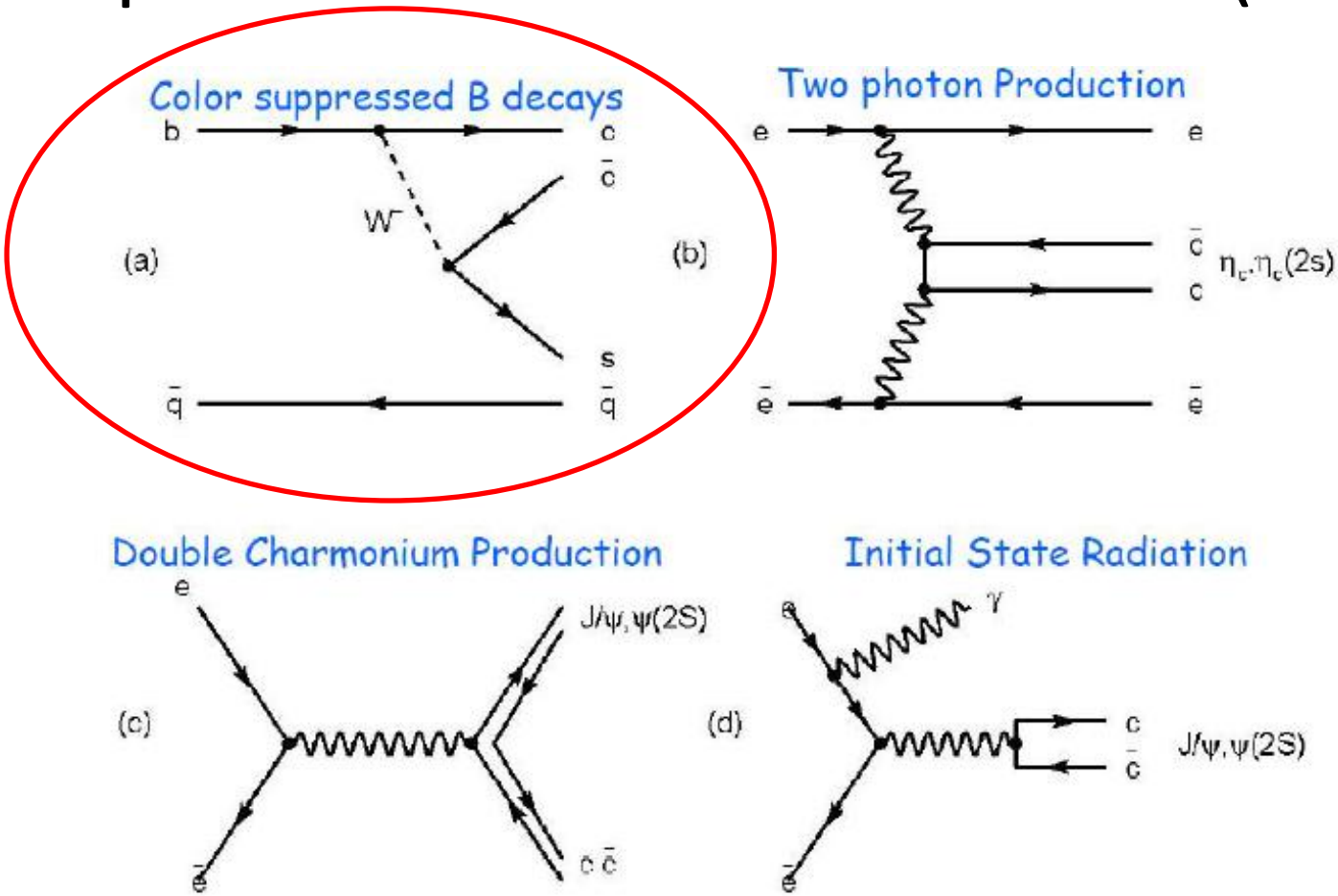
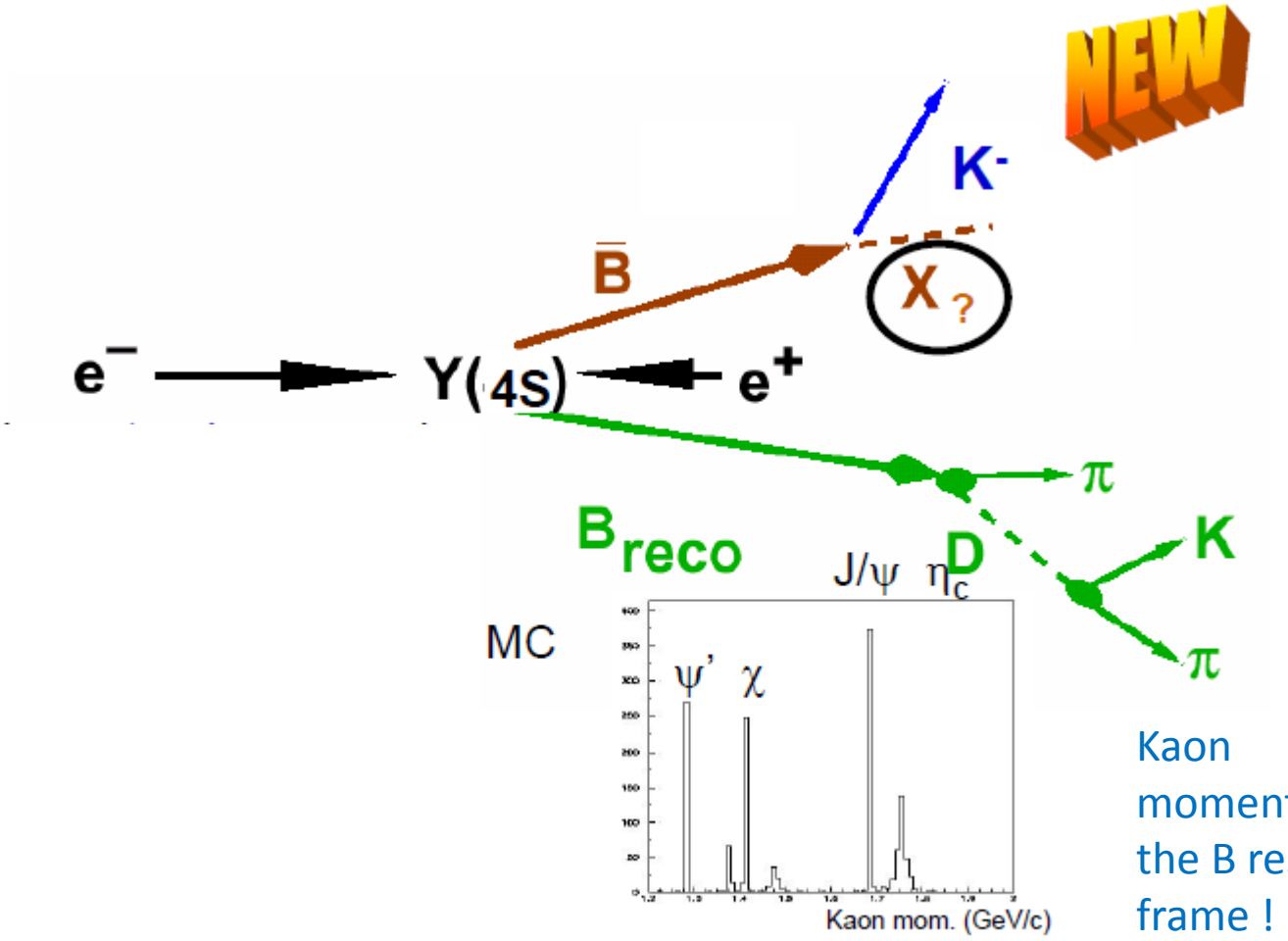
Results and prospects from inclusive charmonium measurements

G. Wormser
IN2P3/CNRS and Paris Sud University
March 6, 2013
Charmonium workshop , Orsay

How to produce charmonium at the Y(4S)



The exclusive reconstruction of one B gives unbiased access to the B->KX decav !!



Kaon momentum in the B rest frame !

Each peak is expected to be ~10 MeV wide

Principle of the analysis

- Study the two-body decays $B^+ \rightarrow X K^+$

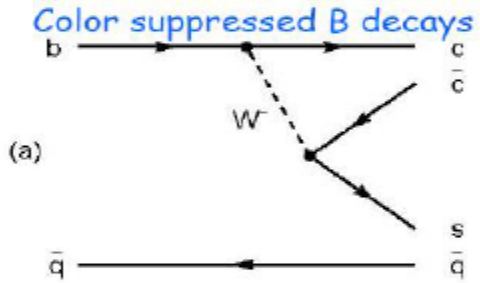
  (X =cc) by simply studying the K momentum spectrum in the B center of mass: one peak per particle X
- Access to the B center of mass frame is provided thru exclusive reconstruction of the other B
- Works equally well for neutral X (B^+ Reco) or charged X (B^0 Reco)
- This work was performed in BABAR in 2004-2005 and published in **Phys.Rev.Lett. 96 (2006) 052002**
- Used 200 fb-1 (50% of the full present BBAR statistics)

Physics goals for kaon recoil

- Direct measurements: Properties of the full charmonium spectrum
  - Access to unbiased measurements of mass and widths of known or unknown particles
  - Measurement of production rate: absolute branching ratios of BR ($B^+ \rightarrow$ X K^+)
- Knowing this absolute BR and observation of exclusive channels B→K X, X→abc, one gets a measurement of BR(X→abc)

Charmonium production in B decays

- B meson is an interesting charmonium factory



  - Large phase space, « democratic production » at zeroth order of all charmonium states
  - Selection rule : Factorisation suppression for χ_0 χ_2 states. Is it respected? Can we undestand the source of the violations if any
  - Understand the pattern in ψ,ψ',ψ'', η_c,η'_c,χ_1 production rates

Search for Factorization-Suppressed $B \to \chi_{cJ} K^{(*)}$ Decays : Motivation

Hypothesis: Factorization of hadronic currents:

$$\langle XY|\mathcal{H}_{eff}|B\rangle \;=\; \langle X|\mathcal{J}_{EW}|0\rangle\langle Y|\mathcal{J}_S|B\rangle$$

Terms in J_{EW}:

$$\begin{aligned}
\langle S(q)|\bar{c}\gamma^\mu c|0\rangle &= -if_S q^\mu \\
\langle P(q)|\bar{c}\gamma^\mu\gamma_5 c|0\rangle &= -if_P q^\mu \\
\langle V(q,\varepsilon)|\bar{c}\gamma^\mu c|0\rangle &= -if_V m_V \varepsilon^\mu \\
\langle A(q,\varepsilon)|\bar{c}\gamma^\mu\gamma_5 c|0\rangle &= -if_A m_A \varepsilon^\mu
\end{aligned}$$

- Weak current produces no $J = 2 : \Rightarrow \chi_{c2}$ suppressed.
- $J^{PC} = 1^{--}$ (J/ψ, $\psi(2S)$), and $J^{PC} = 1^{++}$ (χ_{c1}) allowed
- $J^{PC} = 0^{++}$ (χ_{c0}) forbiden M. Diehl, G. Hiller, JHEP 0106:067,2001, hep-ph/0105194

But sizeable $B \to \chi_{c0} K^+$ was found:

- $(6.0^{+2.1}_{-1.8} \pm 1.1) \times 10^{-4}$, Belle PRL **88** 031802 , $(2.7 \pm 0.7) \times 10^{-4}$, *BABAR* PRD **69** 071103

Interesting measurements regarding the η_c

- Measure the absolute BR($B^+ \rightarrow \eta_c K^+$), only known today with a 30% error:

  PDG2004: BR($B^+ \rightarrow \eta_c K^+$)=$9 \mp 2.7\ 10^{-4}$

- This will in turn gives better measurements of the η_c BR decays
- This will in turn give a better measurement of the BR($J/\psi \rightarrow \gamma\ \eta_c$) previously used to normalize the exclusive η_c decays.

Interesting measurements regarding the X(3872)

- Measure the absolute BR ($B^+ \rightarrow X\ K^+$) (or get an upper limit)
- Deduce the BR($X \rightarrow J/\psi\ \pi^+\pi^-$) (or get a LOWER limit)
- Look for a charged partner, irrespective of its decay modes
- These three informations are very useful to know more about the true nature of this particle

Search for other high mass states

- Various high mass states have been reported in **BR ($B^+ \rightarrow X K^+$)** channels: X(3940), Y(3940),…
- Try to confirm their existence, measure their production rate, etc,…

Sensitivity up to 4.8 GeV!

Description of the analysis

- B selection
  - SemiExclusive B reconstruction sample candidate, Very high yield (~2000 B/fb^{-1}), low purity.
  - B purification: NN based on event shape variables and angular information (Breco-rest of the event, Breco-recoil Kaon)
    - NN_sel> cut_b
    - M_min<Mes<M_max
- Kaon Selection
  - Kaon Identification:Tight Kaon id (LH selector)
  - Kaon Purification:
    - Correct sign
    - Rejection of secondary kaons: NN based on energy flow around the kaon track and angular correlations
      - NN_top>cut_top
- Cuts optimization : cut_b, M_min, M_max, cut_top
- Fits to the Kaon momentum spectrum

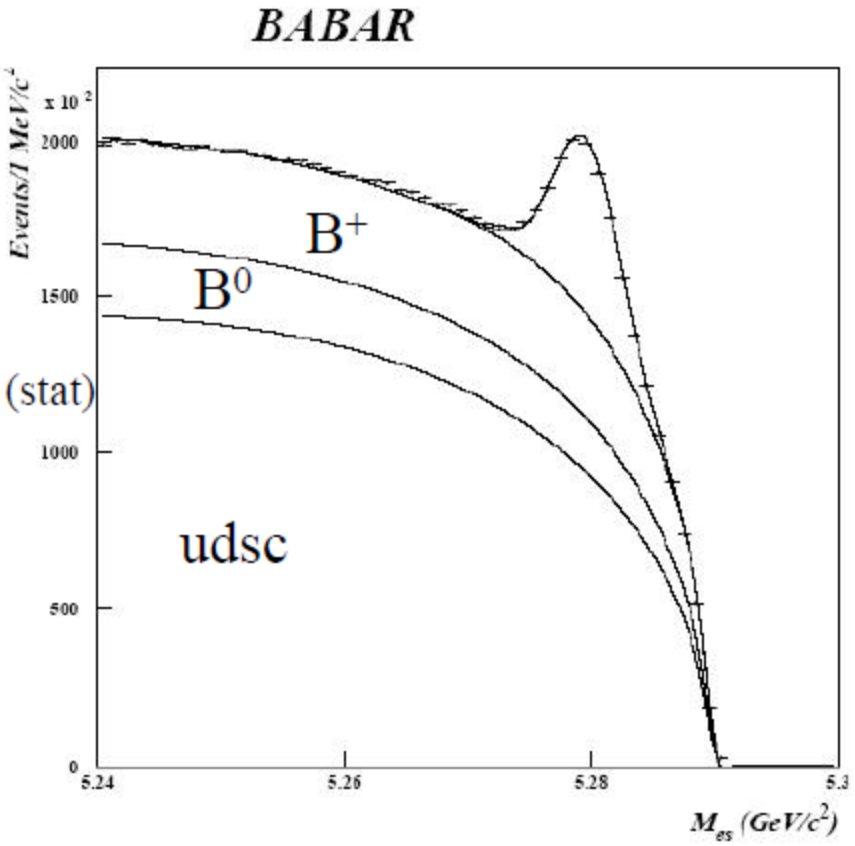
The fit to the B mass spectrum

Data B^+ :378530 ± 1110 (stat)

Normalized MC B+: 413693 ± 680 (stat)

Data B^0 :245597 ± 719(stat)

200 fb-1 Data up to 2004



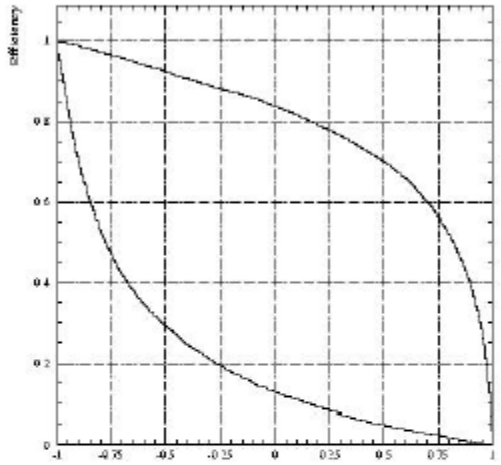
B counting results

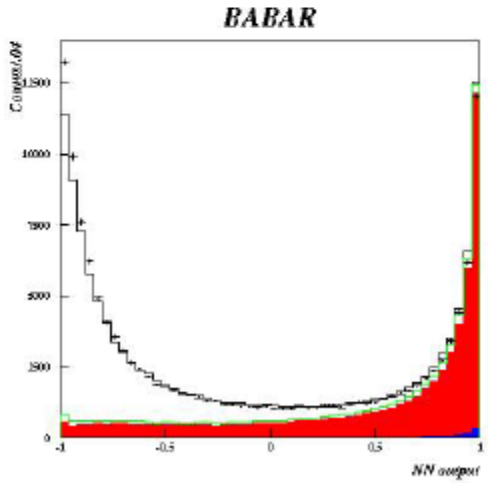
Parameter	MC	Runs 1-2	Run3	Run4	Total Data	Typical error
Endpoint (MeV)	5288.76	5290.20	5289.85	5289.25		0.05
Peak Mass(MeV/c^2)	5279.42	5279.83	5279.67	5279.42		0.05
Peak Width (MeV/c^2)	2.50	2.69	2.65	2.615		0.06
α Cristal Ball	1.41	1.7	2.9	1.67		0.13
N Cristal Ball	19.9	27.8	48	23.9		6
High purity $B^{\pm}$ (kB/fb^{-1})	0.173	0.133	0.147	0.125	0.131	0.01
High purity $B^{\pm}$ MC-truth (kB/fb^{-1})	0.173	0.179	0.169	0.168		0.004
$B^{\pm}$	1313311	145789	56499	176292	378580	800
$B^{\pm}$ (kB/fb^{-1})	1.97	1.83	1.88	1.76	1.80	0.007
$B^{\pm}$ MC truth (kB/fb^{-1})	2.06	2.11	1.99	2.04		
MC $B^{\pm}$ only fits (kB/fb^{-1})	2.01	2.05	1.97	1.99		

Table 1: Summary of all $B^{\pm}$ mass fit results.

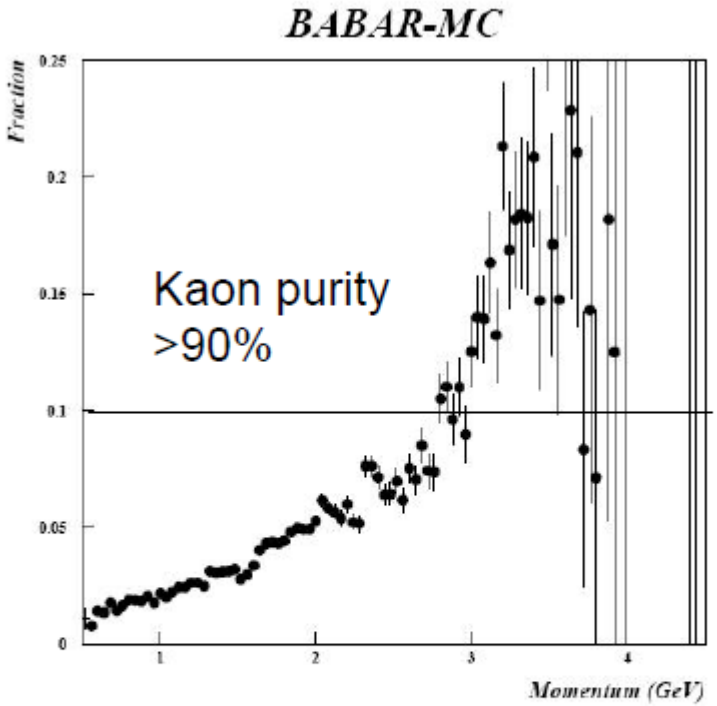
B purification

- NN based on
  - usual cocktail of discriminating variables between BB and continuum (thrust, R_2, Wolfram moments,etc)
  - $\cos(B_1\text{-}B_2)$
  - $\cos(B_{reco}\text{-}K)$





A very good Kaon ID is essential

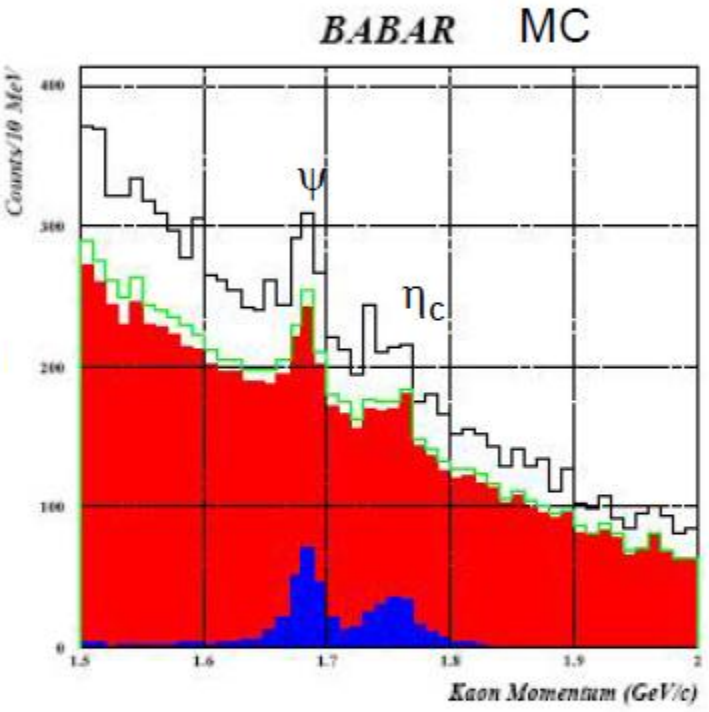


Fraction of MisID Kaons as function of Kaon momentum

Less than 5% contamination !

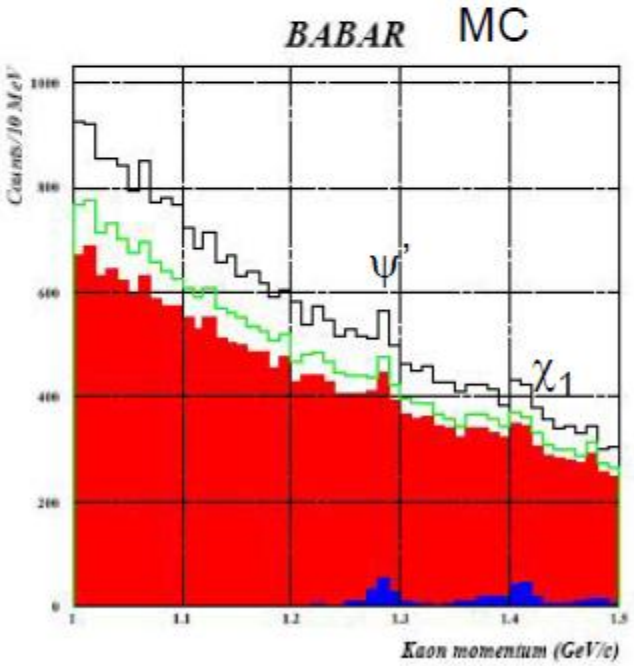
MC expectations for the kaon spectrum

ψ-η_c region



Spectrum dominated by real Kaons from real B decays

High mass region



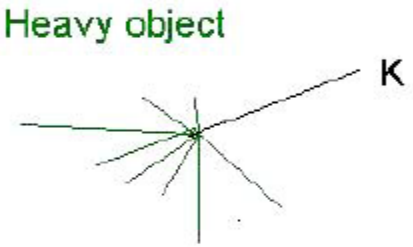
Blue : two-Bodydecays

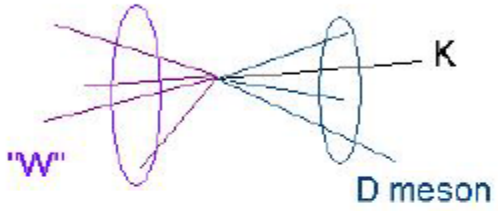
Red B+

Green B0

Black Full MC

Performance of the topology NN selector



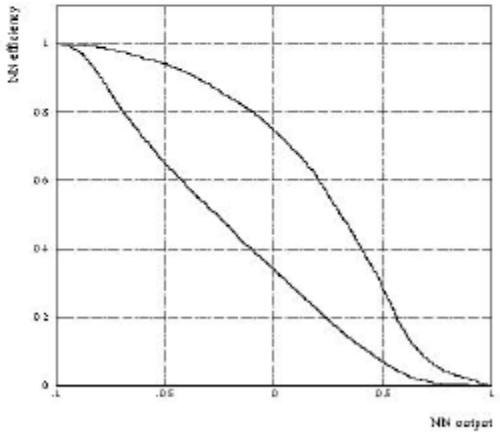


BABAR

Training done with B+ MC: Primary K from charmonia (signal), K from D decays (background) in two kinematic regions m>3.2 GeV and below

Primary K–

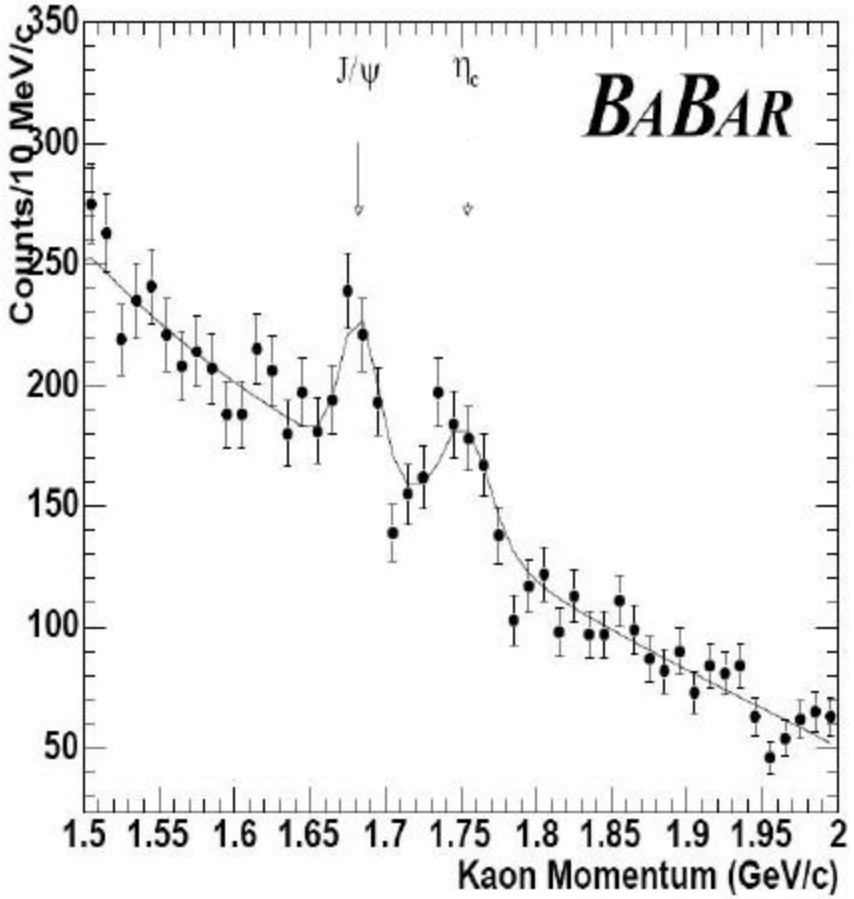
Secondary K-



Results in the low mass region

Very clear J/ψ and η_c signals

Significance> 6 σ
N J/ψ=258 ± 42
N_ η_c =266 ± 42



210 fb-1

Background: Cubic polynomial free in the fit

Initial values taken as in MC

Measurement of the BR($B^+ \to \eta_c K^+$)

- N_J/ψ=258 ± 42
- N_η_c =266 ± 42

using MC efficiency

BR($B^+ \to J/\psi K^+$)= (8.1 ± 1.2(stat) ± 0.9(sys) 10^{-4}

BR($B^+ \to \eta_c K^+$)$_{MC}$=(8.3 ± 1.3(stat) ± 0.9(sys)) 10^{-4}

Using Intradata:

- BR($B^+ \to \eta_c K^+$)/BR($B \to J/\psi K^+$)=1.03 ± 0.22(stat) ± 0.06(sys)
- BR($B^+ \to \eta_c K^+$)$_{data}$=(10.3 ± 2.2(stat) ± 0.6(sys) ± 0.4(ref)) 10^{-4}

using the PDG04 BR for the J/ψ decay

PDG 2012: 9.6+1.2

BR($B^+ \to \eta_c K^+$)=(8.9 ± 1.5) 10^{-4}

Summary of results derived concerning η_c and η_c'

	BR(KKπ) (%)	$\Gamma_{\gamma\gamma}$ (KeV)	BR(J/$\psi\rightarrow\gamma\ \eta_c$)(%)
η_c	8.3 ± 1.7 PDG 5.7 ± 1.6	5.8 ± 1.2 PDG 7 ± 1 ± 2	0.81 ± 0.17 PDG 1.30 ± 0.4
η_c'	9 ± 5 First meast PDG 2012 1.9+-1.2	0.8 ± 0.5 First meast <0.2 keV	

Precision can be further improved by combining these measurements

Mass and width of η_c and η'_c

Particle	Mass (MeV) This analysis	Mass (MeV) Other results	Width Limit at 90% CL (MeV) This analysis	Width Other results
η_c	2994 ± 5	PDG: 2979.6 ± 1.2 BABAR 2982± 1.1± 0.9 PDG 2012 2981+- 1.1	<43	PDG 17.3 ± 2.5 BABAR 34 ±2.5 29.7+-1.0
η_c'	3639 ± 7	PDG:3654 ± 6 ± 8 BABAR 3630.8 ± 3.5 PDG 2012 3639+-1.3	<23	PDG <55 BABAR :17.3 ± 8.3 ± 1.5 PDG 2012 10+-4

Results derived from η_c and η'_c production rates

- This analysis gives $BR(B^+ \to \eta_c K^+)=(8.9 \pm 1.5)\ 10^{-4}$
- From BABAR,

  $BR\ (B\to\eta_c K)*BR(\eta_c\to KK\pi) =(\ 74 \pm 5 \pm 7\ )\ 10^{-6}$

  $BR(\ \eta_c\to KK\pi)= (8.3 \pm 1.7\ )\%$

  PDG2012 7.2+-0.6

- From BES, MARKIII and DM2,

  $BR(\ \eta_c\to KK\pi)*BR(J/\psi\to\gamma\ \eta_c\ ) =(6.7 \pm 0.9)\ 10^{-4}$

  $BR(J/\psi\to\gamma\ \eta_c\ )= (0.81 \mp\ \ 0.17\ )\%$

- From PDG2004 $\Gamma(\eta_c\to\gamma\gamma)*\ BR(\eta_c\to KK\pi) =(0.48 \pm 0.06)$ keV

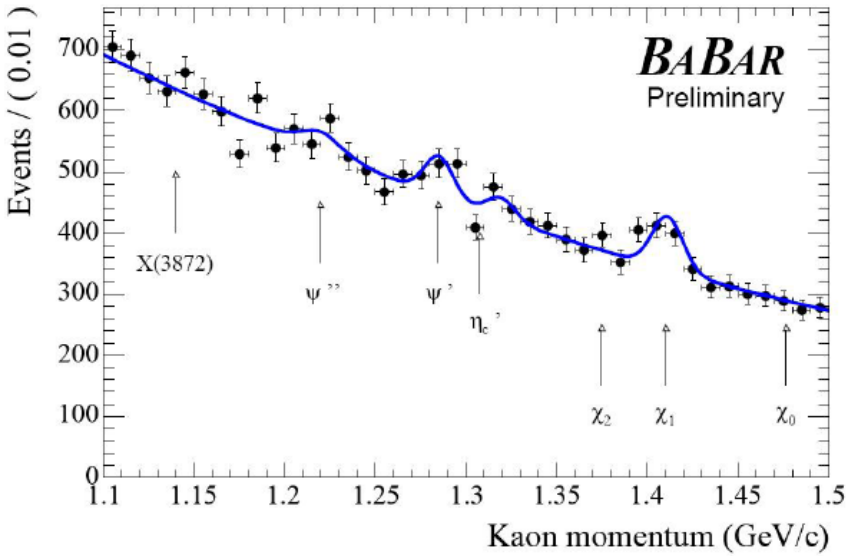
  $\Gamma(\eta_c\to\gamma\gamma)=5.8 \pm 1.2$ keV

Results in the high mass region

-2 clear signals ψ' and χ_1

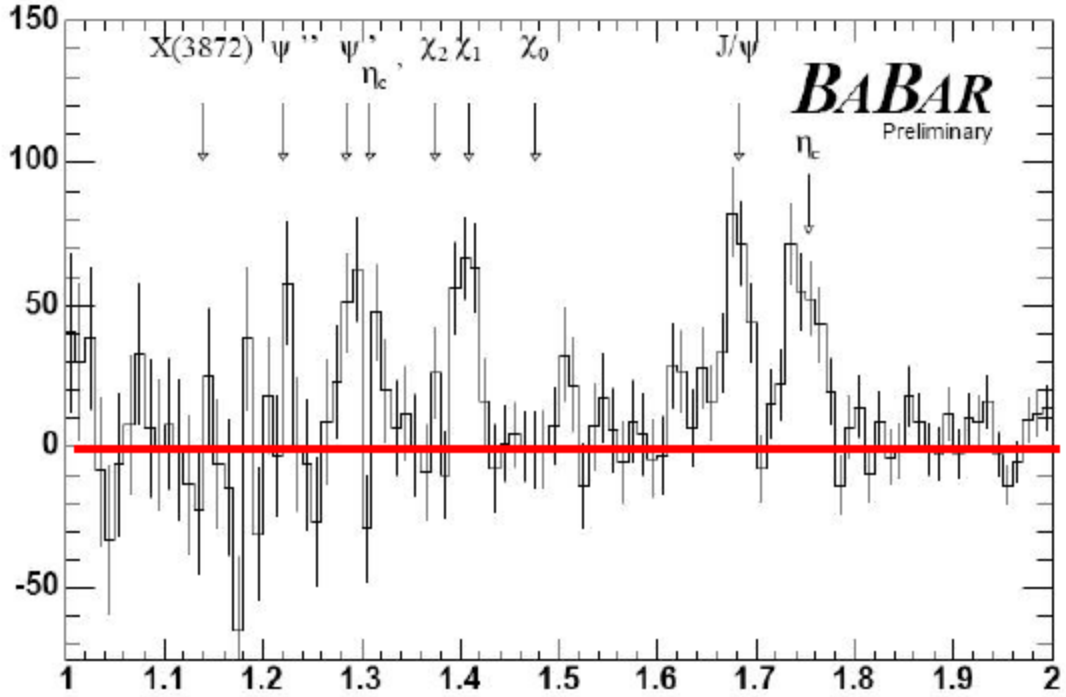
-2 excess of events ψ'' and η_c'

-3 limits χ_0, χ_2 and X(3872)



Zoom in the 3.4-3.9 GeV region

The complete charmonium spectrum from a single analysis!



Fit Results in the high mass region

Particle	Yield	Peak Position	Width	BR(10^{-4})	PDG 2012
χ_{c0}	9±21			<1.8	1.34+-0.19
χ_{c1}	192±35			7.0±1.3(stat)±1.0(sys)	
χ_{c2}	0±36			<2.0	
η_c (2S)	84±39	1.319±0.005	<15	3.1±1.4(stat)±0.4(sys)	0,1+-0,04
ψ'	116±37			4.2±1.3(stat)±0.6(sys)	6,4+-0,3
ψ''	87±60			3.2±2.2(stat)±0.5(sys)	4.9+-1.3
X(3872)	10±18			<3.2	

Note: χ_1 désigne en fait χ_1 + h_c

Table of the Branching Ratios

Particle	BR (10^{-4})	BR(PDG2004)	BR(BABAR)
η_c	8.9±1.5	9.0±2.7	13.4±4.4
J/ψ	8.1±1.6	10.0±0.4	10.6±0.5
χ_{c0}	<1.8	6±2.4±2.1 (*)	2.7±0.7
χ_{c1}	7.0±1.6	6.8±1.2	5.8±0.7
χ_{c2}	<2	No entry	<0.3
$\eta_c(2S)$	3.1±1.5	No entry	
ψ'	4.2±1.4	6.8±0.4	6.2±0.5
ψ''	3.2±2.3	No entry	
X(3872)	<3.2	No entry	

Many improvements compared to PDG2004

(*) based on first BELLE result.
New result :2.0± 0.3± 0.3

hep-ex/0412066

Results concerning X(3872)

- N_X(3872) = 10 ± 18

PDG 2012 <3.2 10-4

- The 90% CL on $BR(B^+ \to X(3872)\ K^+)$ is $3.2\ 10^{-4}$
- From $BR(B^+ \to X(3872)\ K^+) * BR(X(3872) \to \psi\pi\pi) = (13.7 \pm 2.2)\ 10^{-6}$ (BABAR-BELLE averaged), one gets:

$BR(X(3872) \to \psi\pi\pi) > 4.3\%$ at 90% CL

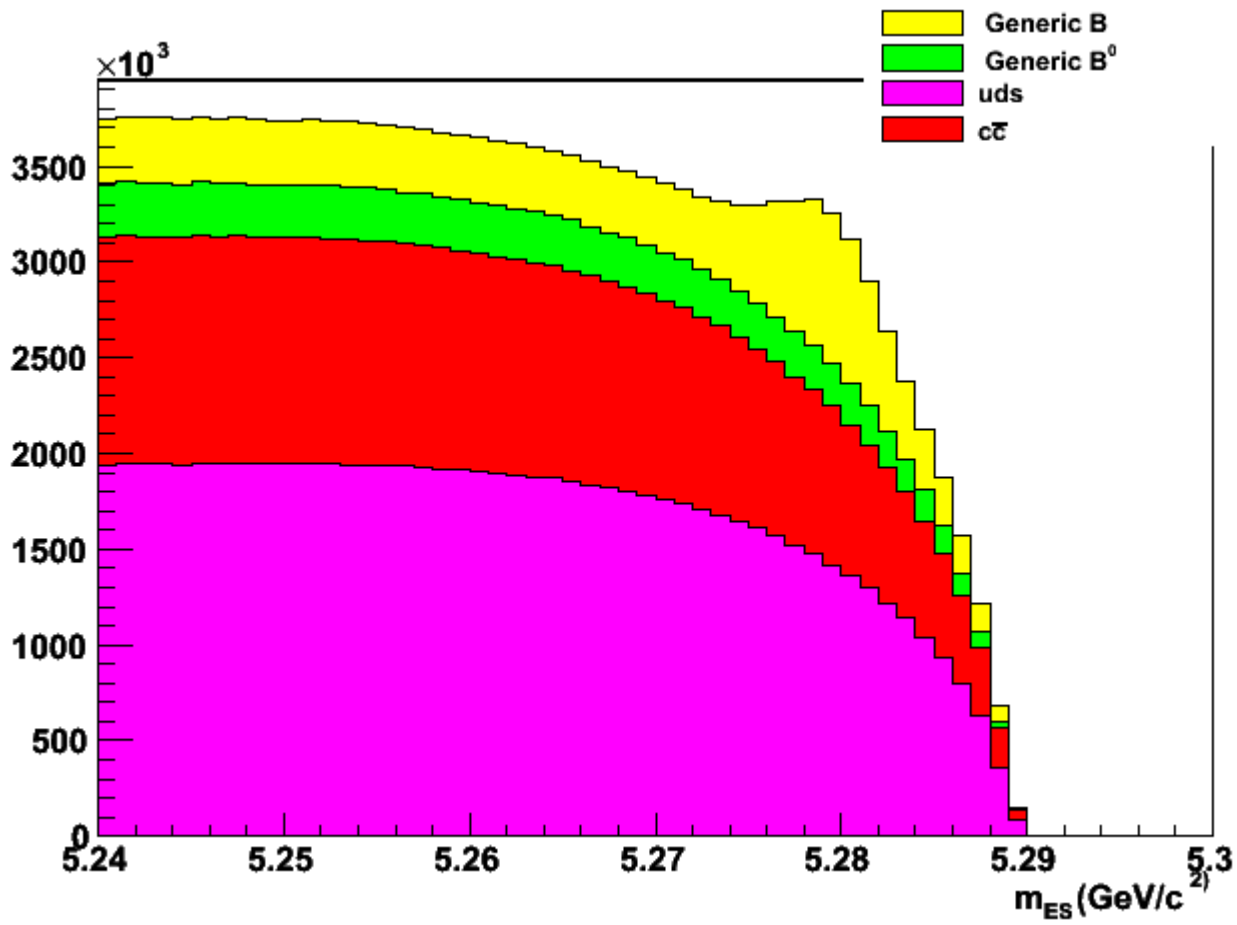
Limits were also set on the production rate of X(3940) and Y(3940) (allowing up to 100 MeV width for this last state) of respectively

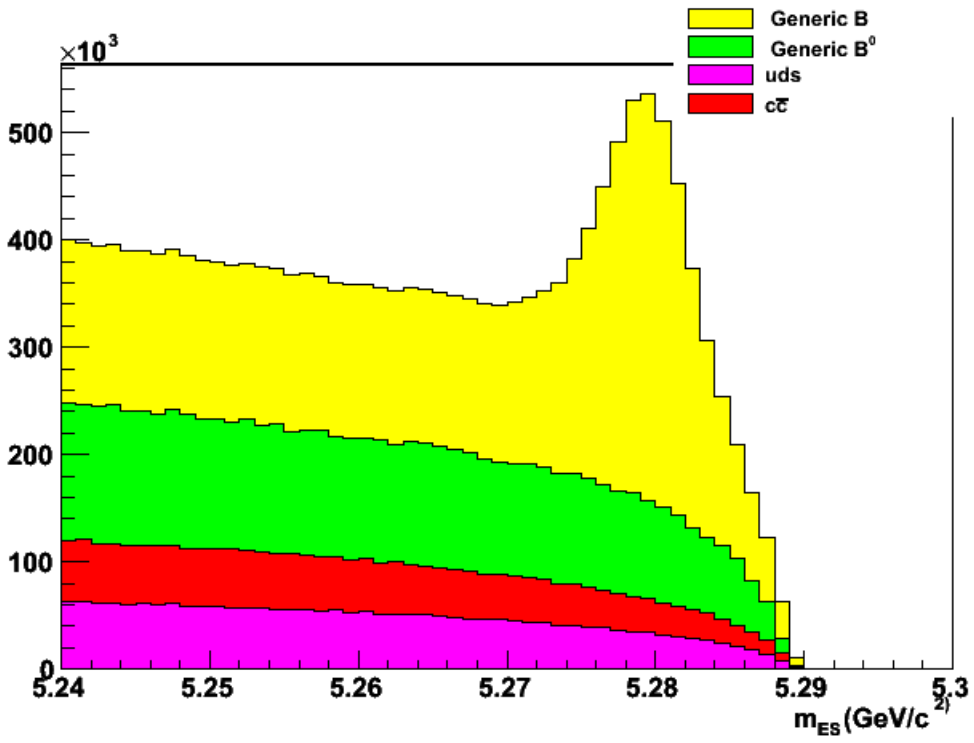
3.3 and $2.4\ 10^{-4}$ at 90% CL

The update of the analysis

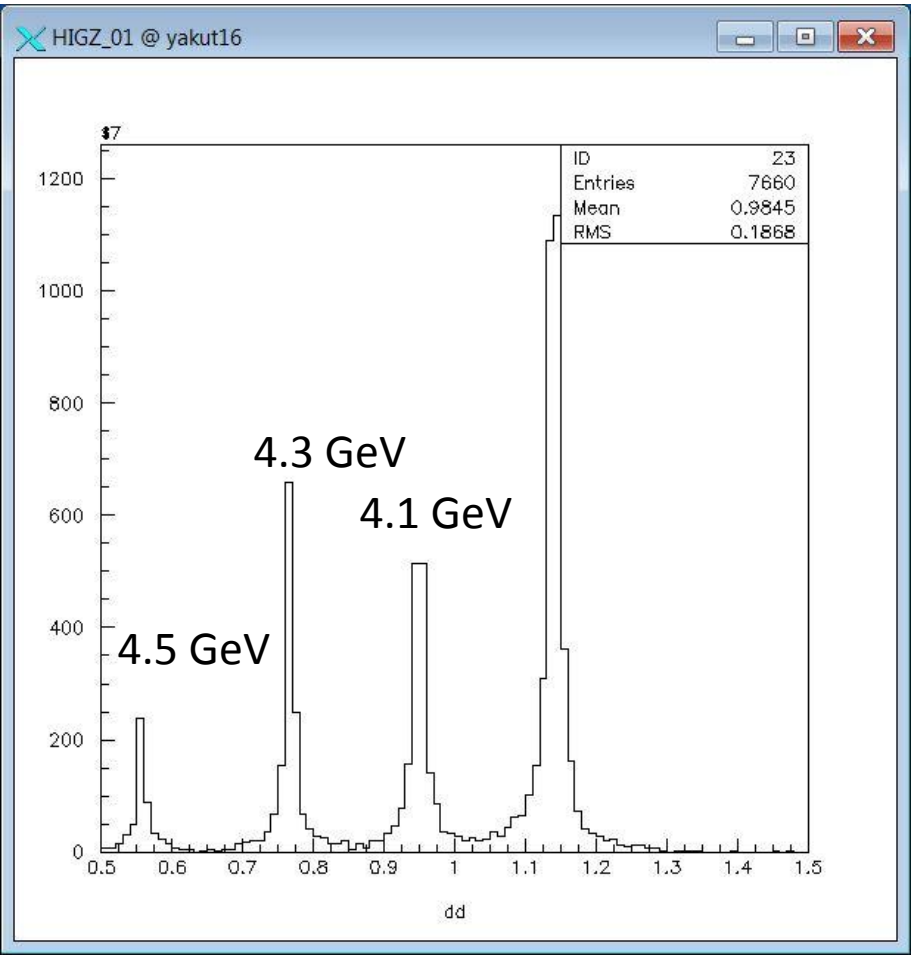
- Goal : Update 2004-2006 analysis published on 200 fb-1 with 378k reconstructed B+ (1.9 kB+/fb-1) (with a focus on high mass)
  - Yield 259 J/Psi 1.25 J/Psi per fb-1
- Hope is to multiply the stat by a factor 2 (not difficult) and the yield by another x2
  - The factor 2 seems easier to get on the B rate rather than on the K rate
  - Goal 4 KB+/fb-1 ; 2.5 J/Psi/fb-1
  - (1 fb-1= 1 M B+-, B reco efficiency of 0,4%)

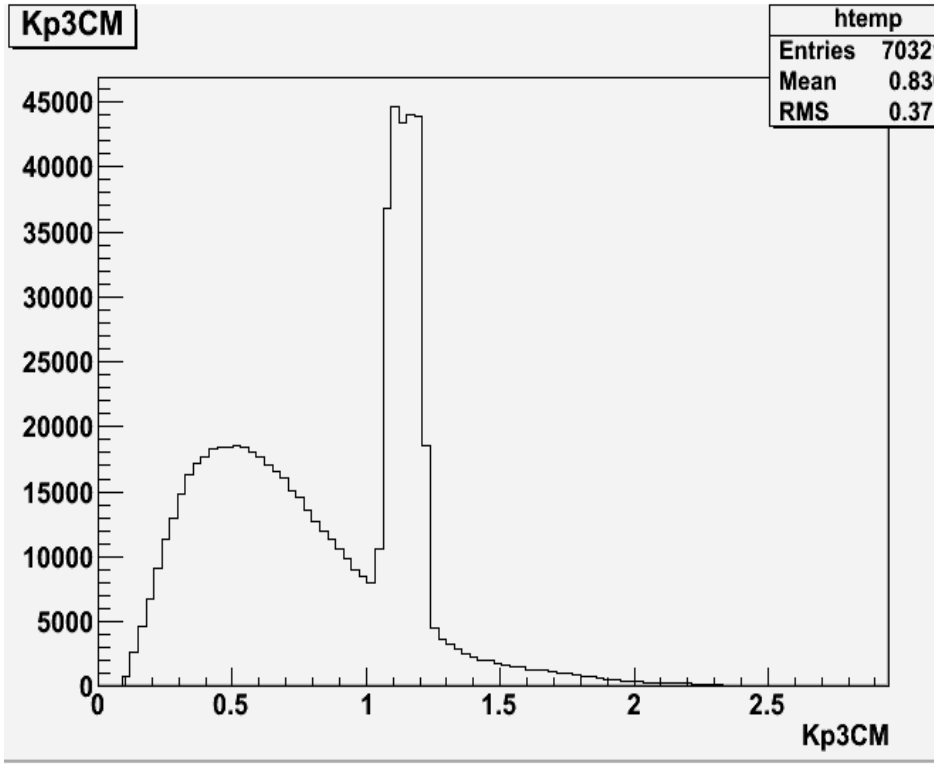
MC distribution with all categories before BDT cut (1.3 ab-1)




Generic B
Generic B^0
uds
$c\bar{c}$
$\times 10^3$
500
400
300
200
100
0
5.24
5.25
5.26
5.27
5.28
5.29
5.3
m_{ES}(GeV/c^2)

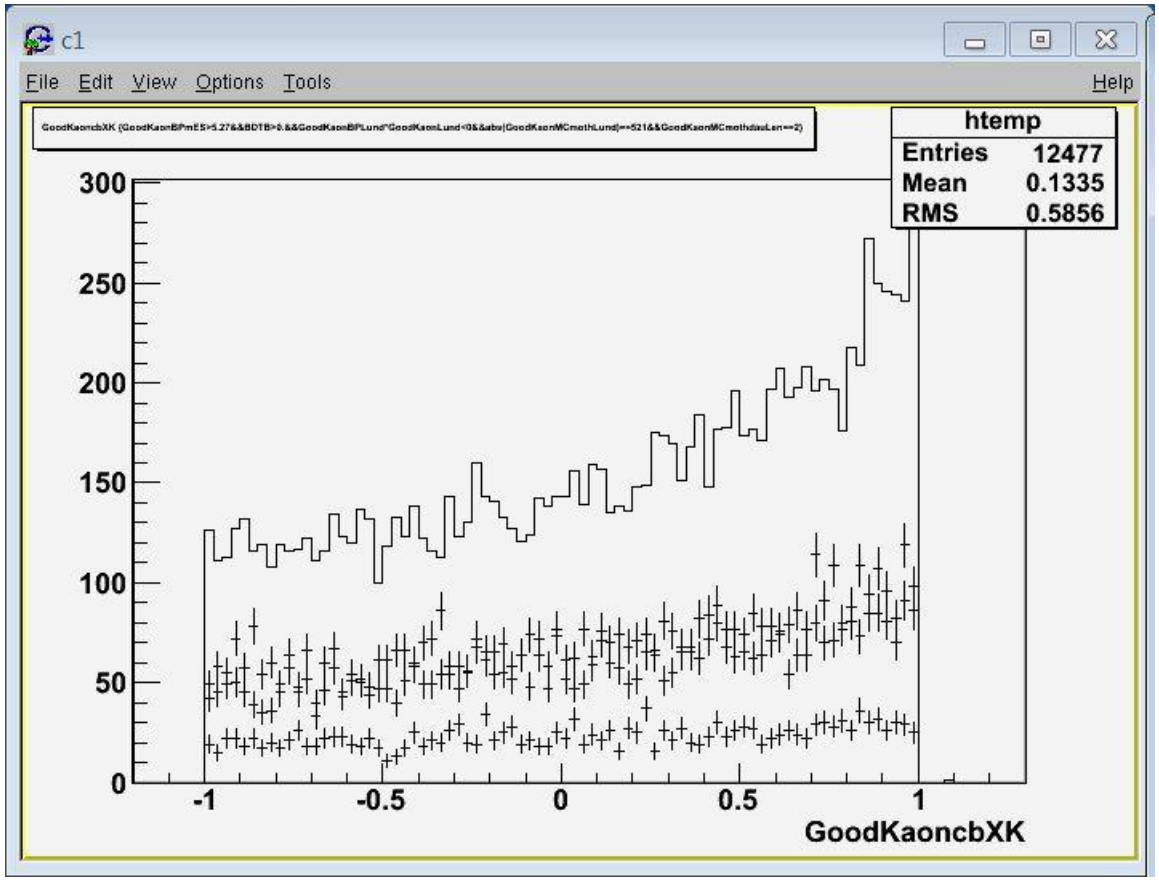
K signals from all signal MC



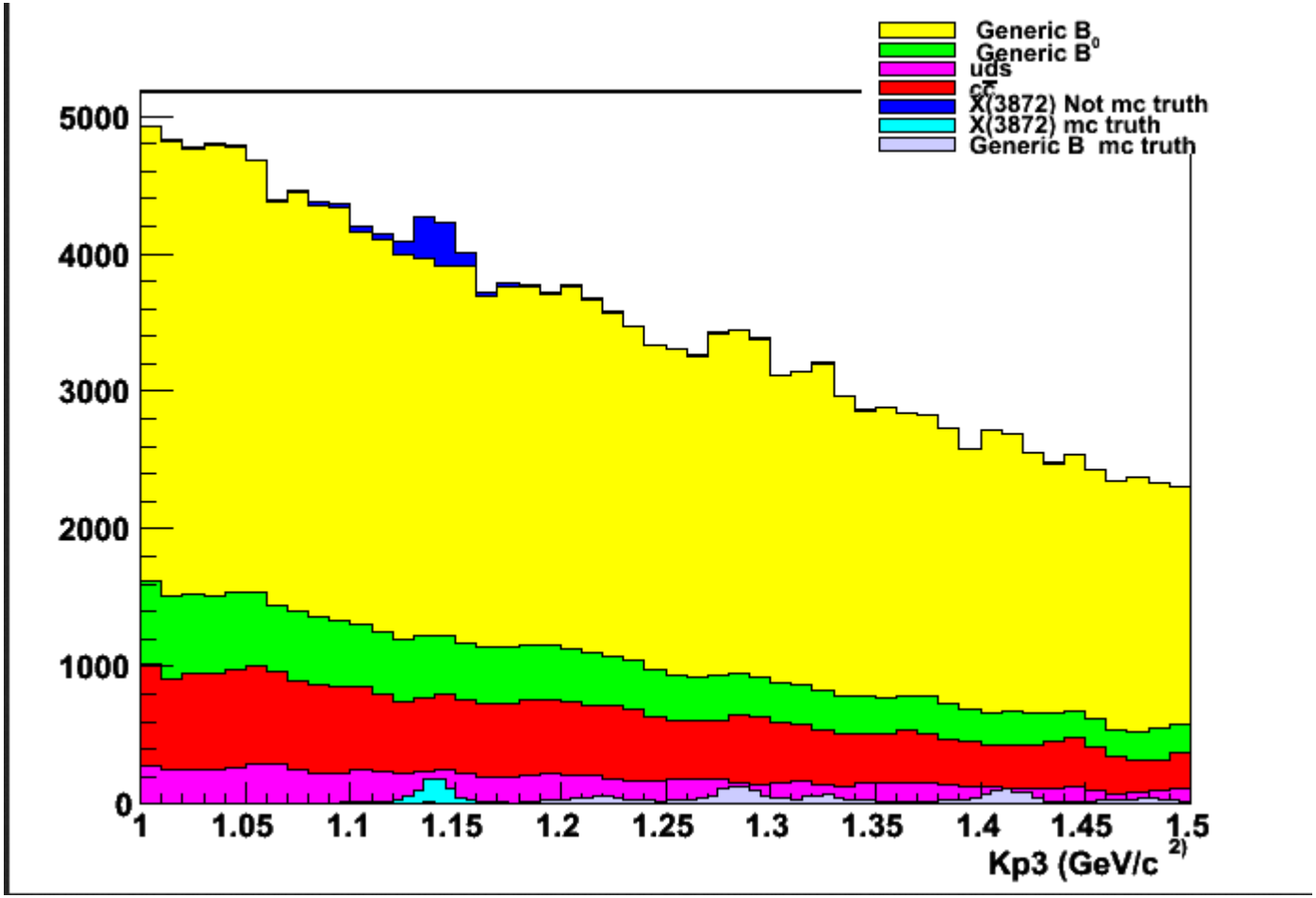


Smaller background in the 4.7-4.8 GeV region

Evolution cos



Visibility of a X3872 in BABAR with 1.3 ab-1 MC (Preliminary)



Expectations

- 1629 J/Psi reconstructed with 0.8 efficiency wrt final selection
- Total number of J/psi for MC (1.4 ab-1):
- 2100 expected, ie 1.5 j/Psi per fb1-> 600 for the full data sample to be compared with 250 in the old analysis
- Regarding the X, final sensivity not yet estimated but should be close to 10-4

Some very preliminary thoughts about inclusive analysis at LHCb

- AT LHCb, one does not have access to the B center of mass
- BUT, one knows the B direction of flight (ie the vector joining the primary vertex and secondary vertex.
- Typical precisions
  - x,y 8 microns/~20 microns
  - Z 100 microns
- Typical flight distance
  - xy 30 Microns
  - Z up to a few cms!
- Very good secondary vertex reconstruction in case of charmonium
- One constraint missing to « forget » one particle :
  - Can be provided by the mass of an intermediate resonance
  - The decay length is a crude measurement of the B energy (to be explored)

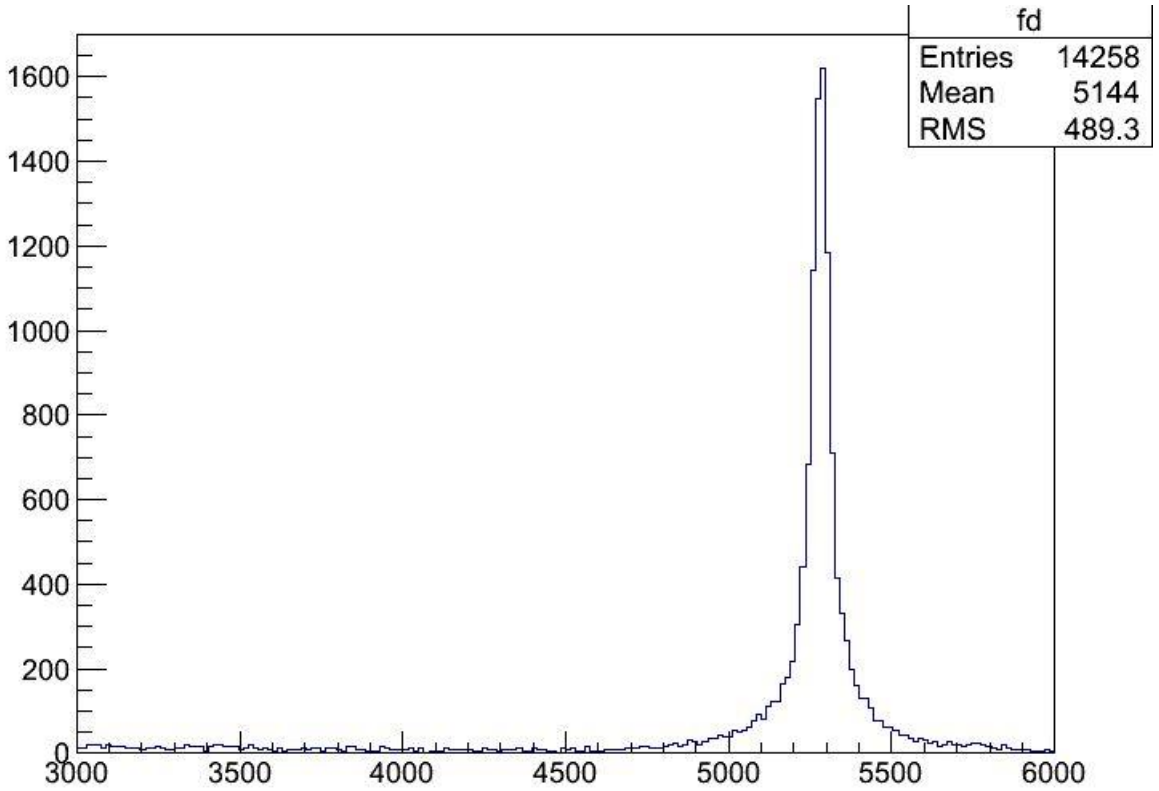
One simple example

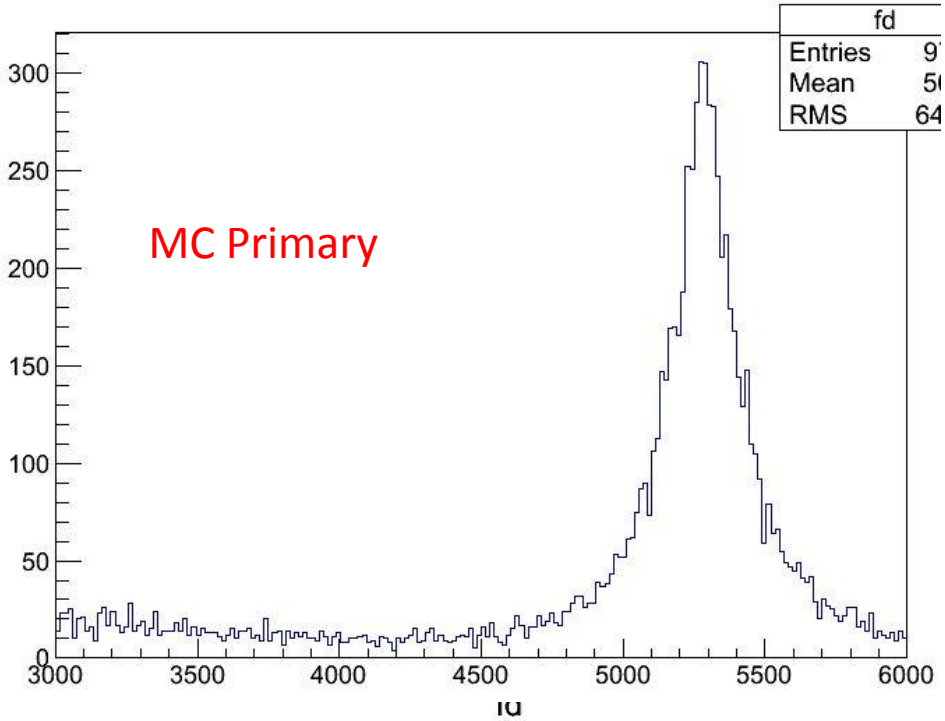
- B+-> Eta’ K+
  - Eta’ ->pi+pi_ gamma
- One forgets about the gamma and reconstructs only pi+pi- and K+
- Second degree equation to be solved to fully reconstruct the gamma and the B
  - Two solutions per event

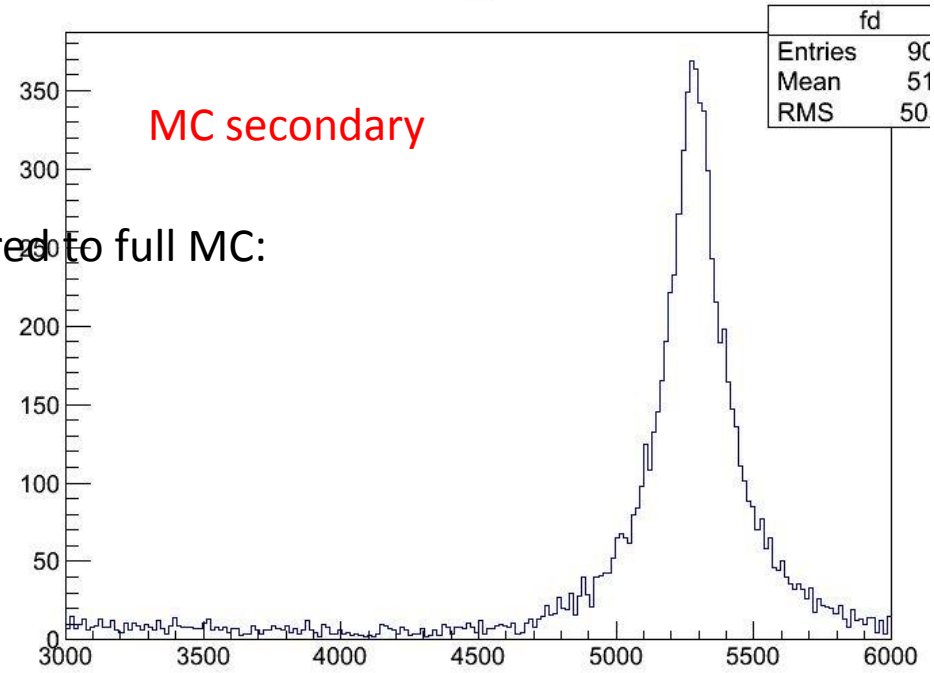
B mass reconstructed with partial technique

MC line of flight

2 entries per event
Sigma =30 MeV
efficiency ~70%



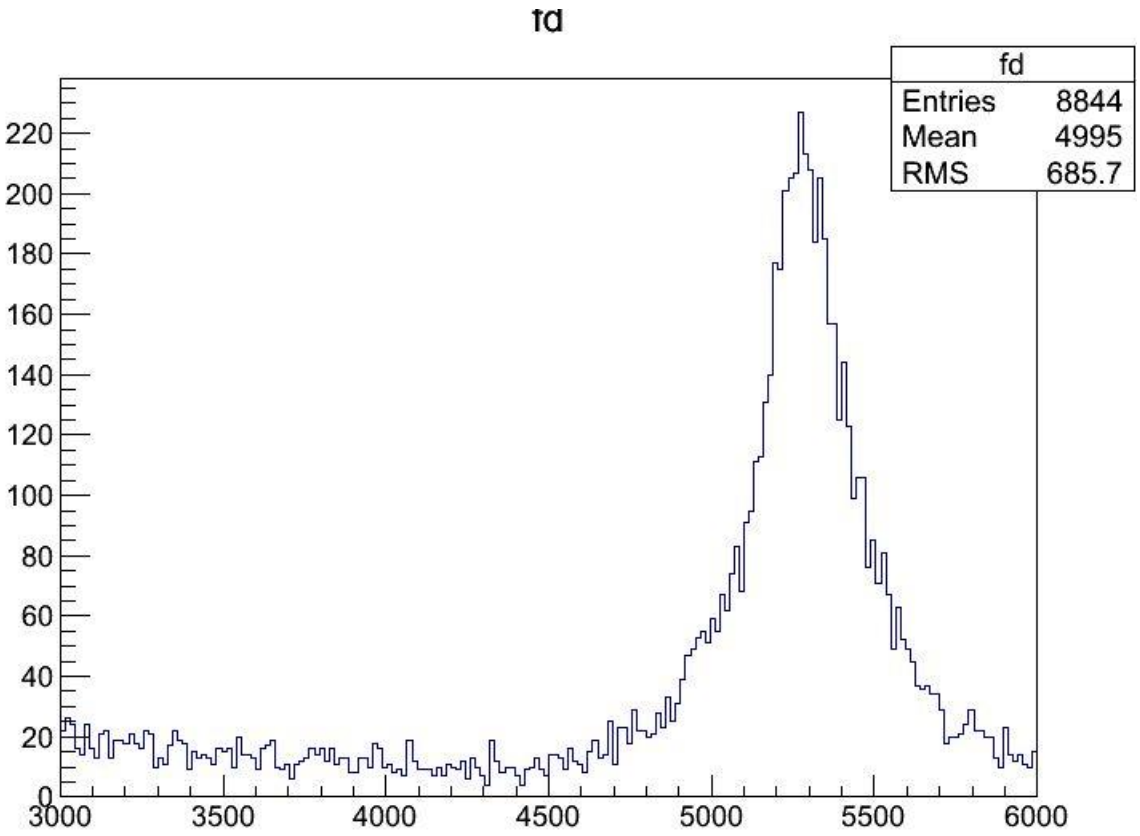




Important degradation compared to full MC:
sigma around 100 MeV

Mass distribution real vertex (MC) No cuts

2 entries per event
Sigma=200 MeV
Can we select events which will have a better mass resolution ?



Much better with charmonium (when using ther J/psi tracks at the secondary vertex)

- Sigma= 40 MeV

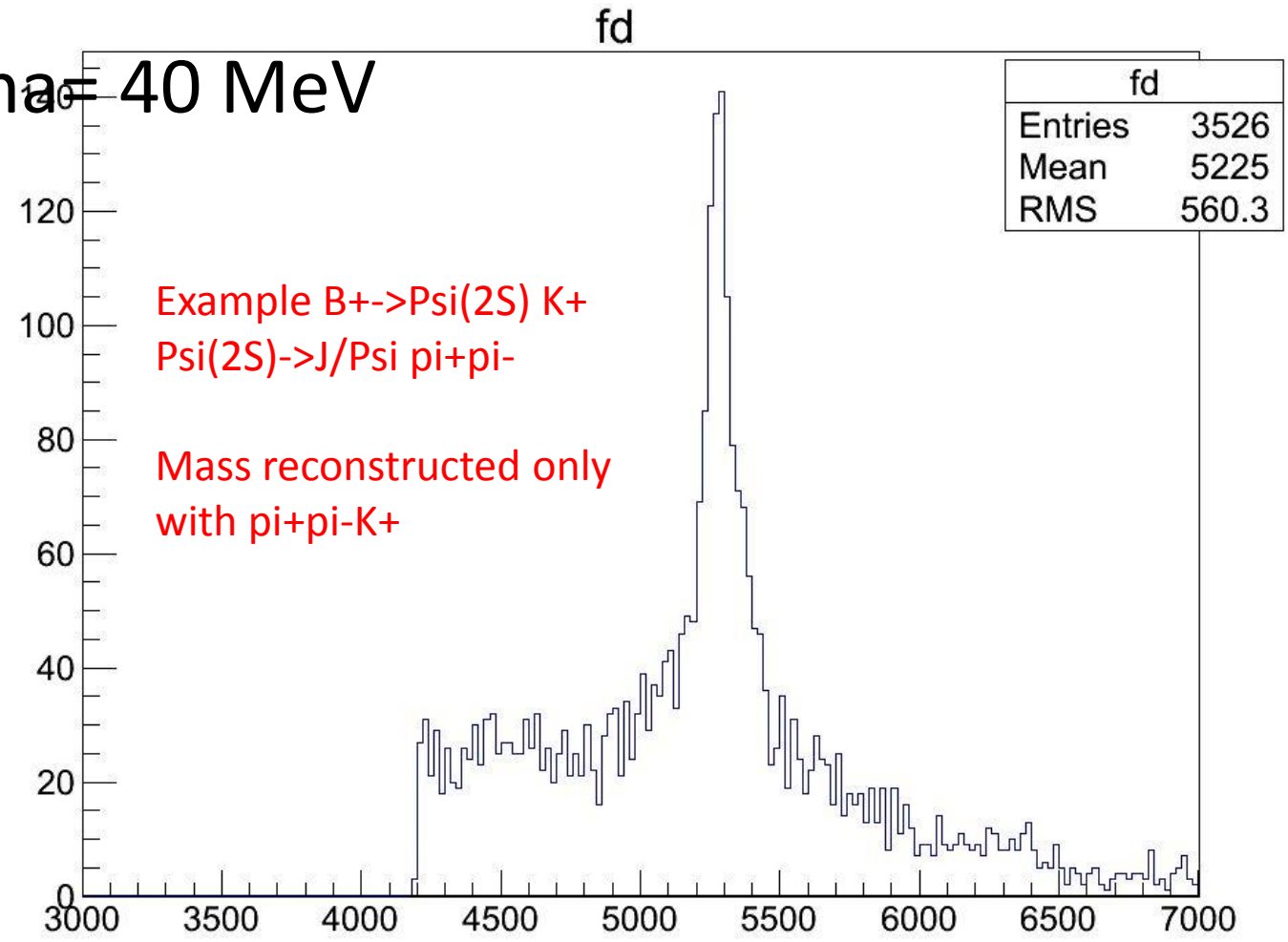


Table of interesting decays in the pipi mode –Low mass

	eta	omega	Eta’	phi					
Gamma			29						
pi0		85	43	15					
eta			40						
Omega									
Eta’									
	In each box, the BR in %								

Table of interesting decays in the pipi mode –High mass

	Eta_c	Psi	chi	psip	X3872	Y	Z		
Psi				65	Stat?	Stat?			
Eta_c					X	X			
chi					X	X			
Psi-2S					X	X			

Also possible to « project » charmonia state into light mesons

Conclusion

- Original results produced by inclusive charmonium method study in BABAR in 2005. (B. Aubert et al. **Phys.Rev.Lett. 96 (2006) 052002)**
  - Still the only one on the market!
- Unique results on absolute BR
- Update of the 2004-2005 analysis quite relevant
- Expected Increase in stats between 2.6 (guaranteed) and 4
  - Should be ready for summer conferences
- Will give improved precision on low mass charmonium and new results or limits on X,Y,Z up to 4.8 GeV/c with a sensitivity close to 10**-4
- Inclusive analysis also possible at LHCb to study states not easy to fully reconstruct
  - Could be interesting to « project » X,Y,Z states to other charmonia states than J/psi