LHC Potential
Energy and luminosity

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- Reminder of achievement
- What might be possible?

Chamonix
25th January 2011

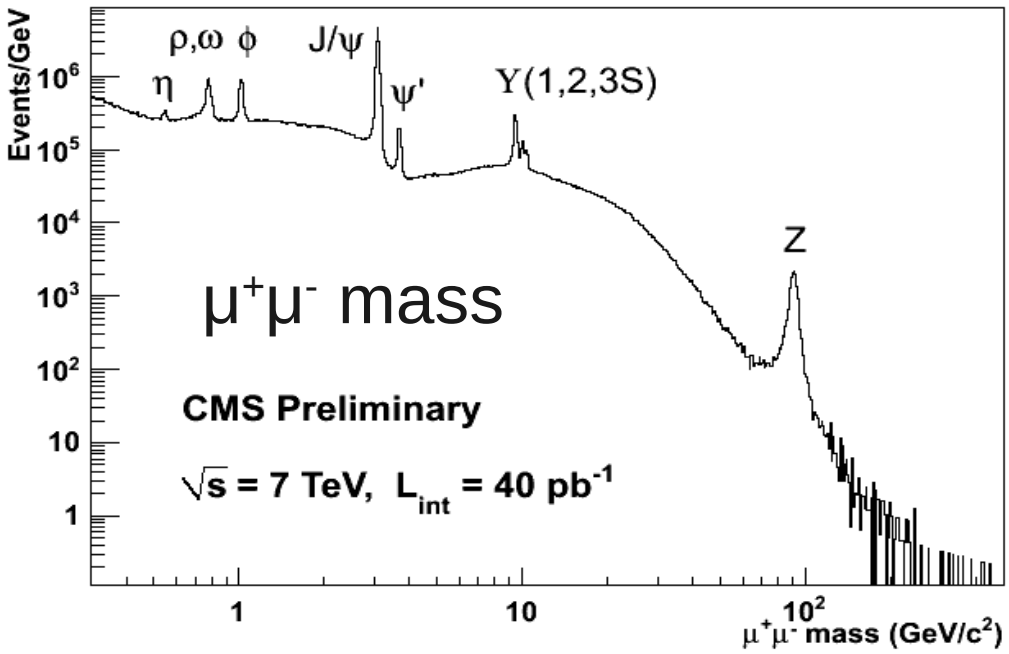
Three separate programmes

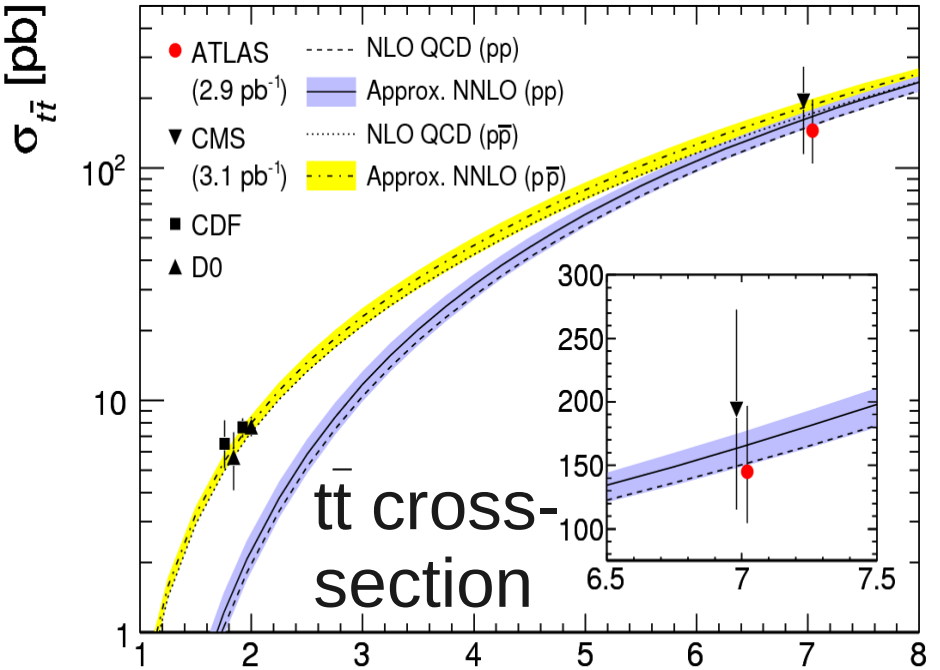
- LHCb
  - Energy is not a driver (E_{cms}=14TeV would help)
  - 2-3 $10^{32}cm^{-2}s^{-1}$
    - Stability is key
- ALICE
  - Derive energy for PbPb from pp programme
  - $10^{30}cm^{-2}s^{-1}$ max
    - Lower luminosity run desired for MinBias
- ATLAS/CMS
  - Maximum energy obtainable
  - ??? $10^{33}cm^{-2}s^{-1}$
    - Maximum obtainable luminosity

All plots are for single experiments

What have we learnt?

- The experiments are working remarkably
  - Operations, detector **performance** and modelling
- The SM is in great shape
  - N(N)LO calculations match data very well





φ, ψ, Ψ, W, Z, top, all well-behaved

What have we *discovered*?

- Great new *limits*, beyond Tevatron on:
  - q*, Quark substructure
  - New massive particles
  - SUSY
  - W', Z', lepto-quarks, b', stable heavy particles, stopped gluinos

- QCD in pp shows some surprises
  - Track multiplicity exceeded expectations
  - Long-range near-side correlations 'ridge'
  - High p_T forward b jet suppression?
- Lead-Lead collisions also gave great interest:
  - Jet quenching
  - Perfect Liquid model in good shape
  - J/ψ suppression confirmed

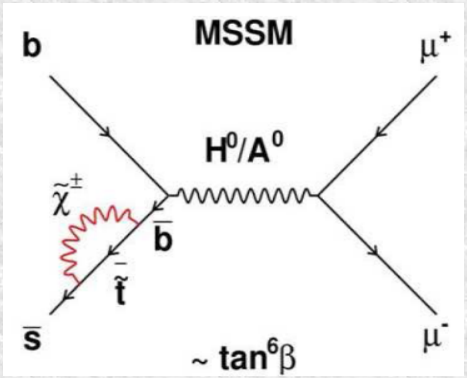
B Physics

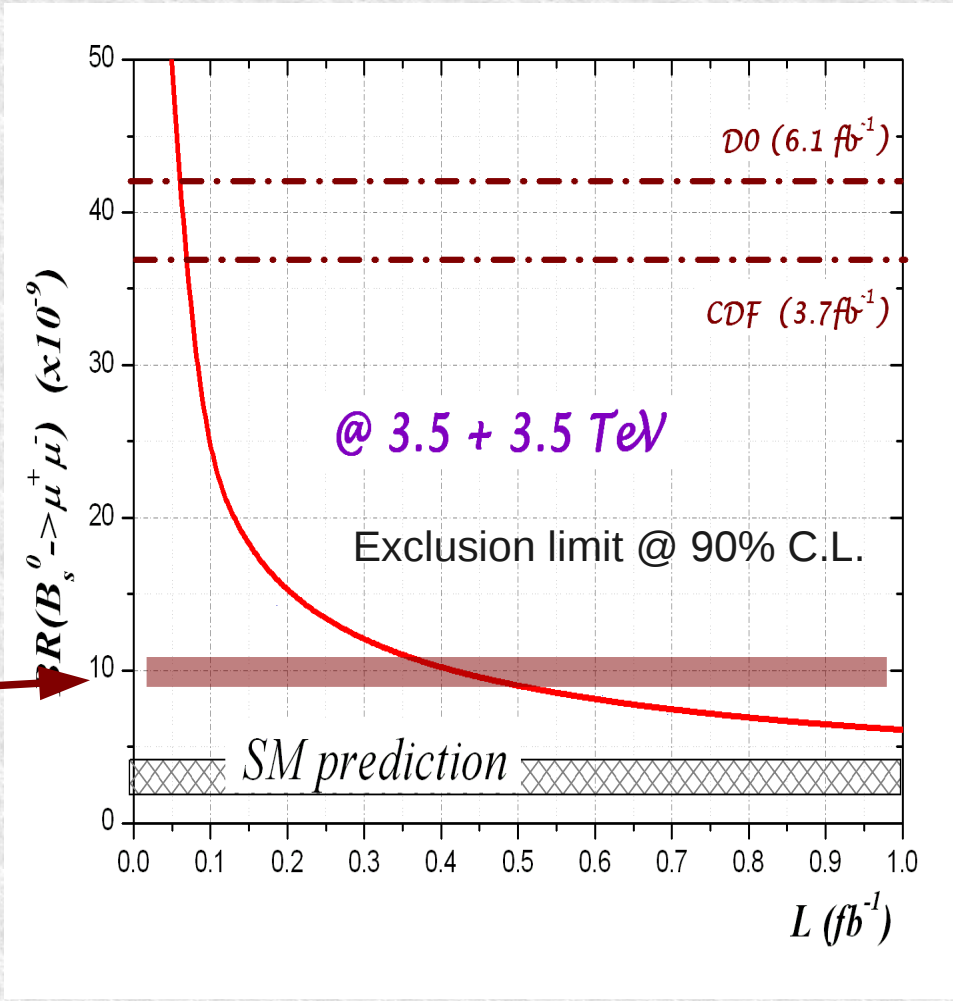
Principal LHCb goals in 2011

- Spotlight physics measurements:
  - $B_s \rightarrow \mu\mu$ search
  - B_s Charge-Parity Violation studies:
    - Interesting hints from Tevatron..
  - $B \rightarrow K^* \mu\mu$.
    - Discrepancy was observed in low mass (q^*) $\mu\mu$ structure
  - CPV search in charm system
  - Unitary triangle studies, especially γ
- In each case:
  - 0.1-0.3fb^{-1} gives worlds best sensitivity
    - Exciting prospects of New Physics discovery
  - 1fb^{-1} gives much increased reach
  - Ultimately sensitivity requires from a few fb^{-1}

$B_s \rightarrow \mu^+\mu^-$ search at LHCb

- 2010 LHCb results:
  - coming soon
- 2011 data will approach SM
- Sensitive to e.g. SUSY Higgs
- M_A=600, tanβ~30 excludeable
  - Need hundreds of fb^{-1} in direct search



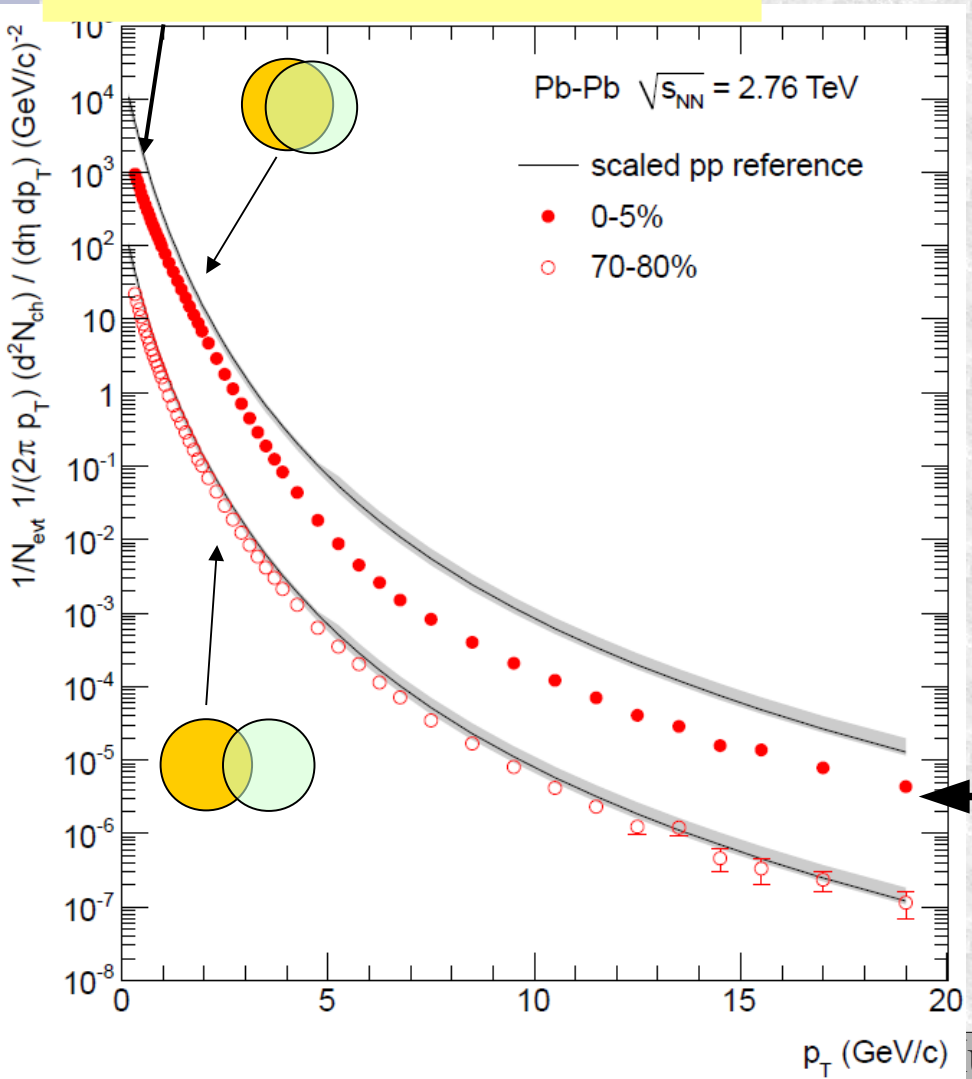


ALICE programme

- Luminosity in pp physics is pileup limited
  - ~100μs drift time in TPC
- Luminosity currently limited to 10^{30} in pp
  - Work to see if this can be increased
  - Less in minimum bias mode ~ 20% of running
  - Maximum run time needed as limited by pp stats.
  - Massi will discuss this
- PbPb physics will use energy settings from pp
  - p-Pb is of great interest
    - needs RF hardware; not for 2011
    - But inject/ramp should be tested
- Few days of pp requested at E_{beam}=1.38TeV
  - See next slide

p_T spectra in PbPb

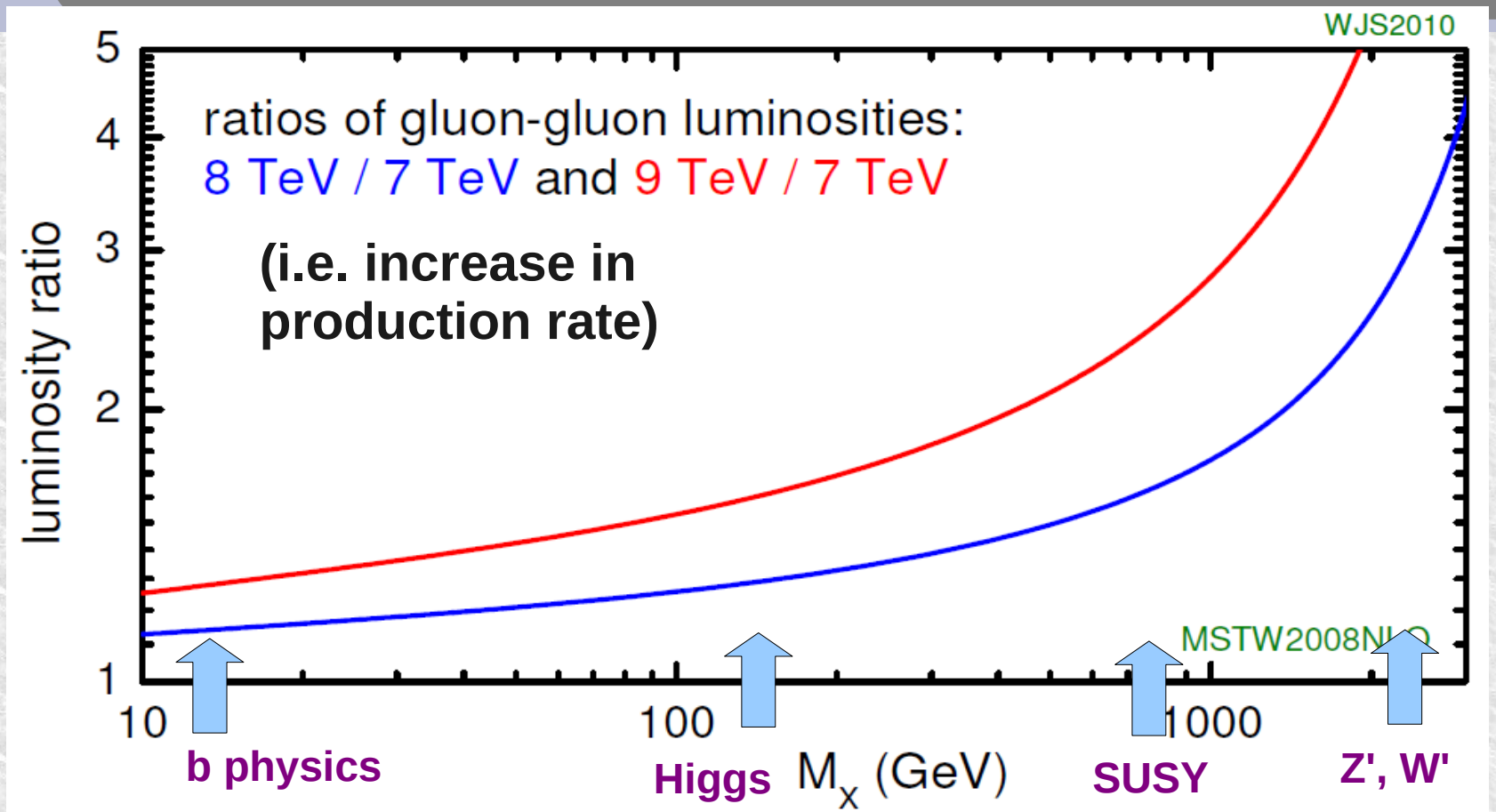
Data driven Interpolation
900 GeV & 7 TeV
or using NLO for change in shape
7 TeV * NLO (2.76 TeV)/NLO(7 TeV)



- Many measurements compare PbPb to pp
- Biggest error is lack of pp at 1.38TeV/nucleon
  - Scale from 0.45/3.5TeV
  - Need dedicated run
    - No need to repeat for 4TeV
- In this example
  - Solid red is head-on PbPb collision
  - c/f pp (grey)

High energy frontier

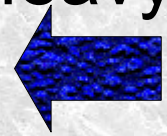
Effect of raising E_{CMS}



- 8TeV: 10% to factor 4 increases
  - Doubled for 9TeV
  - Higgs increased by 30%

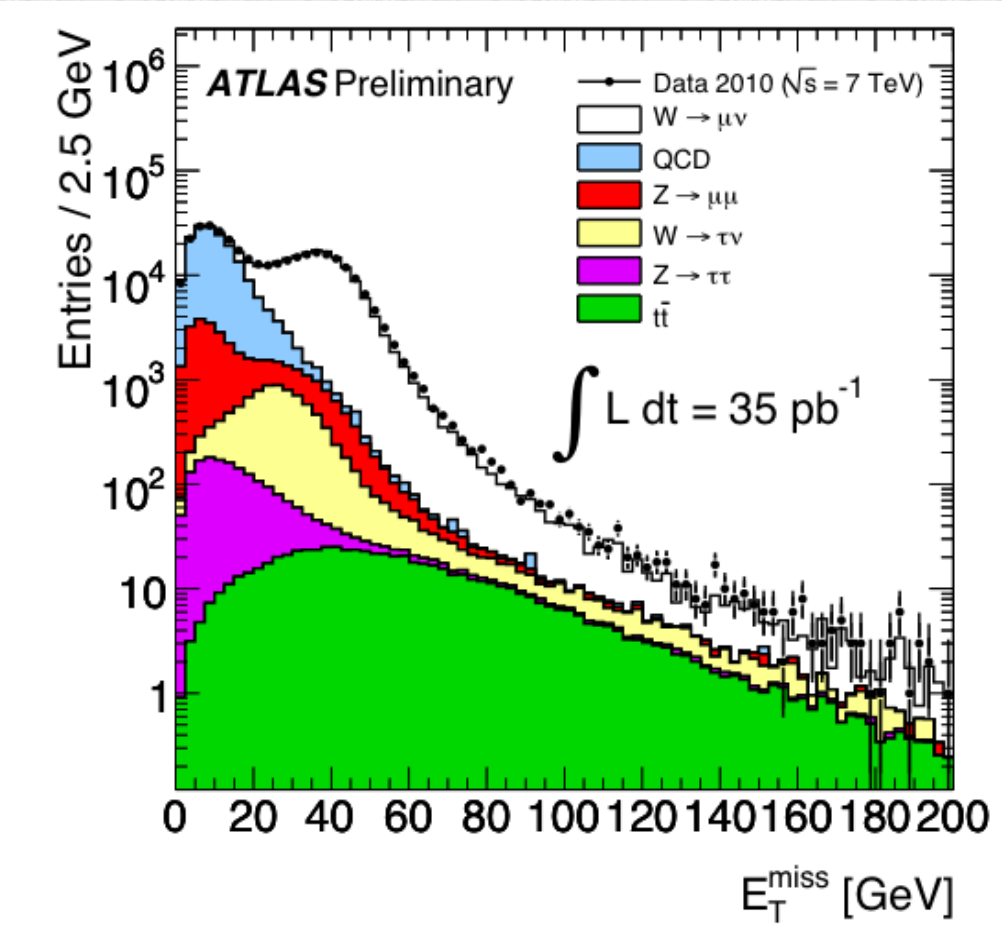
Thanks to James Stirling

What physics will we do?

- A few personal favourites
  - Electro-weak
  - top
  - SUSY
  - New Heavy Z' or W'
  - Higgs 

W bosons

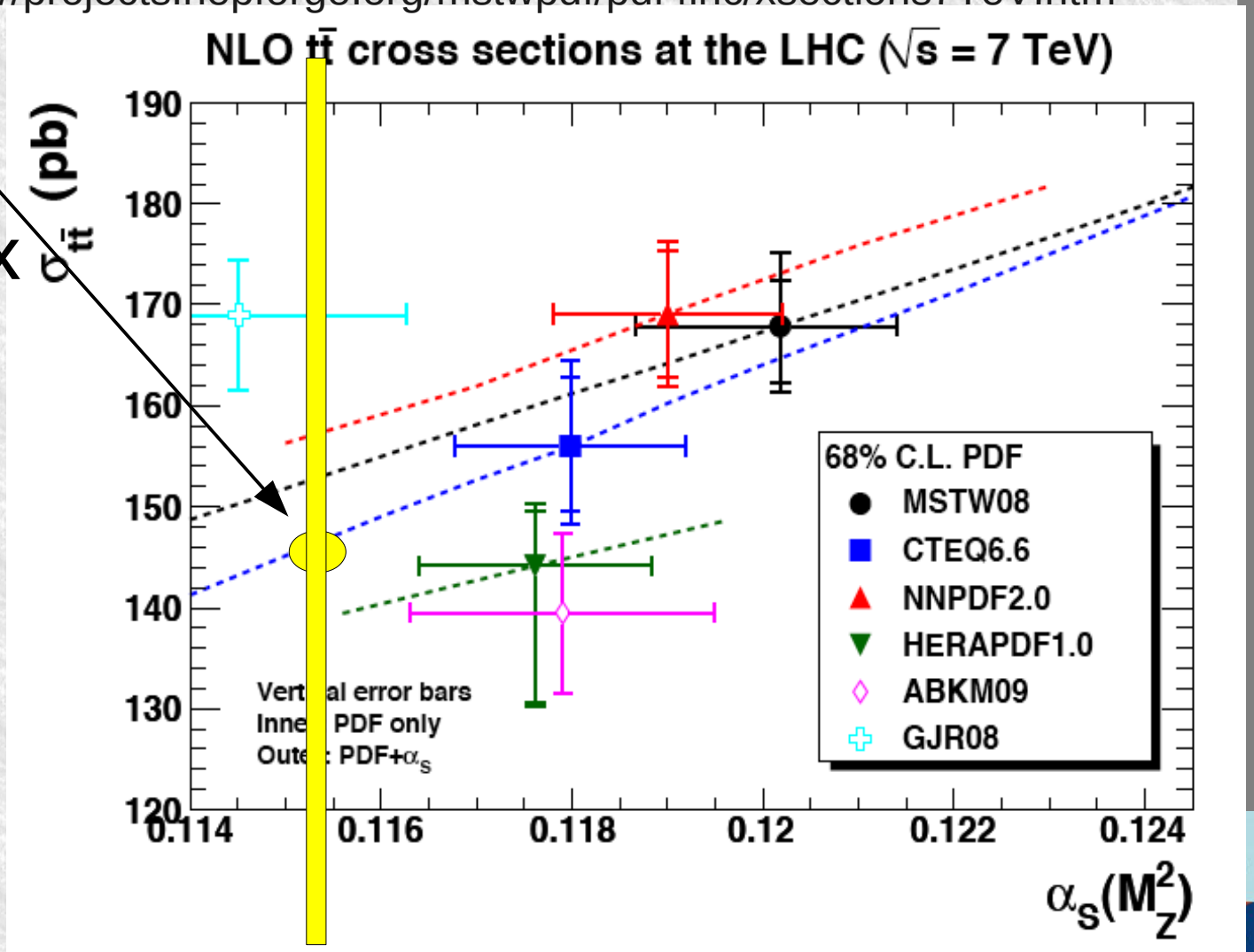
- W measurements have begun in earnest
  - Amazing agreement with the Standard Model
  - Over orders of magnitude
- These will become precise tools in 2011
  - Measure m_W
  - A key piece of the standard model
  - The only particle whose mass is predicted by Higgs' theory



Top cross-section

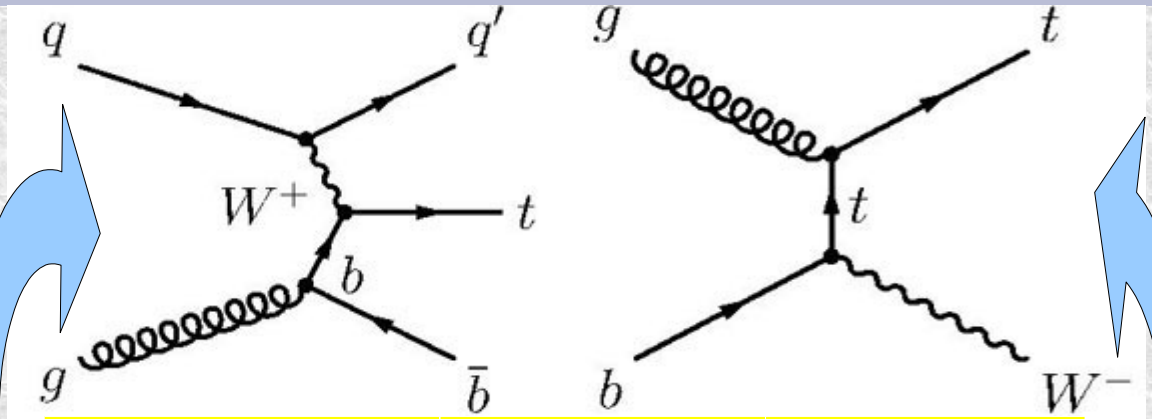
- Current measurements used ~3pb^{-1}
  - ATLAS
- 40% errors at present
- Aim for 1000 x times data
  - 8TeV gives 40% top
- Pins down gluon momentum distribution in the proton (PDF) at middle x

http://projects.hepforge.org/mstwpdf/pdf4lhc/xsections7TeV.html



Single Top properties

t-channel



Wt

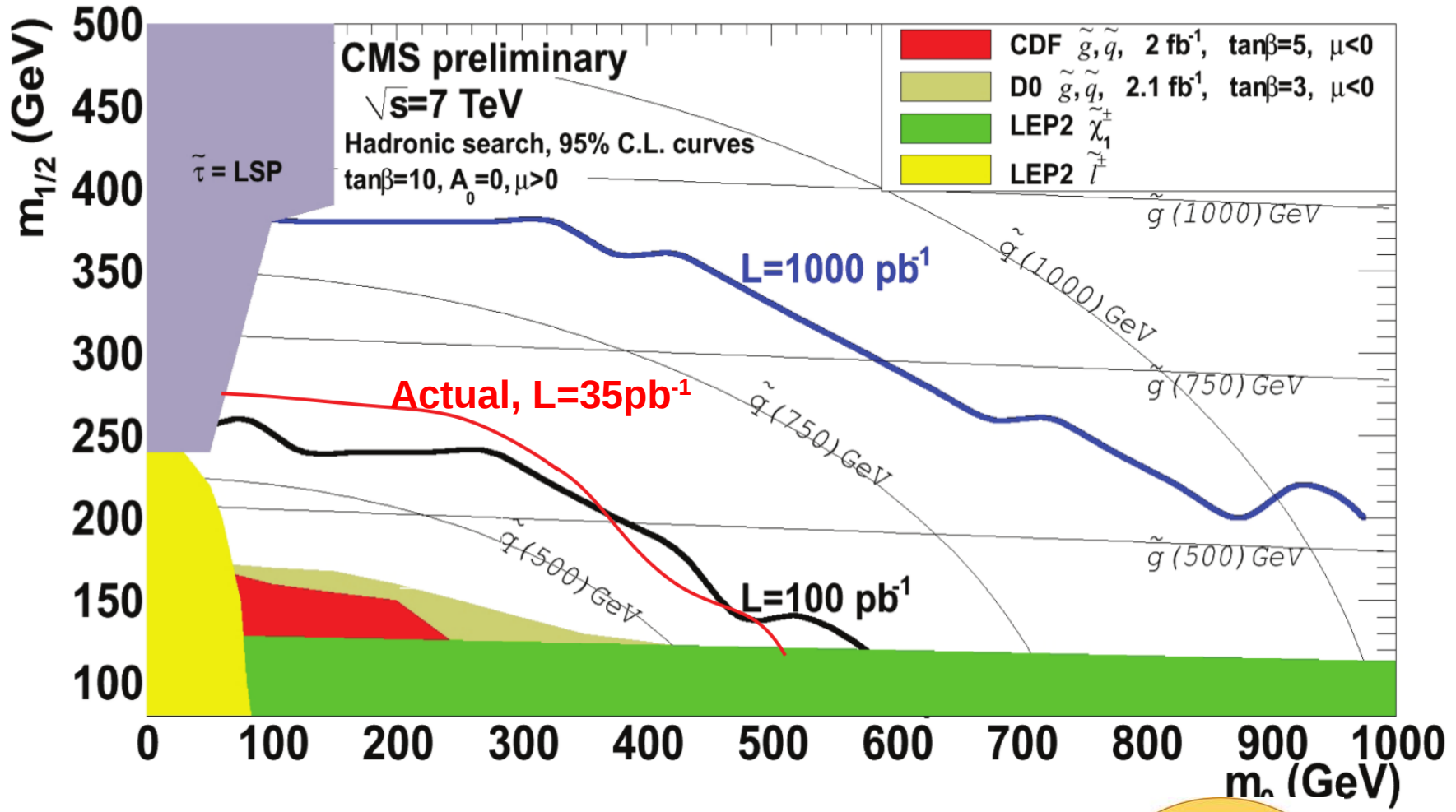
ATLAS projections	Errors, 1fb^{-1}	Errors, 5fb^{-1}
t-channel	32%	13%
Wt	68%	32%

Multivariate analysis

- Important test of model and detectors
  - Only seen at Tevatron in 2009
- Wt channel visible only with 5fb^{-1}
- Errors ~ halved by increased dataset
- Signal rises 20-40% passing to 8TeV E_{CMS}

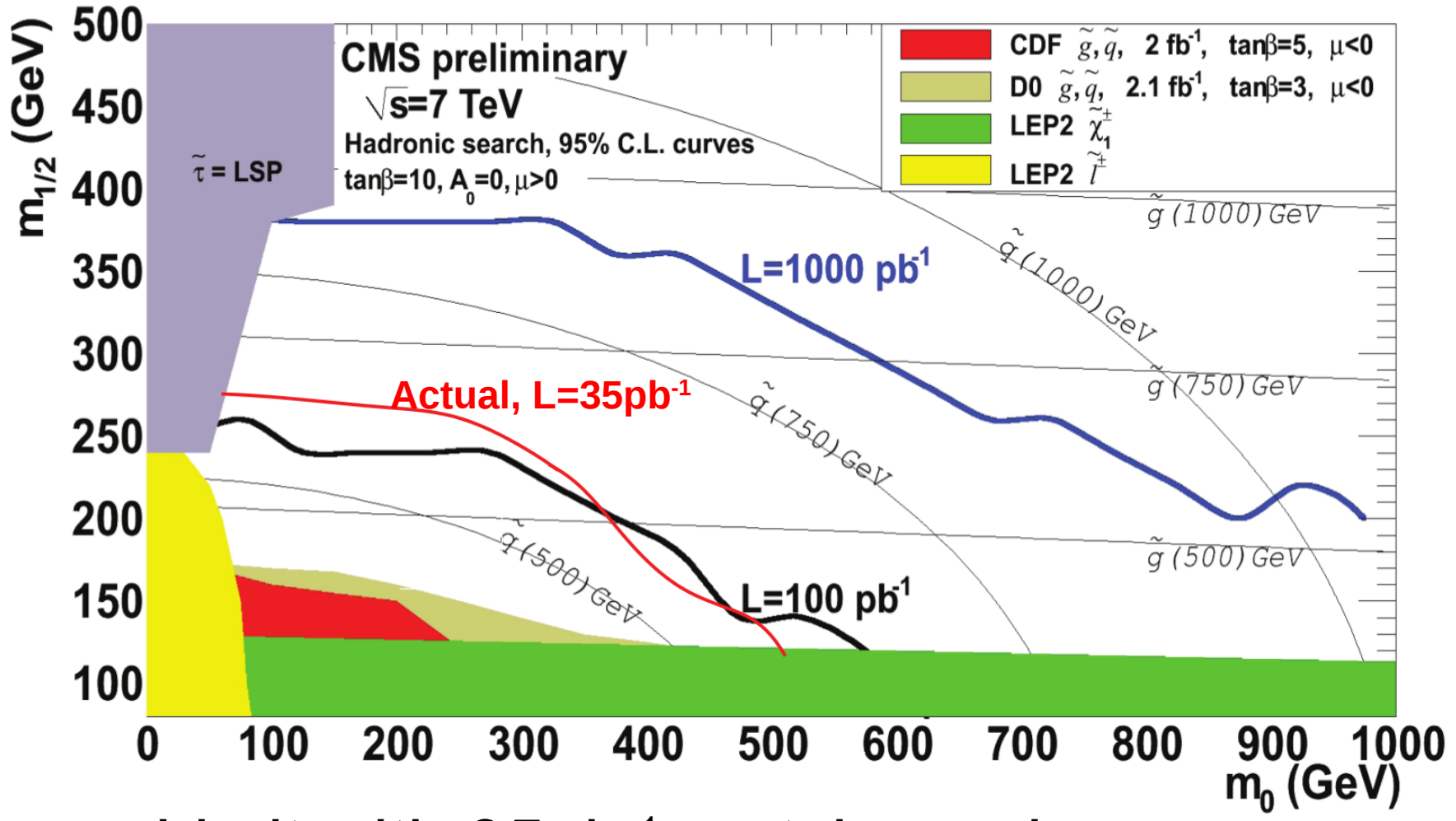
Searches

SUSY: Jets and E_T^{miss}



- Limits **far** exceeds Tevatron
- m_{SUSY}>600GeV

SUSY: Jets and E_T^{miss}

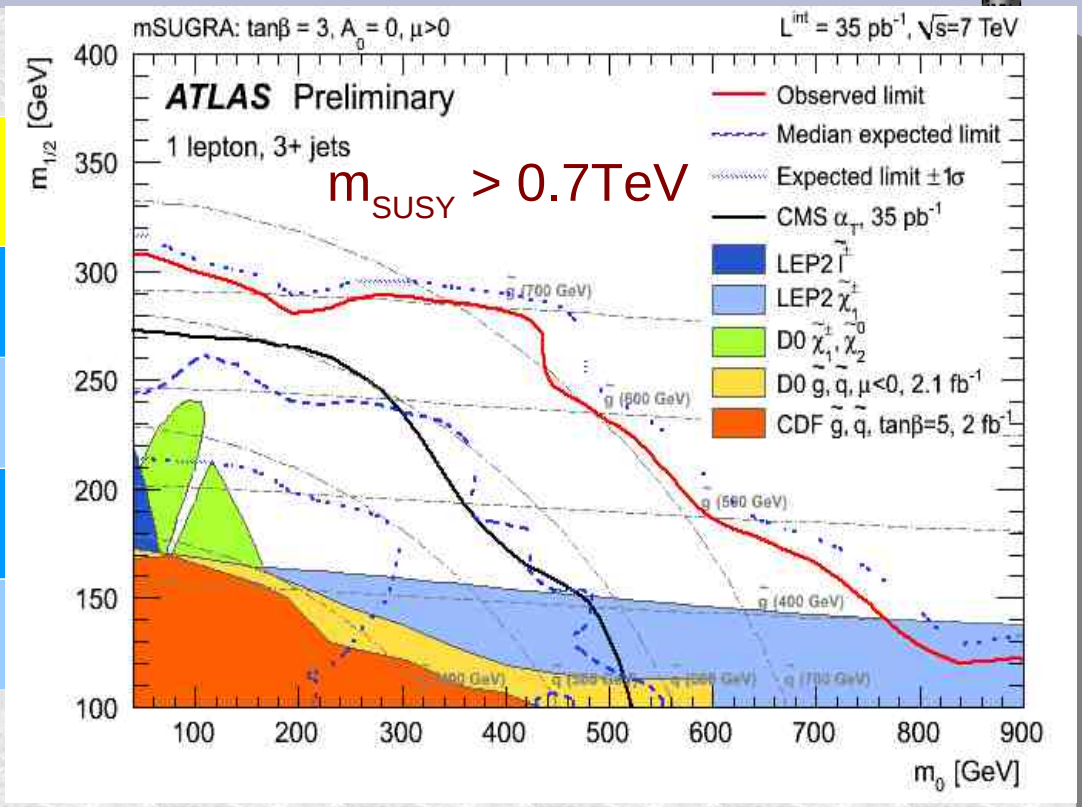


- Limit with 35pb^{-1} matches prior expectations for 100pb^{-1}

SUSY potential

m_{SUSY} lower limit 0.7TeV

5σ	$\mathcal{L}$, fb^{-1}			
√s, TeV	1	2	5	10
7	0.7	0.8	1.0	1.2
8	0.8	1.0	1.2	1.4
9	0.9	1.1	1.3	1.6



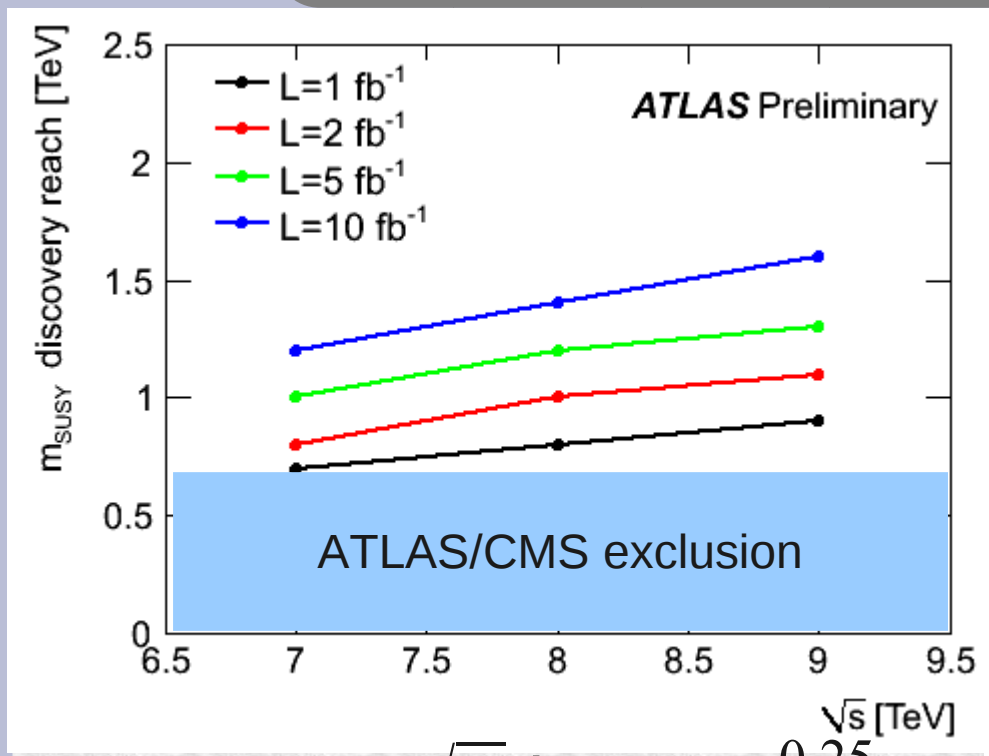
$$m_{SUSY} = \sqrt{s}/10 \times L^{0.25}$$

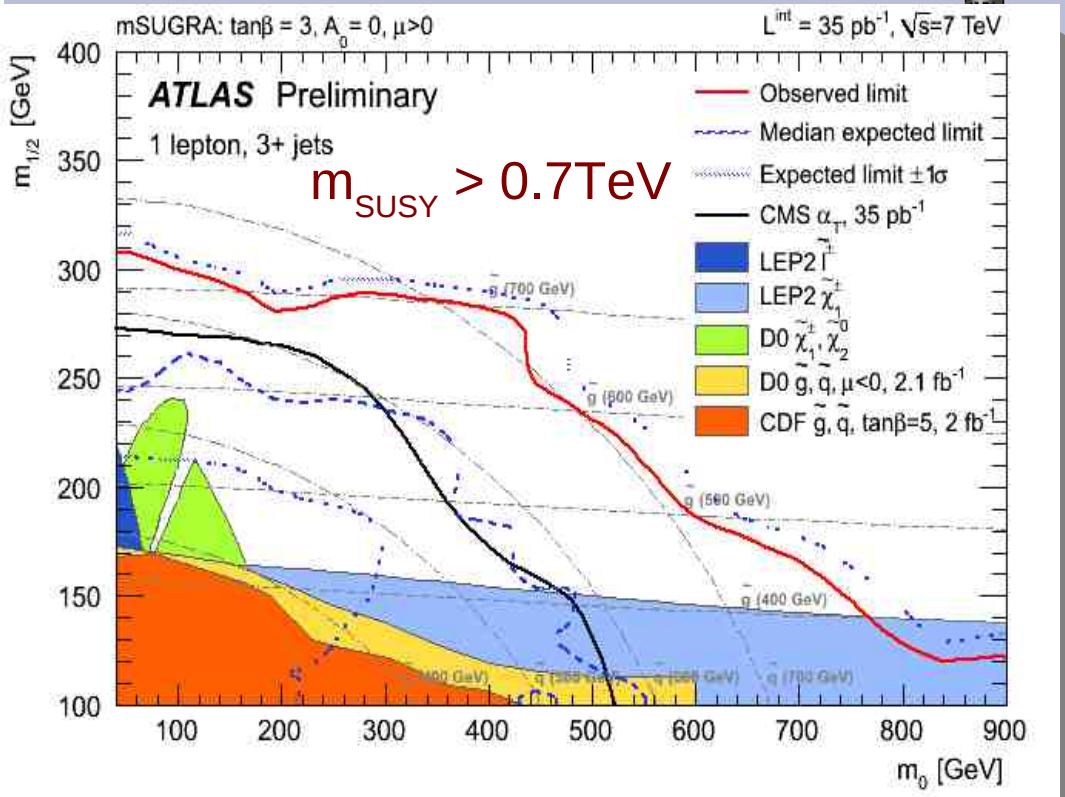
Can go beyond 1TeV provided :

$\mathcal{L}$>5fb^{-1} and √s=7TeV

or $\mathcal{L}$>1fb^{-1} and √s≥8TeV

SUSY potential





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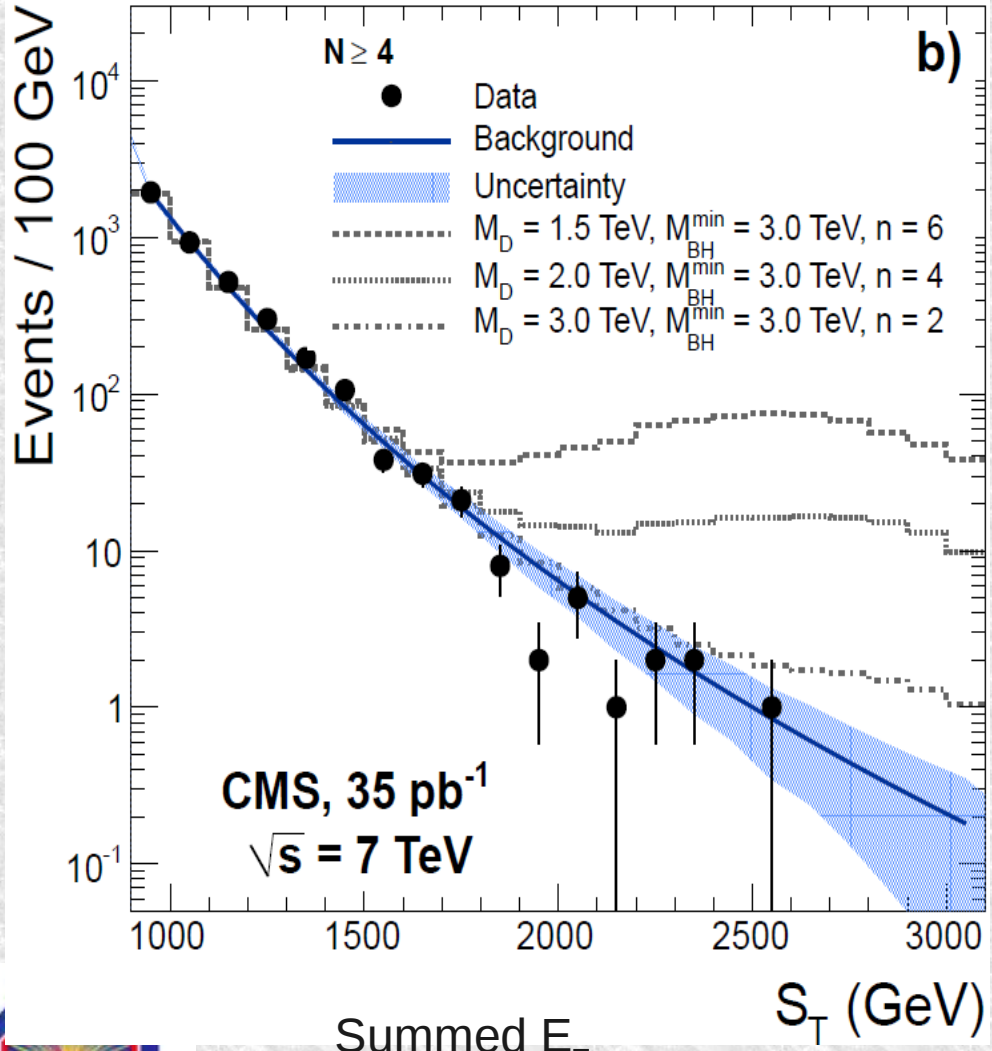
Black hole searches

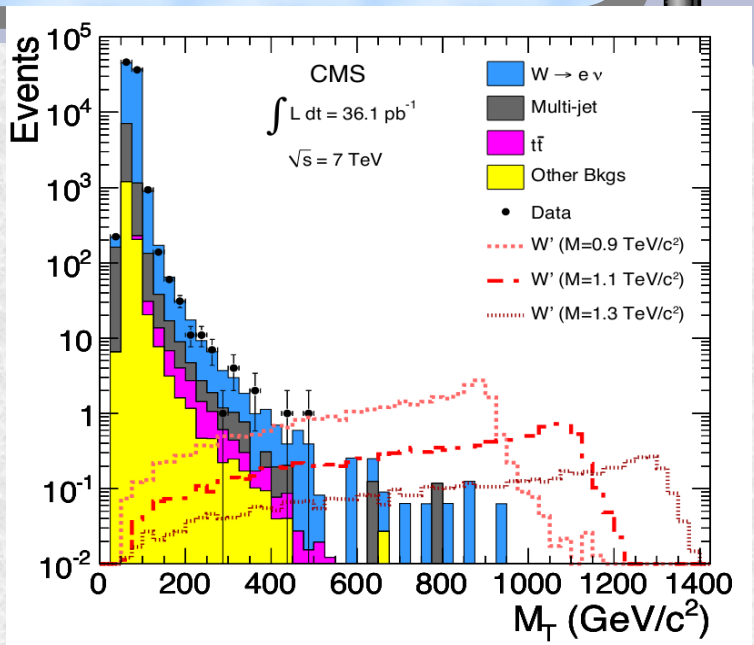


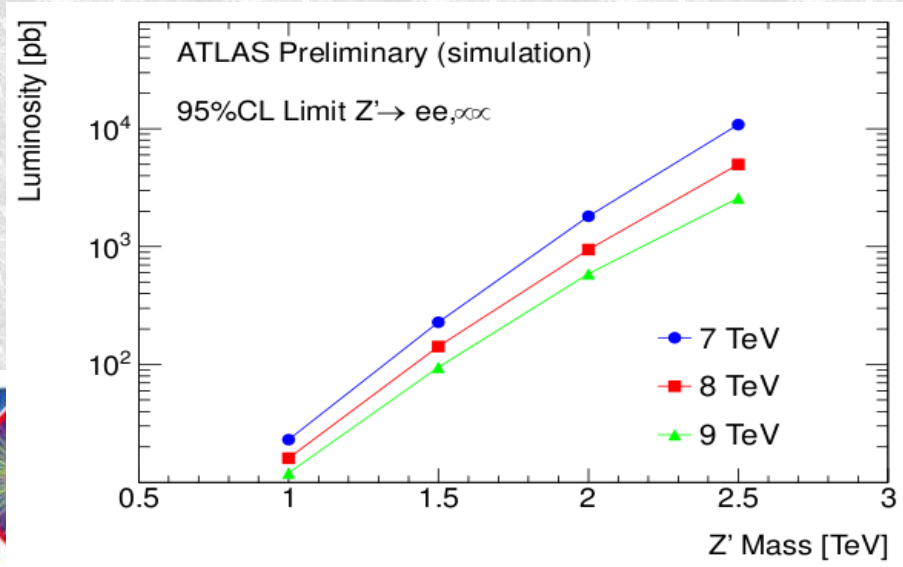
Summed E_T

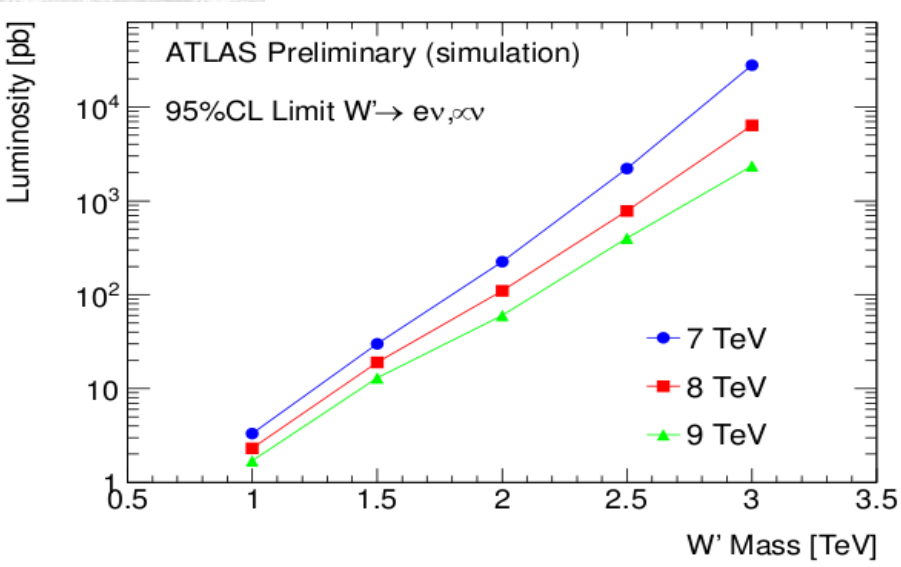
- Black holes would decay to multi-body states
- Examine the energy spectra of these
- No sign of deviation
- Exclude black holes with mass below 3.5-4.5TeV
  - Model dependent
- Future gains from E_{beam}

Heavy W'/Z'

- There may be new heavy Z,W
  - Would indicate new forces
  - We already learnt
    - $m_{W'}$>1.36TeV and $M_{Z'}$>1.14TeV
  - 2011 should probe to ~2.5TeV
  - Each 1TeV in E_{CMS} halves the data needed



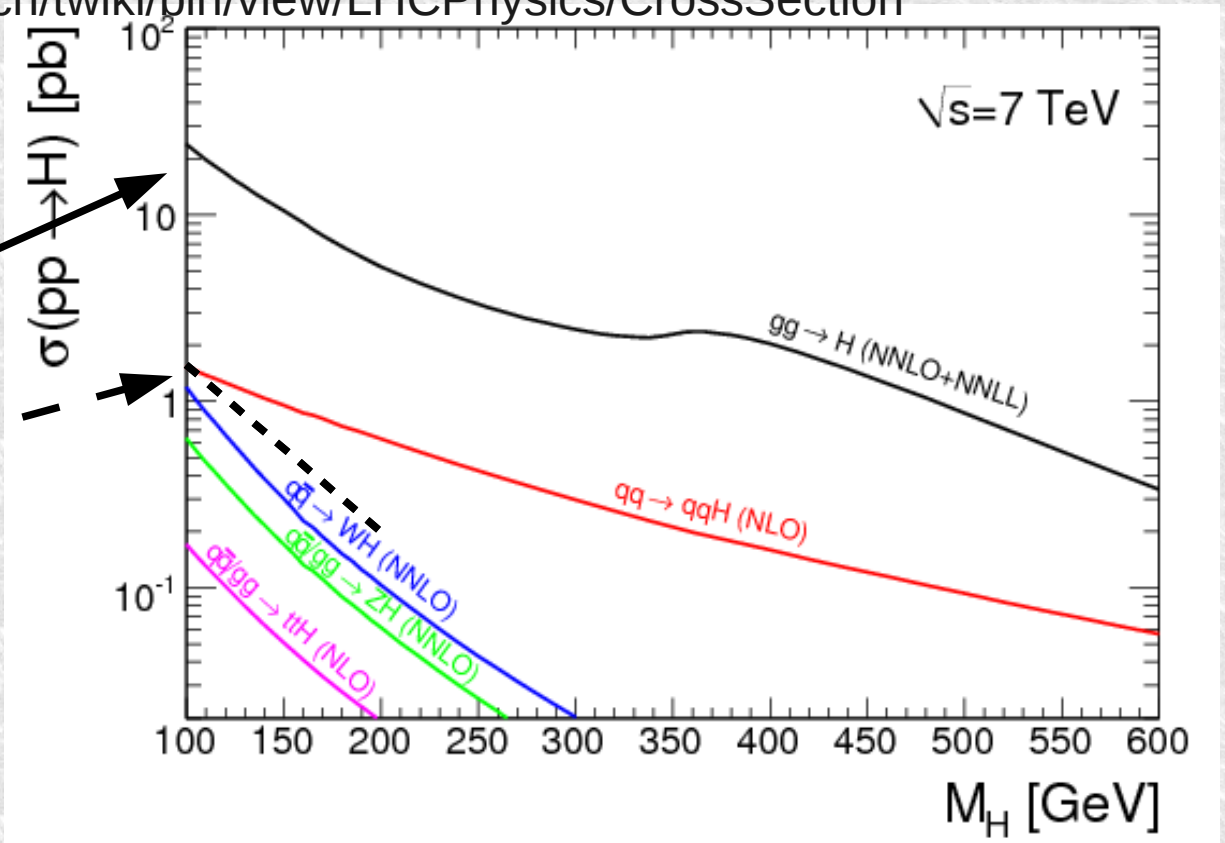




Higgs production

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

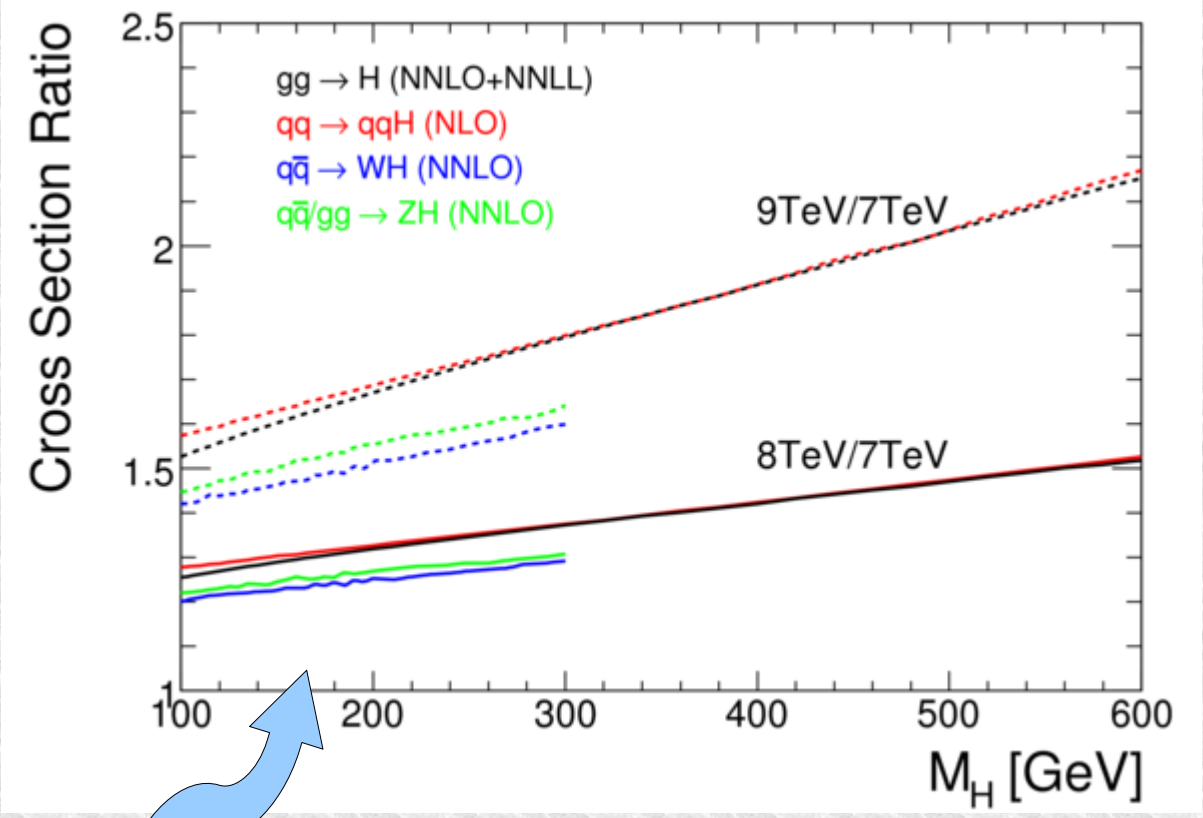
- Latest Higgs cross-sections for gluon fusion
  ----- LHC
  TeVatron
- At least a factor 10 advantage



- Backgrounds to WW, γγ are from quark-antiquark annihilation – they should collide pp in Fermilab, not $p\bar{p}$, to reduce these!

Higgs production II

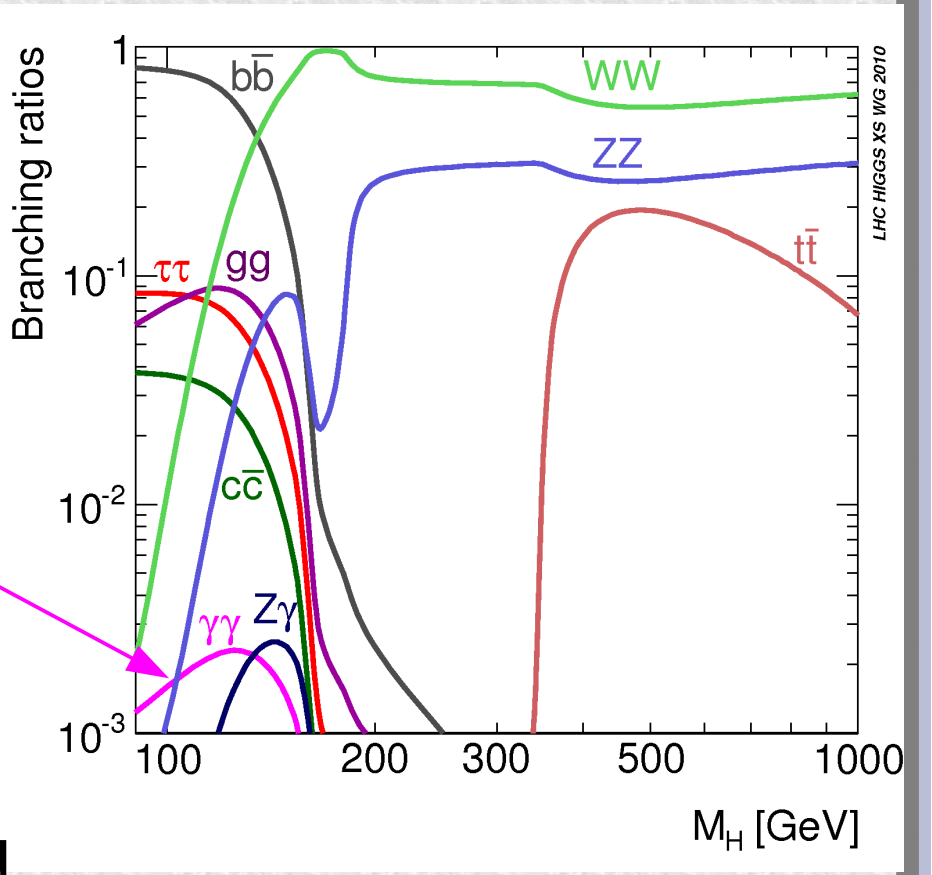
- Impact of energy depends on
  - Mass
  - Production mode
- Red/Black are most powerful
  - 30% gain for 8TeV
  - 60% for 9TeV



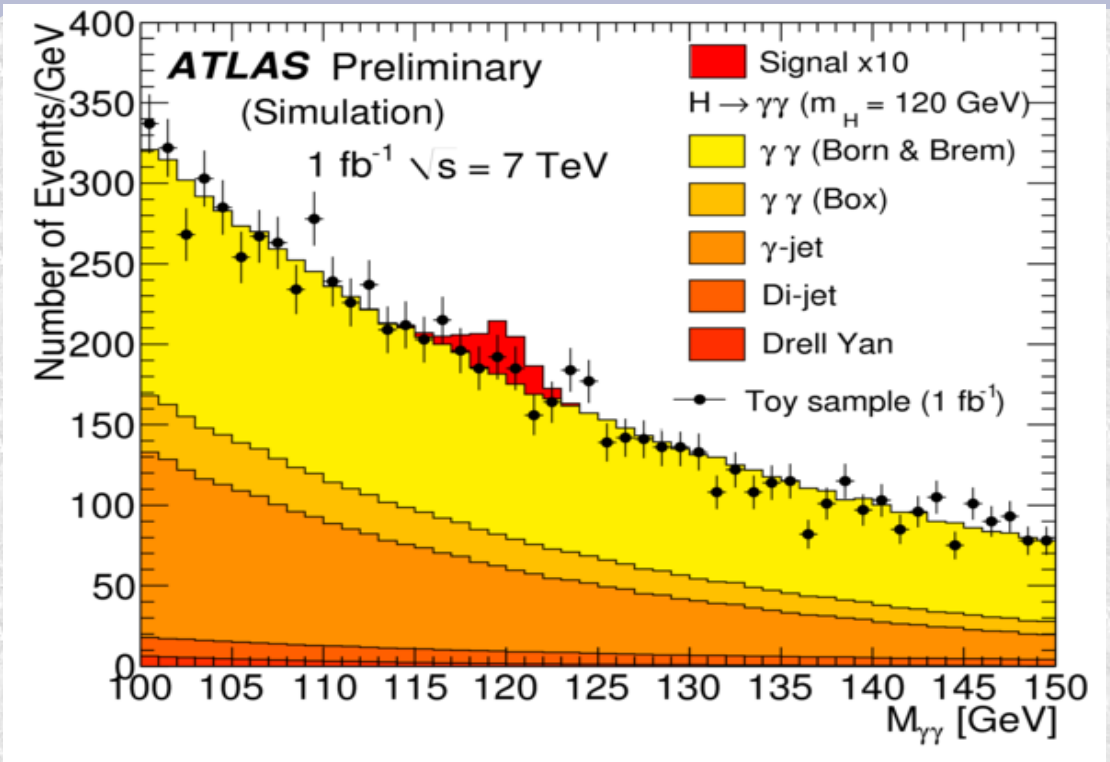
Region 114GeV to ~200GeV is the most interesting

Higgs analyses Channels

- H→ZZ
  - ZZ→llll: Golden mode
  - ZZ→llνν: Good High mass
  - ZZ→llbb: Also high-mass
- H→WW
  - WW→lνlν: Most sensitive
- H→γγ
  - Rare, best for low mass
- H→ττ
  - Good s/b, low mass,rare
- H→bb
  - $t\bar{t}$H, WH, ZH useful but hard



ATLAS H →γ γ

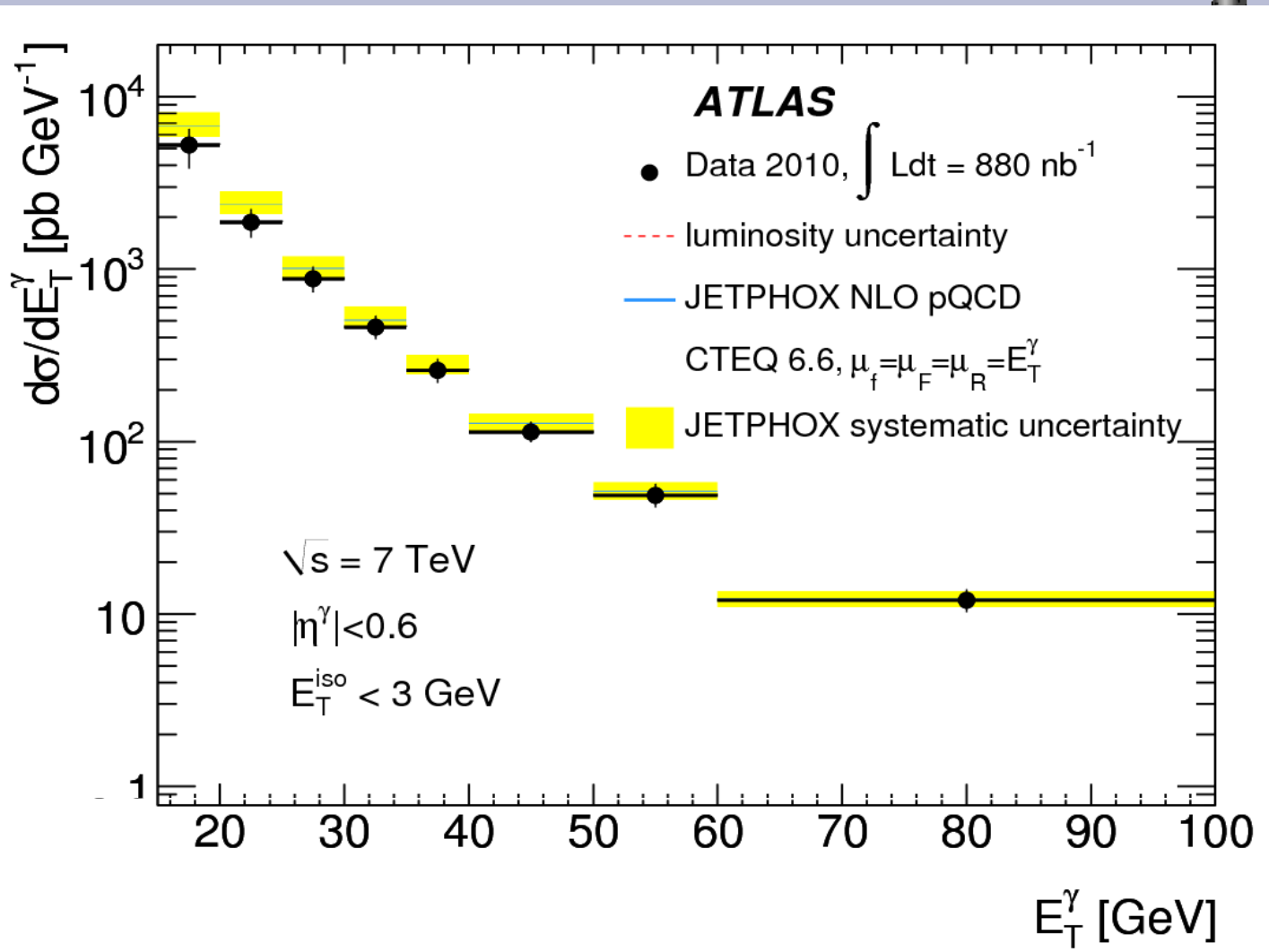


- ATLAS fit just to Mass spectrum
  - Signal shown x10
- Some uncertainty over rate

- Could do multi-dimensional analysis using:
  - p_T, njets, Higgs decay angles, resolution
  - Previous studies showed 80% more powerful
  - A 50% optimised assumption taken here

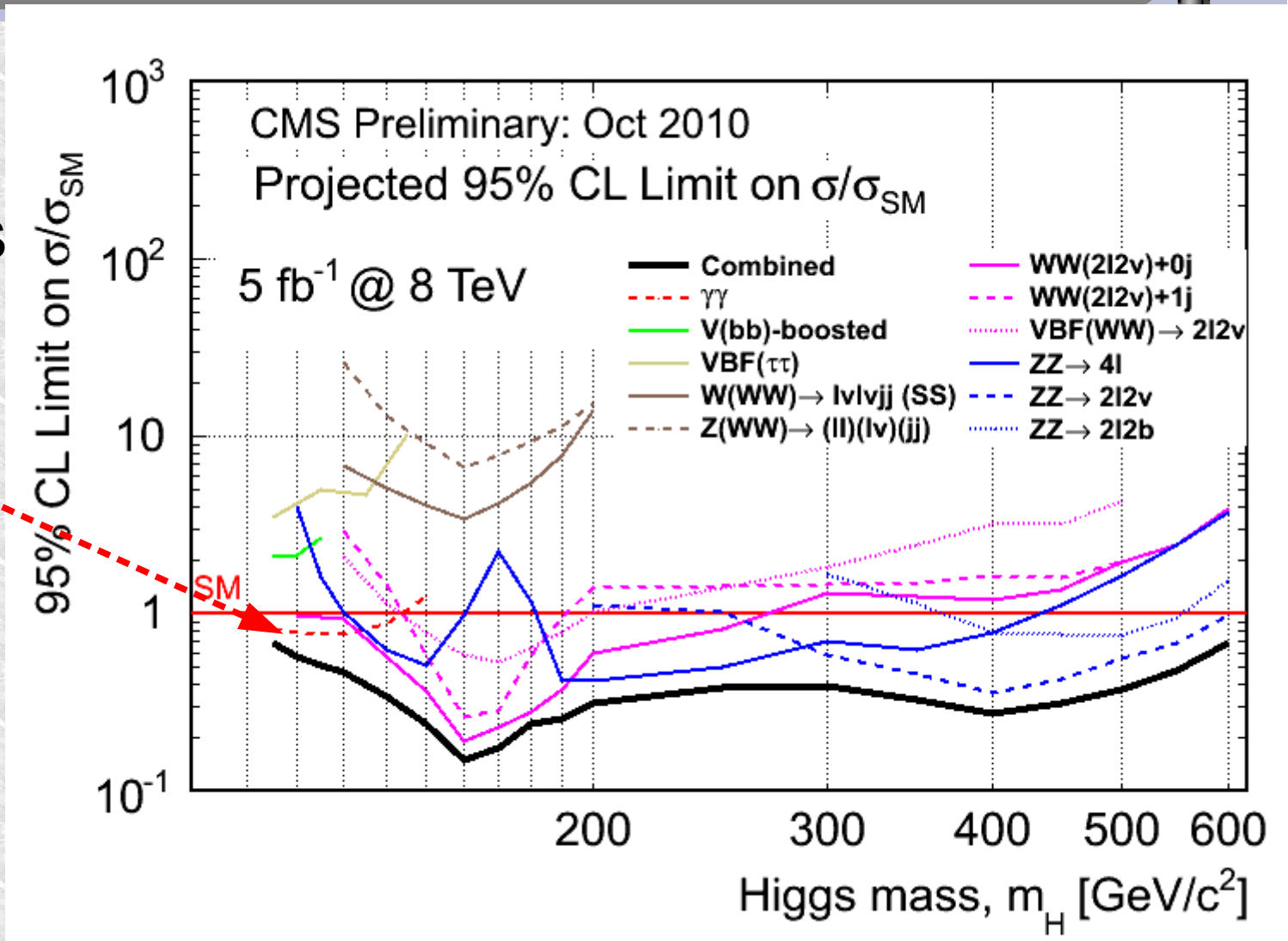
Photon yields

- Photon kinematics are described by simulation
- H→ γγ are likely to be too.

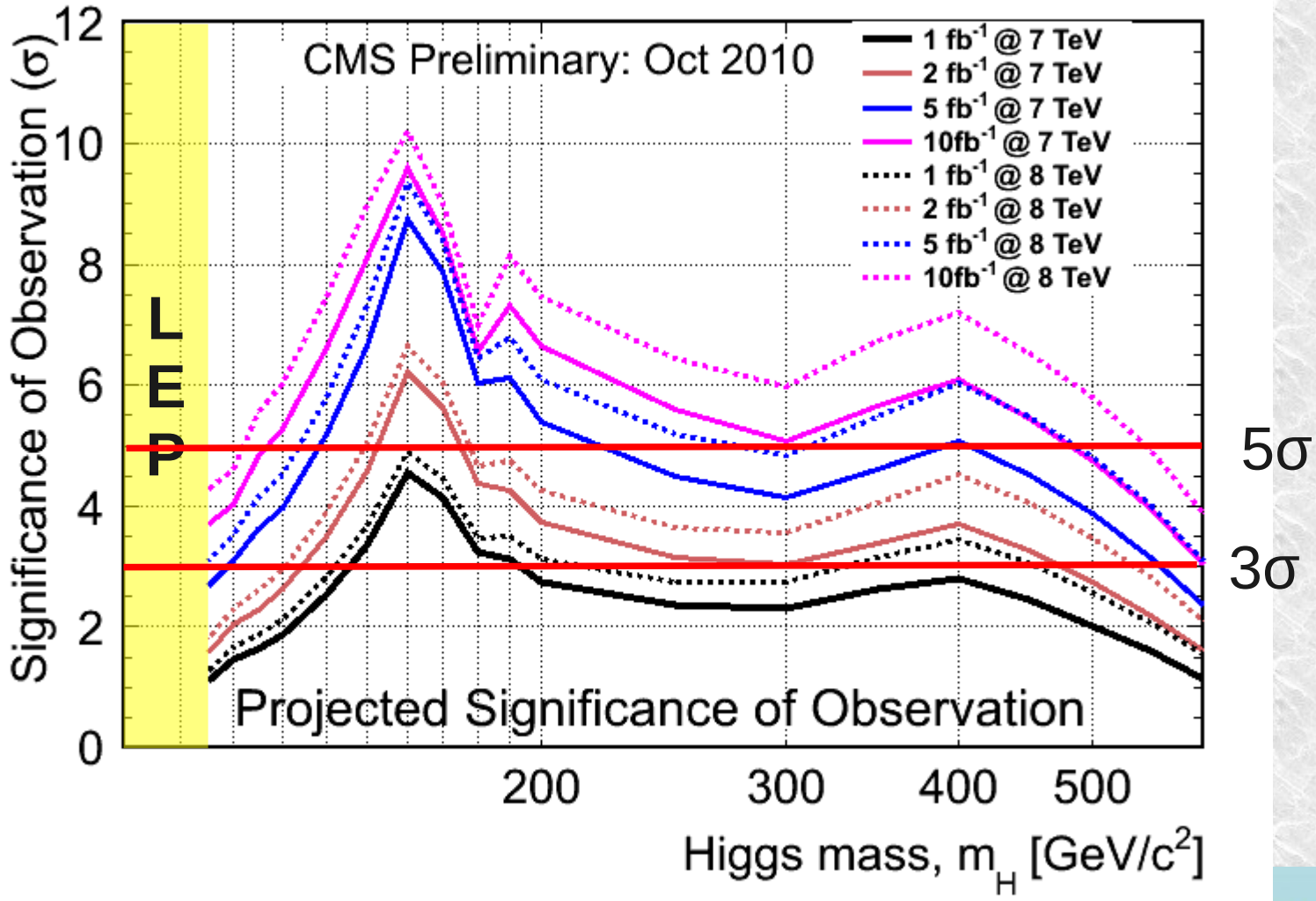


Contributions by channel

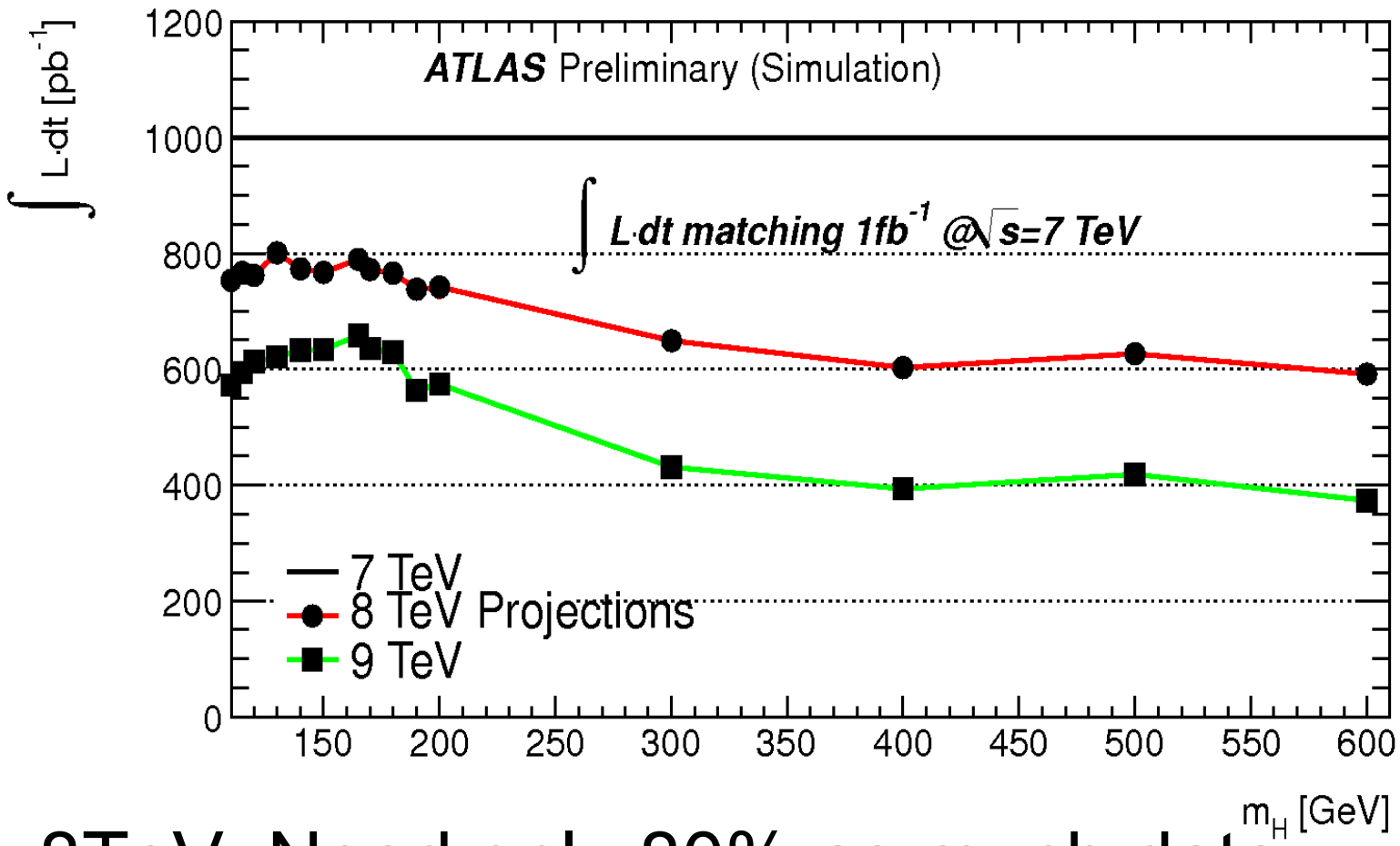
- Hardest point is lowest mass
- 5 channels at 120GeV
- H→γγ best



Sensitivity to SM Higgs

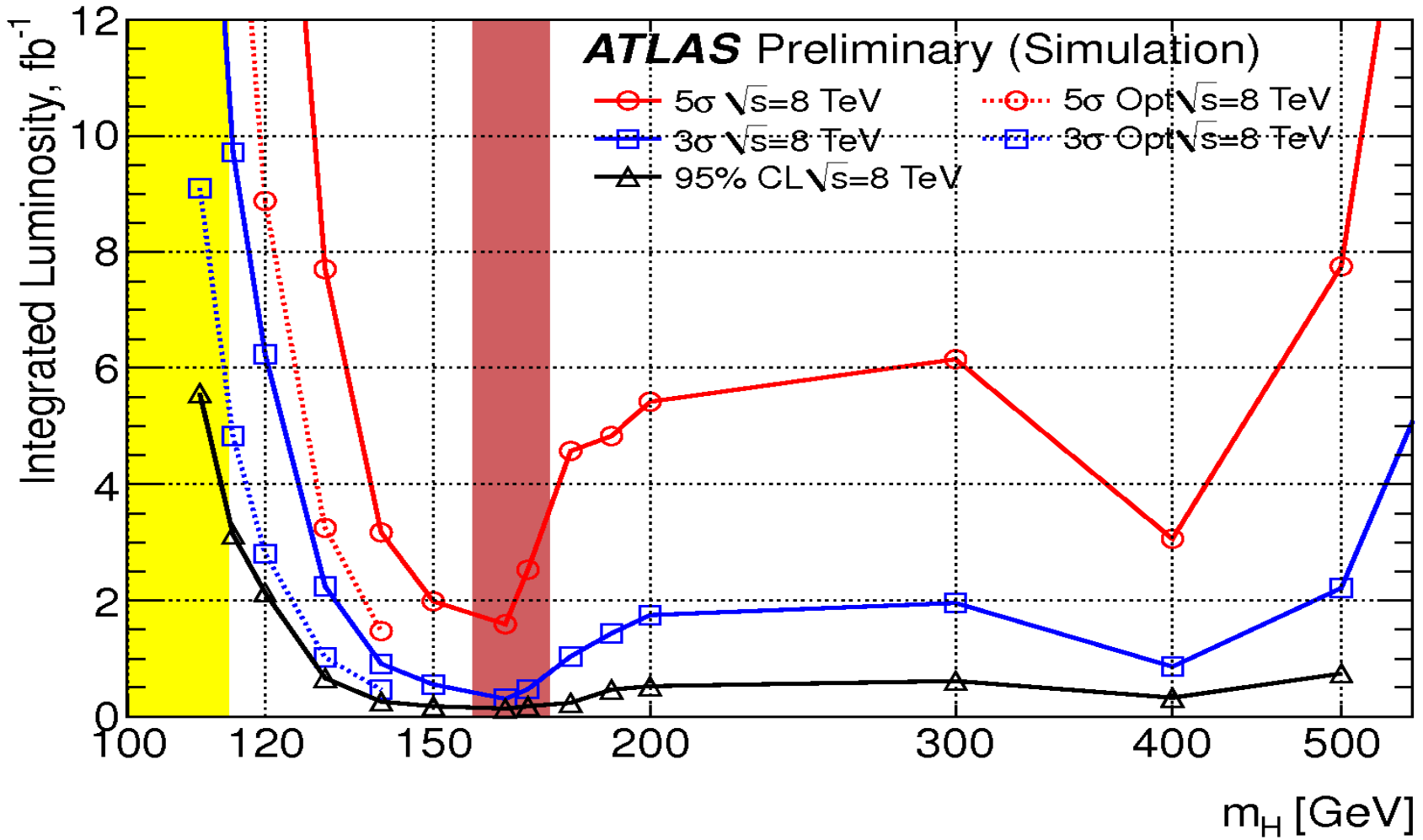


Higgs sensitivity v E_{CMS}



- 8TeV: Need only 80% as much data
  - Less for a high mass Higgs boson
- 9TeV 60% of data suffices

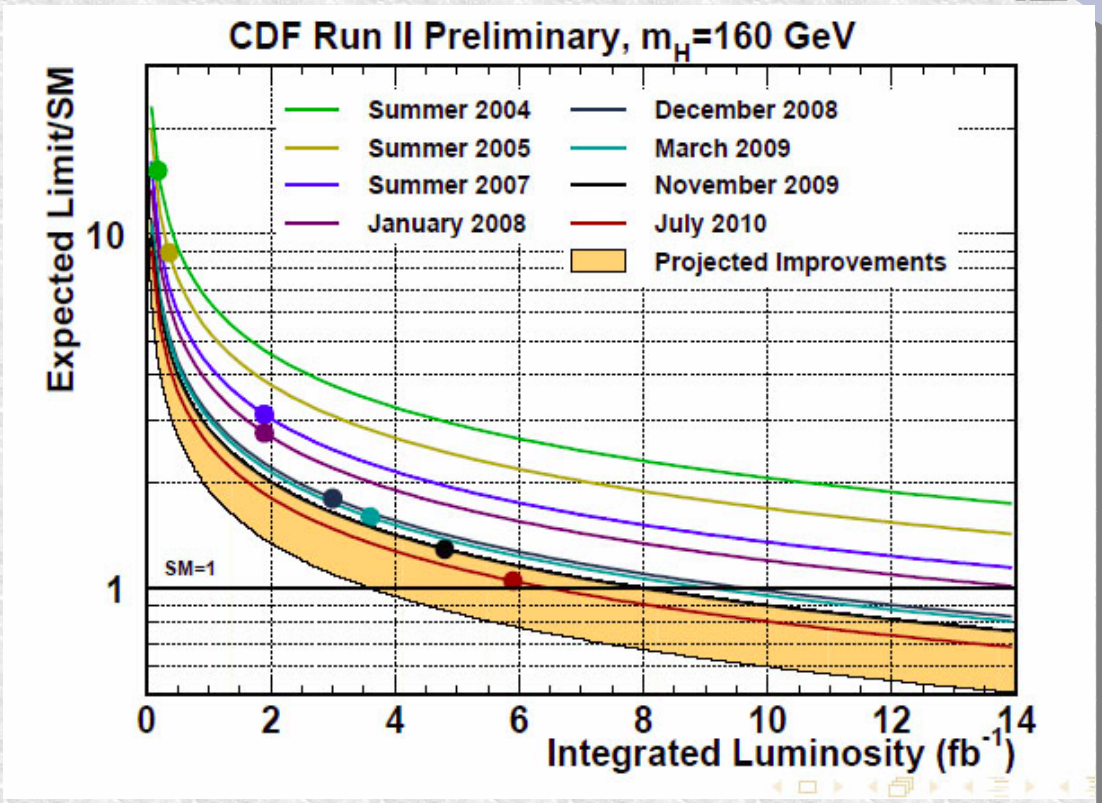
Sensitivity of Higgs search



5fb^{-1} at 8TeV gives 3σ for 114 to >500GeV

TeVatron Higgs sensitivity

- The Tevatron is still running
  - They will announce improved Higgs results in Summer and Winter
- Each new set uses better methods
  - Hard work pays off
  - We will work hard too – given some data



CDF Higgs at 160GeV

ATLAS+CMS combined Higgs Sensitivity

- Analysis can be further optimised
  - We will do our best to improve the sensitivity by improving our analyses
- But every 0.1fb^{-1} or raising E_{CMS} helps
- Estimated sensitivity region, assuming 8TeV:

	2fb^{-1}	5fb^{-1}	10fb^{-1}
95% CL	Any	Any	Any
3σ	118-500+GeV	Any	Any
5σ	130-200GeV	120-500GeV	Any

- Nb: LEP limit m_H>114;
- Tevatron excluded <110 and 158-175GeV;
  - Aim for 2.4σ in 100GeV-185GeV by end of 2011

Reminder of Gain from E_{beam}

- Compare E_{beam}=4TeV with 3.5TeV

	Gain at E_{beam}=4TeV
SUSY	Need 60% as much data
W', Z'	Half data needed
Black holes	Factor 5 or more in production rate
top	40% more top quarks
Higgs	Needs 80% as much data

Summary

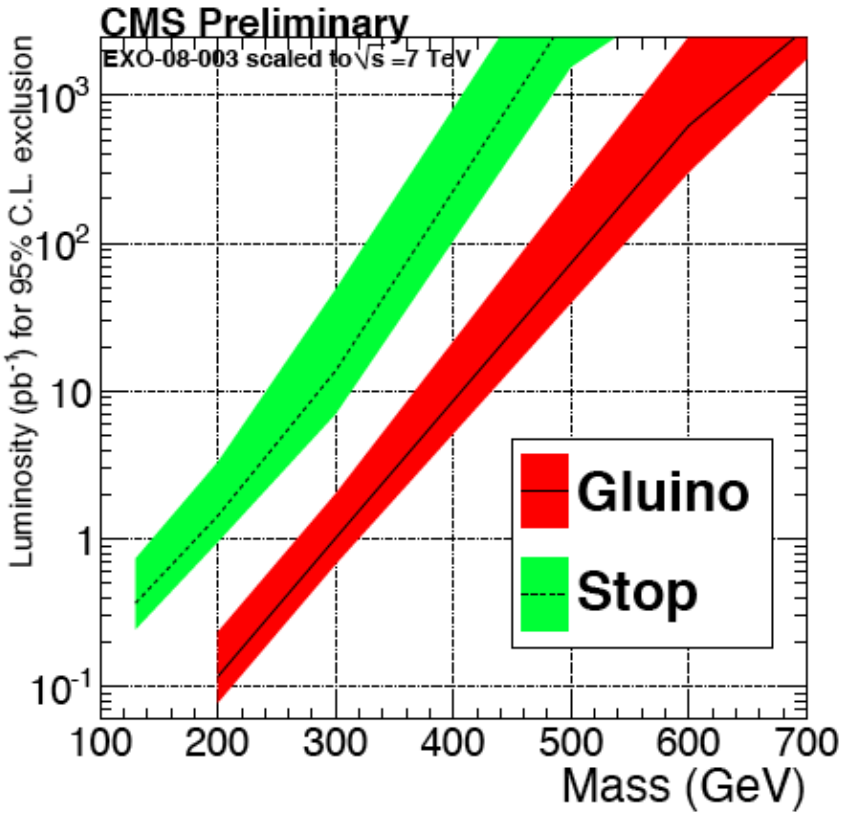
- LHC Physics analyses producing results beyond the most optimistic expectations
  - Thanks to all the LHC people who made it possible
- In 2011 we are envisaging two orders of magnitude more data than last year
- 5fb^{-1} at 8TeV should give ATLAS/CMS
  - at least 3σ Higgs evidence PER EXPERIMENT
    - 30% more for every TeV in E_{CMS}
  - At 7TeV we need ~6fb^{-1} for 3σ
  - Possible SUSY discovery up to 1.2TeV
  - More in combination
- Huge potential in so many other places

Summary 2012

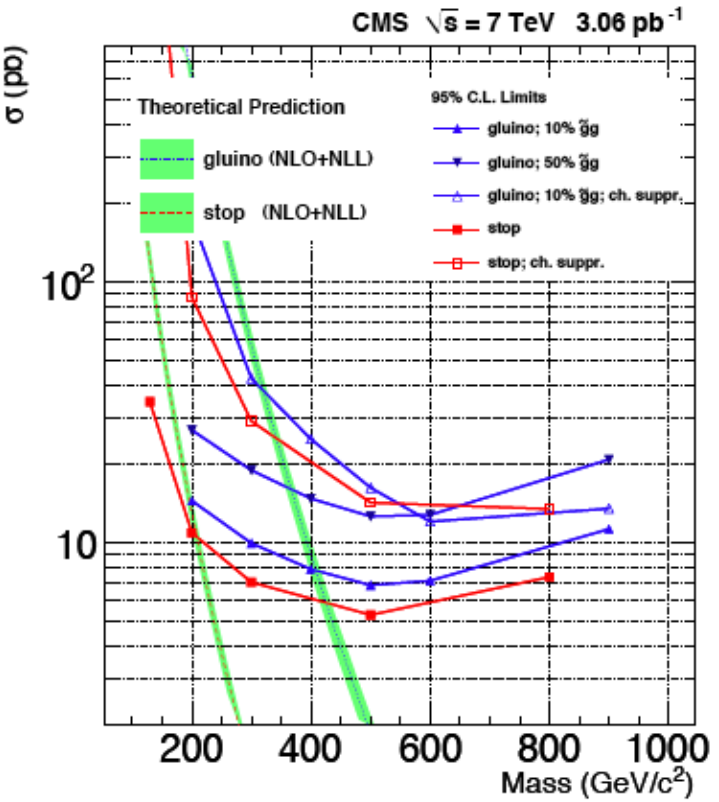
- Running in 2012…
  - Assumed order of $10fb^{-1}$
- LHC combination will offer over 5σ sensitivity to all SM Higgs
  - Two years before going to 14TeV would
- The luminosity from a 2 year run will
  - Allow exploration of TeV scale ASAP
  - Provide huge scope for analysis in the long year(s) of the shutdown for energy upgrade
- In next year or two, together, we will change the physics landscape

Backup

Exclusion

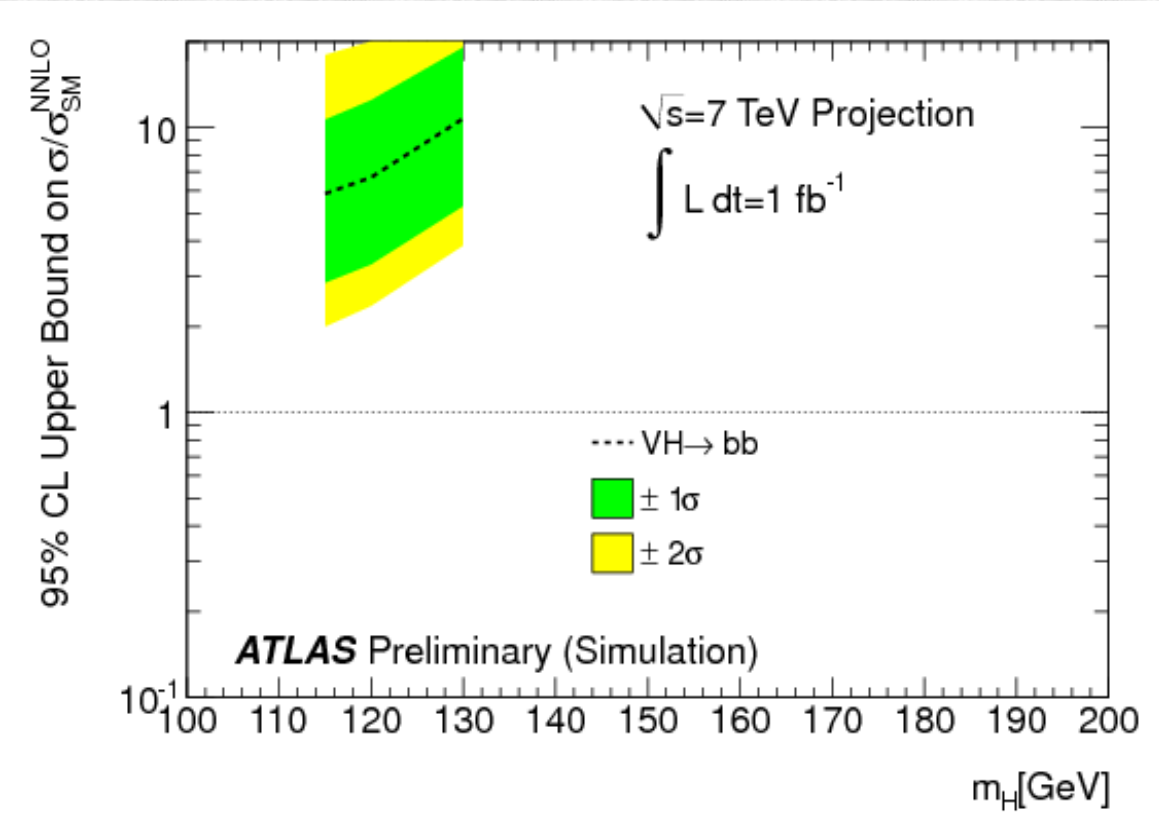


Exclusion



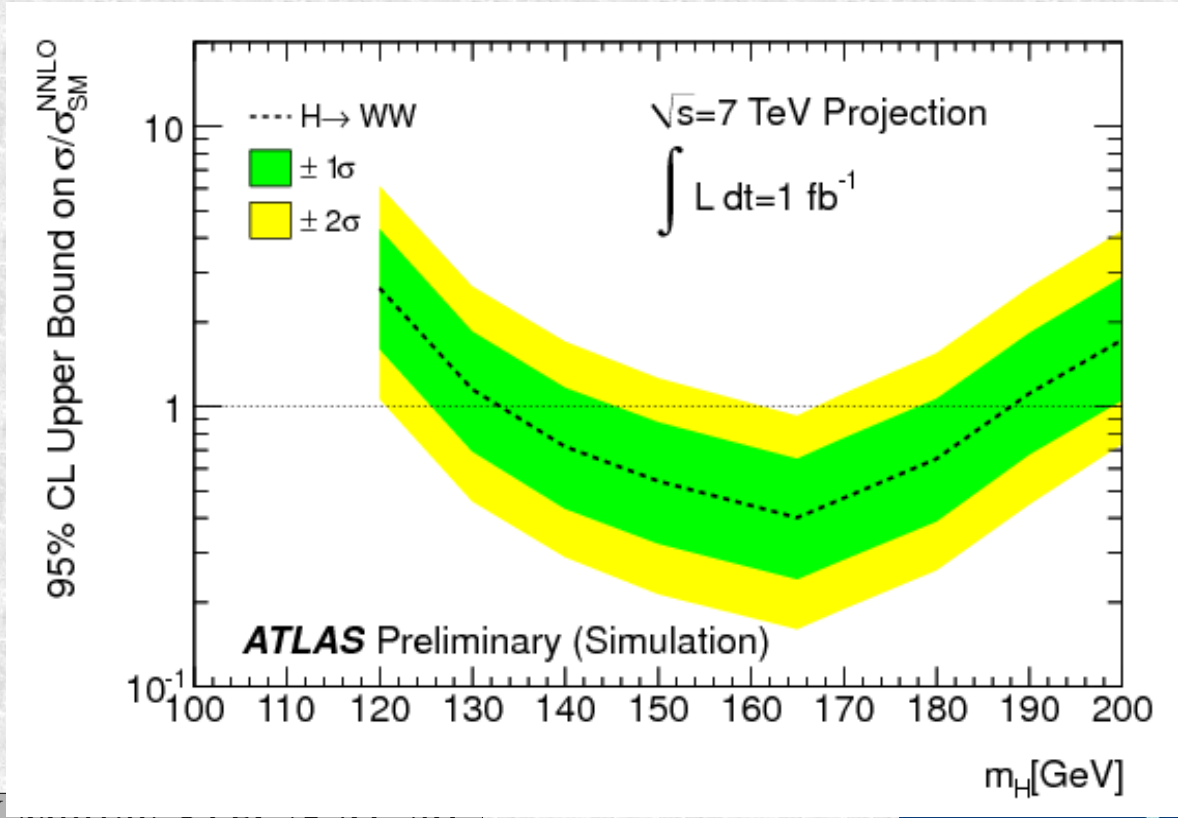
H→bb

- VH analysis from 14TeV note (W,Z→ll,Z→νν)
  - ATL-PHYS-PUB-2009-088
  - Boosted Higgs > 200GeV p_T
  - Extended mass scan done for ZH
  - Kinematic cut efficiency allowed for in scaling



H → WW

- lvlv from PUB ATL-PHYS-PUB-2010-009
- NNLO cross-section improve performance
- This is a rather safe analysis (no NN..)
  - Counting expt.
  - In bins of n jets
  - Backgrounds under study
    - CONF-2010-092

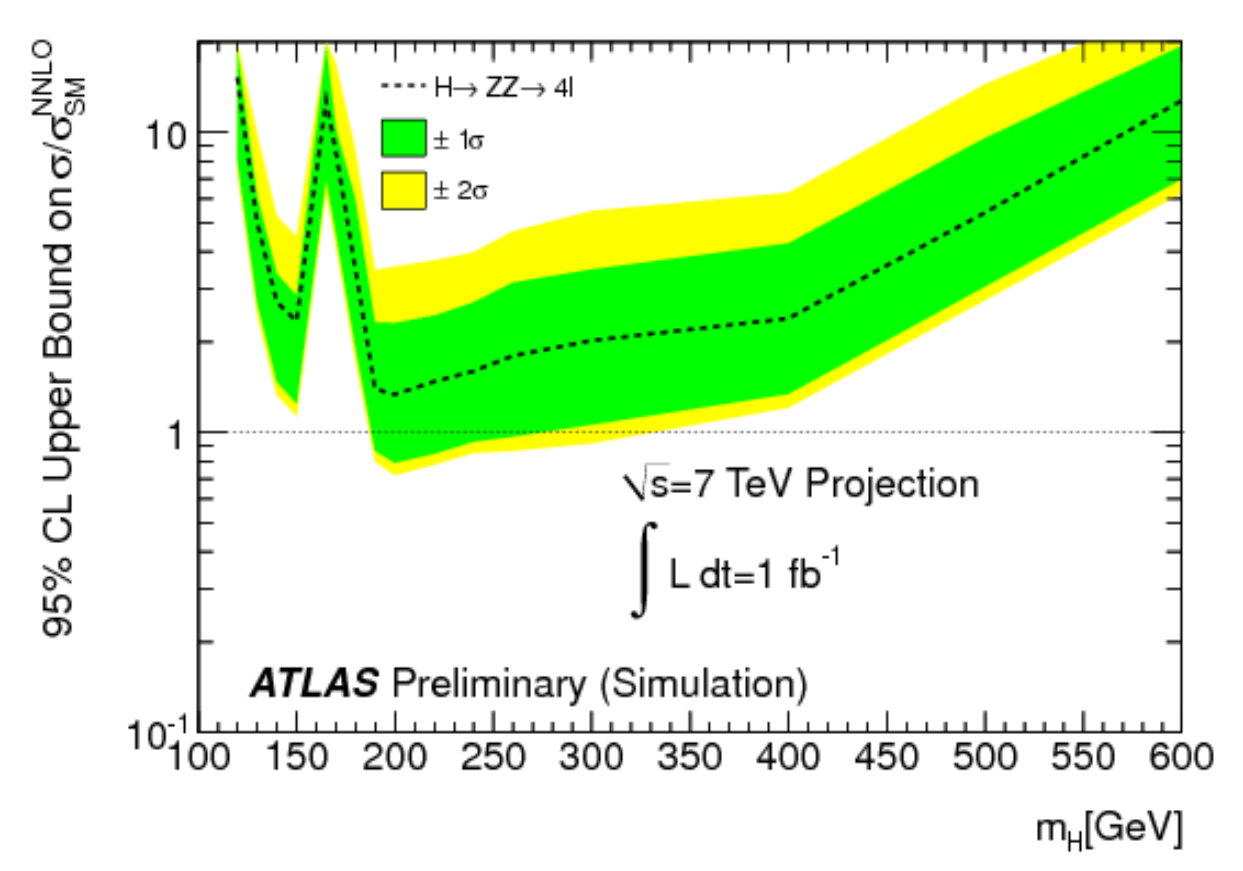


2010: Example from ATLAS

- A great year for measurement papers
  - Charged particles multiplicities at 900GeV
  - Inclusive jet and dijet cross-sections
  - W→lν and Z→ll cross-sections
  - Underlying event characteristics
  - The top quark pair-production cross-section
  - The inclusive prompt photons cross-section
  - Charged particle multiplicities at 7TeV
  - Production cross-section for W bosons with jets
  - Centrality dependence of J/ψ yields in lead-lead
  - Jet shapes in inclusive jet production
- No so good for discovery papers
  - Search for new particles in 2-jet final states (Q*)
  - Search for quark contact interactions
  - *Observation* of a centrality dependent dijet asymmetry in lead-lead collisions
  - Search for dijet events with large missing transverse energy

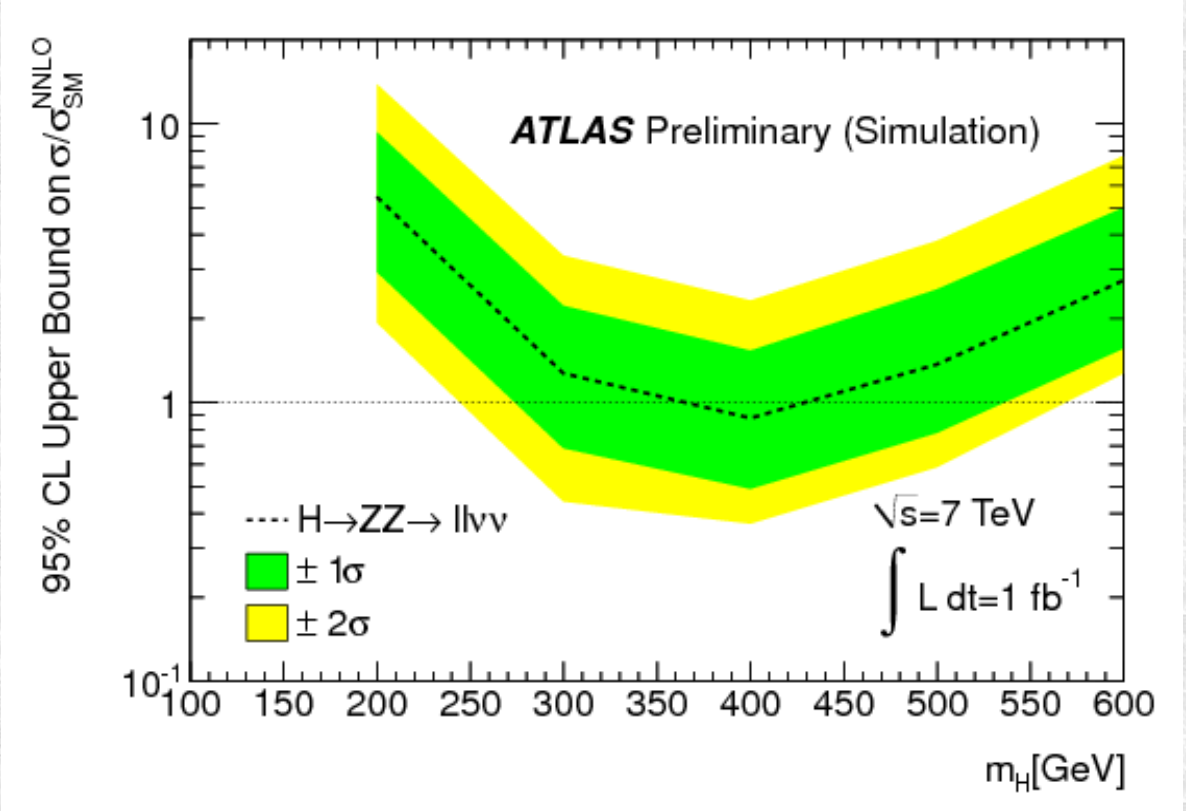
H to ZZ→llll

- ZZ→llll
  - Count single bin
  - 1fb at 7TeV Gives limit 1.2xSM at m_H=200GeV
- Very clean
  - ~ZZ only bkd above 200GeV
  - Also Zbb below
- No real candidates in 2010
- See: ATL-PHYS-PUB-2010-009

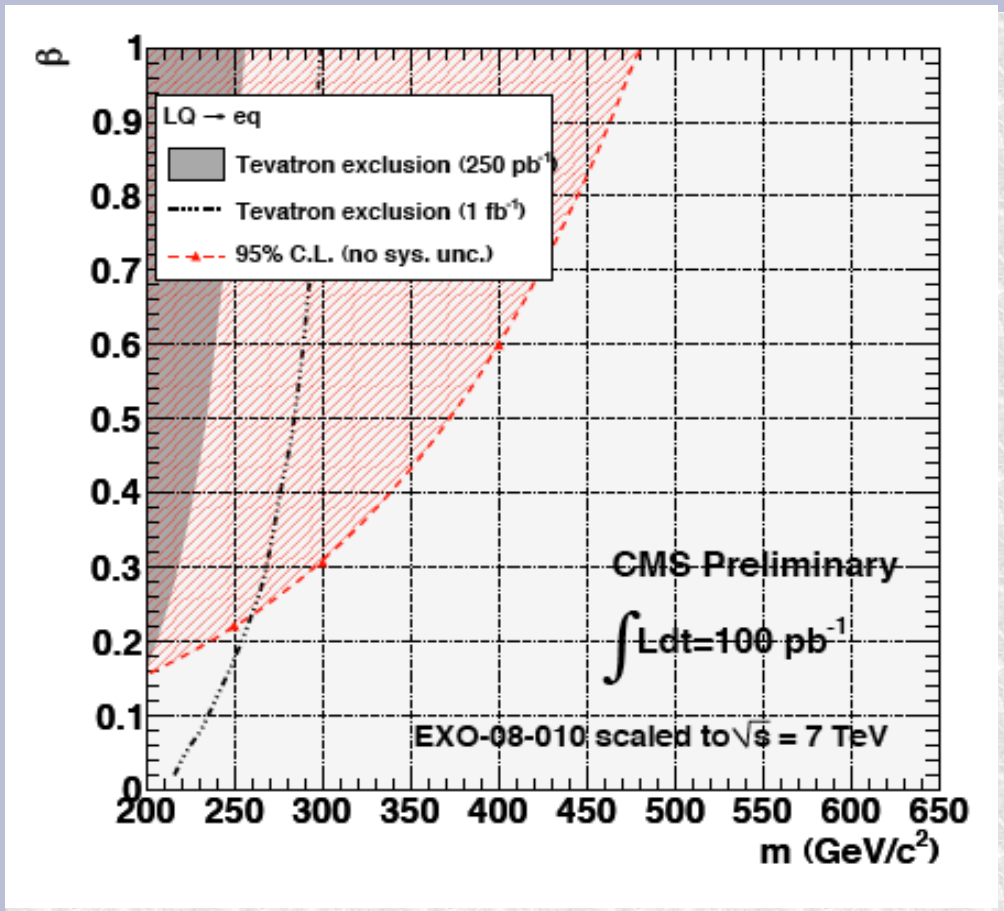


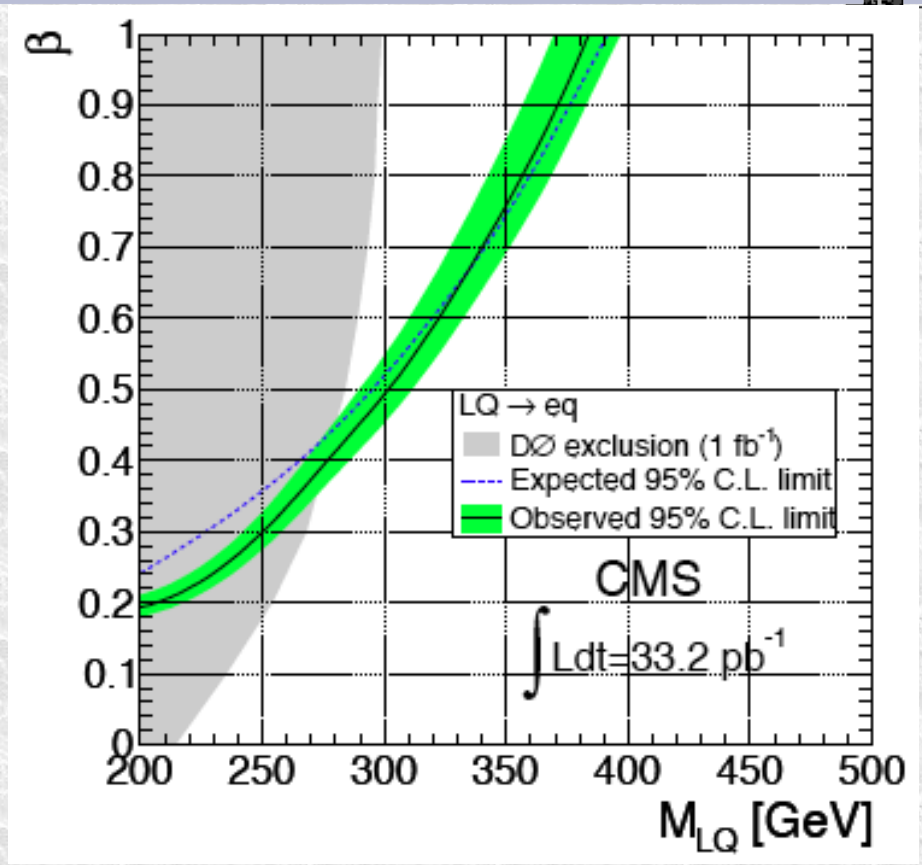
H to ZZ→llνν

- ZZ→llνν
  - Full 7TeV analysis
  - Clean trigger
  - Z to ll is pure
  - Z to νν requires Z has some p_T
- Contributes most at high mass (~400GeV)
- ATL-PHYS-INT-2010-117



Lepto-quarks





- LHC has best limits above 250GeV
- Roughly as predicted beforehand

Current Constraints on CMSSM

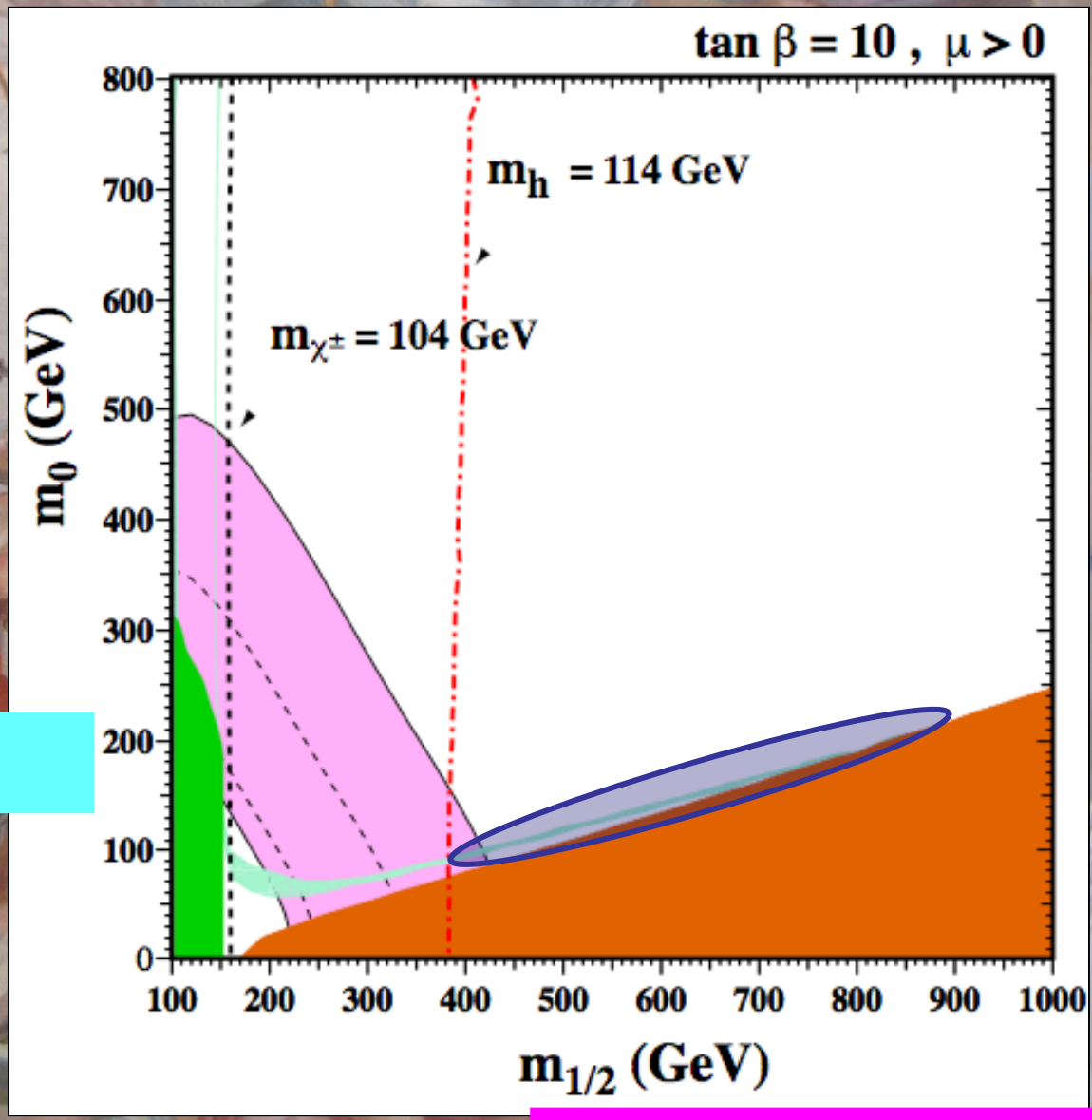
Assuming the lightest sparticle is a neutralino

Excluded because stau LSP

Excluded by b → s gamma

WMAP constraint on relic density

Preferred (?) by latest g - 2



JE + Olive + Santoso + Spanos