Update on Lambda Finding Performance in Belle & Belle II

$$\Lambda^0 \rightarrow p\pi^- \;\&\; \overline{\Lambda^0} \rightarrow \overline{p}\pi^+$$

Generated Continuum $c\bar{c}$ ~2500k Events
Belle II Phase 3 on **release-01-01** (without background)
Belle Generic $c\bar{c}$ mDST (with background)
Selection ~200k events with exactly one Λ^0 (or $\overline{\Lambda^0}$) by
vpho → Λ^0 ($\overline{\Lambda^0}$)→ $p^\pm$ $\pi^\pm$

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Outline

- Analysis procedure on Belle and Belle II mDST
- Integrated Results from previous talk on MCMatched, best candidates
- Validated MCMatching by “Kinematic” Matching results
- Efficiency distributions of candidates and tracks with respect to the flight length R and the track transverse momenta
- Conclusions on the inefficiencies in Belle II

Comparing Lambda Reconstructions and V0s in basf and basf2

- The **V0FinderModule** - An mDST level module identifying V0 vertices with available track information – correct energy loss without user extrapolation through material
- The **ParticleCombinerModule** - An Analysis level module combining all TrackFitResults from given ParticleLists to generate a new ParticleList (no information on material effects)

- Belle Analysis
  - Generic $c\bar{c}$ Belle mDST is converted by the b2bii module
  - The new b2bii mDST is steered on analysis level through the LambdaEffModule selecting events with exactly one vpho→Λ^0→pπ (**feature/Florida_LambdaV0** branch on GIT)

- Belle II Analysis (**release-01-01**)
  - Generate Continuum $c\bar{c}$ for mDST in basf2
  - The Belle II mDST is steered on analysis level through the LambdaEffModule selecting events with exactly one vpho→Λ^0→pπ
  - All cuts made by the V0Finder in basf2 are removed, except rejectCandidate() used to reduce 'background' when generating mDST
    - By default, the V0Fitter removes V0 candidates produced inside the BeamPipe (R < 1.cm) and those V0s whose vertex χ^2 > 50.

Analysis Procedure on Belle and Belle II mDST

```
#V0 mdst
# reconstruct Lambda:V0
fillParticleList('Lambda0:V0','')
vertexKFit('Lambda0:V0',-1.)
looseMCTruth('Lambda0:V0')

fillParticleList('pi-:std', '')
fillParticleList('p+:std', '')
looseMCTruth('pi-:std')
looseMCTruth('p+:std')

#reconstruct Lambda0:ppi
reconstructDecay('Lambda0:ppi -> p+:std pi-:std', '')
#vertexTree('Lambda0:ppi',-1.)
vertexKFit('Lambda0:ppi',-1.)
looseMCTruth('Lambda0:ppi')
```

- The analysis uses four ParticleLists (**pi-:all**, **p+:all**, **Lambda0:V0**, and **Lambda0:ppi**) with decay reconstructions vertexed using KFit on analysis level (CL = -1)
- MCMatching and “Kinematic” Matching is applied and a single, best matched candidate per event is selected (based on p-value) due to multiple candidate matching during events
- The results are fit to a Double Gaussian with a zero order Chebyshev polynomial background to determine the efficiency, resolution, and background fractions

INTEGRATED RESULTS

The efficiencies and resolutions are extracted from a fit to the best matched (per event) candidate with a Double Gaussian and flat Chebyshev polynomial background fraction

Integrated Efficiencies, Resolutions, and Background After MCMatching

	Belle Efficiency	Belle II Efficiency	Belle Resolution (MeV)	Belle II Resolution (MeV)	Belle Bkgd Fraction	Belle II Bkgd Fraction
pi-:all	**0.809** (0.807)	**0.721** (0.721)				
p+:all	**0.896** (0.961)	**0.877** (0.86)				
Lambda0:V0	**0.57 +/- 0.0063** (0.57 +/- 0.0062)	**0.43 +/- 0.0031** (0.47 +/- 0.0039)	**1.17 +/- 0.018** (1.21 +/- 0.026)	**1.41 +/- 0.008** (1.32 +/- 0.026)	**0.096 +/- 0.0099** (0.108 +/- 0.0097)	**0.17 +/- 0.006** (0.15 +/- 0.007)
Lambda0:ppi	**0.63 +/- 0.0094** (0.66 +/- 0.01)	**0.45 +/- 0.004** (0.48 +/- 0.0049)	**1.33 +/- 0.024** (1.35 +/- 0.036)	**1.45 +/- 0.013** (1.35 +/- 0.031)	**0.104 +/- 0.013** (0.114 +/- 0.013)	**0.20 +/- 0.007** (0.19 +/- 0.008)

Effective resolutions defined as the weighted RMS: $\sigma_{RMS} = \frac{\sqrt{w_1\sigma_1{}^2 + w_2\sigma_2{}^2}}{\sum w_i}$

Belle vs Belle II

- Belle II inefficiencies are caused by the pion tracking efficiency (~9% higher efficiency in Belle)
- At this momentum, Belle outperforms Belle II by >10% efficiency and ~0.2MeV resolution with half the background from matching

V0s vs Reconstructions

- Limited V0 mDST improvement to the resolution by ~0.035MeV in Belle II (~0.15MeV improvement in Belle)
- Belle II V0's reduce the background by ~3-4%
- The ParticleCombiner and V0Finder have nearly equivalent efficiency

Kinematic Matching

- Kinematic Matching is based on two degrees of freedom from the reconstructed values of p_T and p_z
  - δp_T, δp_z are calculated as the differences between the MC generated value and the reconstructed value of the transverse and parallel momenta

- These discrete values for each candidate are compared to an expected value (RMS) found from the variable distribution over all MCMatched candidates (see bonus slides for distributions)

- A discrete kinematic deviation value is then defined by least squares
  - $\delta\Lambda = \surd\ \delta p_T^2/\delta p_{T,RMS}^2 + \delta p_z^2/\delta p_{z,RMS}^2$
  - Deviations are found for all particles: δΛ, δπ, and δp

- We restrict that δΛ, δπ, and δp be less than 5 for a good, "tight" matched lambda candidate
  - Allows an order of 5 per 2 degrees of freedom deviation
  - A "loose" kinematic match may require only δΛ and δπ <u>or</u> δp be less than 5

- Of these selected good, matched lambda candidates, the best candidate is selected based upon the highest vertex p-value and used for fitting

Integrated Efficiencies, Resolutions, and Background After Kinematic Matching

	Belle Efficiency	Belle II Efficiency	Belle Resolution (MeV)	Belle II Resolution (MeV)	Belle Bkgd Fraction	Belle II Bkgd Fraction
pi-:all	**0.627** (0.619)	**0.537** (0.573)				
p+:all	**0.819** (0.81)	**0.81** (0.794)				
Lambda0:V0	**0.56 +/- 0.006** (0.55 +/- 0.006)	**0.44 +/- 0.003** (0.48 +/- 0.0043)	**1.16 +/- 0.016** (1.19 +/- 0.025)	**1.41 +/- 0.008** (1.3 +/- 0.03)	**0.088 +/- 0.01** (0.092 +/- 0.01)	**0.17 +/- 0.006** (0.16 +/- 0.008)
Lambda0:ppi	**0.59 +/- 0.035** (0.58 +/- 0.009)	**0.45 +/- 0.0043** (0.49 +/- 0.0054)	**1.3 +/- 0.08** (1.34 +/- 0.04)	**1.45 +/- 0.01** (1.35 +/- 0.03)	**0.096 +/- 0.05** (0.094 +/- 0.01)	**0.20 +/- 0.008** (0.19 +/- 0.009)

Effective resolutions defined as the weighted RMS: $\sigma_{RMS} = \frac{\sqrt{w_1 {\sigma_1}^2 + w_2 {\sigma_2}^2}}{\sum w_i}$

MCMatching vs Kinematic Matching

- Overall comparable to MCMatching, less efficient particularly in pion (and proton) track efficiency since tracks are before vertexing, without a lambda candidate

- Approximately equal background to MCMatching,
- Implying that fitting is required for both efficiency and resolution calculations

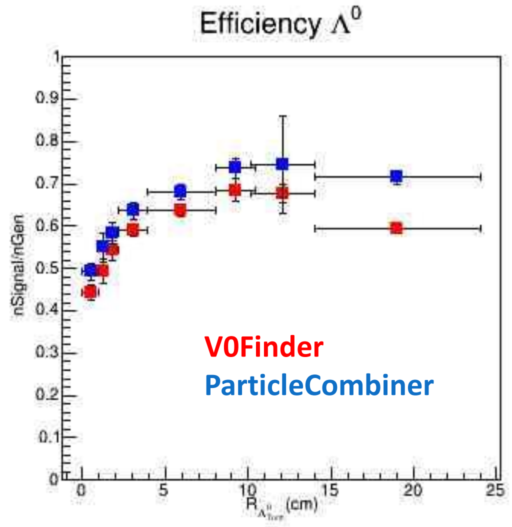
- In Belle, the asymmetry due to low momentum protons is gone
- Implying the high efficiency in low momentum proton tracks is due to the converted MCMatching relationship when using b2bii

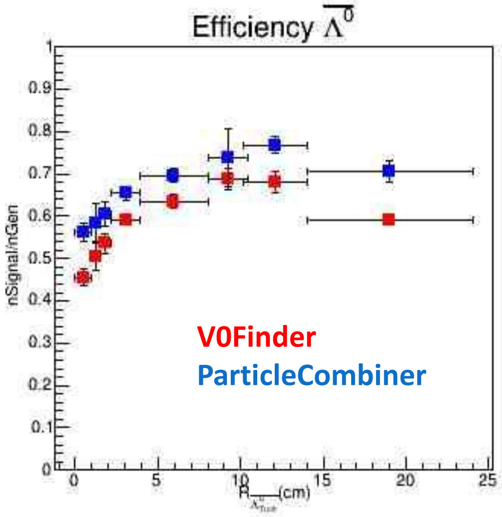
RESOLUTION AND EFFICIENCY WITH RESPECT TO $R_{\Lambda 0}$, P_T^{Π}, AND P_T^{P}

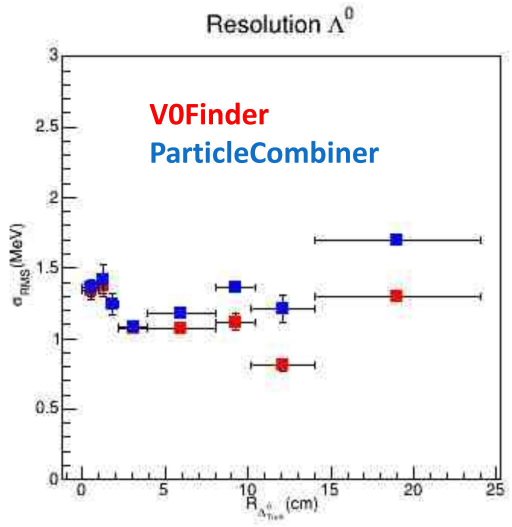
The efficiencies and resolutions are extracted from a fit to the best matched (per event) candidate with a Double Gaussian and flat Chebyshev polynomial background fraction

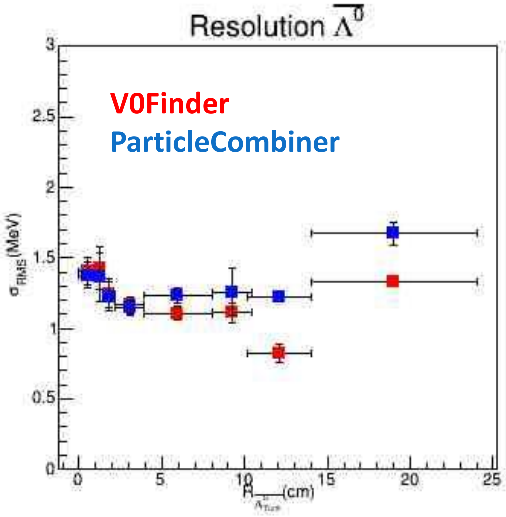
Efficiency and Resolution as a function of Flight Length $R_{\Lambda 0}$ from MCMatching Fits

Belle

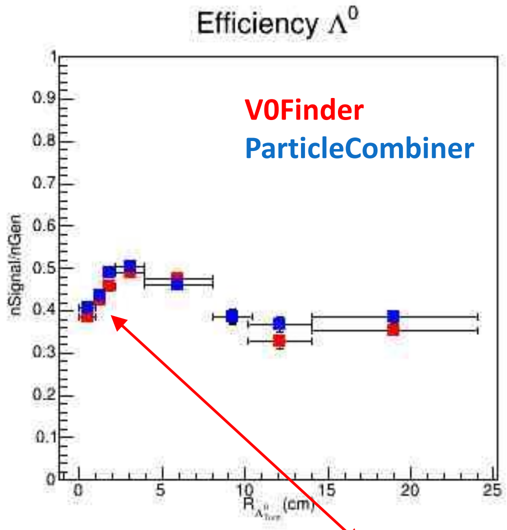


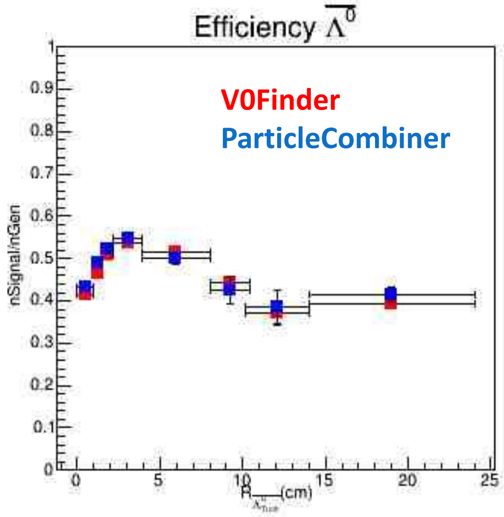




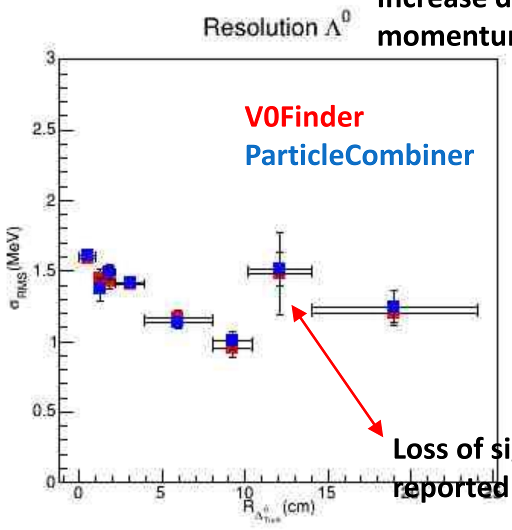


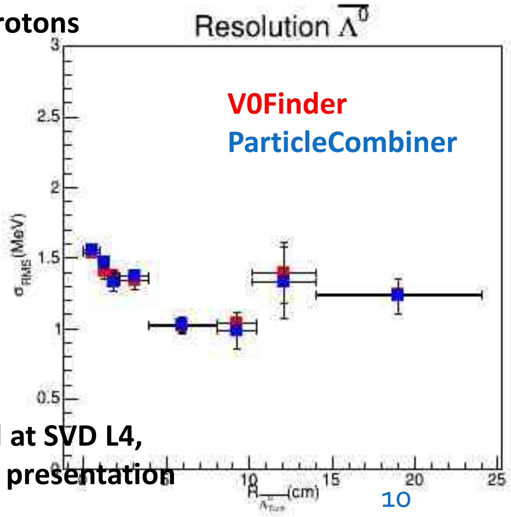
Belle II





Increase due to low momentum protons

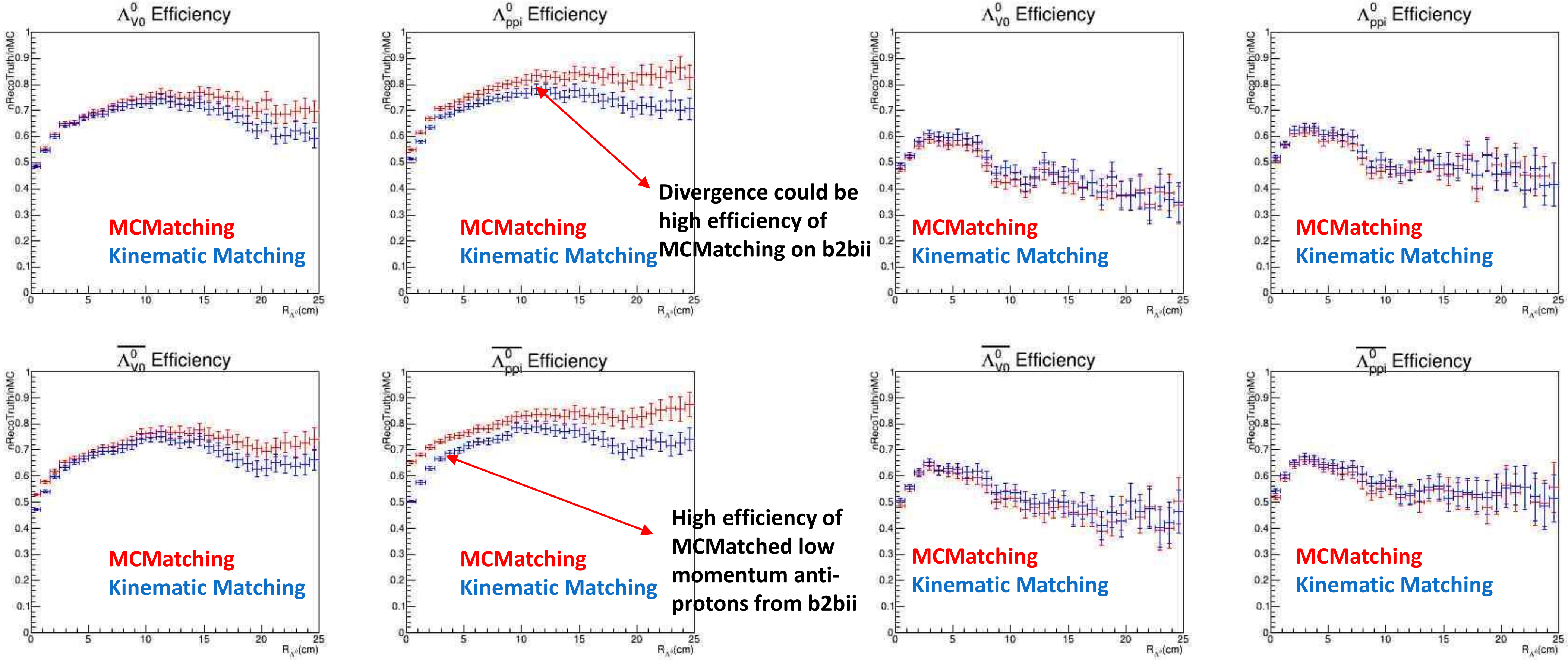




Loss of signal at SVD L4, reported last presentation

Expected Lambda Efficiency (with background) vs R Distributions

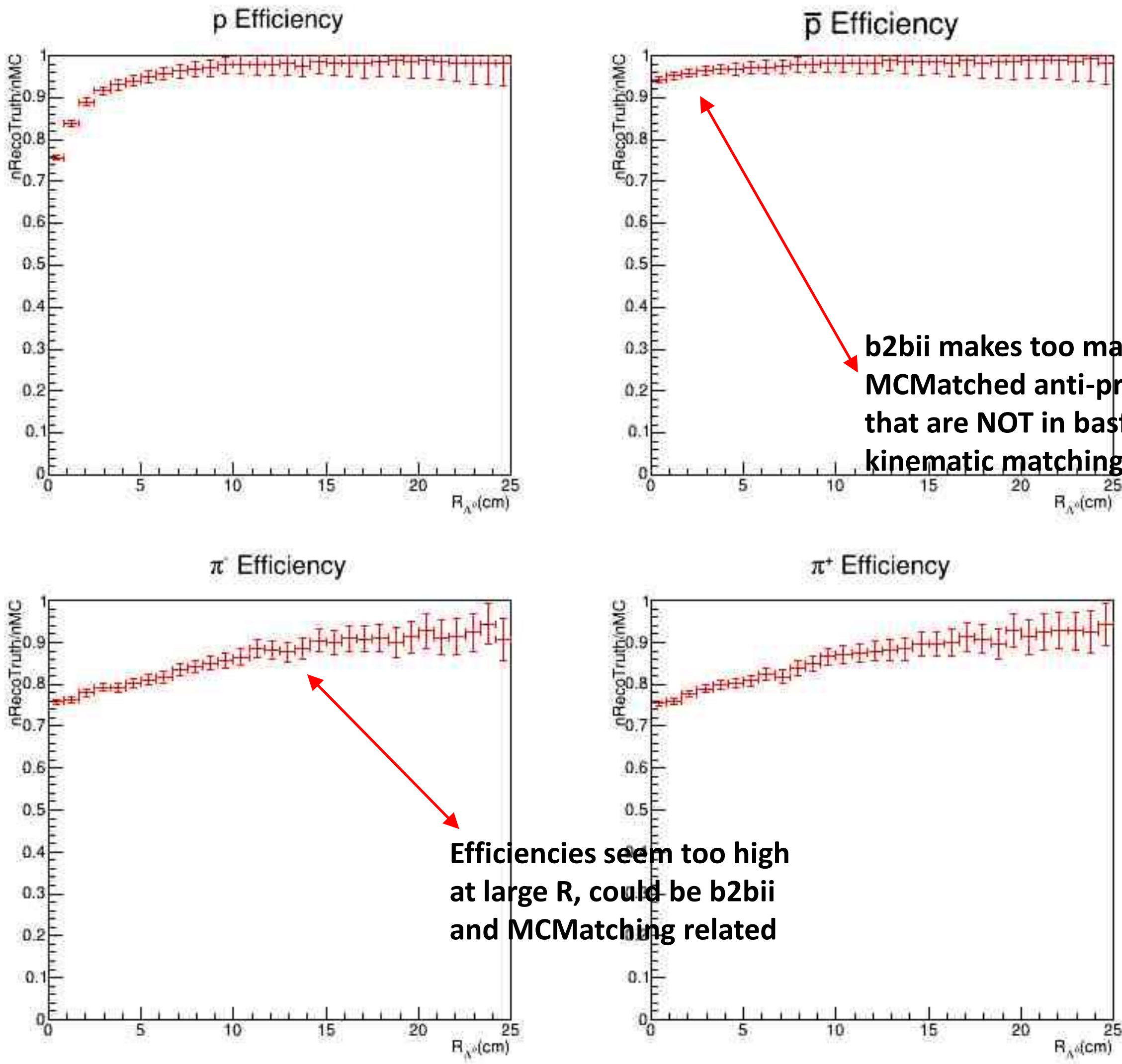
Belle   Belle II



- Results from divided TH1F classes on the Lambda0:V0 and Lambda0:ppi after selecting a single, best matched candidate
- These distributions include an approximately uniform background, but comparable to fitting results
- Loss of efficiency w.r.t. R is seen using the MCMatching and kinematic matching, kinematic matching validated

MCMatched Track Efficiency (with background) as a function of Flight Length $R_{\Lambda 0}$

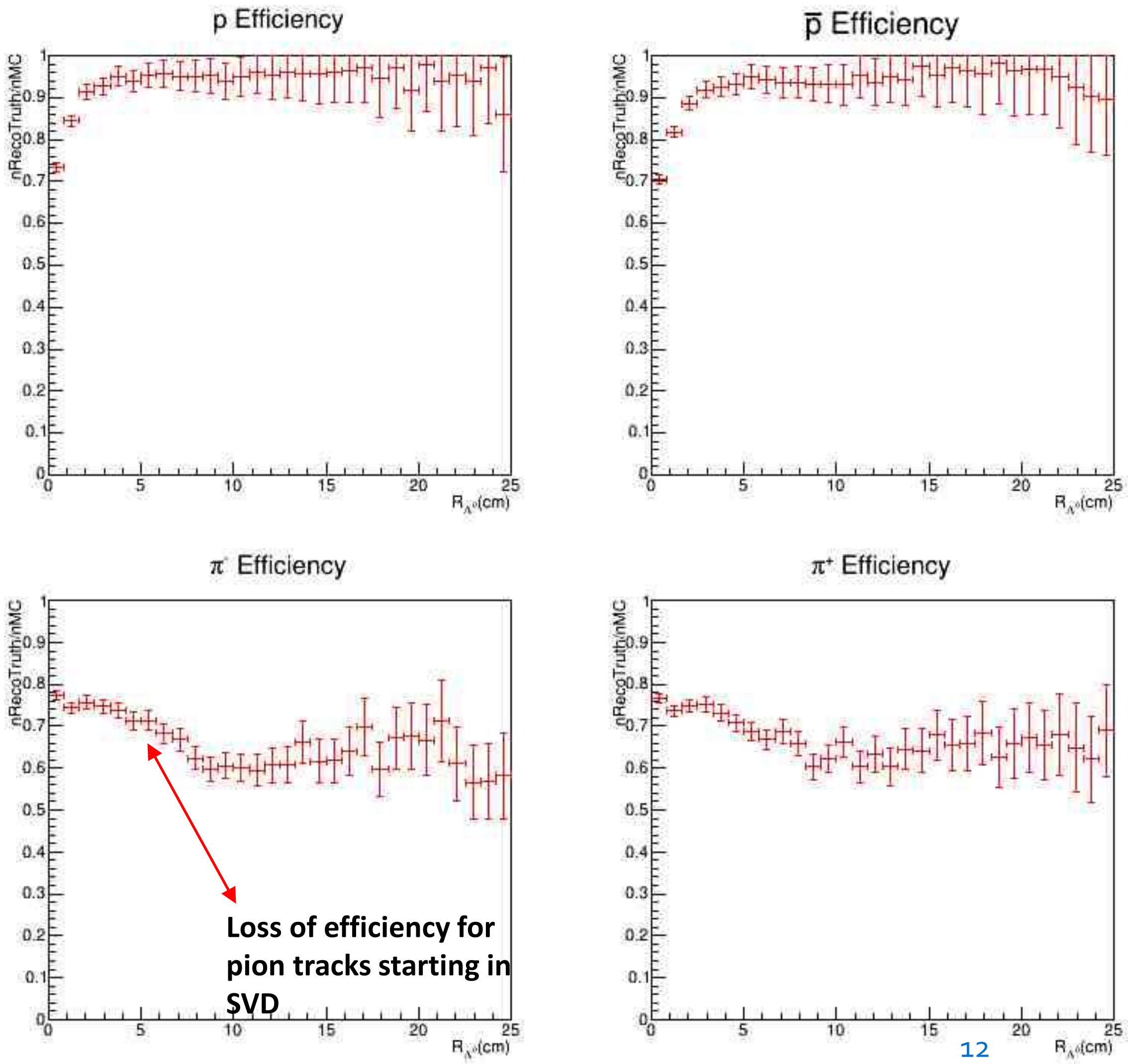
Belle



b2bii makes too many MCMatched anti-protons that are NOT in basf or kinematic matching

Efficiencies seem too high at large R, could be b2bii and MCMatching related

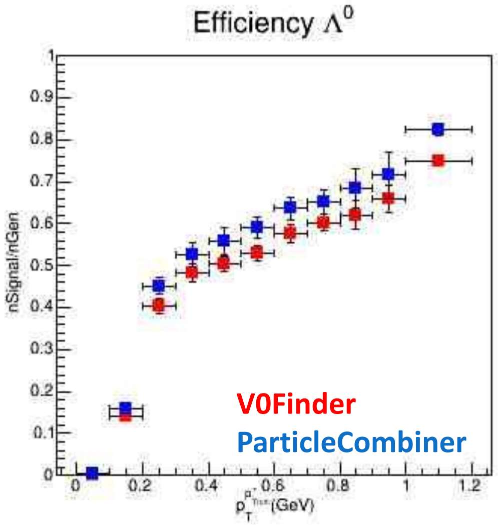
Belle II

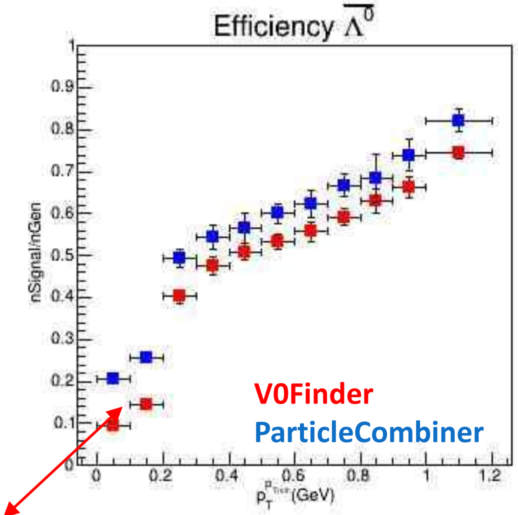


Loss of efficiency for pion tracks starting in SVD

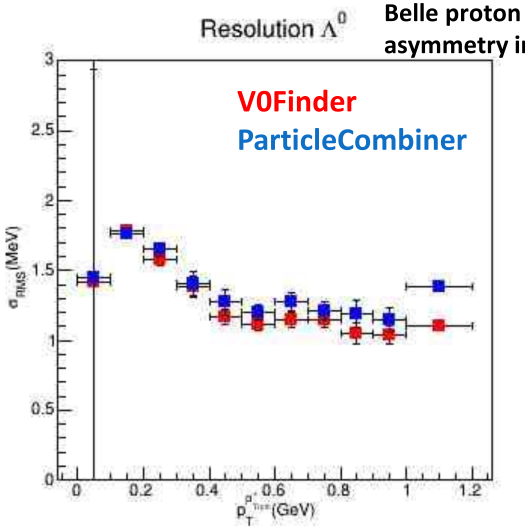
Efficiency and Resolution as a function of p_T^p from MCMatching Fits

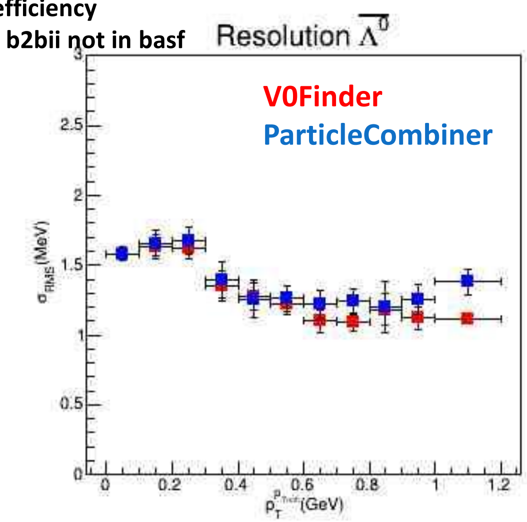
Belle



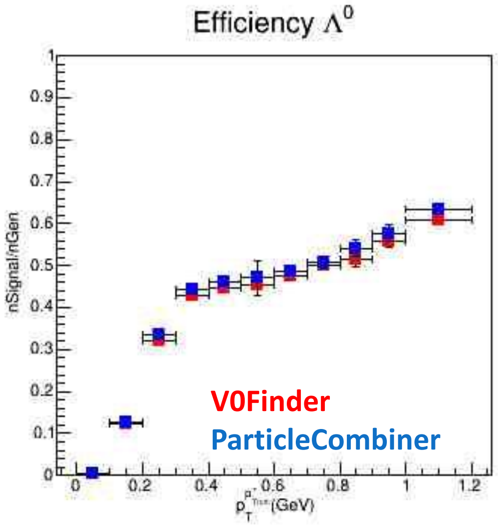


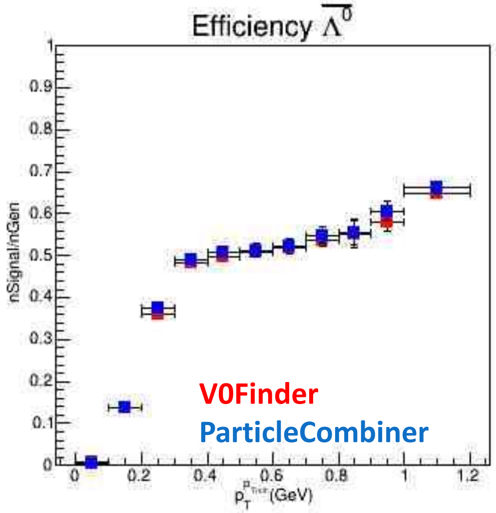
Belle proton efficiency asymmetry in b2bii not in basf

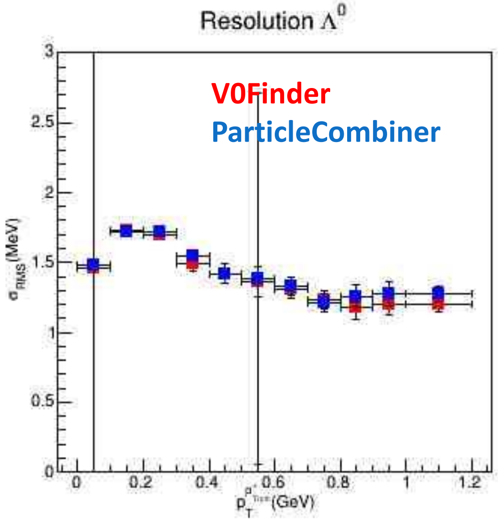


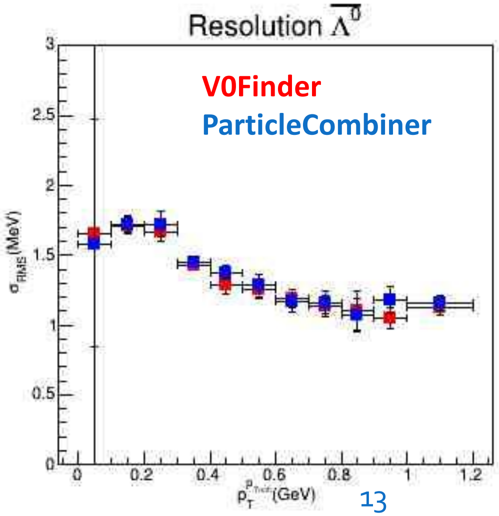


Belle II



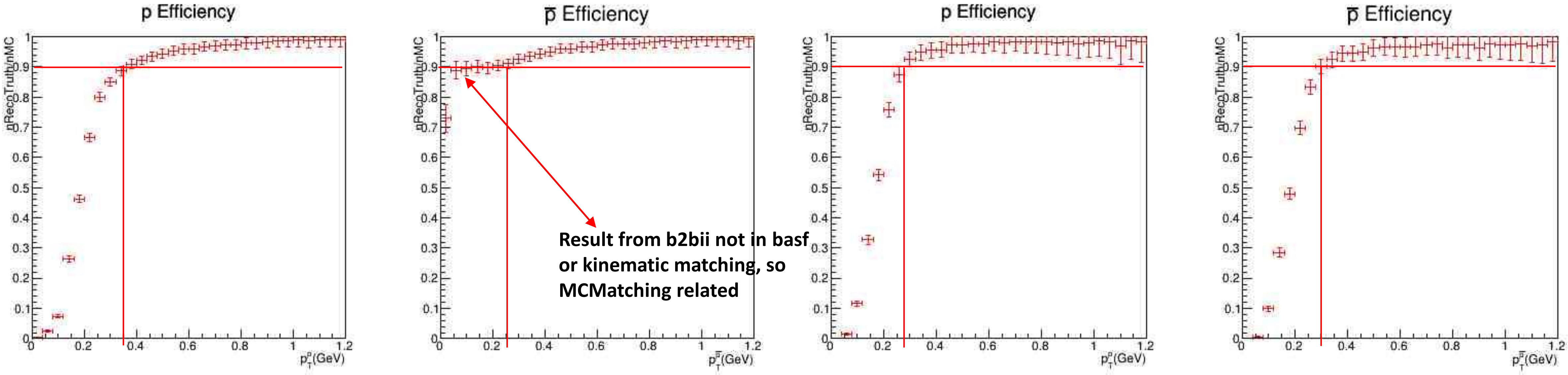






Track Efficiency (with background) as a function of p_T^p

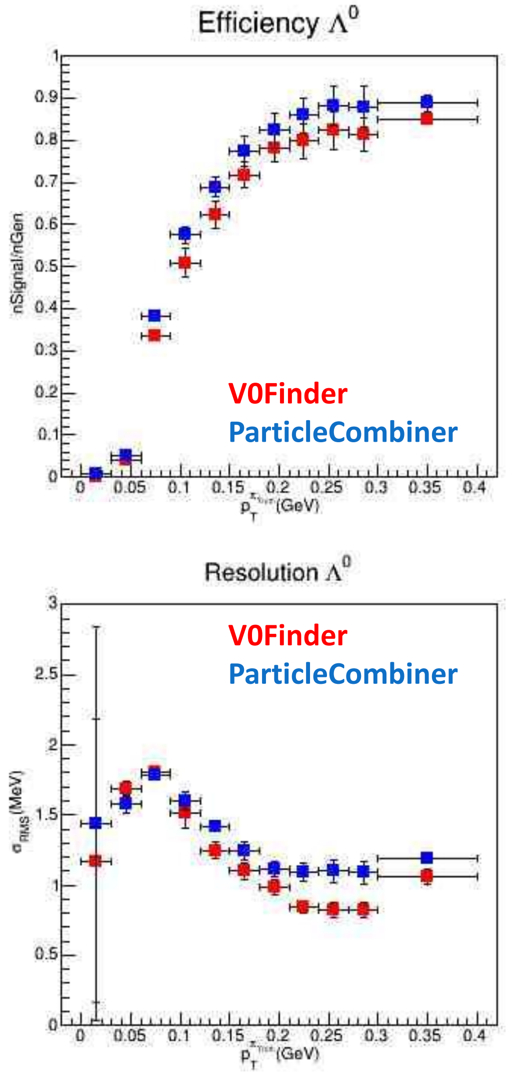
Belle **Belle II**



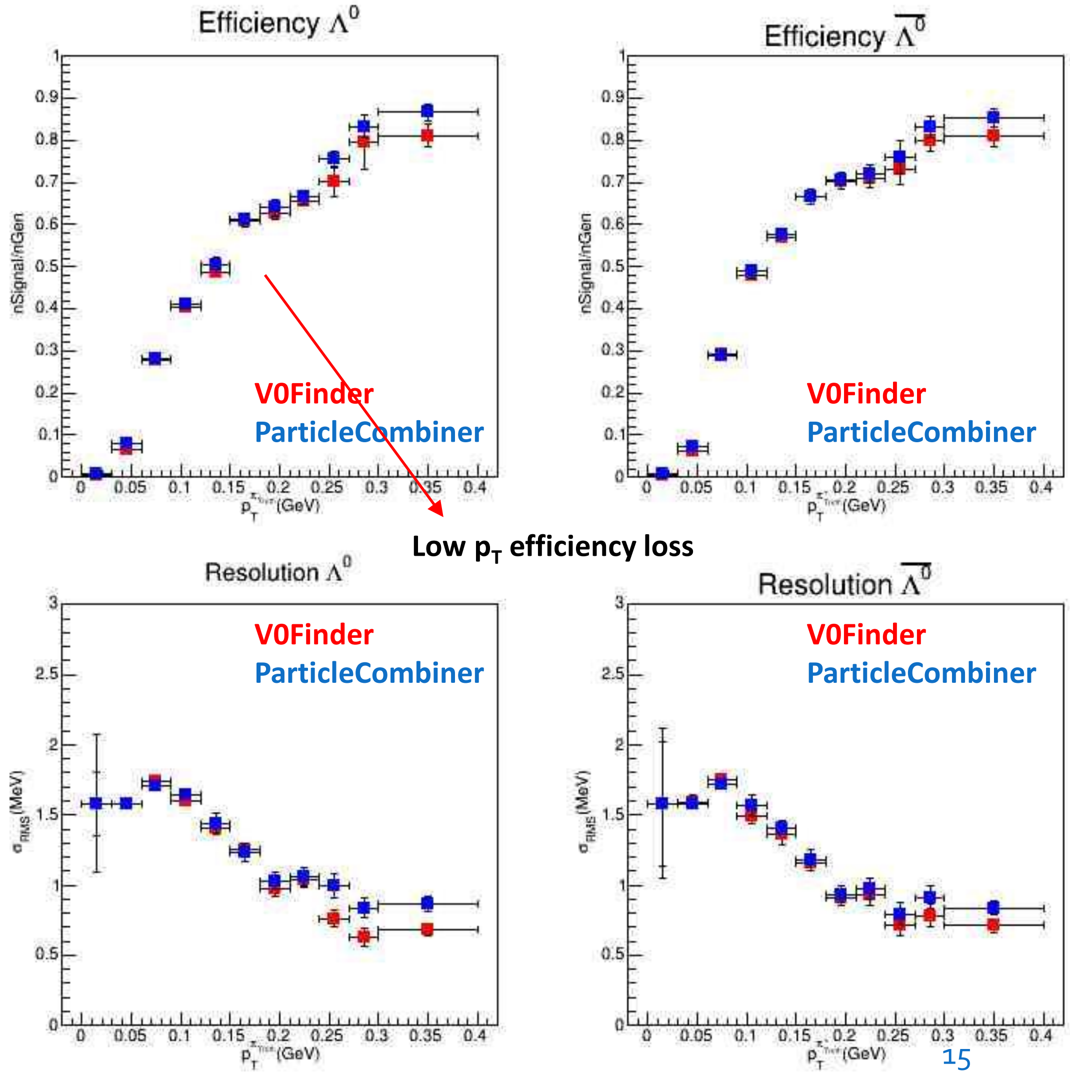
- Belle II is tracking higher momentum (p_T > 300 MeV) protons with better efficiency, reaching a 90% efficiency threshold sooner than Belle
- Belle does appear better in the low (p_T < 300MeV) range at finding MCMatched protons, but at least approximation Belle and Belle II preform comparably
- Anti-proton efficiency asymmetry seen explicitly at low momentum (p_T < 300MeV) due to MCMatching converted in b2bii

Efficiency and Resolution as a function of p_T^{π} from MCMatching

Belle

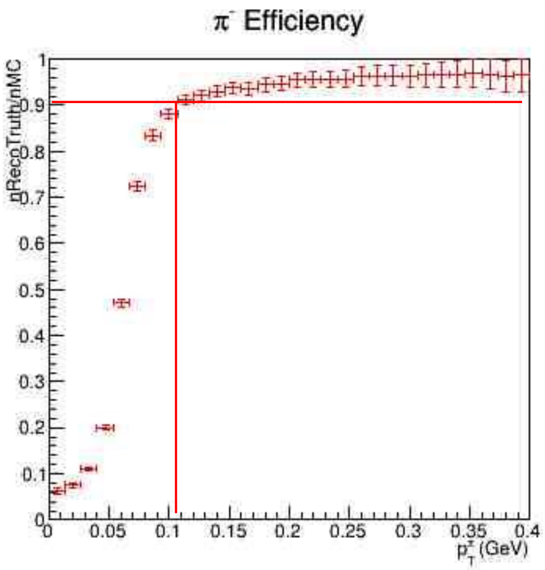


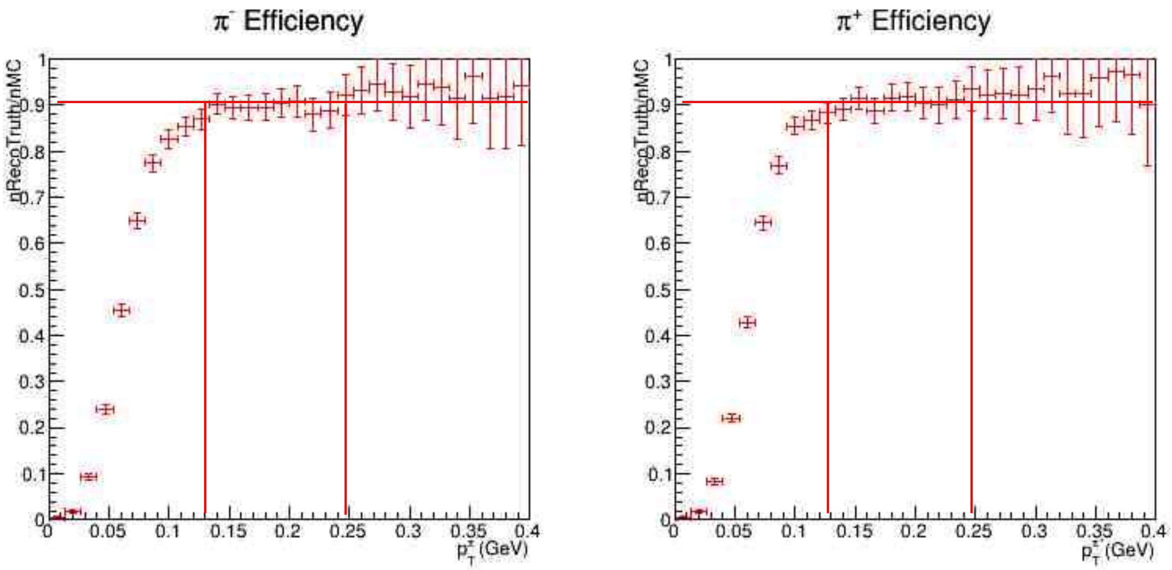
Belle II



Track Efficiency (with background) as a function of p_T^{π}

Belle **Belle II**





- Belle II reaches a 90% efficiency threshold near 150MeV, as opposed to Belle at ~100MeV
- Belle II does not reach a comparable efficiency of MCMatched pion tracks until momentums higher than 300MeV
- Belle II pion efficiency plateaus with apparent missing tracks between 125-250MeV

Conclusions

- To validate the MCMatching, the kinematic matching shows that the efficiency distributions and background fractions found from fitting are genuine when matching

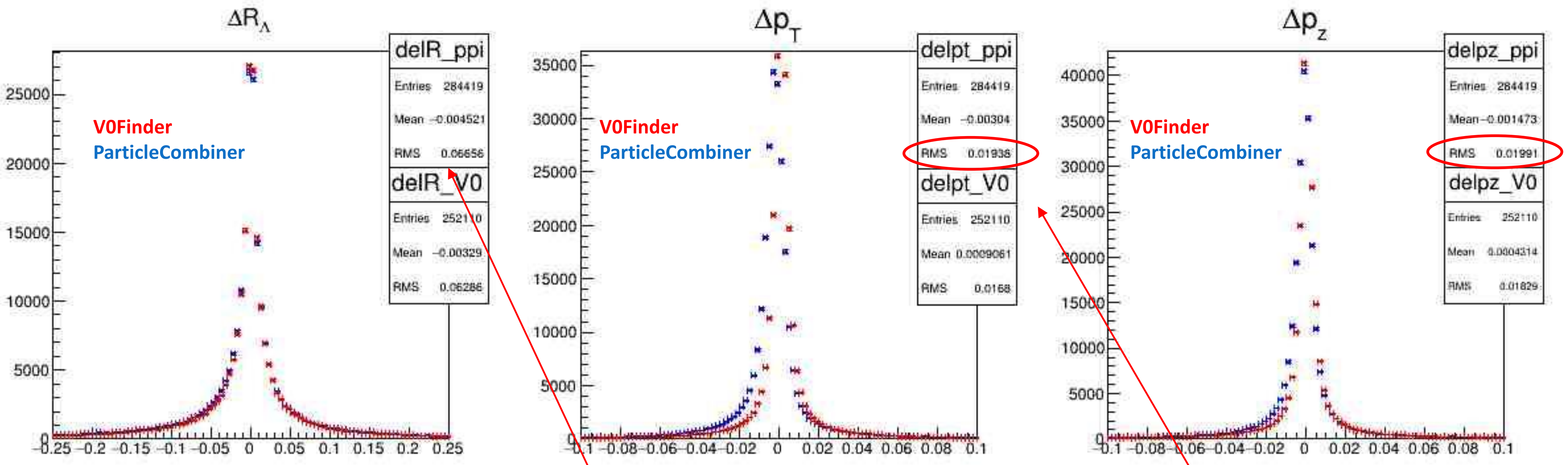
- As well as an underperforming efficiency, Belle II V0s show limited or negligible improvement to the lambda resolutions when compared to Belle
  - Some higher momentum studies (I. Jaegle and Y. Tao) show no statistical advantages to using to V0 mDST vs the ParticleCombinerModule reconstructions

- The efficiency differences between Belle and Belle II lambdas are due to the pion efficiency
  - In Belle II, the pion efficiency decreases w.r.t. the decay vertex position and plateaus in the $125\text{MeV} < p_T < 250\text{MeV}$ region
  - The efficiency distributions are comparable when kinematic matching, thus inefficiencies are due to missing pions from decays outside the PXD and those with $p_T < 250\text{MeV}$
  - Charge identification multiplicity is less than 1% total integrated efficiency effect, and the missing pions are not due to this misidentification

- The anti-proton asymmetry from b2bii is due to the converted MCMatching of low momentum anti-proton tracks and is not found in basf or the kinematic matching
  - These MCMatching problems in b2bii could correlate to other efficiency abnormalities, such as the increased lambda efficiency (and track efficiency) w.r.t. the flight length R

BONUS SLIDES

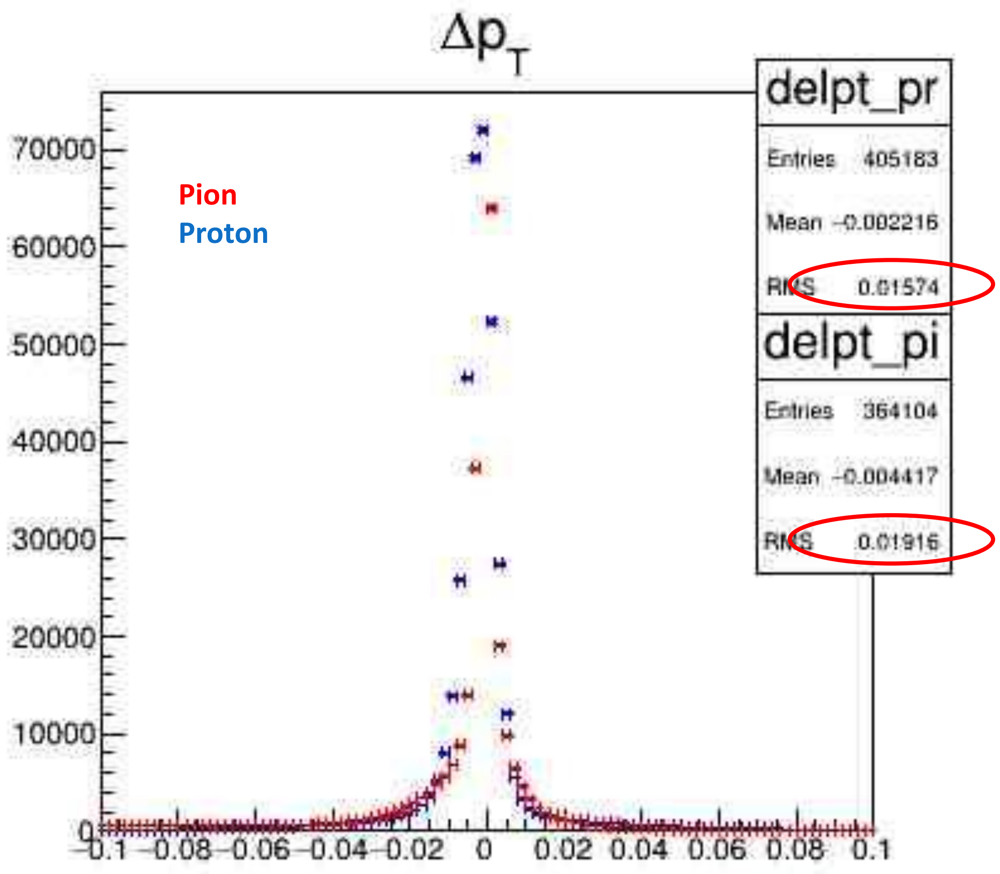
Truth – Reco Kinematics of MCMatched Lambda Candidates

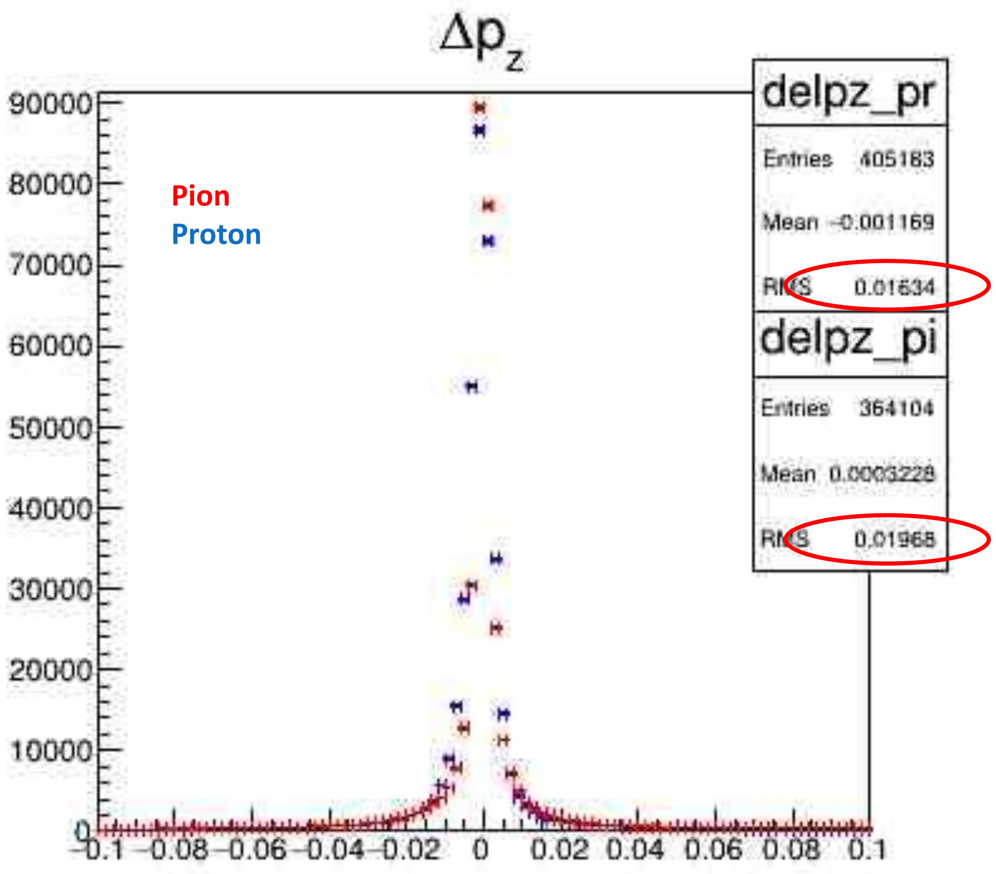


Selected the highest RMS to compare with discrete δp_T and δp_z loosely

RMS is a function of the flight distance, this variable may be considered later

Truth – Reco Kinematics of MCMatched Track Candidates (before Vertexing – Particle Class)



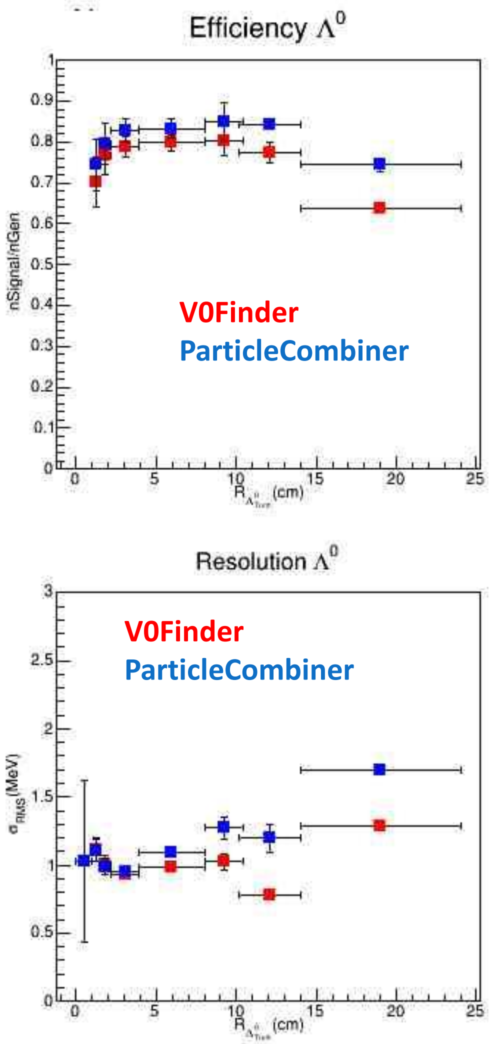


Integrated Efficiencies, Resolutions, and Background after MCMatching with $R_{\Lambda 0}$≥1cm, p_T^{π}≥100MeV, and p_T^{p}≥300MeV

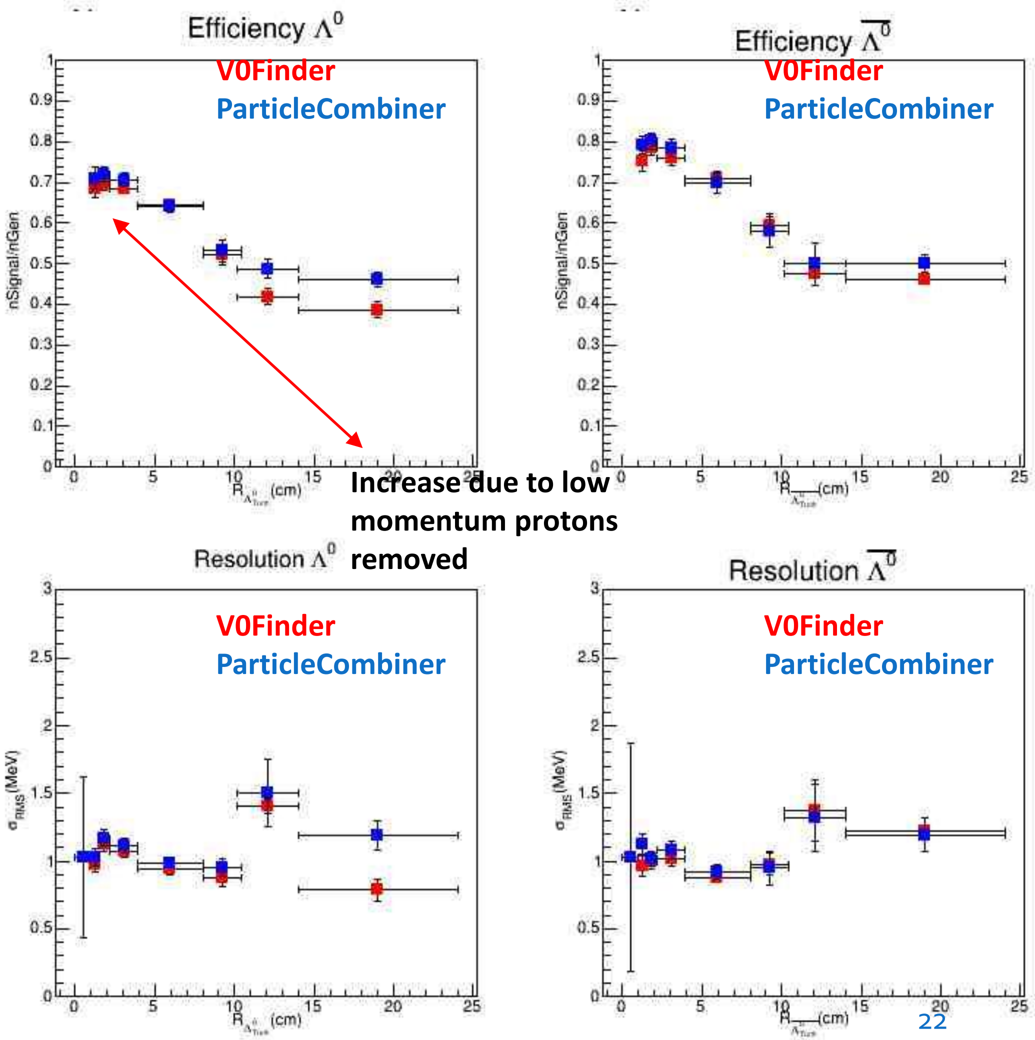
	Belle Efficiency	Belle II Efficiency	Belle Resolution (MeV)	Belle II Resolution (MeV)	Belle Bkgd Fraction	Belle II Bkgd Fraction
pi-:all	**0.932** (0.916)	**0.869** (0.877)				
p+:all	**0.959** (0.92)	**0.966** (0.957)				
Lambda0:V0	**0.75 +/- 0.0124** (0.746 +/- 0.0097)	**0.596 +/- 0.00656** (0.664 +/- 0.0075)	**1.007 +/- 0.022** (1.044 +/- 0.0251)	**1.022 +/- 0.0246** (0.984 +/- 0.0265)	**0.076 +/- 0.0125** (0.0758 +/- 0.01197)	**0.135 +/- 0.0095** (0.122 +/- 0.00995)
Lambda0:ppi	**0.803 +/- 0.0145** (0.802 +/- 0.015)	**0.618 +/- 0.0074** (0.678 +/- 0.00987)	**1.209 +/- 0.0249** (1.227 +/- 0.0376)	**1.085 +/- 0.0242** (1.029 +/- 0.0306)	**0.08 +/- 0.0145** (0.08 +/- 0.0172)	**0.154 +/- 0.0102** (0.148 +/- 0.012)

Efficiency and Resolution as a function of Flight Length $R_{\Lambda 0}$ after MCMatching with $R_{\Lambda 0} \geq 1$cm, $p_T^{\pi} \geq 100$MeV, and $p_T^{p} \geq 300$MeV

Belle



Belle II



Integrated Efficiencies, Resolutions, and Background after Kinematic Matching with $R_{\Lambda 0} \geq 1cm$, $p_T^{\pi} \geq 100MeV$, and $p_T^{p} \geq 300MeV$

	Belle Efficiency	Belle II Efficiency	Belle Resolution (MeV)	Belle II Resolution (MeV)	Belle Bkgd Fraction	Belle II Bkgd Fraction
pi-:all	**0.783** (0.779)	**0.637** (0.696)				
p+:all	**0.894** (0.889)	**0.92** (0.912)				
Lambda0:V0	**0.728 +/- 0.0099** (0.721 +/- 0.0096)	**0.595 +/- 0.0067** (0.657 +/- 0.0083)	**0.996 +/- 0.018** (1.019 +/- 0.024)	**1.037 +/- 0.027** (0.972 +/- 0.0279)	**0.0635 +/- 0.013** (0.066 +/- 0.012)	**0.128 +/- 0.00992** (0.119 +/- 0.011)
Lambda0:ppi	**0.747 +/- 0.0146** (0.745 +/- 0.0145)	**0.603 +/- 0.0075** (0.668 +/- 0.0106)	**1.174 +/- 0.024** (1.207 +/- 0.037)	**1.097 +/- 0.0257** (1.028 +/- 0.034)	**0.072 +/- 0.018** (0.069 +/- 0.018)	**0.15+/- 0.011** (0.146 +/- 0.014)