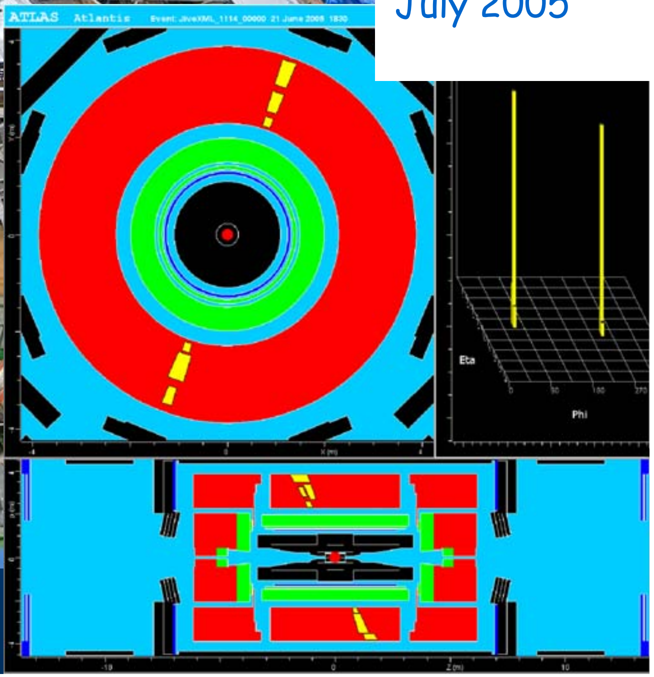
ATLAS PHYSICS POTENTIAL

International Workshop
"Quantum Particles and Fields - 4"
Zagulba Settlement
19^{th}-25^{th} September 2005
Baku
Azerbaijan



First ATLAS Data:Cosmic Muons in TileCal July 2005

Francesco Spanò
CERN
On behalf of the ATLAS collaboration

A WORD OF NOTICE AT THE BEGINNING OF THE JOURNEY

Given the time at disposal, it is impossible to cover in detail all the topics that ATLAS will be able to explore

Mine will be a (partial) selection of main highlights

It will be focused on what is achievable in the early years (including detector commissioning) with a hint to what might come later

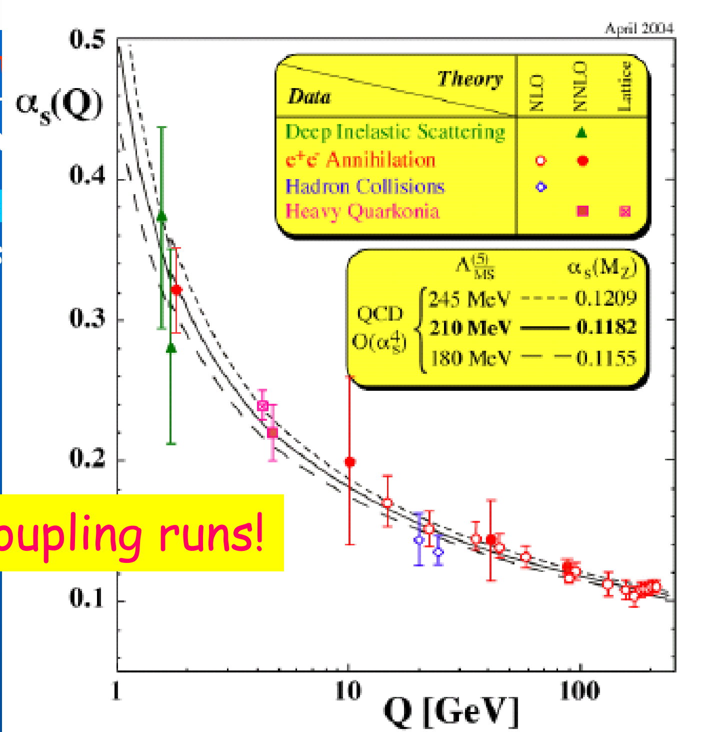
Outline

- The Reasons
- ATLAS at LHC: Status and challenges (now)
- Commissioning: living up to expectations and face reality (soon)
- Future Physics: succeeding with what one has (later)
- Conclusions

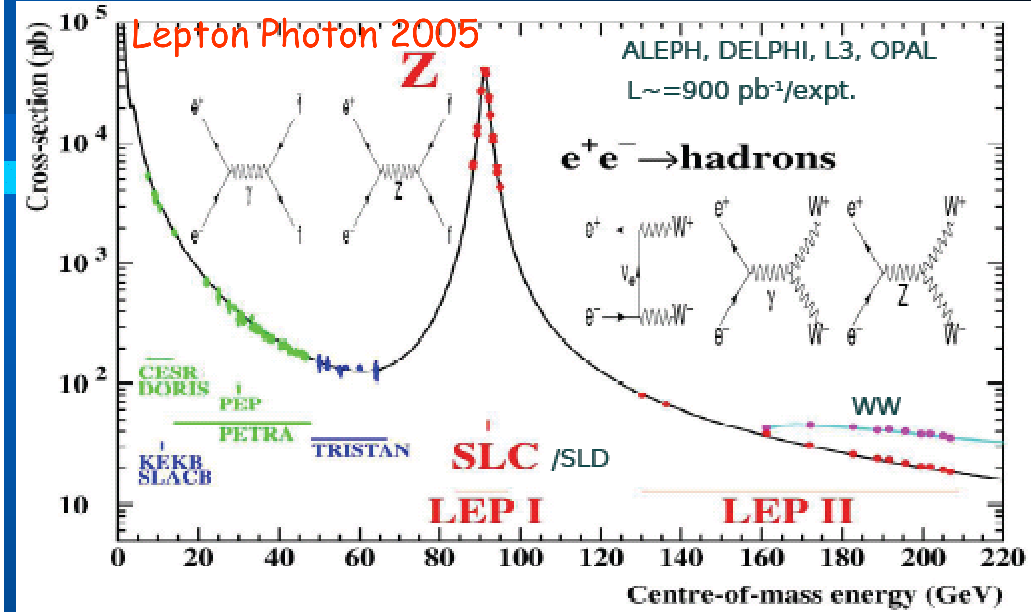
The Reasons

The SM is a great success..

- The Reason
- Atlas at LH
- Commission
- Future Physics
- Conclusions



QCD coupling runs!



EWK unification is real!

...But there is need to go beyond

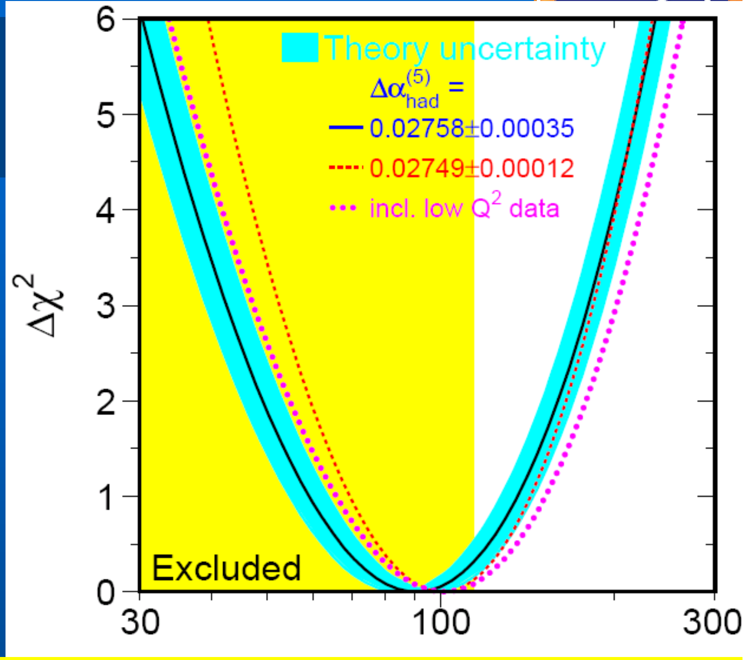
- No explanation for its 19 independent parameters
- Gravity is missing (2 more parameters = G_N, cosmological constant)
- Cosmology is incomplete: inflation, baryon asymmetry, universe energy content
- First physics beyond the SM: neutrinos have mass (18 more par.)

4 groups of of questions

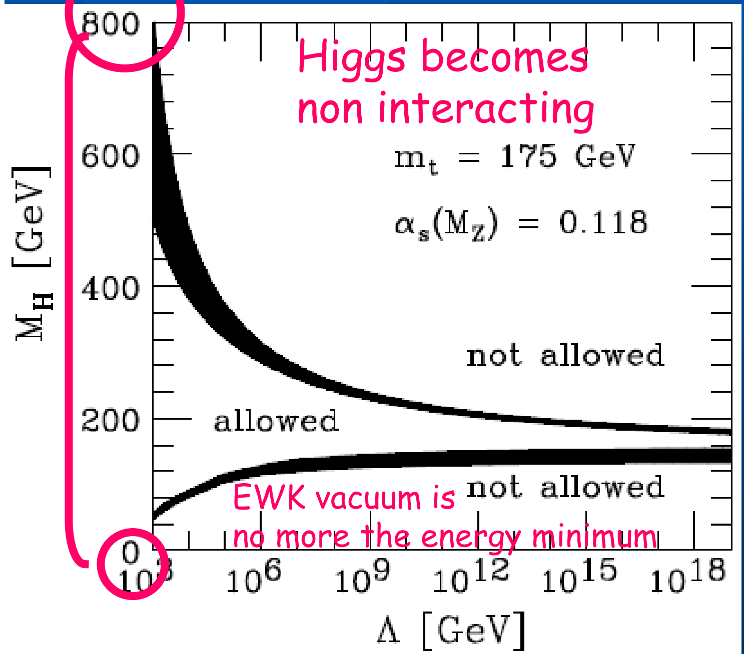
1) Mass i.e, how is symmetry broken?

$M_W, M_Z \neq 0 \Leftrightarrow$ there exists a field breaking gauge symmetry in SM vacuum → Elementary: Higgs particle; Composite: quark condensate

- **Spin zero**
- **Generates mass for W,Z and fermions**
- **M_H: only free parameter with upper limit:~ 800 GeV**



M_H Theory



EXP Status

- **LEP direct search: M_H >114.4 GeV**
- **LEP+Tevatron fit: $M_H = 129^{+74}_{-49}$ GeV**

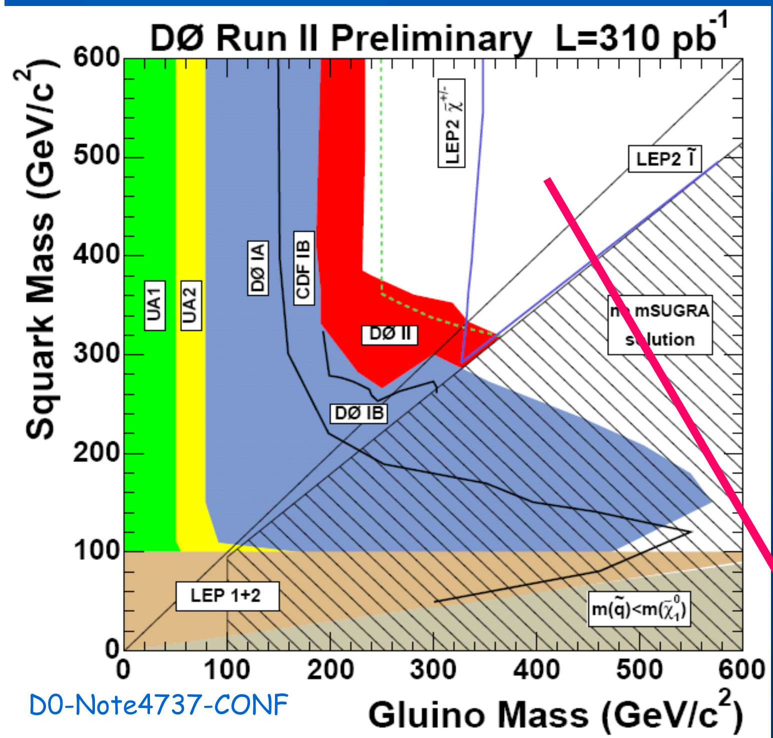
Search on allowed M_H range = **explore TeV scale**

2) Hierarchy and Unification

- Why is coulomb(e^2)>>gravity(G)? I.e. why $M_{Planck}>>M_w$?
- Do forces eventually unify ? At what scale?

- Hard to keep the electroweak scale far away from the Planck scale in presence of quantum fluctuations.

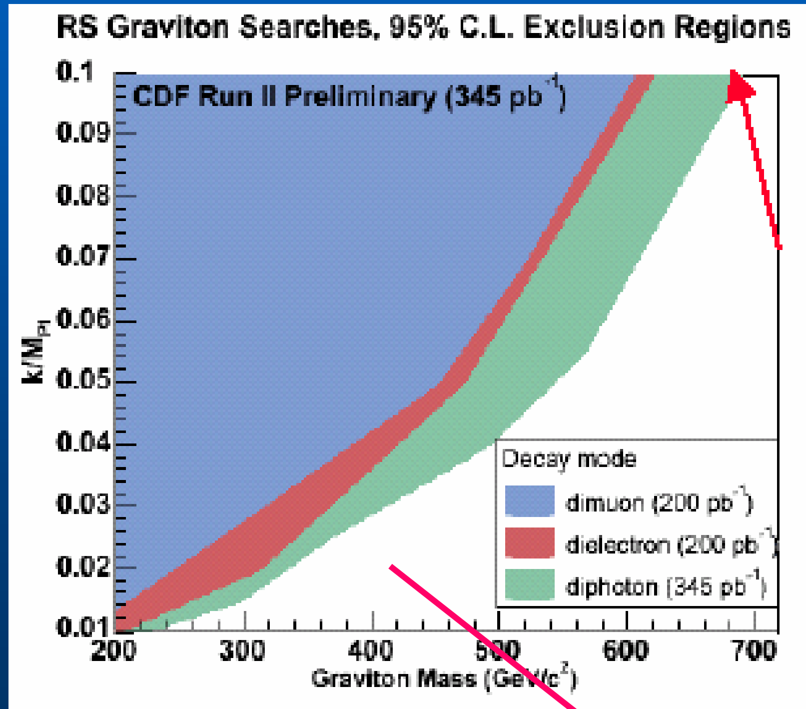
SUSY



D0-Note4737-CONF

Conserve R parity
→ Pair-Produced
Sparticles:

EXTRA DIMENSIONS



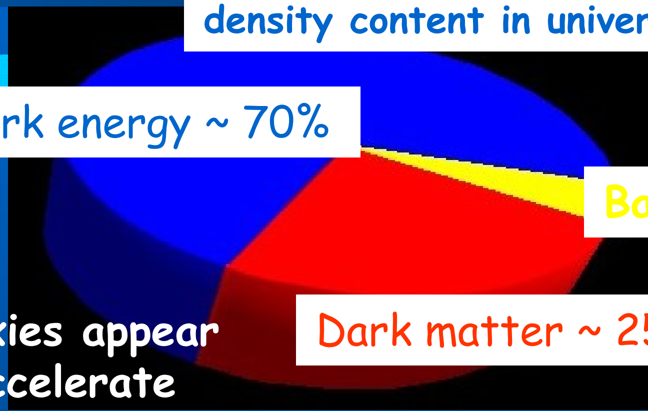
TeV scale is lower bound

3&4)Flavour and Universe content

What are the reasons for particles families and their behaviour?

- Why so many types of quarks and leptons (i.e. different masses)?
- Why do their weak interactions mix with different strengths i.e. mass eigenstates ≠ weak eigenstates ?
- How is this connected to CP violation i.e the matter-antimatter imbalance in the universe?
- Is there any additional substructure (compositeness?)

What is the universe made of?



galaxies appear to accelerate away← dark energy spread over space, slowly-varying in time

Rotational velocity inside galaxies+

fits to CMB →total matter density~0.3 and baryonic Matter density~0.04→Dark Matter: feels gravity, interacts weakly

Search for weakly interacting particle with M=10-1000 GeV →SUSY (neutralino) ?

Pointing at TeV scale again

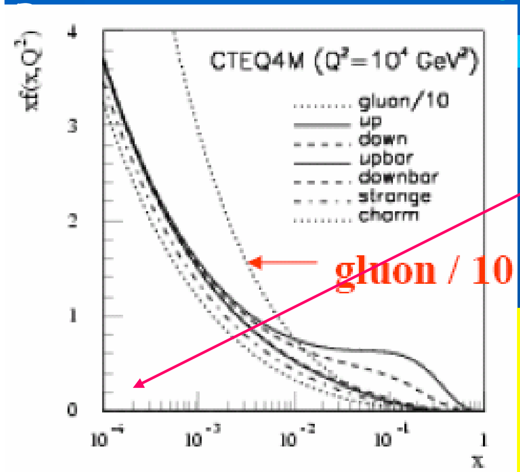
A new tool is required: the LHC

- The Reasons
- Atlas at LHC
- Commission

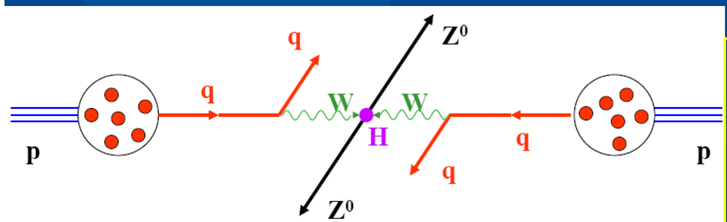
The rationale

- Explore TeV energy scale: high mass and rare signatures → increase collision energy
- Use pp collisions. Proton is composite → $\sigma(pp)=\sum_{1,2}\int_{xlow}^{1} F_1 F_2\, \sigma(1,2)\, dx_1 dx_2$ $(xlow=m^2/E_{cm})$
  - point-like $\sigma \sim 1/s$
  - proton structure functions increase very rapidly at low x

significant increase of σ with energy: $\sigma(pp) \propto C\,(\log(E_{cm}))^2$



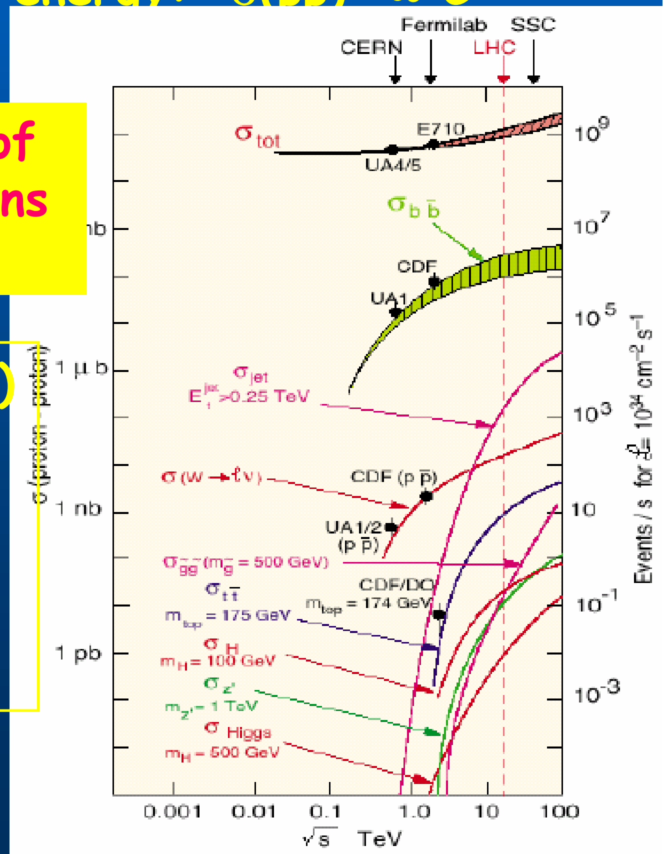
Energy and Lumi req. ("back of enevelope"): use H→ZZ→leptons (m_H~1 TeV)



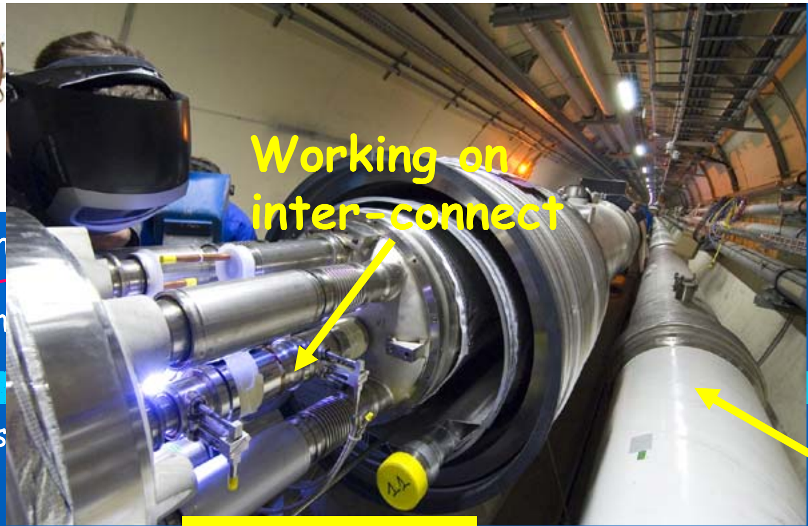
- $E_W \sim 500$ GeV → $E_{quark} \sim 1$ TeV → $E_{proton} \sim 6$ TeV

E_{cm} >~12 TeV

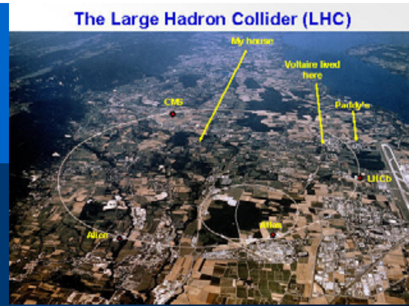
Lumi=(#ev)/(σ·BR·time)
σ(pp→H)~0.1 pb
BR(H→ ZZ)~0.1
BR(ZZ→lep)~10^{-3}
To get 10 events in 1 year →L~10^{34} cm^{-2}s^{-1}



LHC



Cryo service line



Parameters

Max energy	7 TeV (~7 x Tevatron)
Circumference	26,659 m
Protons per bunch	$1.1 \cdot 10^{11}$
Filled bunches	2808 / 3564
Bunch spacing	24.95 ns
Lumi	10^{34} cm^{-2} s^{-1} (>100 x Tevatron)
Superconducting Dipoles	1232 (15m long at 1.9 K, B=8.33 T);
E_{beam}(Stored)	350 MJ (200 x Tevatron)
Bunch spacing	24.95

Status

- 1000/1650 main magnets delivered
- ~100 dipoles installed
- Installation: cryogenics service line + magnets are "critical to maintain the schedule" (L.Evans 12/09/05)

Schedule = Start colliding protons in Summer 2007

Operation with Heavy ions at 2.7 TeV /nucleon

Updated status is at: http://lhc-new-homepage.web.cern.ch/lhc-new-homepage/DashBoard/index.asp

Facing the challenge:
A ToroidaL ApparatuS
at the
Large Hadron Collider

Detecting "interesting" physics at LHC

Aim: Operate at high Luminosity with detecting as many "signatures" as possible

- Higgs multiple signature →forward and central jets, leptons and E_T^{miss}
- SUSY→excellent E_T^{miss}

Requirements

Trigger	Pipelined with reduction factor of 10^7	Cope with 10^9 events/s
Electromagnetic Calorimetry	$\|\eta\|<3$: $\sigma(E)/E \sim 10\%/\sqrt{E} \oplus 0.7\%$	e/γ identification
Combined electromagnetic and hadronic calorimetery	$\|\eta\|<3$: $\sigma(E)/E \sim 50\%/\sqrt{E} \oplus 3\%$ $3<\|\eta\|<5$: $\sigma(E)/E \sim 100\%/\sqrt{E} \oplus 10\%$	Jets and E_T^{miss} Hermetic coverage Forward jet tag
Inner Tracker	30% at p_T = 500 GeV $\|\eta\|<2.5$	Tracking high p_T lepton, tau ID, btag
Muon detection	10%at p_T= 1 TeV	standalone, at highest Lumi

Fine granularity to separate signal from 20 events pile-up in same bunch crossing

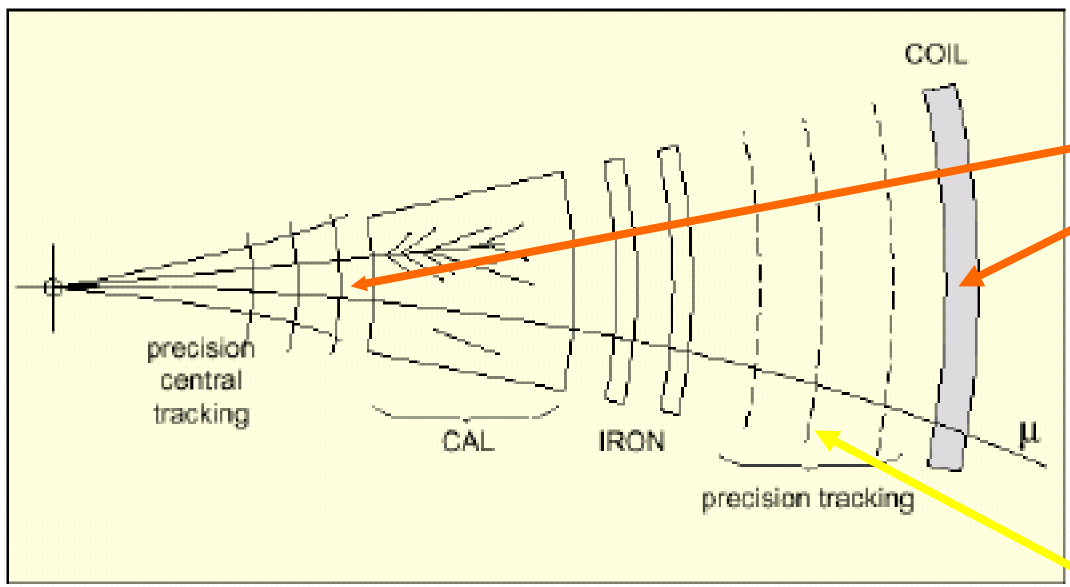
Fast electronics to minimize pile-up of events from different bunch crossings →25-50ns

Radiation hard electronics: fluence up to 10^{16}n/cm²/year~ 10^5 Gray/year (1Gray=1J/Kg)

ATLAS: the concept

High multiplicity environment →Absorb/measure all hadrons and measure leftover muons (cylindrical symmetry around beam ; θ=polar, φ=azimuthal).

Inner tracker and calorimetry decoupled from muon system



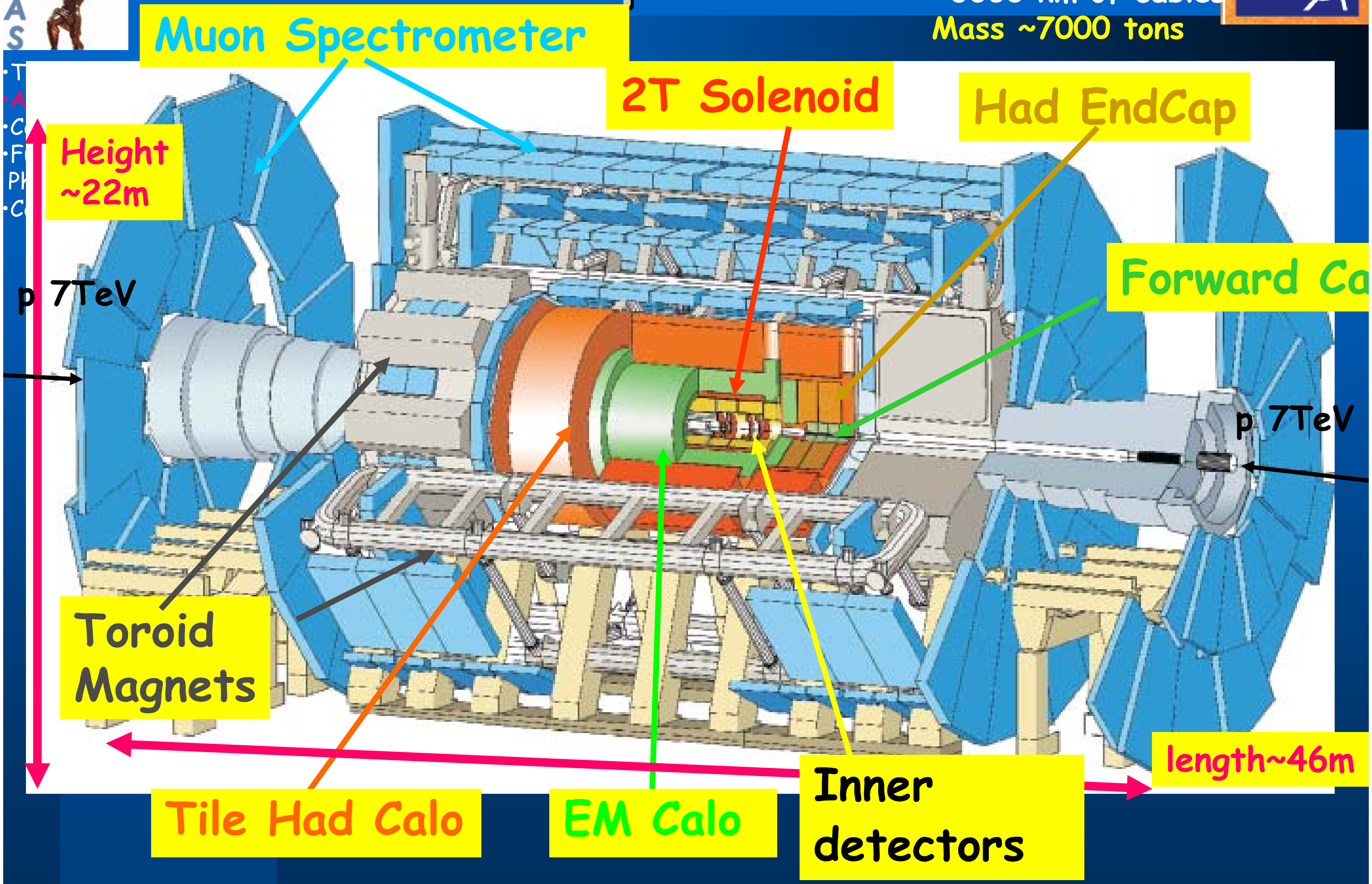
2 magnet systems (solenoidal, toroidal)→ uniform bending for muon. High res, large-acceptance standalone muon spectrometer

Parameter choices: some examples

- For p_T>20 GeV, $dp_T/p_T \sim p_T/B(\text{Tesla})L^2(m^2)$ → large B and volumes minimize uncertainty at high p_T. B in Inner Det ~ 2T, B in μ spectrometer up to 3.9 T →high currents → superconducting coils
- λ(Fe) ~ 17,6 cm. Need ~10 (14) int length before barrel (forward) muon chambers: need ~9.5 λ for calo → ~1.7 m of iron (TileCal is ~82% iron/18% scint)
- $\eta=-\ln(tg(\theta/2))$: a) precision physics coverage (μ, e) : $|\eta|<2.2$; b) good E_T^{miss} resolution →$|\eta|<5$ coverage → detectors up to about 1° from beam axis!

ATLAS as expected...

~10^8 channels
~3000 km of cables
Mass ~7000 tons



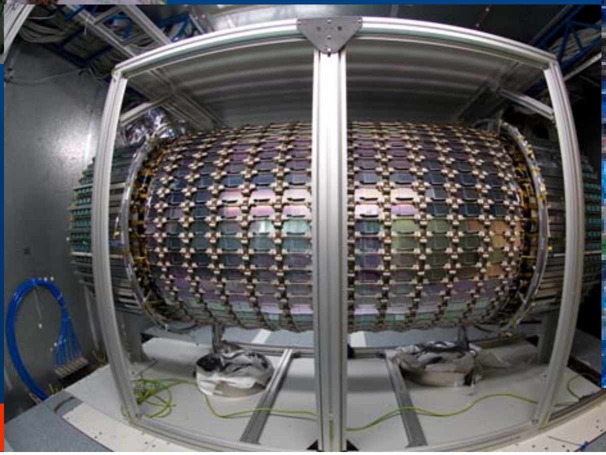
..and ATLAS "Today" (1)

26th Oct. 04: 1st coil is lowered

Dec.04 Barrel EM + Had calorimeters installed

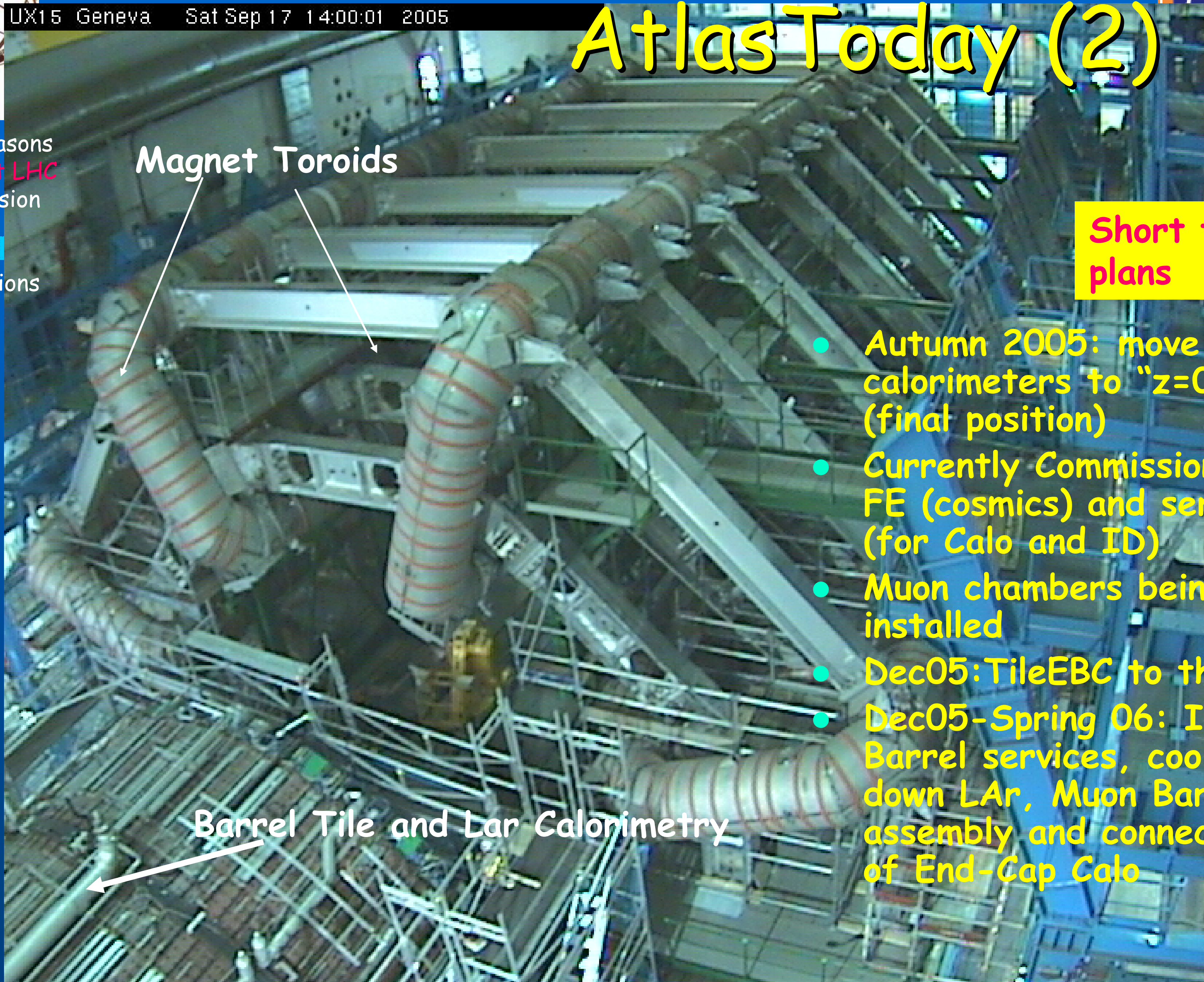
25th August 05: final 8th coil is lowered in place!

SCT barrel completed! (4th segment left Oxford on 24th Aug 05)



AtlasToday (2)

- The Reasons
- Atlas at LHC
- Commission
- Future Physics
- Conclusions

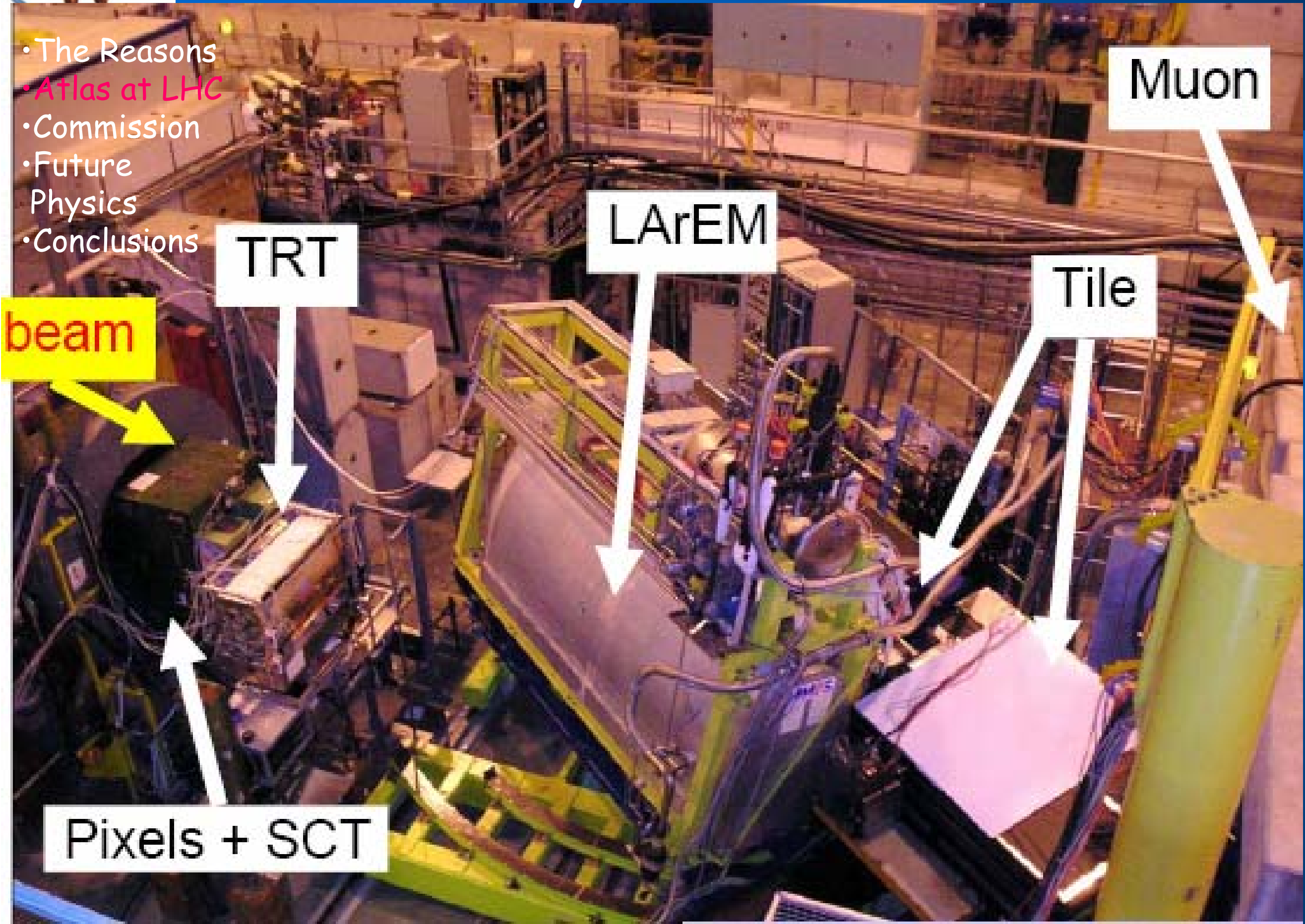


Short term plans

- Autumn 2005: move calorimeters to "z=0" (final position)
- Currently Commissioning FE (cosmics) and services (for Calo and ID)
- Muon chambers being installed
- Dec05:TileEBC to the pit
- Dec05-Spring 06: Install Barrel services, cool down LAr, Muon Barrel assembly and connection of End-Cap Calo

The ATLAS 2004 Combined Test beam

CERN- May-Nov 2004



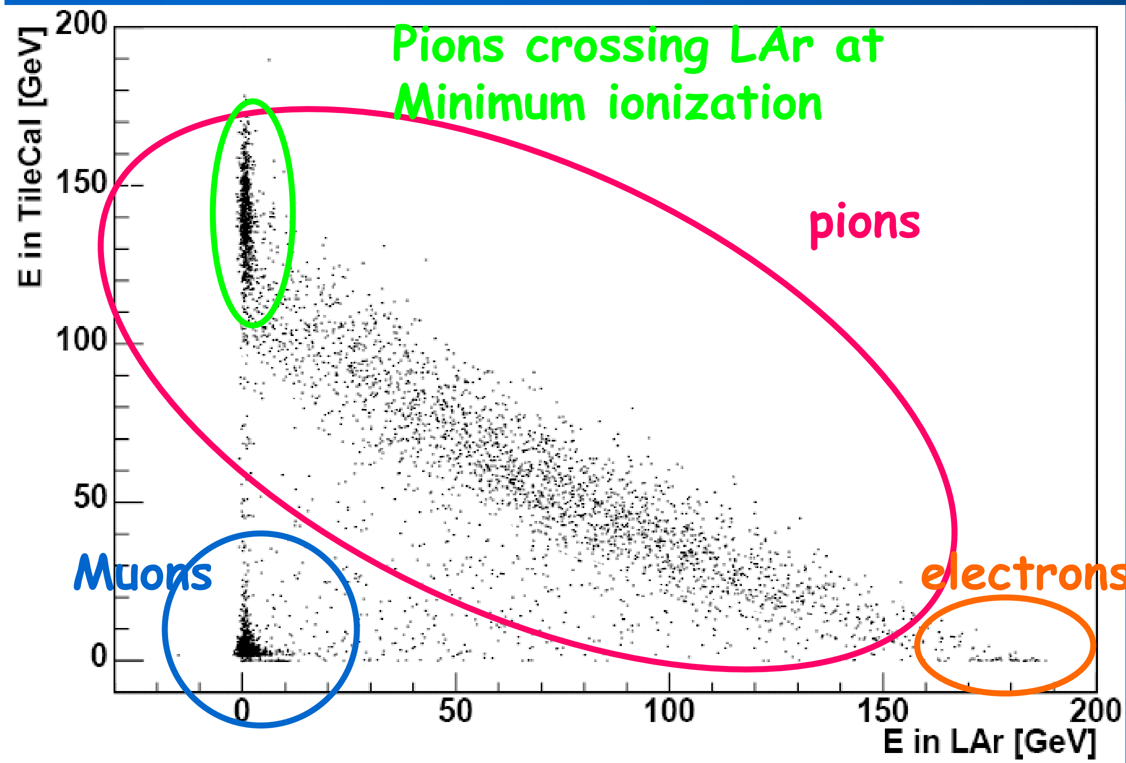
- 90 million events collected
- 4.6 TBytes of Data
- Beams:
  $e^{\pm}, \pi^{\pm}$ 1 → 250 GeV
  $\mu^{\pm}$ $\pi^{\pm}$ p up to 350 GeV
  γ ~30 GeV
- B from 0 to 1.4 T

- For the first time, all ATLAS sub-detectors operated together with:
  - "final electronics"
  - Common DAQ
  - Slow control
  - Common ATLAS software to analyse data

First experience with

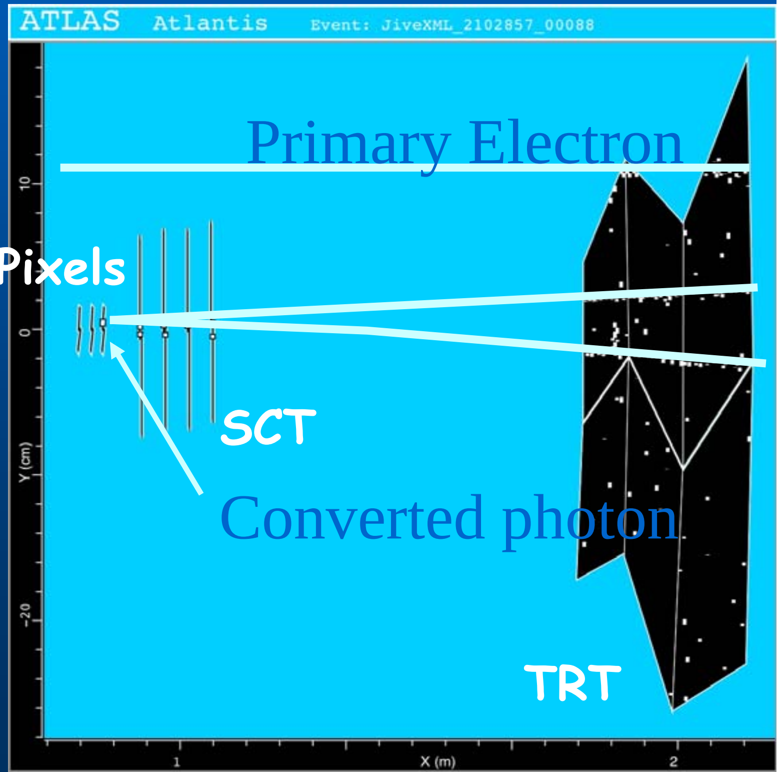
- •Inner Detector alignment
- •ID/Calo Alignment
- •ID/Calo track matching
- •ID/Calo combined reconstruction
- •ID/Muon combined reconstruction

CTB data: towards integrating ATLAS



Pion beam in calorimeters, E=180 GeV, η=0.35

Photon conversion in Inner detectors: Matching tracks to clusters



- The Reasons
- Atlas at LHC
- Commission
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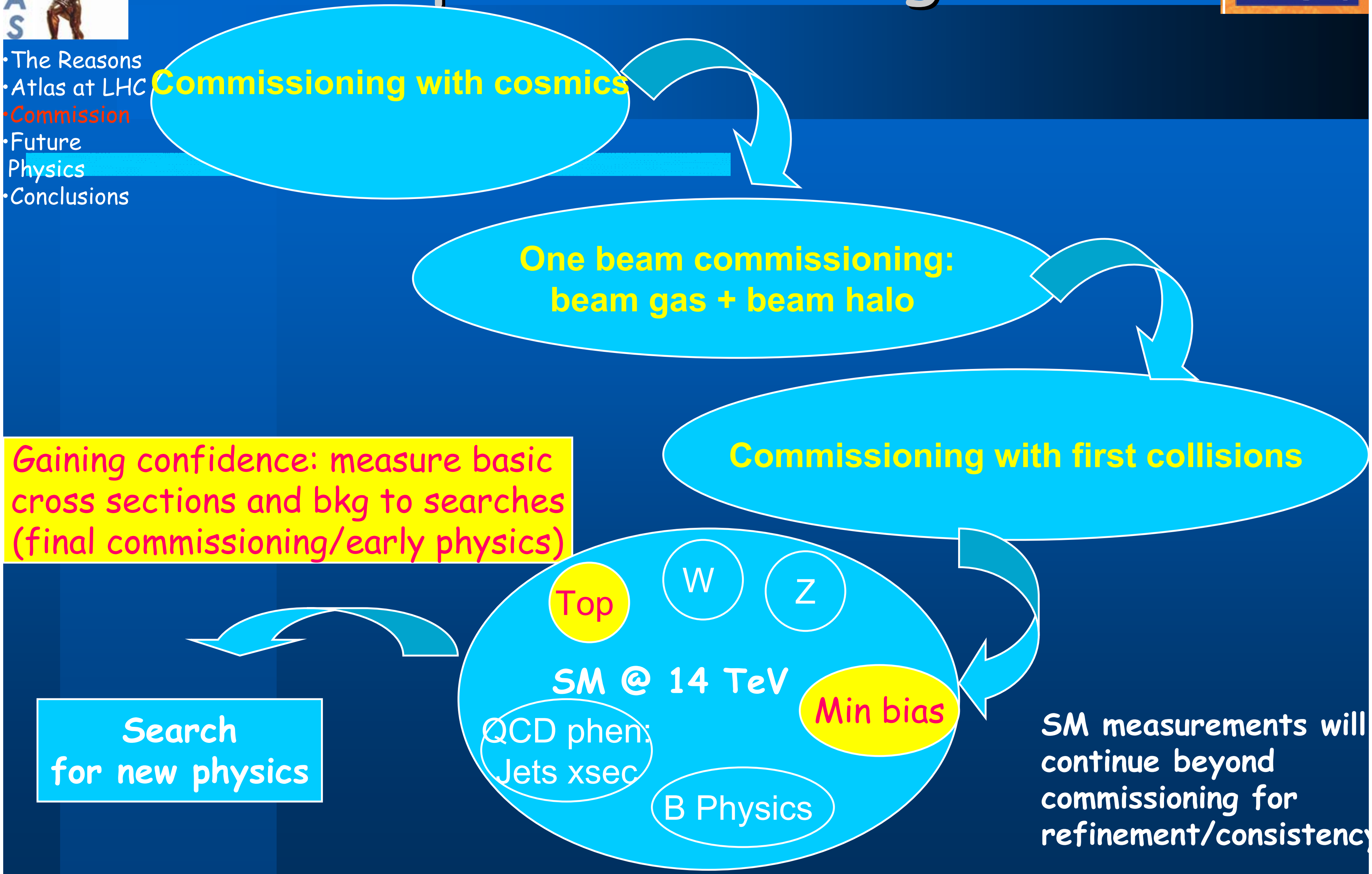
Commissioning and early physics: the stepping stone towards physics i.e learning to walk before running

The plan: four stages

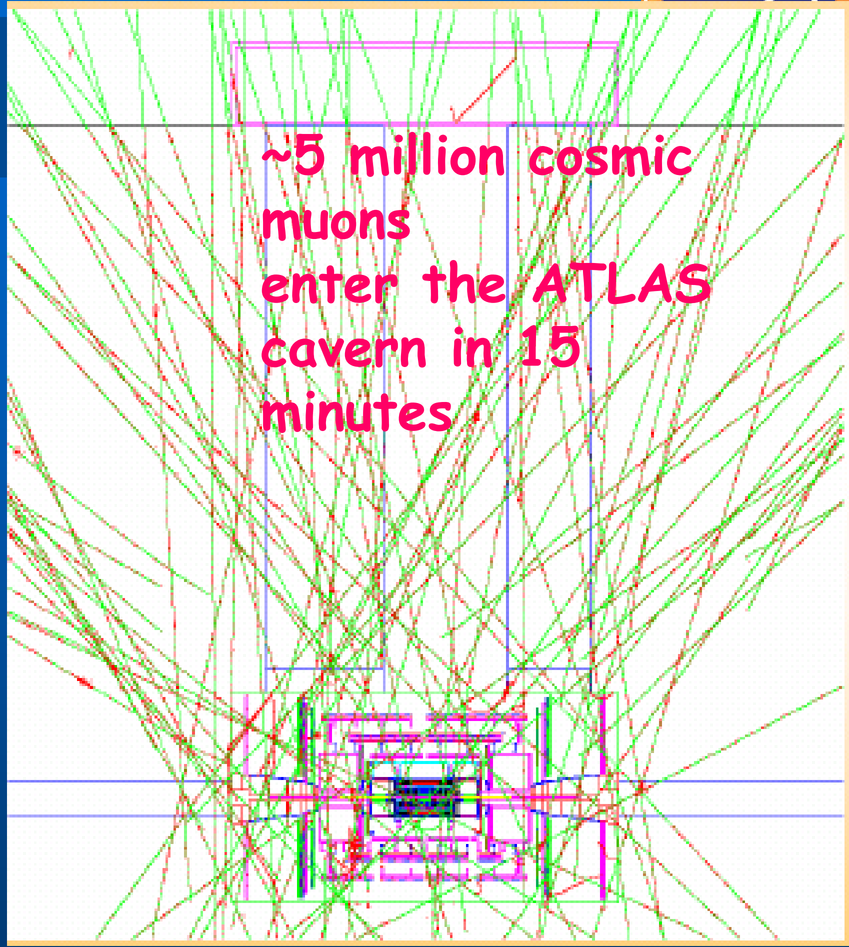
- The Reasons
- Atlas at LHC
- Commission
- Future Physics
- Conclusions



Commissioning with cosmics

Goals

- Build experience with final detector
- Check stability
- Integrate subdetectors, Commission common systems, trigger-DAQ, exercise offline software
- Understand bkg to rare events



Strategy and schedule

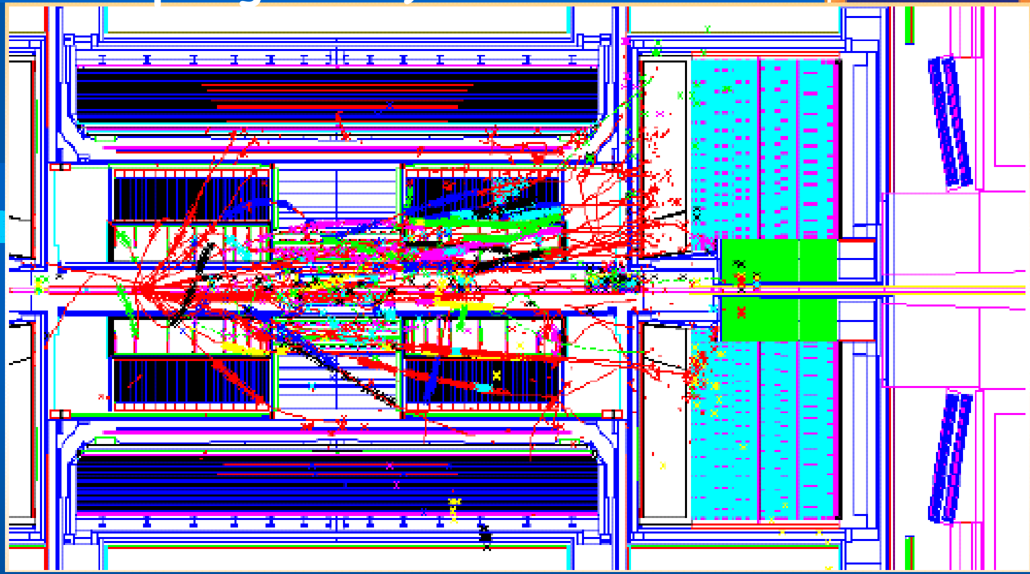
- From Sept 05 – July 2007
- Commission individual sub-detectors first, then add the rest
- Now: Hadronic Tile Calorimeter
- End '05: add section of muon system
- Spring '06: Add LAr Electromagnetic Calorimeter
- Spring '07: global ATLAS cosmic run

Commissioning with single beam

(schedule: ~2 months after spring 2007)

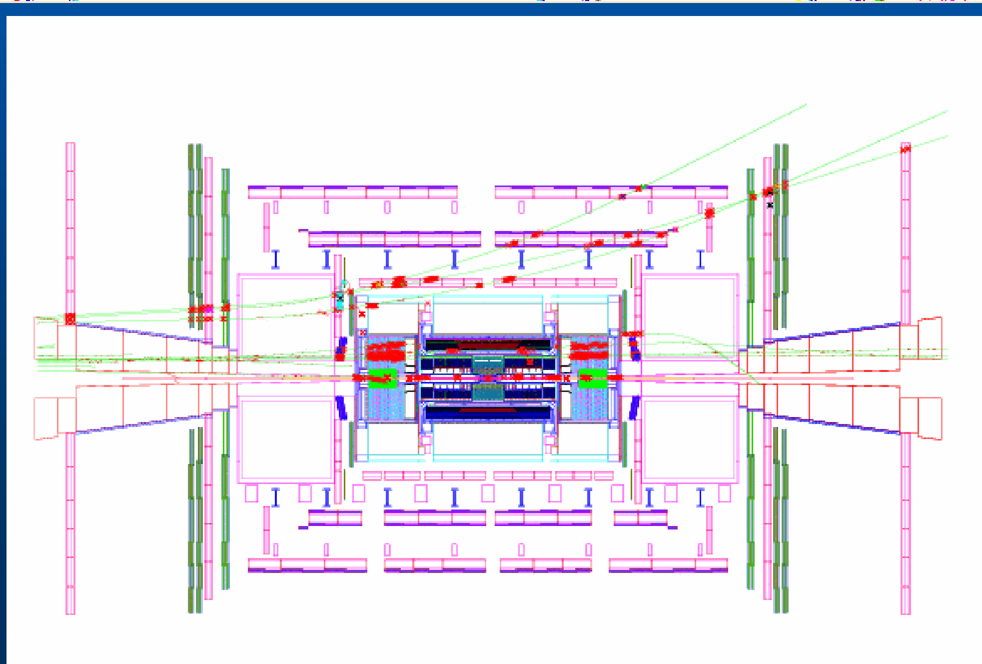
Beam-gas

- Estimated vacuum ~3 10^{-8} Torr
- 7 TeV protons on p,H,C,O..
- Vertices uniformly distributed over ±23m
- ~2500 interactions/m/s (rate ~115kHz)
- Goals: boosted min bias events →Use to check trigger backgrounds, alignment for endcap ID and forward muons(?)



Beam halo

- Low p_t particles from LHC
- Total muon rate: ~105 kHz
  - E_μ>10 GeV ~16 kHz
  - E_μ>100 GeV ~1kHz
  - E_μ>1 TeV ~10 Hz
- Goals: Use to check dead channels, initial alignment, inter-calibration



Commissioning with first collisions

Initial Detector

- Reduced acceptance for Transition Radiation Tracker (TRT) over $|\eta|<2$ (instead of 2.4)
- Deferrals of HLT/DAQ processors → LVL1 output rate limited to 35KHz (instead of 75kHz)
- Impact on physics: significant, but not excessive. Main loss in reduced B-Physics program (muon p_T threshold ~6 GeV → ~14-20 GeV)

Goal: Understand trigger and initial detector with real events

Strategy

Sub-det	Expected on day 1	Samples
ECAL uniformity e/γ en scale	1% 1-2%(?)	Min Bias, $Z \to e^+e^-$ $Z \to e^+e^-$
HCAL uniformity Jet scale	2-3% <10%	Single pions, QCD jets Z/γ ($\to ll$) +1j; $W \to jj$ in tt
Tracker Alignment	20-500 μm in Rφ	$Z \to \mu^+\mu^-$

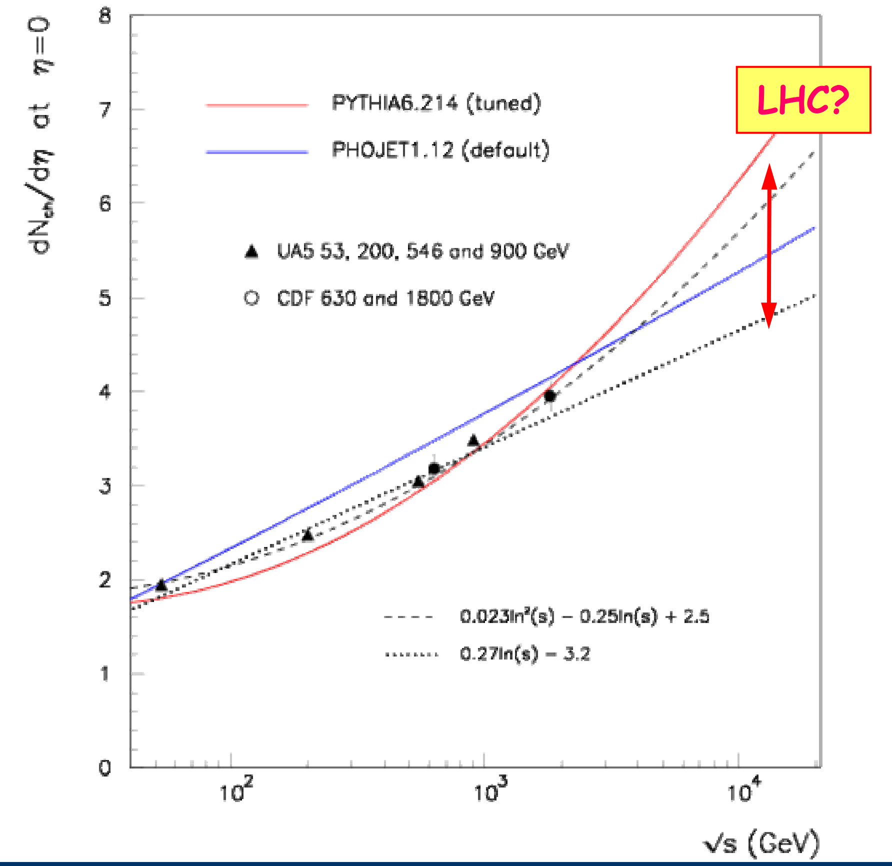
Also usable

- Z/γ+jets for inter-calibration (cracks and DM)
- E/p for single hadrons: mainly from tau decays

Gaining confidence : minimum bias

- Example of "very early" physics: only need a few thousands interactions
  - "Soft" part of pp interactions not described by PQCD → Worthy of study on their own: provide insight into structure of proton
  - Unavoidable background to all physics channels
- Measure typical quantities using full ATLAS chain:
  - $dN_{ch}/d\eta$
  - dN_{ch}/dp_T
- Large uncertainty track densities!

- Plan to Install dedicated minimum bias scintillator trigger in ATLAS



Multiple interaction model in PHOJET predicts a ln(s) rise in energy dependence. PYTHIA suggests a rise dominated by the $\ln^2(s)$ term.

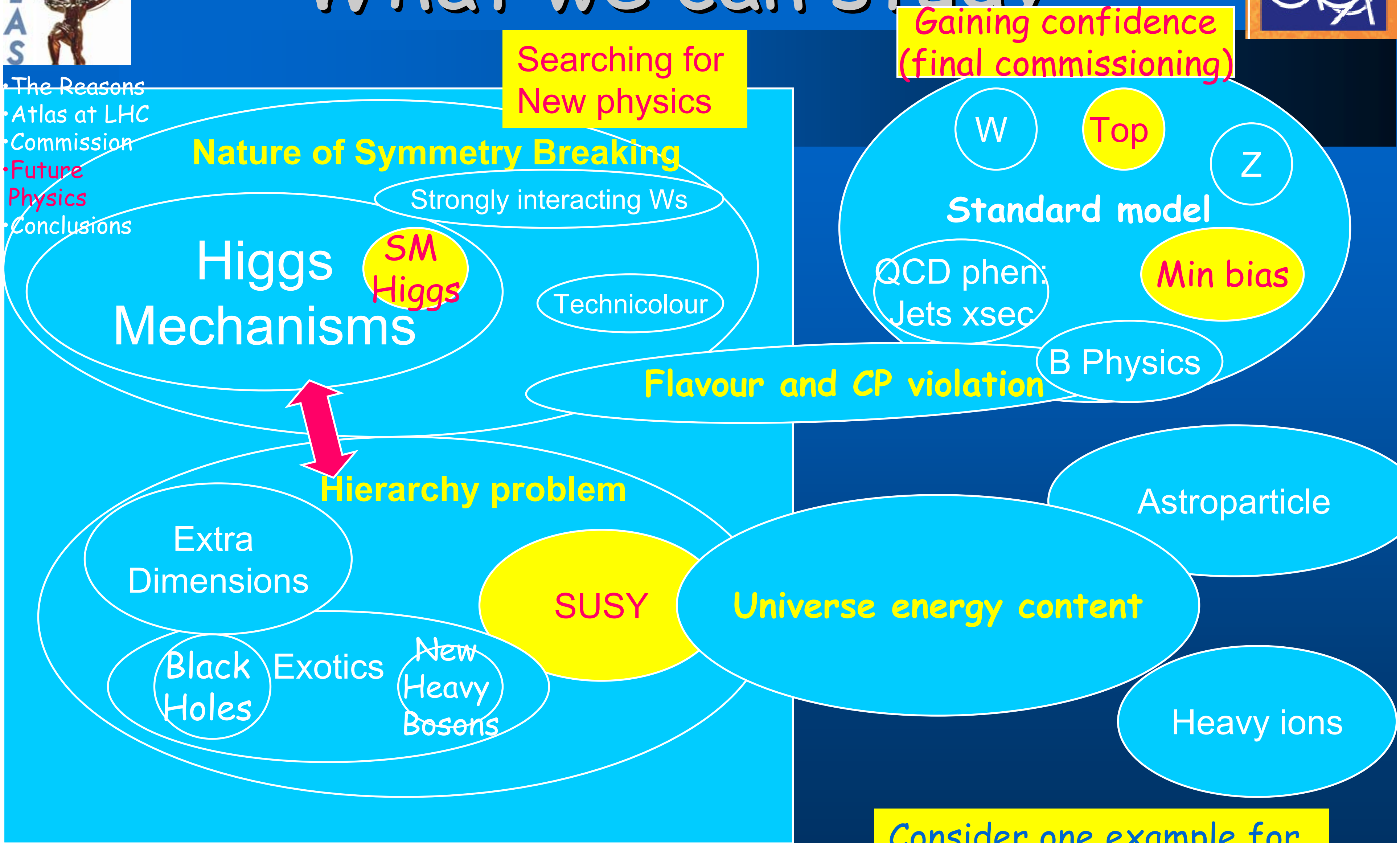
The Expected Physics Reach: where do we go from here?

The Program

- What we need: commissioned detector
- What we can search: vast number of things
- What do we start with?: a) things to give us confidence (SM) b) things that are "easy" to find
- What do we continue with?: c) unexplored avenues (even more if simple ones fail) d) harder and more exotic things
- Order is logical one, some steps after a) can/should go in parallel

What we can study

- The Reasons
- Atlas at LHC
- Commission
- Future Physics
- Conclusions



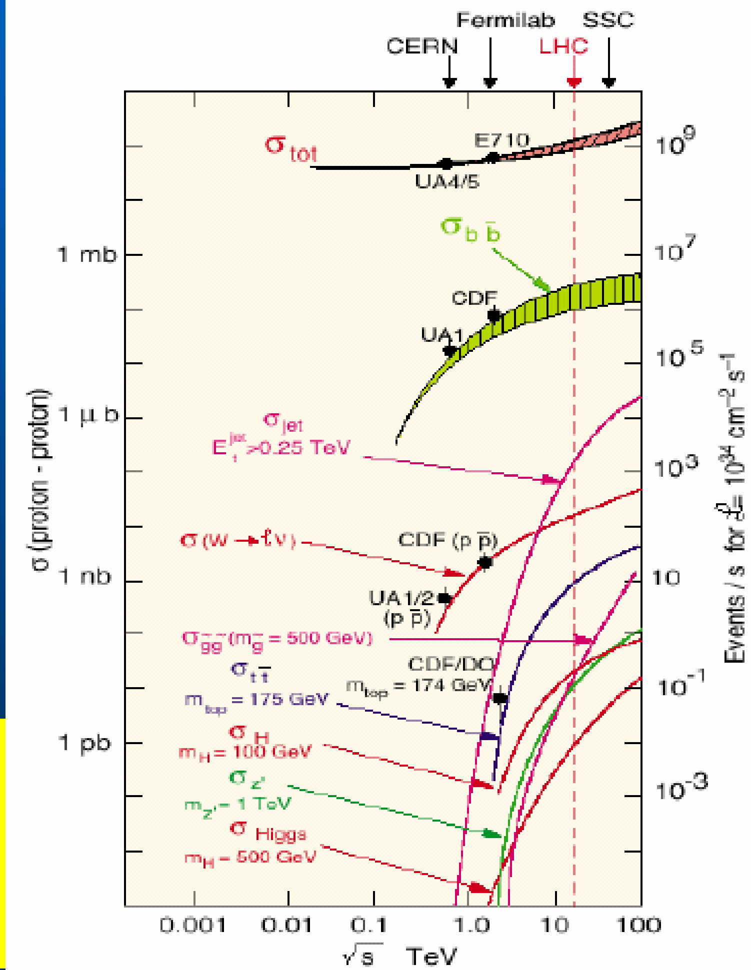
Consider one example for highlight

Add stuff from PDG…

ATLAS: doing physics with the trigger

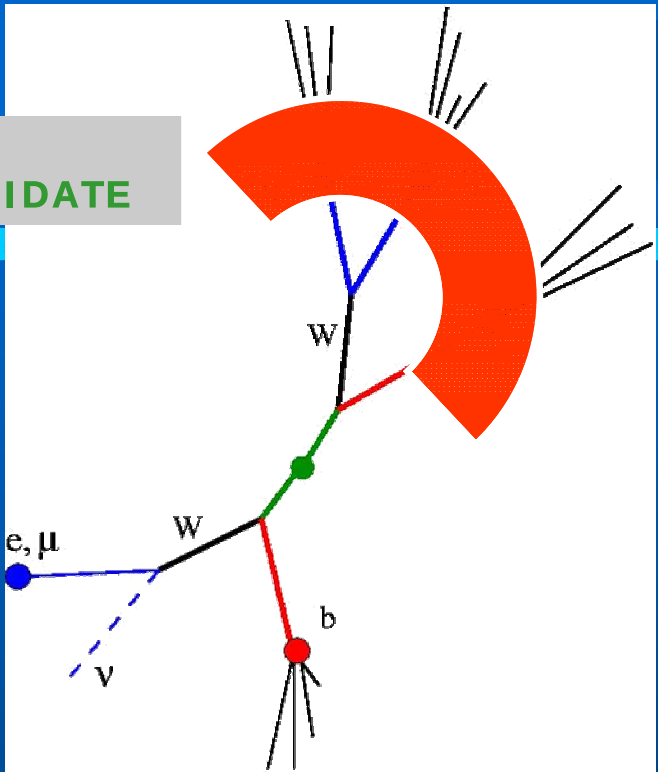
Process	Ns^{-1} ($L=10^{33}cm^{-2}s^{-1}$)	Events/year ($\mathcal{L}$ = 10 fb^{-1})
Min Bias (inelastic)	10^9	$\sim 10^{16}$
Inclusive jets p_T > 200 GeV	100	$\sim 10^9$
$W \to e\nu$	15	$\sim 10^8$
$Z \to e^+ e^-$	1.5	$\sim 10^7$
tt	~1	$\sim 10^7$
bb	$\sim 10^6$	$\sim 10^{12}$-10^{13}
H (m_H~ 130GeV)	0.02	10^5
$\tilde{g}\tilde{g}$	0.001	10^4
Di-bosons	10^{-3}	$\sim 10^4$

- **LHC is a factory for SM processes: QCD, heavy flavours (top,bottom), gauge bosons (W,Z)**



Statistics: **Throw out 99.9995% of events** (record 200 Hz out of 40 MHz) **and still have enough for precision measurements ! Need to understand trigger efficiencies**,detector (→syst.)

Gaining confidence: Top Physics



σ_{tt} (tot) = 825 pb
BR(e,μ+jets) ~ 30%

→ ~850 events/hour

Reconstruction

Hadronic top:

Three jets with highest vector-sum P_T as the decay products of the top

W boson:

Two jets with highest momentum in reconstructed jjj C.M. frame.

Selection:

Missing E_T > 20 GeV
1 lepton P_T > 20 GeV
4 jets P_T > 40 GeV

→ 1500 tt→bW(lν)bW(jj)/day at low L (=$10^{33}cm^{-2}s^{-1}$)

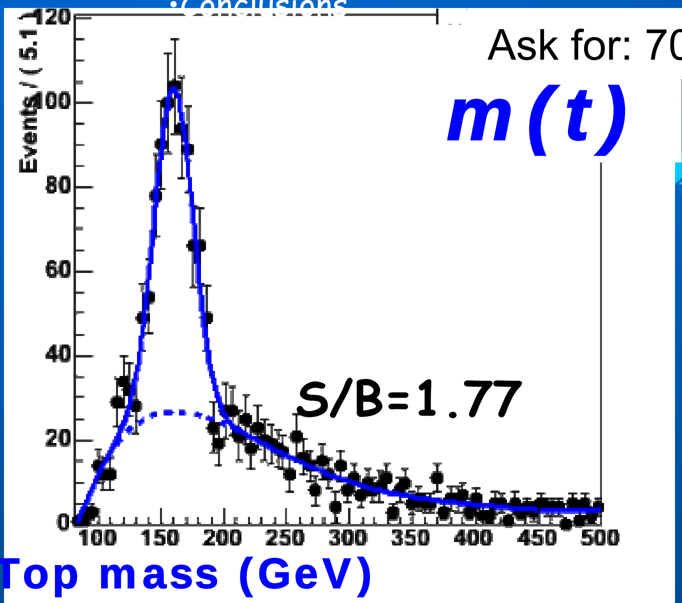
Selection efficiency = 5.3%
Trigger efficiency not accounted for yet

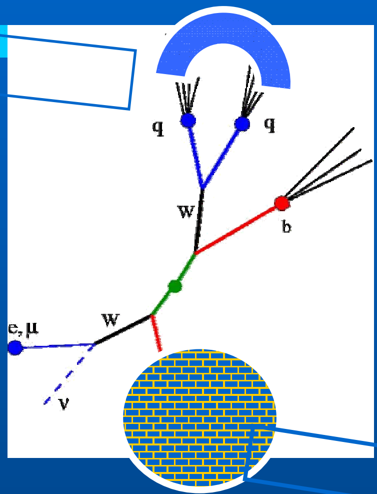
Assume no b-tag! →

Gaining confidence: Using "purer" Top samples

ATLAS PRELIMINARY

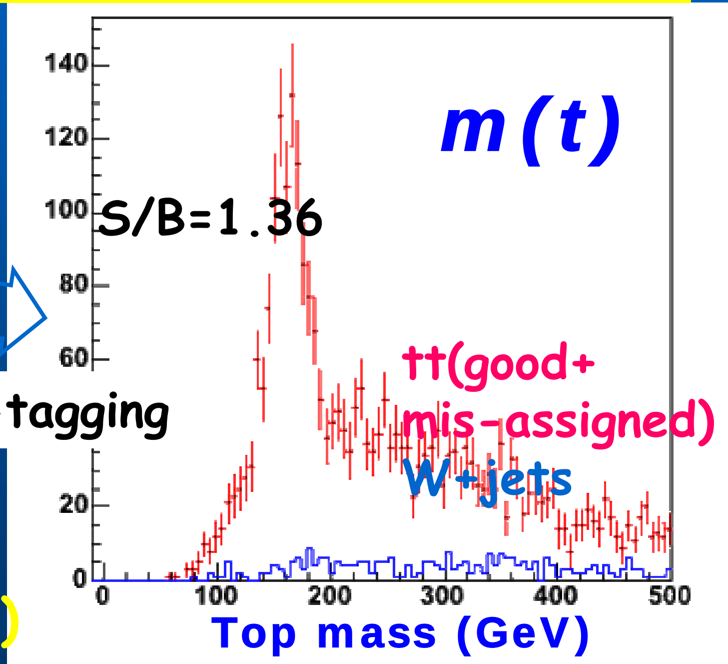
Ask for: 70 < M(jj) < 90 GeV





Top peak clearly visible after 1 week of LHC data

300 pb^{-1} (1 week @ 10% L_{max})



Initial Use of Top

Use b-tagging

- Check top mass (to ~7 GeV)
  - If b-jet en scale known to 10%
- Check jet energy scale using M_W (and M_{top})
- Gold plated sample for b-tagging commissioning
- Initial check on tt cross section (bkg to many searches)
  - luminosity meas. limits precision to 10%

Final goal: ΔM_{top}~2GeV if jet en. scale known to 1%

Mass: SM Higgs around LEP limit

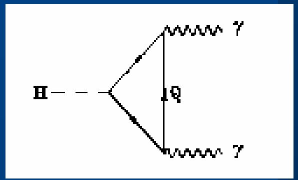
- Begin with counting experiment: signal out of bkg in mass dist.
- Significance=#signal/√(#background)
- Carefull: usually using LO predictions for signal (NLO increase) "conservative"

- If M_H ~LEP lower limit (~115-125 GeV), discovery is difficult; need to combine three complementary channels

$H \to \gamma\gamma$

σxBR~1.2pb

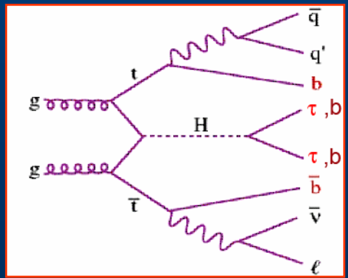
- extract signal from irriducible $\gamma\gamma$ and QCD di-jet fakes
- Need 1% resolution on M_H; excellent $\gamma/e/\pi^0$ separation



$ttH \to ttbb \to 6j+l\nu$

σxBR~0.3pb

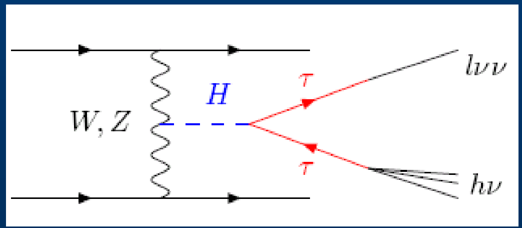
- Complementary to $H\gamma\gamma$
- 6jets(4b) → b-tagging is crucial to reduce ttjb and ttjj bkgs
- Irreducible ttbb



$H \to \tau\tau$

σxBR~0.36pb

- Need efficient jet-rec over|η|<5 to tag forward jets + Veto additional central jets
- missing E_T rec.:crucial

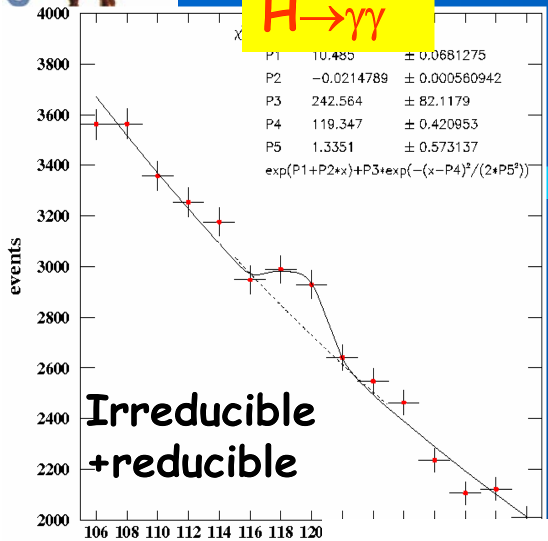


Mass: SM Higgs around LEP limit

M_H=120 GeV - L_{int}=30 fb^{-1}

ATLAS PRELIMINARY

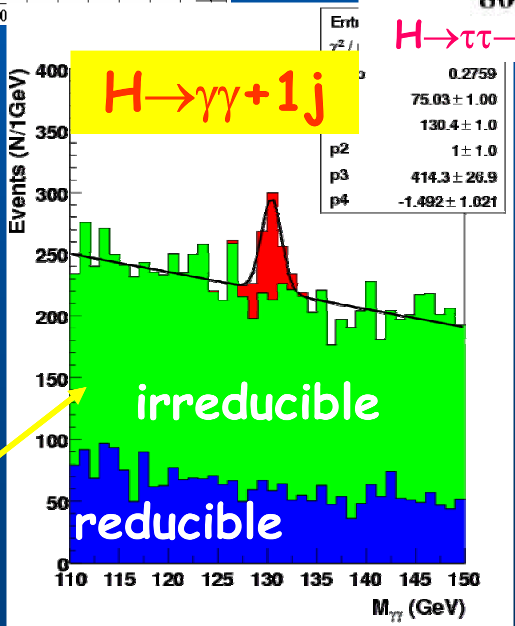
H→γγ



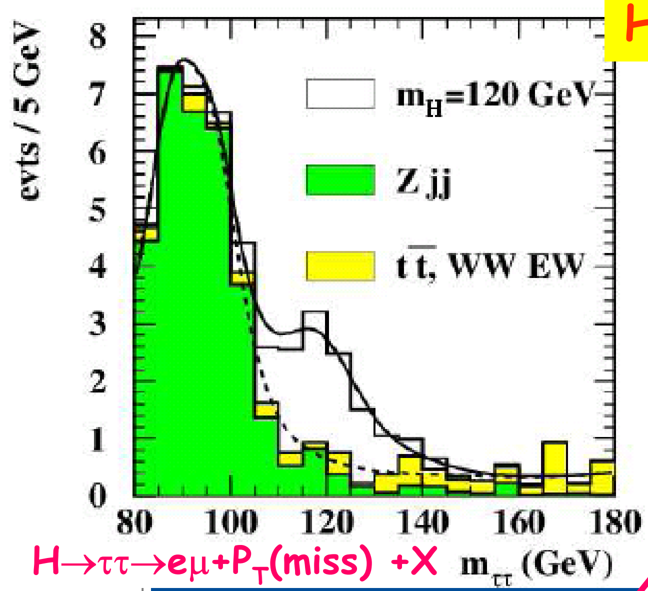
- Signal and BKG at NLO
- Get isolated photons
- Bkg from sidebands
- S/√B~3.9

may improve by requiring 1 additional jet

H→γγ+1j



H→ττ



H→ττ→eμ+P_T(miss) +X

S/√B~5.7

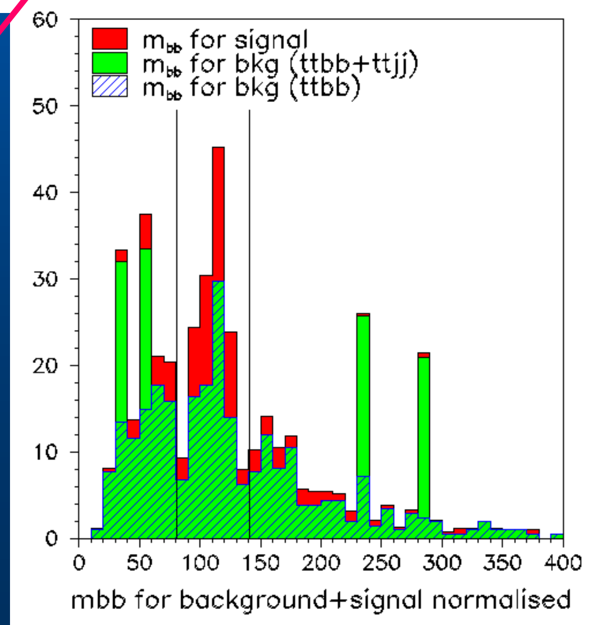
- Tag forward (Δη>4.4) jets and veto additional central jets→ large bkg reduction
- M(ττ): only from E_T^{miss} and τ decays

Need control over bkg normalization and shape

ttH→ttbb

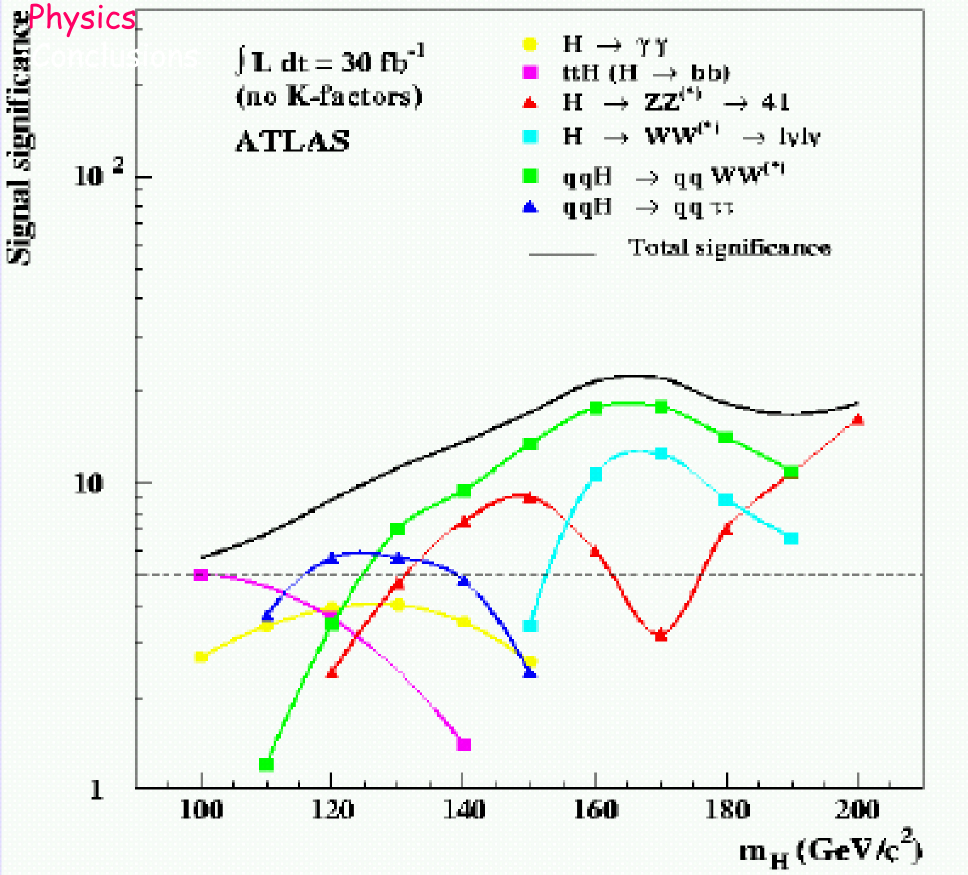
S/√B~3.6

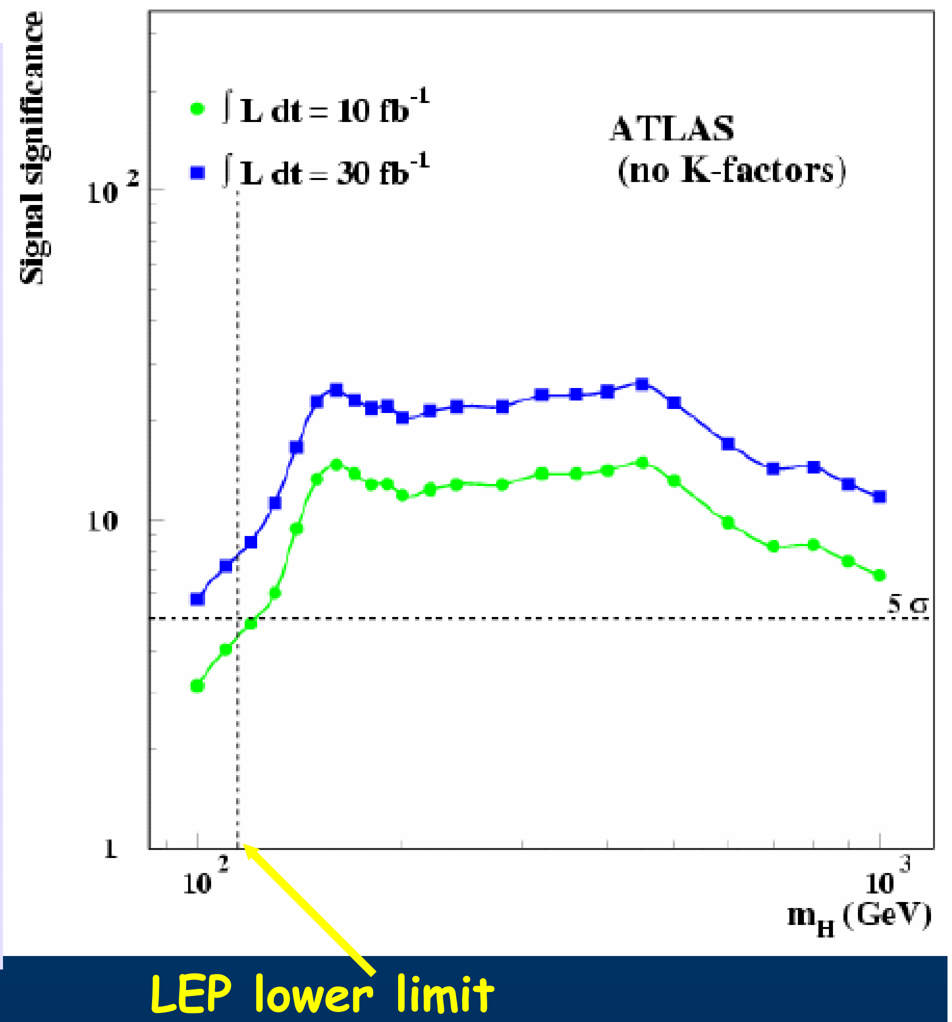
- Including realistic b-tagging
- Use likelihood for jet pairing



Mass: SM Higgs full discovery potential

The first good year of data taking at low luminosity (~ first good 10fb^{-1}) can still deliver the SM Higgs, but discovery is more difficult close to the LEP limit





Hierarchy: SUSY

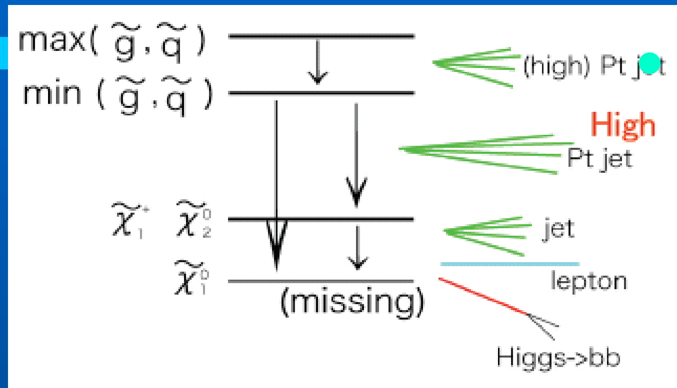
Nutshell SUSY

- SUSY: fermion-boson symmetry → all SM particles have SUSY partners with Δspin=1/2
- no evidence for m(SM)= m(SUSY)→ models for SUSY breaking (MSUGRA,GMSB,AMSB)
- R parity (no proton decay)→ SUSY particles pair-produced and decay to stable lightest SUSY particle

Pheno

(MSUGRA as example)

Copious gluino/squark production then cascade dec



Event topology:

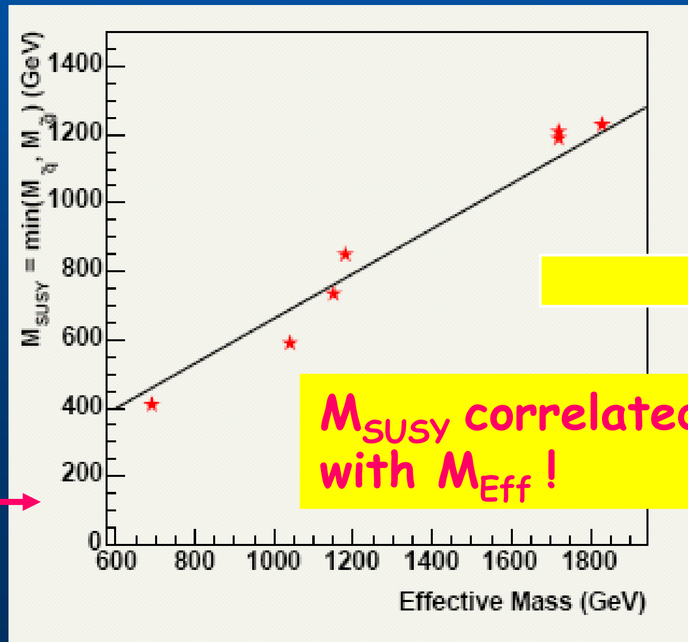
- Large missing ET
- Large multiplicity of High P_T jets
- Possibly leptons

Strategy

- Inclusive searches to extract SUSY excess from bkg

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

- Measure kin. edges in chain decays to determine SUSY masses and parameters



M_{SUSY} correlated with M_{Eff} !

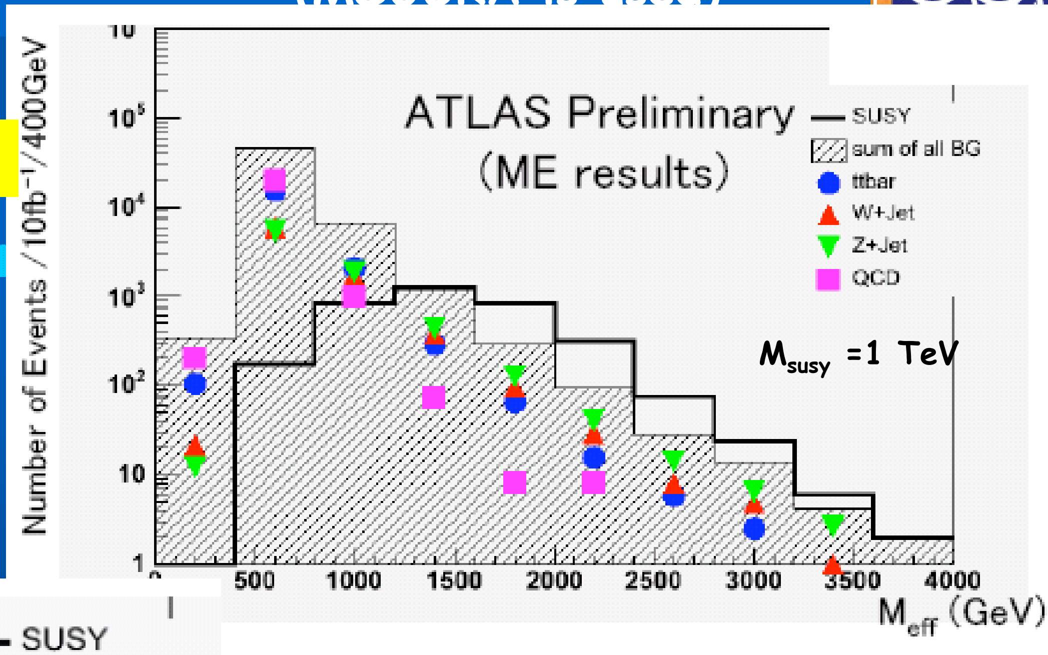
Hierarchy: SUSY Inclusive searches

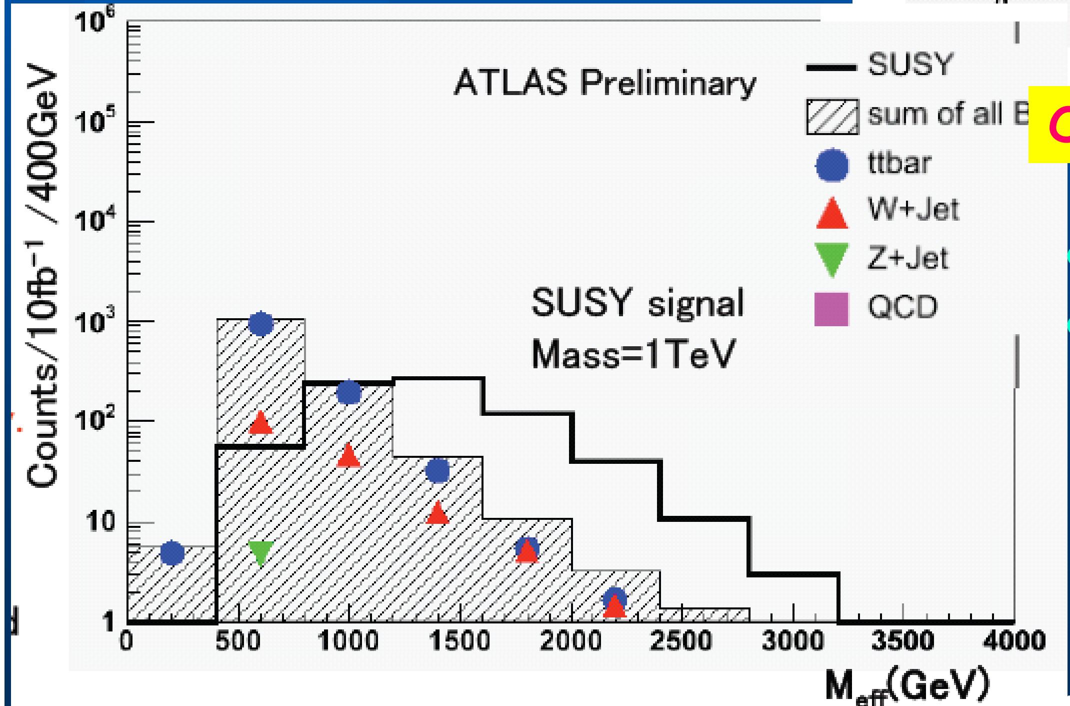
(MSUGRA is used)

Build M_{Eff} distributions
(P_T(jet)>20 GeV)

No leptons in final state

- Better estimate of high pt jets bkg by matching parton shower and matrix element description
- SUSY slope similar to SM bkg →careful bkg estimation is required





One lepton in final state

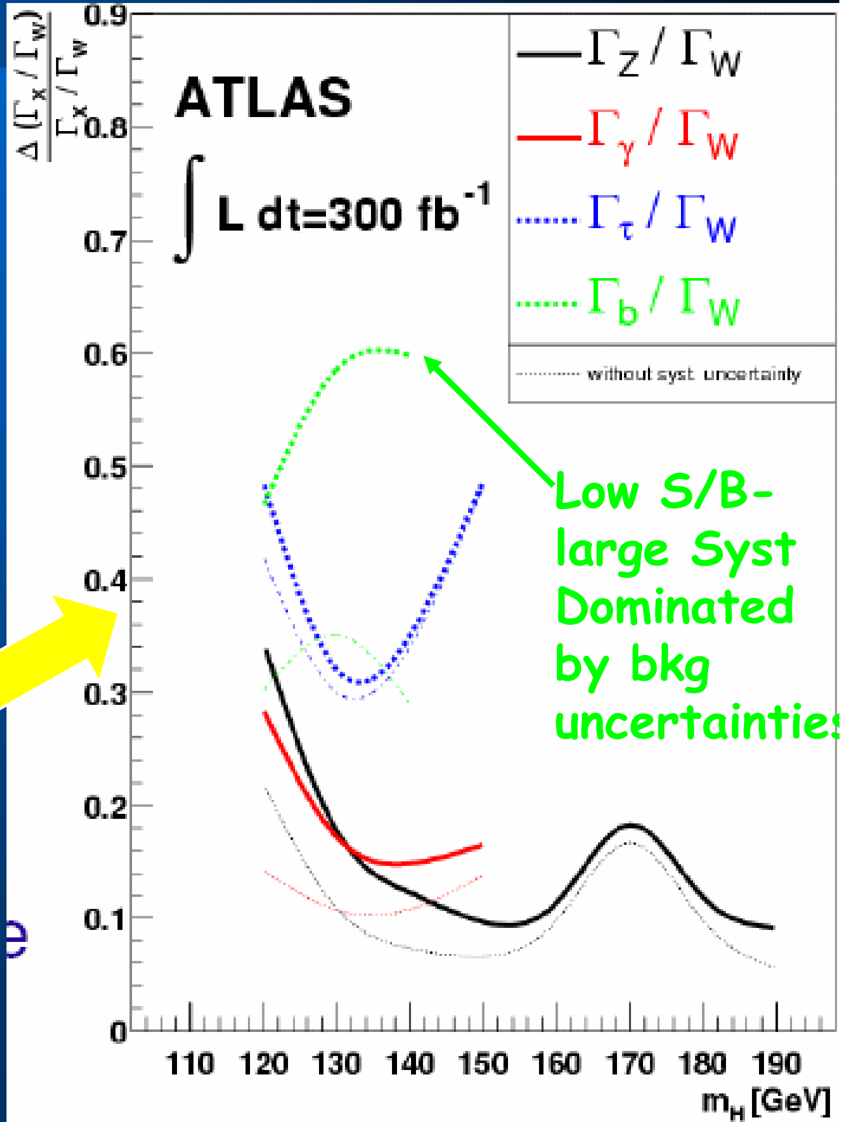
- Very promising for clean discovery
- Top is dominant bkg: more under control

Estimate SM Bkg from data. Normalize MC to low E_T miss and extrapolate to high E_T^{miss}

ATLAS PRELIMINARY

Ultimate performance example: Higgs parameters

- Higgs Mass can be measured with good resolution for all m_H($1^0/_{00}$ for)
- Non SM spin/CP (0/1) hypothesis can be ruled out with 100fb for m_H>230 GeV
- Coupling constants could be measured combining all available signals with a precision of 10-50% with 300 fb^{-1} of data
- Higgs self coupling might be accessible at an upgraded SLHC

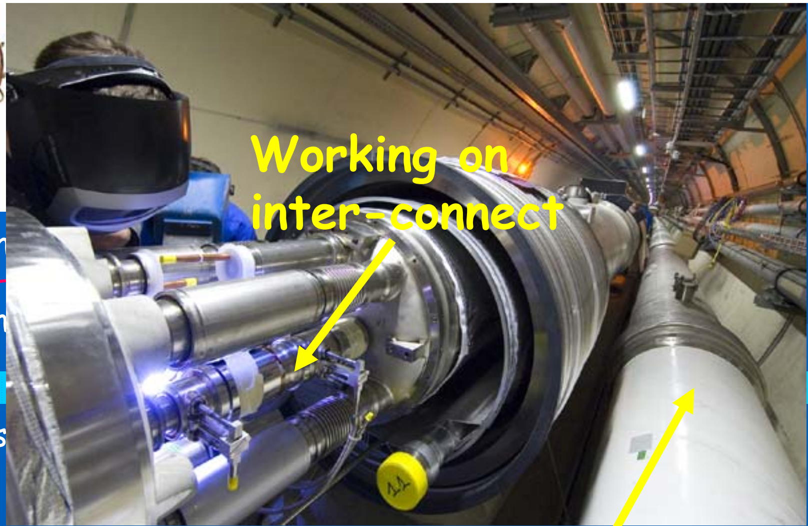


Conclusions

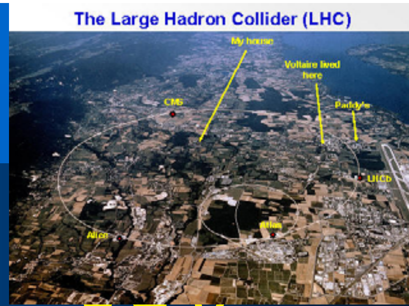
- ATLAS is a multi-purpose detector well poised to take advantage of the wealth of physics at LHC
- Installation for both ATLAS and LHC is progressing well
- Commissioning activity will be essential to
  - understand the detector
  - mark the smooth transition to measuring the SM @ $\sqrt{s}$=14 TeV
  - solid starting point to search for new physics
- ATLAS is well equipped to search for physics beyond the SM, even in difficult areas
- The scientific community is eager to test its view of the universe and discover more about it. 2007 is not far away!

Back-up Slides

LHC



Cryo service line



Technical Challenges

- Control Large beam current (0.53A) in superconducting environment (T~2K) to avoid magnet quench from beam losses
- Reach high luminosity: curb beam-beam and collectivge instability losses ; stabilize beam against non-linear effects of magnetic forces
- Flexibility for further upgrades
- 8 independent sectors to manage
- Deal with 10GJ stored in magnets,

Parameters

- Max. energy: 7 TeV (~7 X Tevatron)
- $1.1 \cdot 10^{11}$ protons per bunch
- Filled bunches: 2808 / 3564
- Bunch spacing: 24.95 ns
- Lumi: 10^{34} cm^{-2} s^{-1} (>100 X Tevatron)
- 1232 superconducting dipoles (15m long at 1.9 K, B=8.33 T);
- Circumference: 26.659m
- E_{beam}(Stored)=350 MJ (200 x Tevatron)
- Operation with Heavy ions at 2.7 TeV /nucleon

Status

- 1000/1650 main magnets delivered
- ~100 dipoles installed
- Installation: cryogenics service line + magnets are "critical to maintain the schedule" (L.Evans 12/09/05)

Updated status is at:
http://lhc-new-homepage.web.cern.ch/lhc-new-homepage/DashBoard/index.asp

LHC: more basics and facts

- 100 GeV electrons looses 2.9 GeV
- dE(turn)=2pi/ x Pcirc
- A 500 GeV electron will loose all its energy after going along ~27% of LEP

Particles used: Protons and heavy ions (Lead, full stripped 82+)
Circumference: 26,659 m.
Injector: SPS
Injected beam energy: 450 GeV (protons)
Nominal beam energy in physics: 7 TeV (protons)
Magnetic field at 7 TeV: 8.33 Tesla
Operating temperature: 1.9 K
Number of magnets: ~9300
Number of main dipoles: 1232
Number of quadrupoles: ~858
Number of correcting magnets: ~6208
Number of RF cavities: 8 per beam; Field strength at top energy ~5.5 MV/m
RF frequency: 400.8 MHz
Revolution frequency: 11.2455 kHz.
Power consumption: ~120 MW
Gradient of the tunnel: 1.4%
Difference between highest and lowest points: 122 m.

Main dipoles:1232
Main quadrupoles:430
Total main magnets:~1650

LHC Statistics

Conclusions

Lyn Evans
12th September 2005
Scientific Policy Committee
CERN

- Main objectives:
  - terminate installation in February 2007
  - first collisions in summer 2007
- The industrial production of standard components is compatible with this objective.
- The ramping up of QRL activities and magnet installation is critical to maintain this schedule.
- Additional actions have been implemented to ensure proper QRL production and installation rates.
- The installation and interconnection of cryomagnets have started in the tunnel.
- The commissioning of technical systems will take place in two adjacent sectors in parallel.
- Main next actions:
  - partial test of sector 7-8 in autumn 2005
  - commissioning test of the two first sectors (7-8 and 8-1) in summer 2006
  - find external collaborators to help with commissioning.

Inclusive Selection Signatures

- To select an extremely broad spectrum of "expected" and "unexpected" Physics signals (hopefully!).
- The selection of Physics signals requires the identification of **objects** that can be **distinguished** from the high particle density environment.

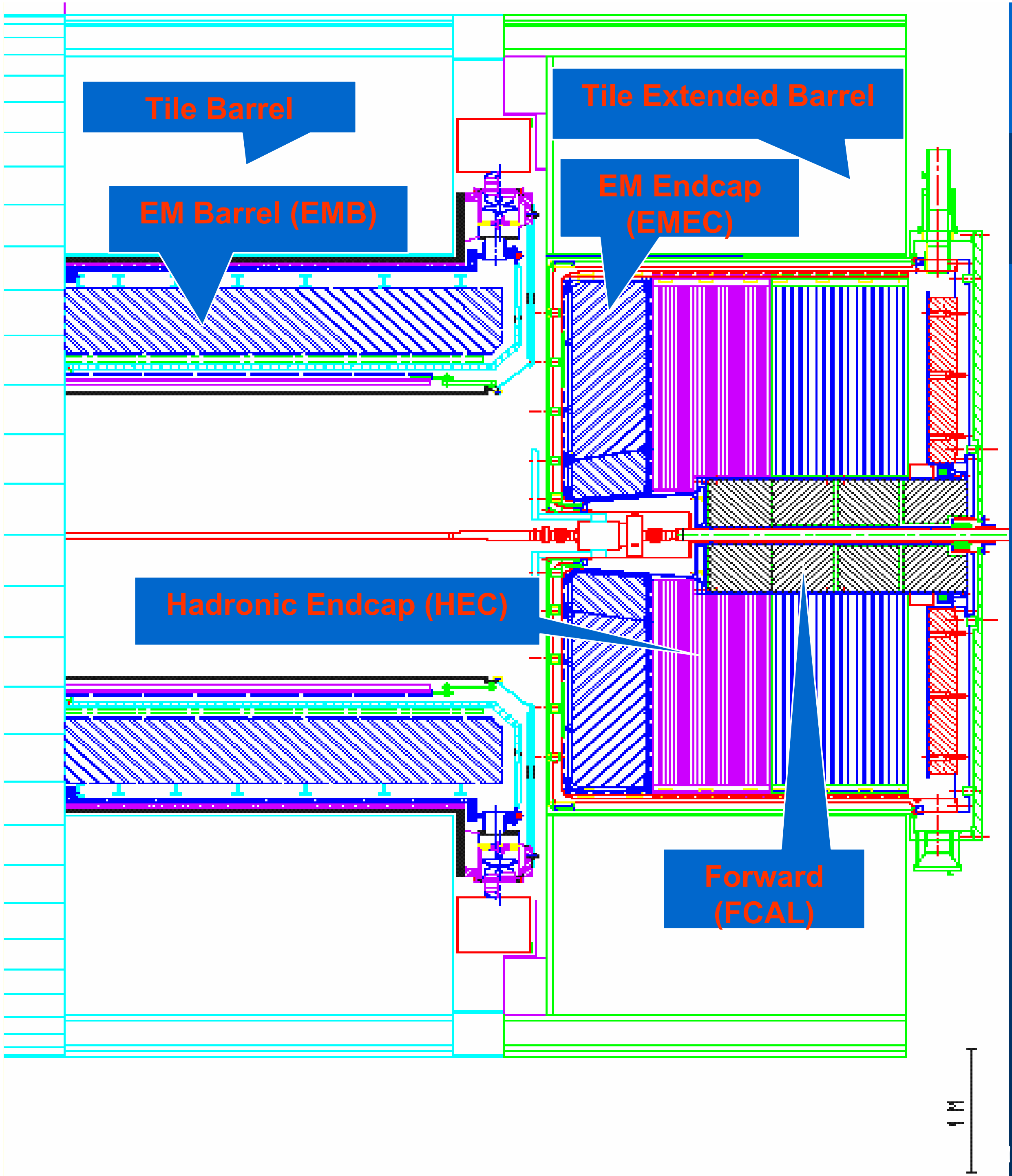
Object	Examples of physics coverage	Nomenclature
Electrons	Higgs (SM, MSSM), new gauge bosons, extra dimensions, SUSY, W/Z, top	e25i, 2e15i
Photons	Higgs (SM, MSSM), extra dimensions, SUSY	γ60i, 2γ20i
Muons	Higgs (SM, MSSM), new gauge bosons, extra dimensions, SUSY, W/Z, top	μ20i, 2μ10
Jets	SUSY, compositeness, resonances	j360, 3j150, 4j100
Jet+missing E_T	SUSY, leptoquarks, "large" extra dimensions	j60 + xE60
Tau+missing E_T	Extended Higgs models (e.g. MSSM), SUSY	τ30 + xE40

also inclusive missingET, SumET, SumET_jet

& many prescaled and mixed triggers

The list must be non-biasing, flexible, include some redundancy, extendable, to account for the "unexpected".

M. Bosman
ATL Phys
Work June05



ATLAS Calorimetry

- EM LAr-Pb :
  - Barrel (EMB): |η| < 1.5
  - EndCap (EMEC): 1.4<|η|<3.2
- Hadron Calorimeters
  - Barrel (Tile) Scintil.-Steel: |η|<1.7
  - End-Cap (HEC): LAr-Cu 1.5<|η|<3.2
- Forward Calorimeter 3.2 <|η|< 5.0
  - Fcal1: LAr-Cu
  - Fcal2&3: LAr-W

Variety of materials, techniques, granularity, different performances

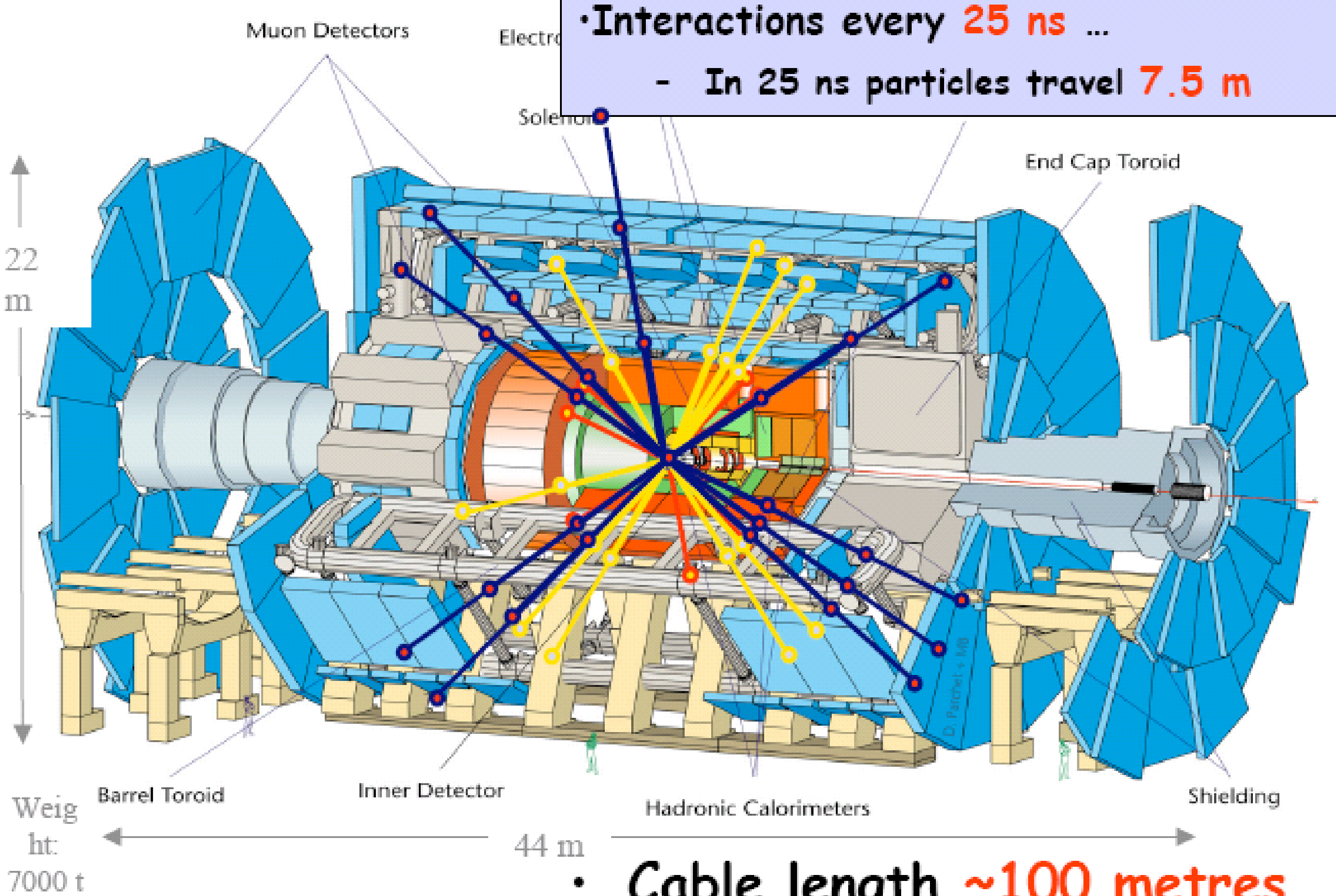
↓

Need coherent view!

Physics challenges at the LHC

Time-of-flight

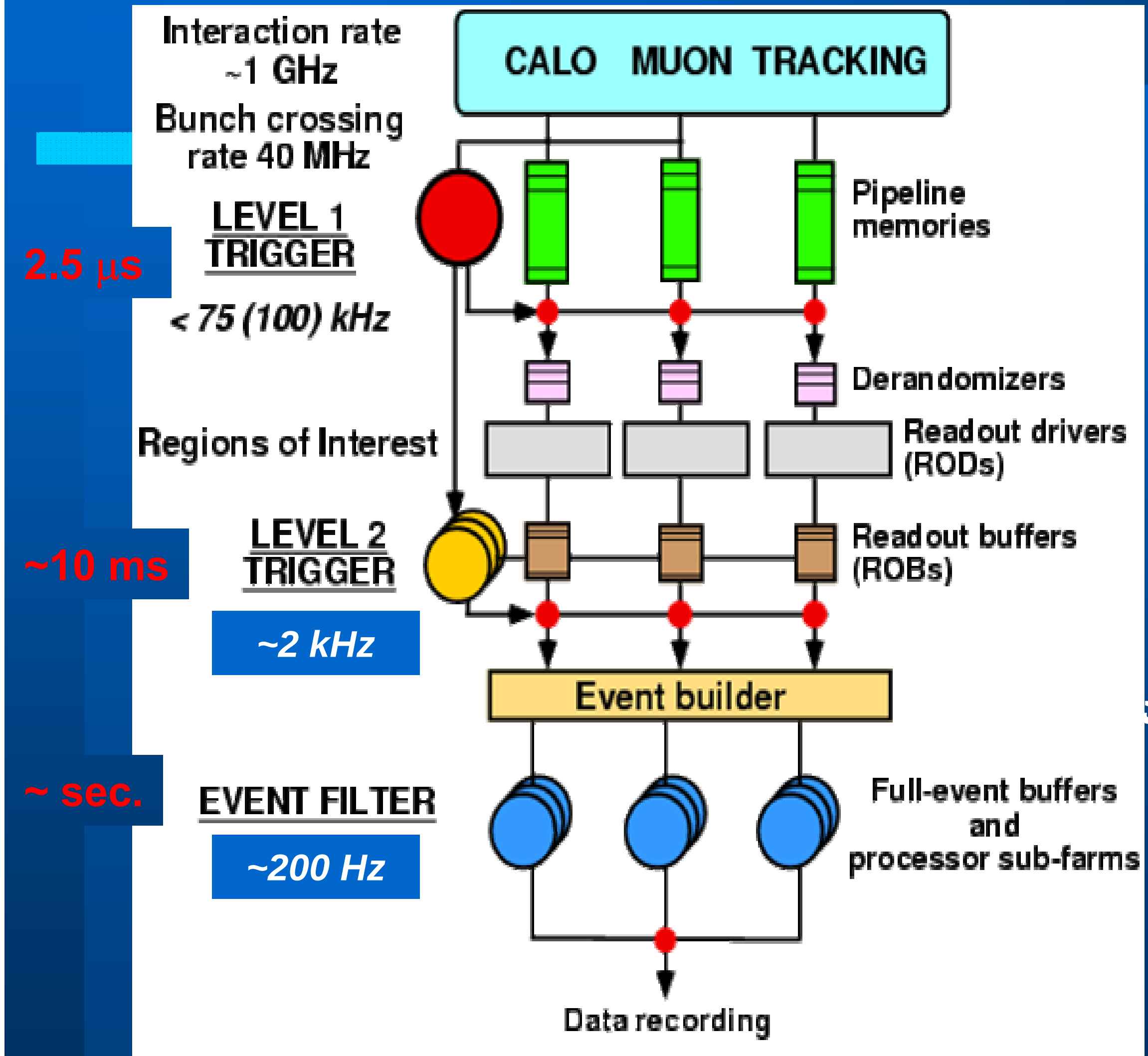
- Interactions every 25 ns …
  - In 25 ns particles travel 7.5 m



- Cable length ~100 metres …
- In 25 ns signals travel 5 m

D. Froidevaux, TRDs for the Third Millenium, Ostuni, 08/09/2005 15

ATLAS Three Level Trigger Architecture



hardware

- **LVL1 decision** made
  with **calorimeter** data with relatively coarse granularity
  and **muon trigger chambers** data.
  - Buffering on detector

software

- **LVL2 uses Region of Interest data** (ca. 2%)
  with full granularity
  combines information from all detectors
  performs fast rejection.
  - Buffering in ROBs
- **EventFilter** refines the selection
  can perform **event reconstruction** at full granularity
  using latest alignment and calibration data.
  - Buffering in EB & EF

CTB04- Summary of alignment & calibration

- Alignment corrections for the complete Pixel+SCT+TRT slice available in Athena from database
  - Alignment accuracy of corrections obtained with B=0 better than 10(80) μm for Si(TRT)
  - Residual distributions comparable to MC
- LAr calibration constants available in Athena from database
  - Harder environment than ATLAS: temperature problems, many timing changes etc.
  - Electronic calibration well understood (OFC)
  - Started "high level" calibration (cluster corrections etc.)
- MS alignment corrections available in Athena from database
  - Accuracy of relative alignment for both barrel and endcap obtained from optical systems ~20μm
  - For absolute alignment (optical systems) sagitta mean value of 350 μm for barrel and 150 μm for endcap
  - Reconstruction of tracks allows backtracking to Inner Detector with rms of 44mm (over 40m)

R Petti
ATLAS
Phys Plenary
June 05

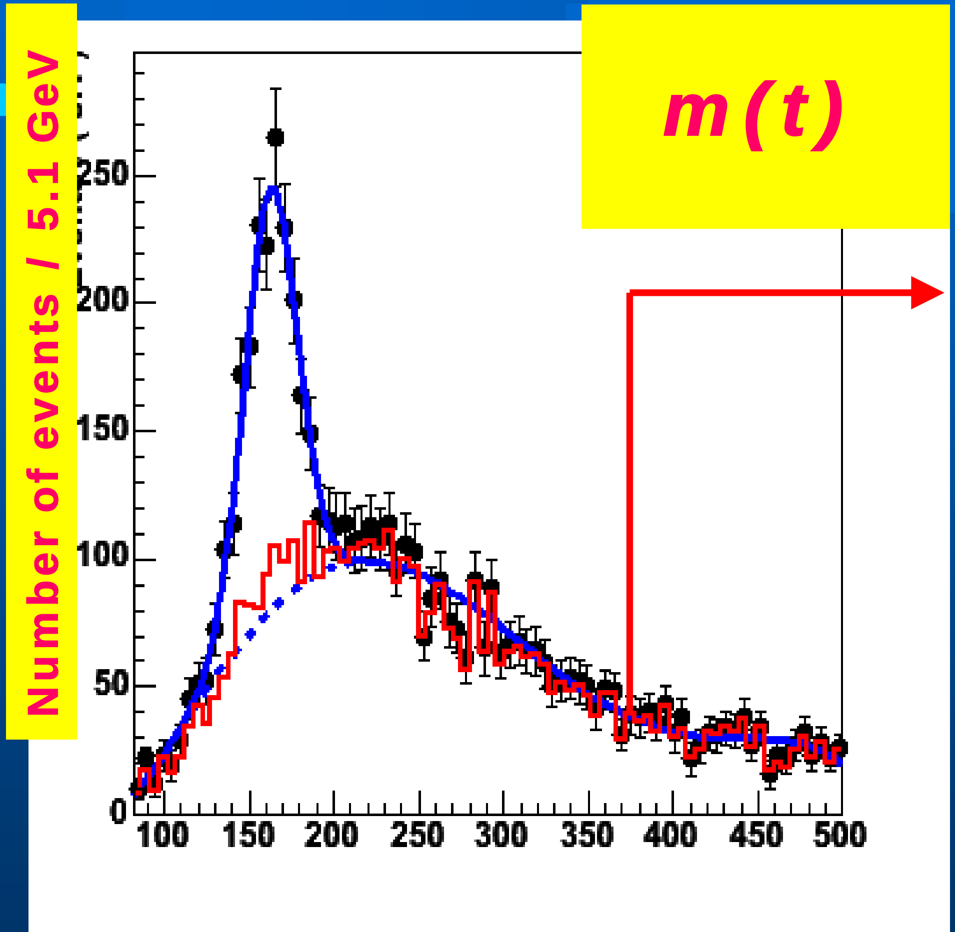
TileCal Standalone resolution

P. Johansson

- Fit function : $\sigma/E = a/\sqrt{E} \oplus b$
- For extended barrel (1997) geometry was different

	2004 Combined TB		1997 and 1998 standalone TB	
η	a [%] $GeV^{1/2}$	b [%]	a [%] $GeV^{1/2}$	b [%]
0.25	54 ± 1	5.9 ± 0.1	59.10	5.40
0.35	57 ± 1	5.6 ± 0.1	56.30	6.88
0.45	54 ± 1	5.4 ± 0.1	56.50	5.35
0.55	50 ± 2	5.3 ± 0.1	55.20	5.10
1.1	43 ± 5	5.0 ± 0.4	46.7	5.34
1.2	52 ± 6	5.4 ± 0.5	43.7	4.8

Top Physics: Check combinatoric bkg using MC@NLO signal Monte Carlo



Definition

Subset of events where chosen 3-jet combination does not line up with top quark (using MC truth information)

Empirical background shape describes combinatoric background well under peak

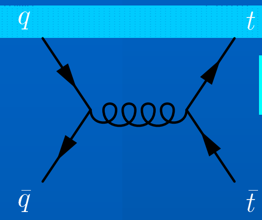
I Van Vulpen
ATLAS Phys Workshop
June 05

Top Physics: Production at the LHC

Strong tt pair production

EW single top quark production

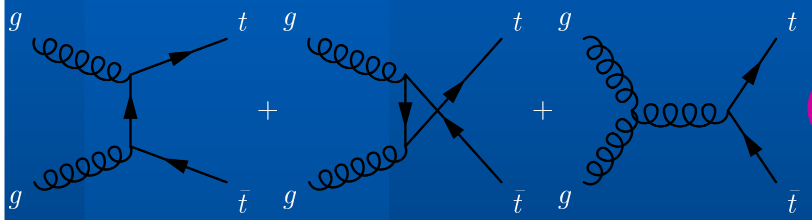
M Cobal ATLAS Phys Workshop June05



$q\bar{q} \to t\bar{t}$

(13%)

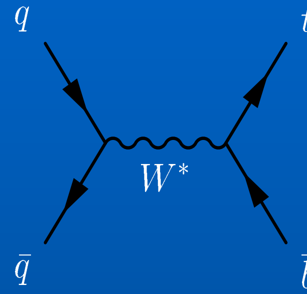
$gg \to t\bar{t}$



(87%)

σ_{tt}(th)=**825±150 pb**

NNLO-NNNLL: Kidonakis, Vogt, PRD 68 (03) 114014

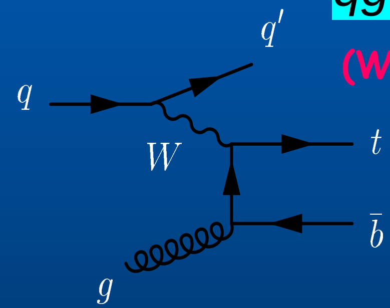


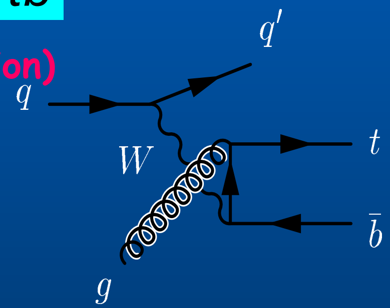
$q\bar{q} \to t\bar{b}$

(Drell-Yan)

$qg \to q' t\bar{b}$

(W-g fusion)





σ_{tt}(th)= $\approx$ **300 pb**

This means 8 millions tt pairs/year (1 pair/second) at low luminosity!

Top Quark decay

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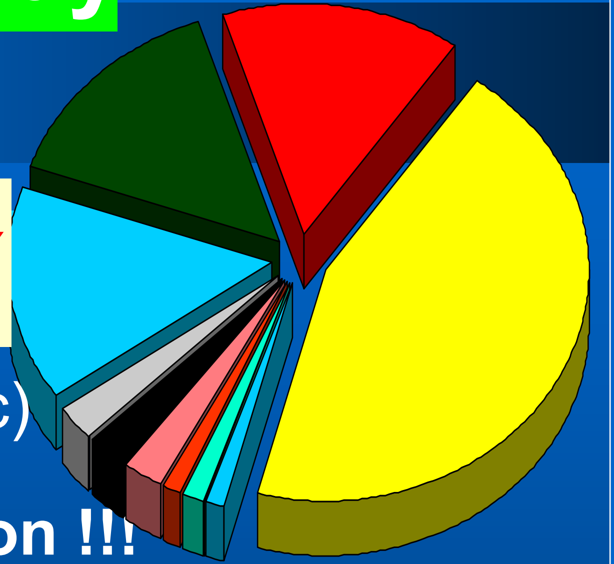
SM: by far dominant $t \rightarrow bW$

$$\frac{\Gamma(t \rightarrow bW)}{|V_{tb}|^2} \approx 0.807 \times \frac{G_F m_t^3}{8\pi\sqrt{2}} = 1.42\,GeV$$

$\tau_{top} \approx 5 \times 10^{-25}$sec << τ_{hadr} (10^{-23}sec)



Top decays before hadronization !!!

- **No tt-bar bound states (gluon exchange)**
- **W helicity from SM V-A (no depolarization)**

tt-bar samples defined via W decays } ⇒

– Dilepton channels (ee, eμ, $\mu\mu$)
topological variables and b-tagging

– Lepton + jets ch. (e+jets, μ+jets)
topological variables and b-tagging

– All hadronic channel

Top Physics: Overview of fit results

- Signal only

	Mtop (GeV)	Resolution (GeV)	σ(N) stat
Truth jets	171.1 ± 0.4	7.0 ± 0.2	6.0%
Full simulation	162.7 ± 0.8	15.8 ± 0.8	6.3%

- Adding W+jet background:

50%	164.1 ± 1.0	17.0 ± 1.5	10%
100%	165.9 ± 1.4	19.8 ± 2.8	17%

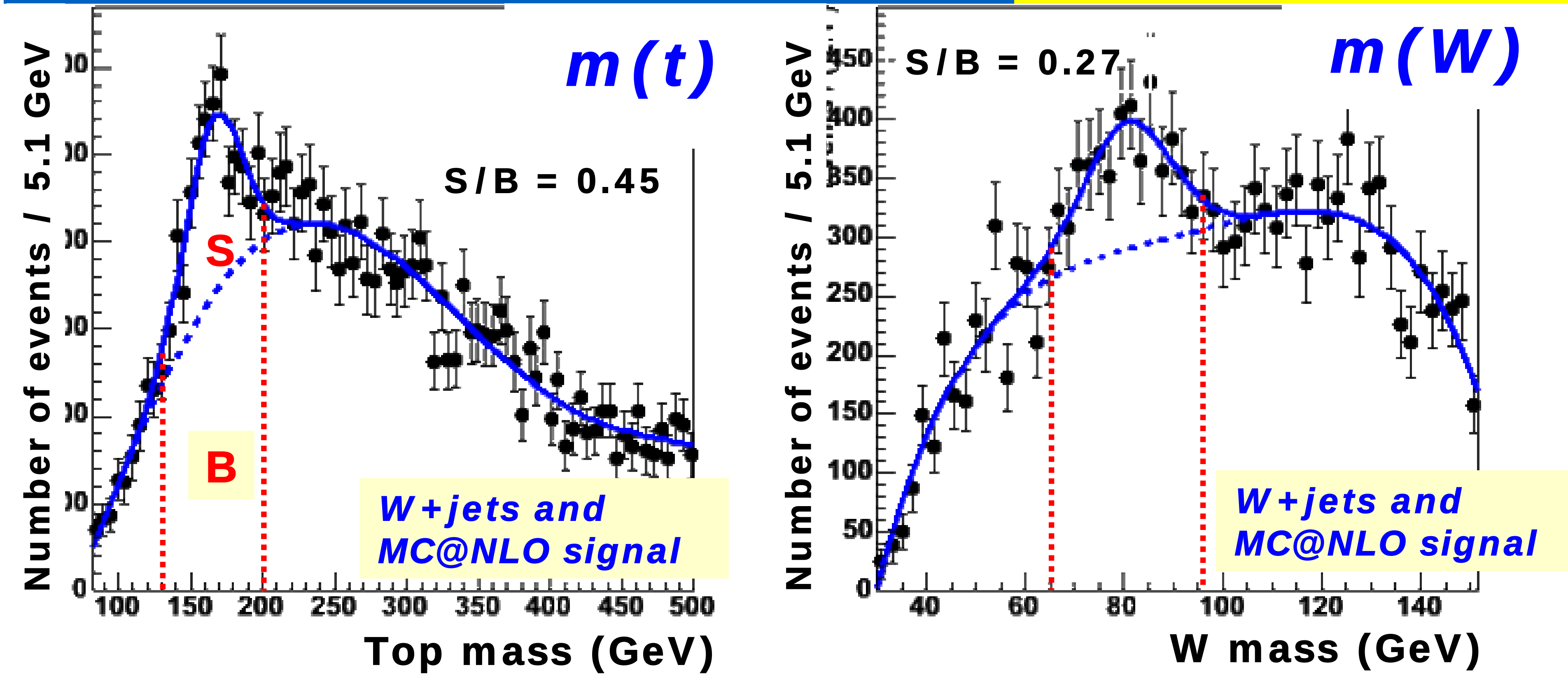
- 100% background plus cut on m(W)

Hadronic M_W= 80.4±10 GeV	160.0 ± 1.0	15.4 ± 1.2	8.3%

Gaining confidence: Top Physics Masses + W+4jets background

Observe both top and hadronic W peaks!
No b-tag assumed!

ATLAS PRELIMINARY
300 pb^{-1}(1 week @ 10%L_{max})



Background = W+jets events (large , with large uncertainty) *and* improperly reconstructed ttbar events

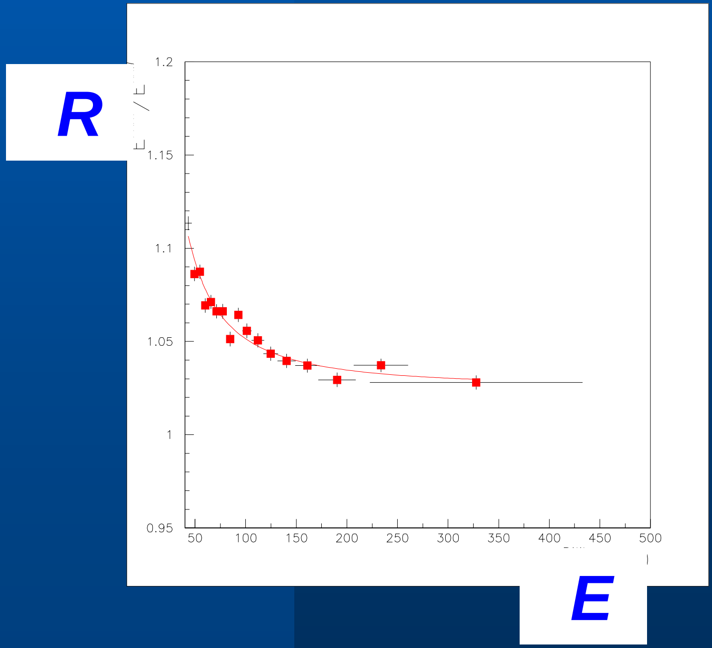
Use peak position M(W) for light jet energy calibration

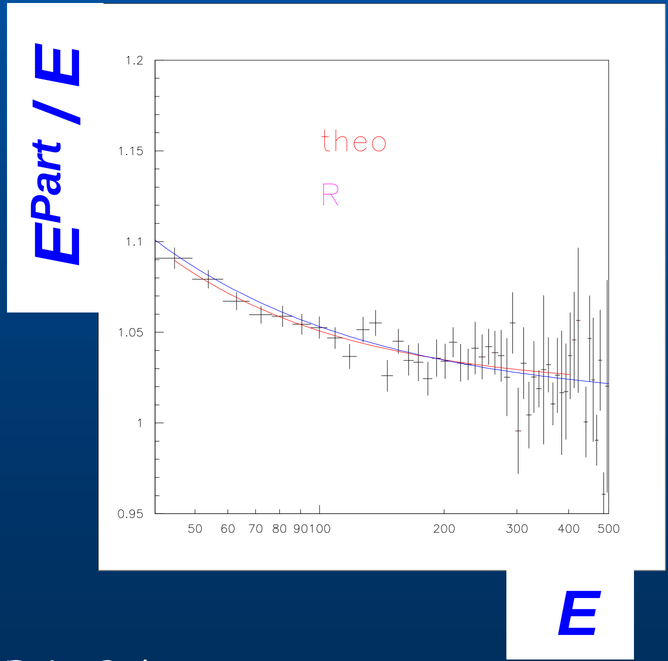
Use W in top events for jet calibration

Effect of a mis-calibration of jet energy dominant systematics
Several methods to calibrate. Simplest one:

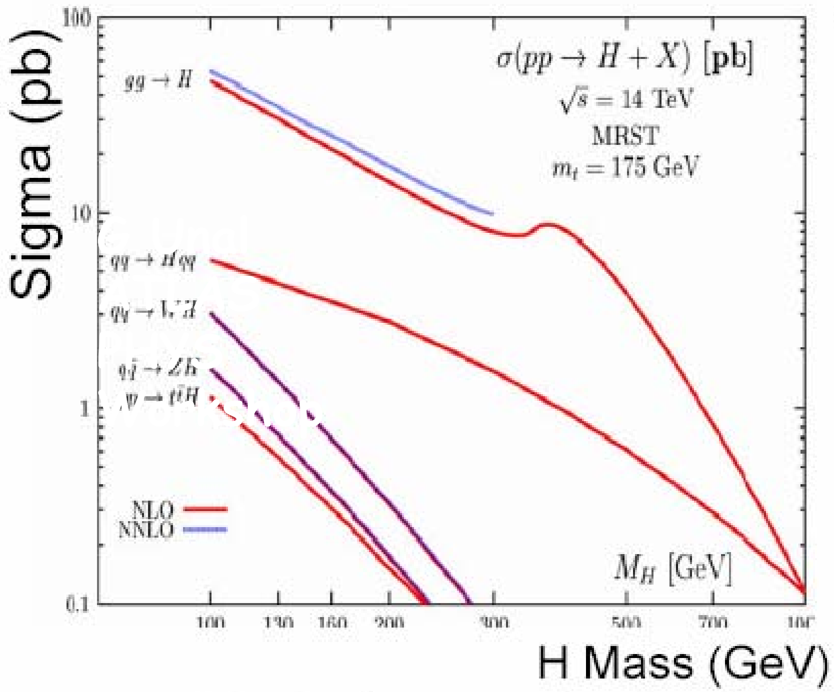
$$R \equiv M_W^{PDG} / M_W = \sqrt{\alpha_1 \alpha_2} \qquad \text{with} \qquad \alpha_i = \frac{E_i^{part}}{E_i^{jet}}$$

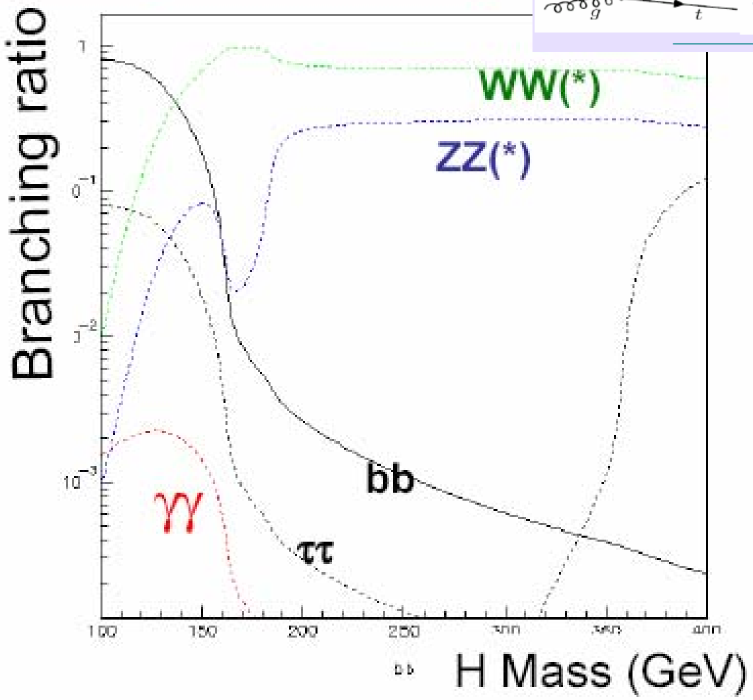
- compute R for k bins in E $\quad \alpha_k = < \alpha_{j1} \alpha_{j2} >$
- apply α_k factors on R and recompute R n times => $\alpha_k^{True} = \prod_n \alpha_k^n$

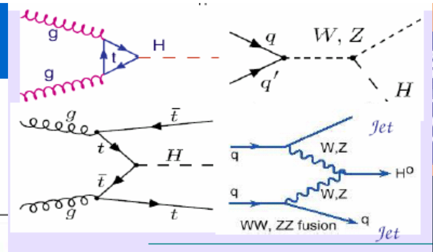




Higgs production and decay in a nutshell







- $gg \to H$: dominant production, large QCD corrections, H often produced associated with a "hard" jet (ZZ*,WW*, γγ decays)
- $qq \to Hqq$ (WW,ZZ fusion "VBF"). Specific signature allowing better background rejection (ττ,WW*, γγ decays)
- ttH production Lepton from top allows to trigger (bb decay, also ττ,WW* for coupling measurements, γγ at high lumi.) *(Eilam's talk)*

G Unal
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$H \rightarrow \gamma\gamma$: Main Experimental Issues

Central analysis issues have been covered with DC1 and are being re-assessed with DC2/Rome production:

- Photon calibration (energy scale and resolution)
  - Separation of converted and unconverted photons
- Photon angle correction
  - Photon angle with help of calorimeter pointing and tracking vertex
- Photon ID
  - Achieve best rejection against jets
    - Photon/π^0 rejection

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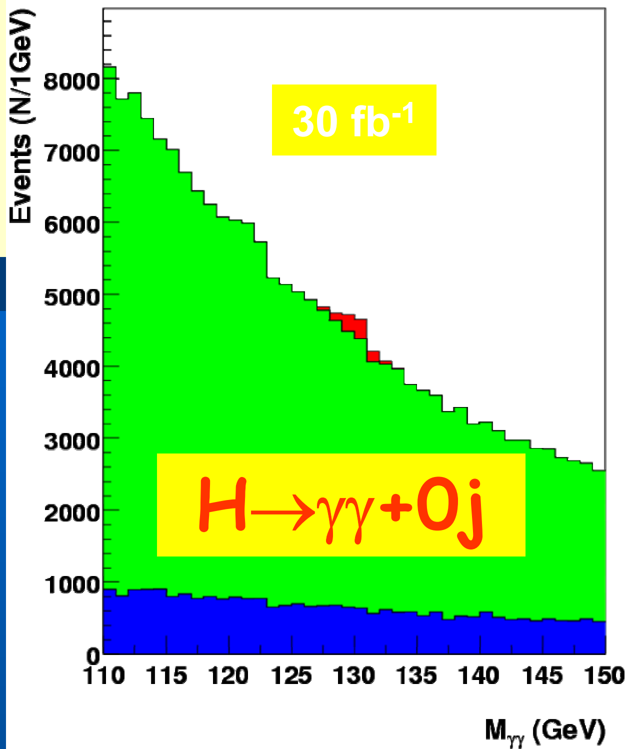
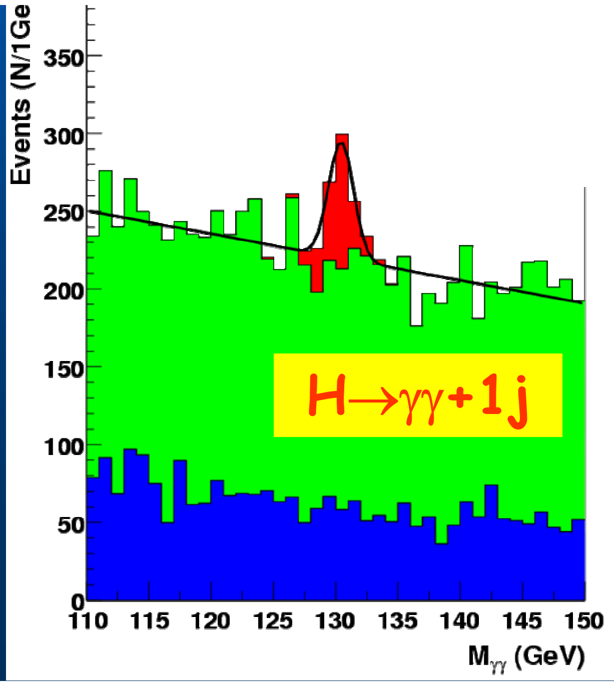
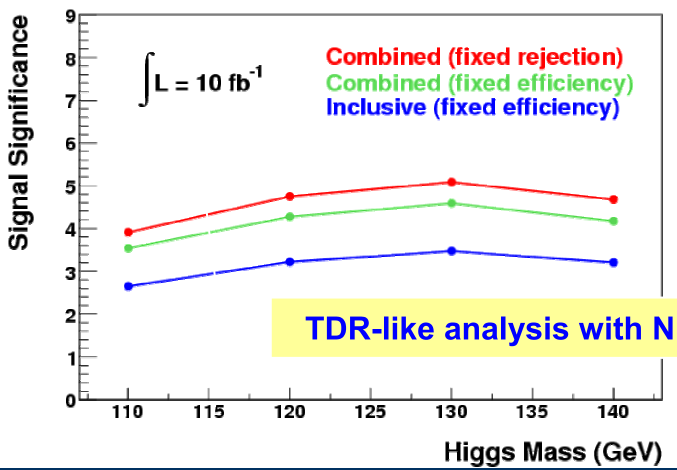
Inclusive H→γγ to NLO

- NLO QCD corrections
  - Higgs production via MC@NLO generator
  - Higgs decay via HDecay program
  - Used QCD NLO corrections to background pp→γγ+X
  - Signal significance possibly further enhanced by 40%.
- H→γγ may be a discovery channel on its own for 10 fb^{-1}





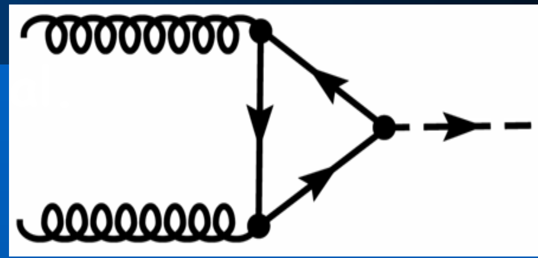
M.Cobal Summary ATLAS PHYS WOrkshop



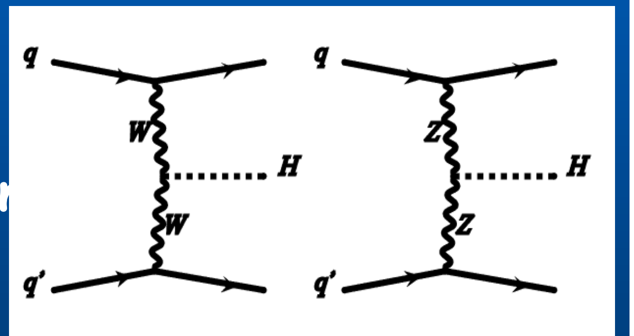
TDR-like analysis with NLO σ

QCD NLO Corrections to Signal

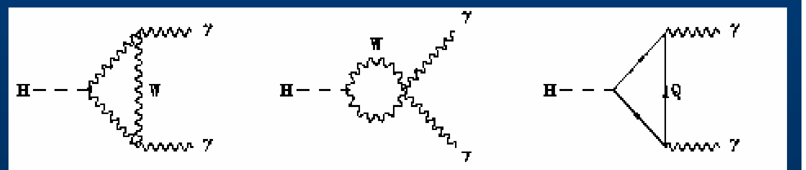
- Main production mechanism: gg→H
  - NLO corrections calculated by M.Spira et. Nucl.Phys. B453 (1995) 17-82
  - Use MC@NLO as a MC generator
    - Implements NLO diagrams. Higgs P_T description to LO. Re-sumation effects well modeled



- Second dominant process: VBF H
  - NLO corrections first calculated by T.Ha G.Valencia, S.Willenbrock PRL69 (1991)
  - VBF H not implemented in MC@NLO yet
    - Use Pythia and scale cross-section by 1.1



- NLO QCD corrections to H→γγ
  - Use HDecay (M.Spira)



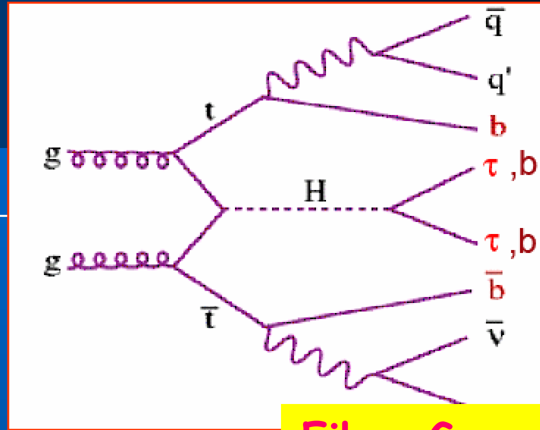
B Mellado ATLAS Phys Workshop – June 05

ttH, H→bb, DC1 Based Full Simulation

- Signal: ttH(120) → lνb jjb bb (0.52 pb, H→bb 70%), 20k events
- Background: ttjj (474 pb), 100k (filtered)~250K events ~ $0.5fb^{-1}$!

- CBNT Analysis

S. Correard, CPPM



- using "realistic" b-tagging performance and selection/rejection efficiencies of signal/background (SV2 method)

→ b-tag session this afternoon

→W>3

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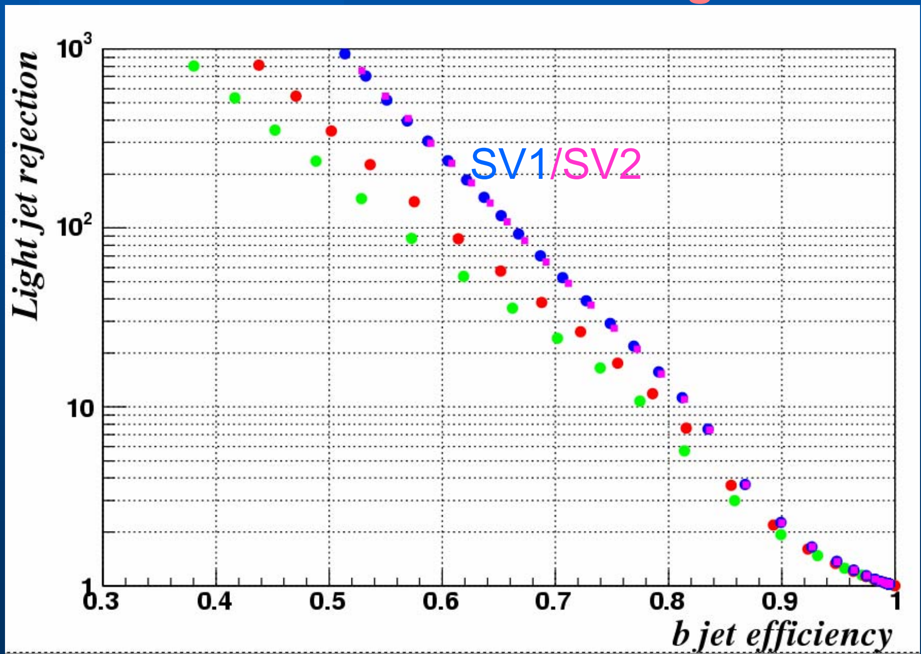

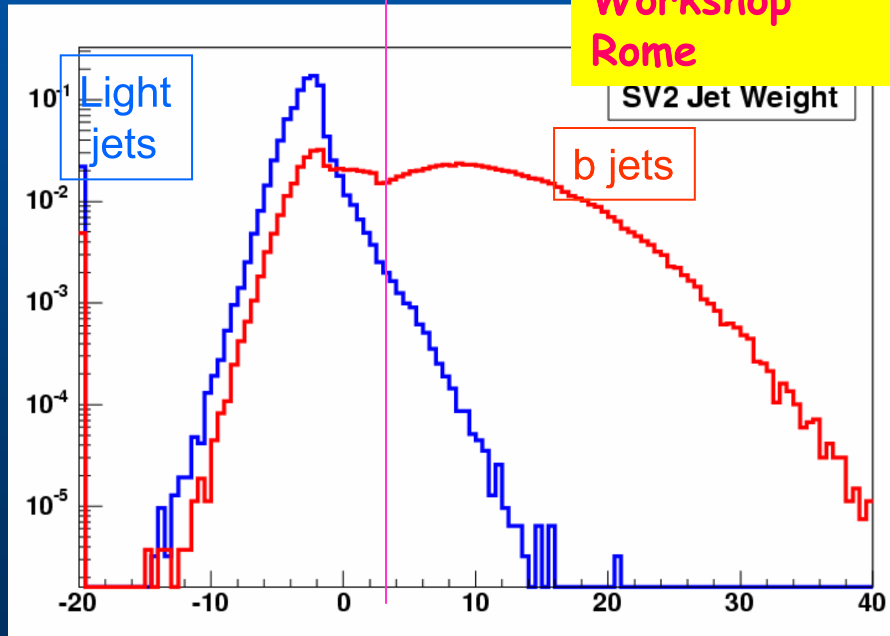

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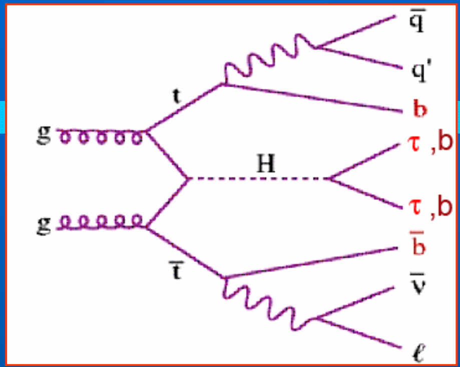
ttH→ttbb:Full Simulation Likelihood Analysis



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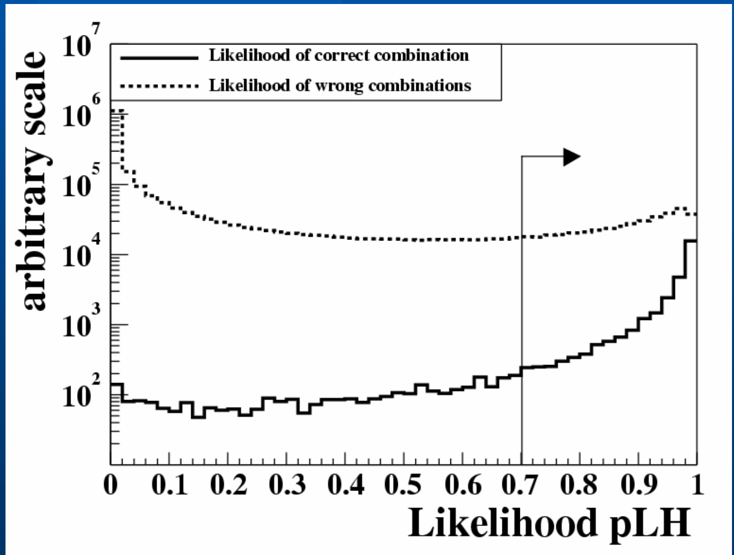
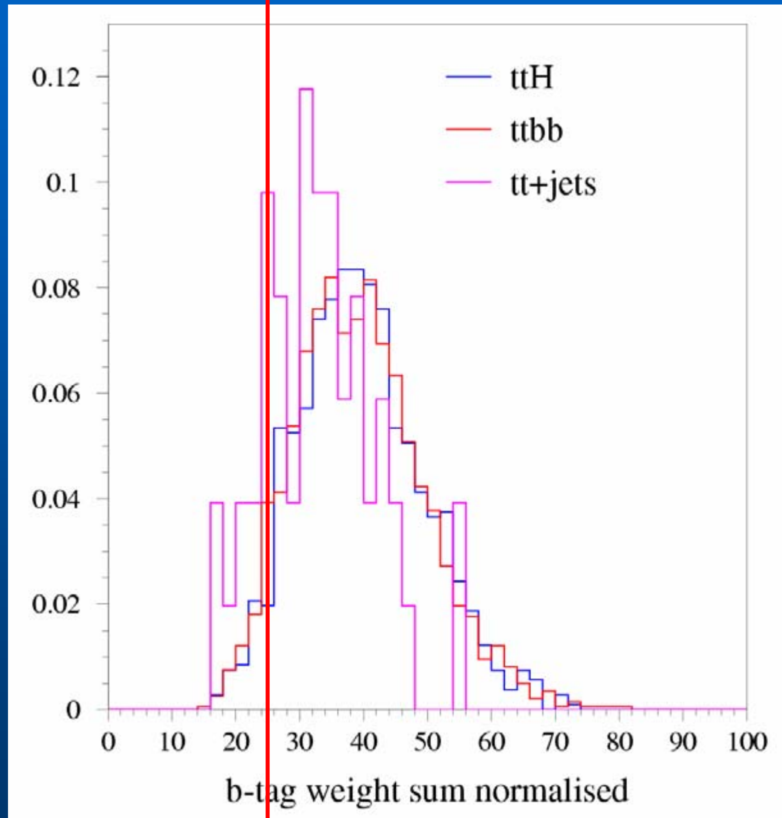
Jet pairing
Likelihood Cut
Is replaced by





Use likelihood to find the jet best pairing, do not cut on likelihood, but replace it with a cut on the sum of weights of four b quarks

Light Higgs Search: ttH → ttbb

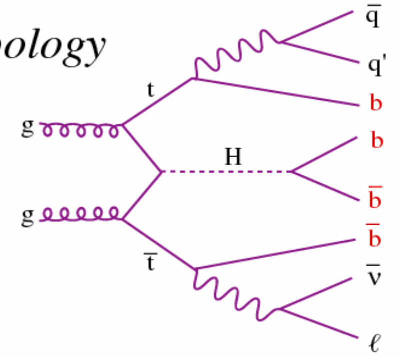
Challenging and complex topology

4 b-jets, 2 jets, 1 lepton

H → bb

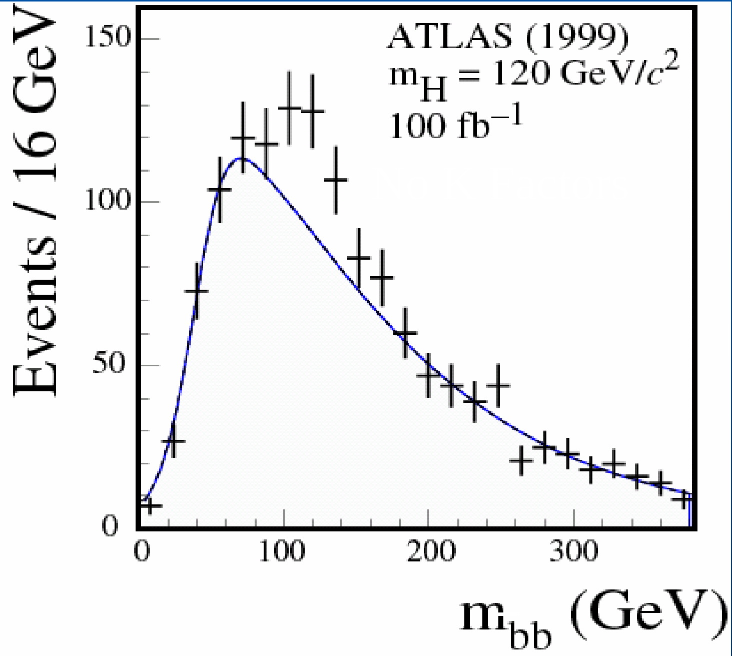
t → bqq'

t → bℓν



$\sigma \times BR \approx 300$ fb

- Complementary to $H \to \gamma\gamma$
- Fully reconstructed final state (except ν)
- Requires good b-tagging
  - $\varepsilon_b \approx 60\%$, $R_{uds} \approx 100\%$
- Backgrounds:
  - Combinatorial from signal
  - Irreducible ttbb (ttjb, ttjj)
- Signal significance (5σ) :
  - $m_H < 120$ GeV needs 100 fb^{-1}
  - $m_H < 130$ GeV needs 300 fb^{-1}



Summary ttH→ttbb

Low Luminosity 30 fb^{-1}

	TDR FAST	Likelih FAST J.C.	Likelih FULL truth b S.C.	AOD A.W.
ttH (120)	28	45.6	51.4	53
ttbb	148.4	187	86.1	
ttjj	44.7	63	<45 (0)	63
signific	2.0	2.9	4.4 (5.5)	
Signific (inc syst)	1.3	2.0	3.6 (4.5)	
1/(S/B) *Δ_{syst}	6.8 *7.6%	7.7 *6.1%	2.5	

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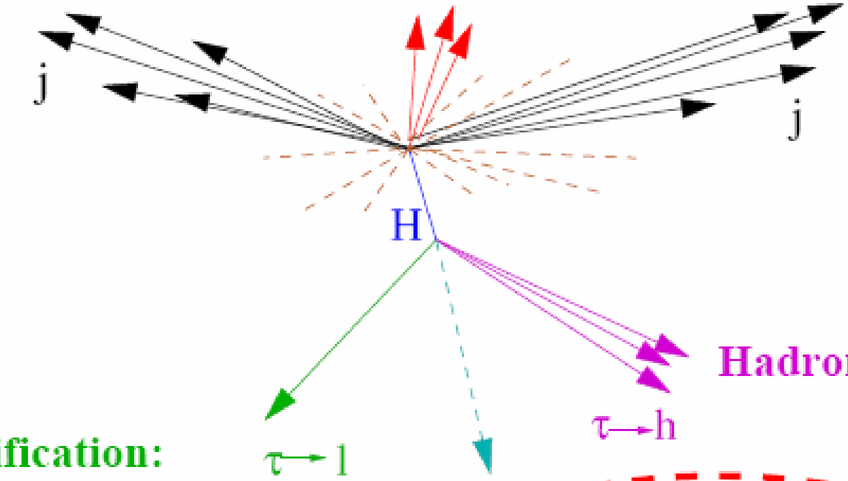
Mass: SM Higgs $\rightarrow\tau\tau$: Experimental issues

Experimental Issues

Central Jet Veto:
–Sensitive to pileup

Forward Tagging Jets:
–Difficult Forward Region
–Jet Calibration

+Multiple Interactions
+Electronic Noise
+PileUp



Hadronic Tau Identification:

Electron Identification:

Muon Identification:

ET Miss:
–Central to Tau Reconstruction
–Reconstructed Higgs Mass
–Dominant Experimental Issue

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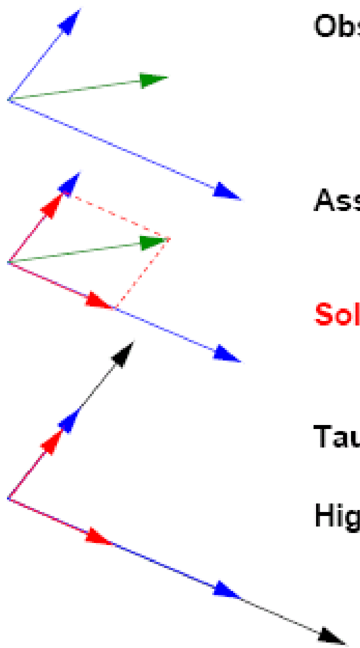
Mass: SM Higgs →ττ - Mass reconstruction

Collinear Approximation & Central Jet Veto

Mass Reconstruction:



Observe
missing transverse momentum
and visible Tau−decay products

Assume Tau decay products
collinear with original Tau

Solve 2 linear equations
for the neutrinos

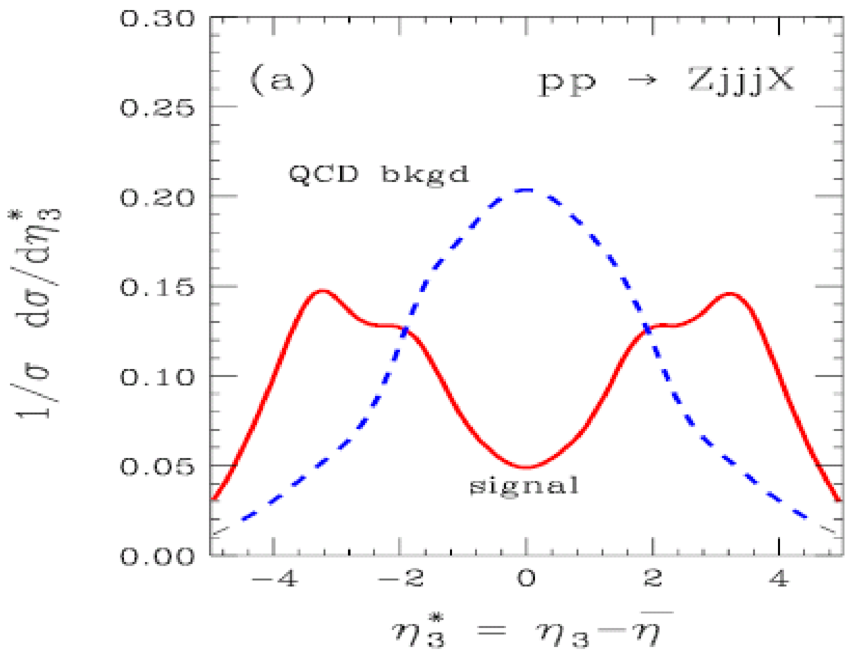
Taus can be reconstructed

Higgs can be reconstructed

$$x_{\tau h} = \frac{h_x l_y - h_y l_x}{h_x l_y + \not{p}_x l_y - h_y l_x - \not{p}_y l_x}$$

$$x_{\tau l} = \frac{h_x l_y - h_y l_x}{h_x l_y - \not{p}_x h_y - h_y l_x + \not{p}_y h_x}$$

Central Jet Veto:



Because the signal is an electroweak process, we expect depleted jet activity in the central region ⇒ Veto on central jets

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Local Hadron Calibration Strategy

Electronic Calibration and EM scale

•Equalize detectors' response to energy deposited by electrons: common scale for Test Beam/ATLAS/DATA/MC

Noise Suppression

Local Signal Definition

Cluster Formation and Classification

•Noise suppression
•Topological correlations to build energy blobs i.e. localize energy deposit
•Classification in e.m., had based on cluster shape

Important Features

- **Disentangle and factorize different effects**
  - Discriminate em and had deposits
  - Local energy scale to separate separate signal calibration from acceptance/hardware corrections (dead material, containment…)
- **Connect local energy "blobs" at Test Beam with those in jets**: aim at extracting normalization from single particles

Specific Weighting to calibrate Cluster

•Signal Weighting: calibrate local energy depositions of had. clusters to compensate for e/pi

Correct for acceptance and Dead Mat

Final Physics Calibration/ Reconstruction

•From clusters :perform particle ID, build jets; apply final corrections (ID ,jet algorithm dependent)

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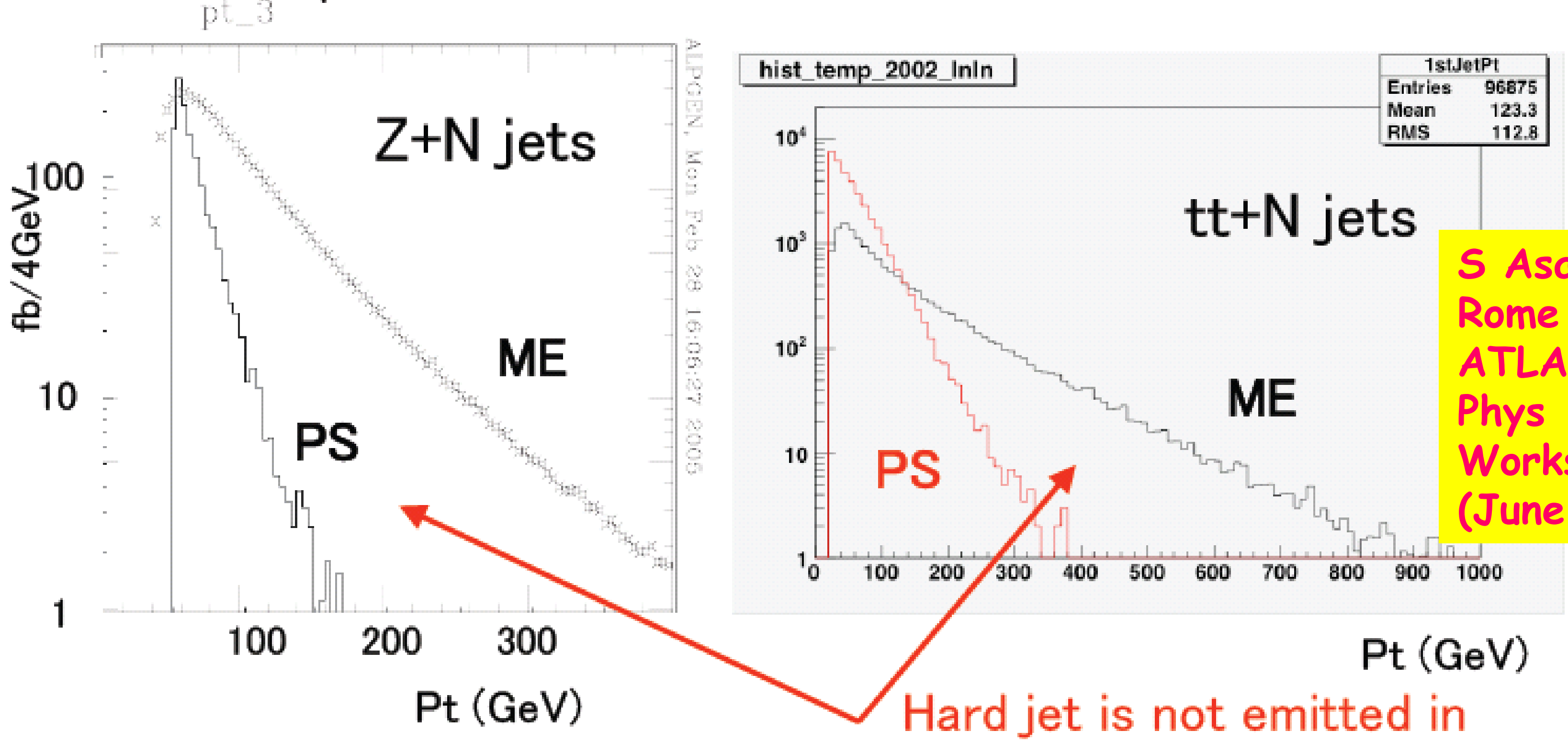
Matching parton shower and matrix element

Parton Shower is the good model in the collinear region, but PS has some problem in the high P_T region.

P_T distributions of the additional jets for



Hard jet is not emitted in Parton Shower.
(It is famous problem.)

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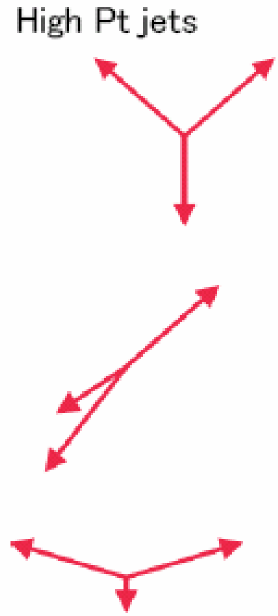
3rd and 4th jets in multijet(QCD) were also estimated with PS in the previous study.
They have the same problem. -> P_T of jets were underestimated in the previous.

SM background to SUSY

[1−2] Production with Matrix Elements



- **ALPGEN(V1.33)** is used to produce W+Njets, Z+Njets and tt+Njets. P_T>20GeV and R_{jj}>0.7 are required to remove collinear and soft divergence.
  (N=<6 for W/Z, N<=3 for top are produced)

- Collinear and soft kinematic regions are covered by the Parton Shower (PYTHIA).
  ME−PS matching is performed with MLM method.
  About 60% of generated events are rejected
  −> corresponding to Sudakov factor

- ATLFAST is used for the Detector Simulation (Fast Simulation: ATHENA9.0.2)

Fake E_T^{miss} is important to estimate the Multijet(QCD) background. Detail study using the full simulation with realistic experimental condition is necessary to estimate Fake E_T^{miss}. Non−Gaussian tail of E_T^{miss}, material effect, imperfect calibration in the first year, and the noise effect should be carefully parametrised for the Fast simulation. (otherwise we can not estimate Multijet)

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SUSY parameter space

- Various ways to create some order in the chaos of multi-parameter space
  - Unified boson (m0) and fermion (m1/2) masses at GUT scale as in mSUGRA models:
  - Only 4 free parameters remain: m_0, $m_{\frac{1}{2}}$, $\tan\beta$, A_0, sign $\mu=\pm$

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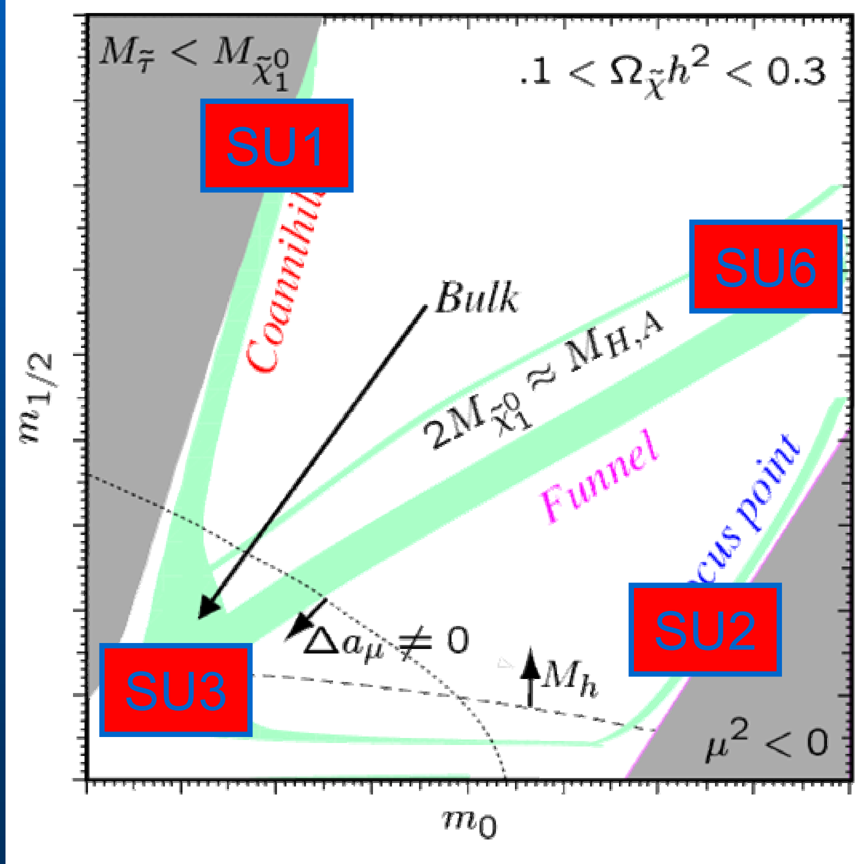
- Select several mSUGRA points
  - Consistent with WMAP data for cold dark matter
  - Don't believe mSUGRA, but use it to suggest interesting possible particle spectra
  - Typically σ>1 pb, so early discovery physics
- Analyze each of these points
  - E.g. point SU1:

$$m_0 = 70\,\text{GeV},\ m_{1/2} = 350\,\text{GeV},\ A_0 = 0,\ \tan\beta = 10,\ \text{sgn}\,\mu = +$$

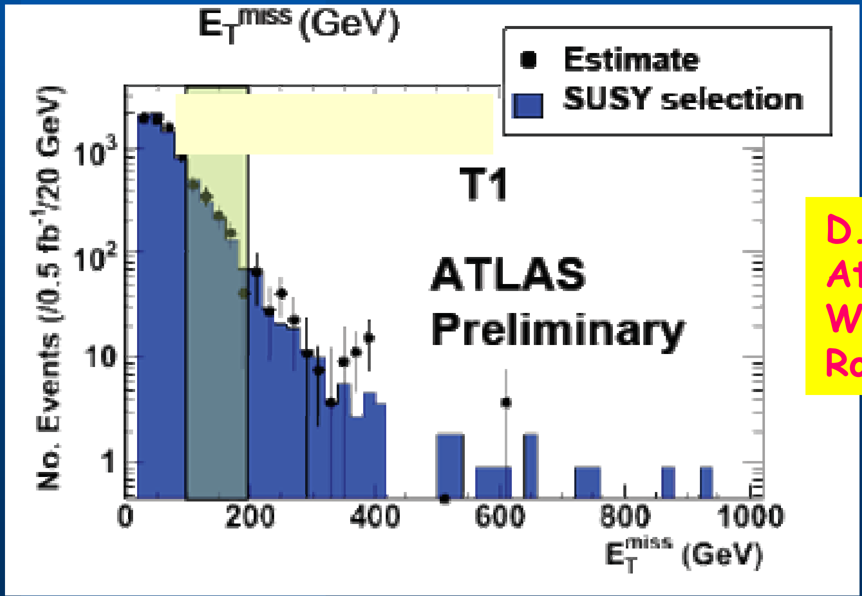
$$M(\tilde{\chi}_2^0) - M(\tilde{\ell}_L) = 8.5\,\text{GeV},\ M(\tilde{\ell}_R) - M(\tilde{\chi}_1^0) = 17\,\text{GeV}$$

$$M(\tilde{\chi}_2^0) - M(\tilde{\tau}_2) = 6.6\,\text{GeV},\ M(\tilde{\tau}_1) - M(\tilde{\chi}_1^0) = 9.5\,\text{GeV}$$



SUSY: Top background from data

- Obtain the E_T^{miss} distribution from data using top events
  - By fixing the top mass in the leptonic channel, predict E_T^{miss}
  - Select top without b-tagging
- E_T^{miss} for top signal minus sideband
  - Reduce combinatorical background
  - Normalise at low E_T^{miss}, where SuSy signals are small
- Add SUSY
  - Repeat procedure with SuSy signal included
  - E_T^{miss} distribution from data
  - Clear excess from SuSy at high E_T^{miss} observed: method works!



D.Tovey
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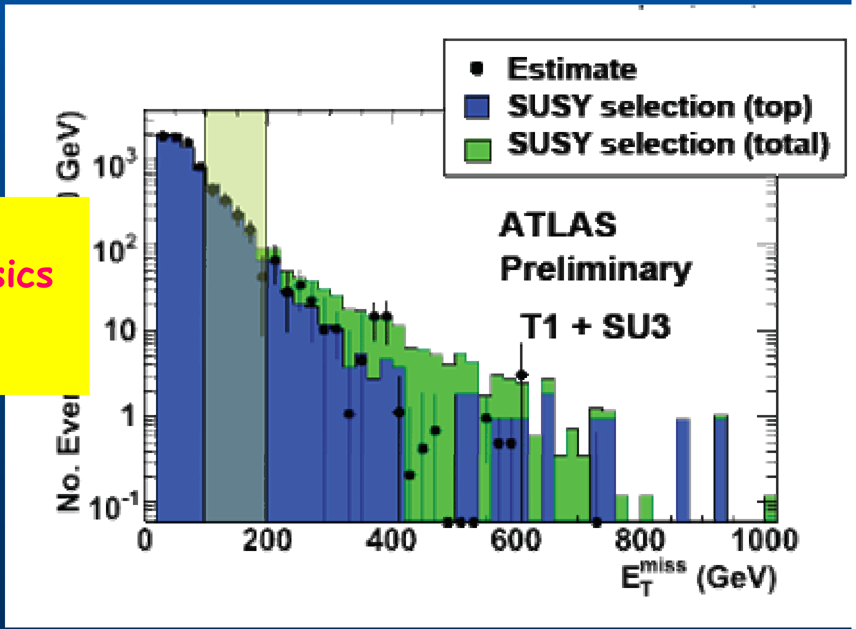
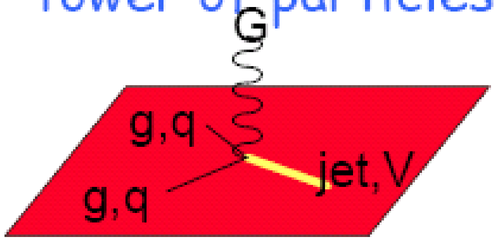


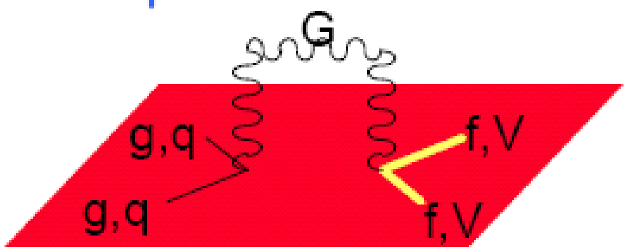
Extra Dimensions

Phenomenology at Tevatron collider:

- Direct production of graviton/Kaluza Klein excitations (a whole tower of particles…)



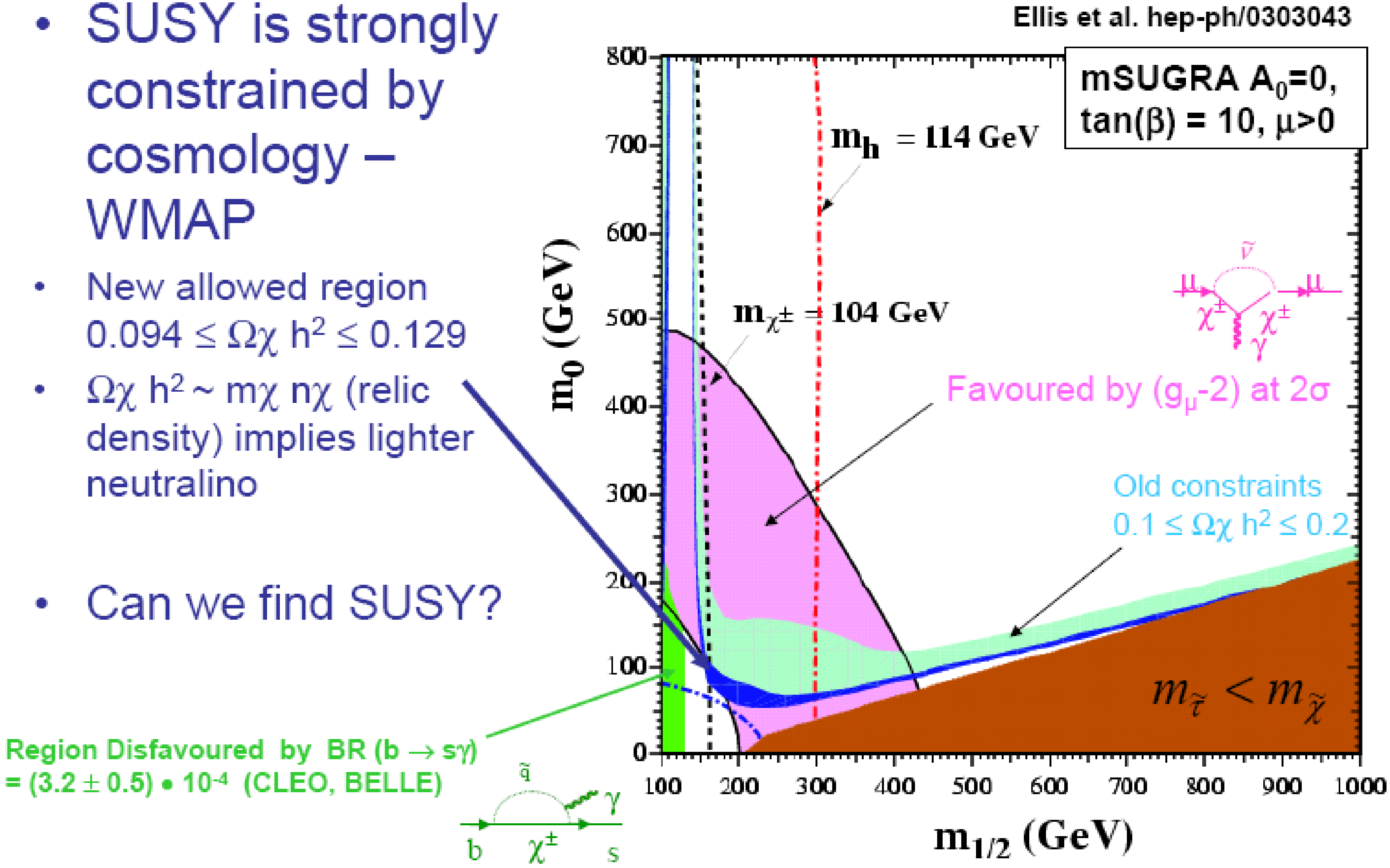
- Indirect effect (i.e. modification of spectra/cross section)



- CDF and D0 searched for modification of ee,$\mu\mu$,$\gamma\gamma$ production
  - ⇨ Interpreted in both LED and RS models
- D0 also searched for effects of TeV^{-1} ED in its ee data

- Searches for excess of missing energy in jet events could be interpreted within the ED framework
  - ⇨ CDF performed a search in 70 pb-1 which has not been updated to the current dataset

- SUSY is strongly constrained by cosmology – WMAP
  - New allowed region $0.094 \leq \Omega\chi\, h^2 \leq 0.129$
  - $\Omega\chi\, h^2 \sim m\chi\, n\chi$ (relic density) implies lighter neutralino
- Can we find SUSY?



SUSY: M_{Eff} for discovery

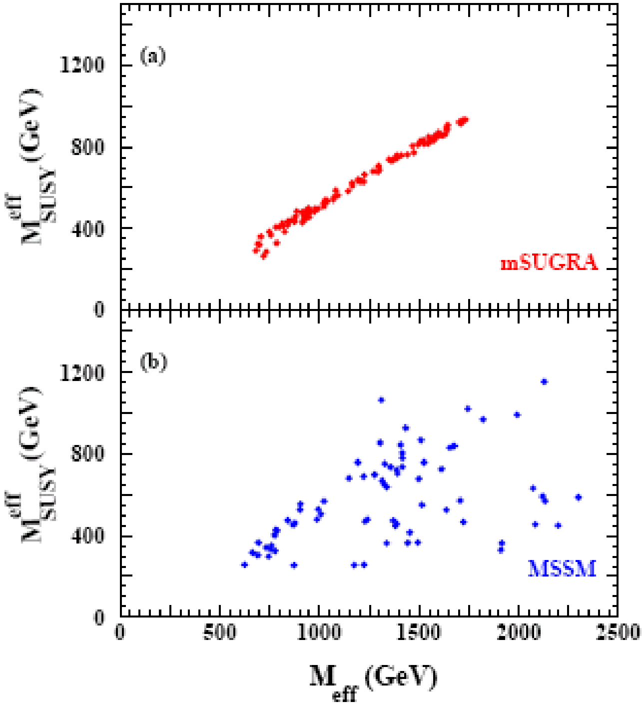
SUSY mass scale from inclusive analysis

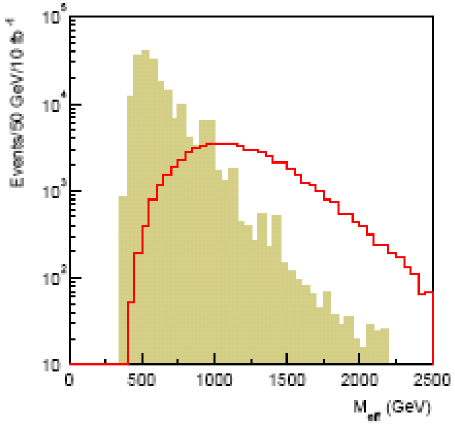
Inclusive variable:

$$M_{\rm eff} \equiv \sum_i |p_{T(i)}| + E_T^{\rm miss}$$

($p_{T(i)} \equiv$ transverse momentum of jet i)

$M_{\rm eff}$ distribution for SUSY signal shows a peak.





Define SUSY scale:

$$M^{\rm eff}_{\rm susy} = \left(M_{\rm susy} - \frac{M_\chi^2}{M_{\rm susy}}\right), \text{ with } M_{\rm SUSY} \equiv \frac{\Sigma_i M_i \sigma_i}{\Sigma_i \sigma_i}$$

Test the correlation of $M_{\rm eff}$ with $M^{\rm eff}_{\rm susy}$ on a random set of models: mSUGRA and MSSM

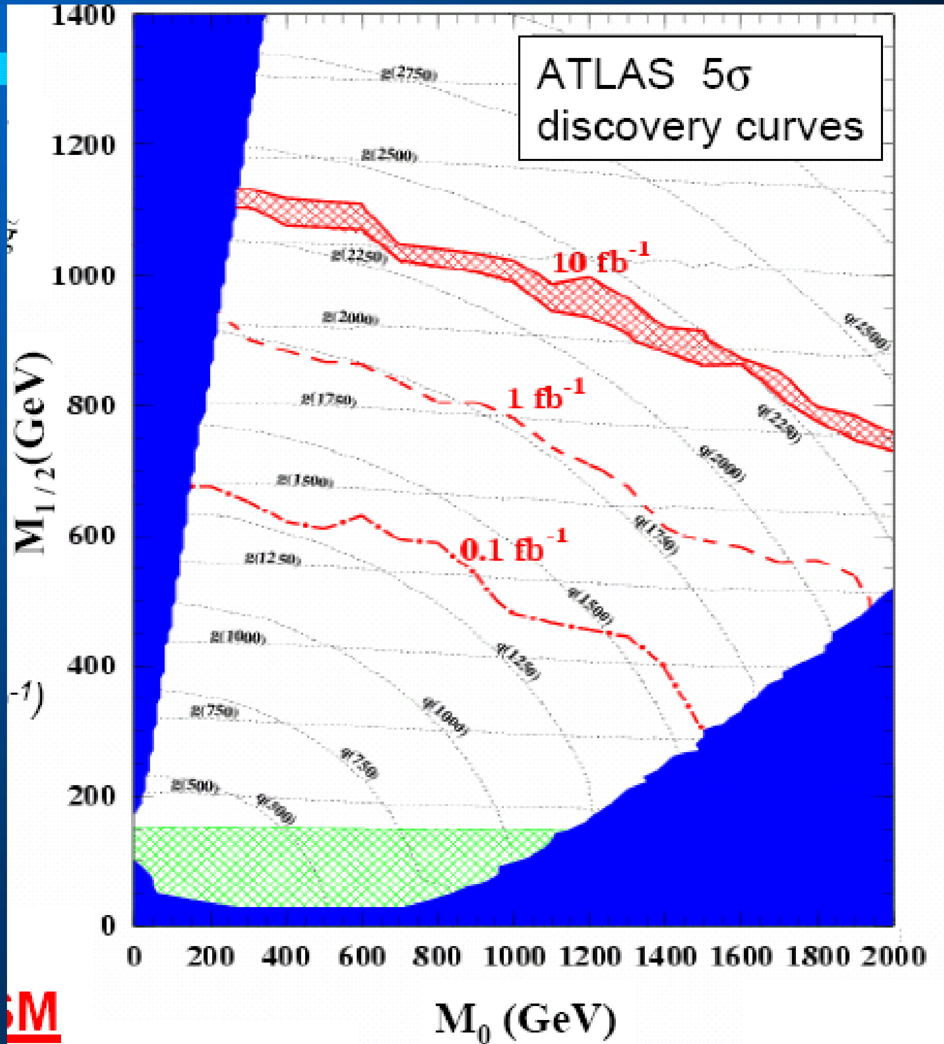
Excellent correlation in mSUGRA, acceptable for MSSM

Mass scale to $\sim 10\%$ (100 fb^{-1})

G. Polesello
ATLAS PHYS Workshop
Athens
May 2003

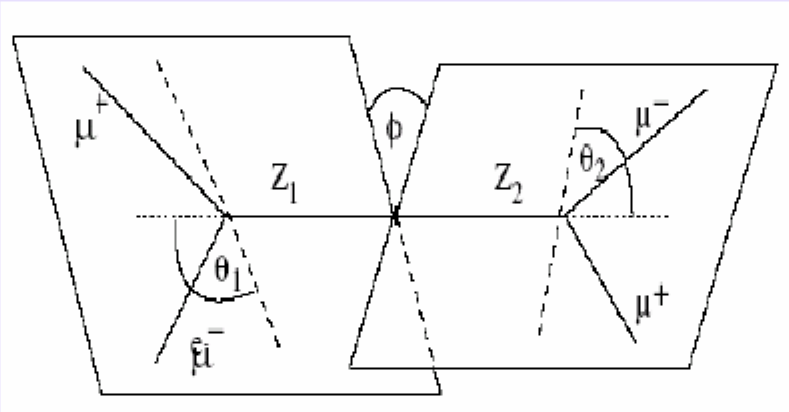
SUSY full discovery potential for ATLAS (MSUGRA)

- **ATLAS reach in SUSY**



Measuring Higgs boson Spin and CP

- Spin 1 discarded if $H \to \gamma\gamma$ or $gg \to H$ are observed.
- Verification of J=0, CP=1: compare angular distributions for different J, CP hypothesis, for $H \to ZZ \to$4leptons.
- For $m_H > 250$ GeV: R can unambiguously separate the hypothesis, for 100 fb^{-1}.



$$G(\theta) = T(1+\cos^2\theta) + L\sin^2\theta$$

$$R = \frac{L-T}{L+T}$$