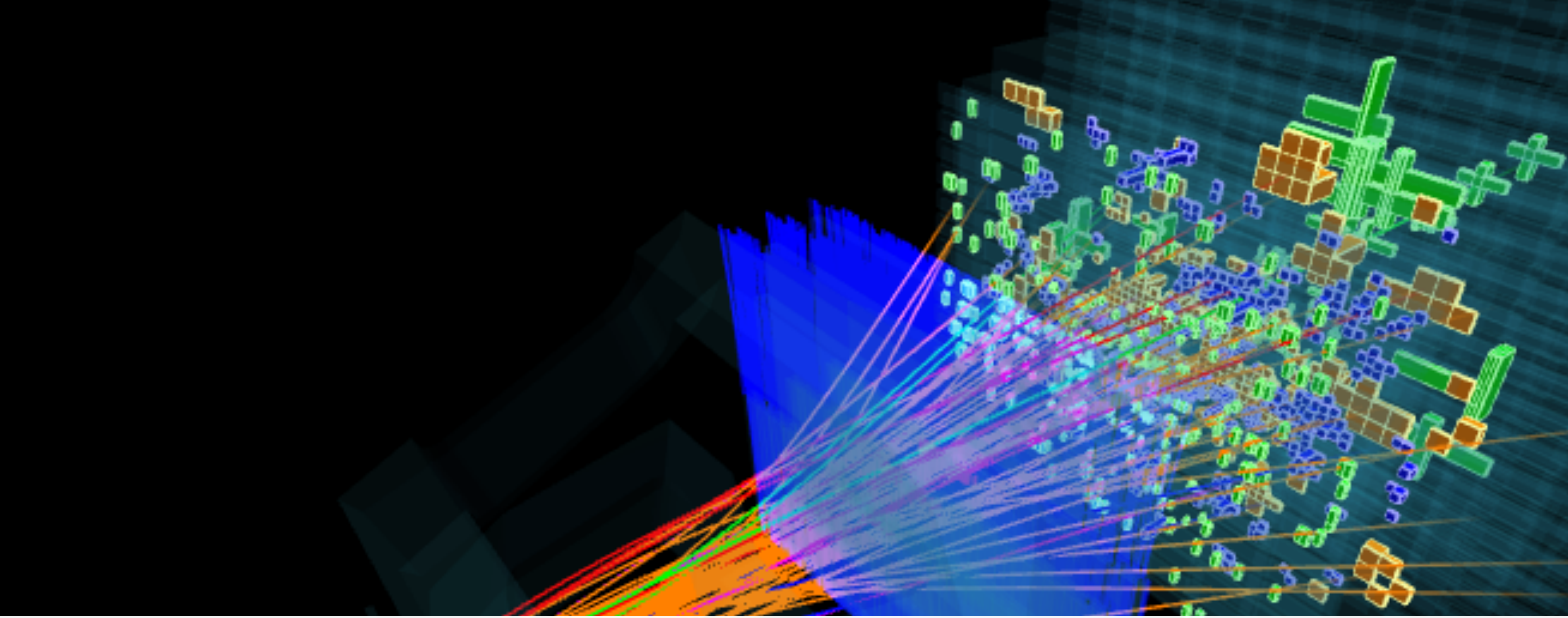

Test of LFU with charm semileptonic decays at the LHCb experiment

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3rd Red LHC
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LHCb
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Outline

- Introduction
  - Lepton Flavour Universality
  - The LHCb detector
- LFU in charm decays
- Test of LFU in $D^0 \to K^- l^+ \nu_l$
  - Analysis strategy
  - The Global Fit algorithm
  - Some results
- Conclusions and future prospects

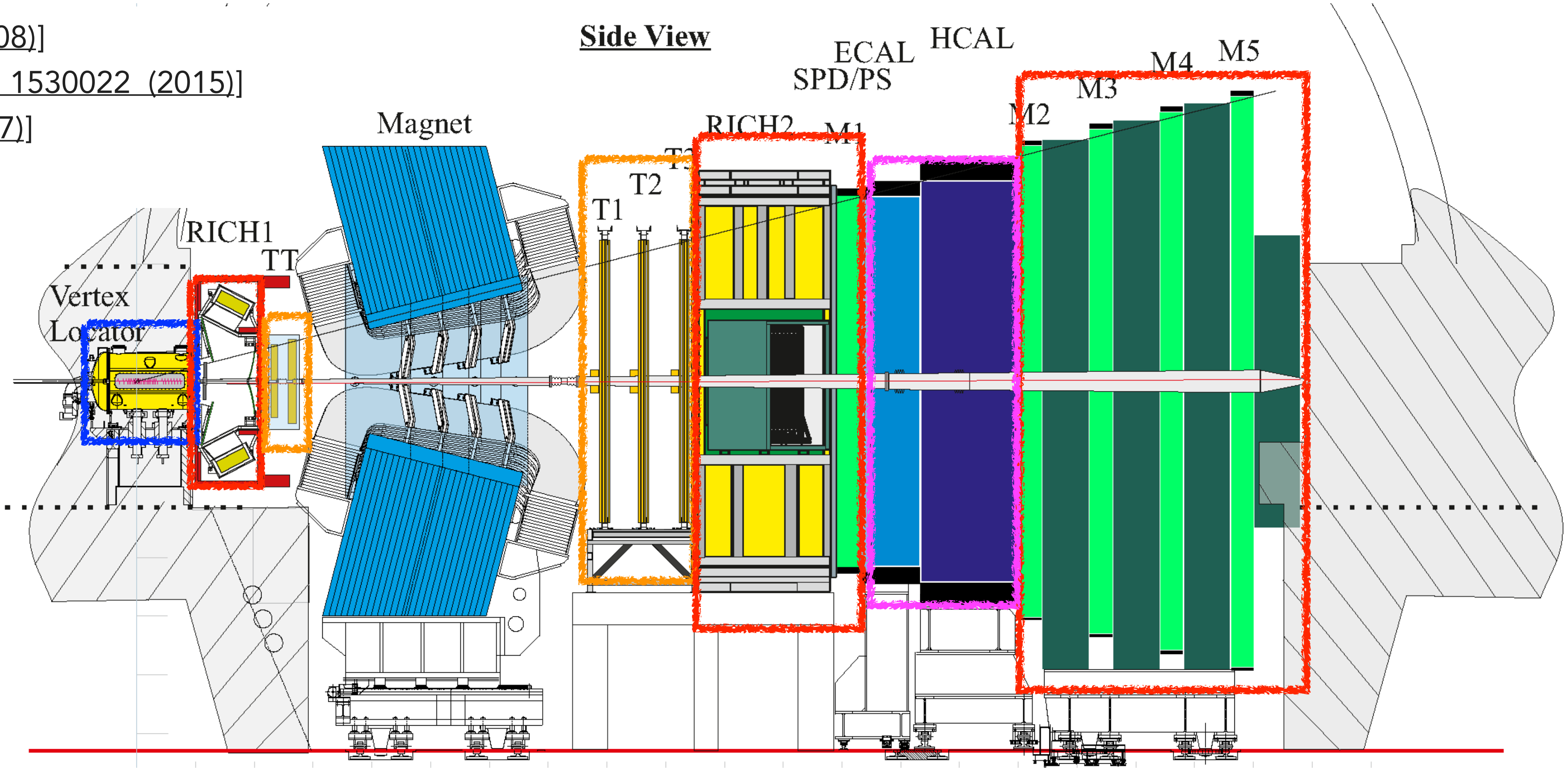
Lepton Flavour Universality

- The SM predicts equal couplings between gauge bosons and the three lepton families. This is called Lepton Flavour Universality (LFU)
  - Observation of LFU violation → sign of New Physics (NP)
- *B* semileptonic decays show main tensions between SM expectations and experimental results:
  - $b \to c$ transitions: R(D^*) and R(D)
  - $b \to s$ transitions: R(K^*) and R(K)
- The charm sector is still a relatively unexplored area
- Tackle SM using similar observables as *B* decays for $c \to s$ and $c \to d$ transitions

The LHCb detector

2015 - 2016 data sample $\sqrt{s}$ = 13 TeV, 1.9 fb^{-1}

[JINST 3 S080005 (2008)]
[Int. J. Mod Phys. A30 1530022 (2015)]
[PRL 118 052002 (2017)]
[JHEP 05 (2017) 074]



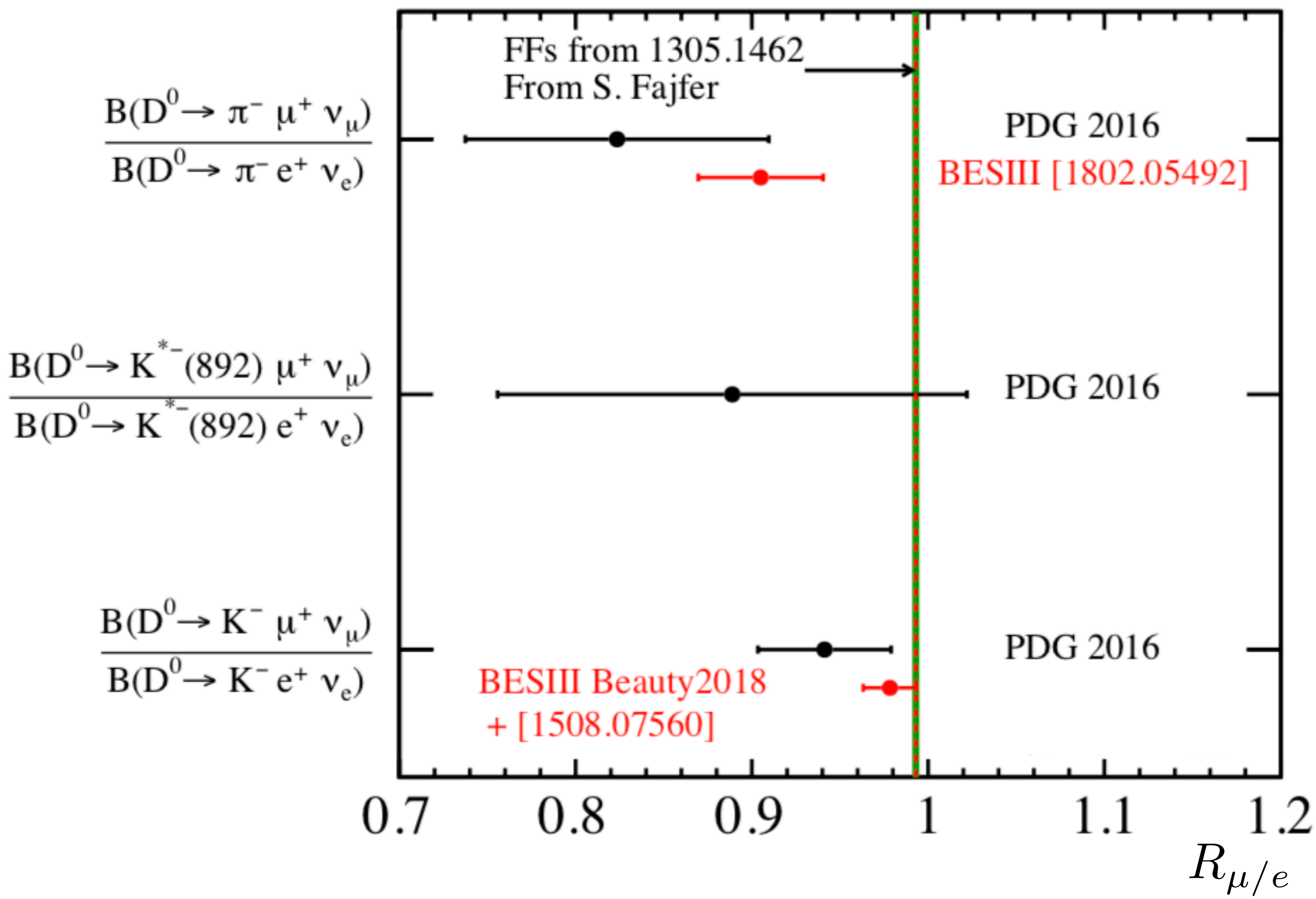
- Forward spectrometer for *b*- and *c*-hadron decays (2<η<5)
  - Good vertex and impact parameter resolution (σ(IP)~20 μm)
  - Excellent momentum resolution ($\delta p/p$ = [0.5 - 1] % p<200 GeV)
  - Excellent charged particle identification (μ ID 97% for (π→μ) misID of 1-3%)
  - Capability for neutral identification
- High production cross section of charmed mesons in LHCb
  - At 13 TeV: $\sigma(pp \rightarrow D^{*+}X)$~784 μb and $\sigma(pp \rightarrow D^0 X)$~2072 μb

LFU in charm decays

[BESIII Beauty 2018]
Adapted by L. Capriotti from [1703.10695]

$$R_{\mu/e}(q^2) = \frac{d\Gamma(D^0 \to \mathcal{H}^- \mu^+ \nu_\mu)/dq^2}{d\Gamma(D^0 \to \mathcal{H}^- e^+ \nu_e)/dq^2}$$

where H contains a s or a d quark, and q^2 is the transfer 4-momentum

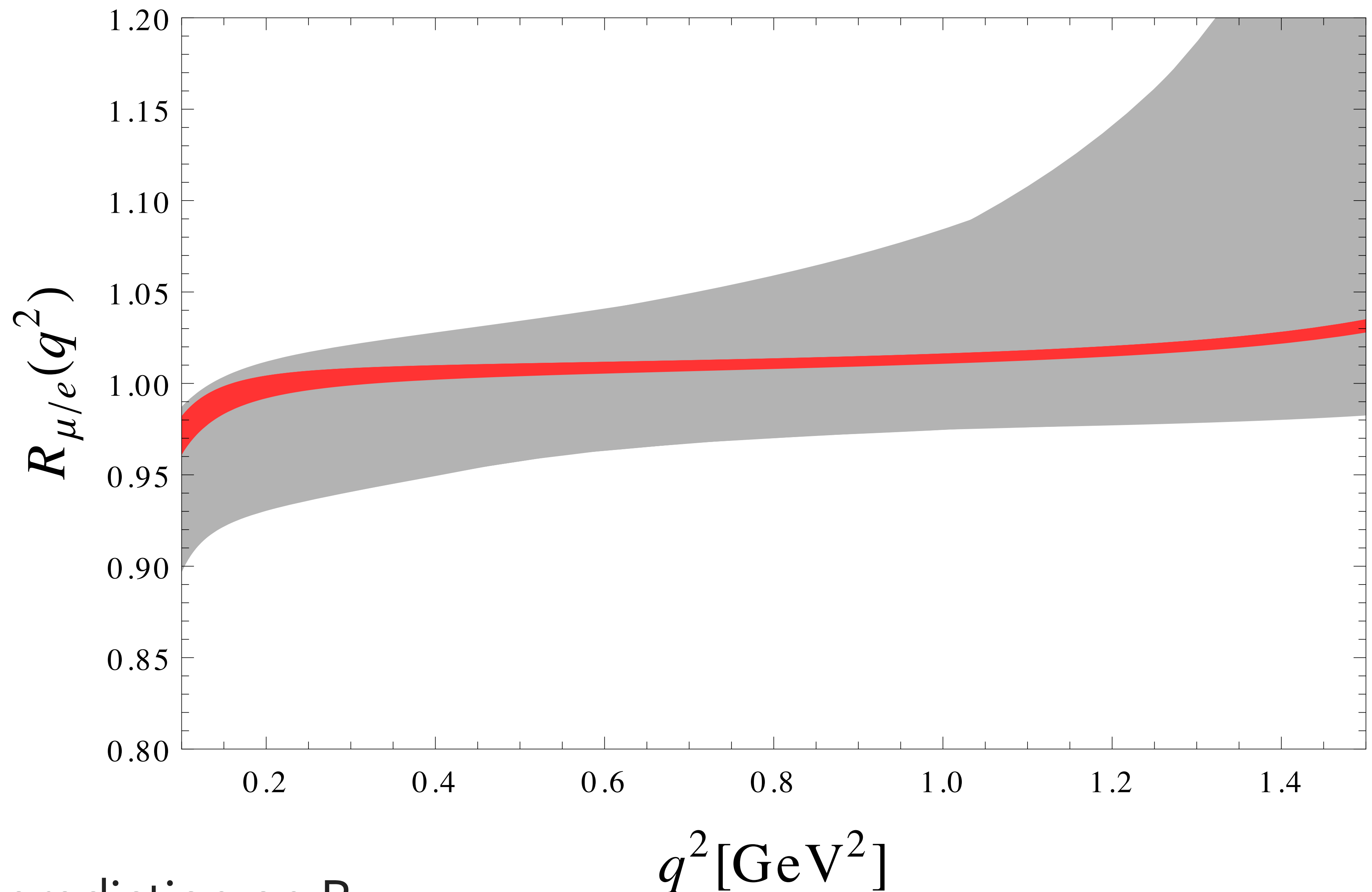


- New results from BESIII compatible with SM expectation within 2σ

LFU in charm decays

[PRD 91 (2015) 094009]

- Study of the decay $D^0 \to K^- \ell^+ \nu_\ell$
- $R_{\mu/e}$ is currently allowed to deviate from the SM value by 10 – 20%, depending on the q^2



Red: SM prediction on $R_{\mu/e}$

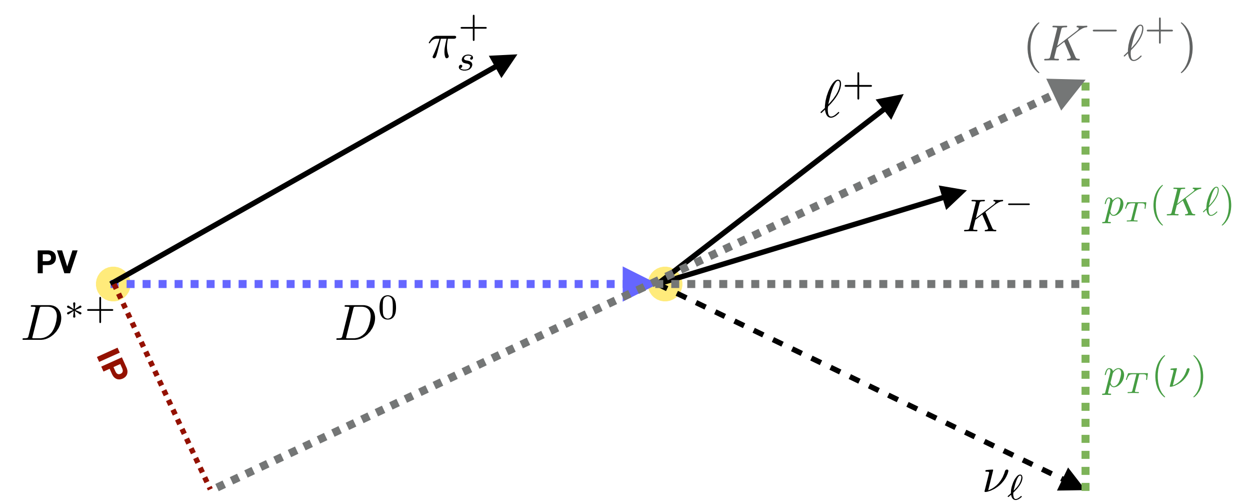
Grey: allowed NP region from constraints on the scalar Wilson coefficients

Analysis strategy

$$R_{e/\mu} = \frac{\mathcal{B}(D^0 \to K^- e^+ \nu_e)}{\mathcal{B}(D^0 \to K^- \mu^+ \nu_\mu)}$$

$$R_{e/\mu} = \frac{N(D^0 \to K^- e^+ \nu_e)}{N(D^0 \to K^- \mu^+ \nu_\mu)} \times \frac{\epsilon_{tot}(\mu)}{\epsilon_{tot}(e)}$$

$$\epsilon_{tot}(X) = \epsilon_{acc} \cdot \epsilon_{rec|acc} \cdot \epsilon_{sel|rec} \cdot \epsilon_{PID|sel}$$



- Theoretically clean observable
- D^0 from prompt $D^{*+} \to D^0 \pi_s^+$

2015 - 2016 data sample $\sqrt{s}$ = 13 TeV, 1.9 fb^{-1}

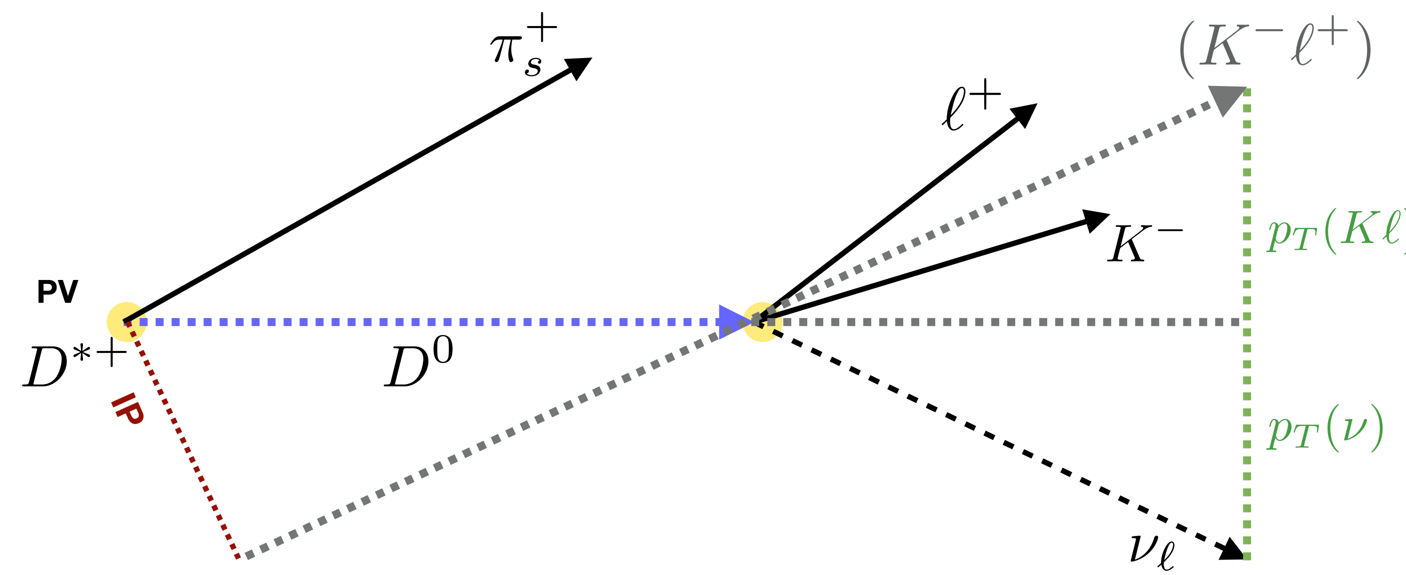
- Measurement in bins of q^2 (reconstructed with the cone closure method)
- Two main challenges:
  - Missing neutrino momentum
  - Bremsstrahlung of the electrons

Analysis strategy

- Two different fit strategies to extract N($D^0 \to K^-\mu^+\nu_\mu$) and $R_{e/\mu}$:
  1. Bidimensional template fit to ΔM_{vis} and M_{corr}
     - $\Delta M_{vis} = m(K^-\ell^+\pi_s) - m(K^-\ell^+)$
     - $M_{corr} = \sqrt{m(K^-\ell^+)^2 + (p_T)^2} + (p_T)$
     - p_T : transverse momentum of the neutrino with respect to the D^0 direction of flight
  2. Bidimensional template fit to m(D^*) and m(K^-l^+)
     - m(D^*) obtained from the "Global fit" algorithm (GF)
- Both methods minimise the Barlow-Beeston log-likelihood, to take into account the limited size of the MC samples
- The value of $R_{e/\mu}$ is blinded in the fits

The “Global Fit” algorithm

- Obtain the neutrino momentum constraining the kinematic of the whole decay
- Write a single χ² function using the measured quantities
- Add kinematical constraints
- The function to minimise is the sum of all the χ²



- Charged particles tracks
- Position of the two decay vertices

The "Global Fit" algorithm

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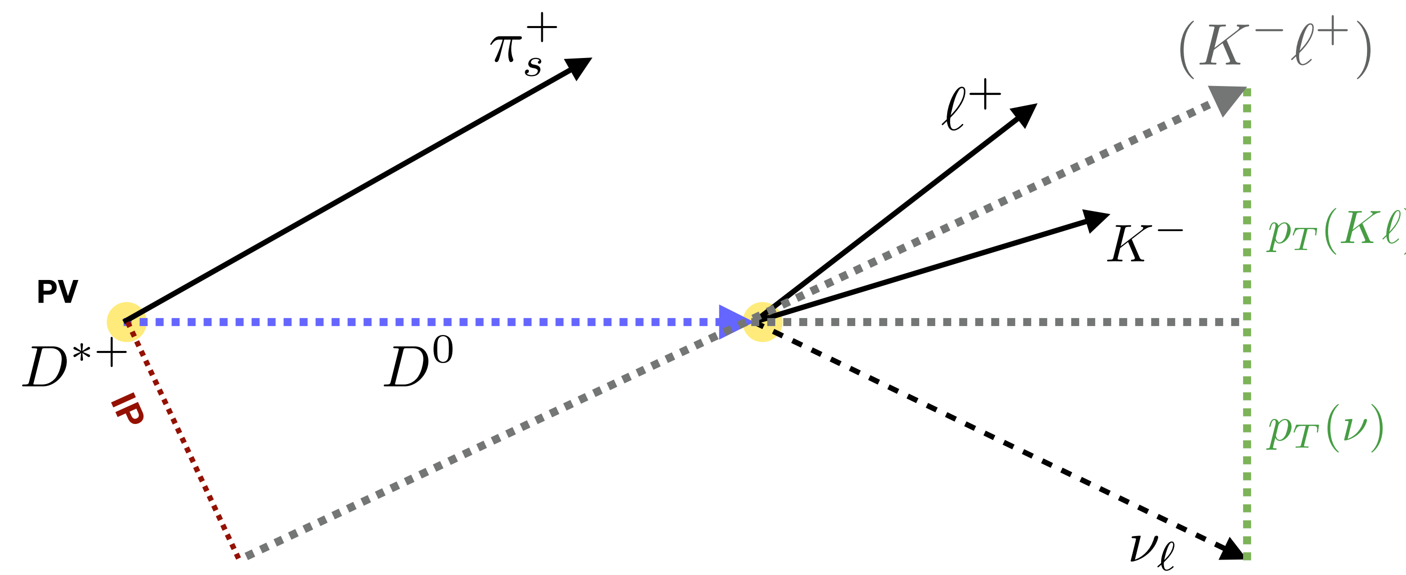

- Invariant mass of the D^0
- The D^* decay vertex must coincide with the primary vertex (PV)
- The D^0 flight direction must coincide with the direction from the PV to the D^0 decay vertex
- K and l tracks must come from the secondary vertex

The "Global Fit" algorithm

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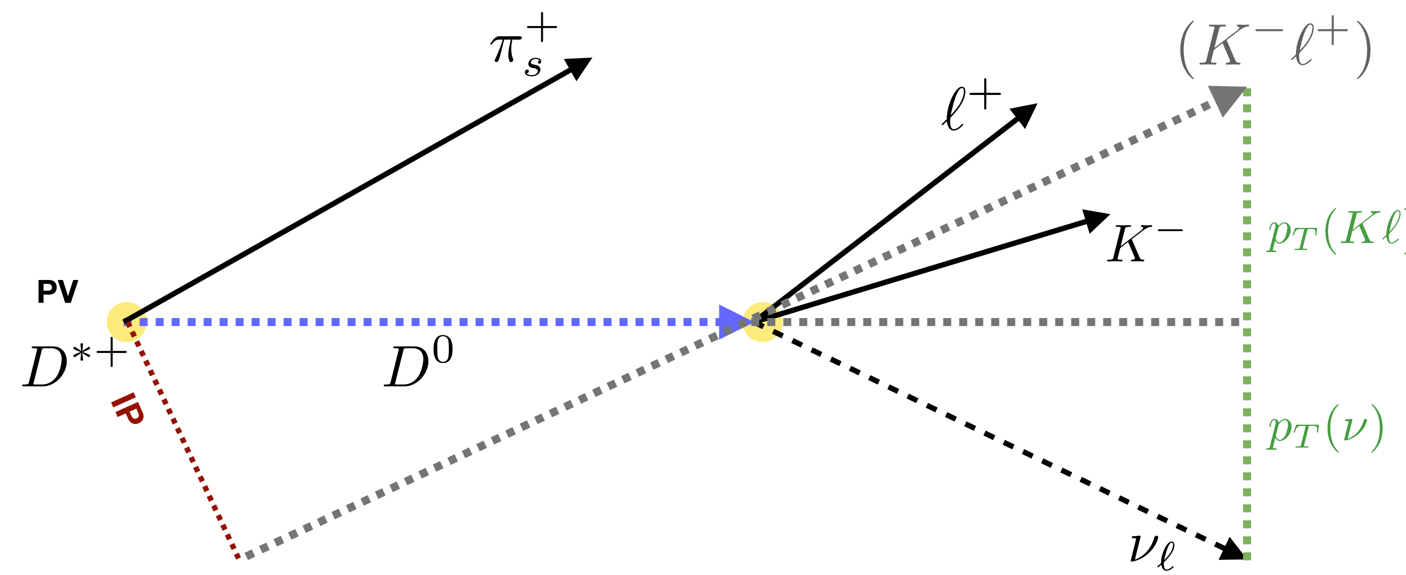
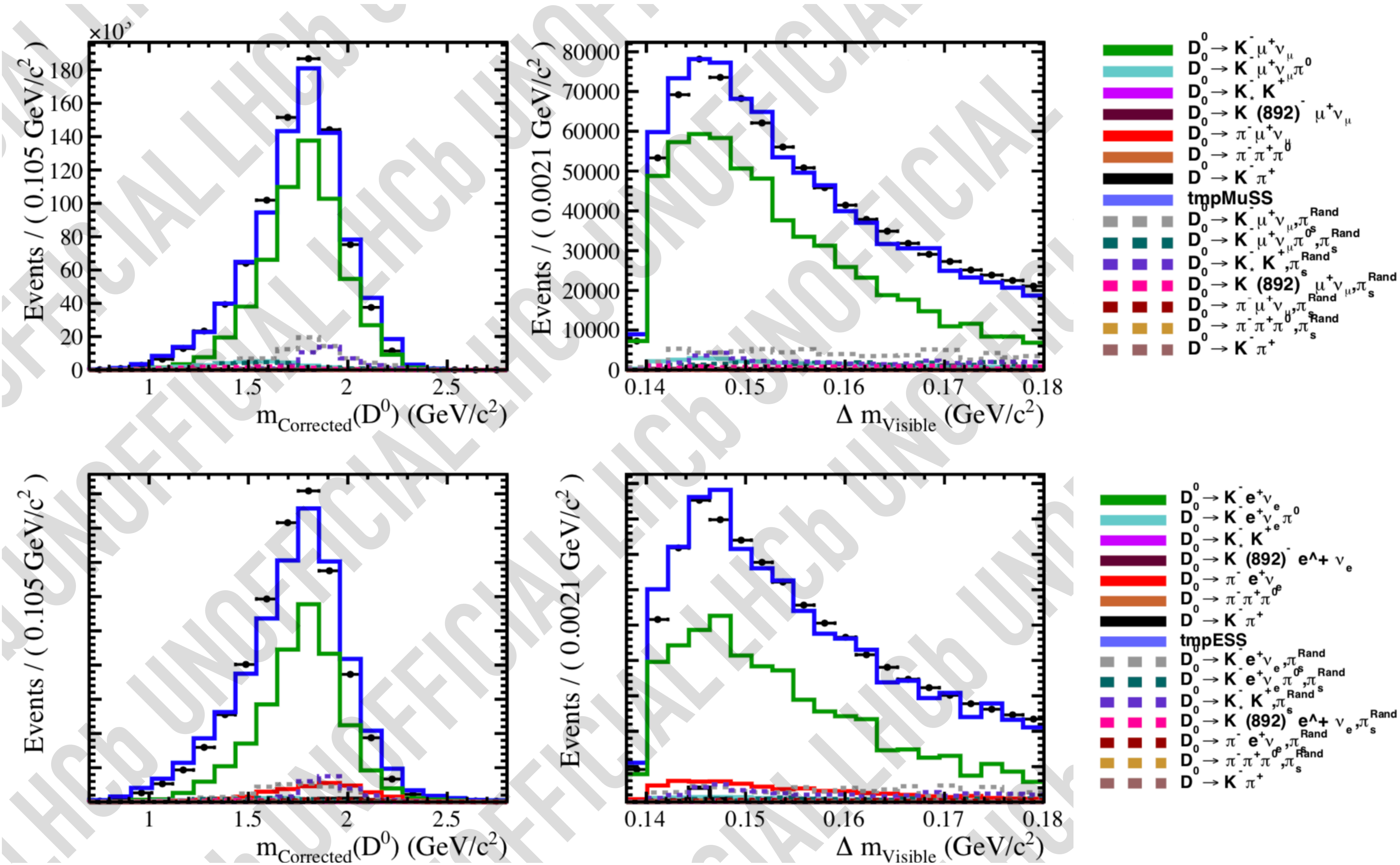


- $$f(\vec{\theta}, \hat{\vec{\theta}}) = \chi^2_{\mathrm{PV}} + \chi^2_\pi + \chi^2_\ell + \chi^2_K + \chi^2_{D^0}$$
- 16 free parameters: $\vec{p}_\pi,\ \vec{p}_\ell,\ \vec{p}_K,\ \vec{p}_\nu,\ \vec{x}_D,\ z_{\mathrm{PV}}$

Template fit results



Conclusions and perspectives

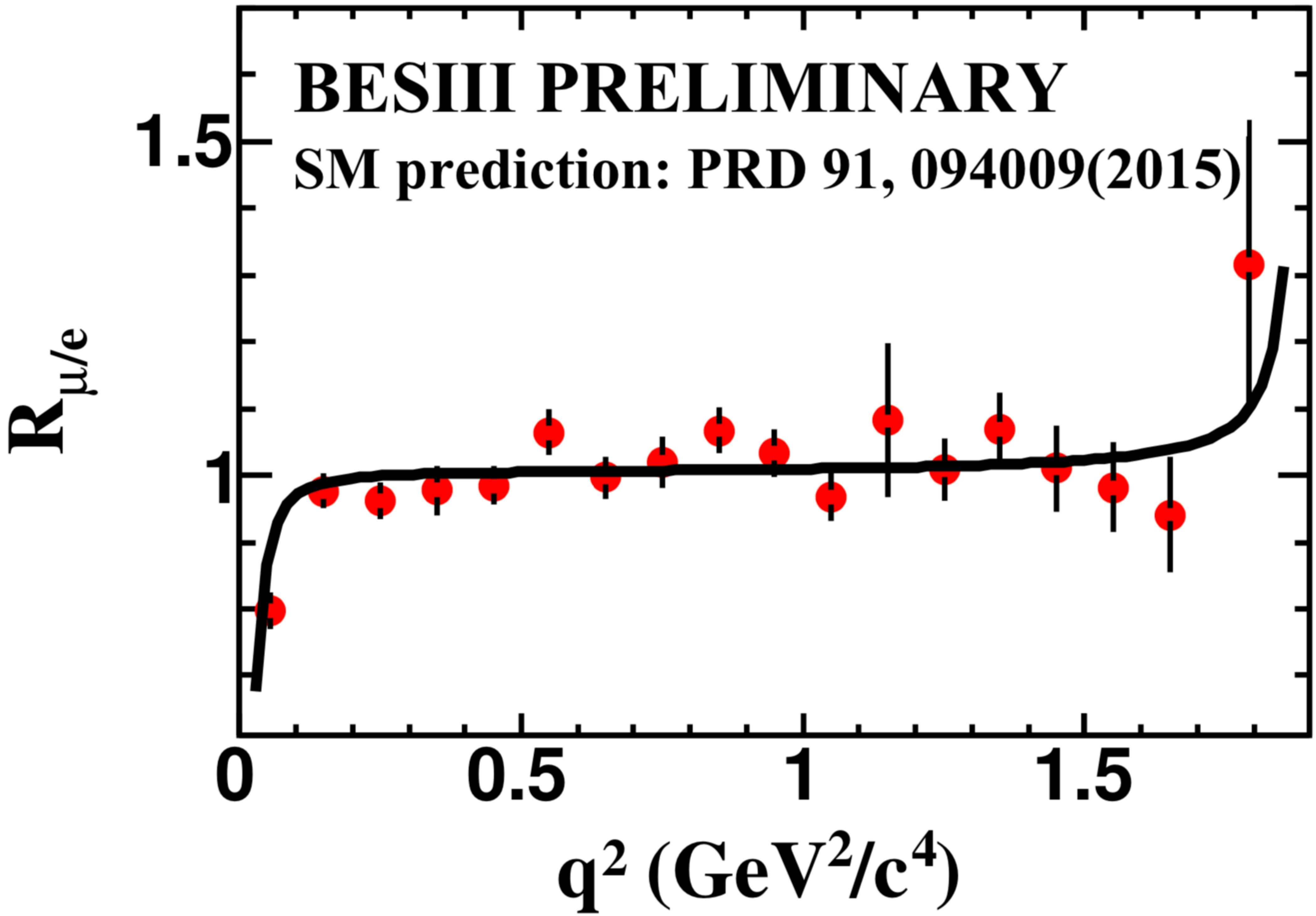
- LFU in charm decays is a potential road to new physics, still not so explored
- The analysis is ongoing and in a good shape
  - The blinding procedure is implemented
  - Fitting framework for the template fit is working and tested and for the GF is in phase of test
- We expect the precision to be limited by systematic uncertainties

STAY TUNED!

BACKUP

BESIII result

[BESIII Beauty 2018]



$R_{\mu/e} = 0.978 \pm 0.007 \pm 0.012$

Global fit algorithm: implementation of the constraints

- In LHCb tracks are parametrised as $$\vec{\alpha} = \left(x,\, y,\, t_x,\, t_y,\, \frac{q}{p}\right)_{z_{Ref}}$$
- It is possible to write the χ^2 function for every track as

$$\chi^2 = (\vec{\alpha} - \hat{\vec{\alpha}})C^{-1}(\vec{\alpha} - \hat{\vec{\alpha}})^T$$

- Where the expected values are calculated as

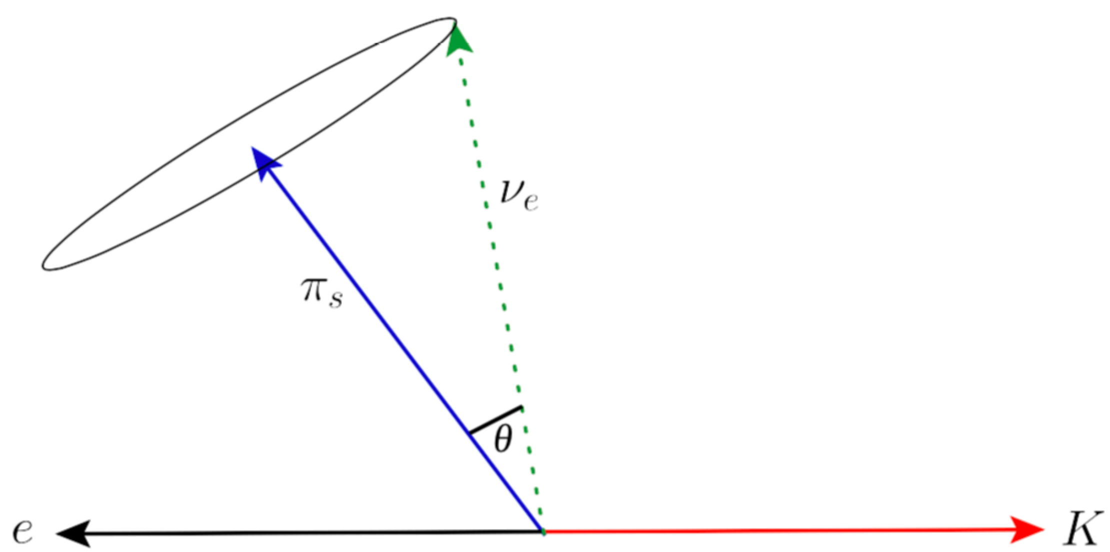
$$\begin{cases} \hat{x}^{K/\ell} = x_{D^0} + (z_{Ref} - z_{D^0})\hat{t}_x^{K/\ell} \\ \hat{y}^{K/\ell} = y_{D^0} + (z_{Ref} - z_{D^0})\hat{t}_y^{K/\ell} \end{cases}$$

$$\begin{cases} x_{PV} = x_{D^0} + (z_{PV} - z_{D^0})t_x^{D^0} \\ y_{PV} = y_{D^0} + (z_{PV} - z_{D^0})t_y^{D^0} \end{cases}$$

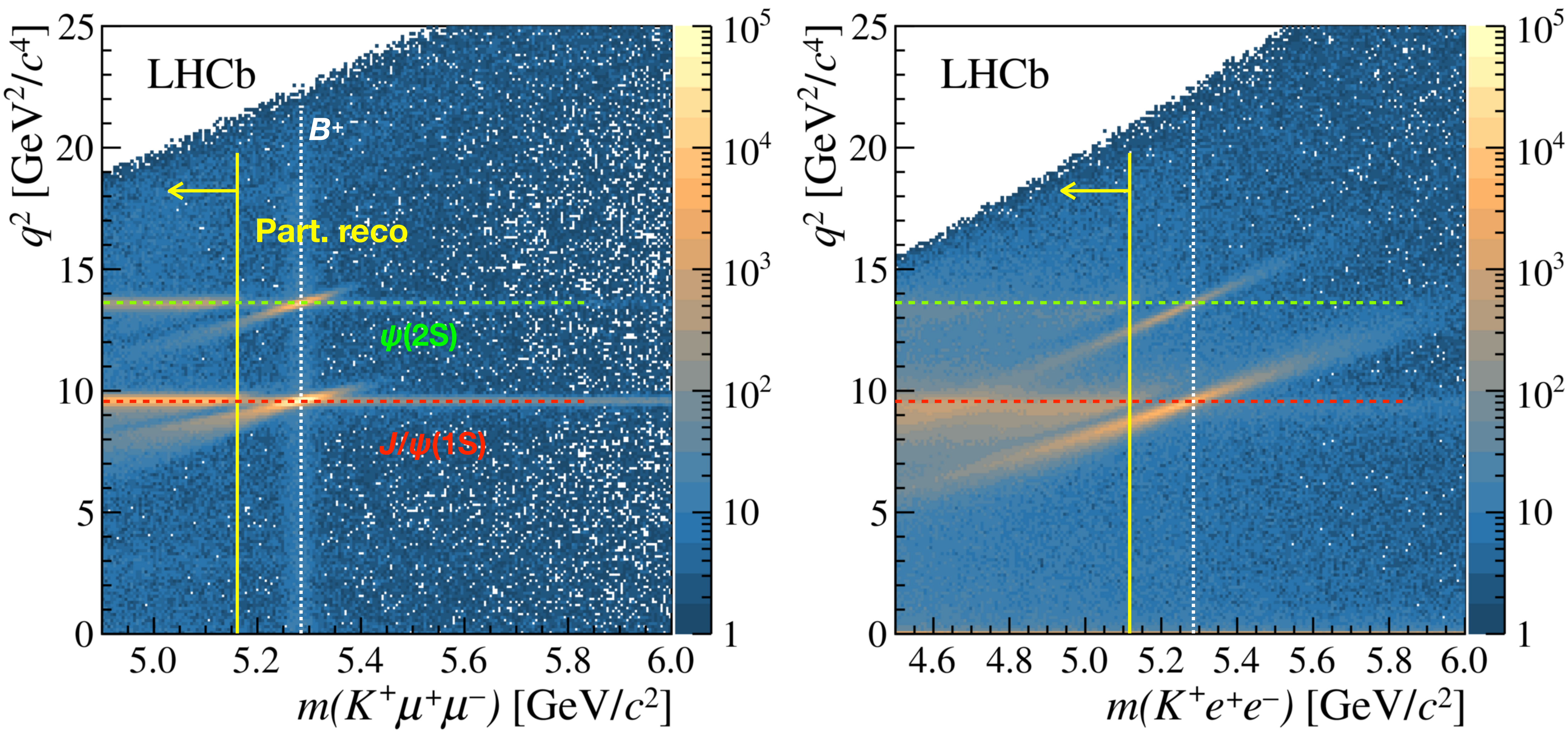
- While for the D^0 mass
  - m(D^0) = 1864.83 ± 0.05 MeV/c^2
  - σ^2 = 1 MeV^2/c^4

$$\chi^2_{D^0} = \frac{(m_{D^0} - \hat{m}_{D^0})^2}{2\sigma^2_{m_{D^0}}}$$

Cone closure method



- Calculating q^2 is not trivial
- Cone closure method: full constraint of the system using the D^{*+} mass constraint
- Boost to Kl rest frame where $p(D^0) = p(\nu)$ holds
- Set m(D^{*+}), m(D^0) to nominal value
- $p(\nu)$ lies on the surface of a cone around the π_s direction
- The polar angle is given by kinematics
- Sample 1000 points along the cone and take the azimuthal angle that best aligns the D^0 direction to the total final-state momentum


LHCb
q^2 [GeV^2/c^4]
$m(K^+\mu^+\mu^-)$ [GeV/c^2]
B+
Part. reco
ψ(2S)
J/ψ(1S)
LHCb
q^2 [GeV^2/c^4]
$m(K^+e^+e^-)$ [GeV/c^2]