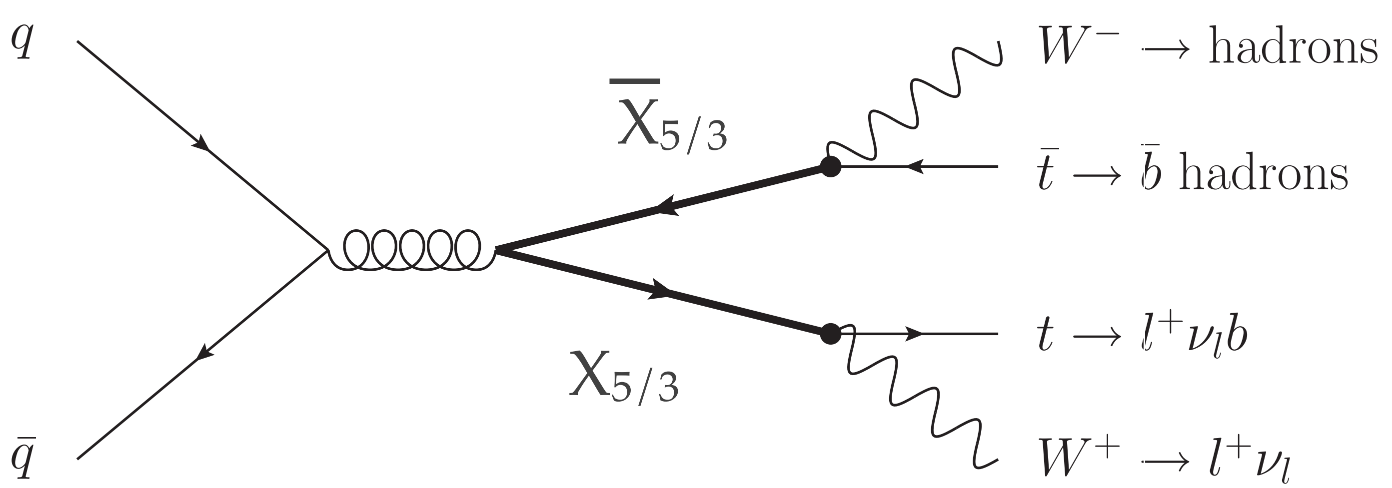
Search for heavy fermionic top partners decaying to same-sign dileptons at 13 TeV

Clint Richardson
for the CMS Collaboration

Introduction/Motivation

- Motivation of this search:
  - Search for fermionic top partner ($X_{5/3}$) as predicted in Composite Higgs Models
    - In general you get many such partners, $X_{5/3}$ often lightest
    - 5e/3 charge gives 100% decay to tW^+ → allows for same-sign dilepton decay
  - CMS excluded $X_{5/3}$ with masses below 800 GeV using 8 TeV data
- Why same-sign dileptons?
  - SM processes relatively rare
    - Striking signature of new physics

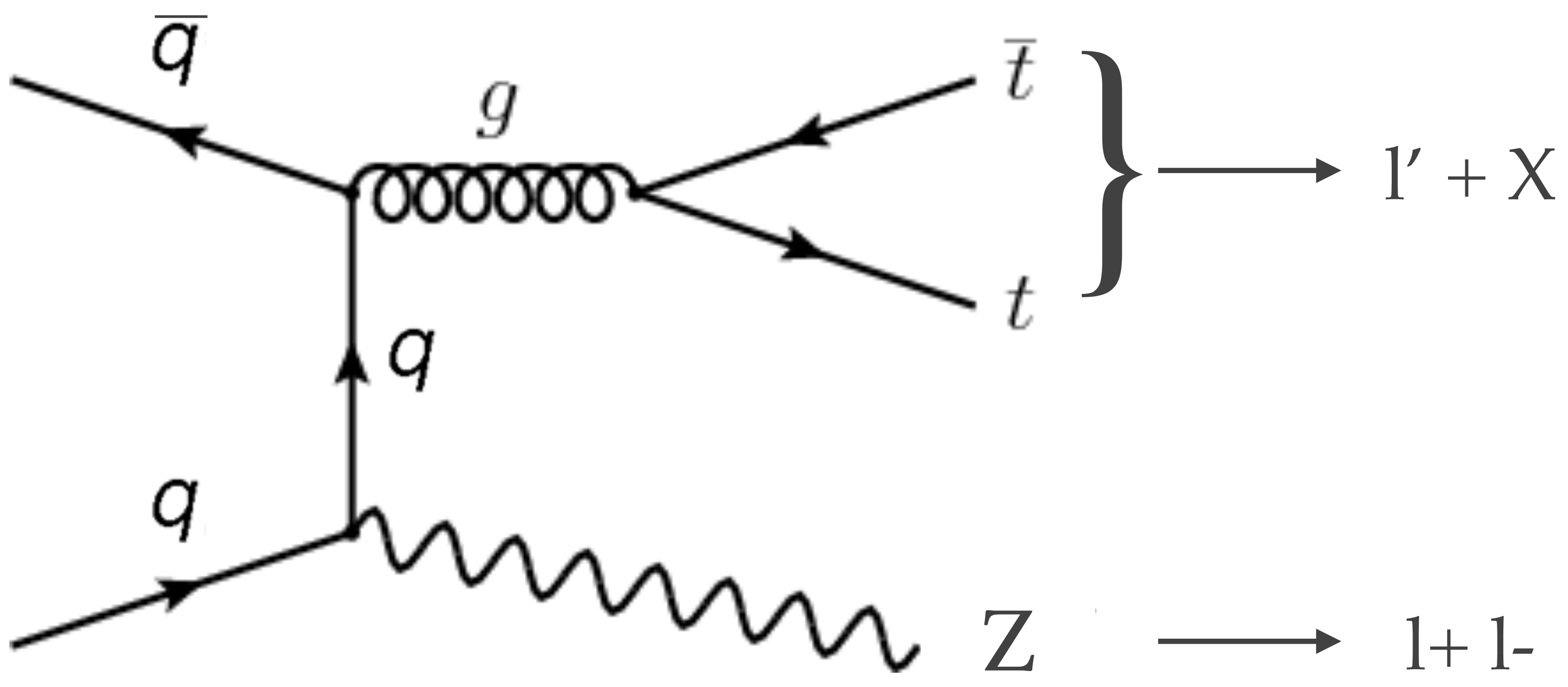


- Characteristics
  - Dominant background is often instrumental
    - Motivation for data-driven estimates (reduce reliance on detector simulation)
  - High quality leptons are essential to exploiting the rarity of this channel

NB: In this talk lepton = electron, muon

Background Sources 1/3

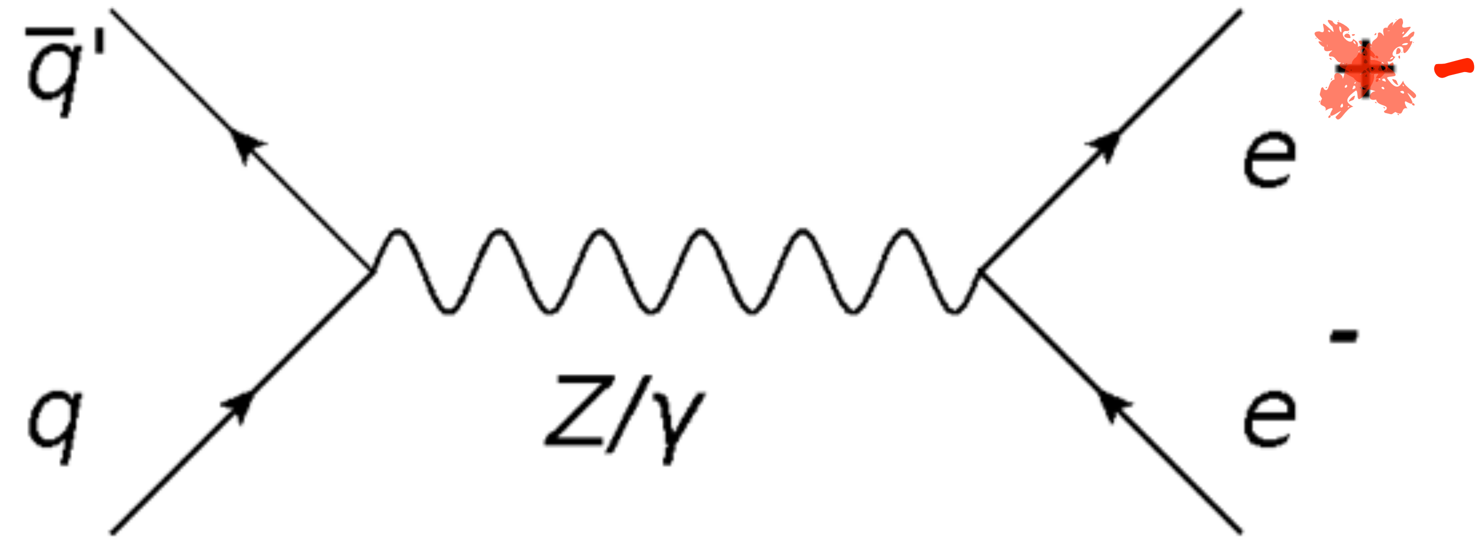
- **Same sign dilepton Standard Model processes**
  - Eg: ttV, WZ, VVV, W+W+, tttt



Example SM process (ttZ) which gives events with two real, prompt same-sign leptons. Background estimate for these sources is taken from Monte Carlo.

Background Sources 2/3

- Same sign dilepton
  - Eg: ttV, WZ, VV
- **Charge MisID**



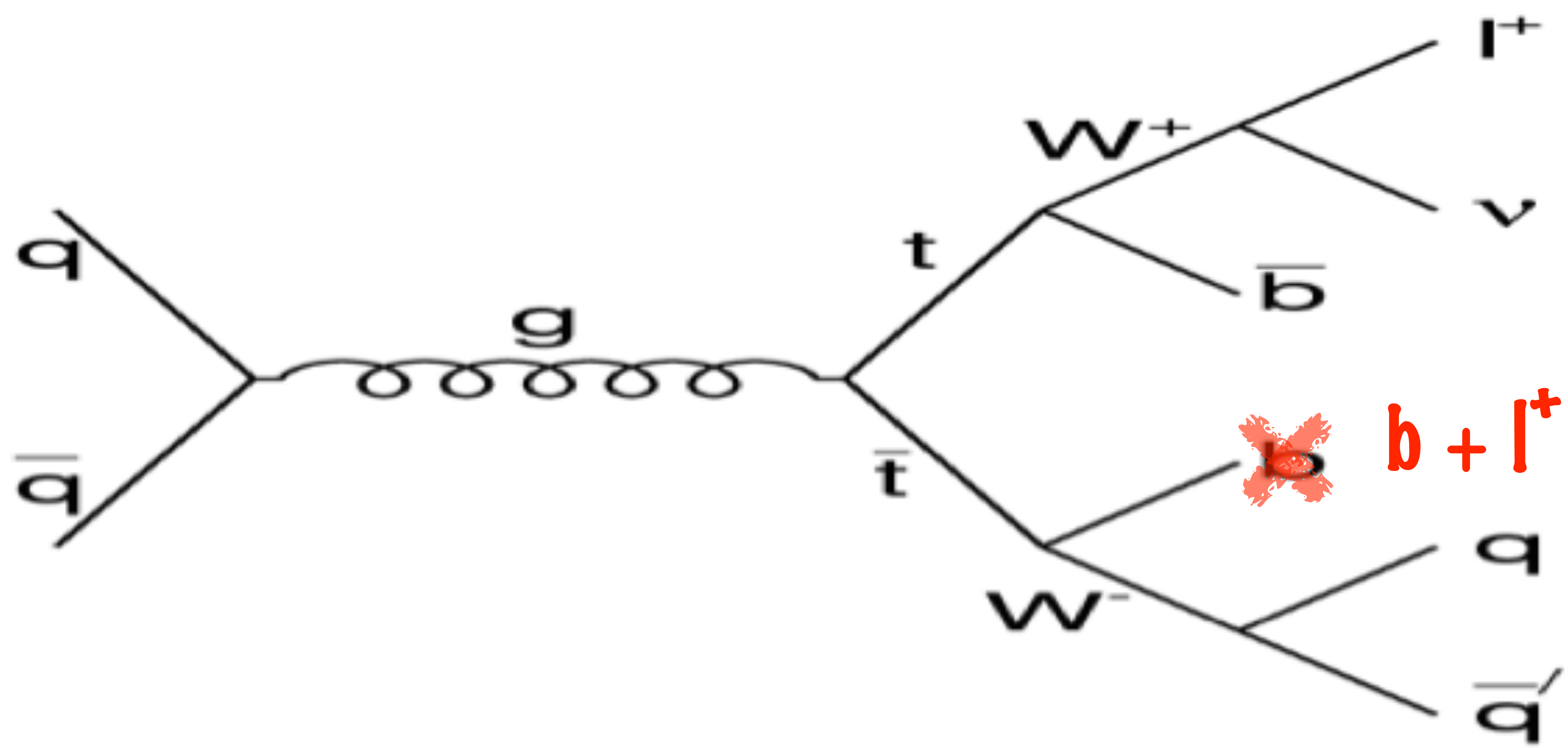
Occurs when charge of one lepton is mis-measured. Background contribution estimated using data-driven technique. Measure probability of mis-measuring electron charge (parametrized by pseudo-rapidity). Derive event weight based on above and apply to opposite sign dilepton events.

$$W_{\text{cmid}} = P_{\text{cmid}}(\eta_1) + P_{\text{cmid}}(\eta_2) - P_{\text{cmid}}(\eta_1) * P_{\text{cmid}}(\eta_2)$$

NB: Muon charge misidentification rate significantly lower than electrons → neglect

Background Sources 3/3

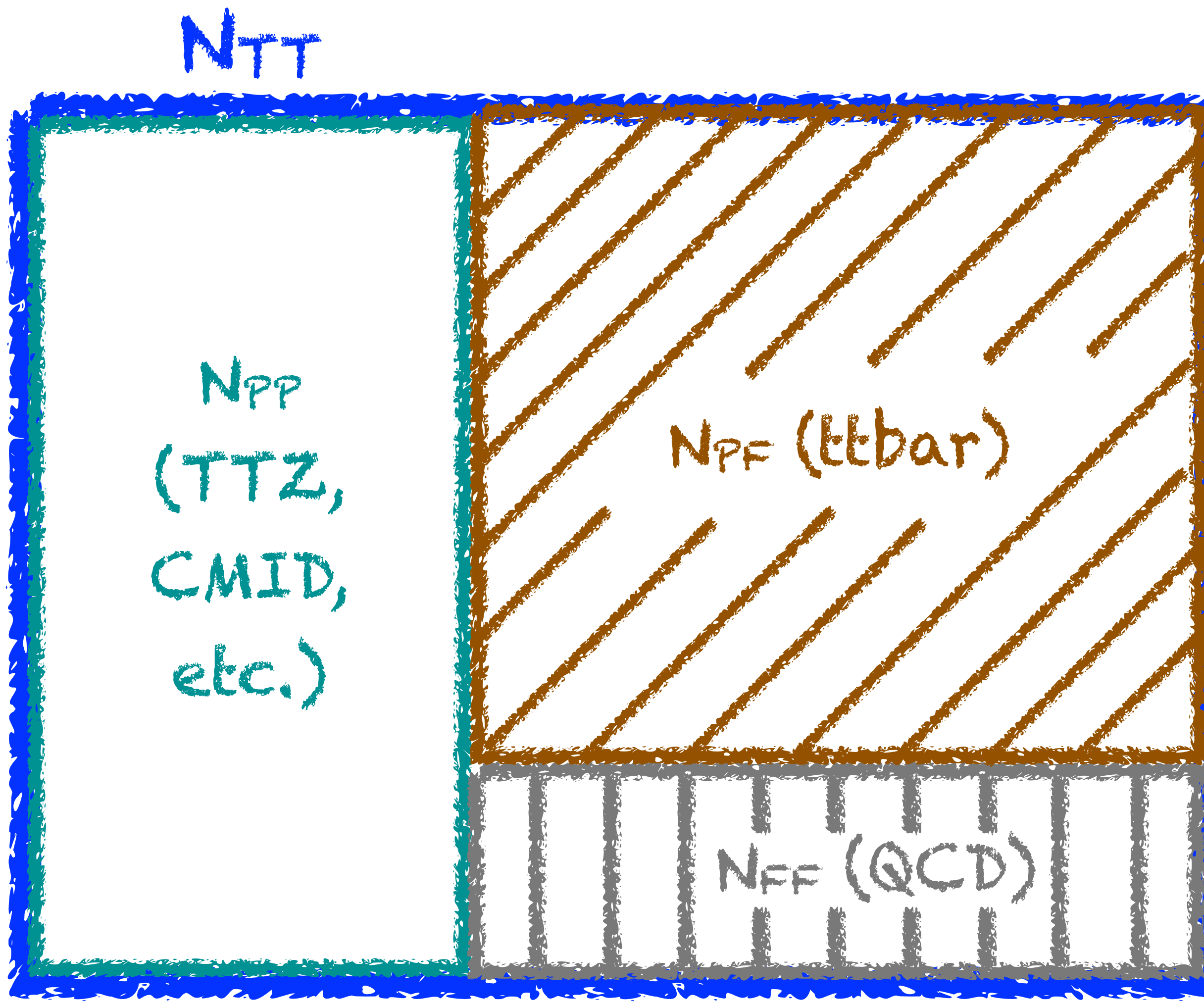
- Same sign dile
  - Eg: ttV, WZ
- Charge MisID
  - Opposite si
    lepton is m
- **NonPrompt**
  - Events with one or more fake leptons



Occurs when one or more objects passing lepton ID requirements are non-prompt leptons (e.g. a lepton from hadronization). Contribution estimated using data-driven technique (next slide).

NonPrompt Background

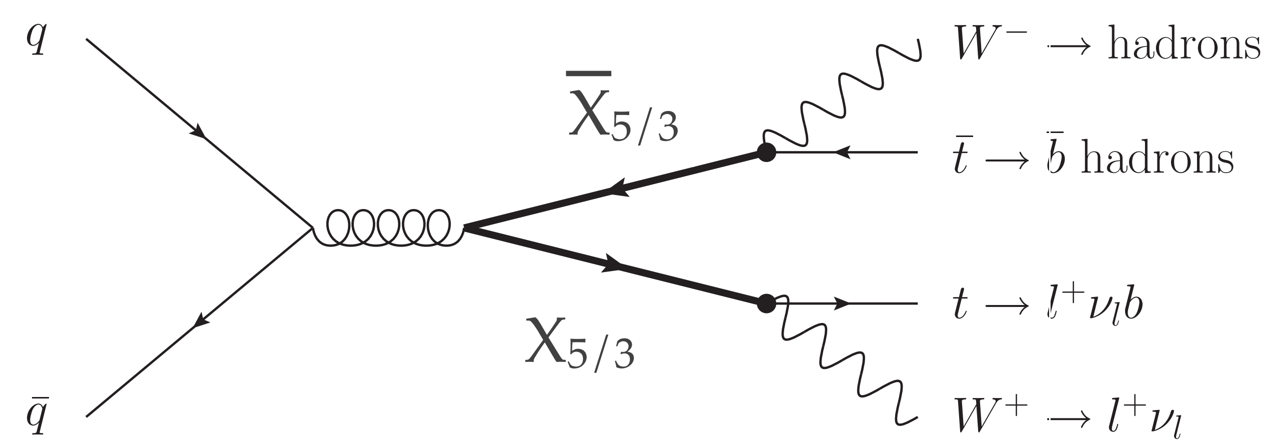
- Some part (often dominant) of events with two high quality ('tight') leptons come from events with one or more 'fake' leptons
- Relative sizes of contributions depend on:
  - Prompt Rate
    - Rate at which prompt leptons pass tight ID
  - Fake Rate
    - Rate at which fake leptons pass tight ID

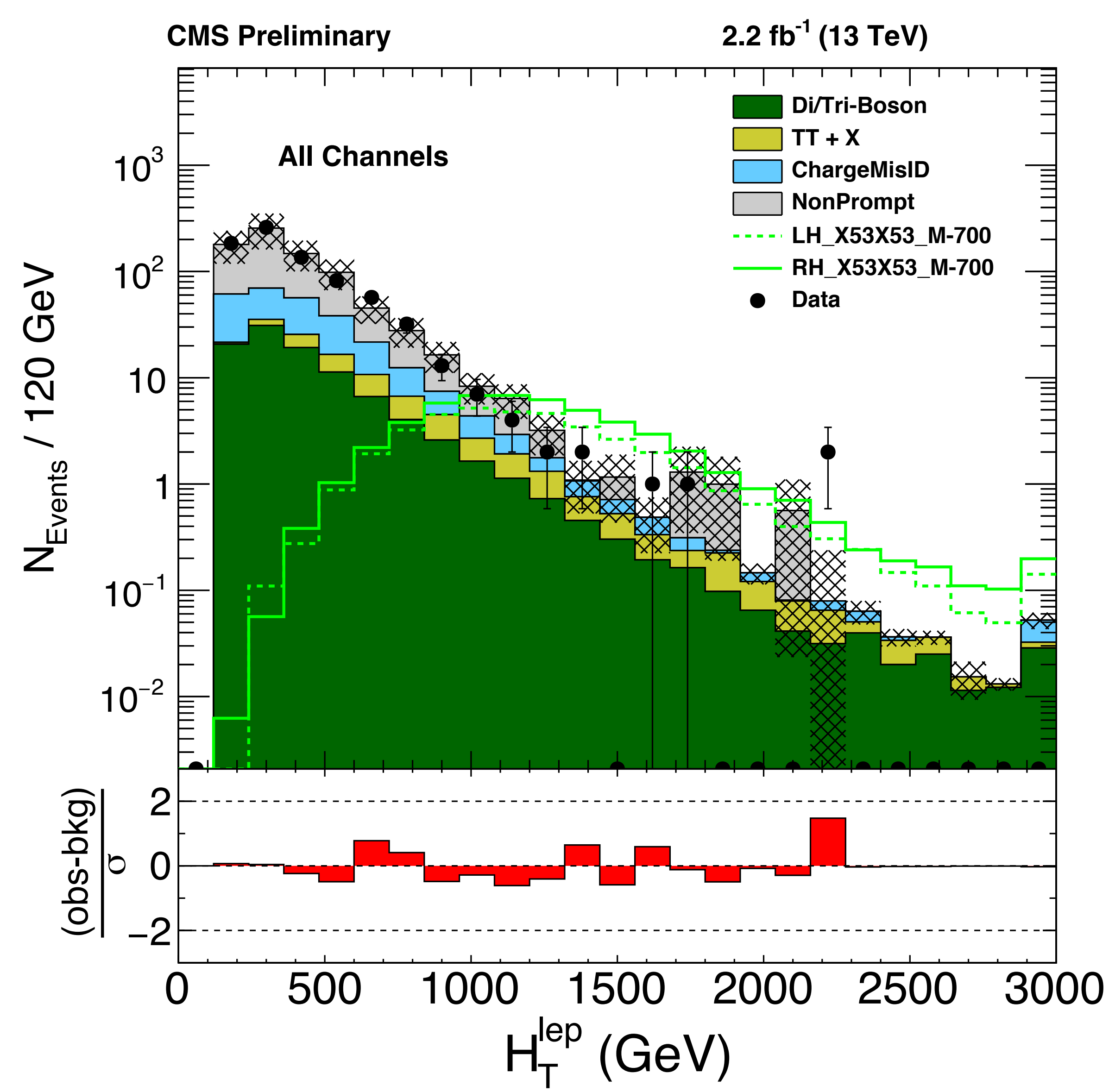


Measured in suitable control regions and used to make prediction for this background

Analysis Event Selection

- Two well-identified, same-sign leptons w/ p_T > 40 (30) GeV for leading (subleading)
- Veto if we find Z boson in the event
- Require large number of extra jets & leptons in the event (≥ 5 for results, ≥ 2 for plots)
- Optimize H_T^{lep} (scalar sum of p_T of leptons and jets) for sensitivity → H_T^{lep} ≥ 900 GeV



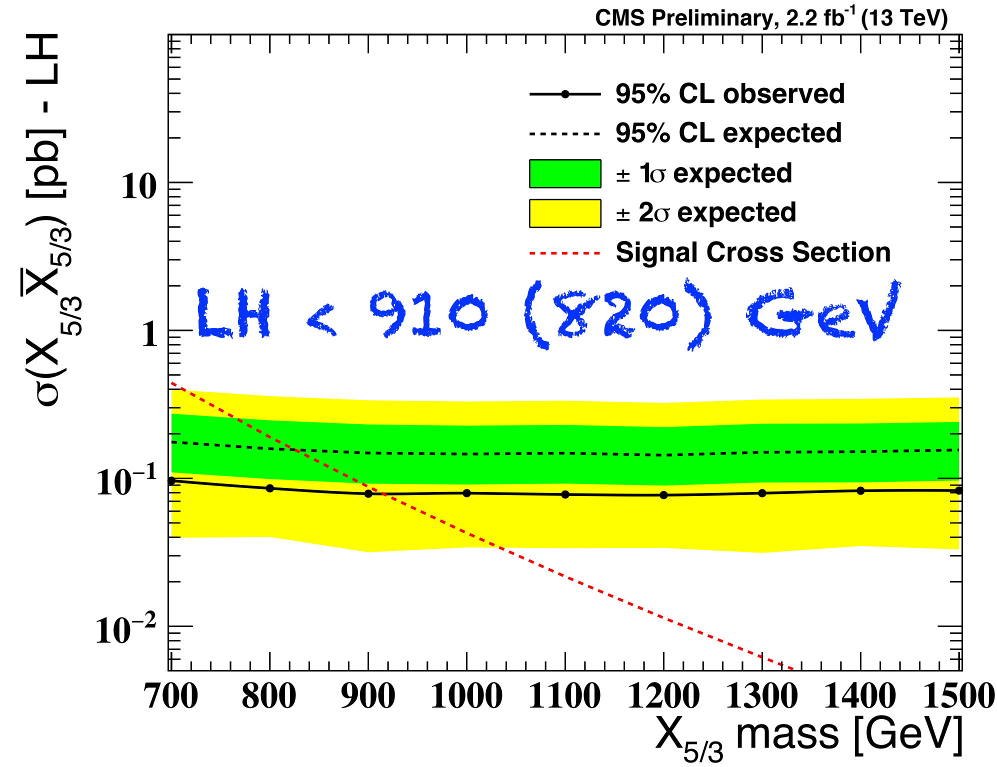


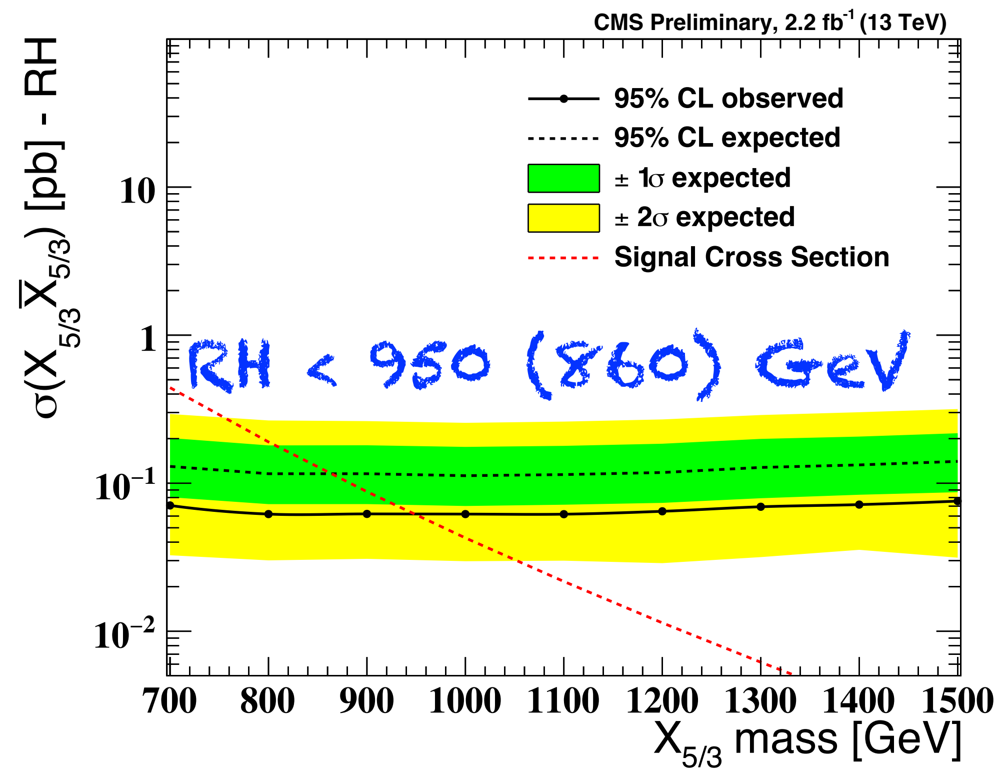
NB: Errors in plots include both statistics and systematics

Results

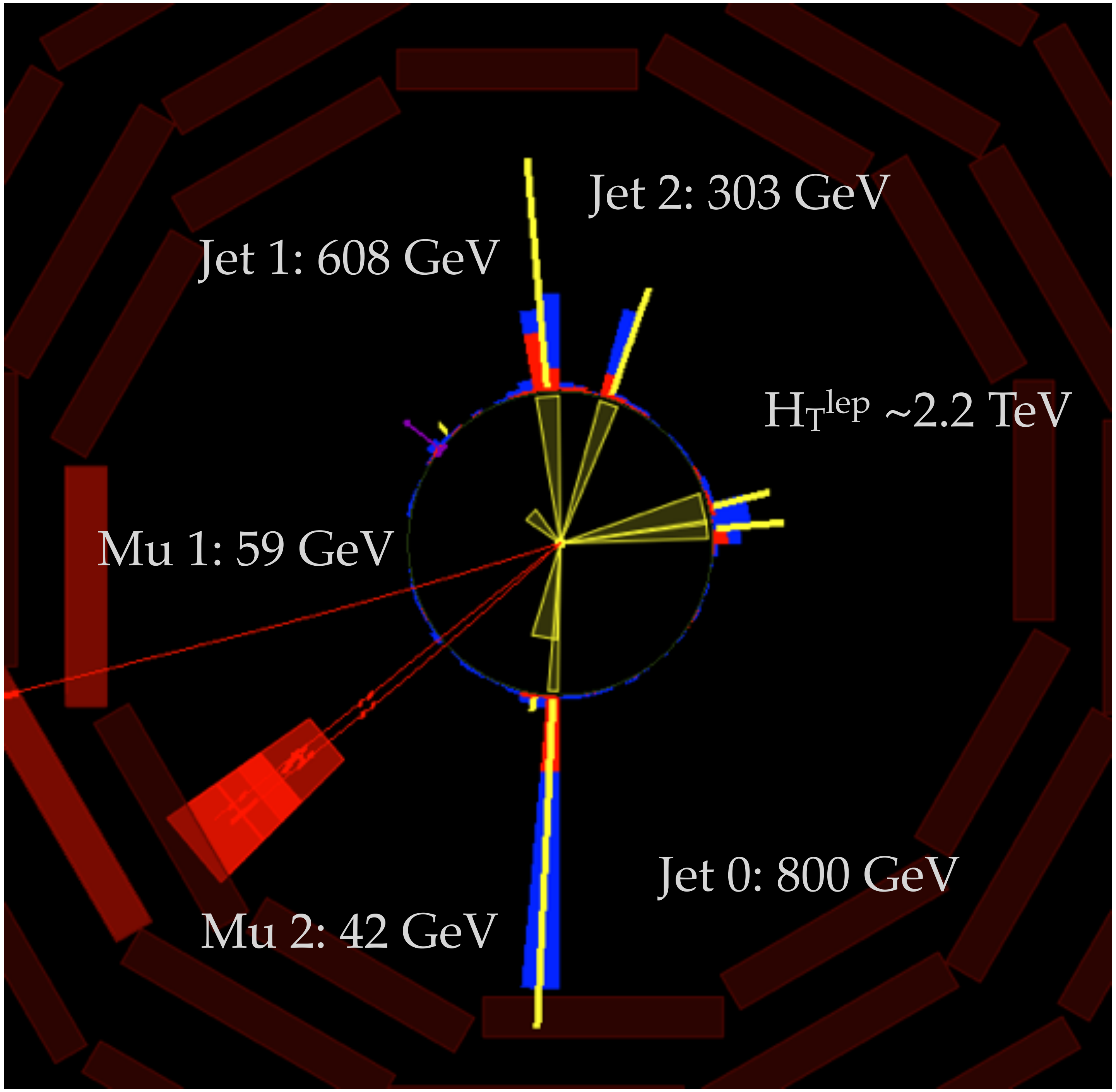
- No significant excess seen
  - Observed (Expected) limits of 950/910 (860/820) GeV for right/left handed $X_{5/3}$
  - Surpassing the 8 TeV result (800 GeV) with only 2.2 /fb
    - And looking forward to more data this year!
  - More information in B2G-15-006:
    - https://cds.cern.ch/record/2114805

Channel	PSS MC	NonPrompt	ChargeMisID	Total Background	800 GeV $X_{5/3}$	Observed
Di-electron	2.41 ± 0.29	2.16 ± 1.91	1.90 ± 0.60	6.47 ± 2.02	4.38	7
Electron-Muon	2.98 ± 0.36	5.20 ± 3.21	0.54 ± 0.18	8.72 ± 3.24	9.14	3
Di-muon	0.70 ± 0.12	2.09 ± 1.69	0.00 ± 0.00	2.80 ± 1.70	3.55	1
All	6.09 ± 0.67	9.45 ± 5.49	2.44 ± 0.76	17.98 ± 5.58	17.06	11





High H_T^{lep} Event

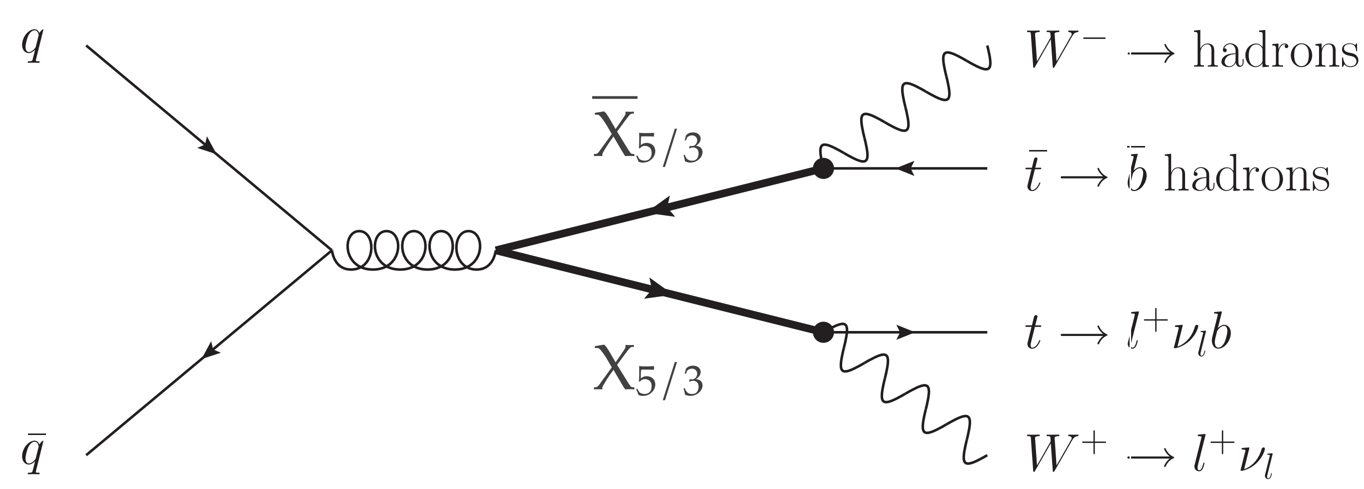


BACKUP

$X_{5/3}$ Signal Topology

- Pair production:
  - Governed by QCD processes → Model Independent
- Decay (consider only 3rd generation couplings):
  - $X_{5/3} \rightarrow tW+ \rightarrow b\ W+\ W+$
    - ➡ Allows same-sign dilepton topology
  - Events have significant numbers of jets and leptons
- Three channels:
  - dielectron, electron-muon, dimuon

$X_{5/3}$ Mass (GeV)	Cross Section [fb]
700	442
800	190
900	88
1000	43
1100	22
1200	11
1300	6.2
1400	3.4
1500	1.9
1600	1.1



Background Systematics

- NonPrompt: 50%
- ChargeMisID: 30%
- Same-sign dilepton Standard Model processes
  - Theory: ~10-50%
  - Jet Energy Scale (JES): 3-6%
  - Jet Energy Resolution: 2%
  - Pileup: 6%
  - Lepton triggering and reconstruction: 1-3%
  - Luminosity: 4.6%

Background Process	JES	Theory
ttW	4%	20%
ttZ	3%	12%
ttH	8%	14%
WZ	5%	12%
ZZ	4%	12%
W+W+	4%	50%
WWZ	4%	50%
WZZ	6%	50%
ZZZ	6%	50%
tttt	6%	50%

Source	Value	Application
Electron ID	1%	per electron
Electron ISO	1%	per electron
Electron Trigger	3%	per event
Muon ID	1%	per muon
Muon ISO	1%	per muon
Muon Trigger	3%	per event
Electron-Muon Trigger	3%	per event

Same-sign NonPrompt Background

- NonPrompt background
  - Instrumental/Fake: Use Tight-Loose Method[1] which utilizes lepton 'Prompt' and 'Fake' rate
  - Relates number of events with one or more leptons which pass a loose selection (but fail a tighter selection) to number of events with one or more fake leptons in signal region
- Prompt Rate:
  - Rate at which real, prompt, loosely selected leptons pass tighter selection requirements (those used in analysis to select leptons)
  - Measured in data using Z peak

Lepton Flavor	Prompt Rate
Electrons	0.873 +/- 0.001
Muons	0.940 +/- 0.001

[1]doi:10.1007/JHEP06(2011)077

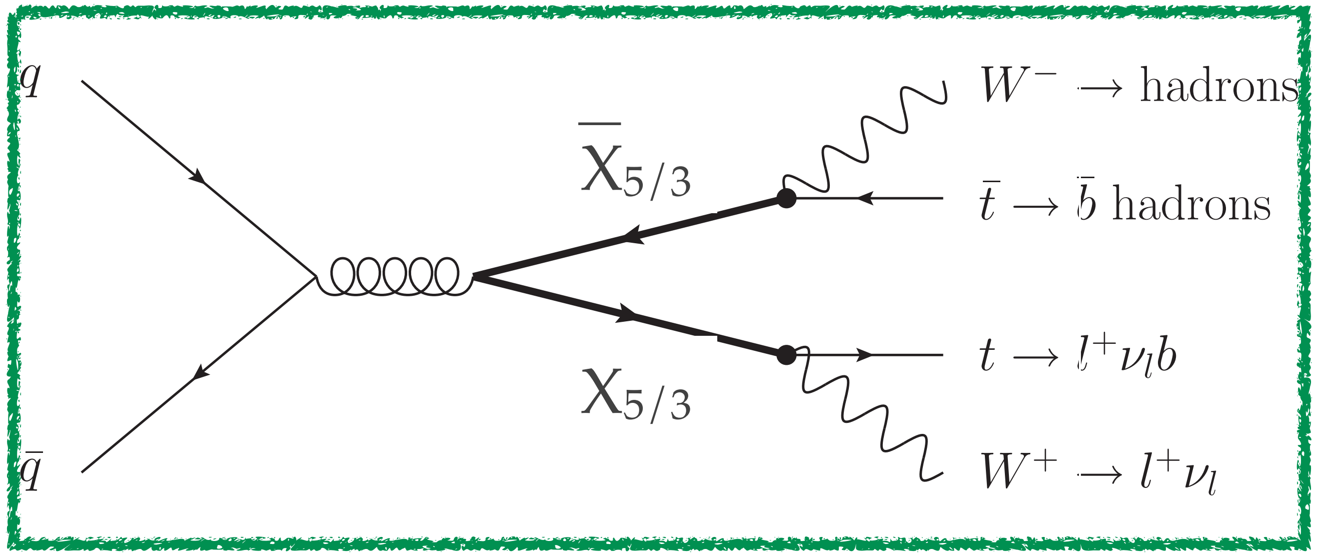
Fake Rate

- Fake Rate measured using control sample collected with single lepton triggers
- Goals for control sample:
  - Enrich in QCD like events:
    - Allow only one lepton per event
    - Require the presence of a jet which is back-to-back with lepton
  - Remove events which have W-boson or Z-boson in them

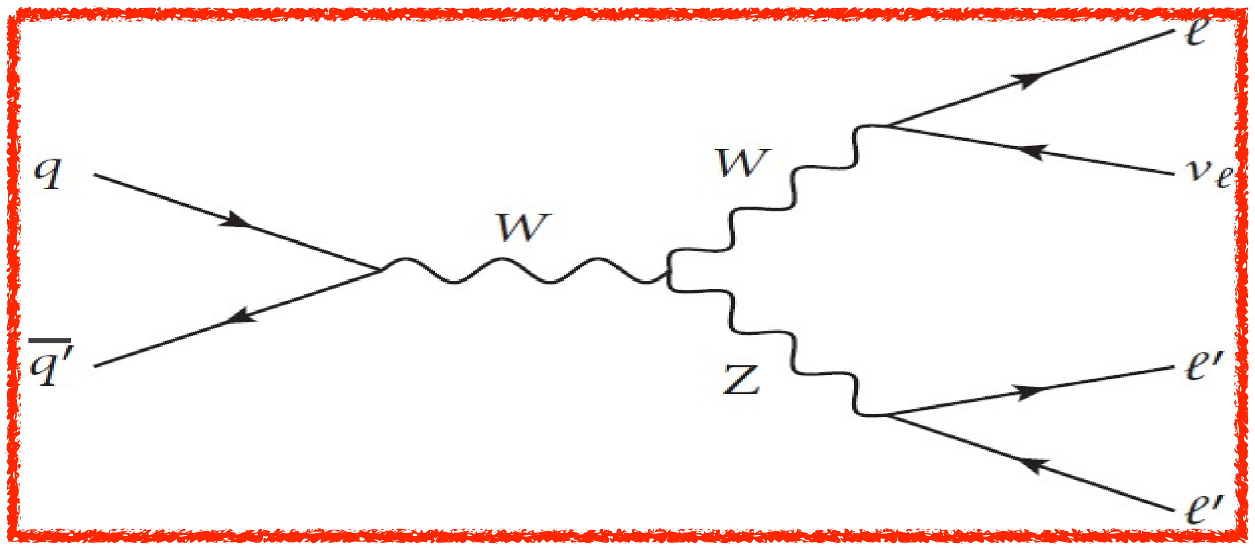
Lepton Flavor	Fake Rate
Electrons	0.298 +/- 0.003
Muons	0.371 +/- 0.002

Discriminating Variables 1/4

- Many SM background processes involve picking up a lepton from Z-boson
  - 'Associated Z-Veto'
    - Veto any event where one lepton in same-sign pair forms a Z-boson with lepton outside of the pair

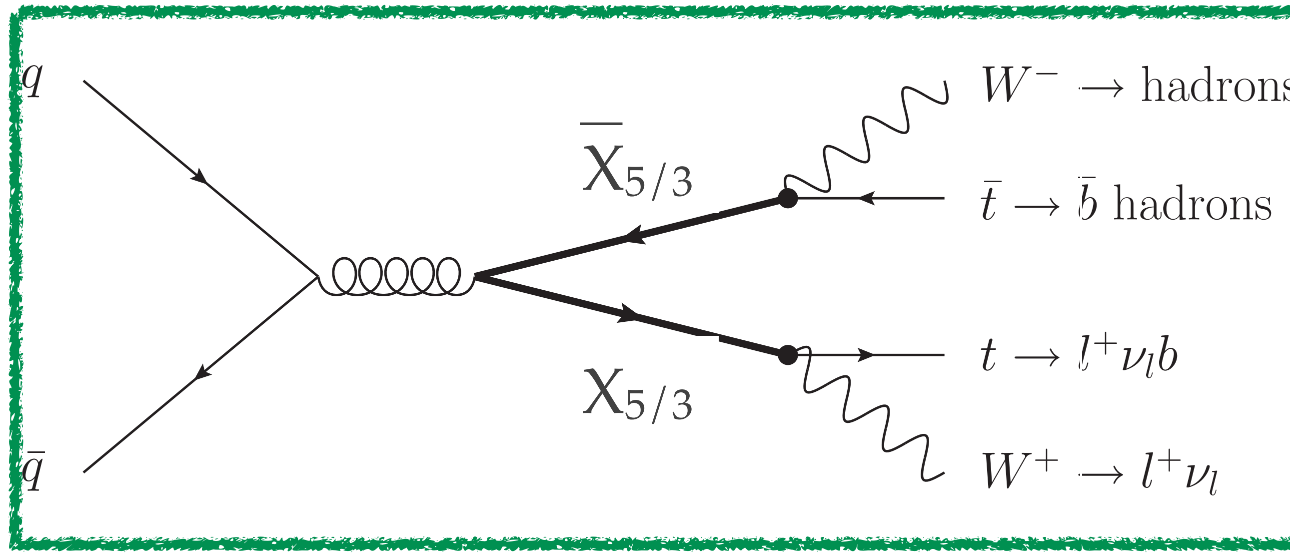


vs.

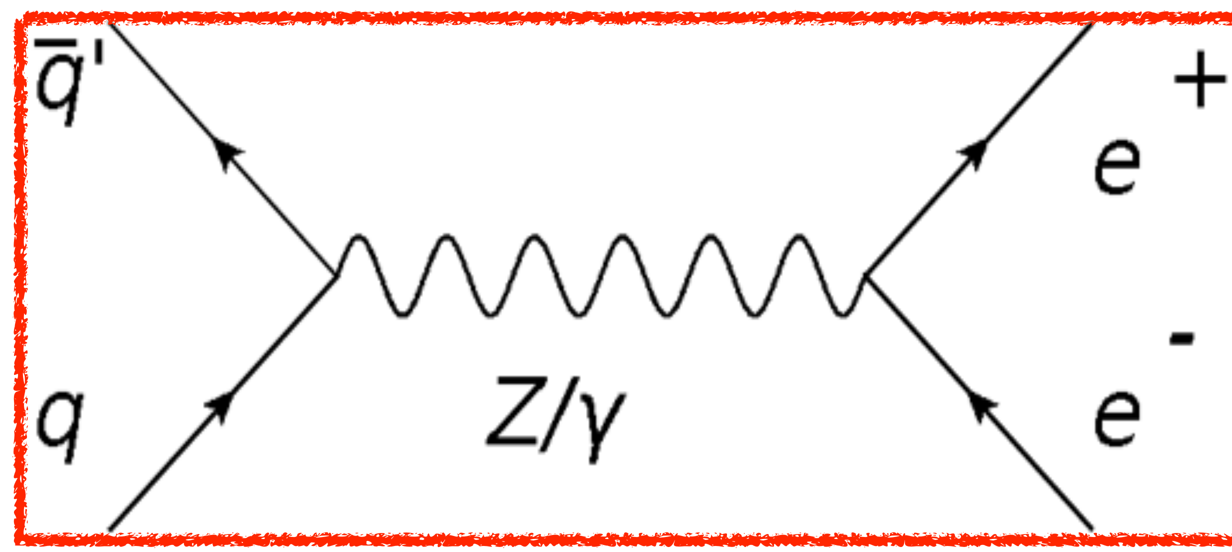


Discriminating Variables 2/4

- Dilepton Mass:
  - Dileptons in signal events are not from resonance
    - Veto events where leptons have low invariant mass, or reconstruct to Z-boson

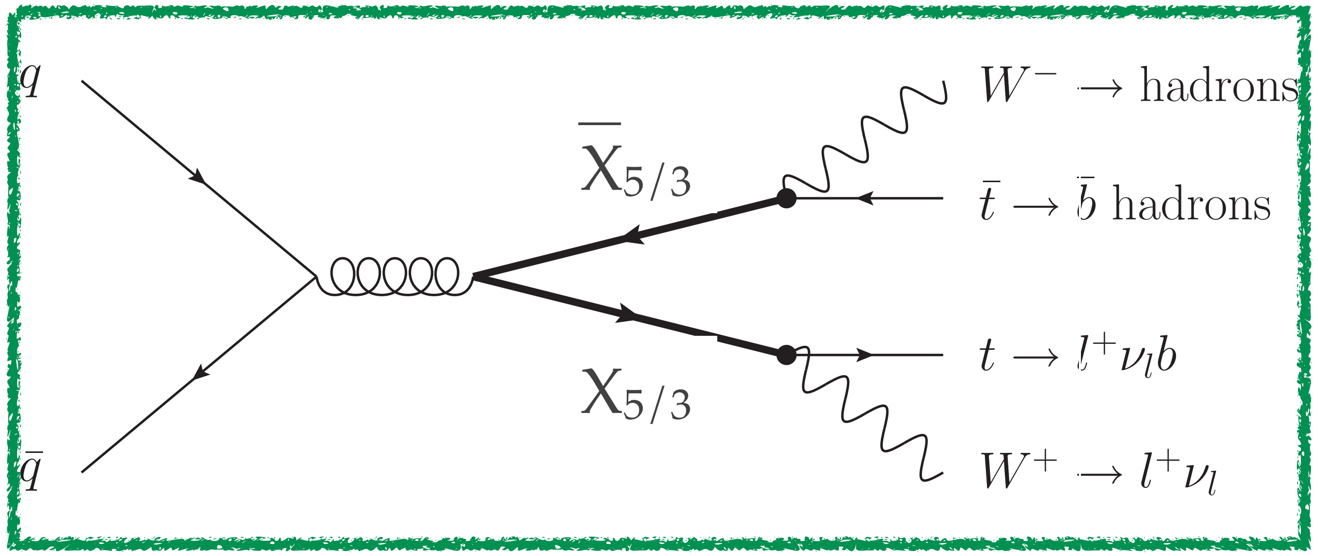


vs.

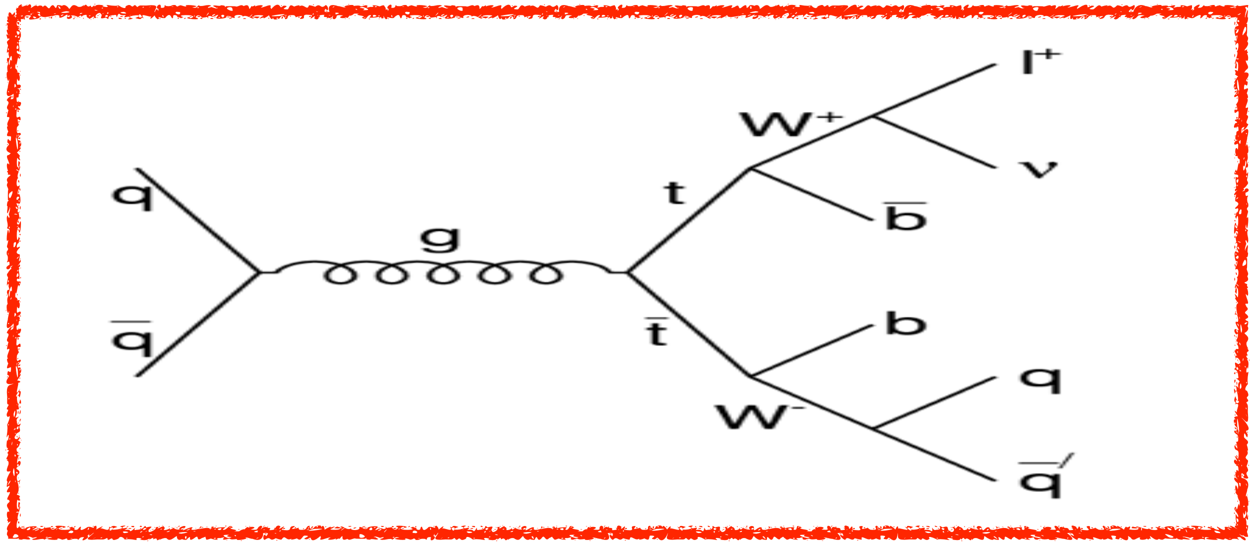


Discriminating Variables 3/4

- Extra W-bosons in event compared to ttbar:
  - Expect larger hadronic energy
  - More final state objects in general



vs.



Tight-Loose Method

$$N_{t00} = (1-p_1)(1-p_2)L_{pp} + (1-p_1)(1-f_2)L_{pf} + (1-f_1)(1-p_2)L_{fp} + (1-f_1)(1-f_2)L_{ff}$$

$$N_{t10} = p_1(1-p_2)L_{pp} + p_1(1-f_2)L_{pf} + f_1(1-p_2)L_{fp} + f_1(1-f_2)L_{ff}$$

$$N_{t01} = (1-p_1)p_2L_{pp} + (1-p_1)f_2L_{pf} + (1-f_1)p_2L_{fp} + (1-f_1)f_2L_{ff}$$

$$N_{t11} = p_1p_2L_{pp} + p_1f_2L_{pf} + f_1p_2L_{fp} + f_1f_2L_{ff}$$

These equations can be solved for the numbers of events with prompt and non-prompt leptons:

$$L_{pf} = D(-f_1p_2N_{t00} + (1-f_1)p_2N_{t10} + f_1(1-p_2)N_{t01} - (1-f_1)(1-p_2)N_{t11})$$

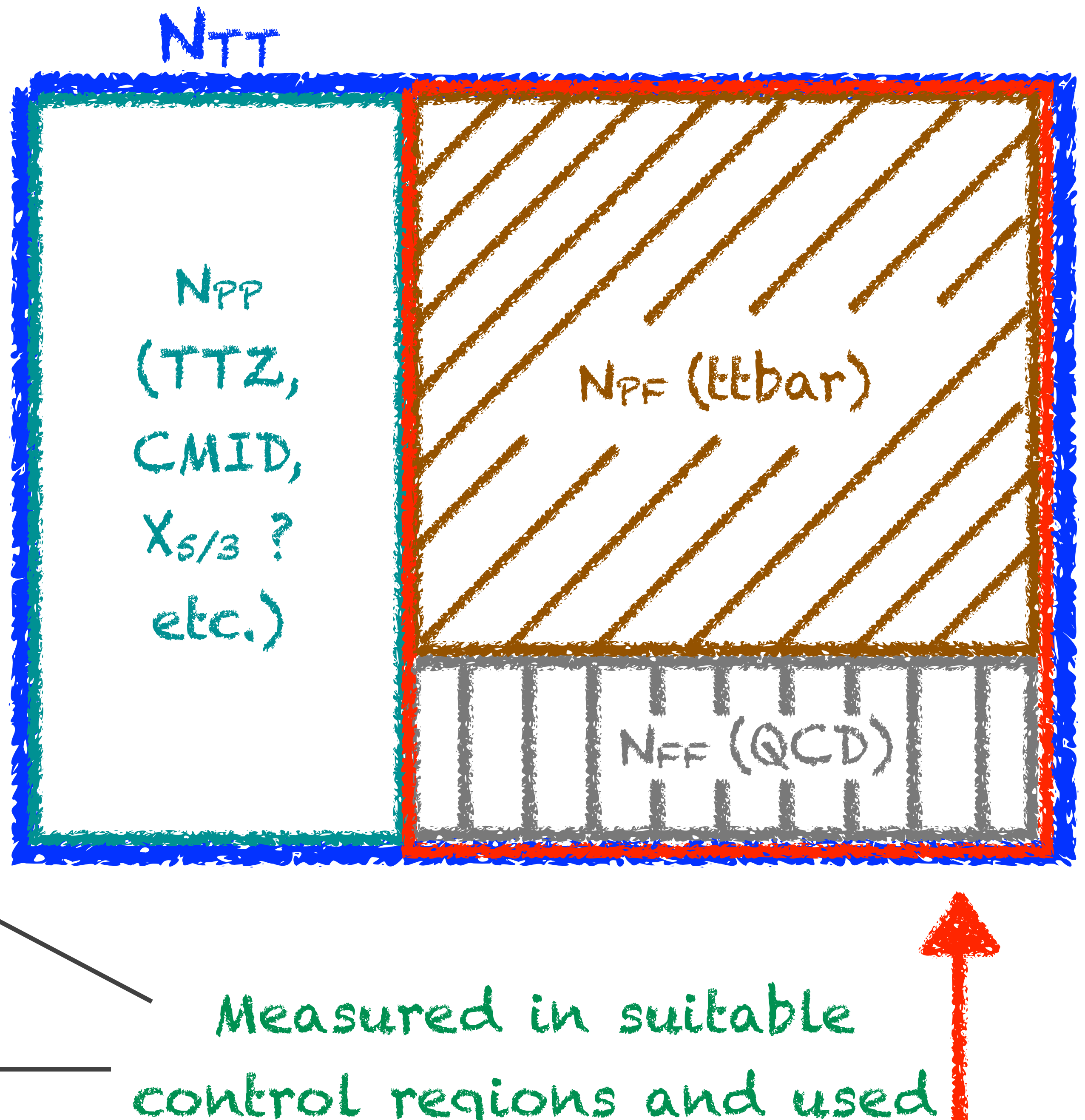
$$L_{fp} = D(-p_1f_2N_{t00} + (1-p_1)f_2N_{t10} + p_1(1-f_2)N_{t01} - (1-p_1)(1-f_2)N_{t11})$$

$$L_{ff} = D(p_1p_2N_{t00} - (1-p_1)p_2N_{t10} - p_1(1-p_2)N_{t01} + (1-p_1)(1-p_2)N_{t11}).$$

$N_{pf} = p_1f_2L_{pf}$, $N_{fp} = f_1p_2L_{fp}$ and $N_{ff} = f_1f_2L_{ff}$

NonPrompt Background

- Some part (often dominant) of events with two high quality ('tight') leptons come from events with one or more 'fake' leptons
- Relative sizes of contributions depend on:
  - Prompt Rate
    - Rate at which prompt leptons pass tight ID
  - Fake Rate
    - Rate at which fake leptons pass tight ID



Measured in suitable control regions and used to make prediction for this background