Search for h→γγ at DØ

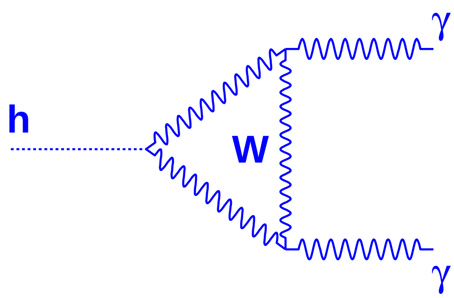
Alex Melnitchouk
University of Mississippi
for the DØ collaboration

TeV4LHC workshop

Fermilab,
September 16, 2004

$h \to \gamma\gamma$ Decay Mode in the SM and Beyond.

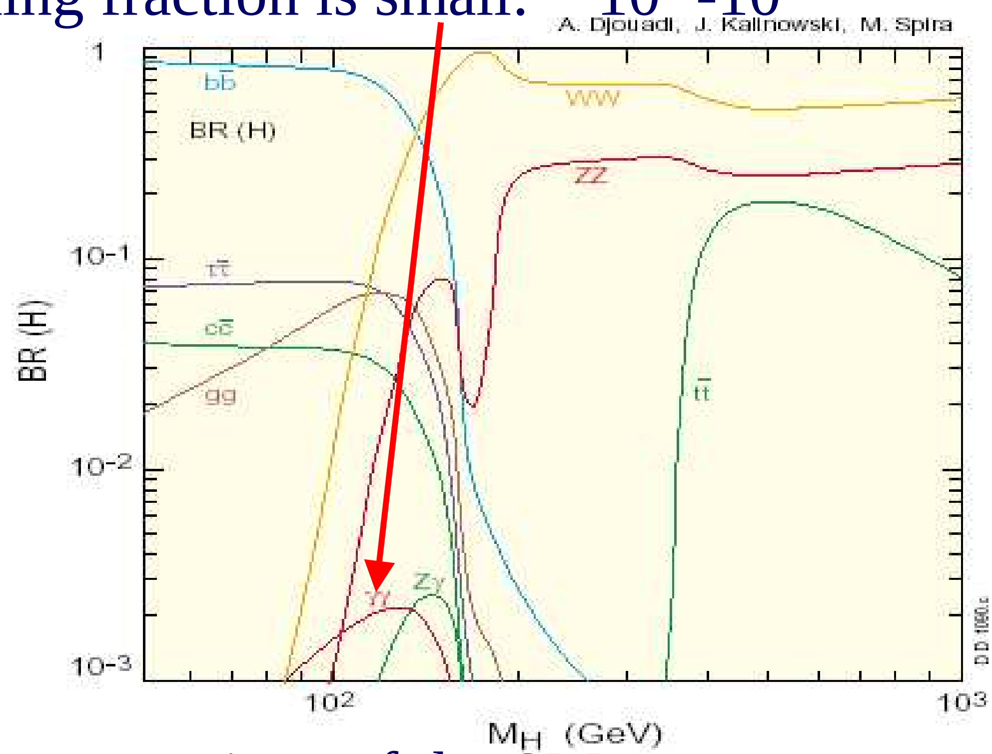
- no tree-level $H\gamma\gamma$ coupling (Higgs boson is neutral)
- Di-photon decays happen via W loop



(top-quark loop reduces $H \to \gamma\gamma$ width by 20-30% due to destructive interference)

⇒

- $H \to \gamma\gamma$ branching fraction is small: ~ 10^{-3}-10^{-4}
  Higgs decays mostly to b-quark and W pairs



- However many extensions of the SM predict enhanced $\gamma\gamma$ decay rate of the Higgs boson

How Can $h \rightarrow \gamma\gamma$ Decays be Enhanced

- One possibility: suppress fermion decay rates (then the full decay width would only be shared with $h \rightarrow WW$ and $H \rightarrow ZZ$ decays)
- In the Standard Model Higgs is responsible for both **Electroweak symmetry breaking (EWSB)** and **fermion masses**
- Higgs-**W,Z**/**fermion** interaction terms in the SM Lagrangian are:

$$\left\{ \begin{array}{l} (1/\mathbf{v})\, 2m^2_W W^+W^-H \\ (1/\mathbf{v})\, m^2_Z ZZH \\ (1/\mathbf{v})\, m_f \psi\psi H \end{array} \right.$$

- Relative strength of **Higgs-W,Z** and **Higgs-fermion** couplings is fixed by **v** (Higgs field vacuum expectation value)
- In a more general situation different sectors of theory (or different mechanisms) could be responsible for **EWSB** and (some of) **fermion masses** => Higgs couplings to fermions and those to weak gauge bosons can vary independently

Some Examples of $h\to\gamma\gamma$ Enhancement

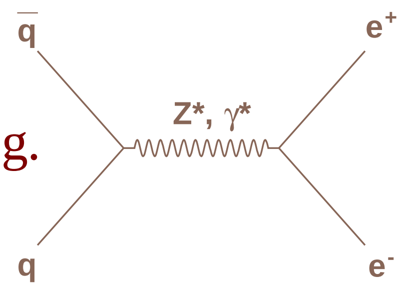
- Strong dynamics [1] :
  EWSB = via technicolor condensation,
  fermion masses = via “extended techncolor”
- Generic two Higgs doublet model [2]:
  v1 – W,Z masses, v2 – fermion masses
- Top-condensation model + Higgs [3]
  top and bottom quarks get their masses from the topcolor interaction while **Higgs gives mass to remaining fermions and gauge bosons**
- Topcolor Higgs=(top,vector-like quark)[4]
  Top quark mass from Higgs, other fermion and **W/Z masses -- from other interactions present in the theory**
- Still another possiblity of $h\to\gamma\gamma$ enhancement arises when the Higgs field extends into **large extra dimensions** (while fermion and gauge boson fields remain confined to 3D) [5]

[1] E.Farhi (CERN), L. Susskind Phys,.Rept.**74**, 277 (1981)
[2] H.E.Haber et al, Nucl. Phys. **B161**, 493 (1979)
[3] J.D. Wells, Phys. Rev. **D56**, 1504 (1997)
[4] B.Dobrescu, Phys. Rev**. D63,** 015004 (2001)
[5] L. Hall, C.Kolda, Phys. Lett. **B459**, 213 (1999)

Major Backgrounds :
Drell-Yan and QCD

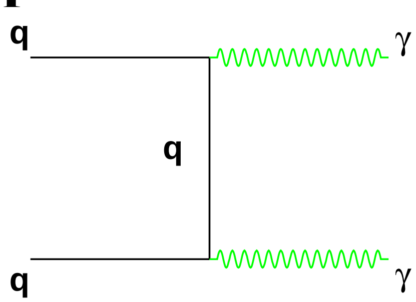
- **$Z/\gamma^* \to e^+e^-$** with e^+e^- misidentified as photons (lost tracks)

e.g.



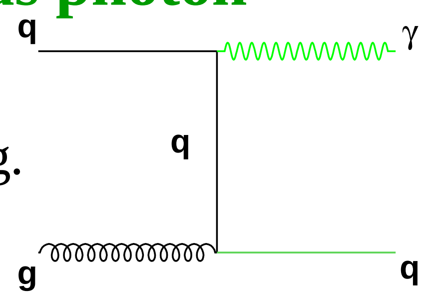
- **QCD processes that in the final state contain :**

1. two photons



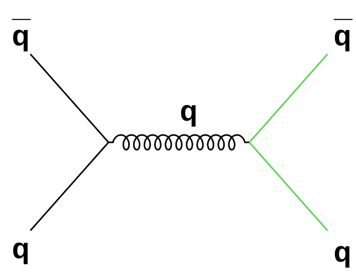
2. a photon and **a hadronic jet misidentified as photon**

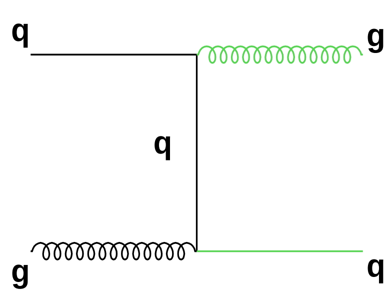
e.g.

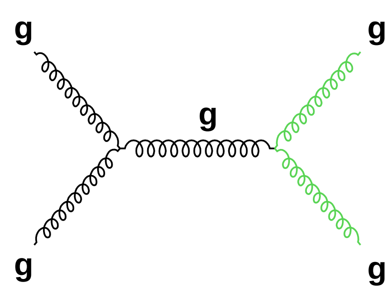


3. two hadronic jets misidentified as photons

e.g.







Analysis Outline

- Select 2 Energetic Photon Objects

- Estimate SM backgrounds:
  - **QCD (jj and γj)** } from data with absolute normalization
  - **$Z/\gamma^* \rightarrow ee$** }
  - direct di-photons (PYTHIA MC with k factor of 1.4)

- Optimize the analysis kinematically

- Look for a bump
  in the diphoton invariant mass spectrum

Selection of $\gamma\gamma$ Candidate Events

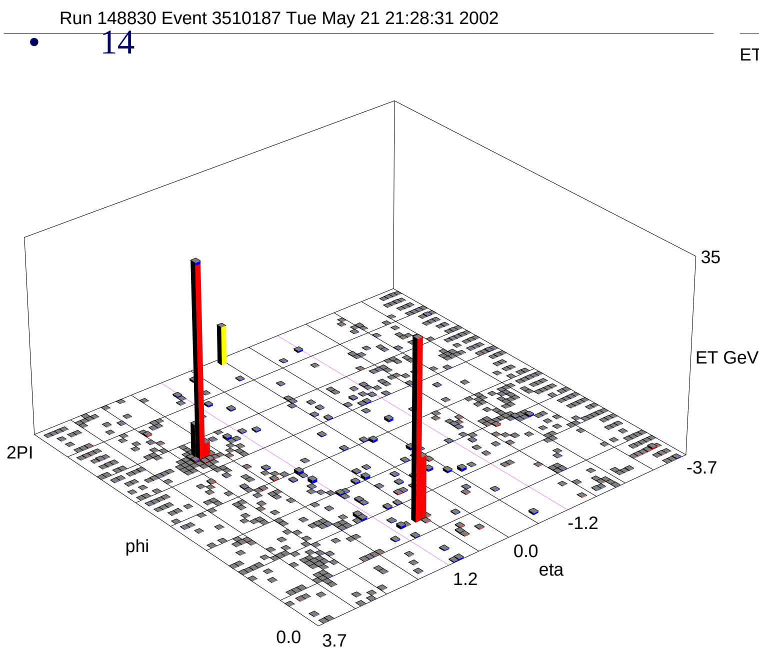
- ***Trigger:***
  di-EM* high p_T trigger

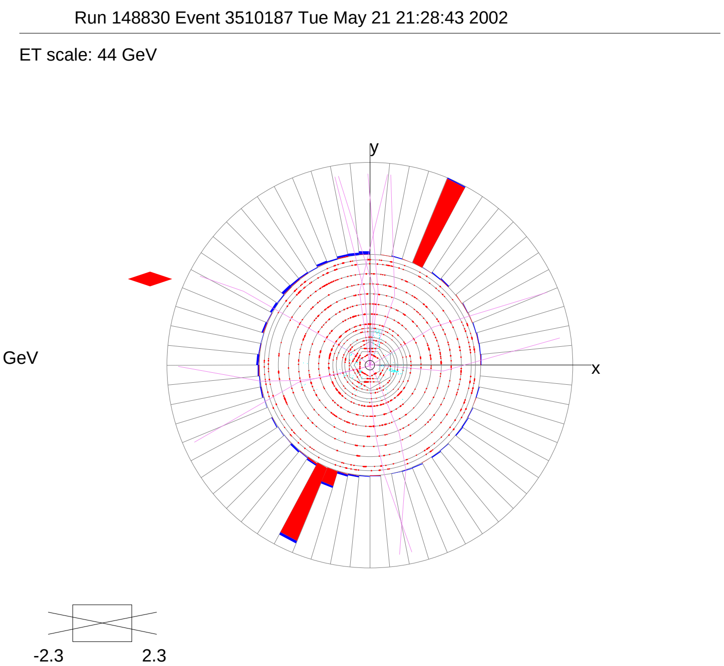
- ***Offline:*** *(on both objects)*
- **Kinematic cuts:** $p_T > 25$GeV
- **Acceptance cuts:** Central or End Cap Calorimeter up to $|\eta|=2.4$
- **Photon ID:** -- shower shape consistent with EM* shape (EMfraction, Isolation, H-matrix $\chi 2$)
  -- sum of p_T of all tracks in a hollow cone of $0.05<R<0.4$ around photon candidate must be < 2.0 GeV
  -- track veto

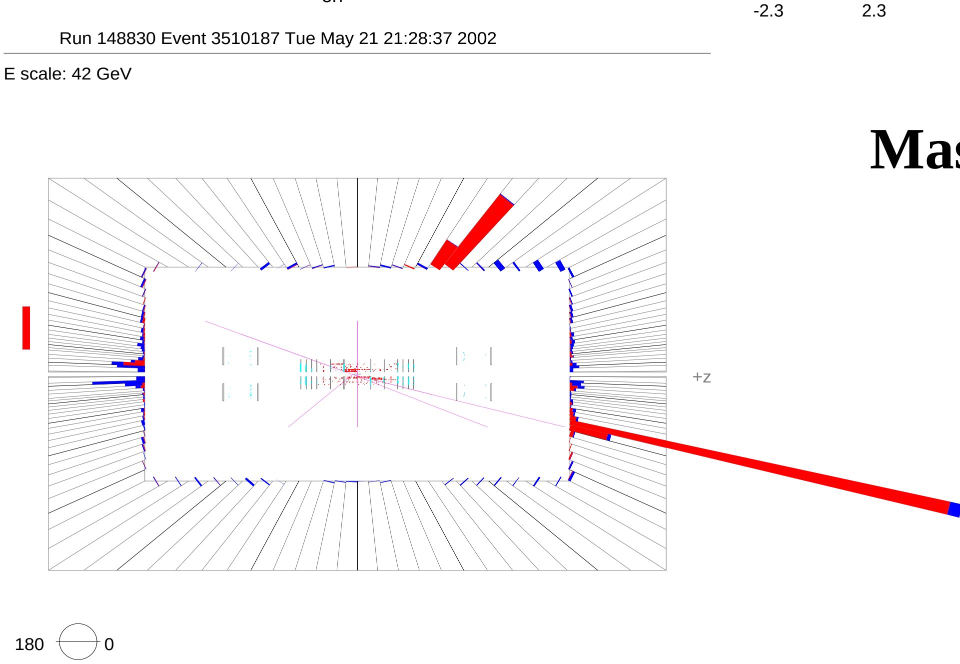
- **EM = Electromagnetic Object (Photon or Electron)*

Event Displays of $\gamma\gamma$ Candidate

- 14







Mass = 125.8 GeV

Definitions of Analysis Objects

LooseEM = reconstructed cluster that passes minimal EMID cuts based on calorimeter info
(EM fraction>0.9 && Isolation<0.15)

Electron/Photon (e/γ) = LooseEM object that passes shower shape cuts and has/NO associated track

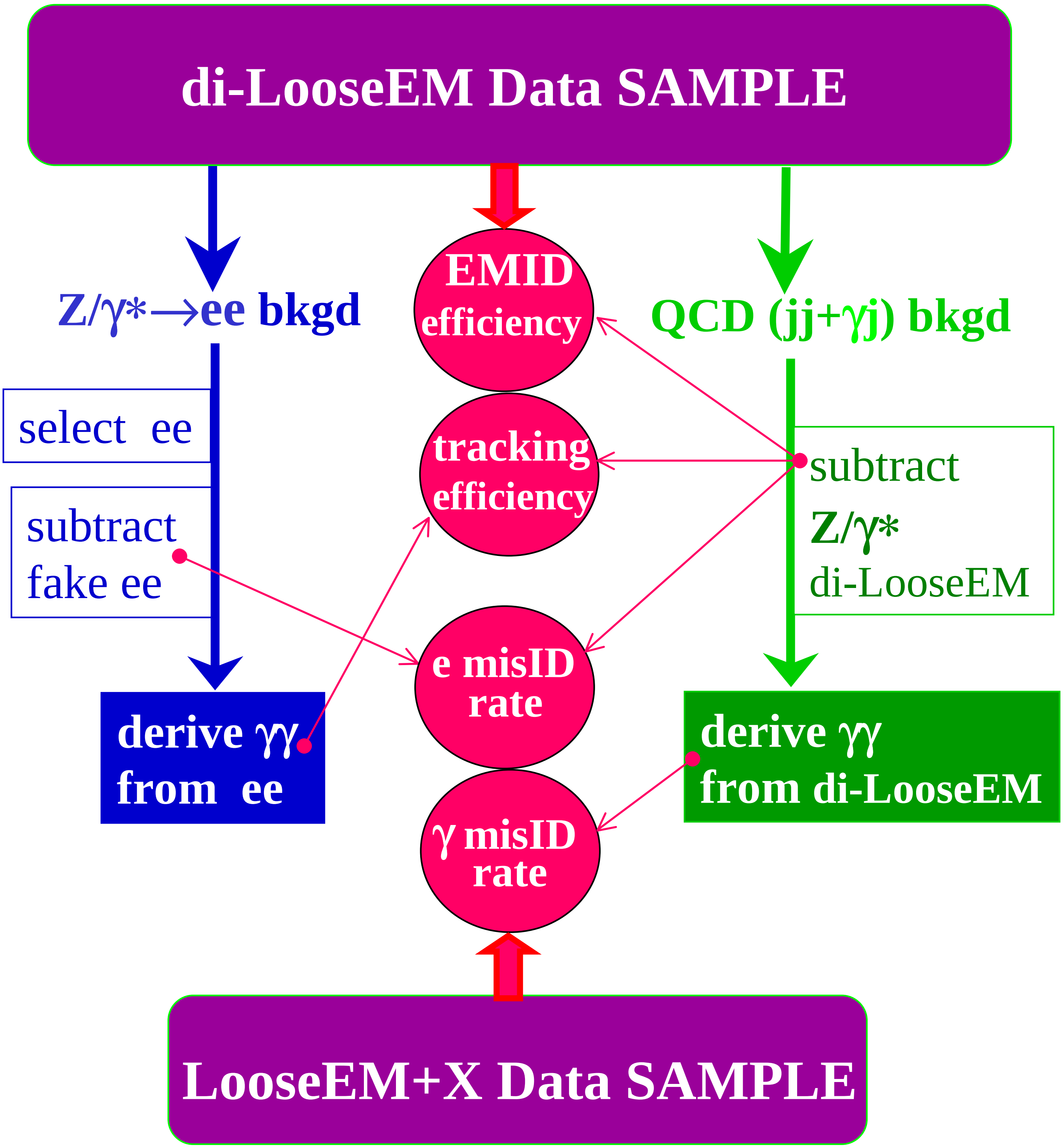
Approximation: Photon = Electron = EM object as far as calorimeter info
(more on this a few slides later)

Deriving $Z/\gamma^* \rightarrow ee$ and QCD jj+ γj backgrounds from data

- Use two orthogonal samples:
  - ü Di-LooseEM
  - ü (Exactly One) Loose EM
    >85% -- misidentified jets
    <15% -- real photons
    } for M_{jj} >100 GeV

- And four measurements :
  - ü EMID efficiency
  - ü Tracking efficiency
  - ü Electron (e) misID rate
  - ü Photon (γ) misID rate

$Z/\gamma^* \rightarrow ee$ and QCD jj+ γj backgrounds (cont'd)



Estimating QCD (jj+γj) Background

$$N_{QCD}(\gamma\gamma) =$$
$$= \{N(\text{di-LooseEM}) - N_{DY}(\text{di-LooseEM})\} \times f^{2}(\gamma)$$

$$N_{DY}(\text{di-LooseEM}) = \frac{N_{DY}(ee)}{\varepsilon^2(EM) \times \varepsilon^2(track)}$$

$$= \frac{[N(ee) - N(\text{di-LooseEM}) \times f^{2}(e)]}{\varepsilon^2(EM) \times \varepsilon^2(track)}$$

$$N_{QCD}(\gamma\gamma) =$$
$$= \{N(\text{di-LooseEM}) - \frac{[N(ee) - N(\text{di-LooseEM}) \times f^{2}(e)]}{\varepsilon^2(EM) \times \varepsilon^2(track)}\} \times f^{2}(\gamma)$$

EMID/tracking efficiencies

Electron/Photon misID rates

Estimating $Z\gamma^* \rightarrow ee$ Background

$$\begin{cases} N_{DY}(ee) = \sigma(pp \rightarrow Z/\gamma^* + X) \times Br(ee) \times L_{int} \times A \times \varepsilon(trigger) \times \varepsilon^2(EM) \times \varepsilon^2(track) \\ N_{DY}(\gamma\gamma) = \sigma(pp \rightarrow Z/\gamma^* + X) \times Br(ee) \times L_{int} \times A \times \varepsilon(trigger) \times \varepsilon^2(EM) \times [1-\varepsilon(track)]^2 \end{cases}$$

$$N_{DY}(\gamma\gamma) = N_{DY}(ee) \times \frac{[1-\varepsilon(track)]^2}{\varepsilon^2(track)} =$$

$$= \{N(ee) - N(\text{misidentified ee})\} \times \frac{[1-\varepsilon(track)]^2}{\varepsilon^2(track)}$$

$$= \{N(ee) - N(\text{di-LooseEM}) \times f^2(e)\} \times \frac{[1-\varepsilon(track)]^2}{\varepsilon^2(track)}$$

Electron misidentification rate

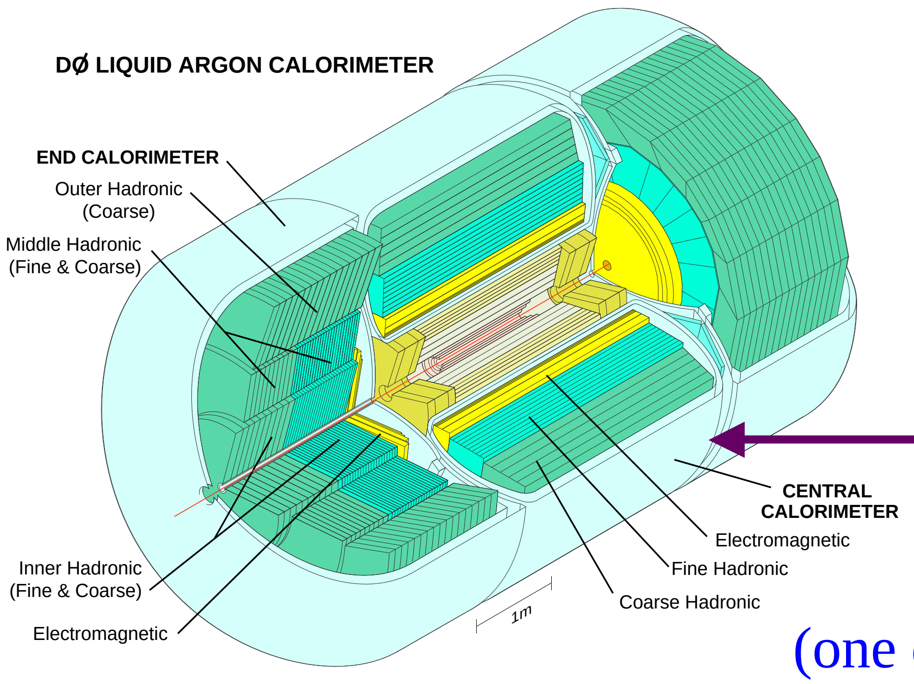
Tracking efficiency

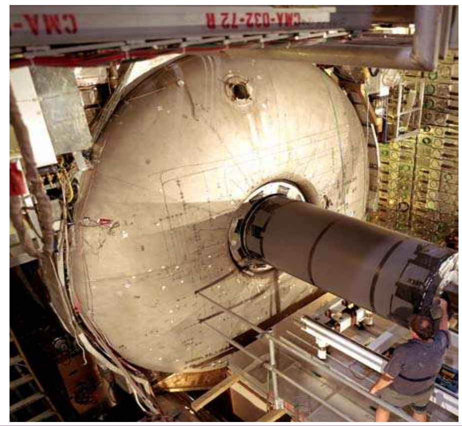
Relying on Electrons for Photon ID

- Ideally we would use high P_T photon sample from diphoton decays of a ~>100 GeV scalar (if there were one available) for Photon ID efficiency for the Higgs search
- In reality we rely on
  - $Z \to ee$ electrons from data
  - $Z \to ee$ and $H \to \gamma\gamma$ Monte Carlo to correct for the difference between electron and photon efficiency
  - **Assumption:** MC e/γ difference = e/γ difference in real data

DØ Calorimeter

Central Calorimeter (CC) and 2 End Calorimeters (EC)





End-View of CC

(one quarter) rz-view of the D0 calorimeter

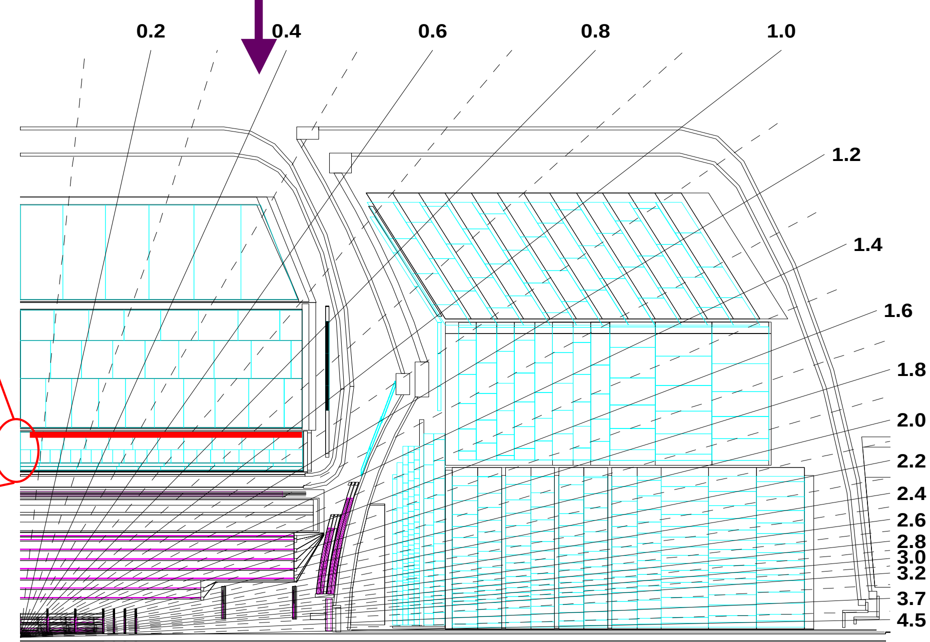
EM calorimeter

EM4: $10X_0$

EM3: $7X_0$

EM2: $2X_0$

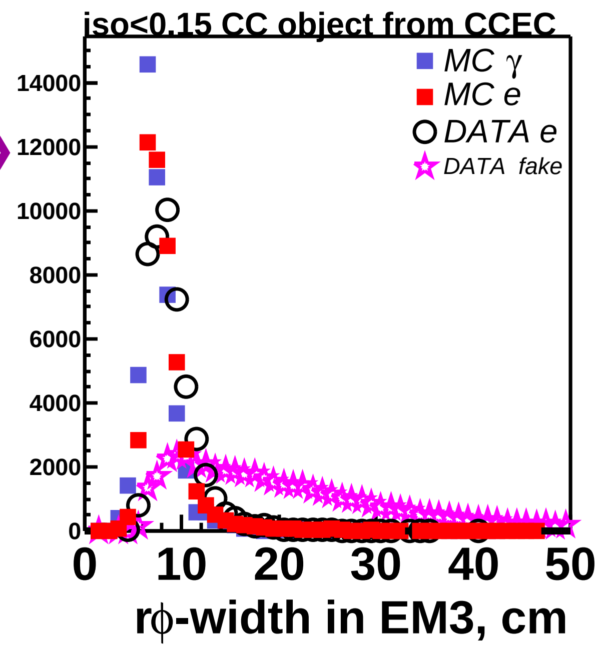
EM1: $2X_0$



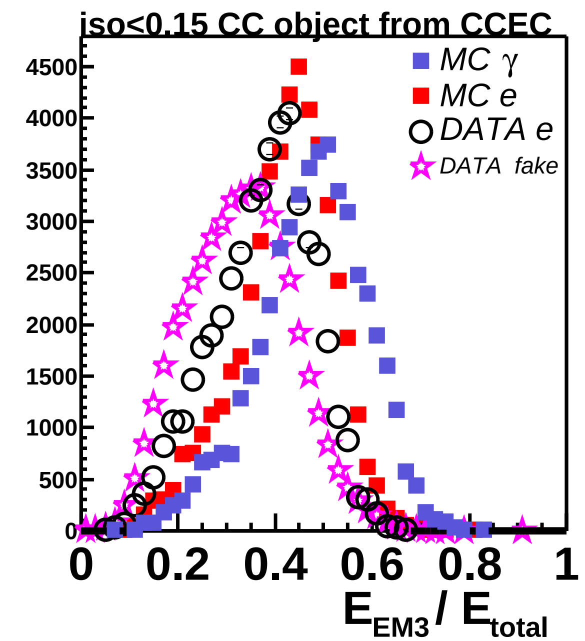
look at some shower properties in EM3

Photon and Electron Shower Properties

rφ-width in EM3



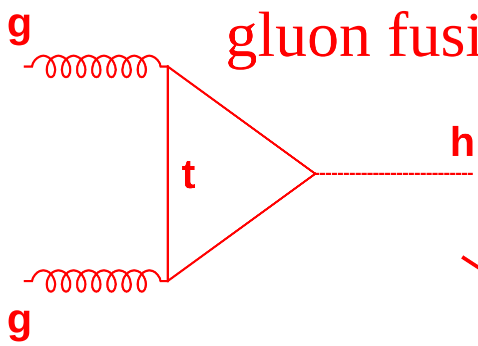
$$\frac{\text{Energy(EM3)}}{\text{Total Energy}}$$

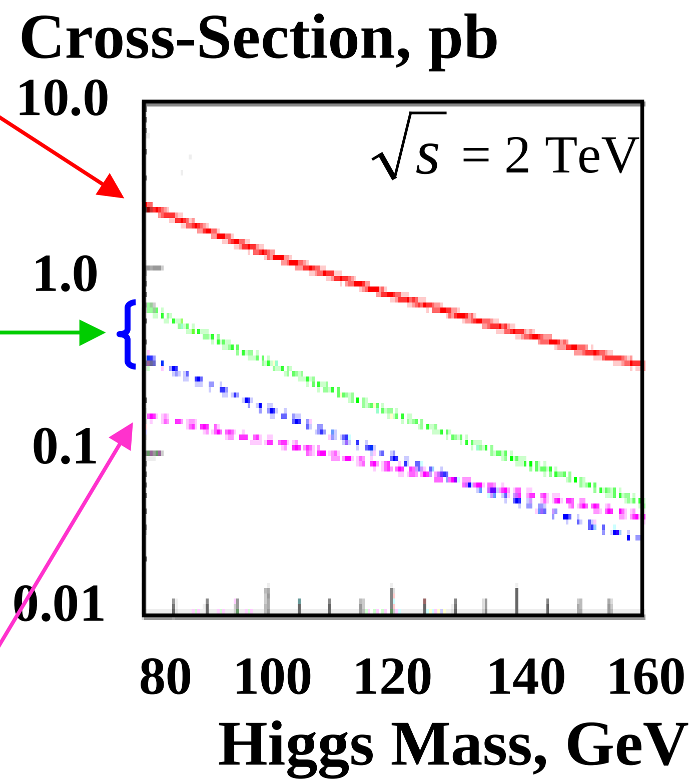


Leading SM Higgs Production Processes at Tevatron

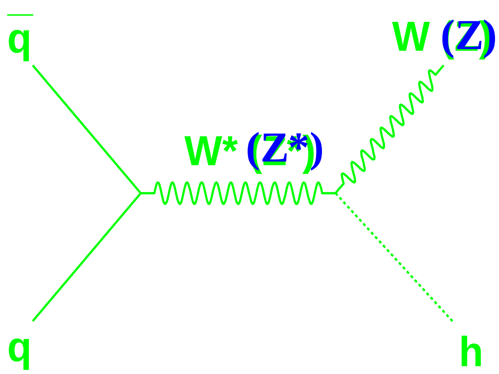
gluon fusion: cross-section ~ m^2

$\Rightarrow$ the top-quark loop is dominant

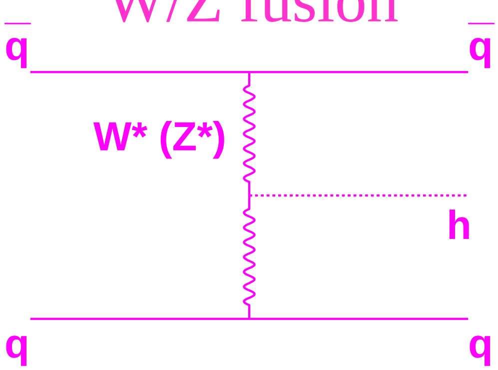




W/Z associated



W/Z fusion

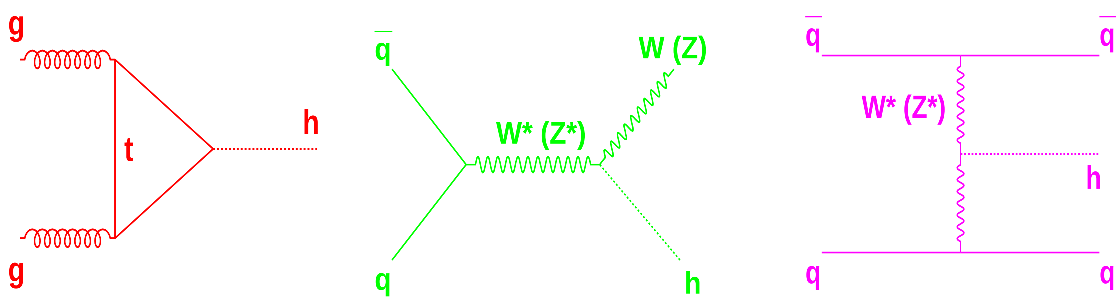


quark-antiquark fusion cross-section is small :

- Higgs-fermion coupling ~ m_f
- Masses of u,d quarks are small

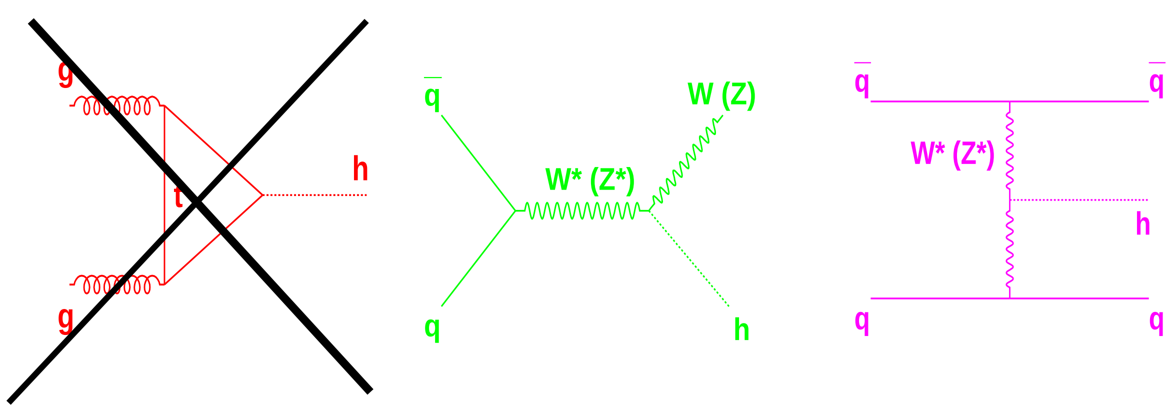
Topcolor and Fermiophobic Scenarios

Topcolor Higgs (all major production mechanisms)



Fermiophobic Higgs (no gluon fusion)

expect large transverse boost of the Higgs

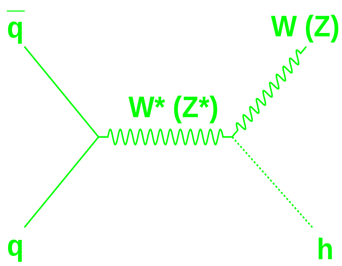


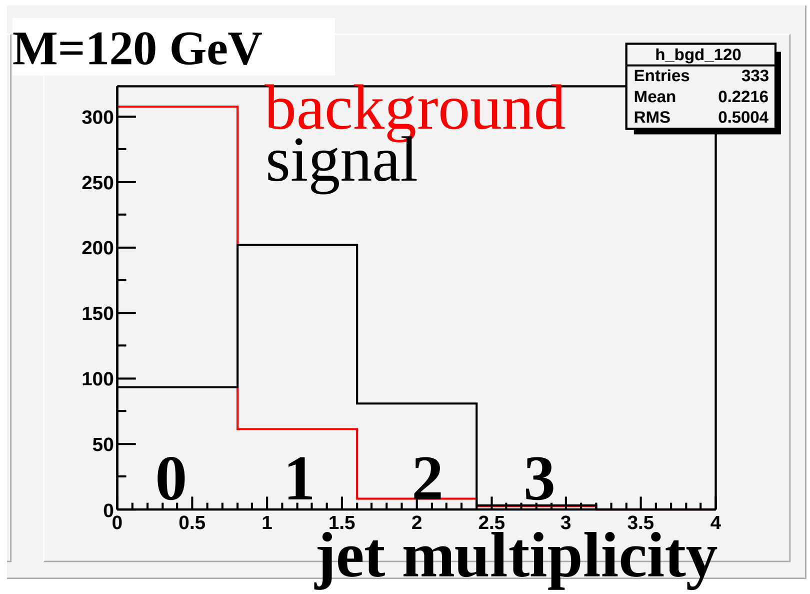
Jet multiplicity and $p_T^{\gamma\gamma}$

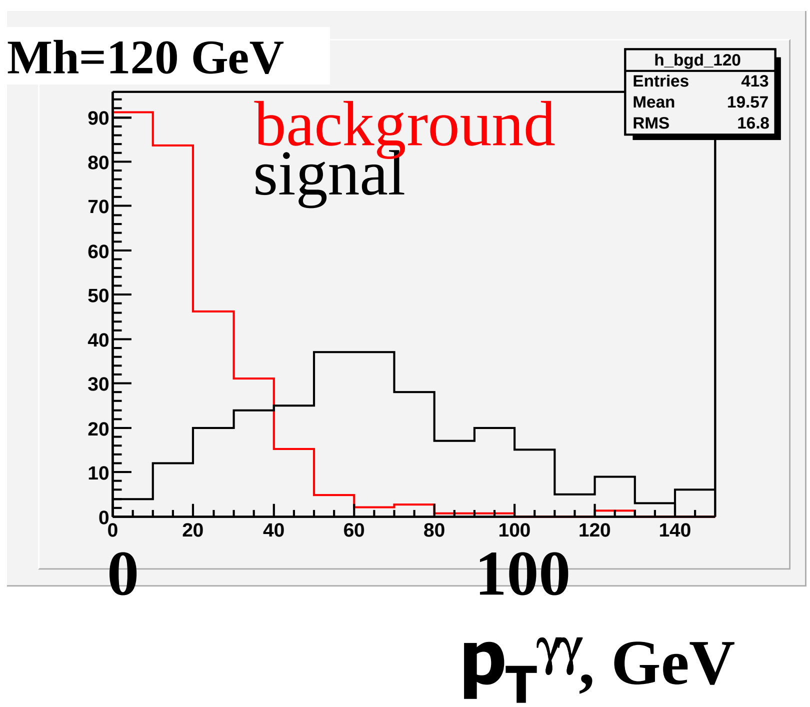
Jet multiplicity and $p_T^{\gamma\gamma}$ are correlated

Signal :

Higgs p_T ($p_T^{\gamma\gamma}$)
is balanced
by the p_T of the jets

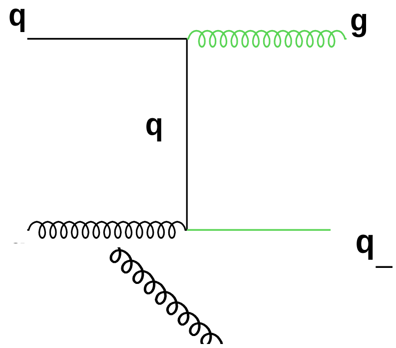






Background :

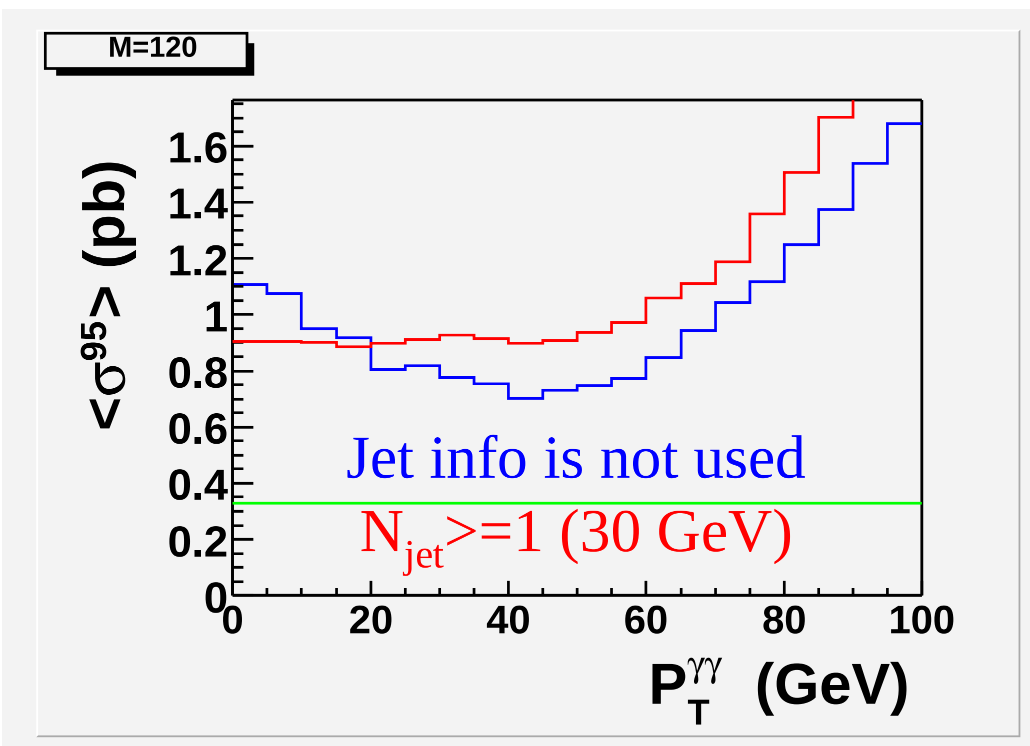
p_T of misidentified
diphotons is balanced
by ISR jet p_T



Expected Cross Section Limit vs $p_T^{\gamma\gamma}$

$$< \sigma^{95} > = \sum_{n=0}^{\infty} \sigma^{95}(n,S|B)\, e^{-B} \frac{B^n}{n!}$$

S = number of signal events
B = number of background events
n = observed events
$\sigma^{95}(n,S|B)$ = 95%CL cross-section limit



Optimal choice of variables to cut on:

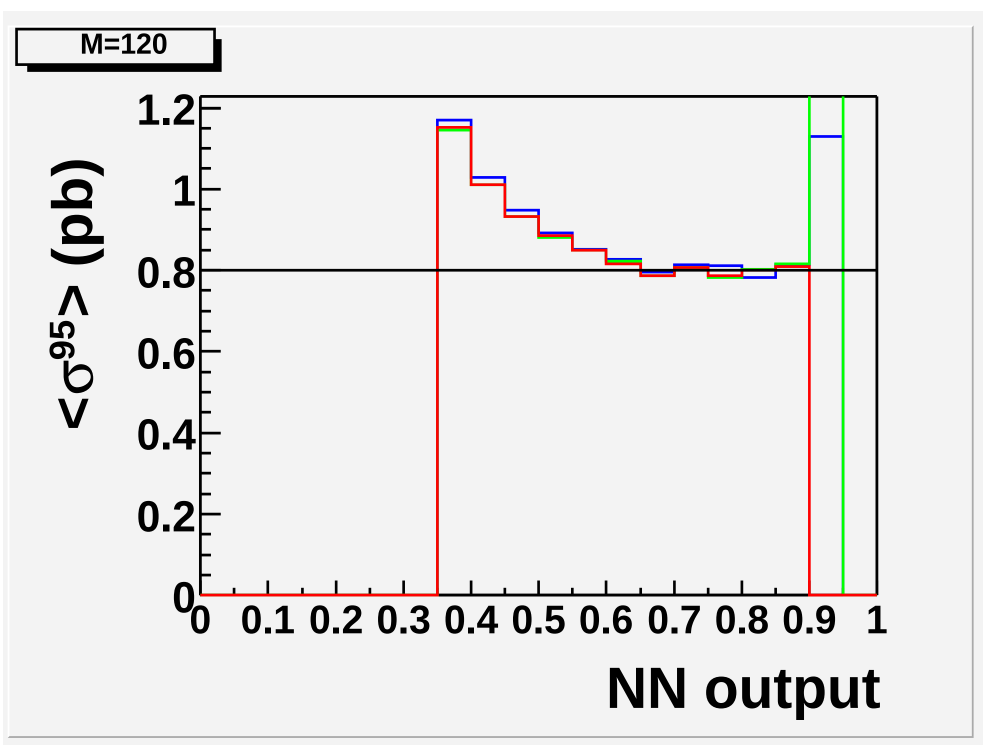
$p_T^{\gamma\gamma}$ -- yes
jet multiplicity -- no

Other Kinematic Variables ?
No.

- Helicity Angle
- Energy Asymmetry

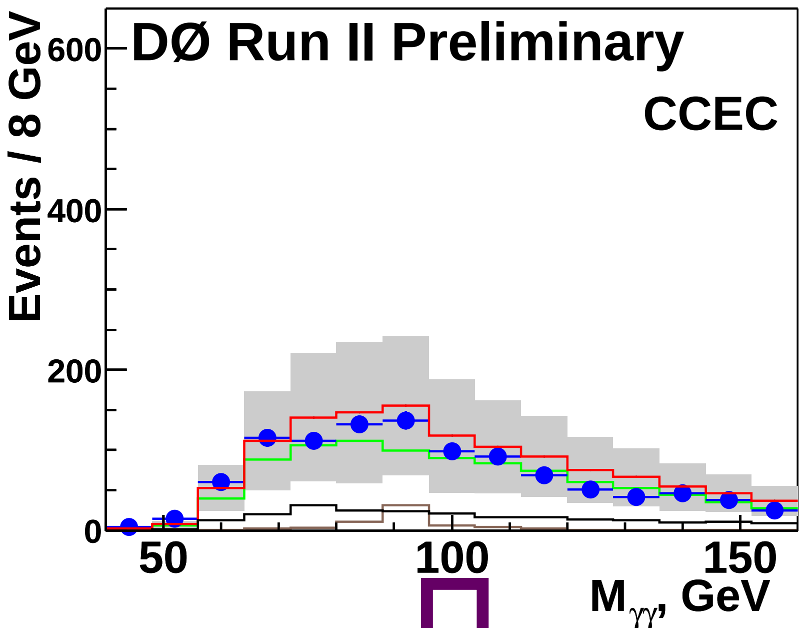
Consider three NN input configurations :

1. Diphoton PT, |cosθ*|, (E1–E2)/(E1+E2)
2. Diphoton PT, |cosθ*|
3. Diphoton PT, (E1–E2)/(E1+E2)



Di-photon mass spectra,

$\int L dt \approx 190 pb^{-1}$ (≈ half of the currently available data)



data = 1037.0

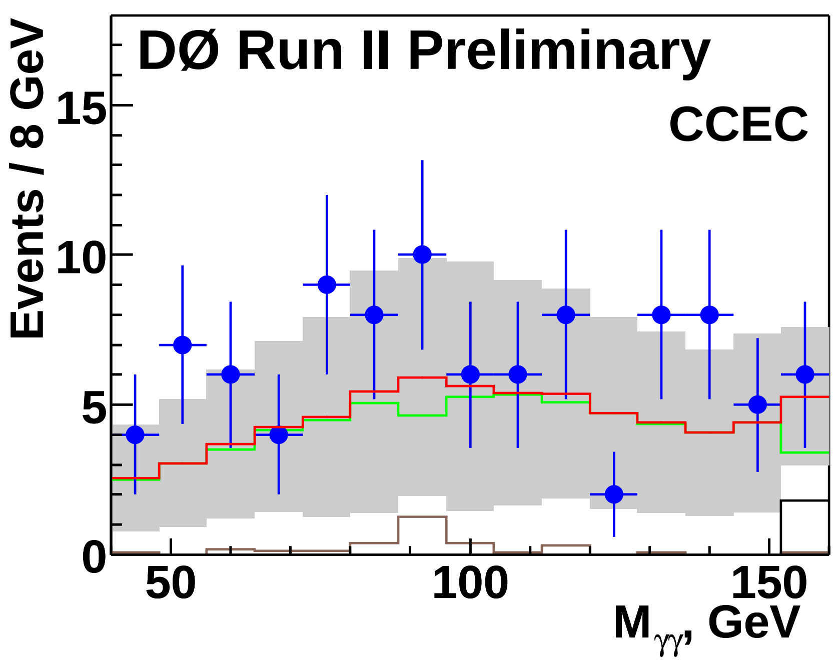
bkgd = 1211.5 +- 671.0

QCD = 922.1 +- 667.2

DY = 64.8 +- 69.4

$\gamma\gamma$ = 224.5 +- 16.6

Diphoton PT (35 GeV)cut



data = 97.0

bkgd = 68.8 +- 45.8

QCD = 64.0 +- 45.7

DY = 3.0 +- 3.0

$\gamma\gamma$ = 1.8 +- 0.1

Setting Limits on the Diphoton Branching Fraction

• Count di-photons in a mass window
G.Landsberg , K.Matchev Phys. Rev. ***D62****, 035004 (2000)*

• Derive Higgs cross section limits using Bayesian Approach

• Convert to limits on branching fractions

• Consider two scenarios:

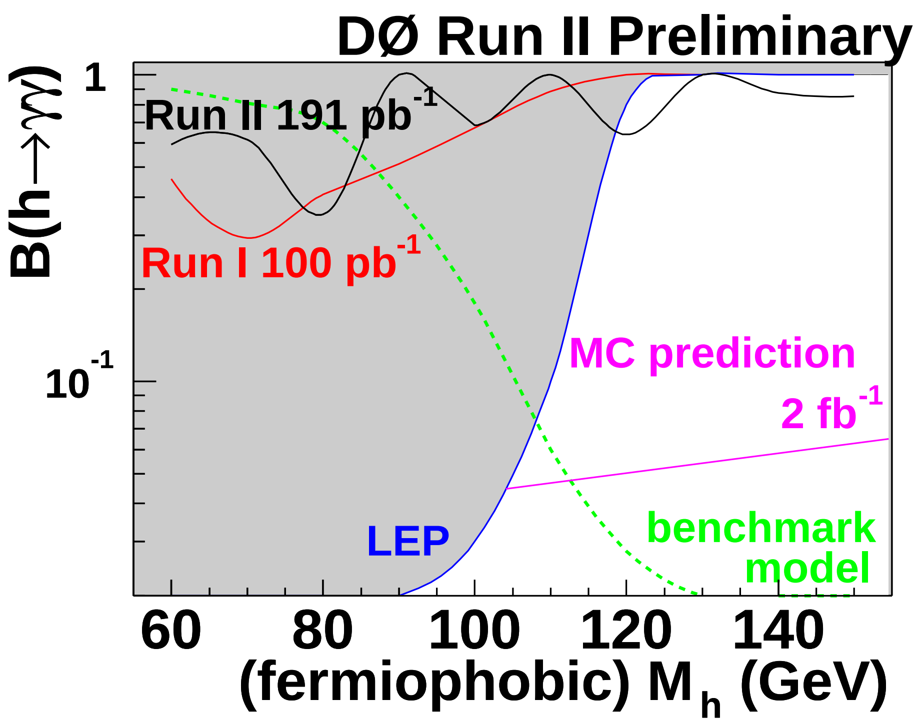
-- Fermiophobic Higgs
(does not couple to fermions)
Production mechanisms:

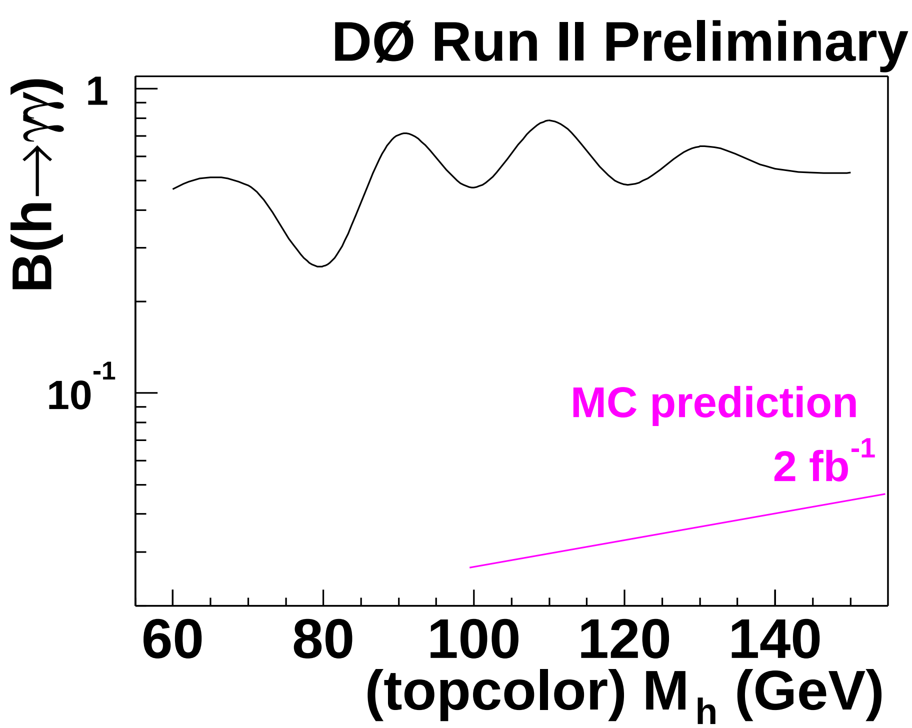
1. W/Z associated production
2. W/Z fusion

--Topcolor Higgs
(of all fermions couples only to top)
Production mechanisms:

1. W/Z associated production
2. W/Z fusion
3. gluon fusion

$B(h \to \gamma\gamma)$ Limits



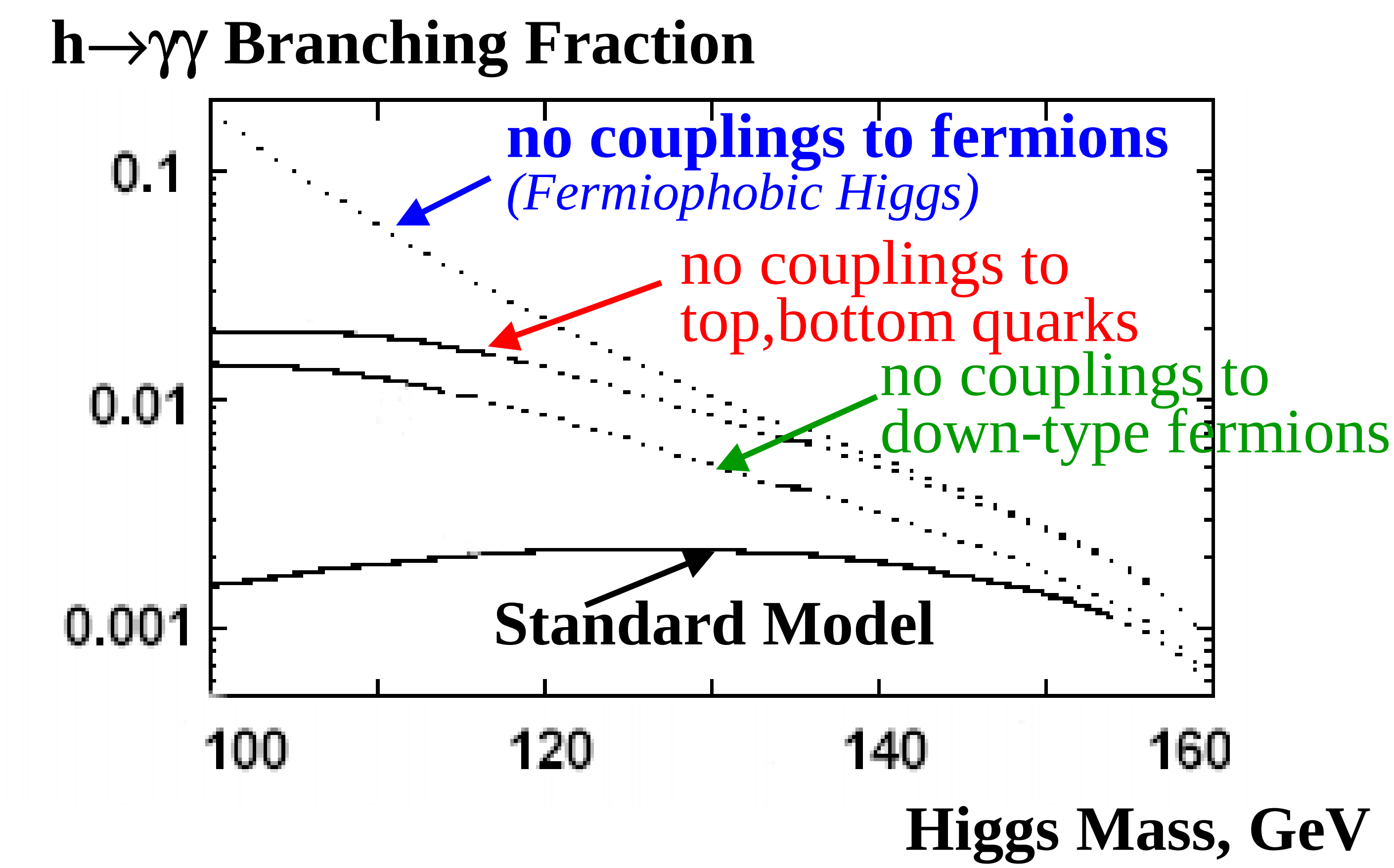


Summary

- A Search for the Fermiophobic and Topcolor Higgs boson has been performed in the inclusive $h \rightarrow \gamma\gamma + X$ channel with 190 pb^{-1} of DØ data collected between April 2002 and September 2003
- In the absence of excess we set limits on the branching fraction
- Limits are comparable with those of DØ Run I
- Work on improving sensitivity is in progress
- More data is being accumulated
- Stay tuned for new results

Back Up Slides Start Here

Examples of Enhancement of h→γγ decays

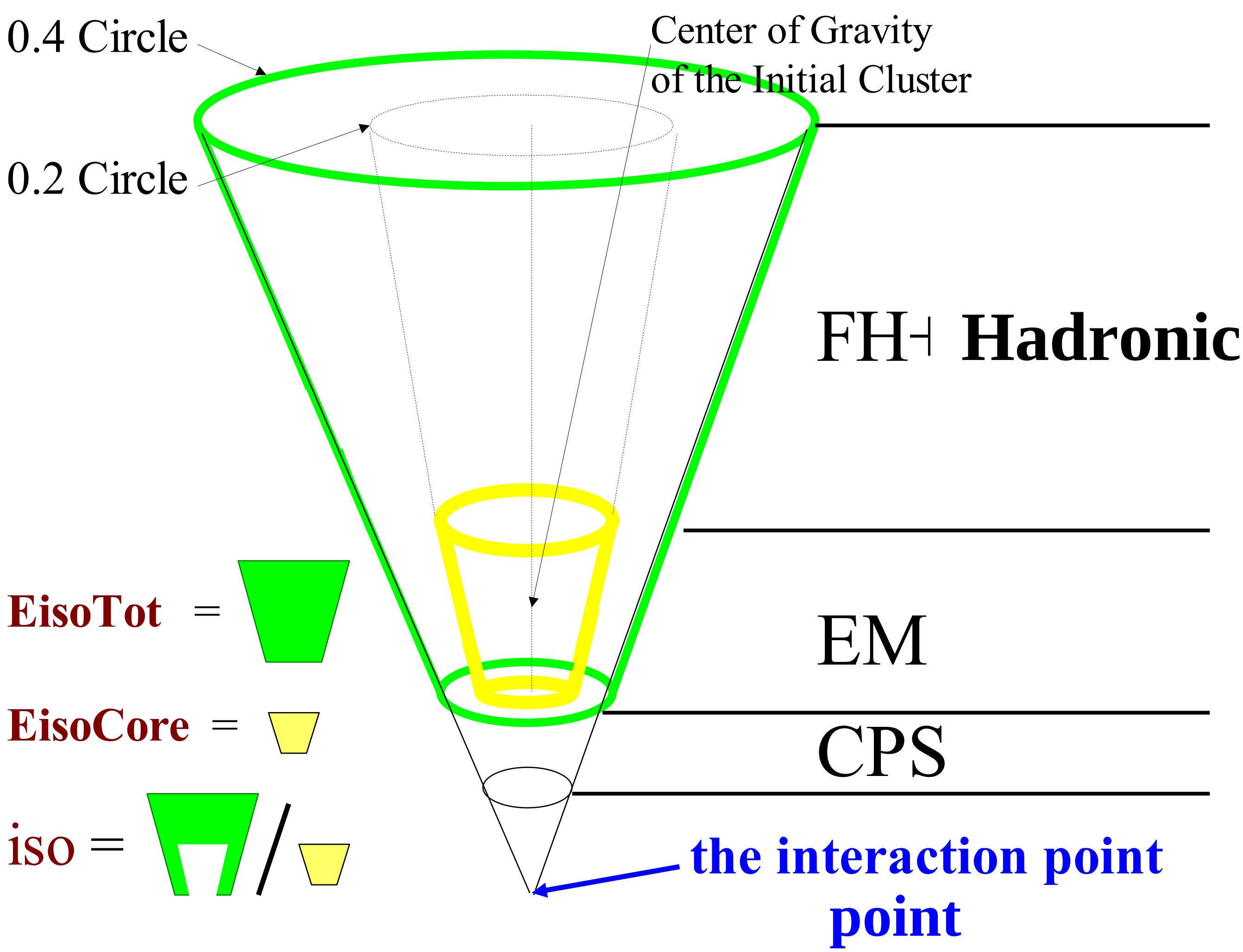


S.Mrenna, J.Wells, Phys. Rev. ***D63****, 015006 (2001)*

in general we should be prepared for any h→γγ branching fraction (up to 1.0) due to new physics

Identification of a Photon Shower in the Calorimeter. Isolation

Photon-induced shower is smaller than quark/gluon shower both transversely and longitudinally



Photon ID Tools
(Monte Carlo Distributions)

EM fraction

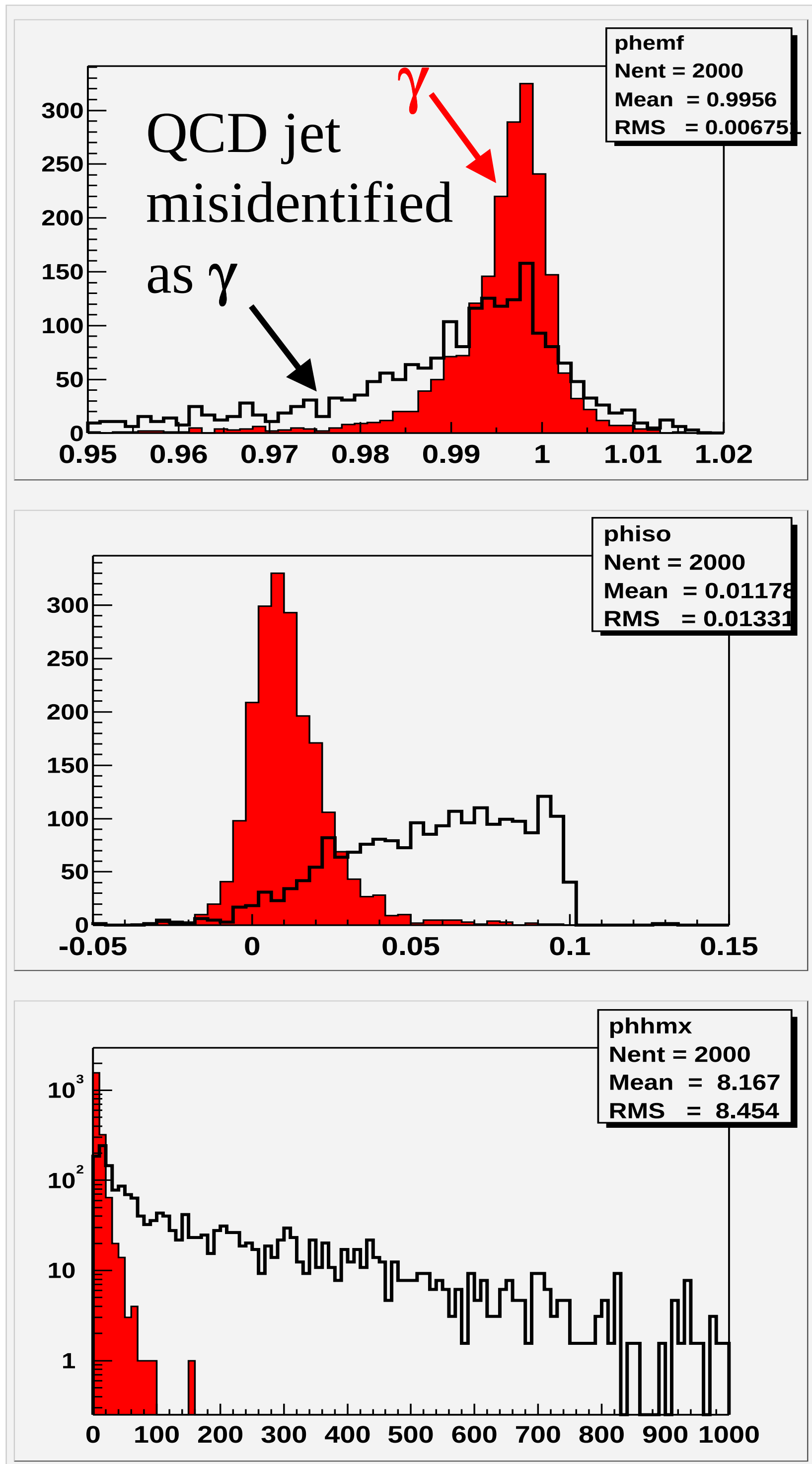
ratio of EM cluster energy deposited in EM calorimeter and total energy

Isolation
(previous slide)

measure of cluster narrowness

multi-variable shower shape tool

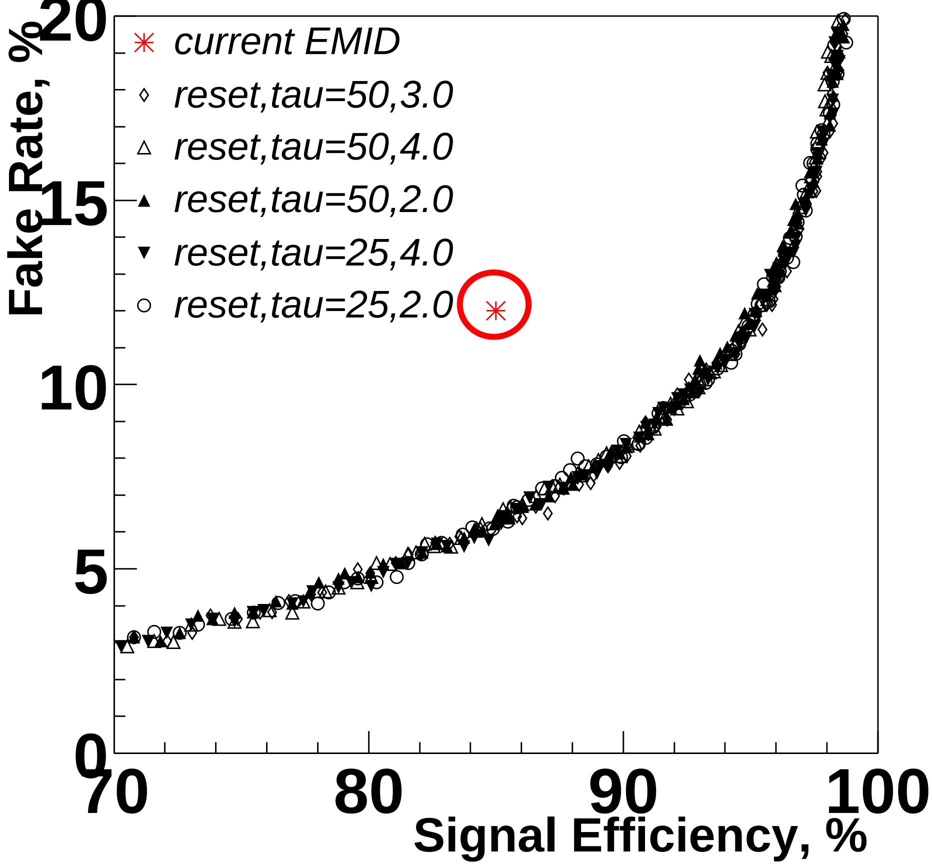
- layer energy fractions
- width at shower maximum



Neural Net Studies

- Try to use Neural Nets for photon identification to suppress background
- Preliminary studies indicate significant improvement over current EMID

Neural Net performance curves.
Varying training method parameters



- Plan to incorporate new ID in the analysis