Reconstruction of $B_s^0 \to J/\psi\ \eta\,,\ \eta_c\ \phi\,,\ J/\psi\ \phi$ events in LHCb

Benjamin Carron
LPHE - EPFL - Lausanne

Neuchâtel, March 3rd, 2004
Swiss Physical Society 2004

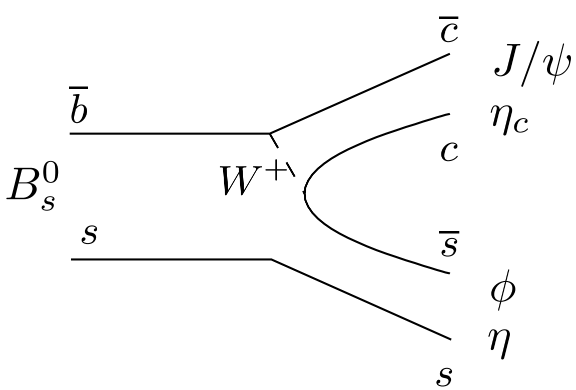
- ✩ Physics Motivations
- ✩ Selection Procedure
- ✩ B_s^0 Channels analysis
  - Selection Cuts
  - Mass and Proper Time Resolutions
  - B/S Ratios
  - Annual Signal Yields
- ✩ Conclusion

Physics Motivations

☞ CP violation studies can provide a profound understanding of quark flavour physics in the framework of the Standard Model (SM) and may reveal a sign of the physics beyond !

☞ An outstanding role is played by B_s^0 mesons decays into CP eigenstates (caused by $\bar{b} \to \bar{c}c\bar{s}$ transitions), such as $B_s^0 \to J/\psi\ \eta$, $B_s^0 \to \eta_c\ \phi$, $B_s^0 \to J/\psi\ \phi$.

Physics model:



☆ Quark transition $\bar{b} \to \bar{c}c\bar{s}$ dominated by only one CKM amplitude ⇒ penguins are negligible

⇒ No CP-violation in the decay amplitude
⇒ Easy channels to look for CP-violation

☆ B_s^0 decays into pure CP-even eigenstates for $J/\psi - \eta$ and $\eta_c - \phi$

☆ B_s^0 decays into an admixture of CP eigenstates for $J/\psi - \phi$ → an angular analysis is required (dilutes the asymmetry)

Physics motivations:

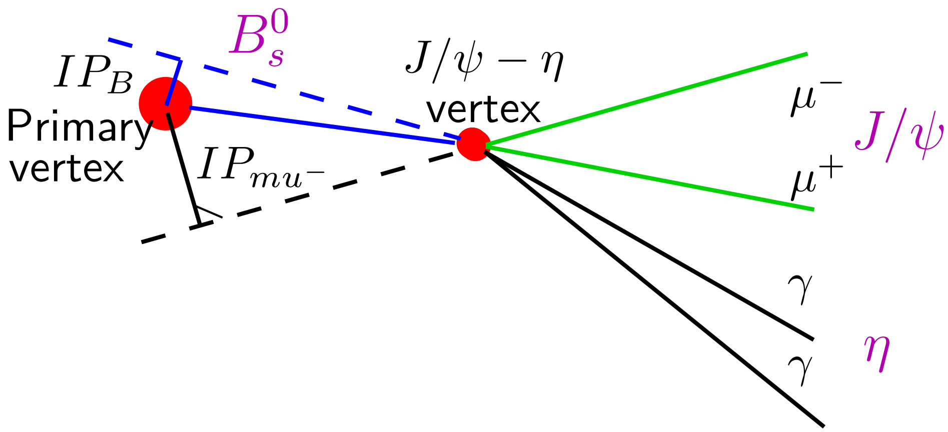
☆ Measure the B_s^0 weak mixing phase $\phi_s \equiv 2\ arg\,(V_{ts}^* V_{tb})$ - expected $\mathcal{O}(-0.04)$ in SM

☆ Extract $B_s^0 - \overline{B_s^0}$ mixing parameters ΔM_s and $\Delta\Gamma_s$

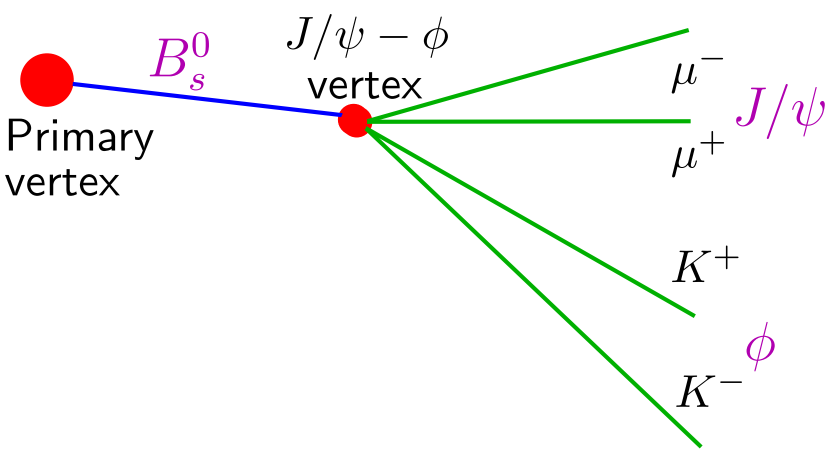
☆ Larger value of ϕ_s would be a clear signal for contributions from new physics ...

Decay Channels

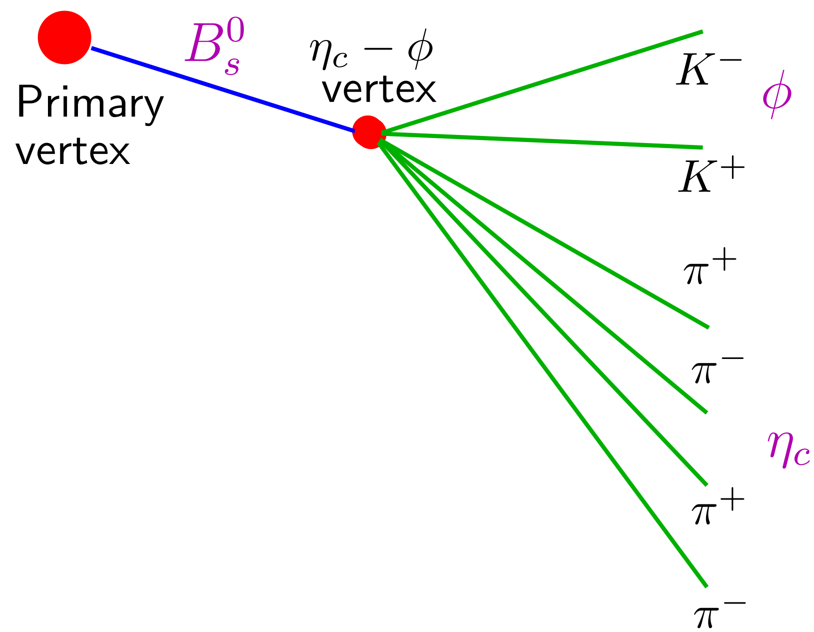
$B_s^0 \to J/\psi\ (\mu^+\mu^-)\ \eta\ (\gamma\gamma)$



$B_s^0 \to J/\psi\ (\mu^+\mu^-)\ \phi\ (K^+K^-)$



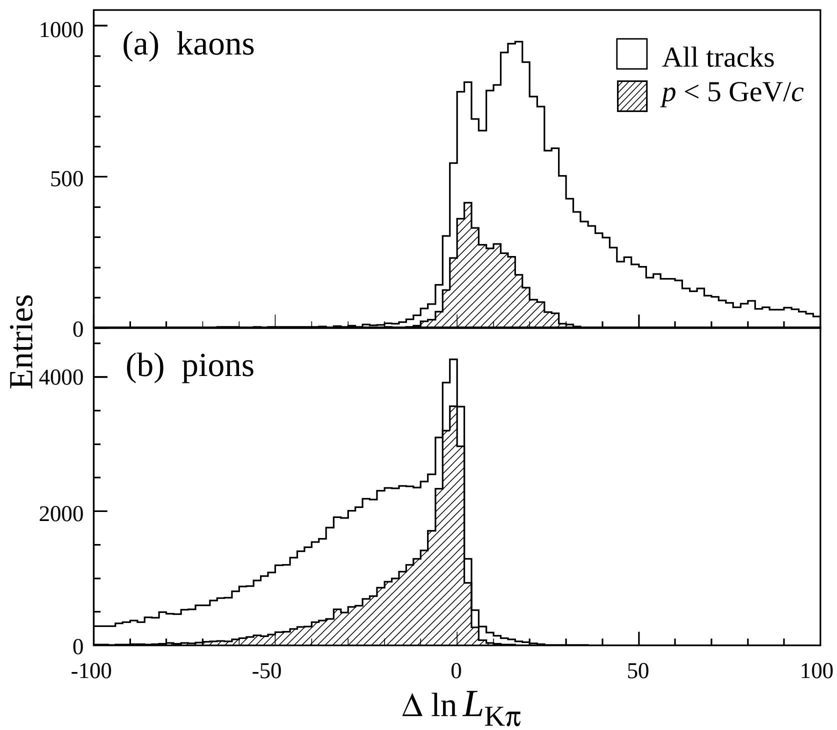
$B_s^0 \to \eta_c\ (2\pi 2K, 4\pi)\ \phi\ (K^+K^-)$



☆ A good particle identification is required in the decay reconstruction

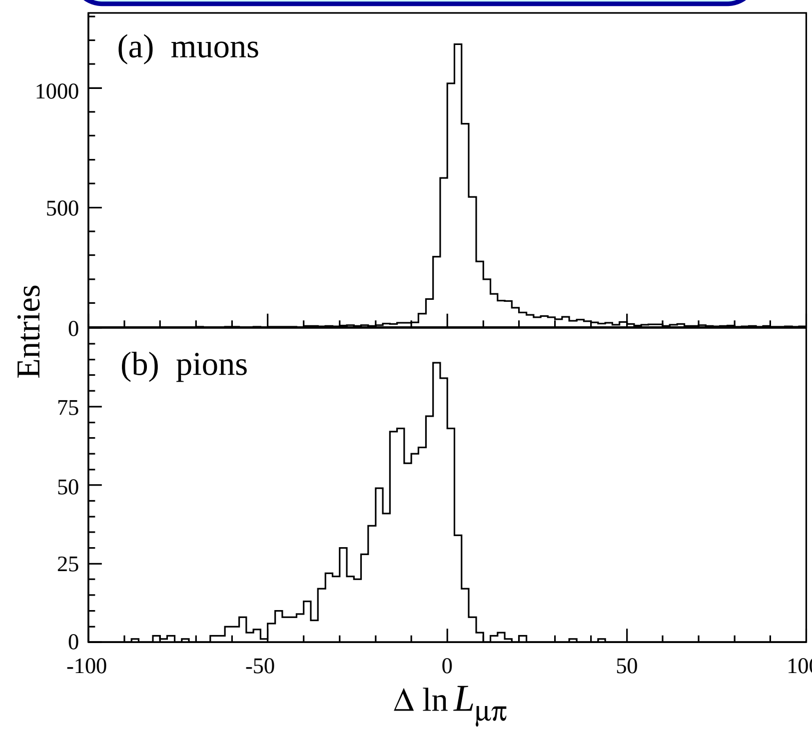
– difference in log-likelihood between the particles hypotheses

$$\Delta \ln \mathcal{L}_{K\pi} = \ln \mathcal{L}_K - \ln \mathcal{L}_\pi$$



$\Delta \ln \mathcal{L}_{K\pi}$ from the RICH system for (a) kaons and (b) pions.

$$\Delta \ln \mathcal{L}_{\mu\pi} = \ln \mathcal{L}_\mu - \ln \mathcal{L}_\pi$$

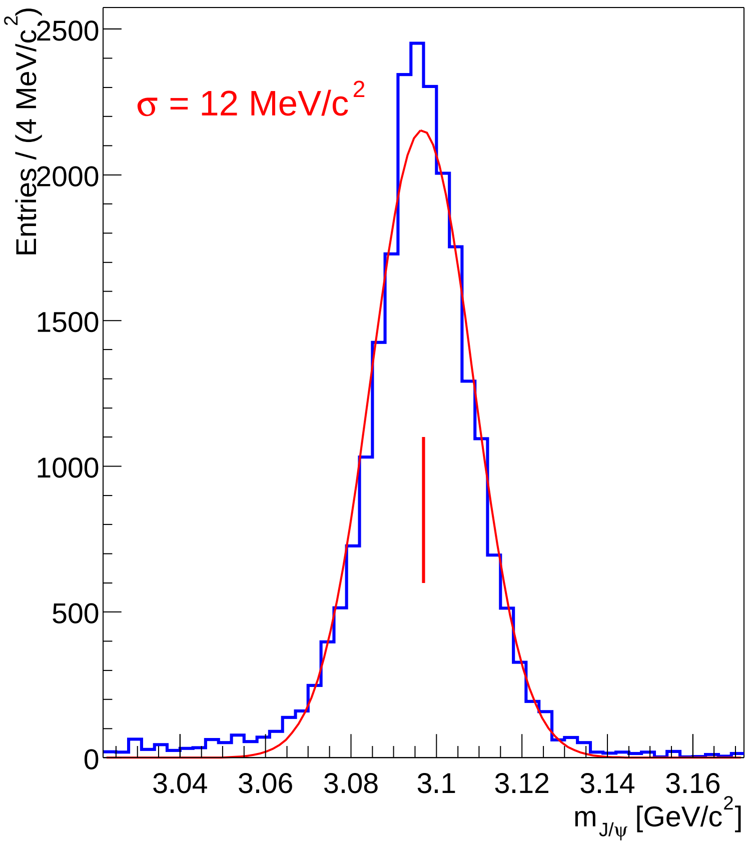


$\Delta \ln \mathcal{L}_{\mu\pi}$ from the Muon Detector system for (a) muons and (b) pions.

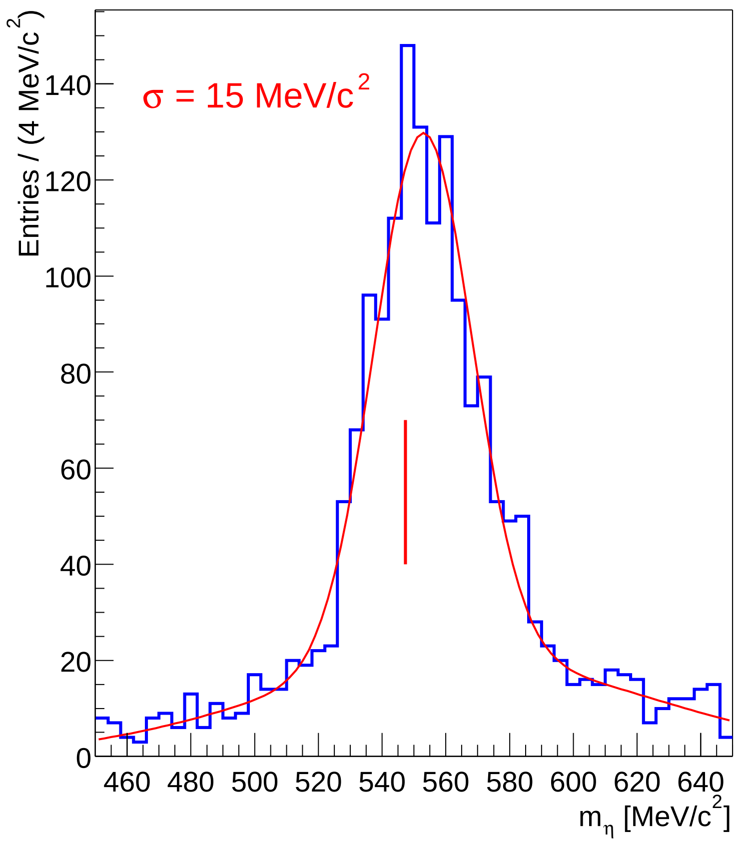
Selection - Resonances Reconstruction

☆ Combination of final decay products (μ^-, μ^+, γ, K^+, ...) to a common vertex to form the resonances of interest (J/ψ, η, η_c, ϕ, ...)

Reconstructed J/ψ



Reconstructed η

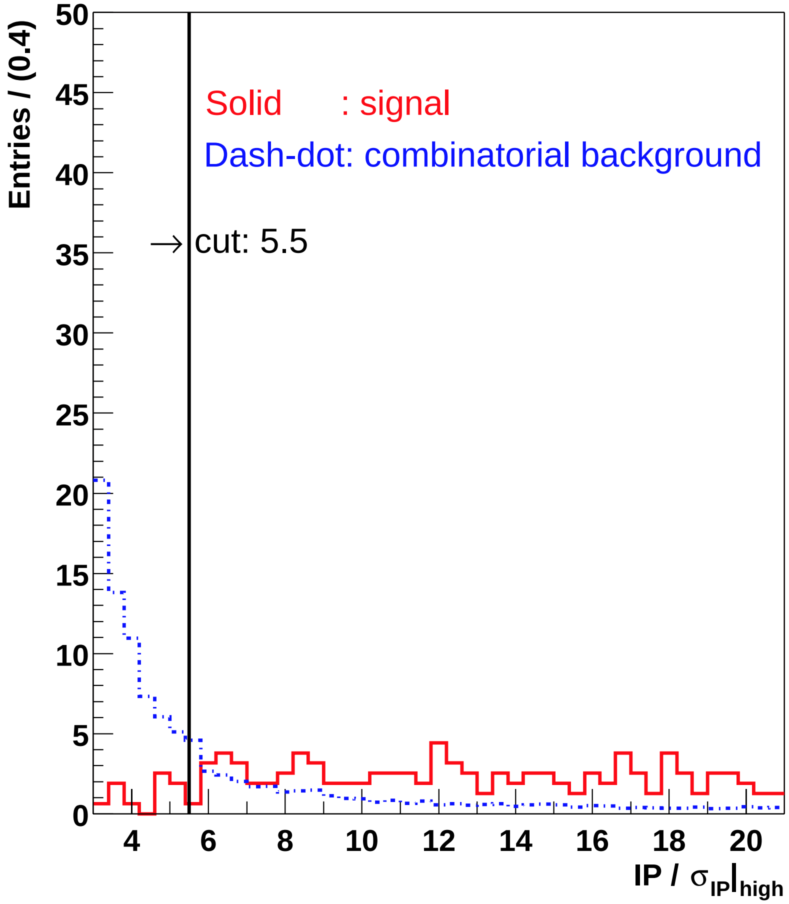


☆ The last step of the selection consists in combining the resonances to form the B_s^0 particles

First example of cut, after a loose selection

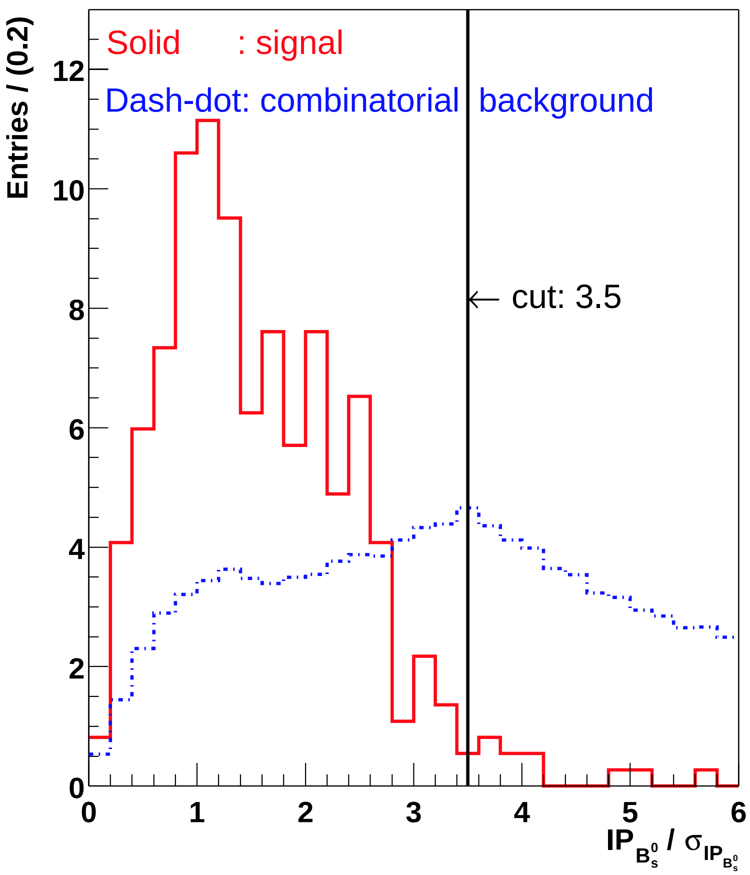
$B_s^0 \to \eta_c\ (\pi^+\pi^-K^+K^-)\ \phi\ (K^+K^-)$

☆ η_c daughters largest $IP/\sigma_{IP} > 5.5$



$B_s^0 \to \eta_c\ (\pi^+\pi^-K^+K^-)\ \phi\ (K^+K^-)$

☆ $B_s^0\ IP/\sigma_{IP} < 3.5$



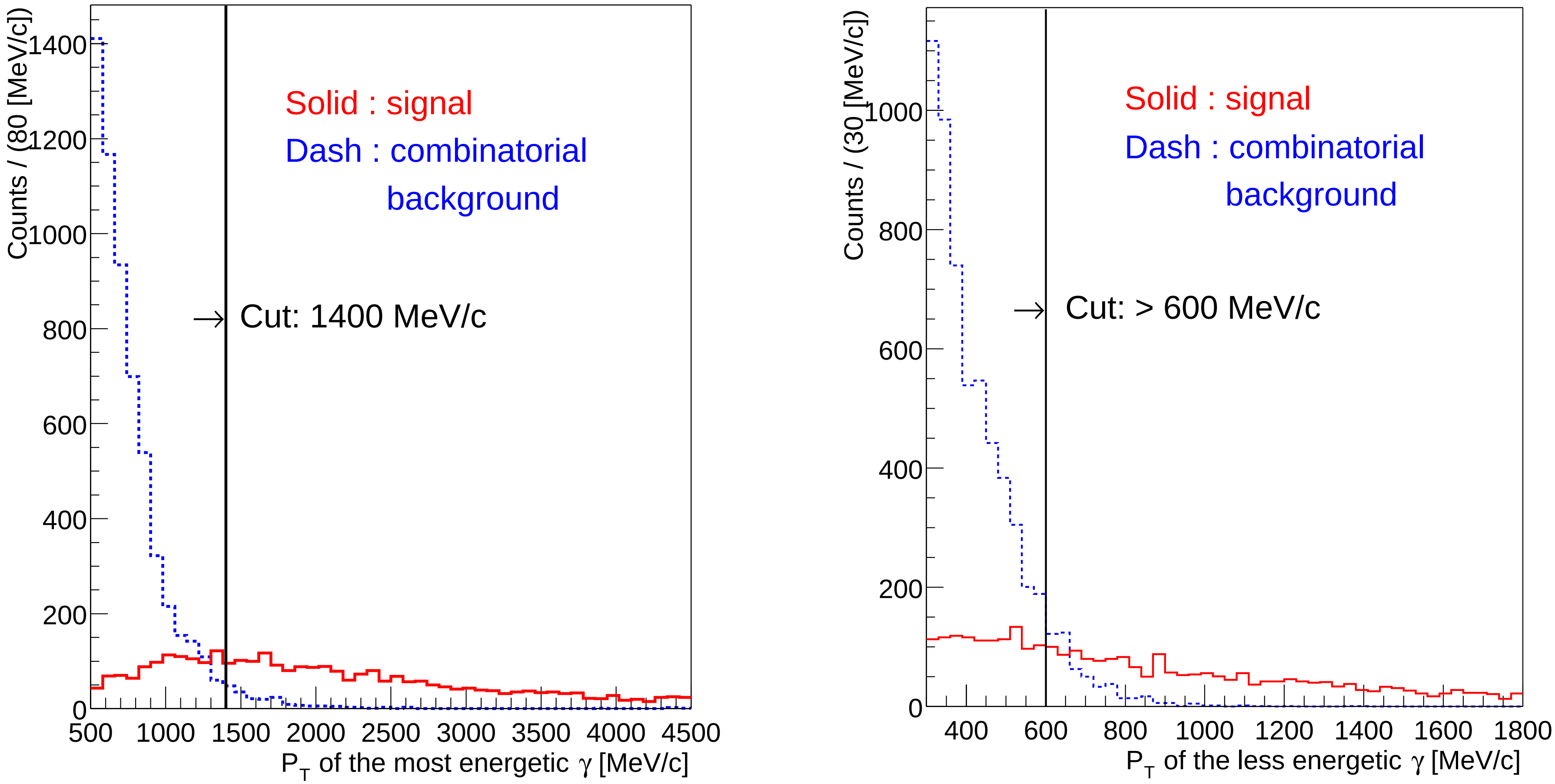
Second example of cut, after a loose selection

$B_s^0 \rightarrow J/\psi\ \eta$

☆ P_T^{min} most energetic $\gamma > 1400[MeV/c]$

$B_s^0 \rightarrow J/\psi\ \eta$

☆ P_T^{min} the less energetic $\gamma >$ 600 $[MeV/c]$

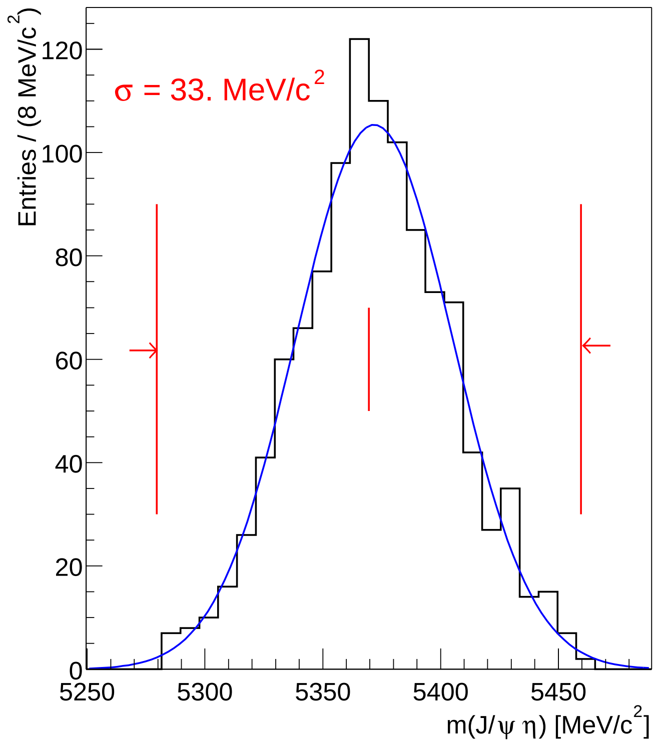


Selection Cuts

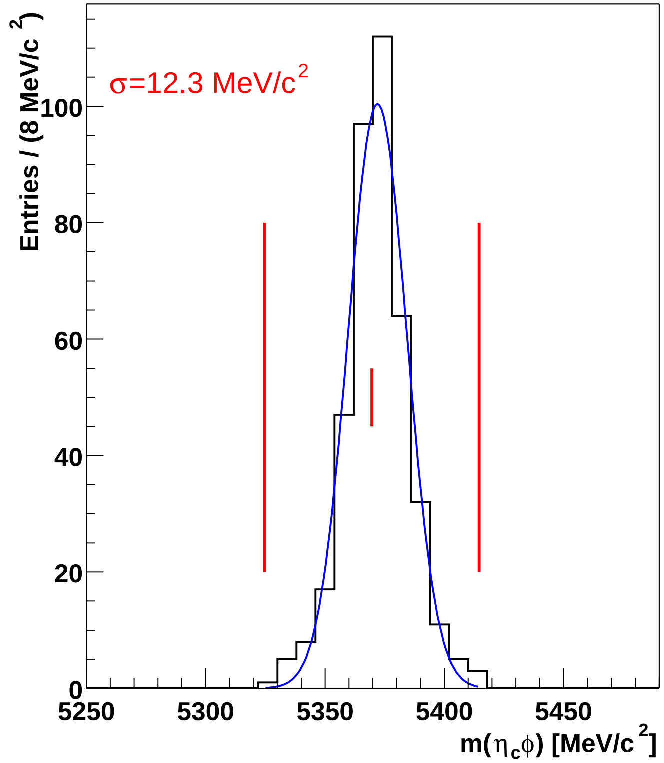
Cuts		$J/\psi\ \eta$	$\eta_c(\pi\pi KK \diagup 4\pi)\ \phi$	$J/\psi\ \phi$
$\Delta \ln L_{\mu\pi}(\mu^+,\mu^-)$	$>$	- 8.0		- 20.0
$\Delta \ln L_{K\pi}(K^+,K^-) \diagdown \Delta \ln L_{\pi K}(\pi^+,\pi^-)$	$>$		-2.0 $\diagdown$ -2.0	0.0 $\diagdown$ -
$\chi^2(J/\psi)$	$<$	10		9
$M(J/\psi)\ [MeV/c^2]$	$\pm$	50		50
$\chi^2(\phi)$	$<$		14	40
$P_T(\phi)\ [MeV/c]$	$>$		1700	1200
$M(\phi)\ [MeV/c^2]$	$\pm$		14	20
$P_T^{min}(\gamma_{low},\gamma_{high})\ [MeV/c]$	$>$	600, 1400		
$Abs\ (p_\perp^{x,y}(\mu^+,\mu^-,\gamma,\gamma))\ [MeV/c]$	$<$	800		
$M(\eta)\ [MeV/c^2]$	$\pm$	30		
$\chi^2(\eta_c)$	$<$		11.5	
$P_T(\eta_c)\ [MeV/c]$	$>$		2450	
η_c daughters min IP/σ_{IP}	$>$		1.9 $\diagup$ 3.1	
η_c daughters largest IP/σ_{IP}	$>$		5.5 $\diagup$ 6.0	
$M(\eta_c)\ [MeV/c^2]$	$\pm$		60	
$\chi^2(B_s^0)$	$<$		16	20
$IP/\sigma_{IP}(B_s^0)$	$<$	3	3.5	
$\alpha(\vec{p}_{B_s^0},\vec{L}_{vertices})\ [rad]$	$<$	0.025		
z_d/σ_{z_d}	$>$	7.5	2.5	
τ/σ_τ	$<$			5
$M(B_s^0)\ [MeV/c^2]$	$\pm$	90	45	50

Mass Resolutions ($m_{B_s^0} = 5369.6\ MeV/c^2$)

Mass spectrum of the $B_s^0 \to J/\psi\ \eta$



Mass spectrum of the $B_s^0 \to \eta_c\ \phi$

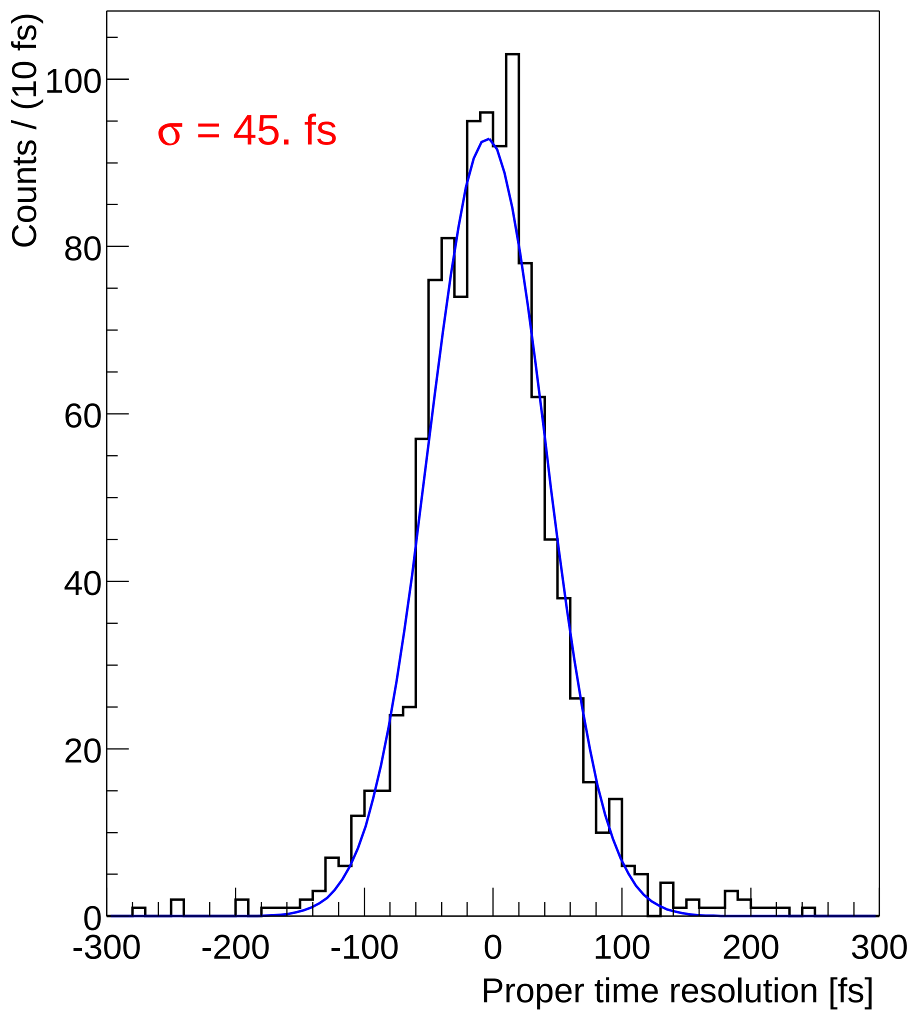


$B_s^0 \to J/\psi\ \phi$ mass resolution

$\sigma = 15\ MeV/c^2$

- ☆ Channels with charged tracks: good B_s^0 mass resolution
- ☆ Channel with γ's: larger mass spectrum width

$B_s^0 \to J/\psi\ \eta$ Proper Time



Because of the fast B_s^0 oscillations, a very good proper time resolution needs to be achieved.

The proper time, τ, of the B_s^0 is given by:

$$\tau = \frac{t}{\gamma} = \frac{\vec{p}_{B_s^0} \cdot \vec{L}_{vert} \cdot m_{B_s^0}}{||\vec{p}_{B_s^0}||^2}$$

- ☆ t the B_s^0 lifetime in the lab,
- ☆ $\vec{L}_{vert}$ the B_s^0 decay length,
- ☆ $m_{B_s^0}$ the mass of the B_s^0 meson
- ☆ and $\vec{p}_{B_s^0}$ its momentum.

The values obtained for this parameter are:

- ☆ $B_s^0 \to J/\psi\ \eta$: 45. [fs]
- ☆ $B_s^0 \to \eta_c\ \phi$: 33. [fs]
- ☆ $B_s^0 \to J/\psi\ \phi$: 38. [fs]

B/S Ratios Estimation

- The most dangerous source of background are $b\bar{b}$ events, i.e. events where at least a b-hadron is emitted forward in the acceptance region.

- For this study:
  - $\mathcal{O}$(50k) signal events were used to tune the selection for each channel,
  - while 10M background events have been analysed.

- The B/S ratio depends on:
  - the $\mathcal{BR}\left(\bar{b} \to B_s^0\right) = 0.2$ - probability for the $\bar{b}$ to decay into a B_s^0,
  - the $\mathcal{BR}_{vis}^{channel}$ - probability for the B_s^0 to decay into one of the specific channels
  - and the number of selected $b\bar{b}$ events.

- B/S 90% unified CL interval

Decays	$\mathcal{BR}_{vis}^{channel}$ (in 10^{-6})	$b\bar{b}$ selected	B/S
$B_s^0 \to J/\psi\ \eta$	7.6	0	[0.00, 1.56]
$B_s^0 \to \eta_c\ \phi$	4.1	0	[0.00, 0.82]
$B_s^0 \to J/\psi\ \phi$	31	7	[0.08, 0.27]

Annual Signal Yield (No Tagging, No HLT, PDG 2003)

Average luminosoty (1 year)	$\mathcal{L}^{\text{int}}_{\text{year}}$	$=$	$2 \times 10^{39}\ cm^{-2}$
$b\bar{b}$ production cross section	$\sigma_{b\bar{b}}$	$=$	$500\ \mu b$
$\#\ b\bar{b}$ pairs	$\mathcal{L}^{\text{int}}_{\text{year}} \cdot \sigma_{b\bar{b}}$	$=$	10^{12}
$\#\ B^0_s$ mesons	$(\#b\bar{b}) \times 2 \cdot \mathcal{BR}(\bar{b} \to B^0_s)$	$=$	2×10^{11}
$\#\ B^0_s \to J/\psi\ (\mu^+\mu^-)\ \eta\ (\gamma\gamma)$	$(\#B^0_s$ mesons$) \times \mathcal{BR}_{\text{vis}}$	$=$	$1.5\ M$
$\#\ B^0_s \to \eta_c\ (2\pi 2K, 4\pi)\ \phi\ (K^+K^-)$	$(\#B^0_s$ mesons$) \times \mathcal{BR}_{\text{vis}}$	$=$	$4.1\ M$
$\#\ B^0_s \to J/\psi\ (\mu^+\mu^-)\ \phi\ (K^+K^-)$	$(\#B^0_s$ mesons$) \times \mathcal{BR}_{\text{vis}}$	$=$	$6.2\ M$

The annual yield is calculated as:
$(\#B^0_s \to$ "final state"$) \times$ "Total efficiency"

Efficiencies (in %)	$B^0_s \to J/\psi\ \eta$	$B^0_s \to \eta_c\ \phi$	$B^0_s \to J/\psi\ \phi$
Geometrical acceptance	10.	3.	8.
Reconstruction	70.	70.	83.
Offline selection	11.	16.	42.
Trigger	65.	27.	64.
Total efficiency	0.50	0.07	1.7
Annual yield [k]	$\sim$ 7	$\sim$ 3	$\sim$ 100

Conclusion

☆ Mass resolutions

– Good for decays with charged and neutral final decay products (33 MeV/c^2)

– Very good for channels with only charged final decay products (12 - 15 MeV/c^2)

☆ Proper time resolutions

– Excellent resolutions (33 - 45 fs) needed for the CP violation study

$\Rightarrow$ As $\Delta M_s = \mathcal{O}(20)\ ps^{-1}$, the resolution are precise enough to resolve the fast $B_s^0 - \overline{B_s^0}$ oscillations.

☆ B/S estimations

– Good rejection of the background

These selections will allow to extract the mixing parameters:

☆ Sensitivity to ϕ_s after five years of LHCb data taking

– $\sigma(\phi_s) \sim$ 0.025, with $\phi_s \sim \mathcal{O}(-0.04)$ in the SM (L. Fernandez talk)

☆ If ϕ_s (and/or ΔM_s) large compare to the SM expectations $\rightarrow$ New physics (SUSY, ...)

BACKUP SLIDES

Bkp: Trigger System

☆ Aim of the L0 trigger stage:

- Rate reduction from 40 MHz (detector output) to 1MHz (L1 input)
- The L0 is implemented in hardware and makes use of the muon stations, ECAL and HCAL detectors using high-p_T of leptons, photons, and hadrons combined with a pile-up veto

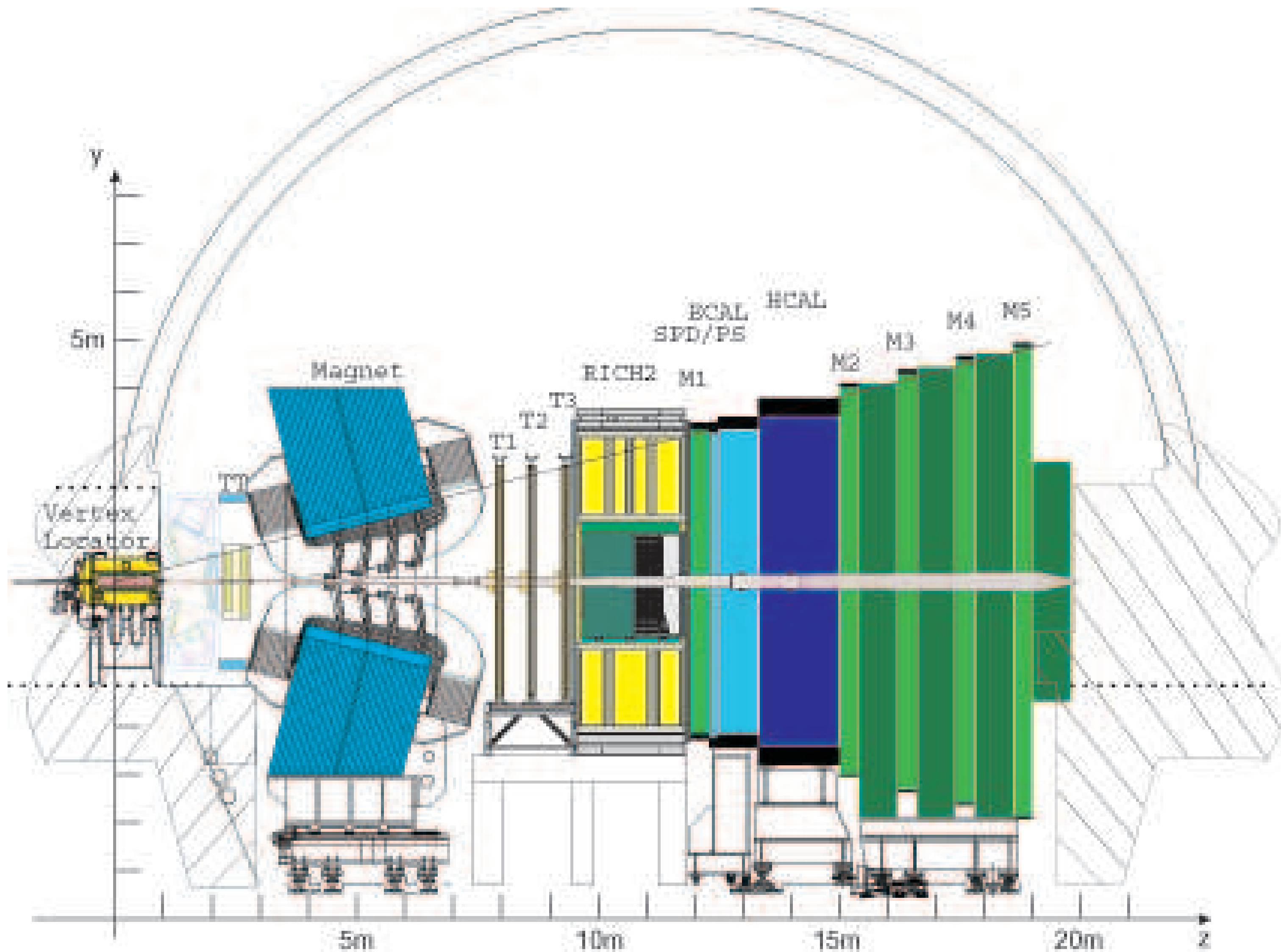
☆ Aim of the L1 trigger stage:

- rate reduction from 1 MHz (L0 output) to 40 kHz (HLT input) such that 4% of the minimum bias events are retained
- The L1 is implemented in software and makes use of the VELO (VErtex LOcator), TT (Trigger Tracker) detectors, and the L0 information
- Requires two tracks with high transverse momentum (p_{T_1} and p_{T_2}) and large impact parameter for the generic algorithm
- Bonus: The efficiency for some benchmark specific channels such as $B_d^0 \to \mu^+\mu^- K^*$, $B_d^0 \to K^*\gamma$, $B_d^0 \to \pi^+\pi^-$, $B_d^0 \to J/\Psi K_s^0$ is enhanced, based on the L0 information

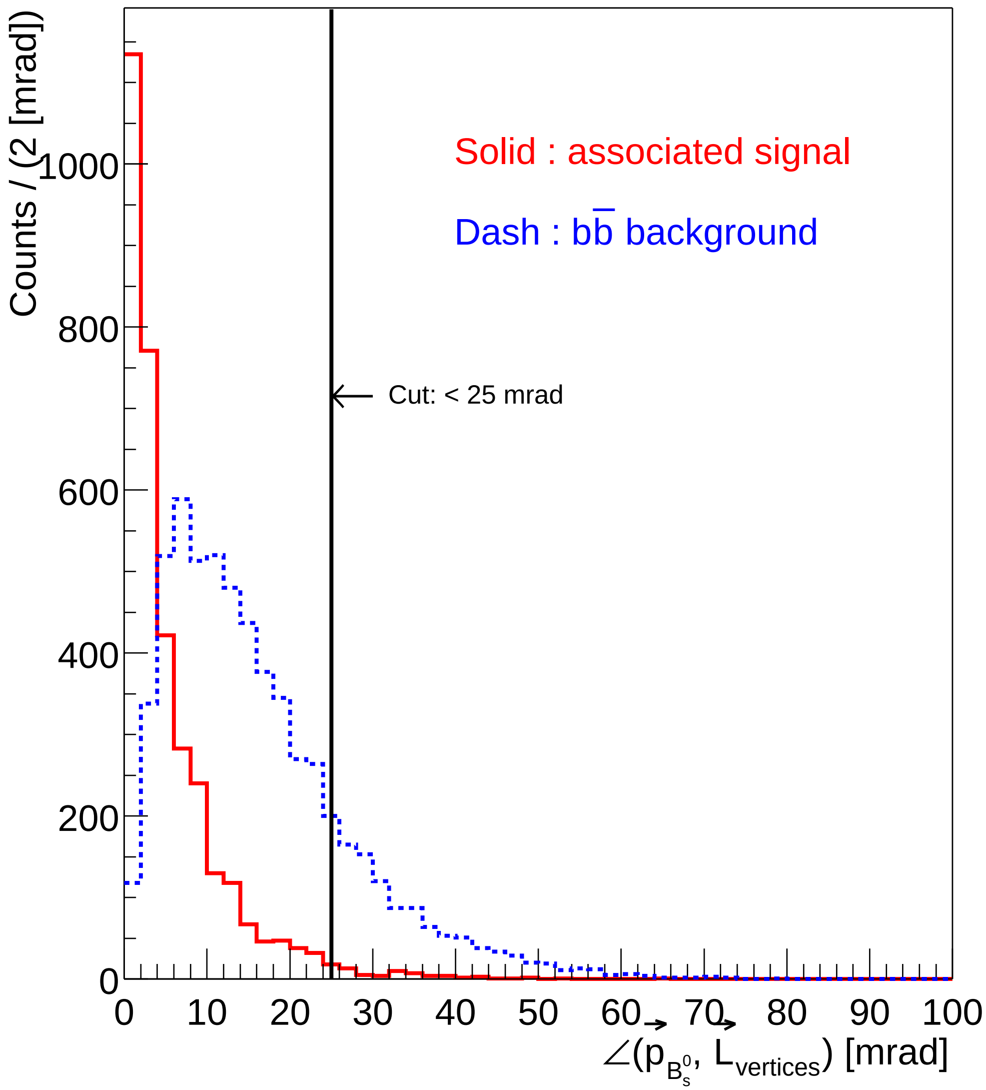
☆ Aim of the HLT trigger stage:

- Final software decision on whether or not to write the event to storage ($\sim$ 200 Hz foreseen)

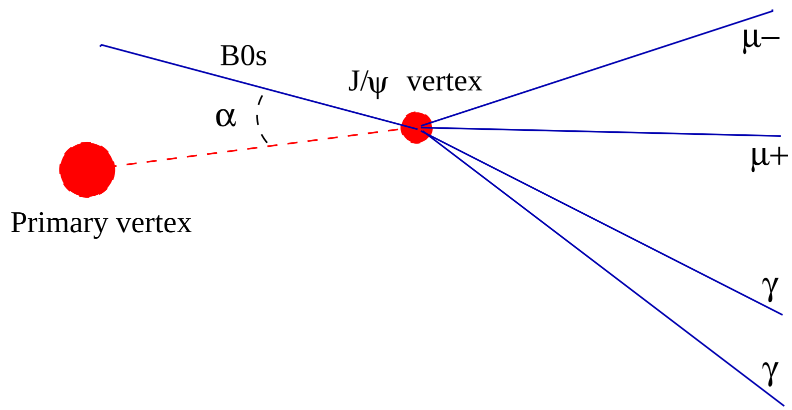
Bkp: LHCb detector



Bkp: $B_s^0 \to J/\psi\ \eta$ Cut: Angle of B_s^0 Directions



- ☆ Cut made on the angle between
  - the direction given by the B_s^0 decay vertex and the primary vertex and
  - the momentum of the reconstructed B_s^0

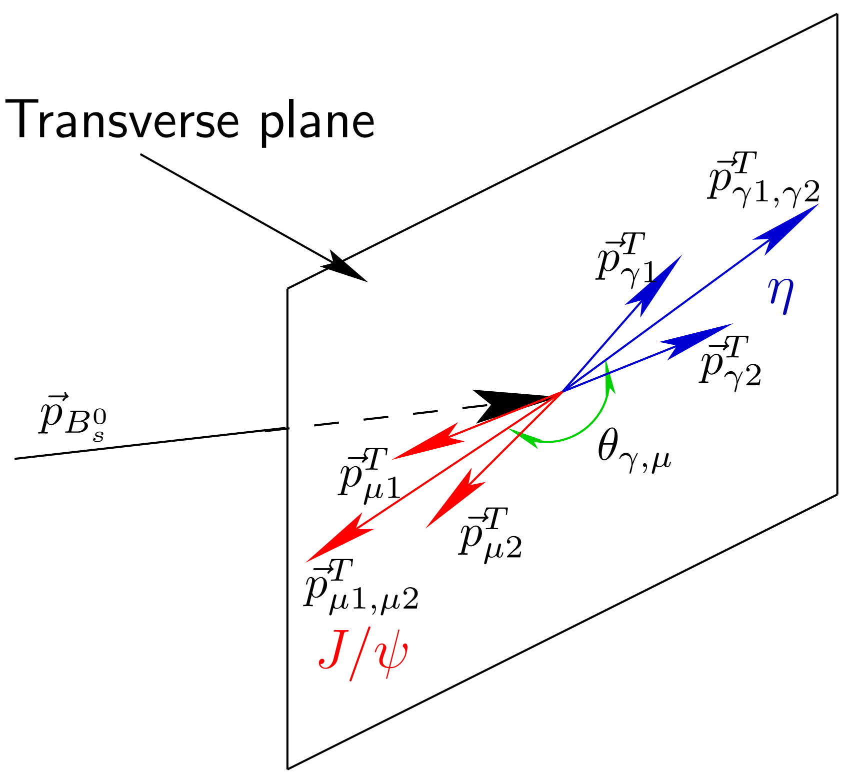


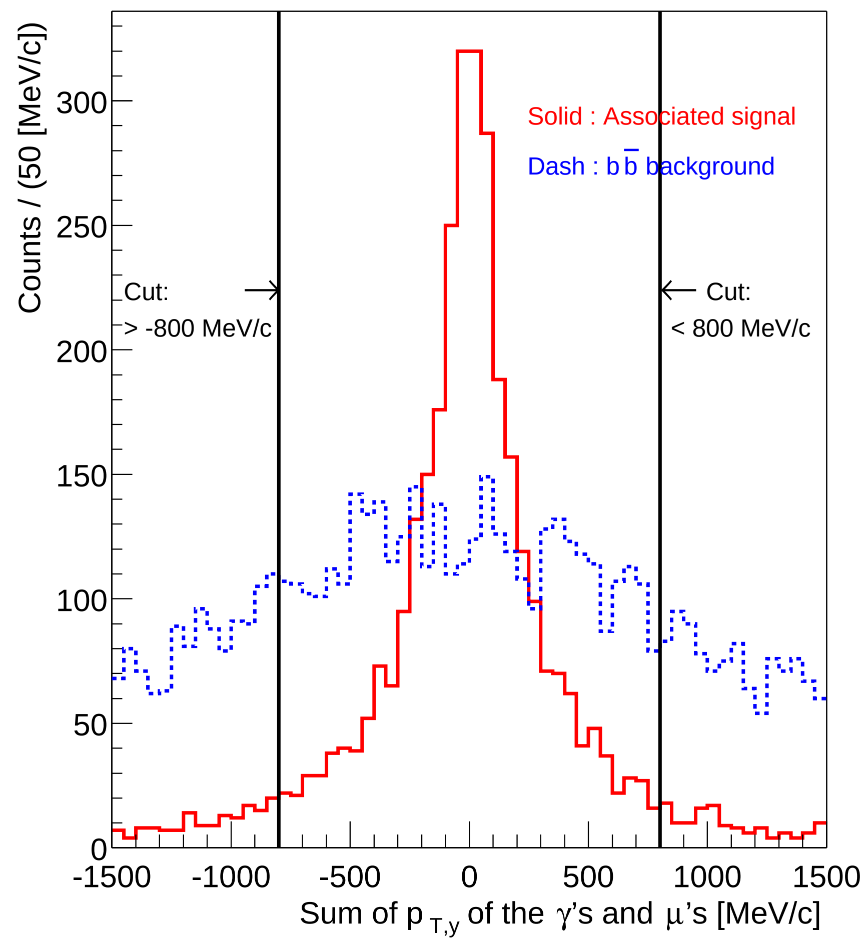
- ☆ selection cut
  - angle < 25 [mrad]

Bkp: Cut in the Transverse Plane for the $B_s^0 \to J/\psi\ \eta$

☆ In the transverse plane, wrt the B_s^0 direction, the J/ψ and the η are emitted back to back

– The cut applied is: $Abs\left(p_{T,i}^{\gamma_1} + p_{T,i}^{\gamma_2} + p_{T,i}^{\mu^+} + p_{T,i}^{\mu^-}\right) < 800 MeV/c,\ i = x, y$





Bkp: Presentation of this Talk's Characters

☆ B_s^0 mesons
- composition: $B_s^0 \rightarrow s\ \overline{b}$
- composition: $\overline{B_s^0} \rightarrow \overline{s}\ b$
- mass : $5369.6\ MeV/c^2$
- width : $4.4 \times 10^{-10}\ MeV/c^2$
- lifetime : $1.461 \times 10^{-12}\ s$

☆ J/ψ mesons
- composition: $c\ \overline{c}$
- mass : $3096.87\ MeV/c^2$
- width : $87\ keV/c^2$
- lifetime : $7.57 \times 10^{-21}\ s$

☆ η mesons
- composition: superposition of the η_1 and η_8
  - ➠ $\eta_1 \rightarrow \frac{1}{\sqrt{3}}(u\ \overline{u} + d\ \overline{d} + s\ \overline{s})$
  - ➠ $\eta_8 \rightarrow \frac{1}{\sqrt{6}}(u\ \overline{u} + d\ \overline{d} - 2s\ \overline{s})$
- mass : $547.3\ MeV/c^2$
- width : $1.18\ keV/c^2$
- lifetime : $5.58 \times 10^{-19}\ s$

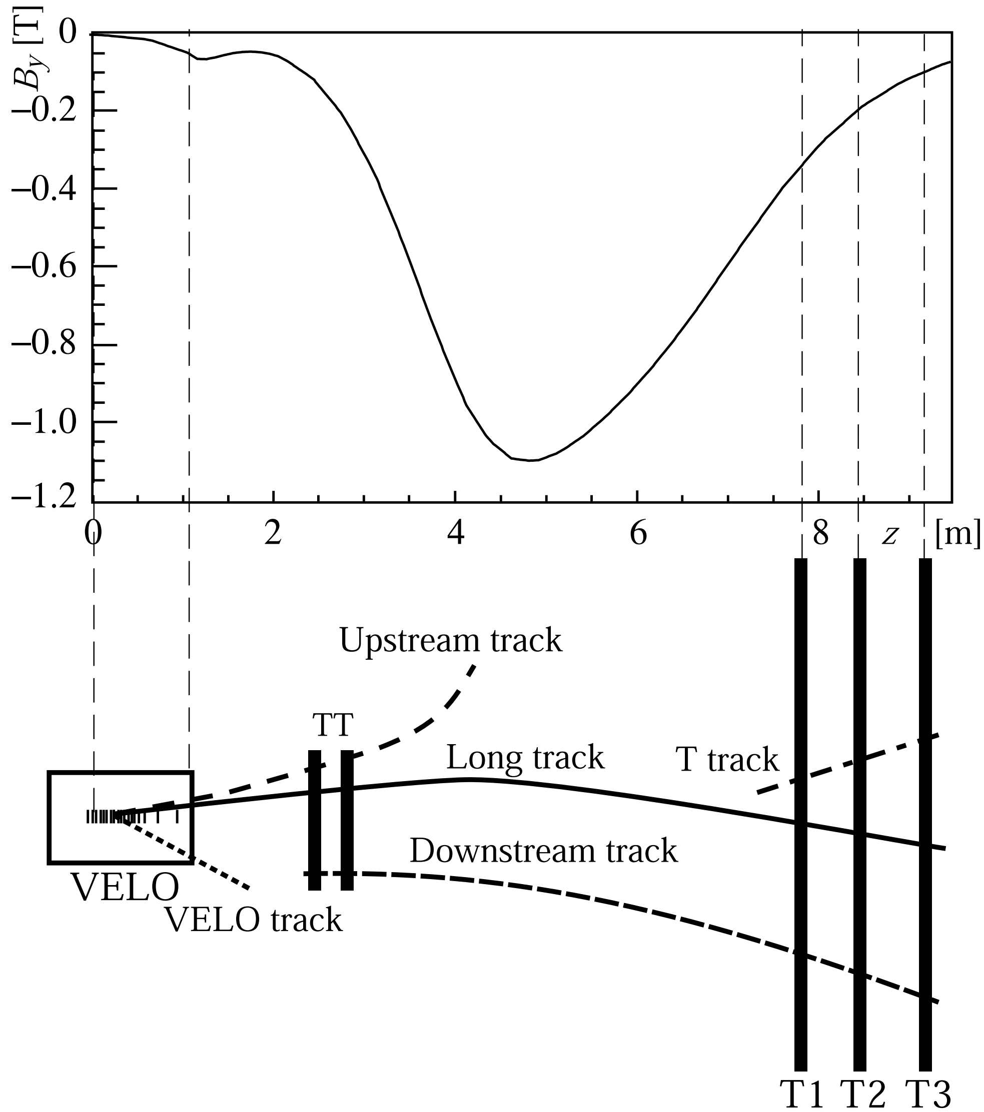
☆ η_c mesons
- composition: $c\ \overline{c}$
- mass : $2979.7\ MeV/c^2$
- width : $16.0\ MeV/c^2$
- lifetime : $4. \times 10^{-23}\ s$

☆ ϕ mesons
- composition: mainly $s\ \overline{s}$
- mass : $1019.46\ MeV/c^2$
- width : $4.26\ MeV/c^2$
- lifetime : $1.5 \times 10^{-22}\ s$

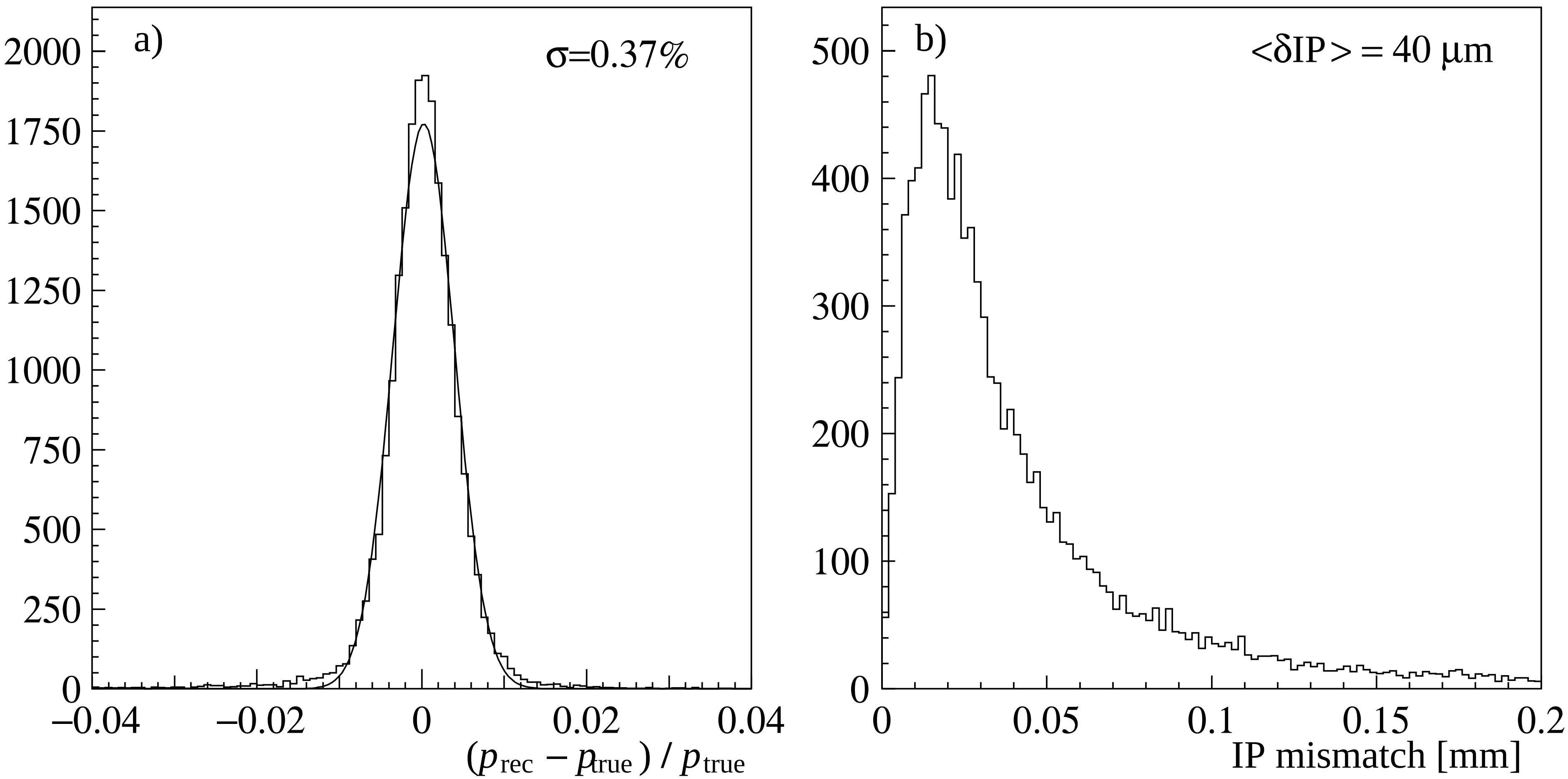
☆ π mesons
- composition: $\pi^+ \rightarrow u\ \overline{d}$, $\pi^- \rightarrow d\ \overline{u}$
- mass : $139.57\ MeV/c^2$
- lifetime : $2.6 \times 10^{-8}\ s$

☆ K mesons
- composition: $K^+ \rightarrow u\ \overline{s}$, $K^- \rightarrow s\ \overline{u}$
- mass : $493.68\ MeV/c^2$
- lifetime : $1.24 \times 10^{-8}\ s$

A shematic illustration of the various track types: long, upstream, downstream, VELO, and T tracks. For reference, the main B-field components (B_y) is plotted above as a function of the z coordinate.



(a) Momentum resolution with a single Gaussian fit, and (b) impact parameter precision, for B-decay tracks (Long tracks).



Bkp: Visible Branching Fractions (PDG 2003)

$B_s^0 \to J/\psi\ \eta$

Taking $\langle\ \eta_1\ | = \frac{1}{\sqrt{3}} \langle\ u\overline{u} + d\overline{d} + s\overline{s}\ |$ instead of $\langle\ \eta_8\ | = \frac{1}{\sqrt{6}} \langle\ u\overline{u} + d\overline{d} - 2s\overline{s}\ |$ or superposition

$$\mathcal{BR}\ (\ B_s^0 \to J/\psi\ \eta\ ) \sim \frac{1}{3} \left|\ \langle\ J/\psi\ s\ \overline{s}\ |\ \mathcal{H}_{eff}\ |\ B_s^0\ \rangle\ \right|^2$$

$$\mathcal{BR}\ (\ B_d^0 \to J/\psi\ K_s^0\ ) \sim \left|\ \langle\ J/\psi\ d\ \overline{s}\ |\ \mathcal{H}_{eff}\ |\ B_d^0\ \rangle\ \right|^2$$

$$\Rightarrow \quad \mathcal{BR}\ (B_s^0 \to J/\psi\ \eta) = (2.83 \pm 0.17) \times 10^{-4}$$

$$\Rightarrow \quad \mathcal{BR}_{vis}\ (B_s^0 \to J/\psi\ (\mu^+\mu^-)\ \eta\ (\gamma\gamma)) = (7.6 \pm 0.5) \times 10^{-6}$$

$B_s^0 \to \eta_c\ \phi$

$$\frac{\mathcal{BR}\ (\ B_s^0 \to \eta_c\ \phi\ )}{\mathcal{BR}\ (\ B_s^0 \to J/\psi\ \phi\ )} = \frac{\mathcal{BR}\ (\ B_d^0 \to \eta_c\ K^0\ )}{\mathcal{BR}\ (\ B_d^0 \to J/\psi\ K^0\ )}$$

$$\Rightarrow \quad \mathcal{BR}\ (B_s^0 \to J/\psi\ \eta) = (1.31 \pm 0.64) \times 10^{-3}$$

$$\Rightarrow \quad \mathcal{BR}_{vis}\ (B_s^0 \to \eta_c\ (2\pi 2K, 4\pi)\ \phi\ (K^+K^-)) = (21 \pm 11) \times 10^{-6}$$

$B_s^0 \to J/\psi\ \phi$

$$\mathcal{BR}\ (B_s^0 \to J/\psi\ \phi) = (9.3 \pm 3.3) \times 10^{-4}$$

$$\Rightarrow \quad \mathcal{BR}_{vis}\ (B_s^0 \to J/\psi\ (\mu^+\mu^-)\ \phi\ (K^+K^-)) = (31 \pm 11) \times 10^{-6}$$