Search for New Physics at LHC

Same-Sign Dileptons and Jets

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Outline

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  - Large Hadron Collider
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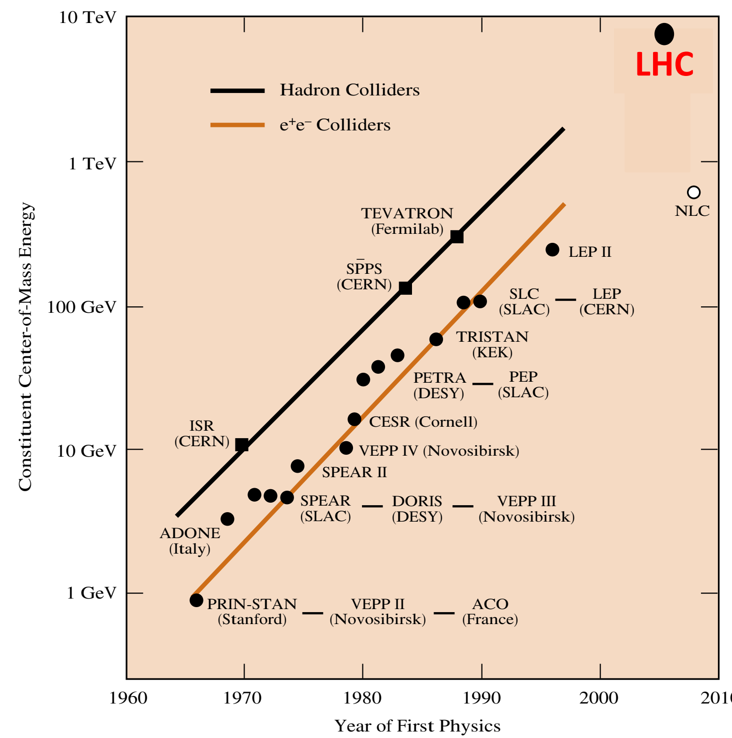
Background

Goal of High Energy Physics (HEP)

- **To study the fundamental constituents of matter and their interactions**

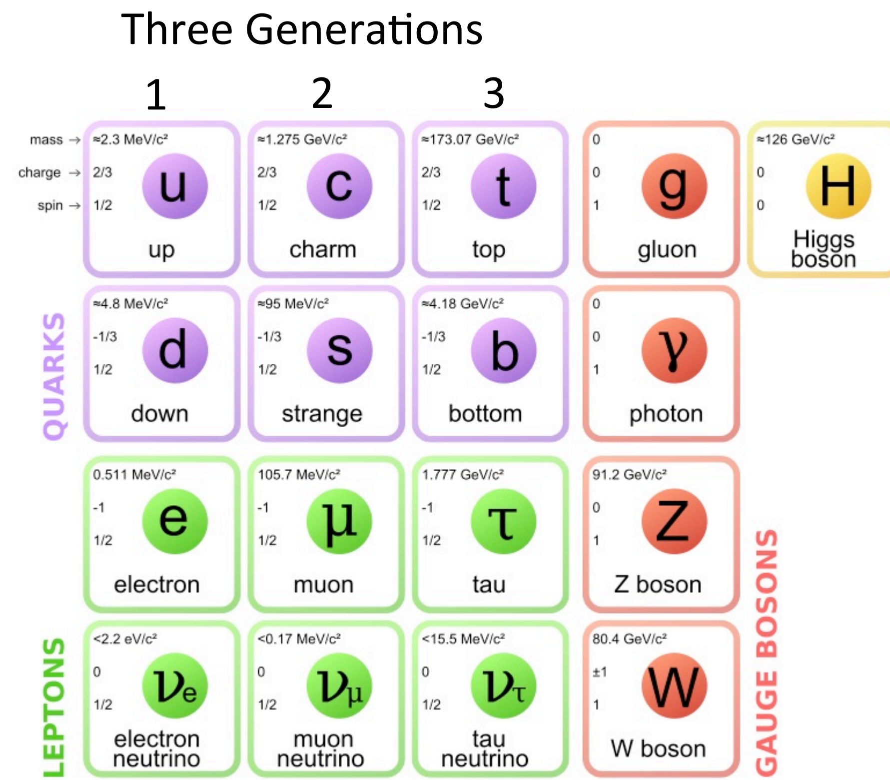
- Many milestones in particle physics over the last century
  - 1897: electron
  - 1911: atomic nucleus
  - 1932: positron (anti-electron)
- Starting in 1960s, probe inside the proton/neutron
  - Collide particles and study the outcome
  - Need higher energy probes
- The available energy has steadily increased over last 50 years
  - ~1 GeV → 8 TeV
  - 1 GeV = 1.6 x 10^{-10} joules ≈ rest mass of the proton ($E = mc^2$)
- **So far, results are consistent with the Standard Model**



The **Standard Model** of Particle Physics

- **Standard Model (SM) is the current theoretical framework for understanding the fundamental particles and how they interact.**

- Uses a Quantum Field Theory
  - Special Relativity + Quantum Mechanics
- Model to describe matter + interaction
  - Electromagnetic (photon)
  - Strong Interaction (gluon)
  - Weak Interaction (W and Z)
  - Higgs Boson
- **So far, all experiments have confirmed SM**

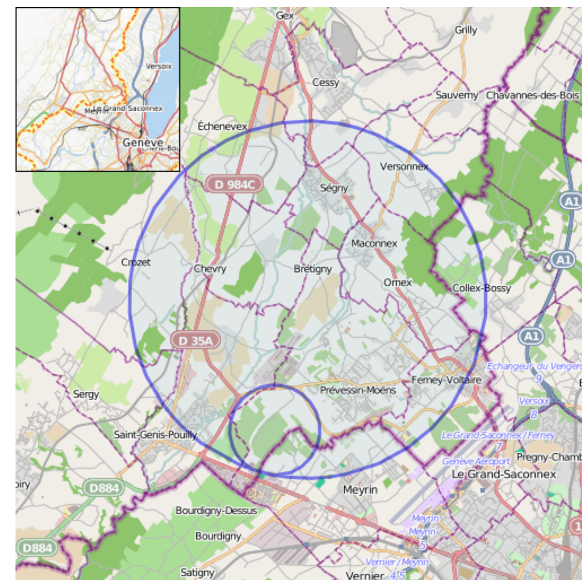


Issues with the Standard Model

- **Unexplained phenomena:**
  - Matter/anti-matter asymmetry
  - Dark matter
  - **Gravity not included!**
  - Hierarchy Problem
    - The observed Higgs mass lighter than expected
    - Requires unlikely delicate cancellation

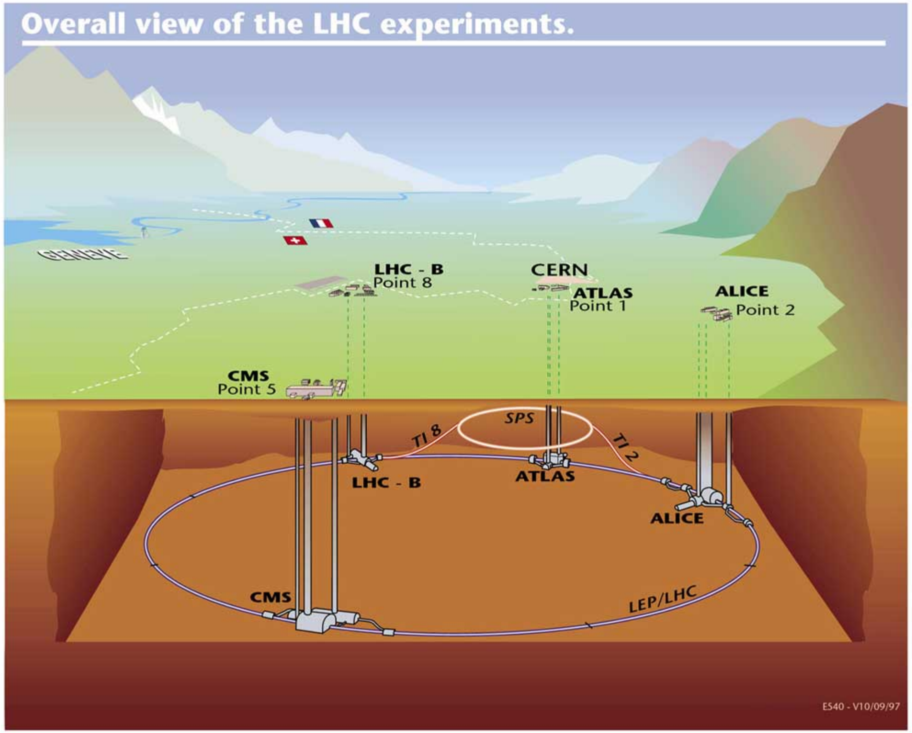
Large Hadron Collider (LHC)

- Completed in 2008
- Began operation in late 2009
- Investigate the mechanism for electro-weak symmetry breaking
  - Higgs Boson
  - First evidence of discovery was in summer 2012
- **Investigate physics beyond the Standard Model**
  - This analysis is one of them…



LHC Details

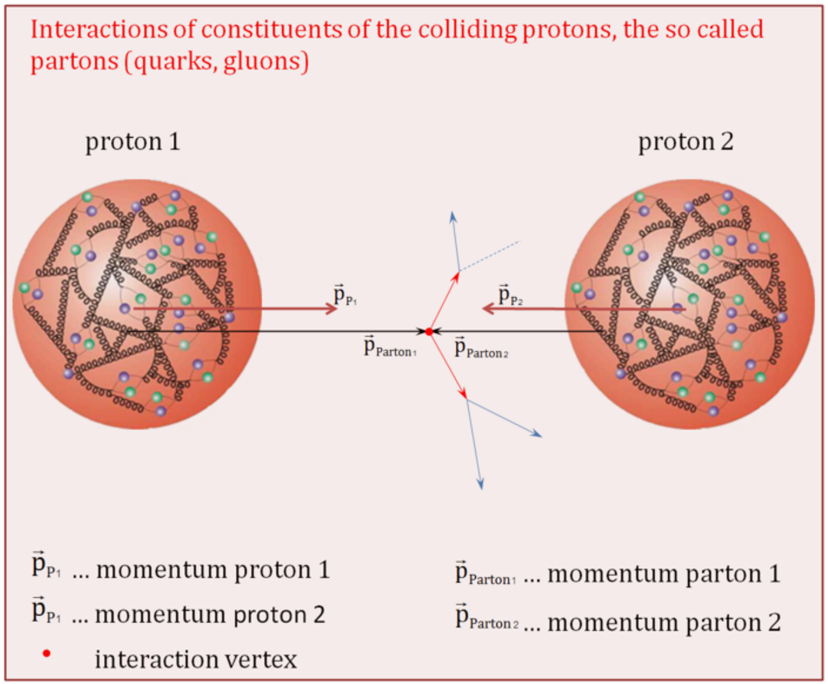
- **proton-proton (pp) collider**
  - 27 km circumference
  - 100 meters underground
  - Provides collisions for several general purpose and specialized experiments
- **Designed to operate at √s = 14 TeV**
  - Currently operated at **√s = 8 TeV**
  - Accelerate protons to 0.999999992c
  - **Large energy needed to produced very massive particles to probe physics at the TeV scale**
- **Designed to have a high luminosity**
  - O(10^8) collisions per second
  - **Large collisions rates needed to observe rare processes (e.g. Higgs production)**

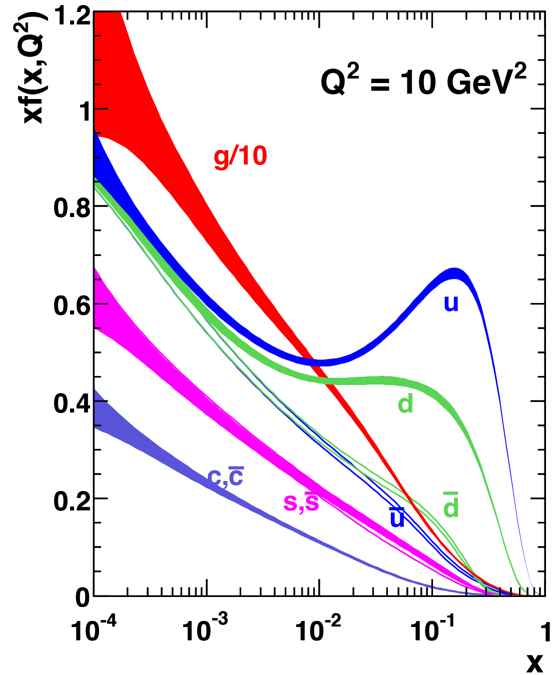


Proton Collisions at a Hadron Collider

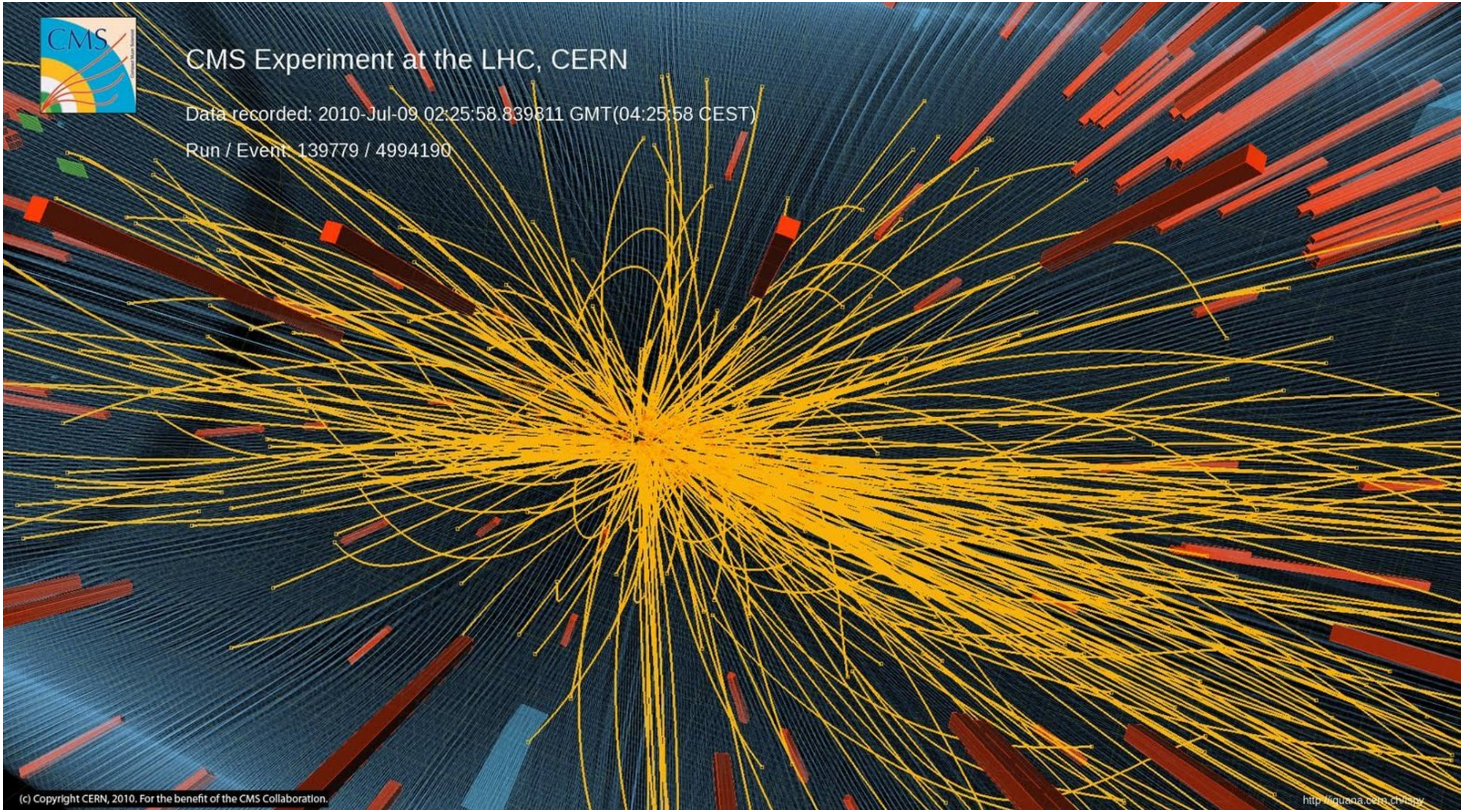
- **It is the protons' constituents that actually collide**
- **Protons are bound states:**
  - quantum bound state of quarks, antiquarks, and gluons (partons)
  - The momentum fraction (x) is probabilistically given by PDF (e.g. bottom right)
- **The initial momentum of the collisions is UNKNOWN**

$$x = \frac{p_{\text{parton}}}{p_{\text{proton}}}$$



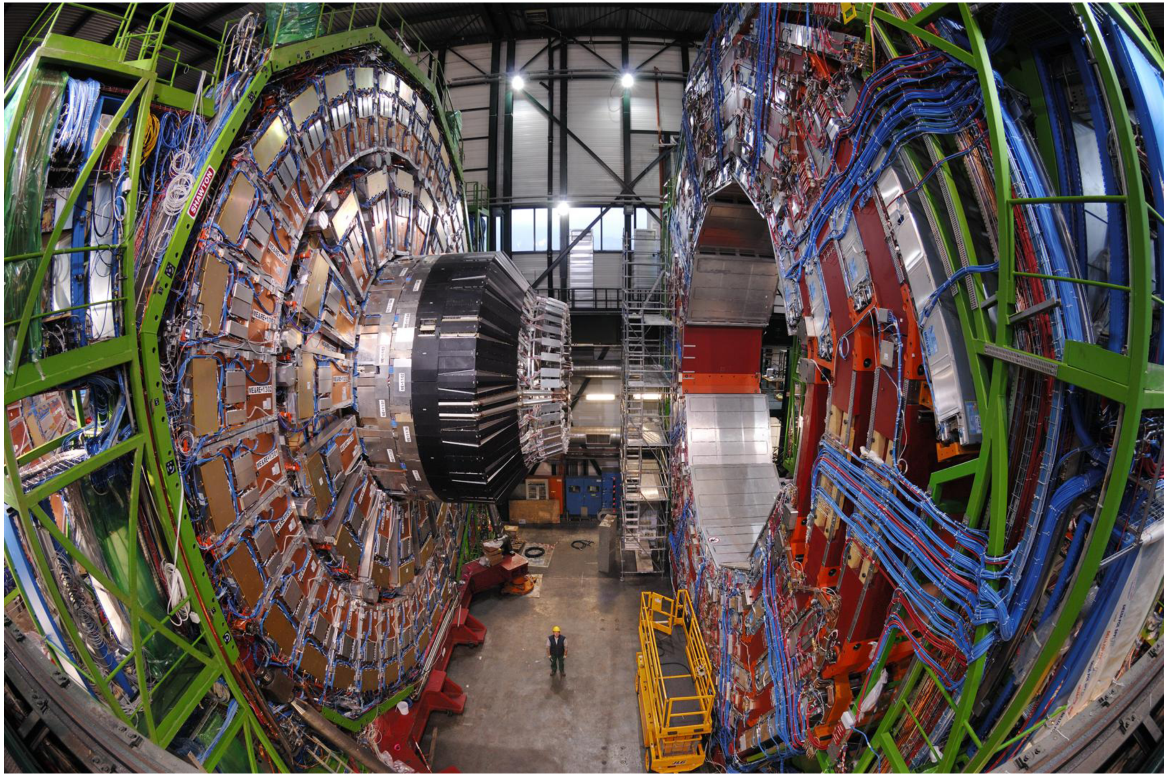


Compact Muon Solenoid (CMS)



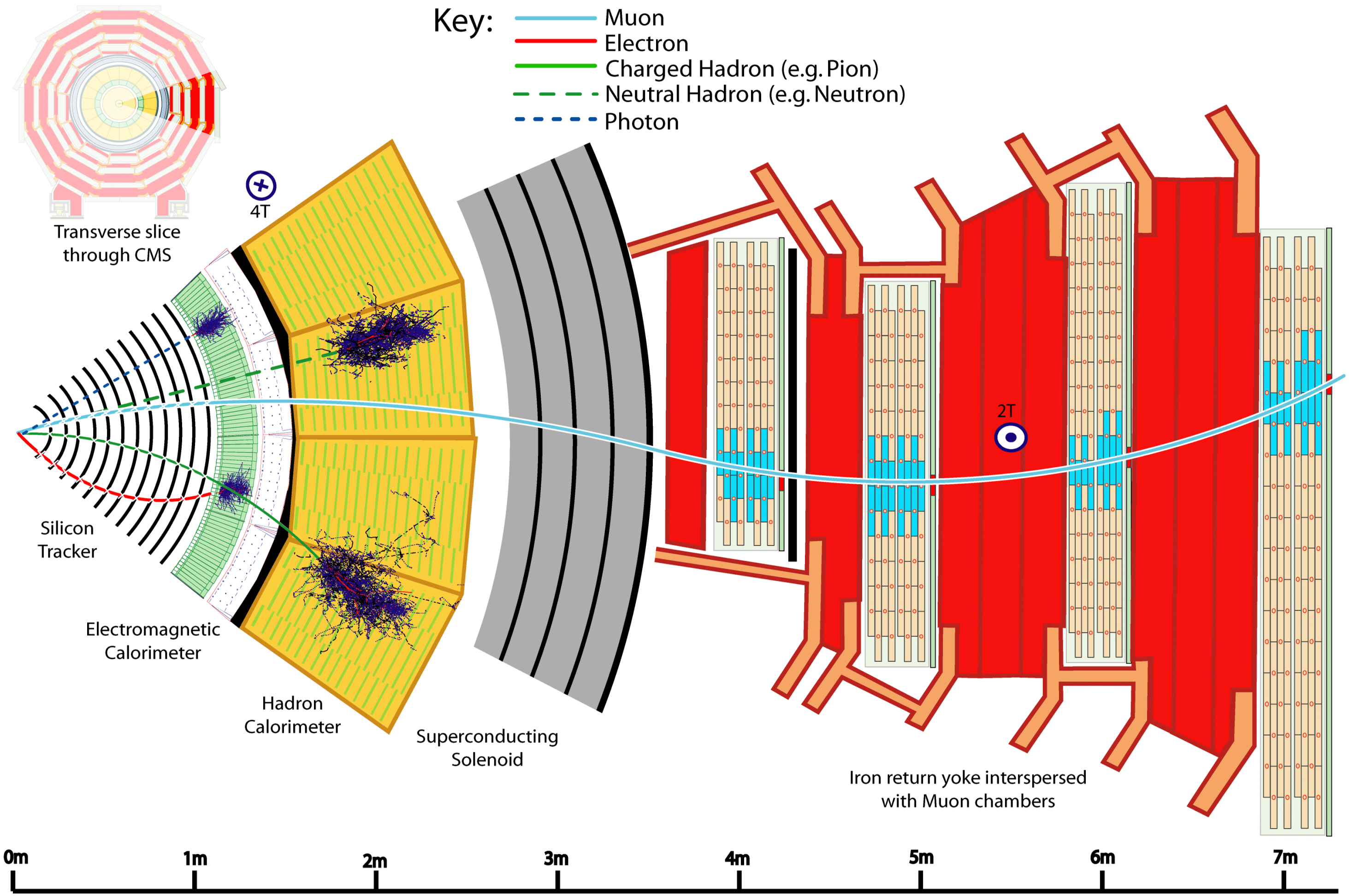
Compact Muon Solenoid (CMS)

- General Purpose Detector
  - 15 m in diameter
  - 12,500 tons
- **Detect and record the outcome of the pp collision**
- Collaboration of over 42 countries
  - ~3,800 people



Reconstructed Objects

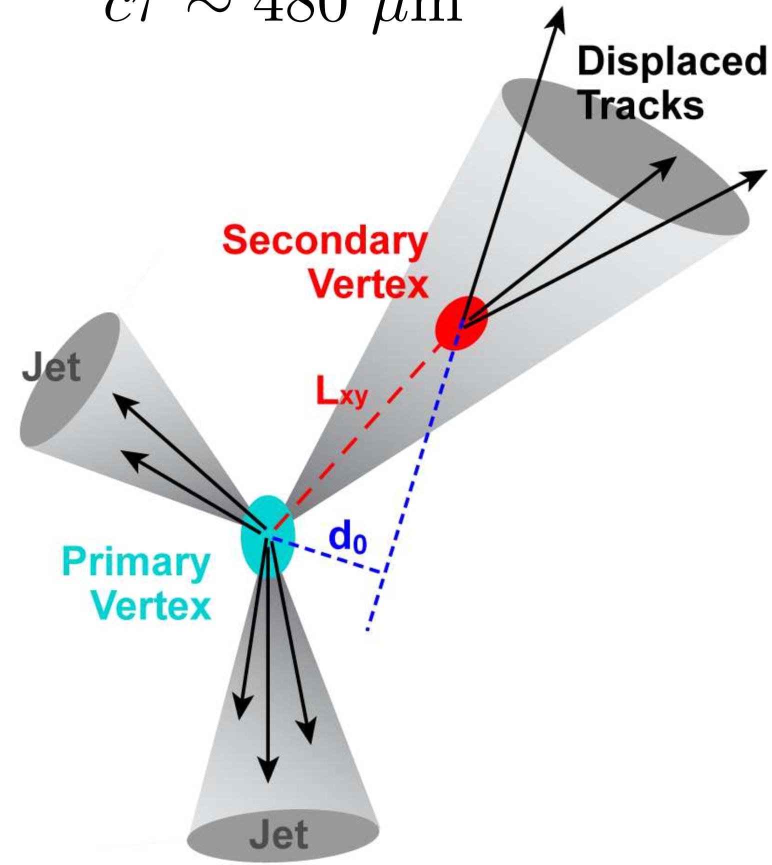
- Electrons shower in ECAL → deposit full energy
- Hadrons shower in HCAL → deposit full energy
- Muons are minimum ionizing → pass through detector
- Weakly interacting particles pass through detector without interacting



Jets from Heavy Flavor Decays

- **Heavy flavor (HF) hadrons (e.g. b-hadrons) have a long decay length**
  - Travel some distance inside tracker before decaying
- Identifying b-hadrons allows us to differentiate between final states with and without HF decays
- Look for this secondary vertex and/or tracks with large impact parameters (d_0)
- **b-tagged jet**: jet originating from HF decays

$c\tau \sim 480\ \mu m$



Missing Transverse Energy

- Motivation:
  - Momentum of the initial state is unknown
  - However, has **zero** transverse momentum (p_T) and **is conserved**
  - Thus, the total p_T of all the **final state particles** must also be zero
- Missing Transverse Energy (E_T^{miss}) is defined

$$\vec{E}_T^{\text{miss}} = -\sum_{\text{particles}} \vec{p}_T$$

- $E_T^{miss} \neq 0$ indicates the presence of particles that **did not interact** with the detector
  - Particles that only interact only through weak interaction
  - e.g. neutrino

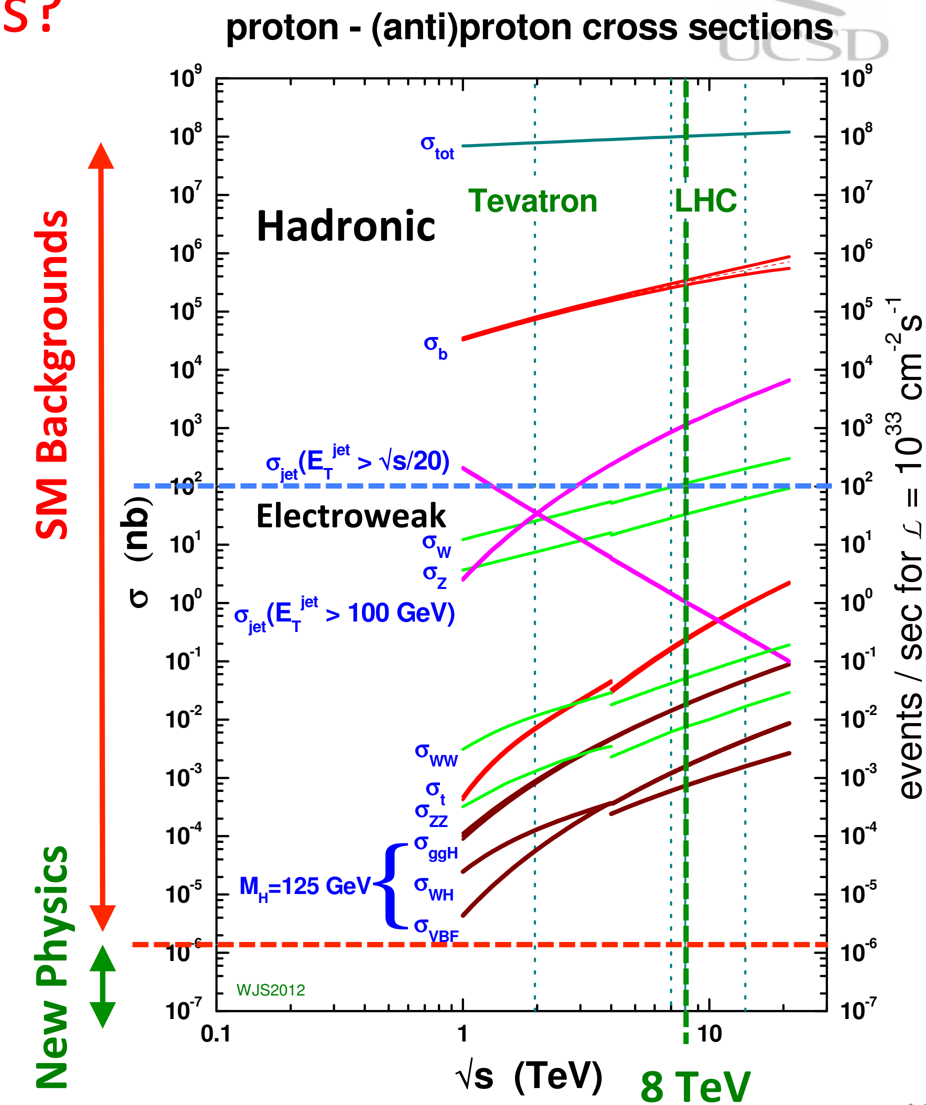
Motivation for Same-Sign Dileptons

Why Same-Sign Dileptons?

- **Same-Sign lepton pair (dileptons)**
  - The same electric charge

$$\boxed{pp \rightarrow \ell^{\pm}\ell^{\pm} + X}$$

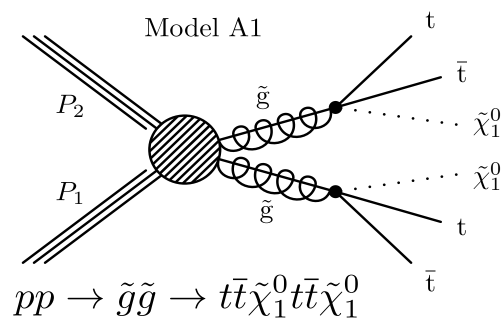
  - $e^{\pm}e^{\pm}$, $e^{\pm}\mu^{\pm}$, $\mu^{\pm}\mu^{\pm}$
- **Leptons are rare in SM**
  - EWK processes ($\alpha_W < \alpha_S$)
  - Cleanest experimental signature
- **Genuine dileptons more rare**
- **Genuine same-sign dileptons (SS) even more rare**
- **Good place to look for new physics**

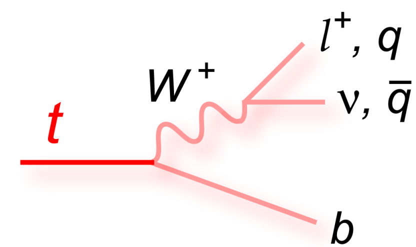


Example New Physics Model

- Popular new physics model is **Supersymmetry**
  - Each standard model particle has a supersymmetric partner (sparticle)
  - Gluino pair production (supersymmetric gluon)

Supersymmetry (SUSY)



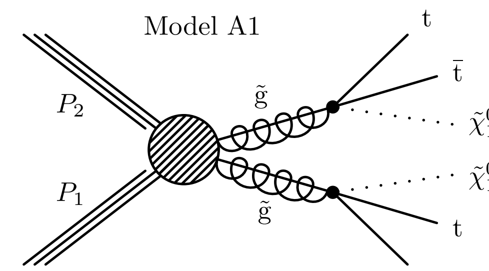


  - Can produce opposite-sign and same-sign lepton pairs in equal numbers
- Show up as **excess** w.r.t SM alone
- **This analysis presents a *general* search sensitive to a wide range of models that produce SS dileptons.**

Search Strategy

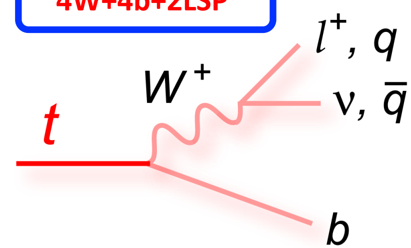
- **Counting Experiment: excess of events w.r.t SM indicates *new physics***
- **Observables:**
  - **Same-sign lepton pairs**
  - Significant hadronic activity
    - N_{jets} = count # jets,
    - N_{bjets} = count of jets originating from HF decays (b-tagged),
    - H_T = scalar sum of transverse momenta (p_T) of selected jets.
  - Missing Transverse Energy (E_T^{miss})
    - Supersymmetry models with R-parity conservation (LSP)
    - Dark matter candidates suggest a weakly-interacting and massive particle (WIMP)

Supersymmetry (SUSY)



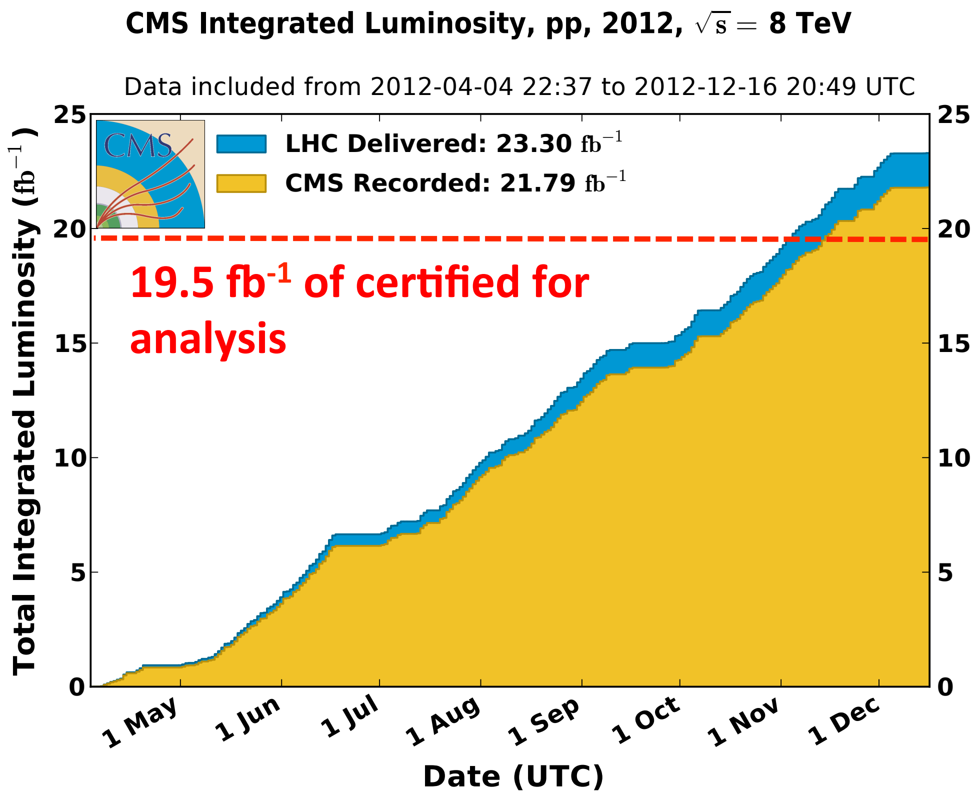
$$pp \to \tilde{g}\tilde{g} \to t\bar{t}\tilde{\chi}_1^0 t\bar{t}\tilde{\chi}_1^0$$

gluino production
4W+4b+2LSP



Event Selection

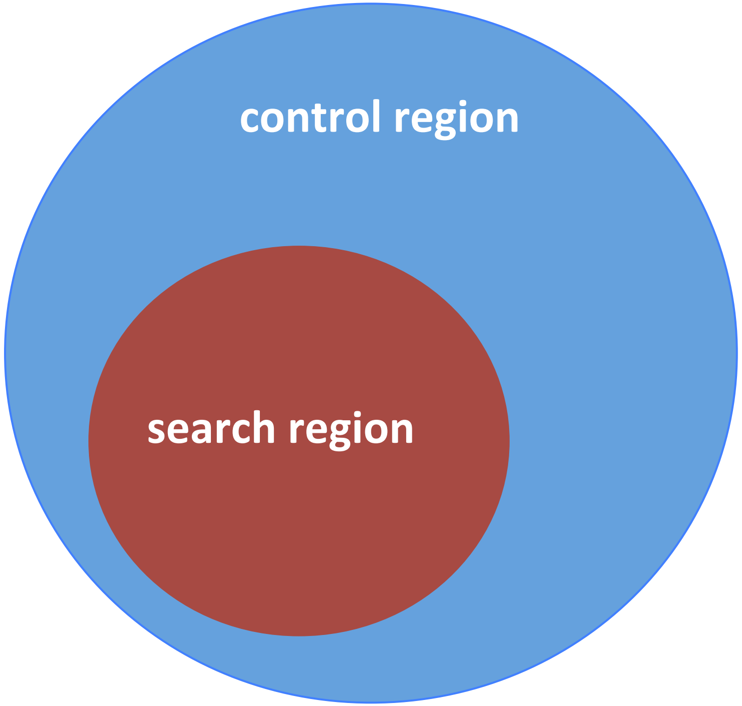
Data



- This analysis uses 19.5 fb^{-1} of integrated luminosity
- Collected during 2012

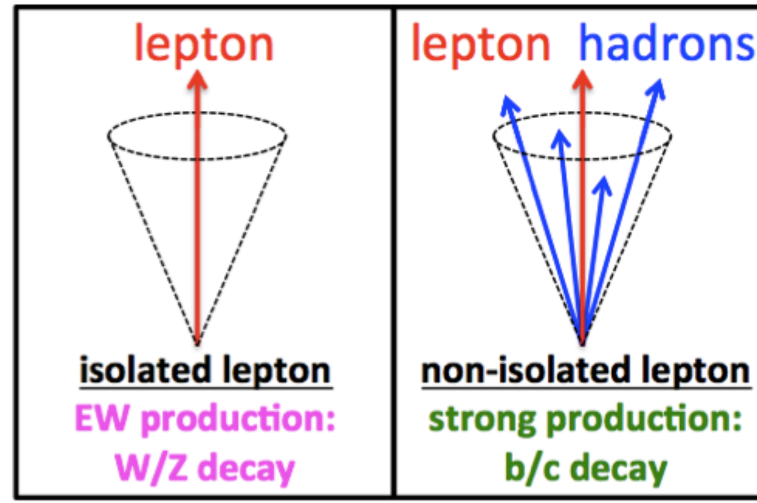
Selection Categories

- Control Region
  - loosest selection
  - used to test SM background predictions
- Search Regions
  - define tighter selection
  - independent exclusive regions
  - maximize the sensitivity



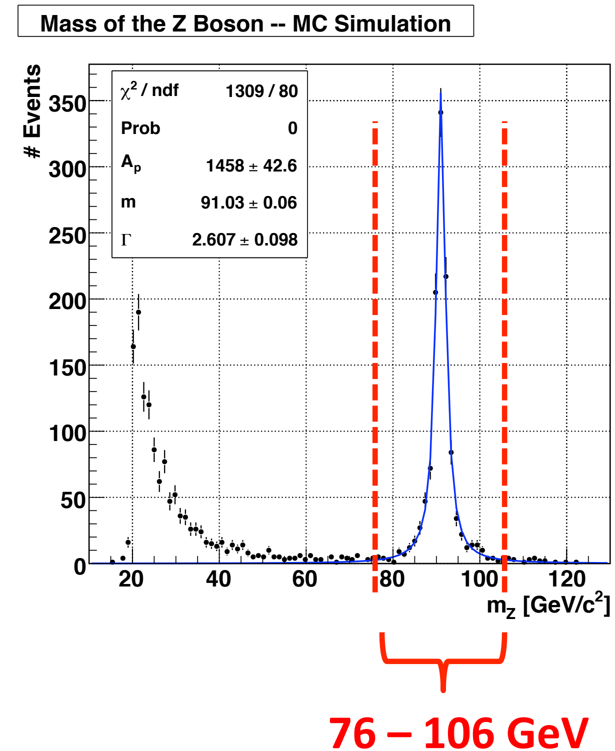
Lepton Selections

- **Require two leptons with the same charge (e/μ)**
- **Require leptons to be prompt and isolated**
  - leptons from heavy flavor decays and decays in flight are considered background for this search
  - We refer to non-prompt and non-isolated leptons as **fake leptons**
- **High p_T selections:**
  - $p_T > 20$ GeV



Remove Events with Z and γ^*

- **Suppress background with Z production (WZ, WWZ, ttZ, …)**
  - Veto events with
    - an additional lepton
    - Z candidate with either of the lepton from the same-sign pair
  - A Z candidate is defined
    - Opposite sign and same-flavor lepton pair (OSSF)
    - invariant mass within 76-106 GeV.
- **Suppress background from processes involving γ^* and HF bound states (Υ)**
  - Veto events with
    - an additional lepton
    - OSSF pair with either of the leptons from the same-sign pair
    - dilepton mass < 12 GeV.



Hadronic and E_T^{miss} Selections

- **At least two jets with $p_T > 40$ GeV**
  - Reject background with no leading order jets (e.g. Drell-Yan production)
  - Implies H_T to be at least 80 GeV
- **E_T^{miss} requirement (2 categories)**
  - if $H_T < 500$ GeV, then $E_T^{miss} > 30$ GeV
    - reject background from Drell-Yan, ZZ and QCD
  - if $H_T > 500$ GeV, then no E_T^{miss} requirement
    - Gives sensitivity to models with many jets and no intrinsic E_T^{miss}
    - e.g. R-Parity violating Supersymmetry models

Search Regions

- 24 exclusive search regions
- **Maximize statistical sensitivity**
  - 3 bins in N_{bjets}
    - 0 N_{bjets}, 1 N_{bjets}, and ≥ 2 N_{bjets}
  - 2 bins in N_{jets}
    - 2-3 jets and ≥ 4 jets
  - 2 bins E_T^{miss}
    - [50-120] and ≥ 120 GeV
  - 2 bins H_T
    - [200-400] and ≥ 400 GeV

SR01-08: N_{bjets} = 0

SR11-18: N_{bjets} = 1

SR21-28: N_{bjets} ≥ 2

High p_T Search Regions

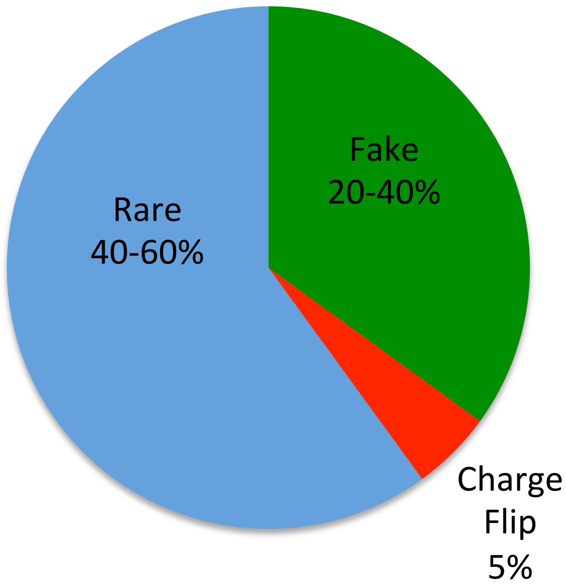
$N_{\text{b-jets}}$	E_T^{miss} (GeV)	N_{jets}	$H_T \in [200, 400]$ (GeV)	$H_T > 400$ (GeV)
$= 0$	50-120	2-3	SR01	SR02
		≥ 4	SR03	SR04
	> 120	2-3	SR05	SR06
		≥ 4	SR07	SR08
$= 1$	50-120	2-3	SR11	SR12
		≥ 4	SR13	SR14
	> 120	2-3	SR15	SR16
		≥ 4	SR17	SR18
≥ 2	50-120	2-3	SR21	SR22
		≥ 4	SR23	SR24
	> 120	2-3	SR25	SR26
		≥ 4	SR27	SR28

Standard Model Background Estimation

Background Sources

source

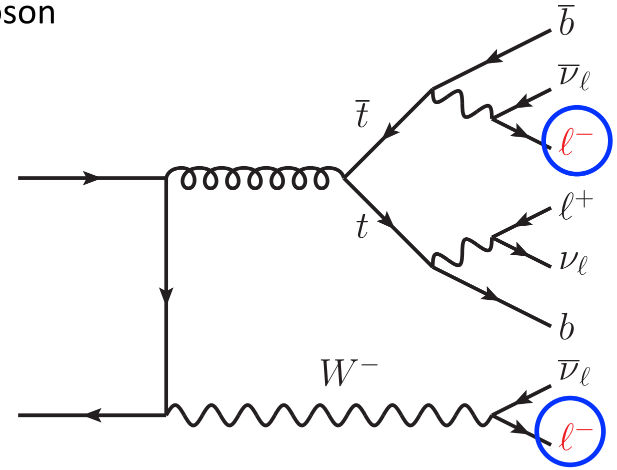
- **Genuine Same-sign dileptons (rare)**
  - Arise from rare SM processes
  - ~ 40-60% of the estimated background
- **Non-prompt lepton backgrounds (fake)**
  - **From heavy flavor decays (b/c)**, hadron misID, decays in flight, photon conversions
  - ~ 25-45% of the estimated background
- **Opposite-sign dileptons with one charge mis-identified (charge flip)**
  - negligible for muons
  - < 5% of estimated background



Sources of Rare SM

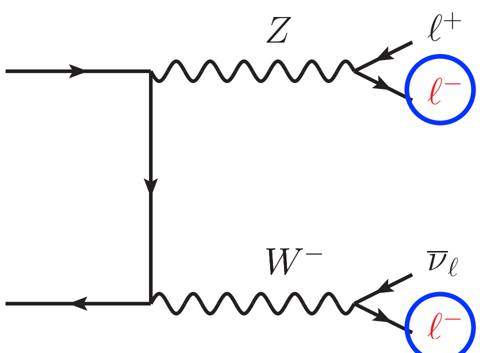
- **Top production with associated Gauge bosons**
  - One lepton from top decay and one from gauge boson

$$t\bar{t}W$$
$$t\bar{t}Z$$
$$t\bar{t}\gamma$$
$$t\bar{b}Z$$
$$t\bar{t}W^+W^-$$



- **Two Gauge bosons**
  - One lepton from each bosons

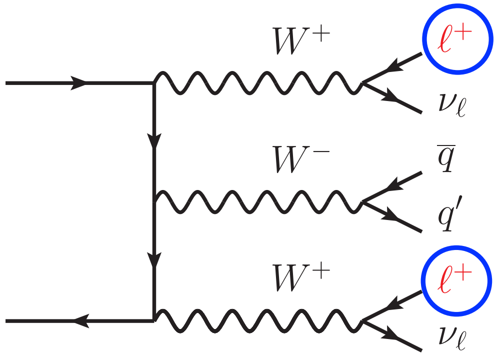
$$WZ$$
$$ZZ$$
$$W\gamma$$



Sources of Rare SM (cont.)

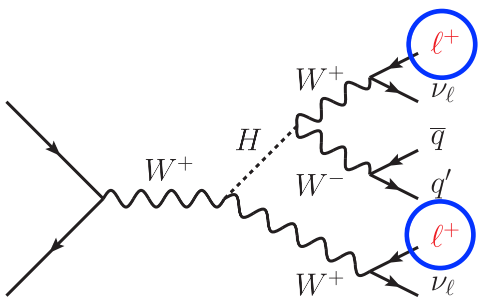
- **Triple Gauge Bosons**
  - Two from gauge boson decays

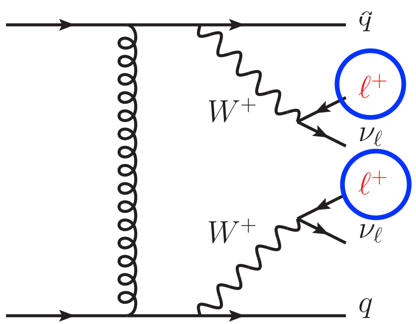
$$WW\gamma$$
$$WWW$$
$$WWZ$$
$$WZZ$$
$$ZZZ$$



- **Other rare processes**
  - Top and/or gauge boson decay

$WH, ZH, t\bar{t}H$
$qqW^\pm W^\pm$
$W^\pm W^\pm$ double parton scattering





Prompt same-sign background from rare SM processes

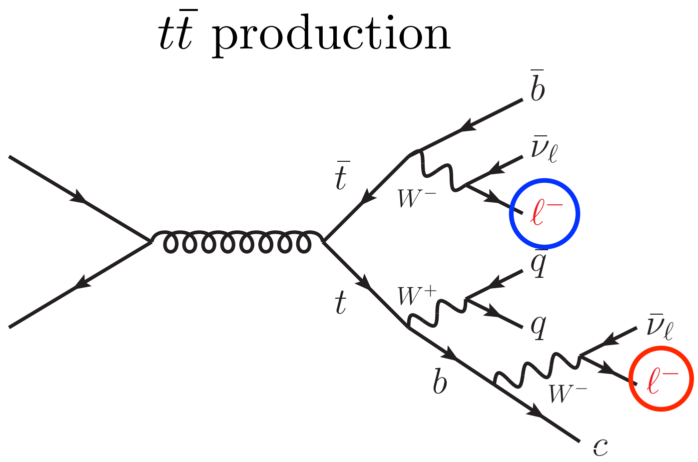
- **Predictions for rare SM processes are taken from simulation**:
  - All samples using Madgraph
  - Use next-to-leading order cross sections
  - Apply data-to-MC scale factors:
    - lepton ID and isolation efficiency
    - trigger efficiency
    - b-tagging efficiency
- **We take a flat 50% systematic uncertainty.**
  - Many of these processes have never or have barely been observed
  - Known inaccuracies in the H_T distributions for madgraph ttW → one of the dominant backgrounds [1]

[1] Campbell & Ellis arxiv:1204.5678

What is a "Fake" Lepton?

- **Real** lepton: W → ℓν or Z → ℓℓ
  - prompt and isolated
- **All other leptons considered Fake leptons**

- **Source 1:** Leptons from HF decays
  - e.g. bound state with b → Wc → ℓνc
  - ℓ is a actual lepton so it will pass identification criteria
  - hadronic system is boosted together (jet)
    - significant amount of energy surrounding the lepton
  - isolation provides the best handle to distinguish between real leptons



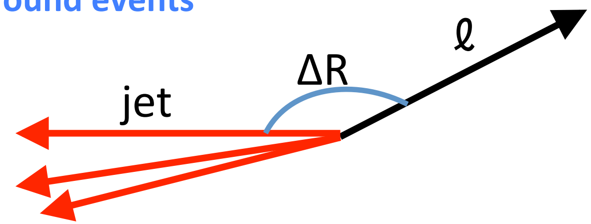
- **Source 2:** Hadrons mistakenly reconstructed as leptons
  - e.g. jets with $\pi^0 \rightarrow \gamma\gamma$ and $\pi^\pm$
  - Lepton identification is best handle to distinguish from a real lepton
    - Energy deposit shape differs between electron and π^0

Fake Rate Method

- **Use a data-driven method to estimate the amount of fake leptons**

$$\textbf{fake rate:}\quad \epsilon(p_T, \eta) = \frac{\#\ \text{leptons passing full selection}}{\#\ \text{leptons passing loose selection}}$$

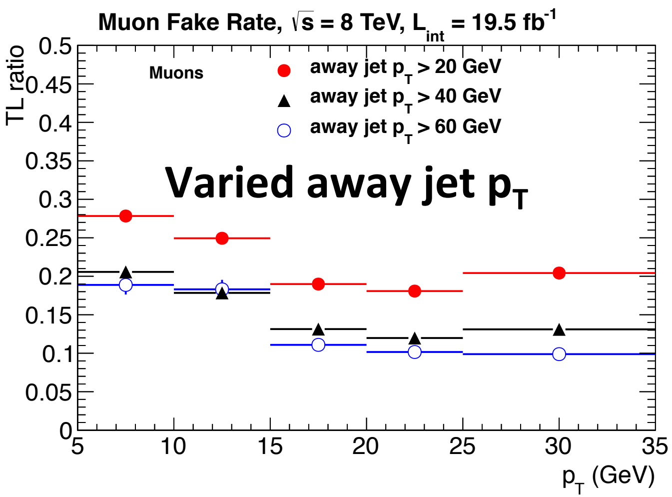
- **The loose selection extrapolates from the full lepton selection**
  - relax the **isolation** and **promptness**
- **We measure the fake rate in an independent data sample enriched in background events**
  - require an away side jet p_T > 40 GeV
    - acts as a proxy for the momentum of the underlying parton for the lepton

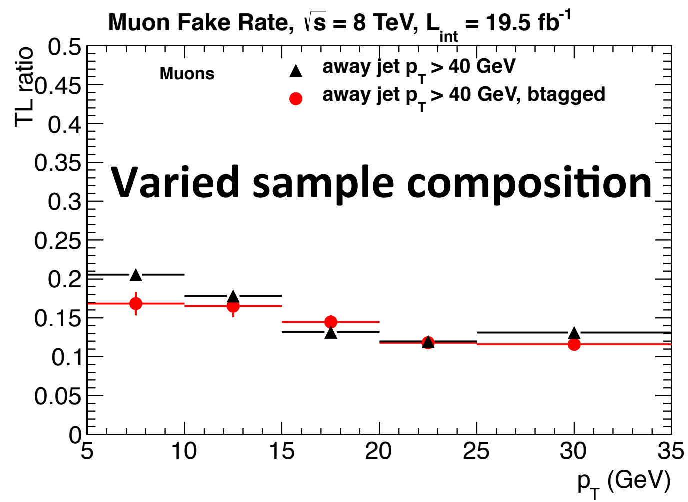


- **Additional requirements are made to reject events from W and Z decays**
- **To get the prediction:**
  - count events in data sample with leptons passing loose but not tight selection
  - weigh each event by the $\epsilon(p_T, \eta)$

Fake Rate Systematics

- **The fake rate is dependent on the p_T of the underlying parton (away jet) and the sample composition**

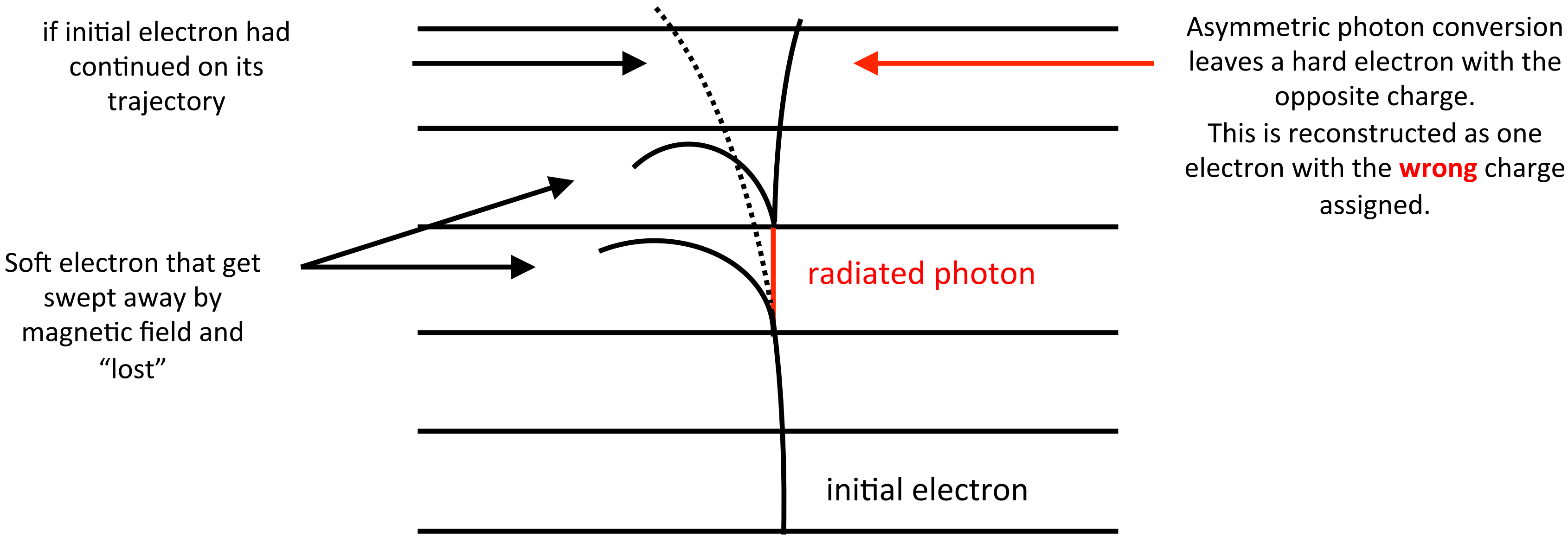




- We test the method in simulation by applying to a simulated sample with one fake lepton from a jet.
  - Over predictions by O(50%)
- Based on these studies
  - Assign 50% systematic uncertainty on the method

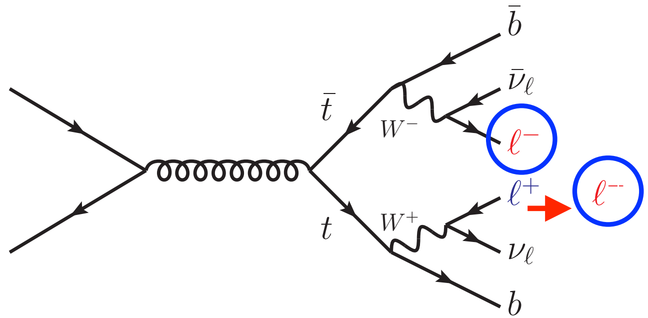
What is a "Charge Flip"?

- **Reconstructed electron with an incorrect charge assignment**



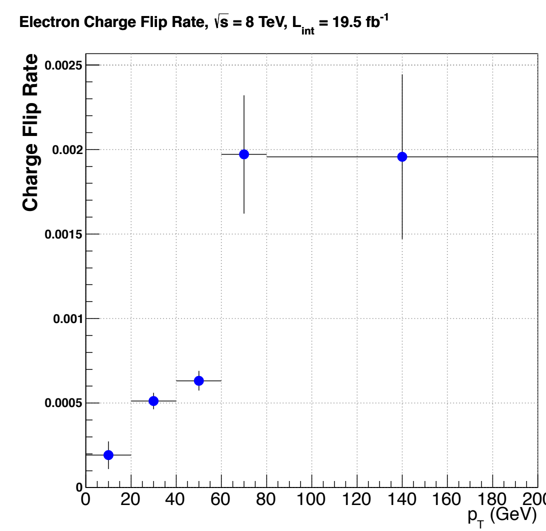
Background from Charge Mis-measurement

- Determine the charge mis-measurement rate using simulated events: $\epsilon(p_T, \eta)$
  - Negligible for muons
  - For elections: 10^{-3} - 10^{-4}
- **Predicted background using opposite sign sample in data:**



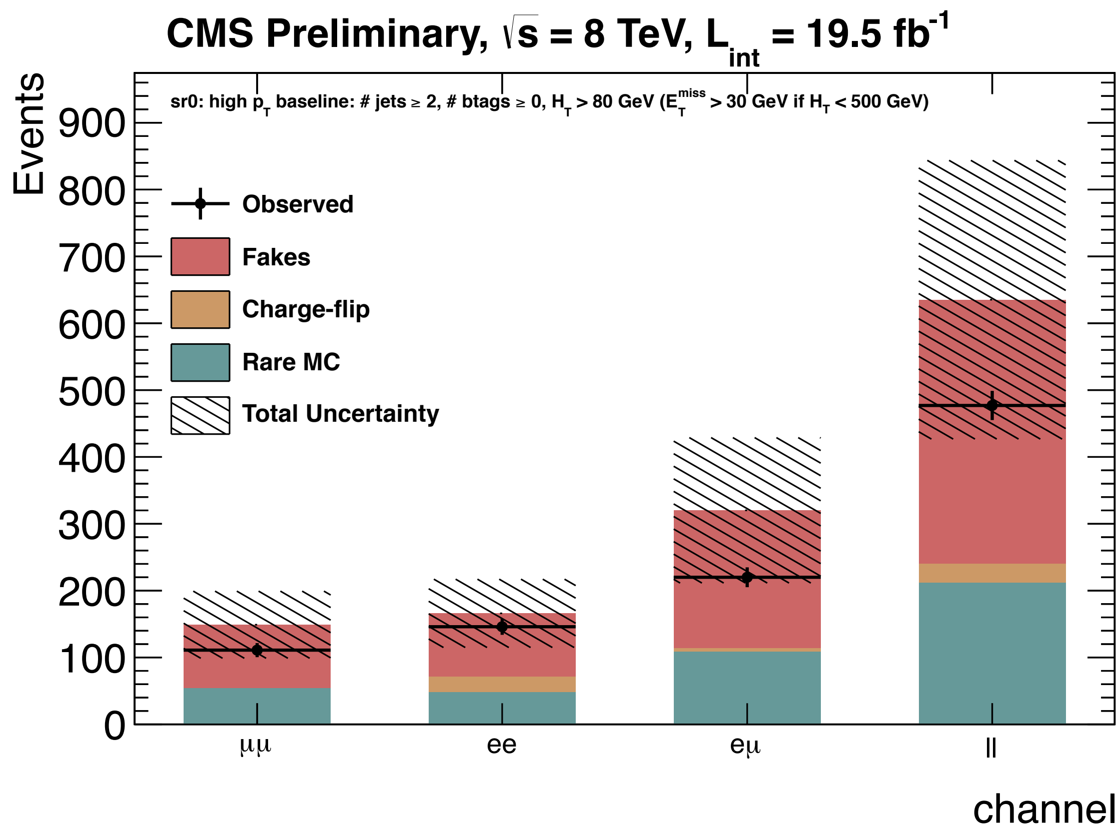
$$N_{\ell^\pm \ell^\pm} = N_{\ell_1^\pm \ell_2^\mp} \cdot \left(\frac{\epsilon_1}{1-\epsilon_1} + \frac{\epsilon_2}{1-\epsilon_2} \right)$$

- Apply a data-to-MC scale factor to account for underestimation in the simulation w.r.t data (1.39)
- **Assign a 30% systematic uncertainty on the estimate.**
  - Based on the size of the data-to-MC scale factor studied in the control region and the low stats at high p_T.



Background Predictions

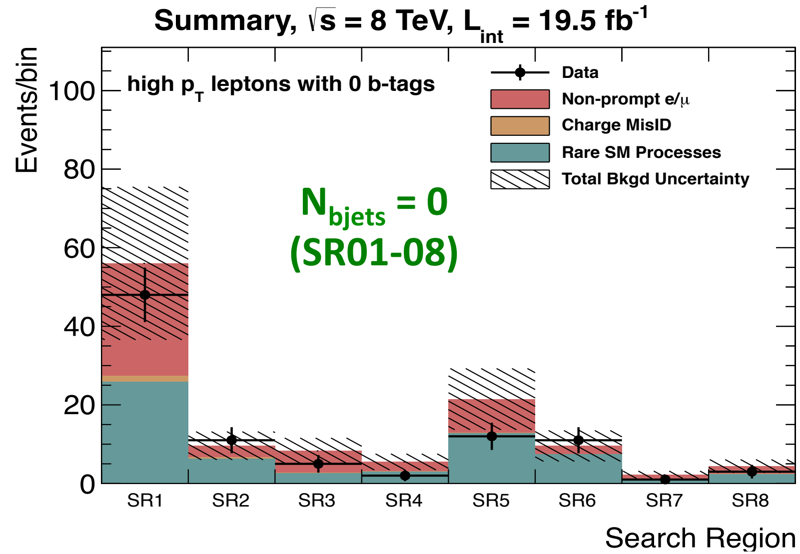
- **Control region predictions in good agreement with observed data.**

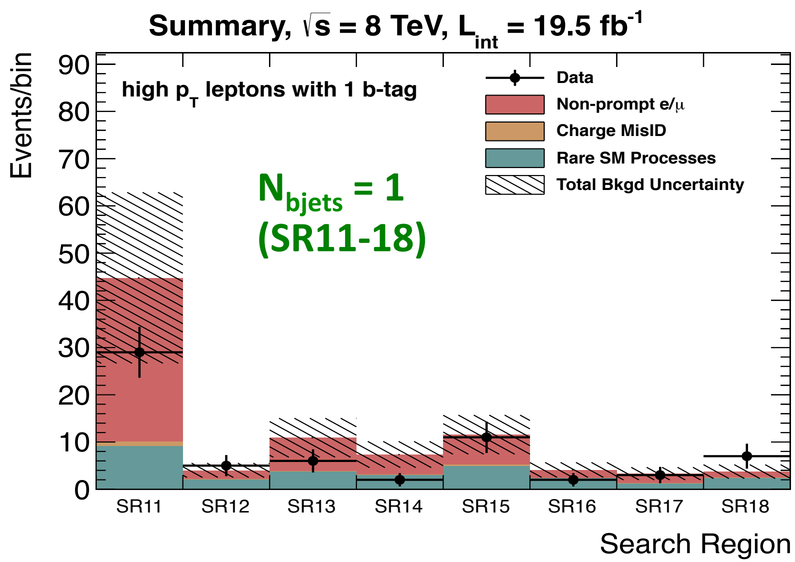


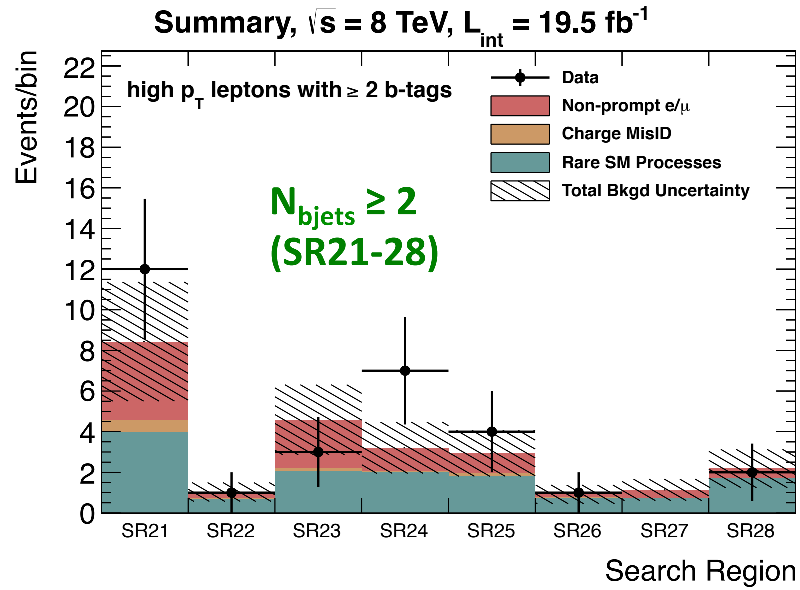
Results and Interpretations

Results

- **Results and Background Predictions**
  - good agreement in data vs. prediction
- **No significant excess over SM background predictions**
- **No evidence for new physics**





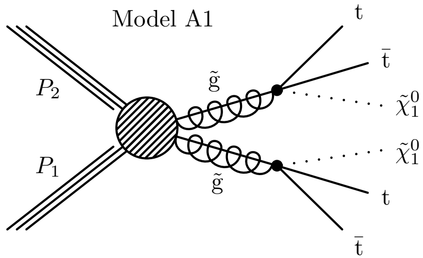


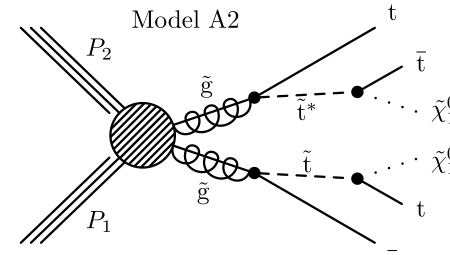
Interpretations

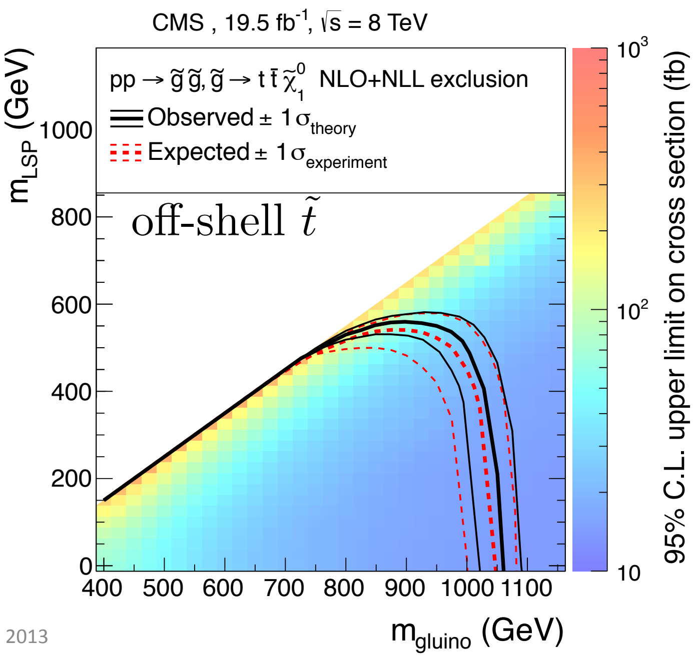
- **Results used to interpret several models that predict same-sign events.**
  - Supersymmetry: Simplified Models Space (SMS)
  - Set upper limits on cross sections at 95% CL
  - Provide exclusions in the parameter space for these models
- Search regions used are determined on a **per model basis**.

Gluino Mediated Stop Production

- Stop is off-shell (left) and on-shell (right) stops.
- Using $N_{bjets} \geq 2$ search regions (SR21-28).







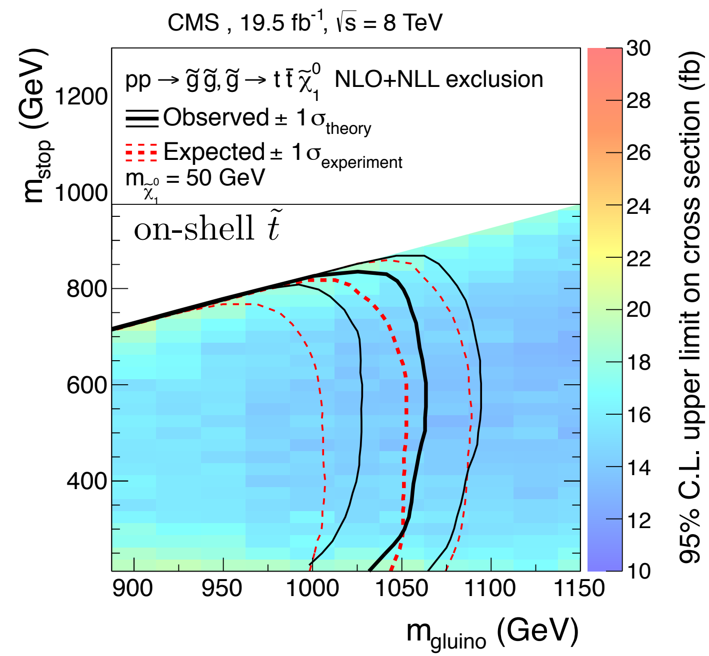
gluino production

4W+4b+2LSP

$2 \times (\tilde{g} \to t\bar{t}\tilde{\chi}^0_1)$

A1: off-shell $\tilde{t}_1$

A2: on-shell $\tilde{t}_1$

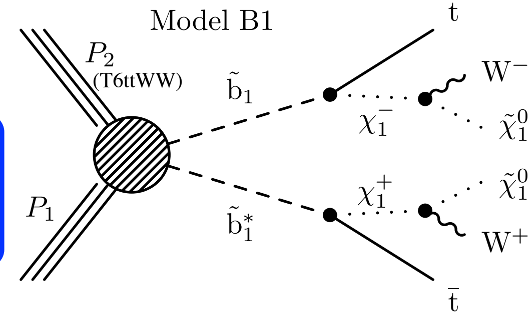


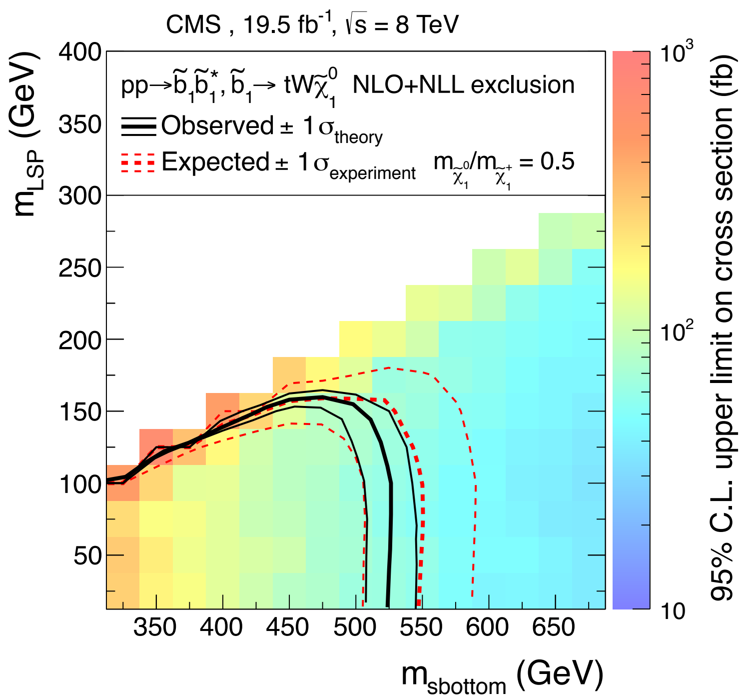
Direct Sbottom-Pair Production

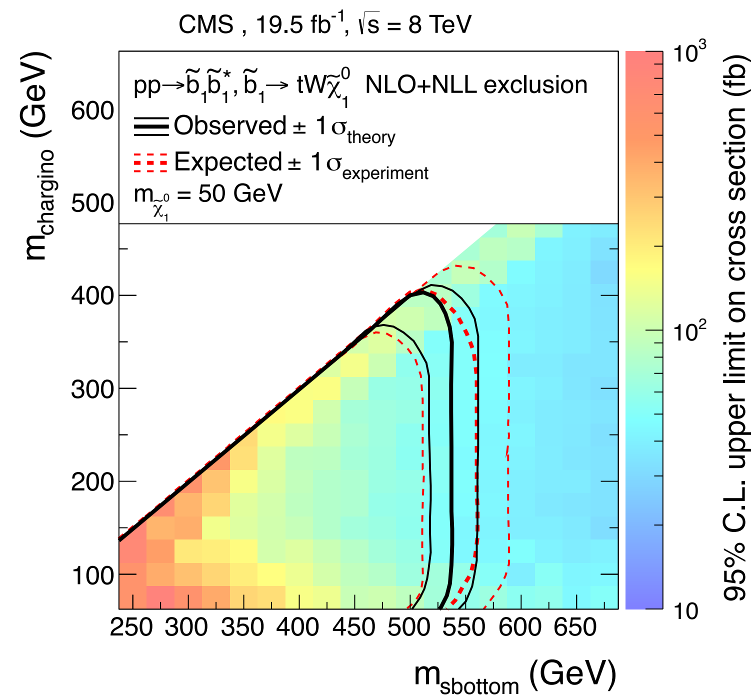
- Using N_{bjets} = 1 and ≥ 2 search regions (SR11-18, SR21-28).
- Two scenarios:
  - center: $m_{sbottom}$ vs m_{LSP}, x = 0.5
  - bottom right: $m_{sbottom}$ vs $m_{chargino}$, m_{LSP} = 50 GeV

$$x = \frac{m_{\tilde{\chi}_1^0}}{m_{\tilde{\chi}_1^+}}$$

direct sbottom production
4W+2b+2LSP

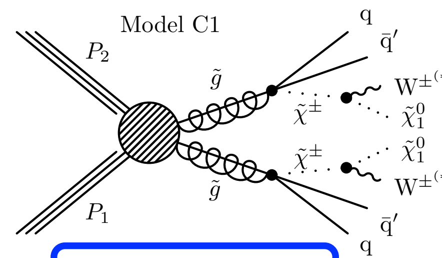




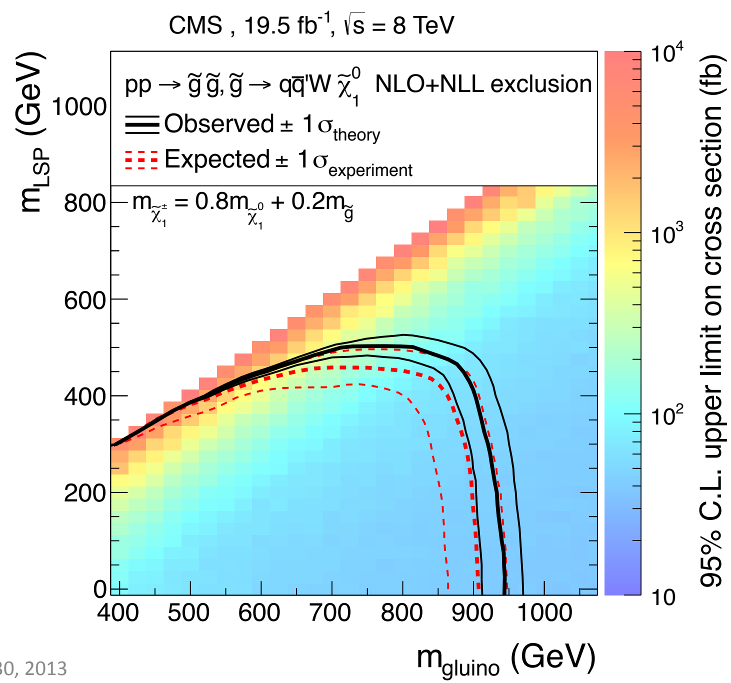


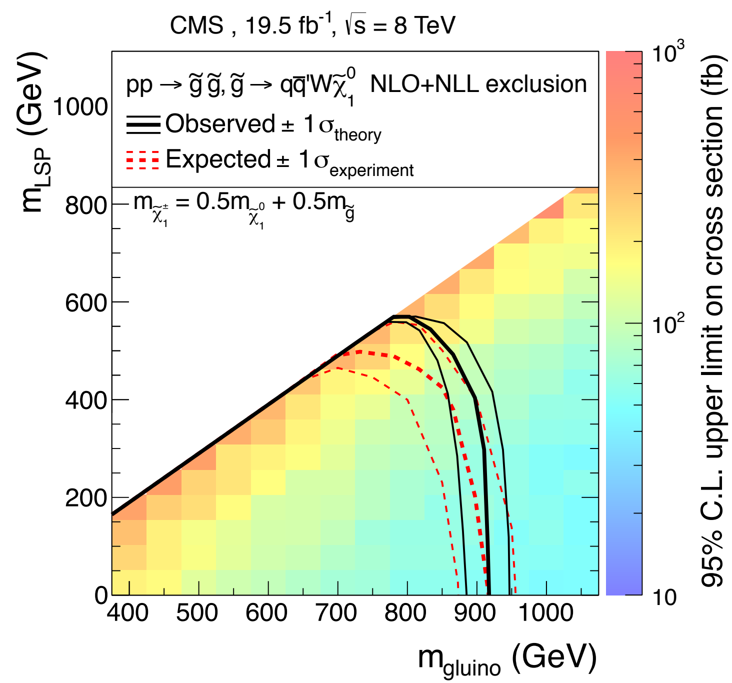
Gluino Mediated Light Squark Production

- Using N_{bjets} = 0 search regions (SR01-08).
- m_{gluino} vs m_{LSP}
- 2 scenarios for fixed relationship between chargino, LSP, and gluino masses
  - left: $m_{chargino} = 0.8m_{LSP} + 0.2m_{gluino}$
  - right: $m_{chargino} = 0.5m_{LSP} + 0.5m_{gluino}$



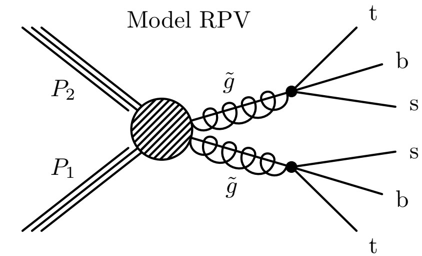
gluino production
2W+2LSP





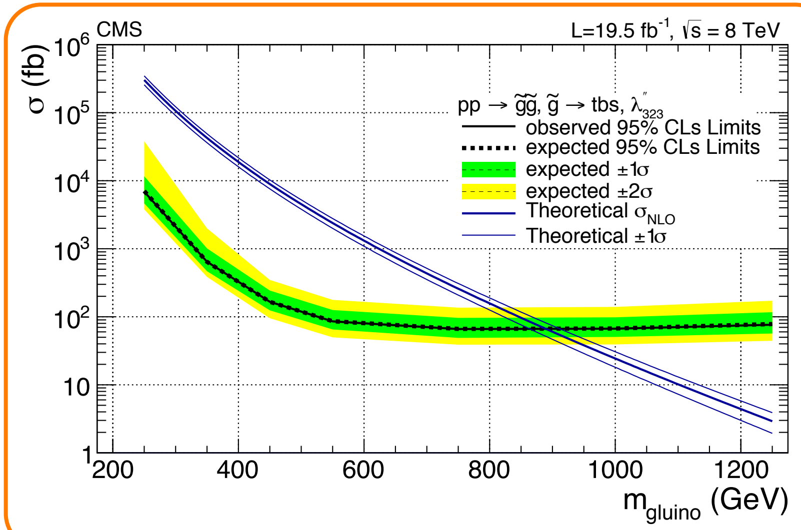
Additional Models

- Additional Search regions designed for R-Parity violating SUSY models and same-sign top production
- RPV gluino → tbs 95% CL σ_{UL} (bottom right)
- Same Sign top production 95% CL σ_{UL} = 0.72 pb
- SM 4-top production 95% CL σ_{UL} = 49 fb
  - using ≥ 2 N_{bjets} search regions (SR21-28)



RPV Model
2W+4b

N_{jets}	$N_{\text{b-jets}}$	E_T^{miss} (GeV)	H_T (GeV)	charge	SR
≥ 2	≥ 0	> 0	> 500	$++/--$	RPV0
≥ 2	≥ 2	> 0	> 500	$++/--$	RPV2
≥ 2	$= 1$	> 30	> 80	$++/--$	SStop1
≥ 2	$= 1$	> 30	> 80	$++$ only	SStop1++
≥ 2	≥ 2	> 30	> 80	$++/--$	SStop2
≥ 2	≥ 2	> 30	> 80	$++$ only	SStop2++



Summary

- **We searched for new physics in events with a same-sign lepton pair and jets in pp collisions at 8 TeV using a dataset corresponding to 19.5 fb^{-1}.**
- **We observe no evidence for new physics.**
- We interpret the results in the context of several Supersymmetry models of stop and sbottom production.
- We set an upper limit on the cross-section for same-sign top and SM four top production.

Backup

Lepton Selections

Electrons

Observable	Value or Range
Missing pixel hits	0
$\sigma_{i\eta i\eta}$ (B/E)	$< 0.01/0.03$
$\Delta\phi_{\mathrm{In}}$ (B/E)	$< 0.06/0.03$
$\Delta\eta_{\mathrm{In}}$ (B/E)	$< 0.004/0.007$
H/E (B/E)	$< 0.1/0.075$
Seed	Ecal-Driven
p_{T}	$> 20(10)$ GeV
$\|\eta\|$	$< 2.4, \notin [1.4442, 1.566]$
$\|d_{0,pv}\|$	< 0.01
$\|d_{z,pv}\|$	< 0.1
RelIso^e	< 0.09
$\Delta\mathrm{R}(e, \mu)$	> 0.1
$\|1/E - 1/p\|$	> 0.05
charge consistency among CTF, GSF and SuperCluster	

Muons

Observable	Value or Range
Id	Particle Flow && Global
p_{T}	$> 20(10)$ GeV
$\|\eta\|$	< 2.4
χ^2/ndof	≤ 10
# silicon layers	> 5
# Valid SA Hits	> 0
# matched muon station	> 1
$\|d_{0,pv}\|$	< 0.005
$\|d_{z,pv}\|$	< 0.1
Ecal/Hcal Non-MIP Veto	$\leq 4/6$ GeV
RelIso^{μ}	< 0.1

Jets

Observable	Value or Range
p_T	> 40 GeV
$\|\eta\|$	< 2.4
Id	Loose

Physics Objects

Electrons

- $p_T > 10$ GeV, $|\eta| < 2.4$.
- ID → Cut-based medium WP.
- Tighter cuts to suppress conversions and charge flips.
- **$d_0 < 100$ µm.**
- PF relative isolation < 0.09, ρ-based PU correction.

Muons

- $p_T > 10$ GeV, $|\eta| < 2.4$.
- ID → Cut-based tight WP.
- Require muon is minimum ionizing.
- **$d_0 < 50$ µm.**
- PF relative isolation < 0.1, Δβ PU correction.

Jets/MET

- PF jets, loose ID.
- $p_T > 40$ GeV, $|\eta| < 2.4$.
- L1FastL2L3 corrections (residual data only).
- $\Delta R(\ell, \text{jet}) > 0.4$.
- b-tagged jets using CSV medium WP.
- MET = type 1 corrected pfMET.

Changes w.r.t. HCP

- **Tightened d_0 cut**:
  - $\epsilon > 95\%$ for signal leptons.
  - reduces non-prompt leptons by 20%
  - suppresses charge mis-ID by 50%
- **Lowered lepton p_T threshold to 10 GeV.**
  - Previous value was 20 GeV
  - Allows for more general search.
    - **low p_T** analysis → $p_T > 10$ GeV
      - sensitive to compressed spectra
    - **high p_T** analysis → $p_T > 20$ GeV
      - suppresses most background

Trigger Selection

- Triggers used for the high and low p_T analysis.
  - The high p_T analysis uses the same dilepton triggers used for the ICHEP and HCP analysis.
    - p_T > 17/8 GeV and electrons have calo and track based ID and isolation.
  - The low p_T triggers have lower p_T thresholds on the leptons but require H_T > 175 GeV.
    - p_T > 8/8 GeV and electrons only have calo and track based ID.
  - Efficiencies measured in data (e.g. bottom right: double ele trigger)
  - Use the measured efficiency to scale simulated events (top right table).

Scale Factors: applied in MC
(applied based on trailing p_T or |η|)
6% systematic uncertainty on SF

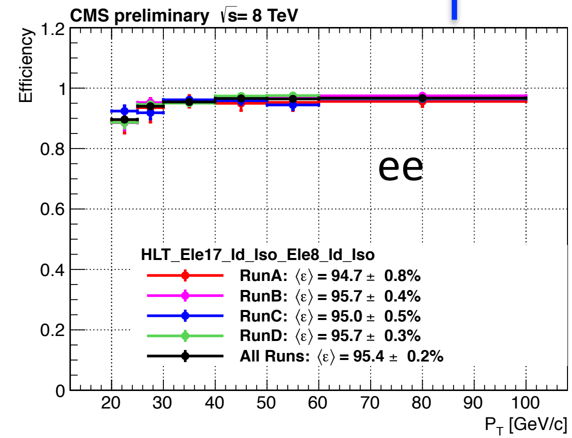
Low-p_T	Scale Factor	High-p_T	Scale Factor
$\mu\mu$, $\lvert\eta\rvert < 1$	0.94	$\mu\mu$, $\lvert\eta\rvert < 1$	0.90
$\mu\mu$, $\lvert\eta\rvert > 1$	0.90	$\mu\mu$, $\lvert\eta\rvert > 1$	0.81
$e\mu$	0.93	$e\mu$	0.93
ee	0.93	ee, $p_T < 30$	0.92
		ee, $p_T > 30$	0.96

High p_T

Channel	Trigger names
$\mu\mu$	HLT_Mu17_Mu8
ee	HLT_Ele17_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_Ele8_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL
$e\mu$	HLT_Mu17_Ele8_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL HLT_Mu8_Ele17_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL

Low p_T

Channel	Trigger names
$\mu\mu$	HLT_DoubleMu8_Mass8_PFNoPUHT175 HLT_DoubleMu8_Mass8_PFHT175
ee	HLT_DoubleEle8_CaloIdT_TrkIdVL_Mass8_PFNoPUHT175 HLT_DoubleEle8_CaloIdT_TrkIdVL_Mass8_PFHT175
$e\mu$	HLT_Mu8_Ele8_CaloIdT_TrkIdVL_Mass8_PFNoPUHT175 HLT_Mu8_Ele8_CaloIdT_TrkIdVL_Mass8_PFHT175



Signal Triggers

High-p_T

Channel	Trigger names
$\mu\mu$	HLT_Mu17_Mu8 HLT_DoubleMu8_Mass8 HLT_DoubleMu14_Mass8
ee	HLT_Ele17_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_Ele8_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL HLT_DoubleEle8_CaloIdT_TrkIdVL_Mass8 HLT_DoubleEle14_Mass8_CaloIdT_TrkIdVL_pfMHT40
$e\mu$	HLT_Mu17_Ele8_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL HLT_Mu8_Ele17_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL HLT_Mu8_Ele8_CaloIdT_TrkIdVL_Mass8 HLT_Mu14_Ele14_Mass8_CaloIdT_CaloIsoVL_TrkIdVL_pfMHT40

Low-p_T

Channel	Trigger names
$\mu\mu$	HLT_DoubleMu8_Mass8_PFNoPUHT175 HLT_DoubleMu8_Mass8_PFHT175
ee	HLT_DoubleEle8_CaloIdT_TrkIdVL_Mass8_PFNoPUHT175 HLT_DoubleEle8_CaloIdT_TrkIdVL_Mass8_PFHT175
$e\mu$	HLT_Mu8_Ele8_CaloIdT_TrkIdVL_Mass8_PFNoPUHT175 HLT_Mu8_Ele8_CaloIdT_TrkIdVL_Mass8_PFHT175

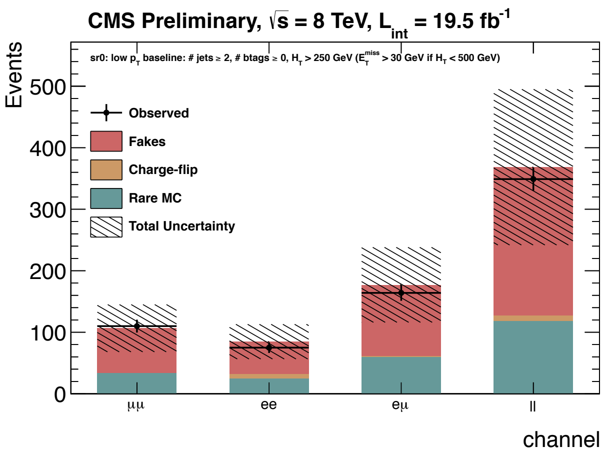
Control Regions

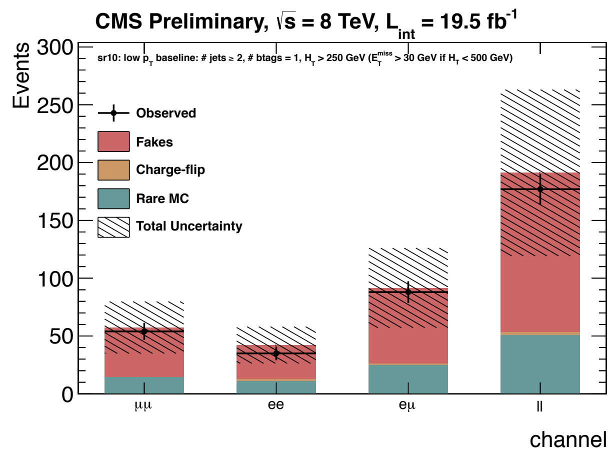
- **6 control regions (3 for each analysis)**
  - **3 bins of N_{bjets}**
    - 10's place represent the N_{bjets}
    - (e.g. SR0 > 0 N_{btags}, SR10 = 1 N_{btags}, SR20 ≥ 2 N_{btags})

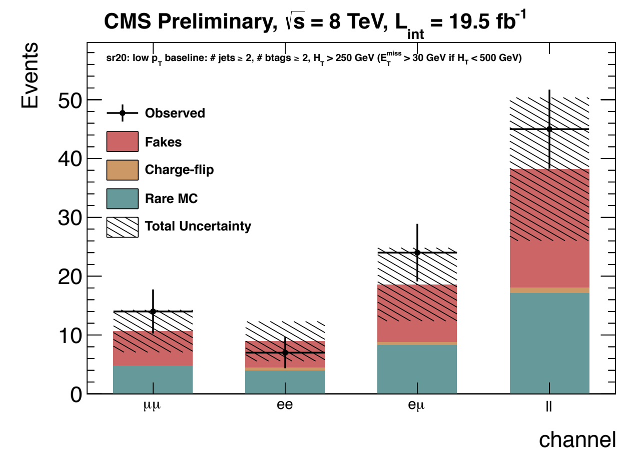
Summary of Control Regions

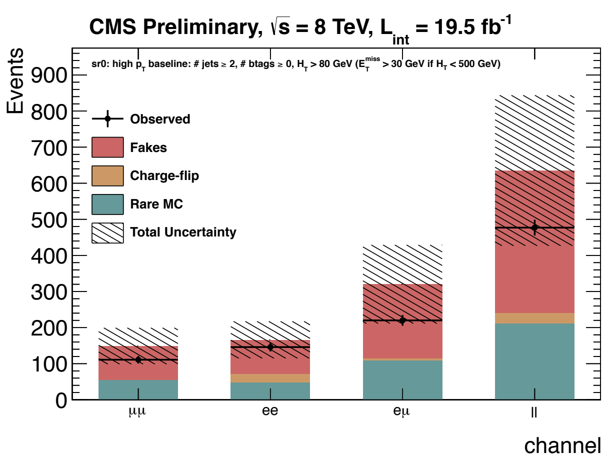
Analysis	lepton $p_T(\mu, e)$ (GeV)	H_T(GeV)	$\not\!\!E_T$(GeV)	# jets	# b-tagged jets	Search Region #
high p_T	20, 20	80	30 if $H_T < 500$ else 0	2	≥ 0	SR0
					$= 1$	SR10
					≥ 2	SR20
low p_T	10, 10	250	30 if $H_T < 500$ else 0	2	≥ 0	SR0
					$= 1$	SR10
					≥ 2	SR20

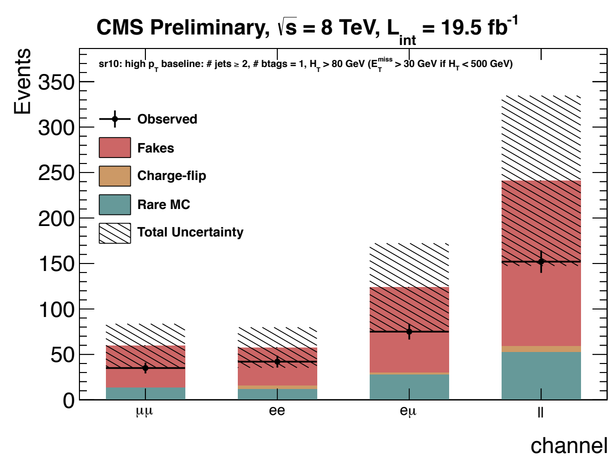
Control Region Yield/Predictions

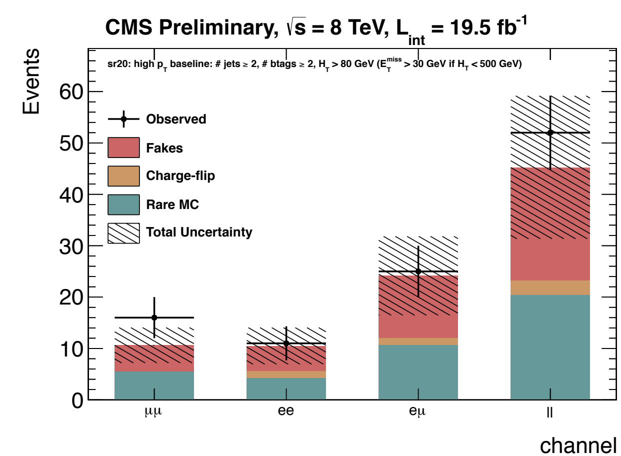












High p_T (SR0 and SR10)

SR0

source	ee	$\mu\mu$	$e\mu$	$\ell\ell$
$t\bar{t} \rightarrow \ell\ell X$	6.40 ± 2.90	0.00 ± 1.21	5.81 ± 2.80	12.21 ± 3.71
$t\bar{t} \rightarrow \ell(b \rightarrow \ell)X$	13.86 ± 3.98	10.25 ± 3.56	22.25 ± 4.78	46.36 ± 6.65
$t\bar{t} \rightarrow \ell(\not{b} \rightarrow \ell)X$	3.47 ± 2.35	0.51 ± 1.51	6.95 ± 2.99	10.93 ± 3.56
$t\bar{t}$ other	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
t, s-channel	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52
t, t-channel	0.27 ± 0.68	0.75 ± 0.86	1.55 ± 1.05	2.56 ± 1.25
tW	0.76 ± 1.14	0.71 ± 1.14	2.26 ± 1.55	3.72 ± 1.85
$DY \rightarrow \ell\ell$	18.03 ± 9.25	0.00 ± 4.14	5.81 ± 6.57	23.85 ± 10.26
$W + jets \rightarrow \ell\nu$	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20
WW	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11
$W\gamma^* \rightarrow \ell\nu\mu\mu$	0.00 ± 0.23	0.20 ± 0.33	0.22 ± 0.33	0.42 ± 0.39
$W\gamma^* \rightarrow \ell\nu\tau\tau$	0.11 ± 0.30	0.22 ± 0.34	0.00 ± 0.24	0.33 ± 0.38
WZ	18.53 ± 0.47	17.10 ± 0.47	36.72 ± 0.66	72.35 ± 0.93
ZZ	1.19 ± 0.03	0.90 ± 0.03	2.22 ± 0.04	4.31 ± 0.06
$t\bar{t}\gamma$	0.53 ± 1.35	0.00 ± 1.08	3.07 ± 2.10	3.60 ± 2.21
$t\bar{t}W$	10.61 ± 0.55	14.72 ± 0.66	26.55 ± 0.85	51.88 ± 1.19
$t\bar{t}Z$	2.80 ± 0.26	3.16 ± 0.29	6.25 ± 0.39	12.20 ± 0.54
$tbZ(Z \rightarrow \ell\ell)$	0.44 ± 0.03	0.34 ± 0.03	0.82 ± 0.04	1.59 ± 0.05
$t\bar{t}WW$	0.22 ± 0.01	0.29 ± 0.01	0.51 ± 0.01	1.01 ± 0.01
$WW\gamma$	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09
WWW	1.84 ± 0.13	2.44 ± 0.15	4.17 ± 0.19	8.45 ± 0.27
WWZ	0.40 ± 0.05	0.32 ± 0.05	0.80 ± 0.07	1.52 ± 0.10
WZZ	0.08 ± 0.01	0.08 ± 0.01	0.19 ± 0.02	0.36 ± 0.03
ZZZ	0.01 ± 0.00	0.00 ± 0.00	0.01 ± 0.00	0.02 ± 0.00
$qqW^{\pm}W^{\pm}$	8.07 ± 0.66	11.04 ± 0.79	20.11 ± 1.01	39.22 ± 1.40
WW(DPS)	0.10 ± 0.06	0.19 ± 0.07	0.31 ± 0.08	0.60 ± 0.11
WH, ZH, $t\bar{t}H$; $H \rightarrow WW$	2.72 ± 0.31	2.97 ± 0.33	5.94 ± 0.44	11.63 ± 0.61
WH, ZH, $t\bar{t}H$; $H \rightarrow ZZ$	0.12 ± 0.01	0.15 ± 0.02	0.29 ± 0.02	0.55 ± 0.03
WH, ZH, $t\bar{t}H$; $H \rightarrow \tau\tau$	0.40 ± 0.04	0.44 ± 0.05	0.74 ± 0.06	1.58 ± 0.08
Total MC	90.94 ± 74.03	66.77 ± 73.48	153.54 ± 73.85	311.24 ± 74.51
SF	90.86 ± 8.69	92.64 ± 5.45	200.91 ± 11.00	384.41 ± 15.04
DF	5.89 ± 0.48	4.09 ± 0.29	9.72 ± 0.55	19.69 ± 0.79
SC	2.30 ± 0.53	2.24 ± 0.50	4.59 ± 1.04	9.14 ± 2.00
SF + DF	96.75 ± 8.65	96.73 ± 5.43	210.62 ± 10.96	404.10 ± 14.98
SF + DF - SC	94.44 ± 8.66 ± 47.22	94.49 ± 5.45 ± 47.24	206.03 ± 11.01 ± 103.02	394.96 ± 15.11 ± 197.48
Charge Flips	23.44 ± 1.16 ± 7.03	0.00 ± 0.00 ± 0.00	5.22 ± 0.45 ± 1.57	28.66 ± 1.24 ± 8.60
MC Pred	48.15 ± 1.77 ± 24.08	54.56 ± 1.71 ± 27.28	108.91 ± 2.68 ± 54.46	211.62 ± 3.20 ± 105.81
Total Pred	166.04 ± 8.92 ± 53.47	149.04 ± 5.71 ± 54.55	320.17 ± 11.34 ± 116.53	635.24 ± 15.50 ± 224.21
Data	146	111	220	477

SR10

source	ee	$\mu\mu$	$e\mu$	$\ell\ell$
$t\bar{t} \rightarrow \ell\ell X$	3.51 ± 2.35	0.00 ± 1.21	3.47 ± 2.35	6.99 ± 2.99
$t\bar{t} \rightarrow \ell(b \rightarrow \ell)X$	6.13 ± 2.90	5.39 ± 2.80	11.45 ± 3.64	22.96 ± 4.89
$t\bar{t} \rightarrow \ell(\not{b} \rightarrow \ell)X$	1.70 ± 1.91	0.51 ± 1.51	4.06 ± 2.47	6.27 ± 2.90
$t\bar{t}$ other	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
t, s-channel	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52
t, t-channel	0.27 ± 0.68	0.26 ± 0.68	0.53 ± 0.77	1.06 ± 0.93
tW	0.37 ± 1.00	0.00 ± 0.80	1.87 ± 1.46	2.24 ± 1.55
$DY \rightarrow \ell\ell$	8.11 ± 7.12	0.00 ± 4.14	1.97 ± 5.18	10.08 ± 7.61
$W + jets \rightarrow \ell\nu$	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20
WW	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11
$W\gamma^* \rightarrow \ell\nu\mu\mu$	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23
$W\gamma^* \rightarrow \ell\nu\tau\tau$	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24
WZ	1.41 ± 0.14	1.21 ± 0.13	2.63 ± 0.19	5.26 ± 0.26
ZZ	0.09 ± 0.01	0.08 ± 0.01	0.18 ± 0.01	0.35 ± 0.02
$t\bar{t}\gamma$	0.26 ± 0.67	0.00 ± 1.08	1.52 ± 1.04	1.78 ± 1.10
$t\bar{t}W$	5.63 ± 0.41	7.36 ± 0.48	13.35 ± 0.61	26.33 ± 0.86
$t\bar{t}Z$	1.53 ± 0.20	1.69 ± 0.22	2.96 ± 0.27	6.17 ± 0.39
$tbZ(Z \rightarrow \ell\ell)$	0.22 ± 0.02	0.17 ± 0.02	0.43 ± 0.03	0.82 ± 0.04
$t\bar{t}WW$	0.10 ± 0.00	0.15 ± 0.01	0.25 ± 0.01	0.49 ± 0.01
$WW\gamma$	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09
WWW	0.15 ± 0.04	0.22 ± 0.05	0.37 ± 0.06	0.74 ± 0.09
WWZ	0.05 ± 0.02	0.08 ± 0.03	0.12 ± 0.03	0.24 ± 0.04
WZZ	0.01 ± 0.01	0.01 ± 0.01	0.03 ± 0.01	0.05 ± 0.01
ZZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
$qqW^{\pm}W^{\pm}$	0.44 ± 0.20	1.04 ± 0.28	1.48 ± 0.31	2.96 ± 0.42
WW(DPS)	0.01 ± 0.03	0.00 ± 0.03	0.04 ± 0.04	0.05 ± 0.04
WH, ZH, $t\bar{t}H$; $H \rightarrow WW$	1.34 ± 0.22	1.12 ± 0.21	2.89 ± 0.31	5.35 ± 0.42
WH, ZH, $t\bar{t}H$; $H \rightarrow ZZ$	0.05 ± 0.01	0.05 ± 0.01	0.09 ± 0.01	0.18 ± 0.02
WH, ZH, $t\bar{t}H$; $H \rightarrow \tau\tau$	0.11 ± 0.02	0.13 ± 0.03	0.24 ± 0.03	0.48 ± 0.05
Total MC	31.49 ± 73.70	19.46 ± 73.43	49.92 ± 73.60	100.86 ± 73.93
SF	41.00 ± 4.36	45.33 ± 3.19	91.84 ± 5.69	178.17 ± 7.84
DF	1.53 ± 0.23	1.57 ± 0.17	2.97 ± 0.28	6.07 ± 0.40
SC	0.65 ± 0.19	0.56 ± 0.16	1.14 ± 0.29	2.35 ± 0.59
SF + DF	42.53 ± 4.34	46.90 ± 3.17	94.81 ± 5.67	184.24 ± 7.81
SF + DF - SC	41.88 ± 4.35 ± 20.94	46.34 ± 3.18 ± 23.17	93.66 ± 5.67 ± 46.83	181.89 ± 7.83 ± 90.94
Charge Flips	4.00 ± 0.22 ± 1.20	0.00 ± 0.00 ± 0.00	2.52 ± 0.22 ± 0.76	6.53 ± 0.31 ± 1.96
MC Pred	11.40 ± 0.94 ± 5.70	13.30 ± 1.31 ± 6.65	26.57 ± 1.38 ± 13.29	51.27 ± 1.63 ± 25.63
Total Pred	57.28 ± 4.45 ± 21.74	59.64 ± 3.43 ± 24.11	122.76 ± 5.84 ± 48.69	239.68 ± 8.01 ± 94.51
Data	42	35	75	152

High p_T (SR20)

SR20

source	ee	$\mu\mu$	$e\mu$	$\ell\ell$
$t\bar{t} \to \ell\ell X$	1.16 ± 1.73	0.00 ± 1.21	1.74 ± 1.91	2.89 ± 2.22
$t\bar{t} \to \ell(b \to \ell)X$	0.00 ± 1.21	0.56 ± 1.51	2.26 ± 2.07	2.81 ± 2.22
$t\bar{t} \to \ell(\not{b} \to \ell)X$	1.16 ± 1.73	0.00 ± 1.21	0.00 ± 1.21	1.16 ± 1.73
$t\bar{t}$ other	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
t, s-channel	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52
t, t-channel	0.00 ± 0.54	0.00 ± 0.54	0.77 ± 0.86	0.77 ± 0.86
tW	0.00 ± 0.80	0.00 ± 0.80	0.00 ± 0.80	0.00 ± 0.80
$DY \to \ell\ell$	0.00 ± 4.14	0.00 ± 4.14	0.00 ± 4.14	0.00 ± 4.14
$W + jets \to \ell\nu$	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20
WW	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11
$W\gamma^* \to \ell\nu\mu\mu$	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23
$W\gamma^* \to \ell\nu\tau\tau$	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24
WZ	0.04 ± 0.03	0.08 ± 0.04	0.15 ± 0.05	0.26 ± 0.07
ZZ	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.02 ± 0.01
$t\bar{t}\gamma$	0.15 ± 0.37	0.00 ± 1.08	0.85 ± 0.58	1.00 ± 0.61
$t\bar{t}W$	2.73 ± 0.29	3.80 ± 0.35	7.20 ± 0.46	13.73 ± 0.63
$t\bar{t}Z$	0.70 ± 0.14	0.69 ± 0.15	1.78 ± 0.22	3.17 ± 0.28
$tbZ(Z \to \ell\ell)$	0.05 ± 0.01	0.05 ± 0.01	0.10 ± 0.01	0.19 ± 0.02
$t\bar{t}WW$	0.06 ± 0.00	0.07 ± 0.00	0.14 ± 0.01	0.27 ± 0.01
$WW\gamma$	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09
WWW	0.01 ± 0.02	0.02 ± 0.02	0.04 ± 0.03	0.07 ± 0.03
WWZ	0.00 ± 0.01	0.00 ± 0.01	0.01 ± 0.01	0.02 ± 0.02
WZZ	0.01 ± 0.00	0.00 ± 0.00	0.01 ± 0.00	0.01 ± 0.01
ZZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
$qqW^{\pm}W^{\pm}$	0.00 ± 0.09	0.03 ± 0.05	0.07 ± 0.12	0.10 ± 0.12
WW(DPS)	0.00 ± 0.03	0.00 ± 0.03	0.00 ± 0.03	0.00 ± 0.03
WH, ZH, $t\bar{t}H$; $H \to WW$	0.55 ± 0.15	0.70 ± 0.17	0.95 ± 0.19	2.20 ± 0.28
WH, ZH, $t\bar{t}H$; $H \to ZZ$	0.02 ± 0.01	0.03 ± 0.01	0.06 ± 0.01	0.12 ± 0.01
WH, ZH, $t\bar{t}H$; $H \to \tau\tau$	0.05 ± 0.02	0.06 ± 0.02	0.10 ± 0.02	0.21 ± 0.03
Total MC	6.69 ± 73.39	6.09 ± 73.38	16.23 ± 73.41	29.02 ± 73.44
SF	5.05 ± 1.05	5.05 ± 0.87	12.40 ± 1.54	22.50 ± 2.06
DF	0.20 ± 0.08	0.28 ± 0.07	0.25 ± 0.07	0.73 ± 0.13
SC	0.30 ± 0.10	0.24 ± 0.08	0.50 ± 0.17	1.05 ± 0.32
SF + DF	5.25 ± 1.04	5.33 ± 0.86	12.65 ± 1.53	23.23 ± 2.04
SF + DF - SC	4.95 ± 1.04 ± 2.48	5.09 ± 0.87 ± 2.54	12.15 ± 1.54 ± 6.07	22.18 ± 2.07 ± 11.09
Charge Flips	1.41 ± 0.09 ± 0.42	0.00 ± 0.00 ± 0.00	1.42 ± 0.12 ± 0.43	2.83 ± 0.15 ± 0.85
MC Pred	4.37 ± 0.63 ± 2.19	5.54 ± 1.21 ± 2.77	11.47 ± 0.88 ± 5.73	21.38 ± 1.03 ± 10.69
Total Pred	10.74 ± 1.22 ± 3.33	10.62 ± 1.49 ± 3.76	25.03 ± 1.78 ± 8.36	46.39 ± 2.32 ± 15.43
Data	11	16	25	52

Low p_T (SR0 and SR10)

SR0

source	ee	$\mu\mu$	$e\mu$	$\ell\ell$
$t\bar{t} \to \ell\ell X$	2.21 ± 2.07	0.00 ± 1.21	1.74 ± 1.91	3.95 ± 2.47
$t\bar{t} \to \ell(b \to \ell)X$	8.86 ± 3.33	19.77 ± 4.57	31.96 ± 5.63	60.59 ± 7.49
$t\bar{t} \to \ell(\not{b} \to \ell)X$	1.05 ± 1.73	1.18 ± 1.73	6.16 ± 2.90	8.38 ± 3.25
$t\bar{t}$ other	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
t, s-channel	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52
t, t-channel	0.47 ± 0.77	0.77 ± 0.86	0.53 ± 0.77	1.76 ± 1.11
tW	0.36 ± 1.00	0.76 ± 1.14	1.50 ± 1.37	2.63 ± 1.63
$DY \to \ell\ell$	5.86 ± 6.57	2.01 ± 5.18	0.00 ± 4.14	7.87 ± 7.12
$W + jets \to \ell\nu$	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20
WW	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11
$W\gamma^* \to \ell\nu\mu\mu$	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23
$W\gamma^* \to \ell\nu\tau\tau$	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24
WZ	6.54 ± 0.29	7.37 ± 0.30	15.12 ± 0.43	29.03 ± 0.59
ZZ	0.40 ± 0.02	0.36 ± 0.02	0.82 ± 0.03	1.58 ± 0.04
$t\bar{t}\gamma$	1.00 ± 1.55	0.00 ± 1.08	1.01 ± 1.55	2.01 ± 1.86
$t\bar{t}W$	6.76 ± 0.45	10.59 ± 0.55	16.61 ± 0.68	33.96 ± 0.96
$t\bar{t}Z$	1.80 ± 0.22	2.68 ± 0.26	4.77 ± 0.34	9.25 ± 0.47
$tbZ(Z \to \ell\ell)$	0.20 ± 0.02	0.18 ± 0.02	0.40 ± 0.03	0.78 ± 0.04
$t\bar{t}WW$	0.18 ± 0.01	0.28 ± 0.01	0.44 ± 0.01	0.91 ± 0.01
$WW\gamma$	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09
WWW	1.00 ± 0.10	1.39 ± 0.11	2.21 ± 0.14	4.60 ± 0.20
WWZ	0.23 ± 0.04	0.23 ± 0.04	0.45 ± 0.06	0.91 ± 0.08
WZZ	0.04 ± 0.01	0.05 ± 0.01	0.12 ± 0.02	0.22 ± 0.02
ZZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.00
$qqW^{\pm}W^{\pm}$	4.91 ± 0.54	7.74 ± 0.66	13.23 ± 0.84	25.88 ± 1.15
WW(DPS)	0.01 ± 0.03	0.01 ± 0.03	0.02 ± 0.04	0.05 ± 0.04
WH, ZH, $t\bar{t}H$; $H \to WW$	1.78 ± 0.26	2.37 ± 0.29	4.10 ± 0.37	8.24 ± 0.51
WH, ZH, $t\bar{t}H$; $H \to ZZ$	0.09 ± 0.01	0.12 ± 0.01	0.22 ± 0.02	0.43 ± 0.03
WH, ZH, $t\bar{t}H$; $H \to \tau\tau$	0.15 ± 0.03	0.22 ± 0.03	0.29 ± 0.04	0.65 ± 0.06
Total MC	43.89 ± 73.67	58.09 ± 73.60	101.71 ± 73.68	203.69 ± 74.12
SF	50.69 ± 3.49	69.22 ± 5.05	109.64 ± 5.55	229.55 ± 8.28
DF	3.28 ± 0.26	5.59 ± 0.37	8.60 ± 0.43	17.47 ± 0.63
SC	1.06 ± 0.24	1.83 ± 0.41	2.64 ± 0.56	5.54 ± 1.15
SF + DF	53.97 ± 3.46	74.80 ± 5.01	118.25 ± 5.50	247.02 ± 8.20
SF + DF - SC	52.91 ± 3.47 ± 26.45	72.97 ± 5.03 ± 36.49	115.60 ± 5.53 ± 57.80	241.48 ± 8.28 ± 120.74
Charge Flips	6.75 ± 0.47 ± 2.03	0.00 ± 0.00 ± 0.00	1.68 ± 0.17 ± 0.50	8.43 ± 0.50 ± 2.53
MC Pred	25.09 ± 1.79 ± 12.54	33.60 ± 1.51 ± 16.80	59.82 ± 2.04 ± 29.91	118.51 ± 2.59 ± 59.25
Total Pred	84.75 ± 3.93 ± 29.35	106.57 ± 5.25 ± 40.17	177.10 ± 5.89 ± 65.08	368.42 ± 8.69 ± 134.52
Data	75	110	164	349

SR10

source	ee	$\mu\mu$	$e\mu$	$\ell\ell$
$t\bar{t} \to \ell\ell X$	1.11 ± 1.73	0.00 ± 1.21	1.14 ± 1.73	2.25 ± 2.07
$t\bar{t} \to \ell(b \to \ell)X$	1.67 ± 1.91	10.11 ± 3.49	16.77 ± 4.29	28.55 ± 5.37
$t\bar{t} \to \ell(\not{b} \to \ell)X$	0.00 ± 1.21	0.00 ± 1.21	3.40 ± 2.35	3.40 ± 2.35
$t\bar{t}$ other	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
t, s-channel	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52
t, t-channel	0.00 ± 0.54	0.24 ± 0.68	0.26 ± 0.68	0.50 ± 0.77
tW	0.00 ± 0.80	0.37 ± 1.00	1.50 ± 1.37	1.87 ± 1.46
$DY \to \ell\ell$	5.86 ± 6.57	0.00 ± 4.14	0.00 ± 4.14	5.86 ± 6.57
$W + jets \to \ell\nu$	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20
WW	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11
$W\gamma^* \to \ell\nu\mu\mu$	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23
$W\gamma^* \to \ell\nu\tau\tau$	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24
WZ	0.57 ± 0.09	0.63 ± 0.10	1.35 ± 0.14	2.55 ± 0.18
ZZ	0.04 ± 0.01	0.04 ± 0.01	0.09 ± 0.01	0.16 ± 0.01
$t\bar{t}\gamma$	0.51 ± 1.35	0.00 ± 1.08	0.50 ± 1.35	1.01 ± 1.55
$t\bar{t}W$	3.42 ± 0.33	5.37 ± 0.40	8.42 ± 0.49	17.21 ± 0.69
$t\bar{t}Z$	0.97 ± 0.17	1.25 ± 0.18	2.15 ± 0.24	4.38 ± 0.33
$tbZ(Z \to \ell\ell)$	0.11 ± 0.02	0.10 ± 0.01	0.21 ± 0.02	0.41 ± 0.03
$t\bar{t}WW$	0.08 ± 0.00	0.14 ± 0.01	0.21 ± 0.01	0.44 ± 0.01
$WW\gamma$	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09
WWW	0.06 ± 0.03	0.15 ± 0.04	0.27 ± 0.05	0.48 ± 0.07
WWZ	0.04 ± 0.02	0.05 ± 0.02	0.07 ± 0.03	0.17 ± 0.04
WZZ	0.01 ± 0.00	0.01 ± 0.01	0.02 ± 0.01	0.03 ± 0.01
ZZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
$qqW^{\pm}W^{\pm}$	0.30 ± 0.18	0.90 ± 0.27	1.09 ± 0.27	2.29 ± 0.38
WW(DPS)	0.00 ± 0.03	0.00 ± 0.03	0.00 ± 0.03	0.00 ± 0.03
WH, ZH, $t\bar{t}H$; $H \to WW$	0.80 ± 0.18	1.06 ± 0.20	2.09 ± 0.27	3.95 ± 0.36
WH, ZH, $t\bar{t}H$; $H \to ZZ$	0.04 ± 0.01	0.04 ± 0.01	0.08 ± 0.01	0.17 ± 0.02
WH, ZH, $t\bar{t}H$; $H \to \tau\tau$	0.06 ± 0.02	0.08 ± 0.02	0.10 ± 0.02	0.25 ± 0.04
Total MC	15.64 ± 73.59	20.54 ± 73.46	39.74 ± 73.55	75.92 ± 73.81
SF	24.31 ± 2.13	35.48 ± 2.93	53.34 ± 3.39	113.13 ± 4.96
DF	0.98 ± 0.14	1.94 ± 0.21	3.03 ± 0.25	5.94 ± 0.35
SC	0.30 ± 0.09	0.54 ± 0.16	0.76 ± 0.20	1.60 ± 0.42
SF + DF	25.29 ± 2.12	37.42 ± 2.90	56.37 ± 3.36	119.07 ± 4.92
SF + DF - SC	24.99 ± 2.12 ± 12.50	36.87 ± 2.91 ± 18.44	55.61 ± 3.36 ± 27.80	117.47 ± 4.94 ± 58.74
Charge Flips	1.25 ± 0.09 ± 0.37	0.00 ± 0.00 ± 0.00	0.75 ± 0.08 ± 0.22	2.00 ± 0.12 ± 0.60
MC Pred	7.01 ± 1.47 ± 3.51	9.82 ± 1.27 ± 4.91	16.66 ± 1.55 ± 8.33	33.49 ± 1.85 ± 16.74
Total Pred	33.25 ± 2.58 ± 12.98	46.69 ± 3.17 ± 19.08	73.01 ± 3.71 ± 29.03	152.96 ± 5.27 ± 61.08
Data	28	40	64	132

Low p_T (SR20)

SR20

source	ee	$\mu\mu$	$e\mu$	$\ell\ell$
$t\bar{t} \to \ell\ell X$	0.56 ± 1.51	0.00 ± 1.21	0.60 ± 1.51	1.16 ± 1.73
$t\bar{t} \to \ell(b \to \ell)X$	2.69 ± 2.22	2.22 ± 2.07	1.69 ± 1.91	6.61 ± 2.99
$t\bar{t} \to \ell(\not{b} \to \ell)X$	1.05 ± 1.73	0.59 ± 1.51	0.50 ± 1.51	2.13 ± 2.07
$t\bar{t}$ other	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
t, s-channel	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52
t, t-channel	0.00 ± 0.54	0.00 ± 0.54	0.00 ± 0.54	0.00 ± 0.54
tW	0.00 ± 0.80	0.00 ± 0.80	0.00 ± 0.80	0.00 ± 0.80
$DY \to \ell\ell$	0.00 ± 4.14	2.01 ± 5.18	0.00 ± 4.14	2.01 ± 5.18
$W + jets \to \ell\nu$	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20
WW	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11
$W\gamma^* \to \ell\nu\mu\mu$	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23
$W\gamma^* \to \ell\nu\tau\tau$	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24
WZ	0.04 ± 0.03	0.03 ± 0.03	0.09 ± 0.04	0.16 ± 0.05
ZZ	0.01 ± 0.00	0.00 ± 0.00	0.01 ± 0.00	0.02 ± 0.00
$t\bar{t}\gamma$	0.49 ± 1.35	0.00 ± 1.08	0.00 ± 1.08	0.49 ± 1.35
$t\bar{t}W$	2.21 ± 0.27	2.97 ± 0.30	5.17 ± 0.39	10.34 ± 0.54
$t\bar{t}Z$	0.52 ± 0.13	0.88 ± 0.16	1.56 ± 0.20	2.96 ± 0.27
$tbZ(Z \to \ell\ell)$	0.03 ± 0.01	0.03 ± 0.01	0.07 ± 0.01	0.13 ± 0.02
$t\bar{t}WW$	0.06 ± 0.00	0.08 ± 0.00	0.13 ± 0.01	0.27 ± 0.01
$WW\gamma$	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09
WWW	0.01 ± 0.02	0.01 ± 0.02	0.03 ± 0.02	0.05 ± 0.03
WWZ	0.00 ± 0.01	0.00 ± 0.01	0.01 ± 0.01	0.02 ± 0.02
WZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.01
ZZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
$qqW^{\pm}W^{\pm}$	0.00 ± 0.09	0.02 ± 0.04	0.07 ± 0.12	0.09 ± 0.12
WW(DPS)	0.00 ± 0.03	0.00 ± 0.03	0.00 ± 0.03	0.00 ± 0.03
WH, ZH, $t\bar{t}H$; $H \to WW$	0.54 ± 0.15	0.70 ± 0.17	1.03 ± 0.20	2.27 ± 0.28
WH, ZH, $t\bar{t}H$; $H \to ZZ$	0.02 ± 0.01	0.04 ± 0.01	0.07 ± 0.01	0.14 ± 0.02
WH, ZH, $t\bar{t}H$; $H \to \tau\tau$	0.02 ± 0.01	0.06 ± 0.02	0.08 ± 0.02	0.16 ± 0.03
Total MC	8.26 ± 73.42	9.66 ± 73.47	11.10 ± 73.41	29.02 ± 73.53
SF	4.47 ± 0.87	5.83 ± 1.00	9.68 ± 1.29	19.98 ± 1.85
DF	0.28 ± 0.08	0.28 ± 0.07	0.49 ± 0.10	1.05 ± 0.14
SC	0.25 ± 0.11	0.27 ± 0.09	0.39 ± 0.12	0.92 ± 0.27
SF + DF	4.75 ± 0.86	6.10 ± 1.00	10.18 ± 1.28	21.03 ± 1.83
SF + DF - SC	4.50 ± 0.86 ± 2.25	5.83 ± 1.00 ± 2.91	9.78 ± 1.28 ± 4.89	20.11 ± 1.85 ± 10.06
Charge Flips	0.48 ± 0.04 ± 0.14	0.00 ± 0.00 ± 0.00	0.50 ± 0.05 ± 0.15	0.98 ± 0.06 ± 0.29
MC Pred	3.96 ± 1.44 ± 1.98	4.83 ± 1.20 ± 2.42	8.32 ± 1.24 ± 4.16	17.10 ± 1.55 ± 8.55
Total Pred	8.94 ± 1.68 ± 3.00	10.66 ± 1.56 ± 3.79	18.60 ± 1.78 ± 6.42	38.20 ± 2.42 ± 13.21
Data	7	14	24	45

SR28

high p_T analysis

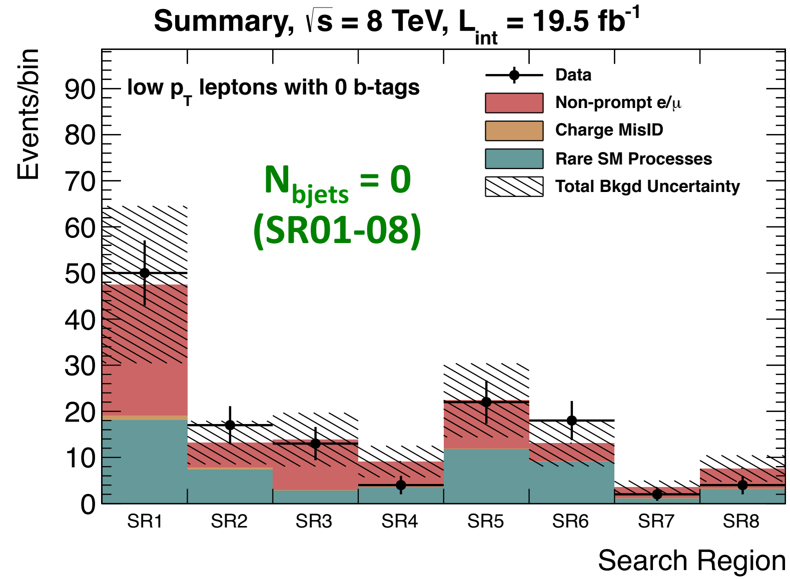
source	ee	$\mu\mu$	$e\mu$	$\ell\ell$
$t\bar{t} \to \ell\ell X$	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
$t\bar{t} \to \ell(b \to \ell)X$	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
$t\bar{t} \to \ell(\not{b} \to \ell)X$	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
$t\bar{t}$ other	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
t, s-channel	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52
t, t-channel	0.00 ± 0.54	0.00 ± 0.54	0.00 ± 0.54	0.00 ± 0.54
tW	0.00 ± 0.80	0.00 ± 0.80	0.00 ± 0.80	0.00 ± 0.80
$DY \to \ell\ell$	0.00 ± 4.14	0.00 ± 4.14	0.00 ± 4.14	0.00 ± 4.14
$W + jets \to \ell\nu$	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20
WW	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11
$W\gamma^* \to \ell\nu\mu\mu$	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23
$W\gamma^* \to \ell\nu\tau\tau$	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24
WZ	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.02
ZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
$t\bar{t}\gamma$	0.00 ± 0.01	0.00 ± 1.08	0.03 ± 0.02	0.03 ± 0.02
$t\bar{t}W$	0.20 ± 0.10	0.26 ± 0.11	0.68 ± 0.16	1.15 ± 0.20
$t\bar{t}Z$	0.02 ± 0.04	0.03 ± 0.05	0.13 ± 0.07	0.18 ± 0.08
$tbZ(Z \to \ell\ell)$	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.01	0.01 ± 0.01
$t\bar{t}WW$	0.01 ± 0.00	0.02 ± 0.00	0.03 ± 0.00	0.05 ± 0.00
$WW\gamma$	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09
WWW	0.01 ± 0.02	0.01 ± 0.02	0.01 ± 0.02	0.02 ± 0.02
WWZ	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.01 ± 0.01
WZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
ZZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
$qqW^{\pm}W^{\pm}$	0.00 ± 0.09	0.00 ± 0.09	0.02 ± 0.04	0.02 ± 0.04
WW(DPS)	0.00 ± 0.03	0.00 ± 0.03	0.00 ± 0.03	0.00 ± 0.03
WH, ZH, $t\bar{t}H$; $H \to WW$	0.02 ± 0.06	0.06 ± 0.07	0.09 ± 0.08	0.17 ± 0.10
WH, ZH, $t\bar{t}H$; $H \to ZZ$	0.01 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.01
WH, ZH, $t\bar{t}H$; $H \to \tau\tau$	0.00 ± 0.01	0.01 ± 0.01	0.00 ± 0.01	0.01 ± 0.01
Total MC	0.27 ± 73.37	0.40 ± 73.38	1.00 ± 73.37	1.67 ± 73.37
SF	0.00 ± 0.46	0.10 ± 0.19	0.44 ± 0.31	0.54 ± 0.37
DF	0.00 ± 0.14	0.00 ± 0.08	0.00 ± 0.10	0.00 ± 0.14
SC	0.03 ± 0.02	0.02 ± 0.01	0.03 ± 0.01	0.09 ± 0.03
SF + DF	0.00 ± 0.37	0.10 ± 0.10	0.44 ± 0.23	0.54 ± 0.25
SF + DF - SC	-0.03 ± 0.02 ± -0.02	0.08 ± 0.10 ± 0.04	0.41 ± 0.23 ± 0.20	0.45 ± 0.25 ± 0.23
Charge Flips	0.02 ± 0.00 ± 0.00	0.00 ± 0.00 ± 0.00	0.02 ± 0.00 ± 0.01	0.03 ± 0.01 ± 0.01
MC Pred	0.27 ± 0.38 ± 0.14	0.40 ± 1.15 ± 0.20	1.00 ± 0.40 ± 0.50	1.67 ± 0.42 ± 0.84
Total Pred	0.25 ± 0.38 ± 0.14	0.48 ± 1.15 ± 0.20	1.43 ± 0.46 ± 0.54	2.16 ± 0.49 ± 0.87
Data	0	1	1	2

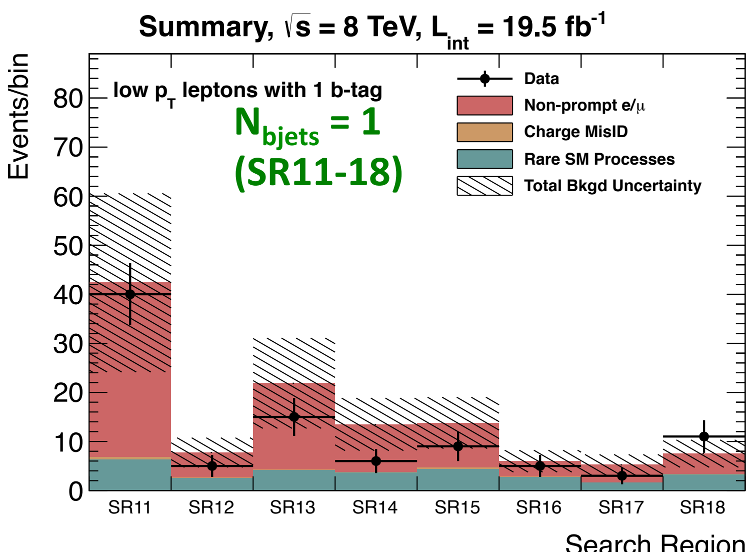
low p_T analysis

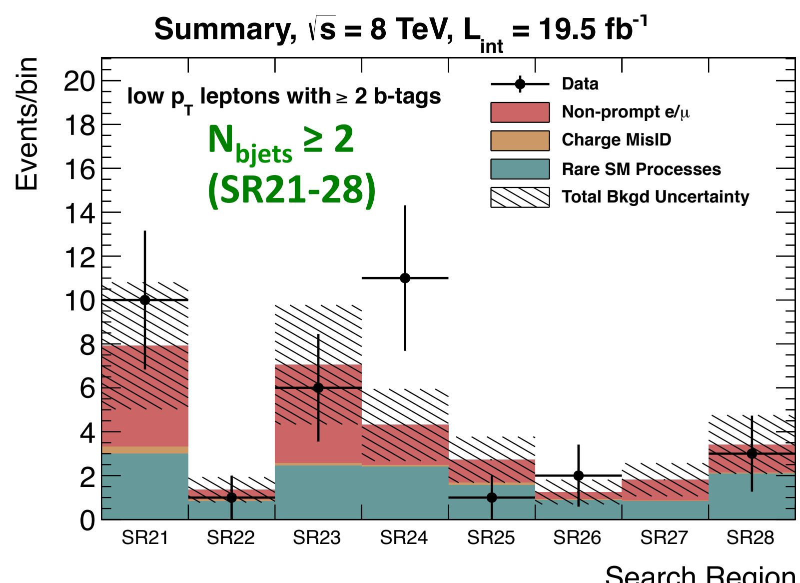
source	ee	$\mu\mu$	$e\mu$	$\ell\ell$
$t\bar{t} \to \ell\ell X$	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
$t\bar{t} \to \ell(b \to \ell)X$	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
$t\bar{t} \to \ell(\not{b} \to \ell)X$	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
$t\bar{t}$ other	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21	0.00 ± 1.21
t, s-channel	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52	0.00 ± 0.52
t, t-channel	0.00 ± 0.54	0.00 ± 0.54	0.00 ± 0.54	0.00 ± 0.54
tW	0.00 ± 0.80	0.00 ± 0.80	0.00 ± 0.80	0.00 ± 0.80
$DY \to \ell\ell$	0.00 ± 4.14	0.00 ± 4.14	0.00 ± 4.14	0.00 ± 4.14
$W + jets \to \ell\nu$	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20	0.00 ± 73.20
WW	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11	0.00 ± 0.11
$W\gamma^* \to \ell\nu\mu\mu$	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23	0.00 ± 0.23
$W\gamma^* \to \ell\nu\tau\tau$	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24	0.00 ± 0.24
WZ	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.02
ZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
$t\bar{t}\gamma$	0.02 ± 0.03	0.00 ± 1.08	0.02 ± 0.03	0.04 ± 0.04
$t\bar{t}W$	0.25 ± 0.11	0.36 ± 0.12	0.74 ± 0.16	1.36 ± 0.21
$t\bar{t}Z$	0.02 ± 0.04	0.07 ± 0.06	0.15 ± 0.08	0.23 ± 0.09
$tbZ(Z \to \ell\ell)$	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.01	0.01 ± 0.01
$t\bar{t}WW$	0.01 ± 0.00	0.02 ± 0.00	0.03 ± 0.00	0.07 ± 0.00
$WW\gamma$	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09	0.00 ± 0.09
WWW	0.01 ± 0.02	0.01 ± 0.02	0.01 ± 0.02	0.02 ± 0.02
WWZ	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.01 ± 0.01
WZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
ZZZ	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
$qqW^{\pm}W^{\pm}$	0.00 ± 0.09	0.00 ± 0.09	0.02 ± 0.04	0.02 ± 0.04
WW(DPS)	0.00 ± 0.03	0.00 ± 0.03	0.00 ± 0.03	0.00 ± 0.03
WH, ZH, $t\bar{t}H$; $H \to WW$	0.02 ± 0.06	0.11 ± 0.09	0.13 ± 0.09	0.26 ± 0.11
WH, ZH, $t\bar{t}H$; $H \to ZZ$	0.01 ± 0.00	0.01 ± 0.00	0.00 ± 0.00	0.02 ± 0.01
WH, ZH, $t\bar{t}H$; $H \to \tau\tau$	0.00 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.02 ± 0.01
Total MC	0.34 ± 73.37	0.60 ± 73.38	1.13 ± 73.37	2.07 ± 73.37
SF	0.00 ± 0.24	0.46 ± 0.32	0.93 ± 0.37	1.39 ± 0.46
DF	0.00 ± 0.05	0.00 ± 0.08	0.02 ± 0.02	0.02 ± 0.02
SC	0.03 ± 0.01	0.04 ± 0.02	0.05 ± 0.02	0.13 ± 0.04
SF + DF	0.00 ± 0.22	0.46 ± 0.28	0.95 ± 0.37	1.41 ± 0.46
SF + DF - SC	-0.03 ± 0.01 ± -0.02	0.42 ± 0.28 ± 0.21	0.90 ± 0.37 ± 0.45	1.29 ± 0.46 ± 0.64
Charge Flips	0.02 ± 0.00 ± 0.01	0.00 ± 0.00 ± 0.00	0.02 ± 0.00 ± 0.01	0.04 ± 0.01 ± 0.01
MC Pred	0.34 ± 0.38 ± 0.17	0.60 ± 1.15 ± 0.30	1.13 ± 0.40 ± 0.56	2.07 ± 0.44 ± 1.03
Total Pred	0.33 ± 0.38 ± 0.17	1.01 ± 1.18 ± 0.36	2.06 ± 0.54 ± 0.72	3.40 ± 0.63 ± 1.22
Data	0	1	2	3

Results (low p_T)

- **Results and Background Predictions**
  - good agreement in data vs. prediction
- **No significant excess over SM background predictions**
- **No evidence for new physics**







Search Regions

search region	# b-tagged jets	$\not\!\!E_T$	# jets	H_T
SR0		30 if $H_T < 500$ else 0	2	80
SR1	≥ 0	50-120	2-3	200-400
SR2				> 400
SR3			≥ 4	200-400
SR4				> 400
SR5		> 120	2-3	200-400
SR6				> 400
SR7			≥ 4	200-400
SR8				> 400
SR10		30 if $H_T < 500$ else 0	2	80
SR11	$= 1$	50-120	2-3	200-400
SR12				> 400
SR13			≥ 4	200-400
SR14				> 400
SR15		> 120	2-3	200-400
SR16				> 400
SR17			≥ 4	200-400
SR18				> 400
SR20		30 if $H_T < 500$ else 0	2	80
SR21	≥ 2	50-120	2-3	200-400
SR22				> 400
SR23			≥ 4	200-400
SR24				> 400
SR25		> 120	2-3	200-400
SR26				> 400
SR27			≥ 4	200-400
SR28				> 400
SR30 SR31 (++)	≥ 2	> 30	≥ 2	> 80
SR32 SR33	≥ 0 ≥ 2	> 0	≥ 2	> 500
SR34 SR35 (++)	$= 1$	> 0	≥ 2	> 80

- Search Regions expanded to be sensitive to a broad range of signatures
- Made exclusive to allow for statistical combination
  - Contrast to HCP: inclusive regions and $N_{btags} \geq 2$.
  - binned in N_{btags}
    - SR0-8: no N_{btags} req
    - SR10-18: $N_{btags} = 1$
    - SR20-28: $N_{btags} \geq 2$
  - Three baseline regions
    - loose MET and H_T cuts
  - General SUSY search regions binned in H_T, MET, and N_{jets}
  - Same-sign top.
  - R-parity violation (RPV)
- Low p_T same except
  - H_T 200 GeV → 250 due to H_T trigger turn on
  - Only defined for SRs 0-28

Results Tables (High P_T)

Search Region	Observed	Fake Leptons	Incorrect Charge	Simulation	Total Prediction
1	48	29 ± 15	1.56 ± 0.48	26 ± 13	56 ± 19
2	11	2.9 ± 1.6	0.37 ± 0.12	6.3 ± 3.2	9.6 ± 3.6
3	5	5.6 ± 3.0	0.13 ± 0.04	2.5 ± 1.3	8.3 ± 3.3
4	2	2.3 ± 1.3	0.15 ± 0.05	3.0 ± 1.6	5.5 ± 2.1
5	12	8.5 ± 4.4	0.19 ± 0.06	13 ± 6	21 ± 8
6	11	2.1 ± 1.2	0.06 ± 0.02	7.4 ± 3.7	9.6 ± 3.9
7	1	1.3 ± 0.8	0.02 ± 0.01	0.9 ± 0.5	2.2 ± 1.0
8	3	2.0 ± 1.1	0.02 ± 0.01	2.4 ± 1.2	4.4 ± 1.7
11	29	35 ± 18	1.00 ± 0.31	9.1 ± 4.6	45 ± 18
12	5	1.9 ± 1.1	0.12 ± 0.04	2.0 ± 1.0	4.0 ± 1.5
13	6	7.0 ± 3.7	0.16 ± 0.05	3.8 ± 1.9	11 ± 4
14	2	4.3 ± 2.3	0.09 ± 0.03	3.0 ± 1.5	7.4 ± 2.8
15	11	6.3 ± 3.3	0.33 ± 0.10	4.9 ± 2.5	12 ± 4
16	2	1.7 ± 1.0	0.07 ± 0.02	2.3 ± 1.2	4.1 ± 1.6
17	3	2.0 ± 1.2	0.04 ± 0.01	1.2 ± 0.7	3.3 ± 1.3
18	7	1.3 ± 0.8	0.05 ± 0.02	2.4 ± 1.2	3.7 ± 1.5
21	12	3.9 ± 2.1	0.56 ± 0.17	4.0 ± 2.0	8.4 ± 2.9
22	1	0.3 ± 0.3	0.06 ± 0.02	0.7 ± 0.4	1.0 ± 0.5
23	3	2.4 ± 1.3	0.11 ± 0.04	2.1 ± 1.1	4.6 ± 1.7
24	7	1.1 ± 0.7	0.06 ± 0.02	2.0 ± 1.0	3.2 ± 1.3
25	4	1.0 ± 0.6	0.14 ± 0.05	1.8 ± 0.9	2.9 ± 1.1
26	1	0.1 ± 0.2	0.03 ± 0.01	0.8 ± 0.4	0.9 ± 0.5
27	0	0.4 ± 0.3	0.03 ± 0.01	0.7 ± 0.4	1.1 ± 0.5
28	2	0.5 ± 0.3	0.04 ± 0.01	1.7 ± 0.9	2.2 ± 0.9

Red = 0b, Blue = 1b, Green = ≥ 2b

Results Tables (Low P_T)

Search Region	Observed	Fake Leptons	Incorrect Charge	Simulation	Total Prediction
1	50	28 ± 14	0.95 ± 0.29	18 ± 9	47 ± 17
2	17	5.5 ± 2.9	0.41 ± 0.13	7.3 ± 3.7	13 ± 5
3	13	11 ± 6	0.12 ± 0.04	2.8 ± 1.5	14 ± 6
4	4	5.4 ± 2.9	0.16 ± 0.05	3.5 ± 1.8	9.1 ± 3.4
5	22	10 ± 5	0.13 ± 0.04	12 ± 6	22 ± 8
6	18	4.0 ± 2.2	0.07 ± 0.02	9.1 ± 4.6	13 ± 5
7	2	2.4 ± 1.3	0.02 ± 0.01	1.1 ± 0.6	3.5 ± 1.5
8	4	4.4 ± 2.4	0.03 ± 0.01	3.1 ± 1.6	7.6 ± 2.9
11	40	36 ± 18	0.56 ± 0.17	6.3 ± 3.2	42 ± 18
12	5	5.1 ± 2.7	0.14 ± 0.04	2.5 ± 1.3	7.7 ± 3.0
13	15	18 ± 9	0.14 ± 0.05	4.1 ± 2.1	22 ± 9
14	6	9.7 ± 5.0	0.10 ± 0.03	3.6 ± 1.9	13 ± 5
15	9	9.1 ± 4.7	0.23 ± 0.07	4.4 ± 2.2	14 ± 5
16	5	3.2 ± 1.7	0.07 ± 0.02	2.7 ± 1.4	6.0 ± 2.2
17	3	3.6 ± 1.9	0.04 ± 0.01	1.6 ± 0.8	5.2 ± 2.1
18	11	4.2 ± 2.2	0.05 ± 0.02	3.2 ± 1.7	7.5 ± 2.8
21	10	4.6 ± 2.4	0.32 ± 0.10	3.0 ± 1.5	7.9 ± 2.9
22	1	0.5 ± 0.4	0.06 ± 0.02	0.8 ± 0.5	1.4 ± 0.6
23	6	4.5 ± 2.4	0.11 ± 0.03	2.4 ± 1.3	7.1 ± 2.7
24	11	1.8 ± 1.1	0.07 ± 0.02	2.4 ± 1.2	4.3 ± 1.6
25	1	1.1 ± 0.6	0.10 ± 0.03	1.6 ± 0.8	2.7 ± 1.0
26	2	0.3 ± 0.3	0.03 ± 0.01	0.9 ± 0.5	1.3 ± 0.6
27	0	0.9 ± 0.6	0.03 ± 0.01	0.8 ± 0.5	1.8 ± 0.8
28	3	1.3 ± 0.8	0.04 ± 0.01	2.1 ± 1.1	3.4 ± 1.3

Red = 0b, Blue = 1b, Green = ≥ 2b

Results Tables (SR30-35)

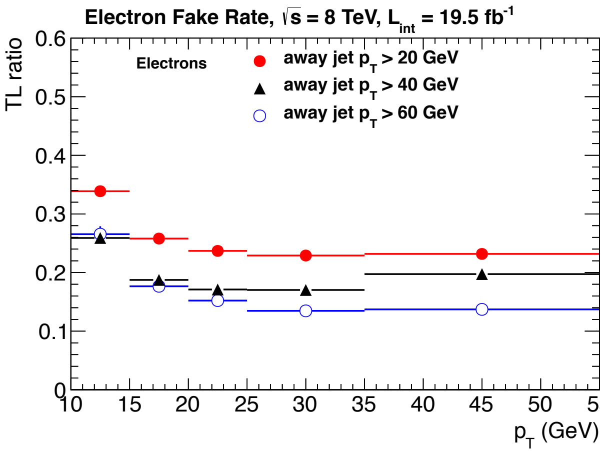
Search Region	Observed	Fake Leptons	Incorrect Charge	Simulation	Total Prediction
30	52	22 ± 11	2.82 ± 0.86	21 ± 11	46 ± 15
31	25	12 ± 6	1.41 ± 0.43	14 ± 7	28 ± 9
32	35	13 ± 7	1.64 ± 0.51	25 ± 12	40 ± 14
33	5	1.8 ± 1.0	0.12 ± 0.04	3.9 ± 2.0	5.8 ± 2.2
34	152	181 ± 91	6.43 ± 1.96	52 ± 26	239 ± 94
35	92	90 ± 45	3.22 ± 0.98	33 ± 17	126 ± 48

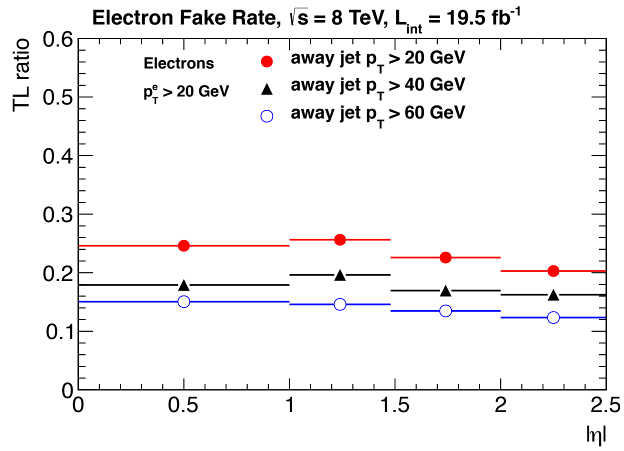
electron FR definition

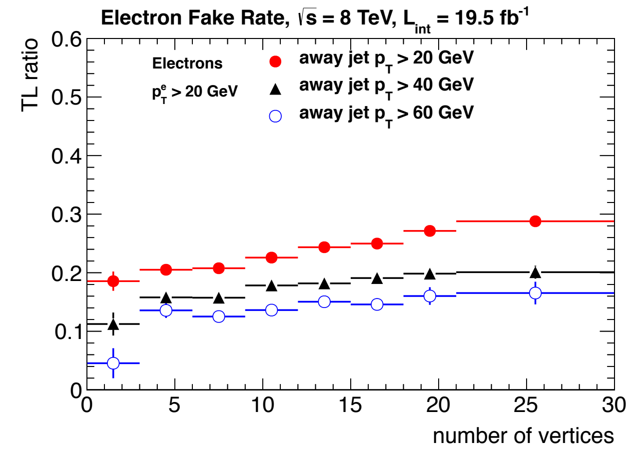
- FO:
  - 10 GeV < p_T < 55 GeV
  - |eta|<2.4
  - W veto
  - Z veto
  - no additional FO's
  - FO ID ssV7
  - Corrected PF relative iso < 0.6
    - Cone size = .03
    - Correction ρ * A_{eff}
  - passes trigger (data only)
  - Away jet > 40 GeV
- numerator (same as FO except)
  - Num ID ssV7
  - Corrected PF relative iso <0.09

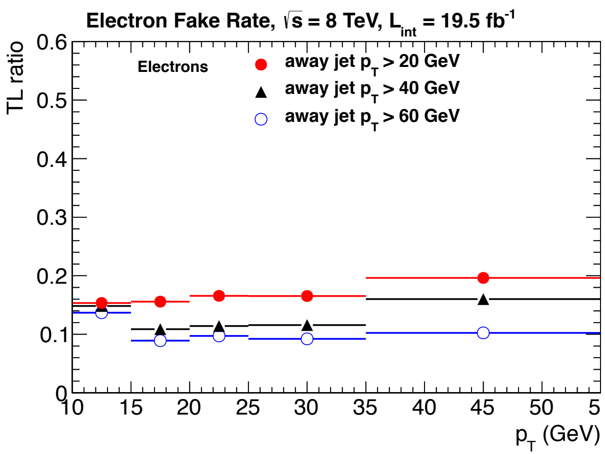
- Ssv7 ID Numerator ID
  - |eta| < 2.4
  - not in transition region 1.4442 < |eta| < 1.556, where eta is from SC
  - ΔR(e, μ) > 0.1 where μ is any muon passing
  - cut-based WP medium noise
  - |dη_in| < (0.004, 0.007)
  - |dϕ_in| < (0.060, 0.030)
  - σ_iηiη < (0.010, 0.030)
  - H/E < (0.120, 0.100)
  - |1/ECAL - 1/Pin| < (0.050, 0.050)
  - |d0| < (0.020, 0.020)
  - |dz| < (0.100, 0.100)
  - vertex fit conversion is successful
  - # missing inner layers ≤ (1, 1)
  - p_T > 20 and pfiso (ρ*A_eff) < (0.150, 0.150)
  - p_T < 20 andpfiso (ρ*A_eff) <(0.100, 0.100)
  - |d0_gsf_track(PV)| < 100 μm
  - |dz_gsf_track(PV)| < 1 mm
  - Conversion removal by veto of a good reconstructed conversion vertex
  - # of missing exptec inner hits == 0
  - triple charge agreement between CTF, GSF and Pixel-Super cluster charges
  - H/E is required to be < 0.1 (0.075) in the barrel (end cap) to match the requirements of the trigger
- FO selection (same as numerator selections except)
  - |d0_gsf_track(PV)| is removed

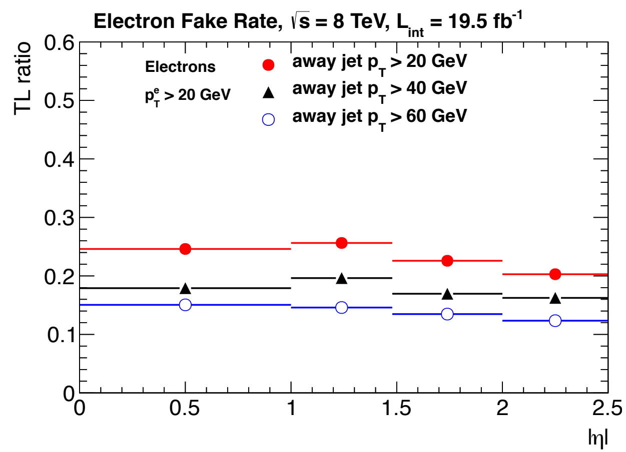
Electron Fake Rates

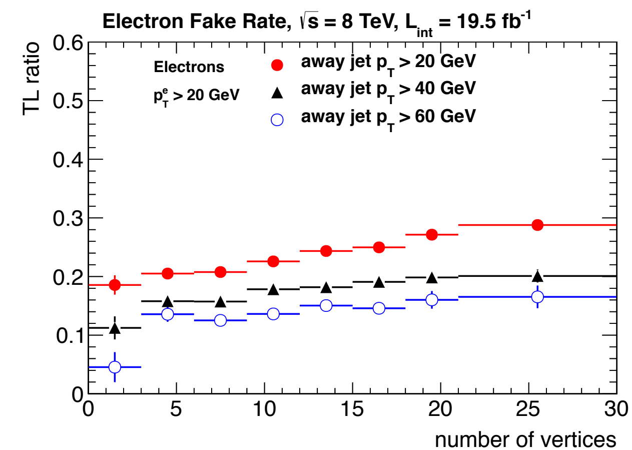










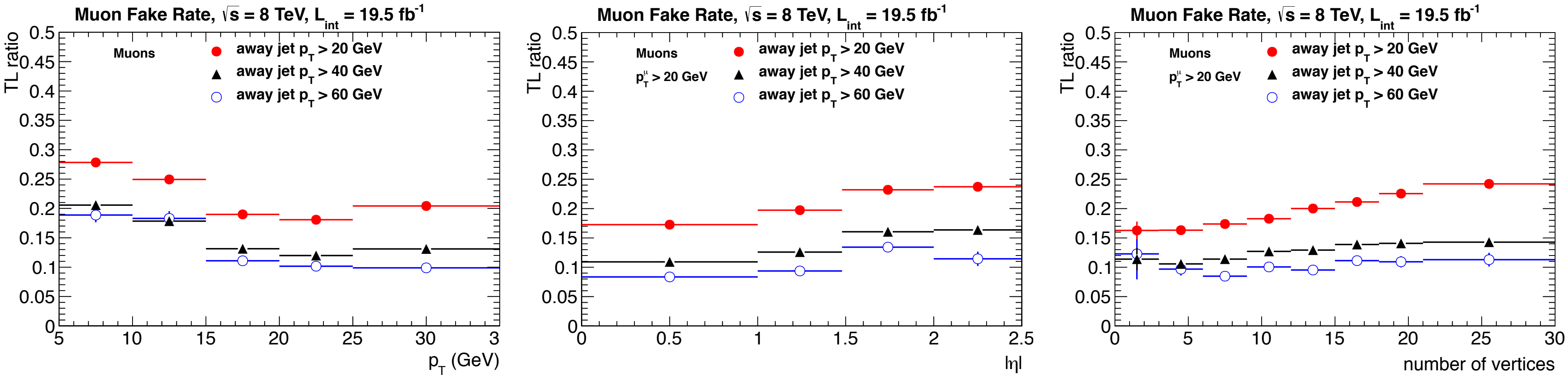


μ FR definition

- FO:
  - 5 < pt < 35 GeV
  - |eta|<2.4
  - W veto
  - Z veto
  - no additional FO's
  - away jet p_T > 40
  - FO ID ssV5
  - Corrected PF relative iso < 0.4
    - Cone size = 0.3
    - Correction Δß
  - passes trigger (data only)
- numerator (same as FO except)
  - Num ID ssV5
  - Corrected PF relative iso <0.1

- ssv5 ID:
  - Numerator
    - |eta| < 2.4
    - global chi2/ndof < 10
    - global and PF μ
    - # layers hits ≥ 6
    - # pixel hits ≥ 1
    - # valid STA hits ≥ 1
    - ECAL deposits < 4
    - HCAL deposits < 6
    - |d0_inner_track(PV)| ≤ 50 μm
    - |dz_inner_track(PV)| ≤ 1 mm
  - FO Selection
    - |eta| < 2.4
    - **global chi2/ndof < 50**
    - global and PF μ
    - # layers hits ≥ 6
    - # pixel hits ≥ 1
    - # valid STA hits ≥ 1
    - **|d0(PV)| ≤ 2 mm**
    - |dz(PV)| ≤ 1 mm

Muon Fake Rates



Closure Test Results

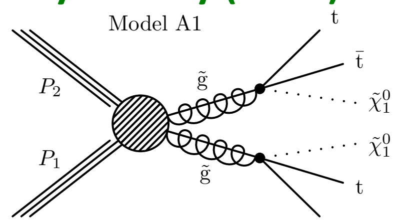
Sample	search region	result	ee	$\mu\mu$	$e\mu$	$\ell\ell$
$t\bar{t}$	SR0	pred	756.8 ± 194.8	830.9 ± 13.0	1592.7 ± 230.0	3180.5 ± 301.6
		obs	339	318	656	1313
		pred/obs	2.23 ± 0.59	2.61 ± 0.15	2.43 ± 0.36	2.42 ± 0.24
		(p-o)/p	0.55 ± 0.12	0.62 ± 0.02	0.59 ± 0.06	0.59 ± 0.04
	SR10	pred	381.3 ± 99.1	420.3 ± 7.9	804.4 ± 116.3	1606.0 ± 153.0
		obs	167	177	354	698
		pred/obs	2.28 ± 0.62	2.37 ± 0.18	2.27 ± 0.35	2.30 ± 0.24
		(p-o)/p	0.56 ± 0.12	0.58 ± 0.03	0.56 ± 0.07	0.57 ± 0.04
	SR20	pred	59.0 ± 14.9	45.3 ± 2.1	99.0 ± 13.7	203.4 ± 20.3
		obs	34	23	53	110
		pred/obs	1.74 ± 0.53	1.97 ± 0.42	1.87 ± 0.36	1.85 ± 0.26
		(p-o)/p	0.42 ± 0.18	0.49 ± 0.11	0.46 ± 0.10	0.46 ± 0.07
W + jets	SR0	pred	23.7 ± 5.9	4.5 ± 0.7	33.7 ± 7.3	61.9 ± 9.4
		obs	29	4	21	54
		pred/obs	0.82 ± 0.25	1.13 ± 0.59	1.60 ± 0.49	1.15 ± 0.23
		(p-o)/p	-0.22 ± 0.38	0.12 ± 0.46	0.38 ± 0.19	0.13 ± 0.18

Flip Rate

$\|\eta\|/p_T$	0-20 GeV	20-40 GeV	40-60 GeV	60-80 GeV	80-200 GeV
0.0-1.0	2.52e-05 $\pm$ 2.52e-05	3.44e-05 $\pm$ 6.18e-06	2.06e-05 $\pm$ 4.38e-06	1.03e-04 $\pm$ 3.27e-05	9.16e-05 $\pm$ 4.58e-05
1.0-2.0	1.67e-04 $\pm$ 6.29e-05	1.81e-04 $\pm$ 1.82e-05	2.16e-04 $\pm$ 1.94e-05	5.31e-04 $\pm$ 1.00e-04	9.87e-04 $\pm$ 2.06e-04
2.0-2.4	0.00e+00 $\pm$ 4.52e-05	2.96e-04 $\pm$ 4.52e-05	3.96e-04 $\pm$ 5.49e-05	1.34e-03 $\pm$ 3.34e-04	8.79e-04 $\pm$ 4.39e-04

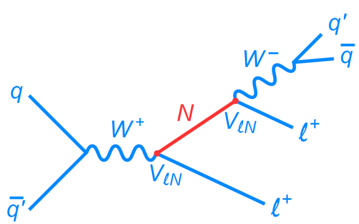
Model Examples

Supersymmetry (SUSY)



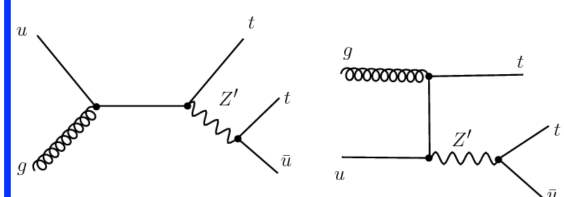
$$pp \to \tilde{g}\tilde{g} \to t\bar{t}\tilde{\chi}_1^0 t\bar{t}\tilde{\chi}_1^0$$

Heavy Majorana Neutrinos



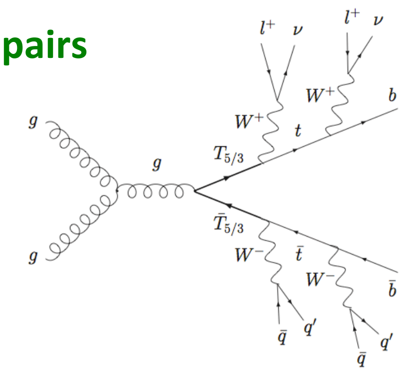
$$pp \to \ell^+ \overline{N} \to \ell^- \ell^- q' \bar{q}$$

Same-Sign Top Pairs



$$pp \to tt\bar{u}$$

$T_{5/3}$ pairs

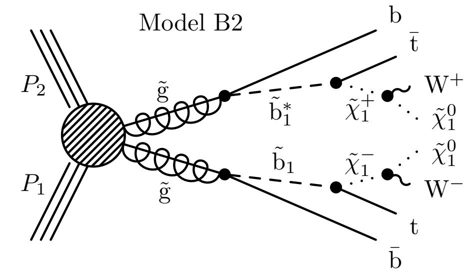


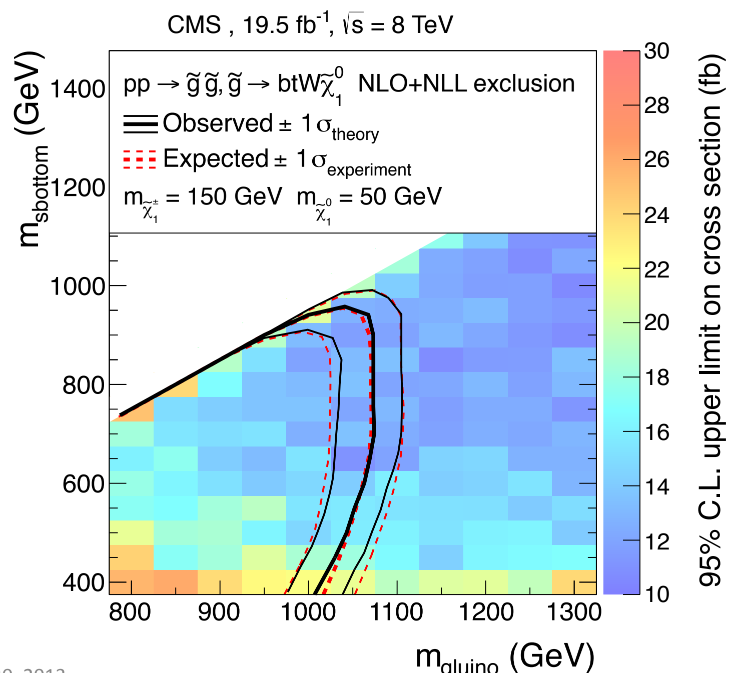
$$pp \to T_{5/3}\overline{T}_{5/3} \to \ell^{\pm}\nu\ell^{\pm}\nu b\bar{b} + \text{jets}$$

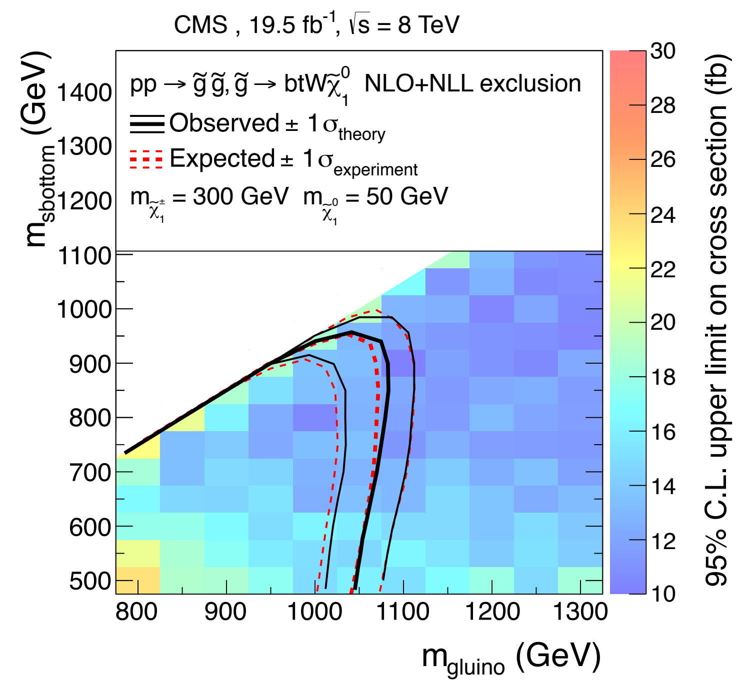
Gluino Mediated Sbottom Production

- Using high p_T leptons and ≥ 2 N_{bjets} search regions (SR21-28).
- m_{gluino} vs $m_{sbottom}$
- $m_{chargino}$ = 150 GeV (left) and 300 GeV (right)
- m_{LSP} held fixed at 50 GeV

gluino mediated
sbottom production
4W+4b+2LSP

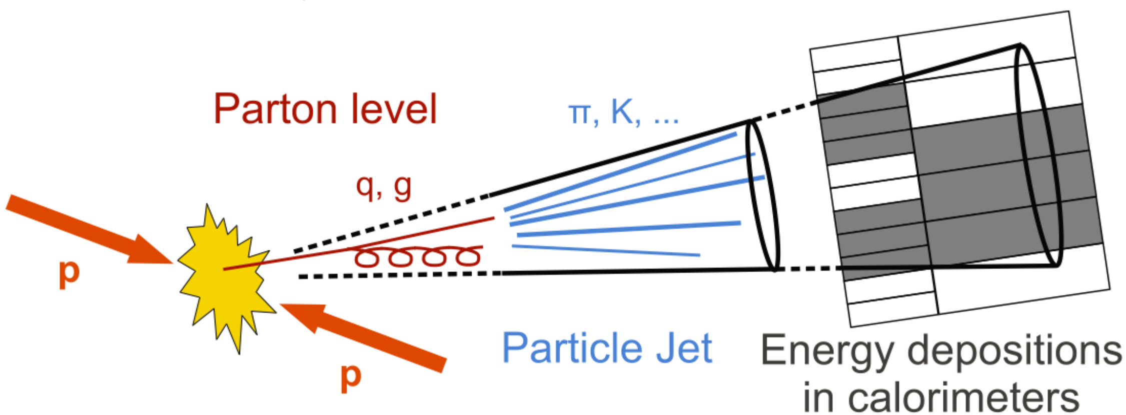






Hadronic Signature

- Quarks and Gluons carry color charge (strong interaction)
- **No free color exists → must be composite color free particle (hadrons)**
  - baryons (3 quarks): protons, neutrons
  - mesons (quark and anti-quark): pions, kaons
- **Jets:** Experimental signature is culminated spray of particles in the form of tracks and Calorimeter Deposits



$t\bar{t}\gamma$ Scale Factor

- ttγ MC sample has low statistics
  - ~70k generated events
  - SS analysis yields (7 events high p_T, 4 events low p_T)
  - Leads to high statistical uncertainties in the event with no yield
    - 0 ± 1.08 using the Clopper-Peason method
- Use ttbar MC to extrapolate from these 7(4) events into all SRs
  - The assumption is that the MET and HT distributions of ttbar → 1 lepton ≈ ttγ → 1 lepton + γ conversion
- Procedure:
  - Using ttbar MC, make a single lepton count (N_{ttbar_SR0})
    - 1 lepton
      - truth matched to W decay
      - passes ID/Isolation
      - pT > 20/10 GeV (high/low pT analysis)
    - # jets ≥ 2
    - passes baseline signal region (SR0)
    - call this
  - Repeat this for all SRs (N_{ttbar_SRx})
  - Take the predictions from ttγ in SR0 ($N_{tt\gamma\_SR0}$)
  - Scale the ttγ prediction from ttbar

Search Region	high-p_T SF	low-p_T SF
SR1	$1.81 \times 10^{-1} \pm 4.44 \times 10^{-4}$	$2.04 \times 10^{-1} \pm 7.22 \times 10^{-04}$
SR2	$1.48 \times 10^{-2} \pm 1.39 \times 10^{-4}$	$3.57 \times 10^{-2} \pm 3.32 \times 10^{-04}$
SR3	$9.68 \times 10^{-2} \pm 3.41 \times 10^{-4}$	$1.88 \times 10^{-1} \pm 7.00 \times 10^{-04}$
SR4	$5.11 \times 10^{-2} \pm 2.54 \times 10^{-4}$	$1.23 \times 10^{-1} \pm 5.87 \times 10^{-04}$
SR5	$4.89 \times 10^{-2} \pm 2.49 \times 10^{-4}$	$7.01 \times 10^{-2} \pm 4.57 \times 10^{-04}$
SR6	$1.06 \times 10^{-2} \pm 1.18 \times 10^{-4}$	$2.56 \times 10^{-2} \pm 2.83 \times 10^{-04}$
SR7	$1.70 \times 10^{-2} \pm 1.49 \times 10^{-4}$	$3.71 \times 10^{-2} \pm 3.38 \times 10^{-04}$
SR8	$2.22 \times 10^{-2} \pm 1.70 \times 10^{-4}$	$5.33 \times 10^{-2} \pm 4.02 \times 10^{-04}$
SR10	$4.96 \times 10^{-1} \pm 5.77 \times 10^{-4}$	$4.73 \times 10^{-1} \pm 8.93 \times 10^{-04}$
SR11	$9.02 \times 10^{-2} \pm 3.31 \times 10^{-4}$	$1.01 \times 10^{-1} \pm 5.39 \times 10^{-04}$
SR12	$7.49 \times 10^{-3} \pm 9.95 \times 10^{-5}$	$1.80 \times 10^{-2} \pm 2.38 \times 10^{-04}$
SR13	$4.43 \times 10^{-2} \pm 2.38 \times 10^{-4}$	$8.60 \times 10^{-2} \pm 5.02 \times 10^{-04}$
SR14	$2.30 \times 10^{-2} \pm 1.73 \times 10^{-4}$	$5.54 \times 10^{-2} \pm 4.09 \times 10^{-04}$
SR15	$2.53 \times 10^{-2} \pm 1.81 \times 10^{-4}$	$3.59 \times 10^{-2} \pm 3.33 \times 10^{-04}$
SR16	$5.35 \times 10^{-3} \pm 8.41 \times 10^{-5}$	$1.29 \times 10^{-2} \pm 2.02 \times 10^{-04}$
SR17	$8.23 \times 10^{-3} \pm 1.04 \times 10^{-4}$	$1.79 \times 10^{-2} \pm 2.37 \times 10^{-04}$
SR18	$1.02 \times 10^{-2} \pm 1.16 \times 10^{-4}$	$2.44 \times 10^{-2} \pm 2.76 \times 10^{-04}$
SR20	$2.77 \times 10^{-1} \pm 5.16 \times 10^{-4}$	$3.47 \times 10^{-1} \pm 8.52 \times 10^{-04}$
SR21	$5.29 \times 10^{-2} \pm 2.58 \times 10^{-4}$	$6.25 \times 10^{-2} \pm 4.33 \times 10^{-04}$
SR22	$4.11 \times 10^{-3} \pm 7.38 \times 10^{-5}$	$9.89 \times 10^{-3} \pm 1.77 \times 10^{-04}$
SR23	$3.71 \times 10^{-2} \pm 2.18 \times 10^{-4}$	$7.31 \times 10^{-2} \pm 4.66 \times 10^{-04}$
SR24	$2.05 \times 10^{-2} \pm 1.64 \times 10^{-4}$	$4.93 \times 10^{-2} \pm 3.87 \times 10^{-04}$
SR25	$9.65 \times 10^{-3} \pm 1.13 \times 10^{-4}$	$1.49 \times 10^{-2} \pm 2.16 \times 10^{-04}$
SR26	$2.52 \times 10^{-3} \pm 5.79 \times 10^{-5}$	$6.07 \times 10^{-3} \pm 1.39 \times 10^{-04}$
SR27	$5.62 \times 10^{-3} \pm 8.63 \times 10^{-5}$	$1.23 \times 10^{-2} \pm 1.97 \times 10^{-04}$
SR28	$8.25 \times 10^{-3} \pm 1.04 \times 10^{-4}$	$1.98 \times 10^{-2} \pm 2.50 \times 10^{-04}$

$$N_{t\bar{t}\gamma}^{SRx} = N_{t\bar{t}\gamma}^{SR0} \times \frac{N_{t\bar{t}}^{SRx}}{N_{t\bar{t}}^{SR0}}$$

Samples Used:

ttγ MC: /TTGJets_8TeV-madgraph/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM (~70k events)

ttbar MC: /TTJets_MassiveBinDECAY_TuneZ2star_8TeV-madgraph-tauola/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM (~6M events)

Lepton Efficiency SF

- Lepton Efficiency was measured using Tag & Probe.
  - Details are in AN-2013/120.
- The scale factors applied:

Electrons

p_T, GeV		10 – 15	15 – 20	20 – 30	30 – 40	40 – 50	50 – 200
$\|\eta\|$	0.0 – 0.8	0.834 ± 0.012	0.918 ± 0.006	0.954 ± 0.002	0.960 ± 0.001	0.972 ± 0.001	0.969 ± 0.001
	0.8 – 1.4442	0.973 ± 0.023	0.906 ± 0.009	0.923 ± 0.003	0.935 ± 0.001	0.955 ± 0.001	0.956 ± 0.001
	1.566 – 2.0	0.954 ± 0.028	0.909 ± 0.012	0.921 ± 0.005	0.924 ± 0.002	0.950 ± 0.001	0.995 ± 0.002
	2.0 – 2.4	1.119 ± 0.036	0.944 ± 0.015	0.993 ± 0.004	0.959 ± 0.003	0.968 ± 0.002	0.969 ± 0.004

Mouns

p_T, GeV		10 – 15	15 – 20	20 – 30	30 – 40	40 – 50	50 – 200
$\|\eta\|$	0.0 – 1.2	0.956 ± 0.010	0.957 ± 0.004	0.964 ± 0.001	0.971 ± 0.000	0.978 ± 0.000	0.974 ± 0.001
	1.2 – 2.4	0.960 ± 0.016	0.971 ± 0.005	0.959 ± 0.001	0.978 ± 0.001	0.984 ± 0.000	0.977 ± 0.001

Lepton data/MC SF Systematic Uncertainties

	lepton flavor	$p_T < 15$ GeV	$p_T > 15$ GeV
tag & probe	electron	10%	5%
	muon	5%	3%
		$p_T < 30$ GeV	$p_T > 30$ GeV
composition	electron	3%	3%
	muon	5%	3%

Composition → based on the difference in efficiency in DY events versus signal-like events (studied with MC). See AN-2013/120.

Datasets

High p_T

Name	Run Range
/DoubleMu/Run2012A-13Jul2012-v1/AOD	190456-193621
/DoubleMu/Run2012B-13Jul2012-v1/AOD	193834-196531
/DoubleMu/Run2012A-recover-06Aug2012-v1/AOD	190949 190945 190906 190895 190782
/DoubleMu/Run2012C-24Aug2012-v1/AOD	198022-198523
/DoubleMu/Run2012C-PromptReco-v2/AOD	198934-203755
/DoubleMu/Run2012D-PromptReco-v1/AOD	203773-208913
/DoubleElectron/Run2012A-13Jul2012-v1/AOD	190456-193621
/DoubleElectron/Run2012B-13Jul2012-v1/AOD	193834-196531
/DoubleElectron/Run2012A-recover-06Aug2012-v1/AOD	190949 190945 190906 190895 190782
/DoubleElectron/Run2012C-24Aug2012-v1/AOD	198022-198523
/DoubleElectron/Run2012C-PromptReco-v2/AOD	198934-203755
/DoubleElectron/Run2012D-PromptReco-v1/AOD	203773-208913
/MuEG/Run2012A-13Jul2012-v1/AOD	190456-193621
/MuEG/Run2012B-13Jul2012-v1/AOD	193834-196531
/MuEG/Run2012A-recover-06Aug2012-v1/AOD	190949 190945 190906 190895 190782
/MuEG/Run2012C-24Aug2012-v1/AOD	198022-198523
/MuEG/Run2012C-PromptReco-v2/AOD	198934-203755
/MuEG/Run2012D-PromptReco-v1/AOD	203773-208913

Low p_T

Name	Run Range
/MuHad/Run2012A-13Jul2012-v1/AOD	190456-193621
/MuHad/Run2012B-13Jul2012-v1/AOD	193834-196531
/MuHad/Run2012A-recover-06Aug2012-v1/AOD	190949 190945 190906 190895 190782
/MuHad/Run2012C-24Aug2012-v1/AOD	198022-198523
/MuHad/Run2012C-PromptReco-v2/AOD	198934-203755
/MuHad/Run2012D-PromptReco-v1/AOD	203773-208913
/ElectronHad/Run2012A-13Jul2012-v1/AOD	190456-193621
/ElectronHad/Run2012B-13Jul2012-v1/AOD	193834-196531
/ElectronHad/Run2012A-recover-06Aug2012-v1/AOD	190949 190945 190906 190895 190782
/ElectronHad/Run2012C-24Aug2012-v1/AOD	198022-198523
/ElectronHad/Run2012C-PromptReco-v2/AOD	198934-203755
/ElectronHad/Run2012D-PromptReco-v1/AOD	203773-208913

Certification	Luminosity (fb^{-1})
Cert_190456-196531_8TeV_13Jul2012ReReco_Collisions12_JSON	5.21
Cert_190782-190949_8TeV_06Aug2012ReReco_Collisions12_JSON	0.08
Cert_198022-198523_8TeV_24Aug2012ReReco_Collisions12_JSON	0.50
Cert_190456-208686_8TeV_PromptReco_Collisions12_JSON	19.3

Datasets for Fakes

UFL

Name	Run Range
/MuHad/Run2012A-13Jul2012-v1/AOD	190456-193621
/MuHad/Run2012B-13Jul2012-v1/AOD	193834-196531
/MuHad/Run2012A-recover-06Aug2012-v1/AOD	190949 190945 190906 190895 190782
/MuHad/Run2012C-24Aug2012-v1/AOD	198022-198523
/MuHad/Run2012C-PromptReco-v2/AOD	198934-203755
/MuHad/Run2012D-PromptReco-v1/AOD	203773-208913
/ElectronHad/Run2012A-13Jul2012-v1/AOD	190456-193621
/ElectronHad/Run2012B-13Jul2012-v1/AOD	193834-196531
/ElectronHad/Run2012A-recover-06Aug2012-v1/AOD	190949 190945 190906 190895 190782
/ElectronHad/Run2012C-24Aug2012-v1/AOD	198022-198523
/ElectronHad/Run2012C-PromptReco-v2/AOD	198934-203755
/ElectronHad/Run2012D-PromptReco-v1/AOD	203773-208913

UC/FNAL
ETH/O

Name	Run Range
/DoubleMu/Run2012A-13Jul2012-v1/AOD	190456-193621
/DoubleMu/Run2012B-13Jul2012-v1/AOD	193834-196531
/DoubleMu/Run2012A-recover-06Aug2012-v1/AOD	190949 190945 190906 190895 190782
/DoubleMu/Run2012C-24Aug2012-v1/AOD	198022-198523
/DoubleMu/Run2012C-PromptReco-v2/AOD	198934-203755
/DoubleMu/Run2012D-PromptReco-v1/AOD	203773-208913
/DoubleElectron/Run2012A-13Jul2012-v1/AOD	190456-193621
/DoubleElectron/Run2012B-13Jul2012-v1/AOD	193834-196531
/DoubleElectron/Run2012A-recover-06Aug2012-v1/AOD	190949 190945 190906 190895 190782
/DoubleElectron/Run2012C-24Aug2012-v1/AOD	198022-198523
/DoubleElectron/Run2012C-PromptReco-v2/AOD	198934-203755
/DoubleElectron/Run2012D-PromptReco-v1/AOD	203773-208913
/SingleMu/Run2012A-13Jul2012-v1/AOD	190456-193621
/SingleMu/Run2012B-13Jul2012-v1/AOD	193834-196531
/SingleMu/Run2012A-recover-06Aug2012-v1/AOD	190949 190945 190906 190895 190782
/SingleMu/Run2012C-24Aug2012-v1/AOD	198022-198523
/SingleMu/Run2012C-PromptReco-v2/AOD	198934-203755
/SingleMu/Run2012D-PromptReco-v1/AOD	203773-208913

Rare SM Monte Carlo Samples

Name	Cross section, pb	Luminosity, fb^{-1}
TTZJets_8TeV-madgraph/Su12-v1	0.206	1021.68
TTWWJets_8TeV-madgraph/Su12-v1	0.002037	106931.76
TTWJets_8TeV-madgraph/Su12-v1	0.232	845.03
TTGJets_8TeV-madgraph/Su12-v1	2.166	33.06
TBZToLL_4F_TuneZ2star_8TeV-madgraph/Su12-v1	0.0114	13026.67
ZZZNoGstarJets_8TeV-madgraph/Su12-v1	0.0055269	40692.61
WWWJets_8TeV-madgraph/Su12-v1	0.08217	2737.02
WWGJets_8TeV-madgraph/Su12-v1	0.528	407.43
WZZNoGstarJets_8TeV-madgraph/Su12-v1	0.01922	12946.70
WWZNoGstarJets_8TeV-madgraph/Su12-v1	0.05798	3832.94
ZZJetsTo4L_TuneZ2star_8TeV-madgraph-tauola/Su12-v1	0.1769	27177.36
WZJetsTo3LNu_TuneZ2_8TeV-madgraph-tauola/Su12-v1	1.0575	1908.25
WmWmqq_8TeV-madgraph/Su12-v1	0.08888	1084.52
WpWpqq_8TeV-madgraph/Su12-v1	0.2482	402.84
WW_DoubleScattering_8TeV-pythia8/Su12-v1	0.5879	1418.68
WGstarToLNu2Mu_TuneZ2star_7TeV-madgraph-tauola/Su12-v1	1.914	156.73
WGstarToLNu2Tau_TuneZ2star_7TeV-madgraph-tauola/Su12-v1	0.336	148.80
WH_ZH_TTH_HToWW_M-125_8TeV-pythia6/Su12-v1	0.2604	769.72
WH_ZH_TTH_HToZZ_M-125_8TeV-pythia6/Su12-v1	0.0320	15652.26
WH_ZH_TTH_HToTauTau_M-125_lepdecay_8TeV-pythia6-tauola/Su12-v1	0.0177	5478.02

Other Monte Carlo Samples

Name	Cross section, pb	Luminosity, fb^{-1}
TTJets_MassiveBinDECAY_TuneZ2star_8TeV-madgraph/Su12-v1	225.21	29.59
TTJets_FullLeptMGDecays_8TeV-madgraph/Su12-v1	24.56	493.45
TTJets_SemiLeptMGDecays_8TeV-madgraph/Su12-v1	102.50	247.66
TTJets_HadronicMGDecays_8TeV-madgraph/Su12-v1	106.93	292.00
T_s-channel_Tune2star_8TeV-powheg-tauola/Su12-v1	3.89	68.59
Tbar_s-channel_Tune2star_8TeV-powheg-tauola/Su12-v1	1.76	79.53
T_t-channel_Tune2star_8TeV-powheg-tauola/Su12-v1	55.5	66.10
Tbar_t-channel_Tune2star_8TeV-powheg-tauola/Su12-v1	30.0	63.03
T_tW-channel-DR_Tune2star_8TeV-powheg-tauola/Su12-v1	11.18	44.83
Tbar_tW-channel-DR_Tune2star_8TeV-powheg-tauola/Su12-v1	11.18	44.45
DYJetsToLL_M-50_TuneZ2Star_8TeV-madgraph-tarball/Su12-v1	3532.8	8.62
WJetsToLNu_TuneZ2Star_8TeV-madgraph-tarball/Su12-v1	37509	inf
WWJetsTo2L2Nu_TuneZ2star_8TeV-madgraph-tauola/Su12-v1	5.81	332.61

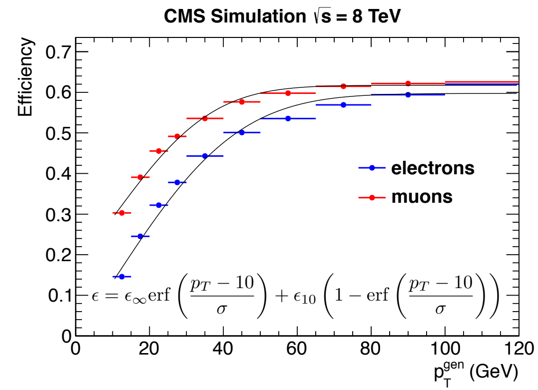
Name	Cross section, pb	Luminosity, fb^{-1}
TTJets_FullLeptMGDecays_8TeV-madgraph/Su12-v1	24.56	493.45
TTTT_TuneZ2star_8TeV-madgraph-tauola/Su12-v1	.000716	139656.43

Signal Acceptance Parameterization

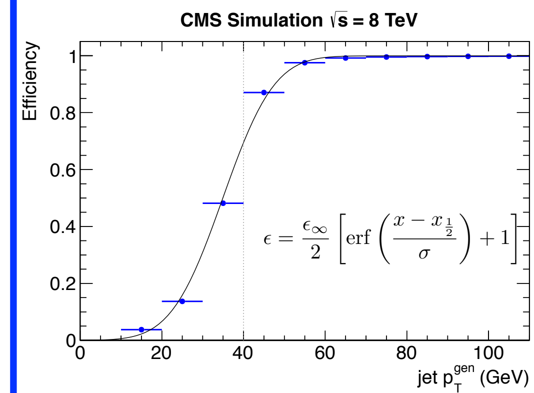
- Use to get an approximate acceptance for any New Physics model
  - defined w.r.t generator level
  - good to within 30% of using full detector simulation/reconstruction
- Parameters for the fit functions are provided in PAS [1] (and backup)

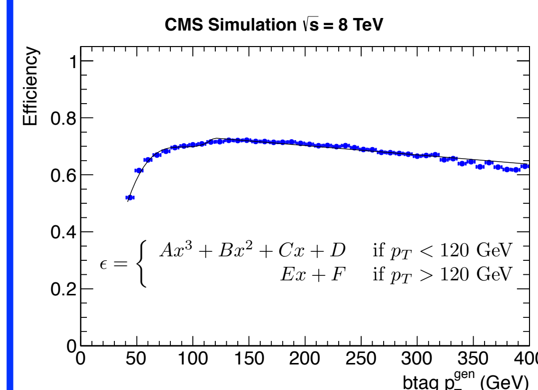
[1] CMS-PAS-SUS-13-013: http://cds.cern.ch/record/1563301

Lepton Efficiency



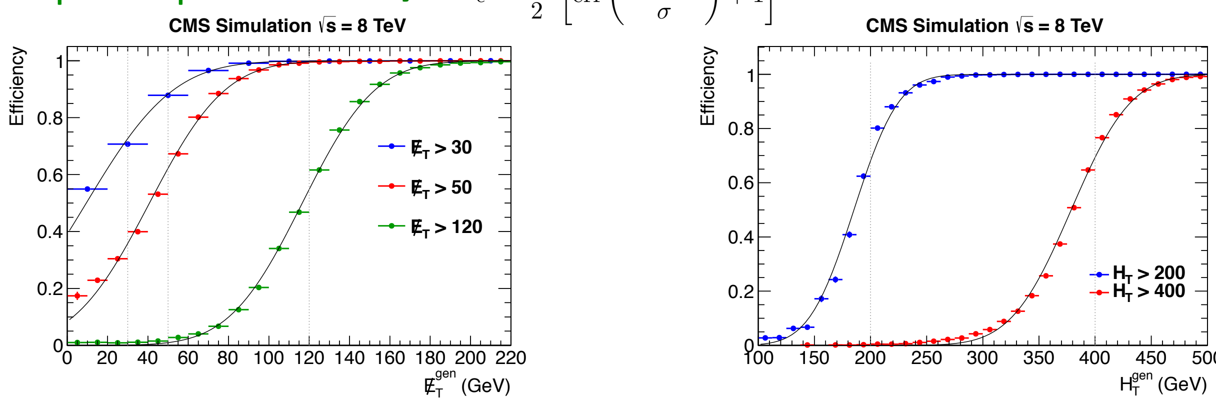
Jet and b-tag Efficiency





H_T and E_T^{miss} Efficiency

$$\epsilon = \frac{\epsilon_\infty}{2}\left[\mathrm{erf}\left(\frac{x - x_{\frac{1}{2}}}{\sigma}\right) + 1\right]$$



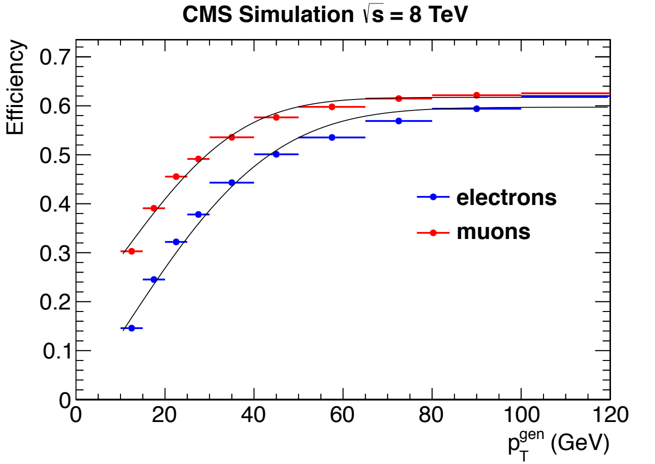
Signal Acceptance Parameterization

- Acceptance model defined w.r.t status 3 generator level using T1tttt.

Lepton Efficiency

$$\epsilon = \epsilon_\infty \mathrm{erf}\left(\frac{p_T - 10}{\sigma}\right) + \epsilon_{10}\left(1 - \mathrm{erf}\left(\frac{p_T - 10}{\sigma}\right)\right)$$

Parameter	Electrons	Muons
ϵ_∞	0.640 ± 0.001	0.673 ± 0.001
ϵ_{10}	0.170 ± 0.002	0.332 ± 0.003
σ	36.94 ± 0.320	29.65 ± 0.382



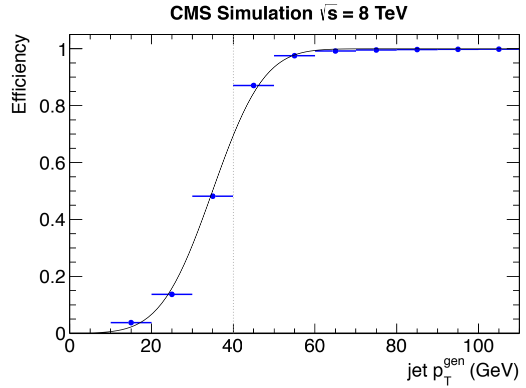
Jet and b-tag Efficiency

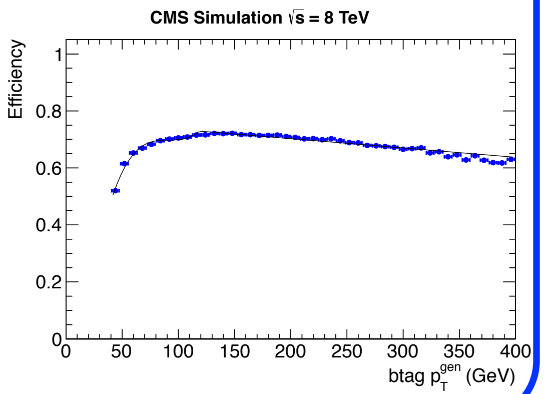
$$\epsilon = \frac{\epsilon_\infty}{2}\left[\mathrm{erf}\left(\frac{x - x_{\frac{1}{2}}}{\sigma}\right) + 1\right]$$

Parameter	Value
ϵ_∞	1.000 ± 0.001
$x_{1/2}$, GeV	29.81 ± 0.100
σ, GeV	18.75 ± 0.099

$$\epsilon = \begin{cases} Ax^3 + Bx^2 + Cx + D & \text{if } p_T < 120 \text{ GeV} \\ Ex + F & \text{if } p_T > 120 \text{ GeV} \end{cases}$$

Parameter	Value
A	$(1.55 \pm 0.05) \times 10^{-6}$
B	$(-4.26 \pm 0.12) \times 10^{-4}$
C	0.0391 ± 0.0008
D	-0.496 ± 0.020
E	$(-3.26 \pm 0.01) \times 10^{-4}$
F	0.7681 ± 0.0016



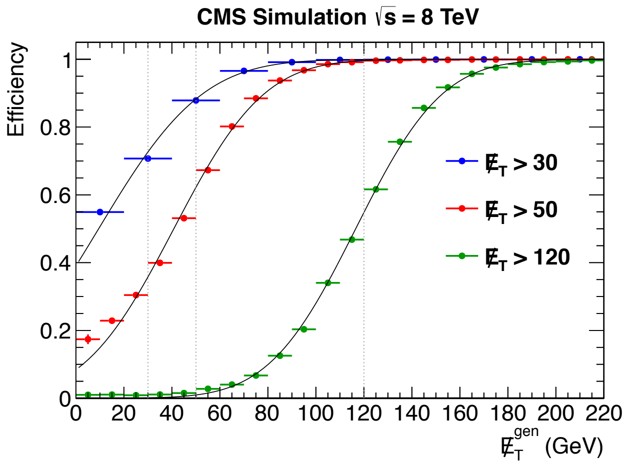


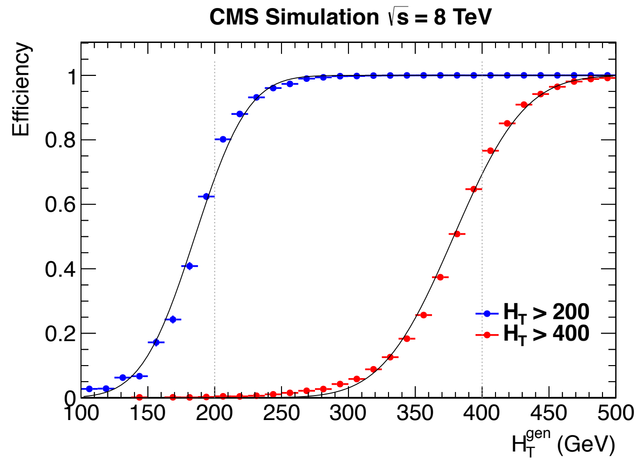
Signal Acceptance Parameterization (2)

H_T and MET Efficiency

$$\epsilon = \frac{\epsilon_\infty}{2}\left[\mathrm{erf}\left(\frac{x - x_{\frac{1}{2}}}{\sigma}\right) + 1\right]$$

Parameter	H_T		E_T^{miss}		
	> 200 GeV	> 400 GeV	> 30 GeV	> 50 GeV	> 120 GeV
ϵ_∞	0.999 ± 0.001	0.999 ± 0.001	1.000 ± 0.001	1.000 ± 0.001	0.999 ± 0.001
$x_{1/2}$, GeV	185.2 ± 0.4	378.69 ± 0.17	13.87 ± 0.30	42.97 ± 0.14	117.85 ± 0.09
σ, GeV	44.5 ± 0.6	59.41 ± 0.26	42.92 ± 0.34	37.47 ± 0.20	36.90 ± 0.14

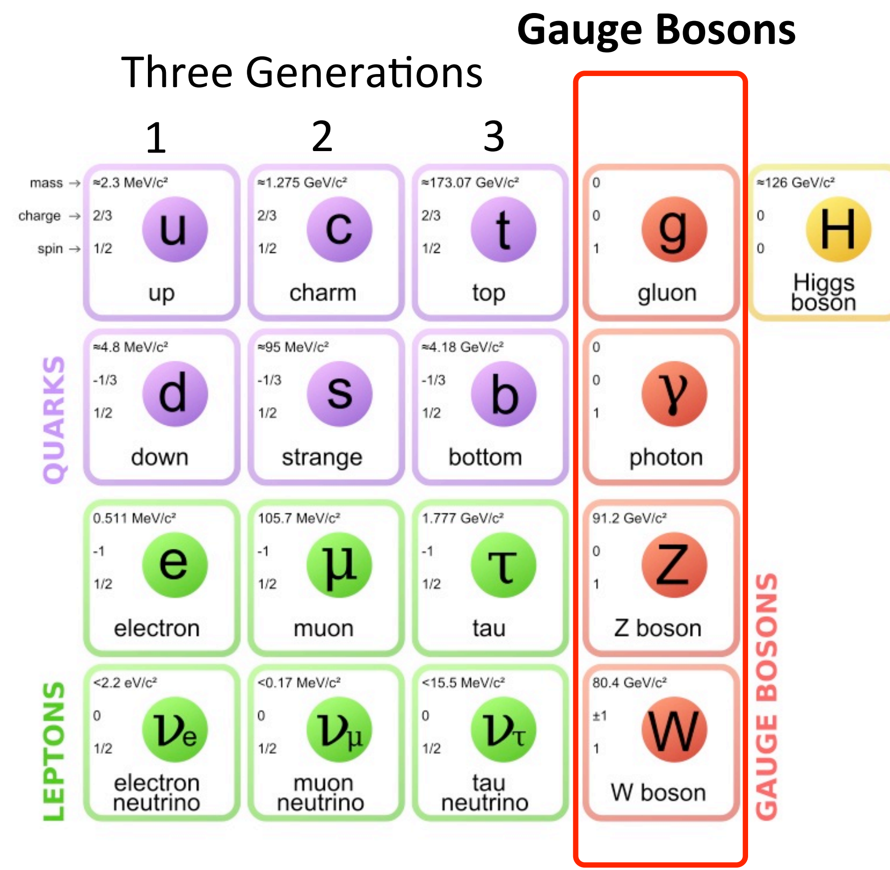




The **Standard Model** of Particle Physics

• Gauge Fields → spin 1 (boson)

- **Mediate** the interactions (forces)
  - strong, electromagnetic, and weak
- photon (γ): electromagnetic (EM)
  - **massless**
  - interact with all electrically charged particles
- gluon (g): strong
  - **massless**
  - interact with color charged particles
- Z and W$^{\pm}$ bosons: weak
  - **massive** (Z = 91.2 GeV/c^2 and W = 80.4 GeV/c^2)
  - interact quarks, leptons and Higgs boson
  - W's interact with Z and other W's
  - W are charged (±), Z is neutral

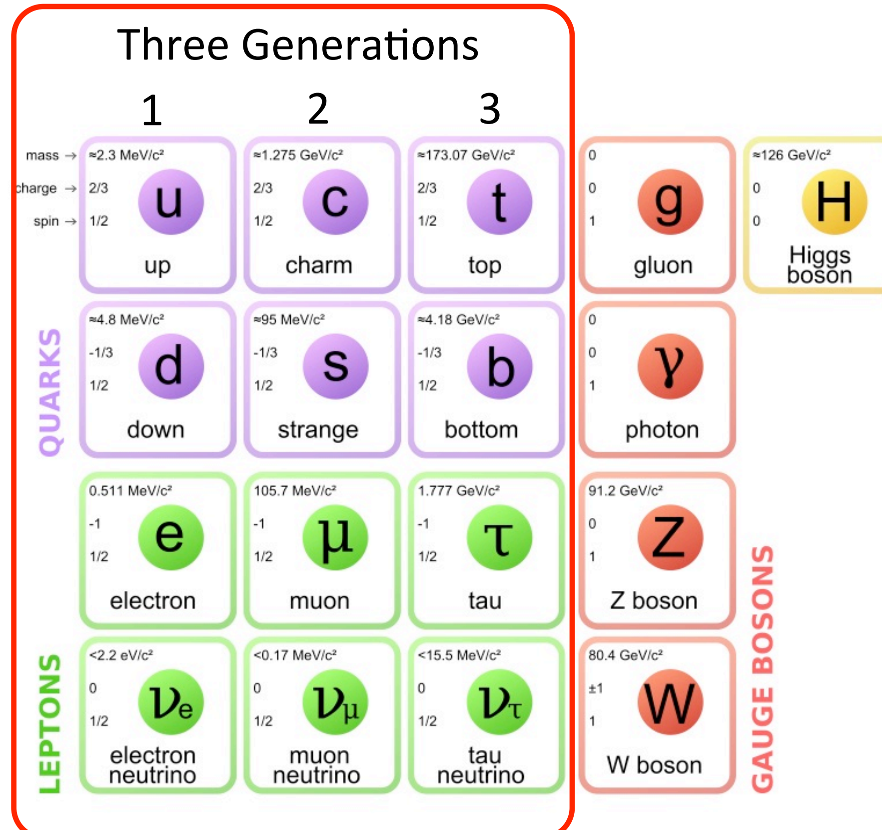


The Standard Model of Particle Physics

• Matter Fields → spin ½ (fermions)

- **Make up all ordinary matter and anti-matter**
  - **anti-matter denoted with bar: $\bar{t}$**
- **Quarks**
  - carry color, charge, and flavor
  - strong, weak, and electromagnetic
- **Leptons**
  - do **NOT** carry color
    - no strong interaction
  - charged leptons (e, μ, τ): electromagnetic and weak
  - neutrinos (ν): weak **only**
    - difficult to **directly** detect experimentally

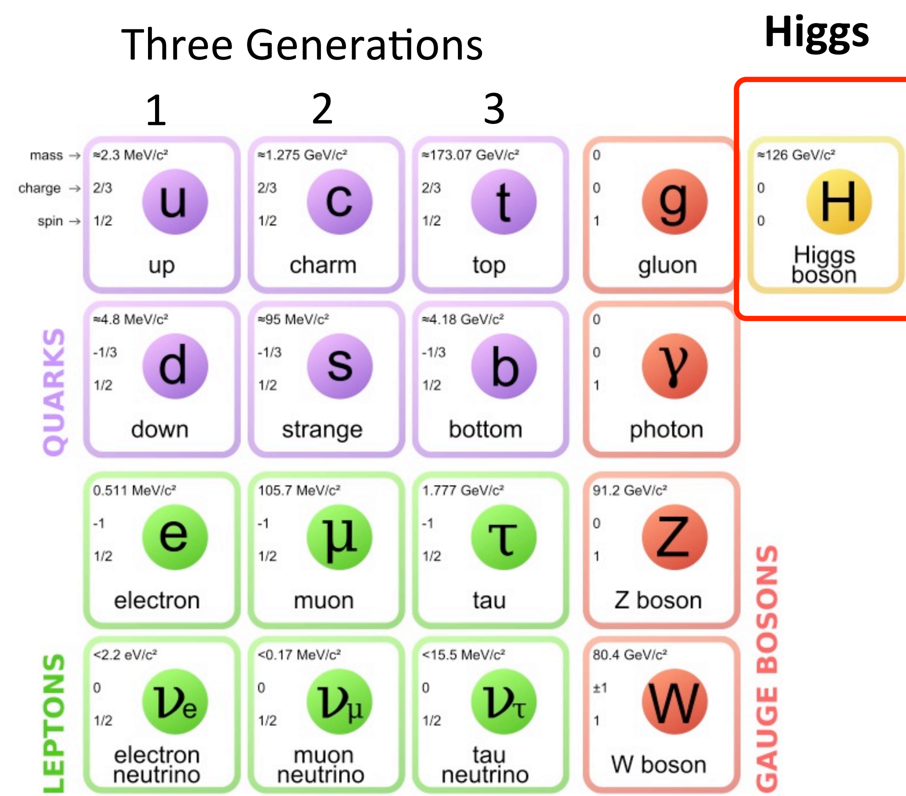
Fermions



The **Standard Model** of Particle Physics

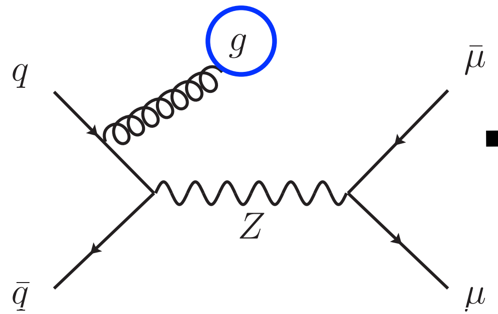
• Higgs boson → spin 0 (scalar)

- **Massive:** (126 GeV/c^2)
- **Key roll in electroweak theory**
  - Unifies the EM and weak interaction through a spontaneously broken symmetry
  - Gives mass to matter and weak gauge bosons (W and Z)

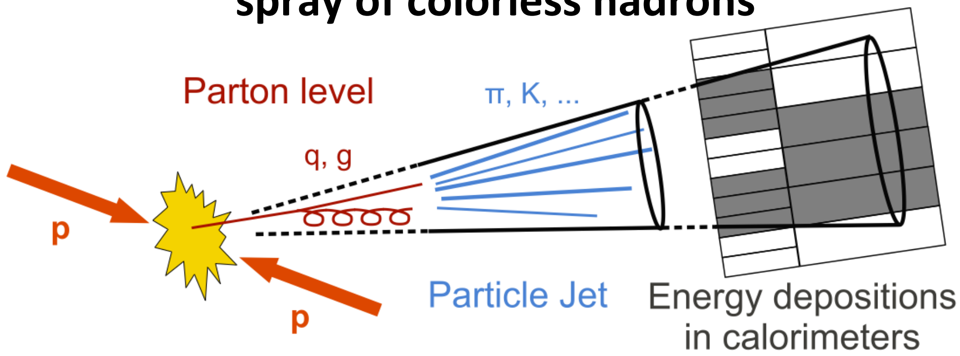


Hadronic Signature: Jets

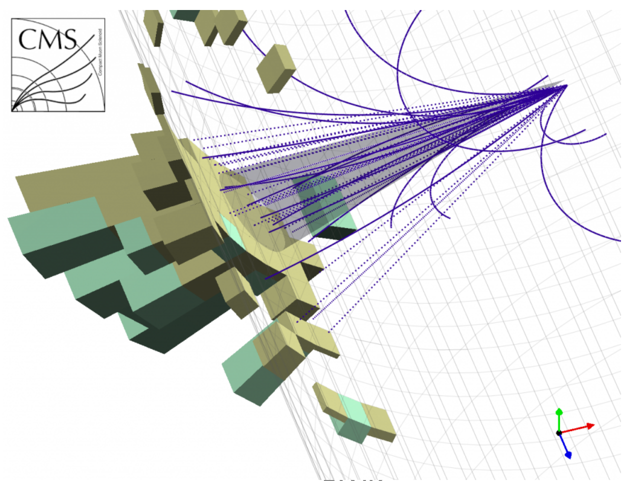
Color particle resulting from collision: quark or gluon



QCD confinement: spray of colorless hadrons



Jet



CMS Subsystems