Search for H→ γγ at DØ

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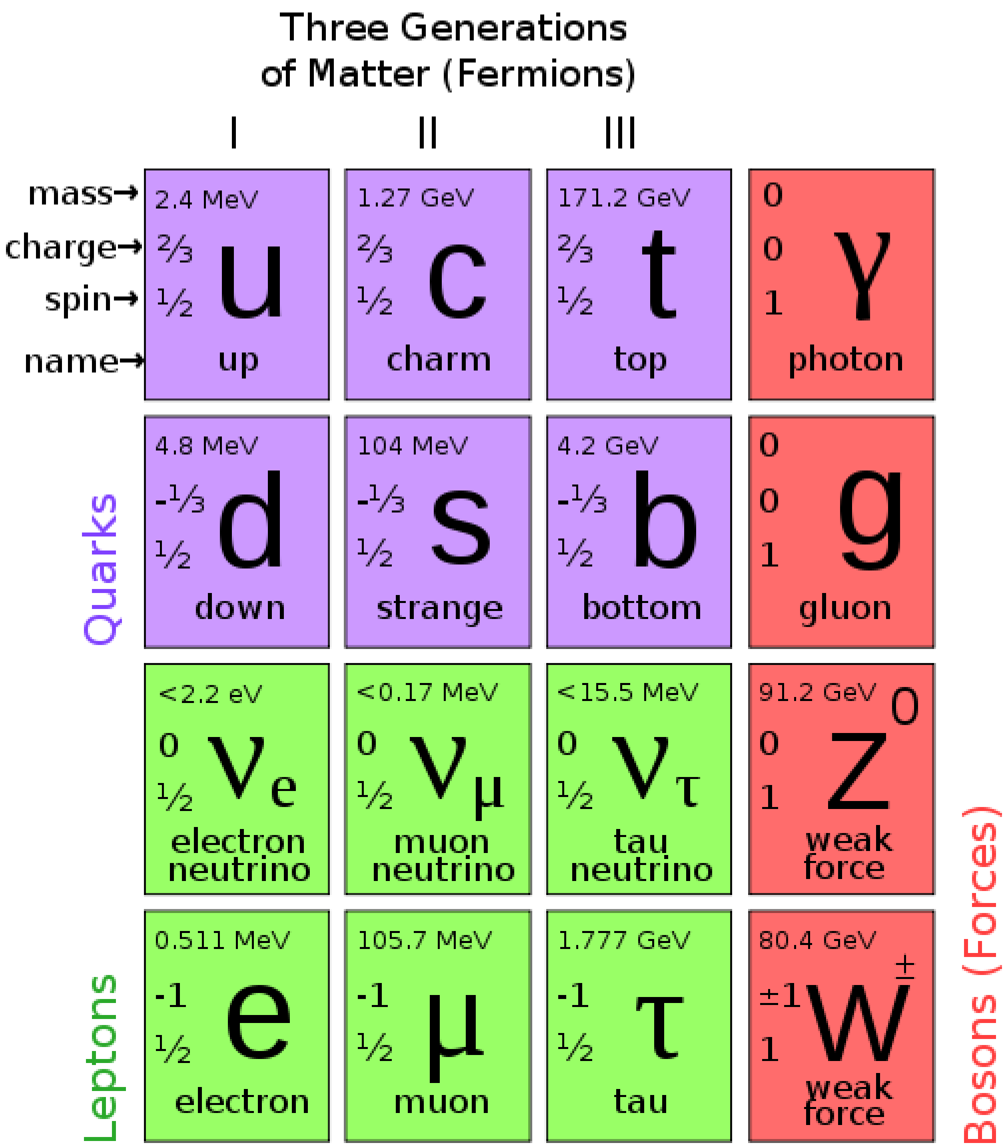
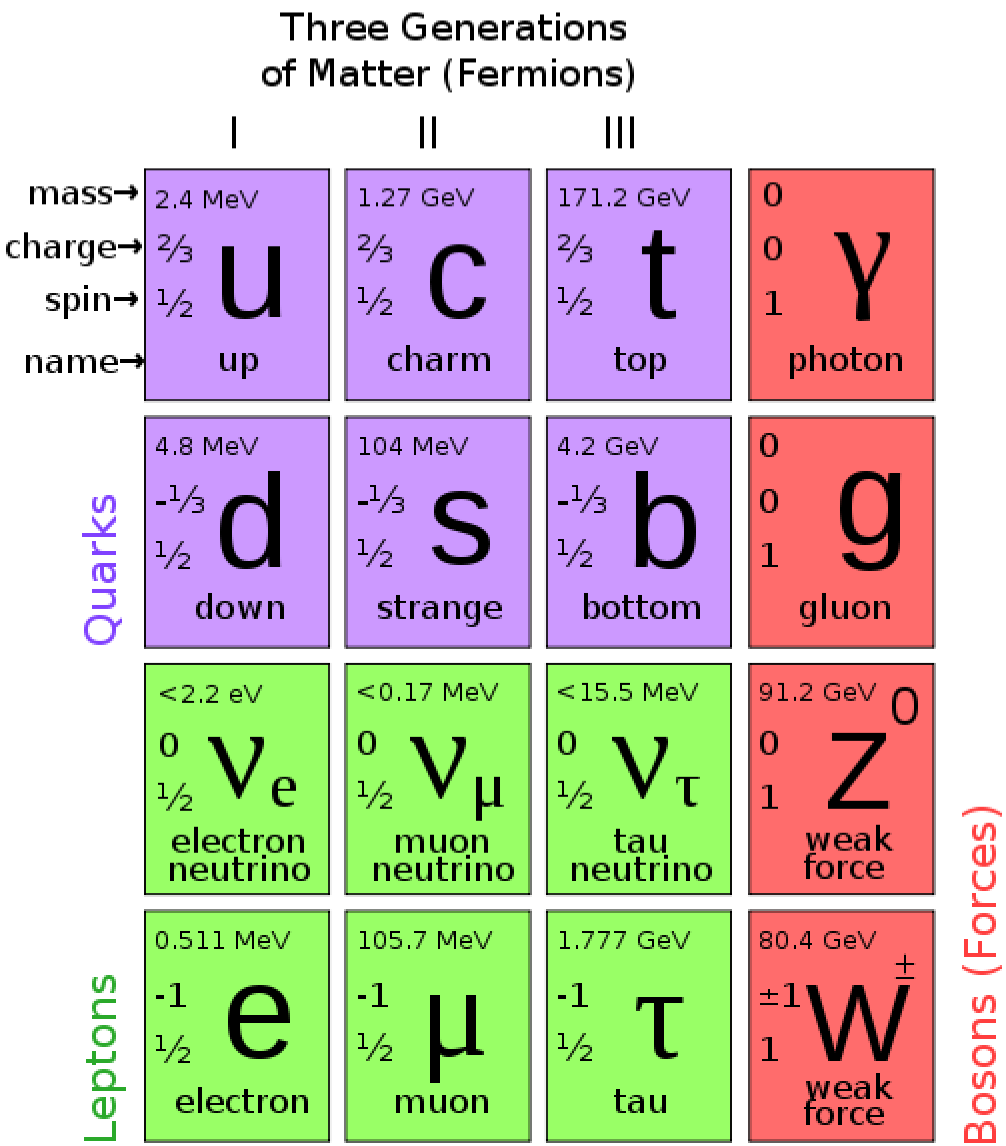
Outline

- Standard Model & Higgs boson
- Standard Model Higgs search @ Tevatron
- $H \rightarrow \gamma\gamma$ @ DØ
  - SM Higgs search
  - Fermiophobic Higgs search
- Conclusion

Standard Model of Particle Physics



Mass puzzle



Why is the photon massless, and W/Z massive ?

Why do the fermions have mass ?

How do they acquire the mass ?

SM Higgs mechanism

- Our universe is filled with a quantum field, called the Higgs field
- All elementary particles are massless
- They interact with the “Higgs fluid” and thus appear to be massive
- The quanta of this Higgs field is the Higgs boson
- Higgs boson is the only unobserved SM particle

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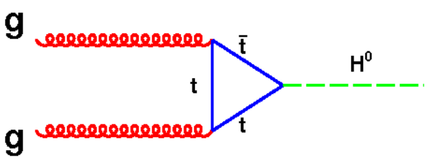
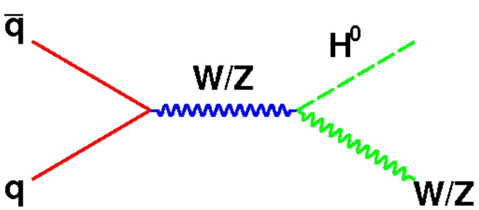
SM Higgs at Tevatron

- Major production mechanisms

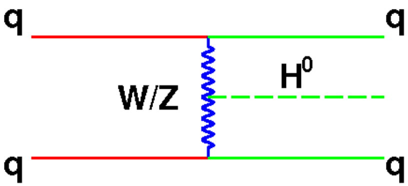
1. Gluon fusion ($gg \rightarrow h$)



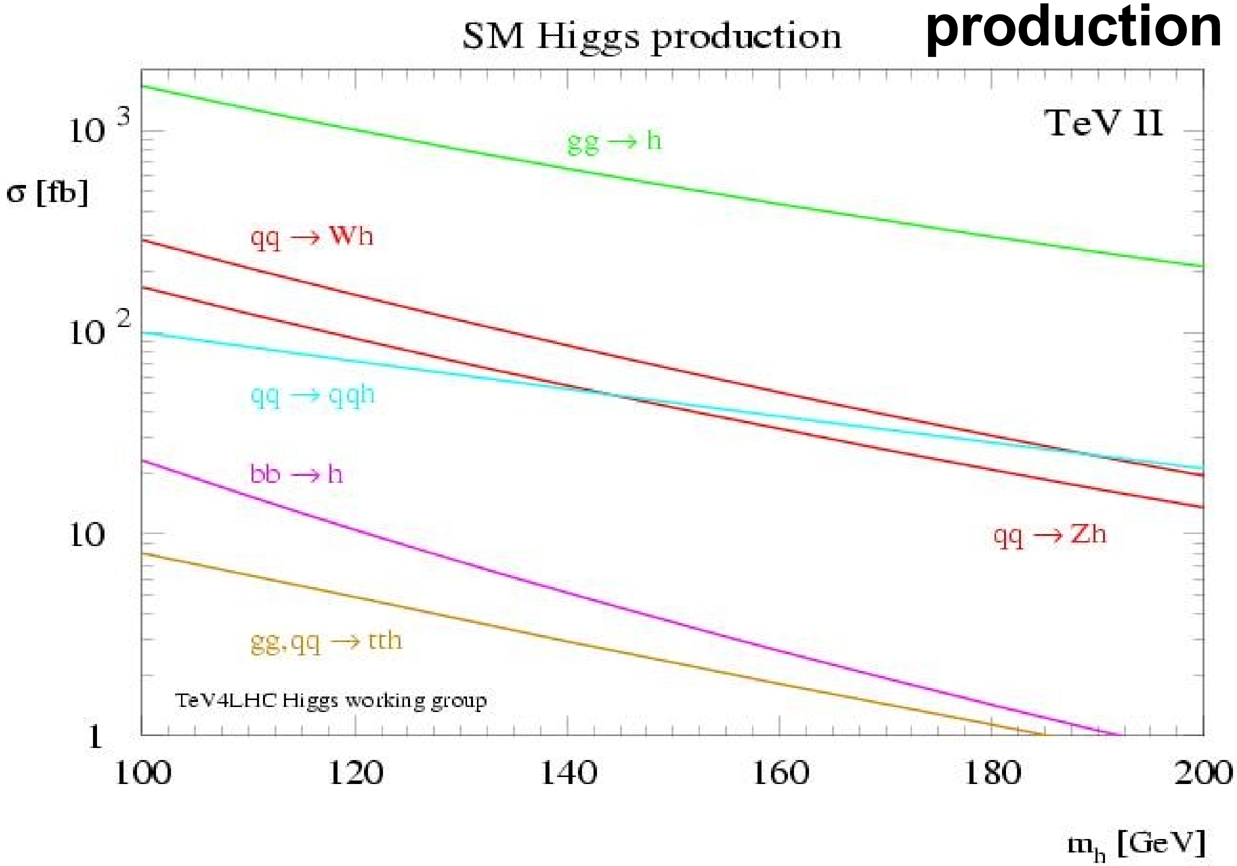
2. Associated production with a vector boson ($qq \rightarrow W/Zh$)



3. Vector boson fusion ($qq \rightarrow qqh$)

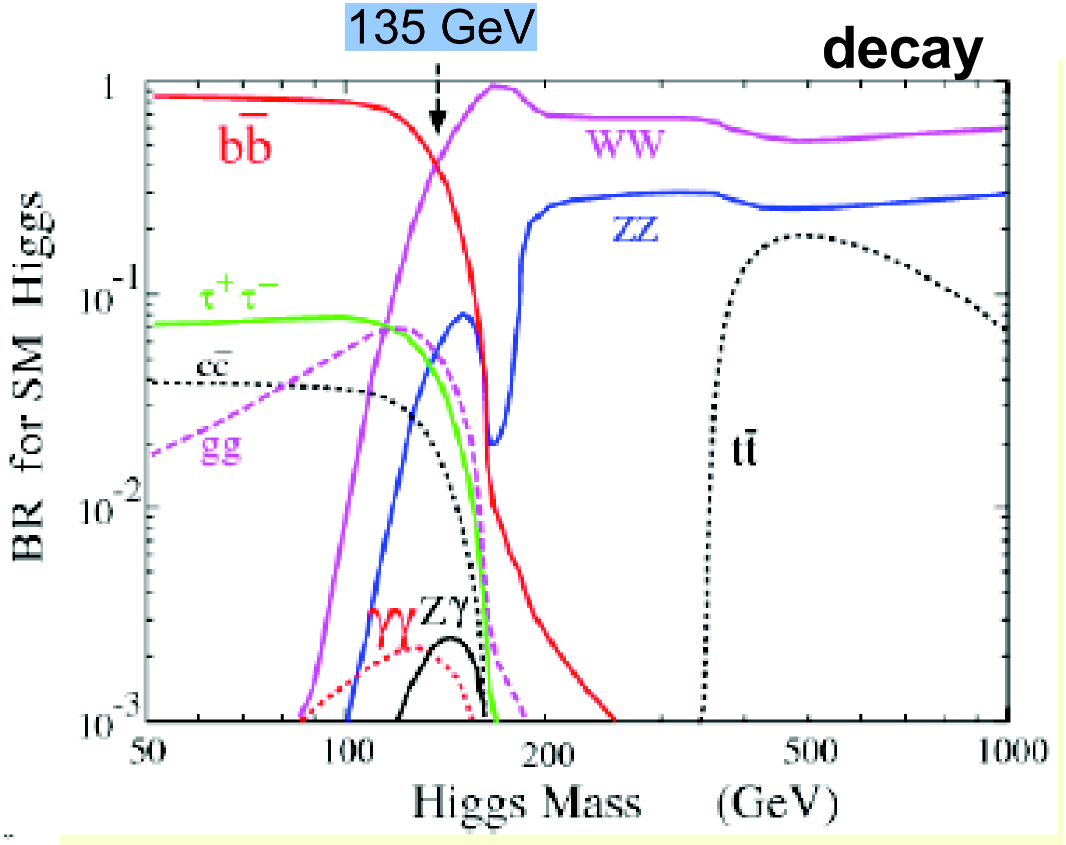


production



SM Higgs at Tevatron

- Major decay channels
  - H->bb @ M_H<135 GeV
  - H->WW @ M_H>135 GeV

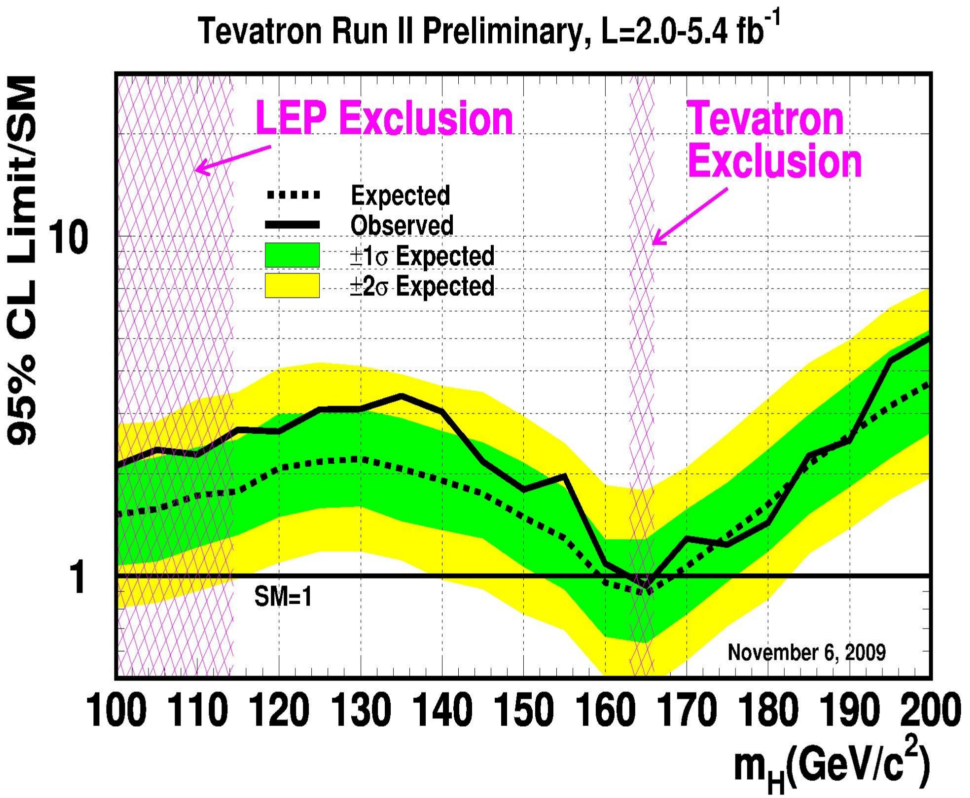


- Current results (limits @95% CL)
  - SM LEP direct search: M_H>114.4 GeV
  - SM indirect constraint + LEP direct search: M_H<185 GeV

Tevatron is sensitive over the whole "interesting" mass range.

Tevatron SM Higgs combination

- Combination of 75 (CDF: 23, DØ: 52) mutually exclusive channels.
  - SM Higgs excluded for $163<M_H<166$ GeV @ 95% CL
  - Expected limits < 3xSM for $M_H<200$ GeV



Why searching for H→ γγ at Tevatron

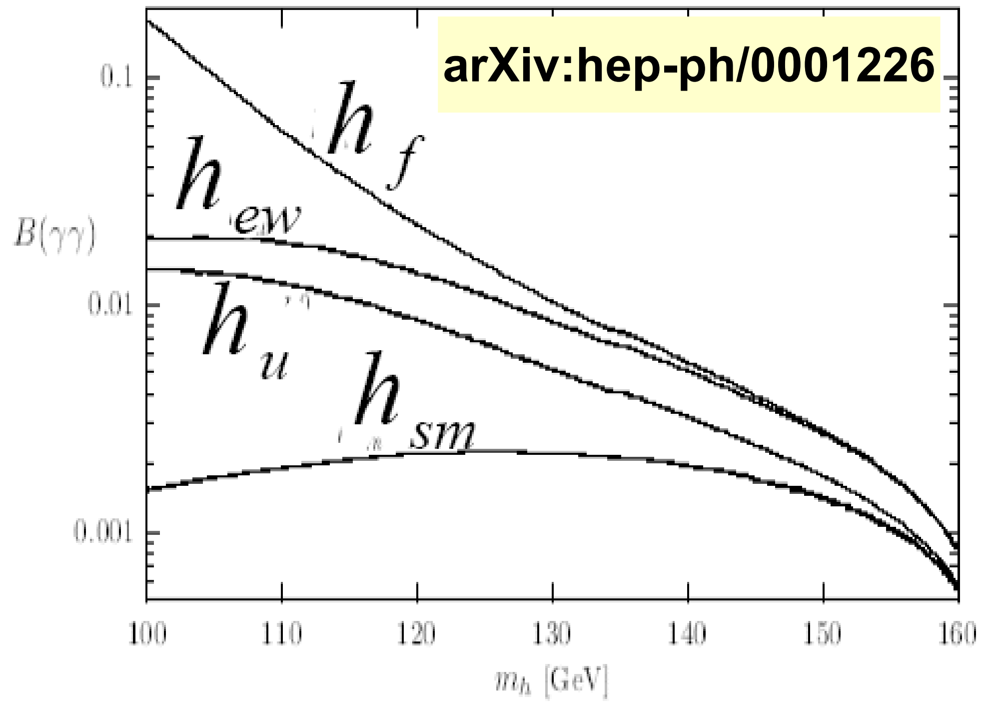
- Within SM, the BR (H→ γγ) is small (~0.2%)
  - Current direct experimental search + indirect constraint prefer to a light Higgs boson.
  - Contribute to the Tevatron SM Higgs combination, especially in the difficult intermediate mass region around 125 GeV.
  - Golden channel for the discovery of SM Higgs at LHC.

- Beyond SM, the BR (H→ γγ) could be significantly large

h_f :suppressed couplings to all fermions.

h_{ew} :suppressed couplings to top and bottom quarks.

h_u :suppressed couplings to only down-type fermions.



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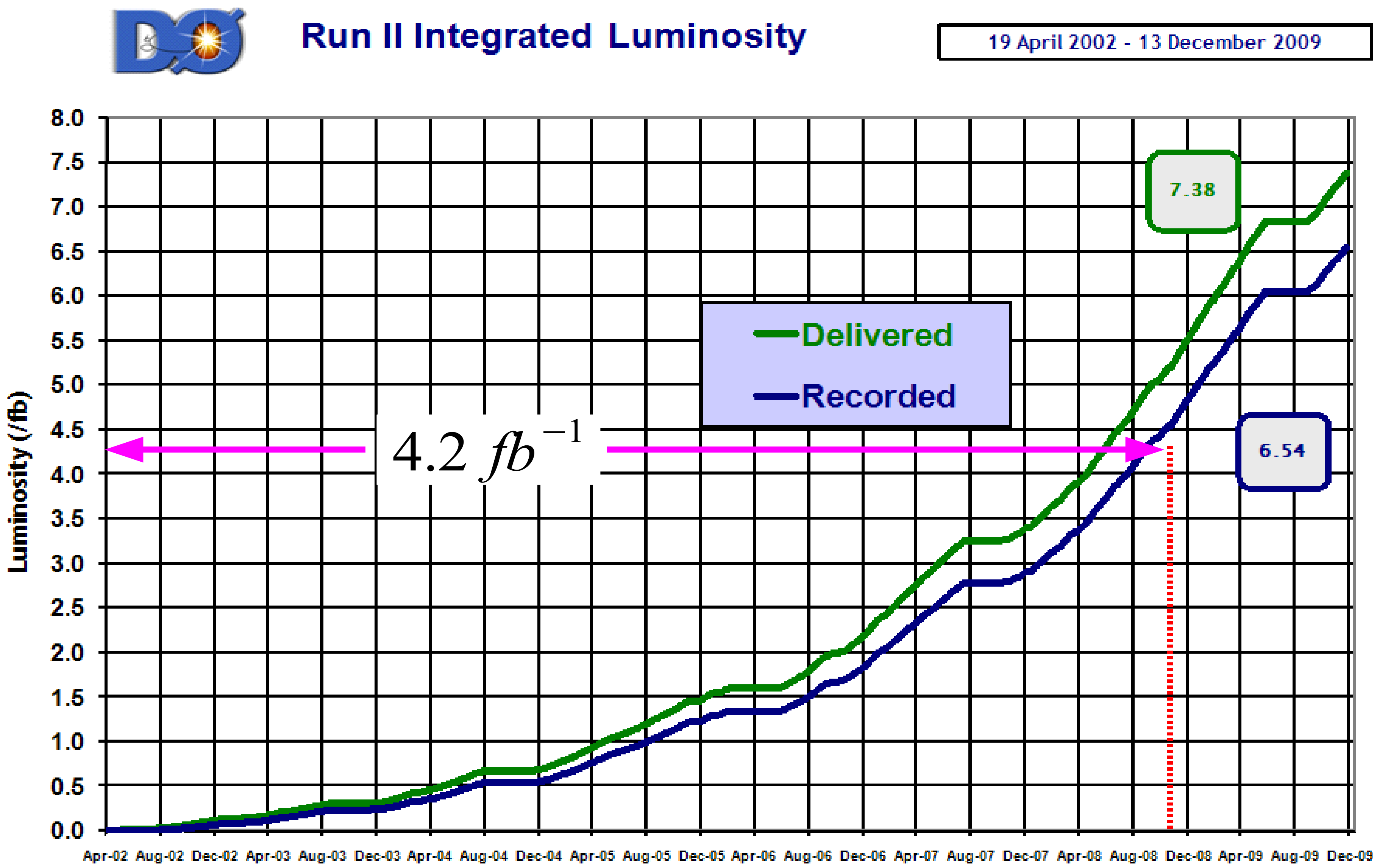
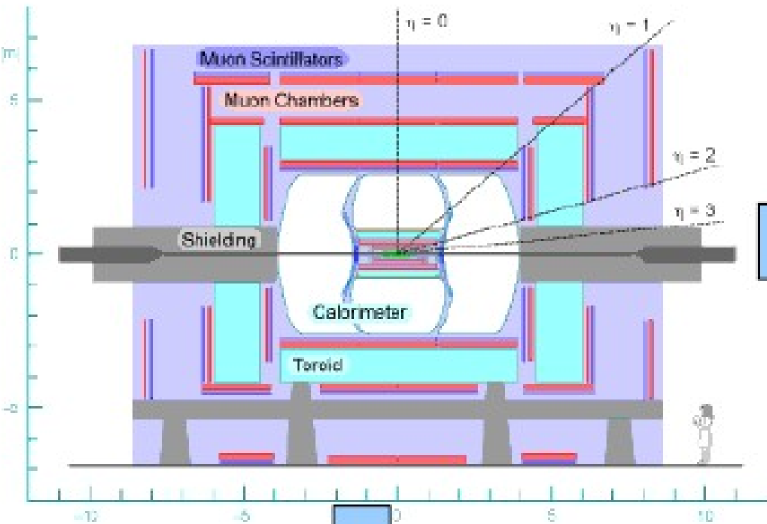
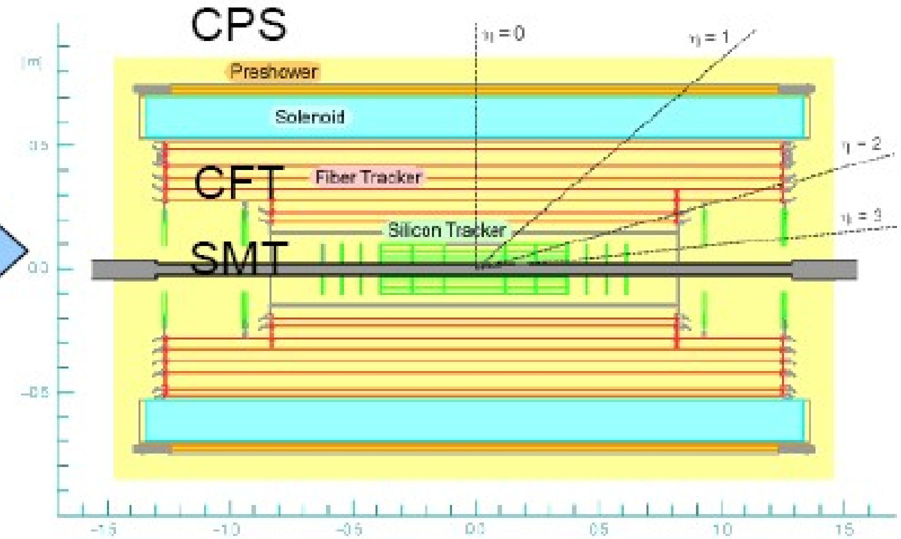
Integrated Luminosity



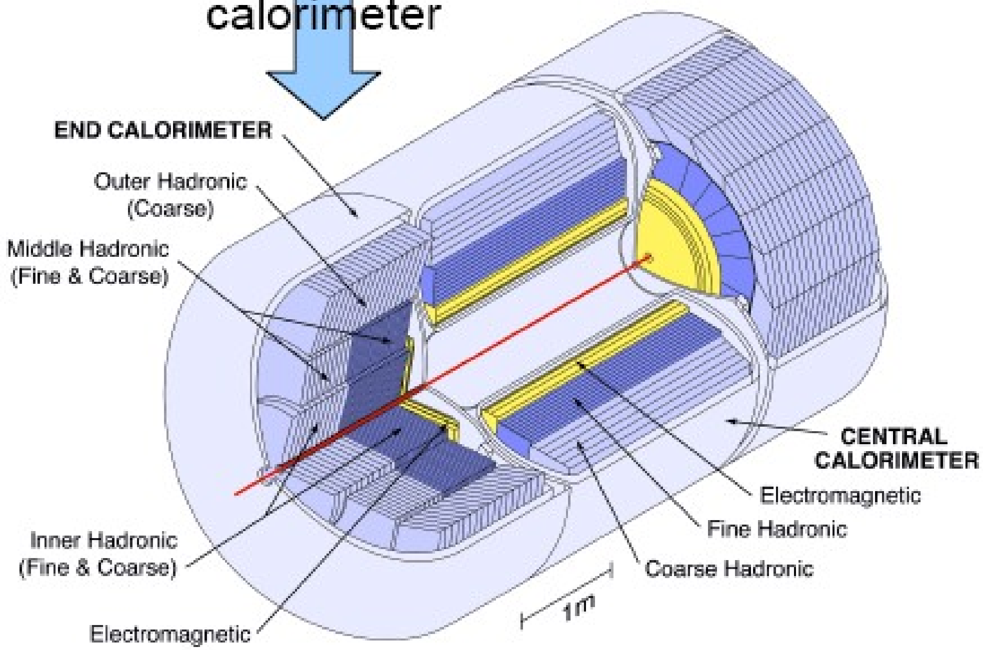
DØ detector



tracking

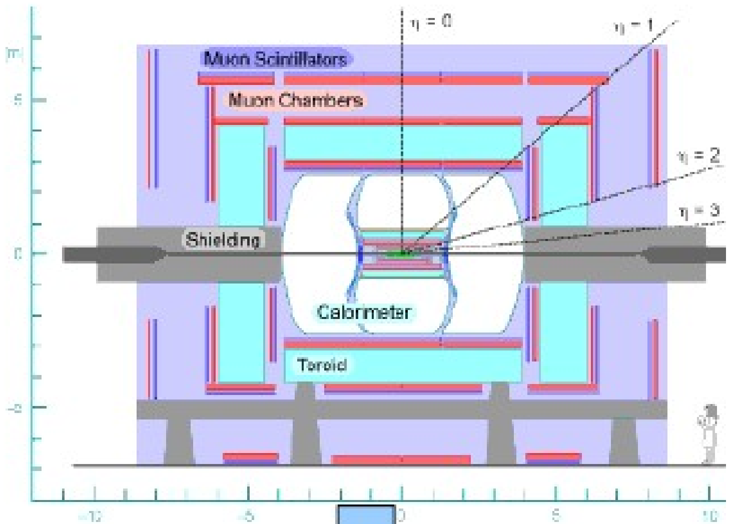


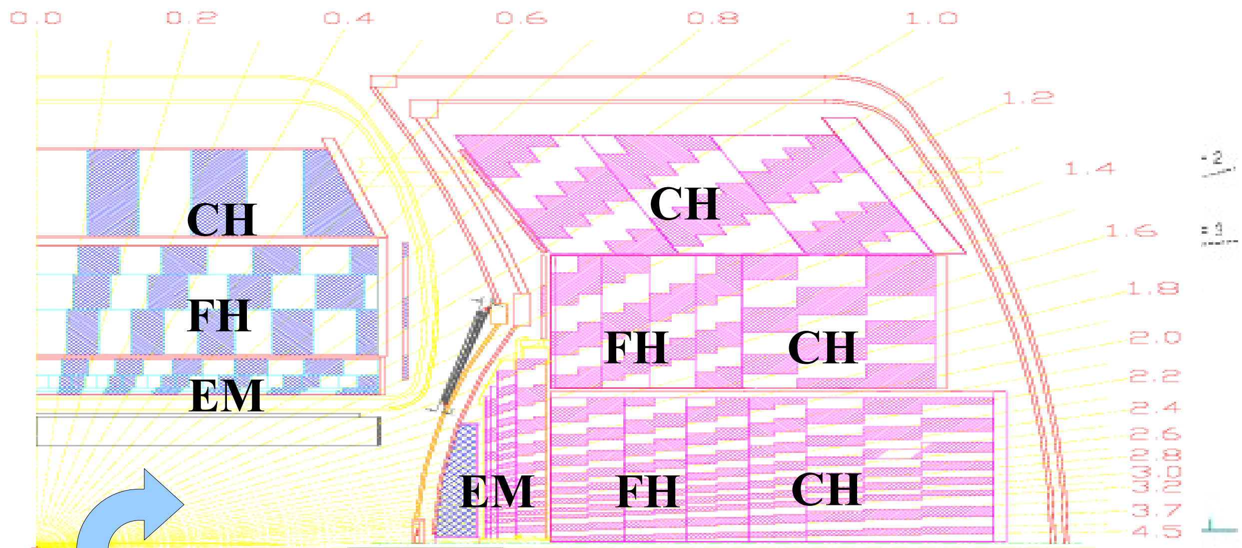
calorimeter



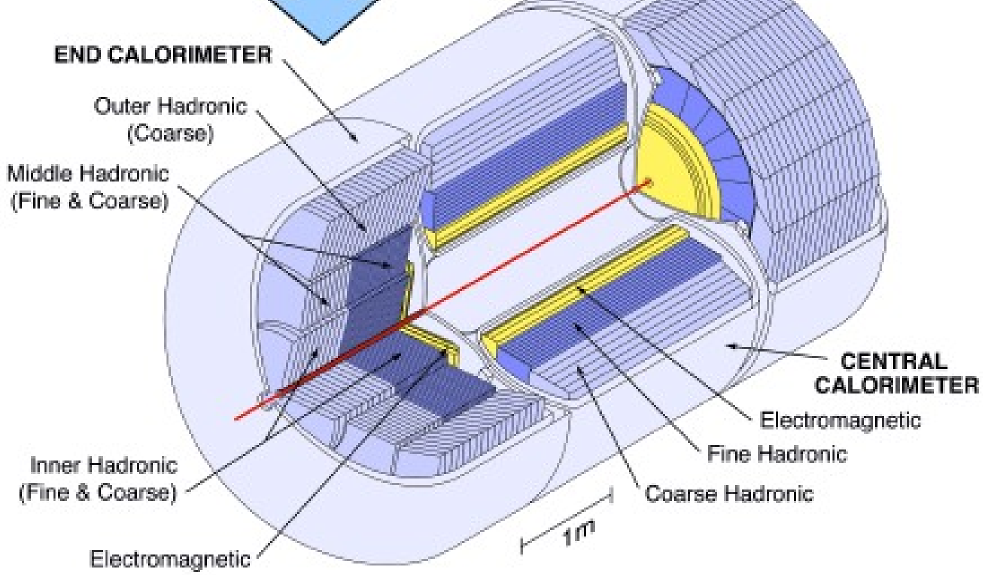
- Electrons: $|\eta|<3.0$
- Muons: $|\eta|<2.0$
- Silicon tracking: $|\eta|<3.0$
- Calorimetry: $|\eta|<4.2$
- High data taking efficiency ~ 90%
- Well-understood detectors and mature analysis tools

DØ detector





calorimeter



Liquid Argon active medium
uranium and Fe,Cu absorber
46K readout channel
4EM layers with ~20 X0
EM transverse segmentation:
$\Delta\eta \times \Delta\Phi = 0.1 \times 0.1$
→ except in EM3, where it is 0.05x0.05

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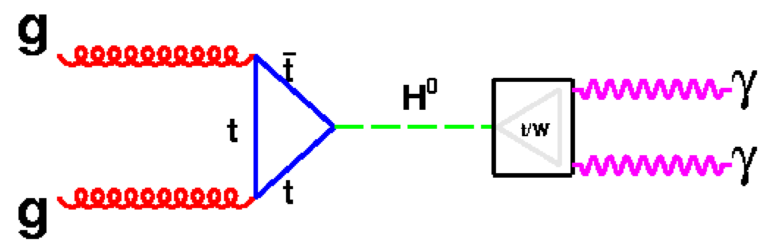
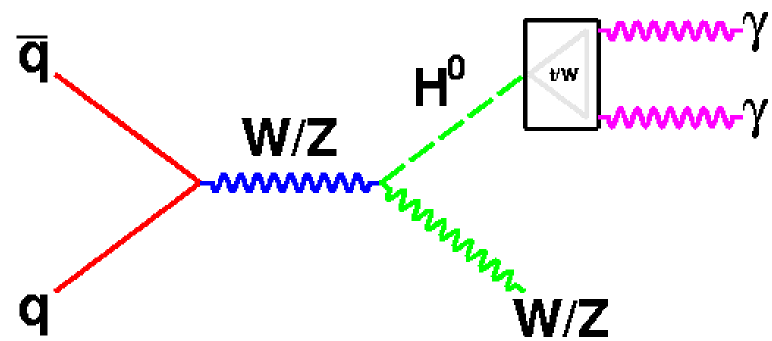
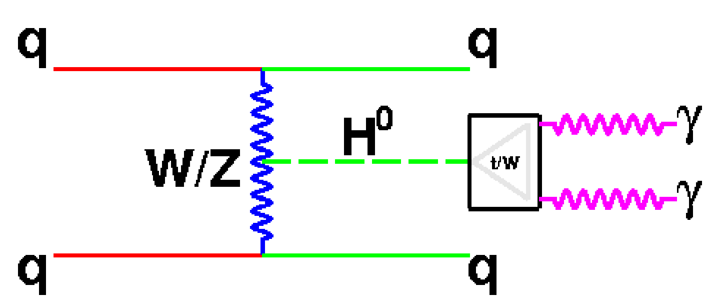
H→ γγ

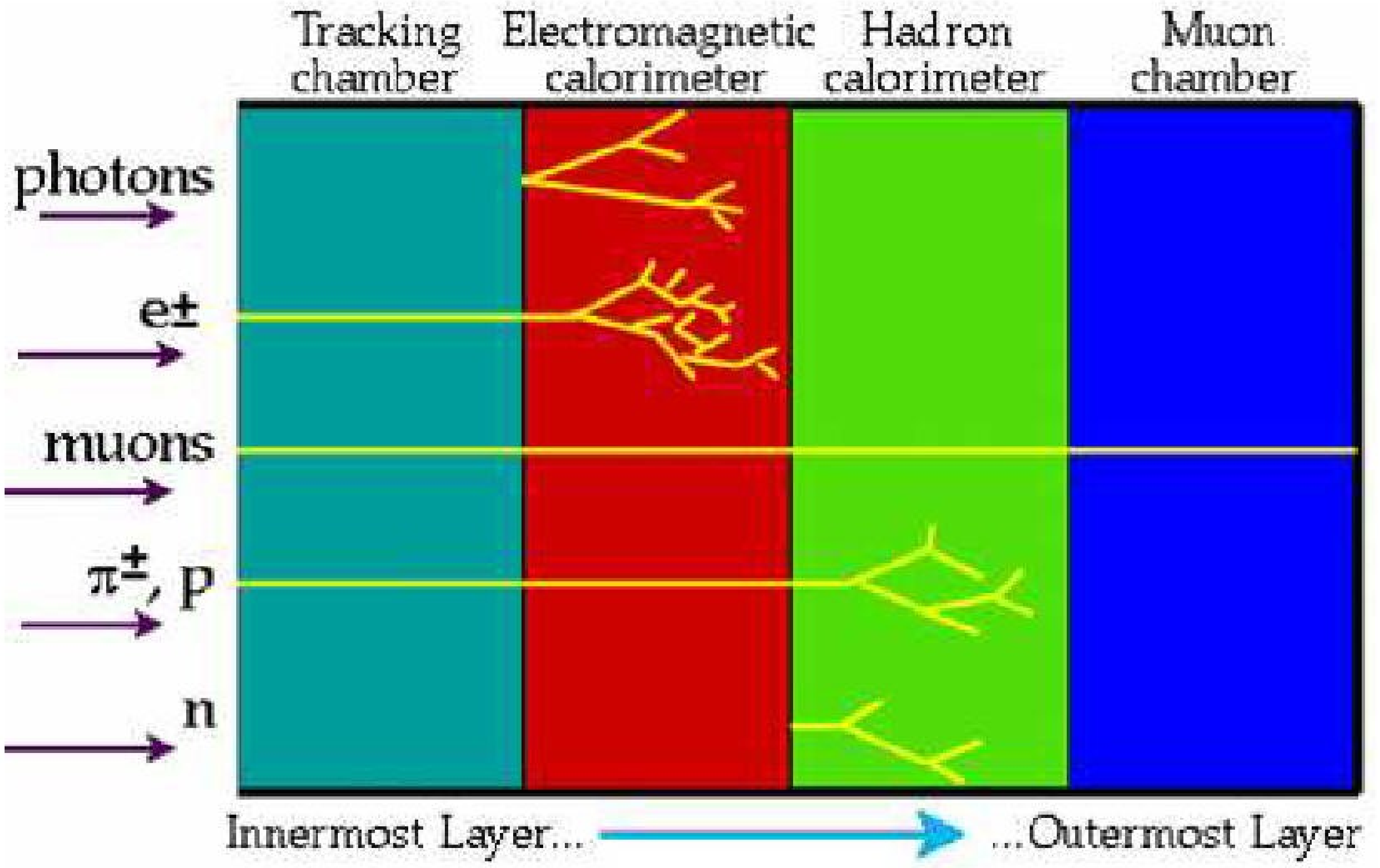
- Model-independent approach:
  - Examine the inclusive di-photon dataset (γγ+X) to search for the high mass resonances
  - SM Higgs is used as a possible model:
    - Gluon fusion (ggH)
    - Associated production (VH)
    - Vector boson fusion (VBF)







Photon identification



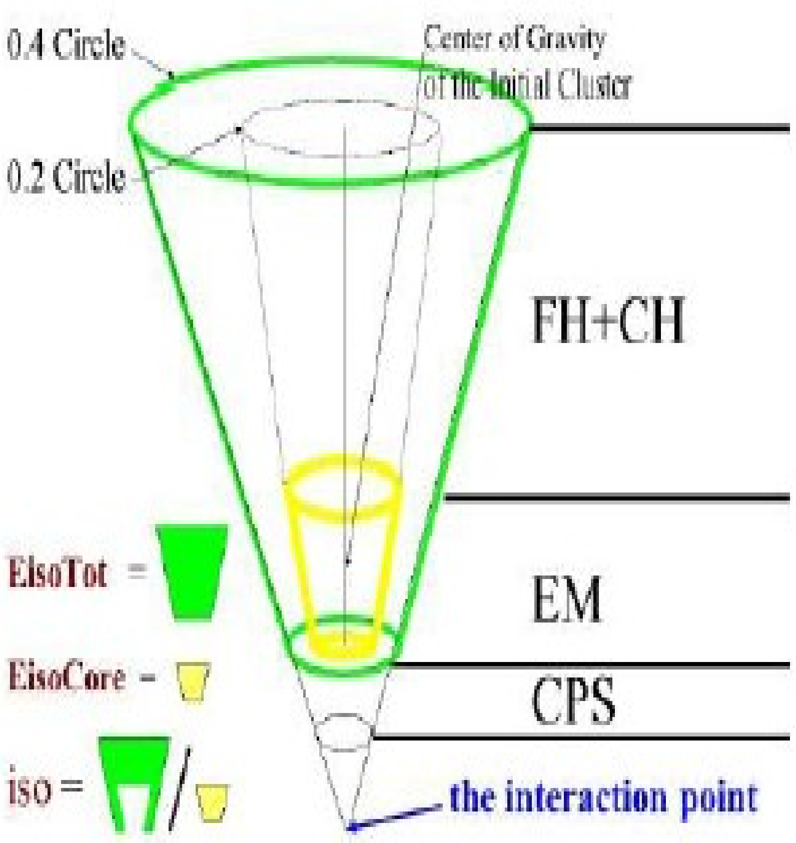
Reconstruct EM cluster

- Central photons ($-1.1 < \eta < 1.1$) are selected from EM clusters (reconstructed within R=0.2 cone):

$\epsilon \sim 90\%$

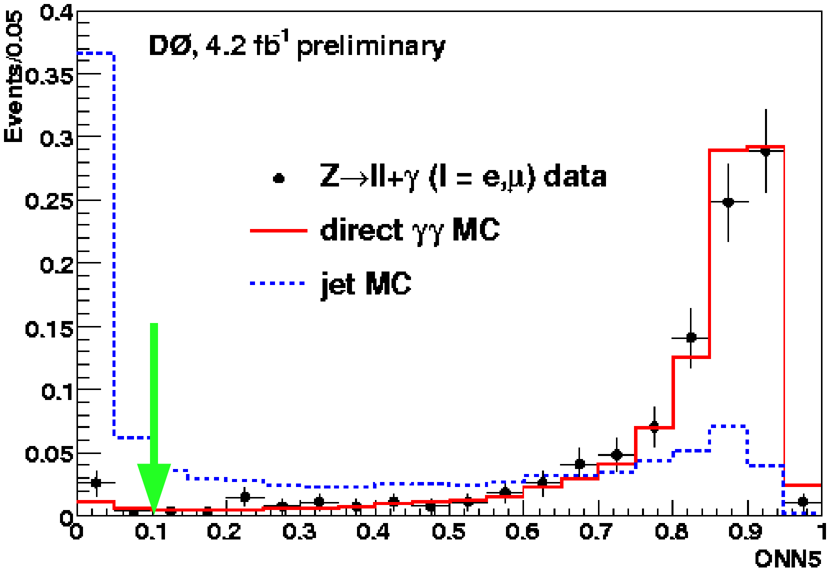
1. Most energy in EM calorimeter: EM energy fraction > 97%.
2. Isolated in the calorimeter: iso<0.07.
3. Isolated in the tracker: $\sum_{0.05 < dR < 0.4} p_T^{track} < 2$ GeV
4. Shower width in the third-EM layer is consistent with the EM.

- Difference between data and MC simulation is calibrated with using Z→ee events.



Separate γ and jet

- To suppress the jets mis-identified as photons
  - Training samples: γ and jet MC
  - Testing samples: $Z \rightarrow ee$ data&MC, $Z \rightarrow l\,l + \gamma\,(l = e, \mu)$ data
  - Input variables:
    - # of EM1 cells in R<0.2
    - # of EM1 cells in 0.2<R<0.4
    - Tracker isolation
    - # of CPS clusters in R<0.1
    - Energy-squared-weighted width of the energy deposited in CPS



Photon candidatess: ONN>0.1

~98% efficiency for photons.

~50% reduction for jets

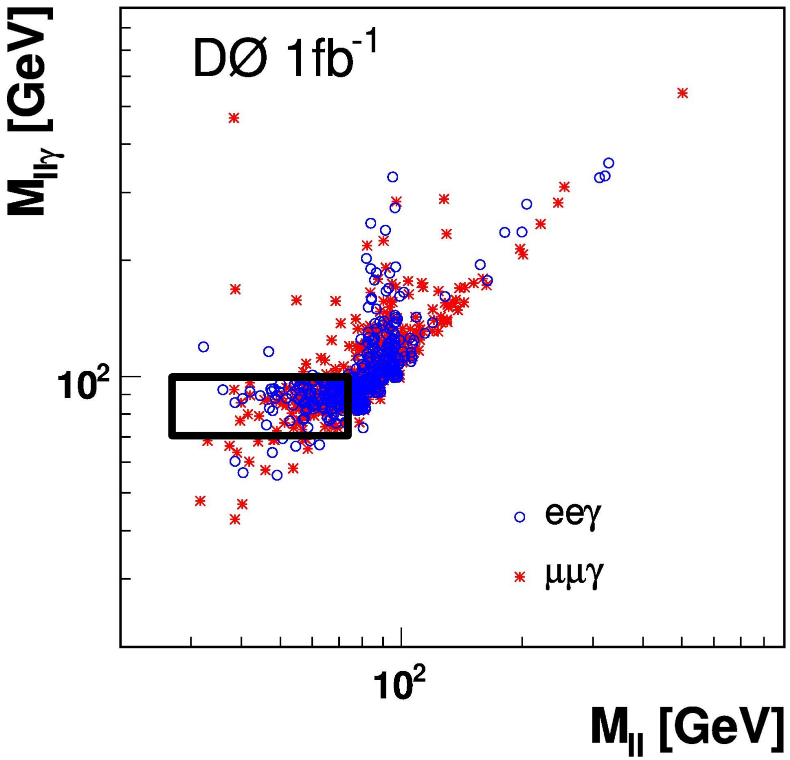
Separate γ and electron

•To suppress the electrons mis-identified as photons

$\epsilon \sim 90\%$

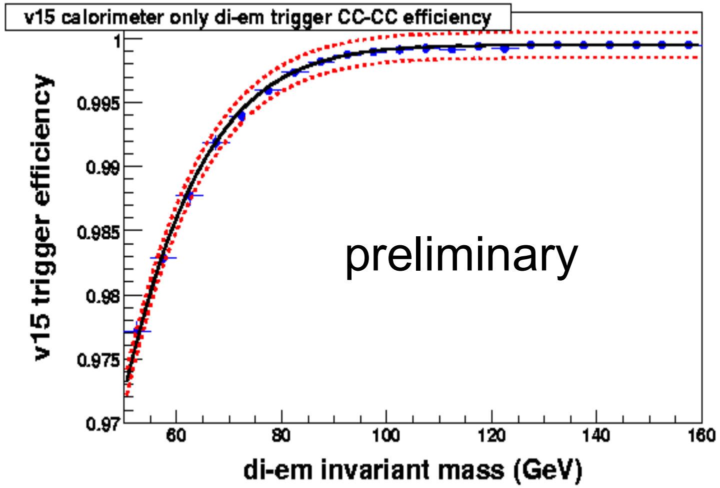
- No-spatially well-matched track;
- No pattern of hits in the tracker in a road around the EM cluster consistent with electron.

- Difference between data and Monte Carlo simulation is calibrated with using $Z \rightarrow l\,l + \gamma\,(l = e, \mu)$ events.



Event selection

- Select two photons with pT>25 GeV
- Di-photon mass $M_{\gamma\gamma}$>60 GeV
- Trigger efficiency: ~100%



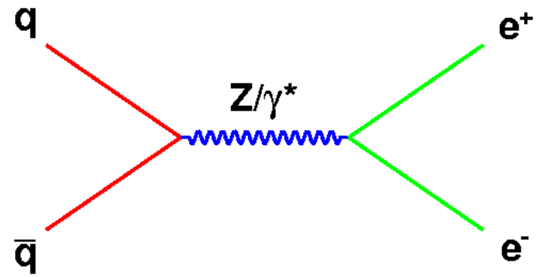
- Signal efficiency (~20%) is dominant by the geometrical acceptance, and independent of production mechanism.

	100 GeV	110 GeV	120 GeV	130 GeV	140 GeV	150 GeV
ϵ_{sel}(ggH)	0.195±0.001	0.200±0.001	0.207±0.001	0.213±0.001	0.216±0.001	0.219±0.001
ϵ_{sel}(VH)	0.185±0.001	0.195±0.001	0.203±0.001	0.209±0.001	0.218±0.001	0.219±0.001
ϵ_{sel}(VBF)	0.198±0.001	0.211±0.001	0.218±0.001	0.226±0.001	0.233±0.001	0.238±0.001

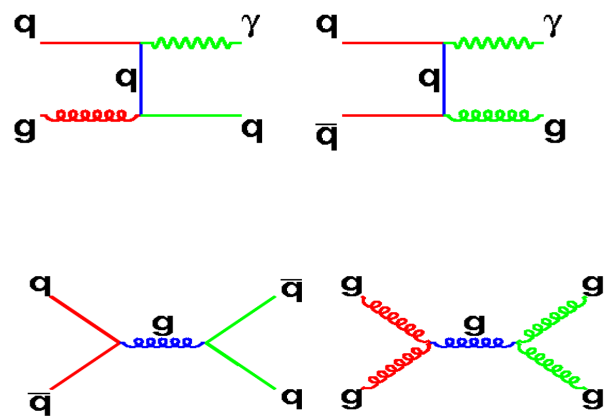
Backgrounds

- Reducible background

    1. Z/γ* → ee , both electrons are misidentified as photons, estimated with Geant MC.

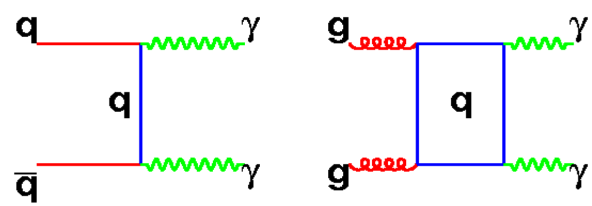


    2. Non-γγ (γ+jet,jet+jet), when the jet(s) is(are) misidentified as photon(s), estimated from data.



- Irreducible background – direct γγ

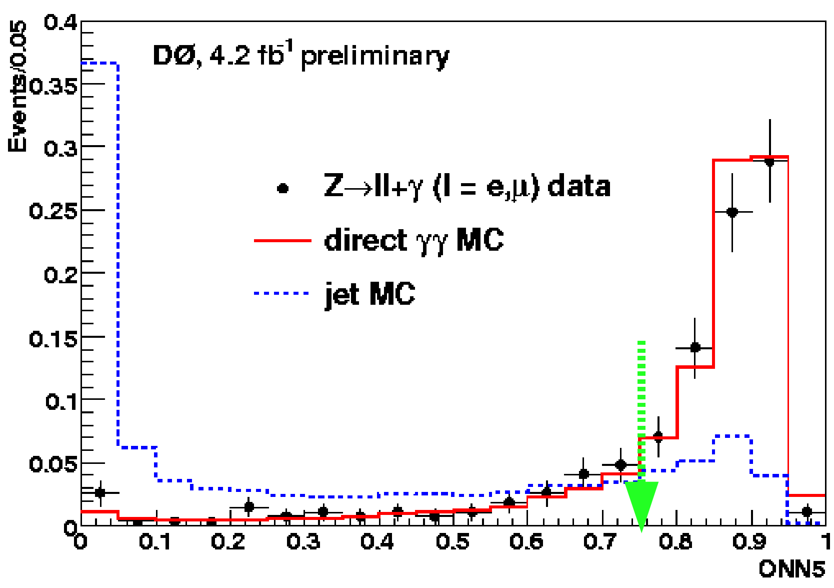
estimated from data



4X4 Matrix Method

Using ONN=0.75 as a boundary to separate the events to 4 categories:

- Npp: both pass the ONN>0.75
- Npf: first passes, second failes
- Nfp: vice-versa
- Nff: both fail



$$\begin{pmatrix} N_{ff} \\ N_{fp} \\ N_{pf} \\ N_{pp} \end{pmatrix} = E \times \begin{pmatrix} N_{jj} \\ N_{j\gamma} \\ N_{\gamma j} \\ N_{\gamma\gamma} \end{pmatrix}$$

$\epsilon_{j1}, \epsilon_{j2}$ are jet ONN>0.75 efficiencies.

$\epsilon_{\gamma 1}, \epsilon_{\gamma 2}$ are photon ONN>0.75 efficiencies.

$$E = \begin{pmatrix} (1-\epsilon_{j1})(1-\epsilon_{j2}) & (1-\epsilon_{j1})(1-\epsilon_{\gamma 2}) & (1-\epsilon_{\gamma 1})(1-\epsilon_{j2}) & (1-\epsilon_{\gamma 1})(1-\epsilon_{\gamma 2}) \\ (1-\epsilon_{j1})\epsilon_{j2} & (1-\epsilon_{j1})\epsilon_{\gamma 2} & (1-\epsilon_{\gamma 1})\epsilon_{j2} & (1-\epsilon_{\gamma 1})\epsilon_{\gamma 2} \\ \epsilon_{j1}(1-\epsilon_{j2}) & \epsilon_{j1}(1-\epsilon_{\gamma 2}) & \epsilon_{\gamma 1}(1-\epsilon_{j2}) & \epsilon_{\gamma 1}(1-\epsilon_{\gamma 2}) \\ \epsilon_{j1}\epsilon_{j2} & \epsilon_{j1}\epsilon_{\gamma 2} & \epsilon_{\gamma 1}\epsilon_{j2} & \epsilon_{\gamma 1}\epsilon_{\gamma 2} \end{pmatrix}$$

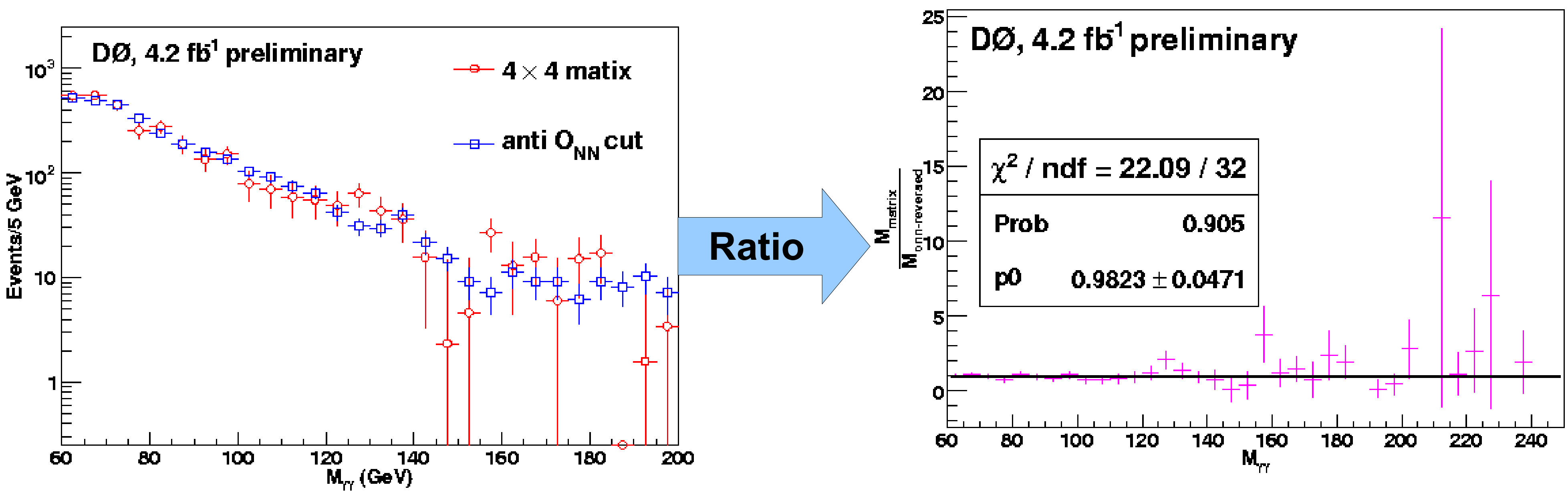
Total	7939
Total - N_{DY}	7722.7
$N_{\gamma\gamma}$	4538.8 ± 144.7
$N_{\gamma j} + N_{j\gamma}$	2189.0 ± 170.3
N_{jj}	994.9 ± 106.6
non-$\gamma\gamma$	3183.9 ± 200.9

Includes potential signal.

The quoted uncertainties are statistical only.

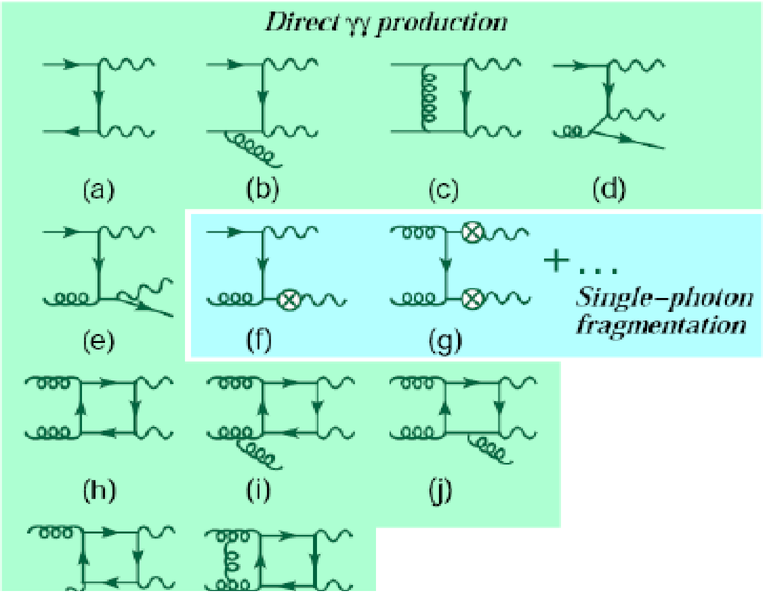
Non-γγ (γ+jet, jet+jet) background

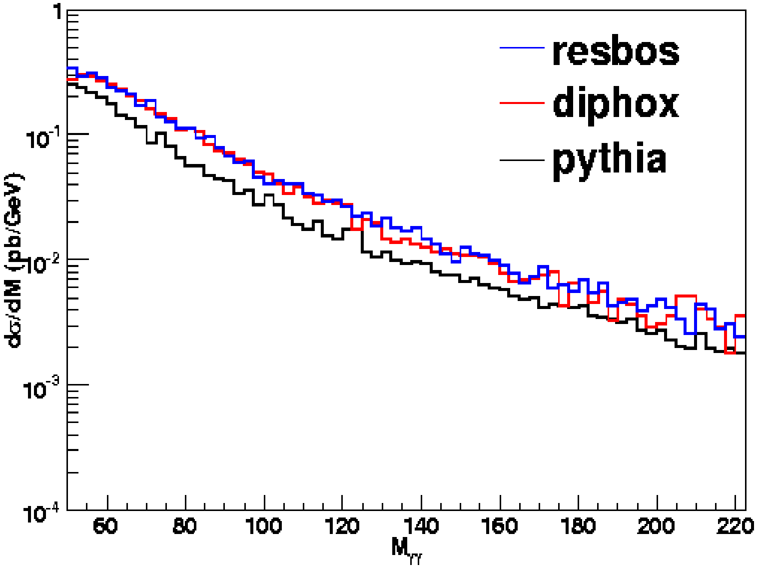
1. Shape from reversing the ONN cut (0.1) for one photon candidate.
2. Normalization to the number of events from 4X4 matrix method.



Direct γγ production (DDP) – irreducible background

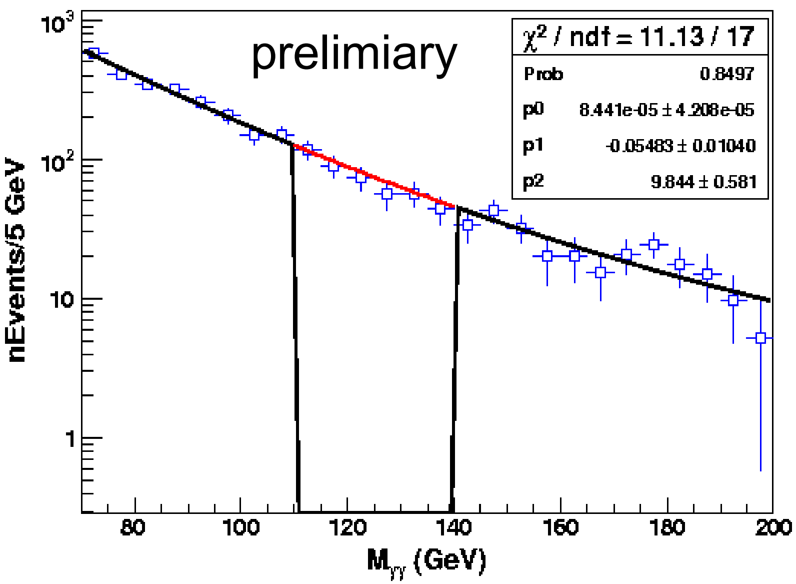
- Challenge to model by theoretical prediction so far, each generator has its own deficit
    - Pythia
    - Resbos
    - Diphox
- In the high mass region ($M_{\gamma\gamma}$>50GeV), $M_{\gamma\gamma}$ spectrum agrees reasonably very well between diphox and resbos.

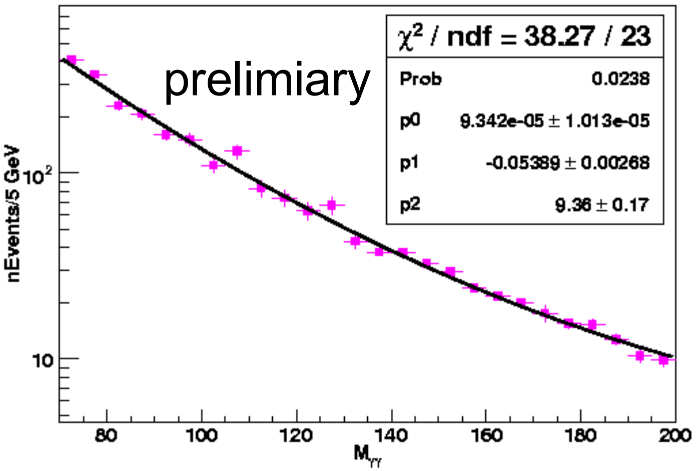




Direct γγ production (DDP) – irreducible background

- DDP background is estimated from data with using side-band fitting after subtraction of the reducible background
  - avoid ~20% uncertainty on the theory cross section
  - Fitting range: [70,200]GeV, with excluding the ±15GeV signal regions.
  - Validate the shape from the full pythia MC after reweighting to diphox at generator level.





systematic uncertainties

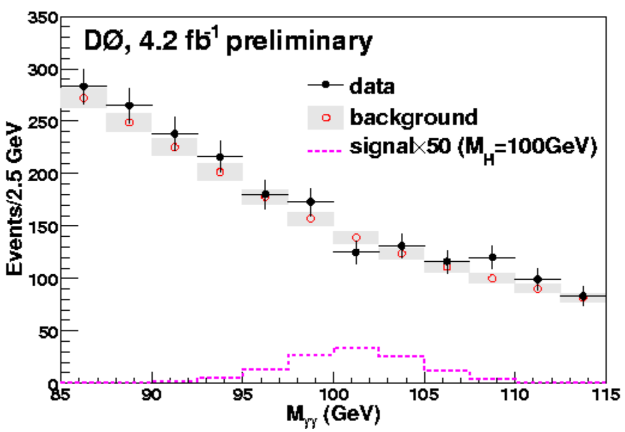
source	uncertainty
luminosity	6.1% [15]
trigger	0.1%
PDF for $h_f \rightarrow \gamma\gamma$ acceptance	0.6% - 1.0%
electron misidentification efficiency	19.0%
Z/γ^*(ee) cross section	3.9%
photon identification efficiency	6.8%
background subtraction	shape (10%-15%)
photon energy scale	shape (0.6%)

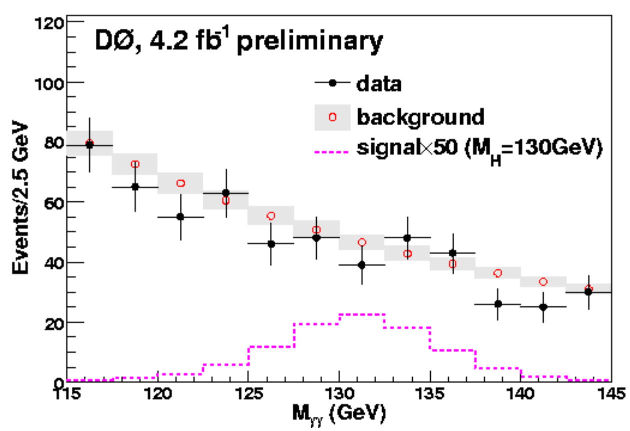
→ dominant one (background subtraction)

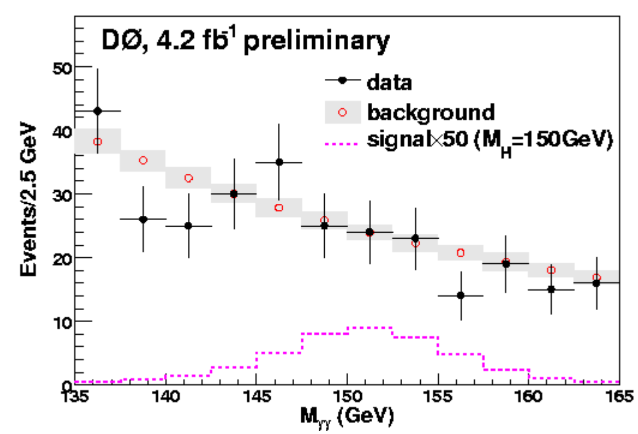
Event yield

- Good agreement between data and SM background prediction:

	100 GeV	110 GeV	120 GeV	130 GeV	140 GeV	150 GeV
$Z/\gamma* \rightarrow ee$	134±27	53±12	17±5	9±3	5±2	3±2
γj+jj	712±102	455±65	299±43	202±29	140±20	100±14
QCD $\gamma\gamma$	1080±96	764±62	539±41	404±28	280±19	207±14
total background	1926±35	1272±21	855±14	615±10	425±7	310±5
data	2029	1289	861	567	412	295
signal	2.53±0.18	2.53±0.18	2.38±0.17	2.01±0.14	1.45±0.10	0.87±0.06

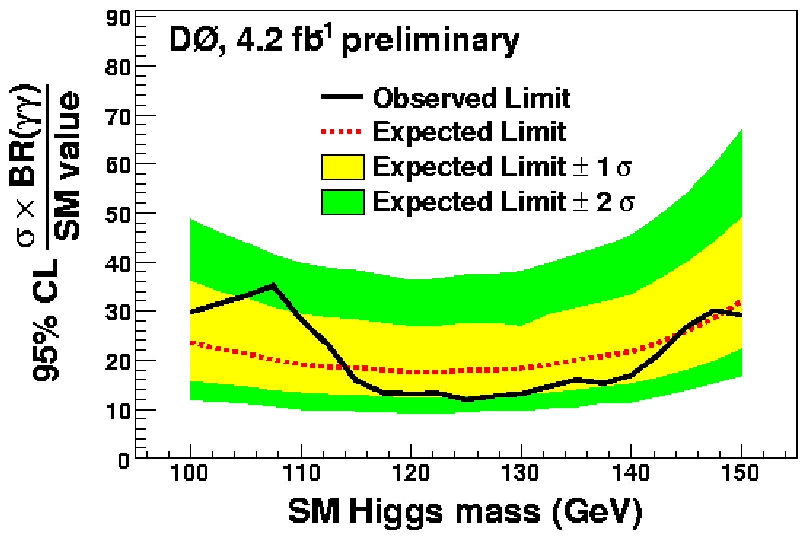


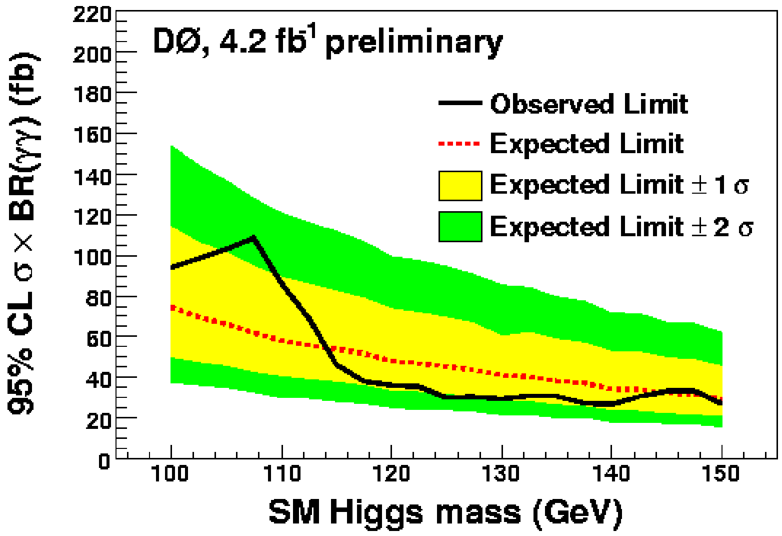




Results: SM Higgs

- 95% C.L. Limits
  - Use diphoton mass spectrum.
  - Almost mass independent.
  - Contributes ~5% for 115<M_H<130 GeV in the DØ SM Higgs combination.
  - Improved ~20% by comparison with the 2.7 fb^{-1} published results (PRL 102 231801 (2009))





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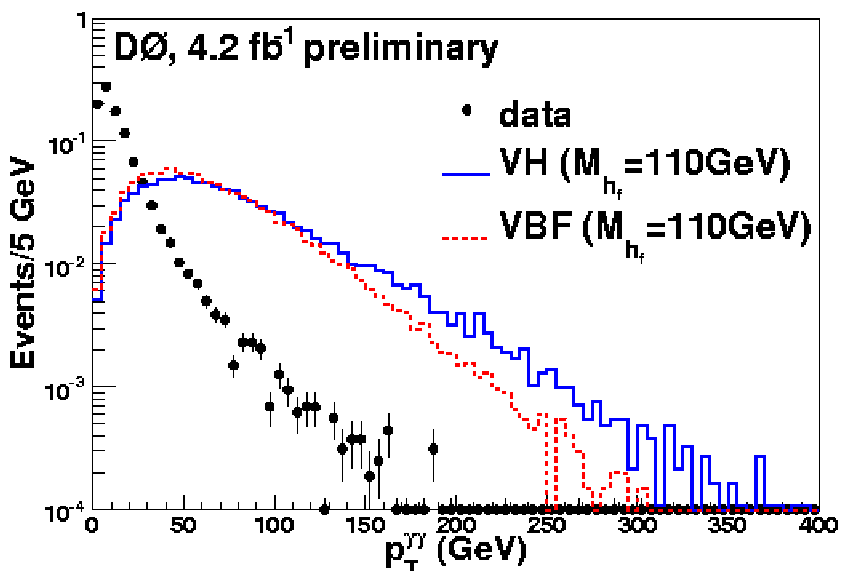
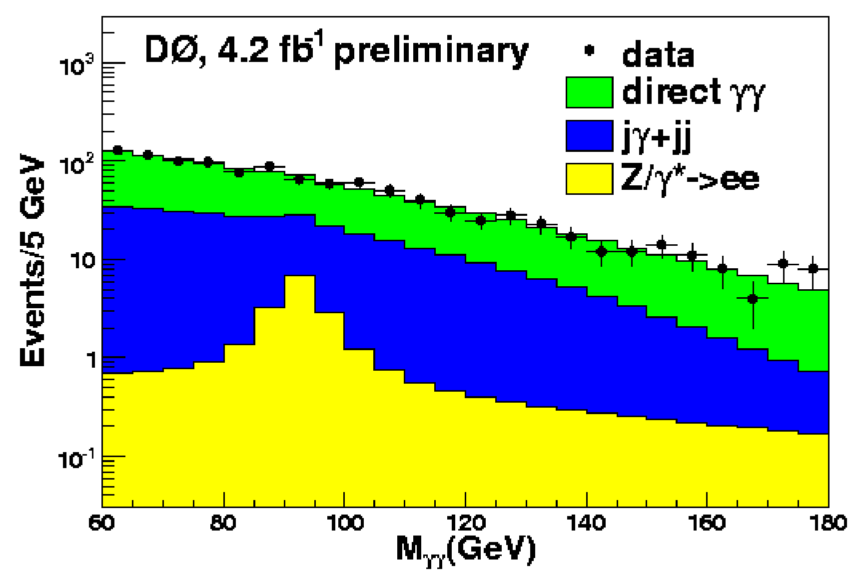
Results: Fermiophobic Higgs

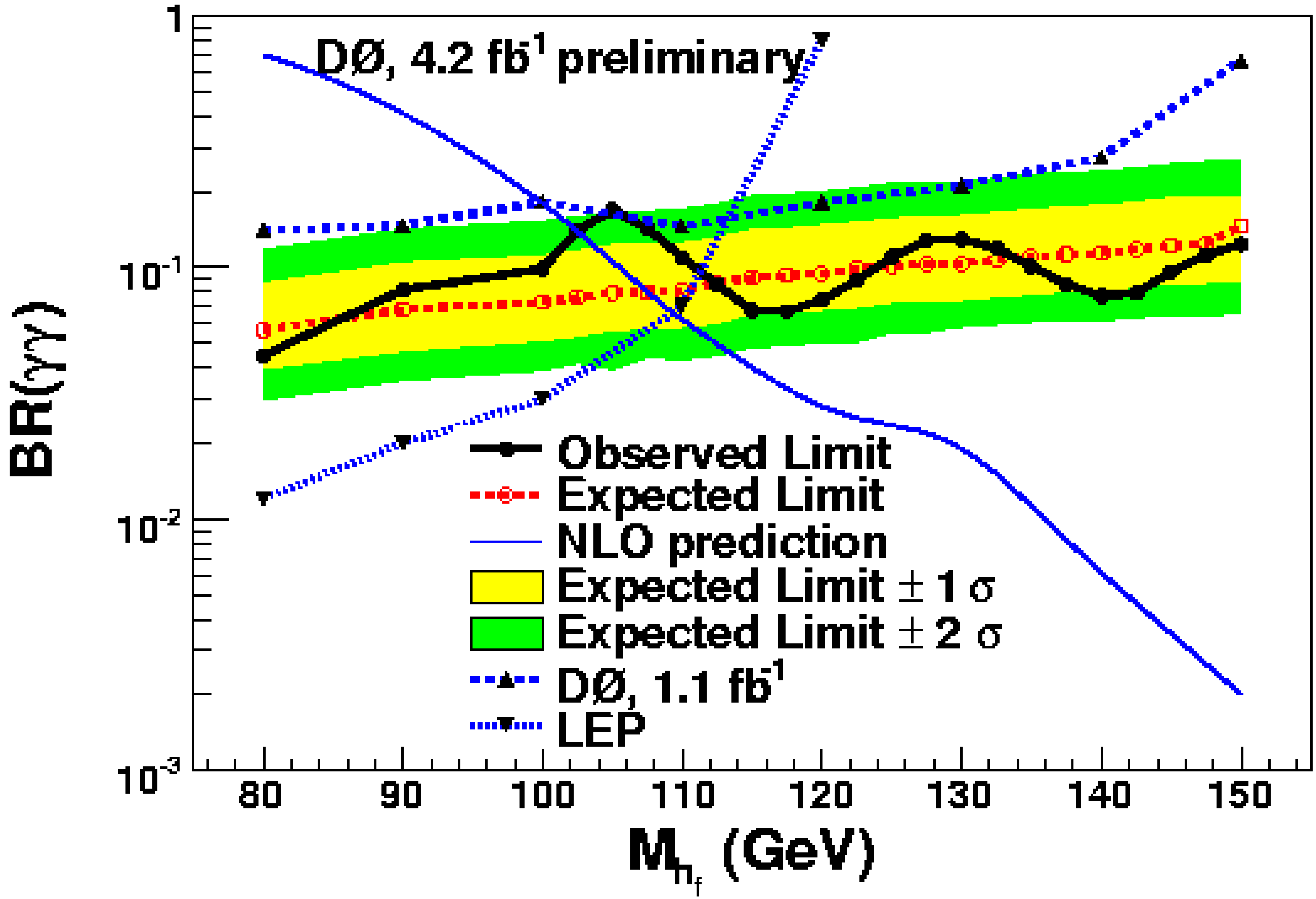
- No Higgs couplings to all fermions
  - no gluon fusion contribution
- Using the same technique as SM Higgs search, except

$$p_T^{\gamma\gamma} > 35\,GeV$$





Results: Fermiophobic Higgs



Results: Fermiophobic Higgs

Compare with LEP results

LEP exp.

ALEPH	104.6 GeV
DELPHI	105.1 GeV
OPAL	104.9 GeV
L3	105.2 GeV
combined	109.0 GeV

Tevatron exp.

DØ 101.2 pb^{-1}	78.5 GeV
CDF 100 pb^{-1}	82.0 GeV
DØ 1.1 fb^{-1}	100.0 GeV
CDF 3.0 fb^{-1} pre.	106.0 GeV
DØ 4.2 fb^{-1} pre.	107.5 GeV

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Conclusion

- SM Higgs search
  - 2.7 fb^{-1} results has been published in PRL 102 231801 (2009).
  - 4.2 fb^{-1} preliminary results contributes significantly to the DØ SM Higgs combination in the intermediate mass region (115 < M_H < 130 GeV).
  - Almost mass independent.
- Fermiophobic Higgs search
  - Set world's most stringent limits on the branching ratio ($H \to \gamma\gamma$) of a fermiophobic Higgs.
  - Achieve the same sensitivity as a single LEP experiment.
  - Provide access to M_H > 125GeV region which is inaccessible by LEP
  - The combination of CDF and DØ results could potentially exceed LEP results.

back-up

Work in progress

Currently working on the direct $\gamma\gamma$ cross section measurement (paper in preparation)

- The direct $\gamma\gamma$ is the largest and irreducible background for the $H \rightarrow \gamma\gamma$ search, and just di-photon invariant mass used for the final limits setting.
- Better understand the direct $\gamma\gamma$ generator, then use multivariate technical method to bring in some other information, for instance, the azimuthal angel between the two photons, to improve the sensitivity for the $H \rightarrow \gamma\gamma$ search (as well as other di-photon involved new phenomena searches).

Tevatron Accelerator

Current status

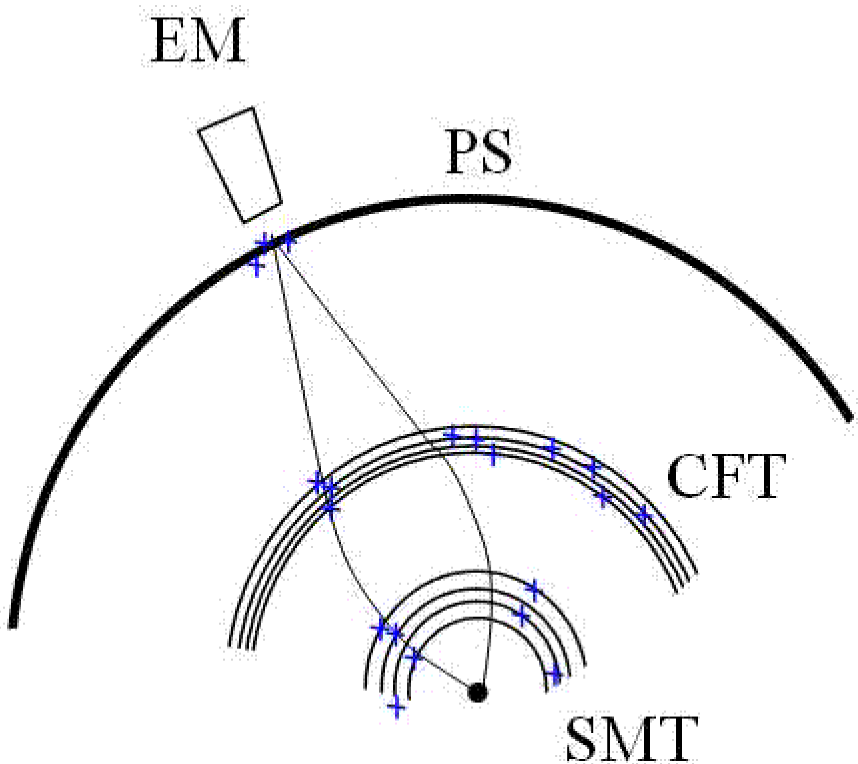
Peak instantaneous luminosity:

$$3.5\times10^{32} cm^{-2}\cdot s^{-1}$$

Integrated lumi/week: >$70\ pb^{-1}$ ~ 2X Run I dataset in 2 weeks

End of FY11: ~ $12-13\ fb^{-1}$

Hits in the road



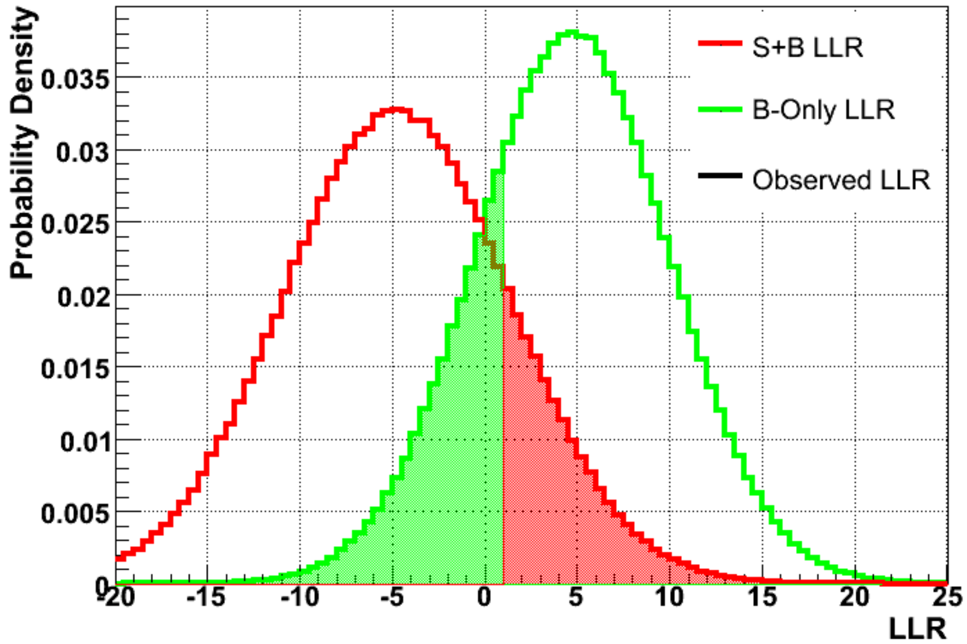
CL Limits calculation

$$Q_i = \frac{\frac{e^{-(s_i+b_i)}\cdot(s_i+b_i)^{d_i}}{d_i!}}{\frac{e^{-b_i}\cdot b_i^{d_i}}{d_i!}} = e^{-s_i}\cdot(1+\frac{s_i}{b_i})^{d_i} \quad (7.15)$$

where s_i and b_i are the numbers of signal and background events per bin of invariant mass distribution; and d_i is the number of selected events per bin in data. Poisson sampling is performed for d_i in each bin with the poisson mean set to b_i and $s_i + b_i$ respectively for the "background-only" and "signal+ background" hypotheses. And the likelihood ratio is computed as

$$Q = \prod_{all\ bins} Q_i \quad (7.16)$$

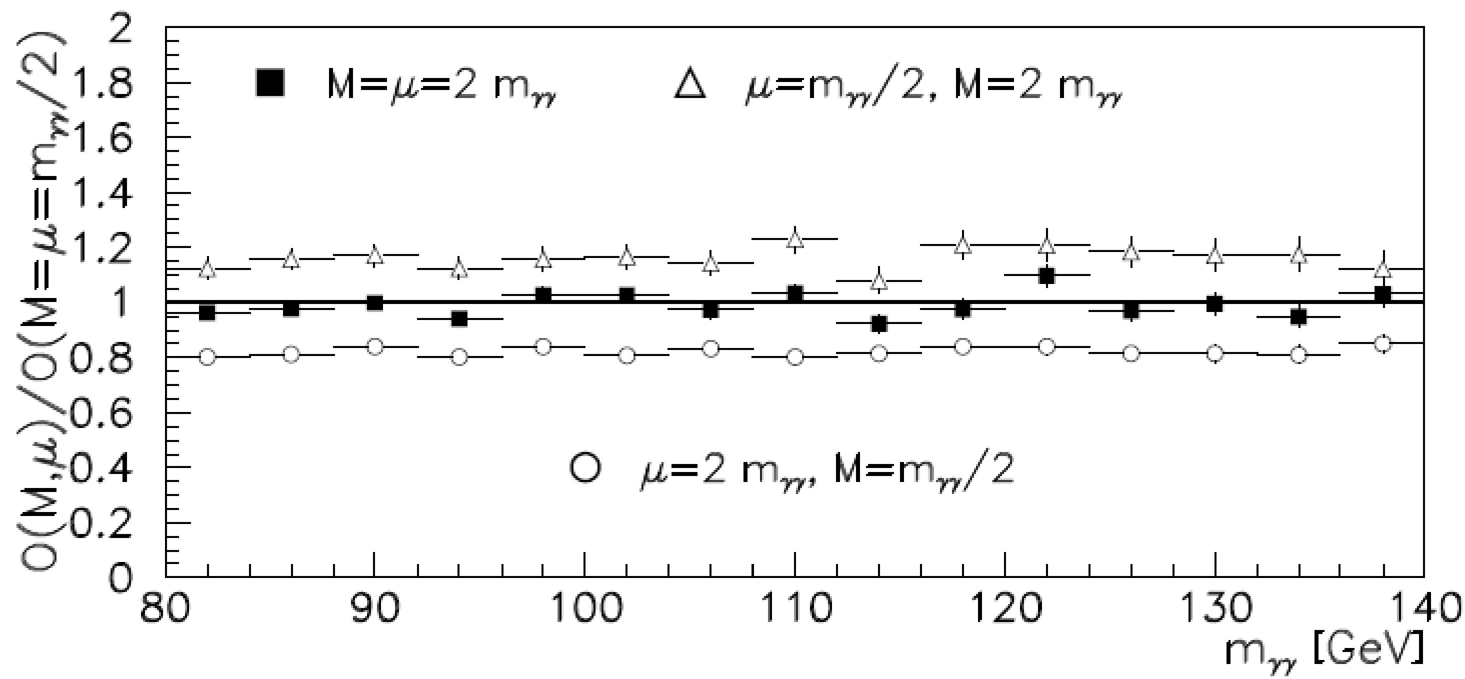
Probability distribution function (p.d.f) of the -2lnQ variable under the background-only and signal+background hypotheses can be obtained from the Poisson sampling.

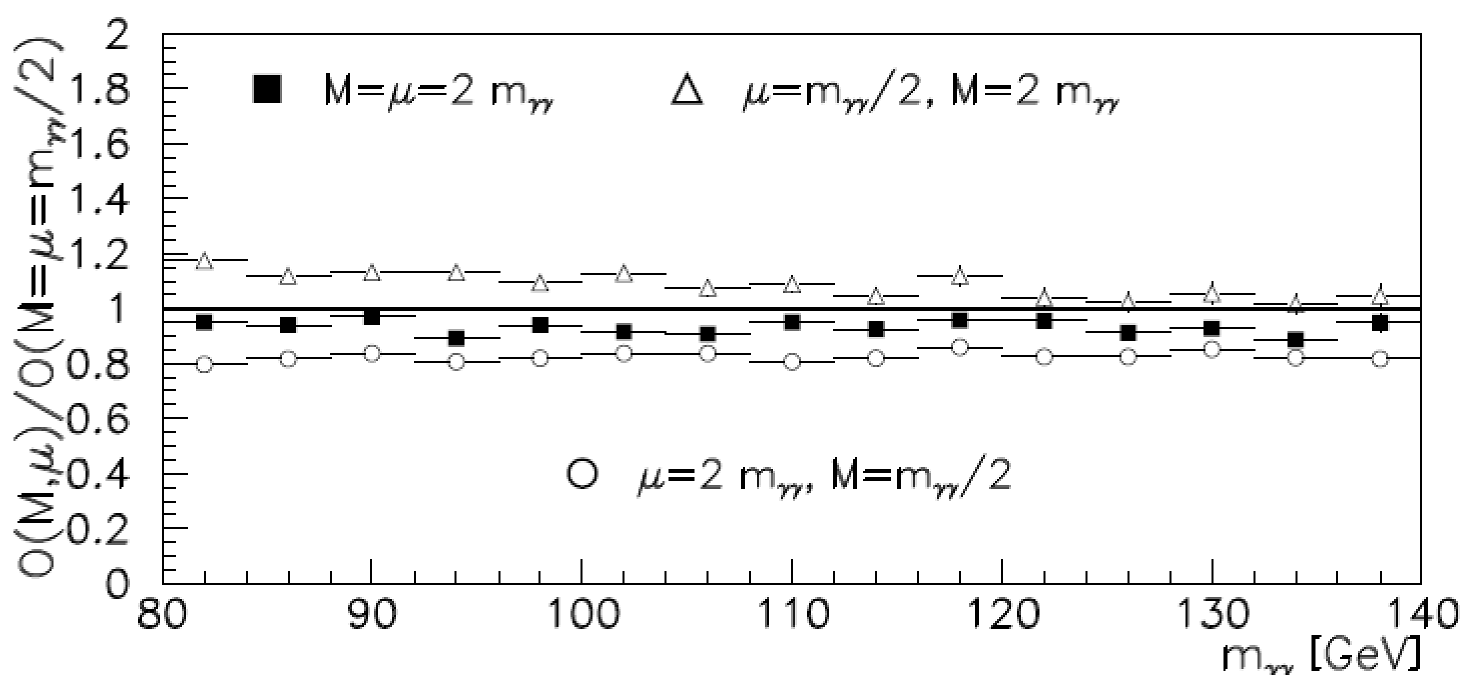


where the two histograms are the p.d.f of the -2lnQ statistic under background-only hypothesis and signal+background hypothesis and the vertical line stands for the value of data. The integral of the signal+background (background-only) p.d.f from the vertical data line to $+\infty$ is called CL_{s+b} (CL_b). If CL_{s+b} <0.05, exclusion can be claimed at 95% C.L. A more conservative exclusion estimator is defined in place of CL_{s+b} as

$$CL_s = \frac{CL_{s+b}}{CL_b}$$

T. Binoth, J. Ph.Guillet, E. Pilon, and M. Werlen, Eur. Phys. J. C 16, 311 (2000).





BSM

New Heavy resonances

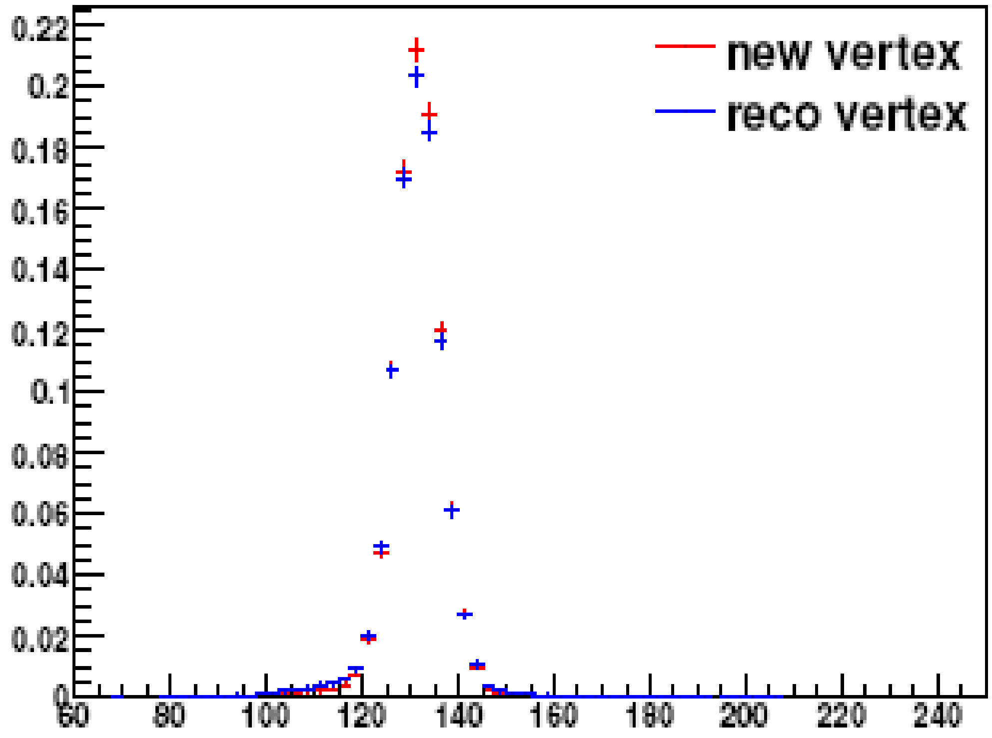
Phys. Rev. D 63, 015006 (2000),

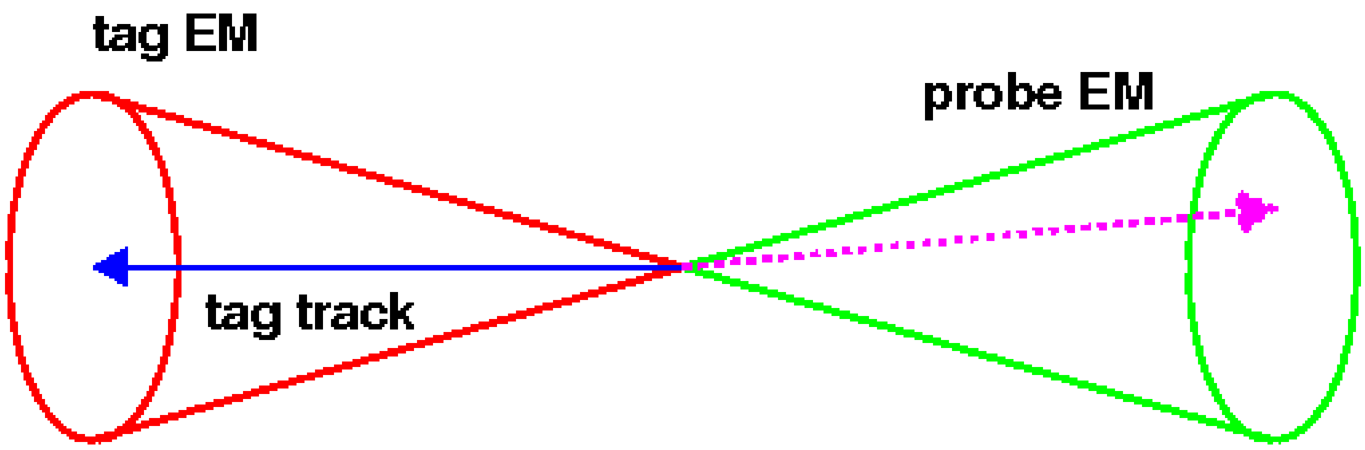
Cascade decay of heavy new particles

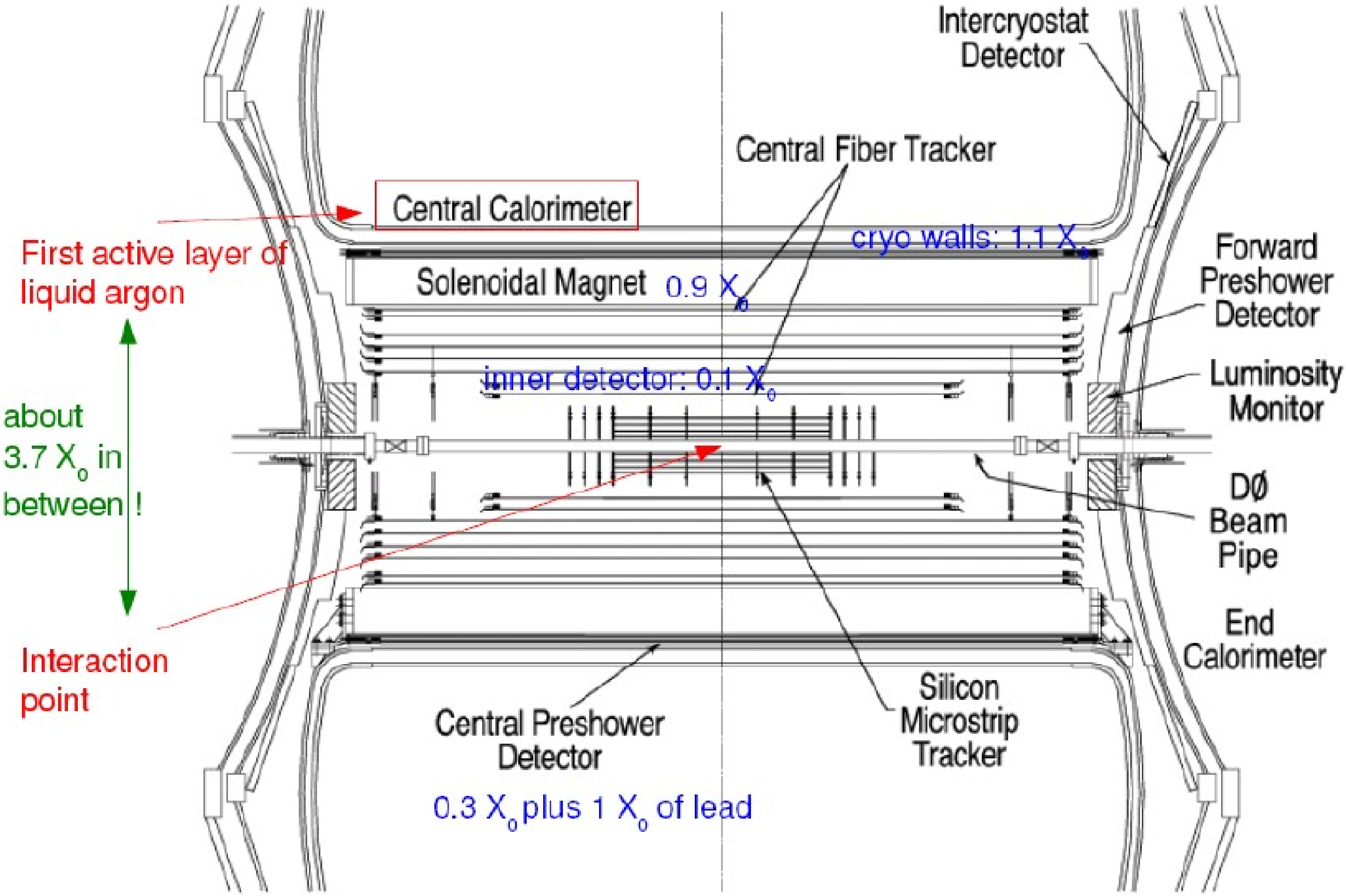
Phys. Lett. B 672, 45 (2009),

Primary vertex: highest track-multiplicity

signal sample	reco vertex	new vertex
ggH	0.762±0.001	0.937±0.001
VH	0.931±0.001	0.954±0.001
VBF	0.959±0.001	0.960±0.001




tag EM
probe EM
tag track


Intercryostat Detector
Central Fiber Tracker
Central Calorimeter
First active layer of liquid argon
cryo walls: 1.1 X_0
Solenoidal Magnet
0.9 X_0
Forward Preshower Detector
inner detector: 0.1 X_0
Luminosity Monitor
about 3.7 X_0 in between !
DØ Beam Pipe
End Calorimeter
Interaction point
Silicon Microstrip Tracker
Central Preshower Detector
0.3 X_0 plus 1 X_0 of lead