UNIVERSITÄT SIEGEN

Naturwissenschaftlich Technische Fakultät

$B^{\pm} \rightarrow J/\psi(\mu^{+}\mu^{-})K^{\pm}$ as Reference Channel in the Search for $B^{0}_{s} \rightarrow \mu^{+}\mu^{-}$ with ATLAS

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Federal Ministry of Education and Research

ATLAS EXPERIMENT

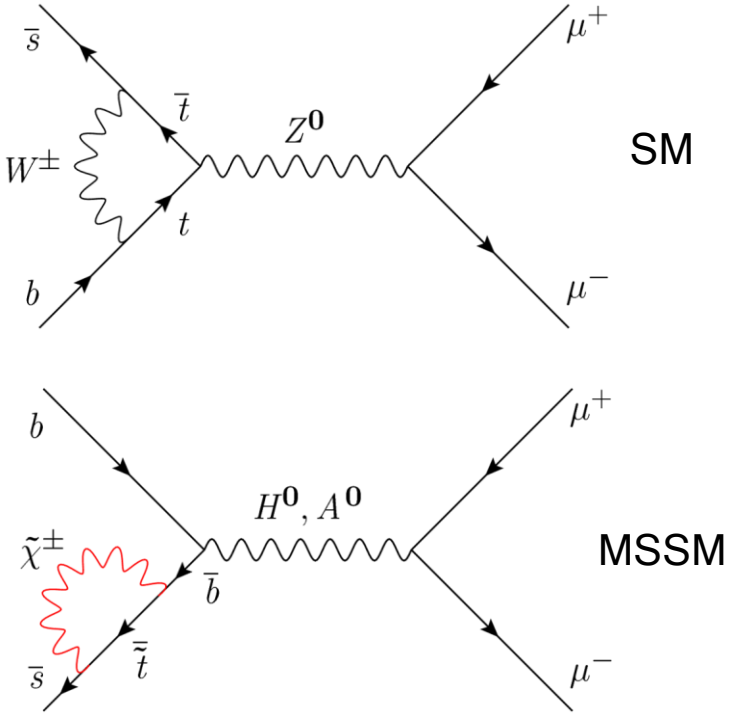
FSP 101 ATLAS

Overview

- Overview of rare *B*-decays
  - Motivation
  - $B_s \rightarrow \mu\mu$ studies in ATLAS
  - The reference channel $B^{\pm} \rightarrow J/\psi\, K^{\pm}$
- Estimation of $B^{\pm}$ yield using 2011 data
  - $B^{\pm}$ selection
  - Un-binned maximum likelihood fit on $B^{\pm}$ invariant mass spectrum using per event mass errors
  - $B^{\pm}$ yield and computation of its uncertainties

Motivation

- Standard Model
  - $B_s \to \mu^+\mu^-$ forbidden at tree level
  - Lowest order contributions are CKM suppressed
  - $\mathscr{B}(B_s \to \mu^+\mu^-)$ is small
- Standard Model extensions
  - $\mathscr{B}(B_s \to \mu^+\mu^-)$ considerably enhanced



	Limit on $\mathscr{B}(B_s \to \mu^+\mu^-)$	Data
SM expectation	$(3.2 \pm 0.2) \times 10^{-9}$	
DØ	5.1×10^{-8} @ 95% CL	6.1 fb^{-1}
CDF	4.0×10^{-8} @ 95% CL	7 fb^{-1}
LHCb	1.3×10^{-8} @ 95% CL	0.3 fb^{-1}
CMS	1.9×10^{-8} @ 95% CL	1.14 fb^{-1}
LHC combined	1.08×10^{-8} @ 95% CL	

[AJ Buras, Acta Phys. Polon. B41:2487-2561, 2010]

[FERMILAB-PUB-10-202-E]

[FERMILAB-PUB-11-315-E]

[EPS-HEP, 2011]

[CMS-BPH-11-002]

[LHCb-CONF-2011-047]

The $B^{\pm} \rightarrow J/\psi\, K^{\pm}$ (Reference) Channel

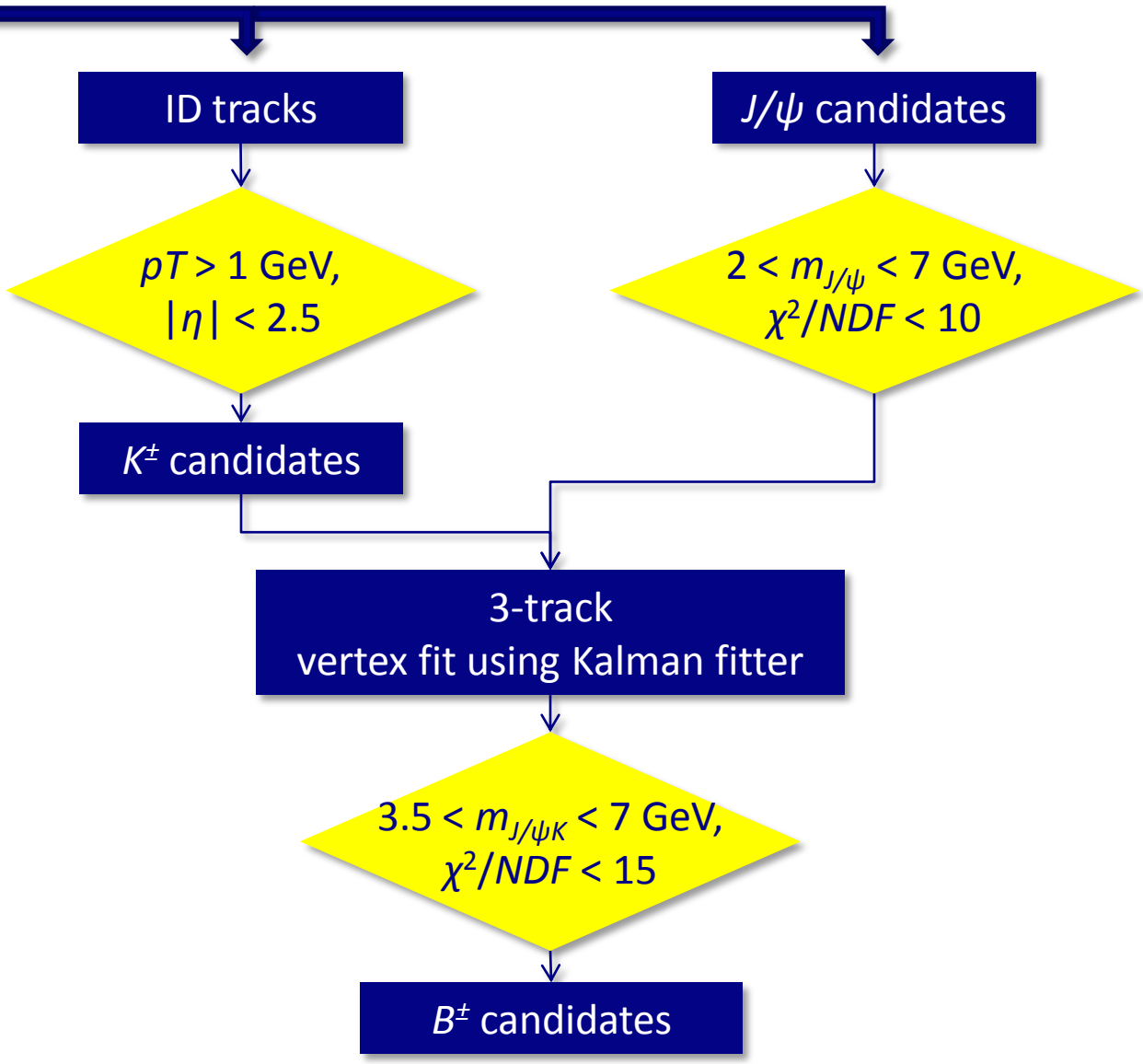
- $N_{B\pm}$ required for estimating branching ratio of $B_s \rightarrow \mu\mu$
- Two muons in final state (from J/ψ decay) and a charged track
- Baseline cuts applied to both channels should be similar
- Hence, most systematic uncertainties will cancel out:

$$\mathcal{B}\left(B_s \rightarrow \mu^+\mu^-\right) = \frac{N_{B_s}}{N_{B^+}} \underbrace{\frac{\alpha_{B^+}}{\alpha_{B_s}}}_{\text{Acceptance ratio}} \underbrace{\frac{\varepsilon_{B^+}}{\varepsilon_{B_s}}}_{\text{Trigger, reconstruction and selection efficiencies}} \underbrace{\frac{1}{\varepsilon_N}}_{\text{Final signal selection efficiency}} \underbrace{\frac{f_u}{f_s}}_{\text{Ratio of } b \rightarrow B^+ \text{ to } b \rightarrow B_s} \mathcal{B}\left(B^+ \rightarrow J/\psi\, K^+\right) \cdot \mathcal{B}\left(J/\psi \rightarrow \mu^+\mu^-\right)$$

Pre-selection of $B^{\pm}$ Candidates

pp collisions data

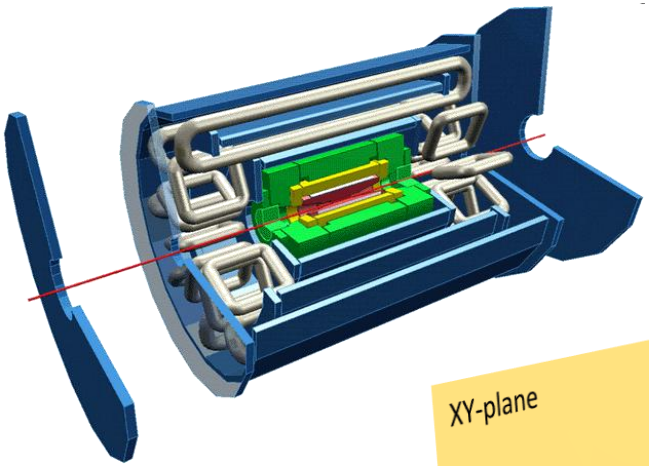
- $\sqrt{s}$ = 7 TeV
- $\int Ldt$ = 2.42 fb^{-1}
  ↑ *subject to change*
  (Mar 22 – Aug 21, 2011)
- Good run selection based on data quality
- Events chosen by a topological muon trigger ($p_{T,\mu 1} \geq 4$ GeV; $p_{T,\mu 2} \geq 2$ GeV)

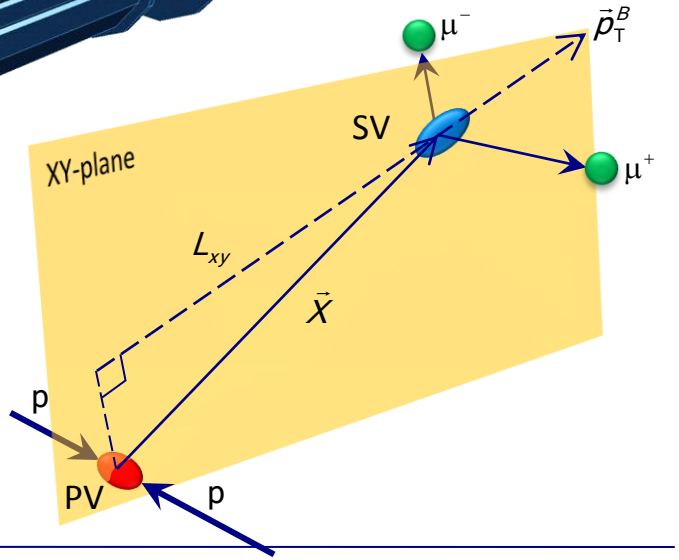


$B^{\pm}$ Selection Cuts

- J/ψ selection
  - $p_{T,\mu 1} \geq 4.0$ GeV, $p_{T,\mu 2} \geq 4.0$ GeV
  - Muons reconstructed in inner detector as well as muon spectrometer
  - $2.915 \leq m_{J/\psi} \leq 3.275$ GeV
  - Vertex $\chi^2/NDF \leq 10$
- $K^{\pm}$ selection
  - $p_{T,K} \geq 2.5$ GeV
- Cuts on all three tracks
  - Pixel hits ≥ 1
  - Silicon tracker hits ≥ 6

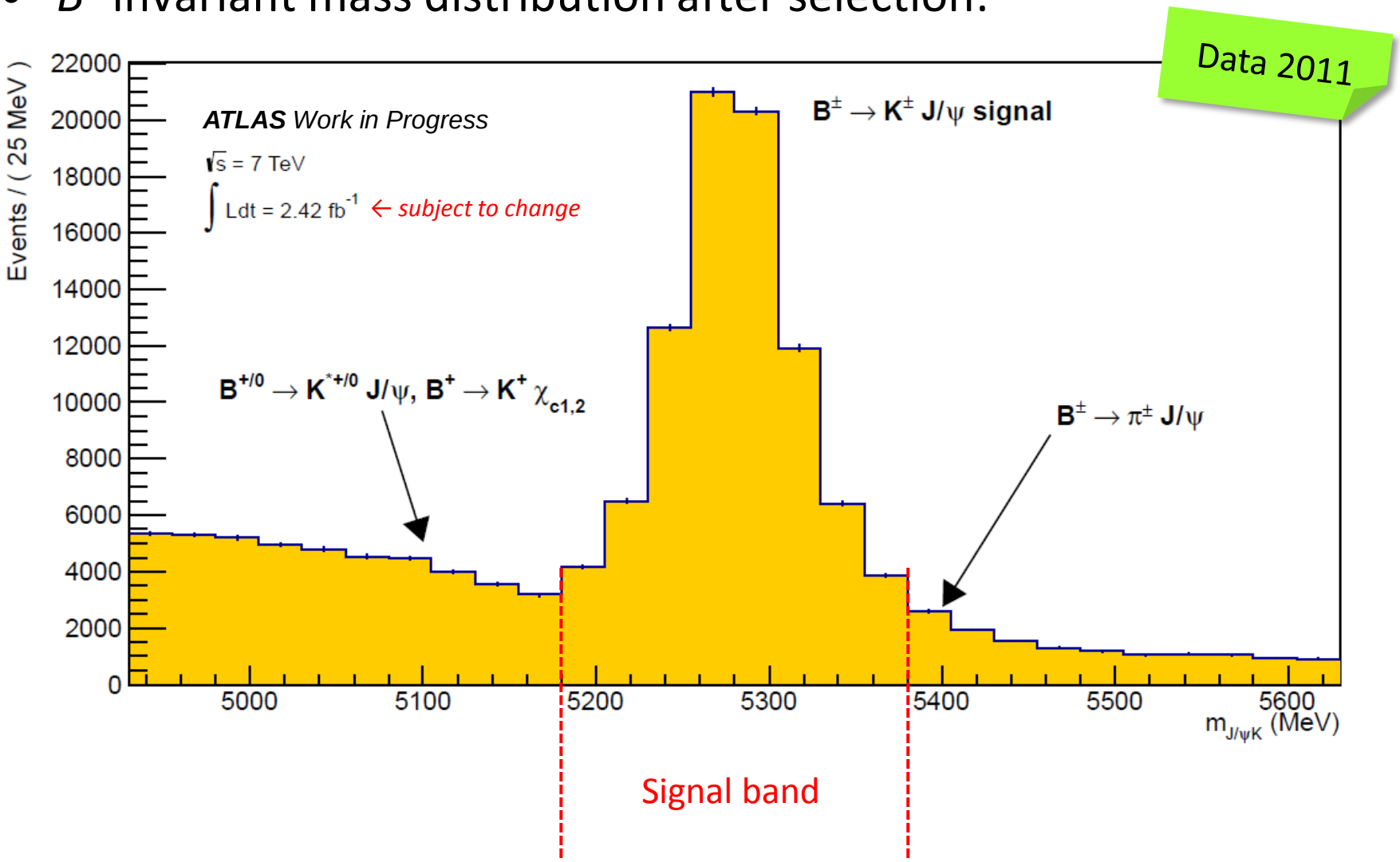
- $B^{\pm}$ selection
  - $4.930 \leq m_B \leq 5.630$ GeV
  - Vertex $\chi^2/NDF \leq 6$
  - $L_{xy} \geq 0.3$ mm (PV with highest track p_T sum)





$B^{\pm}$ Mass Spectrum

- $B^{\pm}$ invariant mass distribution after selection:



Maximum Likelihood Fit Model (M)

Gaussian

Exponential

+

Complementary error function

+

Gaussian ($B^{\pm} \rightarrow J/\psi\pi^{\pm}$)

(*for modeling only!*)

Background

+

Fit Model

Signal model:

$$G\left(m_{J/\psi K}\right) = e^{\frac{-\left(m_{J/\psi K} - m_{B^{\pm}}\right)^2}{2\left(S\cdot\delta m_{J/\psi K}\right)^2}}$$

Conditional probability

$$F_{sig}\left(m_{J/\psi K}\middle|\delta m_{J/\psi K}\right) = G\left(m_{J/\psi K}\middle|\delta m_{J/\psi K}\right)\cdot F\left(\delta m_{J/\psi K}\right)$$

Mass error distribution

Background model:

$$E\left(m_{J/\psi K}\right) = e^{\lambda m_{J/\psi K}}$$

$$Erfc\left(m_{J/\psi K}\right) = Erfc\left(\frac{m_{J/\psi K} - \mu_{erfc}}{\sigma_{erfc}}\right)$$

$$G_{\text{MisID}}\left(m_{J/\psi K}\right) = e^{\frac{-\left(m_{J/\psi K} - m_{\text{MisID}}\right)^2}{2\left(\sigma_{\text{MisID}}\right)^2}}$$

$$M\left(m_{J/\psi K}\middle|\delta m_{J/\psi K}\right) = \frac{N_{sig}\cdot G + N_{bkg}^{Exp}\cdot E + N_{bkg}^{Erfc}\cdot Erfc + N_{bkg}^{MisID}\cdot G_{MisID}}{N_{sig} + N_{bkg}^{Exp} + N_{bkg}^{Erfc} + N_{bkg}^{MisID}}$$

Maximum Likelihood Fit

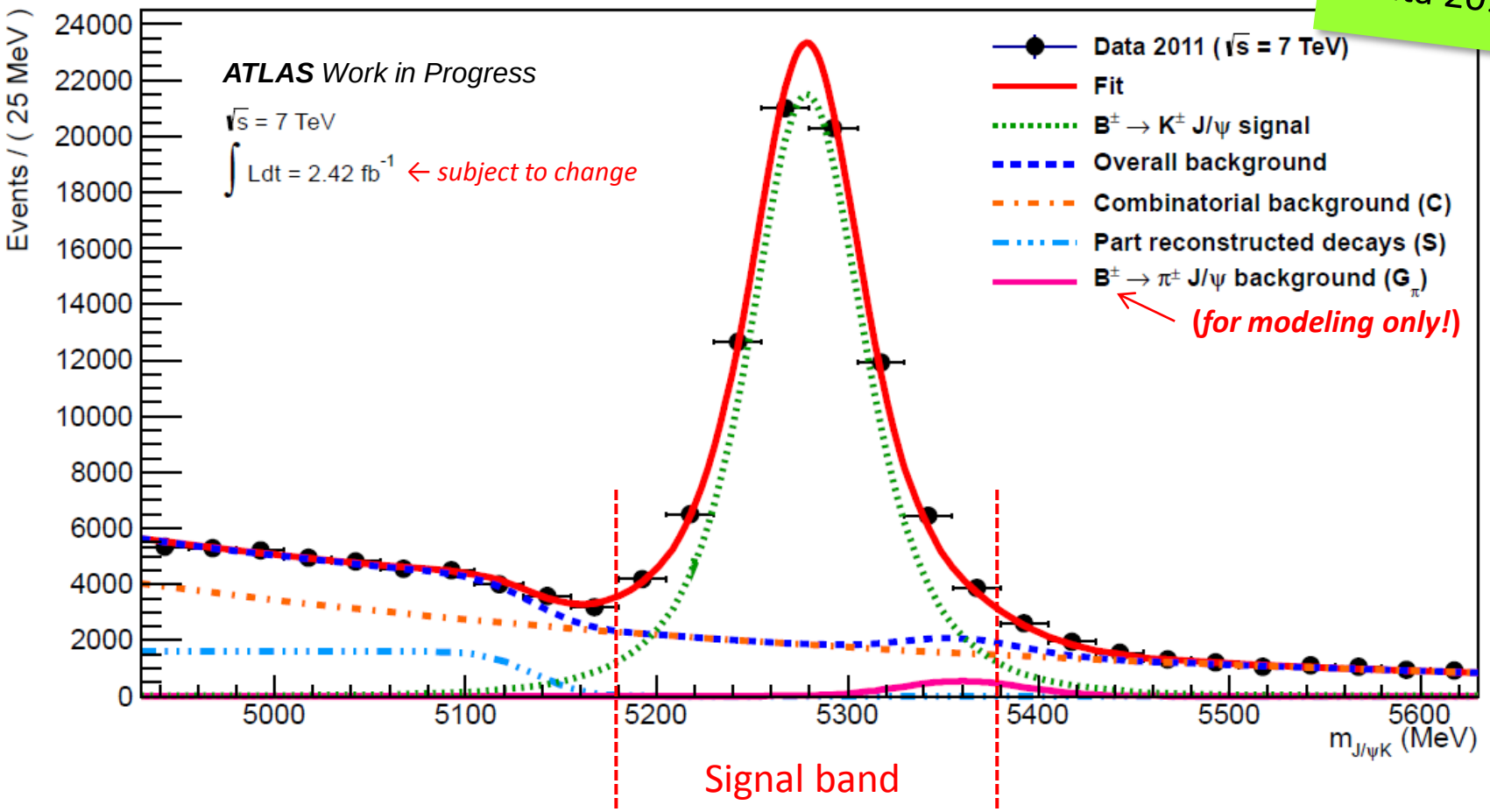
- Likelihood function:

$$-\log L = -\sum_i \log M\left(m^i{}_{J/\psi K} \mid \delta m^i{}_{J/\psi K}\right) - \log Poisson\left(N_{exp} \mid N_{obs}\right)$$

- ML fit is un-binned
- Uses vertex fit mass ($m_{J/\psi K}$) and mass errors ($\delta m_{J/\psi K}$)
  - $B^{\pm}$ candidates in mass range: $[4930, 5630]$ MeV
  - $B^{\pm}$ candidates (after selection cuts): 145 820

Maximum Likelihood Fit

Data 2011



$B^{\pm}$ yield in '**full range**':

$N_{B\pm}$:	74356 ± ??

$B^{\pm}$ yield in '**signal band**':

$N_{B\pm}$:	70849 ± ??

Computation of Uncertainties

Using a sampling method as used in RooAbsReal::plotOnWithErrorBand()

Signal band $\int F_{sig}(m|\delta m;\mu)dm$

$N_{B\pm}$

$G(x;\mu,\Sigma)$

$x=[x_1,x_2,...,x_n]$

$\mu=[\mu_1,\mu_2,...,\mu_n]$

$\Sigma=[Cov[\mu_i,\mu_j]]$

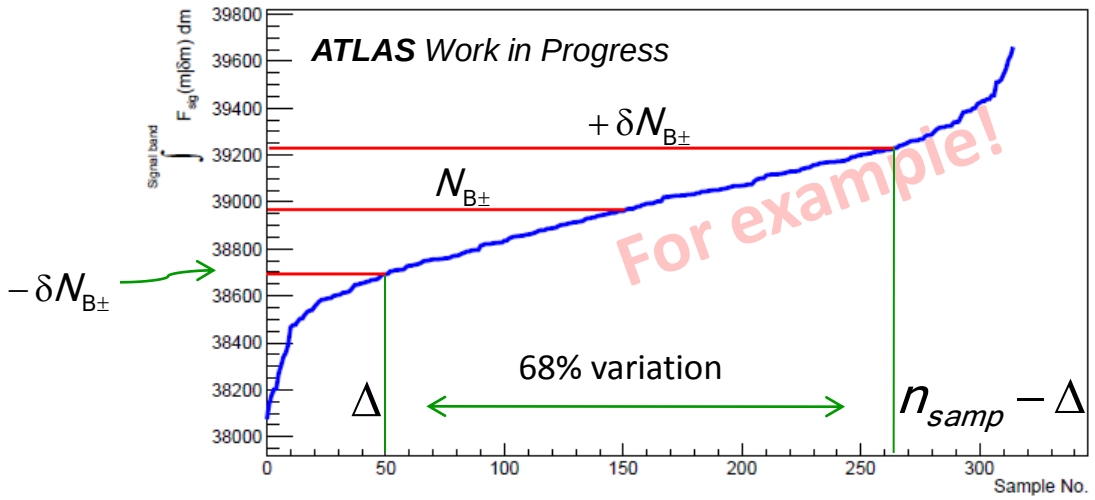
$i,j=1,2,...,n$

Toy MC

$P=[p_1,p_2,...,p_n]$

$S=[P_1,P_2,...,P_{n_{samp}}]$

Signal band $\int F_{sig}(m|\delta m;P)dm$



$\Delta = n_{samp}\cdot Q(z)+\frac{1}{2}$

See next slide for def. ⟶

Computation of Uncertainties

Signal band

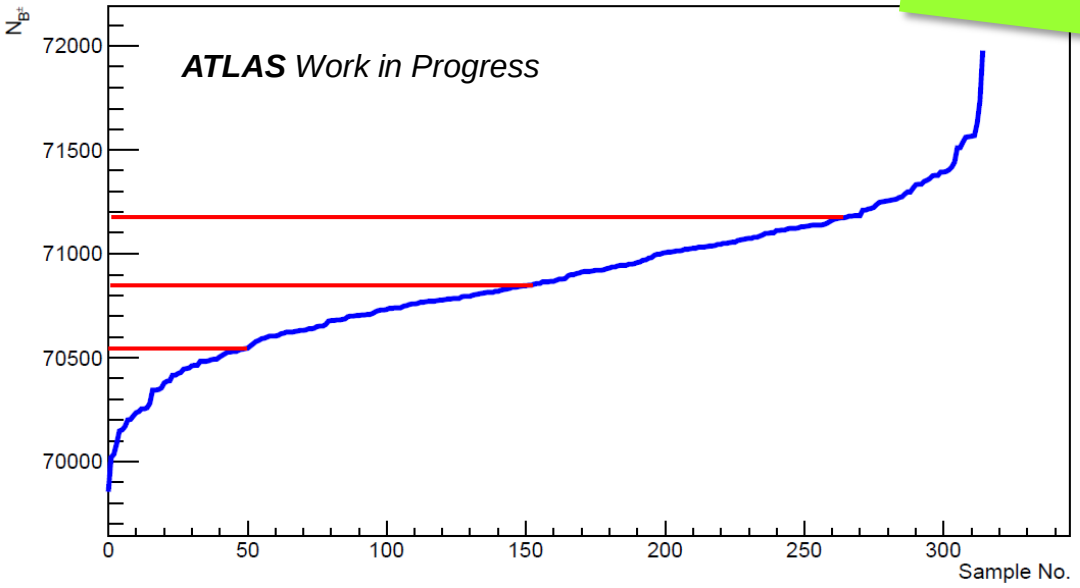
$\int F_{sig}(m\|\delta m;\mu)dm$	Integral (in signal band) of the signal model used in the fit (slide #8)
$N_{B\pm}$	Number of signal events in signal band
$+\delta N_{B\pm}, -\delta N_{B\pm}$	Asymmetric error on $N_{B\pm}$
n	Number of fit parameters
$\mu = [\mu_1, \mu_2, ..., \mu_n]$	Fit parameter vector
$\Sigma = [Cov[\mu_i, \mu_j]]$	Fit covariance matrix of size n x n
$G(x;\mu,\Sigma)$	n-dimensional multivariate Gaussian of fit parameters
$P = [p_1, p_2, ..., p_n]$	Vector of parameters after a toy MC experiment
$S = [P_1, P_2, ..., P_{n_{samp}}]$	Sample set: set of P vectors after n_{samp} experiments
z	Significance level (z = 1 implies 68% variation in central band)
$Q(z)$	p-value; Q-function is defined as $Q(z) = \frac{1}{\sqrt{2\pi}} \int_z^\infty e^{-t^2/2} dt$

Computation of Uncertainties

- Statistical uncertainty using the sampling method:

Integrals of F_{sig} in "signal band"

Data 2011



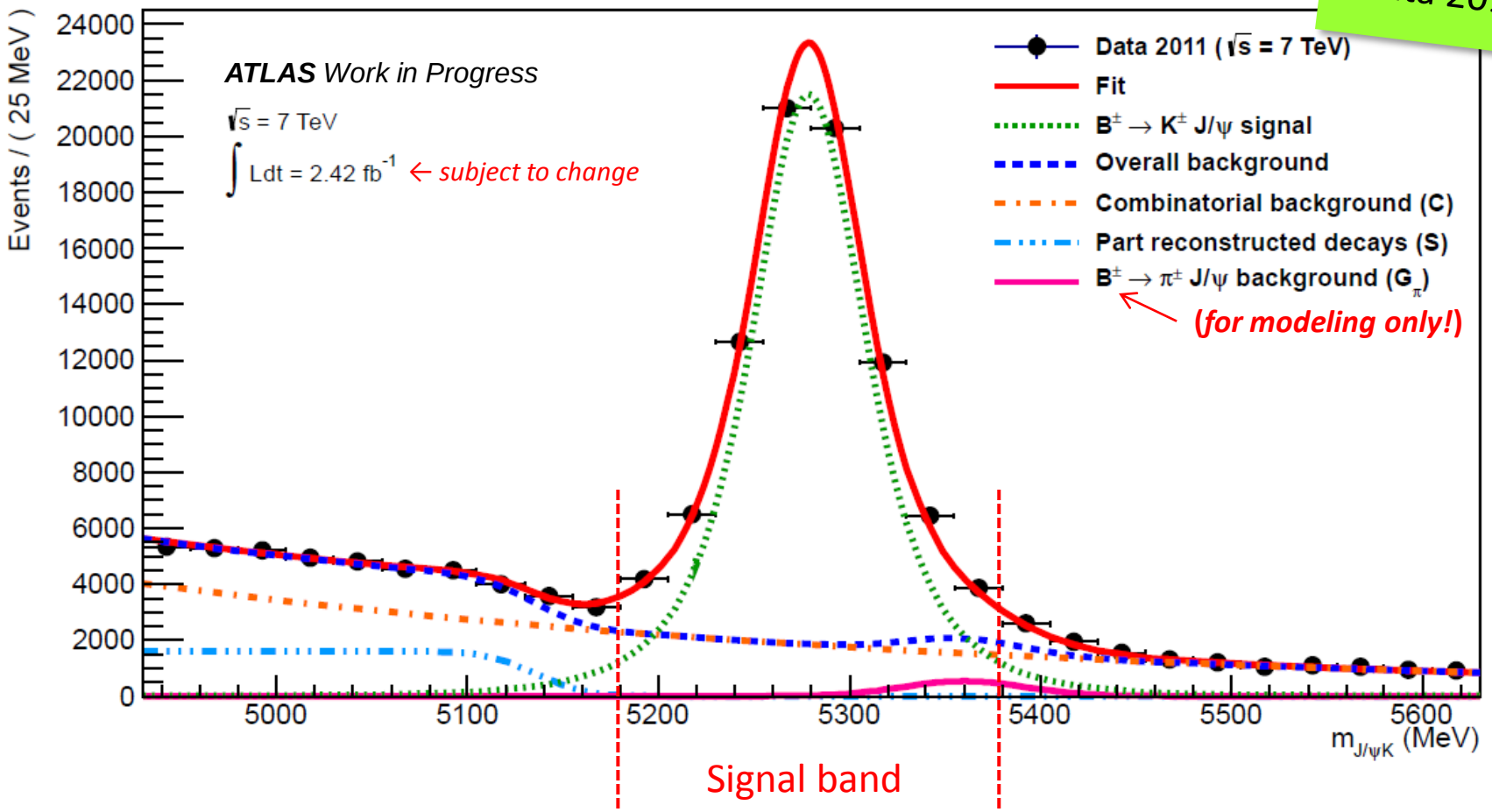
$$\delta N_{B\pm}^{stat} = \begin{matrix} +326 \\ -303 \end{matrix}$$

- Systematic uncertainty:
  - Yield estimate variation when a polynomial model is used for the combinatorial background instead of an exponential:

$$\delta N_{B\pm}^{syst} = 71951 - 70849 = +1102$$

Maximum Likelihood Fit

Data 2011



$B^{\pm}$ yield in '**full range**':

$N_{B\pm}$: 74356 $^{+\ 394}_{-\ 315}$

$B^{\pm}$ yield in '**signal band**':

$N_{B\pm}$: 70849 $^{+\ 326}_{-\ 303}$ (stat) + 1102 (syst)

Summary

- ATLAS will measure $\mathscr{B}\left(B_s \to \mu^+\mu^-\right)$ using $B^\pm \to J/\psi K^\pm$ as the reference channel
- $B^\pm$ yield is determined from un-binned maximum likelihood fit on 2011 data using per event errors
  - **$B^\pm$ yield estimate** (in signal band): **$70849\ ^{+326}_{-303}$ (stat) + 1102 (syst)**
  - Statistical uncertainty takes into account the uncertainties in fit parameters and their correlations
  - Systematic uncertainty due to choice of background model is 1.5% (insignificant compared to the uncertainty in the f_s/f_u ratio ~7.9%)

[LHCb-CONF-2011-034]

- A paper on expected limit on $\mathscr{B}\left(B_s \to \mu^+\mu^-\right)$ is being prepared

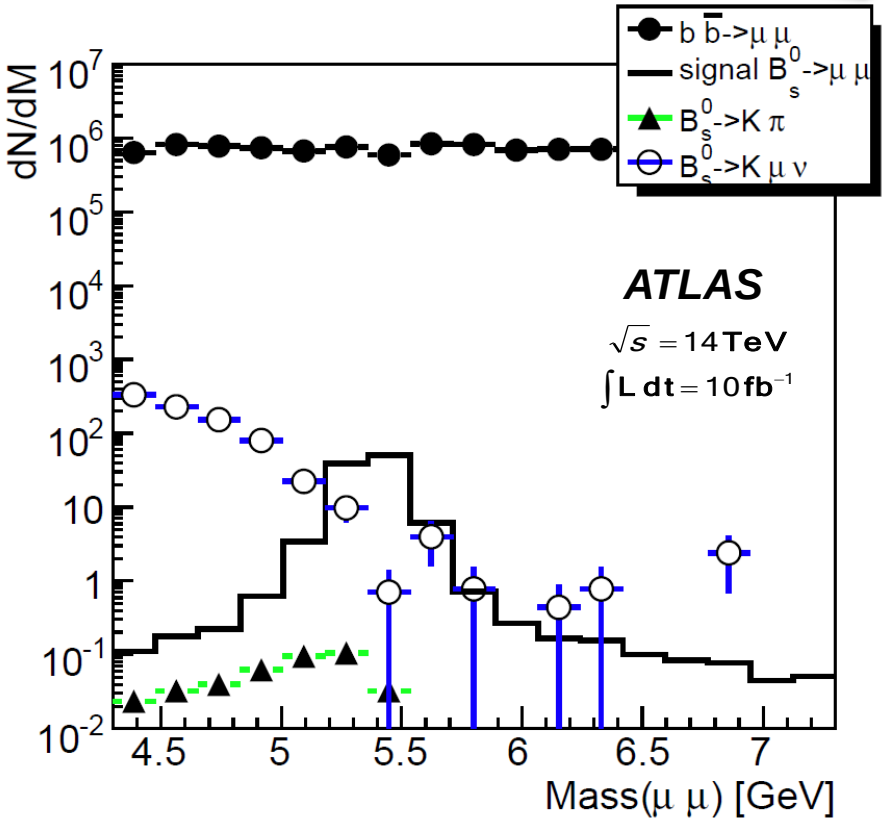
Extra Slides

$B_s \rightarrow \mu^+\mu^-$ Studies in ATLAS

Selection of the B_s

- Pre-selection cuts:
  - $\mu^+\mu^-$ pairs:
    $p_{T,\mu 1} \geq 6.0$ GeV,
    $p_{T,\mu 2} \geq 4.0$ GeV,
    $|\eta| < 2.5$
  - Vertex fit χ^2/NDF < 10
  - Transverse decay length
    $L_{xy} < 20$ mm
  - 4 GeV < $m_{\mu\mu}$ < 7.3 GeV

14TeV MC



[CERN-OPEN-2008-020]

$B_s \rightarrow \mu^+\mu^-$ Studies in ATLAS

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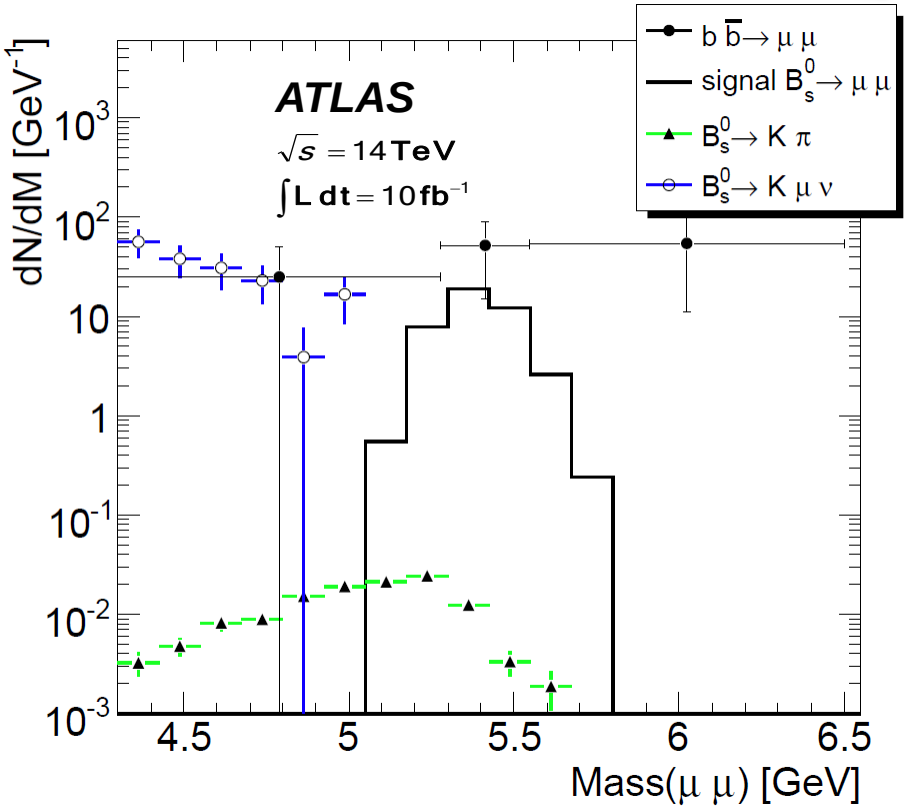
14TeV MC

Selection of the B_s

- Selection cuts:
  - $I_{\mu\mu} > 0.9$
  - $L_{xy} > 0.5$ mm
  - $\alpha < 0.017$ rad
  - Mass in$[-\sigma, 2\sigma]$, $\sigma = 90$ MeV



Selection efficiencies:

	$B_s \rightarrow \mu^+\mu^-$	$b\bar{b} \rightarrow \mu^+\mu^- X$ (background)
Total efficiency	0.04	$(2.0 \pm 1.4) \cdot 10^{-6}$
Event yield	5.7	14^{+13}_{-10}

[CERN-OPEN-2008-020]

Fit Results

- Fit results for the fit on slide #10

λ :	-0.002251 ± 0.000057
μ_{erfc} :	5135.5 ± 1.8
σ_{erfc} :	29.8 ± 4.1
$\mu_{B\to J/\psi\pi}$:	5360 (fixed)
$\sigma_{B\to J/\psi\pi}$:	31.6 ± 3.3
N_{bkg}^{Exp} :	56654 ± 1045
N_{bkg}^{Erfc} :	13131 ± 802
$N_{bkg}^{B\to J/\psi\pi}$:	1680 ± 197
N_{sig} :	74356 ± 377
$m_{B\pm}$:	5278.66 ± 0.16
S :	1.160 ± 0.005
χ^2/NDF :	4.314