Search for BSM Physics (non-SUSY) in Final States with Photons at the Tevatron

Enrique Palencia

Fermilab

for the CDF and DØ Collaborations

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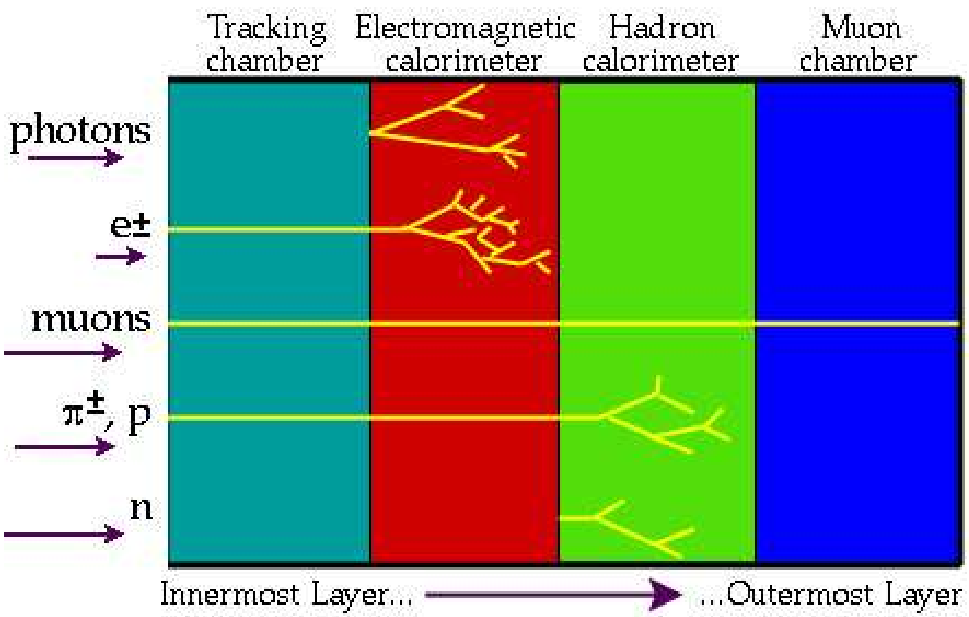
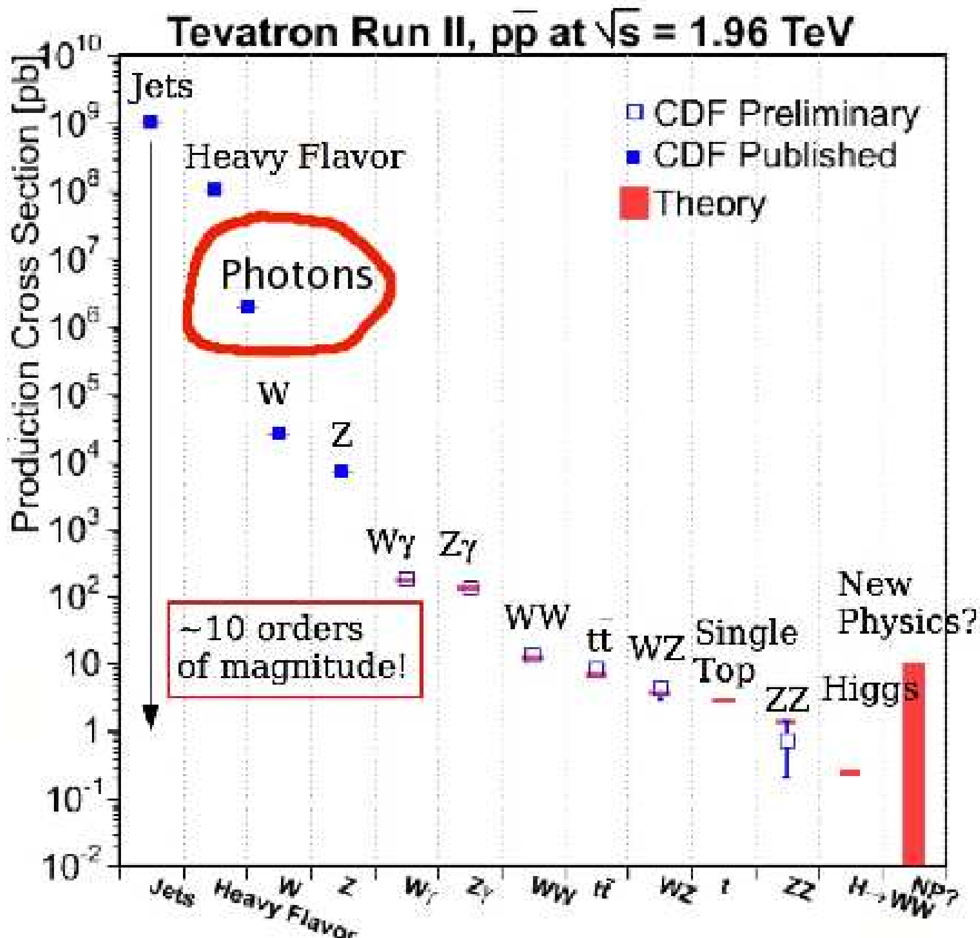
Motivation: Many models with final state photons!!!

- **SUSY** (See Andrey Loginov's talk)
  - ♢ mSUGRA: $\chi_2^0 \longrightarrow \gamma\chi_1^0$
  - ♢ GMSB (Gauge-Mediated Supersymmetry Breaking): $\chi_1^0 \longrightarrow \gamma G$
- **Compositeness**: $X^* \longrightarrow \gamma X$
  - ♢ $ee\gamma$, $\mu\mu\gamma$
- **Large Extra Dimensions**: γ + MET, $\gamma\gamma$
- **Higgs**: $\gamma\gamma$, $\gamma\gamma ee$, $\gamma\gamma\mu\mu$, $\gamma\gamma e\nu$, $\gamma\gamma\gamma\gamma$
- **Technicolor**: ω_T, $\rho_T \longrightarrow \gamma\pi_T$
  - ♢ γbb, γjj, γtt, $\gamma\gamma\gamma$...
- **4th Generation**: $b' \longrightarrow b\gamma$
  - ♢ $\gamma\gamma bb$, $ee\gamma bb$, $\mu\mu\gamma bb$, $jj\gamma\gamma bb$

Photons at the Tevatron

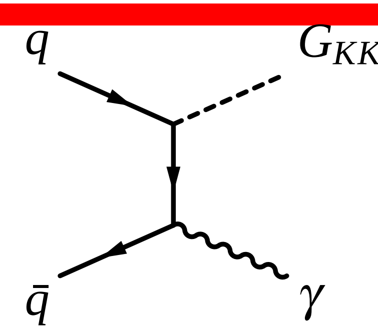
- Photon is one of the 7 fundamental objects at a collider
- 2^{nd} most common object after the jets





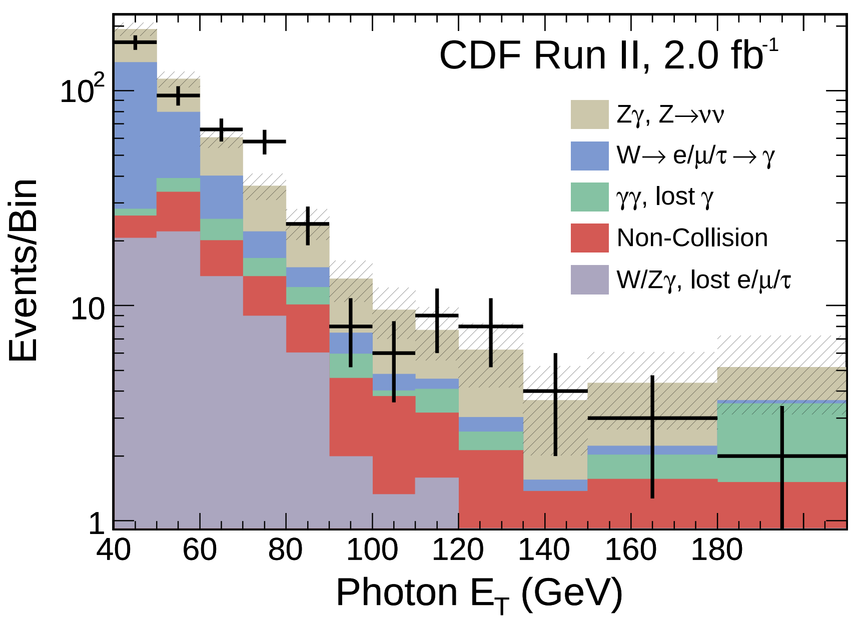
- Photon (γ) $\equiv$ shower in the EM calorimeter with no associated track
- Backgrounds from jet $\rightarrow \pi^0 \rightarrow \gamma\gamma$ and electrons with not reconstructed track
  - ◇ Reduced with photon isolation, hits in the preshower detector, ...

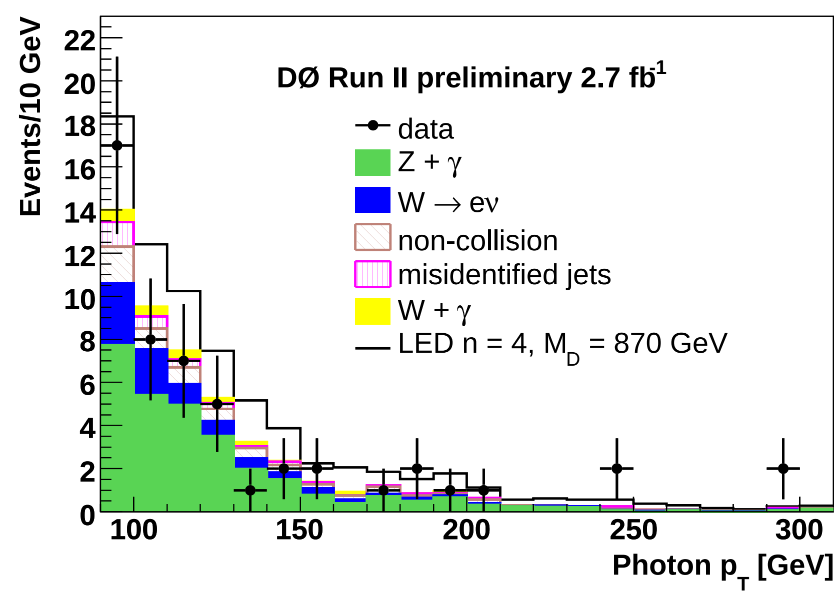
LED in γ + MET



- This signature arises from the process $q\bar{q} \longrightarrow \gamma G_{kk}$
  - ◇ G all possible integer spin states from 0 to 2
- Both experiments perform similar event selection ($E_T^{\gamma} > 90$ GeV)
  - ◇ CDF: MET$>$50 GeV, 2.0 fb^{-1}
  - ◇ D0: MET$>$70 GeV, 2.7 fb^{-1}

# Events	CDF	D0
Predicted	46.3 ± 3.0	49.9 ± 4.1
Observed	40	51





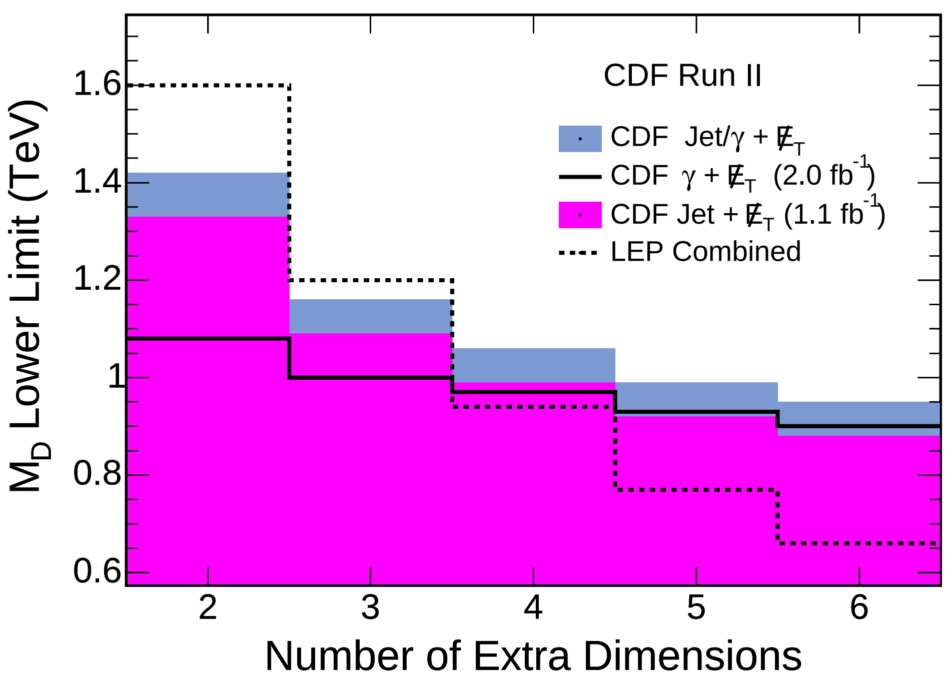
- Consistent with SM $\Longrightarrow$ Set limits on LED

LED in γ + MET

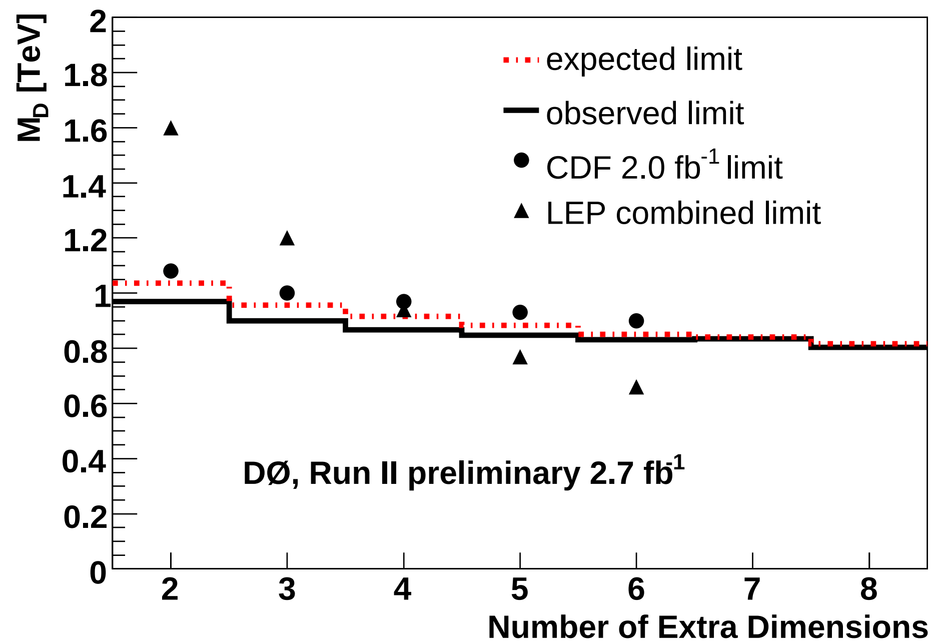
- 95% C.L. lower limits on the fundamental 4+n dimensional Planck scale M_D (in GeV)

$$M_{Pl}^2 \sim R^n M_D^{n+2}$$

95% C.L. Lower Limits (GeV)		
n	CDF	D0
2	1080	900
6	970	831



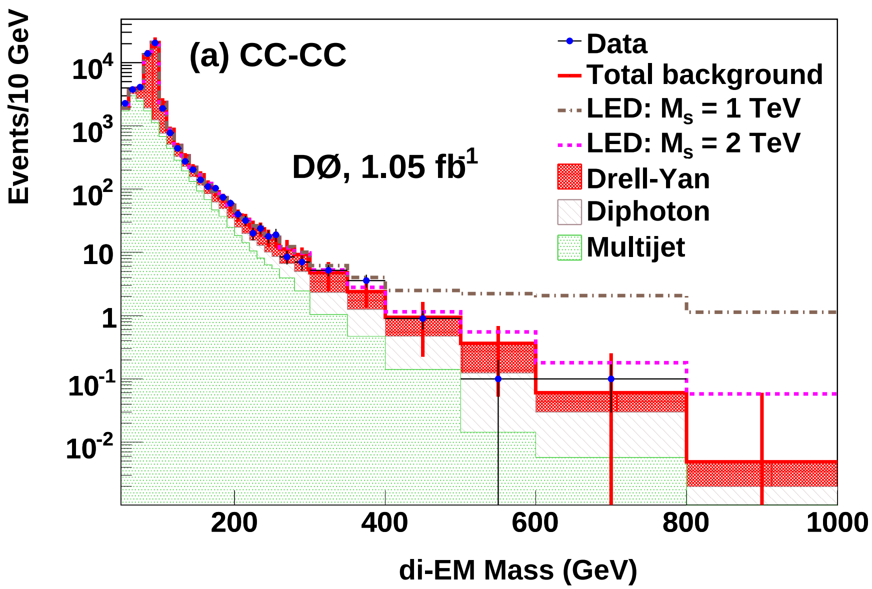
PRL 101, 181602 (2008)

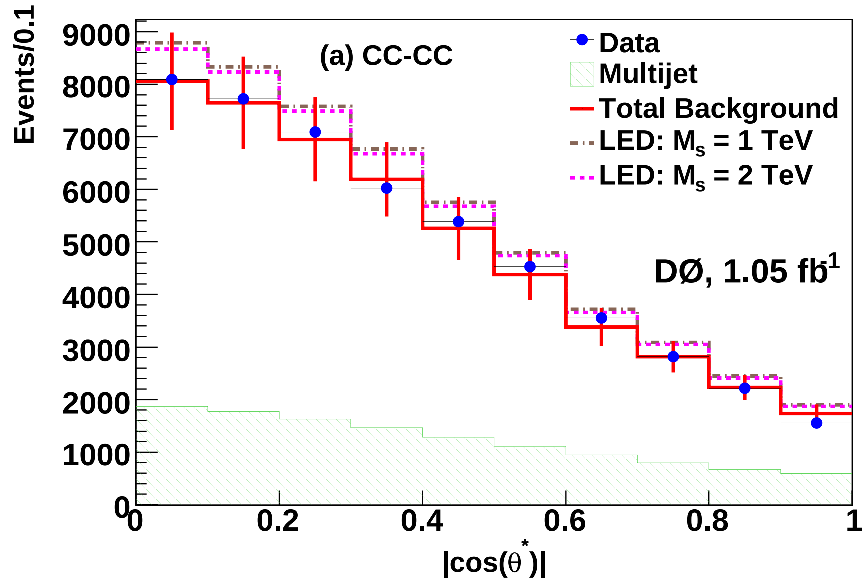


PRL 101, 011601 (2008) (1 fb^{-1})

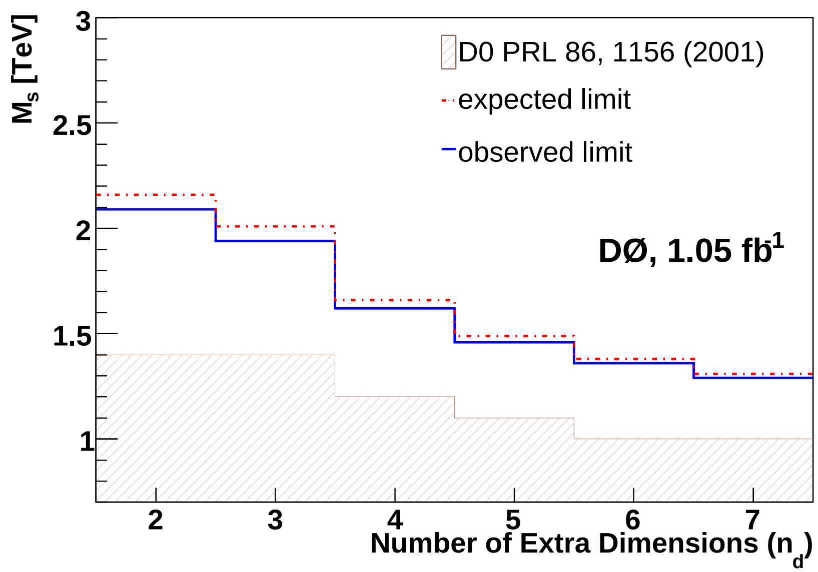
LED in $ee, \gamma\gamma$

- Look for deviations from the SM in the 2D di-EM mass and $|cos(\theta^*)|$ distributions
- # of events is consistent with the # of expected events from the SM expectation



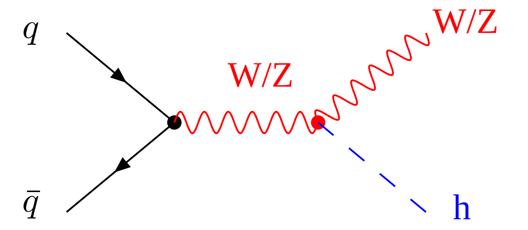


- Set 95% C.L. lower limits on the effective Planck scale, M_s:
  - ◇ GRW (leading order, n_d independent): $M_s > 1.62$ TeV
  - ◇ HLZ (sub-leading, n_d independent): $M_s > 2.1$ (1.29) TeV for n_d = 2 (7)
- PRL 102, 051601 (2009)



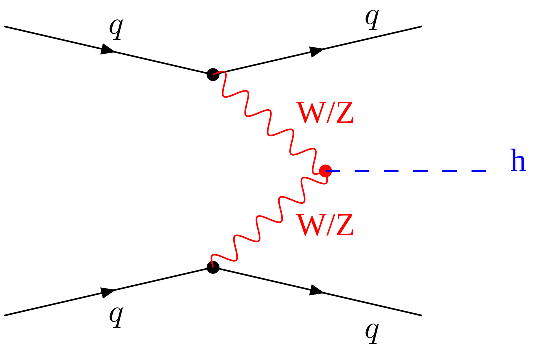
Fermiophobic Higgs in Diphotons

- Diphoton final state appealing since photon ID efficiency and energy resolution is better than jets



- In SM, B($H \longrightarrow \gamma\gamma$)$\sim$ 0.2% for M_H=120 GeV
  - ◇ See Michele Giunta's talk

- Fermiophobic Higgs models does not allow couplings to fermions

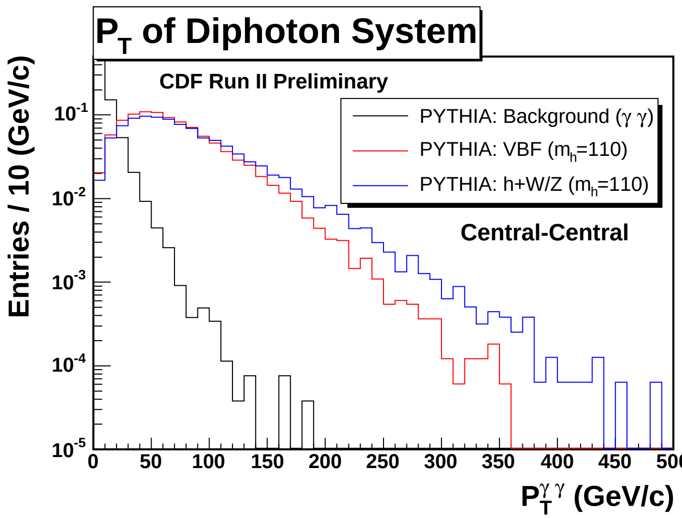


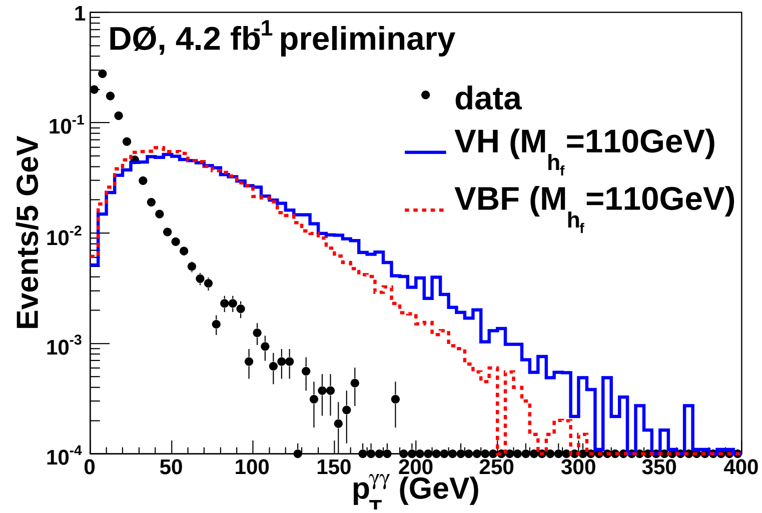
  - ◇ No gluon fusion
  - ◇ Only production processes possible are
    - Associated production with a W or Z boson
    - Vector boson fusion (VBF)
  - ◇ Reduction in production cross section but B($H \longrightarrow \gamma\gamma$) is greatly enhanced

- Since $p_T(\gamma\gamma)$ is large, both experiments cut very hard on $p_T(\gamma\gamma)$ and search for a narrow resonance in M($\gamma\gamma$)

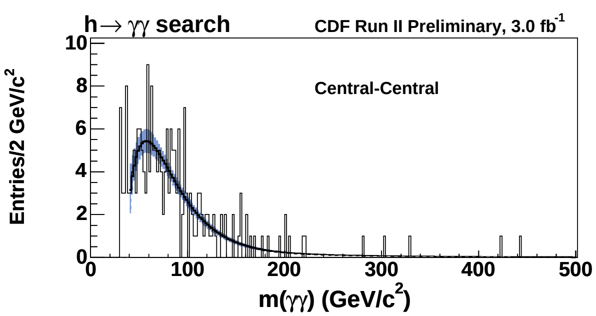
Fermiophobic Higgs

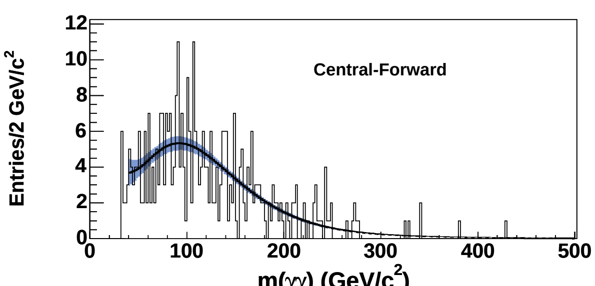
- CDF: $p_T(\gamma\gamma) > 75$ GeV $\Rightarrow$ remove $\sim$99.5% of the bkg ($\sim$30% of signal remains)

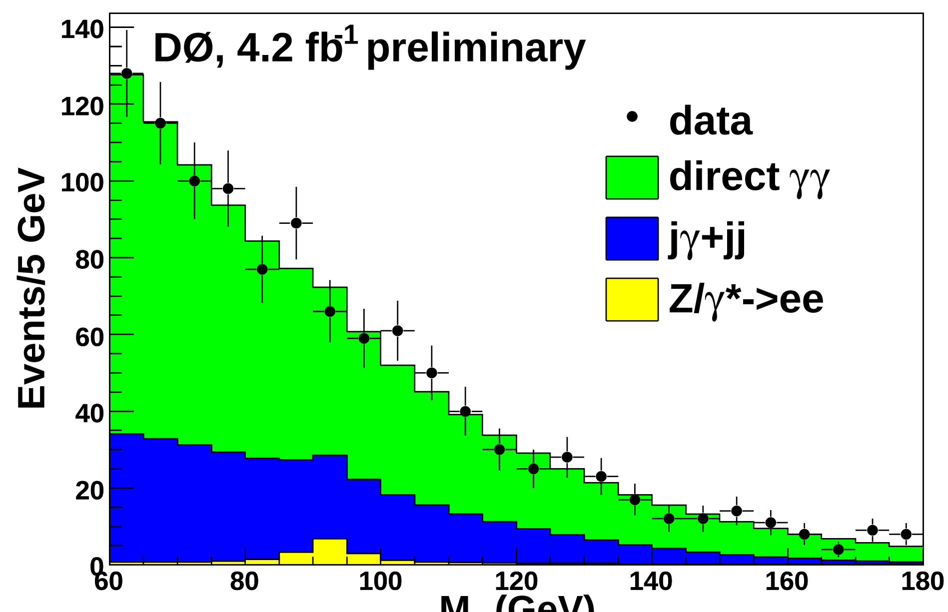




- Look for a resonance in the diphoton mass distribution

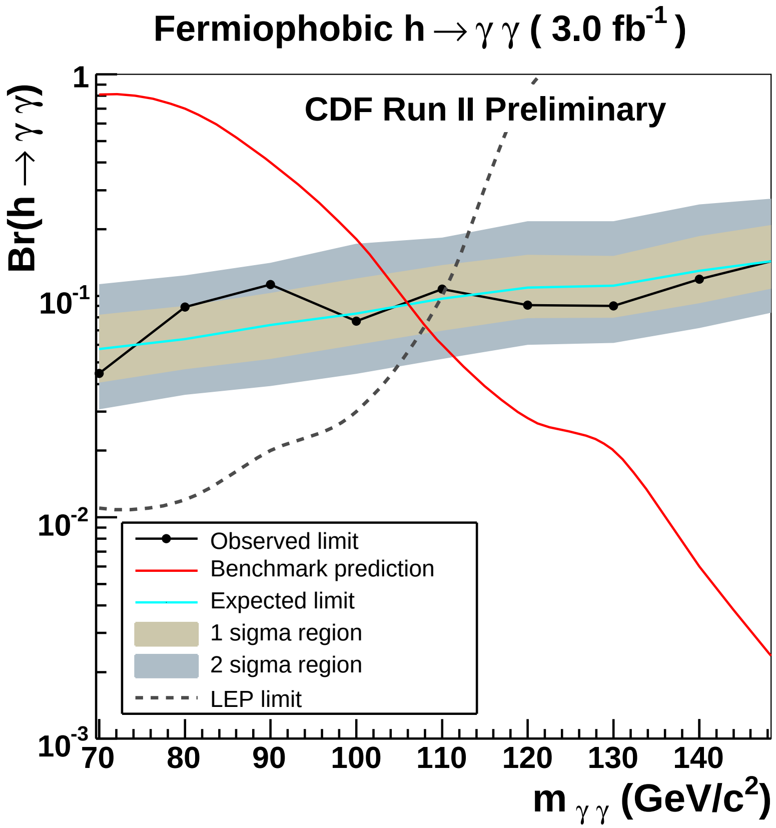


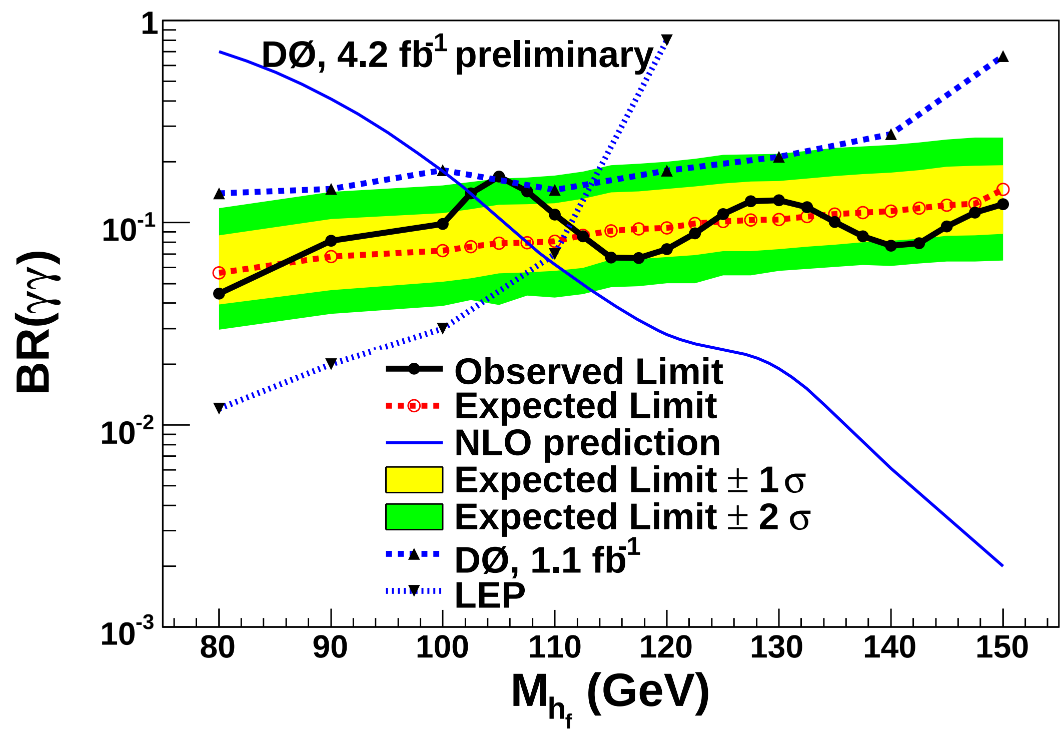




Fermiophobic Higgs

- No evidence of resonance is found. Set 95% C.L. lower limits





Submitted to PRL (arXiv:0905.0413 [hep-ex])

	CDF (3.0 fb^{-1})	D0 (4.2 fb^{-1})
M(h$_f$) lower limit (GeV)	106	102.5

- Both analysis are now sensitive to M(h$_f$) $\sim$ 110 GeV (inaccessible to LEP)

Signature Based Searches

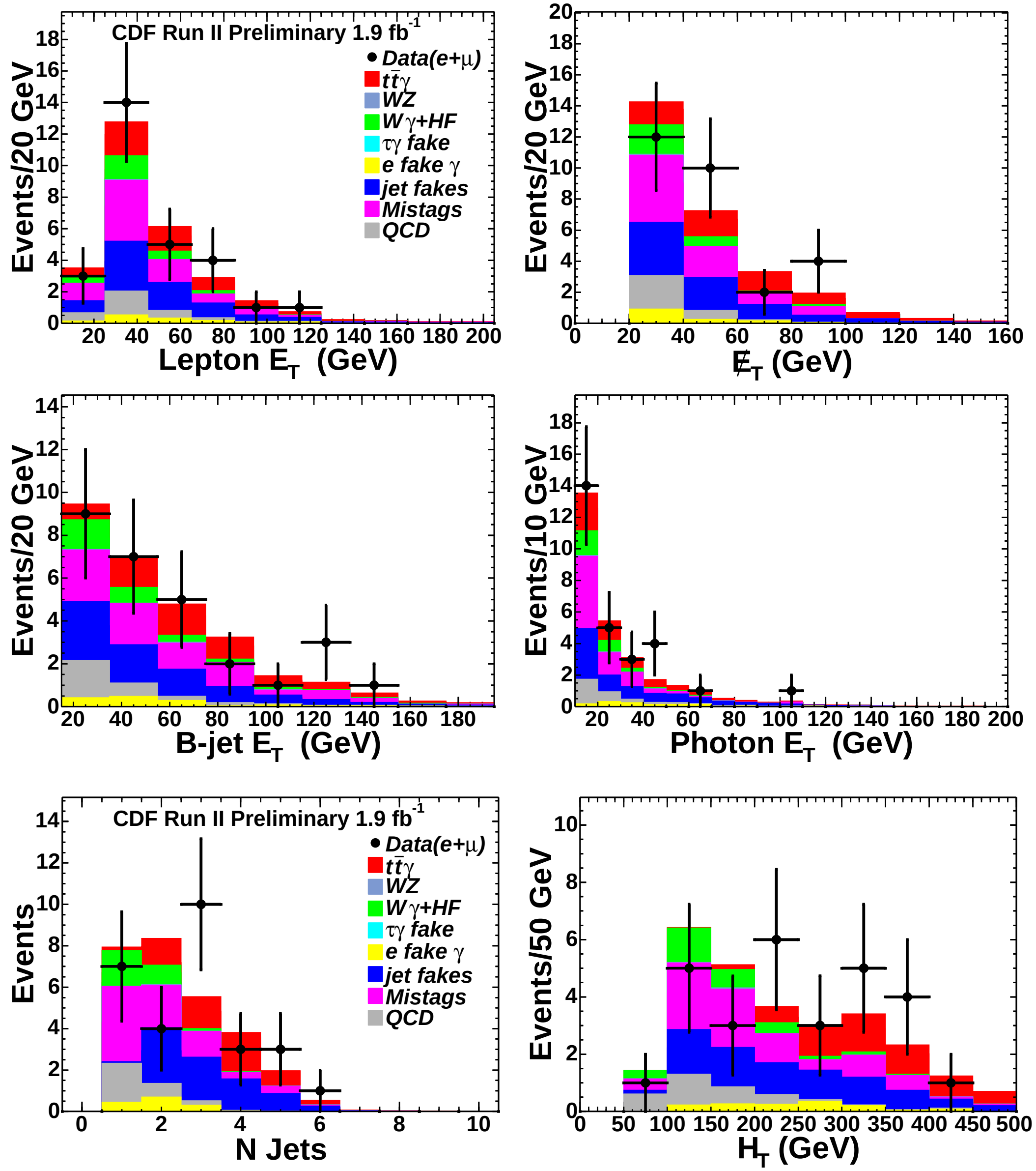
- So far, have tested a couple of non standard models, but...
- There are reasons for not picking a given exotic model
  - Which one? There are a lot!
  - New models may exist in the future
  - Is not the Standard model a good model to test?
- CDF has performed some signature-based searches
  - lepton + γ + b-jet + MET
  - γ + jet + b-jet + MET

lepton + γ + b-jet + MET

- Compare the inclusive production of events with a lepton, photon, MET and a b jet, to SM predictions

- Basic selection
  - Central e (μ) with E_T^e (P_T^μ) > 20 GeV
  - Central photon with $E_T^\gamma > 10$ GeV
  - A b-tagged jet with $E_T^j > 15$ GeV
  - MET > 20 GeV

# events	$e\gamma b\not{E}_T$	$\mu\gamma b\not{E}_T$	$(e+\mu)\gamma b\not{E}_T$
Predicted	18.4 ± 2.4	$12.6\ ^{+1.9}_{-1.6}$	$31.0\ ^{+4.1}_{-3.9}$
Observed	16	12	28



- Consistent with the SM

$t\bar{t} + \gamma$

- $H_T > 200$ GeV, N(jets) $> 2 \Longrightarrow t\bar{t} + \gamma$ enhanced sample

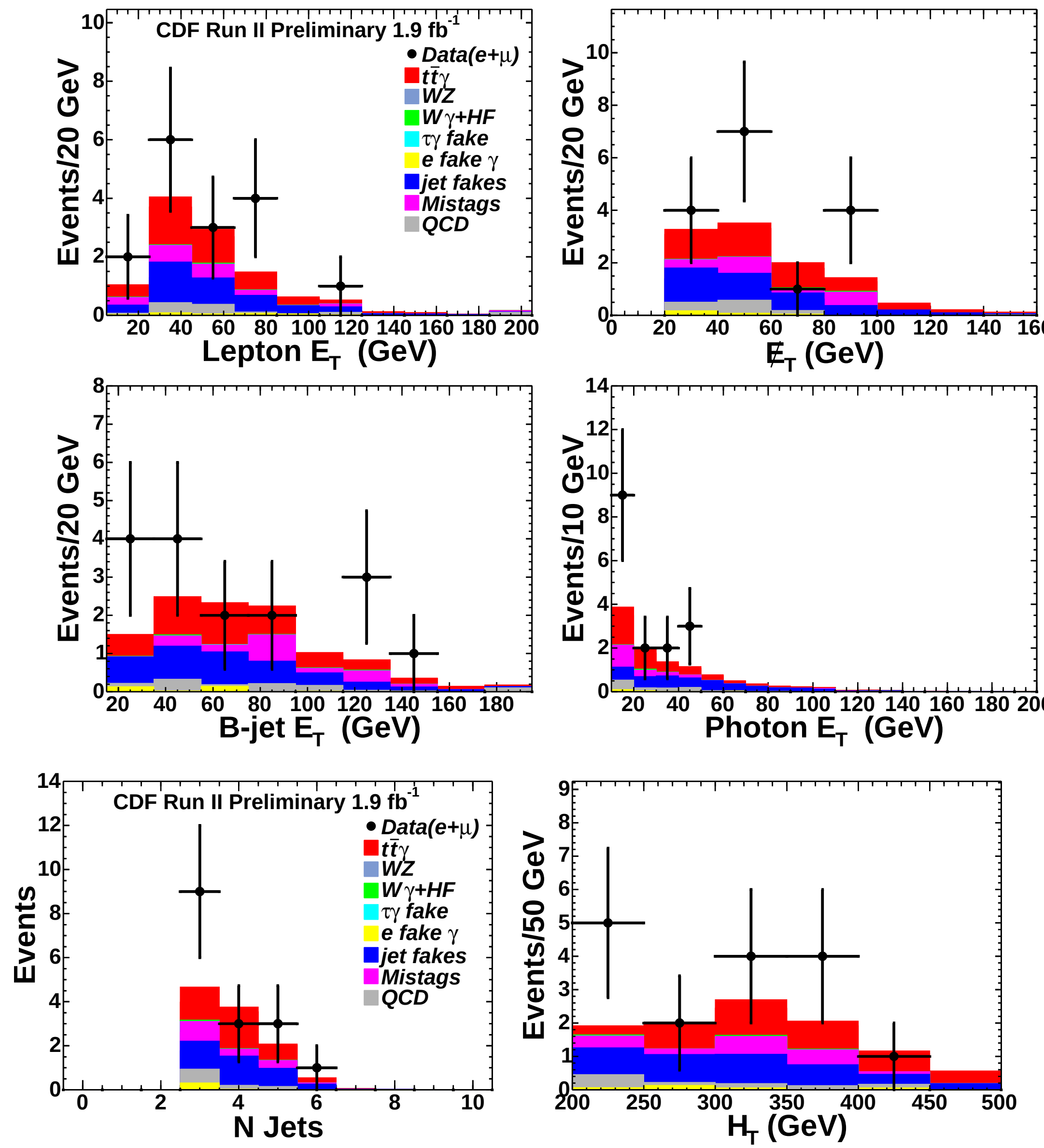
# events	$e\gamma b\not{E}_T$	$\mu\gamma b\not{E}_T$	$(e+\mu)\gamma b\not{E}_T$
Predicted	6.7 ± 1.4	$4.4\,^{+1.3}_{-0.8}$	$11.2\,^{+2.3}_{-2.1}$
Observed	8	8	16

- Probability, assuming there is no SM $t\bar{t}\gamma$ production, for the bkgs. alone to produce as many events as observed (16), is 1% (2.3σ)

- Assuming that the difference between the non top bkg. and the number of observed events is due to $t\bar{t}\gamma$ SM production, $\sigma_{t\bar{t}\gamma} = 0.15 \pm 0.08$ pb

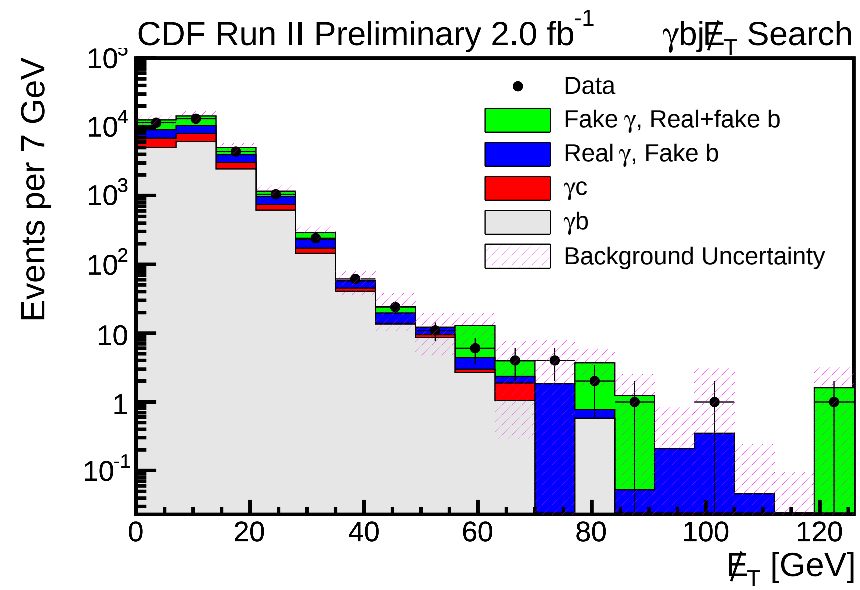
  ◇ $\sigma_{t\bar{t}\gamma}$(SM) = 0.080 ± 0.011 pb

- Submitted to PRD (arXiv:0906.0518)

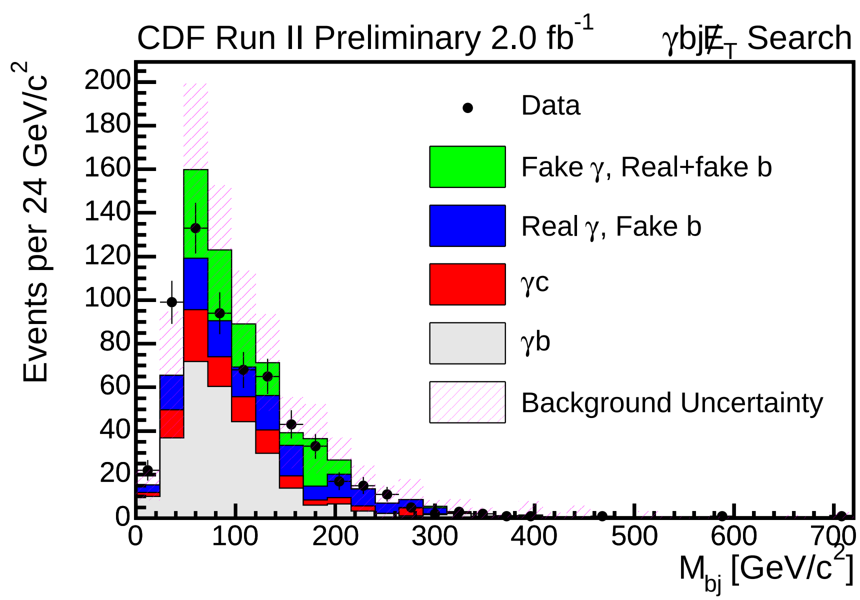


γ + jet + b-jet + MET

- Very few SM processes lead to a γ+b+jet+MET (most due to mismeasured jets)
- Basic selection
  - Central photon with $E_T^{\gamma} > 25$ GeV
  - At least 2 jets with $E_T^{j} > 15$ GeV
  - At least 1 b-tagged jet
  - MET > 25 GeV
- $607 \pm 74 \pm 86$ (617) exp. (obs.) events
- Consistent with the SM even with additional selection



Selection	No additional cuts		with MET$>$ 50 GeV	
	Obs.	Exp	Obs	Exp
MET$>$ 50 GeV	28	$30 \pm 10 \pm 5$		
N(jets)$>$ 3	321	$329 \pm 46 \pm 46$	15	$17 \pm 7 \pm 3$
$p_T(\gamma) > 50$ GeV	257	$247 \pm 45 \pm 39$	16	$21 \pm 8 \pm 5$
$H_T > 200$ GeV	304	$322 \pm 45 \pm 46$	25	$28 \pm 9 \pm 5$
$E_T(b) > 50$ GeV	286	$310 \pm 43 \pm 44$	18	$22 \pm 8 \pm 6$
$\Delta\phi$(jet, MET) > 0.5	343	$368 \pm 47 \pm 49$	15	$16 \pm 8 \pm 4$



- Submitted to PRD (arXiv:0905.0231)

Conclusions

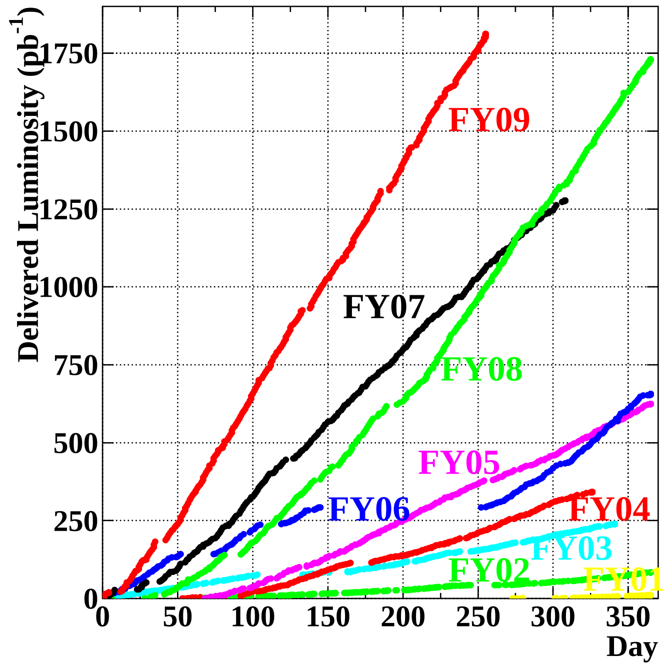
- **Tevatron is performing better than ever**
- **Well understood detectors taking data with very high efficiency**
- **Large photon search program at the Tevatron covering many final states and testing several exotic models**
- **So far, everything looks consistent with the SM...**
- **But still lots of data to record and analyze**
  - ◊ **expect to almost double the dataset by the end of the run**

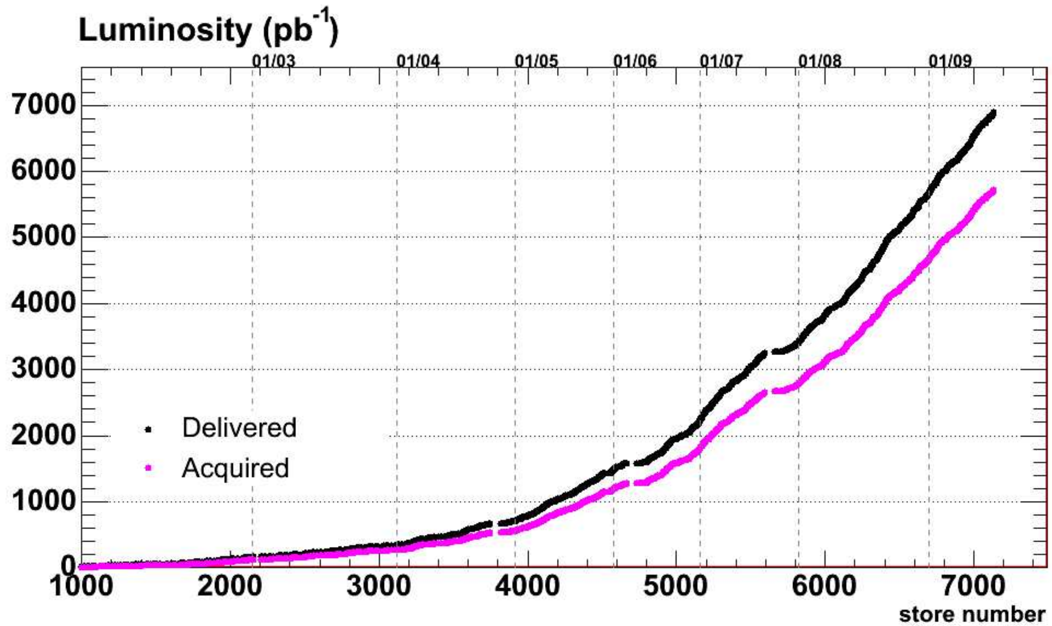
http://www-cdf.fnal.gov/physics/exotic/exotic.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm

BACK-UP SLIDES

Tevatron Performance

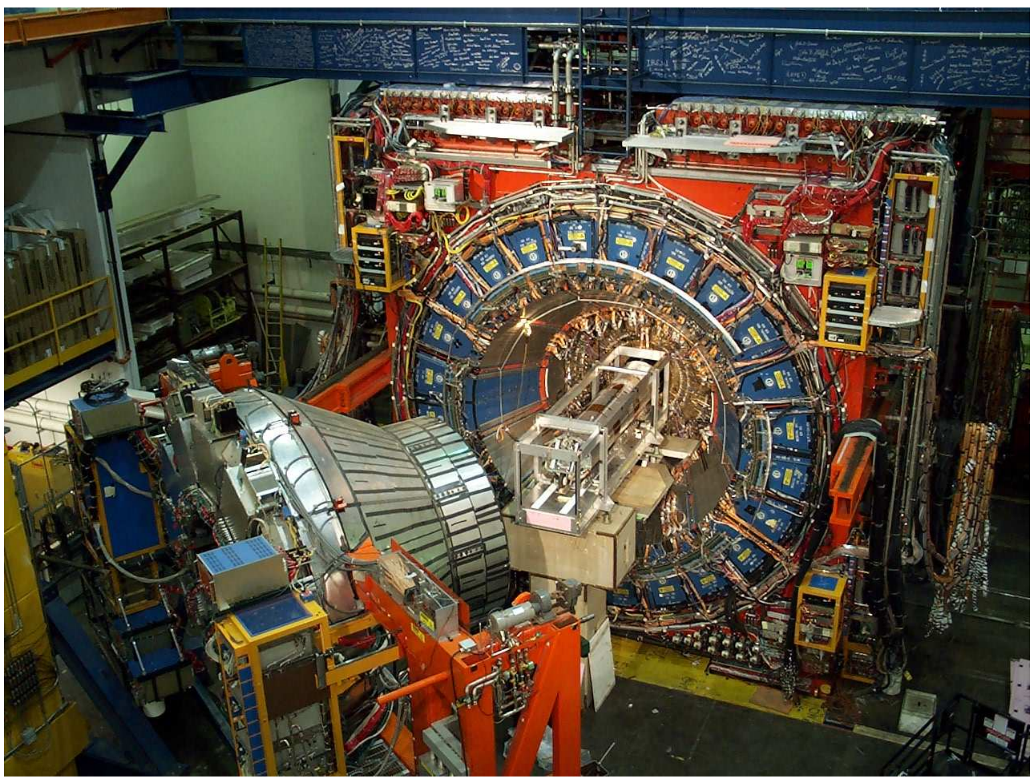
- $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV
- Tevatron is performing better than ever
  - ◇ Peak luminosity $\sim 360 \times 10^{30}$cm^{-2}s^{-1}
  - ◇ Expected 7-8 fb^{-1} by end of 2009
  - ◇ Possibly run in 2010-11 (9-11 fb^{-1})
- Tevatron delivered $\sim$ 6.9 fb^{-1}
  - ◇ Collected $\sim$ 5.8 fb^{-1}
- Analyses shown here use 1-4 fb^{-1}





CDF and DØ Detectors

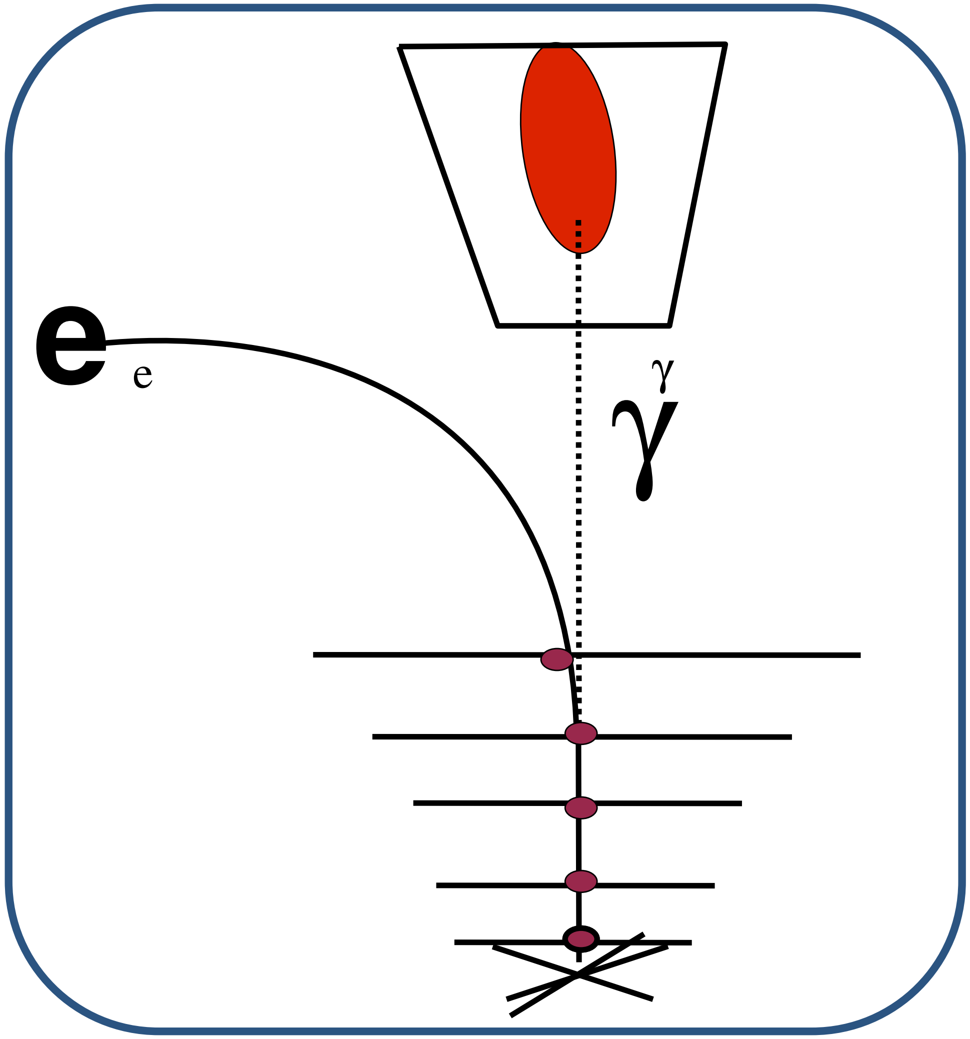
- Two multipurpose detectors at Tevatron collecting data efficiently
- Large acceptance and good ID for leptons
  - Tracking and EM calorimeter
  - Muon systems
- Good calorimetry for jet energy resolution
- Silicon detectors for b-jet tagging



- Data taking efficiency ∼85-90%

How to Supress Photon Backgrounds

- Single photons are note produced in hard scattering processes
- π^0 ($\gamma\gamma$), $K_s(\pi^0\pi^0)$ and η ($\gamma\gamma$ or $\pi^0\pi^0\pi^0$) in jets. To supress these, we require:
  - ◇ Isolated photons
  - ◇ Good shower χ^2 (good at low E$_T$)
  - ◇ Low # hits in the preshower detector (from conversions)



- Electron bremsstrahlung, FSR, tracking ineffiency...
  - ◇ Road from the EM cluster to the event vertex
  - ◇ Search for hits along the road
  - ◇ Reduces electron by a factor of 3-7