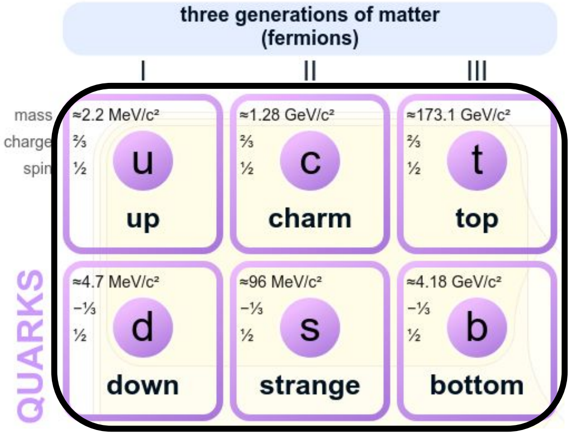
Quantification of backgrounds in the high-q^2 region of R_Λ

Sander Bouma
MSc Thesis Presentation
03-07-2024

Outline

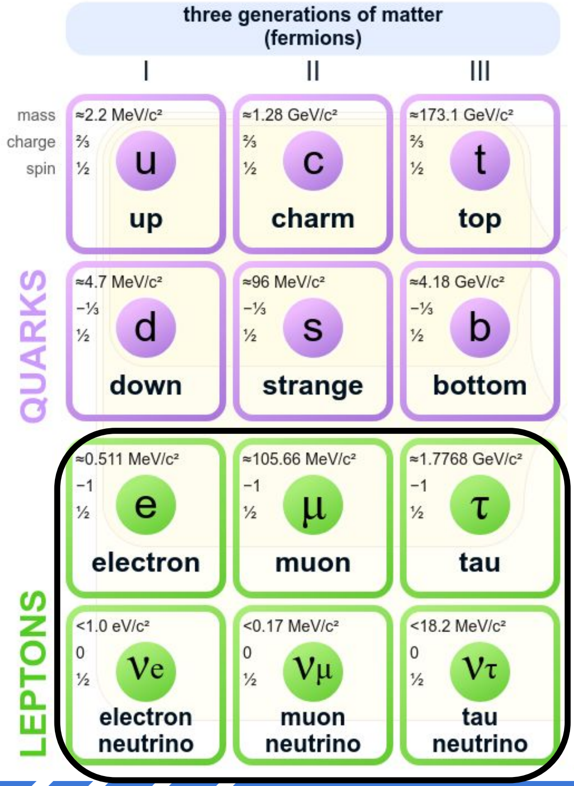
- Standard Model of Particle Physics
- Lepton Flavour Universality
- The R(Λ) analysis
- Backgrounds in R(Λ)
- Results
- Outlook

A brief overview of the Standard Model



Six different flavours of quarks

A brief overview of the Standard Model

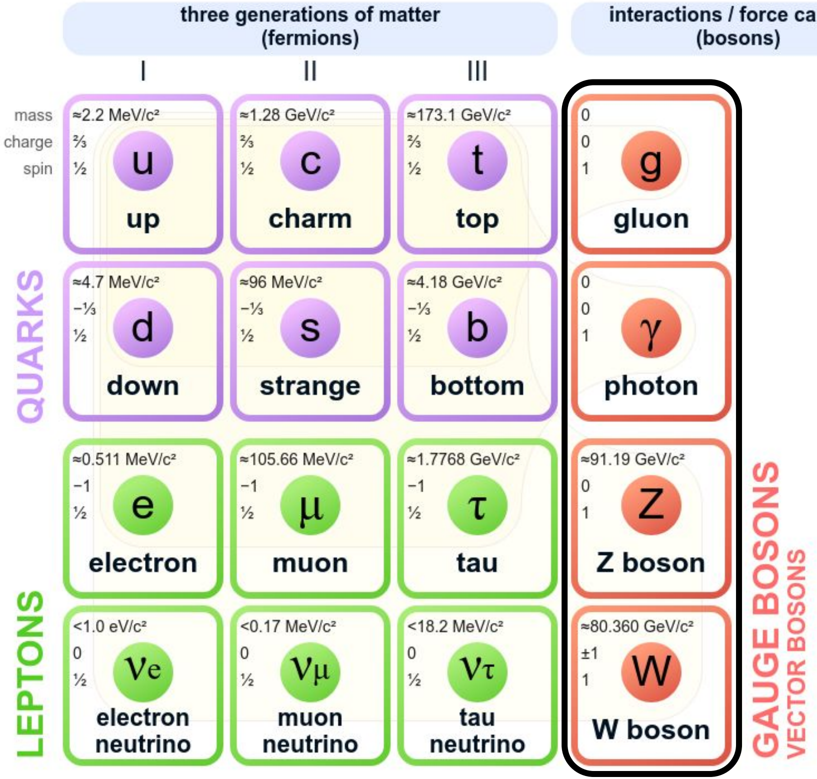


three generations of matter (fermions)

		I	II	III
QUARKS	mass charge spin	≈2.2 MeV/c² ⅔ ½ u up	≈1.28 GeV/c² ⅔ ½ c charm	≈173.1 GeV/c² ⅔ ½ t top
		≈4.7 MeV/c² −⅓ ½ d down	≈96 MeV/c² −⅓ ½ s strange	≈4.18 GeV/c² −⅓ ½ b bottom
LEPTONS		≈0.511 MeV/c² −1 ½ e electron	≈105.66 MeV/c² −1 ½ μ muon	≈1.7768 GeV/c² −1 ½ τ tau
		<1.0 eV/c² 0 ½ ν_e electron neutrino	<0.17 MeV/c² 0 ½ ν_μ muon neutrino	<18.2 MeV/c² 0 ½ ν_τ tau neutrino

Six different flavours of leptons

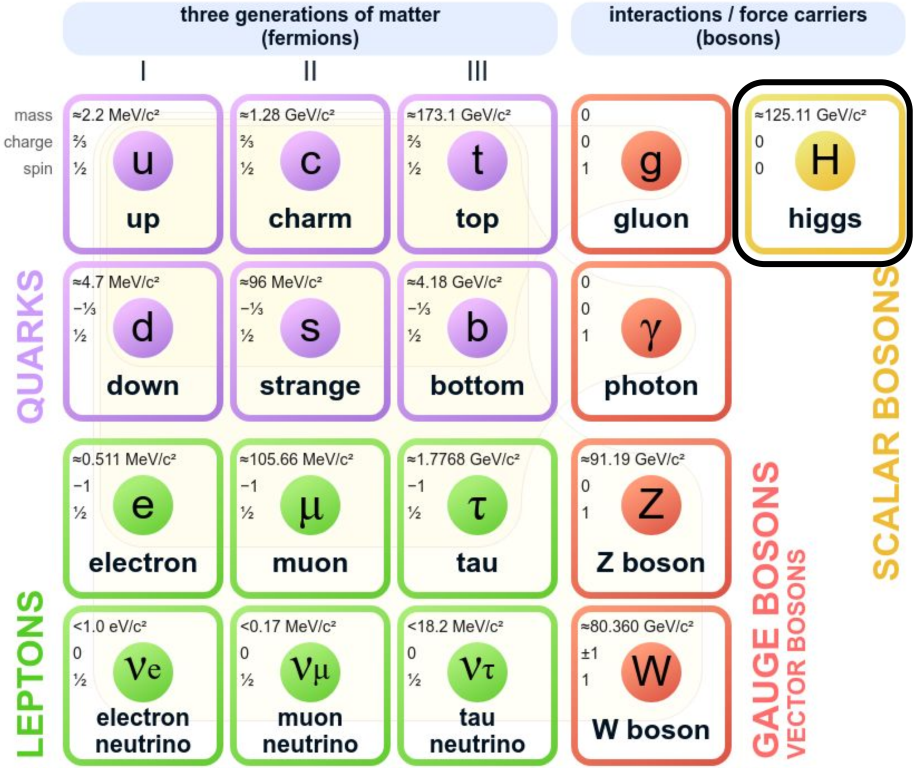
A brief overview of the Standard Model



	three generations of matter (fermions) I	II	III	interactions / force carriers (bosons)
mass charge spin QUARKS	≈2.2 MeV/c^2 ⅔ ½ u **up**	≈1.28 GeV/c^2 ⅔ ½ c **charm**	≈173.1 GeV/c^2 ⅔ ½ t **top**	0 0 1 g **gluon**
QUARKS	≈4.7 MeV/c^2 −⅓ ½ d **down**	≈96 MeV/c^2 −⅓ ½ s **strange**	≈4.18 GeV/c^2 −⅓ ½ b **bottom**	0 0 1 γ **photon**
LEPTONS	≈0.511 MeV/c^2 −1 ½ e **electron**	≈105.66 MeV/c^2 −1 ½ μ **muon**	≈1.7768 GeV/c^2 −1 ½ τ **tau**	≈91.19 GeV/c^2 0 1 Z **Z boson**
LEPTONS	<1.0 eV/c^2 0 ½ ν_e **electron neutrino**	<0.17 MeV/c^2 0 ½ ν_μ **muon neutrino**	<18.2 MeV/c^2 0 ½ ν_τ **tau neutrino**	≈80.360 GeV/c^2 ±1 1 W **W boson**

Four gauge bosons that carry the forces

A brief overview of the Standard Model



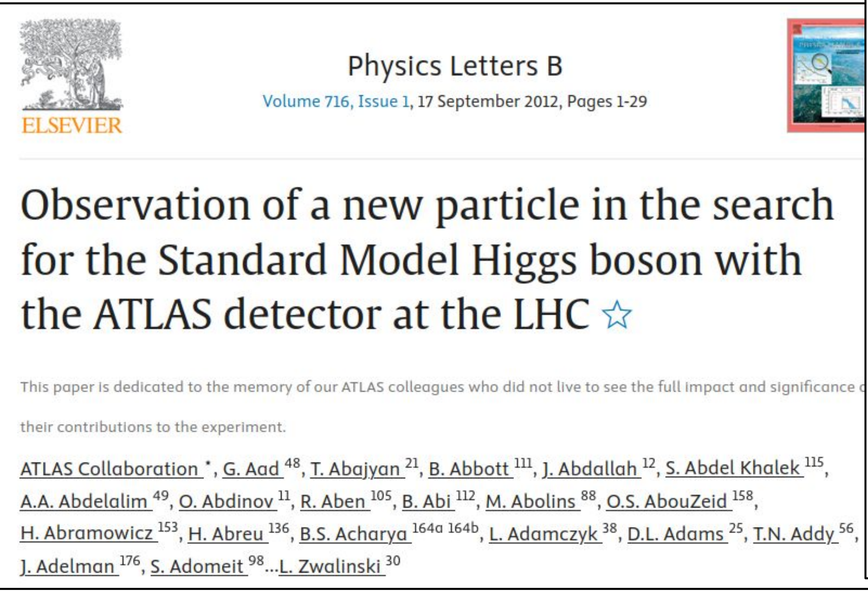
	three generations of matter (fermions)			interactions / force carriers (bosons)	
	I	II	III		
QUARKS mass charge spin	≈2.2 MeV/c^2 ⅔ ½ u up	≈1.28 GeV/c^2 ⅔ ½ c charm	≈173.1 GeV/c^2 ⅔ ½ t top	0 0 1 g gluon	≈125.11 GeV/c^2 0 0 H higgs
	≈4.7 MeV/c^2 −⅓ ½ d down	≈96 MeV/c^2 −⅓ ½ s strange	≈4.18 GeV/c^2 −⅓ ½ b bottom	0 0 1 γ photon	
LEPTONS	≈0.511 MeV/c^2 −1 ½ e electron	≈105.66 MeV/c^2 −1 ½ μ muon	≈1.7768 GeV/c^2 −1 ½ τ tau	≈91.19 GeV/c^2 0 1 Z Z boson	
	<1.0 eV/c^2 0 ½ ν_e electron neutrino	<0.17 MeV/c^2 0 ½ ν_μ muon neutrino	<18.2 MeV/c^2 0 ½ ν_τ tau neutrino	≈80.360 GeV/c^2 ±1 1 W W boson	

GAUGE BOSONS
VECTOR BOSONS

SCALAR BOSONS

One scalar boson that allows W and Z to have mass

The SM has made many accurate predictions



Physics Letters B

Volume 716, Issue 1, 17 September 2012, Pages 1-29

Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC ☆

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance

their contributions to the experiment.

ATLAS Collaboration *, G. Aad[48], T. Abajyan[21], B. Abbott[111], J. Abdallah[12], S. Abdel Khalek[115], A.A. Abdelalim[49], O. Abdinov[11], R. Aben[105], B. Abi[112], M. Abolins[88], O.S. AbouZeid[158], H. Abramowicz[153], H. Abreu[136], B.S. Acharya[164a 164b], L. Adamczyk[38], D.L. Adams[25], T.N. Addy[56], J. Adelman[176], S. Adomeit[98]...L. Zwalinski[30]

Physics Letters B

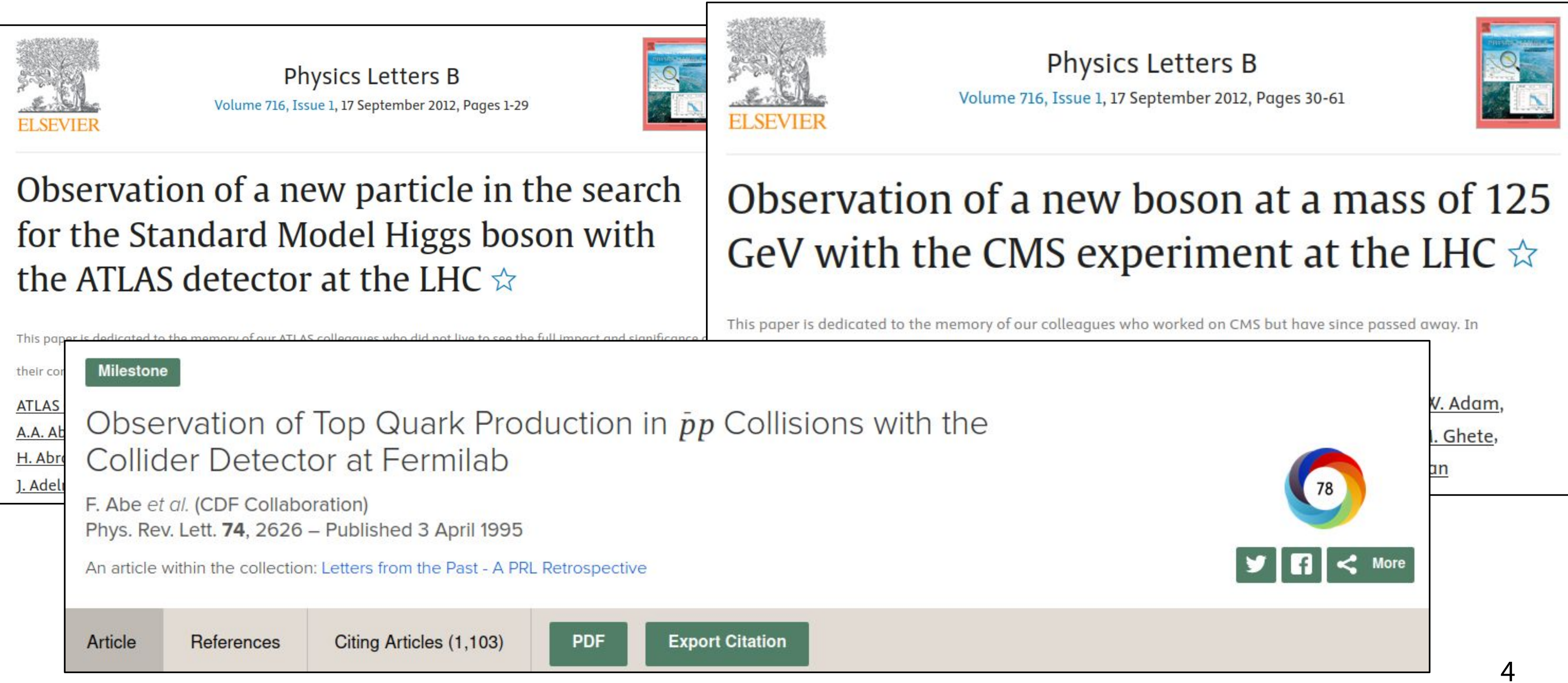
Volume 716, Issue 1, 17 September 2012, Pages 30-61

Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC ☆

This paper is dedicated to the memory of our colleagues who worked on CMS but have since passed away. In recognition of their many contributions to the achievement of this observation.

CMS Collaboration *, S. Chatrchyan, V. Khachatryan, A.M. Sirunyan, A. Tumasyan, W. Adam, E. Aguilo, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan[1], M. Friedl, R. Frühwirth[1], V.M. Ghete, J. Hammer, M. Hoch, N. Hörmann, J. Hrubec, M. Jeitler[1], W. Kiesenhofer...D. Wenman

The SM has made many accurate predictions



ELSEVIER

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ATLAS
A.A. Ab
H. Abr
J. Adel

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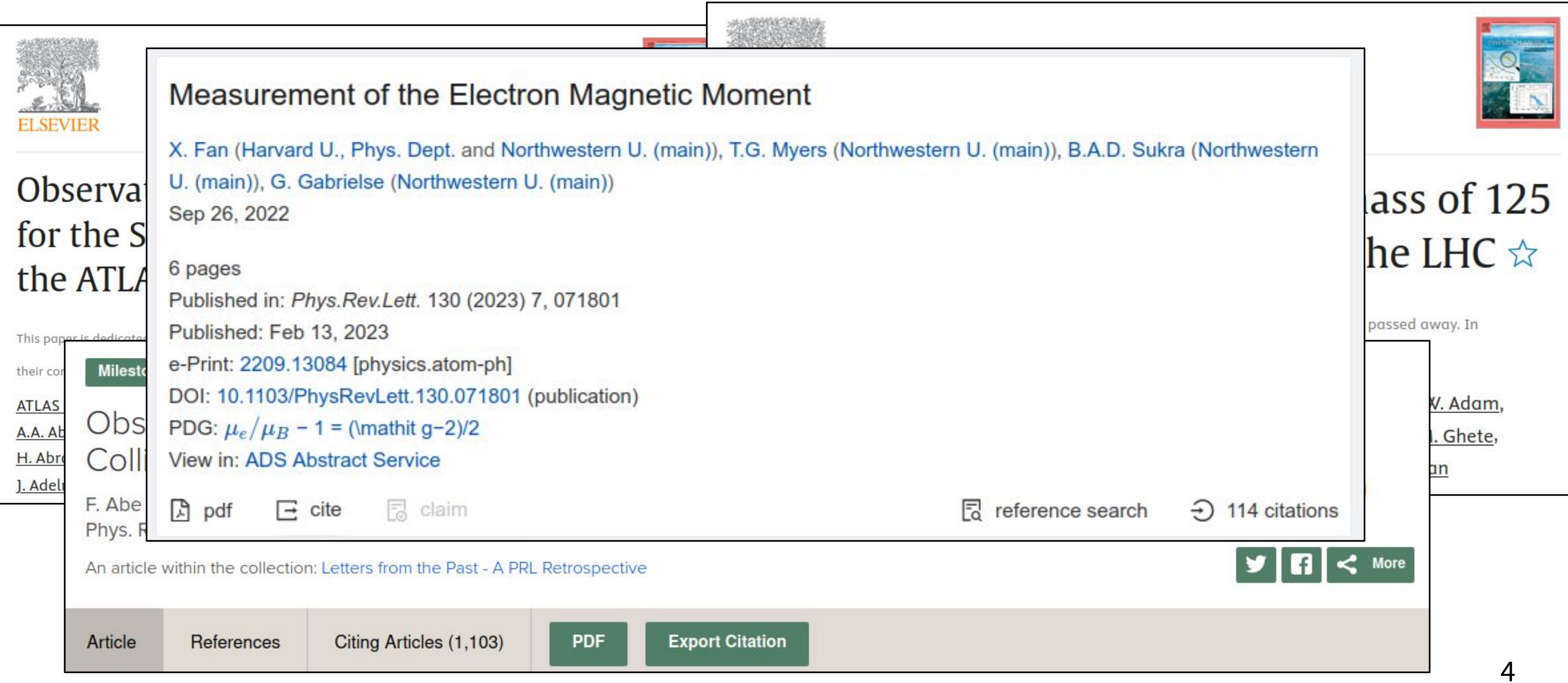
V. Adam,
. Ghete,
an

Observation of Top Quark Production in $\bar{p}p$ Collisions with the Collider Detector at Fermilab

F. Abe *et al.* (CDF Collaboration)
Phys. Rev. Lett. **74**, 2626 – Published 3 April 1995

An article within the collection: Letters from the Past - A PRL Retrospective

The SM has made many accurate predictions



Measurement of the Electron Magnetic Moment

X. Fan (Harvard U., Phys. Dept. and Northwestern U. (main)), T.G. Myers (Northwestern U. (main)), B.A.D. Sukra (Northwestern U. (main)), G. Gabrielse (Northwestern U. (main))

Sep 26, 2022

6 pages

Published in: *Phys.Rev.Lett.* 130 (2023) 7, 071801

Published: Feb 13, 2023

e-Print: 2209.13084 [physics.atom-ph]

DOI: 10.1103/PhysRevLett.130.071801 (publication)

PDG: μ_e/μ_B − 1 = (\mathit g−2)/2

View in: ADS Abstract Service

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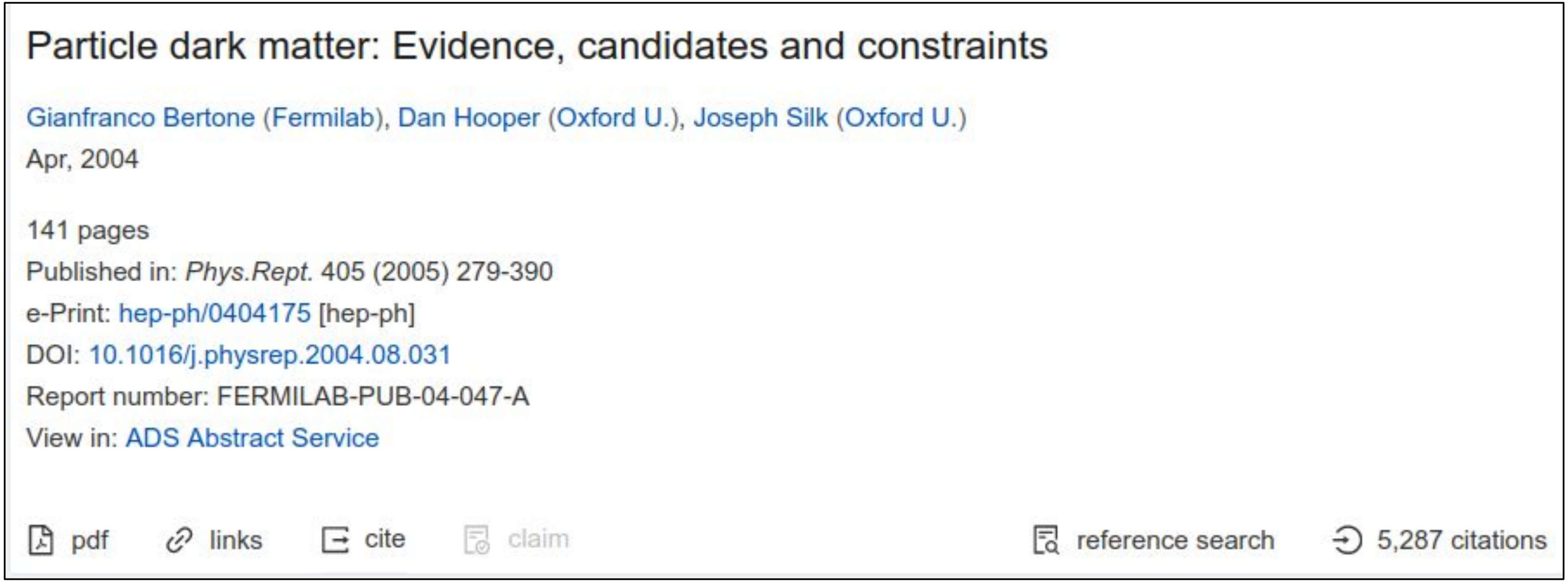
However, there remain unsolved mysteries



Particle dark matter: Evidence, candidates and constraints

Gianfranco Bertone (Fermilab), Dan Hooper (Oxford U.), Joseph Silk (Oxford U.)
Apr, 2004

141 pages
Published in: *Phys.Rept.* 405 (2005) 279-390
e-Print: hep-ph/0404175 [hep-ph]
DOI: 10.1016/j.physrep.2004.08.031
Report number: FERMILAB-PUB-04-047-A
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However, there remain unsolved mysteries

Particle dark matter: Evidence, candidates and constraints

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Feature Article | Free Access

Matter-antimatter asymmetry - aspects at low energy

Lorenz Willmann, Klaus Jungmann

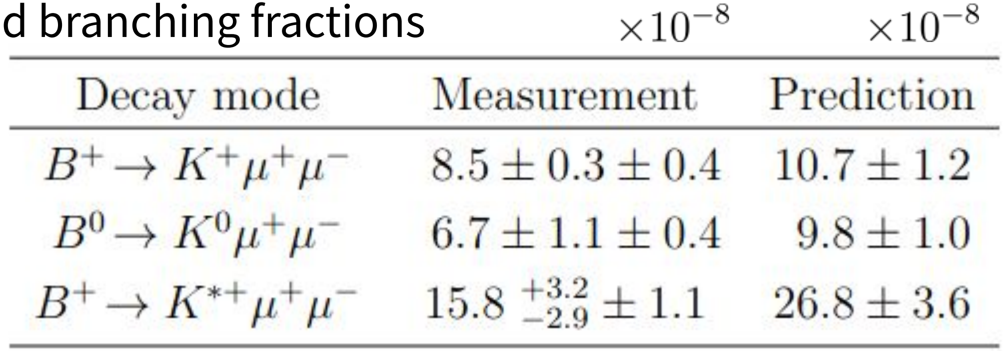
First published: 01 July 2015 | https://doi.org/10.1002/andp.201500008 | Citations: 8

Hint for new physics?

The LHCb Public results

Differential branching fractions and isospin asymmetries of $B \to K^{(*)}\mu^+\mu^-$ decays (2014)

Integrated branching fractions



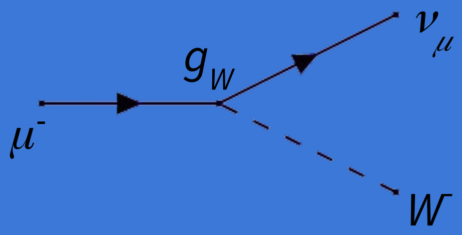
	$\times 10^{-8}$	$\times 10^{-8}$
Decay mode	Measurement	Prediction
$B^+ \to K^+\mu^+\mu^-$	$8.5 \pm 0.3 \pm 0.4$	10.7 ± 1.2
$B^0 \to K^0\mu^+\mu^-$	$6.7 \pm 1.1 \pm 0.4$	9.8 ± 1.0
$B^+ \to K^{*+}\mu^+\mu^-$	$15.8\ ^{+3.2}_{-2.9} \pm 1.1$	26.8 ± 3.6

Lepton Flavour Universality

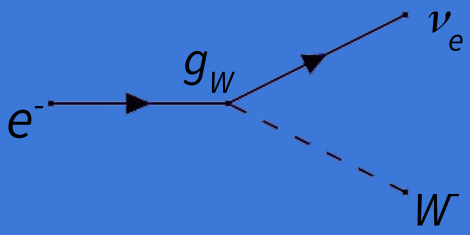
Lepton Flavour Universality

According to SM

Muons:



Electrons:



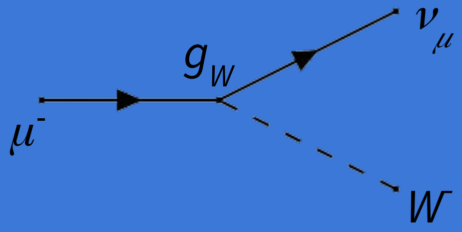
Same interactions, same coupling[†]

[†] also applies to taus

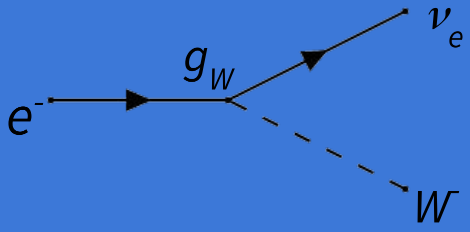
Lepton Flavour Universality

According to SM

Muons:



Electrons:



Same interactions, same coupling[†]

Thus,*

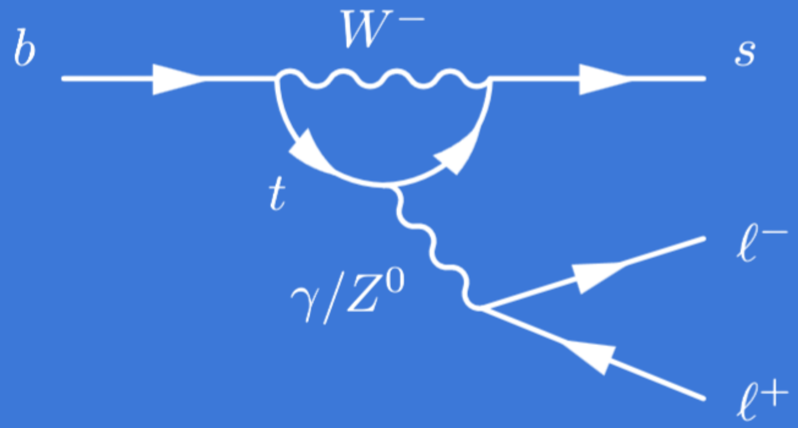
$$R = \frac{\mathcal{B}(b \to s\mu^+\mu^-)}{\mathcal{B}(b \to se^+e^-)} \approx 1$$

[†] also applies to taus

*aside from small corrections due to mass differences

b→sl⁺l⁻ transitions

Standard Model:



b⟶sl^{+}l^{-} transitions

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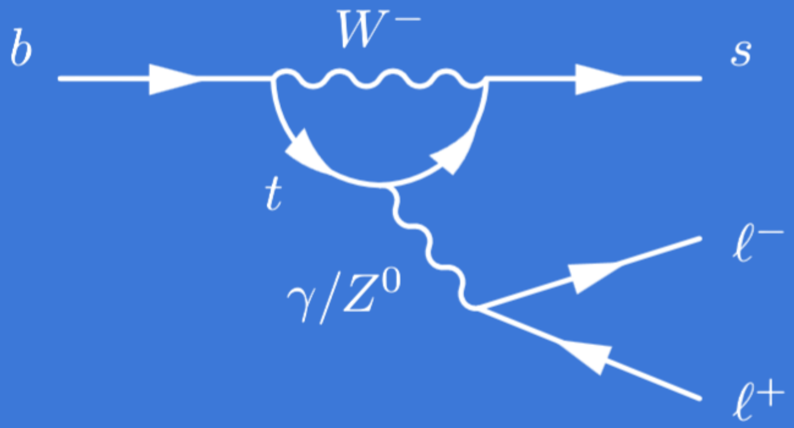
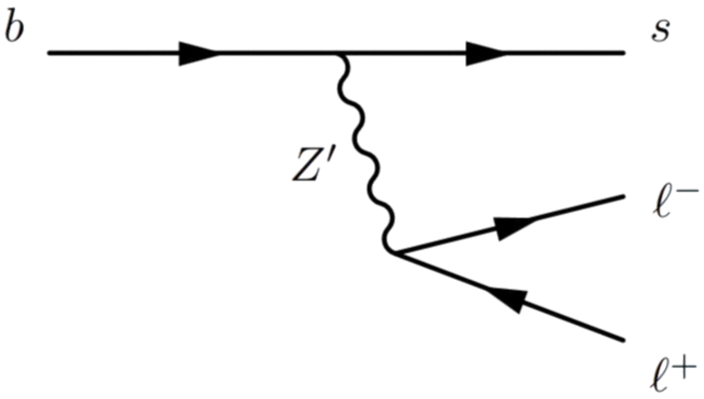
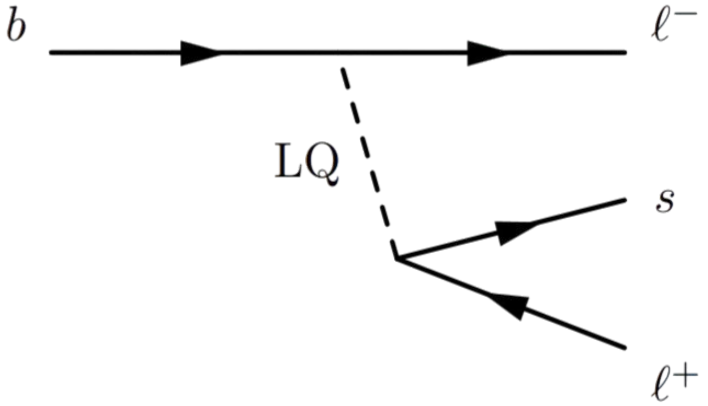


Beyond Standard Model:



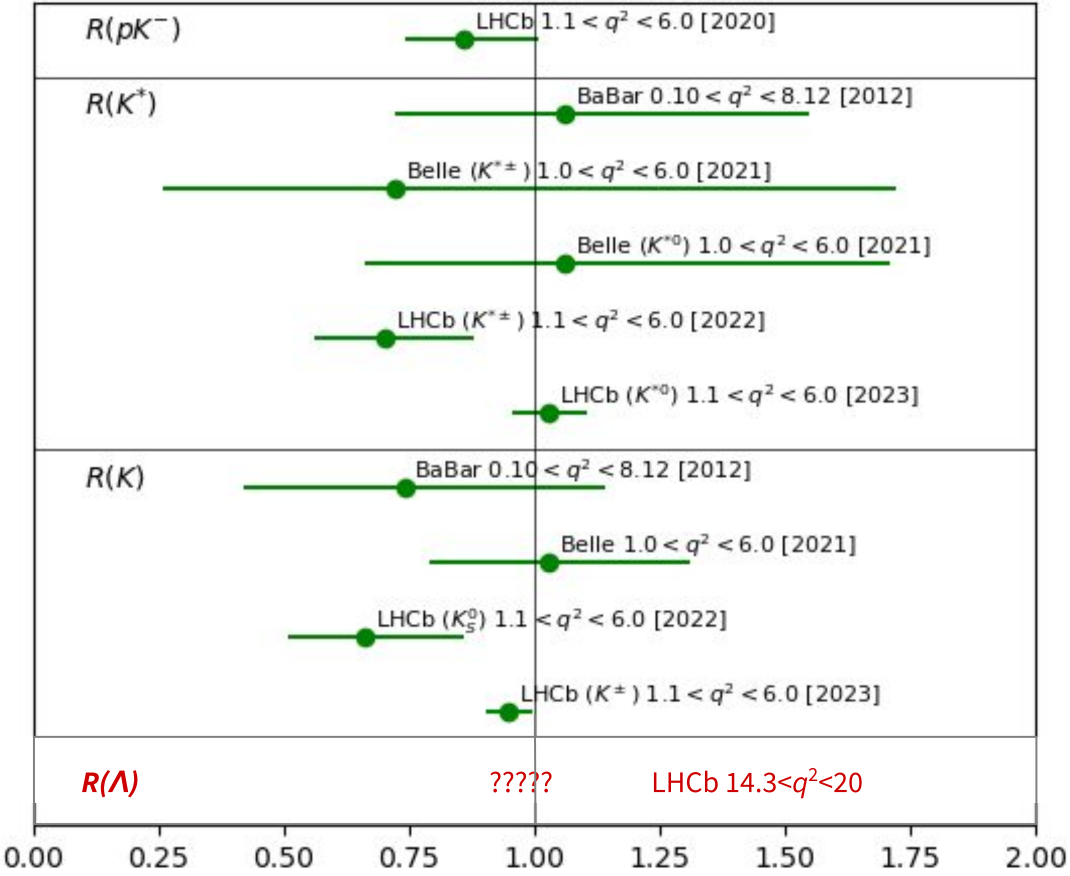
Andrzej J. Buras & Jennifer Girrbach. “Left-handed Z′ and Z FCNC quark couplings facing new b → sμ+μ− data”



Damir Becirevic et al. “Leptoquark model to explain the B-physics anomalies RK and RD ”

R measurements

$$R = \frac{\mathcal{B}(b \to s\mu^+\mu^-)}{\mathcal{B}(b \to s e^+ e^-)} \approx 1$$

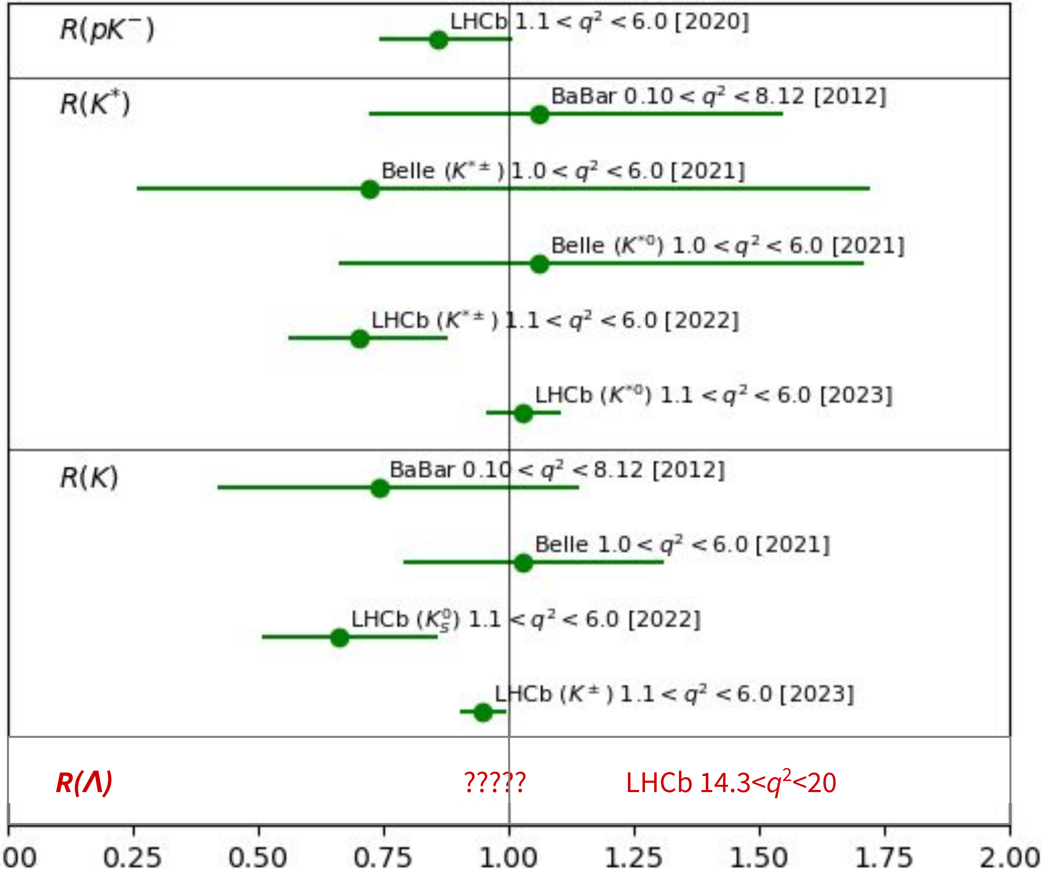


http://www.scholarpedia.org/article/Lepton_flavour_universality

R measurements

$$R = \frac{\mathcal{B}(b \to s\mu^+\mu^-)}{\mathcal{B}(b \to se^+e^-)} \approx 1$$

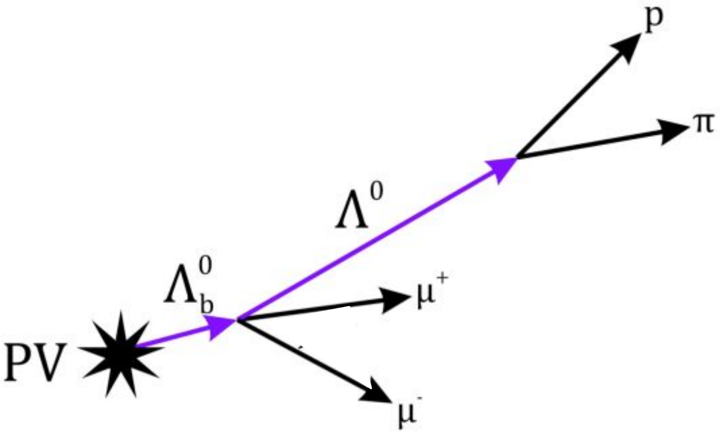
$$q^2 \equiv m(\ell^+\ell^-)^2 = (\mathbf{p}_{\ell+} + \mathbf{p}_{\ell-})^2$$

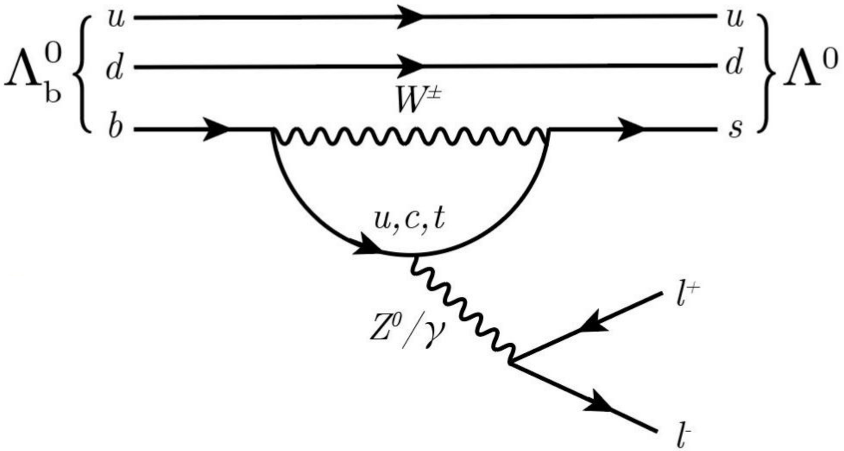


http://www.scholarpedia.org/article/Lepton_flavour_universality

The R(Λ) analysis

$$R(\Lambda) = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda^0\mu^+\mu^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda^0 e^+e^-)}, \qquad \text{where } \Lambda^0 \to p\pi^-$$



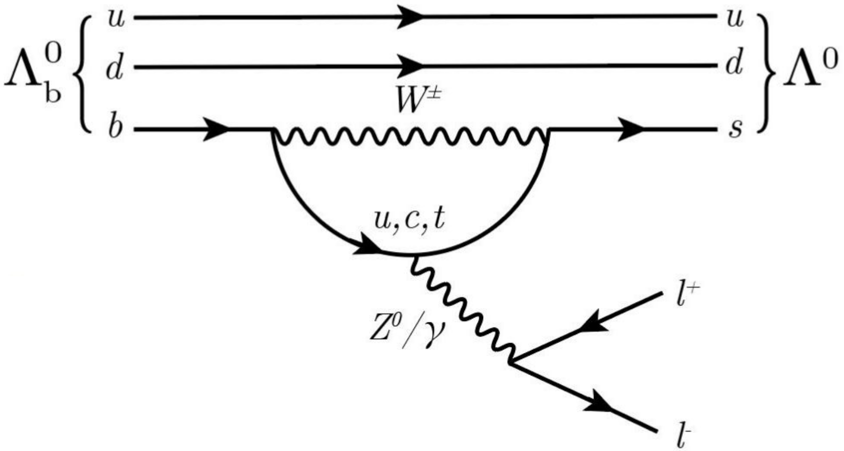


The R(Λ) analysis

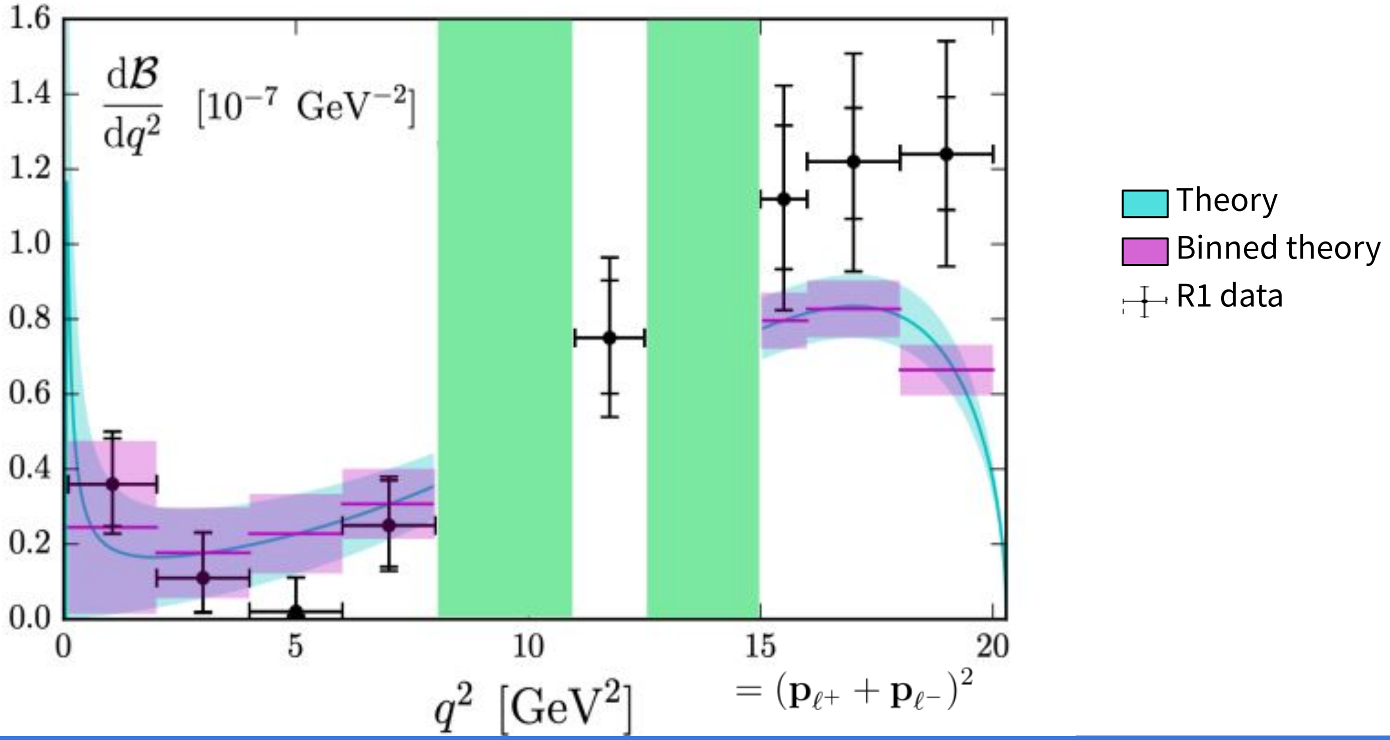
$$14.3\ \mathrm{GeV}^2/c^4 < q^2 < 20.0\ \mathrm{GeV}^2/c^4$$

$$R(\Lambda) = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda^0 \mu^+ \mu^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda^0 e^+ e^-)}, \qquad \text{where } \Lambda^0 \to p\pi^-$$

- ➢ Baryonic $b \to s l^+ l^-$ transition
- ➢ First measurement of $\mathrm{BF}(\Lambda_b \to \Lambda^0 e^+ e^-)$
- ➢ New, unexplored q^2 region



Branching fraction vs q^2 of $\Lambda_b \rightarrow \Lambda^0 \mu^+ \mu^-$



LHCb collaboration, R. Aaij et al., Differential branching fraction and angular analysis of Λ0b → Λμ+ μ− decays.

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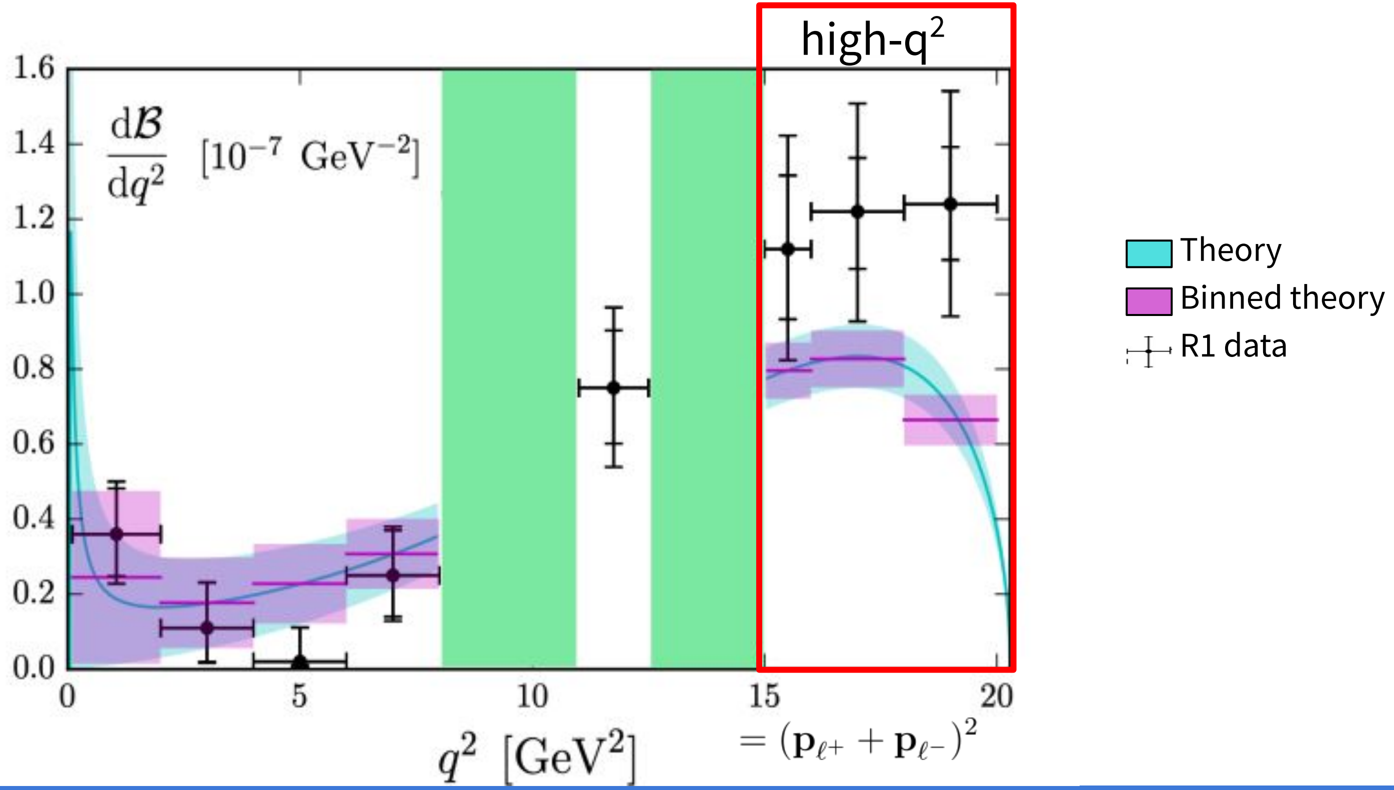

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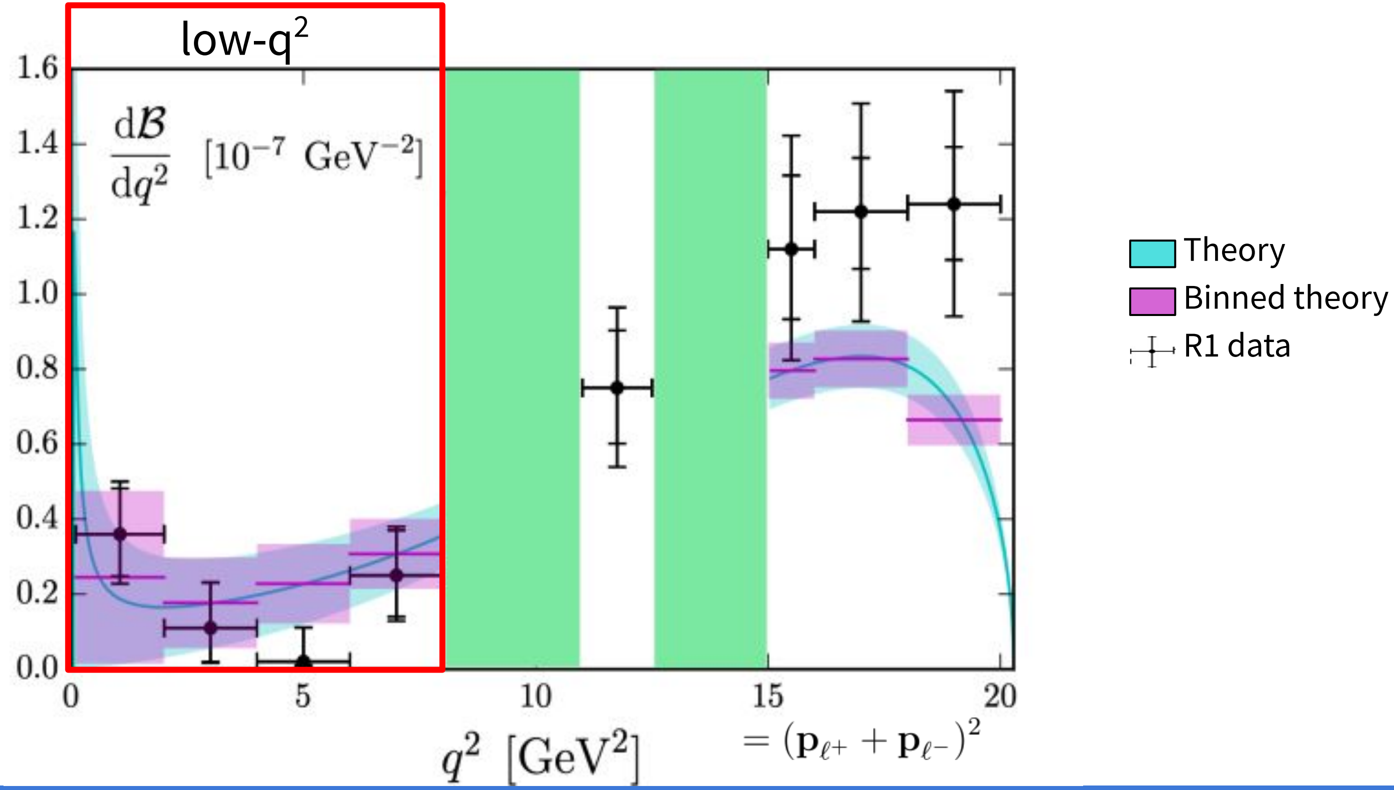

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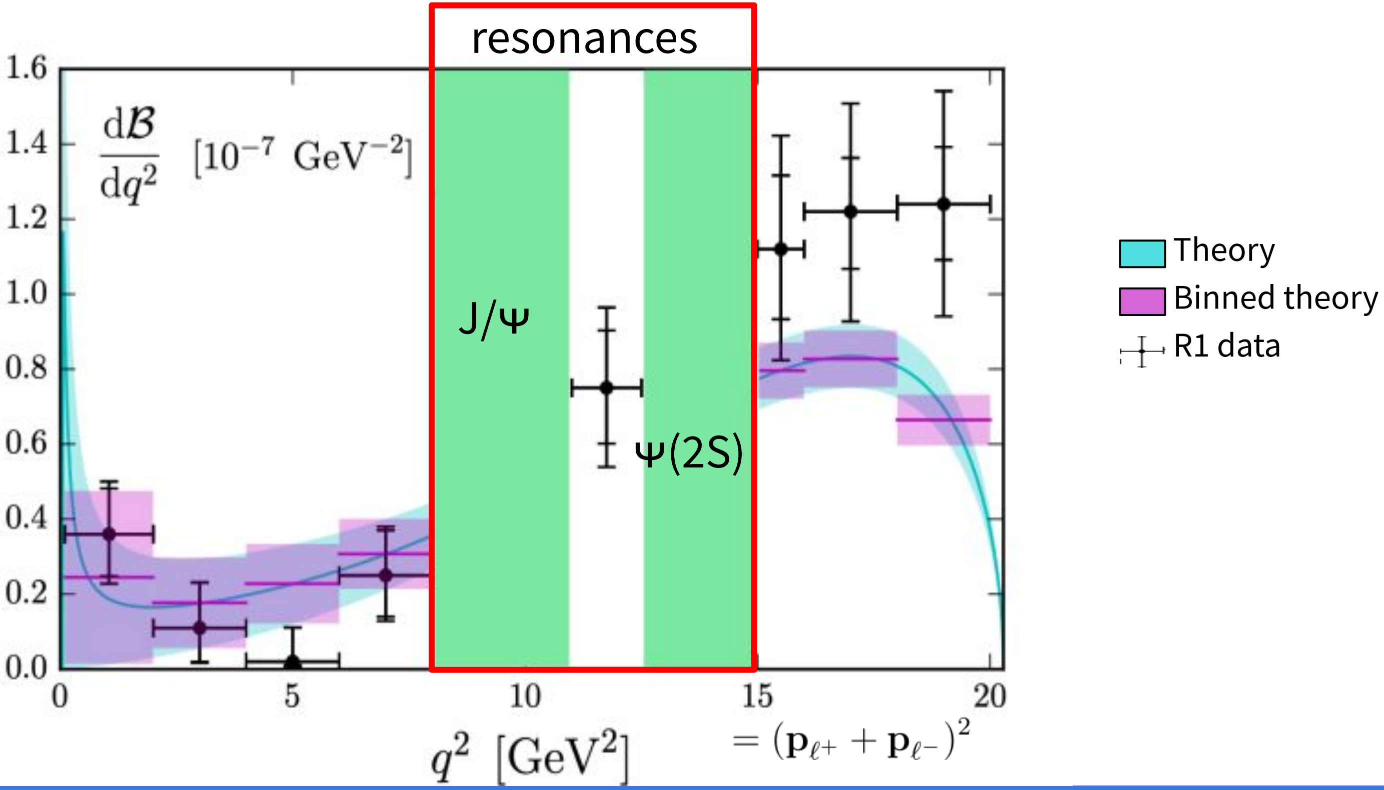
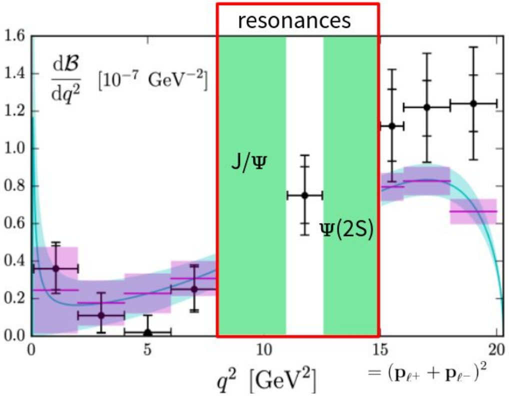


LHCb collaboration, R. Aaij et al., Differential branching fraction and angular analysis of Λ0b → Λμ+ μ− decays.

About resonances ($c\bar{c}$)

$$\Lambda_b^0 \to \Lambda^0 J/\psi$$
$$\Lambda_b^0 \to \Lambda^0 \psi(2S)$$

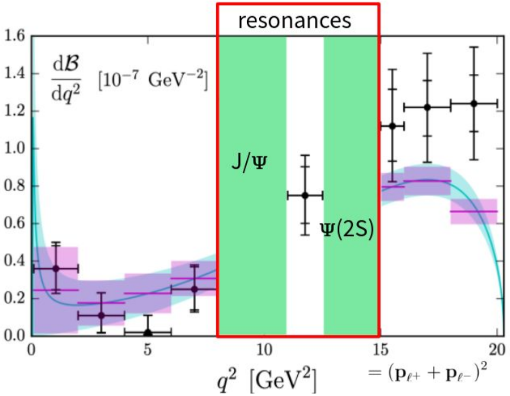


About resonances ($c\bar{c}$)

$$\left.\begin{array}{l}\Lambda_b^0 \to \Lambda^0 J/\psi \\ \Lambda_b^0 \to \Lambda^0 \psi(2S)\end{array} \xrightarrow{\tau \sim 10^{-21}} \begin{array}{l} J/\psi \to \ell^+\ell^- \\ \psi(2S) \to \ell^+\ell^- \end{array}\right\}$$

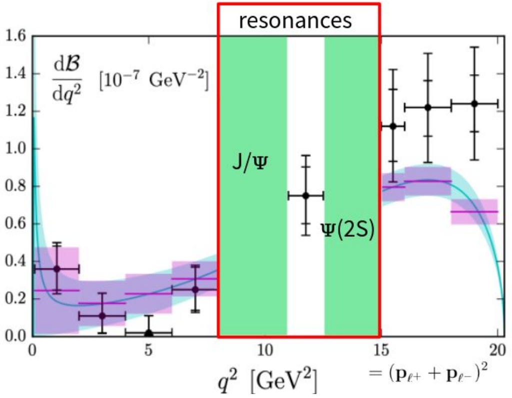
looks like

$$\Lambda_b^0 \to \Lambda^0 \ell^+\ell^-$$



About resonances ($c\bar{c}$)

$$\begin{matrix}\Lambda_b^0 \to \Lambda^0 J/\psi \\ \Lambda_b^0 \to \Lambda^0 \psi(2S)\end{matrix} \xrightarrow{\tau \sim 10^{-21}\ \mathrm{s}} \left.\begin{matrix} J/\psi \to \ell^+\ell^- \\ \psi(2S) \to \ell^+\ell^-\end{matrix}\right\} \begin{matrix}\text{looks like} \\ \Lambda_b^0 \to \Lambda^0\ell^+\ell^-\end{matrix}$$

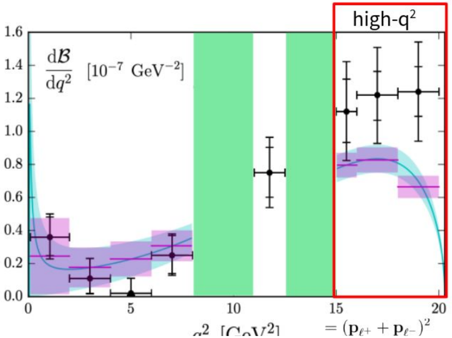


$$\left.\begin{matrix}\mathcal{B}(\Lambda_b^0 \to \Lambda^0 J/\psi(\to \ell^+\ell^-)) \\ \mathcal{B}(\Lambda_b^0 \to \Lambda^0 \psi(2S)(\to \ell^+\ell^-))\end{matrix}\right\} >> \mathcal{B}(\Lambda_b^0 \to \Lambda^0\ell^+\ell^-)$$

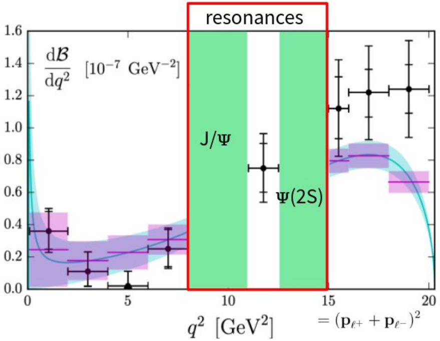
$$\text{if } q^2 = m(J/\psi)^2$$

$$\text{then it is probably } J/\psi$$

q² regions of R(Λ)



$$R(\Lambda) = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda^0 \mu^+\mu^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda^0 e^+e^-)}, \quad \text{where } \Lambda^0 \to p\pi^-$$



Can be used for cross-checks

$$: \frac{\mathcal{B}(J/\psi \to e^+e^-)}{\mathcal{B}(J/\psi \to \mu^+\mu^-)} = 0.9983 \pm 0.0078.$$

My role:
Quantifying the backgrounds in the high-q^2 region of R(Λ)

Backgrounds in $\Lambda_b \rightarrow \Lambda^0 l^+ l^-$

Mis-identified particles

- A particle in our selection is actually a different particle,
- looks like it was $\Lambda_b \rightarrow \Lambda^0 l^+ l^-$
- but it was a different decay

Backgrounds in $\Lambda_b \rightarrow \Lambda^0 l^+ l^-$

Mis-identified particles

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Example

$$B_d \rightarrow K_s\, l^+\, l^-$$
$$K_s \rightarrow \pi^+\, \pi^-$$

Becomes

$$B_d \rightarrow K_s\, l^+\, l^-$$
$$K_s \rightarrow p\, \pi^-$$

Backgrounds in $\Lambda_b \rightarrow \Lambda^0 l^+ l^-$

Mis-identified particles

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$$B_d \rightarrow K_S\, l^+ l^-$$
$$K_S \rightarrow \pi^+ \pi^-$$

Becomes

$$B_d \rightarrow K_S\, l^+ l^-$$
$$\Lambda^0 \rightarrow p\, \pi^-$$

Backgrounds in $\Lambda_b \to \Lambda^0 l^+ l^-$

Mis-identified particles

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Example

$$B_d \to K_s\, l^+\, l^-$$
$$K_s \to \pi^+\, \pi^-$$

Becomes

$$\Lambda_b \to \Lambda^0\, l^+\, l^-$$
$$\Lambda^0 \to p\, \pi^-$$

Backgrounds in $\Lambda_b \rightarrow \Lambda^0 l^+ l^-$

Partially reconstructed decays

- We missed particles in the reconstruction,
- looks like it was $\Lambda_b \rightarrow \Lambda^0 l^+ l^-$
- but it was a different decay

Backgrounds in $\Lambda_b \to \Lambda^0 l^+ l^-$

Partially reconstructed decays

- ➢ We missed particles in the reconstruction,
- ➢ looks like it was $\Lambda_b \to \Lambda^0 l^+ l^-$
- ➢ but it was a different decay

Example

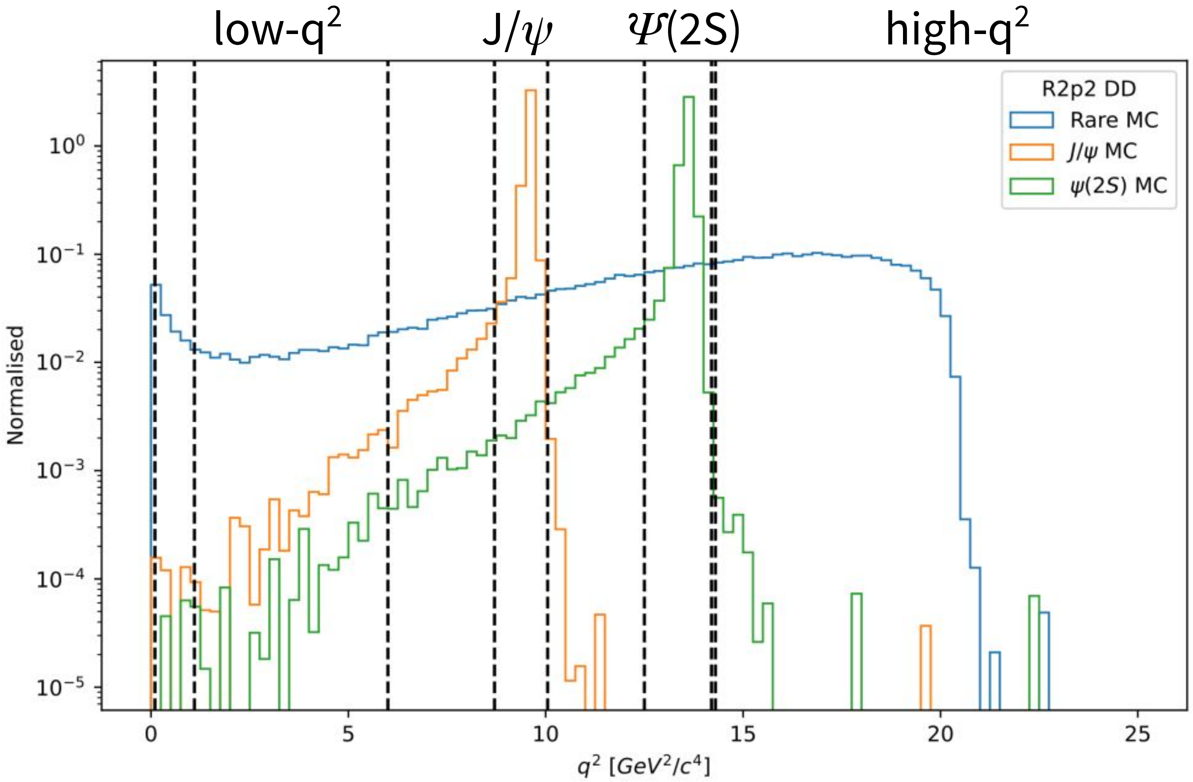
$$\Lambda_b \to \Lambda_c^+ \overline{\nu}_l \, l^-$$
$$\Lambda_c^+ \to \Lambda^0 \, l^+ \, \nu_l$$

Becomes

$$\Lambda_b \to \Lambda_c^+ \overline{\nu}_l \, l^-$$
$$\Lambda_c^+ \to \Lambda^0 \, l^+ \, \nu_l$$

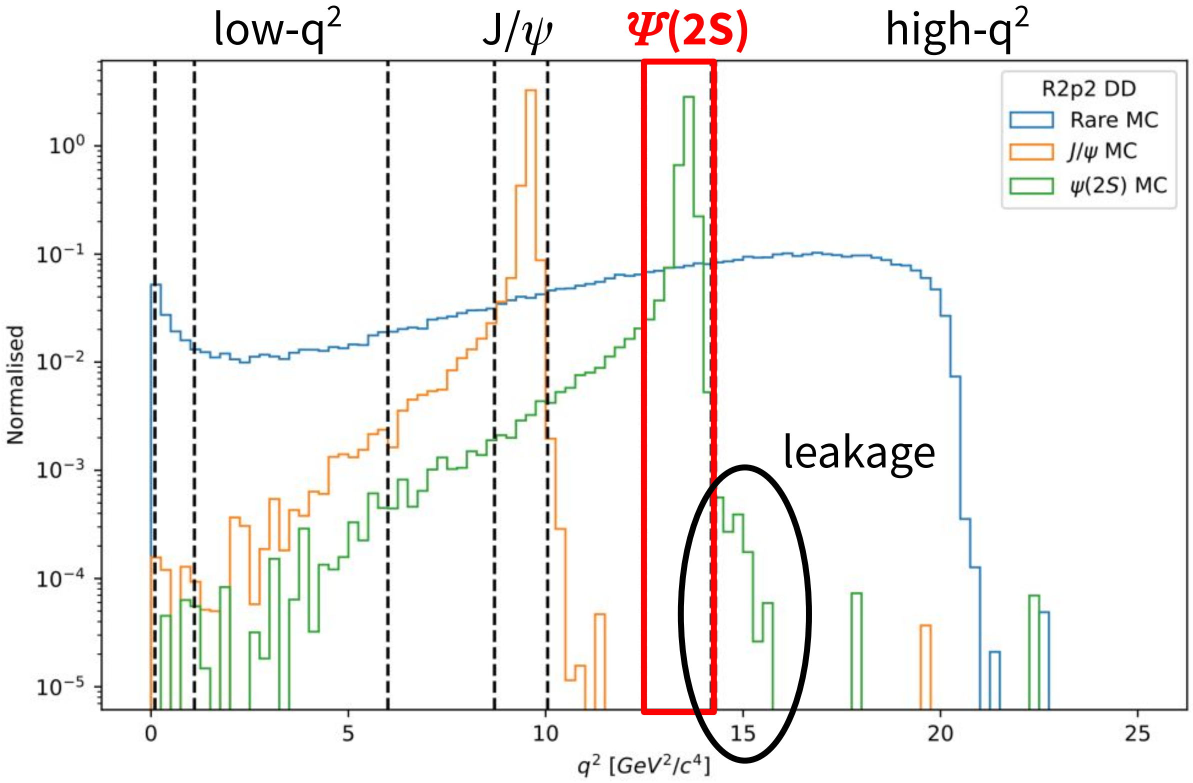
Backgrounds in $\Lambda_b \rightarrow \Lambda^0 l^+ l^-$

Leakage from other q^2 regions



Backgrounds in $\Lambda_b \to \Lambda^0 l^+ l^-$

Leakage from other q^2 regions



Backgrounds in $\Lambda_b \rightarrow \Lambda^0 l^+ l^-$

Combinatorial background

- Accidental combinations of tracks,
- Particle from another decay is matched with the rest of $\Lambda_b \rightarrow \Lambda^0 l^+ l^-$

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Combinatorial background

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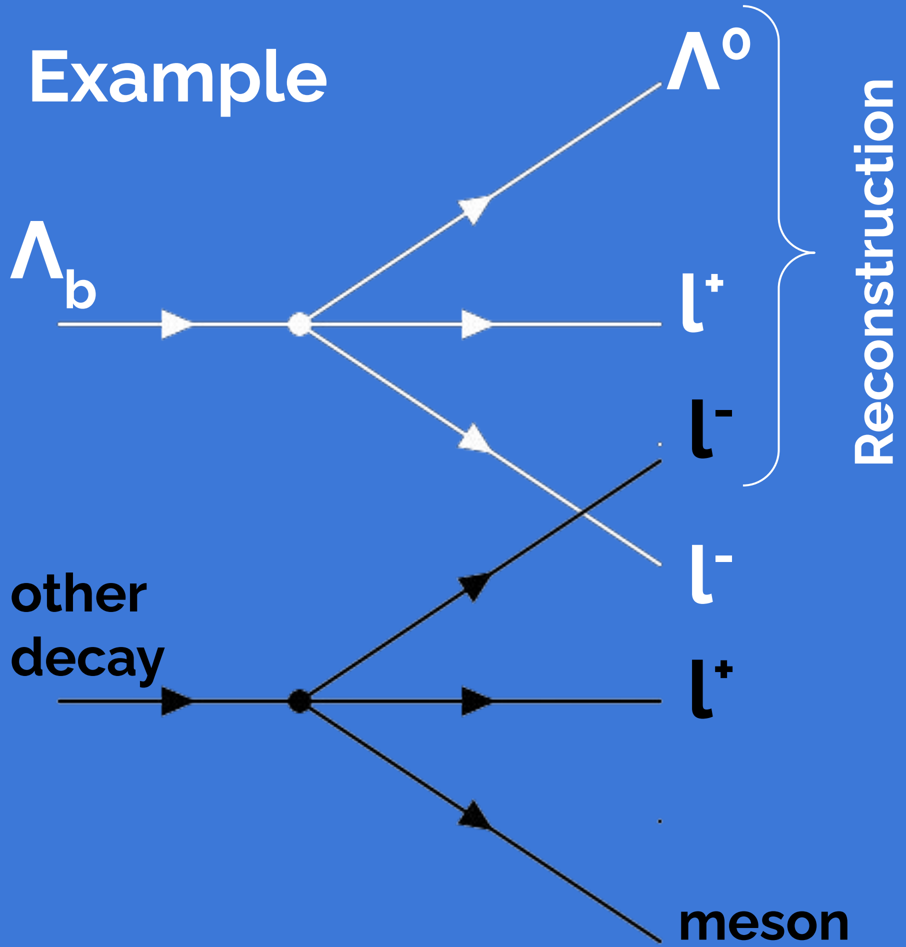
Example



Backgrounds in $\Lambda_b \to \Lambda^0 l^+ l^-$

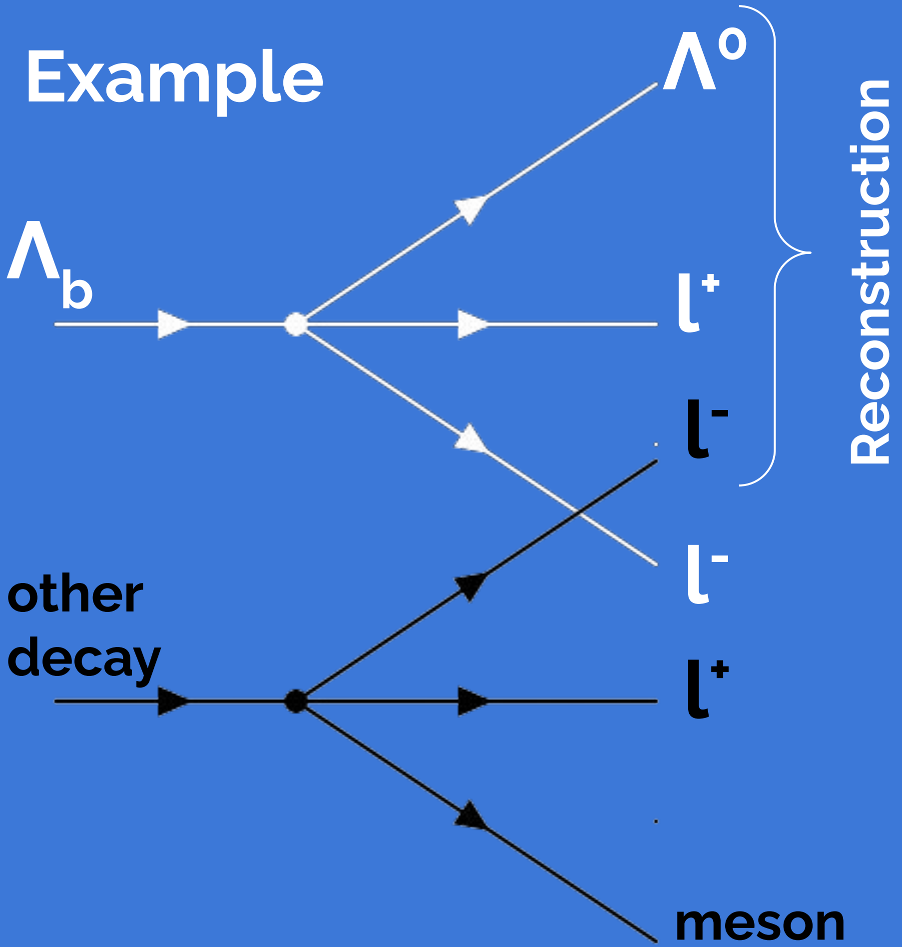
Combinatorial background

- ➢ Accidental combinations of tracks,
- ➢ Particle from another decay is matched with the rest of $\Lambda_b \to \Lambda^0 l^+ l^-$

and more...

- ➢ Combinations of all of the above

Example



Modelling backgrounds by MC fitting

Data

Signal
+
MisID backgrounds
+
PartRec backgrounds
+
Comb background
+
Other…

Modelling backgrounds by MC fitting

MC Signal
+
MC MisID backgrounds
+
MC PartRec backgrounds
+
Same sign data
+
MC Other…

Data

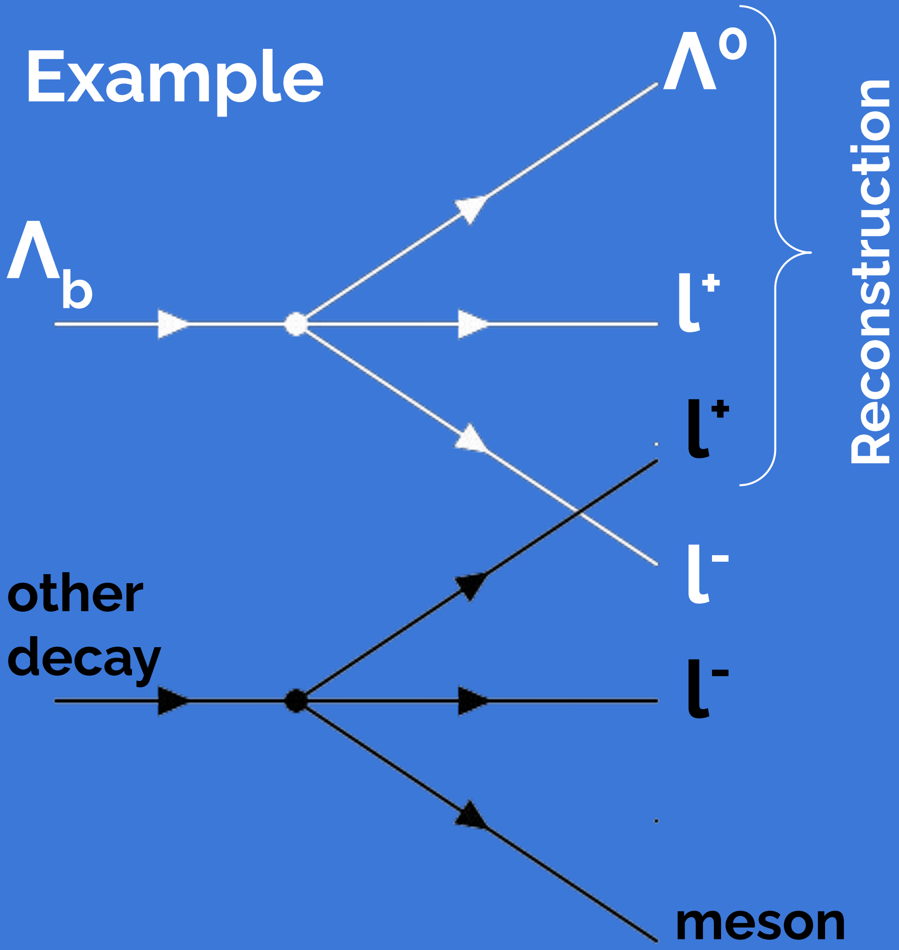
No MC for combinatorial...

- ➢ Use same sign data to describe combinatorial background

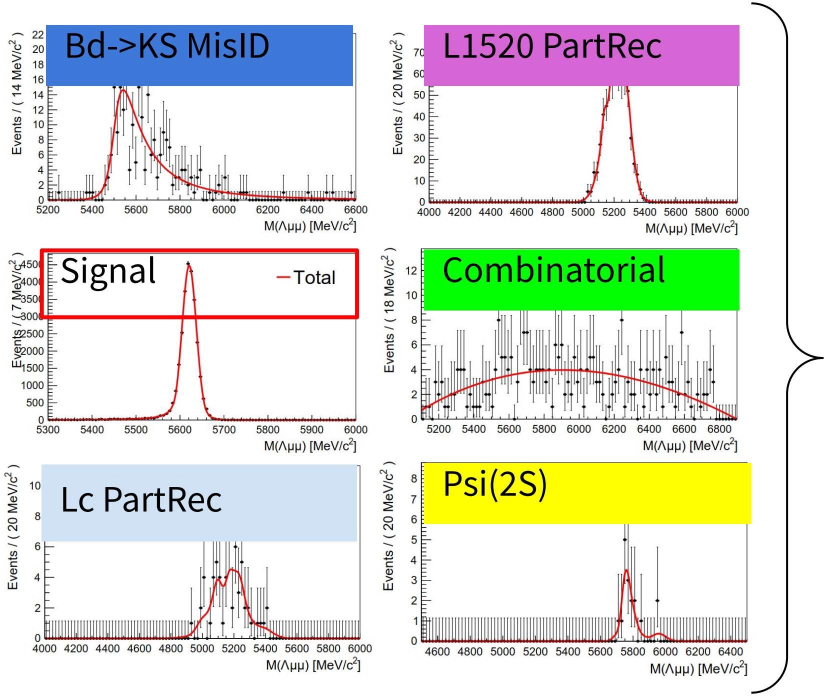
$$\Lambda_b^0 \to \Lambda^0 \ell^+ \ell^+$$
$$\Lambda_b^0 \to \Lambda^0 \ell^- \ell^-$$

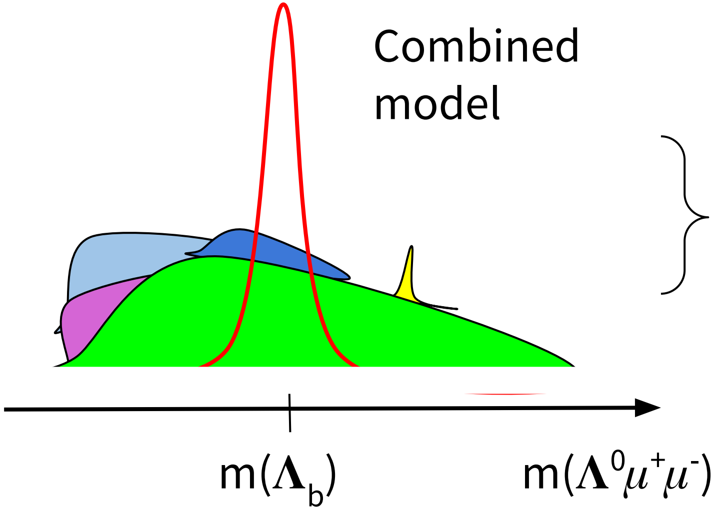
- ➢ Violates lepton number conservation
- ➢ measurements of these decays are due to accidental combinations

Example



Modelling backgrounds by MC fitting



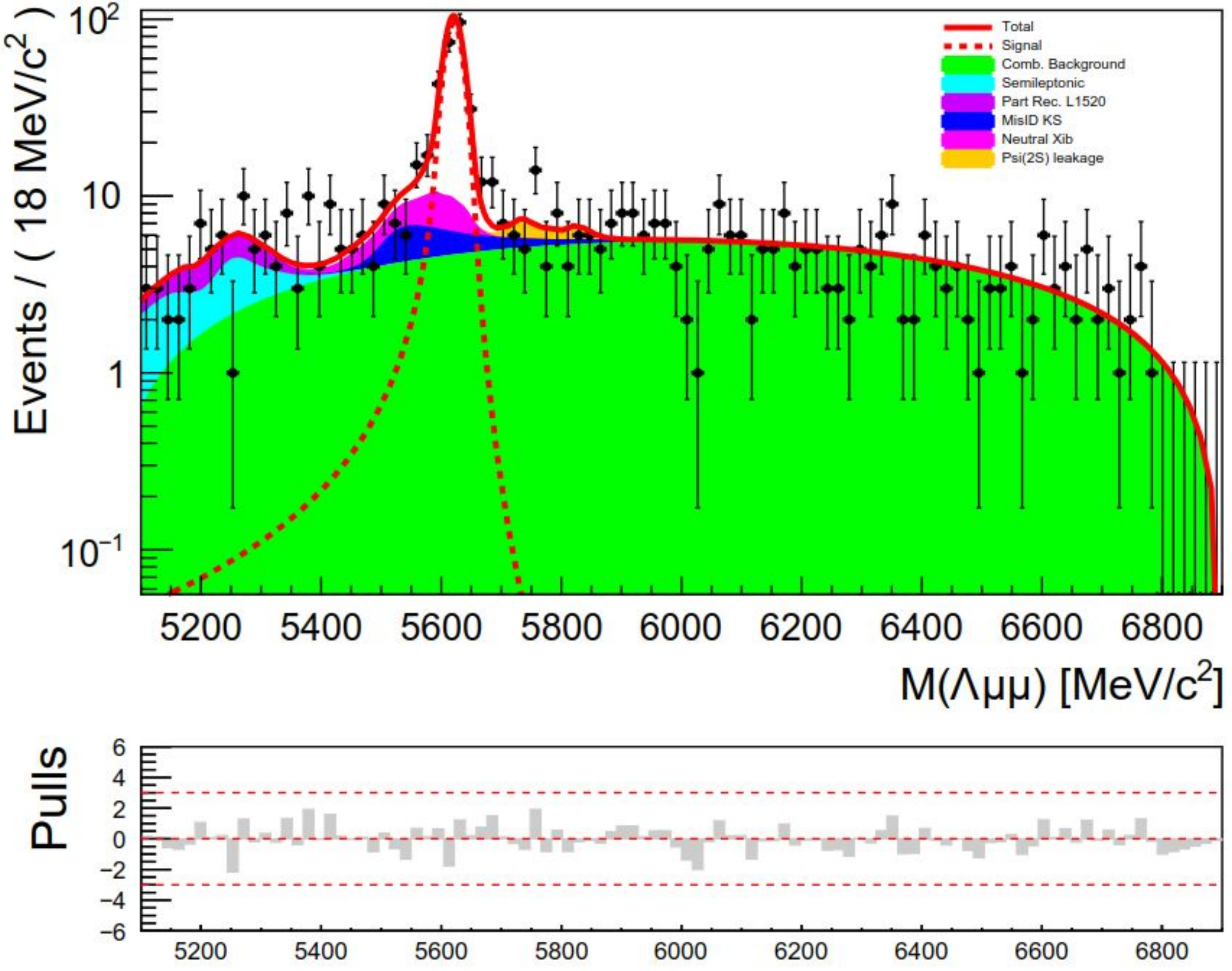


Combined model

Fit to data

Nice fit, but...

Is it also realistic?

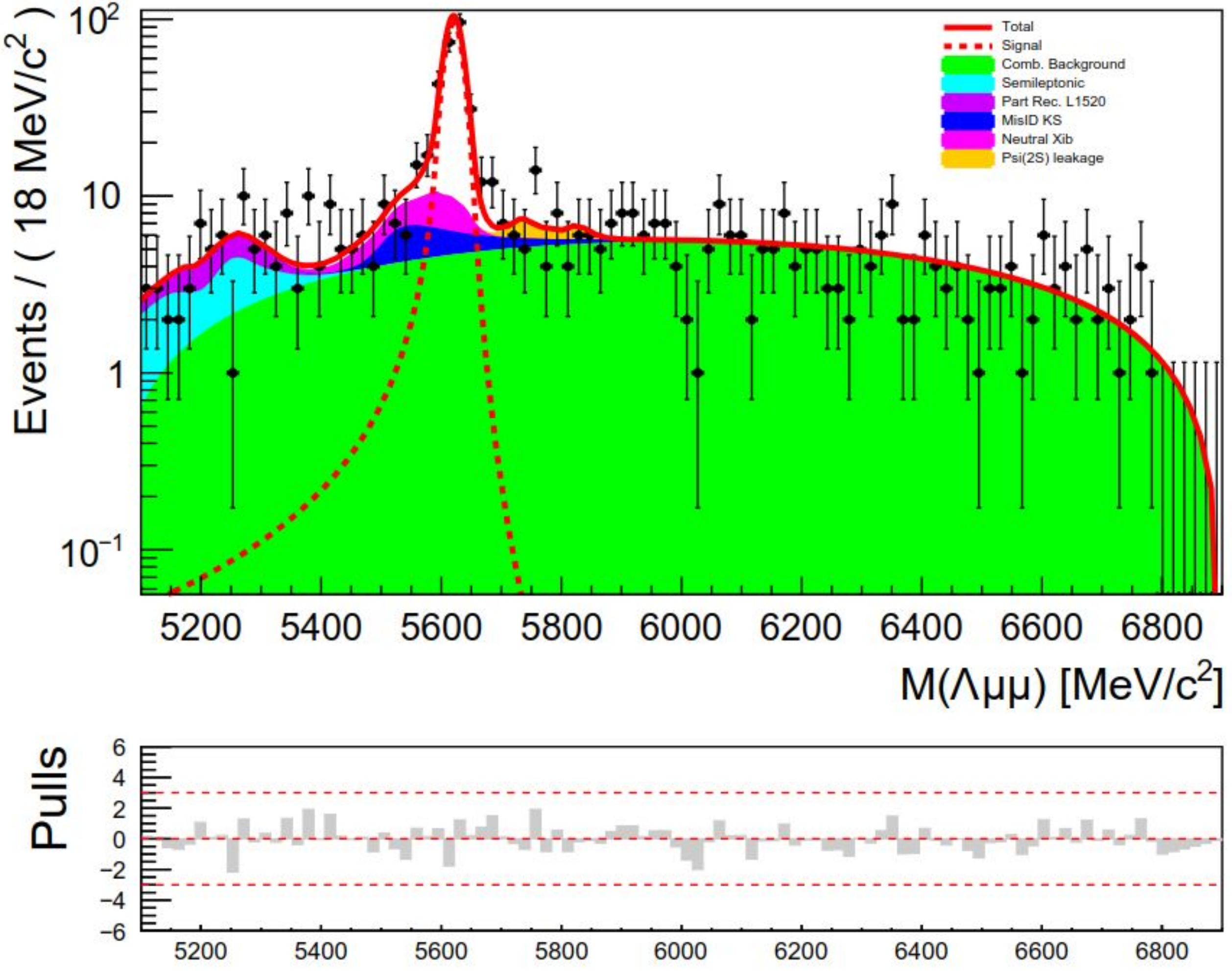


R2p2, DD, MM, no weights, no cuts, floating yields.

Nice fit, but...

Is it also realistic?
→ idk...

How much do we expect each bkg to contribute?



R2p2, DD, MM, no weights, no cuts, floating yields.

Expected background yields

$$\frac{N_{\text{bkg}}}{N_{\text{sig}}} = \frac{f}{f_b} \frac{\text{BF(bkg)}}{\text{BF(sig)}} \frac{\text{Eff(bkg)}}{\text{Eff(sig)}}$$

fragmentation ratio

obtained from PDG

Fraction of decays that make it through selection/reconstruction

Expected background yields

$$\frac{N_{\text{bkg}}}{N_{\text{sig}}} = \frac{f}{f_b}\,\frac{\text{BF}(\text{bkg})}{\text{BF}(\text{sig})}\,\frac{\text{Eff}(\text{bkg})}{\text{Eff}(\text{sig})}$$

fragmentation ratio

obtained from PDG

Fraction of decays that make it through selection/reconstruction

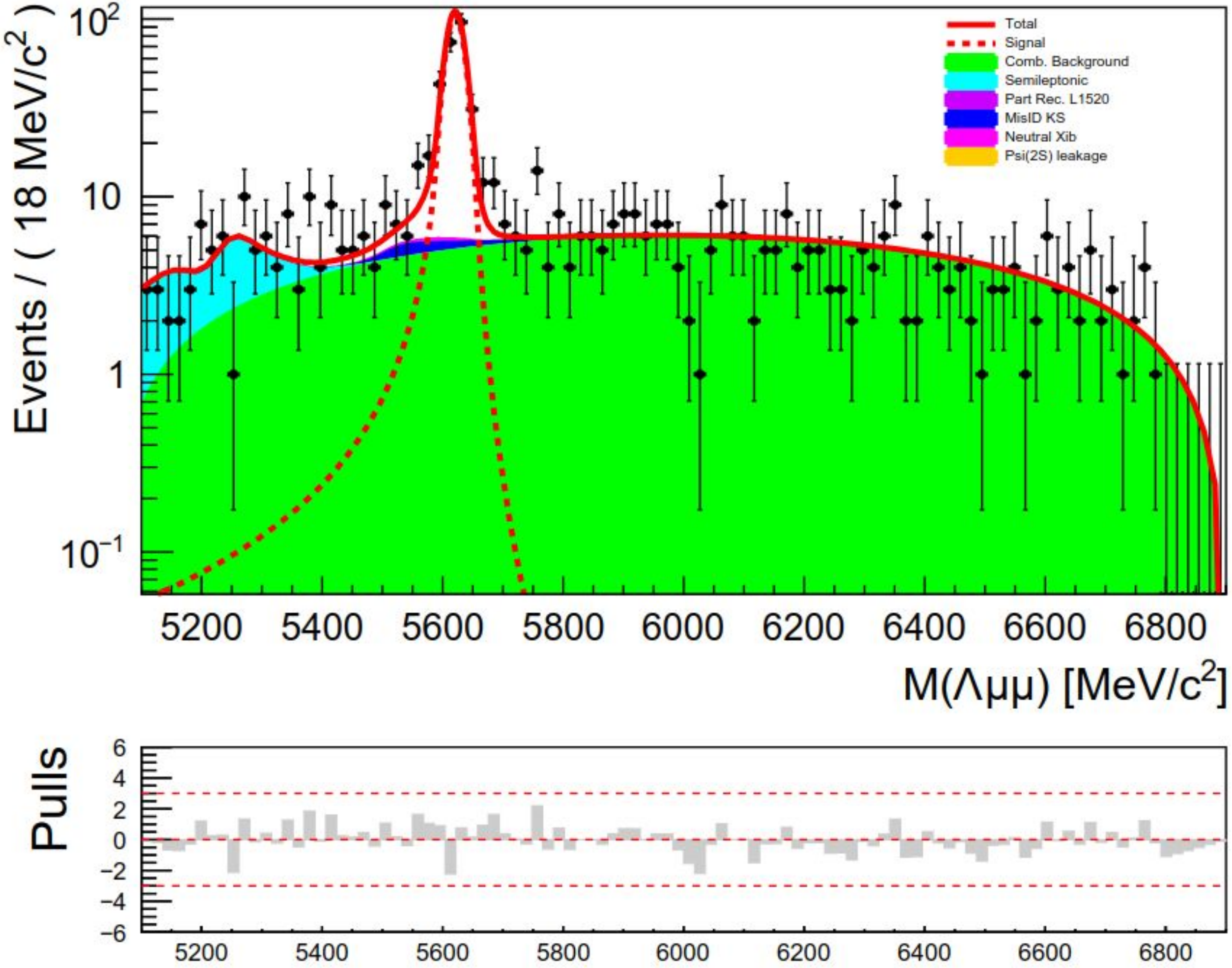
Results*

background	N(bkg)/N(sig)
$\Lambda_b \to \Lambda_c^+ \mu^- \nu_\mu$	26% +- 12%
$B_d \to K_S \mu^+ \mu^-$	1.9% +- 0.6%
$\Xi_b^- \to \Xi^- \mu^+ \mu^-$	0.4% +- 0.3%
$\Lambda_b \to \Lambda(1520) \mu^- \mu^+$	0.1% +- 0.04%
$\Lambda_b \to \Lambda^0\ \Psi(2S)$	0.07% +- 0.04%

*for R2p2, DD, MM, no weights, no cuts

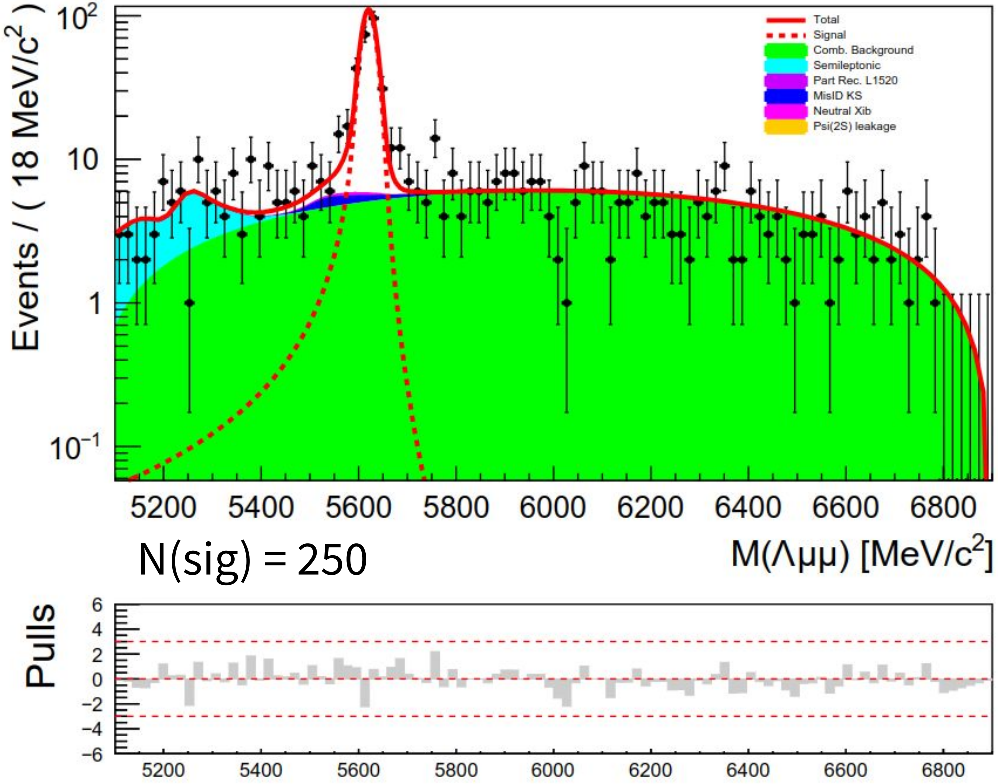
Limiting yields

Using N(bkg)/N(sig) to limit the contributions



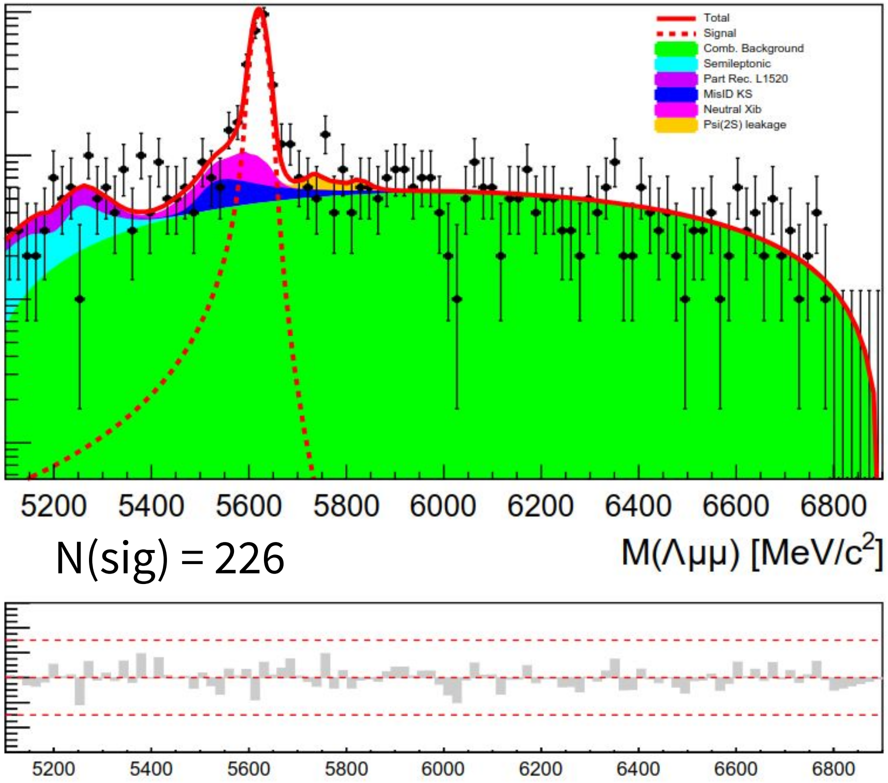
R2p2, DD, MM, no weights, no cuts ,limited yields.

Limiting yields



N(sig) = 250

Floating yields



N(sig) = 226

More realistic, higher signal contribution, similar pulls

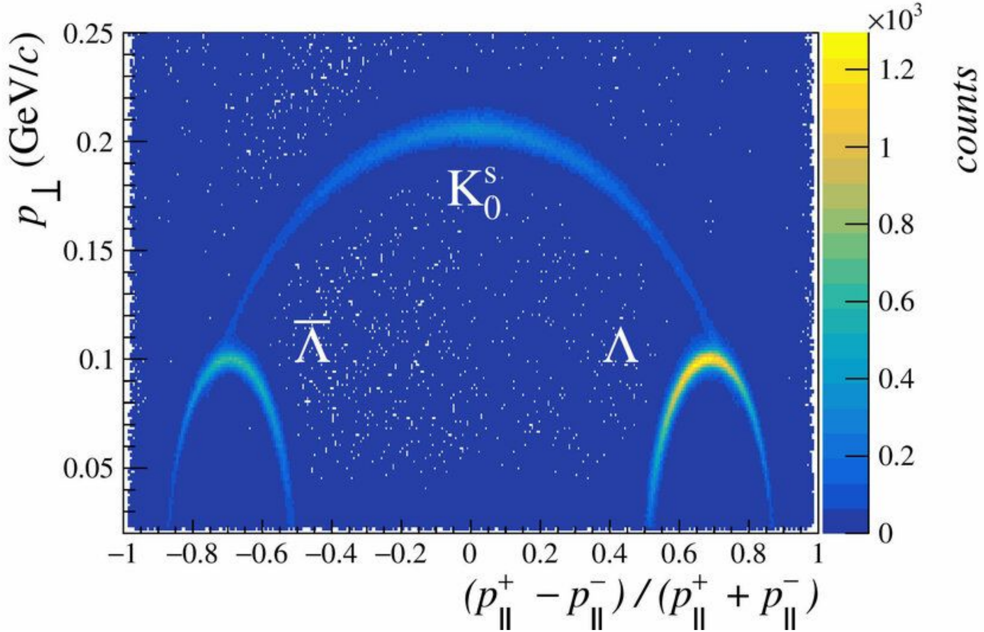
Are these yields consistent with what we see in the data?

Are these yields consistent with what we see in the data?

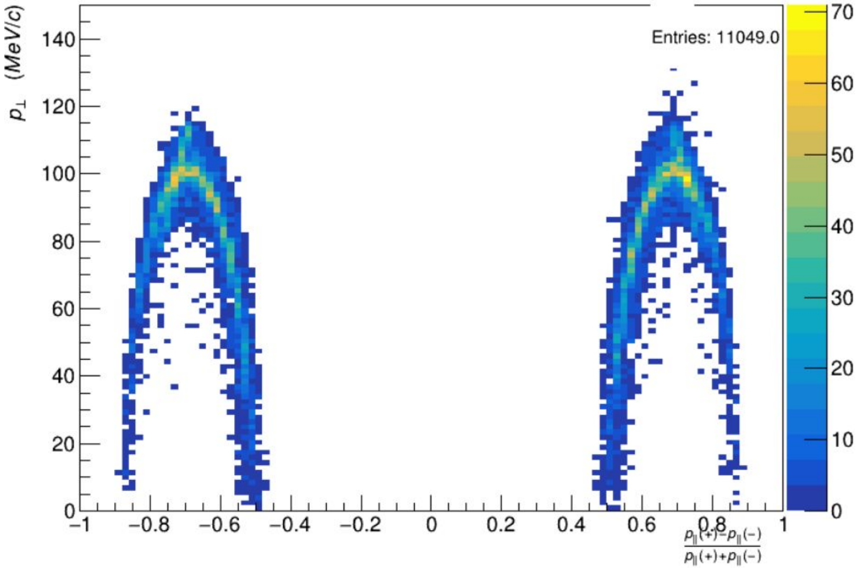
- $B_d \to K_S(\to \pi^+\pi^-)\mu^+\mu^-$
- $\Lambda_b^0 \to \Lambda_c^+(\to \Lambda^0\mu^+\nu_\mu)\mu^-\overline{\nu}_\mu$

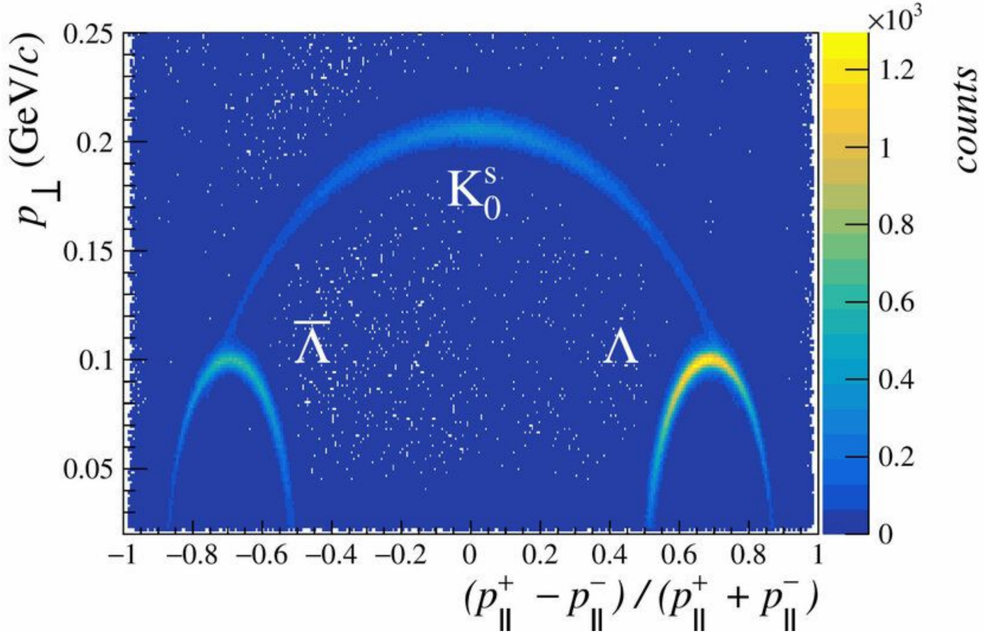
$$B_d \to K_S(\to \overset{\downarrow}{\pi^+}\pi^-)\mu^+\mu^- \qquad \Lambda_b^0 \to \Lambda^0(\to \overset{\downarrow}{p}\pi^-)\mu^+\mu^-$$

- ➢ Armenteros-Podolanski plot
- ➢ uses momentum asymmetry



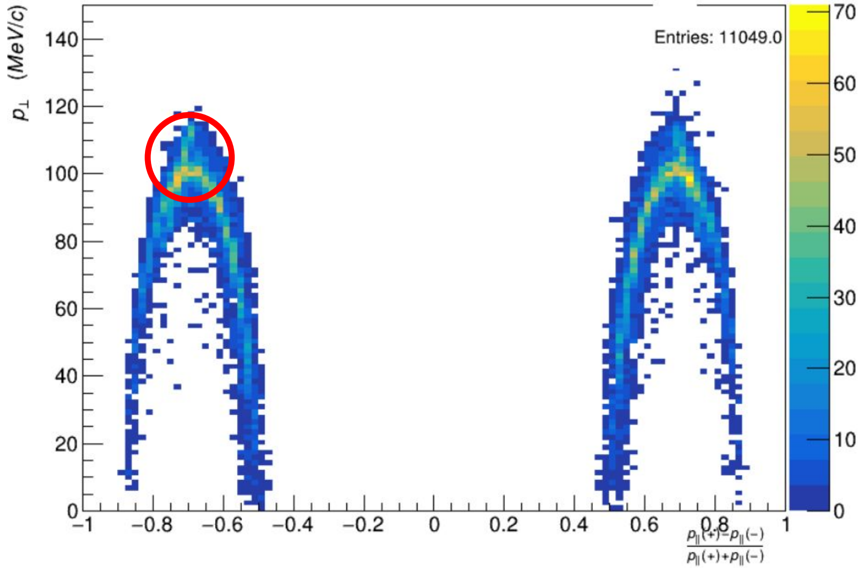
$B_d \to K_S(\to \overset{\downarrow}{\pi^+}\pi^-)\mu^+\mu^-$ $\Lambda_b^0 \to \Lambda^0(\to \overset{\downarrow}{p}\pi^-)\mu^+\mu^-$

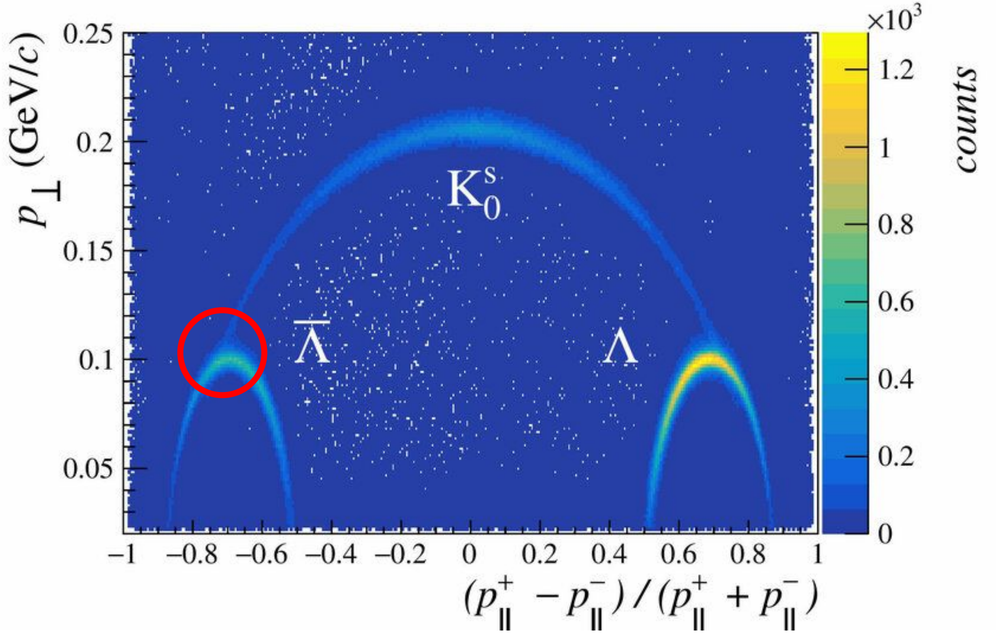




A. Moretti Transversity and Λ polarization in semi-inclusive DIS

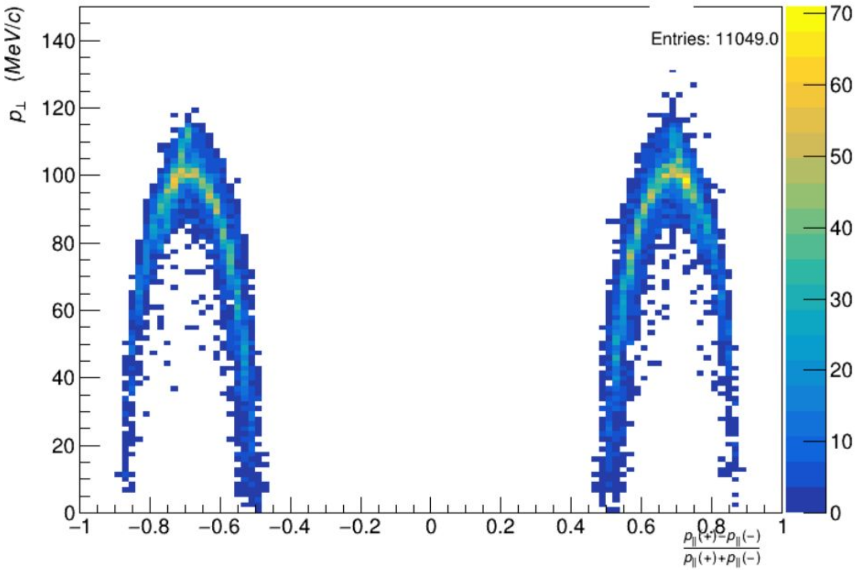
$B_d \to K_S(\to \overset{\downarrow}{\pi^+}\pi^-)\mu^+\mu^-$ $\Lambda_b^0 \to \Lambda^0(\to \overset{\downarrow}{p}\pi^-)\mu^+\mu^-$

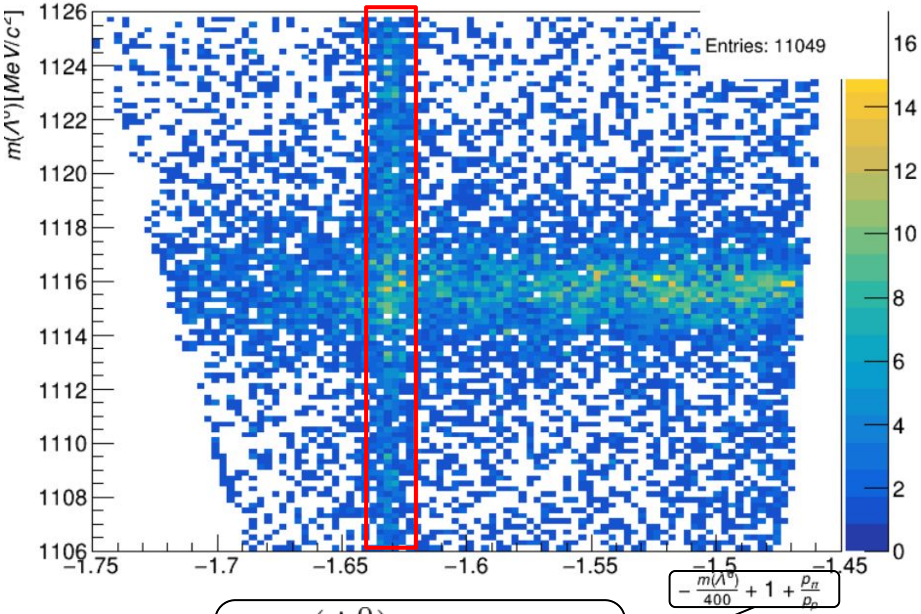




A. Moretti Transversity and Λ polarization in semi-inclusive DIS

$B_d \to K_S(\to \overset{\downarrow}{\pi^+}\pi^-)\mu^+\mu^-$ $\Lambda_b^0 \to \Lambda^0(\to \overset{\downarrow}{p}\pi^-)\mu^+\mu^-$





$$-\frac{m(\Lambda^0)}{400}+1+\frac{p_\pi}{p_p}$$

$B_d \to K_S(\to \overset{\downarrow}{\pi}^+\pi^-)\mu^+\mu^-$ $\Lambda_b^0 \to \Lambda^0(\to \overset{\downarrow}{p}\pi^-)\mu^+\mu^-$

Contains

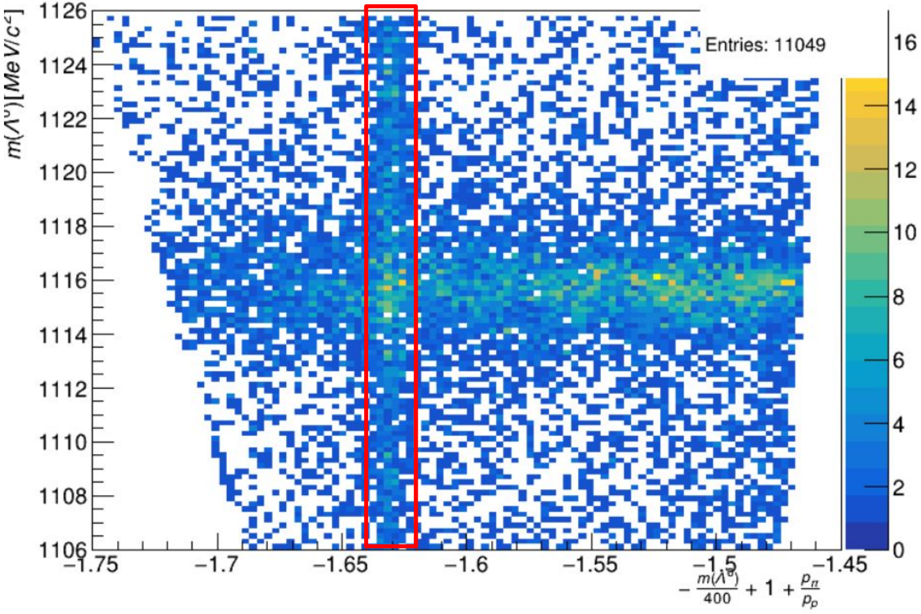
Combinatorial

+

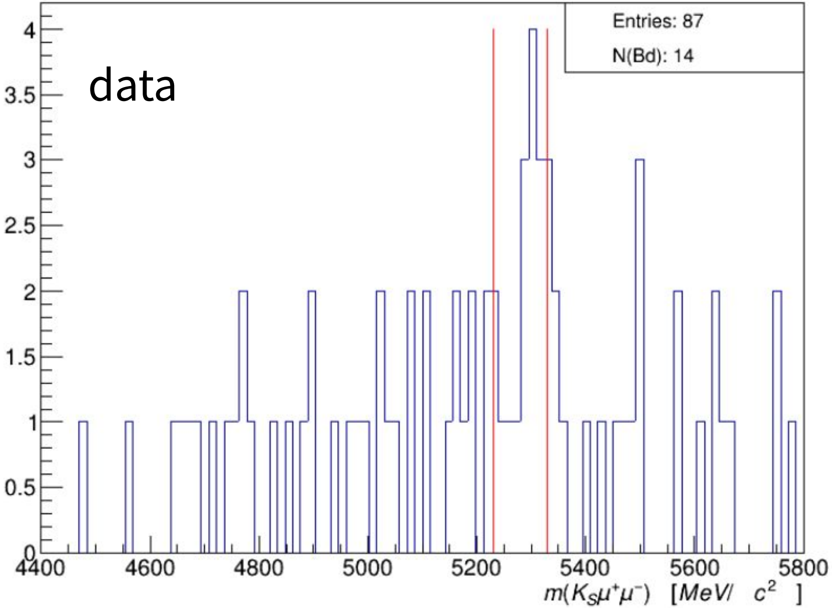
$B_d \to K_S(\to \pi^+\pi^-)\mu^+\mu^-$

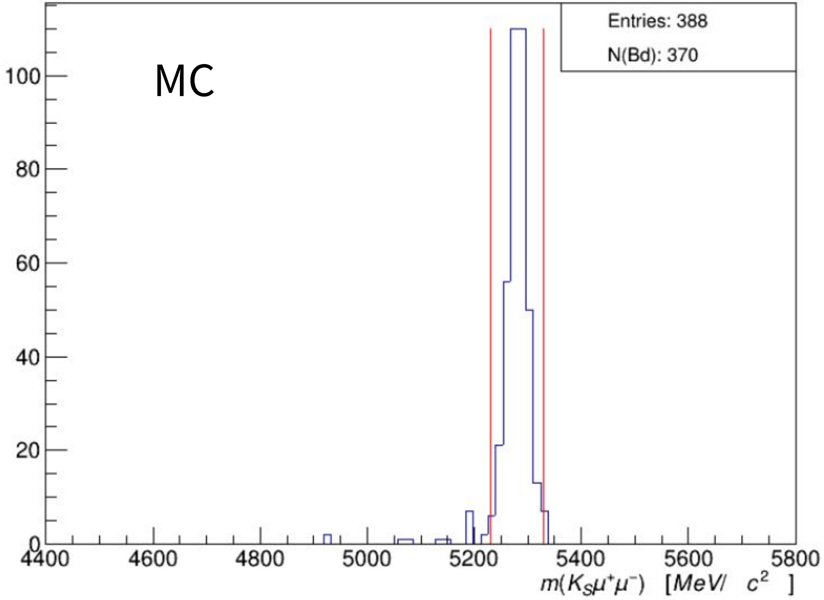
+

$\Lambda_b^0 \to \Lambda^0(\to p\pi^-)\mu^+\mu^-$



$B_d \to K_S(\to \pi^+\pi^-)\mu^+\mu^-$





expected yield
~ 9 events

data
~14 events

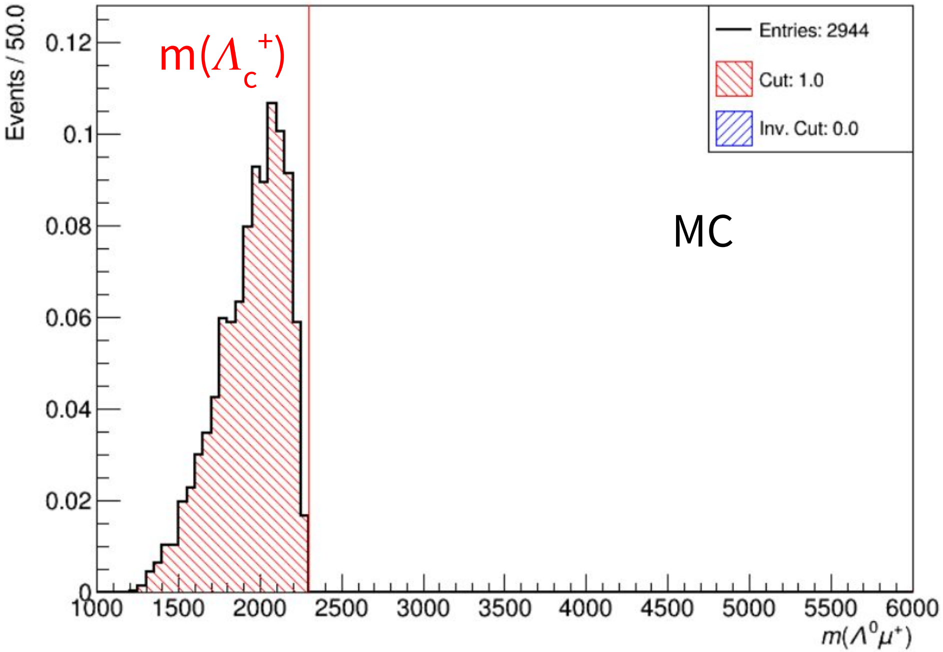
plot m($K_S\mu^+\mu^-$)

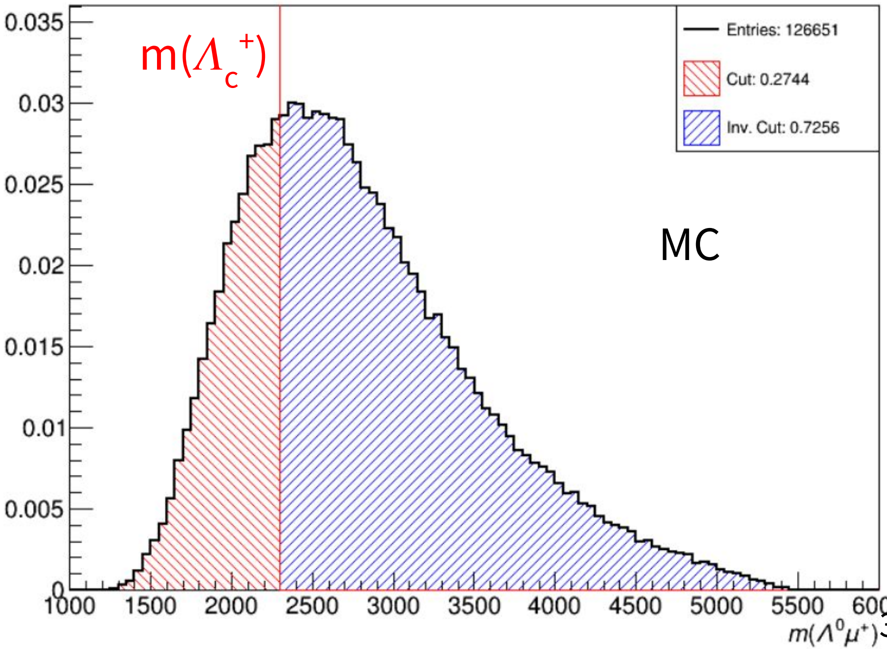
$$\Lambda_b^0 \to \Lambda_c^+(\to \Lambda^0\mu^+\nu_\mu)\mu^-\overline{\nu}_\mu$$

m($\Lambda^0\mu^+$) ≤ m(Λ_c^+)

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

no constraint on m(Λ_c^+)



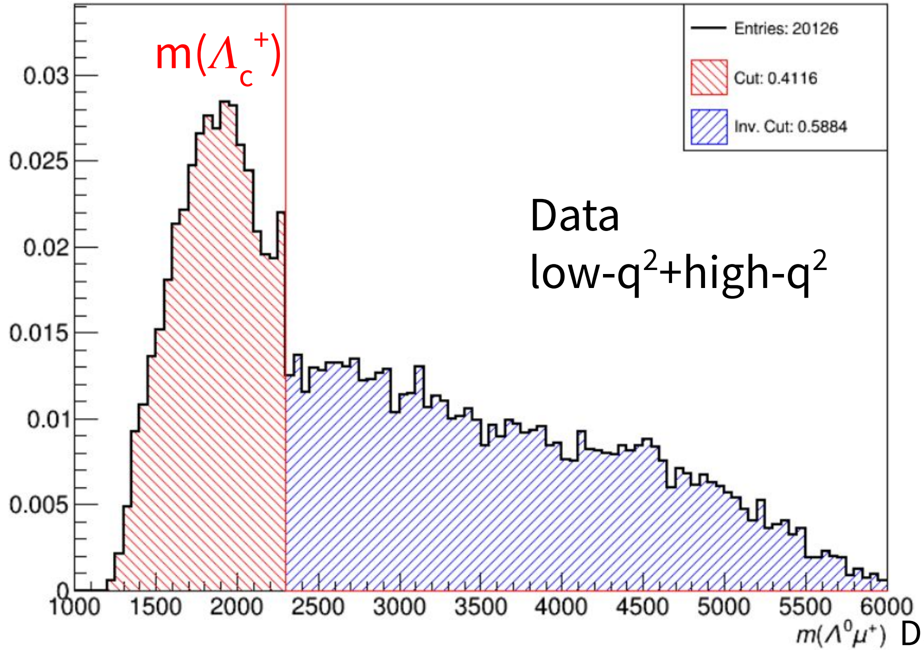


$$\Lambda_b^0 \rightarrow \Lambda_c^+(\rightarrow \Lambda^0\mu^+\nu_\mu)\mu^-\overline{\nu}_\mu$$

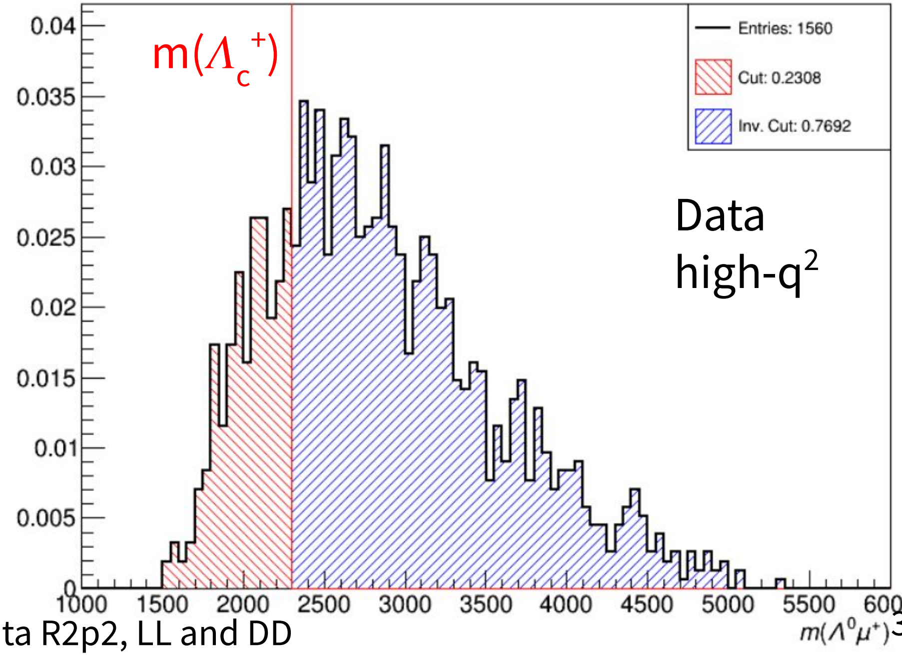
$m(\Lambda^0\mu^+) \leq m(\Lambda_c^+)$

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

no constraint on $m(\Lambda_c^+)$



Data
low-q^2+high-q^2



Data
high-q^2

Data R2p2, LL and DD

$$\Lambda_b^0 \rightarrow \Lambda_c^+(\rightarrow \Lambda^0\mu^+\nu_\mu)\mu^-\overline{\nu}_\mu$$

$m(\Lambda^0\mu^+) \leq m(\Lambda_c^+)$

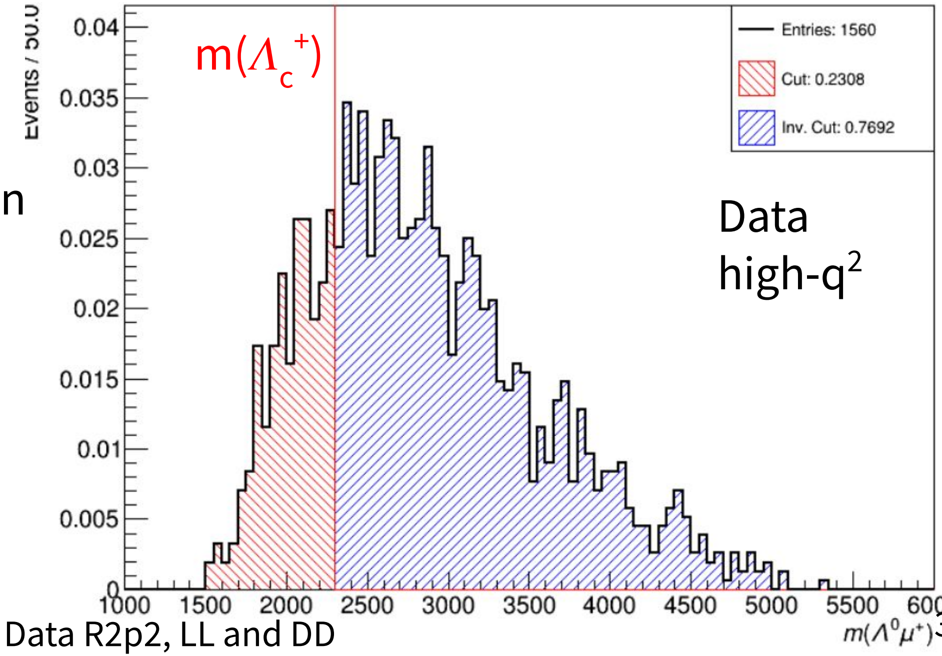
$$\Lambda_b^0 \rightarrow \Lambda^0\mu^+\mu^-$$

no constraint on $m(\Lambda_c^+)$

We expected 26% +- 14% wrt signal

But we don't see a significant contribution in the plot

How?



Data R2p2, LL and DD

$$\Lambda_b^0 \to \Lambda_c^+(\to \Lambda^0\mu^+\nu_\mu)\mu^-\overline{\nu}_\mu$$

m($\Lambda^0\mu^+$) ≤ m(Λ_c^+)

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

no constraint on m(Λ_c^+)

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How?

$$\frac{N_{\text{bkg}}}{N_{\text{sig}}} = \frac{f}{f_b}\frac{\text{BF(bkg)}}{\text{BF(sig)}}\frac{\boxed{\text{Eff(bkg)}}}{\text{Eff(sig)}}$$

overestimated, yet to be corrected for

Are these yields consistent with what we see in the data?

- $B_d \to K_S(\to \pi^+\pi^-)\mu^+\mu^-$ yes
- $\Lambda_b^0 \to \Lambda_c^+(\to \Lambda^0\mu^+\nu_\mu)\mu^-\overline{\nu}_\mu$ no

Outlook

- Get results for electron mode of these backgrounds
- Study partially reconstructed backgrounds in the data
- Study the double misID background

$$\Lambda_b^0 \to \Lambda^0 h h'$$

Outlook

- Get results for electron mode of these backgrounds
- Study partially reconstructed backgrounds in the data
- Study the double misID background

$$\Lambda_b^0 \to \Lambda^0 h h'$$

Thank you!

BACKUP

Combinatorial

$B^0 \to K_S^0 \mu^+ \mu^-$

$\Lambda_b^0 \to \Lambda^*(\to \Sigma^0(\to \Lambda^0 \gamma)\pi^0)\mu^+ \mu^-$

$\Lambda_b^0 \to \Lambda_c^+(\to \Lambda^0 \mu^+ \nu_\mu)\mu^- \overline{\nu}_\mu$

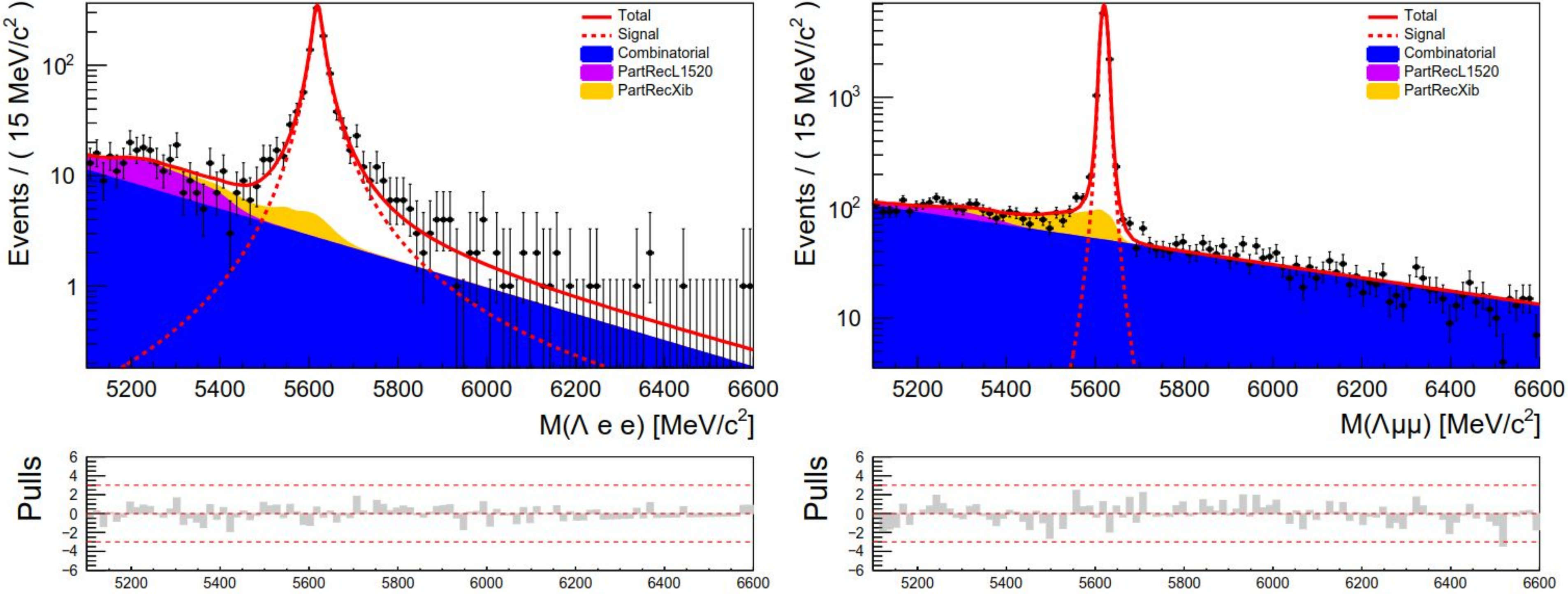
$\Lambda_b^0 \to \Lambda^0 \psi(2S)(\to \mu^+ \mu^-)$

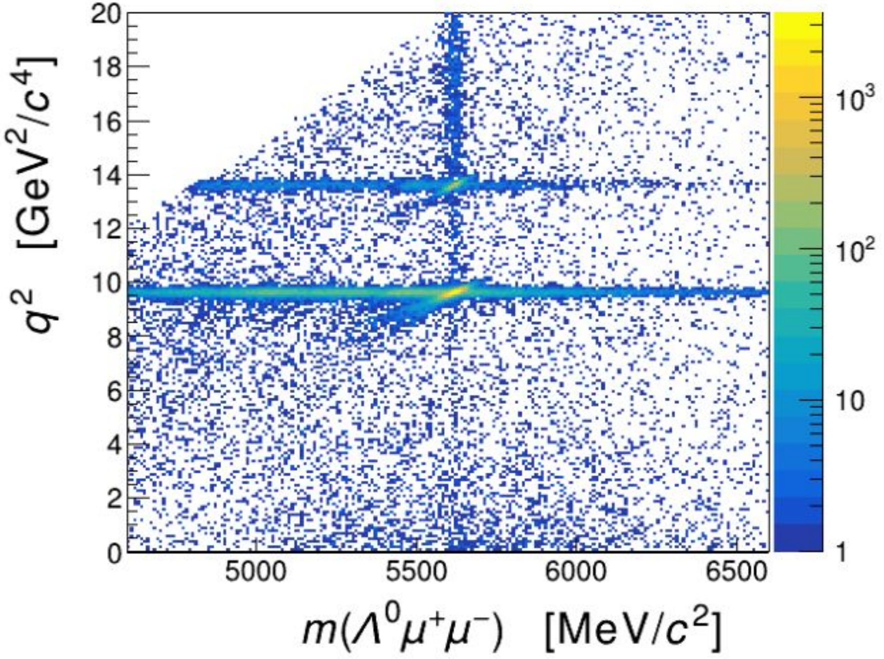
$\Xi_b^- \to \Xi^-(\to \Lambda^0 \pi^-)\mu^+ \mu^-$

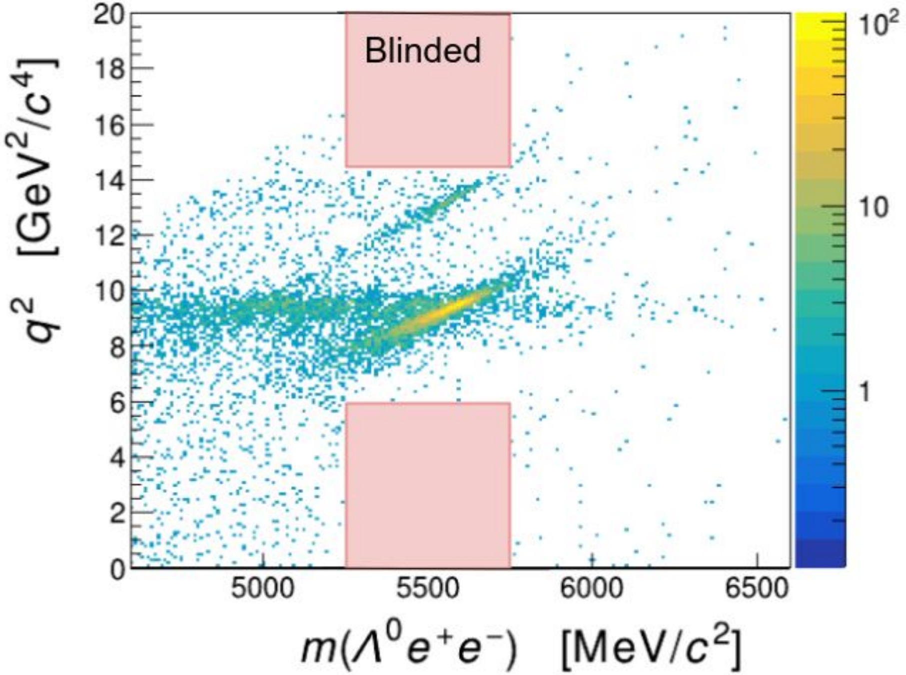
$\Xi_b^0 \to \Xi^0(\to \Lambda^0 \pi^0)\mu^+ \mu^-$

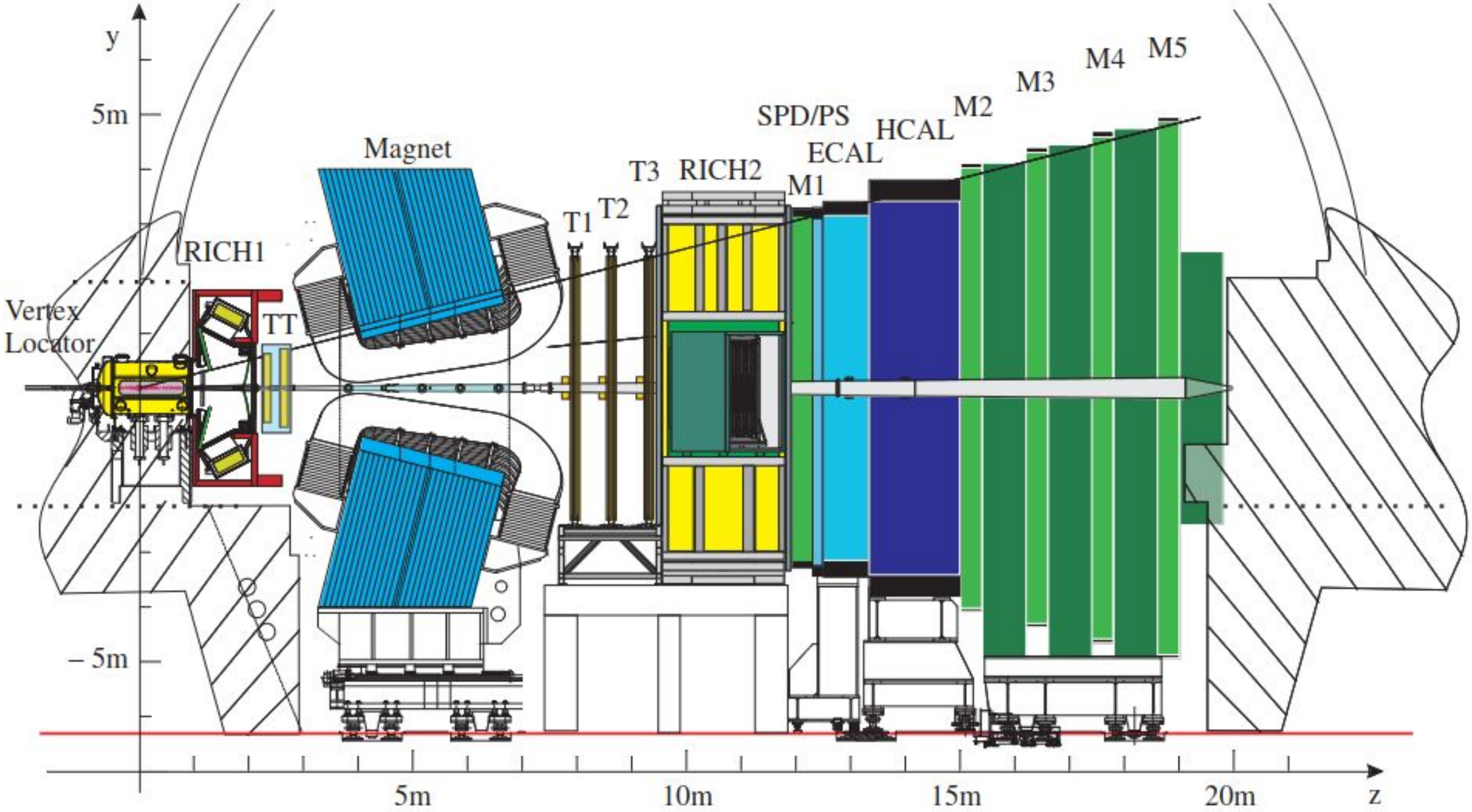
$\Lambda_b^0 \to \Lambda^0 h h'$

Lb->L0 J/Psi mode electrons vs muons



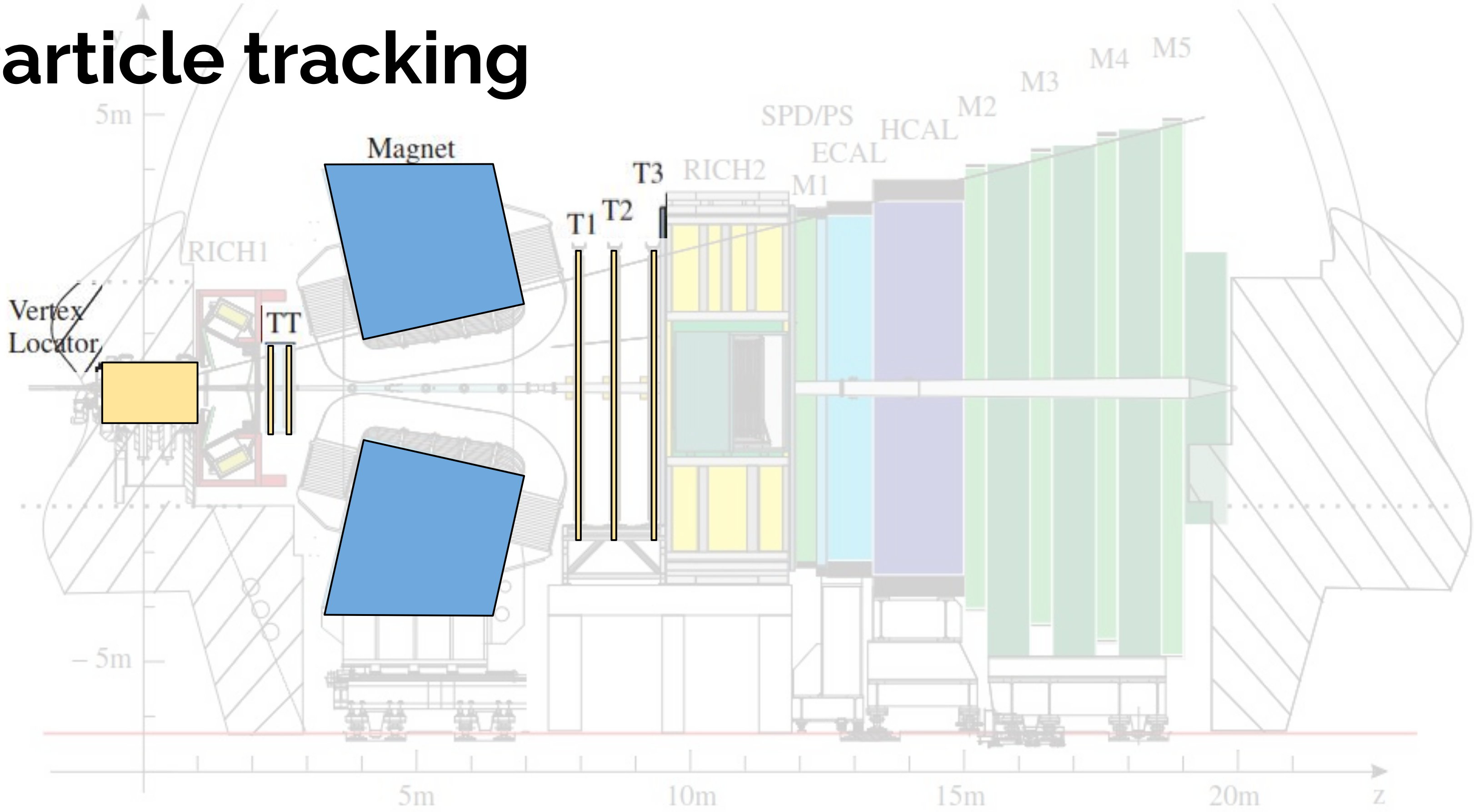

q^2 [GeV^2/c^4]
0
2
4
6
8
10
12
14
16
18
20
5000
5500
6000
6500
$m(\Lambda^0\mu^+\mu^-)$ [MeV/c^2]
1
10
10^2
10^3


q^2 [GeV^2/c^4]
0
2
4
6
8
10
12
14
16
18
20
5000
5500
6000
6500
$m(\Lambda^0e^+e^-)$ [MeV/c^2]
Blinded
1
10
10^2

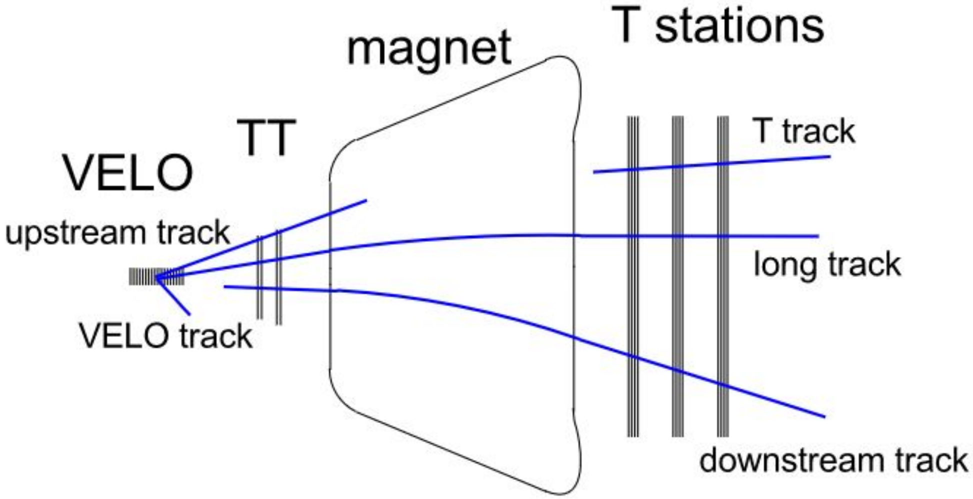


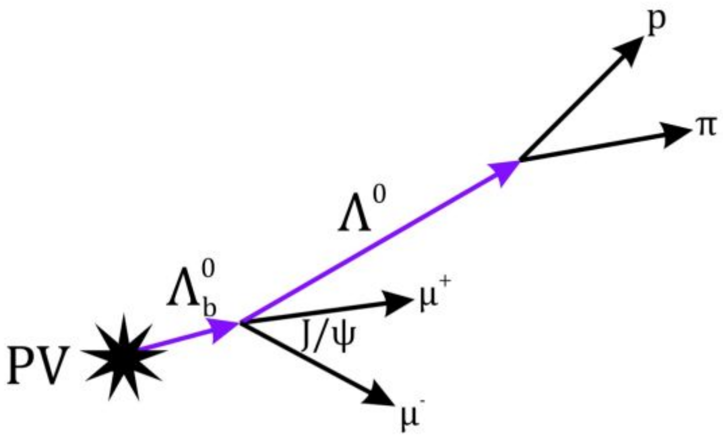
“LHCb detector performance”. In: International Journal of Modern Physics A

Particle tracking

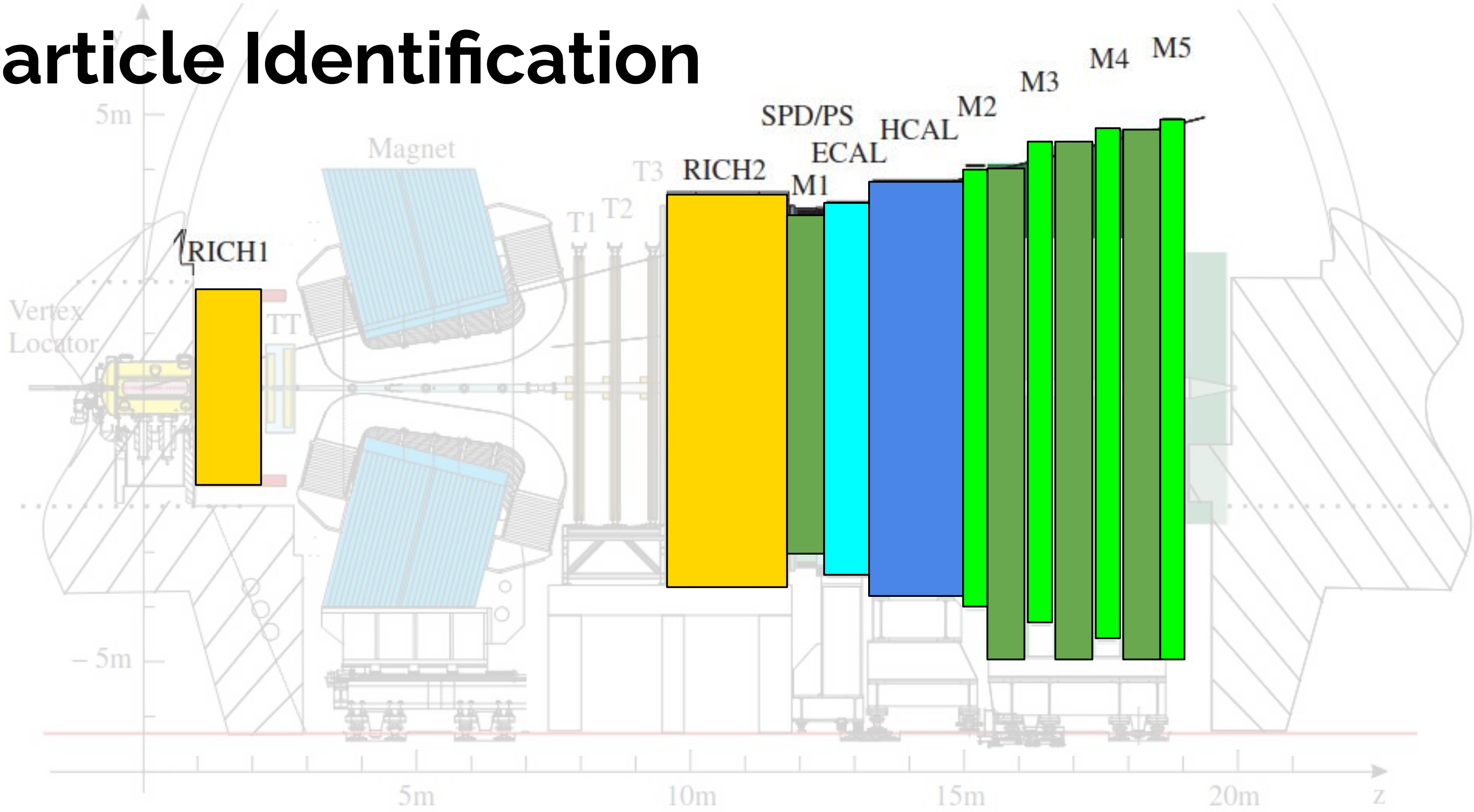


“LHCb detector performance”. In: International Journal of Modern Physics A


T stations
magnet
TT
VELO
upstream track
VELO track
T track
long track
downstream track

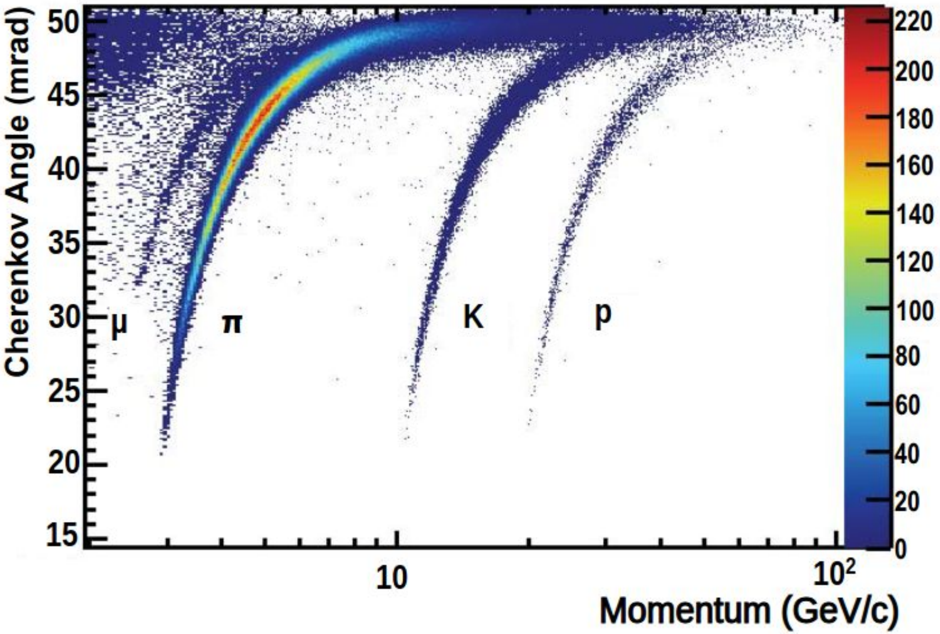

p
π
Λ^0
Λ_b^0
μ^+
J/ψ
PV
μ^-

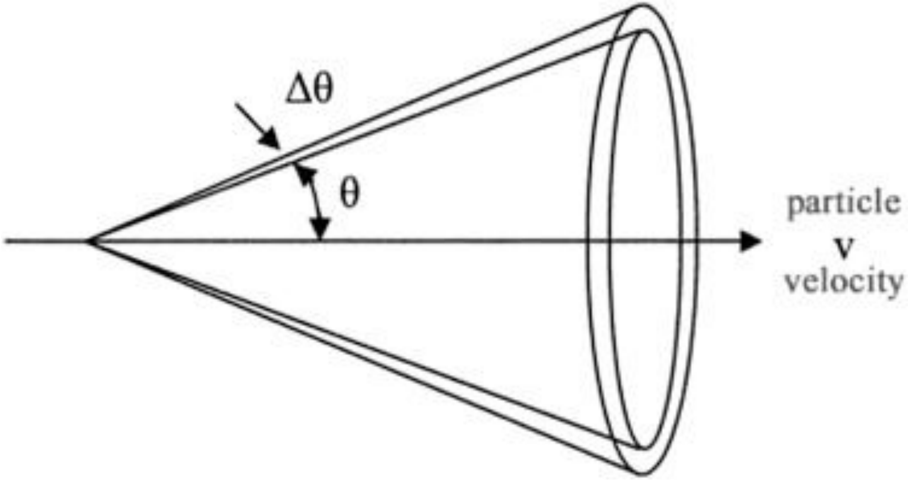
Particle Identification



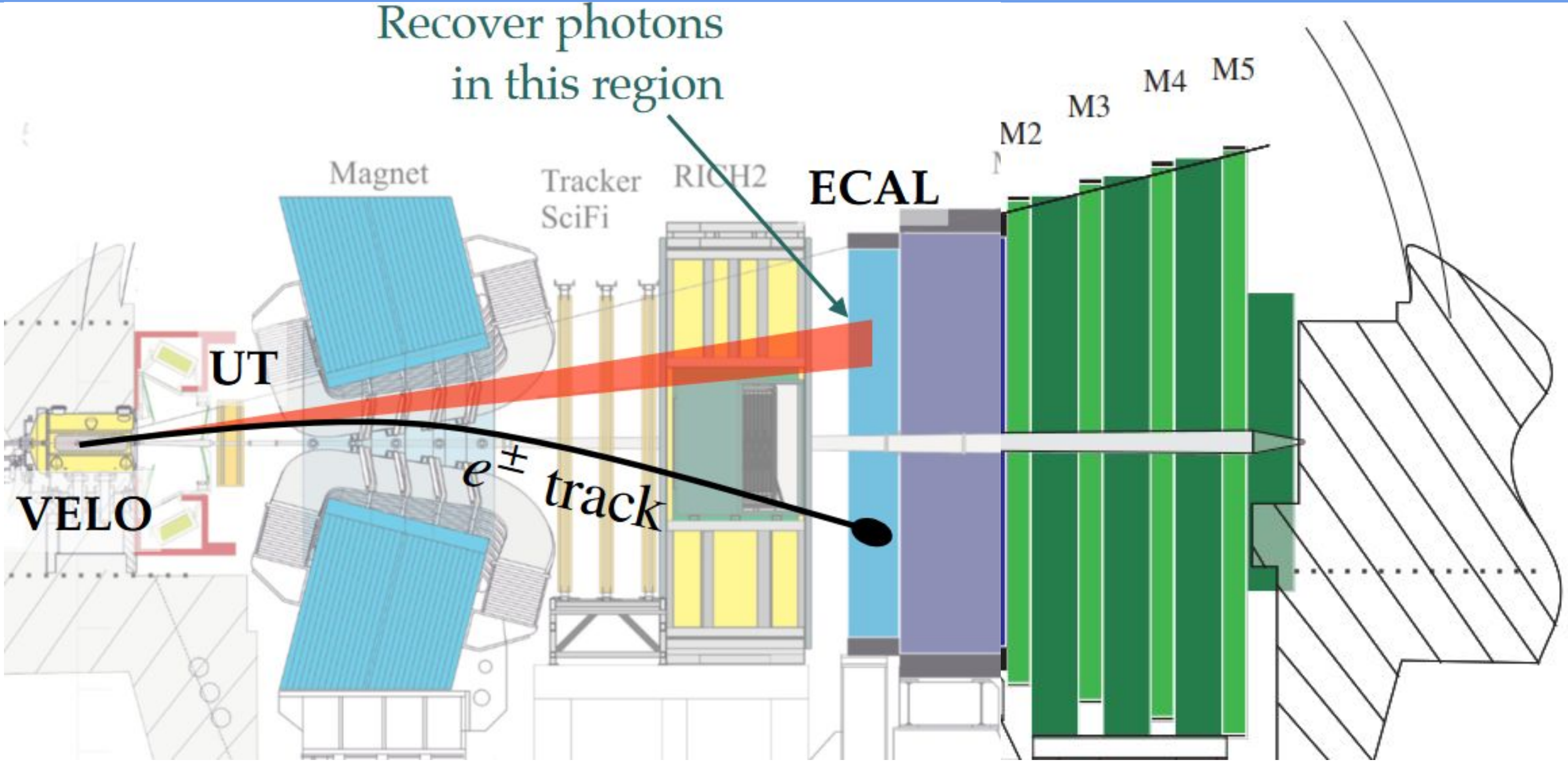
“LHCb detector performance”. In: International Journal of Modern Physics A

Particle Identification

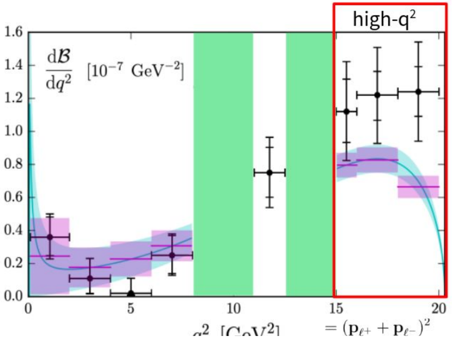




"LHCb detector performance". In: International Journal of Modern Physics A


Recover photons
in this region
M2
M3
M4
M5
Magnet
Tracker
SciFi
RICH2
ECAL
UT
VELO
$e^{\pm}$ track

How do we measure R(Λ)?



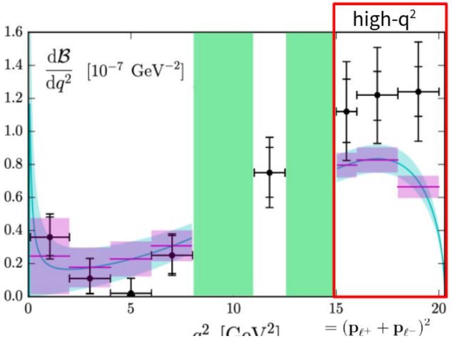
$$R(\Lambda) = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda^0 \mu^+ \mu^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda^0 e^+ e^-)}, \quad \text{where } \Lambda^0 \to p\pi^-$$

$$\mathcal{B}(\Lambda_b^0 \to \Lambda^0 \ell^+ \ell^-) = \frac{N_{\Lambda_b^0 \to \Lambda^0 \ell^+ \ell^-}}{\epsilon_{\Lambda_b^0 \to \Lambda^0 \ell^+ \ell^-} \cdot \mathcal{L} \cdot \sigma_{\Lambda_b^0}},$$

Single ratio:

$$r_\Lambda = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda^0 \mu^+ \mu^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda^0 e^+ e^-)} = \frac{N_{\Lambda_b^0 \to \Lambda^0 \mu^+ \mu^-}}{N_{\Lambda_b^0 \to \Lambda^0 e^+ e^-}} \cdot \frac{\epsilon_{\Lambda_b^0 \to \Lambda^0 e^+ e^-}}{\epsilon_{\Lambda_b^0 \to \Lambda^0 \mu^+ \mu^-}},$$

How do we measure R(Λ)?



$$R(\Lambda) = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda^0 \mu^+ \mu^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda^0 e^+ e^-)}, \quad \text{where } \Lambda^0 \to p\pi^-$$

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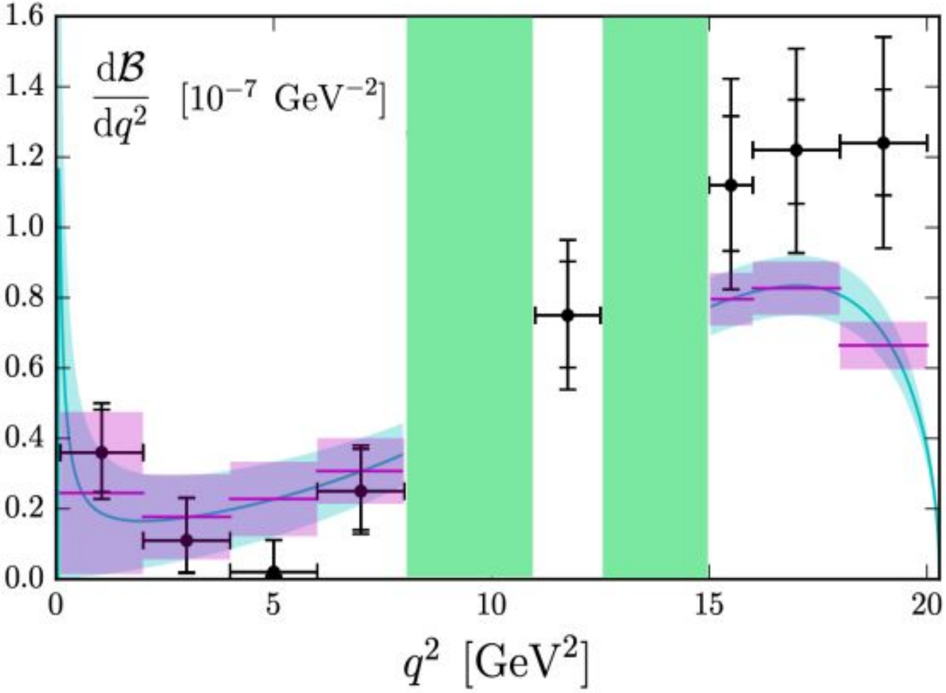
Double ratio:

$$\begin{aligned} R_\Lambda &= r_\Lambda \cdot r_{J/\psi}^{-1} \\ &= \frac{N_{\Lambda_b^0 \to \Lambda^0 \mu^+ \mu^-}}{N_{\Lambda_b^0 \to \Lambda^0 J/\psi(\to \mu^+ \mu^-)}} \cdot \frac{\epsilon_{\Lambda_b^0 \to \Lambda^0 J/\psi(\to \mu^+ \mu^-)}}{\epsilon_{\Lambda_b^0 \to \Lambda^0 \mu^+ \mu^-}} \cdot \frac{N_{\Lambda_b^0 \to \Lambda^0 e^+ e^-}}{N_{\Lambda_b^0 \to \Lambda^0 J/\psi(\to e^+ e^-)}} \cdot \frac{\epsilon_{\Lambda_b^0 \to \Lambda^0 J/\psi(\to e^+ e^-)}}{\epsilon_{\Lambda_b^0 \to \Lambda^0 e^+ e^-}} \end{aligned}$$

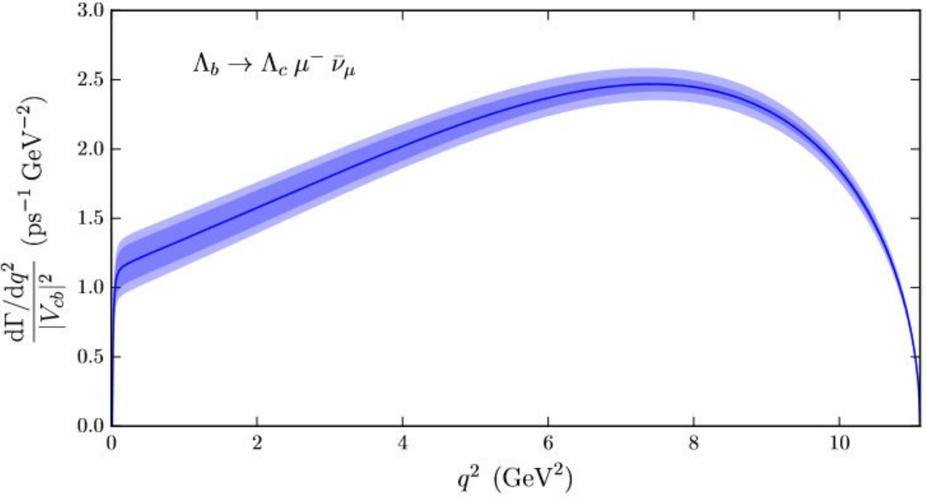
Lb->L0 Mu Mu   branching fraction

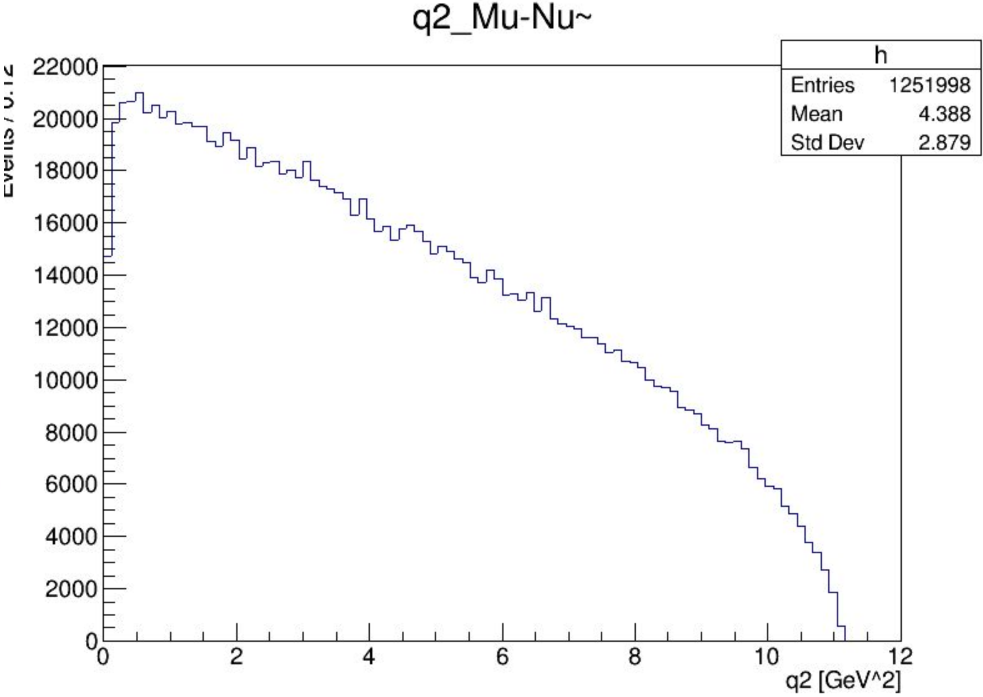


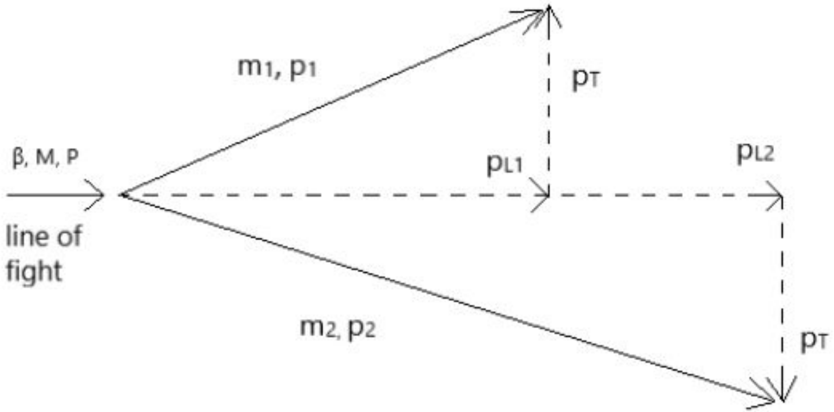
$$m(\Lambda_b)^2 - m(\Lambda^0)^2 \approx 20\ \mathrm{GeV}^2$$

$$m(\Psi(2S) + 50\ \mathrm{MeV})^2 \approx 14.3\mathrm{GeV}^2$$

Lc expected q2 vs MC q2

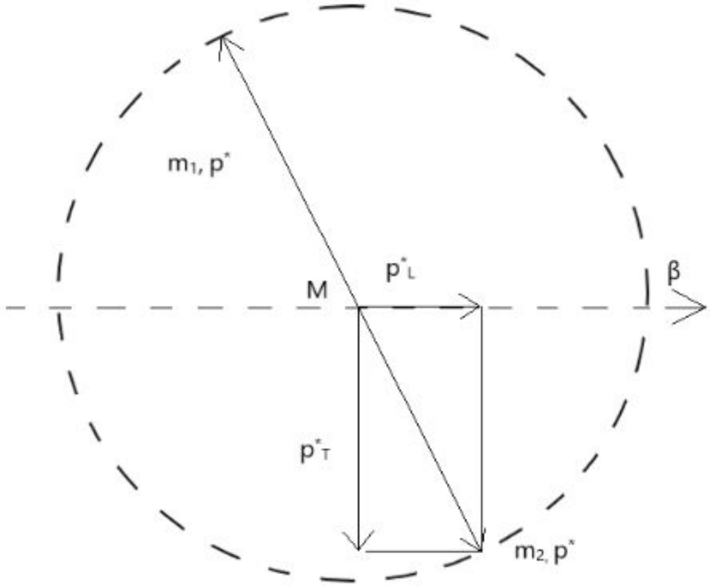






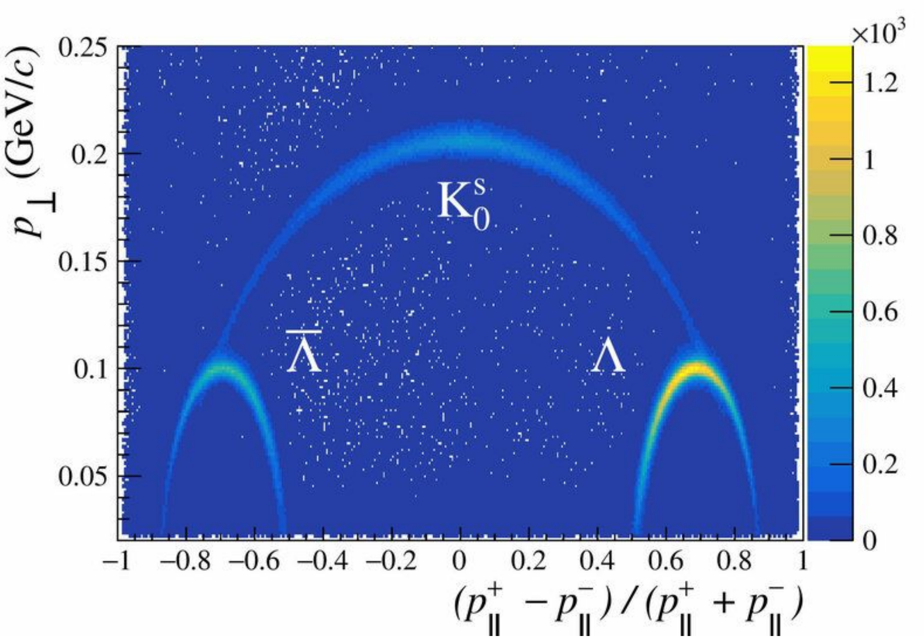
β, M, P
line of fight
m_1, p_1
p_T
p_{L1}
p_{L2}
m_2, p_2
p_T

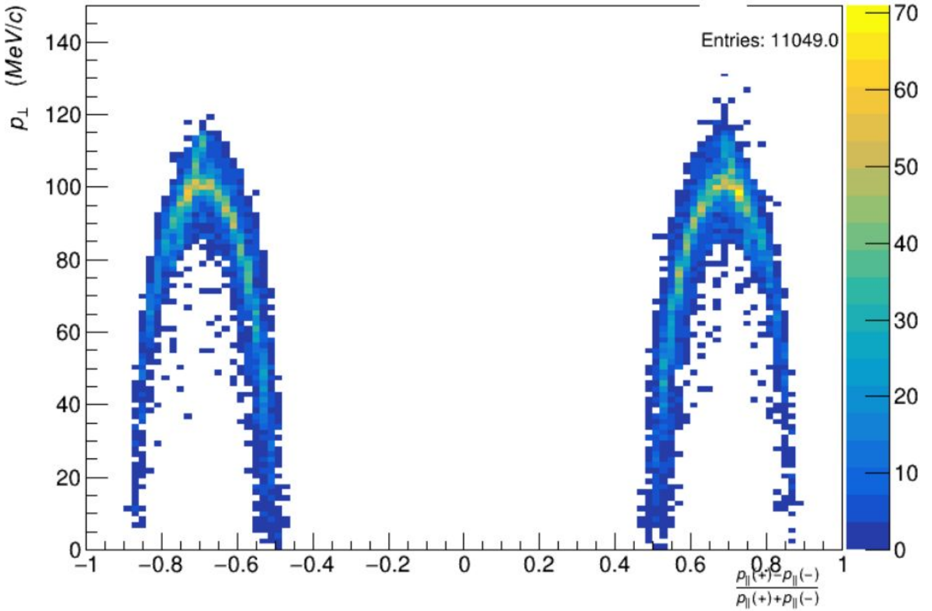
(a) LAB



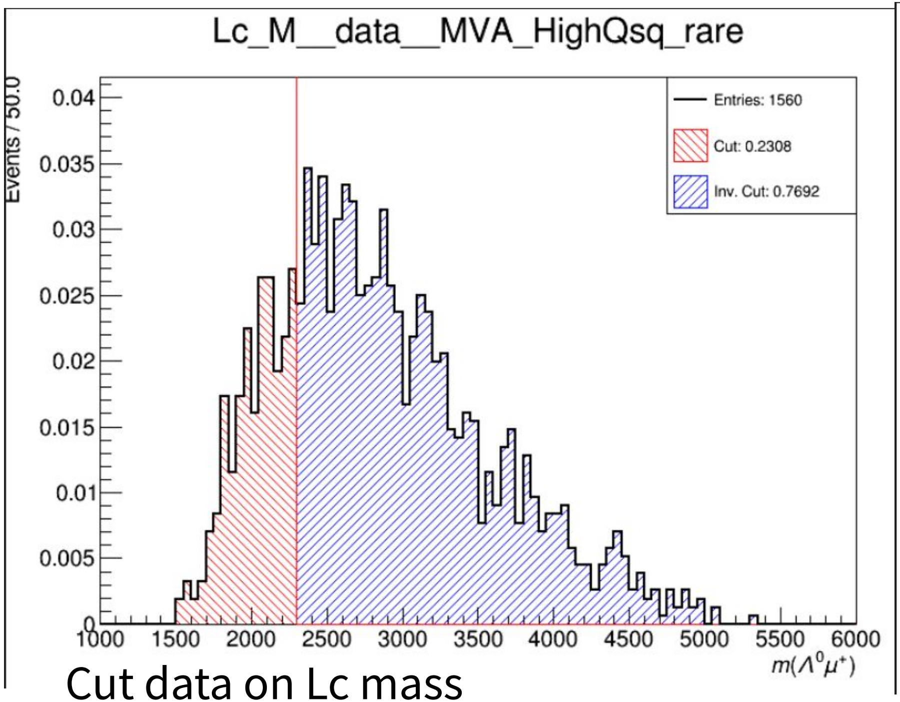
m_1, p^*
p^*_L
M
β
p^*_T
m_2, p^*

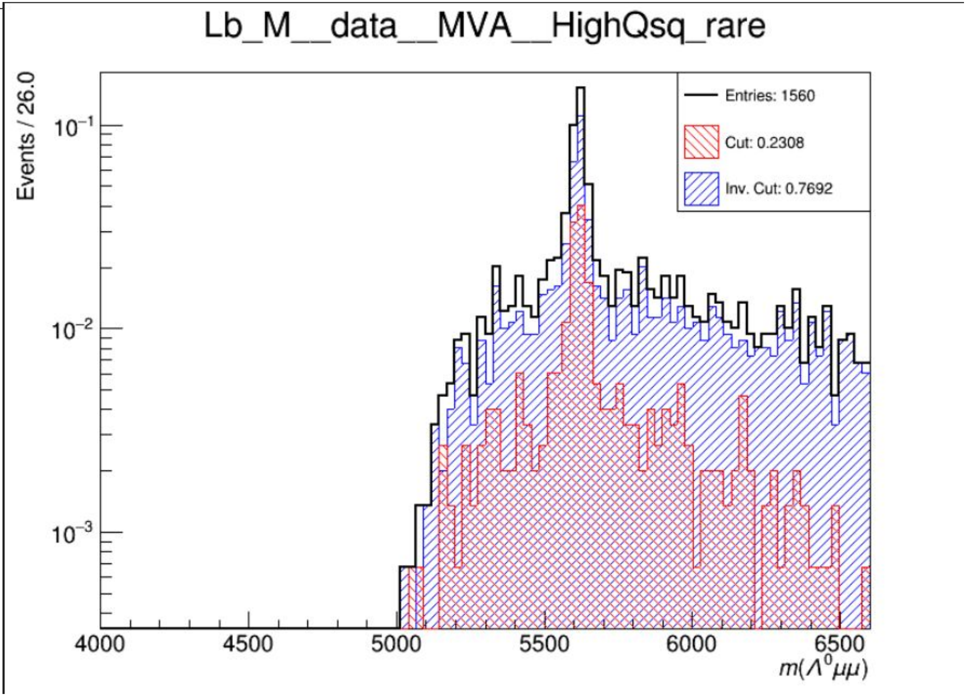
(b) CM


$p_{\perp}$ (GeV/c)
0.25
0.2
0.15
0.1
0.05
$\times10^3$
1.2
1
0.8
0.6
0.4
0.2
0
K_0^s
$\bar{\Lambda}$
Λ
−1
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
0.8
1
$(p_{\parallel}^+ - p_{\parallel}^-)/(p_{\parallel}^+ + p_{\parallel}^-)$


$p_{\perp}$ (MeV/c)
Entries: 11049.0
140
120
100
80
60
40
20
0
70
60
50
40
30
20
10
0
−1
−0.8
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
0.8
1
$\frac{p_{\parallel}(+)-p_{\parallel}(-)}{p_{\parallel}(+)+p_{\parallel}(-)}$

Lc mass cut on data

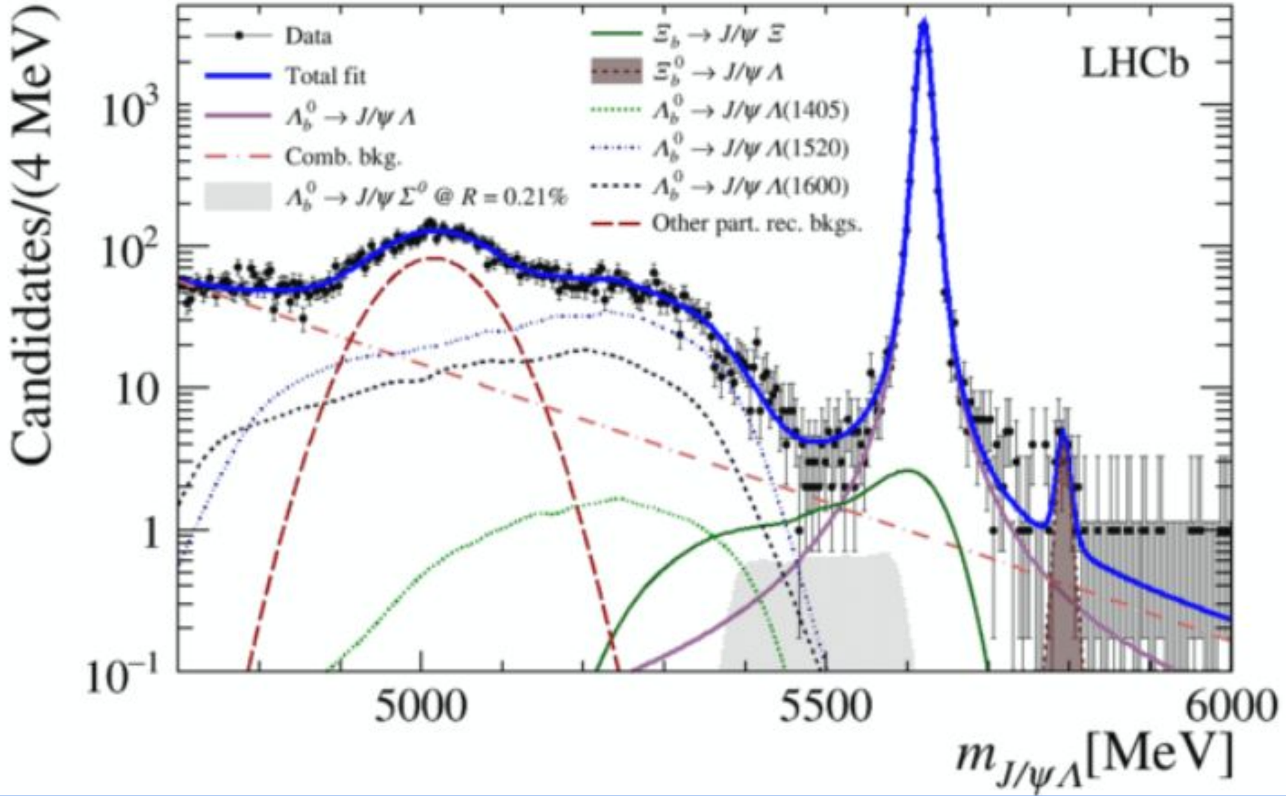




Cut data on Lc mass

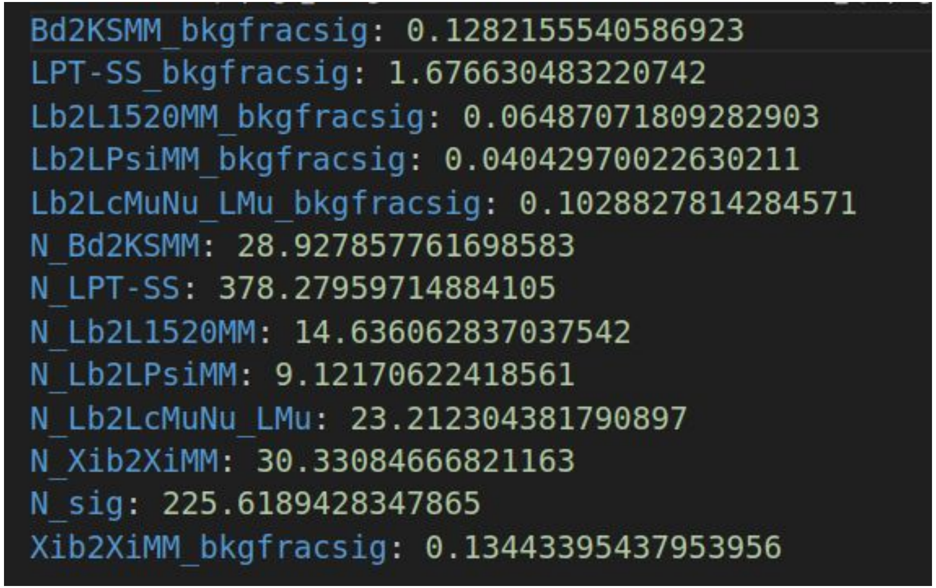
Do you see a difference in red and blue? Me neither

Mick’s favourite plot



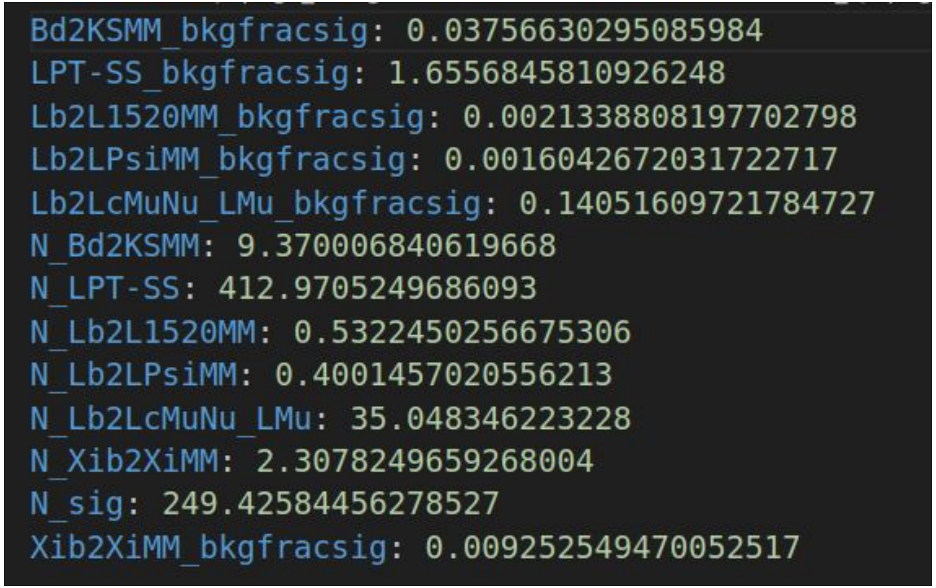
https://arxiv.org/abs/1912.02110

Floating yields



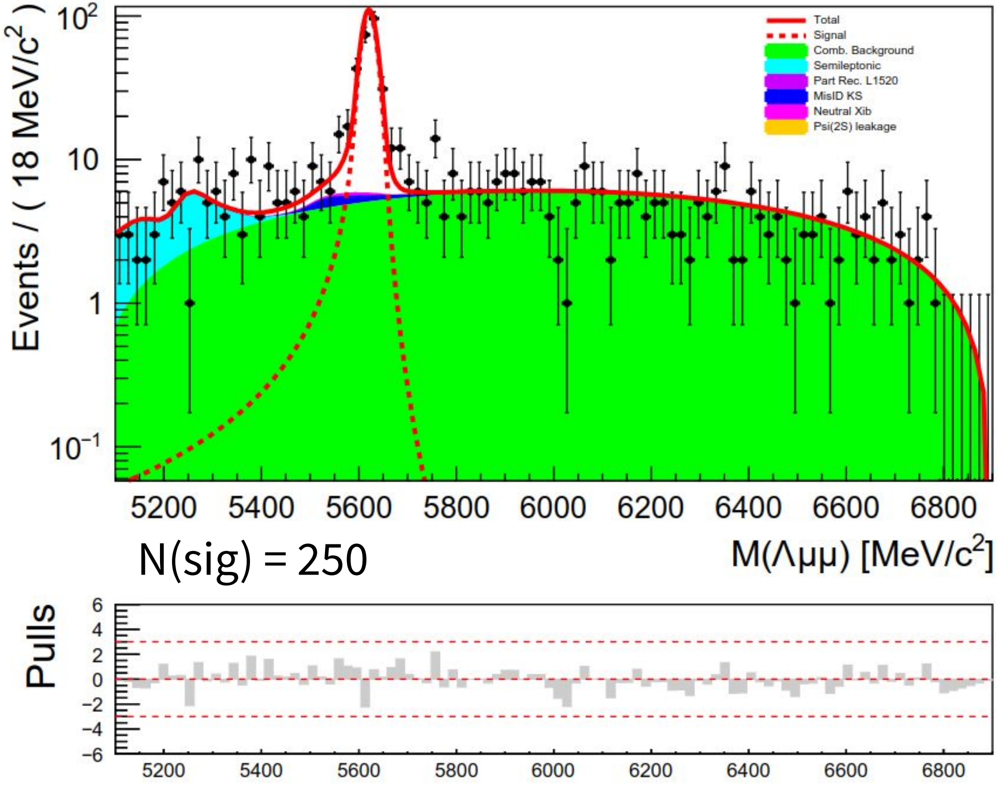
```
Bd2KSMM_bkgfracsig: 0.1282155540586923
LPT-SS_bkgfracsig: 1.676630483220742
Lb2L1520MM_bkgfracsig: 0.06487071809282903
Lb2LPsiMM_bkgfracsig: 0.04042970022630211
Lb2LcMuNu_LMu_bkgfracsig: 0.1028827814284571
N_Bd2KSMM: 28.92785776169858З
N_LPT-SS: 378.27959714884105
N_Lb2L1520MM: 14.636062837037542
N_Lb2LPsiMM: 9.12170622418561
N_Lb2LcMuNu_LMu: 23.212304381790897
N_Xib2XiMM: 30.33084666821163
N_sig: 225.6189428347865
Xib2XiMM_bkgfracsig: 0.13443395437953956
```

Limiting yields



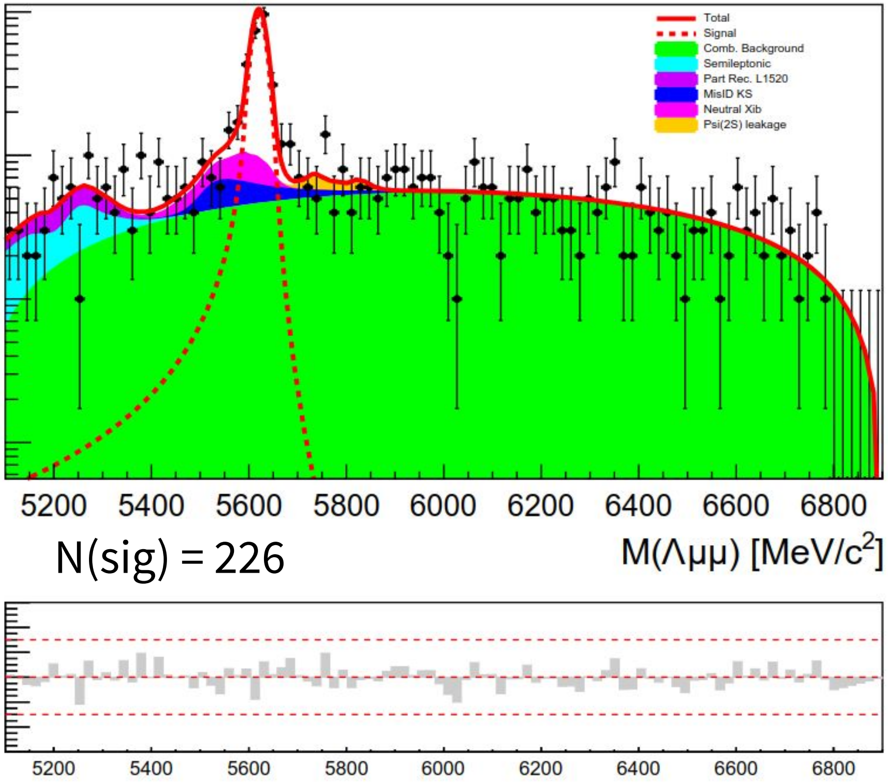
```
Bd2KSMM_bkgfracsig: 0.03756630295085984
LPT-SS_bkgfracsig: 1.6556845810926248
Lb2L1520MM_bkgfracsig: 0.0021338808197702798
Lb2LPsiMM_bkgfracsig: 0.0016042672031722717
Lb2LcMuNu_LMu_bkgfracsig: 0.14051609721784727
N_Bd2KSMM: 9.370006840619668
N_LPT-SS: 412.9705249686093
N_Lb2L1520MM: 0.5322450256675306
N_Lb2LPsiMM: 0.4001457020556213
N_Lb2LcMuNu_LMu: 35.048346223228
N_Xib2XiMM: 2.3078249659268004
N_sig: 249.42584456278527
Xib2XiMM_bkgfracsig: 0.009252549470052517
```

Limiting yields



N(sig) = 250

Floating yields



N(sig) = 226

More realistic, higher signal contribution, similar pulls