Prospects for Higgs and BSM Searches at LHC

with the first 5 fb^{-1}

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Higgs and Beyond the Standard Model at LHC

ElectroWeak Symmetry Breaking:

- *Unitarity violation in $W_L W_L$ scattering at high energy*

  Standard Model (SM) solution: one light Higgs boson
  - *if Higgs → hierarchy problem: fine tuning in radiative corrections to Higgs mass*
    *→ **solution**: new physics at TeV scale (SUSY, Extra Dimensions, LittleHiggs, etc.)*
  - *if no Higgs → **solutions**: new strong interactions (Technicolor, etc…) or other "exotic" theories (compositeness, etc.)*

Other issues of the SM

- *Yukawa hierarchy (explanation of mass patterns for quarks and leptons)*
- *Unification of interactions*
- *Number of quark and lepton generations (why 3?)*
- *….*

***Large Hadron Collider (LHC):** explore the TeV energy scale and search for new particles up to 5 TeV*

First two years of data taking

➔ *First beam: 450 GeV + 450 GeV, end of this year* $\mathcal{L} < 10^{29}\ cm^{-2}s^{-1}$

Minimum bias events, re-discovering of the SM, energy scales fix, understanding the QCD physics at this energy scale, detector calibration in situ using known physics processes….

➔ *First collisions 7 TeV + 7 TeV: summer 2008*

…then if machine schedule will not been modified one can estimate (per experiment)

- *end of 2008: integrated luminosity up to 1* fb^{-1} *at* $\mathcal{L} < 10^{33}\ cm^{-2}s^{-1}$
- *end of 2009: integrated luminosity up to 10* fb^{-1} *at* $\mathcal{L} = 1\text{-}2\ 10^{33}\ cm^{-2}s^{-1}$

How the physics discoveries will evolve according to the integrated luminosity collected and the progressive knowledge of the detector performance?

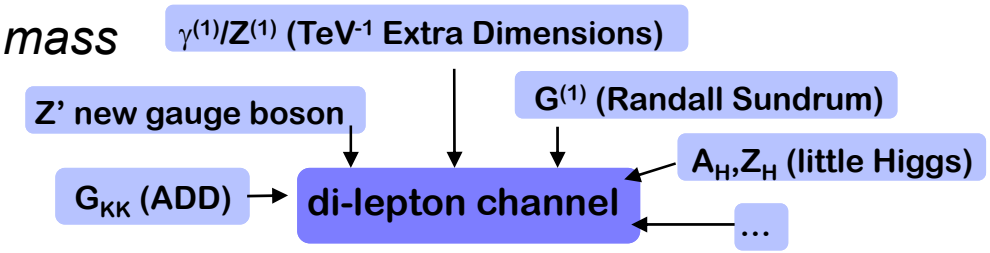
Higgs and BSM physics reaches that can be achieved with few fb^{-1} *of integrated luminosity*

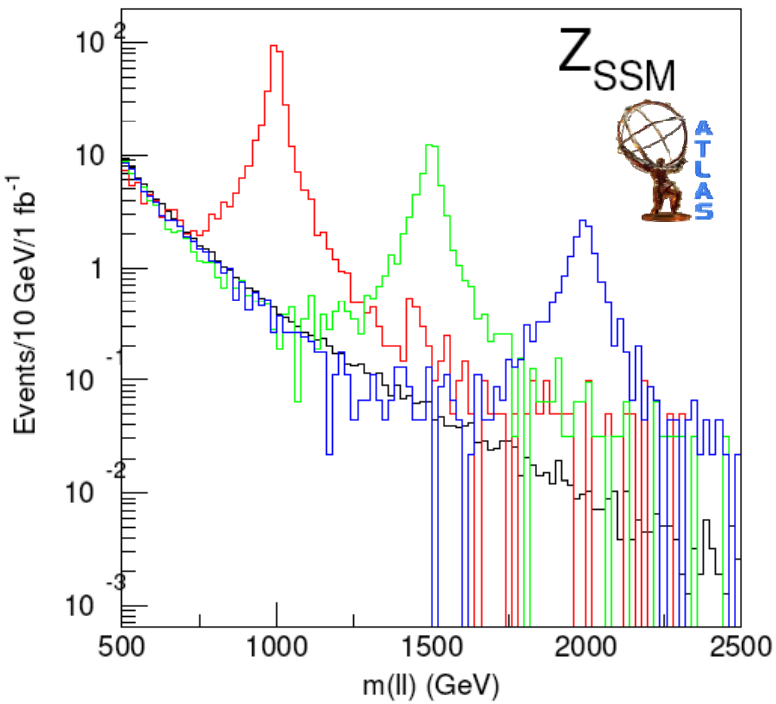
Focus on: cross section O(100 fb) with small SM backgrounds, clear kinematic signature (peak, edge) and (possibly) leptonic final states

High mass di-lepton resonances: Z’ 100 pb^{-1}

Resonances in lepton-lepton invariant mass distributions at the LHC predicted by several BSM models

- *clean decay channel in e^+e^- or $\mu^+\mu^-$*





Z’ with the same couplings as in SM
(Sequential Standard Model, SSM)

- *natural width 3%·M*
- *σ·BR(e^+e^-) ~160 fb for $M_{Z'}$ = 1.5 TeV*

Backgrounds

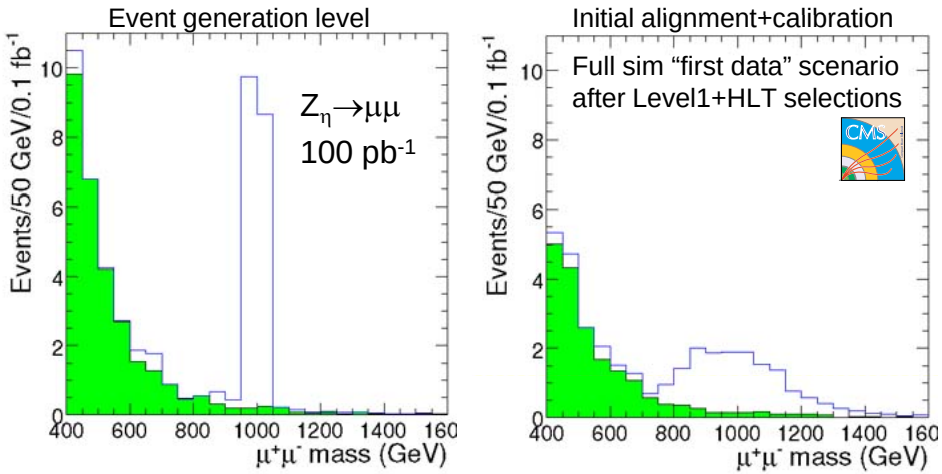
- *Drell-Yan (irreducible)*
- *other backgrounds: ZZ, ZW, WW, tt*

Main selection cuts: pairs of isolated e or μ

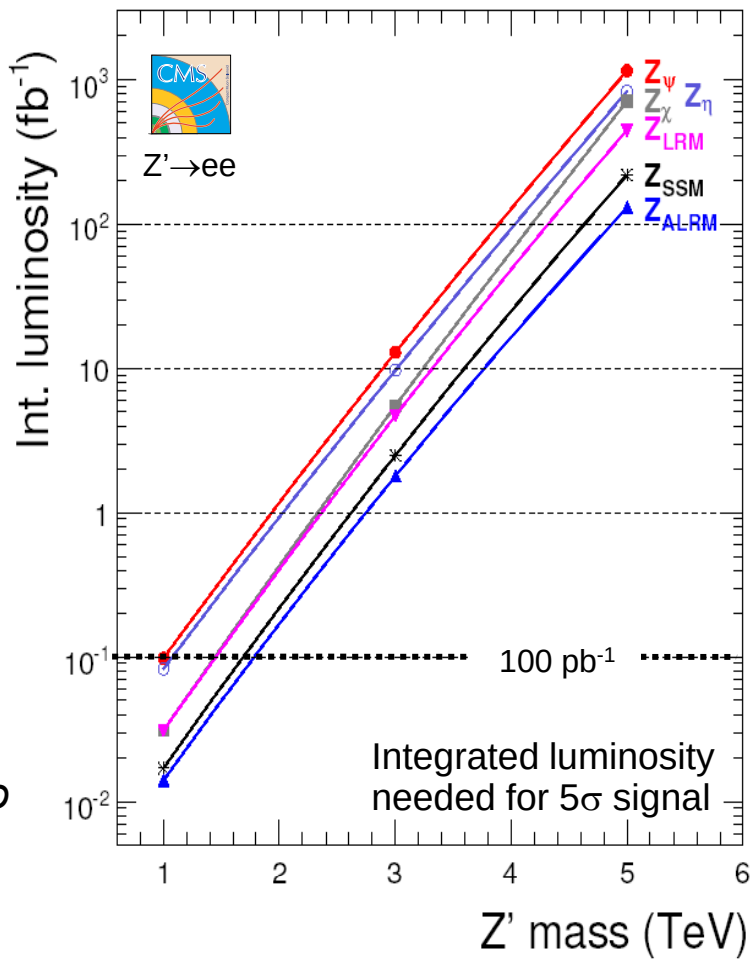
High mass di-lepton resonances: Z’ 100 pb^{-1}

Experimental challenge:

- *track isolation with calorimeters (resolution < 1% in the TeV region) - lepton trigger*



Z’→ee favorite discovery channel
Z’→μμ possible with the initial imperfect knowledge of muon systems
“first data” scenario = alignment expected with 0.1fb^{-1}



Z’→ee 5σ discovery reach (model dependent)

- *For 100 pb^{-1} and SSM couplings, 5σ reach up to 1.6 TeV → May be seen very early: first weeks*

Micro black holes

100 pb^{-1}

Theories of large extra dimensions (ED):

- *Planck mass M_P at TeV scale*
- *microscopic black holes (BH) produced for $E_{cm} > M_P$ when two colliding partons have impact parameter smaller than the radius of a black hole*
- *BH decay (roughly black body) via Hawking radiation (in ~ 10^{-27} sec)*

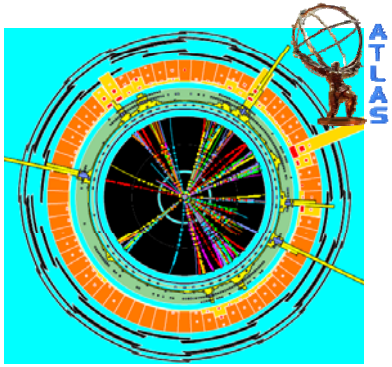
Cross section estimations at LHC

(semi) classical geometric arguments:

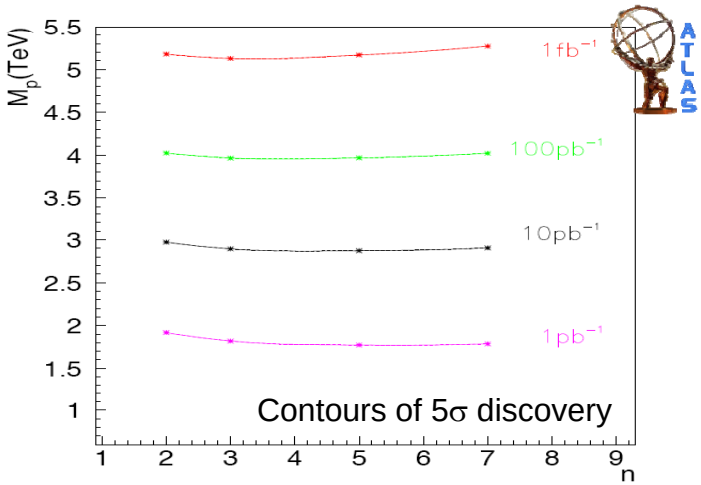
$$\sigma(\hat{s} = M_{BH}^2) \sim \pi R_s^2$$

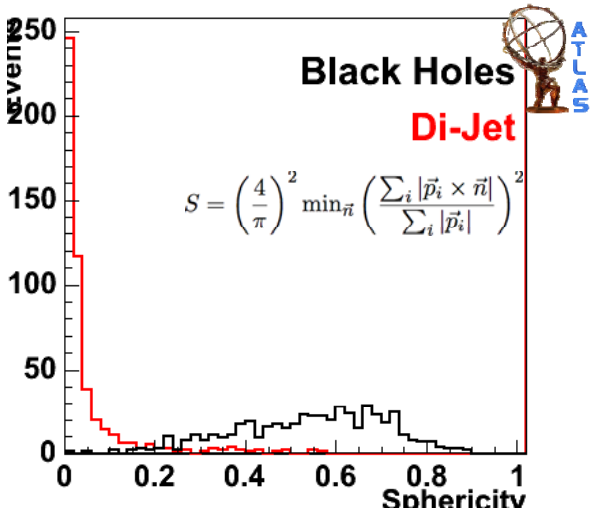
In ED M_P ~ TeV $\Rightarrow$ for M_{BH} ~ M_P ~ $(TeV)^{-2}$ ~ 10^{-38} m^2 ~ 100 pb

At high lumi ~1 BH/s with M_{BH} > 5 TeV



- *Hawking decay isotropic: spherical events - large E_T^{miss}*
- *Decay of BH into all types of SM particles*
- *reducible SM backgrounds (mostly QCD jet production)*





SUSY early searches

1 fb^{-1}

SUSY most popular template for exploration of new physics at the LHC

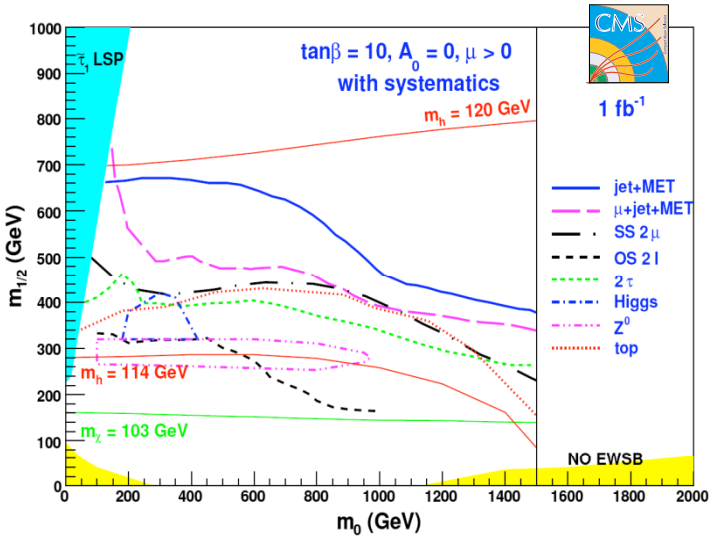
SUSY is a broken symmetry (no sparticles observed to date)→ several models of SUSY breaking (mSUGRA, GMSB, AMSB)

Minimal SUSY Standard Model (MSSM) with R-parity conservation

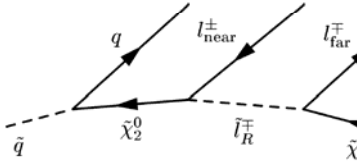
- *sparticles are produced in pairs*
- *the Lightest SUSY Particle (LSP) is stable*

sparticles → lighter sparticles + SM particles down to stable, undetected LSP

large E_T^{miss} + jets + leptons

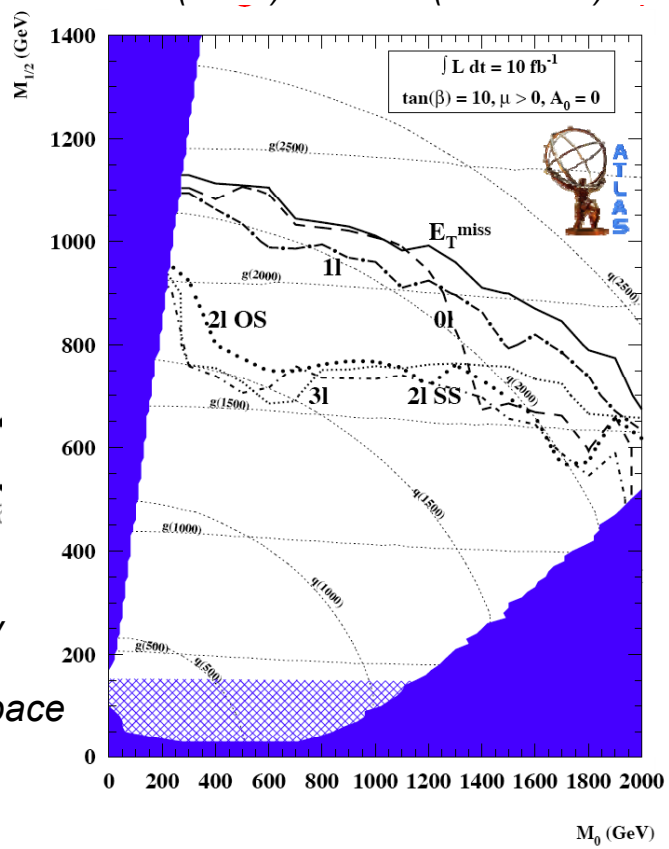


Typical SUSY event



Rich phenomenology
Multiple signature on most of parameter space

Inclusive signatures in mSUGRA parameter spaces - 5σ discovery reach for ATLAS (below) and CMS (bottom-left)



SUSY early discovery

1 fb^{-1}

Fast discovery from signal statistics

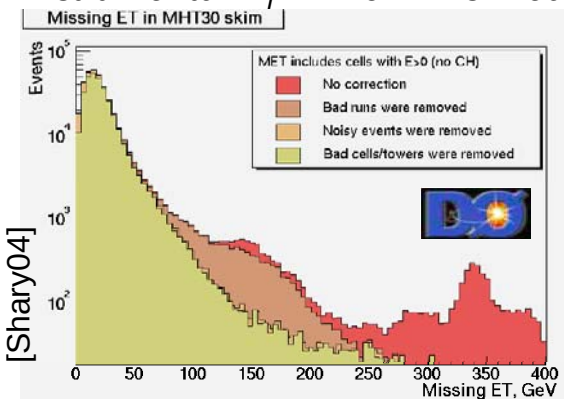
~ 1.3 TeV in 100 pb^{-1}
~ 1.8 TeV in 1 fb^{-1}
~ 2.2 TeV in 10 fb^{-1}

Time discovery bounded by:

- *time to understand detector performance (E_T^{miss} tails, lepton identification, etc.)*
- *time to collect sufficient statistics of SM control samples: W, Z+jets, tt*

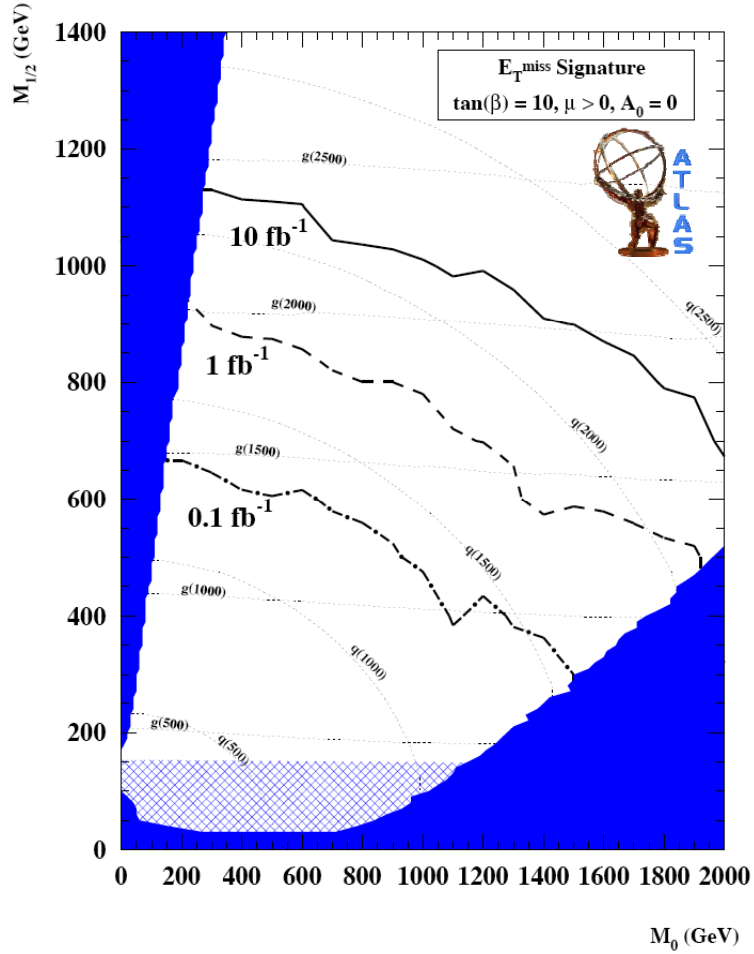
Two main background classes

1. *instrumental E_T^{miss} from mis-measured multi jets*



[Shary04]

2. *real E_T^{miss} from neutrinos (MC + data driven estimate)*



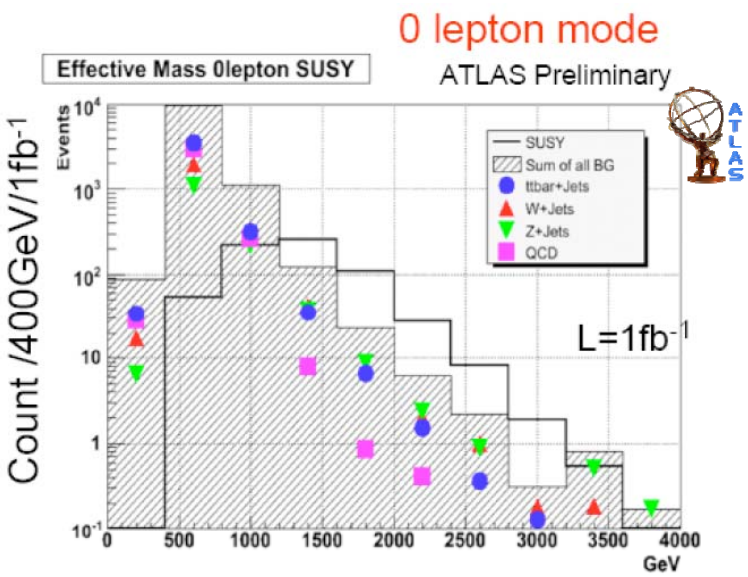
Discovery reach as a function of integrated luminosity in mSUGRA parameter space for E_T^{miss} channel

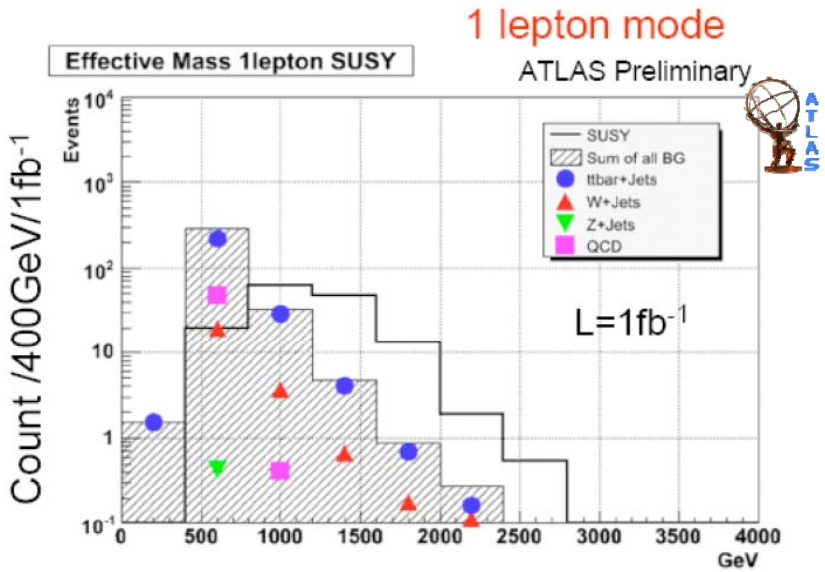
SUSY early discovery

1 fb^{-1}

Evidence of SUSY excess in M_{eff} distribution

$$M_{eff} = \sum_{i=1}^{4} |p_T(jet_i)| + E_T^{miss}$$





Shoulder might be observable

Typical SUSY selection:

- *E_T^{miss} > 100 GeV*
- *at least 1 jet with p_T > 100 GeV*
- *at least 4 jets with p_T > 50 GeV*
- *(leptons)*

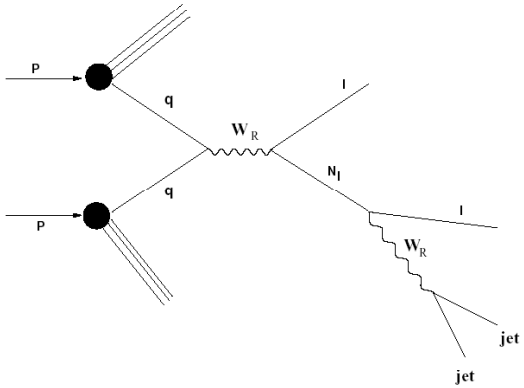
Counting experiment: need precise estimate of backgrounds (SM and instrumental) → will require time before convincing signal can be claimed

W_R and Majorana neutrinos

1 fb^{-1}

Left-right symmetric model $SU_C(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)$

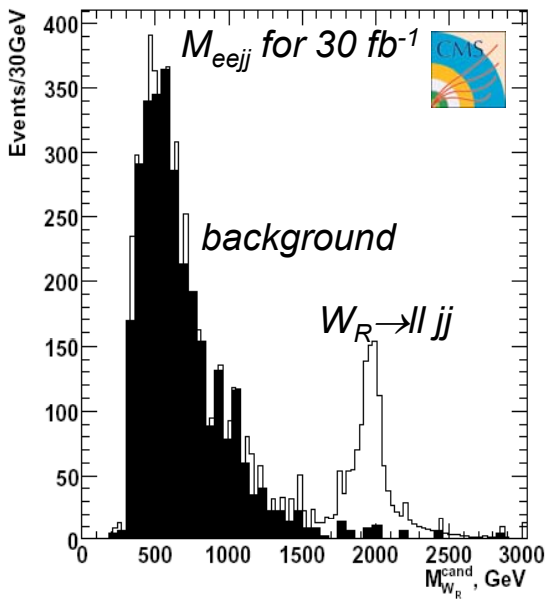
- *Three additional gauge bosons W_R and Z' and heavy RH Majorana neutrinos N_l*



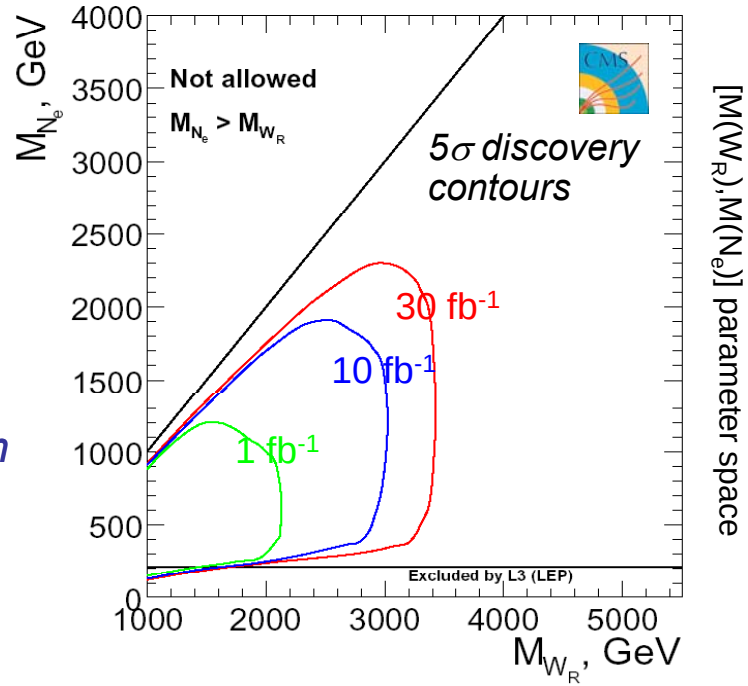
Investigated channel: *production of N_l from heavy gauge boson W_R decay*

Signature: *two isolated leptons and at least two jets*

Backgrounds: *Z+jets and tt*



Sensitivity starting from few fb^{-1}

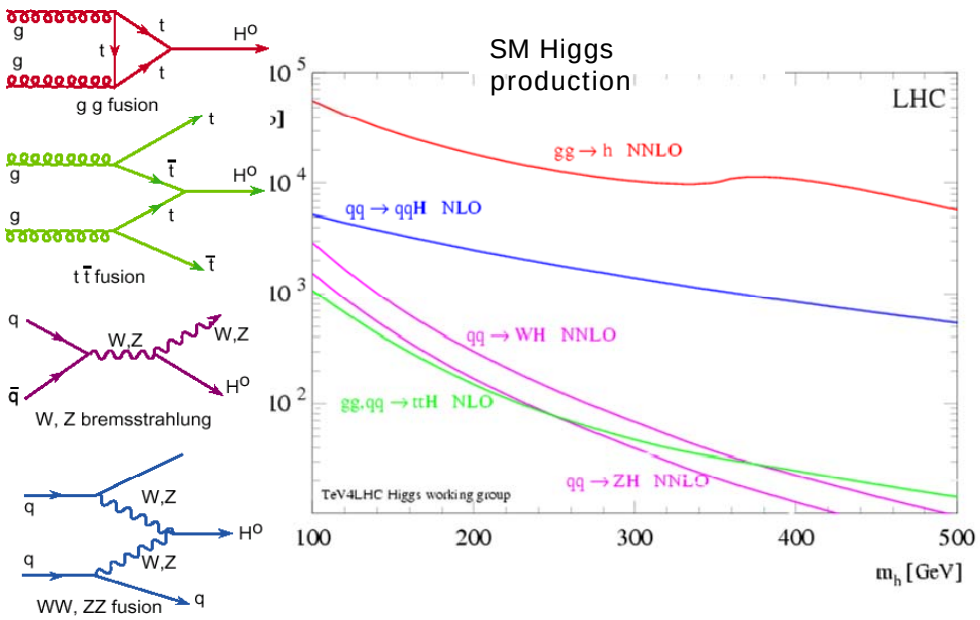


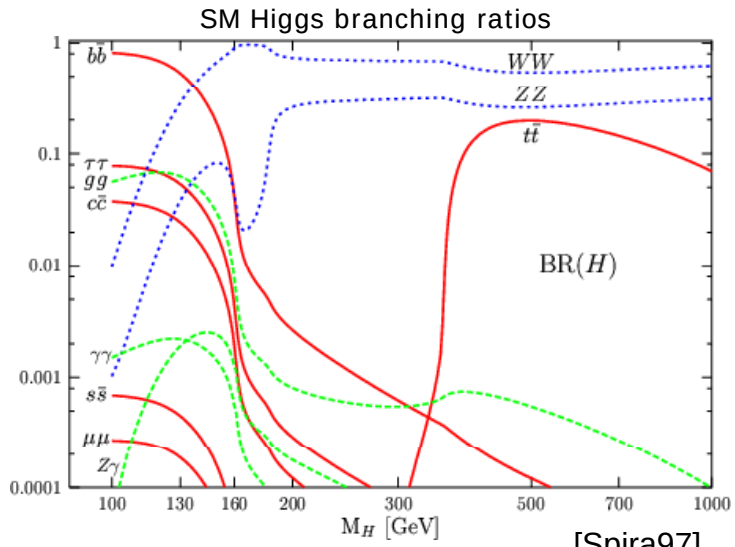
SM Higgs discovery potential

1-3 fb^{-1}

Current limits on M_H from experiments

- *Direct search (LEP) M_H > 114.4 GeV at 95% CL*
- *Indirect searches (fit to EW data) M_H < 144 GeV at 95% CL (2006, ICHEP06)*





[Spira97]

Early discovery/evidence at LHC: decay channels with high production rate and branching ratio, trigger possibility, good signal/background ratio

- *ggF(+VBF)→H→WW(*)* *for M_H > 150 GeV (dominant at the Tevatron)*
- *ggF(+VBF)→H→ZZ(*)* *golden channel for M_H in the 200-450 GeV range*

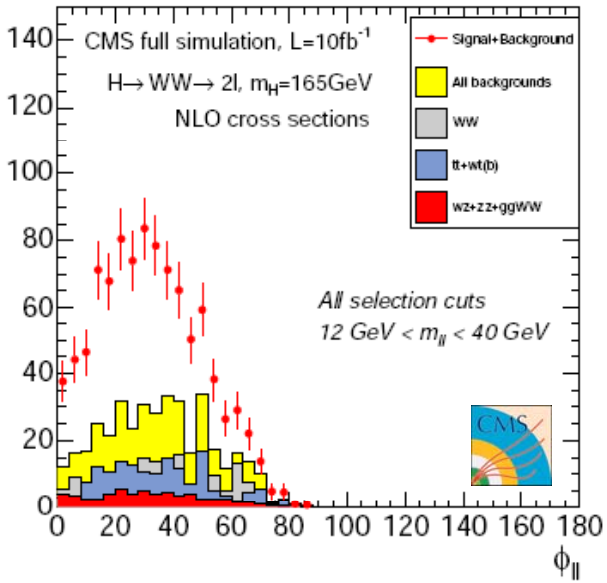
SM $H \to WW^{(*)} \to ll\nu\nu$ 1-3 fb^{-1}

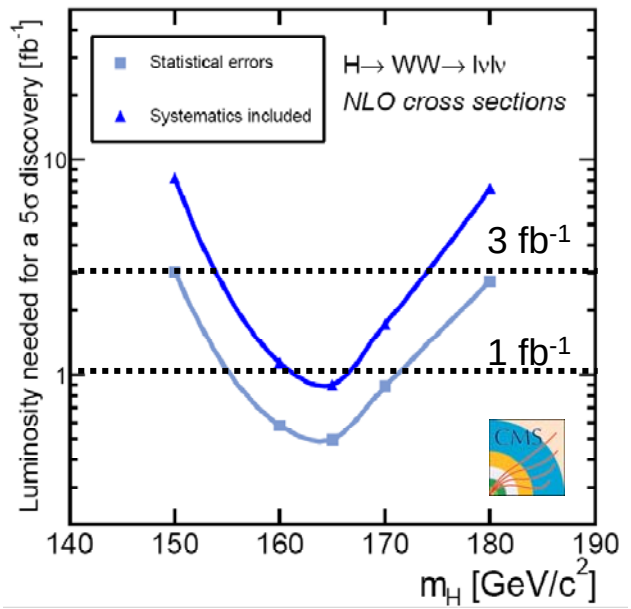
Main backgrounds

- *tt (CMS: uncertainty from the data 16% at 5 fb^{-1})*
- *WW (CMS: uncertainty from the data 17% at 5 fb^{-1})*

Main selection cuts:

- *two oppositely charges isolated high p_T leptons*
- *leptons must have a small opening angle*
- *veto on events with jet activity and large E_T^{miss}*





Evidence of the SM Higgs boson with

- *M_H ~ 160-168 GeV already possible with 1fb^{-1}*
- *M_H ~ 155-175 GeV with 3 fb^{-1}*

If not, a luminosity of about 1fb^{-1} allows to obtain some 95% CL exclusion limit

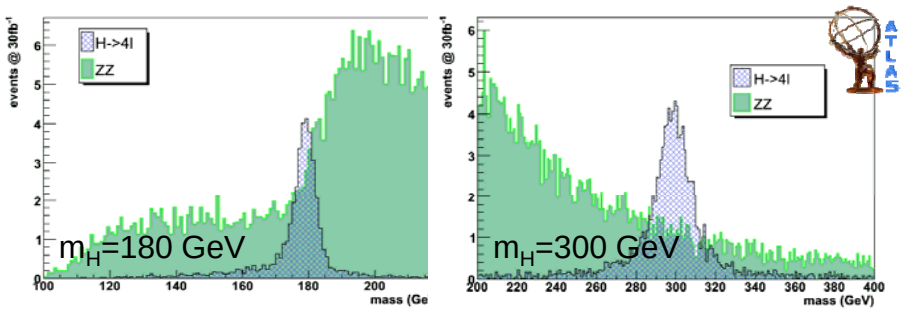
During the first year (1fb^{-1}) a 5σ Higgs signal might be observed!

Counting experiment (no mass peak)… understanding backgrounds from data is crucial

SM $H \rightarrow ZZ^{(*)} \rightarrow 4l$

4 fb^{-1}

Low signal cross section $\sigma \cdot BR$ ~7 fb (M_H = 300 GeV) but narrow mass peak and low background



ZZ background overwhelms when the two Z are on mass shell

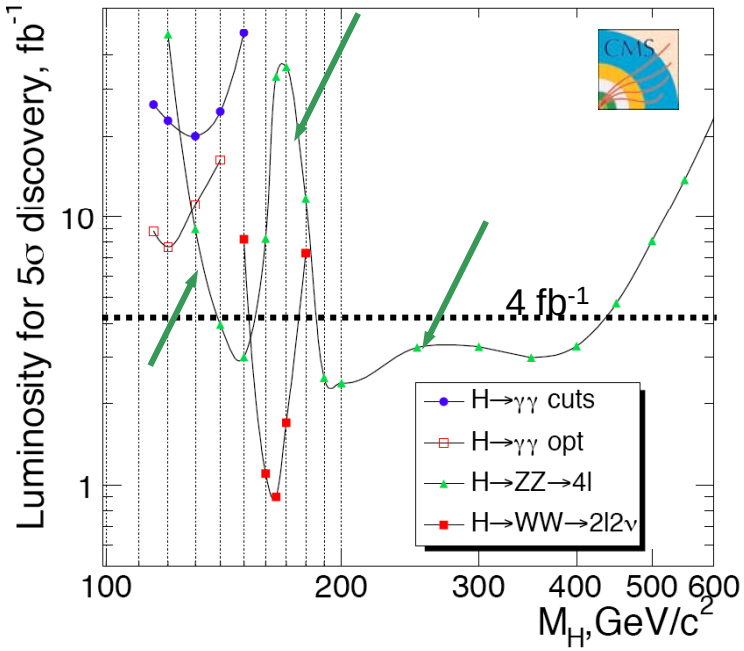
Main backgrounds:

- *reducible: Zbb, tt - irreducible: ZZ*

Main selection cuts:

- *isolated high p_T leptons (muons, electrons) from the interaction vertex*
- *vertex reconstruction and b-jets veto*
- *mass windows $M_{Z(*)}$, M_H*

With 3 fb^{-1} 5σ discovery for M_H ~ 200 GeV
With 4 fb^{-1} 5σ discovery over a large mass range



Dynamical EWSB: Technicolor

5 fb^{-1}

Dynamical EWSB via new strong interaction

Technicolor = QCD-like force acting on technifermions at the scale $\Lambda_{TC} \sim v_{weak}$ = 246 GeV

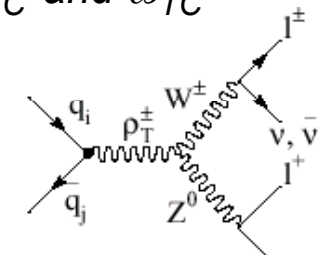
- *no need for Higgs boson(s) → removes fine tuning problem*

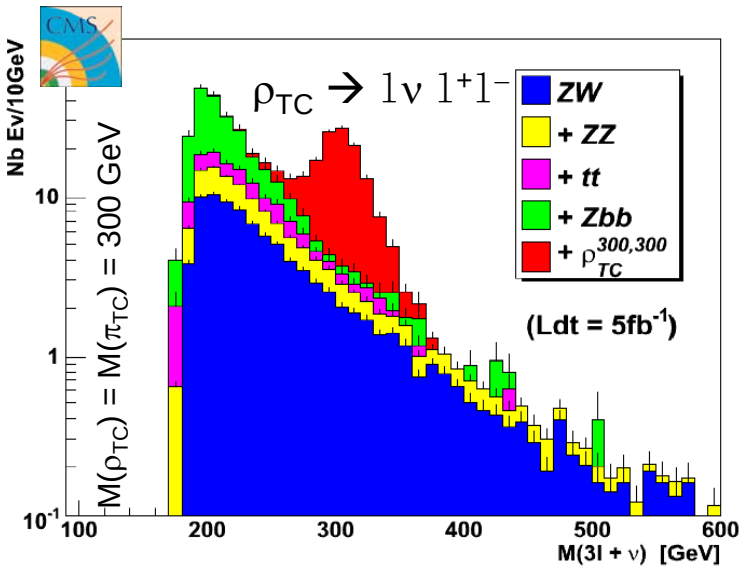
"Technicolor Straw Man" model: spin-0 π_{TC}, spin-1 technimesons ρ_{TC} and ω_{TC}

ρ_{TC}→WZ process: clean with leptonic W and Z decays

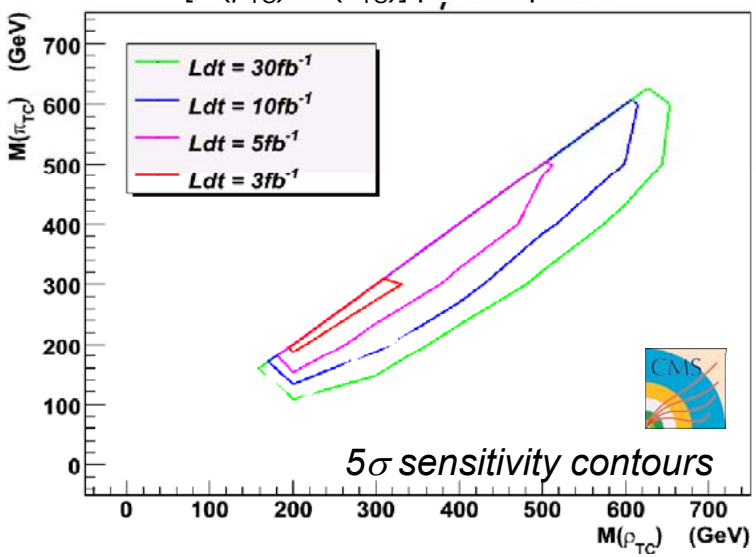
- *isolated leptons, E_t^{miss}, W and Z kinematical constraints*

SM backgrounds: WZ, ZZ, Zbb, tt





[$M(\rho_{TC})$, $M(\pi_{TC})$] phase space



Sensitivity starting from few fb^{-1}

Conclusions

ATLAS and CMS commissioning is well underway

First physics run at 14 TeV in summer 2008 → initial emphasis on understanding the detector performance and SM processes but...

- *Z'(W') TeV mass region can be explored: leptonic signatures with low background promising for an early discovery*
- *both ATLAS and CMS could start to probe SUSY at 1-2 TeV*
- *high potential for a BSM physics discovery (black holes, Majorana neutrinos, Technicolor, etc.)*
- *if lucky, $H \rightarrow WW$ channel will allow to evidence a SM Higgs boson at M_H ~ 165 GeV with 1fb^{-1}, while $H \rightarrow ZZ$ channel will allow a discovery in the mass range [190, 450] GeV with 4 fb^{-1} of integrated luminosity*
  - *If not, a luminosity of ~1fb^{-1} allows for a 95% exclusion limit for M_H between 200 and 450 GeV*

➢ *SM $H \rightarrow \gamma\gamma$ requires more statistics (small BR, small σ)*
➢ *for a MSSM Higgs 5σ discovery at least 10 fb^{-1} needed (for the lightest MSSM Higgs, all the channels combined)*

References

CMS Physics TDR, Volume II, CERN-LHCC-2006-021
ATLAS TDR, Volume II

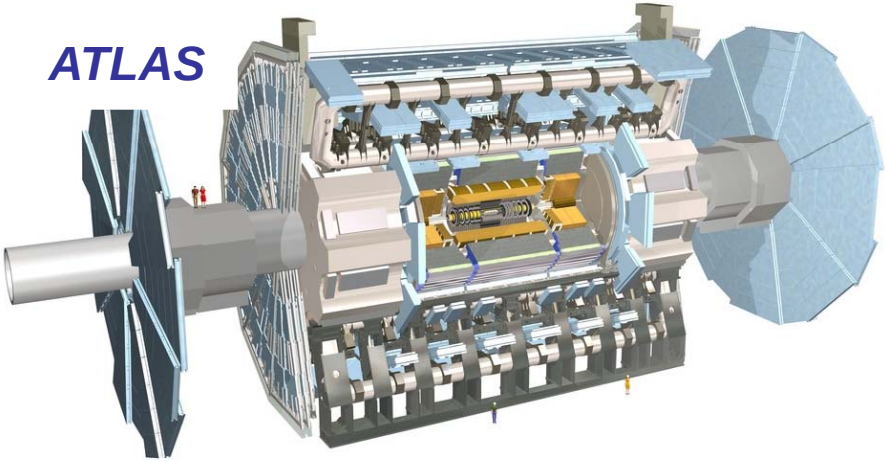
[Gianotti06] F. Gianotti, ICHEP06, Moscow
[Shary04] V.Shary, Calor04, Tevatron-Run II
[Spira97] A. Djouadi, J. Kalinowski, M. Spira, hep-ph/9704448

Acknowledgments to: G. Polesello, F. Gianotti, M. Schumacher, V. Vercesi, L. Fayard, S. Eno, A. Nikitenko, A. Nisati, S. Rosati

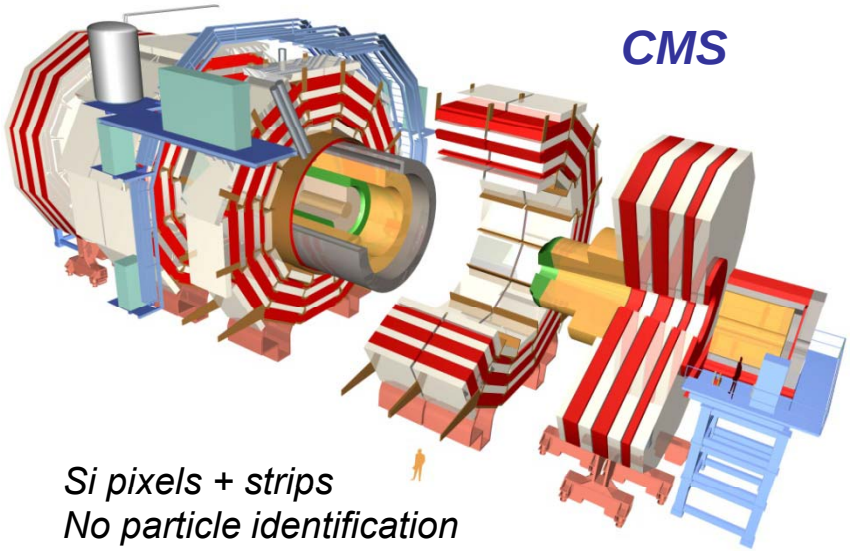
Backup slides

ATLAS and CMS

ATLAS



CMS



	ATLAS	CMS
TRACKER	*Si pixels + strips TRT → particle identification* $\sigma/p_T \sim 5\times10^{-4}\, p_T \oplus 0.01$	*Si pixels + strips* *No particle identification* $\sigma/p_T \sim 1.5\times10^{-4}\, p_T \oplus 0.005$
EM CALO	*Pb-liquid argon* $\sigma/E \sim 10\%/\sqrt{E}$ *uniform* *longitudinal segmentation*	$PbWO_4$ *crystals* $\sigma/E \sim 2\text{-}5\%/\sqrt{E}$ *no longitudinal segmentation*
HAD CALO	*Fe-scint. + Cu-liquid argon* *(≥ 10 λ)* $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	*Brass-scint. (≥ 5.8+catcher)* $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON	*MDT, CSC, RPC, TGC* $\sigma/p_T \sim 7\ \%$ *at 1 TeV* *standalone*	*DT, CSC, RPC* $\sigma/p_T \sim 5\%$ *at 1 TeV* *combining with tracker*

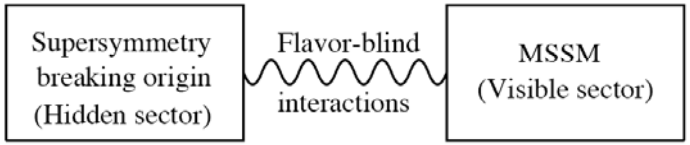
Excellent Standalone Muon Detector ***Excellent EM Calorimeter***

Search for heavy stable SUSY particles 500 pb^{-1}

SUSY most popular template for exploration of new physics at the LHC

SUSY in a broken symmetry (no sparticles observed to date)→ several models of SUSY breaking:

-mSUGRA → 5 parameters m_0, $m_{1/2}$, A_0, tan β, sgn(μ)
-GMSB → 6 parameters Λ, M_m, N_5, tan β, sgn(μ),C_{grav}
-AMSB → 4 parameters m_0, $m_{3/2}$, tanβ, sgn(μ)



***GMSB scenario**: gravitino is the LSP, non-interacting*
Phenomenology defined by the Next to Lightest Supersymmetric Particle (NLSP), which decays into its SM partner with cτ depending on the GMSB parameters

1. NLSP is the lightest slepton, stau $\tilde{l}_R \rightarrow l + \tilde{G}$ *(opposite sign, same-flavor leptons)*
2. NLSP is the lightest neutralino $\tilde{\chi}_1^0 \rightarrow \gamma + \tilde{G}$ *(two hard photons + E_T^{miss})*

- *cτ > detector*
  - *-Stau looks like an heavy muon*
  - *-neutralino escapes detection*

⇨ *Experimental challenge*
stau: tof measurement with the muon chambers

- *cτ ~< detector*
  - *-both NLSP can decay inside the detectors*

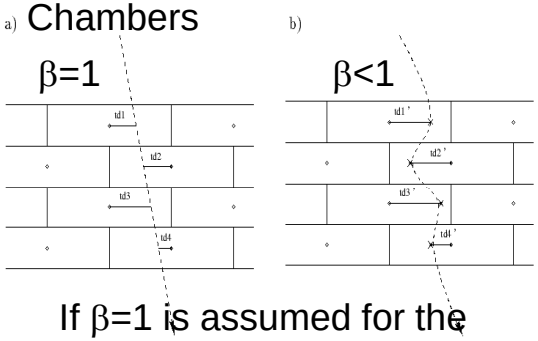
⇨ *stau: specific ionization in the tracker and/or the calorimeters*
neutralino: missing energy and two photons not pointing to the interaction point

Search for heavy stable SUSY particles 500 pb^{-1}

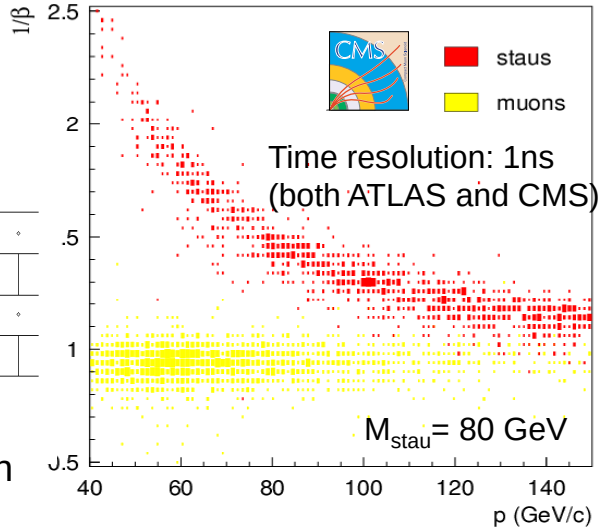
Time of flight measurements

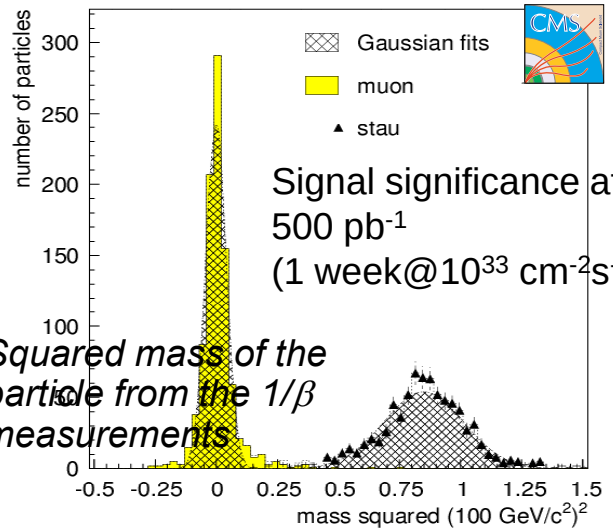
For slow staus

Particle crossing the Muon Chambers



If β=1 is assumed for the stau, points would not align





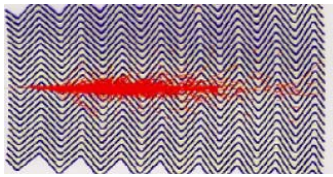
Signal significance after 500 pb^{-1}
(1 week@10^{33} cm^{-2}s^{-1})

Squared mass of the particle from the 1/β measurements

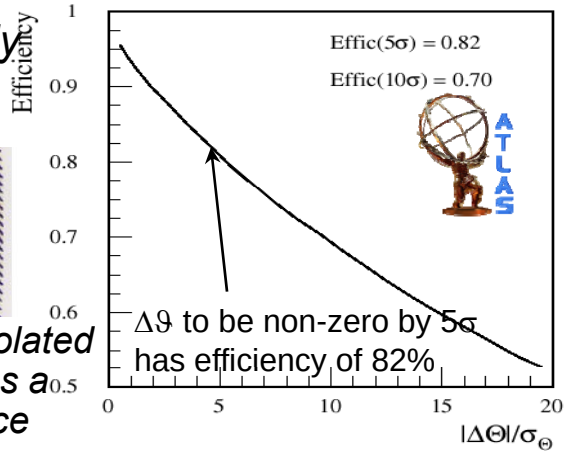
Impact direction reconstruction

For photons non-pointing to the vertex

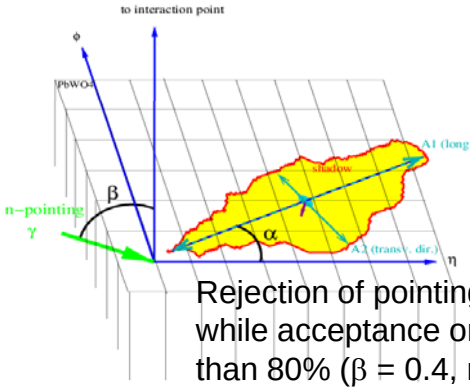
ATLAS: longitudinally segmented EMcalo



Efficiency to detect an isolated photon as non-pointing as a function of the significance



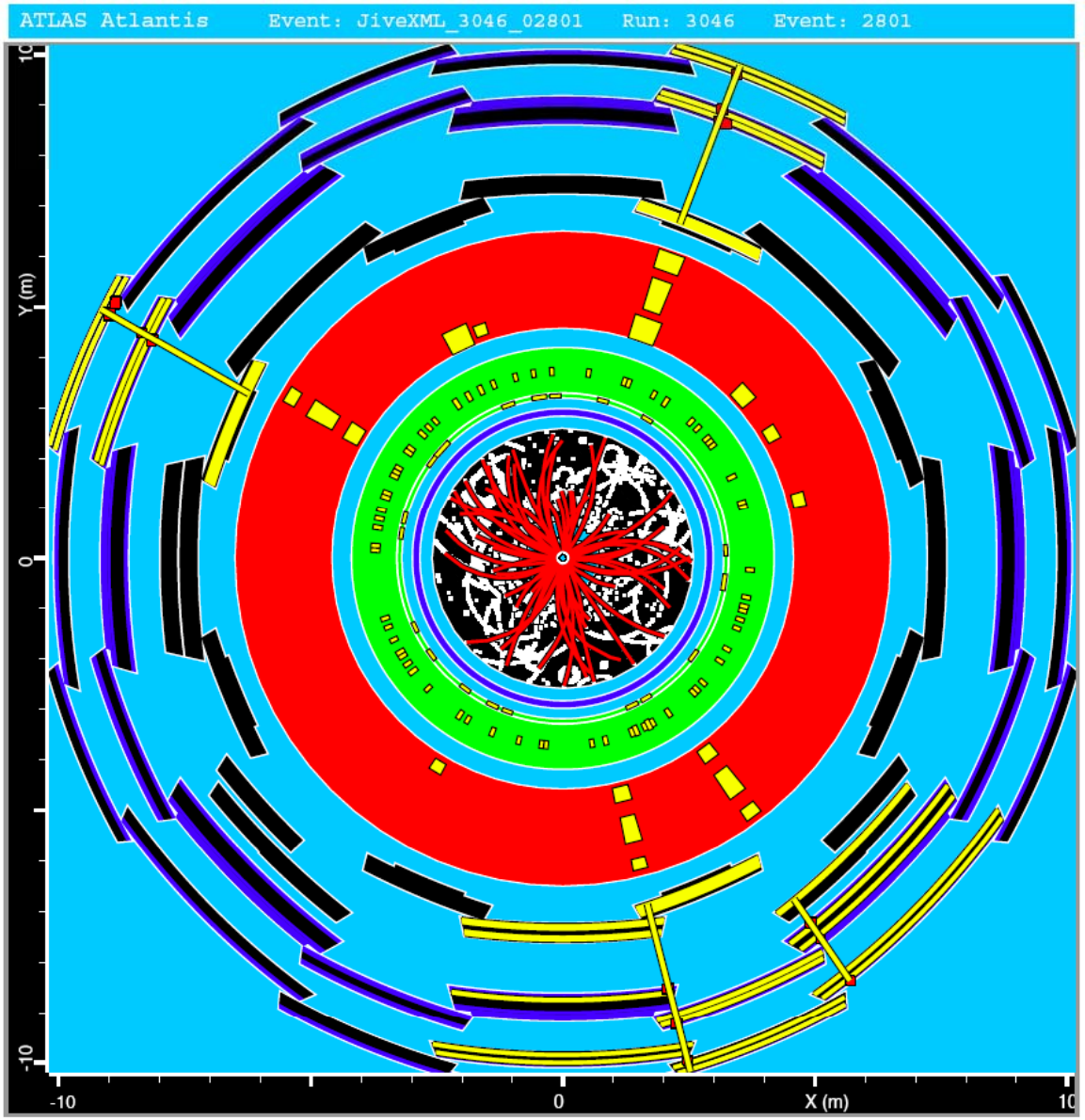
CMS ECAL: no longitudinal segments



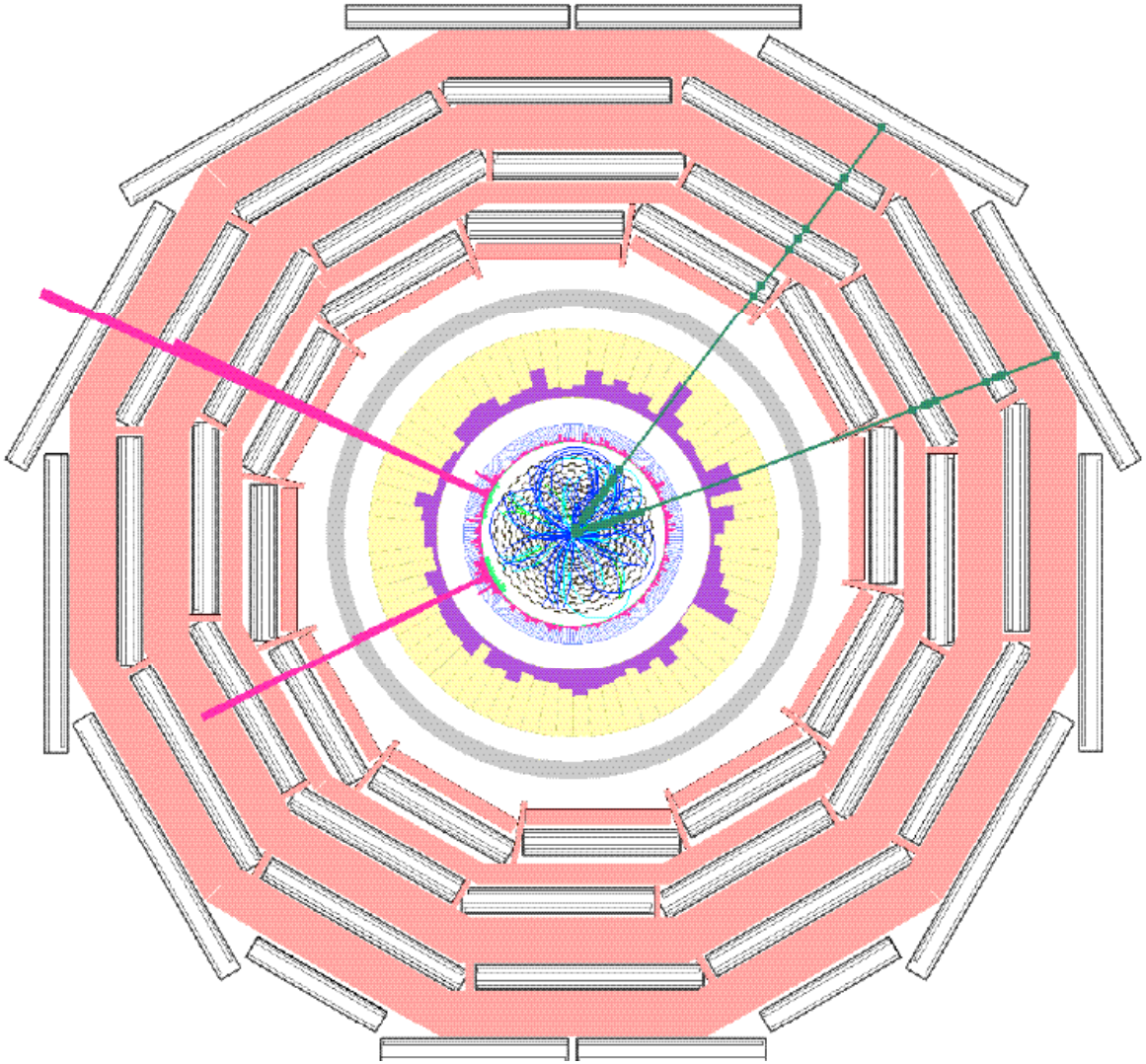
impact direction of the photon inferred from the asymmetry of the energy deposition in the crystals

Rejection of pointing photons at 99% while acceptance on signal photons bigger than 80% (β = 0.4, rad = 23º)

H→ZZ→4μ at ATLAS Event Display



$H \rightarrow ZZ \rightarrow ee\mu\mu$ at CMS Event Display

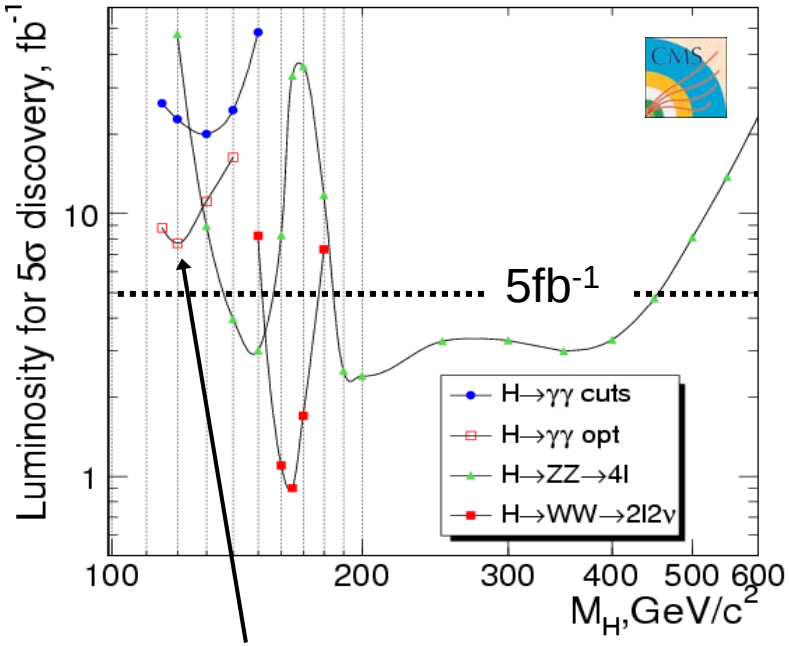


SM Higgs inclusive searches

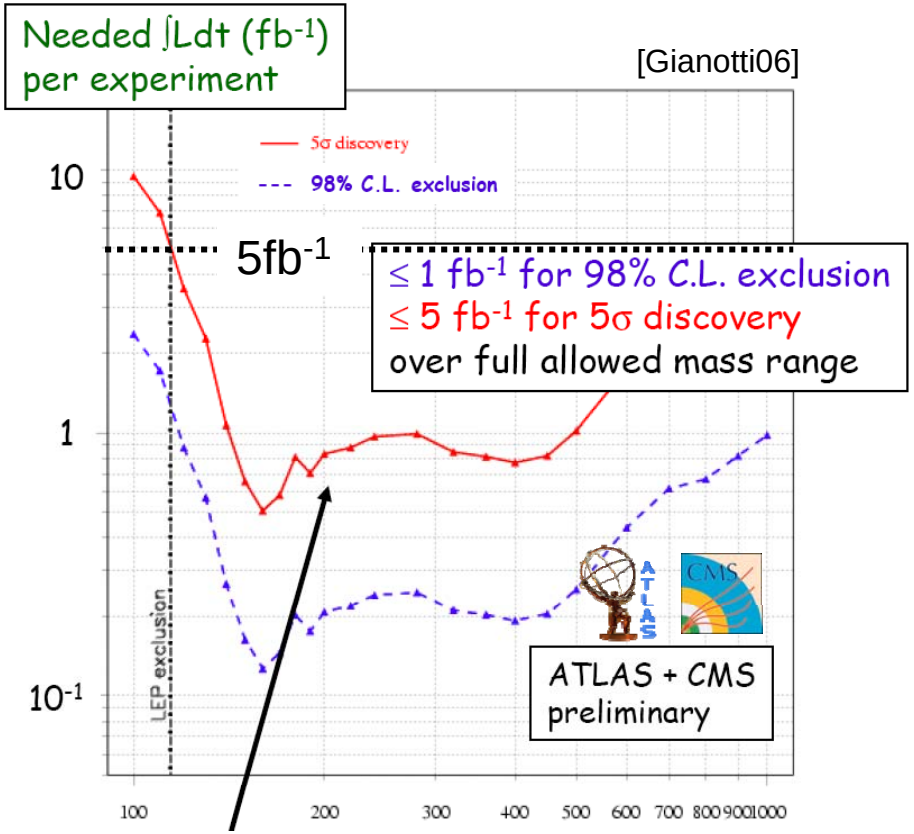
5 fb^{-1}

Integrated luminosity needed for a 5σ SM Higgs discovery

- *similar results for ATLAS*



The detection of a SM Higgs In the low mass range (favorite) requires > 10 fb^{-1} and will not be achievable in the first two years



5 fb^{-1} will allow for a 5σ Higgs inclusive discovery for M_H up to 600 GeV

What will come next (selection)