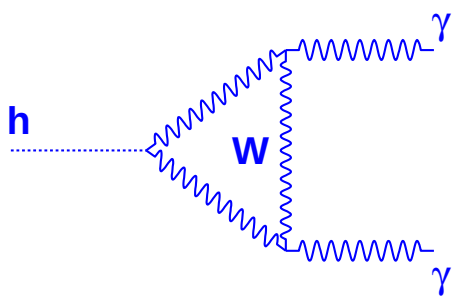
Search for Fermiophobic and Topcolor Higgs in the Diphoton Final States at DØ

Alex Melnitchouk
University of Mississippi
for the DØ collaboration

DPF 2004
August 30
Riverside, CA

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

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

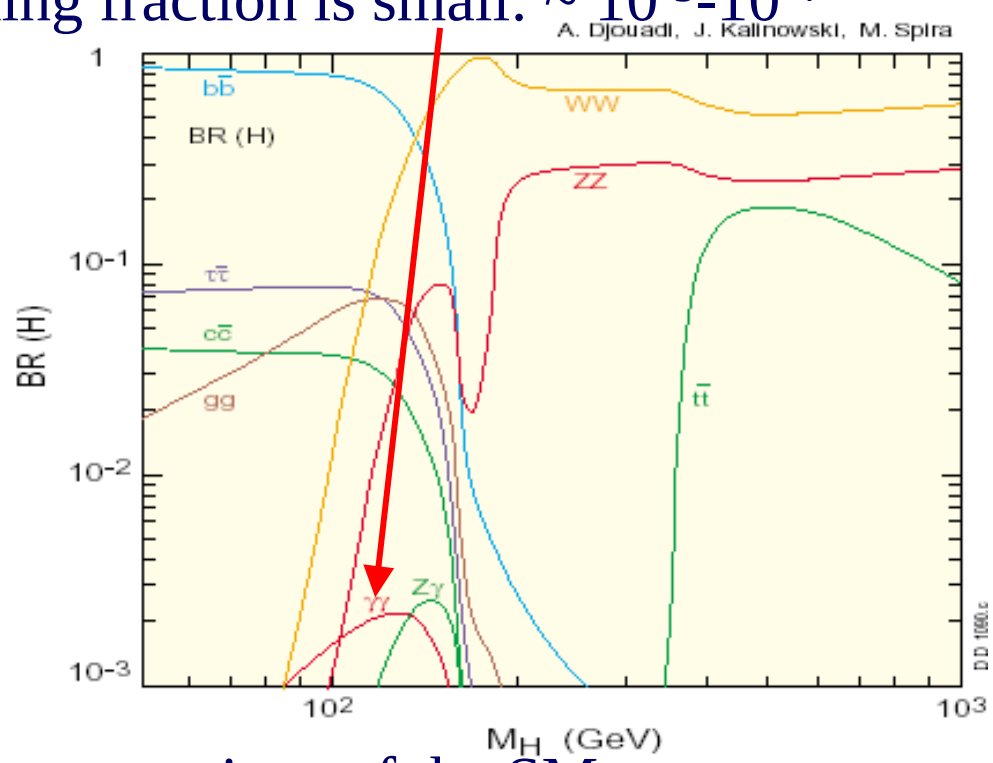


(top-quark loop reduces $H \to \gamma\gamma$ width by 20-30% due to destructive interference)

$\Rightarrow$

- $H \to \gamma\gamma$ 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 $h \to \gamma\gamma$ Decays be Enhanced

- One possibility: suppress fermion decay rates (then the full decay width would only be shared with $h \to WW$ and $H \to ZZ$ 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:

$$(1/\mathbf{v})\, 2m^2_W W^+W^-H$$
$$(1/\mathbf{v})\, m^2_Z ZZH$$
$$(1/\mathbf{v})\, m_f \psi\psi H$$

- 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

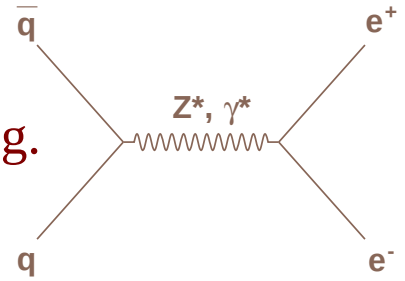
- Strong dynamics [1] :
  EWSB = via technicolor condensation,
  fermion masses = via "extended techncolor"
- Generic two Higgs doublet model [2]:
  v1 – W,Z masses, v2 – fermion masses
- Top-condensation model + Higgs [3]
  top and bottom quarks get their masses from the topcolor interaction while **Higgs 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

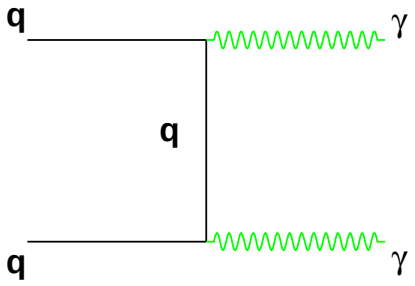
- **$Z/\gamma^* \rightarrow e^+e^-$** with e^+e^- misidentified as photons (lost tracks)

e.g.



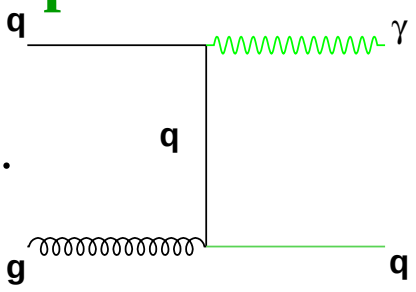
- **QCD processes that in the final state contain :**

1. two photons



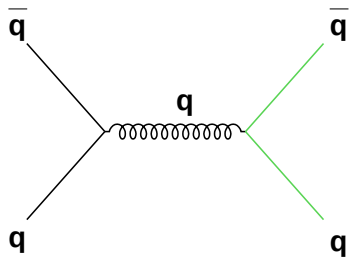
2. a photon and **a hadronic jet misidentified as photon**

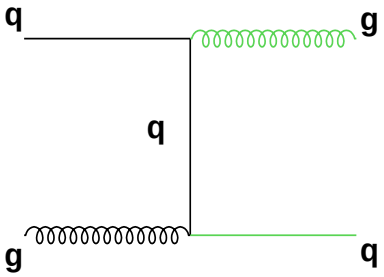
e.g.

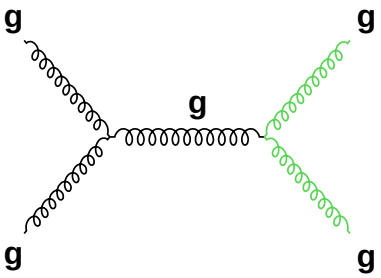


3. two hadronic jets misidentified as photons

e.g.

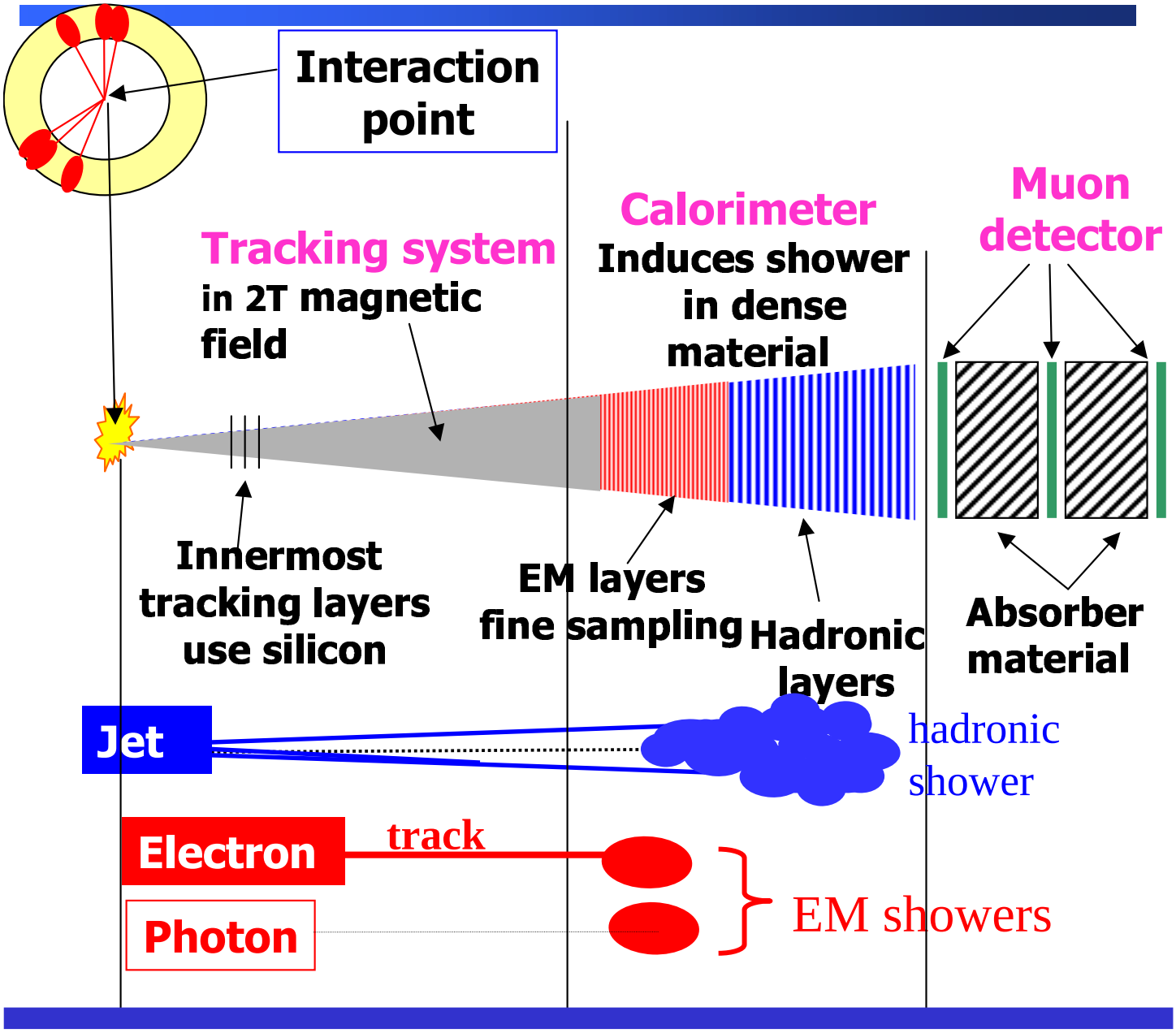






A Slice of the DØ Detector.

Experimental Signature of a Photon



Photon : EM-like shower in the calorimeter WITHOUT associated track

Analysis Outline

- Select 2 Energetic Photon Objects

- Estimate SM backgrounds:

  - **QCD (jj and γj)**
  - **Z/γ*→ee**

  } from data with absolute normalization

  - direct di-photons (PYTHIA MC with k factor of 1.4)

- Look for a bump
  in the diphoton invariant mass spectrum

Selection of $\gamma\gamma$ Candidate Events

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

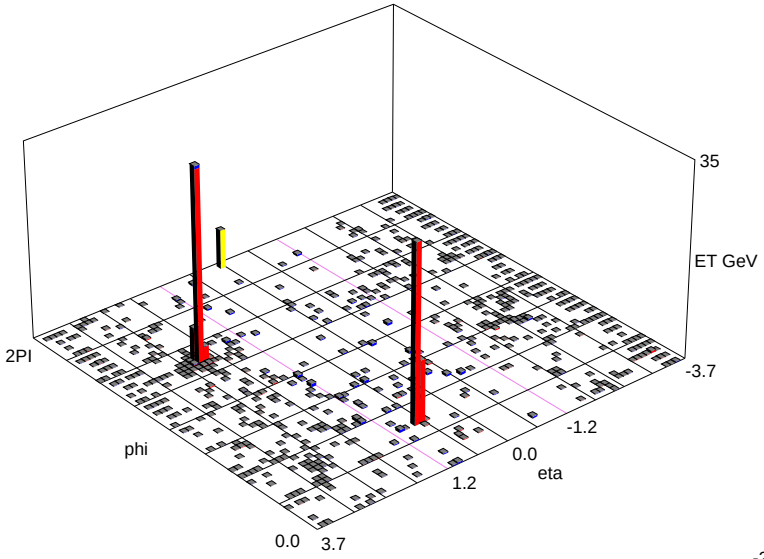
- ***Offline:*** *(on both objects)*
- **Kinematic cuts:** $p_T > 25$GeV
- **Acceptance cuts:** Central or End Cap Calorimeter up to $|\eta|=2.4$
- **Photon ID:** -- shower shape consistent with EM* shape (EMfraction, Isolation, H-matrix $\chi 2$)
  -- sum of p_T of all tracks in a hollow cone of $0.05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

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

Event Displays of γγ Candidate

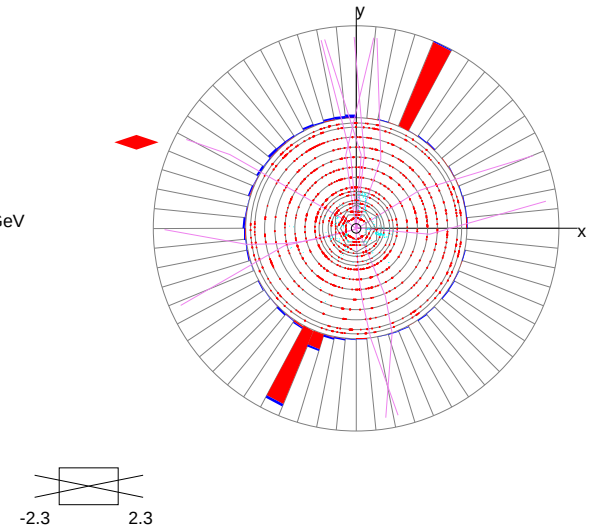
- 14

Run 148830 Event 3510187 Tue May 21 21:28:31 2002



Run 148830 Event 3510187 Tue May 21 21:28:43 2002

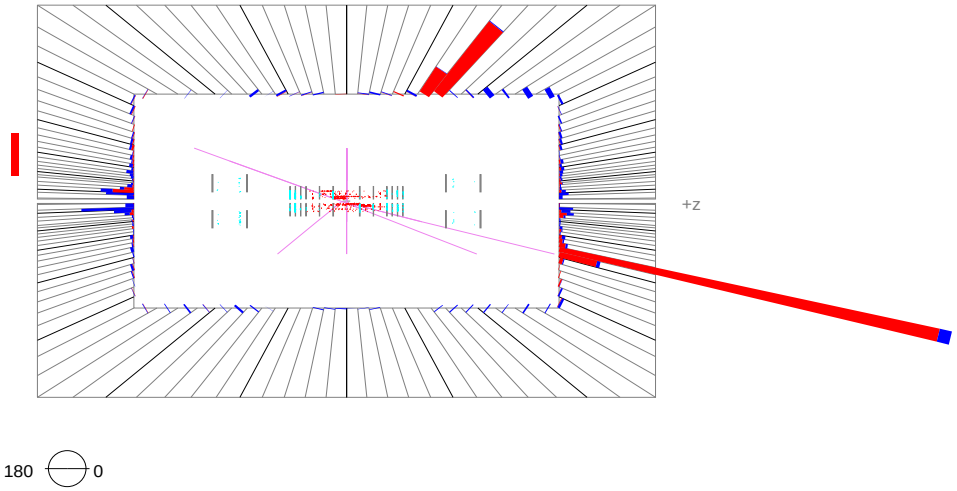
ET scale: 44 GeV



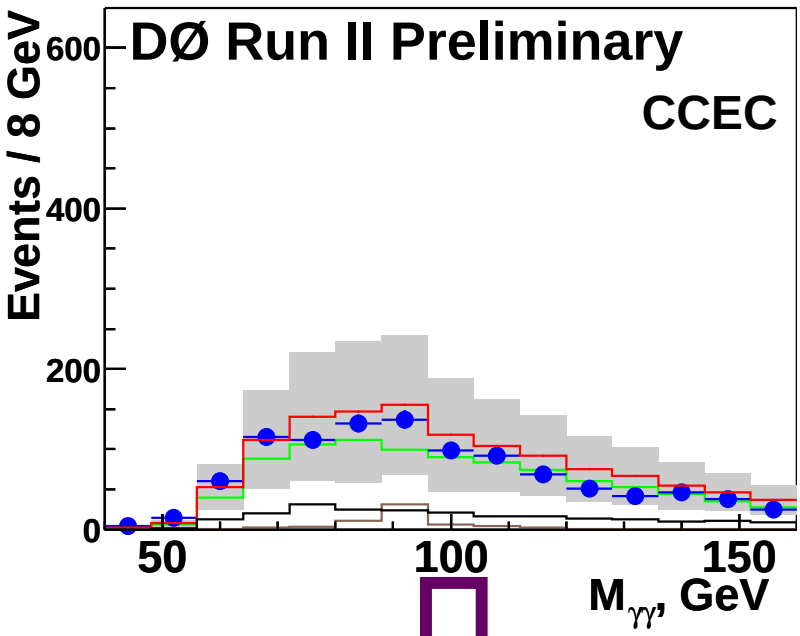
Run 148830 Event 3510187 Tue May 21 21:28:37 2002

E scale: 42 GeV

Mass = 125.8 GeV



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



data = 1037.0

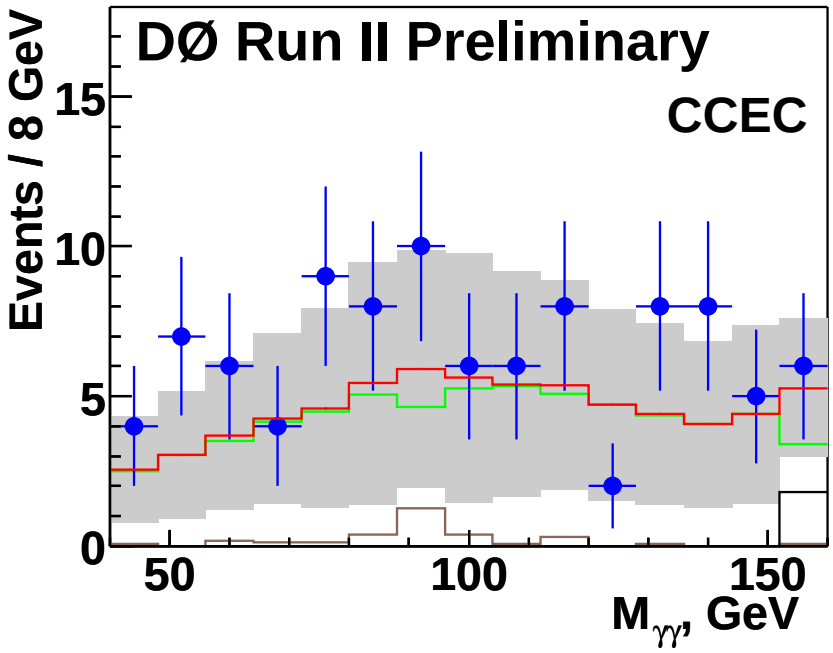
bkgd = 1211.5 +- 671.0

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

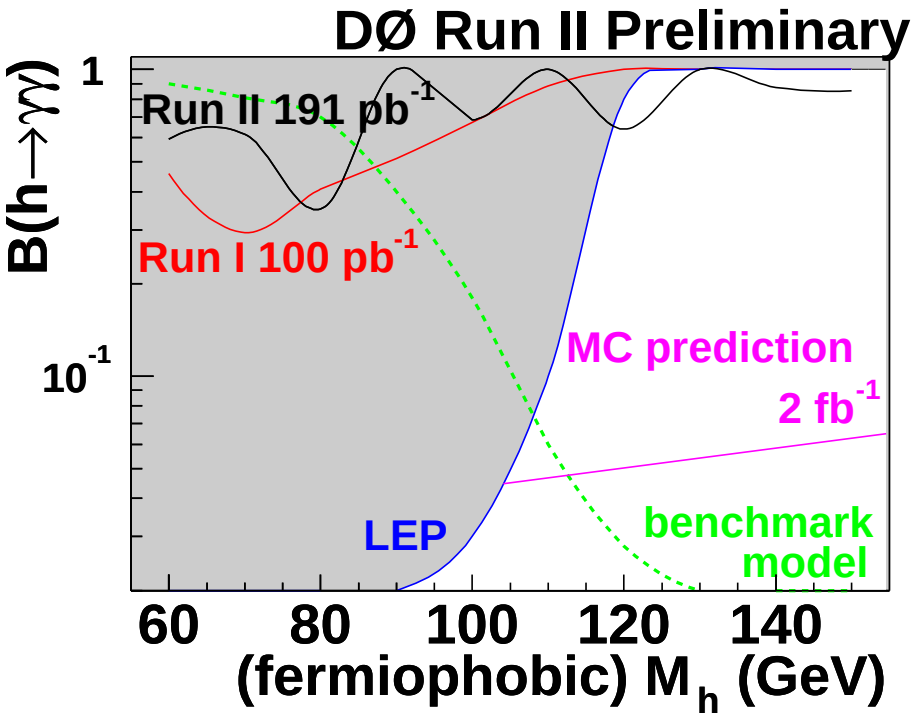
  --Topcolor Higgs

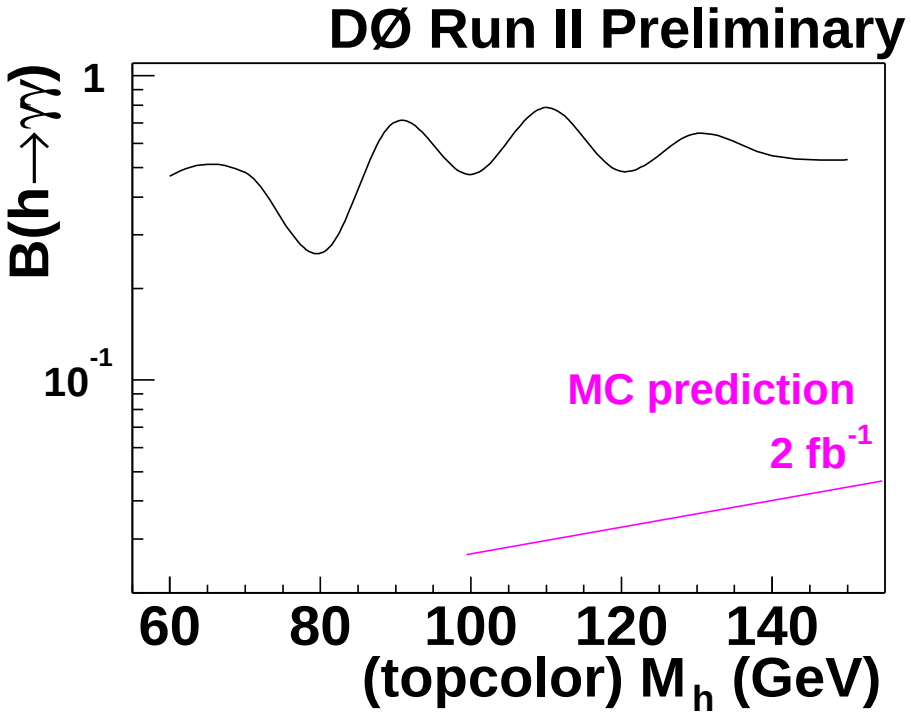
  (of all fermions couples only to top)

  Production mechanisms:

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

B(h→γγ) Limits

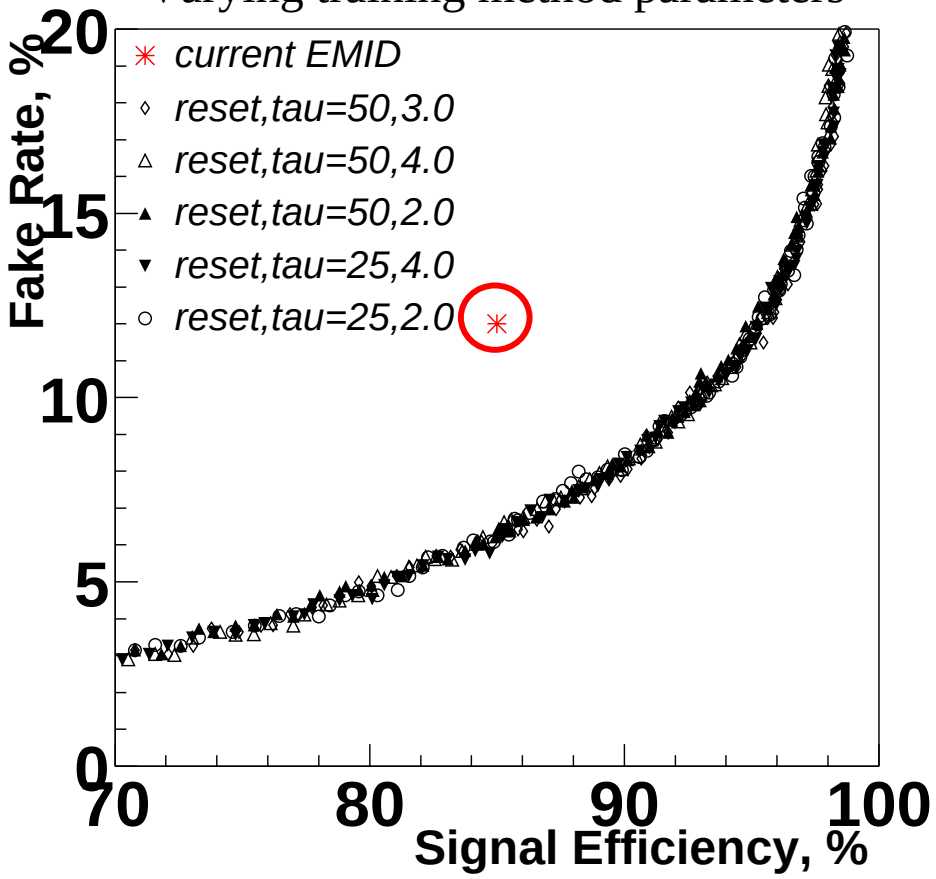

DØ Run II Preliminary
B(h→γγ)
1
10^-1
Run II 191 pb^-1
Run I 100 pb^-1
MC prediction
2 fb^-1
LEP
benchmark
model
60
80
100
120
140
(fermiophobic) M_h (GeV)


DØ Run II Preliminary
B(h→γγ)
1
10^-1
MC prediction
2 fb^-1
60
80
100
120
140
(topcolor) M_h (GeV)

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



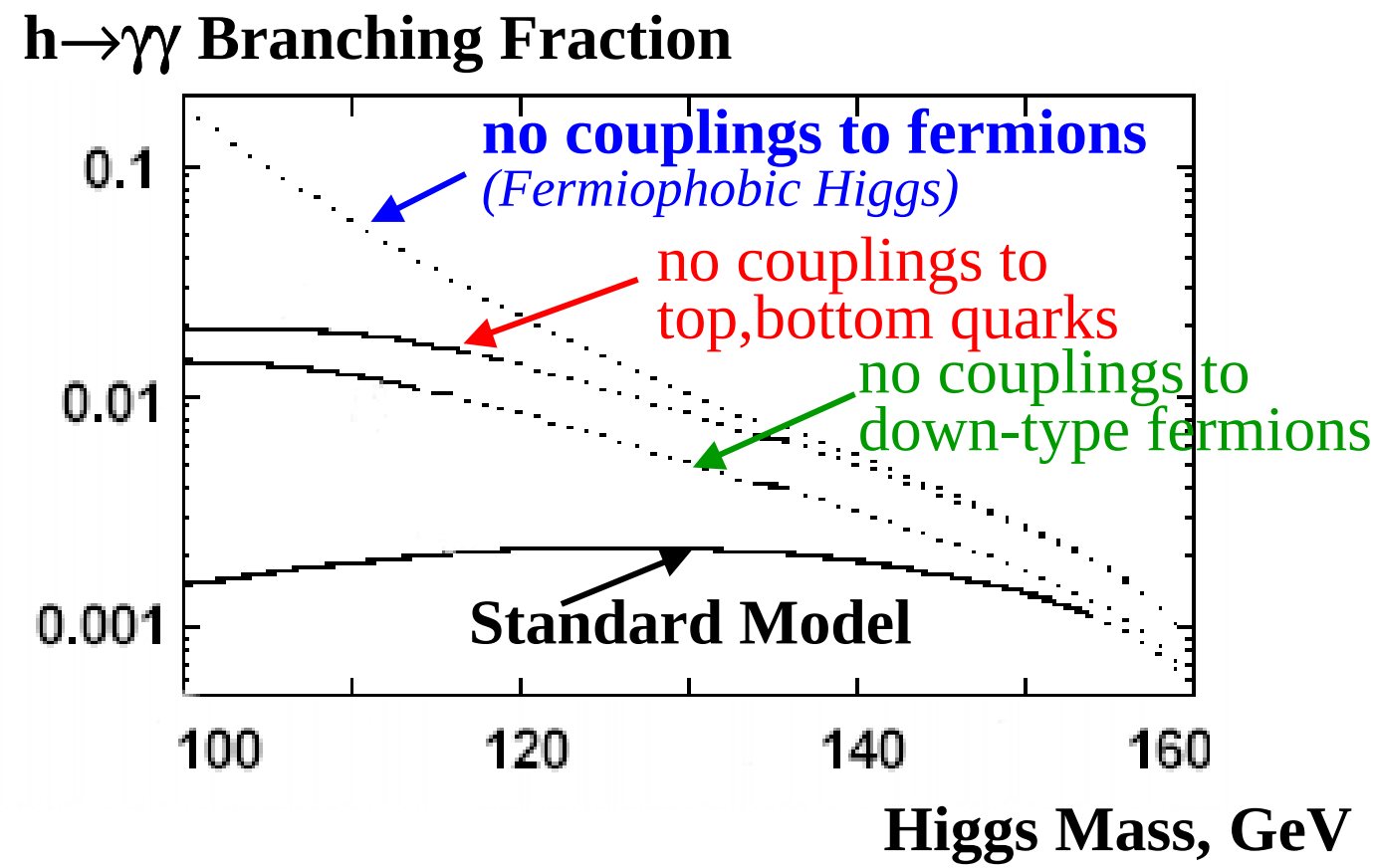
- Plan to incorporate new ID in the analysis

Conclusions

- 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

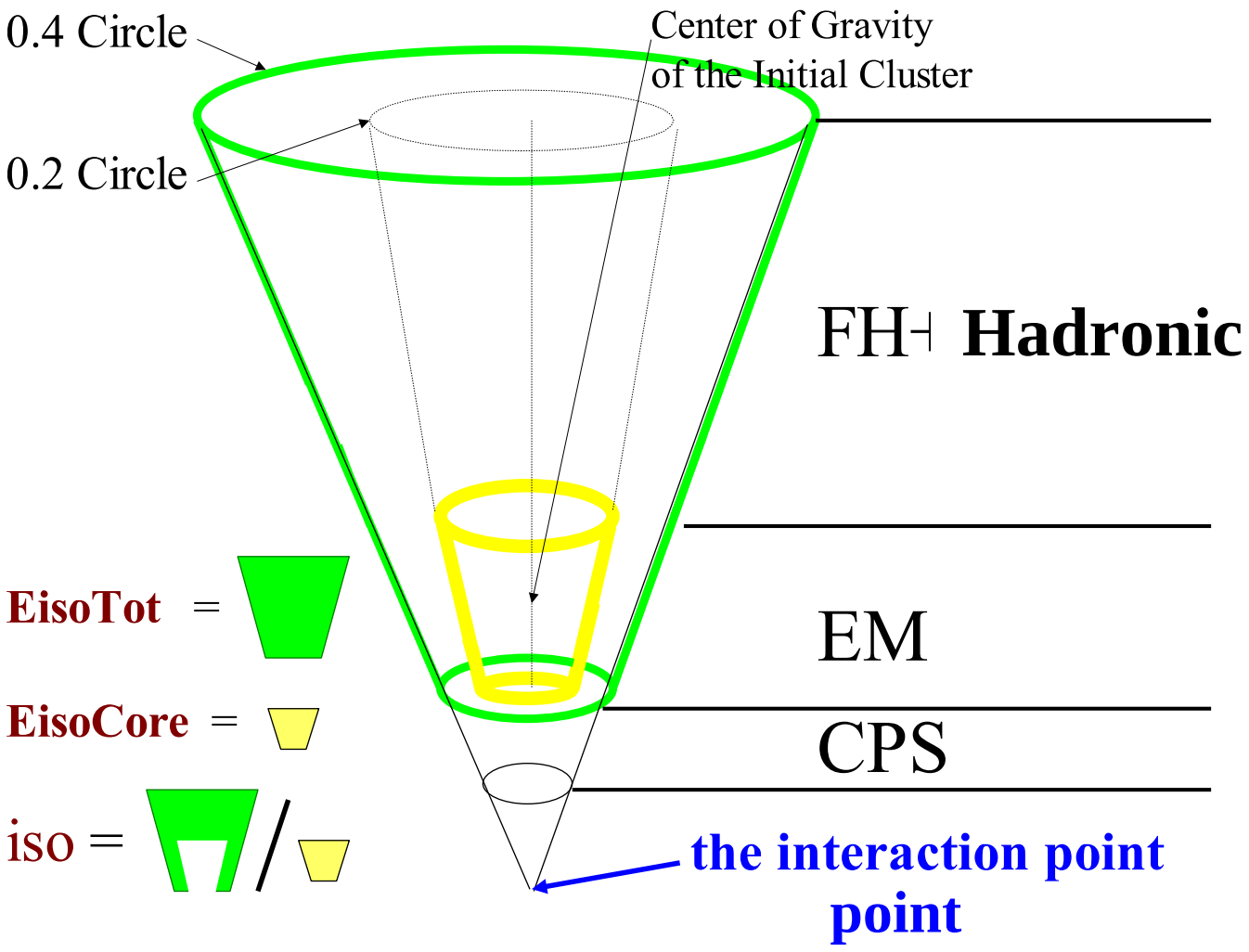


S.Mrenna, J.Wells, Phys. Rev. ***D63****, 015006 (2001)*

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

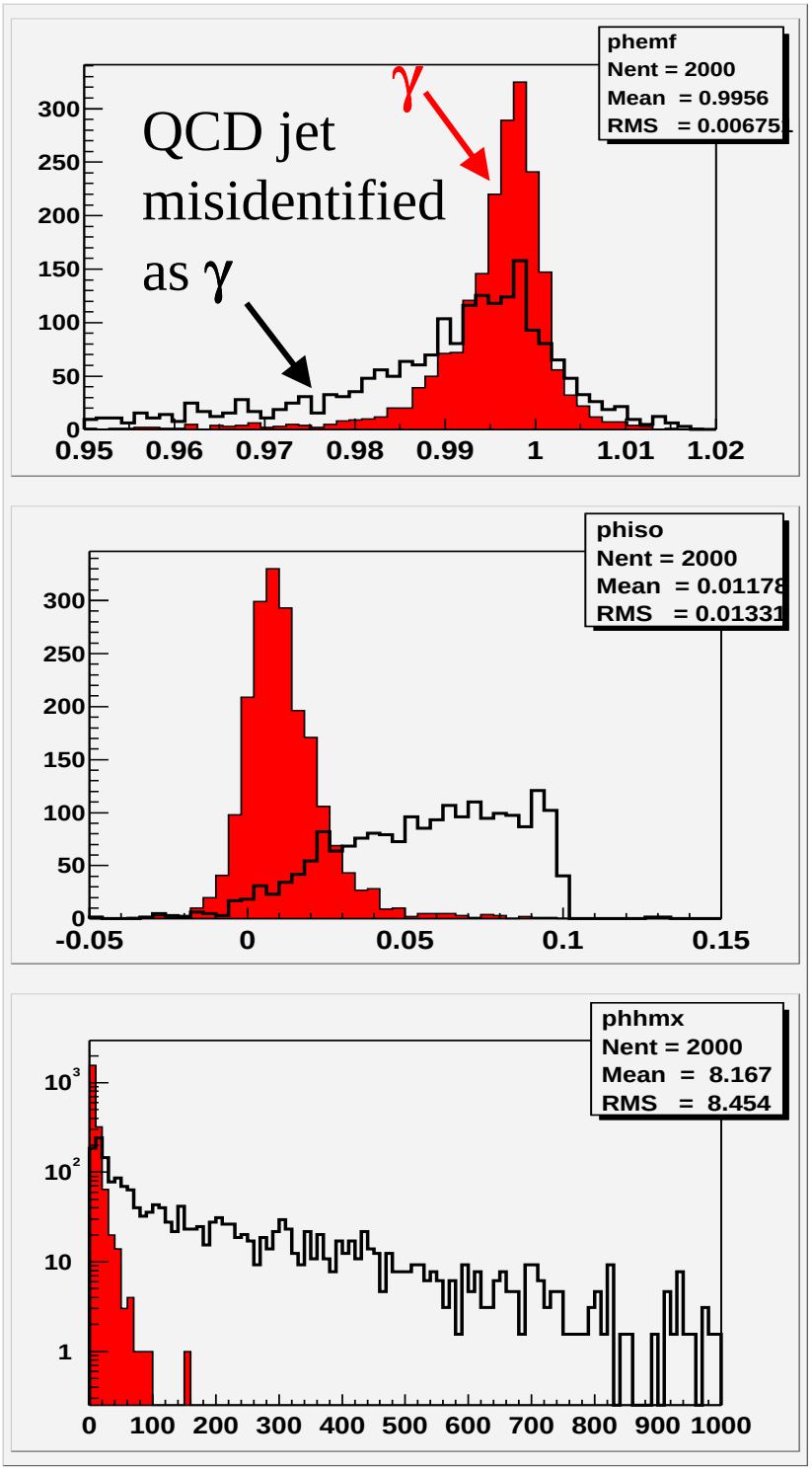
Photon-induced shower is smaller than quark/gluon shower both transversely and longitudinally



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

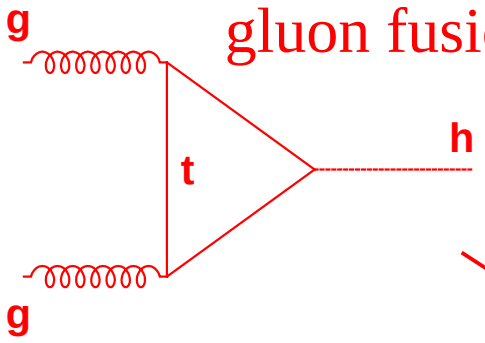
multi-variable shower shape tool

- layer energy fractions
- width at shower maximum

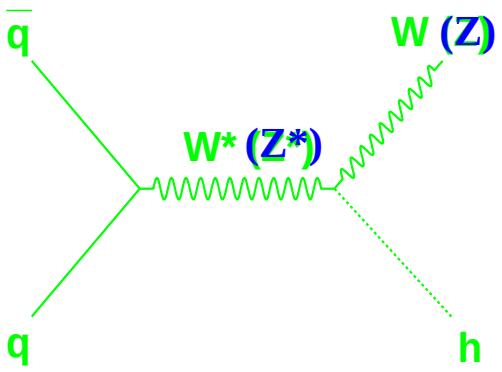
Leading SM Higgs Production Processes at Tevatron

gluon fusion: cross-section ~ m^2

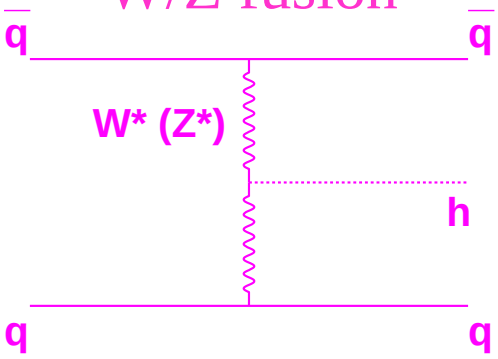
$\Rightarrow$ the top-quark loop is dominant

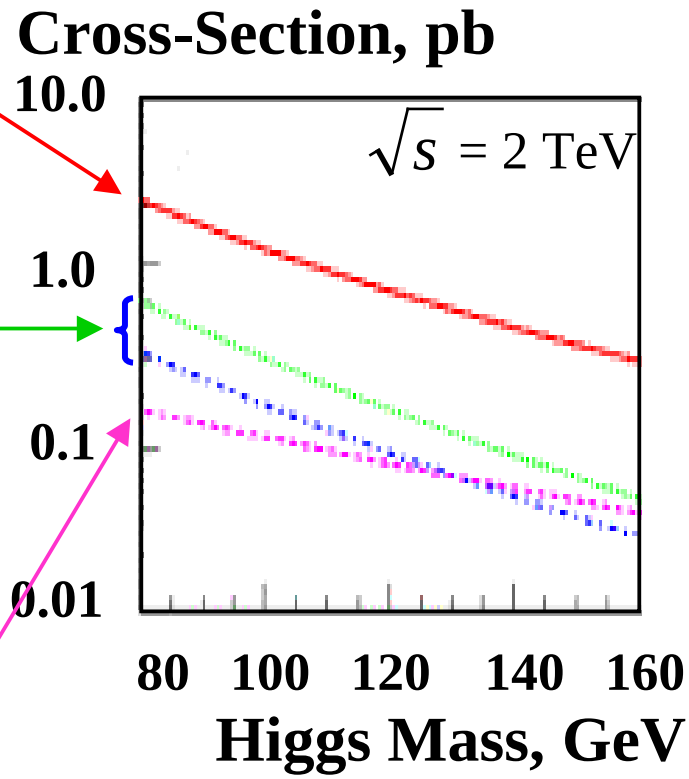


W/Z associated



W/Z fusion



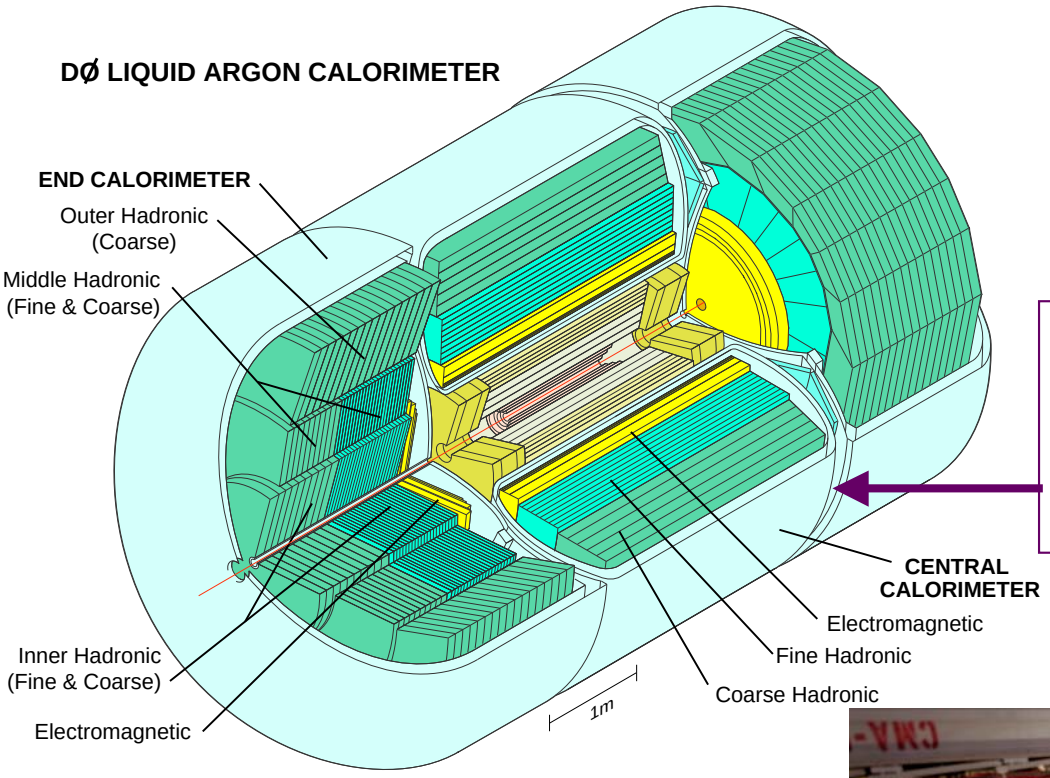


quark-antiquark fusion cross-section is small :

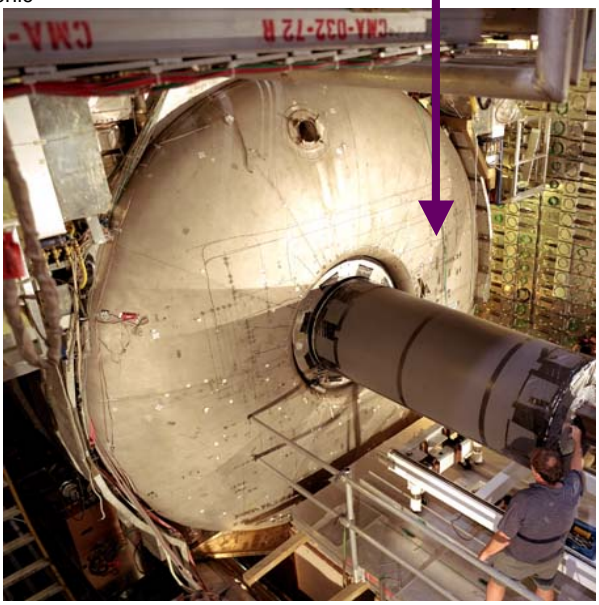
- Higgs-fermion coupling ~ m_f
- Masses of u,d quarks are small

DØ Calorimeter

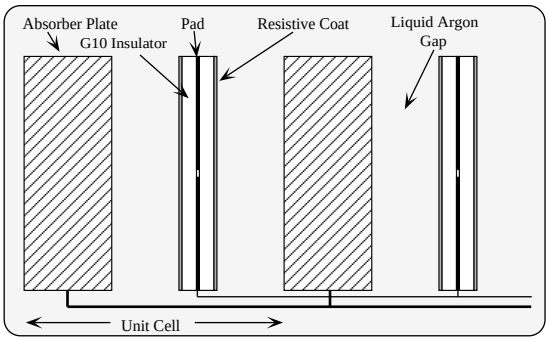
- Uranium/Liquid Argon Sampling Calorimeter
- Three modules: -- Central Calorimeter (CC)
  -- Two End Calorimeters (EC)



End-View of Central Calorimeter



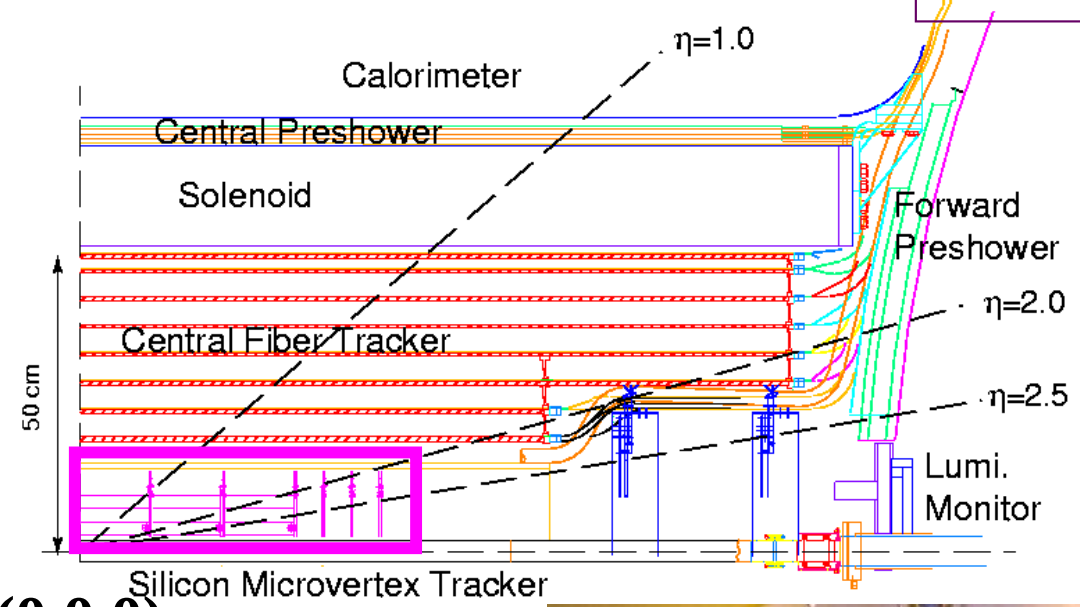
Unit cell



DØ Tracking System

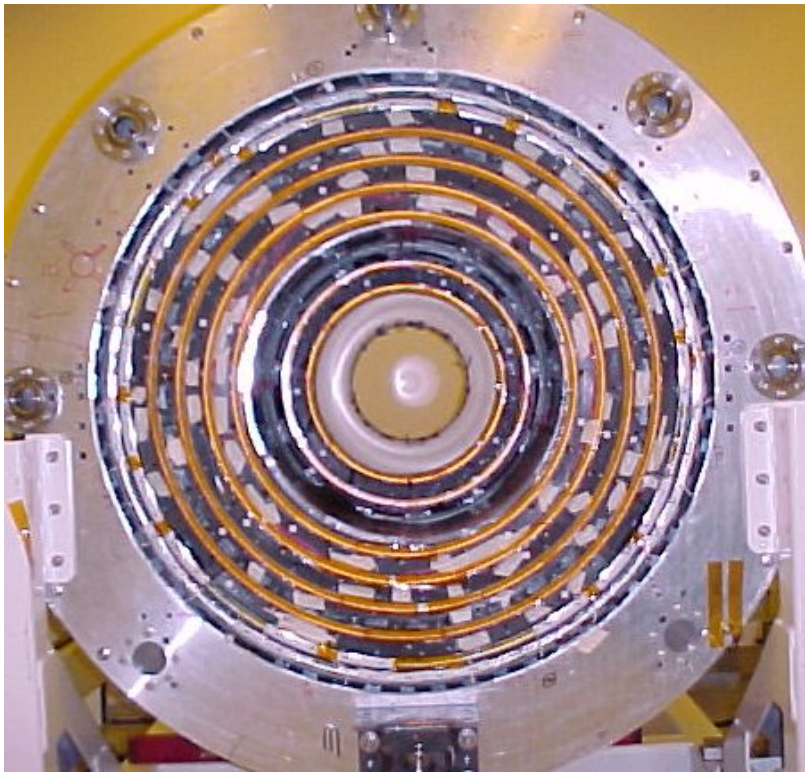
- Central Fiber Tracker
- Silicon Microstrip Tracker

One-quarter r-z view



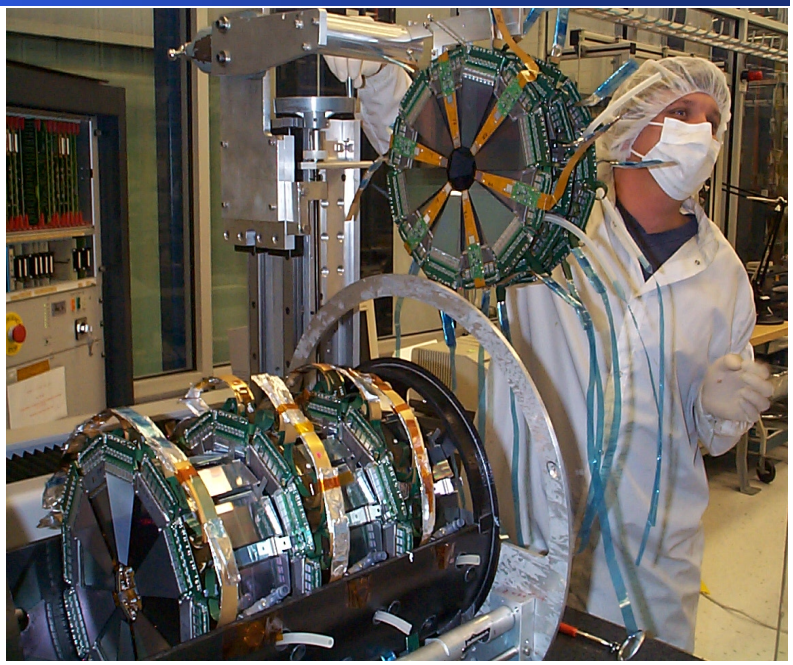
(0,0,0)

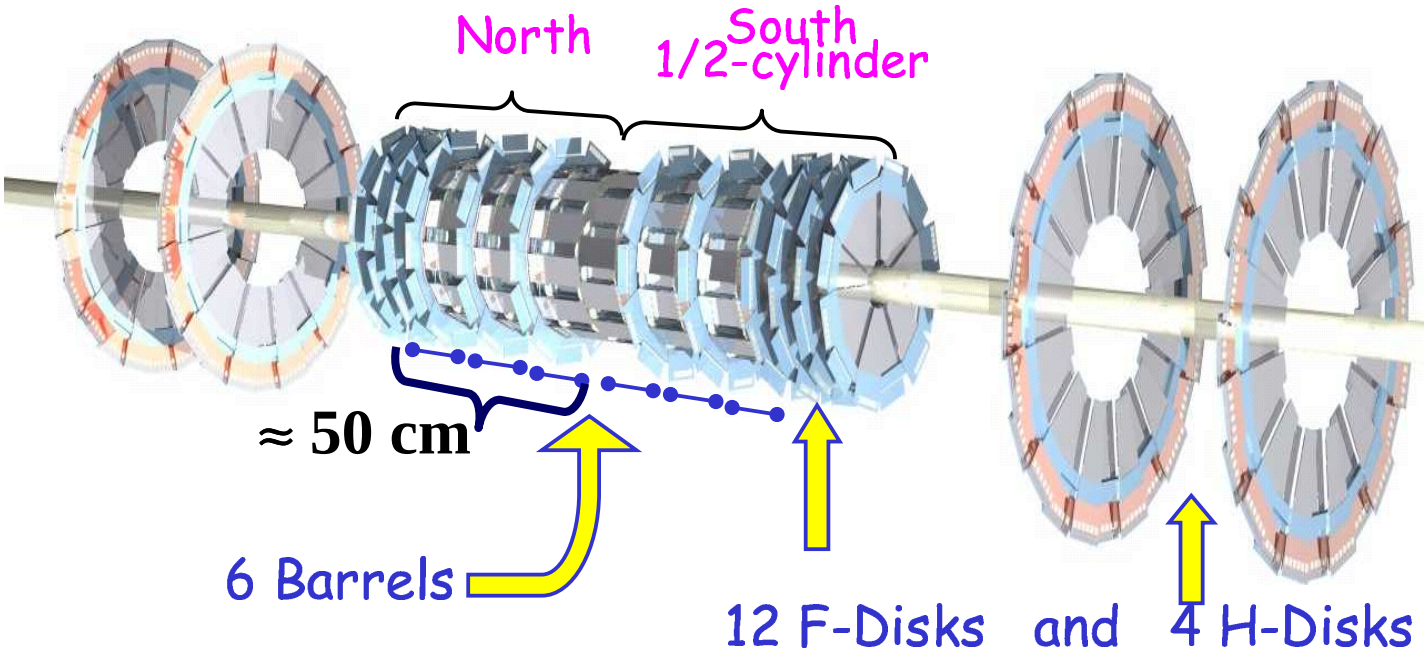
End-View of the Central Fiber Tracker



Silicon Tracker. Longitudinal View

Barrel/Disk Design:





Background Estimation Example: $Z\gamma^* \rightarrow ee$

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

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

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

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

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

Electron misidentification rate

Tracking efficiency