Light Meson Spectroscopy in LHCb.

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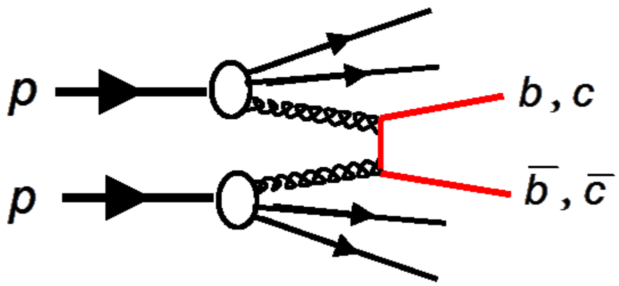
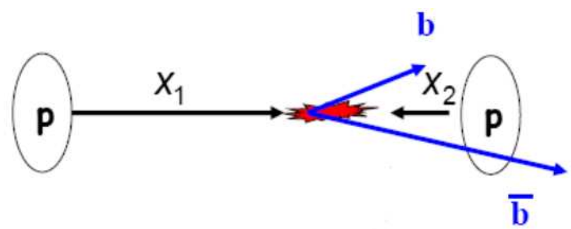
Summary:

- The LHCb experiment
- Light meson spectroscopy in:
  - Charm and B_s decays.
  - Charmless B decays.
  - $B \to D^* X$ decays.
- Conclusions.

The LHCb experiment.

□ LHCb experiment is collecting very large samples of $c\bar{c}$ and $b\bar{b}$ events.



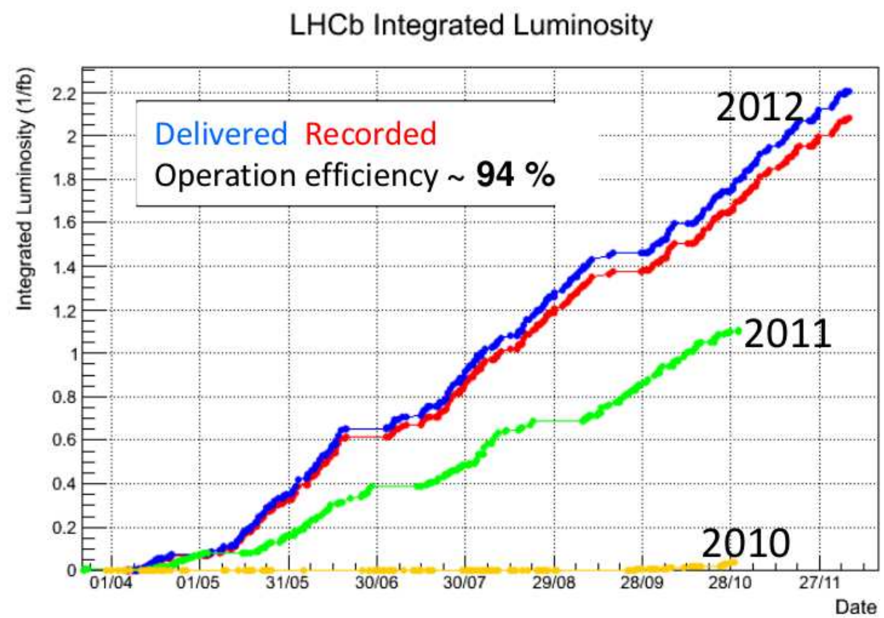


$\sigma(b\bar{b}) \quad at\ 7\ TeV \ \approx 290\ \mu b$

□ Expect a 15% increase in the 2012, 8 TeV run.

□ Expect a 100% increase in the 2015, 14 TeV run.

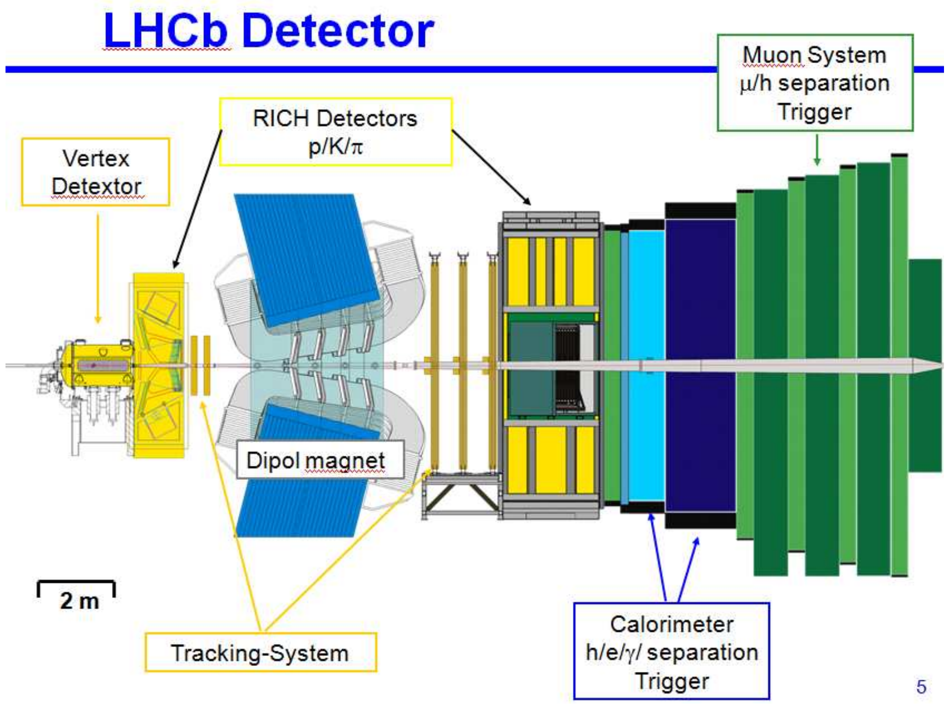
$\sigma(c\bar{c}) \approx 20 \times \sigma(b\bar{b})$

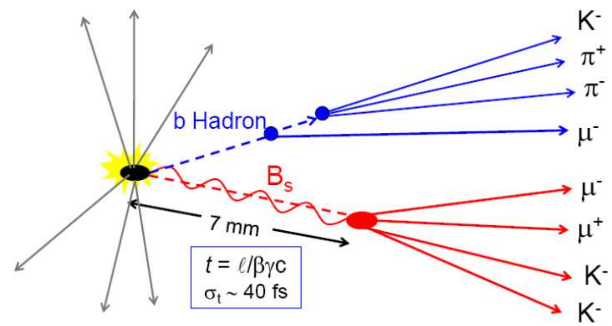


□ Collected $\approx 3.2\ fb^{-1}$.

□ Present publications deal mostly with 1 fb^{-1} 2011 data.

The LHCb experiment.

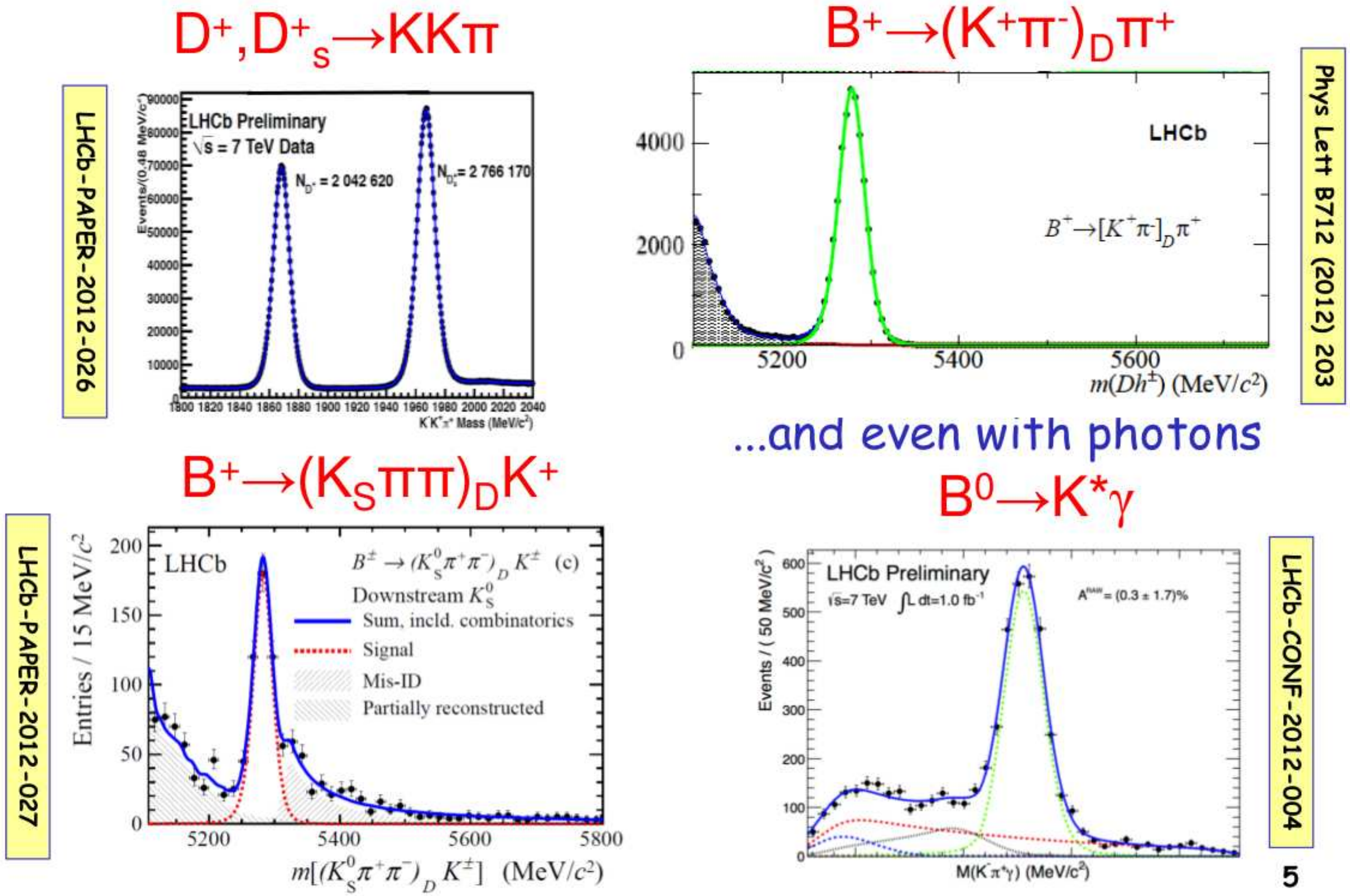




- □ Precise reconstruction of primary and secondary vertices (resolution = 45 fs for $B_s \to J/\psi\phi$.
- □ Excellent K/π separation (K identification efficiency = 95% with 5% of pion misidentification).
- □ All type of B hadrons produced:($B^{\pm}$, B^0, B^0_s, b-baryons, $B^{\pm}_c$).
- □ Main issue for B and charm physics is the large vertex separation. Big boost, long-lived particles fly over long distances.
- □ Easy secondary vertex separation.

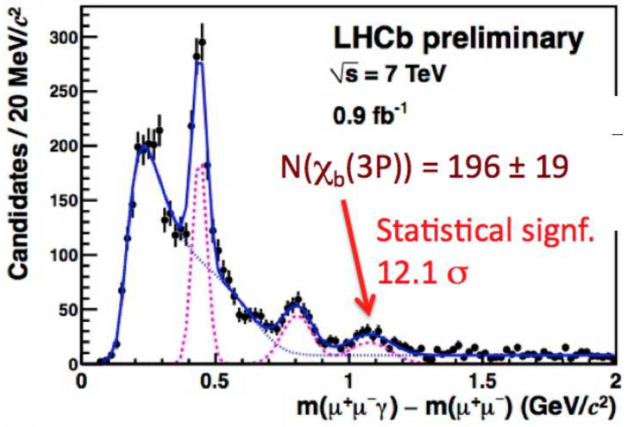
The LHCb experiment.

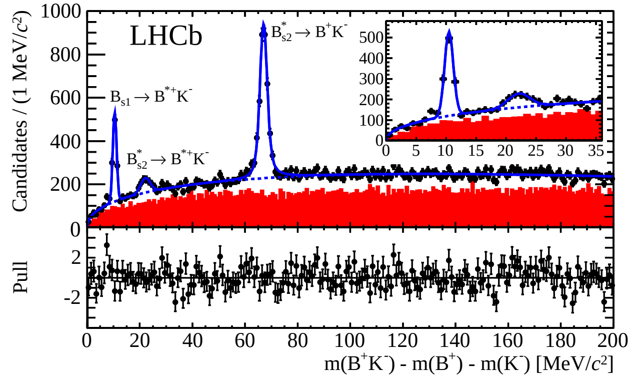
☐ Some examples of reconstructed charmed and B mesons.



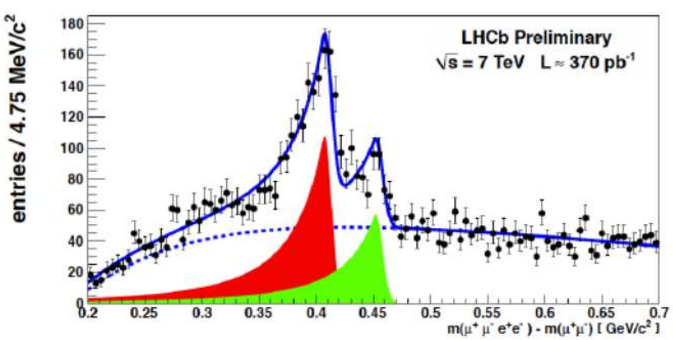
Spectroscopy in LHCb experiment.

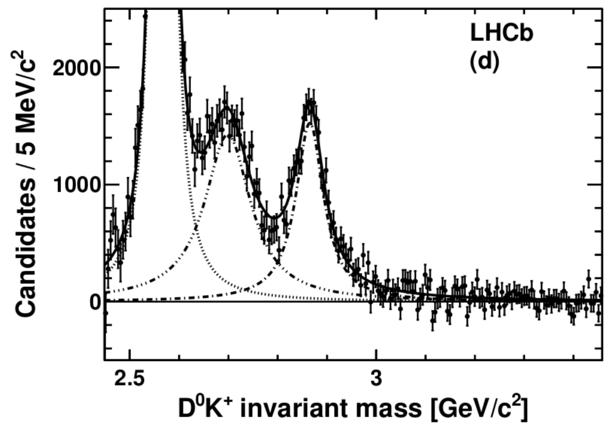
- Spectroscopy is being studied from $b\bar{b}$ states to B_c, B_s, B, charmonium, charm, etc.
- A few examples:
- χ_b (Observation of $\chi_b(nP) \to \Upsilon(1S)\gamma$) and B_s^* spectroscopy (Observation of new B_s^* states).





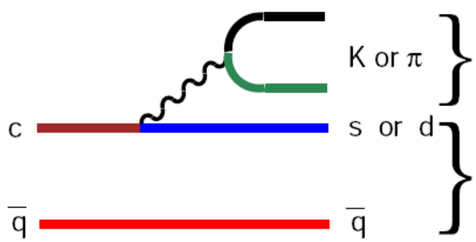
- ($\chi_c \to J/\psi\gamma$ states with converted photons), D_s^* spectroscopy (new D_{sJ}^* states).





Possible Light meson Spectroscopy.

- From past hadronic experiments we gained information on the structure of the light mesons.
- With the availibility of large samples of charmed and B mesons decays, we can obtain new information, which complement or supersede past measurements.
- In particular, D mesons decays are more coupled to $u\bar{u}$, $d\bar{d}$ states, while D_s^+ and B_s mesons are more coupled to $s\bar{s}$ mesons.



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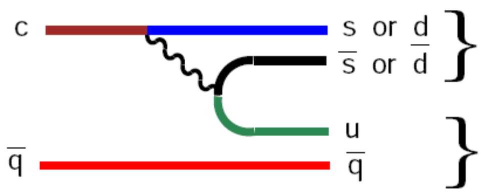
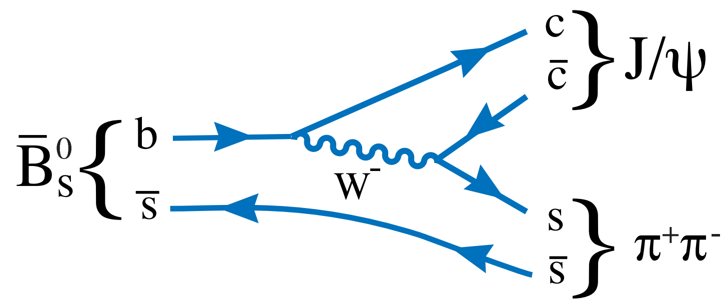


Internal



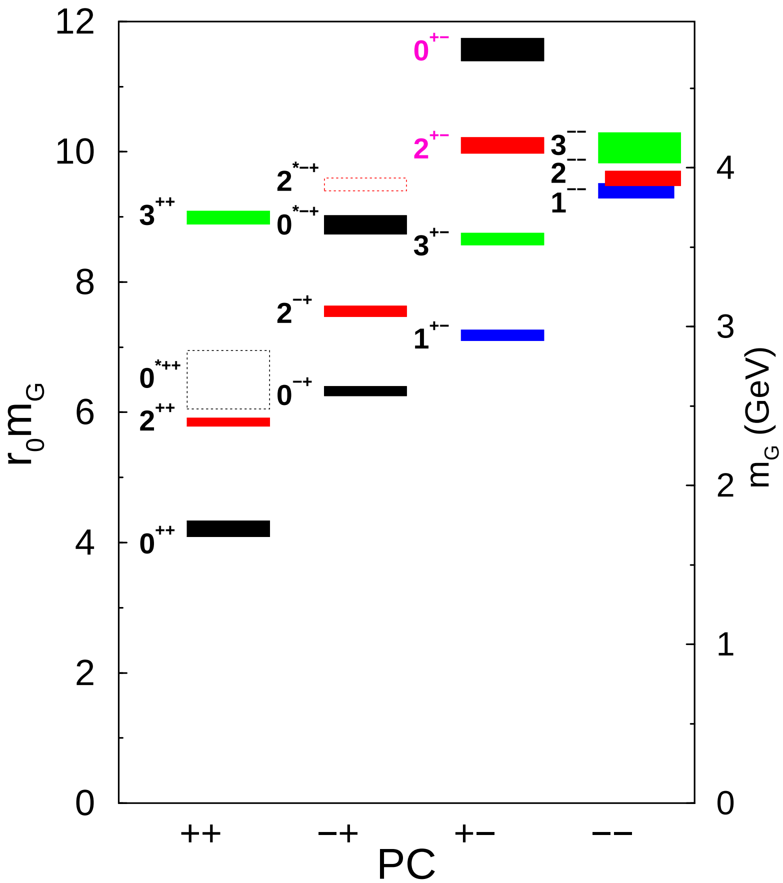
- The table of the scalar mesons.
- Two nonets? 4-quark states? Gluonium?
- Are the $k(800)$ and σ true resonances?

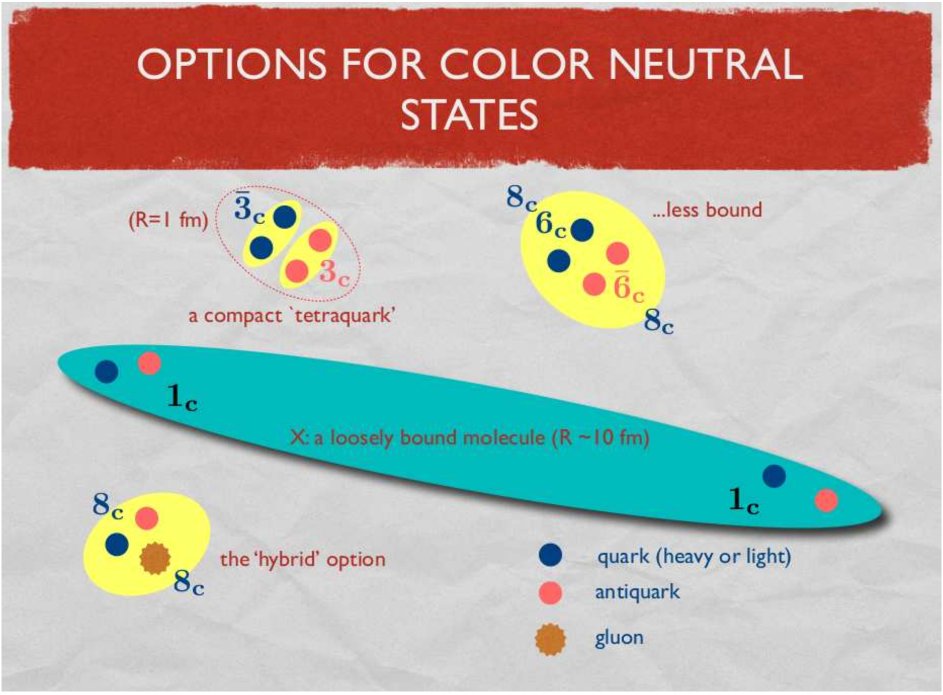
I = 1/2	I = 1	I = 0
$k(800)$		σ
	$a_0(980)$	$f_0(980)$
		$f_0(1370)$
$K_0^*(1430)$	$a_0(1490)$	$f_0(1500)$
		$f_0(1700)$
$K_0^*(1950)$		

Exotic mesons.

☐ Within these states may hide exotic mesons such as gluonium or molecular states.

☐ Glueballs Spectrum from Lattice QCD (see arXiv:0708.4016,hep-ph/0601110) and possible exotic mesons from A. Polosa (CHARM2012).



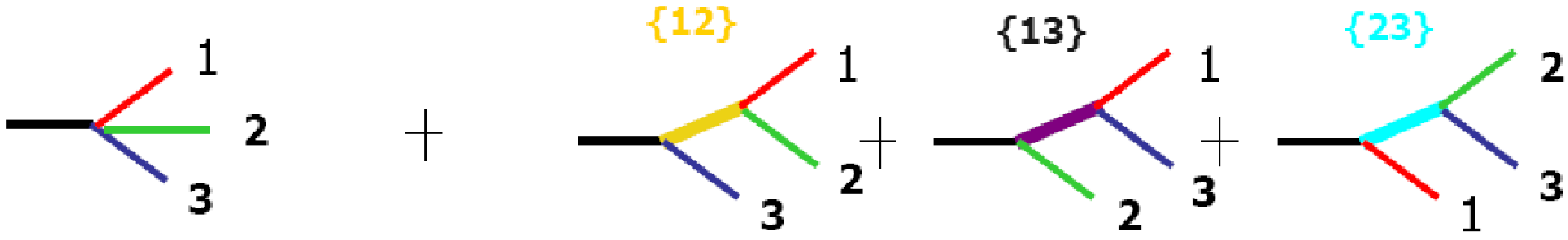


☐ The scalar glueball and light hybrid mesons are expected to have a mass below 2 GeV.

New information on Scalar Mesons from charm and B_s decays.

□ Charmed mesons decay to light hadrons, therefore a fundamental laboratory for studying light meson spectroscopy, especially for spin 0 and spin 1 mesons.

□ Isobar model: the decay proceedes through a (flat?) Non Resonant contribution + intermediate resonance production:



□ In some cases some of the decay channels can be switched off by physics.

□ Model-Independent Partial Wave Analysis (Introduced by B. Meadows, Experiment E791).

□ BaBar has performed a Dalitz plot analysis of $D_s^+ \to \pi^+\pi^-\pi^+$ (arXiv:0808.0971).

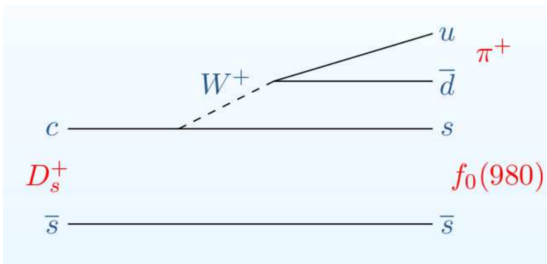
□ Instead of including the $\mathcal{S}$-wave amplitude as a superposition of relativistic Breit-Wigner functions, the $\pi^+\pi^-$ mass spectrum is divided into 29 slices and the $\mathcal{S}$-wave is parametrized by an interpolation between the 30 endpoints in the complex plane:

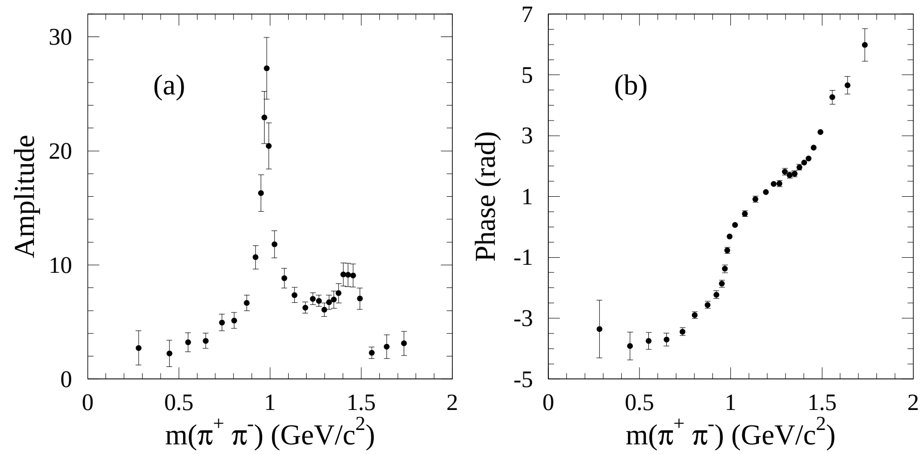
$$A_{\mathcal{S}-\mathrm{wave}}(m_{\pi\pi}) = \mathrm{Interp}(c_k(m_{\pi\pi})e^{i\phi_k(m_{\pi\pi})})_{k=1,..,30}. \quad (1)$$

□ The amplitude and phase of each endpoint are free parameters.

Dalitz Plot Analysis of $D_s^+ \to \pi^+\pi^-\pi^+$

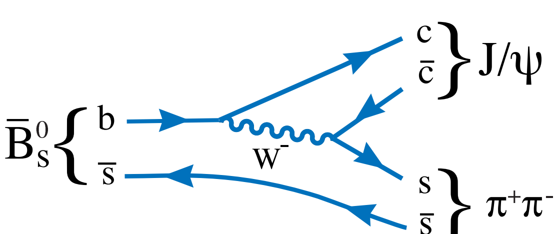
□ Resulting $\mathcal{S}$-wave $\pi^+\pi^-$ amplitude and phase.

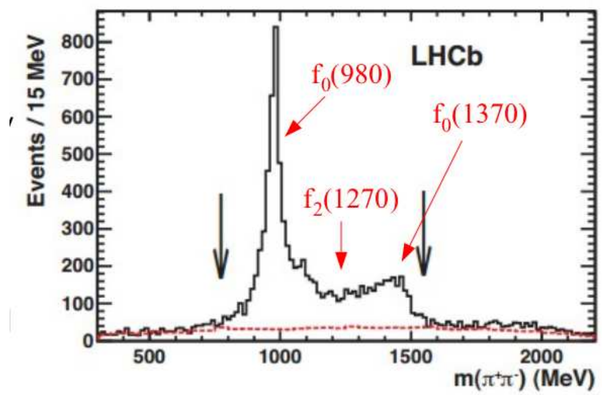




□ Dalitz analysis of $B_s \to J/\psi\pi^+\pi^-$ at LHCb (arXiv:0804.0411), ≈ 7600 events.

□ Use Isobar model.





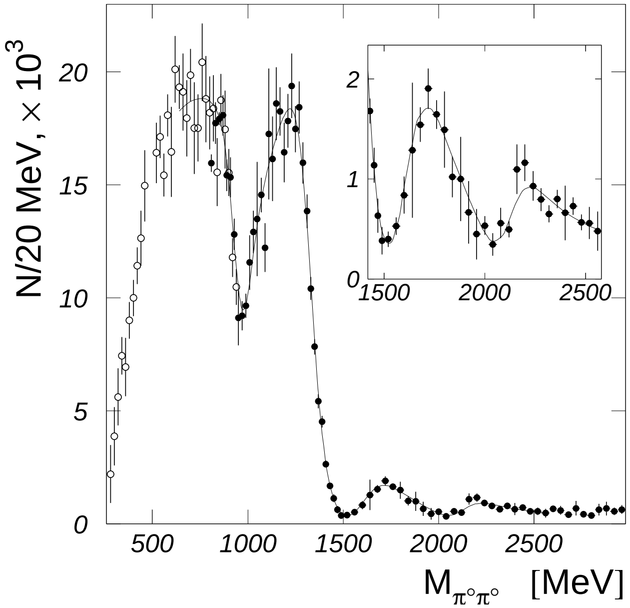
□ Decay dominated by scalar mesons. The largest component is the $f_0(980)$. The data are best described by adding the $f_0(1370)$, the $f_2(1270)$ and a non-resonant contribution.

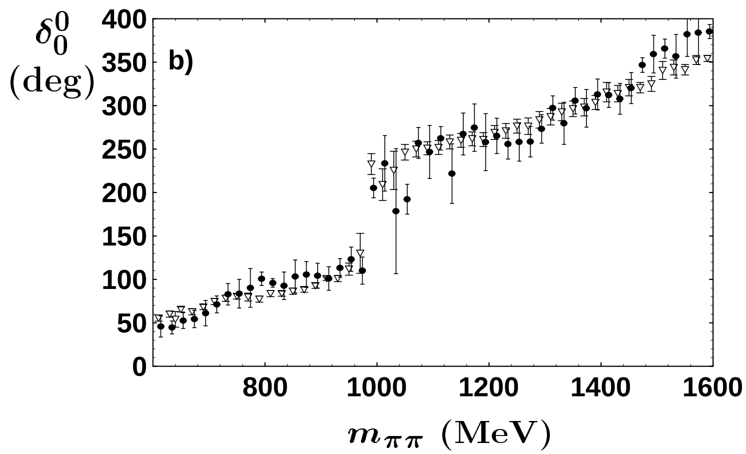
□ Impressive similarities between the $\mathcal{S}$-wave in D_s^+ and B_s decays.

Scalar mesons: the σ.

□ The σ is a very wide amplitude extending from the $\pi\pi$ threshold up to 1.5 GeV. (arXiv:0708.4016)
□ The $\pi\pi$ amplitude and phase has been measured in:

$$\pi^- p \longrightarrow \pi\pi n$$





□ Slowly moving phase: a broad resonance? $\sigma(500)$?
□ The spectrum can be understood in terms of a slowly moving phase with the presence of a narrow $f_0(980)$ resonance and broader $f_0(1400)/f_0(1500)/f_0(1700)$ resonances.
□ Alternative proposal: The $\sigma(500)$ identified as the scalar glueball (**Red Dragon**) (hep-ph/9811518).
□ The existence of the $\sigma(500)$ as a resonance has been recently triggered again by the Dalitz Plot analysis of $D^+ \to \pi^+\pi^+\pi^-$ (E791) ($\approx$ 1200 events) (hep-ex/0007028).
□ They extract the following σ parameters: $m = 478 \pm 24 \pm 17\ MeV, \Gamma = 324 \pm 41 \pm 21\ MeV$

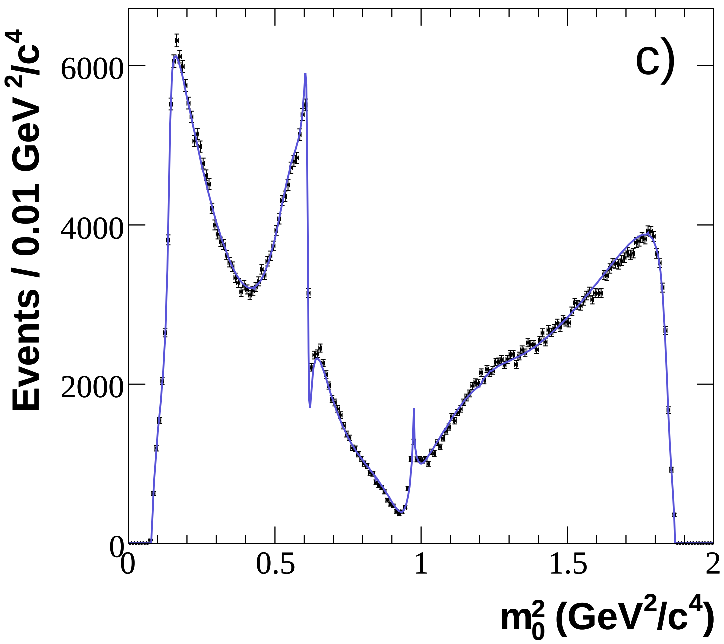
The $\pi\pi$ $\mathcal{S}$-wave in B and charm decays.

□ Two methods are currently used.

□ The isobar model. Amplitude described in terms of several overlapping resonances. (Violates unitarity).

□ K-matrix approach. Include information from past experiments. Good description of the data.

□ Example from BaBar. $\pi\pi$ projection of the $D^0 \to K^0_S \pi^+\pi^-$ Dalitz plot. (arXiv:0804.2089).



□ However these approaches do not add new information on our understanding of the $\pi\pi$ S-wave.

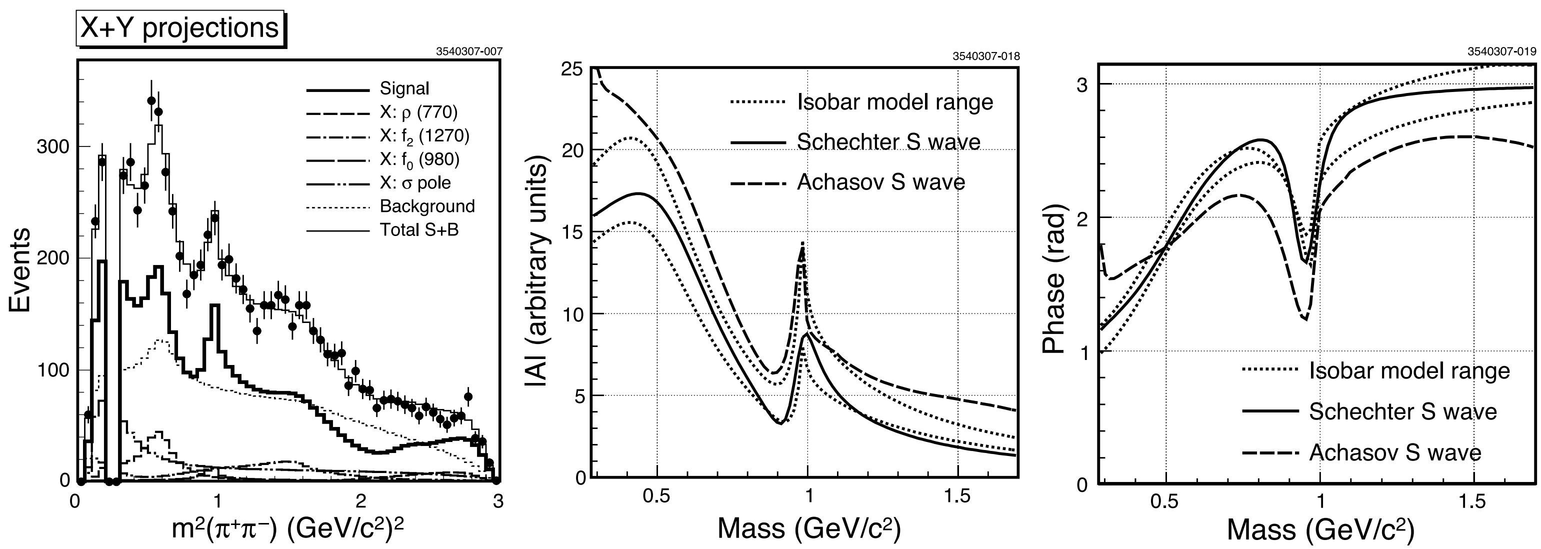
Dalitz analysis of $D^+ \to \pi^+\pi^+\pi^-$ from CLEO.

□ Data collected at the $\psi(3770) \to D^+D^-$ resonance (arXiv:0704.3954) ($\approx$ 2600 events).

□ They perform a Dalitz analysis using three different models: isobar, Schechter and Achasov.

□ The isobar model includes the best description of the σ and the Flatté parameterization for the threshold effects on the $f_0(980)$.

□ Comparison between three different models for the $\pi\pi$ S-wave.



□ LHCb has accumulated very large samples of $D^+ \to \pi^+\pi^+\pi^-$ decays. $\approx$ 2.9 M events in 2011 data only.

□ A Model Independent PWA can be performed to extract the $\pi\pi$ $\mathcal{S}$-wave.

□ Technical issue: very large computer time needed. Integrals need to be recomputed at each minimization step.

□ In the case of $D^+ \to K^-\pi^+\pi^+$, with 600 K events and 50 bins (110 parameters): 3 days on a normal workstation.

Charmless B decays

□ These decay have been studied mostly for CP violation studies.

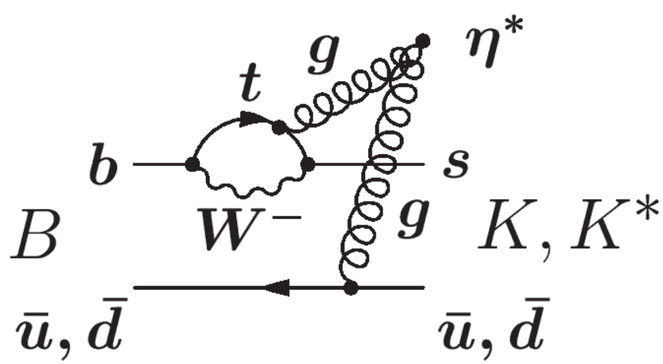
□ However there are issues related to the search for exotics.

□ The possibility of searching for gluonium in B decays has been suggested by the experimental measurement of a large decay rate for:

$$B \to \eta' X, \qquad B \to \eta' K$$

□ The diagram giving rise to these processes can be:

$$b \to sg$$



□ There are arguments in favour of a gluonic content of the η', therefore gluonium states may be produced in B decays.

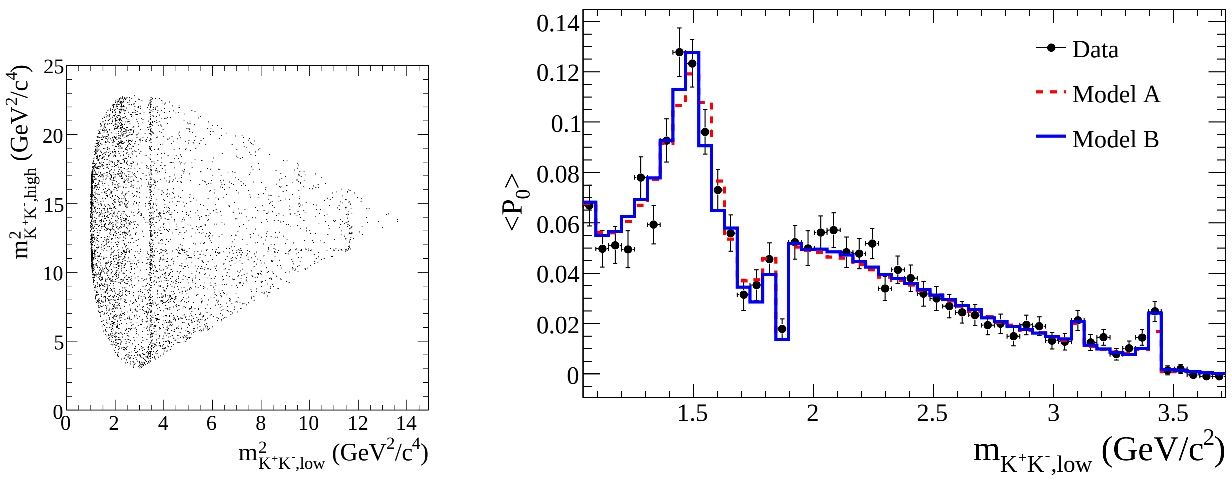
H. Fritzsch, Phys. Lett. B415 (1997) 83

P. Minkowski and W. Ochs hep-ph/0404194

$B^+ \to K^+K^-K^+$.

□ BaBar and Belle have studied the $B^+ \to K^+K^-K^+$.

□ Dalitz plot from BaBar ($\approx$ 5300 events) (arXiv:1201.5897).



□ One important goal is to understand the nature of the so-called $f_X(1500)$ resonance. The $f_0(1500)$ resonance, discovered in $\bar{p}p$ annihilations, was claimed for long time to be a gluonium state.

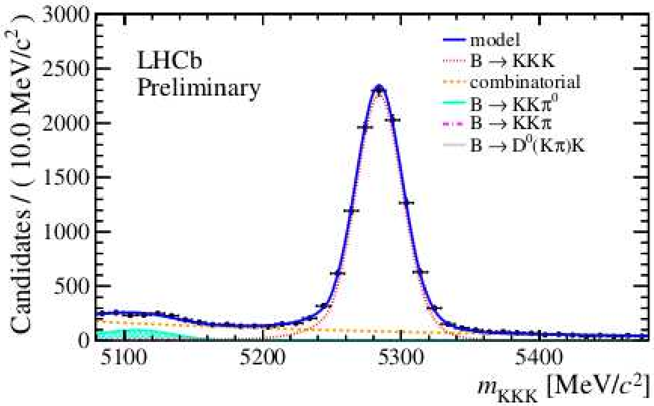
□ Both BaBar and Belle have modeled this resonance as a scalar particle, but while BaBar has found its mass and width to be inconsistent with any established resonance, Belle has found a mass and width consistent with the $f_0(1500)$.

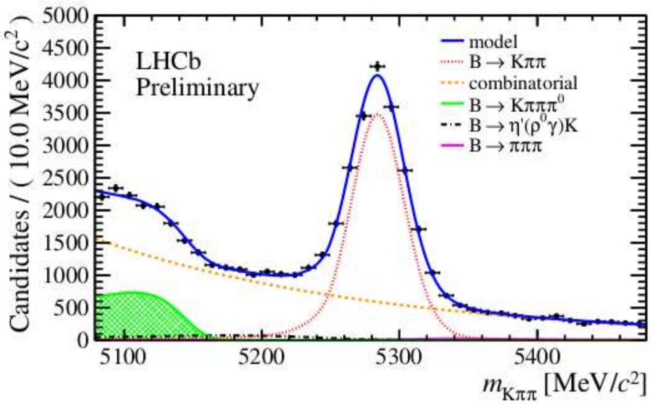
□ In a new analysis BaBar concludes that the hypothetical particle $f_X(1500)$ is not a single scalar resonance, but instead can be described by the sum of established resonances $f_0(1500)$, $f_2'(1525)$, and $f_0(1710)$.

$B^+ \to K^+K^-K^+$, $B^+ \to K^+\pi^+\pi^-$ in LHCb.

□ LHCb has reconstructed $B^+ \to K^+K^-K^+$ and $B^+ \to K^+\pi^+\pi^-$ for a study of CP violation.

□ Mass spectra ($\approx$ 22 K and 36 K events).

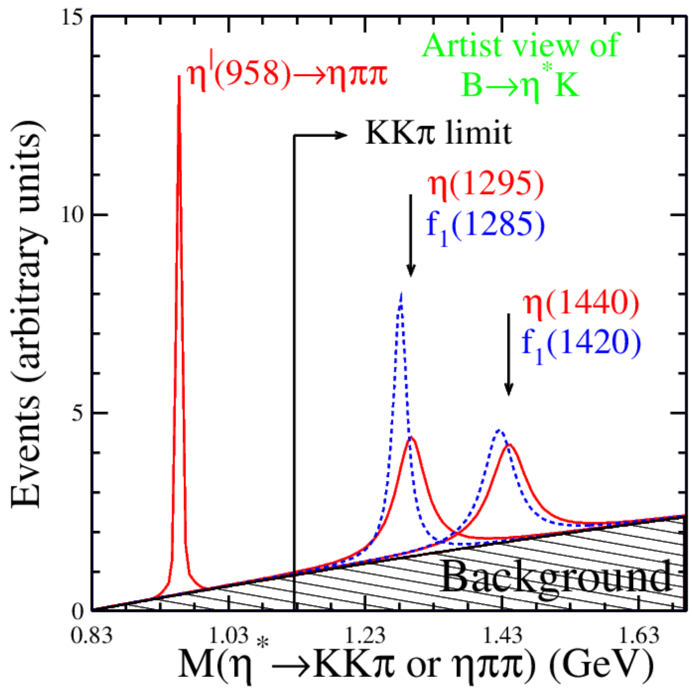




□ With more statistics it could be possible to perform a Model Independent PWA to extract the KK and $\pi\pi$ $\mathcal{S}$-wave on a very wide mass range.

Search for the pseudoscalar glueball.

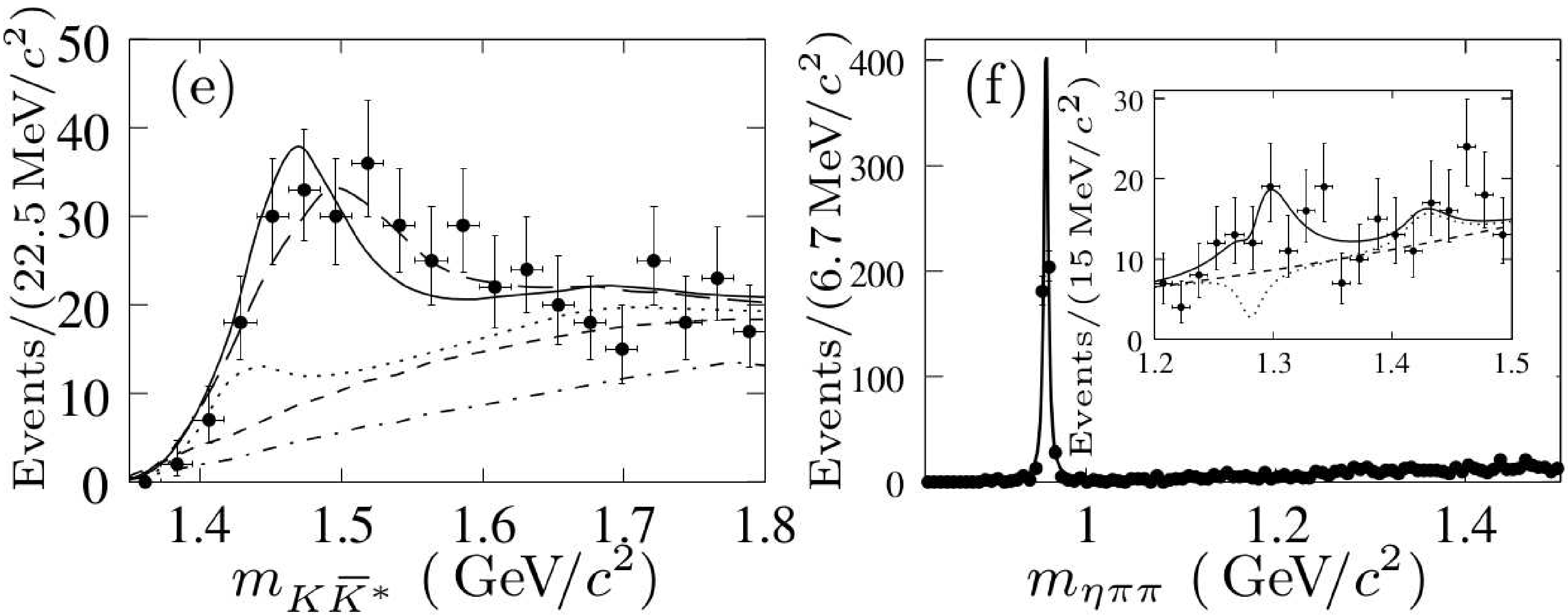
□ For many years a discussion has been taken place on the possibility that radiative J/ψ decays could be a source of gluonium states.
□ In particular the $\iota/\eta(1400)$ resonance, observed $J/\psi \rightarrow \gamma\iota$ was supposed to be the pseudoscalar glueball.
□ More careful analysis has revealed the ι to consist by three different resonances.



□ These states can be searched for in charmless B decays.

Search for the pseudoscalar glueball.

□ BaBar has searched for these states in $B \to K(K_S^0 K\pi)$ and $B \to K(\eta\pi\pi)$ (arXiv:0804.0411).

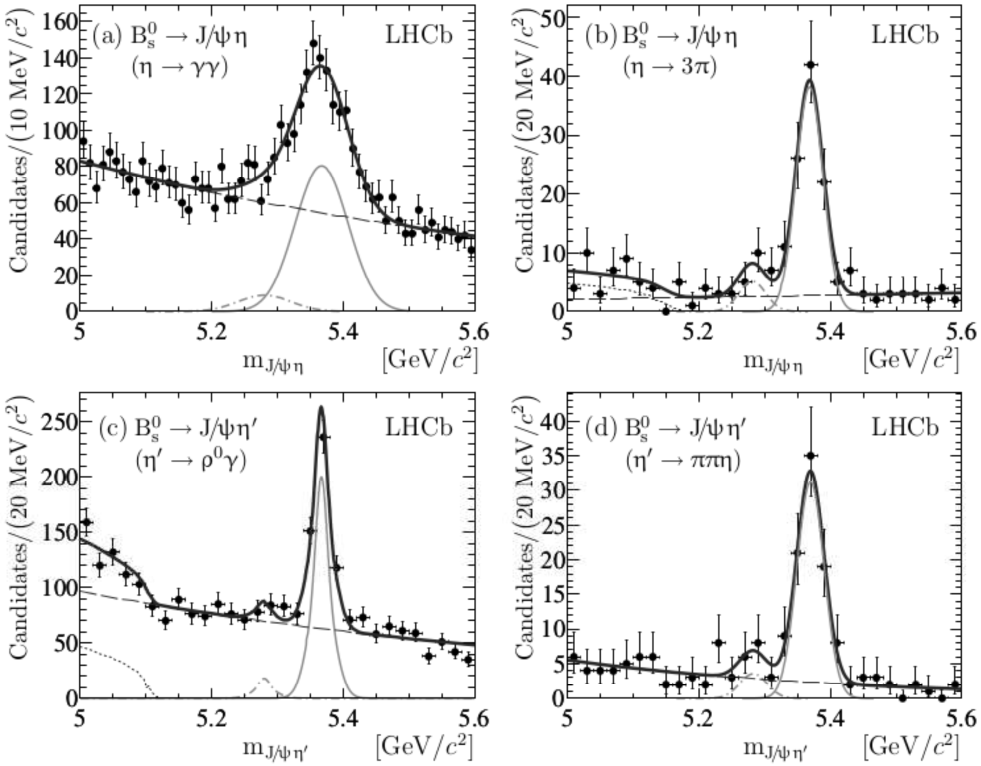


□ A $\eta(1475)$ signal has been observed with $\mathcal{B}(13.8^{+1.8+1.0}_{-1.7-0.6})\,10^{-6}$ and evidence for $\eta(1295)$ has been found with $\mathcal{B}(2.9^{+0.8}_{-0.7} \pm 0.2)\,10^{-6}$.

□ Scale factor. With $\mathcal{B}(B^+ \to K^+K^-K^+) = 34.6\ 10^{-6}$ LHCb obtains 22 K events.

Charmless B decays to η or η'?

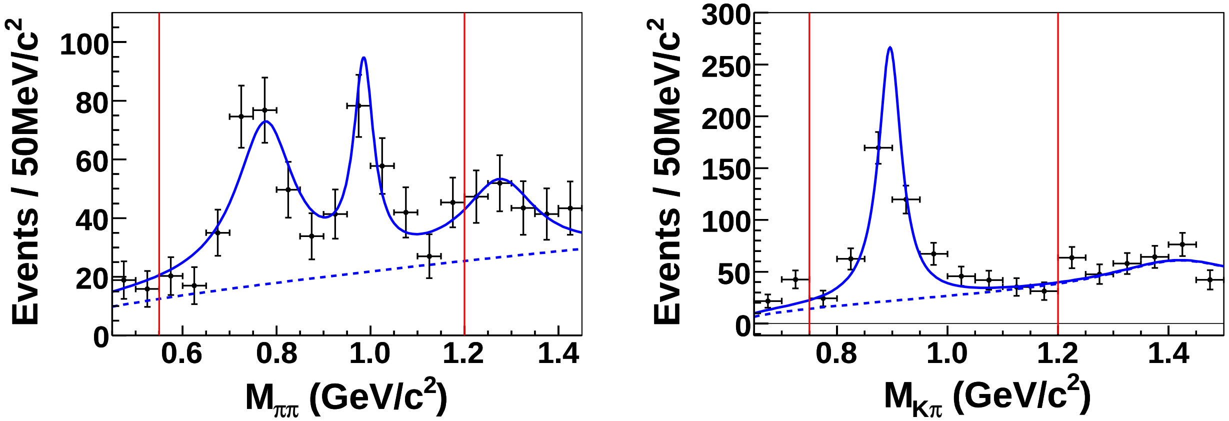
- LHCb is able to reconstruct B decays to η and η'.



- Possible exotic states are suggested to decay to $\eta\pi$ or $\eta'\pi$.
- $B \to K\eta^{(')}\pi$ could be reconstructed in a search for exotic resonances.

Charmless B decays to 4-body

□ Other possibilities involve $B^0 \to K^-\pi^+\pi^+\pi^-$. This decay mode has been reconstructed by Belle arXiv:0905.0763.



□ Branching froctions for resonant modes are of the order of a few 10^{-6}.

Light meson spectroscopy in B decays with charm.

□ Another possibility of using the Dalitz analysis is to perform a mass dependent Partial Wave Analysis. See the unpublished PhD thesis on BABAR data (http://www.infn.it/thesis/PS/getfile.php?filename=563-Monorchio-dottorato.ps).

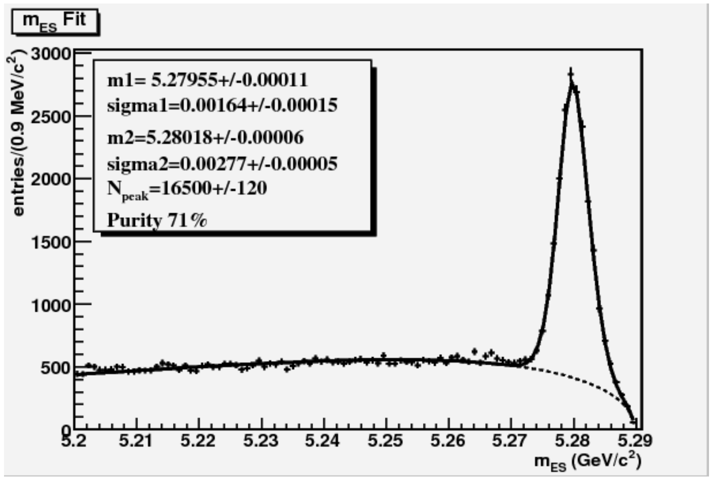
□ They study the decay:

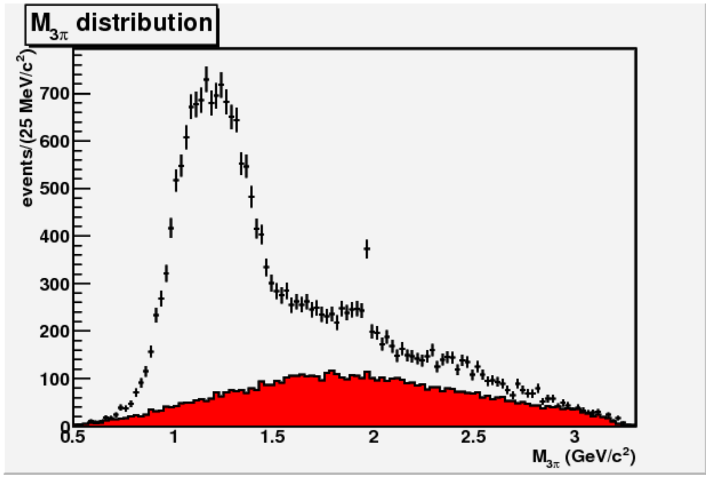
$$B^0 \to D^{*+}(\pi^+\pi^-\pi^-)$$

divide the $(\pi^+\pi^-\pi^-)$ mass spectrum in slices and perform a Dalitz analysis in each slice.

□ Then plot the resulting yields for each partial wave as a function of the $(\pi^+\pi^-\pi^-)$ mass.

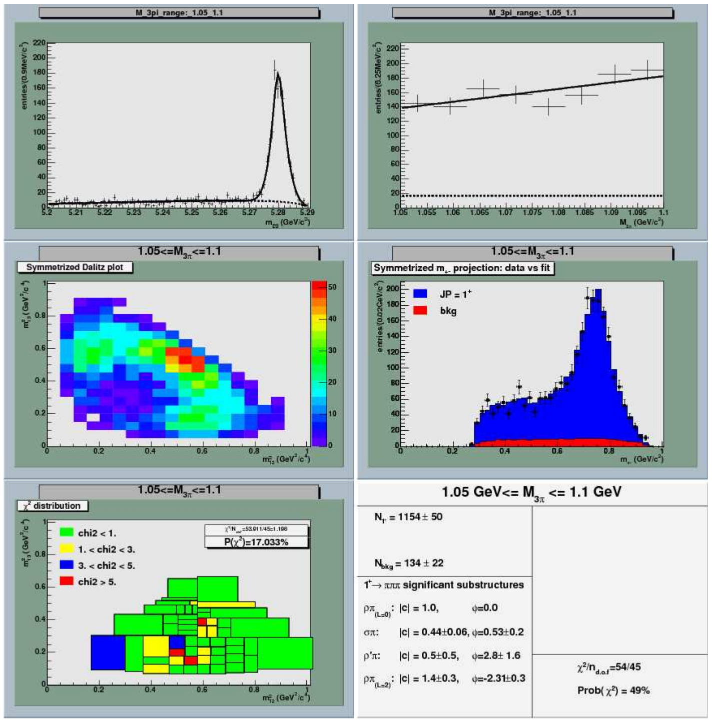
□ B^0 signal and $(\pi^+\pi^-\pi^-)$ mass spectrum with background in red.

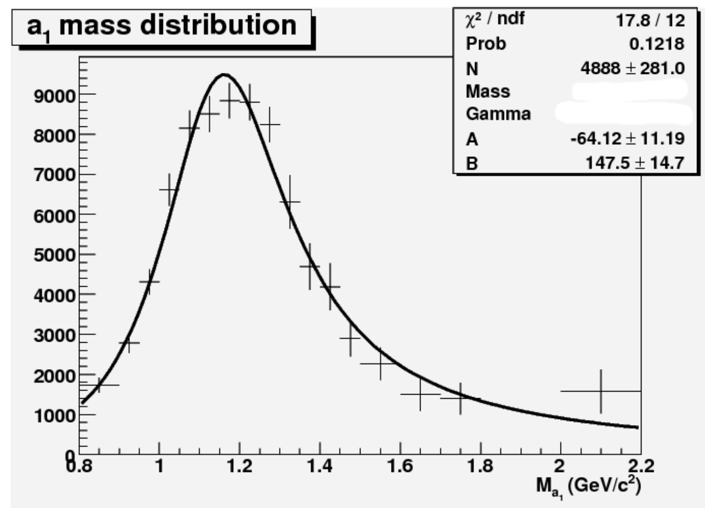




Light meson spectroscopy in B decays.

□ An example of a Dalitz analysis in a $(\pi^+\pi^-\pi^-)$ mass range.





□ The Dalitz analysis allows to measure partial branching fractions and lineshapes for each partial wave.

□ Plot of the $J^P = 1^+$ amplitude with a nice $a_1(1260)^+$ signal.

□ In 1 fb^{-1} LHCb has collected $\approx$ 7000 events with negligible background.

□ Other possibilities: $B \to D^* 4\pi$. $a_1(1260)^+\pi^-$ in S-wave can give exotic $J^{PC} = 1^{-+}$ quantum numbers.

Conclusions.

□ Very large datasets will be accumulated by LHCb in the next years.

Year	Energy	Int. Lumi.
2010	7 TeV	37 pb^{-1}
2011	2.76 TeV	71 pb^{-1}
2011	7 TeV	1.0 fb^{-1}
2012	8 TeV	2.2 fb^{-1}
2013	LHC splice repair	
2014		
2015	13 TeV 25 ns bunch crossing	> 5 fb^{-1}
2016		
2017		
2018	LHCb upgrade	
2019	5 fb^{-1}/year	
2020		
2021		
2022	LHC lumi upgrade	
2023		
2024		

□ There are interesting possibilities to obtain new information on the possible existence of light or heavy exotic mesons.

□ See the spectroscopy section in "Implications of LHCb measurements and future prospects" LHCb Collaboration arXiv:1208.3355.