SUSY Tau, Muon and Electron Signatures

Maxwell Chertok
UC Davis

West Coast LHC Theory Network Meeting
UC Davis
December 8, 2006

Overview

- UC Davis Experimental Group
- Tau leptons in exotics physics
- Tevatron
- LHC
- Conclusions

UCD HEP Experiment Faculty

Maxwell Chertok
Associate Professor

John Conway
Associate Professor

Robin Erbacher
Assistant Professor

Winston Ko
Professor and Dean

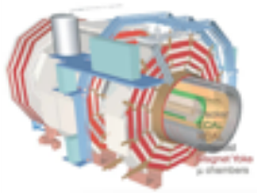
Richard Lander
Professor

David Pellett
Professor

S. Mani Tripathi
Professor

Philip Yager
Professor

Experimental activities



CMS - Compact Muon Solenoid

Faculty: Chertok, Conway, Erbacher, Ko, Lander, Pellett and Tripathi
Research Physicists: Breedon, Cox, Soha and

http://ucdcms.ucdavis.edu/CMS/UCD_CMS.html

CDF - Collider Detector at Fermilab

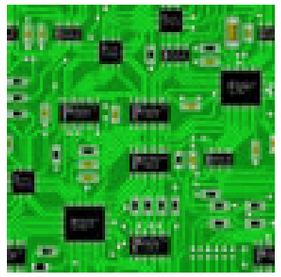
Faculty: Chertok, Conway, Erbacher, Lander and Pellett
Research Physicists: Safonov, Smith and Soha

FOCUS (FNAL E-831)

Faculty: Yager

CACTUS Observatory

Faculty: Chertok and Tripathi



Electronics Development

Various Faculty
Principal Engineer: Britt Holbrook

Linear Collider R&D

Faculty: Pellett and Tripathi

details at http://ucdcms.ucdavis.edu/

UCD Exotics Team

Senior researchers

- Smith, advanced MC methods
- Breedon, Cox jumping in

Postdocs

- Soha -- CDF, CMS
- CMS tau's: Sierra, Veelken
- Lister, Schwarz -- CDF top & top exotics

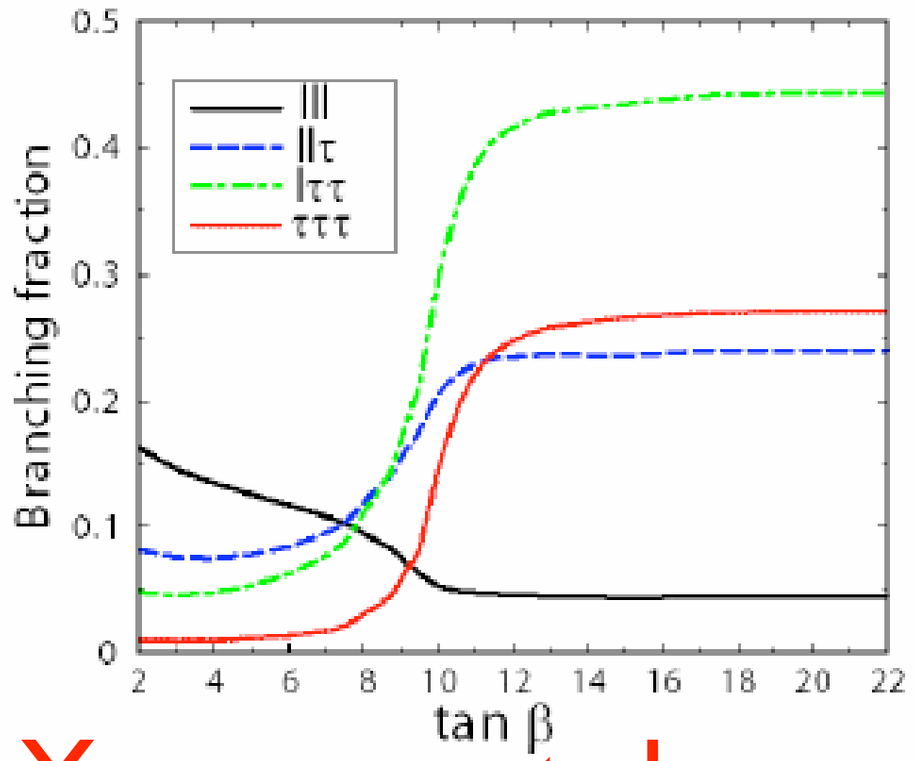
Students

- 4 Ph.D.s this year!
- Maruyama, Stilley, Friis, Dolen, Searle...
- Undergrads, too: (Sandalski, del Toro, etc.)

Golden Signatures

- Colliding hadrons at 40 MHz messy
- Jets copious but SM sources overwhelming
- Leptons are clean
  - SM rates well understood, but
  - Leptonic BRs are relatively "rare"
- Multi-object leptons very powerful
  - LS dileptons, trileptons, etc. We validated this claim in Run I.
- What if nature prefers 3rd gen.?

Taus in Exotics



You cannot do exotics with taus without real SM tau preparation:

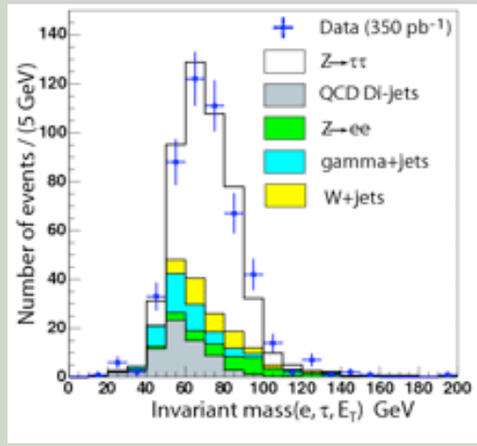
- Z → tau tau, W → tau nu
  - Our CDF Z→ tau tau analysis is with Collaboration for comments
- Top with taus
  - Br (pp → ttbar) ~ 830 pb @NLO @ LHC!!

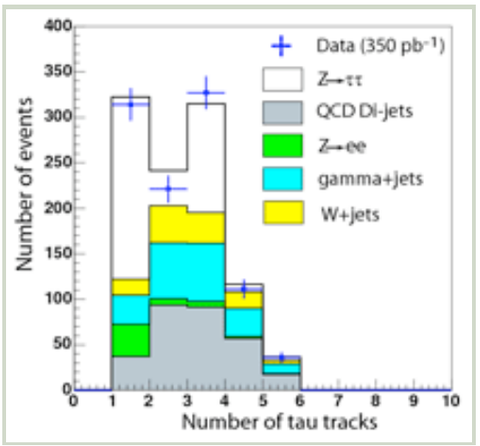
Fermilab Today

Thursday, January 12, 2006

Fermilab Result of the Week

When "Heavy Photons" Decay to Taus





Distribution of invariant mass for an electron + tau + missing E_T system, where we choose narrow jets with N_{track} = 1 and 3.

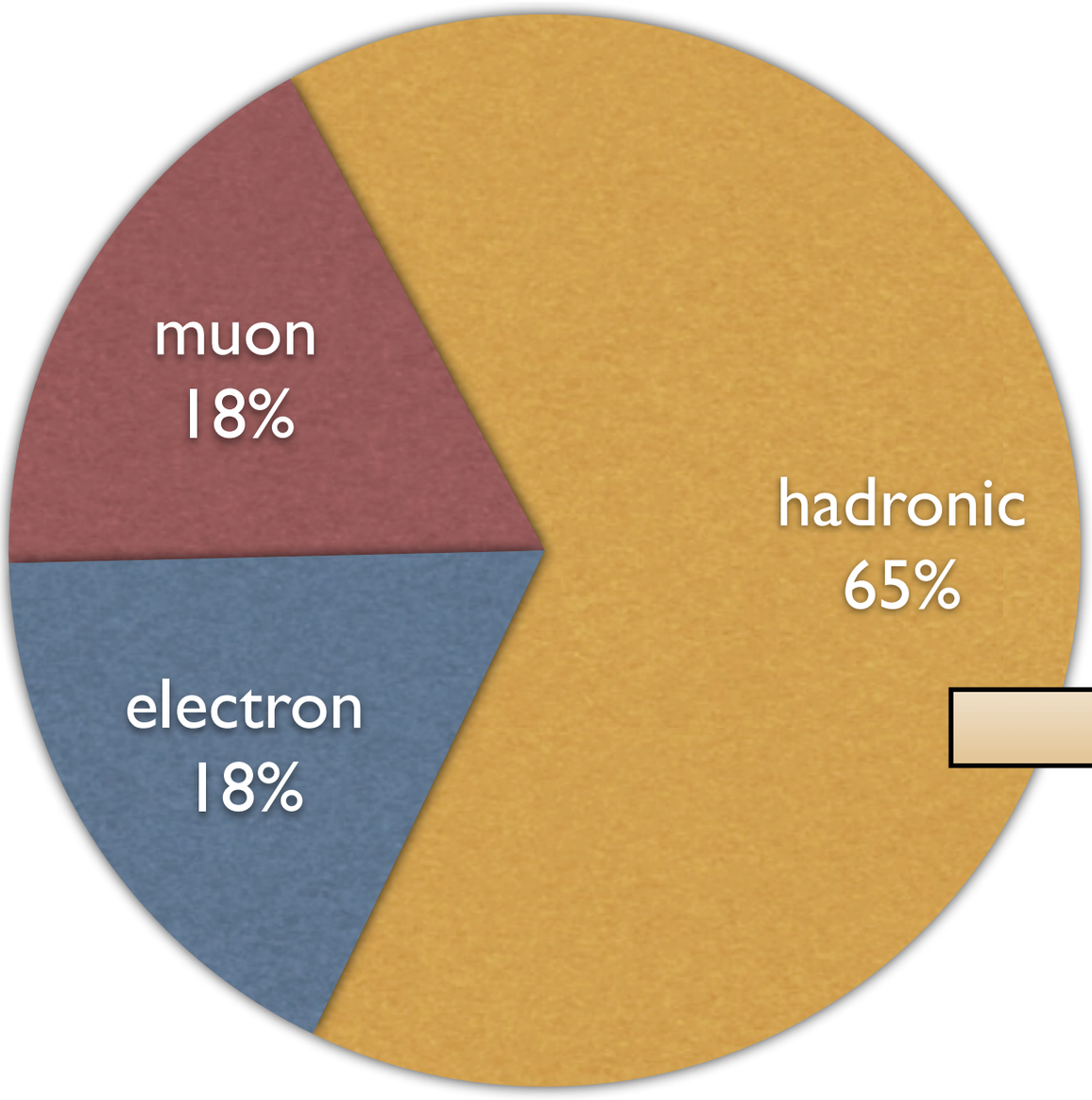
The Monte Carlo prediction for Z decays to tau pairs and its background agree with the data. The difference between the data and the total background (a sum of colored histograms) is accounted as the number of Z's detected and used to determine the production cross section. (Click on image for larger version.)

Sometimes a photon is not just a photon. Sometimes it's really heavy, and we call it a Z. You don't get many Z's from your flashlight, but when particles and antiparticles collide at high energy, occasionally we get Z's instead of photons.

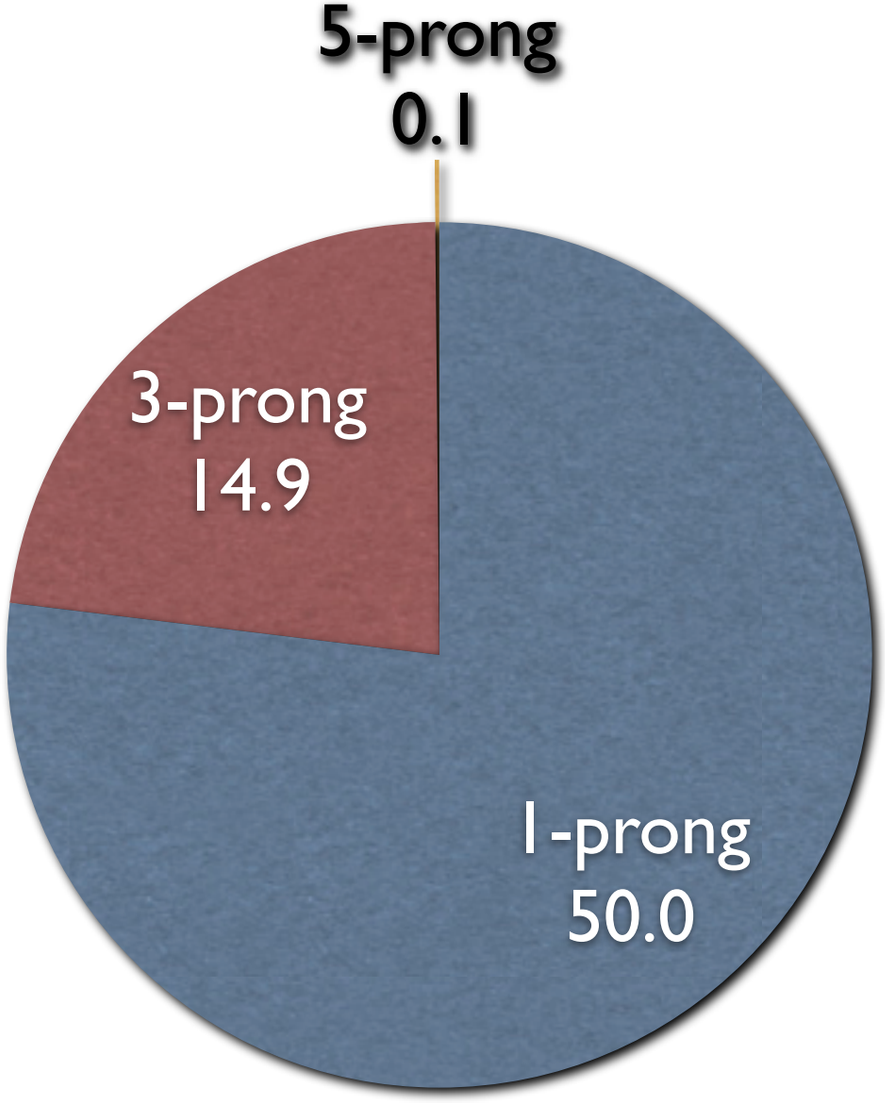
These Z's don't hang around long and decay into a pair of leptons or quarks as long as they sum up to zero electric

Tau Leptons in Exotics

- "Interesting" decays!



Hadronic Tau Decays

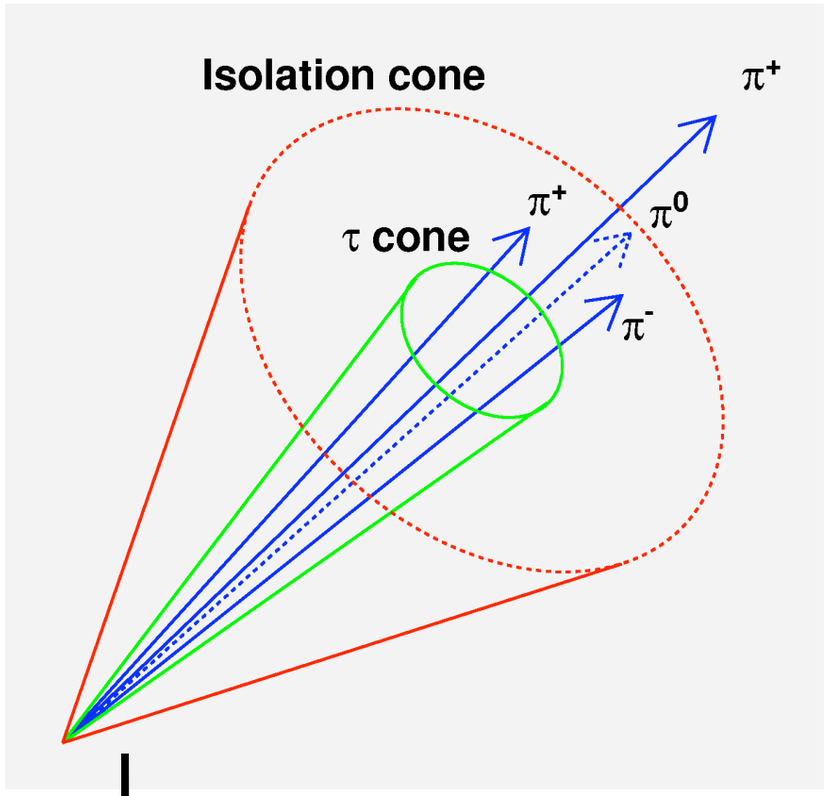


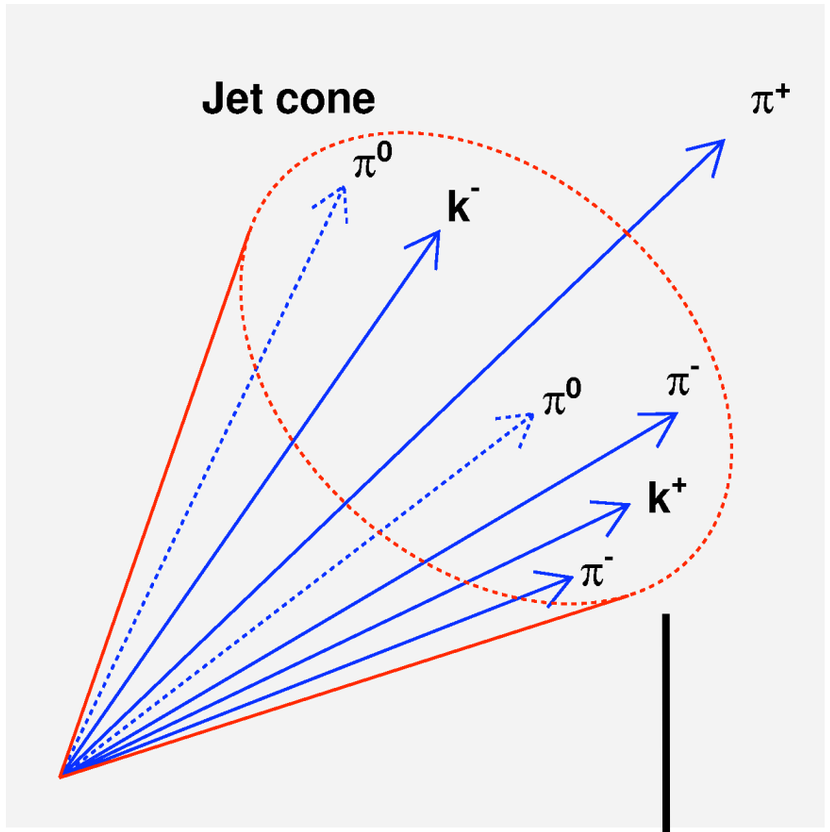
Tau Triggering at CDF

- Lepton + Track triggers - created for SUSY cascades: low P_T
  - Central electron or muon
  - Isolated track (seed for tau)
- Tau + Missing E_T trigger
- Di-tau trigger

Level 2 tracking trigger upgrade (now) will keep these viable at high inst. luminosity running

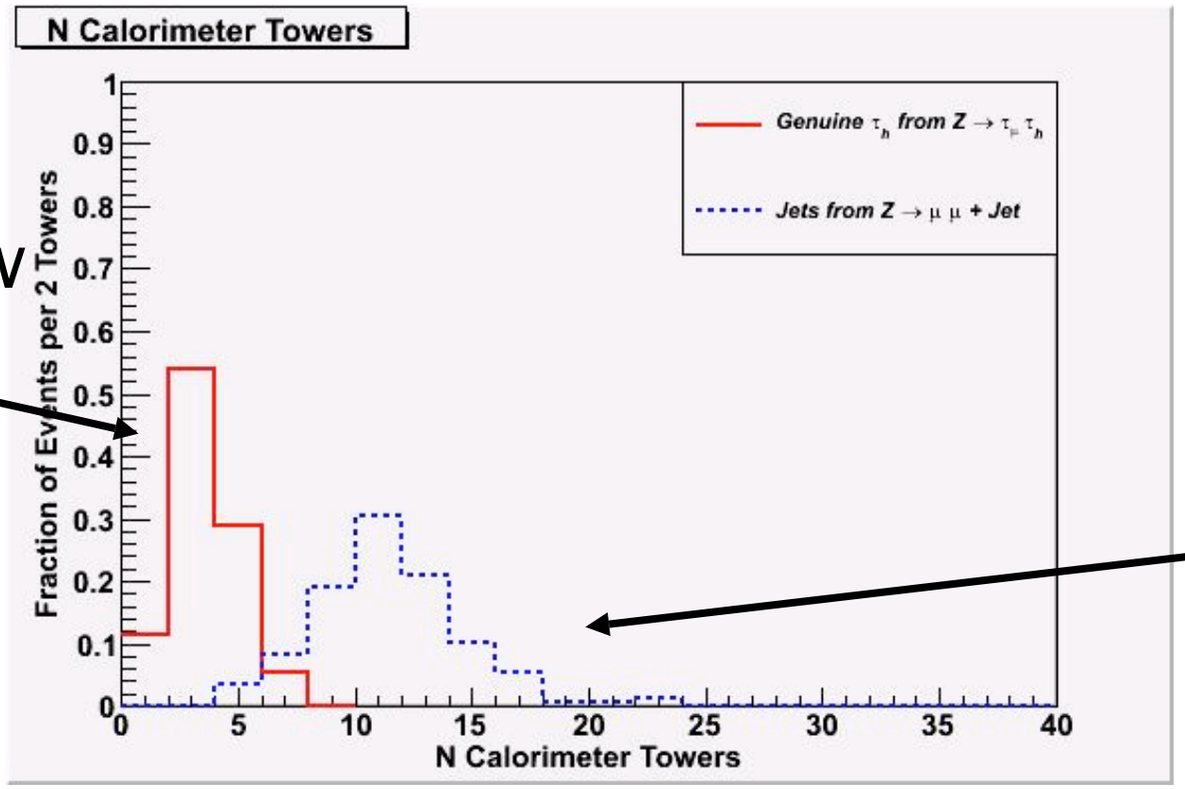
Tau Identification at CDF



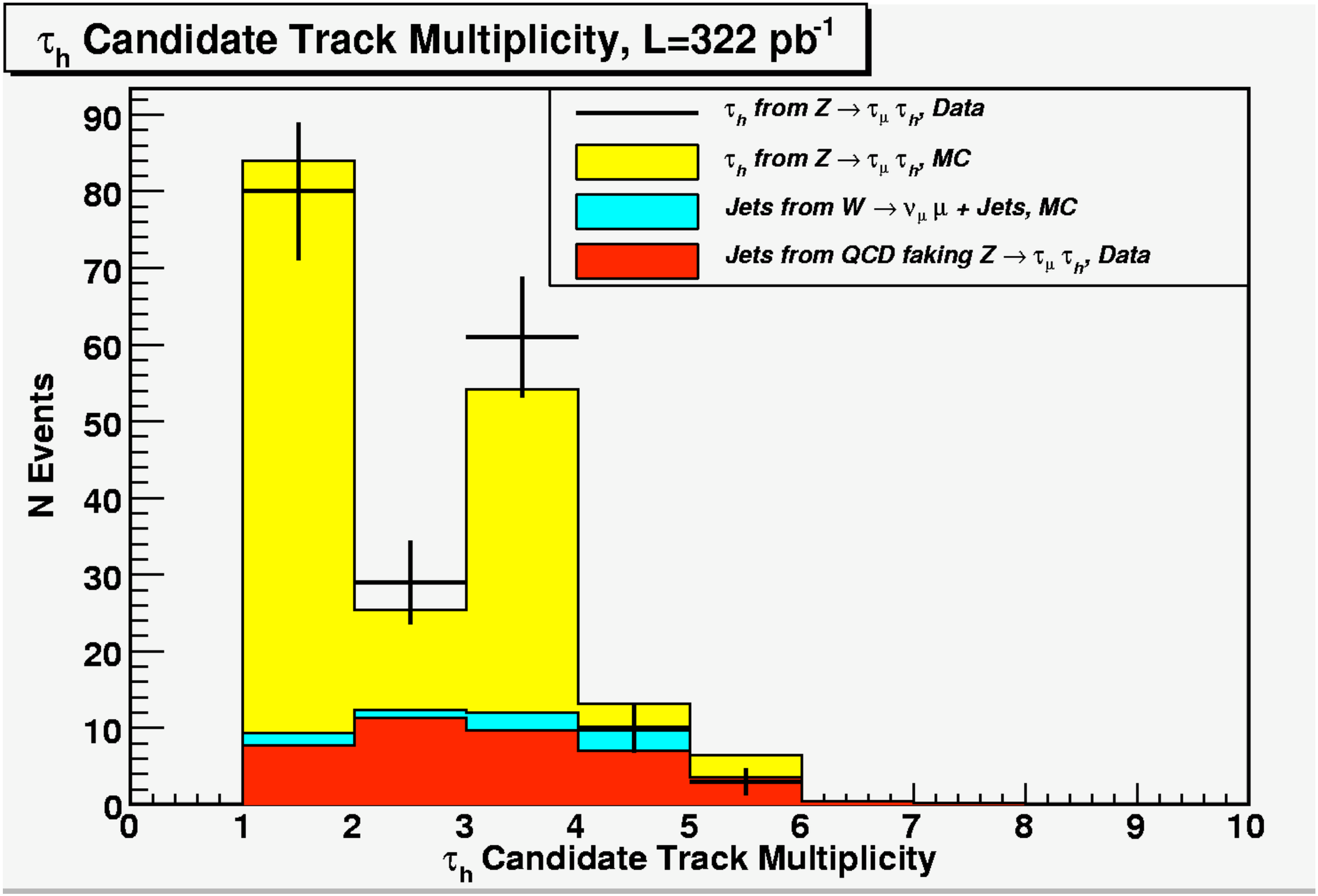


Taus are narrow

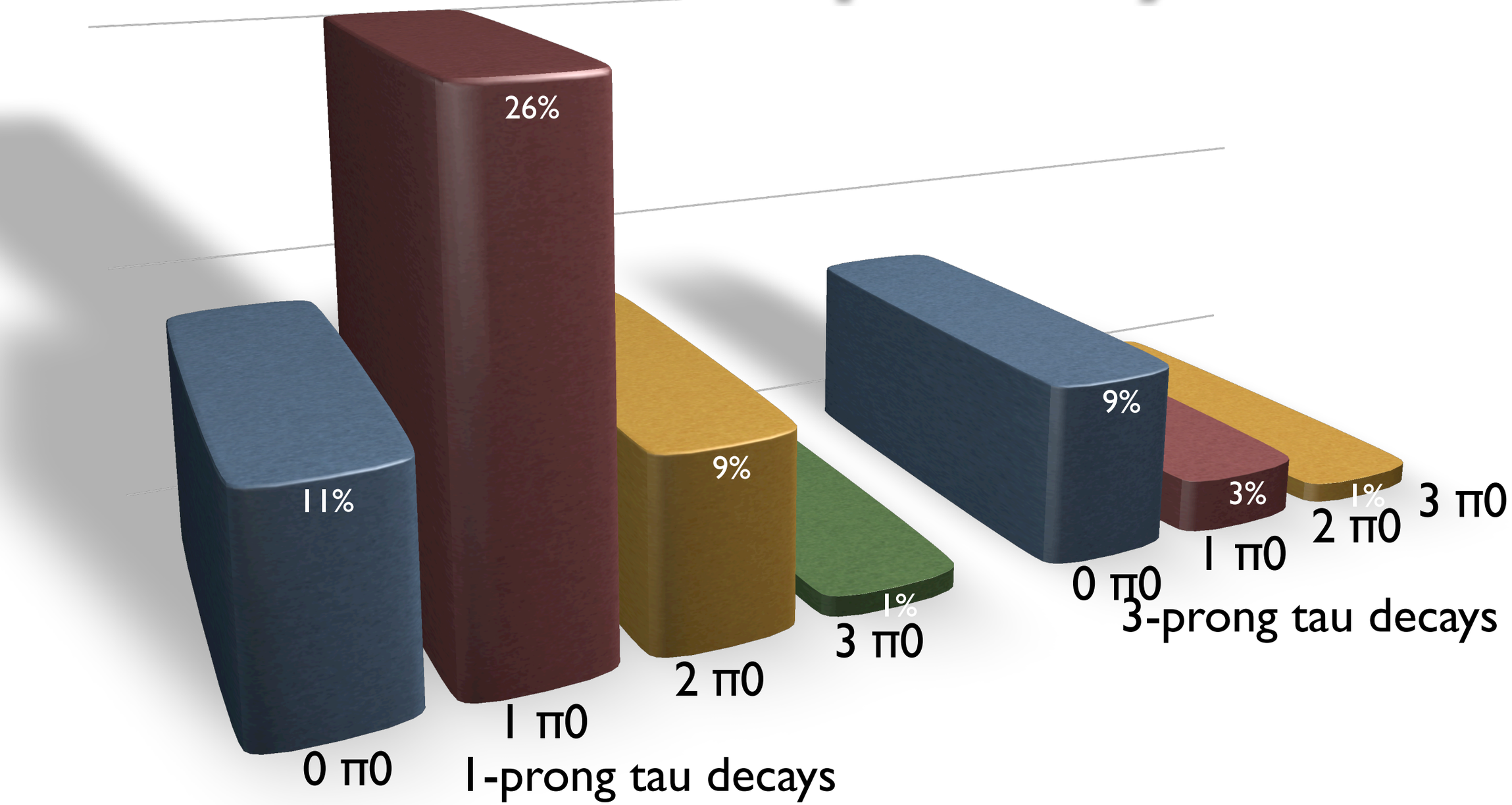
Jets are wide



Hadronic Tau Charged Tracks

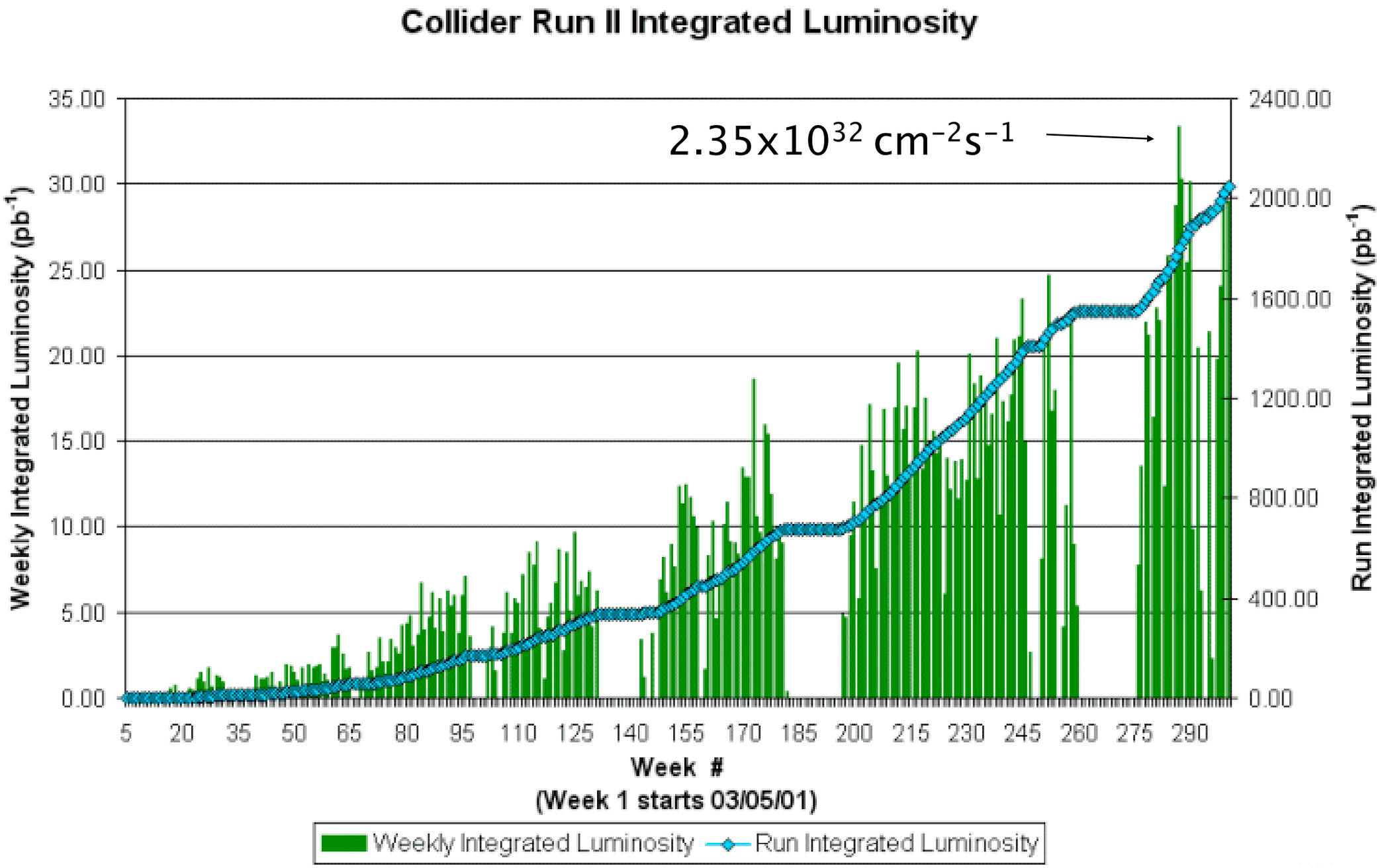


Neutral pion multiplicity



Recent results from the Tevatron

2/fb delivered/experiment!



Selected Tevatron analyses

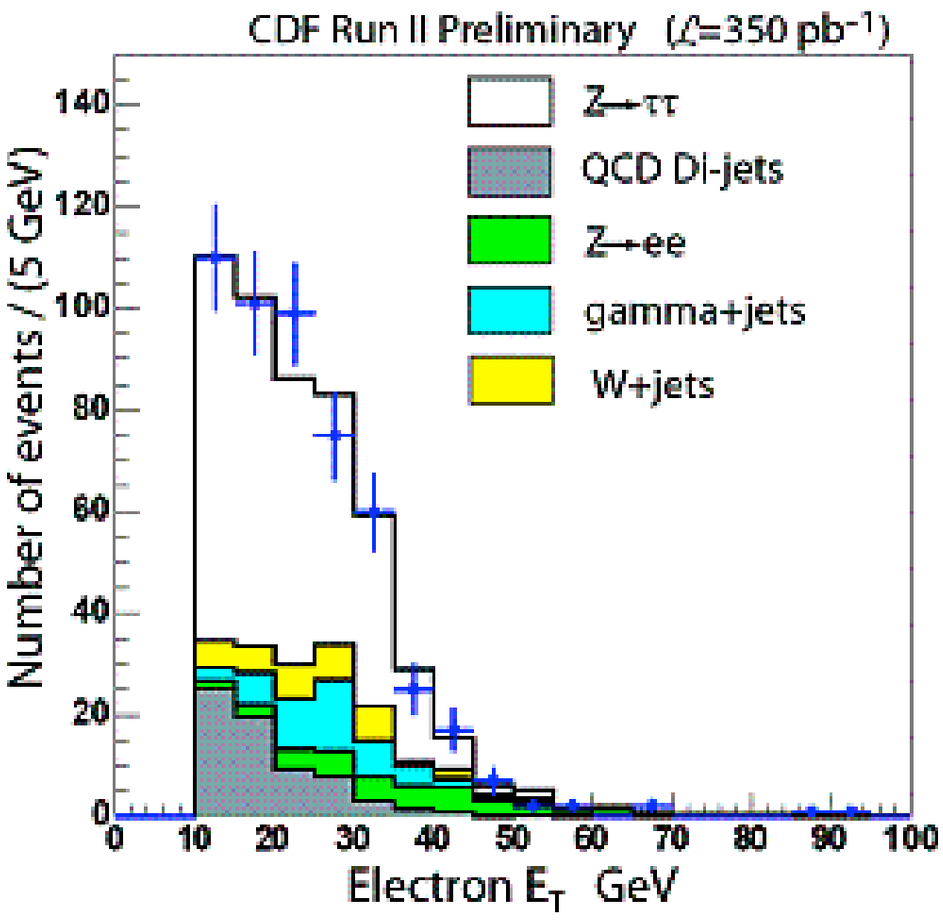
- $Z \rightarrow$ tau tau
- WZ cross section with trileptons
- R-parity violating Stop
- 3rd Generation VLQ
- Like-sign dilepton search

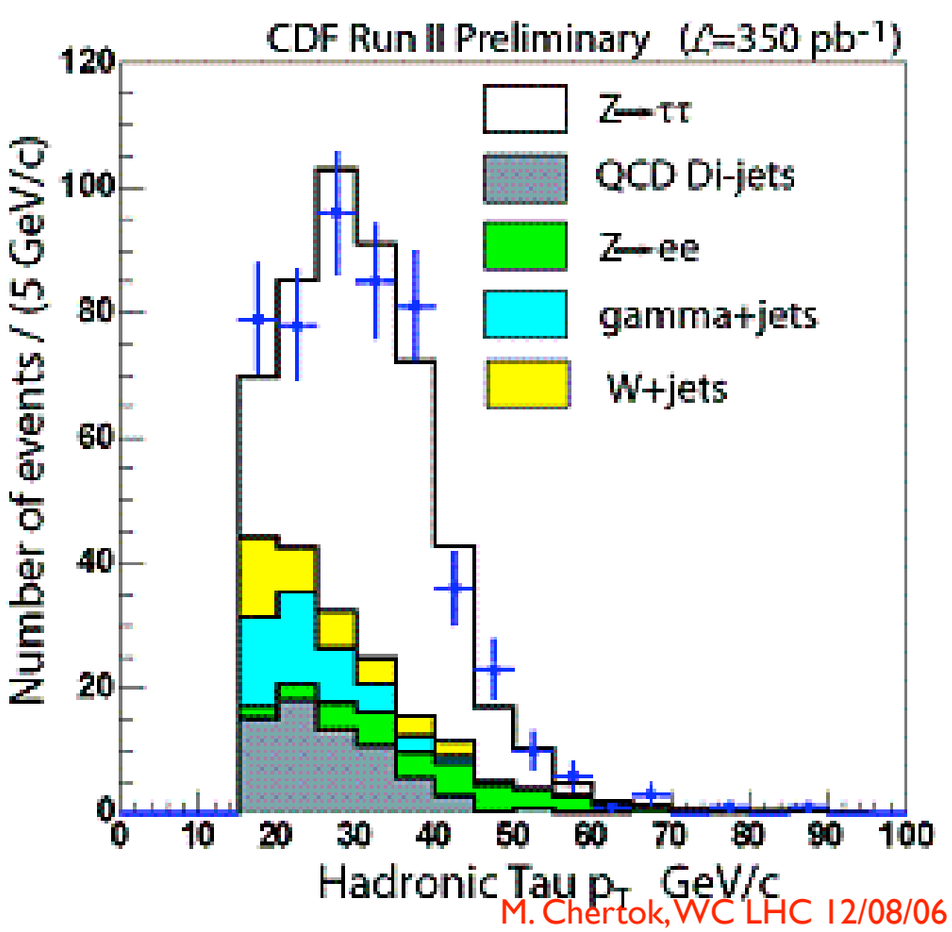
Z decays to τ pairs

- This is "the" tune-up (and background) for Z' favoring taus
- Shouldn't believe any H→ τ τ results before seeing this

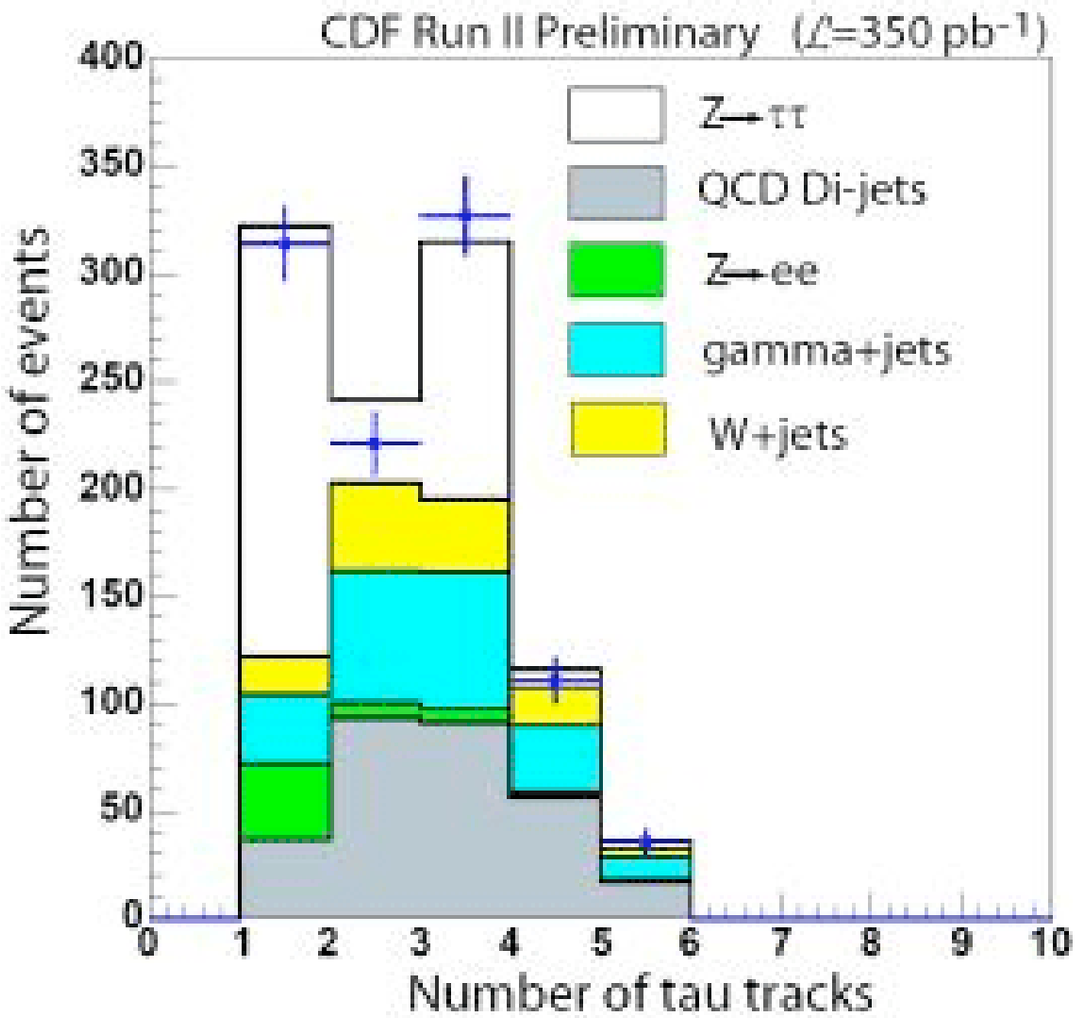
$Z \rightarrow \tau\ \tau$

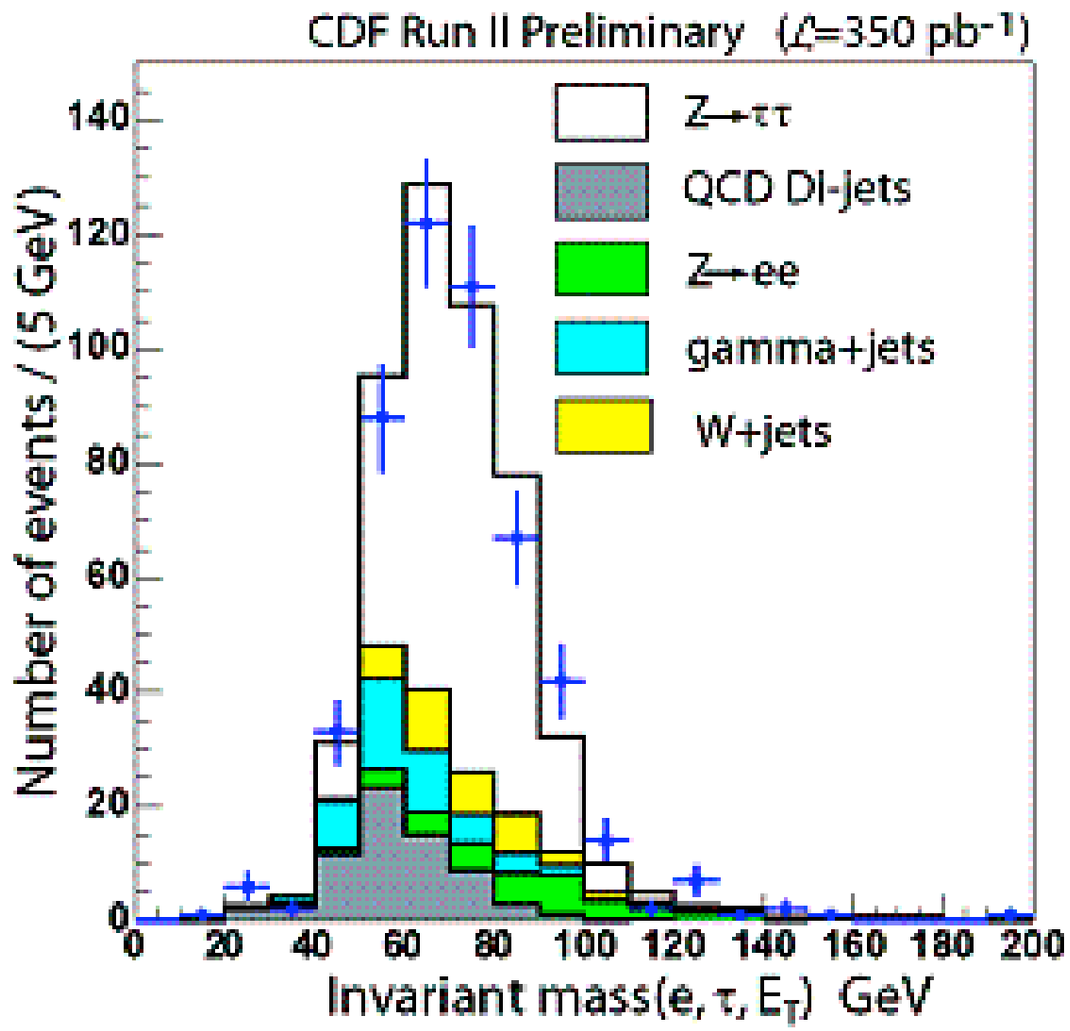
Process	Yield (in number of events)
$Z \rightarrow ee$	$34.8 \pm 1.4 \pm 7.0$
W+jets	$36.6 \pm 3.5 \pm 4.9$
γ+jets	$47.8 \pm 2.2 \pm 12.0$
QCD di-jets	68.6 ± 3.6
Total:	$187.7 \pm 5.7 \pm 15.0^*$
Data	504
$Z \rightarrow \tau\tau$	$316 \pm 23 \pm 15$





$Z \rightarrow \tau\ \tau$





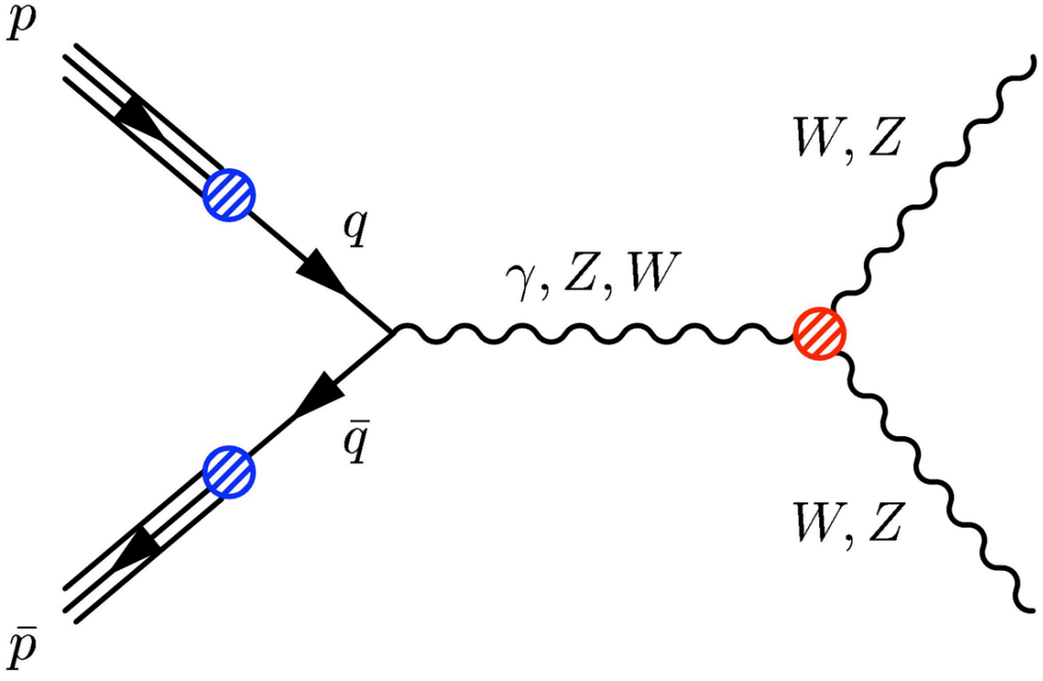
Measured cross section x Br:

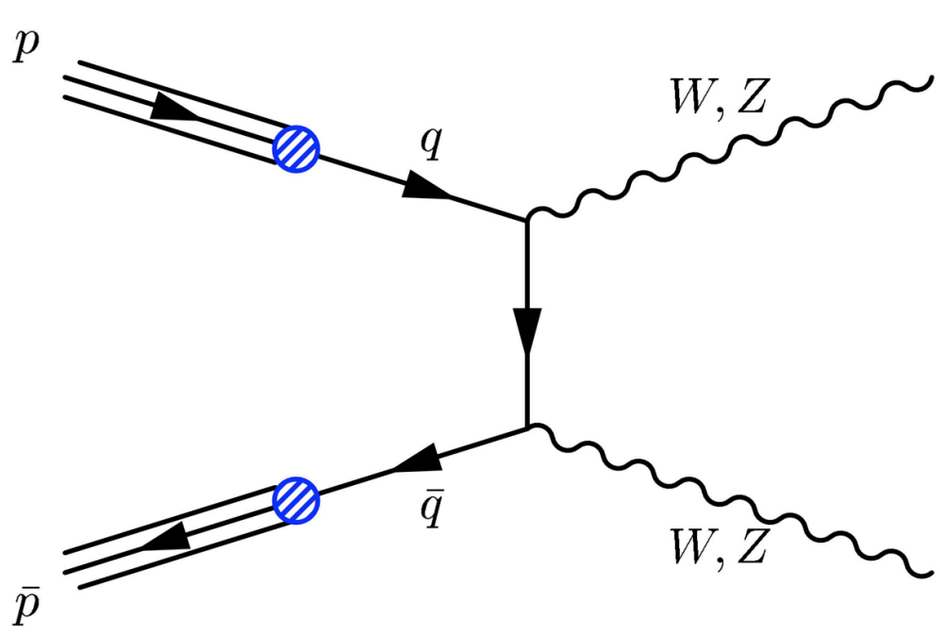
- 265 ± 20 (stat) ± 21 (sys) ± 15 (lumi) pb

New CDF WZ, ZZ results

Search for WZ, ZZ in 1.1/fb

- WZ: 3 leptons (e, mu) + MET
- ZZ: 4 electrons and/or muons
- Both: use "tracks" to increase acceptance
- Some additional acceptance from $\tau \rightarrow e,\mu$





New CDF WZ, ZZ results

- WZ analysis: σ(NLO) = 3.7 ± 0.3 pb

Source	Expectation ± Stat ± Syst ± Lumi
Z+jets	$1.22 \pm 0.27 \pm 0.28 \pm$ -
ZZ	$0.89 \pm 0.01 \pm 0.09 \pm 0.05$
$Z\gamma$	$0.48 \pm 0.06 \pm 0.15 \pm 0.03$
$t\bar{t}$	$0.12 \pm 0.01 \pm 0.01 \pm 0.01$
WZ	$9.79 \pm 0.03 \pm 0.31 \pm 0.59$
Total Background	$2.70 \pm 0.28 \pm 0.33 \pm 0.09$
Total Expected	$12.50 \pm 0.28 \pm 0.46 \pm 0.68$
Observed	**16**

$\sigma(WZ) = 5.0^{+1.8}_{-1.6}\,(\text{stat.} + \text{syst.})\,\text{pb}$

=5.9σ

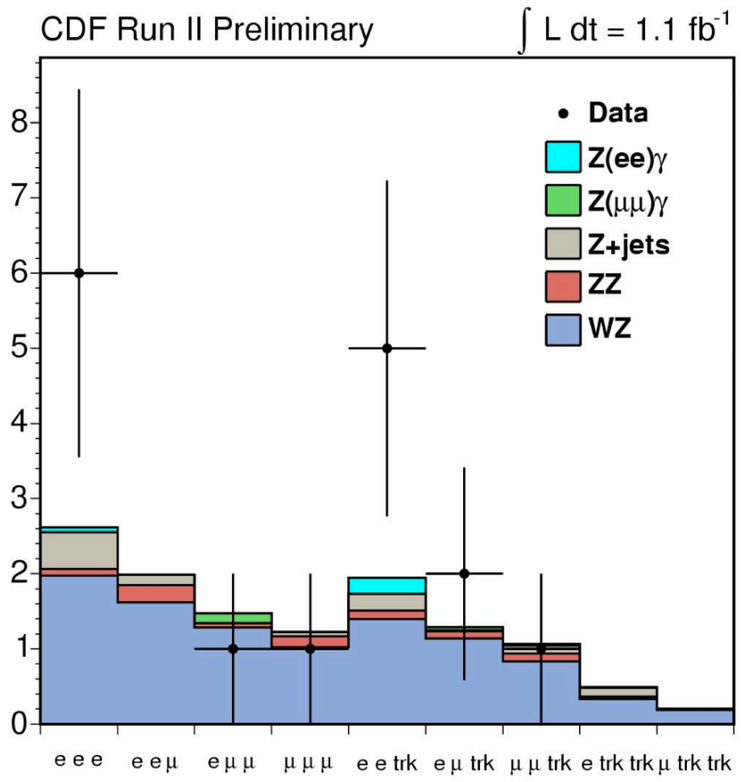
- ZZ analysis: σ(NLO) = 1.4 ± 0.1 pb

Source	Expectation ± Stat ± Syst ± Lumi
Z+jets	$0.007 \pm 0.007 \pm 0.004 \pm$ -
$Z\gamma\gamma$	$0.002 \pm 0.001 \pm 0.000 \pm 0.000$
ZZ	$1.884 \pm 0.015 \pm 0.061 \pm 0.113$
Total Background	$0.009 \pm 0.007 \pm 0.004 \pm 0.000$
Total Expected	$1.893 \pm 0.017 \pm 0.062 \pm 0.113$
Observed	**1**

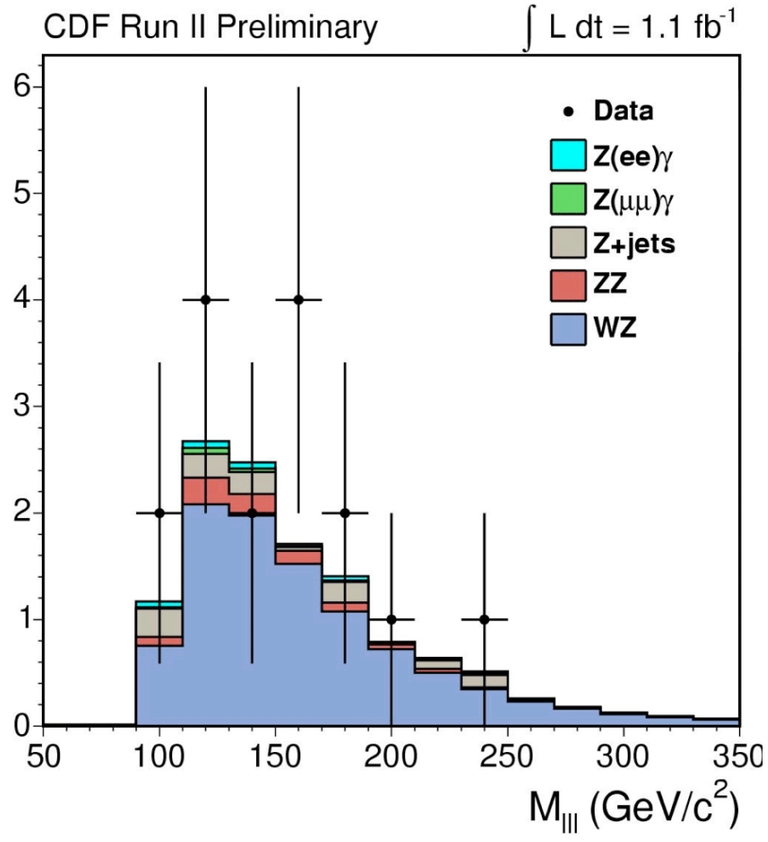
$\sigma(ZZ) < 3.8\,\text{pb}\ (95\%\ \text{C.L.})$

WZ Signal region plots

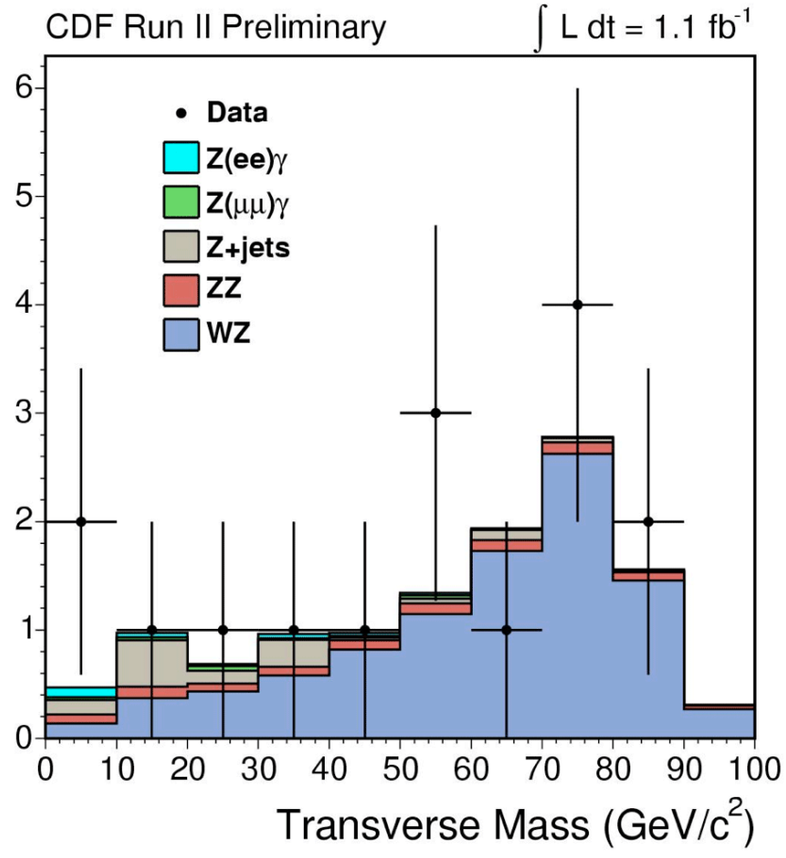
Signal region: Z window and MET>25



Trilepton types



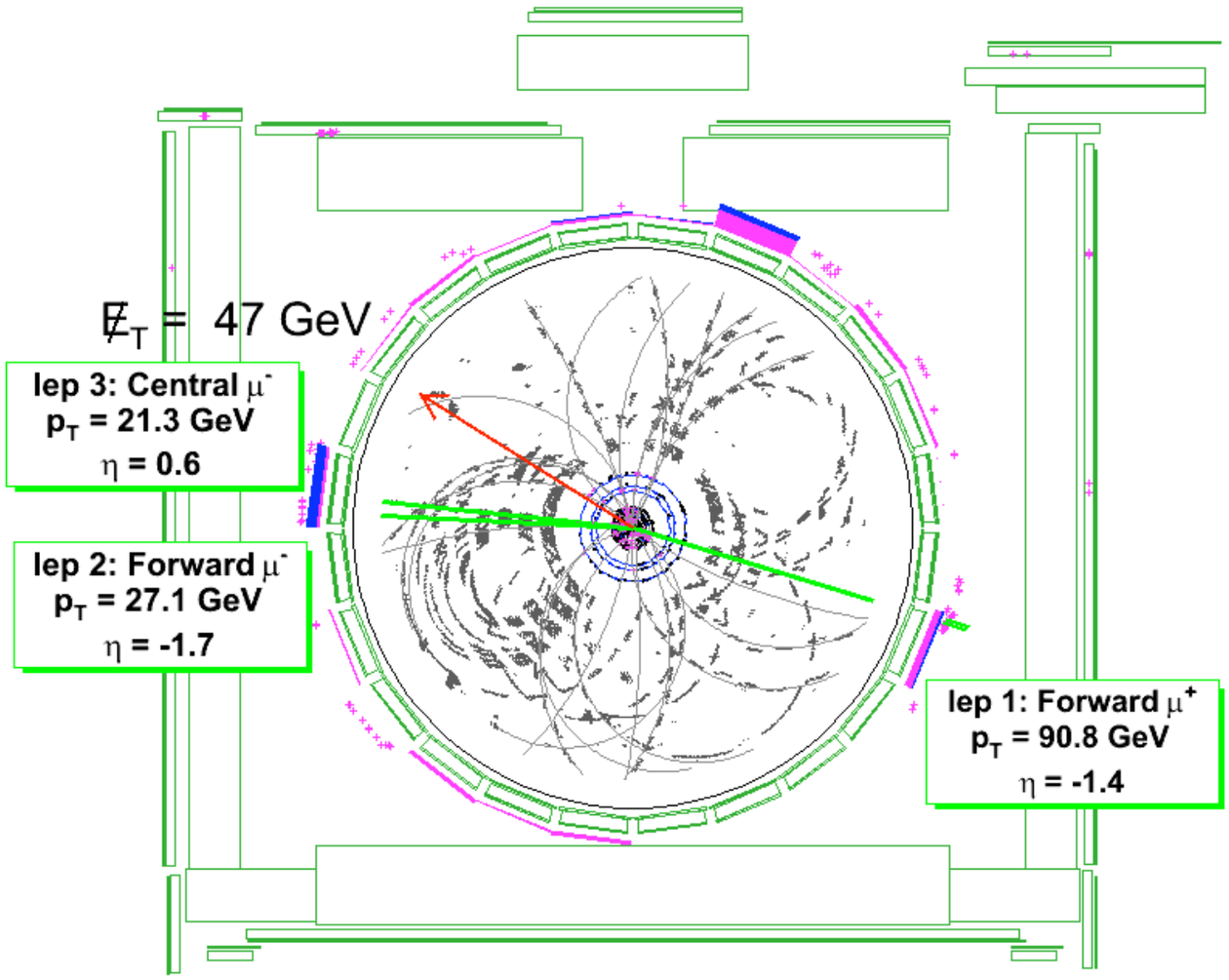
M(lll)

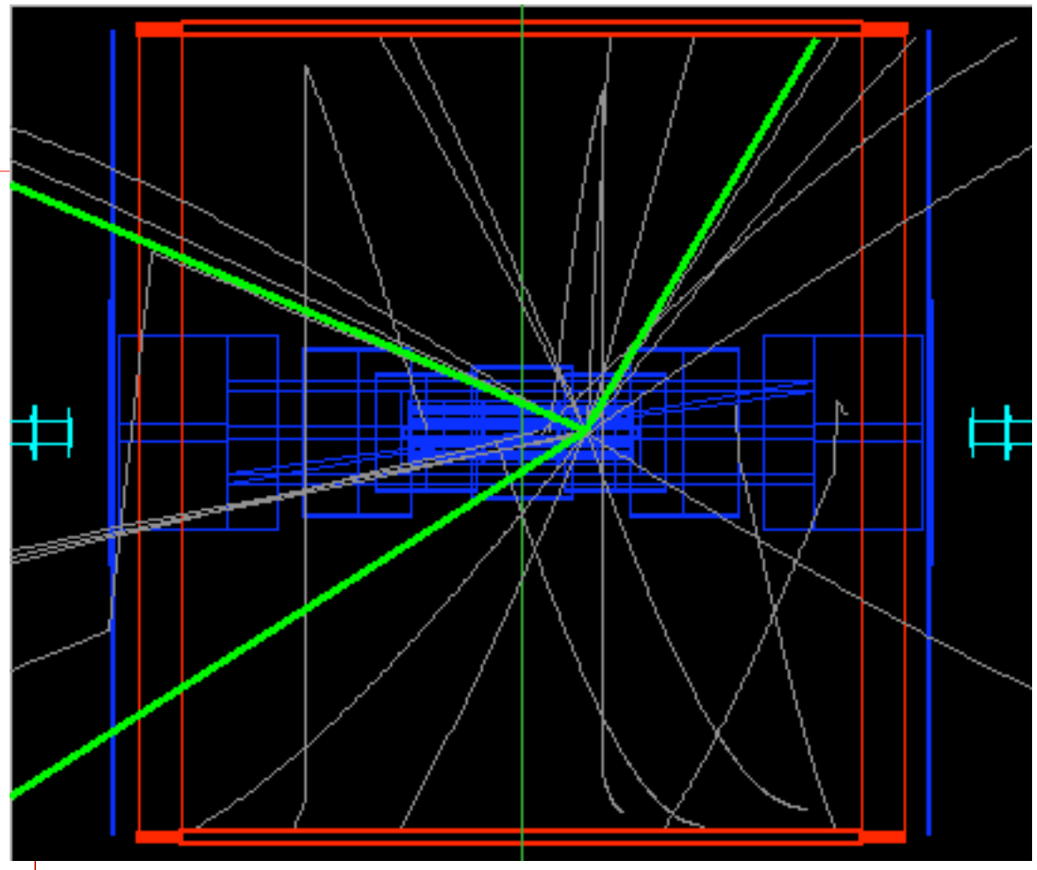


M_T is for non-Z lepton and MET

A Few WZ Event Displays

Trimuon





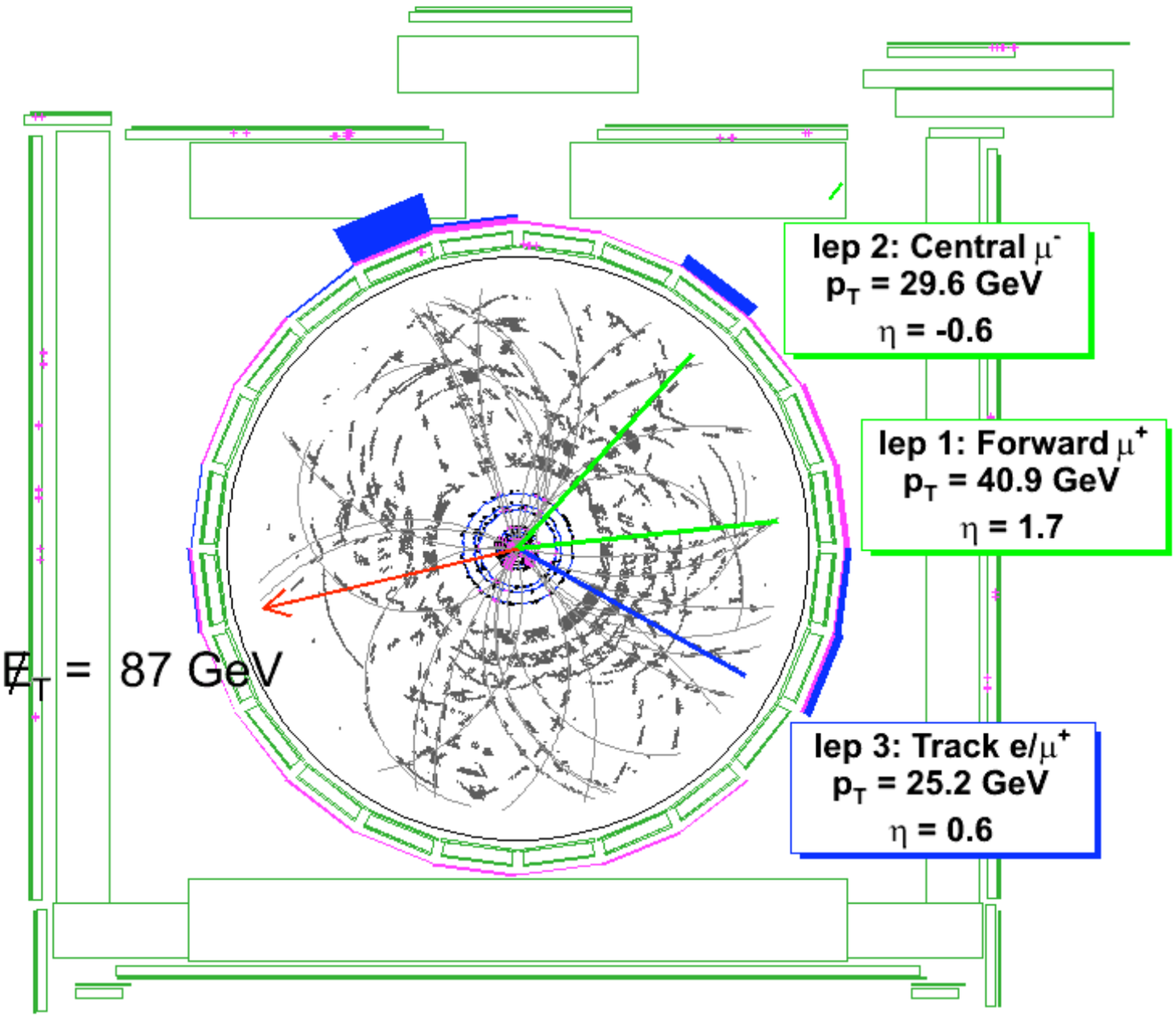
Run=186591 Event=1398363

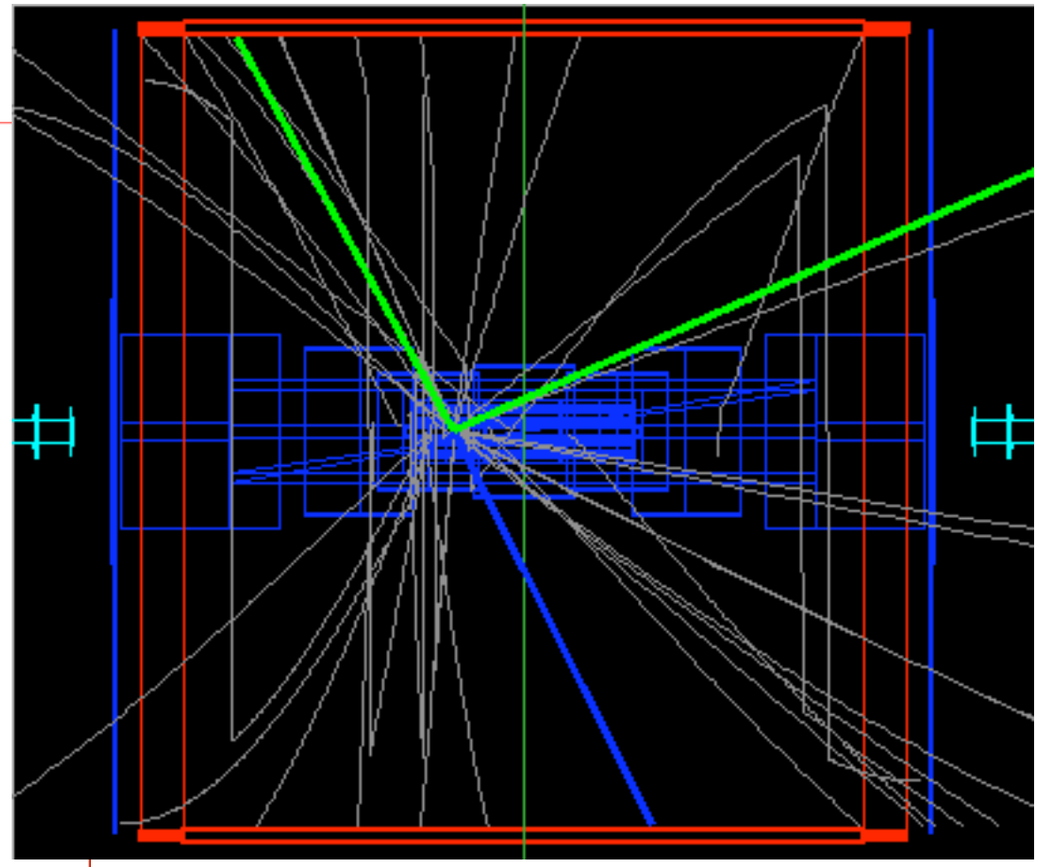
m_{12}=100.10 GeV $\quad |\not\!\!E_T|$=47.3 GeV
m_{13}=136.69 GeV $\quad \Delta\phi(\not\!\!E_T, \text{lepton, jet})$=0.4
m_{23}=71.50 GeV

Type	p_t	η	ϕ
Forward μ	90.8	-1.4	-0.3
Forward μ	27.1	-1.7	3.1
Central μ	21.3	0.6	3.0

WZ Event Displays

mu mu track





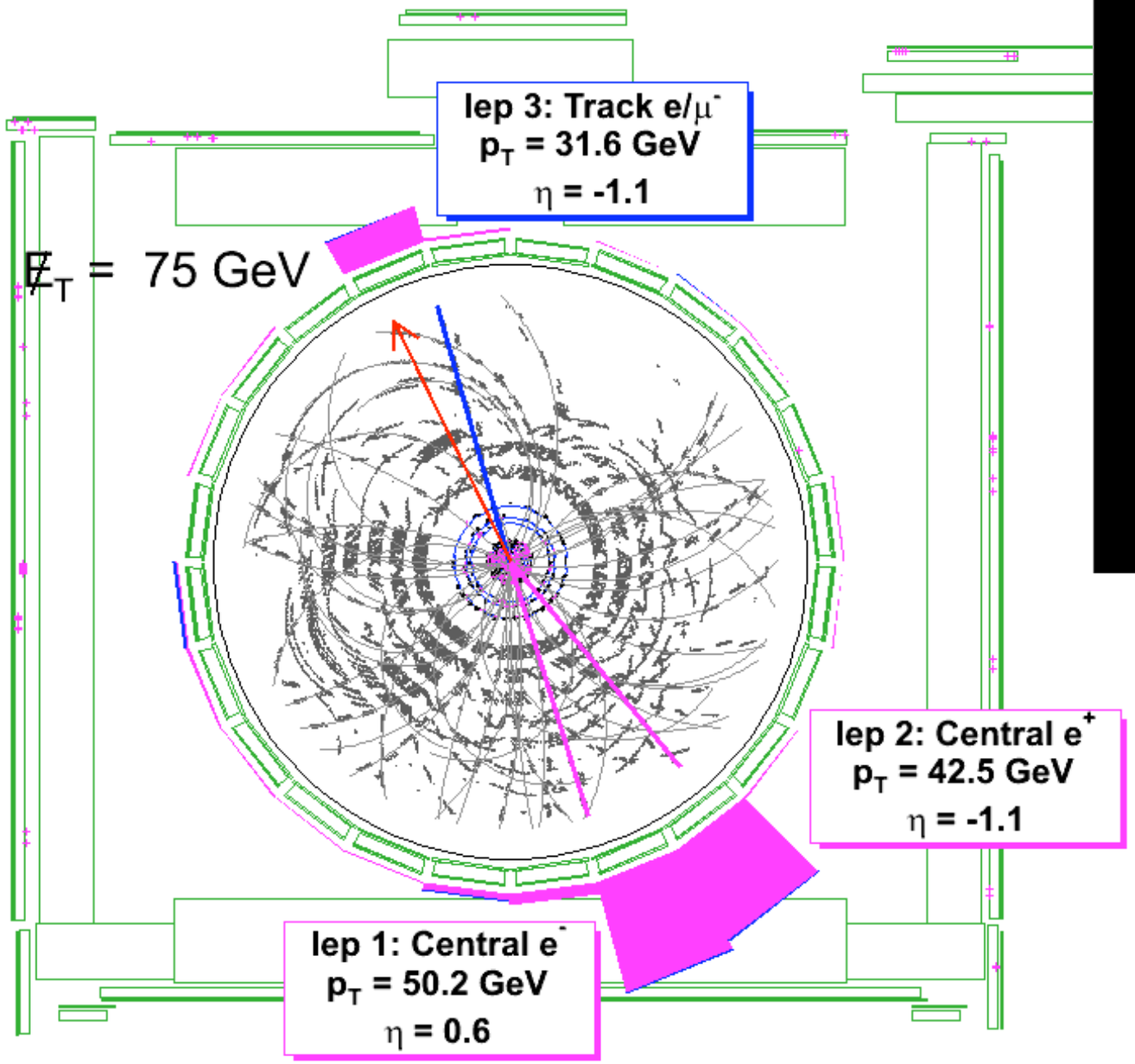
Run=198154 Event=14937629

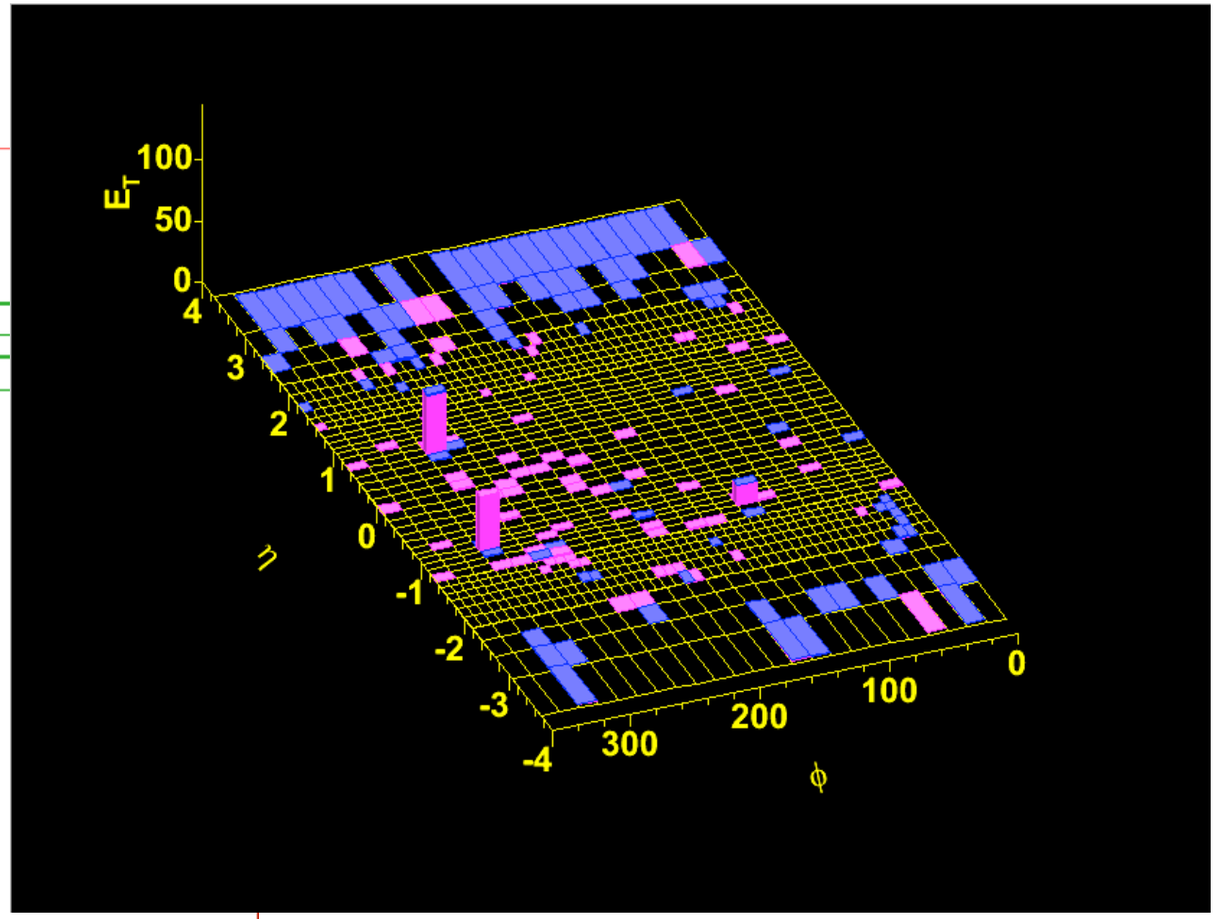
m_{12}=101.82 GeV $|\not\!\!E_T|$=86.7 GeV
m_{13}=42.64 GeV $\Delta\phi(\not\!\!E_T, \text{lepton, jet})$=2.4
m_{23}=47.59 GeV

Type	p_t	η	ϕ
Forward μ	40.9	1.7	0.1
Central μ	29.6	-0.6	0.8
Track e/μ	25.2	0.6	-0.5

WZ Event Displays

e e track





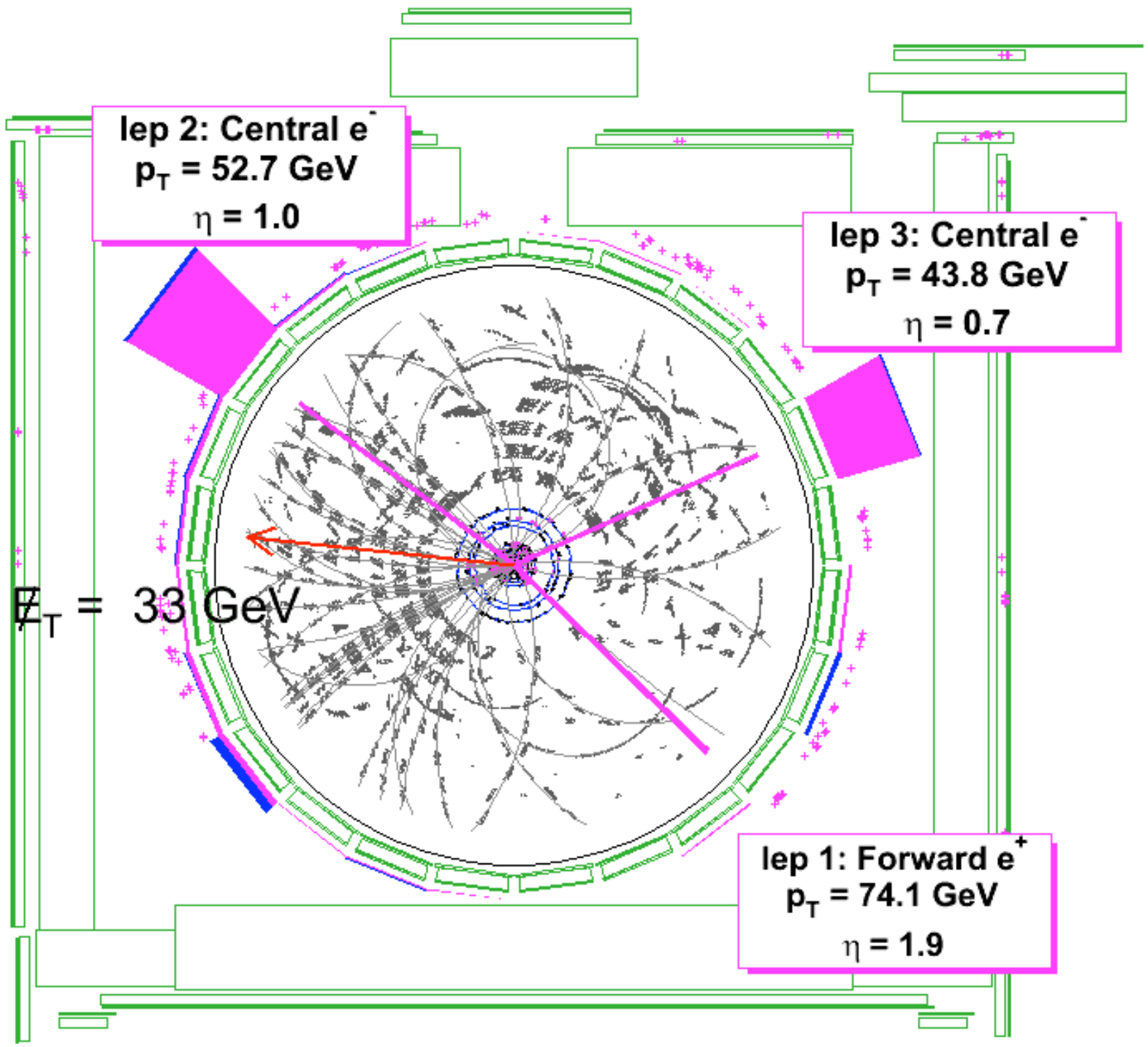
Run=201644 Event=1308790

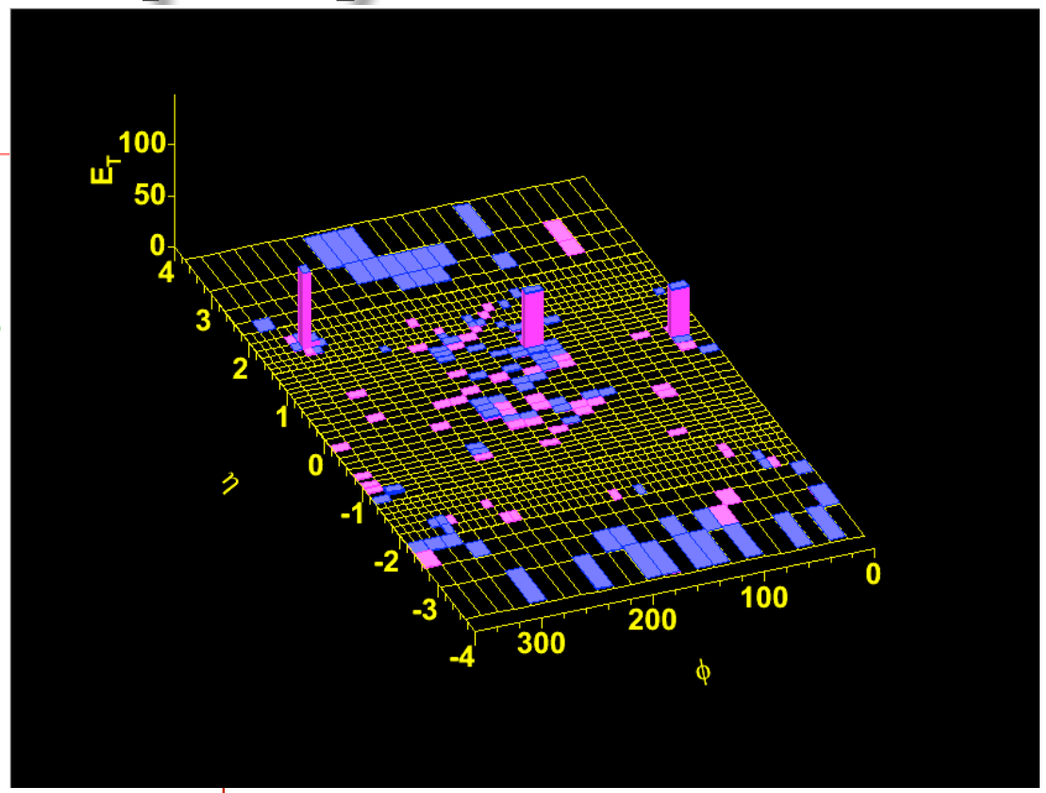
m_{12}=85.59 GeV	$\lvert\not\!\!E_T\rvert$=74.8 GeV
m_{13}=110.94 GeV	$\Delta\phi(\not\!\!E_T, \text{lepton, jet})$=0.2
m_{23}=71.77 GeV	

Type	p_t	η	ϕ
Central e	50.2	0.6	-1.3
Central e	42.5	-1.1	-0.9
Track e/μ	31.6	-1.1	1.8

WZ Event Displays

trielectron





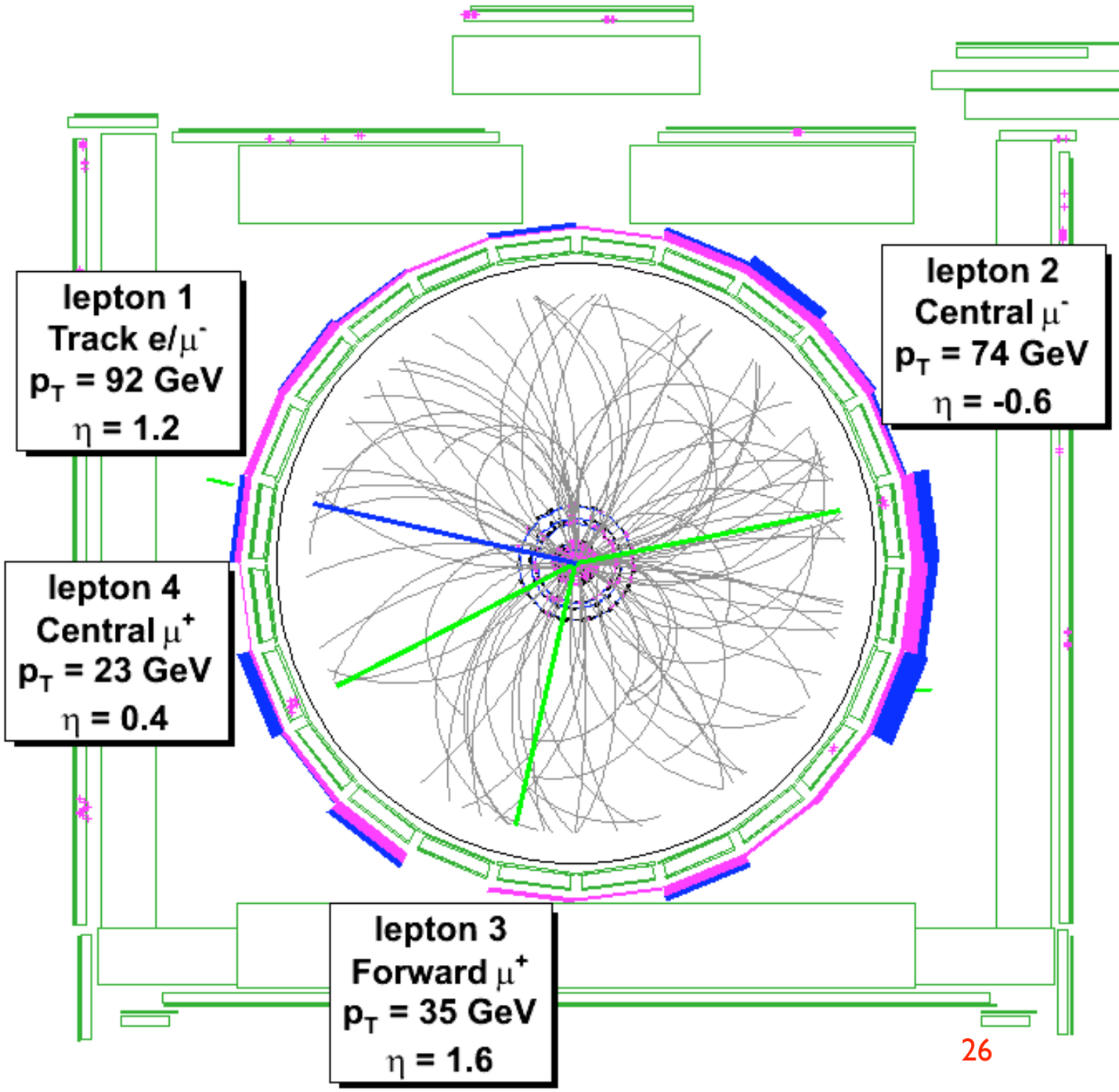
Run=207115 Event=8740187

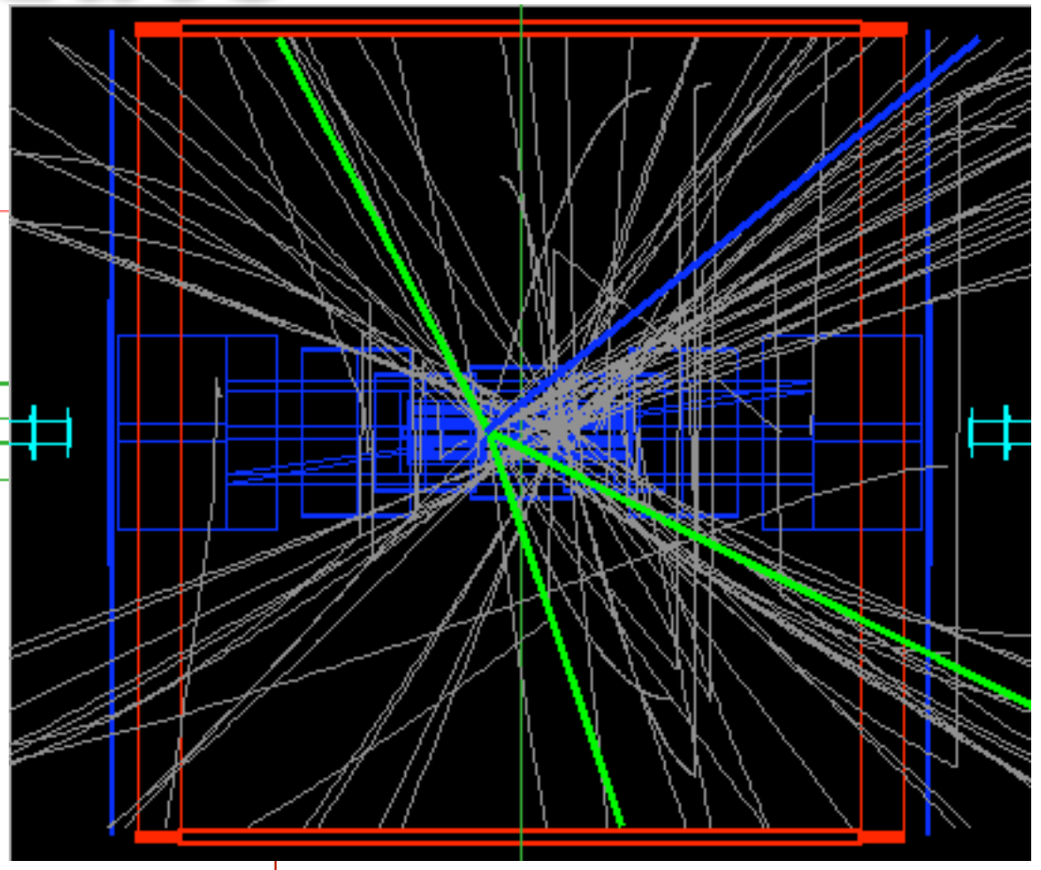
m_{12}=137.02 GeV $|\not\!\!E_T|$=32.9 GeV
m_{13}=94.70 GeV $\Delta\phi(\not\!\!E_T, \text{lepton, jet})$=0.6
m_{23}=83.80 GeV

Type	p_t	η	ϕ
Forward e	74.1	1.9	-0.8
Central e	52.7	1.0	2.5
Central e	43.8	0.7	0.4

ZZ Candidate

mu mu mu track



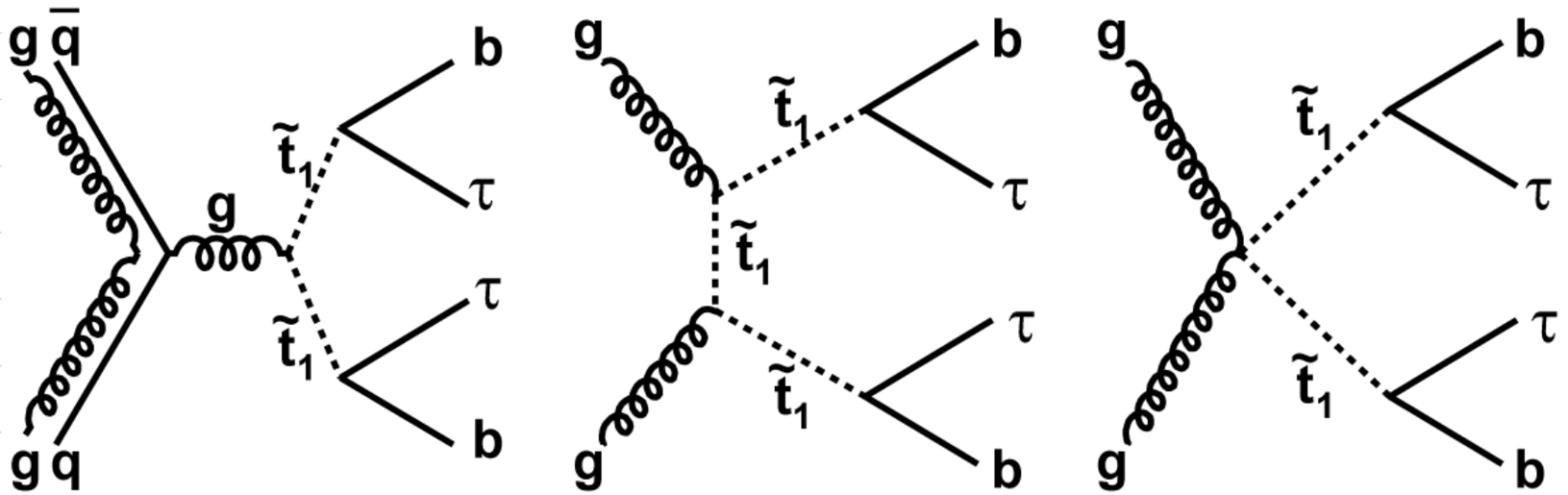


Run=211311 Event=233113

m_{ll1}=90.92 GeV $|\not\!\!E_T|$=8.7 GeV
m_{ll2}=83.03 GeV $N_{jets} = 0$
M_{llll}=312.4 GeV/c^2

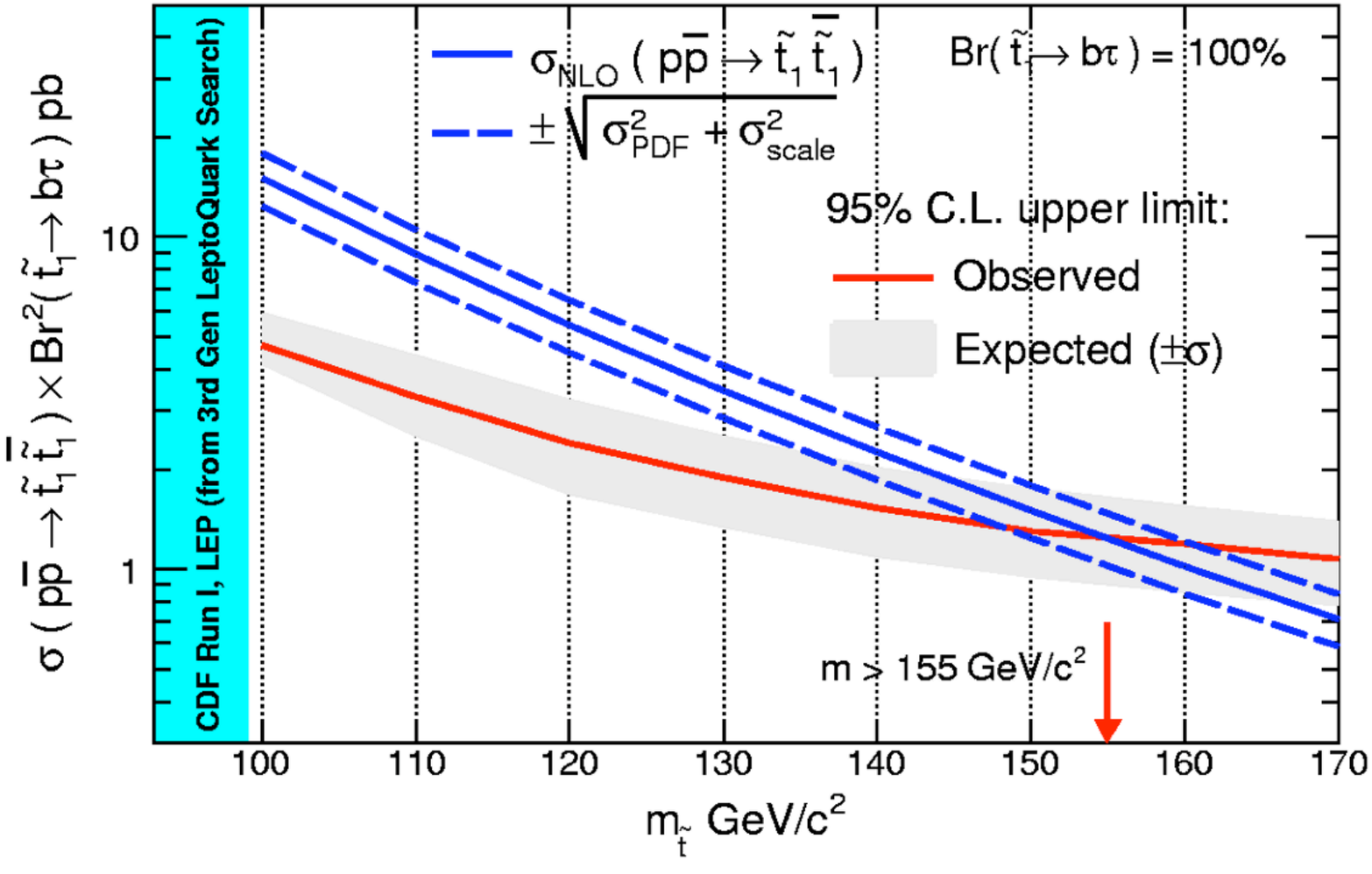
Type	p_t	η	ϕ
Track e/μ	91.5	1.2	2.9
Central μ	74.1	-0.6	0.2
Forward μ	34.5	1.6	-1.8
Central μ	22.5	0.4	-2.7

RPV SUSY search w/ τ's



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

CDF Run II Preliminary (322 pb^{-1})



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

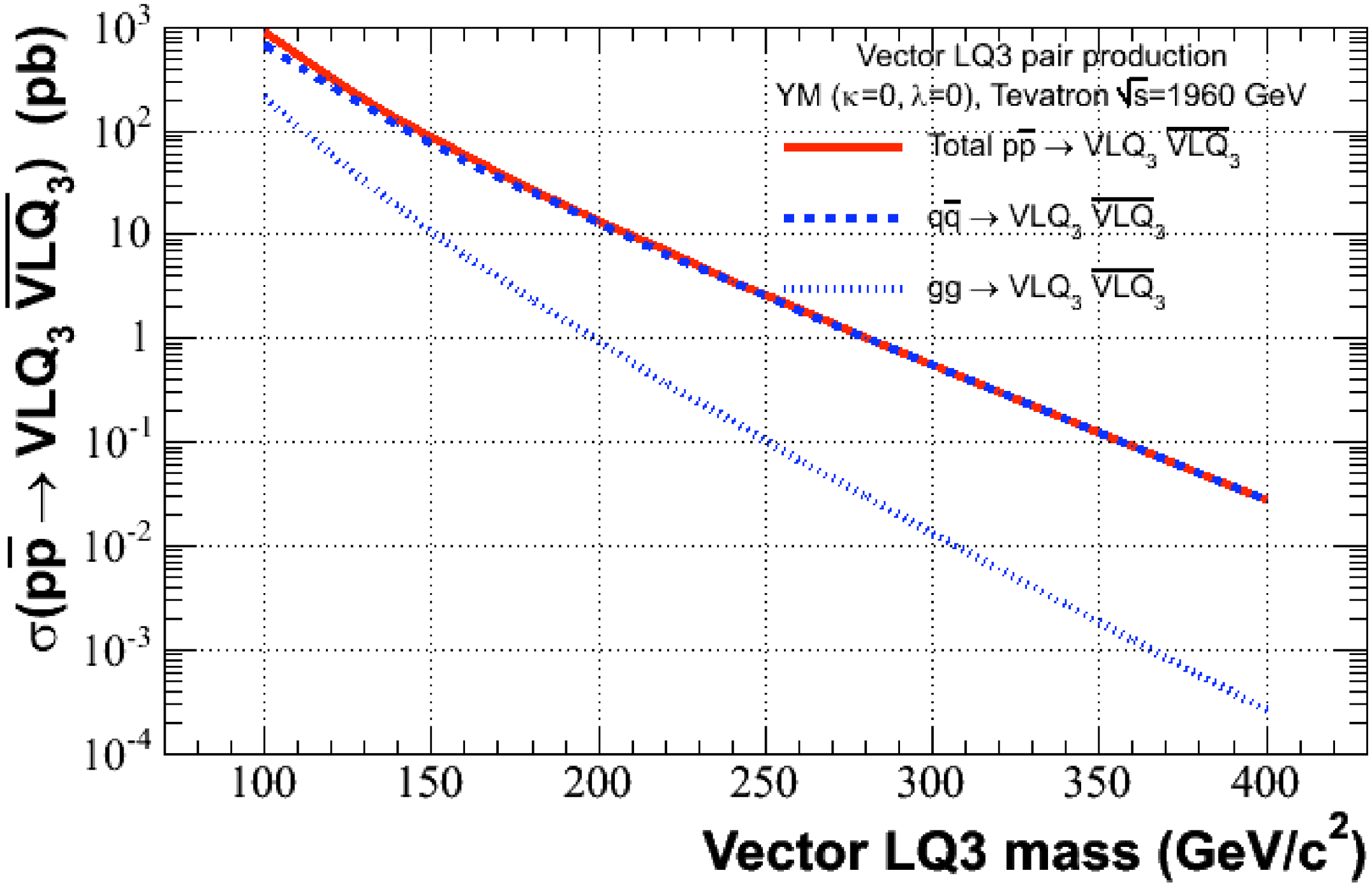
2.2 expected,
2 observed

M. Chertok, WC LHC 12/08/06

3rd Gen. Vector Leptoquarks

- VLQ3 case (S=1), work of John R. Smith and Soushi Tsuno
  - Helicity amplitudes required because acceptance depends on tau helicity, but these were not available.
  - GRACE/GR@PPA implements Feynman rules and uses helicity basis. Thus, event-by-event, tau polarization can be passed to TAUOLA
    - MadGraph could be used as well
    - CompHEP, up-to-now, sums over final-state spins
- Similar procedure necessary for other exotic (S≠0) decays to taus
  - Philosophy: if we <u>can</u> use correct MC, we <u>should</u>!

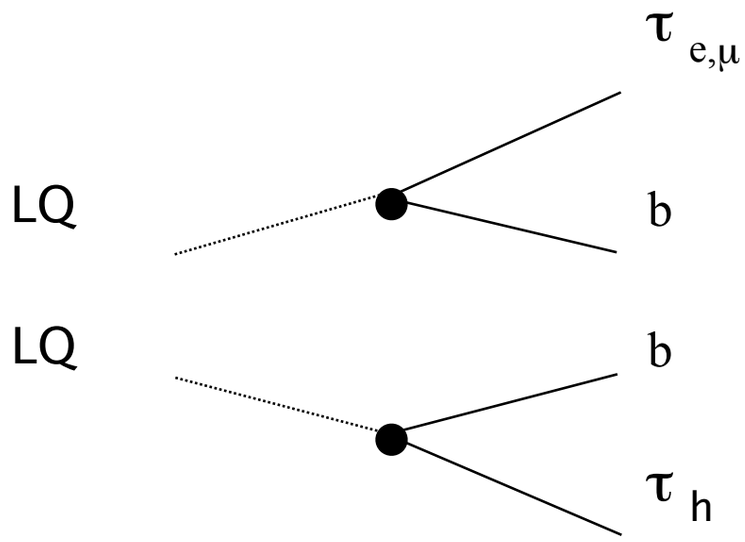
VLQ3 Cross Section



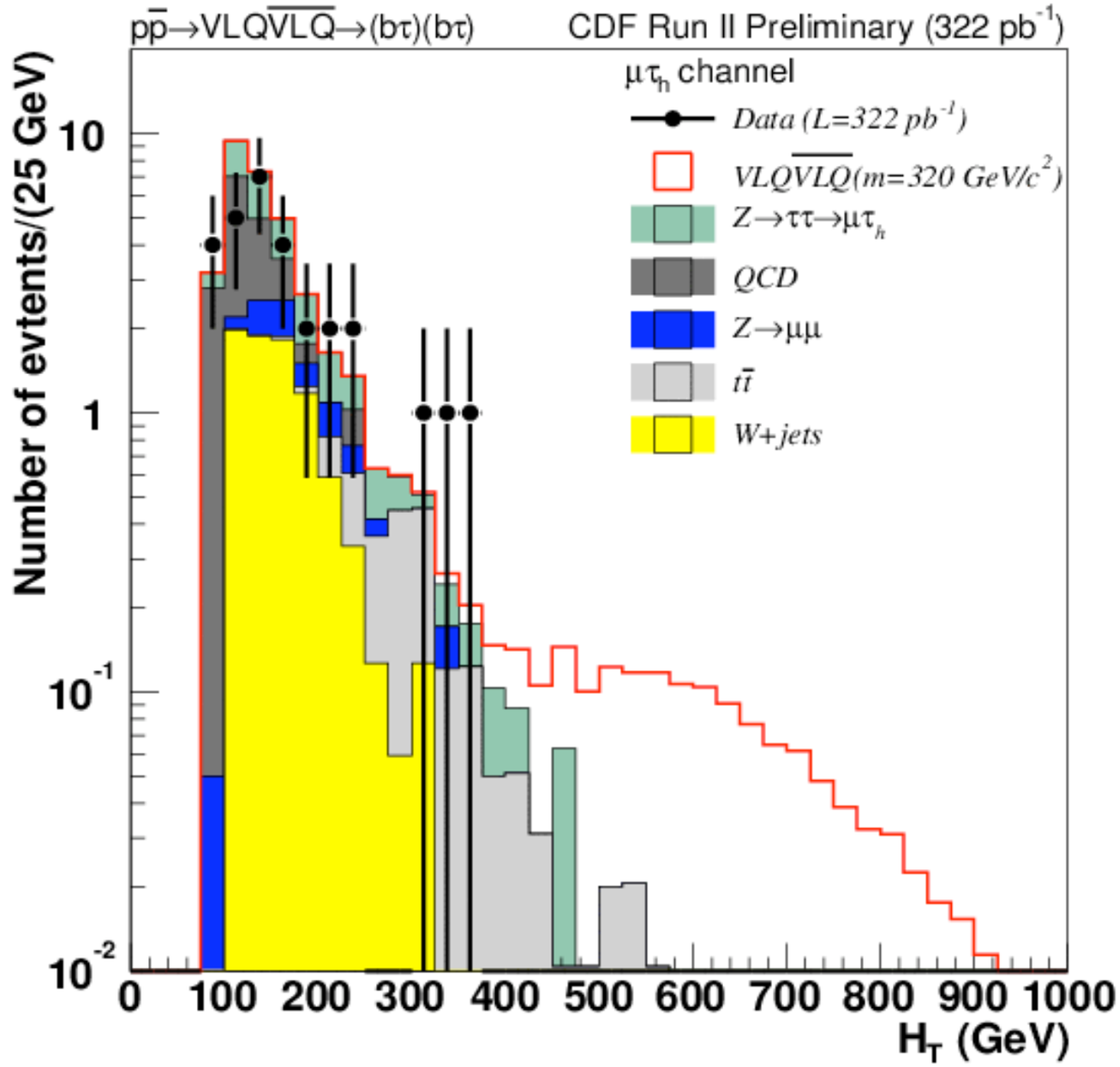
At LHC, situation ~ reversed

VLQ3 Analysis

- Use Lepton+Track trigger

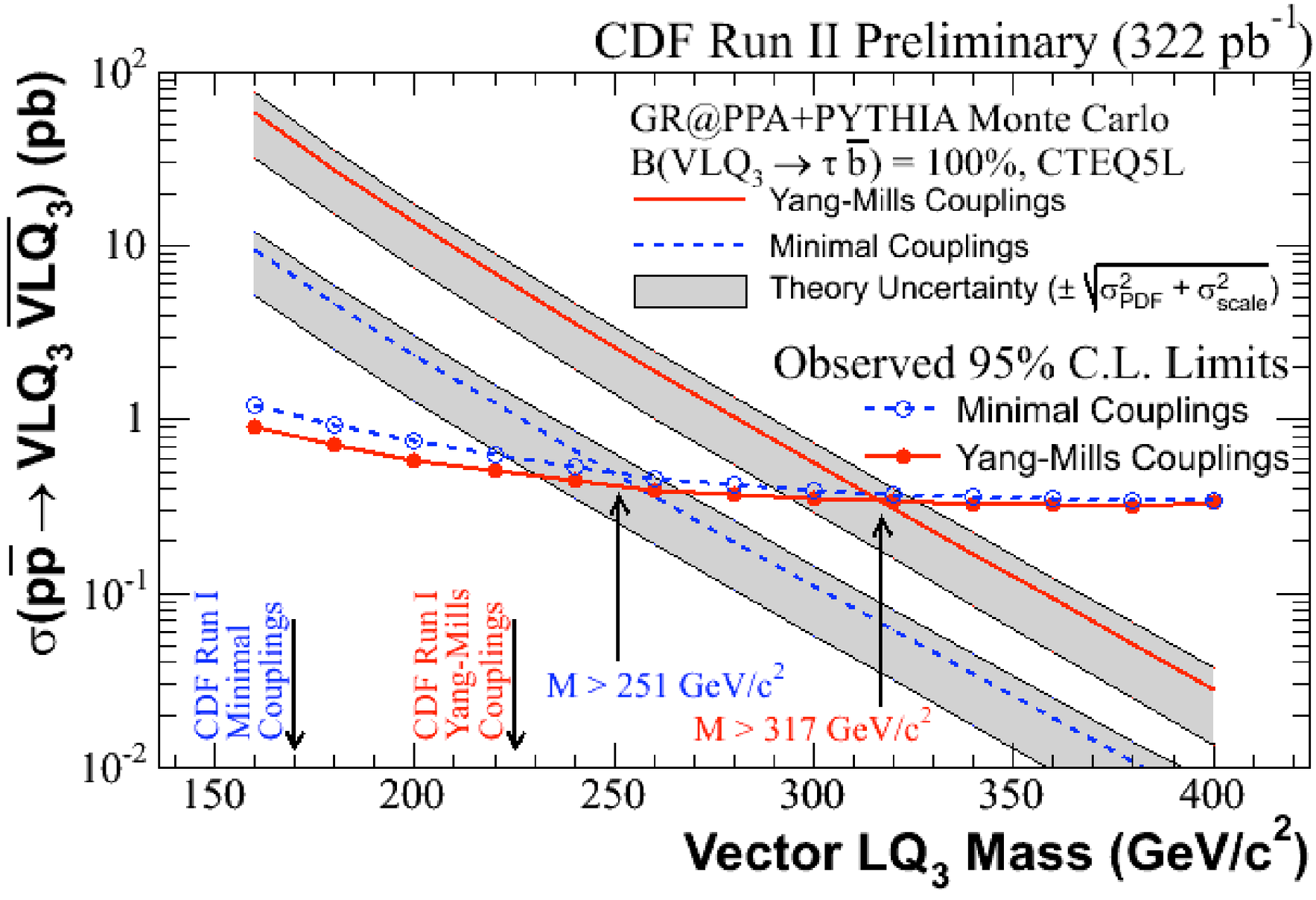


- $H_T = E_T(\text{lepton}) + E_T(\tau_h) + \not{E}_T + \sum E_T(\text{jets})$



VLQ3 Results

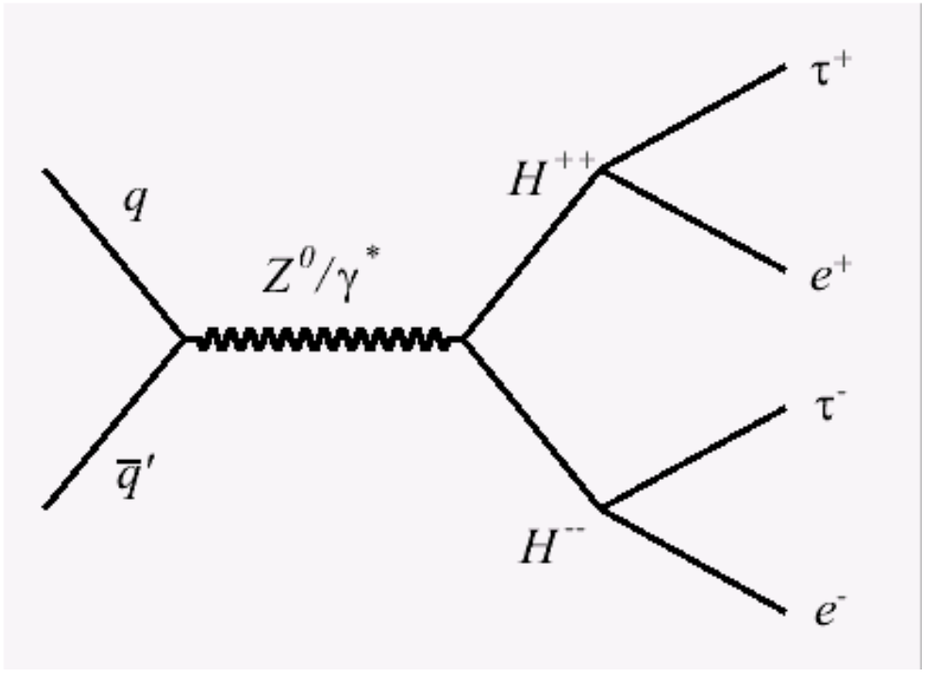
No events observed

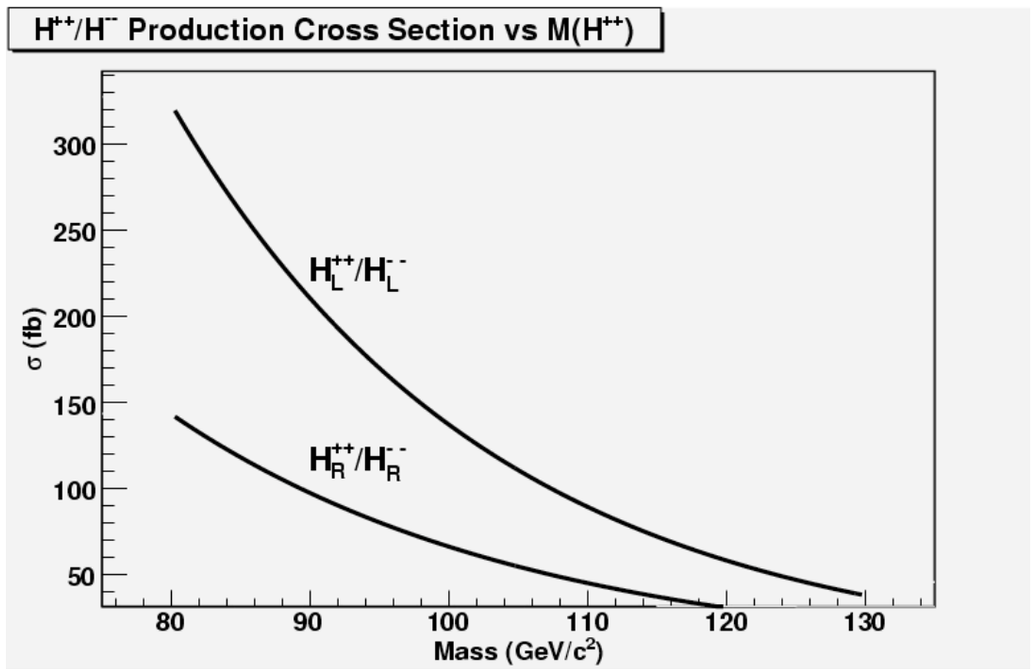


- Minimal Coupling type
  m > 251 GeV/c^2
- Yang-Mills type
  m > 317 GeV/c^2

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)

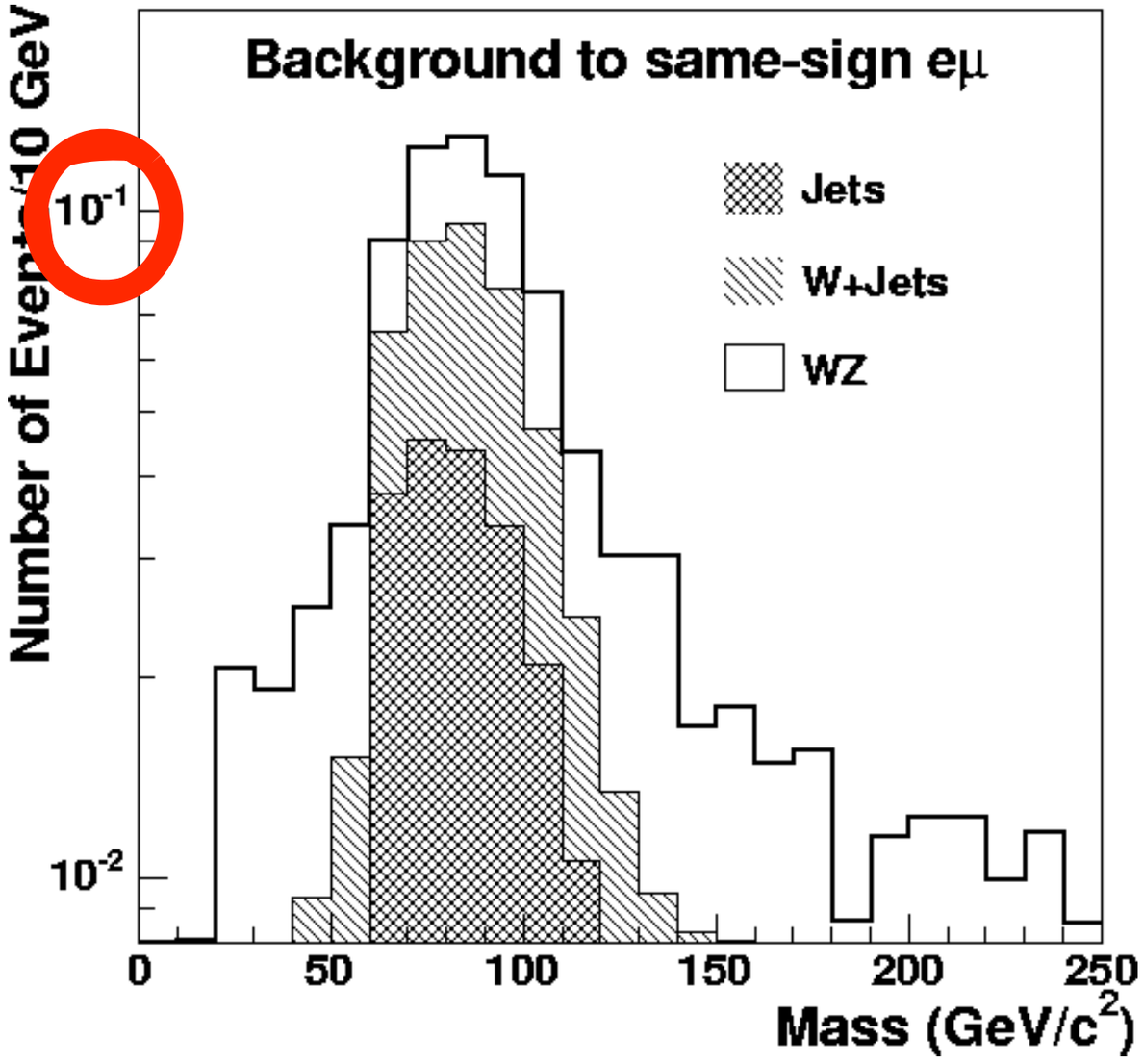


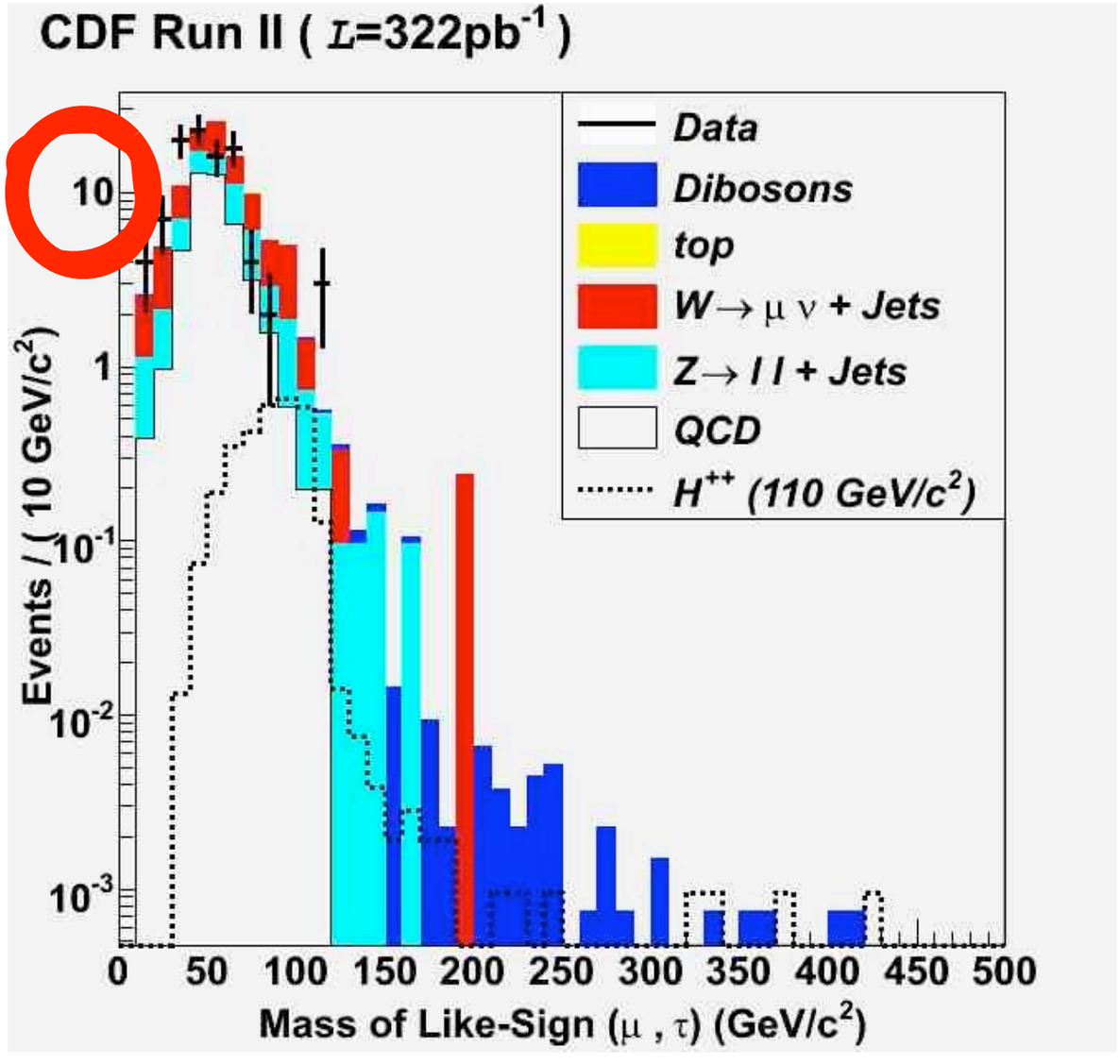


(At present, not considering $p\bar{p} \rightarrow H^{++}H^{-}$)

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

LS signature not feasible for tau channels because R(jet →τ) ~100X R(jet →e,μ)



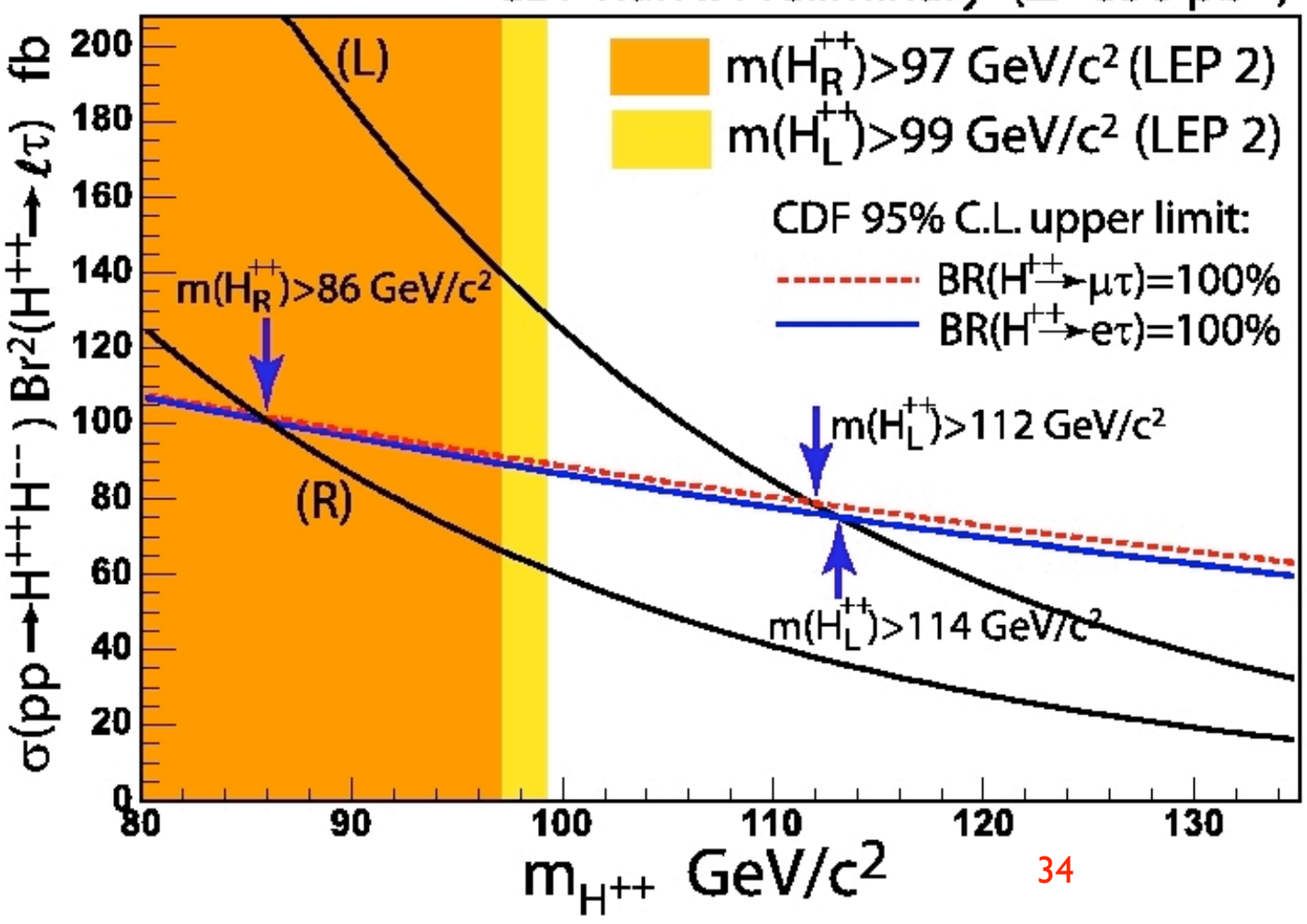


H++ → eμ

H++ →τμ

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

- Employ "lepton+track" triggers (low P_T)
  - Will be critical for $H^{++} \rightarrow \tau\tau$ search
- Require 3 or 4 leptons to suppress W+jets
- H_T cut, Z mass veto, LS mass window
  - No events survive



To examine SUSY variants on this model, we need custom MC for $\tilde{\Delta}^{++}$ production

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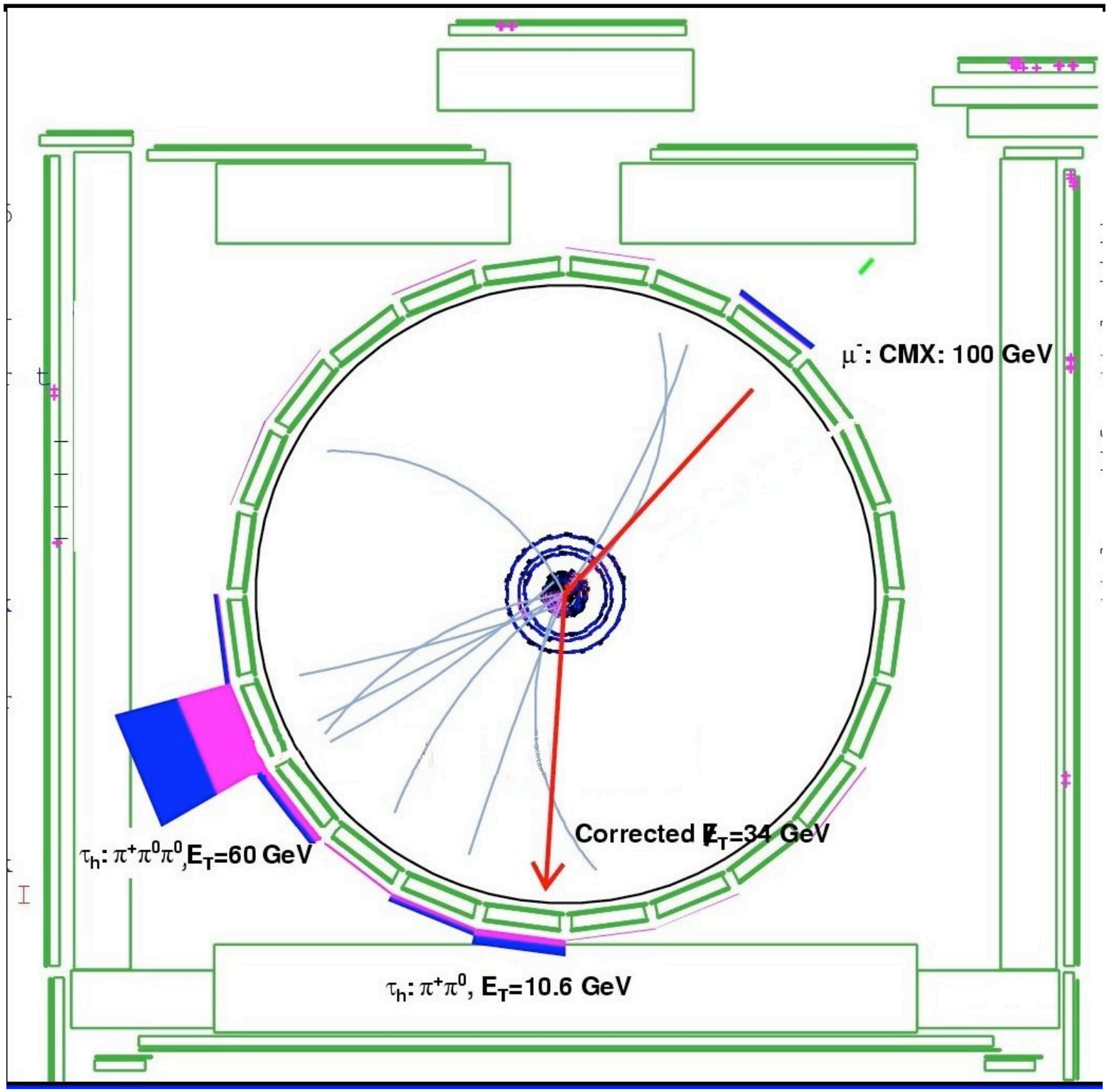
H^{++} interesting event

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



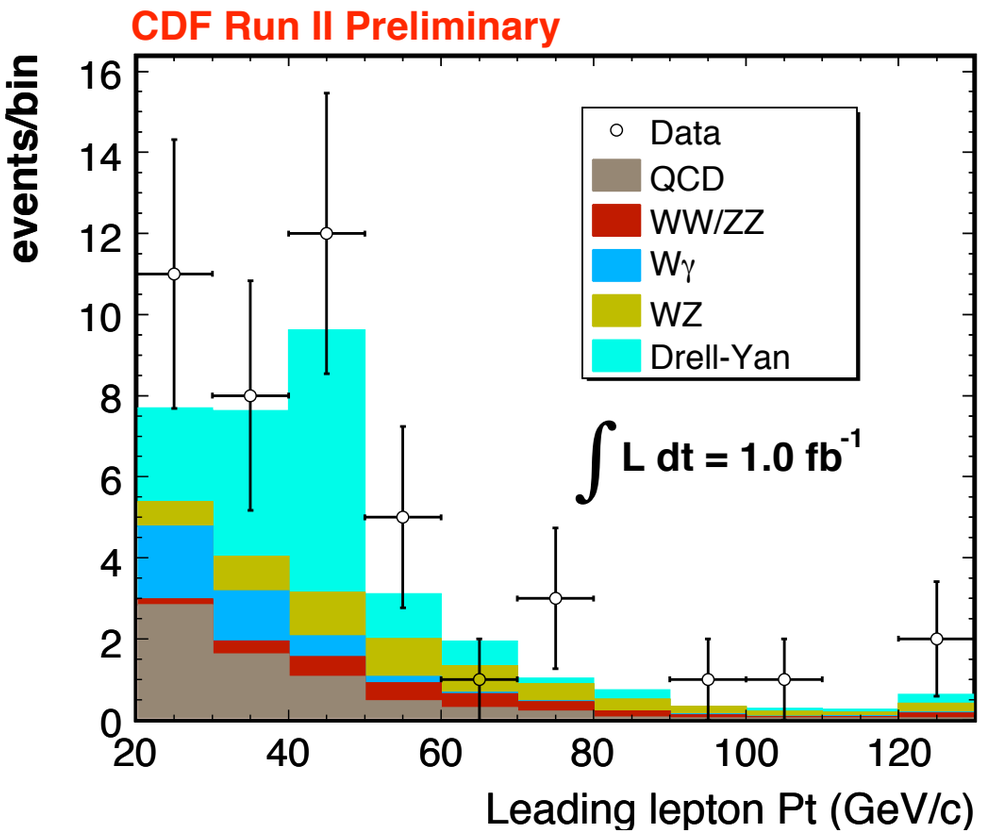
All Tracks with $p_T > 500$ MeV/c are shown

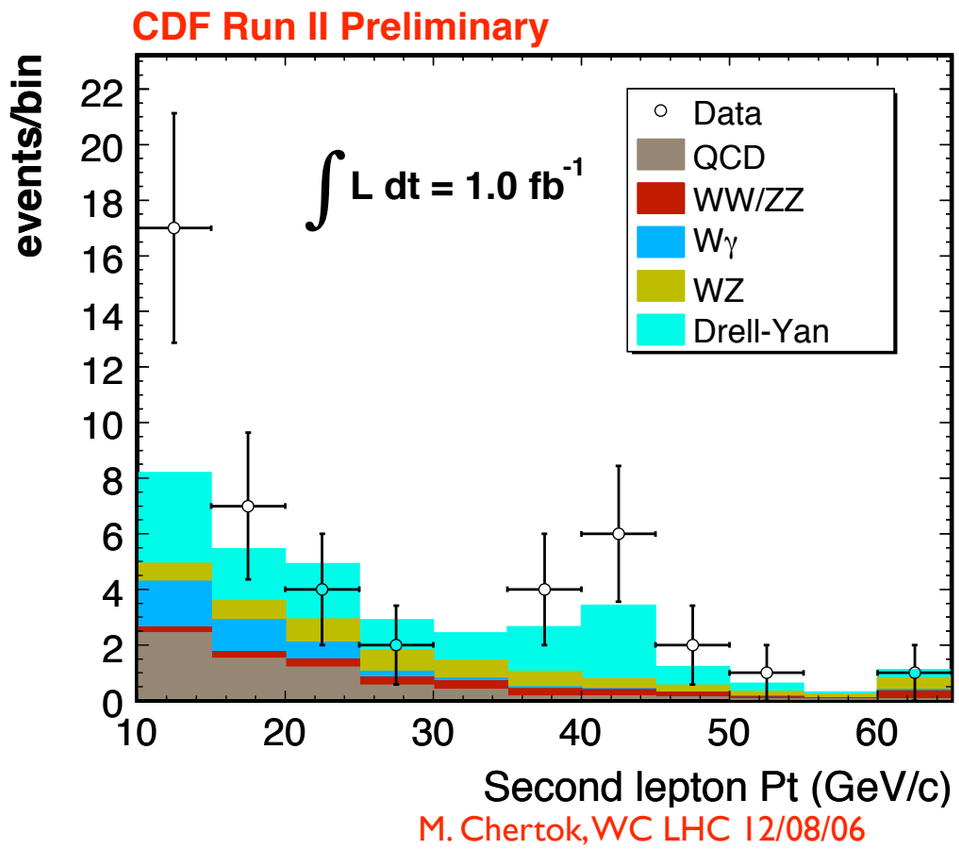
LS Dilepton Search

- LS Dileptons appear, notably in:
  - Decays of gluino pairs or gluino-squark prod.
  - Chargino-neutralino production
- CDF search in 1/fb electrons and muons
  - High Pt lepton triggered sample
  - Pt(lep1)>20 GeV/c, Pt(lep2)> 10 GeV/c

LS Analysis

- Inclusive search:
  - Predict 33.7±4.7 from SM, Observe 44
  - Probability of fluctuation 10%
- Tighter cuts: MET>15, Z mass veto
  - Predict 7.9±1.1 from SM, Observe 13
  - Probability of fluctuation 7.3%





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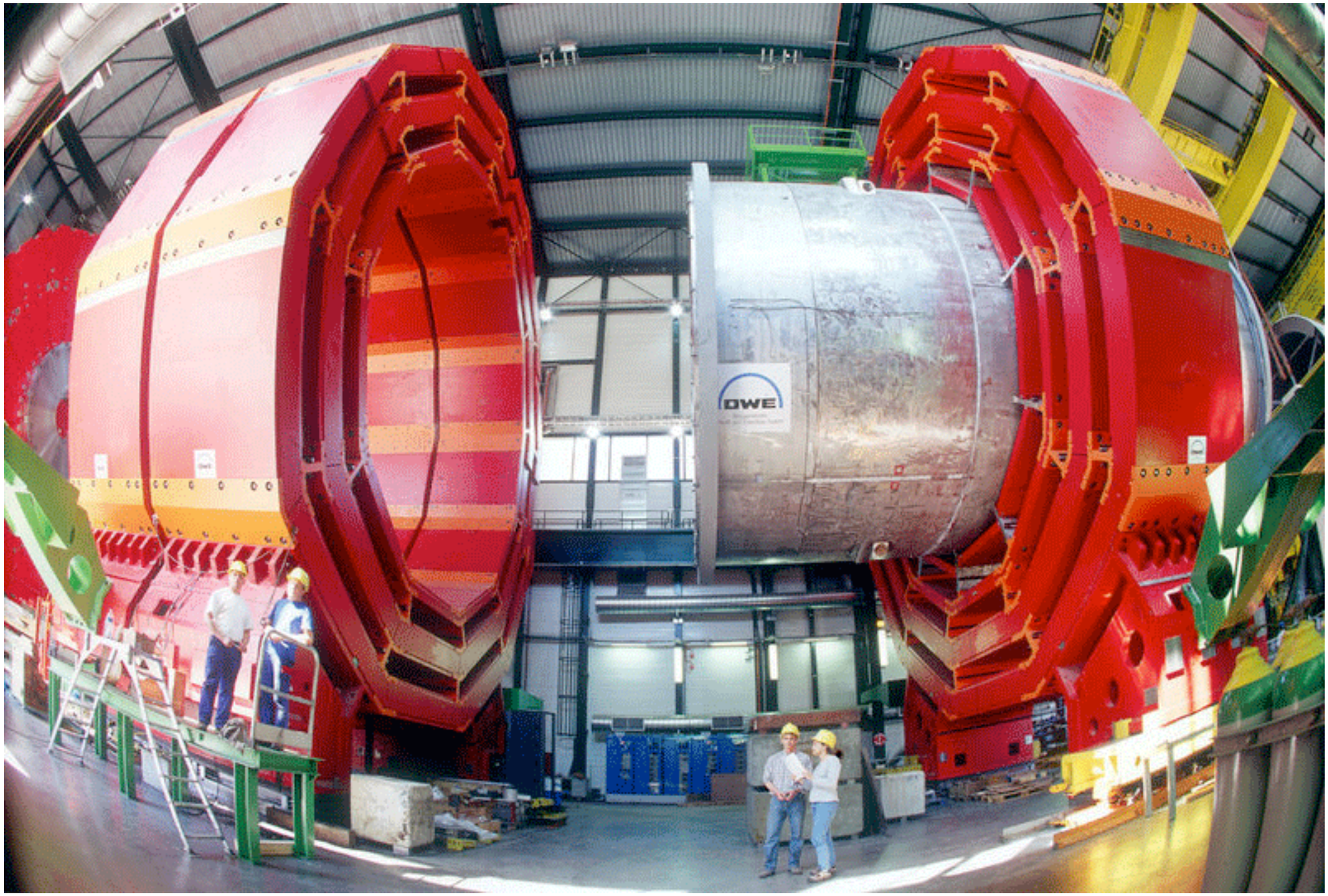
Tevatron Prospects

- Assume several /fb/experiment
- Substantial, well-understood datasets
- New L2 tracking trigger (upgrade) will improve tau triggering
- LHC experiments will require a couple of years to really understand their data
- Need to keep up effort until final Tevatron data analyzed!
- Those trilepton events keep rolling in

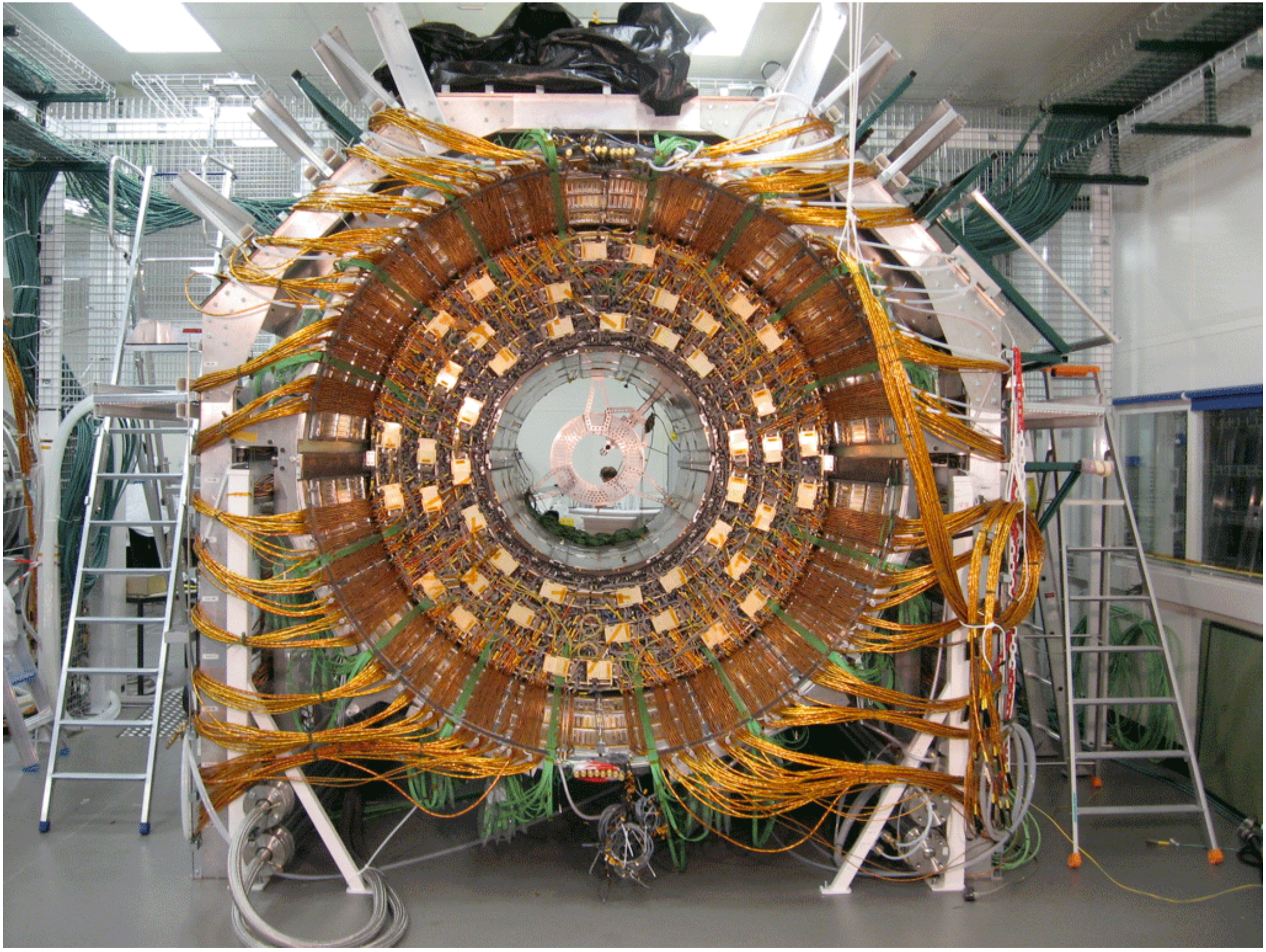
CERN: at the foot of the Alps

CMS at CERN's LHC

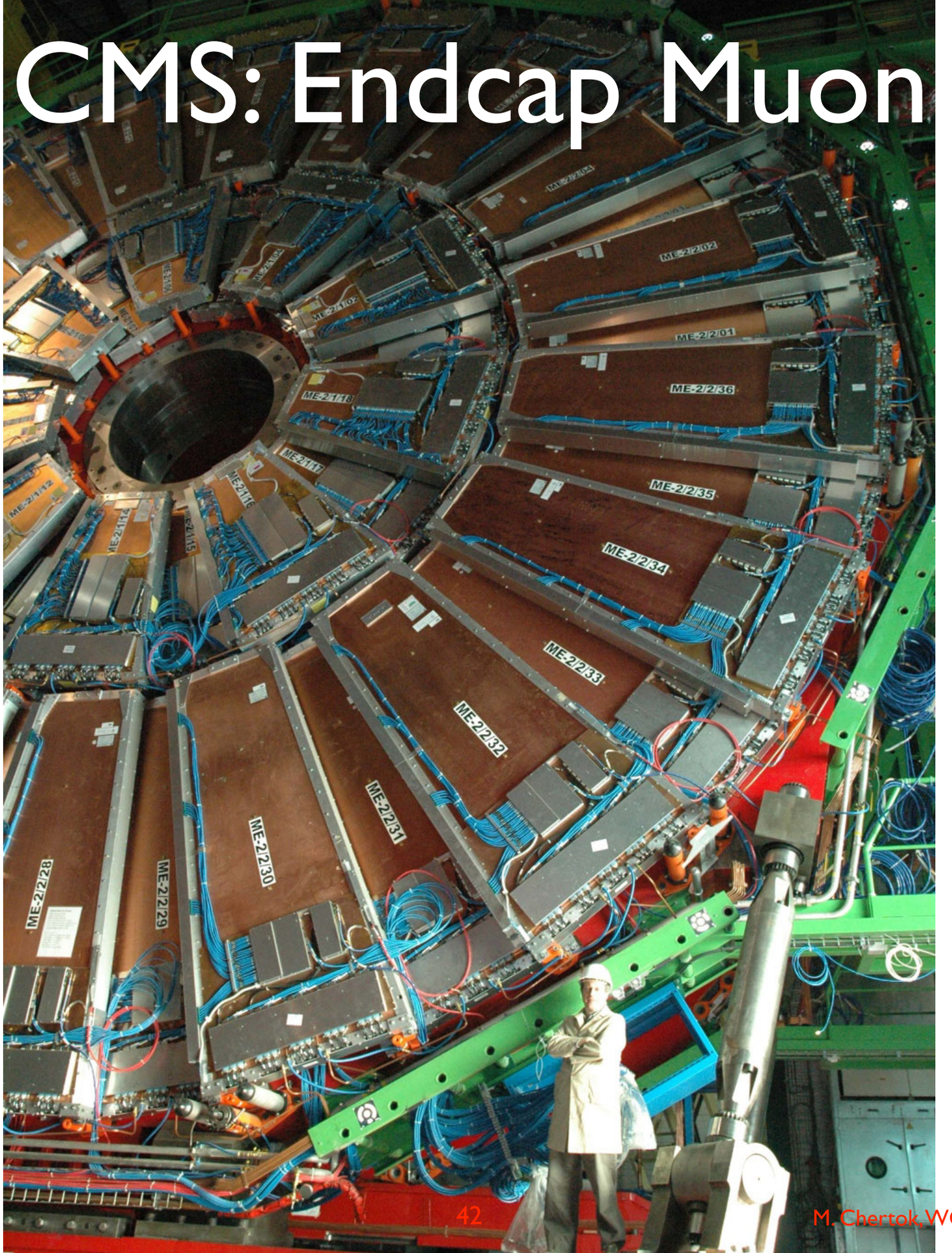


Starts in 2008 (high energy)

CMS : TOB



CMS: Endcap Muon

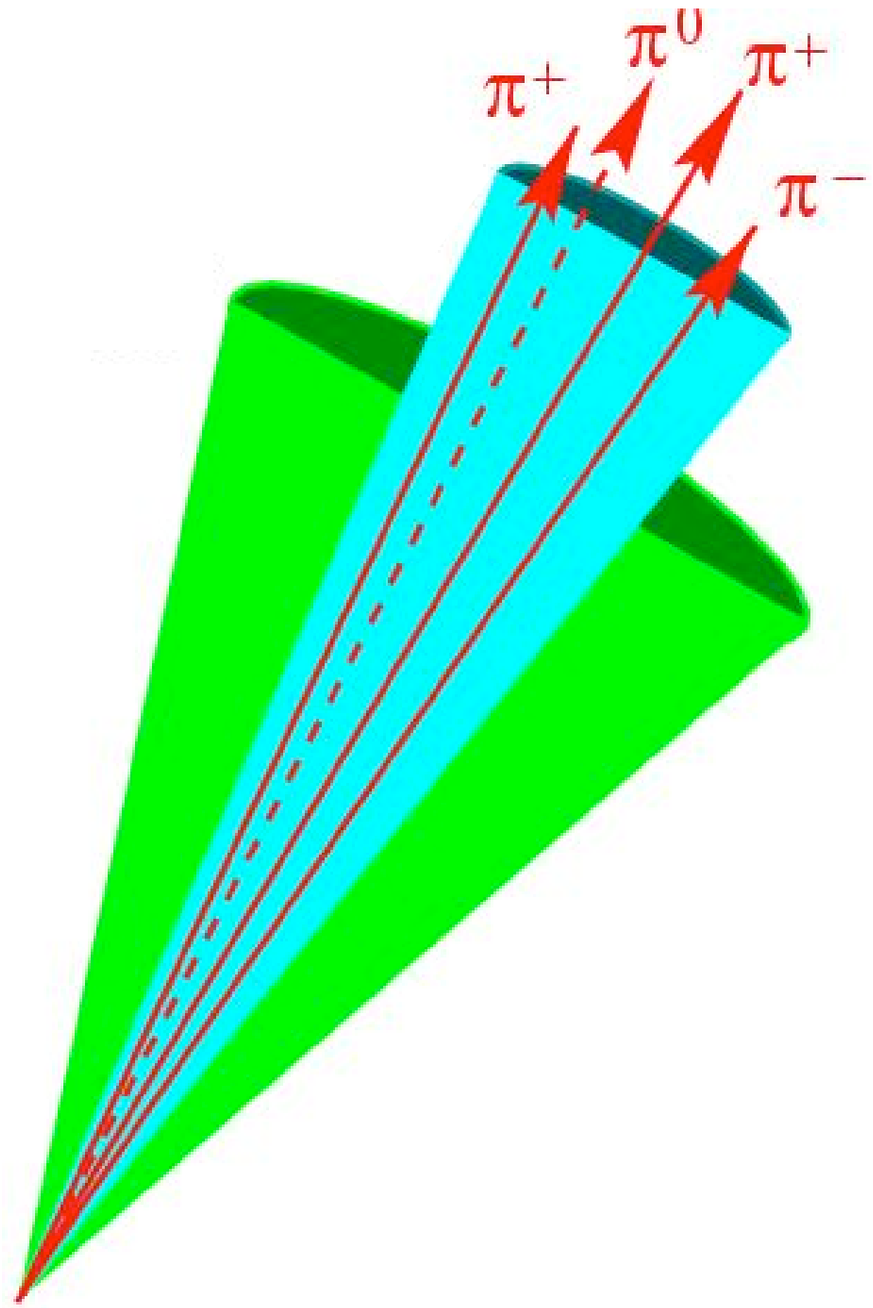


CMS: World's largest solenoid

The 100m dash

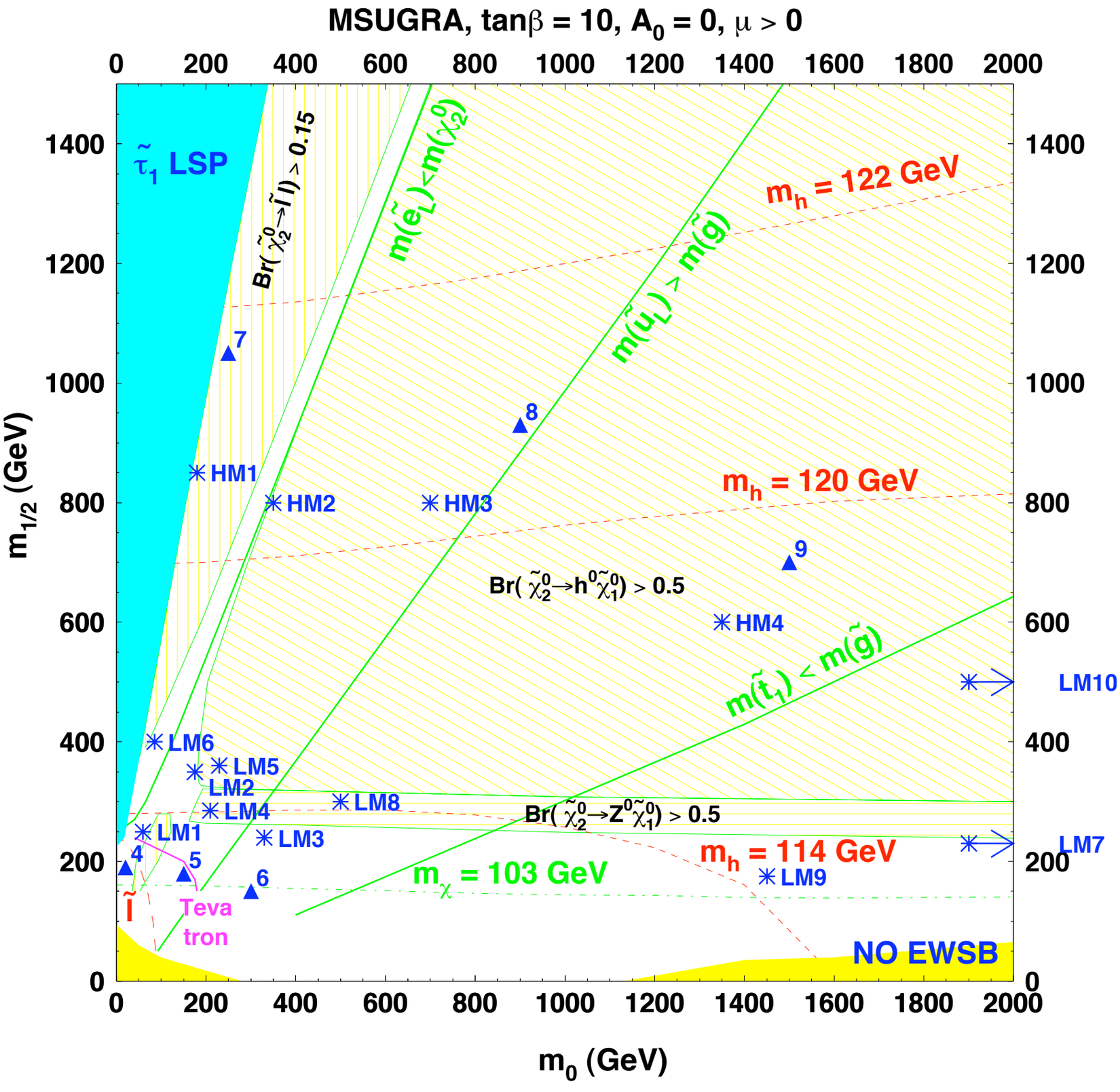
Neutral pions in tau decay

- Brand new: ~50% of photons will pair produce in tracker!
- Modify our tau cone definitions?
- Benefit of additional tracking for e^+e^- pair?



τ decay

CMS SUSY Space



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e.g., SUSY LM1

- m_0=60, $m_{1/2}$=250,tanβ=10,μ>0,A_0=0
  - *Like B' (m_0=57)*
- σ(LM1) ~50 pb, σ(LM1,N2C1) ~1 pb
- SParticle SPectrum:
  - *M(N1)~95, M(N2)~M(C1)~180*
  - *M(gluino)~610, M(squark)~500, M(stop$_1$)~400*
  - *M(slep$_R$)~120, M(slep$_L$)~190, M(stau$_1$)~110*
- Edge = ΔM ~M(Z) !!
  - *Other ideas? Counting expt. only?*
  - *Tau channels would change edge...*

LM1 Decay Table

- The sleptons, esp. the stau, are light.
  - *2-body decays dominate*
- Neutralino$_2$ decays:
  - *Br(N2 → slepton lepton) ~ 11%*
  - *Br(N2 → stau tau) ~ 46%*
    - Br(stau → tau N1) = 100%
  - *Br(N2 → neutrinos and N1's) ~ 42%*
- Chargino$_1$ decays:
  - *Br(C1 → sneutrino lepton) ~ 36%*
    - Br(sneutrino → nu N1) = 100%
  - *Br(C1 → sneutrino tau) ~ 20%*
  - *Br(C1 → stau neutrino) ~ 41%*

LM1 Decays

- Thus, best approach on LM1 is to reconstruct:
  - *the even lower-Pt e's and mu's from tau decay, and*
  - *hadronic taus*
- Both are challenging
  - *How low can we go in Pt(e), Et(e) and Pt(mu)?*
  - *Can CMS do low-Pt tau jets?*

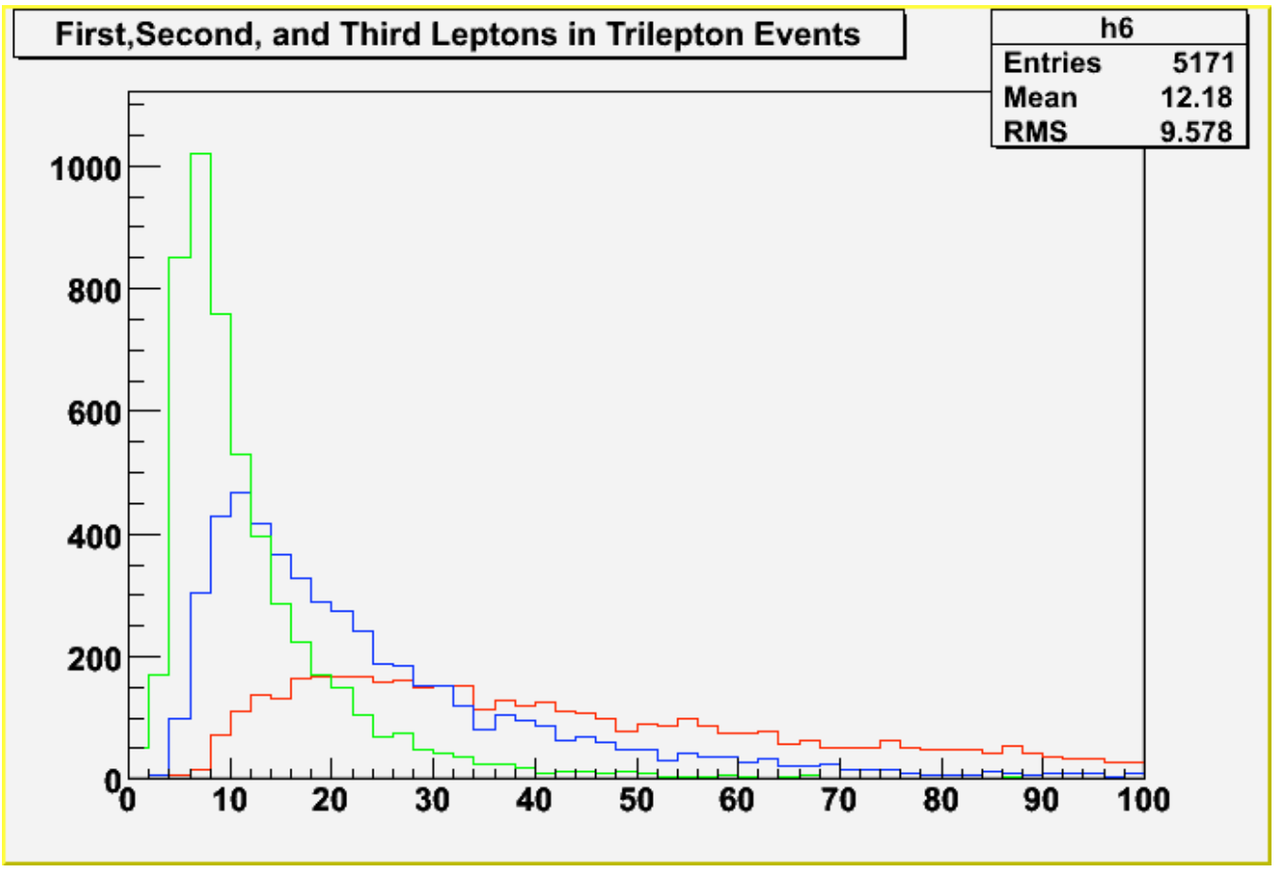
LM1 *Br* summary, including τ decays

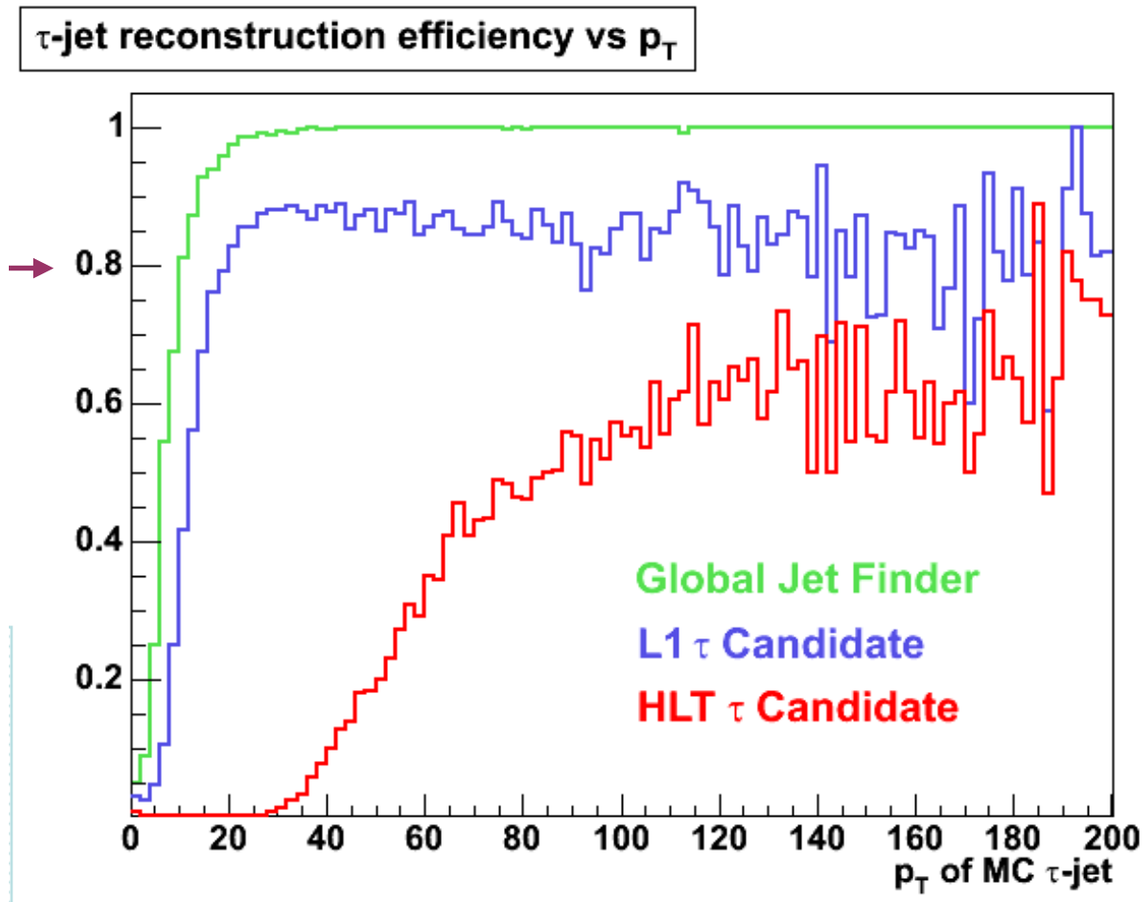
channel	*Br*
lll (l=e,mu)	10%
l l τ_h	18%
τ_h τ_h l	19%
$\tau_h\tau_h\tau_h$	8%

Lepton Momenta

Pt(l_{1-3}) from LM1 trilepton events

- *e's and mu's from tau decays substantially softer*
- *leptons from direct N2C1 production also softer*

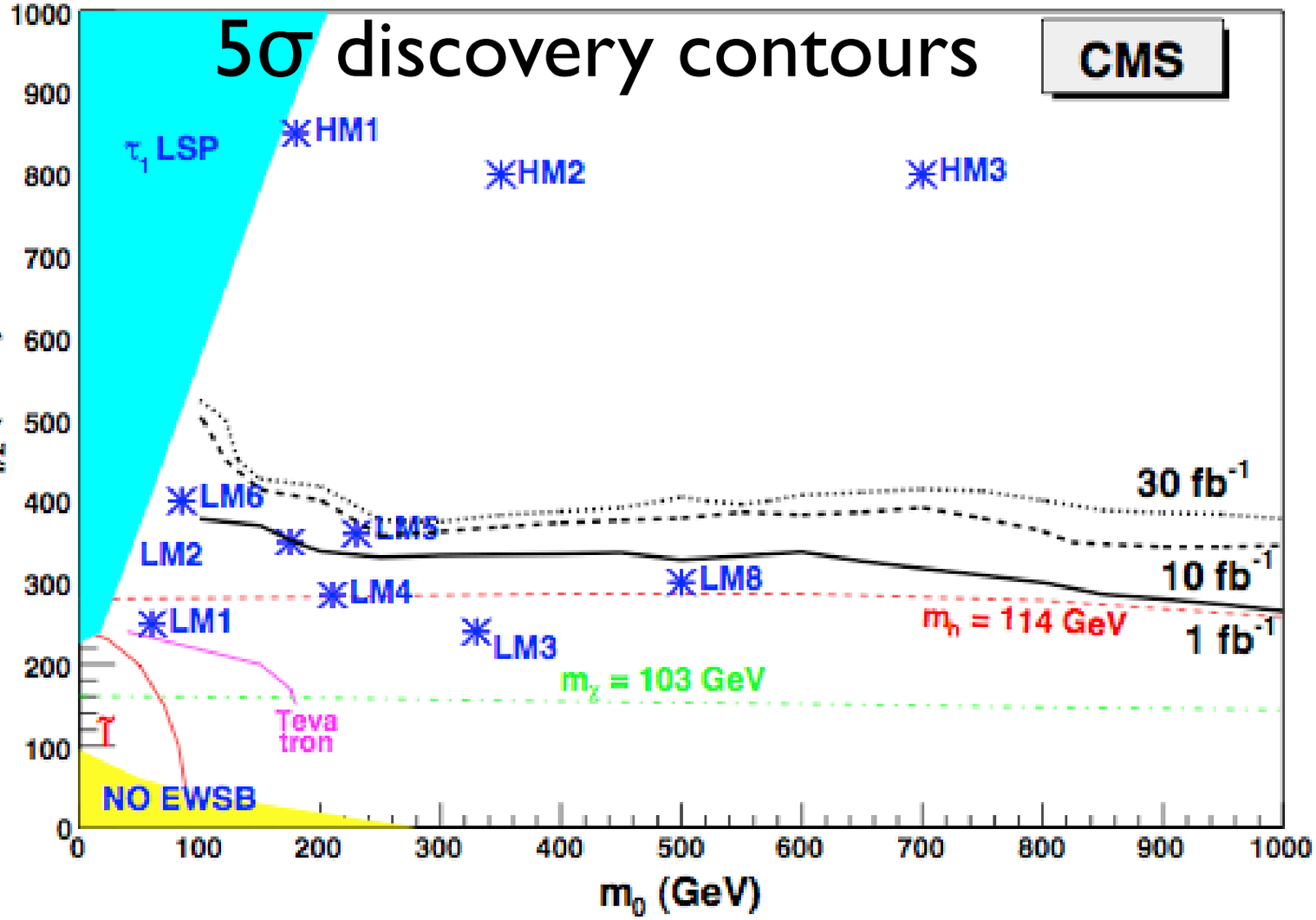


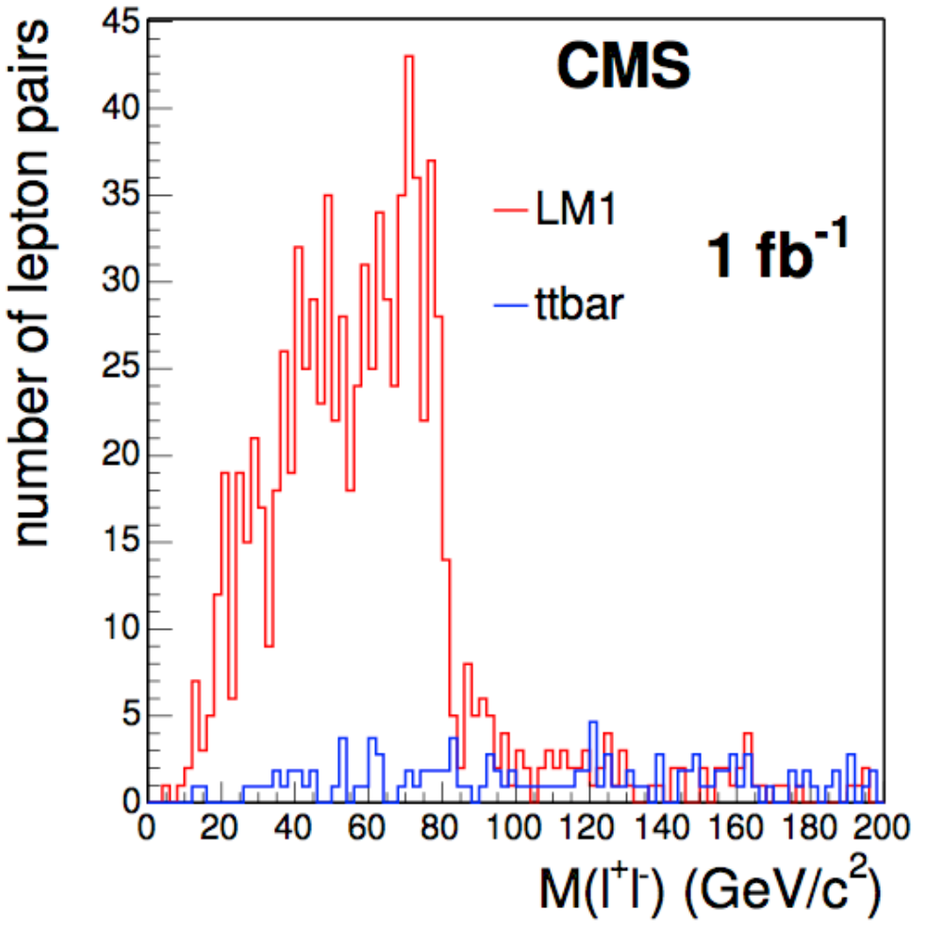


τ_h: Any ideas?
International team working on this

CMS SUSY with e,μ

- OS dileptons from N2 decays at LM1





Method: full simulation at LM1, used as normalization to fast sim. for scan

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Conclusions

- Tevatron may finish with a bang
- Experimentalists need theorist help with advanced MC
- Startup of LHC will not be step function
- Taus showing worth. The "b" of the 2000 decade?