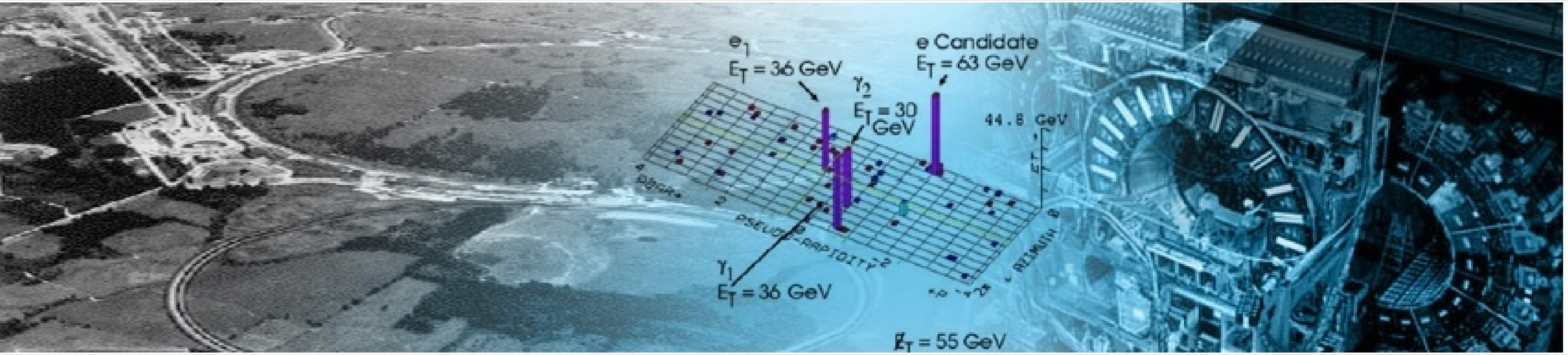


What CDF Diphoton Search teaches us about $H \rightarrow \gamma\gamma$

Sung-Won Lee
Texas A&M University

Outline

- Introduction (TeV4LHC Plenary Talk)
  What TeV can do for Higgs @ LHC? [A.Nikitenko]
- SM Higgs Production @ LHC
  Low Mass Higgs: $H \rightarrow \gamma\gamma$
- Open Questions
- What CDF diphoton search teaches us?
  Review of 4 Diphoton Results from CDF I & II
- Summary and Outlook

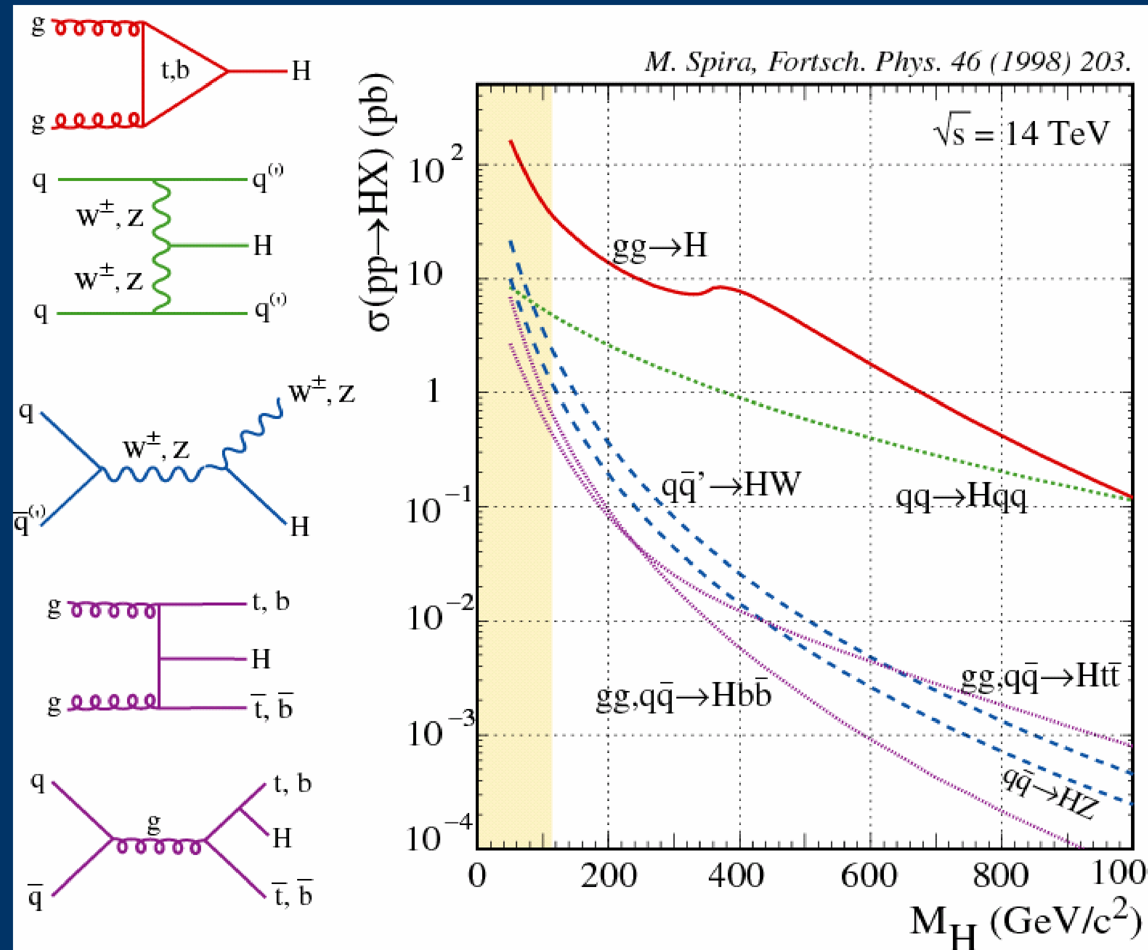
SM Higgs Production @ LHC

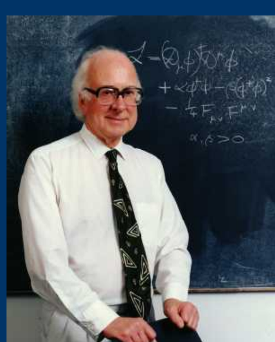
Gluon Fusion
- dominant process

Vector Boson Fusion
- 20% of gg@120GeV

Associated Production
- WH/ZH (1-10% of gg)

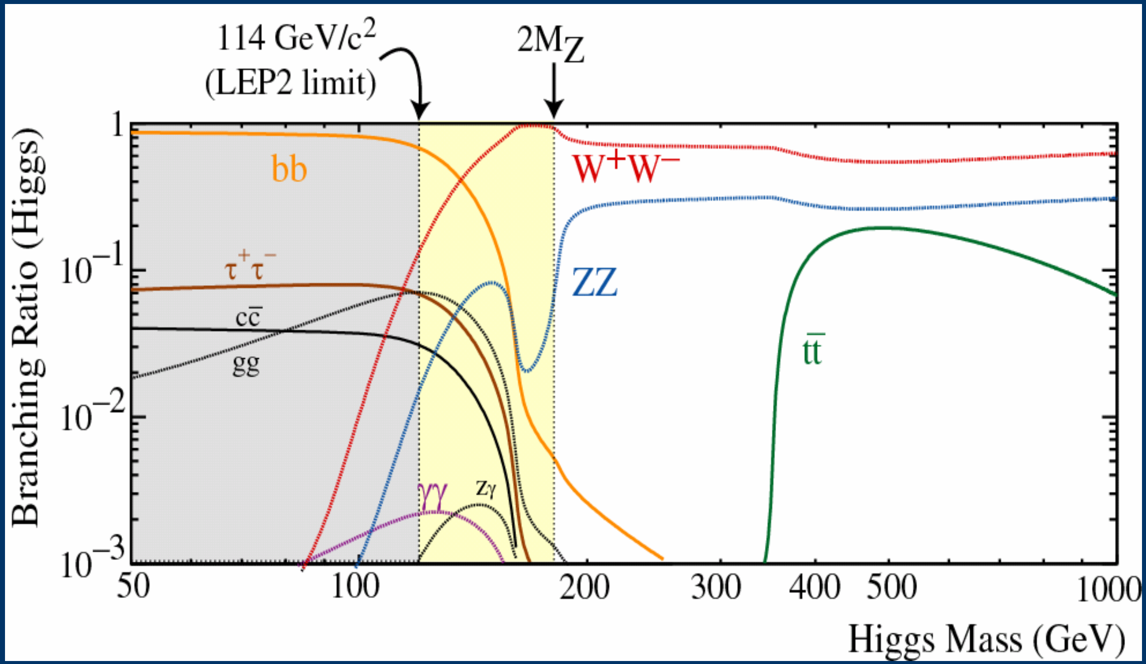
Associated Production
- $t\bar{t}H/b\bar{b}H$ (1-5% of gg)

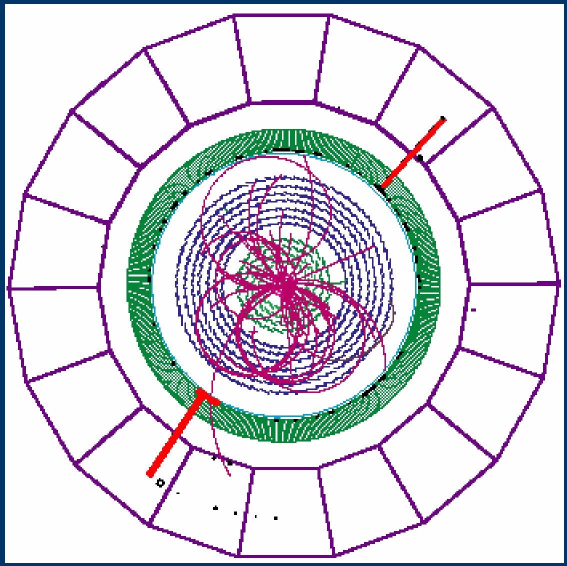


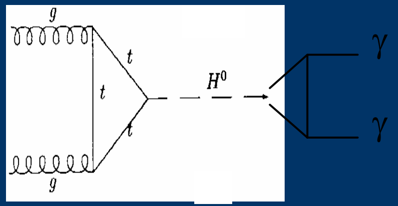


Having available four production mechanisms is a key for measurements of Higgs parameters

Higgs Discovery Channels







$100 \leq m_H \leq 150$ GeV

$H \rightarrow \gamma\gamma$ is a clean decay mode for low mass Higgs.

Rare decay channel: BR~10^{-3} (0.1%), but best resolution.

Production mechanism: gluon fusion/associated production

Low Mass Higgs: $H \rightarrow \gamma\gamma$

① Select events with two high p_T photons
② Measure photon's energy and direction,
③ Look for invariant mass → if Higgs: peak @ m_H
if $m_{\gamma\gamma}$ is measured well enough, signal will form a peak above the background (narrower peak, easier to see above background)

Background to $H \rightarrow \gamma\gamma$:

① QCD diphoton production (irreducible background):
→ same final state as signal so can't be entirely eliminated
② γ-jet or jet-jet production where jet(s) fake photon
→ require good calorimeter to distinguish isolated photons from jets

Need excellent ECAL performance:

- good acceptance, energy, angle and mass resolution,
- good γ/jet and γ/π^0 separation
- motivation for LAr(ATLAS)/$PbWO_4$(CMS) calorimeters

Low Mass Higgs: $H \rightarrow \gamma\gamma$

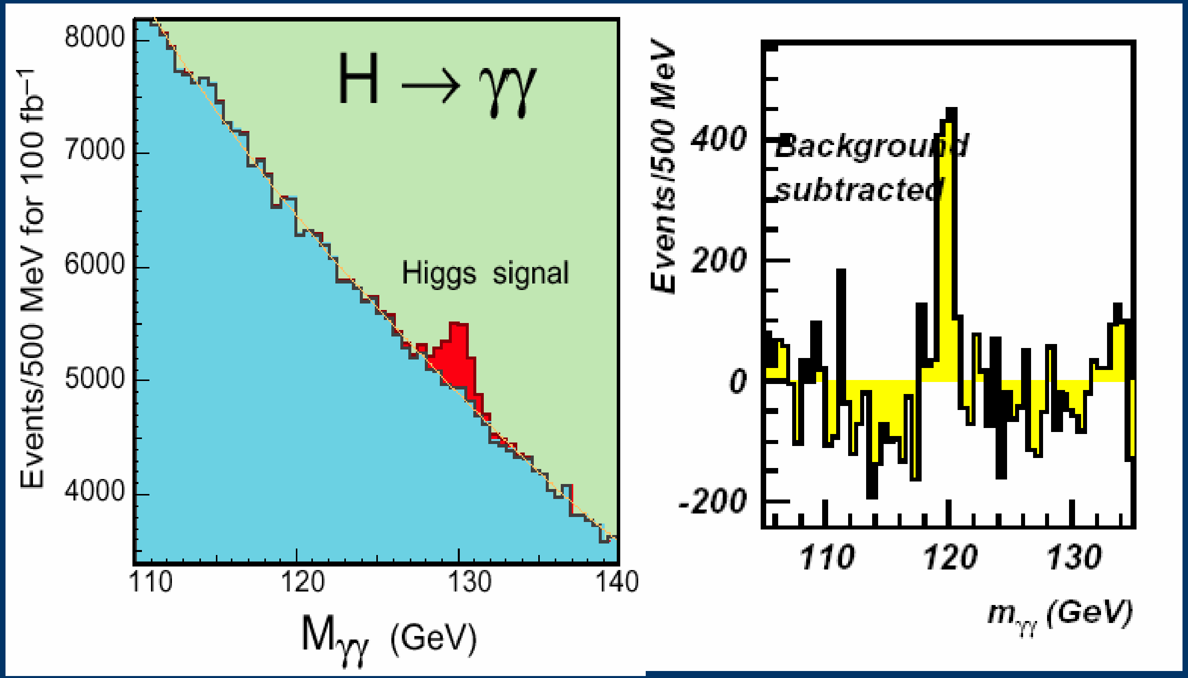
Two isolated photons:

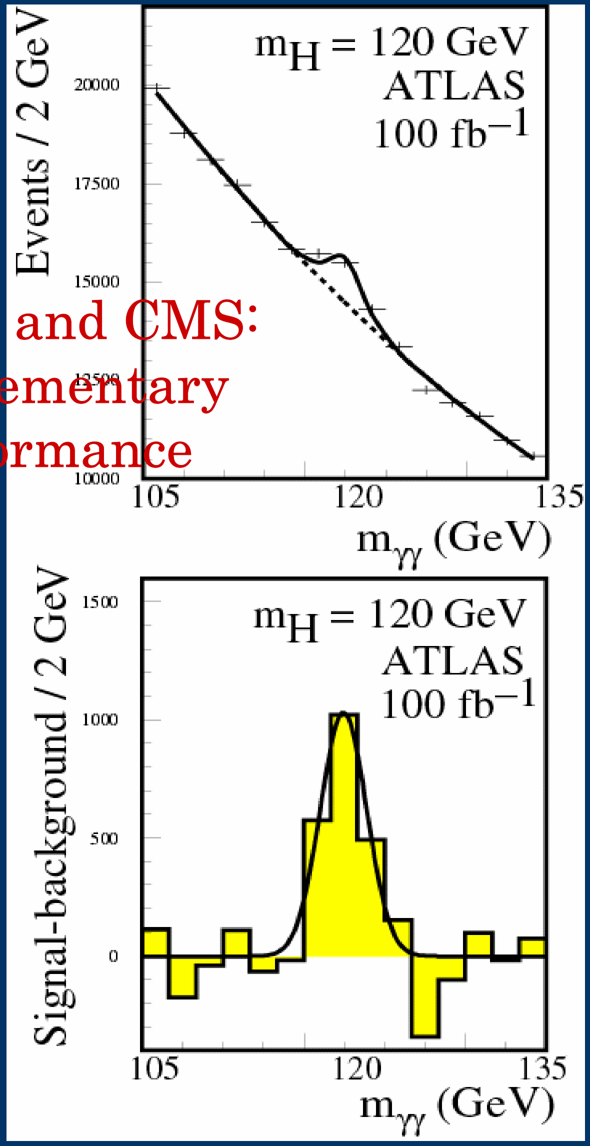
$E_T(\gamma 1) > 40$ GeV, $E_T(\gamma 2) > 25$ GeV

Mass resolution @ $m_H = 100$ GeV/c^2

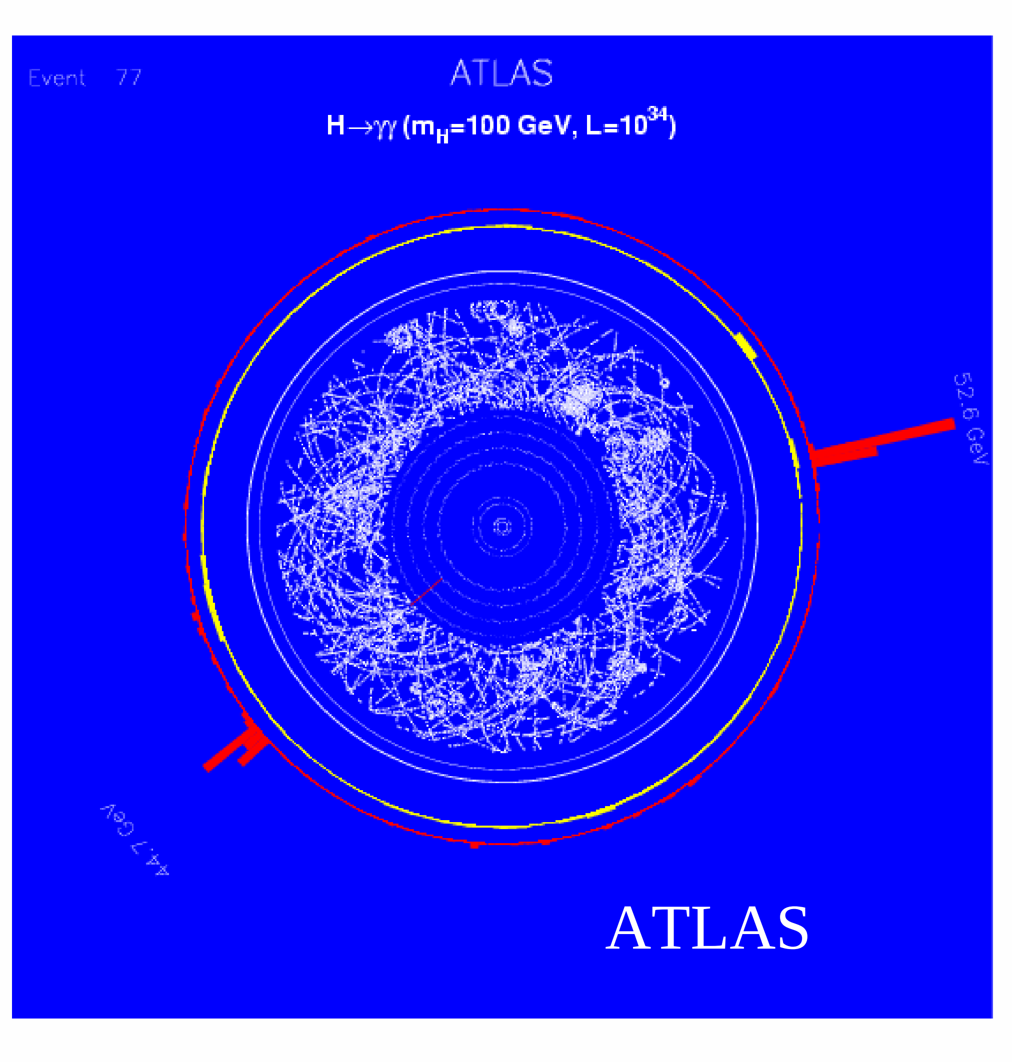
ATLAS	:	1.1 GeV	(LAr-Pb)
CMS	:	0.6 GeV	($PbWO_4$)

ATLAS and CMS: complementary performance





A simulated $H \rightarrow \gamma\gamma$ event in ATLAS



Open Questions

Apart from a brief presentation of CDF results, the biggest questions might be:

- Does LO/NLO get the SM diphoton x-sec and p_T right ?
- How accurately can we state that?
- Is that the only significant background to the Higgs search or will dijets be a big problem?
- The latter probably can't answered by us easily, but if we look into the existing LHC work, we could probably comment on it.

  e.g.) If the fake rate seems reasonable, or

  Does CDF Monte Carlo predict the right fake rate?

Parton Showering

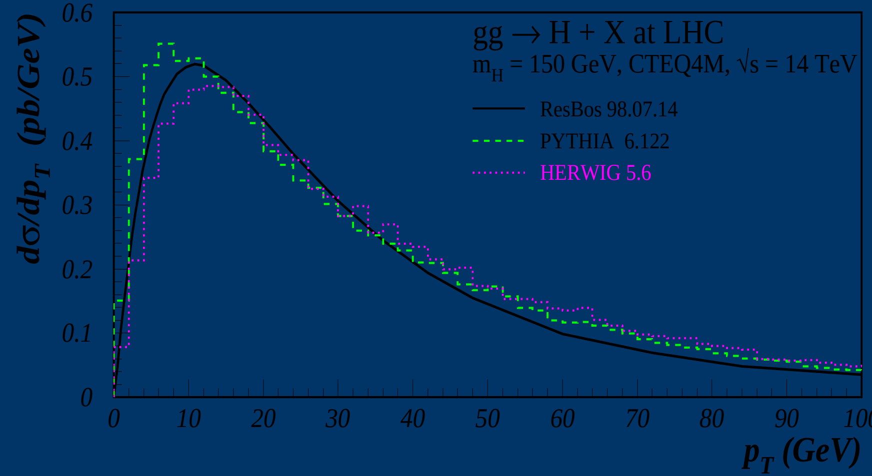
Joy Huston (CDF/MSU)

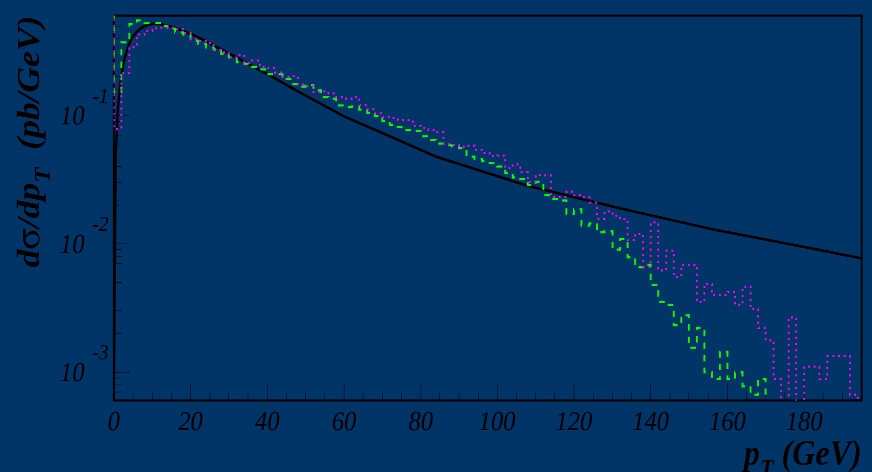
- Determination of the Higgs signal requires an understanding of the Higgs p_T distribution at both LHC and Tevatron
  - eg) For $\gamma\gamma \rightarrow HX \rightarrow \gamma\gamma X$, the shape of the signal p_T distribution is harder than that of the $\gamma\gamma$ background
- To reliably predict the Higgs p_T distribution, especially for low to medium p_T region, have to include effects of soft gluon radiation
  - can either use parton showering a la HERWIG, PYTHIA, ISAJET or k_T resummation a la ResBos
  - parton showering resums primarily the (universal) leading logs while an analytic k_T resummation can resum all logs with Q^2/p_T^2 in their arguments
- Backgrounds to $\gamma\gamma$ production in Higgs mass region arise from fragmentation of jets to high z π^o's
  - PYTHIA and HERWIG predict very different rates for high z
- DIPHOX can calculate $\gamma\gamma$, $\gamma\pi^o$, and $\pi^o\pi^o$ cross sections to NLO
- Still important to understand level of background

Comparison of PYTHIA, ISAJET and ResBos for Higgs Production @ LHC

Joy Huston
(CDF/MSU)

- ResBos agrees much better with the recent version of PYTHIA
  - Suppression of gluon radiation leading to a decrease in the average p_T of the produced Higgs
- Note that PYTHIA does not describe the high p_T end well unless Q_{max}^2 is set to s (14 TeV)
- HERWIG (v5.6) similar in shape in PYTHIA 6.1, and perhaps even more similar in shape to ResBos





SM Higgs Production

How CDF can help?

QCD Diphoton Production → common issues (see next slide)

Peak Search → common issues (see next slide)

common issues (see next slide) → $H \to \gamma\gamma$

There may be an interesting connection between the Tevatron and LHC

Tevatron data and experience are invaluable for success of Higgs searches at LHC !

- Physics environment at the LHC is very similar to that at the Tevatron.
- For LHC Higgs physics it is very important what Tevatron is doing with:
- Understanding of reliability and limitations of MC generators; uncertainties
- Test of theoretical N…LO calculations; uncertainties.
- Experimental methods and techniques for
  - measurement of background from the data
  - measurement of jet -> γ miss ID efficiency from the data
- Understanding of the signal and background systematic; Theory + Experiment

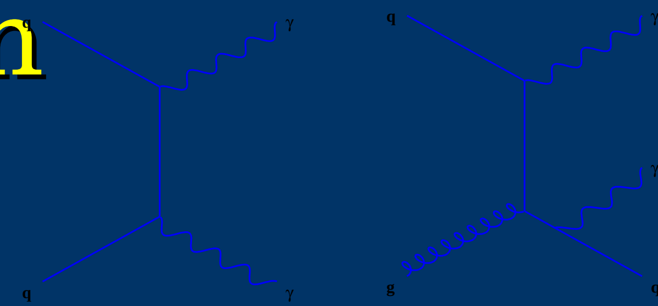
TeV4LHC Plenary Talk [A. Nikitenko]
What TeV can do for Higgs @ LHC?

Four Diphoton Results from CDF I, II

Fermiophobic Higgs

Cross Section **Peaks Search** **MET Search**

Motivation



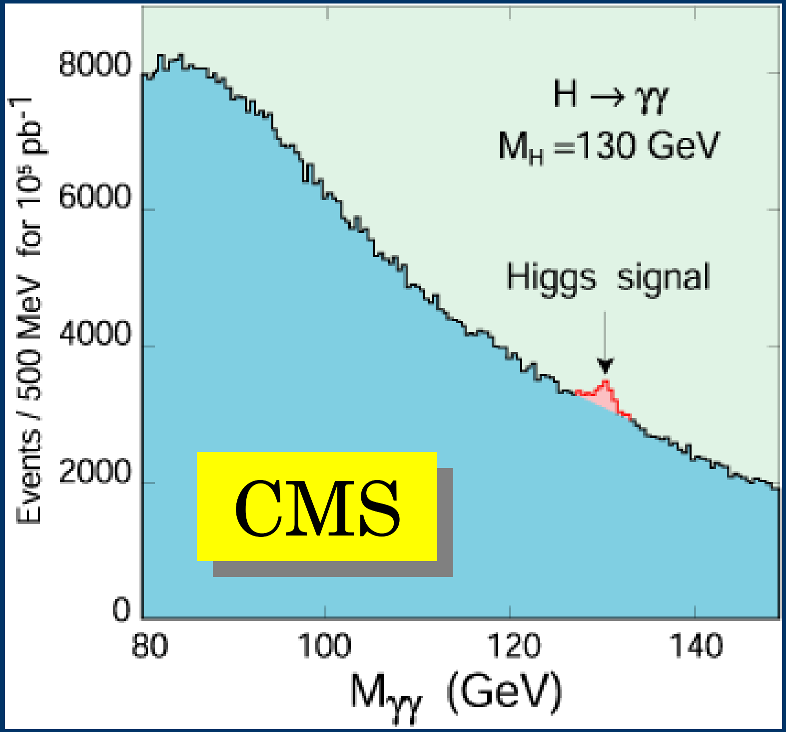
Experimentally:

- Very clean signature
- Excellent Resolution
  (Precision measurement of photons 4-vectors)

Background to Higgs Hunting

Theoretically:

- Higgs discovery channels @ LHC
- may infer presence of Extra Dimension
- Possible signature of GMSB SUSY
- The measurement can be used to test NLO pQCD (Soft gluon resummations, Fragmentations etc…)



Understand the QCD diphoton production is needed before any other possible search!!

Diphoton Triggers and Selections

Triggers

- $2 \times Et > 12$, w/ cal Isolation
- $2 \times Et > 18$, w/o cal Isolation

high-mass search includes high-Et very loose trigger

Main Cuts	Searches	Cross Section
• Central ($\|\eta\|<1.0$) only	$\|\eta\|<1.0$	$\|\eta\|<0.9$
• Had/EM	<0.055+sliding	<0.055+sliding
• Cal Iso, cone 0.4	< 2 GeV	< 1 GeV
• Shower in CES, χ^2	< 20	< 20
• Leading track Pt	< 1 GeV	< 0 GeV
• Track isolation, cone 0.4	< 2 GeV	-
• Second CES cluster Et	< 2 to 3 GeV	< 1 GeV

- MET search adds anti-cosmic cuts on Hadron TDC times, topology, unattached muon stubs.
- All analyses use $Z \rightarrow ee$ and minbias to study/correct ID eff.

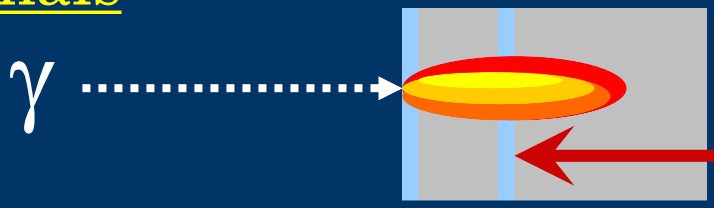
Photon Identification

Photon candidate: Isolated EM showers in the calorimeter, with no charged tracks pointing at the calorimeter cluster

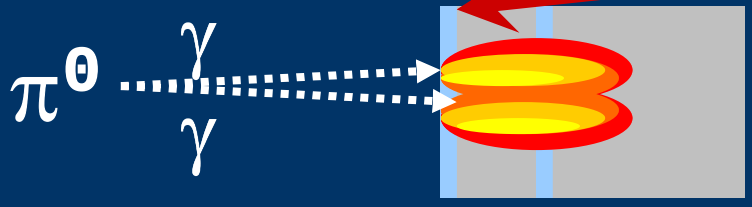
Background: Multiple photon decays of mesons ($\pi^0/\eta/K_S$ …) can only be subtracted on a statistical basis

Central Calorimeter

- Signals



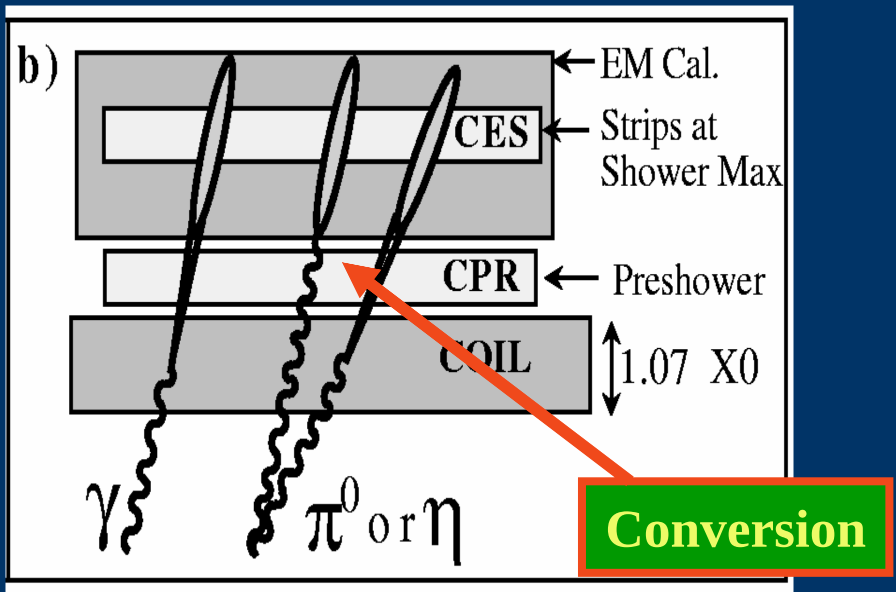
- Backgrounds

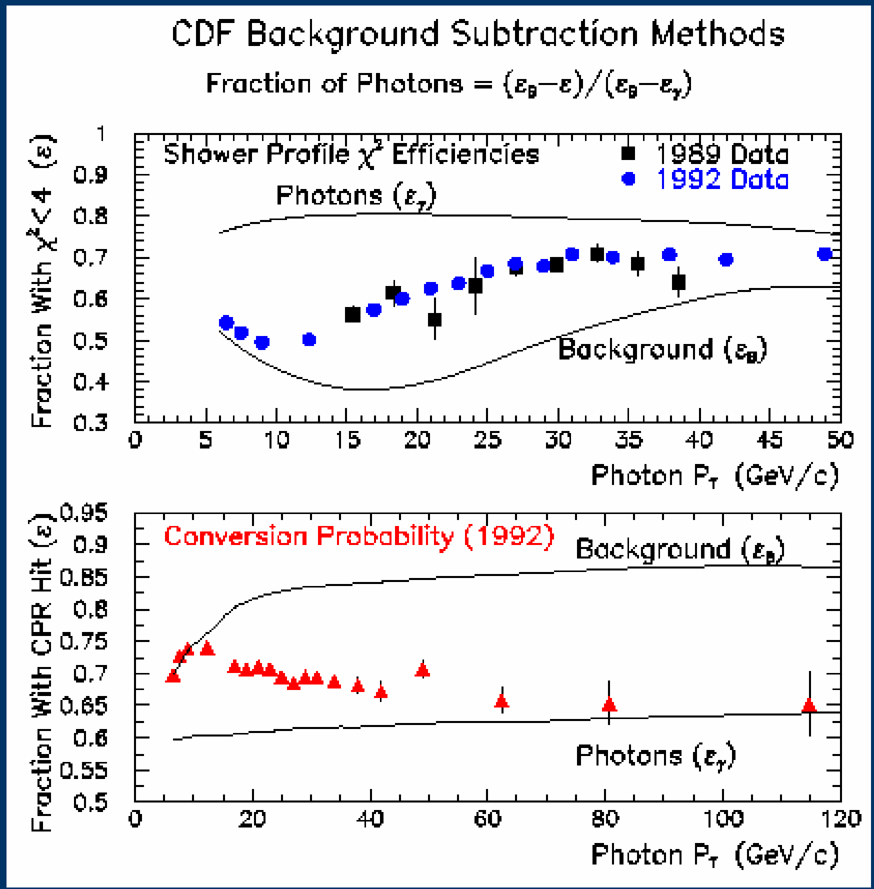


- CDF uses two techniques for determination of photon signals;
  1. EM Shower width (shape): using **Shower Max. Detector**
  2. Conversion Probability: using **Pre-radiator hits**

	γ-γ	γ-Jet	Jet-Jet
CES	29±4%	47±6%	24±4%

Background Subtraction





- Et < 35 GeV, CES

  transverse profile of showers generated by multiple photons statistically broader than single photon: CES $\chi 2$
- Et > 35 GeV, CPR

  Conversion in coil more likely to occur for multiple photons : CPR hit rate.
- Validated

  Control samples, ρ, η, and isolation

For every photon, using the conversion and profile info, CDF find the fraction of candidates with this info. (evaluated signals statistically)

Photon Fake Rate

Helen Hayward (CDF/Liverpool)

- Measure the raw fake rate. The fraction of jets which are matched to a photon candidate.

$$P_{RAW}(E_T^{jet}) = \frac{N_{\gamma-candidate}}{N_{jet}}$$

- Jet sample contains two categories of photon candidates:
  - Fake photon : due to decay product of meson (π^0, η)
  - Prompt photon : due to hard scattering process or radiate off a quark
- Correction Required:

$$F_{QCD} = \frac{N_{jet\to\gamma}}{N_{\gamma candidate}} = 1 - F_{\gamma}$$

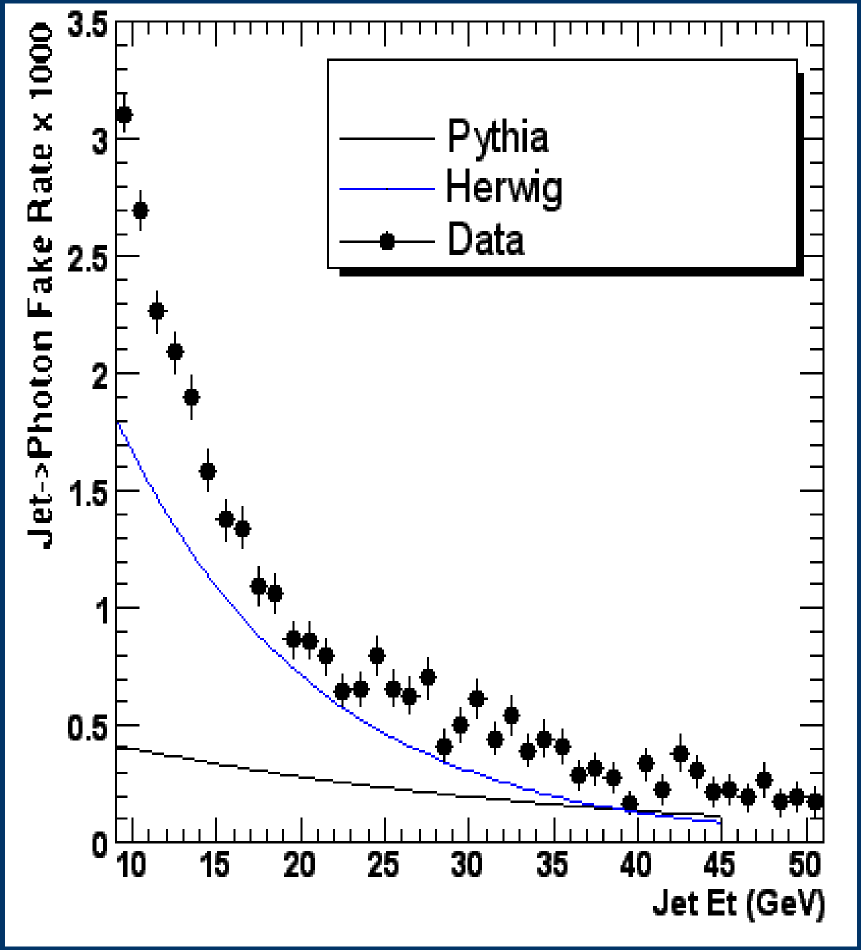
Rate at which a jet will "fake" a photon is given by:

$$P_{jet\to\gamma}(E_T^{jet}) = F_{QCD} \times P_{RAW}(E_T^{jet})$$

Photon Fake Rate from Data

A. Nikitenko (Plenary Talk)

CDF (preliminary result)



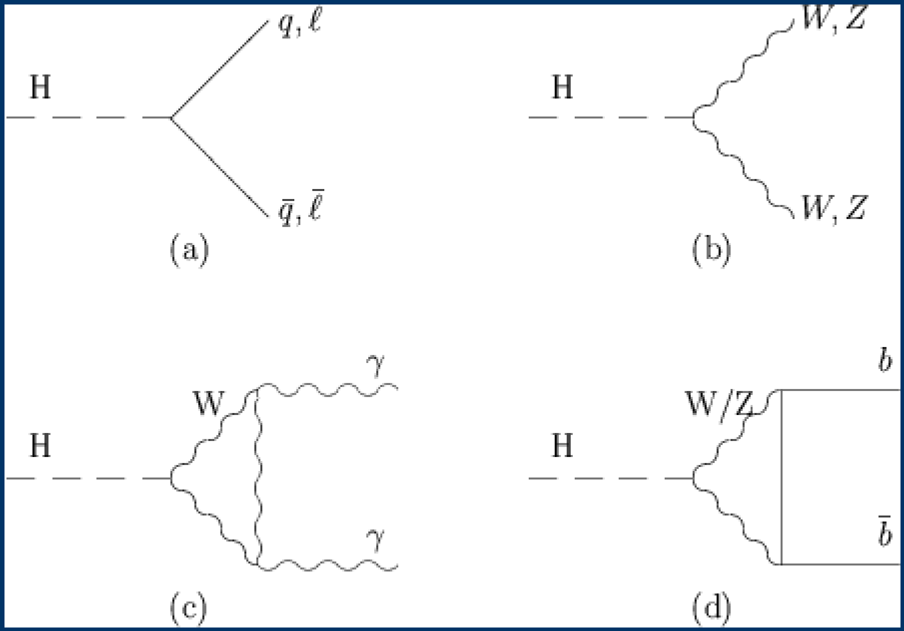
- Rate of jets with leading meson (π^0,η) which cannot be distinguished from prompt photons: Depends on
  - detector capabilities, e.g. granularity ofcalorimeter
  - cuts!
- Systematic error about 30-80% depending on Et
- Data higher than PYTHIA and HERWIG
- PYTHIA describes data better than HERWIG

At TeV Jet→γ miss ID is obtained from γ+jet data.
We should evaluate how does it work with LHC detectors

Diphoton Results at CDF I
“Fermiophobic” Higgs

Search for $H \to \gamma\gamma$ @ CDF

- Models with two Higgs doublets can have one Higgs coupling at tree level only to boson
- These are know as "Bosophilic" or "fermiophobic" Higgs
- CDF searched for $\gamma\gamma$ production in association with a W/Z boson.



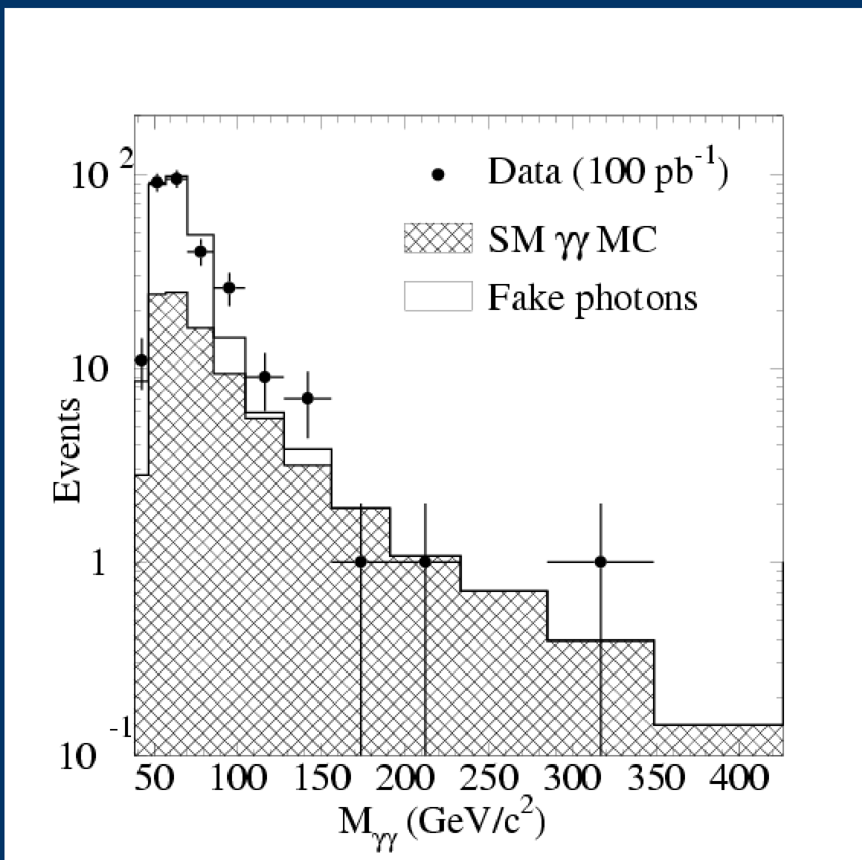
Bosephilic Higgs: V(W/Z)+H $\to$ W/Z+$\gamma\gamma$
Two isolated photons + [e/μ+MET or jj]

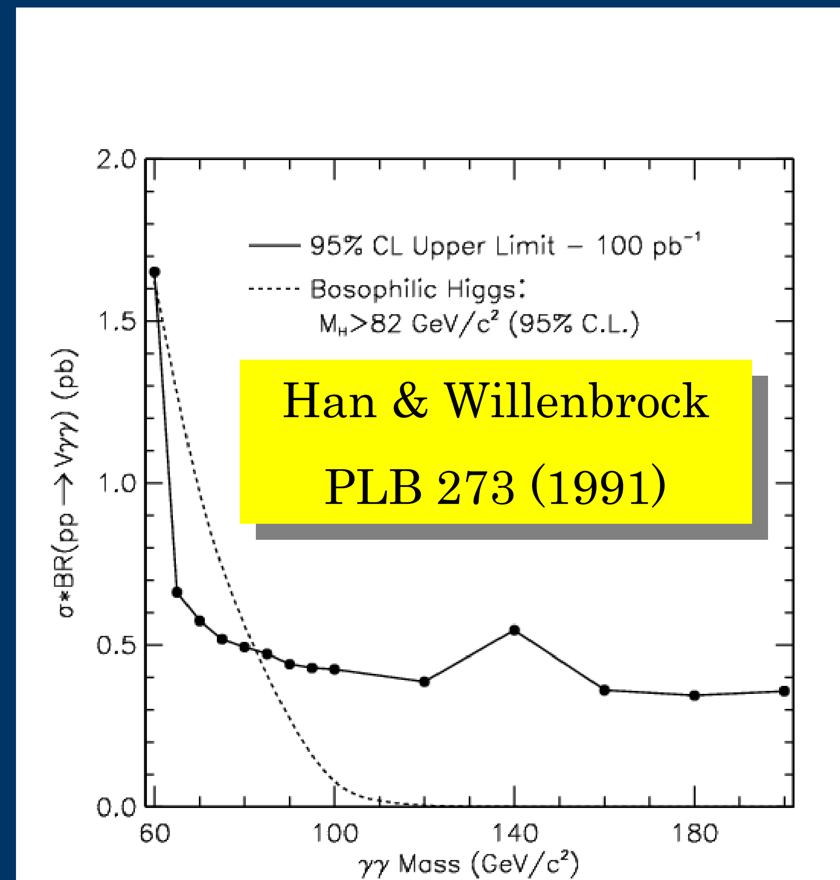
- In some models Higgs couples only to vector bosons
- BR($H \to \gamma\gamma$) dominant for light Higgs (m(H) < 100)

Search for H → γγ @ CDF

- Diphoton Mass distribution
- compare with backgrounds

Bosophilic Higgs:
M(Higgs) > 83 GeV @ 95% C.L.





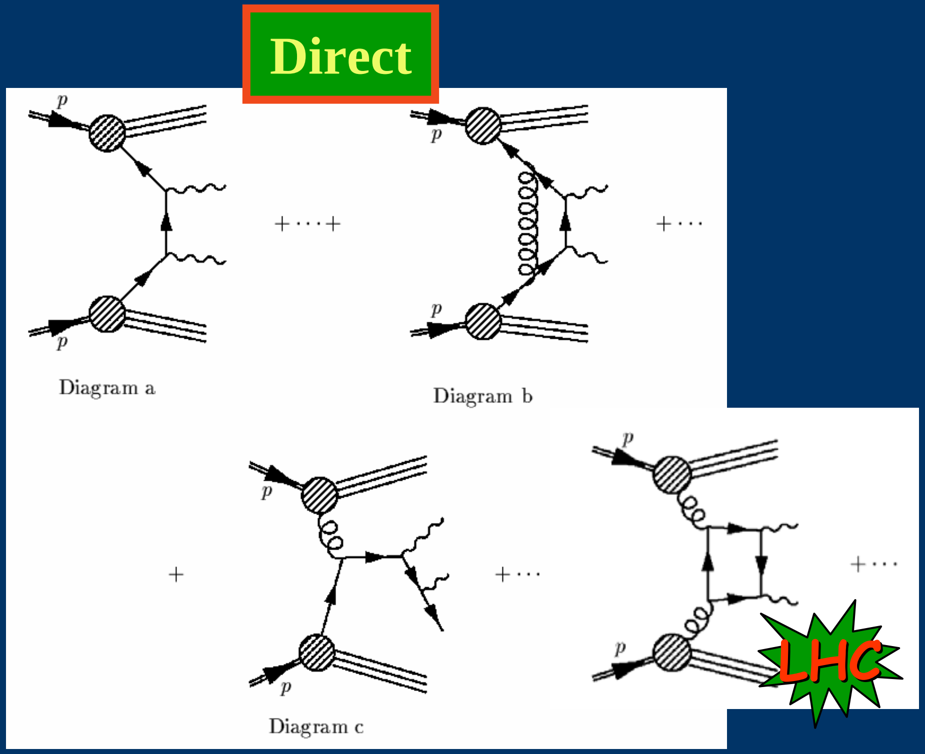
Diphoton Results at CDF II

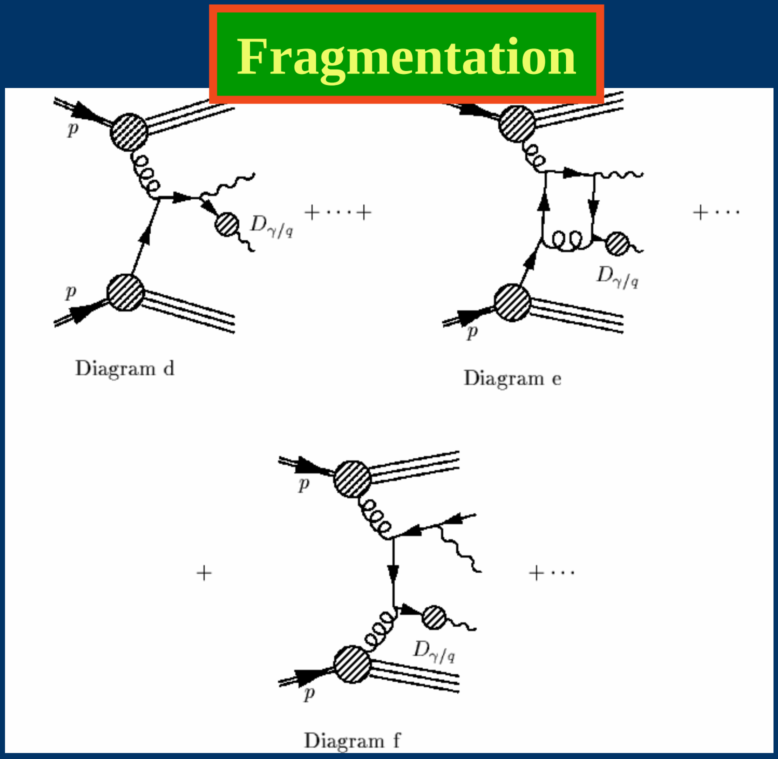
1. QCD Cross-section

Production Mechanism I

"Prompt Photon": not from hadrons decays

- **Direct:** Directly from the hard subprocess
- **Fragmentation:** from a collinear fragmentation of a hard parton





Production Mechanism II

"Prompt Photon": not from hadrons decays

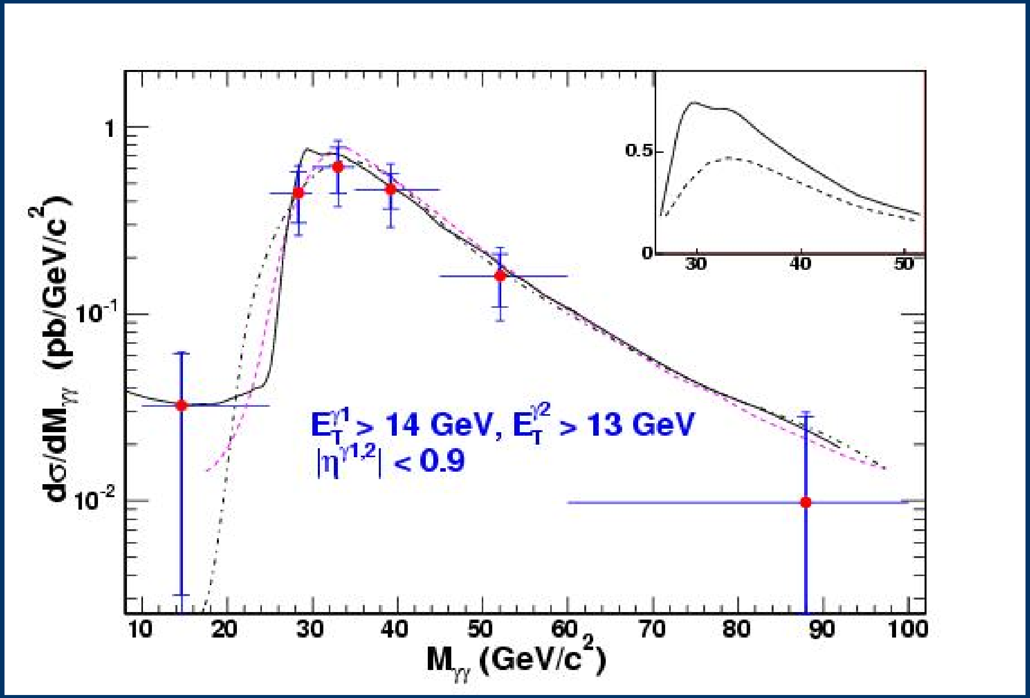
- Direct: Directly from the hard subprocess
- Fragmentation: from a collinear fragmentation of a hard parton

DIPHOX	ResBos
• Fixed QCD NLO calculation for both Direct and Fragmentation mechanism • No Resummation for initial and final gluon radiation	• QCD NLO calculation for direct and LO for the other subprocess • Resummation of soft gluon emissions to all orders

Diphoton Cross Section

Sample **[Data: 207 pb^{-1}]**

- Et>13,14 GeV, $|\eta| < 0.9$
- Tight photon ID cuts
- 426±59 $\gamma\gamma$ in 889 events
- Background subtraction dominates uncertainty



Compare PYTHIA

- All LO + ISR model
- Scaled ×2 for plots

Compare RESBOS

- LO + qq $\rightarrow\gamma\gamma$ @ NLO
- Soft gluon ISR resummed

Compare DIPHOX

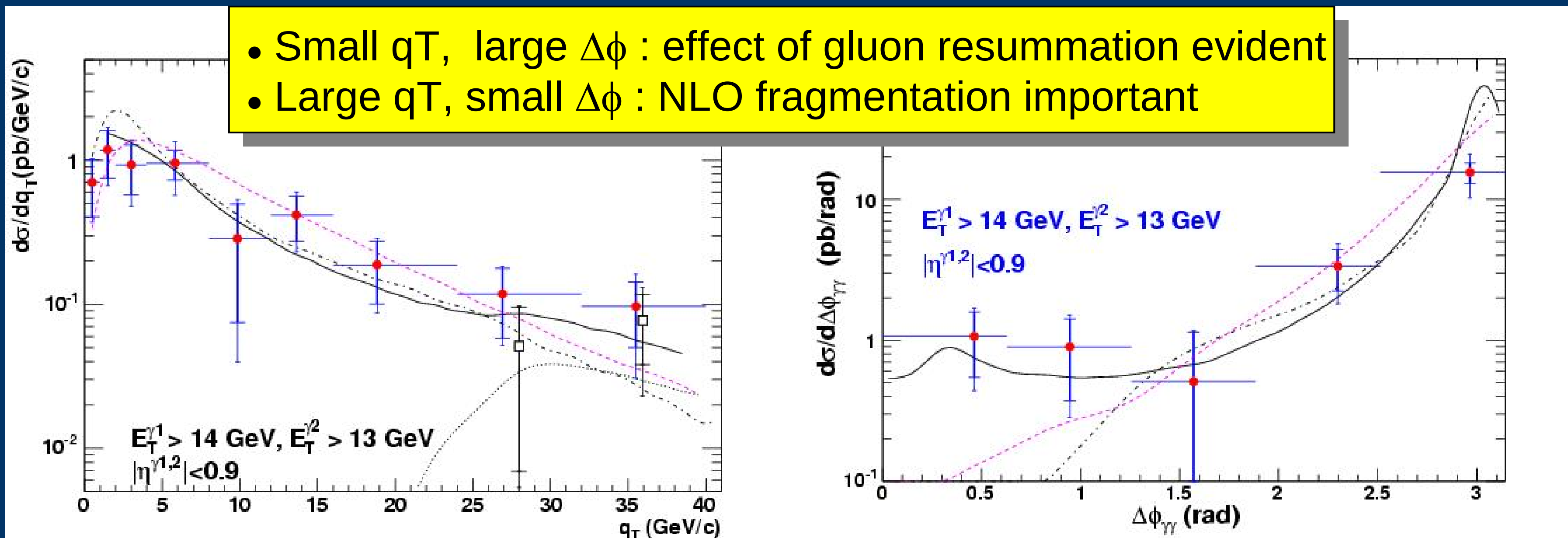
- All NLO but gg$\rightarrow\gamma\gamma$ Box

- Good data/theory agreement.
- At low mass, DIPHOX higher than ResBos because DIPHOX has 2→3 fragmentation contribution. Data points seem to favor DIPHOX.

Diphoton Cross Sections

qt = diphoton systemPt Δϕ between photons

- Small qT, large Δϕ : effect of gluon resummation evident
- Large qT, small Δϕ : NLO fragmentation important



- LO PYTHIA low by a factor ~2.0, but reasonable mass shape
- DIPHOX breaks down at low qt due to singularities in NLO
- RESBOS does better at low qt due to continuous ISR resumming
- DIPHOX shows additional source at low m(γγ), small Δϕ, and qt>30 GeV. These are (qg → gqγ → gγγ) where the q fragmented to a photon

What CDF QCD Diphoton teaches us?

- Data points in agreement with NLO QCD calculations : DIPHOX, and ResBos.
- CDF data indicate both soft gluon emissions and NLO fragmentations are important: ResBos will have the 2->3 fragmentation in, and DIPHOX will do soft gluon resum, in near future.

Diphoton Results at CDF II

2. Peak Search

Search for Diphoton Peaks

Model

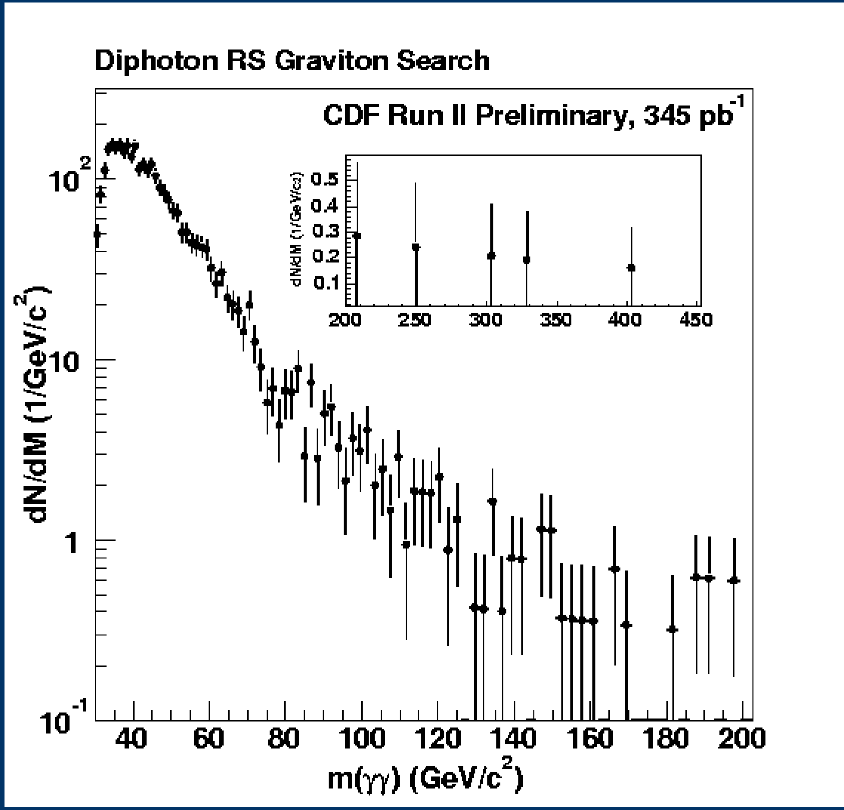
- Randall-Sundrum Gravitons
- Extra Dimension is "warped", warp factor k
- S-channel Graviton yields ee,μμ,γγ peaks at high-mass

Analysis

- 2 Central γ (|η|<1), Et>15 GeV
- Mass > 30 GeV

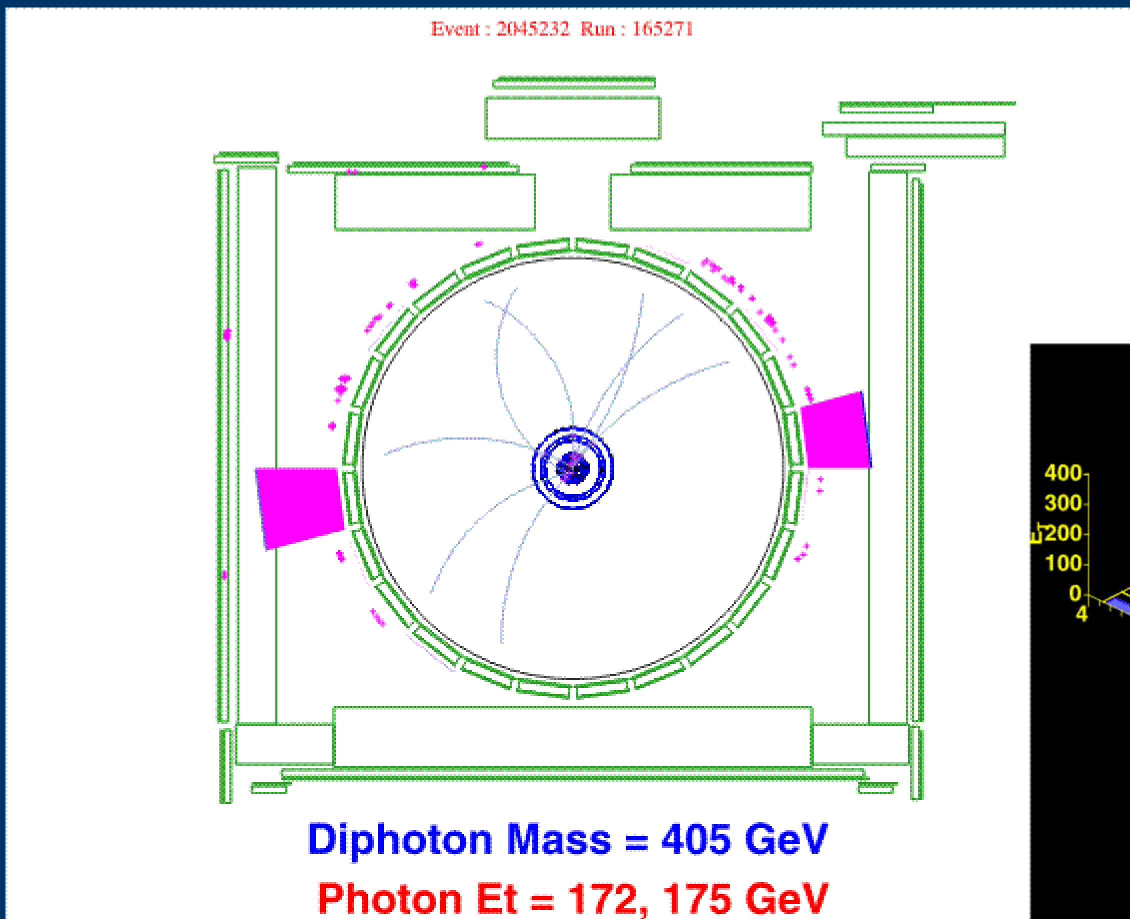
High-Mass Events

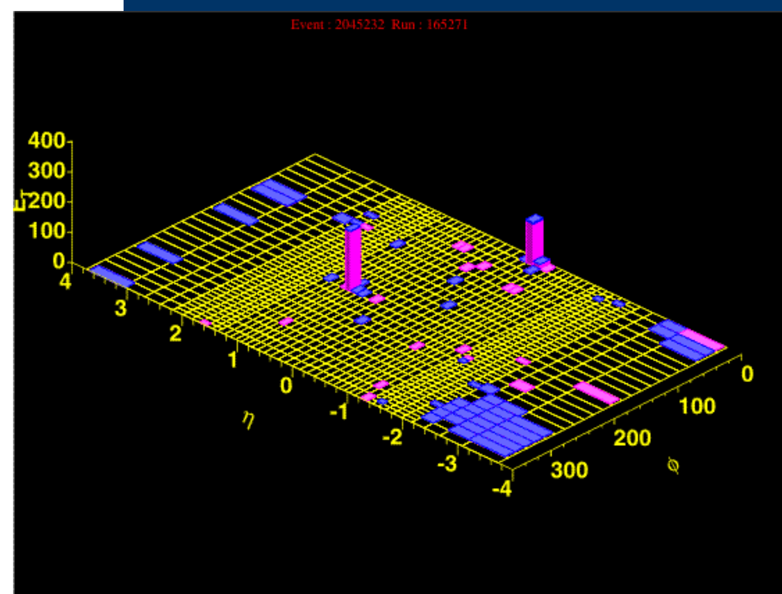
- Mass=207, 248, 305, 329, 405
- No sign of cosmics



γγ Mass in Bins of 1σ Mass Resolution

γγ Highest Mass Event

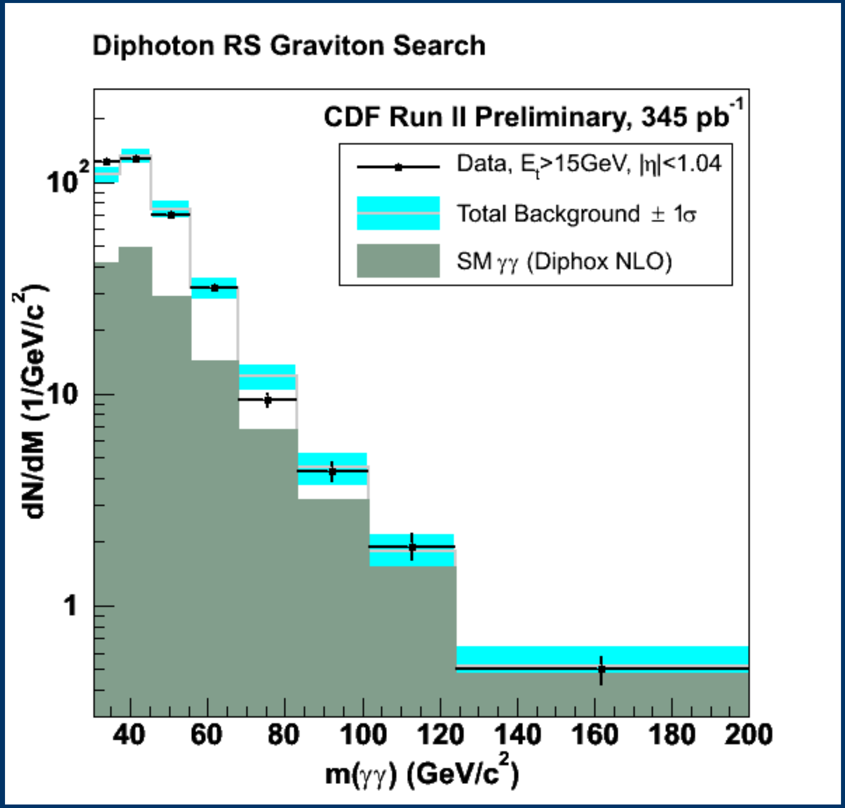


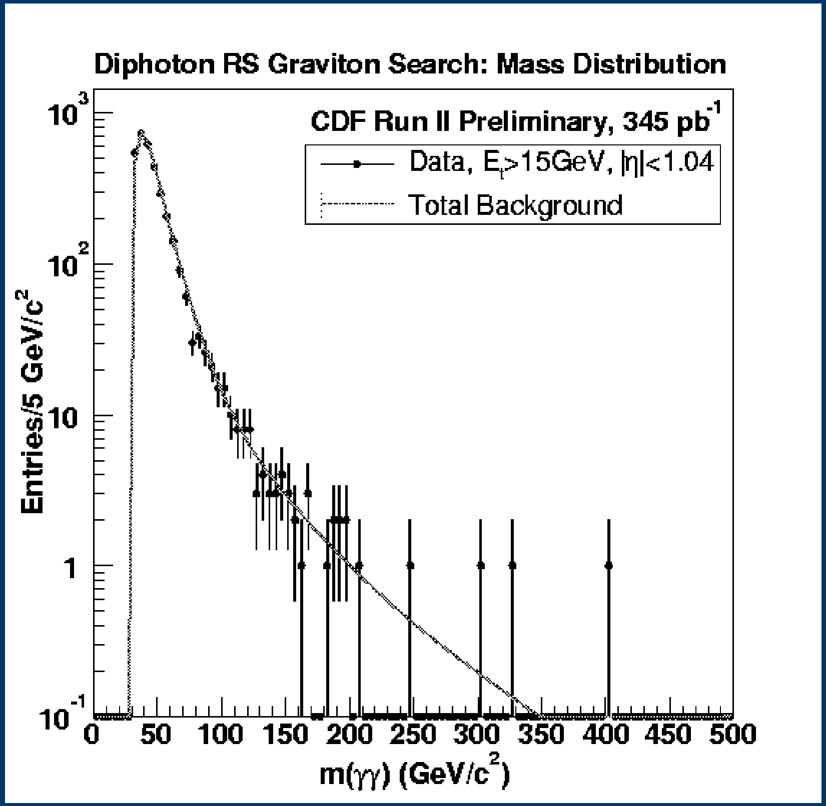


Search for Diphoton Peaks

SM Diphoton Background
- NLO DIPHOX calculation
- Normalized to Luminosity

Jets Faking Photons
- Mass shape from a sample of loose diphotons
- Normalized to low Mass



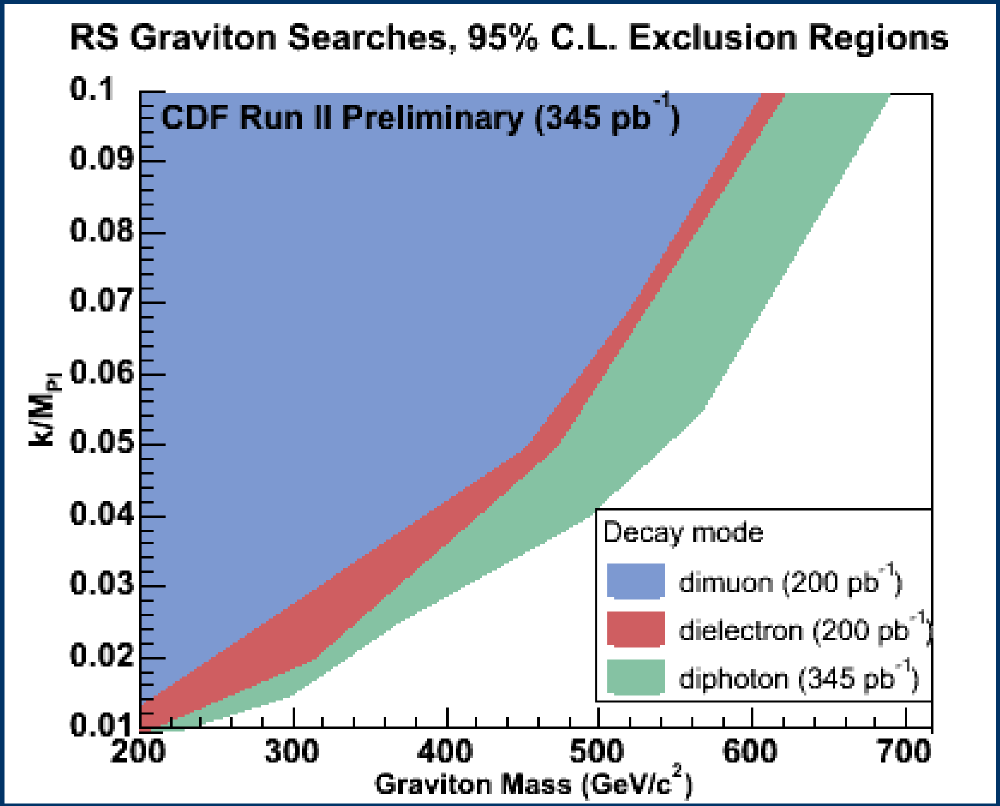


Randall-Sundrum Graviton Limits

Limits

- k/M_{pl}=0.1, M(G)>690 GeV
- ee, μμ ~ 200 pb

  γγ ~ 350 pb
- γγ has larger BR
- γγ spin factors improve acceptence



Acceptence Potential

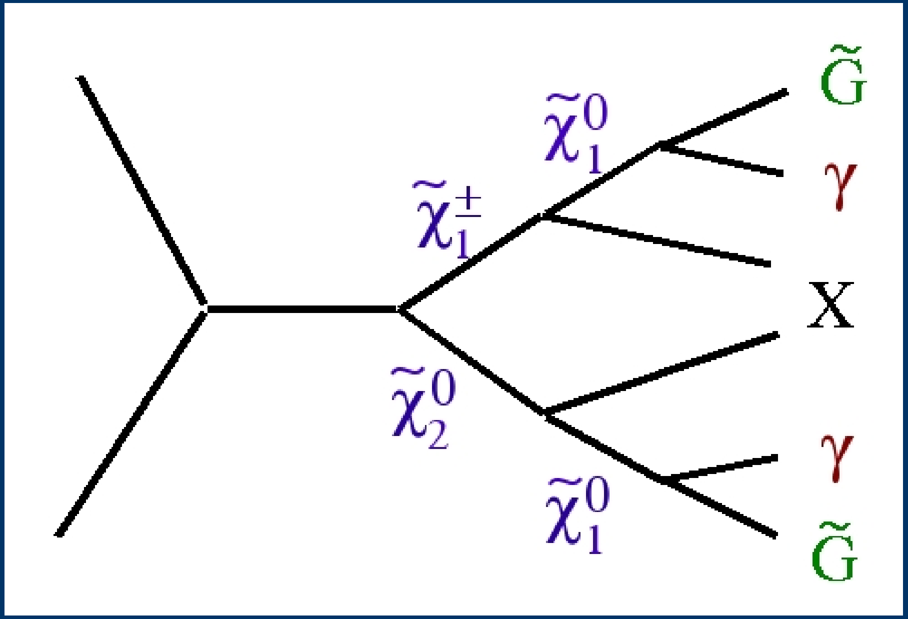
- γγ combined with ee
- accept conversions
- add plug (x2 at high-η)

Diphoton Results at CDF II

3. $\gamma\gamma$+MET Search

Search in Diphoton and MET

$$(p\bar{p} \rightarrow \chi\chi \rightarrow N_1 N_1 + X \rightarrow \gamma\gamma GG + X)$$

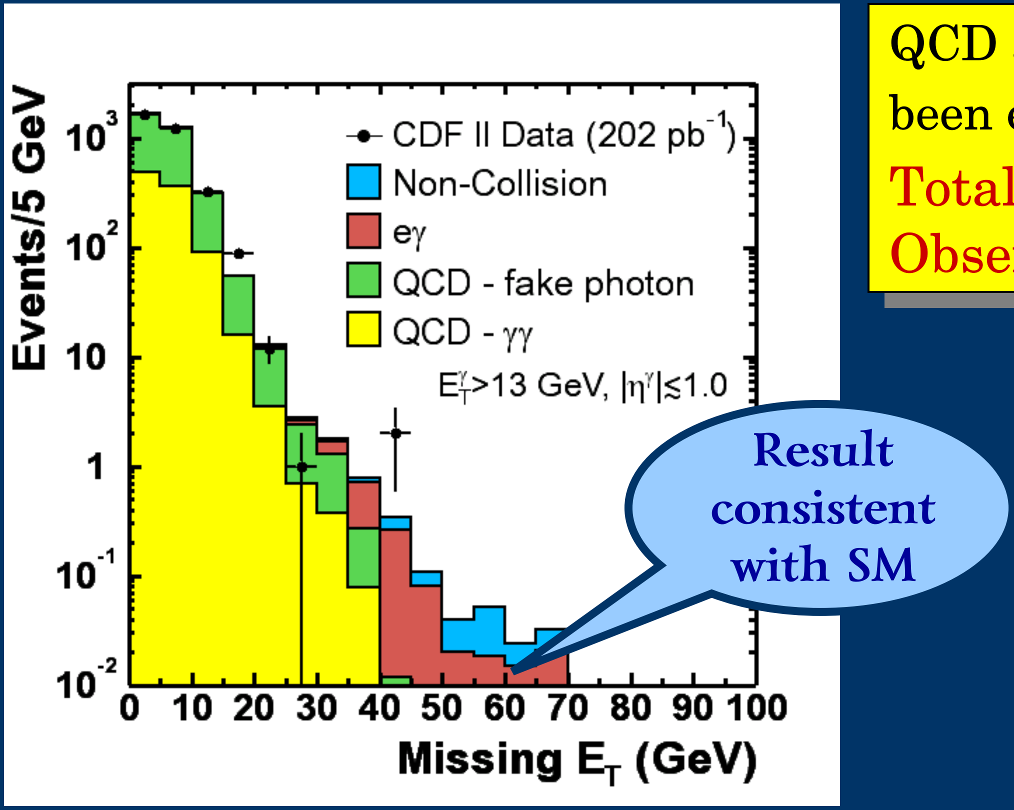


Model

- Gauge-Mediated SUSY Breaking
- LSP: Gravitino
- NLSP: Neutralino N1→ γG
- Snowmass model*
- Lambda parameter scales masses
- Largest cross section C1N2 and C1C1
- All production leads to events with diphoton+MET

* Allanch et al. Eur Phys. J. C25 113 (2002)

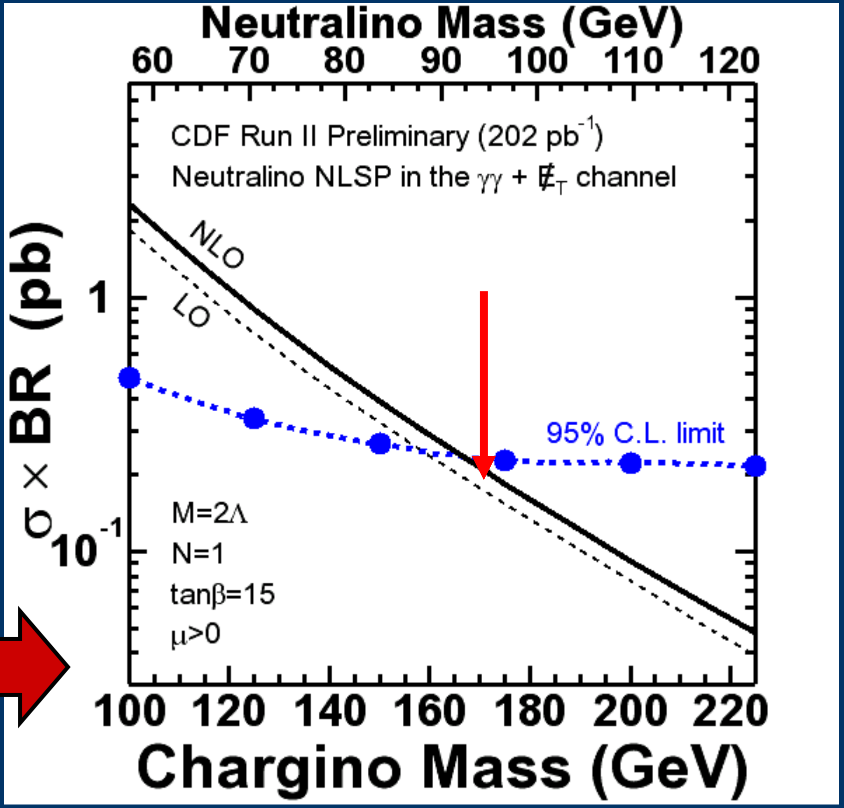
Search in Diphoton and MET



QCD and SM background contribution has been estimated using data

Total background: $0.27 \pm 0.07 \pm 0.10$

Observed: 0



Set the lower mass limit on the lightest chargino in GMSB:

$M_c > 113$ GeV @ 95% C.L.

Diphoton Results from CDF II

DiPhoton Cross Section

- Consistent with NLO Diphox
- Interesting comparison with generators

Diphoton Peaks Search

- Data well-modeled by background estimates
- Set limts on R.S. Gravitons

Diphoton and MET Search

- Central, Et >13, MEt>45, 0 events observed
- M(C1) > 167 GeV in Snowmass GMSB Model

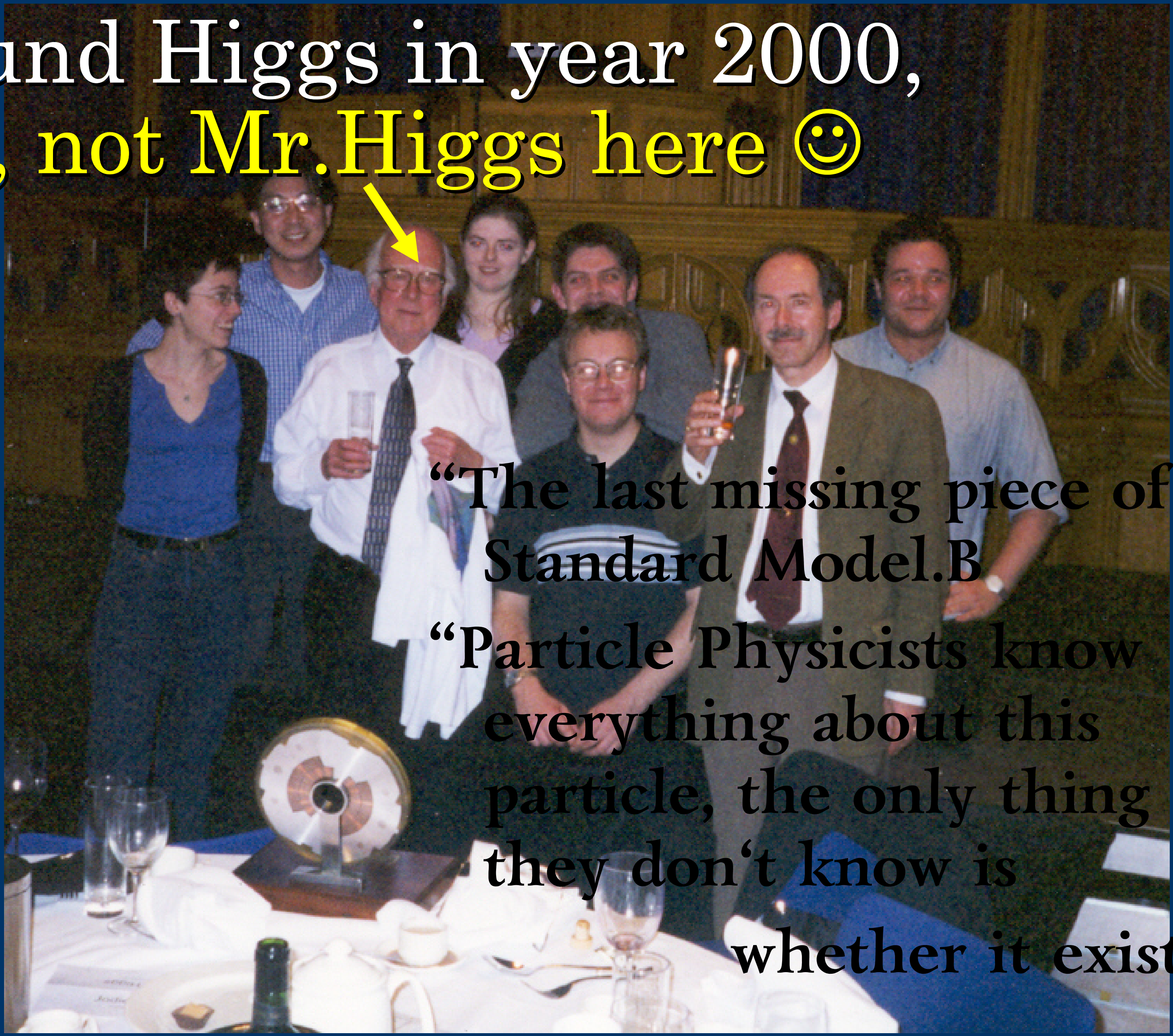
Summary and Outlook

Important to understand QCD (prompt) diphoton production in order to reliably search for the Standard Model Higgs and New Physics..

There may be an interesting connection between the Tevatron and LHC..

Tevatron data and experience are invaluable for success of Higgs searches at LHC !

I found Higgs in year 2000,
But, not Mr.Higgs here ☺



"The last missing piece of the Standard Model.B

"Particle Physicists know everything about this particle, the only thing they don't know is whether it exists.B