MESON 2014

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on Meson Production,
Properties and Interaction

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Study of rare and suppressed processes in B meson decays with ATLAS

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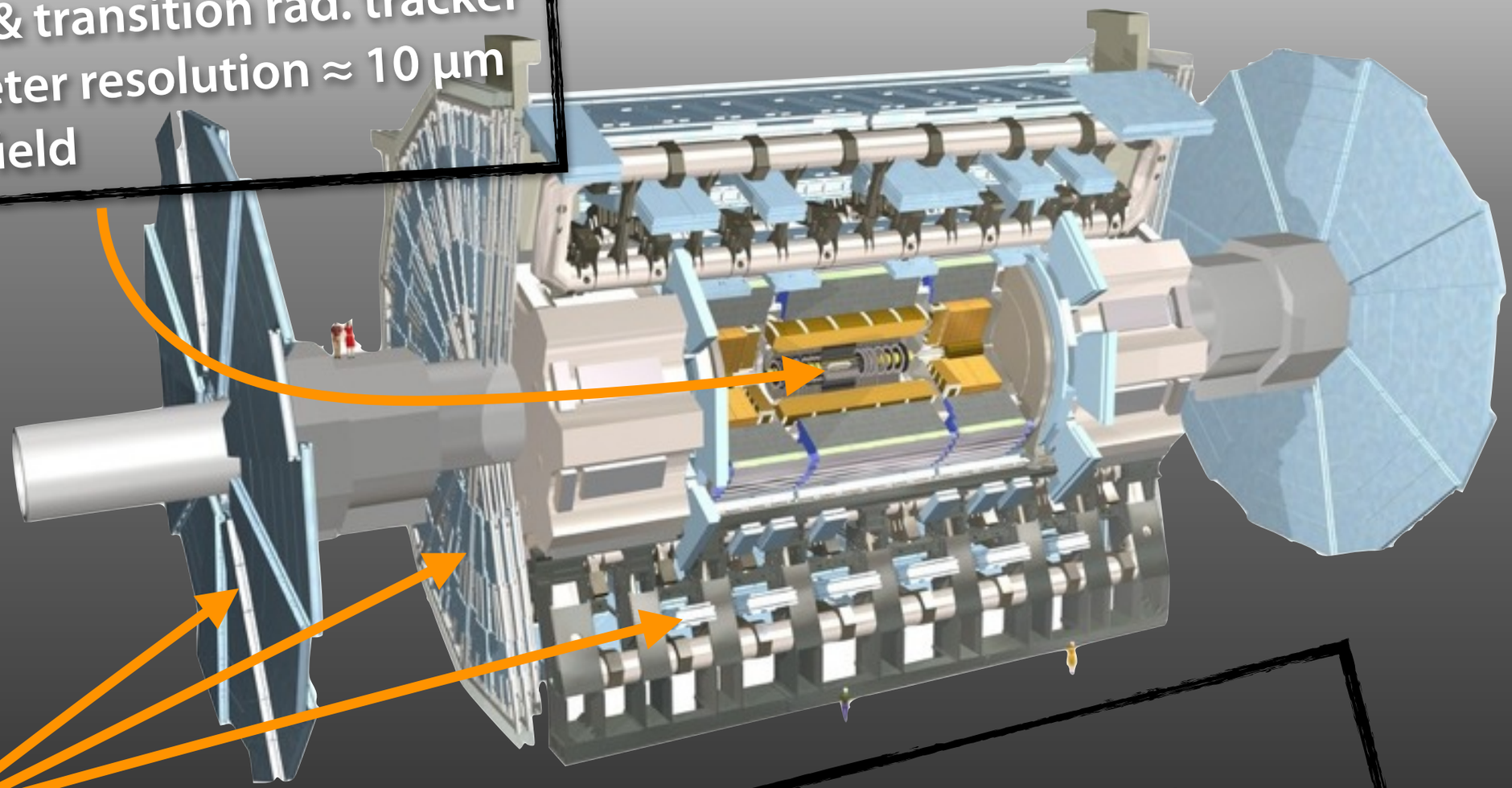
Outline

- ATLAS detector at LHC
- Study of the decay $B_d \rightarrow K^* (\rightarrow K^+\pi^-)\ \mu^+\mu^-$
- Search for $B_s \rightarrow \mu^+\mu^-$
- Conclusions

The ATLAS Detector

Inner Detector ($|\eta| < 2.4$)

- silicon pixel, strip & transition rad. tracker
  - Impact parameter resolution ≈ 10 μm
  - 2T solenoidal field



Muon Spectrometer ($|\eta| < 2.7$)

- Trigger chambers (RPC, TGC),
- Tracking chambers (MDT, CSC)
- 0.5-2 T toroidal field

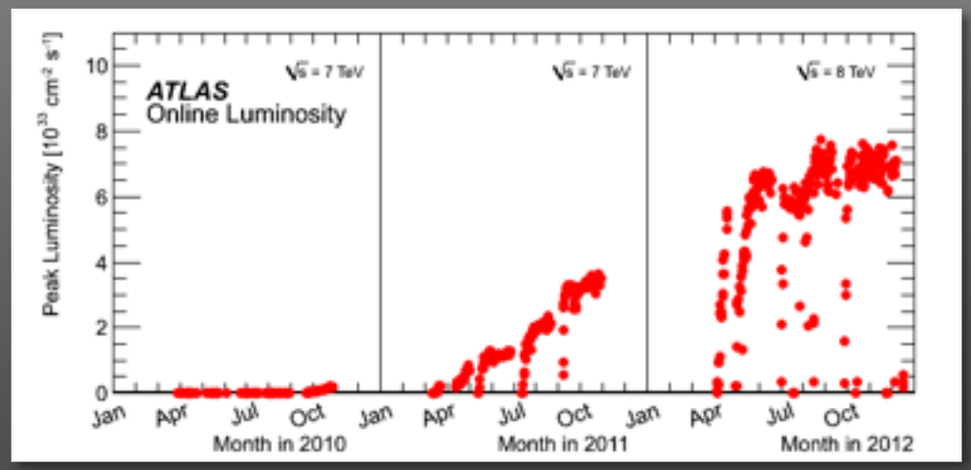
Tracking

- $\sigma_{pT}/p_T \sim 0.05\%\ p_T \oplus 1.5\%$
  (for pT < 100 GeV, ID dominant)
- $\sigma_M(J/\psi\text{-}\Upsilon) \sim 60\text{-}120$ MeV

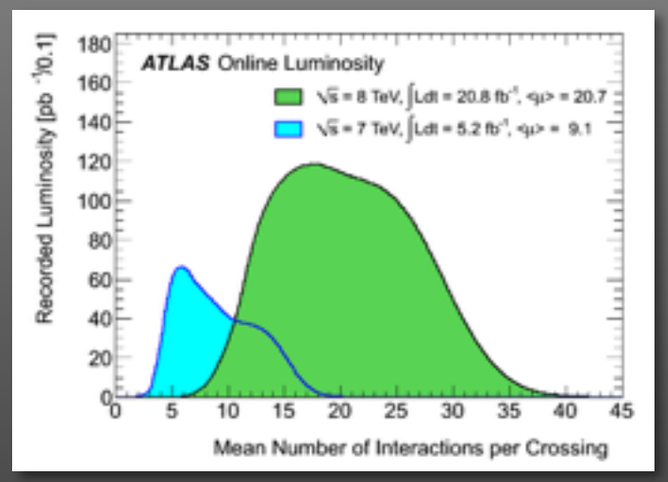
ATLAS Data Taking

2011
- > 5 fb^{-1} recorded
- instantaneous luminosity & pile-up steadily increasing

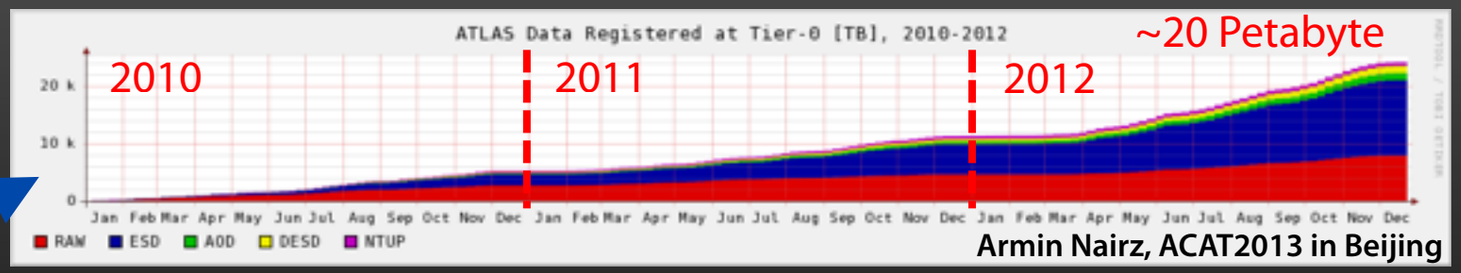
2012
- ~ 20fb^{-1} recorded
- Flatter instantaneous luminosity profile
- Challenging pile-up conditions !

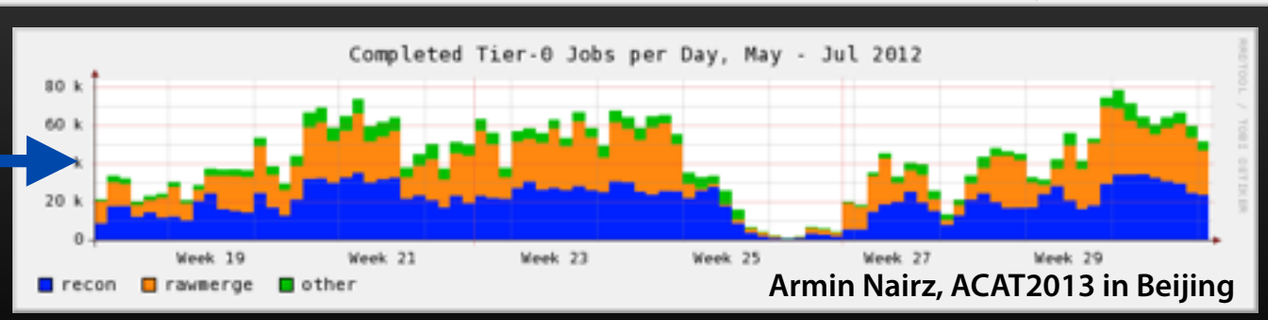


di-muon trigger selection

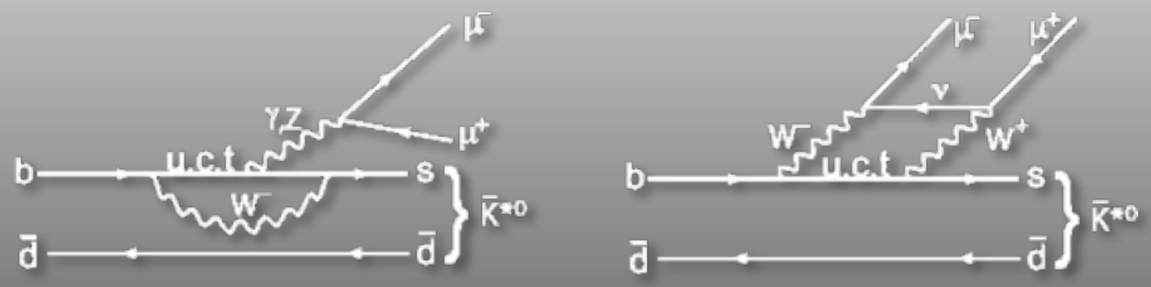


Tier-0 processing
- RAW and derived data products registered for export (2010-12)
- Up-to 80k Tier-0 jobs completed/day (May to July 2012)





Study of the decay $B_D \to K^* (\to K^+\pi^-)\ \mu^+\mu^-$



Motivation

- relatively small SM BR $\approx 1.1 * 10^{-6}$
- provides exclusive final state for $b \to s + l^+l^-$ transition
- only loop-mediated within SM

Observables sensitive to NP:

- Lepton forward-backward asymmetry – A_{FB}
- K^{*0} longitudinal polarization fraction – F_L
  (hadronic uncertainties drop out - at some order)

$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_\ell\, d\cos\theta_{K^*}\, d\phi}$$

Measurement:

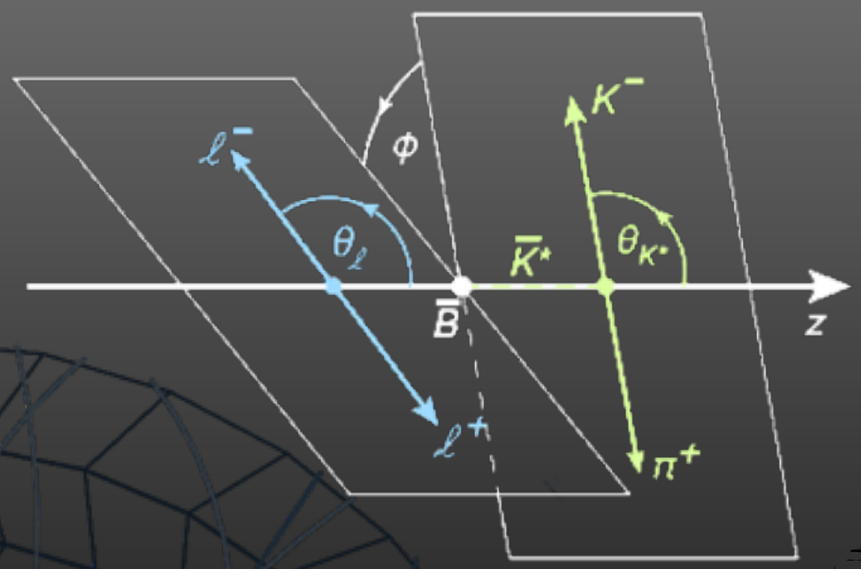
- differential angular distributions of the 4-particle final state as a function of di-muon mass (q^2)

$B_D \to K^* (\to K^+\pi^-)\ \mu^+\mu^-$ decay & analysis method

Kinematic observables:
- 3 angles (θ_L, θ_K, Φ)
- dimuon mass q^2 (K^{*0} on shell)
- differential decay rate

Measured angular distributions:
- insufficient statistics 2 out of 3 angles integrated out from the 4 diff. decay rate

$$\frac{1}{\Gamma}\frac{d^2\Gamma}{dq^2 d\cos\theta_K} = \frac{3}{2}F_L(q^2)\cos^2\theta_K + \frac{3}{4}(1-F_L(q^2))(1-\cos^2\theta_K)$$



$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_\ell\, d\cos\theta_{K^*}\, d\phi}$$

$$\frac{1}{\Gamma}\frac{d^2\Gamma}{dq^2 d\cos\theta_l} = \frac{3}{4}F_L(q^2)(1-\cos^2\theta_l) +$$
$$\frac{3}{8}(1-F_L(q^2))(1+\cos^2\theta_l) + A_{FB}(q^2)\cos\theta_l$$

$\langle A_{FB}\rangle$ & $\langle F_L\rangle$ extraction:
- extended unbinned maximum-likelihood fits
- 1-D fits in bins of q^2 to mass and the 2 angles Θ_l , Θ_K

$B_D \rightarrow K^* (\rightarrow K^+\pi^-)\ \mu^+\mu^-$ signal yield

Constraints on measurement:

- $q^2 < 2\ GeV^2$, limited statistics due to trigger acceptance
- experimental veto on J/ψ & ψ(2S) ($c\bar{c}$ regions)
  - $8.68 < q^2 < 10.09$ $J/\psi \rightarrow \mu^+\mu^-$ (3σ)
  - $12.86 < q^2 < 14.18$ $\psi(2S) \rightarrow \mu^+\mu^-$ (3σ)
- to remove radiative c-decays and remaining J/ψ & ψ(2S) in tails :
  - cut $|(m(B_d)_{REC} - m(B_d)_{PDG}) - (m(\mu^+\mu^-)_{REC} - m(c\bar{c})_{PDG})| < \Delta m$

B_d mass likelihood fit :

- cut based selection optimised on MC
- Gaussian for signal (with per-event errors)
- Exponential for the background
- K^{*0} accepted if $m(K^+\pi^-) \in (846,946)MeV$

- $N_{sig} = 466 \pm 34$
- $N_{bkg} = 1132 \pm 43$

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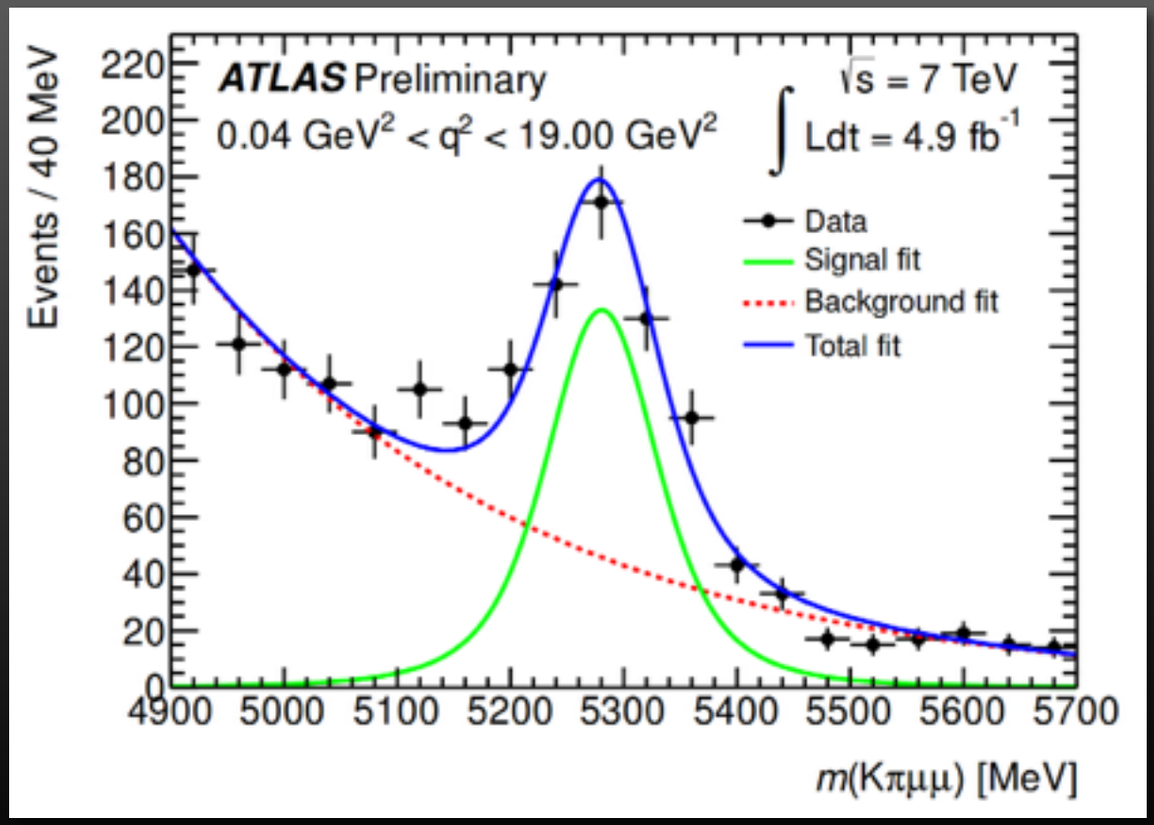
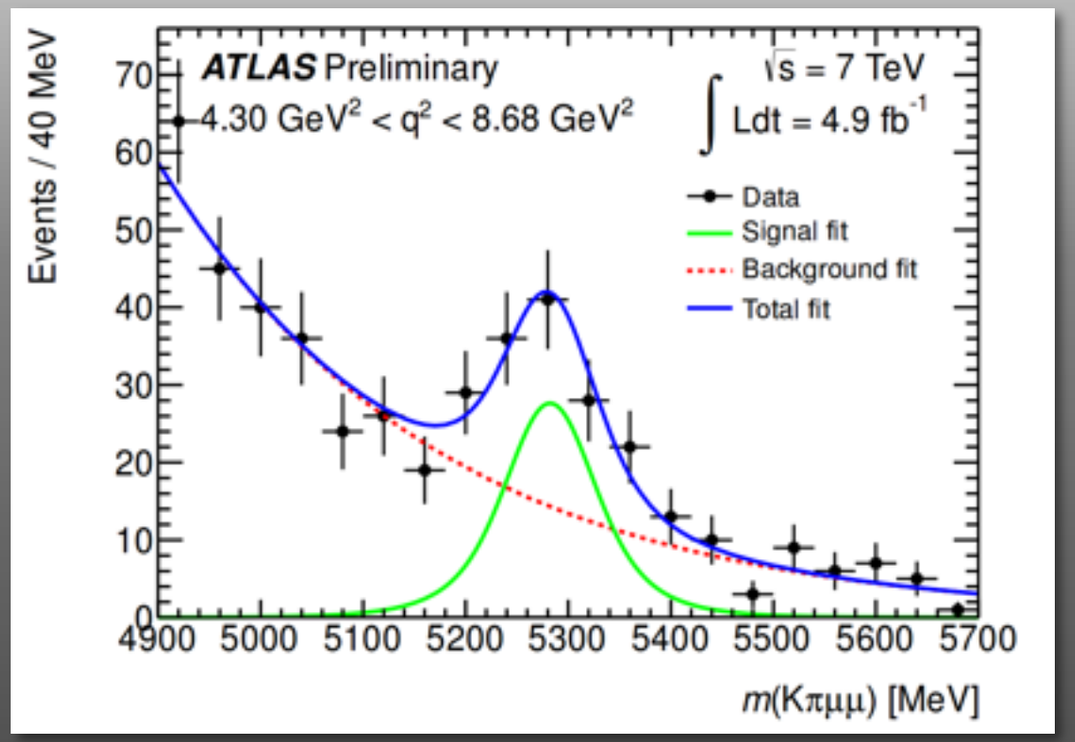


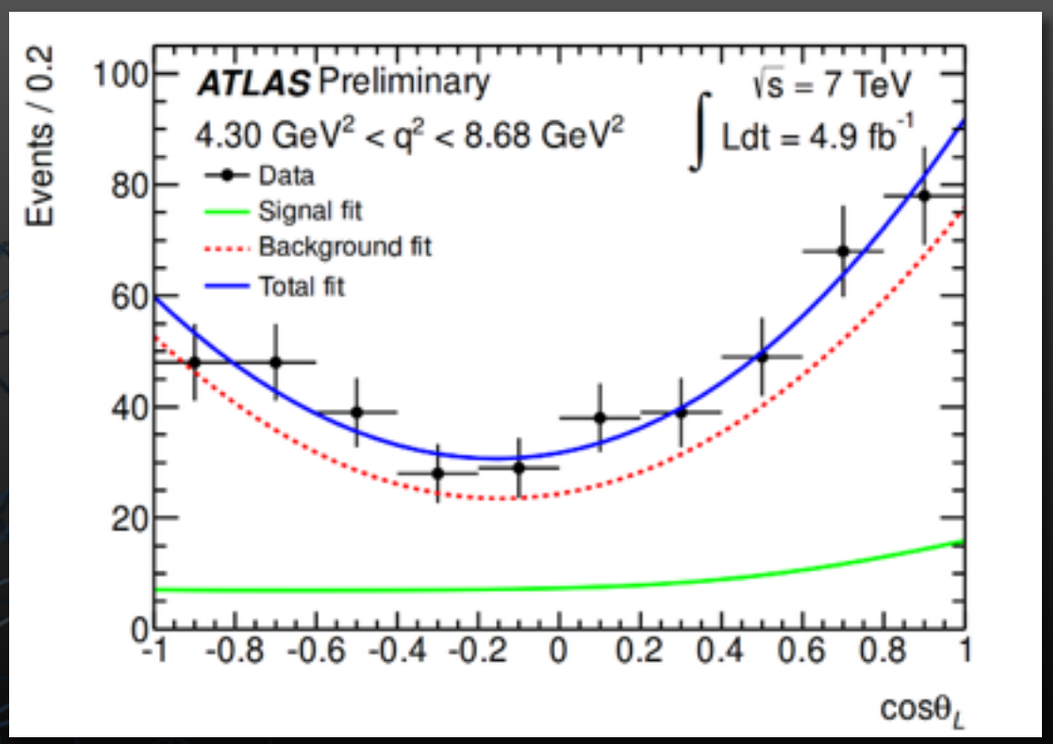
$B_D \to K^* (\to K^+\pi^-)\ \mu^+\mu^-$ LIKELIHOOD FIT

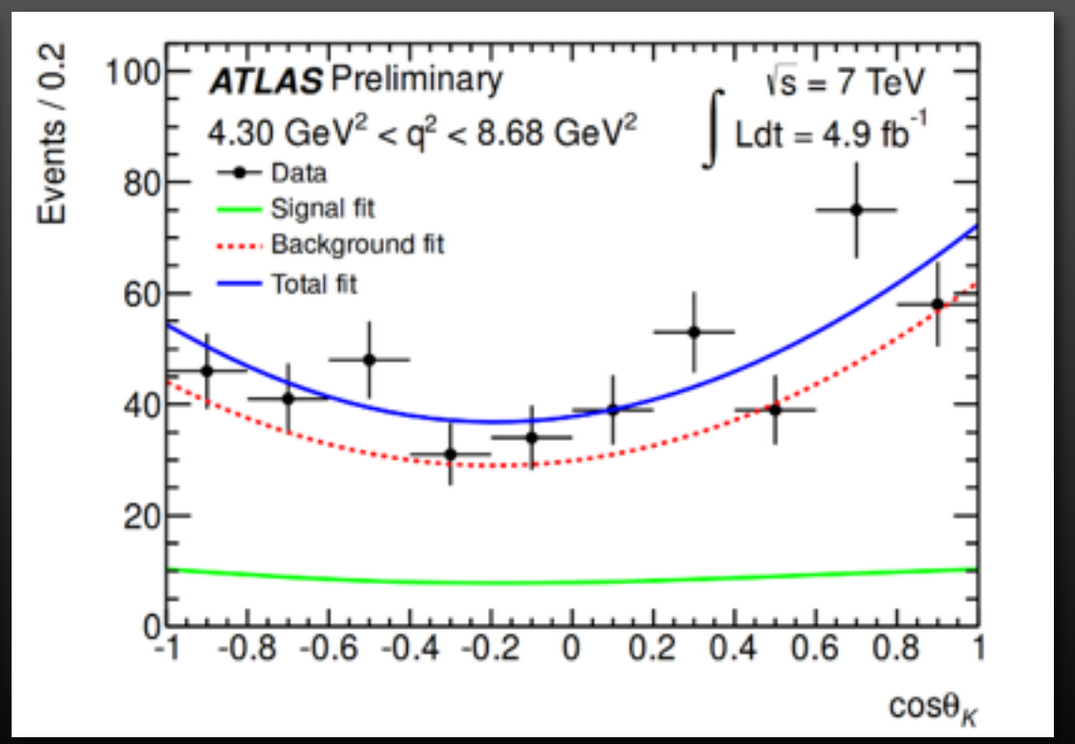
ATLAS-CONF-2013-038

Extended unbinned max-likelihood fit :

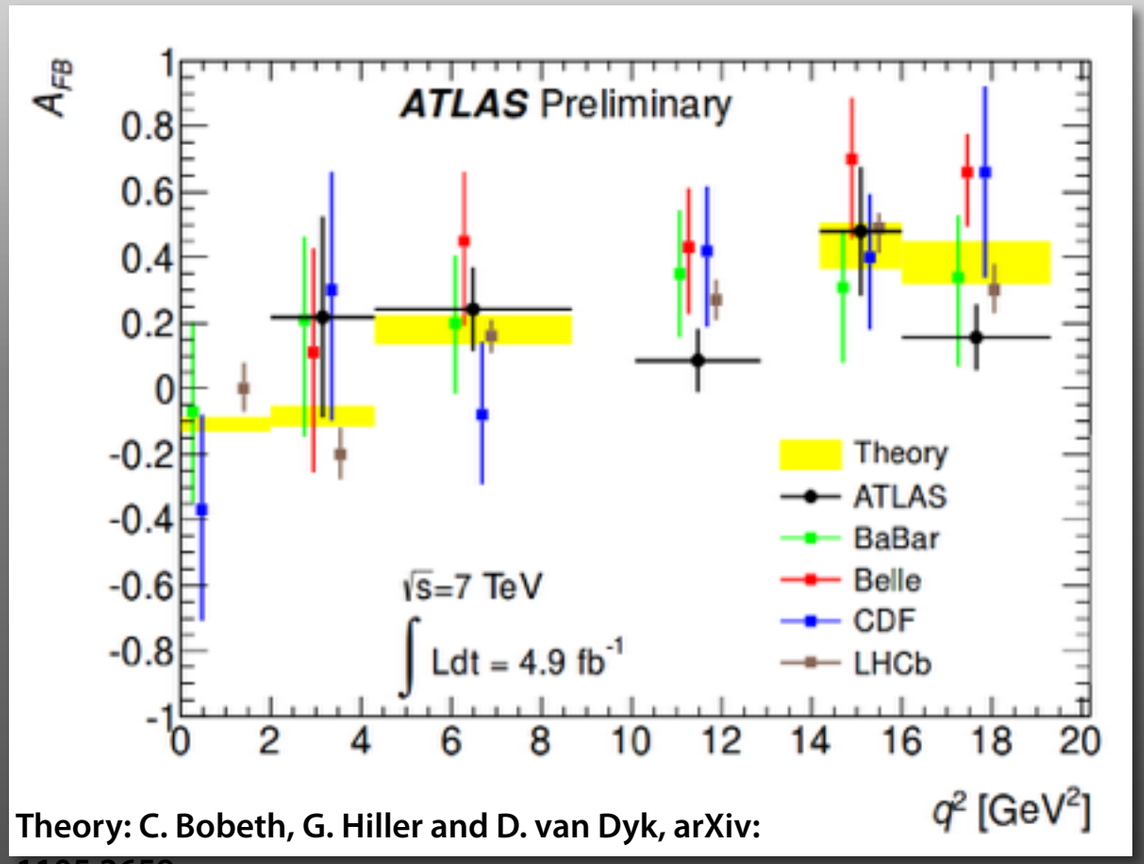
- performed sequentially
  1. fit mass distribution, & fixed signal yield
  2. simultaneous unbinned mass-angular fit (a la "BaBar")
     (the mass PDF param. & signal fraction kept fixed from previous fit)
- done separately in each of 6 q^2 bins



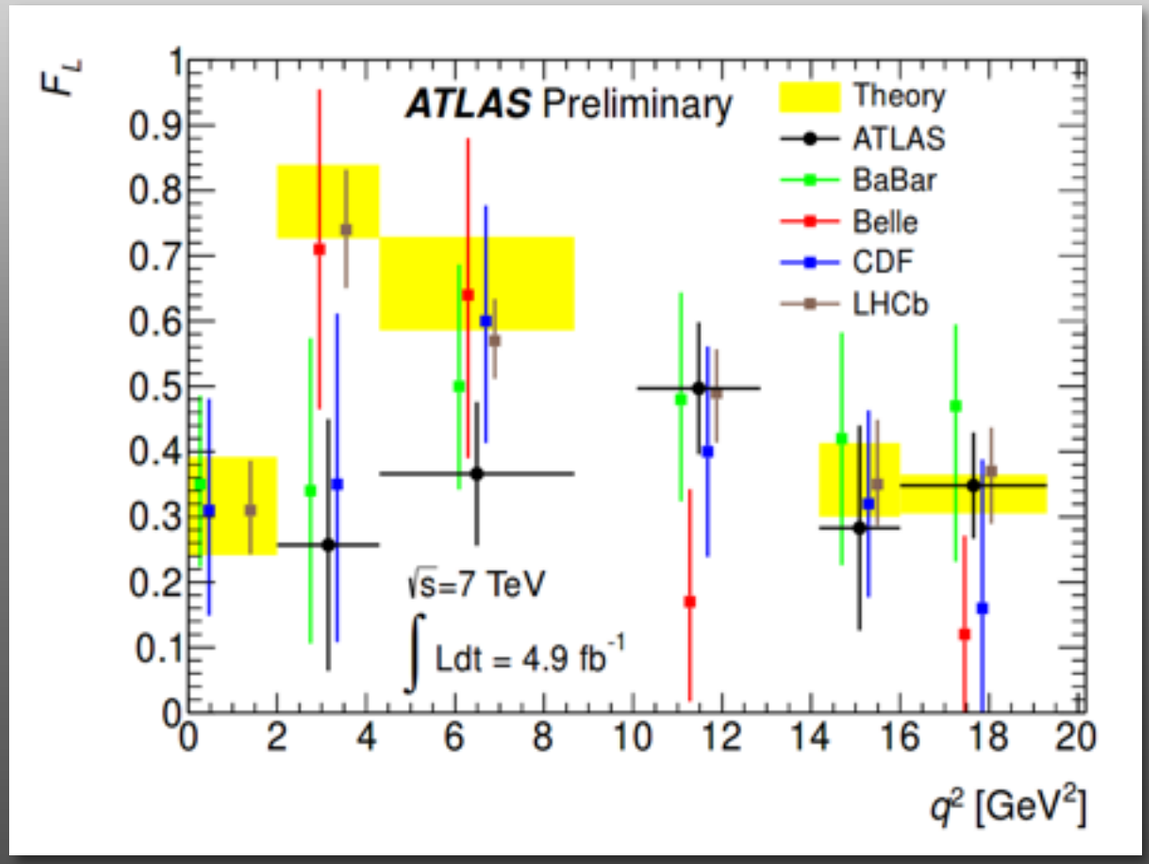




$B_D \to K^*(\to K^+\pi^-)\,\mu^+\mu^-$, $\langle A_{FB}\rangle$ & $\langle F_L\rangle$ fit result



Theory: C. Bobeth, G. Hiller and D. van Dyk, arXiv: 1105.2659



Fit Results:

- statistical uncertainty dominates
- ATLAS measurement in agreement with SM

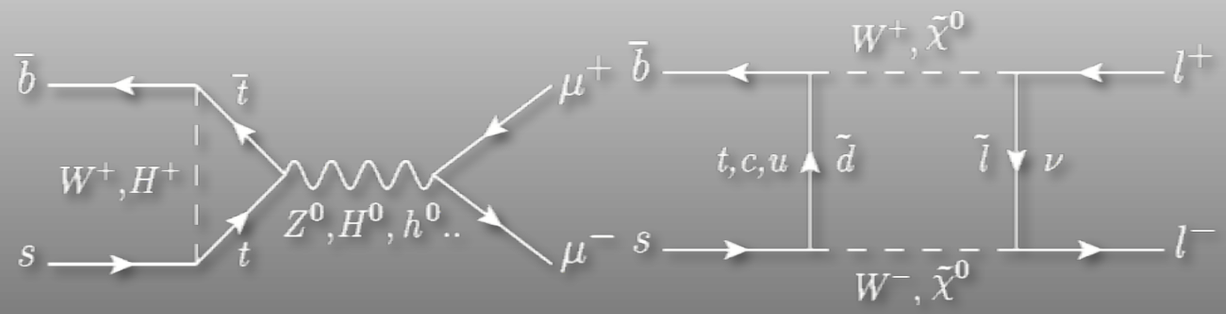
q^2 range (GeV^2)	N_{sig}	A_{FB}	F_L
$2.00 < q^2 < 4.30$	19 ± 8	$0.22 \pm 0.28 \pm 0.14$	$0.26 \pm 0.18 \pm 0.06$
$4.30 < q^2 < 8.68$	88 ± 17	$0.24 \pm 0.13 \pm 0.01$	$0.37 \pm 0.11 \pm 0.02$
$10.09 < q^2 < 12.86$	138 ± 31	$0.09 \pm 0.09 \pm 0.03$	$0.50 \pm 0.09 \pm 0.04$
$14.18 < q^2 < 16.00$	32 ± 14	$0.48 \pm 0.19 \pm 0.05$	$0.28 \pm 0.16 \pm 0.03$
$16.00 < q^2 < 19.00$	149 ± 24	$0.16 \pm 0.10 \pm 0.03$	$0.35 \pm 0.08 \pm 0.02$
$1.00 < q^2 < 6.00$	42 ± 11	$0.07 \pm 0.20 \pm 0.07$	$0.18 \pm 0.15 \pm 0.03$

ATLAS-CONF-2013-038

Search for $B_s \rightarrow \mu^+\mu^-$

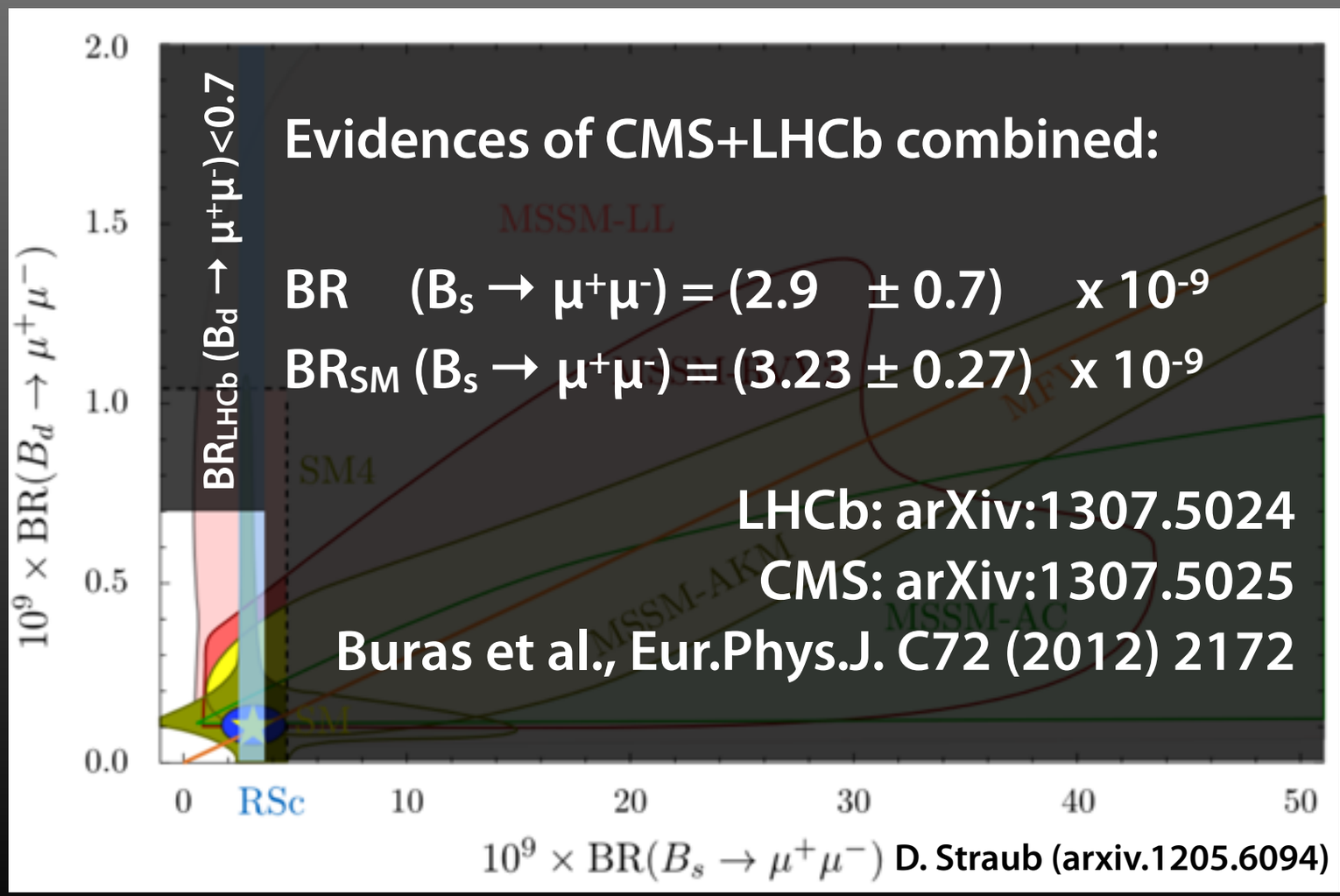
Motivation

- (SM) helicity suppressed FCNC
- strong QCD-free constraint on NP
- genuine probe of Yukawa interactions
- EW precision test (wrt. Z penguin)



Recent results

- very consistent with SM
- hope for > BR due to NP (pseudo-)scalar op.
- room for NP also in :
  - destructive interference between NP and SM
    - BR << BR_{SM} ???
  - waits for LHC RUN II data



$B_s \to \mu^+\mu^-$ strategy @ ATLAS

Analysis Features:

- Blind analysis technique - B_s signal mass region excluded (± 300 MeV)
- sideband events – split in 1/2 :
  - even # events = bkg. interpolation, odd # = selection optimization
- Multivariate analysis (BDT)
- Relative BR measurement:
  - reference signal decay = $B^+ \to J/\psi\, K^+$ (large stat.)
  - partial cancelation of syst. uncertainties on lumi, cross-sec, efficiencies

Data

- efficient di-muon trigger
  → 4.9fb^{-1} (2011)

Monte Carlo

$$(\epsilon_{tot} \times A_{tot}) = \frac{N_{\text{SELECT \& RECON}}}{N_{\text{GENERATED}}}$$

- derived from simulation
- "calibrated" on data
- systematics taken from data-MC discrepancies

$$\mathcal{B}(B_s \to \mu^+\mu^-) = N_{B_s\to\mu^+\mu^-} \times \frac{1}{N_{B^+\to J/\psi K^+}} \times \frac{(\epsilon_{tot} \times A_{tot})_{B^+\to J/\psi K^+}}{(\epsilon_{tot} \times A_{tot})_{B_s\to\mu^+\mu^-}} \times \mathcal{B}(B^+ \to J/\psi K^+) \times \frac{f_u}{f_s}$$

PDG, LHCb

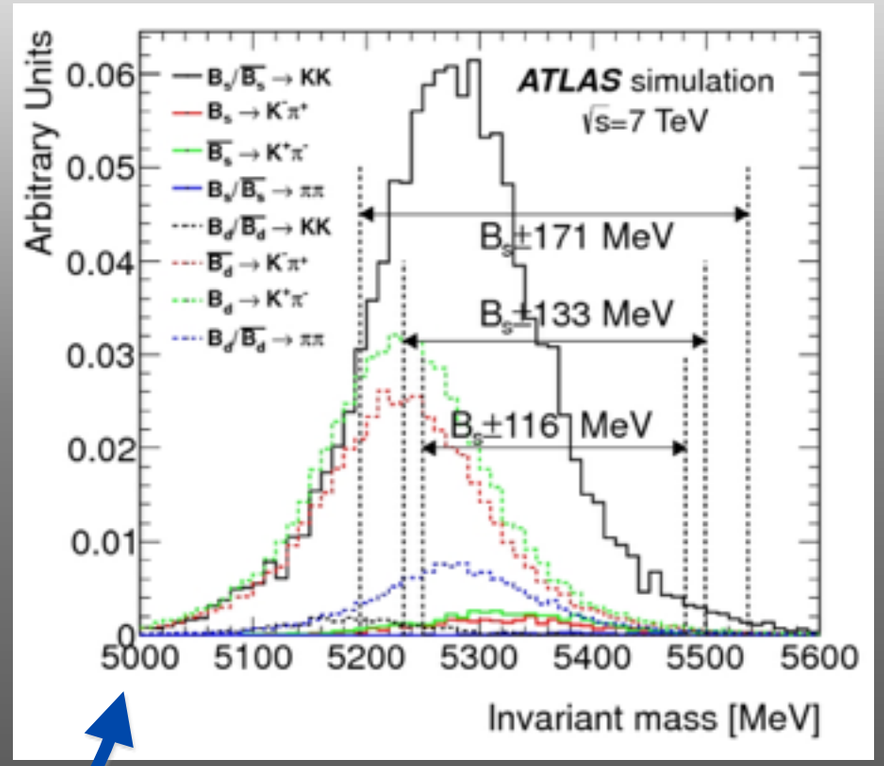
ATLAS-CONF-2013-076

$B_s \to \mu^+\mu^-$ signal & background

Signal extraction:

- N_{Bs} is a CLs limit derived from :
  - candidate count &
  - background estimation in signal region
- N_{B+} is an unbinned extended maximum-likelihood fit

$$N_{B_s \to \mu^+\mu^-} \times \frac{1}{N_{B^+ \to J/\psi K^+}}$$



Background composition:

- resonant: B → hh' (K/π)
  - 'fake'-muon rates (MC) π±/ K+ /K- ~ 2.1/4.1/3.3 ‰
  - 0.3 B → hh' events expected in the signal region
- continuum: non resonant $b\bar{b} \to \mu^+\mu^- X$
  - smooth in dimuon mass
  - sideband interpolation (even # events)

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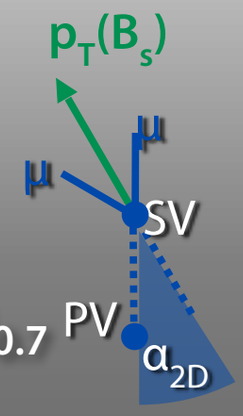
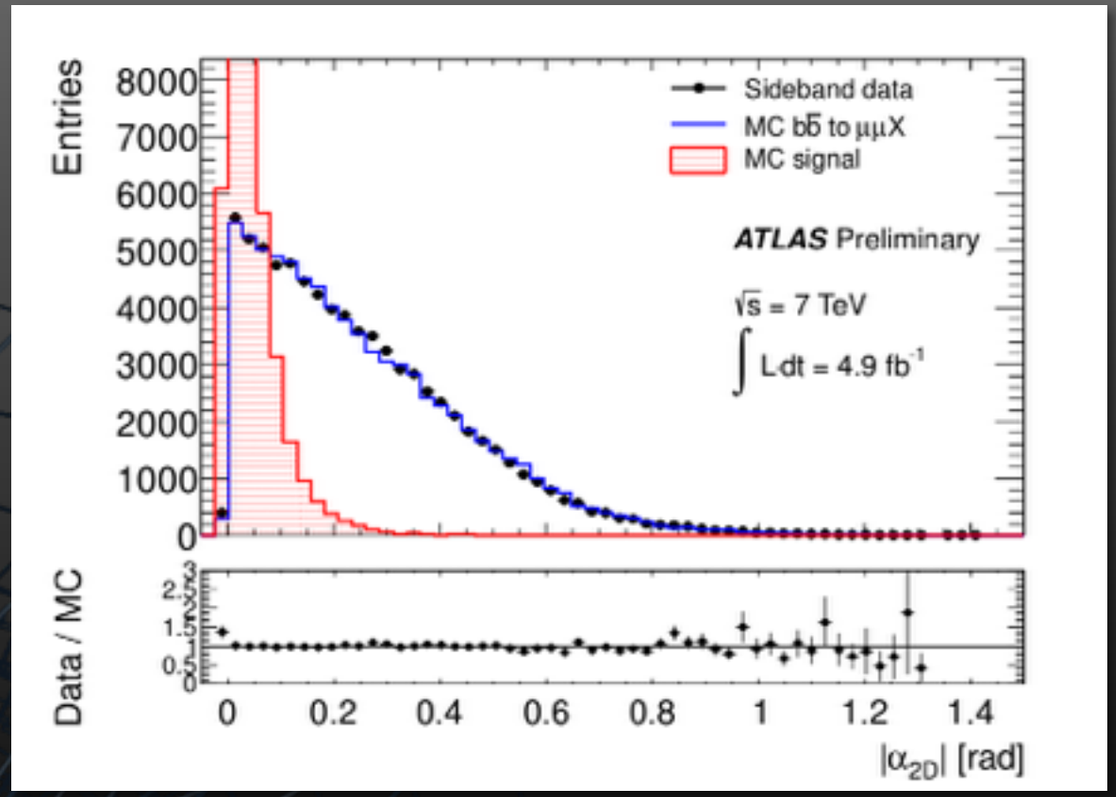
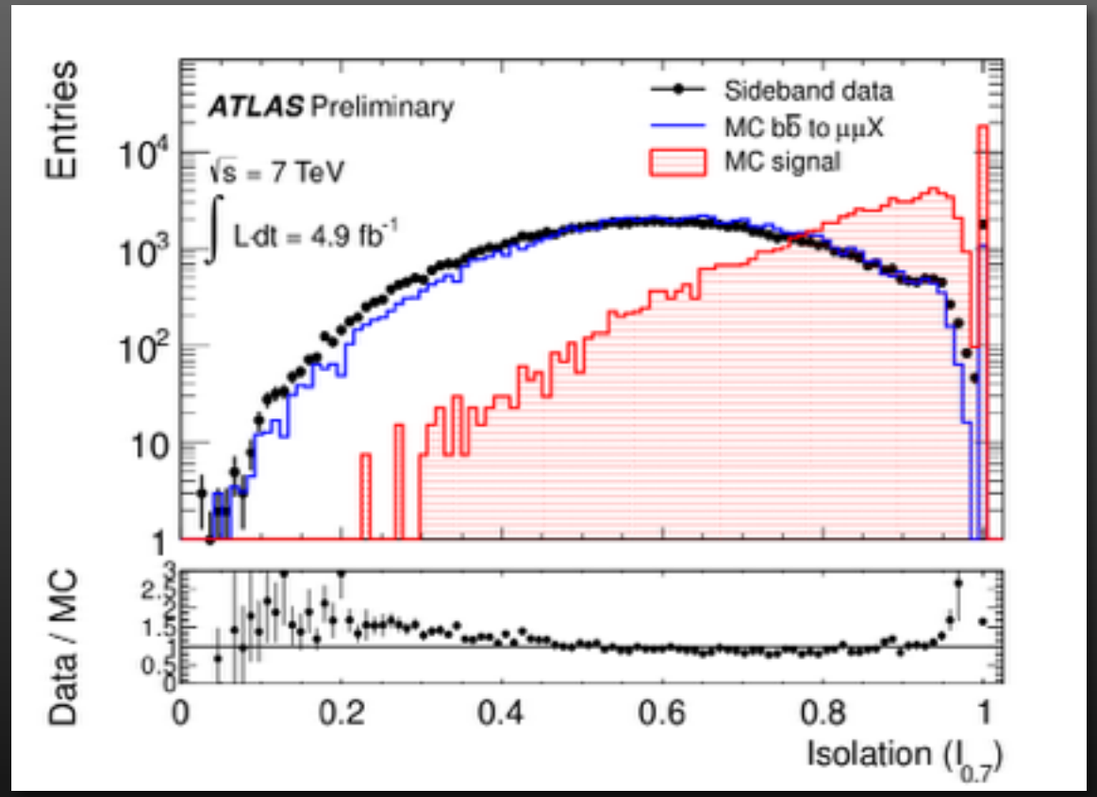
$B_s \to \mu^+\mu^-$ background discrimination

Continuum discrimination:

- 13 best performing discriminating variables chosen by MVA
- BDT shown as most powerful event classifier
  - trained on MC
- plots show Data/MC agreement of pointing angle α_{2D} and Isolation $I_{0.7}$ (among most discriminant variables)







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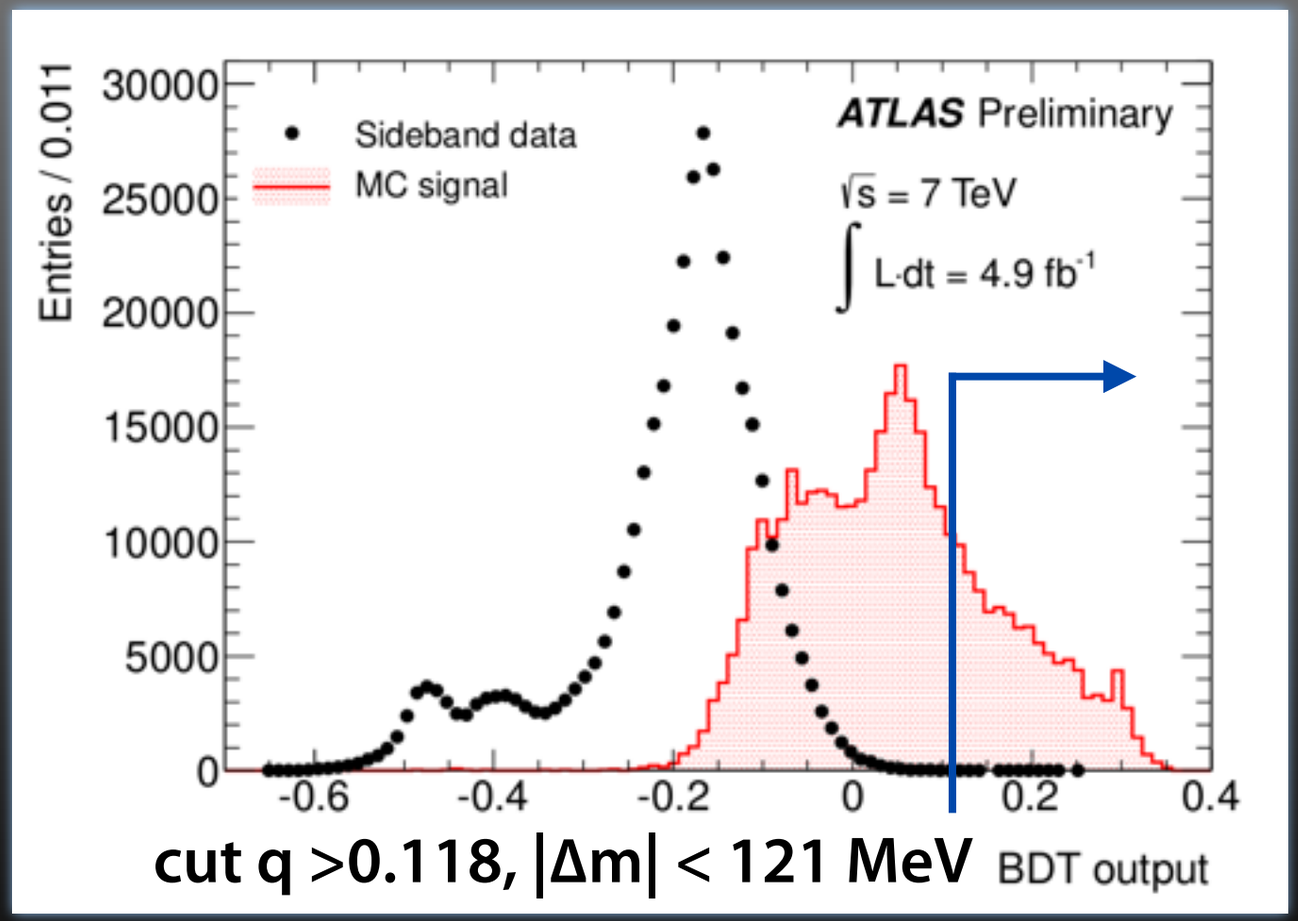
$B_s \rightarrow \mu^+\mu^-$ BDT selection

Selection optimised in 2D space (Δm,q):

- Δm = signal mass window width
- q = BDT output (event classifier)
- odd-numbered sideband events and signal MC used

Working point (Δm,q):

- = max of Punzi estimator
  - $P(\Delta m,q) = \varepsilon_{sig} / (1+\sqrt{N_{bkg}})$ (@95% CL)
- ε_{sig} calculated directly on simulated signal events
- N_{bkg} in sig. region estimated from sideband data



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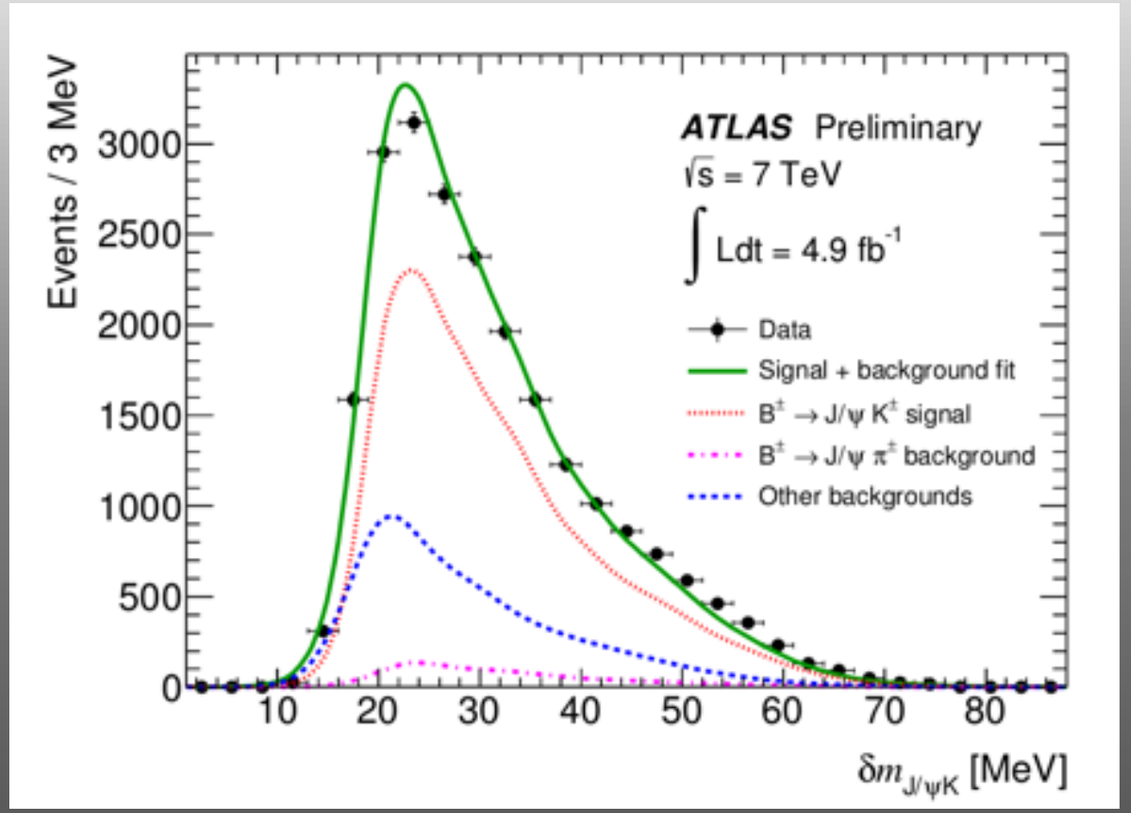
$B_s \to \mu^+\mu^-$ Reference Decay Yield

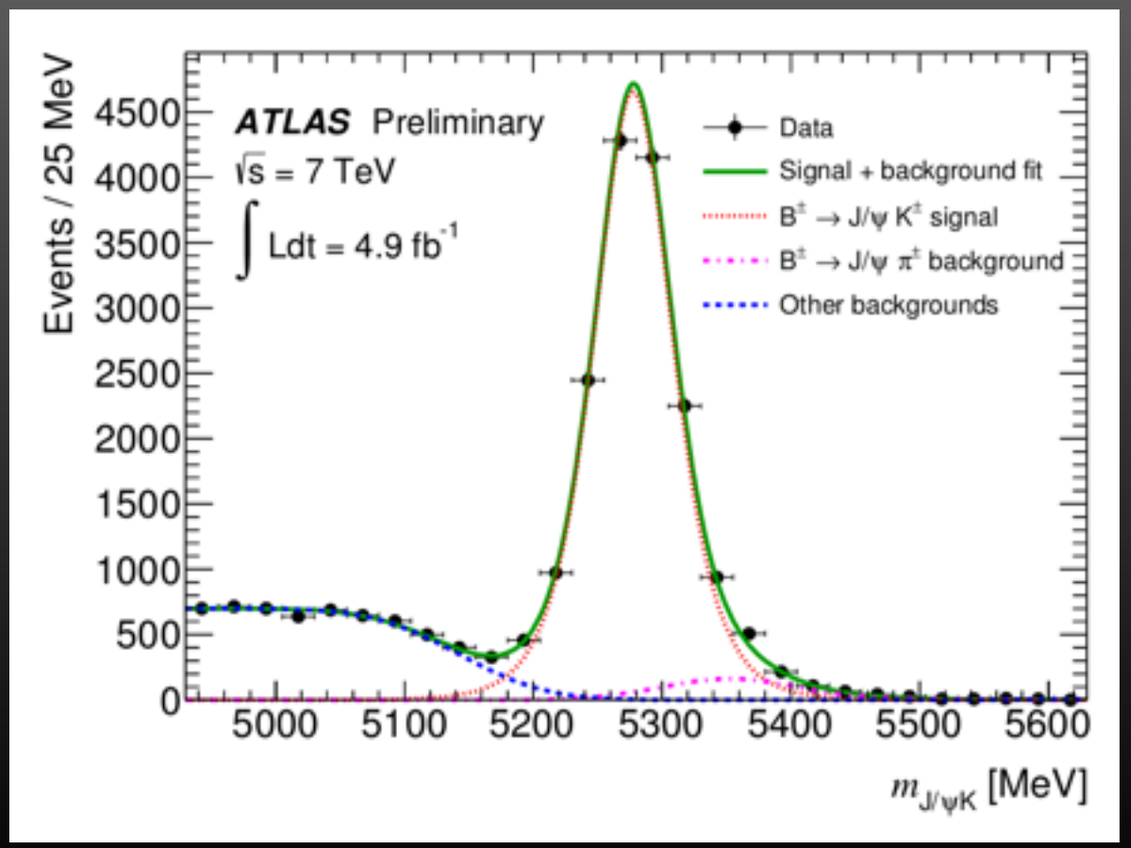
$N_{B+\to J/\psi K+}$ extraction :

- by unbinned maximum likelihood fit
- per-event mass resolution δm in the fit
- selection as close as possible to Bs
- same B_s-trained BDT used to min. systematics
- main systematics from varying continuum background fit models



$B^{\pm} \to J/\psi\,(\to \mu^+\mu^-)\,K^{\pm}$ yield :

- $N_{B\pm \to J/\psi\,(\to \mu+\mu-)\,K\pm}$ =
  15214 ± 1.1%(stat) ± 2.4%(syst)



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$B_s \to \mu^+\mu^-$ Box opening

N_{BS} extraction :

- Single Event Sensitivity
  SES = (2.07 ± 26%(stat)± 12.5%(syst)) x 10^{-9}
- Systematic uncertainty dominated by
  - reference channel BR contribution
  - acceptance and efficiency ratio
- N_{bkg} expected in signal window = 6.75
- N_{obs} in signal window = 6

$$\mathcal{B}(B_s \to \mu^+\mu^-) = N_{B_s\to\mu^+\mu^-} \times \frac{1}{N_{B^+\to J/\psi K^+}} \times \frac{(\epsilon_{tot} \times A_{tot})_{B^+\to J/\psi K^+}}{(\epsilon_{tot} \times A_{tot})_{B_s\to\mu^+\mu^-}} \times \mathcal{B}(B^+ \to J/\psi K^+) \times \frac{f_u}{f_s}$$

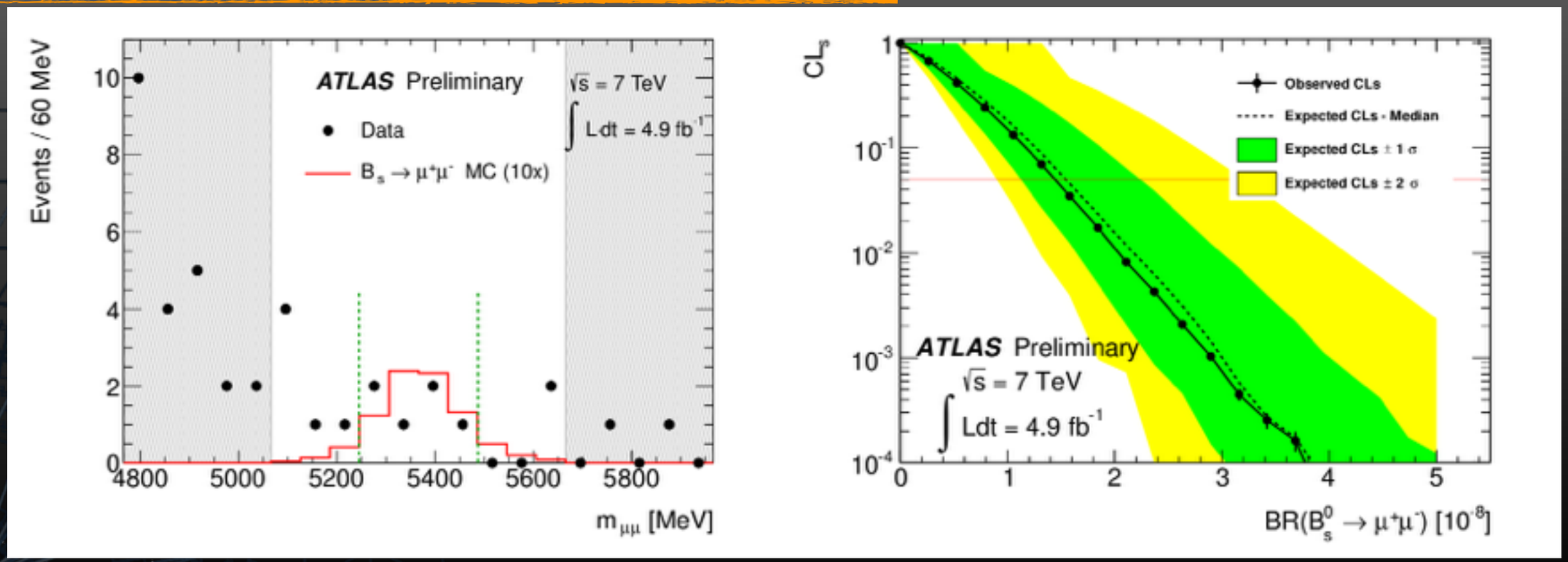
CLs @ 95% CL :

BR($B_s \to \mu^+\mu^-$)< 1.6 x 10^{-9}

BR($B_s \to \mu^+\mu^-$)< 1.5 x 10^{-9}

New ATLAS result on 2012 data soon !

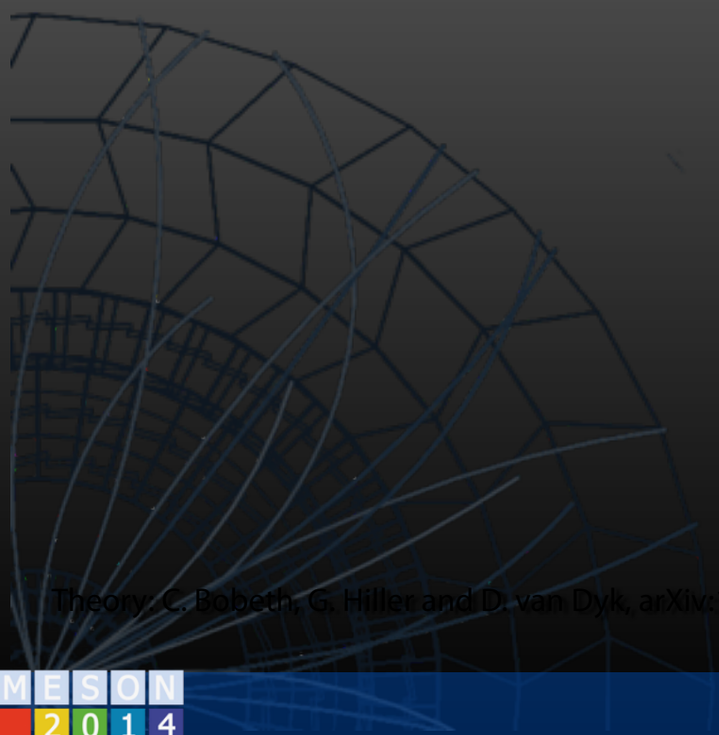
ATLAS-CONF-2013-076



Conclusions

- Results from the full 2011 dataset
- No NP signs or significant deviation from SM predictions
- ATLAS has high quality b-physics program
  - search for the rare decay $B_s \rightarrow \mu^+\mu^-$
  - ✓ ATLAS-CONF-2013-076
  - angular analysis of the decay $B_d \rightarrow K^{*0} (\rightarrow K^+\pi^-) \mu^+\mu^-$
  - ✓ ATLAS-CONF-2013-038
- Improved analysis techniques are being developed
- Plans :
  - ✓ Publish result on the full 2012 dataset (>20fb^{-1}) ASAP stay tuned !

Thank you for your attention !

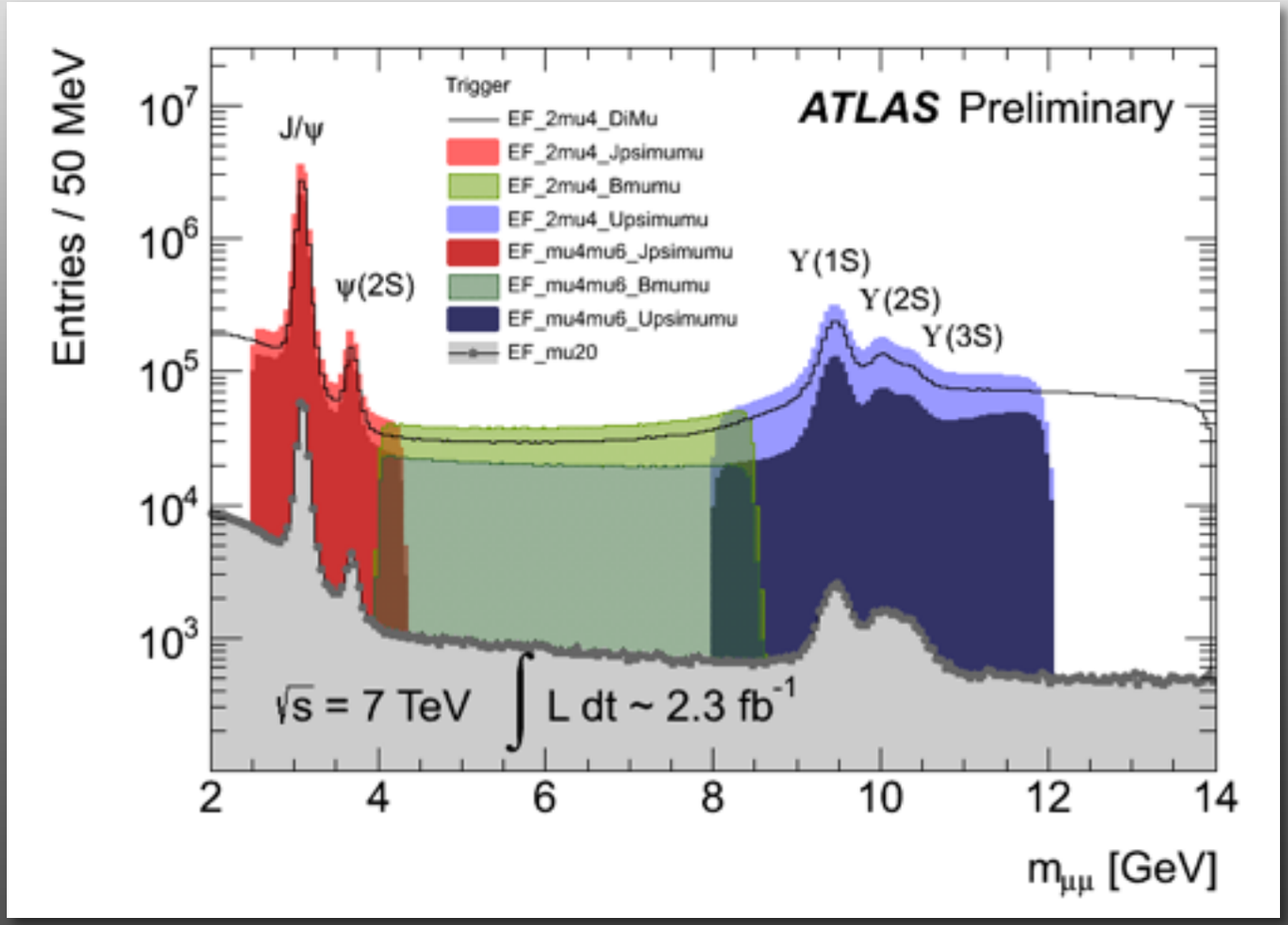


Theory: C. Bobeth, G. Hiller and D. van Dyk, arXiv:1105.2659

BACKUP SLIDES

Theory: C. Bobeth, G. Hiller and D. van Dyk, arXiv:1105.2659

ATLAS trigger



di-muon trigger event selection :

- 5 fb-1 ~ 150G B0–pairs, ~ 30M Bs → J/ψ Φ
- specific dimuon selections with Barrel/Endcap logic introduced in 2012
- new dedicated μ+μ-X trigger introduced in 2012
- B-physics trigger (mu4mu4) thresholds unprescaled during 2011 despite the increasing instantaneous luminosity

$B_s \rightarrow \mu^+\mu^-$ event reconstruction

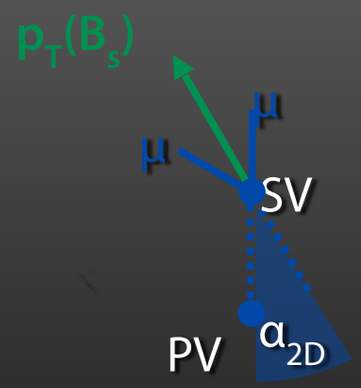
Signal candidate selection

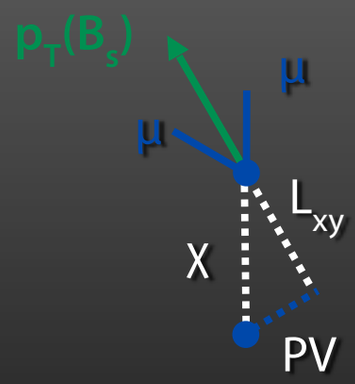
- 2, 3 or 4 prong vertex constraint depending on decay topology
- Primary vertex selection:
  - Closest in z to the B candidate
  - Re-fit excluding B daughters
- Tracks:
  - At least 1 pixel, 6 SCT and 9 TRT hits (good tracks)
  - $|\eta| < 2.5$ and $p_T > 4$ (2.5) GeV for muons (kaons)
  - tracks from the tracking systems matched to muon spectrometer tracks
- B candidates $p_T > 8$ GeV and $|\eta| < 2.5$
  - Events selected based on their decay topology using many discriminating variables

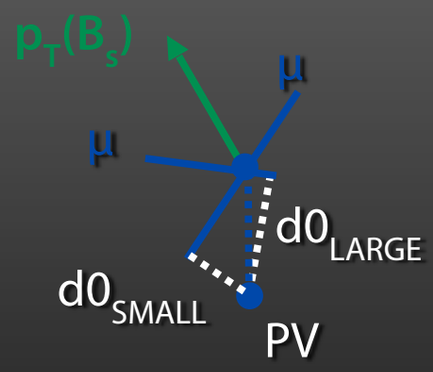
$B_s \rightarrow \mu^+\mu^-$ sel. of discriminating variables

Discriminating variables:

- Distinguish B and continuum events
- Highest discriminating power
- Exclusion of highly correlated variables
- Only variables not correlated with invariant mass were taken
- Exploit PV-SV separation (Lxy) , symmetry of the final state (d0) , pointing angle, b-hadronisation features (isolation, pT of the B)







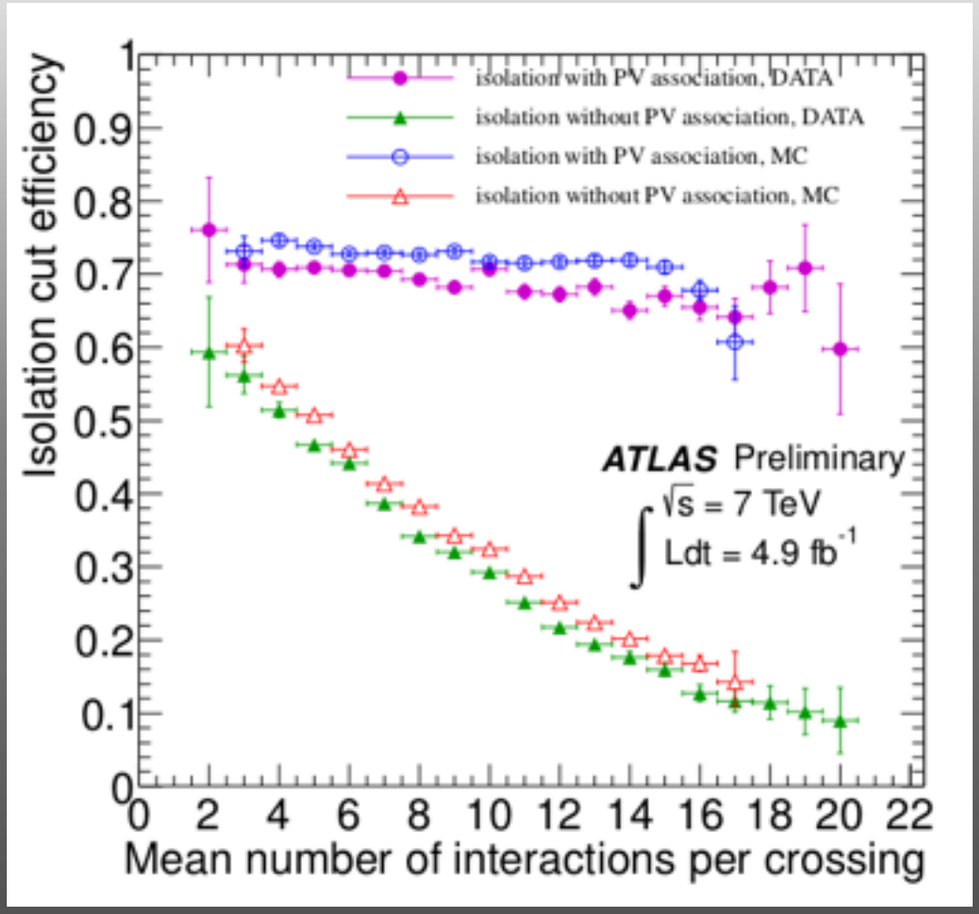
$B_s \to \mu^+\mu^-$ DISCRIMINATING VARIABLES

Variable	Description	Ranking
L_{xy}	Scalar product in the transverse plane of $(\Delta\vec{x} \cdot \vec{p}^B)/\lvert\vec{p}^B_T\rvert$	1
$I_{0.7}$ isolation	Ratio of $\lvert\vec{p}^B_T\rvert$ to the sum of $\lvert\vec{p}^B_T\rvert$ and the transverse momenta of all tracks with $p_T > 0.5$ GeV within a cone $\Delta R < 0.7$ from the B direction, excluding B decay products	2
$\lvert\alpha_{2D}\rvert$	Absolute value of the angle in the transverse plane between $\Delta\vec{x}$ and $\vec{p}^B$	3
p_L^{min}	Minimum momentum of the two muon candidates along the B direction	4
p_T^B	B transverse momentum	5
ct significance	Proper decay length $ct = L_{xy} \times m_B / p_T^B$ divided by its uncertainty	6
χ^2_z, χ^2_{xy}	Significance of the separation between production (PV) and decay vertex (SV) $\Delta\vec{x}^T \cdot \left(\sigma^2_{\Delta\vec{x}}\right)^{-1} \cdot \Delta\vec{x}$, in z and (x, y), respectively	7, 13
$\lvert D_{xy}\rvert^{min}, \lvert D_z\rvert^{min}$	Absolute values of the minimum distance of closest approach in the xy plane or along z of tracks in the event to the B vertex	8, 11
ΔR	Angle $\sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$ between $\Delta\vec{x}$ and $\vec{p}^B$	9
$\lvert d_0\rvert^{max}, \lvert d_0\rvert^{min}$	Absolute values of the maximum and minimum impact parameter in the transverse plane of the B decay products relative to the primary vertex	10, 12

$B_s \rightarrow \mu^+\mu^-$ isolation variable

Isolation variable:

- Tracks with pT > 0.5 GeV excluding B daughters in cone $\Delta R < 0.7$
  $\Delta R = \sqrt{(\Delta\eta^2 + \Delta\varphi^2)}$
- Only tracks associated with the corresponding PV are taken to avoid isolation cut efficiency to depend on pile-up



$B_s \to \mu^+\mu^-$ (acceptance x efficiency) ratio

$$\frac{(\epsilon_{tot} \times A_{tot})_{B^+ \to J/\psi K^+}}{(\epsilon_{tot} \times A_{tot})_{B_s \to \mu^+\mu^-}}$$

- Determined on reweighted Bs and B+ MC samples wrt the fiducial volume
- Systematic uncertainties:
  - Dominant contribution from data-MC discrepancies of separation variables
  - Main discrepancies come from : Isolation and Lxy
  - Isolation is B-flavour dependent
  - Lxy is correlated with the vertex reconstruction (→ with other discriminant variables) but is it B-flavour independent

Channel	$A \times \epsilon$	$R_{A\epsilon}$
B^+	$1.317 \pm 0.008\%$ (stat)	$0.267 \pm 1.8\%$ (stat) $\pm 6.9\%$ (syst)
B_s^0	$4.929 \pm 0.084\%$ (stat)	

$B_s \to \mu^+\mu^-$ systematics on SES

SES systematic uncertainties

- Table shows summary of ΔSES/SES uncertainty (due to syst. uncertainty sources) → SES statistical uncertainty of 2.1%

description	contribution
PDG branching fractions and f_s/f_d	8.5%
$K^\pm$ tracking efficiency	5%
vertexing efficiency	2%
$K^\pm$ charge asymmetry. in $B^\pm \to J/\psi K^\pm$	1%
$B^\pm \to J/\psi K^\pm$ yield	2.4%
$R_{A\epsilon}$	6.9%
total (comb. in quadrature)	12.5%

- contributions from backgrounds:
  - background interpolation from sidebands → 4% on Rbkg
  - B → hh' negligible
- Mainly contribute: BRref and fu/fs , acc-vs-eff ratio (data-MC discrepancies), K tracking efficiency

$B_s \to \mu^+\mu^-$ upper limit extraction

CLs method with profile likelihood function

$$\mathcal{L} = \text{Poisson}(N_{SR}^{obs} | \epsilon\,\mathcal{B} + N_{bkg} + N_{B\to hh})\,\text{Poisson}(N_{bkg,SB}^{obs} | R_{bkg}\,N_{bkg}) \times$$
$$\text{Gauss}(\epsilon^{obs} | \epsilon, \sigma_\epsilon)\,\text{Gauss}(R_{bkg}^{obs} | R_{bkg}, \sigma_{R_{bkg}})$$

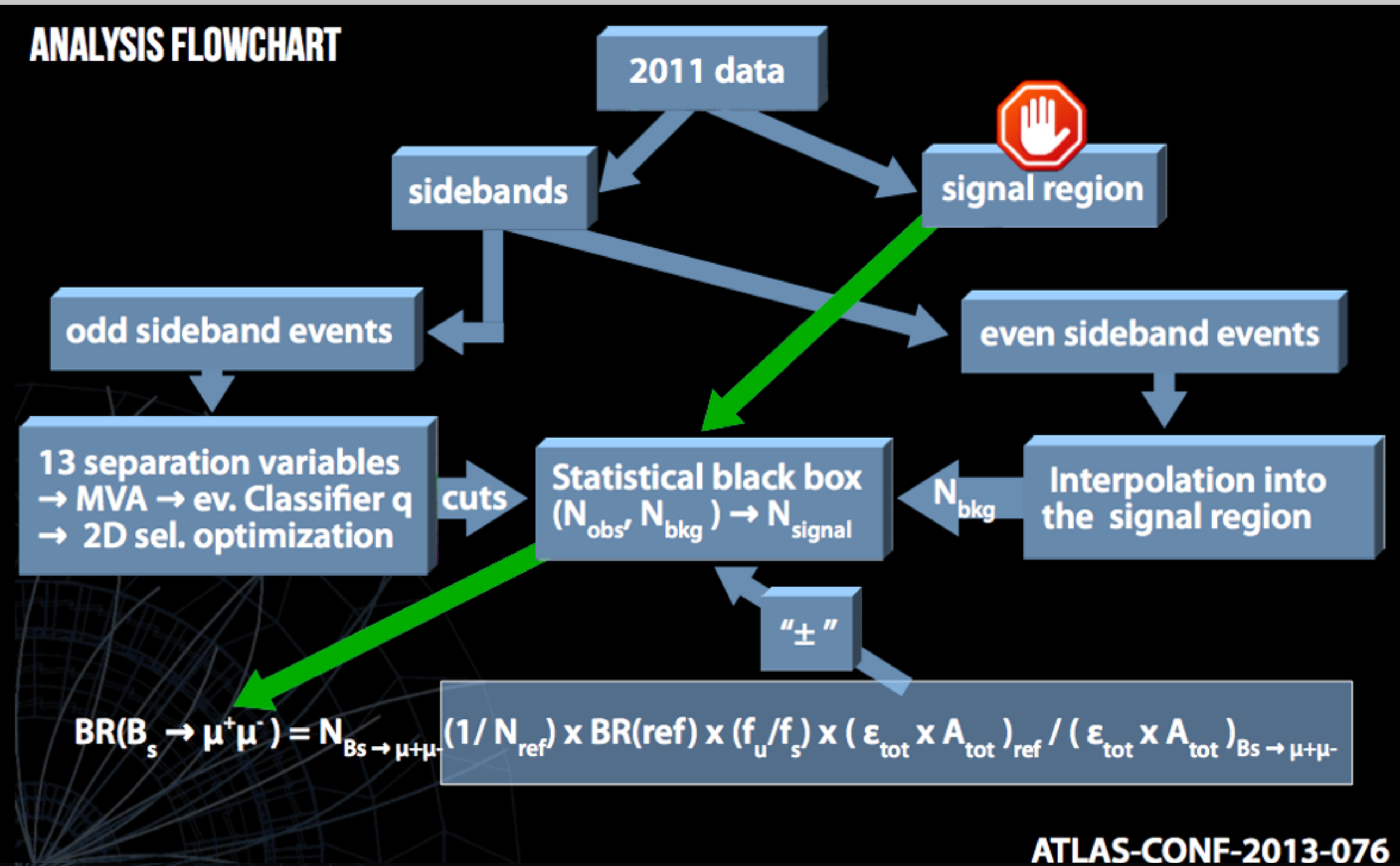
$\varepsilon = 1/\text{SES}$

$R = \Delta_{SB}/\Delta_{SR}$

- the expected UL is calculated assuming the number of events in the signal region as the number of expected events obtained from the sideband interpolation (6.75 events):
- peeking background negligible, but included in the optimization procedure and in the upper limit calculation

quantity	value
$N_{J/\psi K^\pm}$	$15\,214 \pm 1.10\% \pm 2.39\%$
$R_{A\epsilon}$	$0.267 \pm 1.8\% \pm 6.9\%$
SES	$(2.07 \pm 0.26) \cdot 10^{-9}$
R_{bkg}^{obs}	1.240 ± 0.050
N_{SR}^{exp} | N_{SR}^{obs}	6.75 | 6
$N_{bkg,SB}^{obs}$	8
$N_{B\to hh}$	0.30

$B_s \rightarrow \mu^+\mu^-$ analysis flowchart



$B_D \rightarrow K^* (\rightarrow K^+\pi^-)\ \mu^+\mu^-$ baseline cuts

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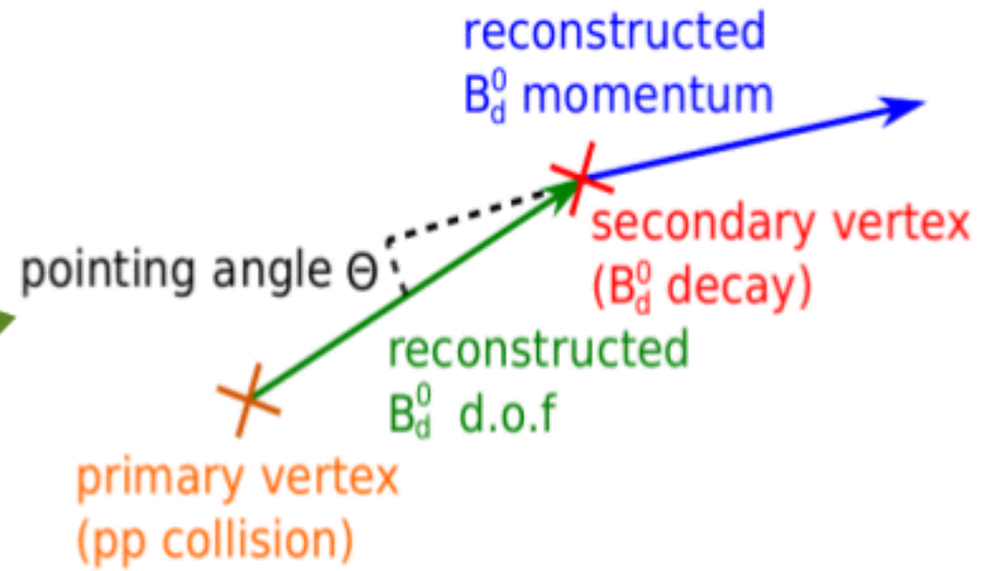
- Baseline:
  - p_T (μ) > 3.5 GeV
  - |η| < 2.5 for all tracks
  - χ^2/n.d.f (μμ) < 10
  - 846 < M(K^{*0}) < 946 MeV
  - p_T (K) > 0.5 GeV
  - p_T (π) > 0.5 GeV
- J/ψ, Ψ'(2S) regions are excluded
- Selection (cut values are optimized):
  - $\tau/\Delta\tau$ (B_d) > 12.75
  - cos(θ) > 0.999
  - χ^2/n.d.f. (B_d) < 2.0
  - p_T (K^*) > 3 GeV
  - $|(M(B^0)_{rec} - M(B^0)_{PDG})| - |(M(\mu\mu)_{rec} - M(J/\psi)_{PDG})|$ > 130 MeV



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$B_D \to K^* (\to K^+\pi^-)\ \mu^+\mu^-$ FIT STRATEGY

- Extended unbinned maximum likelihood fit (performed sequentially):
  - 1) mass (Kπμμ) distribution fitted to separate signal and background yields
  - 2) mass-angular simultaneous fit performed on the signal events from the previous fit (fixed mass)
- Done separately for each of the 6 q^2 bins
- The procedure checked to give the same results as single-step fit except the lowest q2 bin (included in systematics there).

$$\mathcal{M}_{\rm sig}(m_i, \delta_{m_i}) = \frac{1}{\sqrt{2\pi} s_m \delta_{m_i}} \exp\left(\frac{-(m_i - m_{B_d^0})^2}{2(s_m \delta_{m_i})^2}\right)$$

$$\mathcal{L} = \prod_{i=1}^{N} \left[N_{\rm sig} \cdot \mathcal{M}_{\rm sig}(m_i, \delta_{m_i}) + N_{\rm bckg} \cdot \mathcal{M}_{\rm bckg}(m_i) \right], \qquad \mathcal{M}_{\rm bckg}(m_i) = e^{-\lambda \cdot m_i}$$

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$B_D \to K^* (\to K^+\pi^-)\ \mu^+\mu^-$ FIT STRATEGY

- Angular fit (in each q2 bin) :

$$\mathcal{L} = \prod_{i=1}^{N} [N_{\text{sig}}^{\text{fix}} \cdot \mathcal{M}_{\text{sig}}(m_i, \delta_{m_i}|\text{fixed}) \cdot \mathcal{A}_{L,\text{sig}}(\cos\theta_{L,i}) \cdot \alpha_L(\cos\theta_{L,i}) \cdot \mathcal{A}_{K,\text{sig}}(\cos\theta_{K,i}) \cdot \alpha_K(\cos\theta_{K,i}) + N_{\text{bckg}}^{\text{fix}} \cdot \mathcal{M}_{\text{bckg}}(m_i|\text{fixed}) \cdot \mathcal{A}_{L,\text{bckg}}(\cos\theta_{L,i}) \cdot \mathcal{A}_{K,\text{bckg}}(\cos\theta_{K,i})]$$

- Signal PDFd:

$$\mathcal{A}_{L,\text{sig}}(\cos\theta_{L,i}) = \frac{3}{4} F_L(q^2)\left(1-\cos^2\theta_{L,i}\right) + \frac{3}{8}\left(1-F_L(q^2)\right)\left(1+\cos^2\theta_{L,i}\right) + A_{FB}(q^2)\cos\theta_{L,i}$$

$$\mathcal{A}_{K,\text{sig}}(\cos\theta_{K,i}) = \frac{3}{2} F_L(q^2)\cos^2\theta_{K,i} + \frac{3}{4}\left(1-F_L(q^2)\right)\left(1-\cos^2\theta_{K,i}\right)$$

- Background PDF – linear combination of Chebyshev polynomials (to 2nd order)

$$\mathcal{A}_{L(K),\text{bkg}} = 1 + p_{1L(K)}\cos\theta_{L(K),i} + p_{2L(K)}\left(2\cos^2\theta_{L(K),i} - 1\right)$$

- detector and selection effects on the angular shapes taken into account via the acceptance functions $\alpha_L(\cos\theta_{L,i})$, $\alpha_K(\cos\theta_{K,i})$

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$B_D \rightarrow K^* (\rightarrow K^+\pi^-)\ \mu^+\mu^-$ systematic

- Ranges of the mass fit region
  - Differ in q2 bins due to deltaM cut effect
- Angular background shapes
  - Varied between 2nd and 3rd Chebyshev polynomials
- Contribution of $B^\pm \rightarrow \mu^+\mu^- K^\pm$ events
  - estimated by removing potential $B^\pm \rightarrow \mu^+\mu^- K^\pm$ candidates
- Angular acceptance effects
  - Mainly from limited MC statistics
  - Various signal angular shapes tested
- Sequential fitting approach
  - Non-negligible effect only in $2.00 < q2 < 4.30$ GeV2 bin due to low statistics

Negligible sources:

- Contribution from S-wave ($Bd \rightarrow K^+\pi^- \mu^+\mu^-$)
- Contribution from $Bs \rightarrow \Phi(\rightarrow K^+ K^-) \mu^+\mu^-$
- Background mass shape
- Possible bias due to angular fit approach (neglecting correlation)

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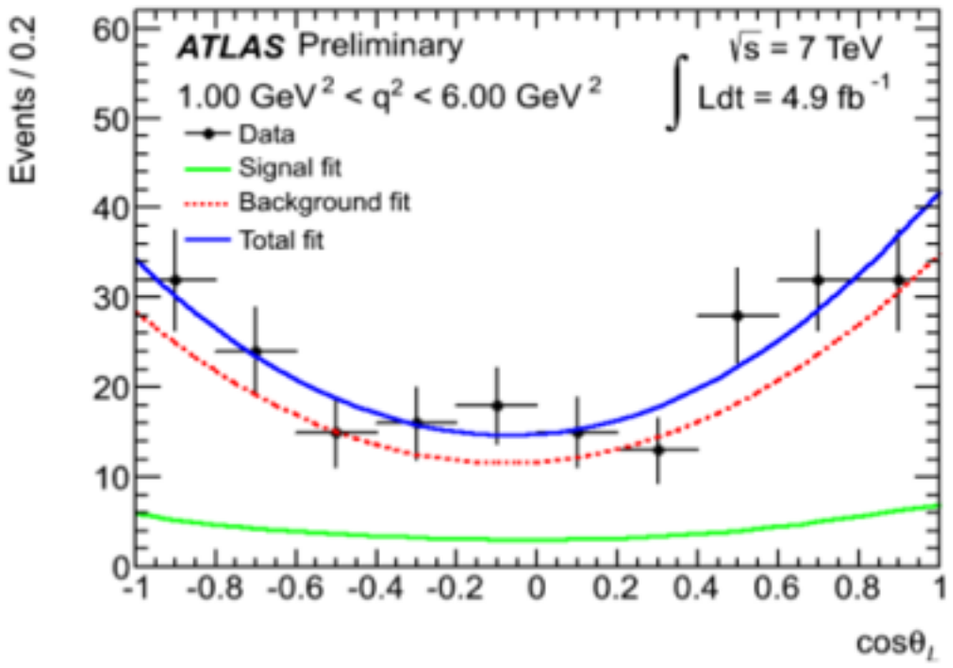
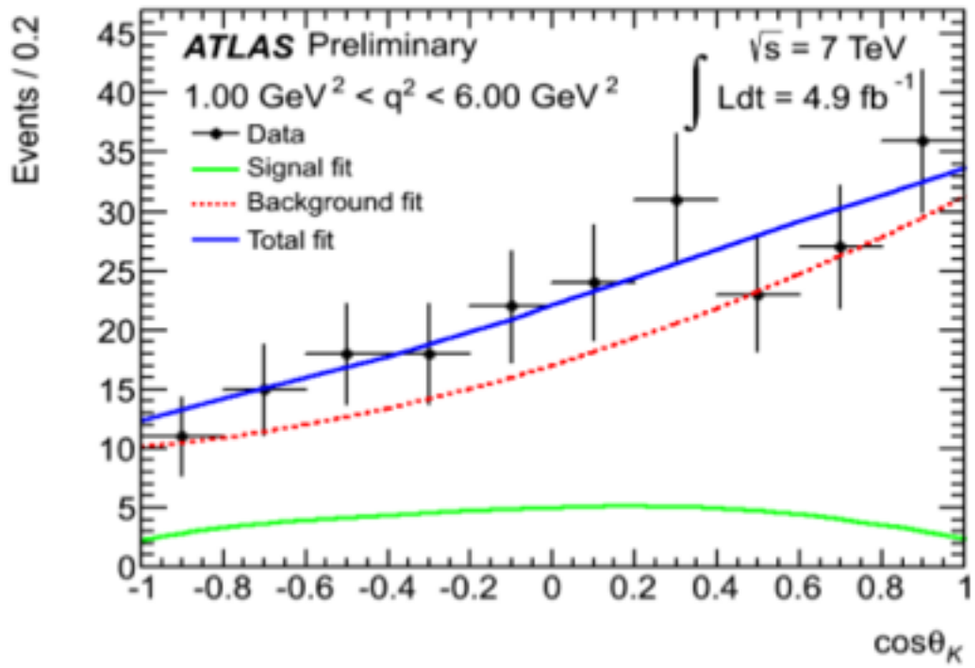
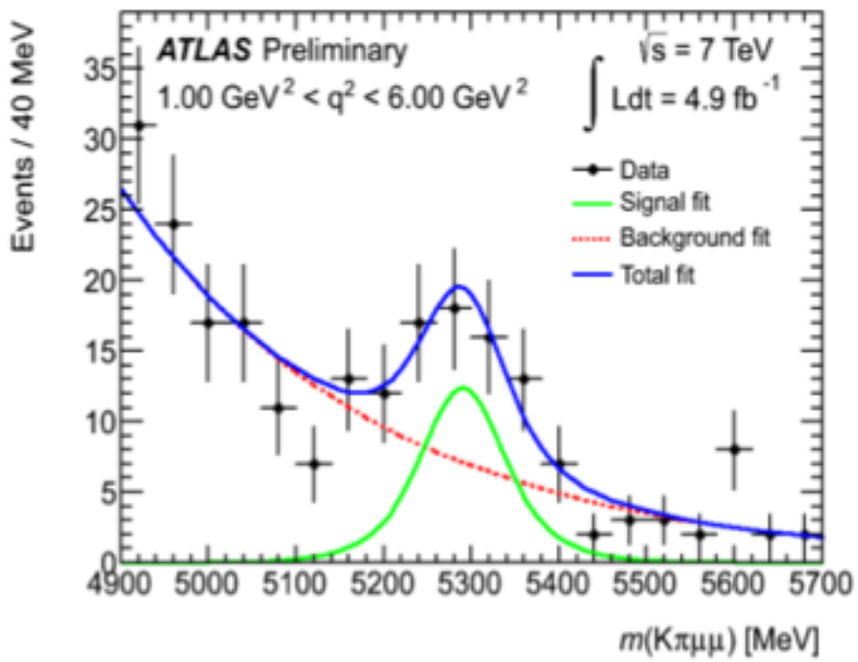
$B_0 \to K^*(\to K^+\pi^-)\,\mu^+\mu^-$ likelihood fit - other bins

$1.00 < q^2 < 6.00$







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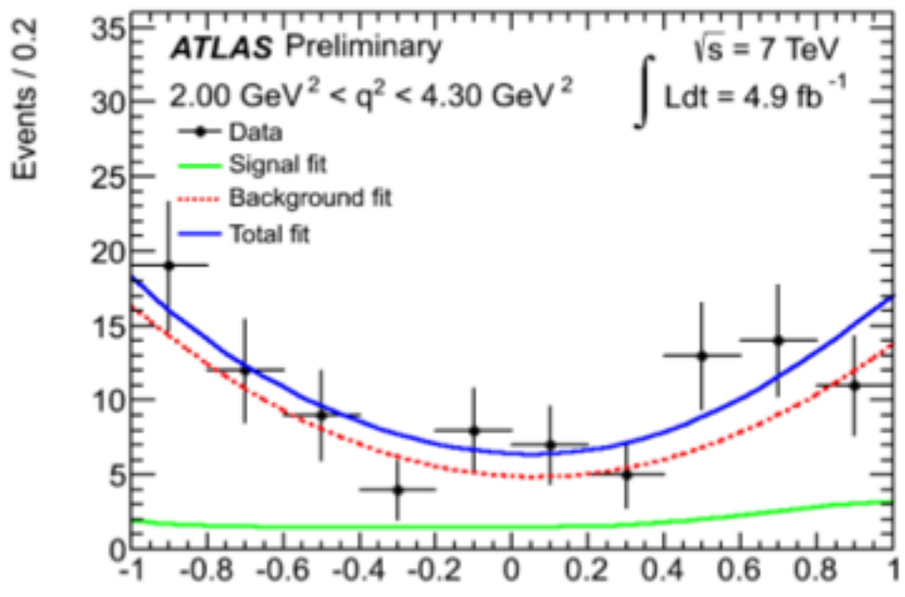
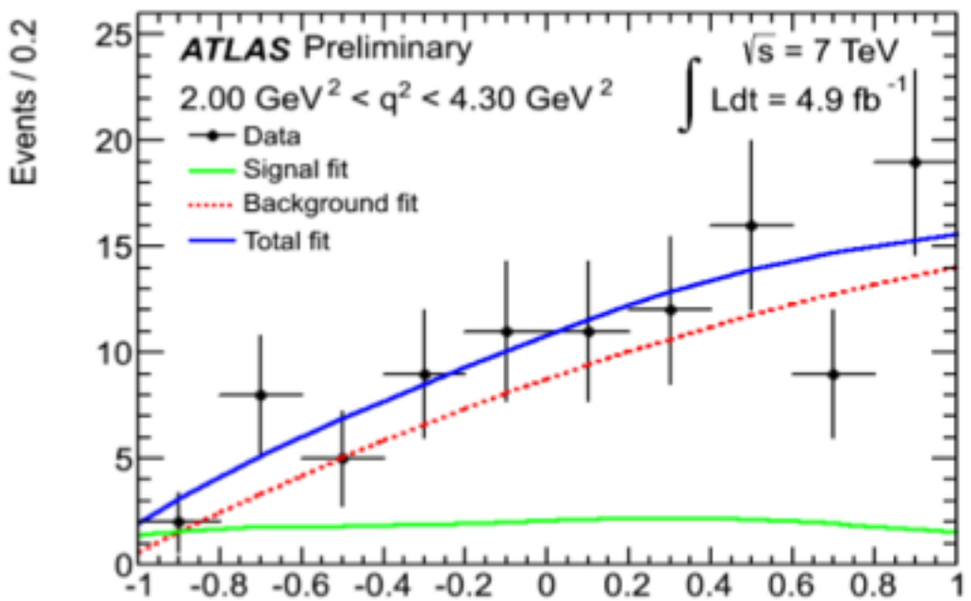
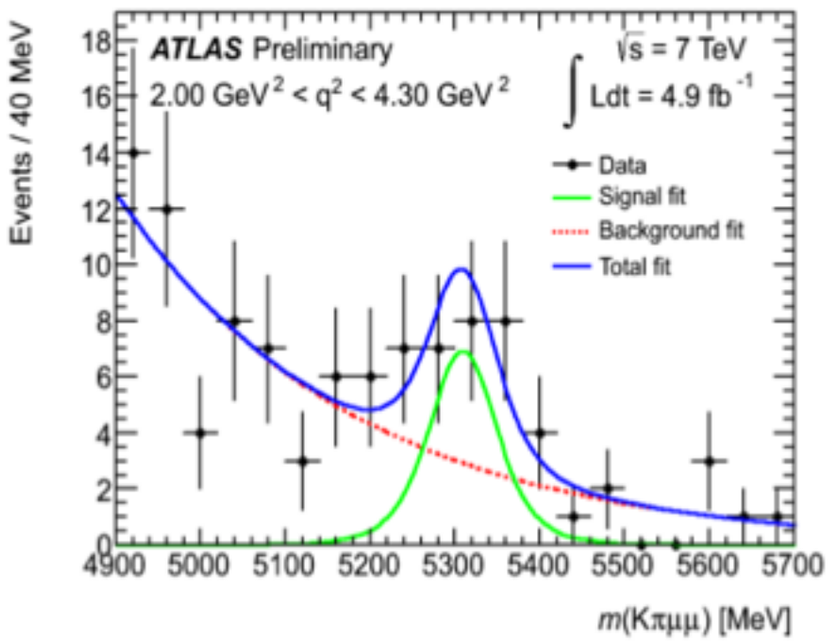
$B_D \to K^* (\to K^+\pi^-)\ \mu^+\mu^-$ LIKELIHOOD FIT - OTHER BINS

$2.00 < q^2 < 4.30$







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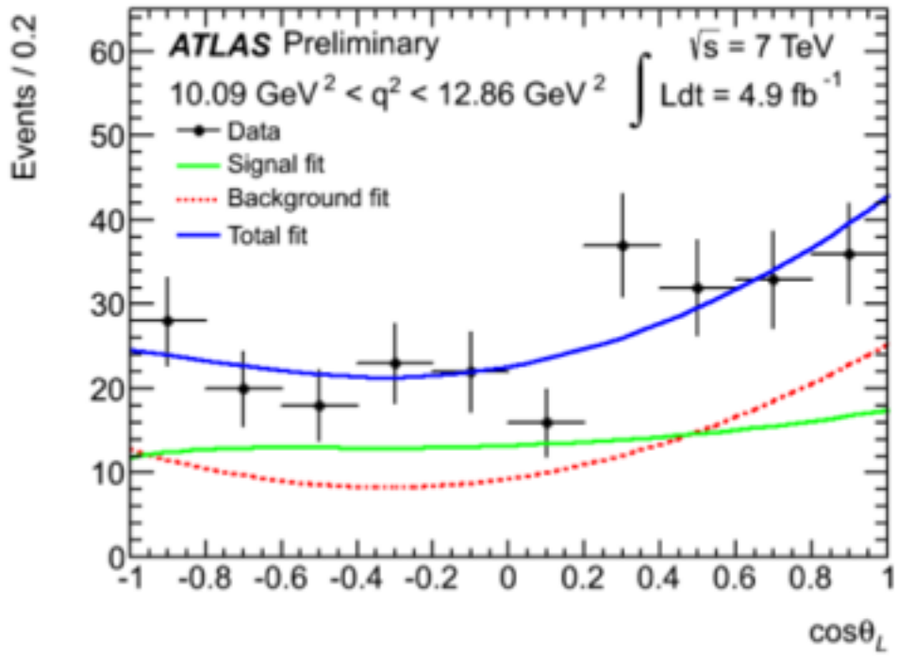
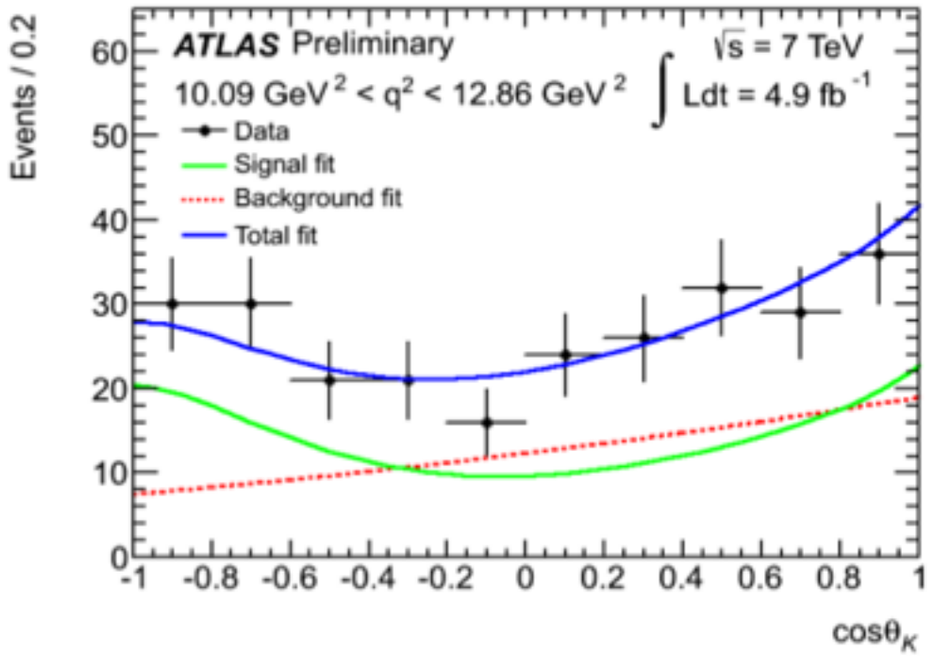
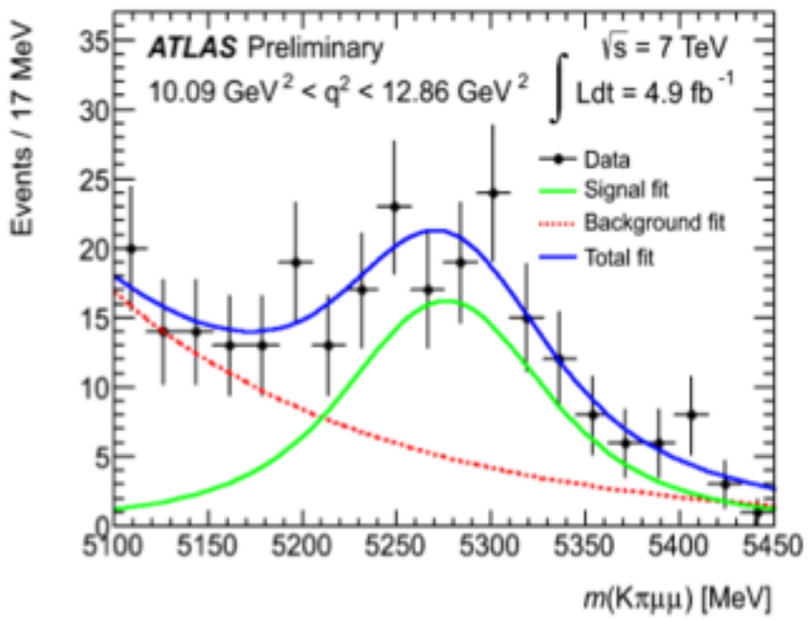
$B_D \to K^* (\to K^+\pi^-)\ \mu^+\mu^-$ likelihood fit - other bins

$10.09 < q^2 < 12.86$







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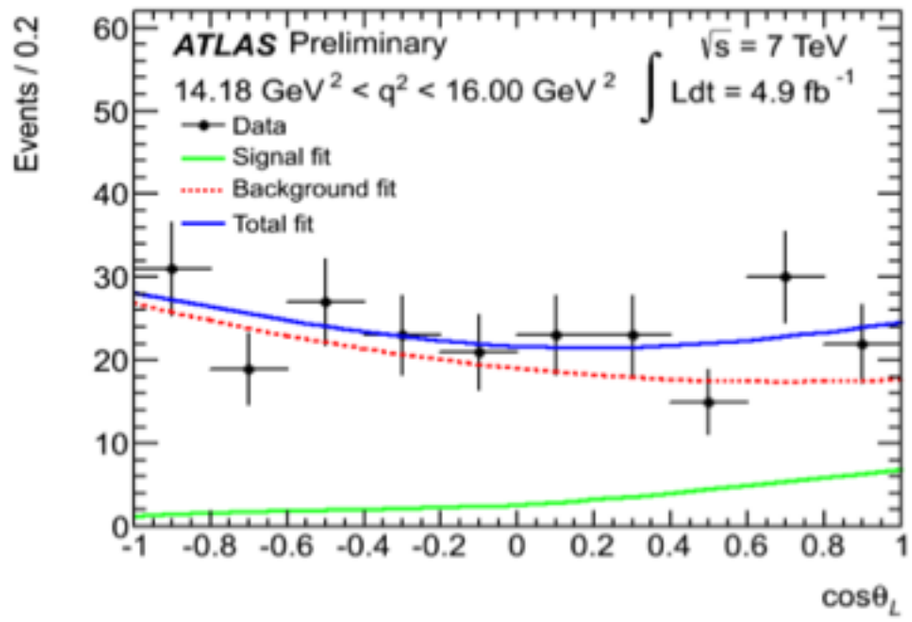
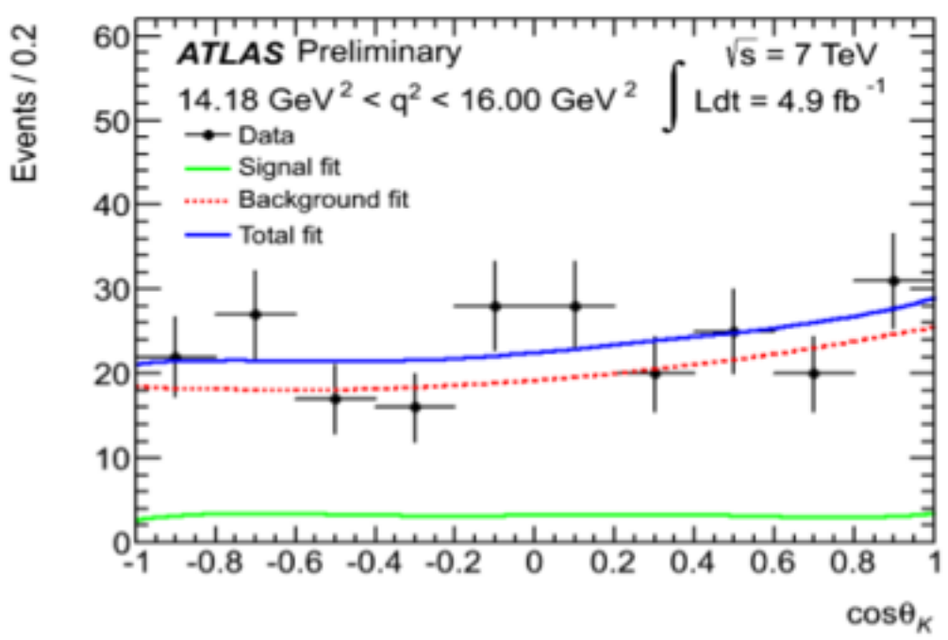
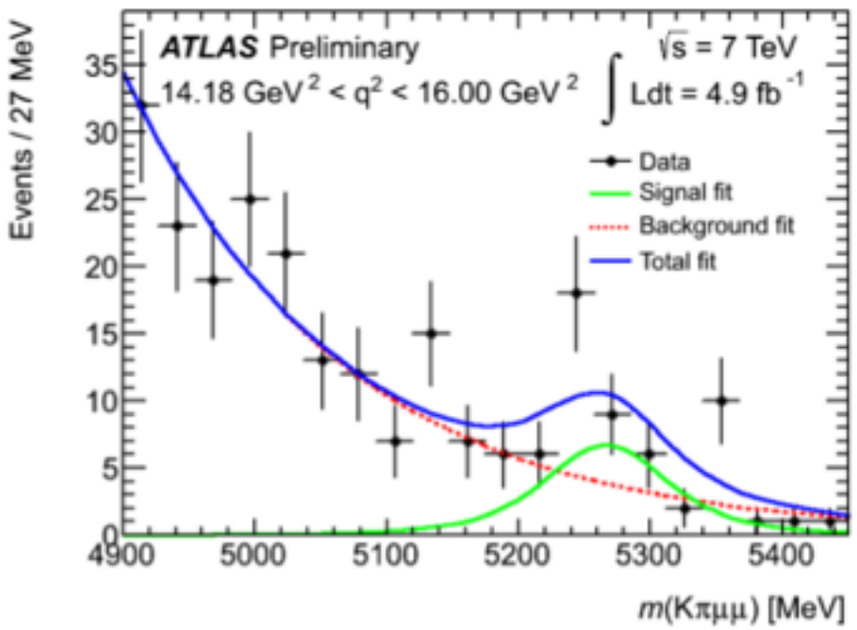
$B_D \to K^* (\to K^+\pi^-)\ \mu^+\mu^-$ LIKELIHOOD FIT - OTHER BINS

$14.18 < q^2 < 16.00$







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