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Searches for exotic baryonic states at LHCb

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Outline

I will highlight the recent progress on baryonic multiparticle modes
For non baryon modes please refer to Daniel Johnson's talk

- Unprecedented statistics on hadrons
- High cross sections for heavy quark production
- LHCb unique environment for baryon spectroscopy
- Pentaquark discovery (2015) opened a new field for exotics
- Searches of new states always ongoing!

In this talk I will cover:

- Observation of the decay $\Lambda^0_b \to \psi(2S) p \pi^-$

  ArXiv1806.08084

- Search for weakly decaying b-flavoured pentaquarks

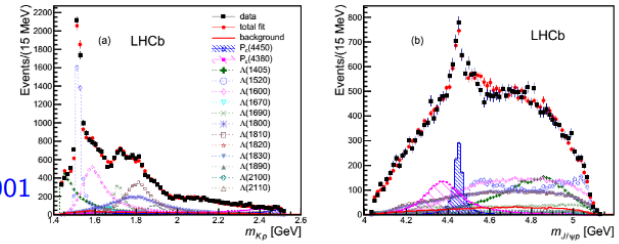
  PRD 97, 032010 (2018)

A brief history

Far from complete and beyond the scope of this talk, but a brief recap is necessary

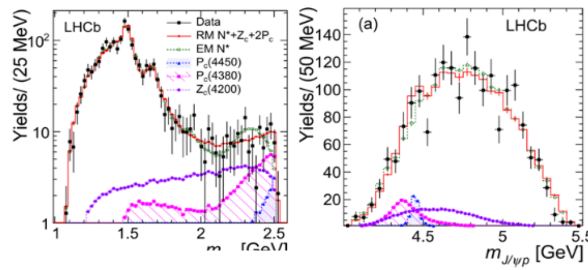
2015

1. $\Lambda_b^0 \to J/\psi\, pK^-$
First observation of pentaquarks
10.1103/PhysRevLett.115.072001



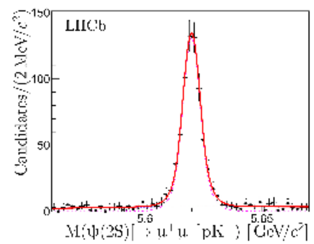
2016

2. $\Lambda_b^0 \to J/\psi\, p\pi^-$
Evidence for pentaquarks and tetraquarks
10.1103/PhysRevLett.118.119901



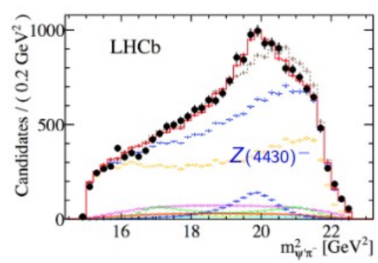
2016

3. $\Lambda_b^0 \to \psi(2S)pK^-$
The most precise measurement of $m_{\Lambda_b^0}$
10.1007/JHEP05(2016)132



This builds on
2014

4. $B^0 \to \psi(2S)\pi^- K^+$
First observation of the tetraquark $Z(4430)^-$
10.1103/PhysRevLett.112.222002



This is the history so far...

Observation of the decay $\Lambda^0_b \rightarrow \psi(2S) p \pi^-$

ArXiv1806.08084 (submitted 21st June)

Strategy

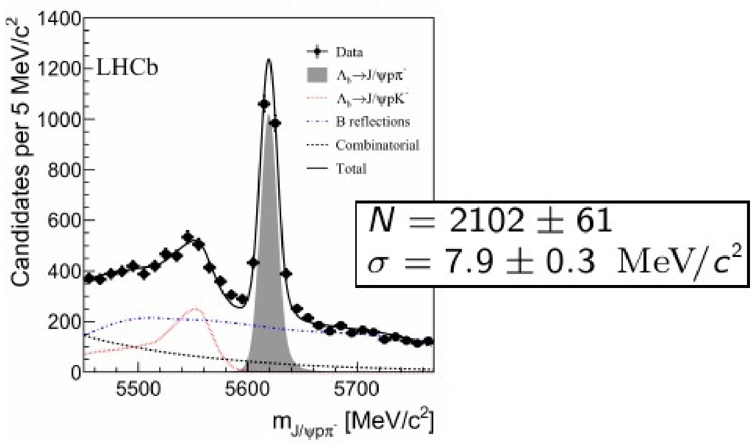
- Look to complete the picture of interesting decays → now look at CS decay
- Investigate and mass spectra of ψ(2S)p and ψ(2S)π
- DATASET 1.0, 2.0 and 1.9fb^{-1} of integrated luminosity at 7, 8 and 13TeV
- Channel under studies are:

$$\text{Signal: } \Lambda_b^0 \to \psi(2S)p\pi^- \; [\psi(2S) \to \mu^+\mu^-]$$
$$\text{Normalization: } \Lambda_b^0 \to \psi(2S)pK^- \; [\psi(2S) \to \mu^+\mu^-]$$
$$\text{Control: } \Lambda_b^0 \to J/\psi\, pK^- \; [J/\psi \to \mu^+\mu^-]$$

- Selection and strategy similar to other decays for consistency

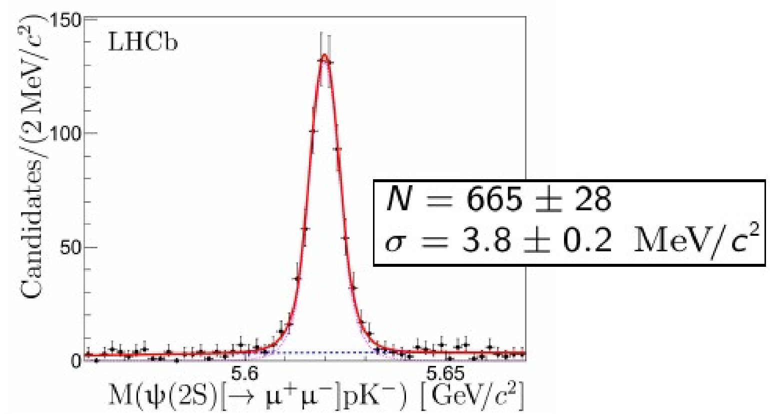
$\Lambda_b^0 \to J/\psi\, p\pi^-$

10.1007/JHEP07(2014)103



$\Lambda_b^0 \to \psi(2S)pK^-$

10.1007/JHEP05(2016)132



Selection & Analysis

ArXiv1806.08084

- Need to remove reflections from several modes, e.g.
- Several vetos applied

Reflection from $B_s^0 \to \psi(2S)K^+K^-$ with $K \to p$ and $K \to \pi$ misID

Loose cuts + $M(\psi(2S)p\pi^-) \in [5.56; 5.67]\,\mathrm{GeV}/c^2$ + veto($B^0 \to \psi(2S)K^+\pi^-$)

- The BF is then measured →

$$R_{\pi/K} = \frac{\mathcal{B}(\Lambda_b^0 \to \psi(2S)p\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \psi(2S)pK^-)} = \frac{N_{\psi(2S)p\pi^-}}{N_{\psi(2S)pK^-}} \times \frac{\varepsilon_{\psi(2S)pK^-}}{\varepsilon_{\psi(2S)p\pi^-}},$$

- Split by year
- Recombine according to Lumi
- Several checks for consistency

where N — yield and ε — total efficiency in certain channel:

$$\varepsilon = \varepsilon^{gen\&acc} \times \varepsilon^{rec\&sel} \times \varepsilon^{trig} \times \varepsilon^{PID}.$$

$\varepsilon^{gen\&acc}$, $\varepsilon^{rec\&sel}$, ε^{trig} } from MC

ε^{PID} — data-driven method

Results (1)

- Many systematics considered

Source	Uncertainty [%]
Fit model	0.7
Track reconstruction and hadron identification	0.2
Trigger	1.1
Selection criteria	1.0
Size of the simulation samples	0.5
Total	1.7

- FIRST OBSERVATION!

$$\frac{\mathcal{B}(\Lambda_b^0 \to \psi(2S)p\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \psi(2S)pK^-)} = \frac{N_{\Lambda_b^0 \to \psi(2S)p\pi^-}}{N_{\Lambda_b^0 \to \psi(2S)pK^-}} \times \frac{\varepsilon^{total}_{\Lambda_b^0 \to \psi(2S)pK^-}}{\varepsilon^{total}_{\Lambda_b^0 \to \psi(2S)p\pi^-}}$$

$$R_{\pi/K} = \frac{\mathcal{B}\left(\Lambda_b^0 \to \psi(2S)p\pi^-\right)}{\mathcal{B}\left(\Lambda_b^0 \to \psi(2S)pK^-\right)} = (11.4 \pm 1.3 \pm 0.2)\%$$

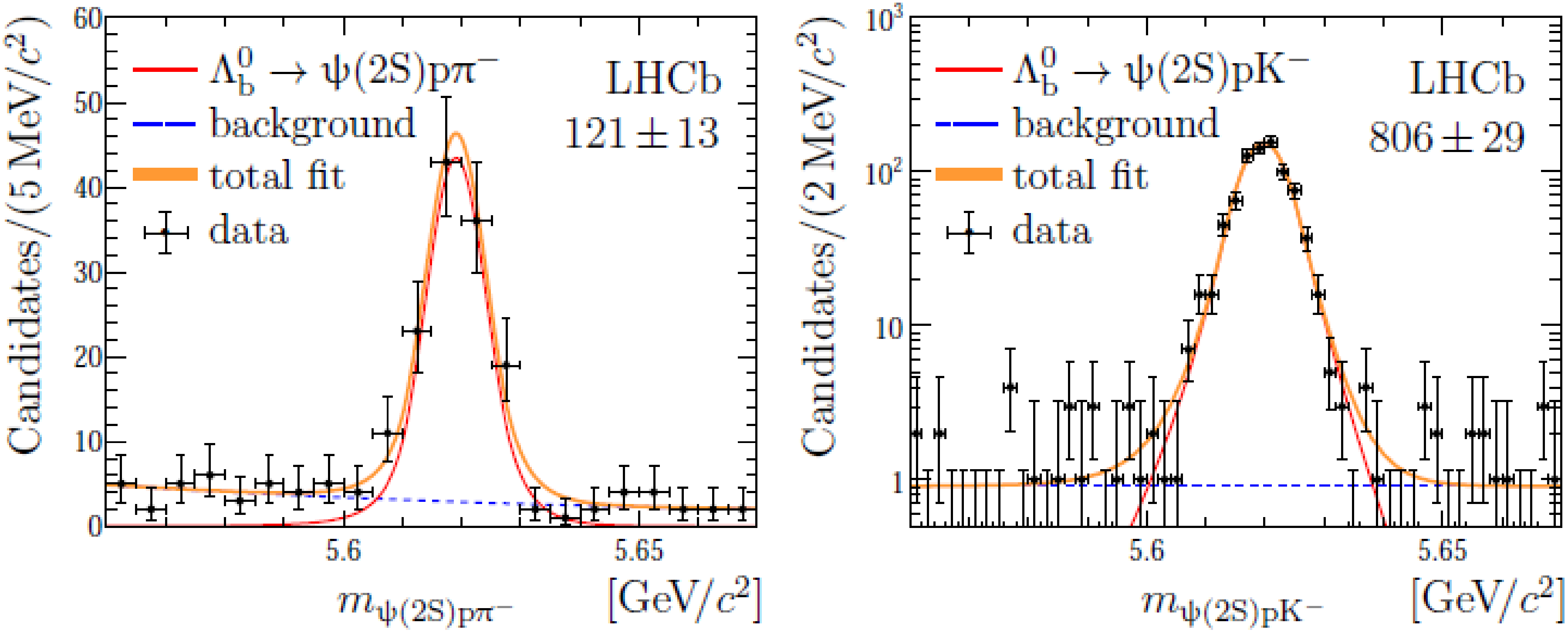
- Results in good agreement wrt theory

$$R^{th}_{\pi/K} = \frac{\Phi_3\left(\Lambda_b^0 \to \psi(2S)p\pi^-\right)}{\Phi_3\left(\Lambda_b^0 \to \psi(2S)pK^-\right)} \times \tan^2\theta_C = 0.11$$

PHSP of the decay

Results (2)

ArXiv1806.08084



- ψ(2S)p and ψ(2S)π spectra show no evidence for contributions from exotic states
- With a larger data sample a detailed amplitude analysis will be possible

Search for weakly decaying b-flavoured pentaquarks

PRD 97, 032010 (2018)

Introduction

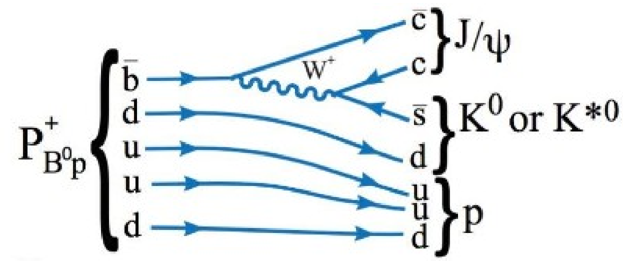
PRD 97, 032010 (2018)

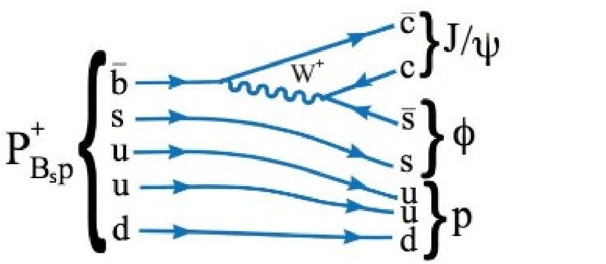
- In 2015, LHCb observed 2 new states, consistent with pentaquark states
- In 2016, Model-independent confirmation (Λ* resonance)
    - **Are there more?**
    - **How are they bound?**

- Look in the b-sector → heavier constituents more tightly bound
- Can decay both strongly and weakly. We consider weak decays
- **Search for b-flavoured pentaquarks below strong threshold**
- Specifically:

Mode	Quark content	Decay mode	Search window
I	$\bar{b}duud$	$P^+_{B^0p} \to J/\psi K^+\pi^- p$	4668–6220 MeV
II	$b\bar{u}udd$	$P^-_{\Lambda^0_b\pi^-} \to J/\psi K^-\pi^- p$	4668–5760 MeV
III	$b\bar{d}uud$	$P^+_{\Lambda^0_b\pi^+} \to J/\psi K^-\pi^+ p$	4668–5760 MeV
IV	$\bar{b}suud$	$P^+_{B^0_sp} \to J/\psi \phi p$	5055–6305 MeV

Different quark content,
different final state



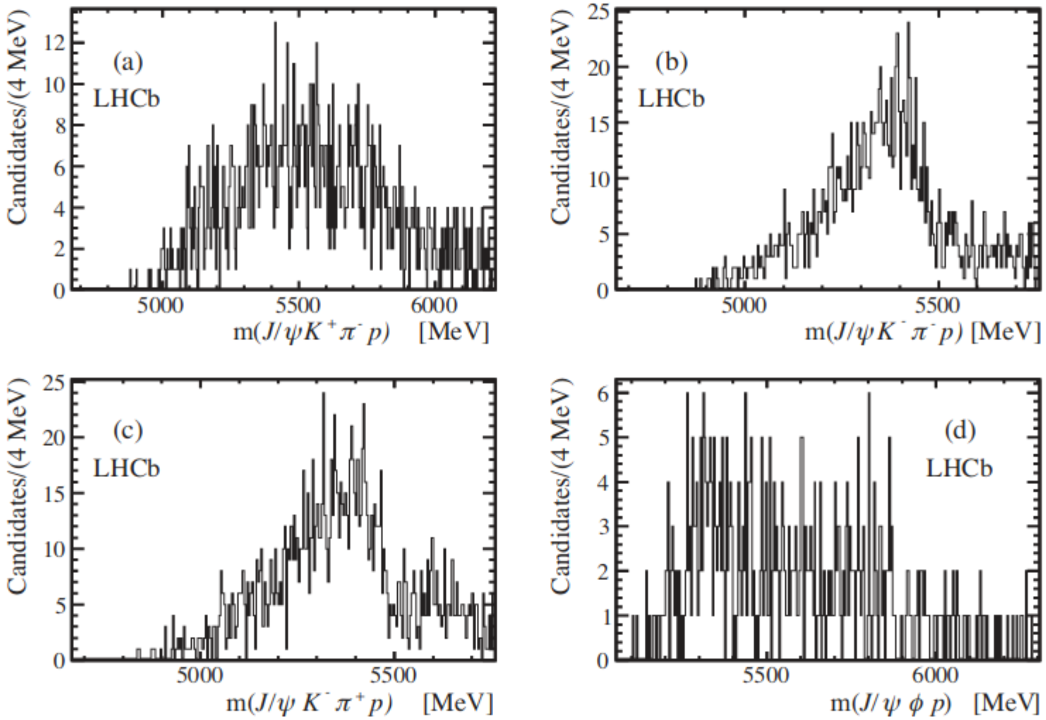


Strategy (1)

PRD 97, 032010 (2018)

- Search regions below m(Bp), m(Λ_bp), m(B_sp)
- In order to avoid bias, blind data in search region
- Make very loose cuts to clean up background
- Use BDT for intelligent suppression of background
- Train BDT using MC for signal, data above threshold for backgrounds
- Vetos on possible reflections of known decays (PID requirements)

- UL if no signal is found
- Use Run1 dataset
- Invariant masses →
- Perform a scan
- Peak resolution from MC



Strategy (2)

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- If a signal is found, measure masses and lifetime with a fit
- If no signal, put an upper limit on the mass window of interest

- No significant excess of signal candidates is observed over the expected bkg

- UL limits are set using the profile likelihood technique
- Statistical test at each mass based on the profile likelihood ratio of Poisson process hypotheses with and without a signal contribution

- We put UL on the ratio:

$$R = \frac{\sigma(pp \to P_B X) \cdot \mathcal{B}(P_B \to J/\psi\, X)}{\sigma(pp \to \Lambda_b^0 X) \cdot \mathcal{B}(\Lambda_b^0 \to J/\psi\, K^- p)}$$

Control sample, cross section measured by LHCb

Limits

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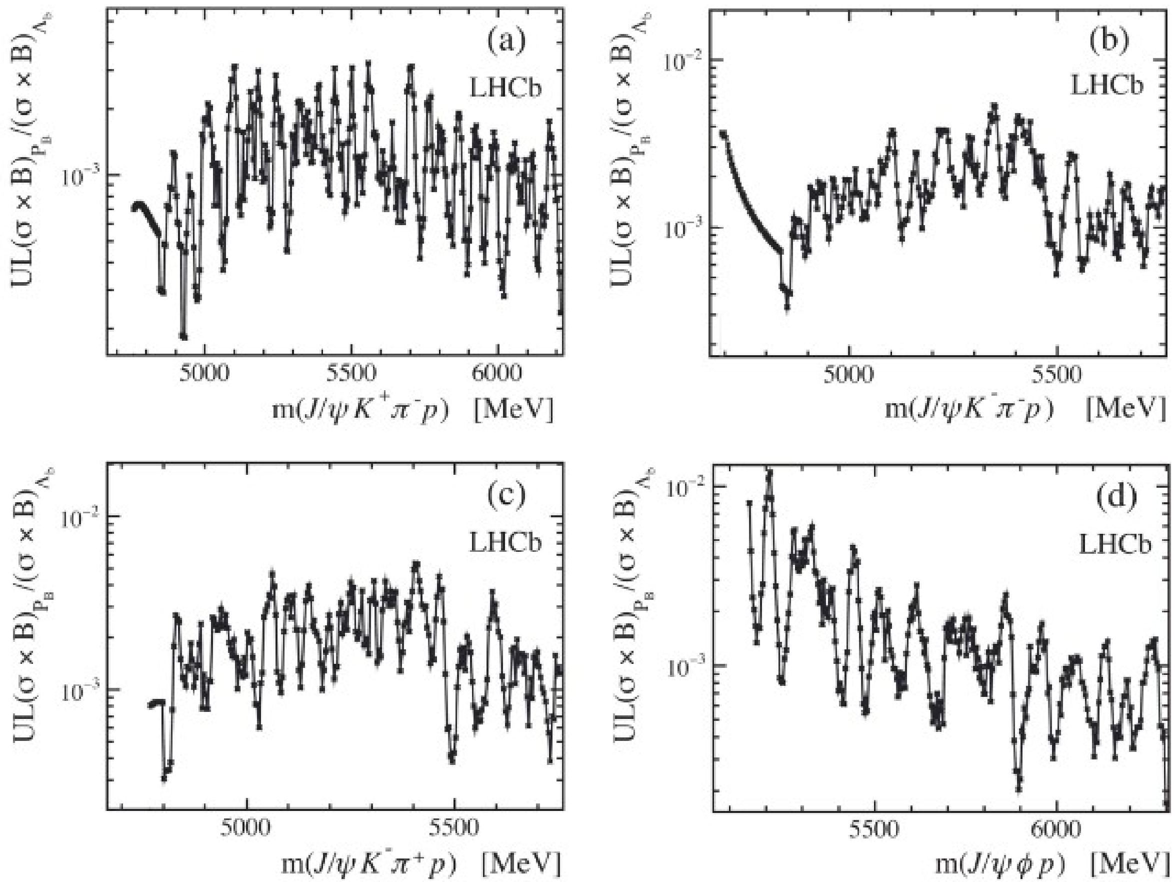
- Scan the kinematic up to strong decay threshold
- Above, strong decays will dominate the transition



- Largest systematic comes from selection differences wrt the normalisation mode

Conclusions

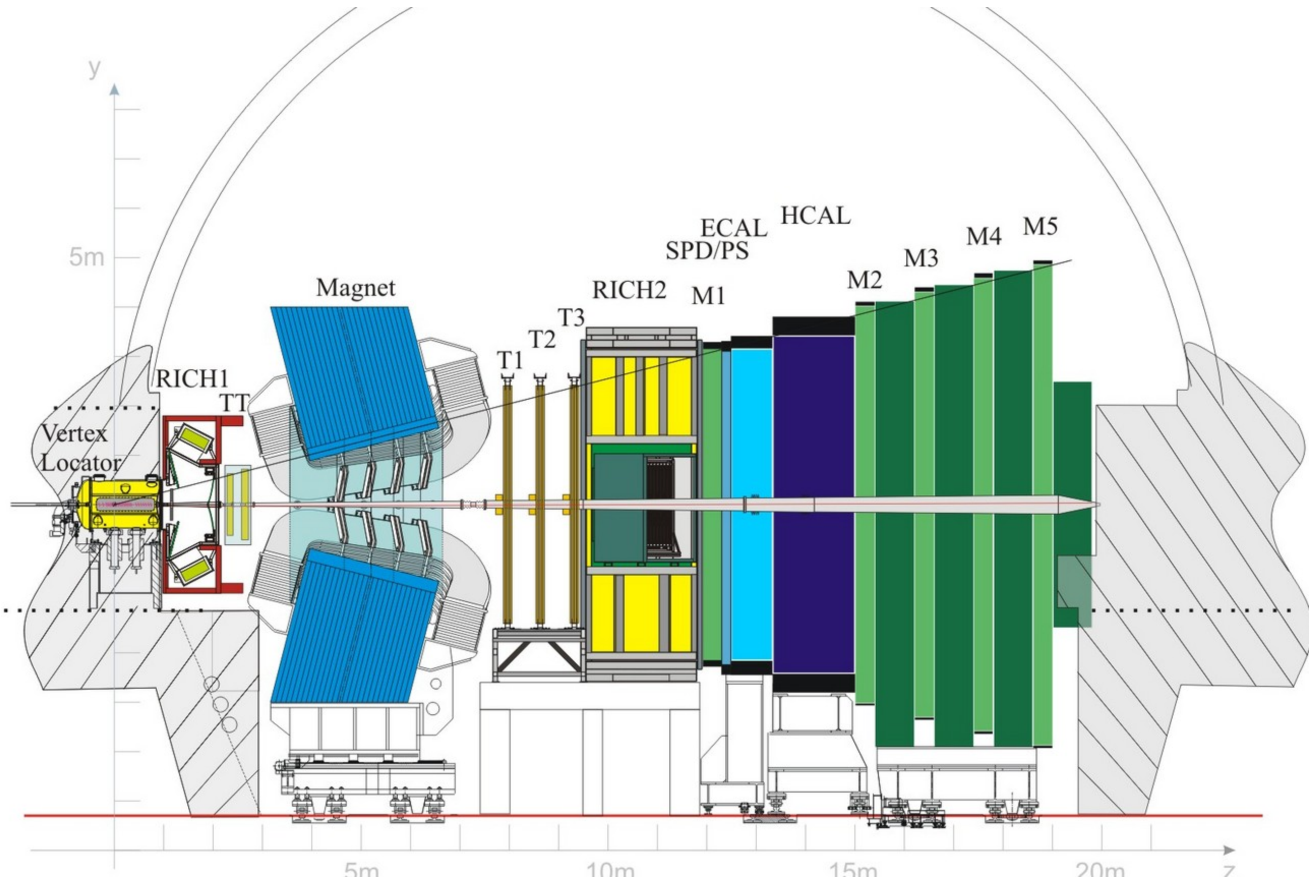
- Many analysis will appear in the future
- More final states to investigate
- Exciting field even in the Upgrade phase!

So stay tuned…
exciting times ahead!

Thank for your attention !

Backup

The LHCb Detector



Fully instrumented: 2 < η < 5
Some sensitivity: -3.5<η<-1.5

- Forward spectrometer
- Good Vertex measurements
- Precise Tracking
- Excellent PID up to 100GeV
- Versatile Trigger (L0+Hlt)

Detector Coverage