Outline

- Working group goals
- B2hh selection: current status
- CP asymmetry fit: status and future plans
- Working group organization

Goal: do the full B → hh exercise!

- B→hh channels have been identified by the PPG amongst the key measurements for the initial phase of LHCb
- The idea is that the physics book should be a path toward realistic analyses, that means
  - "study how these measurements will be performed by giving not only the expected statistical sensitivity, but also the list of systematics to consider and the actual procedures to tackle them; it also means going in as much details as possible/useful in the various calibrations and checks which will be needed, including control samples, etc …"
- B→hh can be in fact an effective proof-of-principle of a realistic analysis, in particular crucial to understand and demonstrate the LHCb PID performance with hadrons
- B→hh can be used to practice the CP fit tools

Stable since (2004)

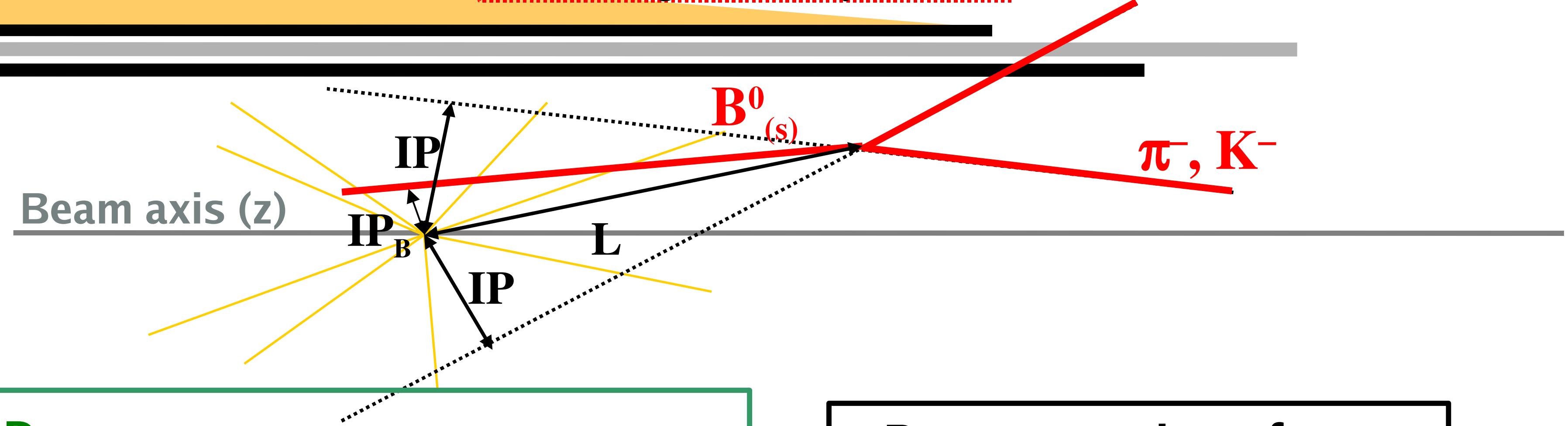
B selection strategy

LHCb Note 2003-123

- Designed to maximize signal efficiency and minimize backgrounds
- Two major sources of backgrounds taken into account
- **Combinatorial background from bb inclusive events**
  - Due to the huge minimum bias MC statistics required for a detailed study of combinatorics, we make the plausible assumption that most of the combinatorial background will come from beauty events (presence of high p_T and large IP tracks from B)
  - For the moment we prefer not to adopt dangerous tricks (e.g. cuts at generator level or fast MC simulations)
- **Specific background from B decays with same two-track topology**
  - e.g. $B_d \rightarrow K^+\pi^-$, $B_s \rightarrow K^+K^-$, $B_s \rightarrow \pi^+K^-$ as backgrounds for $B_d \rightarrow \pi^+\pi^-$
- Selection cuts are simultaneously optimized in order to maximize S/sqrt(S+B)
- After event selection, tagging and trigger algorithms are tuned on selected events

Selection cuts

See V.Vagnoni talk at CP meeting 14th July 2005



- Reconstruction of long tracks
  - a B flights 1 cm on average

- **Particle ID**
  - Each charged track identified as a Pion or Kaon using the Particle ID detectors (RICHs in particular)

- **Tracks selection cuts**
  - DLL cut (PID)
  - $\mathrm{Max}[p_T(h^+), p_T(h^-)]$
  - $\mathrm{Min}[p_T(h^+), p_T(h^-)]$
  - $\mathrm{Max}[IP/\sigma_{IP}(h^+), IP/\sigma_{IP}(h^-)]$
  - $\mathrm{Min}[IP/\sigma_{IP}(h^+), IP/\sigma_{IP}(h^-)]$
  - χ^2 of common vertex

- **B Selection cuts**
  - p_T
  - IP/σ_{IP}
  - L/σ_L
  - Invariant mass

B selection (2005)

Momentum cuts have been replaced by DLL cuts:

- Bd2PiPi: Combined pID (excl.) but vetoing pion hypotesis with DLL(K-pi)>-2 for the Kaon hypotesis (default is DLL(K-pi) > 2)
- Bd2KPi: Combined pID (excl.)
- Bs2KK: Combined pID (excl.)
- Bs2PiK: Combined pID (excl.) selection but pions must have DLL(pi-K)> 2

	$B^0 \to h^+h^-$		$B^0_s \to h^+h^-$	
Channel	$\pi\pi$	$K\pi$	KK	πK
Selection cuts				
p_{min} [GeV/c]	2.50	2.75	2.75	2.75
p_{max} [GeV/c]	100	200	125	100
$(p_T)_{each}$ [GeV/c]	1.2	1.2	0.8	1.4
$(p_T)_{one}$ [GeV/c]	3.2	3.0	2.6	3.4
$(IP/\sigma_{IP})_{each}$	6	6	5	7
$(IP/\sigma_{IP})_{one}$	12	11	9	14
χ^2_{max}	4	5	5	4
$(p_T^B)_{min}$ [GeV/c]	1.6	1.4	1.0	1.6
$(IP_B/\sigma_{IP_B})_{max}$	2.25	2.50	2.75	2.25
$(L/\sigma_L)_{min}$	19	17	14	20
δm [MeV/c^2]	50	50	50	40
B/S ratios				
two-body	0.13	0.04	0.04	0.41
combinatorial ($b\bar{b}$)	< 0.72	< 0.22	< 0.51	< 1.28

S/B (used for Feb 04 studies)

Event type	Assumed BR ($\times 10^{-6}$)	N_B/N_S	Untagged annual yield	εD^2
$B_d \to \pi^+\pi^-$	4.8	0.42	26000	4%
$B_d \to K^+\pi^-$	18.5	0.16	135000	4%
$B_s \to K^+K^-$	18.5	0.31	37000	6%
$B_s \to \pi^+K^-$	4.8	0.67	5300	6%

- Annual yields after L0+L1 triggers and offline selection (assumed $\sigma_{bb} = 0.5$ mb)
- N_B/N_S here quoted only from combinatorial bb background

Presented at Joint meeting in Feb 04

Analysis strategy

- What do we want to do with selected Bs?
  - Build the asymmetries
  - Extract time and mass distributions for signal and background candidates using PID information (to be changed)
  - Fit simultaneously mass and time distributions with an extended unbinned maximum likelihood fit
  - Extract gamma from Asymmetry with a Bayesian approach

CP asymmetries

$$A_{CP}(t) = \frac{\Gamma(\overline{B}^0_{(s)}(t) \to f) - \Gamma(B^0_{(s)}(t) \to f)}{\Gamma(\overline{B}^0_{(s)}(t) \to f) + \Gamma(B^0_{(s)}(t) \to f)} = \frac{A_{CP}^{dir}\cos\Delta m \cdot t + A_{CP}^{mix}\sin\Delta m \cdot t}{\cosh\frac{\Delta\Gamma}{2}\cdot t - A_{CP}^{\Delta\Gamma}\sinh\frac{\Delta\Gamma}{2}\cdot t}$$

$$A_{CP}^{dir}(B_d^0 \to \pi^+\pi^-) = f_1(d,\vartheta,\gamma)$$

$$A_{CP}^{mix}(B_d^0 \to \pi^+\pi^-) = f_2(d,\vartheta,\gamma,\phi_d)$$

$$A_{CP}^{dir}(B_s^0 \to K^+K^-) = f_3(d',\vartheta',\gamma)$$

$$A_{CP}^{mix}(B_s^0 \to K^+K^-) = f_4(d',\vartheta',\gamma,\phi_s)$$

$\phi_d = 2\beta$ B_d-$\overline{B}_d$ mixing phase (measured with $B_d \to J/\psi K_s$)

$\phi_s = -2\lambda^2\eta$ B_s-$\overline{B}_s$ mixing phase (can be probed with $B_s \to J/\psi\phi$)

4 equations and 5 unknowns: d, ϑ, d', ϑ' e γ

One needs other inputs to solve for γ

Using U spin symmetry d = d' and θ=θ'. We end up with 3 unknowns and 4 equations

R. Fleischer,
Phys. Lett. B459 (1999)

(old-current) Fit strategy

- $B_d \to K^+ \pi^-$ is a flavour specific decay, hence it can be used to extract the wrong tag probability from data
- $B_d \to \pi^+ \pi^-$ ($B_s \to K^+ K^-$) and $B_d \to K^+ \pi^-$ ($B_s \to \pi^+ K^-$) have the same two-track topology (the full simulation shows the same tagging power)

- In order to extract CP asymmetries and mistag fraction simultaneously from data a combined extended maximum likelihood fit of $B_d \to \pi^+ \pi^-$ and $B_d \to K^+ \pi^-$ ($B_s \to K^+ K^-$ and $B_s \to \pi^+ K^-$) event samples

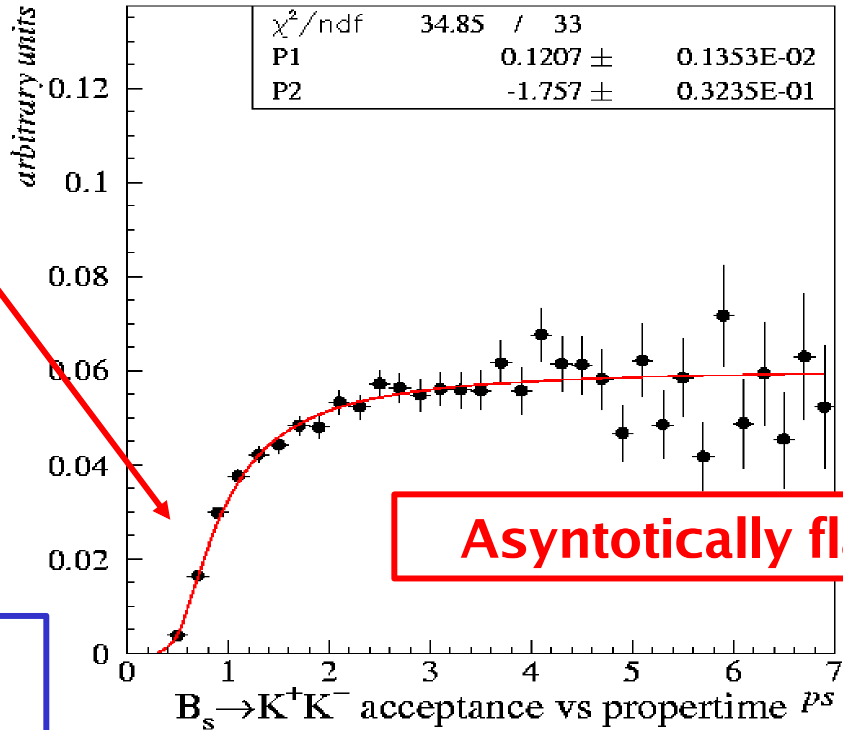
(old-current) Likelihood fit

The likelihood fit is performed with **17 free parameters**:

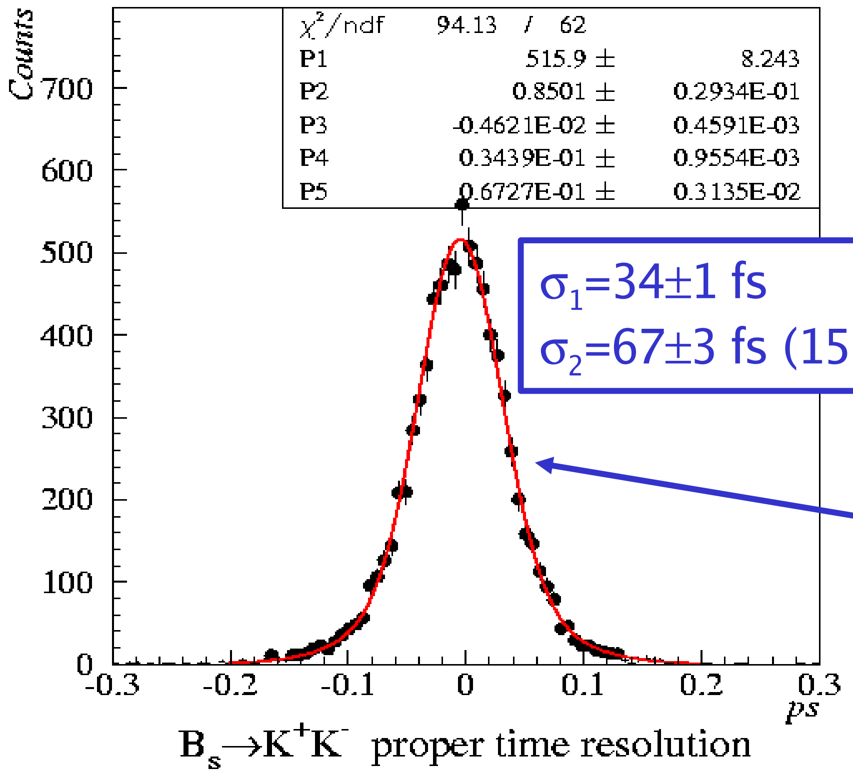
- A_{dir} and A_{mix} for $B_d \rightarrow \pi^+\pi^-$ ($B_s \rightarrow K^+K^-$)
- Charge asymmetry for $B_d \rightarrow K^+\pi^-$ ($B_s \rightarrow \pi^+K^-$)
- Mean B_d (B_s) mass and mass resolution (2 parameters)
- 1 parameter for background mass distribution of $B_d \rightarrow \pi^+\pi^-$ ($B_s \rightarrow K^+K^-$)
- 1 parameter for background mass distribution of $B_d \rightarrow K^+\pi^-$ ($B_s \rightarrow \pi^+K^-$)
- 2 parameters for background proper time of $B_d \rightarrow \pi^+\pi^-$ ($B_s \rightarrow K^+K^-$)
- 2 parameters for background proper time of $B_d \rightarrow K^+\pi^-$ ($B_s \rightarrow \pi^+K^-$)
- ΔM , Γ , $\Delta\Gamma$ for the B_d (B_s)
- Mistag fraction for $B_d \rightarrow \pi^+\pi^-$ and $B_d \rightarrow K^+\pi^-$ ($B_s \rightarrow K^+K^-$ and $B_s \rightarrow \pi^+K^-$)
- Tagged event yield for $B_d \rightarrow \pi^+\pi^-$ ($B_s \rightarrow K^+K^-$)
- Tagged event yield for $B_d \rightarrow K^+\pi^-$ ($B_s \rightarrow \pi^+K^-$)

Fit input (I): Proper time and resolution

Acceptance suppression at low proper time due to cuts on distance of flight and IP



Asyntotically flat



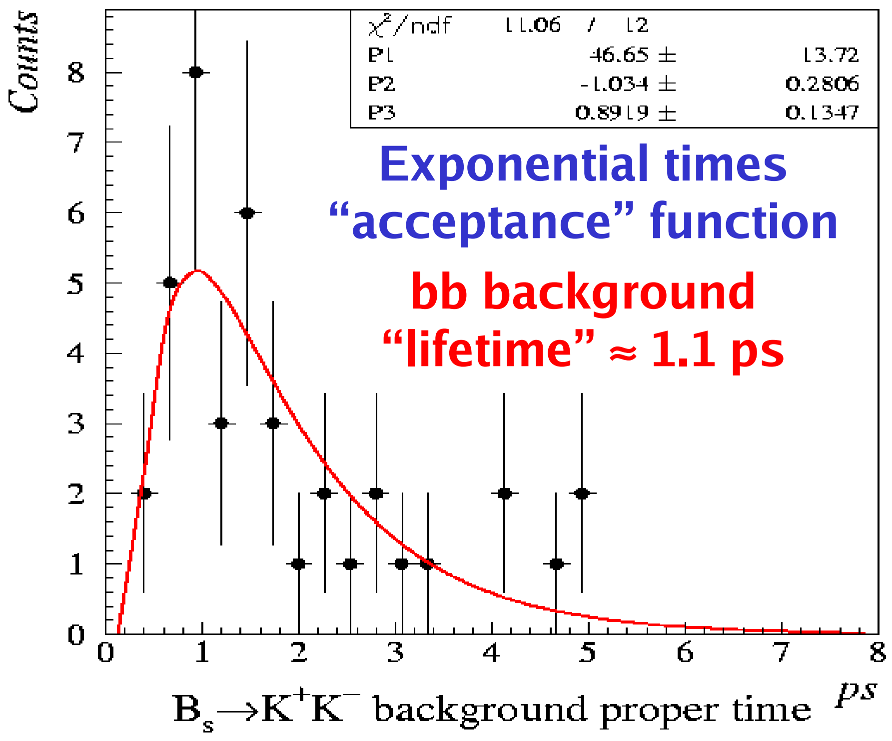
σ_1=34±1 fs

σ_2=67±3 fs (15%)

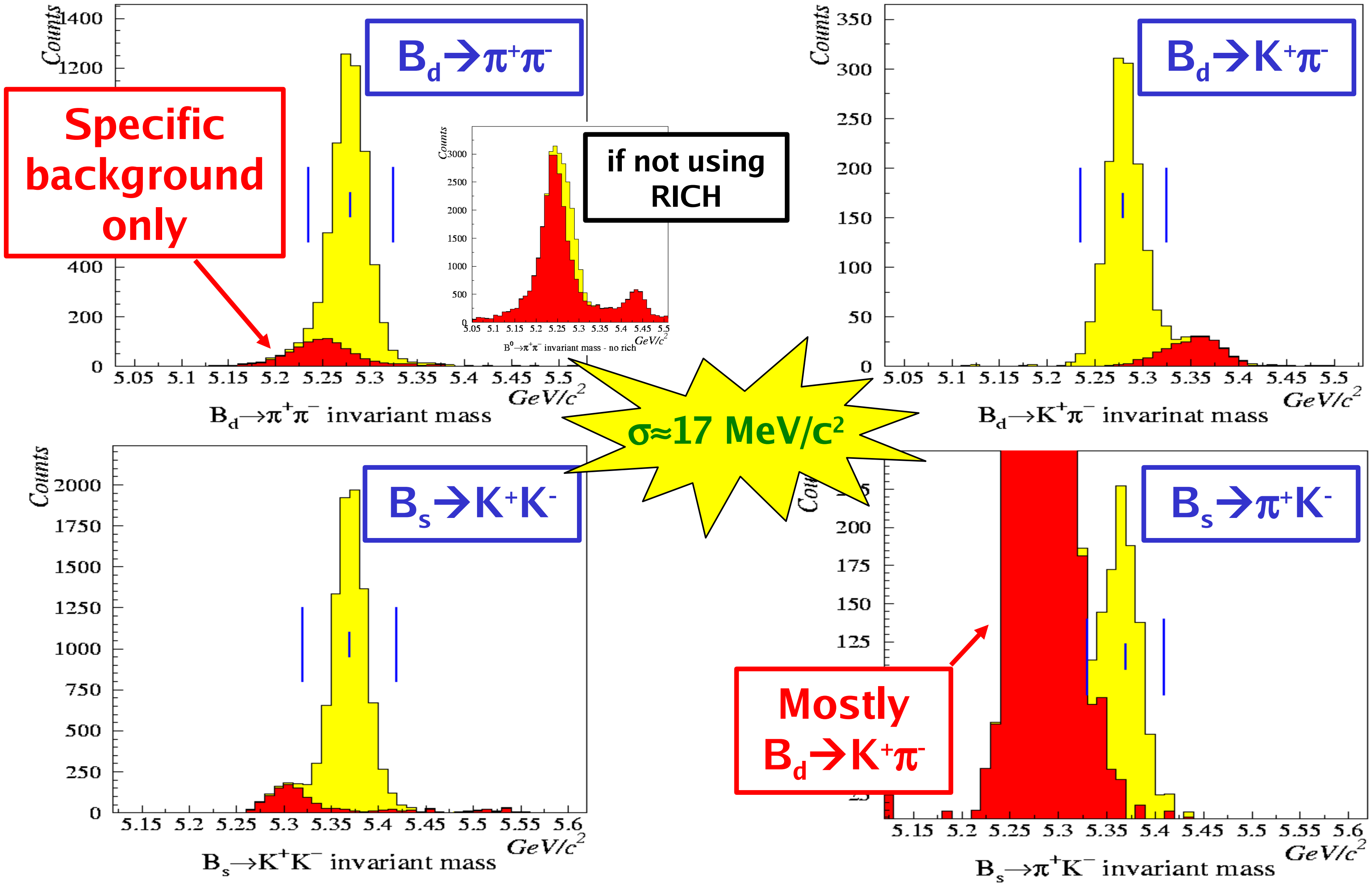
Resolution on proper time fitted with double gaussian

Fit input (II): Bkg proper time distribution

- Only a handful of bb events surviving after event selection due to "limited" (10^7) fully simulated bb event sample…

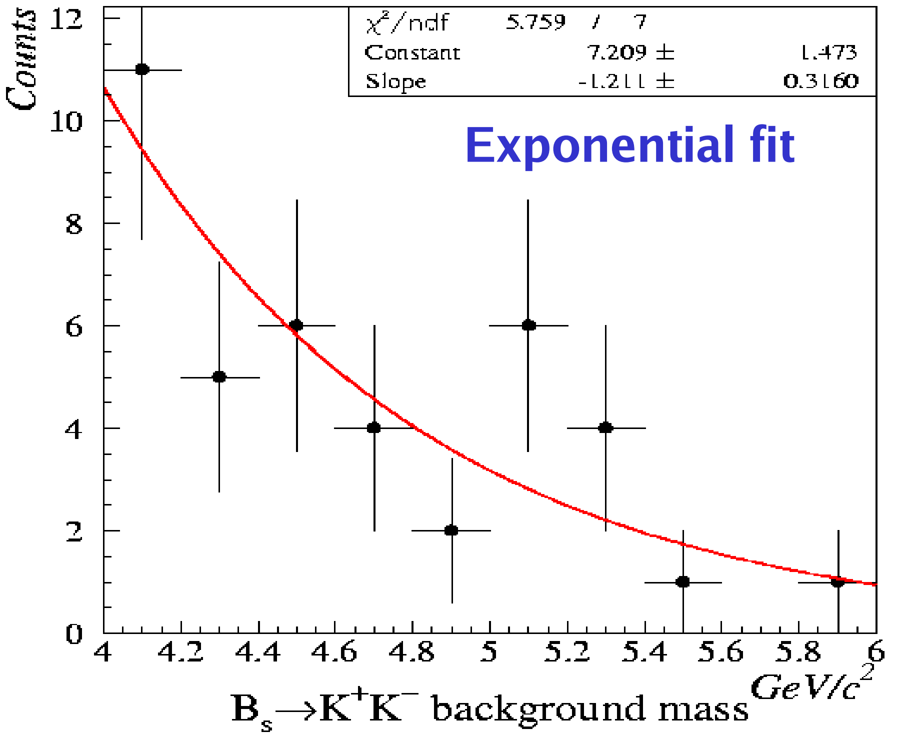


Fit input (III): mass spectra



Fit input (IV): background mass distr.

- Only a handful of bb events surviving after event selection due to "limited" (10^7) fully simulated bb event sample…



Calibration issues

- Particle ID
  - for pions and kaons we have large D* samples
  - Calibration for protons would be needed as well. Can we do this with Lambda decays?
- Invariant mass & Vertex resolution
  - mass resolution is crucial for the 2-body studies. Large J/Psi and friends samples available
- All of this is fairly clear, but we need still to formalize how the information obtained from various light-house processes is propagated to the CP fits

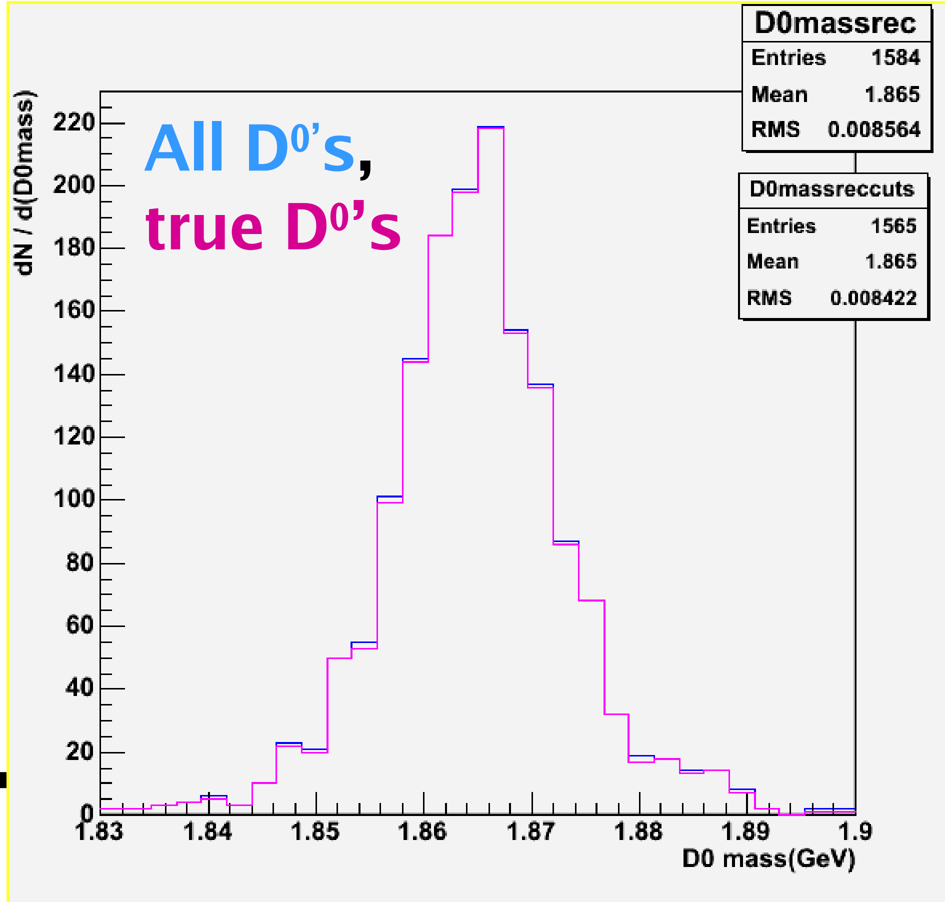
Large D* samples used for PID studies

R. Muresan

- Plan to use **$D^* \rightarrow D^0 \pi$, $D^0 \rightarrow K\pi$:**
  - "Golden" kinematics – easy to supress the bkg:
    $(M_{D^*} - M_{D^0}) = 144.5$ MeV ($M_\pi = 139.5$ MeV)
  - Good branching ratios:
    - **BR($D^* \rightarrow D^0 \pi$) = 67.7 %,**
    - **BR($D^0 \rightarrow K \pi$) = 3.83 %**

Selected events (**HLTFilterDstars)**

After L0, L1	6768
+ HLT	2099 (31%)
+ off-line HLT	2718 (40%)
+ HLT & off-line HLT	1565 (23%)

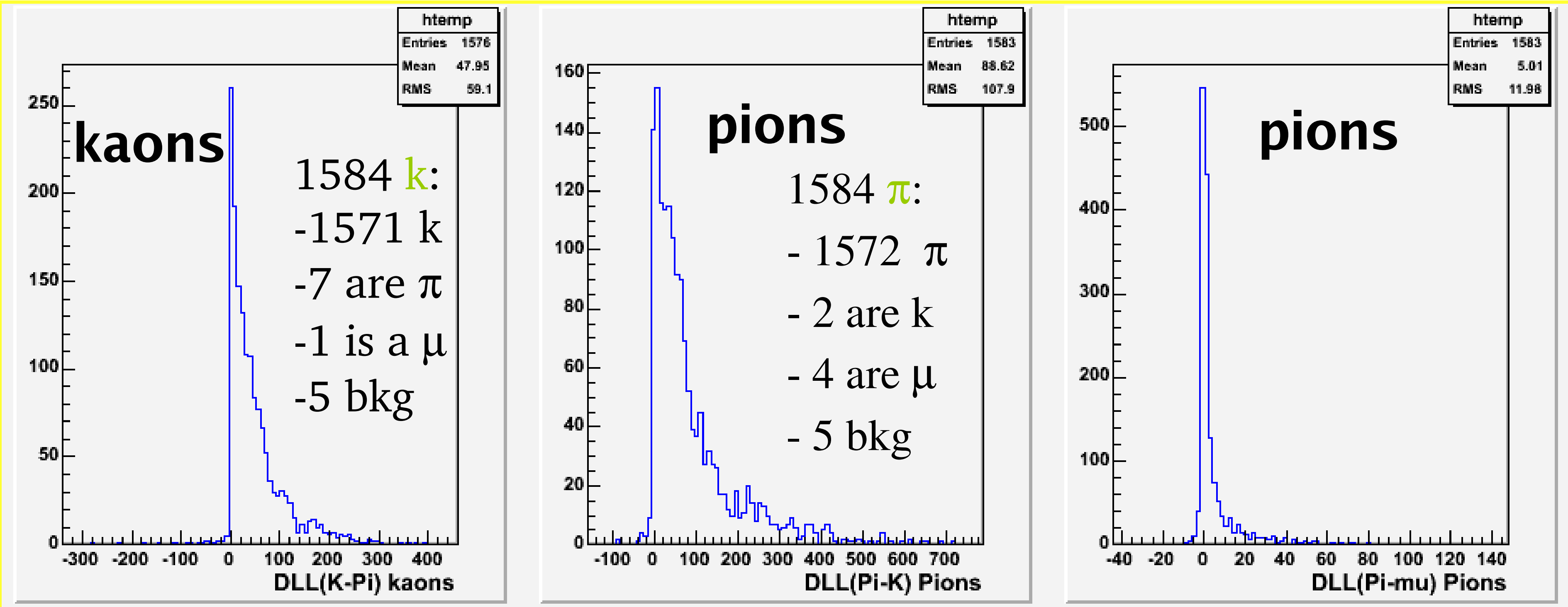


Results (after HLT)

R. Muresan

K, Pi RICH – PID decision Bd->D*π
L0, L1, HLT flag, off-line HLT cuts

Those events can be used to calibrate the PID (see few slides later)



Entries below 0
4 ghosts,1 muon

Entries below 0
2 ghosts one kaon

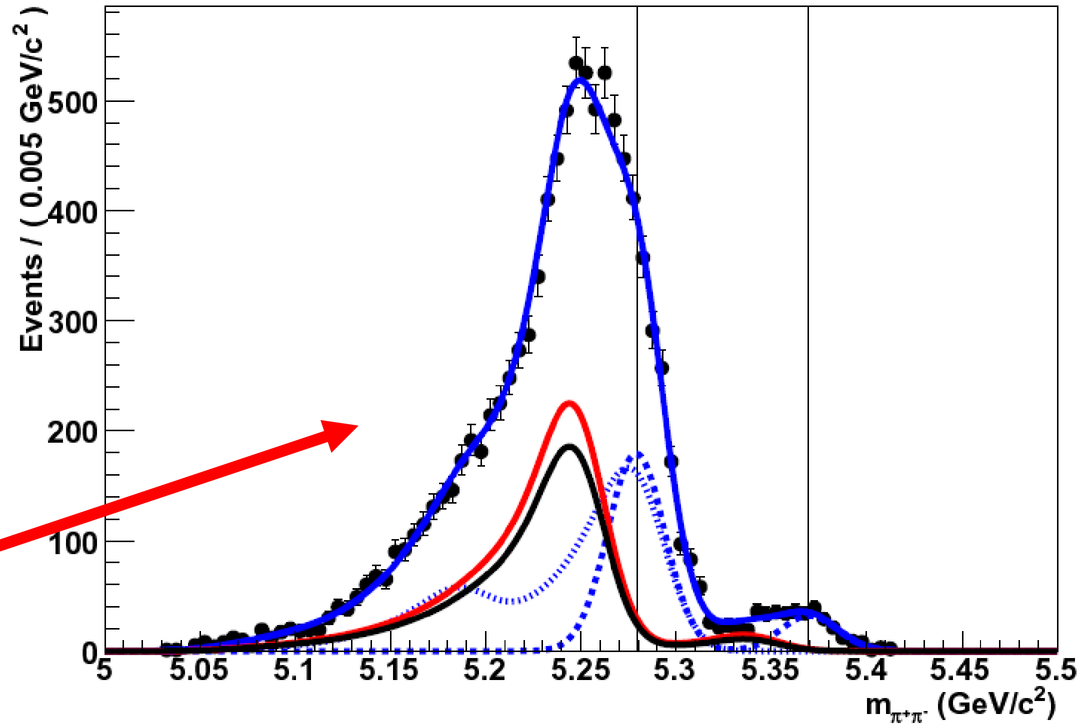
Entries below 0
1 ghost, 2muons,1 el

Fit technology: RooFit

- Started with a Fortran code (using Minuit) and now ended with a RooFit based fit: results are consistent :) !!

  – Should push for a common code for all the other analyses that are doing such likelihood fits…. (see proposal in CP meeting of 14 Jul 05)

  – The PID information is not used, now, in the fit: plans are to go for a simultaneous fit of all the 8 different B to hh samples.



Can be done! (G. Raven CP meeting)

Fitting using the PID information

- 8 signal samples:
  - B^0,B_s pi^+pi^-,K^+pi^-,pi^+K^-,K^+K^- (Convention: positive charge first)
- The above 8 samples, for non-perfect PID, crossfeed amongst each other
  - Eg. Bs Kpi is a background for B0 pipi, and vice versa…
  - Need to relative Kpi yield for pipi background estimate, but need pipi yield to get Kpi background…
- Separation of samples depends on PID performance, which will depend on eg. track momenta, which eg. distorts the shape of Kpi cross-feed background in mpipi…
- Cutting on PID to select 8 samples will result in non-trivial analysis
- Invariant mass also has some power to separate the signals..

- Alternative: use both invariant mass and PID observables directly in fit, get all 8 signals simultaneously
  - Let MINUIT worry about correlations…
- But need to use consistent observables:
  - For Kpi, should compute invariant mass under pipi hypothesis to allow comparison with pipi…

Fitting using the PID information (II)

- Need to Model the m(pipi) mass.
  - Assume $M(\pi^+\pi^-)$ is a Gaussian, with a mean which depends on the observed value of β (Similar to resolution models which depend on the observed per-event propertime error derived from the vertex and momentum)
  - Use *conditional PDF* to describe this distribution: $L(m\pi\pi,\beta) = L(m\pi\pi|\beta)\, L(\beta)$

  - Model the PID
    - Need to parameterize the momentum (and charge) dependence of PID observables
    - RICH TDR shows this plot that is 'just what you want"
    - This would lead to an observable "PID" with the following properties L(PID,p) = L(PID|p)L(p)
    - Again, this is a 'Conditional PDF', given the momentum distribution of a track.

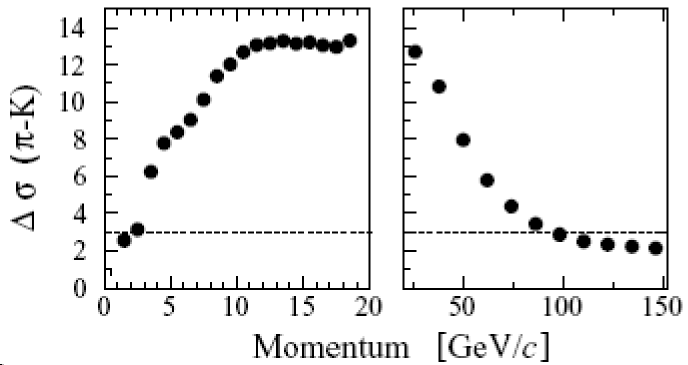
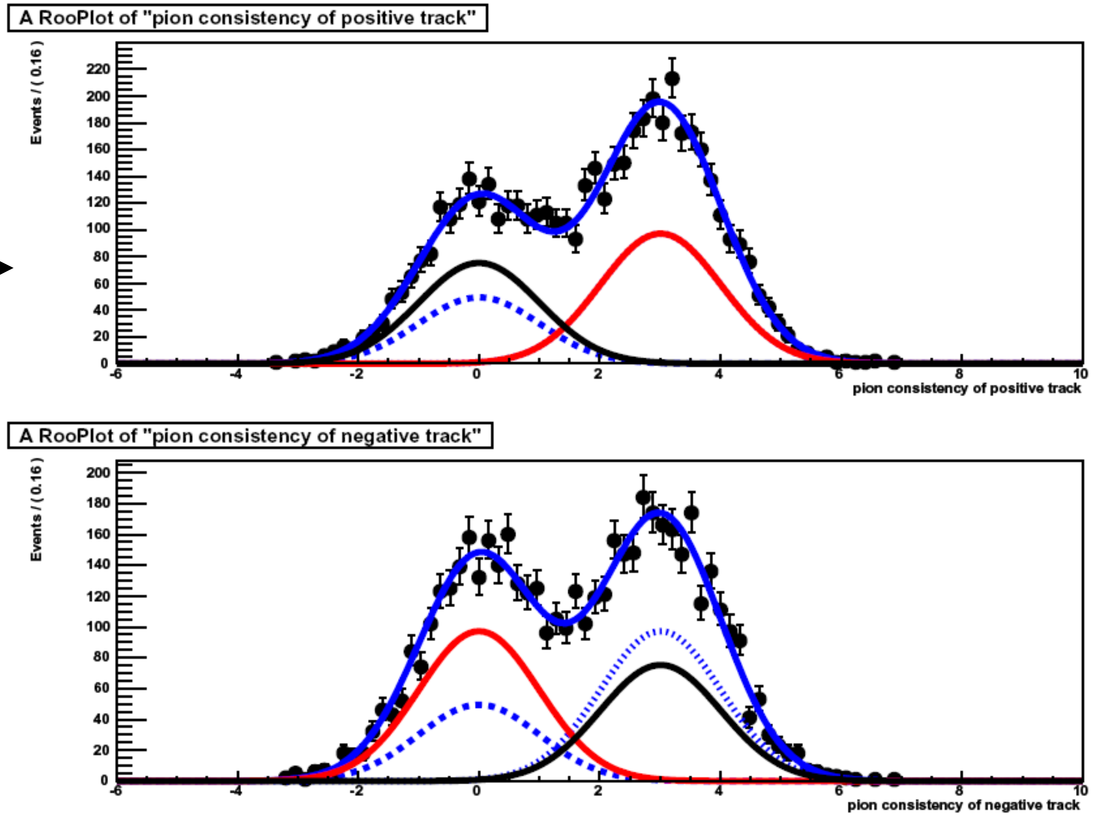


Figure 18: Number of sigma separation between pion and kaon hypothesis versus momentum for true pions in triggered and accepted signal events.

Future Plans

PID observables



- PID categorization and simultaneous fit to all B to hh samples
- HLT Trigger studies
- Tagging studies (ω)
- D to hh studies (helping the PID categorization)

Conclusions and outlook

- Started a joint work on B->hh in order to perform the full exercise in time for Phys Book (or whatever else)