Early Measurement of V⁰ production in Run 3



Run 3 Starterkit: Early Measurements 14.03.2022

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Production cross-section ratios

- \rightarrow uncertainties of luminosity measurements before calibration limit precision of absolute crosssection measurement transfer (from pp to $\bar{\Lambda}^0$)
- Yields and efficiencies need to be calculated $R(\bar{\Lambda}^0, K_{\rm S}^0) = \frac{\sigma(pp \to \bar{\Lambda}^0 X)}{\sigma(pp \to K_{\rm S}^0 X)} = \frac{N(\bar{\Lambda}^0 \to \bar{p})}{N(K_{\rm S}^0 \to \pi^+)}$
- \rightarrow Efficiencies include only selection and reconstruction → uncertainties on luminosity and trigger efficiency cancel
- •Analysis is performed in bins of (crossing-angle corrected) $p_{\rm T}$ and y (rapidity)

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 Ratios of production cross-sections are experimentally easier accessible and from special interest $R(\bar{\Lambda}^{0}, \Lambda^{0}) = \frac{\sigma(pp \to \bar{\Lambda}^{0}X)}{\sigma(pp \to \Lambda^{0}X)} \quad , \quad R(\bar{\Lambda}^{0}, K_{\rm S}^{0}) = \frac{\sigma(pp \to \bar{\Lambda}^{0}X)}{\sigma(pp \to K_{\rm S}^{0}X)}$

 \rightarrow ratios are interesting for understanding of baryon-meson suppression and baryonic number

$$(\bar{p}\pi^+) = \frac{\varepsilon(K^0_{\rm S} \to \pi^+\pi^-)}{\varepsilon(\bar{\Lambda}^0 \to \bar{p}\pi^+)} \cdot \frac{\mathscr{B}(K^0_{\rm S} \to \pi^+\pi^-)}{\mathscr{B}(\bar{\Lambda}^0 \to \bar{p}\pi^+)}$$







Motivation for V^0 production measurements Here

- •Unique acceptance range of LHCb among the LHC experiments
- Production in forward region ($\eta > 2$) particularly interesting for astro-particle physics (muonpuzzle of cosmic ray induced air showers), especially multiplicity studies [arXiv:2105.06148]
- Important input for MC generators and the understanding of hadronization processes
- •Strangeness production cross-sections are huge at the LHC ($\sim 1b$)
- V^0 particles are easy to reconstruct → well suited for Early Measurements in Run 3 with a few days of data
- •Earlier measurements of cross-section ratios at the LHC can be used for comparisons - previously measured at LHCb on Run 1 pp-data at 0.9 and 7 TeV [arXiv:1107.0882] - recent measurements by ALICE at 7 and 13 TeV [arXiV:2005.11120] [arXiv:1908.01861]
- •Could be extended to study hyperon Ξ^0 , Ξ^- , Ω^- production





Cross-checks

• More stable checks can be done with $R(\bar{\Lambda}^0, \Lambda^0)$ when making use of both magnet polarities

 $\varepsilon_{\text{MagDown/Up}}(\Lambda^0) \approx \varepsilon_{\text{MagUp/Down}}(\bar{\Lambda}^0)$

 $\rightarrow p/\bar{p}$ detection asymmetries are expected to be a second order effect

 efficiencies cancel, only measure yields \rightarrow check is independent from simulation

$$R = \sqrt{R_{\rm UD}R_{\rm DU}} = \sqrt{\frac{N_{\rm MagUp}(\bar{\Lambda}^0 \to \bar{p}\pi^+)N_{\rm MagDown}(\Lambda^0 \to \bar{p}\pi^+)}{N_{\rm MagUp}(\Lambda^0 \to \bar{p}\pi^+)N_{\rm MagUp}(\Lambda^0 \to \bar{p}\pi^+)}}$$

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- only works with symmetric detector halves:
 - \rightarrow not given at early stage for VELO & SciFi
 - \rightarrow could still be used to understand the
- impact of the detector asymmetry

 $\rightarrow p\pi^-$









Analysis strategy

- •Measure cross-section ratios $R(\bar{\Lambda}^0, \Lambda^0)$ and $R(\bar{\Lambda}^0, K_S^0)$ as function of p_T and y on 2018 Run 2 and early Run 3 data
- •Measure total cross-section once luminosity measurements are available
- Reconstruct V0 particles in with two long tracks (LL) for measurement and use reconstruction with two downstream tracks as cross-check on Run 2 data
- Monitor simple kinematic and topological variables when data taking is starting





Developing an unbiased event selection





- PID performance and resolutions of new detector have to be calibrated/measured before they can be used reliably \rightarrow variables have to avoided for event selection
- Studied a set of simple kinematic and topological variables on upgrade MC to select minimal set of selection requirements
- IP/IPCHI2 cuts are crucial for signal extraction with a minimal set of variables















Fisher discriminant - Separation power

 New variable that combines IP information (derived from Fisher discriminant) analysis in previous analyses [arXiv:1107.0882] [arXiv:1008.3105])



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$\mathscr{F}_{\mathrm{IP}}(\Lambda^0 \to p\pi^-) = \log_{10}(\mathrm{IP}(p)) + \log_{10}(\mathrm{IP}(\pi^-)) - \log_{10}(\mathrm{IP}(\Lambda^0))$

Fisher discriminant - Cut point optimisation

 Optimize cut on this variable with Punzi FOM [arXiv:physics/0308063]



- \rightarrow selection efficiency $\varepsilon_{\rm sel}$ is calculated on the truth matched simulation
- \rightarrow background yield estimation from fit to sidebands on data
- Optimal cut value is determined separately for $K_{\rm S}^0$ and Λ^0 and LL and DD samples, same for both magnet polarities







Mass fits - Fitting procedure



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Fitting procedure for stabilised fits:

- 1. Parameters α and *n* are fixed from fitting the signal-only model to truth matched simulation
- 2. Fit background-only model to data sidebands and fix parameters of background model
- 3. Fit signal+background model to
- full range and estimate μ and σ
- 4. Let background params float and fit again
- (5. Let everything float and take result if pulls are better than after 4.)













Preliminary Run 2 results: $R(\Lambda^0, K_s^0) - p_T$

- •Expected trend with $p_{\rm T}$ observed in both LL and DD sample, compatible with Run 1 results (only long tracks considered) [arXiv:1107.0882]
- Scaling factor between LL and DD sample needs to be understood



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Non-prompt contributions - Cut point

 \rightarrow Can be suppressed by applying additional cut on IP(V⁰)



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•Secondary contributions from $\Omega^- \to \Lambda^0 K^-$, $\Xi^- \to \Lambda^0 \pi^-$ and charm decays ($N_{\rm bkg}$)







Non-prompt contributions

- Much better agreement among track types
- Residual non-prompt background needs to be estimated









Background from hadron misidentification

- •No PID information is used \rightarrow mass association for tracks purely random
- • K^0_{S} contribution under Λ^0 peak when p mass hypothesis falsely given to π^+ track
- Simulation is truth-matched \rightarrow contribution biases efficiencies if taken 60 from simulation
- Can easily be vetoed by recalculating invariant mass with swapped mass hypothesis and cutting around $K_{\rm S}^0$ mass

 $|m([p \to \pi^+]\pi^-) - m_{\text{PDG}}(K_{\text{S}}^0)| > 10 \,\text{MeV}/c^2$







Tracking efficiency corrections

- Checking for data/MC disagreement of proton/pion tracking efficiencies to calculate weights for simulation
- as function of kinematic and topological variables

$$\omega(p_{\rm T}, y, N_{\rm tracks}^{\rm VELO}, z, ...) = \frac{\varepsilon_{\rm tr}^{\rm MC}(p_{\rm T}, y, N_{\rm tracks}^{\rm VELO}, z, ...)}{\varepsilon_{\rm tr}^{\rm data}(p_{\rm T}, y, N_{\rm tracks}^{\rm VELO}, z, ...)}$$

Tag-and-probe approach for long proton tracks

$$\varepsilon_{\rm tr}^{\rm UT+SciFi} = \frac{N^{\rm LL}(\Lambda^0 \to p\pi^-)}{N^{\rm VELO+Long}(\Lambda^0 \to p\pi^-)}$$

- Long tracks have to be matched to VELO tracks by comparing hit IDs

$$\varepsilon_{\rm tr} = \varepsilon_{\rm tr}^{\rm UT+SciFi} \cdot \varepsilon_{\rm tr}^{\rm VELC}$$

- VELO tracking efficiency close to 100%, could be tested via tag-and-probe with downstream+long tracks
- Same approach with $K_{\rm S}^0 \rightarrow \pi^+ \pi^-$ for pion tracking efficiency
- Tracking efficiencies for DD samples very challenging







Applying Run 2 selection to upgrade MC

${\cal U}$	Candidates	After F_IP > 2 cut	Truth matched	Truth matched + F_IP > 2 cut	efficiency
3.6	884209	659	647	222	34 %
7.6	2735445	1117	1131	389	34 %





Running over 20k minbias events







Outlook

- •Use larger MC samples for Run 2 part of the analysis Estimation of residual background from secondary contributions •Calculate tracking efficiency corrections as function of $p_{\rm T}$ and y •Work on analysis note and analysis preservation is ongoing!

- •Finalise work on trigger lines
- •Produce $K_{\rm S}^0$ samples
- •study PV association: Compare failure rate of "best" PV between $\nu = 3.8$ and $\nu = 7.6$ samples
- •Run full analysis workflow on upgrade MC and identify missing features



- Stay tuned for the next (larger) updates!









Backup - LL and DD track types







Truth matching





- If explicit decay chains are known \rightarrow truth matching can be done in simulation by requiring explicitly IDs for particle, parent particle, ...
- Strongly or electromagnetically decaying hadrons are short-lived
- \rightarrow Flight distance very small, no detached vertex, hard to separate in data from really prompt V0 particles
- Therefore, kept in truth matching, but V0's from weakly decaying hadrons (hyperons and charm) removed









Mass fit examples for different $p_{\rm T}$ bins















Crossing angle

- Crossing angle in horizontal plane causes asymmetry in production \rightarrow introduces shifts $p_{\rm T}$ and y distributions • Effect is expected to be small in LHCb acceptance \rightarrow In Run 3 the crossing angle will be moved to the vertical plane \rightarrow Allow better comparisons to other experiments
- correction of crossing angle recovers isotropic distribution in azimuthal angle φ



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Effective crossing angle (internal+external):

 $\theta_{h,MagDown}(\sqrt{s} = 13 \text{TeV}) = \mp 790 \mu \text{rad}$ $\theta_{h.MagUp}(\sqrt{s} = 13 \text{TeV}) = \mp 210 \mu \text{rad}$



21