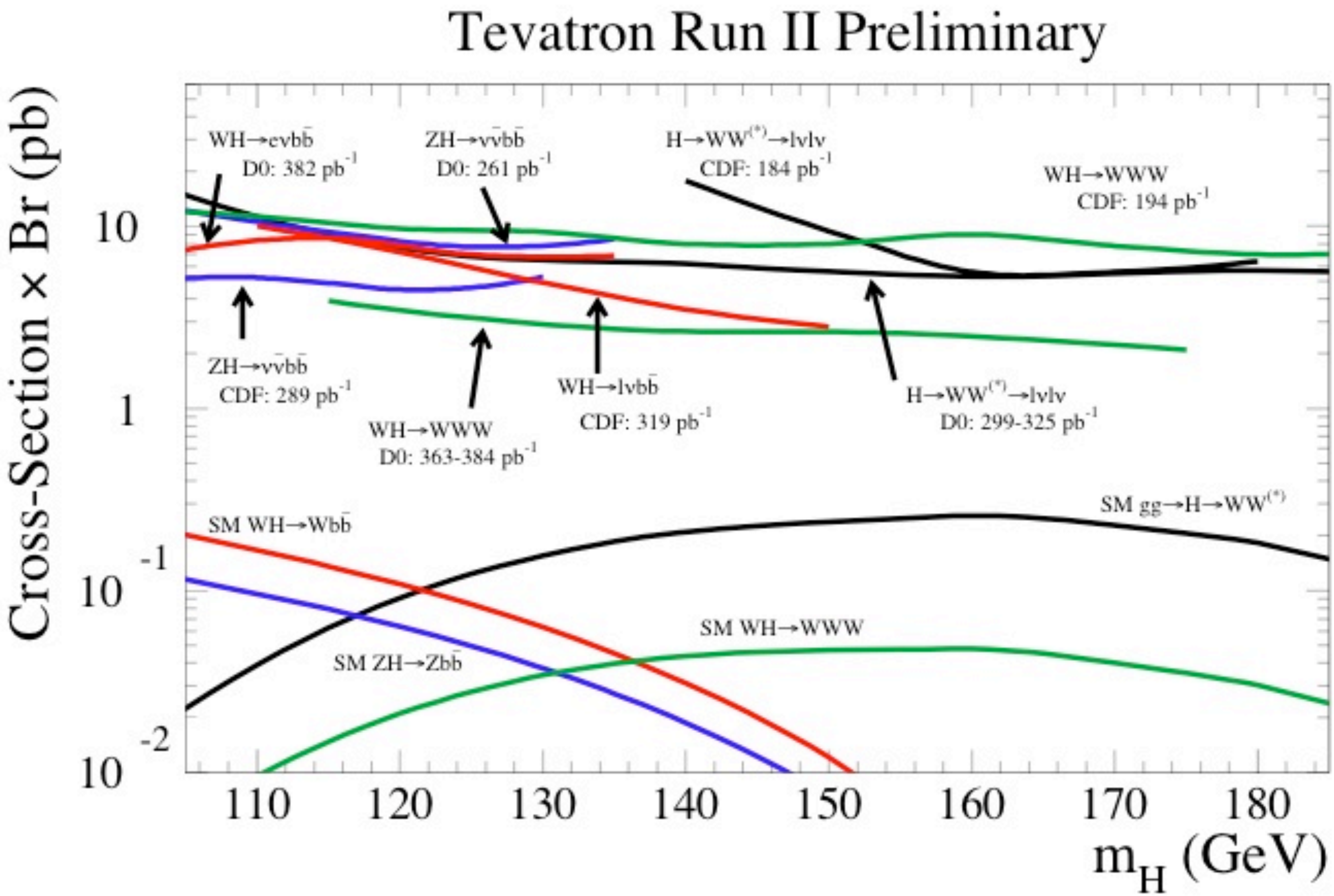
# ricerca dell’Higgs ai collider adronici

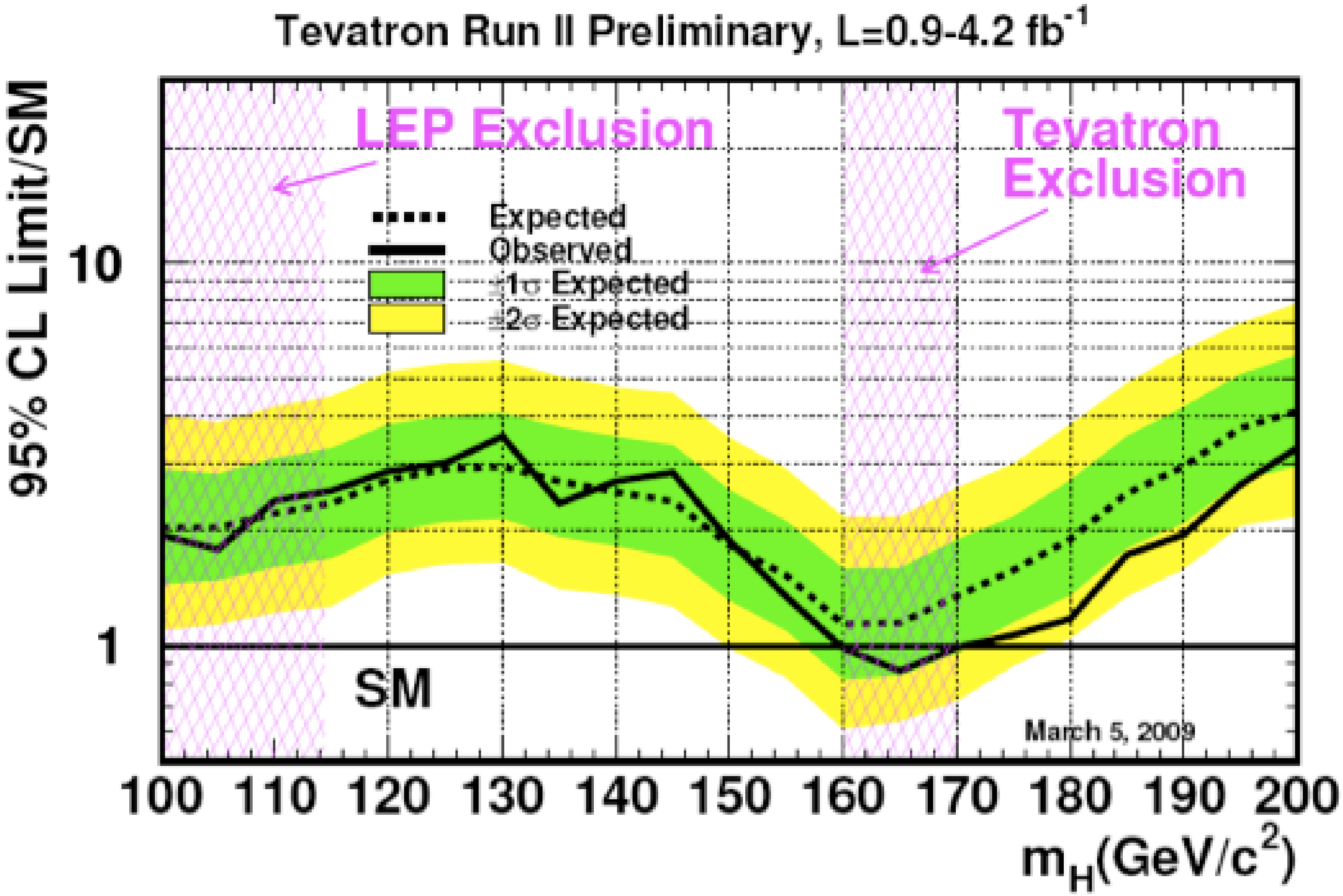
Produzione

1. gluon fusion in tutto il range
2. Higgs-strahlung per Higgs leggeri
3. WW,ZZ fusion per Higgs pesanti

Segnature:

1. nel range tra 100 e 180 GeV, si può ricostruire la massa invariante da $\gamma\gamma$ o bb (al Tevatron, p.e.)
2. nel range intermedio, i decadimenti in coppie virtuali e reali di W o Z possono essere identificati dai dacadimenti leptonici (4 leptoni carichi per ZZ)
3. oltre la soglia ZZ, 4 leptoni!
4. All’estremo superiore, anche i decadimenti in  jet e neutrini sono utili.


Tevatron Run II Preliminary
Cross-Section × Br (pb)
m_H (GeV)
WH→evbb̄
D0: 382 pb^-1
ZH→νν̄bb̄
D0: 261 pb^-1
H→WW^(*)→lνlν
CDF: 184 pb^-1
WH→WWW
CDF: 194 pb^-1
ZH→νν̄bb̄
CDF: 289 pb^-1
WH→WWW
D0: 363-384 pb^-1
WH→lνbb̄
CDF: 319 pb^-1
H→WW^(*)→lνlν
D0: 299-325 pb^-1
SM gg→H→WW^(*)
SM WH→Wbb̄
SM ZH→Zbb̄
SM WH→WWW



Tevatron Run II Preliminary, L=0.9-4.2 fb-1
95% CL Limit/SM
LEP Exclusion
Tevatron Exclusion
Expected
Observed
±1σ Expected
±2σ Expected
10
1
SM
March 5, 2009
100 110 120 130 140 150 160 170 180 190 200
mH(GeV/c2)

# LHC: la macchina

Energia dei fasci: 7 TeV

Luminosità: $10^{34}$cm$^{-2}$s$^{-1}$

(Luminosità dei primi anni? 1-2 $10^{33}$cm$^{-2}$s$^{-1}$ ?)

Multibunch (2835 per fascio, spaziati di 25 ns)

$\sigma_{inel} = 100$ mb $\rightarrow 10^{-25} \cdot 10^{34}$ s$^{-1}$ = $10^{9}$ eventi/s

25 eventi/crossing

$\sigma_{higgs} = 1$ pb $\rightarrow 10^{-36} \cdot 10^{34}$ s$^{-1}$ = $10^{-2}$ eventi/s

Radiazione di fondo, neutroni e gamma

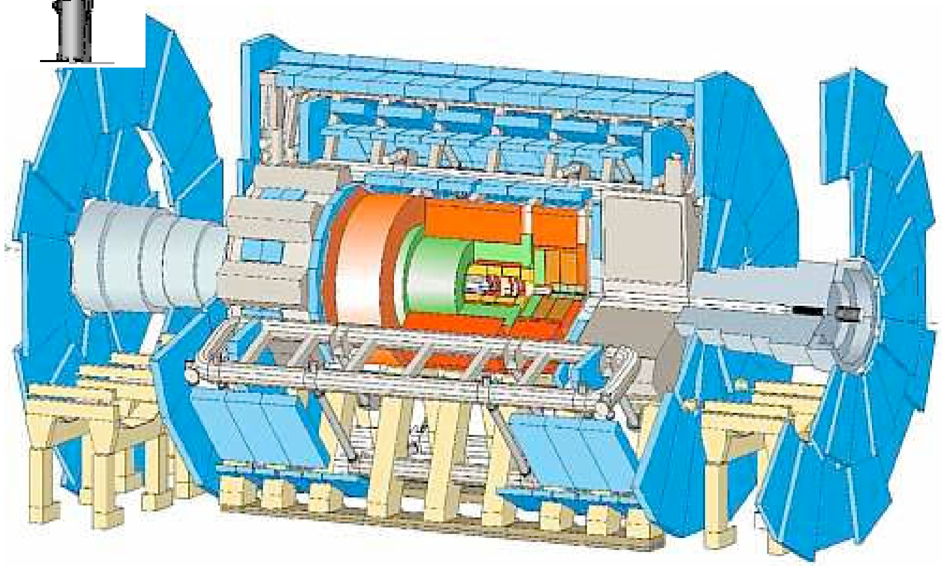
Sfida per i rivelatori:

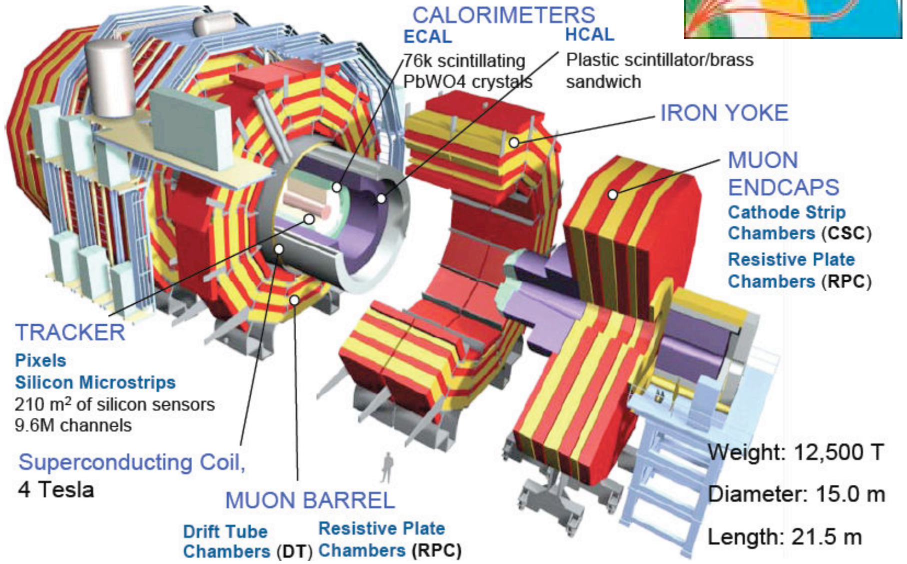
- granularità
- velocità di risposta
- acquisizione dei dati
- resistenza alla radiazione

1 barn = $10^{-24}$cm$^{-2}$s$^{-1}$
1 pb = $10^{-36}$cm$^{-2}$s$^{-1}$
1 fb = $10^{-39}$cm$^{-2}$s$^{-1}$
1 anno = 100 g = $10^{7}$s
[Luminosità integrata]=[l$^{-2}$]
1 anno HL = 100 fb$^{-1}$
1 anno LL = 10 fb$^{-1}$

# LHC: gli esperimenti

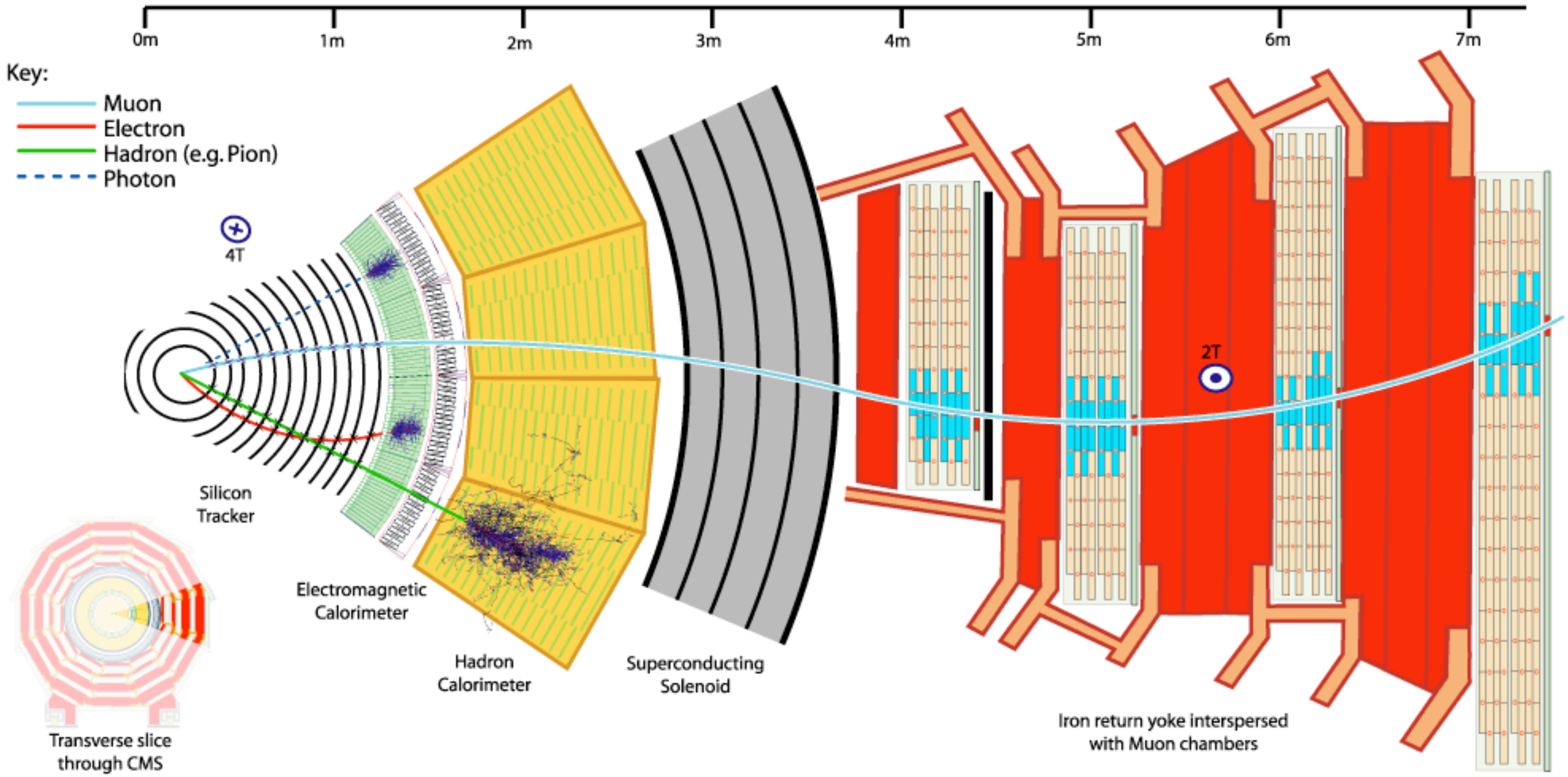
## ATLAS and CMS Detectors



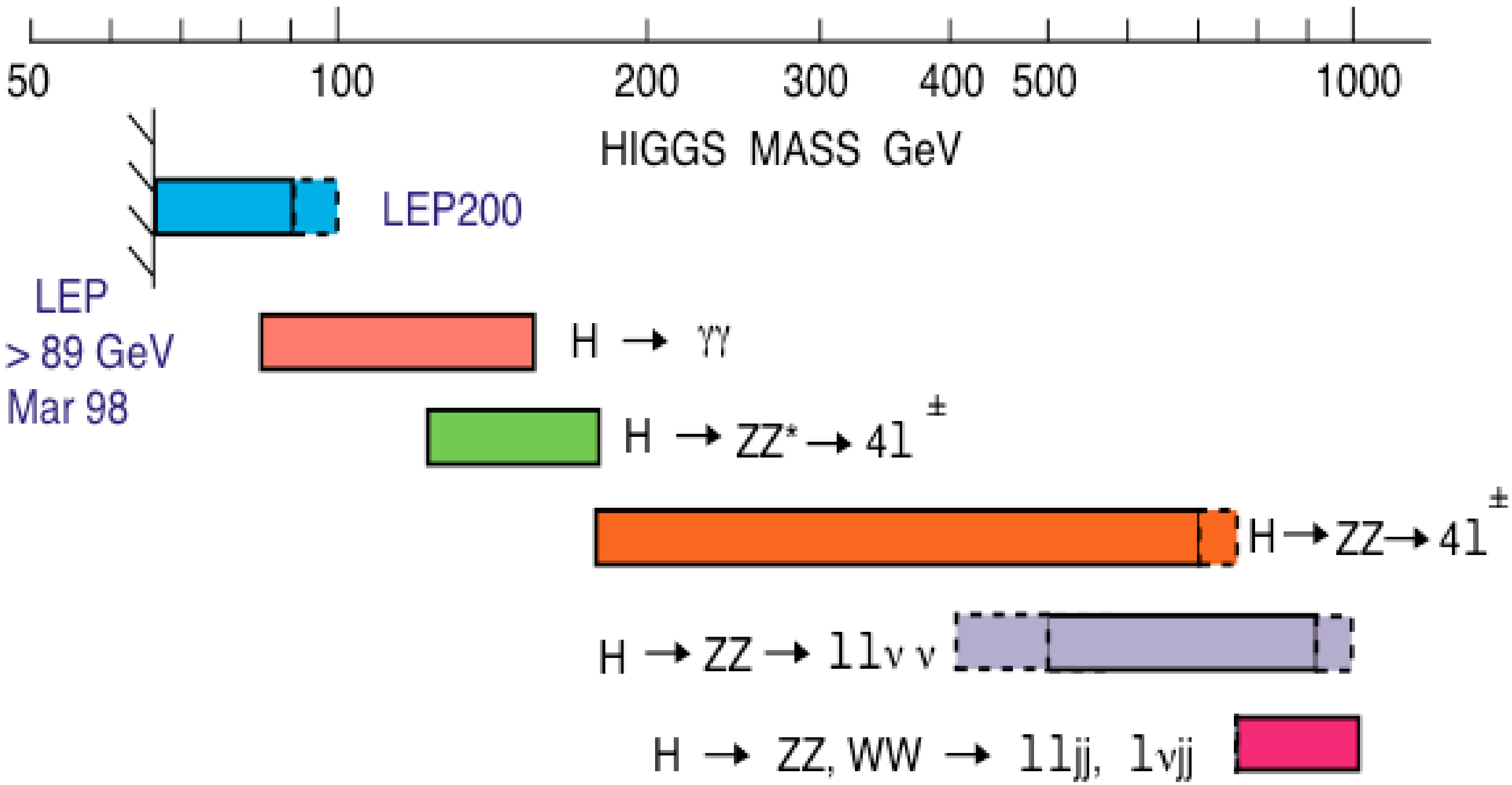


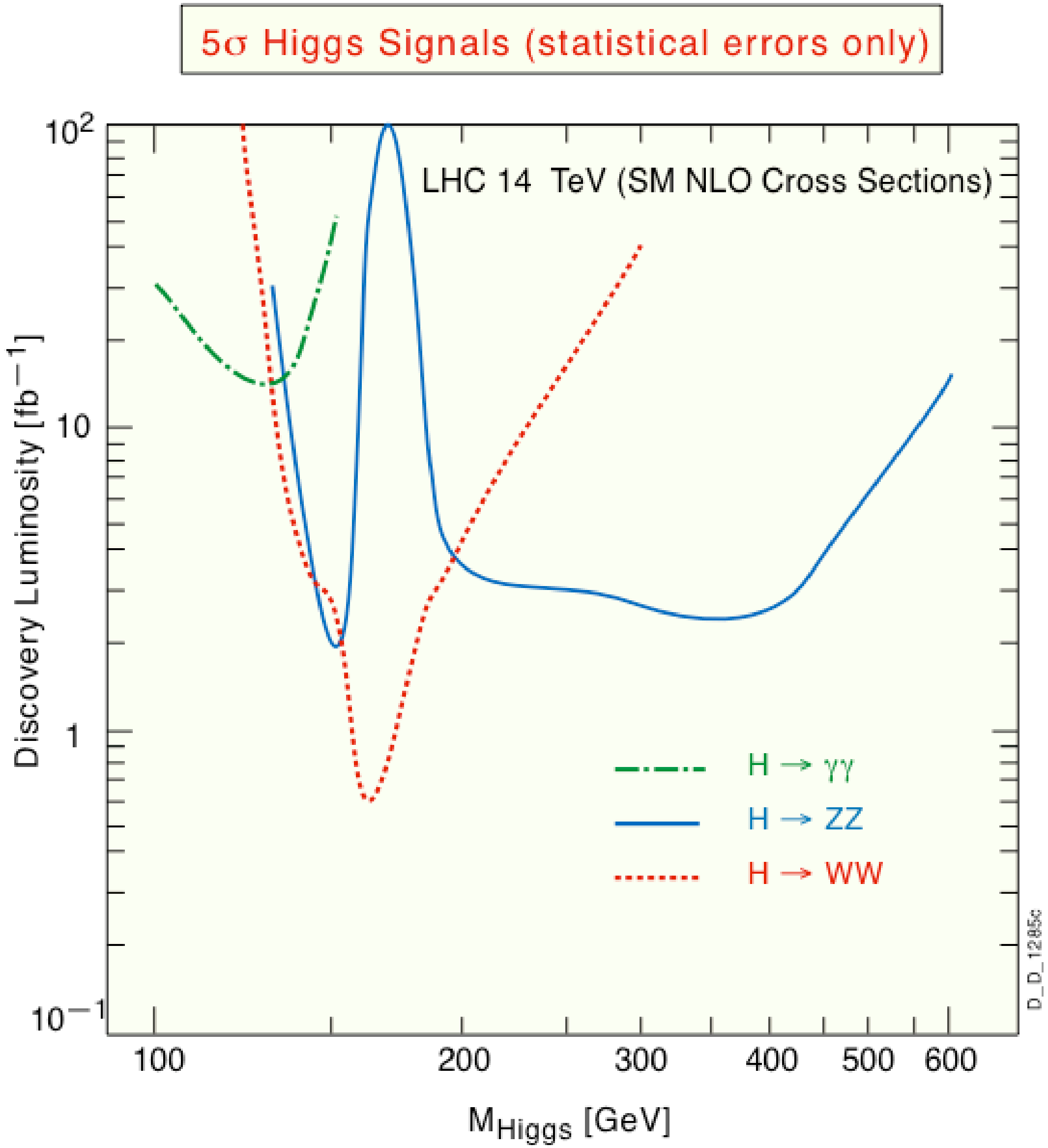

| | Weight (tons) | Length (m) | Height (m) |
|---|---|---|---|
| ATLAS | 7,000 | 42 | 22 |
| CMS | 12,500 | 21 | 15 |

# LHC: gli esperimenti



# canali di scoperta

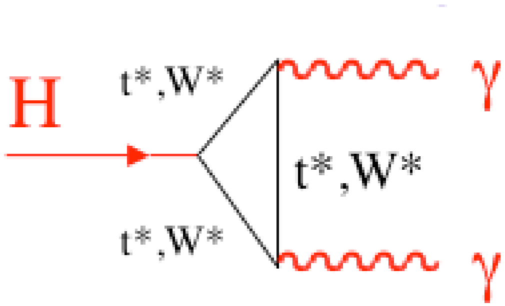




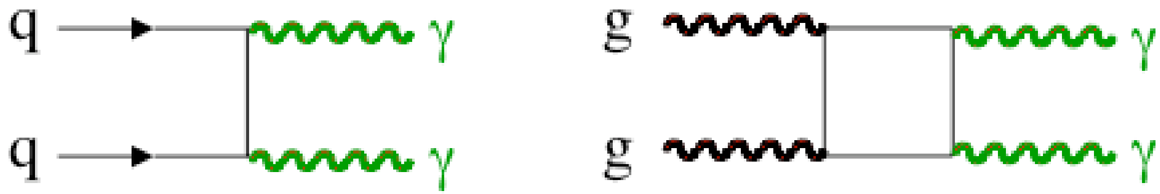
5σ Higgs Signals (statistical errors only)
LHC 14 TeV (SM NLO Cross Sections)
Discovery Luminosity [fb⁻¹]
10²
10
1
10⁻¹
100
200
300
400
500
600
M_Higgs [GeV]
H → γγ
H → ZZ
H → WW
D_D_1285c

# $H \to \gamma\gamma$

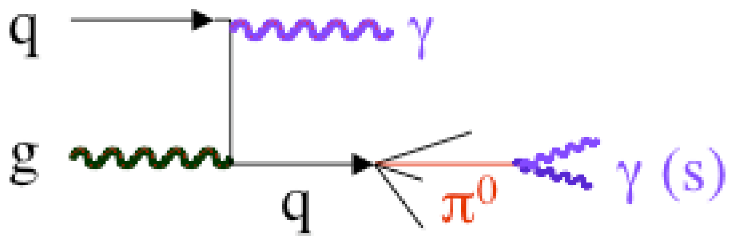
segnale




fondo irriducibile




fondo riducibile



# $H \to \gamma\gamma$

significatività = segnale/√(fondo)

fondo ∝ larghezza del segnale

per $m_H < 150$ GeV, $\Gamma_H / m_H \leq 10^{-3}$

larghezza del segnale = risoluzione sperimentale

$m^2_{\gamma\gamma} = 2\, E_1\, E_2\, (1 - \cos\theta_{\gamma\gamma})$ $\quad\quad$ $1 - \cos\theta_{\gamma\gamma} = 2\sin^2\theta_{\gamma\gamma}/2$

$$\frac{\sigma_m}{m} = \frac{1}{2}\left[\left(\frac{\sigma_1}{E_1}\right)^2 + \left(\frac{\sigma_2}{E_2}\right)^2 + \left(\frac{\sigma_\theta}{tg\theta/2}\right)^2\right]^{1/2}$$

per θ = 90°

15 milliradianti in angolo sono come 1% in energia

# risoluzione di un calorimetro

risoluzione di un calorimetro $$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

a. termine stocastico, fluttuazioni poissoniane
   calorimetri omogenei vs campionamento
b. termine di rumore, indipendente dall'energia
   rumore elettronico (tempo vs capacità)
   a LHC anche rumore fisico (pile up)
c. termine costante, dovuto a varie instabilità, prima tra tutte l'intercalibrazione

# pesi relativi dei termini

calorimetro campionamento $\rightarrow$ omogeneo

a ~ 10% $\rightarrow$ 3%

fissiamo E = 100 GeV

$a/\sqrt{E}$ = 1%,  b = 1 GeV, c = 1% $\Rightarrow \sigma$ = 1.7%

$a/\sqrt{E}$ = 0.3%, b = 300 MeV, c = 0.3% $\Rightarrow \sigma$ = 0.5%

# caratteristiche geometriche dei calorimetri

lunghezza di radiazione

$$X_0 \approx \frac{A}{Z^2}$$

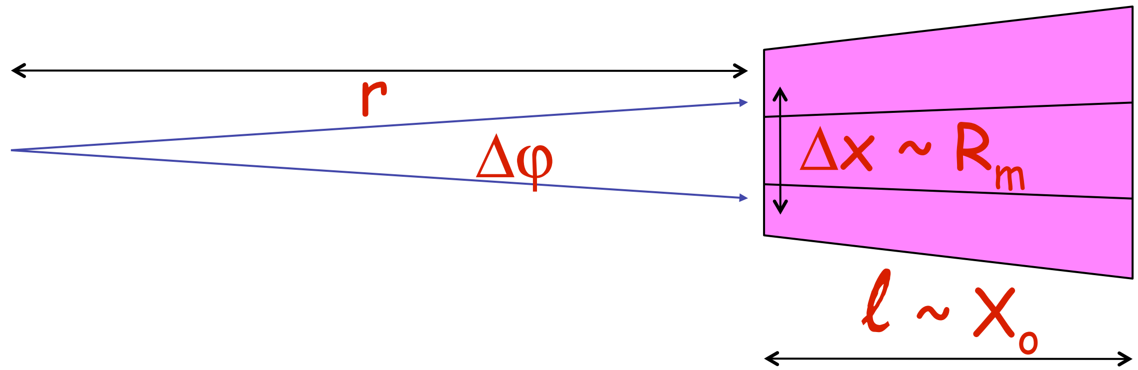
in lunghezze di radiazione, le dimensioni dello sciame crescono logaritmicamente con l'energia
nella regione di 100 GeV, 25 $X_0$

raggio di Molière

$$R_M \propto \frac{X_0}{E_C} \propto \frac{A}{Z}(Z >> 1)$$

# dimensioni

per una data separazione angolare $\Delta\varphi$:




$$\Delta x = r\Delta\varphi \Rightarrow r \propto R_m/\Delta\varphi$$

$$V_{calor.} \sim r^2 X_0 \sim R_m{}^2 X_0 /\Delta\varphi$$

piccolo $\Delta\varphi \Rightarrow$ grandi dimensioni (e costi)

# The Crystal Ball

672 + 60 NaI crystals pioneering most of the features of barrel calorimeters

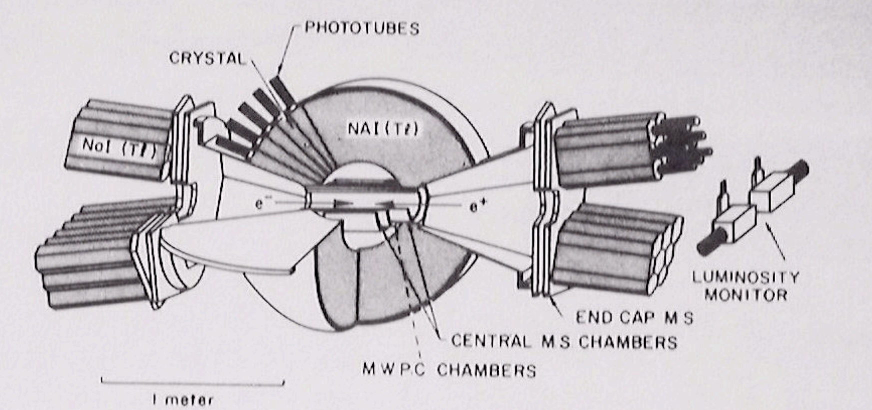



FIG. 2. Schematic of the detector.

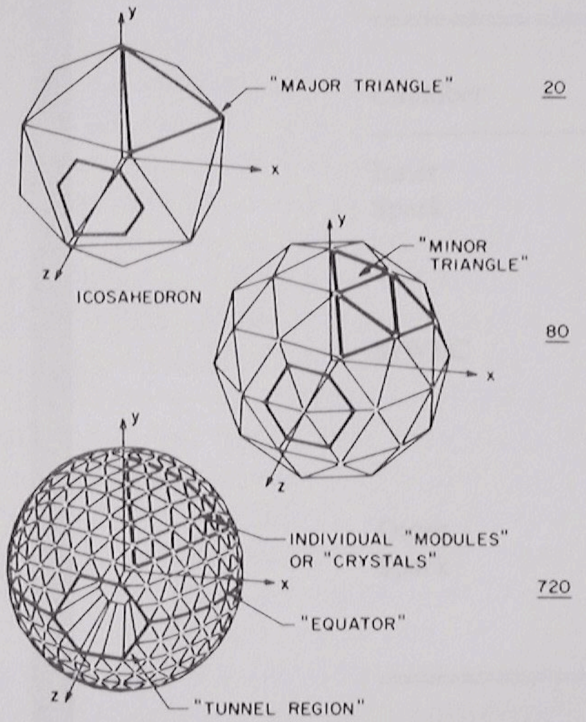
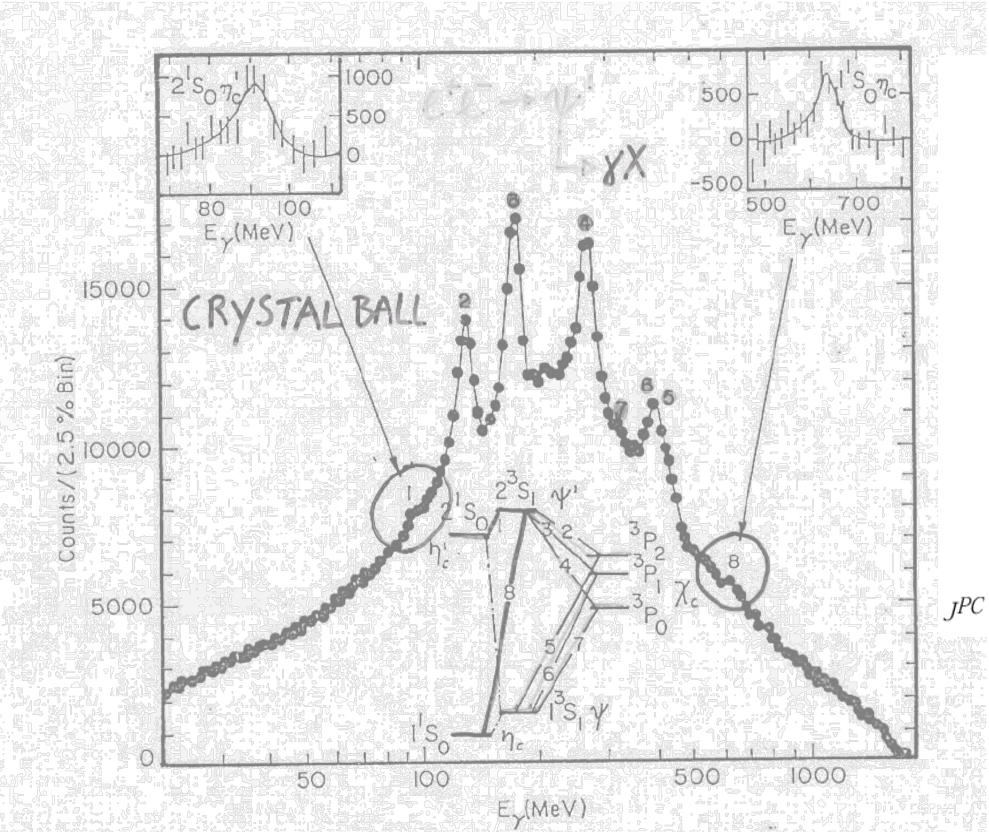
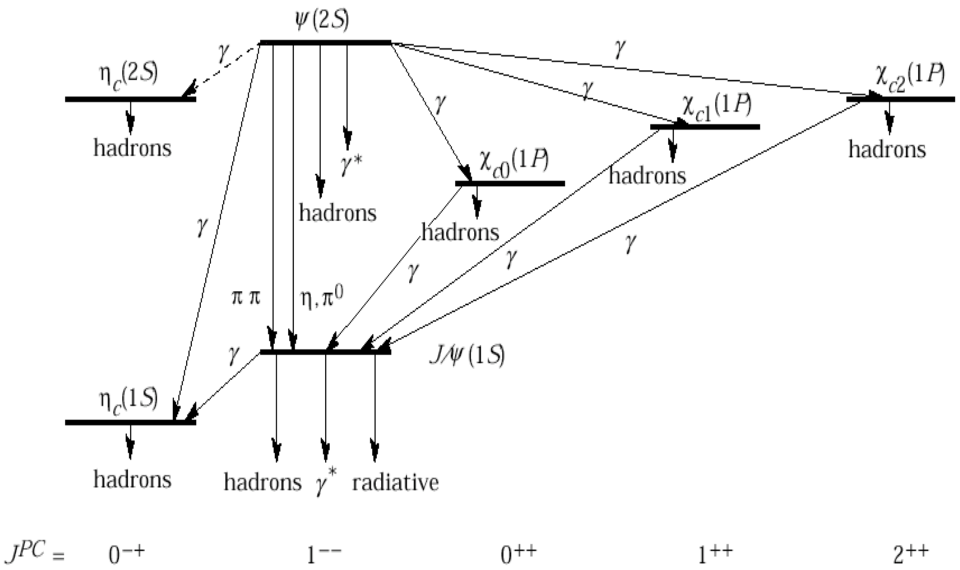



FIG. 3. Development of the ball geometry and nomenclature.

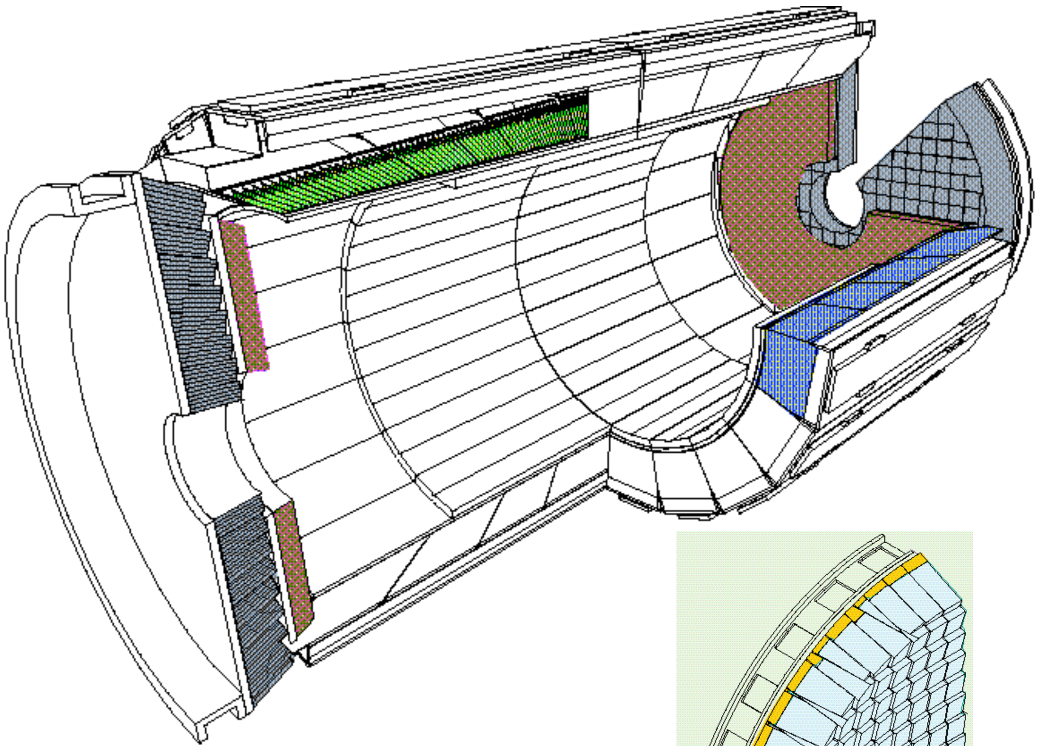
# Crystal Ball results



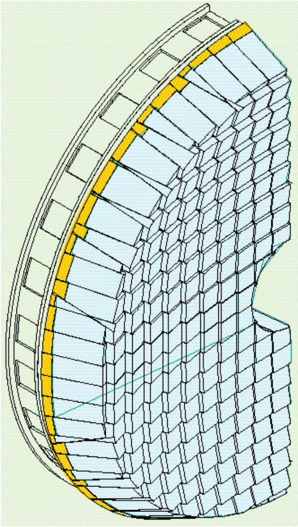

e+e- → Ψ' →γX

# calorimetro a cristalli di CMS



- 75000 PWO crystals
- APD read out (gain 50)
- Eγ range 1 GeV → 1 TeV

PWO: $PbWO_4$
about 10 $m^3$, 80 ton



| Parameter | Barrel | Endcap |
|---|---|---|
| η coverage | \|η\| < 1.48 | 1.48 < \|η\| < 3.0 |
| Granularity (Δη×Δφ) | 0.0175×0.0175 | varies in η |
| Crystal Dims. ($cm^3$) | 2.18×2.18×23 | 2.85×2.85×22 |
| Depth in $X_0$ | 25.8 | 24.7 (+3$X_0$) |
| No. of crystals | 61,200 | 14,950 |
| Crystal Volume ($m^3$) | 8.14 | 3.04 |
| Photodetector | APDs | VPTs |
| Modularity | 36 supermodules | 4 Dees |

# photodetectors

**Barrel: Avalanche photodiodes (APD)**

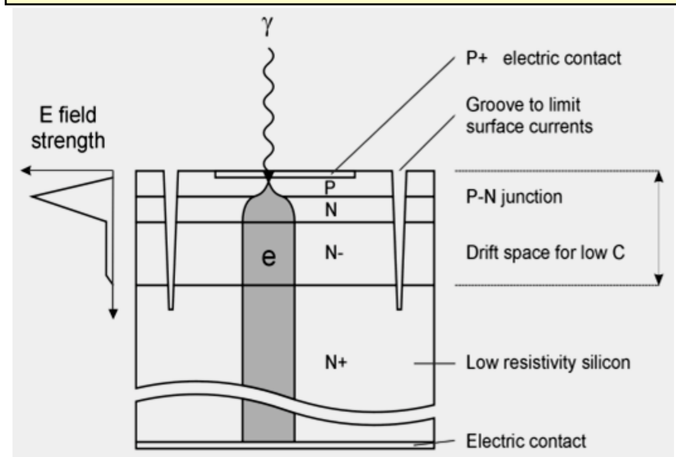
Two 5x5 mm² APDs/crystal

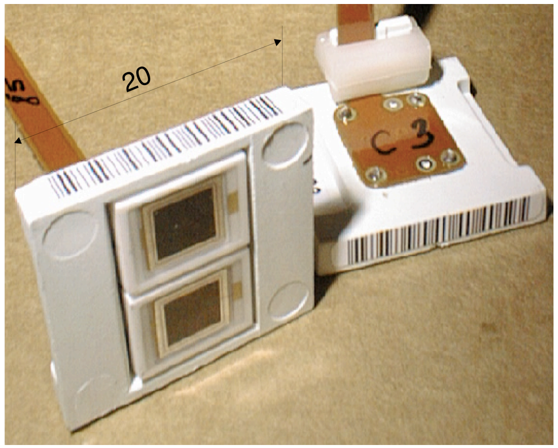
- Gain: 50
- QE: ~75% at 420 nm
- Temperature dependence: -2.4%/°C
- Delivery complete

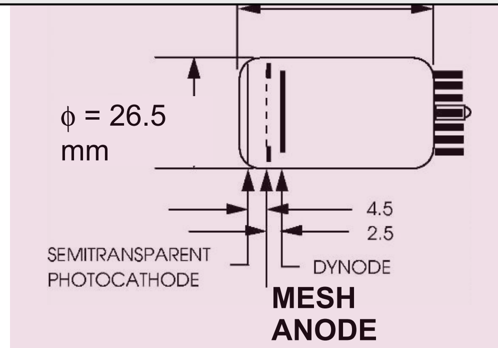
**Endcaps: Vacuum phototriodes (VPT)**

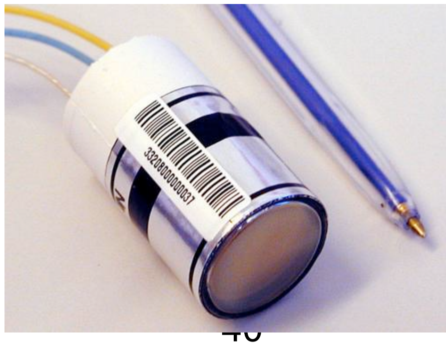
More radiation resistant than Si diodes

- Active area ~ 280 mm²/crystal
- Gain 8 -10 (B=4T)   Q.E.~20% at 420nm
- Delivery ~80%

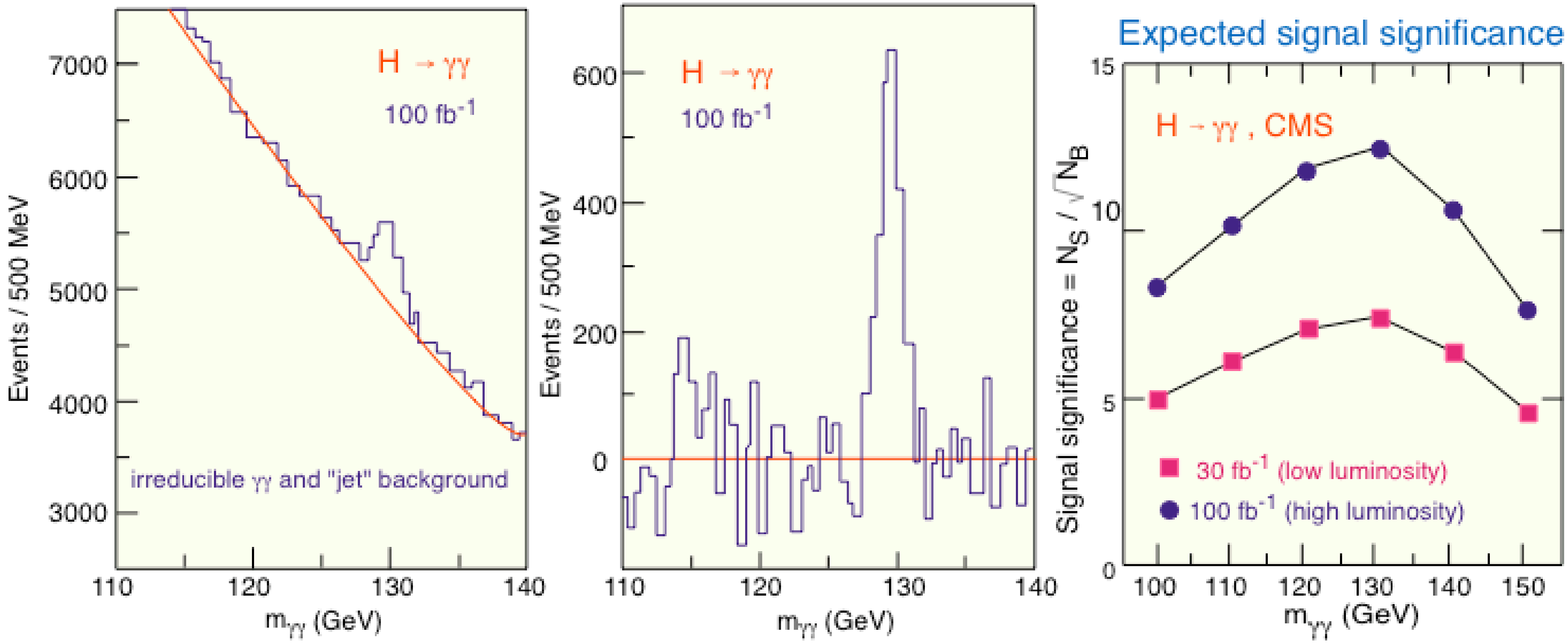


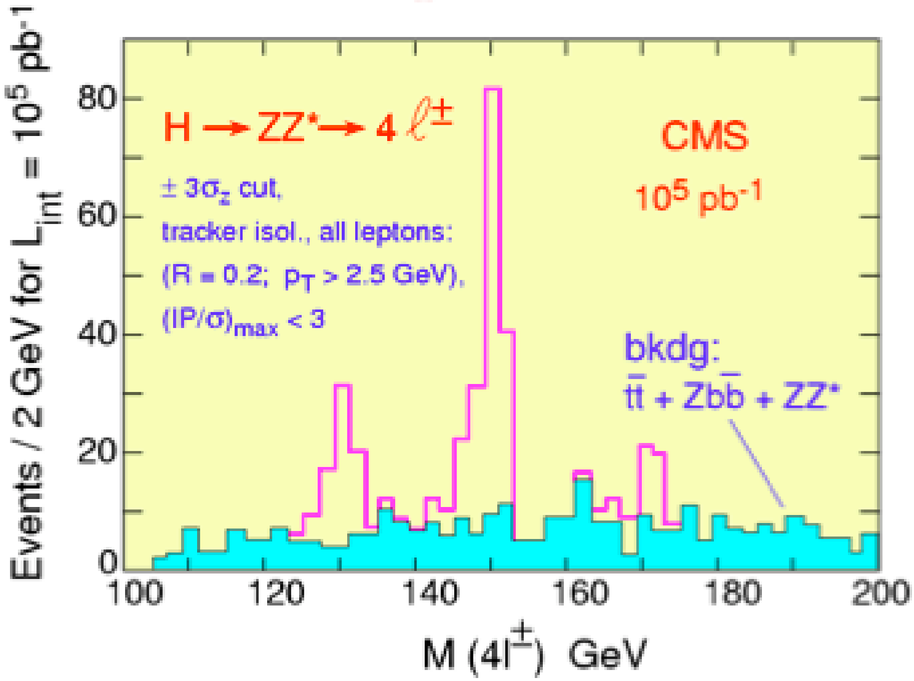



# $H_{SM} \rightarrow \gamma\gamma$ in CMS $PbWO_4$ calorimeter



# H→ZZ*→4 leptoni

~90% of bkg comes from ZZ*




**1 experiment, 30 fb$^{-1}$**

| $m_H$ (GeV) | 120 | 130 | 150 | 170 | 180 |
|---|---|---|---|---|---|
| S | 4 | 11 | 27 | 8 | 20 |
| S/B | 2.7 | 4.4 | 9 | 2.7 | 6.7 |
| S/√B 30 fb$^{-1}$ (Poisson) | 2.4 | 4.8 | 15.5 | 3.2 | 11.2 |
| S/√B 100 fb$^{-1}$ (Poisson) | 3.8 | 10.3 | 22.6 | 5.3 | 16.7 |

# $H \rightarrow WW \rightarrow l\nu l\nu$

Importante intorno a 170 GeV dove ZZ è depresso

$\sigma \times BR \approx$ 700 fb

misura di conteggio, non ci sono picchi di massa invariante

fondi:

| | |
|---|---|
| - $WW^{(*)}$ (irreducible) | $\sigma \approx 5$ pb |
| - $WZ \rightarrow \ell\nu\ell\ell$, $ZZ \rightarrow \ell\ell\nu\nu$ | $\sigma \approx 1$ pb |
| - Wt, Wbb $\rightarrow 2\ell$+X | $\sigma \approx 120$ pb |

tagli tipici:

leptoni isolati di segno opposto, alto pt

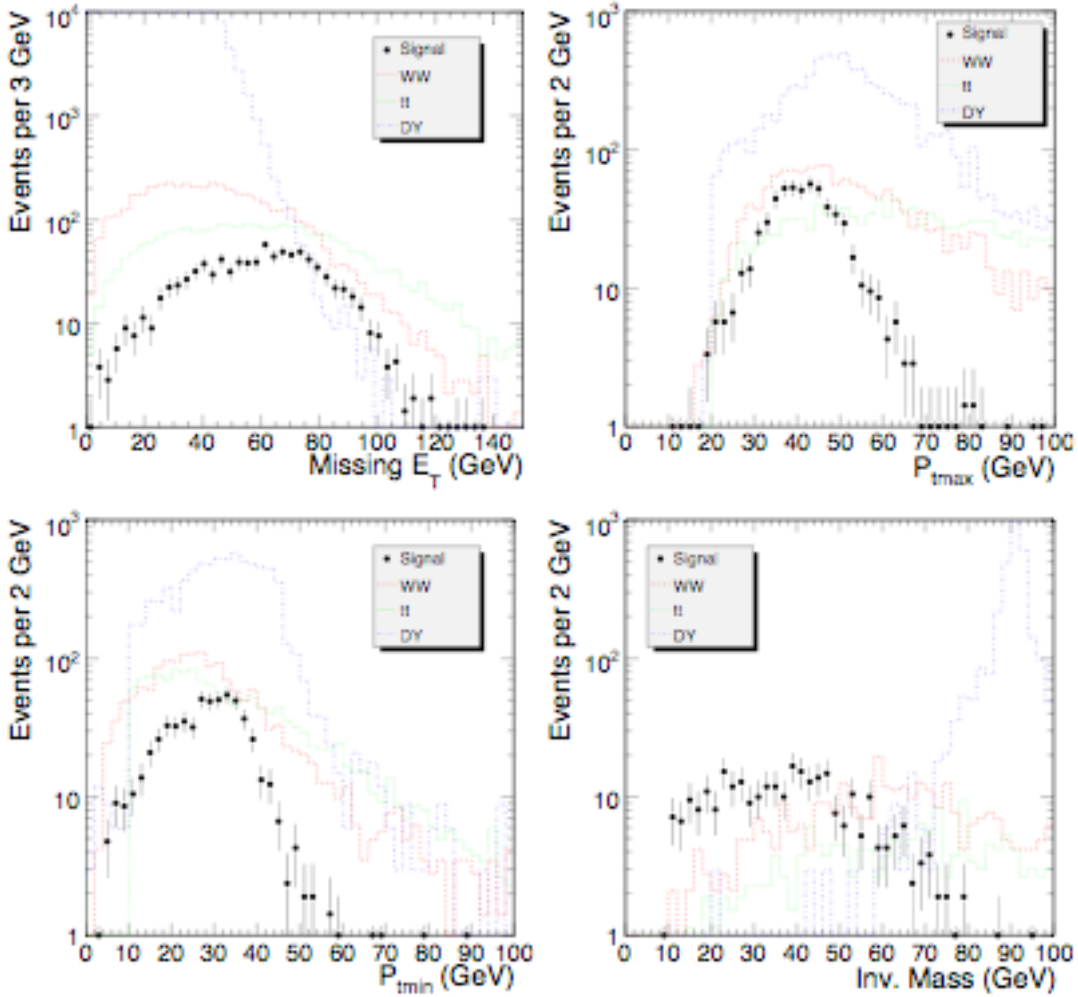
$M_{ll}$<80 GeV (contro WZ, ZZ)

nessun jet energetico

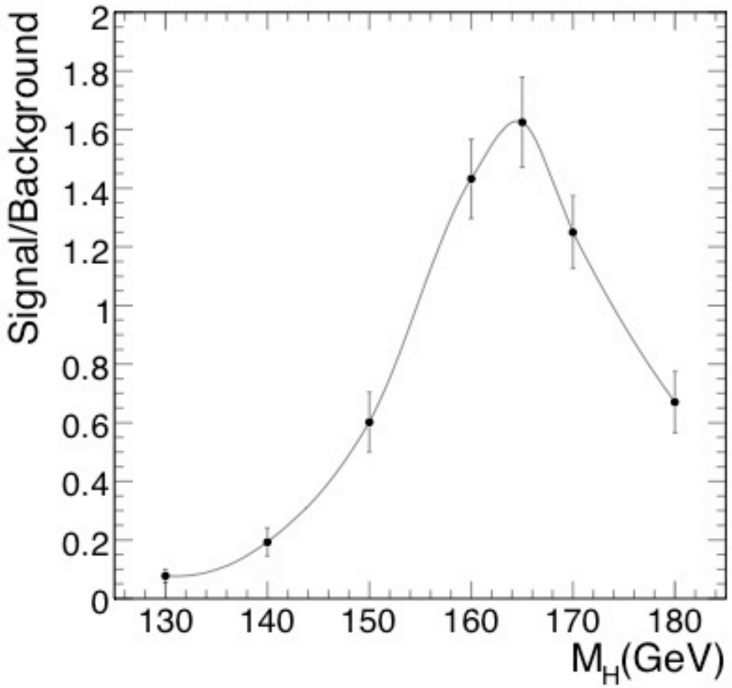
missing energy

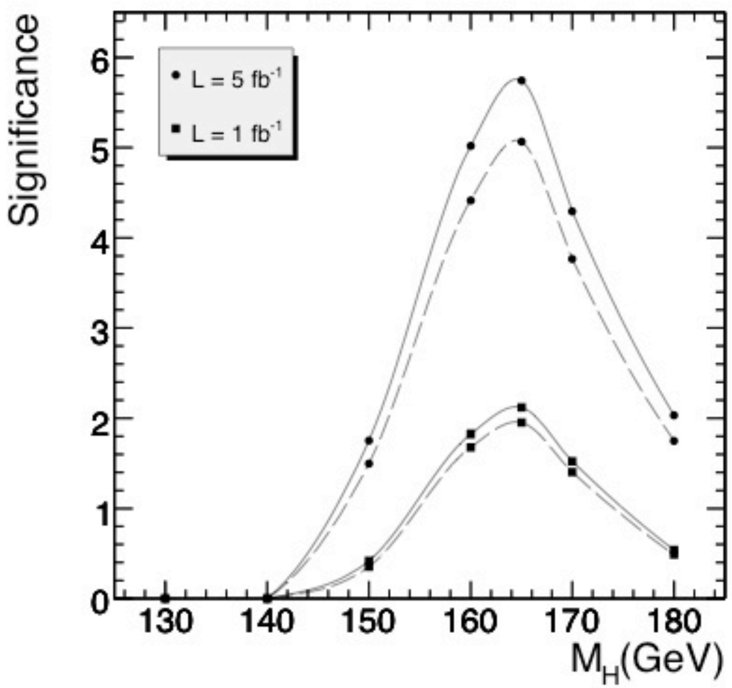
## $H \to WW \to \mu\nu\mu\nu$

la conoscenza del fondo è essenziale per la misura



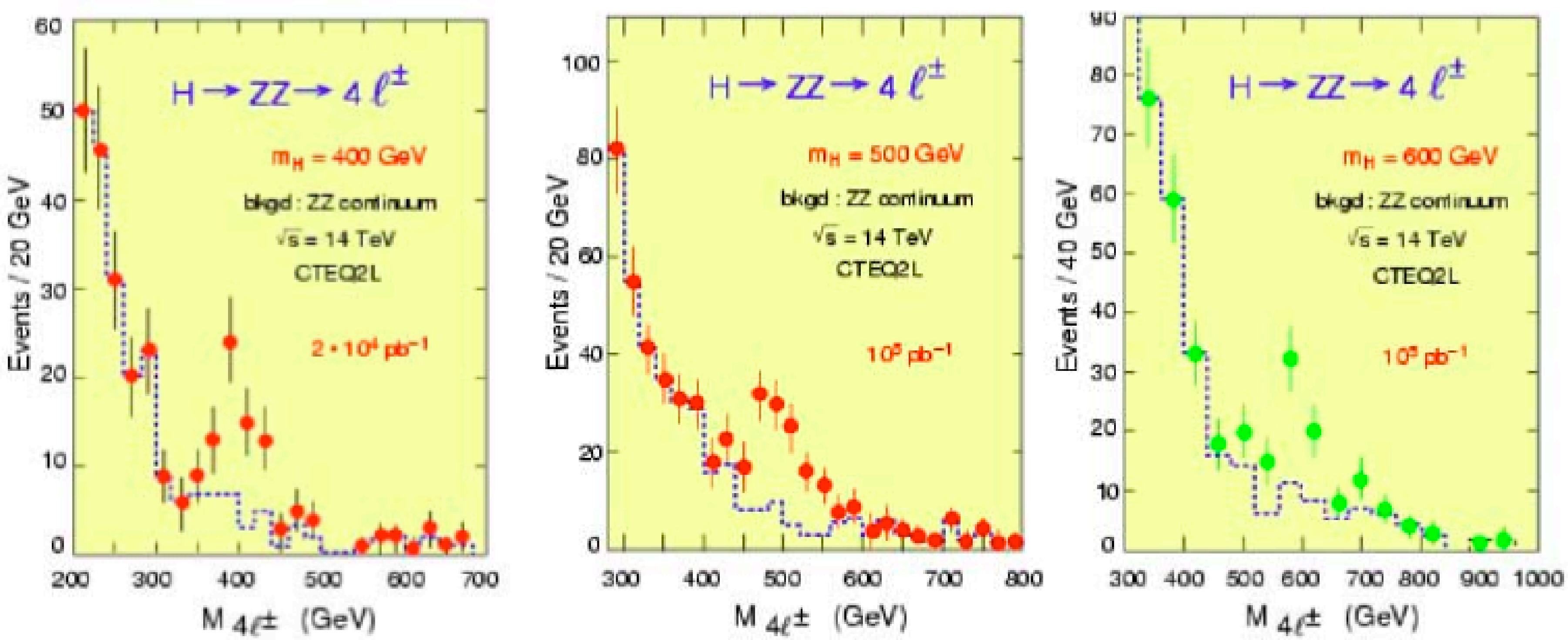
# $H \rightarrow WW \rightarrow \mu\nu\mu\nu$ scoperta in CMS



# $H \to ZZ \to 4\ell$ : Signal - High $m_H$

20 fb$^{-1}$ 100 fb$^{-1}$

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# $m_H \sim 1$ TeV : $H \rightarrow ZZ \rightarrow \ell\ell\ \nu\nu$

As $m_H$ increases further, $\Gamma_H$ increases and $\sigma$ falls ⇨ turn to higher BR modes

Signal: Jacobian peak in $E_T^{miss}$ in events with Z + large $E_T^{miss}$

**Typical Cuts**

2 isol $\ell$ : $p_T^{\ell}$ >20 GeV, $p_T(Z)$>60 Ge

$E_T^{miss}$ > 100 GeV

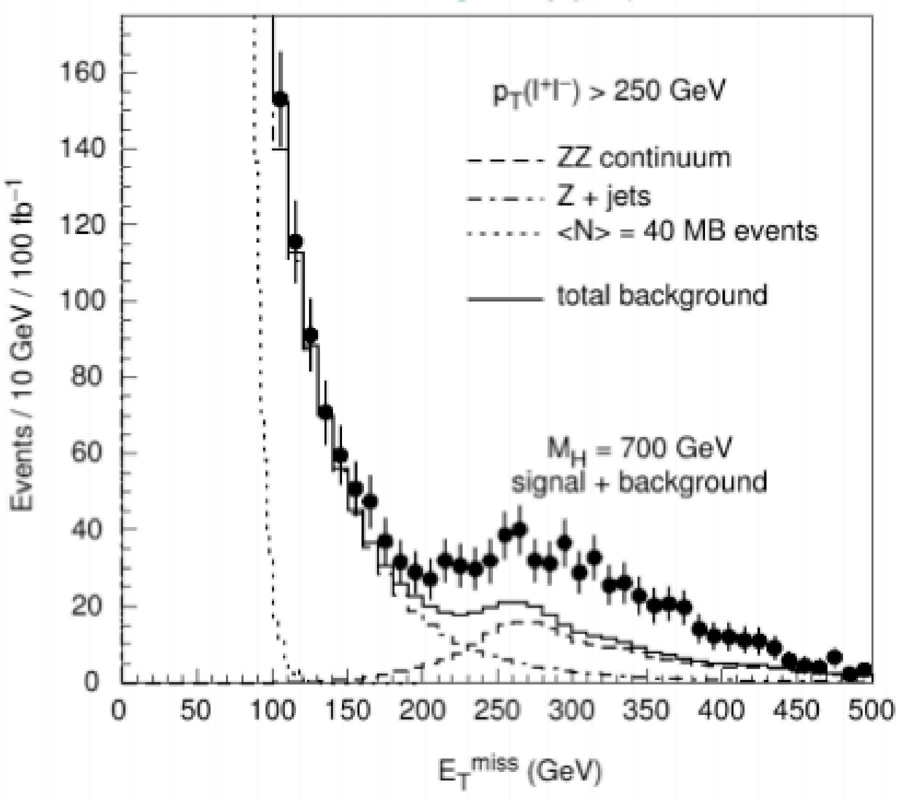
1 tagging jet $E^j$ > 1 TeV, in $|\eta|$>2.5

Backgrounds: irreducible – ZZ, reducible – Z + jets

Z+jets: parton level simulation

Forward jets can be used

ATLAS : 100 fb$^{-1}$



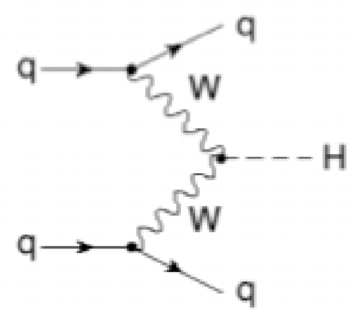
# $m_H \sim 1$ TeV : $H \to \ell\ell$ jj, $\ell\nu$ jj

Larger statistics if use decay modes $H \to WW \to \ell\nu$+jets and $H \to ZZ \to \ell\ell$+jets
BUT need to reduce enormous W+jets and Z+jets background

**Consider WW final state** (ZZ similar)
Find jets in $\Delta R=0.2$ with $E_T>50$ GeV, reconstruct $W \to jj$
$E_T(jj) > 150$ GeV, $m_W-2\sigma < m_{jj} < m_W+2\sigma$
$p_T(\ell) > 50$ GeV, $E_T^{miss} > 50$ GeV
$p_T(W) > 200$ GeV
Backgrounds from W+jets and $tt \to WbWb$ roughly equal but still large

$\varepsilon(W \to jets) \sim 60\%$,
$\sigma(m_W) \sim 7$ GeV

Use **forward tagging jets from $qq \to Hqq$**
$E_T^{tag} > 15$ GeV, $E > 600$ GeV with $2 < |\eta| < 5$
$E_T^{cell} > 3$ GeV
Low L : no additional jets with $E_T>20$ GeV in $|\eta|<2$




Fake tag prob. from MinBias
Single jet - 4.6%, double jet - 0.07%

# $m_H \sim 1$ TeV : $H \rightarrow ZZ \rightarrow \ell\ell\, jj$,

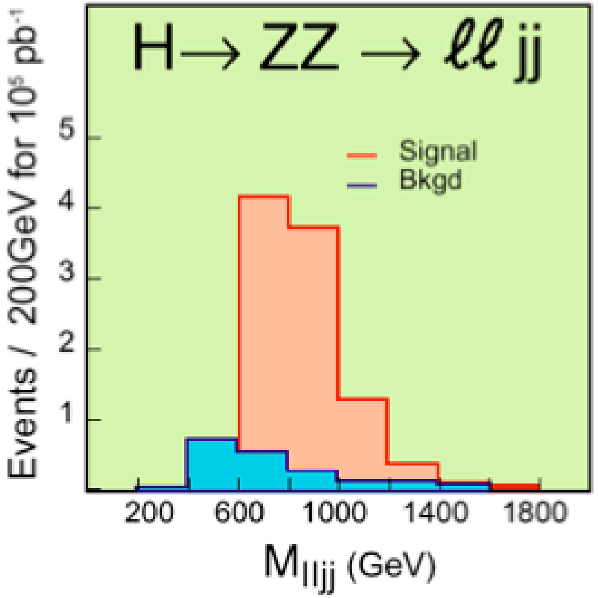
**Typical Cuts**

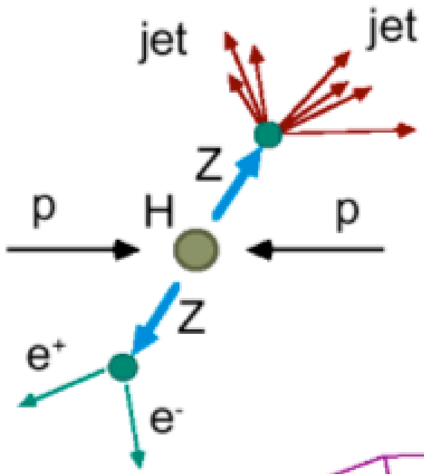
2 isol $\ell$ : $p_T^{\ell} > 50$ GeV, $p_T(Z) > 150$ GeV

$M_{\ell\ell} = m_Z - 10$ GeV

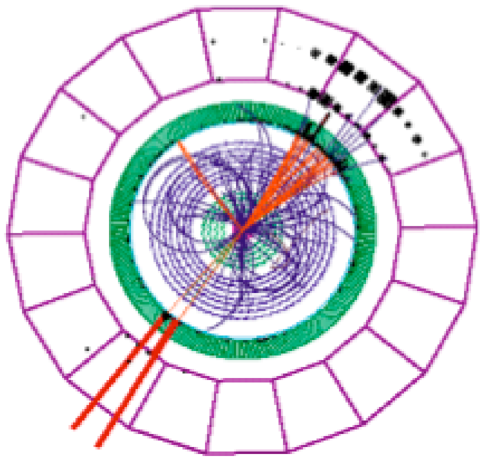
I.e. 2 central jets $E_T^j > 40$ GeV in $|\eta| < 3$

2 tagging jets $E^j > 400$ GeV, $E_T^j > 20$ GeV




CMS



# $m_H \sim 1$ TeV : $H \rightarrow WW \rightarrow \ell\nu\, jj$

**Typical Cuts**

1 isol $\ell$ : $p_T^{\ell} > 30$ GeV in $|\eta|<2.5$

$E_T^{miss} > 100$ GeV

I.e. 2 central jets $E_T^j > 40$ GeV in $|\eta|<3$

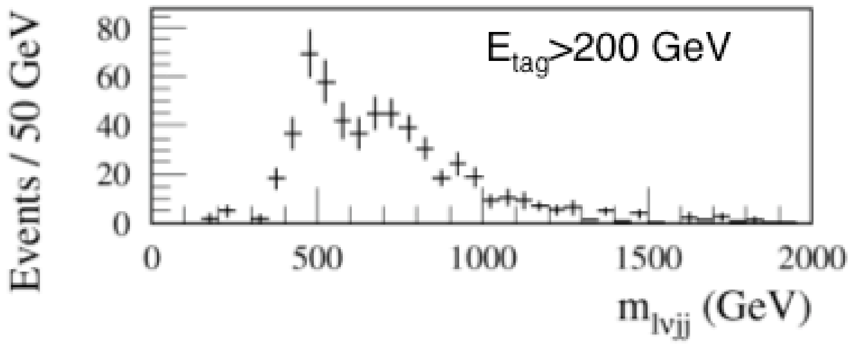
2 tagging jets $E^j > 400$ GeV, $E_T^j > 20$ GeV

$p_T^W > 100$ GeV in $\ell\nu$ and jj modes

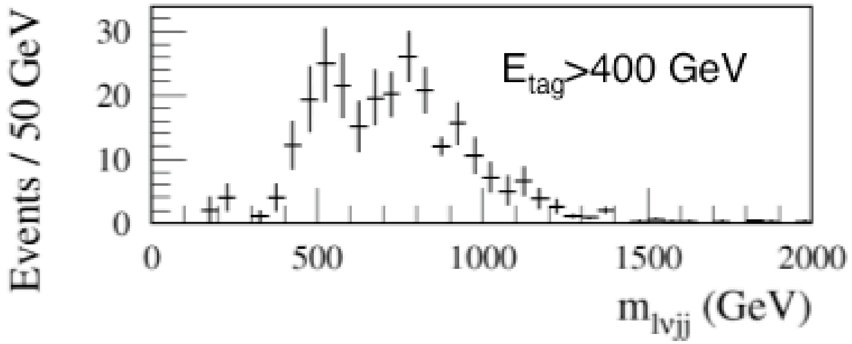
**ATLAS**

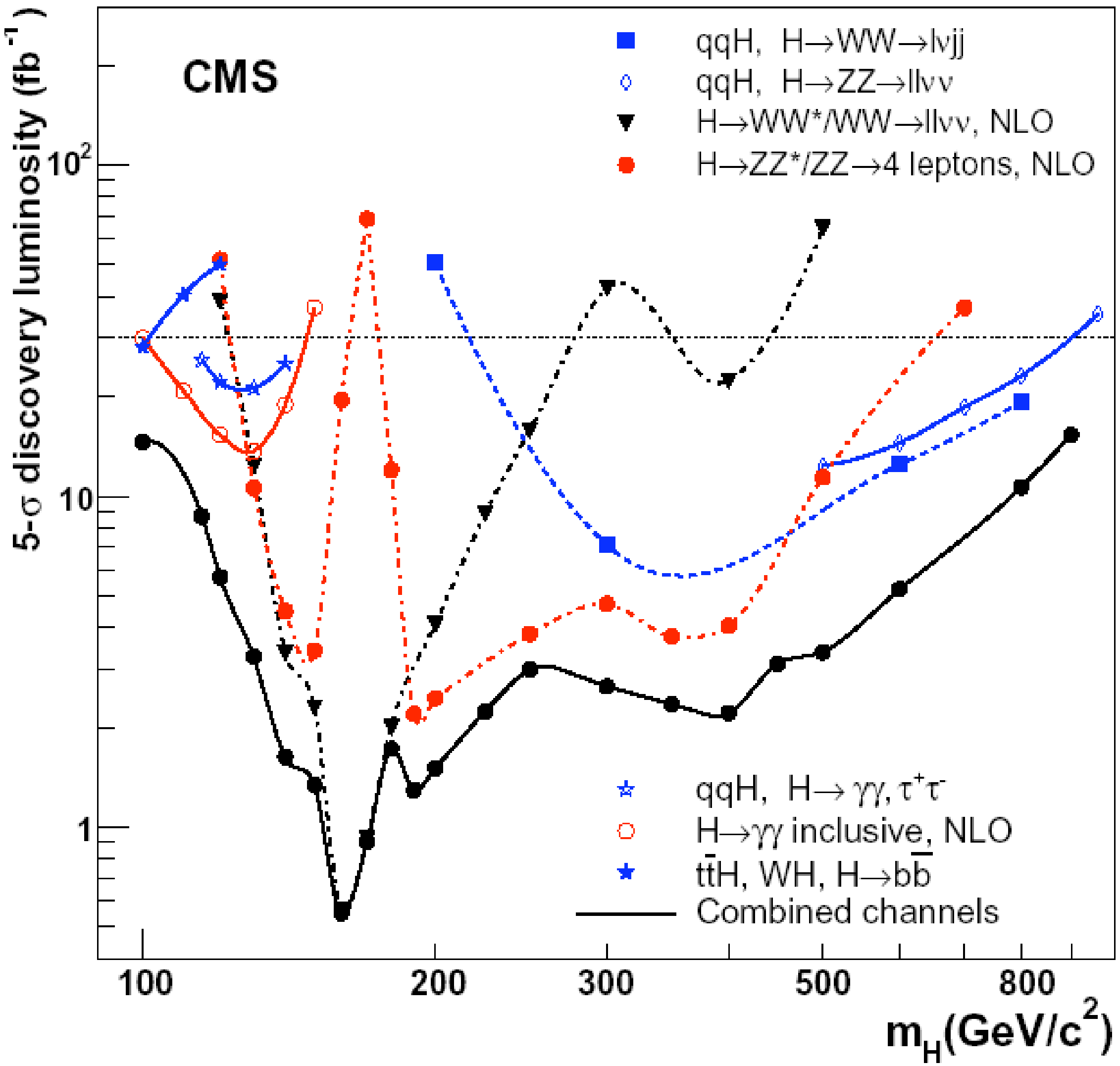
**$m_H$ = 1TeV, 30fb$^{-1}$**

| Process | Central cuts | Jet veto | Double tag |
|---|---|---|---|
| $H \rightarrow WW$ | 222 | 143 | 73 |
| $t\bar{t}$ | 38300 | 2800 | 85 |
| $W + jets$ | 15700 | 6900 | 62 |




**$m_H$ = 800 GeV, 30 fb$^{-1}$**





CMS
qqH, H→WW→lνjj
qqH, H→ZZ→llνν
H→WW*/WW→llνν, NLO
H→ZZ*/ZZ→4 leptons, NLO
qqH, H→ γγ, τ⁺τ⁻
H→γγ inclusive, NLO
tt̄H, WH, H→bb̄
Combined channels
5-σ discovery luminosity (fb⁻¹)
$m_H$(GeV/c²)
100
200
300
500
800
1
10
10²