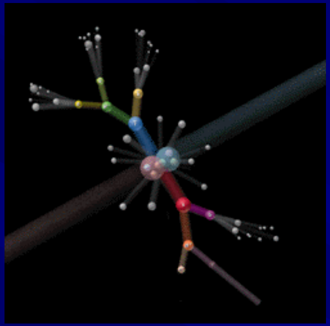
Search for the MSSM Higgs boson decay $A \to \mu^+\mu^-$ with ATLAS



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Outline

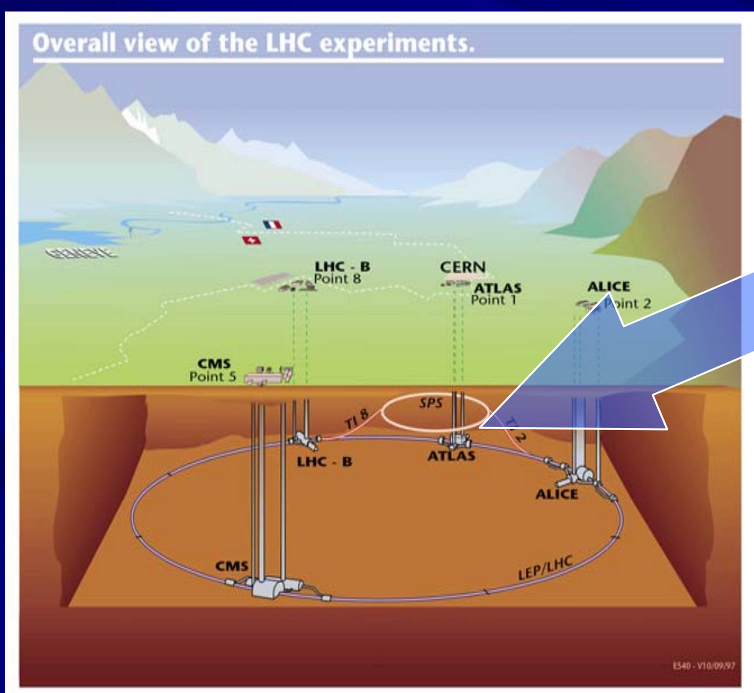
- LHC - ATLAS detector
- Higgs physics in ATLAS
- SUSY - MSSM Higgs
- A->$\mu^+ \mu^-$ decay channel
- ATLFAST vs FullSim
- Detector performance (μ – bjets)
- Analysis Results
- Summary

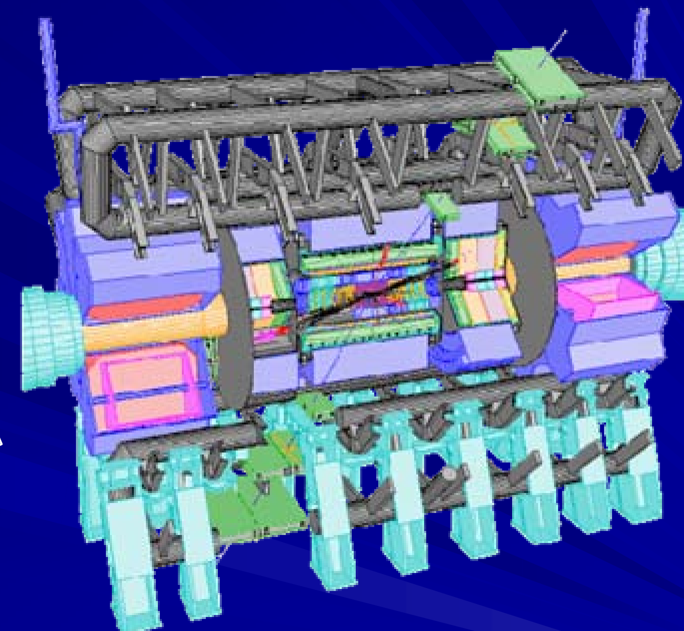
LHC

- LHC , p-p collider with $\sqrt{s}$ = 14 TeV
- 2 luminosity phases

  low luminosity : 20 fb^{-1} per year

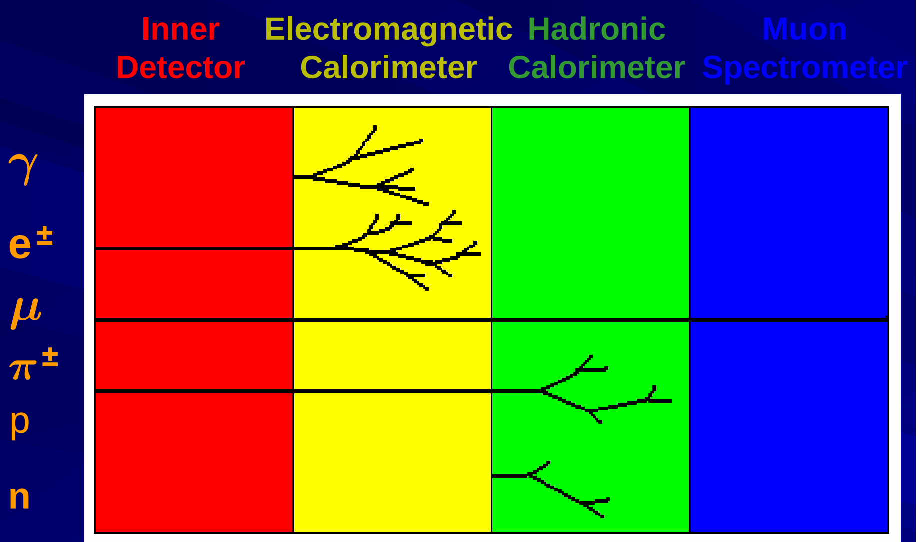
  high luminosity : 100 fb^{-1} per year
- 4 LHC experiments (ATLAS,CMS,ALICE,LHC-B)

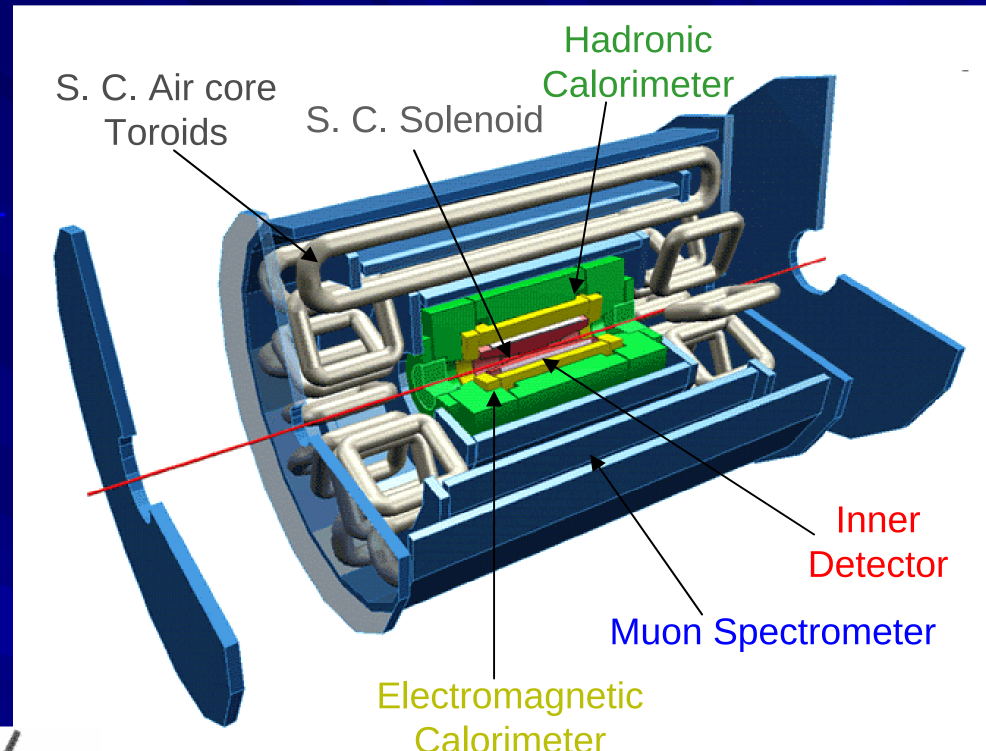


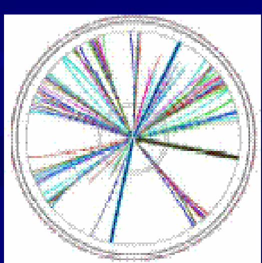


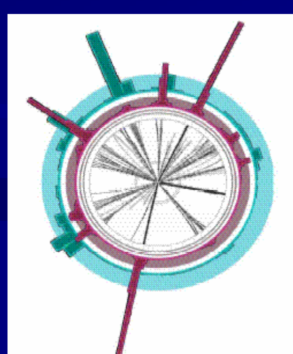
The ATLAS detector

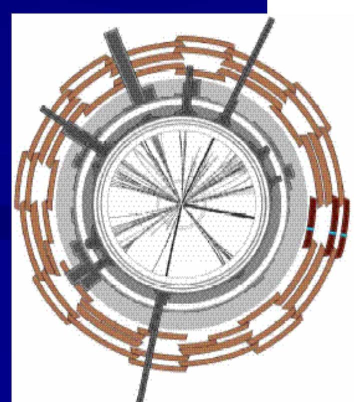
- A Toroidal LHC ApparatuS







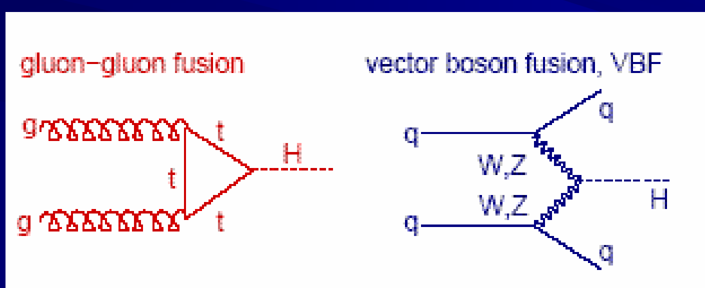


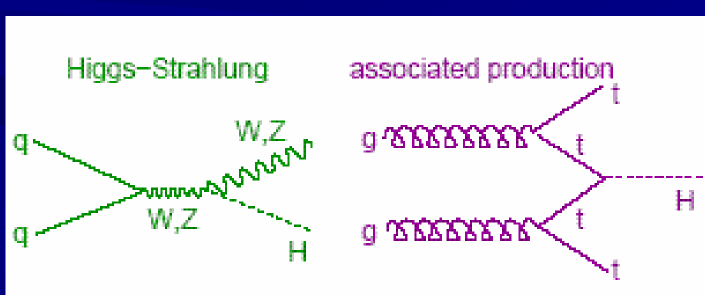


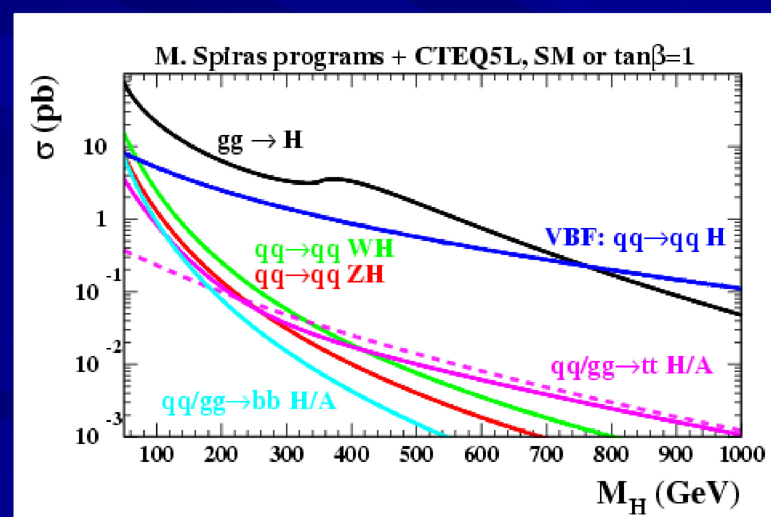
Diameter	25 m
Barrel toroid length	26 m
End-cap end-wall chamber span	46 m
Overall weight	7000 Tons

Higgs physics in ATLAS

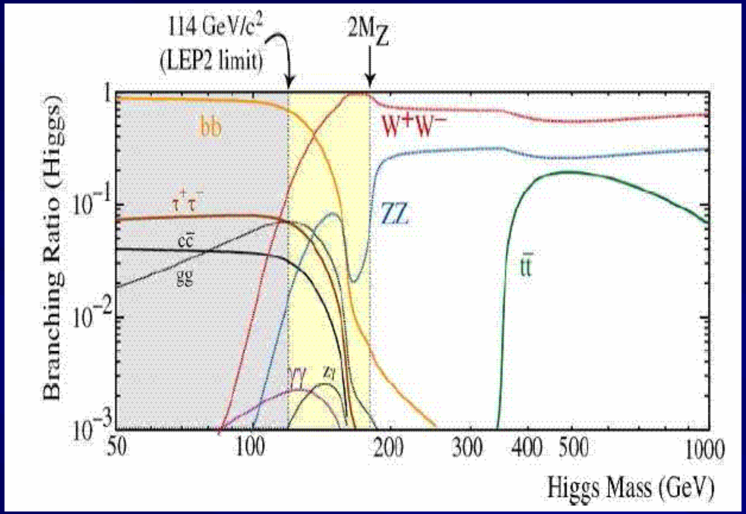
- Standard Model is a well established theory of particles and their interactions ➡ numerous predictions such as c, b, t quarks , ν_τ , gluon , W , Z bosons
- $W^{\pm}$, Z need to acquire masses through the electroweak symmetry breaking mechanism ➡ existence of Higgs Particle predicted
- Still one parameter missing: The Higgs mass

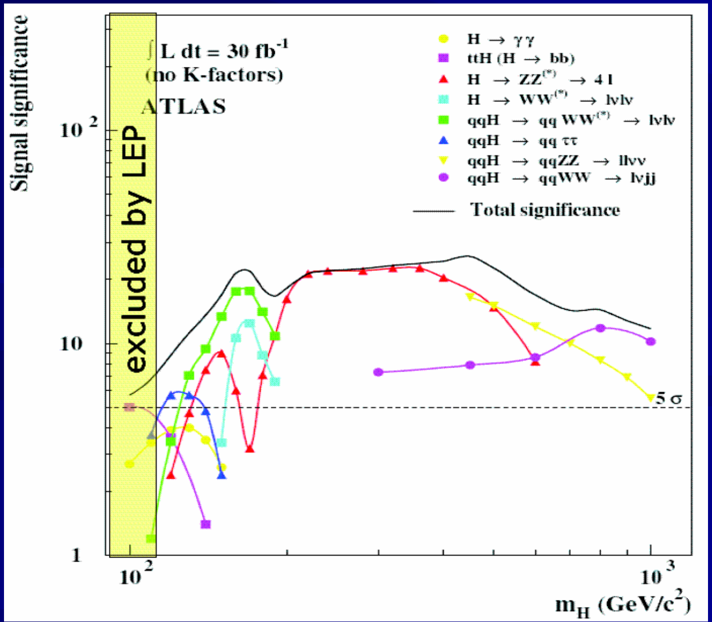






Higgs physics in ATLAS



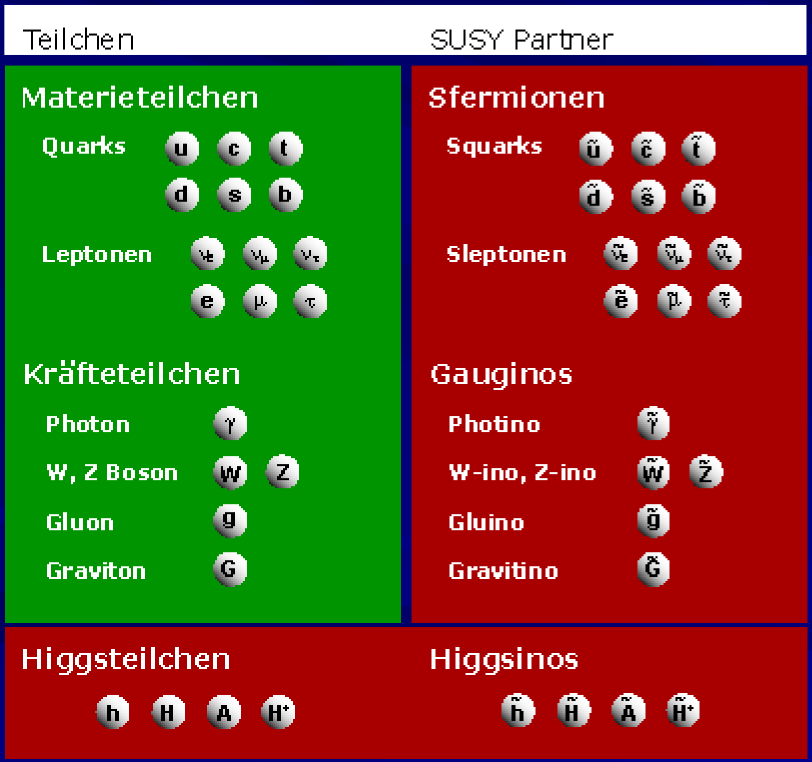


- Searches performed already in LEP and the region m_H < 114 GeV (95% CL) is excluded
  e^+e^- -> ZH -> (qq)(bb)

- Discovery channels in ATLAS
  H -> $\gamma\gamma$
  H -> ZZ -> 4l
  H -> ZZ -> ll$\nu\nu$
  H -> WW -> ll$\nu\nu$
  H -> WW -> llqq
  H -> bb
  H -> $\tau\tau$

SUSY and MSSM

- A possible extension of the SM could be SUSY
- Predicts supersymmetric partners with spin difference ½ for every SM particle



- In MSSM , SUSY breaking described by 105 parameters
- In MSSM Higgs sector:

  2 Higgs doublets
- After electroweak symmetry breaking

  5 Higgs particles => h , H , A , $H^{\pm}$

  2 free parameters => m_A , tanβ

m_A : mass of A boson

tanβ : ratio of the vacuum expectation values of the 2 Higgs doublets

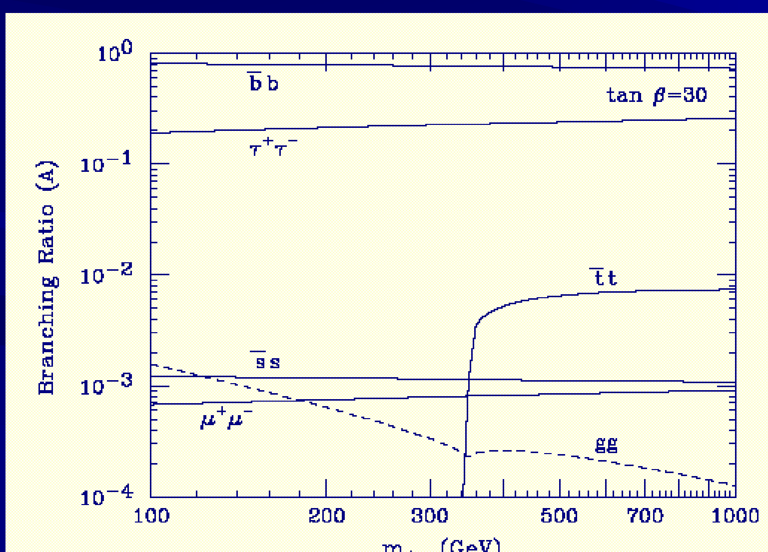
MSSM Higgs production cross sections

$$
\begin{aligned}
\text{GGF}: \quad & \sigma_{MSSM} && = \frac{\Gamma(h(H,A) \to gg)_{MSSM}}{\Gamma(H_{SM} \to gg)_{SM}} \times \sigma_{SM} \\
\text{VBF}: \quad & \sigma_{MSSM}(h) && = \sin^2(\alpha - \beta) \times \sigma_{SM} \\
& \sigma_{MSSM}(H) && = \cos^2(\alpha - \beta) \times \sigma_{SM} \\
\text{W(Z)}\Phi: \quad & \sigma_{MSSM}(h) && = \sin^2(\alpha - \beta) \times \sigma_{SM} \\
& \sigma_{MSSM}(H) && = \cos^2(\alpha - \beta) \times \sigma_{SM} \\
\text{bb}\Phi: \quad & \sigma_{MSSM}(h) && = \sin^2(\alpha)/\cos^2(\beta) \times \sigma_{SM} \\
& \sigma_{MSSM}(H) && = \cos^2(\alpha)/\cos^2(\beta) \times \sigma_{SM} \\
& \sigma_{MSSM}(A) && = \tan^2(\beta) \times \sigma_{SM} \\
\text{tt}\Phi: \quad & \sigma_{MSSM}(h) && = \sin^2(\alpha)/\sin^2(\beta) \times \sigma_{SM} \\
& \sigma_{MSSM}(H) && = \cos^2(\alpha)/\sin^2(\beta) \times \sigma_{SM} \\
& \sigma_{MSSM}(A) && = \cot^2(\beta) \times \sigma_{SM} \\
\text{gb} \to \text{H}^{\pm}\text{t}: \quad & \sigma_{MSSM} && = [(M_b \tan\beta)^2 + (M_t \cot\beta)^2] \times \sigma_{SM}
\end{aligned}
$$

- MSSM cross section are given by SM production cross sections times MSSM correction factors

α : mixing angle between CP-even neutral H bosons

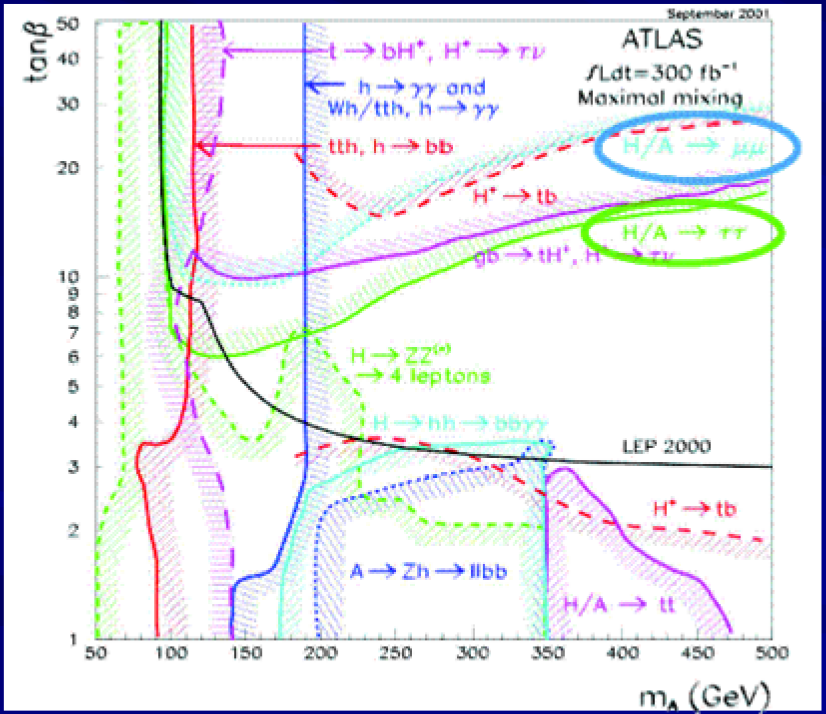
$\tan\beta$: ratio of the vacuum expectation values of the 2 Higgs doublets



- Dominant decay channel is bbar
- Leptonic decays to $\tau\tau$ and $\mu\mu$
- Rates for $\mu\mu$ governed by the same couplings as for $\tau\tau$ but BR scales as $(m_\mu/m_\tau)^2$

MSSM Higgs searches

- If SUSY particles masses are large, MSSM H decays only to SM particles
- Higgs searches can therefore be performed in different decay channels (usually with SM particles in the final state)



- LEP(OPAL) limits :
  m_h>84.5 GeV and m_A>85 GeV (95% CL)
- The complete region of parameter space (m_A=50 – 500 GeV , tanβ = 1-50) accessible in ATLAS , but
- Difficult regions: intermediate tanβ and masses (m_A) where only h would be observable

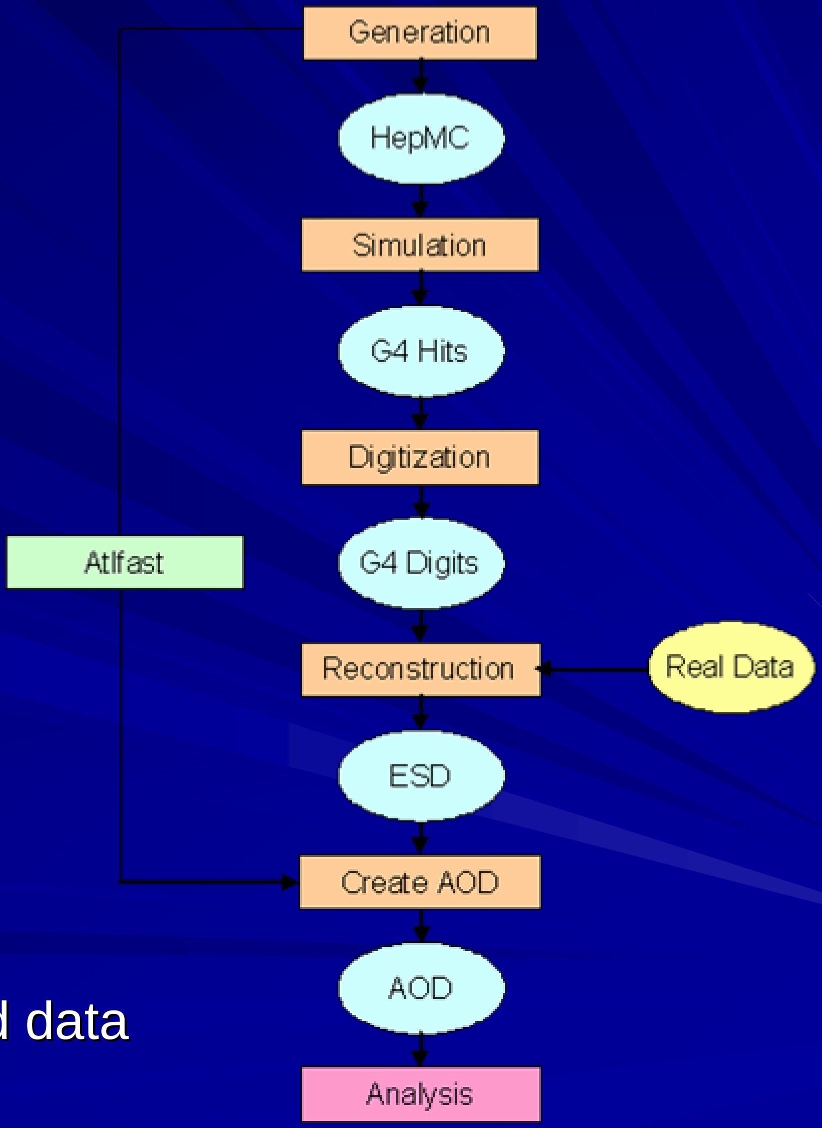
- Our interest is exploring the discovery potential of: H/A -> μμ , H/A -> ττ

Simulation Software

- PYTHIA generator program used
- 2 possible ways to simulate data :

  ATLFAST: A fast simulation program with parametrised detector response
  (Less accurate – Less CPU time consuming)

  Full Simulation: A detailed description of the detector response by following every particle in each measurement unit of the detector
  (More accurate – More CPU time consuming)



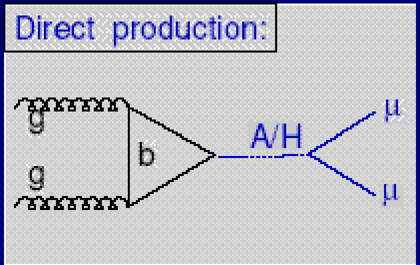
- Study with ATLFAST already done
  Now finishing analysis with fully simulated data

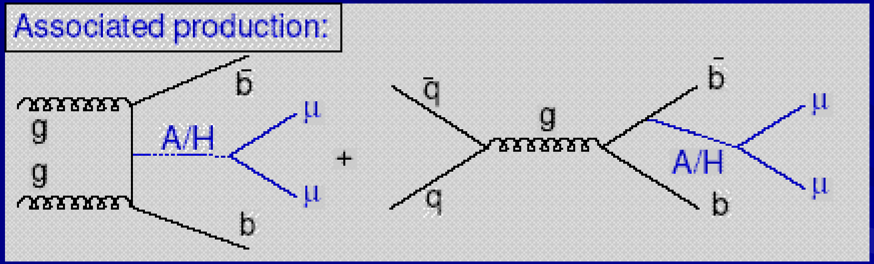
A->$\mu^+ \mu^-$ decay channel

- Cannot be observed for SM Higgs ➡ small BR , too large background
- In MSSM enhanced production rates with respect to the SM

  $\sigma_{MSSM} = (\tan\beta)^2 \times \sigma_{SM}$
- Higher BR comparing to SM

  (SM BR comparable only for M_A < 160GeV, then suppressed by the opening of the gauge boson channel)
- Two production mechanisms

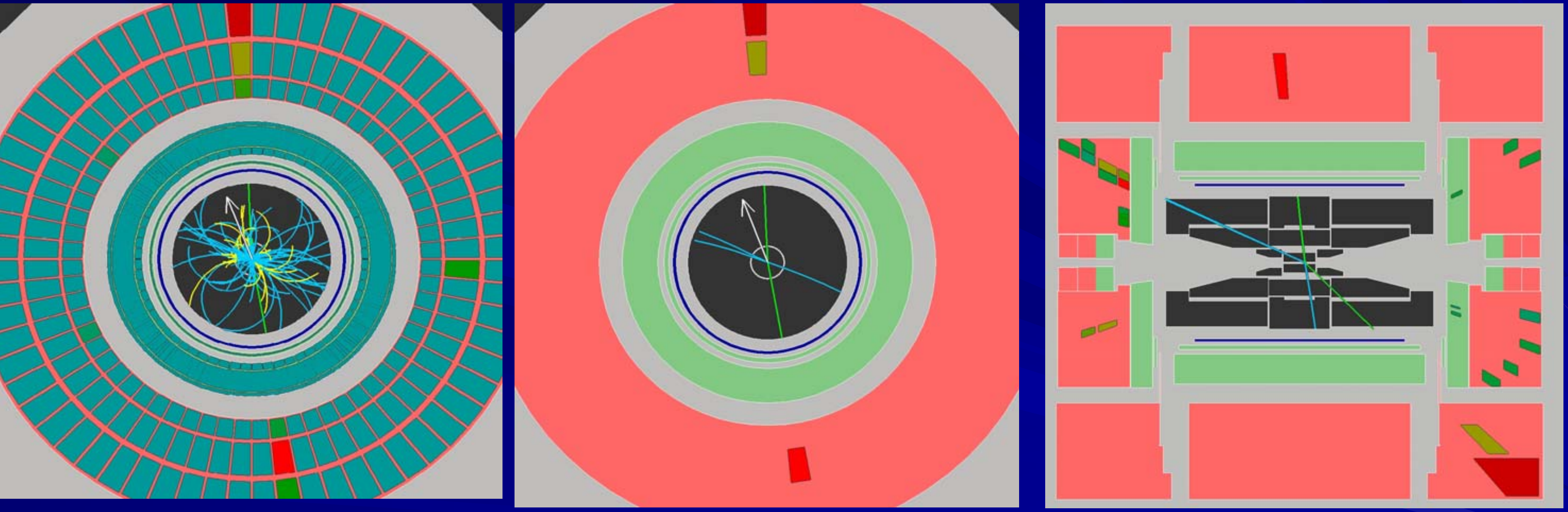




- For large tanβ (>10), associate production becomes dominant

Signal

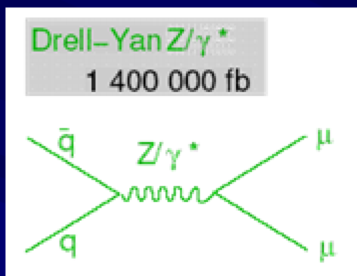
- Clean signature from 2 high p_T muons
- In associated production 2 tagging b-jets

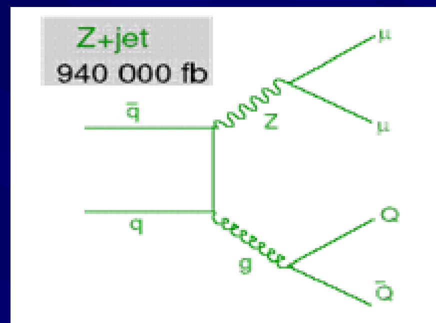


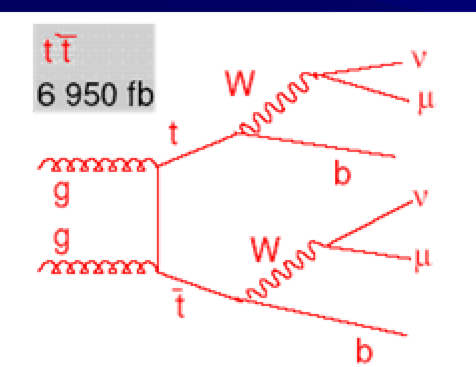
- For bbA->bb($\mu^+\mu^-$) , m_A=300 GeV , tanβ = 30 : (σ x BR)$_{signal}$ ~ 5 fb

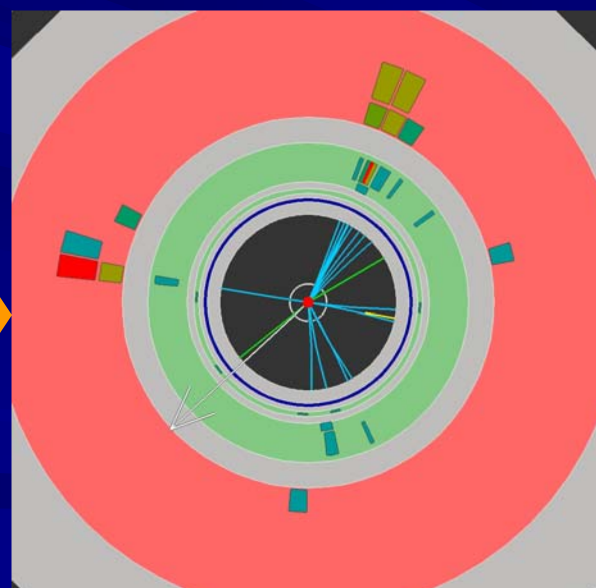
Background

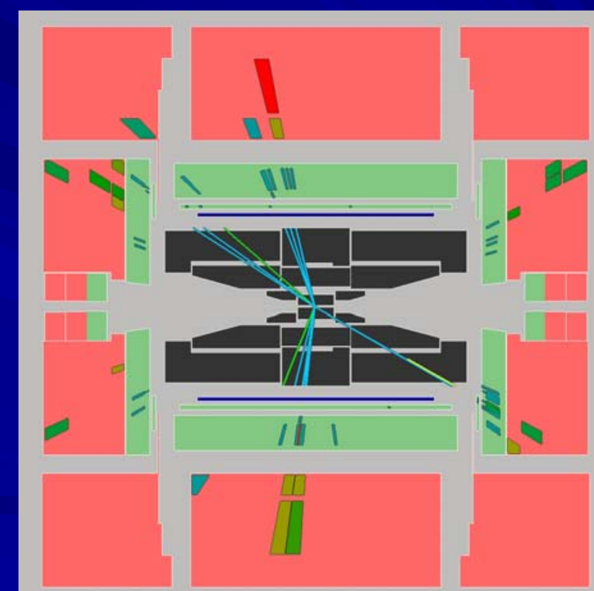
- Large background contribution from the following processes:







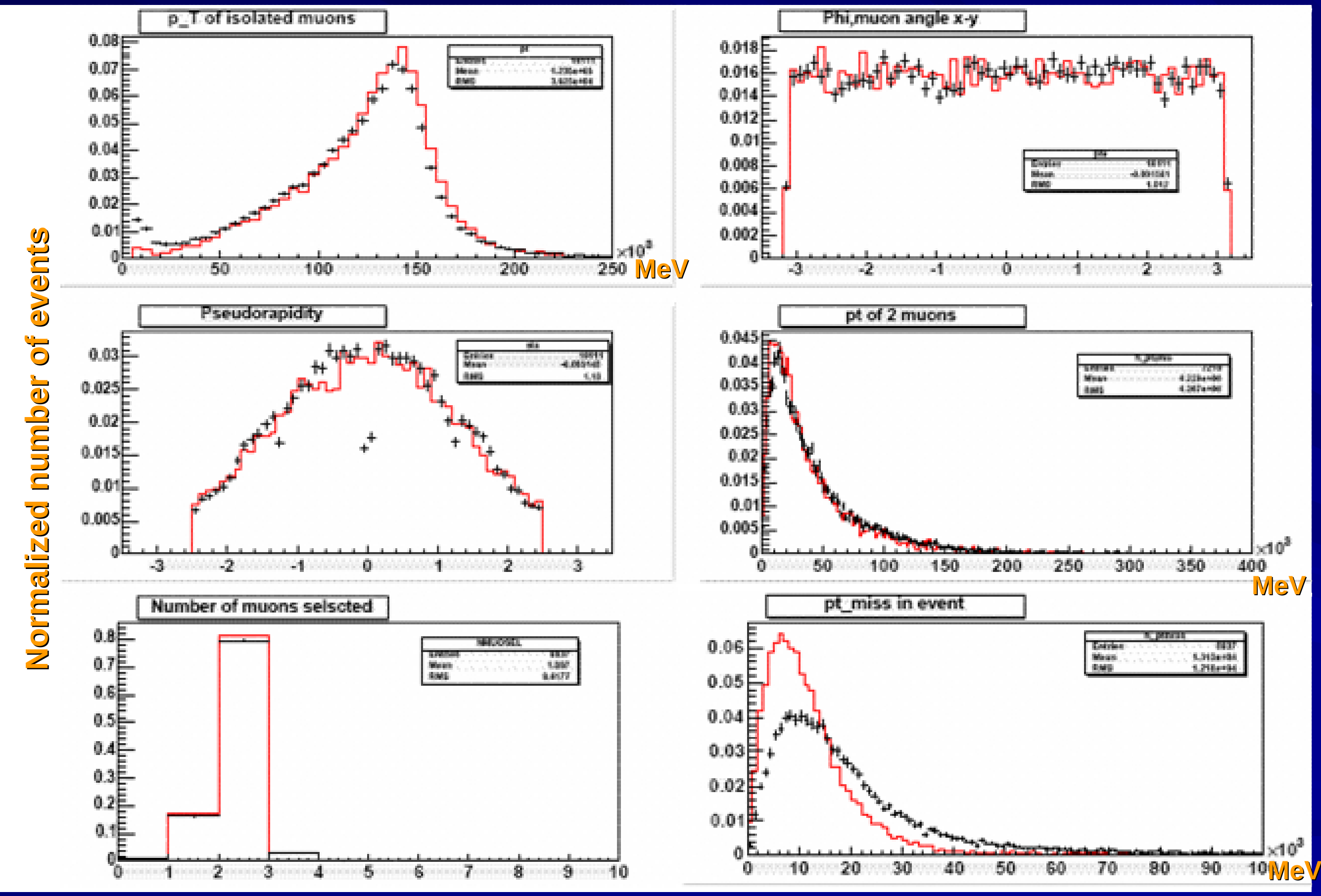


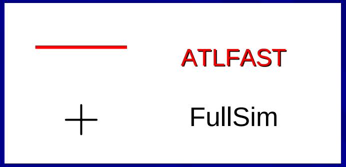


- $(\sigma x BR)_B$ is $(10^3 - 10^6)x(sxBR)_s$ <u>Strong rejection needed</u>

ATLFAST vs FullSim (muons)

- Very good agreement between fast and full simulation

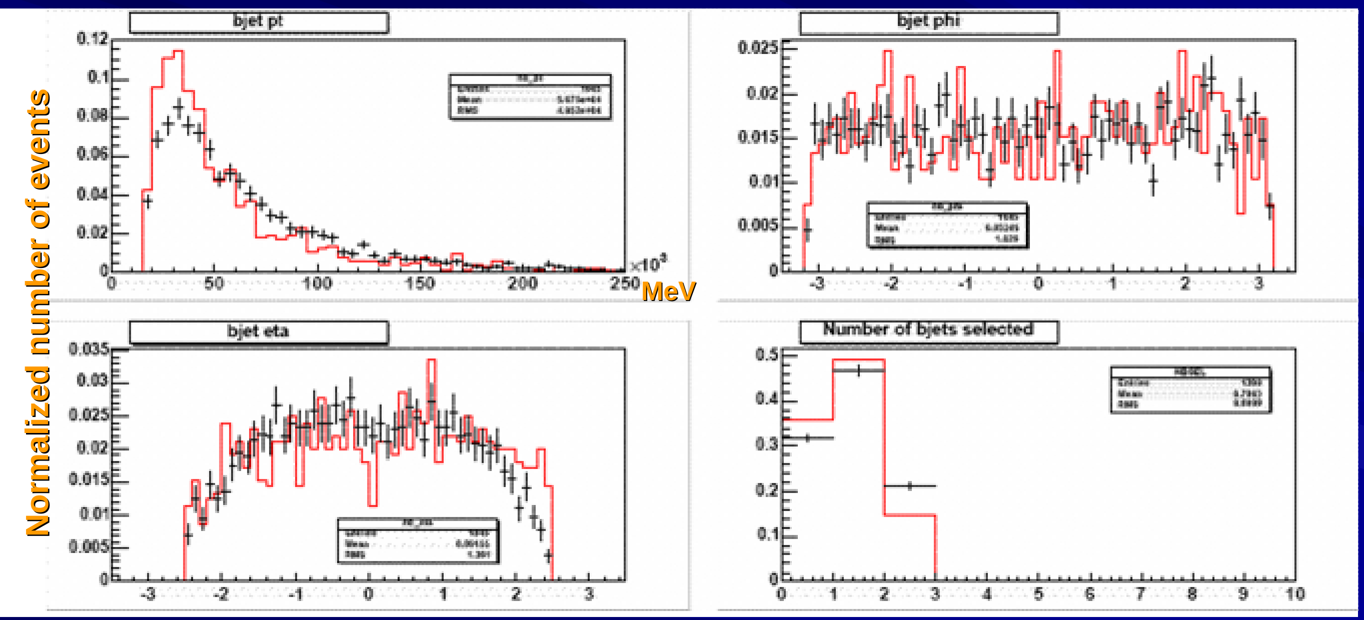




- Except for the missing energy
  (Problems with muons in release 10.0.4)

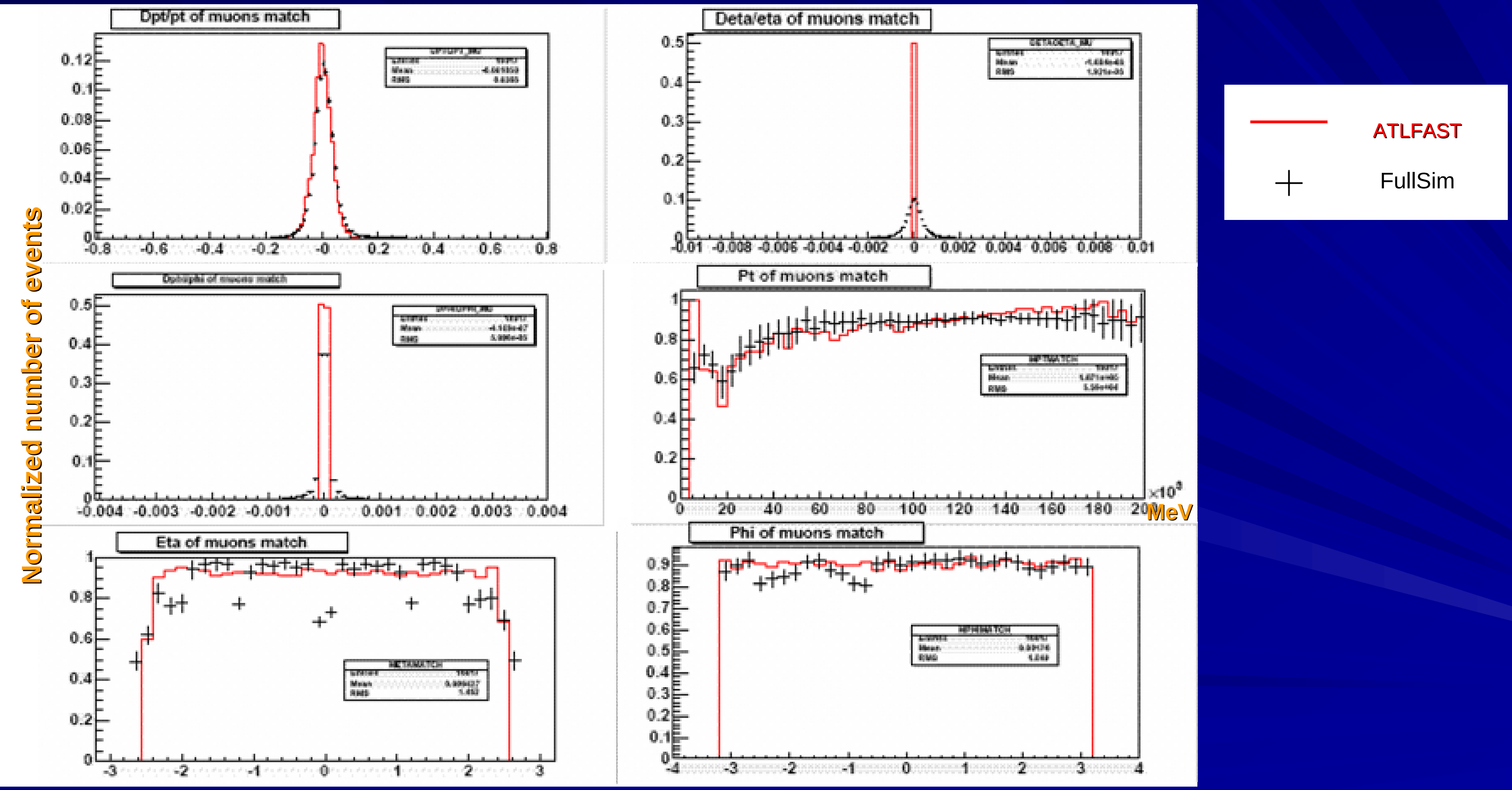
ATLFAST vs FullSim (bjets)

- More bjets are reconstructed in full simulation, leading to slightly bigger efficiency



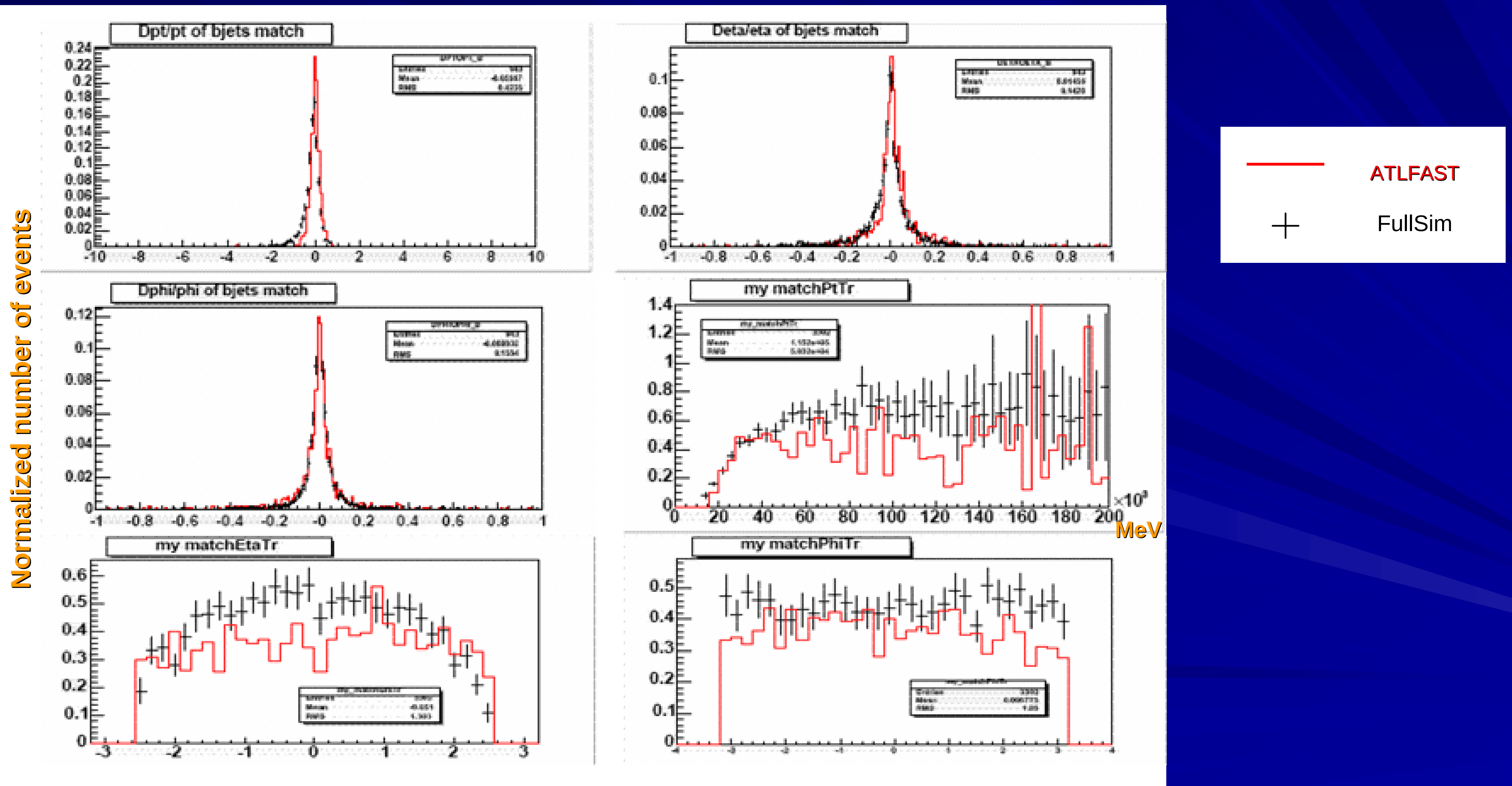
Detector Performance (muons)

- Average muon efficiency ~ 90%



Detector Performance (bjets)

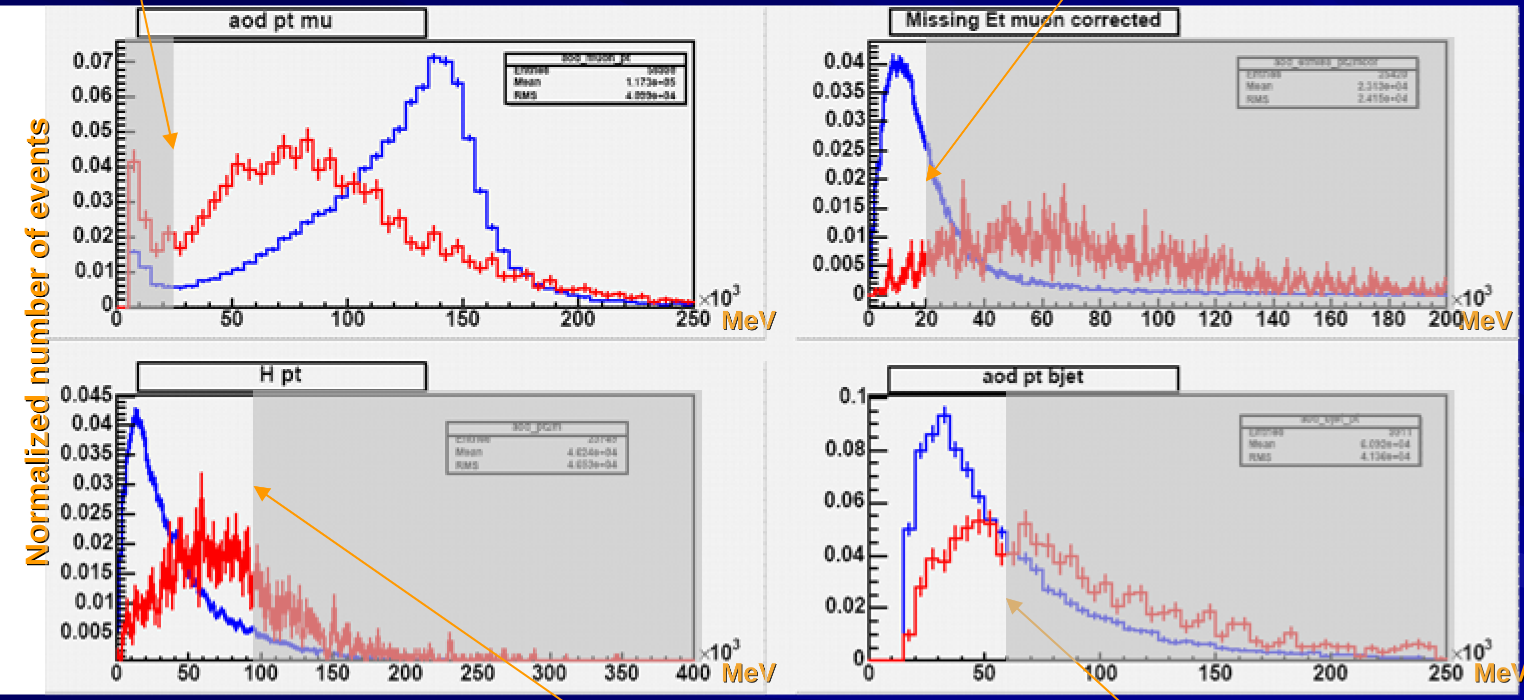
- Average b-tagging efficiency of ~ 50%



Discriminating variables

$p_T > 20$ GeV , trigger selection

$p_T^{miss} < 20$ GeV



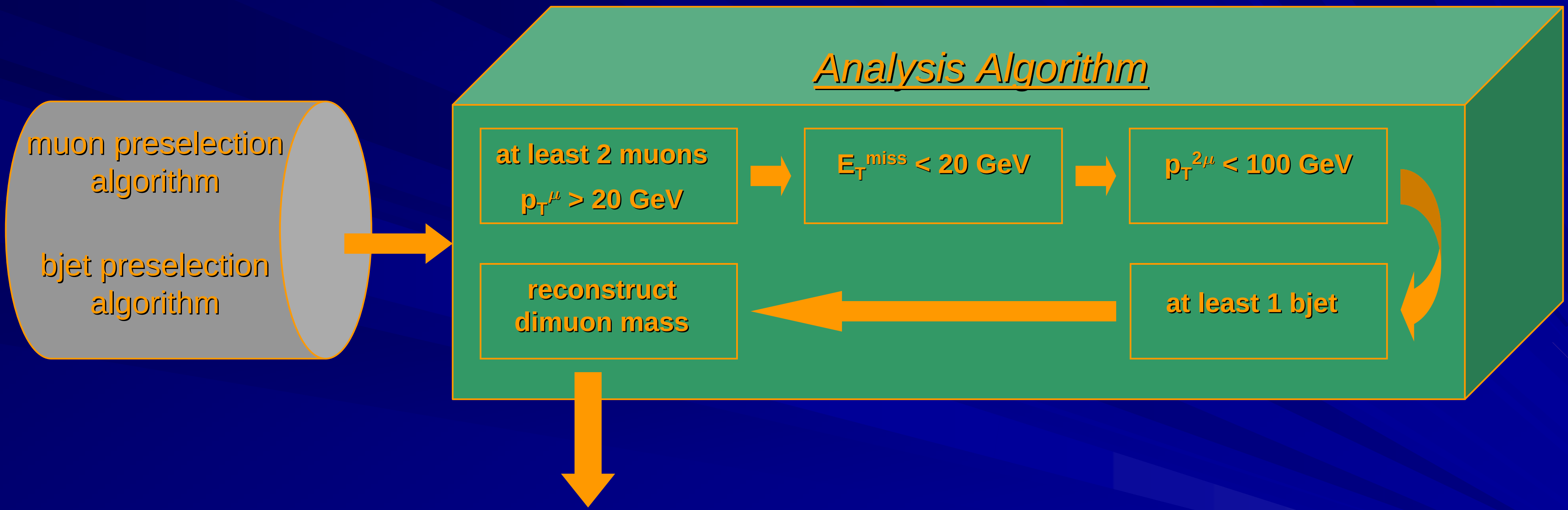
$p_T^{2\mu} < 100$ GeV

$p_T^{bjet} < 60$ GeV

tt

bbA

Analysis scheme

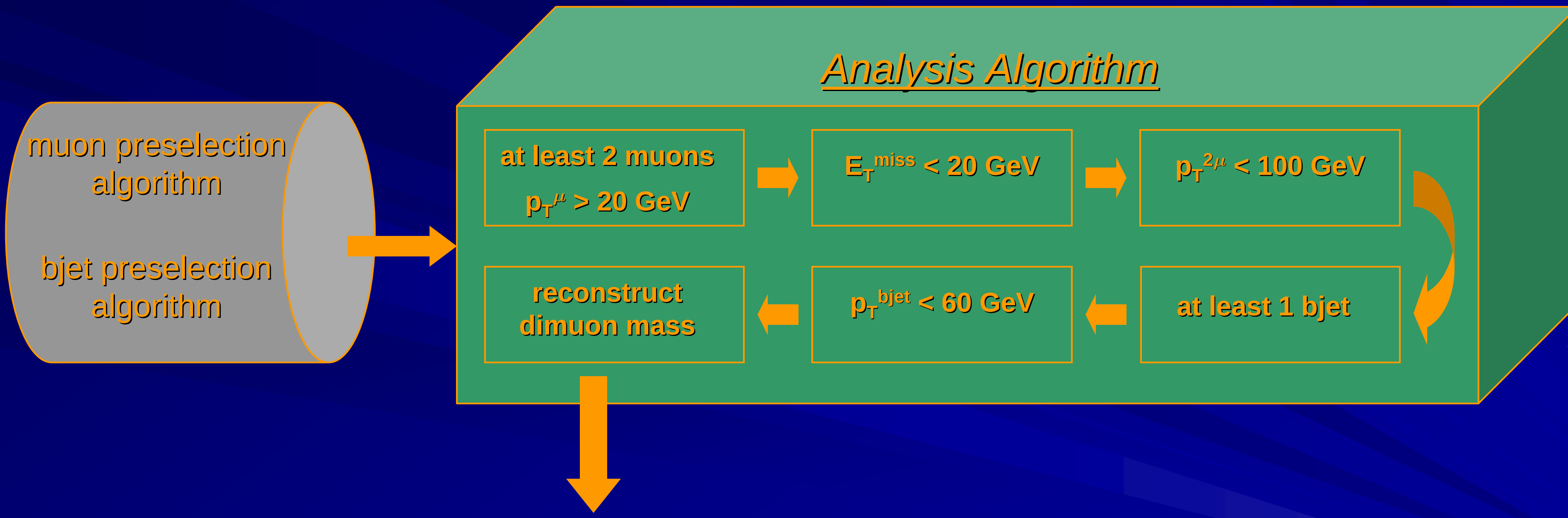


Selected signal / background events
in a mass window $m_{\mu\mu} = m_A \pm \delta m$

$$\delta_m = 1.64 \cdot \sqrt{\left(\frac{\Gamma_{tot}}{2.36}\right)^2 + \sigma_m^{\ 2}}$$

(Keep 90% of gaussian curve)

Analysis scheme



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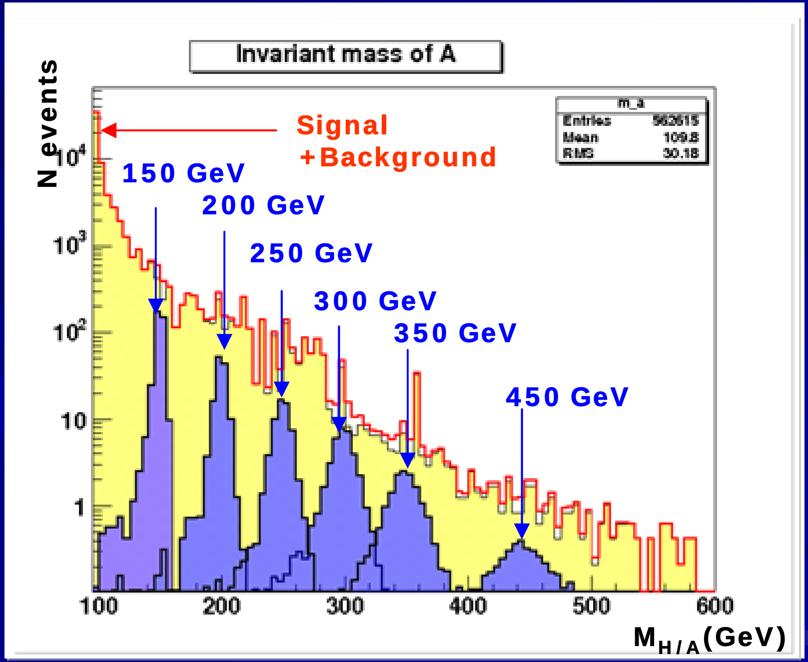
(Keep 90% of gaussian curve)

Results (ATLFAST)

- Data samples produced with ATLFAST

Data	N events
$A \to \mu^+\mu^-$	20.000
$bbA \to \mu^+\mu^-$	20.000
$Z/\gamma^* \to \mu^+\mu^-$	1.000.000
$Z(\to \mu^+\mu^-)$+jet	1.000.000
$tt \to (\mu\nu b)\ (\mu\nu b)$	1.000.000



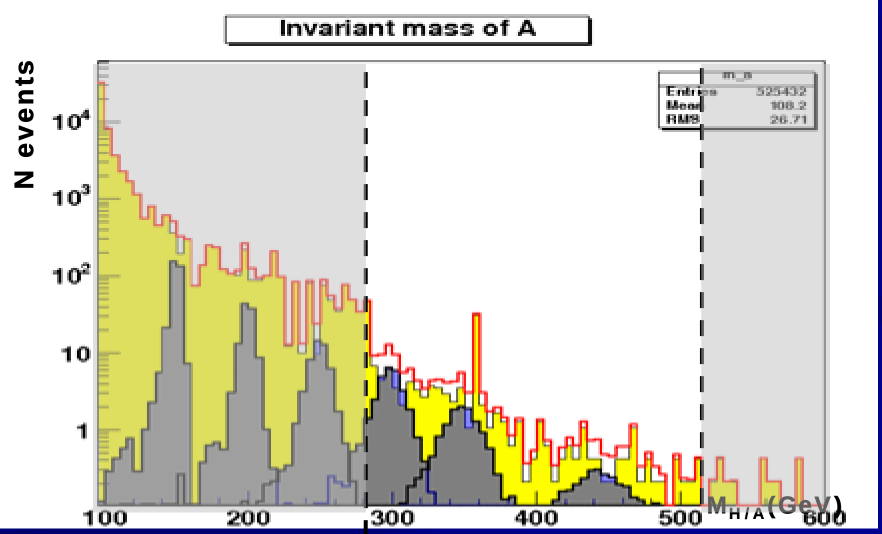
- $\tan\beta = 30$, L = 30 fb^{-1}
- tt background dominant

Results (ATLFAST)

	150GeV	200GeV	250GeV	300GeV	350GeV	450GeV
Signal significance	12.6	5.1	2.6	4.2	2.1	0.7

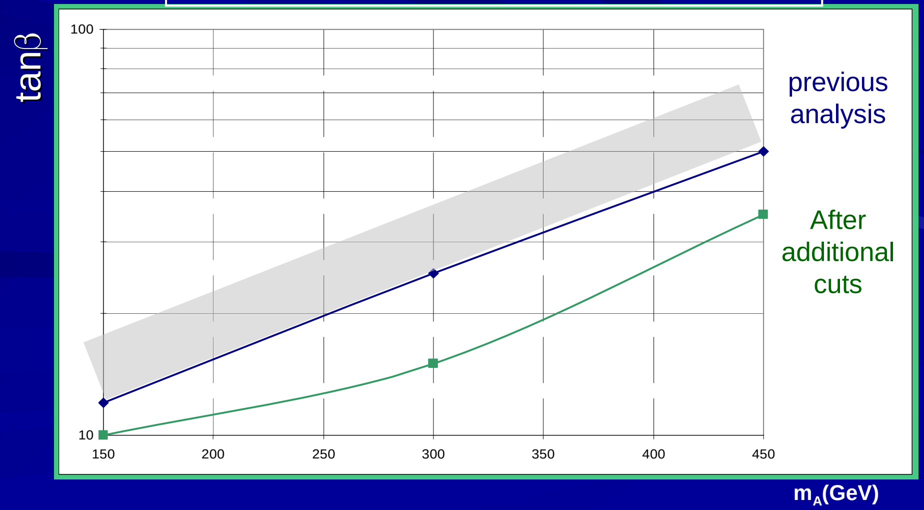
- Can be further improved by using the properties of bjets

	150GeV	200GeV	250GeV	300GeV	350GeV	450GeV
no p_T^{bjet} cut	**12.6**	**5.1**	**2.6**	**4.2**	**2.1**	**0.7**
p_T^{bjet} cut	**12.1**	**4.6**	**2.6**	**5.1**	**2.4**	**1.1**



5σ discovery curves at L=30 fb^{-1}

before – after additional cuts



Results

- Signal significance at m_A = 300 GeV , $\tan\beta$=30 , L=30 fb^{-1}

  (1,5 - 3 years running at initial luminosity)

$$N_{S,B} = \left(n_{S,B}^{selected}\right) \cdot \frac{(\sigma \times BR)_{S,B} \cdot \mathcal{L}}{n_{S,B}^{total}}$$

$n_{S,B}^{selected}$: number of events selected in mass window

$(\sigma \times BR)_{S,B}$: production c.s. times branching ratio of each process

$\mathcal{L}$: integrated luminosity

$n_{S,B}^{total}$: number of events generated

Data	N events
$bbA \rightarrow \mu^+\mu^-$	~ 32.000
$tt \rightarrow (\mu\nu b)\ (\mu\nu b)$	~ 71.000

FullSim

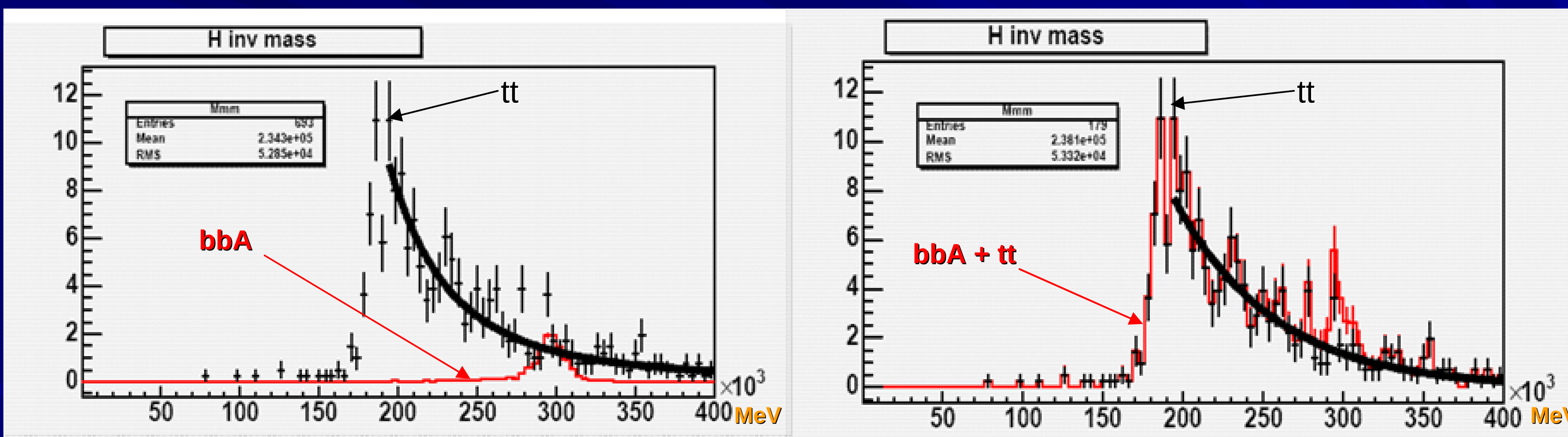
$$s = \frac{n_s}{\sqrt{n_B}} = 2.4 \pm 0.2$$

↔

- Only tt background!
- Only A boson, not H/A combined

Invariant mass

m_A = 300 GeV , tanβ=30 , L=30 fb^{-1}



Summary

- Possibility and limits for discovery of one additional Higgs particle (MSSM , heavy , neutral) in ATLAS
- Discovery potential of A->$\mu^+\mu^-$ already explored with ATLFAST
- First results of fully simulated data analysis
- ATLFAST and FullSim seem to be in agreement , but
- Some differences have to be investigated and exploited for fine tuning of FullSim analysis
- More background data and different Higgs masses to be produced
- Moving to MSSM A->$\tau\tau$ decays