New Boson Searches at the Tevatron

Maxwell Chertok
UC Davis

on behalf of the CDF and D0 Collaborations

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Why search for heavy bosons?

Spin 0 Bosons

- Intriguingly absent to date
- Could be SUSY
  - See M. Titov's talk
- Could be the Higgs
  - Well-covered in other talks at this conference!
  - However, some are more exotic than others:
    - Doubly-charged higgs bosons
- Could be scalar leptoquarks
  - Appear in SU(5), GUTs, Pati-Salam, Compositeness, Technicolor

New Spin-1 Bosons

Major effort: Z', W'

- Decays to leptons yield spectacular signatures
- Decays involving top quark
  - See R. Erbacher's talk

Other ideas

- New symmetries between quarks and leptons
  - Vector leptoquarks

New Spin-2 Bosons

- M(graviton) = 0, but
- Towers of Kaluza-Klein excitations in extradimensional models are, by definition, heavy (and new)

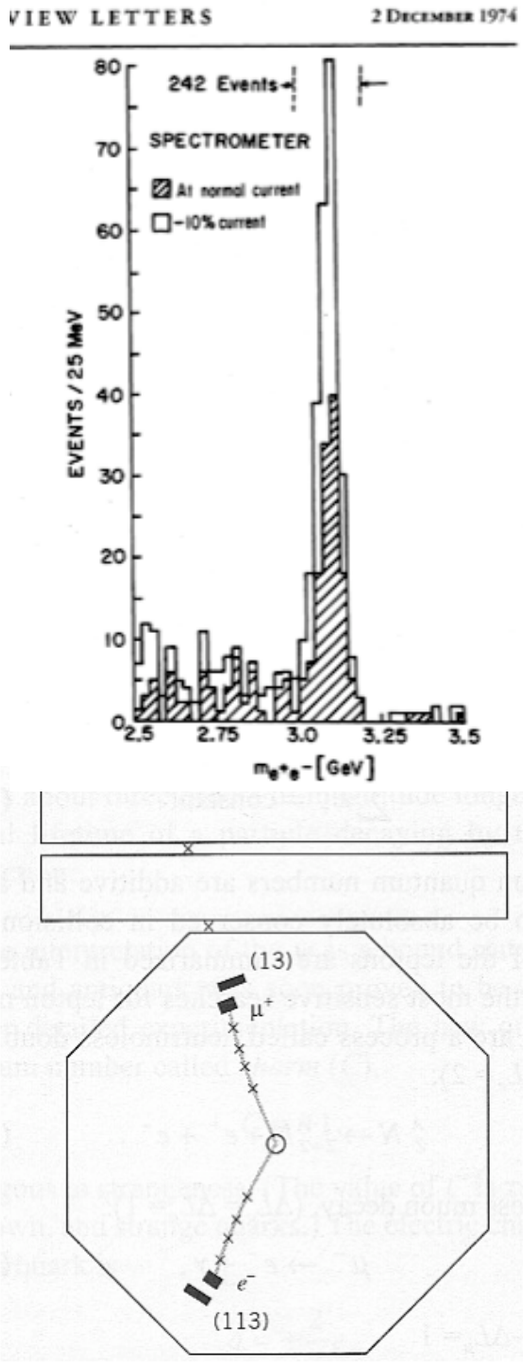
Higher spins?

Outline

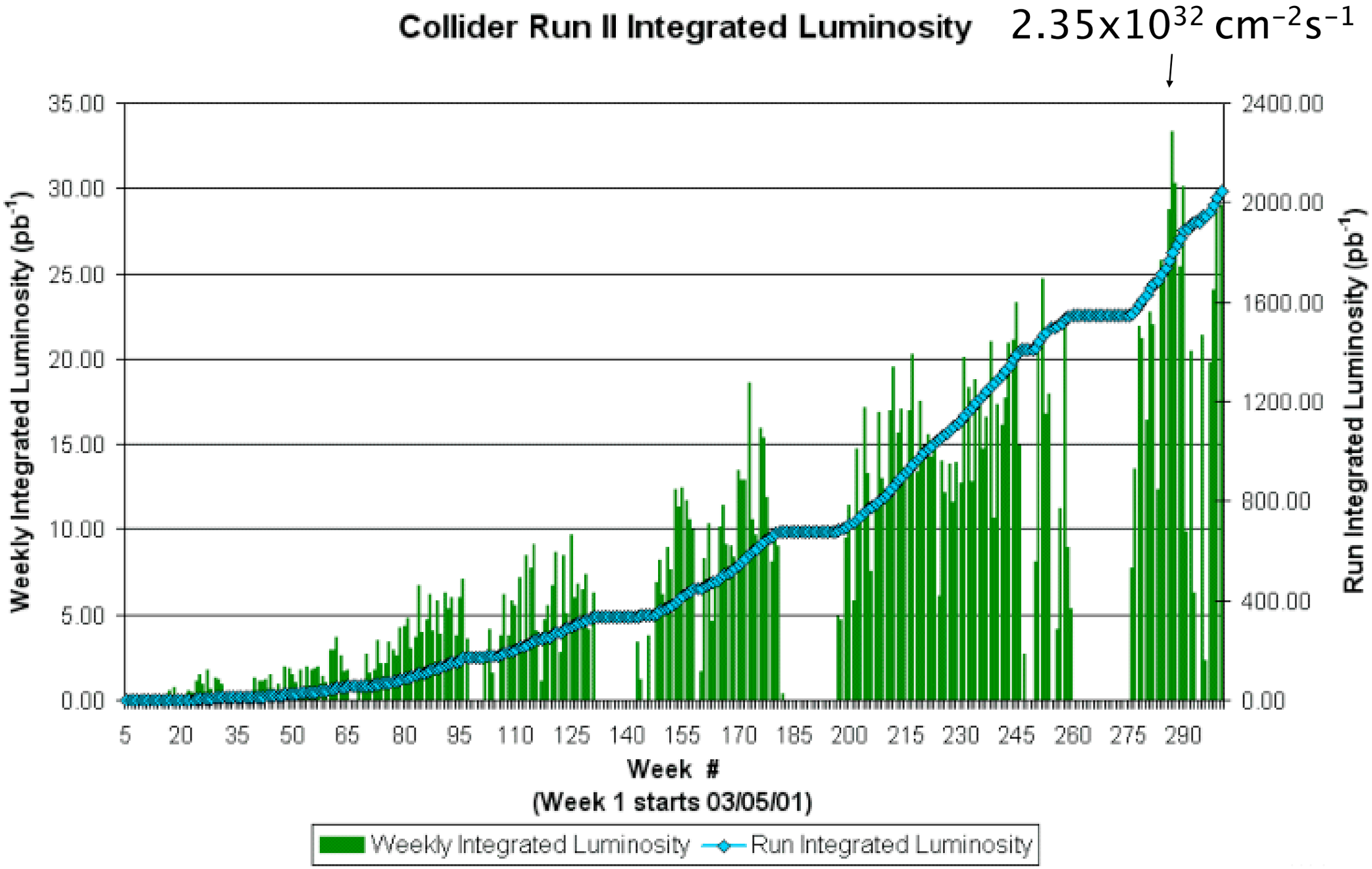
- Tools for searches
- Tevatron
- Recent results
- Prospects & conclusions

Objects & Tools for Searches

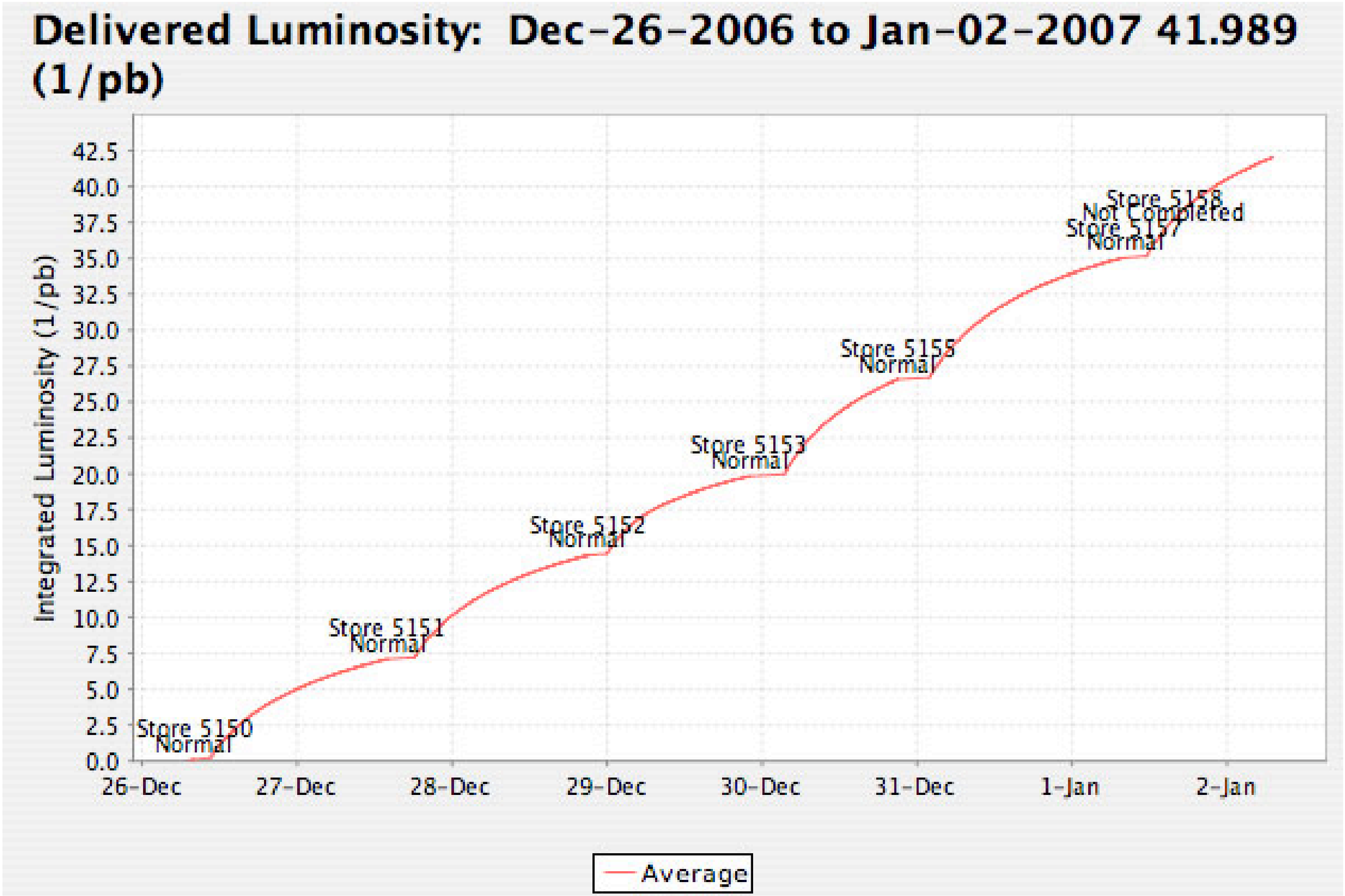
- The workhorses of exotics physics: electrons and muons
  - clean, especially important in hadronic environment
- Photons
  - Cheapest way to get another gauge boson in events
  - clean like electrons
- Tau leptons
  - Because the theorists tells us to
- DAQ/Trigger improvements
  - Critical as instantaneous lumi ↑



Tevatron Performance:2+/fb delivered/experiment!



Recent Tevatron Performance



Recent Tevatron analyses

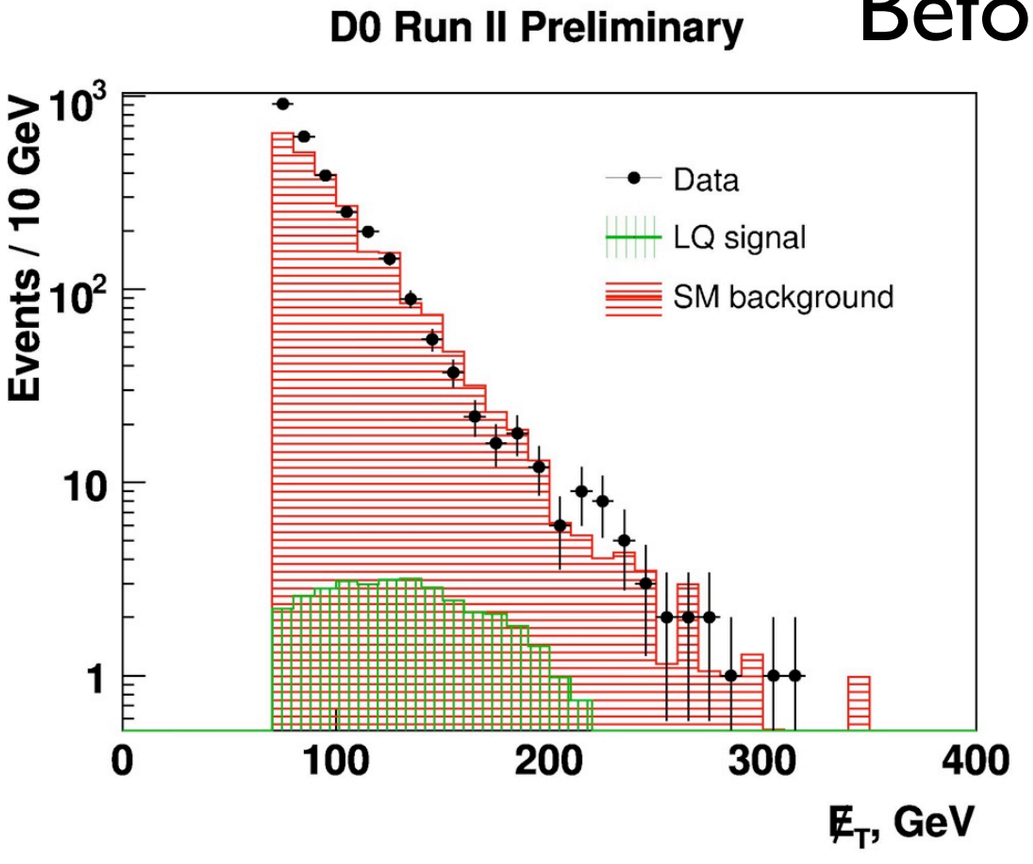
- 3rd Generation leptoquarks
  - D0 Scalar: heavy flavor + MET
  - CDF Vector: di-tau + di-jet channel
- CDF H^{++} with taus
- Z' from CDF and D0
- D0 W' searches
- Signature-based searches
  - CDF LS leptons, trileptons

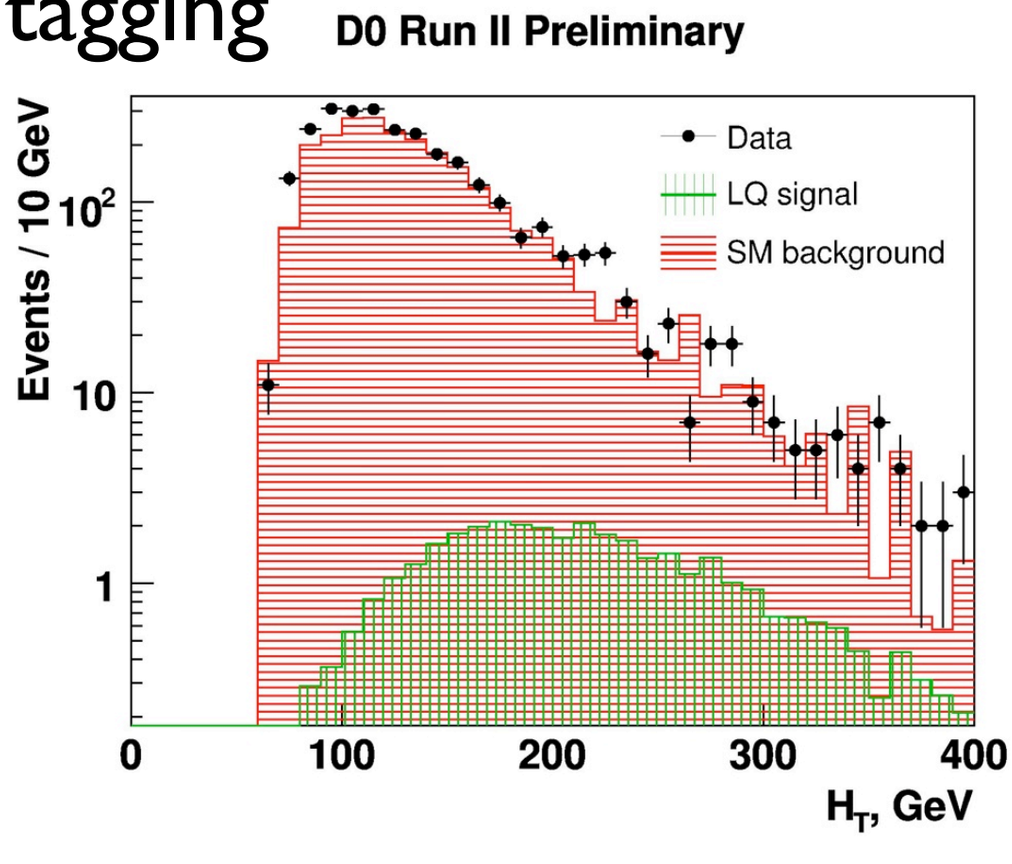
D0: 3rd Gen. Scalar LQ

Assume |charge| = 1/3

- Either LQ3 → ν+b, or LQ3 → τ+top
- Pair-production via q-qbar annihilation dominates for M(LQ3)>100 GeV
- bb νν final state: heavy flavor + MET

Before b tagging





D0: 3rd Gen. Scalar LQ

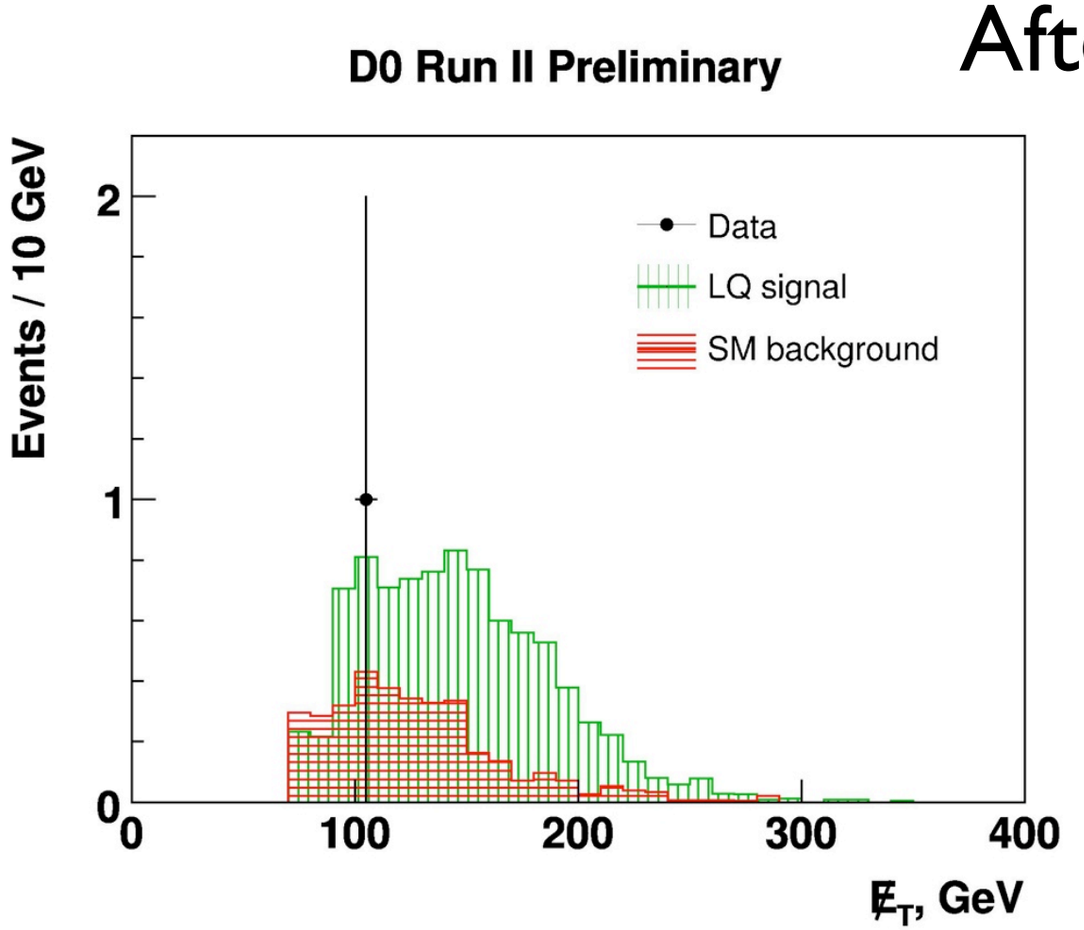
- Strategy
  - Require 2 tagged b's, either tracks' IP or soft muon tag
    - Total energies of these b's should dominate the total event hadronic energy
  - Reconstruct event MET
- Data: two j+MET triggers: 310/pb
- Particle (object) ID
  - veto e, γ, μ
  - MET: corrected for muons
  - jets: cone of ΔR=0.5, cleanup applied
- Signal: PYTHIA for M(LQ3):150-220 GeV

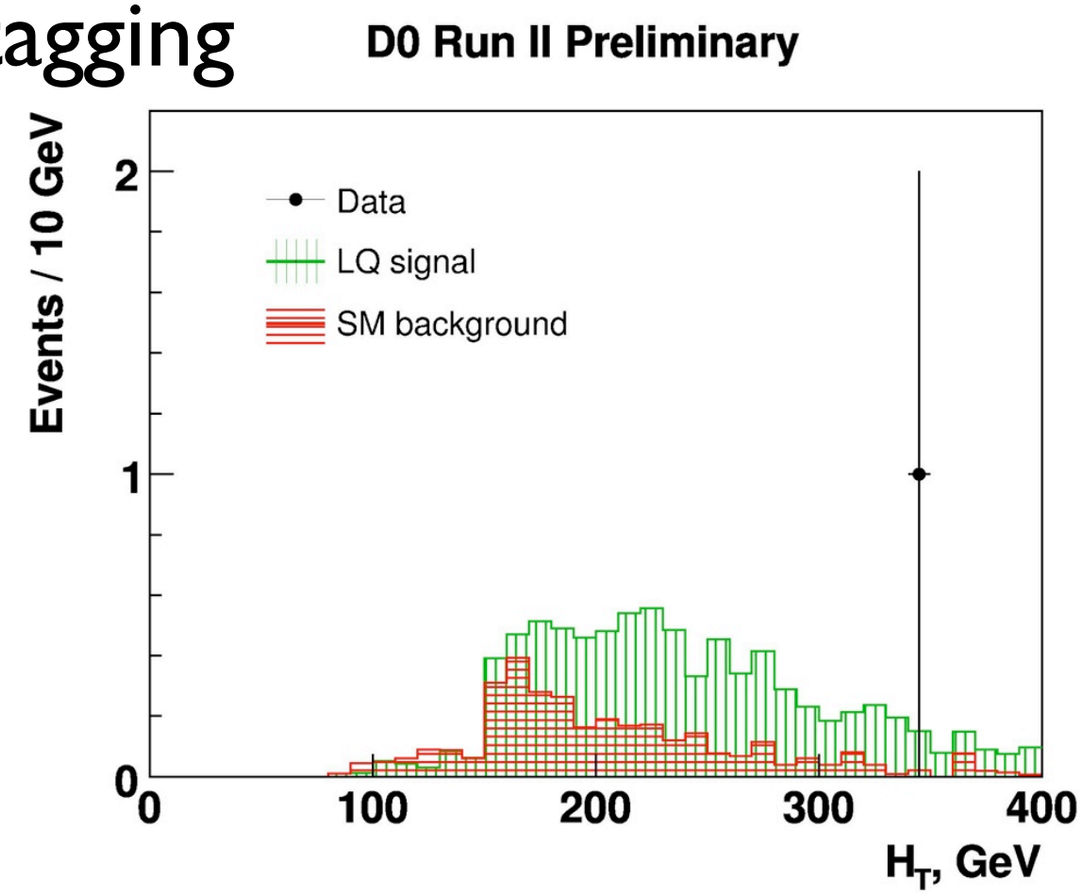
D0: 3rd Gen. Scalar LQ

- Instrumental backgrounds:
  QCD + MET from mismeasurement.
  Dominates at low MET
- Physical (SM) backgrounds: Processes with real MET
  - Largest are W/Z + jets
    - lepton unreconstructed or mis-IDed as jet
  - and Top quarks
- All SM backgrounds evaluated in MC:
  - Single top: COMPHEP, others: ALPGEN
  - → PYTHIA → D0 GEANT Simulation

D0: 3rd Gen. Scalar LQ

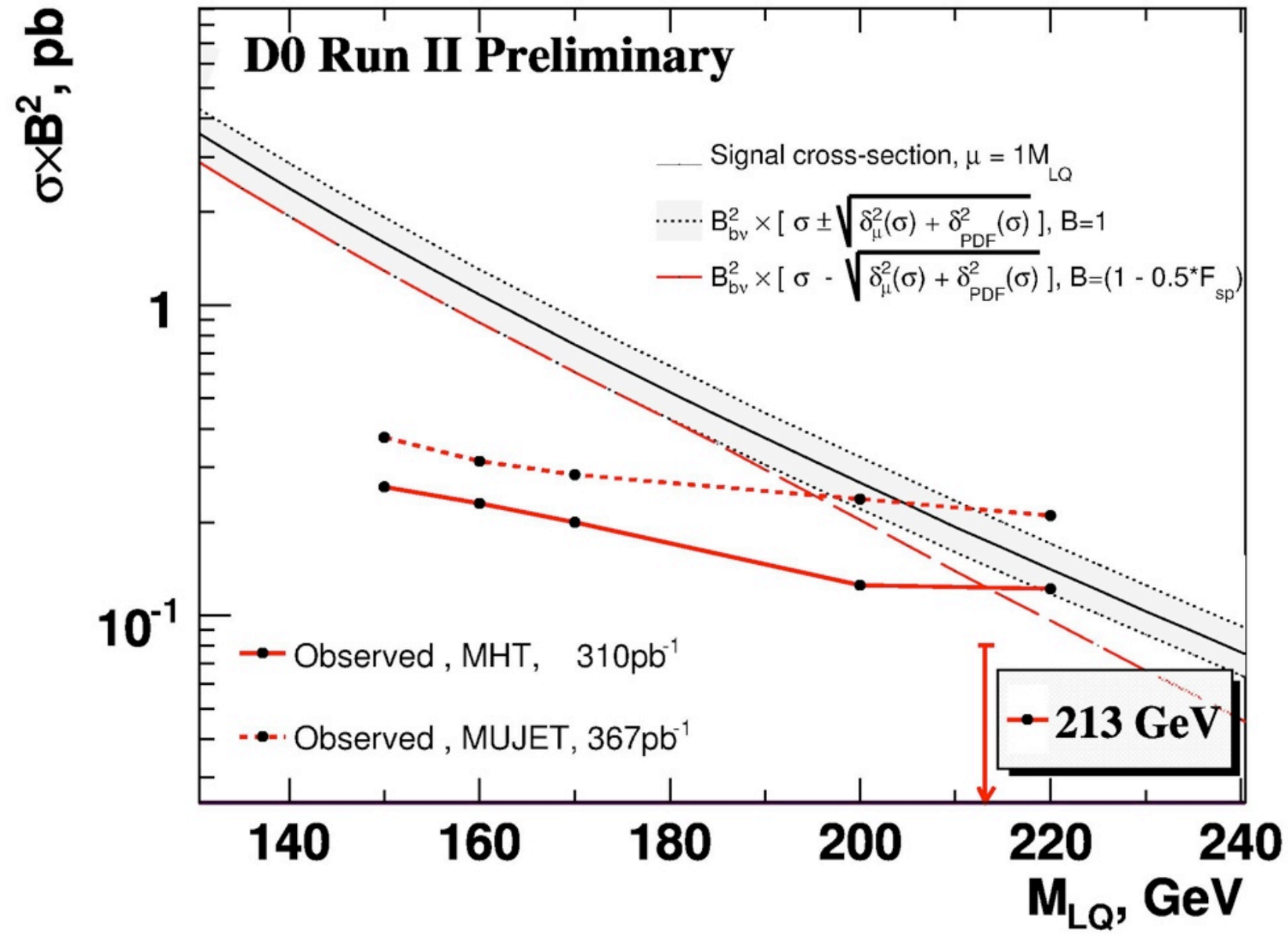
After b tagging





No appreciable excess,
Set limits

D0: 3rd Gen. Scalar LQ

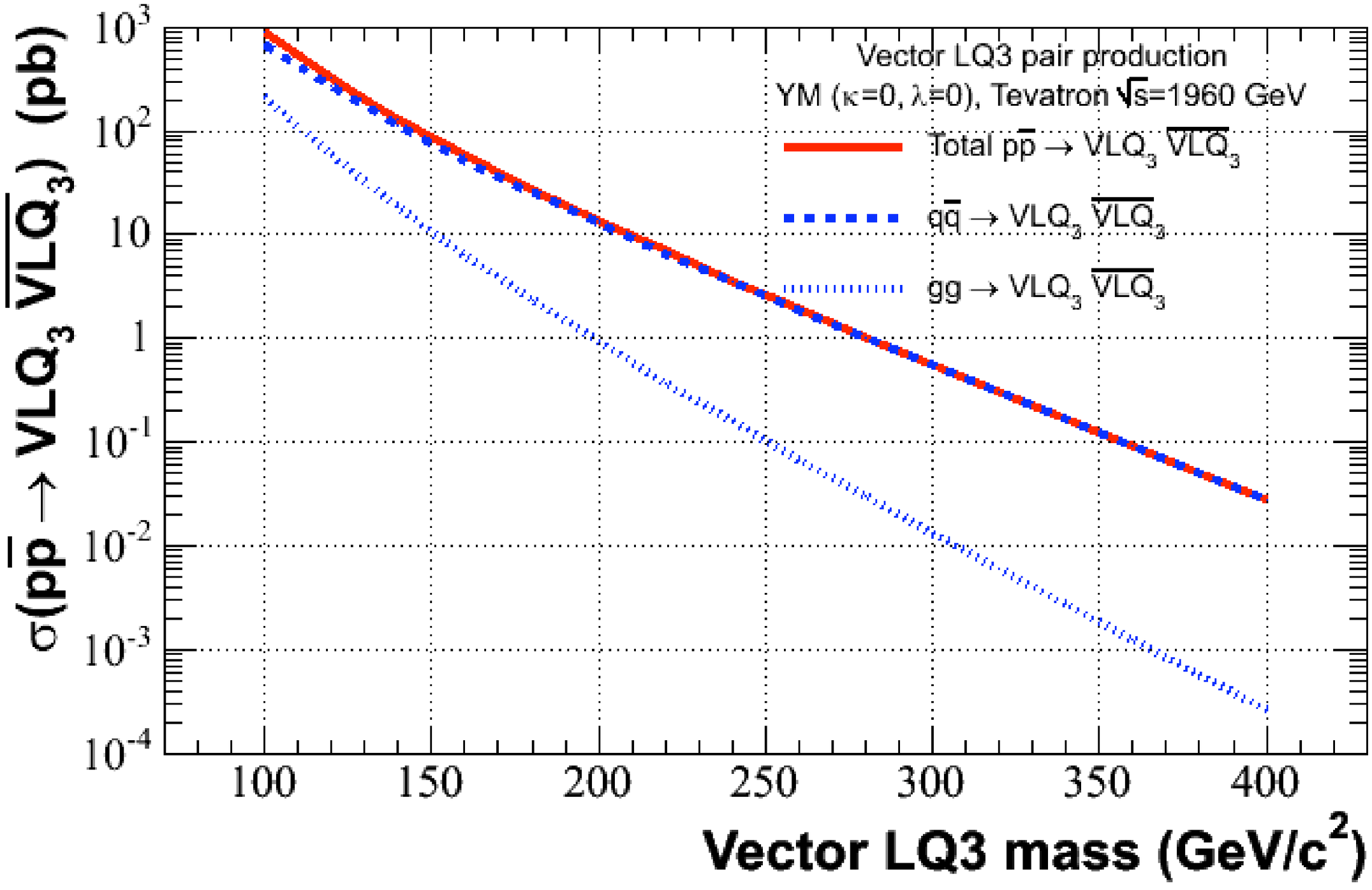


- Result shown also for muon+jet trigger sample analysis
- Threshold effect for t+τ shown with long red dash
- assume branching fraction
  BF(LQ3 → νb) = 1 - 0.5 x phase space suppression factor

CDF: 3rd Gen. Vector LQ

- VLQ3 MC 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>!

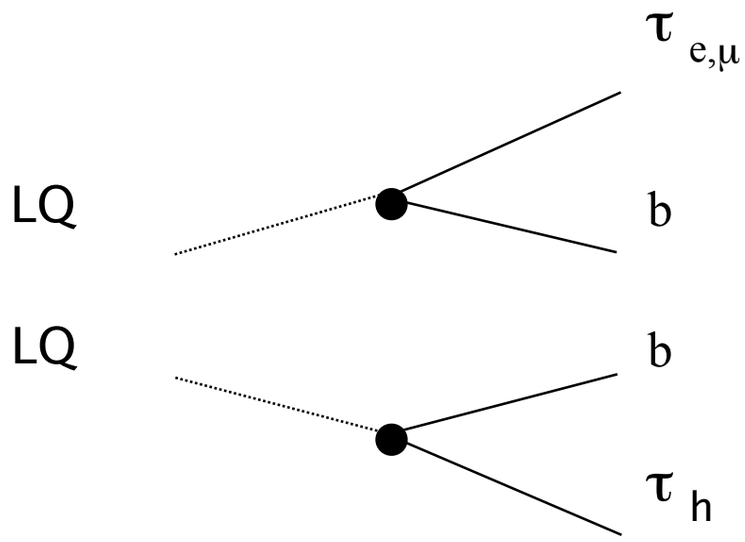
VLQ3 Cross Section



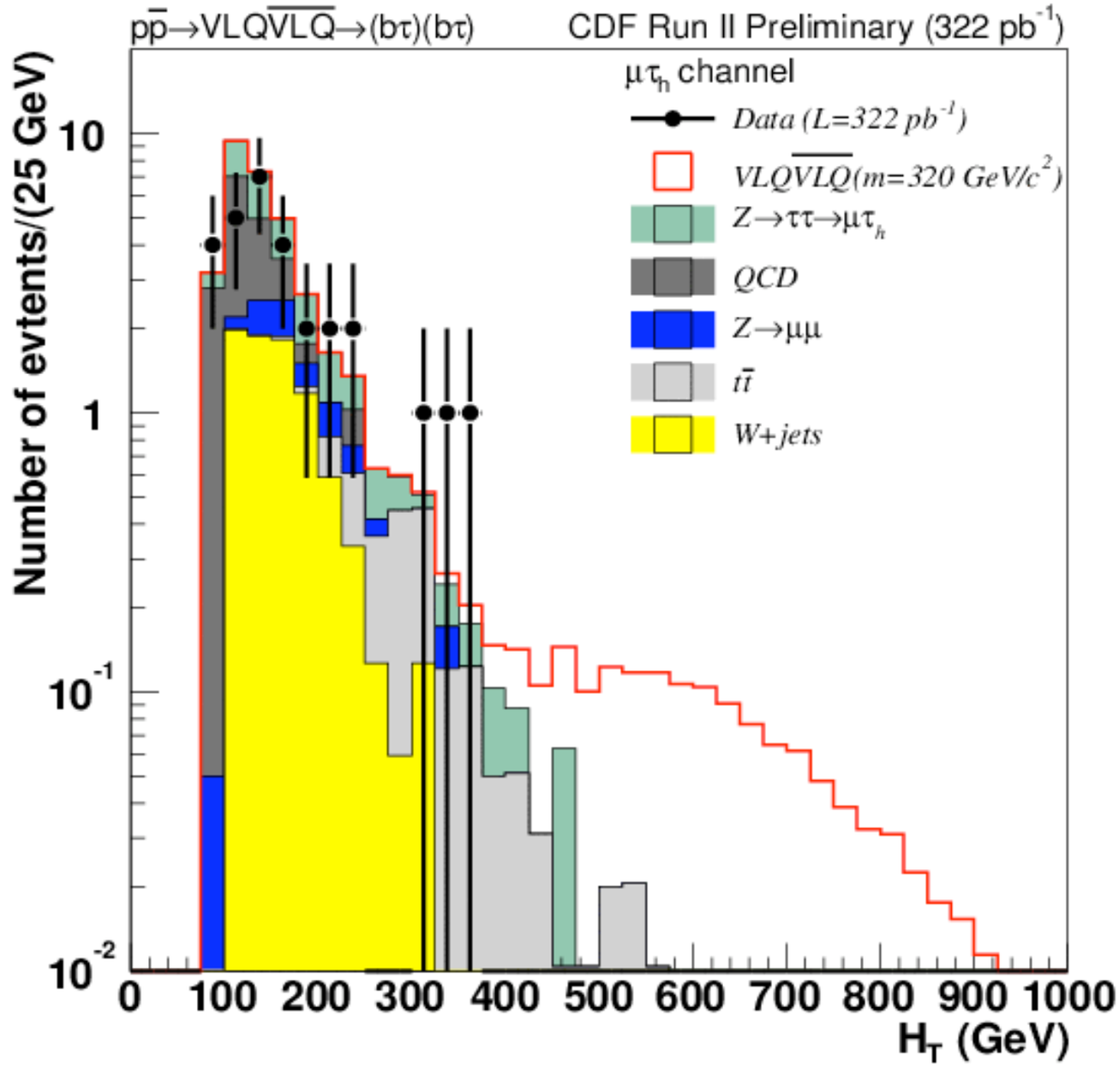
At LHC, situation ~ reversed

CDF VLQ3 Analysis

- Use Lepton+Track trigger

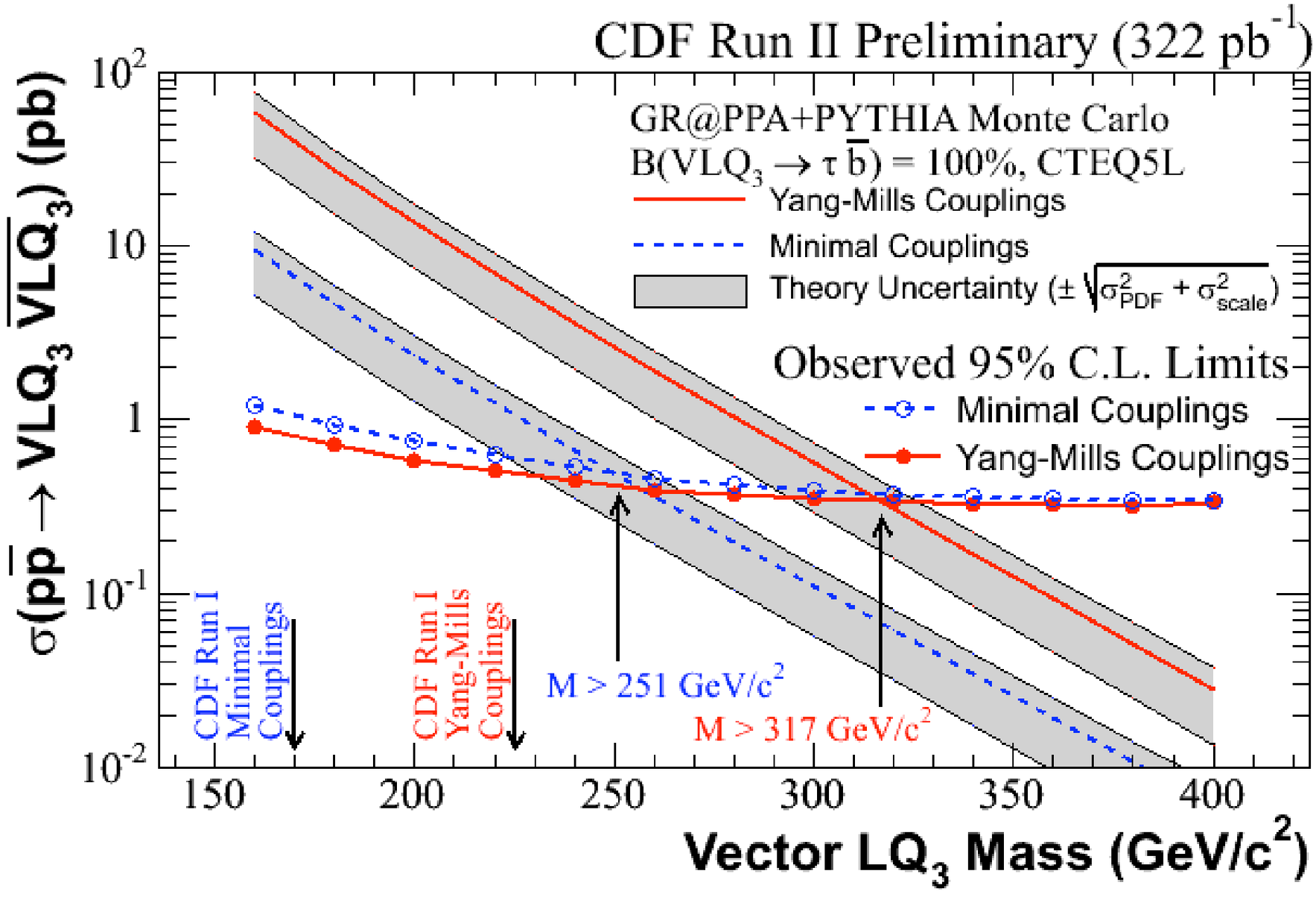


- $H_T = E_T(\text{lepton}) + E_T(\tau_h) + \not{E}_T + \sum E_T(\text{jets})$



CDF VLQ3 Results

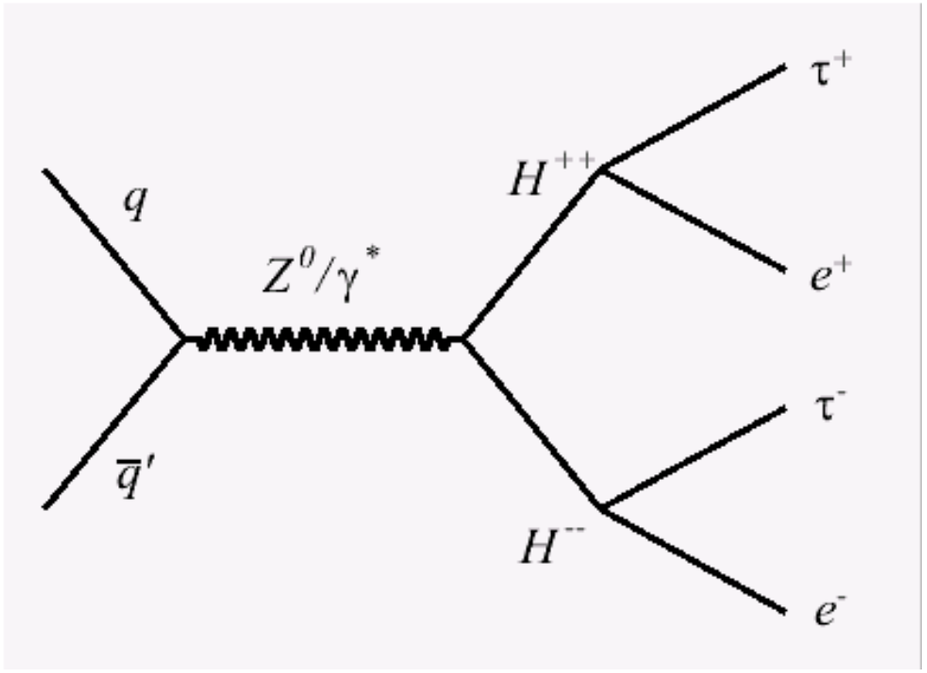
No events observed

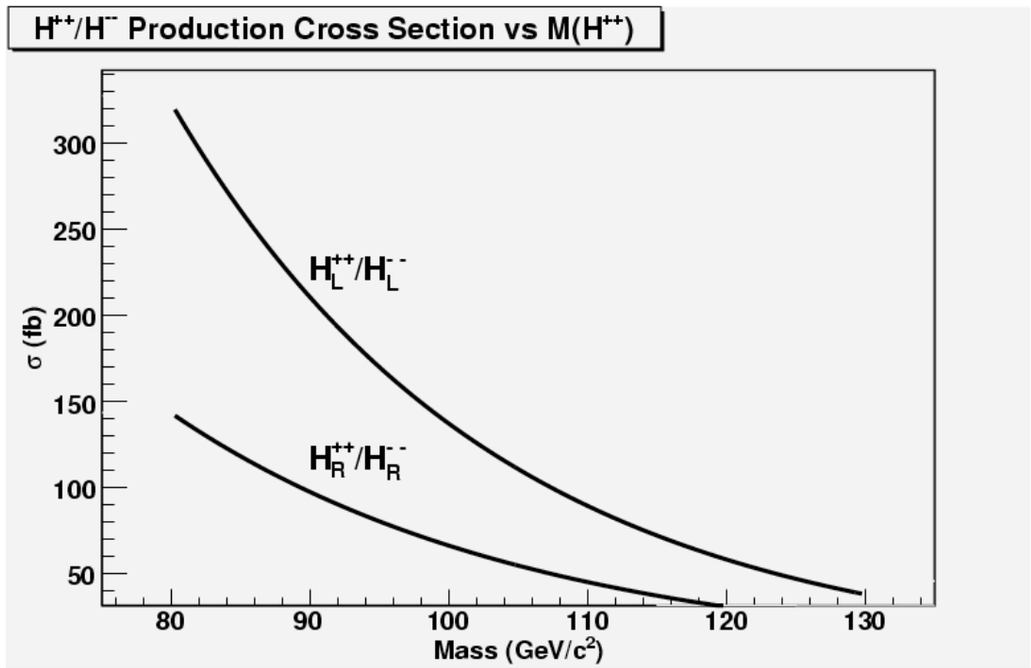


- Minimal Coupling type
  m > 251 GeV/c^2
- Yang-Mills type
  m > 317 GeV/c^2

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)

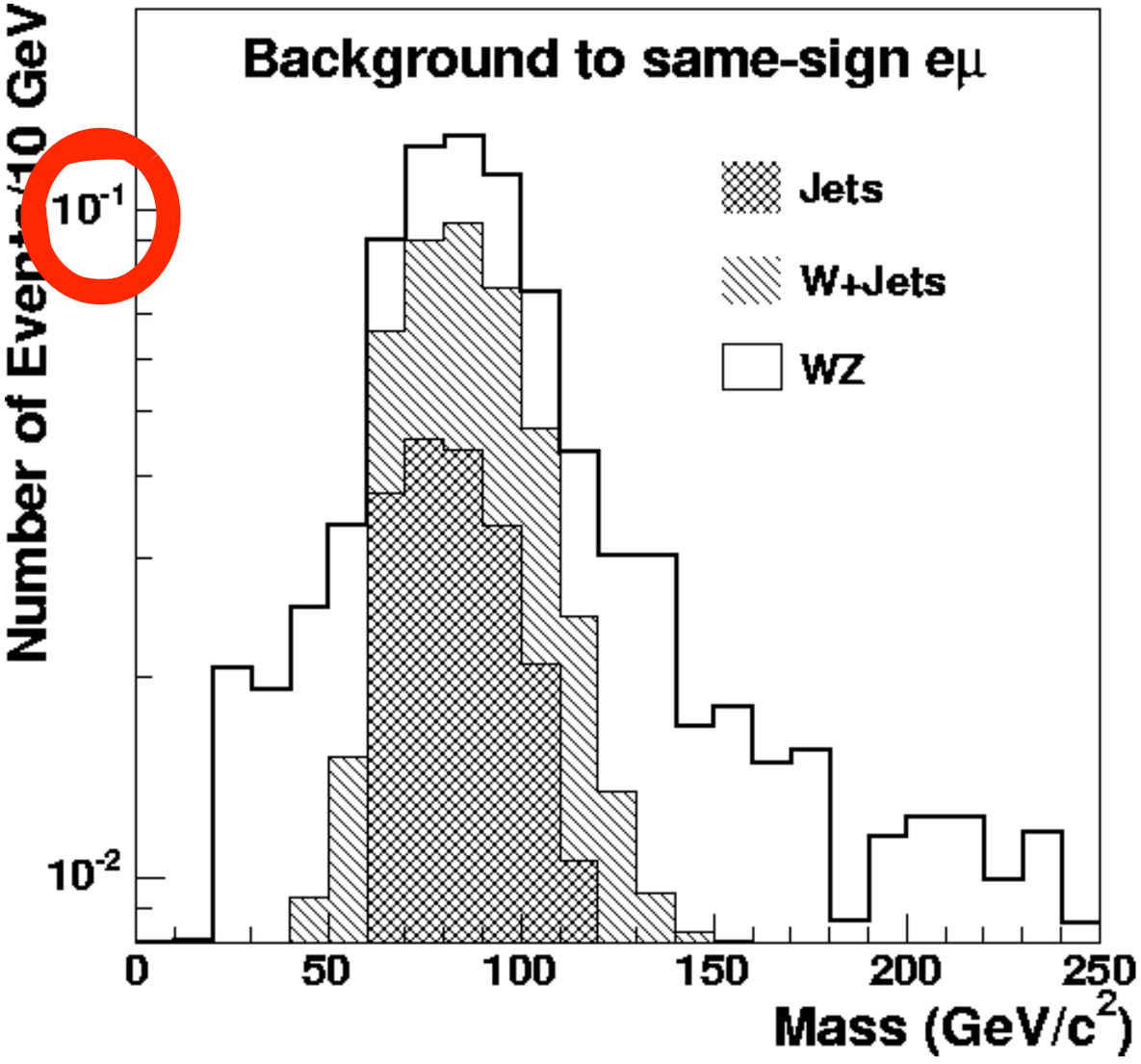


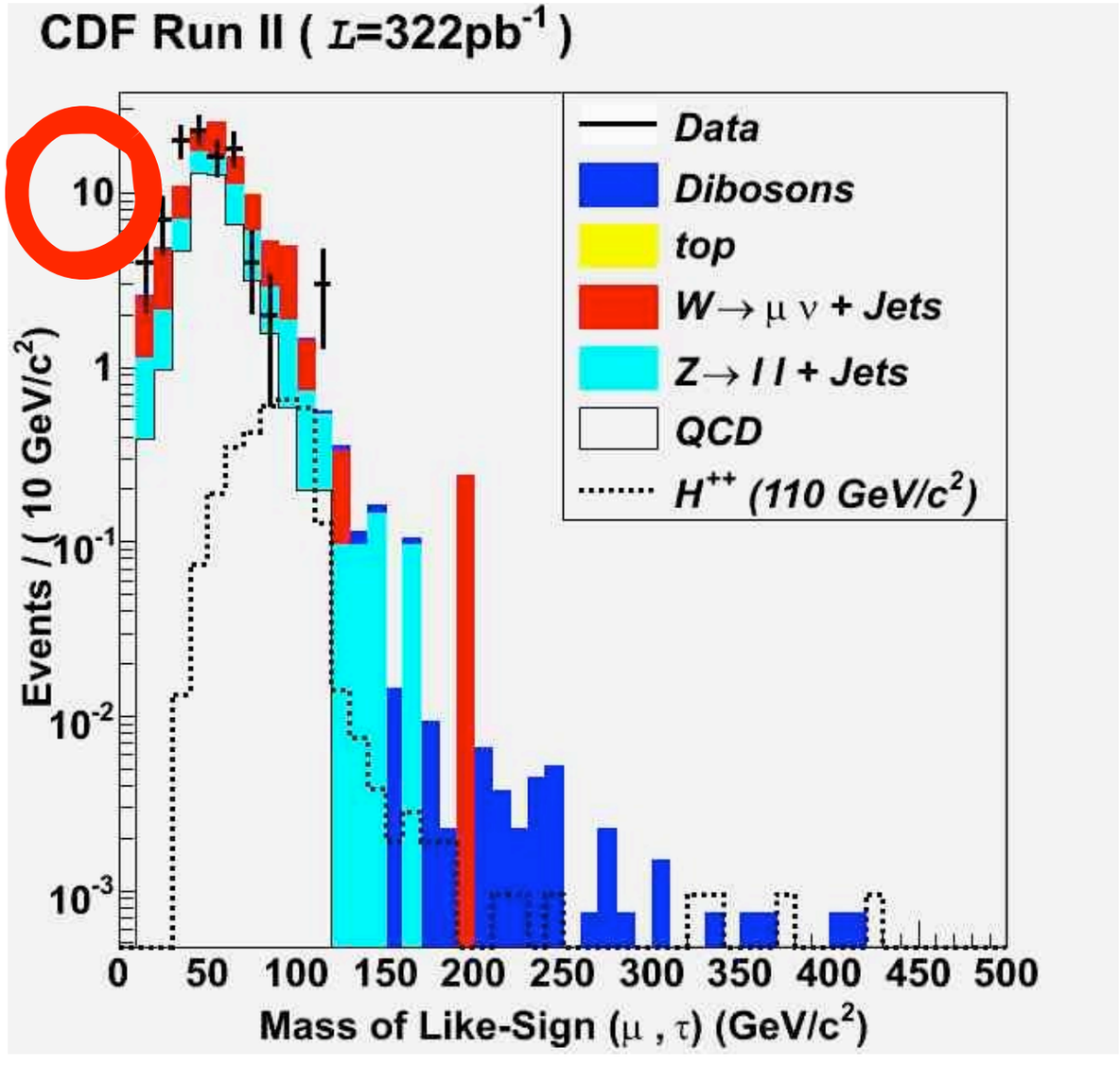


(At present, not considering $p\bar{p} \rightarrow H^{++}H^{-}$)

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

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



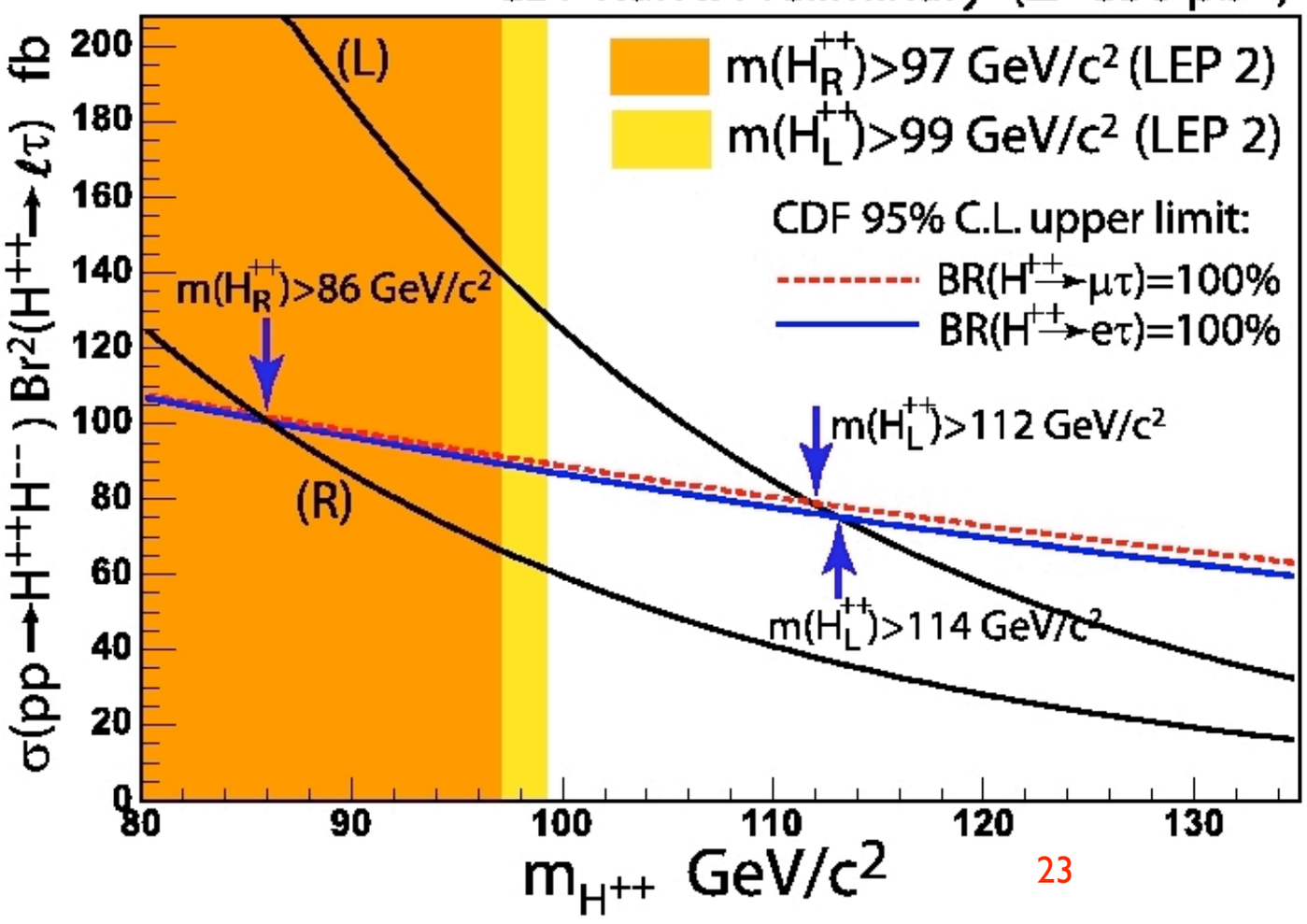


H++ → eμ

H++ →τμ

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

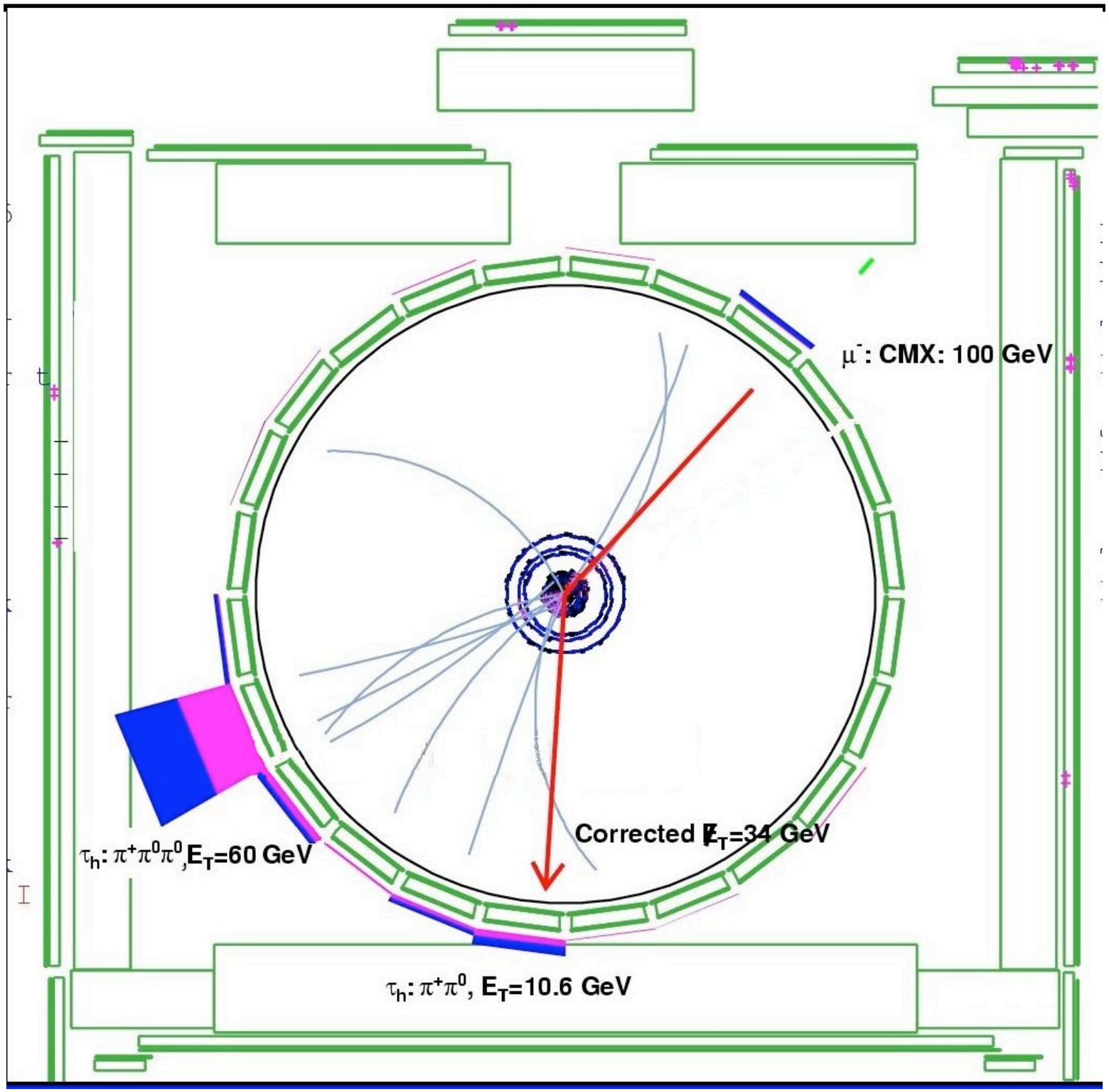
- Employ "lepton+track" triggers (low P_T)
  - Will be critical for $H^{++} \rightarrow \tau\tau$ search
- Require 3 or 4 leptons to suppress W+jets
- H_T cut, Z mass veto, LS mass window
  - No events survive



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

H^{++} interesting event

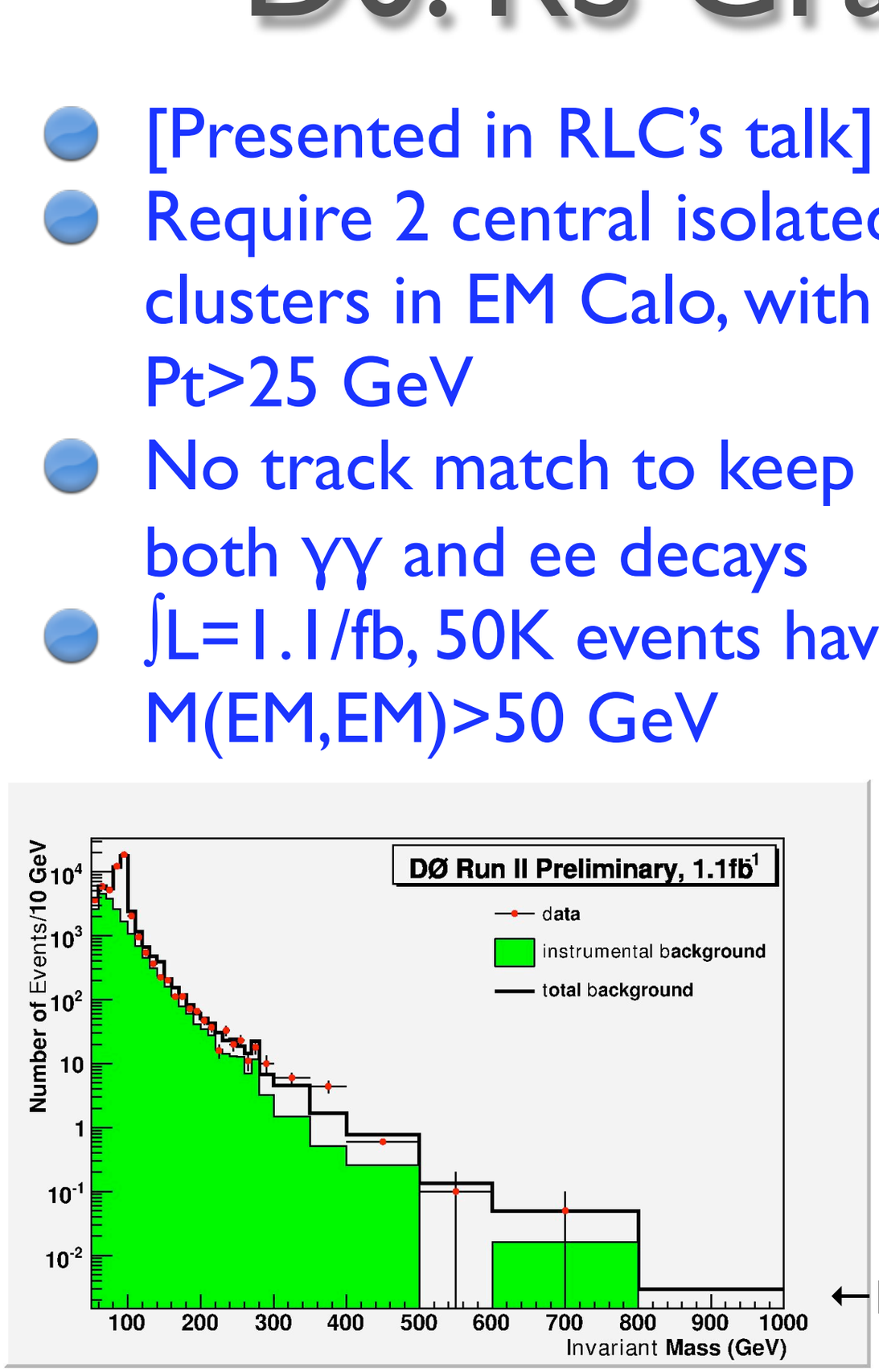
- $\mu^-\tau^+\tau^+$
- Fails LS mass window cut
- Likely SM process is W+jets



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

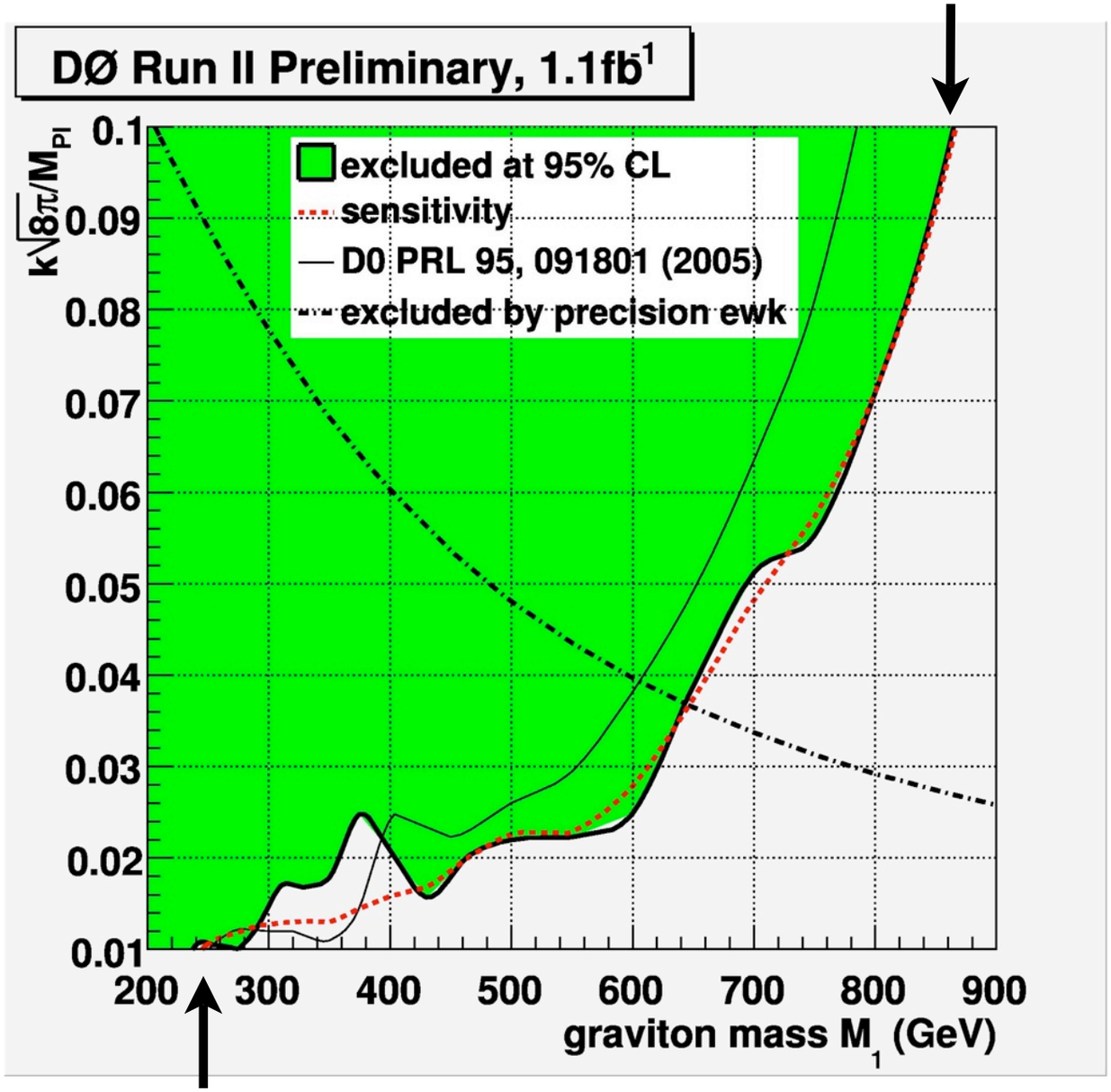
D0: RS Graviton Search

- [Presented in RLC's talk]
- Require 2 central isolated clusters in EM Calo, with Pt>25 GeV
- No track match to keep both γγ and ee decays
- ∫L=1.1/fb, 50K events have M(EM,EM)>50 GeV



←Examine with sliding mass window, no excess seen

M_1>865 GeV



M_1>240 GeV

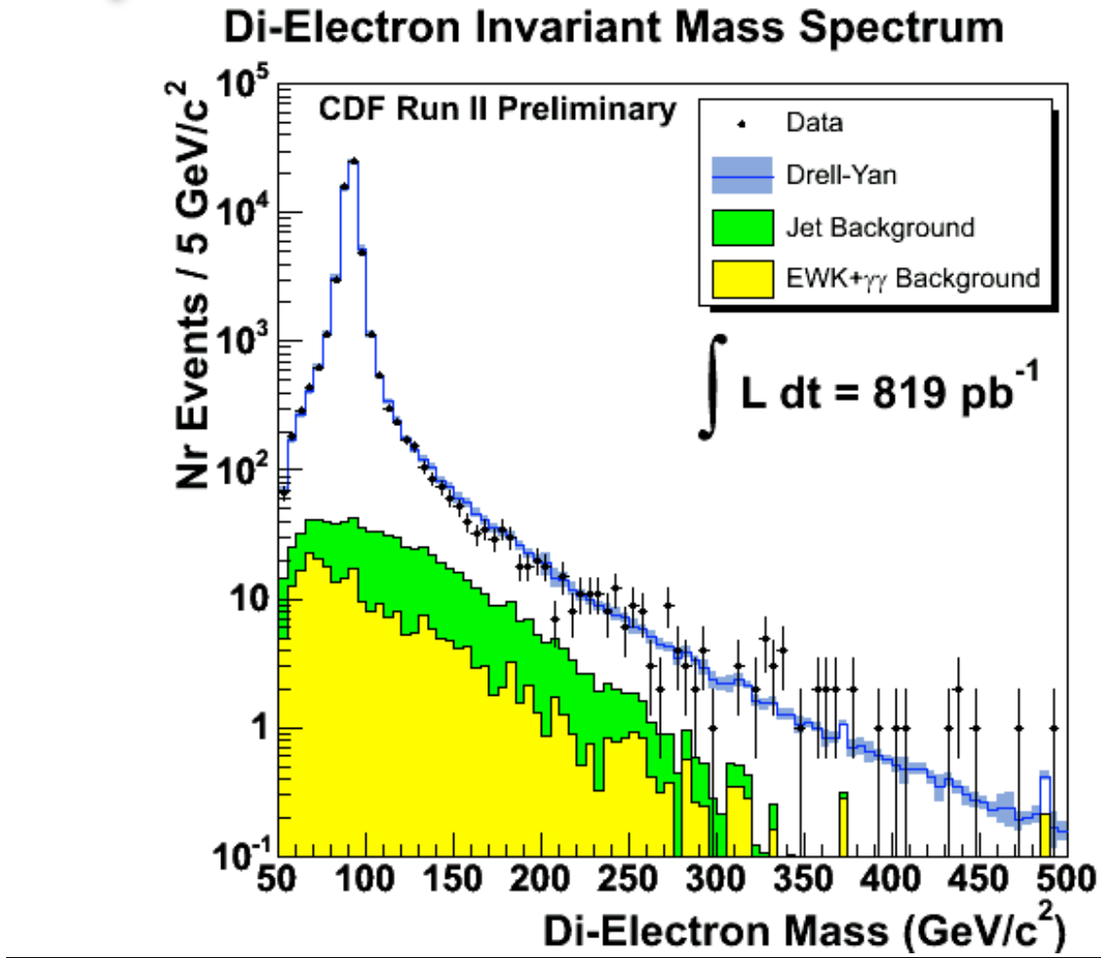
CDF High Mass Search

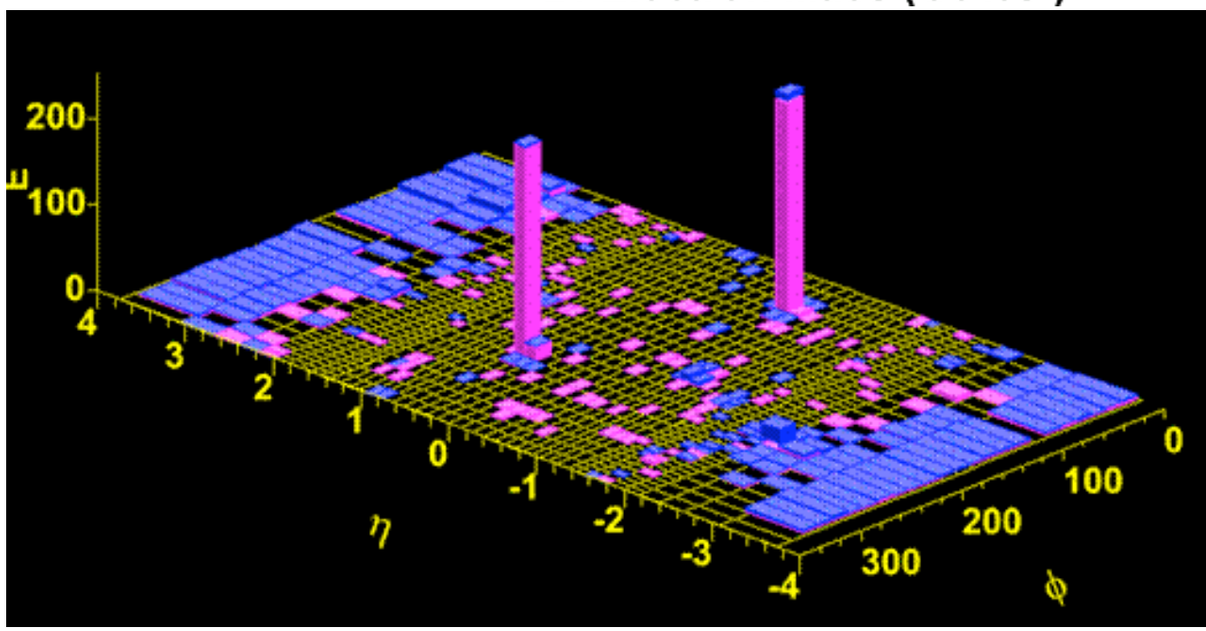
- Search 819/pb data for high mass narrow resonance in ee channel
- Selection: di-EM objects, Et>25 GeV
  - Both Central and Forward Calos used
- Signal: SM like Z' (S=1) and RS-1 Graviton (S=2)
  - Pythia + CTEQ5L + CDF GEANT Simulation
- Backgrounds
  - Drell-Yan, Diboson, $Z \rightarrow \tau\tau$, tt
  - Di-jet, W+j, W+γ, γγ {at least 1 fake}

CDF Z', $G_1 \rightarrow ee$

Normalization

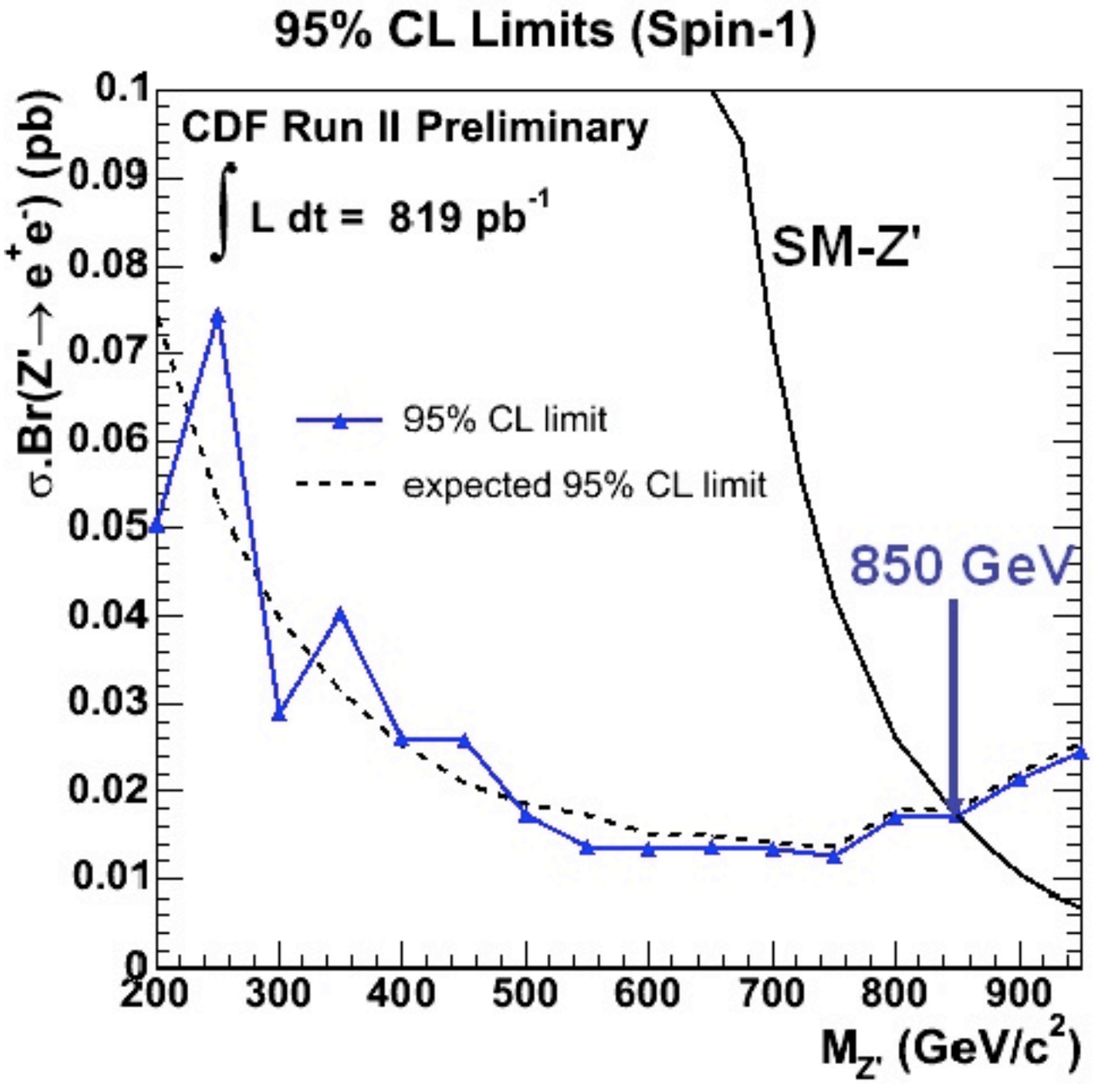
- DY to data around Z peak
- Di-jet, W+jets: extrapolate from events with unisolated leptons, and shapes taken from di-jet events with one j→e
- Other BG from MC, with theoretical σ
- Clearly, the SM fits the data→set limits

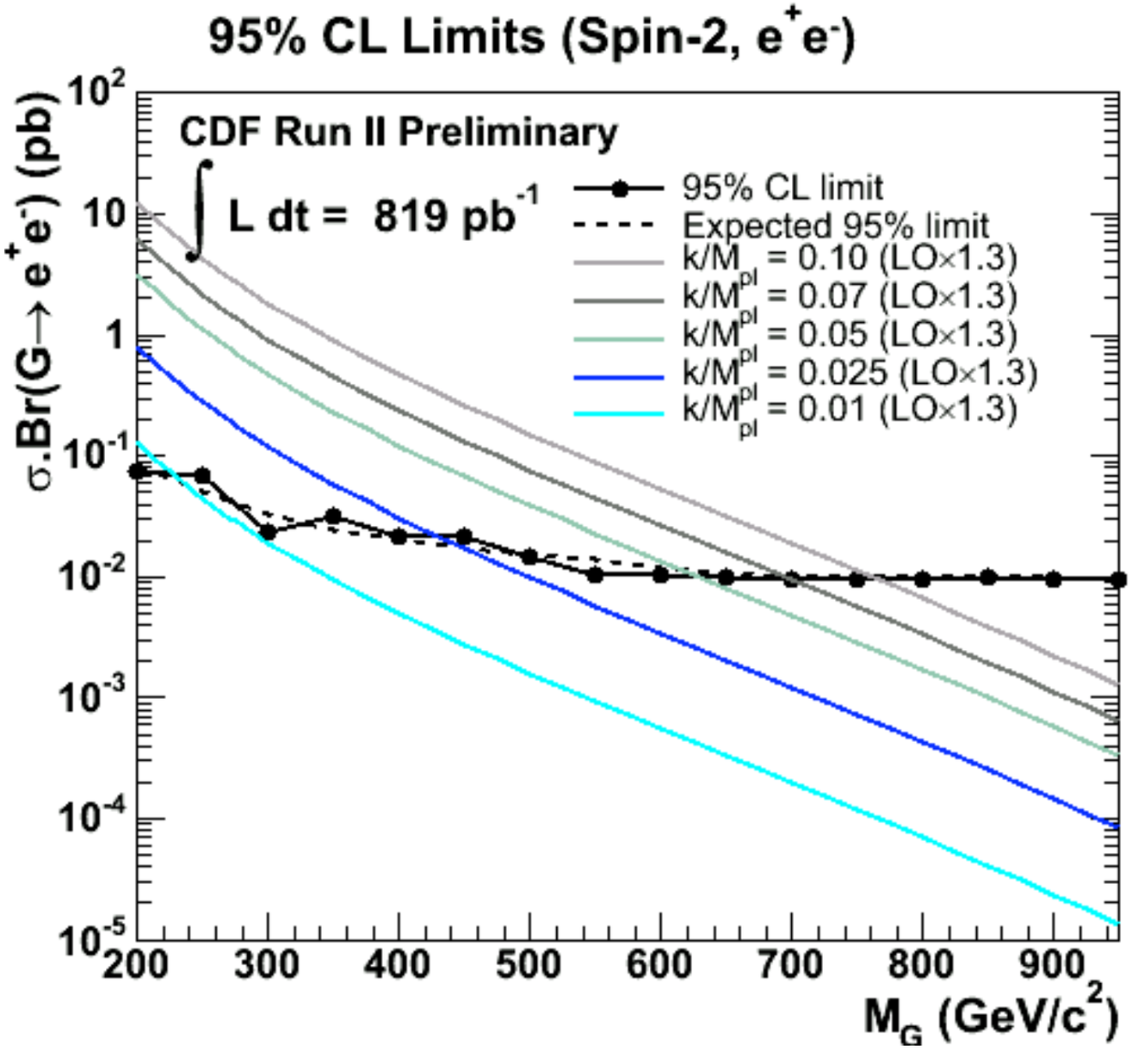




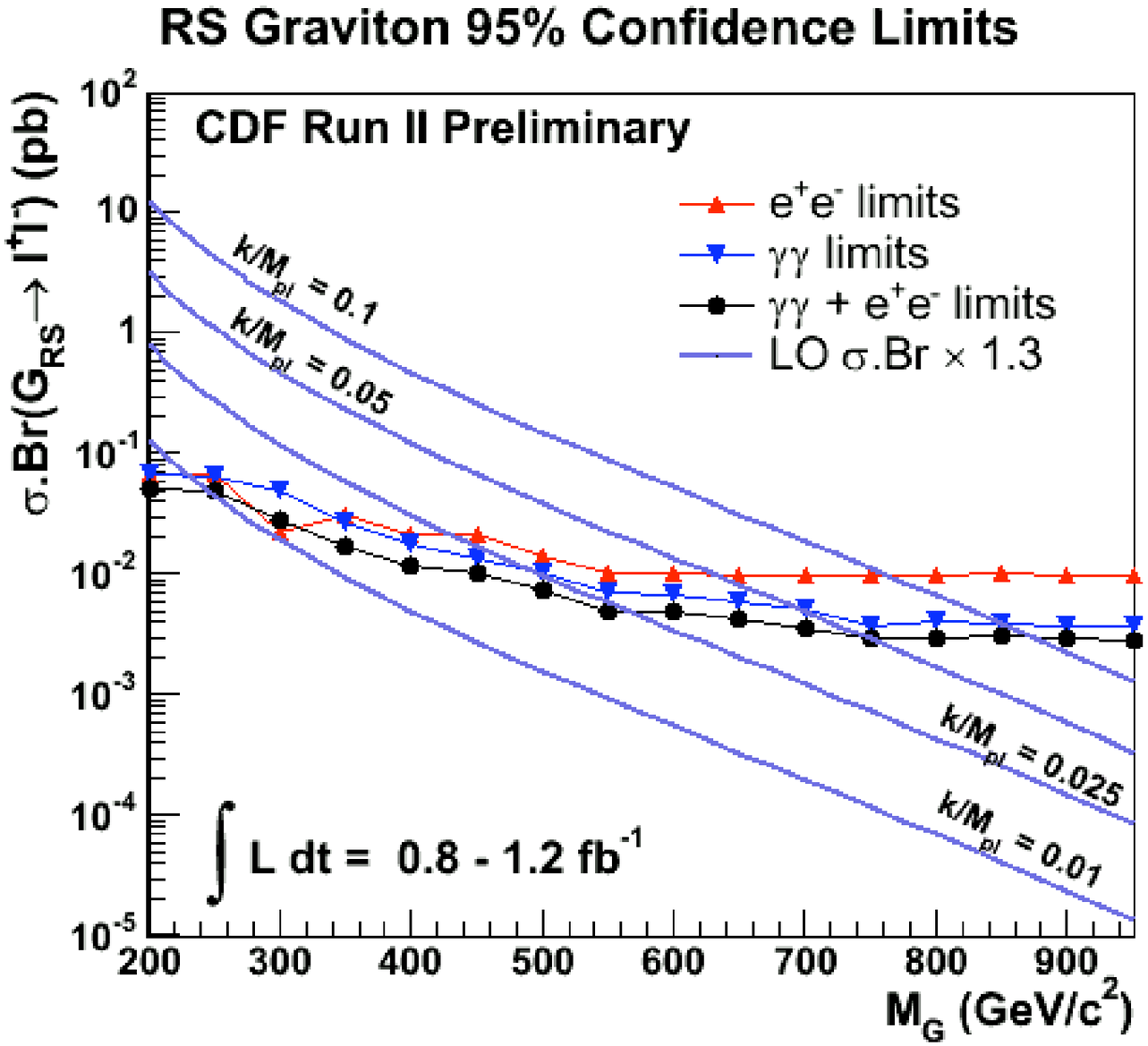
High Mass ee limits

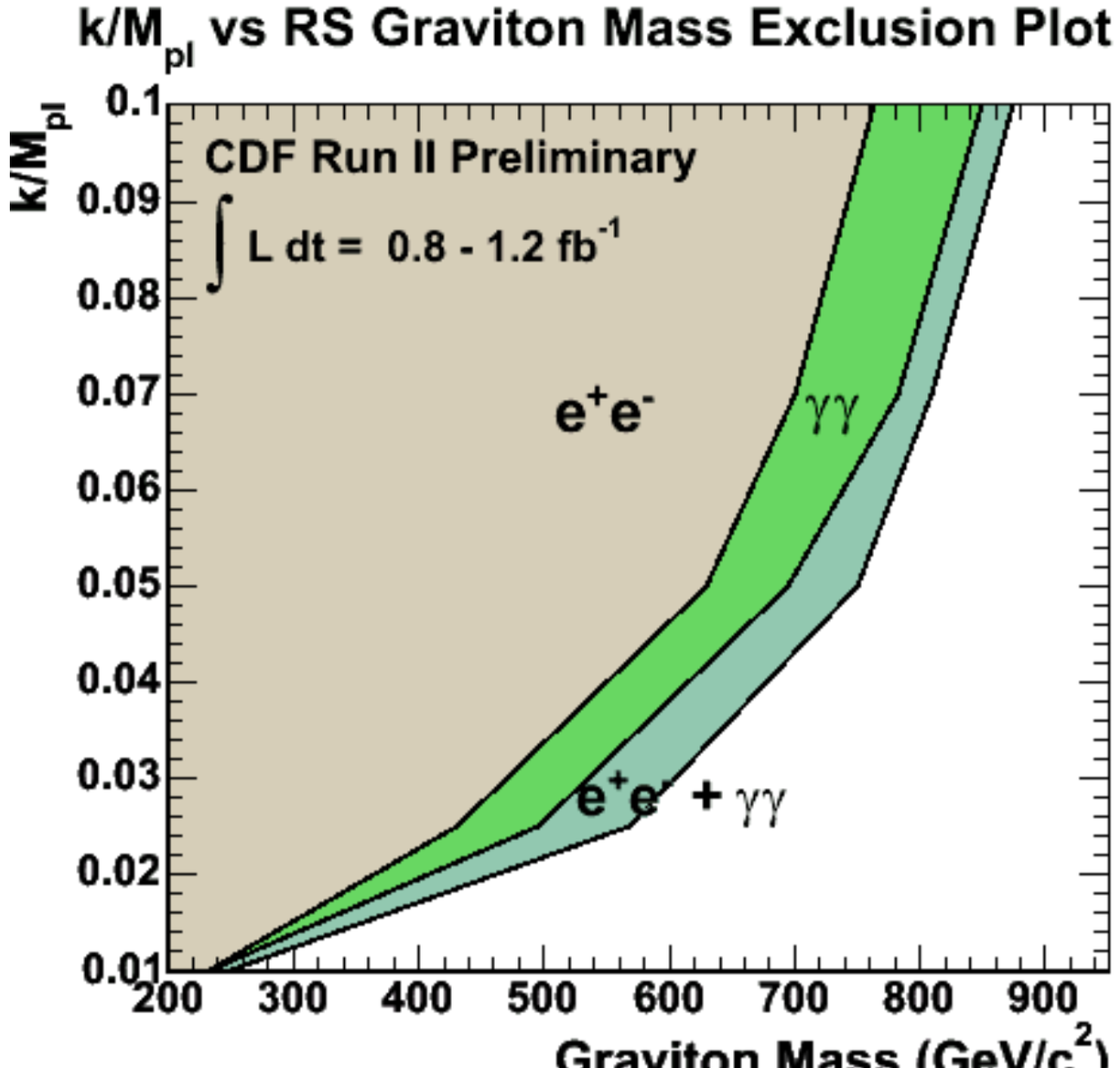
- Mass spectrum scan: 150-950 GeV @ 1 GeV intervals
- Bayesian binned likelihood fit to extract limits





Combination with γγ search





D0: W'→eν Search

- W' bosons appear in various SM extensions:
  - L-R models, GUTs with or w/o SUSY
  - Can have new mixing angle, couplings and CKM matrix.
  - Keep it simple: No mixing, same couplings, matrix, and W' → WZ suppressed
- W' assumed width:

$$\Gamma_{W'} = \frac{4}{3}\frac{m_{W'}}{m_W}\Gamma_W$$

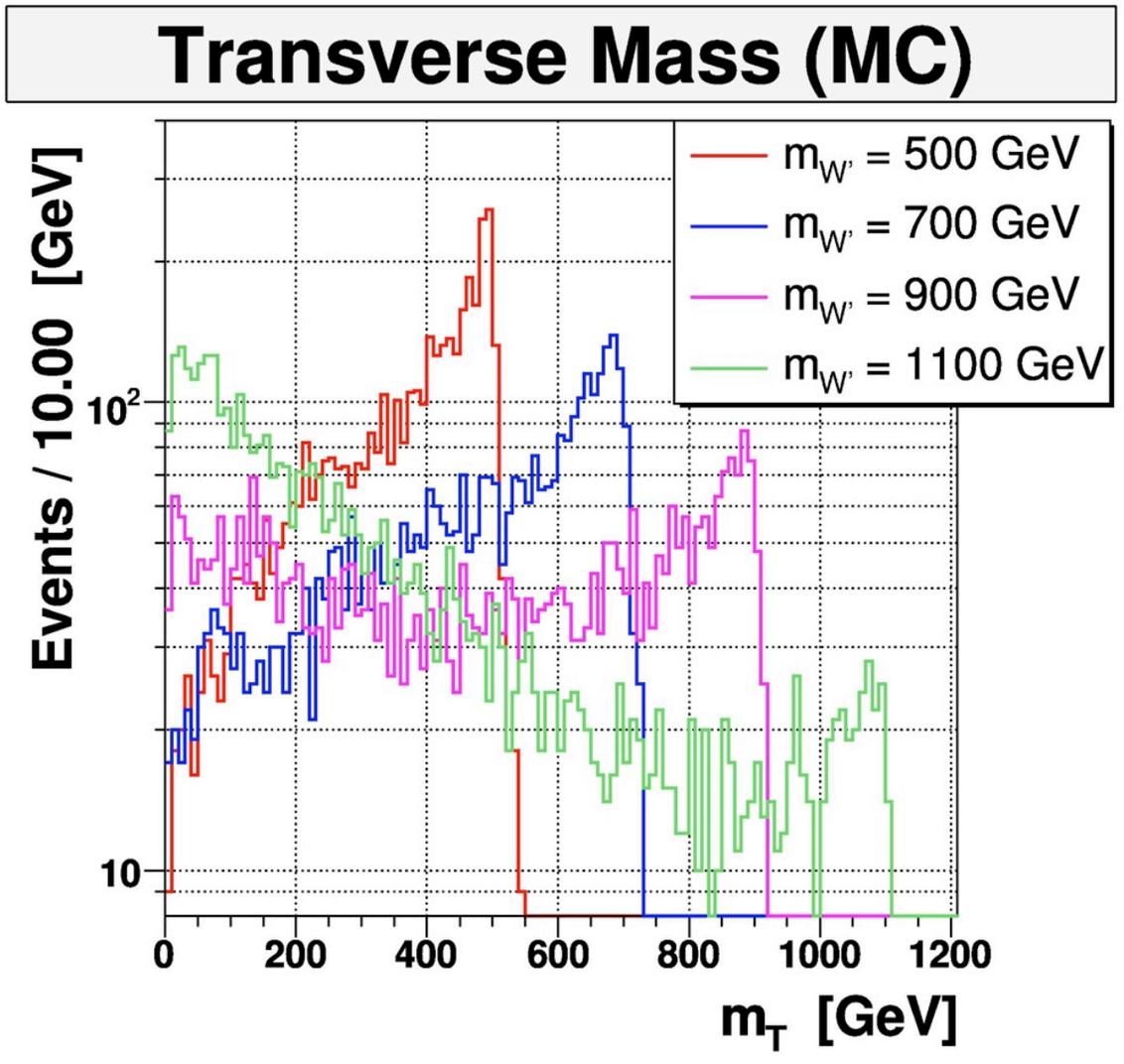
4/3 accounts for W'→tb for m(W')>180 GeV

D0: W'→eν Search

- Signature: $p\bar{p} \rightarrow W' + X \rightarrow e\nu + X$
- Data: 900/pb
- Backgrounds
  - W,Z,Diboson: MET comes from neutrino
  - QCD multijet with j→e plus mismeasurement
  - Z→ee, one electron lost giving rise to MET
- QCD from data, others from Pythia
- W' Signal
  - Pythia, with NNLO corrections applied to σ

D0: W'→eν Search

Jacobian blurs at high mass

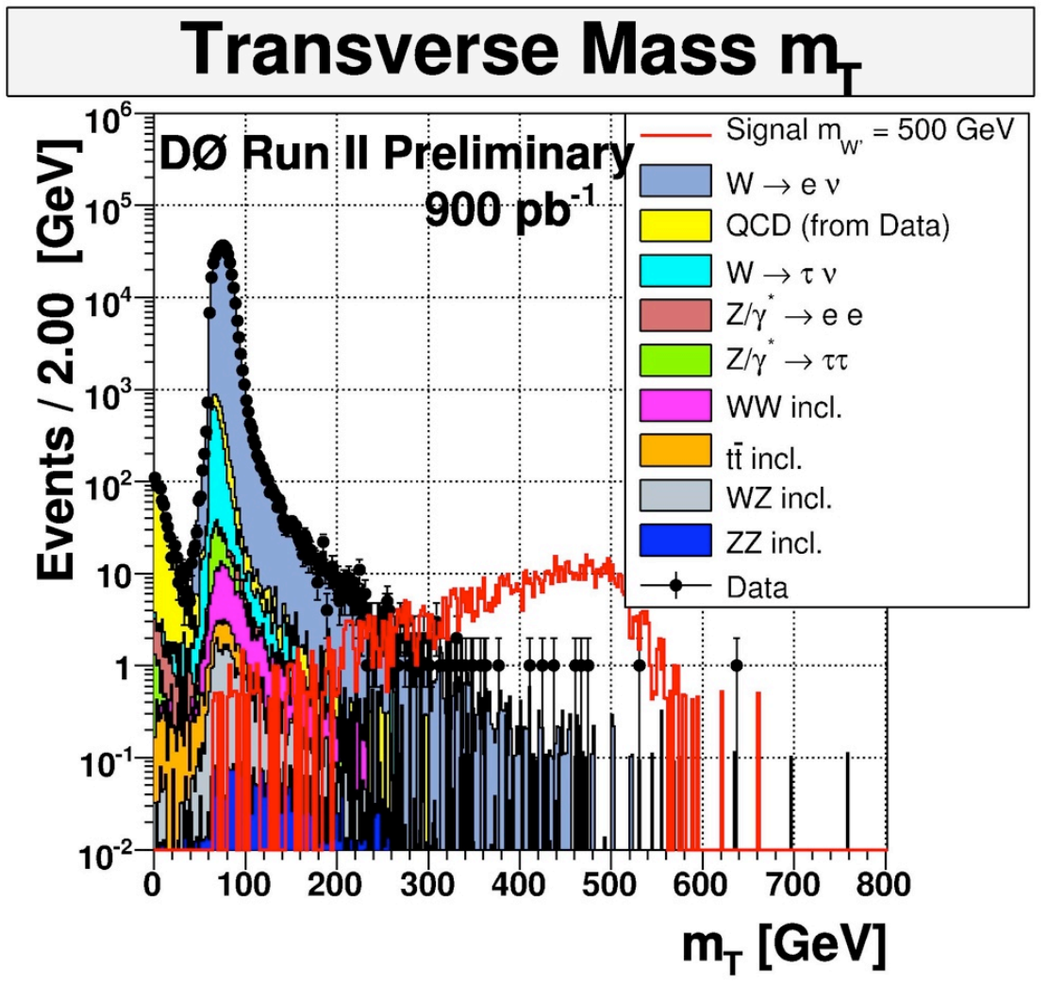


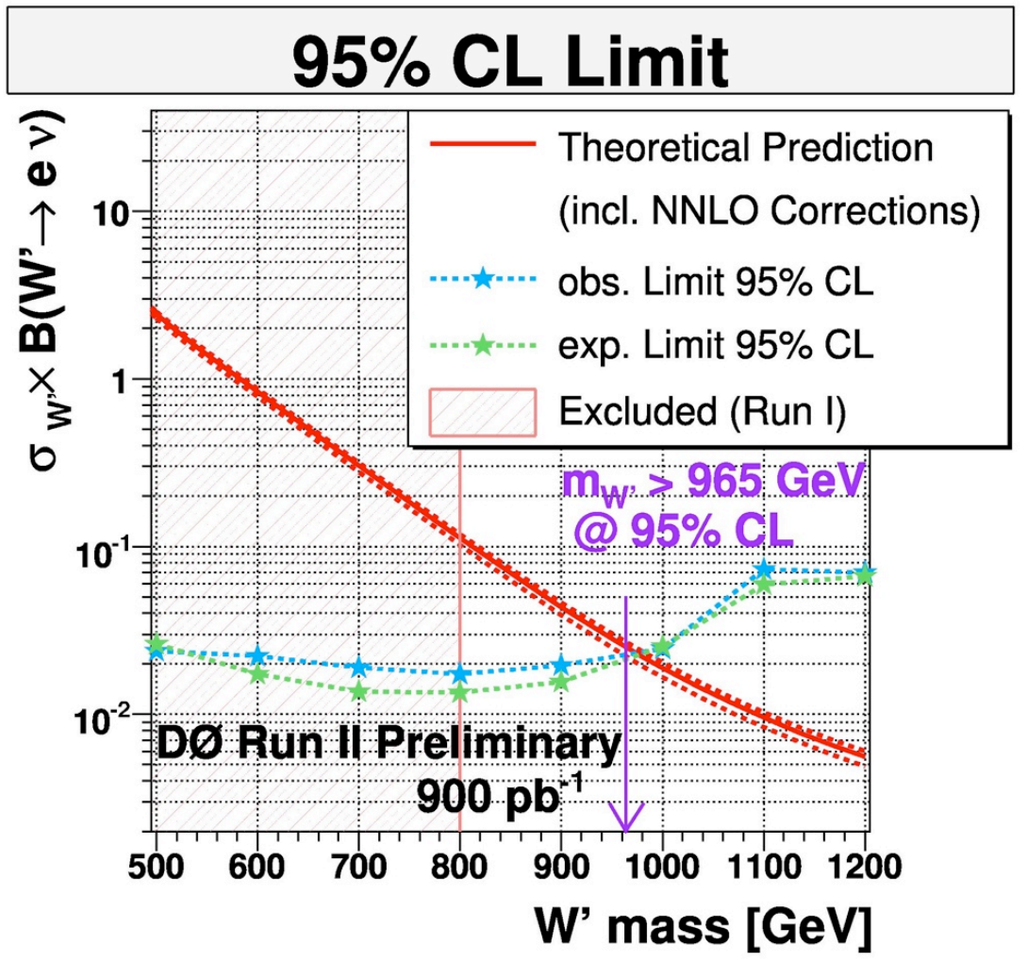
Selection

- Isolated Central electron, Et>30 GeV
- MET > 30 GeV
- 0.7<Et(e)/MET<1.3
- Δφ cuts: jet-e and jet-MET -- Rejects QCD

W'→eν Results

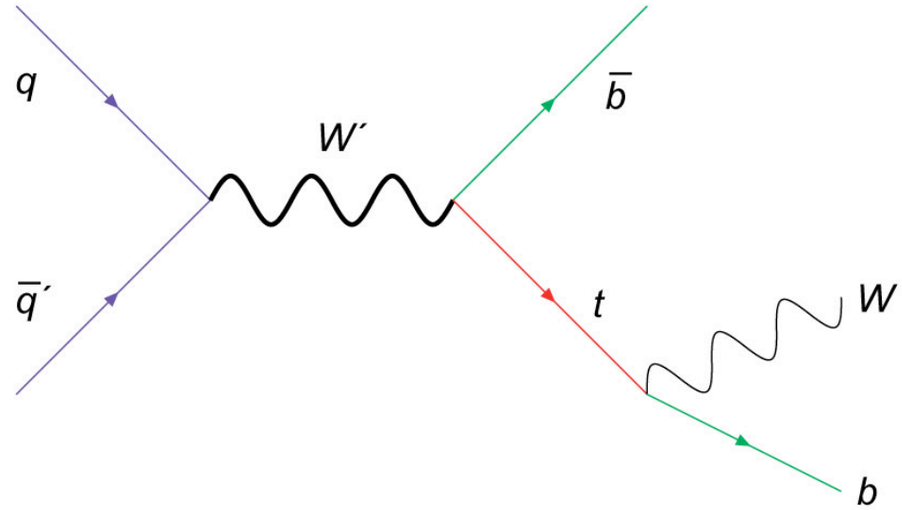
- QCD from data for $m_T < 40$ GeV
- Overall normalization to W peak
- Excellent agreement with SM seen
- Set limits: fit m_T spectrum above 150 GeV

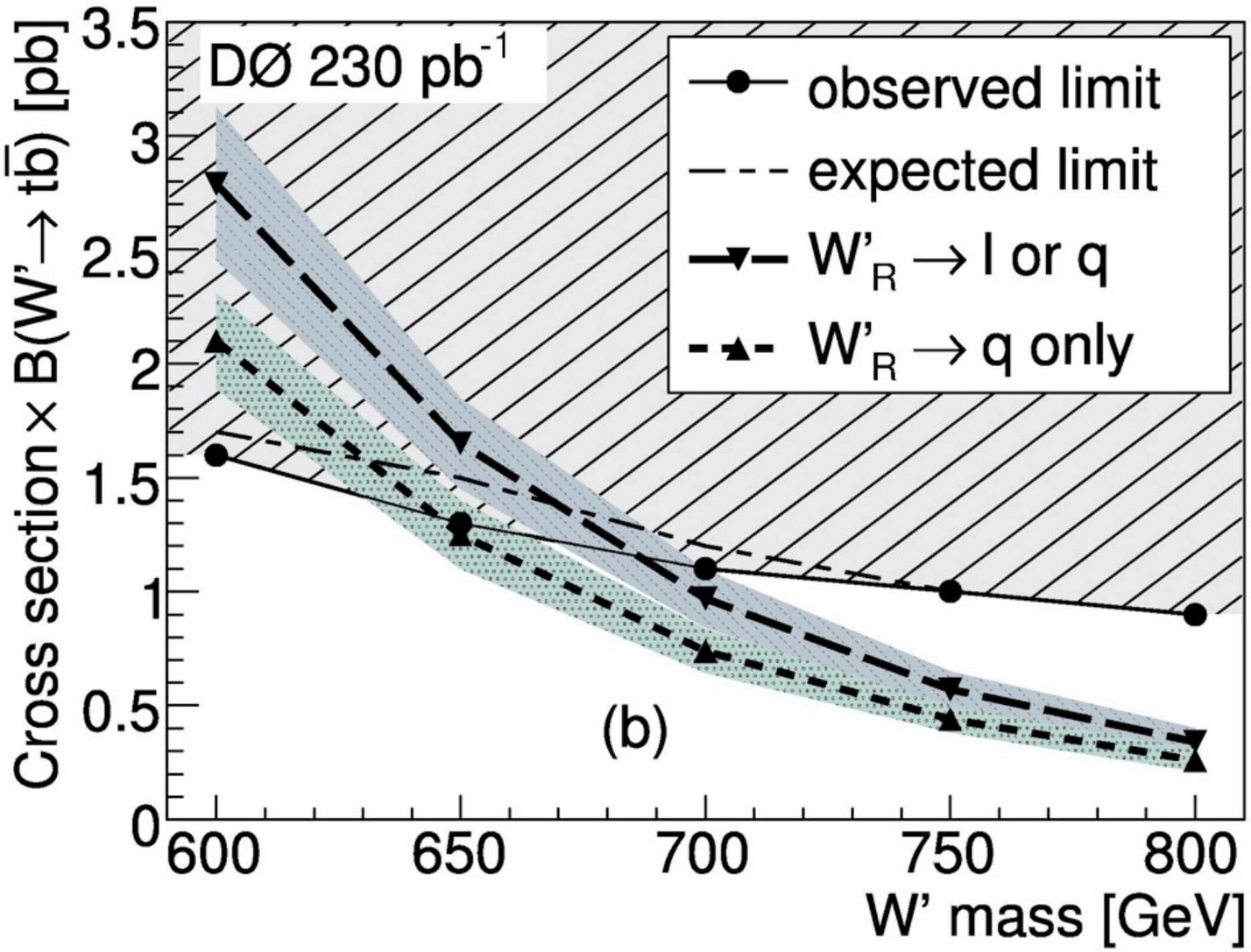




D0: W'→tb Search

- If W' massive enough, decay to top+bottom can occur
- Sig: ≥1b + e or μ +MET
- No excess observed





CDF Version ready soon

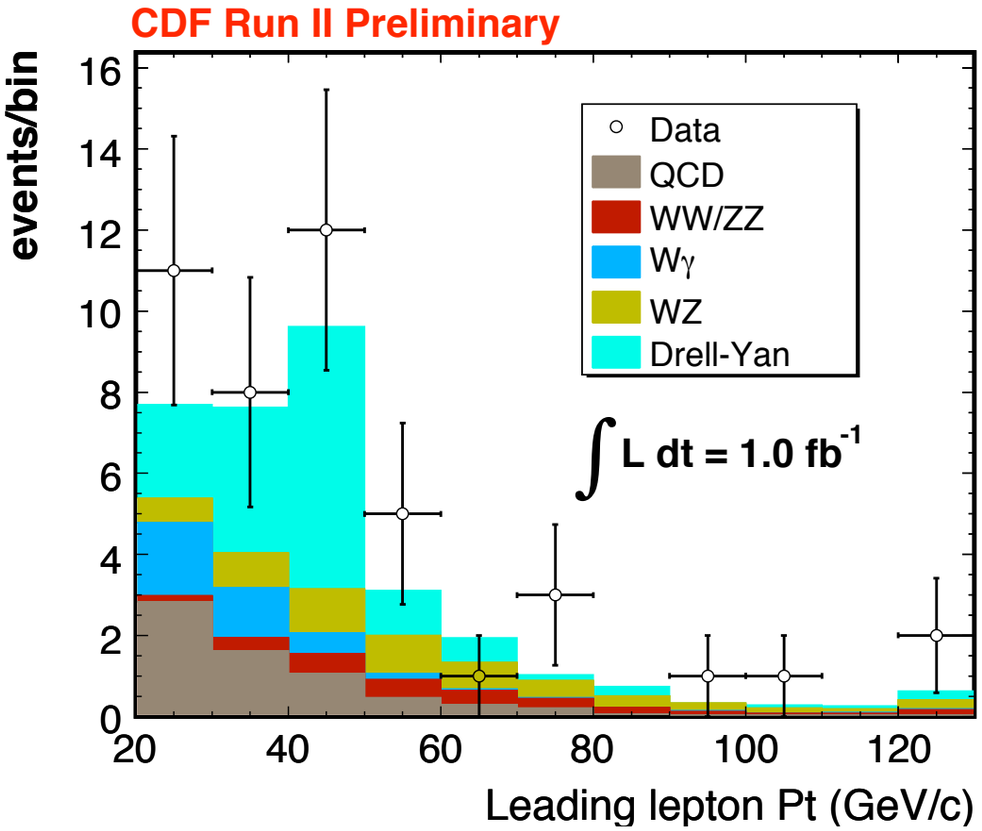
CDF: LS Dilepton Search

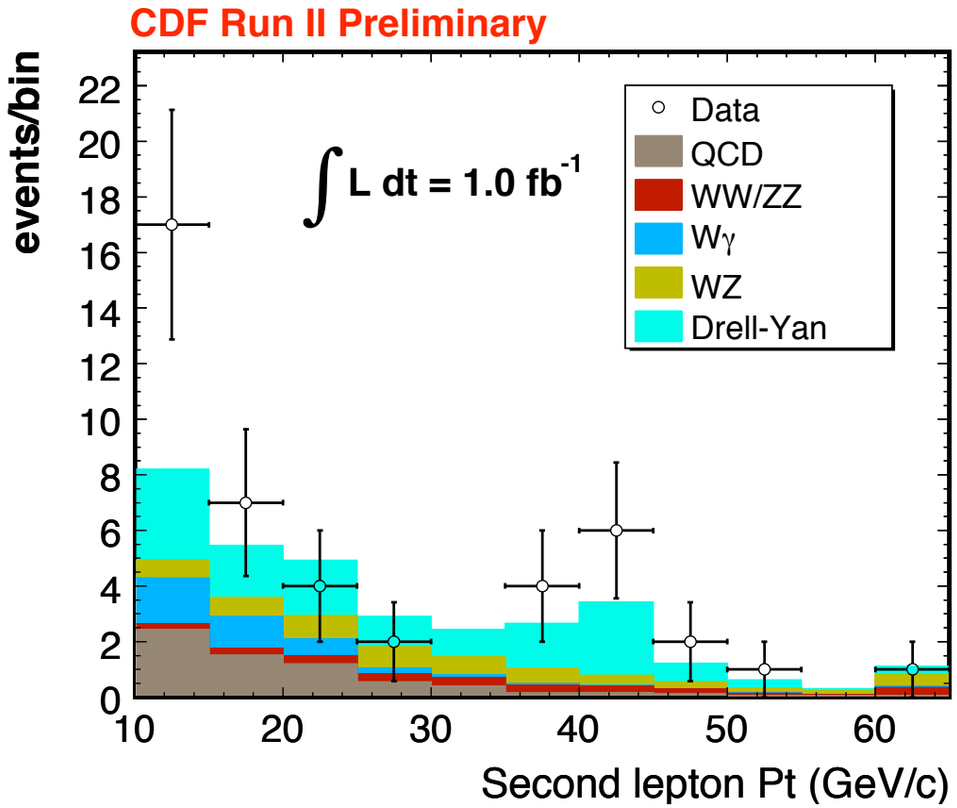
- LS Dileptons appear, notably in:
  - Decays of gluino pairs or gluino-squark prod.
  - Chargino-neutralino production
- CDF signature-based search in 1/fb electrons and muons
  - High Pt lepton triggered sample
  - Pt(lep1)>20 GeV/c, Pt(lep2)> 10 GeV/c

LS Analysis

Inclusive search:

- Predict 33.7±4.7 from SM, Observe 44
  - Probability of fluctuation 10%





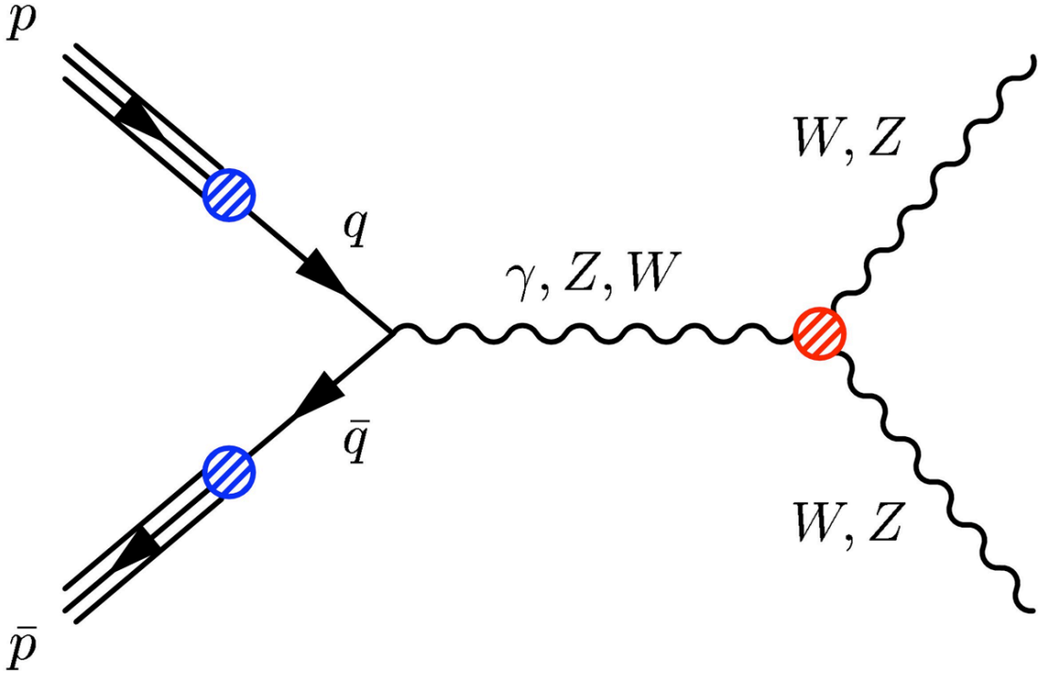
Tighter cuts: MET>15, Z mass veto

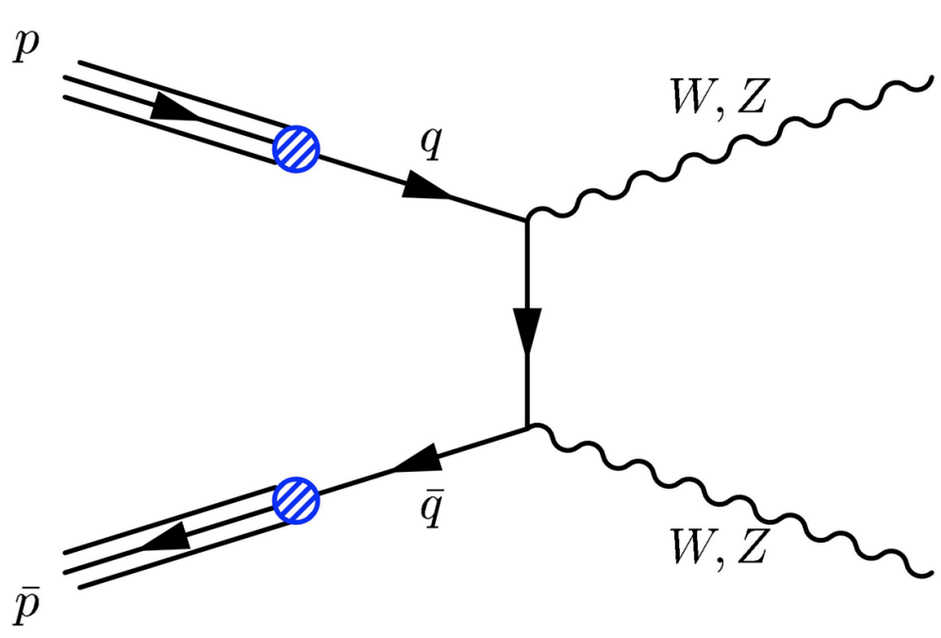
- Predict 7.9±1.1 from SM, Observe 13
  - Probability of fluctuation 7.3%

CDF: WZ, ZZ → leptons

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 $\tau \rightarrow e, \mu$





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**

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

16 Trilepton events!

=5.9σ

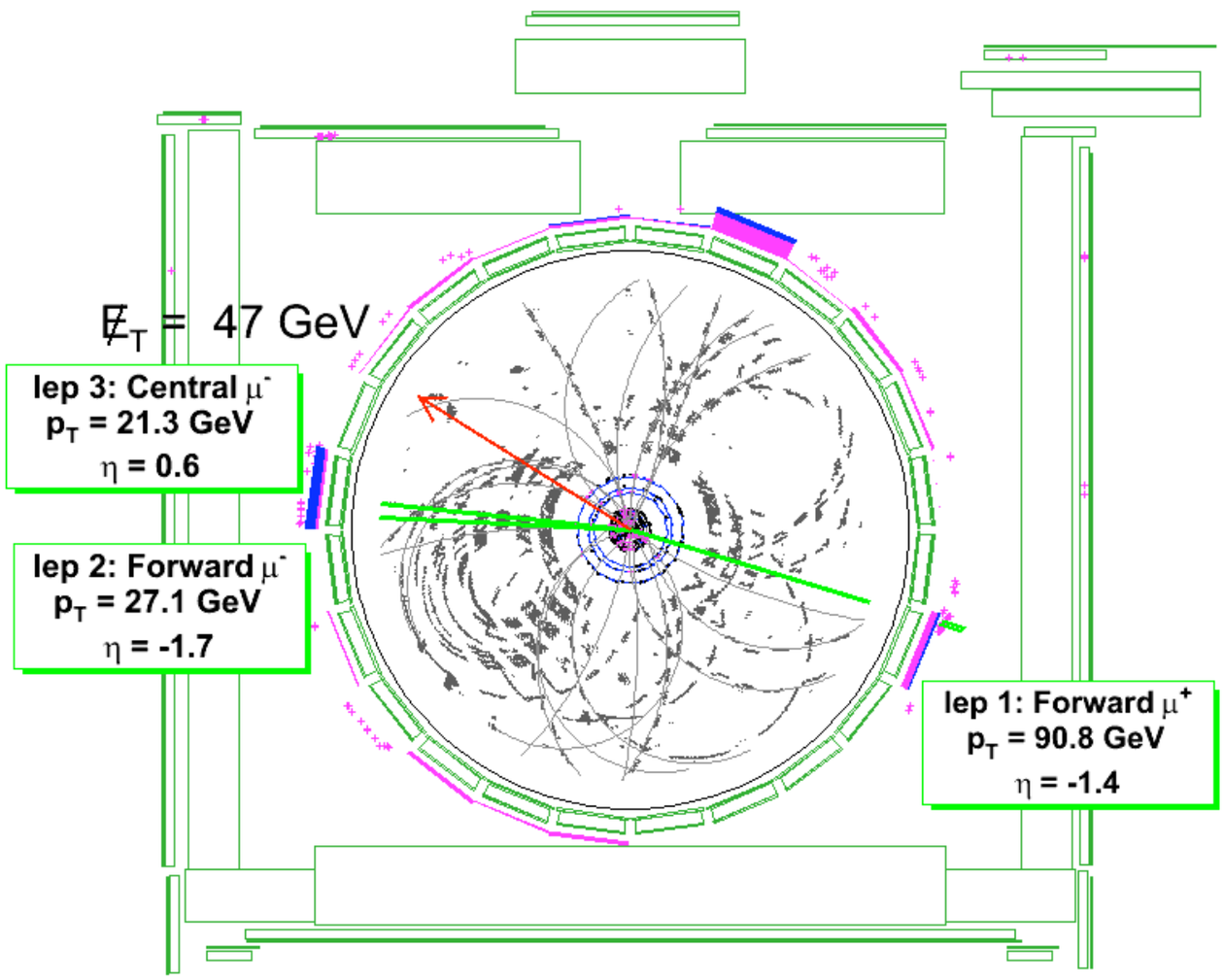
- ZZ analysis: σ(NLO) = 1.4 ± 0.1 pb

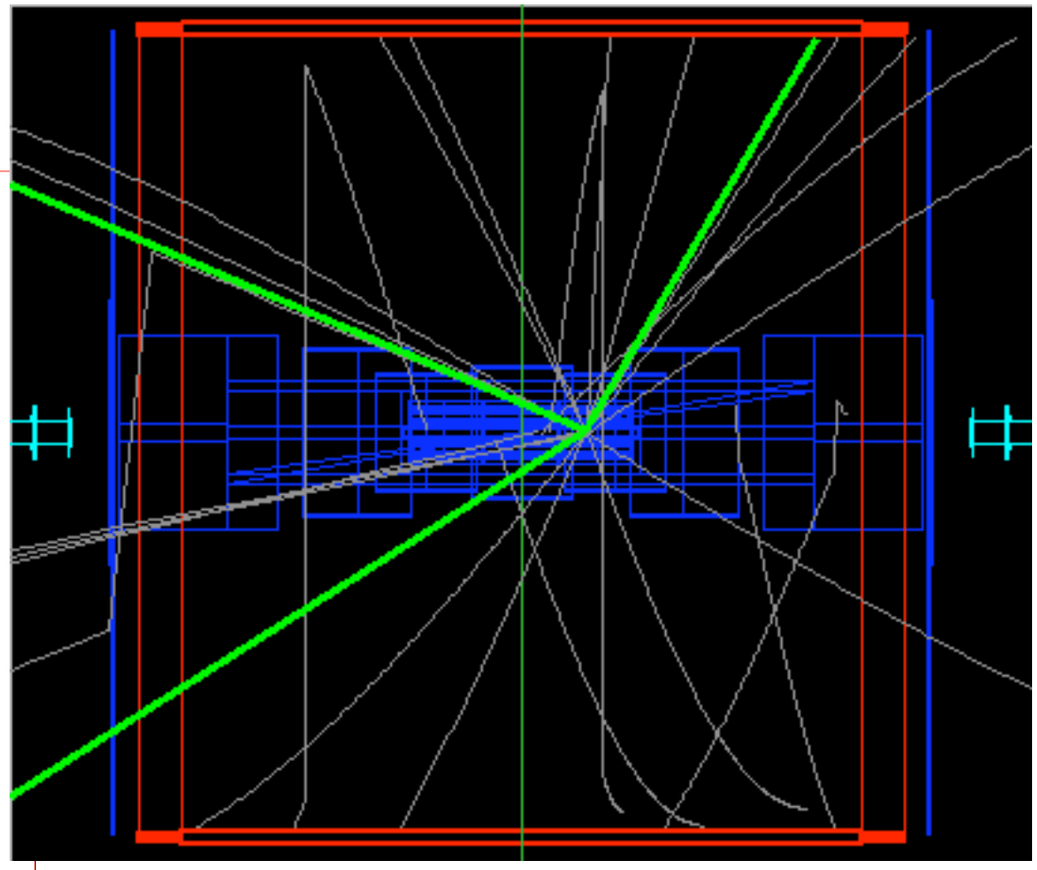
Source	Expectation ± Stat ± Syst ± Lumi
Z+jets	$0.007 \pm 0.007 \pm 0.004 \pm$ -
$Z\gamma\gamma$	$0.002 \pm 0.001 \pm 0.000 \pm 0.000$
ZZ	$1.884 \pm 0.015 \pm 0.061 \pm 0.113$
Total Background	$0.009 \pm 0.007 \pm 0.004 \pm 0.000$
Total Expected	$1.893 \pm 0.017 \pm 0.062 \pm 0.113$
Observed	**1**

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

A Few WZ Event Displays

Trimuon





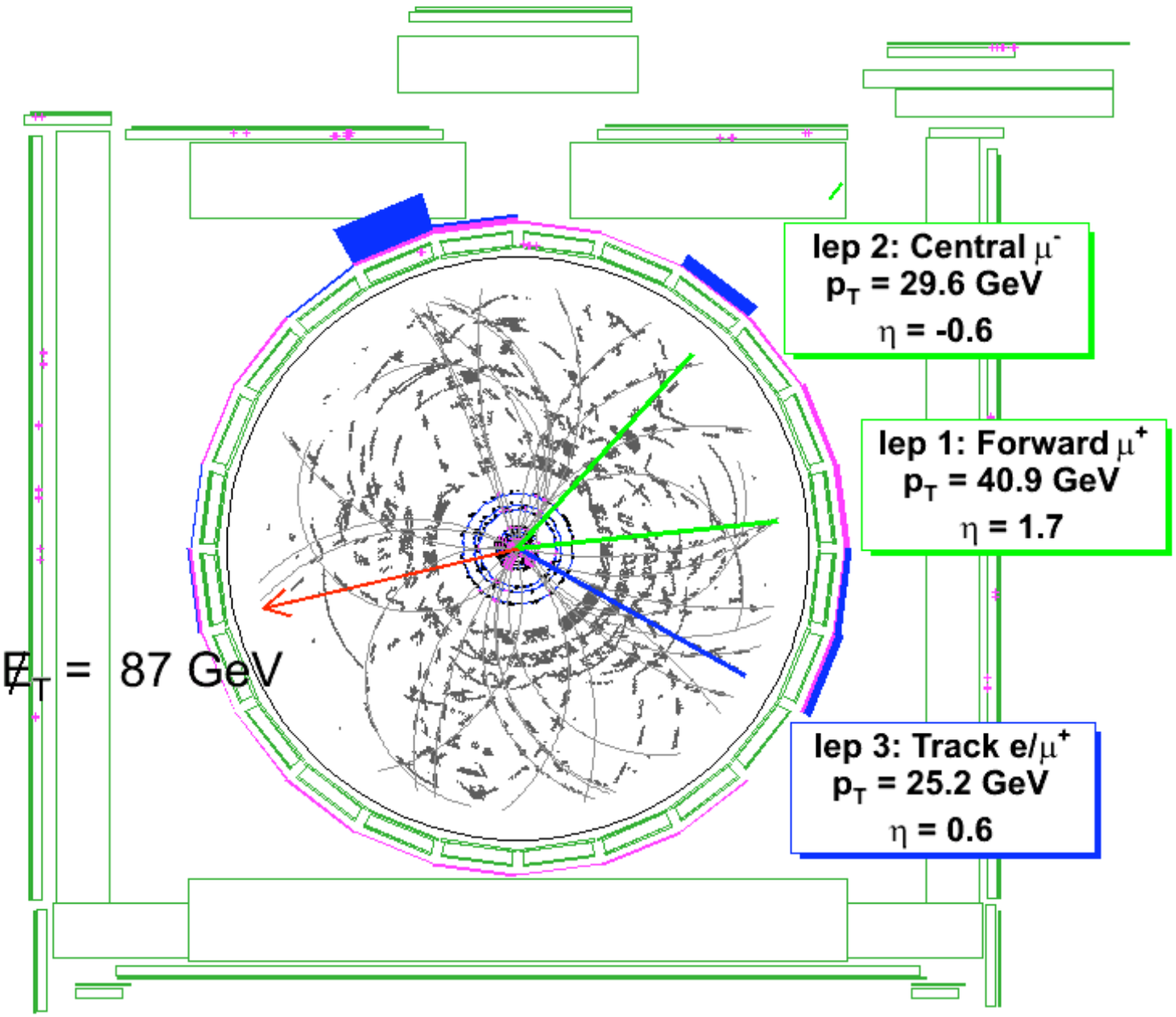
Run=186591 Event=1398363

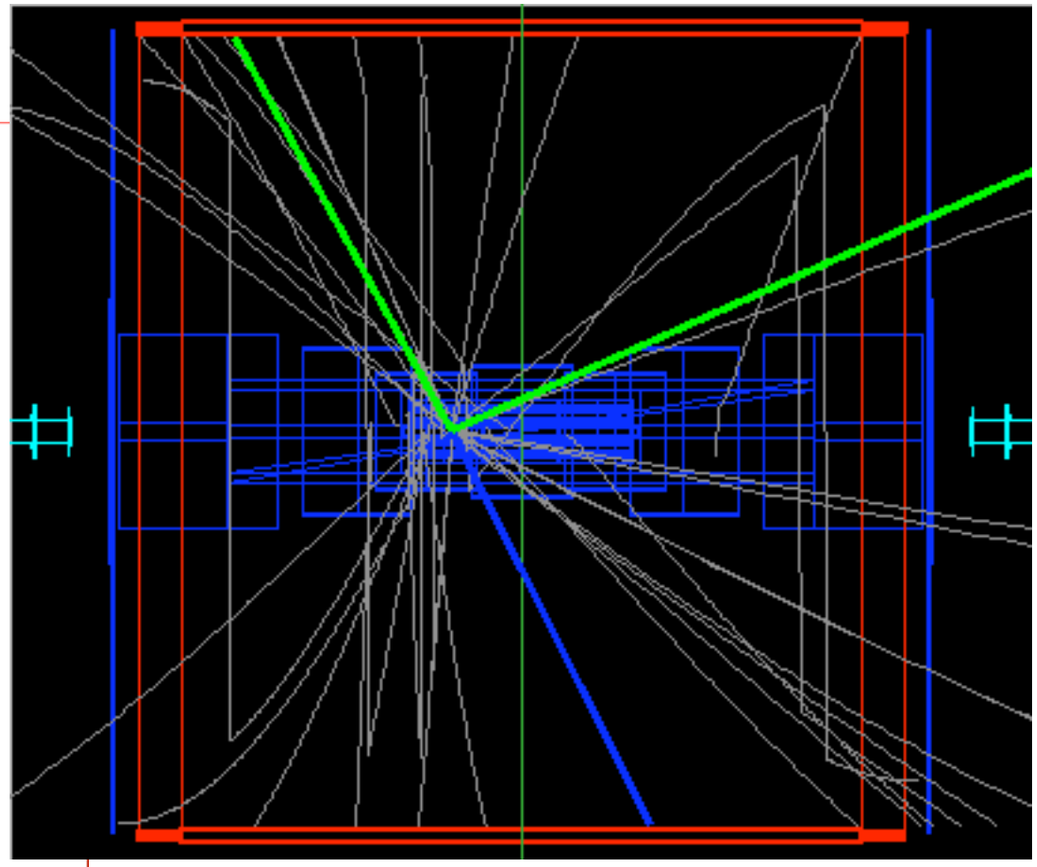
m_{12}=100.10 GeV $\quad |\not\!\!E_T|$=47.3 GeV
m_{13}=136.69 GeV $\quad \Delta\phi(\not\!\!E_T, \text{lepton, jet})$=0.4
m_{23}=71.50 GeV

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





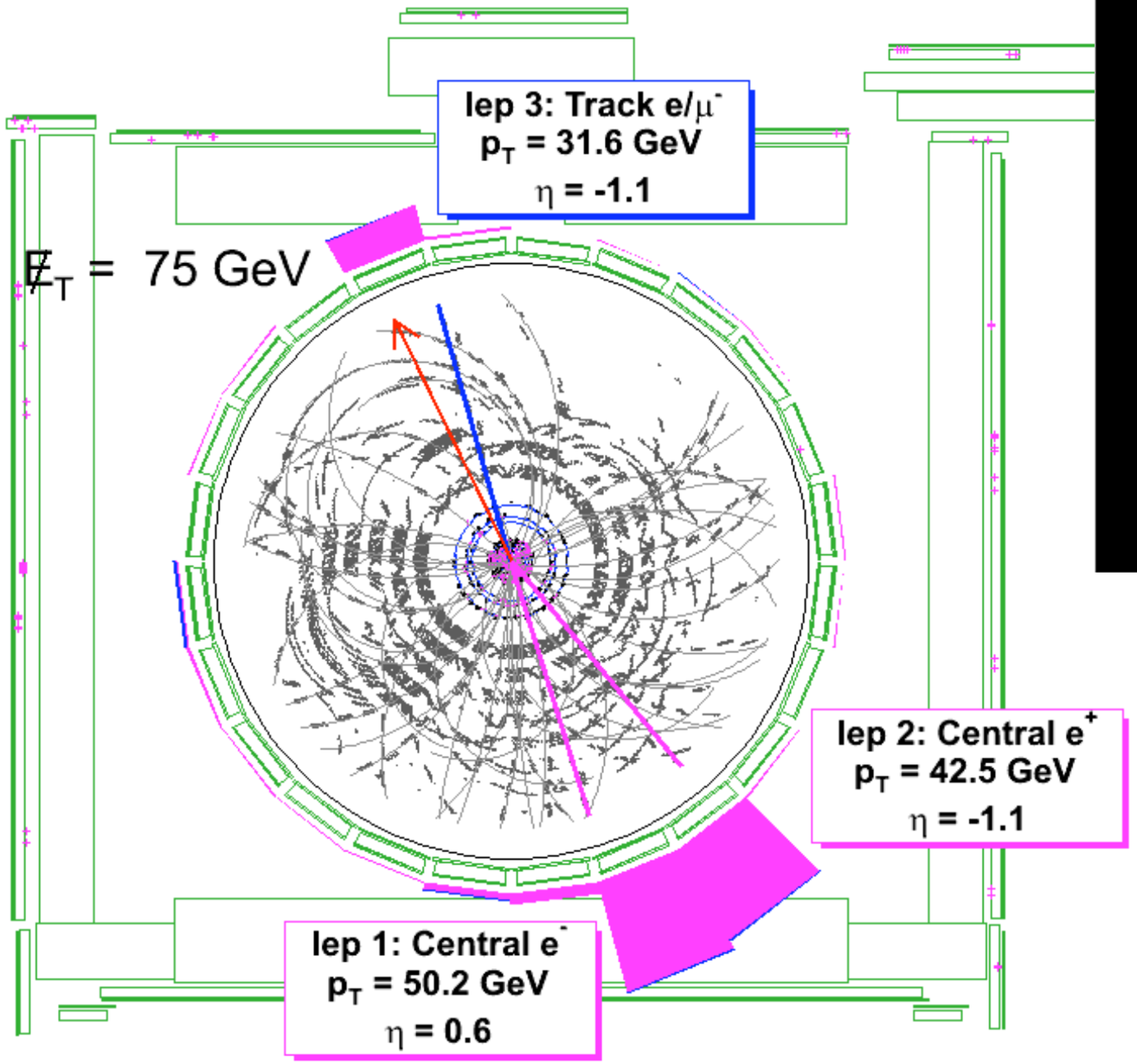
Run=198154 Event=14937629

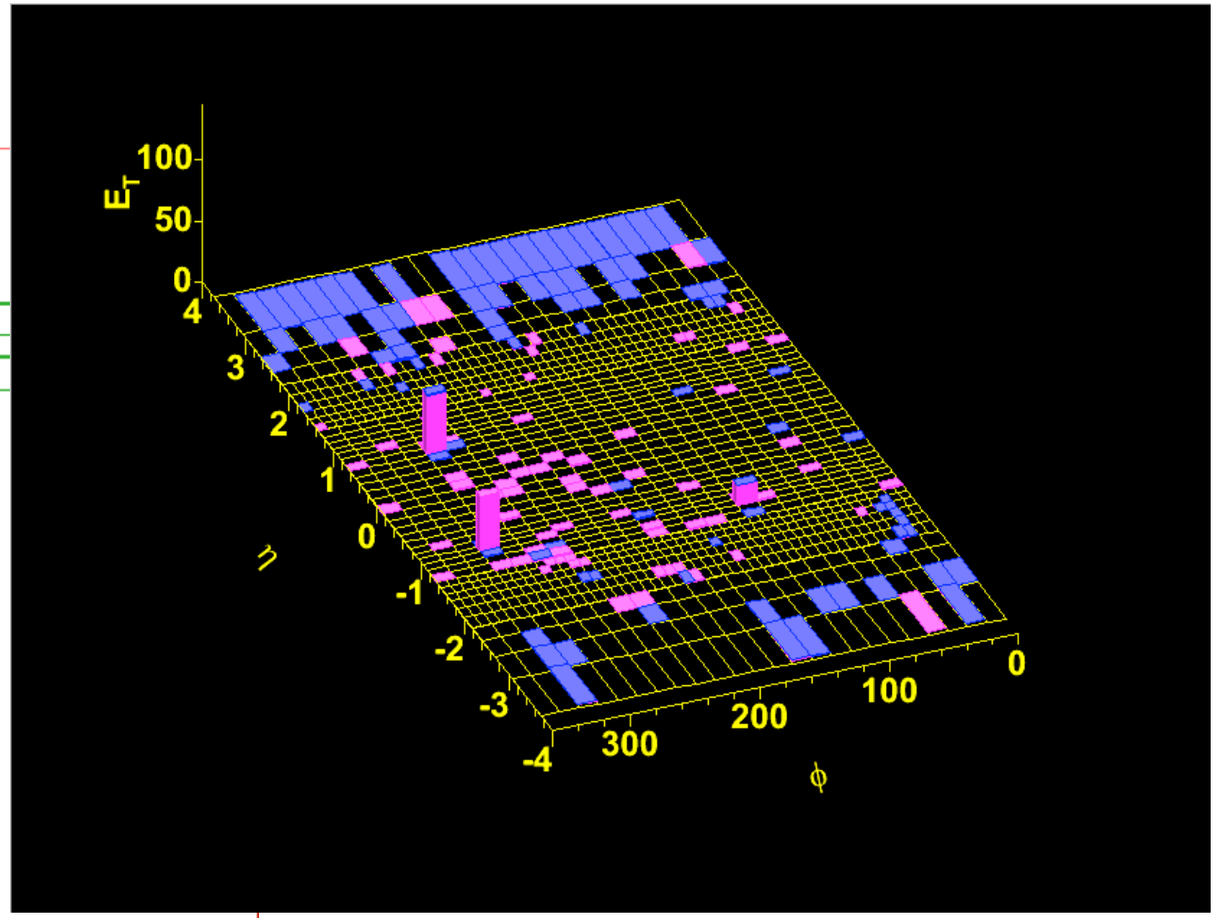
m_{12}=101.82 GeV $|\not\!\!E_T|$=86.7 GeV
m_{13}=42.64 GeV $\Delta\phi(\not\!\!E_T, \text{lepton, jet})$=2.4
m_{23}=47.59 GeV

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





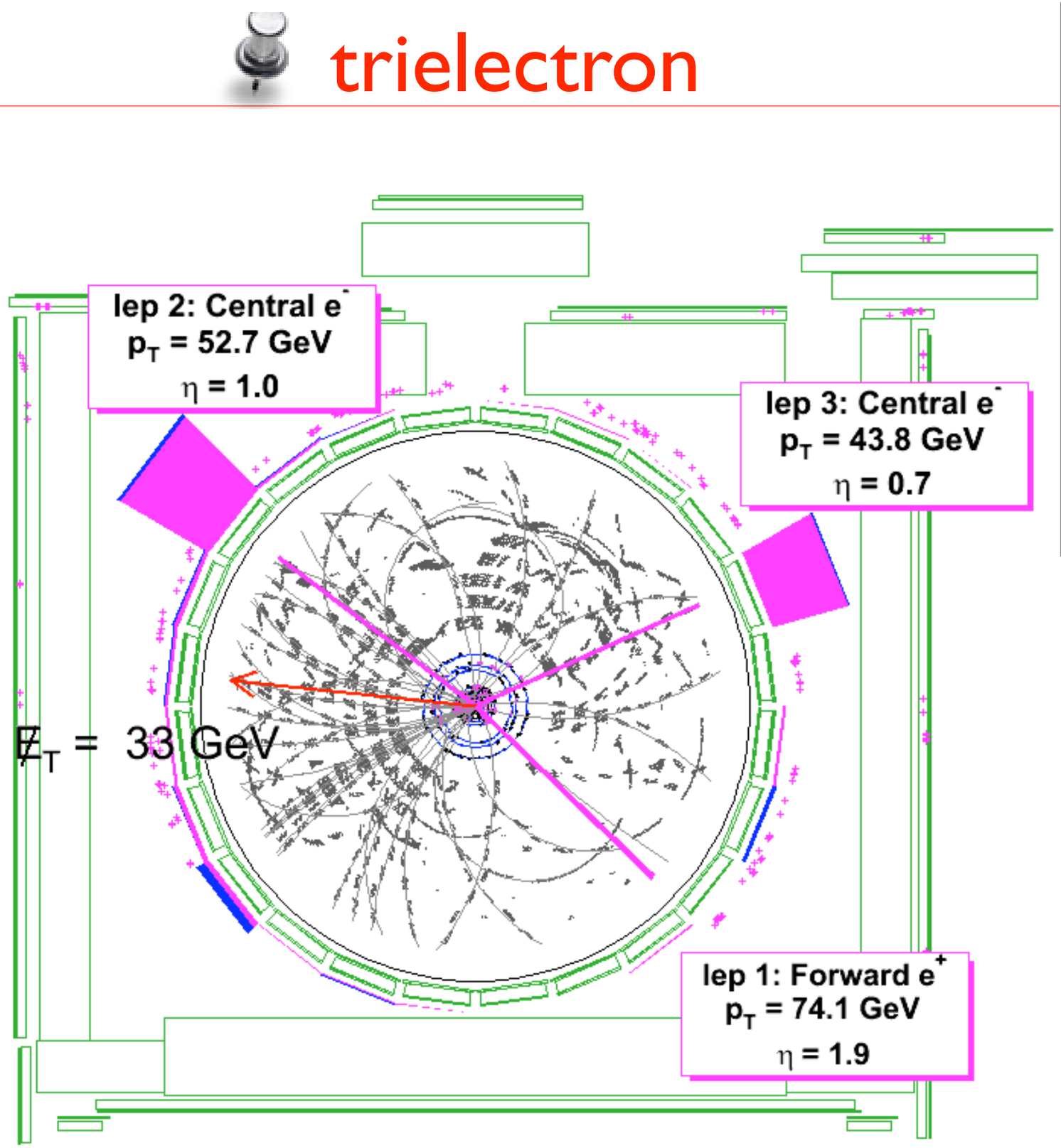
Run=201644 Event=1308790

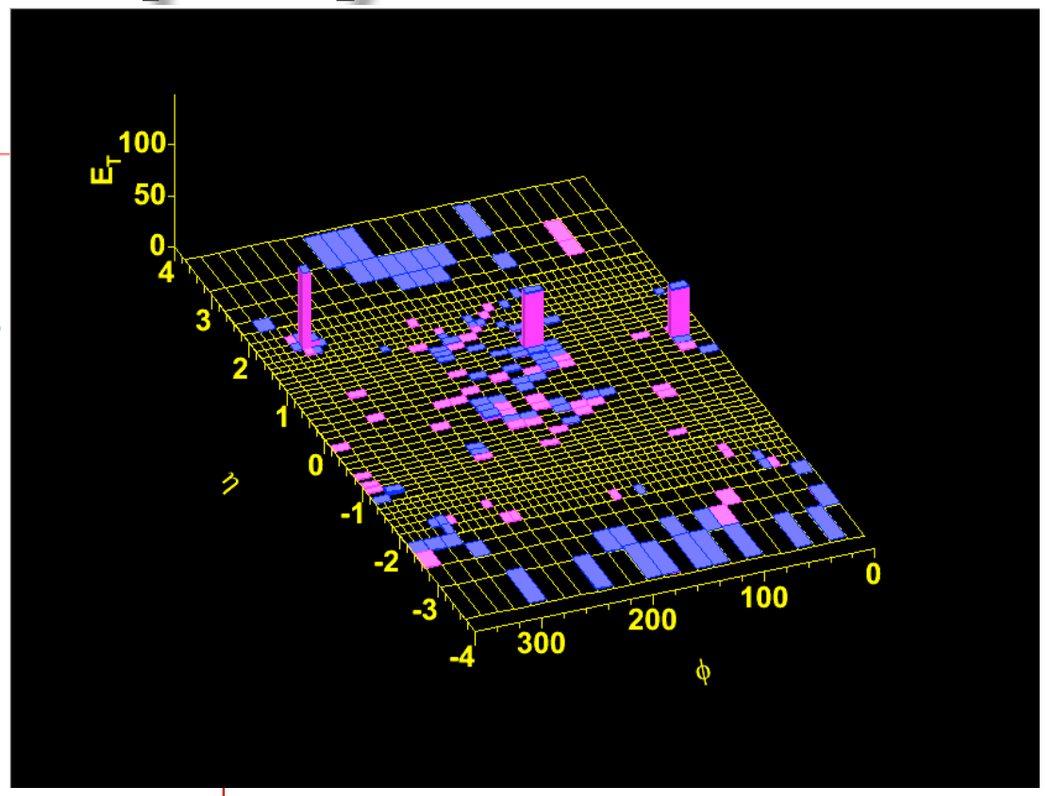
m_{12}=85.59 GeV	$\lvert\not\!\!E_T\rvert$=74.8 GeV
m_{13}=110.94 GeV	$\Delta\phi(\not\!\!E_T, \text{lepton, jet})$=0.2
m_{23}=71.77 GeV	

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





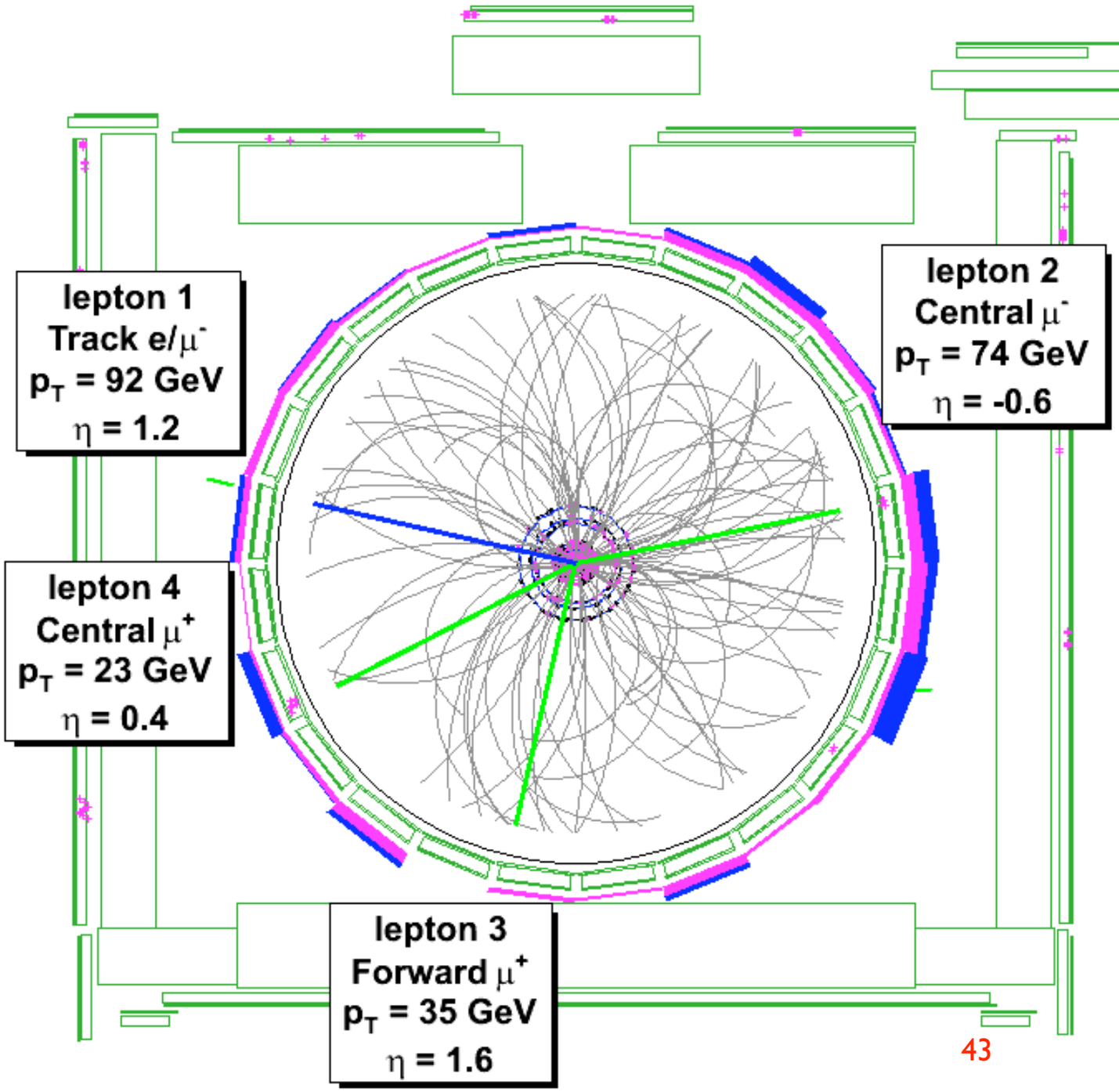
Run=207115 Event=8740187

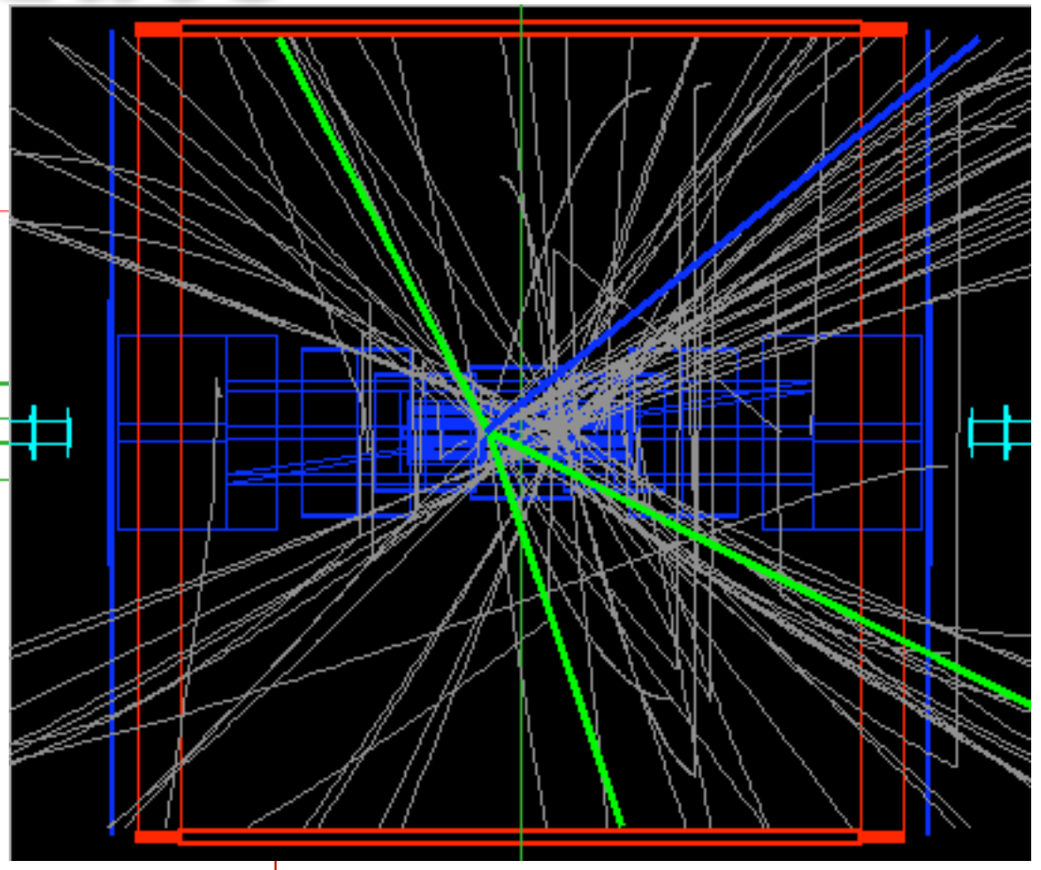
m_{12}=137.02 GeV $|\not\!\!E_T|$=32.9 GeV
m_{13}=94.70 GeV $\Delta\phi(\not\!\!E_T, \text{lepton, jet})$=0.6
m_{23}=83.80 GeV

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

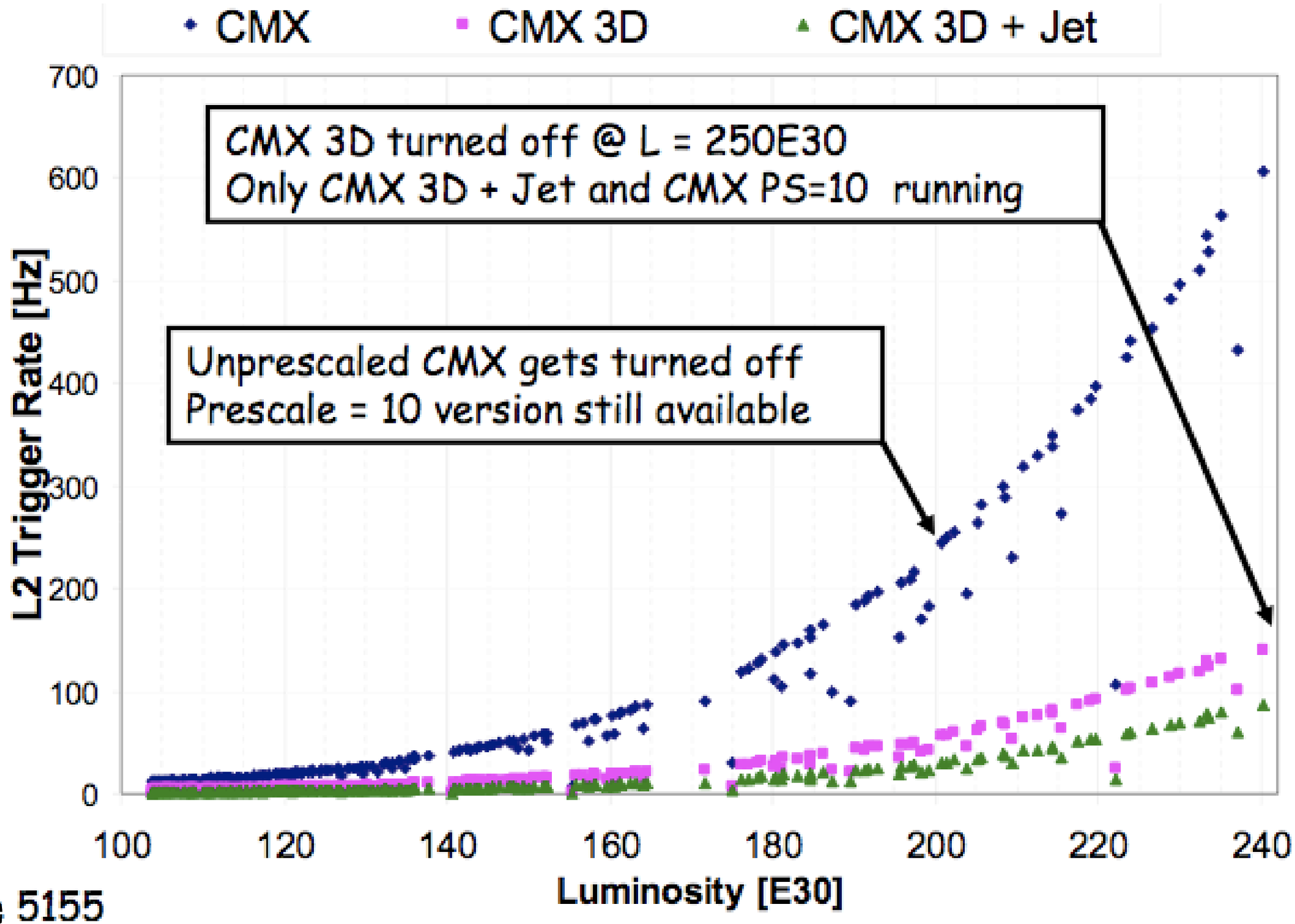
m_{ll1}=90.92 GeV $|\not\!\!E_T|$=8.7 GeV
m_{ll2}=83.03 GeV $N_{jets} = 0$
M_{llll}=312.4 GeV/c^2

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

CDF Trigger Upgrade

- Searches need good rapidity coverage and unprescaled triggers, even at high inst. luminosity
- FNAL decision to run Tevatron with 396 ns BS triples number of interactions/crossing
- CDF presently upgrading tracking trigger so that critical triggers will still be usable, w/o prescales, at high rates.
- Status:
  - L1 commissioned, L2 being finalized now.
  - 96% eff at high pt for leptons
  - single track fake rejection ~7x
  - high-eta muon trigger rates reduced by ~3-4 (as shown on plot)
  - Full 3D track reconstruction at L2 will improve online track selection quality,
- Also enhances capabilities for electrons, central muons, taus, etc.

CDF Trigger Upgrade



Store 5155

Tevatron Prospects

- Assume several /fb/expt by end of Run II
  - Results with ~ 4X data shown here
- Substantial, well-understood datasets
  - Era of high-precision exotics searches upon us!
- Trigger enhancements will further enhance exotics searches
- Tevatron may finish with a bang!
- Experimentalists need theorist help with advanced MC

That's all, Folks!

Heavy Bozo(n)