Slow pion reconstruction at HEPHY

Christoph Schwanda
Institute of High Energy Physics,
Austrian Academy of Sciences

FSP Workshop: Slow pion tracking, Nov 8-12, 2021, MIAPP (Garching)

Outline

- In this talk, I would like to comment on the physics impact of slow pion reconstruction on two analyses done in Vienna:

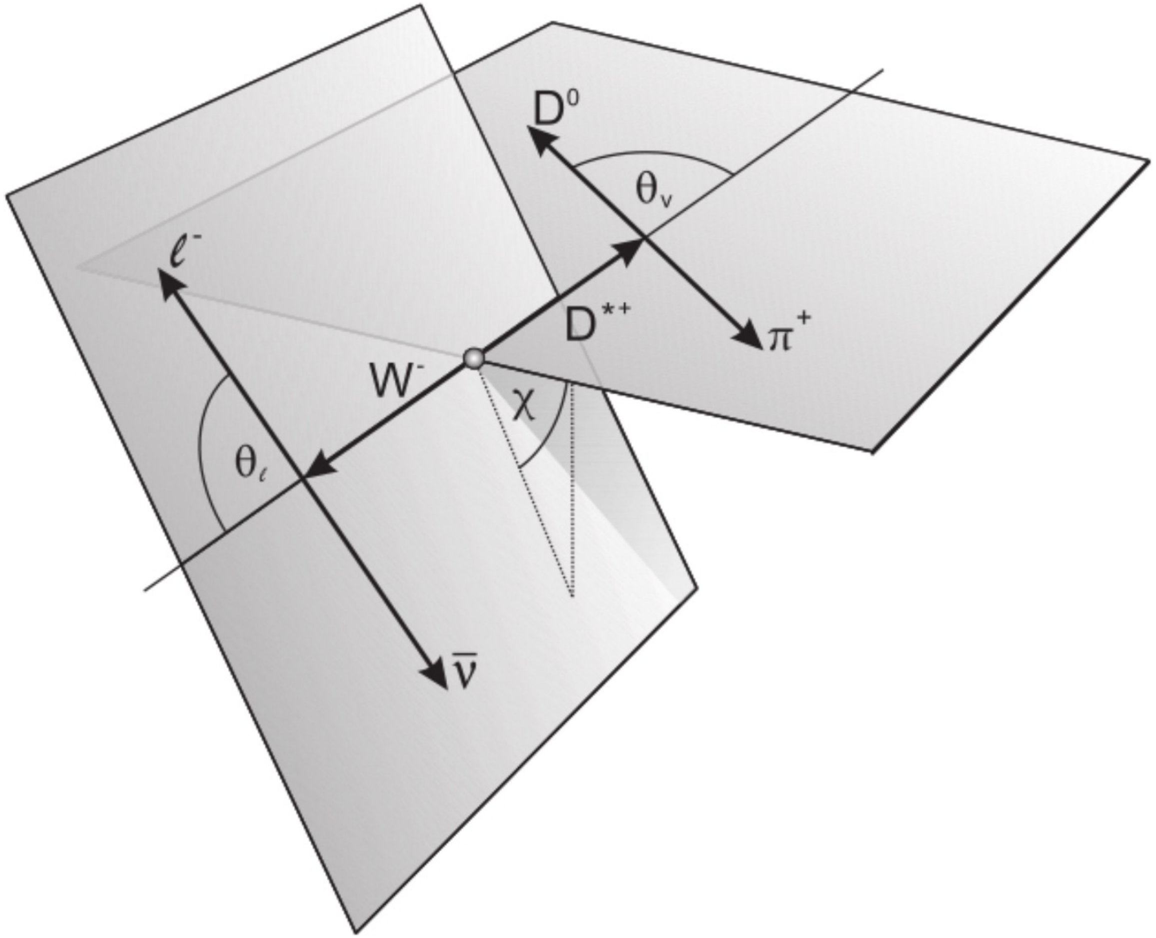
1. $B^0 \rightarrow D^{*-}(\bar{D}^0\ \pi^-)\ l^+\ \nu$ untagged (Daniel Dorner, Sebastian Dorer)

2. $B^+ \rightarrow \bar{D}^0\ l^+\ \nu$ untagged (Philipp Horak)

$B \to D^*(D\pi)\, l\, \nu$ untagged

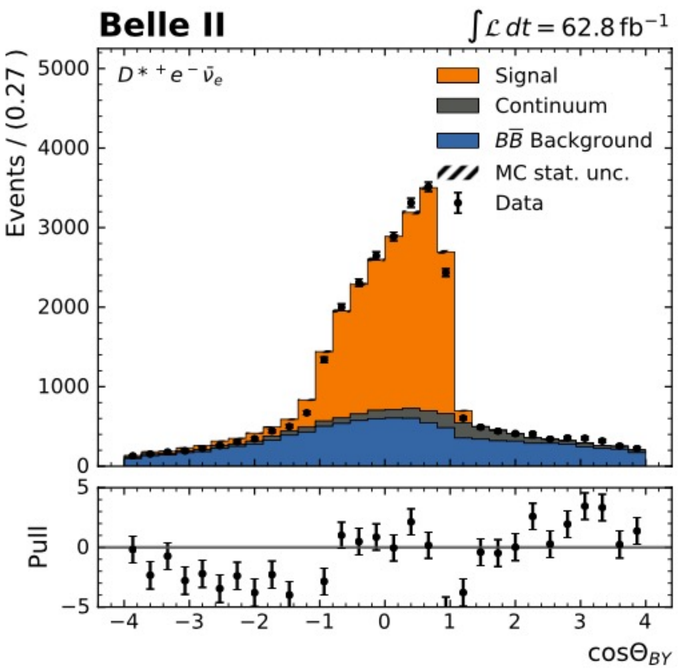
- D^{*+} is searched for in the decays modes $D^{*+} \to D^0 \pi^+_s$ and $D^0 \to K^- \pi^+$, where π_s is the slow pion
- No requirement on the second B meson in Belle II Y(4S) event
- Inclusive reconstruction of the neutrino to determine kinematic variables of the decay (w/q^2, cos θ_l, cos θ_V, χ)
- Signal is extracted from the cos θ_{BY} distribution:

$$\cos\theta_{BY} = \frac{2\,E_B^* E_Y^* - m_B^2 - m_Y^2}{2|p_B^*||p_Y^*|}, \quad Y = D^{*+}\ell$$

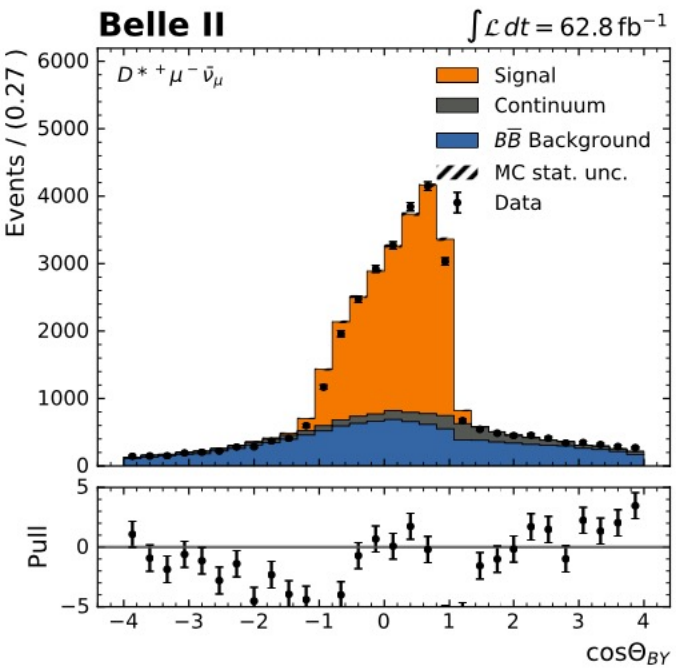


Belle II internal release 4 results preliminary

Electron mode



Muon mode



Branching Fractions	
***e*-mode** [%]	4[redacted] $\pm$ 0.056(stat.) $\pm$ 0.277(sys.)
***μ*-mode** [%]	4[redacted] $\pm$ 0.051(stat.) $\pm$ 0.287(sys.)
combined [%]	4[redacted] $\pm$ 0.037(stat.) $\pm$ 0.288(sys.)

Statistics are not an issue for this analysis but systematics are very significant!

Belle II internal release 4 results (2)

Rel. Systematics		
	e-mode [%]	μ-mode [%]
K, π, ℓ Tracking	2.1	2.1
π_s Tracking	4.8	4.8
MC Statistics	0.1	0.1
Charm Br	1.1	1.1
N_{B^0}	1.8	1.8
Lepton ID	1.0	1.9
Form Factor	0.3	0.4
Total	5.7	6.0

Systematics are dominated by the uncertainty in slow pion reconstruction

In comparison: Belle PRD 100, 052007 (2019)

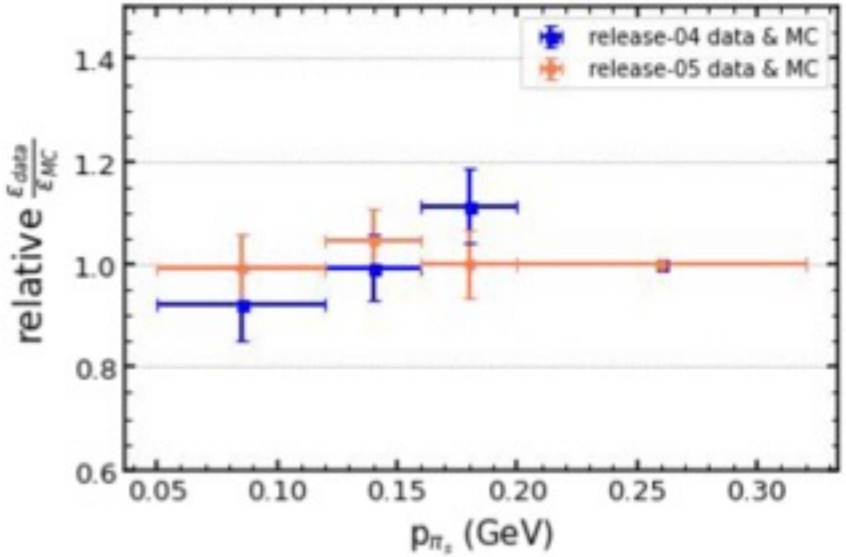
Source	ρ^2	$R_1(1)$	$R_2(1)$	$\mathcal{F}(1)\lvert V_{cb}\rvert$ [%]	$\mathcal{B}(B^0 \to D^{*-}\ell^+\nu_\ell)$ [%]
Slow pion efficiency	0.005	0.002	0.001	0.65	1.29
Lepton ID combined	0.001	0.006	0.004	0.68	1.38
$\mathcal{B}(B \to D^{**}\ell\nu)$	0.002	0.001	0.002	0.26	0.52
$B \to D^{**}\ell\nu$ form factors	0.003	0.001	0.004	0.11	0.22
f_{+-}/f_{00}	0.001	0.002	0.002	0.52	1.06
Fake e/μ	0.004	0.006	0.001	0.11	0.21
Continuum norm.	0.002	0.002	0.001	0.03	0.06
K/π ID	< 0.001	< 0.001	< 0.001	0.39	0.77
Fast track efficiency	-	-	-	0.53	1.05
$N\Upsilon(4S)$	-	-	-	0.68	1.37
B^0 lifetime	-	-	-	0.13	0.26
$\mathcal{B}(D^{*+} \to D^0\pi_s^+)$	-	-	-	0.37	0.74
$\mathcal{B}(D^0 \to K\pi)$	-	-	-	0.51	1.02
Total systematic error	0.008	0.009	0.007	1.60	3.21

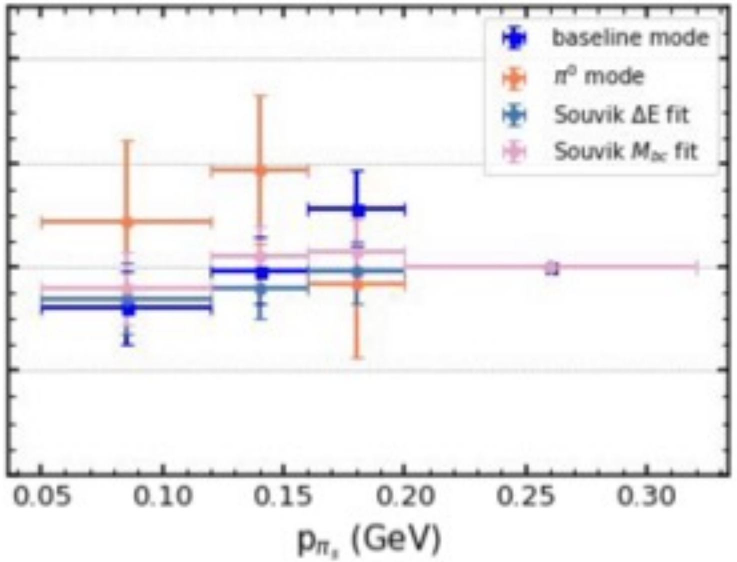
Slow pion efficiency

BELLE2-NOTE-PH-2020-036

S. Maity (IIT Bhubaneswar), S. Ipsita (IIT Hyderabad)
C. Lyu, F. Bernlochner (Bonn)

- Results on MC14ri_a vs proc12_chunk1 + buckets 16-20 data are available
- No significant change in results going from release-4 to release-5 data and MC
- Consistent results b/w two analysis teams (Chaoyi et al, and Souvik et al)
- Tried decay chain containing π^0, but the postfit distributions are not ideal. Plan to try π^0 efficiency correction in future.





- There is also a third study from J. Borah *et al*, inspired by the inclusive D^0 method from BABAR. Progressing well (see update here).

  Provides an independent cross-check that can benefit from higher statistics and wider momentum coverage. Backgrounds more challenging.

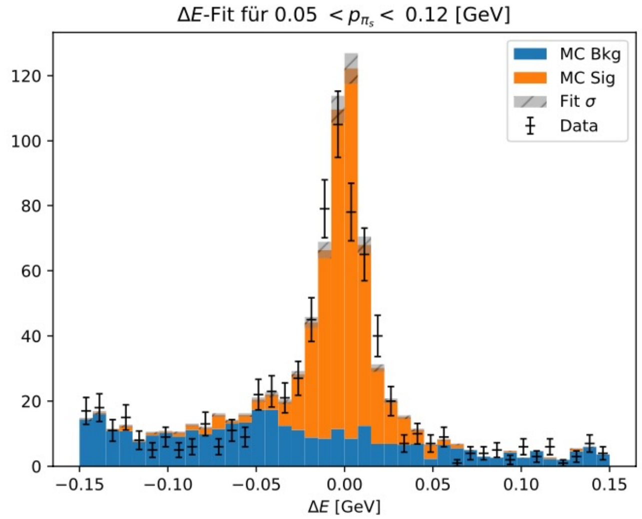
Relative π_s efficiency

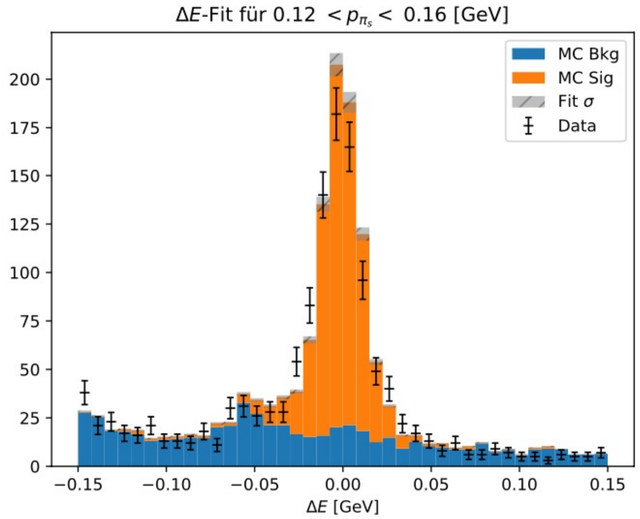
- Reconstruct $B^0 \rightarrow D^{*-}(\bar{D}^0 \pi^-) \pi^+$ in data and MC
- Measure relative yields in bins of π_s momentum
- Normalise highest momentum bin to 1

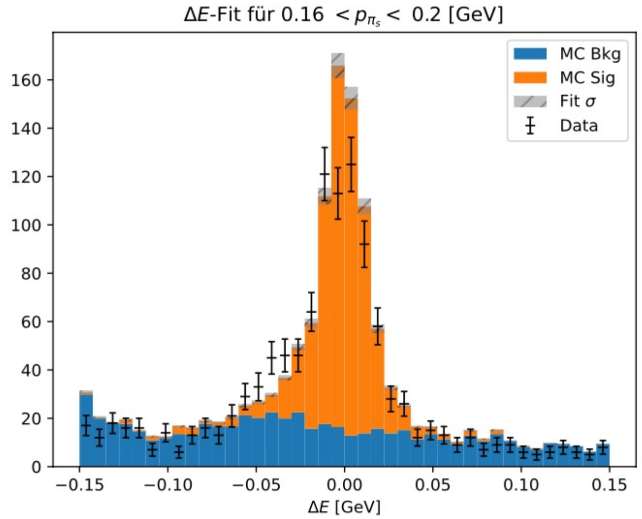
- 4 D^0 modes

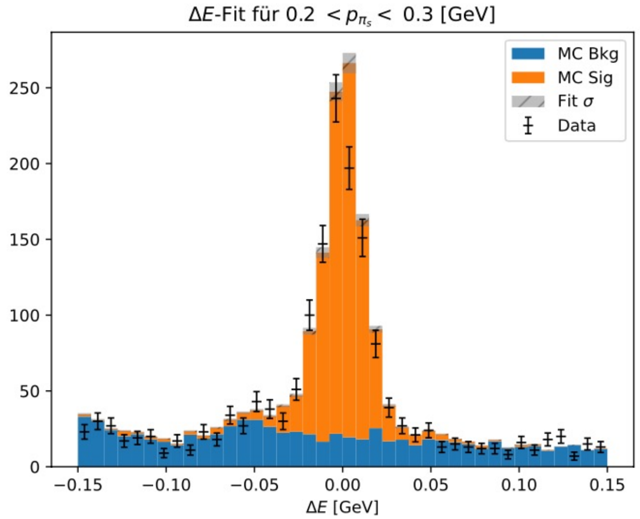
1. $\bar{D}^0 \rightarrow K^+\pi^-$
2. $\bar{D}^0 \rightarrow K^+\pi^-\pi^+\pi^-$
3. $\bar{D}^0 \rightarrow K^+\pi^-\pi^0$
4. $\bar{D}^0 \rightarrow K_s\pi^-\pi^+$

Fit results, e.g., Delta E, Mode 1

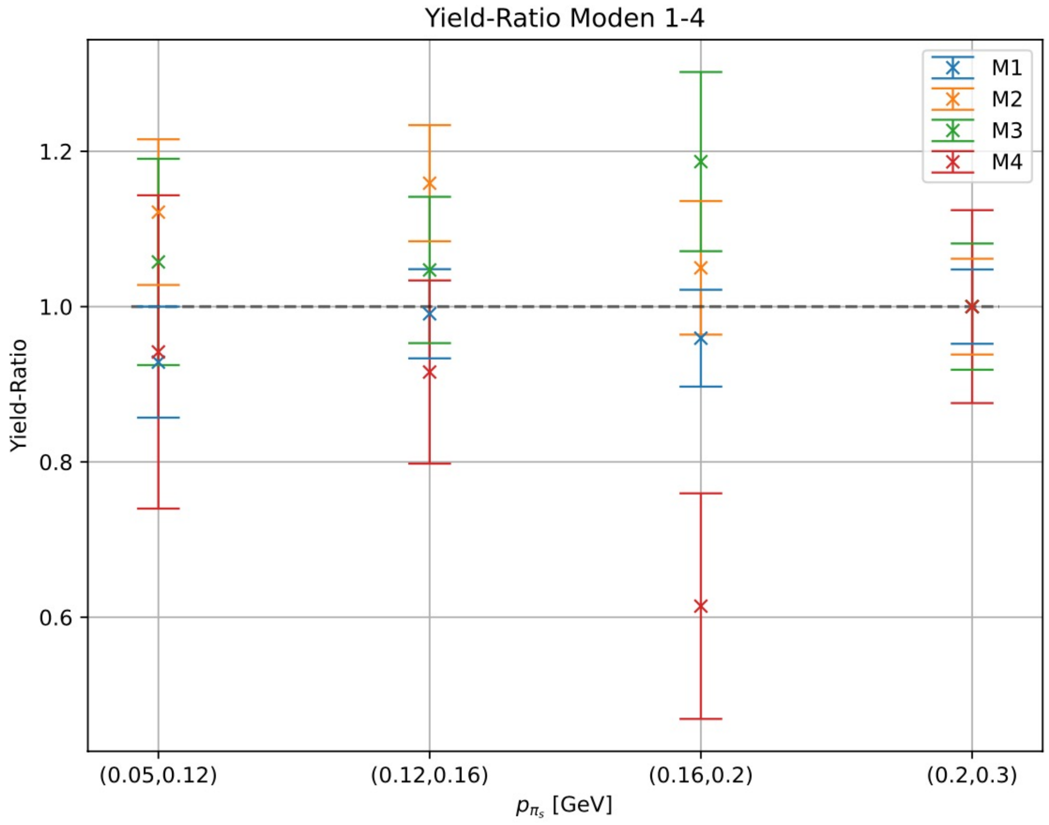




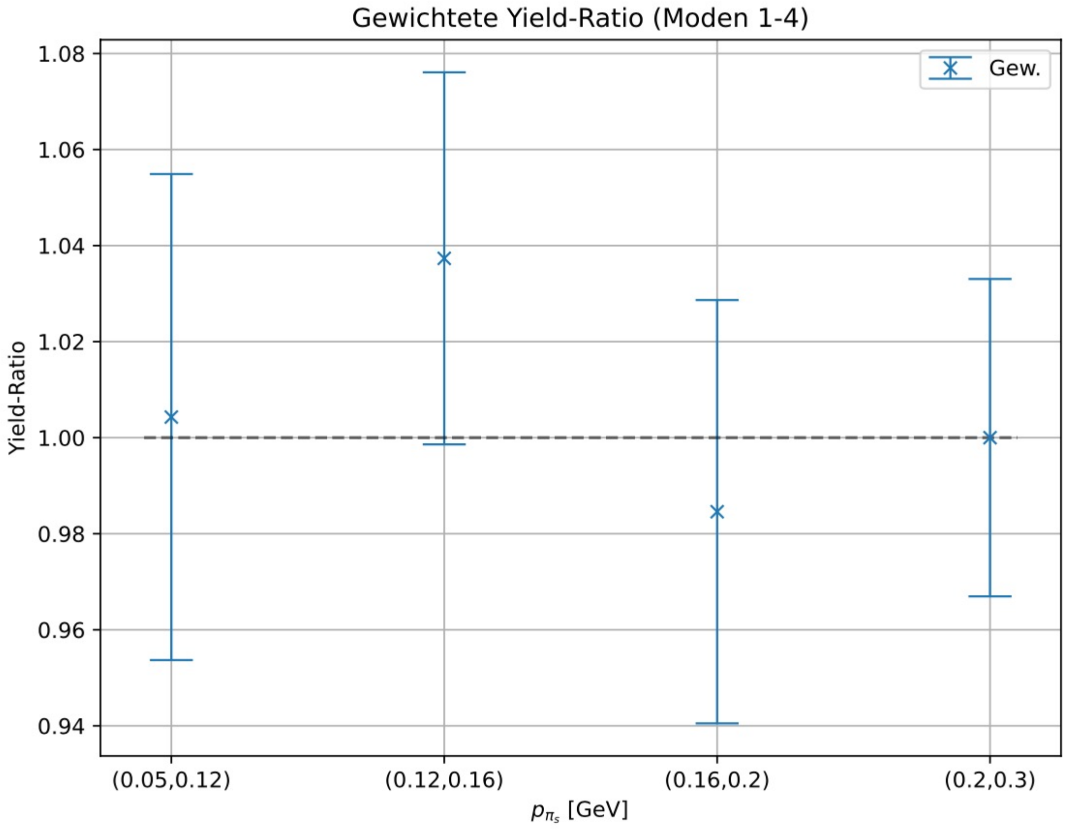




Overall results M_{bc} fit preliminary

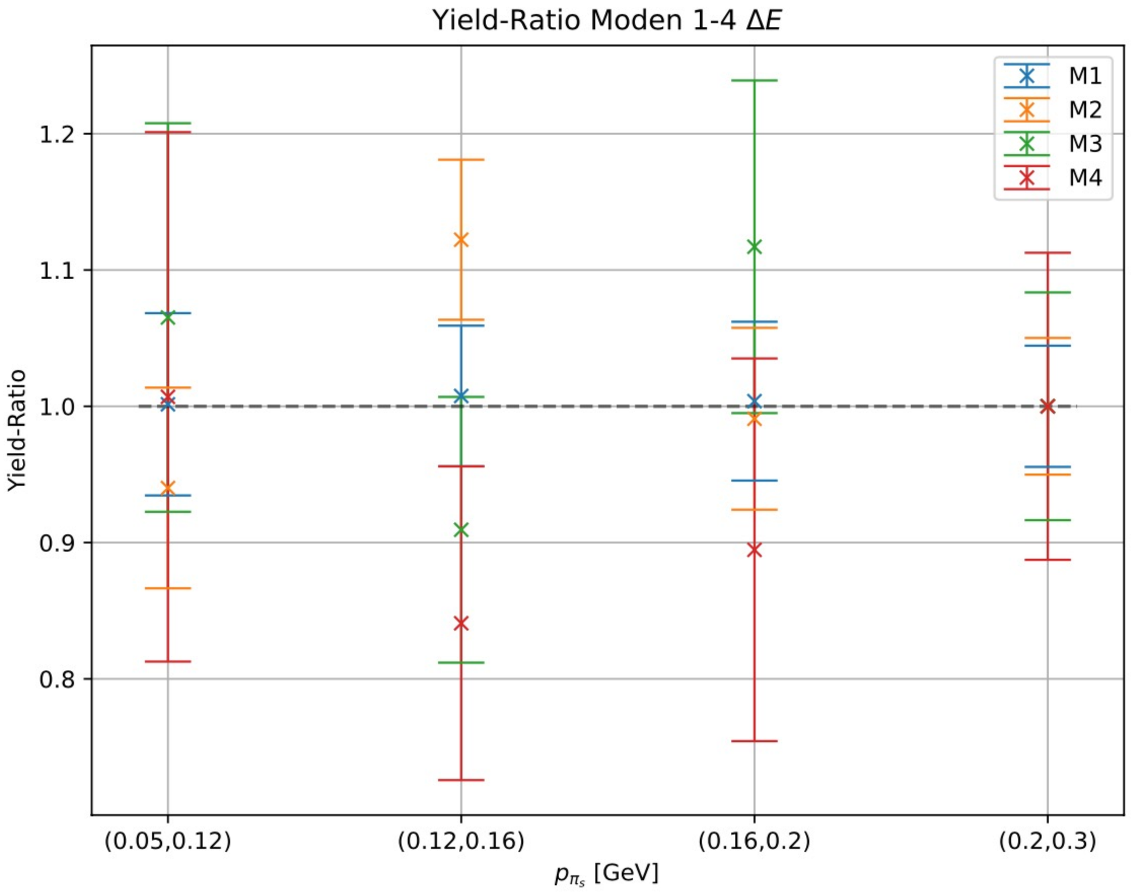


Individual D modes

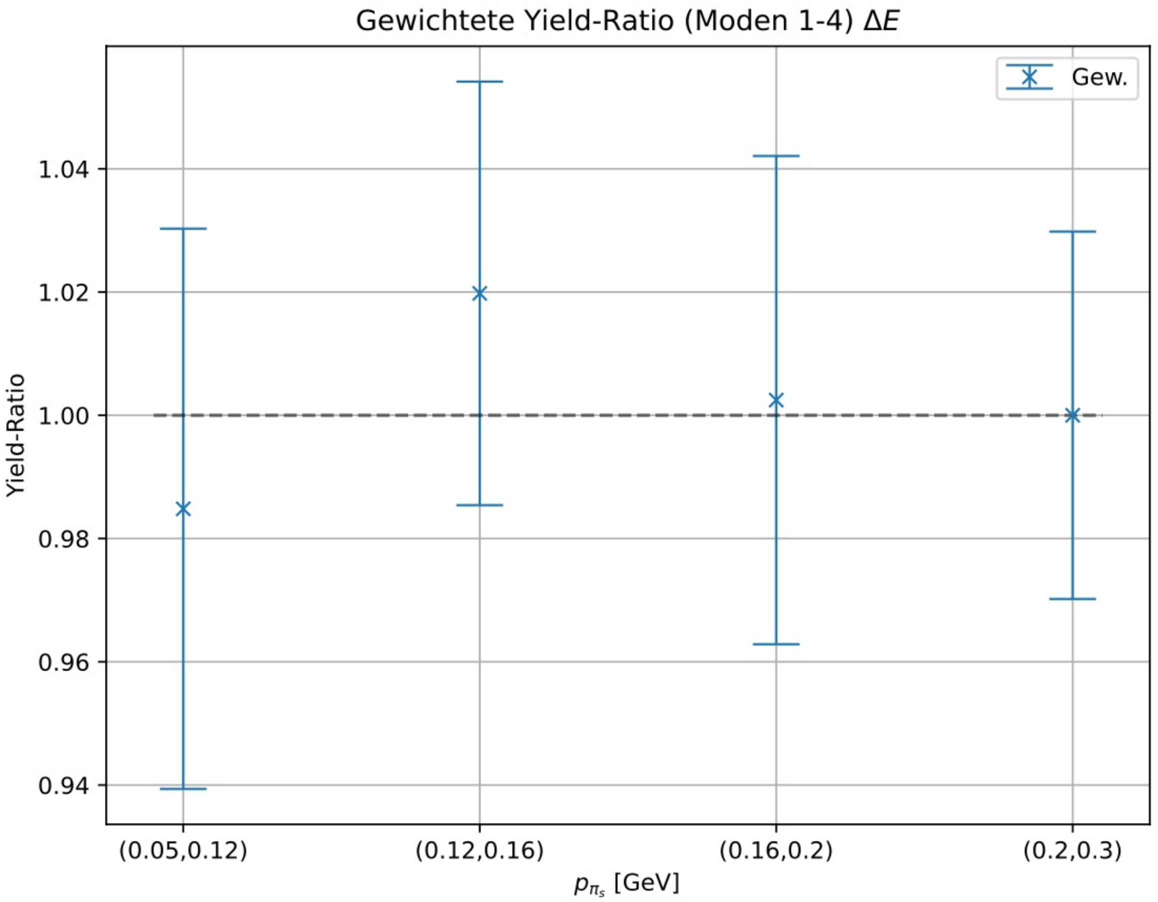


Weighted mean

Overall results Delta E fit preliminary



Individual D modes



Weighted mean

Numerical results (π_s error) preliminary

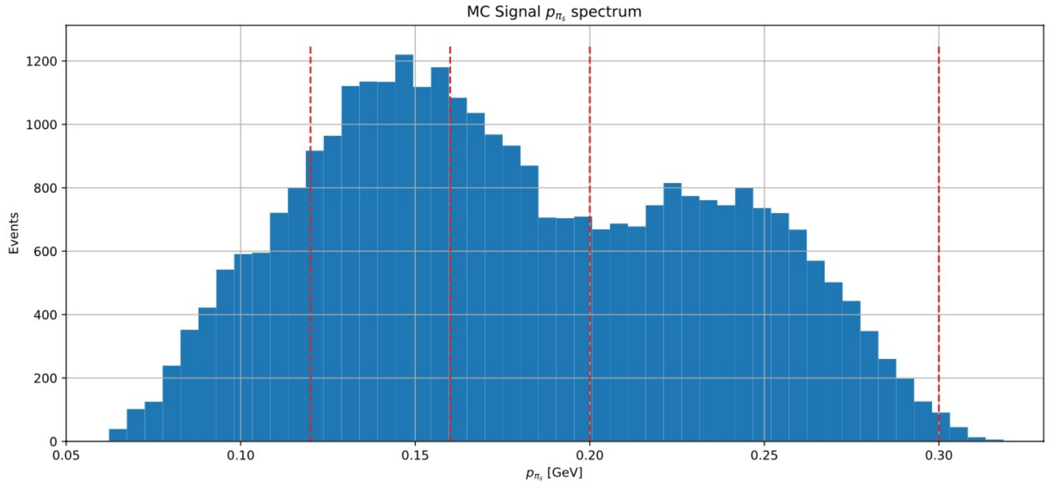
M_{bc} fit

Bin	Rel. Err [%]
(0.05, 0.12)	5.04
(0.12, 0.16)	3.73
(0.16, 0.2)	4.48
(0.2, 0.3)	3.3

Delta E fit

Bin	Rel. Err [%]
(0.05, 0.12)	4.62
(0.12, 0.16)	3.37
(0.16, 0.2)	3.95
(0.2, 0.3)	2.98

Average over π_s spectrum preliminary



Bin	% of events
(0.05, 0.12)	0.15
(0.12, 0.16)	0.27
(0.16, 0.2)	0.22
(0.2, 0.3)	0.36

Fit type	rel. error [%]
Mbc 3 Modes	4.50
deltaE 3 Modes	3.91
Mbc 4 Modes	3.94
deltaE 4 Modes	3.54

Modest improvement compared to the current Belle II value though still far from Belle…

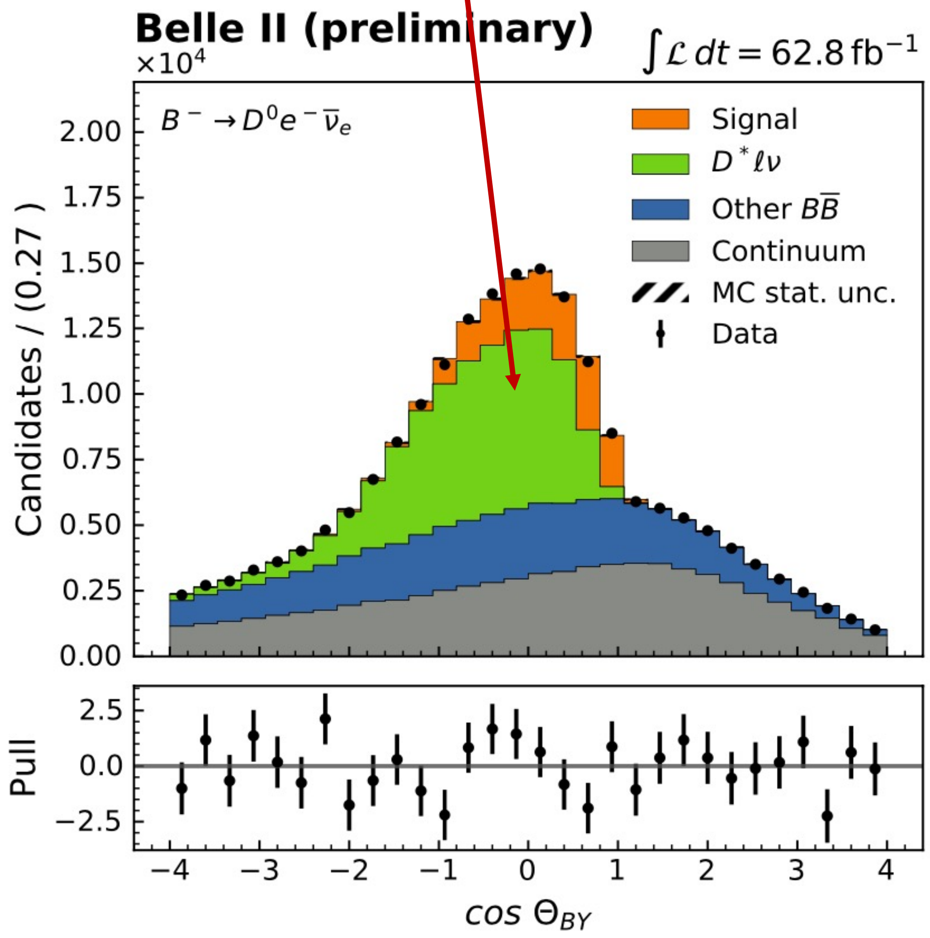
$B^+ \rightarrow \overline{D}^0\, l^+\, \nu$ untagged

- Very similar to previous analysis
  - D^0 is searched for in the K- pi+ mode
  - No requirement on second B
  - Yield is extracted from cos θ_{BY}

- Branching fraction [arXiv:2110.02648]

$$\mathcal{B}(B^- \rightarrow D^0 \ell^- \overline{\nu}_\ell) = (2.29 \pm 0.05_{\text{stat}} \pm 0.08_{\text{syst}})\%$$

Very significant D*lν downfeed



(release-04)

D* veto

- To suppress D^* downfeed, implement 2 vetos:
- $B^0 \to [D^{*+} \to D^0\pi^+]\ \ell^-\nu_\ell$
  - Slow π: $p < 0.35$ GeV
  - $144\ \text{MeV} < m_{D^*} - m_D < 148\ \text{MeV}$
- $B^+ \to [D^{*0} \to D^0\ [\pi^0 \to \gamma\gamma]\ ]\ \ell^+\nu_\ell$
  - $\pi^0 \to \gamma\gamma$ selection criteria from recommendations*
  - $141\ \text{MeV} < m_{D^*} - m_D < 145\ \text{MeV}$
  - Opening angle of $D^0\pi^0 < 17°$

D* veto (2)

	Before D*+ veto cuts	After D*+ veto cuts
D*+ events	180k	66k
D*0 events	310k	304k

- Veto leakage is about 37%
  - mostly due to missing π_s
  - could be improved by better ps reconstruction
- Not entirely clear how much this would improve the overall result (D*0)

Summary

- Slow pion reconstruction affects affects ongoing measurements of the CKM element $|V_{cb}|$ from exclusive decays in various ways
- $B^0 \rightarrow D^{*-} l^+ \nu$
  - Here, precise understanding of the slow pion effeciency is most crucial
  - It would be desirable to also develop _absolute_ measurements of the slow pion efficiency
- $B^- \rightarrow D^0 l \nu$
  - Better slow pion reconstruction will improve the D*+ veto and reduce downfeed from $B \rightarrow D^* l \nu$
  - However, downfeed background from D^{*0} is still substantial. So, not clear how much the overall result can improve

Thank you for your attention!