Beyond the Standard Model at the Tevatron – Searches and Limits

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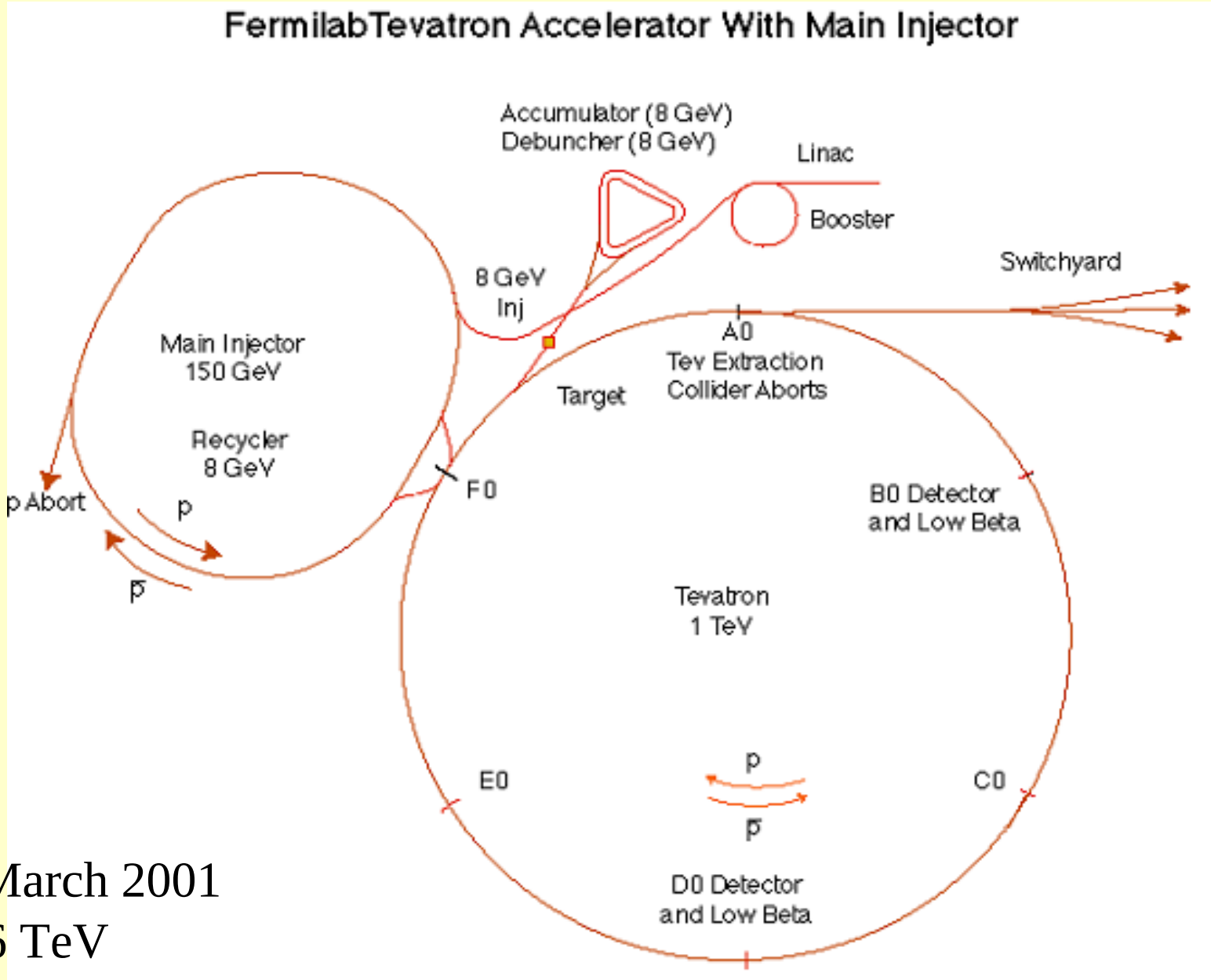
for the CDF and D0 collaborations

Introduction

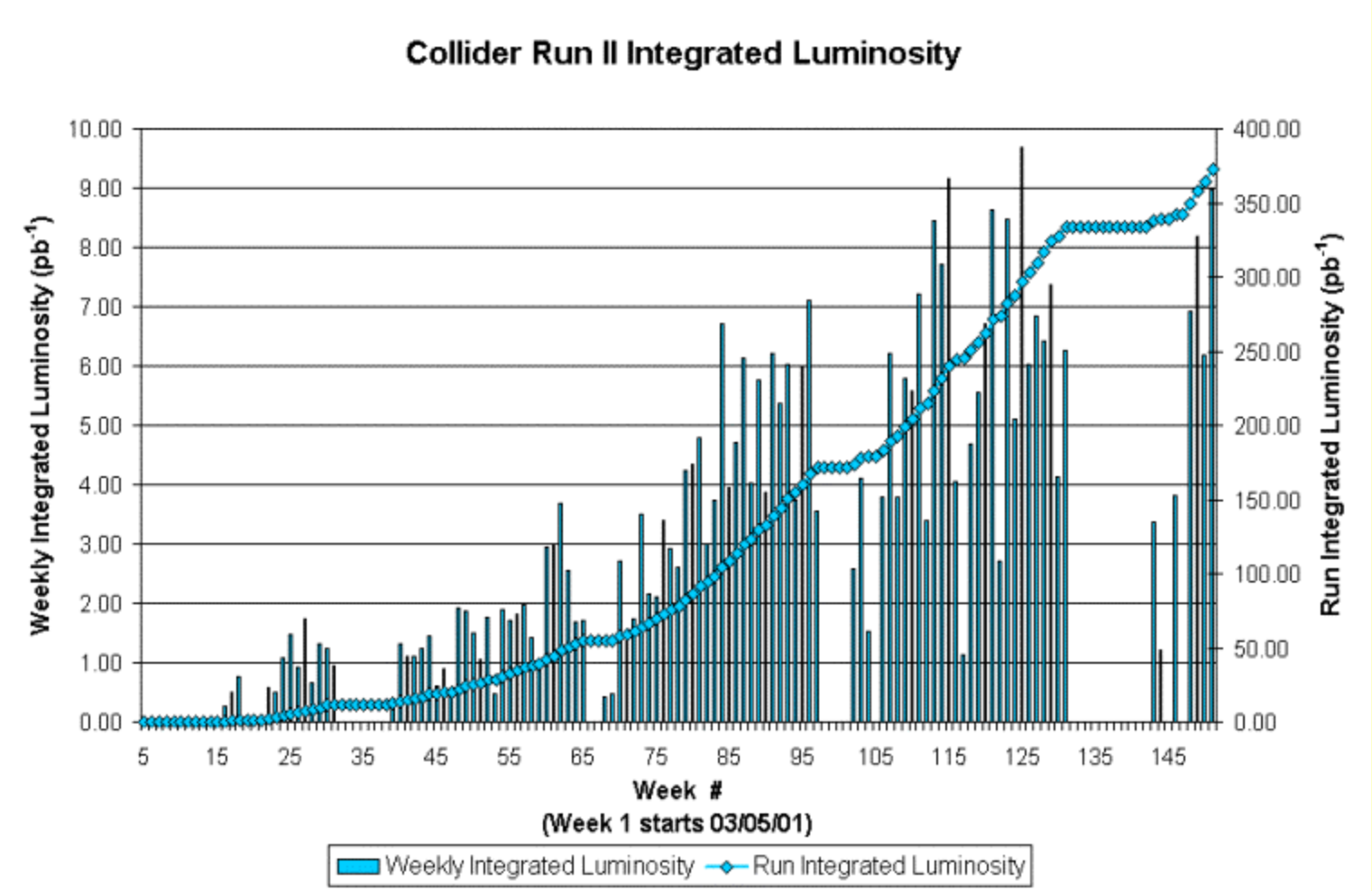
- The Tevatron's Run 2 is beginning to produce many new results in searches for new physics -- too many to cover everything in this talk.
  - Will focus on a few new/interesting results from CDF and D0
- Outline of my talk
  - Brief Tevatron intro
  - Signatures of new physics at Tevatron
  - Searches and limits
    - Lepton-based searches
      - High-mass dileptons – Z', H^{++}
      - Large Extra Dimensions
    - Photons
      - LED, SUSY(GMSB)
    - Jets, Leptons, Missing Et
      - Leptoquarks
      - SUSY (MSSM, RPV)
    - Indirect limits from $B_s \rightarrow \mu\mu$
  - Conclusion

The Tevatron



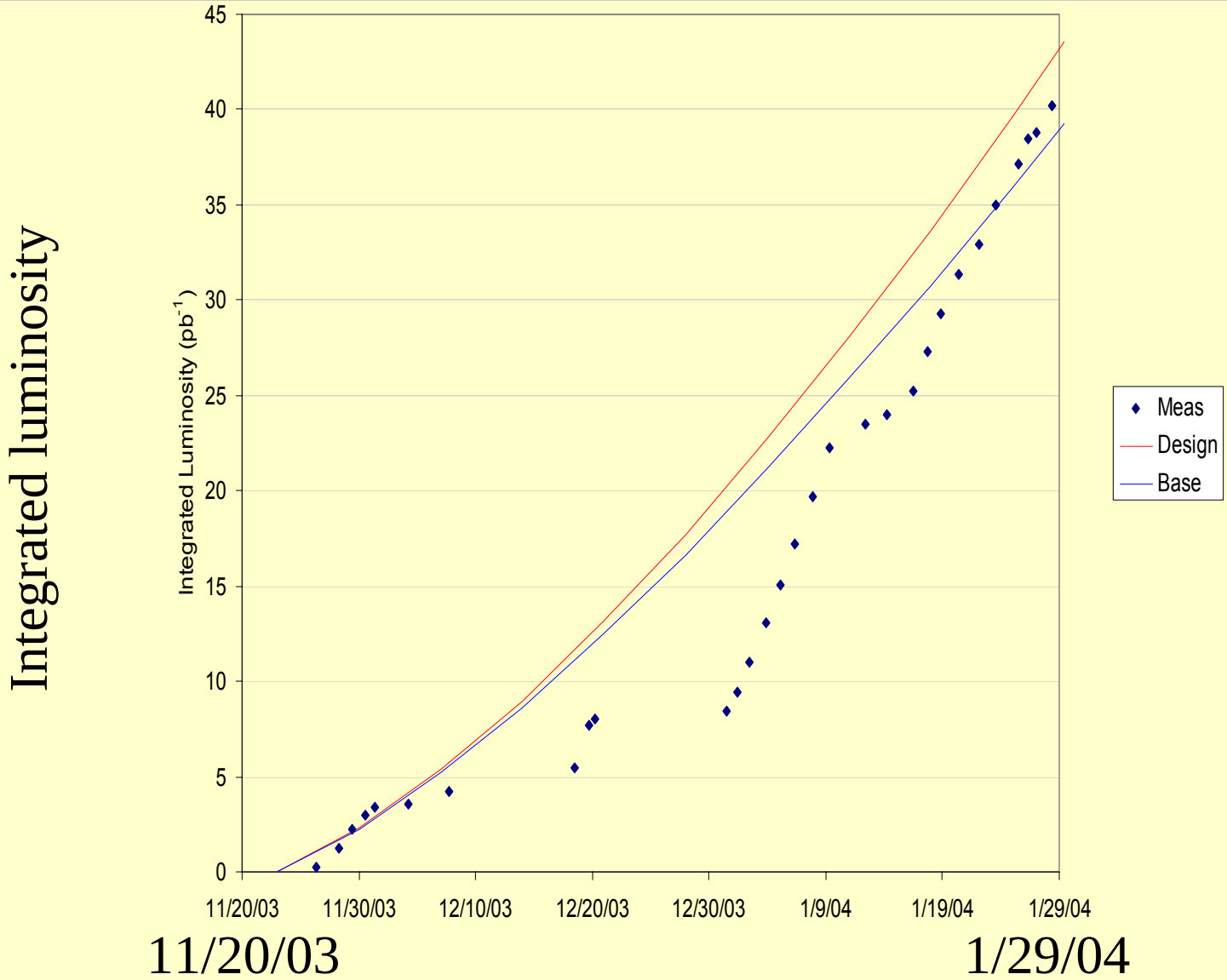
Run 2:
started March 2001
$\sqrt{s}$ = 1.96 TeV

Tevatron Luminosity



- Rough guide to datasets in today's talk:
  - 60-70 pb^{-1} – up to Jan 2003
  - ≤130 pb^{-1} – up to summer 2003
  - ≤200 pb^{-1} – up to Sept 2003

Recent Accelerator Performance



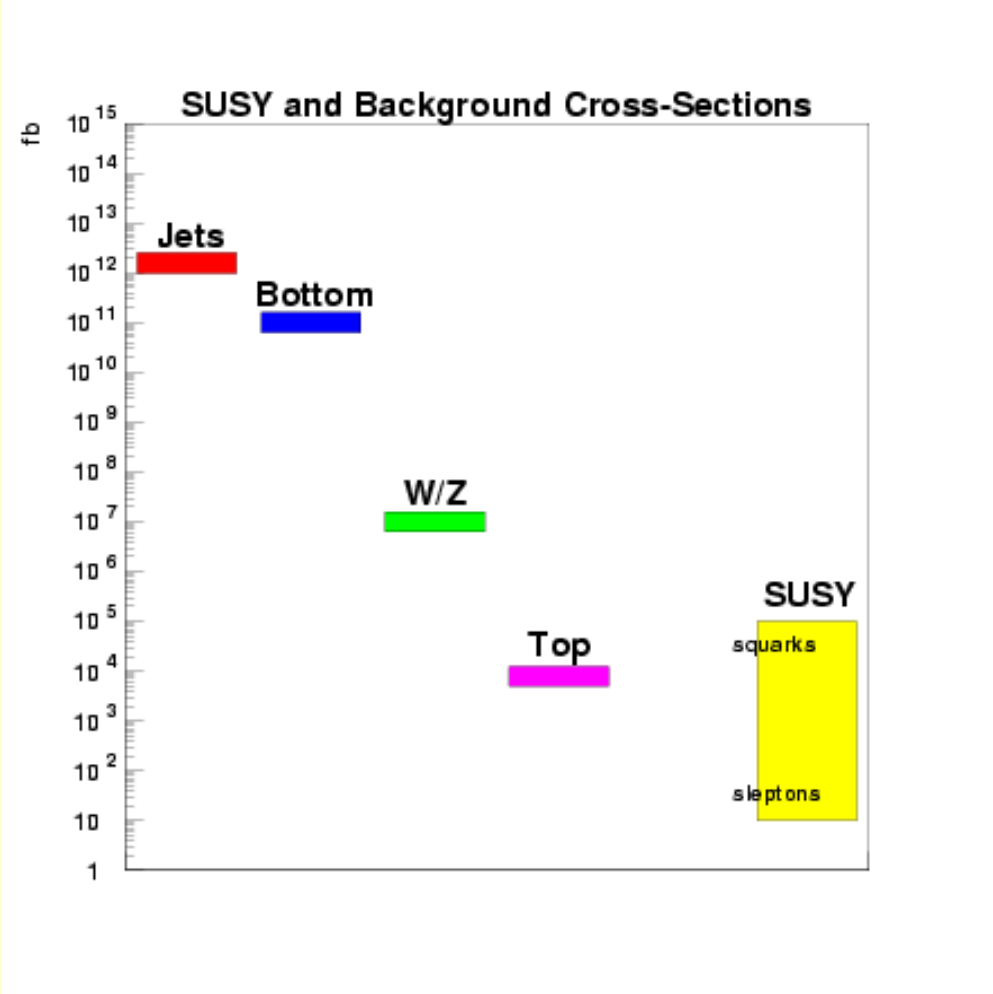
- Turn-on after fall 2003 shutdown
- Currently achieving base goals for FY04

CDF and D0

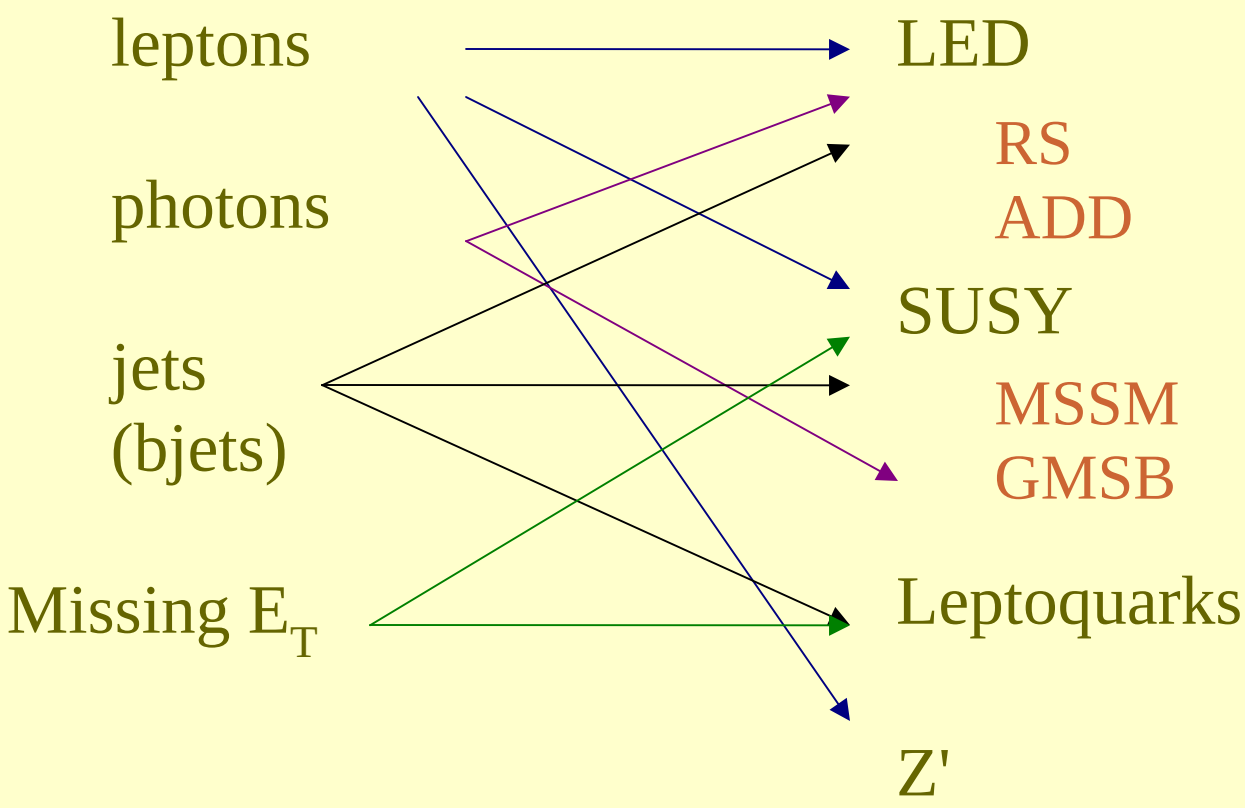
- Both detectors had major upgrades for Run 2
  - CDF
    - Upgraded tracking system
      - New Silicon inner tracker (silicon tracking in endplug)
      - New drift chamber
    - Upgraded muon detector
    - New plug calorimeter
    - electrons,muons, tracking $|\eta| \leq 2.0$
  - D0
    - New solenoid tracking system
      - Silicon and fiber tracker
    - Preradiator
    - Tracking $|\eta| \leq 3.0$
    - electrons,muons $|\eta| \leq 2.5$
- Both detectors running well
  - Improve, maintain detector (esp silicon)
  - Optimizing trigger, DAQ to maximize data to tape

Beyond the Standard Model at the Tevatron

- Searches for new physics at the Tevatron
  - "needle in a haystack"
- Can't find what you are not looking for….but what to look for?
- Intersection of theoretical interest
  - Models proposed to test hypotheses
- & experimental capabilities
  - Cross section*Luminosity
  - Efficiency, acceptance
- Rely on theoretical and experimental input
  - precise calculations
  - measurements of SM processes



Signatures versus models

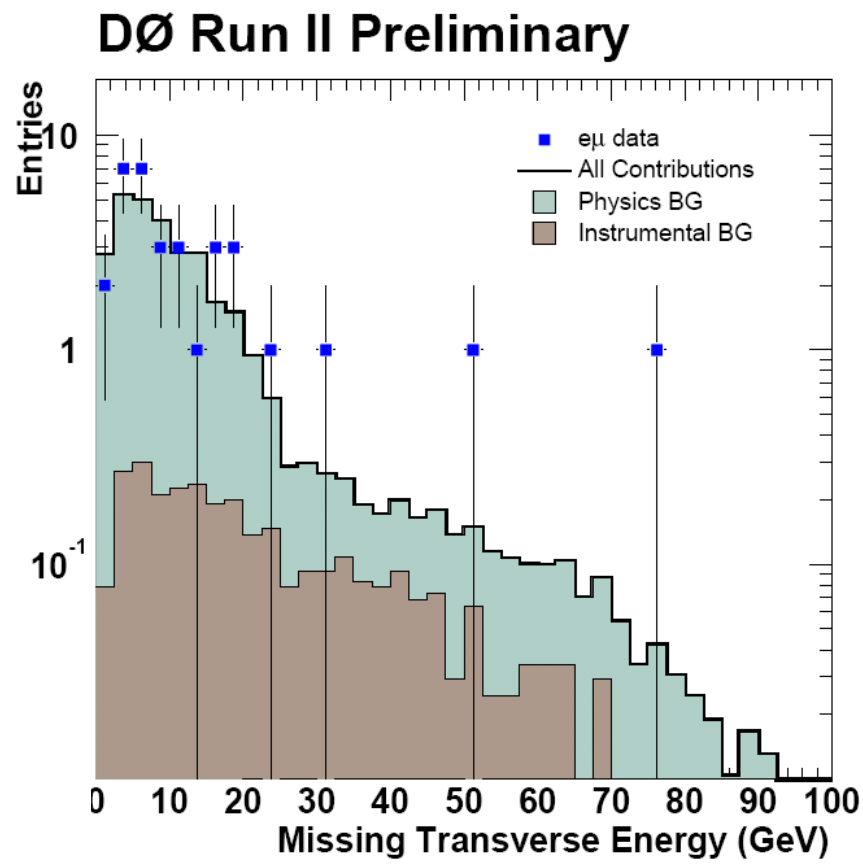


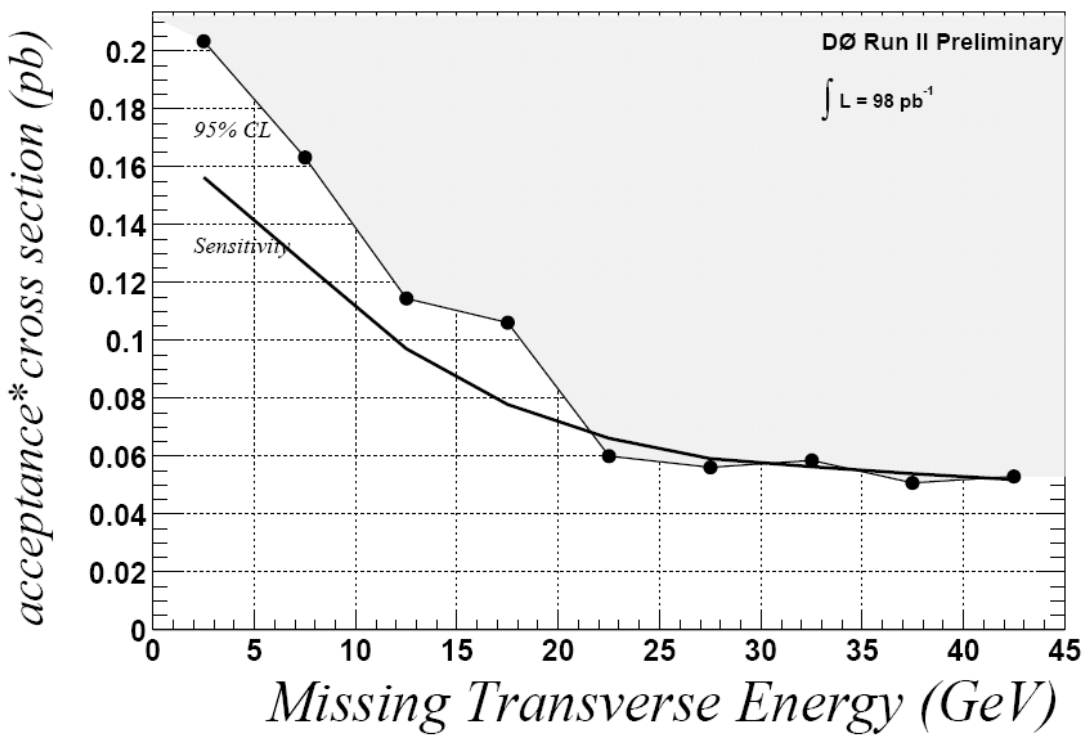
combinations
- lepton+jet
- photon+MET
- etc...

Strategy:
signature-based approach
apply to interesting models

Lepton-based searches

- Energetic eμ pair
- Many possible interpretations
- Compare to expected Missing Et, for Njet = 0,1,2



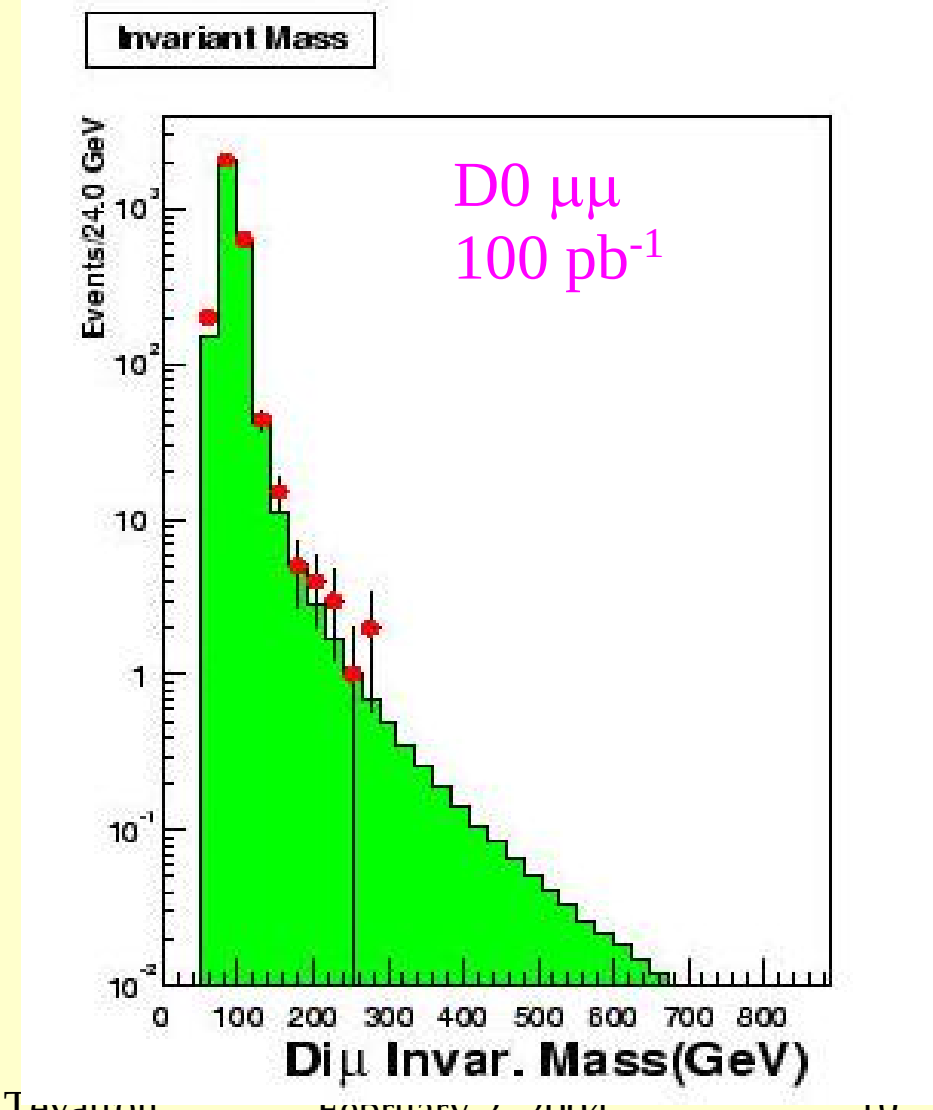


μe + 0 jet

98 pb^{-1}

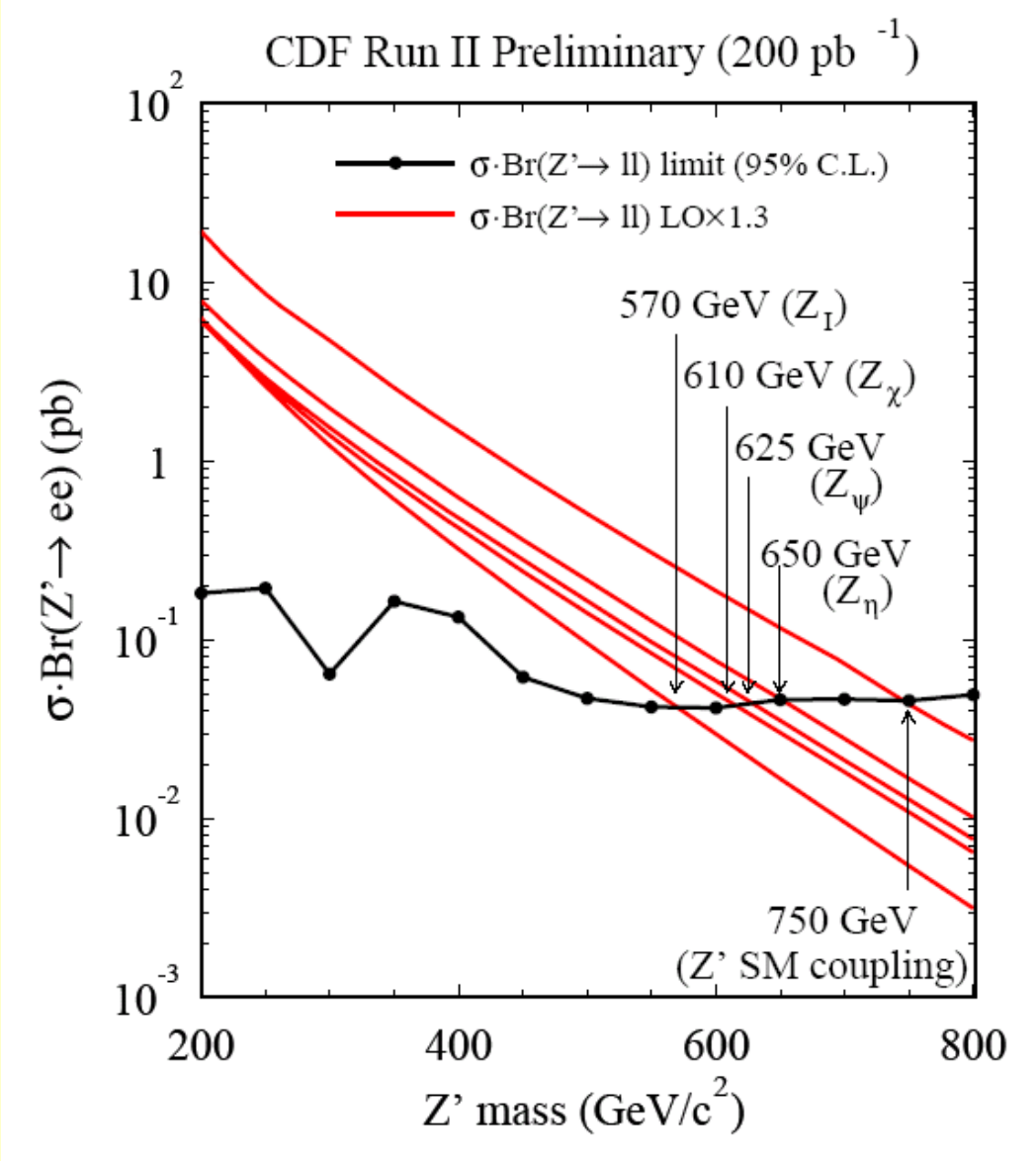
High-mass dilepton searches

- Energetic ee, μμ , (ττ) pairs w/ high invariant mass
- Both CDF and D0 have looked at ee, μμ
  - CDF has combined results
- Good agreement w/expections
- Interpret in models:
  - Z' with SM coupling
  - Z' in E6 models
  - RS Graviton
  - Little Higgs
  - Technicolor ρ_T,ω_T
  - SUSY
  - LED



Interpret high-mass dileptons as Z'

- SM couplings and low-energy E6 models
- CDF – increase sensitivity
  - Combine ee, μμ
  - New analysis : forward electron pairs



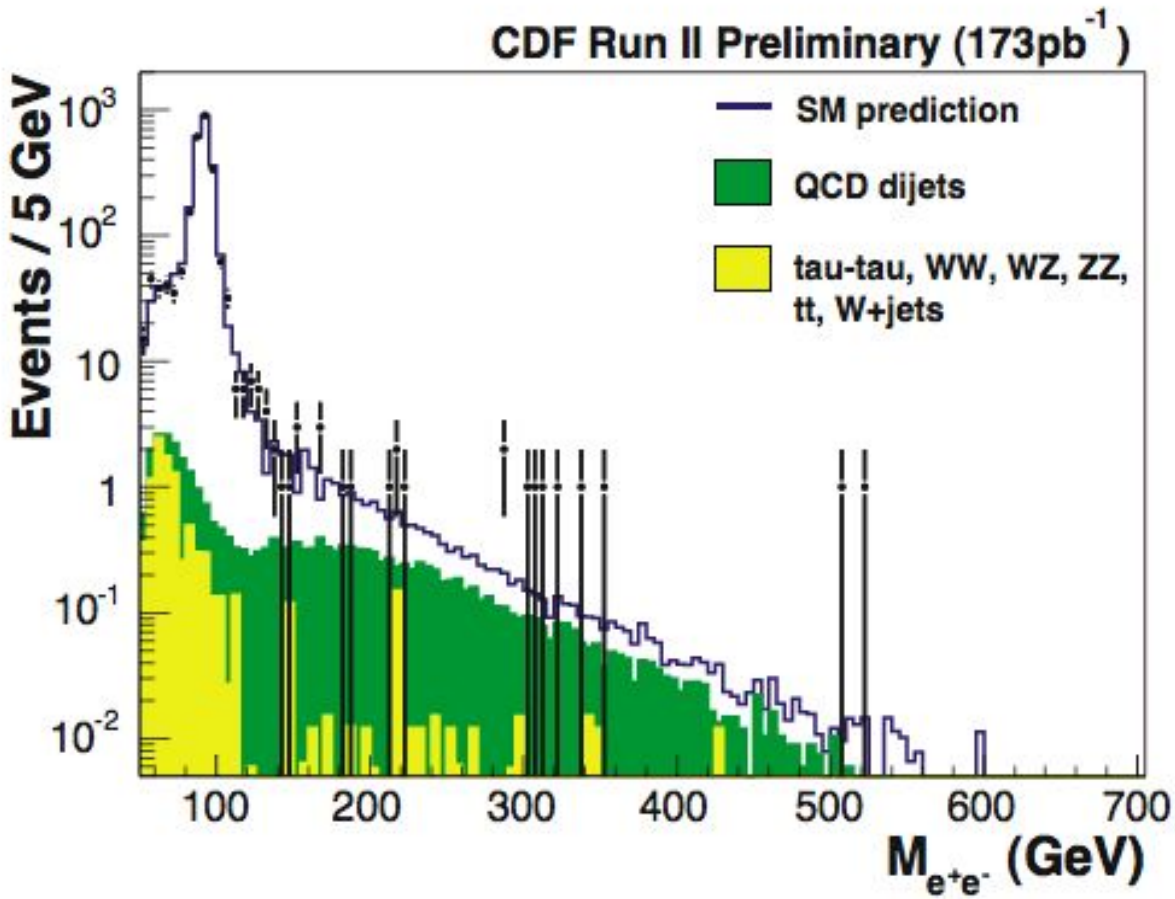
Limit on M(Z') : SM coupling:

	D0		CDF	
	Lum	M(Z')	Lum	M(Z')
• ee	122	719	200	750
•μμ	100	610	126	585
•eeμμ			126	730

High Mass Forward Electron Pairs

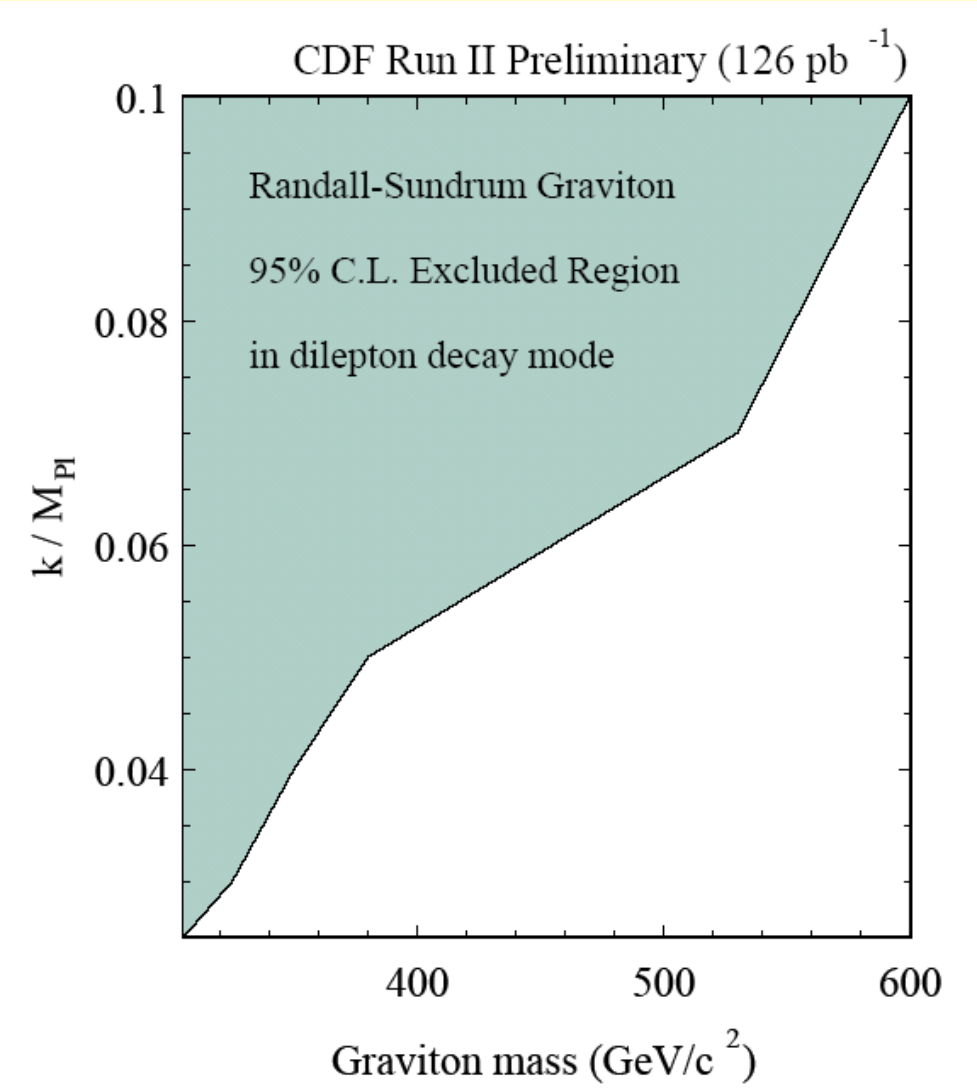
- CDF forward electrons – incomplete tracking
  - Previously required ≥1 central electron (w/track – suppress fake bg)
- Use region $1.2 < |\eta| < 2.5$
  - Calorimeter-seeded silicon track -- "Phoenix" for at least one electron

Mass>	NPred	Ndata
0	2414 ± 58	2387
100	144 ± 6.7	149
200	10.2 ± 2.2	14
250	5.0 ± 1.2	10
300	2.5 ± 0.7	8
350	1.4 ± 0.3	3
400	0.71 ± 0.07	2
450	0.39 ± 0.09	2
500	0.21 ± 0.04	2
550	0.10 ± 0.03	0



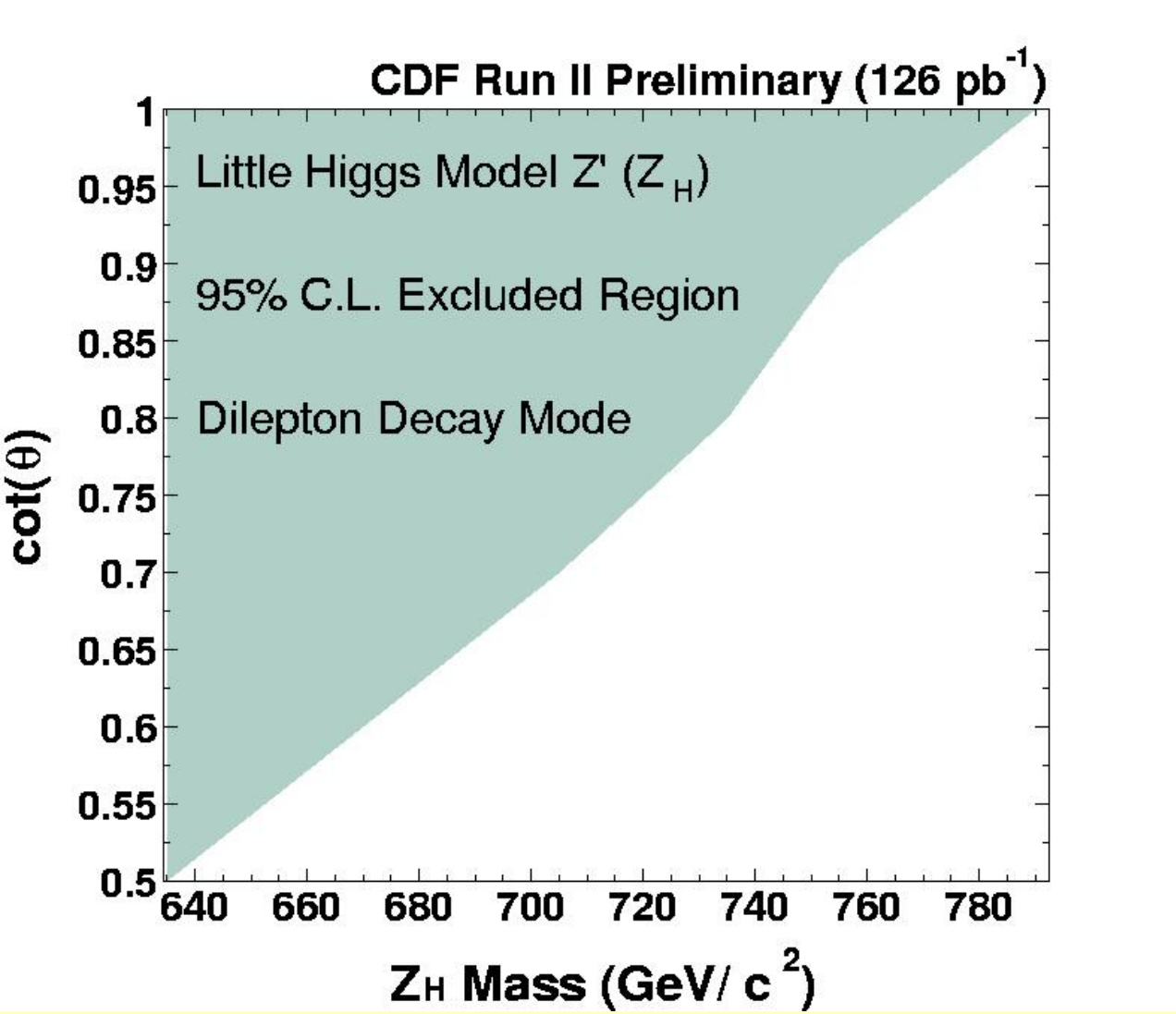
Interpret High-Mass dileptons as RS Graviton

- Randall-Sundrum model
- Excited Graviton Kaluza-Klein state
  - decays to lepton pairs
- Relevant parameter:
  - Coupling: k/M_{Pl}
- For k/M_{Pl} =0.1, M_G>620 from CDF combined ee,μμ analysis



Interpret in Little Higgs Model

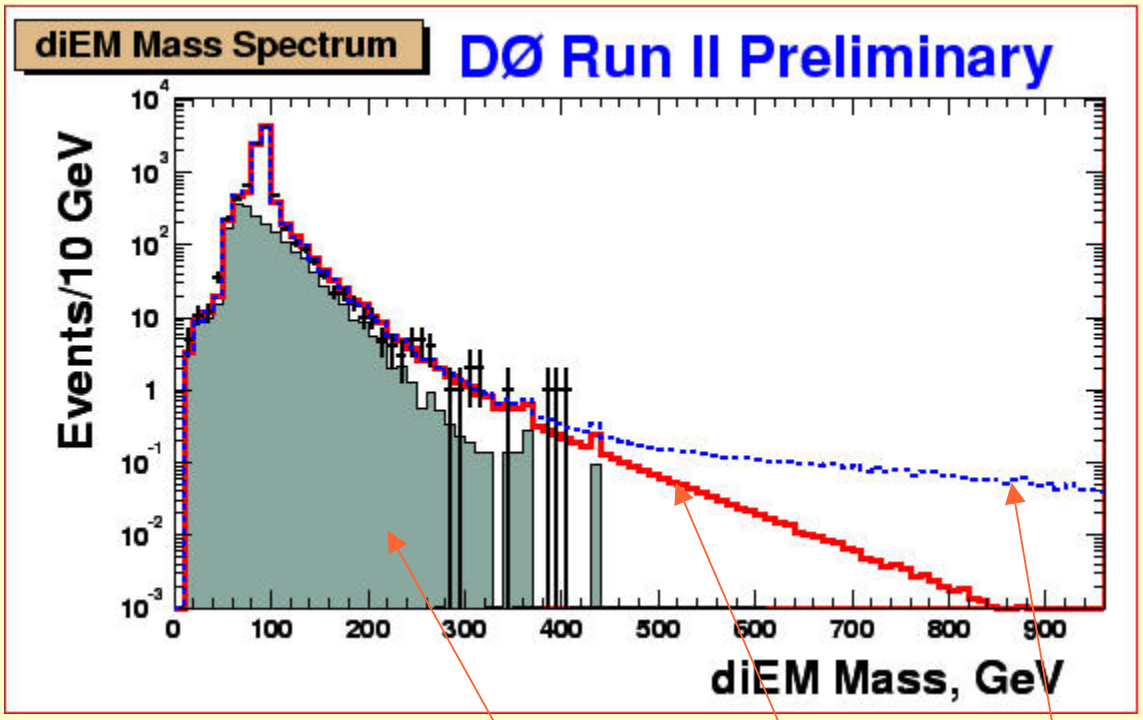
- Little Higgs model "littlest Higgs" **
- Predicts Z_H accessible to Tevatron
  - decays into leptons
- Apply CDF high-mass dilepton analyses



**Han,Logan,McElrath,Wang;
PRD 67, 95004, 2003

Large Extra Dimensions

- ADD model of Large Extra Dimensions
  - Use GRW convention
- Set limits on Planck scale (MP)



SM bg

With LED

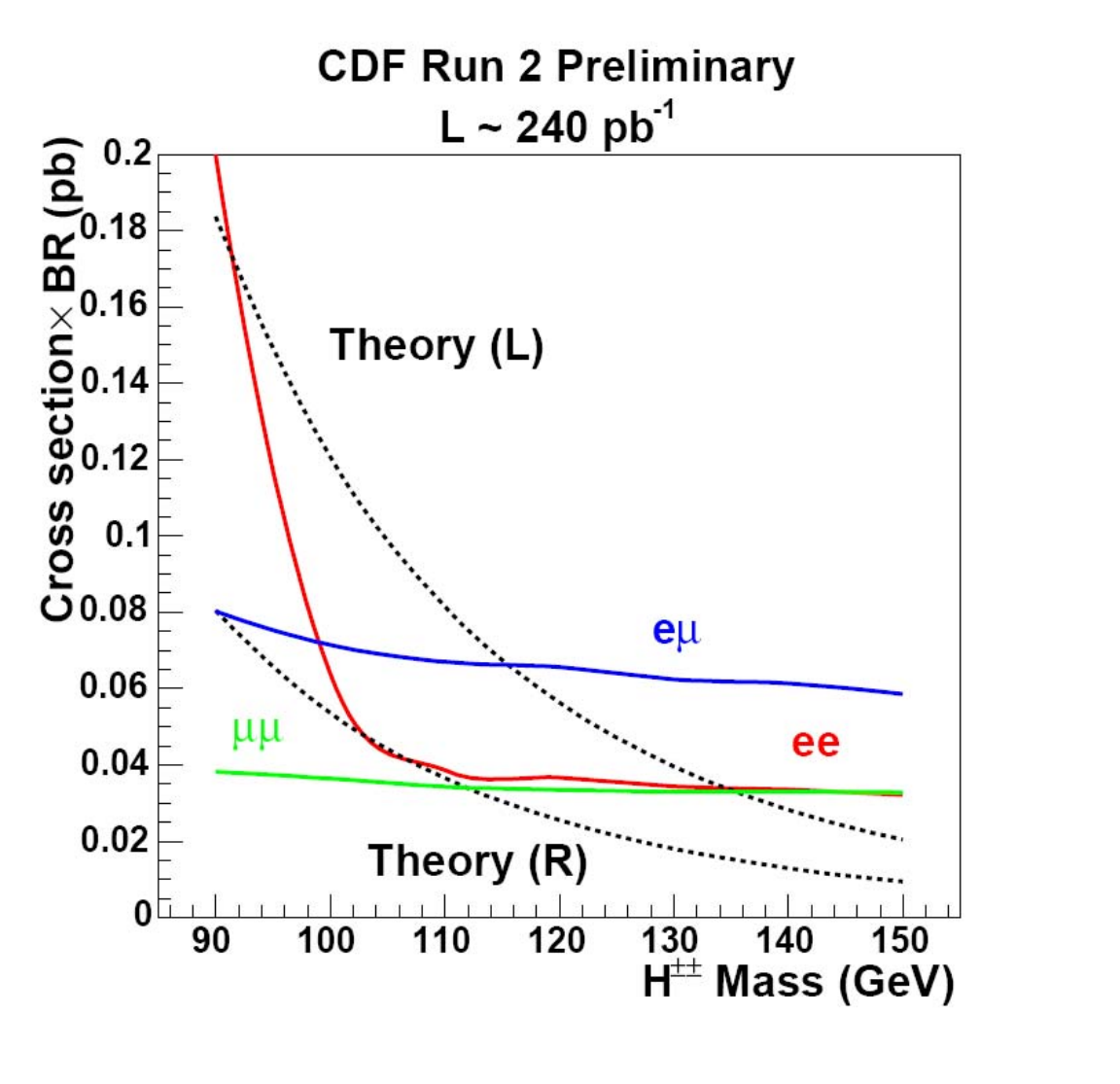
Instrumental background

Summary of limits

Channel	Lum (pb-1)	MP>( )
D0 diEm	130	1.28 TeV
D0 diEm comb w/Run 1		1.37 TeV
D0 μμ	100	880 GeV
CDF ee	200	1.11 TeV

H++

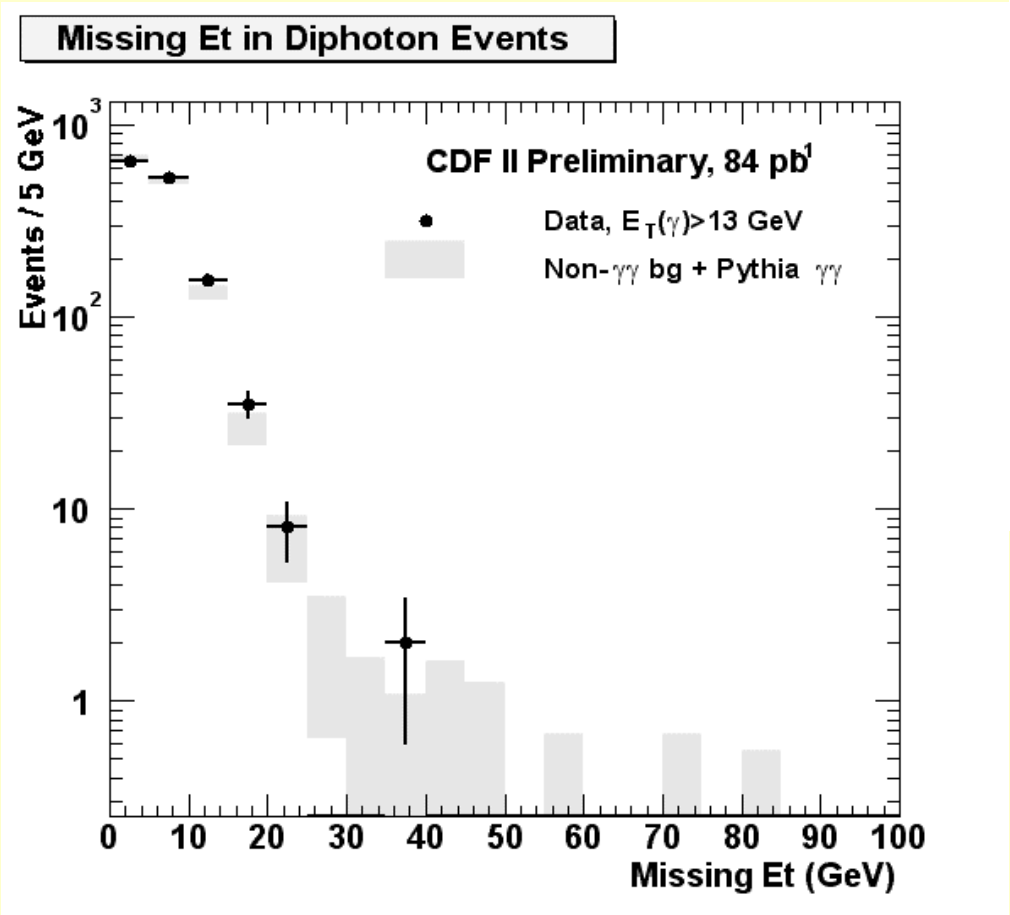
- predicted by left-right (LR) symmetric models
- SUSY LR models : low mass (~100 GeV -1 TeV)
- Signature – energetic like-sign dileptons ee, eμ, μμ
- Compare expected bg with data – derive limits as a function of mass

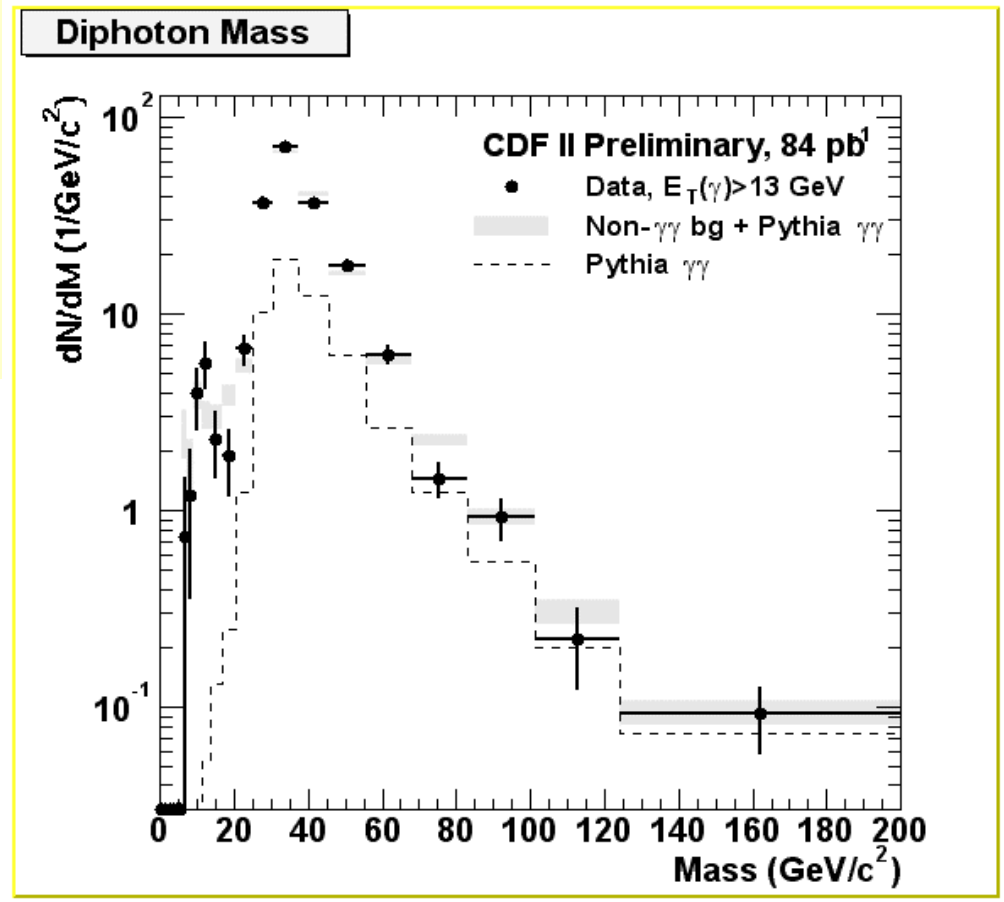


Photon-based searches

Missing Et, Mass in diphoton events

-- look for excess, bumps

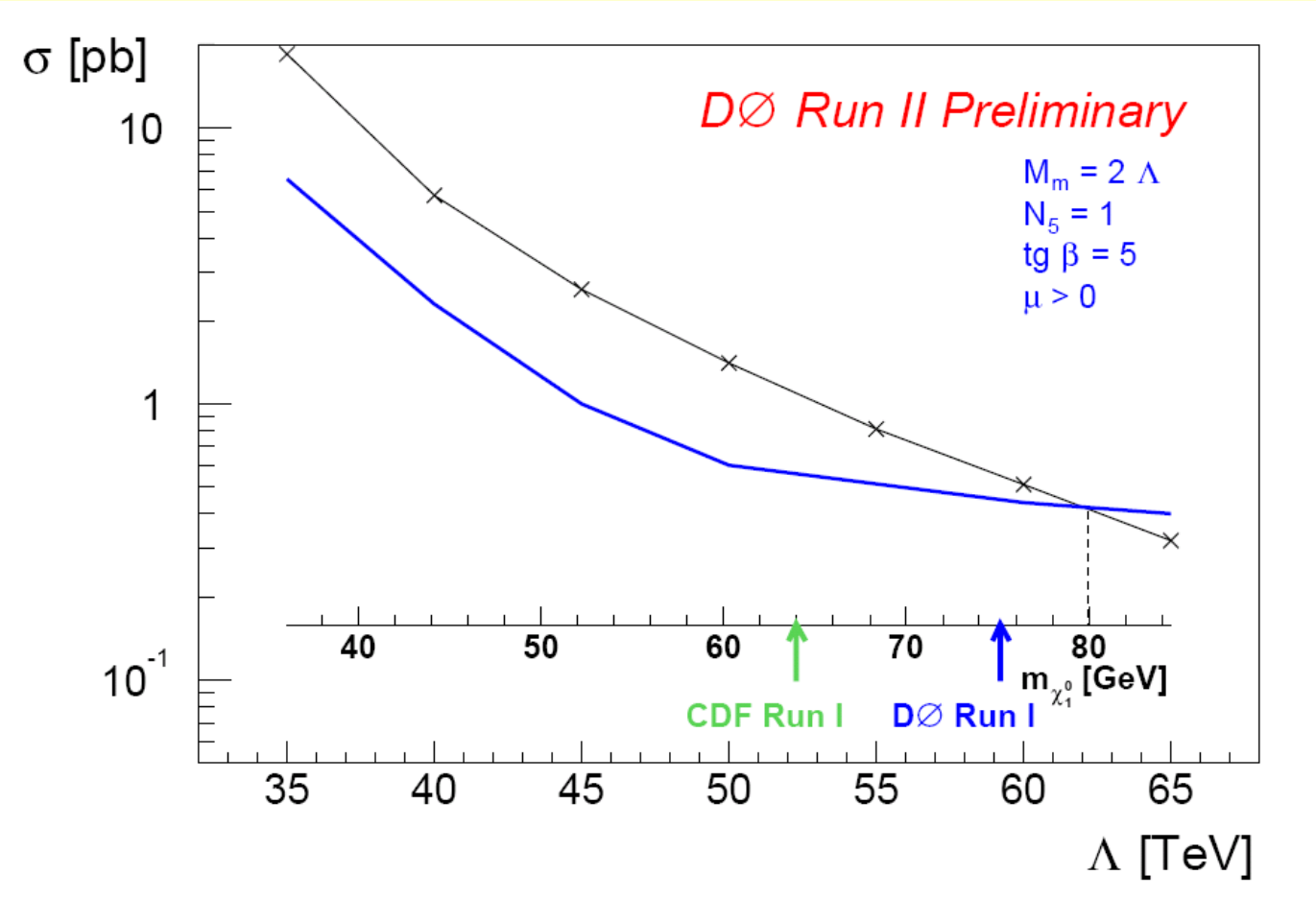




Agrees with expectations for SM, fake backgrounds...

Diphotons as sign of SUSY

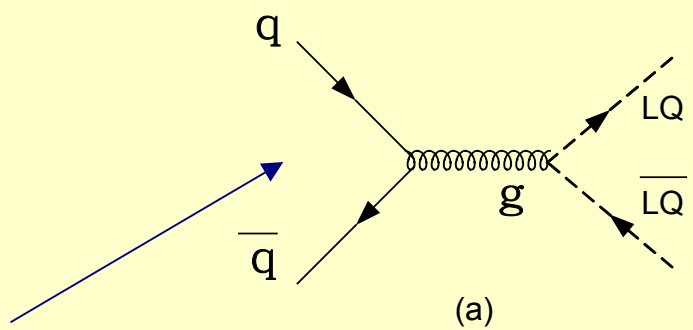
- GMSB models – $\chi\chi \rightarrow \gamma\gamma GG$
- D0 looks at diphotons with high Missing ET (>35)
  - Similar analysis from CDF



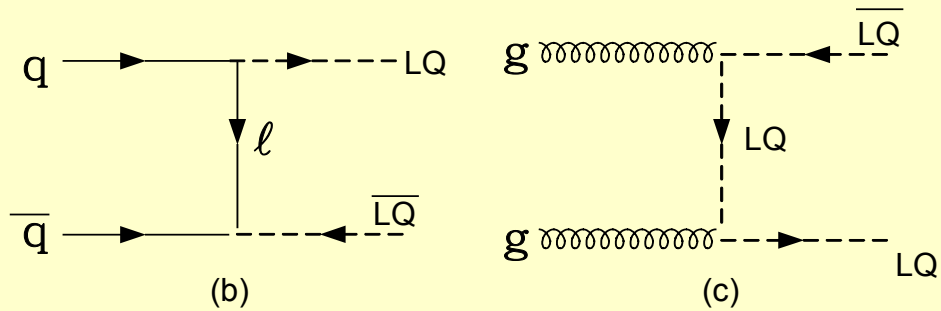
Leptoquarks

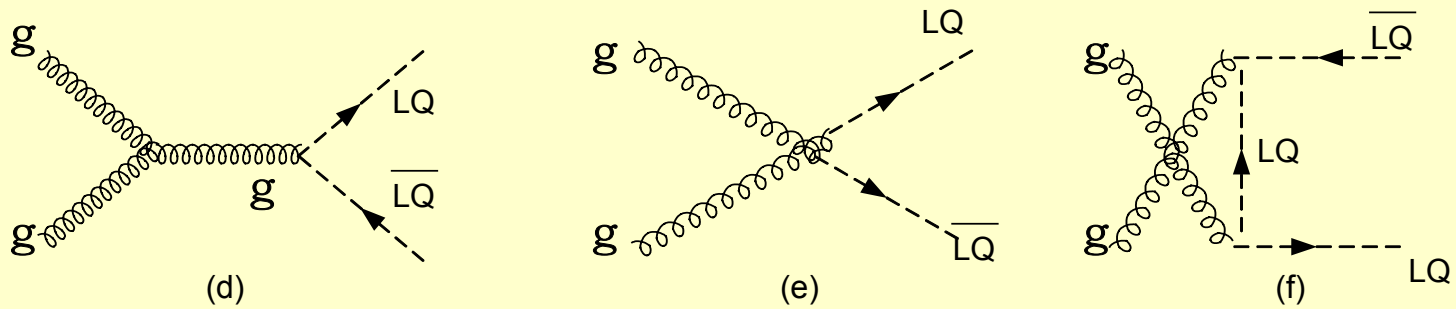
- Lepton-quark resonances
  - Extensions of the Standard Model
    - eg, extended gauge sectors, composite models
  - Pair production, σ~0.3pb for M(LQ)=200.
  - decay to a lepton + quark w/branching ratio beta
  - Should be three generations
    - 1st gen : → eν + jet
    - 2nd gen : → μν + jet
    - 3rd gen : → τν + bjet

1st , 2nd generation explored with Run 2 data



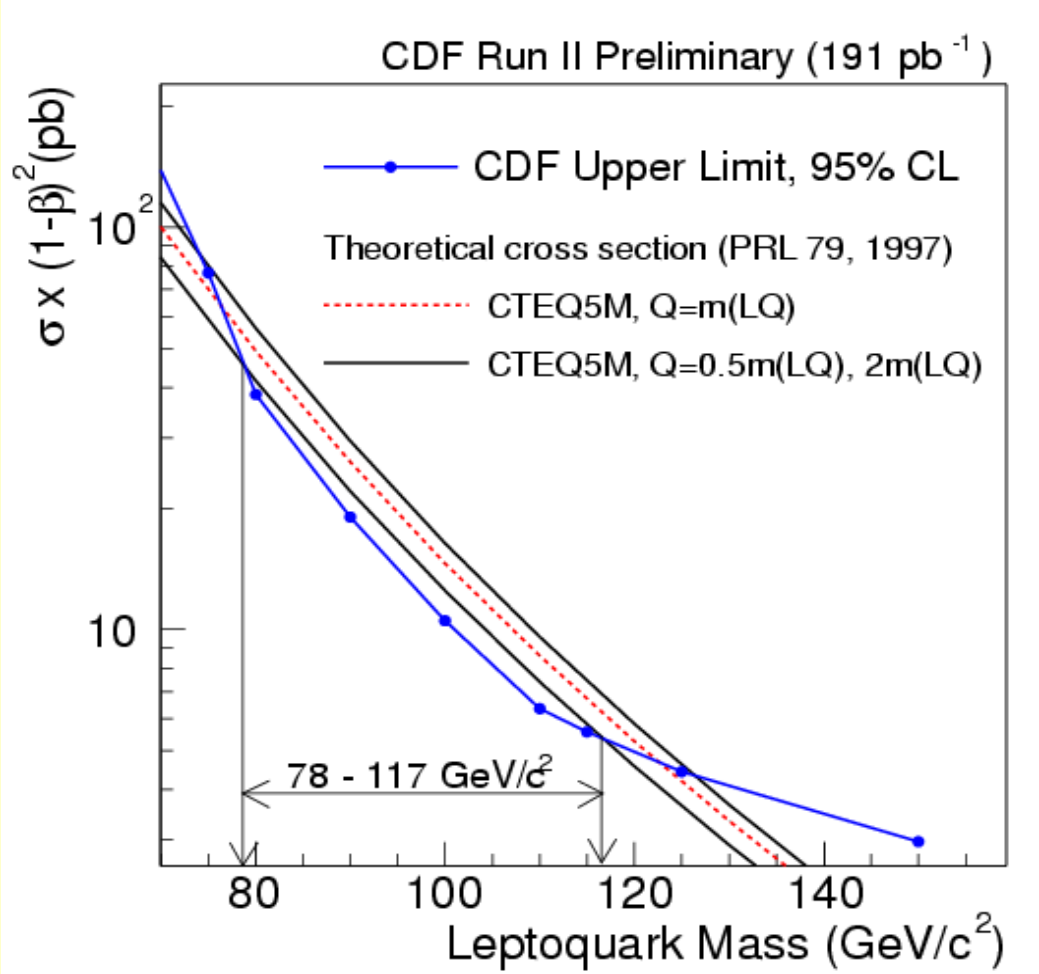
Dominant at Tevatron

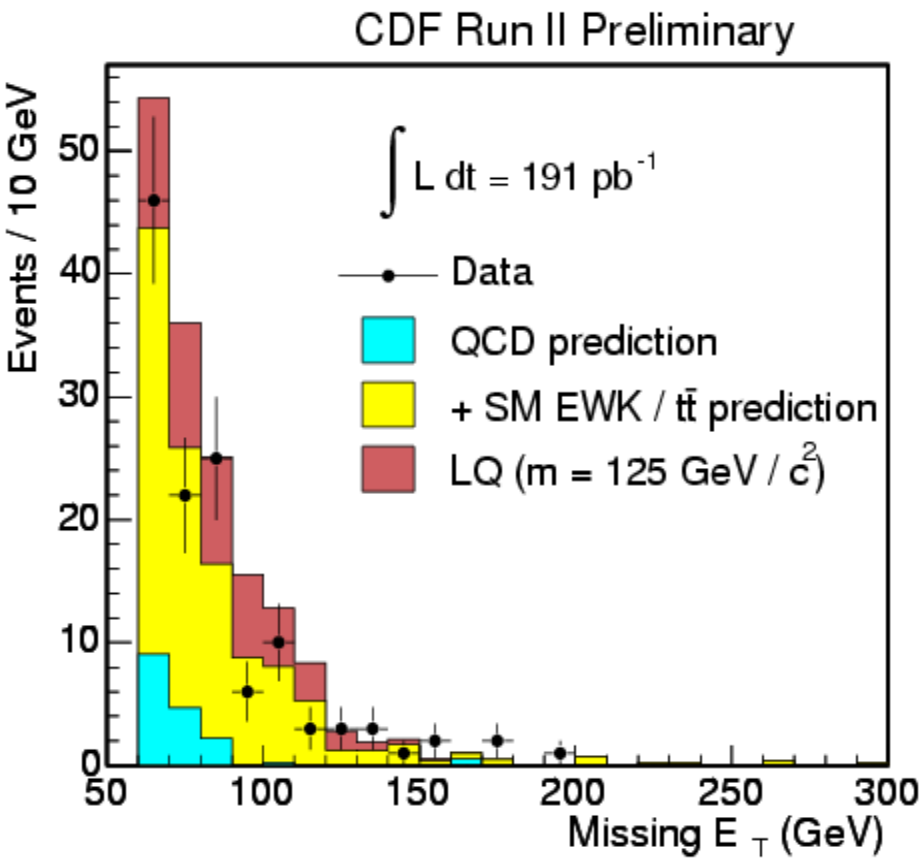




1st Generation – eejj, eνjj, ννjj

- ννjj (MET+jets) difficult
  - Missing Et difficult to model – beam and detector effects

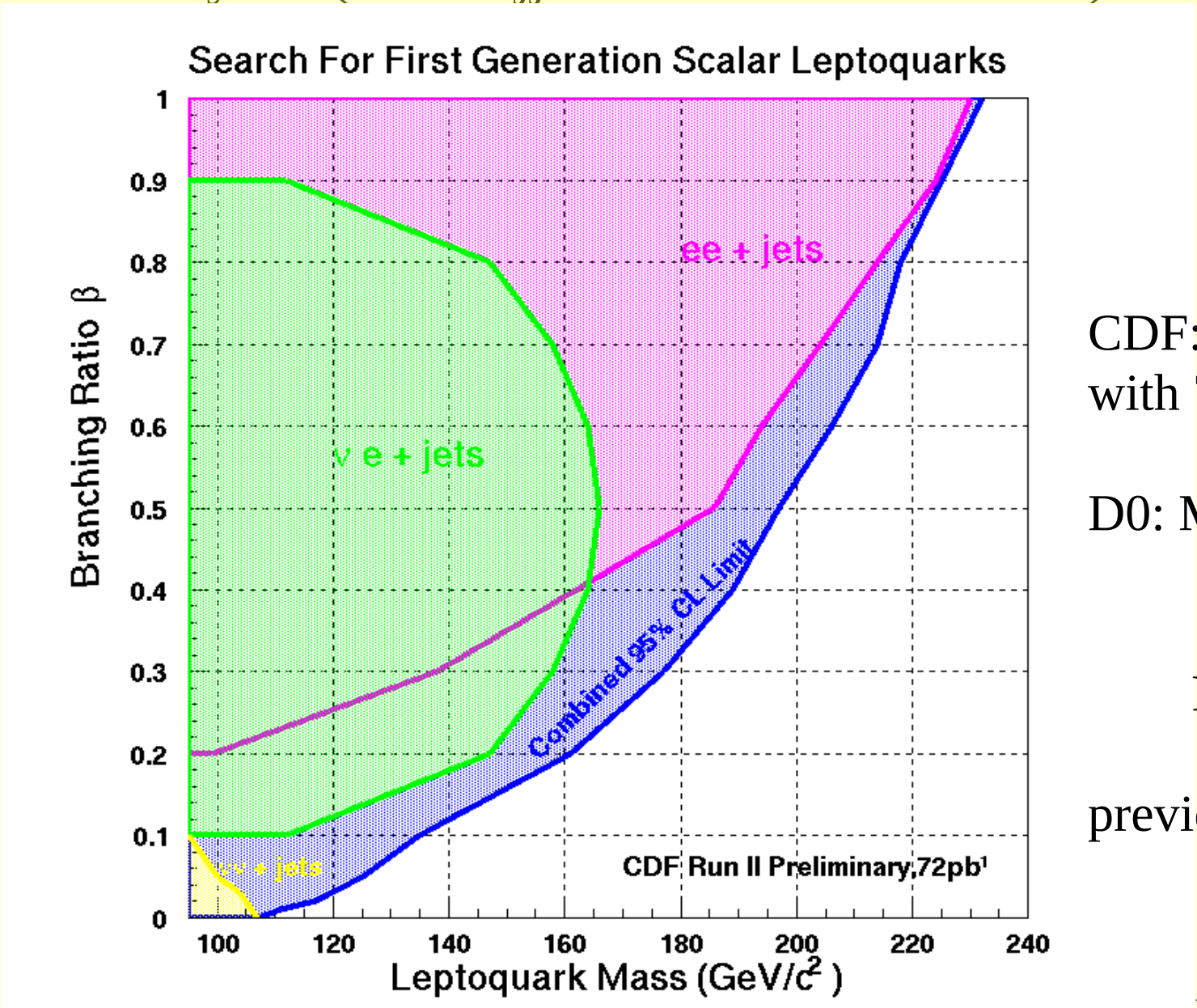




Assume β=0
Previous best limit M>98

First Generation Leptoquarks

- Set comprehensive limits with combination of eejj, eνjj, ννjj analyses (new ννjj result not included here):



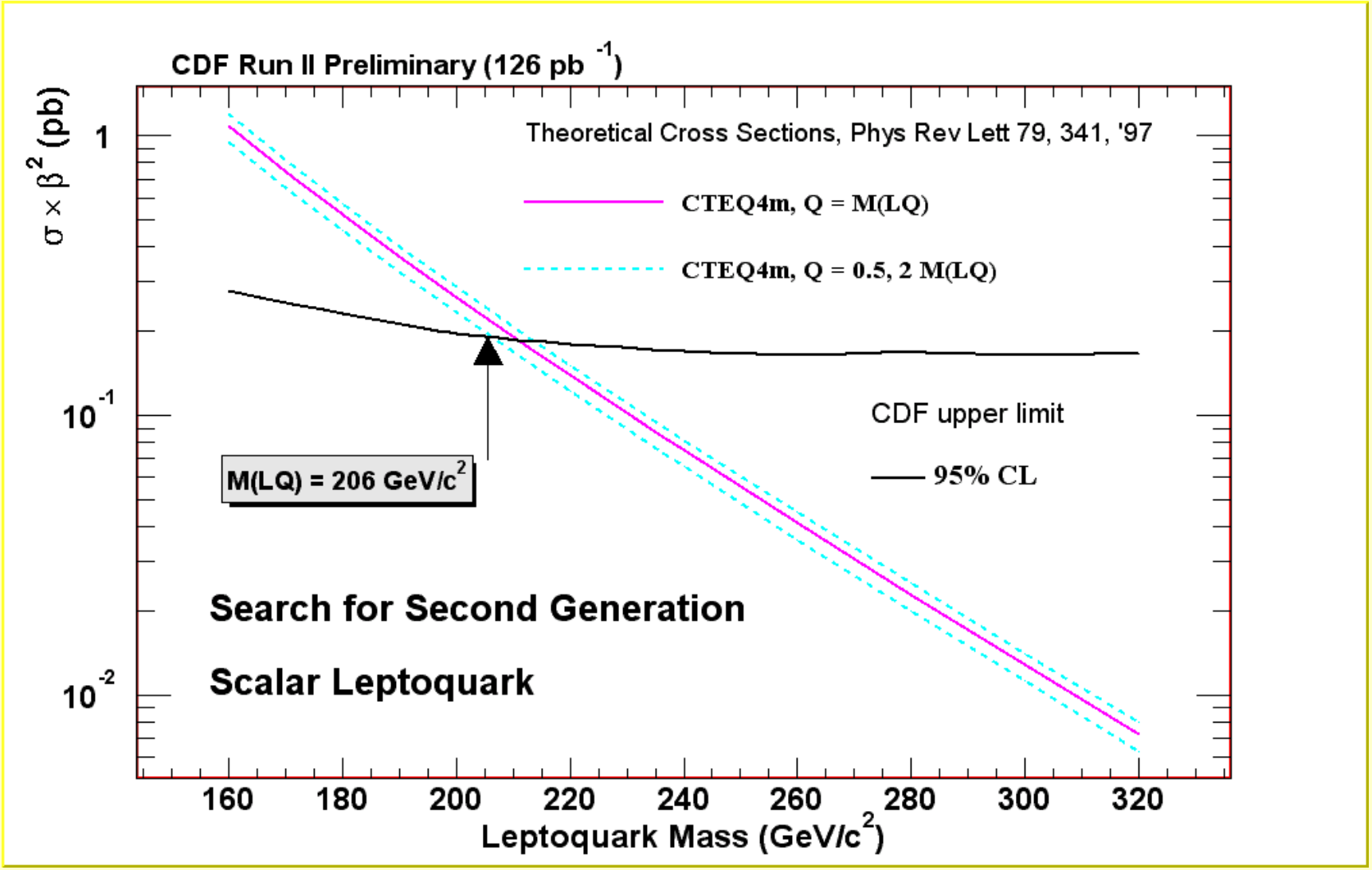
CDF: M(LQ)>230 with 72 pb-1

D0: M(LQ)>231 with 121 pb-1 (>253 if combine Run 1&2)

previous limit: 225

Second Generation Leptoquarks

- μμjj analysis

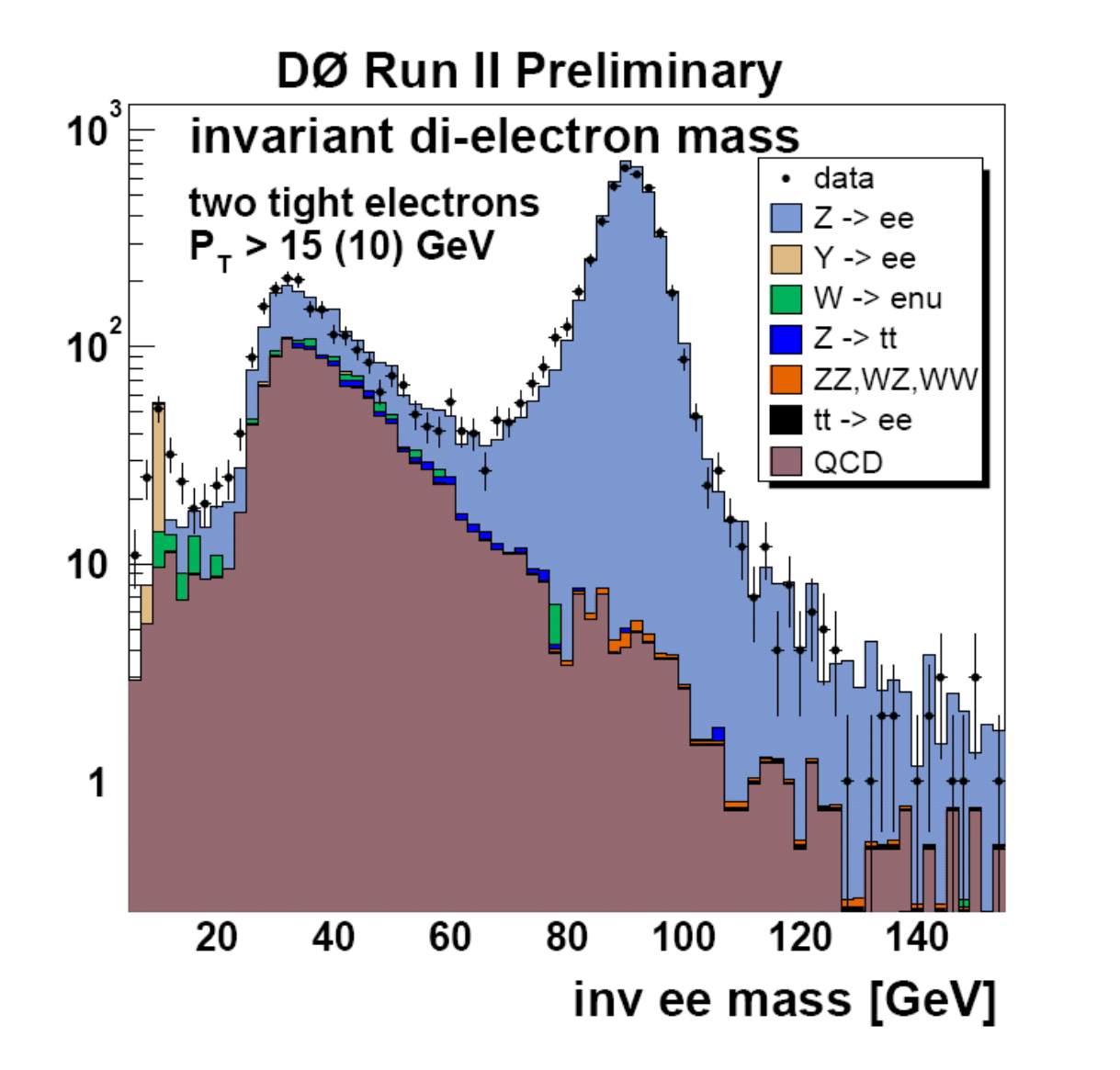


New limits on M(LQ): CDF >206 with 126 pb^{-1}

D0 >186 with 104 pb^{-1}

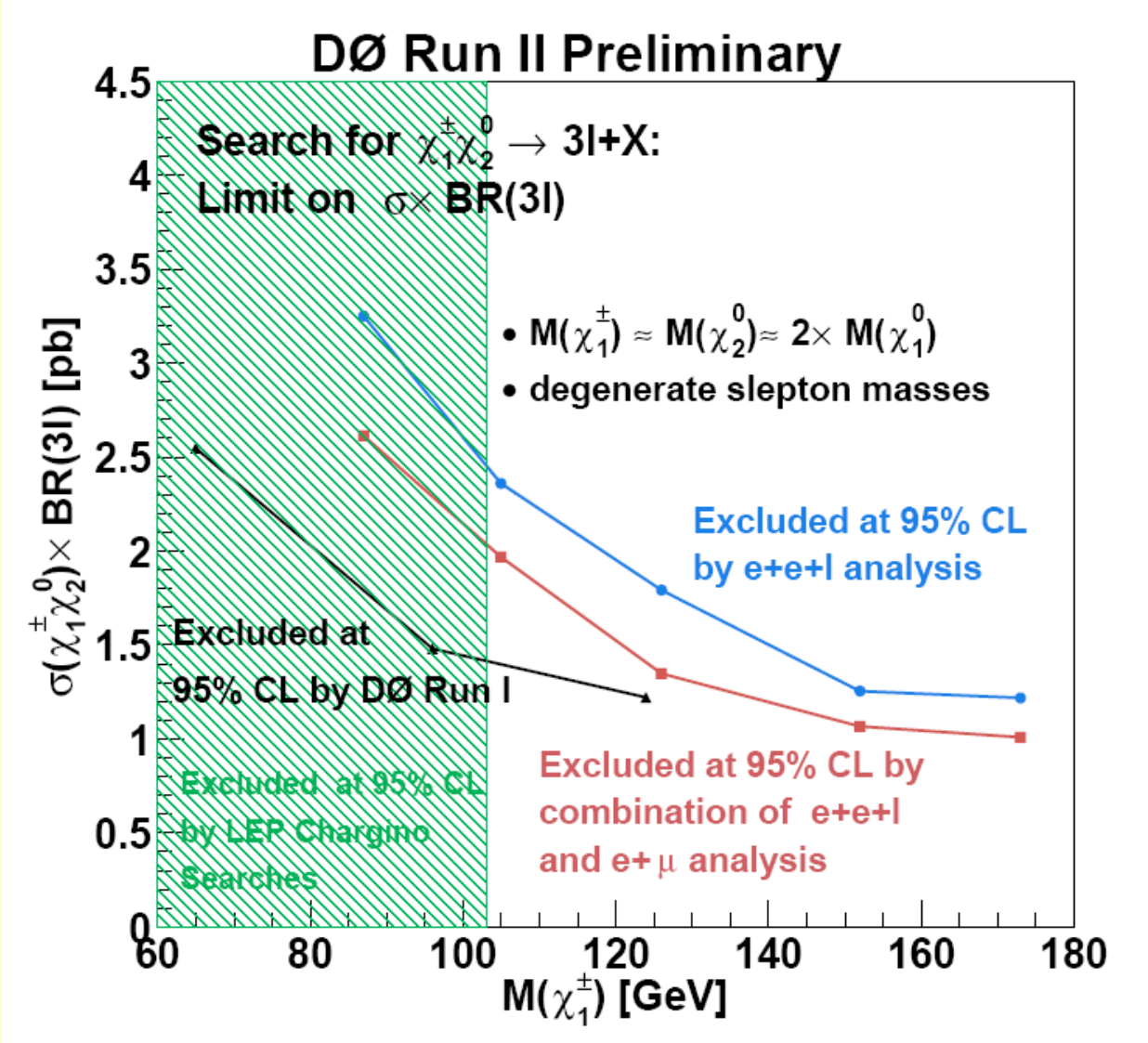
Lepton-based SUSY analysis: Trileptons

- Many SUSY processes could be produced at Tevatron
  - Low cross section, need more data for sensitivity
- Trileptons: flagship analysis for discovery of SUSY at the Tevatron
  - $\tilde{\chi}_1^+\tilde{\chi}_2^0 \rightarrow \ell\nu\tilde{\chi}_1^0+\ell\ell\tilde{\chi}_1^0$
  - Clear signature : 3 isolated leptons
- Low SM background – diboson (WZ,ZZ) and leptons+fake
  - D0: validate bg estimates with ee distributions



Trilepton limit from D0

- Preliminary limit in mSUGRA model
  - ee+track and e+μ (reinterpret model-indep search)

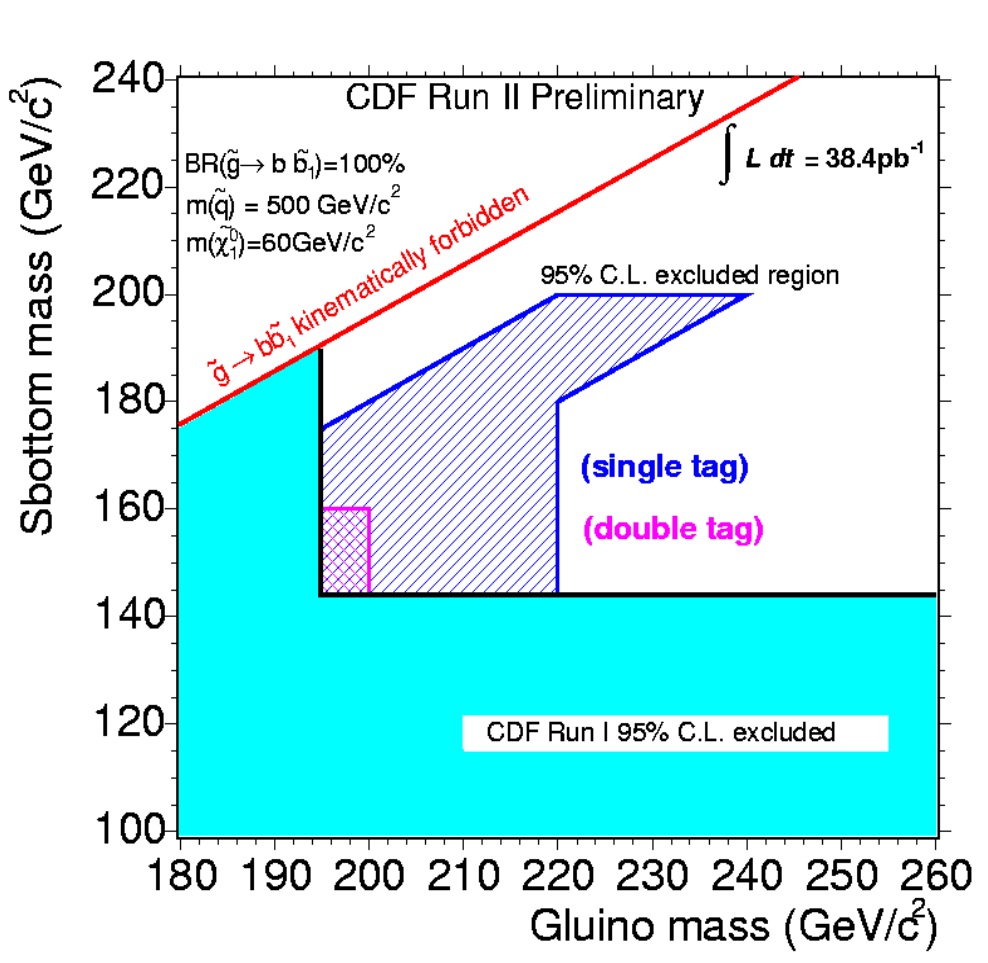


Tevatron gluino/sbottom search

- Squarks and gluinos – relatively high cross sections
  - But difficult to detect – jet-based searches
- Search for scalar Bottom quark:
  - Gluino pair production:

    g →sbottom + b

    (4 b-jets)
  - Sbottom pair production
- Use Missing Et + jets data sample
  - 1st Run 2 search to tag b-jets
- Analysis on a small sample so far
  - Update coming soon



R-parity violation

- R-parity assumed conserved in most analyses:
  - Convenience to evade p decay limits
  - LSP doesn't decay
    - Missing energy
- CDF analysis uses high-mass ee analysis
  - Single $\tilde{\nu}$ production determined by $\lambda' LQD^c$, decay to ee determined by λLLE^c
  - Limits for λ',RPV Yukawa coupling in production vertex
    - $M(\tilde{\nu}) >$ $\lambda' * BR(\tilde{\nu} \rightarrow ee)$

$M(\tilde{\nu}) >$	$\lambda' * BR(\tilde{\nu} \rightarrow ee)$
840	0.1
660	0.01
400	0.0001

- D0's R-Parity violation analysis
  - Choose coupling eg λ_{121}
  - $\tilde{\chi}^0_1 \rightarrow e^+e^-\nu$
  - $\mu^+e^-\nu$
    - 75% of final states have eee
  - Apply eee analysis to 118 pb^{-1} of data

3e analysis

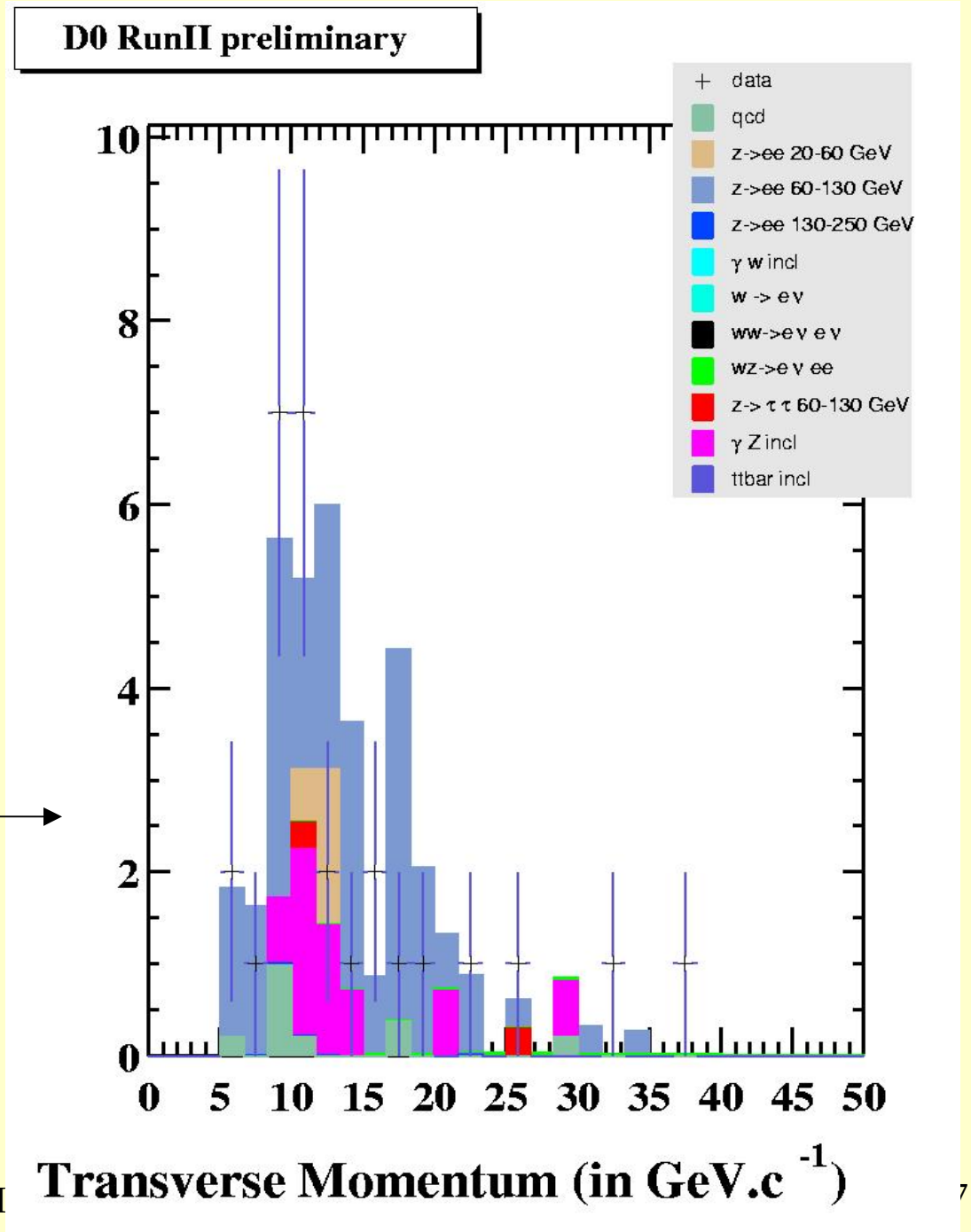
- Low background
  - expect 3, observe 3
- 95% CL limit

  σ <1.3pb (μ<0)

  <1.4 pb (μ>0)

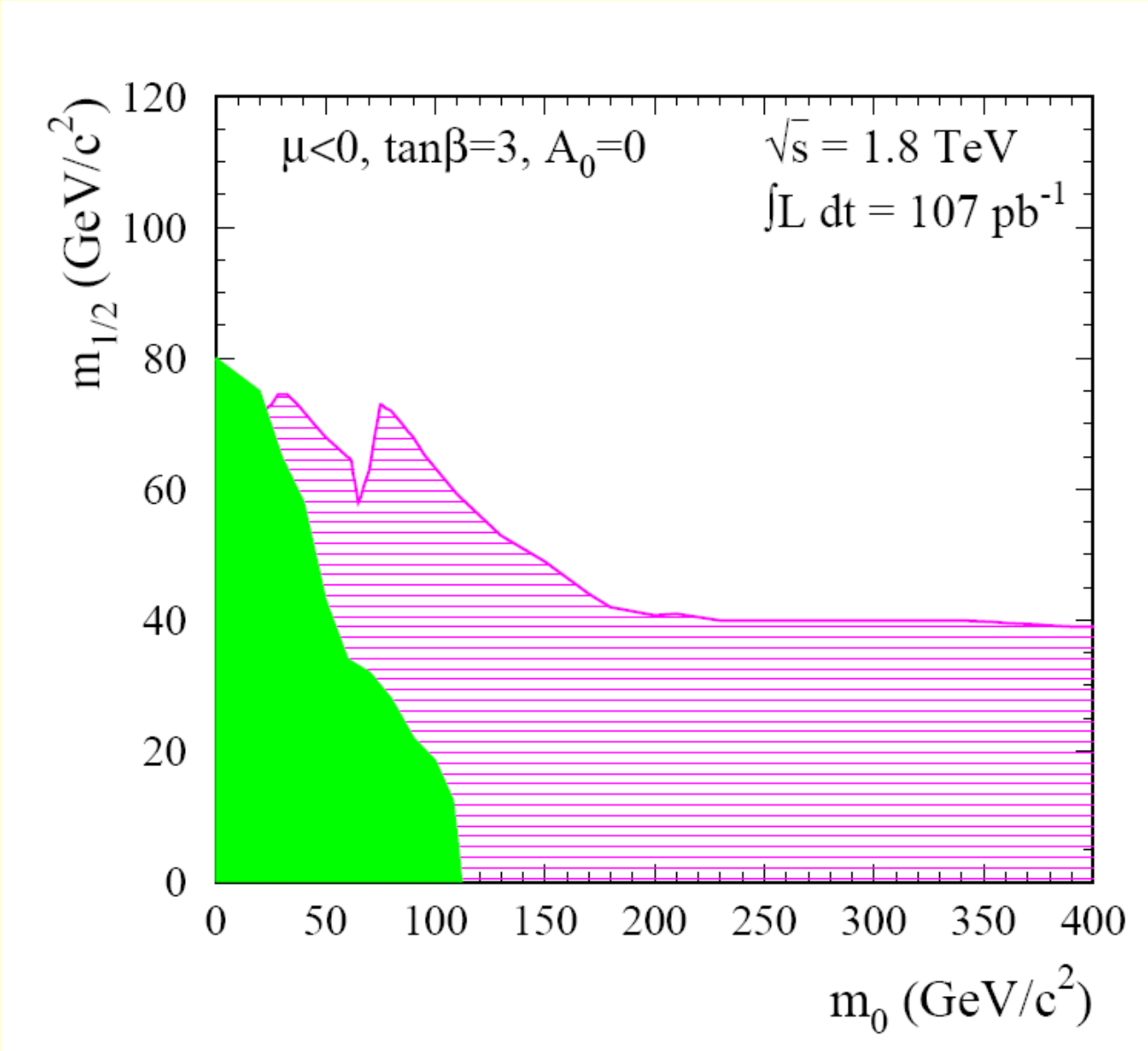
pt of 3rd lepton

--understanding of fake leptons



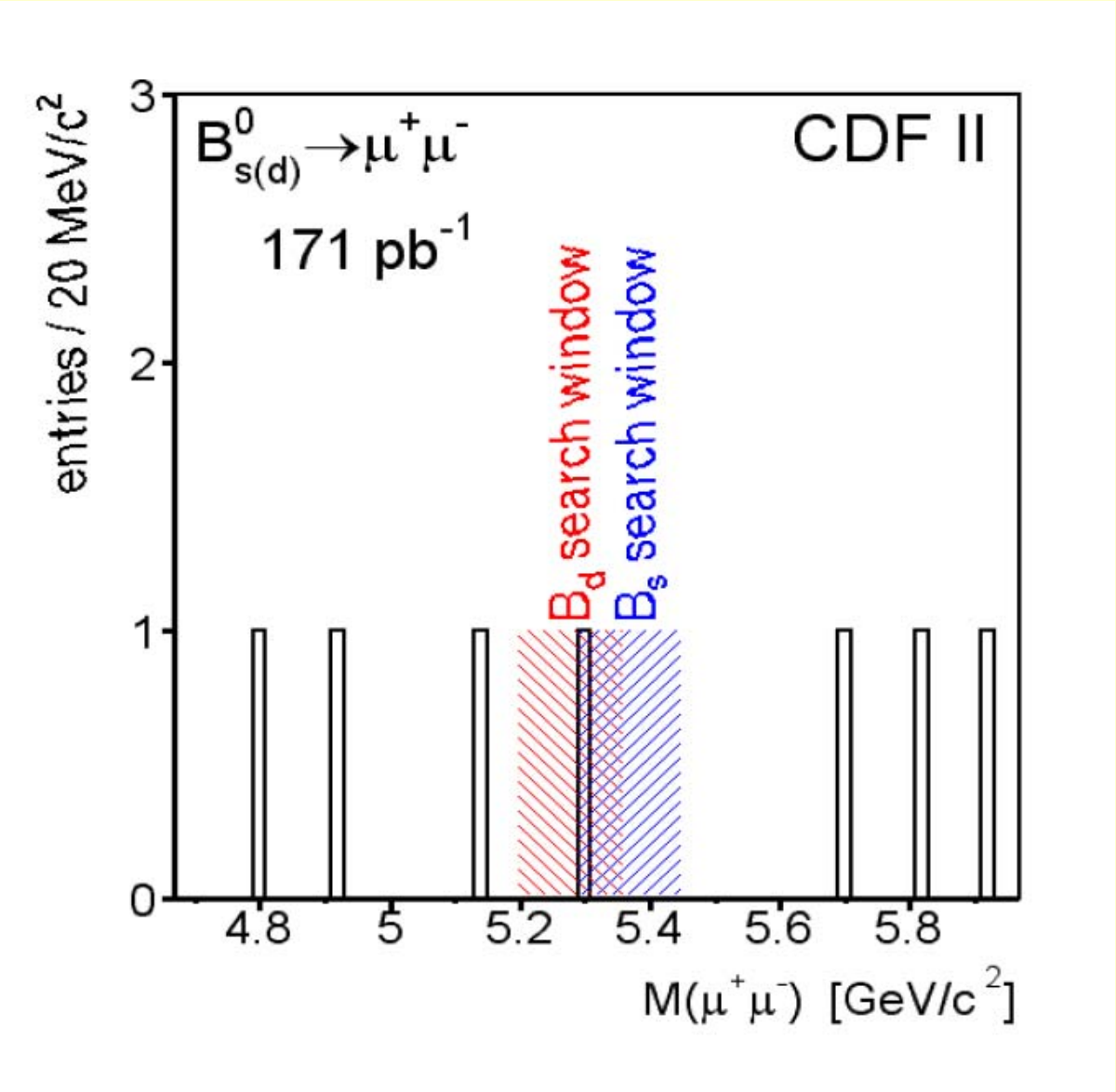
Inclusive mSUGRA Analysis

- CDF -- Inclusive mSUGRA analysis for like-sign dileptons in Run 1
- Sensitive to chargino,neutralino,squark, gluino production
- Combination with trilepton result will significantly increase CDF's sensitivity

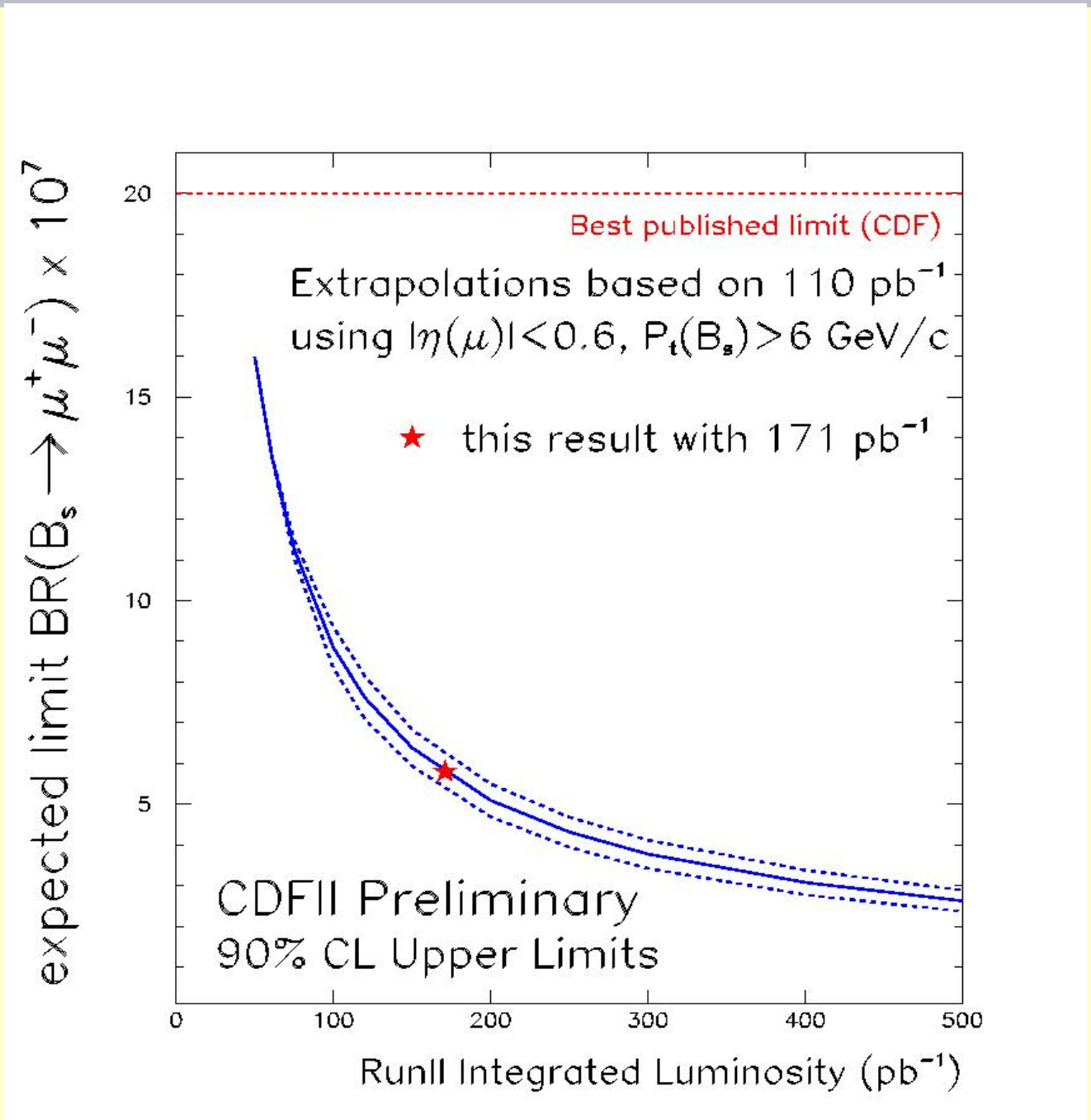


Indirect Limits from $B_s \rightarrow \mu\mu$

- SM: $BR(B_s \rightarrow \mu\mu)$= 3.8+/-1.0 x 10-9
- CDF Run 1 limit <2.6 x 10-6
- SUSY predicts 10 – 1000 x SM
- CDF updated analysis B_s, $B_d \rightarrow \mu\mu$ with 171 pb^{-1} of data



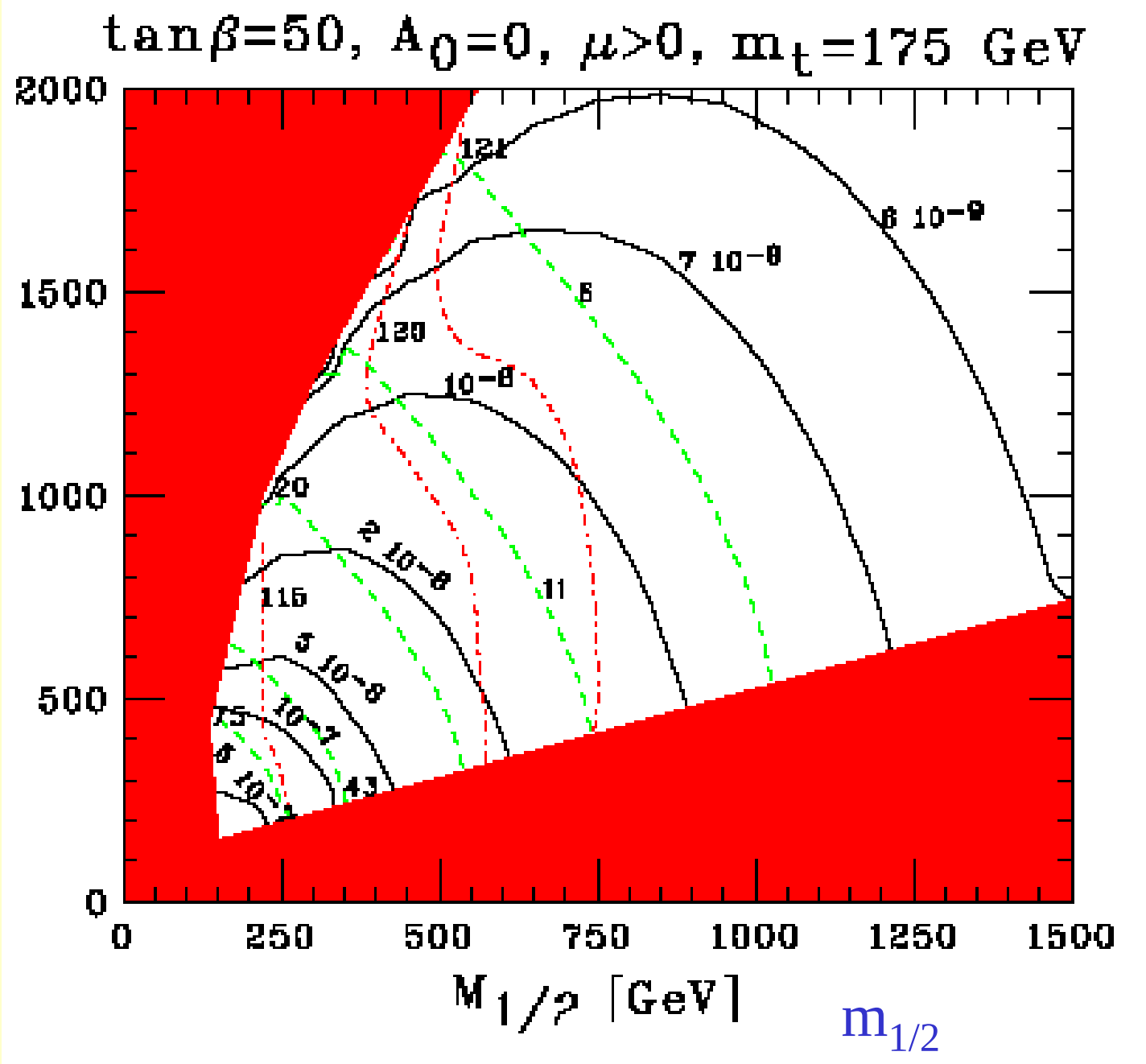
New Limit and Expected Sensitivity



SUSY exclusion

mSUGRA model

m0



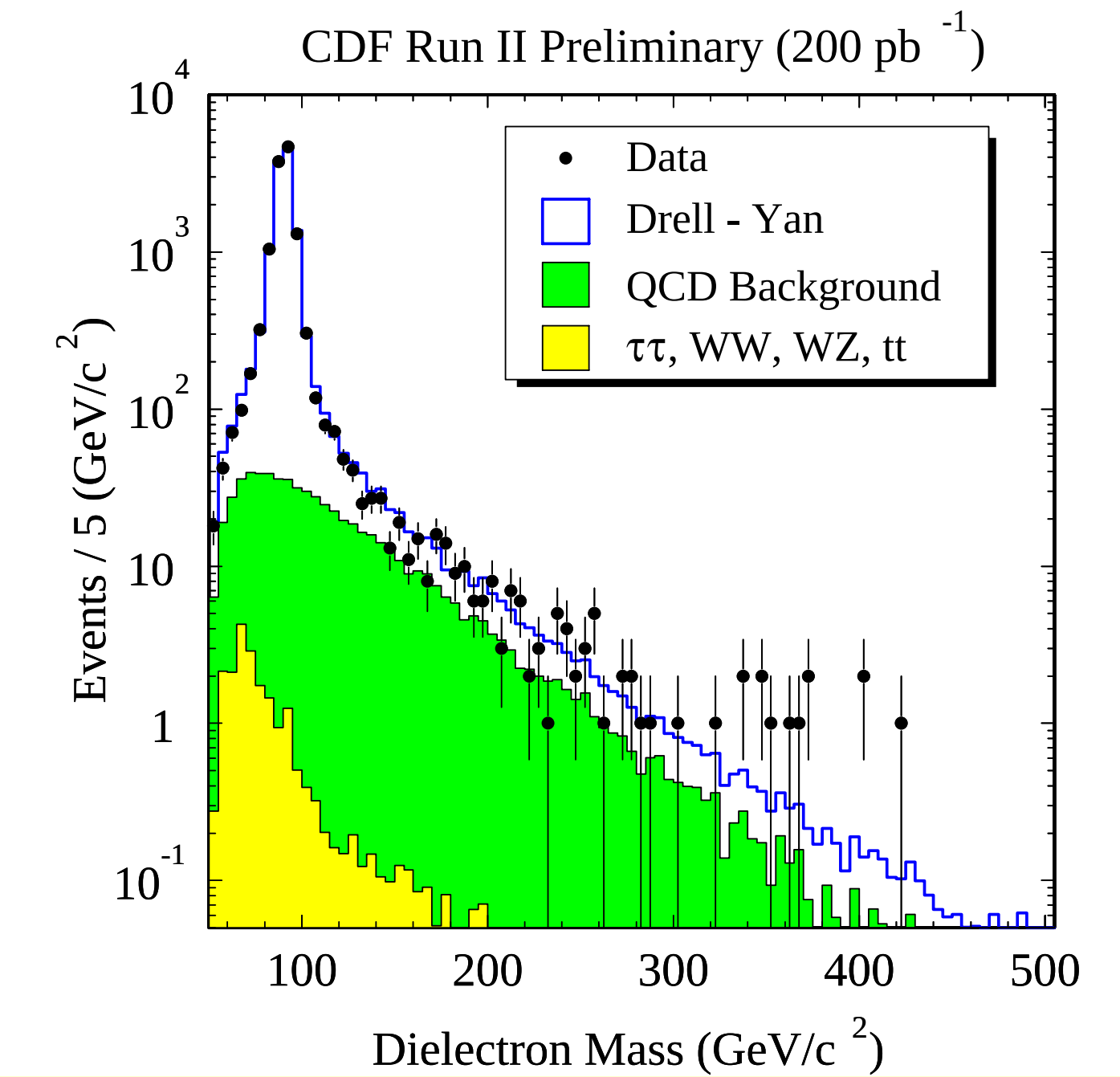
$m_{1/2}$

More results

- Run 2 Results that I didn't have time to mention:
  - CDF : e*
  - CDF : dijet resonances
  - CDF : charged heavy min. ionizing particles (CHAMPS)
  - CDF: High-Et photon + Missing Et
  - D0: dimuon resonances
- Apologies if I missed anything
- Both CDF and D0 have more new results coming in the next few months

Conclusion

- Tevatron Run 2 is really underway
  - We have analyzed up to 200 pb^{-1}
    - Many interesting results already
  - And have ambitious plans for the coming years
- The promise of more to come
  - Tevatron is running better than ever
    - Expect 230-340 pb^{-1} this year
    - 1 fb^{-1} by end of FY05
- The next few years will be very exciting!!

- Thanks to Ulla Blumenschein, Ben Brau, Volker Buescher, Doug Glenzinski, Matt Herndon, Koji Ikado, Muge Karagoz Unel, Greg Landsberg, Tim Nelson, Daniel Whiteson

CDF high-mass electron pair