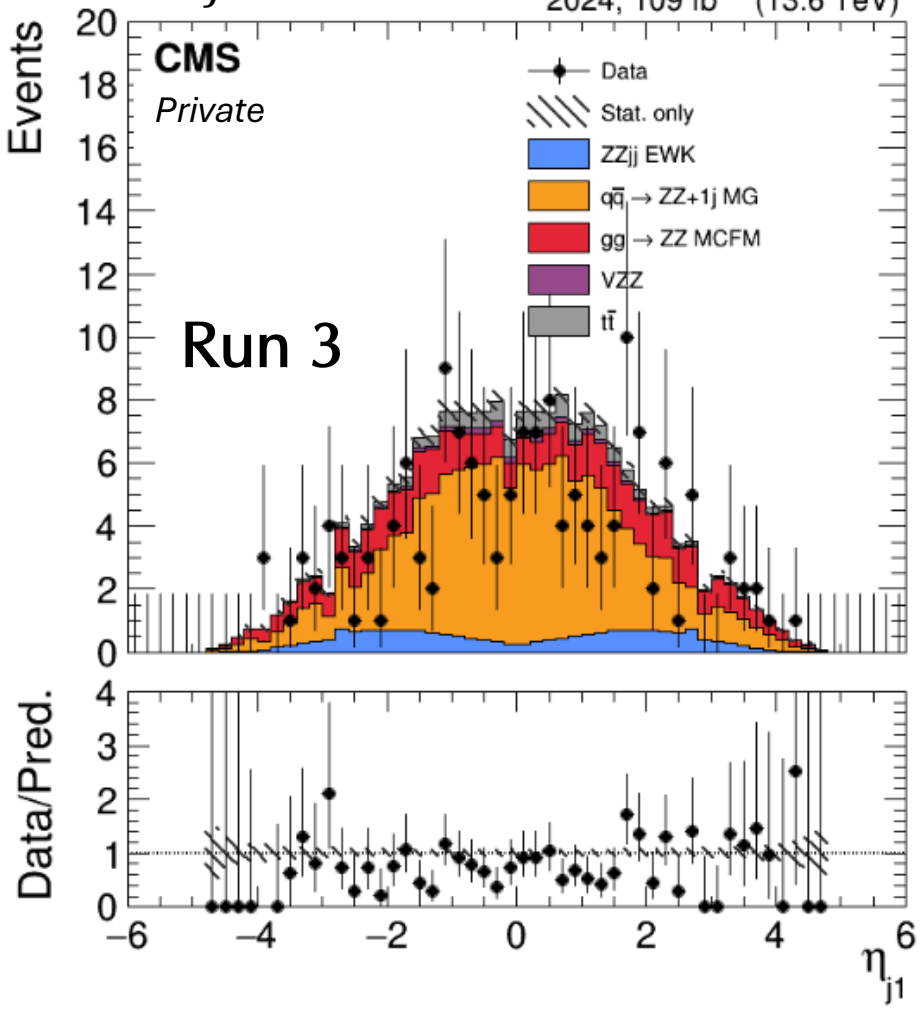
m_{Z1}



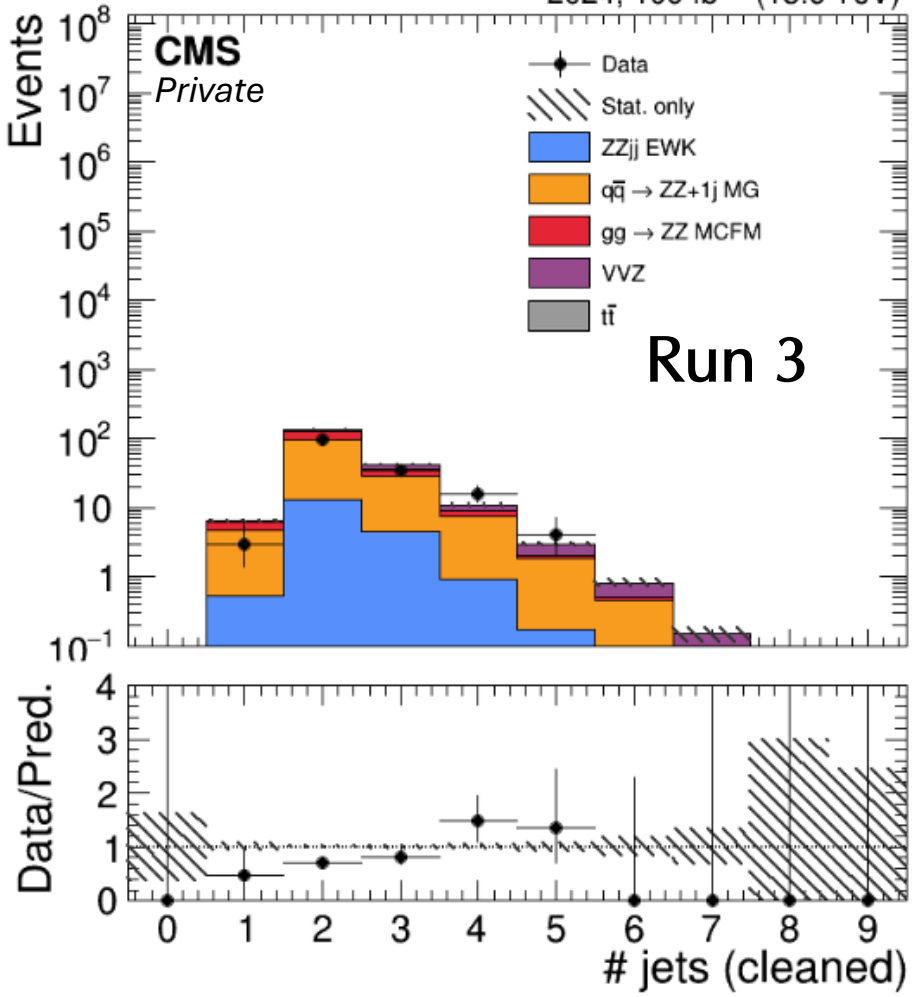
Run 3 (2022 - 2026) plots

My work with Run 3

η_{j1}

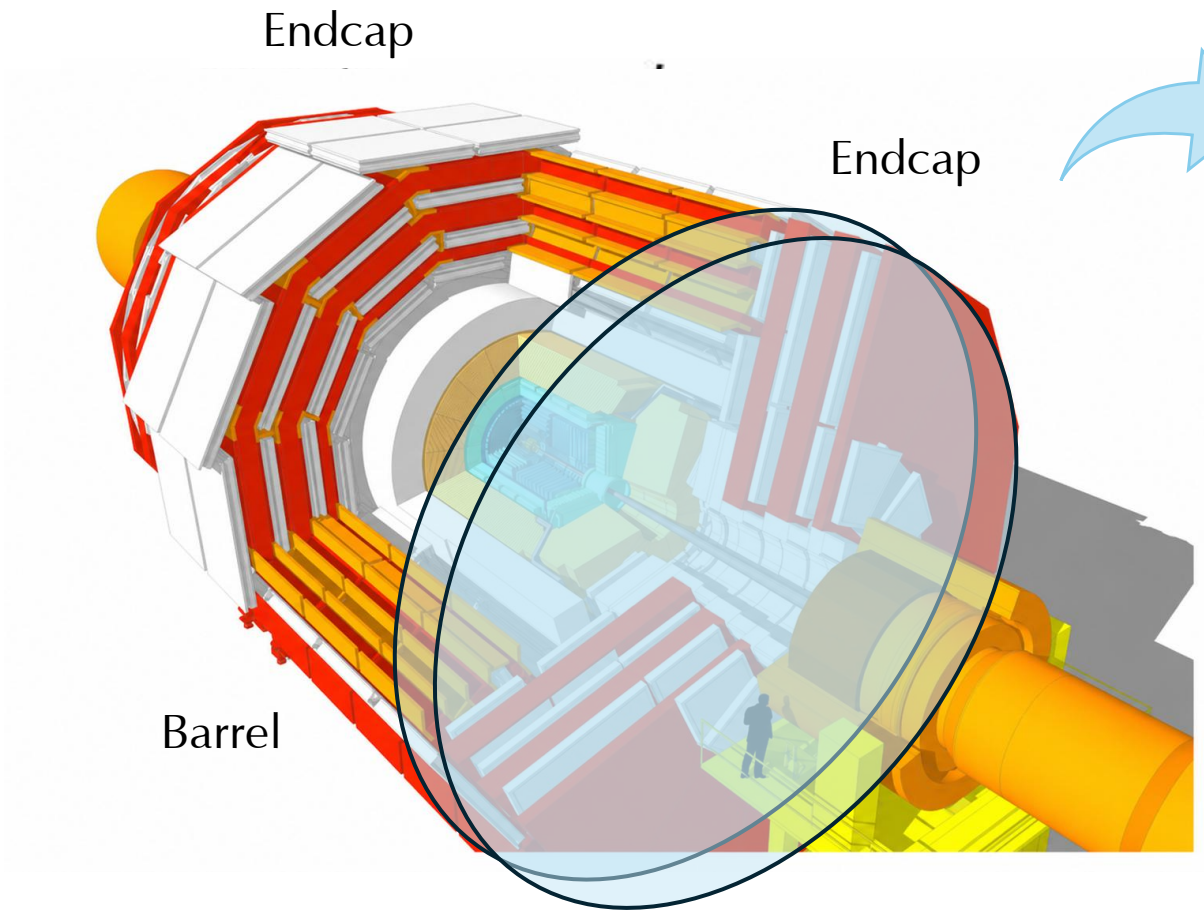


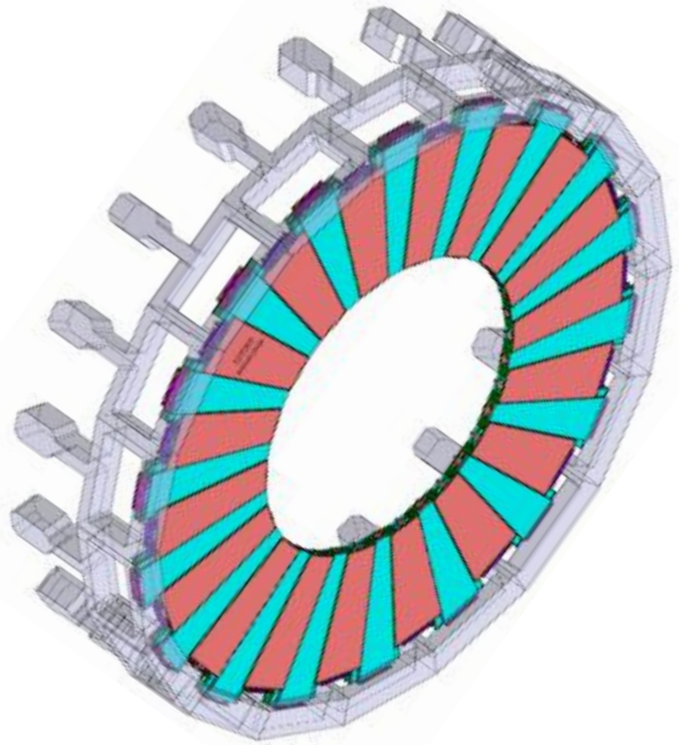
$n\ jets$



Run 3 (2022 - 2026) plots

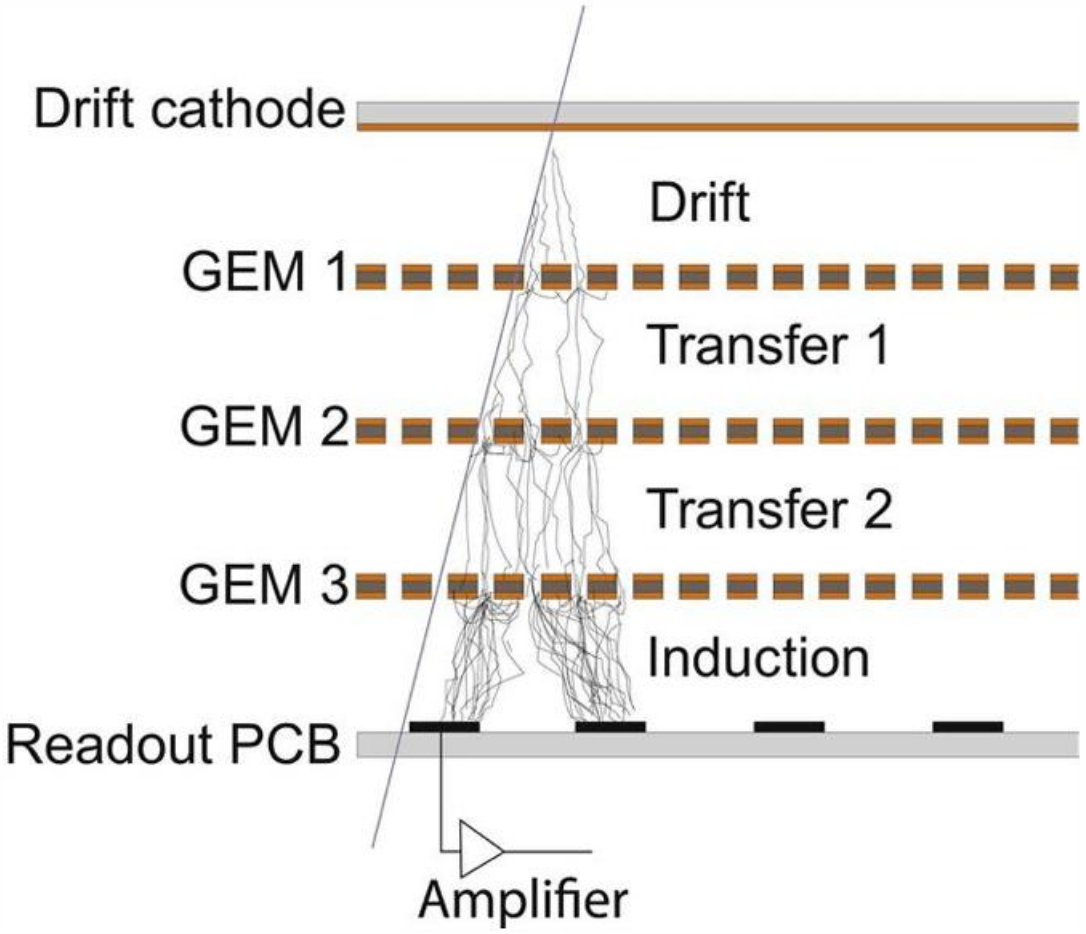
Triple GEM detectors in CMS



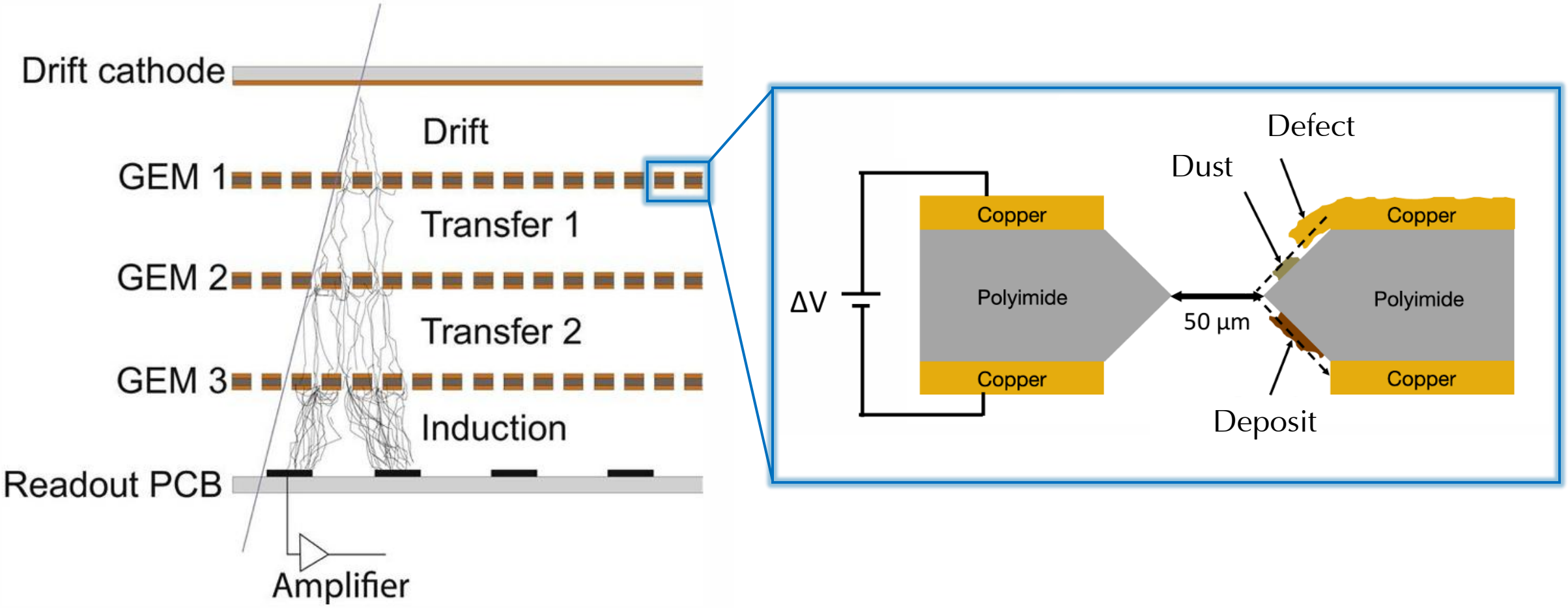


Triple GEM detector disposition in the endcaps

Triple GEM detector in CMS

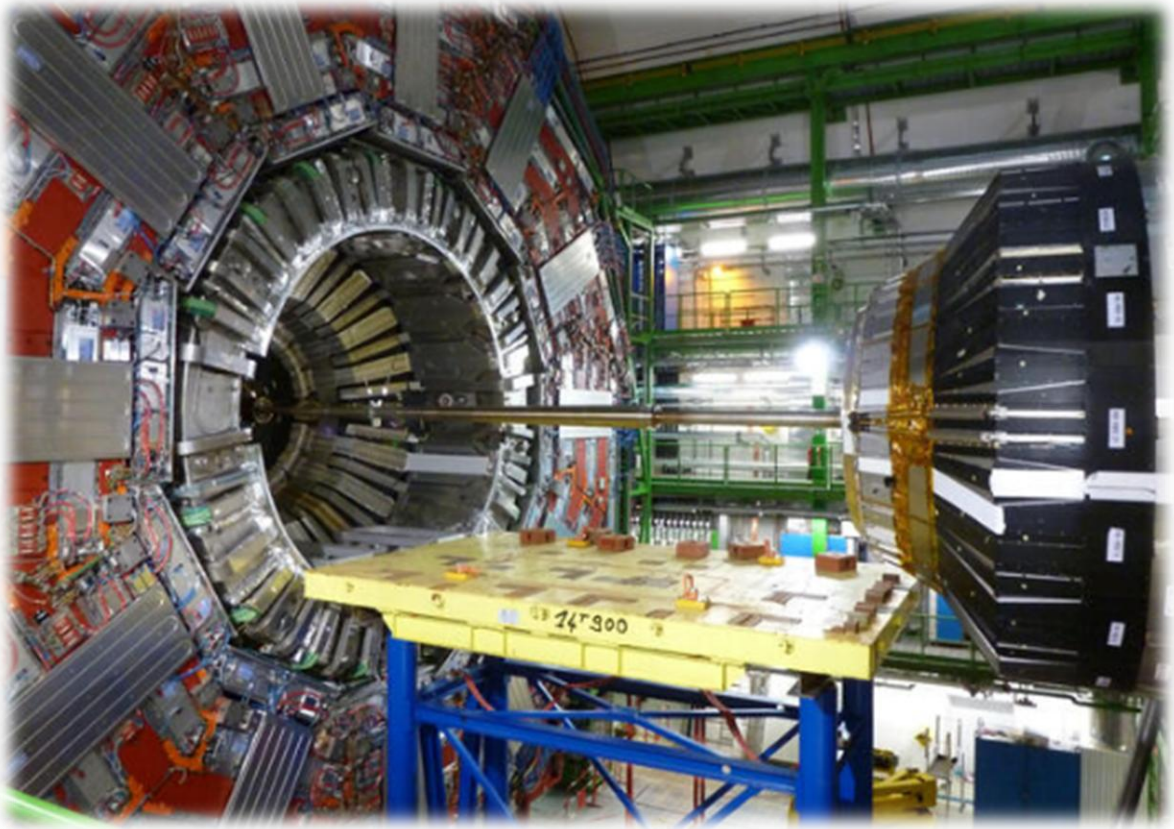


Triple GEM detector: short circuits problem



Triple GEM detector: Long Shutdown 3 (LS3)

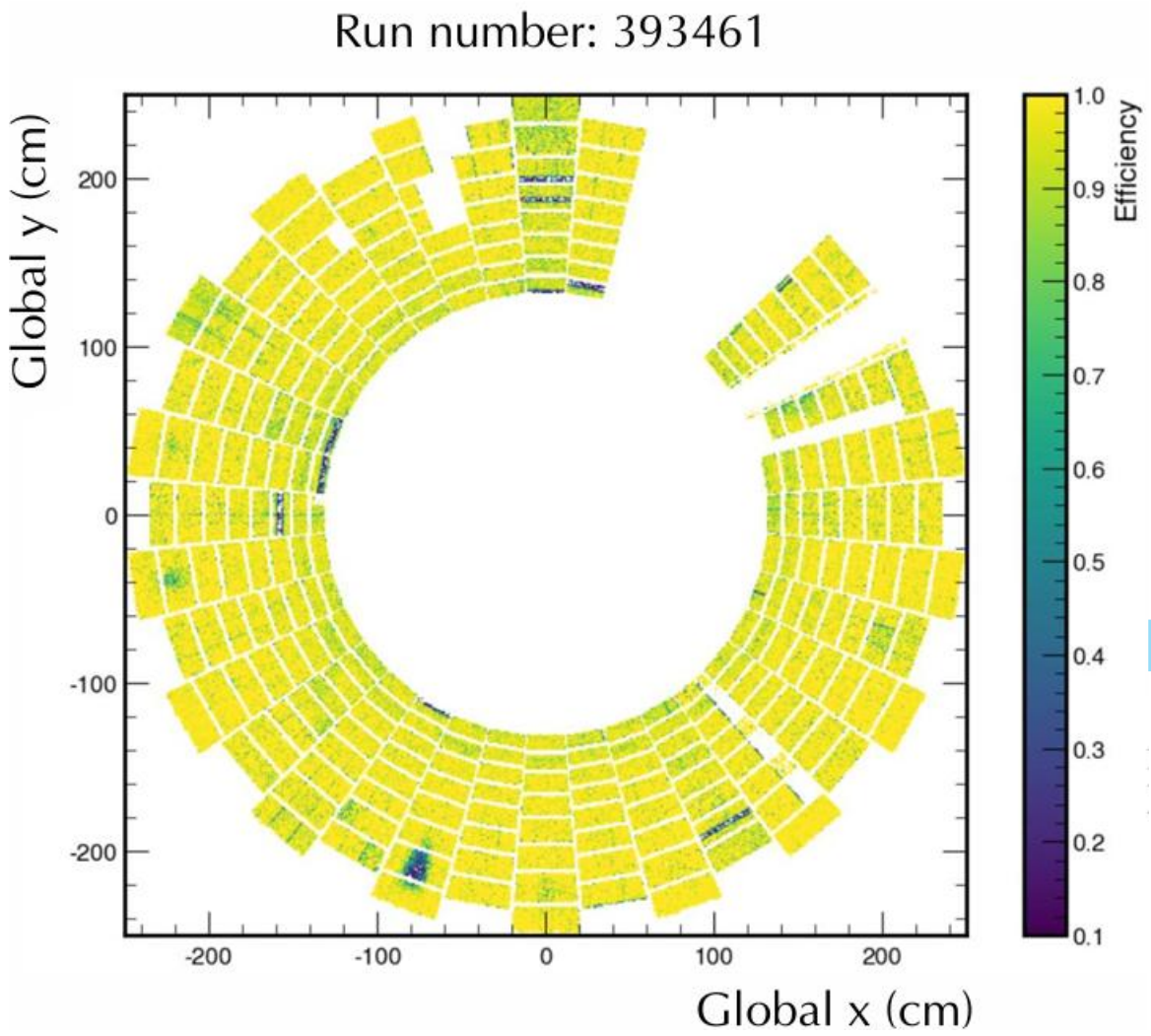
Long shutdown 3 (2026 – 2030)



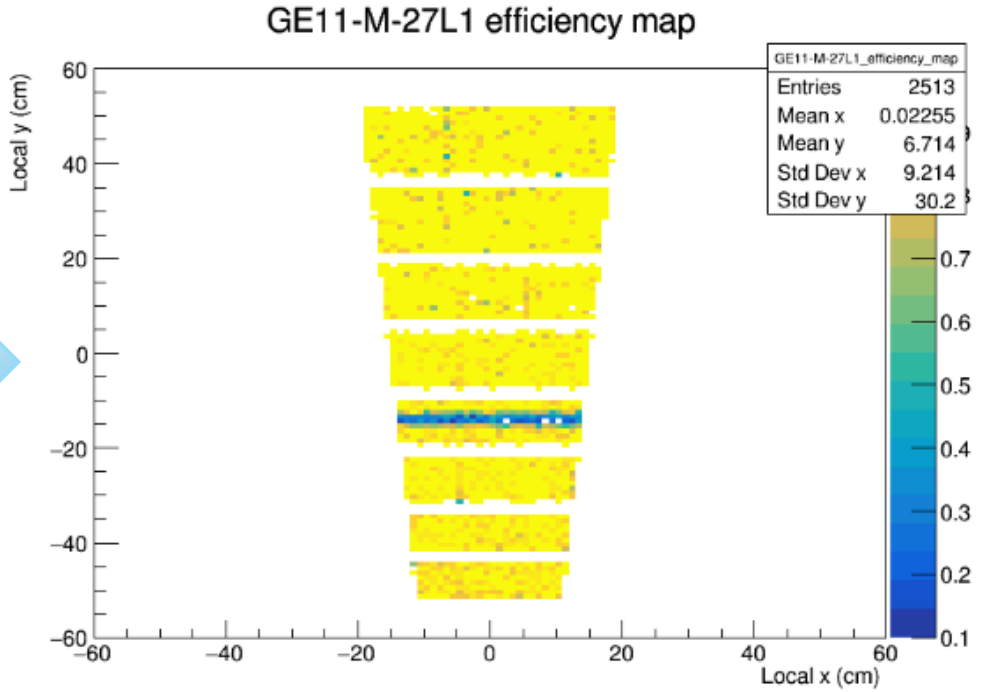
- No beam for 4 years
- GEM detectors will be removed and repaired

Which chambers should be prioritized?

Triple GEM detector: efficiency and performance



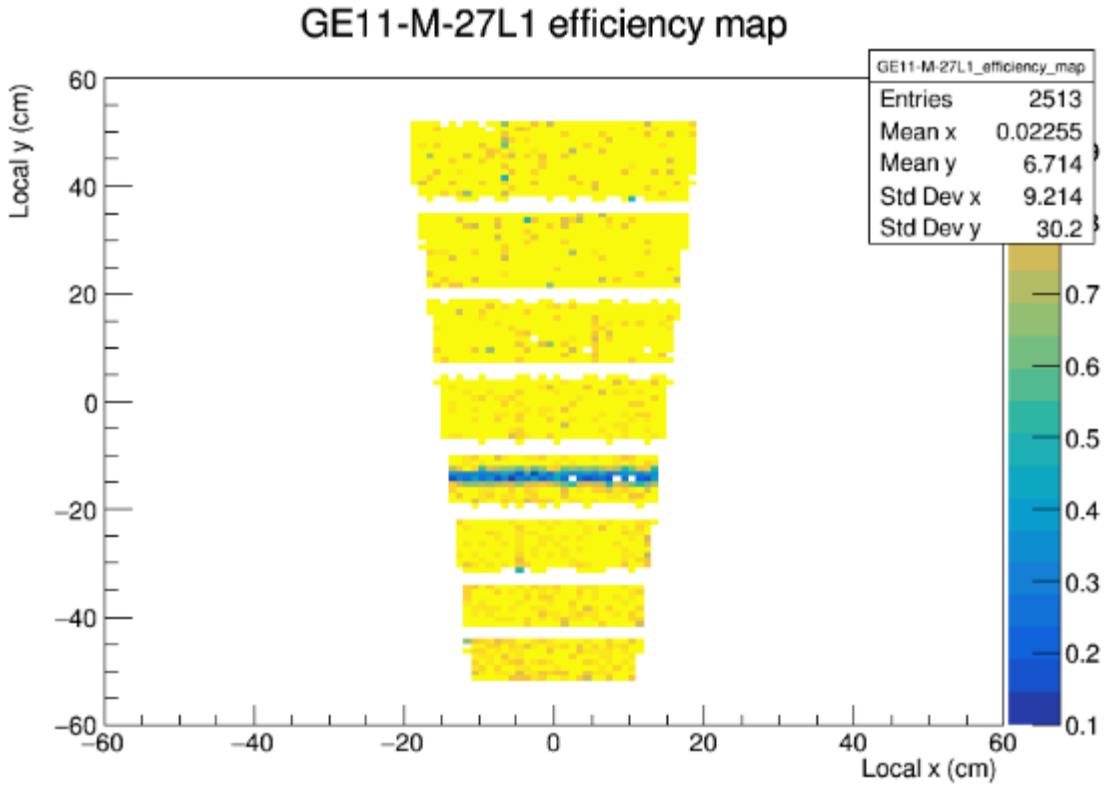
First step: identify shorts from data



Blue line is shorted HV sectors

Triple GEM detector: efficiency and performance

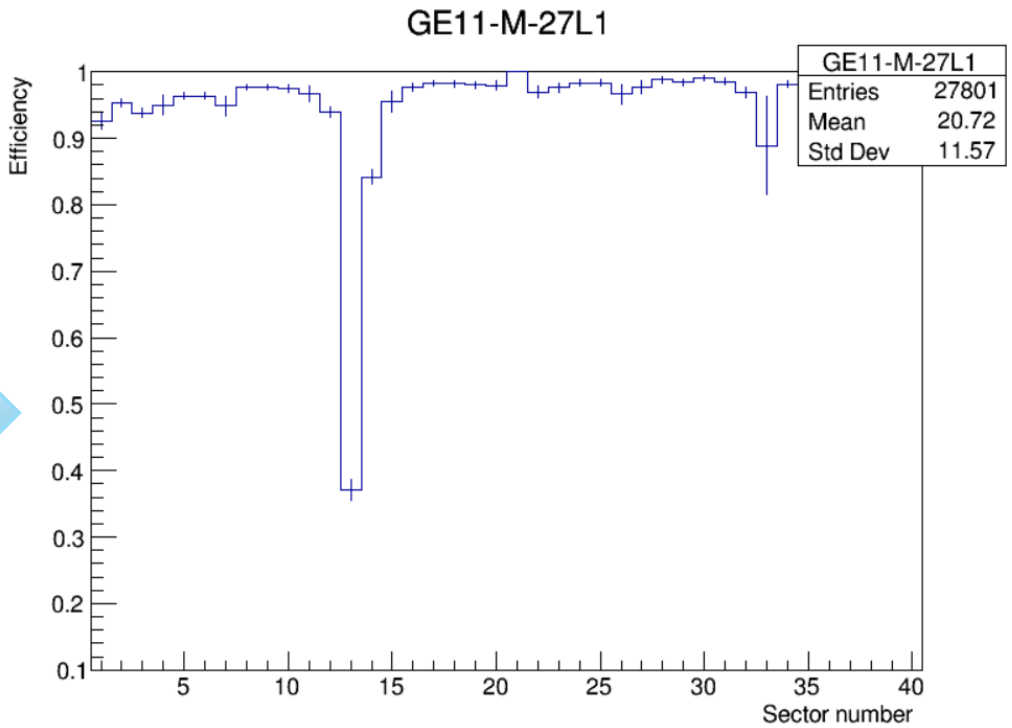
Efficiency plot



Blue strip is shorted HV sectors

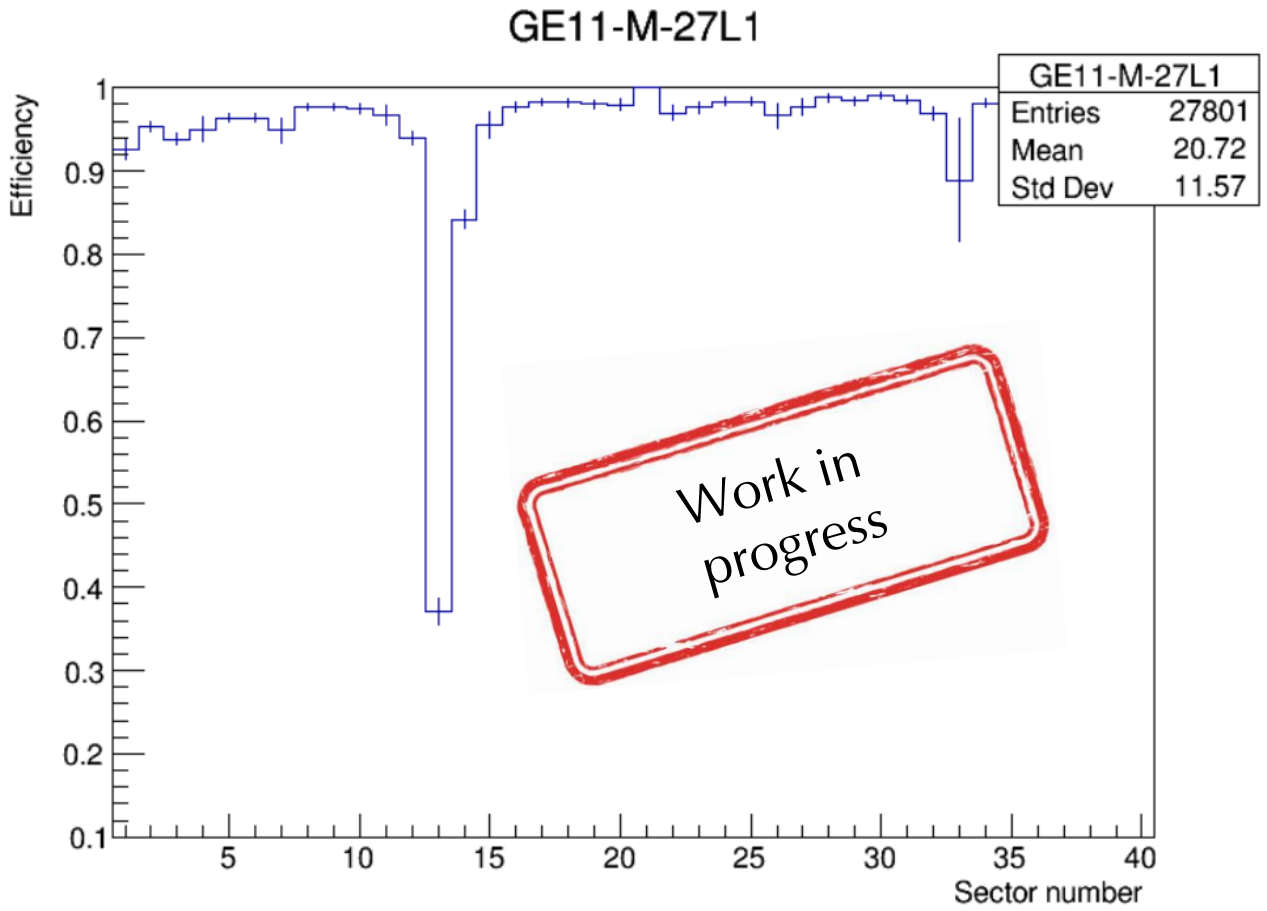
First step: identify shorts from data

Second step: performance evaluation



Triple GEM detector: efficiency and performance

Efficiency plot



First step: identify shorts from data

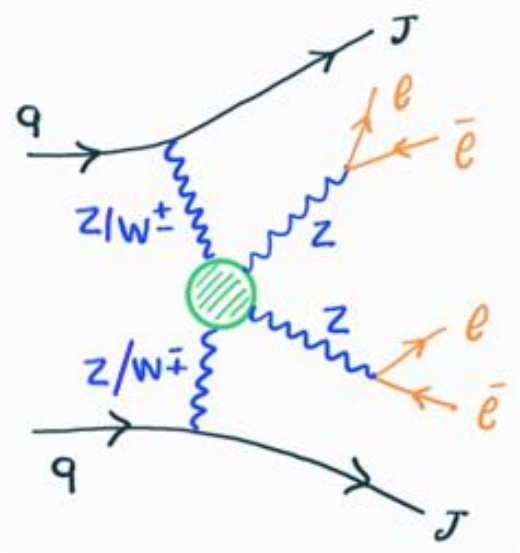
Second step: performance evaluation

Third step: performance evaluation over time

Conclusions

VBS Analysis

- Improve selection
- Improve the cross-section by reducing statistical uncertainty
- Improve significance



Detector performance

- Refine the short-circuit detection algorithm
- Automate the algorithm to monitor performance over time
- Prioritize chamber repairing during LS3