B-physics overview in ATLAS

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(on behalf of the ATLAS collaboration)

1. **ATLAS B-Physics programme and trigger strategy**
2. **CP violation:**
   - Δm_s with $B_s \to D_s \pi$
   - $\sin 2\beta$ in $B_d \to J/\psi K_s$
   - ϕ_s with $B_s \to J/\psi \phi$
3. **Rare decays:**
   - $B^0_{d,s} \to \mu^+\mu^-$
   - $\Lambda_b \to \Lambda \mu^+\mu^-$
   - radiative penguins
4. **Λ_b polarisation**
5. **Conclusion**

ATLAS strategy for B-physics

LHC luminosity periods
early <10^{33} cm^{-2}s^{-1}
low 2×10^{33} cm^{-2}s^{-1}
nominal 10^{34} cm^{-2}s^{-1}

- **Exploit the strong points of ATLAS detector : tracking, calorimetry & muon detection**
  On the other hand ATLAS has no K/π PID detector
  - centrally produced events in proton-proton collisions at 14 TeV centre of mass energy
  - concentrate on multileptonic and photon decay channels
    - they are possible to trigger on
    - they are sensitive to New Physics

- **Concentrate on measurements that extend the discovery potential of ATLAS for physics beyond the Standard Model**
  - measurements of CP violation parameters that are predicted to be small in the SM (e.g in $B_s \to J/\psi\phi(\eta)$)
  - measurements of rare B-decays ($B_d \to K^*\gamma$, $B_d \to K^*\mu\mu$, $B_s \to \phi\gamma$, $B_s \to \phi\mu\mu$, $B_s \to \gamma\mu\mu$)

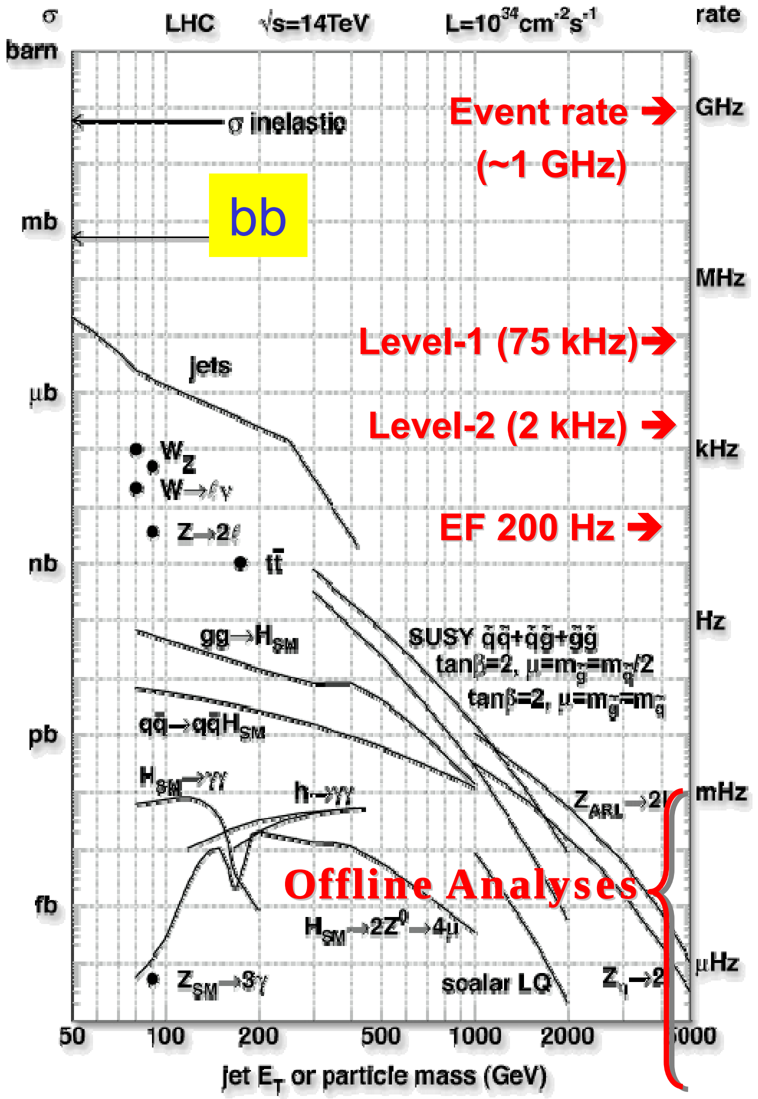
- **Focus on physics topics that will not be accessible for the B-factories**
  - mainly B_s, baryon and doubly heavy flavour hadrons ($B_s \to D_s\pi$, $B_s \to J/\psi\phi(\eta)$, $\Lambda_b \to J/\psi\Lambda^0$, …)

ATLAS trigger strategy

- **About 1% of collisions produce a bb pair**
  ATLAS is a multipurpose physics experiment with emphasis in high-p_T physics

b-production at LHC
σ_{tot} = 100 mb
σ_{bb} = 500 μb
(2×10^{12} $b\bar{b}$ pairs/year
@ low lumi)

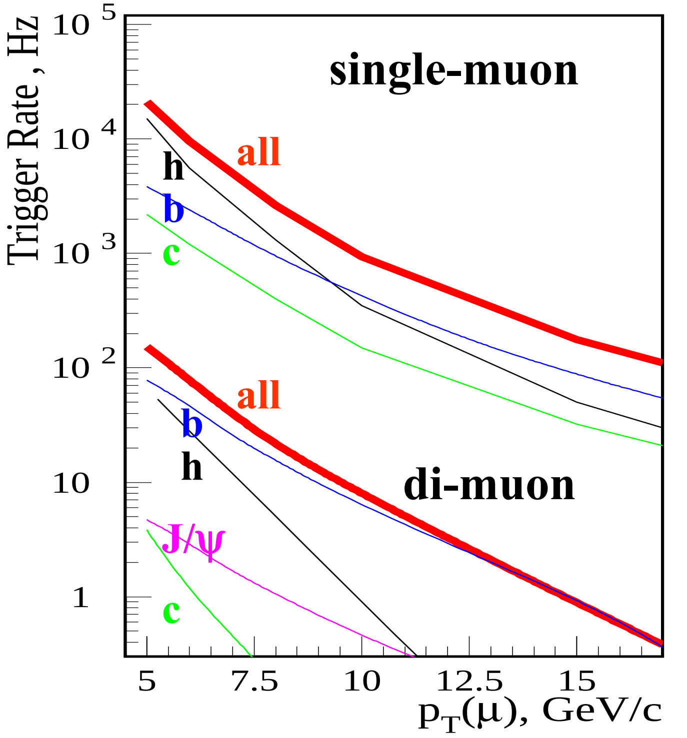
- **In the illustrative trigger menus (presented in the HLT/DAQ TDR) more than 50% of the rate at LVL1 and almost 40% of the rate at HLT come from electron signatures**
  - difficult to decrease the E_T threshold of the selected electrons/photons without additional trigger resources
  - the key to the B-physics programme is muons that can be identified cleanly at early stages of the trigger. They also give a clean flavour tag
  - trigger must be more selective than only concentrating in basic signatures (e.g 23 kHz at LVL1 from single muons of p_T>6 GeV)
    - concentrate on exclusive channels (reconstruct online the mass of the B hadron)
    - select online on transverse decay length (reconstruct primary and secondary vertex)



ATLAS trigger strategy

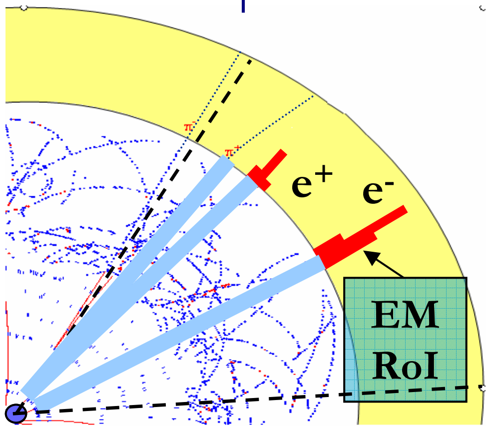
- **di-muon trigger (low and nominal luminosities)**
  $B_d \rightarrow J/\psi K^0_S$, $B_s \rightarrow J/\psi\phi$, $B \rightarrow \mu\mu$, $\Lambda_b \rightarrow \Lambda^0 J/\psi$
  - LVL1: two μ p_T>6 GeV (barrel) and 3 GeV (end-caps)
  - LVL2 & Event Filter : confirm μ, refit tracks in ID, decay vertex rec., select decays using mass/decay length
    ⇒ first μ 85%, $J/\psi(\mu\mu)$ 77%, ε~65%

LVL1Trigger rates @10^{33}cm^{-2}s^{-1}



- **μ + ECAL (low luminosity)**
  $B_d \rightarrow J/\psi(ee)K^0_S$ + $b \rightarrow \mu X$, $B_d \rightarrow K^{0*}\gamma$ $B_s \rightarrow \phi\gamma$ + $b \rightarrow \mu X$
  - LVL1 : 1 μ p_T>6 GeV + 1 EM cluster E_T>5 GeV
  - LVL2 & Event Filter : confirm μ & ECAL, decay vertex rec., refit tracks, selections

    ⇒ $J/\psi(ee)$ ~72%, ε~60%

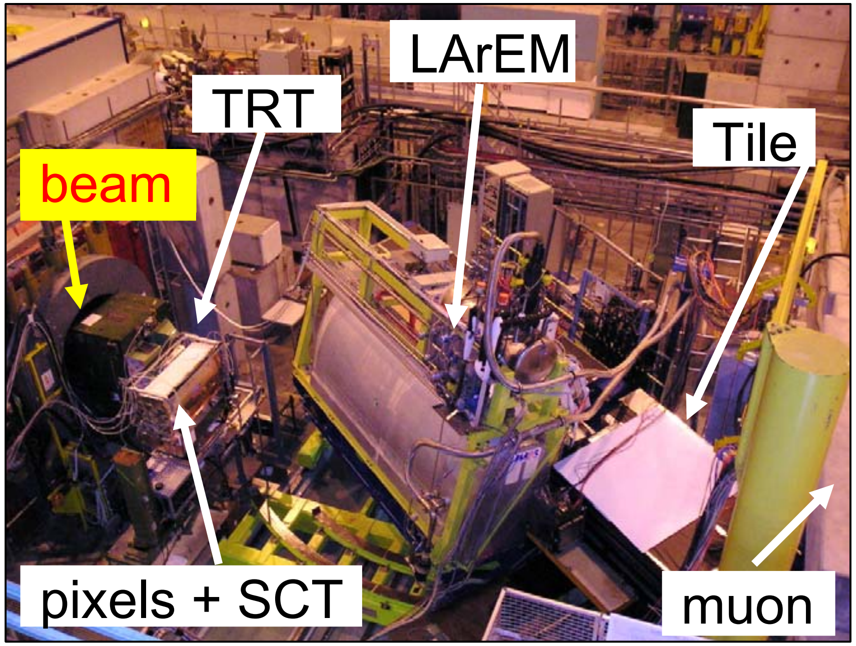


- **Hadronic (low luminosity)**
  $B_s \rightarrow D_s\ \phi(KK)$, $B_s \rightarrow D_s\ (\phi(KK))\ a_1(\rho^0\pi^+)$, $B^+ \rightarrow K^+K^+\pi^-$ $B_d \rightarrow \pi^+\pi^-$ (+ $b \rightarrow \mu X$)
  - LVL1 : 1 μ p_T>6 GeV + 1 jet cluster E_T>10 GeV
  - LVL2 & Event Filter : confirm μ and jet cluster, decay vertex rec., refit tracks

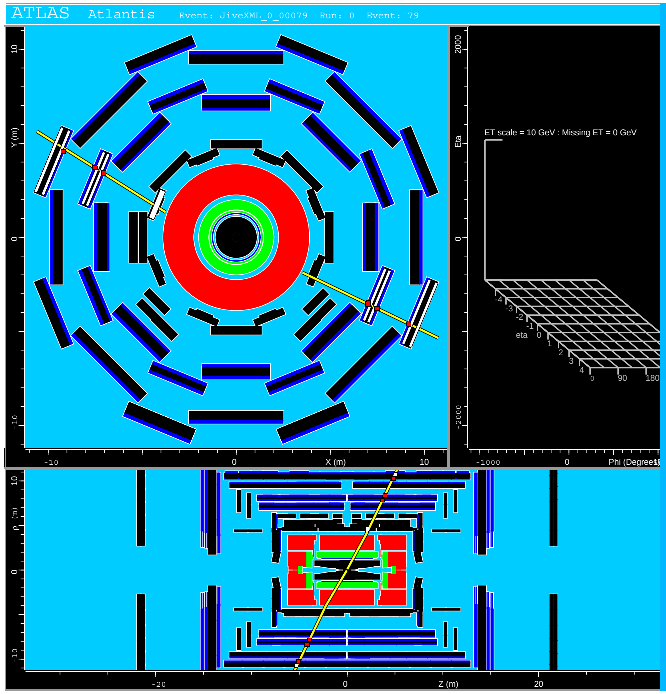
Luminosity drops by a factor 2 during a 10 hours run. Use spare capacity for B-physics …

Which data are used ?

- **All results presented are based on fully simulated data (DC1, Rome, CSC). A large part of them were produced under the computing Grid**
- **Some detector performance required for these studies have already been obtained with data taken with H6 and H8 beam lines at CERN in 2001-2002 and during the combined test beam of 2004 with a full « vertical slice » of ATLAS. Some others will be checked during the cosmic run (2006)**



for the first time, all ATLAS sub-detectors integrated and run together with:
- « final » electronics
- common DAQ
- slow control
- common analysis software



Use of cosmic running will take place during commissioning to test detector performance and to integrate the trigger and DAQ systems

white: MDT hit
red: RPC hit
yellow: muon track

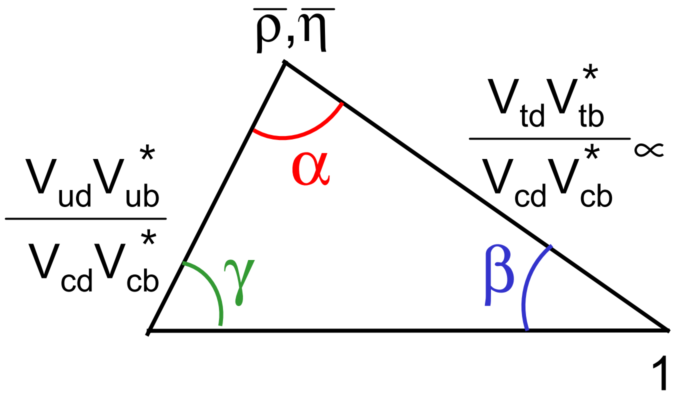
will illustrate few performance
- electron/π separation (b-flavour tagging)
- γ/π^0 separation (needed for $B_d \rightarrow K^{0*}\gamma$)

CP violation studies

- **Unitarity of the CKM matrix**

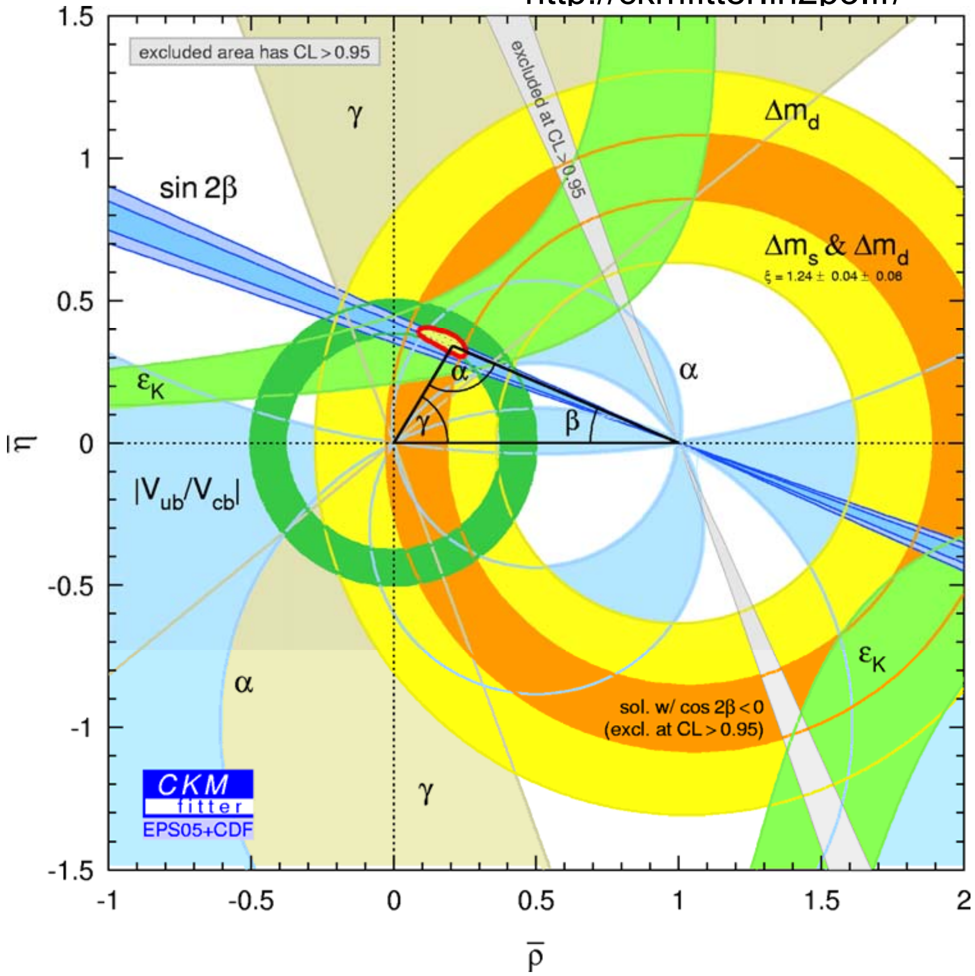
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \cdot \begin{pmatrix} d \\ s \\ b \end{pmatrix} ; \begin{pmatrix} 1-(\lambda^2/2) & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-(\lambda^2/2) & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

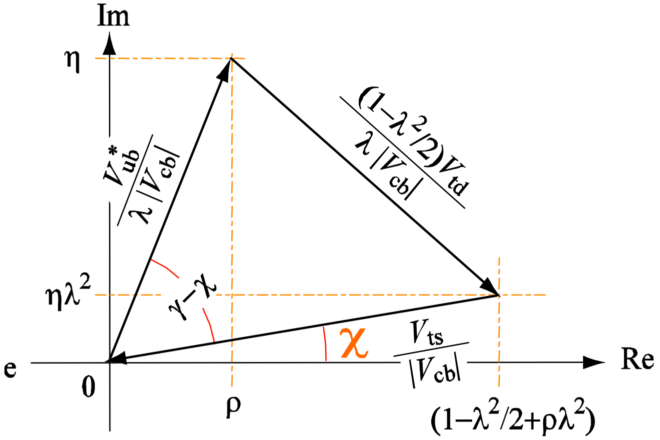
$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$



$$\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*} \propto \frac{|V_{td}|}{|V_{ts}|} \propto \sqrt{\frac{\Delta m_d}{\Delta m_s}}$$

http://ckmfitter.in2p3.fr/



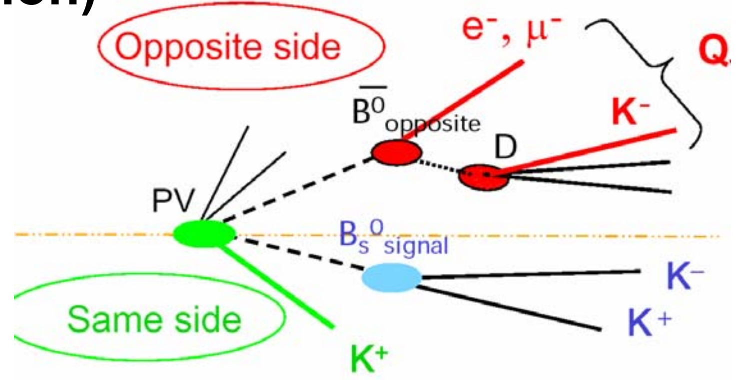


B^0_q-B^0_q system ($q \in \{d,s\}$)
Exchange of NP particles
$\Delta m_q = \Delta m_q^{SM} + \Delta m_q^{NP}$
$\phi_q = \phi_q^{SM} + \phi_q^{NP}$

for this talk :
$B_s \rightarrow D_s\pi$
$B_d \rightarrow J/\psi\, K_s$
$B_s \rightarrow J/\psi\, \phi$

Tagging the B production flavour

- **Estimate tagging quality factor efficiency × $(\text{Dilution})^2$ with dilution = 1-2W “wrong” tag probabilty**
- **B-flavour tagging technique**
  - use jet charge of same or opposite side
  - use muon or electron from opposite side

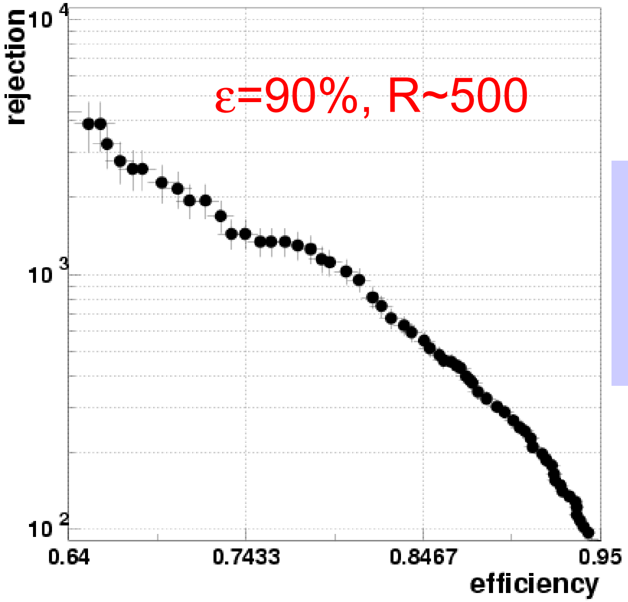


Jet charge	Lepton tag
Tagging efficiency ε_{tag} = 0.63	$\varepsilon_{tag}e(\mu)$ = 0.012 (0.025)
Wrong-tag fraction W_{tag} = 0.38	$W_{tag}e(\mu)$ = 0.27 (0.24)

← $B_s \rightarrow J/\psi\ \phi$

Electron tagging requires the rejection of hadrons misidentified as electrons. Use of TRT + ECAL

Full simulation “Rome”

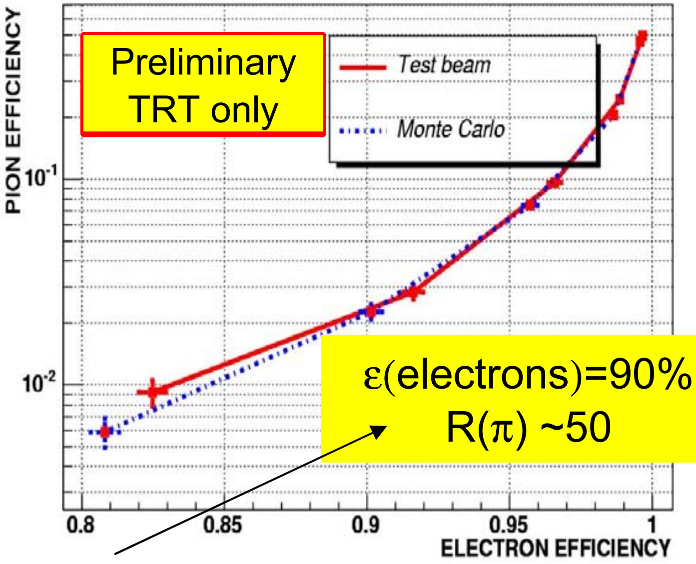


ε=90%, R~500

Rejection of bb→μ(6)X events without electron vs. efficiency of events bb→μ(6)e(2)X

Requires good rejection of single particles such as π This performance is already checked it test beams

Combined Test Beam 2004 electron beam @9 GeV



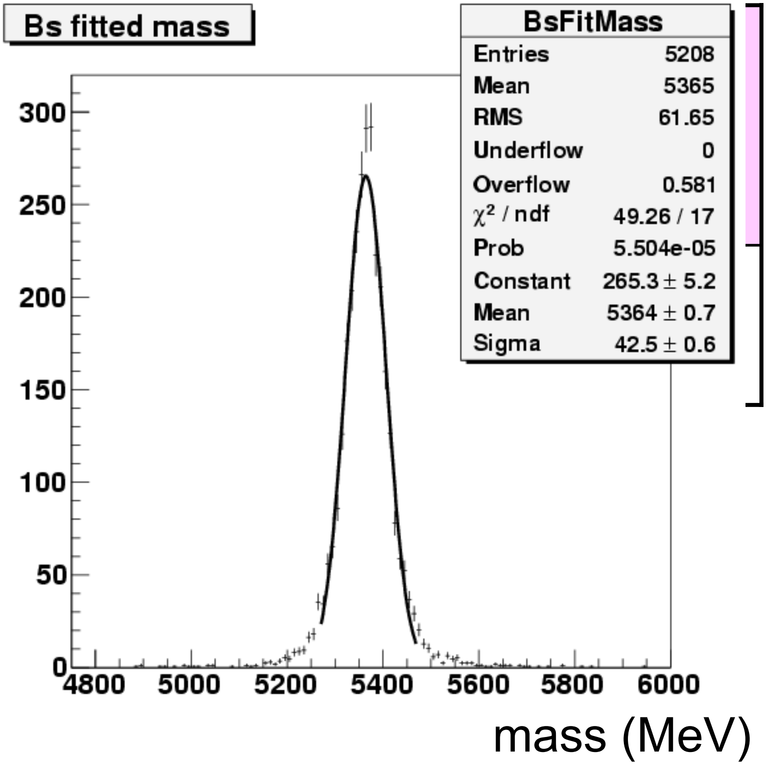
Preliminary TRT only

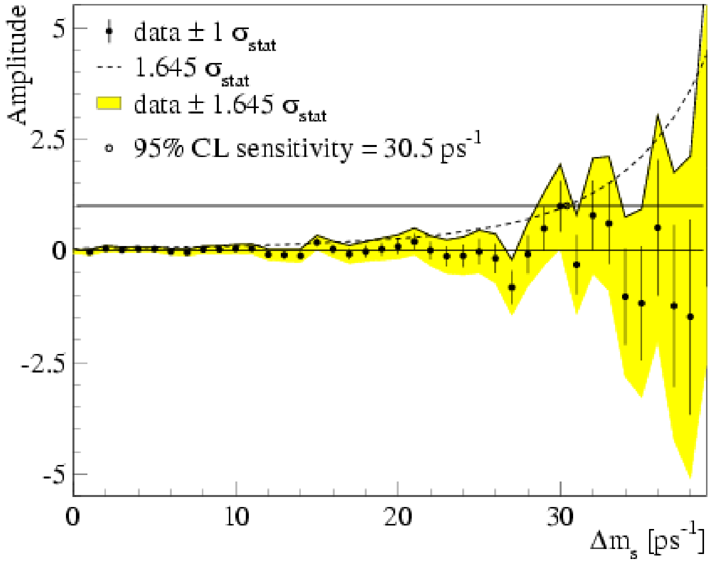
ε(electrons)=90% R(π) ~50

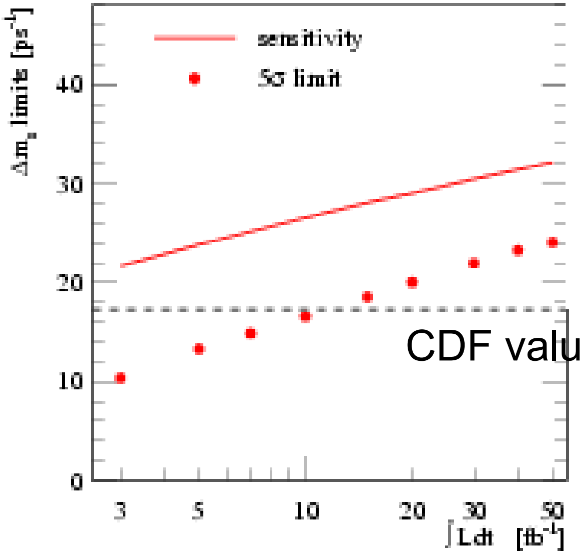
Ongoing work to ameliorate performance using ECAL Rejection also strongly depends on energy of the beam

Δm_s with $B_s \rightarrow D_s \pi$

		Number of events after trigger + offline rec. 30 fb^{-1}	
		Signal	Backgr
$B_s \rightarrow D^-_s \pi^+$	Δm_s	8250	<100%
$B_s \rightarrow D^-_s a_1^+$		4060	<100%







$$CDF: \Delta m_s = 17.31^{+0.33}_{-0.18} \pm 0.07\ ps^{-1}$$

$$D0: 17 < \Delta m_s < 21\ ps^{-1}\quad @90\%\ c.l.$$

Luminosity (fb^{-1})	5σ limit (ps^{-1})	95% CL sensitivity (ps^{-1})
10	16.5	26.5
20	20.0	29.0
30	21.9	30.5

Given the low value measured by CDF, ATLAS will be able to measure Δm_s with ~10 fb^{-1} (one year)

CP violation in $B_d \to J/\psi K_s$

- **Maximum likelihood fit using event by event tag and decay time information**
- **Experimental inputs: proper time resolution, tag probability, wrong-tag fraction, background composition. Direct CP violation term neglected**

		Number of events after trigger + offline rec. 30 fb^{-1}	
		Signal	S/B
$B_d \to J/\psi(\mu6\mu3)$	sin(2β)	490k	28
$B_d \to J/\psi(\mu6\mu5)$		250k	32
$B_d \to J/\psi(ee) + b \to \mu6$		15k	16

- **Physics Technical Design Report results**
  - σ sin2β stat : J/ψ(μ6μ3) + J/ψ(ee) : 0.010, for J/ψ(μ6μ5) + J/ψ(ee) : 0.012
  - σ sin2β syst : prod. asym, tagging, background : 0.005

⇒Improving the precision on sin 2β with the decay
$B_d \to J/\psi K_s$ will be possible

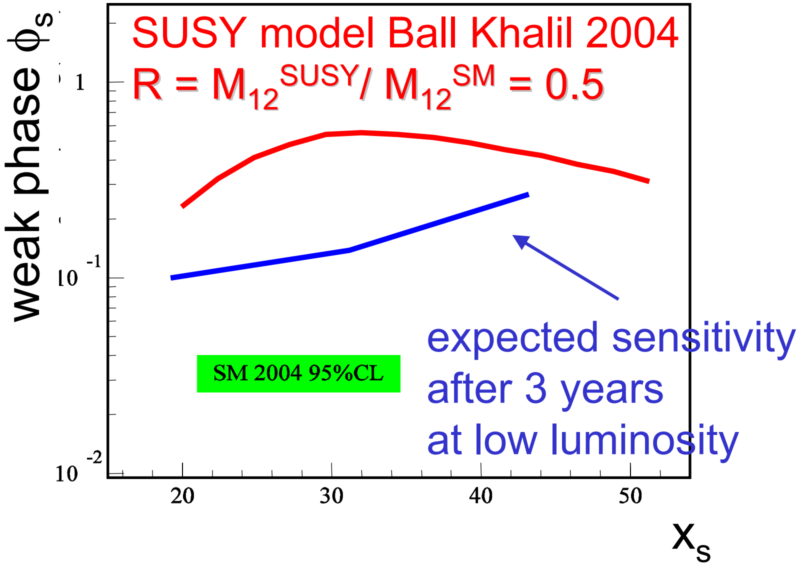
(it is an important measurement that must be done)

CP violation in $B_s \to J/\psi\phi$

- $\phi_s = -2\lambda^2\eta = -2\chi$ tiny in SM (-0.036 ± 0.003 from CKMfitter) and not accessible by any of the LHC experiments

		Number of events after trigger + offline reconstruction 30 fb^{-1}		Models used in MC or to confront experimental sensitivities.
		Signal	Backgr	
$B_s \to J/\psi\ \phi$	ϕ_s $\Delta\Gamma_s$	270k	15%	SM: Fleisher CERN-TH-2000-101 NP: Ball,Khalil, Phys.Rev.D69:115011,2004

- **New Physics could lead to enhanced and measurable CP violation**
- **8 parameters extracted in maximum likelihood fit to angular distribution of the decay : $A_{||}(t=0)$ $A_T(t=0)$, δ_1, δ_2, Δm_s, $\Delta\Gamma_s$, Γ_s and ϕ_s**
  - despite enormous LHC statistics and well controlled background – several parameters get highly correlated
  - to avoid failing a fit due to high x_s-ϕ_s correlation, x_s was fixed



SUSY model Ball Khalil 2004

$R = M_{12}^{SUSY}/ M_{12}^{SM} = 0.5$

expected sensitivity after 3 years at low luminosity

$\sigma(\phi_s) \sim 0.046$ for $x_s = 20\ ps^{-1}$

$\sigma(\Delta\Gamma_s)/\Delta\Gamma_s = 13\%$

$\sigma(\Gamma_s)/\Gamma_s = 1\%$

Rare B decays in ATLAS

- **b → d, s transitions (FCNC) are forbidden at the tree level in SM and occur at the lowest order through one-loop-diagrams “penguin” and “box”**

- **Main points to study**
  - good test of SM and its possible extensions
  - information of the long-distance QCD effects
  - determination of the $|V_{td}|$ and $|V_{ts}|$
  - some of the rare decays as background to other rare decays
    (for example $B_d \to \pi^0 \mu^+ \mu^-$ as bkg for $B_{d,s} \to \mu^+ \mu^-$)

- **Decays presented today**
  - $B_s \to \mu^+ \mu^-$ (SM BR prediction is $\sim 10^{-9}$), $B_d \to \mu^+ \mu^-$ (SM BR prediction is $\sim 10^{-10}$)
  - $\Lambda_b \to \Lambda \mu^+ \mu^-$: BR of this decay will be measured before the LHC.
    However, there might not be enough statistics to measure
    the angular distributions precisely, where New Physcis effects
    can be seen and constraints to different New Physics models might be obtained
  - radiative decays $B_s \to \phi \gamma$, $B_s \to K^{*0} \gamma$

ATLAS performance for $B_{d,s} \to \mu\mu$

- **Clear theoretical picture in the SM for BR' prediction. Good potential for SUSY**
- **ATLAS can also exploit data at nominal luminosity (10^{34} cm^{-2}s^{-1})**

BR used in the MC		Signature after trigger +offline reconstruction 30 fb^{-1}		Models used in MC or to confront experimental sensitivities.
		Signal	Backgr	
3.5×10^{-9}	$B_s \to \mu\mu$	21	<60	Ali, Greub, Mannel, DESY-93-016
0.9×10^{-10}	$B_d \to \mu\mu$	4	<60	
1.0×10^{-10} 1.9×10^{-8} 1.9×10^{-8}	$B_d \to \mu\mu\gamma$, $B_s \to \mu\mu\gamma$, $B_d \to \mu\mu\pi^0$	particle level since far		Melikhov, Nikitin, PRD70, 2004 WC: SM Buras, Munz, PRD52, 1995.

- **Results at low luminosity (10^{33} cm^{-2}s^{-1})**
  - with 100 pb^{-1} upper limit of BR($B_s \to \mu\mu$)=6.4×10^{-8} @ 90% CL
  - with 30 fb^{-1} upper limit of BR($B_s \to \mu\mu$)=6.6×10^{-9} @ 90% CL

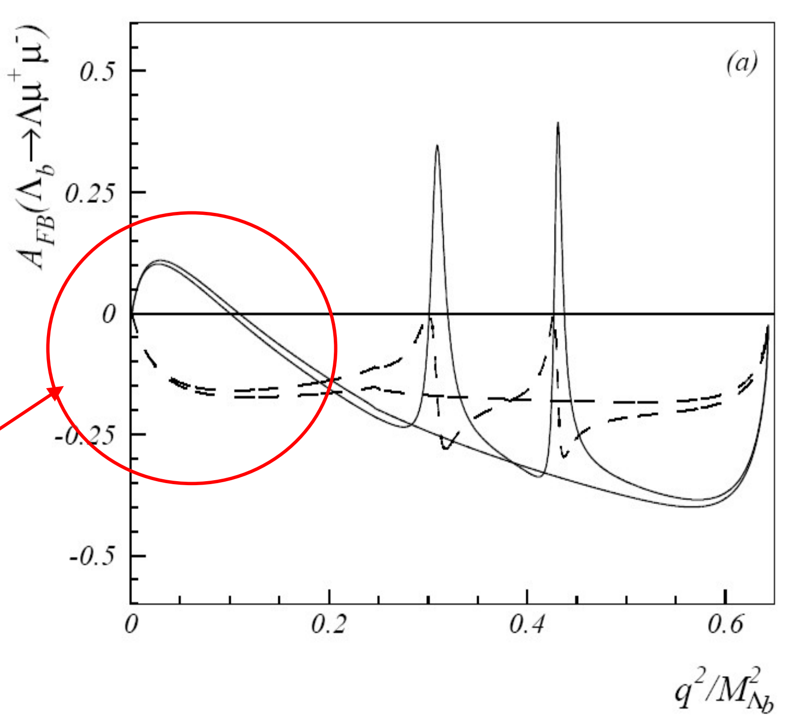
CDF upper limits (~780 pb^{-1})
B_s @ 8.0×10^{-8}
B_d @ 2.3×10^{-8}

- **Full trigger and detector TDR study was made also for luminosity 10^{34} cm^{-2}s^{-1}**
  - the $B \to \mu\mu$ program can be continued at nominal LHC luminosity
  - already after one year (100 fb^{-1}) a signal of 92 $B_s \to \mu\mu$ events (660 bkg) can be extracted and an upper limit of 3×10^{-10} @ 95% CL can be posed on $B_d \to \mu\mu$

Semi-muonic rare decays

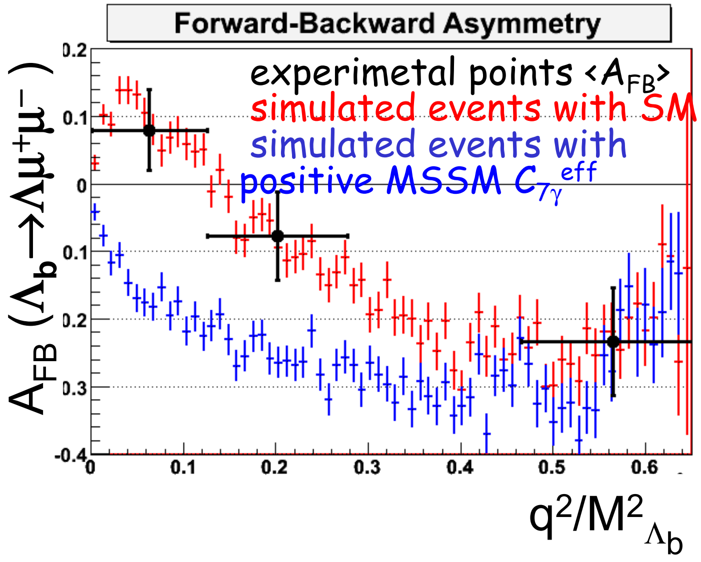
- **di-muon mass spectra and A_{FB} in low di-muon invariant mass region (outside J/ψ resonances) show significant sensitivity to new physics effects**

BR used in the MC			Signature after trigger + offline reconstruction 30 fb^{-1}	
			Signal	Backgr
1.3×10^{-6}	$B_d \to K^{0*}\mu\mu$	Br.fraction μμ-mass A_{FB}	2500	<50000
3.5×10^{-7}	$B^+ \to K^+ \mu\mu$		1500	<10000
1.0×10^{-6}	$B_s \to \phi \mu\mu$		900	<10000
2.0×10^{-6}	$\Lambda_b \to \Lambda\mu\mu$		800	< 4000



- $\Lambda_b \to \Lambda\mu^+\mu^-$:
  - shape of distributions are sensitive to trigger and offline selection cuts – especially for small opening angles and for p_T near threshold
  - A_{FB}- q^2/M_b^2 is less sensitive to trigger than q^2/M_b^2 distribution

ATLAS statistical error<5%



Radiative rare decays in ATLAS

- **Interesting channels with possible effects from physics beyond SM**

	Signature after trigger + offline reconstruction 30 fb^{-1}		Models used in MC or to confront experimental sensitivities.
	Signal	Backgr	
$B_d \rightarrow K^{0*}\gamma$	10700	$S/\sqrt{B} > 5$	Ali, Braun, Simma, Z.Phys.C63,1994; Melikhov, Stech, PRD62,2000
$B_s \rightarrow \phi\gamma$	3400	$S/\sqrt{B} > 7$	WC SM : Buras, Munz, PRD52, 1995.

- **A complete trigger strategy to select these channels has been studied showing that at a luminosity of 1-2×10^{33} cm^{-2}s^{-1} the output rate is controllable**
  - LVL1 : μ p_T>6 GeV + secondary EM RoI E_T>5 GeV
    - μ trigger not required by signal, however reduce rate while enrich B yield 25 times.
    - in CP violation studies all events will be tagged
  - LVL2 : γ identification and reconstruction of K^{*0} and ϕ
  - Event Filter : invariant mass and vertex reconstruction
- **Reject $B \rightarrow K^{*0}\pi^0$ requires good γ/π^0 separation (see next slide)**
- **Estimated yield for an integrated luminosity of 30 fb^{-1} after trigger and offline selection cuts is ($BR=4.3\times10^{5}$) :**
  - $B_s \rightarrow \phi\gamma$: 3400 events with $S/B > \sqrt{7}$
  - $B_s \rightarrow K^{*0}\gamma$: 10000 events with $S/B > \sqrt{5}$

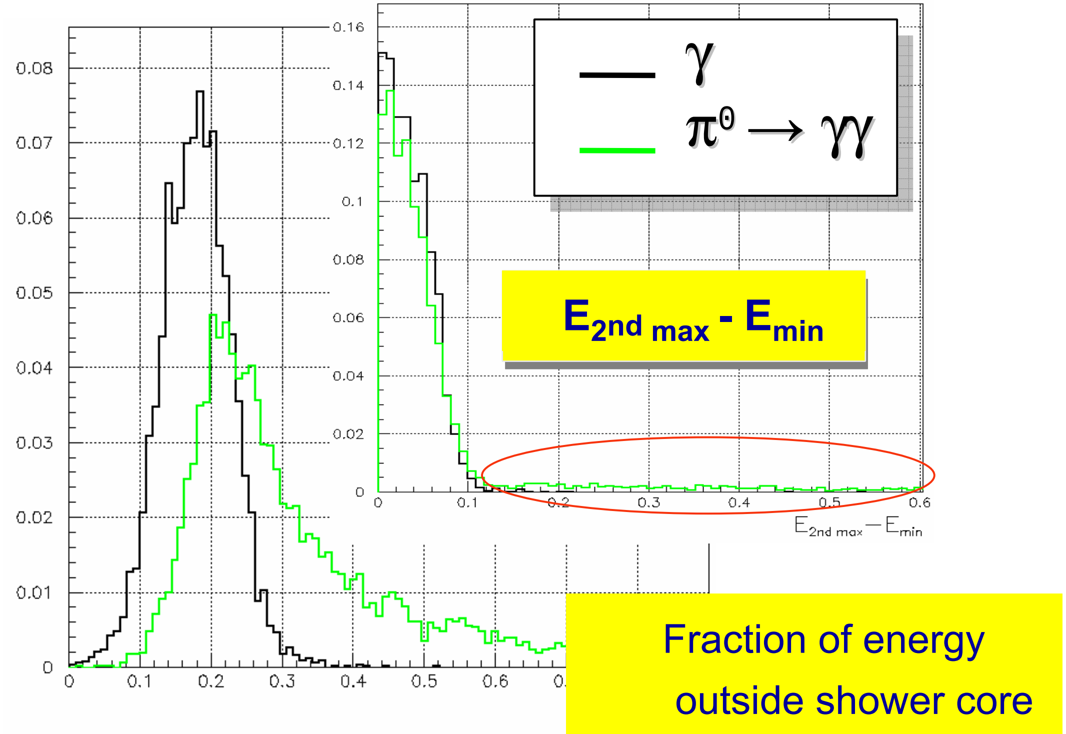
γ/π^0 separation in full simulation and test beam

- **The identification of photons is based on set of cuts applied on calorimeters information (no leakage in HCAL, narrow shower in EM2 Calorimeter). After application of HCAL + EM2 criteria, the remaining background is composed at ~80% of isolated π^0's produced by jet fragmentation**

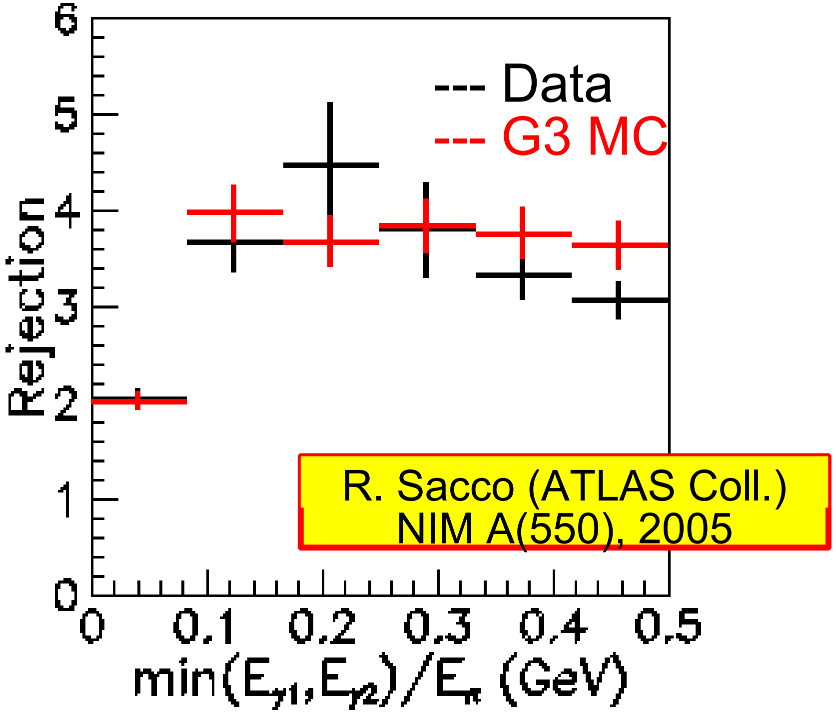
- **A γ/π^0 separation ~3 is needed for ε_γ=90%. For this the fine granularity of the EM sampling 1 is used**

G4 full simulation

Test beam 2002 @50 GeV



Fraction of energy outside shower core



R. Sacco (ATLAS Coll.)
NIM A(550), 2005

ε_γ = 90 %

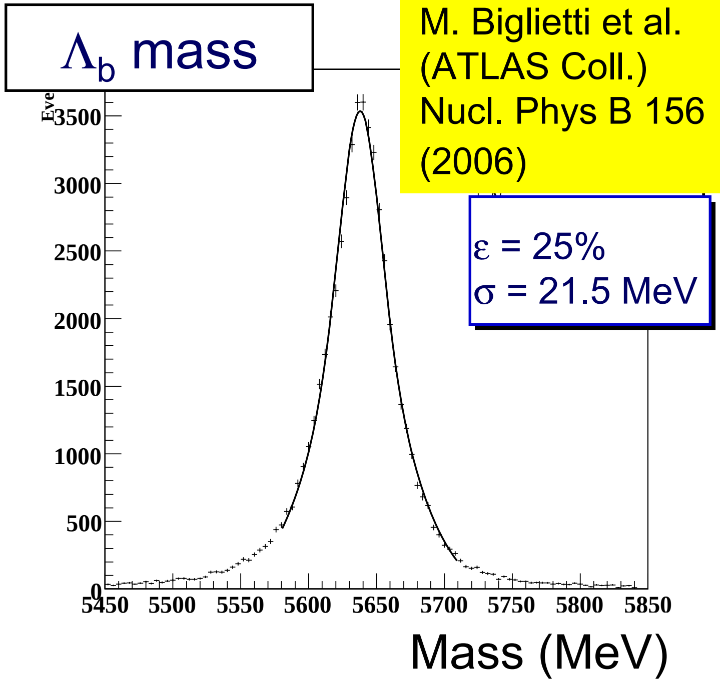
$R_{\pi0}$ (G4) = 3.2 ± 0.2

$R_{\pi0}$ (data) = 3.18 ± 0.12 (stat)
$R_{\pi0}$ (MC) = 3.29 ± 0.10 (stat)

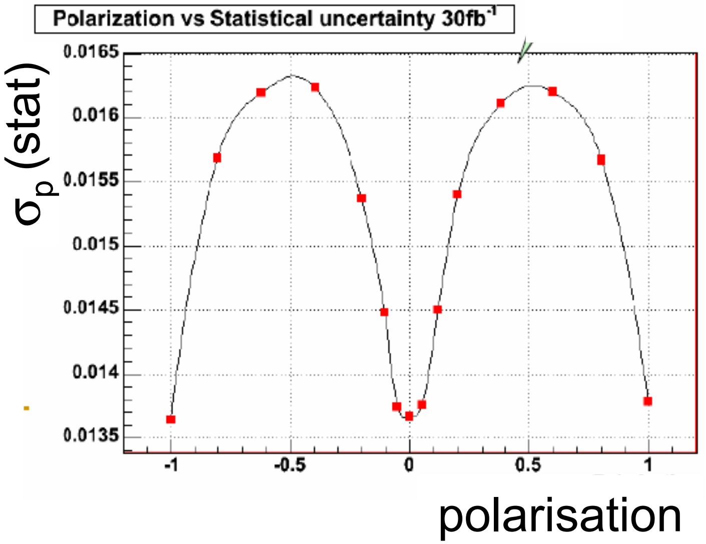
$\Lambda_b \rightarrow J/\psi \Lambda$

- **There is a large number of unanswered questions about the role of spin in production of hyperons at high energies which we wish to explore**
  - Λ hyperon (uds) : why is polarisation so large and shape unusual
  - Λ_b hyperon (udb) : are the mechanisms of Λ and Λ_b polarisation different. What is the asymmetry parameter α_b and polarisation P_b of Λ_b

- **Polarization analysis**
  - ~75k events with 30 fb^{-1}
  - Λ efficiency depends strongly on track impact parameter cut at reconstruction
  - EvtGen generator has been adapted
  - fits distributions and correlations of 5 decay angles. Obtain the polarization, asymmetry parameter and 4 helicity amplitudes



M. Biglietti et al.
(ATLAS Coll.)
Nucl. Phys B 156
(2006)



work still ongoing…
expected uncertainties for asymmetry α_b and polarisation P_b parameters measurements looks very promising

Conclusion