Investigation of the decays $B^0_{d,s}$-> $J/\psi\eta$ in the ATLAS experiment at the LHC

by

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17'th Nordic Particle Physics Meeting

Spåtind, January 2002

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People involved

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Note ISN-01.68, LUNDF6/(NFFL-7198)2001 submitted as an ATLAS Scientific Note.

Physics Motivation (1)

- Probing the mixing phase: $\phi_s = -2\lambda\eta = 2\lambda \sin\gamma |V_{ub}/V_{cb}|$

  $\phi_s^{SM} \sim 0.039$ ➔ γ is very hard to extract!

$B^0_{s,d}$ ->J/ψη modes are U-spin related (d<->s) can be used to extract the γ-angle of the Unitarity triangle (hep-ph9903455) :

- General parametrization of the $B^0_{s,d}$ ->J/ψη decay amplitudes:

$$A_{s,d}(t) \propto 1 - b_{s,d} e^{i\rho_{s,d}} e^{i\gamma}$$

$\rho_{s,d}$ the strong phases.

$$b_s = \frac{\lambda^2}{1-\lambda^2} a_s \qquad b_d = a_d$$

b_s is strongly Cabibbo suppressed ➔ Small CP violation effects

➔ use B^0_d ->J/ψη channel to calculate CP asymmetry

Physics Motivation (2)

- Calculate the time-dependent asymmetries: $A_{cp}^{dir}, A_{cp}^{mix}, A_{\Delta\Gamma}$

However due to: $\left(A_{cp}^{dir}\right)^2 + \left(A_{cp}^{mix}\right)^2 + \left(A_{\Delta\Gamma}\right)^2 = 1$

➔ need new observable :

$\langle\Gamma_s\rangle$ and $\langle\Gamma_d\rangle$ ➔build new observable $H=f(b,\rho,\gamma)$

3 unknowns (b,ρ,γ) , 3 independent observables :

U-spin symmetry: $a_s = a_d$ $\rho s - \rho_d = \pi$

$$\tan\gamma \approx \frac{\sin\phi - \eta A_{cp}^{mix}}{(1-H)\cos\phi_M}$$

ϕ is the B_d-B_d mixing phase.

Physics Motivation (3)

- Branching ratio of $B^0_{s,d} \to J/\psi\eta$:

LEP/L3 $Br(B^0_s \to J/\psi\eta) < 3.8\ 10^{-3}$

By combining these modes and using the U-spin symmetry one was able to predict the branching ratios for both channels depending on the $\eta-\eta'$ mixing angle (-20 to -10):

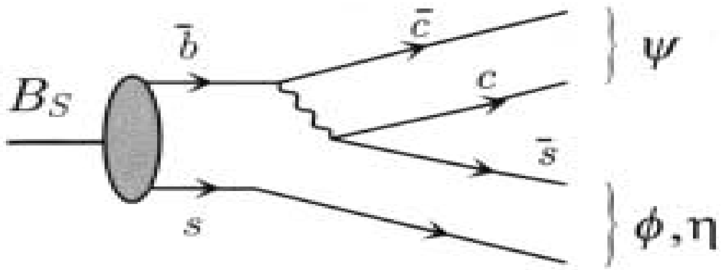
$Br(B^0_s \to J/\psi\eta) = 9.5 - 8.3\ 10^{-4}$

$Br(B^0_d \to J/\psi\eta) = 1.6 - 4.1\ 10^{-6}$

Physics Motivation (5)

- Decays $B^0_s \to J/\psi\phi$, $B^0_{s,d} \to J/\psi\eta$, $B^0_{s,d} \to D^+_s D^-_s$ are analogous, but up to now, only the first one has been studied.

- Advantages of $B^0_s \to J/\psi\eta$: no angular analysis needed since the final state is a CP eigenstate (V-PS).



- Cross-check of the decay mode $B^0_s \to J/\psi\phi$. New input to B-Physics measurements: $B^0_d \to J/\psi\eta \equiv B^0_d \to D^+_d D^-_d \Rightarrow \sin 2\beta$.

Simulation Tools

- **Generation**: ATGEN-B (PYTHIA 5.7)
  - b-quarks produced via: lowest order process, gluon splitting, flavour excitation.
  - Exclusive modes $B_{s,d}$ --> $J/\psi\eta$ ($\mu 6 \mu 3$, $|\eta| < 2.5$) $\eta(\gamma\gamma)$ for signal.
  - Inclusive mode B --> J/ψ($\mu 6 \mu 3$, $|\eta| < 2.5$) X for physics back.
  - p-p --> J/ψ X is not used, harmless for B_s--> $J/\psi\phi$ (TDR).

- **Simulation**: Dice 98_2, full detector
  - srt release 1.3.0, OLD layout

17 000 B_s --> $J/\psi\eta$ events ,15 000 B_d --> $J/\psi\eta$ events

23 000 B --> J/ψ X events

- **Reconstruction**: ATRECON
  - srt release 1.3.0, using xKalman

Physics analysis

$B^0_{s,d}$ → $J/\psi\ \eta$

J/ψ → $\mu^+\mu^-$ 5.88%

Idet, TDR:567
$m=3.097, \sigma=0.04$ GeV/c^2

η → $\gamma\gamma$ 39.33% — ECAL

η → $\pi^0\pi^0\pi^0$ 32.24%

η → $\pi^-\pi^+\pi^0$ 28%

J/psi Reconstruction

- Pairs of muons with $p_T(\mu 1)>6$ GeV, $p_T(\mu 2)>3$ GeV have been selected: **efficiency: 85% for μ1 (incl. level-1 and reconstruction in muon spectrometer), 78% for μ2 (incl. Reconstruction in muon spectrometer and tilecal). Fake rate is very small.**

- Cuts:
  - Fit Quality: $\chi^2/ndf<6$
  - Transverse Decay Length: Lxy >250 μm

➔ **J/ψ mass resolution ~ 39 MeV**

➔ **J/ψ reconstruction efficiency: 79%**

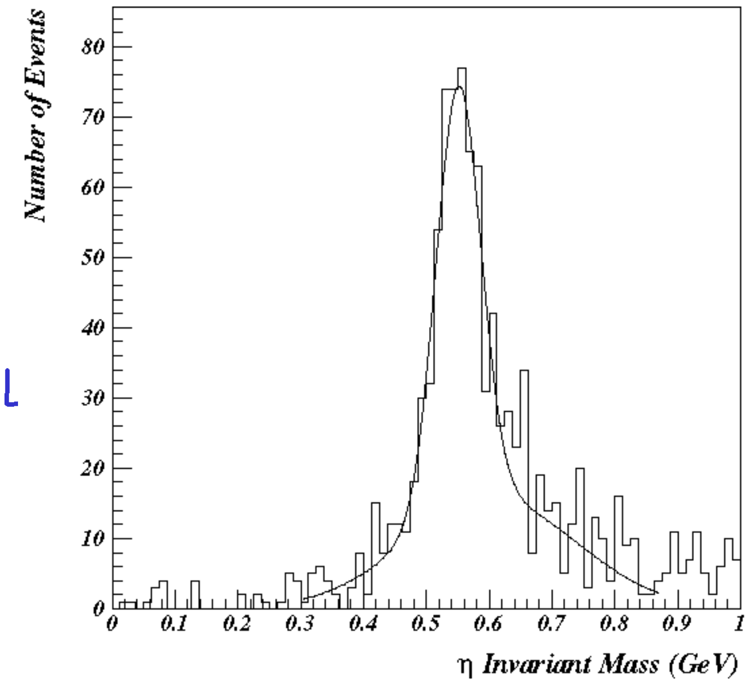
η Reconstruction

- Reconstructed in the ATLAS LAr Calorimeter:
  - Cell size: $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$
  - Energy resolution : $\sigma(E)/E = 10\%/\sqrt{E} \oplus 1\%$
  - Cluster size 3x3 cells with E_{thr} >1 GeV:
  - γγ openning angle > 5°

➔ 20% of η –> γγ retained.

- Further selection cuts:
  - Energy sharing in the 3 ECAL/lay and HCAL
  - Cluster width
  - Energy containment in the 3x3 window

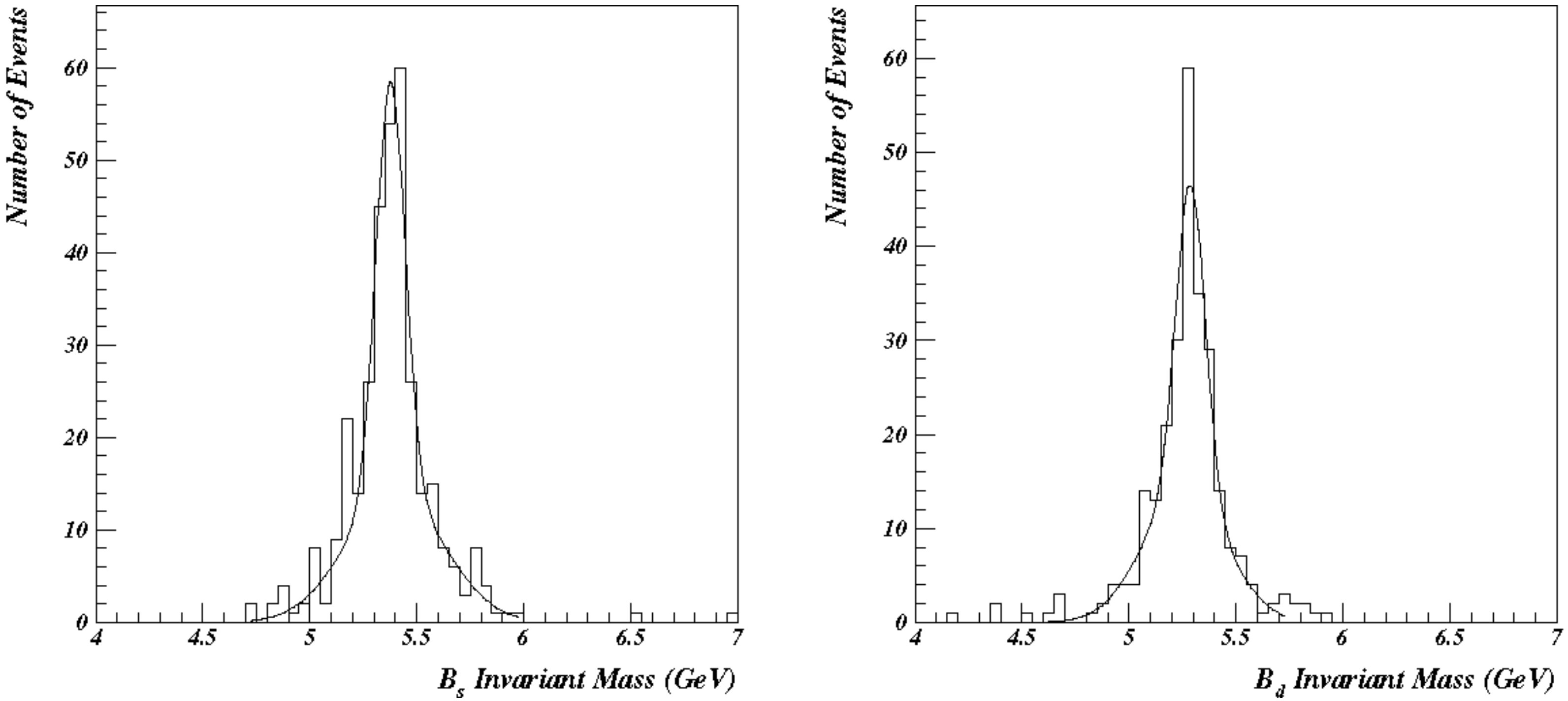
➔ η mass resolution ~35 MeV
➔ Reconstruction efficiency ~2.3%



$B^0_{s,d}$ Reconstruction

Combining reconstructed J/ψ and η candidates, and choosing events with $P_t(B) > 5$ GeV.

➔ mass resolution : $\sigma(B^0_{s,d})$= 67 MeV.



Results for 30 fb^{-1} (???)

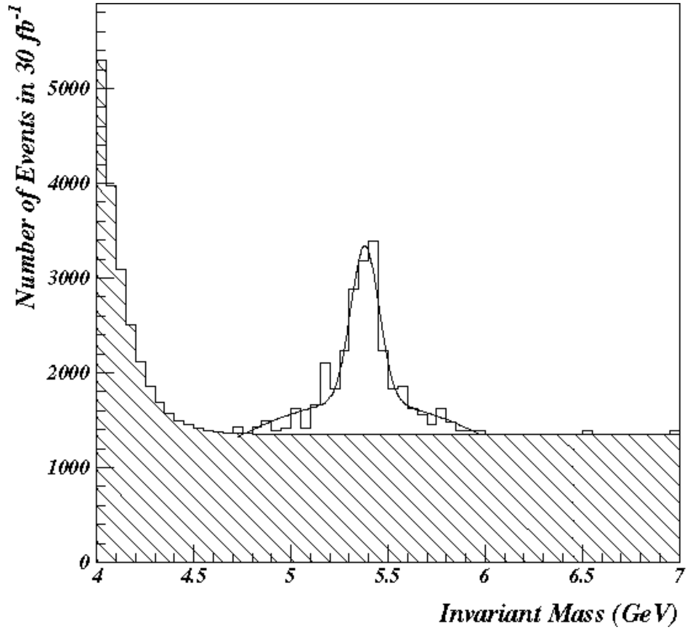
$$N^{prod}_{signal} = 2\sigma(pp \to b\bar{b})\mathcal{B}r(b \to B^0_{s,d})\mathcal{B}r(B^0_{s,d} \to J/\psi\eta)\mathcal{B}r(J/\psi \to \mu^+\mu^-) \cdot A(\mu 6)A(\mu 3)\mathcal{B}r(\eta \to \gamma\gamma)\int \mathcal{L}dt,$$

$$N^{prod}_{back} = \sigma(pp \to b\bar{b} \to J/\psi X)A(\mu 6)A(\mu 3)\int \mathcal{L}dt.$$

$$N^{prod}_{Bs} = 9.2 \cdot 10^8 \cdot \mathcal{B}r(B^0_s \to J/\psi\eta),$$
$$N^{prod}_{Bd} = 4.9 \cdot 10^9 \cdot \mathcal{B}r(B^0_d \to J/\psi\eta).$$

$$N^{prod}_{back} = 1.2 \cdot 10^8.$$

	$\theta_P = -10^o$	$\theta_P = -20^o$
$\mathcal{B}r(B^0_s \to J/\psi\eta)$	$8.3 \cdot 10^{-4}$	$9.5 \cdot 10^{-4}$
N^{obs}_{Bs}	8 500	9 700
$\mathcal{B}r(B^0_d \to J/\psi\eta)$	$4.1 \cdot 10^{-6}$	$1.6 \cdot 10^{-6}$
N^{obs}_{Bd}	200	80
N^{obs}_{back}	10 800	10 800



- ➔ Clear B_s signal S/B~0.8
- ➔ B_d CANNOT be observed

CP-asymmetry measurement (1)

Reminder:

Decay amplitude parametrization :

$$A_s(t) \propto 1 + a_s \frac{\lambda^2}{1-\lambda^2} e^{i\theta_s} e^{i\gamma} \quad A_d(t) \propto 1 - a_d e^{i\theta_d} e^{i\gamma}$$

where $\theta_{s,d}$ the strong phases, $a_{s,d}$ their respective amplitude,
λ the wolfenstein parameter.

CP asymmetry is doubly cabbibo suppressed in the B_s --> J/ψ.

Since the B_d --> $J/\psi\eta$ cannot be observed, one thought of calculating the CP asymmetry in the B_s --> $J/\psi\eta$ channel.

CP-asymmetry measurement (2)

- Events need to be tagged as B or anti-B:

  - Lepton tagging: Not possible due to low statistics.

  - Jet Charge Tagging (SST): exploits the correlation between the charge of a jet and the charge of the quark producing the jet:

$$Q_{jet} = \frac{\sum_i q_i P_i^k}{\sum_i P_i^k}$$

q_i is the charge of the i^{th} particle in the jet, P_i its momentum.

Charged particles with: $P_T > 0.5$ *GeV and* $|\eta| < 2.5$, $\Delta R < 0.8$, $d_0 < 1cm$, $|z| < 5cm$ were considered. $\mu^+\mu^-$ were excluded.

CP-asymmetry measurement (3)

The reconstructed B-meson was defined as Bs-meson (anti Bs-meson) if the $Q_{jet} > +c$ ($Q_{jet} < -c$). c is a tunable cut.

The exponent (K) was optimized to maximize the the tagging quality factor $Q=\varepsilon_{tag} \cdot D^2_{tag}$, *where* D_{tag} *is the dilution factor and* ε_{tag} *is the tagging efficiency*

Optimal parameters were found to be: K=0.2, c=0.2

➔ $Q = 3.85\%$ $D_{tag} = 0.26$ $\varepsilon_{tag} = 0.57$

CP-asymmetry measurement (4)

The observable asymmetry is:

$$a_{obs}(t)= D.a_{cp}(t)=D.\sin\phi_s.\sin\Delta m_s t$$

where $D=D_{tag}.D_{back}$, $D_{back}=N_s/N_s+N_{back}$.

Assuming the decay time resolution to be $\Delta\tau=0.073$ps, the Bs lifetime $\tau_{Bs}=1.464$ps:

Fit:

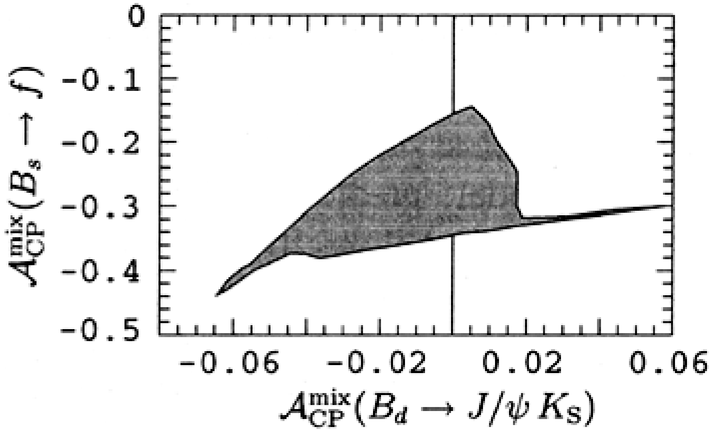
➔ $\delta(\sin\phi_s)$ = 0.27 for $x_s = \Delta m_s/\Gamma_s$ = 19
➔ $\delta(\sin\phi_s)$ = 0.31 for $x_s = \Delta m_s/\Gamma_s$ = 30

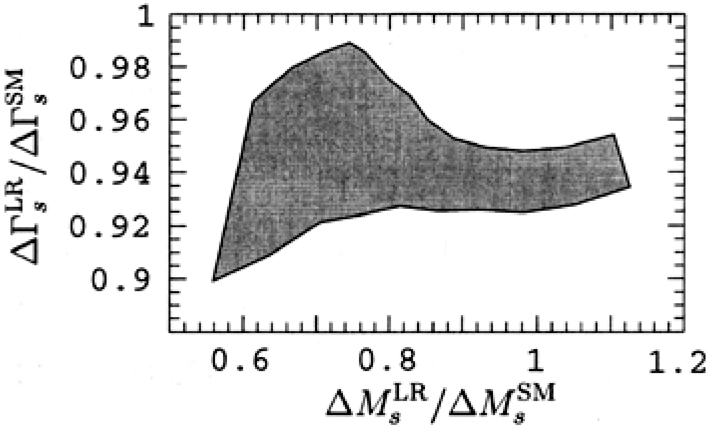
CP-asymmetry measurement (5)

In case of New Physics, ex: SB-LR model (phys. lett. B 475 (2000) 111)

$A_{CP}^{mix}(Bs \longrightarrow f) = \sin\phi_s, \quad \phi_s = \phi_s^{SM} + \phi_s^{NP} = -2\lambda^2\eta + \phi_s^{NP}$

$\Delta\Gamma_s = \Delta\Gamma_s^{SM}\cos(\phi_s)$





- CP asymmetry as large as ϑ(40%) may arise in the Bs channel while for B_d -> $J/\Psi\ K_s$, A_{cp} as large as ϑ(10%).
- Affects also the B^0_s-B^0_s mass and width differences, where Δm_s may be reduced significantly

Lund Layout v.s. Old layout

Geometry has been changed

- Simulation: 6000 B_s --> $J/\psi\eta$ events (srt release 1.3.7).
- Reconstruction: xKalman++.

Calo : No damage caused (η-->$\gamma\gamma$).

INDet : Mass resolution of (J/ψ-->$\mu^+\mu^-$) ~ 50 MeV.

Comparison and Conclusions

Simple estimates:

- B-factories PEPII, KEKB cannot produce B_s
- Tevatron CDF 2 fb^{-1}: 190 $B_s \to J/\psi\eta$
- LHC ATLAS 30 fb^{-1}: 9700 $B_s \to J/\psi\eta$
- LHC LHCb 10 fb^{-1}: 260 000 $B_s \to J/\psi\eta$, 2150 $B_d \to J/\psi\eta$

ATLAS can see a clear signal of $B_s \to J/\psi\eta$, measure BR and other parameters measurement (mixing parameters), cross-check of other experiments. New sizeable effects beyond the SM can be observed.

Improve statistics by

- investigating $\eta \to \pi^+\pi^-\pi^0$ (BR=23%)
- improve η efficiency by better use of the fine granularity of the first ECAL sampling (cluster fine structure)