$\Lambda_b \rightarrow \Lambda^0 \mu^+ \mu^-$ rare decay at ATLAS

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Outline:

Introduction

Theory

Trigger Studies

Atlas Simulations

Conclusions

Introduction

- $b \to s l^+ l^-$ transition in baryon sector
  - forbidden at tree level, at lowest order occur through 1-loop diagrams (penguin, box)
  - branching ratio ~ 10^{-6} of the same order as for meson decays
- **differential crossection sensitive to new physics similarly as in meson decays**
  - forward-backward asymmetry, di-muon mass spectrum
- **polarization aspects:**
  - polarization of the initial Λ_b baryon affects angular distribution
  - various asymmetry parameters exihibit dependence on new physics contributions as well as Λ^0 polarization

Theory Background

- H^{eff} written as Operator Products Expansion:

$$\mathcal{H} = -4\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} C_i(\mu) O_i(\mu)$$

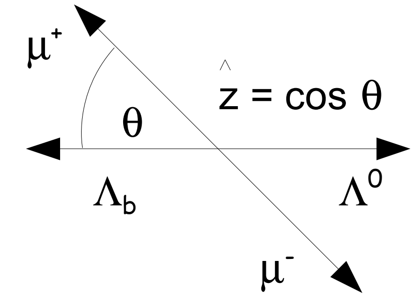
- New physics through Wilson Coefficients C_i in $H_{b \to s l^+ l^-}$
  - SM NLO calculation taken from [A.Buras, M.Munz, PRD52, p.182, 1995]
- Amplitude $b \to s l^+ l^-$ using 12 model independent four-Fermi interactions [T.M. Aliev et al., Nucl.Phys.B649,1681 2003]:

$$\begin{aligned}\mathcal{M} = \frac{G\alpha}{4\sqrt{2}\pi} V_{tb} V_{ts}^* \Big\{ & C_{SL} \bar{s} i \sigma_{\mu\nu} \frac{q^\nu}{q^2} L b \bar{\ell} \gamma_\mu \ell + C_{BR} \bar{s} i \sigma_{\mu\nu} \frac{q^\nu}{q^2} b \bar{\ell} \gamma_\mu \ell + C_{LL}^{tot} \bar{s}_L \gamma^\mu b_L \bar{\ell}_L \gamma_\mu \ell_L \\ & + C_{LR}^{tot} \bar{s}_L \gamma^\mu b_L \bar{\ell}_R \gamma_\mu \ell_R + C_{RL} \bar{s}_R \gamma^\mu b_R \bar{\ell}_L \gamma_\mu \ell_L + C_{RR} \bar{s}_R \gamma^\mu b_R \bar{\ell}_R \gamma_\mu \ell_R \\ & + C_{LRLR} \bar{s}_L b_R \bar{\ell}_L \ell_R + C_{RLLR} \bar{s}_R b_L \bar{\ell}_L \ell_R + C_{LRRL} \bar{s}_L b_R \bar{\ell}_R \ell_L + C_{RLRL} \bar{s}_R b_L \bar{\ell}_R \ell_L \\ & + C_T \bar{s} \sigma^{\mu\nu} b \bar{\ell} \sigma_{\mu\nu} \ell + i C_{TE} \epsilon^{\mu\nu\alpha\beta} \bar{s} \sigma_{\mu\nu} s \sigma_{\alpha\beta} \ell \Big\} ,\end{aligned}$$

  - forward-backward asymmetry, di-muon mass specrum etc. studied according to parametrization by C_X coreficients

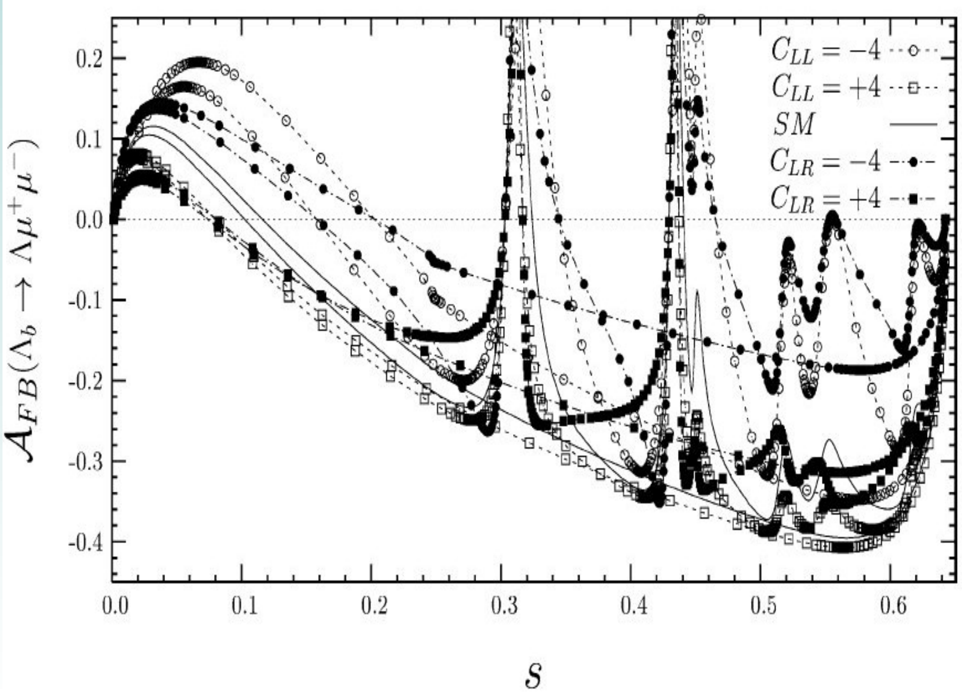
Forward-Backward Asymmetry

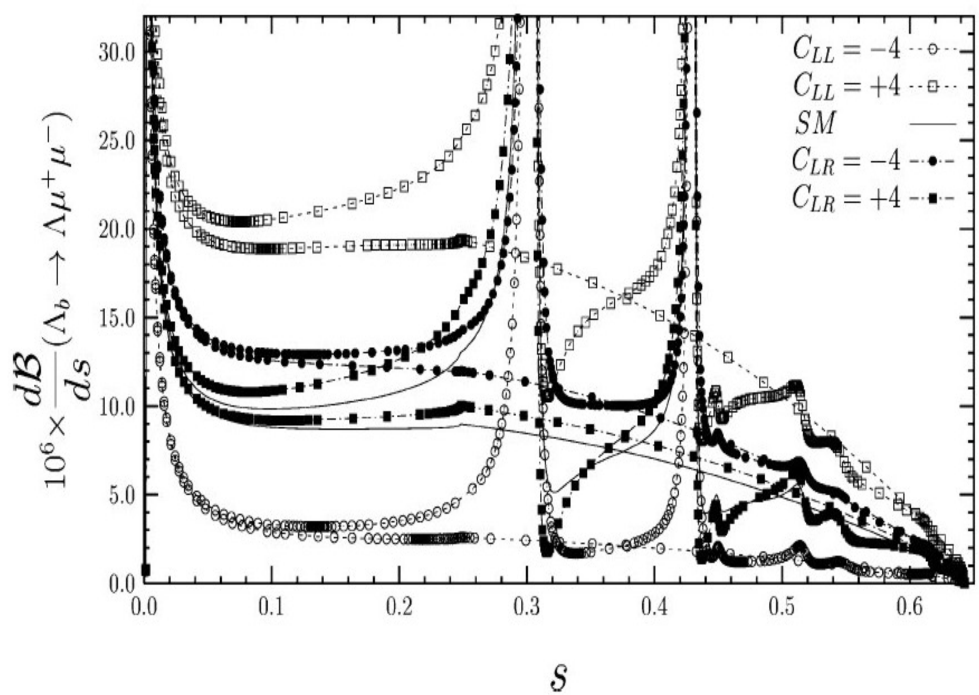
- Sensitivity of F-B asymmetry A_{FB} to Wilson Coeficients – trends of F-B asymmetry are similar to the B-meson decays



$$A_{FB}(s) = \frac{1}{d\Gamma(s)/ds}\left[\int_0^1 d\hat{z}\frac{d^2\Gamma(s,\hat{z})}{dsd\hat{z}} - \int_{-1}^0 d\hat{z}\frac{d^2\Gamma(s,\hat{z})}{dsd\hat{z}}\right]$$

- Model independent analysis (W.C. parametrization) of di-muon mass spectra and A_{FB} according to [T.M.Aliev et.al, Nucl.Phys.B649(2003),168-188)]:





$\Lambda_b \to \Lambda^0$ Form Factors

- For the decay amplitude, following matrix elements are needed:

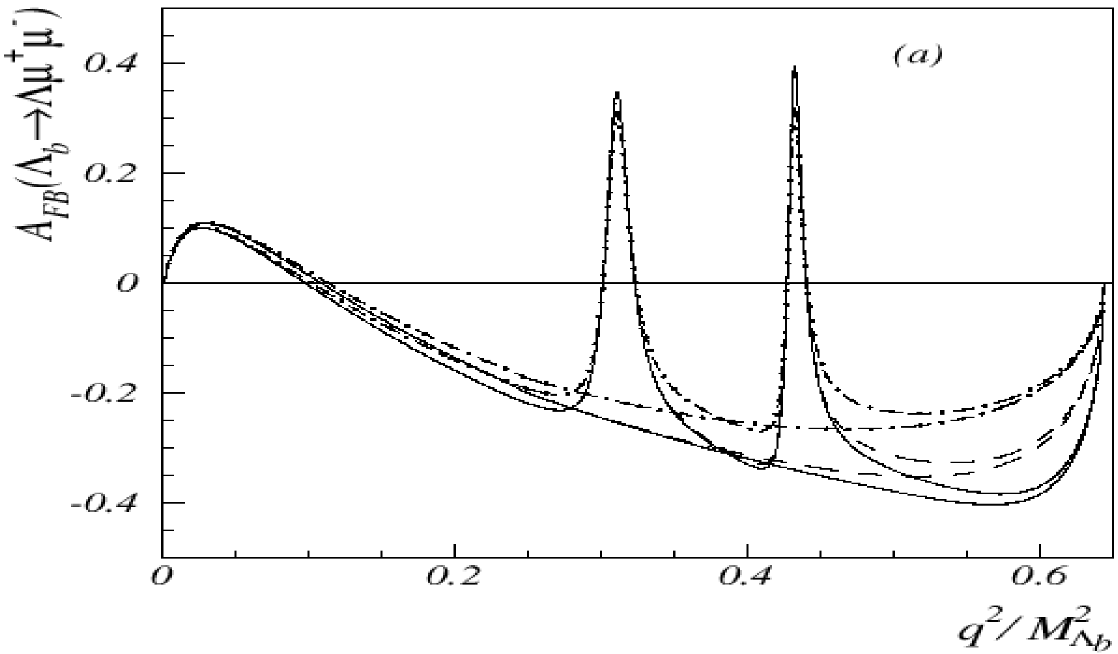
$$\langle \Lambda \,|\bar{s}\gamma_\mu(1 \mp \gamma_5)b|\, \Lambda_b\rangle \quad ,$$
$$\langle \Lambda \,|\bar{s}\sigma_{\mu\nu}(1 \mp \gamma_5)b|\, \Lambda_b\rangle \quad ,$$
$$\langle \Lambda \,|\bar{s}(1 \mp \gamma_5)b|\, \Lambda_b\rangle \quad .$$

  - 12 form-factors are used to parametrize these matrix elements

- QCD sum rule + HQET reduce number of independent form-factors to just two: F_1, F_2:

$$\langle \Lambda(p_\Lambda)|\, \bar{s}\Gamma b\,|\Lambda_b(p_{\Lambda_b})\rangle = \bar{u}_\Lambda \left(F_1(q^2) + \not{v} F_2(q^2)\right) \Gamma u_{\Lambda_b}$$

- Senstivity of A_{FB} was studied in [C.-H. Chen et al., hep-ph/0101201,2001]
  - comparing **QCD sum rule** approach (solid curve) with two **pole models**
  - uncertainity growing with di-muon invariant mass



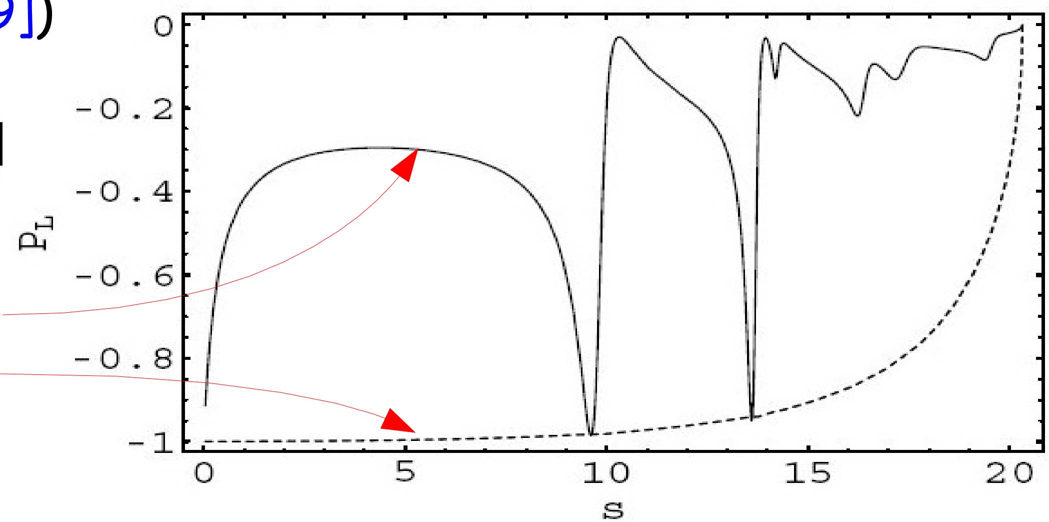
Polarization / Asymmetry Parameters

- Longitudal, normal and transverse polarizations P_L, P_N and P_T of Λ^0 differ significantly from SM in some Beyond-SM models (i.e. [A.K.Giri at al., J.Phys.G.Nucl.Part.31,2005,1959-1969])

$$\frac{\mathrm{d}\Gamma(\hat{\eta})}{\mathrm{d}s} = \frac{1}{2}\left(\frac{\mathrm{d}\Gamma}{\mathrm{d}s}\right)_0 \left[1 + (P_L\hat{e}_L + P_N\hat{e}_N + P_T\hat{e}_T)\cdot\hat{\eta}\right]$$

R-parity violating SUSY model

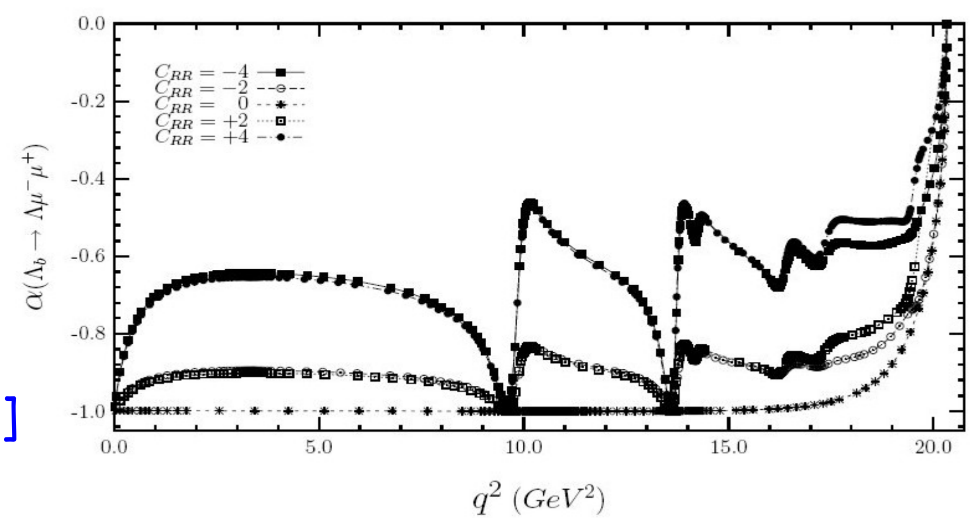
Standard Model



- Asymmetry parameter α from expression for distribution of polar angle θ_Λ of proton in rest frame of Λ^0

$$\frac{d\Gamma}{dq^2\, d\cos\theta_\Lambda} \sim 1 + \alpha\alpha_\Lambda \cos\theta_\Lambda$$

[T.M.Aliev et al.,hep-ph/0507324,2005]



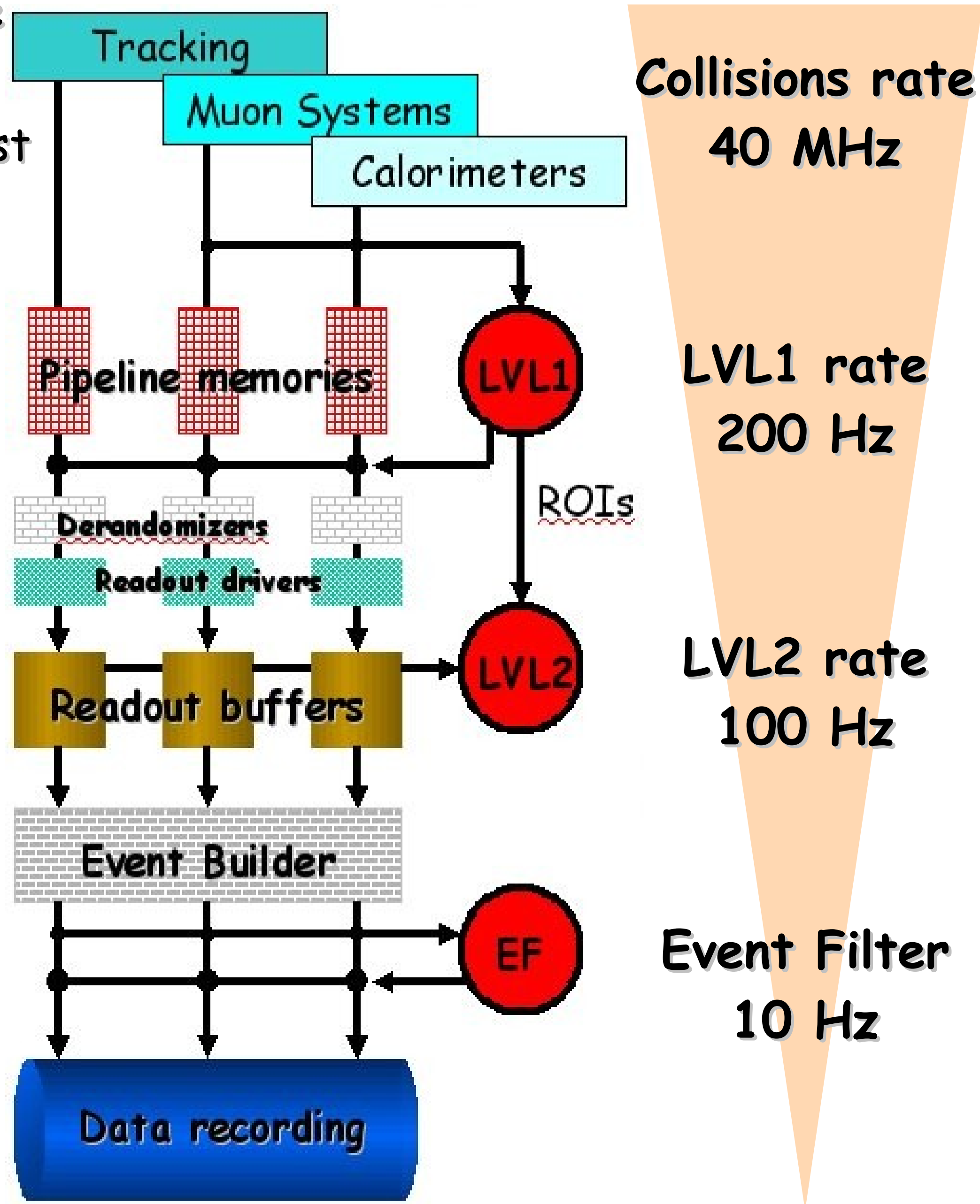
- Full helicity amplitude analysis to be performed

Calculations in Specific Models

- $\Lambda_b \rightarrow \Lambda^0 \mu^+ \mu^-$ decay properties were studied in several models, resulting in various A_{FB} shapes and BR enhancements over SM:
  - **R-parity violating SUSY models**
    [A.K.Giri at al., J.Phys.G.Nucl.Part.31,2005,1959-1969]
  - **Effect of FCNC mediated Z-boson**
    [A.K.Giri et al., hep-ph/051017,2003]
  - **Two Higgs doublet model**
    [G.Turan, J.Phys.G.Nucl.Part.31,2005,525-537],
    [T.M.Aliev,hep-ph/9906473,1999]
  - **Model with fourth generation**
    [G.Turan,JHEP05(2005)08]

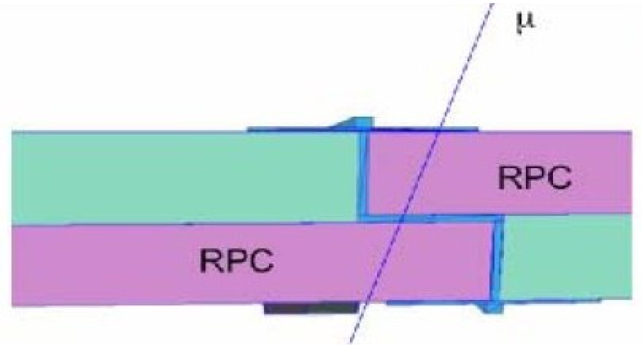
Di-muon Trigger

- B-physics mostly during initial stage of low luminosity ~ $10^{33}\ cm^{-2}s^{-1}$
  - vary by factor ~ 2 during beam-coast
  - 2-3 interactions/collision
- $b\bar{b}$ pairs production ~ 500 kHz
  - 1% of collisions
  - $5{\cdot}10^{12}$ $b\bar{b}$ pairs / year = 10^7 sec.
- LVL1 trigger is based on detection of two muons ($p_{T\mu 1} > 6$ GeV, $p_{T\mu 2} \geq 4$ GeV) by muon trigger chambers
- LVL2 trigger + Event Filter confirms LVL1 measurement by precise MDT, calorimeters and tracks extrapolation to Inner Detector
  - refits tracks in LVL2 ROIs
  - decay vertices search, mass cuts, decay length, opening angles, etc.



Di-muon Trigger: Overlaps

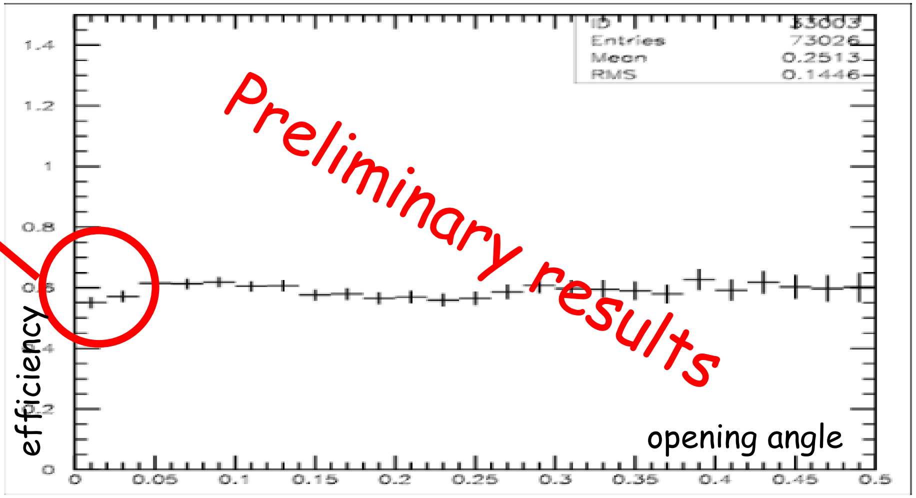
- The LVL1 rate is dominated by:
  - real di-muons i.e. $b\bar{b}$ and $c\bar{c}$ events with two muons ~ 150 Hz
  - events with one muon doubly counted due to overlap of trigger chambers
- Study based on 50 kEvents of rare Λ_b decay fully simulated+digitized by ATLAS software with layout Q
- **Overlaps**: some regions are covered by more trigger chambers
  - overlaps between barrel and end-cap, η-overlaps, ϕ-overlaps
  - single muon can produce fake di-muon signal in these region



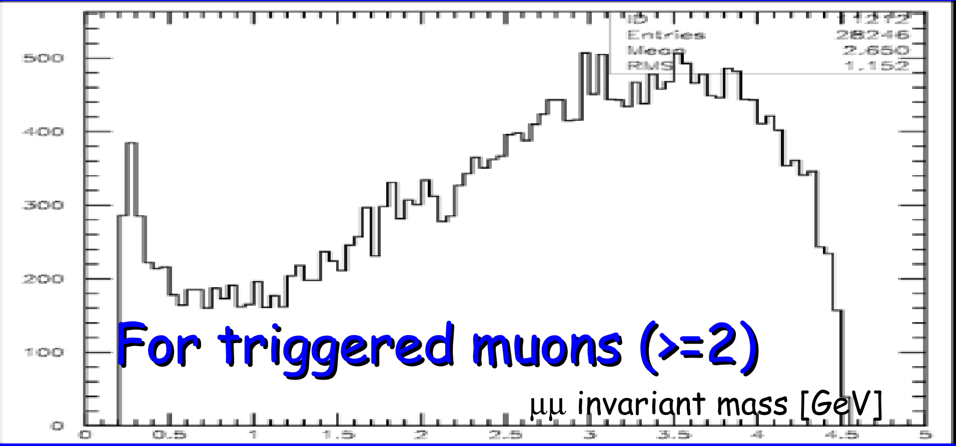
- overlap flags (Sector Logic, MuCTPI) to resolve these fake di-muon triggers
- using overlap flags reduces the fake di-muon trigger barrel rate from ~ 550 Hz to ~ 170 Hz
- the overlap removing mechanism can cause loss of real di-muon signal if both muons pass through the same overlap region
  - effect found to be less than 0.5% in total and less than 1.6% for di-muons with $\Delta\eta < 0.1$ and $\Delta\phi < 0.1$ (small opening angle)

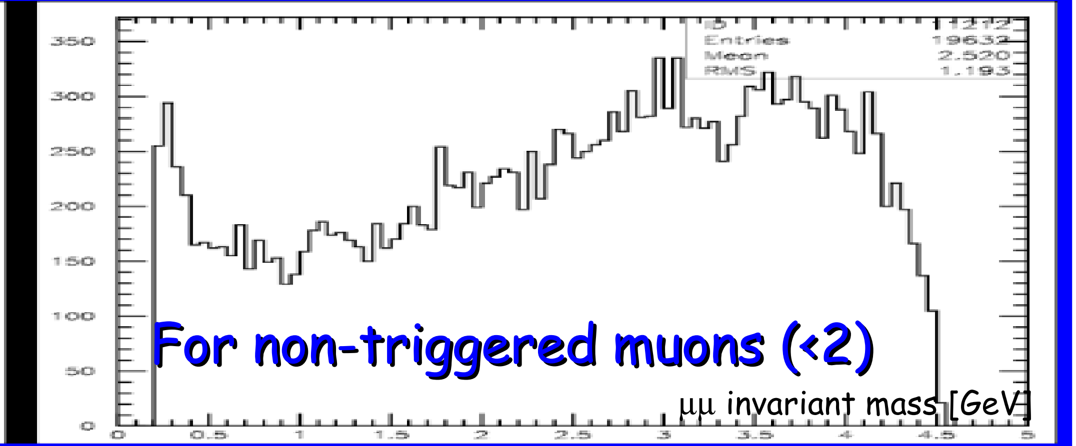
Di-muon Trigger: Efficiency, Opening Angle

- The trigger efficiency study
  - barrel trigger efficiency is ~ 10% lower with $\Delta\eta < 0.1$ and $\Delta\phi < 0.1$ than in the barrel without opening angle constraint, but overall loss is almost unaffected because of small fraction (7%) of events with such small opening angle



    - $\Delta\eta$ and $\Delta\phi$ distributions have **sigma around 0.25** and there is **no correlation** between $\Delta\eta$ and $\Delta\phi$ values
- Non-triggered di-muons advance lower di-muon invariant masses (58% of non-triggered events has di-muon invariant mass below J/ψ mass) compared to triggered di-muons (54% events below J/ψ mass)



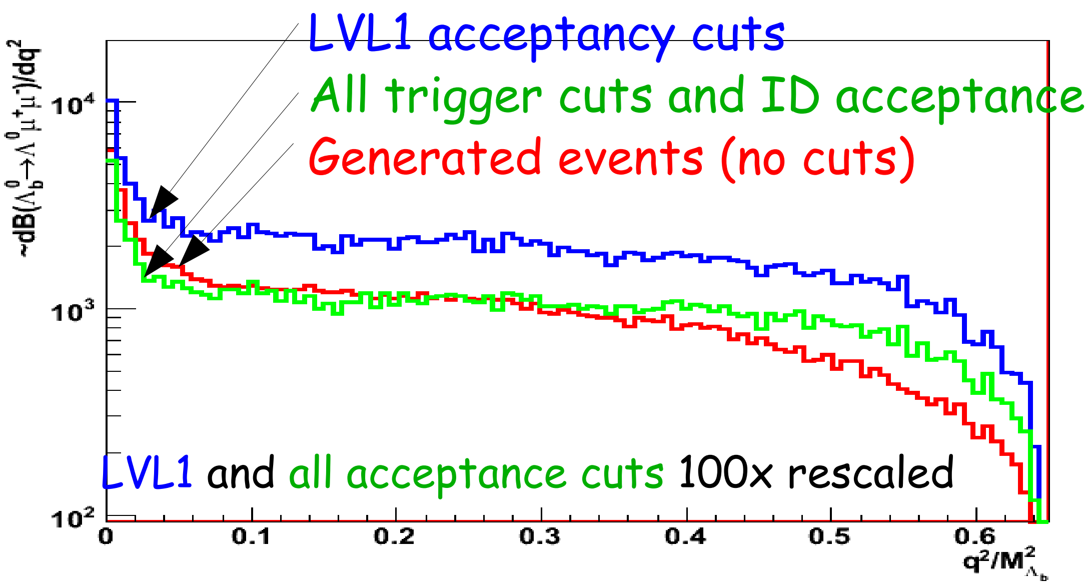


MC Generator

- **Pythia** (with parameters tuned for B-physics, MSEL=1) under ATLAS software framework **Athena**, but using **EvtGen** for Λ_b and consequent Λ^0 decay
  - Λ_b decay amplitude according to [T.M.Aliev at al.], with NLO Wilson Coefs. from [A.J.Buras et al.], Λ^0 decay follows model from [Review of Part. Phys.]
- No. of triggerable and reconstructable $\Lambda_b \to \Lambda^0{}_{\to p\pi}\,\mu^+\mu^-$ events for L_{int} = 30 fb^{-1}:

Λ_b production	$\sigma_{b\bar{b}}$ = 500 μb, $BR_{b\to\Lambda b}$ = 0.071	1.1*10^{12}
Λ_b rare decay	$BR_{\Lambda b\to\Lambda\mu\mu} = 2\cdot10^{-6}$, $BR_{\Lambda\to p\pi}$ = 0.64	1.400.000
Di-muon LVL1 cuts + acceptance	p_T > 6 / 4 GeV , $\lvert\eta\rvert$ < 2.5	26.000
Hadron acceptance by ID	p_T > 0.5 GeV, $\lvert\eta\rvert$ < 2.5	**14.000**

- Impact of trigger/acceptance:
  - higher di-muon masses are prefered – fraction of events with di-muon mass below J/ψ mass changed from 67% to 58%



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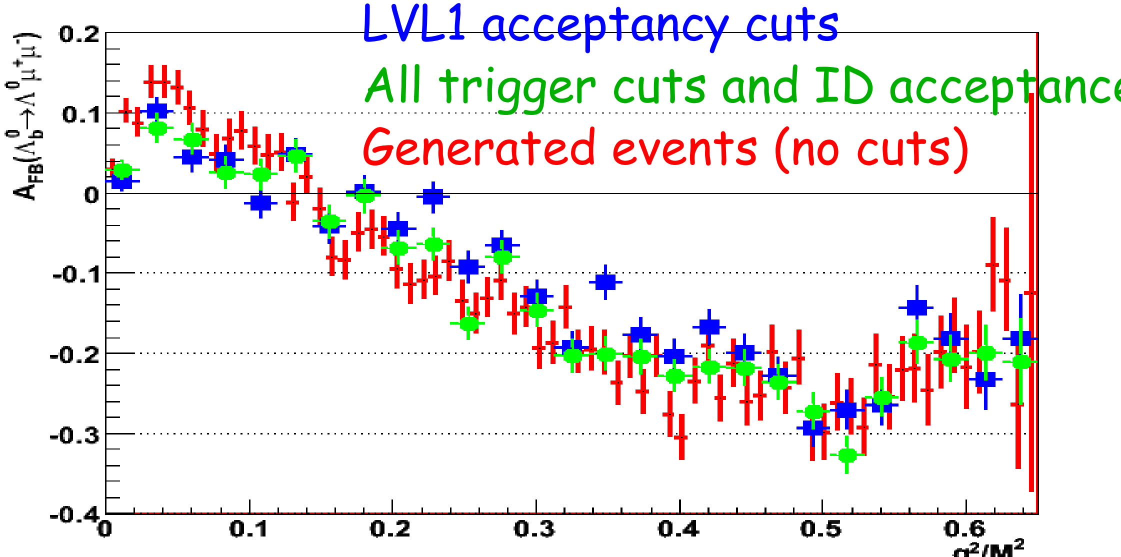
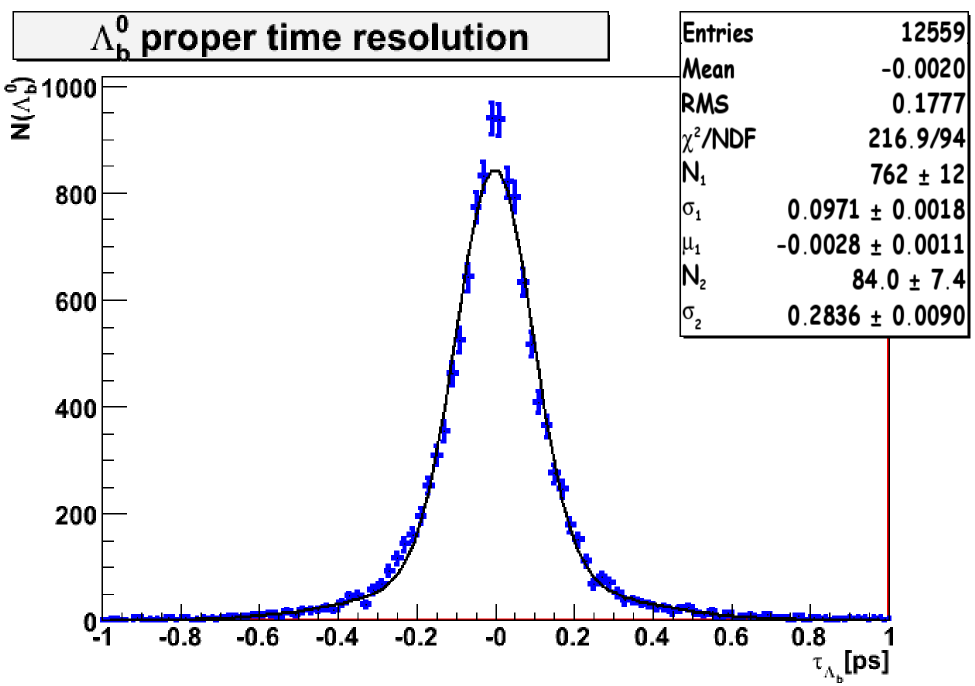
Hadron acceptance by ID	$p_T > 0.5$ GeV, $\lvert\eta\rvert < 2.5$	14.000

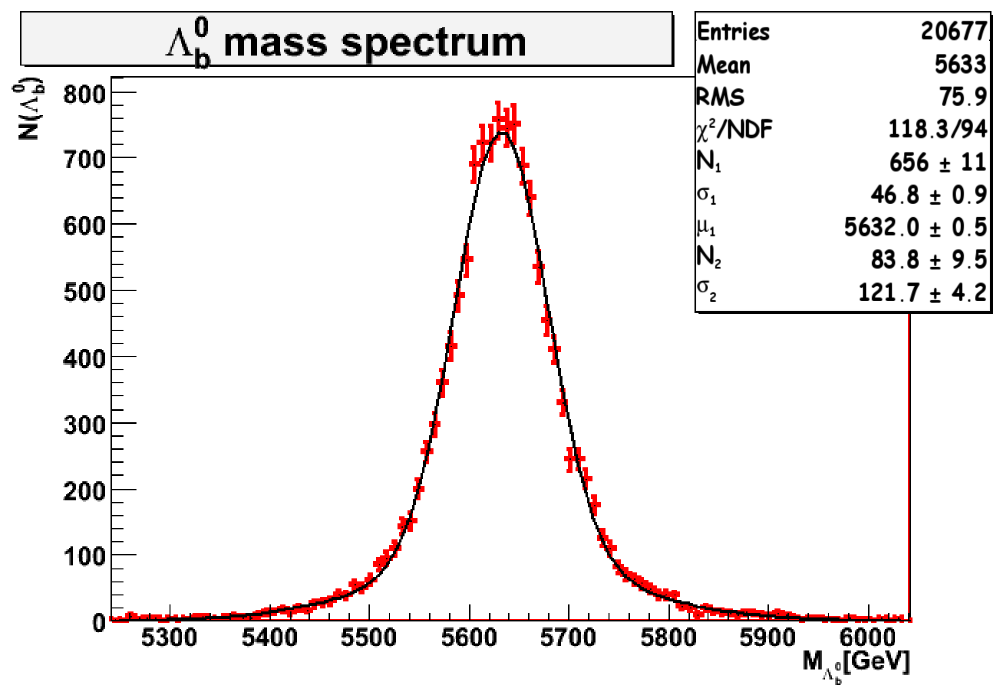
- Impact of trigger/acceptance:
  - 40% suppresion of $\lvert A_{FB}\rvert$ in region $q^2/M_{\Lambda b}^2 < 0.1$ was found



Signal Reconstruction

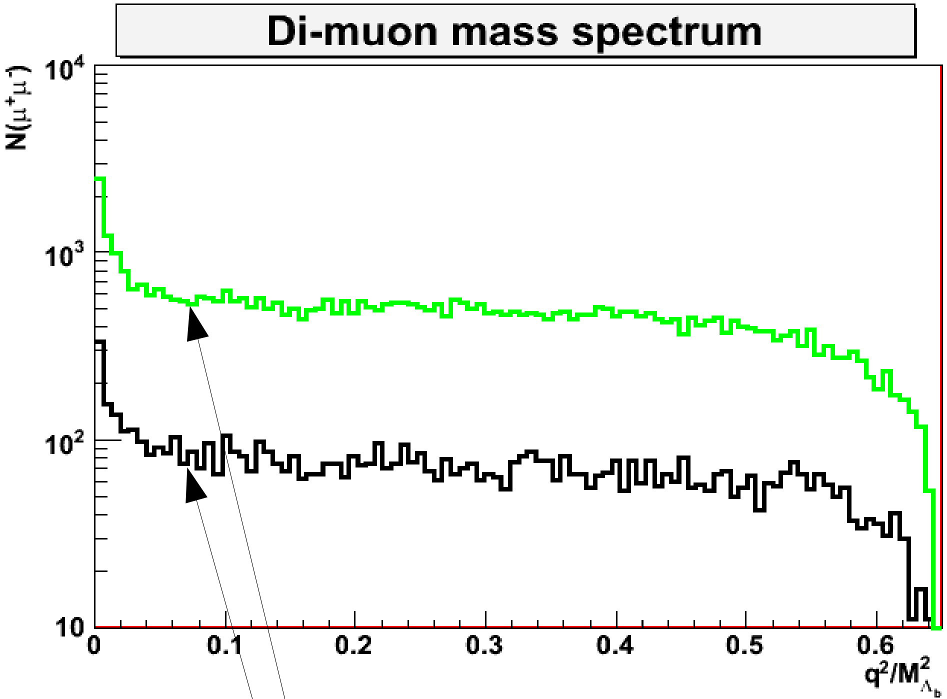
- Preselection of di-muon candidates and Λ^0 candidates:
  - muon identification, mass inside allowed interval (q_{min} … q_{max}, $m_{\Lambda 0} \pm 3 \cdot \sigma$) before (wider cuts) and after vertex fitting, vertex fit quality cut
- Λ_b reconstruction: using CDF vertex fitting routine – fits whole decay topology at once
  - total reconstruction efficiency ~ **27%** (preliminary result)
- Study based on ~ 50 kEvents fully simulated and reconstructed by ATLAS software with layout Q





Di-muon Spectrum, F-B Asymmetry

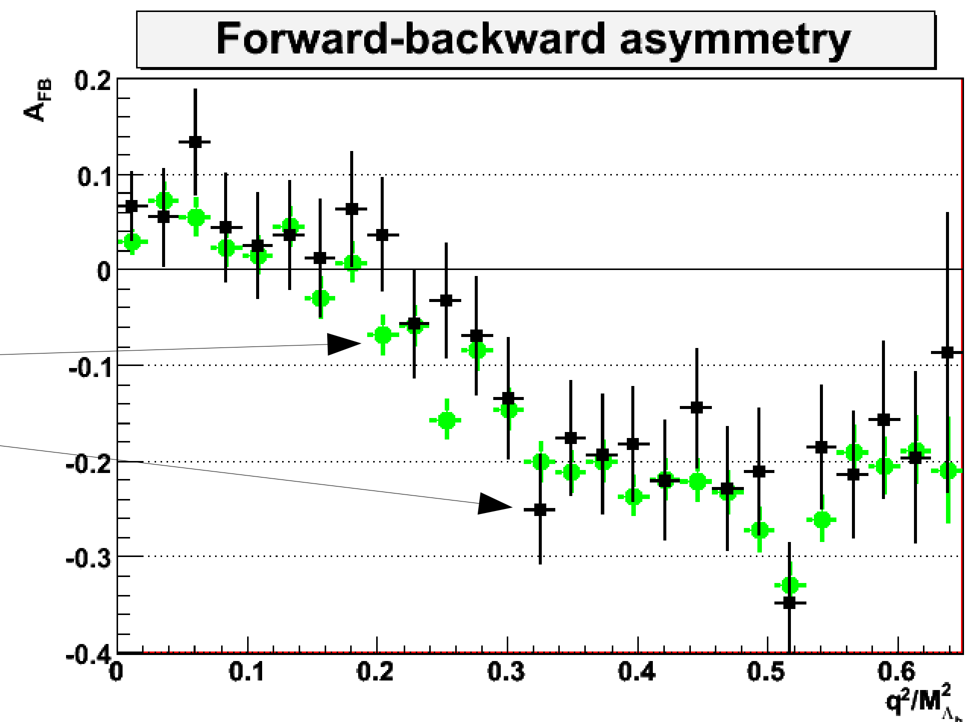
- Other cuts introduced for background reduction



overall reconstruction efficiency **14%**

after cuts:

- Λ^0_b and Λ^0 masses $3\cdot\sigma$ around nominal
- di-muon mass in between $q_{min}-1\cdot\sigma_{\mu\mu(0.2GeV)}$ and $q_{max}+1\cdot\sigma_{\mu\mu(4.5GeV)}$
- Λ^0 decay radius $R > 1$ cm and $R < 45$ cm
- Λ^0_b proper time $\tau > 0.5$ ps



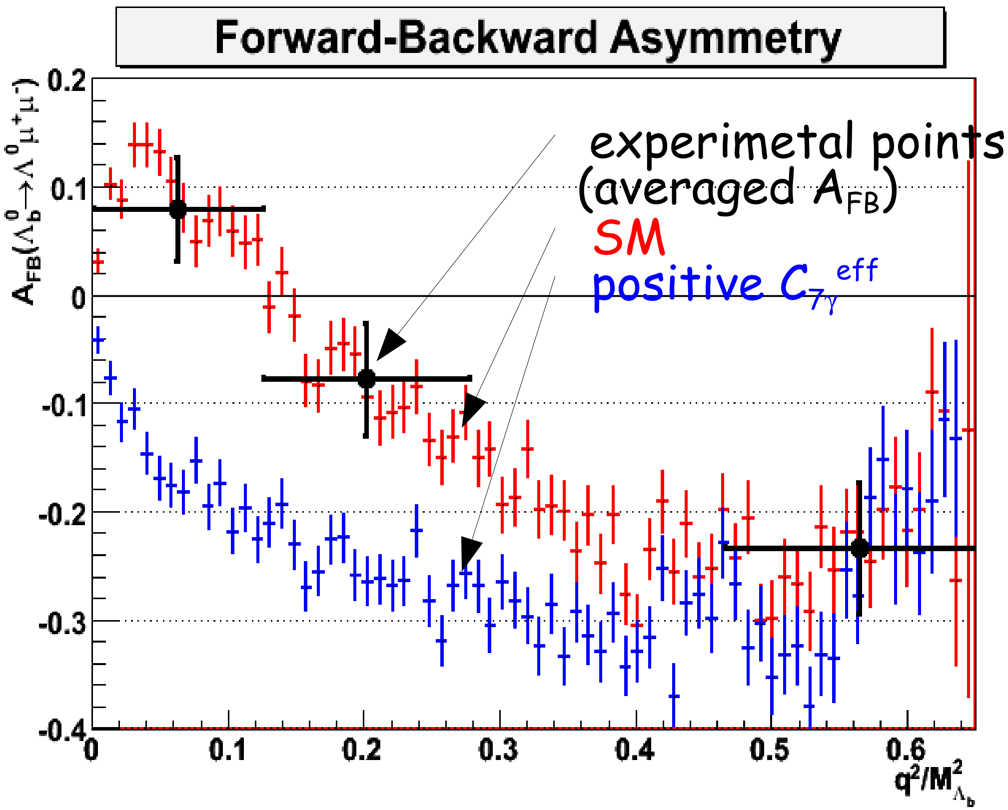
simulated events

reconstructed events

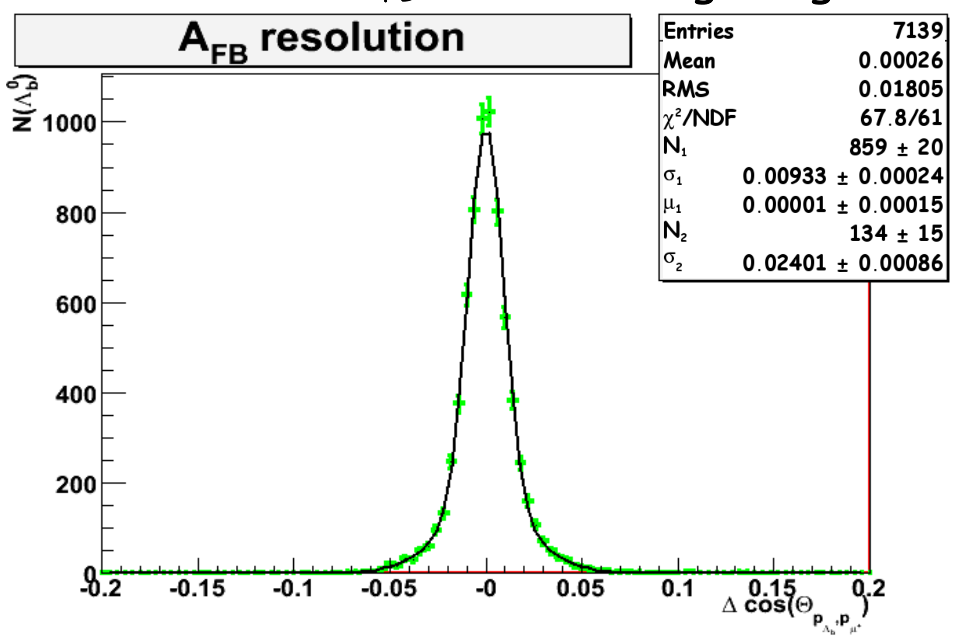
Forward-Backward Asymmetry

- expected precision after 3 years:
  - 14% reconstruction efficiency
  - accounting 75% LVL1 efficiency
  - ➔ **1500 events**

q^2/M_{Λ_b}	min .. 0.13	0.13 .. 0.28	0.47 .. max
$\langle A_{FB}\rangle$ for SM	7,9%	-7,8%	-23,3%
$\langle A_{FB}\rangle$ for $C_{7\gamma}^{eff} > 0$	-13,8%	-25,0%	-27,9%
$\langle A_{FB}\rangle$ statistical error	4,8%	5,2%	6,2%
Number of events	430	370	280

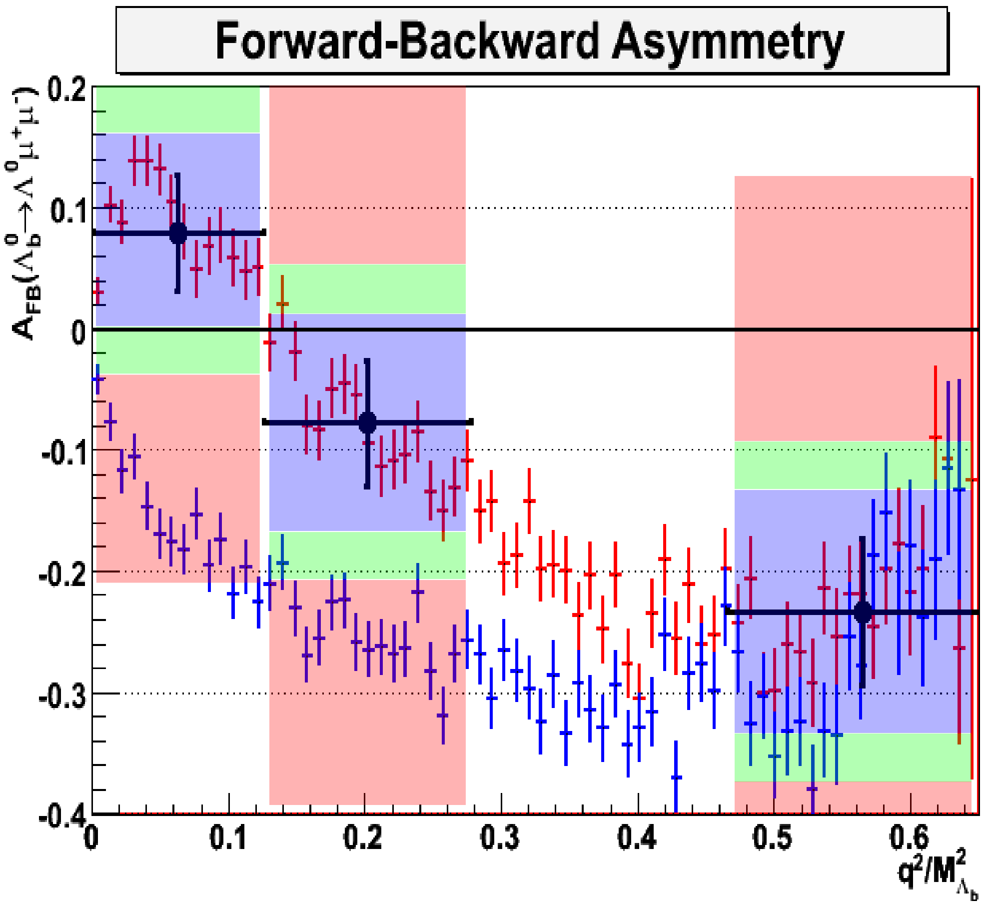


Resolution of $\hat{z}$: introduces systematical error 0.8% to A_{FB} due to wrong $\hat{z}$ sign



A_{FB} of $\Lambda_b \to \Lambda^0 \mu^+ \mu^-$ with Early Data

$q^2/M_{\Lambda_b}^2$		s_{min} .. 0.13	0.13 .. 0.28	0.47 .. s_{max}
$\langle A_{FB} \rangle$ for SM		8%	-8%	-23%
$\langle A_{FB} \rangle$ for $C_{7\gamma} > 0$		-14%	-25%	-28%
Number of events:	L_{int} = 30 fb^{-1}	430	370	280
$\langle A_{FB} \rangle$ statistical error:	L_{int} = 30 fb^{-1}	**5%**	**5%**	**6%**
	L_{int} = 10 fb^{-1}	**8%**	**9%**	**10%**
	L_{int} = 5 fb^{-1}	**12%**	**13%**	**14%**
	L_{int} = 0.8 fb^{-1}	**29%**	**32%**	**36%**



- starting from around 5 fb^{-1}, SM and MSSM with opposite $C_{7\gamma}$ sign can be distinguished better than at $2 \cdot \sigma_{stat}$ level
- at lower luminosities, SUSY effects can be searched in BR measurement

Conclusions

- Analysis of $\Lambda_b \rightarrow \Lambda^0\mu^-\mu^+$ rare decay can provide similar signatures of new physics (NP) as $b\rightarrow sl^-l^+$ decay in mesons sector
  - to allow understanding of angular effects, Λ_b polarization have to be know from independent source
  - NP effects can be searched in angular distribution of Λ^0 decay
- Di-muon trigger studies at ATLAS showing negligible loss of events due to small opening angles and/or overlaps treatment algorithm
- Trigger, acceptancy and offline analysis cuts slightly suppress ~ 10% more events with di-muon mass below J/ψ mass, but A_{FB} is affected only in region $q^2/M_{\Lambda b}^2 < 0.1$ ($|A_{FB}|$ is ~ 40% lower in this region)
- A_{FB} statistical precision after 3 years of low luminosity LHC running: will allow to distinguish at $1.6\cdot\sigma$ level between models having A_{FB} different by more than ~ 8% in di-muon invariant mass below J/ψ mass
  - with early data, NP effects can be searched in BR, and with integrated luminosity ~ 5 fb^{-1} statistics is enough to distinguish C_7^{eff} sign
- A lot of effort is being given for background analysis