IoP - Joint annual HEPP and APP conference
University of Sussex
21st Mar 2016

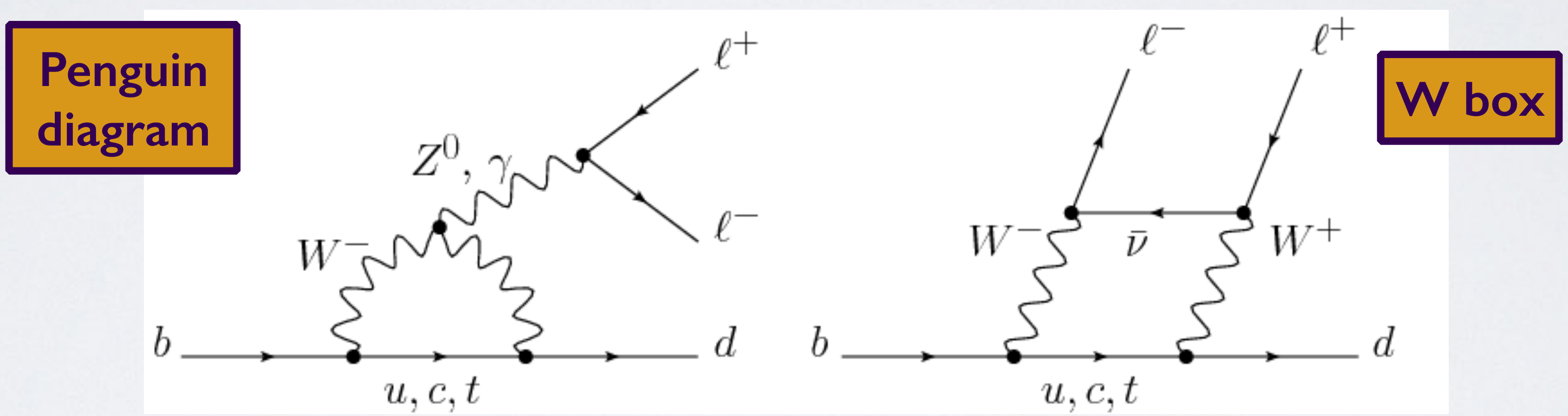
Testing lepton flavour universality in rare decays at the LHCb experiment

Luca Pescatore
on behalf of the LHCb collaboration

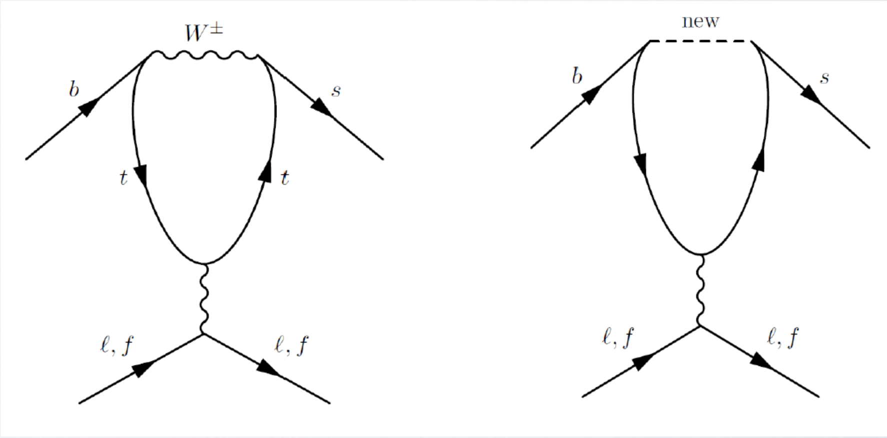
Lepton universality and rare decays

- **Lepton universality**: equality of the EW couplings for leptons
- Rare decays: processes suppressed in the SM that can happen **only at loop level**.
  - Flavour Changing Neutral Currents
    → forbidden at tree level in the SM (e.g $b \to s$ or $b \to d$ transitions)
    → branching fractions typically ~10^{-6} or less

arXiv:1501.03309

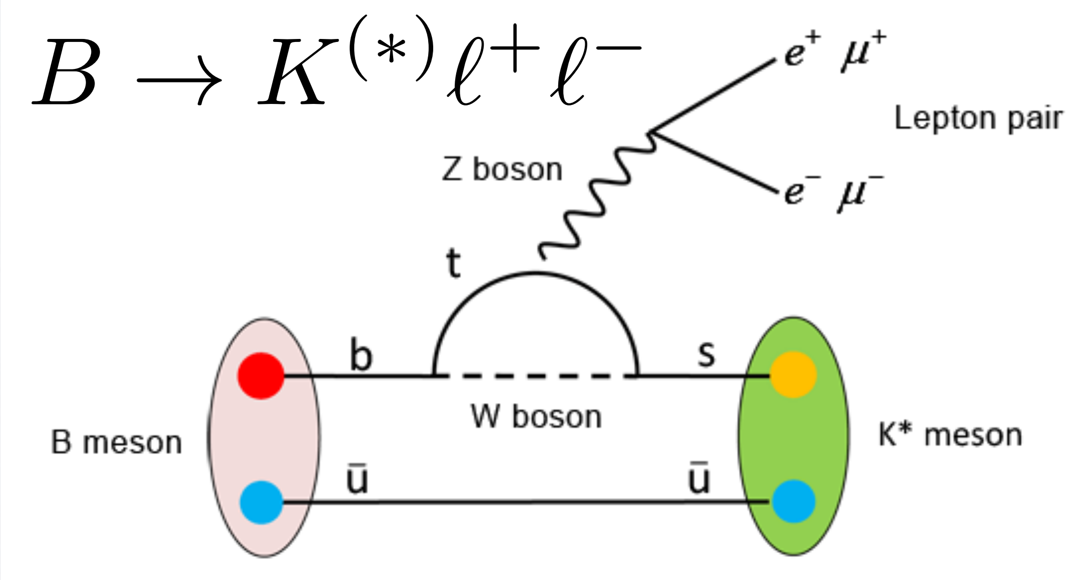


- **New Physics** can enter in the loops
  - Very sensitive to new physics effects
    → NP enters at the same level as SM
  - No evidence in direct searches so far
    → loops can probe **high energy scales**



Decay amplitudes of semileptonic decays

$$A(M \to F) = \langle M|\mathcal{H}_{eff}|F\rangle =$$
$$= \frac{G_F}{\sqrt{2}} \sum V^i_{CKM} C_i(\mu) \langle M|\mathcal{O}_i(\mu)|F\rangle$$

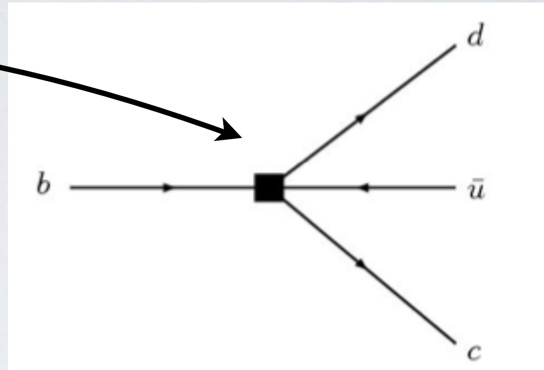


Decay amplitudes of semileptonic decays

Short distance physics: high energy scale

Perturbative contribution.

Wilson Coefficients



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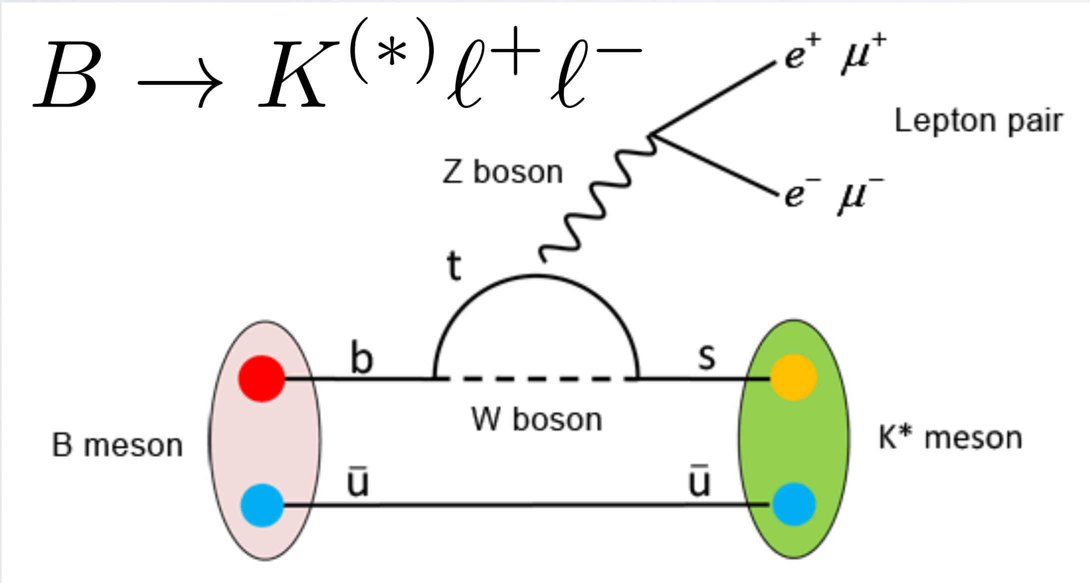

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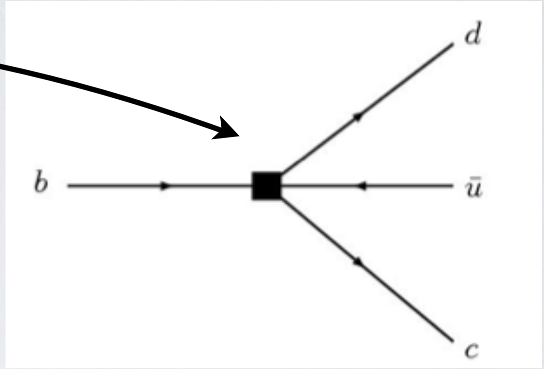
Short distance physics: high energy scale

Perturbative contribution.



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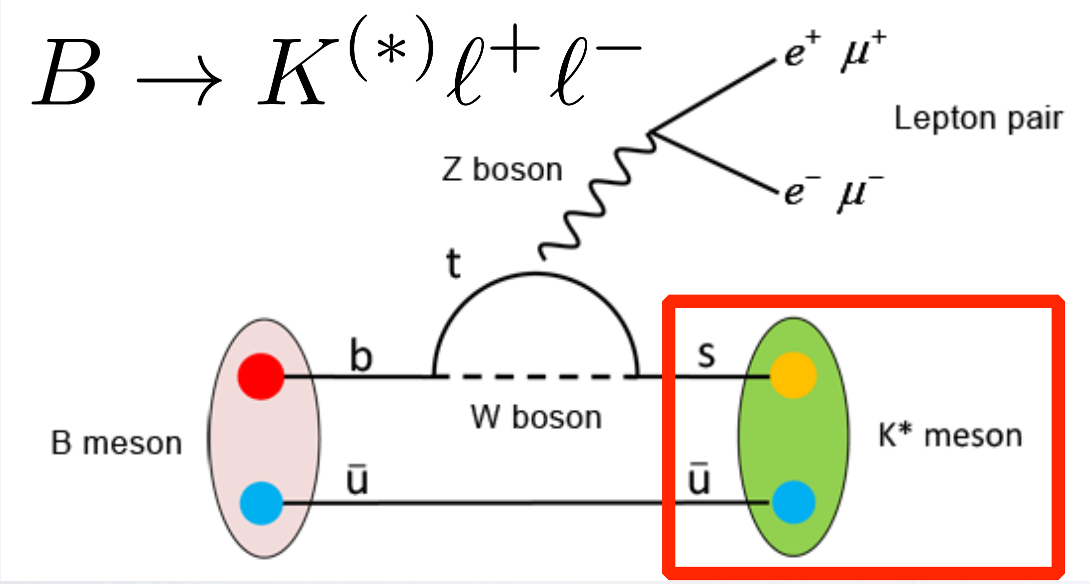


Form factors: low energy physics describing the hadronization process. Need to be obtained with non perturbative methods e.g. Lattice QCD

Form factors = **main source of uncertainty** in theory predictions

Lepton Flavour Universality and R_H

- Idea: test LFU using rare decays, where there is space for new physics

$$R_H = \frac{\int_{4m_\mu^2}^{m_b} \frac{d\mathcal{B}(B\to H\mu^+\mu^-)}{dq^2}}{\int_{4m_\mu^2}^{m_b} \frac{d\mathcal{B}(B\to He^+e^-)}{dq^2}} dq^2$$

PRD 69 074020 (2004)

$H = K, K^{*0}, \phi, ...$

- Universality → R_K ~ 1 with o($(m_\mu/m_b)^2$) corrections (JHEP 12 (2007) 040)
- Hadronic uncertainties cancel in the ratio
  ➡ precisely predicted: R_K = 1.0000 ± 0.0001

	BaBar $0.1 < q^2 < 8.12\,\mathrm{GeV}^2/c^4$	BaBar $q^2 > 10.11\,\mathrm{GeV}^2/c^4$	Belle Full q^2 region	LHCb $1 < q^2 < 6\,\mathrm{GeV}^2/c^4$
R_K	$0.74^{+0.40}_{-0.31} \pm 0.06$	$1.43^{+0.65}_{-0.44} \pm 0.12$	$1.03 \pm 0.19 \pm 0.06$	$0.745^{+0.090}_{-0.074} \pm 0.036$
R_{K^*}	$1.06^{+0.48}_{-0.33} \pm 0.08$	$1.18^{+0.55}_{-0.37} \pm 0.11$	$0.83 \pm 0.17 \pm 0.08$	–

2.6σ from the SM

PhysRevLett.113.151601

R_{K^*}: making R_K stronger and more

$$R_H = \frac{\int_{4m_\mu^2}^{m_b} \frac{d\mathcal{B}(B\to H\mu^+\mu^-)}{dq^2}}{\int_{4m_\mu^2}^{m_b} \frac{d\mathcal{B}(B\to He^+e^-)}{dq^2}} dq^2$$

$$H = K^{*0}$$

- Independent confirmation of R_K result
- Different combinations of left- and right-handed Wilson Coefficients

JHEP 1502 (2015) 055
[arXiv:1411.4773]

$$C + C' : \quad K, K^*_\perp, ...$$

$$C - C' : \quad K_0(1430), K^*_{0,\|}, ...$$

R_K and R_{K^*} give complementary information

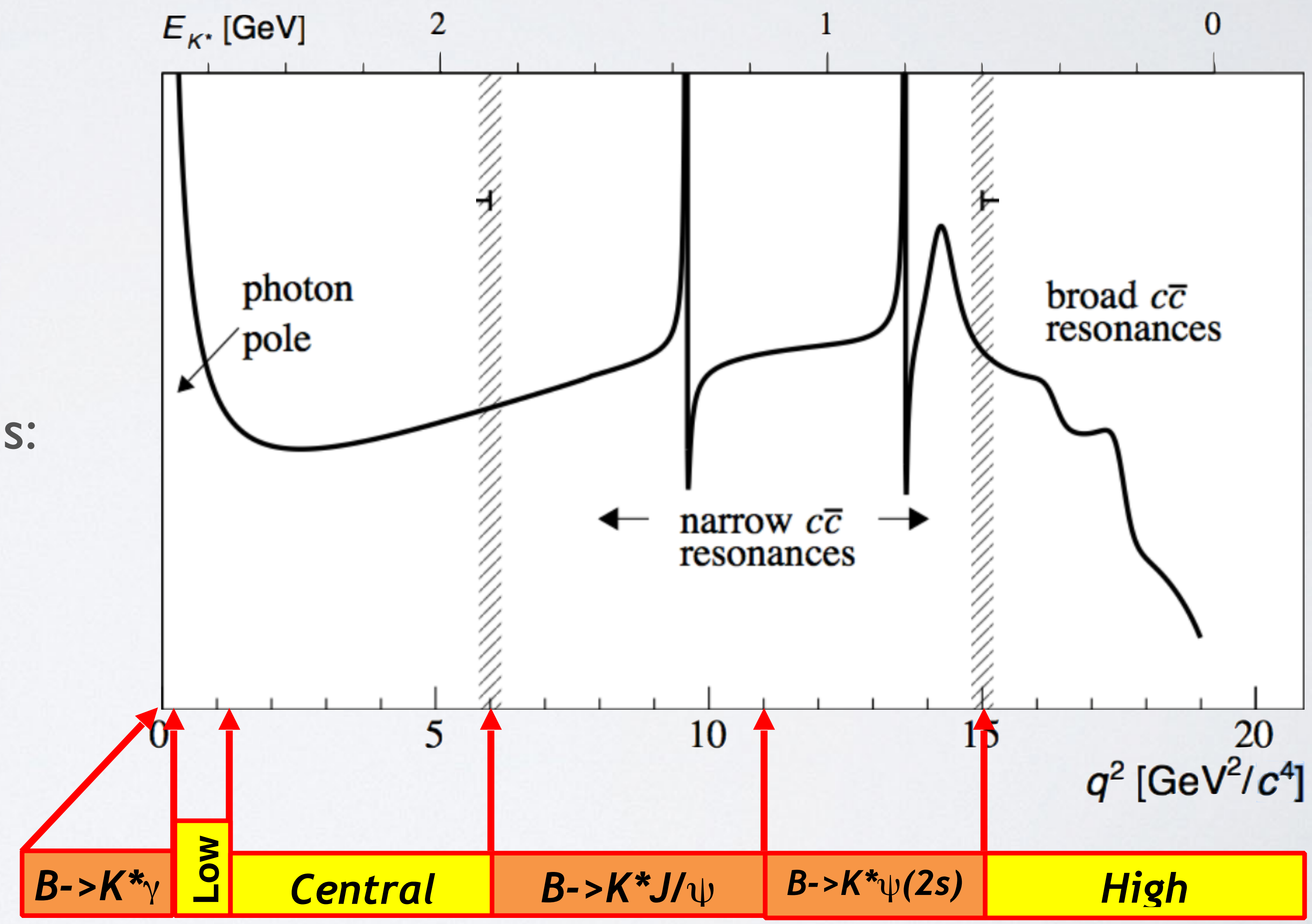
Analysis strategy

- Three q^2 regions considered:
  - Low-q^2: $0.0004 < q^2 < 1.1$ dominated by the photon pole (SM)
  - Central-q^2: $1.1 < q^2 < 6$ most interesting to observe new physics
  - High-q^2: $q^2 > 15 GeV^2/c^4$

- Normalisation channels
  - ✓ $J/\psi \to \mu\mu/ee$

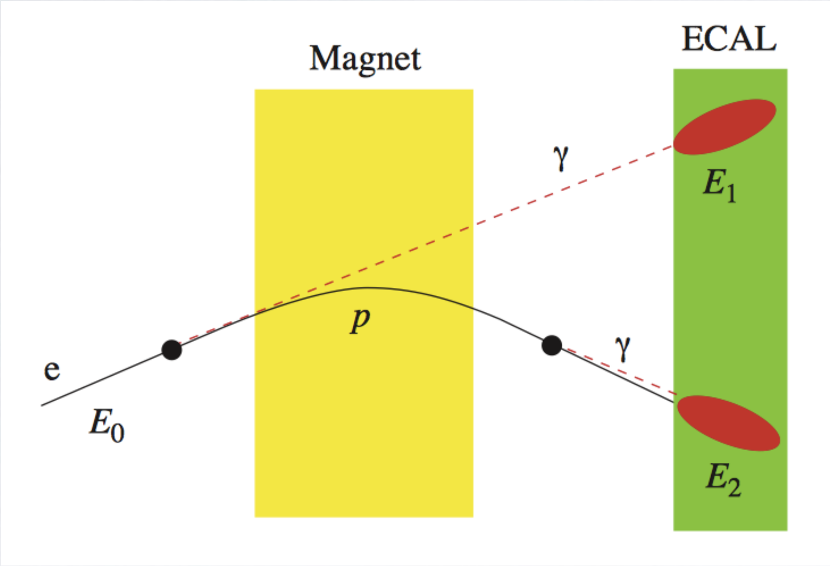
- Control samples for ee channels:
  - ✓ $B \to K^*(\gamma \to ee)$
  - ✓ $B \to K^*(\psi(2S) \to ee)$

$$q^2 = m_{\ell\ell}^2$$

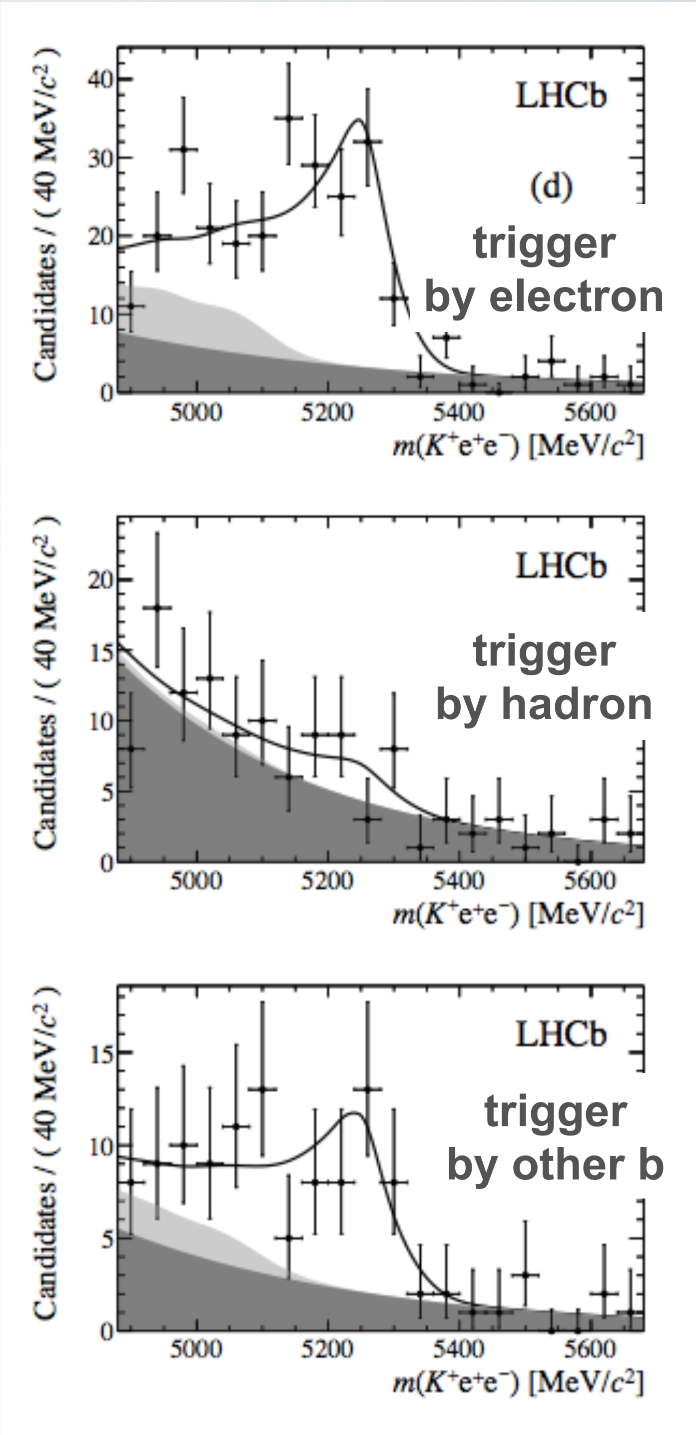


Dealing with electrons

- The ee channels are the challenge in this analysis:
  - **Bremsstrahlung:** degrades resolution
    → energy recovered looking at calorimeter hits

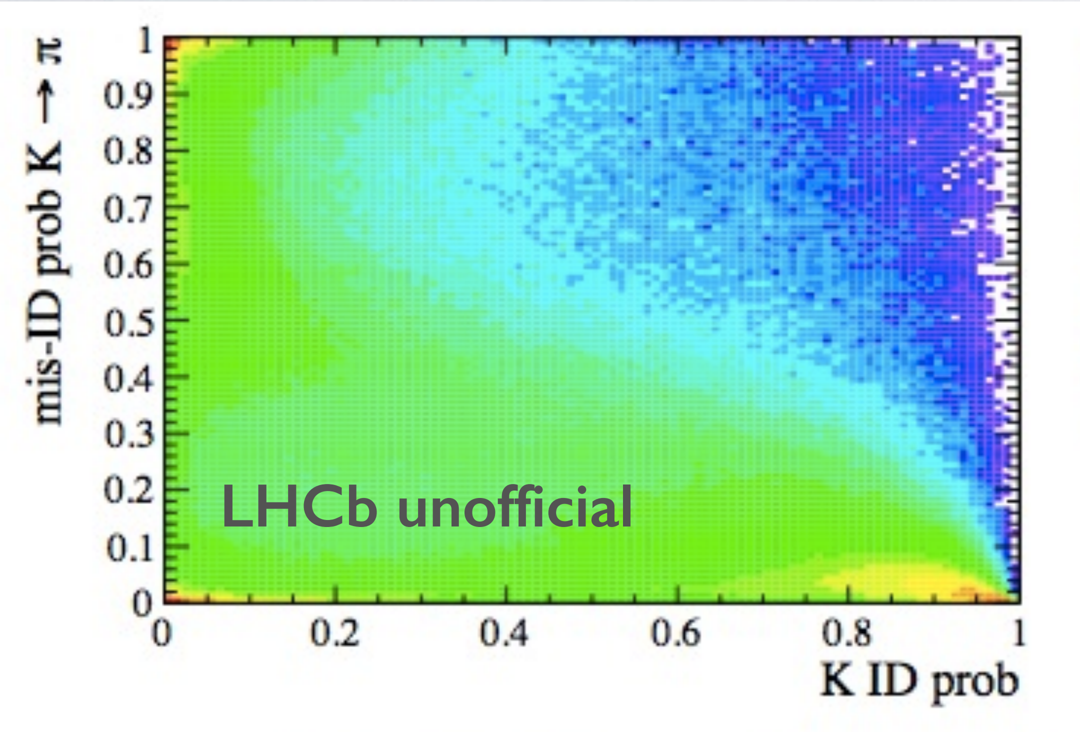


PhysRevLett.113.151601
arXiv:1406.6482



  - **Low trigger efficiency**
    → Use events triggered by the electrons, by the hadrons and by other particles in the event

Selection for R_{K^*}



- <u>PID</u> from variables combining information from RICH, calorimeters, muon detector and tracking

Performances in LHCb:
$\varepsilon(K) \sim 95\ \%$ for $\varepsilon(\pi \rightarrow K) \sim 5\ \%$
$\varepsilon(\mu) \sim 97\ \%$ for $\varepsilon(\pi \rightarrow \mu) \sim 1\text{-}3\ \%$

Correct ID probability — Mis-ID probabilities

$$\pi \rightarrow \texttt{ProbNNpi} \times (1 - \texttt{ProbNNk}) \times (1 - \texttt{ProbNNp}) > 0.1$$
$$K \rightarrow \texttt{ProbNNk} \times (1 - \texttt{ProbNNp}) > 0.05$$

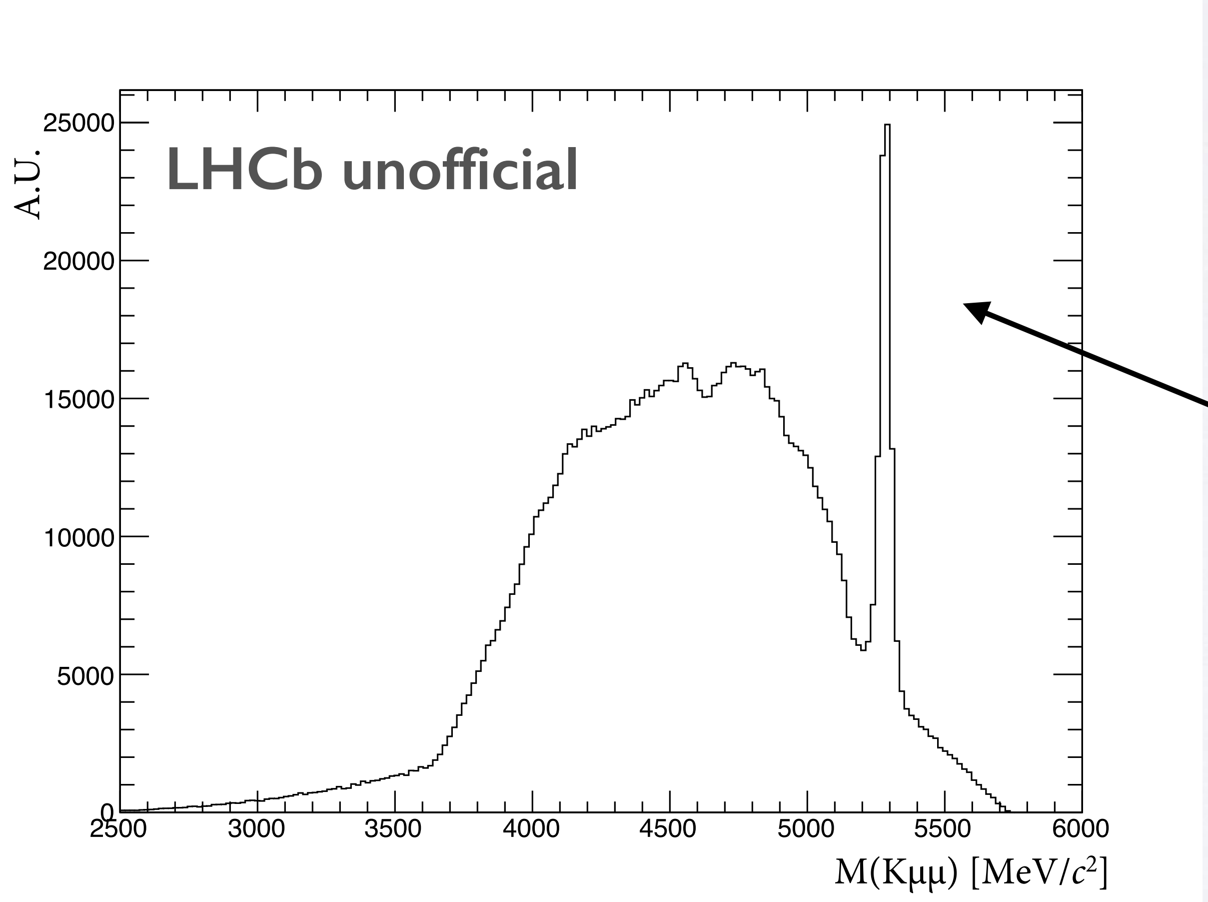
Combined cuts to exploit the full PID power.

- Cuts to remove specific backgrounds (next slides)
- Multivariate analysis base on a Neural Network

Physics backgrounds

Other decays may mimic the decays of interest:

- ✓ $B^+ \to K^+\ell\ell$ plus a random pion
- ✓ $B_s \to \phi\ell\ell$ with $\phi \to KK$ and a K mis-identified as a π
- ✓ $\Lambda_b \to pK\ell\ell$ with misidentified particles
    - Not peaking: need to be modelled in the fit



3-body Kμμ invariant mass shows a narrow B^+ peak easy to remove

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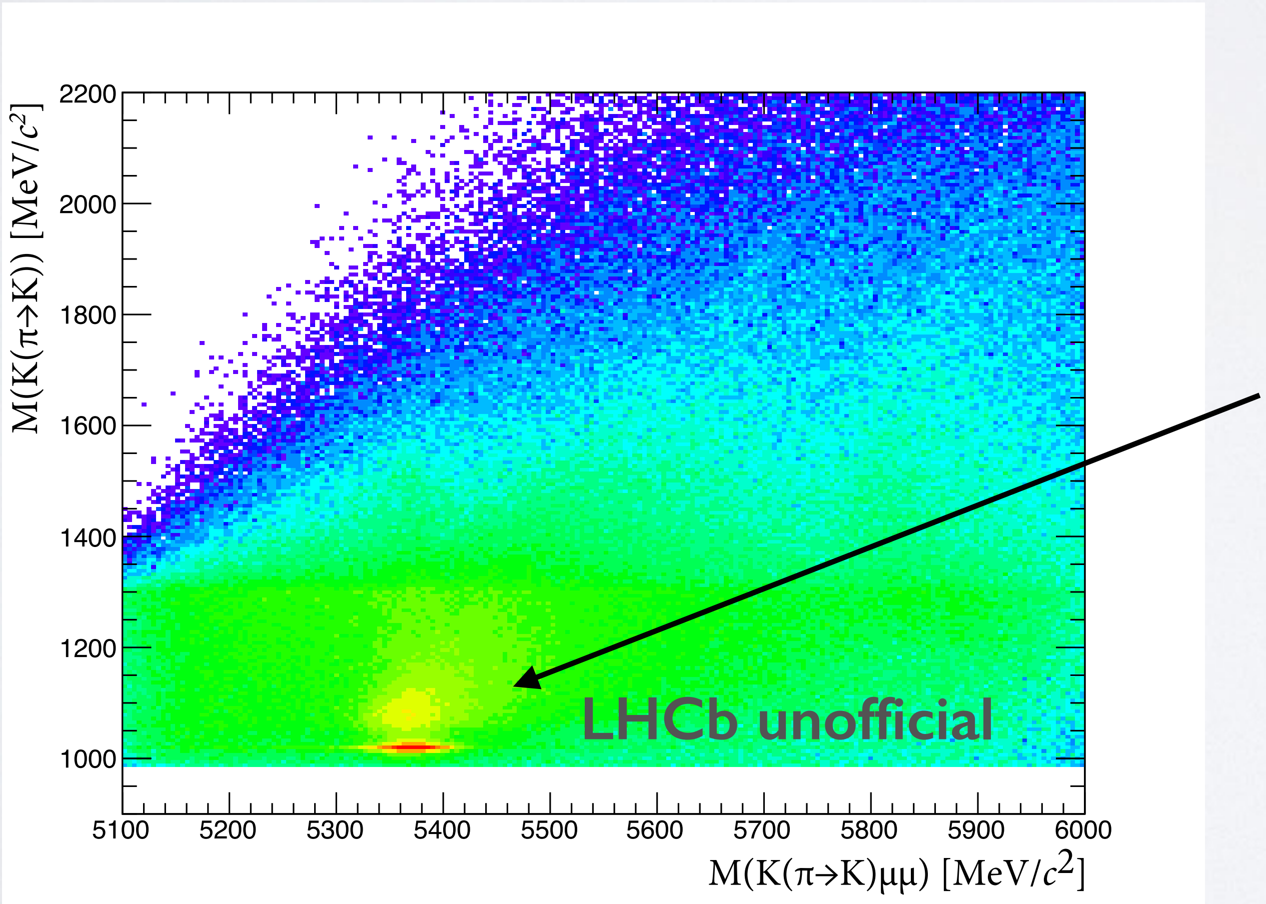
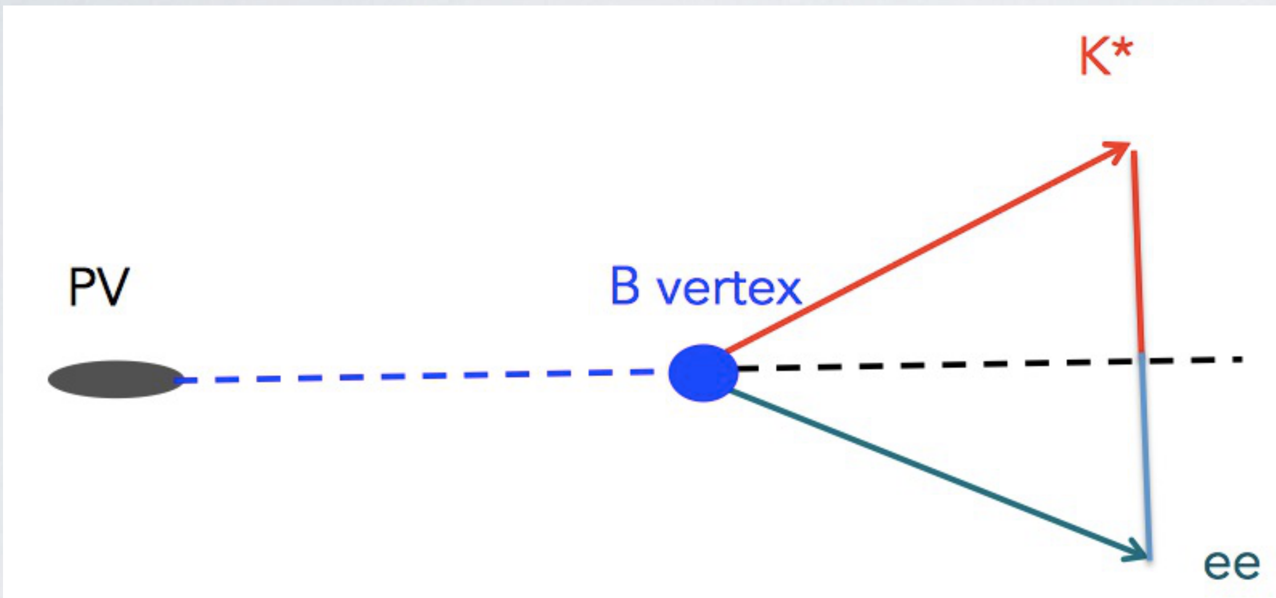


Mass recalculated using $m(\pi) \to m^{PDG}(K)$ and a peak appears in a limited region of the plane.

The HOP cut for electrons

Correct electron momentum assuming the energy is lost due to bremsstrahlung

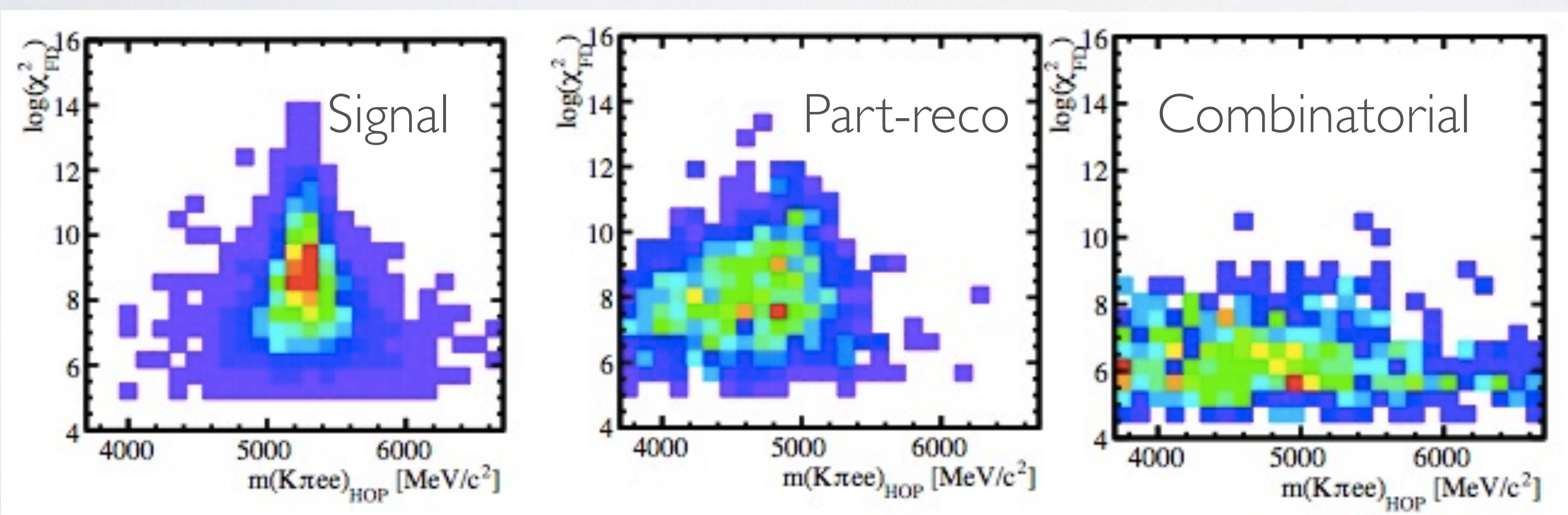


$$p_T^{K^{*0}} = -p_T^{ee}$$

$$p_{x,y,x}^{corr} = \left(\frac{p_T^{K^{*0}}}{p_T^{ee}}\right) p_{x,y,z}^{meas}$$

then recompute

the 4-body mass (m_{HOP})



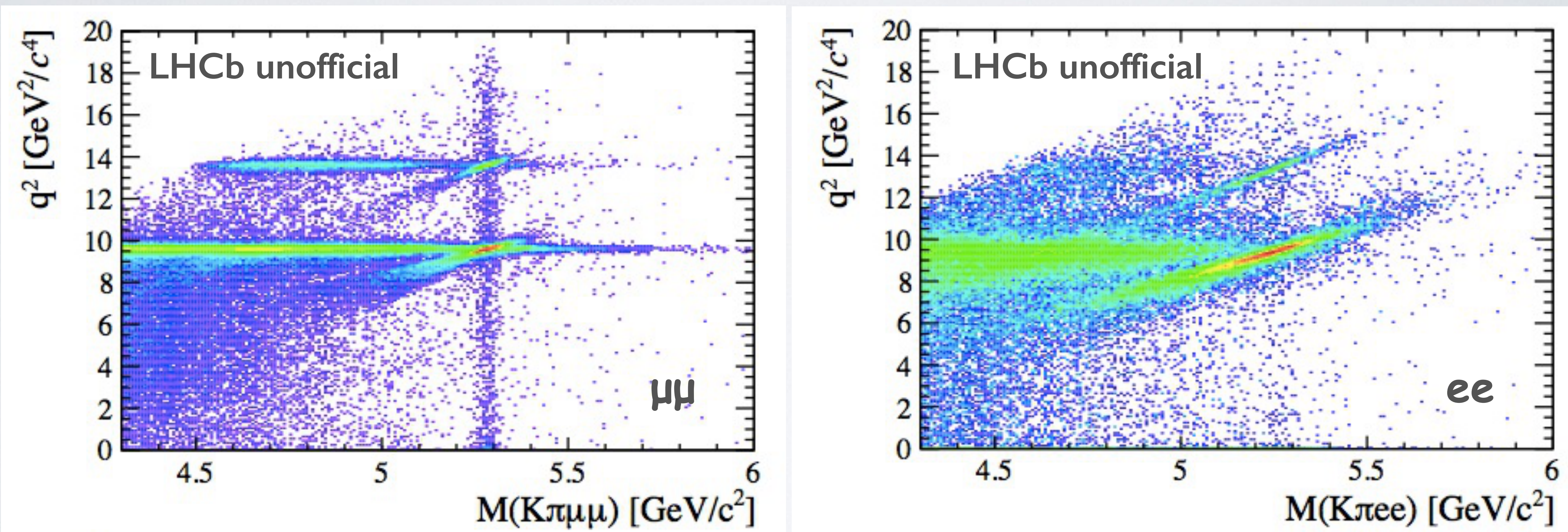
Flight distance χ^2 vs m_{HOP}

Backgrounds have low values of m_{HOP} which gives us discriminating power.

Charmonium channels

- Charmonium channels $B \to K^*(J/\psi \to \ell\ell)$ peak in the q^2 spectrum.
- Naturally distinguished from the rare channels by the q^2 binning

[0.0004,1.1] - [1.1,6] - J/ψ - $\psi(2S)$ - [15,20]

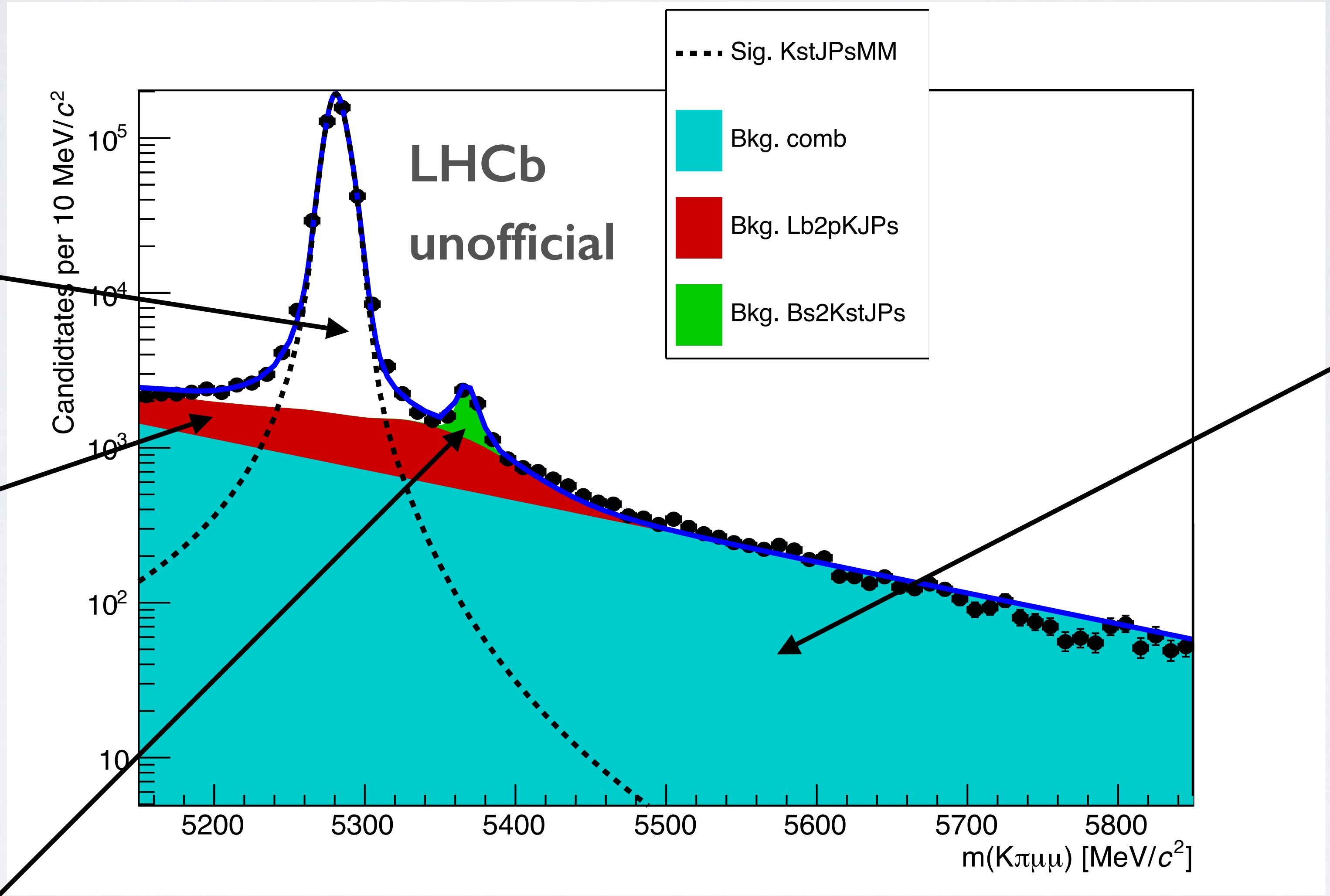


Resonant samples used as normalisation and control samples

Mass fits: $B^0 \to K^{*0}(J/\psi \to \mu\mu)$

- Resonant and rare samples fit simultaneously
  - initial parameters taken from a fit to simulated events
  - mass shift to take into account data-MC differences.

Signal:
sum of two
Crystal Ball functions



Combinatorial:
exponential

Λ_b decays:
modelled with
a simulated shape

$B_s \to K^*(J/\psi \to \mu\mu)$:
same shape as signal
but shifted in mass

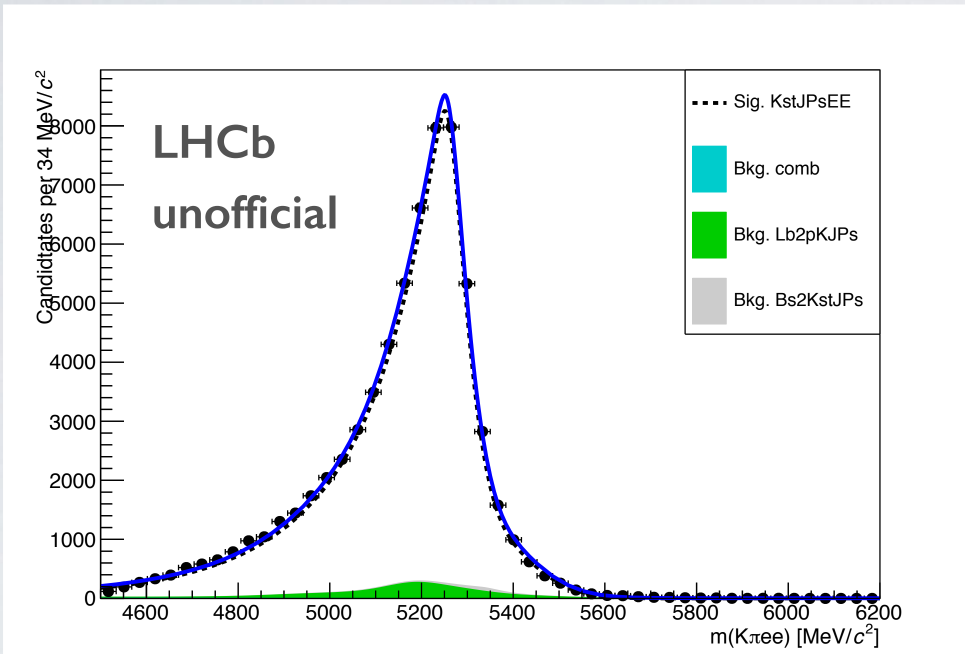
- Kinematic constraints applied to improve resolution

Electron control samples

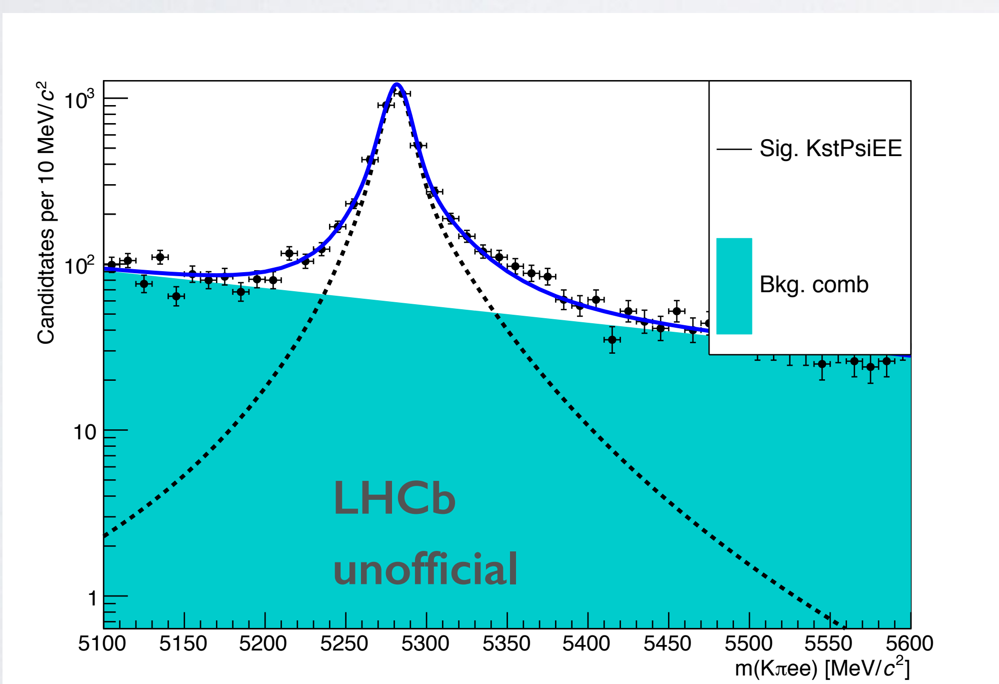
Simultaneous fit including

3 control samples

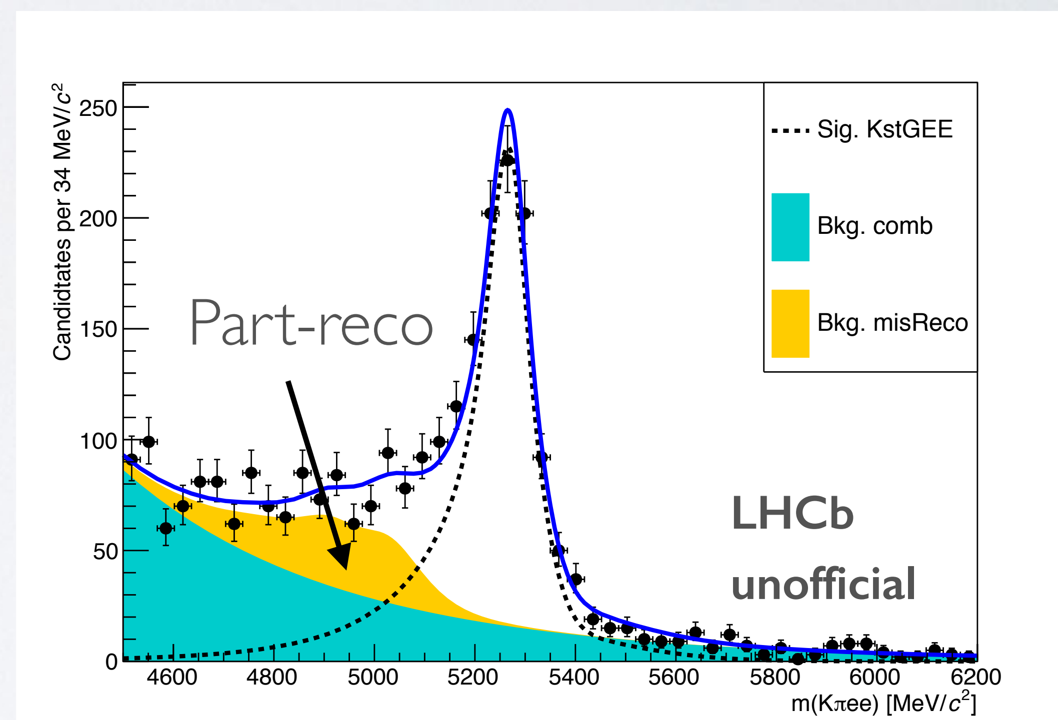
to constrain fit parameters



K*J/ψ → shape parameters and leakage

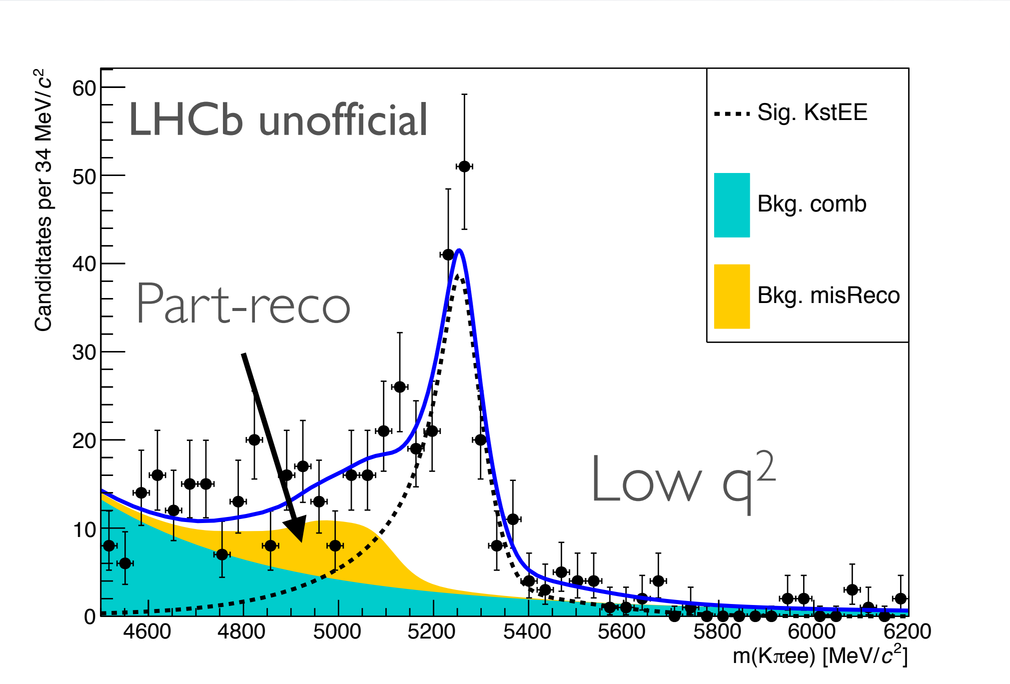


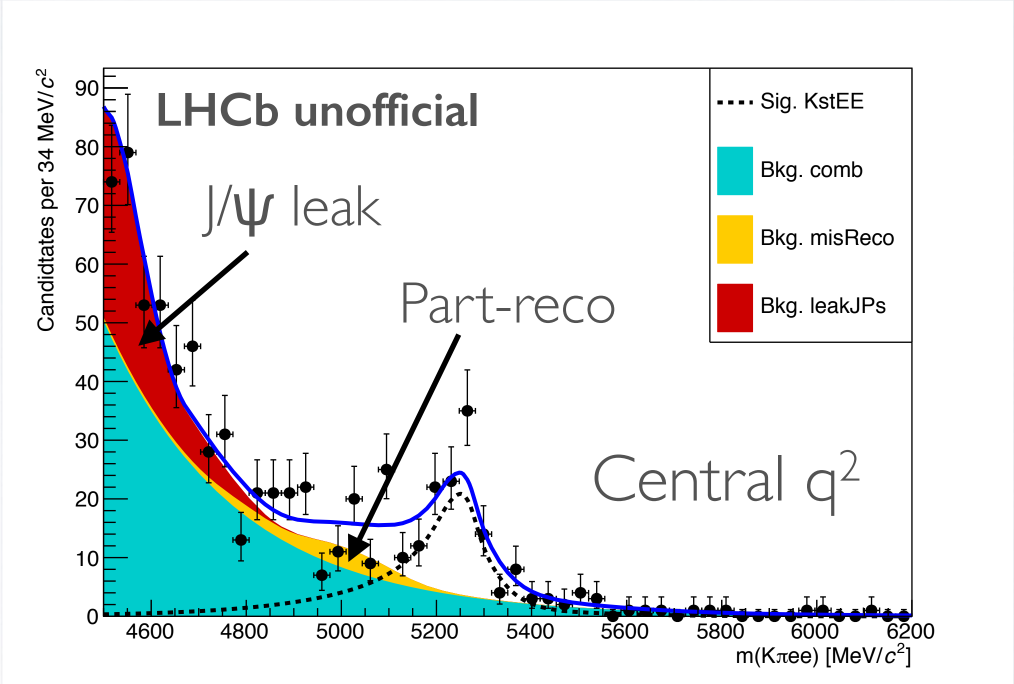
ψ(2S) → leakage into the high q^2



K*γ → leakage into the low q^2 and part-reco background parameters

Results and systematics





Result as a double ratio over the resonant channels (similar kinematics)

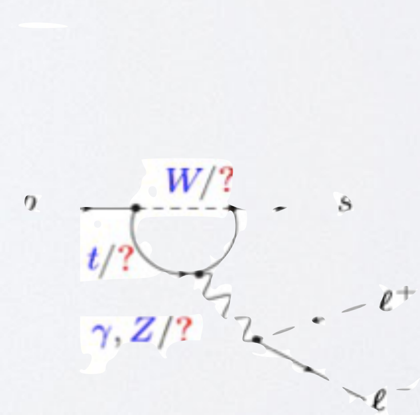
→ reduces systematic uncertainties in efficiency determination

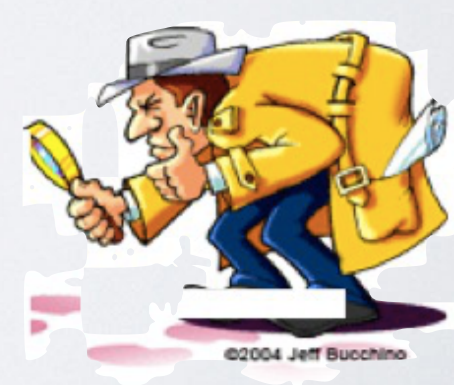
$$R_{K^*} = \frac{R_{ee}}{R_{\mu\mu}} = \frac{N_{ee}}{N_{J/\psi(ee)}} \cdot \frac{N_{J/\psi(\mu\mu)}}{N_{\mu\mu}} \cdot \frac{\varepsilon_{J/\psi(ee)}}{\varepsilon_{ee}} \cdot \frac{\varepsilon_{\mu\mu}}{\varepsilon_{J/\psi(\mu\mu)}}.$$

Results not approved yet, but soon!

Summary

- Rare decays offer many opportunities to test the SM
- We are testing Lepton Universality with RK*
  - Selection finalised
  - Preliminary efficiency and systematics estimates done
  - Currently under experiment review.
- Results coming soon!





Backup

Systematic uncertainties

Where possible systematics are evaluated using pseudo-experiments.

Source	low-q^2 (%)	central-q^2 (%)	high-q^2 (%)
Signal shape	1.65	1.10	2.92
Swap	0.30	0.12	0.13
$\Lambda_b^0 \to pK\ell^+\ell^-$	0.25	0.28	0.77
Partially-reconstructed	0.11	4.13	0.10
Combinatorial	0.00	0.02	8.02
J/ψ leakage	0.06	0.01	0.10
$\psi(2S)$ leakage	0.03	0.01	2.00
Efficiency	0.65	0.74	0.83
TISTOS	2.47	2.30	2.80
Bin migration	0.69	1.43	1.19

Choice of signal and background PDFs:

- Vary fixed parameters
- Use different PDF

Efficiency determination:

- Statistics of the MC
- Compare data-driven methods and simulation
- Use different decay models

Sanity checks

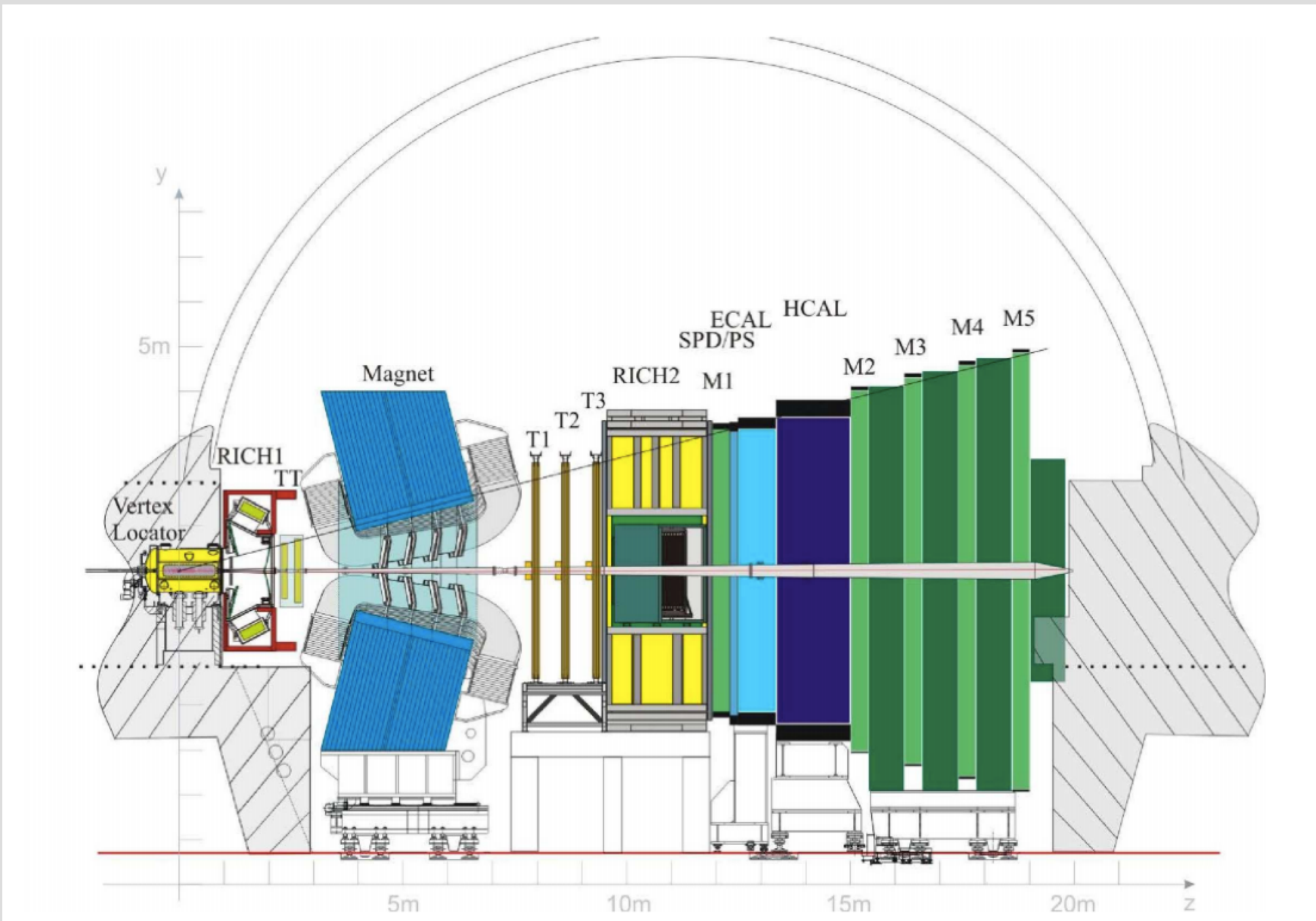
- How can we check the robustness of our results?

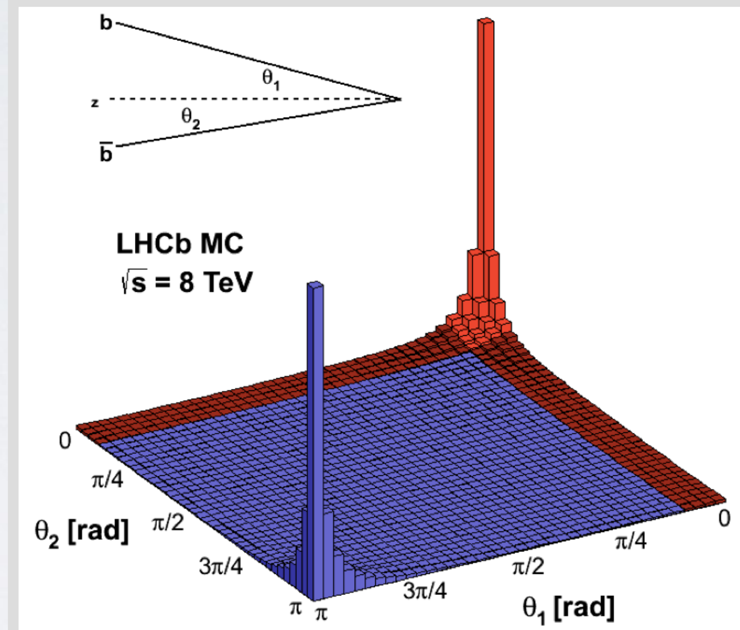
- **$R_{J\backslash\psi}$** : b → ccs process: no new physics expected
  - → Ratio corrected for efficiency should be 1
  - → Unaffected by luminosity and fragmentation fraction knowledge

$$R_{J/\psi} = \frac{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to \mu^+\mu^-))}{\mathcal{B}(B^0 \to K^{*0} J/\psi(\to e^+e^-))} = \frac{N_{J/\psi(\mu\mu)}}{N_{J/\psi(ee)}} \cdot \frac{\varepsilon_{J/\psi(ee)}}{\varepsilon_{J/\psi(\mu\mu)}}.$$

- **BR(B^0→$K^*\gamma$)** = (4.33 ± 0.15) × 10^{-5} (PDG)
  - → Dominated by SM physics
  - → Involved only electrons: most challenging channels

The LHCb detector





JINST 3 (2008) S08005

Forward geometry optimised for for b and c decays.

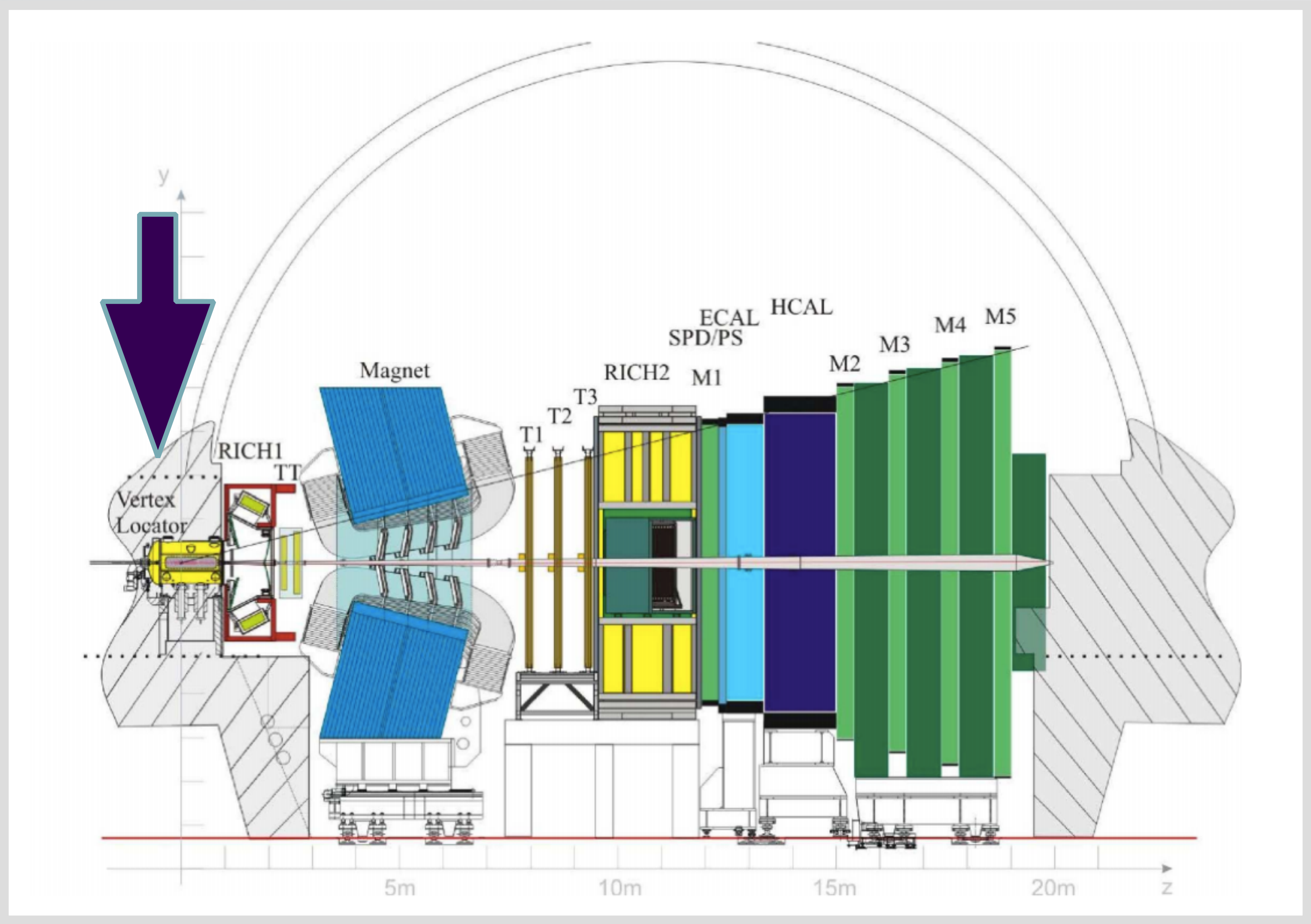
Fully instrumented in 2 < η < 5

Cleanest LHC events: <Pile-Up> ~ 2 in Run I

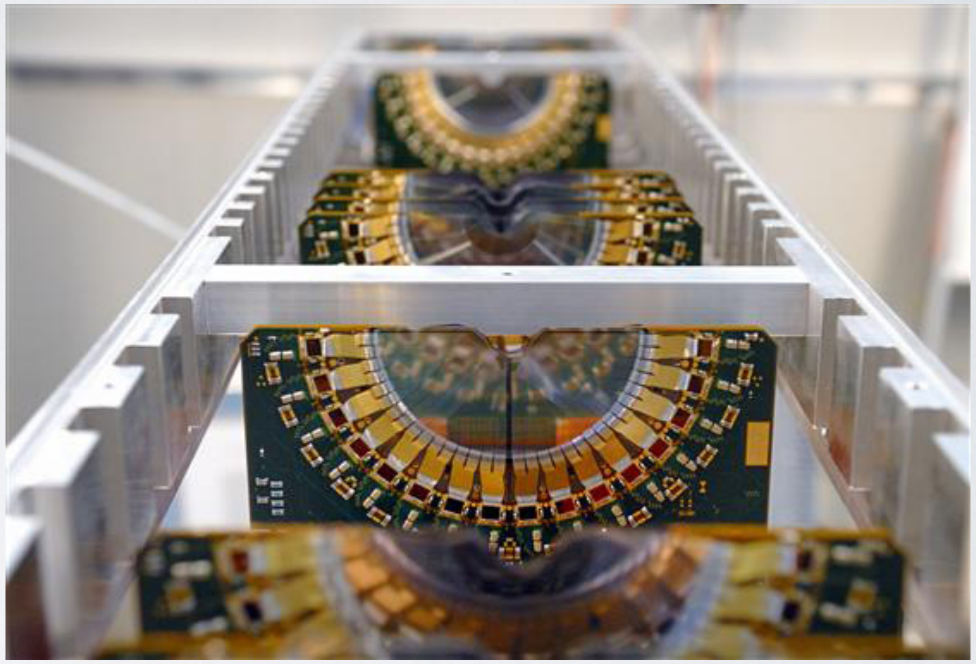
$3fb^{-1}$ collected: $1fb^{-1}$ in 2011 at TeV and $2fb^{-1}$ in 2012 at 8TeV

The LHCb detector

JINST 3 (2008) S08005

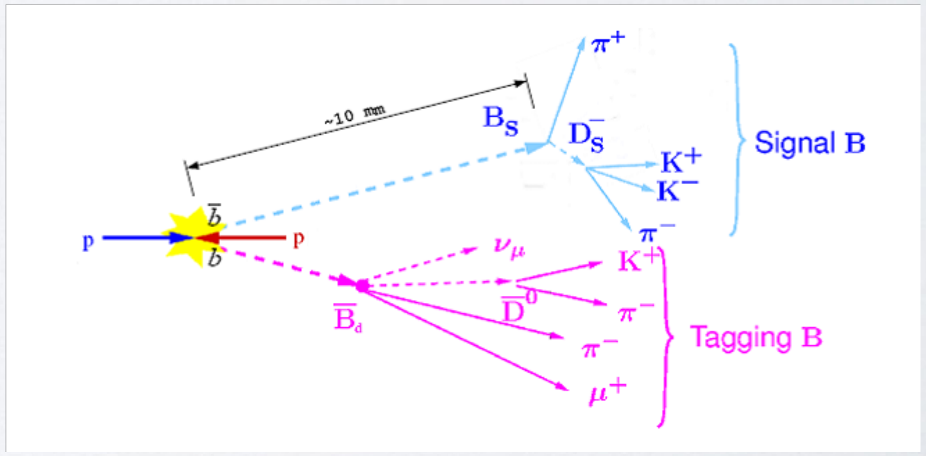


VeLo



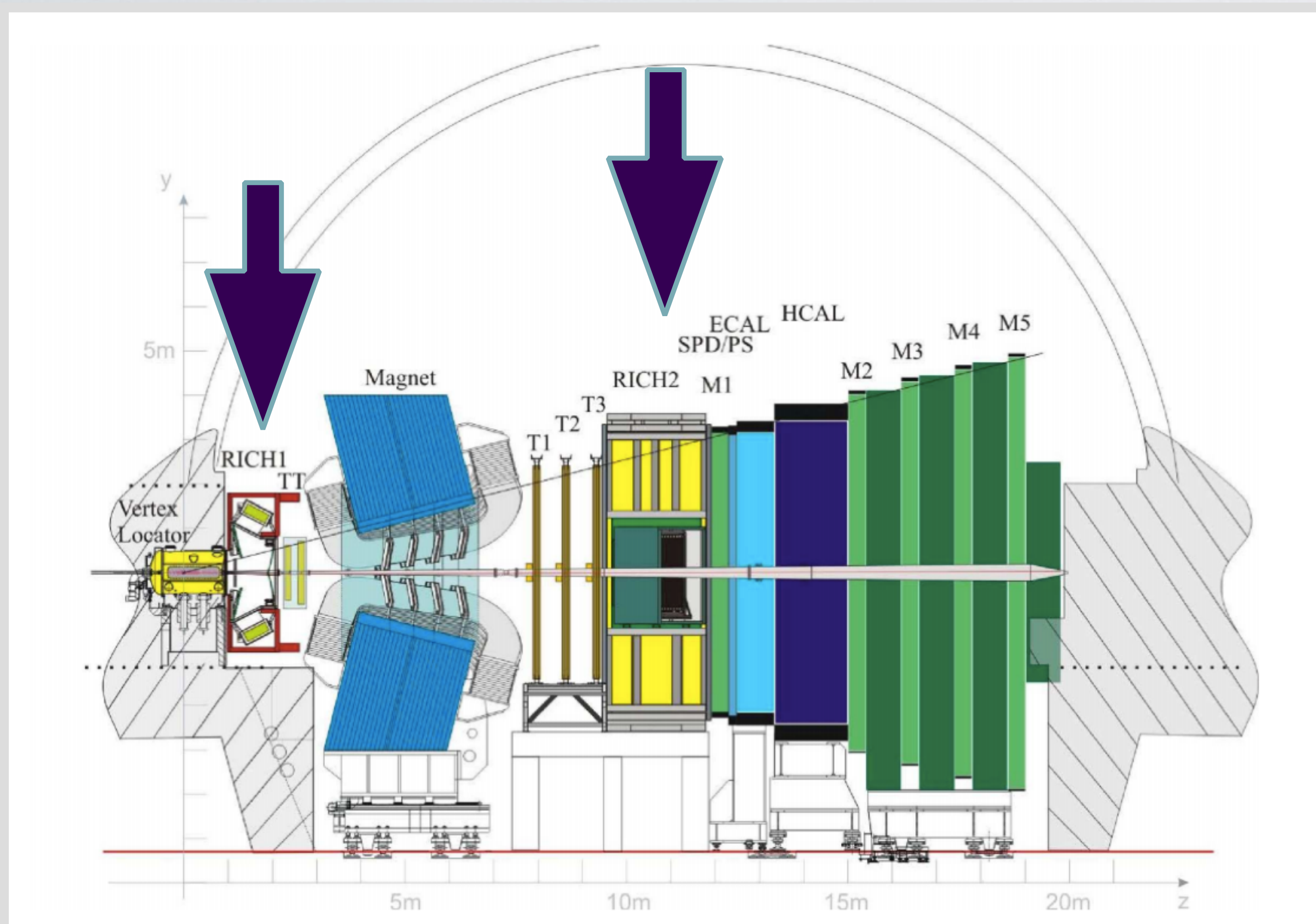
Silicon tracker → Needed for precise determination of secondary vertices

B mesons travel ~1cm into the detector. VeLo is essential to reconstruct secondary vertices of B and D hadrons.



The LHCb detector

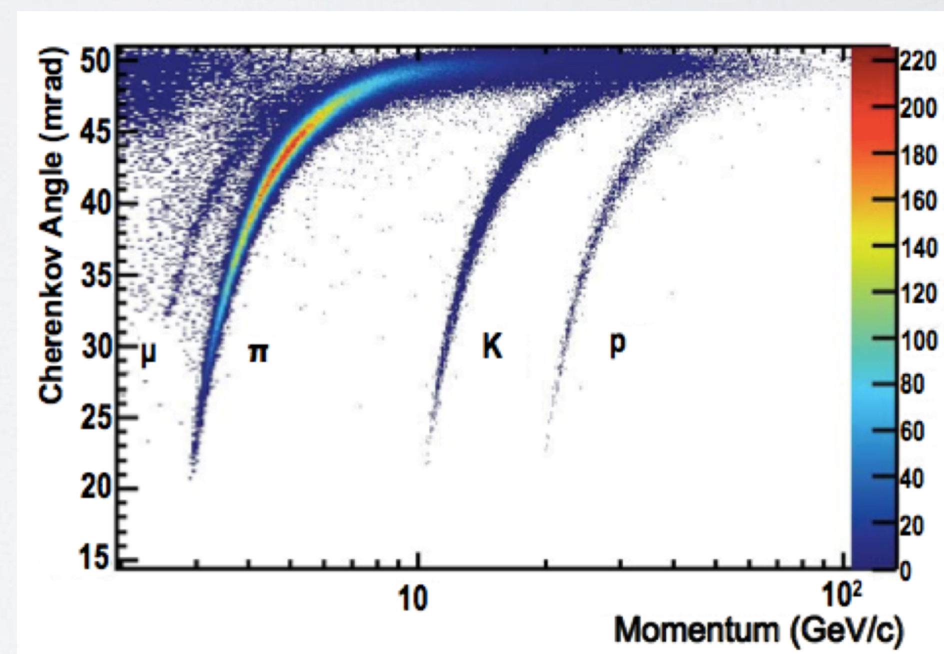
JINST 3 (2008) S08005

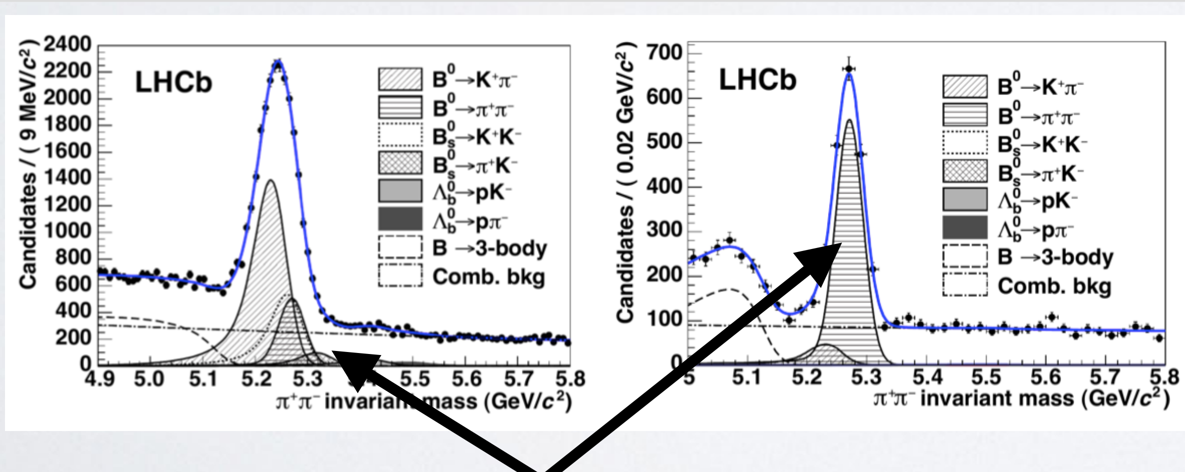


RICH

RICH I: before magnet
for 1 < p < 70 GeV/c
RICH II: before magnet
for 20 < p < 200 GeV/c

Provide particle ID

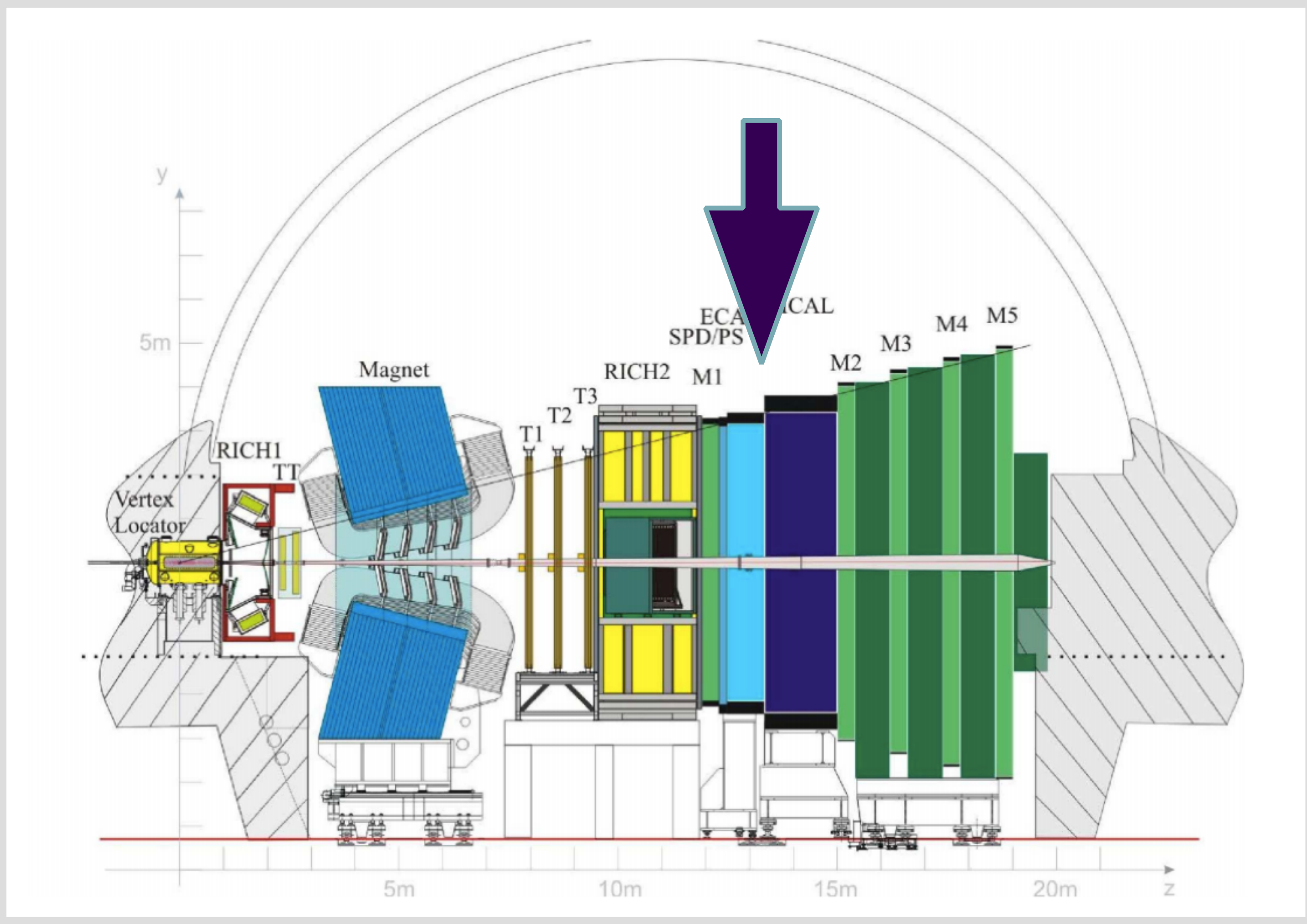




Essential to distinguish kinematically similar decays with different final states

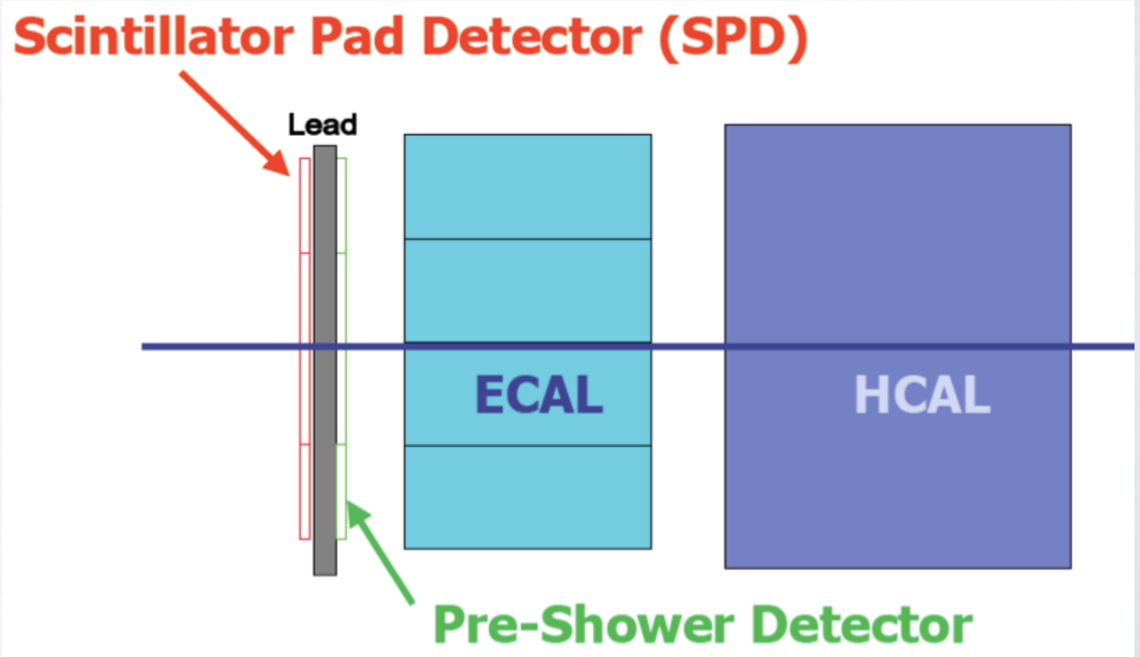
The LHCb detector

JINST 3 (2008) S08005

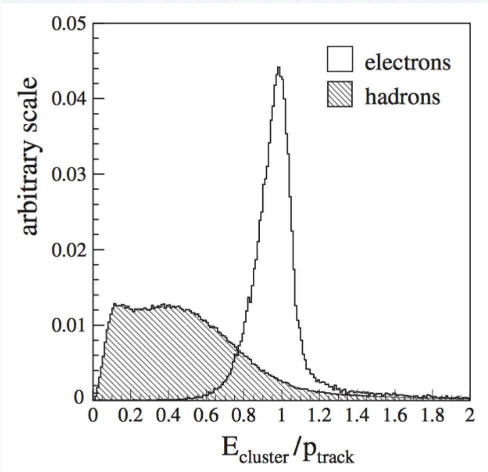


Calorimeters

PD for charged pions rejection
SPD for neutral pions rejection
ECAL fully contains electrons
HCAL for hadrons ID

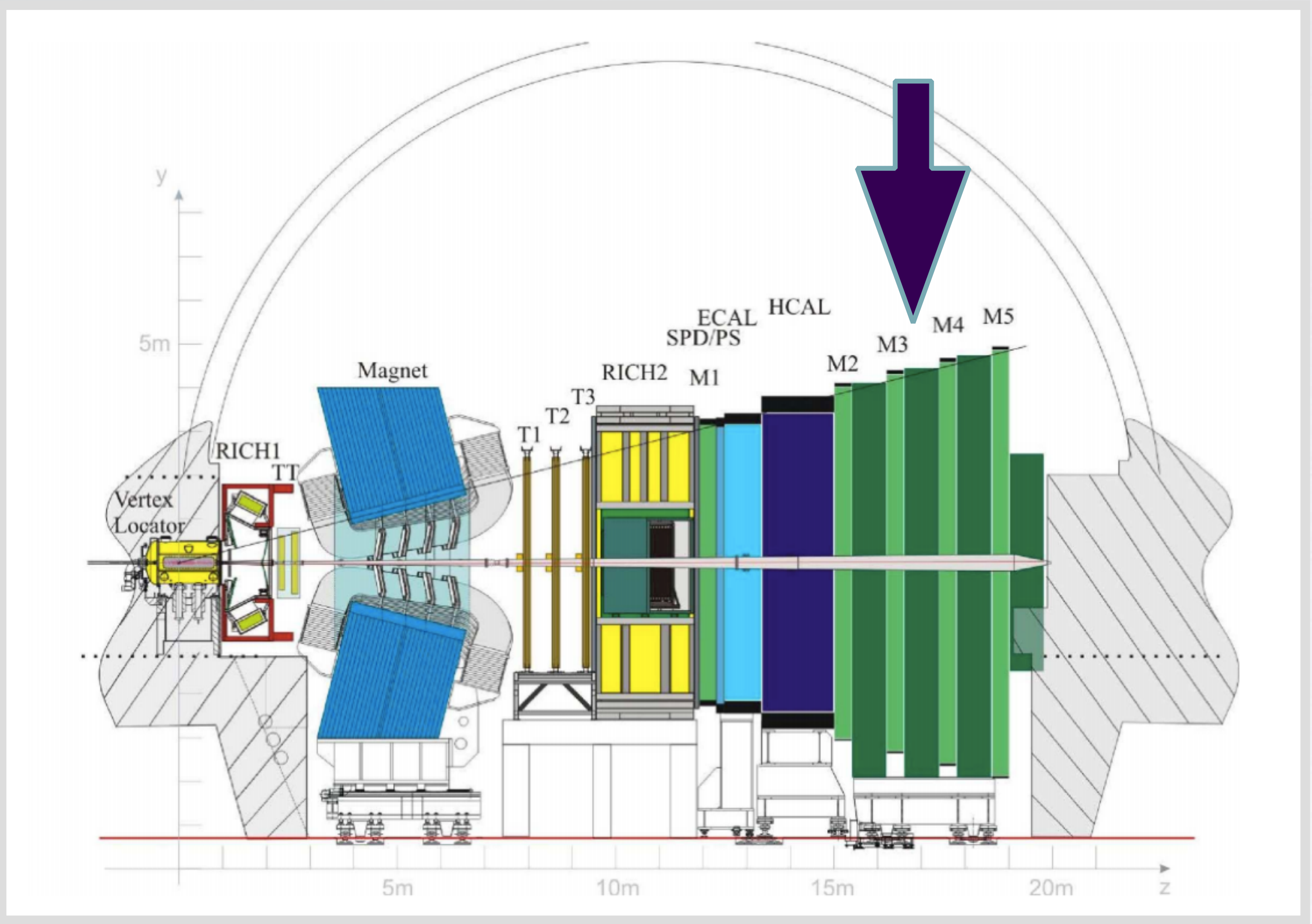


Example of e/h discrimination



The LHCb detector

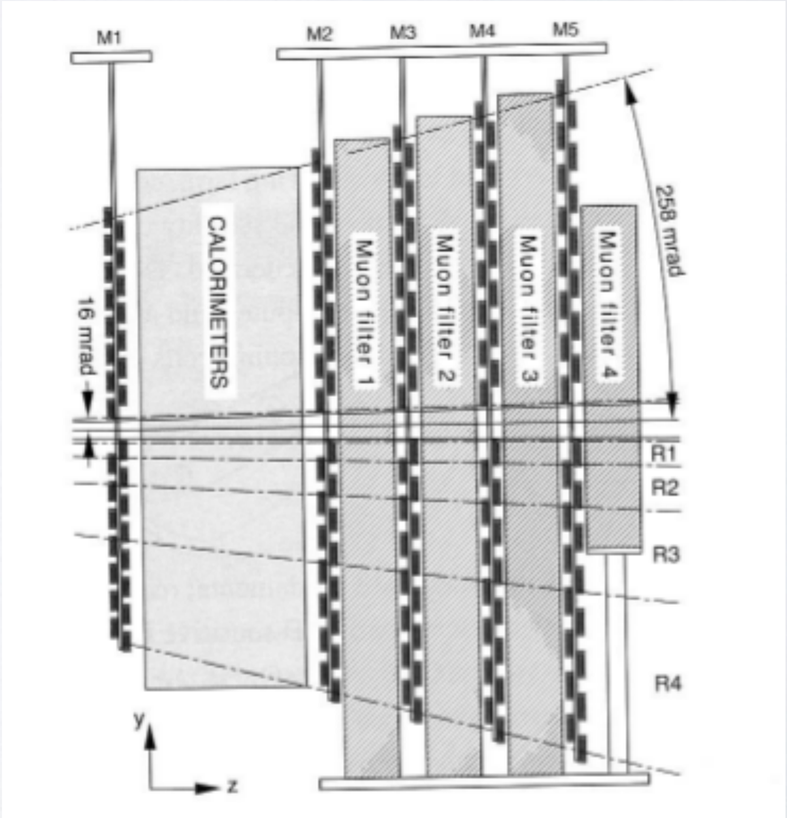
JINST 3 (2008) S08005



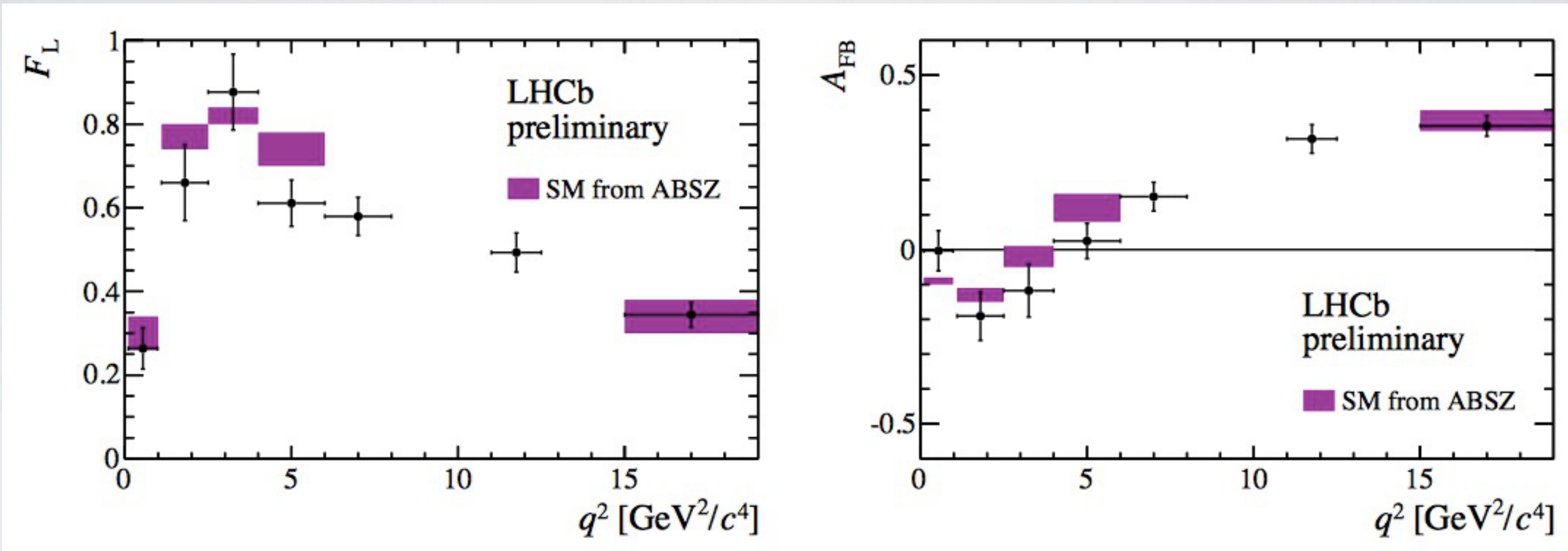
Muon detector

5 tracking station separated
by iron layers
Drift tubes in the outer region
GEM in the inner region
due to higher track density

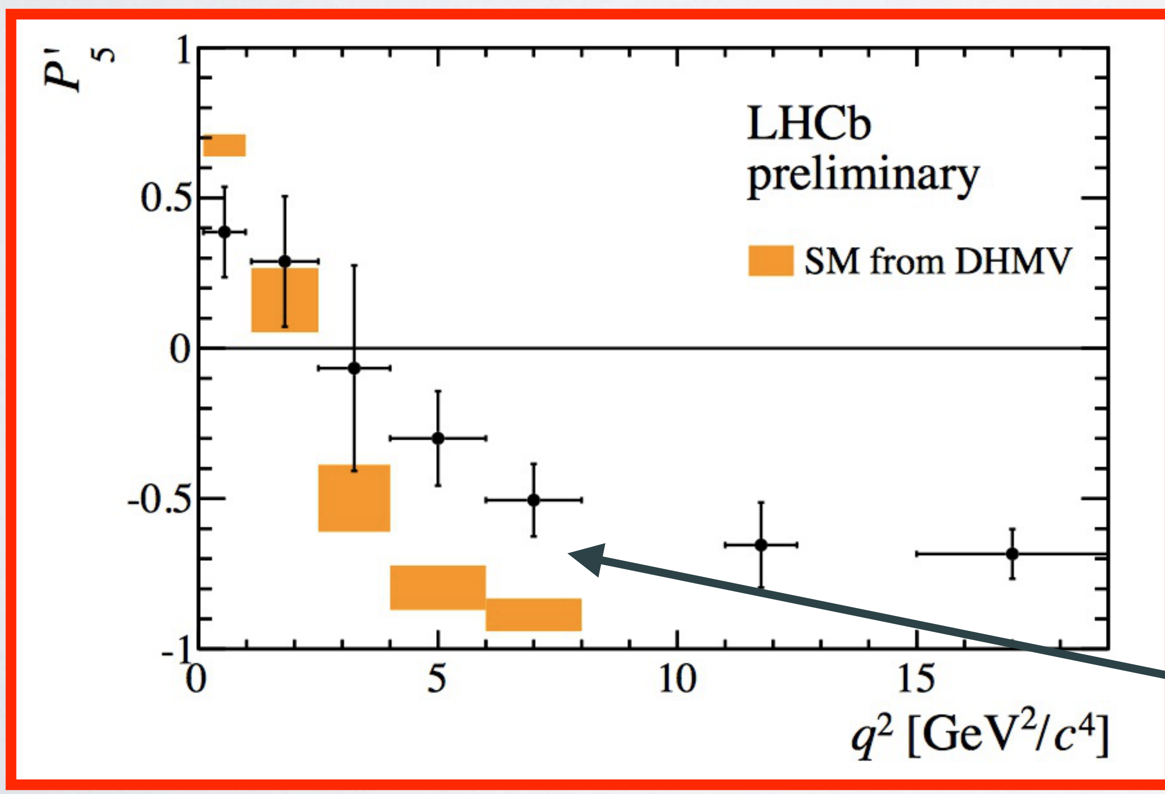
Each station has 95% efficiency.
Provides good triggering.
Only 10 GeV/c muons pass through.



$B^0 \to K^{*0}\mu\mu$ angular analysis



JHEP 08 (2013) 131, [arXiv:1304.6325]
LHCb-CONF-2015-002

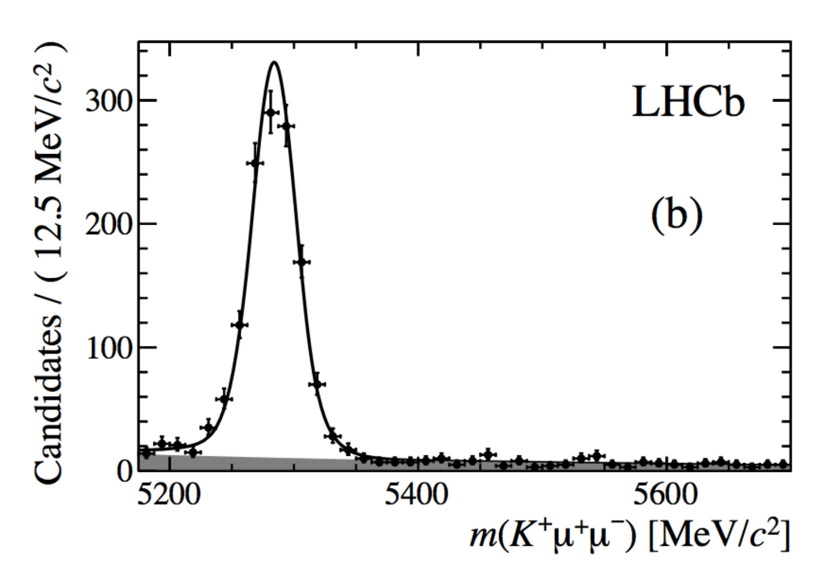


Many observables found to be in agreement with the SM predictions

BUT

Local 3.7σ deviation on P'₅ found on 2011 data and confirmed on 2012.

The R_K measurement

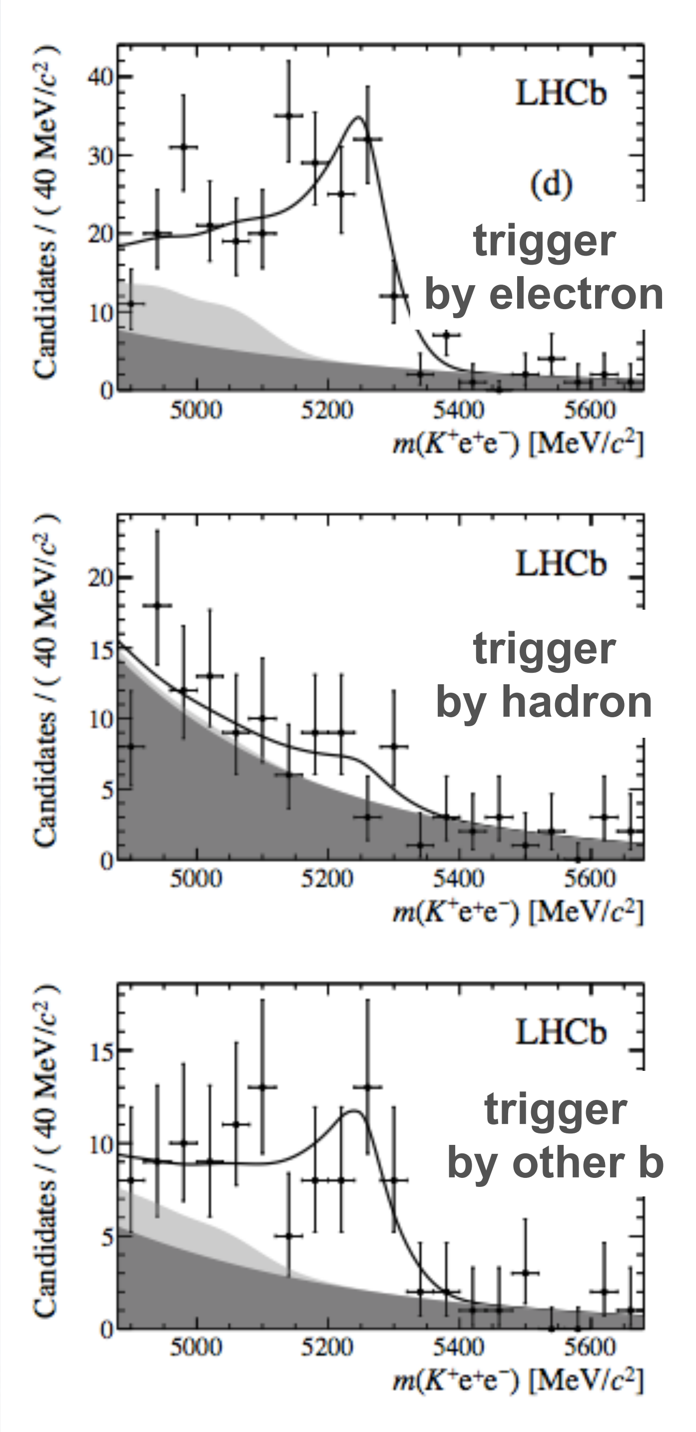


← **Kμμ** triggered by muons

1266 ± 41 evts

Kee in 3 categories →

172 + 20 + 62 evts



$$R_K = 0.745^{+0.090}_{-0.074}\,(\text{stat})\,^{+0.036}_{-0.036}\,(\text{syst}),$$

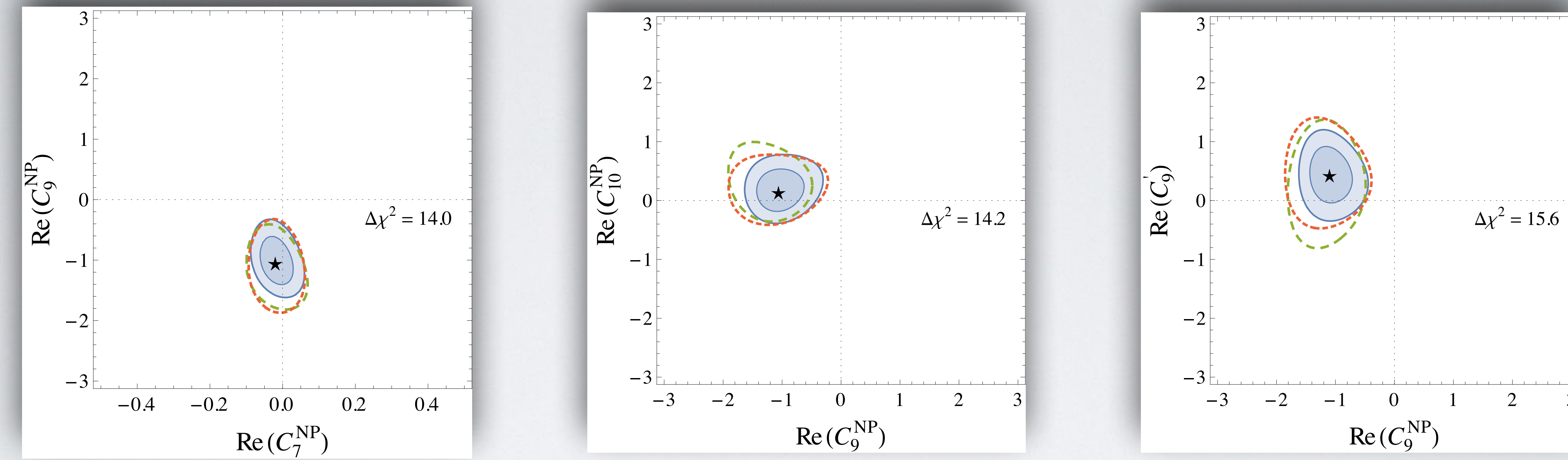
2.6σ from the SM

PhysRevLett.113.151601
arXiv:1406.6482

The *ee* BR is also reported:

$$B(B^+ \to K^+e^+e^-) = (1.56\,^{+0.19}_{-0.15}\,^{+0.06}_{-0.04}) \times 10^{-7}\,,$$

Global fits



Coefficient	Best fit	1σ	3σ	Pull_{SM}
$\mathcal{C}_9^{NP}$	-1.13	$[-1.33, -0.91]$	$[-1.72, -0.42]$	**4.6**

Presented at moriond 2015

- Global fits including information from many results combining many observables.
  [S. Descotes-Genon et al. PRD 88, 074002] [Altmannshofer et al. arxiv:1411.3161] [Beaujean et al. EPJC 74 2897]
  - A consistent picture can be built putting most results in agreement
  - Possible explanation with Z' bosons.
  - Based on assumptions
    → we need more data to be sure

A shift of C_9 by -1 is favoured with respect to the SM

Electron channels: trigger

- The trigger categories (with different mass shapes and efficiencies)
  - ✓ L0E ⇒ triggered by the electron
  - ✓ L0H ⇒ triggered by the hadron and not the electron
  - ✓ L0I ⇒ triggered by other particles in the event (and not the first two)
- Yields parameterised as a function of a common parameter:

$$N_{\ell\ell} = N_{J/\psi\,(\ell\ell)} \cdot \frac{\varepsilon^{\ell\ell}}{\varepsilon^{J/\psi\,(\ell\ell)}} \cdot R_{\ell\ell},$$

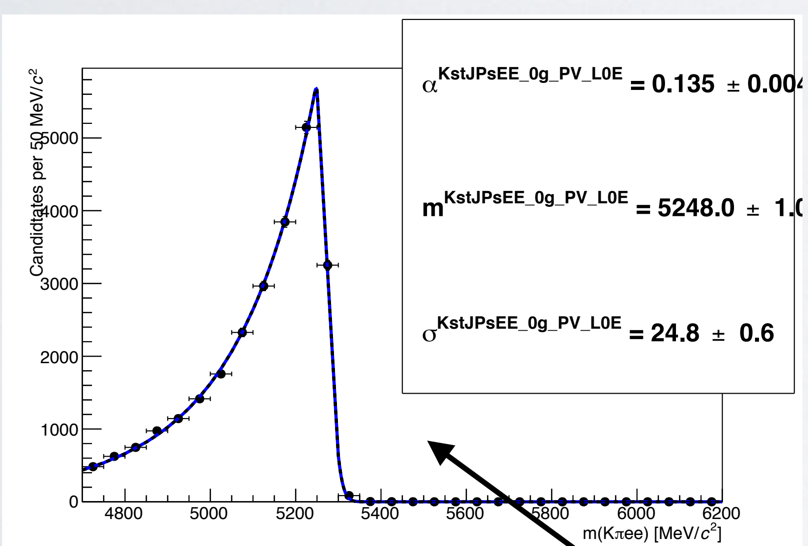
Simultaneous fit to the three trigger categories

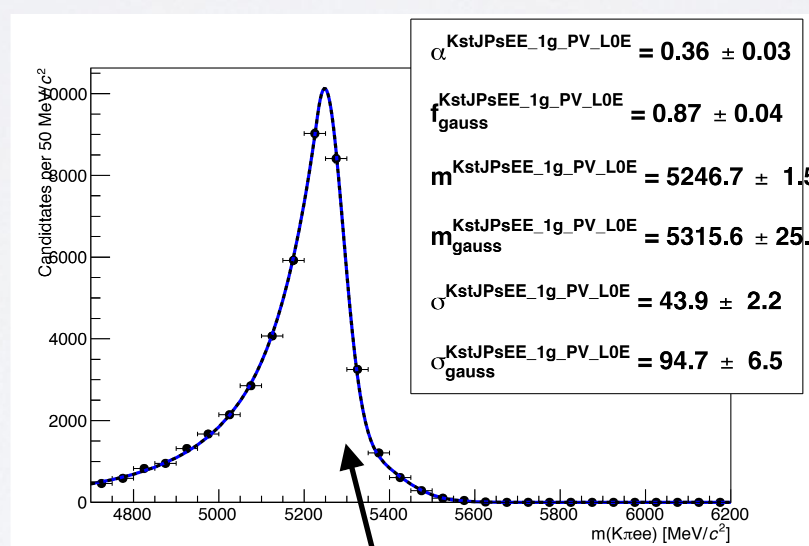
➡ Allows to get a combined result directly out of the fit
➡ More stable fit as it gathers information form 3 samples at once

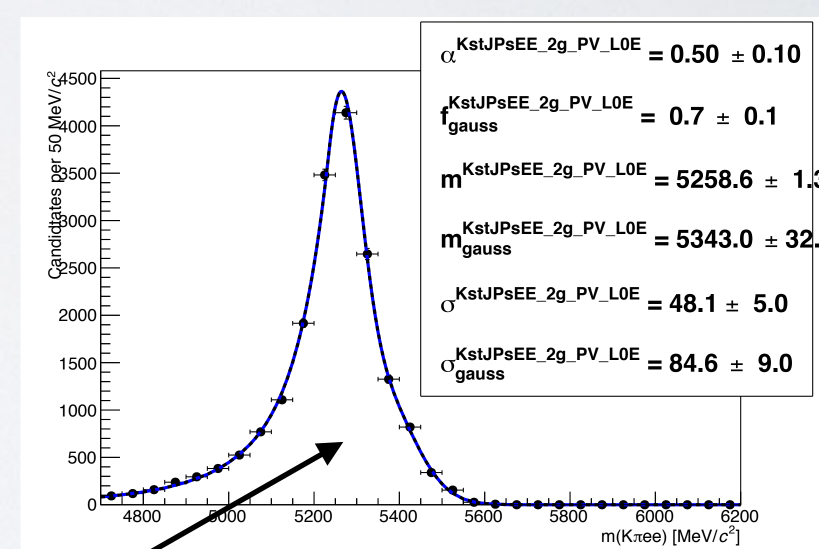
Electron channels: signal description

- Mass shapes depend on how many bremsstrahlung photons are recovered
  - ✓ Fit simulation split in brem categories
  - ✓ Using simulated fractions of 0, 1 and 2 γ
  - ✓ Build a combined PDF

$$\mathcal{P}^{\rm L0}(m|\vec{\lambda}) = f^{\rm L0}_{0\gamma}\cdot\mathcal{P}^{\rm L0}_{0\gamma}(m|\vec{\lambda}_{0\gamma}) + f^{\rm L0}_{1\gamma}\cdot\mathcal{P}^{\rm L0}_{1\gamma}(m|\vec{\lambda}_{1\gamma}) + (1 - f^{\rm L0}_{0\gamma} - f^{\rm L0}_{1\gamma})\cdot\mathcal{P}^{\rm L0}_{2\gamma}(m|\vec{\lambda}_{2\gamma}),$$





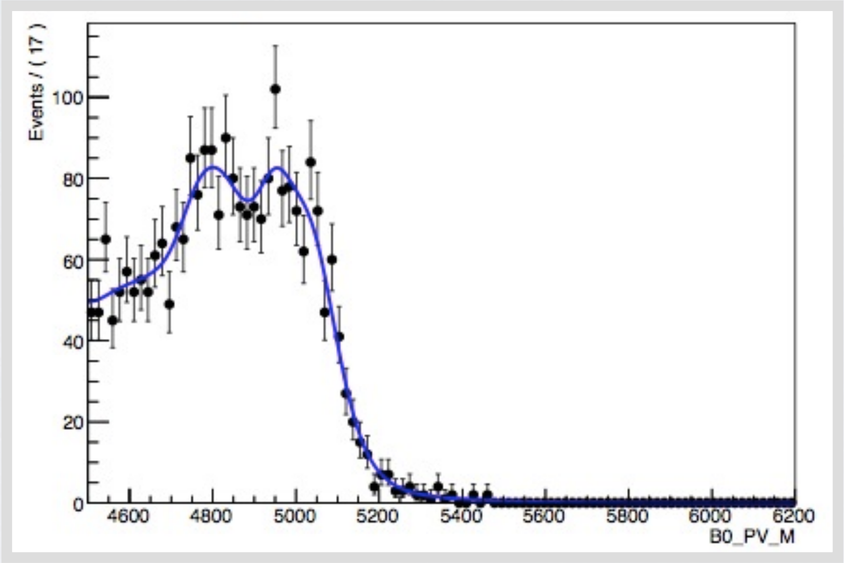


0γ: simple CB 1γ: CB+gauss 2γ: CB+gauss

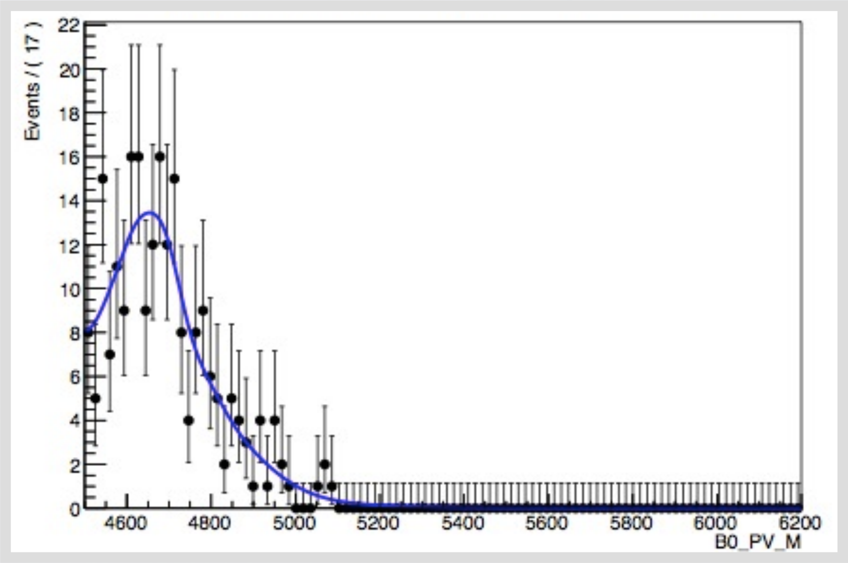
Electron channels: background description

- Combinatorial: exponential
- Background from higher hadronic and leptonic resonances
- Leak of the J/ψ and $\psi(2S)$ tails into the rare intervals

$B \to (Y \to K\pi X)(J/\psi \to ee)$



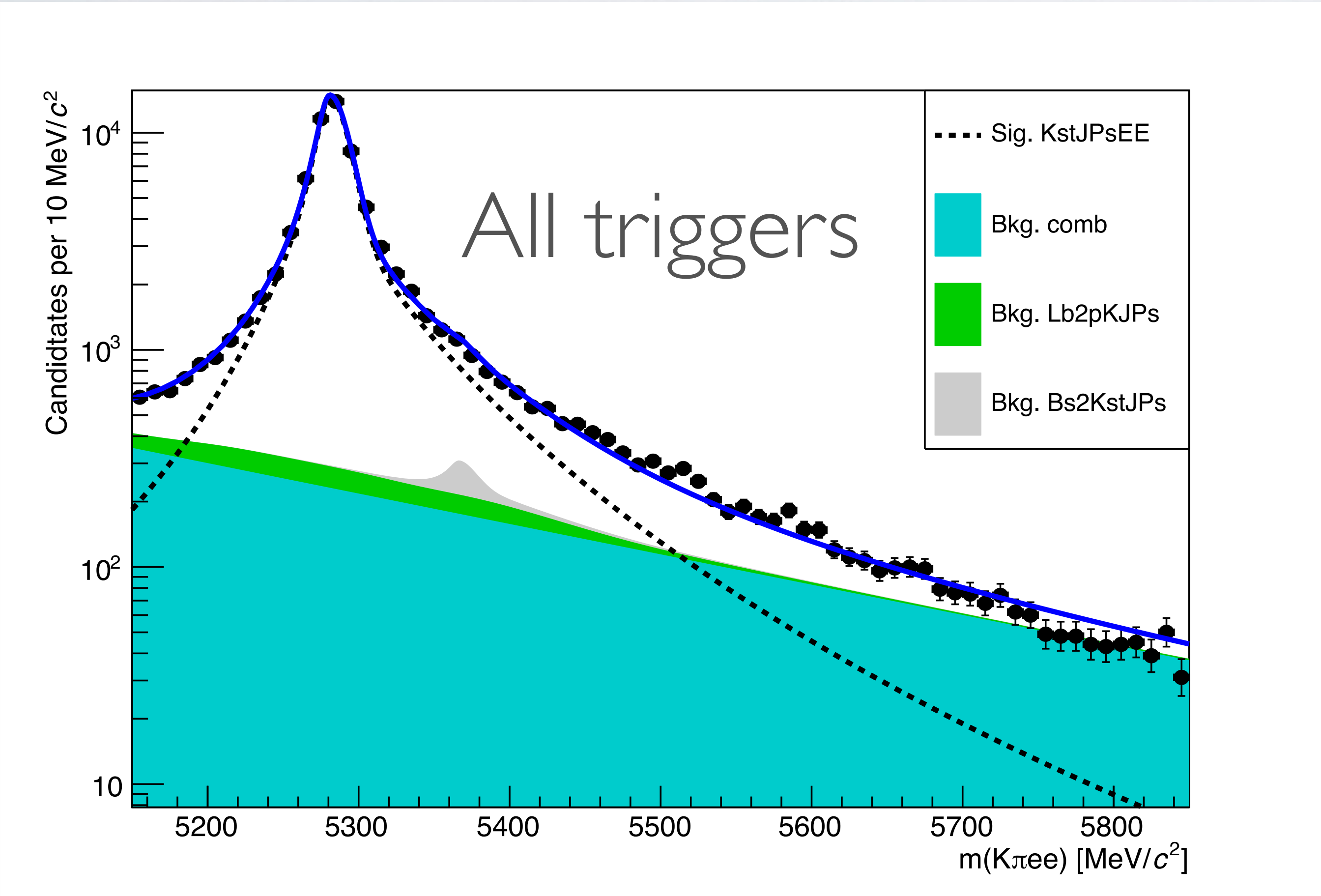
$B \to (K^* \to K\pi)(Y\text{->}J/\psi \to ee)$

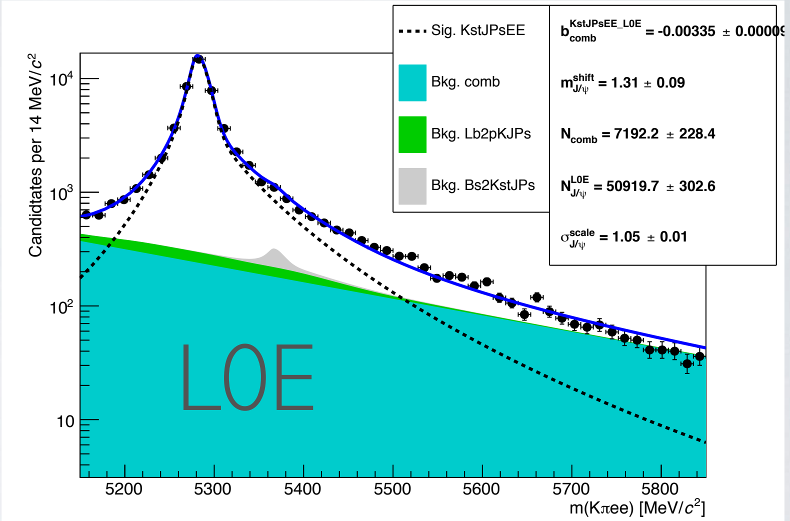


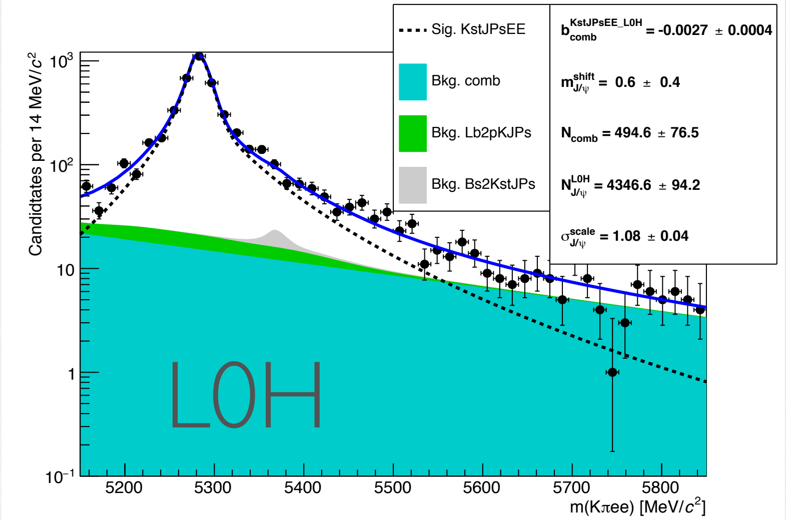
Modelled with simulated distributions

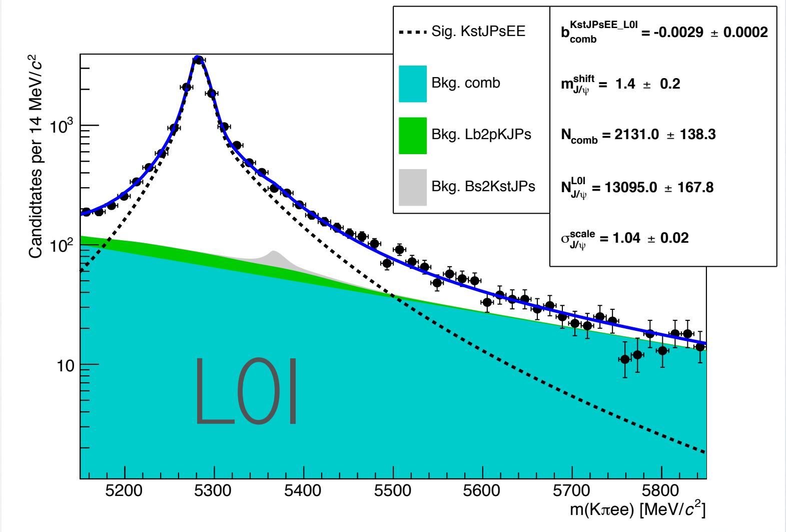
Mass fits: $B^0 \to K^{*0}(J/\psi \to ee)$

Yields obtained from a J/ψ mass constrained fit.









For simplicity from now on I won't show the trigger categories separately

No part-reco background in this case.

Theoretical framework:
the effective Hamiltonian

- M(b) << M(W, Z, top) ⇒ an **effective theory** can be built
- Separate aptitude calculations into 2 parts:
    - "**long-distance**": below *b* mass scale (known SM physics)
    - "**short-distance**": above *b* mass scale (Z,W and top + all new physics)
    - An example of effective theory is the Fermi-theory of weak interactions

Effective theory

arXiv:1501.03309

Phys.Lett. B400 (1997) 206–219

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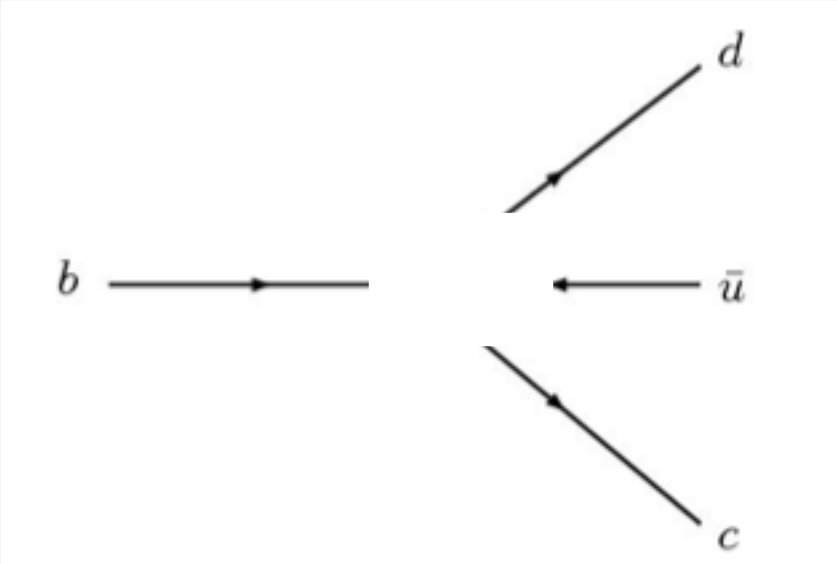

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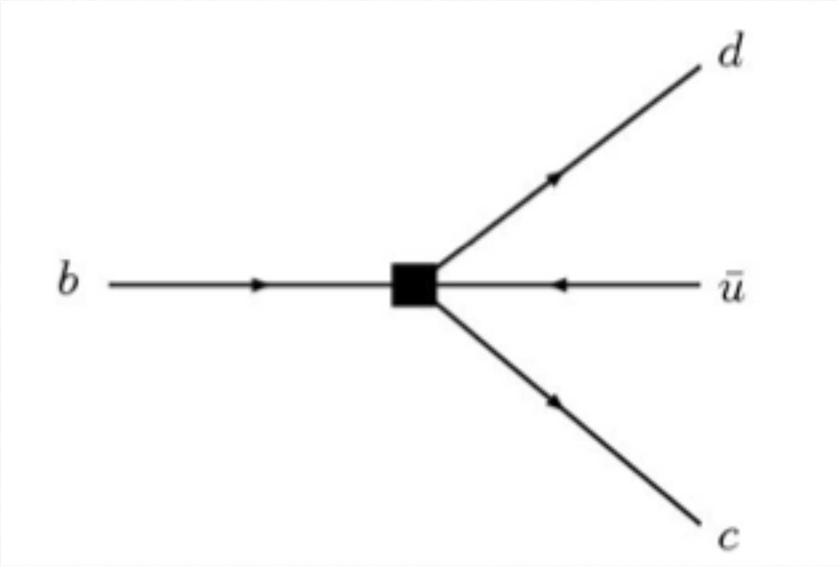

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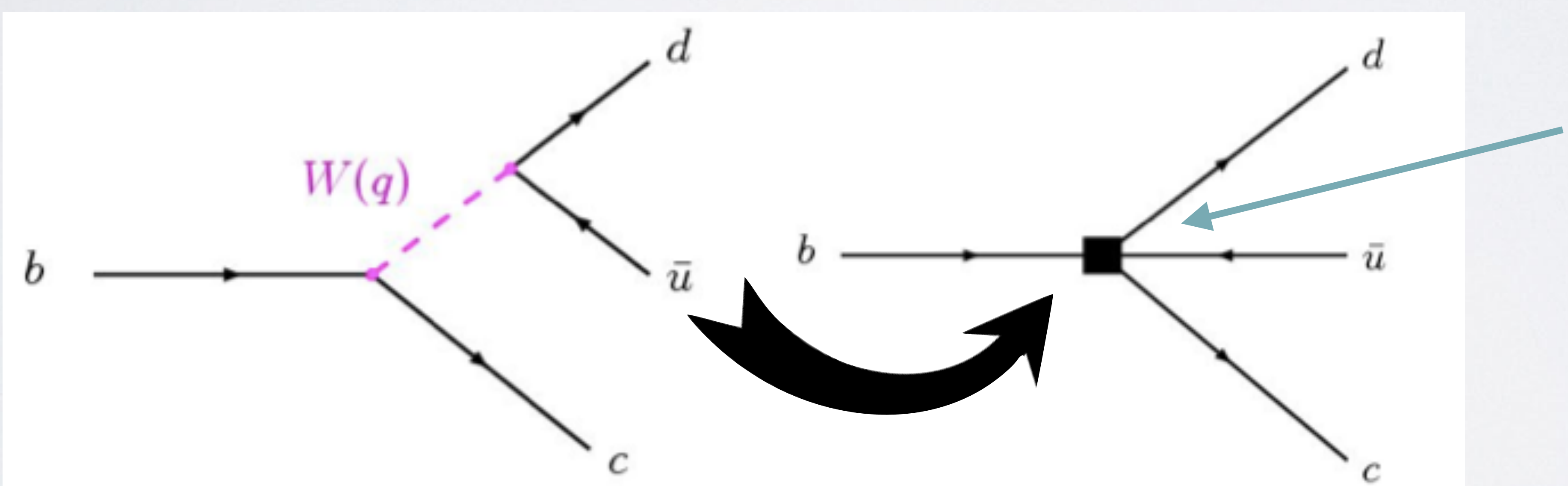

Short distance contribution associated with G_F

Full theory

Effective theory

arXiv:1501.03309

Phys.Lett. B400 (1997) 206–219

Theoretical framework:
the effective Hamiltonian

Effective Hamiltonian for *b*→*d* and *b*→*s* transitions

$$\mathcal{H}_{eff} = \frac{-4G_F}{\sqrt{2}} \left[\lambda_q^t \sum C_i(\mu)\mathcal{O}_i(\mu) + \lambda_q^u \sum C_i(\mu)(\mathcal{O}_i(\mu) - \mathcal{O}_i^u(\mu)) \right]$$

Phys.Lett. B400 (1997) 206–219

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physics encoded in
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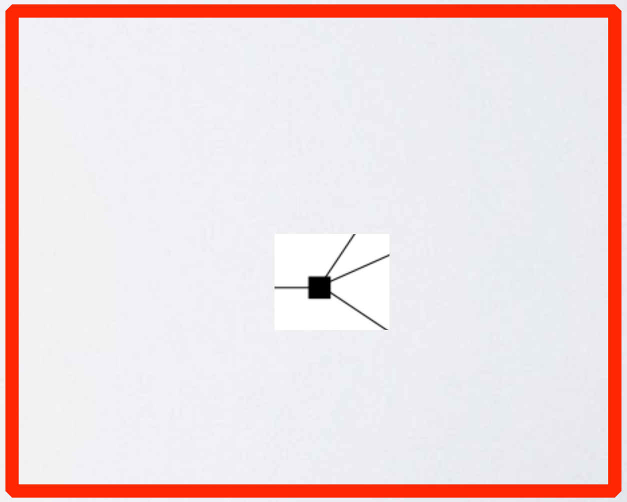

Phys.Lett. B400 (1997) 206–219

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Long-distance
described by a finite
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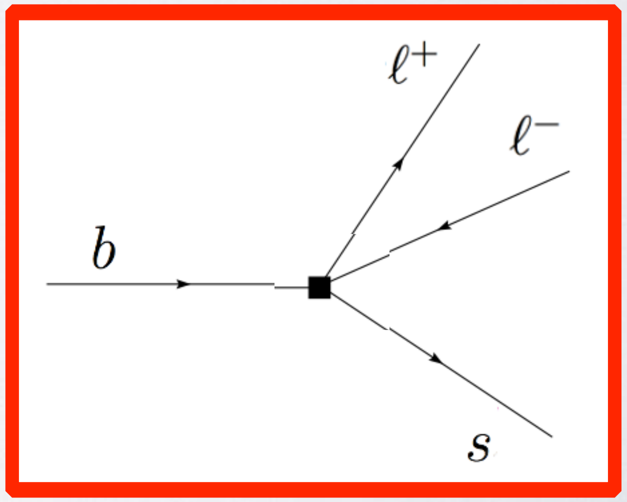

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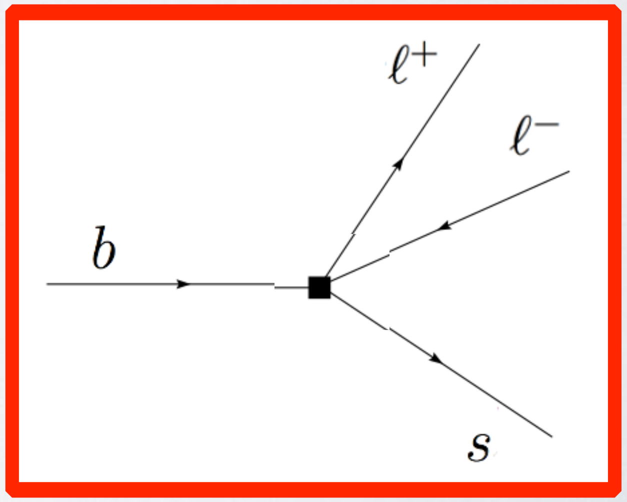
CKM factors: $\lambda_q^{q'} = V_{q'b}V_{q'q}^*$

For $b \rightarrow s$ transitions $V_{us} << V_{ts}$

⇒ the second term can be neglected



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Left-handed and right-handed

$$C_i \mathcal{O}_i + C_i' \mathcal{O}_i'$$

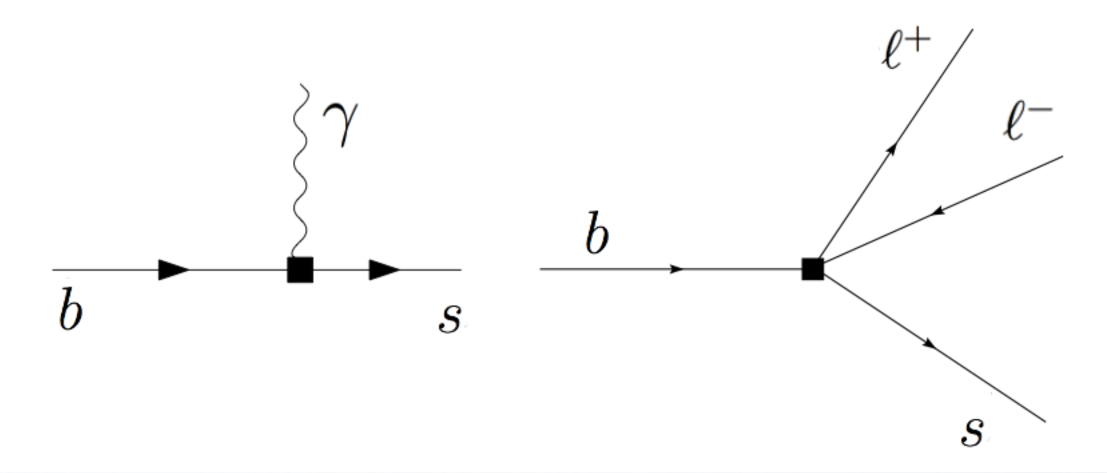
In the SM: C' ~ m_s/m_b C

Contributions to $b \rightarrow s \ell^+ \ell^-$:

✓ O_7 : radiative penguin

✓ $O_{9,10}$: semileptonic decays

(Z penguin and W-box)



Theoretical framework:
the effective Hamiltonian

Effective Hamiltonian for $b \to d$ and $b \to s$ transitions

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physics encoded in the Wilson Coefficients

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$$C_7^{SM} = -0.3, \quad C_9^{SM} = 4.2, \quad C_{10}^{SM} = -4.2.$$

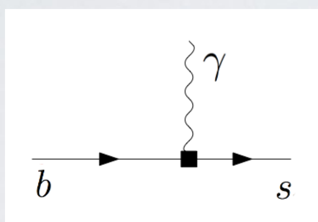
$$C_i = C_i^{NP} + C_i^{SM}$$

Phenomenology of $b \to s\ell^+\ell^-$ decays

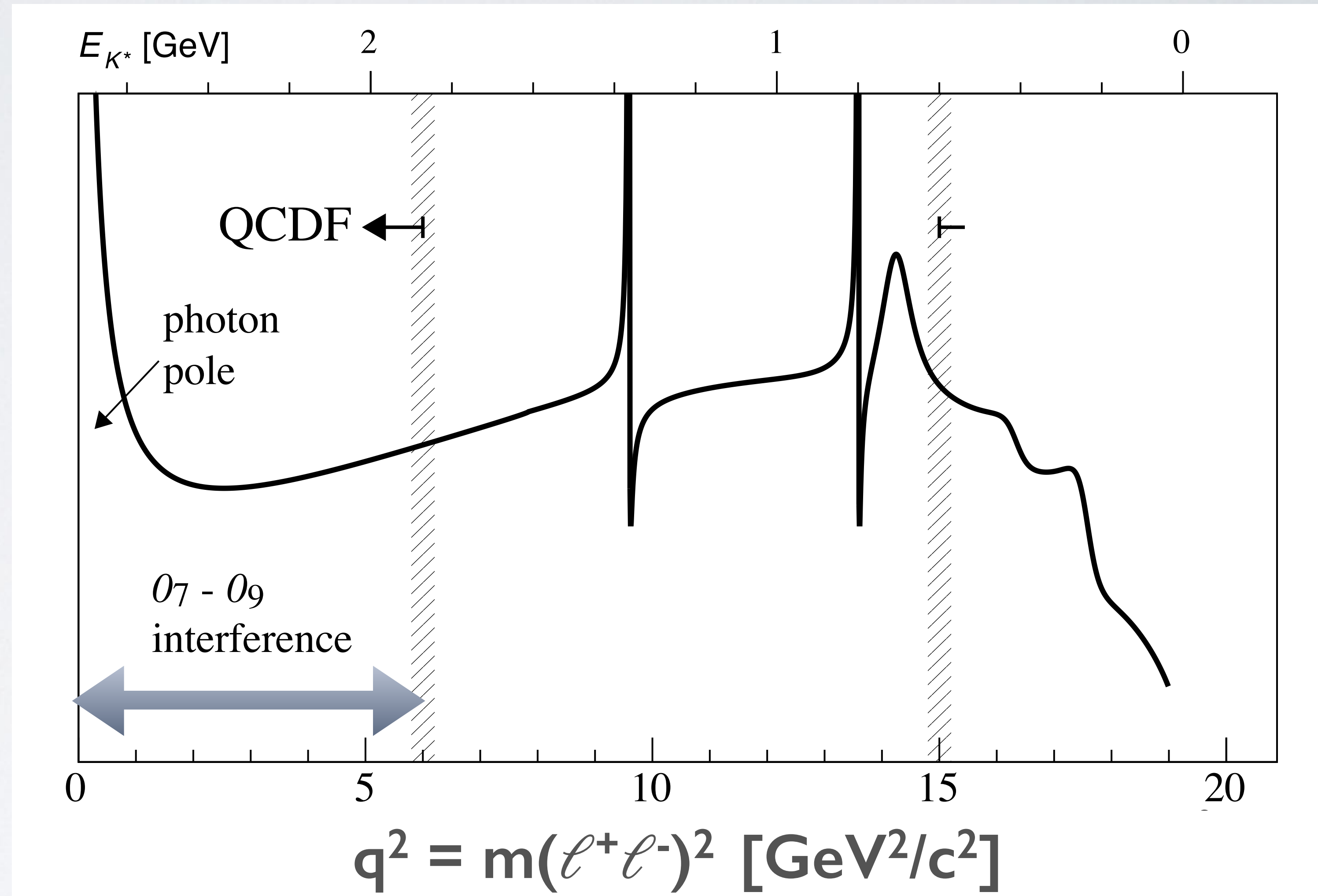
Low q^2

region of large hadron recoil

- photon pole → linked to C_7



- OPE in $1/E_h$ applies (SCET)
- up to open-charm threshold $2m_c \sim 7 GeV^2/c^4$
- Interval 1-6 GeV^2/c^4 cleanest
  - ✓ Far from photon pole
  - ✓ Far from charm threshold



arXiv:1501.03309

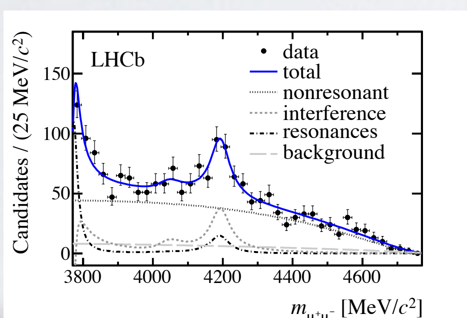
$q^2 = 0$	$E_{K^{*0}} >> \Lambda_{QCD}$	$q^2 \sim m^2_{J/\psi,\psi(2S)}$	$E_{K^{*0}} \sim \Lambda_{QCD}$	$q^2 = (m_B - m_K^{*0})^2$
max. recoil	large recoil (SCET)	$c\bar{c}$ resonances	low recoil (HQET)	zero recoil

Phenomenology of $b \to s\ell^+\ell^-$ decays

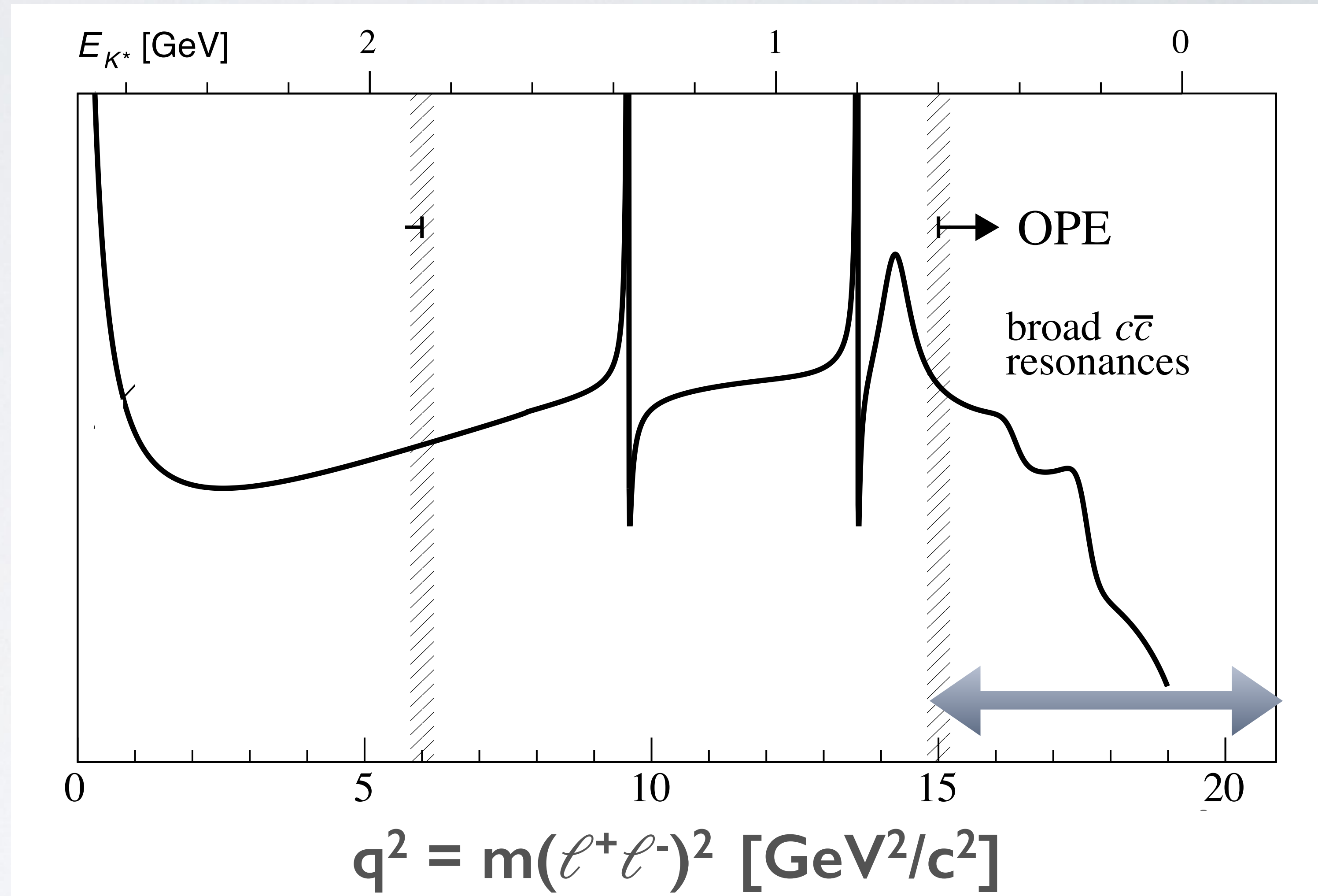
High q^2

region of low hadron recoil

- can use limit $m_b \to \infty$
- OPE in $1/m_b$ applies (HQET)
- potential contribution from charm resonances



	Unconstrained	$\psi(4160)$
$\mathcal{B}[\times 10^{-9}]$	$3.9^{+0.7}_{-0.6}$	$3.5^{+0.9}_{-0.8}$
Mass $[\mathrm{MeV}/c^2]$	4191^{+9}_{-8}	4190 ± 5
Width $[\mathrm{MeV}/c^2]$	65^{+22}_{-16}	66 ± 12



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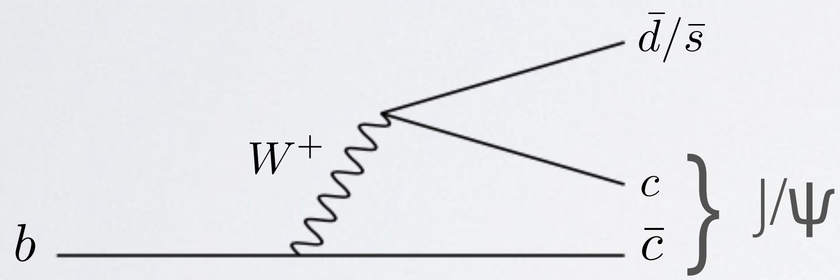
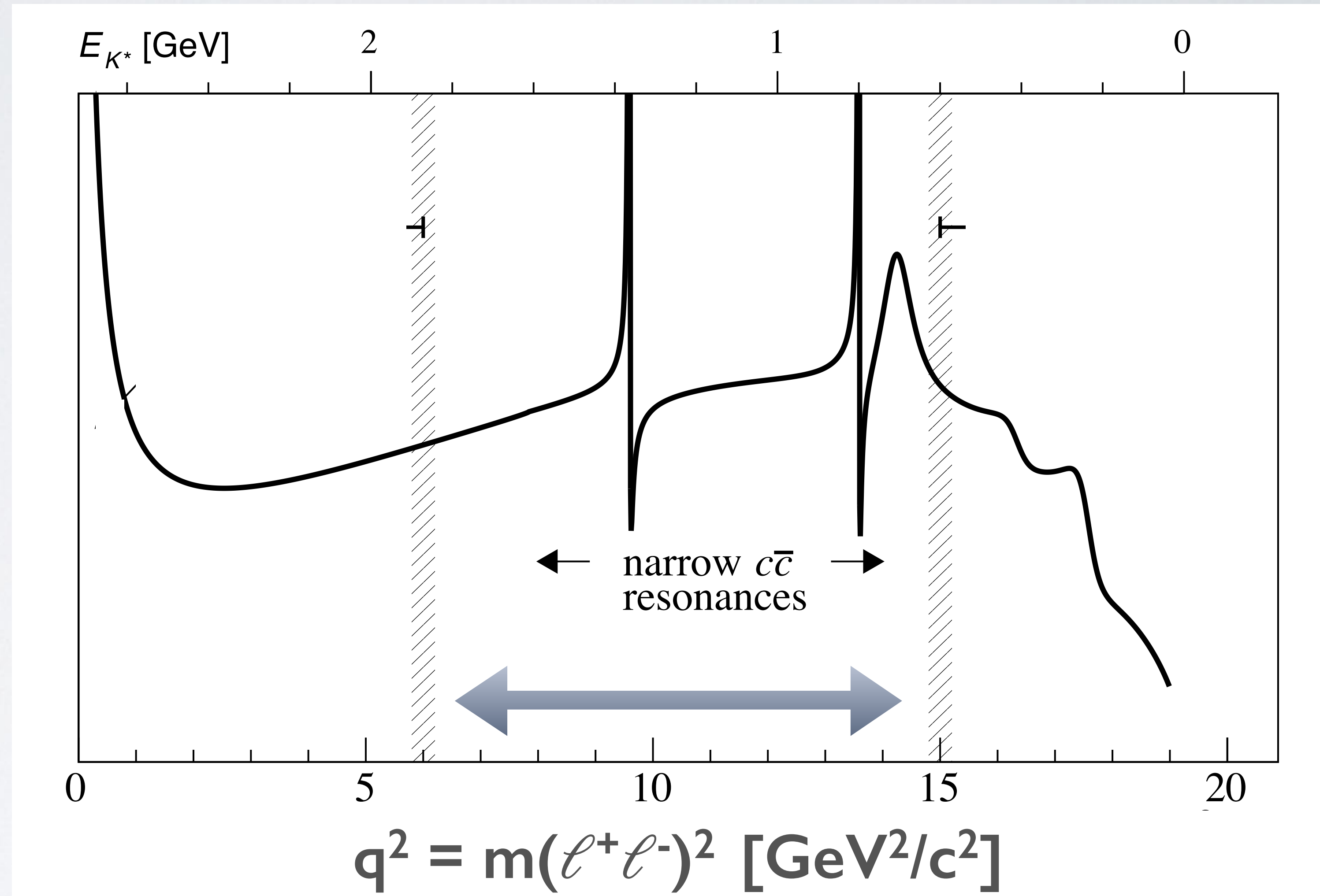
Phenomenology of $b \to s\ell^+\ell^-$ decays

Central q^2

- Dominated by J/ψ and ψ(2S)
- Charm resonances through tree level b→scc transitions
- No predictions possible
- Vetoed experimentally





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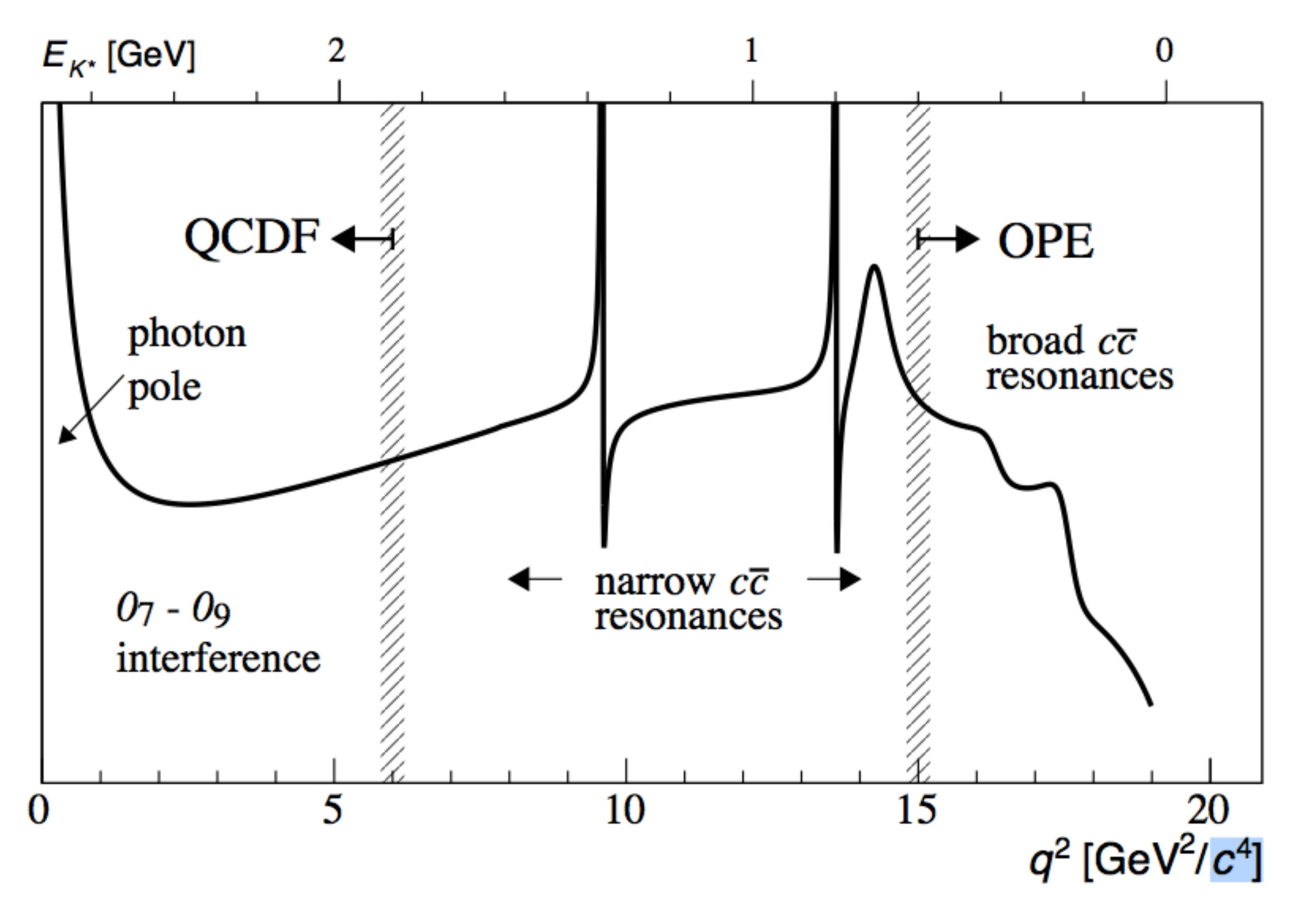
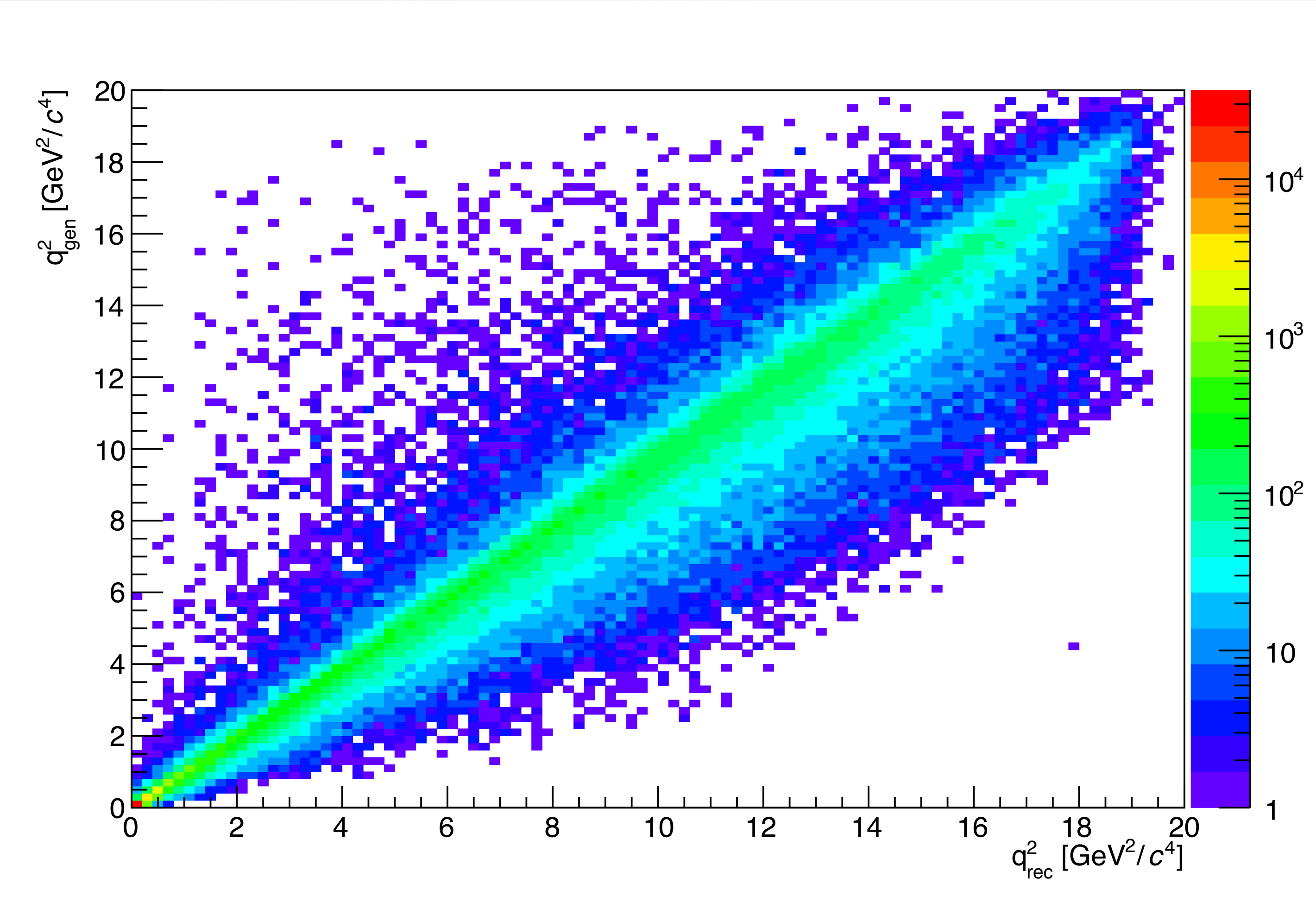
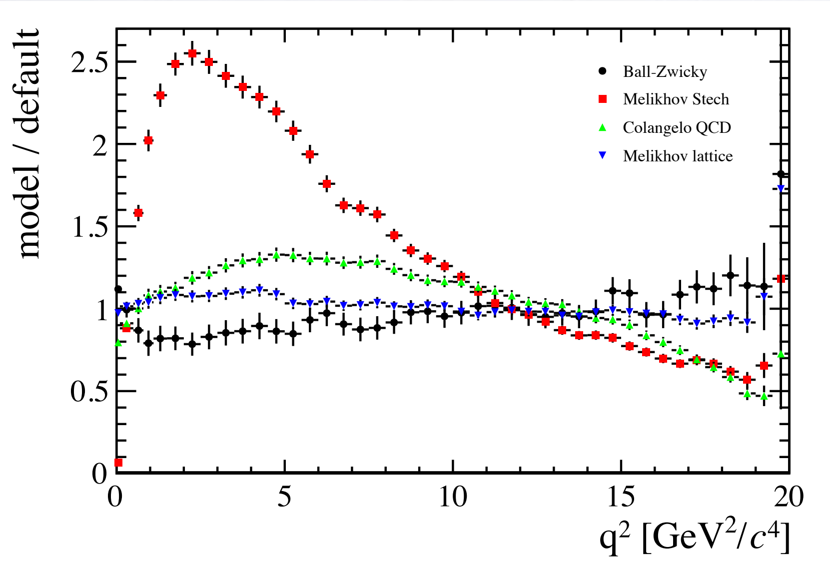
q^2 spectrum DNA



Blake, Gershon & Hiller: arXiv:1501.03309v1

Bin migration

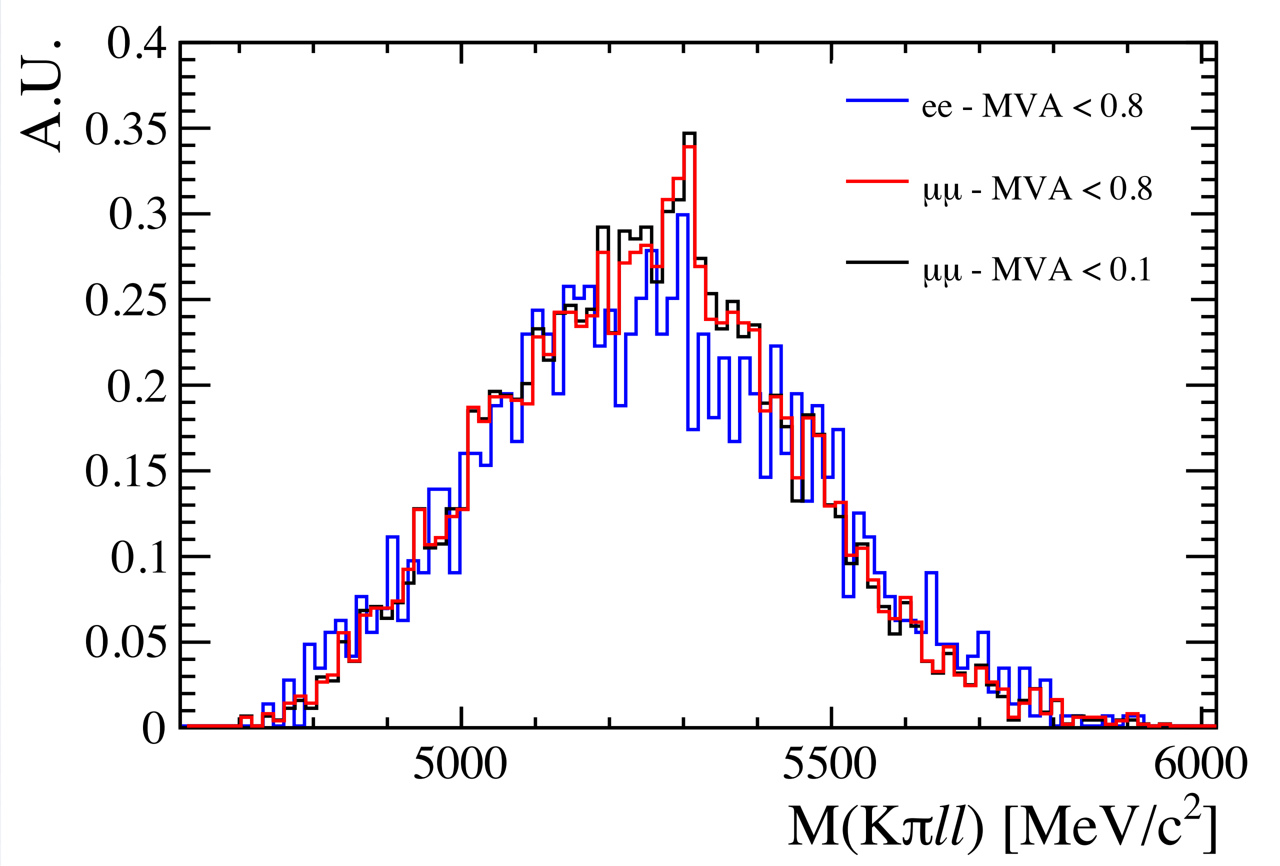




- Events generated in a q^2 can be reconstructed in an other.
- E.g. Due to bremsstrahlung
- Can cause bias is the migration of events is asymmetric
- We generate events with different models to verify how much we are sensitive to this

Combinatorial background for high q^2

In the high q^2 region - above $\psi(2S)$ - due to threshold effect the combinatorial is not exponential



By inverting the MVA cut one selects only combinatorial background!

Wilson coefficients

The effective theory matched with the full SM calculation at the EW scale (μ_W)

$$C_7^{SM} = -0.3, \quad C_9^{SM} = 4.2, \quad C_{10}^{SM} = -4.2.$$

Renormalization equations allow to evolve to different scales.

Any particle above the *b* mass, including Z, W and t, affects at least one coefficient.

New physics enters into Wilson coefficients as additive factors.

$$C_i = C_i^{NP} + C_i^{SM}$$

hep-ph/9806471.

Operators

Separating left-handed and right-handed components:

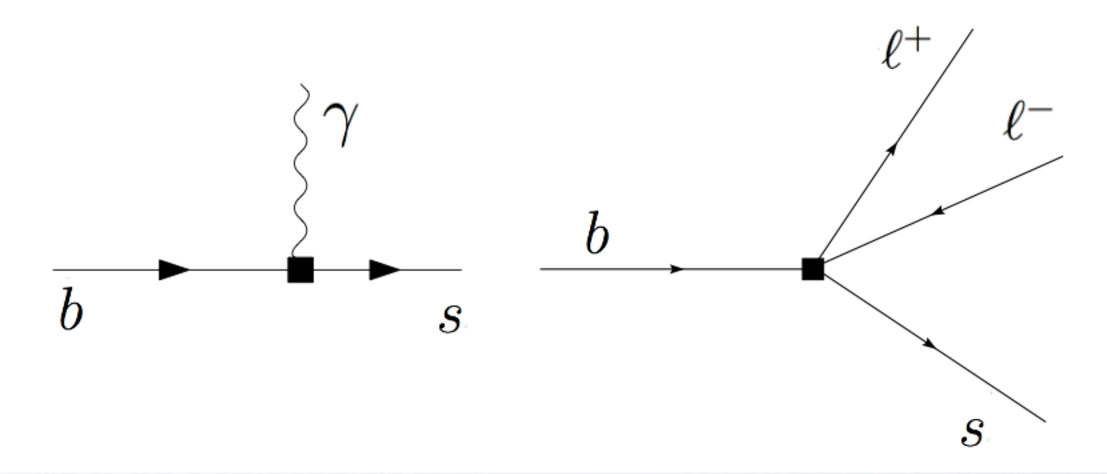
$$\mathcal{H}_{eff} = \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha_e}{4\pi} \sum_{i=1}^{10} [C_i \mathcal{O}_i + C_i' \mathcal{O}_i']$$

Suppressed
C' ~ m_s/m_b C

A complete basis is given by:

- ✓ $O_{1,2}$: tree level
- ✓ $O_{3\text{-}6}$ and O_8 : mediated by gluons
- ✓ O_7 : radiative penguin
- ✓ $O_{9,10}$: semileptonic decays

 (Z penguin and W-box)



arXiv:1501.03309

$$\mathcal{O}_7 = \frac{m_b}{e}(\bar{s}\sigma^{\mu\nu}P_R b)F_{\mu\nu}$$
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Right-handed operators can be obtained swapping P_R and P_L

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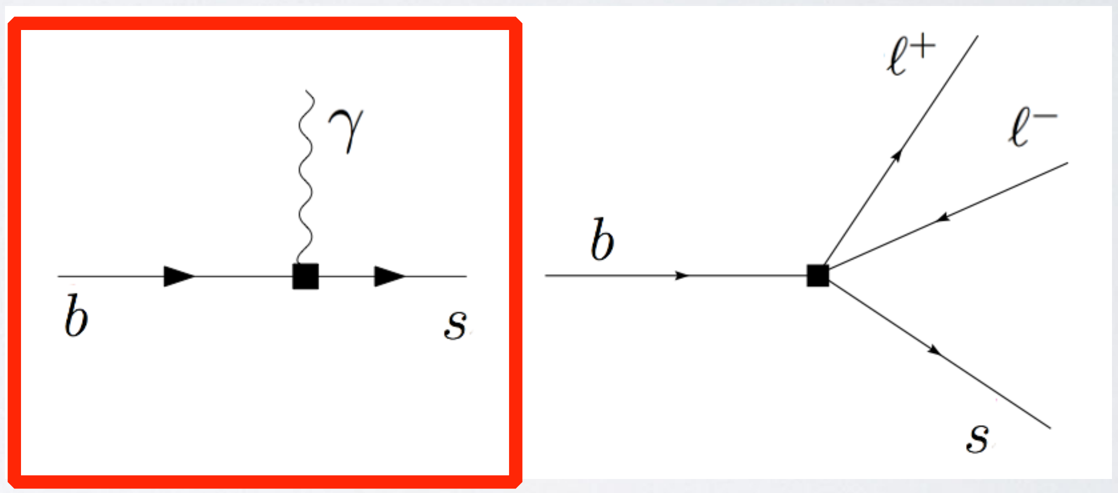

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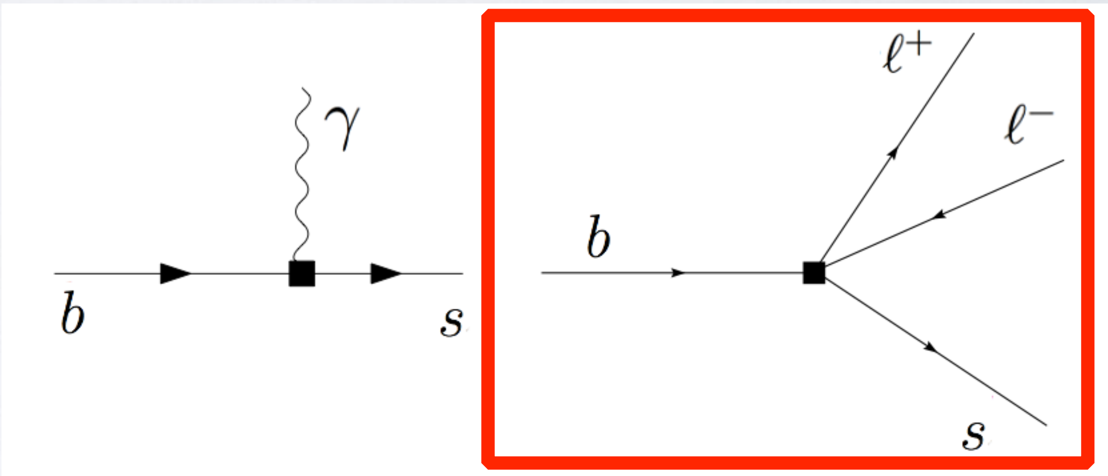

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Right-handed operators can be obtained swapping P_R and P_L

The LHCb experiment

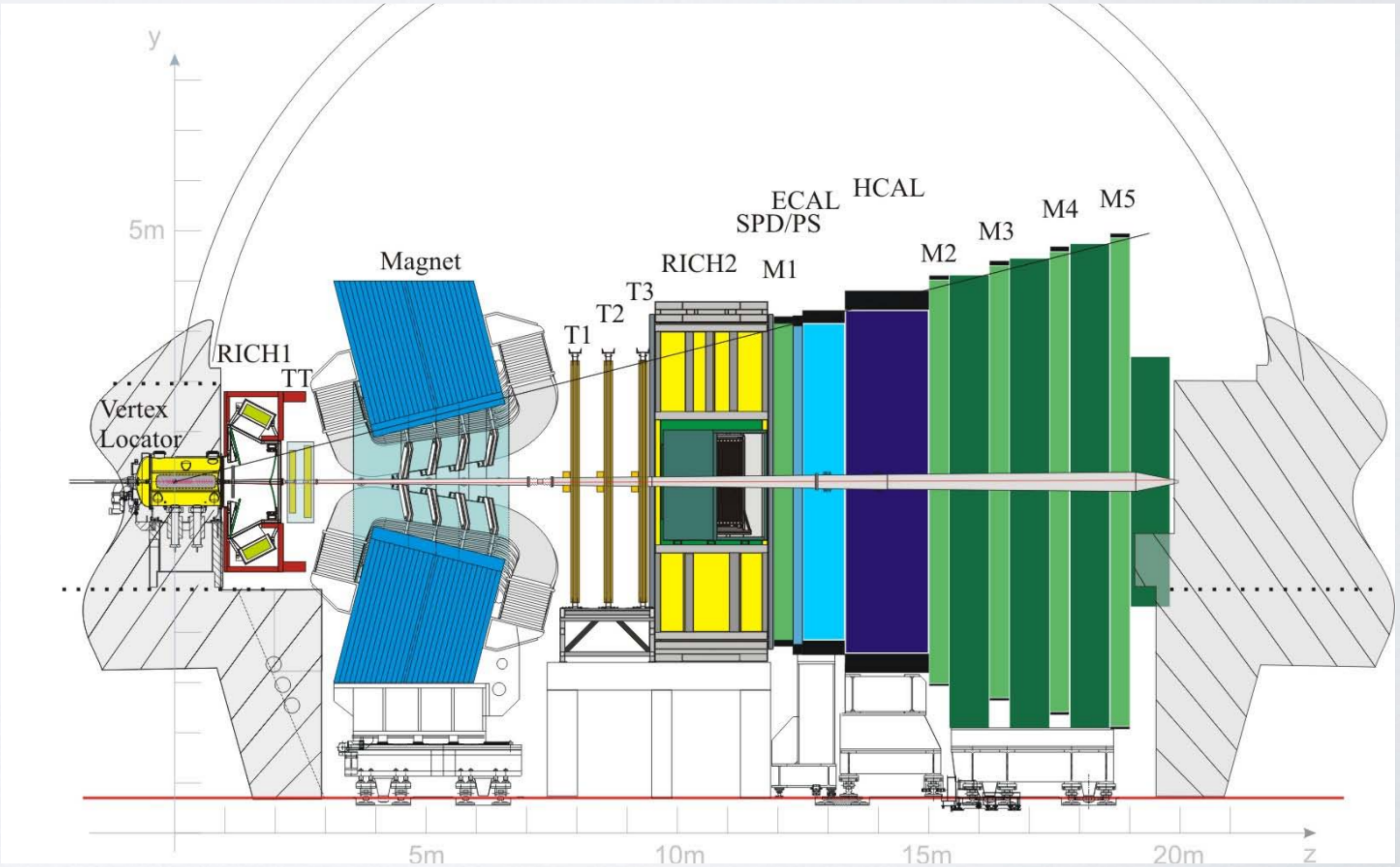
- Precise vertex reconstruction: σ(IP) ~20μm
- Good PID (RICH): $\varepsilon_{PID}(K)$ = 95% for MisID(π→K) = 5%

- Excellent mass resolution δp/p~0.5%
- Very clean muon ID for trigger ~97%

Forward spectrometer fully instrumented in $2 < \eta < 5$

Flexible 2-level trigger:

- Hardware level → on muons, hadrons, electrons and photons
- Software level (HLT) → using partial reconstruction



JINST 3 (2008) S08005

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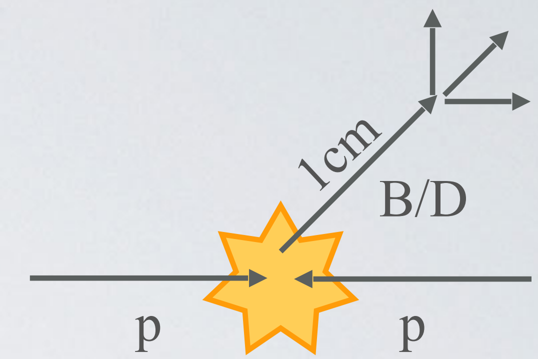

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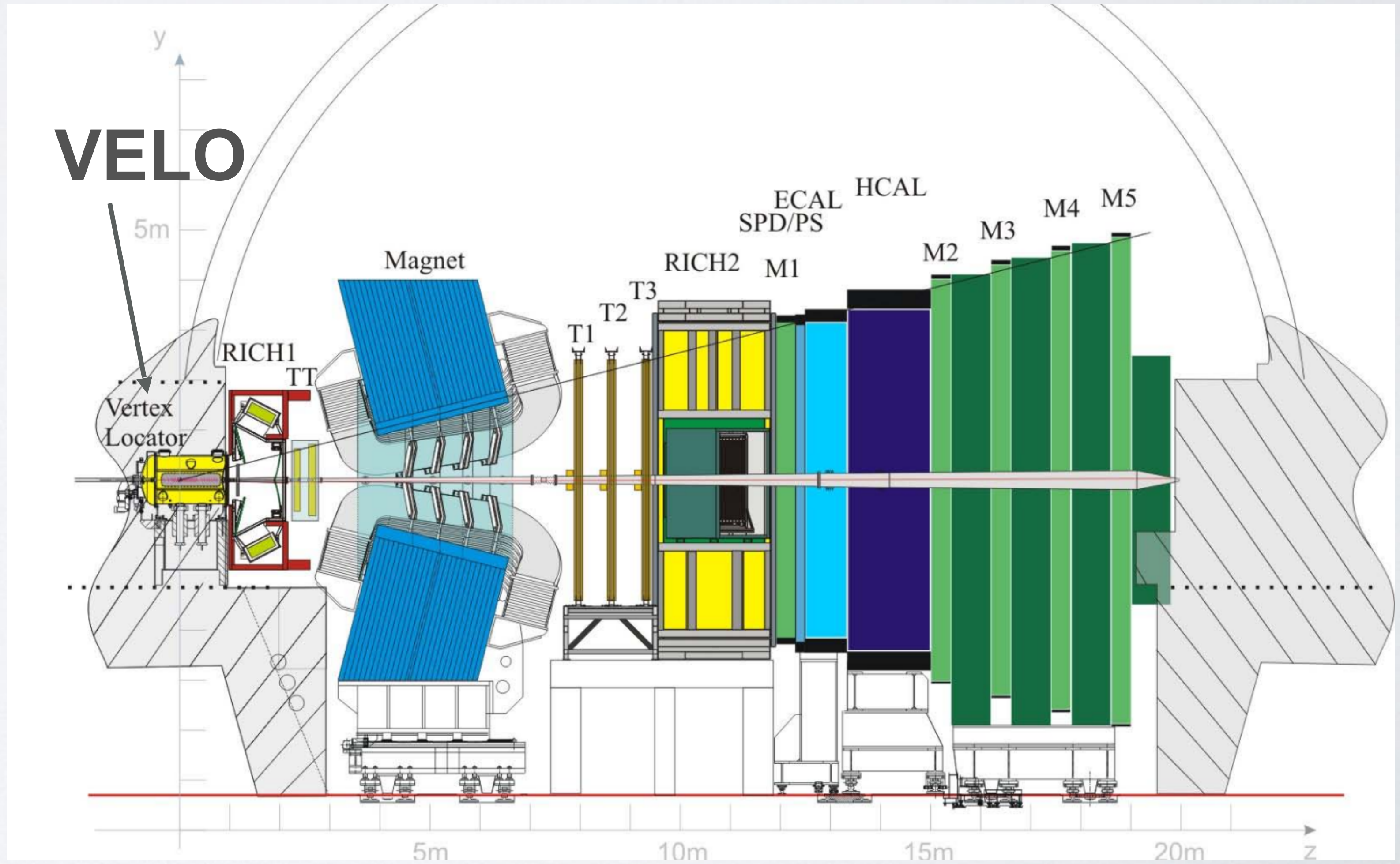
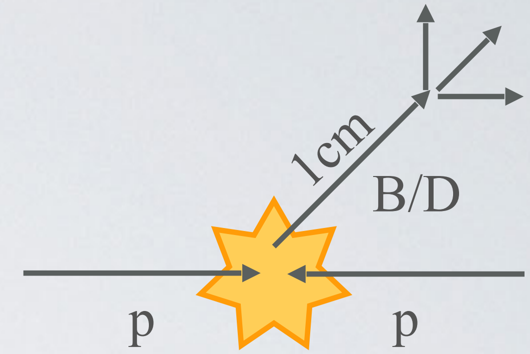
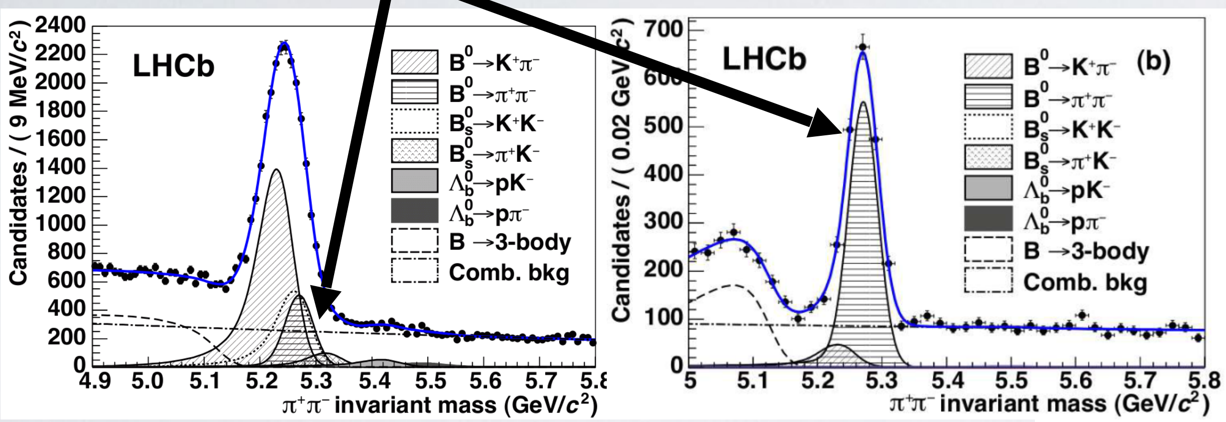


JINST 3 (2008) S08005

The LHCb experiment

- Precise vertex reconstruction: σ(IP) ~20μm
- Good PID (RICH): $\varepsilon_{PID}(K)$ = 95% for MisID(π→K) = 5%





JHEP 10 (2012) 037

- Excellent mass resolution δp/p~0.5%
- Very clean muon ID for trigger ~97%

Forward spectrometer fully instrumented in $2 < \eta < 5$

Flexible 2-level trigger:

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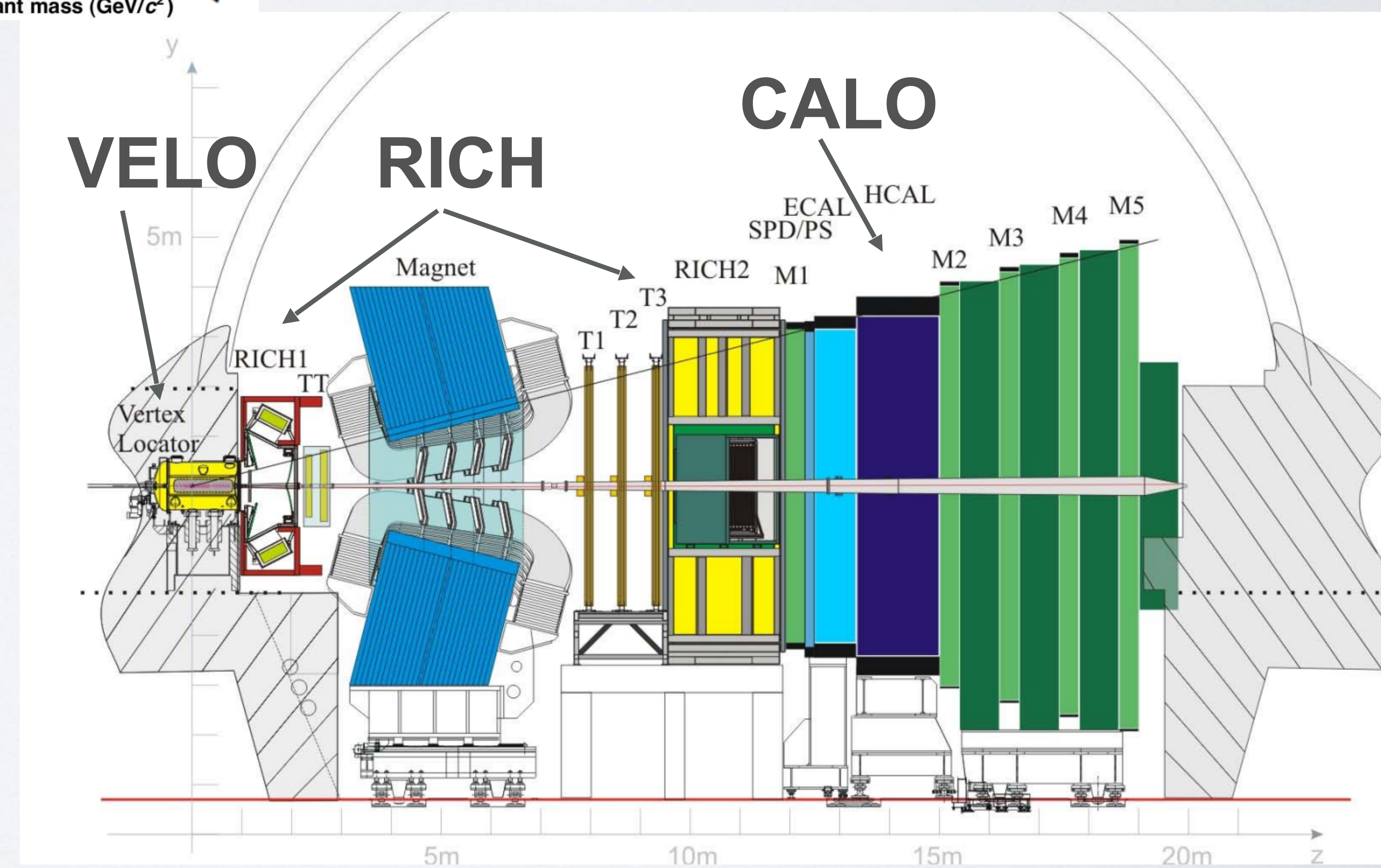

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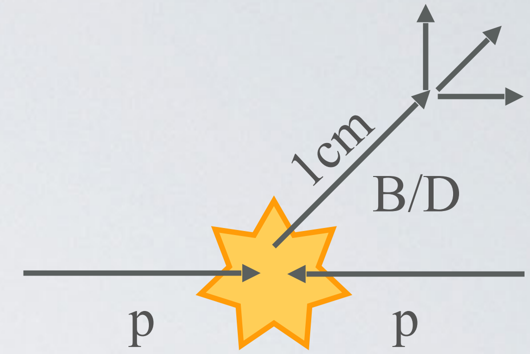

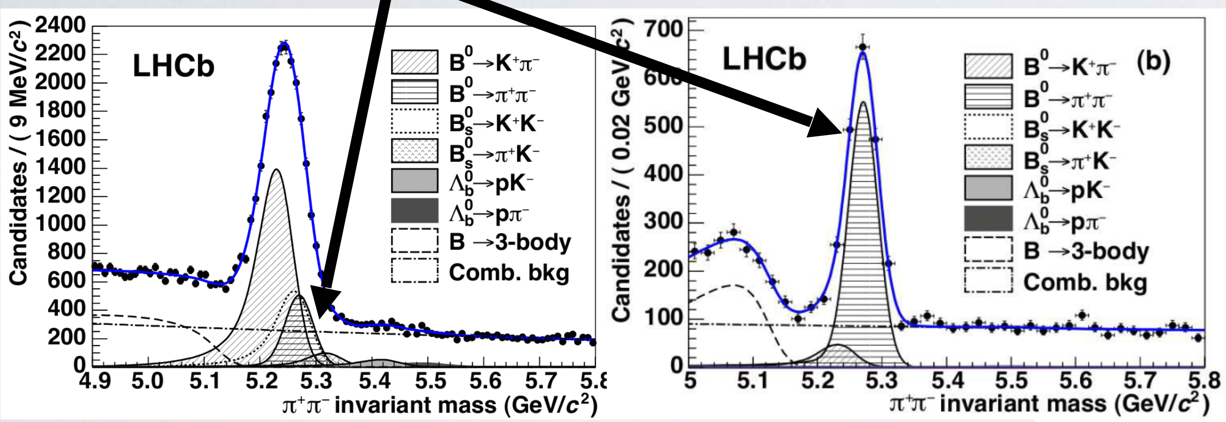

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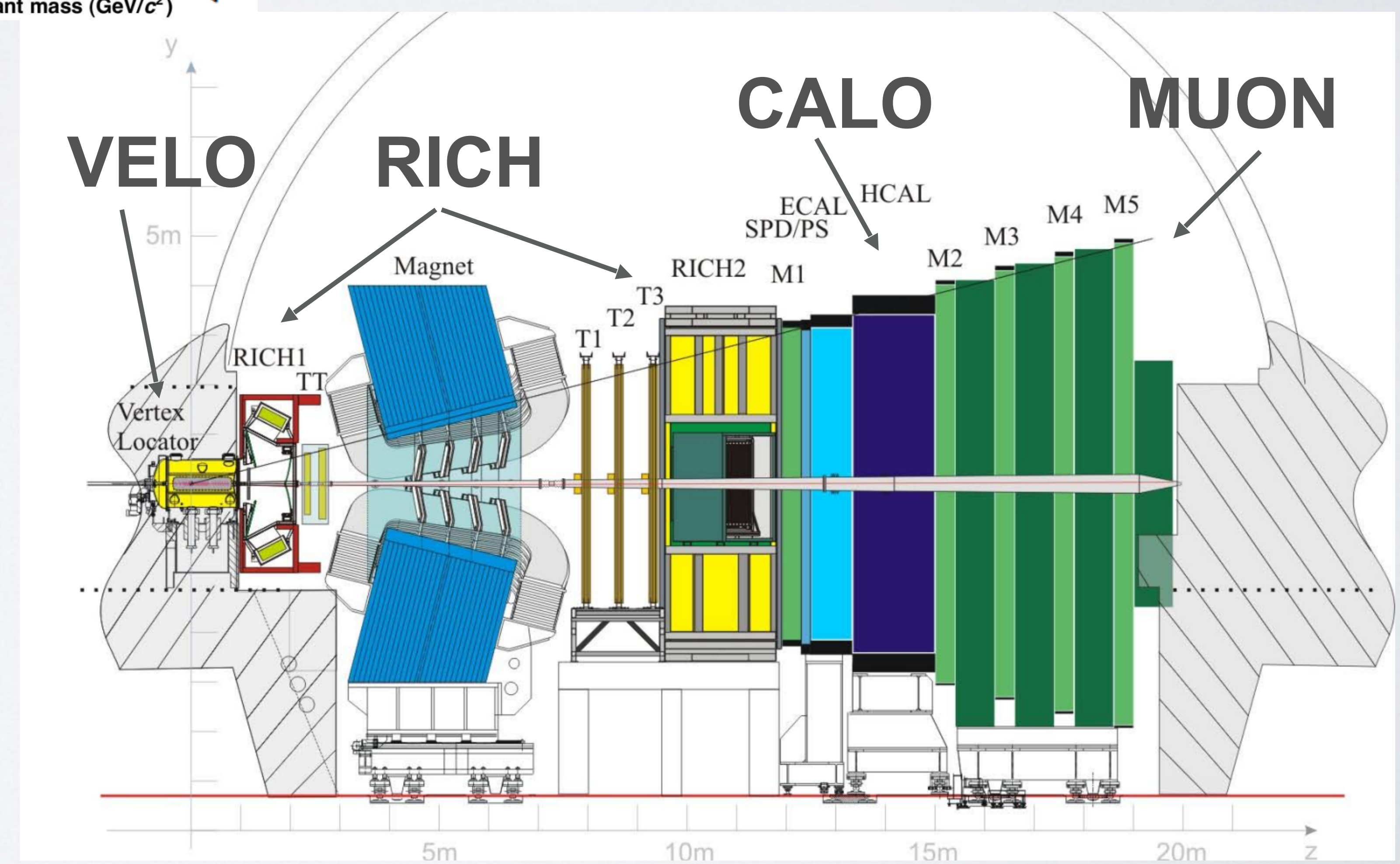

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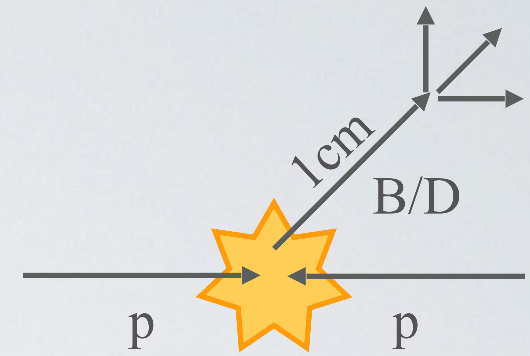

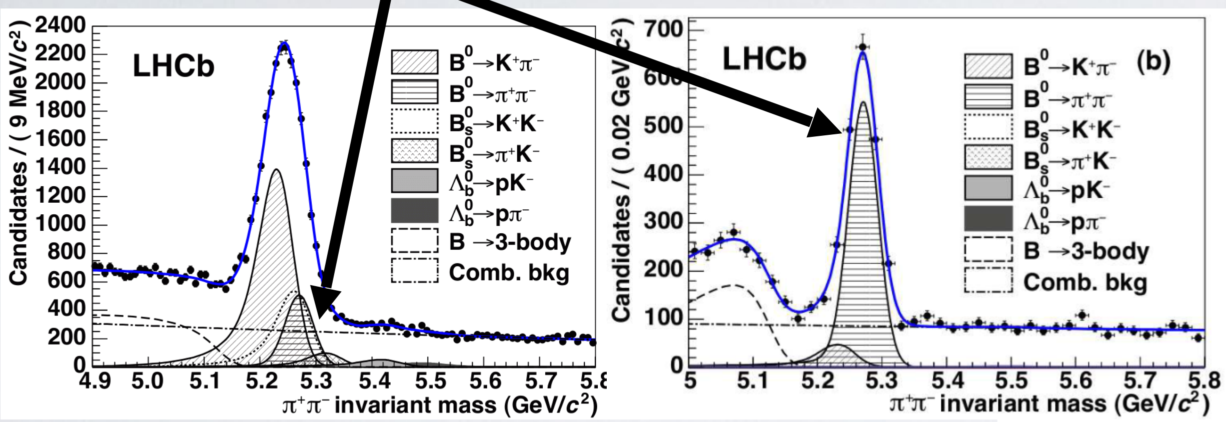

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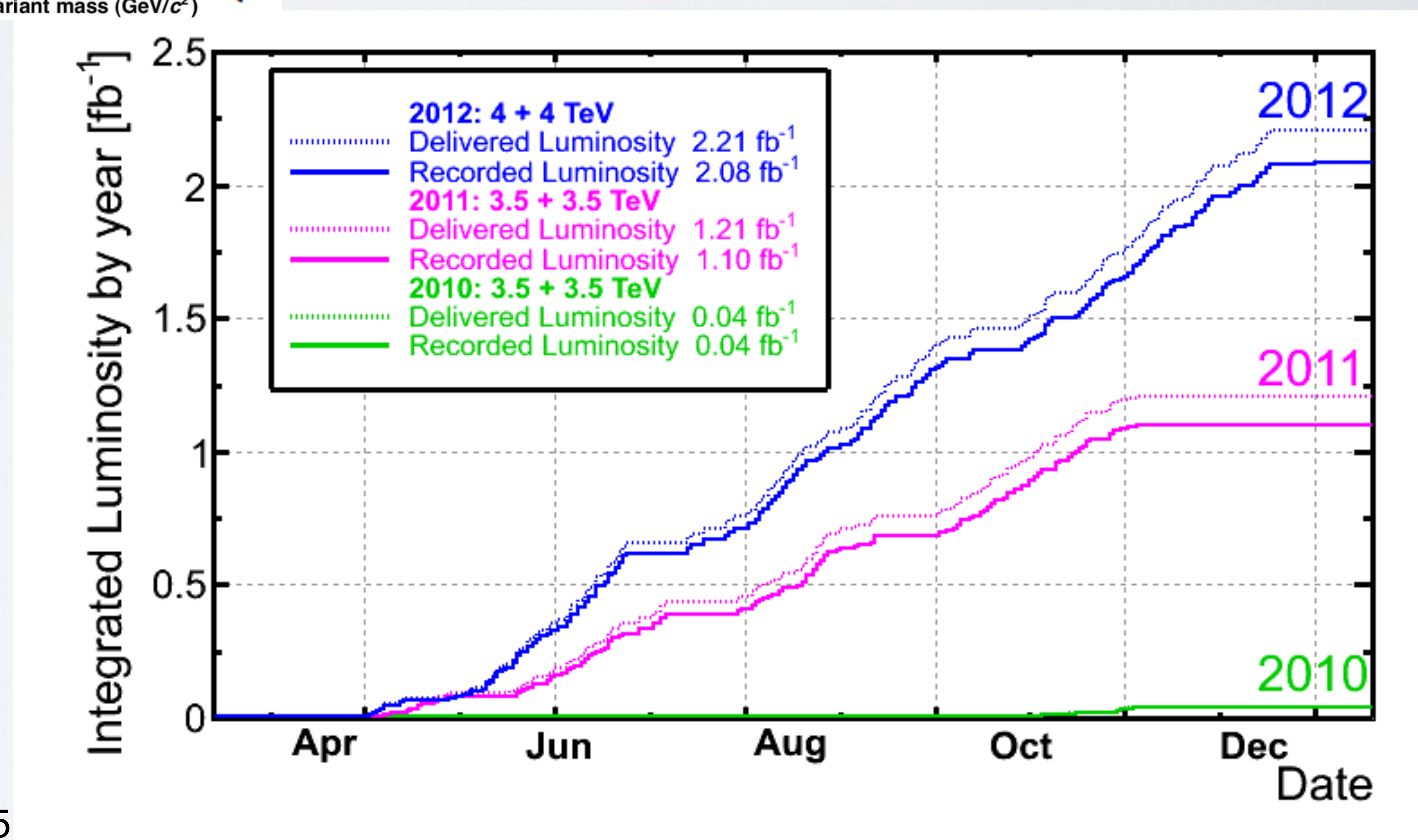
3 fb^{-1} of data on tape:
1fb^{-1} @ 7TeV 2011
2fb^{-1} @ 8 TeV 2012



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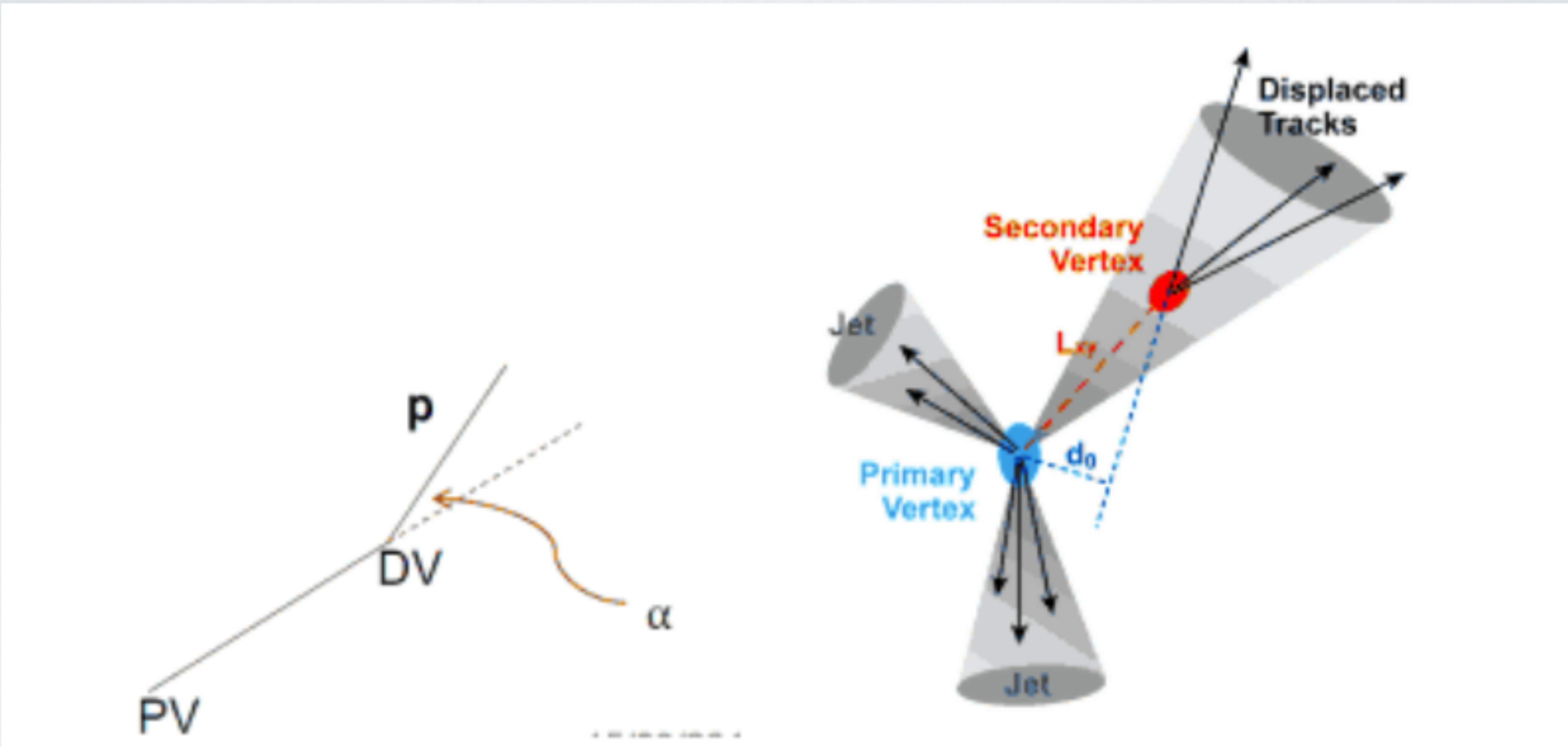
IPχ^2 and DIRA



Global fit results

Coefficient	Best fit	1σ	3σ	Pull_{SM}
$\mathcal{C}_7^{\text{NP}}$	-0.02	$[-0.04, -0.00]$	$[-0.07, 0.04]$	1.0
$\boldsymbol{\mathcal{C}_9^{\text{NP}}}$	-1.13	$[-1.33, -0.91]$	$[-1.72, -0.42]$	**4.6**
$\mathcal{C}_{10}^{\text{NP}}$	0.47	$[0.21, 0.74]$	$[-0.28, 1.35]$	1.8
$\mathcal{C}_{7'}^{\text{NP}}$	0.02	$[-0.01, 0.04]$	$[-0.06, 0.09]$	0.7
$\mathcal{C}_{9'}^{\text{NP}}$	0.48	$[0.19, 0.77]$	$[-0.36, 1.37]$	1.7
$\mathcal{C}_{10'}^{\text{NP}}$	-0.24	$[-0.45, -0.04]$	$[-0.87, 0.38]$	1.2