



# Precision CP measurements at LHCb

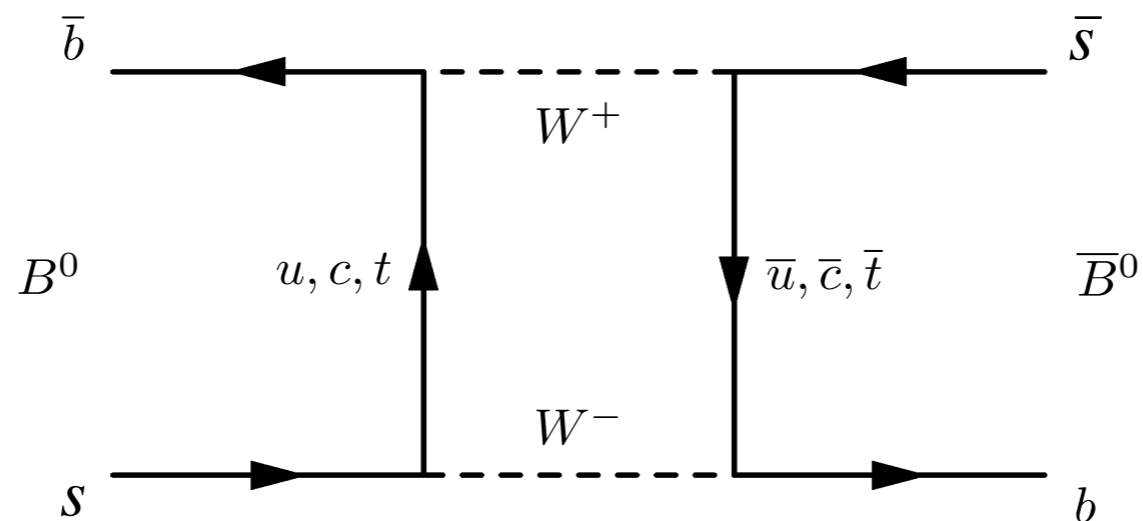
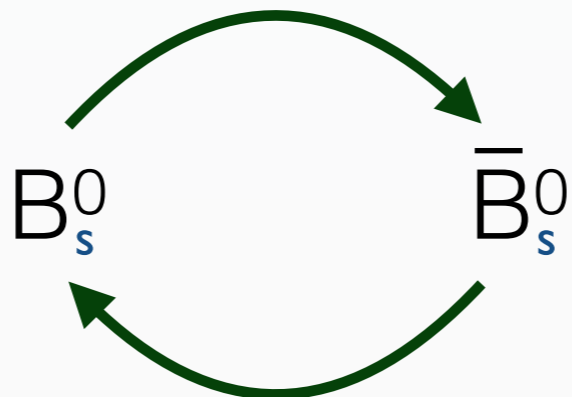
**Nikhef Jamboree** December 12, 2017  
Laurent Dufour



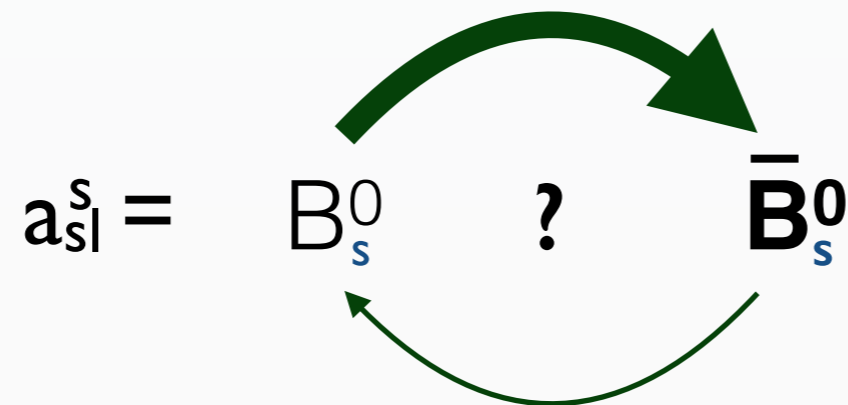
# How we do precision (CP) measurements at LHCb in Run 2, and in particular how we improved

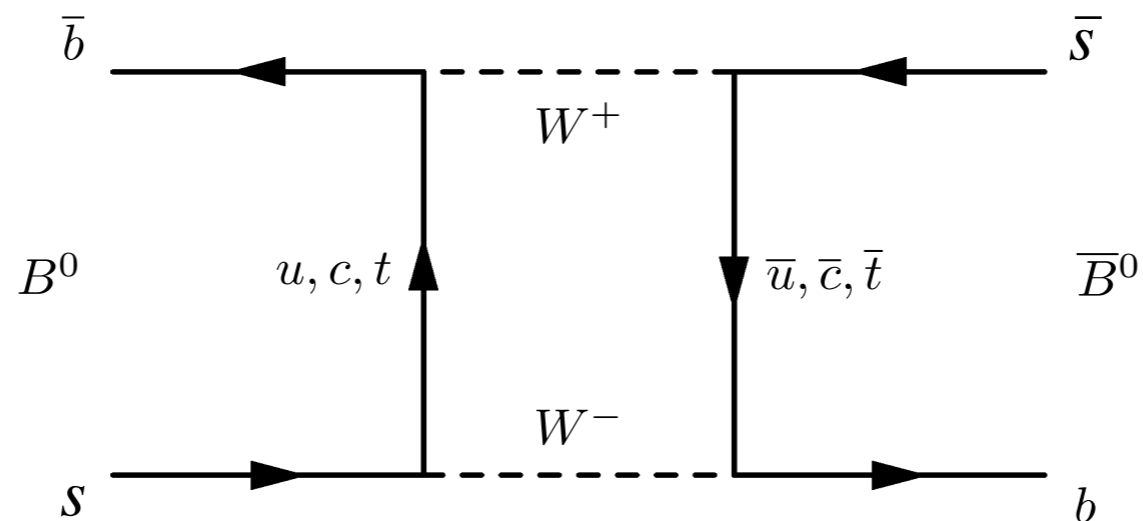
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# B meson mixing

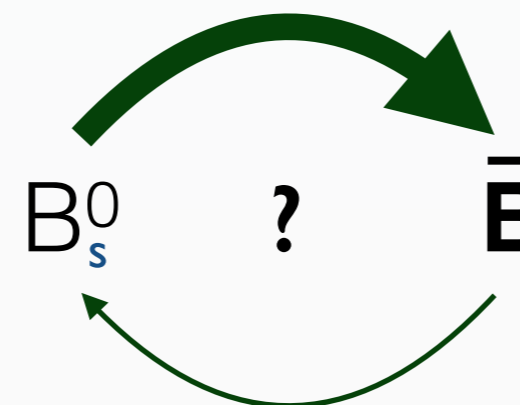


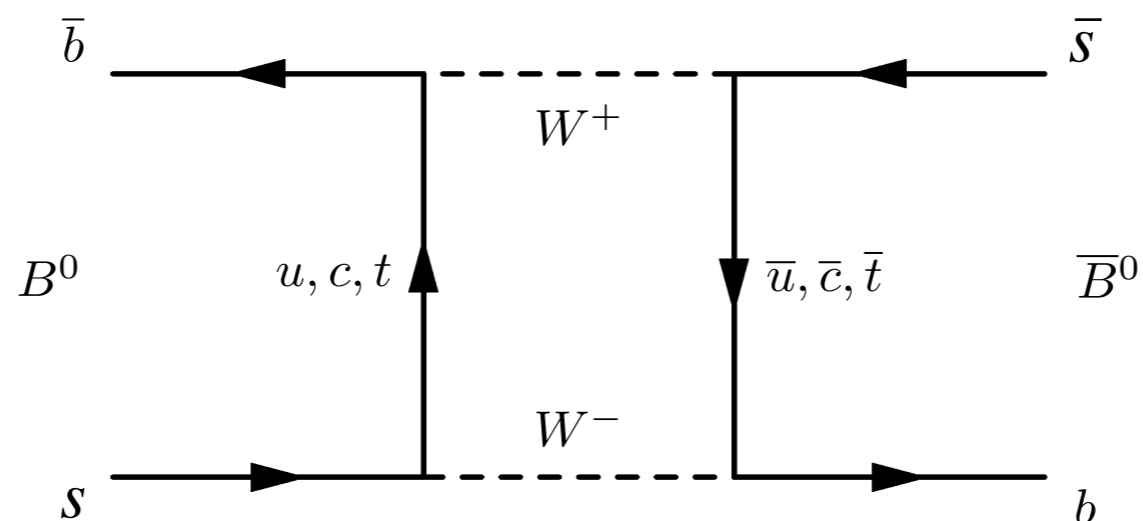
# Asymmetry in B meson mixing

$$a_{sl}^s = B_s^0 \quad ? \quad \bar{B}_s^0$$


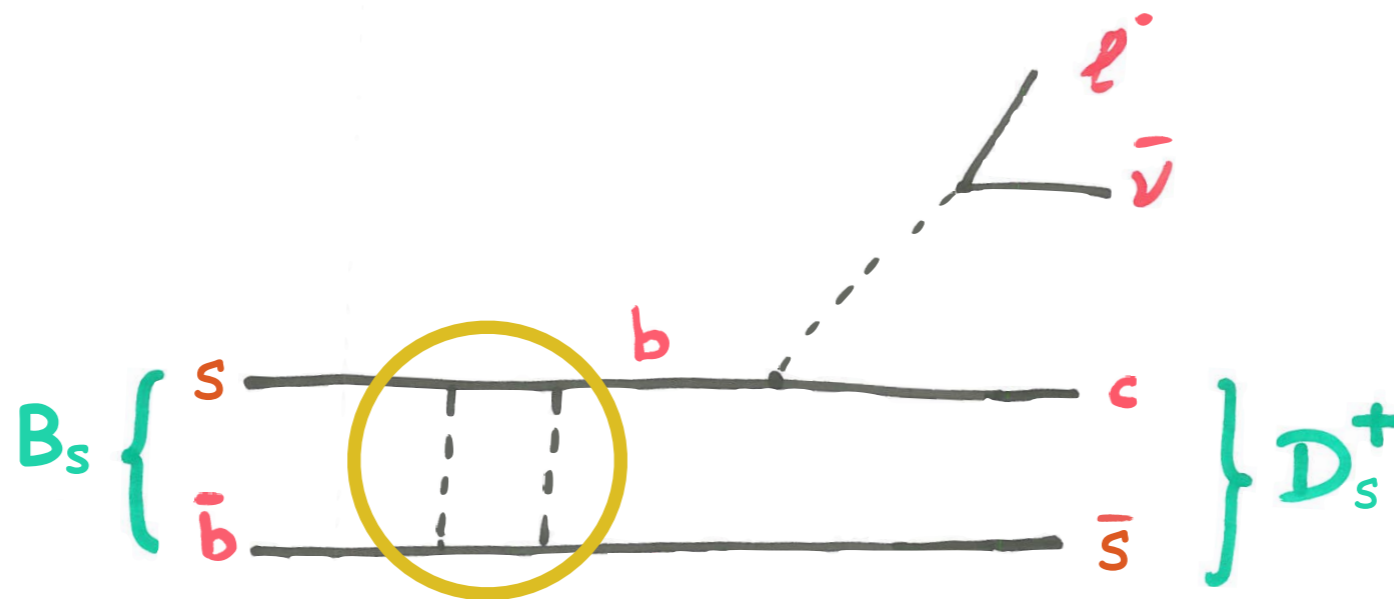


# Asymmetry in B meson mixing

$$a_{sl}^s = \text{B}_s^0 \quad ? \quad \bar{\text{B}}_s^0 \quad \approx \text{ZERO in SM}$$




$a_{sl}^S$ , measured in LHCb

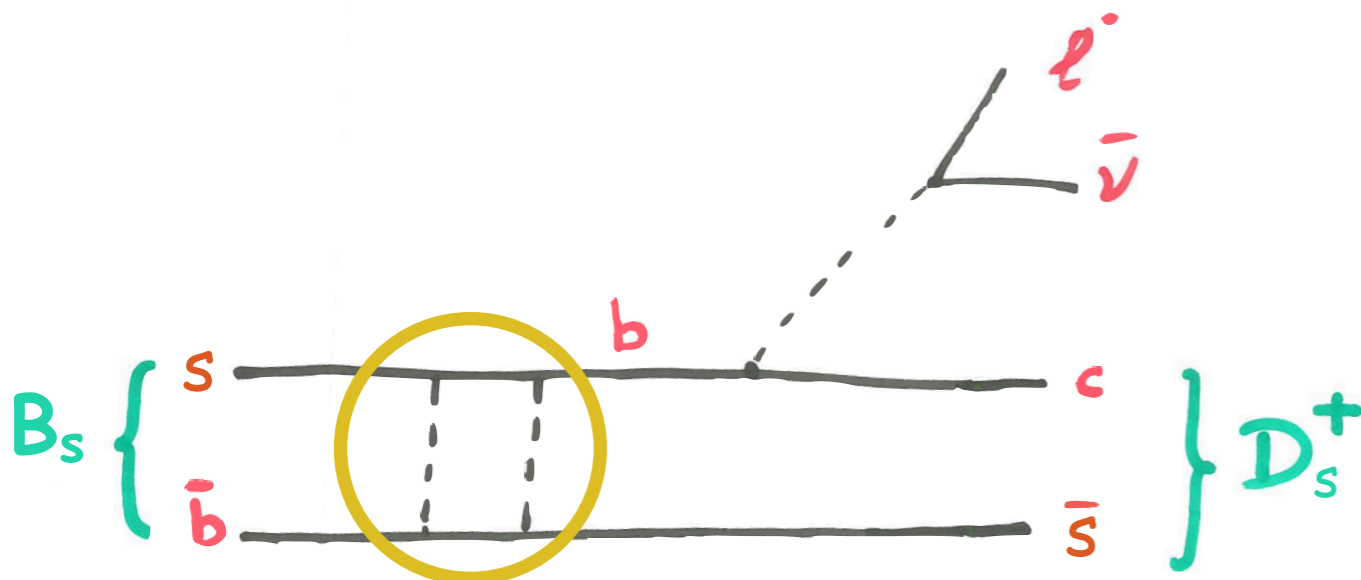
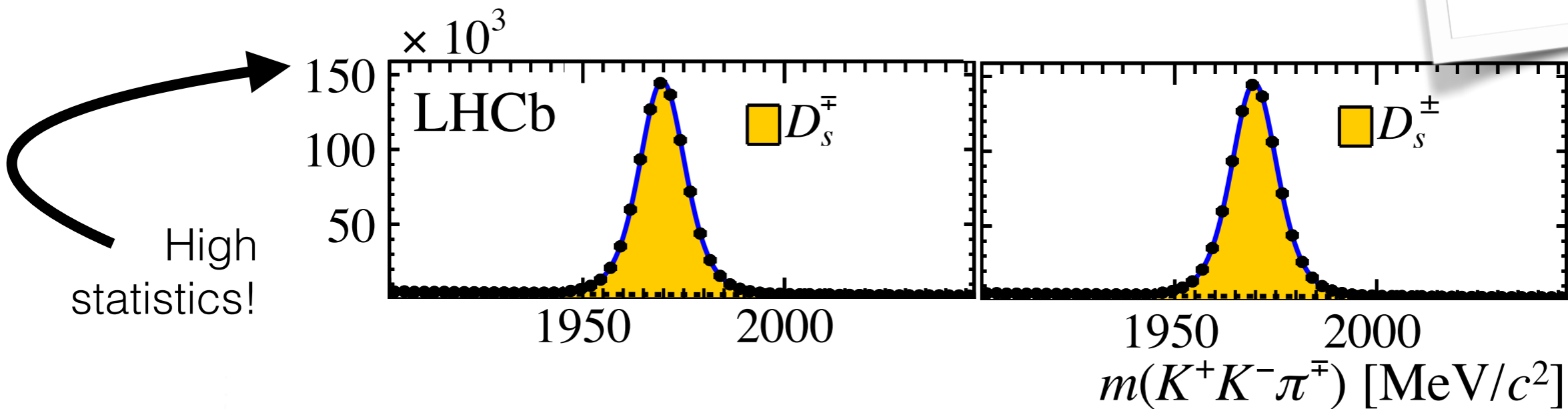
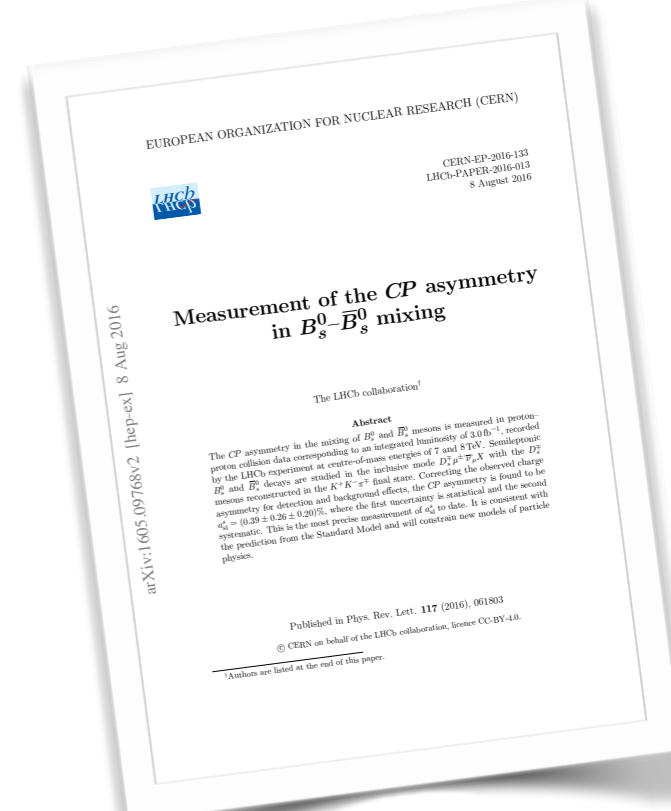


Mixing asymmetry visible via the use of **semileptonic decays**

**= Muons at LHCb**

# $a_{sl}^S$ , in a nutshell

Counting experiment: select high pT muons, combine with charm.

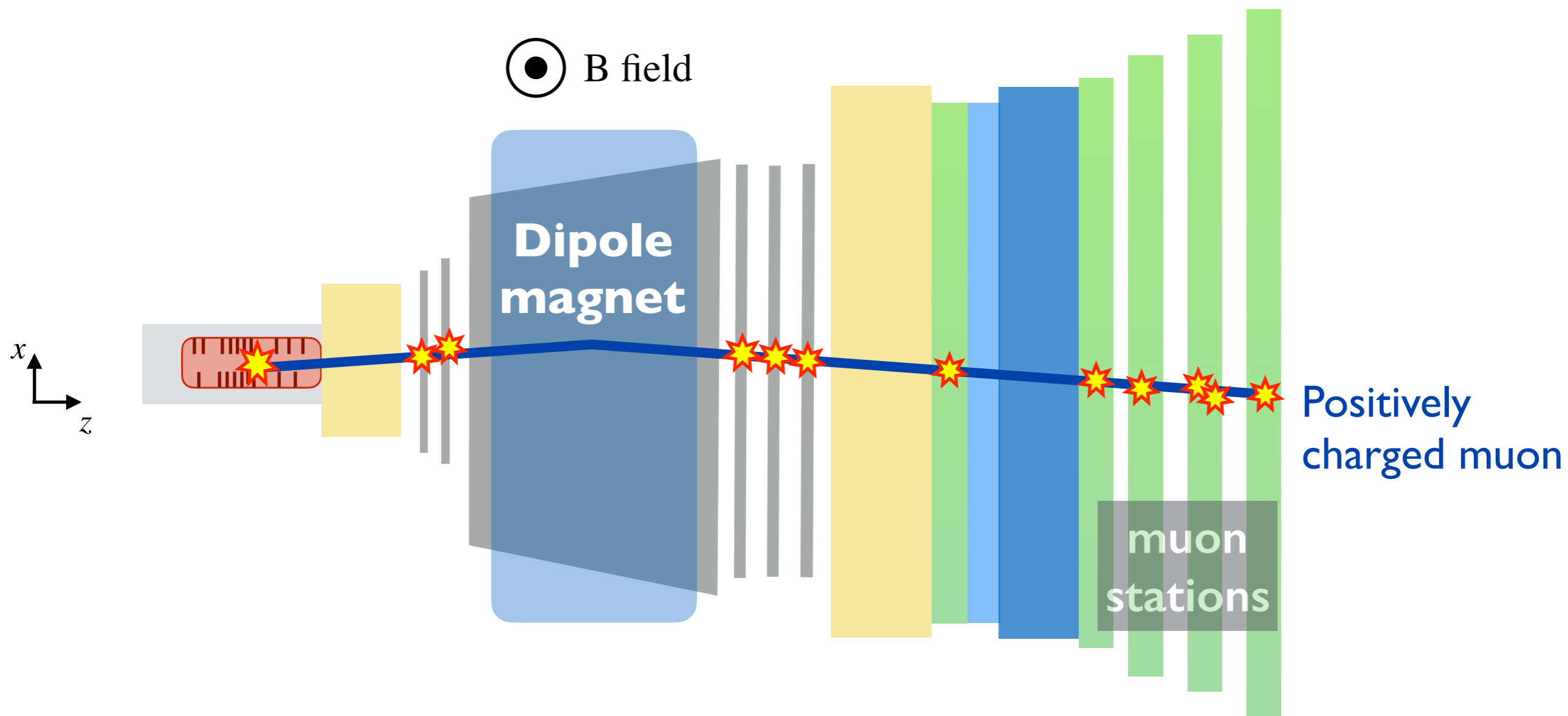


$$a_{sl}^S = (0.39 \pm 0.26 \pm 0.20) \%$$

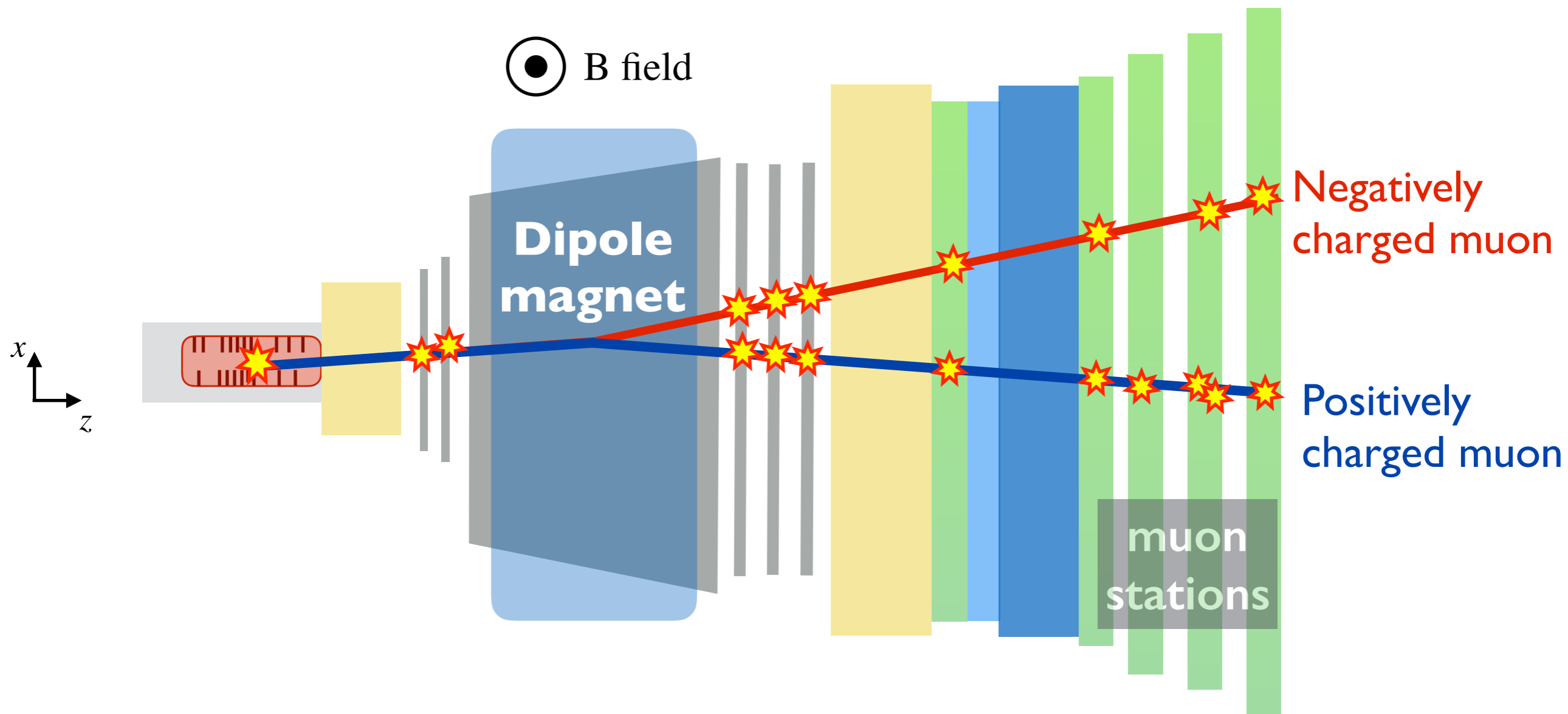




# LHCb's charge separation

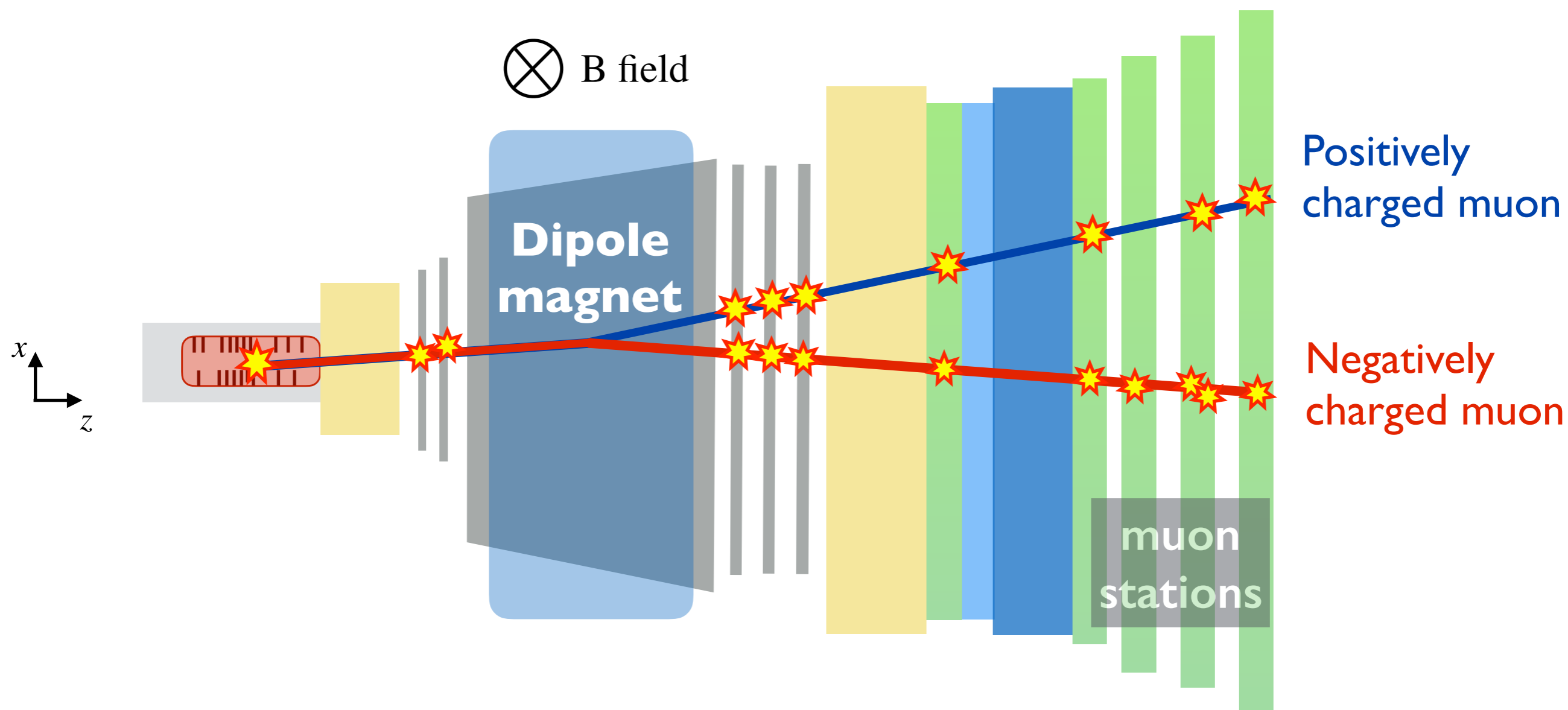


# LHCb's charge separation



Magnet: measurement of CP violation ~ the measurement of left-right symmetry

# LHCb's charge separation



Reversing the magnet polarity doesn't cancel asymmetries of order  $10^{-3}$

Need to understand asymmetries for polarities separate

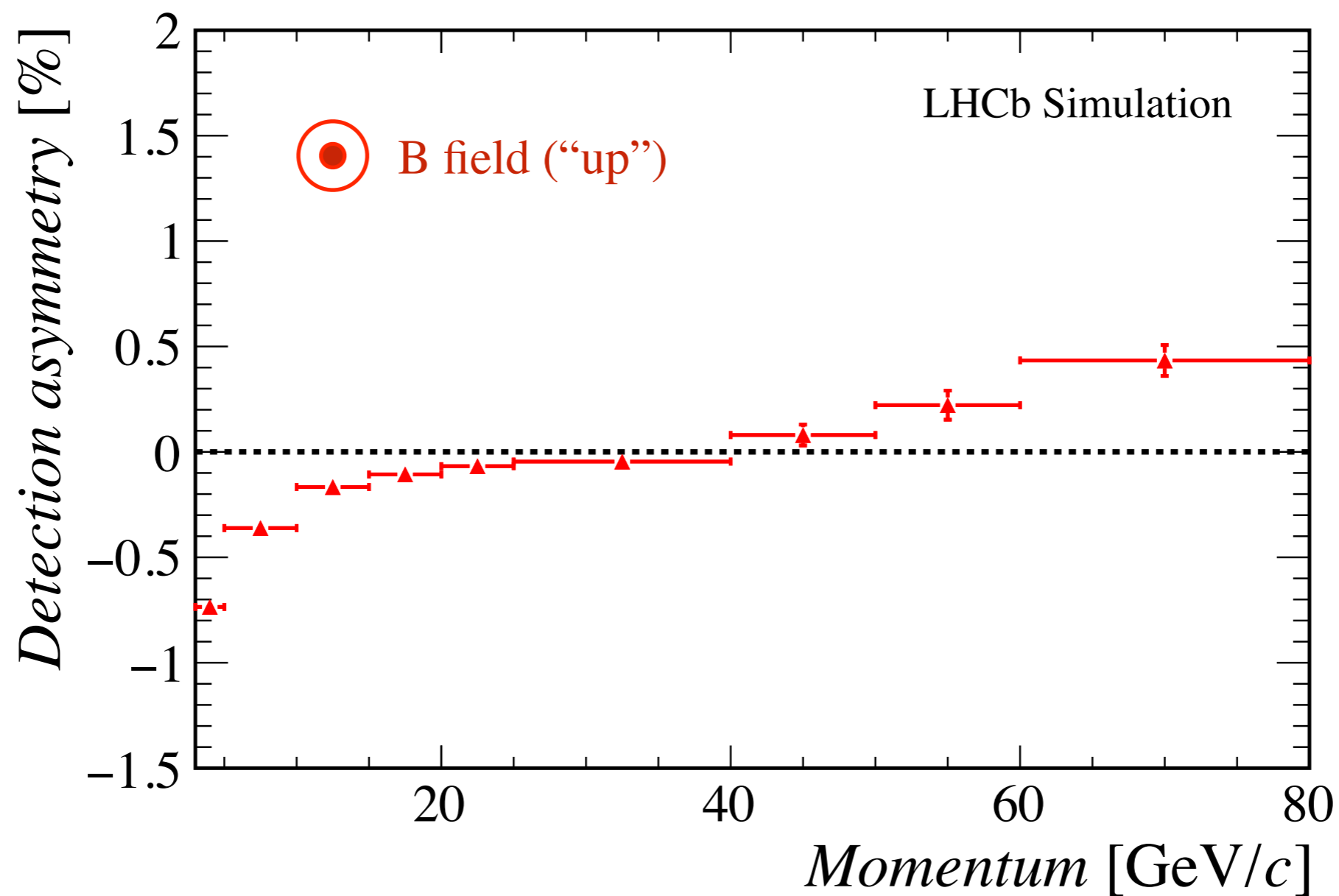
# LHCb's charge separation



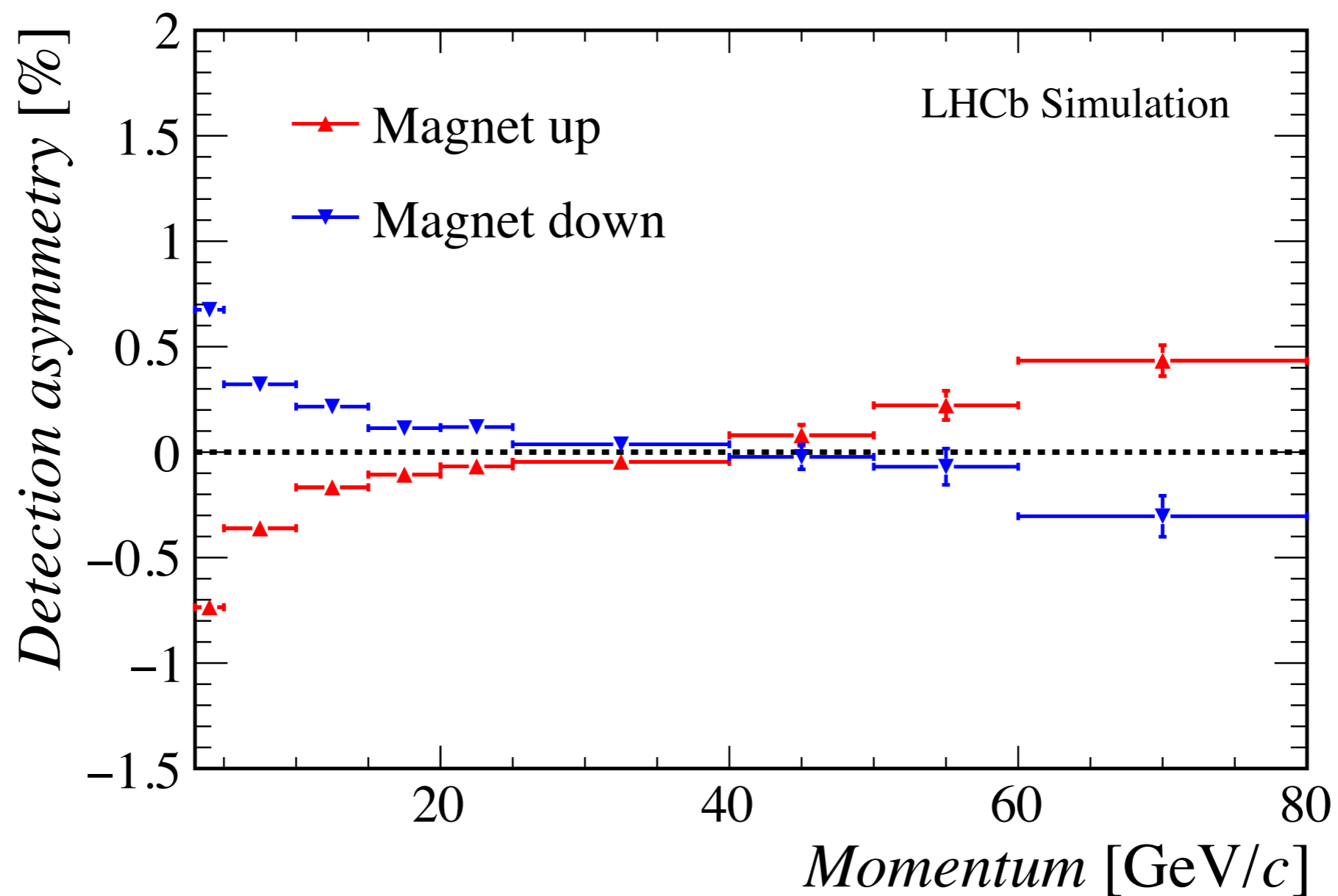
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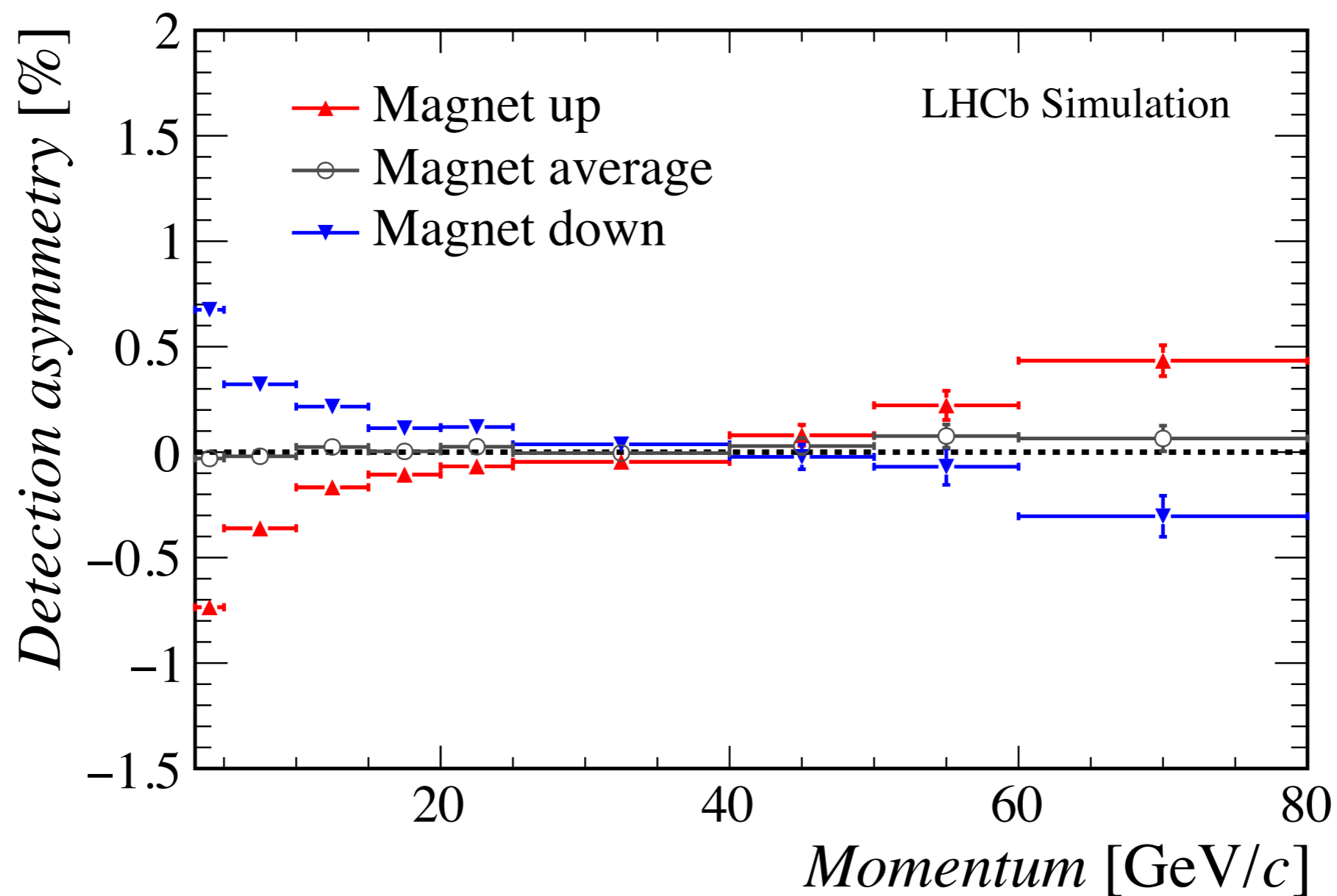
# Asymmetry in our simulation



# Asymmetry in our simulation



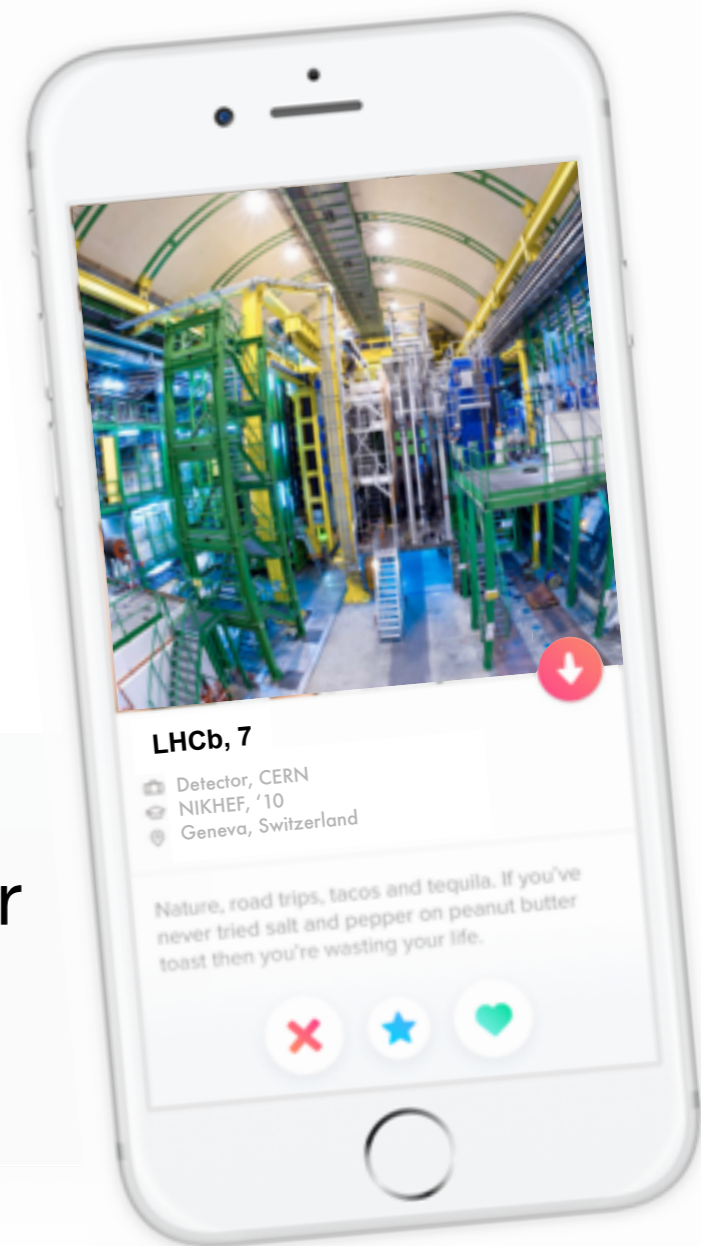
# Asymmetry in our simulation



Compare with  $a_{sl}^s = (0.39 \pm 0.26 \pm 0.20) \%$

# Get to know your detector

Doing precision (CP) measurements ~ calibrating your detector *very well!*





# Get to know your detector

## Alignment

- VELO left & right half alignment
- Outer tracker space between modules
- Imperfect magnetic field
- Movement of detectors under influence of the magnetic field

## Defects

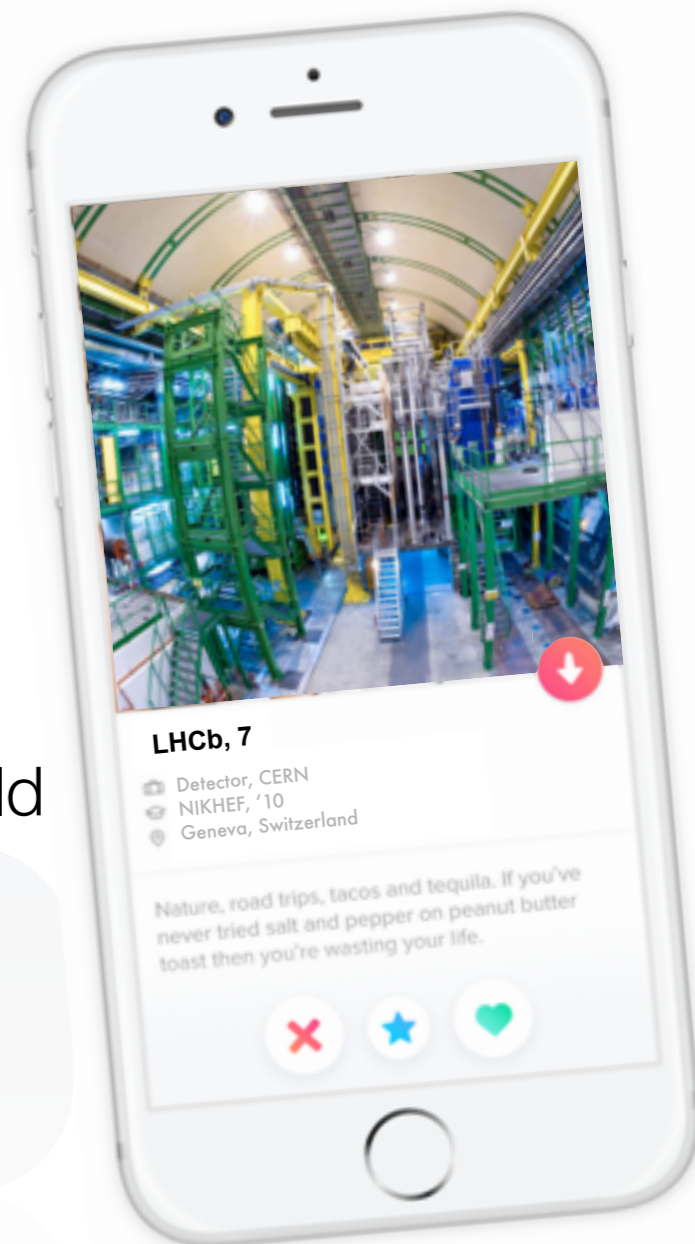
- VELO sensor design
- VELO ageing near the end of the sub detector
- Sensor defects in T/OT

## Beam

- Beam crossing angle
- **Beam spot position offset**

## Physics

- Support structure placement
- Asymmetric occupancy due to production asymmetry (secondaries)
- Asymmetric interaction cross-sections

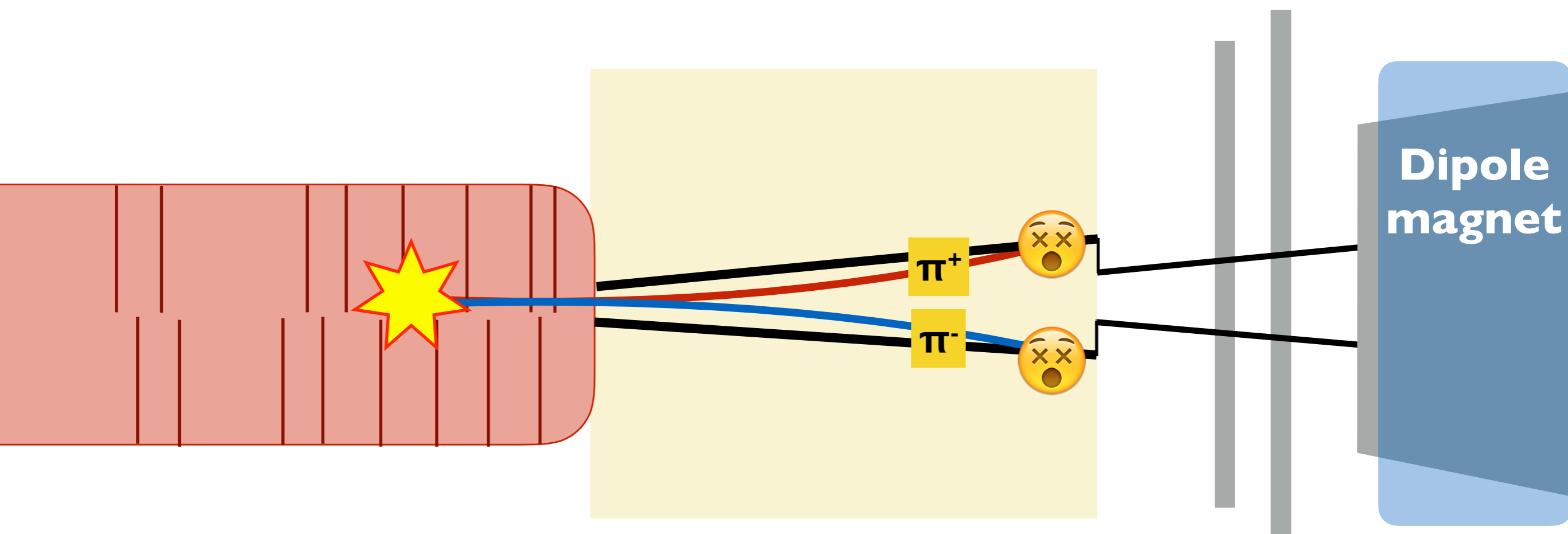


# Effects of beam spot position

VELO detector

RICH detector

TT

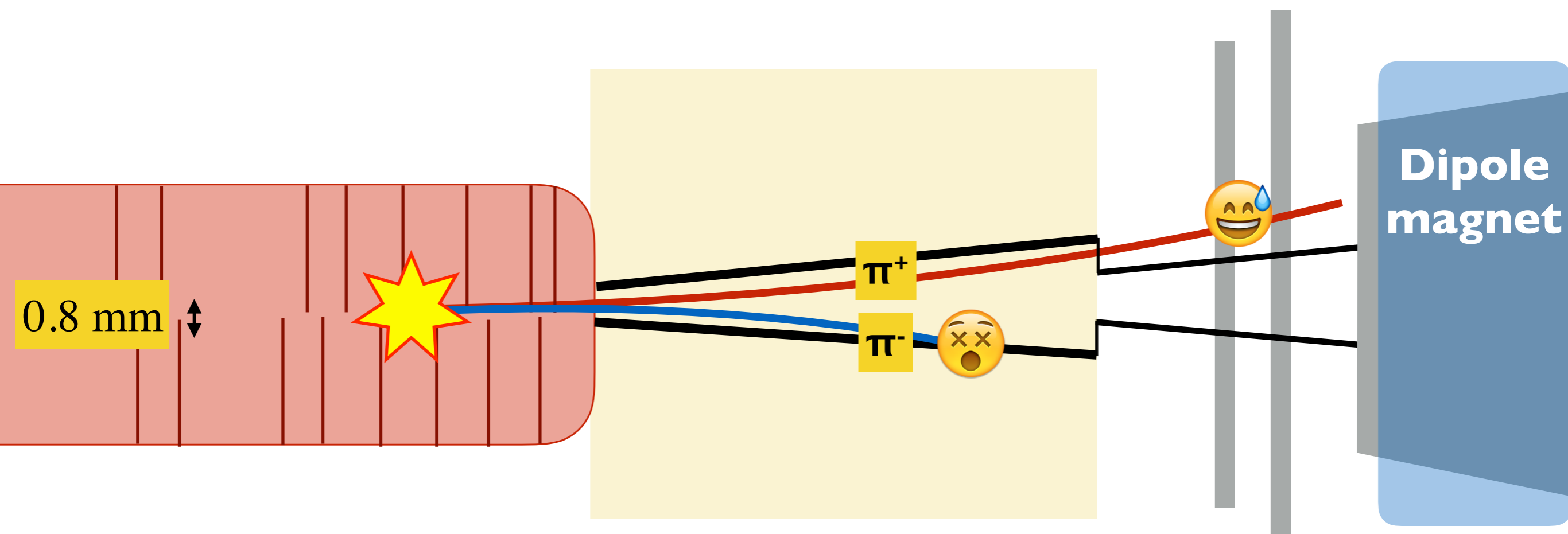


# Effects of beam spot position

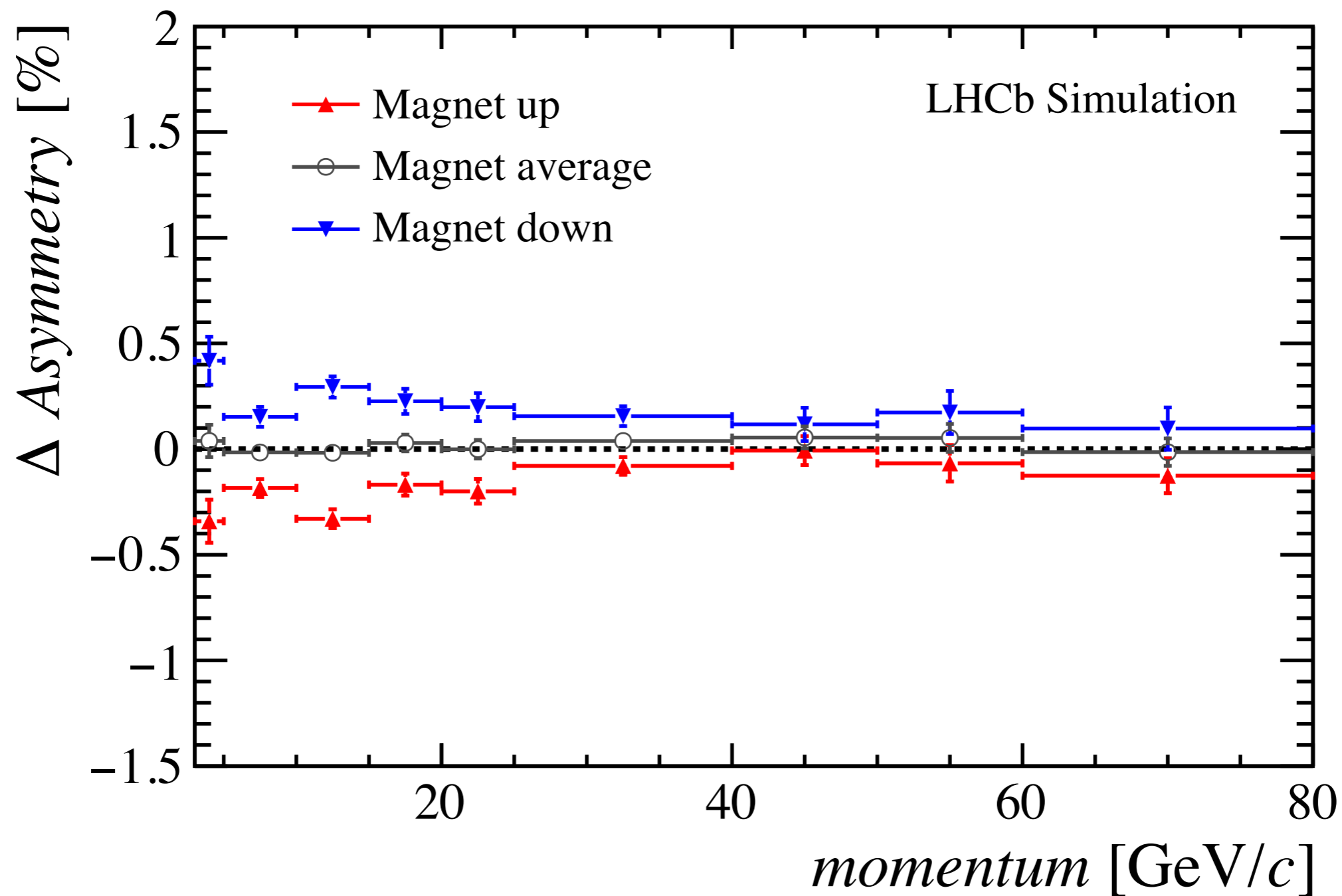
VELO detector

RICH detector

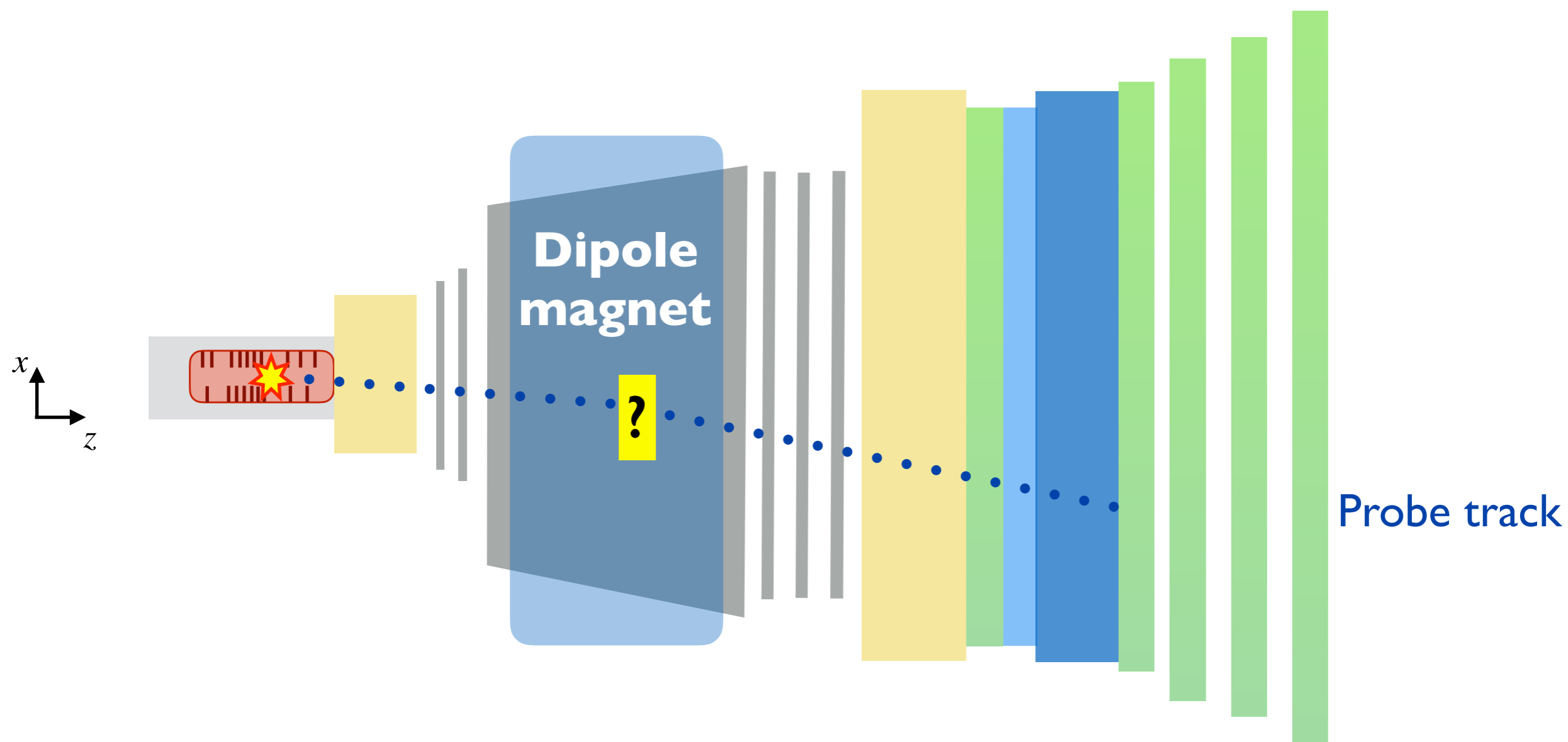
TT



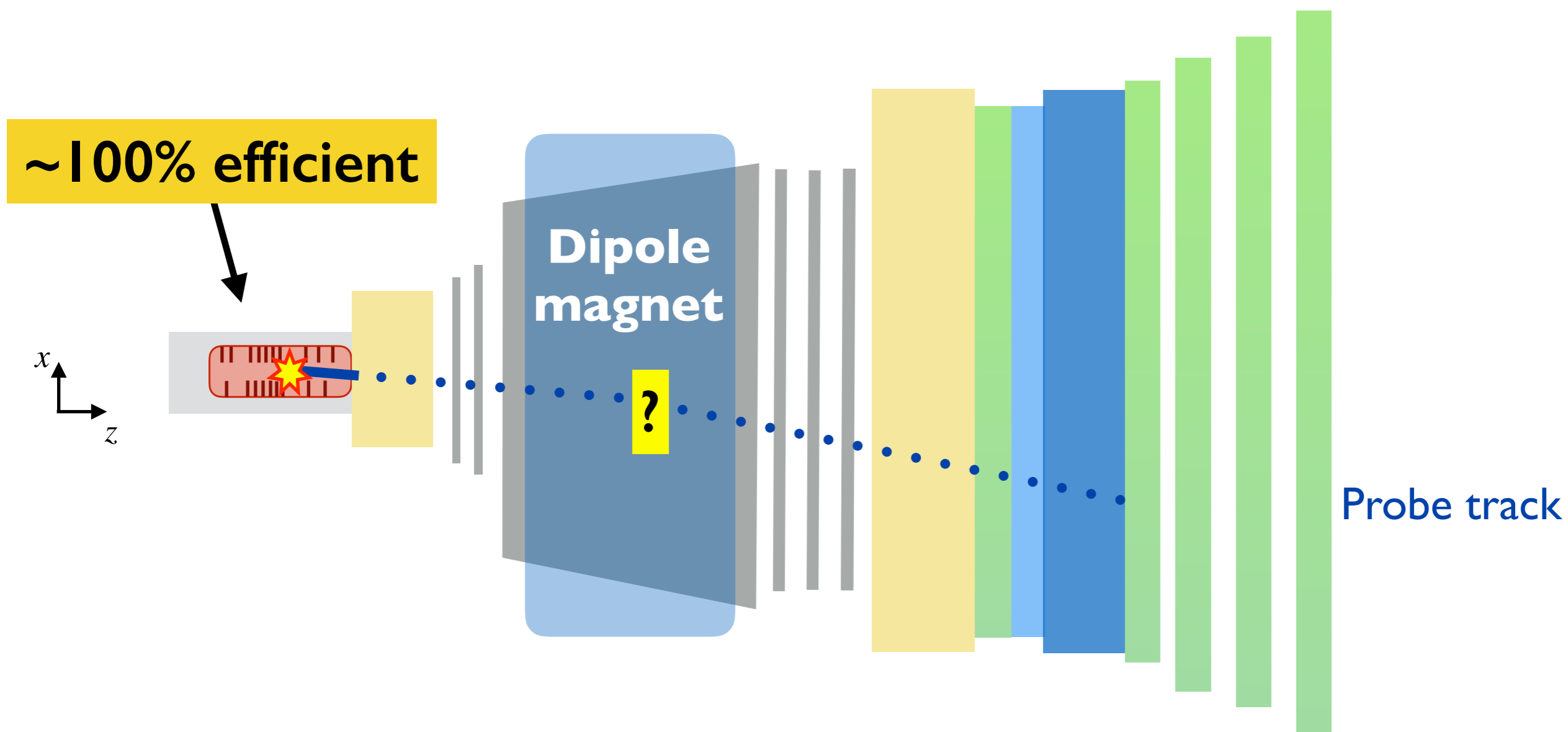
# Effects of beam spot position



# How to get this information from data



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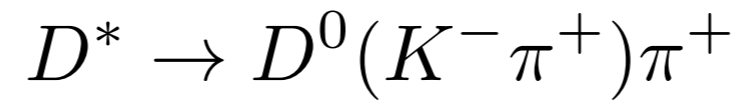
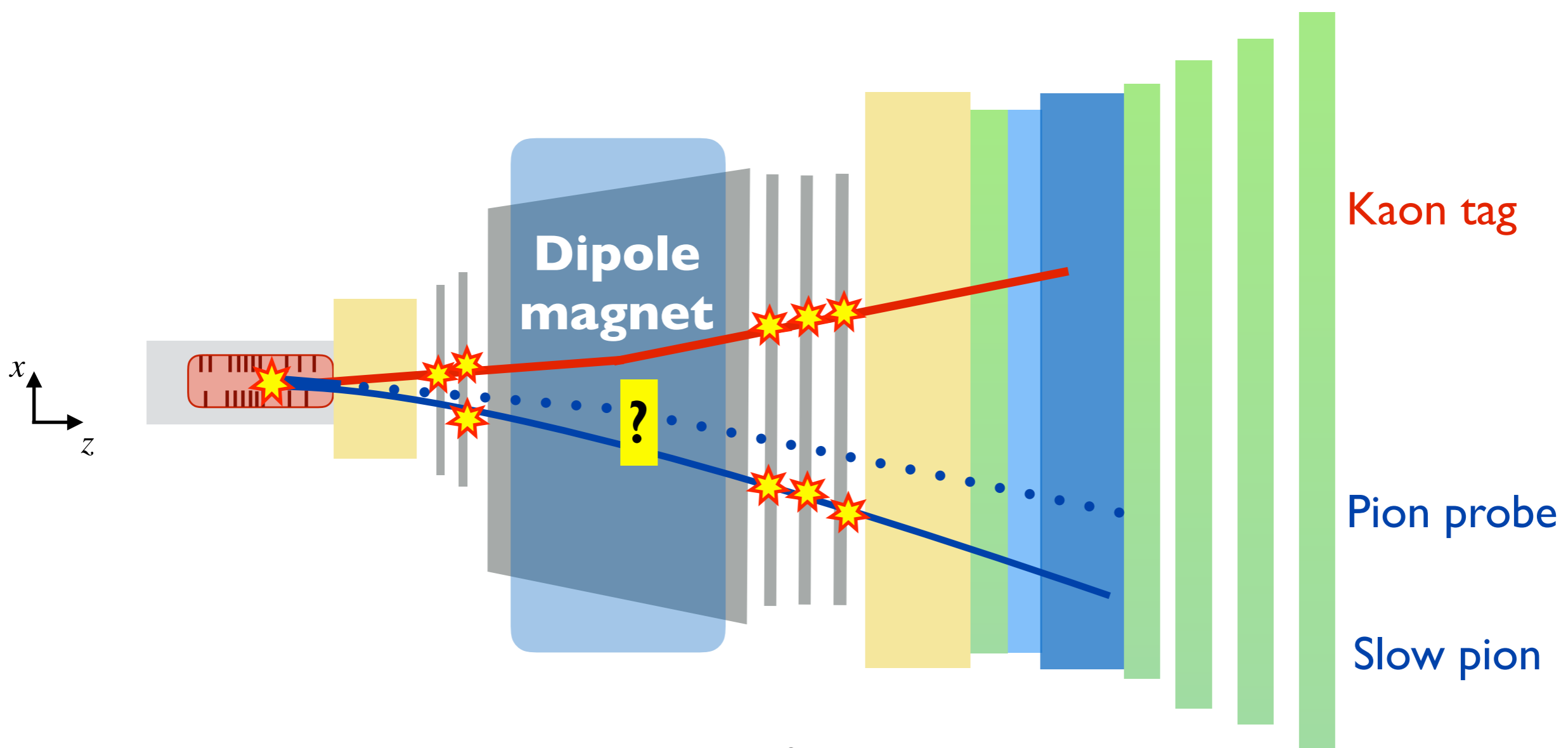


Efficiency (LHCb)  $\sim$  Efficiency (LHCb | VELO)

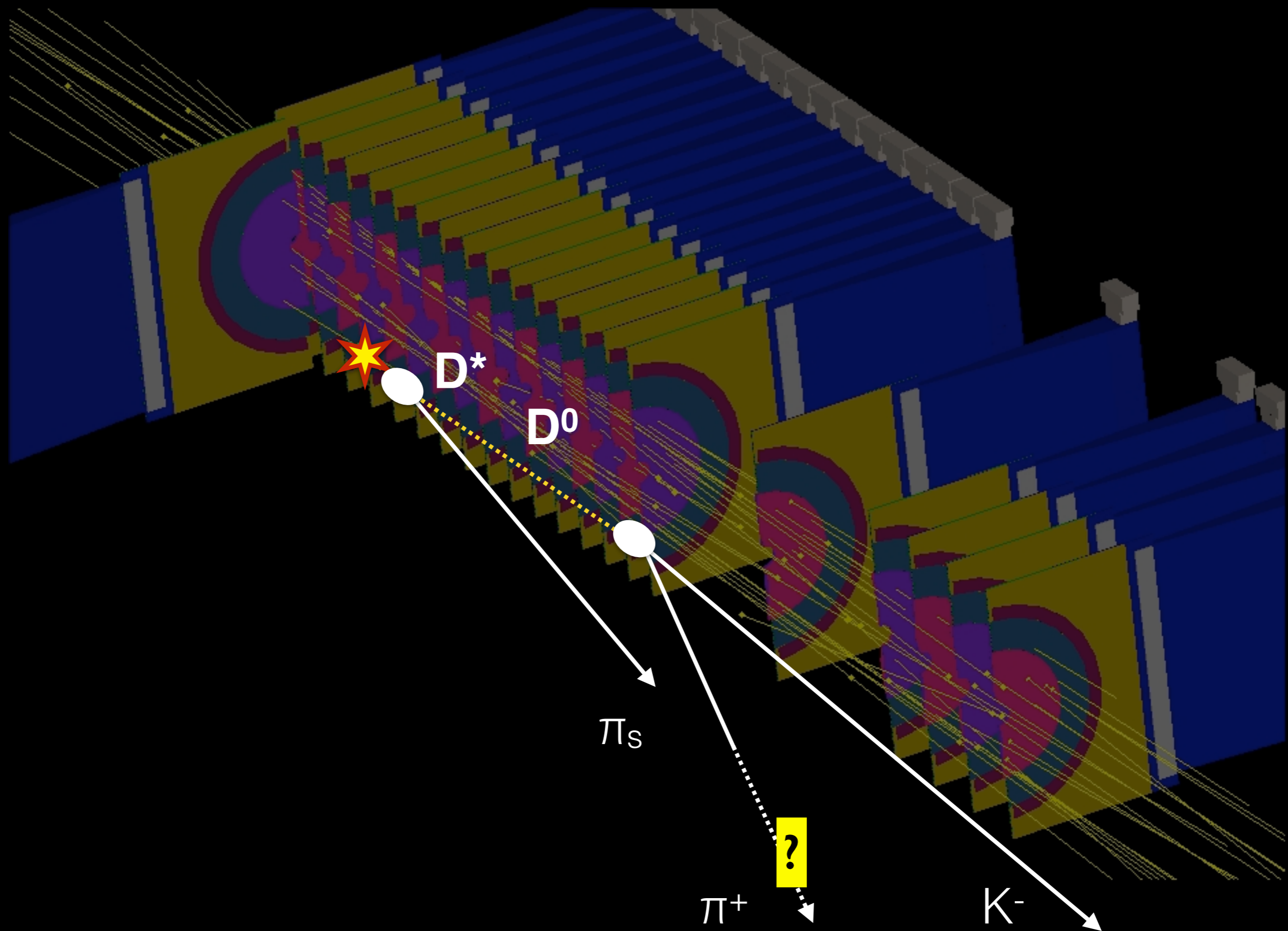
Can we find the rest of the track, with just the VELO segment?

IMPROVED IN RUN 2

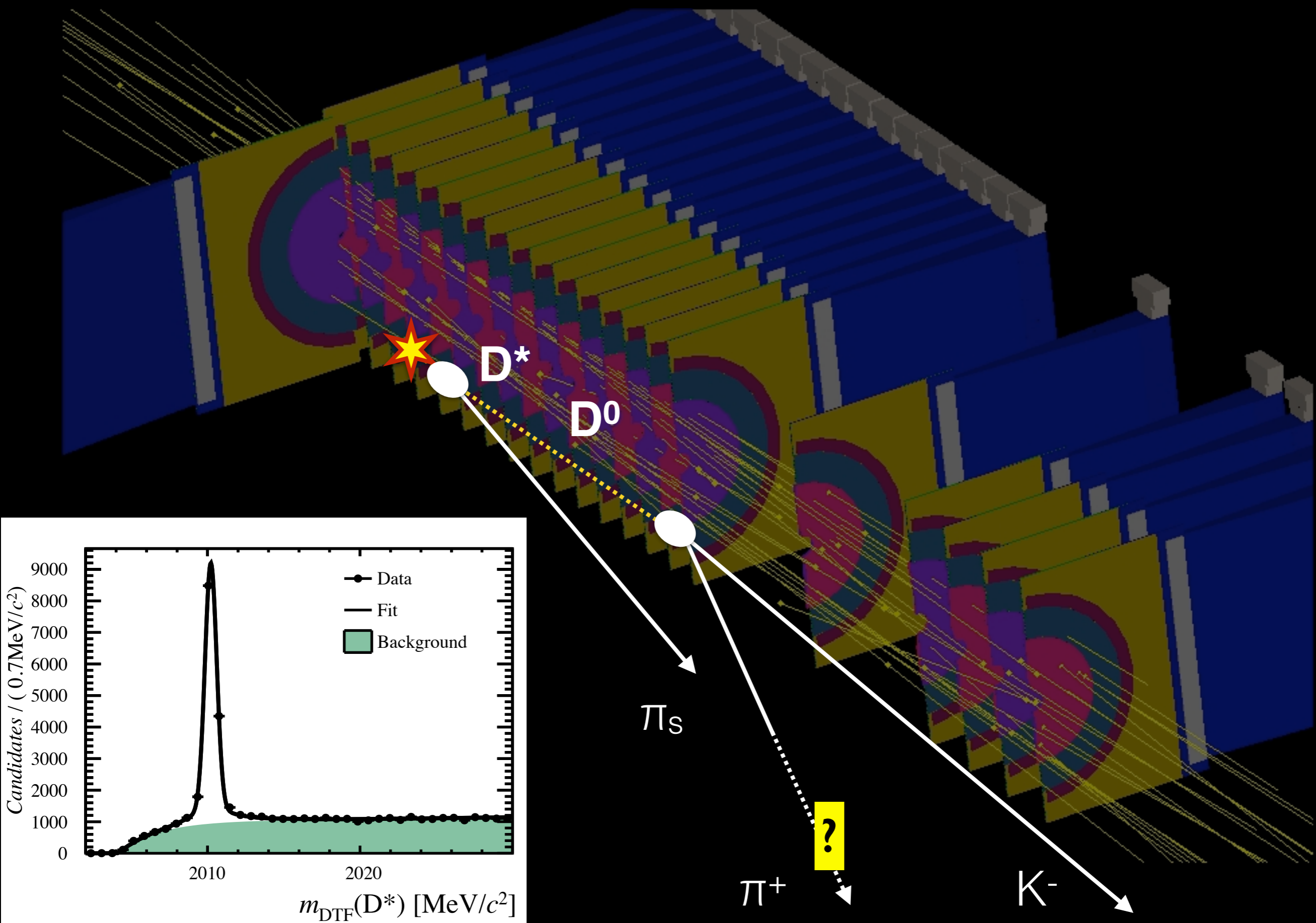
# How to get this information from data



**Decay: momentum estimate**







# Sensitivity

## Alignment

- ✓ VELO left & right half alignment
- ✓ Outer tracker space between modules
- ✓ Imperfect magnetic field
- ✓ Movement of detectors under influence of the magnetic field

## Defects

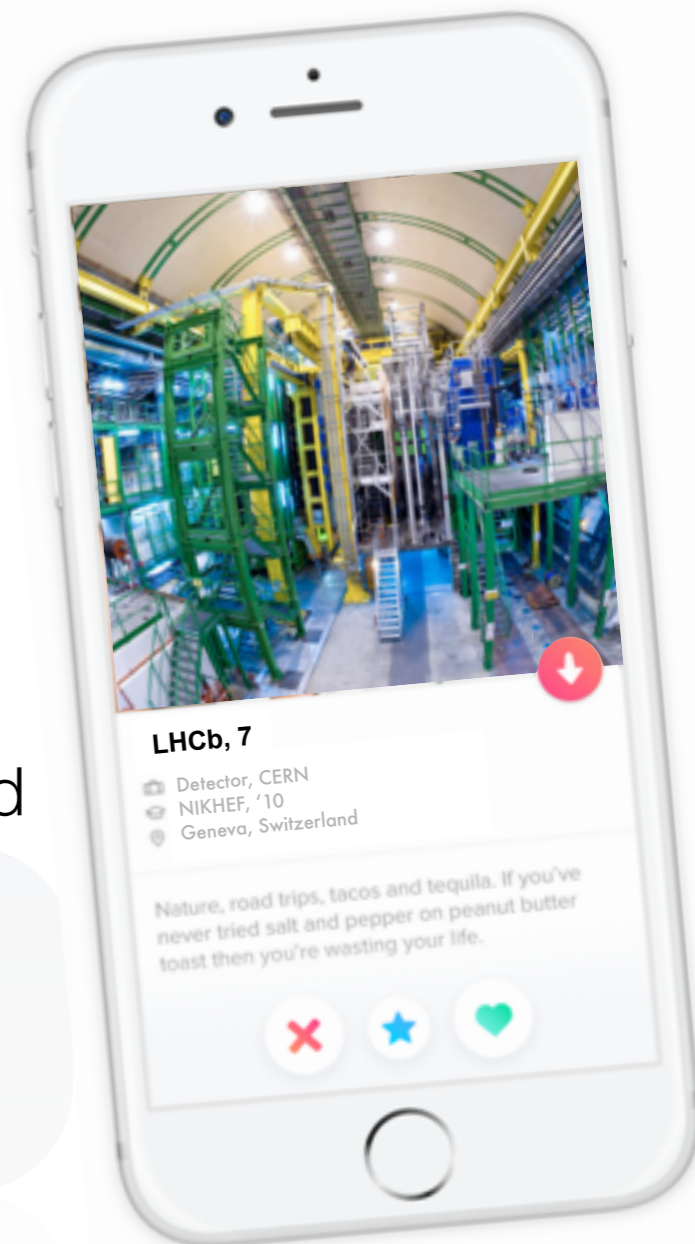
- **VELO sensor design**
- **VELO ageing near the end of the sub detector**
- ✓ Sensor defects in T/OT

## Beam

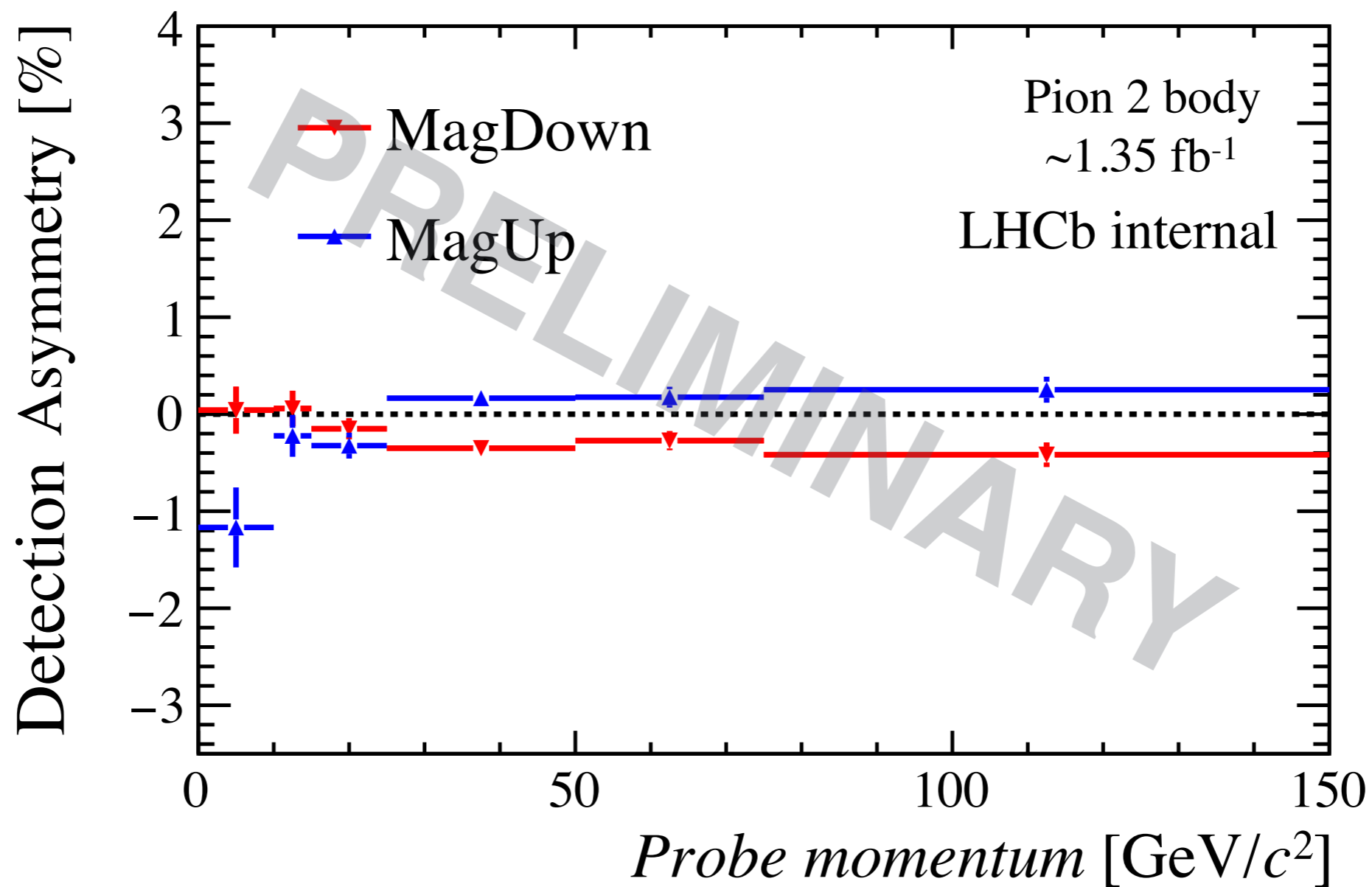
- ✓ Beam crossing angle
- ✓ Beam spot position offset

## Physics

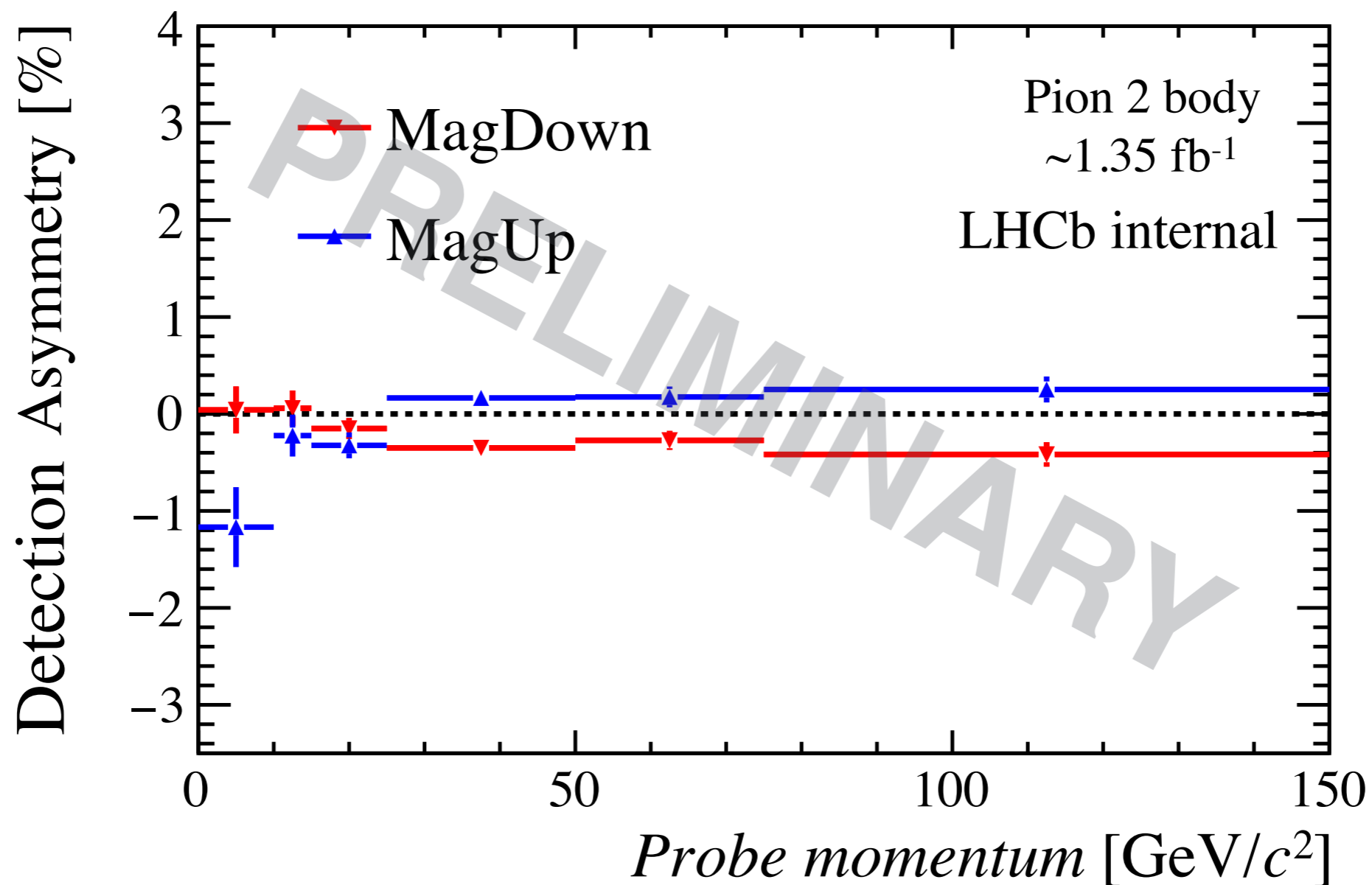
- ✓ Support structure placement
- ✓ Asymmetric occupancy due to production asymmetry (secondaries)
- ✓ Asymmetric interaction cross-sections



# Pion asymmetry



# Impact on our example



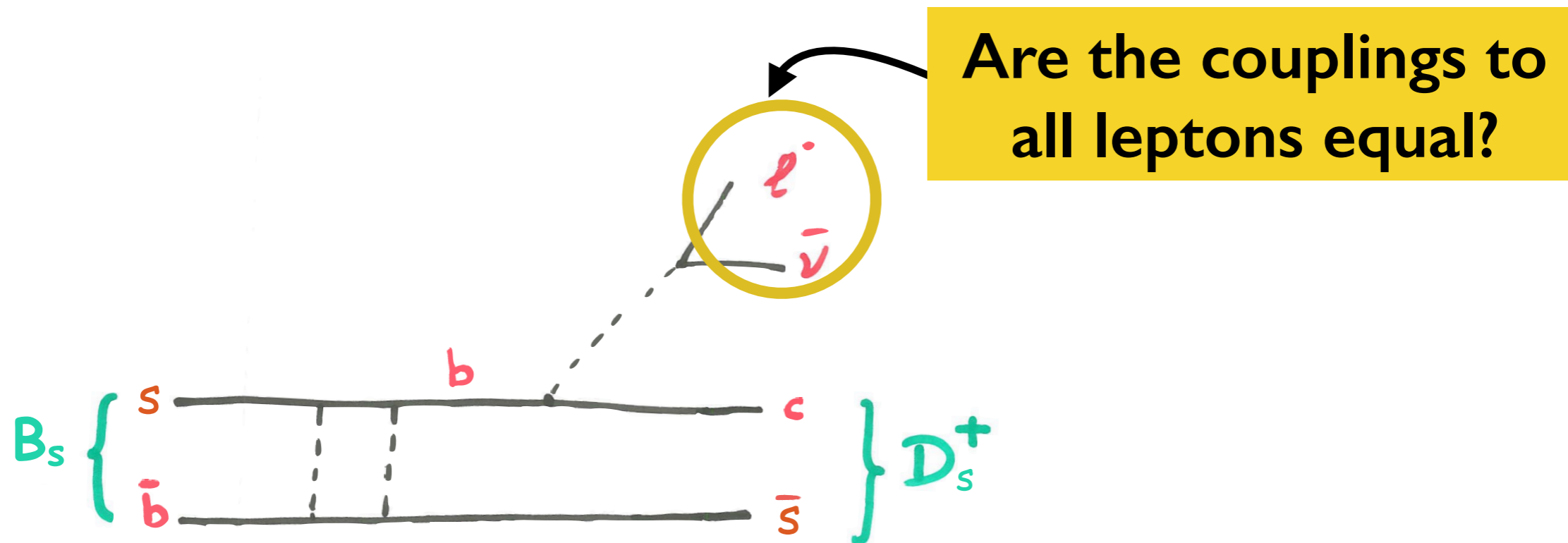
Projected uncertainty on  $a_{sl}$ :  
0.1% per  $3 \text{ fb}^{-1}$  (was 0.2%)

# Impact on our example



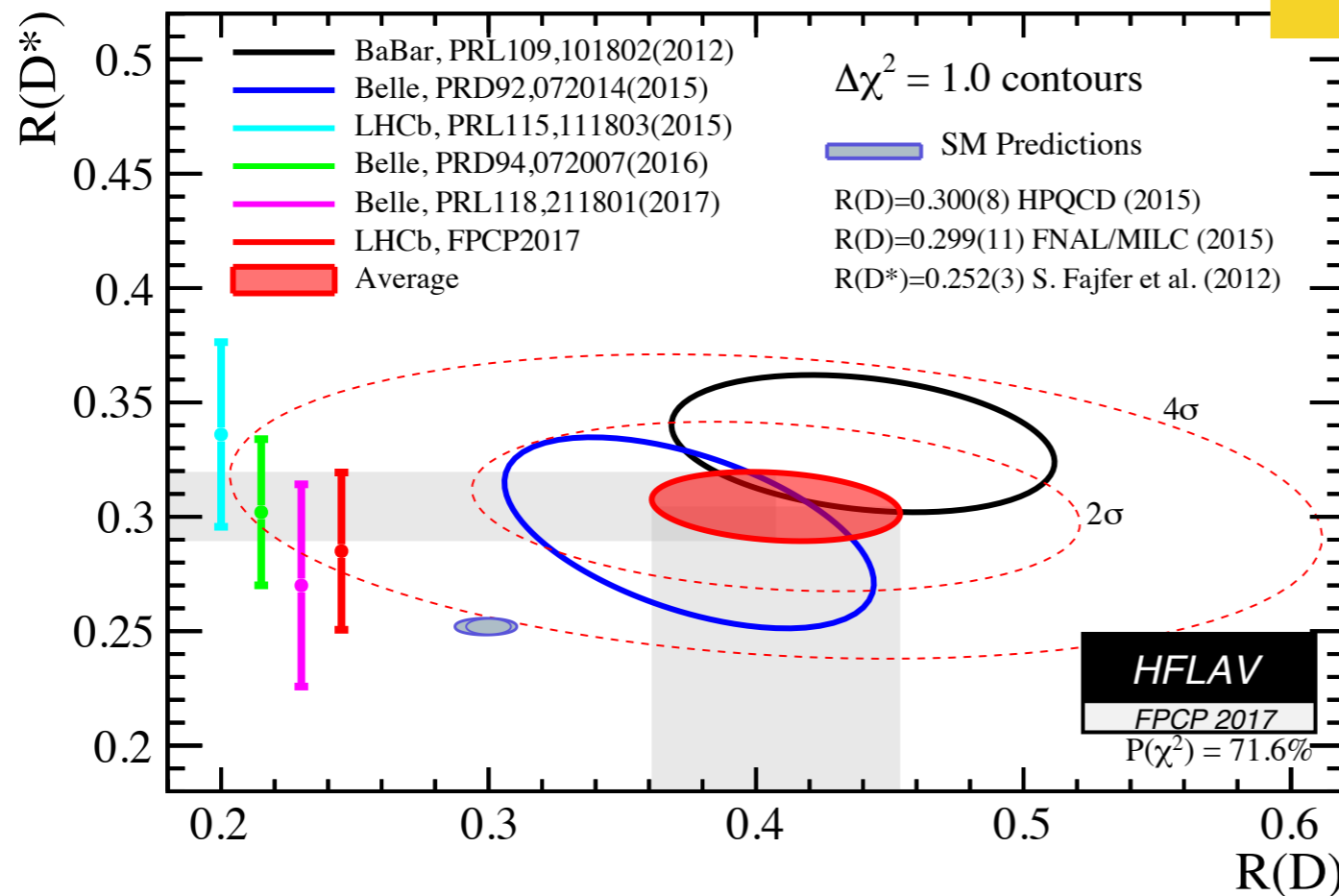
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# Prospects for new physics channels



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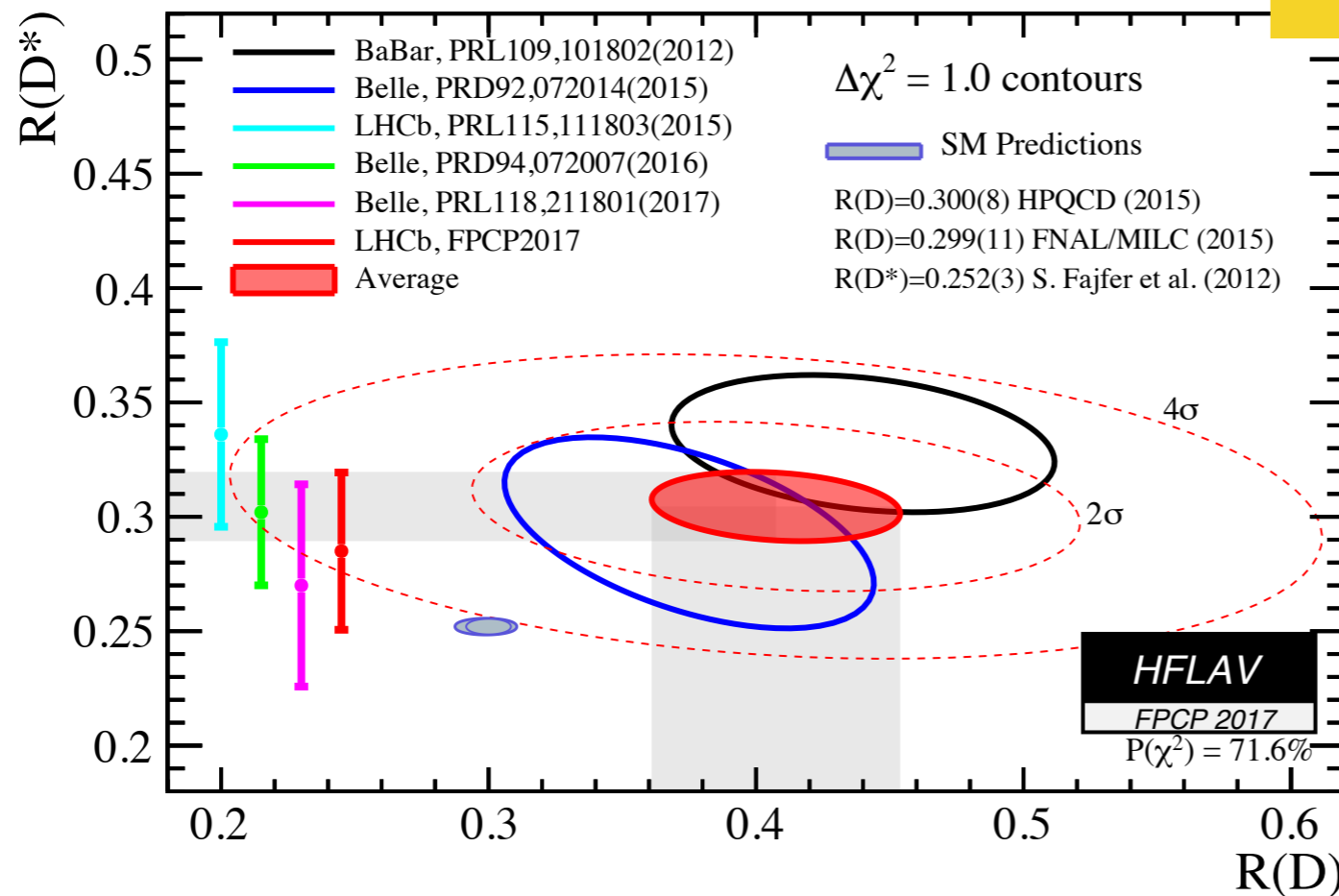
**Are the couplings to all leptons equal?**



$$R(D) = \frac{\mathcal{B}(B \rightarrow D\tau\nu)}{\mathcal{B}(B \rightarrow D\mu\nu)}$$

# Prospects for new physics channels

**Are the couplings to all leptons equal?**



...maybe (4.1 $\sigma$ ) not?

$$R(D) = \frac{\mathcal{B}(B \rightarrow D\tau\nu)}{\mathcal{B}(B \rightarrow D\mu\nu)}$$



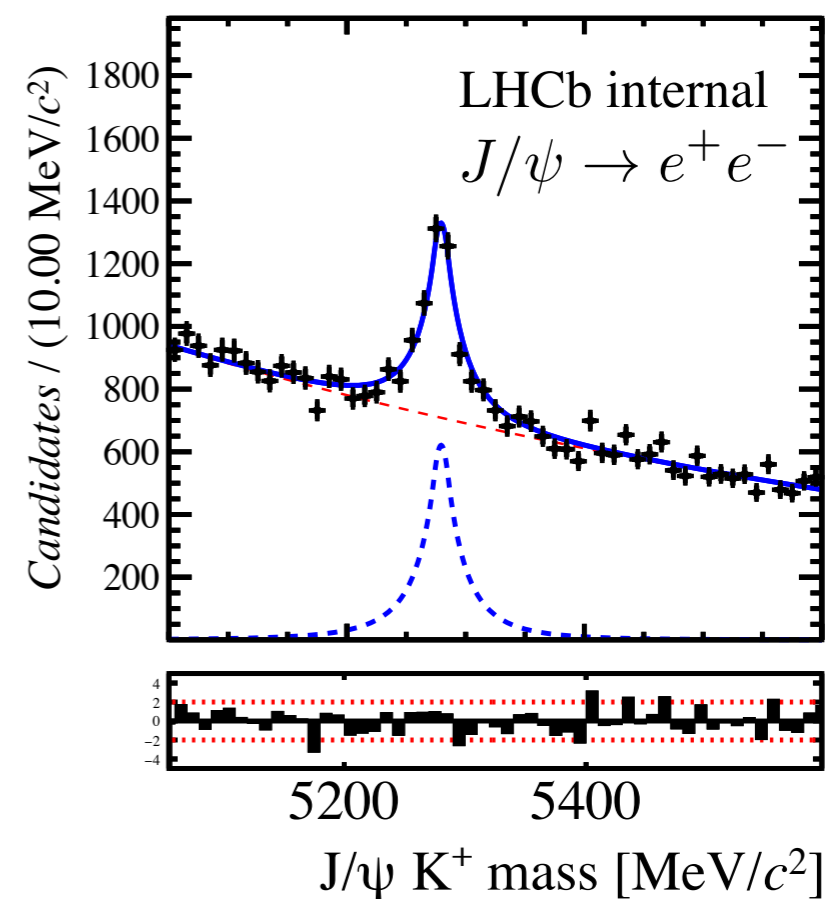
# Prospects for new physics channels

Now have direct access to a data-driven input for the electron detection efficiency.

The missing input to measure the non-universality with **electrons!**

$$\frac{\mathcal{B}(B \rightarrow De\nu)}{\mathcal{B}(B \rightarrow D\mu\nu)}$$

**Are the couplings to all leptons equal?**



# Summary & conclusion

LHCb is **not symmetric**, but this is not a problem! (Only possible by the understanding of our detector, and **calibrating** constantly.)

LHCb will measure CP asymmetries with even better precision in Run 2. **All in the trigger (@Sean)**

Motivated by the measurement of asymmetries, now have access to new channels original thought outside of design.



# Precision CP measurements at LHCb

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Many thanks to M. Vesterinen

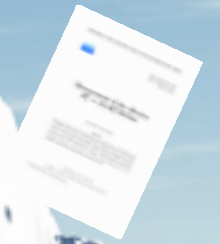
Physics

**Calibration**

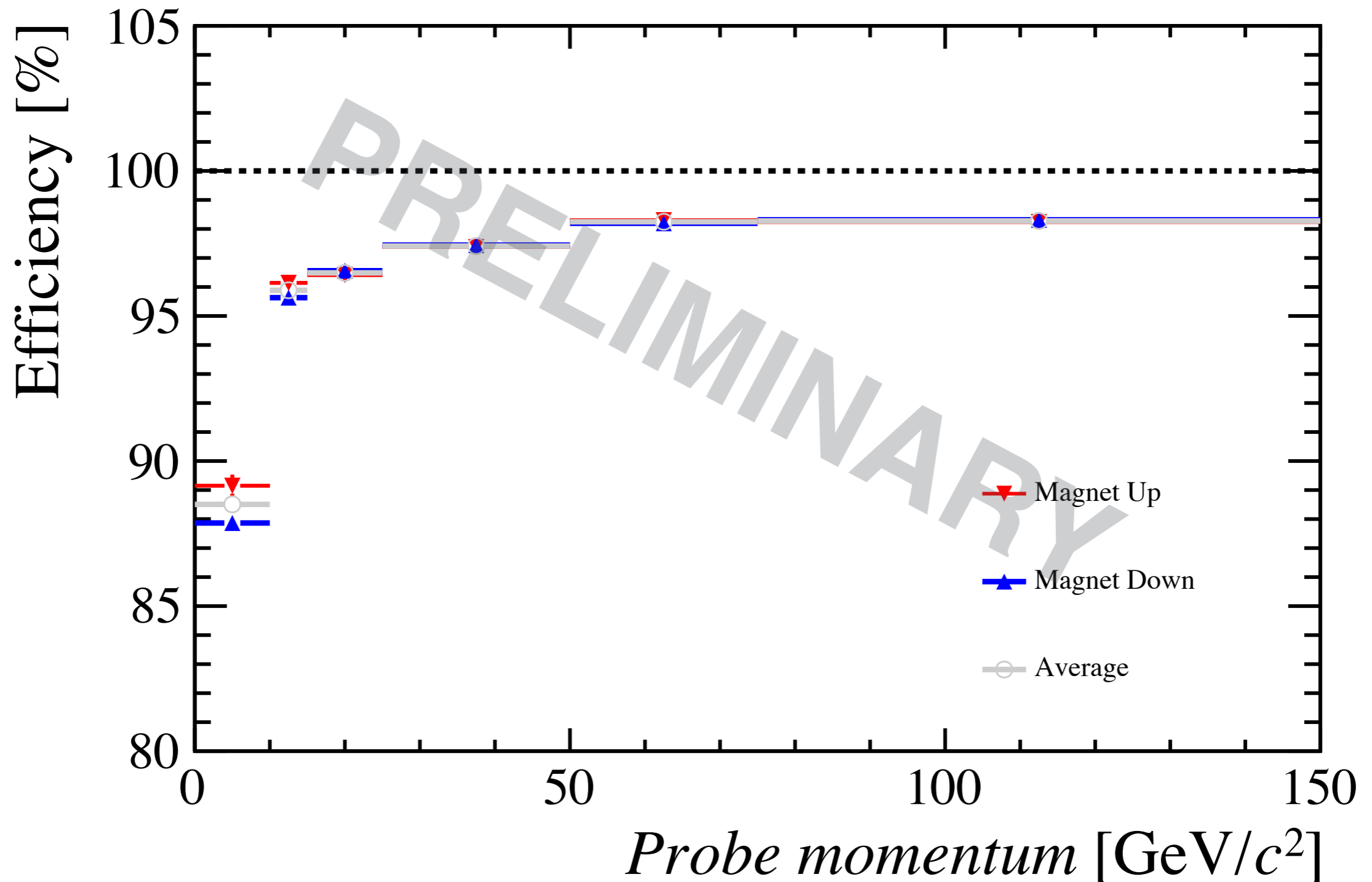
Software & Trigger

Operations

Hardware



# Pion long|velo efficiency



# Effects of inner tracker support

- Picture of IT support
- Effect on measurements

