Search for the Standard Model Higgs boson in the decay channel into four muons

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on behalf of CMS Collaboration

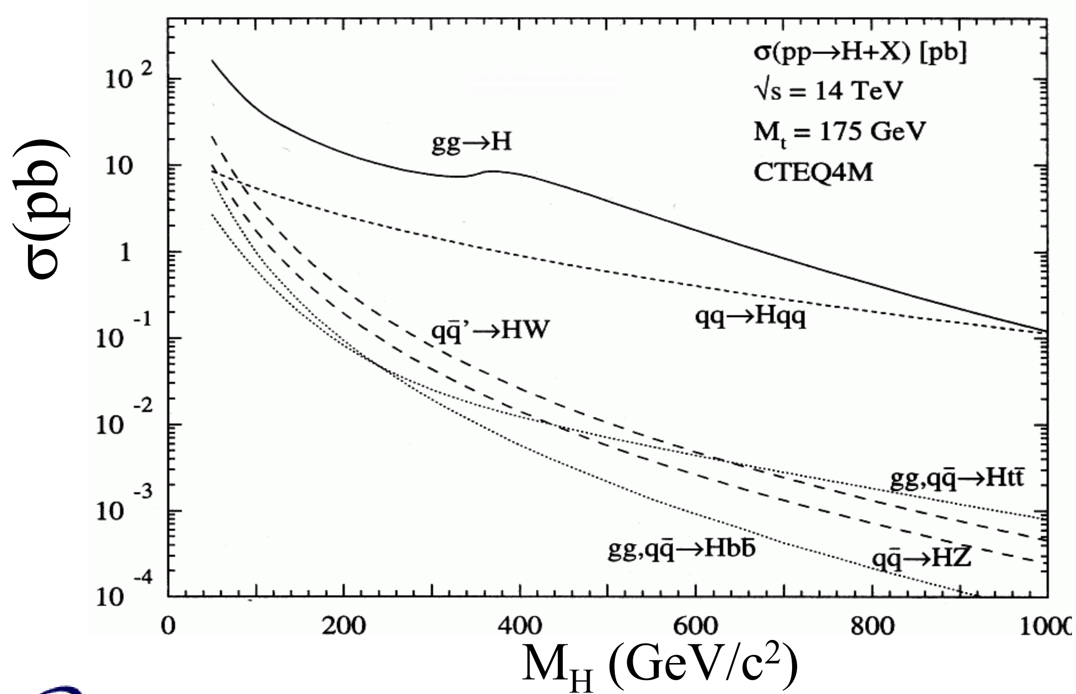
Contents

- ✓ Signal and main backgrounds
- ✓ Muon reconstruction
- ✓ Signal selection
- ✓ Visibility of the $H \rightarrow 4\mu$ signal
- ✓ Conclusion

Higgs production at LHC

Total production cross section for each Higgs boson mass studied.

(M. Spira program HIGLU used)



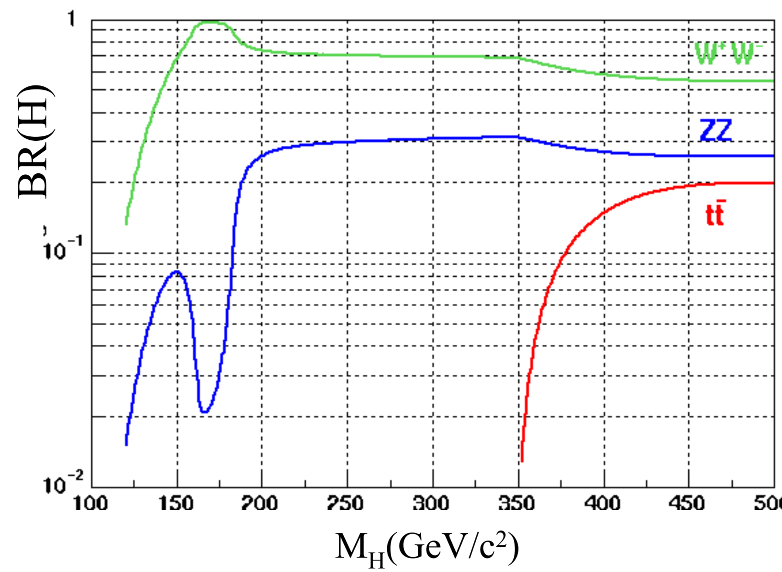
M_H (GeV/c²)	σ_{tot} * (pb)
115	43.0
120	42.6
125	39.8
130	37.3
140	32.5
200	17.3
300	9.2
500	4.3

* NLO corrections included except for process:

$$pp \to Hq\bar{q} \quad (< 1\%)$$

$H \to ZZ^{(*)} \to 4\mu$ signal

M_H (GeV/c^2)	BR_{TOT}	ξ	$\sigma * \xi * BR_{TOT}$ (fb)
115	$9.4 \cdot 10^{-6}$	-	0.22
120	$1.7 \cdot 10^{-5}$	0.53	0.39
125	$2.9 \cdot 10^{-5}$	0.56	0.64
130	$4.3 \cdot 10^{-5}$	0.57	0.92
140	$7.7 \cdot 10^{-5}$	0.60	1.51
200	$3.0 \cdot 10^{-4}$	0.67	3.43
300	$3.5 \cdot 10^{-4}$	0.70	2.27
500	$2.9 \cdot 10^{-4}$	0.79	1.00



- ξ is the acceptance for a final state with four μ with:
  - $|\eta| < 2.5$
  - $p_T > 3.0$ GeV/c
- $BR_{TOT} = BR(H \to 4\mu)$

Main background sources

- ✓ $\mathrm{ZZ}^{(*)} \rightarrow 4\mu$
- ✓ $\mathrm{t\bar{t}} \rightarrow \mathrm{W^+W^-b\bar{b}} \rightarrow 4\mu + X$
- ✓ $\mathrm{Zb\bar{b}} \rightarrow \mu^+\mu^-\mathrm{b\bar{b}} \rightarrow 4\mu + X$
- ✓ $\mathrm{Zc\bar{c}} \rightarrow \mu^+\mu^-\mathrm{c\bar{c}} \rightarrow 4\mu + X$

Muons from different proton-proton interactions rejected by a common vertex cut.

Background

Bg.	σ_{tot} (pb) (NLO)	$\xi * BR_{TOT}$	$\sigma * \xi * BR_{TOT}$ (fb)
$ZZ^{(*)}$	18.2	$4.60 \cdot 10^{-4}$	8.37
$t\bar{t}$	886	$4.63 \cdot 10^{-4}$	410.2
$Zb\bar{b}$	525(*)	$2.45 \cdot 10^{-4}$	129.1
$Zc\bar{c}$	1100	$< 10^{-5}$	//

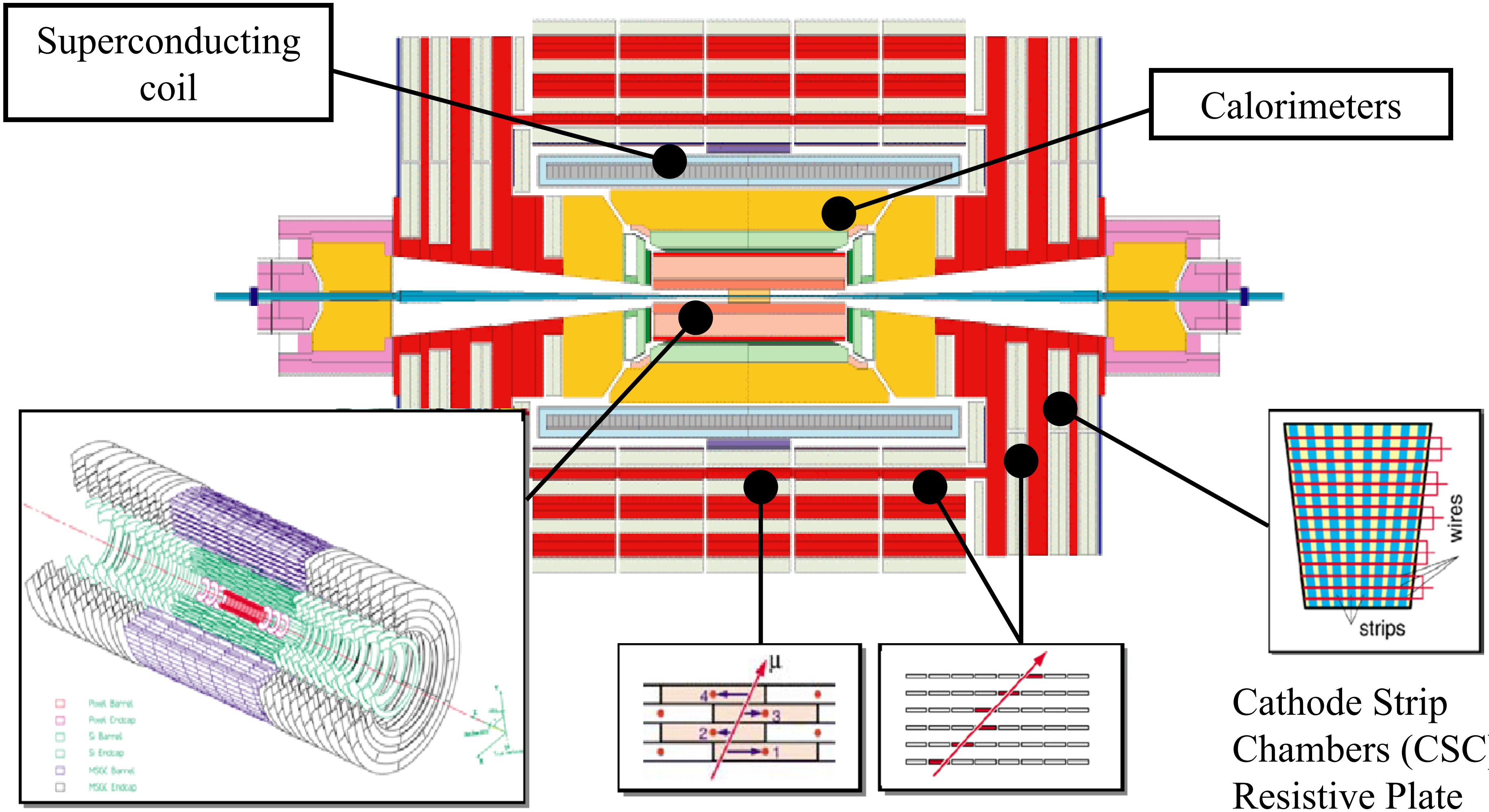
(*) for $|\eta^b| < 2.5$

ξ is the acceptance for a four μ final state, each one with:

- $|\eta^\mu| < 2.5$
- $p_T > 3.0$ GeV/c

All events generated with PYTHIA except Zbb generated with CompHep generator.

CMS Detector



Silicon Microstrips, Pixels

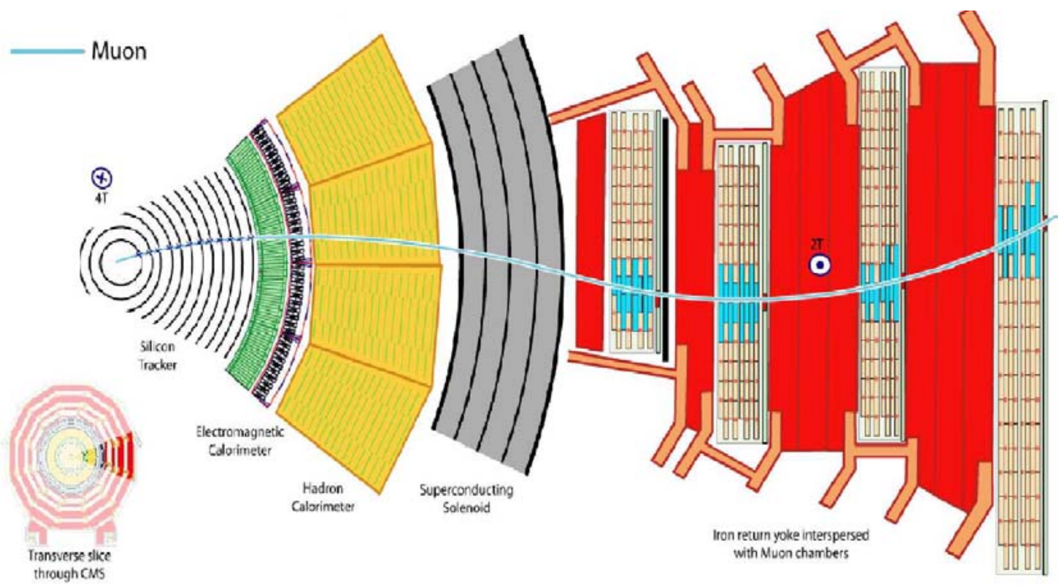
Drift Tube Chambers (DT)

Resistive Plate Chambers (RPC)

Cathode Strip Chambers (CSC), Resistive Plate Chambers (RPC)

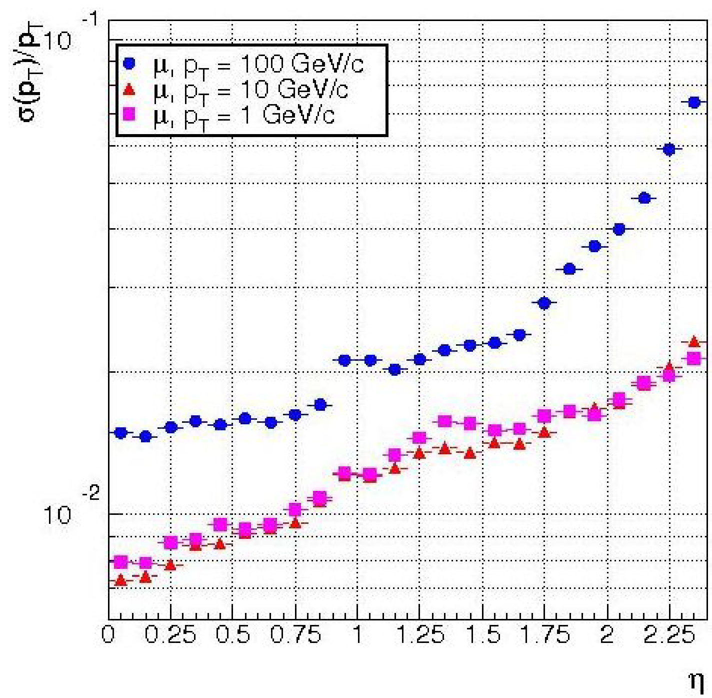
Muon reconstruction

Precise Higgs reconstruction needs a good muon momentum resolution.



μ reconstruction efficiency ~ 98 % (p_T^μ < 100 GeV/c)

CMS μ momentum resolution

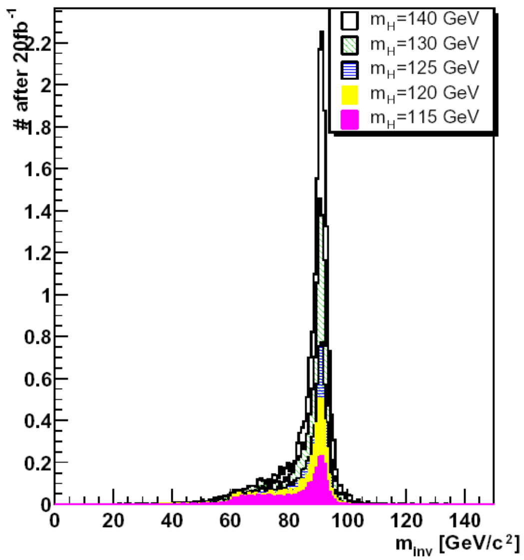


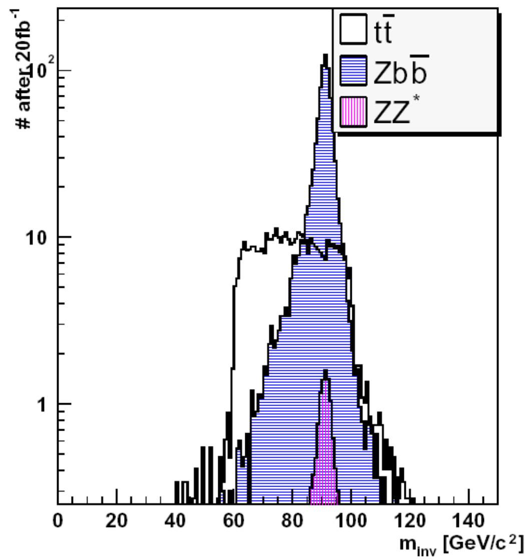
Selection ($M_H < 2M_Z$)

Since $M_H < 2\ M_Z$ signal events are selected by requiring:

- ✓ one muon-antimuon pairs with an invariant mass compatible with a Z hypothesis
- ✓ high muon transverse momenta
- ✓ four isolated muons

Z mass cut ($M_H < 2M_Z$)





The invariant mass of two unlike sign muons closest to M_Z.

Mass depend thresholds are applied, as an example for M_H = 130 GeV/c^2:

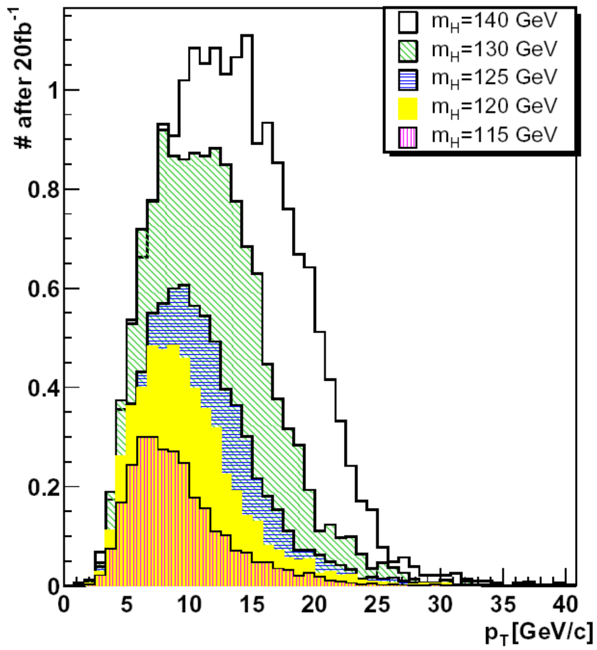
- $18 < M_{Z*} < 60$ GeV/c^2
- $80 < M_Z < 96.7$ GeV/c^2

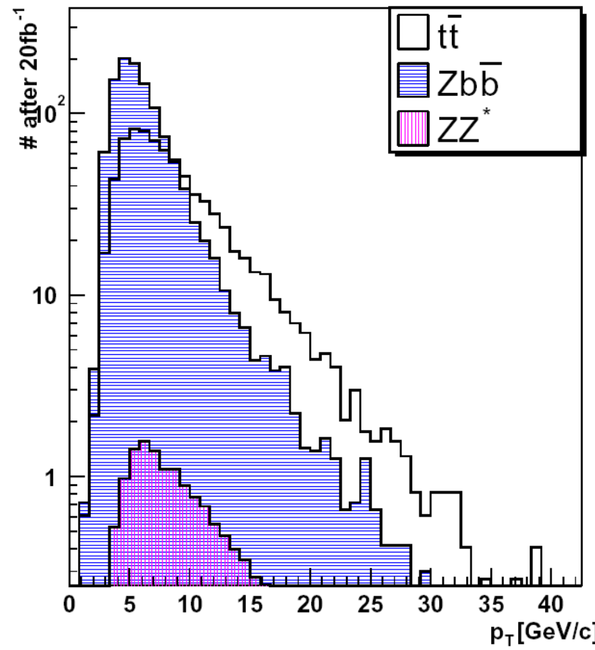
	Eff.
H (130 GeV/c^2)	68 %
ZZ^*	47 %
$t\bar{t}$	11 %
$Zb\bar{b}$	19 %

Muon p_T cut ($M_H < 2M_Z$)

pT of the muon with the lowest pT value. Mass dependent thresholds: for M_H = 130 GeV/c^2

15, 12, 12, 8 GeV/c



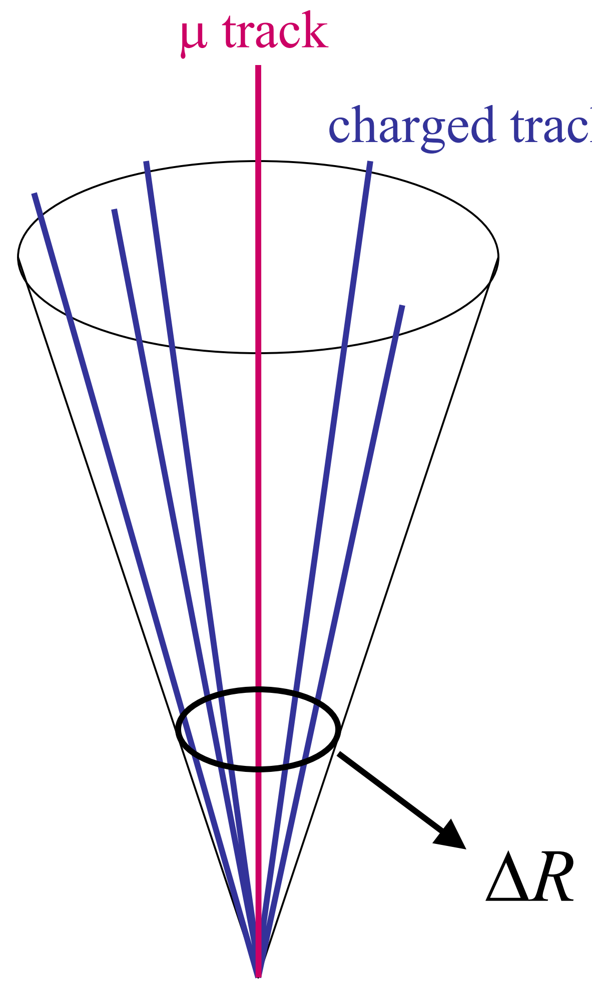


	Signal 130 GeV/c^2	ZZ*	$t\bar{t}$	$Zb\bar{b}$
Efficiency	72 %	59 %	45 %	17 %

Isolation ($M_H < 2M_Z$)

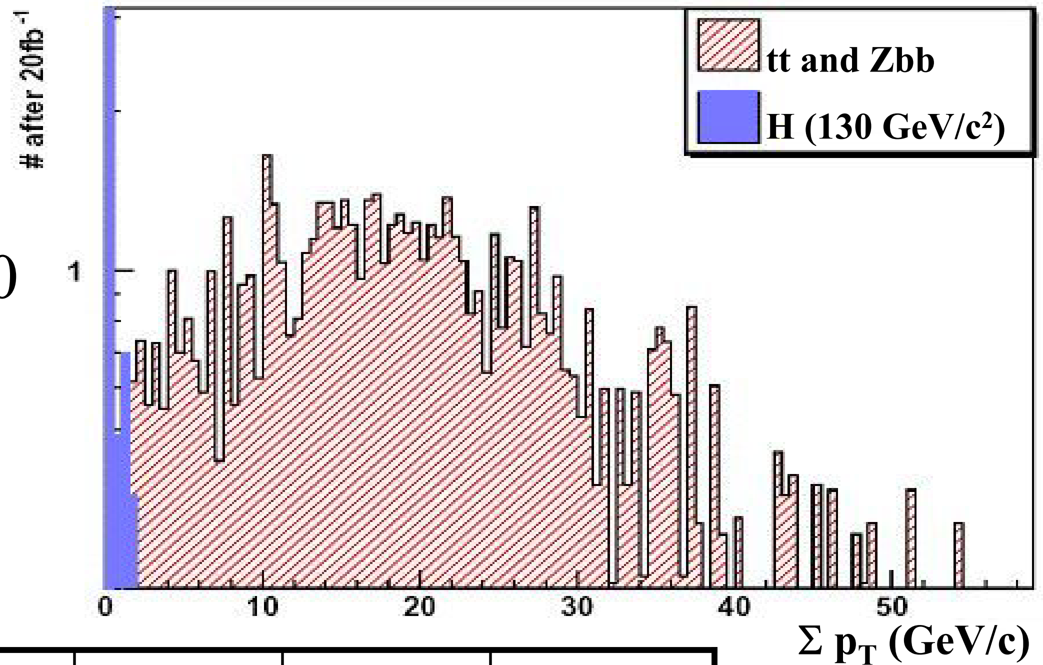
- ✓ define a cone $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$ around muon direction
- ✓ for the muon to be isolated (in the tracker) demand the sum of the transverse momenta of the charged tracks (with the same vertex) in the cone was less than a given threshold:

$$\sum p_t < p_t^{max}$$



Isolation ($M_H < 2M_Z$)

- ✓ For all masses tracker isolation used: $\Delta R = 0.24$
- ✓ For the masses 125, 130, 140 GeV/c² also calorimeter isolation used: $\Delta R = 0.45$

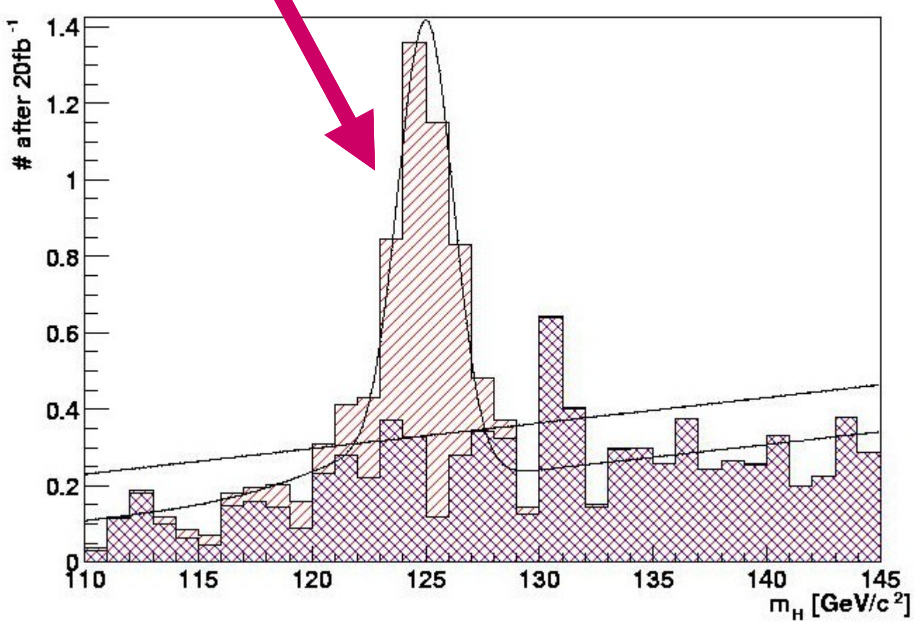


	Signal 130 GeV/c²	ZZ*	$t\bar{t}$	$Zb\bar{b}$
Tracker iso ($p_T > 4.0$)	91 %	92%	2%	11%
Calo iso ($E_T > 11.5$)	84 %	87%	38 %	45 %

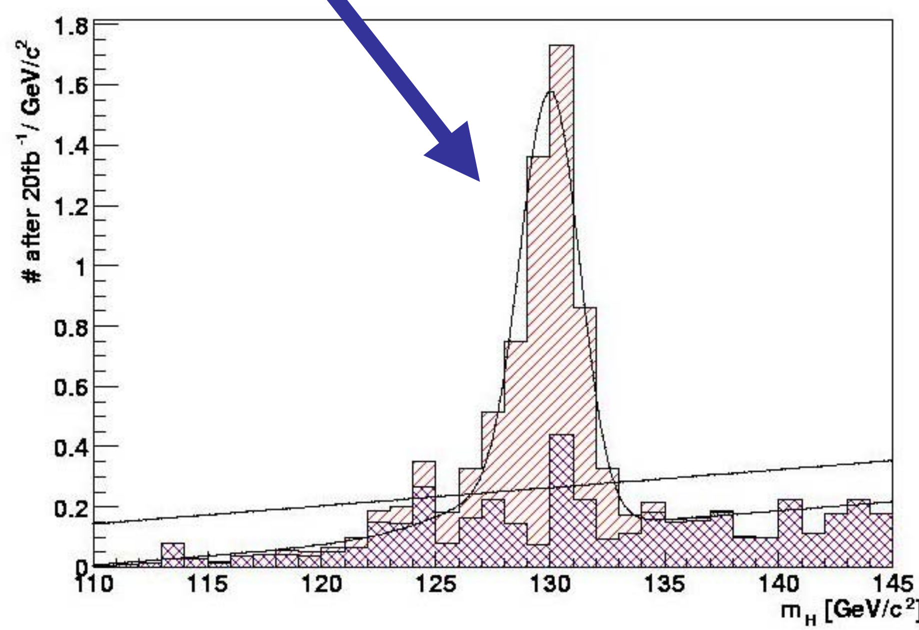
Higgs mass resolution

The Higgs mass resolution is dominated by the momentum resolution of the CMS detector for $M_H < 200$ GeV/c^2

$\sigma = 1.2$ GeV/c^2



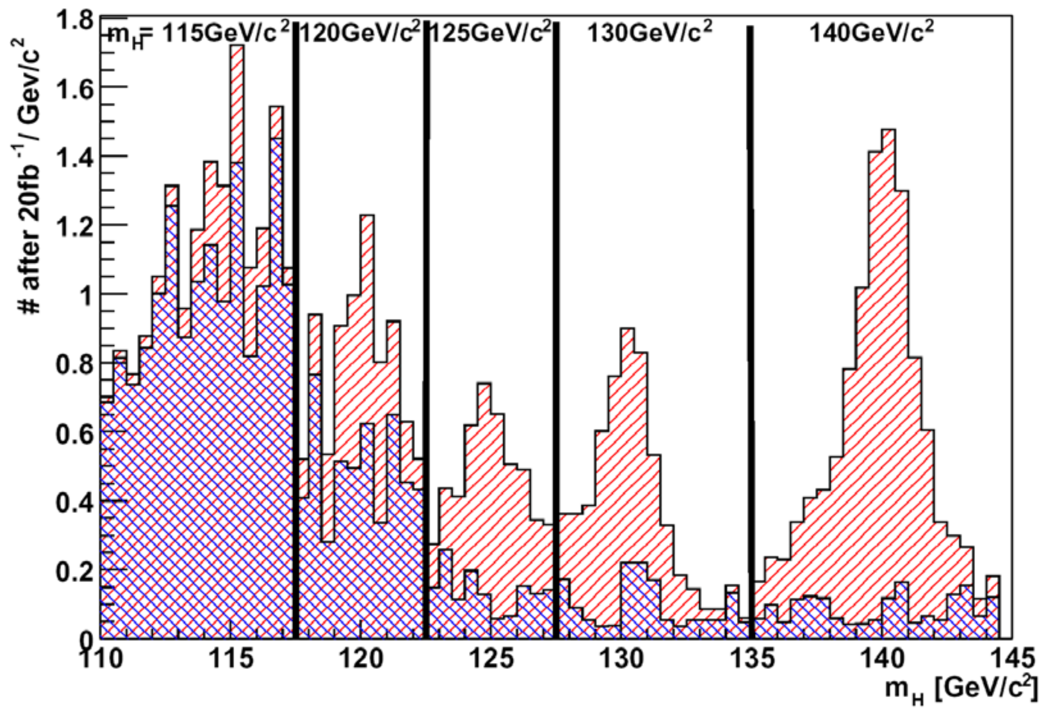
$\sigma = 1.3$ GeV/c^2



Final cross section ($M_H < 2M_Z$)

Final cross sections for signal and background in a mass window of $\pm 2\sigma_H$.

M_H (GeV/c²)	signal (fb)	bg. (fb)
115	0.08	0.50
120	0.14	0.25
125	0.18	0.05
130	0.23	0.03
140	0.39	0.05



Invariant mass distribution for $\mathcal{L} = 20\ fb^{-1}$, after the selection described above for signal and background.

Selection ($M_H > 2M_Z$)

Since $M_H > 2\ M_Z$ signal events are selected by requiring:

- ✓ two muon-antimuon pairs with an invariant mass compatible with a Z hypothesis
  - – thus rejecting $t\bar{t}$ and $Zb\bar{b}$ events almost completely
- ✓ high muon transverse momenta
- ✓ high p_T of the Higgs candidate

p_T of the four μ system

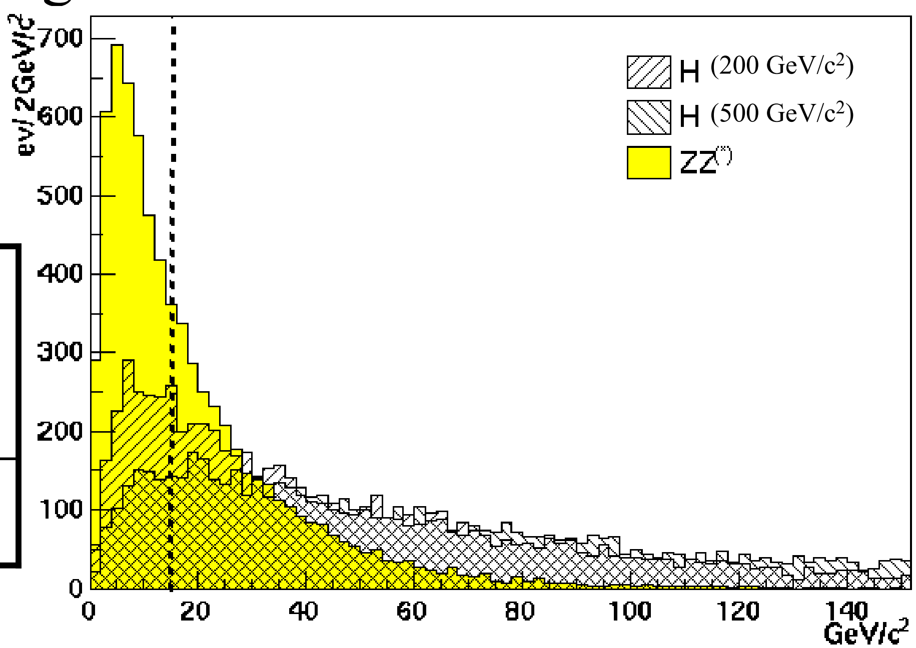
✓ high $p_T^{4\mu}$ is due to higher order processes with one or more partons in the final state

✓ such processes are more probable for gluon-gluon interactions such as $gg \rightarrow H$

✓ since ZZ comes mainly from $q\bar{q}$ annihilation a softer $p_T^{4\mu}$ distribution is expected for this background

$p_T^{4\mu} > 15$ GeV/c

	H 200 GeV/c²	H 300 GeV/c²	H 500 GeV/c²	ZZ
eff.	76 %	82 %	86 %	43 %

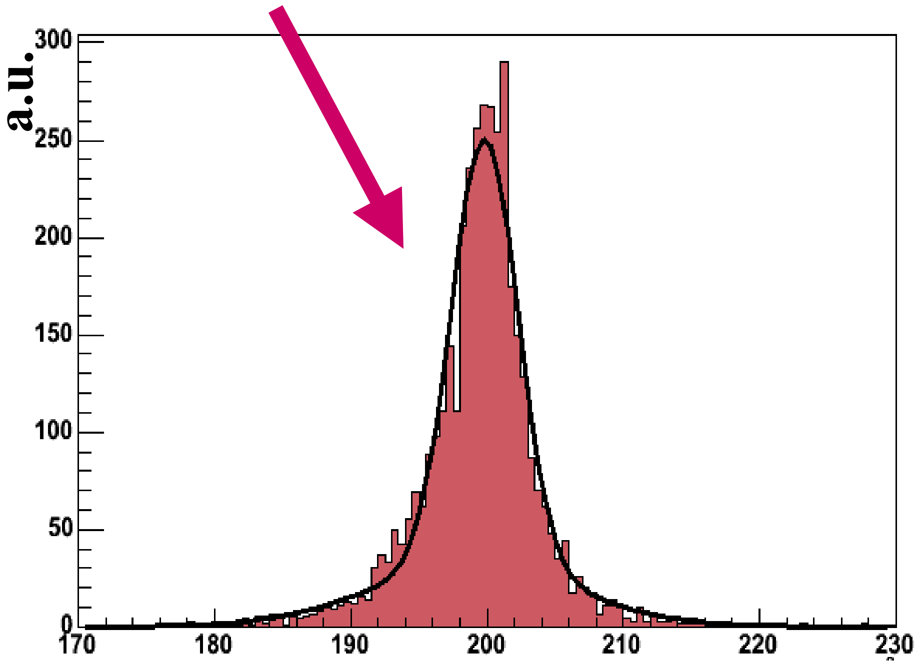


Higgs mass resolution

The resolution is dominated by the natural width of the Higgs for $M_H > 200$ GeV/c^2

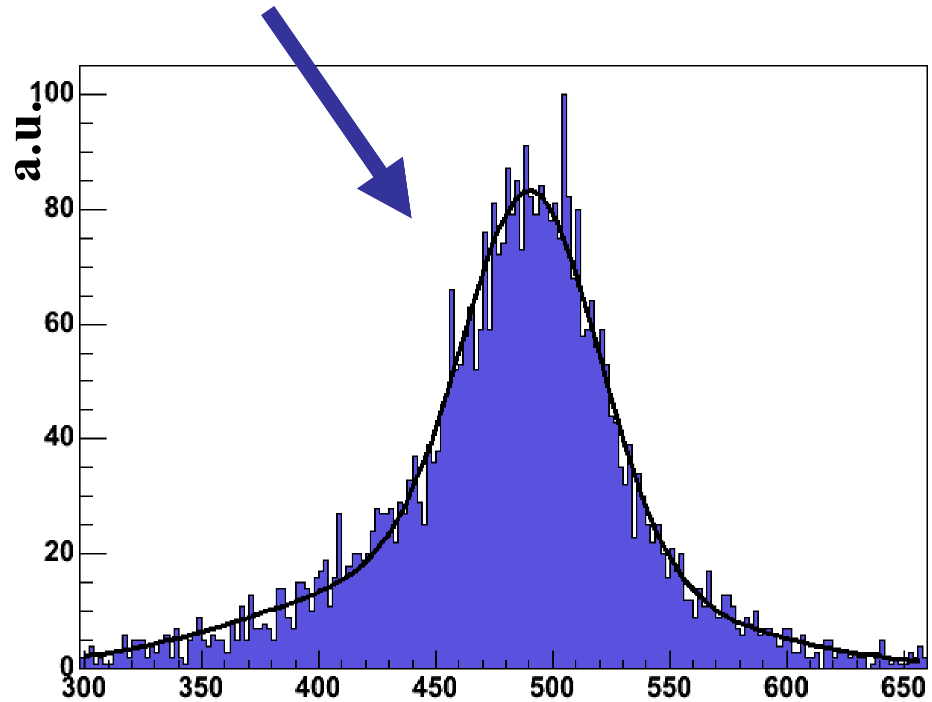
$\sigma = 2.8$ GeV/c^2

$\sigma = 38$ GeV/c^2



GeV/c^2

natural width = 1.4 GeV/c^2



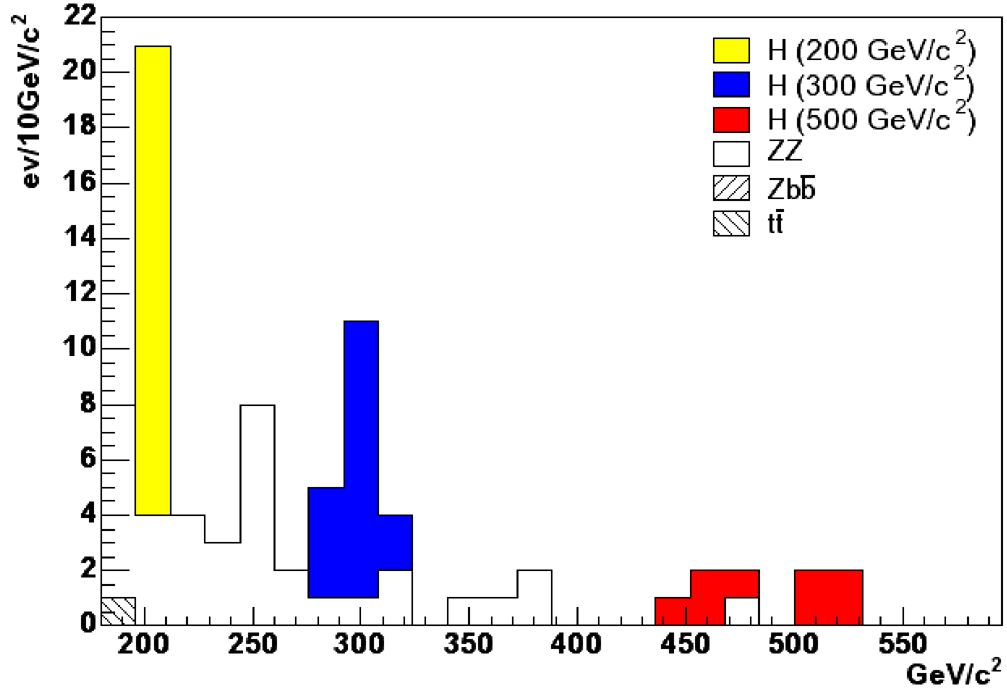
GeV/c^2

natural width = 67.8 GeV/c^2

Final cross section ($M_H > 2M_Z$)

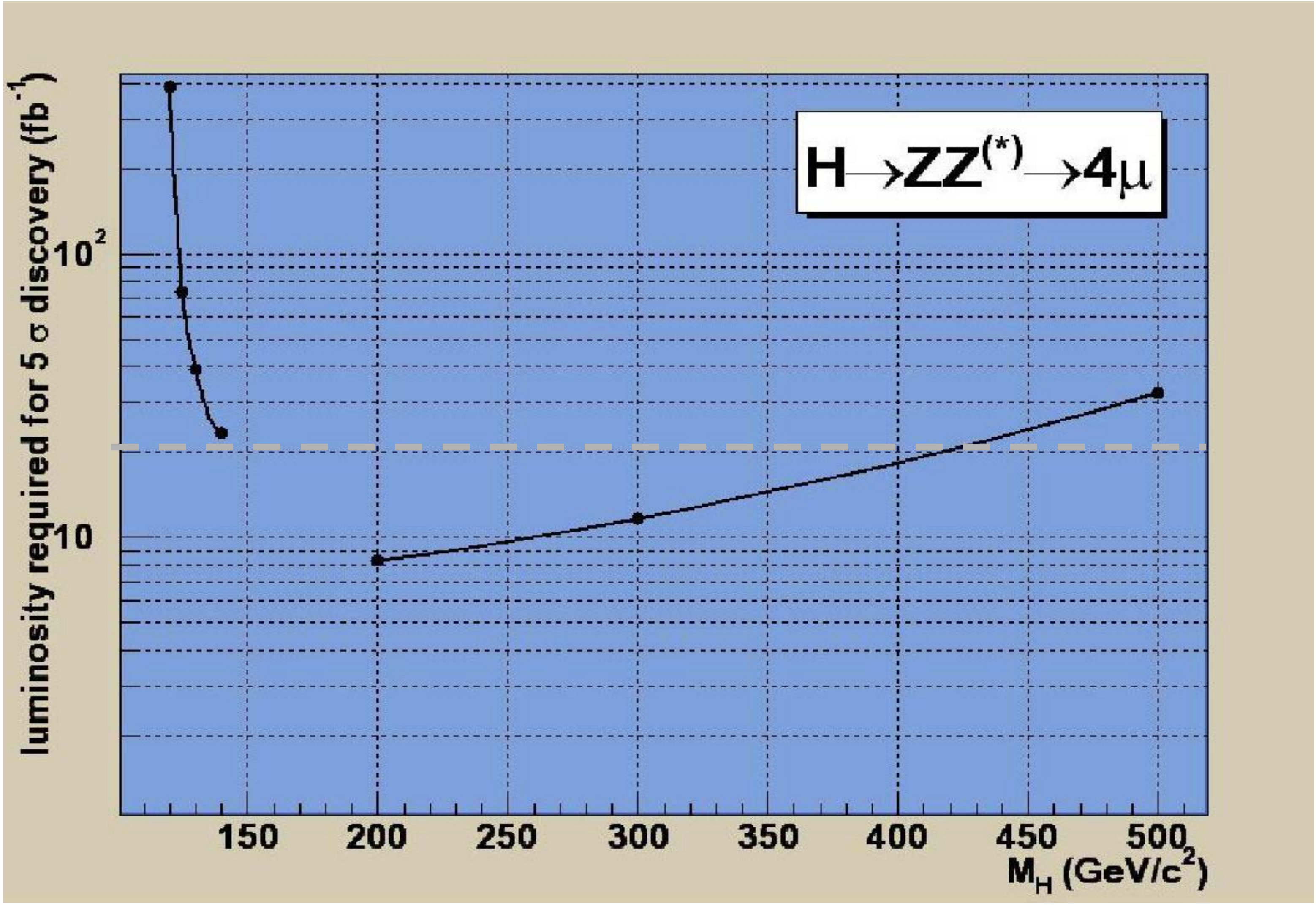
Final cross sections for signal and background in a mass window of $\pm 2\sigma_H$.

M_H (GeV/c^2)	Signal (fb)	bg. (fb)
200	1.12	0.14
300	0.79	0.11
500	0.38	0.09



A random example of expected invariant mass distribution for $\mathcal{L} = 20\ fb^{-1}$, after the selection described above.

Luminosity for S = 5



Significance ($\mathcal{L}$ = 20 fb^{-1})

M_H (GeV/c^2)	Ns	Nb	S
115	1.6	10.0	0.6
120	2.8	5.1	1.2
125	3.6	1.0	2.7
130	4.6	0.7	3.6
140	7.8	1.1	4.7
200	22.4	2.7	8.2
300	15.9	2.1	6.7
500	7.6	1.7	4.0

Significances S are calculated using Poisson distribution for one year running at low luminosity.

Conclusions

- ✓ The very good momentum resolution achievable with the CMS detector can be fully exploited in the study of the channel: $H \rightarrow ZZ^{(*)} \rightarrow 4\mu$
- ✓ An Higgs with a mass from 200 up to about 400 GeV/c^2 could be discovered with this channel in less than one year of low luminosity of data taken at LHC.
- ✓ Few years are needed for a Higgs with a mass between 125 and 140 GeV/c^2.

Back up slides

Online selection

- ✓ Online selection of signal events in CMS relies on single muon and dimuon triggers
- ✓ Trigger thresholds are
  - 19 GeV/c for single muon trigger
  - 7 Gev/c for dimuon trigger
- ✓ Only in a fraction of $2*10^{-3}$ of signal events those requirements are not satisfied by μ's in $|\eta|< 2.1$
- ✓ Inefficiency of online selection expected below 1% therefore neglected

Efficiencies ($M_H < 2M_Z$)

M_H (GeV/c^2)	Signal	ZZ	$t\bar{t}$	$Zb\bar{b}$
115	90 %	91 %	3 %	25 %
120	90 %	91 %	2 %	19 %
125	85 %	84 %	1 %	6 %
130	77 %	80 %	1 %	3 %
140	80 %	78 %	1 %	3 %

Final efficiencies on signal and background after the selection described above.

Z mass cut and muon pT cut

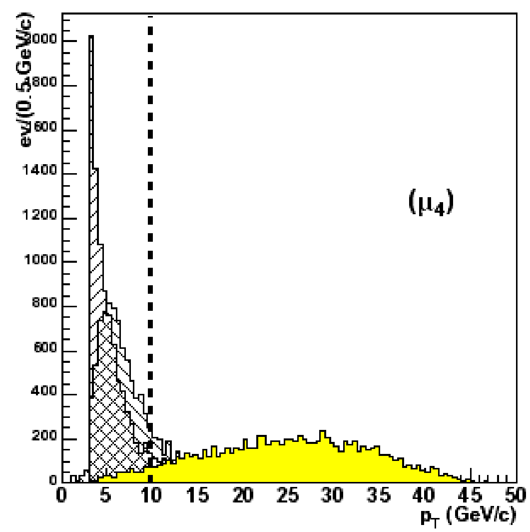
$$\left| m_{\mu^+\mu^-} - M_Z \right| < 8.0\ \mathrm{GeV/c^2}$$

	Eff.
H (200 GeV/c²)	71 %
H (300 GeV/c²)	69 %
H (500 GeV/c²)	67 %
ZZ	53 %
$t\bar{t}$	< 1 %
$Zb\bar{b}$	< 1 %

p_T distribution of the four muons sorted in decreasing order.

Applied thresholds are:

20, 15, 15, 10 GeV/c



Efficiencies ($M_H > 2M_Z$)

	Z mass + p_T	$p_T^{4\mu}$
$t\bar{t}$	0.04 %	0.04 %
$Zb\bar{b}$	0.1 %	0.1 %
ZZ	35.1 %	14.9 %
H (200 GeV/c^2)	48.7 %	36.9 %
H (300 GeV/c^2)	51.2 %	41.9 %
H (500 GeV/c^2)	50.6 %	43.8 %

Final efficiencies on signal and background after the selection described above.

Significance (Poisson)

In the limit of large bg. events:

$$S = \frac{N_s}{\sqrt{N_b}}$$

Since we are not in that limit the significance is calculated using:

$$S_L = \sqrt{2 \ln Q}$$

$$Q = \frac{L_{S+B}}{L_B} = \left(1 + \frac{N_s}{N_b}\right)^{(N_s + N_b)} e^{-N_s}$$

S_L = 5 corresponds to 50 % discovery probability.