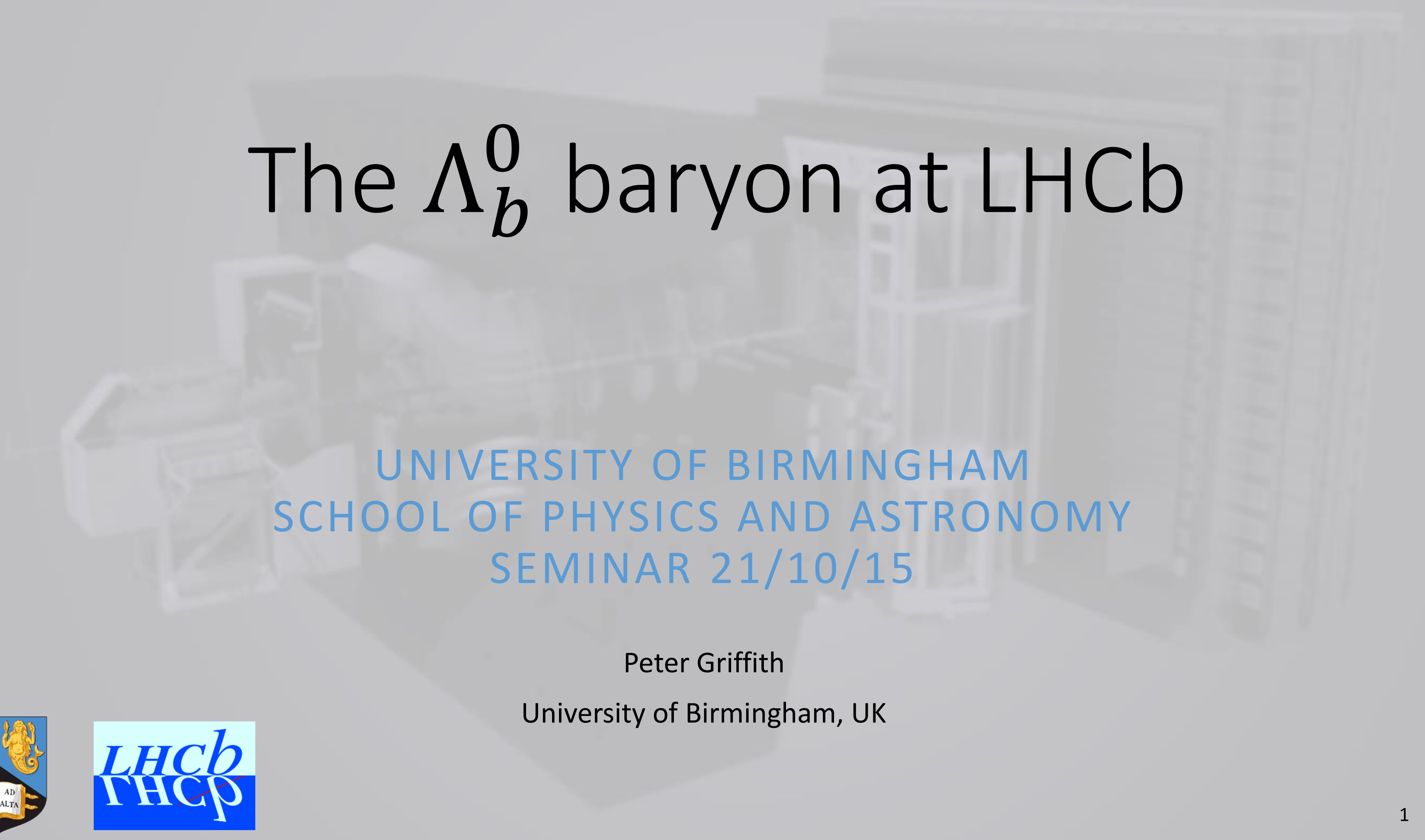
The Λ_b^0 baryon at LHCb



UNIVERSITY OF BIRMINGHAM
SCHOOL OF PHYSICS AND ASTRONOMY
SEMINAR 21/10/15

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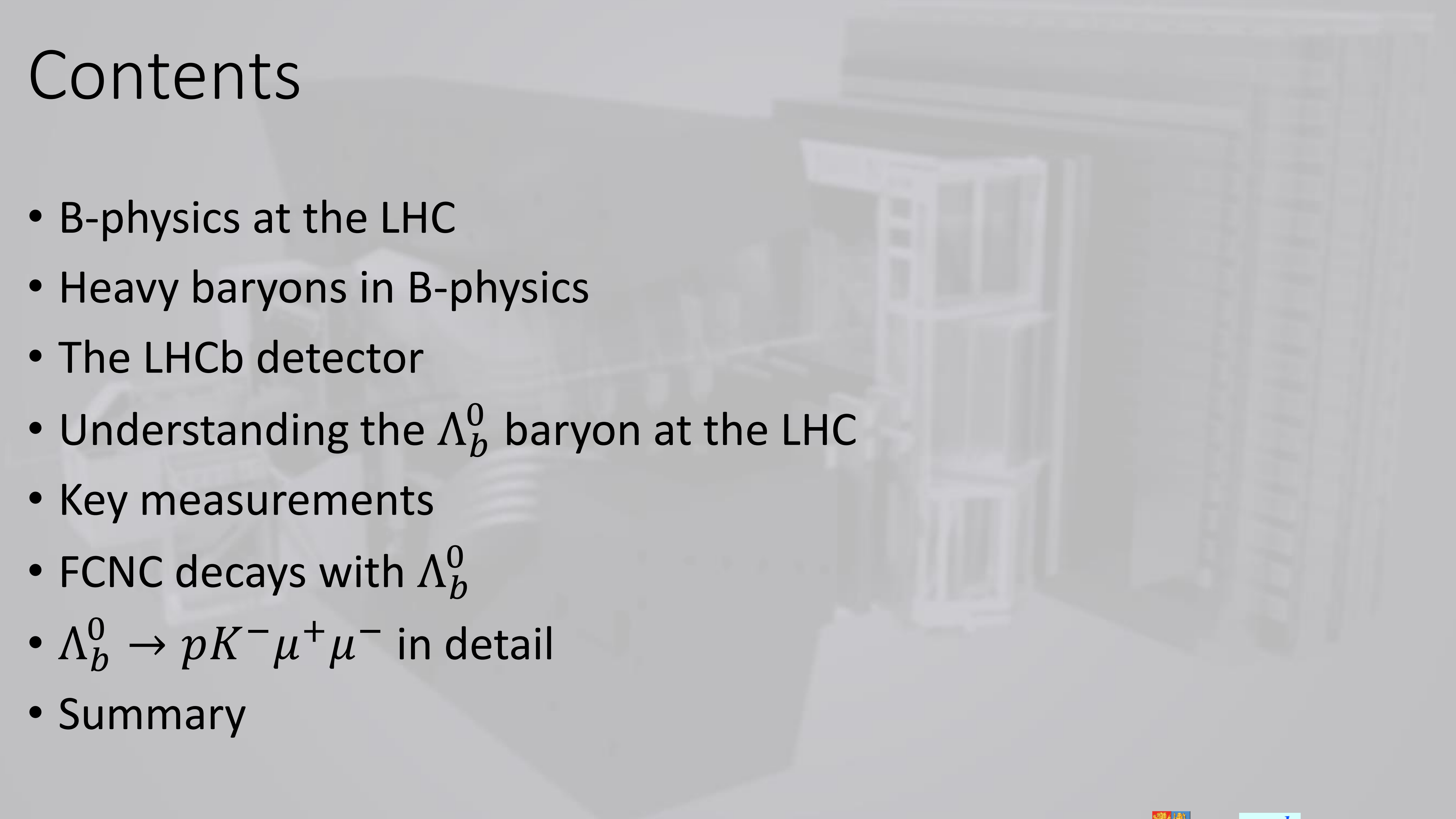
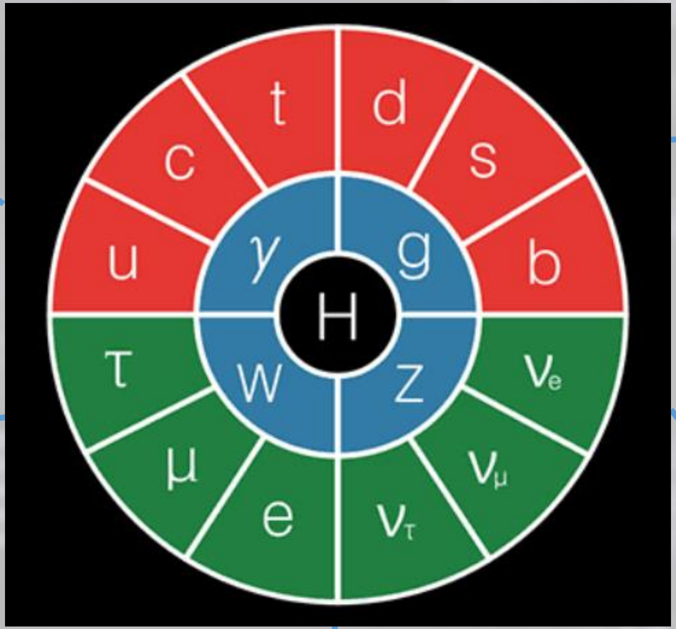


- B-physics at the LHC
- Heavy baryons in B-physics
- The LHCb detector
- Understanding the Λ_b^0 baryon at the LHC
- Key measurements
- FCNC decays with Λ_b^0
- $\Lambda_b^0 \to pK^-\mu^+\mu^-$ in detail
- Summary

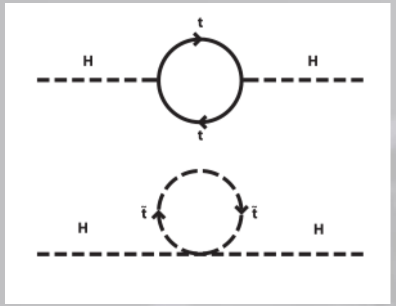
Flavour physics, SM and BSM

The very successful Standard Model



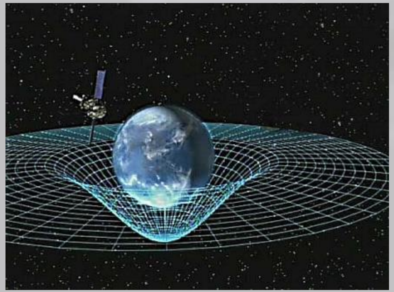
Hierarchy Problem

?



?

Gravity

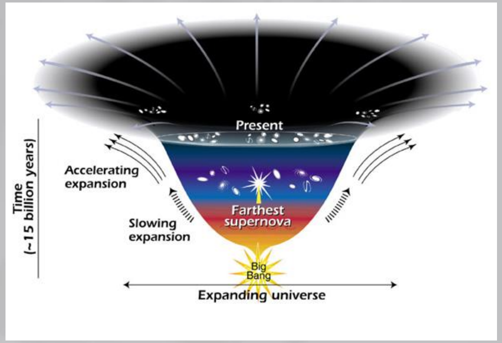


?

Dark Matter

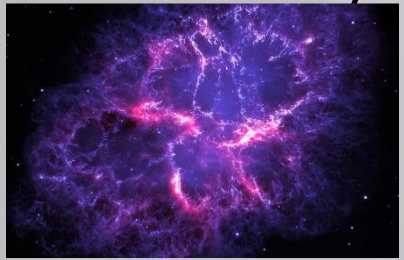
?

Dark Energy



?

Matter/antimatter asymmetry



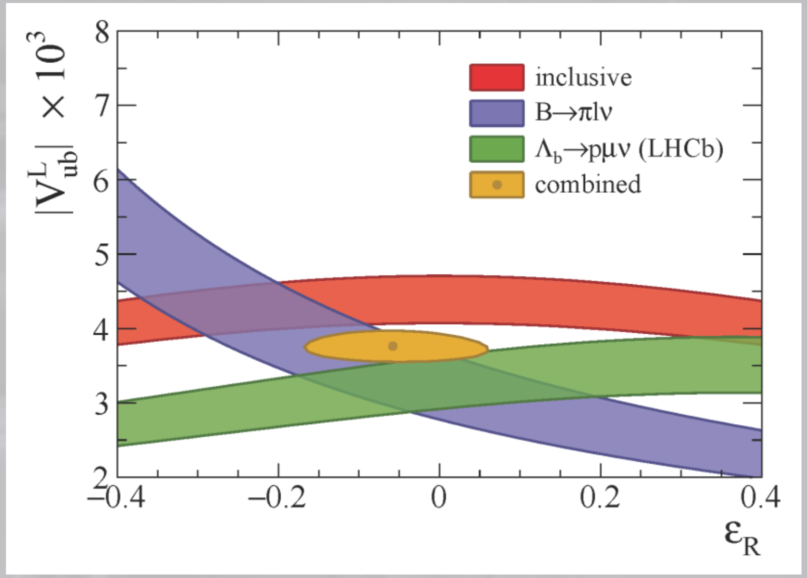
B-physics at LHCb:

- B-physics presents many ways to test and constrain the SM
- Excellent probes for New Physics

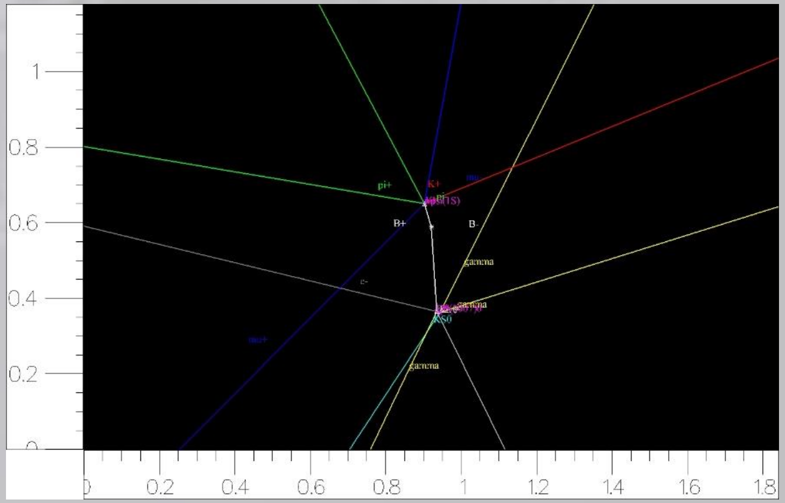
& precise measurements of SM

  - CP measurements
  - FCNC observables (bs->ll etc.)
  - New intermediate states/particles

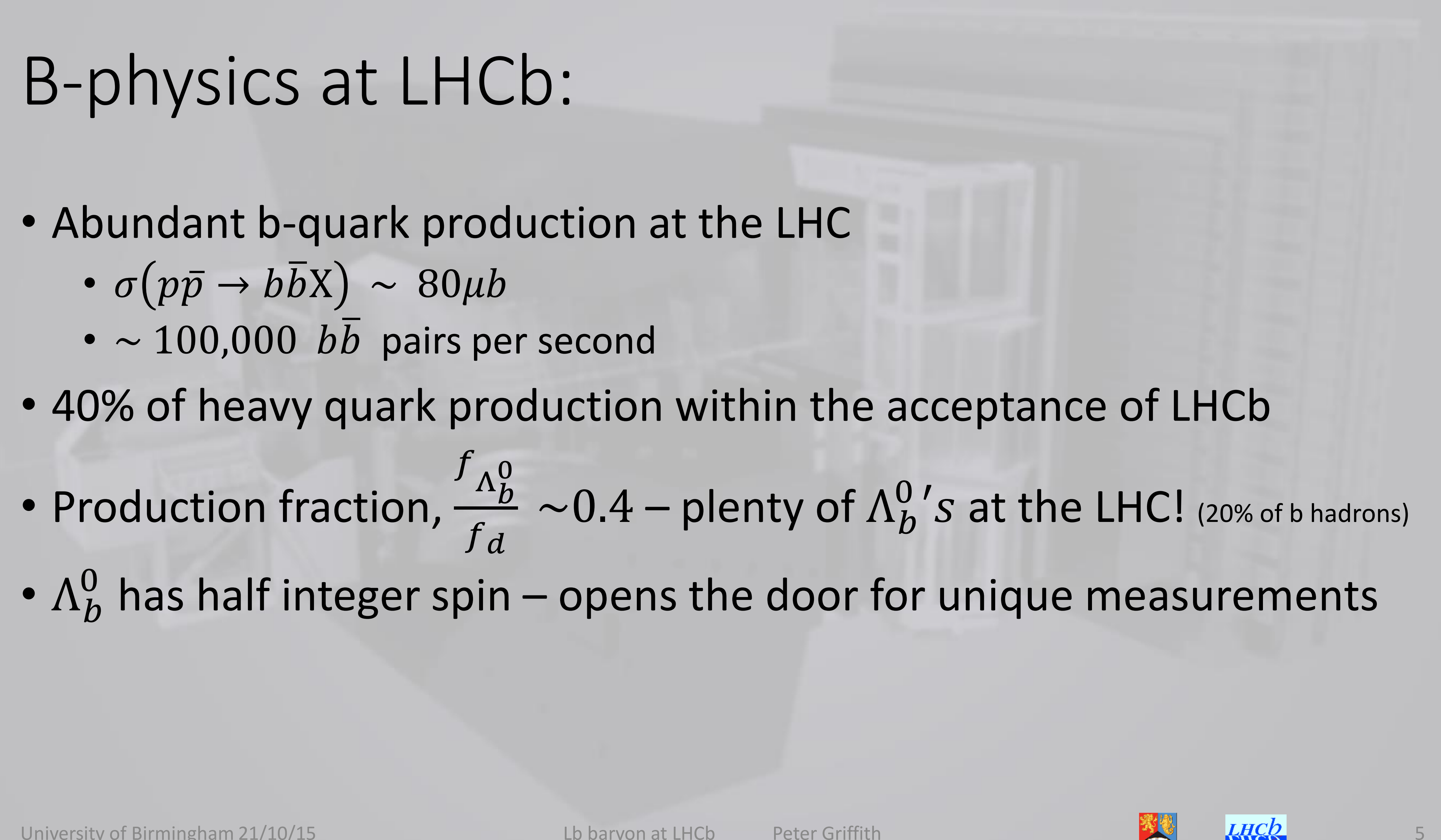
LHCb $|V_{ub}|$ measurement



reconstructed decay $B \to X(3872)K$



B-physics at LHCb:

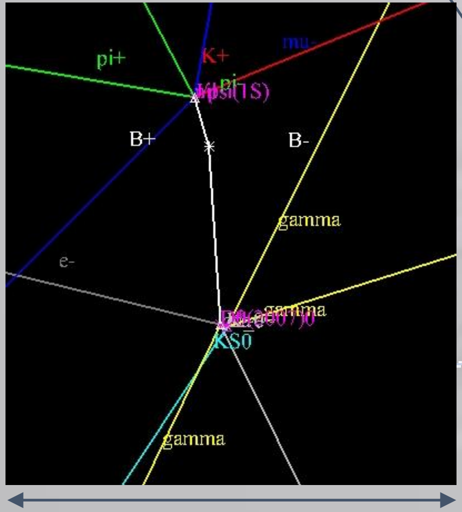


- Abundant b-quark production at the LHC
  - $\sigma(p\bar{p} \rightarrow b\bar{b}\mathrm{X}) \sim 80\mu b$
  - $\sim 100{,}000\ \ b\bar{b}$ pairs per second
- 40% of heavy quark production within the acceptance of LHCb
- Production fraction, $\frac{f_{\Lambda_b^0}}{f_d} \sim 0.4$ – plenty of $\Lambda_b^0{}'s$ at the LHC! (20% of b hadrons)
- Λ_b^0 has half integer spin – opens the door for unique measurements

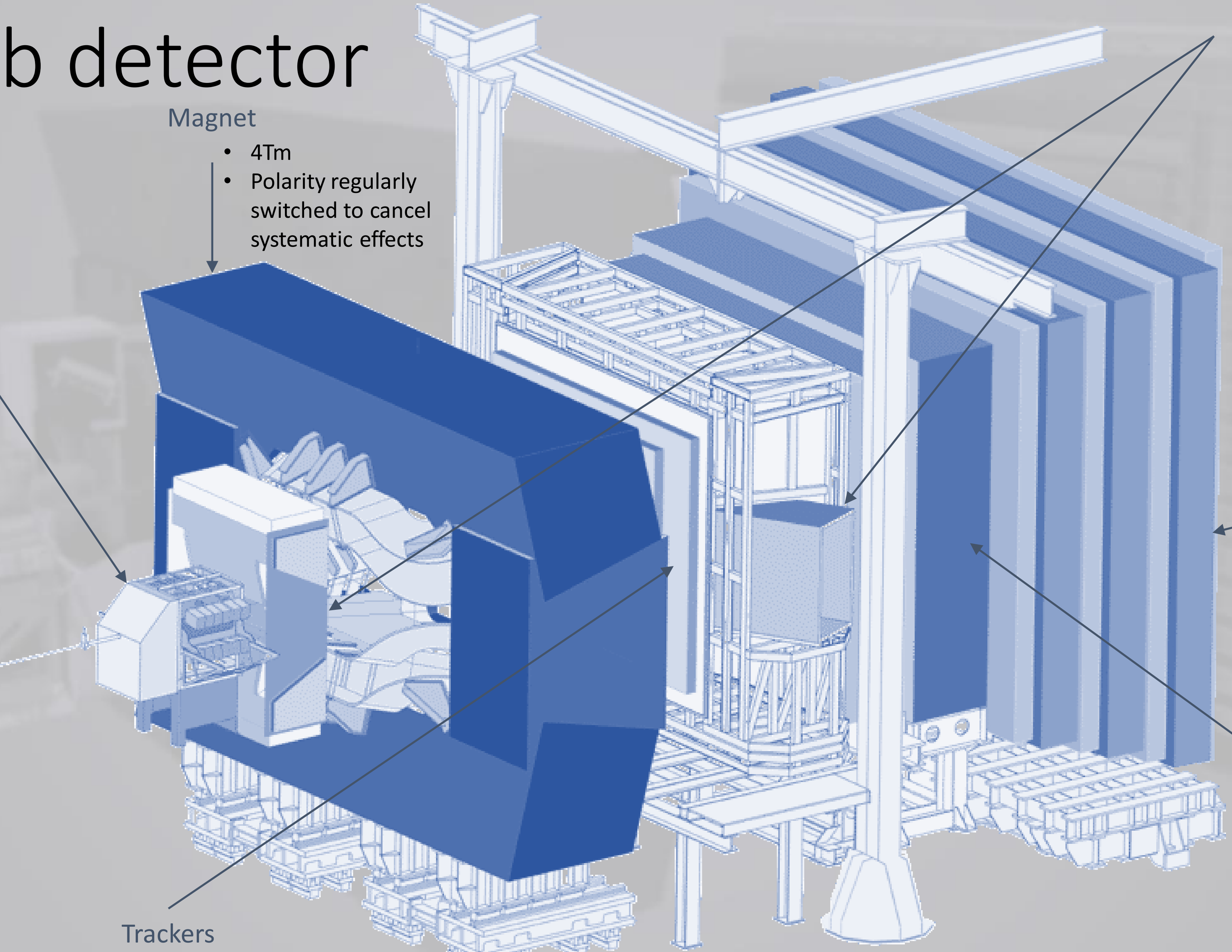
The LHCb detector

VELO - high precision tracking and tagging

- $\sim 4mm$ from beam
- able to reconstruct secondary vertices (B meson flight distance $\sim 10mm$)



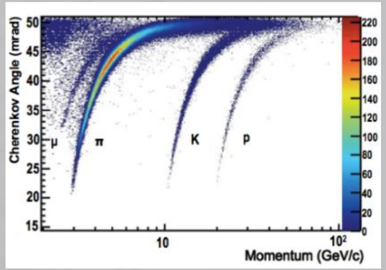
$O(1mm)$



Magnet

- 4Tm
- Polarity regularly switched to cancel systematic effects

RICH – large background rejection from PID



Extensive muon detection system with clean muon triggering

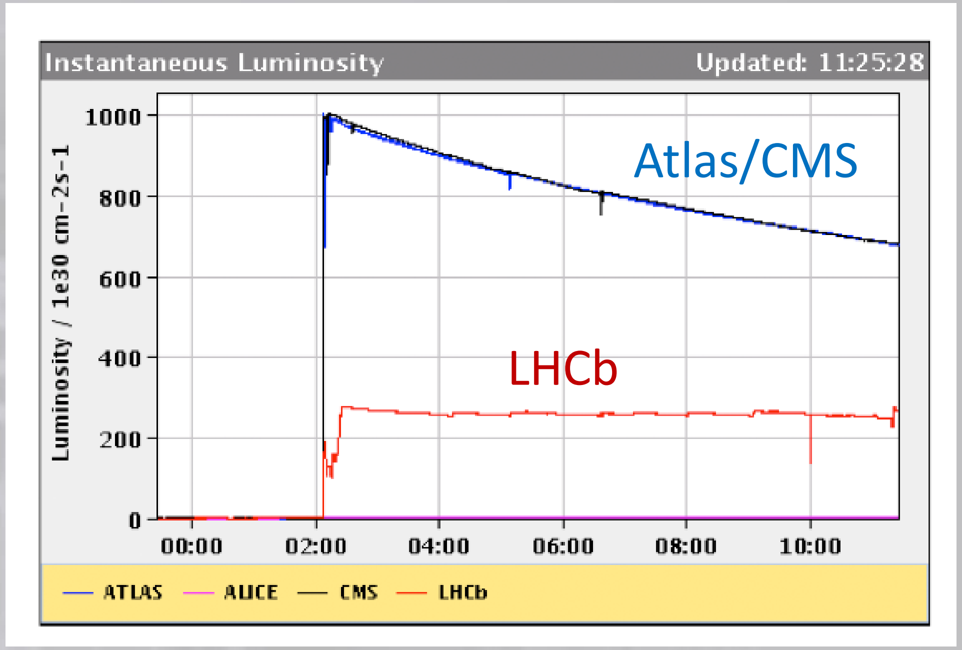
Calorimeters

- SPD
- PD
- ECAL
- HCAL

Trackers

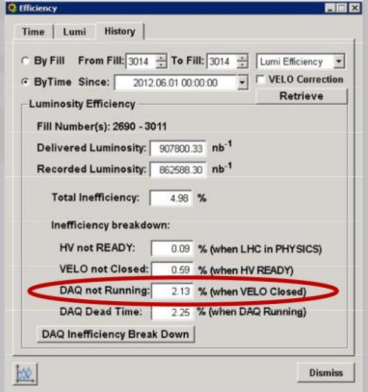
Data taking at LHCb

- Total amount of data after Run1: $3fb^{-1}$
  - $\sim 1fb^{-1}$ in 2011 $< \ell > \sim 2.7e32\ cm^{-2}s^{-1}$
  - $\sim 2fb^{-1}$ in 2012 $< \ell > \sim 4.0e32\ cm^{-2}s^{-1}$
- Comparatively low
  - LHCb employs 'lumi levelling' – constant rather than high instantaneous luminosity preferred.
  - Some precision measurements require very well known luminosity
  - PID system becomes 'saturated' at higher luminosities



$\sim 5\ kHz$ read out rate to disk ($1\ kHz$ originally planned)

High operational efficiency ($\sim 2\%$ deadtime)



○ By Fill From Fill: 3014 To Fill: 3014 Lumi Efficiency

● ByTime Since: 2012.06.01 00:00:00 ☐ VELO Correction

Luminosity Efficiency

Fill Number(s): 2690 - 3011

Delivered Luminosity: 907800.33 nb^{-1}

Recorded Luminosity: 862588.30 nb^{-1}

Total Inefficiency: 4.98 %

Inefficiency breakdown:

HV not READY: 0.09 % (when LHC in PHYSICS)

VELO not Closed: 0.59 % (when HV READY)

DAQ not Running: 2.13 % (when VELO Closed)

DAQ Dead Time: 2.25 % (when DAQ Running)

Λ_b^0 at LHCb

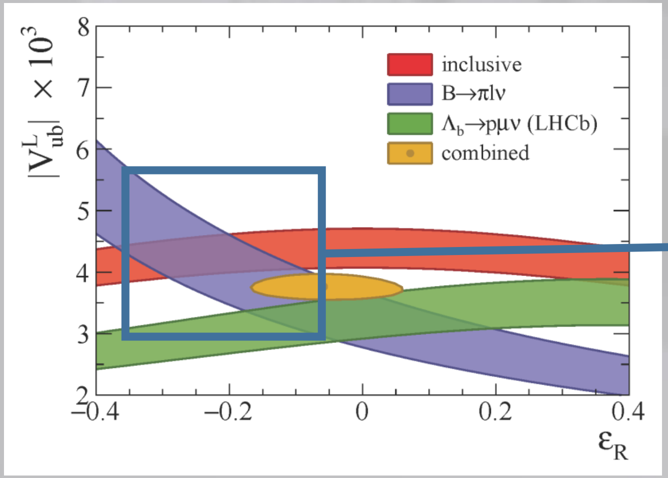
Interesting measurements and discoveries

Measuring $|V_{ub}|$ with $\Lambda_b^0 \rightarrow p\nu\mu$

- Previous inclusive measurements by Babar and Belle
- Large disagreement between inclusive and exclusive measurements – new particle with right-handed coupling?

$$\frac{|V_{ub}|^2}{|V_{cb}|^2} = \frac{B\left(\Lambda_b^0 \rightarrow p\mu^- \,\overline{\nu_\mu}\,\right)}{B\left(\Lambda_b^0 \rightarrow \Lambda_c^+\mu^- \,\overline{\nu_\mu}\,\right)} R_{FF}$$

Where R_{FF} is the ratio of relevant form factors



$\epsilon_R \sim -0.2$
→ new particle would have ~20% coupling strength of the W boson

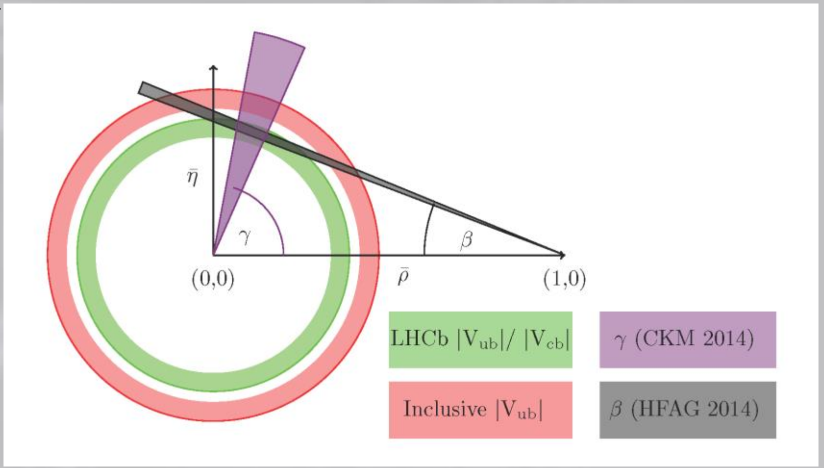
$\Lambda_b^0 \rightarrow p\mu^- \,\overline{\nu_\mu}$ candidates are reconstructed using

$$\mathrm{m}_{corr} = \sqrt{m_{h\mu}^2 + p_\perp^2} + p_\perp$$

Visible mass

Transverse momentum of $h\mu$ pair

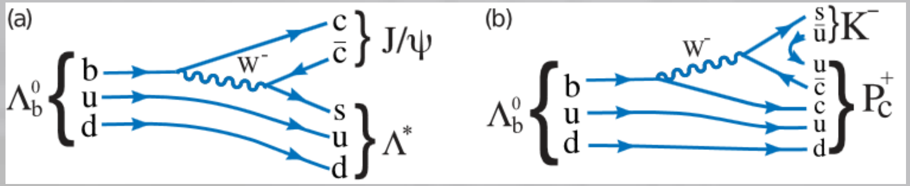
Candidates with $100 MeV/c^2$ uncertainty are selected



New LHCb measurement removes the need for a new particle.

But why the initial disagreement?

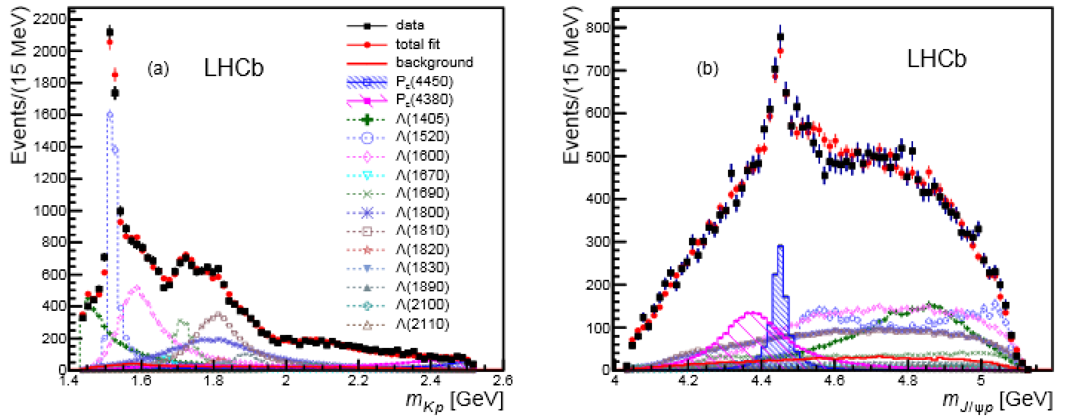
Resonances in $\Lambda_b^0 \to J/\psi p K^-$

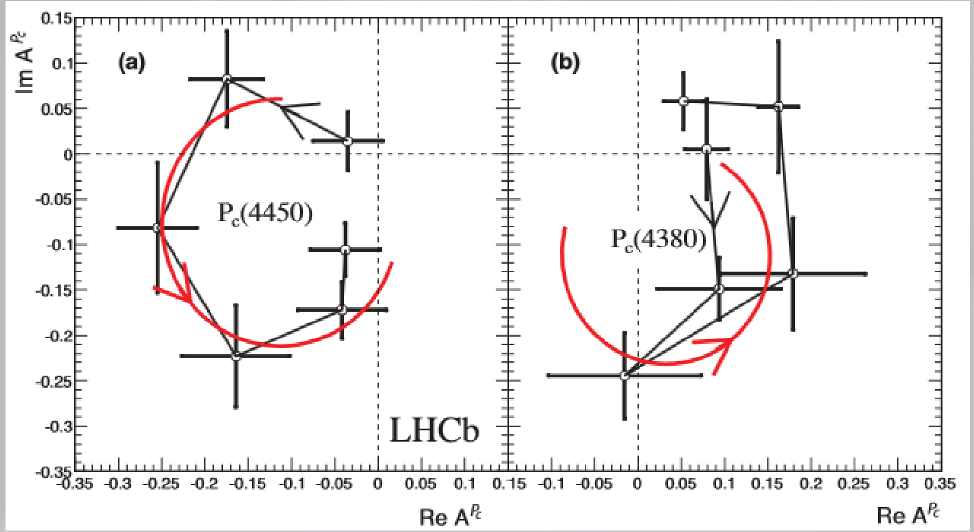


- Two resonances observed in $\Lambda_b^0 \to J/\psi p K^-$
- Consistent with pentaquark state with content quark *cuud*

	$P_c(4450)$	$P_c(4380)$
Mass (MeV/c^2)	4449.8 ± 4.2	4380 ± 37
J^P	$\frac{5}{2}^{+}$	$\frac{3}{2}^{-}$
Significance, σ	12	9

Six dimensional amplitude fit.
Using just Λ^* states is not adequate.
Two additional states required



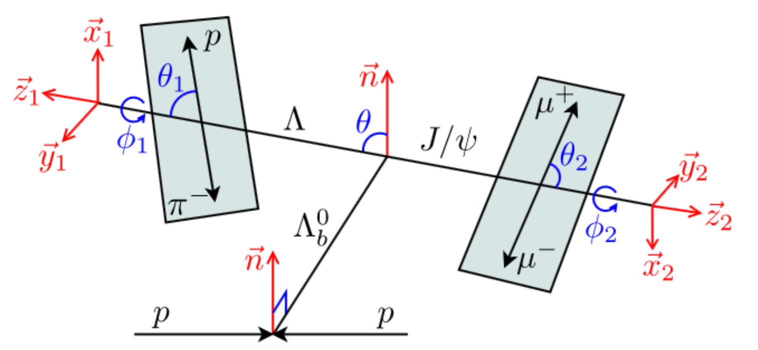


arXiv:1507.03414

Measurement of the Λ_b^0 polarisation

- First of its kind at a hadron collider
- Uses $\Lambda_b^0 \rightarrow J/\psi\Lambda$ decays
  - Decay of a spin $\frac{1}{2}$ particle into spin 1 and $\frac{1}{2}$ particles

Angular analysis performed on all three angles to



Transverse production polarisation:

0.06±0.07±0.02

Appears to be small (O(10%) or less)

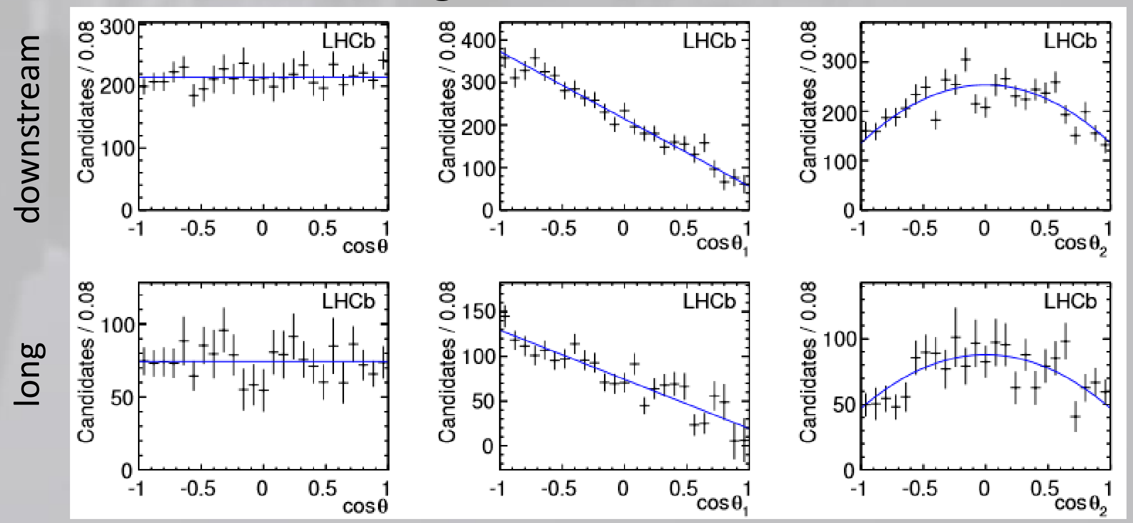
- Not so favourable for studying photon helicity in $\Lambda_b^0 \rightarrow \Lambda\gamma$ and $\Lambda_b^0 \rightarrow \Lambda^*\gamma$ decays if small ☹

Decay amplitudes

$$\begin{aligned}\frac{\mathrm{d}\Gamma}{\mathrm{d}\Omega_3}(\cos\theta,\cos\theta_1,\cos\theta_2) &= \int_{-\pi}^{\pi}\int_{-\pi}^{\pi}\frac{\mathrm{d}\Gamma}{\mathrm{d}\Omega_5}(\theta,\theta_1,\theta_2,\phi_1,\phi_2)\,\mathrm{d}\phi_1\,\mathrm{d}\phi_2\\ &= \frac{1}{16\pi}\sum_{i=0}^{7} f_i\boxed{(|\mathcal{M}_{+\frac{1}{2},0}|^2,|\mathcal{M}_{-\frac{1}{2},0}|^2,|\mathcal{M}_{-\frac{1}{2},-1}|^2,|\mathcal{M}_{+\frac{1}{2},+1}|^2)}\\ &\quad g_i\boxed{(P_b,}\,\alpha_\Lambda)\,h_i(\cos\theta,\cos\theta_1,\cos\theta_2).\end{aligned}$$

Transverse polarisation parameter

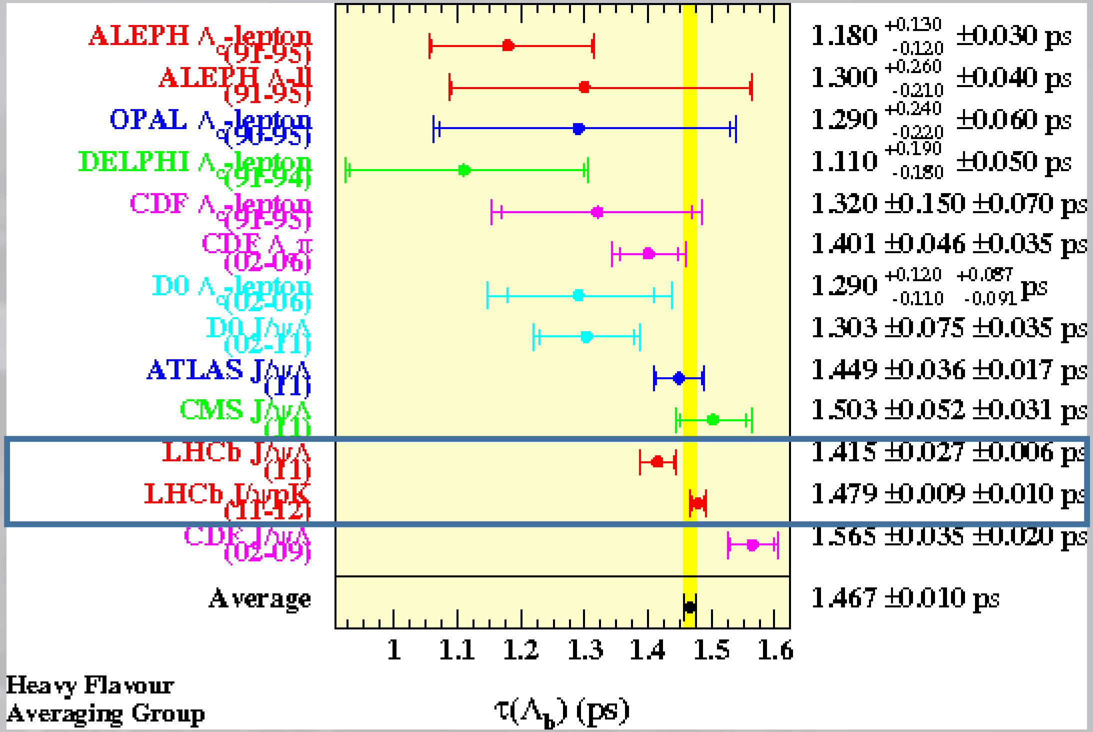
Angular distributions



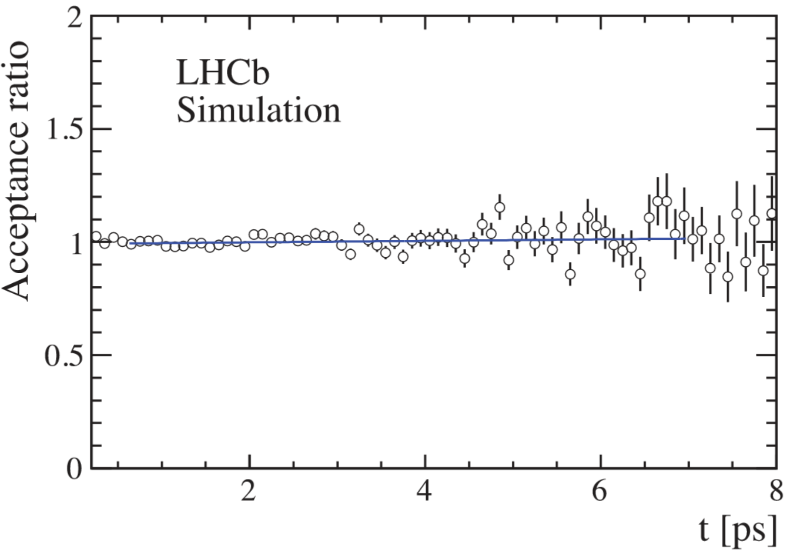
arXiv:1302.5578

Λ_b^0 lifetime measurement

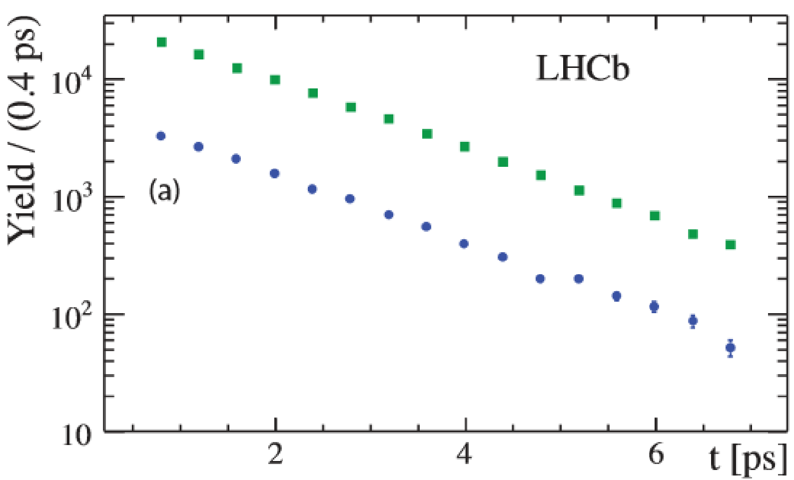
- Lifetime measured with $\Lambda_b^0 \to J/\psi p K^-$ decays
- Relative to $\overline{B^0} \to J/\psi \pi^+ K^-$ lifetime
- $1 fb^{-1}$ of data



Acceptance ratio of Λ_b^0 and $\overline{B^0}$



Decay time distributions for Λ_b^0 and $\overline{B^0}$



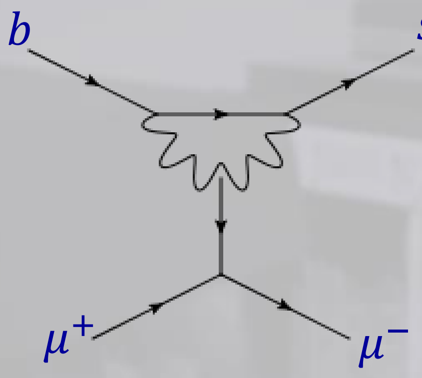
Unprecedented precision dominates world average

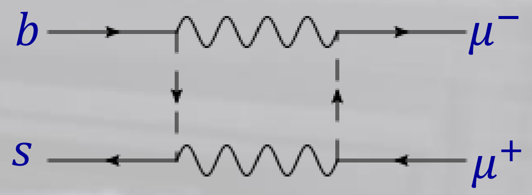
arXiv:1509.00292

$$\tau^{LHCb}_{\Lambda_b^0} = 1.482 \pm 0.018 \pm 0.012 \text{ ps}$$

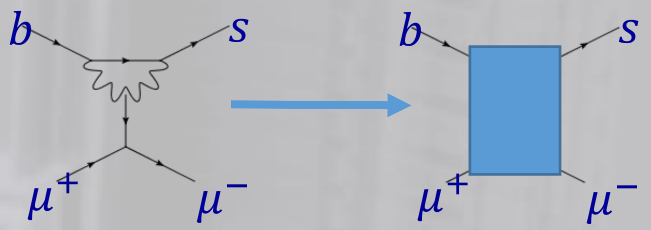
Rare Decays at LHCb

- FCNC's can occur through loops
  - Highly suppressed
  - Sensitive to new physics e.g. additional diagrams from new BSM particles in loops
  - Numerous observables – many very sensitive to NP
- LHCb ideal for studying rare FCNC decays of mesons and baryons, e.g. $b \to s$
  - High resolution tracking
  - High performance PID
  - Muon signals 'clean' at LHCb





An effective field theory is employed



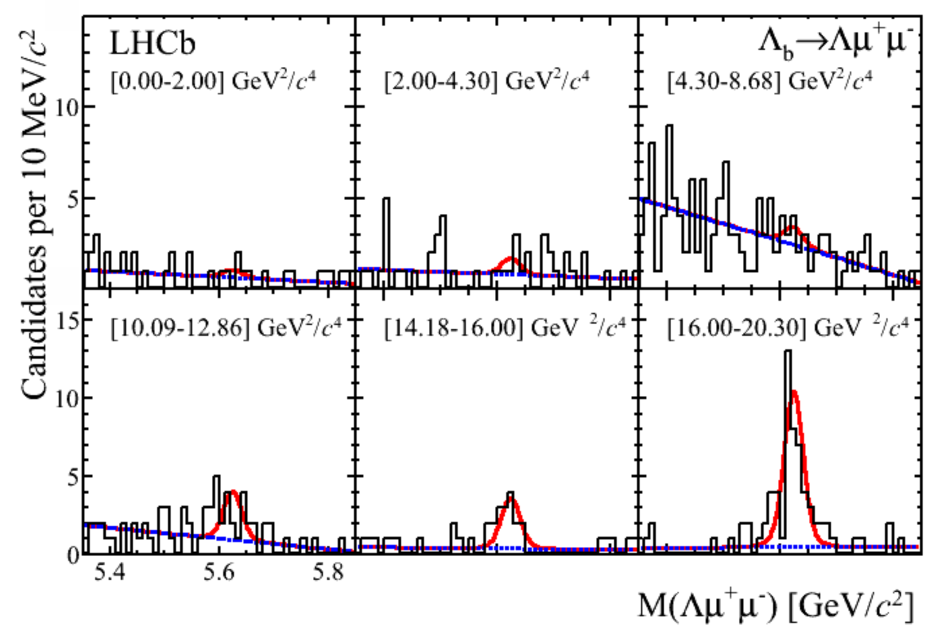
$$\mathcal{L}_{(\text{full EW}\times\text{QCD})} \longrightarrow \mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{QED}\times\text{QCD}}\left(\begin{smallmatrix}\text{quarks} \neq t\\ \text{\& leptons}\end{smallmatrix}\right) + \sum_n C_n(\mu)\, Q_n$$

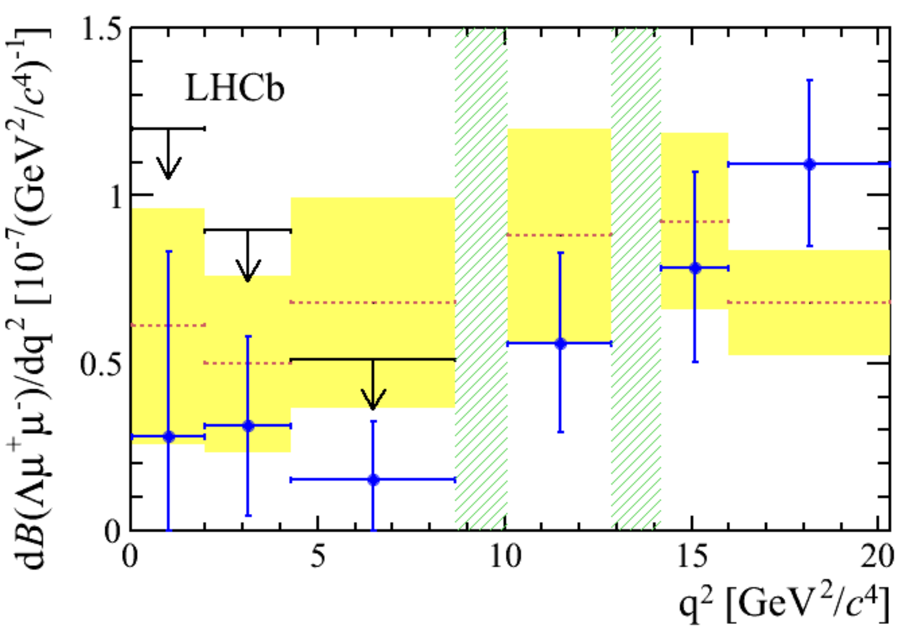
Wilson coefficients

Operators
(local interaction terms)

All Wilson coefficients calculable
→ predictive
NP can be seen in deviations of Wilson coefficients

$\Lambda_b^0 \to \Lambda\,\mu^+\mu^-$ Branching ratio measurement





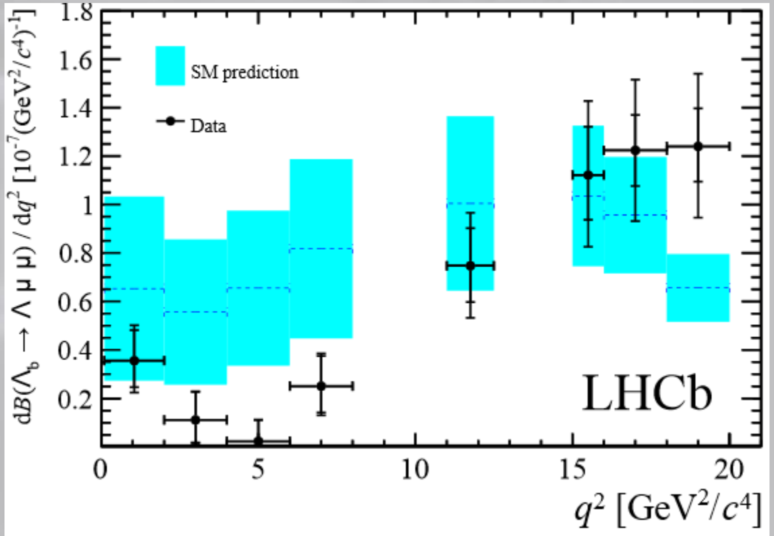
LHCb-PAPER-2013-025

- Previously measured at CDF
- No signal observed at low q^2 at either CDF or LHCb but results consistent with SM
- Now updated to $3fb^{-1}$, with angular analysis

$\Lambda_b^0 \to \Lambda\,\mu^+\mu^-$ $3fb^{-1}$ update

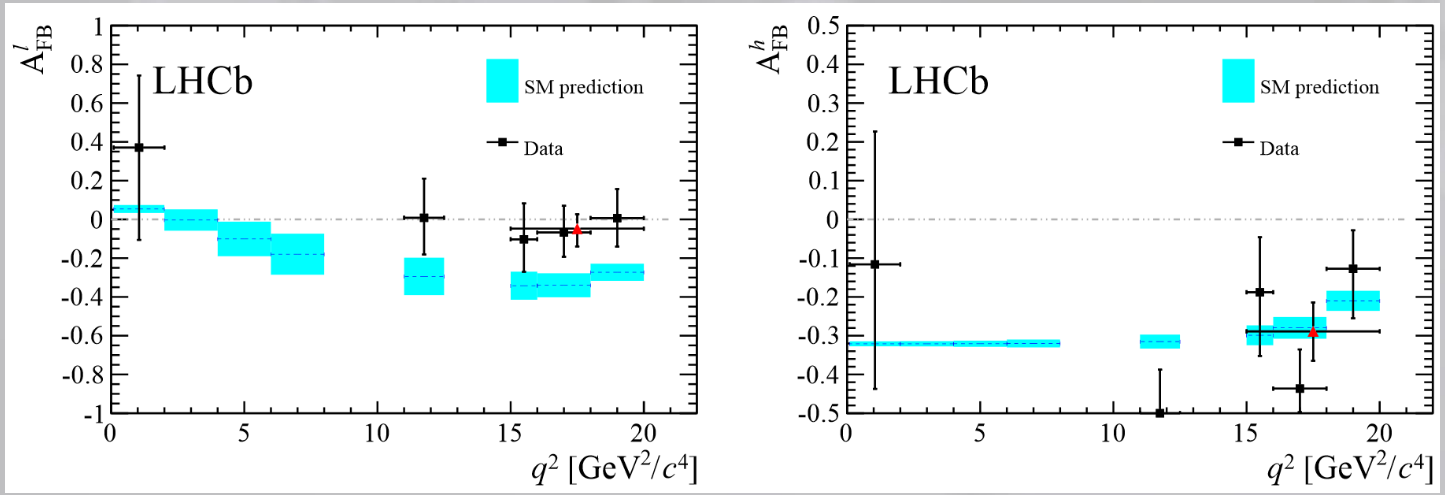
- First evidence of the signal at low q^2! (3σ)
- Slight deviation from SM predictions – similar to other $b \to sll$ measurements
- Forward backward asymmetries measured

BR as a function of q^2

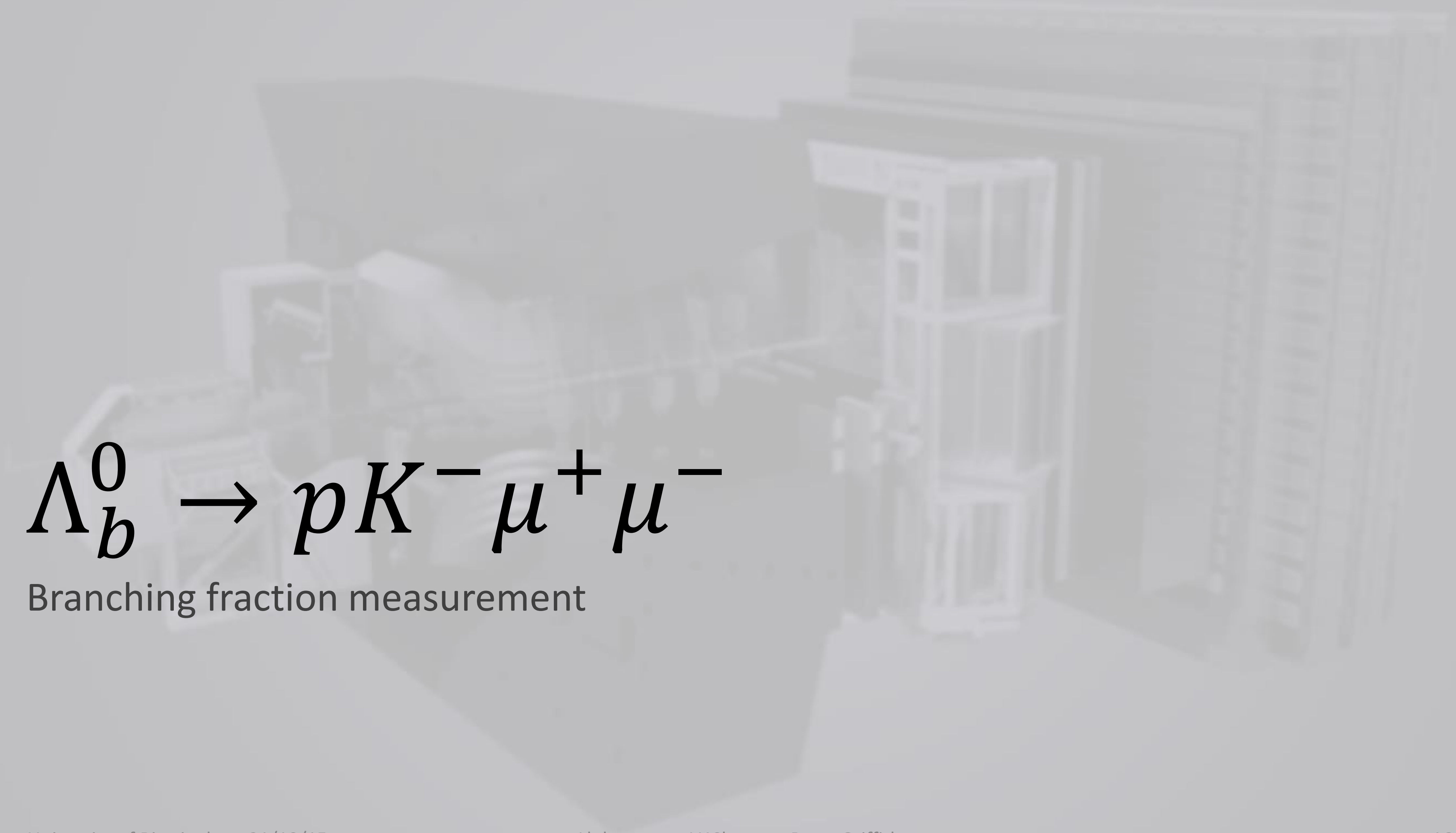


Leptonic A_{FB}

Hadronic A_{FB}



arXiv:1503.07138



$\Lambda_b^0 \to pK^-\mu^+\mu^-$

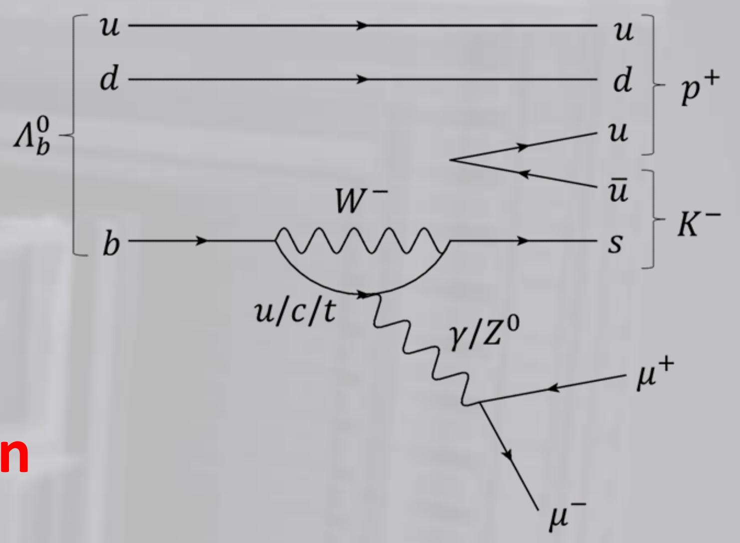
Branching fraction measurement

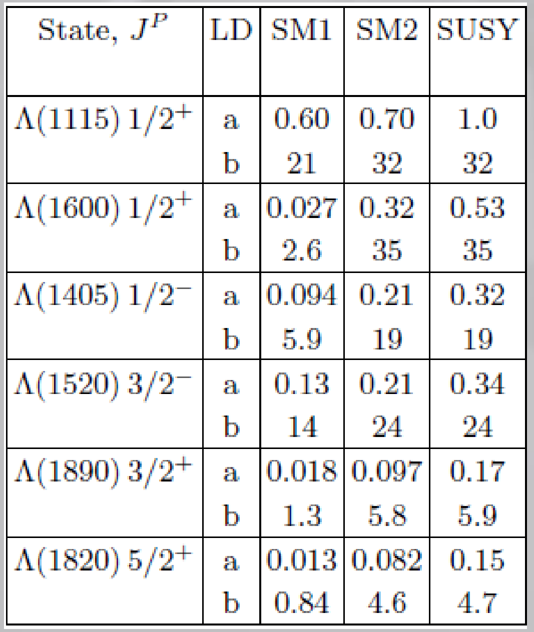
$\Lambda_b^0 \rightarrow pK^-\mu^+\mu^-$

- Rare FCNC decay through excited states
- Likely dominated by $\Lambda_b^0 \rightarrow \Lambda^*(1520)\mu^+\mu^-$
- $m(pK^-)$ structure known
- ‘Unobserved’

All variables blinded in mass region of the Λ_b^0

Non-resonant $\Lambda_b^0 \rightarrow pK^-\mu^+\mu^-$

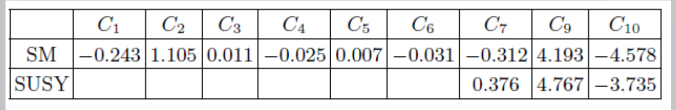




State, J^P	LD	SM1	SM2	SUSY
$\Lambda(1115)\ 1/2^+$	a	0.60	0.70	1.0
	b	21	32	32
$\Lambda(1600)\ 1/2^+$	a	0.027	0.32	0.53
	b	2.6	35	35
$\Lambda(1405)\ 1/2^-$	a	0.094	0.21	0.32
	b	5.9	19	19
$\Lambda(1520)\ 3/2^-$	a	0.13	0.21	0.34
	b	14	24	24
$\Lambda(1890)\ 3/2^+$	a	0.018	0.097	0.17
	b	1.3	5.8	5.9
$\Lambda(1820)\ 5/2^+$	a	0.013	0.082	0.15
	b	0.84	4.6	4.7

- Very limited theoretical knowledge

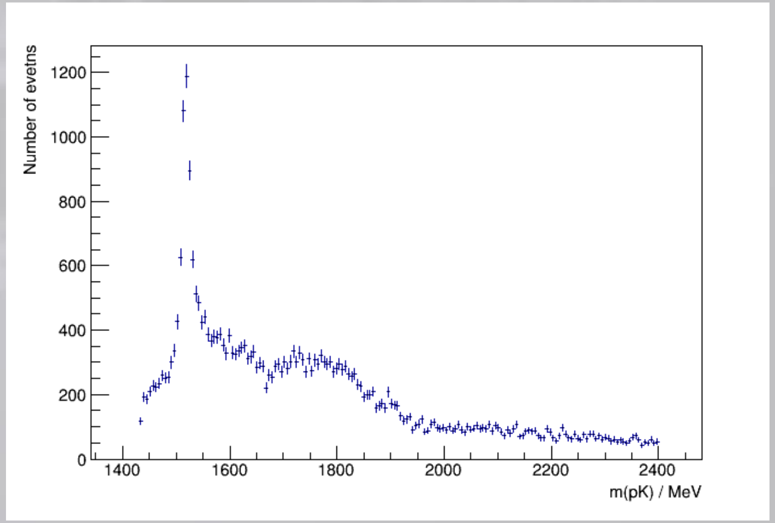
Branching fraction predictions (in units of 10e6) for SCA (SM1) and MCN (SM2) models.
(a and b without and with LD charmonium contributions respectively)
arXiv:1108.6129



	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_9	C_{10}
SM	-0.243	1.105	0.011	-0.025	0.007	-0.031	-0.312	4.193	-4.578
SUSY							0.376	4.767	-3.735

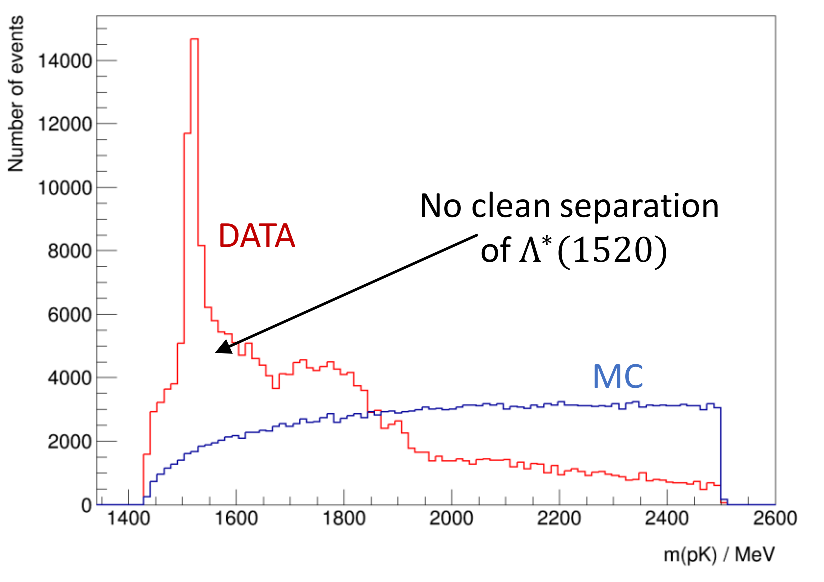
SUSY Wilson coefficients from M. J. Aslam, Y.-M. Wang and C.-D. Lu,
Phys. Rev. D 78, 114032 (2008)

$m(pK^-)$ in $\Lambda_b^0 \rightarrow (J/\psi \rightarrow \mu^+\mu^-)pK^-$



$\Lambda_b^0 \to pK^-\mu^+\mu^-$ branching fraction measurement

- Measured relative to $\Lambda_b^0 \to J/\psi pK^-$
  - Simpler calculation
  - Cancellation of systematic effects
- Lack of theoretical and experimental knowledge
  - →Lots of 'correcting' to be done

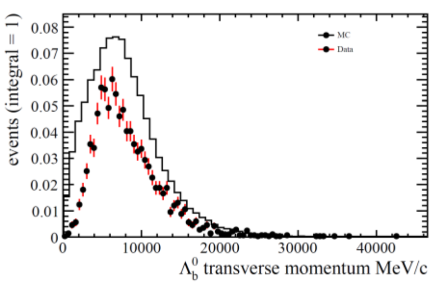


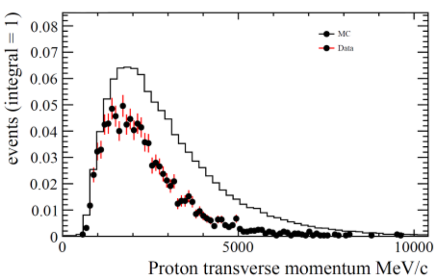
No clean separation of $\Lambda^*(1520)$

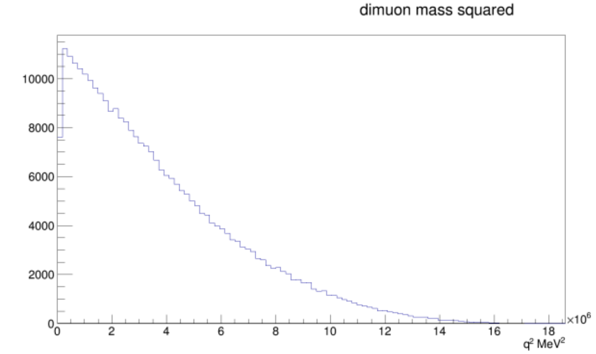
$m(pK^-)$ in $\Lambda_b^0 \to J/\psi pK^-$

MC is produced with only phase-space kinematics

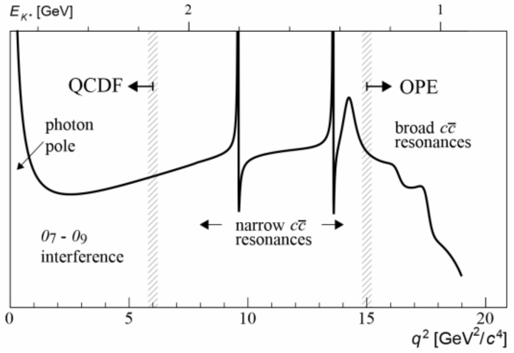
Experimentally motivated model for decay structure would need full amplitude analysis







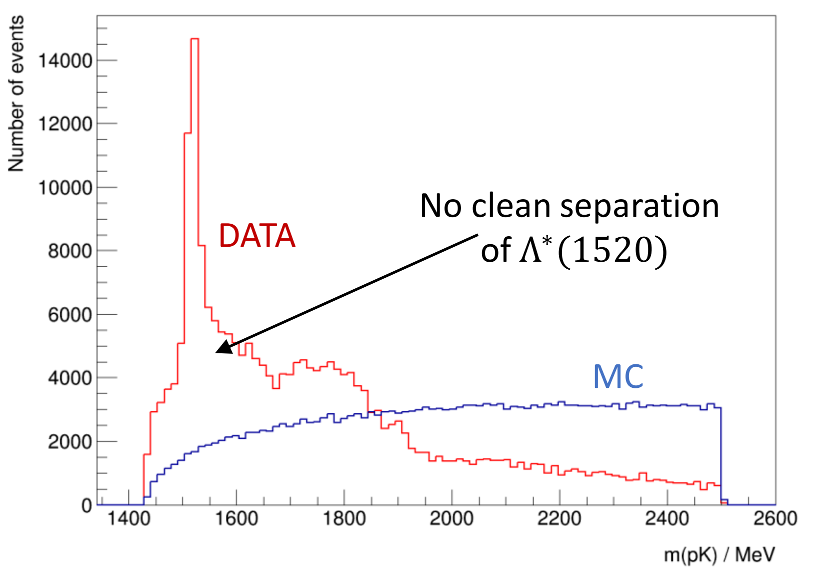
Dimuon mass squared $\Lambda_b^0 \to pK^-\mu^+\mu^-$ MC



'Typical' differential decay rate ($B^0 \to K^{*0}\mu^+\mu^-$) as function of dimuon mass squared

$\Lambda_b^0 \rightarrow pK^-\mu^+\mu^-$ branching fraction measurement

- Measured relative to $\Lambda_b^0 \rightarrow J/\psi pK^-$
  - Simpler calculation
  - Cancellation of systematic effects
- Lack of theoretical and experimental knowledge
  - →Lots of ‘correcting’ to be done



DATA

MC

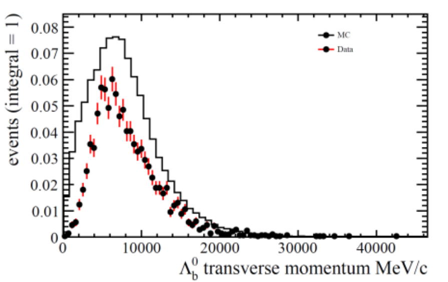
No clean separation of $\Lambda^*(1520)$

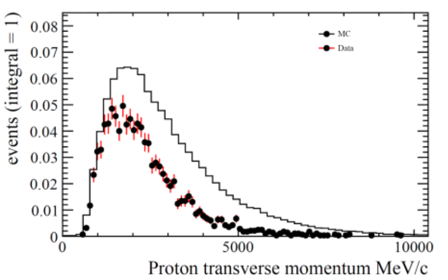
$m(pK^-)$ in $\Lambda_b^0 \rightarrow J/\psi pK^-$

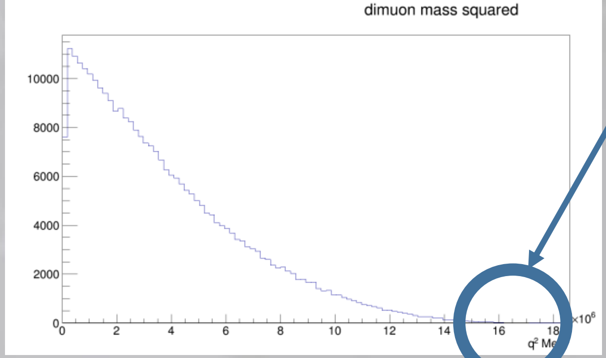
MC is produced with only phase-space kinematics

Experimentally motivated model for decay structure would need full amplitude analysis

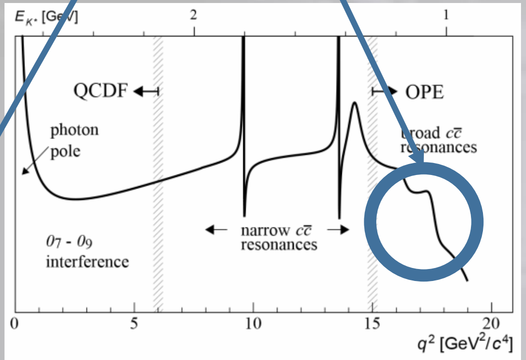
Could see large signal where MC statistics are relatively low







Dimuon mass squared $\Lambda_b^0 \rightarrow pK^-\mu^+\mu^-$ MC



‘Typical’ differential decay rate ($B^0 \rightarrow K^{*0}\mu^+\mu^-$) as function of dimuon mass squared

Analysis strategy:

The LHCb dataflow

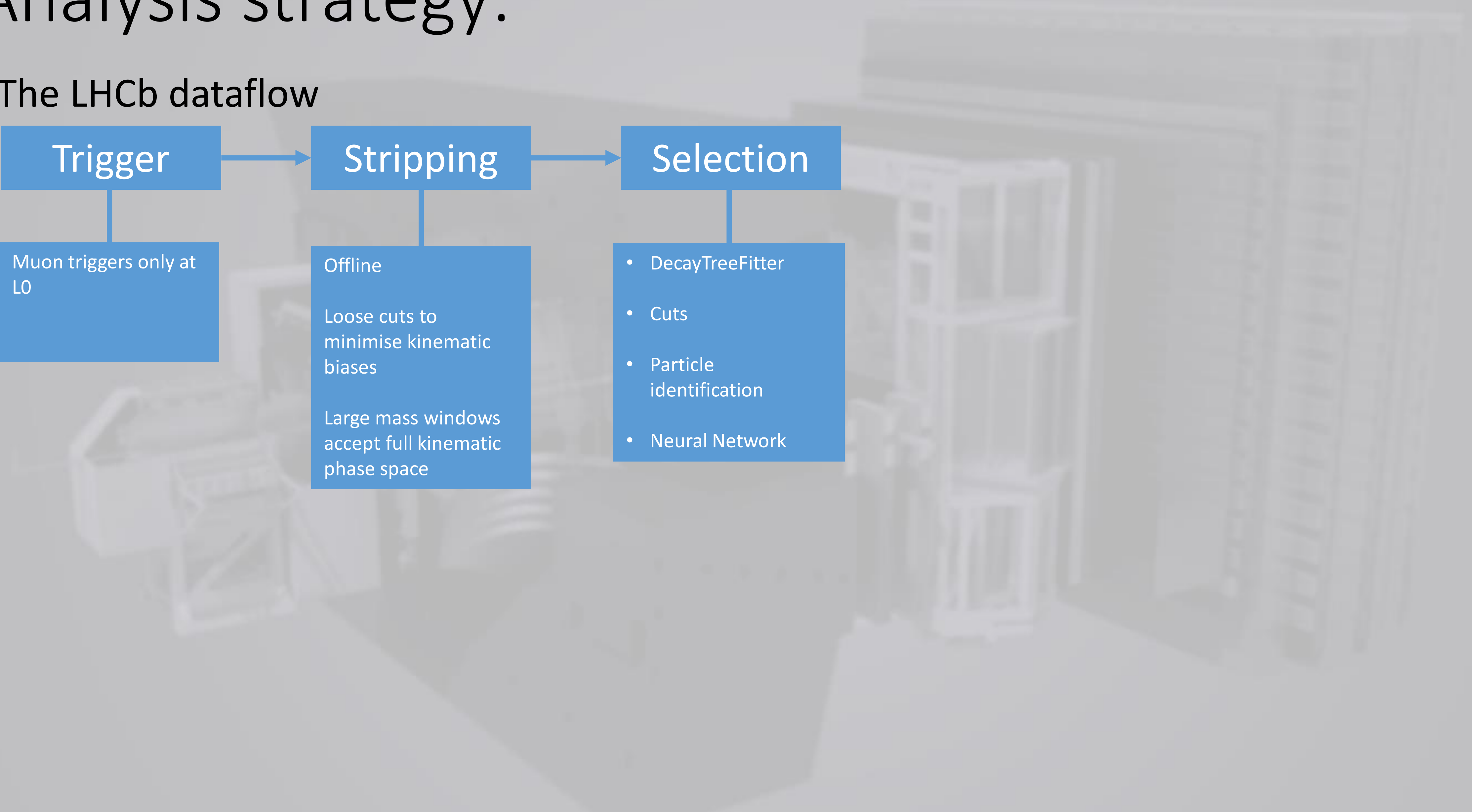
Trigger

Stripping

Selection

Analysis strategy:

The LHCb dataflow



Trigger → **Stripping** → **Selection**

Trigger

Muon triggers only at L0

Stripping

Offline

Loose cuts to minimise kinematic biases

Large mass windows accept full kinematic phase space

Selection

- DecayTreeFitter
- Cuts
- Particle identification
- Neural Network

Analysis strategy:

The LHCb dataflow

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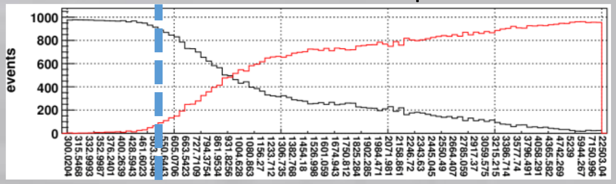
Imposes kinematic constraints based off decay chain to final state

Proton p_T background vs signal from neural net output



500 MeV

Proton $p_T > 500 MeV$
$\Lambda_b^0 \; vtx \; \chi^2/DoF < 5.0$
$q^2 < 17.6 \; GeV^2$

Cuts on the `probNN` variables

Kaon:
- Probability of being kaon > 0.2
- Probability of being proton < 0.8

Proton:
- Probability of being proton > 0.2
- Probability of being kaon< 0.8
- Probability of being pion < 0.7

Training Samples:
- Background: $\Lambda_b^0 \to J/\psi p K^-$ sideband ($> 6 \; GeV$)
- Signal: $\Lambda_b^0 \to p K^- \mu^+ \mu^-$ MC

Most powerful variables:
- DecayTreeFitter χ^2
- Proton p_T
- $Kaon \; IP \; \chi^2$

Optimised with 'punzi figure of merit' $\frac{S}{\sqrt{B}+\frac{\sigma}{2}}$

σ chosen to be 5

Analysis strategy:

The LHCb dataflow

Trigger → **Stripping** → **Selection**

Trigger

Muon triggers only at L0

Stripping

Offline

Loose cuts to minimise kinematic biases

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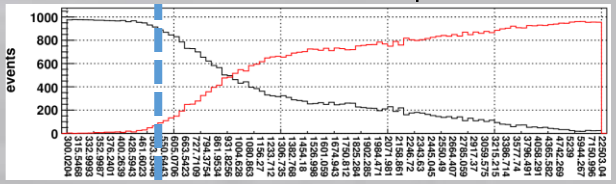

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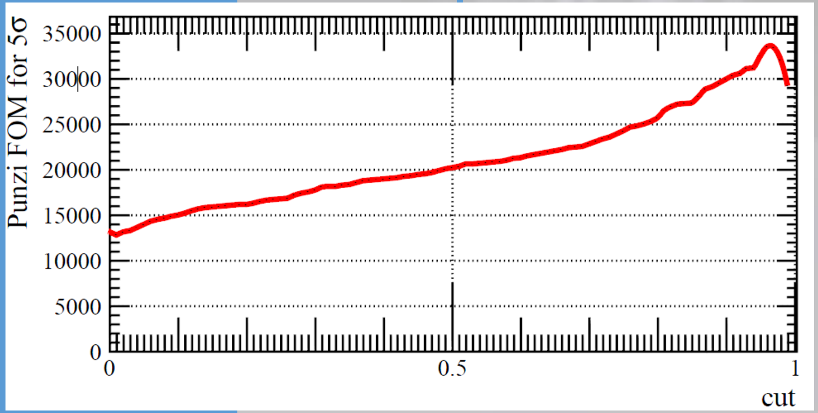


Analysis strategy: acceptance and efficiency

Geometric acceptance → Stripping/ selection → Trigger → PID → Neural Net

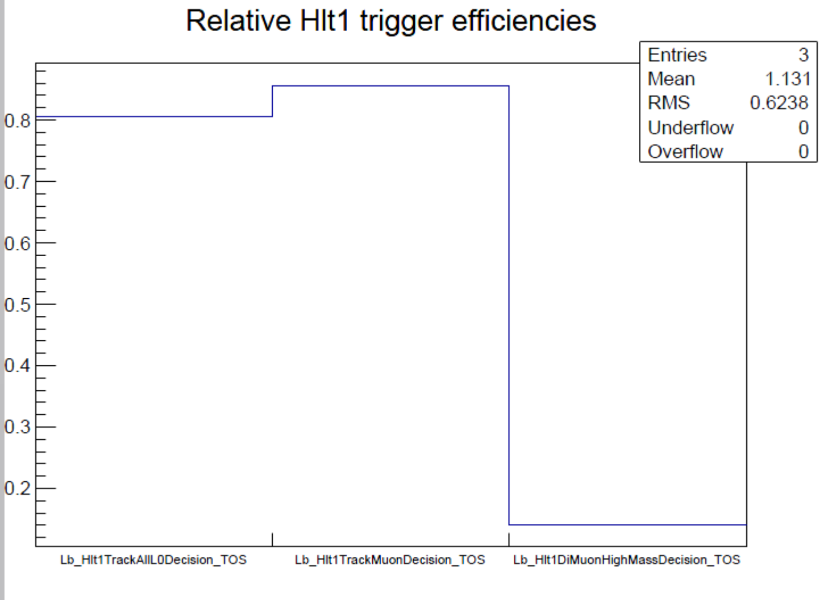
Between 10 and 400 mrad

Strong dependence on kinematics for most selections and acceptances
→ issue with data/MC mismatch

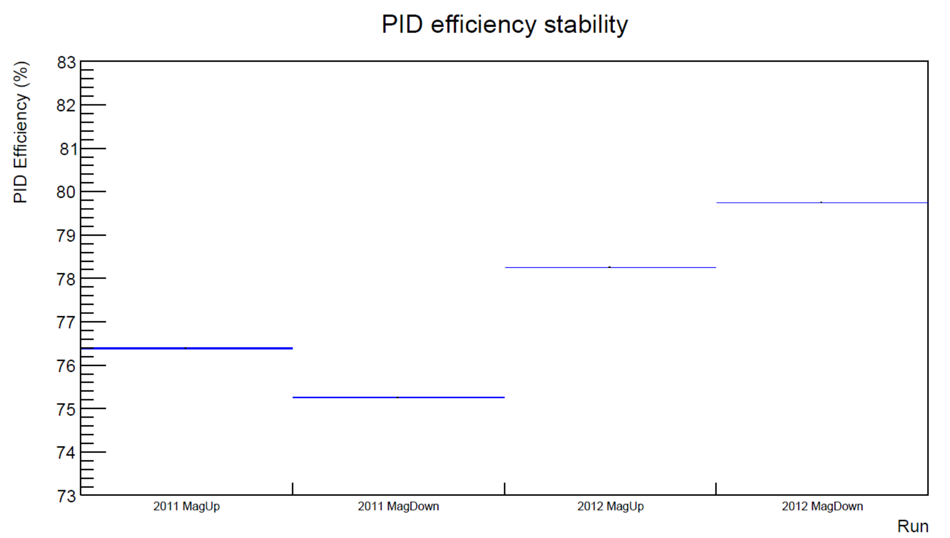
PID behaviour difficult to replicate in MC. Highly dependent on kinematics

Evaluated using ‘calibration samples’
- Data containing high rate, well understood decays.
- Calibration samples binned in kinematic variables
- Essentially a ‘look up table’ for MC event efficiency

$$\epsilon = \frac{N_{pass}}{N}$$



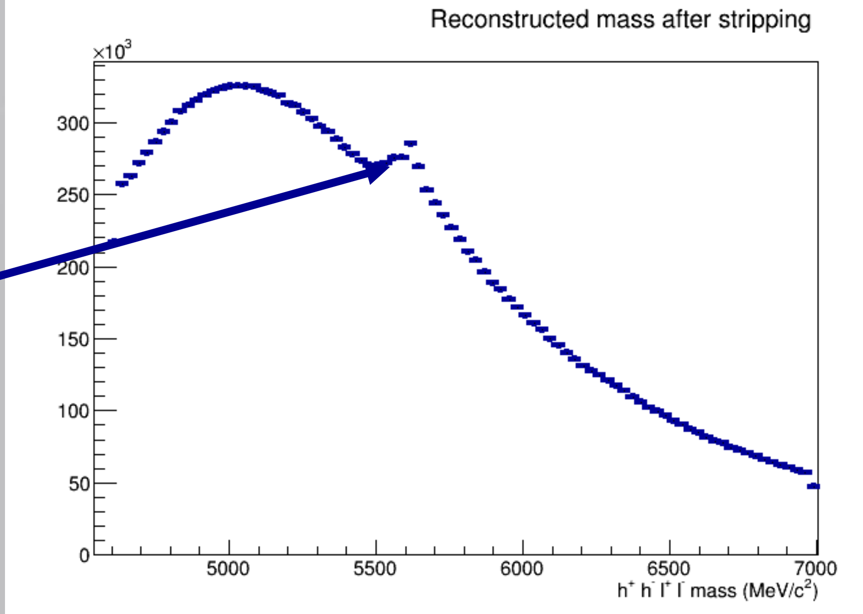
PID efficiency is not stable over time and changes with magnet polarity
→ needs to be treated separately



Dealing with MC discrepancies

Correcting $\mathbf{\Lambda_b^0}$ production kinematics

- Use another Λ_b^0 mode?
  - Only $\boldsymbol{\Lambda_b^0 \to J/\psi p K^-}$ has similar phase-space coverage
  - Need strong cuts to achieve pure sample

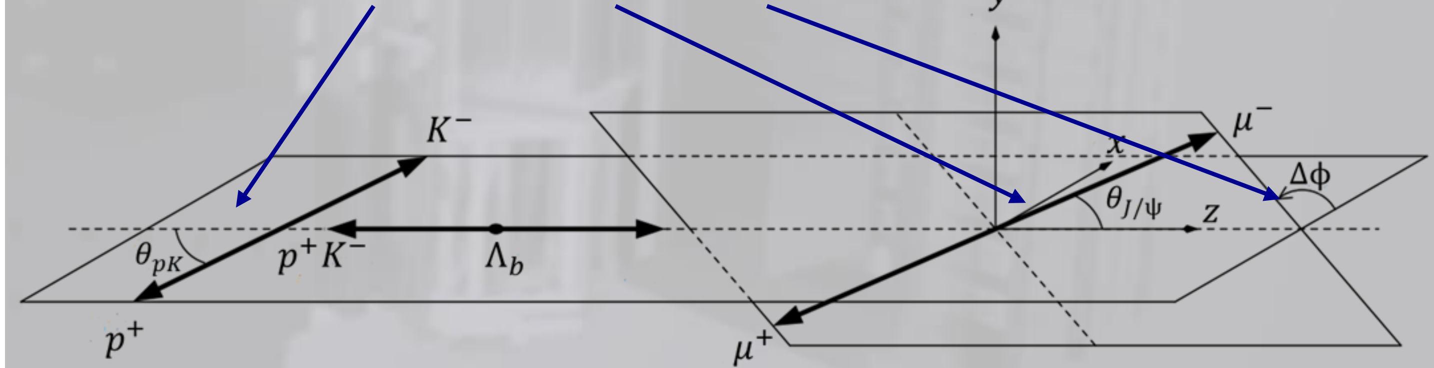


$\mathbf{\Lambda_b^0}$

$\boldsymbol{\Lambda_b^0 \to pK^-\mu + \mu^-}$ decay structure

- Correlation between all angles and the two masses
- Need model of at least 5D to account for all correlations*

$$\epsilon\,(cos\Theta_b, cos\Theta_l, \Delta\phi, m(pK^-), q^2)$$



- Needs to perform well with high no. of dimensions and finite MC stats

* 7D if we do not assume negligible production polarisation

Dealing with MC discrepancies

*background subtracted using fit model to $m(B^0)$ (s-weighting)

Correcting Λ_b^0 production kinematics

- Use LHCb's f_Λ/f_d measurement
  - Measured as function of P_T and η
  - Can use well known B_d decay to extract Λ_b^0 kinematic correction factor
  - $B^0 \to J/\psi K_s$ ←obtain clean sample with loose cuts

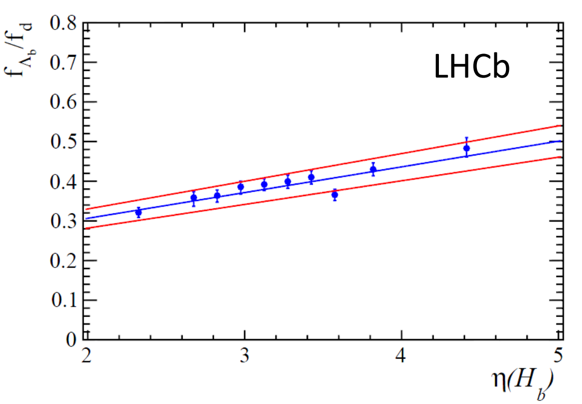
Fit B^0 P_T and η at 'generator level'

Fit Λ_b^0 P_T and η at 'generator level'

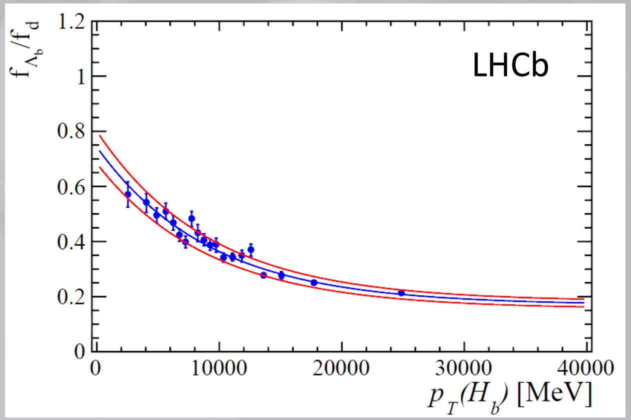
Fit B^0 P_T and η In data* and MC

Small corrections on B^0 MC

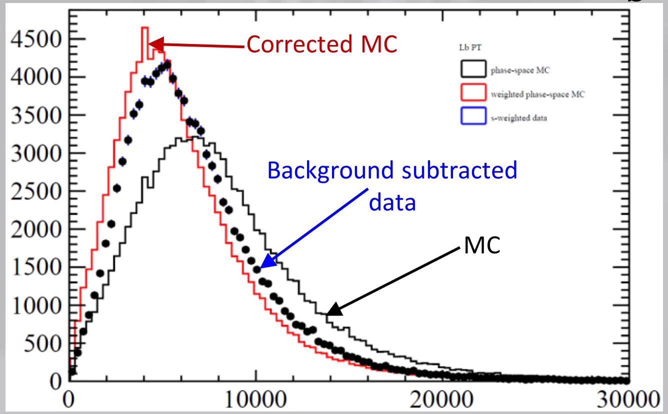
$$w = \frac{f_{\Lambda_b^0}}{f_d}(\mathrm{P}_T,\eta) \times \overbrace{\frac{pdf_{B^0}(P_T,\eta)}{pdf_{\Lambda_b^0}(P_T,\eta)}} \times \overbrace{\frac{1}{w_{B^0}(P_T,\eta)}}$$



doi:10.1007/JHEP08(2014)143



Perfect agreement not expected. Corrects for production kinematics only



- Physics motivated ✓
- Independent of Λ_b^0 decay ✓
- Works! ✓

Dealing with MC discrepancies

Finding a 'goldilocks' model

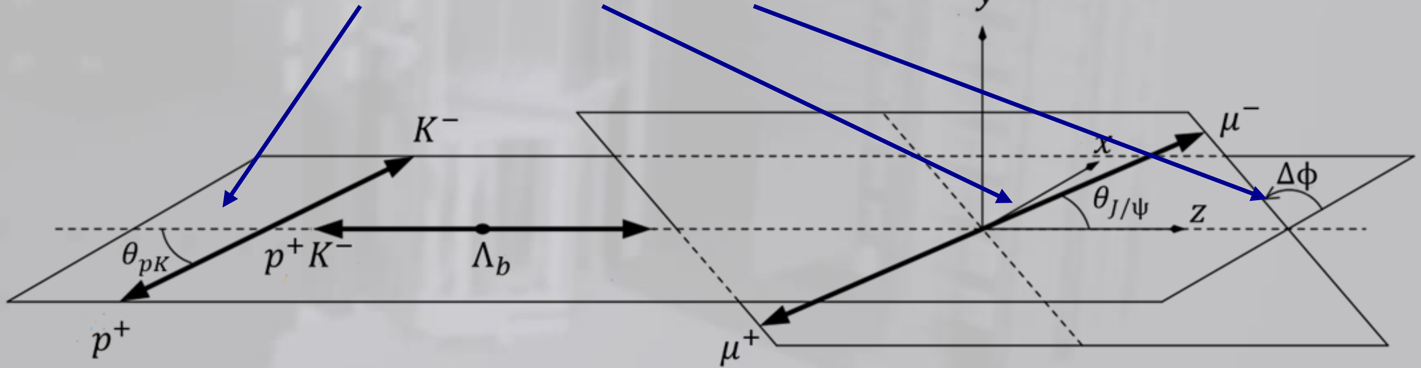
(or an adventure in failed techniques!)

- Always a trade off between accuracy and speed
- Speed important when it comes to systematics (e.g Toy MC's)
- Need to find a trade-off that's 'just right'

$\Lambda_b^0 \to pK^-\mu + \mu^-$ decay structure

- Correlation between all angles and the two masses
- Need model of at least 5D to account for all correlations*

$\epsilon\ (cos\Theta_b, cos\Theta_l, \Delta\phi, m(pK^-), q^2)$



- Needs to perform well with high no. of dimensions and finite MC stats

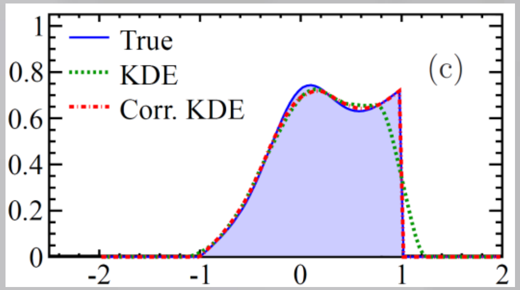
* 7D if we do not assume negligible production polarisation

Dealing with MC discrepancies

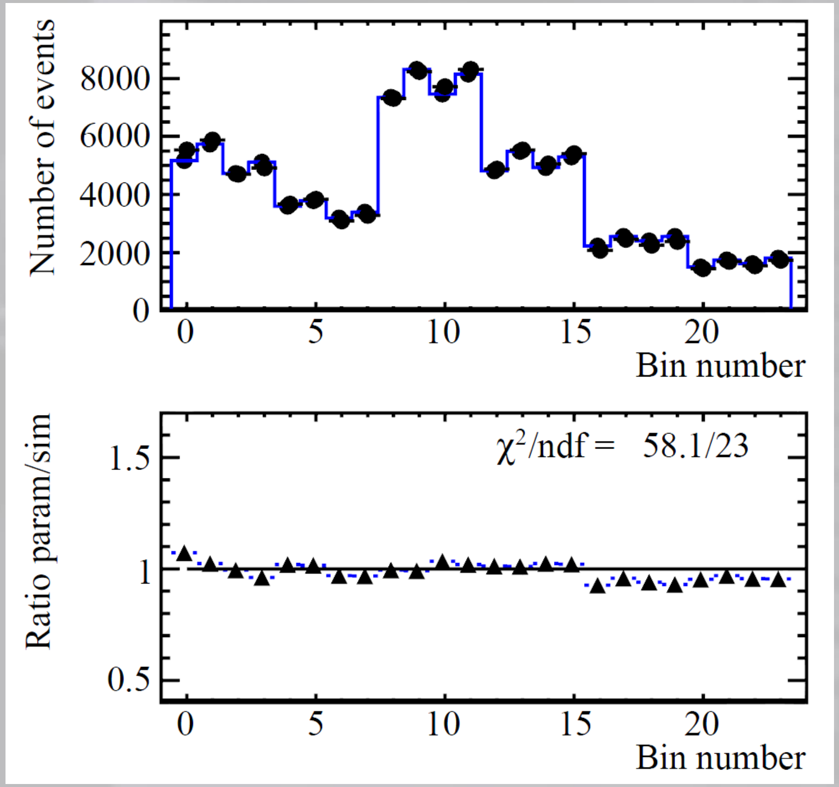
Kernel density estimation?

- Phase space populated with kernels to estimate the pdf.
- A form of ‘data-smoothing’
  - Good for low statistics/many dimensions
- Estimate density in 1D projections
- Then perform correlated multi-dimensional KDE on full phase-space
- Perform boundary correction

$$p_{\mathrm{KDE}}(x) = \frac{1}{N}\sum_{i=1}^{N} K(x - x_i).$$



Good:



Incredibly accurate!

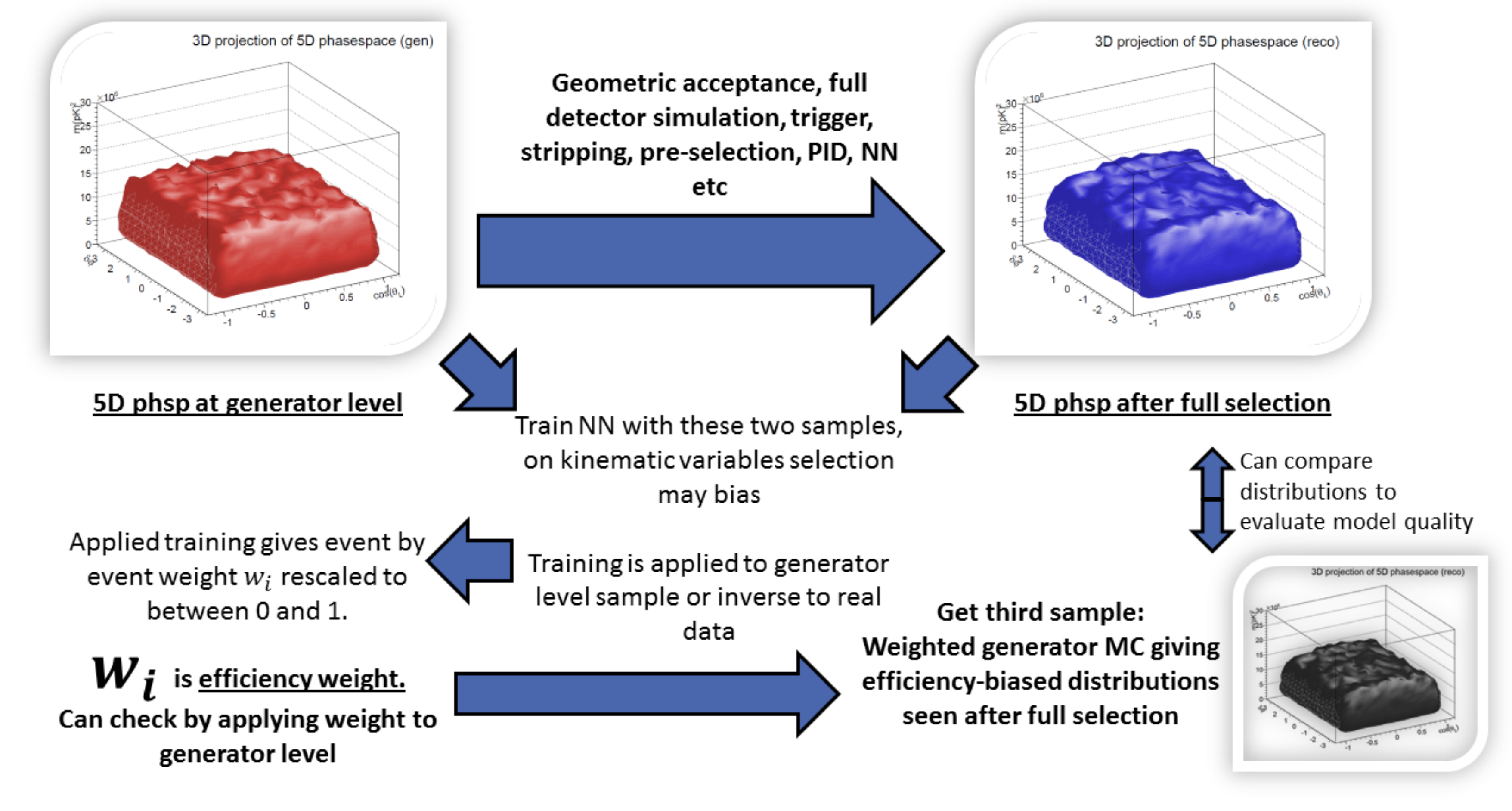
Slices through each plain of the multi-dimensional phase-space, unfolded into 1 dimension, showing ratio between MC after full reconstruction/selection and generator level MC weighted with the KDE pdf.

Bad:

Incredibly CPU intensive!

Dealing with MC discrepancies

Neural Network?



Geometric acceptance, full detector simulation, trigger, stripping, pre-selection, PID, NN etc

5D phsp at generator level

5D phsp after full selection

Train NN with these two samples, on kinematic variables selection may bias

Can compare distributions to evaluate model quality

Applied training gives event by event weight w_i rescaled to between 0 and 1.

Training is applied to generator level sample or inverse to real data

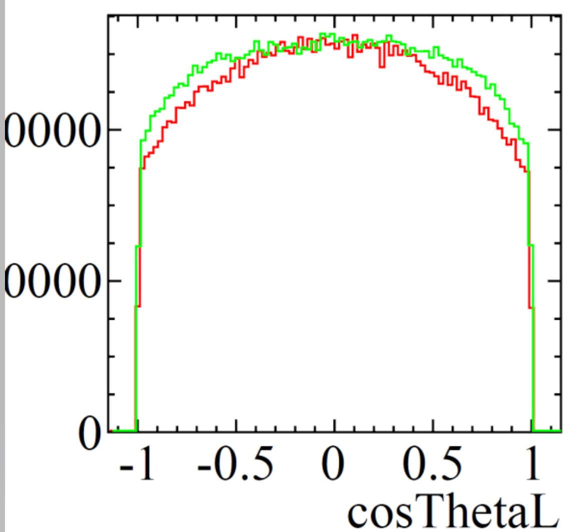
Get third sample:
Weighted generator MC giving efficiency-biased distributions seen after full selection

w_i is **efficiency weight.**
Can check by applying weight to generator level

Good:

Very fast!

Bad:



Comparison of weighted generator level MC and full selection MC

Not so accurate…

Dealing with MC discrepancies - efficiency

Legendre polynomials

- Reweighting function generated for each event.
- Models acceptance effects assuming flat at generator level
  - True for angles (spherically isotropic in phase-space MC)
  - Not true for mass
- → Model both MC samples and perform ratio of efficiency functions

$$\epsilon^{event}\,(cos\Theta_b, cos\Theta_l, \Delta\phi', m[pK^-]^{2\prime}, q^{2\prime}) = \sum_{i,j,k,l,m} c_{ijklm} P_i\left(\cos_{\theta_l}\right) P_j\left(\cos_{\theta_b}\right) P_k(\Delta\phi') P_l\left(m[pK^-]^{2'}\right) P_m(q^{2'})$$

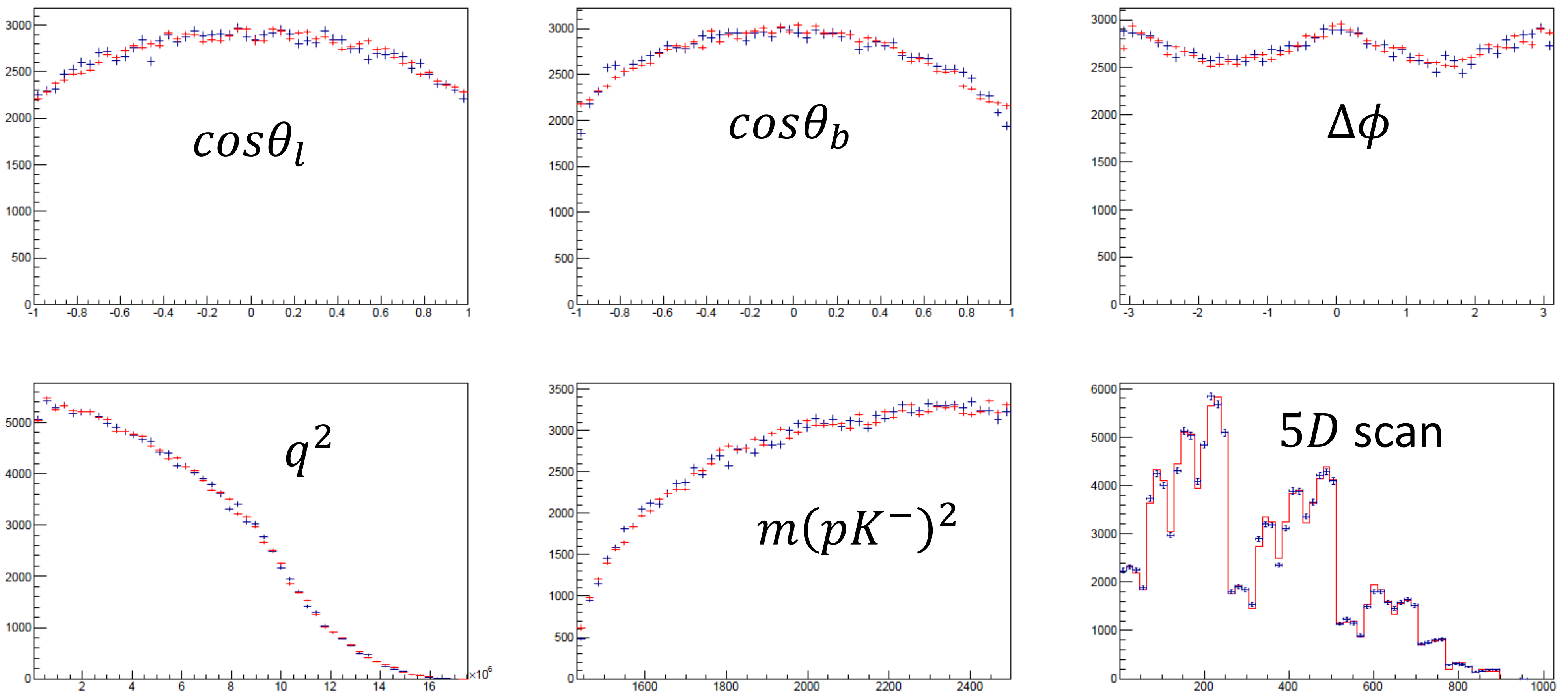
$$c_{ijklm} = c_0 M_{ijklm}(2i+1)(2j+1)(2k+1)(2l+1)(2m+1)$$

c_0 is chosen to be ½ and controls overall integral. Mostly arbitrary as whole model is normalised to the integrated phase-space efficiency

$$M_{ijklm} = \frac{1}{N_{events}} \sum_{0}^{N_{events}} P_i\left(\cos_{\theta_l}\right) P_j\left(\cos_{\theta_b}\right) P_k(\Delta\phi') P_l\left(m[pK^-]^{2'}\right) P_m(q^{2'})$$

Dealing with MC discrepancies - efficiency

Fast enough and accurate enough!



Efficiency correction now largely independent of MC model

Systematic uncertainty evaluated with `bootstrapping`

Calculating $\frac{B(\Lambda_b^0 \to pK^-\mu^+\mu^-)}{B(\Lambda_b^0 \to J/\psi pK^-)}$

Corrected yield

Event weight from background subtraction

$$N = \sum_i \frac{w_i}{\epsilon_i} \rightarrow \frac{B(\Lambda_b^0 \to pK^-\mu^+\mu^-)}{B(\Lambda_b^0 \to J/\psi pK^-)} = \frac{N(\Lambda_b^0 \to pK^-\mu^+\mu^-)}{N(\Lambda_b^0 \to J/\psi pK^-)} = \frac{\sum_i w_i^{\mu\mu}/\epsilon_i^{\mu\mu}}{\sum_j w_j^{J/\psi}/\epsilon_j^{J/\psi}}$$

Event efficiency correction

Systematics propagation:

$$\sigma(N) = \sqrt{\sum_i \left(\frac{w_i}{\epsilon_i}\right)^2}$$

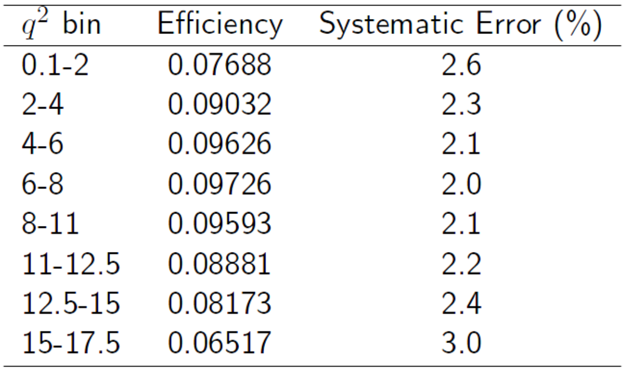
Includes sources of systematic uncertainty on acceptance/efficiency

$$\rightarrow \quad \sigma^{tot}(N) = \sqrt{\sigma(N)^2 + \left(\frac{N}{N_{obs}}\sigma^{shape}(N)\right) + \ldots}$$

Other sources, e.g yield extraction model uncertainties

Sources of systematic uncertainty

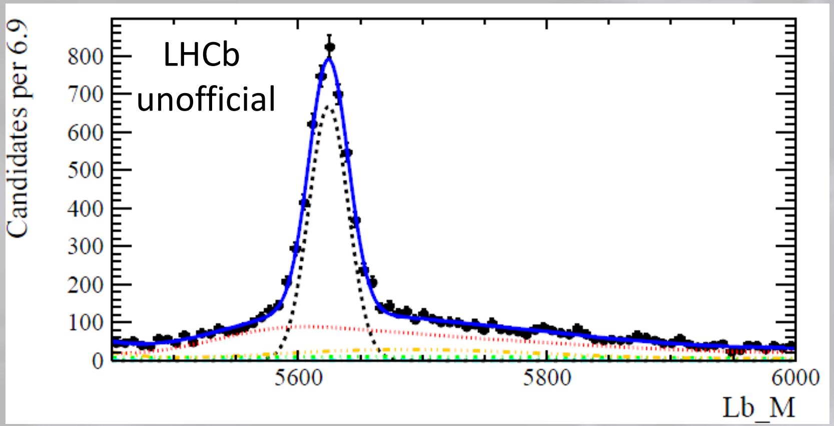
Λ_b^0 lifetime



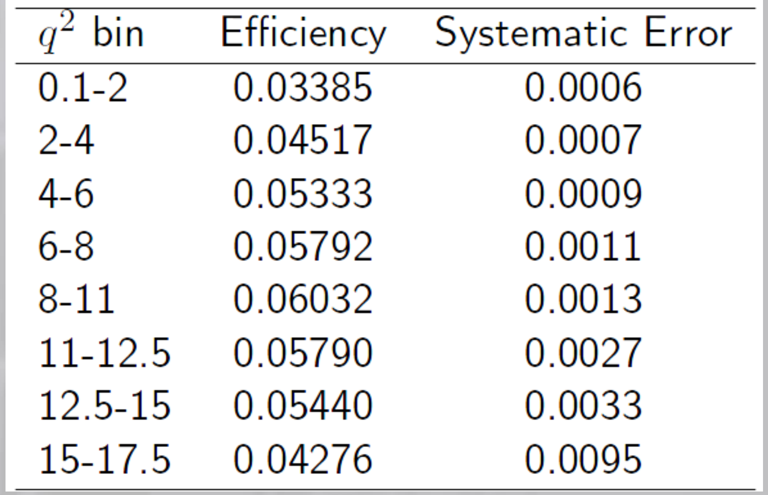
q^2 bin	Efficiency	Systematic Error (%)
0.1-2	0.07688	2.6
2-4	0.09032	2.3
4-6	0.09626	2.1
6-8	0.09726	2.0
8-11	0.09593	2.1
11-12.5	0.08881	2.2
12.5-15	0.08173	2.4
15-17.5	0.06517	3.0

Absolute uncertainty on $\Lambda_b^0 \rightarrow pK^-\mu^+\mu^-$
Relative uncertainty near negligible thanks to LHCb and CMS lifetime measurements

Yield extraction fit

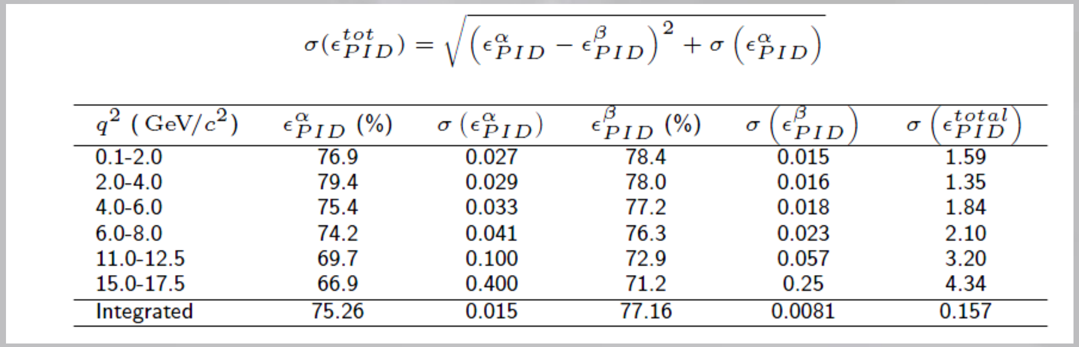


Efficiency model
+ MC statistics



q^2 bin	Efficiency	Systematic Error
0.1-2	0.03385	0.0006
2-4	0.04517	0.0007
4-6	0.05333	0.0009
6-8	0.05792	0.0011
8-11	0.06032	0.0013
11-12.5	0.05790	0.0027
12.5-15	0.05440	0.0033
15-17.5	0.04276	0.0095

Particle Identification



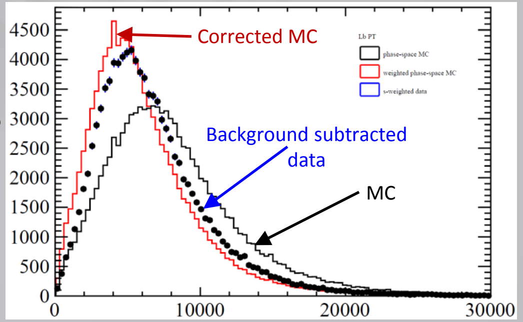
$$\sigma(\epsilon_{PID}^{tot}) = \sqrt{\left(\epsilon_{PID}^{\alpha} - \epsilon_{PID}^{\beta}\right)^2 + \sigma\left(\epsilon_{PID}^{\alpha}\right)}$$

q^2 (GeV/c^2)	ϵ_{PID}^{α} (%)	$\sigma\left(\epsilon_{PID}^{\alpha}\right)$	ϵ_{PID}^{β} (%)	$\sigma\left(\epsilon_{PID}^{\beta}\right)$	$\sigma\left(\epsilon_{PID}^{total}\right)$
0.1-2.0	76.9	0.027	78.4	0.015	1.59
2.0-4.0	79.4	0.029	78.0	0.016	1.35
4.0-6.0	75.4	0.033	77.2	0.018	1.84
6.0-8.0	74.2	0.041	76.3	0.023	2.10
11.0-12.5	69.7	0.100	72.9	0.057	3.20
15.0-17.5	66.9	0.400	71.2	0.25	4.34
Integrated	75.26	0.015	77.16	0.0081	0.157

PID systematic is combination of two uncertainties:

- Statistical uncertainty from bin populations of correction table
- Uncertainty from bin widths (can hide fine structure in PID efficiency space)

Λ_b^0 kinematics correction



Yield extraction

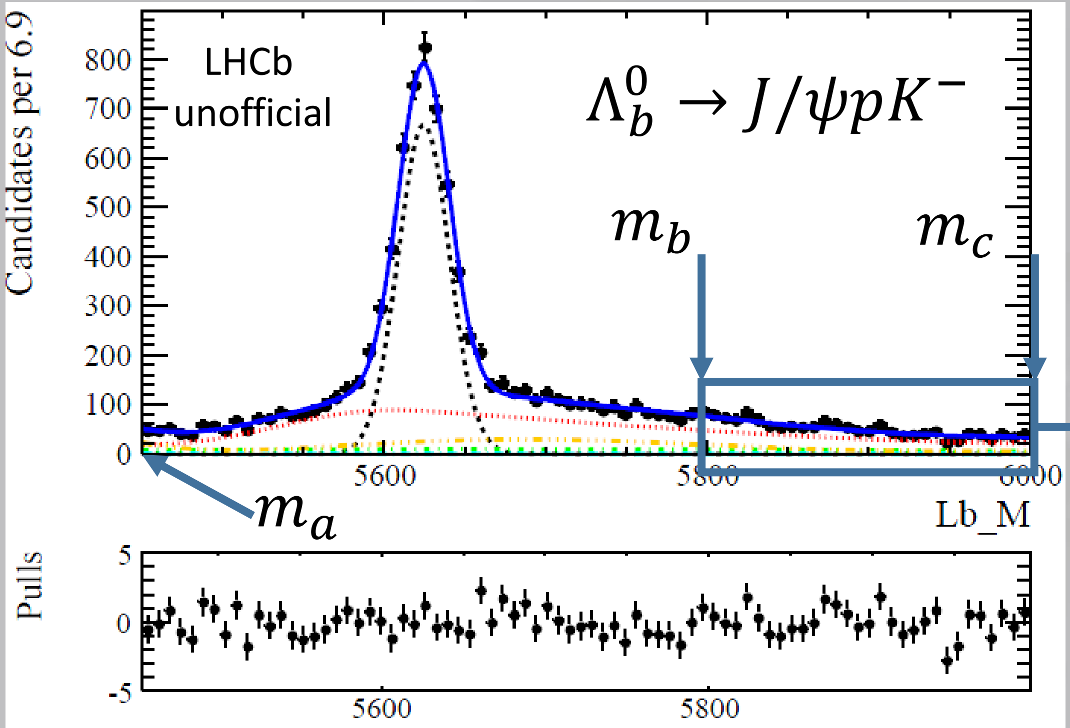


Figure: B_s^0, combinatorial, B^0, $\chi^2 = 1.09$

Signal: Double crystal ball

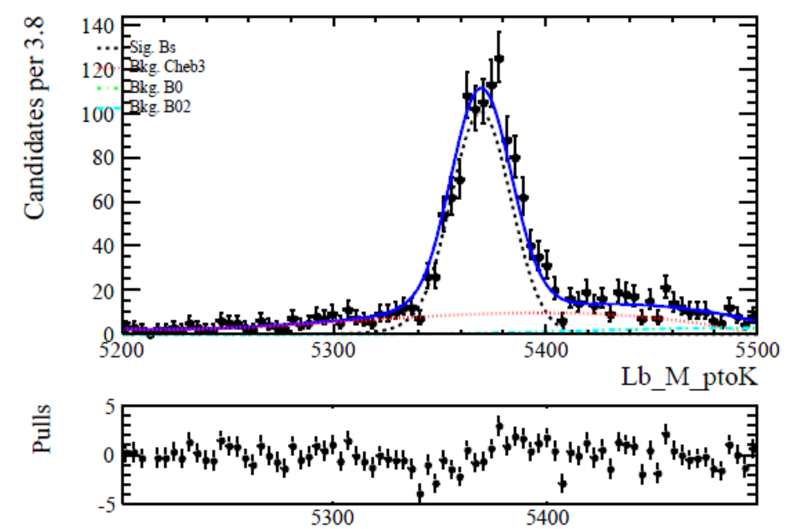
B_s^0 and B^0 backgrounds: DCB (opposite sign tails)

Combinatorial: exponential

$B_s^0 \to K^+K^-\mu^+\mu^-$ yield constrained by fitting mass reflection in upper sideband

Take side band – clean of Λ_b^0

Swap proton → kaon

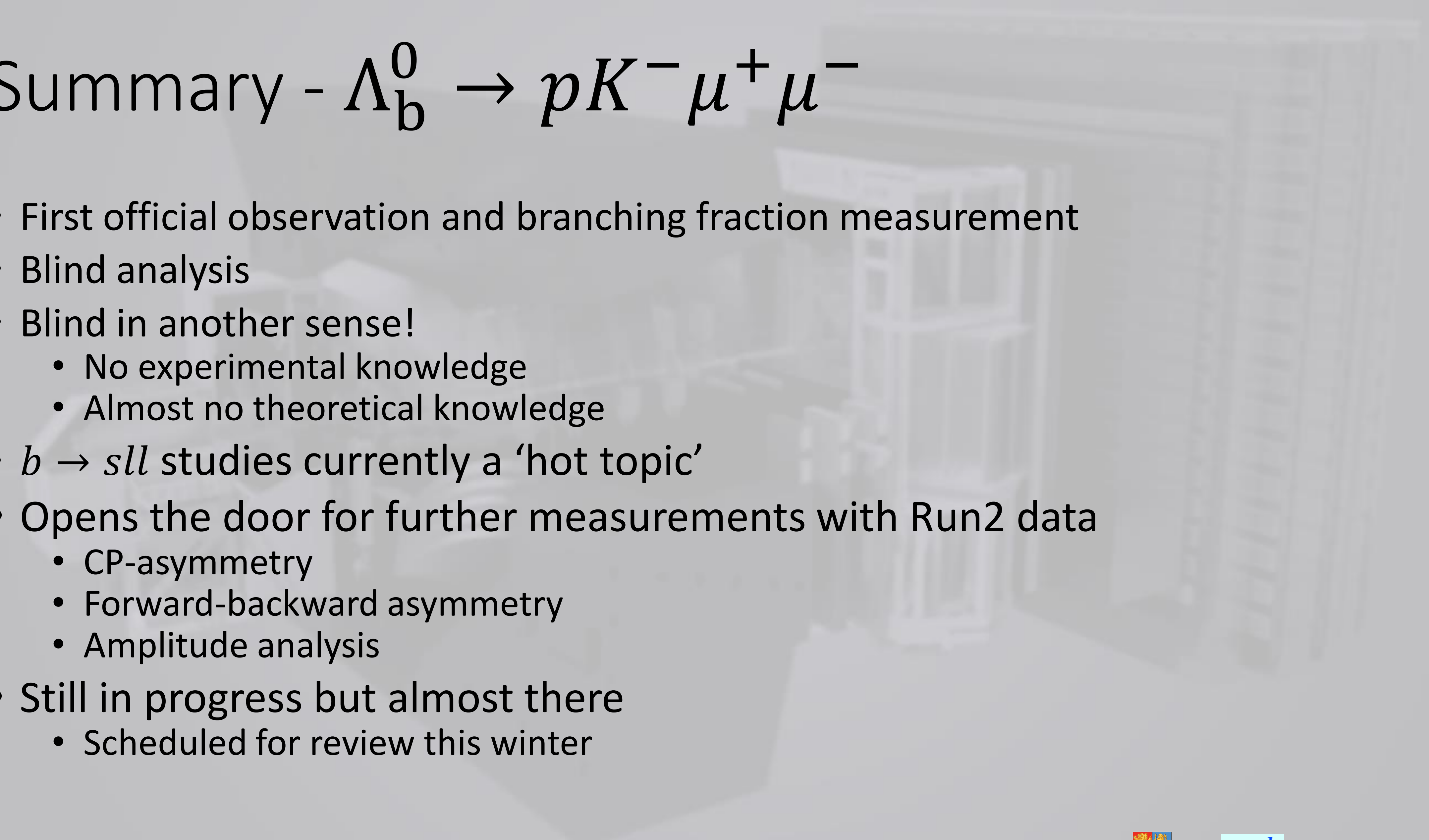


$\Lambda_b^0 \to pK^-\mu^+\mu^-$ to be unblinded in the coming weeks followed by publication -stay tuned!

B_s^0 pdf parameters constrained from MC.
Yield constrained from data using:

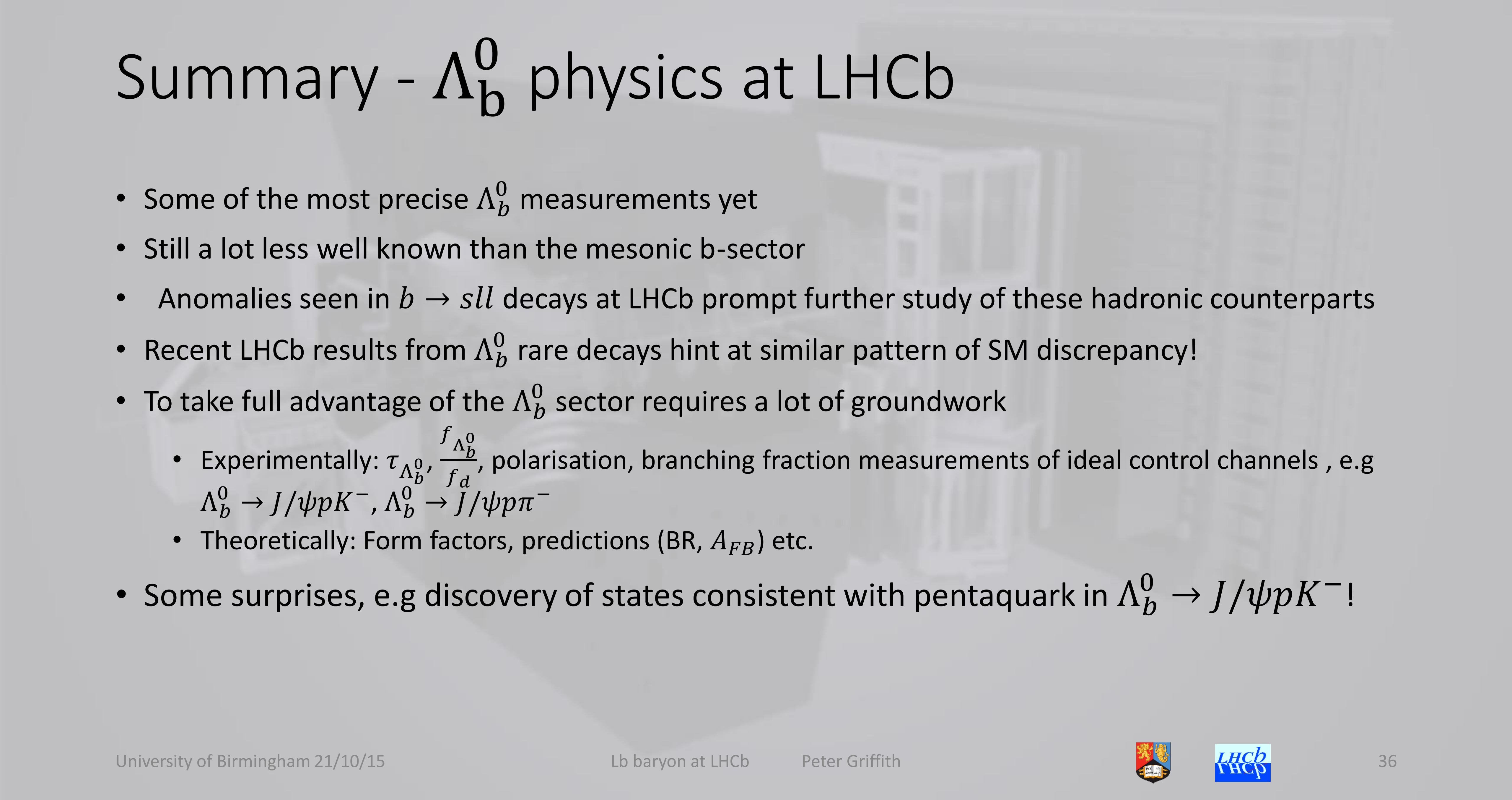
$$I = \int_{m_a}^{m_c} f(x)_{B_s} dx \equiv \int_{m_a}^{m_b} f(x)_{B_s} dx + \int_{m_c}^{m_b} f(x)_{B_s} dx$$

Summary - $\Lambda_{\mathrm{b}}^{0} \rightarrow pK^{-}\mu^{+}\mu^{-}$



- First official observation and branching fraction measurement
- Blind analysis
- Blind in another sense!
  - No experimental knowledge
  - Almost no theoretical knowledge
- $b \rightarrow sll$ studies currently a ‘hot topic’
- Opens the door for further measurements with Run2 data
  - CP-asymmetry
  - Forward-backward asymmetry
  - Amplitude analysis
- Still in progress but almost there
  - Scheduled for review this winter

Summary - Λ_b^0 physics at LHCb



- Some of the most precise Λ_b^0 measurements yet
- Still a lot less well known than the mesonic b-sector
- Anomalies seen in $b \to sll$ decays at LHCb prompt further study of these hadronic counterparts
- Recent LHCb results from Λ_b^0 rare decays hint at similar pattern of SM discrepancy!
- To take full advantage of the Λ_b^0 sector requires a lot of groundwork
  - Experimentally: $\tau_{\Lambda_b^0}$, $\frac{f_{\Lambda_b^0}}{f_d}$, polarisation, branching fraction measurements of ideal control channels , e.g $\Lambda_b^0 \to J/\psi p K^-$, $\Lambda_b^0 \to J/\psi p \pi^-$
  - Theoretically: Form factors, predictions (BR, A_{FB}) etc.
- Some surprises, e.g discovery of states consistent with pentaquark in $\Lambda_b^0 \to J/\psi p K^-$!

Fig1: penguin decay

Thanks for listening!