Searches for Exotic Phenomena with Tau Leptons

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- July 6, 2010
- LHC Seminar, Lisbon

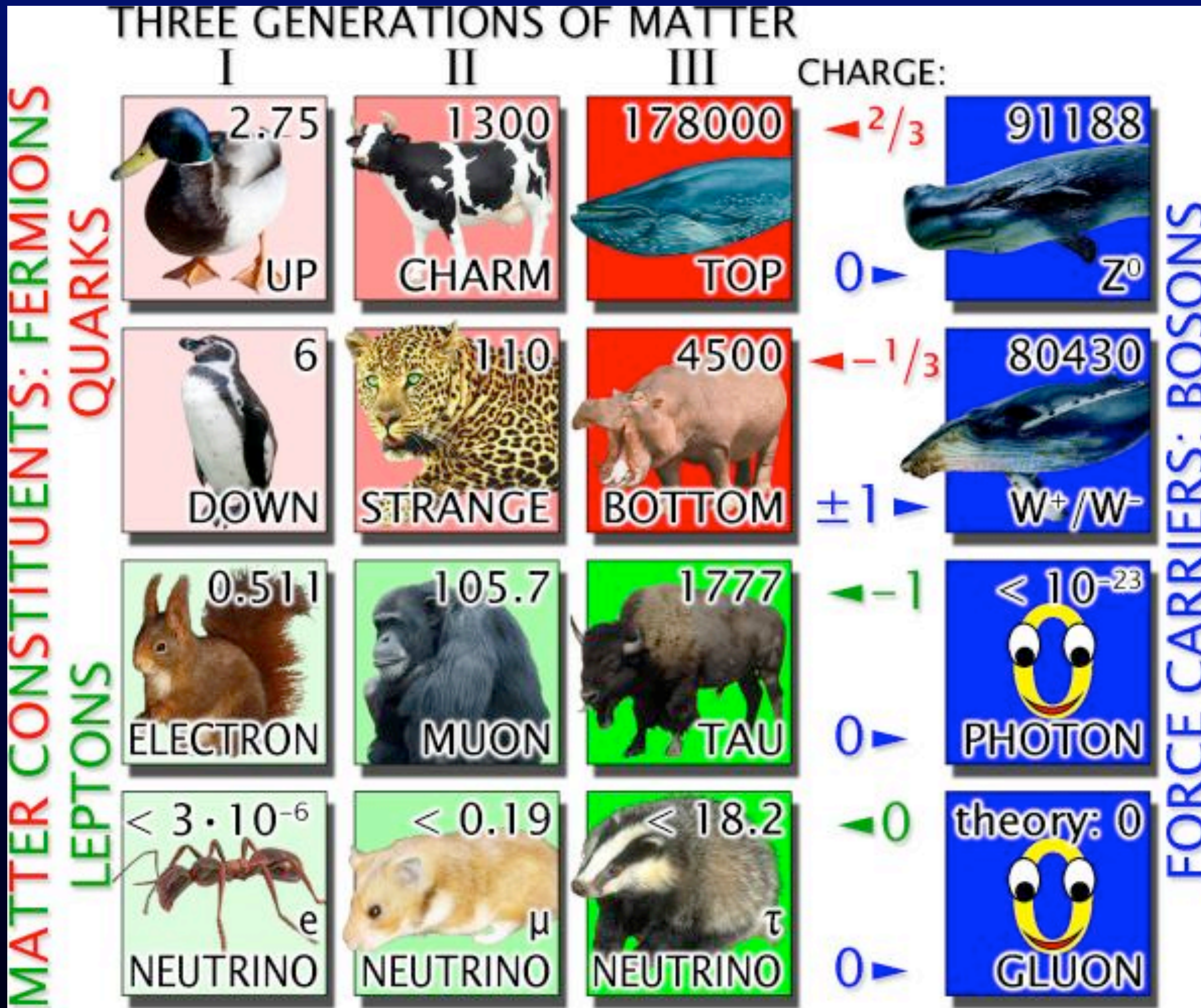
Outline

- Introduction
- CDF at Fermilab
  - Run II Tau triggers
  - $Z \rightarrow \tau\tau$, VLQ3, RPV Stop
  - Trileptons/LS Dileptons
- CMS at CERN
  - PF tau reconstruction
  - Trilepton search
- Conclusions

Introduction

- Central goal for LHC era of particle physics:
  - **Elucidate mechanism of Electroweak Symmetry Breaking: Higgs, SUSY, extra dimensions, TC?**
- Related (?)
  - **Address puzzles from cosmology: Dark energy & Dark Matter**
  - **Flavor physics, neutrino mixing, quantum gravity, string theory**

The Standard Model



Incomplete !

(interdisciplinary research in vogue)

For details, see http://pdg.lbl.gov

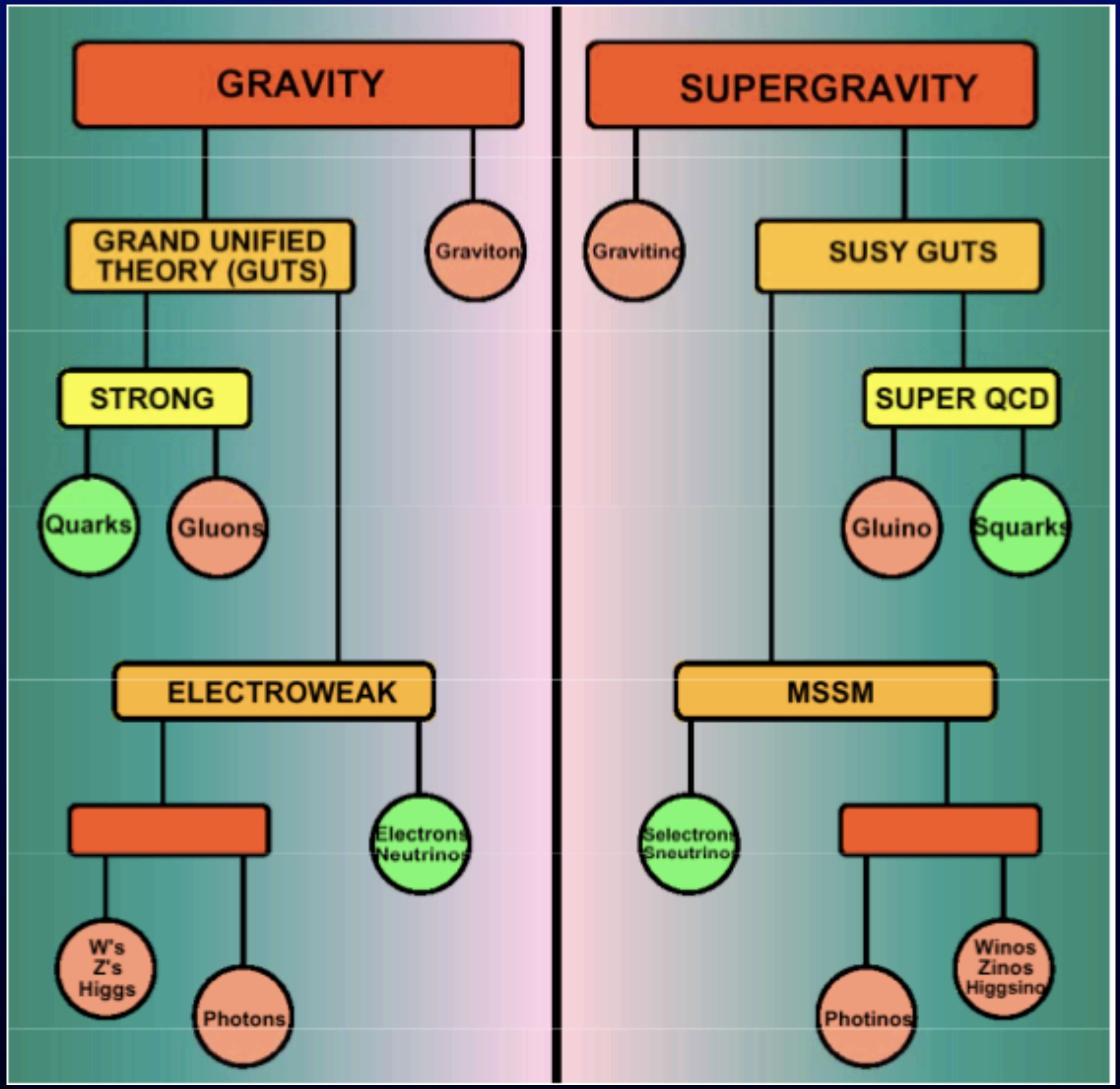
Why is it incomplete?

- Why do these particles have the masses that they do?
- What is the Higgs?
- Why do the Z and W have mass, but not the photon?
- Why are there three forces + gravity, with different strengths?;
- Do they all unify at some scale?
- Why is gravity special?
- Why is there CP and T violation?
- Why are there three families of quarks and leptons?
- Where did the universe’s antimatter go?
- What is the source of dark matter in the universe?

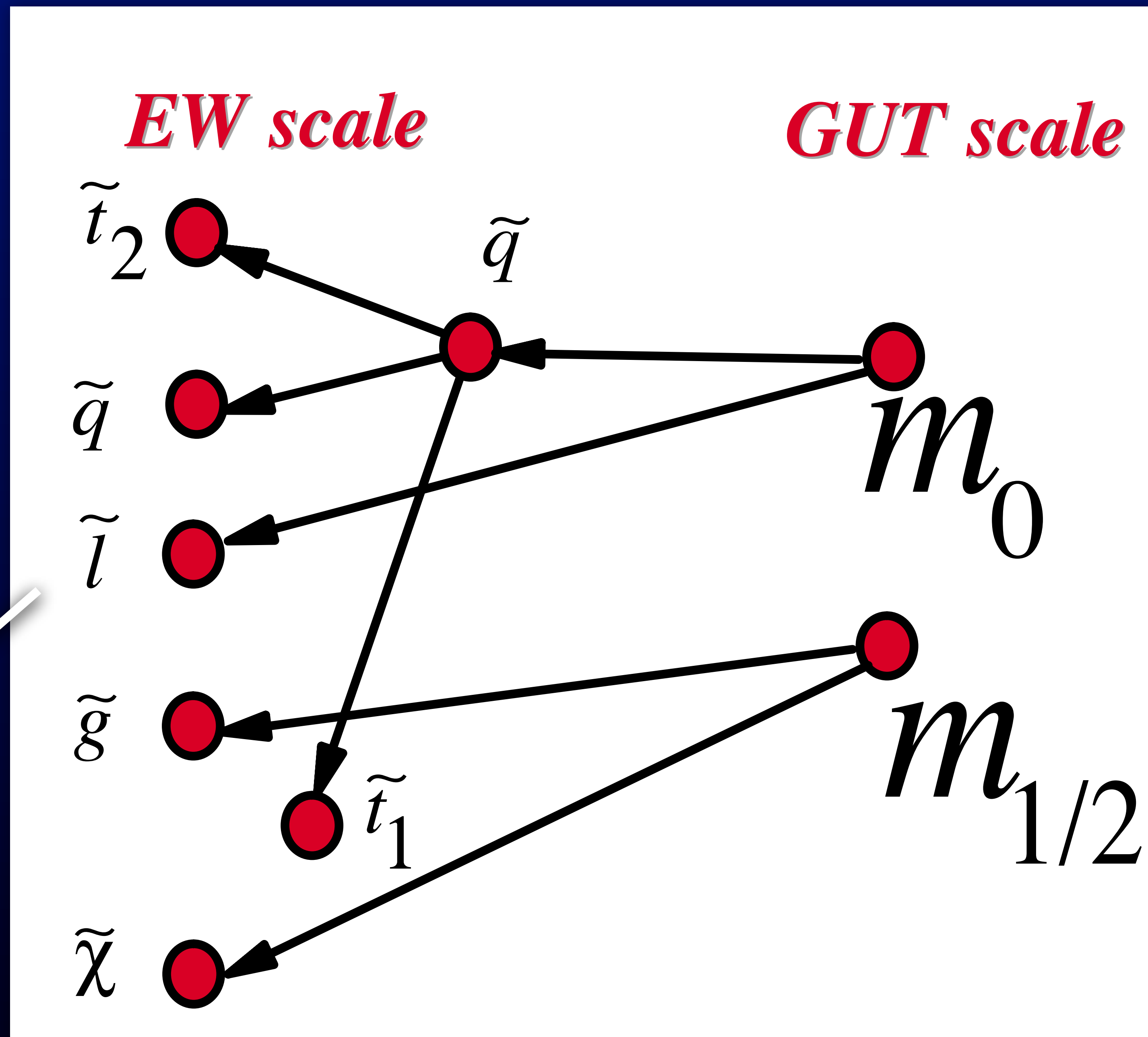
(I won't have time to answer all these in this talk...)

SUSY to rescue!?

- SUPERSYMMETRY is a theory with intriguing features:
  - Plays nicely with string theory
  - Resolves the “hierarchy” problem
  - Unifies force couplings at high energy
  - Includes dark matter candidate



Supergravity Masses

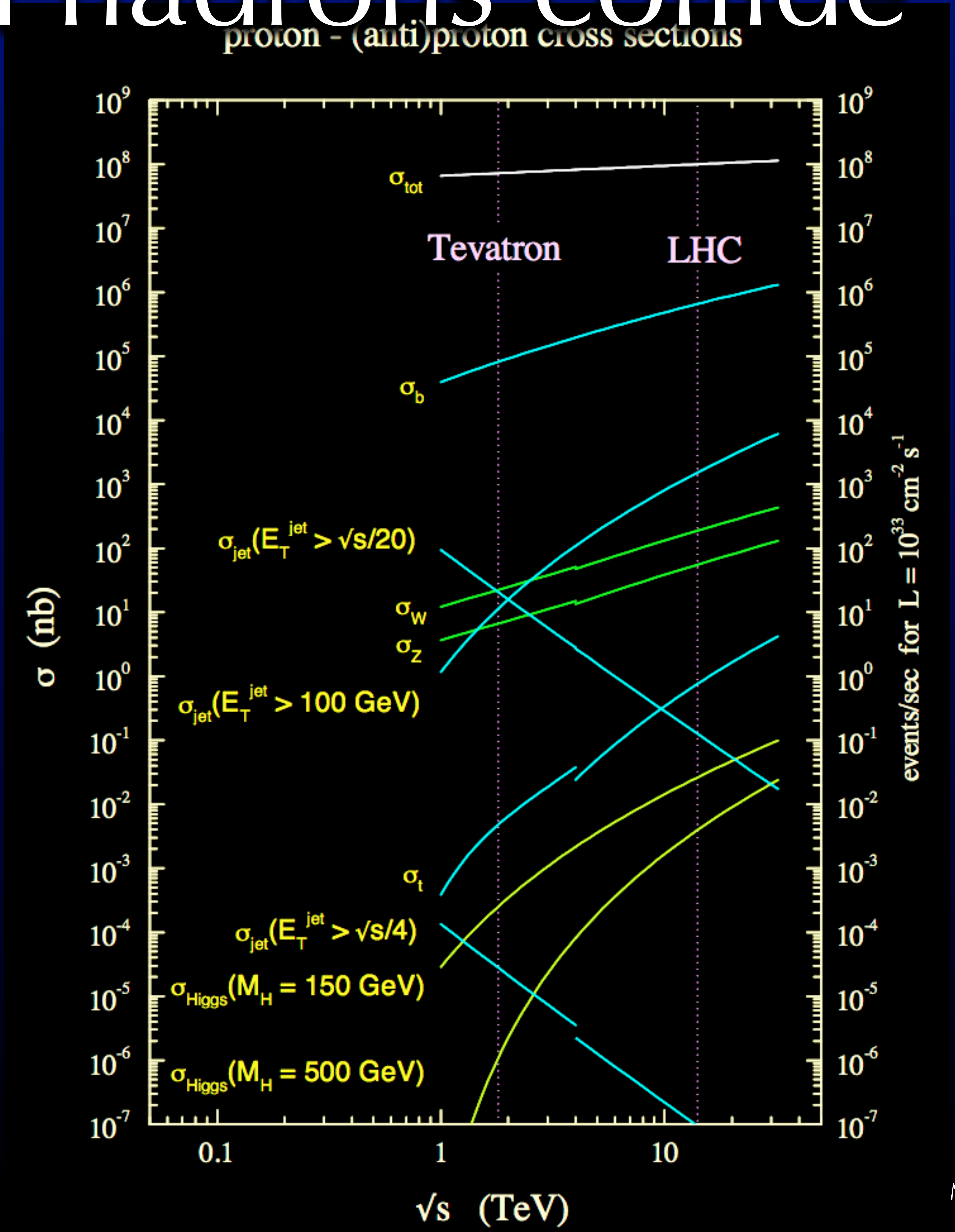


$\tilde{\tau}_1$

stau light if appreciable mixing

mSUGRA Mass Spectrum

When hadrons collide



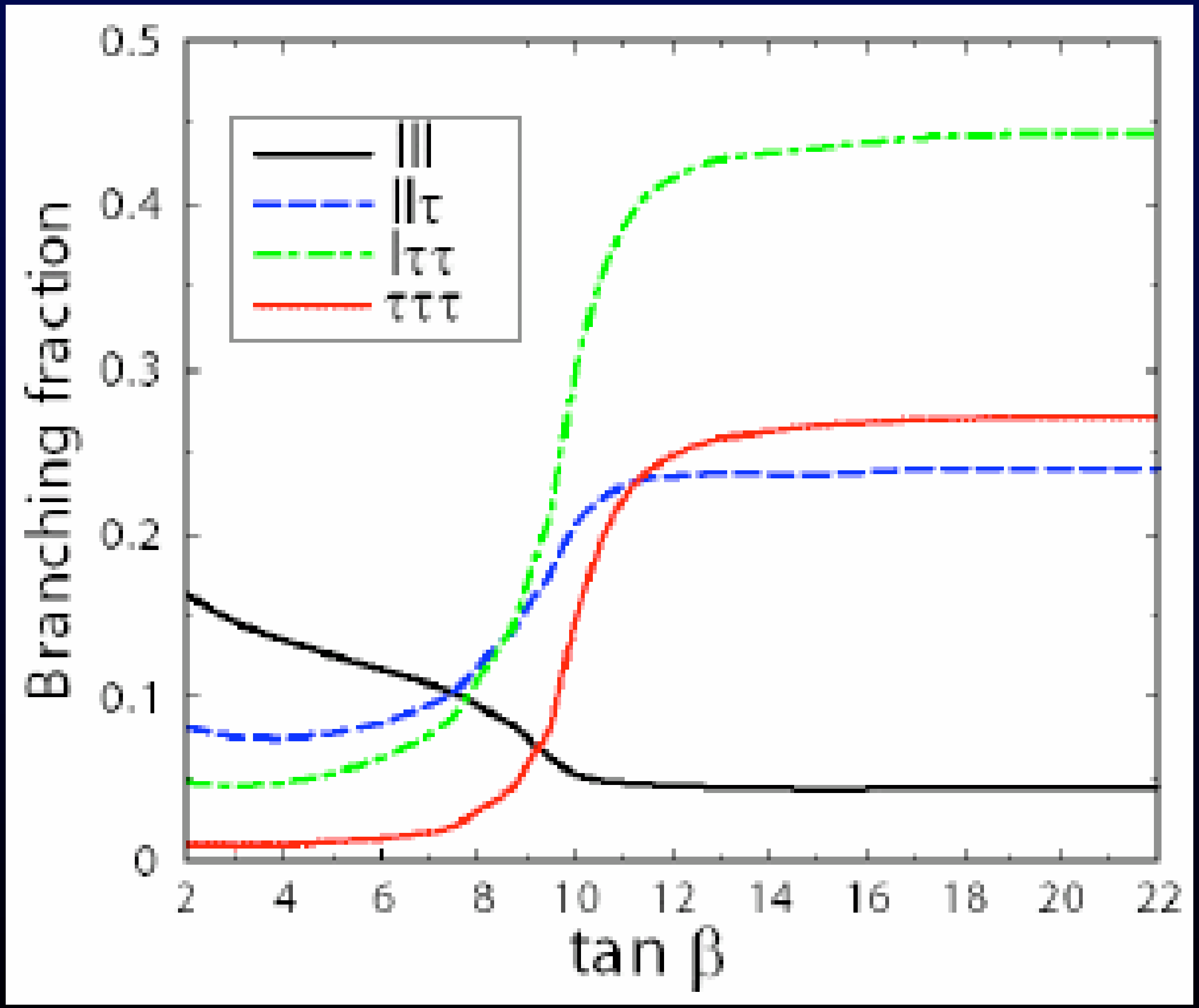
Why Study the Tau?

- Leptonic signatures of new physics critical at hadron colliders due to overwhelming backgrounds

- Multiple physics “object” signatures appealing:
  - **Dileptons: OS and LS, Trileptons, etc**
  - **These signatures dramatically decrease hadronic backgrounds**

Why Study the Tau? (2)

- Lepton universality may not hold in exotics decays (Higgs, SUSY)
  - **Must include the tau to maximize sensitivity**

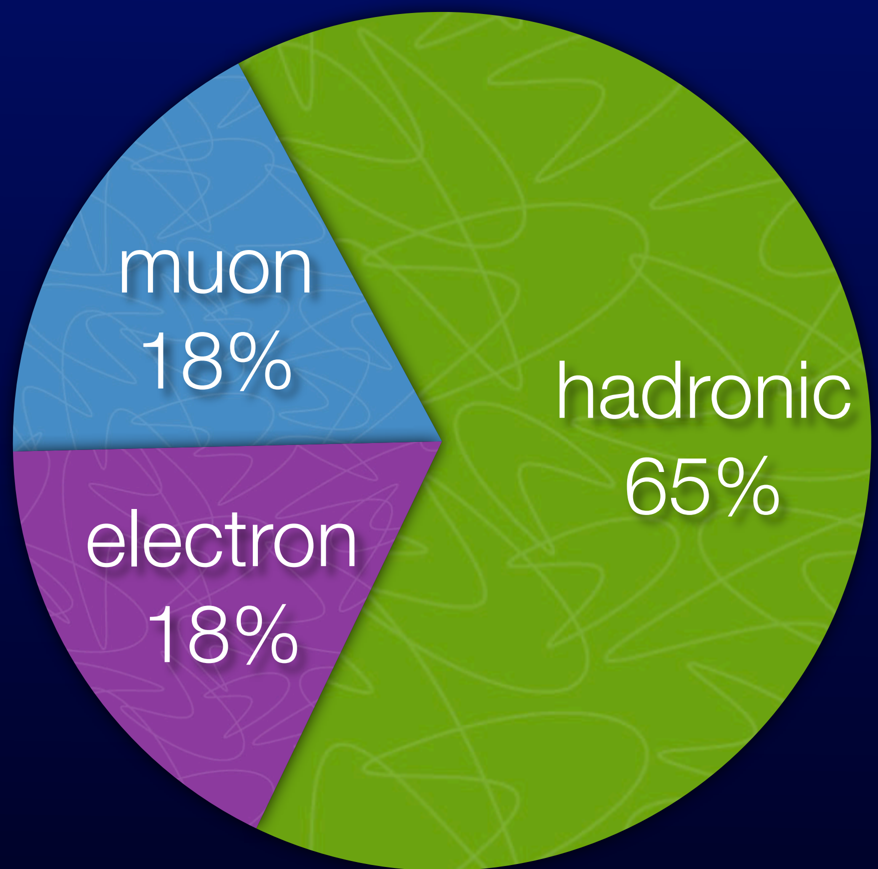


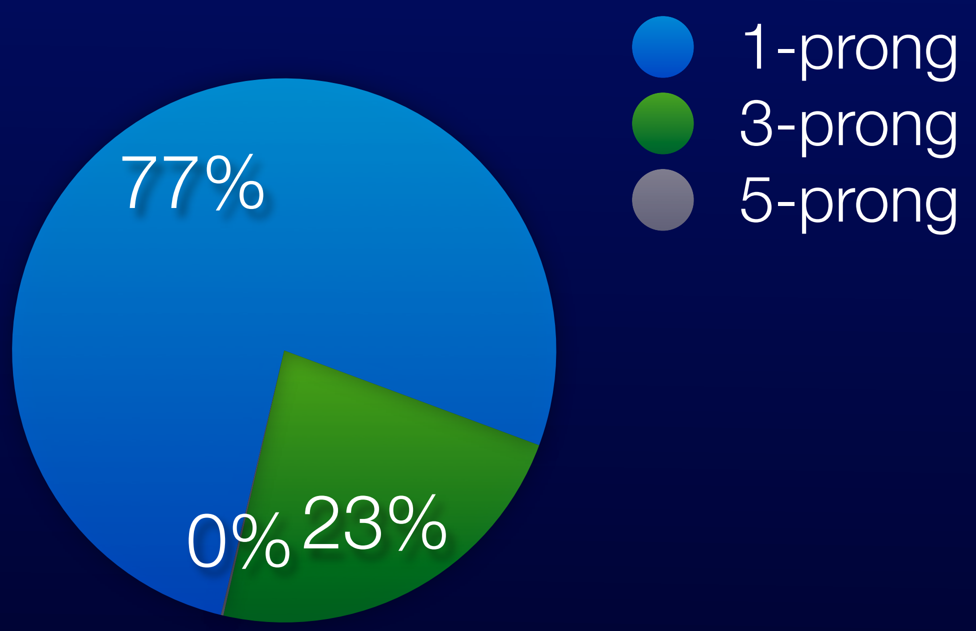
Tau Lepton

- The tau is identical to the electron!
  - (except that it's 3400 X heavier)
  - ∴ "Interesting" decays

$$\tau_\tau = 290.6 \text{ fs}$$
$$c\tau_\tau = 87.11\ \mu\text{m}$$

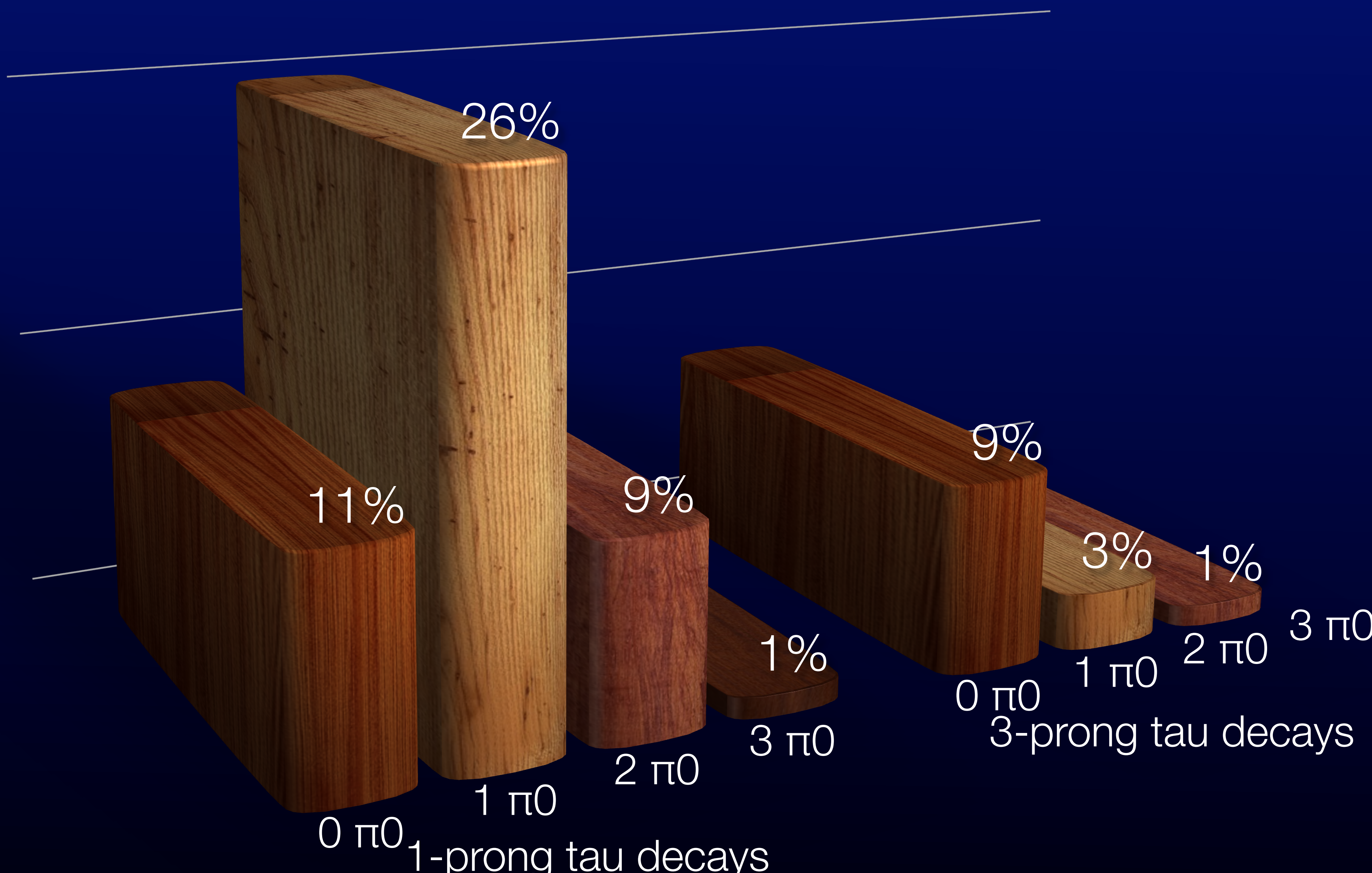
Tau Lepton Decays





Hadronic

Tau Lepton: neutral pions



Tau decays: hadronic modes

- For two taus produced

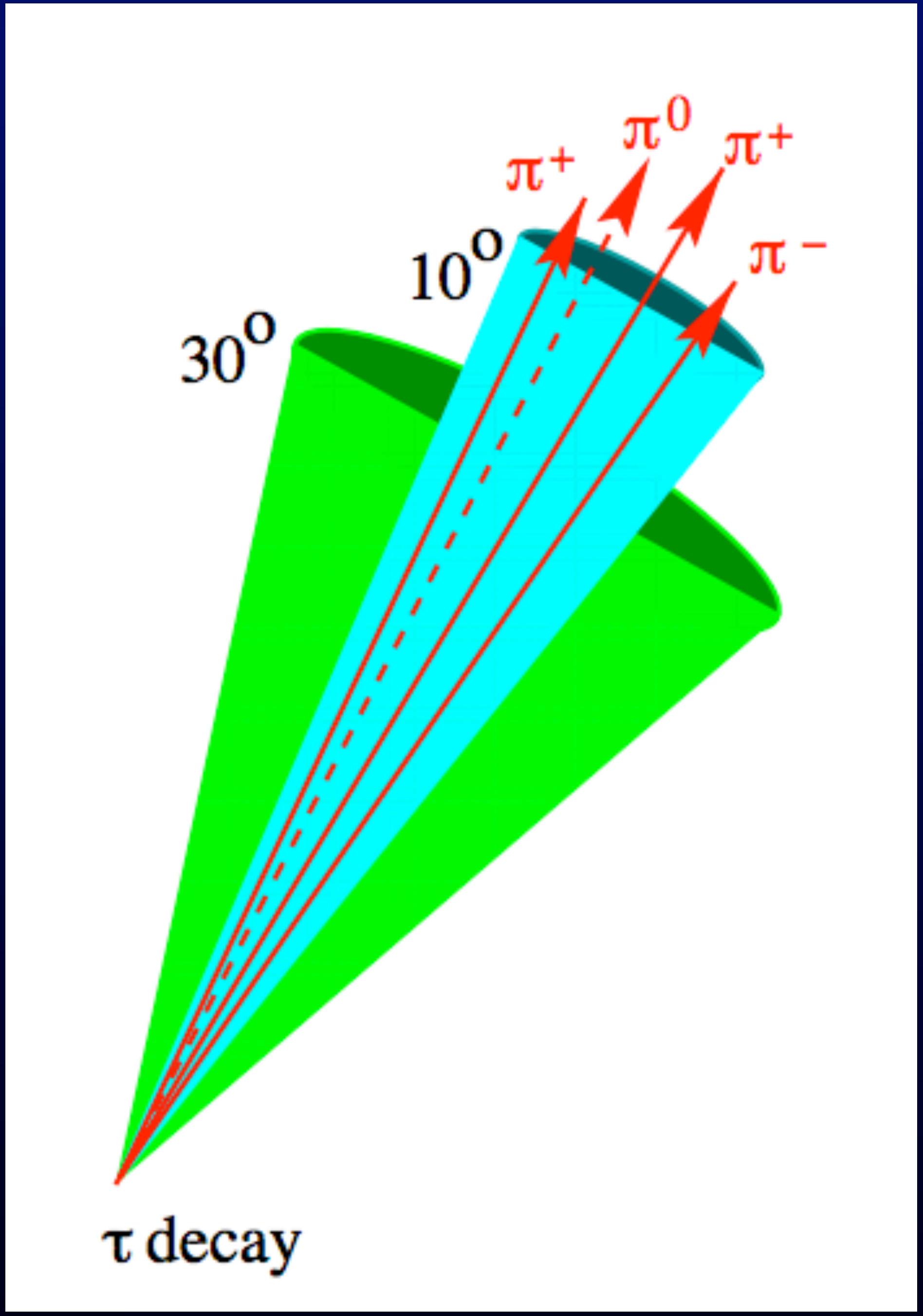
$\tau_h : \tau \rightarrow n\mathrm{h} + \nu$
$\tau_l : \tau \rightarrow e\nu\nu,\ \mu\nu\nu$

mode	%
$\tau_h\tau_h$	44
$\tau_h\tau_l$	44
$\tau_l\tau_l$	12

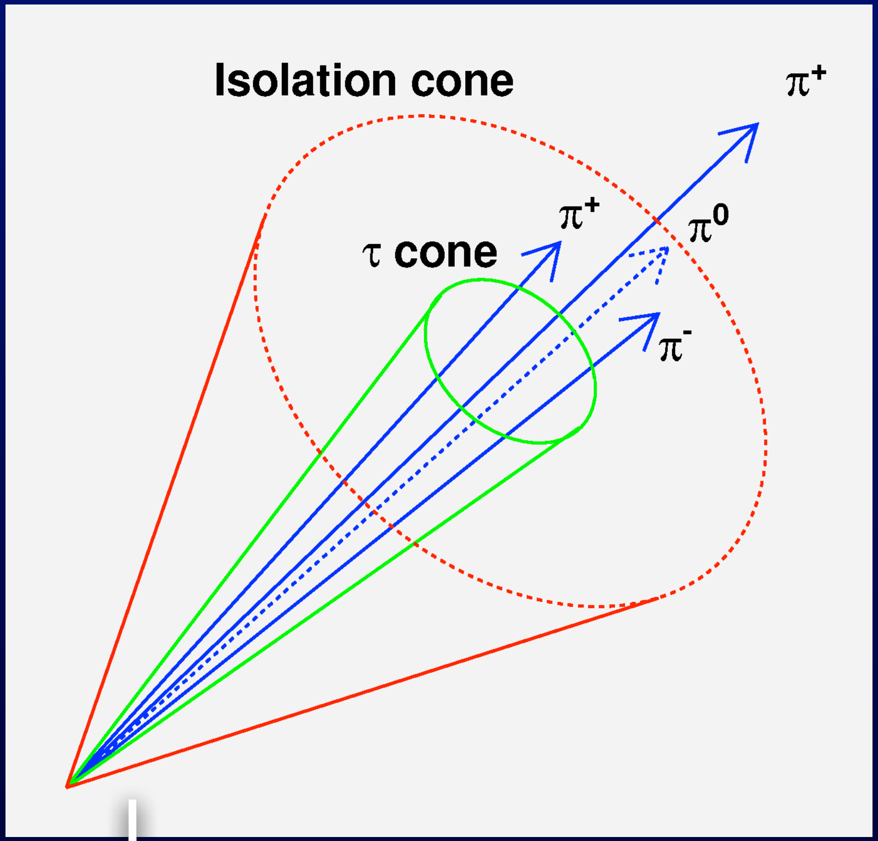
Must trade-off: BR ↔ efficiency

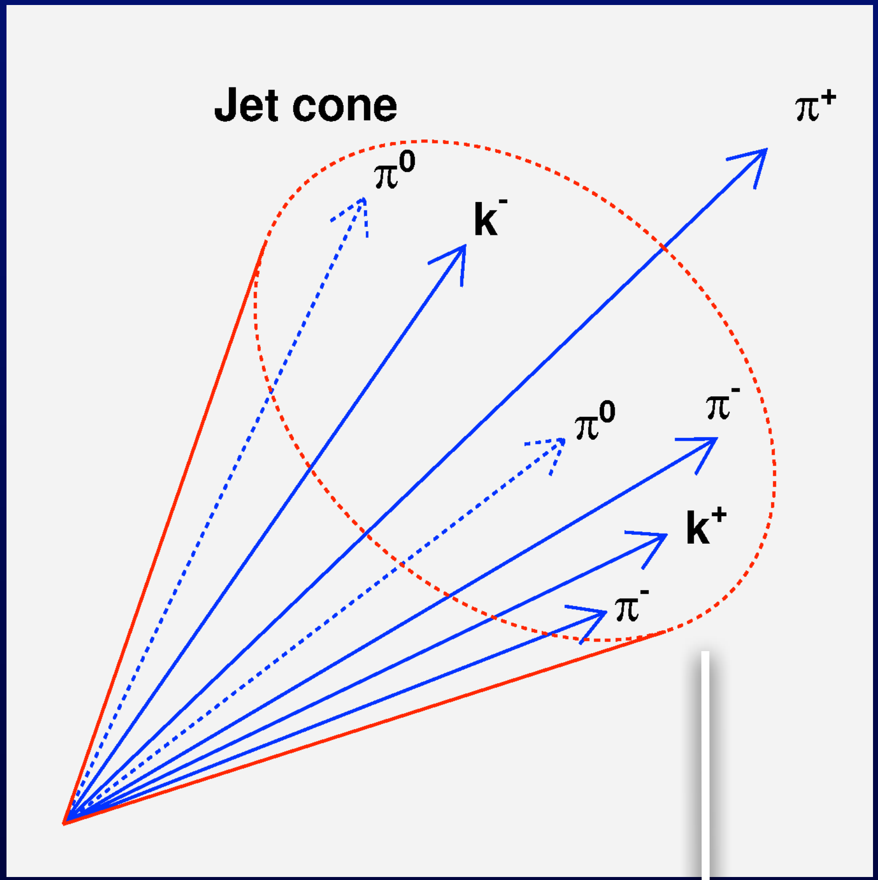
Tau decay product isolation

- Not an intrinsic quality, but result of EWK signal
- Critically important for background rejection
  - **Compare: hadronic jets**



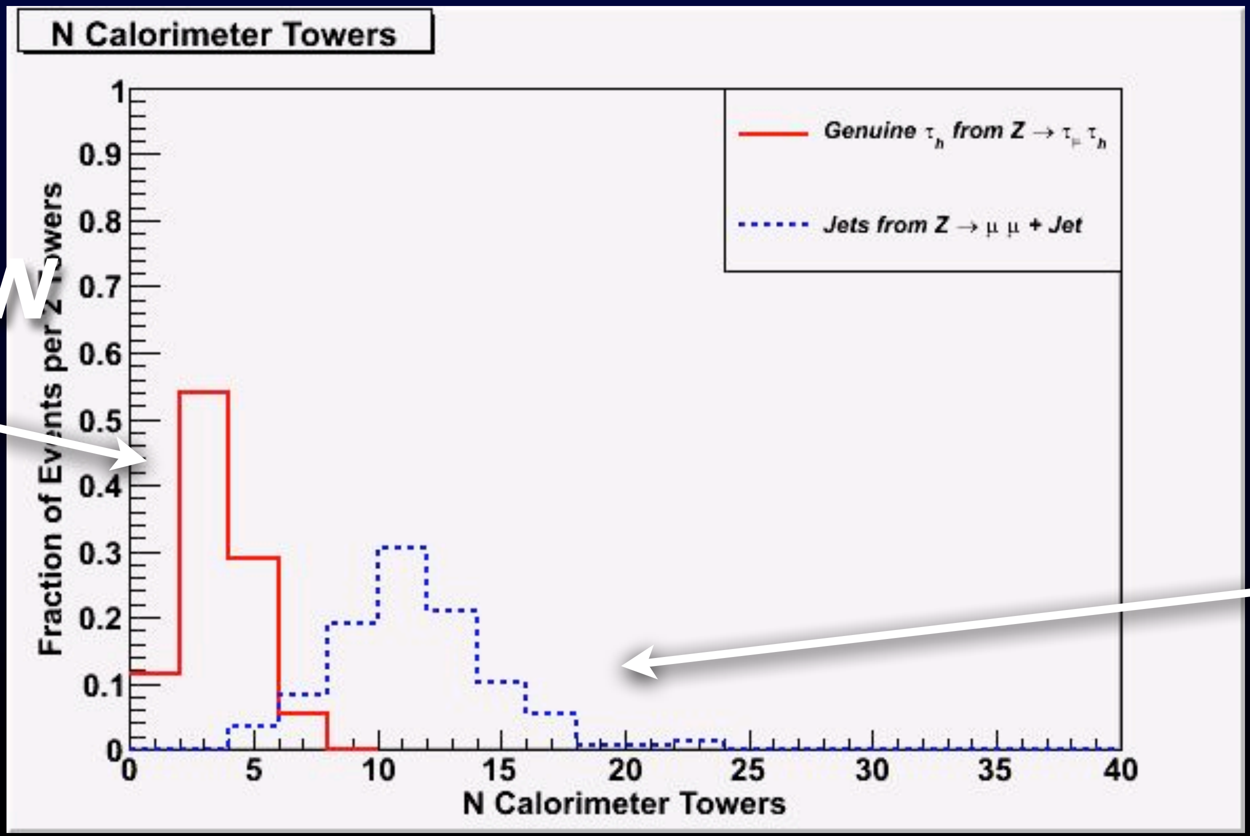
Taus versus Jets





τs are narrow

Jets are wide

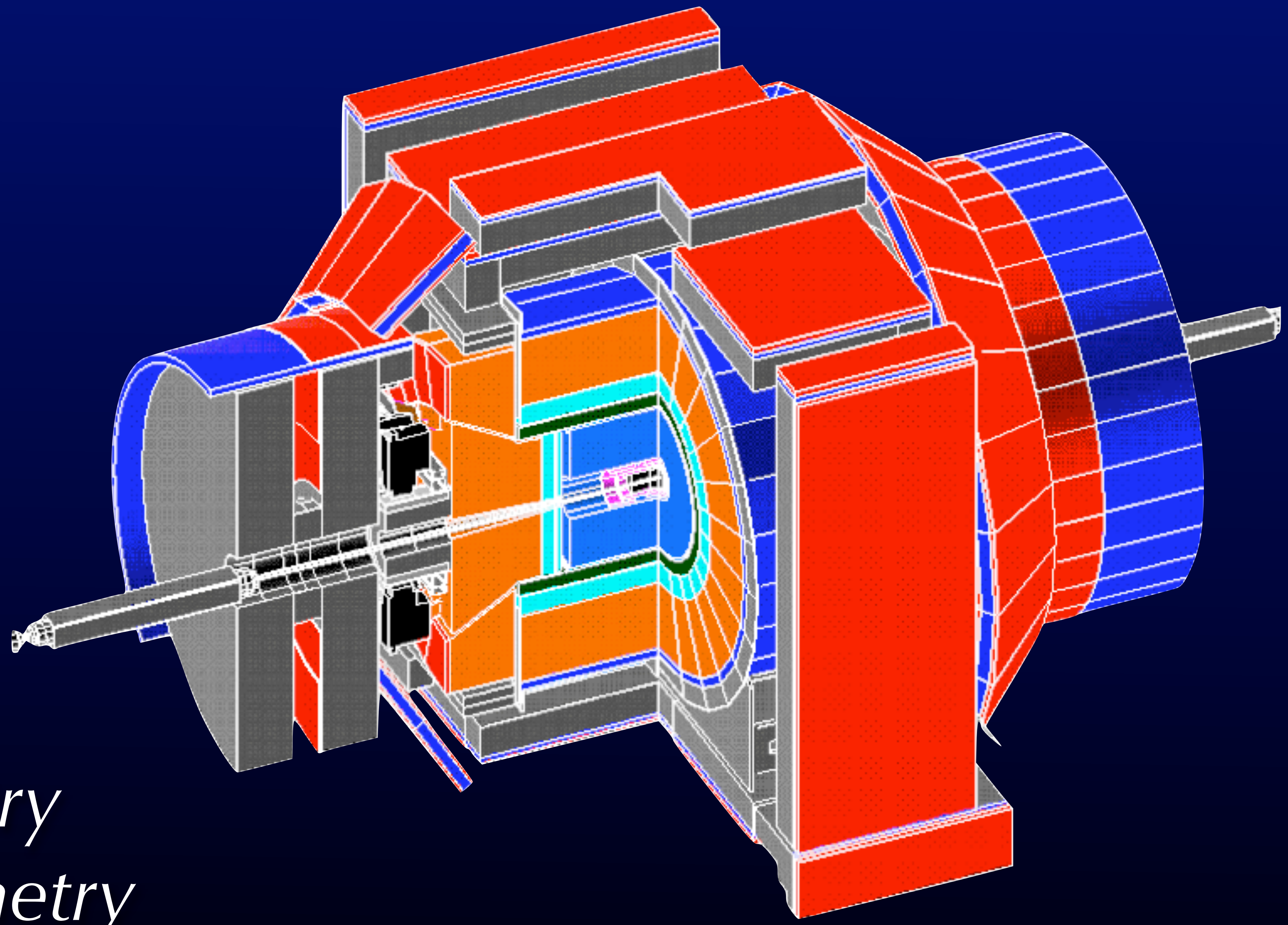


Fermilab Tevatron

World's most powerful $p\bar{p}$ collider!

CDF Run II Detector

Vertexing
Tracking
TOF
Solenoid
EM Calorimetry
Hadron Calorimetry
Muon Chambers



Tau triggering in Run II

- Electron + τ_h, Muon + τ_h
  - **Most used: Higgs, SUSY, VLQ3...**

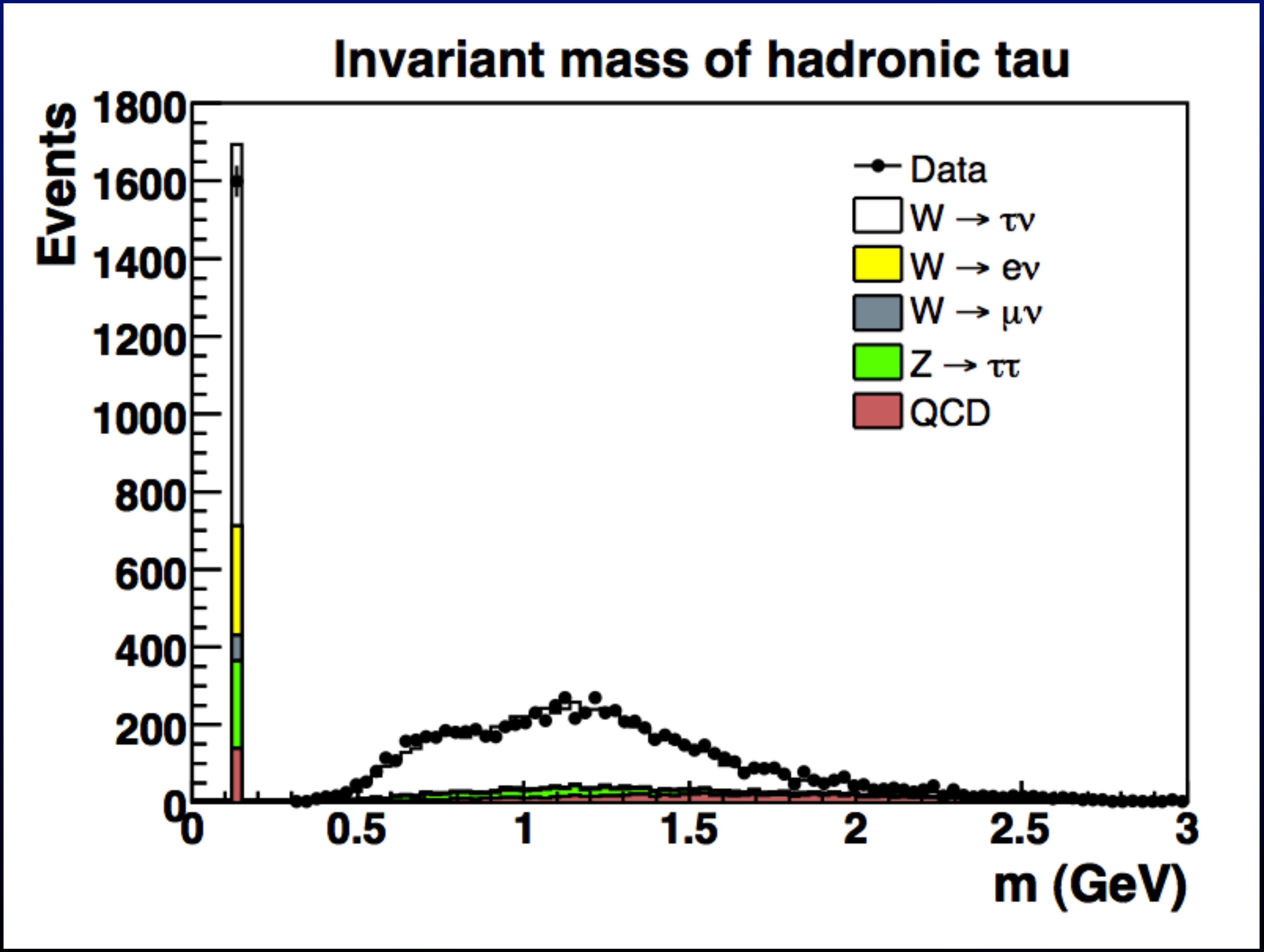
	$e + \tau_h$	$\mu + \tau_h$
L1	EM cluster, Had/Em < 1/8 Track, pT > 8 GeV	muon stub+track $p_T > 6$ GeV
L2	electron: Shower Max signal 2^{nd} track, pT > 5 GeV $\Delta\Phi(e,\text{track}) > 10^0$	-
L3	electron: track-shower match track, $p_T > 5$ GeV $N_{tracks}(10^0\text{-}30^0) = 0$ $\Delta Z < 15$cm, $\Delta R > 0.175$	muon: stub-track match, $p_T > 8$ GeV 2^{nd} track, $p_T > 5$ GeV $N_{tracks}(10^0\text{-}30^0) = 0$ $\Delta Z < 15$cm, $\Delta R > 0.175$

Early Run II Tau Analyses

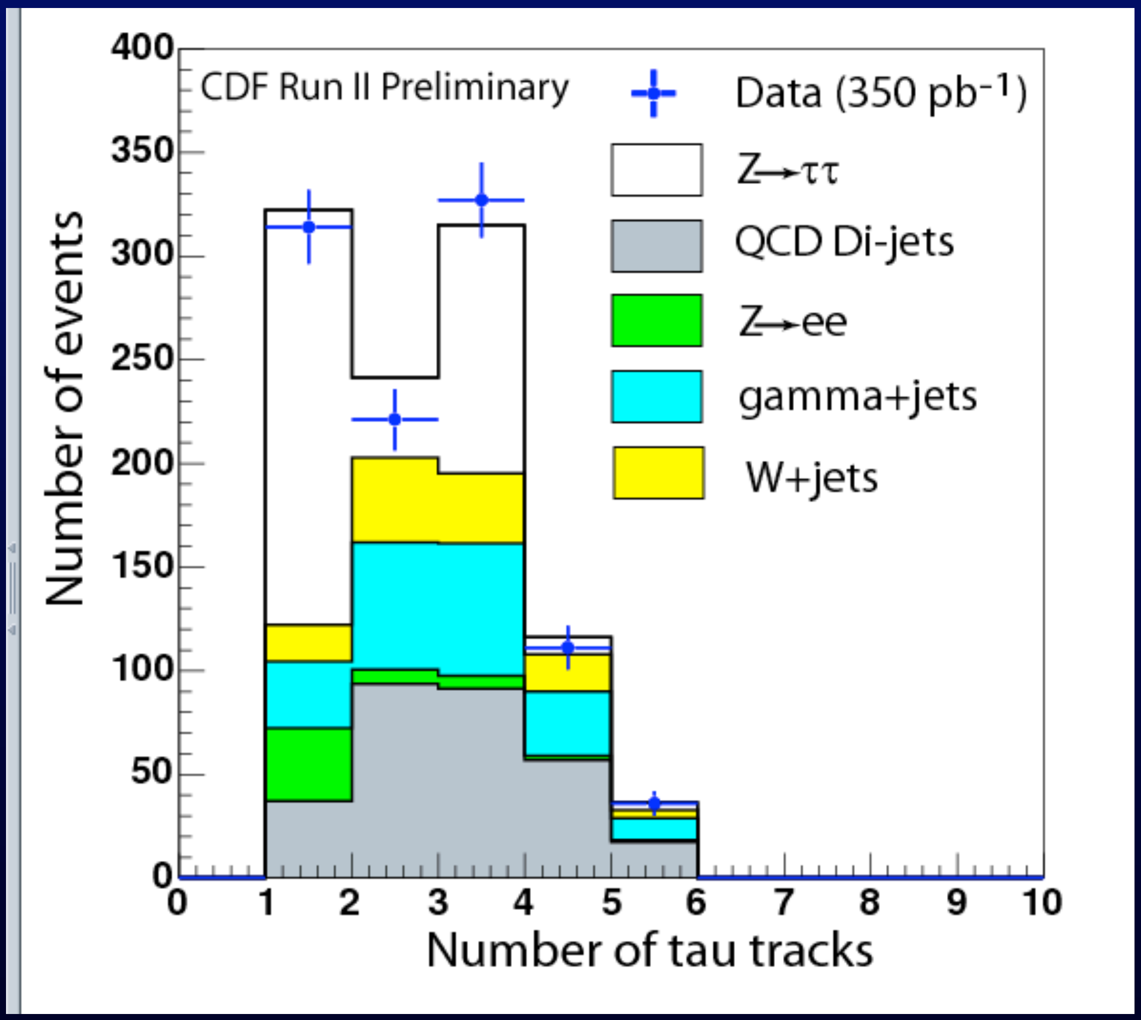
- $Z \to \tau\tau$: Standard Candle
  - **First cross section measurement at hadron collider**

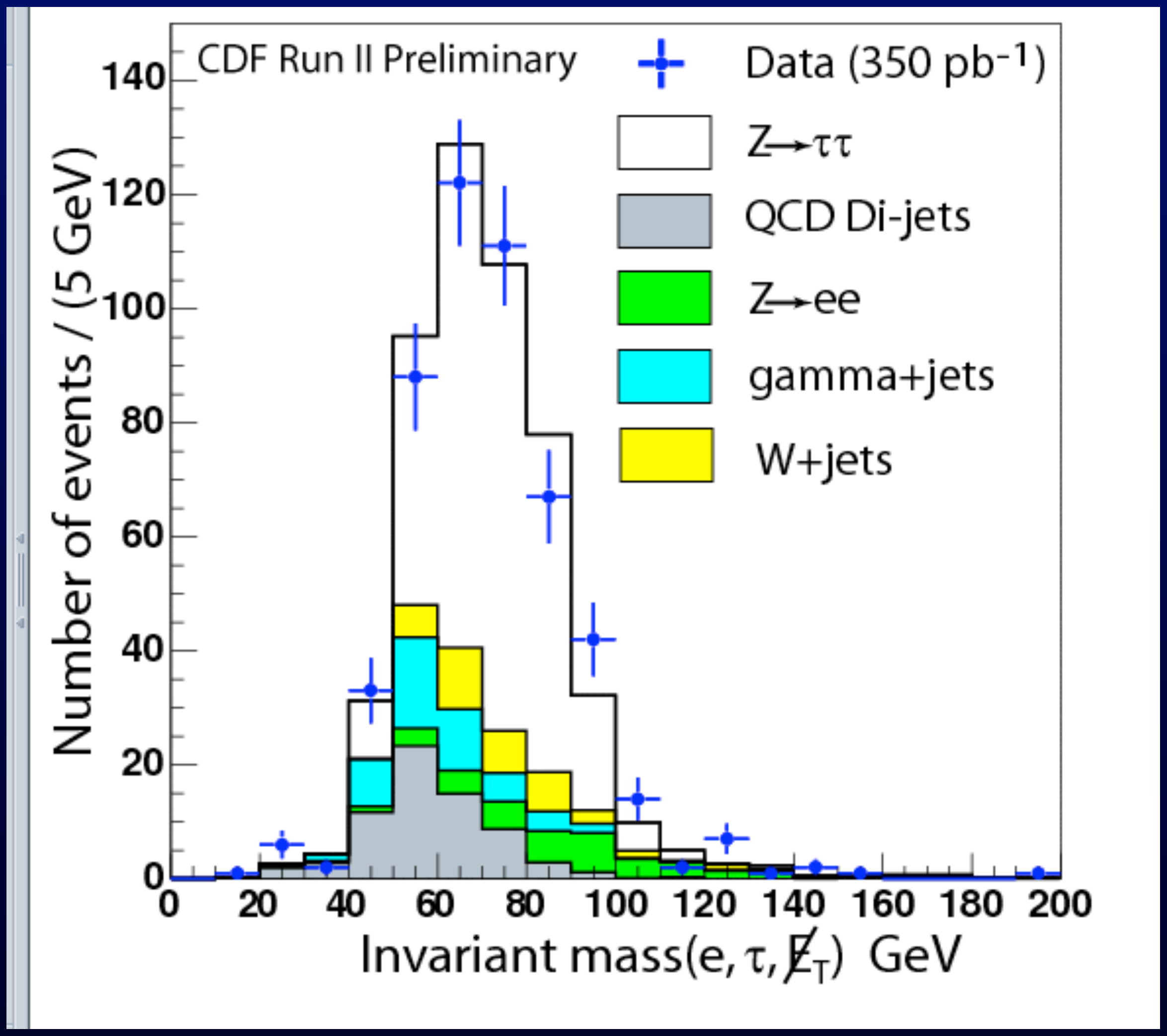
Tau Variables	Cuts
$\|\eta_{det}\|$	< 1.0
E_T^{clu}	> 20 GeV
Seed Tower E_T	> 6 GeV
Seed Track p_T	> 6 GeV$/c$
Mass(tracks+$\pi^0 s$)	< 1.8 GeV$/c^2$
Cal Iso (ΔR=0.4) / E_T^{clu}	< 0.1
$\|z_0(\tau) - z_0(e)\|$	< 5 cm
$N_{\mathbf{axial\ SL}}, N_{\mathbf{stereo\ SL}}$ (for seed track)	≥ 3
$N_{track}^{\mathbf{iso\ cone}}$ ($p_T > 1.0$ GeV$/c$)	0
$N_{\pi^0}^{\mathbf{iso\ cone}}$ ($E_T > 0.5$ GeV)	0
Electron Removal	$\xi \equiv E_T^{had}/\Sigma\|p_T\| > 0.1$
Fiducial Region	$9 < \|z_{CES}\| < 230$ cm

τ visible mass (trks + π^0s)



$Z \rightarrow \tau\tau$ Cross Section

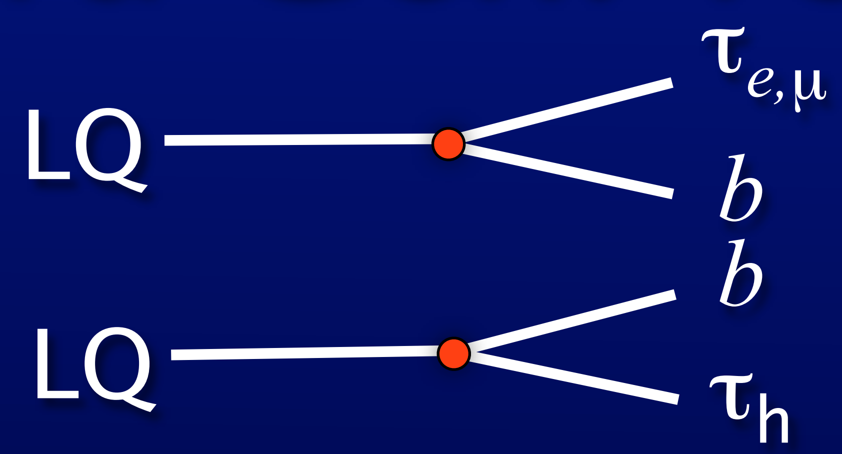




$$\sigma(p\bar{p} \rightarrow Z)Br(Z \rightarrow \tau\,\tau) = 265 \pm 20\ (\text{stat}) \pm 21(\text{syst}) \pm 15\ (\text{lumi})\ \text{pb}$$

Phys. Rev. D75, 092004 (2007)

CDF: 3rd Gen. Vector LQ

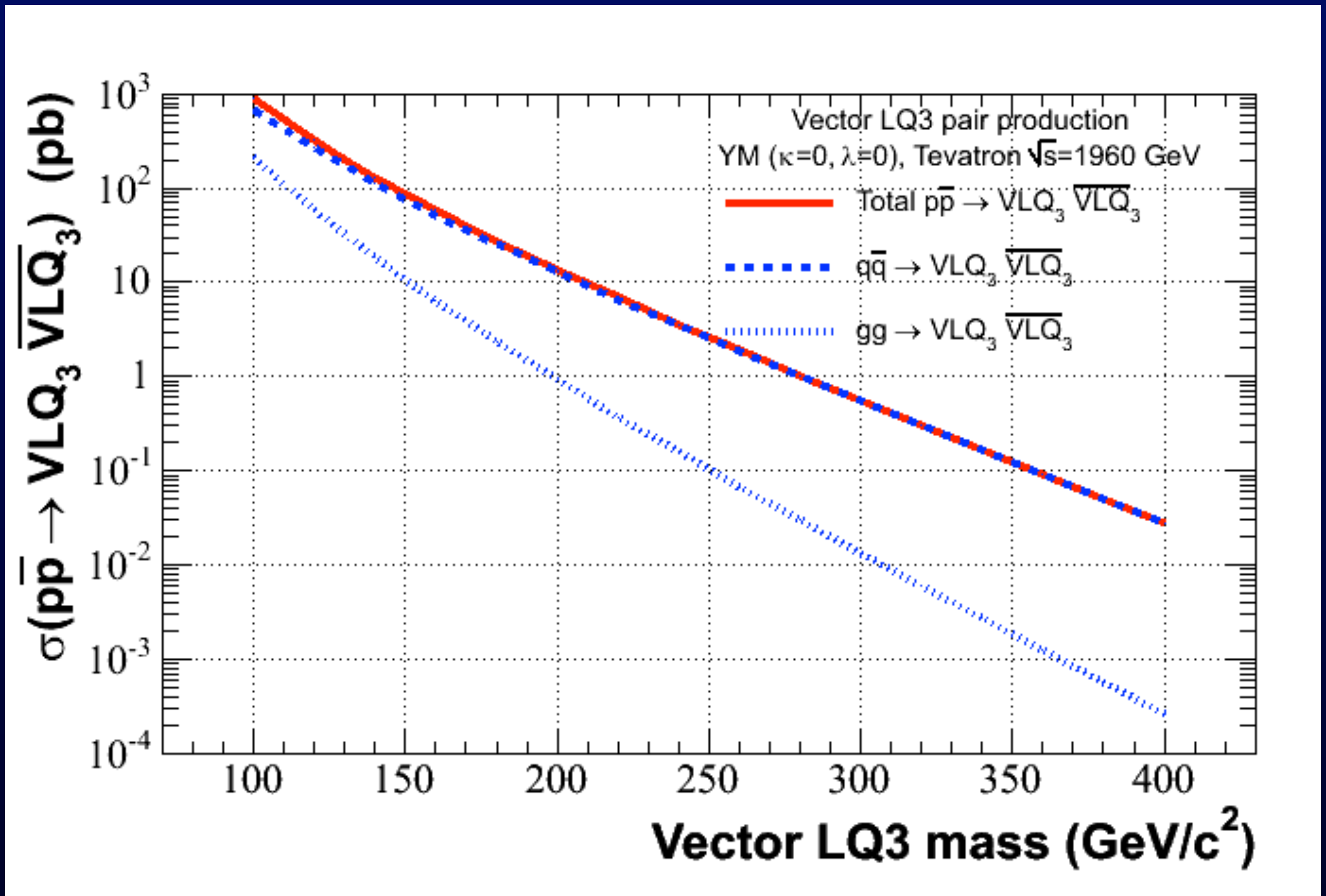


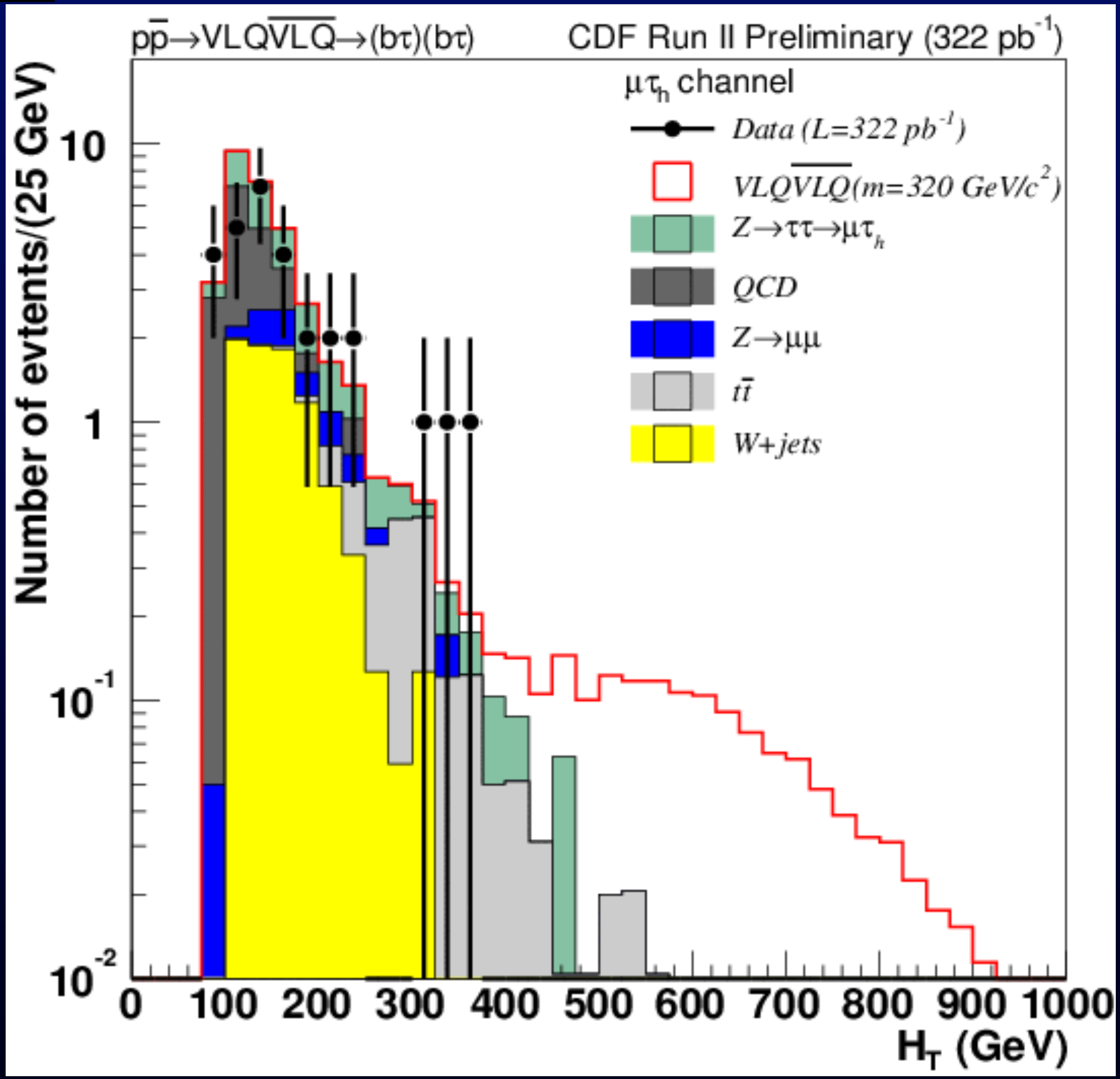
- Helicity amplitudes required because acceptance depends on tau helicity
  - **GRACE/GR@PPA implements Feynman rules and uses helicity basis. Pass tau polarization to TAUOLA**
- Similar procedure necessary for other exotic (J≠0) decays to taus

CDF VLQ3 Search

σ

σ_{LHC}, *situation ~ reversed*

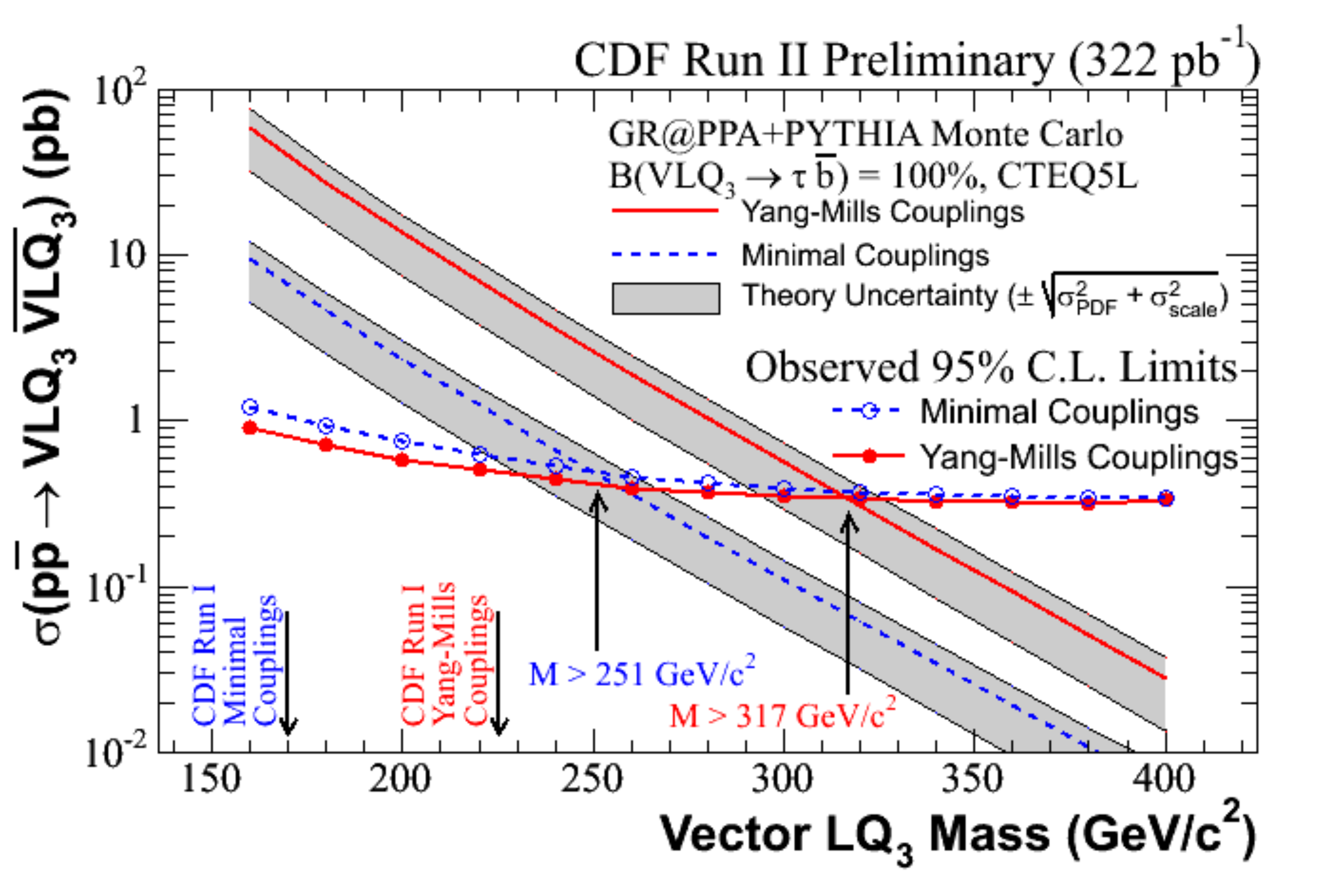




$$H_T = E_T(lep) + E_T(\tau_h) + \not{E}_T + \sum E_T(jets)$$

CDF VLQ3 Results

No events observed

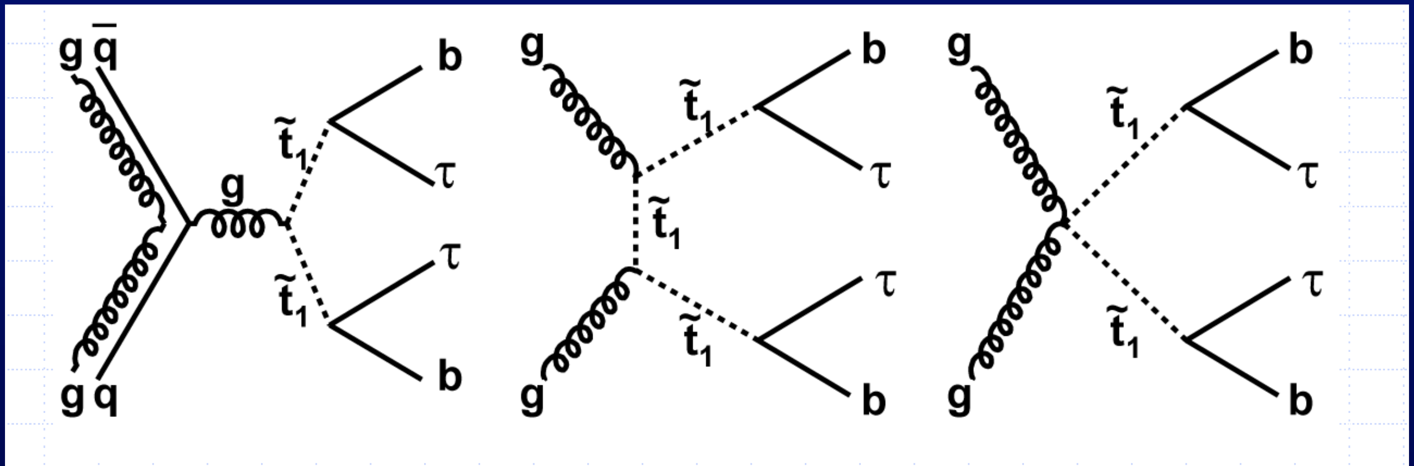


Minimal Coupling type
m > 251 GeV

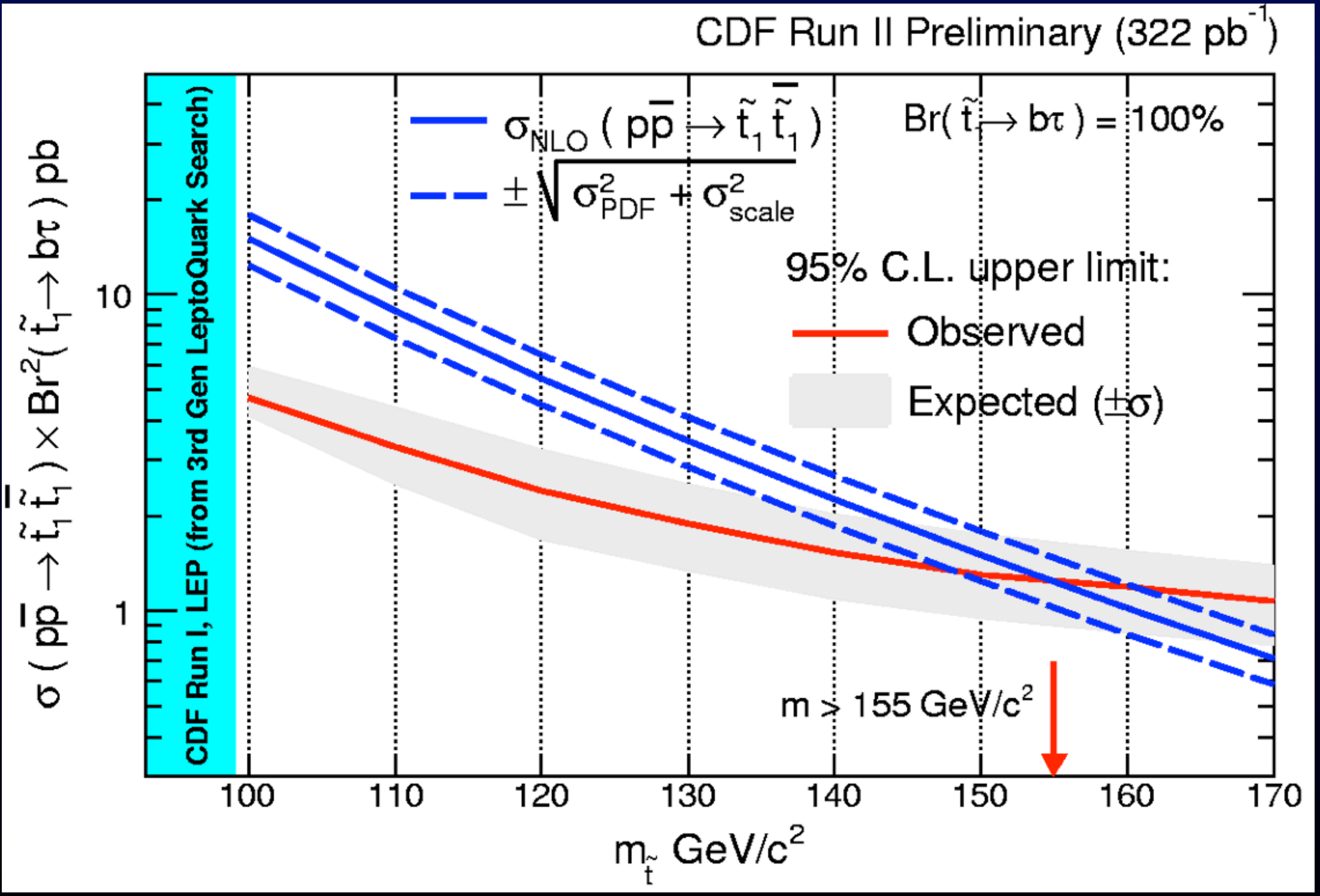
Yang-Mills type
m > 317 GeV

Phys. Rev. D77, 092001 (2008).

R_pV SUSY Search with τ



Signature to look for:
(e or μ) + τ_h + 2 jets



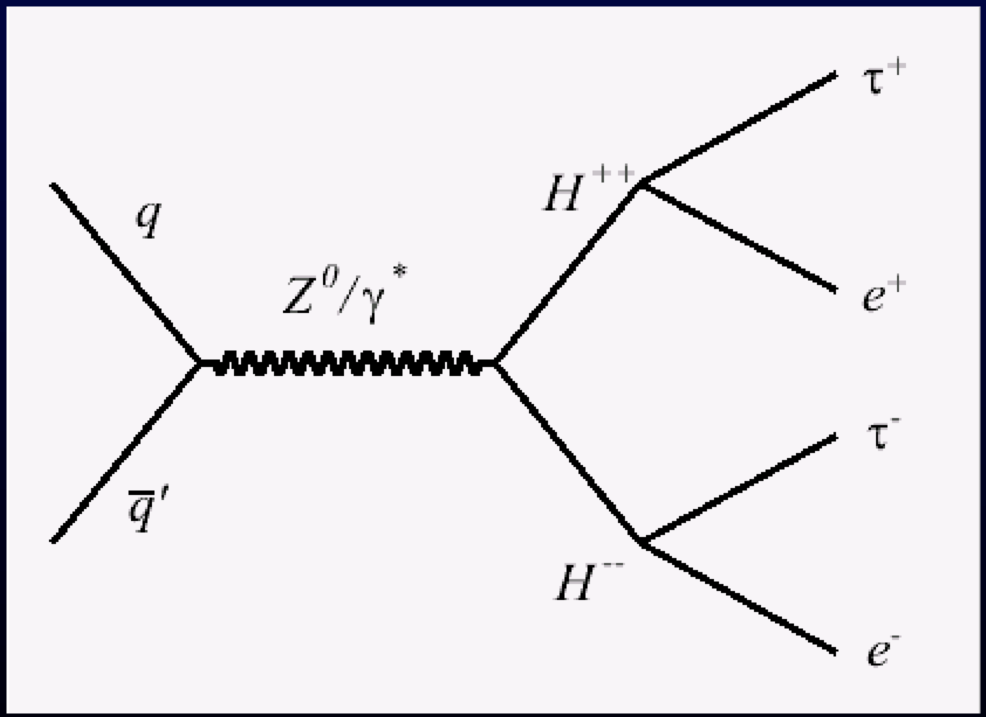
- Good agreement in control regions N_{jet}=0 and N_{jet}=1
- Region $N_{jet}\geq 2$ was looked at after opening the box

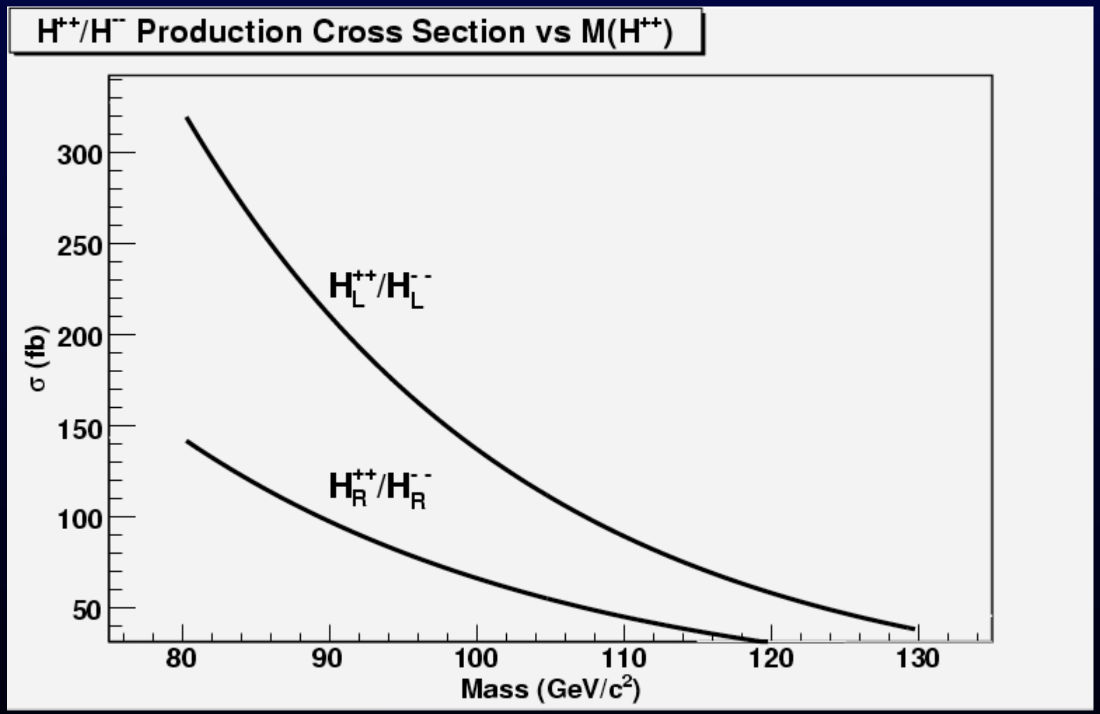
2.2 expected, 2 observed

Phys. Rev. Lett. 101, 071802 (2008)

CDF Doubly-Charged Higgs

- Search for H^{++} pair-production with LFV decay $H^{++} \rightarrow \tau e$ or $H^{++} \rightarrow \tau\mu$
  - **Signature is LS dileptons or multileptons**
- Assume prompt decay, O(10μm)

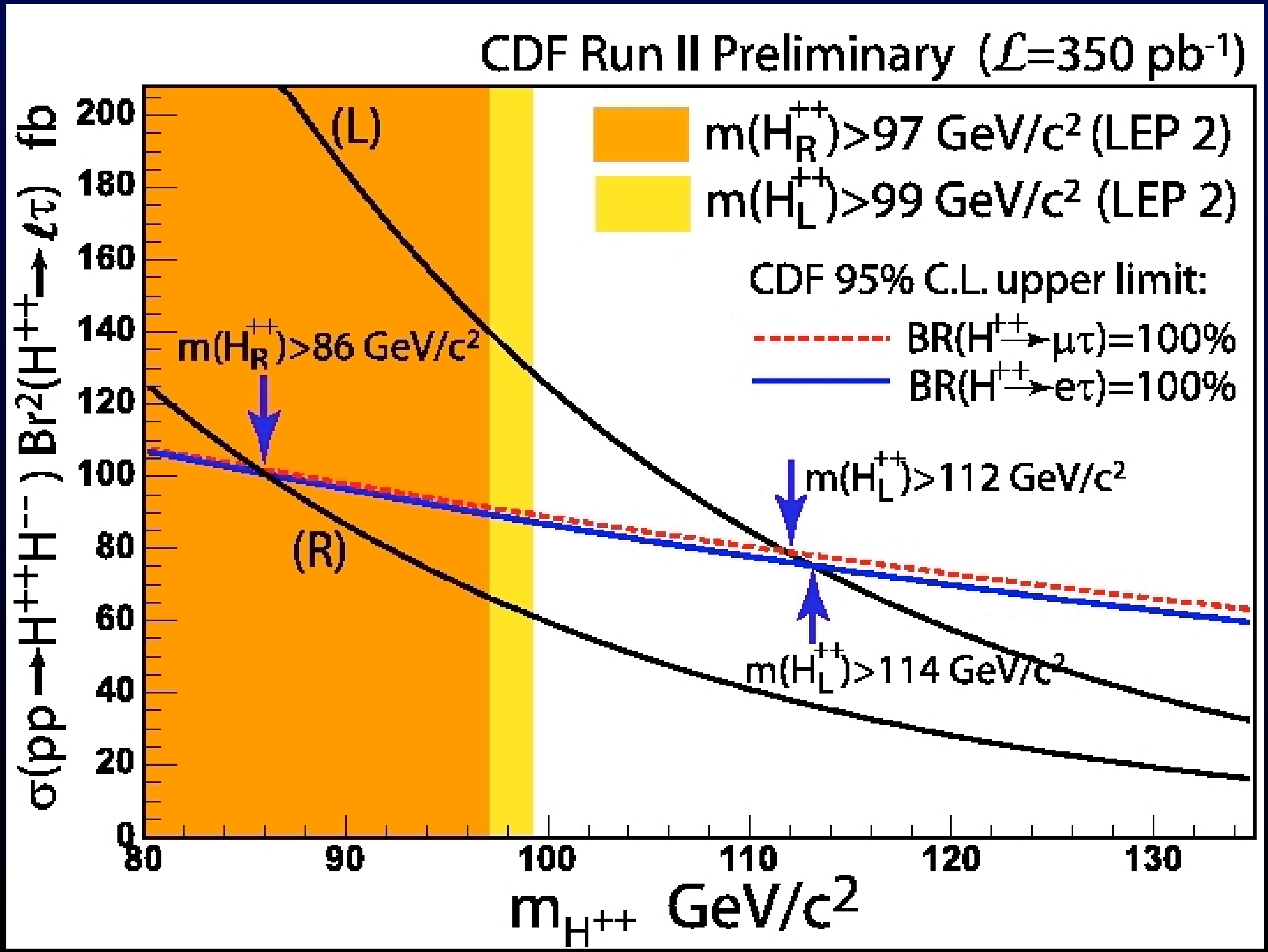




H^{++}/H^{--}

- Employ "lepton+track" triggers (low P_T)
- Require 3 or 4 leptons to suppress W+jets
- H_T cut, Z mass veto, LS mass window
  - **No events survive**

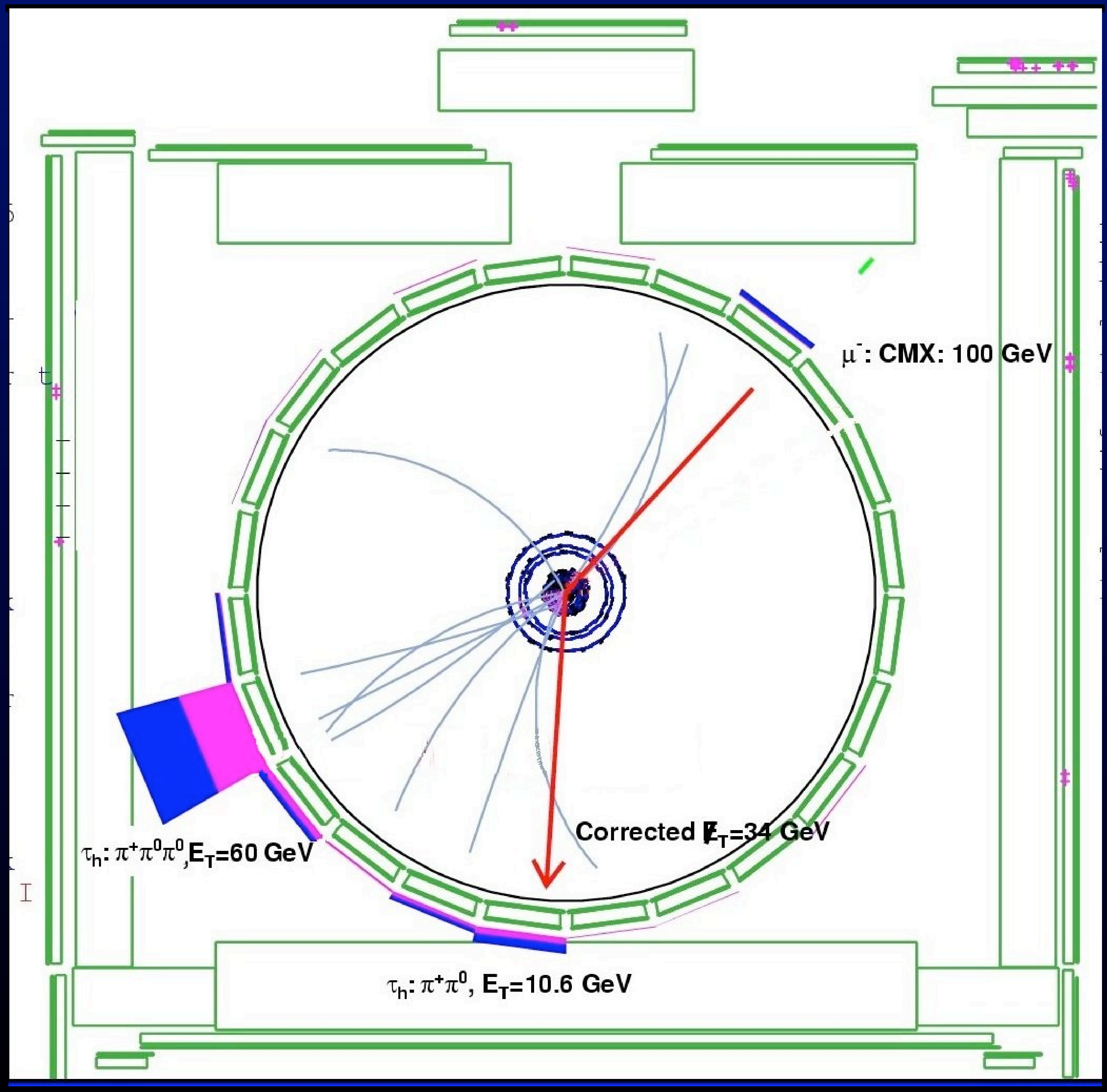
Phys. Rev. Lett. 101, 121801 (2008)



To examine SUSY variants on this model, we need custom MC for Δ^{++} production

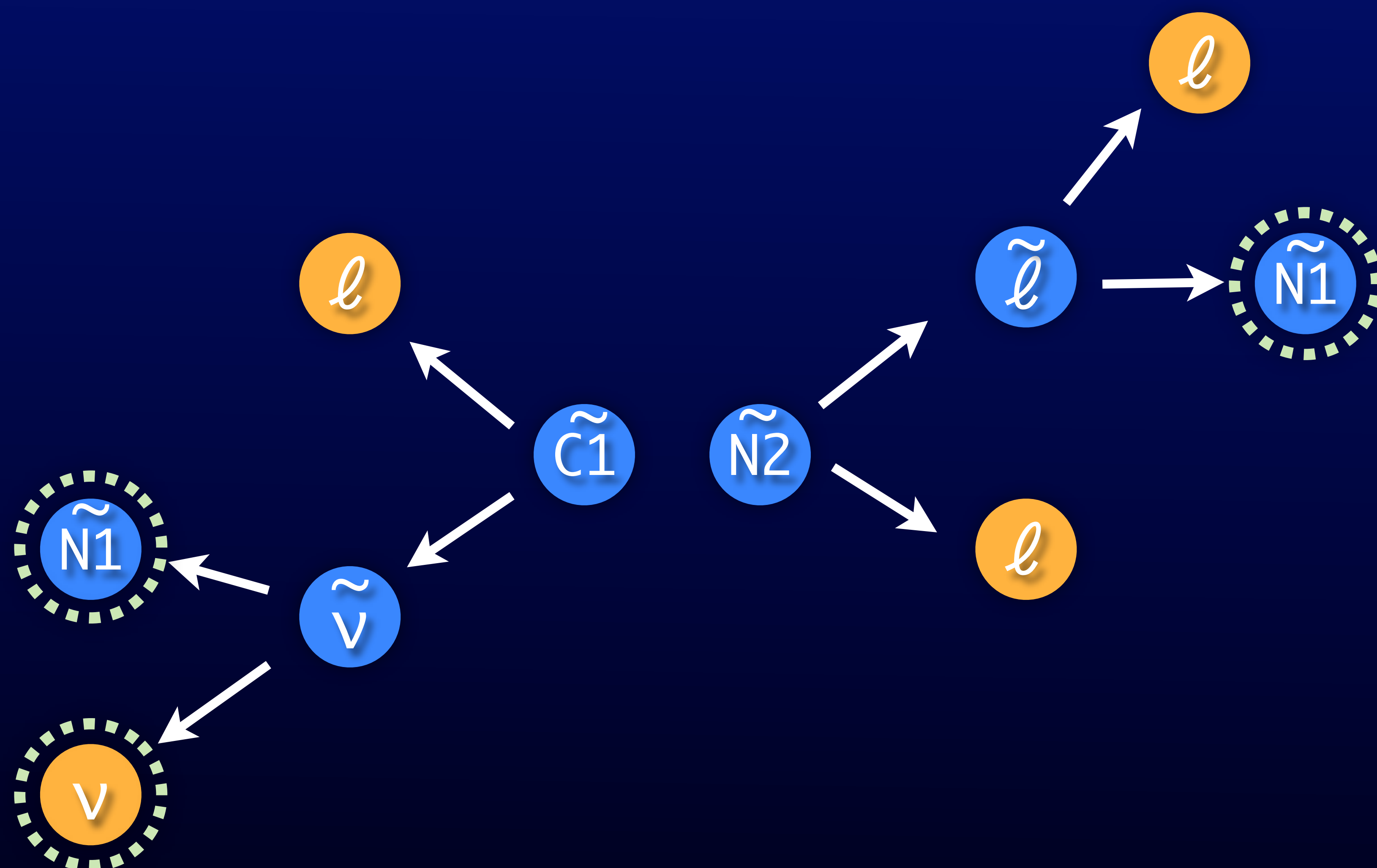
H^{++} interesting event

- $\mu^- \tau^+ \tau^+$
- Fails LS mass window cut
- Likely SM process is W +jets



All tracks with pT>500 MeV shown

Search for SUSY trileptons



$$M_{\tilde{C}1} \approx M_{\tilde{N}2} \approx 2M_{\tilde{N}1}$$

N2C1 Search

- Direct (EWK) or from cascades (strong), imparts boost
  - **Cascades more relevant for LHC**
- Dilepton edge from N2 decay. always OS pair. challenging if stau involved
  - **slepton virtual: modifies edge**
- $|\Sigma Qi|=1$, so 2 OS pairs
- MET cancellation not complete
  - **topology cuts to reduce WZ, ttbar**

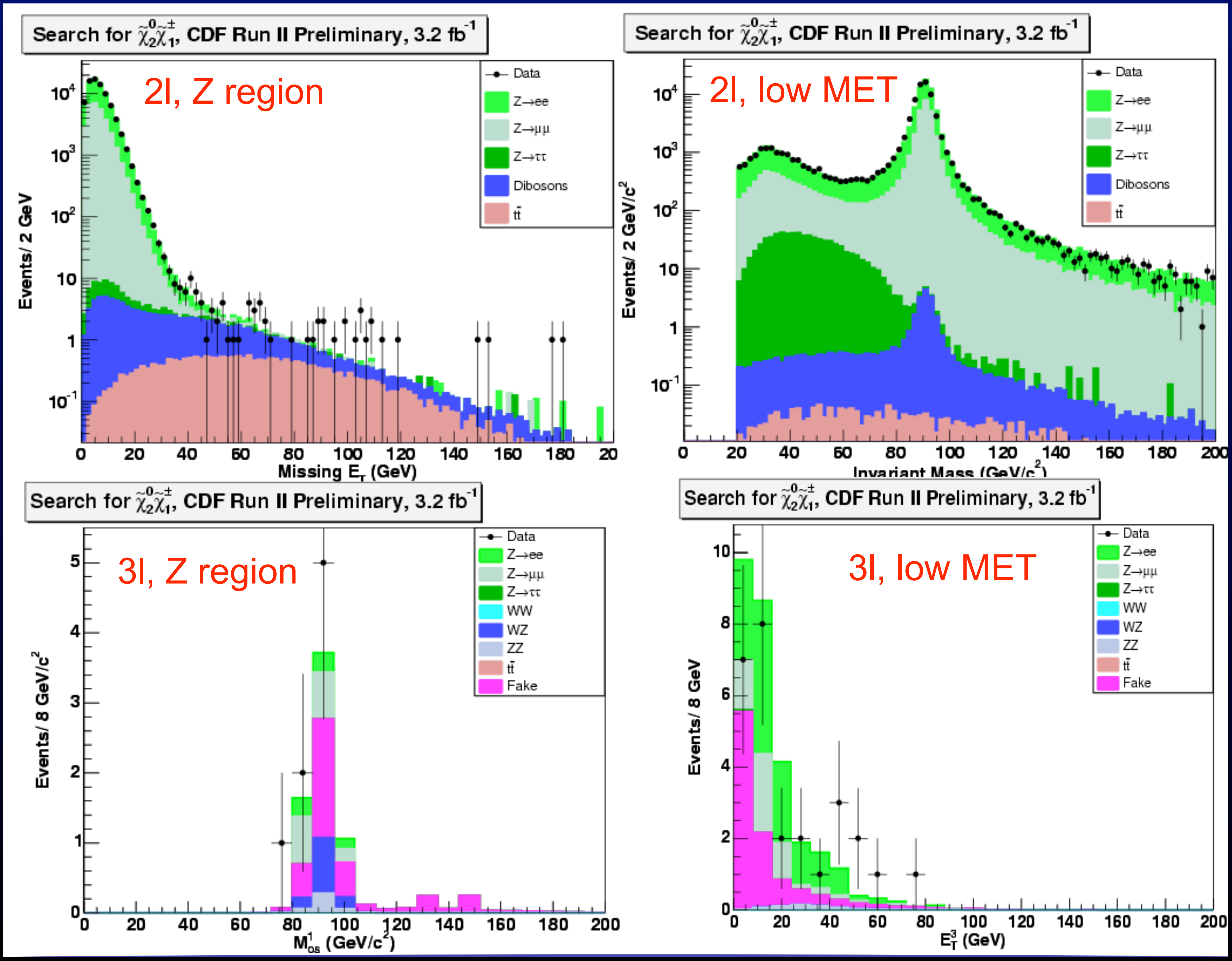
Trilepton channels

- 5 exclusive channels

	CHANNEL	SELECTION	$(E_T \text{ or } P_T)_{123}$ [GeV]
trilepton	3 tight	3 tight l or 2 tight l + 1 loose e	15,5,5
	2 tight + 1 loose	2 tight l + 1 loose muon	15,5,10
	1 tight + 2 loose	1 tight lepton + 2 loose l	20,8,5 *
dilep+track	2 tight + 1 track	2 tight l + 1 iso track	15,5,5
	1 tight + 1 loose +1 track	1 tight l + 1 loose l + 1 iso track	20,8*,5

** 10 GeV if loose muon*

CDF: SUSY lll Search



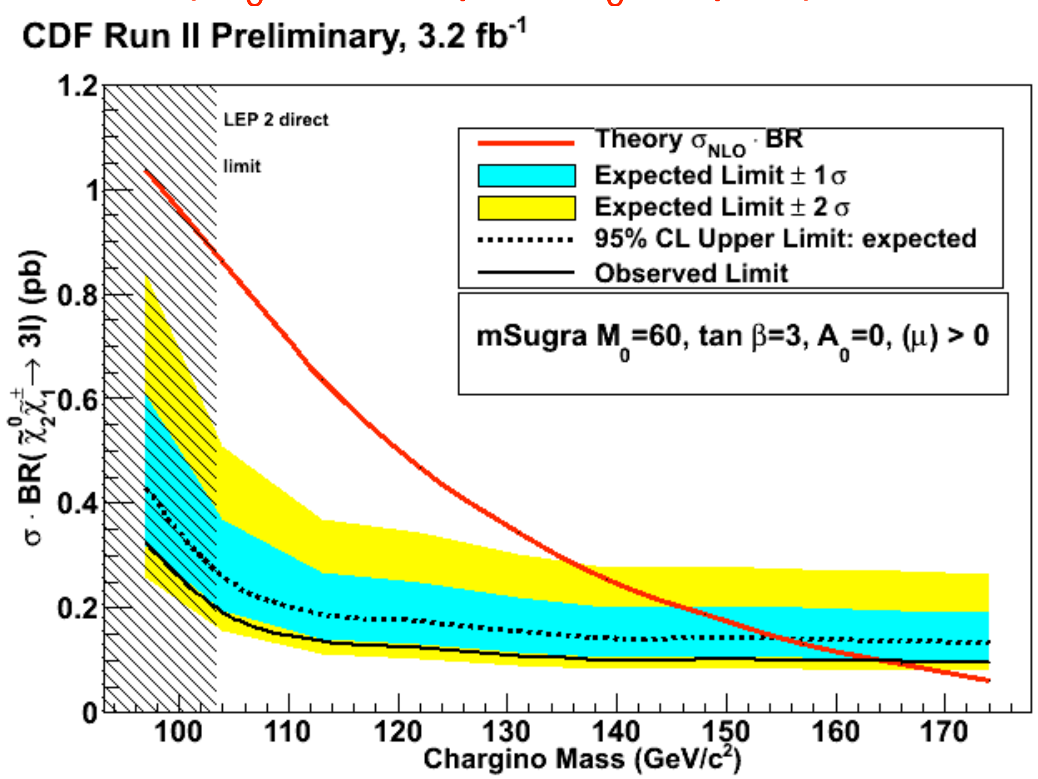
Trilepton results

- Our counting result is consistent with the Standard Model

Analysis	Backg.	Signal	DATA
Trilepton	**1.5 ± 0.2**	7.4 ± 0.7	**1**
Dilepton+Track	**9.4 ± 1.4**	11.2 ± 1.1	**6**

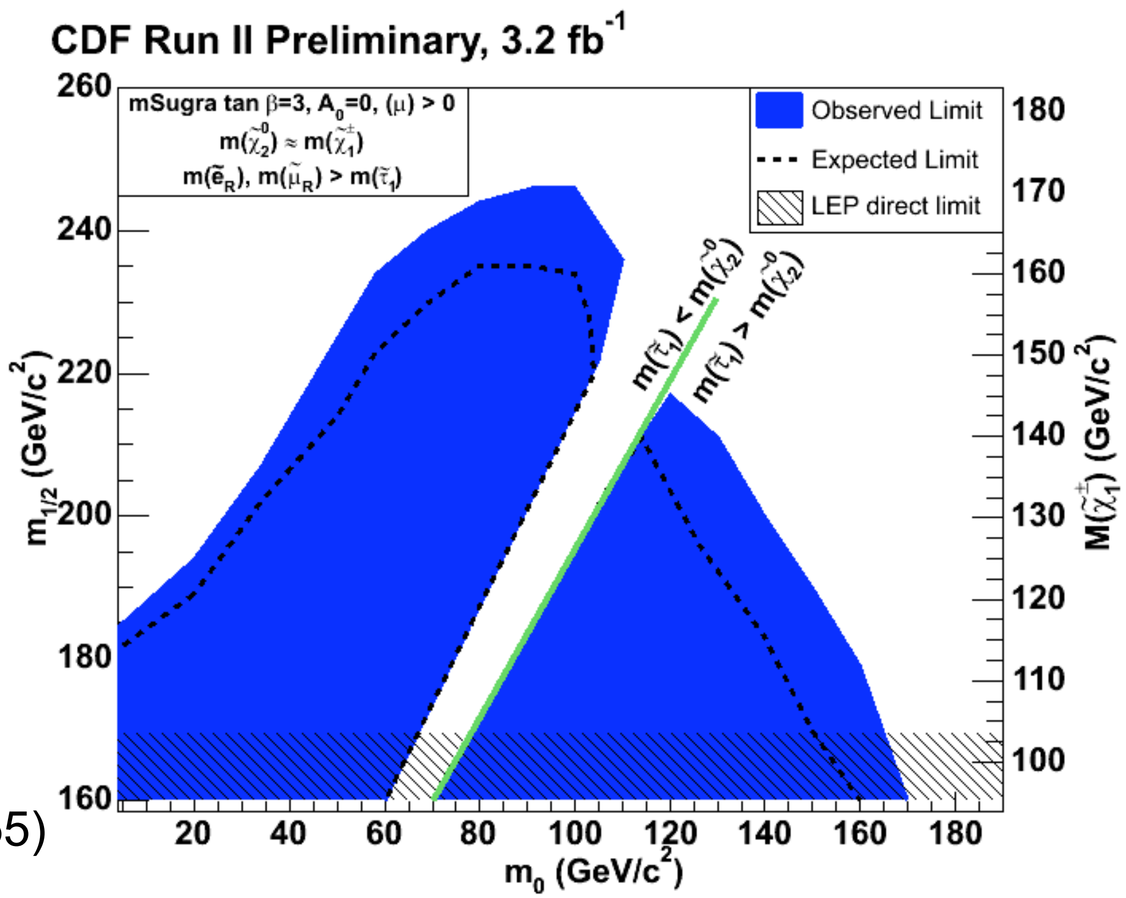
m_0=60 GeV, $m_{1/2}$=190 GeV, tanβ=3, A_0=0, μ>0

(m_0=60 ,tanβ=3, A_0=0, μ>0)



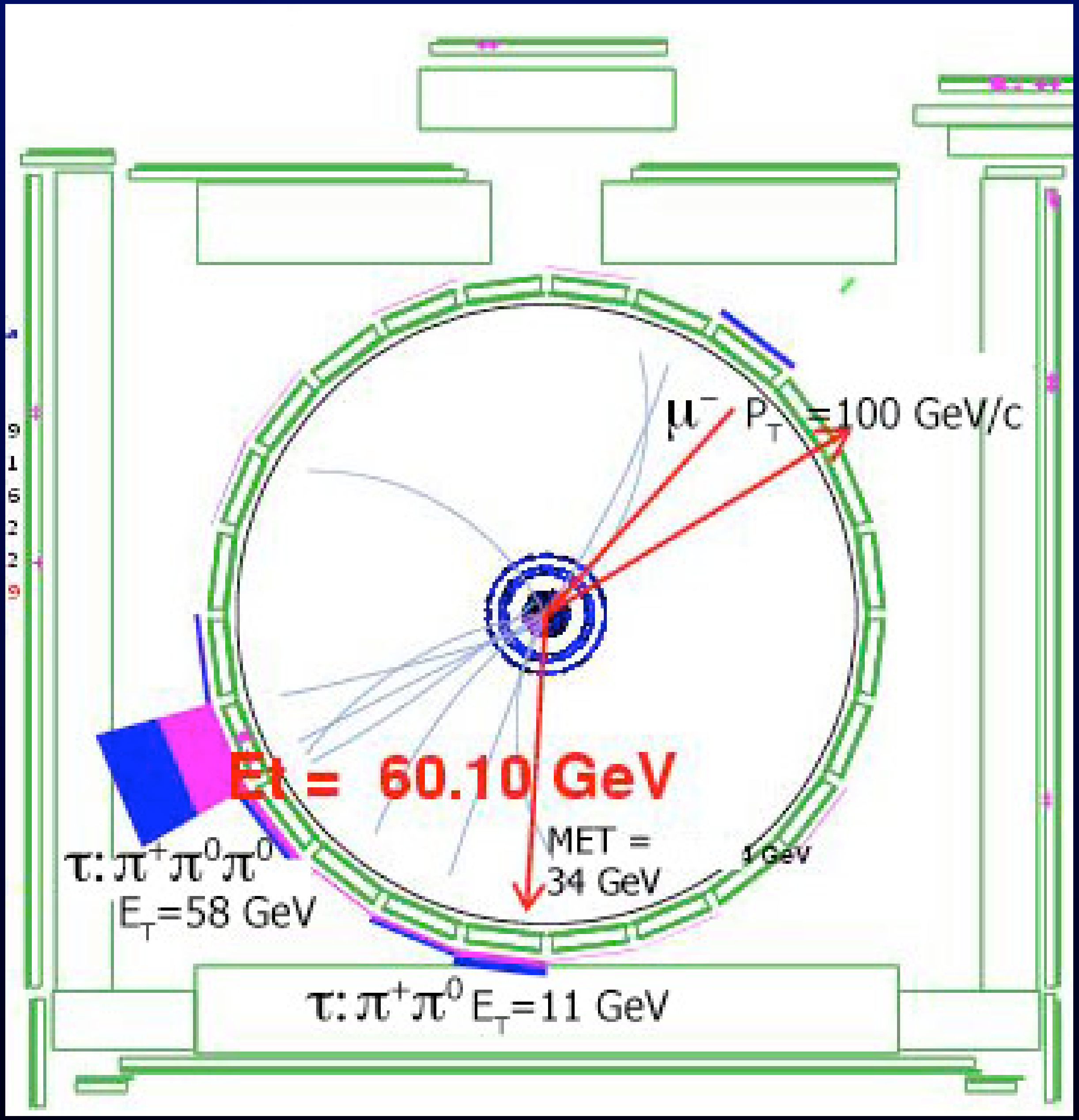
$M(\chi_1^\pm) >$ 164 GeV/c^2 at 95% CL (expected 155)

(tanβ=3, A_0=0, μ>0)

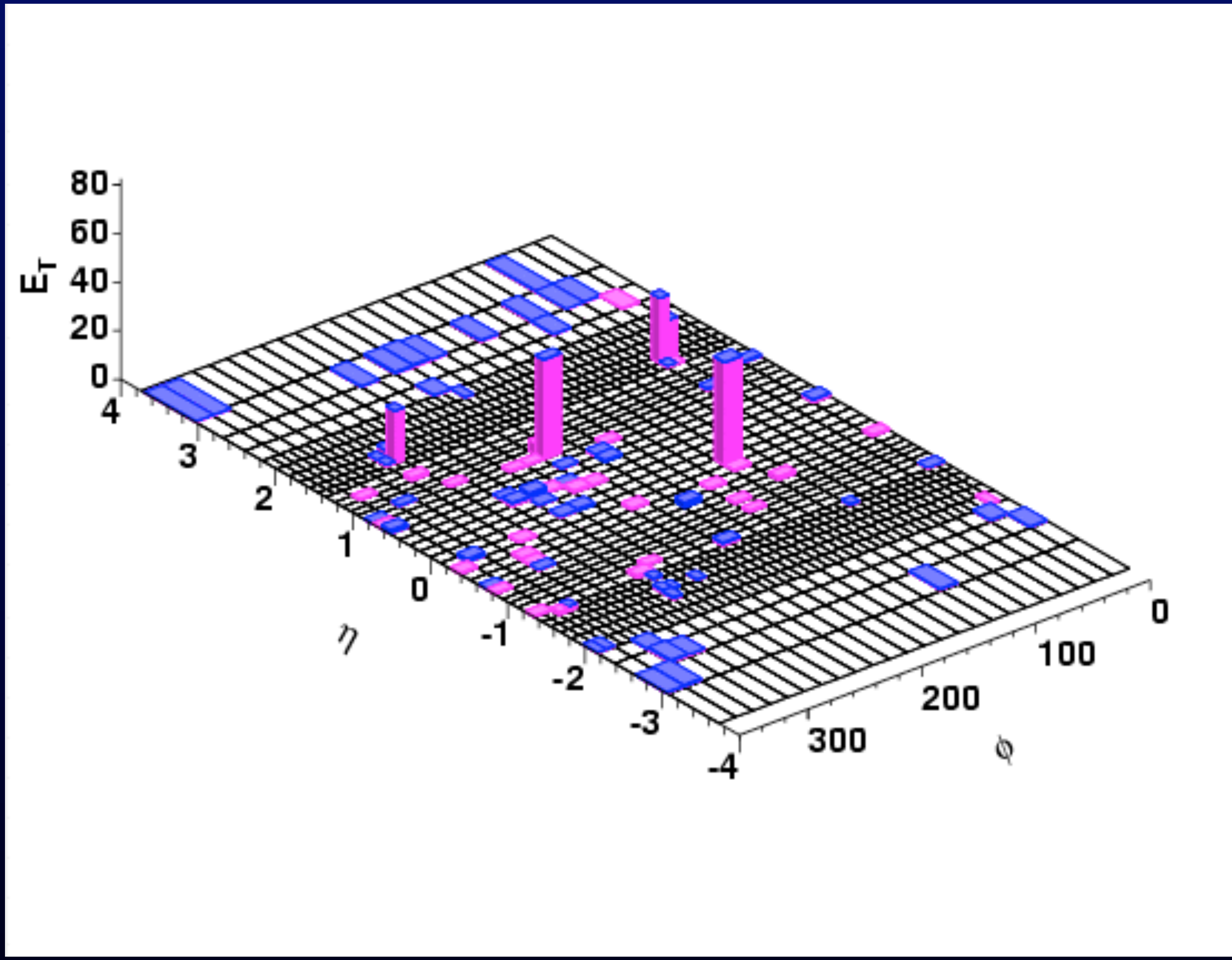


Next: fill in gap, explore high tanβ with LS search

"Interesting" events are piling up at Fermilab



muon+tau+tau event

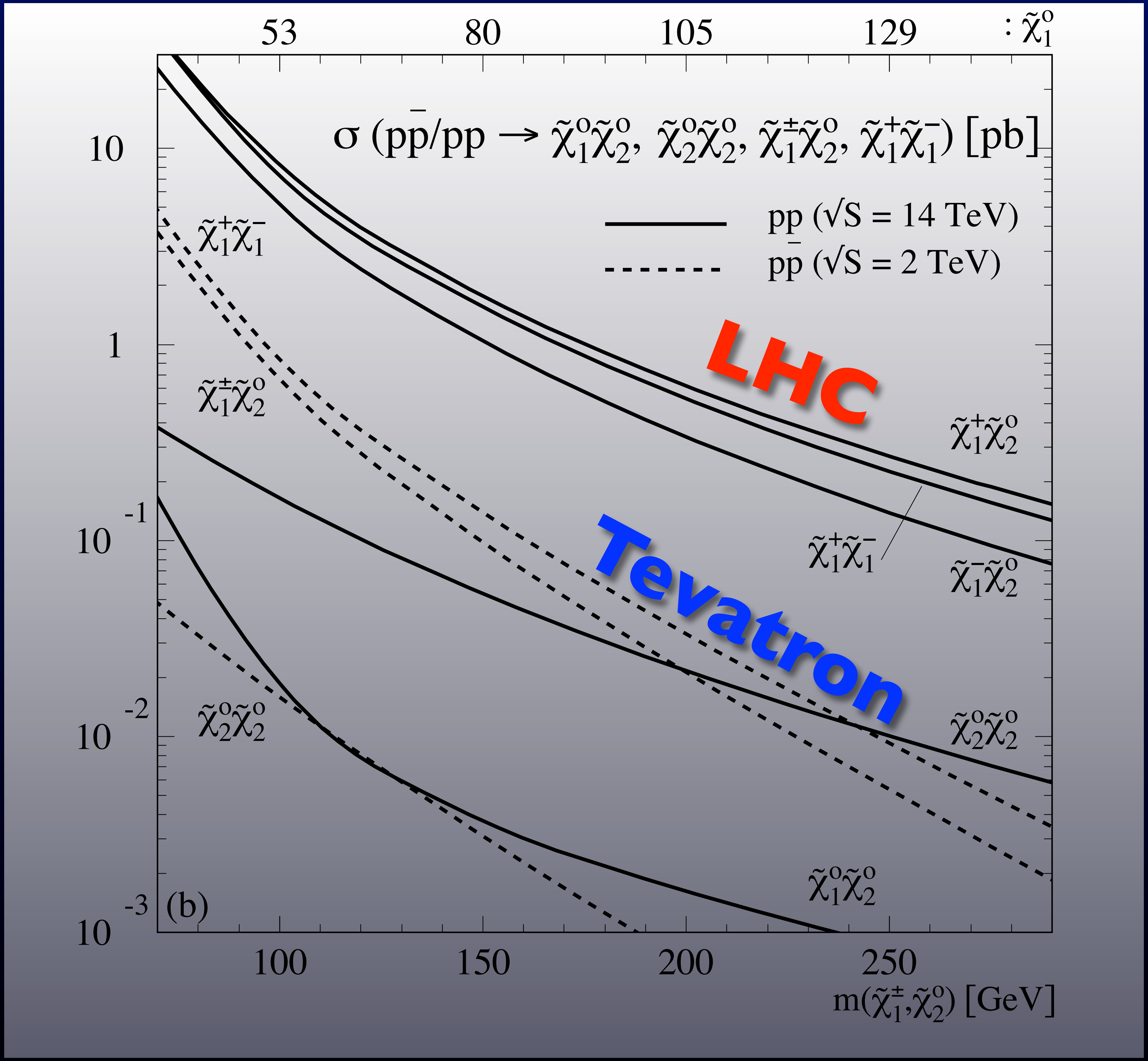


4 electron event

Meanwhile...

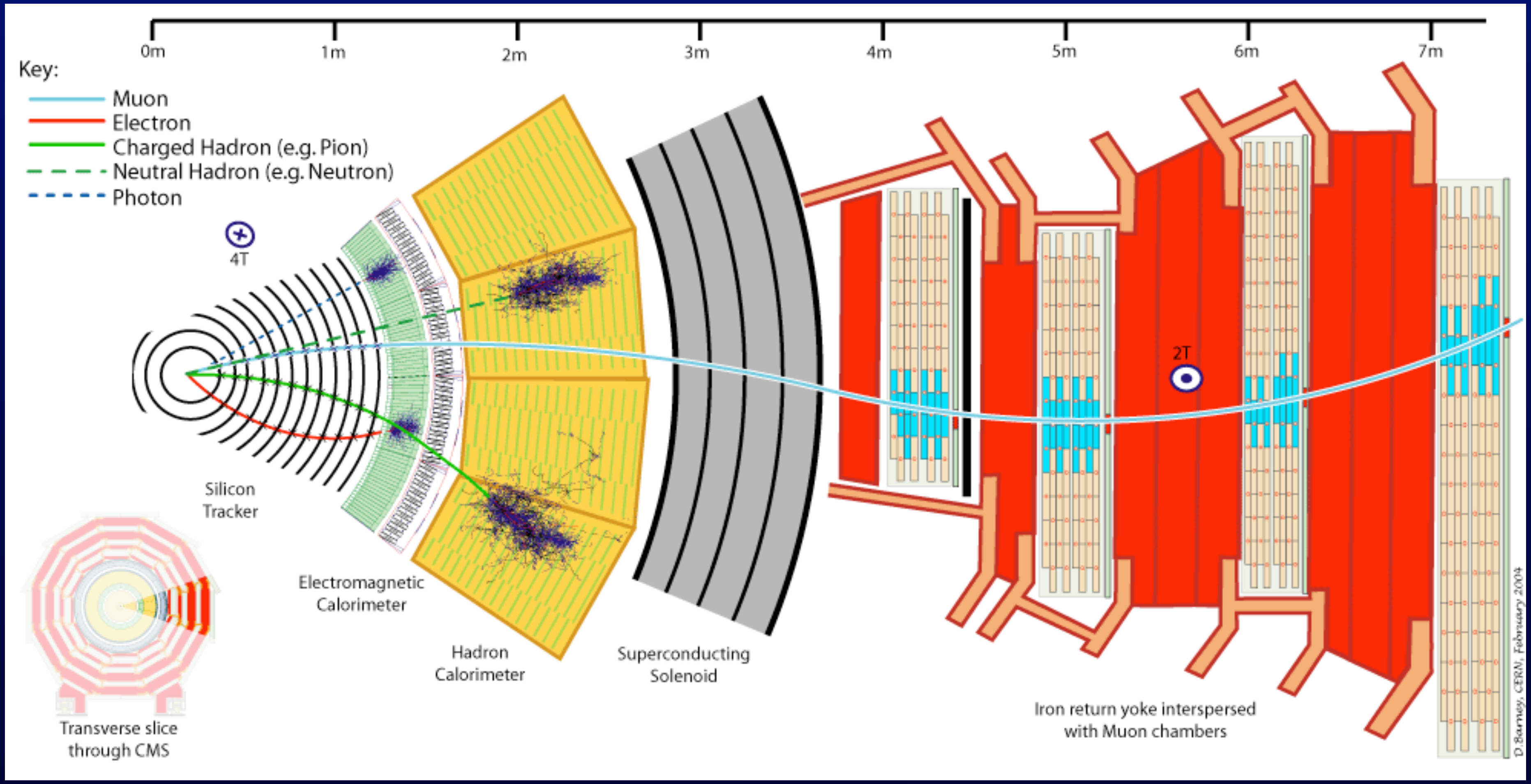
CMS: World's largest solenoid

Why is this so exciting?

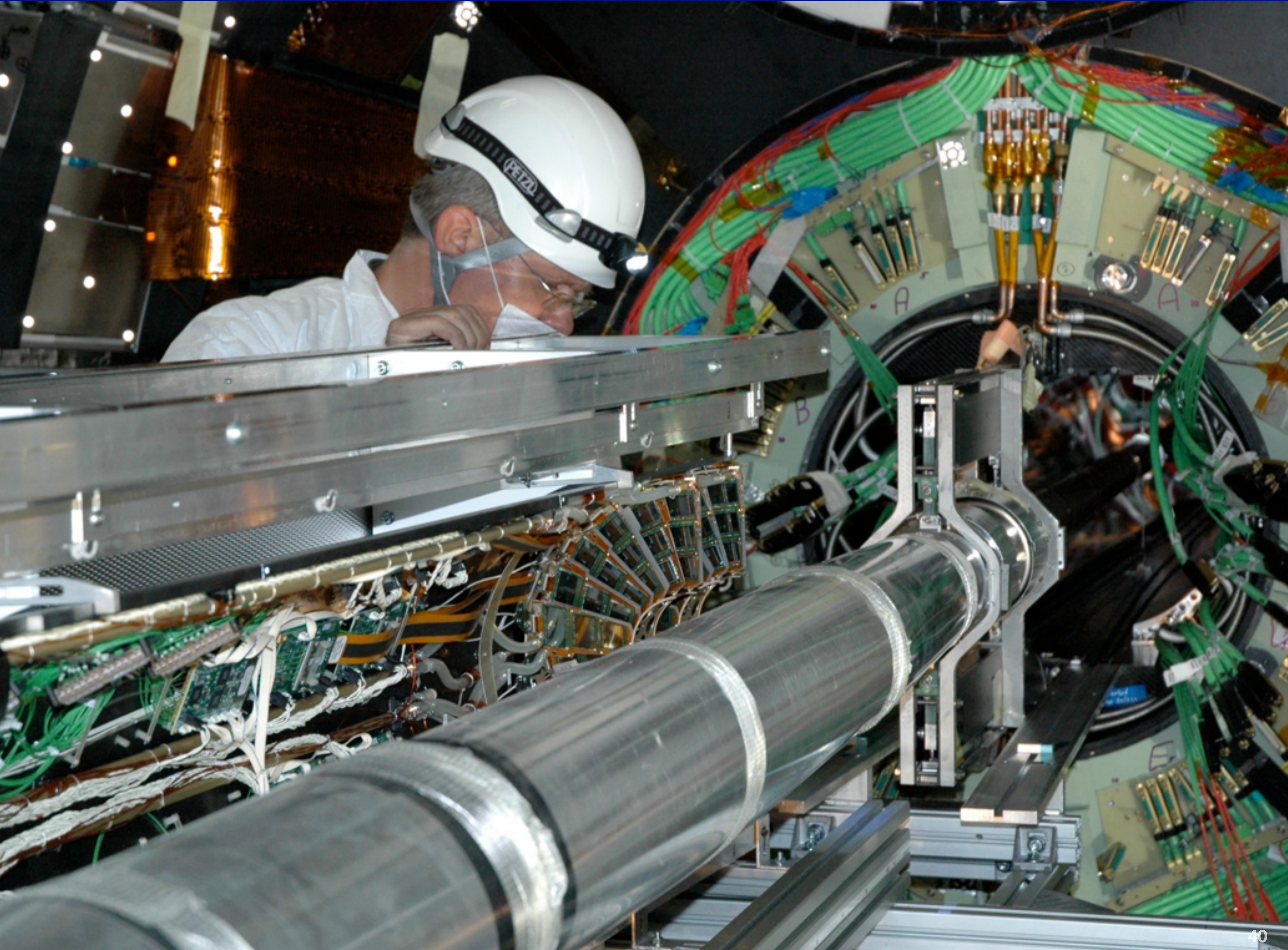


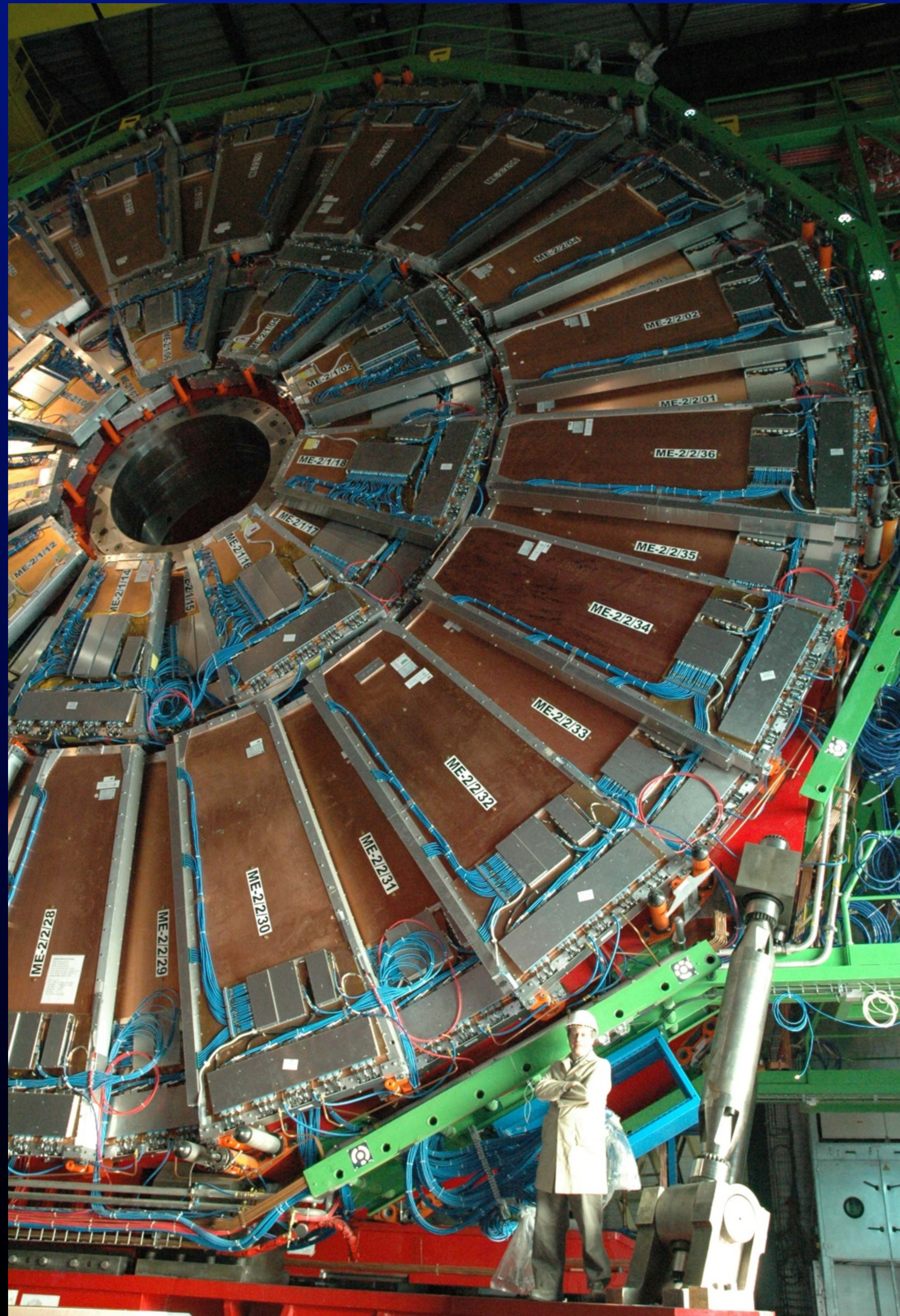
Cross sections, ultimate ∫Ldt much higher

CMS detector slice



Hadronic Tau Decays:
pi$^{+/-}$: tracks,(ECAL),HCAL
pi^{0} gammas:(tracks),ECAL,(HCAL)
punchthrough to MUON sys?


PETZL


ME-2/2/02
ME-2/2/01
ME-2/2/36
ME-2/2/35
ME-2/2/34
ME-2/2/33
ME-2/2/32
ME-2/2/31
ME-2/2/30
ME-2/2/29
ME-2/2/28

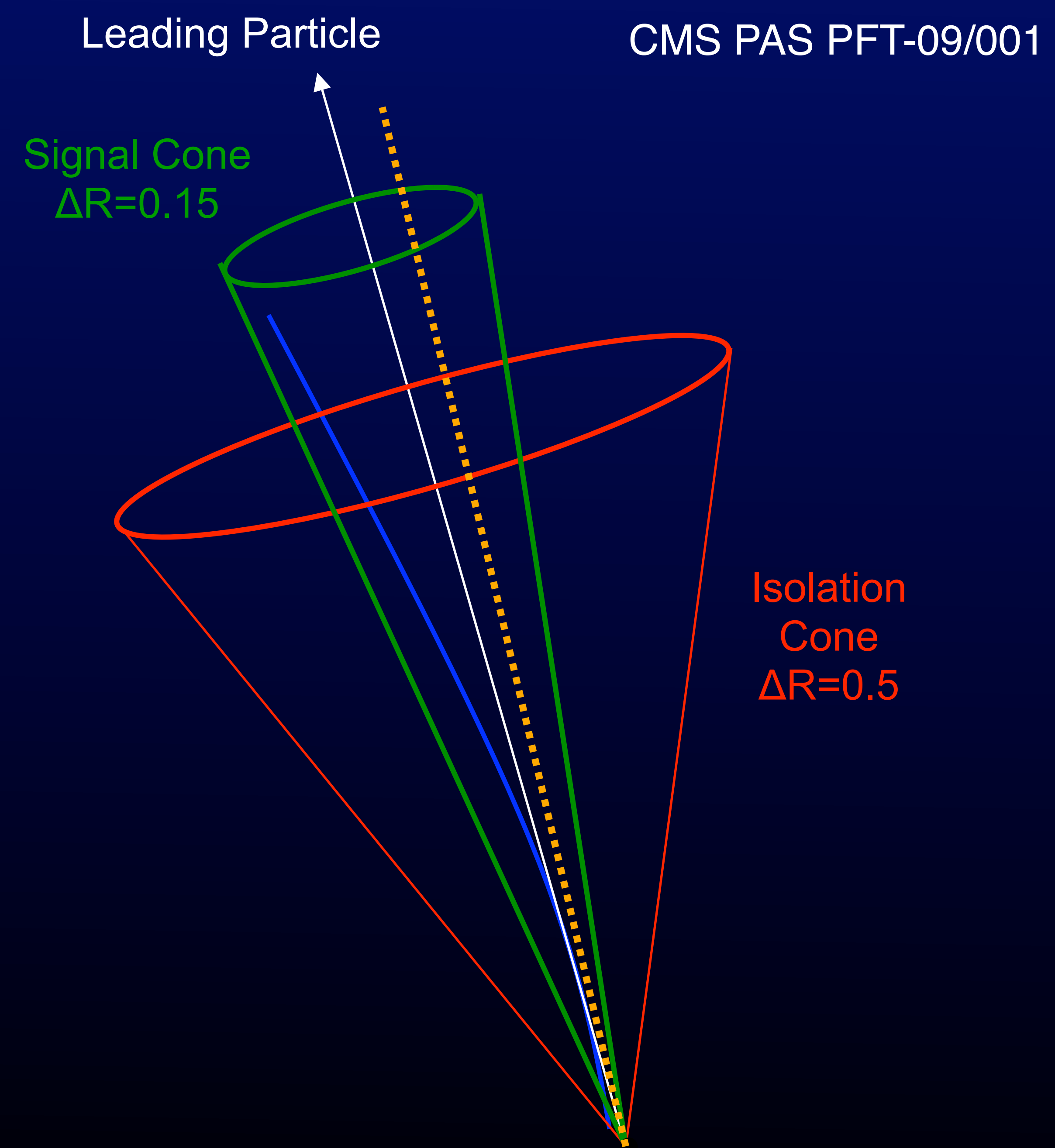
CMS tau strategy

- Use integrated <u>particle flow</u> approach

Leading particle
p_T > 5 GeV/c
ΔRjet axis < 0.1

Signal cone: sum up all particles with p_T>0.5 GeV/c

Isolation cone
Isolation annulus



Tau Algorithms at CMS

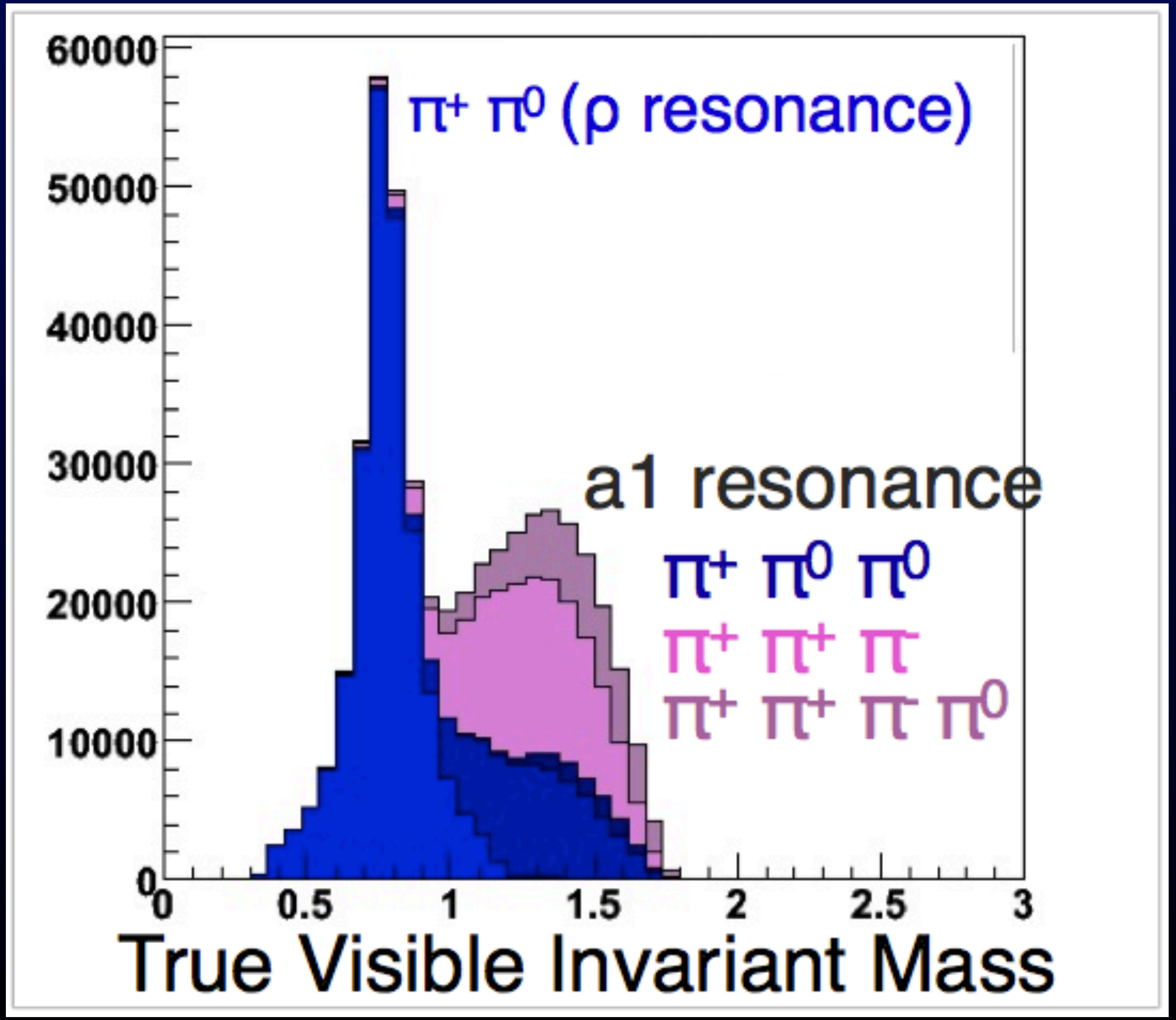
- 4 Algorithms in development
  - **Fixed and shrinking cone**
  - **Tau Neural Classifier**
  - **Hadron Plus Strips**
  - **Cut base track and calorimeter isolation**
- Figures of merit
  - **Efficiencies**
  - **Fake Rates**

Caveat: Not approved results!

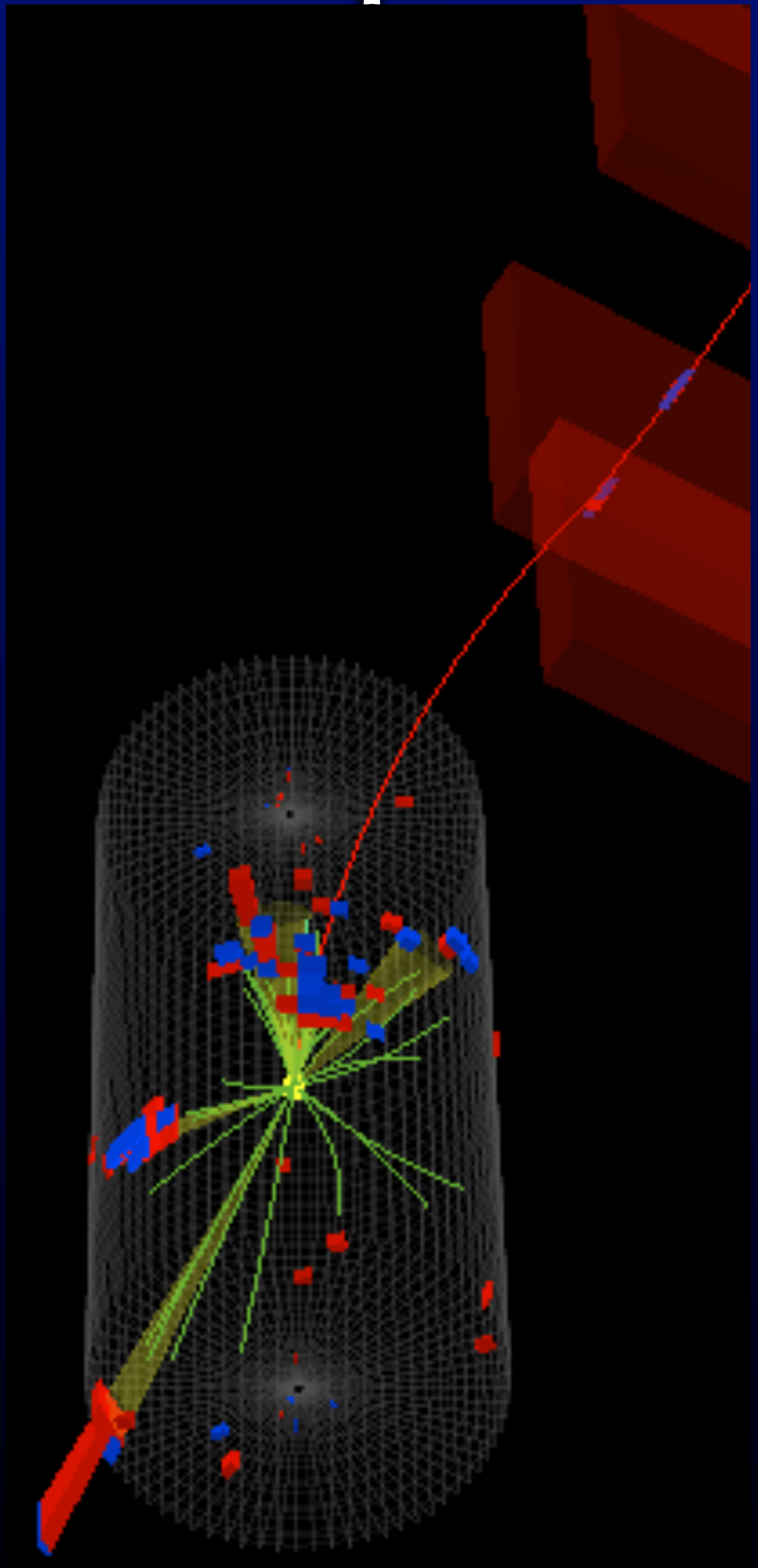
TauNeuralClassifier (TaNC)

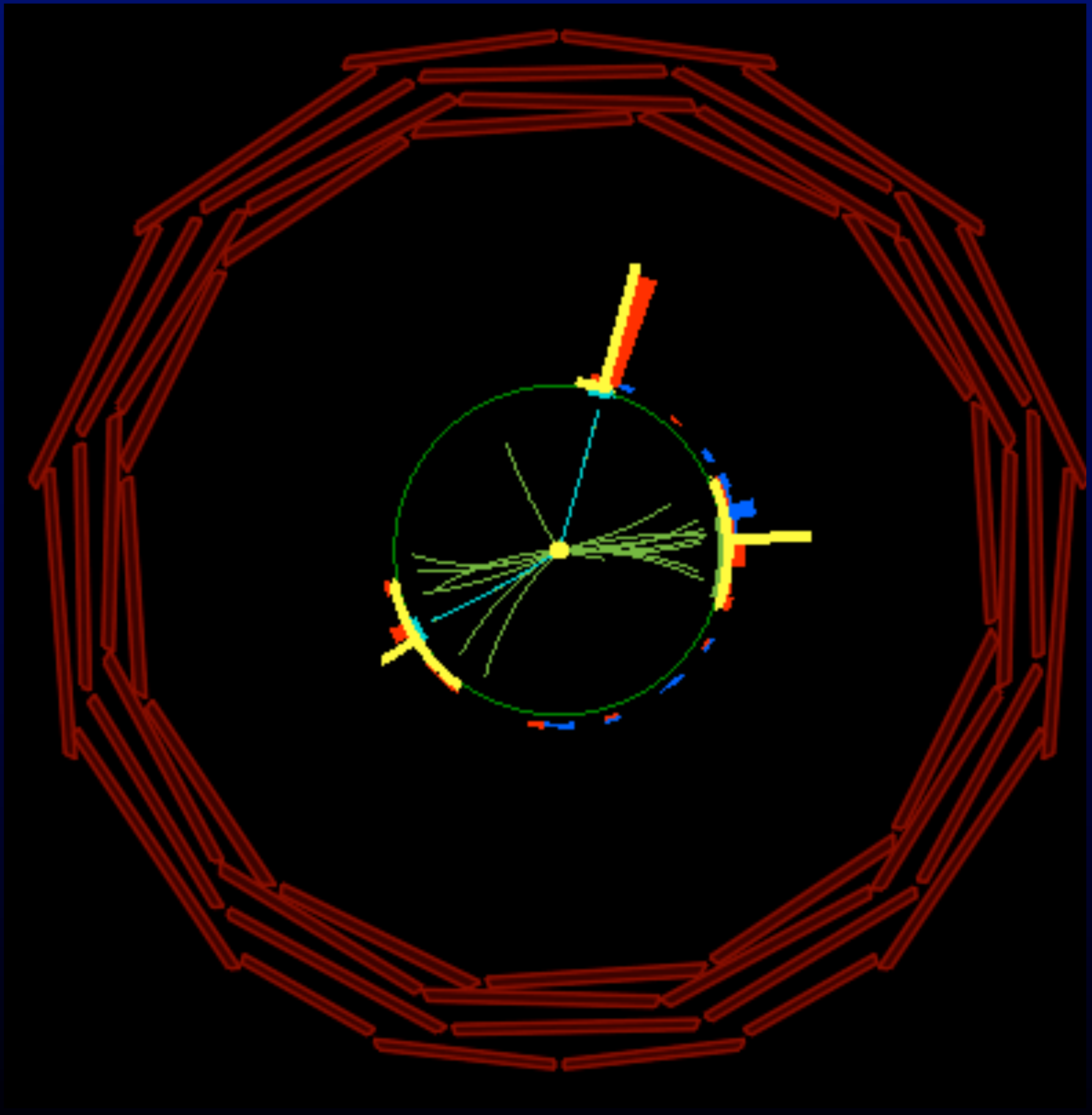
- Goal: improve τ-ID with decay mode information
  - **Different hadronic decay modes have different underlying resonances**
  - **Use to reject QCD**

Decay	BR	Mediator
$\pi^+ \nu$	11%	N/A
$\pi^+ \pi^0 \nu$	25%	ρ (770 MeV)
$\pi^+ \pi^0 \pi^0 \nu$	10%	a1 (1.2 GeV)
$\pi^+ \pi^+ \pi^- \nu$	14%	a1 (1.2 GeV)
Total	60%	
All hadronic modes	65%	



Trileptons with taus



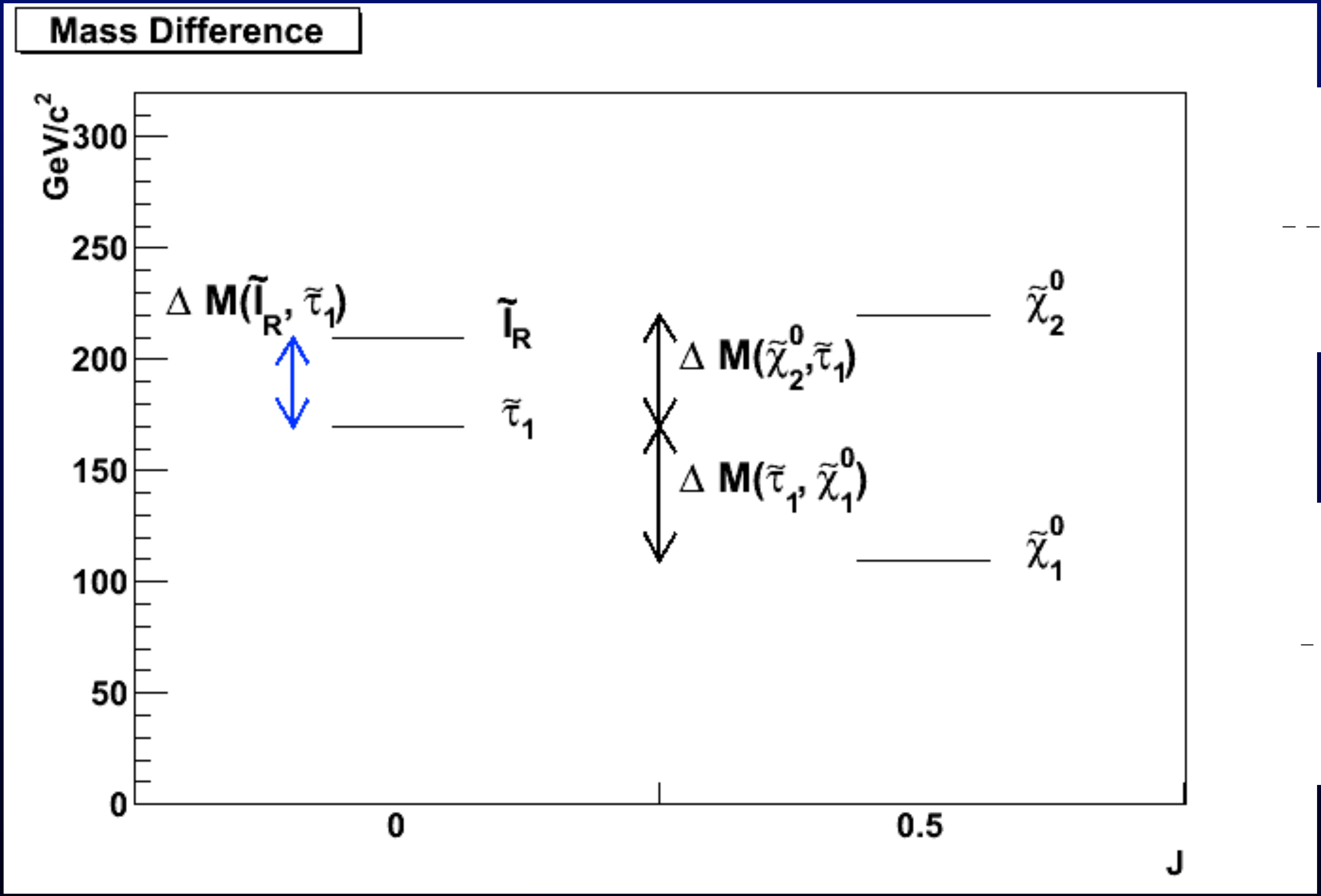


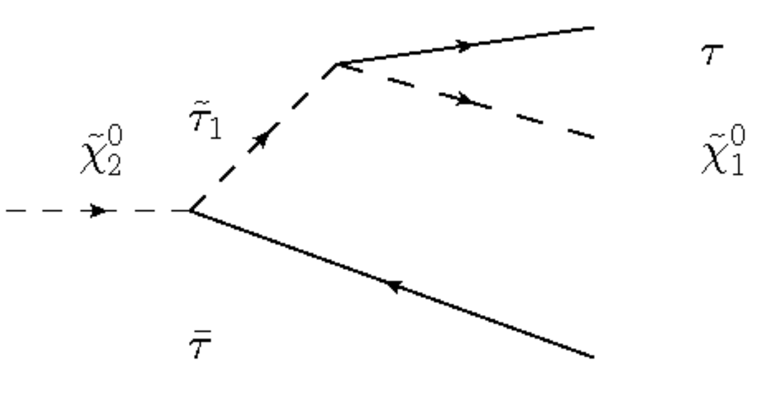
CMS Trilepton Selection

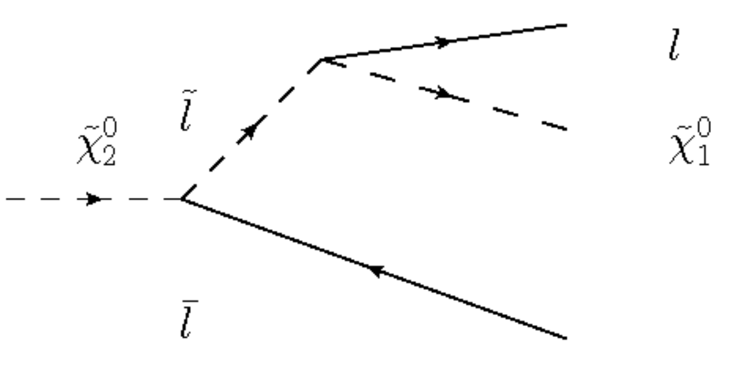
Used for synch. study, not with the TaNC

	Cut and Selection	
τ	E_T	> 8 GeV
	$\|\eta\|$	< 2.4
	$p_{T}{}^{lead}_{track}$	> 5.0 GeV/c
	PF γ Isolation	< 1.5 GeV
	PF Track Isolation	< 1.0 GeV/c
	Discriminator	e, μ
	Prong	1 or 3
	$Hits^{lead}_{track}$	> 8
	$\|dxy(beamspot)^{lead}_{track}\|$	< 0.1
e,μ & Event	#e, or μ	$= 2$
	$\|\Sigma Q_{lepton}\|$	$= 1$
	di-lepton Mass Veto	$<$ 10 or between 75 and 105 GeV/c^2
	$\Delta R(\tau, e\, or\, \mu)$	> 0.3
	$\not{E}_T$	> 35 GeV

Extending to high tan β



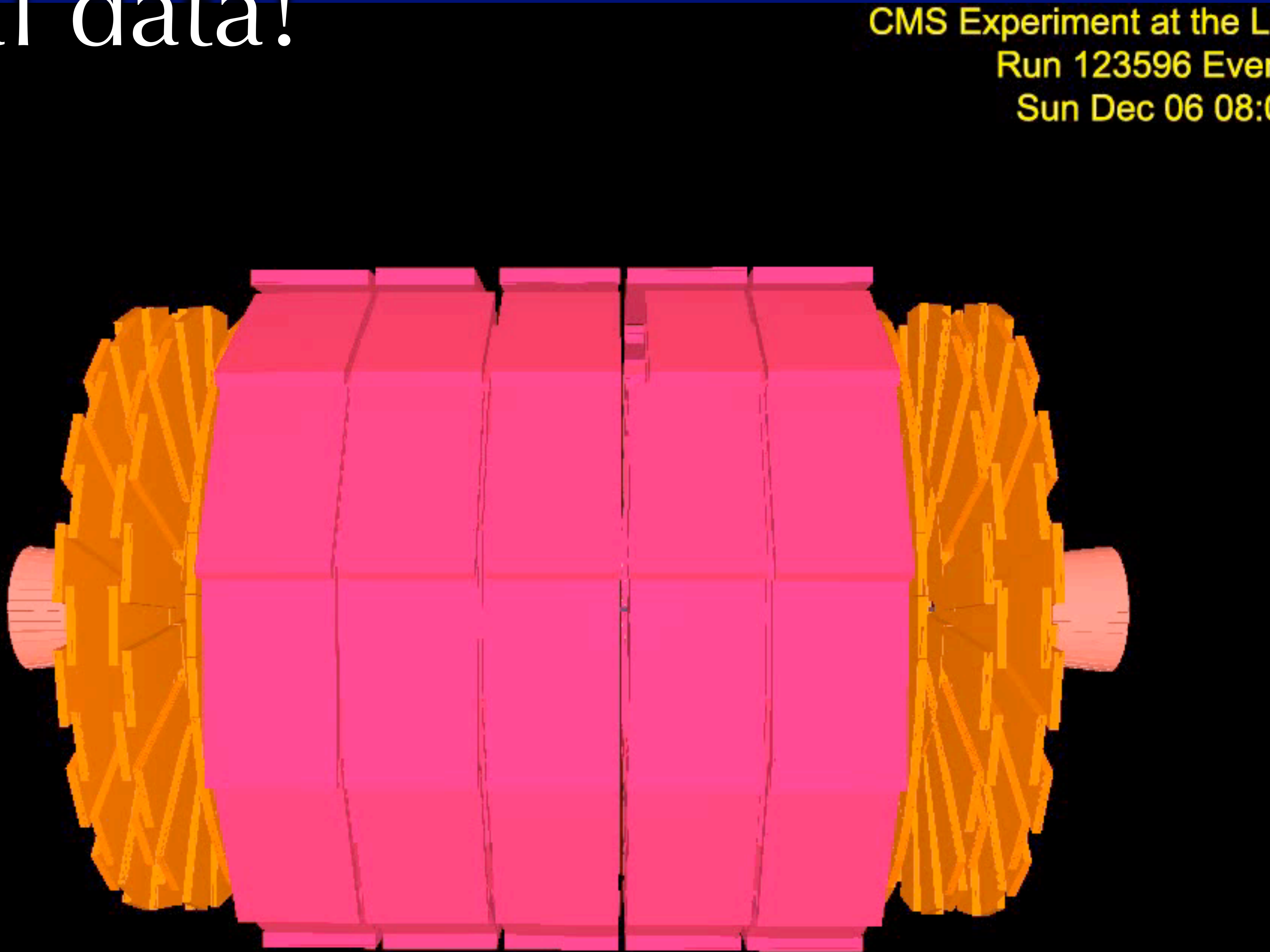




More taus for CMS...

- High mass $Z' \to \tau\tau$
- $H^+ \to \tau\nu$
- NMSSM: $H \to aa$, $a \to \tau\tau$
  - **First searching for $a \to \mu\mu$ near Upsilon**
- Revisit τ triggering

Real data!



Conclusions

Conclusions

- Tevatron might finish with a bang
- LHC startup is not quick but inexorable
- With 1/fb start to take over from Tevatron on SUSY searches
- Taus now "usable" and "useful". Who knows, maybe they will even be "crucial".
  - **the "b" of the 2010's?**

Thank you!