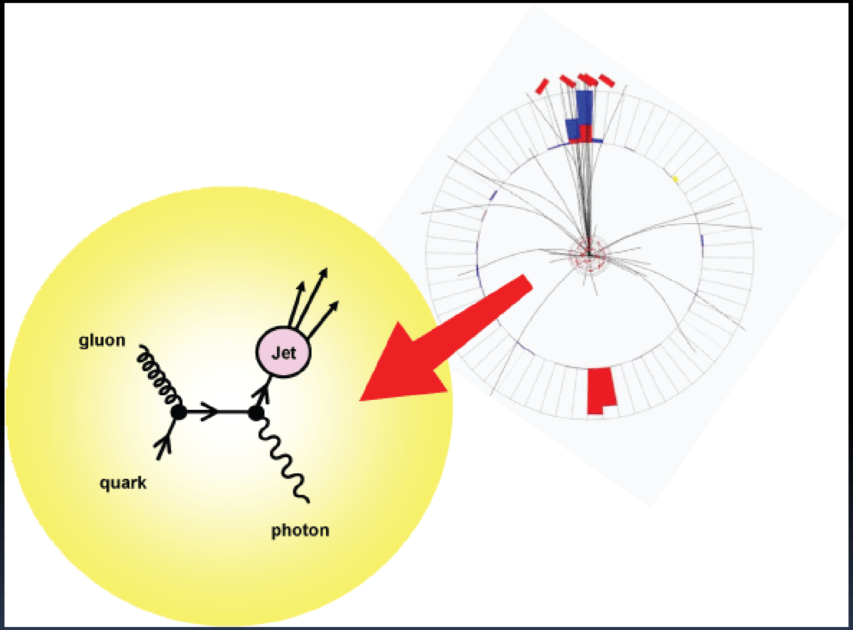
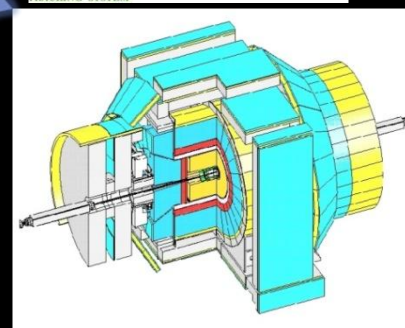
SEARCHES FOR NEW PHYSICS WITH PHOTONS AT THE TEVATRON



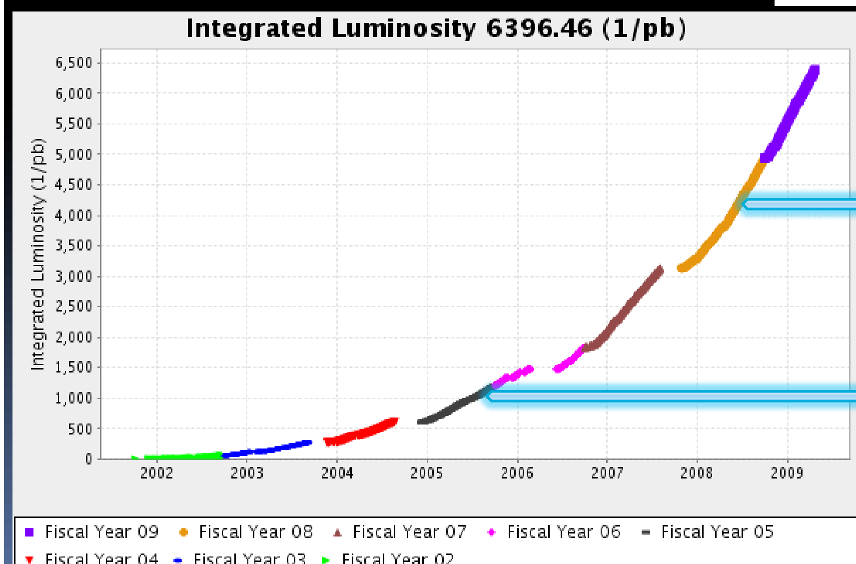
Dan Krop
University of Chicago
for the CDF and DØ Collaborations

Photon 2009, May 11th 2009

The Tevatron

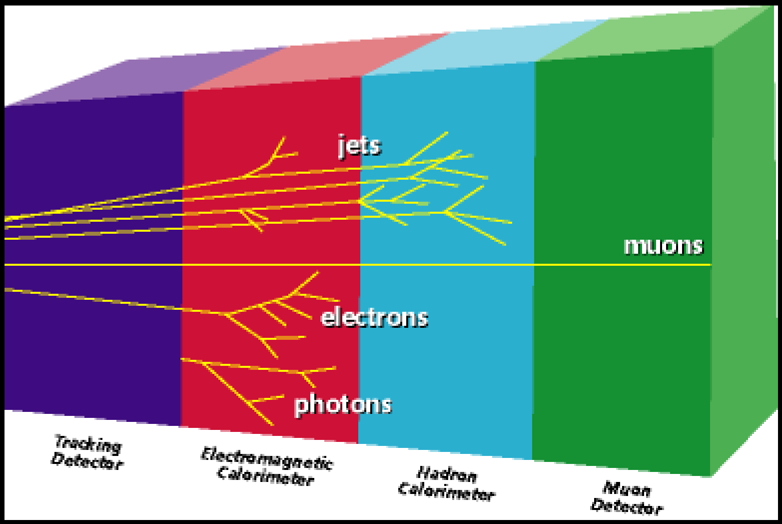


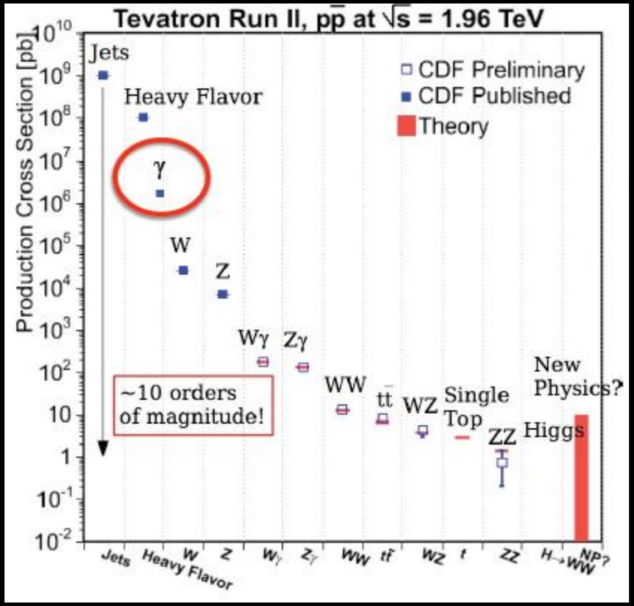
- $p\bar{p}$ Collisions at $\sqrt{s}$=1.96 TeV
- Currently highest energy collider in the world.
- 2 multipurpose detectors
  - CDF & DØ



Analyses shown today use between 1 fb^{-1} and 4.2fb^{-1}

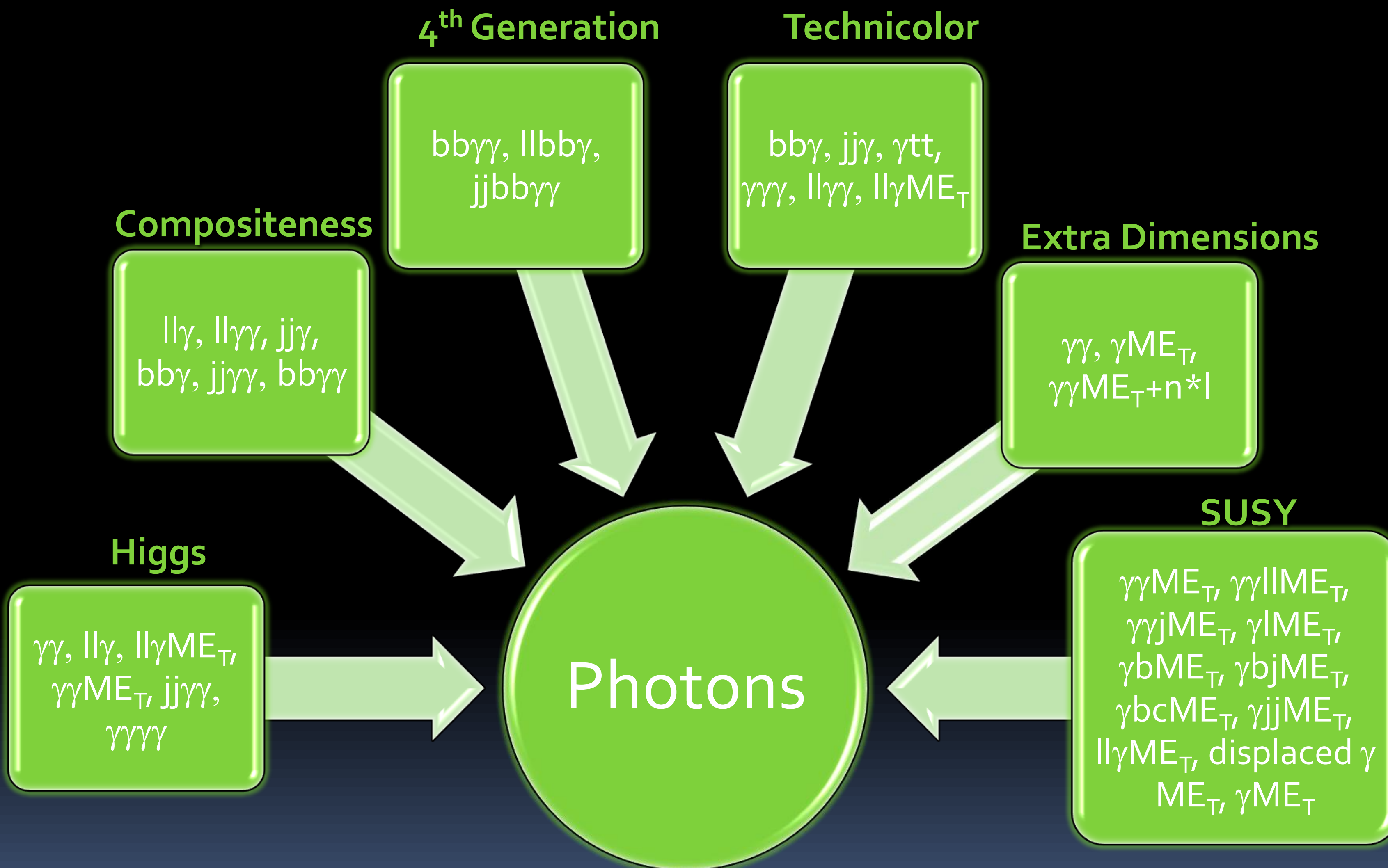
Photons at the Tevatron





- Photon is one of the fundamental objects at a collider.
- 2nd most common object at the Tevatron after jets.
- Backgrounds from jet$\rightarrow\pi^0\rightarrow\gamma\gamma$, electron w/ track not reconstructed.

Photon Analysis Reach



- No shortage of models that predict final state photons

Photon Analysis Reach

4^{th} Generation

bb$\gamma\gamma$, llbbγ, jjbb$\gamma\gamma$

Technicolor

bbγ, jjγ, γtt, $\gamma\gamma\gamma$, ll$\gamma\gamma$, llγME_T

Photoproduction

Exclusive dilepton

Compositeness

llγ, ll$\gamma\gamma$, jjγ, bbγ, jj$\gamma\gamma$, bb$\gamma\gamma$

Extra Dimensions

$\gamma\gamma$, γME_T, $\gamma\gamma ME_T$+n*l

Higgs

$\gamma\gamma$, llγ, llγME_T, $\gamma\gamma ME_T$, jj$\gamma\gamma$, $\gamma\gamma\gamma\gamma$

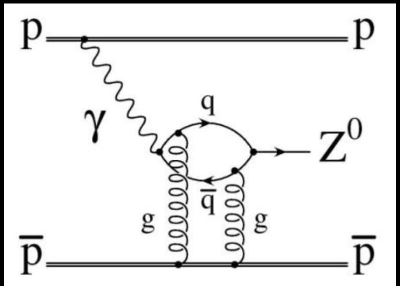
SUSY

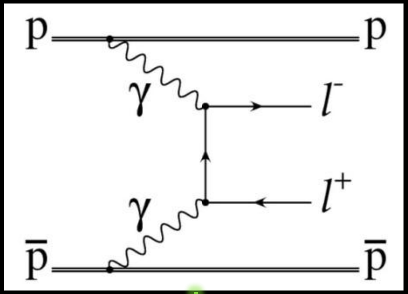
$\gamma\gamma ME_T$, $\gamma\gamma$llME_T, $\gamma\gamma$jME_T, γlME_T, γblME_T, γbjME_T, γbcME_T, γjjME_T, llγME_T, displaced γ ME_T, γME_T

Photons

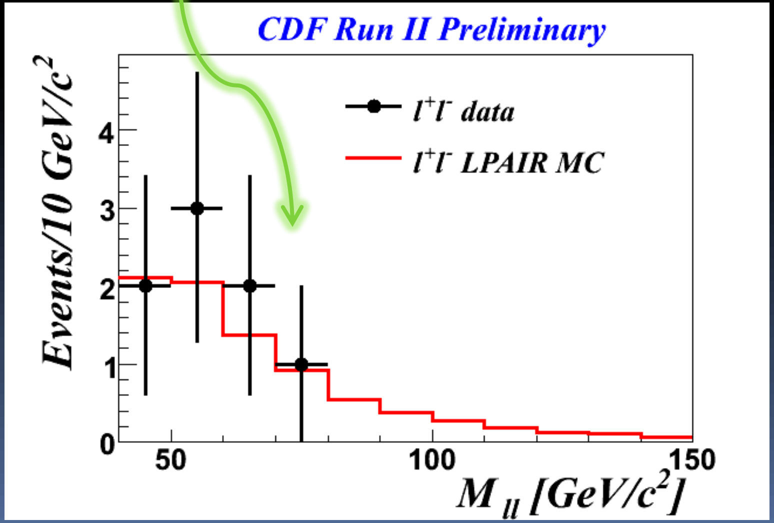
Analyses Presented Today Include These Final States

Initial State Photons: Exclusive Z Production





- Dilepton final state w/ pp intact.
- Proceed via photoproduction.
  - Analogous to J/ψ photoproduction at HERA.
- 8 l^+l^- events observed.
- No exclusive Z events observed.



$$\sigma_{obs}(\gamma\gamma \to l^+l^-) = 0.24^{+0.13}_{-0.10}\, pb$$

$$\sigma_{predicted}(\gamma\gamma \to l^+l^-) = 0.256\, pb$$

$$\sigma_{95\%C.L.}(excl.Z) < 0.96\, pb$$

$$\sigma_{predicted}(excl.Z) = 0.3\, fb$$

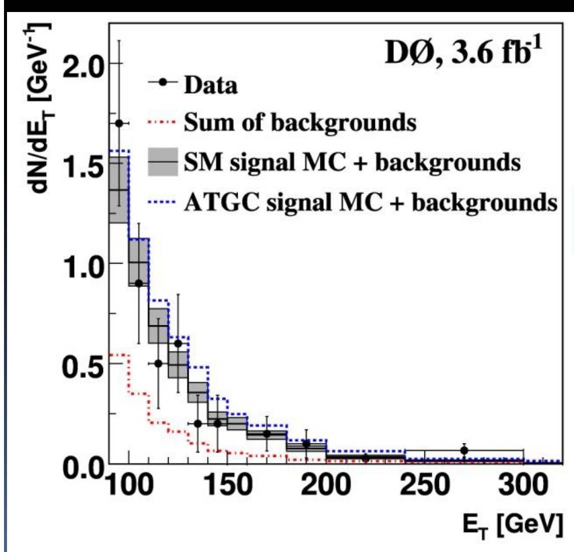
γ+MET: Triple Gauge Coupling

- No SM tree-level Zγγ or ZZγ coupling.
- Reconstruct γ+MET and measure σ(Zγ)*Br(Z→νν)
- Look for deviations at high $E_T(\gamma)$ to set limits on anomalous coupling parameters.

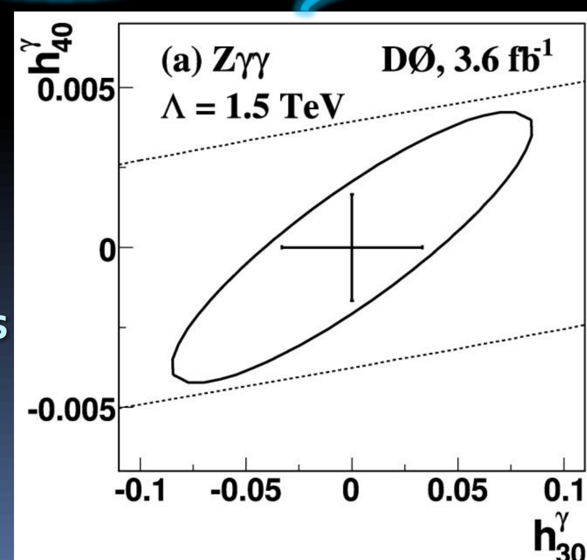
$$N(bg) = 17.3 \pm 2.4$$
$$N(obs.) = 51 \Rightarrow 5.1\sigma$$

1st observation of Zγ→ννγ at Tevatron

$$\sigma \times Br_{obs} = 32 \pm 9.2 \text{ fb}$$
$$\sigma \times Br_{pred} = 39 \pm 4 \text{ fb}$$



Set Limits on anomalous coupling



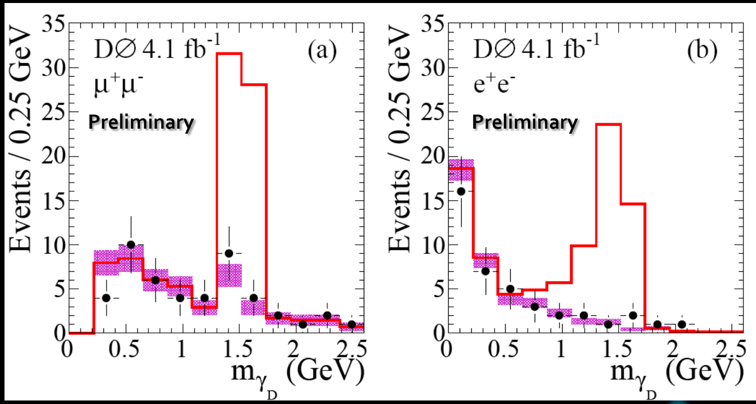
Combine w/ earlier llγ result

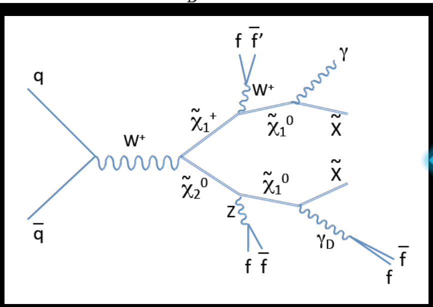
$$|h_{30}^{V}| < 0.033$$
$$|h_{40}^{V}| < 0.0017$$

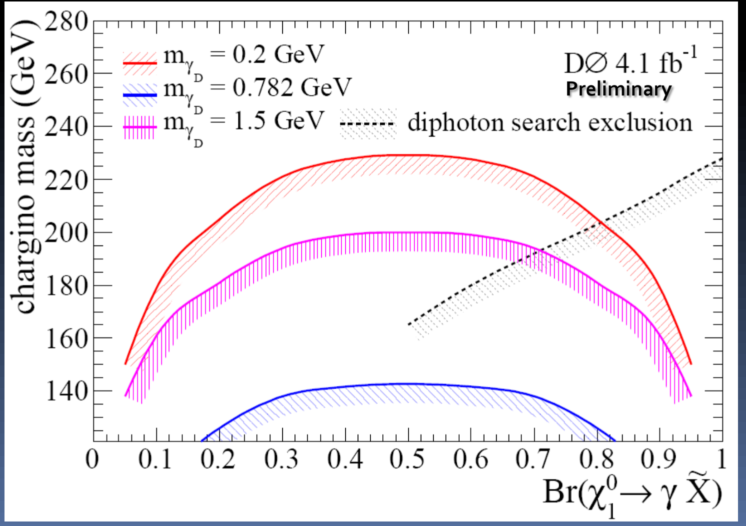
γ+MET+l^+l^-: Dark Photons

- Recent model [*PRD 79, 15014 (2009)*] combining SUSY w/ a hidden valley (dark sector) to explain positron excesses in astrophysical observations (Pamela, ATIC, Fermi) and DAMA modulation signal.
- Can lead to excess γ+MET+l^+l^- at colliders.
- Leptons should be near each other, spoiling each other's isolation.
- Look for 2 close-by leptons ($\Delta R<0.2$) after γ+MET selection.
- Use M(dilepton) to set limits on dark photon mass as function of chargino branching fraction.

At Br=0.5: M(γ_D)=0.78(0.2) GeV→ M(chargino)>142(230) GeV

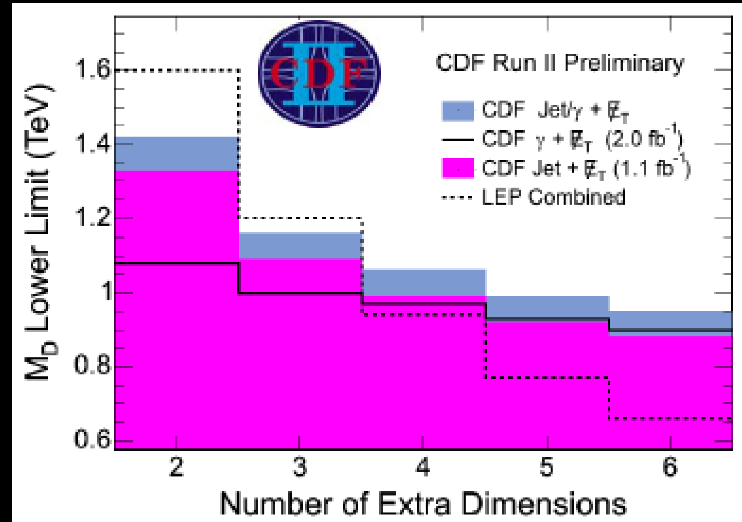




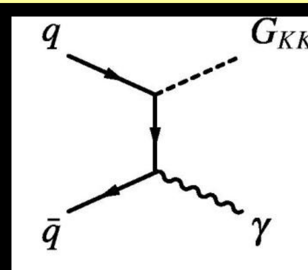


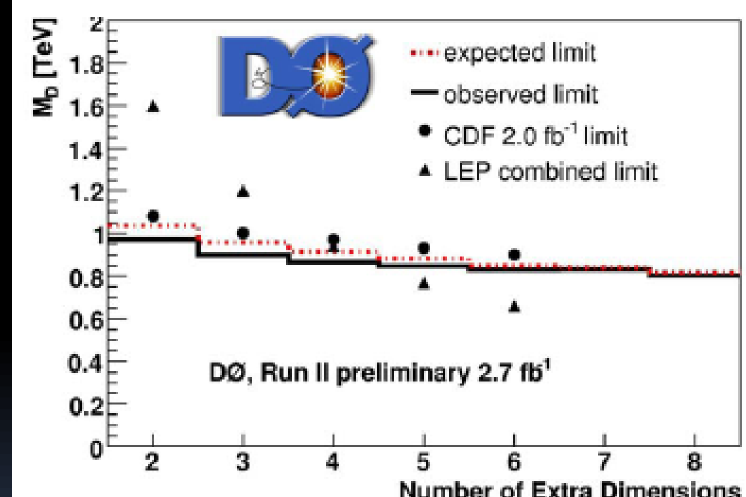
γ+MET LED Search

CDF (2.0 fb^{-1})	DØ (2.7 fb^{-1})
$\not{E}_T > 50$ GeV	$\not{E}_T > 70$ GeV
N(pred.) = 46.7 ± 3	N(pred.) = 49.9 ± 4.1
N(obs.) = 40	N(obs.) = 51



Consistent w/ SM.
Set limits on LED.





<u>CDF limits (2.0 fb^{-1})</u>

M_D<1080(900) GeV for N_d=2(6)

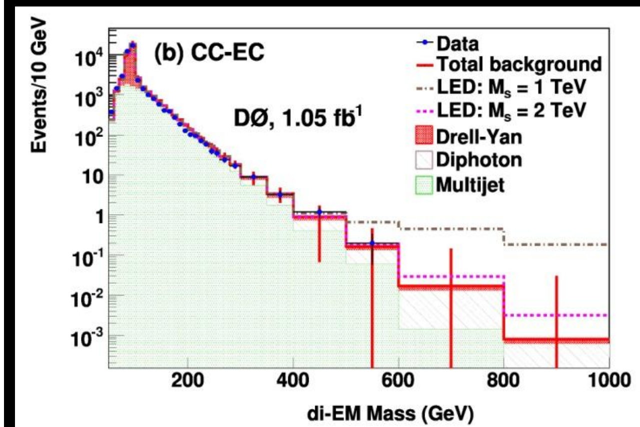
<u>DØ limits (2.7 fb^{-1})</u>

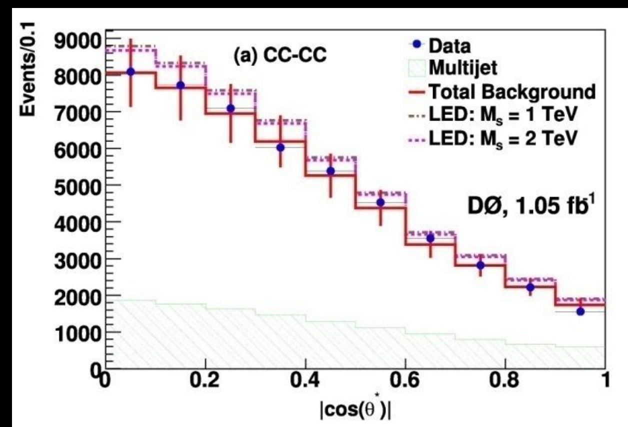
M_D<970(831) GeV for N_d=2(6)

$$\vec{\not{E}}_T = -\sum_i E_T^i \hat{n}_i$$

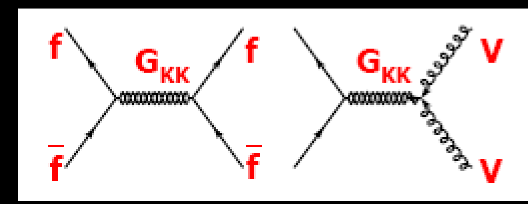
$\gamma\gamma$ LED Search

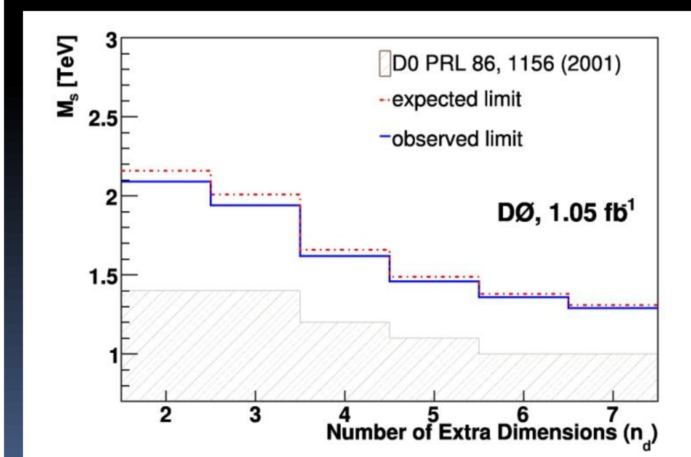
- Look at M(diEM) and |cos(θ*)| for deviations from SM.





Set limits on ADD LED model:





$$\sigma_{NP} = f_{SM} + \eta\, f_{\text{int}} + \eta^2 f_{NP}$$

$$\eta = F / M_S^4$$

Leading order

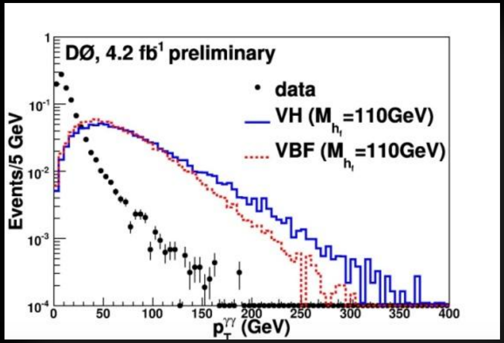
GRW: M_D>1.62 TeV

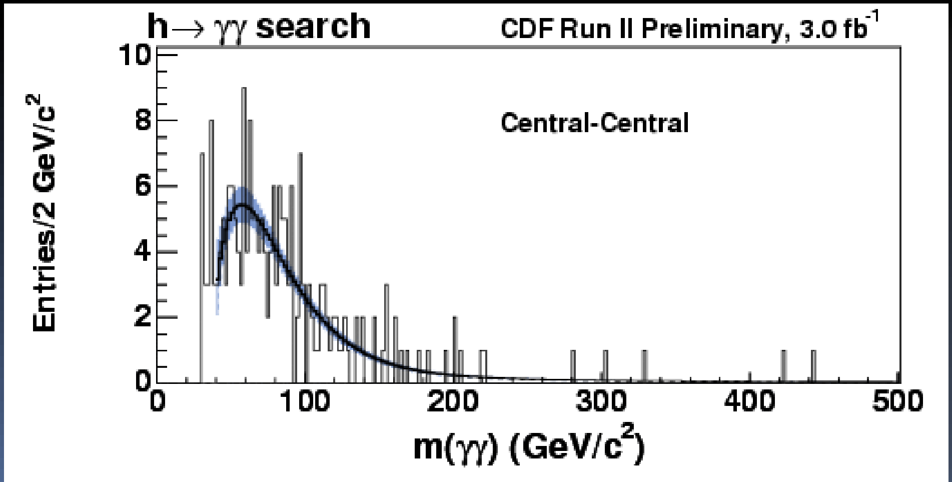
HLZ: M_D>2.09(1.29) TeV for n_d=2(7)

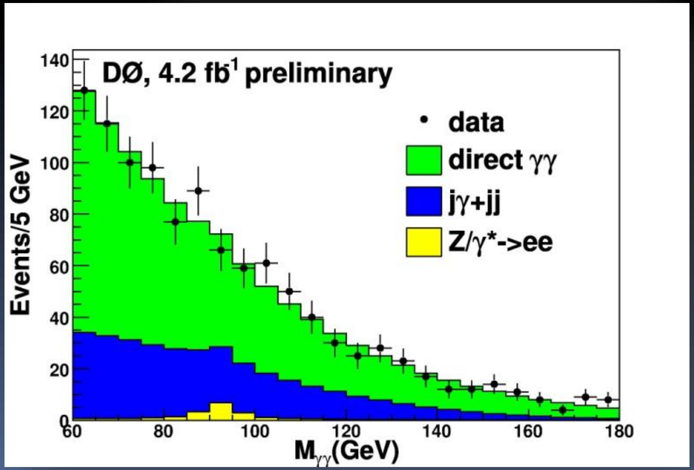
Subleading n_d dependence

Fermiophobic Higgs in Diphotons

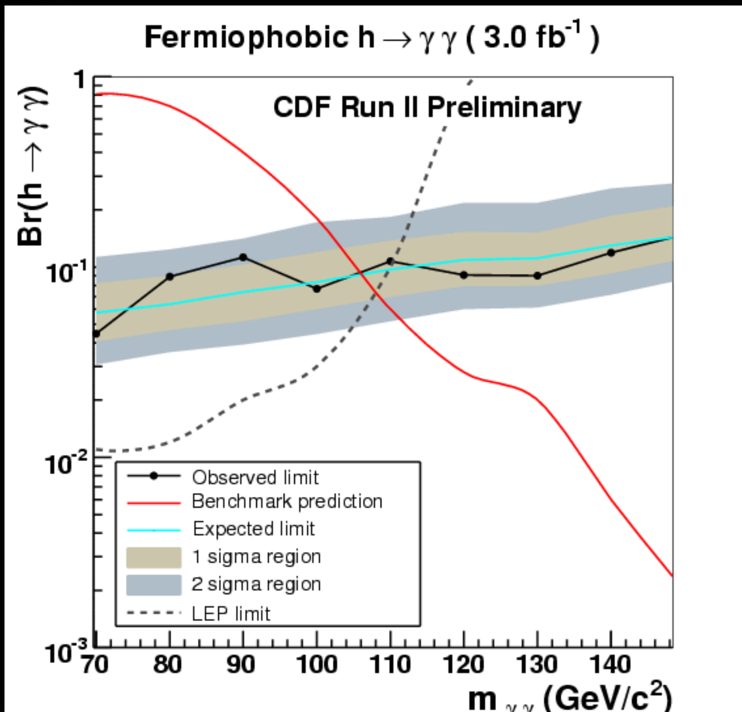
- Fermiophobic Higgs models enhance $B(h \to \gamma\gamma)$.
- Suppressed couplings to fermions → no gluon fusion → $p_T(\gamma\gamma)$ large.
- CDF and DØ cut aggressively on p_T and use $M(\gamma\gamma)$ to set limits.

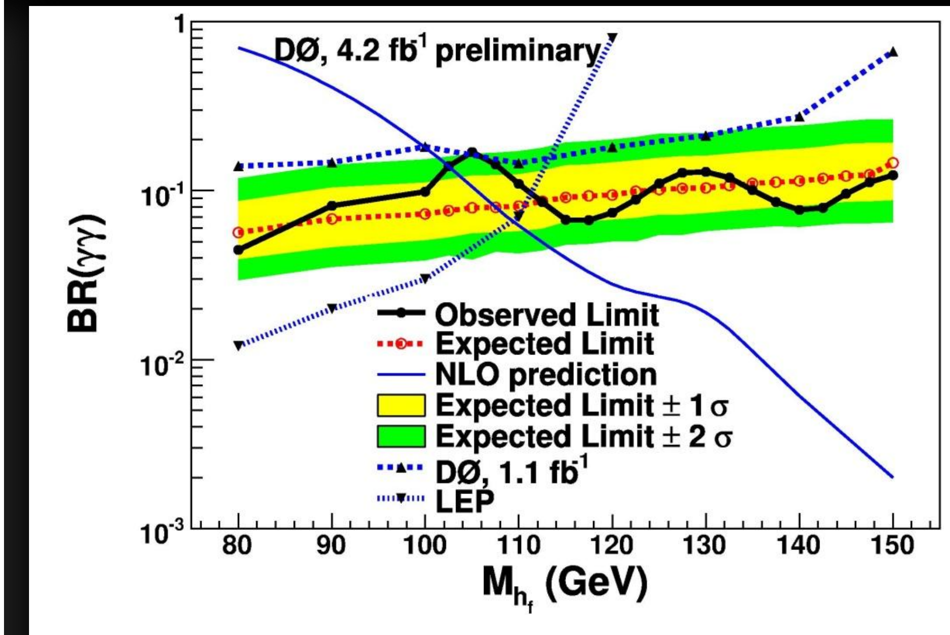






Fermiophobic Higgs Limits





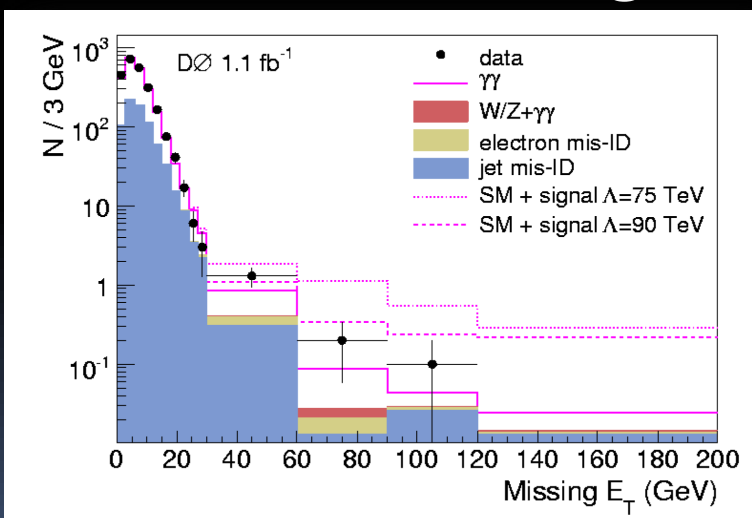
- CDF: $M(h_f)>106$ GeV @ 95% C.L.
- DØ: $M(h_f)>102.5$ GeV @ 95% C.L.
- Both analyses are sensitive to $M(h_f)>110$ GeV that were kinematically inaccessible to LEP.

$\gamma\gamma$ + MET (DØ)

- $\gamma\gamma$ + MET+X final state is a signature in GMSB models, e.g.

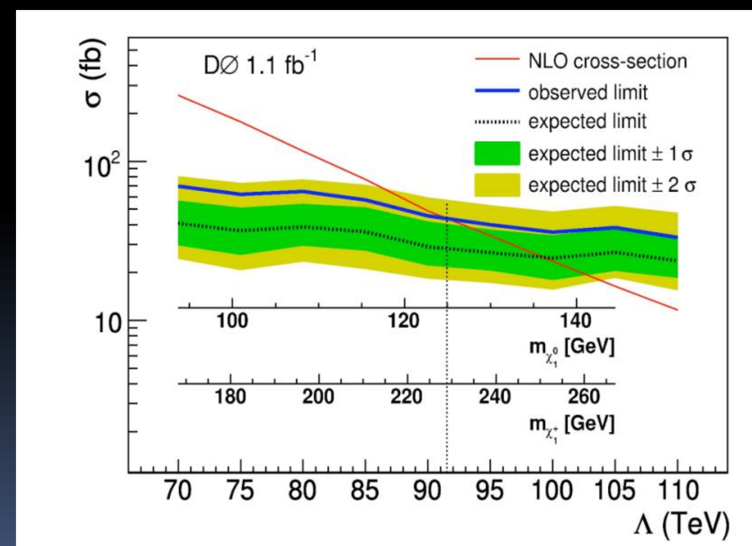
$$q\bar{q} \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 + X \rightarrow \gamma\gamma \tilde{G}\tilde{G} + X$$

- DØ looks at MET distribution in $\gamma\gamma$ events for excess. No significant excess observed.



N(bg)=1.6±0.4 with N(obs)=3 with MET>60 GeV

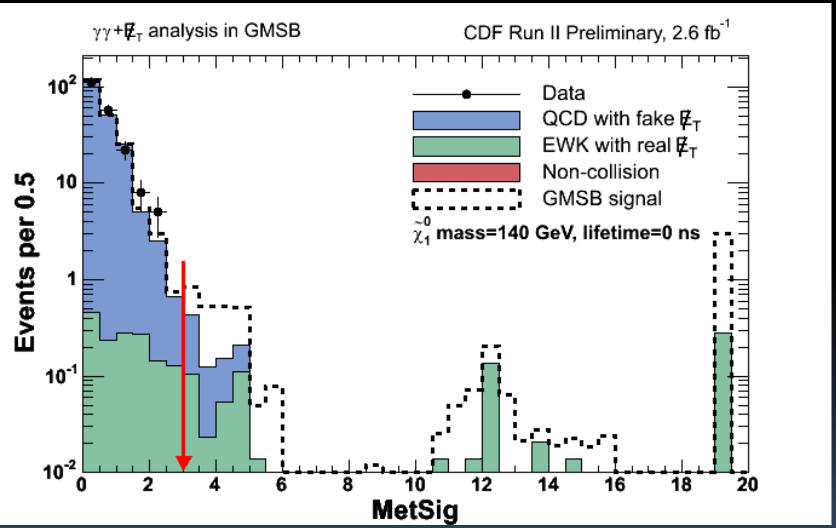
SET LIMITS in benchmark model



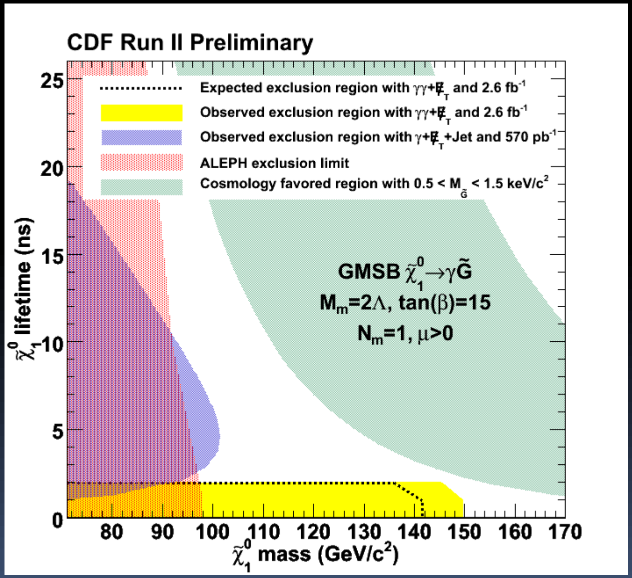
$m(\tilde{\chi}_1^0) > 125\,\text{GeV} @ 95\%\,\text{C.L.}$

$\gamma\gamma$ + MET (CDF)

- Preselection use EM-timing & topology to remove beam halo and cosmic events.
- Optimize selections for GMSB signal.
  - Met siginificance: QCD fake MET → MetSig>3.
  - H_T: heavy gauginos → H_T>200 GeV.
  - $\Delta\phi$: Wγ back-to-back → $\Delta\phi<\pi$-0.35 rad.



SET LIMITS → in benchmark model



N(bg)=1.23±0.38 with N(obs)=0

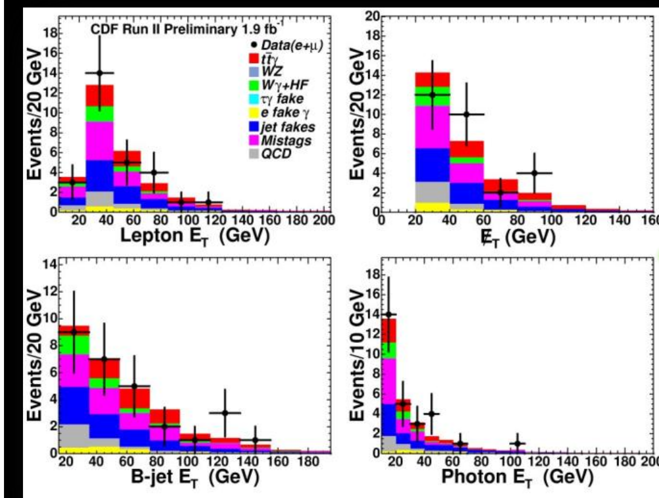
$m(\tilde{\chi}_1^0) > 149\,\mathrm{GeV}$ for $\tau(\tilde{\chi}_1^0) = 0$

Signature-Based Searches

- Why not pick an exotic model?
  - Which one? There are very many.
  - New ones may come out in the future that we can't even think of now.
  - The SM is a pretty good model to test.
- 2 CDF signature-based analyses presented today.
  - $l\gamma b\not{E}_T$ – $t\bar{t}\gamma$, 2 gauge bosons + 3rd gen. object.
  - $\gamma bj\not{E}_T$ – hard to produce in SM.

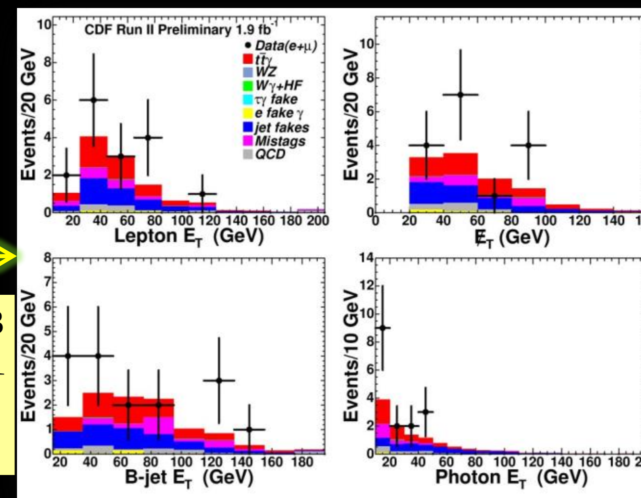
Signature-Based Search: $l\gamma b\not{E}_T$

Base



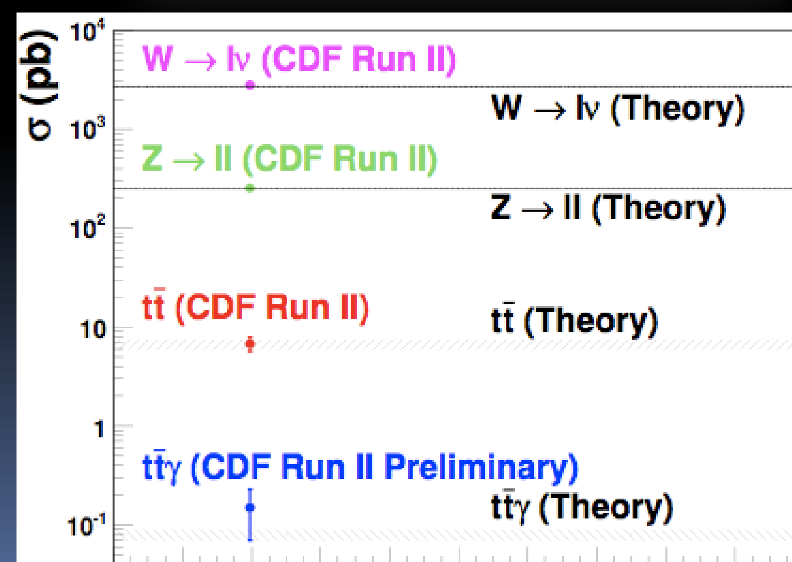
$$N(pred.) = 31.0^{+4.1}_{-3.9}$$
$$N(obs.) = 28$$

Enhanced

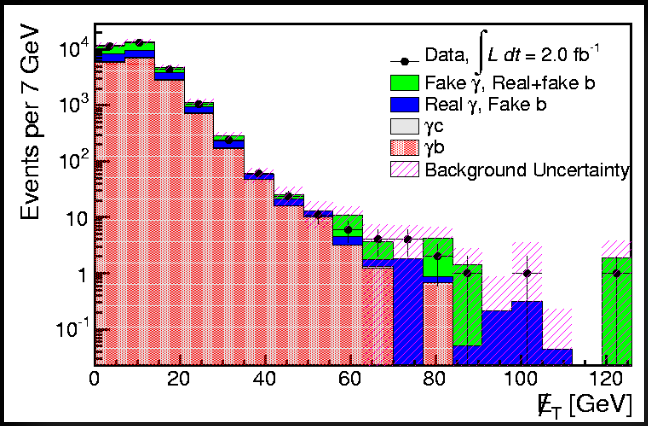


$$N(pred.) = 11.2^{+2.3}_{-2.1}$$
$$N(obs.) = 16$$

- Base sample and ttγ-enhanced sample consistent w/ SM.
  - H_T>200 GeV, N(jets)>2
- Without ttγ in bg, 2.3σ excess.
- Interpreting as ttγ →σ(ttγ)=0.15±0.08 pb
- σ_{theory}(ttγ)=0.08±0.011 pb



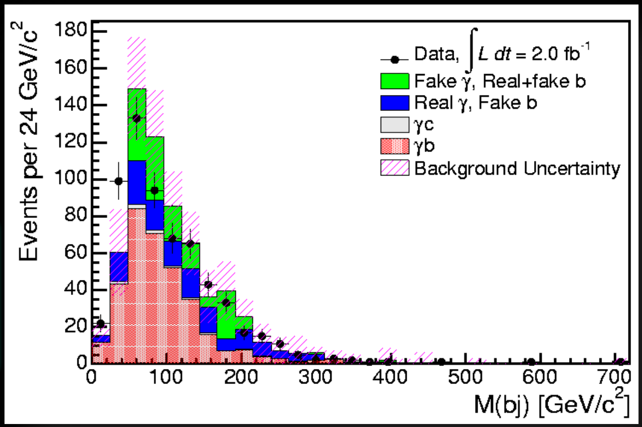
Signature-Based Search: $\gamma b j \not\!\!E_T$



$N(pred.) = 607 \pm 74 \pm 86$

$N(obs.) = 617$

Kinematic p-values
7%-99%

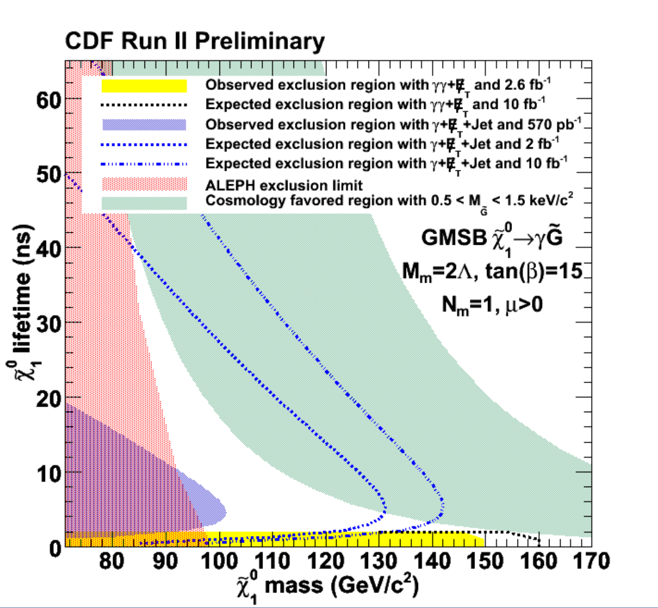


- Apply additional selections to increase sensitivity on tails of distributions.
  - Everything consistent with SM expectations.

Selection	No additional cuts		With $\not\!\!E_T > 50$ GeV	
	Observed	Predicted	Observed	Predicted
$\not\!\!E_T > 50$ GeV	28	$30 \pm 10 \pm 5$		
$N(\text{jets}) \geq 3$	321	$329 \pm 46 \pm 46$	15	$17 \pm 7 \pm 3$
$p_T(\gamma) > 50$ GeV	257	$247 \pm 42 \pm 39$	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	$22 \pm 8 \pm 6$
$\Delta\phi(\text{jet}, \not\!\!E_T) > 0.5$	343	$368 \pm 47 \pm 49$	15	$16 \pm 8 \pm 4$

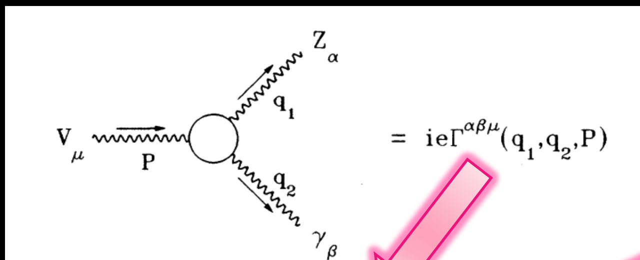
Conclusions and Outlook

- Large Tevatron photon search program covers large list of final states and big chunk of model space.
- Detectors are well understood an analyzers have strong experience.
- Expect to double the dataset by end of run.
- Tevatron has much more potential to see interesting results.
- Example: GMSB limit projection



BACKUPS

Anamolous Triple Gauge Coupling



$$h_i^V(m_Z^2,0,\hat{s}) = \frac{h_{i0}^V}{(1+\hat{s}/\Lambda^2)^n}$$

$$\Gamma^{\alpha\beta\mu}_{Z\gamma Z}(q_1,q_2,P) = \frac{P^2-q_1^2}{m_Z^2}\left\{h_1^Z(q_2^\mu g^{\alpha\beta} - q_2^\alpha g^{\mu\beta}) + \frac{h_2^Z}{m_Z^2}P^\alpha[(P\cdot q_2)g^{\mu\beta} - q_2^\mu P^\beta] + h_3^Z\epsilon^{\mu\alpha\beta\rho}q_{2\rho} + \frac{h_4^Z}{m_Z^2}P^\alpha\epsilon^{\mu\beta\rho\sigma}P_\rho q_{2\sigma}\right\}$$

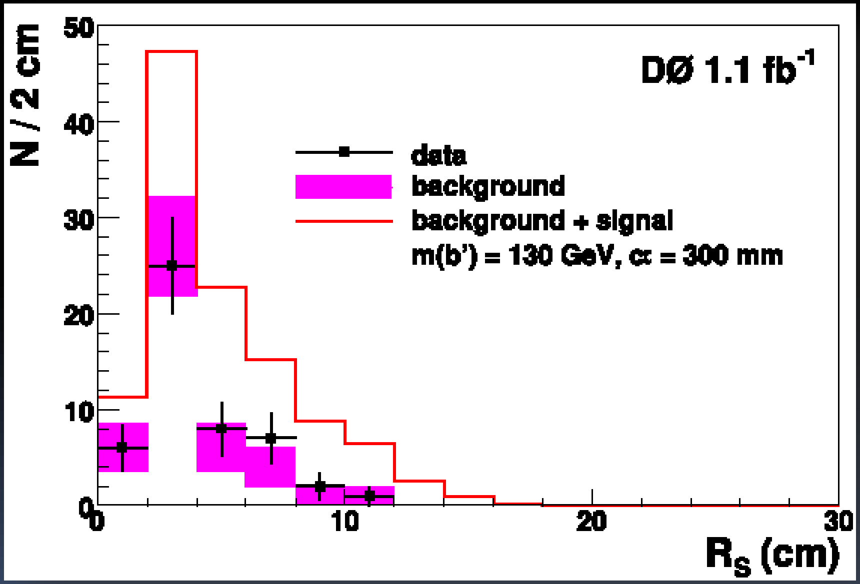
- n=3 for h_1 & h_3
- n=4 for h_2 & h_4
- h_1 & h_2 CP-violating
- h_3 & h_4 CP-conserving

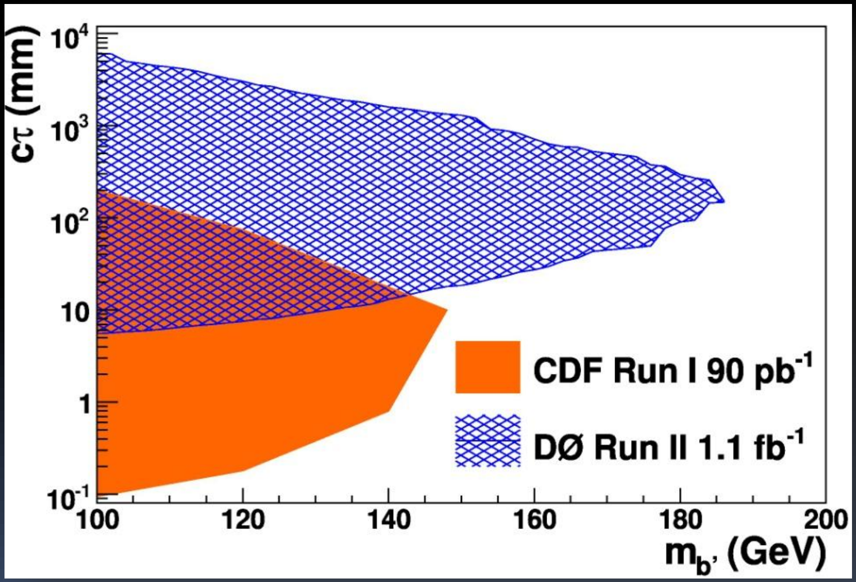
Ensures unitarity and terms w/ h_1 and h_3 behave the same as terms w/ h_2 and h_4

Set limits on real parts of couplings.

Long-lived $\gamma\gamma(e^+e^-)$

- Use fine segmentation of calorimeter to "point" EM cluster.
  - do not make track requirement → get e's & γ's.
- Require 1 cluster to have DCA>2 cm. Look at vertex radius of 2 EM lines, R_s.
  - Background estimated from negative distribution of R_s.





$$Sign[R_s] = Sign[\vec{p}_T^{\gamma\gamma} \bullet \vec{d}_{PV}]$$

Set limits on 4th gen. b' via b'→Zj→e⁺e⁻j

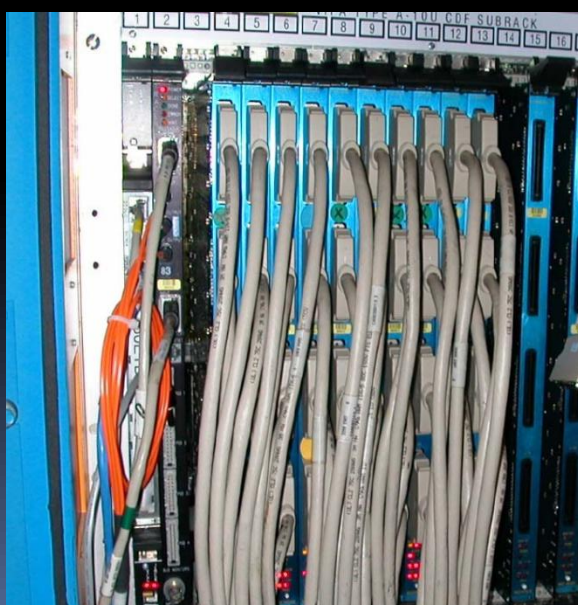
Cosmic & Beam Halo Suppression

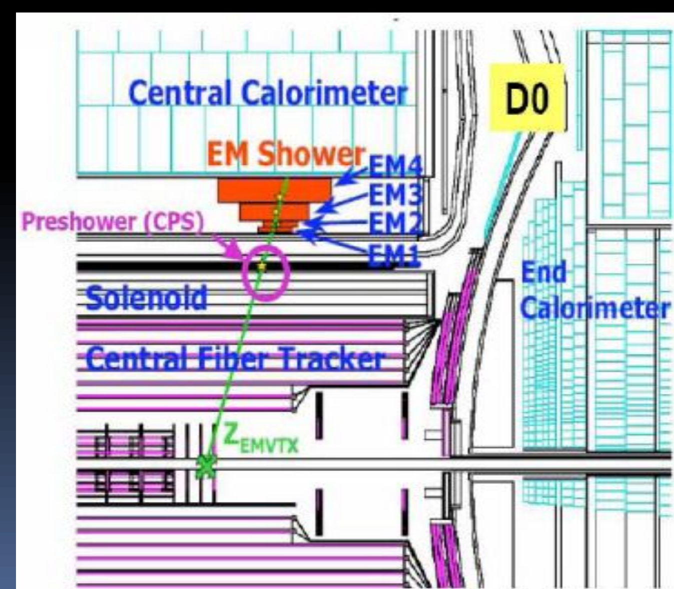
EM Timing at CDF

- Measure time of energy arrival in calorimeter w.r.t beam crossing.

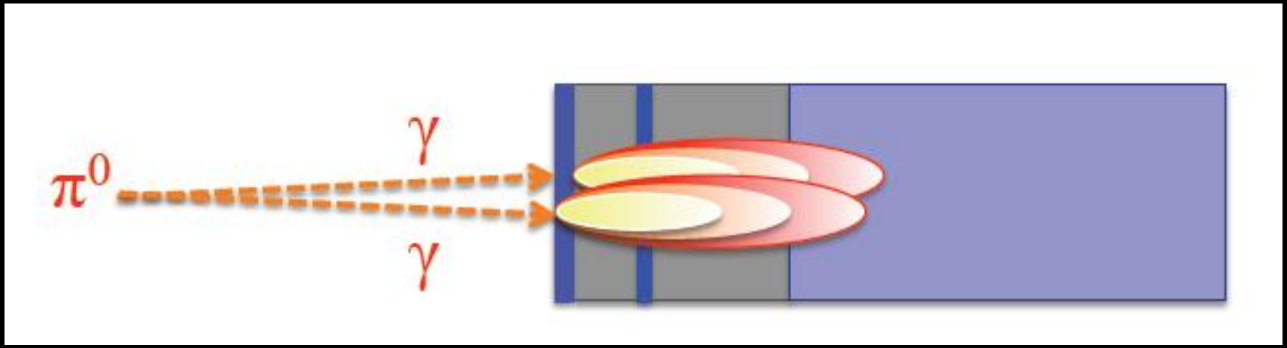
EM Pointing at DØ

- Uses fine segmentation of preshower + calorimeter to "point" cluster back to vertex.



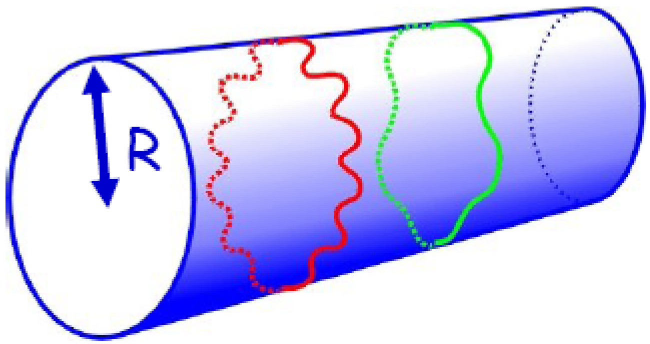


Rejecting π^0 Background

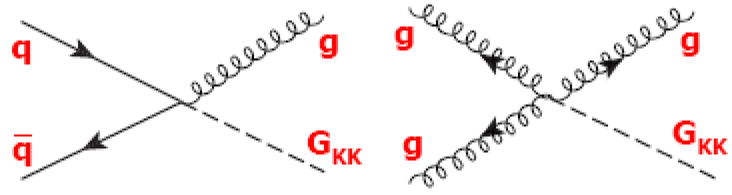


- Transverse shape of $\pi^0 \rightarrow \gamma\gamma$ at shower maximum larger than single γ.
- Larger hit rate in preshower for diphotons
  - Twice the opportunity to convert.

Large Extra Dimension (LED) 101

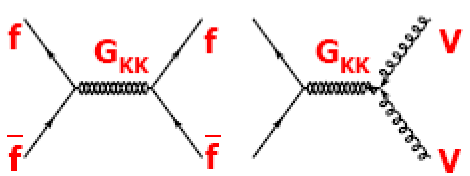


Real Graviton Emission



- Aim to solve hierarchy between EW (1 TeV) and Plank scales (10^{16} TeV)
- n_d extra large spatial dimensions which are compactified on a scale R
- SM fields confined to 4-dim, graviton propagates in the (4+ n_d) bulk
- Mass splitting small enough to integrate all KK modes (meV-MeV)

Virtual Graviton Exchange



$$\sigma_{NP} = f_{SM} + \eta\, f_{int} + \eta^2 f_{NP},$$

$$\text{where } \eta = F(M_s, n_d)$$

M_s: theory cutoff

(~ fundamental Plank scale M_D ~ TeV)

From S.S. Yu