Measurement of ttZ Cross Section at the LHC

Trilepton Final State with Jets and b-Tagged Jets at 8 TeV

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Dissertation Defense

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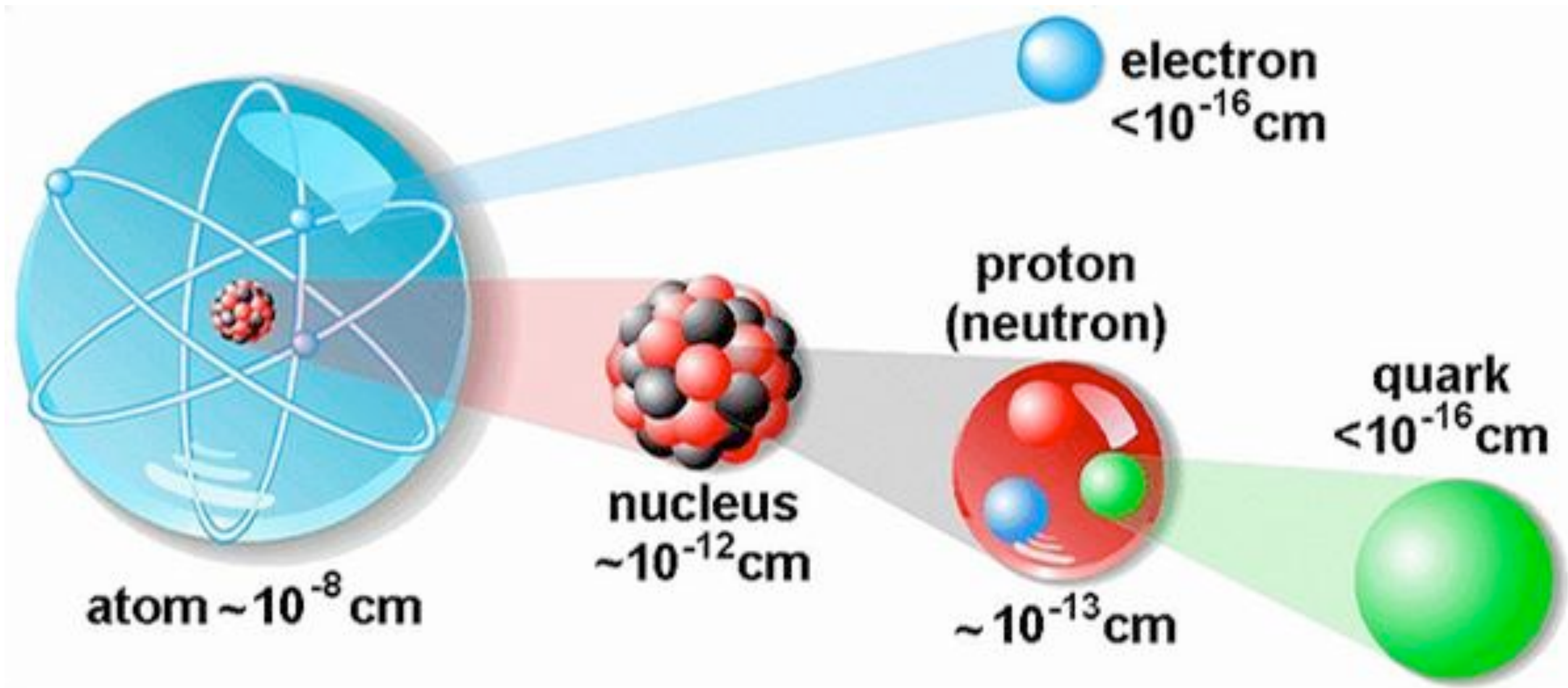
Outline

- Background
  - High Energy Physics and Standard Model
  - Large Hadron Collider
  - Compact Muon Solenoid
- ttZ Cross Section Measurement
  - Motivation
  - Event Selection
  - Background Estimation Techniques
  - Results

Background

High Energy Physics

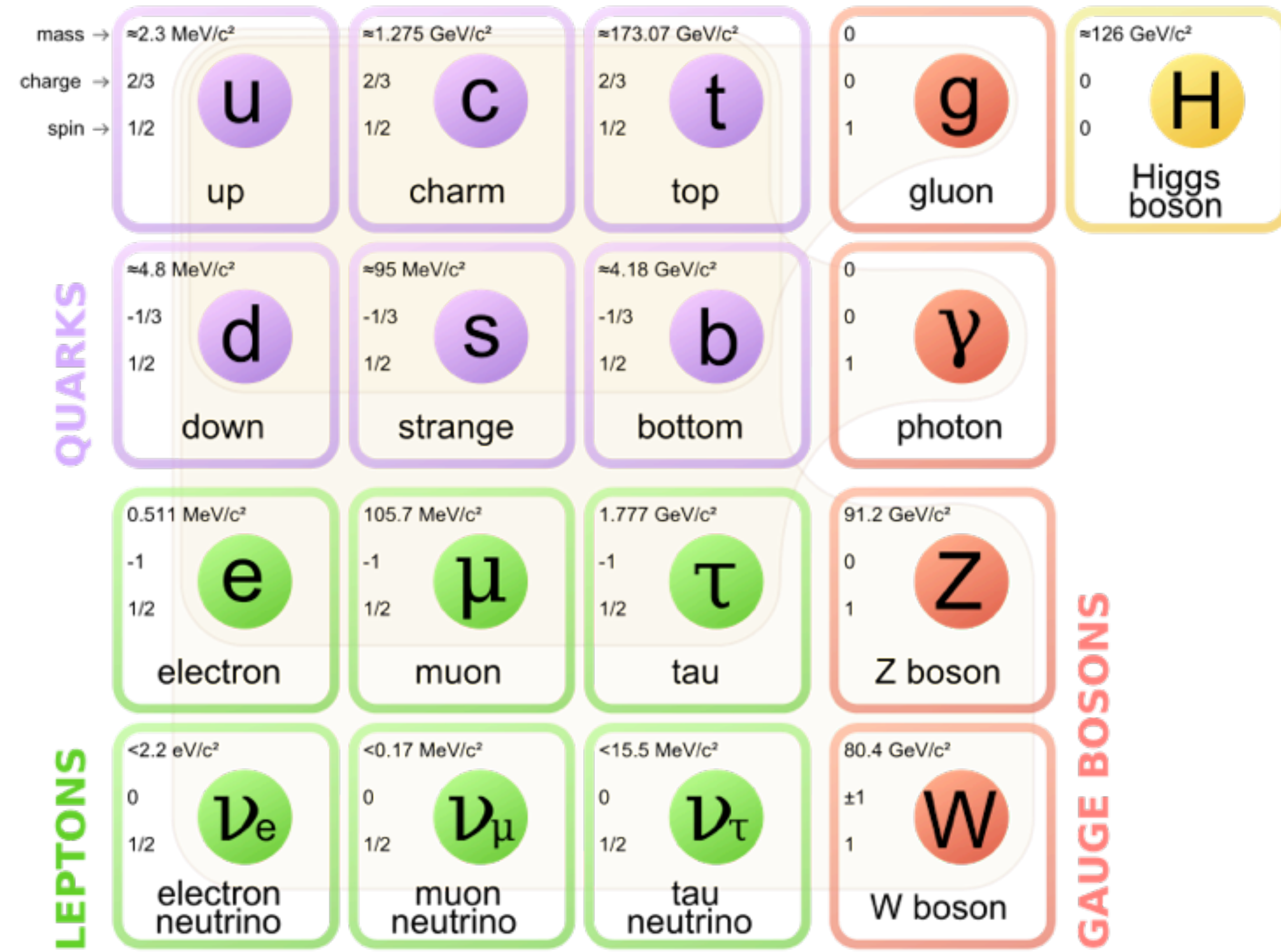
- Fundamental science
- Study of the constituents of matter and their properties
- Primary means of experimentation is at particle accelerators or using astronomical phenomena



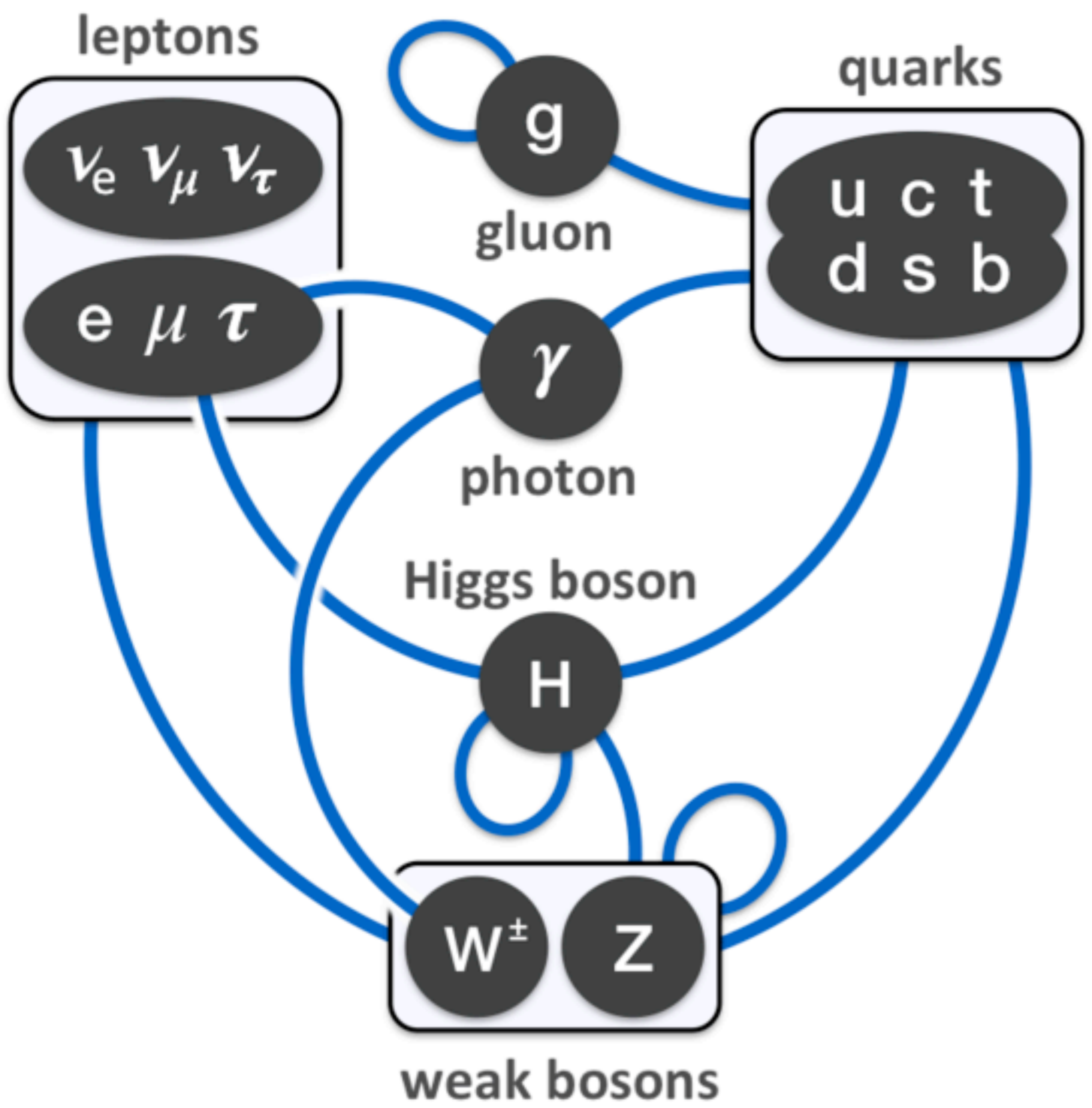
Standard Model

Theoretical framework for understanding fundamental particles and interactions.

- Described by a Quantum Field Theory
- Forces described by Bosons
  - Electromagnetic (Photon)
  - Strong Interaction (Gluon)
  - Weak Interaction (W and Z)
  - Higgs Boson
- Standard Model is extremely well verified by experiments



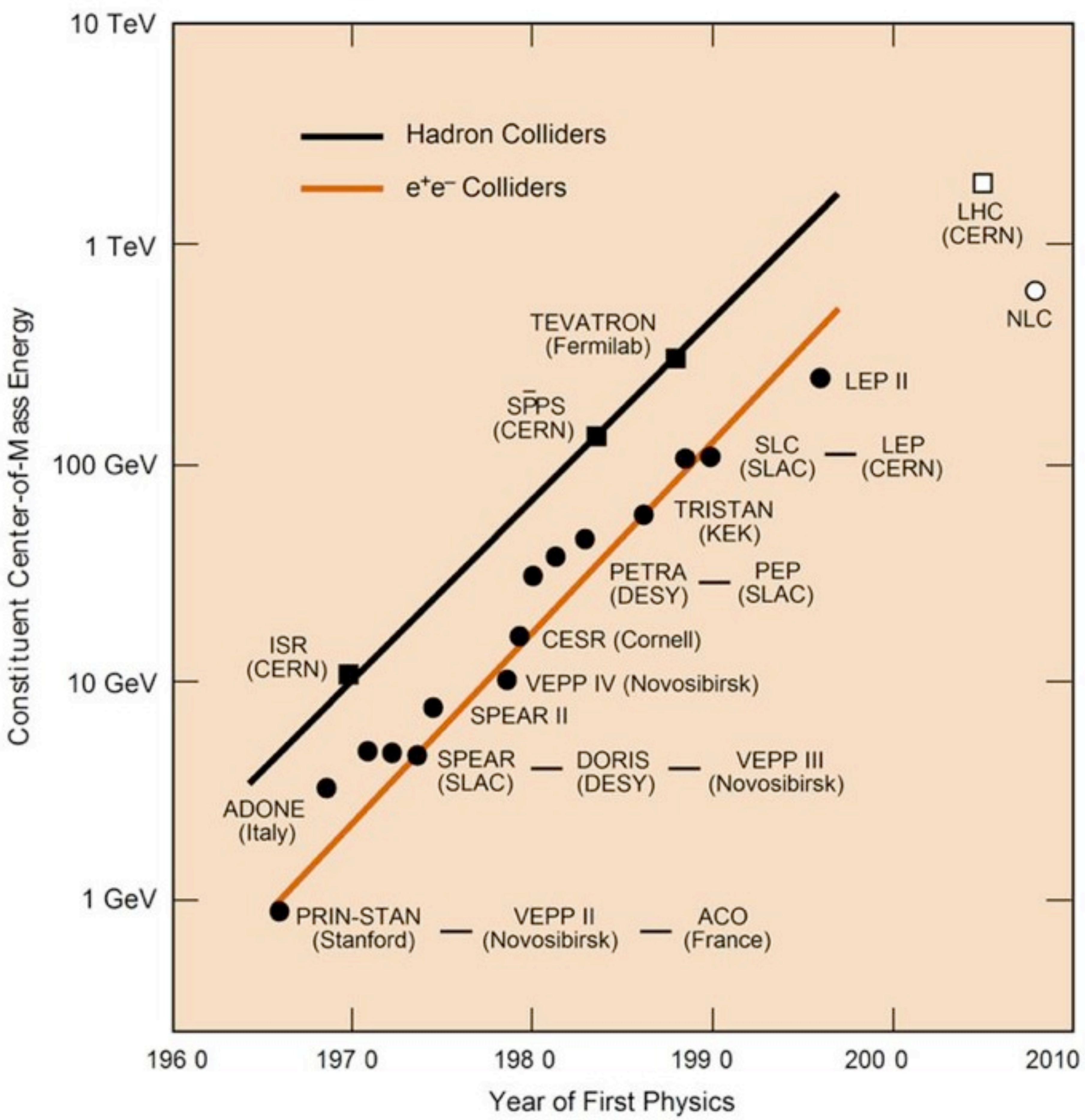
Standard Model Interactions



- Standard Model categorizes particles by mass, spin, charge and other properties inherent to the particle.
- Also characterizes particles by their interactions with each other
  - Particle accelerators rely on these interactions to create new particles and to measure their decays
- The production of ttZ is deeply related to the interactions between the top quark and the Z boson (as yet unmeasured)

Experiment Progression

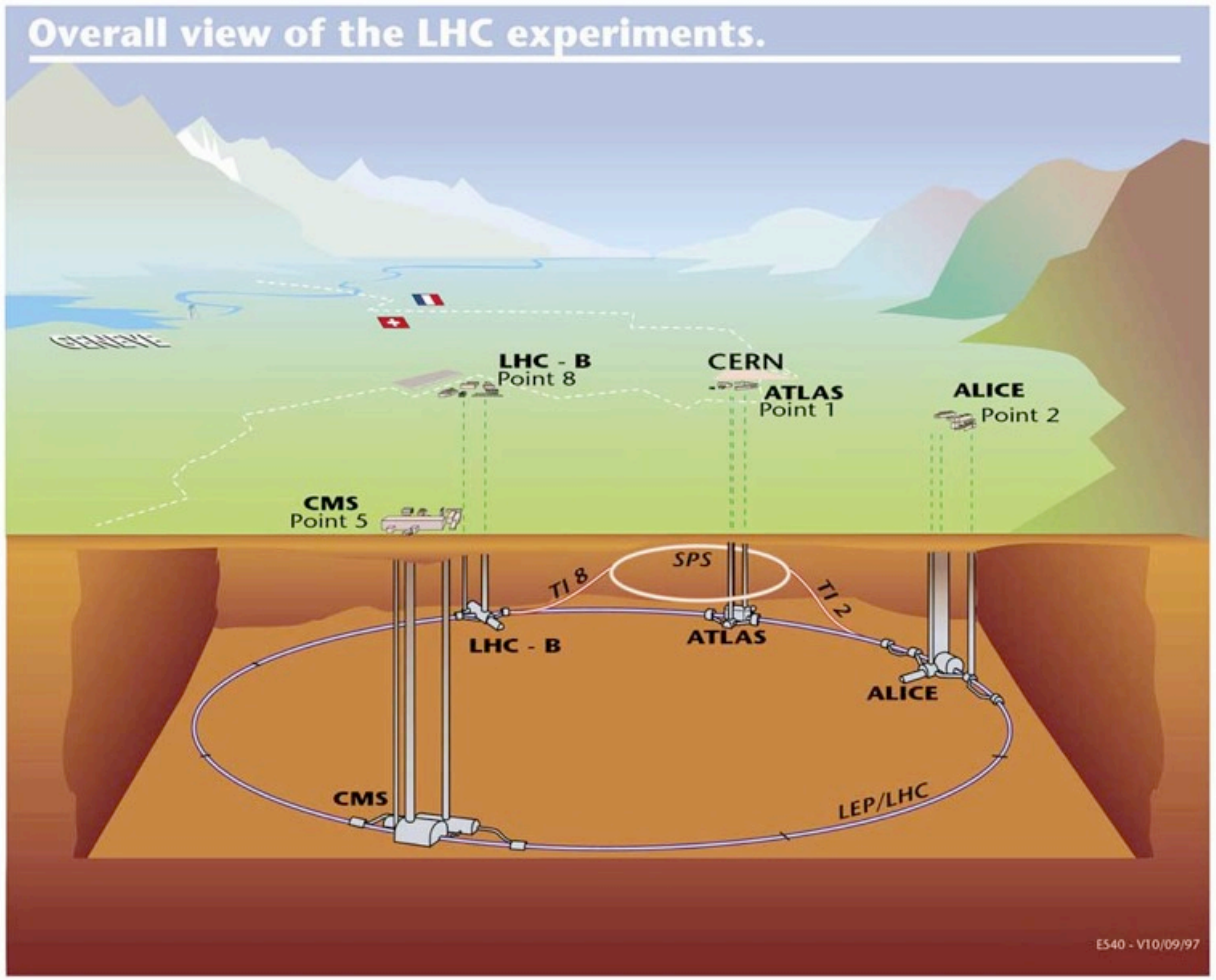
Particle accelerators have increased in energy almost exponentially



- Physicists produce new scenarios via **particle collision**
- Two main collider types:
  - **Hadron colliders** (e.g. Tevatron, LHC)
  - **Lepton colliders** (e.g. SLAC, LEP)
- Ramping up of energy for each new collider
  - Energy, collider type, and other design parameters motivated by the next types of discoveries
    - LHC designed for Higgs discovery and SUSY discovery

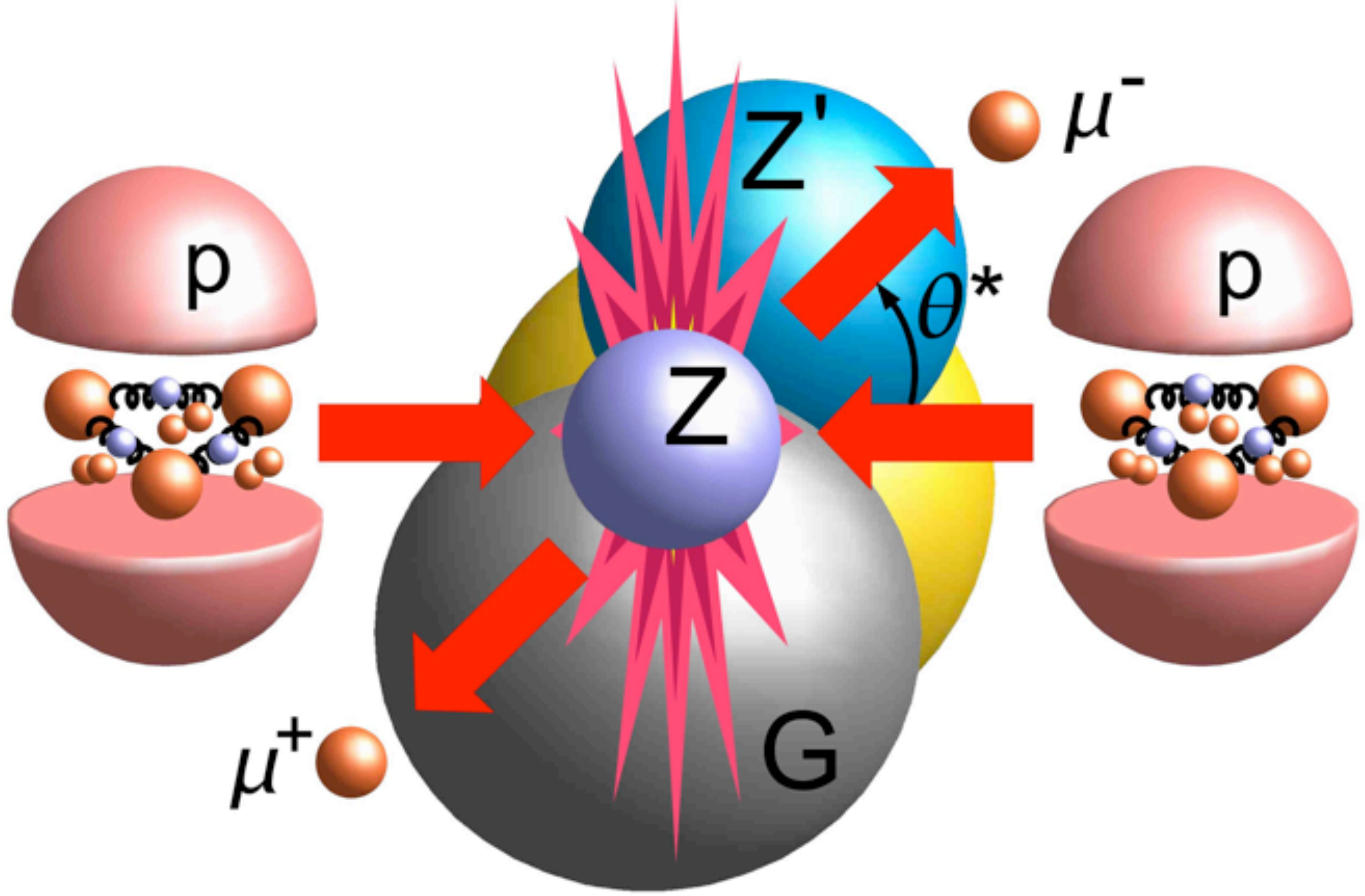
Large Hadron Collider

Proton-proton (pp) collisions



- Worlds largest and most powerful particle accelerator
  - 27 km circumfrance
  - over 50 m underground
- Operated at 7 TeV, **8 TeV**, and soon to be 13 TeV
  - 14 TeV design specification
- High occupancy
  - Up to 2808 bunches of 115 billion protons
  - Max collision rate of 25 ns (40 MHz)
- Multiple collision points
  - General purpose detectors: CMS, ATLAS
  - Special purpose detectors: ALICE, LHC-B

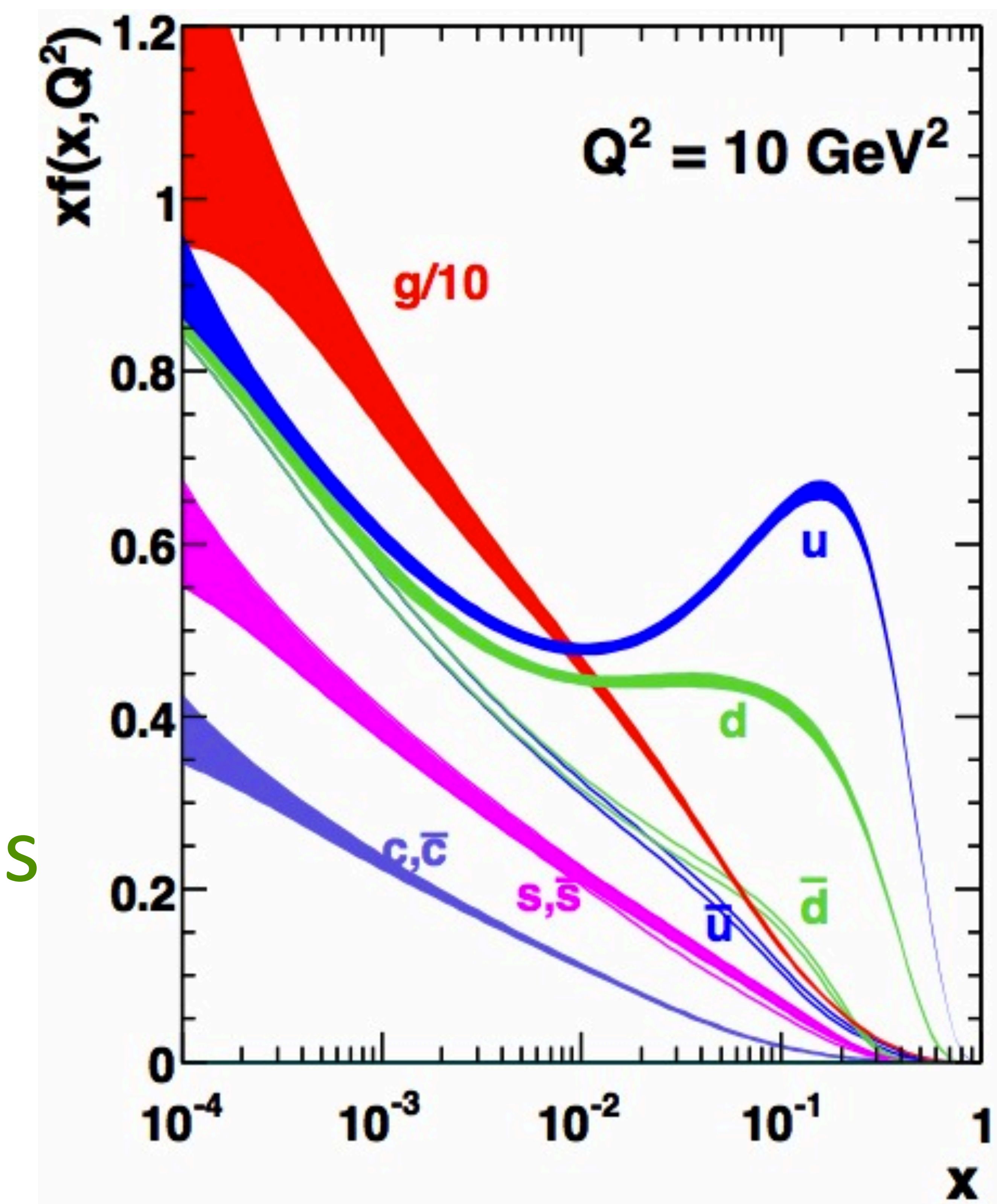
Proton Proton Collisions



Parton Distribution Function

Describes likely fractional momentum of proton constituents

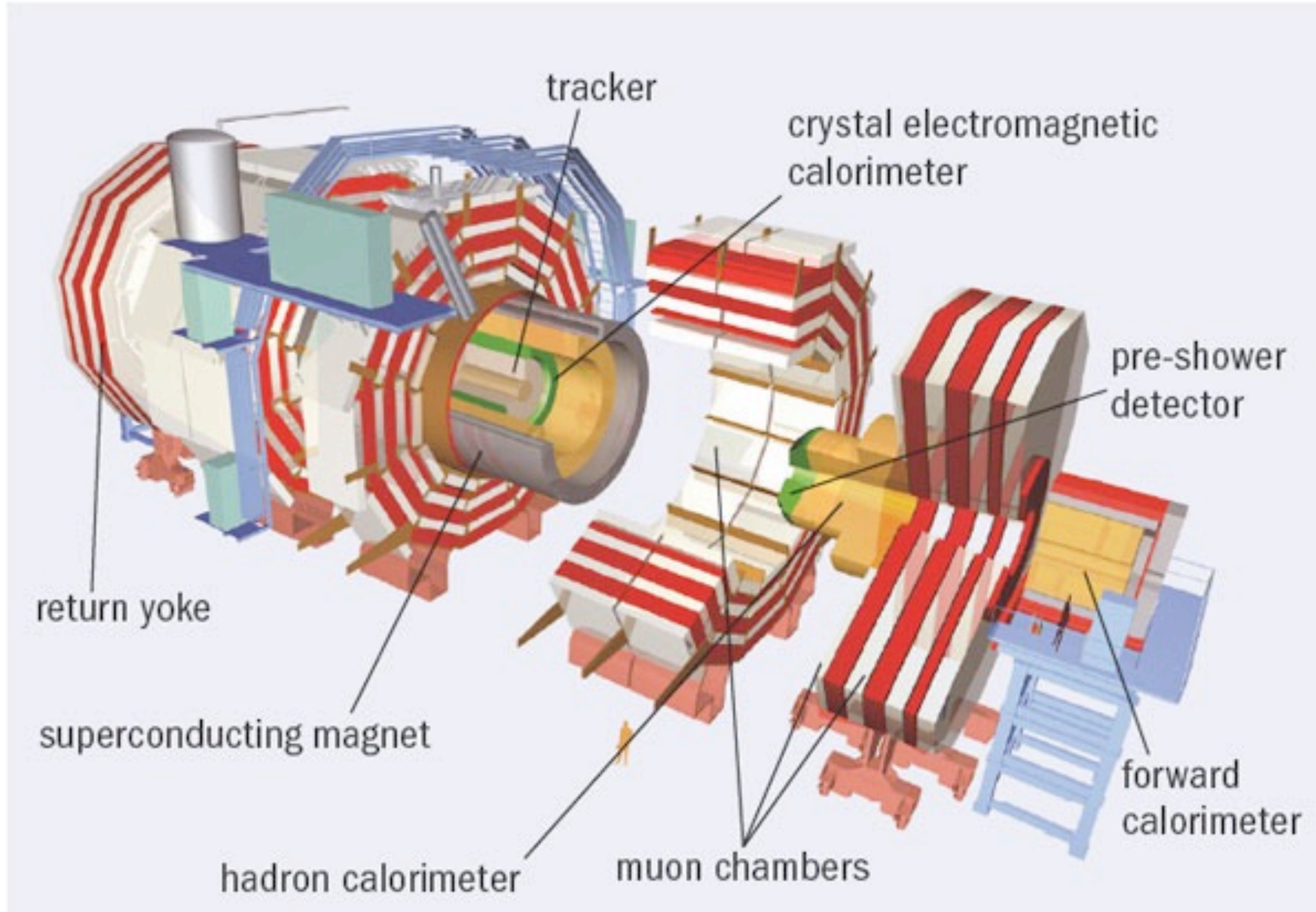
$$x = \frac{p_{\text{parton}}}{p_{\text{proton}}}$$



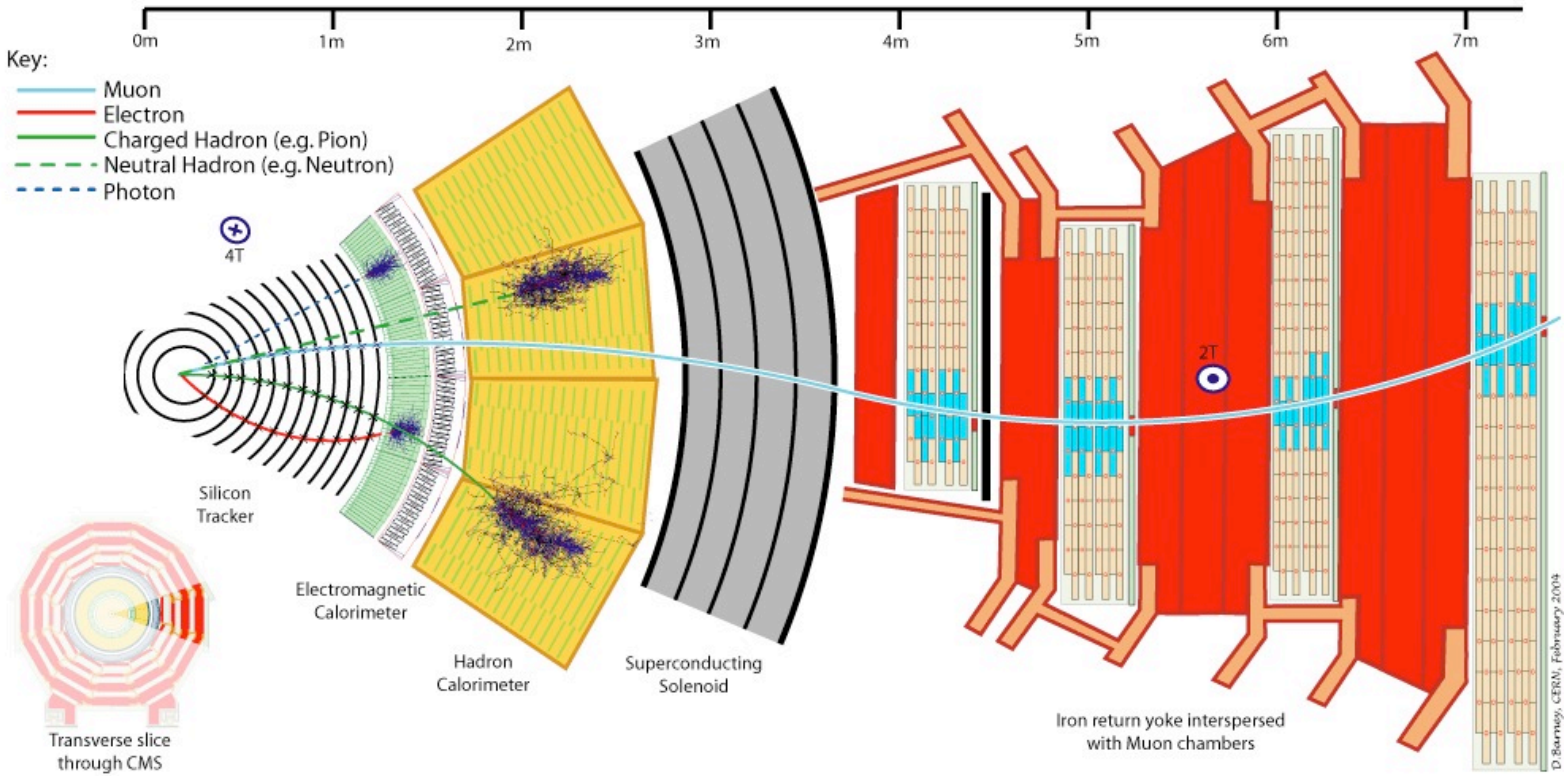
- Protons are composite objects
  - contain quarks and gluons
- Proton collisions are really quark or gluon collisions
- Thus, initial momentum of collision is unknown

Compact Muon Solenoid (CMS)

- General purpose detector
    - many components measured, trajectory, momentum, and energy of particles, etc
- 15 m in diameter, 12,500 tons
- Gets it's name from 4 T solenoid magnet
- Collaboration of over 42 countries and 3800 people



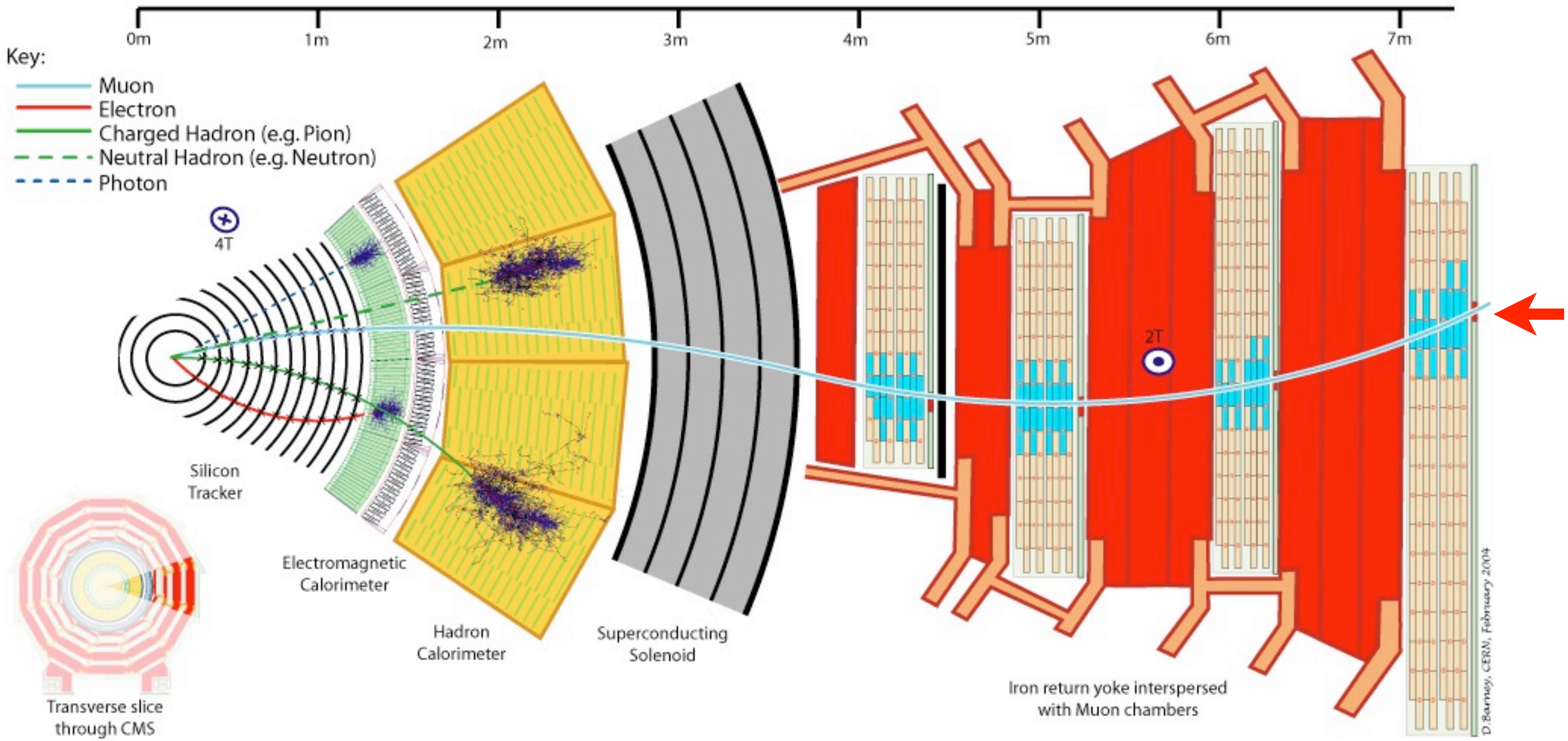
Object Measurement and Reconstruction



- Particles are identified by exploiting their charge and interaction characteristics (e.g. types and thickness of material that they pass through)

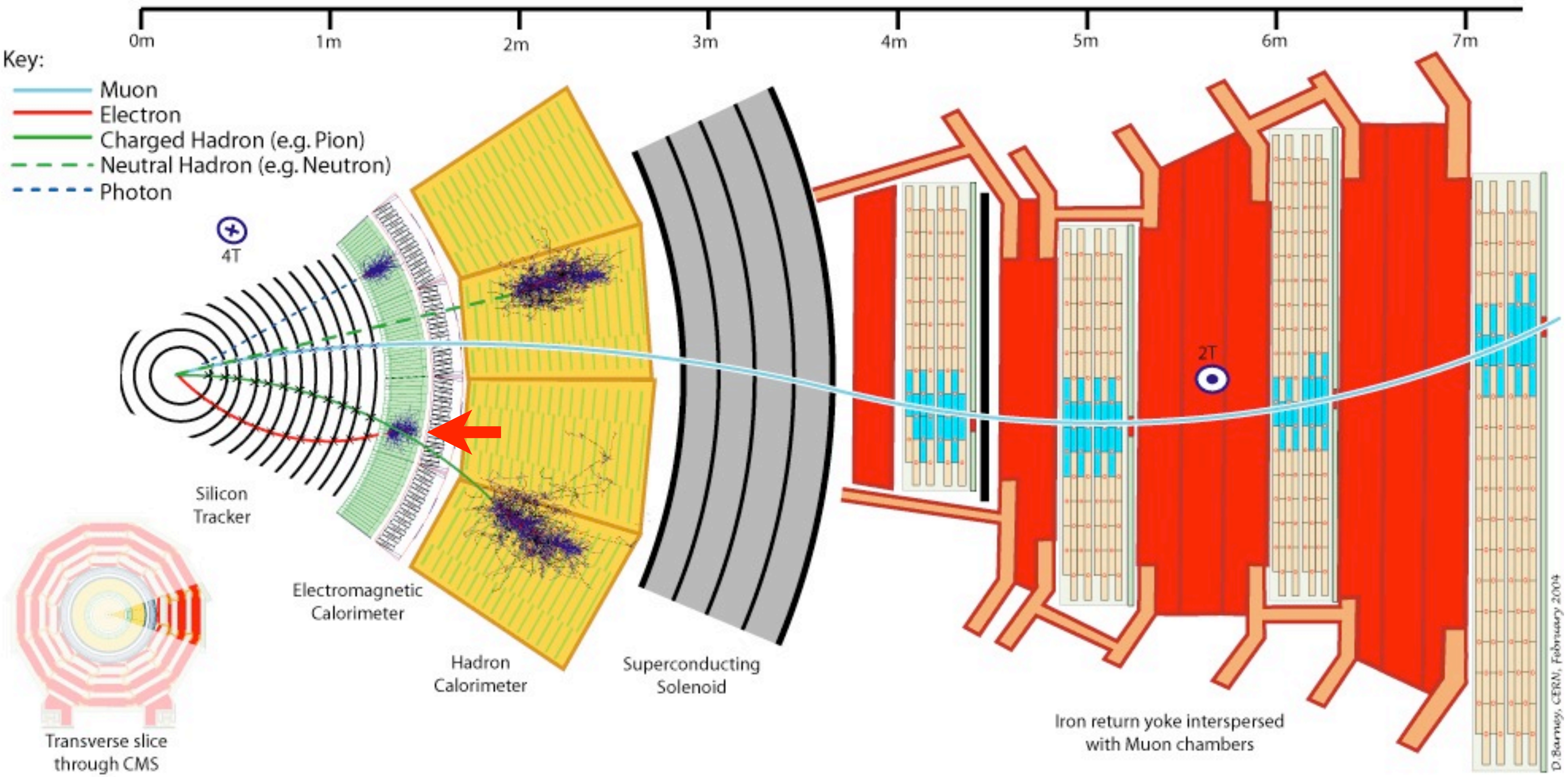
- Silicon and gasses mark the passage of charged particles, while brass and steel cause particles to shower at strategic times

Muons



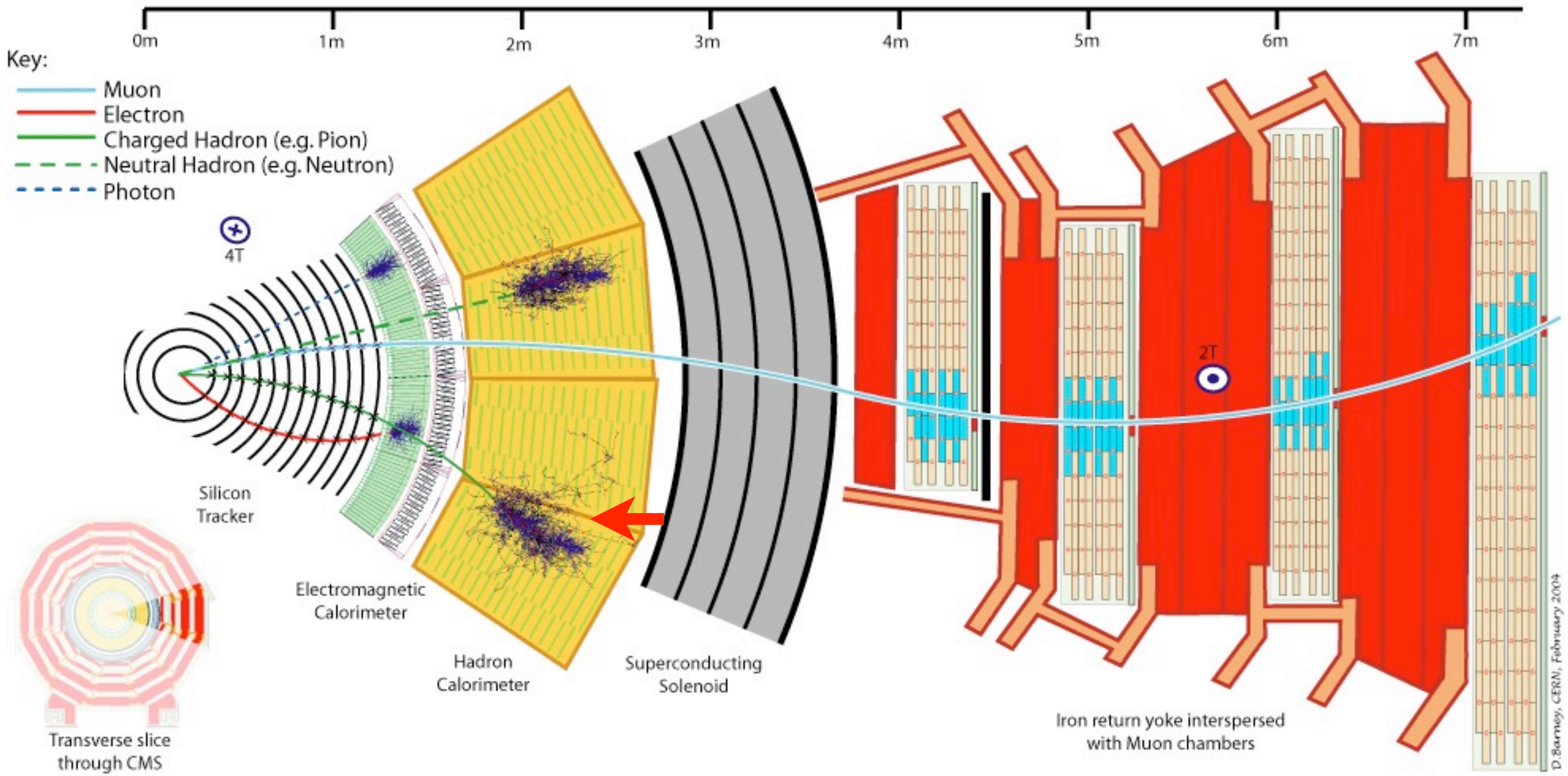
- Weakly interacting particles travel through the detector
- Leaves **track** in tracker and muon chamber, **NO energy** in ECAL and HCAL
- Track curvature changes as the magnetic field flips at the solenoid boundary

Electrons



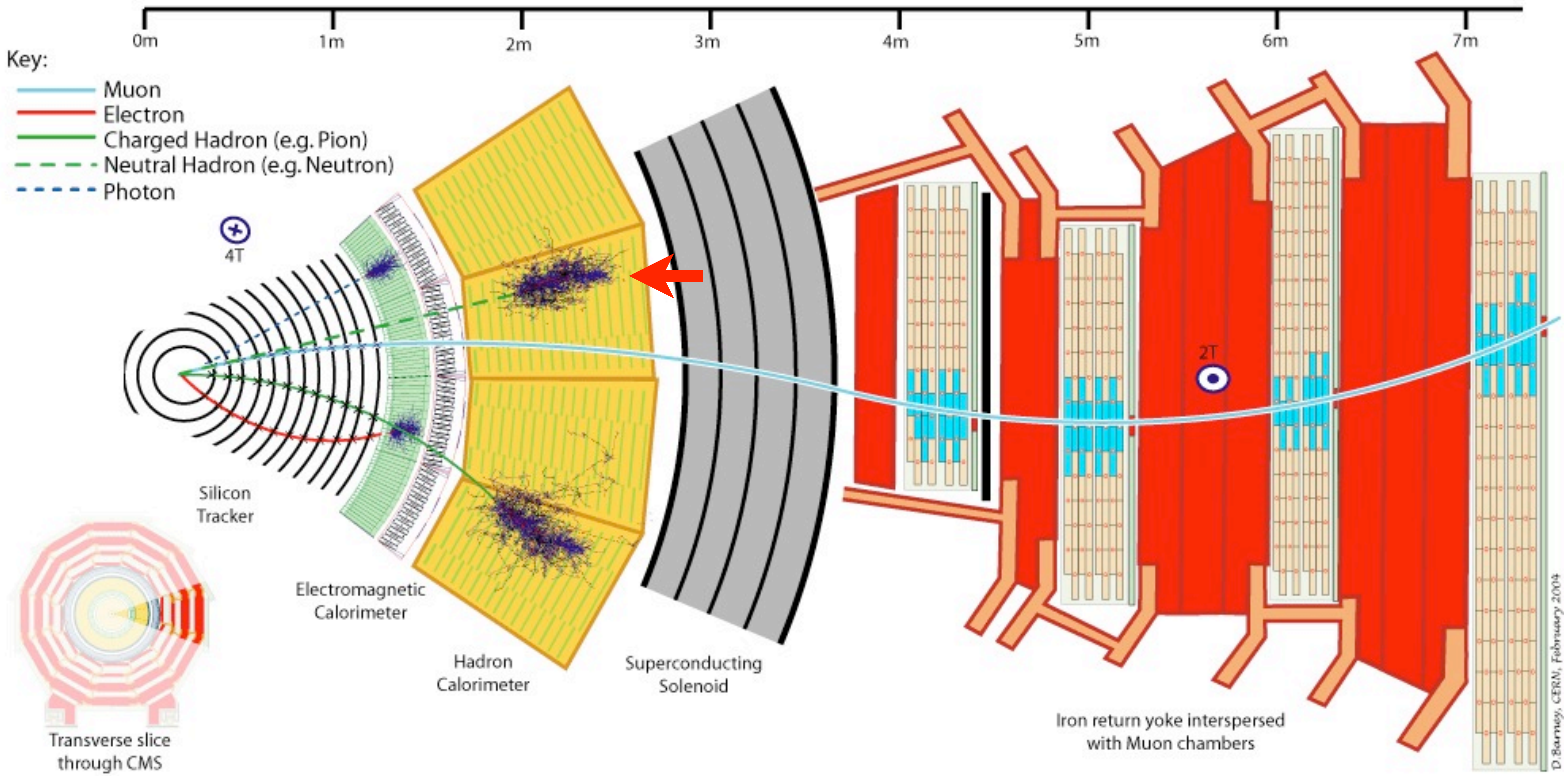
- Leaves **track** in tracker, fully deposits energy in **ECAL**
- Leaves distinctive energy pattern spread in phi axis

Charged Hadrons



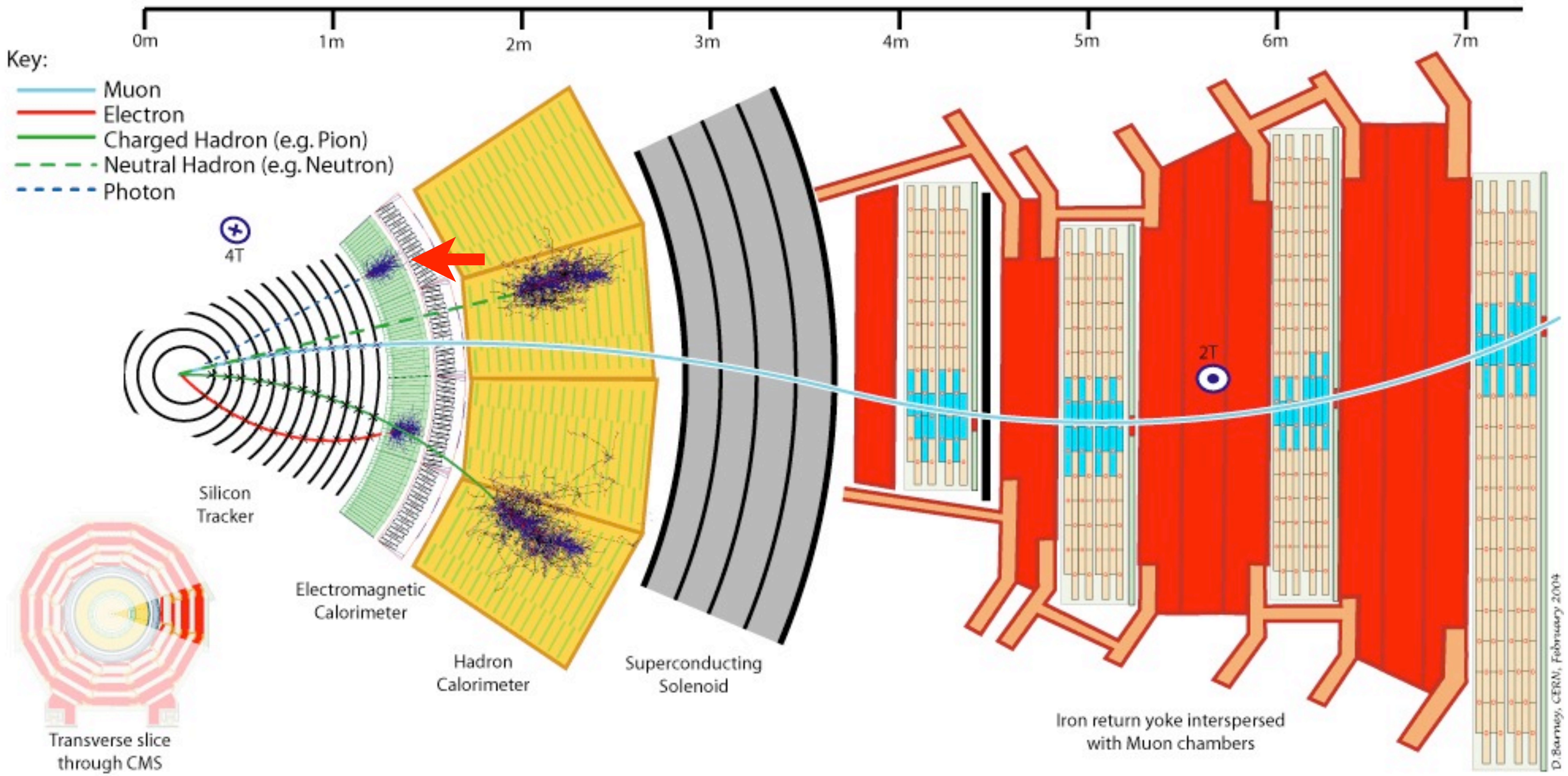
- Leaves **track** in tracker, fully deposits energy in **HCAL**

Neutral Hadron



- Leaves **NO track** in tracker, fully deposits energy in **HCAL**

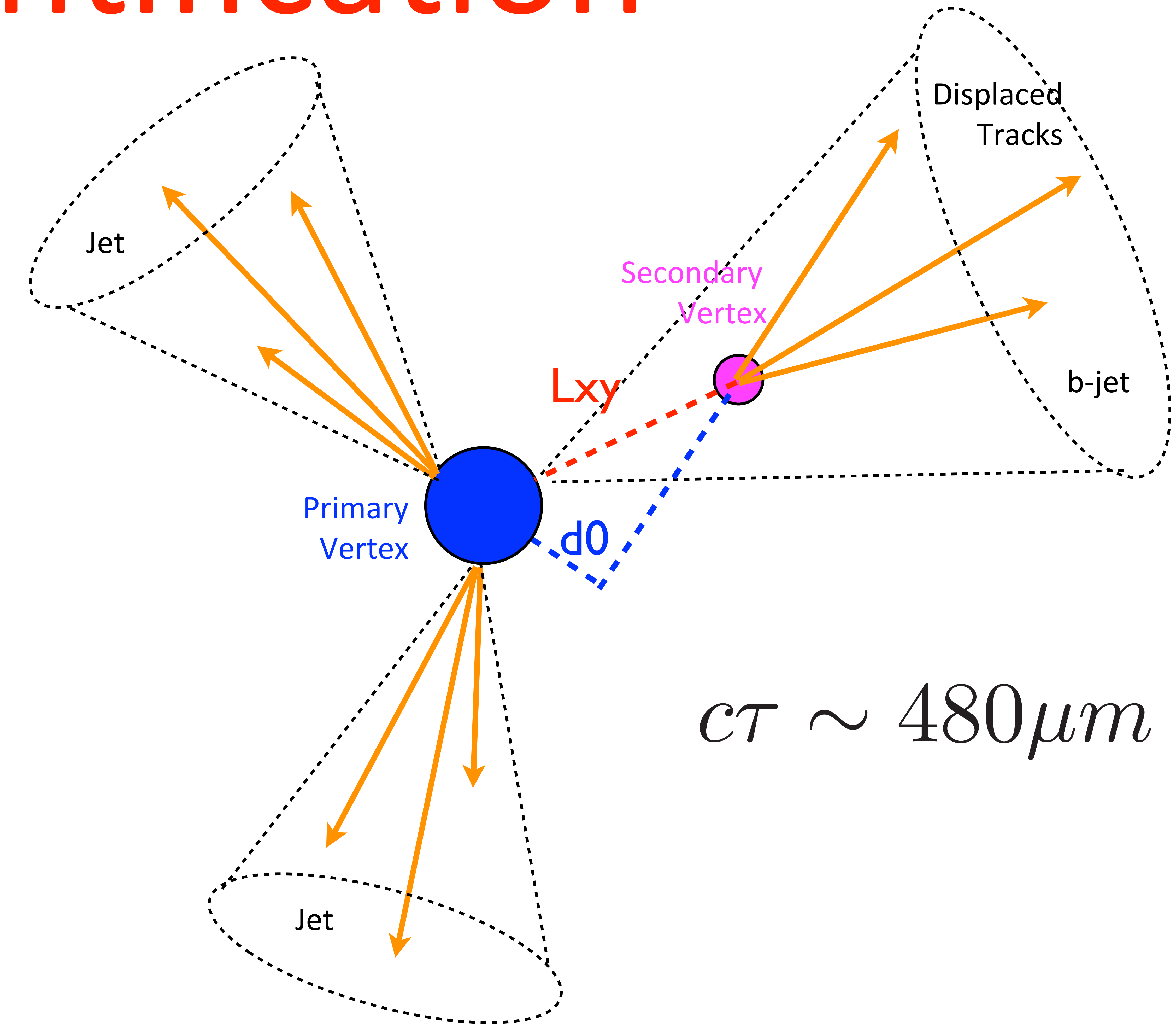
Photon



- Leaves **NO track** in tracker, fully deposits energy in **ECAL**
- Energy shape is not spread in phi as it is with electrons

b-Jet Identification

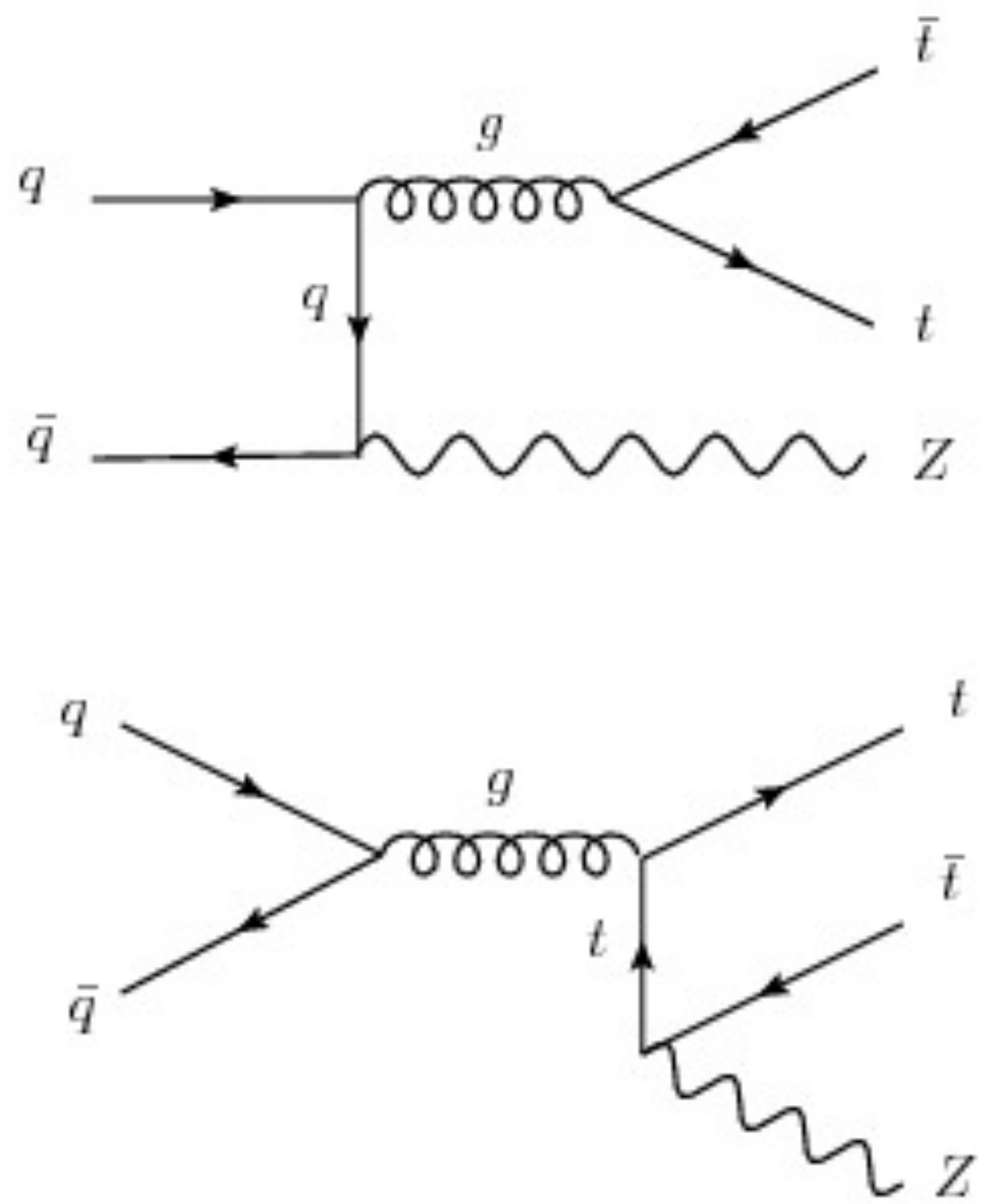
- Jets from Heavy flavor hadrons (contain b-quarks) have **longer decay length**
  - Measurable distance in the tracker
- Information such as a **secondary vertex** or tracks with **large impact parameters** can identify b-jets
- Jets identified as b-jets are called b-tagged jets
- Identification is important because **top quarks decay to b-jets 100%** of the time
  - excellent handle for identifying top quarks



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

ttZ Cross Section Measurement

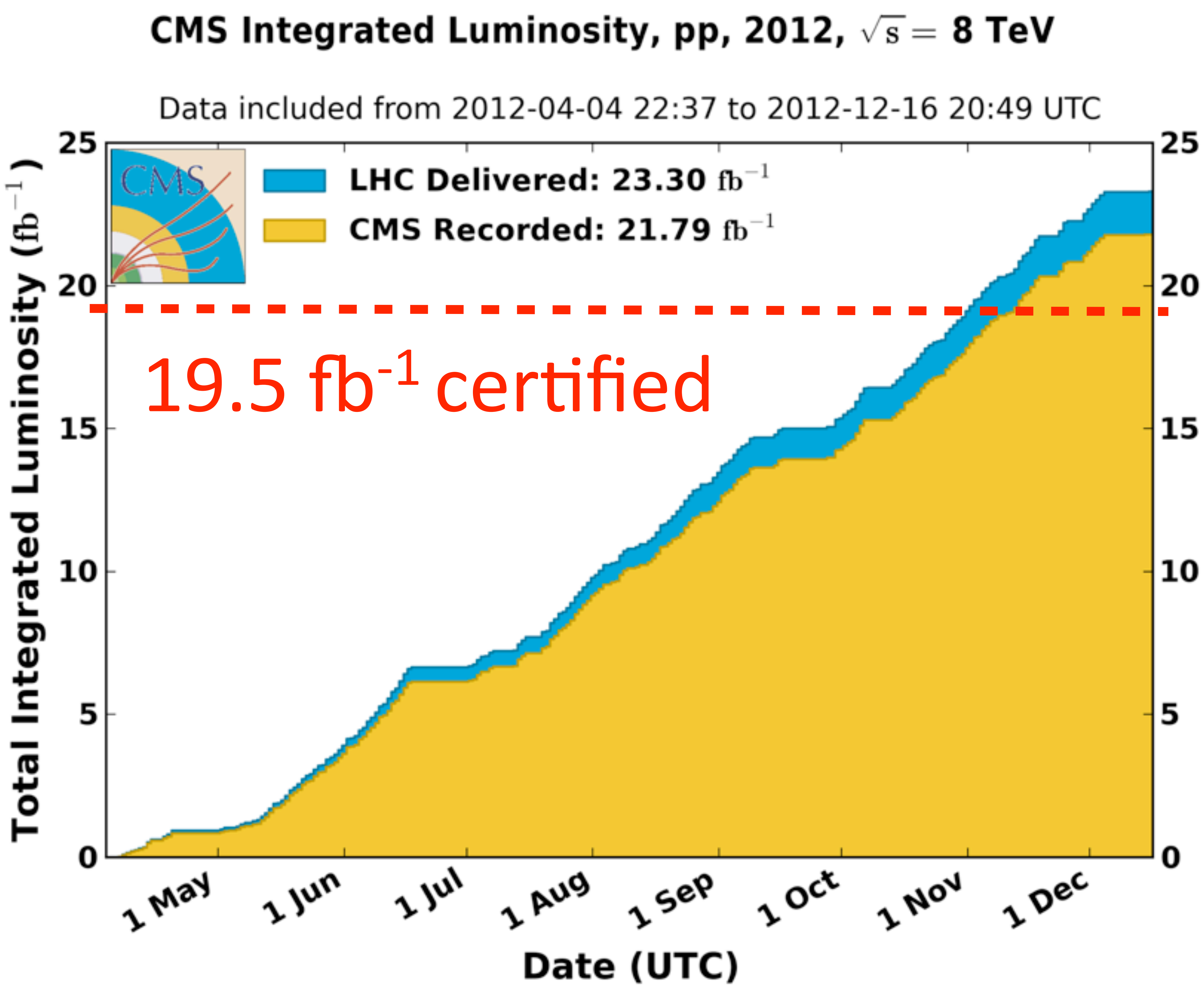
Why Measure ttZ



Example of top/Z coupling
(Still unmeasured)

- Standard Model well verified but still more to confirm
- Exotic physics (such as SUSY) tend to have higher jet multiplicities and leptons multiplicities
  - ttZ decays to several jets and leptons and is an **important background to SUSY searches**
  - An accurate cross section measurement will lower errors on background measurements
- One method of ttZ production involves the top/Z coupling
  - As yet unmeasured
  - Any deviation from the standard model would hint at new physics

Data Collection



- Collected by the CMS detector at the LHC
- Collisions are certified by the experiment
- Collected during 2012
- Theoretical prediction of almost 3800 ttZ events produced
  - Will be reduced by branching fraction to trileptons
  - Will be greatly reduced by efficiency in selections to remove backgrounds
  - Will only measure O(10) ttZ events

Cross Section Comparison

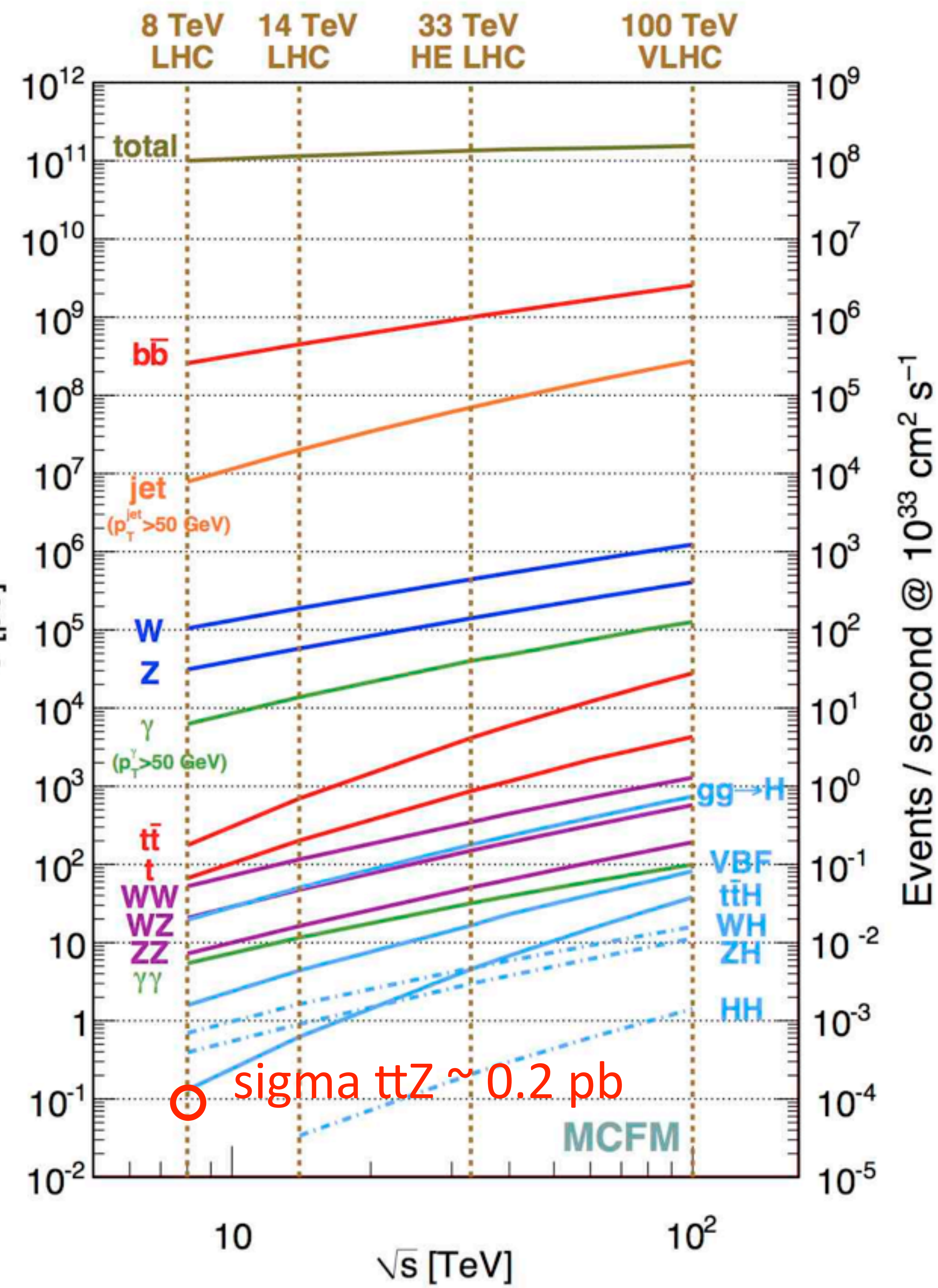
- ttZ is produced infrequently at the LHC
- However, first **major trilepton background** is only factor 100-1000 larger.
- Other very large backgrounds have less leptons and can be easily reduced.

Hadronic

1 lepton

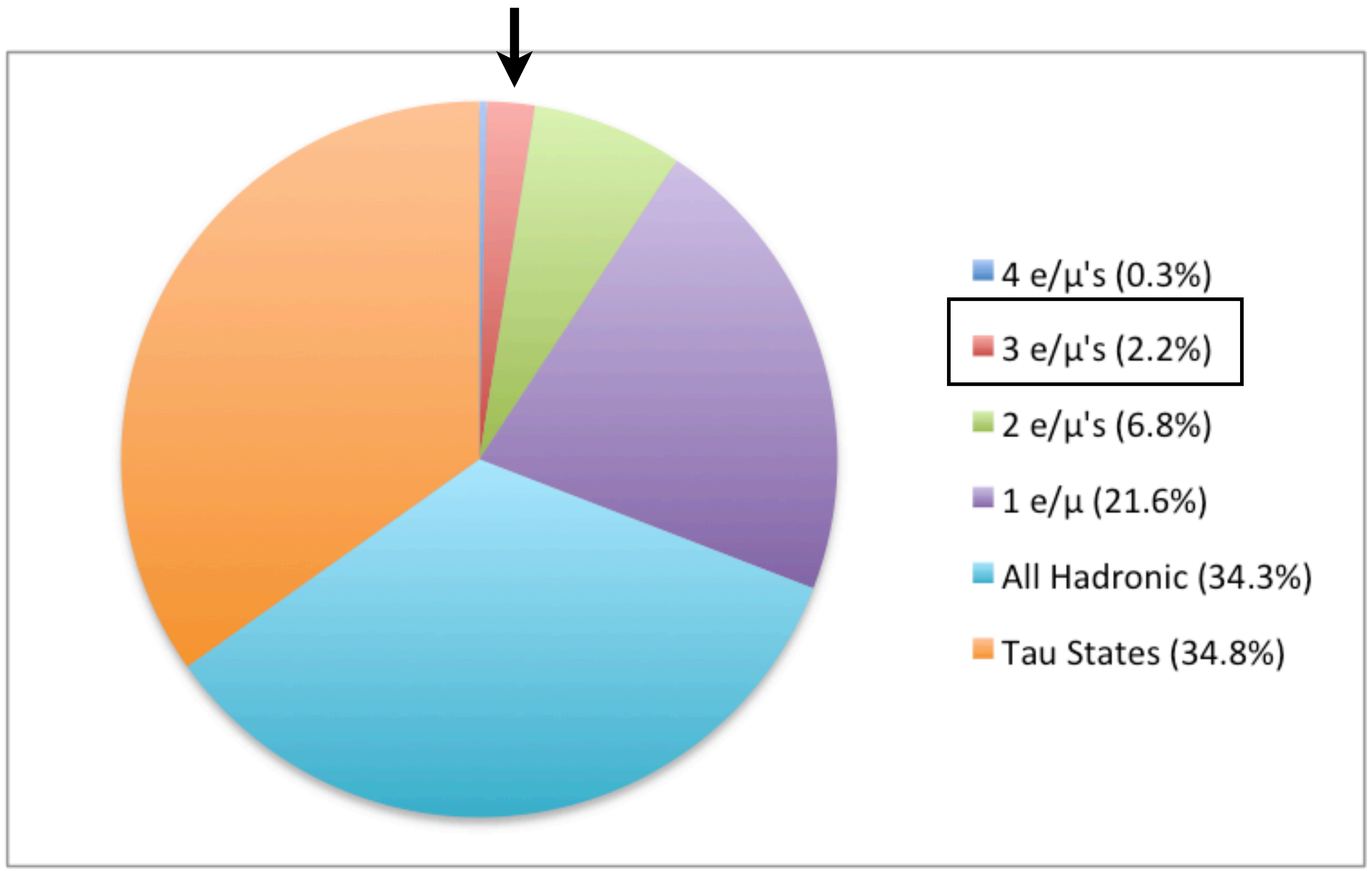
2 leptons

Multileptons



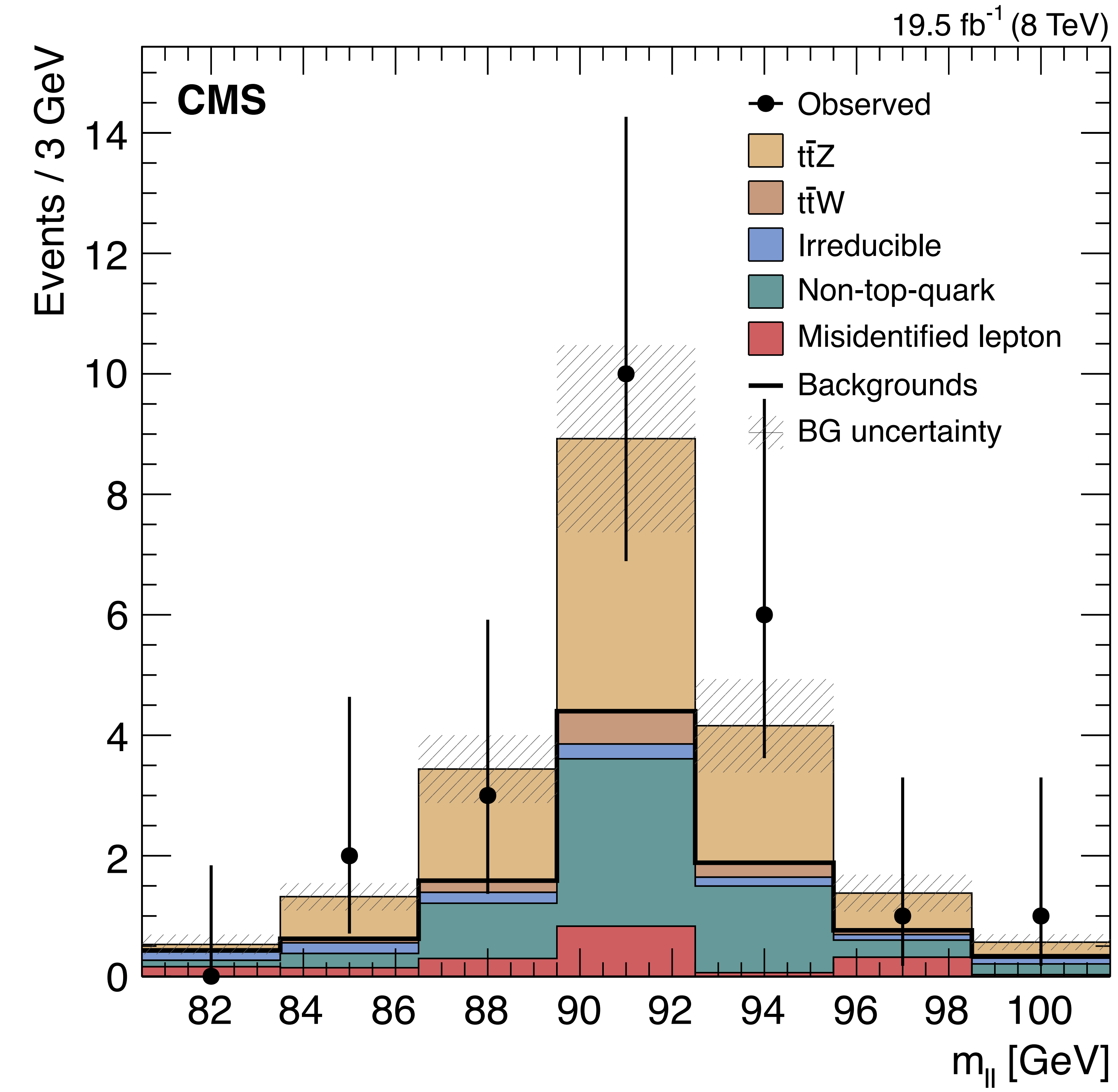
3 Lepton Measurement Channel

- Why deliberately choose the rarer decay?
- **Creates strong identification**
  - Sources with very large cross sections produce less leptons and can still produce a number of jets
  - Leptons have better resolution than jets
    - Can accurately reconstruct a Z mass
  - Leptons are produced by sources with lower cross sections
- Reduce backgrounds
  - 3 Leptons are rare and can only come from multi-top and or multi-boson sources



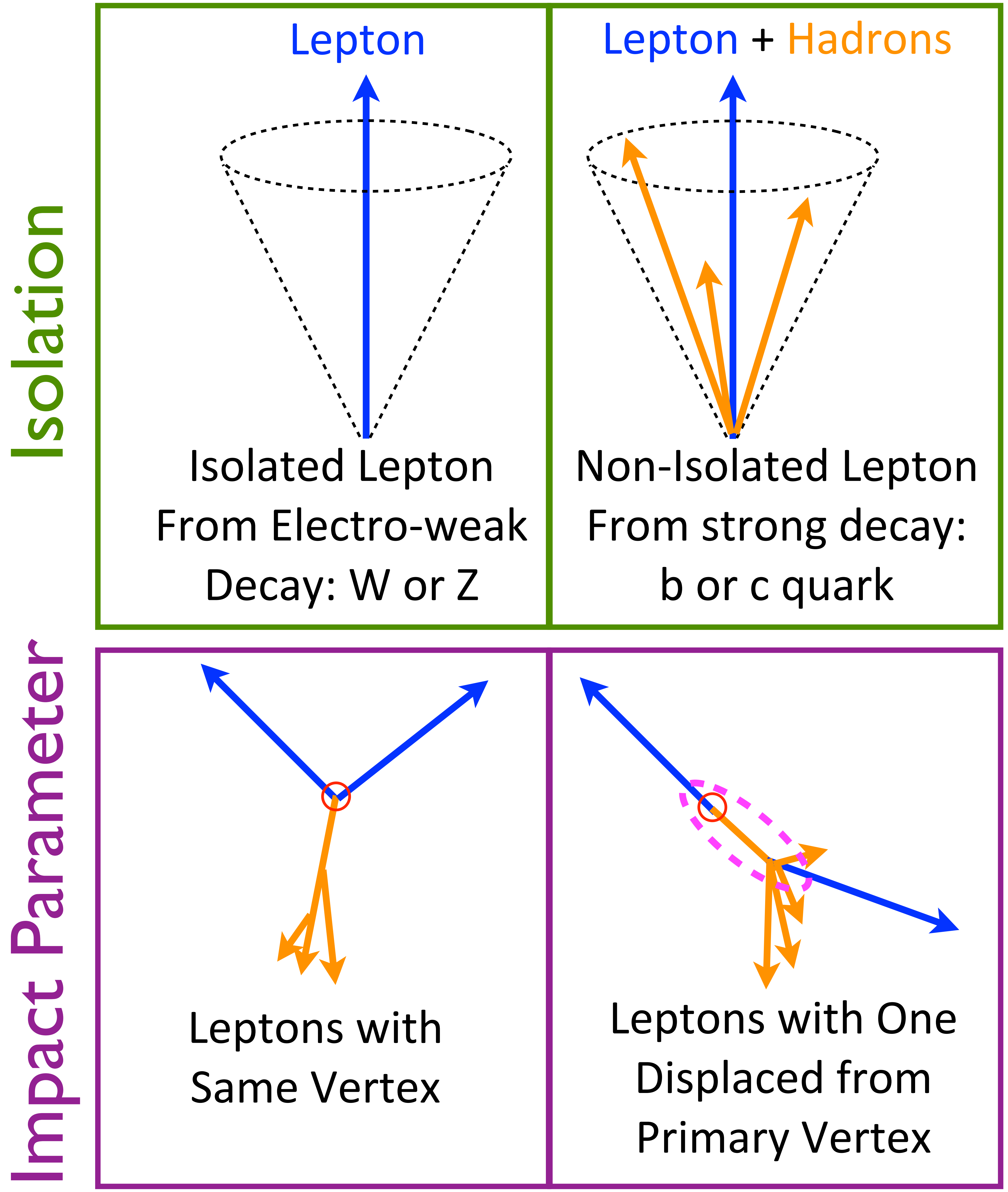
Selection Strategy

- **Identify 3 leptons (Z→2 ℓ , t→Wb→ ℓ νb)**
  - Use strong identification - fake leptons contribute significantly to backgrounds
- **Identify 2 b-jets (2 x t→Wb)**
  - Staggered identification: 1 strongly, 1 weakly. Multiplicity reduces backgrounds.
- **Identify 2 additional jets (t→Wb→jjb)**
  - Just need to be there. Leptons and b-jets are stronger discriminating variables
- **Use 2 leptons to reconstruct a Z mass**
  - Sticks out like a sore thumb and heavily reduces backgrounds without a Z boson



Z boson Mass Peak

Lepton Selections

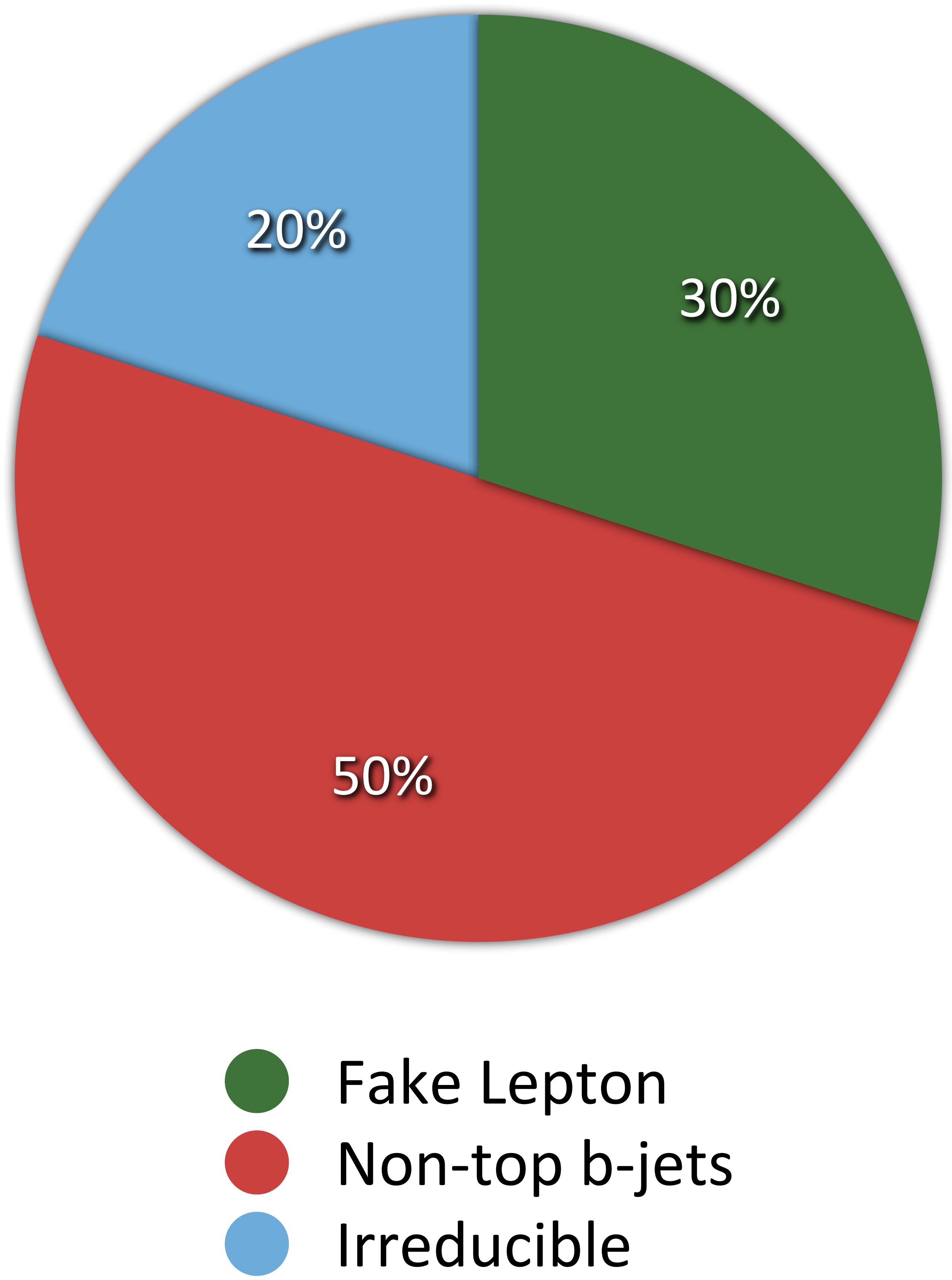


- High p_T: > 20 GeV
- η within the region of the tracker: < 2.4
- Tight isolation
  - targeted to reduce fake leptons
- Leptons consistent with the primary vertex: tight requirement
  - targeted to reduce fake leptons

Background Estimation

Background Sources

Estimated Fraction of Total Background



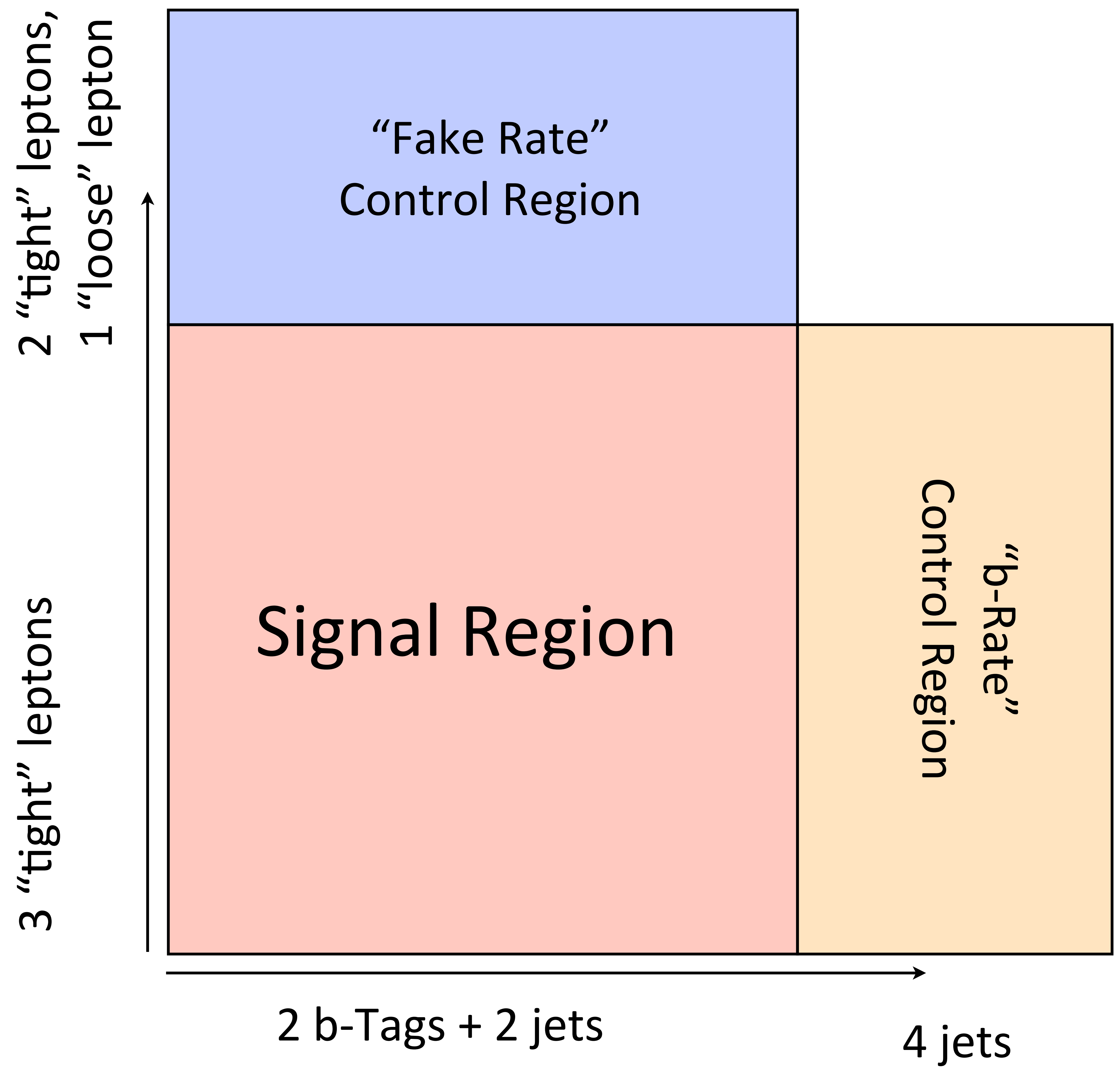
- **Leptons candidates from Fakes leptons**
  - Mostly arise from heavy flavor decay, hadron misID, decays in flight, and photon conversion
  - e.g. tt + fake ℓ

- **b-jets from Non-top Sources**
  - Largely arrises from gluon splitting accompanied by multi-bosons and mis-tags
  - e.g. WZ + ISR gluon splitting

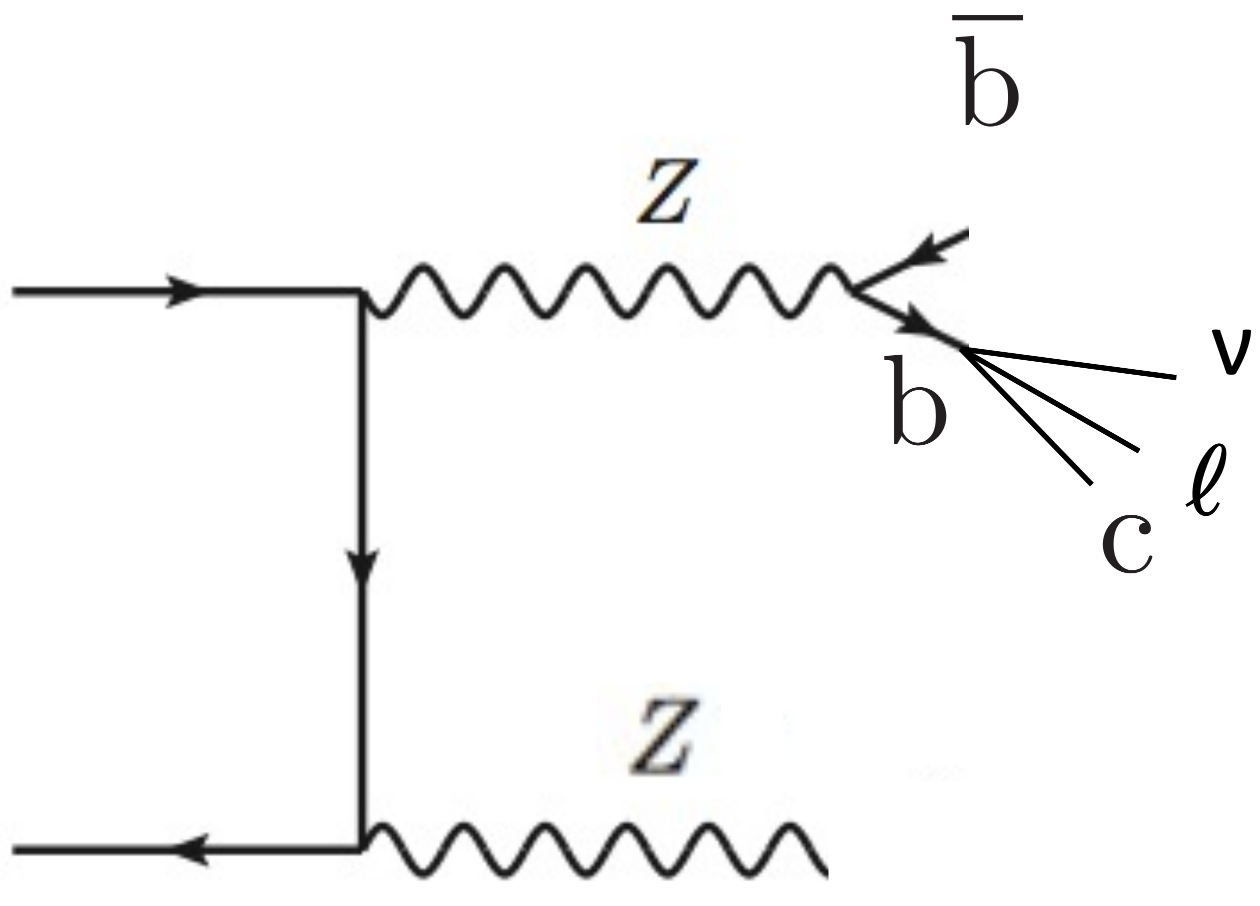
- **Irreducible Sources**
  - Multi-boson samples and mutli-top samples
  - e.g. ttW

Measurement Regions

- Signal region: 3ℓ +2b+2J
- "Fake Rate" region: Relax selections on one lepton
  - Apply fake rate derived elsewhere to estimate fake backgrounds in signal region
- "b-Rate" region: relax b-tag requirements
  - Apply b-rate derived elsewhere to estimate non-top b-jet backgrounds in signal region



Fake Leptons



ex. ZZ where all 3 leptons
(2 real, 1 fake) pass ID and Isolation

- **Real leptons: from W or Z decay**
  - prompt and isolated
- Remaining lepton candidates are Fake leptons
- Example: Semi-leptonic b decay
  - $b \rightarrow c\, \ell\, \nu$
  - Lepton is not isolated because part of boosted jet system
- Example: Mis-reconstructed hadrons
  - e.g. $\pi^0 \rightarrow \gamma\, \gamma$ or $\pi^{\pm}$
  - Identification variables such as energy deposit shape may be different from real lepton

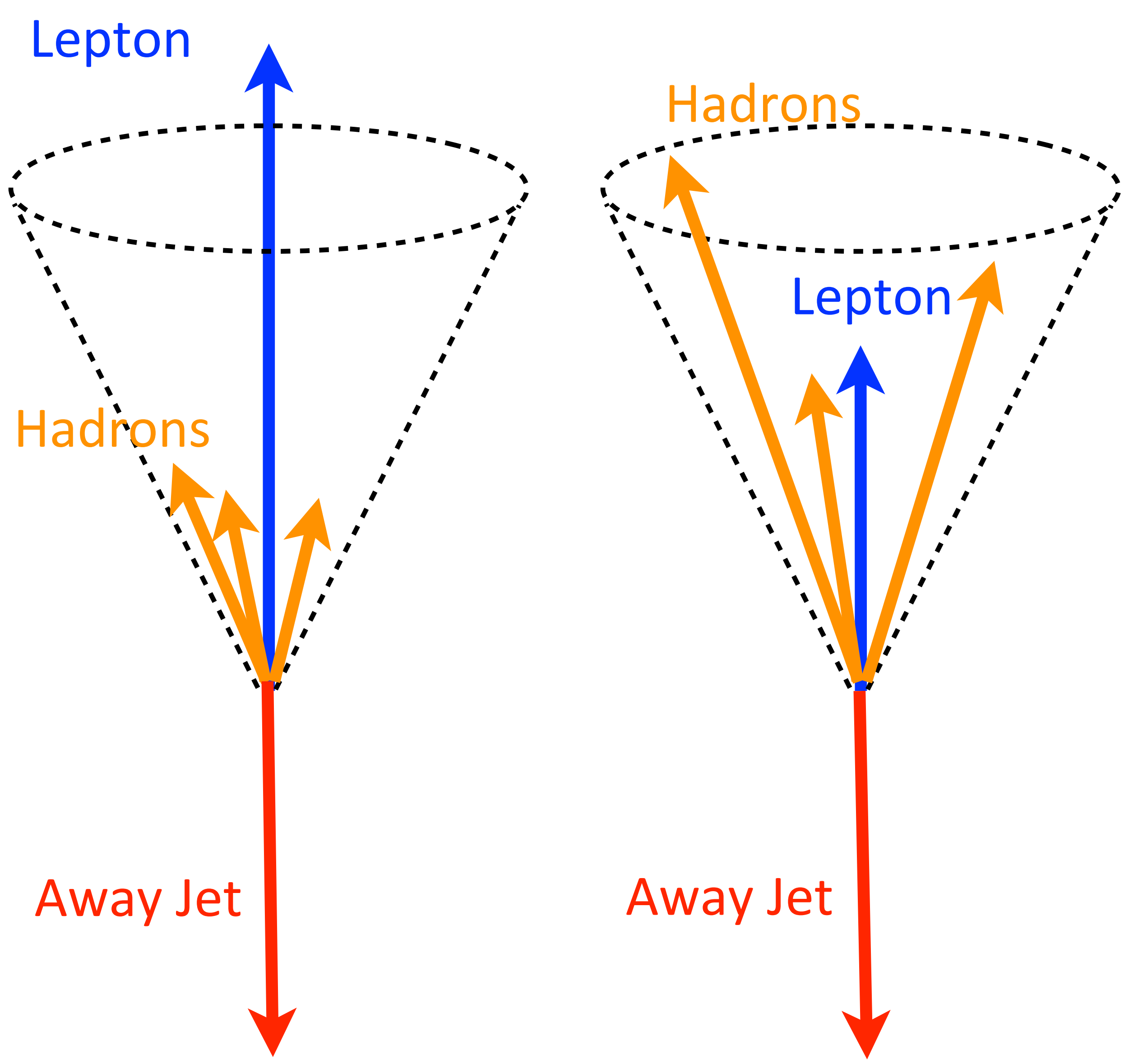
Fake Rate

- **Derivation and prediction uses data**

$$\text{Fake Rate} = \frac{\#\ \text{tight leptons}}{\#\ \text{loose leptons}}$$

- **Loose selection allows extrapolation to full selection**
  - relax the **isolation** and impact **parameter** for loose lepton
- **Measure the fake rate in independent data sample enriched in background events**
  - require away jet of p_T > 40 GeV
  - acts as handle for momentum of the jet the lepton decayed from
- **Additional requirements to reject events with W or Z decays**
- **Apply the rate to similarly prepared control region adjacent to the signal region.**
  - relax the identification and isolation on one of the leptons in the signal region to form fake rich environment
  - apply fake rate to estimate the number of those events that would pass tight selections

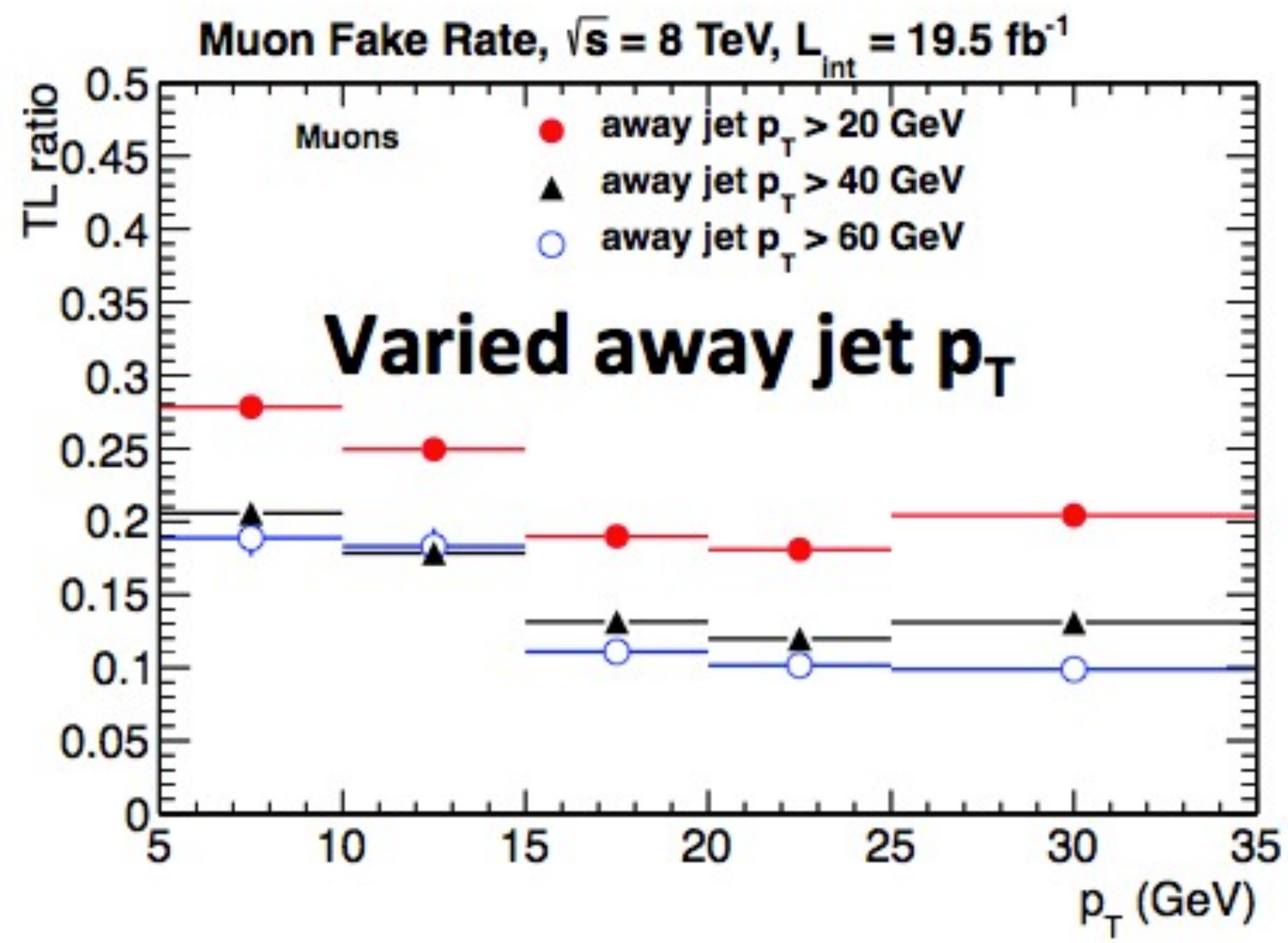
Fake Rate Systematic



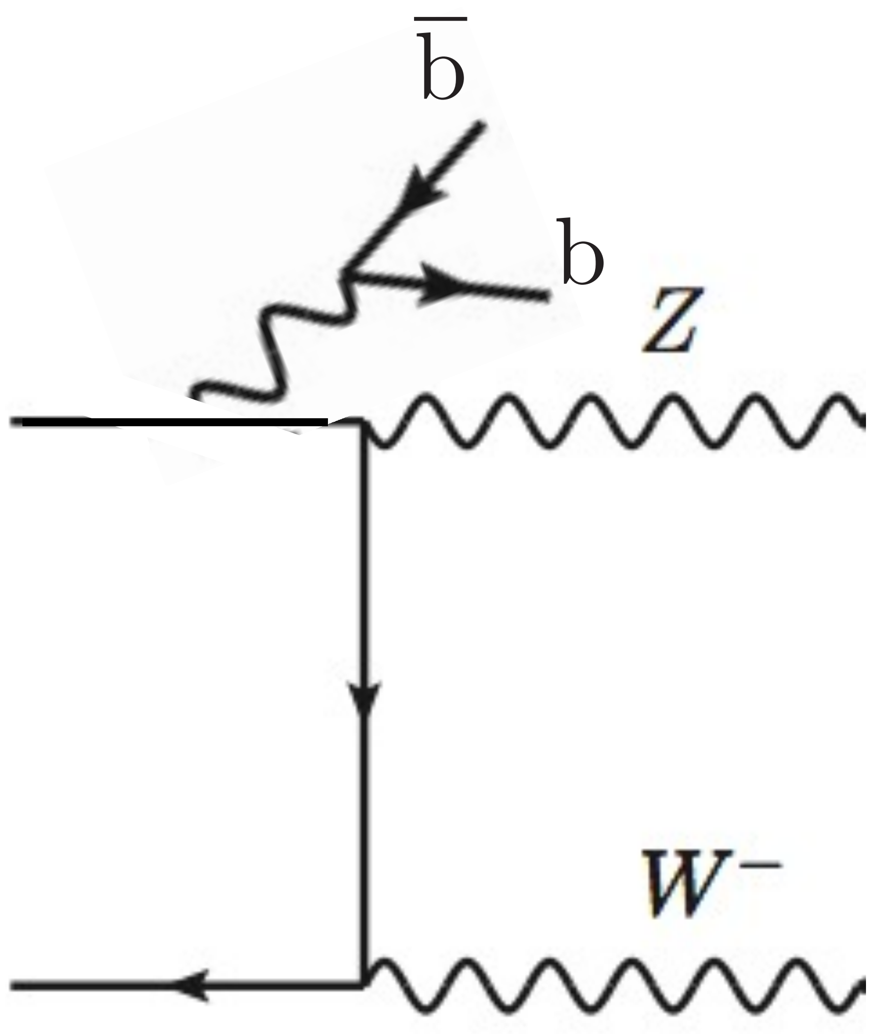
Fake Lepton Produced in Di-jet Event

(Relative Momentum Matters, away jet handle helps to control this)

- Take a flat **50% systematic** uncertainty for method
- Test method by applying to simulated samples
  - Over predicts by O(50%)



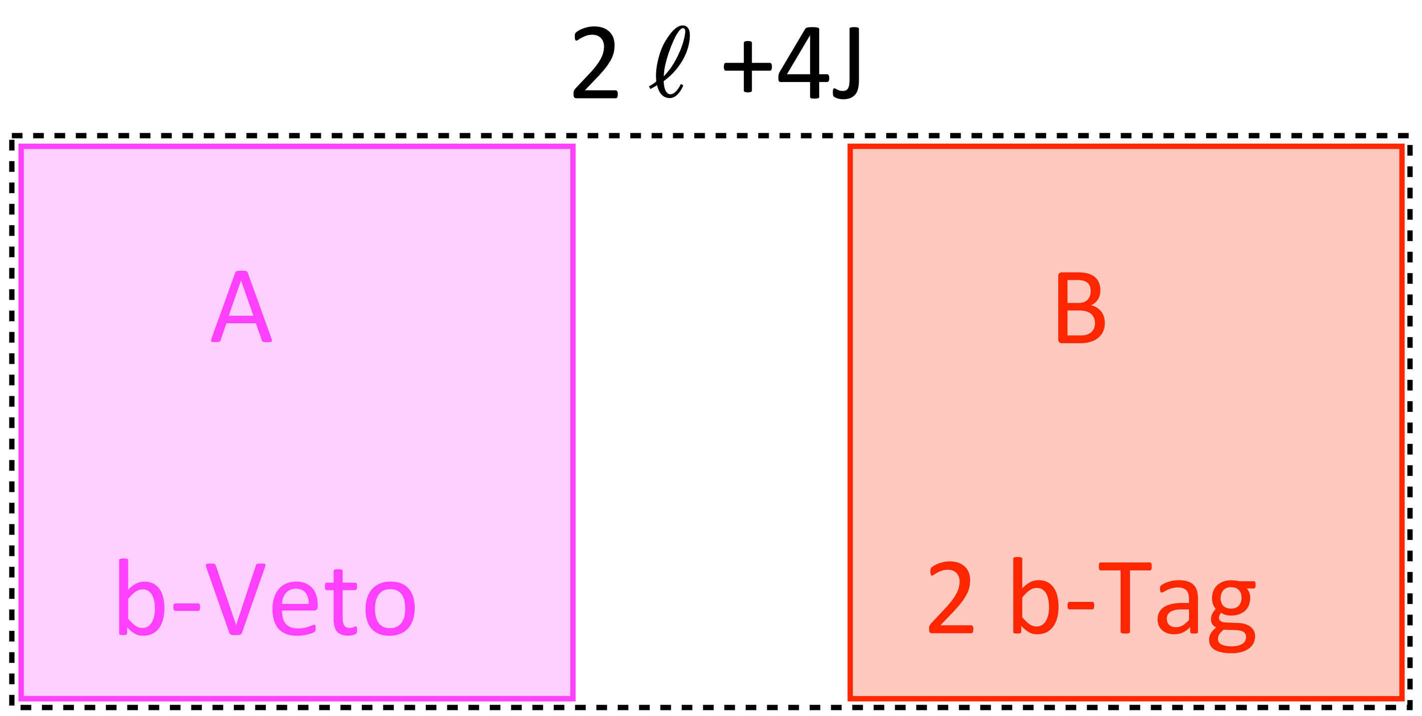
Rate of b-tags not from tops



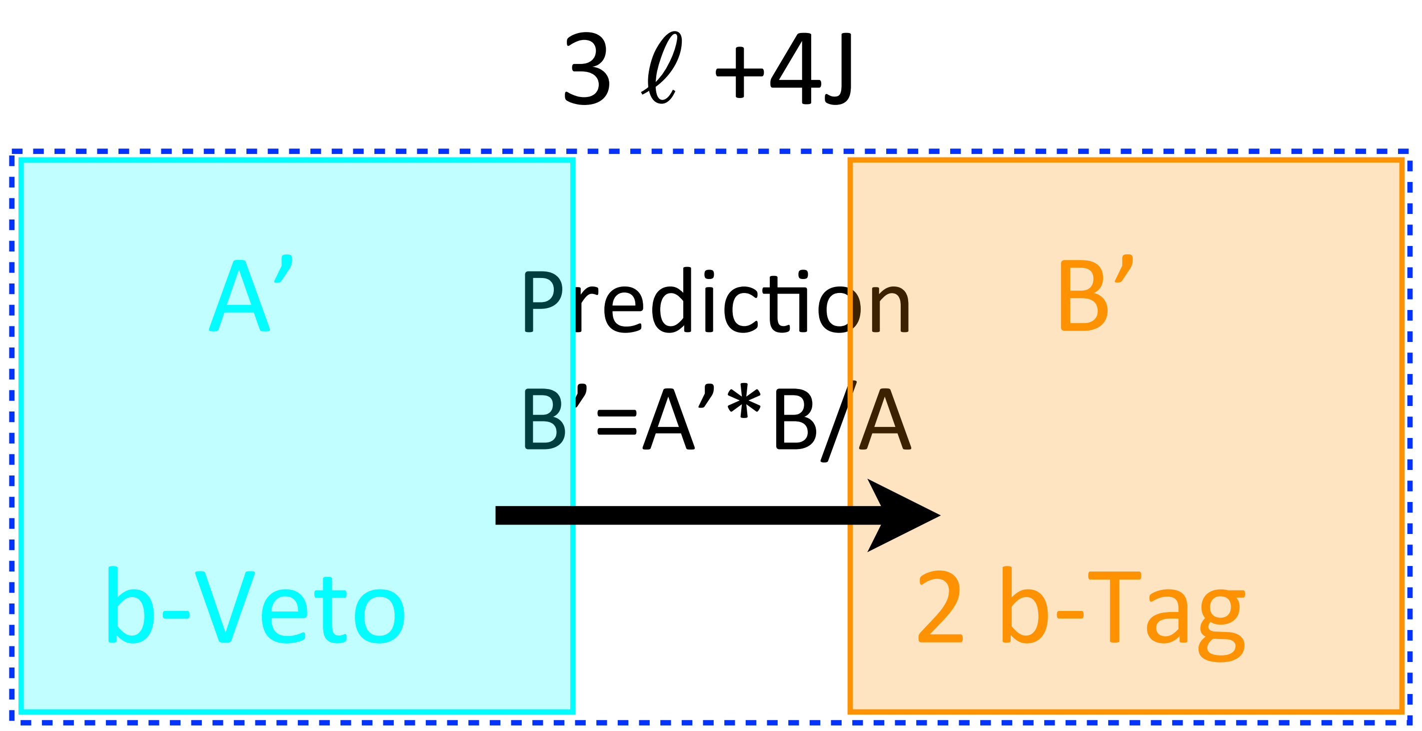
ex. WZ to 3 ℓ with ISR gluon splitting.

- Primarily originates in from **mis-tags** or **gluon splitting**
- **Measured in data**
  - Choose sample with similar jet multiplicites
  - Measure ratio of events with 2 b-jets to events with b-veto applied
- Use ratio to extrapolate to signal region from control region with b-veto applied

Corrections and Uncertainty



* Perform opposite flavor subtraction to kill ttbar and ensure DY dominates control region



Prediction Correction

- Method has been shown to over-predict by ~40% in simulation.
- Use over-prediction to scale down estimate.

Systematic Uncertainty

- Set at 50% due to combination of:
  - over prediction when applied to simulation
  - small dis-agreement between data and MC

Irreducible

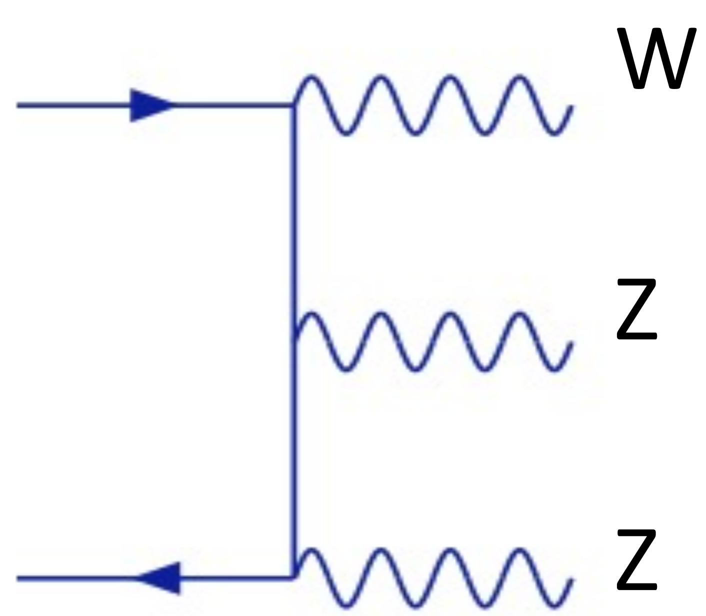
Multi-boson

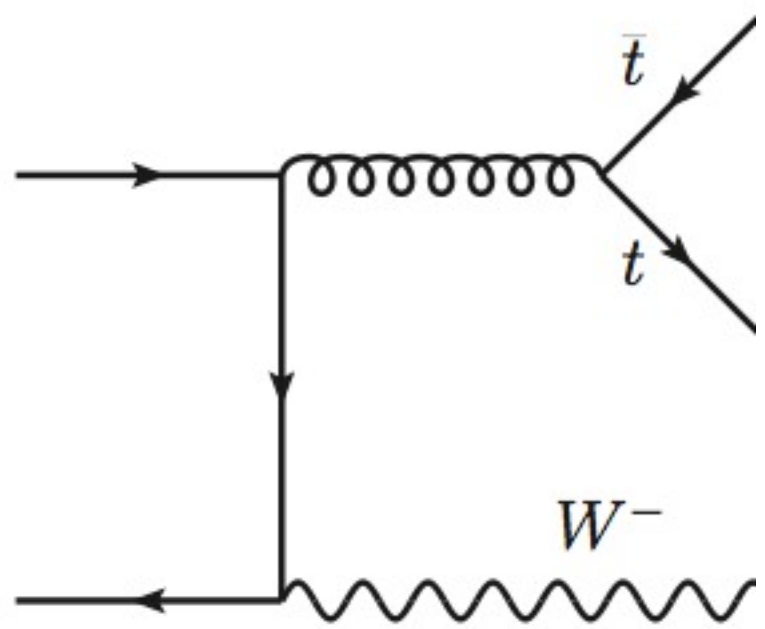
- WZZ
- ZZZ

Top and Boson

- ttγ
- ttWW
- ttW
- tbZ
- ttH

Largest Backgrounds

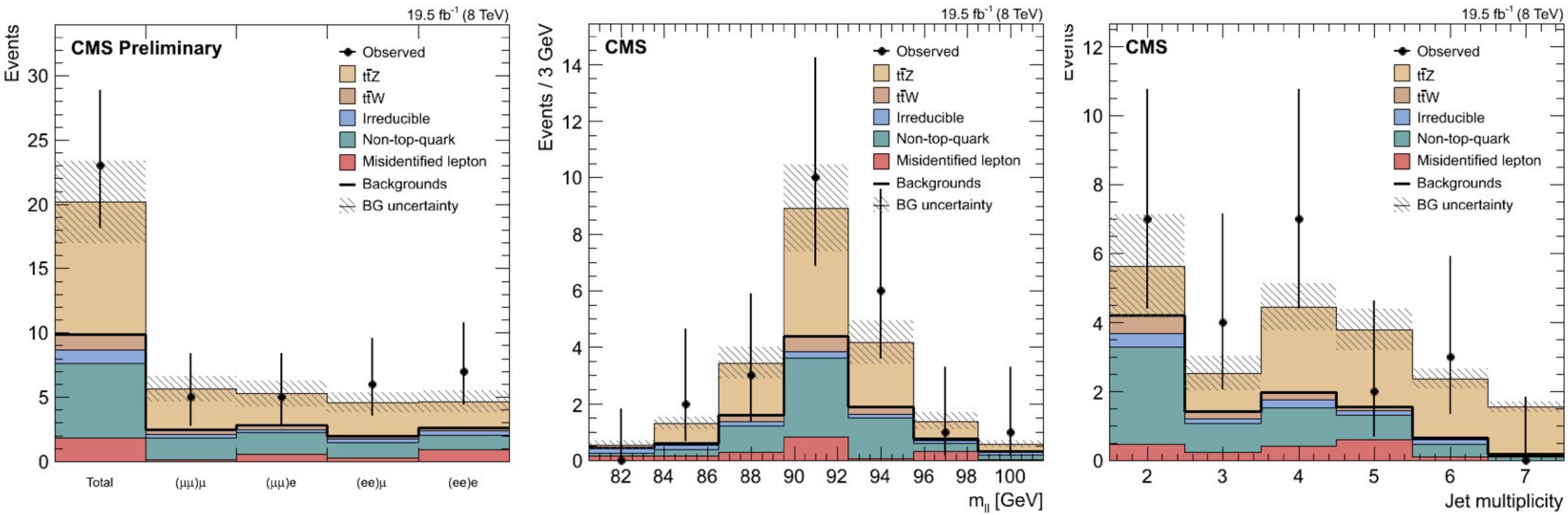




- Samples use **Madgraph**
- Normalized with Next to Leading Order (NLO) cross sections
- Apply data to MC scale factors
  - Lepton ID and Isolation Efficiency
  - b-tagging Efficiency

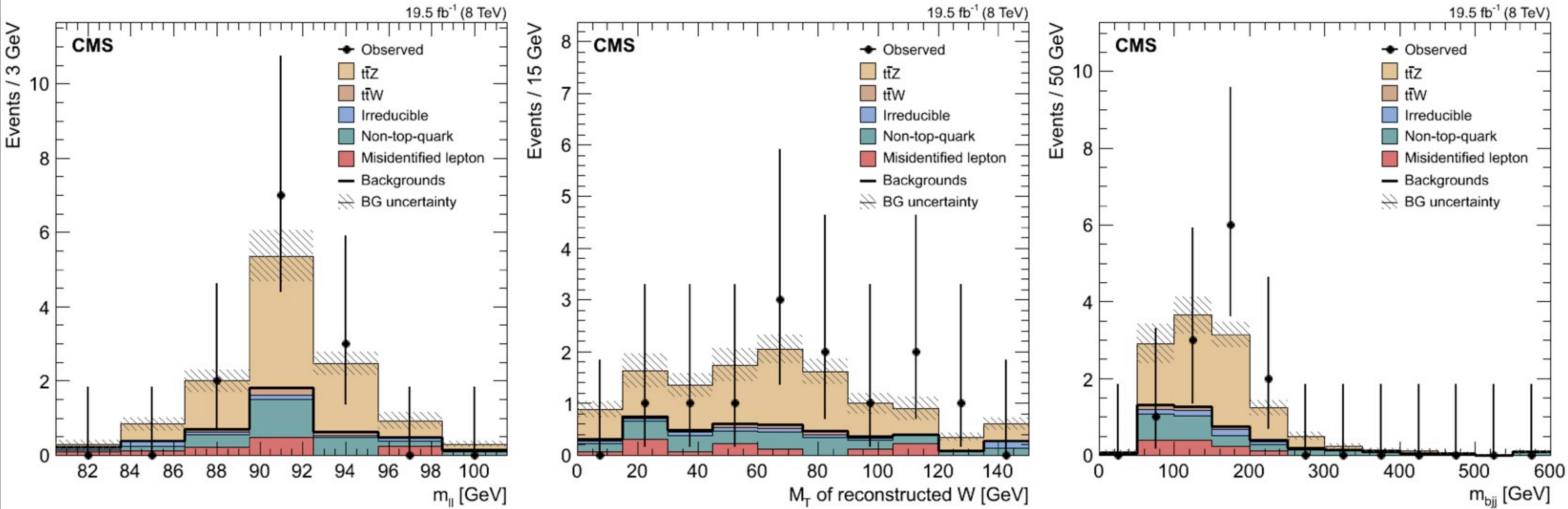
Most of these processes have not been measured and are normalized to a theoretical cross section. As such, in **50% systematic** uncertainty is assessed in addition to the statistical uncertainties listed in the table.

Data/Prediction Agreement



- Relax selections to **3 leptons and 2 b-tags** to gain extra events
- Shows agreement between predictions and measured data

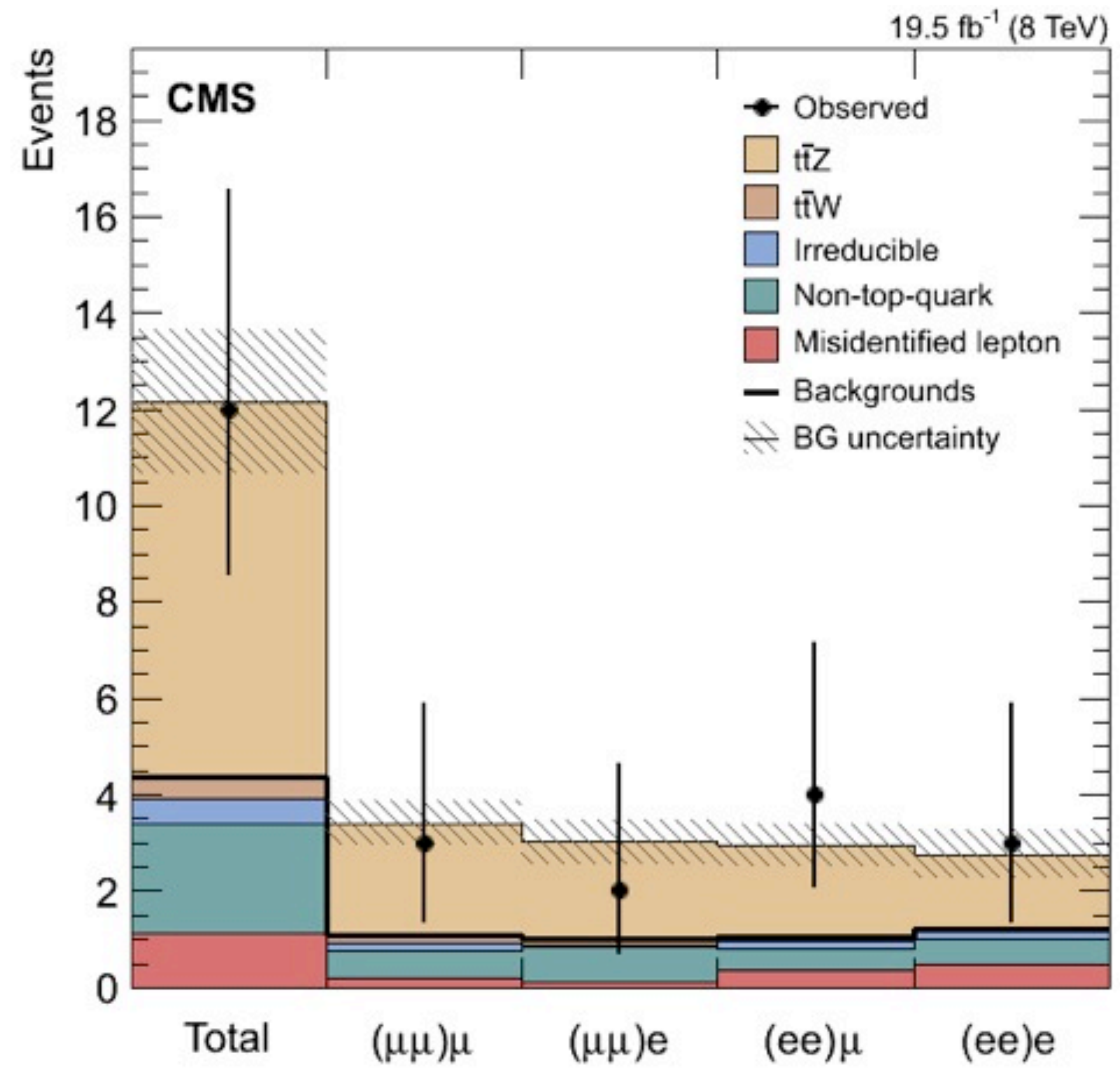
Mass Distributions



- **Full selections**
- Reconstructing parent particles (Z, W, t) help to demonstrate that events are true ttZ events

Results

	Yield
Irreducible	1.0 ± 0.5
Non-top-quark	2.3 ± 1.2
Misidentified lepton	1.1 ± 0.8
Total bkg.	4.4 ± 1.6
Observed	**12**
Obs. − total bkg.	7.6 ± 1.6
$t\bar{t}Z$ (expected)	7.8 ± 0.9



$$\sigma_{t\bar{t}Z} = 190^{+100}_{-80}\ (\text{stat.})\ ^{+40}_{-40}\ (\text{syst.})\quad \text{fb}$$

- Cross section **significance = 2.33**
- Measured ttZ cross section to be consistent with the Standard Model prediction

Multi-Channel ttV Search

ttW (2 ℓ)

Z mass veto with OS,SF Lepton Pair

ttZ (3 ℓ)

Z mass with OS,SF Lepton Pair

4th Lepton Veto

ttZ (4 ℓ)

4th Lepton Requirement

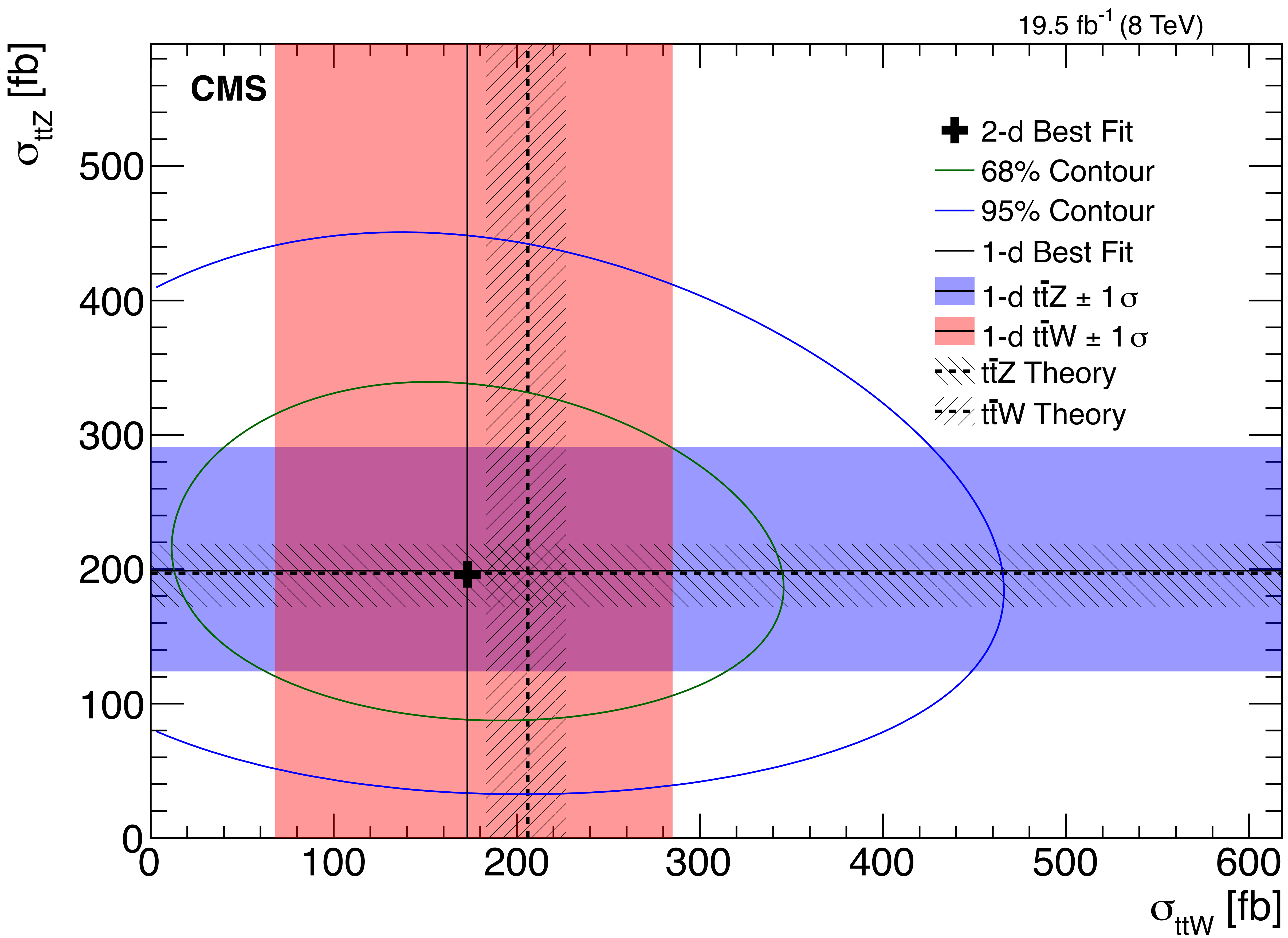
- Must achieve mutually exclusive regions
  - Z veto (selection) in 2 ℓ (3 ℓ) channel
  - 4th lepton veto (selection) in 3 ℓ (4 ℓ) channel

Channels used	Process	Cross section	Significance
2ℓ	$t\bar{t}W$	170^{+90}_{-80}(stat.)$^{+70}_{-70}$(syst.) fb	1.6
$3\ell+4\ell$	$t\bar{t}Z$	200^{+80}_{-70}(stat.)$^{+40}_{-30}$(syst.) fb	3.1
$2\ell+3\ell+4\ell$	$t\bar{t}W + t\bar{t}Z$	380^{+100}_{-90}(stat.)$^{+80}_{-70}$(syst.) fb	3.7

Cross sections for the different processes.

No information from ttW measurement is used in ttZ measurement and vice versa.

Combined Results



Channels used	$t\bar{t}W$ cross section	$t\bar{t}Z$ cross section
$2\ell+3\ell+4\ell$	170^{+110}_{-100}(total) fb	200^{+90}_{-90}(total) fb

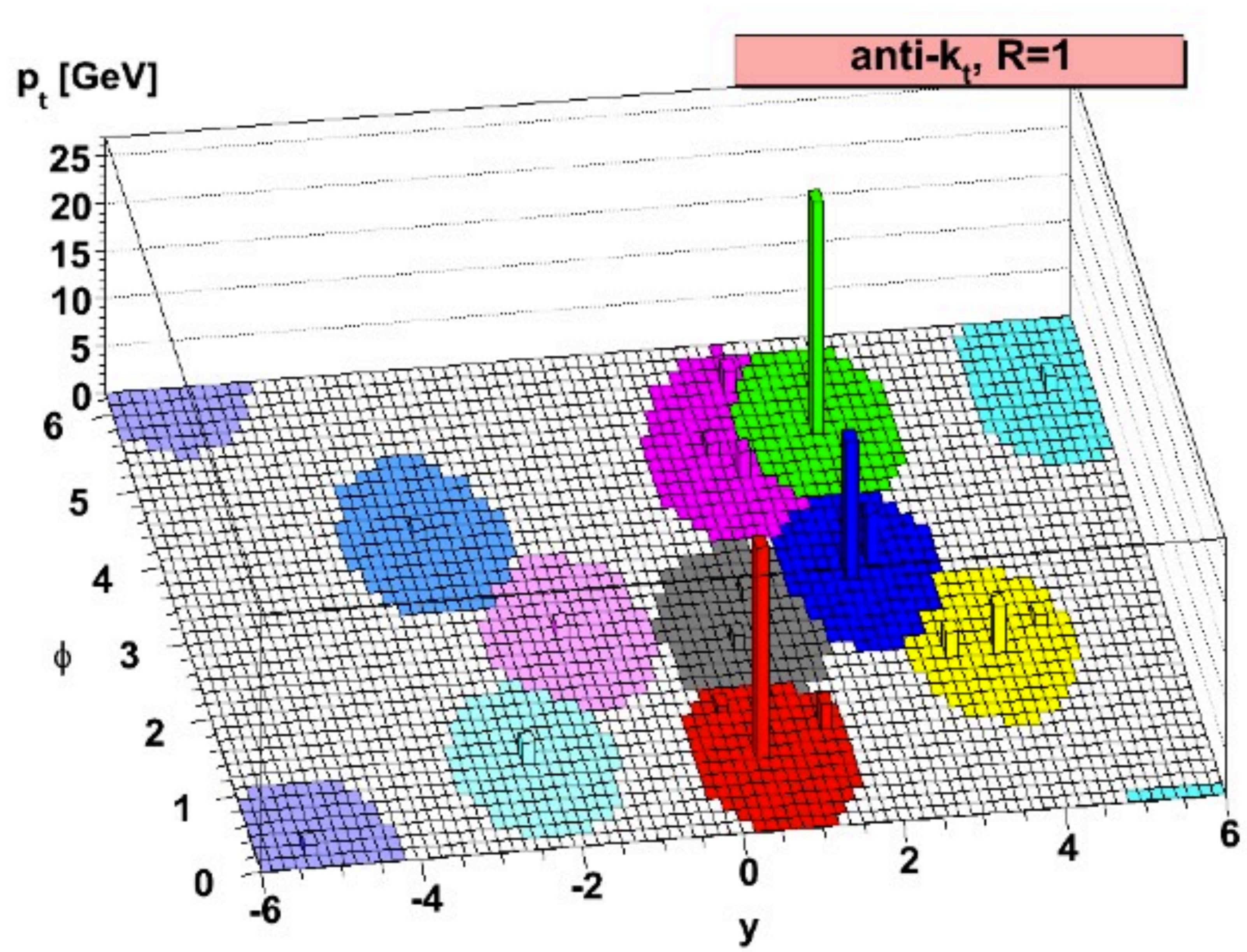
- **Simultaneous 2-d fit**
- 1-d fits were found to be stable with variations in ttW or ttZ backgrounds
  - No surprise that 1-d and 2-d agree

Summary

- Measured ttZ cross section in events with 3 leptons using pp collisions at 8 TeV corresponding to 19 fb^{-1}
    - **Consistent with Standard Model**
- Combined results with other channel measurements to produce better ttZ cross section measurement and ttW+ttZ cross section measurement
    - **Also consistent with Standard Model**

Appendix

anti-kt clustering



3L

Muon ID

- gfit_chi2 / gfit_ndof < 10
- gfit_validSTAHits > 0
- global muon
- pf muon
- >= 6 tracker layers with hits
- >= 1 pixel layer with hits
- muon segments in >= 2 muon stations
- ecalvetoDep < 4
- hcalvetoDep < 6
- d0 < 0.02 cm
- dZ < 0.1 cm

Muon Isolation

- [chiso + max(0.0, nhiso + emiso - 0.5 * deltaBeta)] / pt < 0.10
  - deltaBeta = pf PUpt
  - dR < 0.3 cone size

Electron ID

- Not within dR < 0.1 of muon passing selections
- Medium cut based electron ID
  - 0 missing pixel hits (this is tighter than the medium value of <=1 missing pixel hits on the twiki above)
  - deta in < 0.004 (0.007) barrel (endcap)
  - dphi in <0.06 (0.03) barrel (endcap)
  - sigma ieta ieta < 0.01 (0.03) barrel (endcap)
  - h/e < 0.12 (0.10) barrel (endcap)
  - |1/E-1/P| < 0.05
  - d0 < 0.02 cm
  - dZ < 0.2 cm
  - vertex fit = true
- transition region veto (1.4442 < |eta| < 1.566) based on SC eta
- triple charge consistency

Electron Isolation

- [pfiso_ch + max(pfiso_em+pfiso_nh - rhoPrime *AEff, 0)] / pt > 0.09
  - rhoPrime = max(kt6pf_foregiso_rho, 0)
  - AEff = constant determined by eta of Super Cluster
  - dR < 0.3 cone size

3L

Double Electron

DoubleElectron_Run2012A-13Jul2012-v1_AOD
DoubleElectron_Run2012A-recover-06Aug2012-v1_AOD
DoubleElectron_Run2012B-13Jul2012-v1_AOD
DoubleElectron_Run2012C-24Aug2012-v1_AOD
DoubleElectron_Run2012C-PromptReco-v2_AOD
DoubleElectron_Run2012D-PromptReco-v1_AOD

Double Muon

DoubleMu_Run2012A-13Jul2012-v1_AOD
DoubleMu_Run2012A-recover-06Aug2012-v1_AOD
DoubleMu_Run2012B-13Jul2012-v4_AOD
DoubleMu_Run2012C-24Aug2012-v1_AOD
DoubleMu_Run2012C-PromptReco-v2_AOD
DoubleMu_Run2012D-PromptReco-v1_AOD

Mu EG

MuEG_Run2012A-13Jul2012-v1_AOD
MuEG_Run2012A-recover-06Aug2012-v1_AOD
MuEG_Run2012B-13Jul2012-v1_AOD
MuEG_Run2012C-24Aug2012-v1_AOD
MuEG_Run2012C-PromptReco-v2_AOD
MuEG_Run2012D-PromptReco-v1_AOD

Single Muon

SingleMu_Run2012A-13Jul2012-v1_AOD
SingleMu_Run2012A-recover-06Aug2012-v1_AOD
SingleMu_Run2012B-13Jul2012-v1_AOD
SingleMu_Run2012C-24Aug2012-v1_AOD
SingleMu_Run2012C-PromptReco-v2_AOD
SingleMu_Run2012D-PromptReco-v1_AOD

3L

Choose a wide variety of triggers to be as inclusive as possible.

- Double E
  - Dilepton: HLT_Ele17_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_Ele8_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_v, HLT_Ele17_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_v
  - Trilepton: HLT_DoubleEle10_CaloIdL_TrkIdVL_Ele10_CaloIdT_TrkIdVL_v, HLT_Ele15_Ele8_Ele5_CaloIdL_TrkIdVL_v
- Mu EG
  - Dilepton: HLT_Mu8_Ele17_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_v, HLT_Mu17_Ele8_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_v
  - Trilepton: HLT_DoubleMu5_Ele8_CaloIdT_TrkIdVL_v, HLT_DoubleMu8_Ele8_CaloIdT_TrkIdVL_v, HLT_Mu8_DoubleEle8_CaloIdT_TrkIdVL_v, HLT_Mu8_Ele8_CaloIdT_TrkIdVL_Ele8_CaloIdL_TrkIdVL_v
- Double Mu
  - Dilepton: HLT_Mu17_Mu8_v, HLT_Mu17_TkMu8_v
  - Trilepton: HLT_DoubleMu5_IsoMu5_v, HLT_TripleMu5_v
- Single Mu
  - Singlelepton: HLT_IsoMu24_eta2p1_v, HLT_IsoMu24_v

Two leading optimization choices - 10.5 fb^{-1}

Contribution from Background Only

3L

	Type	Bkg Est	Bkg Stat Error	Bkg Syst Error	Xsec Stat Error	Xsec Syst Error	Total Error
Jets: 30/30/30/15 1 CSVM + 1CSVL	FR	1.75	0.78	0.87	35.13	49.40	60.62
	bR	1.80	0.45	0.90			
	Irr	0.95	0.32	0.48			
Jets: 30/30/30 1 CSVM + Ht > 200	FR	2.16	0.88	1.08	41.25	65.33	77.26
	bR	3.77	1.05	1.89			
	Irr	0.96	0.32	0.48			

Error lower on 4 jet selection. Will help with significance.

Non-prompt Lepton Estimation

3L ttZ Channel

Method already discussed in previous section.

- Additional correction needed for "spillage"
  - spillage = Non-negligible fraction of background estimation from events with an un-isolated "real" lepton.
- Apply data derived fake rate to MC sidebands for processes that contribute to the spillage (e.g. ttW to 3L)
- Subtract spillage from Non-prompt estimate

Estimates for Spillage by Process

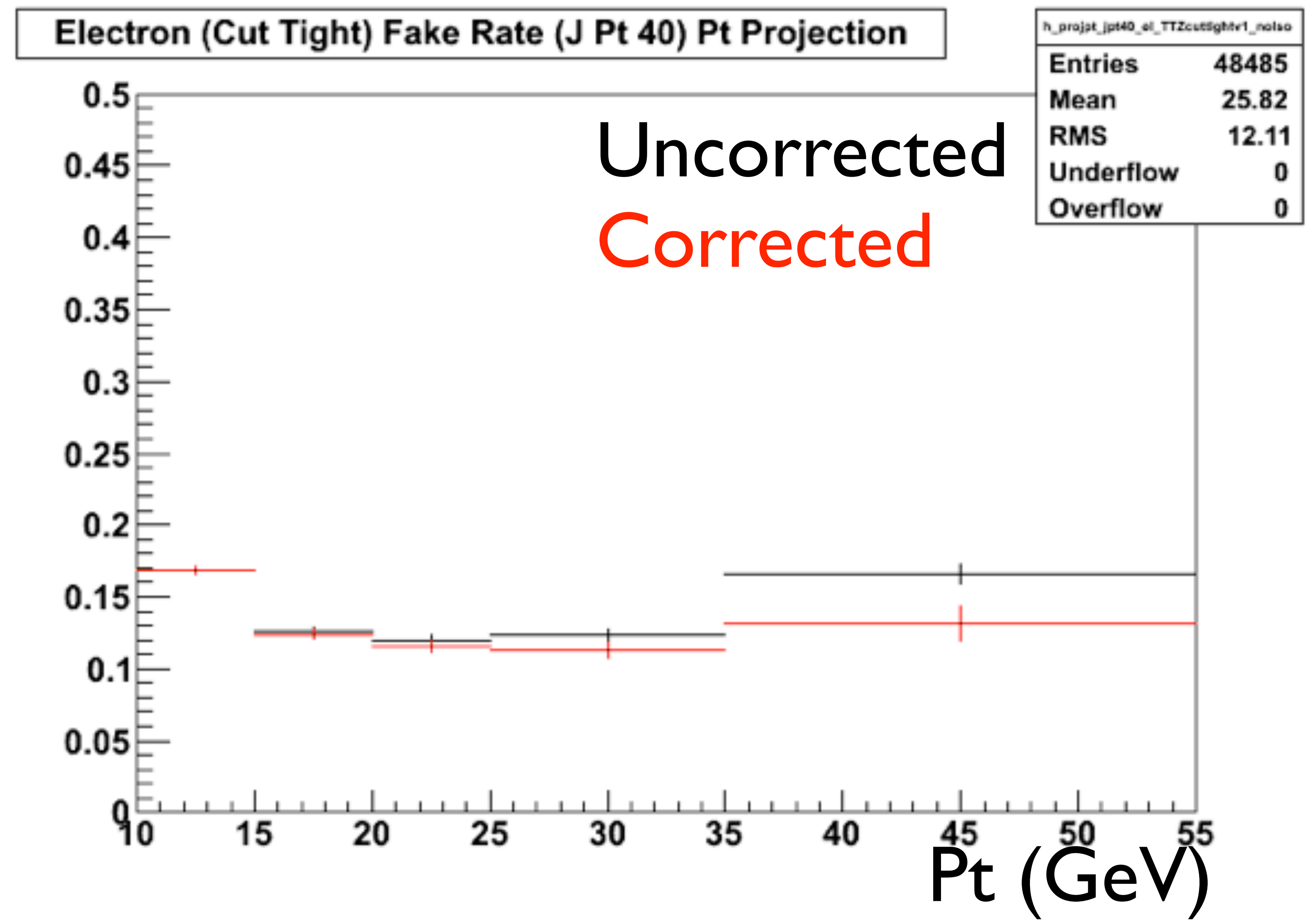
	Estimate
VZ $\rightarrow 3\ell$ or 4ℓ	0.05±0.01
WWV	0.01±0.00
$t\bar{t}X$/tbZ/VZZ	0.09±0.01
$t\bar{t}Z$	0.42±0.03
Contribution From Spillage	0.57±0.04

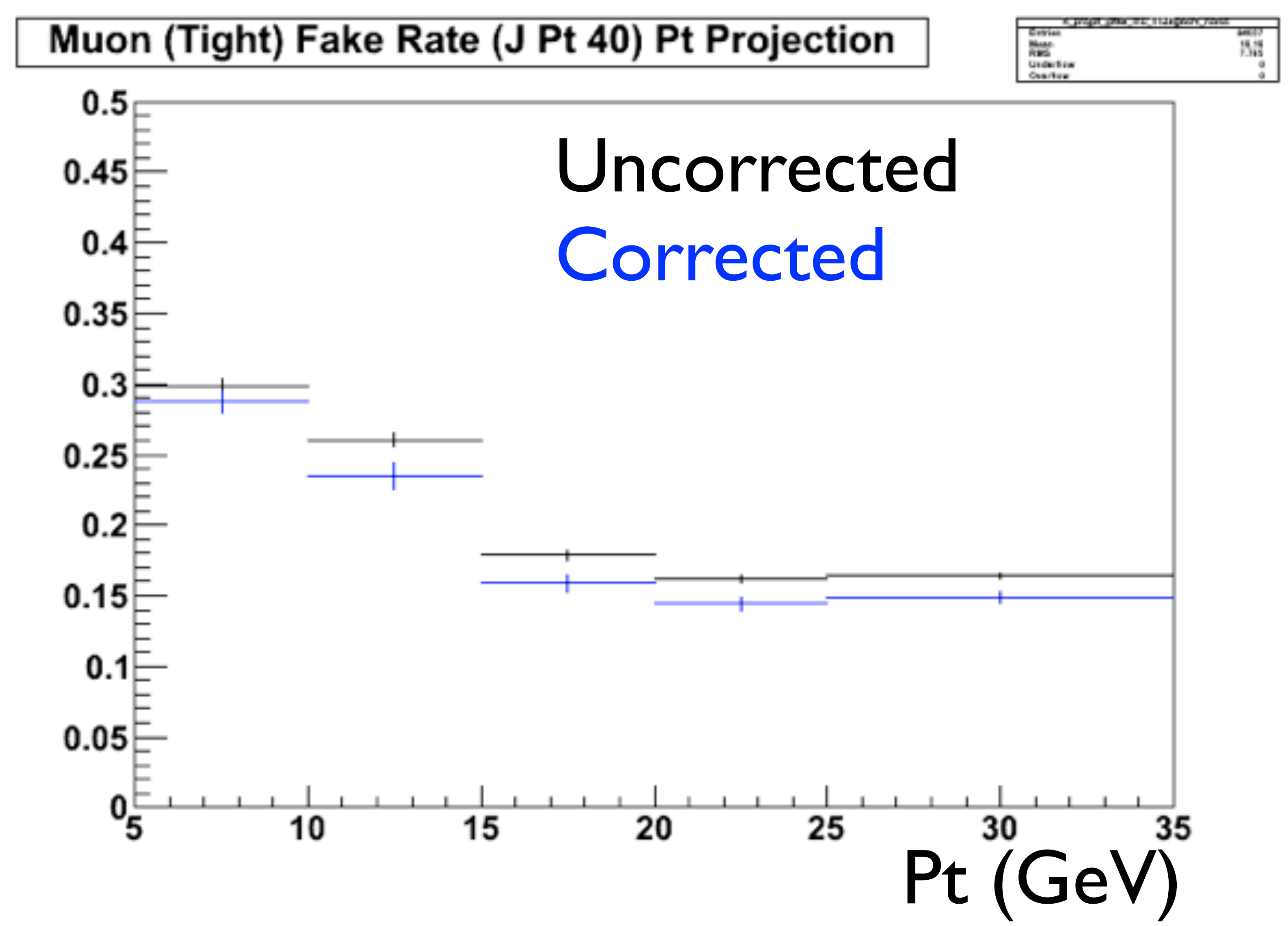
Spillage

Closure

Fake Rate Electro-Weak Contamination Correction

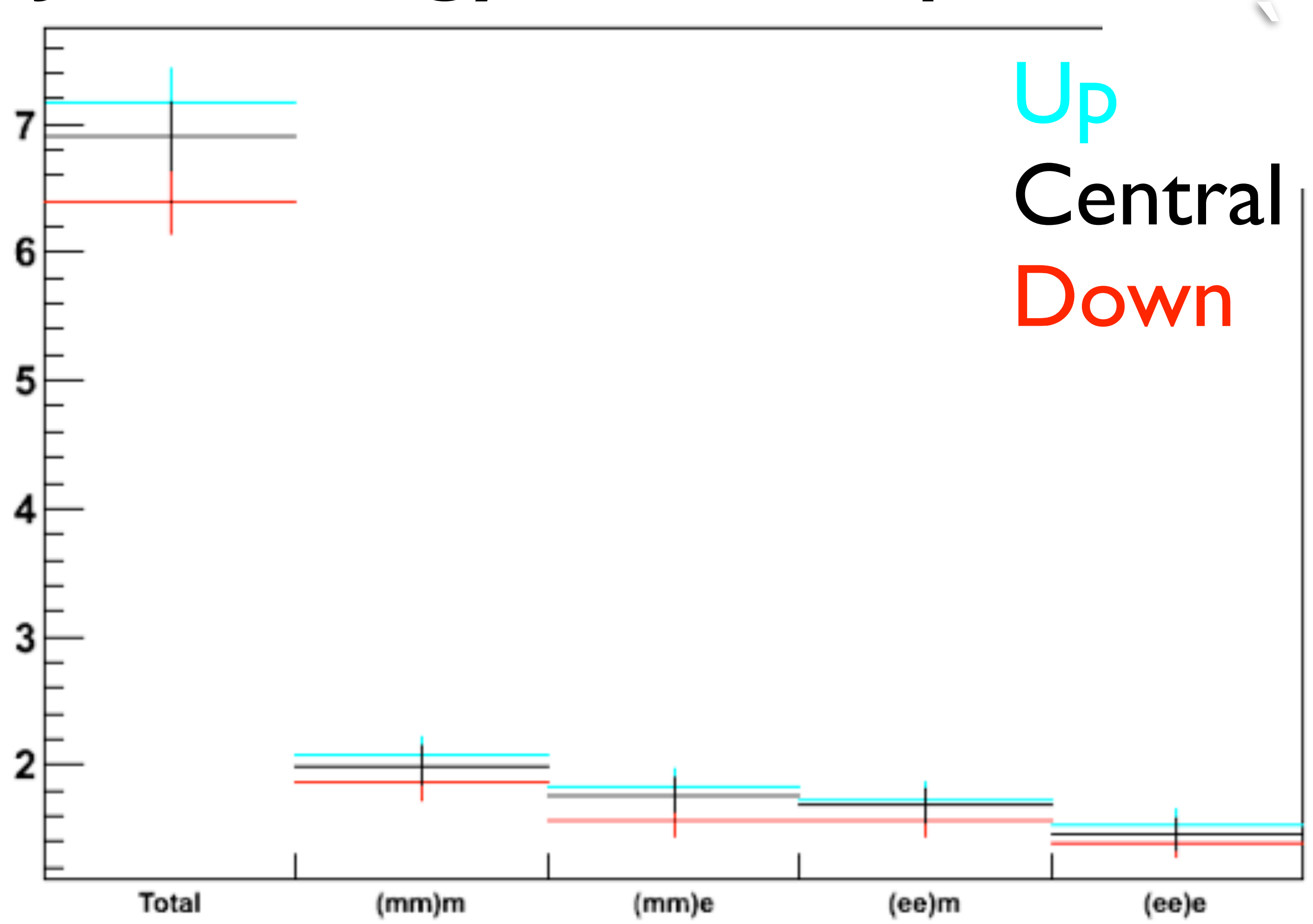
- Measuring the fake rate from data does not yield a pure qcd sample.
- Some “fake” leptons are actually “real” leptons from electro-weak processes.
- Derive a correction from MC.
  - Scale WJets and DY MC to integrated luminosity of FR utility triggers.
  - Select control region with inverted MET and Mt cut and compare to data to determine a scale factor.
  - Apply scale factor to MC in region with normal MET and Mt.
  - Use yields as corrections to num and den in data FR.
- Same technique as in SS SUSY Analysis.
  - Same exact numbers. We did not re-derive them. Fine for muons. Leads to slightly smaller correction in electrons as our num definition is looser.





3L

Jet Energy Scale Up/Down

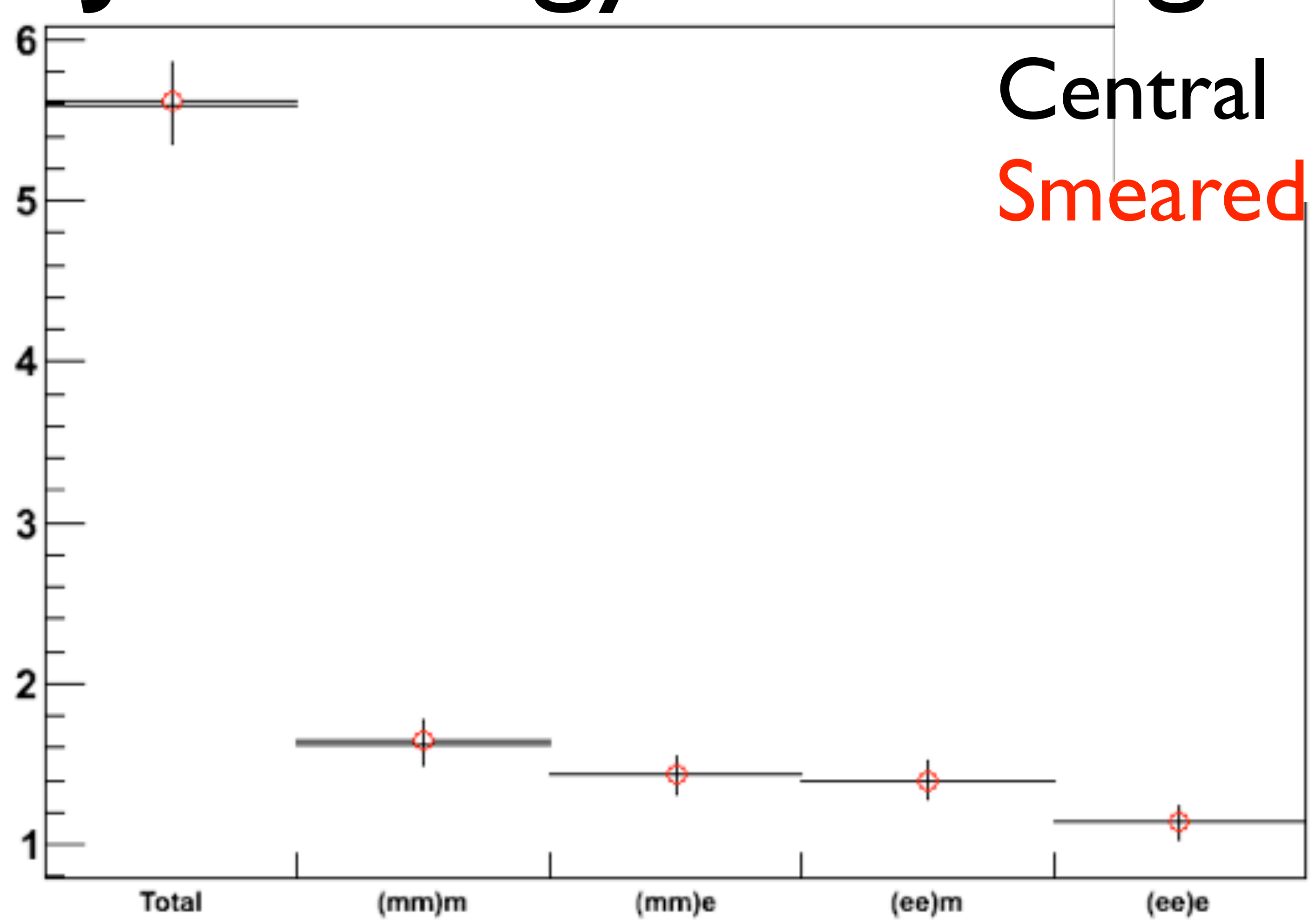


Performed on TTZ signal sample.

JES Syst = (Up - Down) / (Up + Down)
= (5.820 - 5.288) / (5.820 + 5.288)

JES Syst = 4.8%

Jet Energy Smearing



This one will have to be updated to conform to the POG's recommendation

Smear based on gen jet energy or if unmatched a gaussian

JER Syst = |Central - Smeared| / Central
= |5.595 - 5.615| / 5.595

JER Syst = 0.4%

ttV Pre-approval

3L

	Up	Down	Systematic
b	5.758	5.431	2.9%
light	5.626	5.513	1.0%
Total			3.1%

- Performed on TTZ signal MC
- Using discriminant reshaping procedure from Andrea Rizzi
  - https://twiki.cern.ch/twiki/bin/viewauth/CMS/BTagSFMethods#2b_Reshaping_of_the_b_tag_discri
- Up/Down variations vary Data/MC scale factors up and down by their errors.

3L

	NPass	NGen	Fraction	% From Central
Central	4483000	16922639	0.2649	
QSquared Up	382075	1465256	0.2608	-1.5%
QSquared Down	431277	1598225	0.2698	1.8%
Matching UP	422188	1619908	0.2606	-1.6%
Matching Down	427977	1602492	0.2671	0.8%
Mass 166.5	333302	1327522	0.2511	-5.2%
Mass 178.5	389100	1405122	0.2769	4.5%

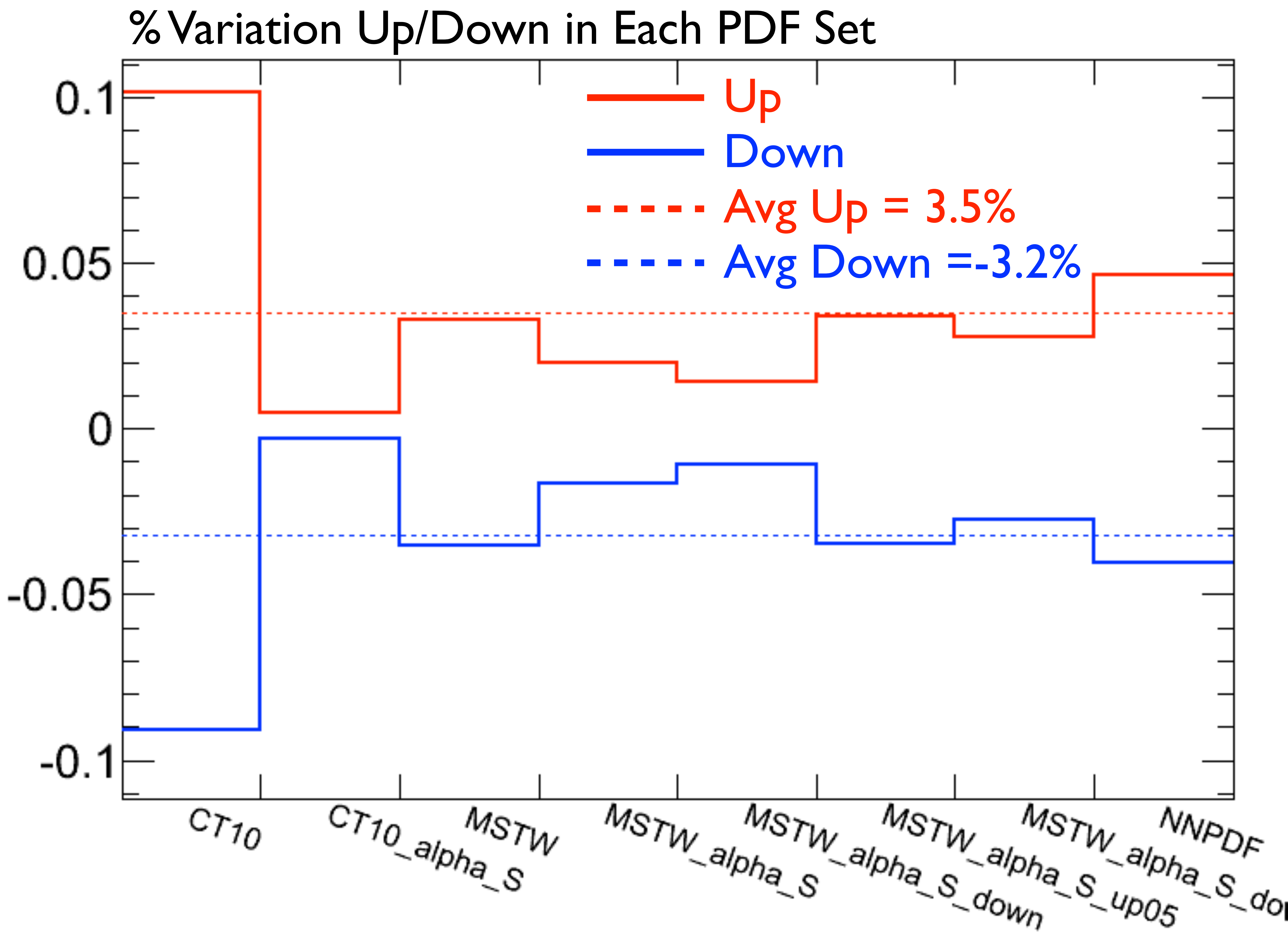
QSquared Syst: 1.7%
Matching Syst: 1.2%
Mass Syst: 4.9% /2
Total: 3.3%

Since mass range is big, use half of this.

- Using TTbar samples because no dedicated ones for TTZ.
- Use 1L+2b+2J selection in TTbar to mimic 3L+2b+2J selection in TTZ.

PDF Systematic

- Average the variations across the different pdf sets and use that as the error.



3L

- PDF Syst Error = (AvgUp - AvgDown)/2 = 3.4%

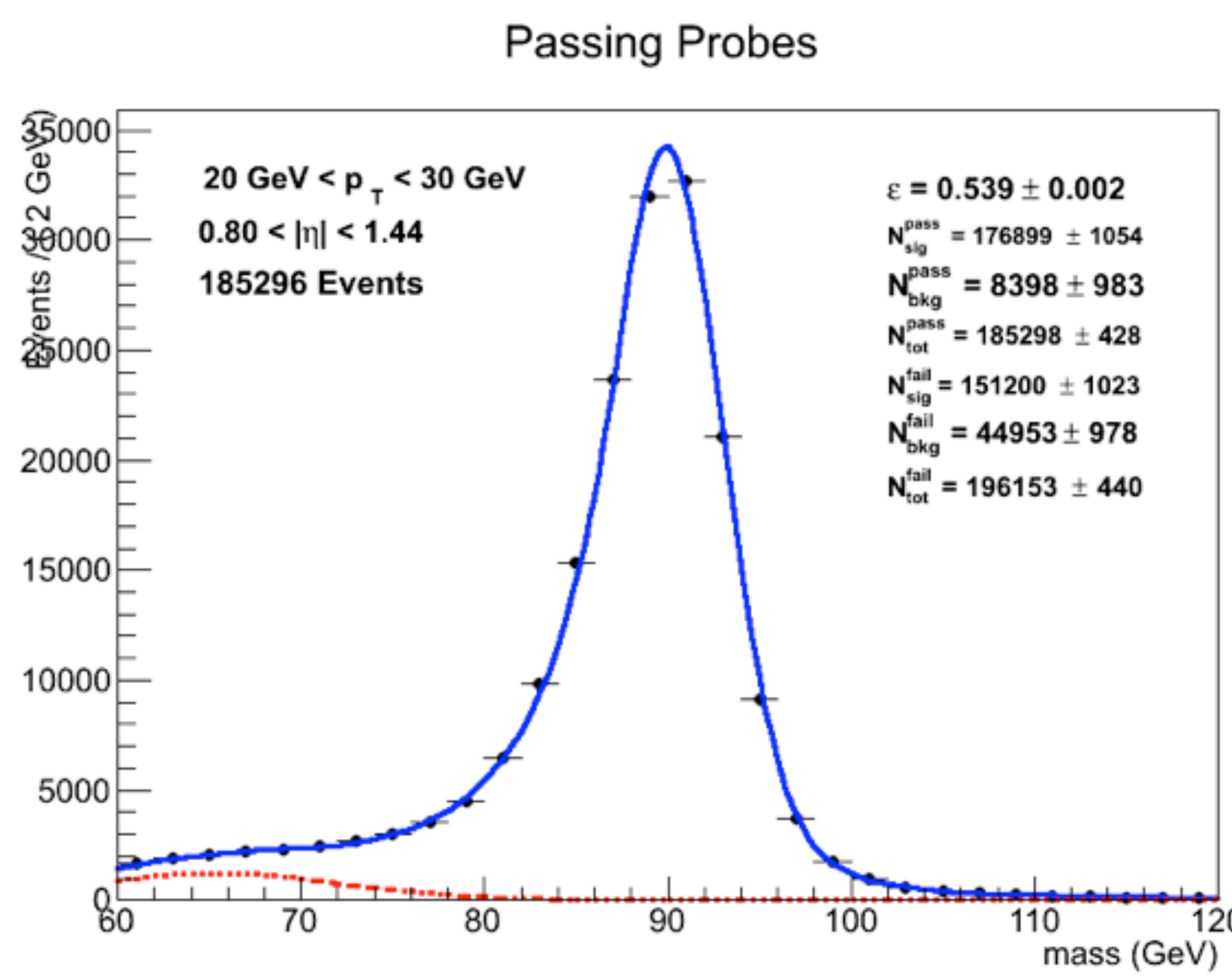
Tag and Probe

- In the past, Scale Factors were set to 1 with a few percent error.
- Current scale factors are farther from 1 and this needs to be treated with more care.
- Can reproduce POG SFs, and have produced SFs for our selections.
- Syst errors on μ are 3% on method and 1.88% on composition. On el are 5% on method and 1.97%.

3L

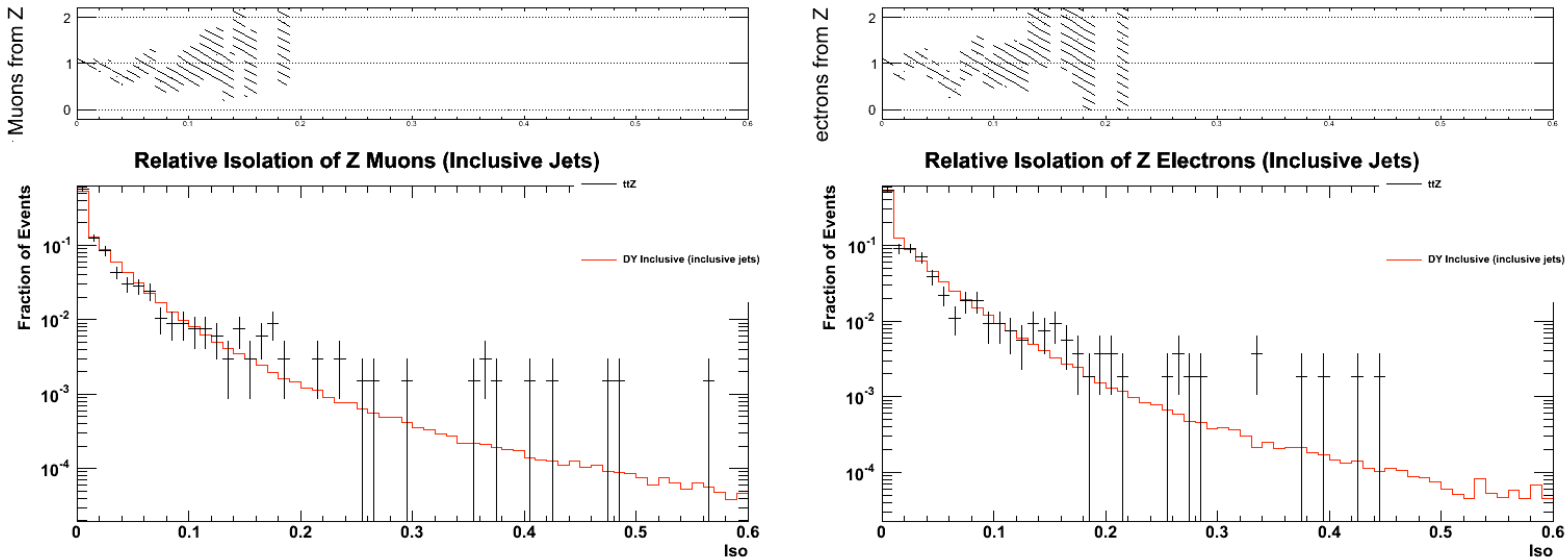
		% Diff
Central	8.33	
Up	9.47	13.7
Down	7.28	-14.4

Syst = (9.47-7.28)/(2* 8.33) = 13%



Hadronic Activity Specification

3L



Extra factor for hadronic activity

syst = [Efficiency_DYInclusive / Efficiency_ttZ+4J - 1] / 2

= ~2% for each flavor

Generator Syst

3L

The exact selections for the denominator are:

- Exactly 3 status 3 generator leptons (electrons or muons)
- All of the above generator leptons with Pt > 20 GeV and $|\eta| < 2.4$.
- All of the above generator leptons came from a W or a Z.
- Exactly 3 reconstructed leptons (electrons or muons) that pass the identification and isolation selections in Section **??**
- Reconstructed leptons that do not match the generator leptons above are rejected.

The exact selections for the numerator are:

- Denominator as above.
- At least 4 pfJets with applicable energy corrections with Pt > 20 GeV and $|\eta$ <2.4.
- Jets within a cone 0.5 of a lepton identified in the numerator are rejected.
- Jets with < 10% of their energy coming from the primary vertex are rejected.

$$\epsilon = \frac{n\ with\ 3\ leptons\ and\ 4\ jets}{n\ with\ 3\ leptons}$$

$$\Delta = |1 - \frac{\epsilon_{aMC@NLO}}{\epsilon_{Madgraph}}|$$

Madgraph	aMC@NLO	Difference
0.38	0.36	5%

ttV Pre-approval

Generator Systematic

3L

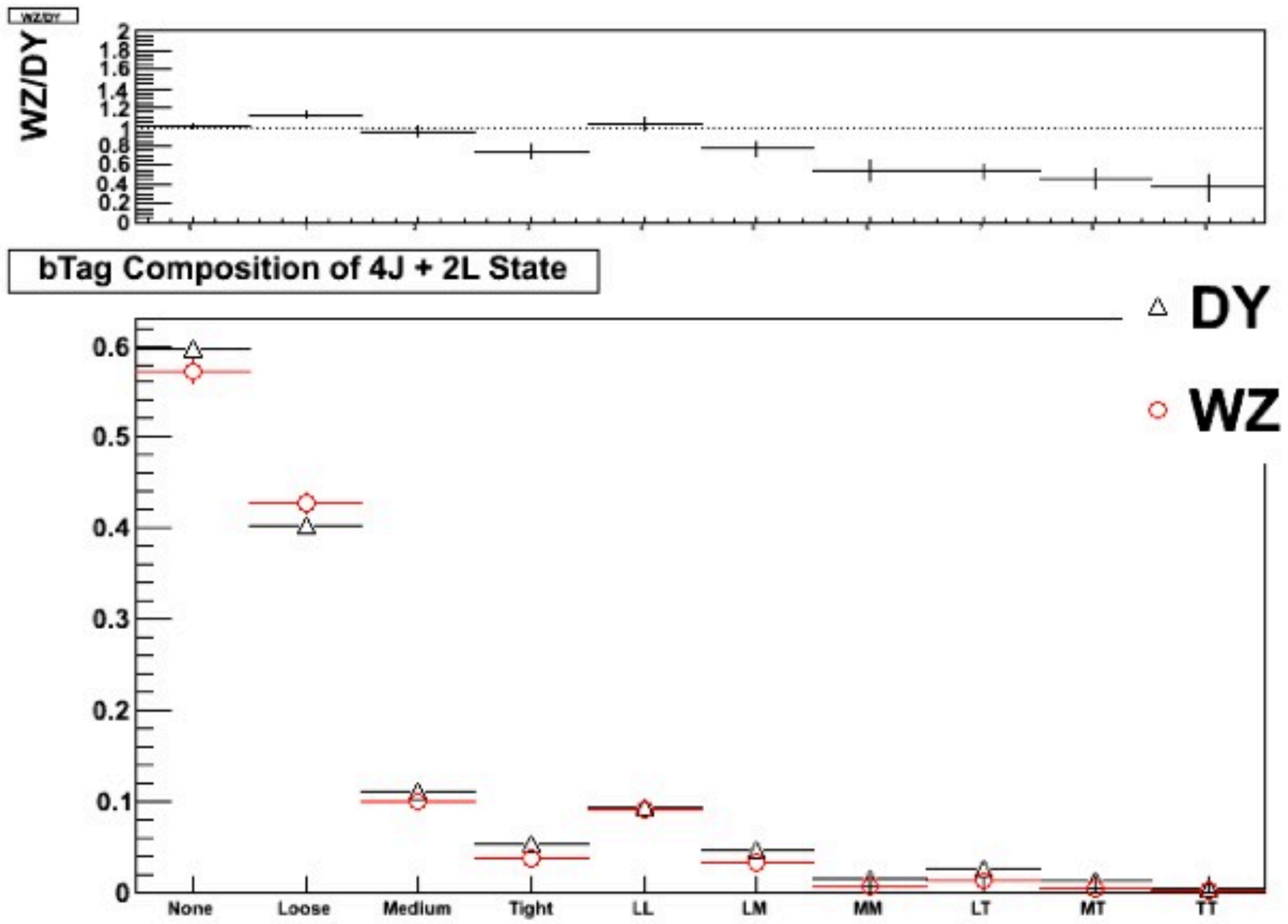
Cuts	NLO/Mad	
	Ratio	Error
3 Reco ID/ISO	1.00	
4 Jets	0.95	0.04
1 CVSM	0.95	0.05
1 CVSL	0.97	0.06

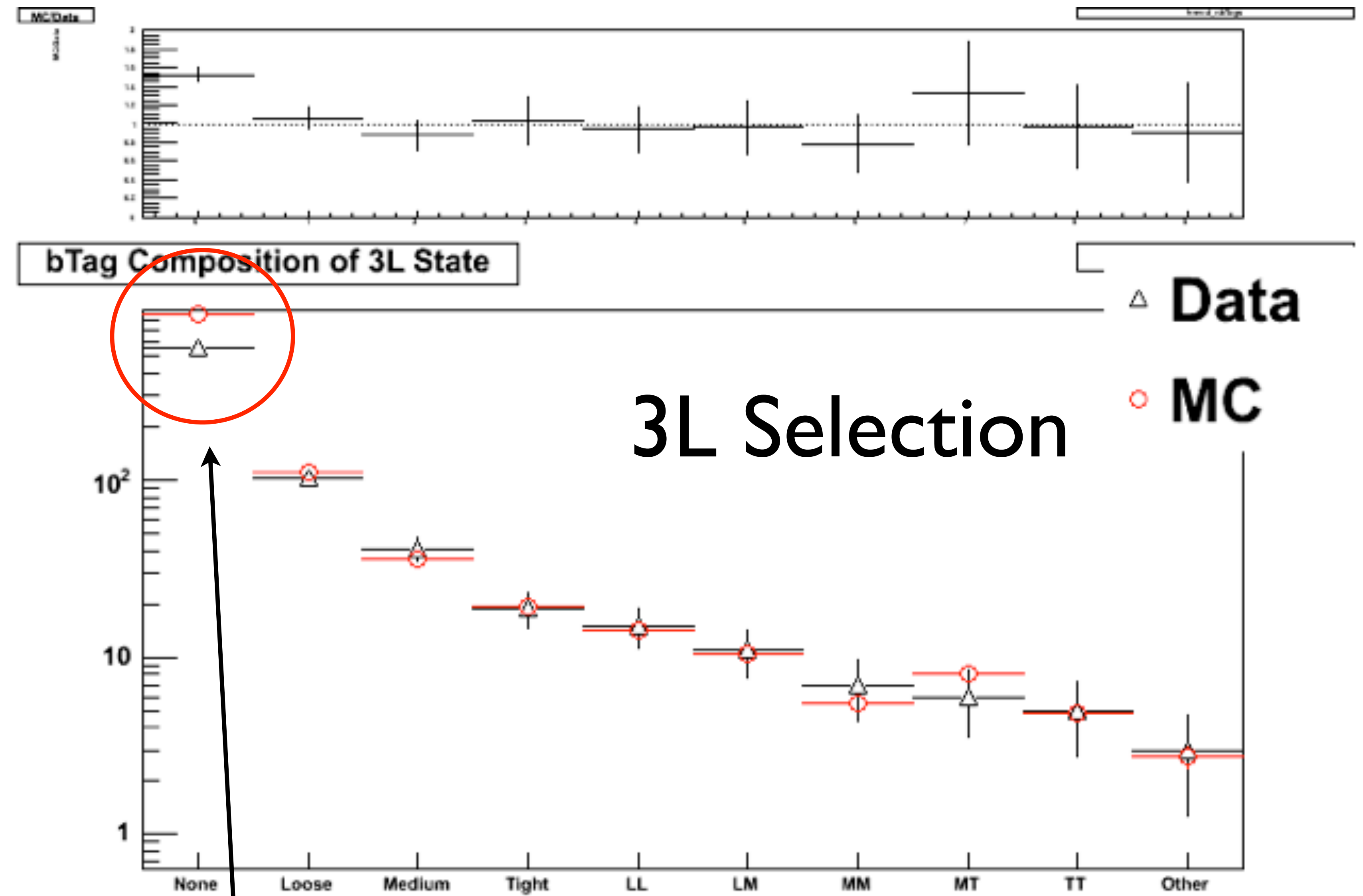
Madgraph	aMC@NLO	Difference
0.38	0.36	5%

bRate Material

Somewhat older material. Some changes since then.

3L





Helps set syst error.

Fake Rate Material

3L

SS Susy Analysis Closure Test

ttZ to 3L

	Prediction	Measured	Pre./Meas.
$t\bar{t}$	0.49±0.08	0.28±0.10	1.75 ±0.69

Note large stat.

	UC-FNAL
SR0 (incl N_{btags})	0.59 ± 0.04
SR10 (N_{btags} = 1)	0.57 ± 0.04
SR20 ($N_{btags} \geq 2$)	0.46 ± 0.07

Consistent with SS Susy closure, but low stat, so use SS Susy systematics.

Source	Method	Total Systematic
Jet Energy Scale	Momentum Scale Up/Down	4.8%
Jet Energy Resolution	Momentum Smearing	0.4%
b-tag (light flavor)	Discriminant Re-weight	1.0%
b-tag (b flavor)	Discriminant Re-weight	2.9%
Q^2	Q^2 Scale Up/Down	1.7%
Matching	Matching Scale Up/Down	1.2%
Top Mass	Mass Scale Up/Down	2.5%
PDF	PDF Re-weight	1.5%
Generator	Compare 2 ttZ Samples	5.0%
Pile Up		1.0%
Trigger		<1%
Lepton Identification, Isolation, and Event Composition	Tag & Probe	6.2%
Total		10.5%