ΛK and Ξ^{-}K$^{\pm}$ femtoscopy in Pb-Pb collisions at 2.76 TeV from ALICE

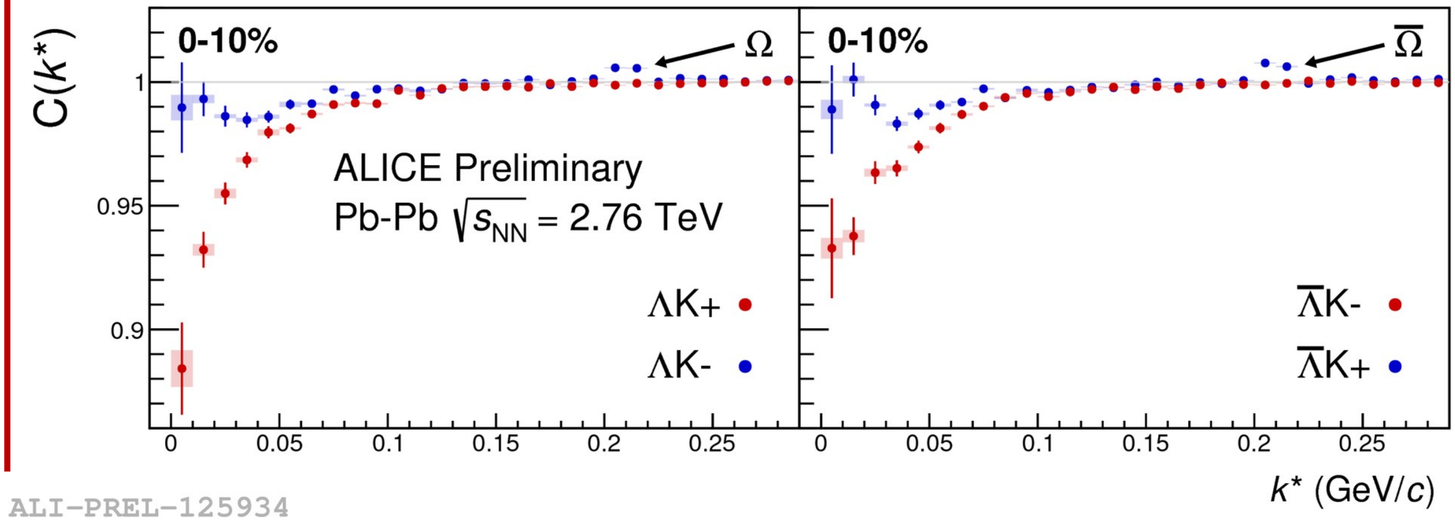
Jesse Thomas Buxton
The Ohio State University
on behalf of the ALICE Collaboration

Motivation

- Study femtoscopic ΛK correlations
  - Result from strong final-state interactions (FSI)
- Characterize ΛK pair emission region
- Extract ΛK interaction scattering parameters
  - **Never before measured**
- $\Xi^{-}K^{\pm}$ study to investigate difference in ΛK^{+} and ΛK^{-}

ΛK^{+}	$uds + u\bar{s}$	S=0
ΛK^{-}	$uds + \bar{u}s$	S=−2

$\Xi^{-}K^{+}$	$dss + u\bar{s}$	S=−1
$\Xi^{-}K^{-}$	$dss + \bar{u}s$	S=−3



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Femtoscopy

- Exploit two-particle correlations of hadrons
- Probe space-time freeze-out structure at femtometer scale (10^{-15} m)
- Measure “regions of homogeneity” [1]
- **Unique environment to measure nuclear scattering parameters**

Theory

- Koonin-Pratt Equation [2,3]

$$C(\mathbf{P},\mathbf{k}^*) = \int S_{\mathbf{P}}(\mathbf{r}^*)|\Psi(\mathbf{k}^*,\mathbf{r}^*)|^2 \mathrm{d}^3 r^*$$

- $S_P(\mathbf{r}^*)$ = source distribution
- $\Psi(\mathbf{k}^*, \mathbf{r}^*)$ = two-particle wave-function
- $k^* = |\mathbf{k}^*|$ = momentum of one particle in pair rest frame

Experiment

$$C(k^*) = \frac{A(k^*)}{B(k^*)}$$

- $A(k^*)$: signal distribution (same-event)
- $B(k^*)$: reference distribution (mixed events)

Theoretical Fit Function

- Lednický and Lyuboshitz formulation [4]
  - Isotropic Gaussian profile & effective range approximation

$$\Psi(\mathbf{k}^*,\mathbf{r}^*) = e^{-i\mathbf{k}^*\cdot\mathbf{r}^*} + f^S(k^*)\frac{e^{ik^*r^*}}{r^*}$$

$$f^S(k^*) = \left(\frac{1}{f_0^S} + \frac{1}{2}d_0^S k^{*2} - ik^*\right)^{-1}$$

$$\sigma = 4\pi\left|f^2\right|$$

- Nice analytic form

$$\boxed{\begin{aligned} C(k^*) &= 1 + \sum_S \rho_S \left[\frac{1}{2}\left|\frac{f^S(k^*)}{R}\right|^2\left(1 - \frac{d_0^S}{2\sqrt{\pi}R}\right) + \right. \\ &\quad \left. \frac{2\Re f^S(k^*)}{\sqrt{\pi}R}F_1(2k^*R) - \frac{\Im f^S(k^*)}{R}F_2(2k^*R)\right] \end{aligned}}$$

- f_0^S – complex scattering length
- d_0^S – effective range of interaction
- R – source size

Residual Correlations

- Measured CF is combination of primary signal and transformed residuals [5]
- λ_{ij} control strength of contribution

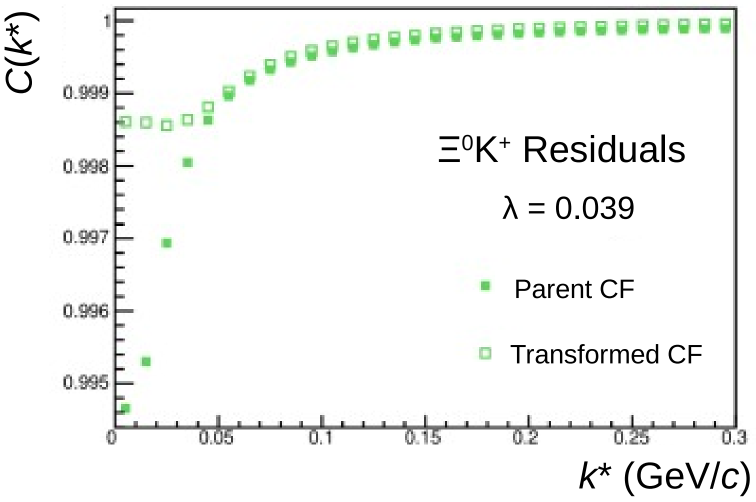
- Modeling parent CF
  - Assume same R, f_0^S, d_0^S as ΛK system
  - $\Xi^-K^\pm$ data or Coulomb-only simulation

$$C_{\text{measured}}(k^*_{\Lambda\text{K}}) = \mathcal{N}\left(1+\lambda'_{\Lambda\text{K}}[C_{\Lambda\text{K}}(k^*_{\Lambda\text{K}})-1]+\sum_{i,j}\lambda'_{ij}[\underline{C_{ij}(k^*_{\Lambda\text{K}})}-1]\right)$$

$$\lambda'_{ij} = \lambda_{\text{Fit}}\underline{\lambda_{ij}}$$

$$\sum_{i,j}\lambda'_{ij} = \lambda_{\text{Fit}}\sum_{i,j}\underline{\lambda_{ij}} = \lambda_{\text{Fit}}$$

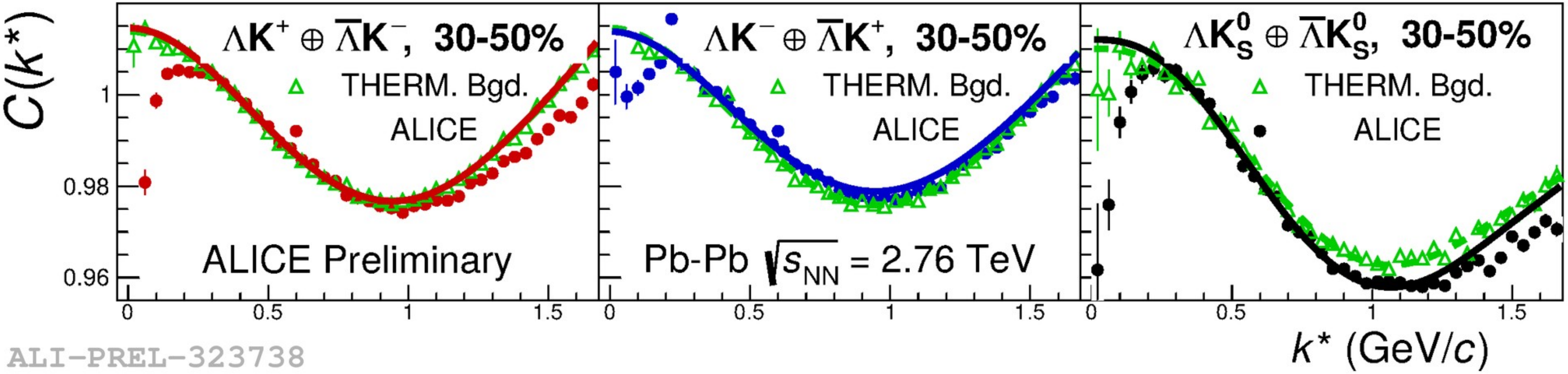
$$\underline{C_{ij}(k^*_{\Lambda\text{K}})} \equiv \frac{\sum_{k^*_{ij}} \underline{C_{ij}\left(k^*_{ij}\right)}\, T\left(k^*_{ij}, k^*_{\Lambda\text{K}}\right)}{\sum_{k^*_{ij}} T\left(k^*_{ij}, k^*_{\Lambda\text{K}}\right)}$$



Pair System	λ-factor
Primary	0.527
Σ^0K+	0.111
Ξ^0K+	0.039
Ξ-K+	0.050
Other	0.226
Fakes	0.048

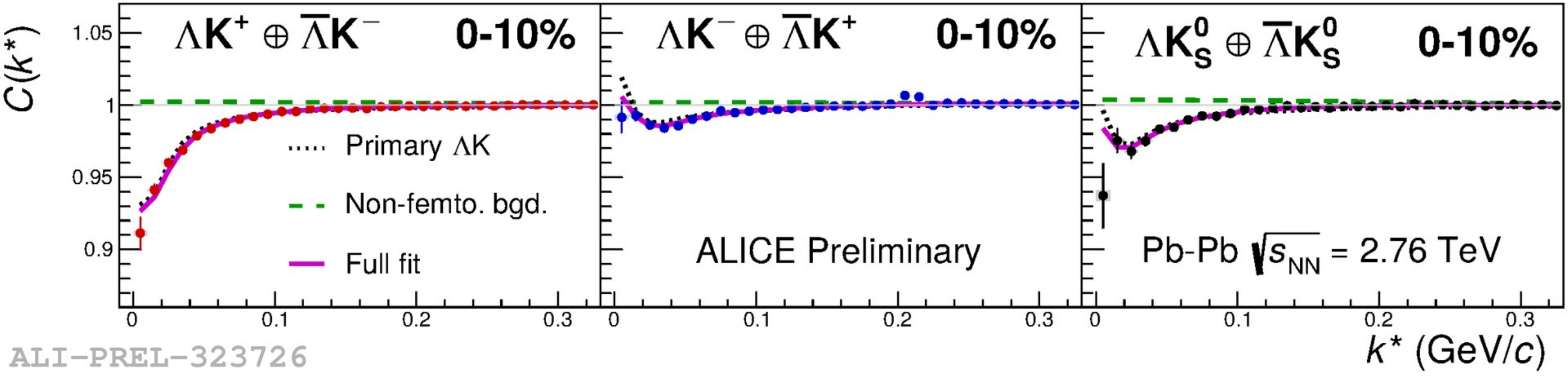
Non-femtoscopic Background

- Significant non-femtoscopic background at large *k**
- Effect due primarily to particle collimation associated with elliptic flow [6]
  - Results from mixing events with unlike event-plane angles
- THERMINATOR 2 simulation to model and account for in fit



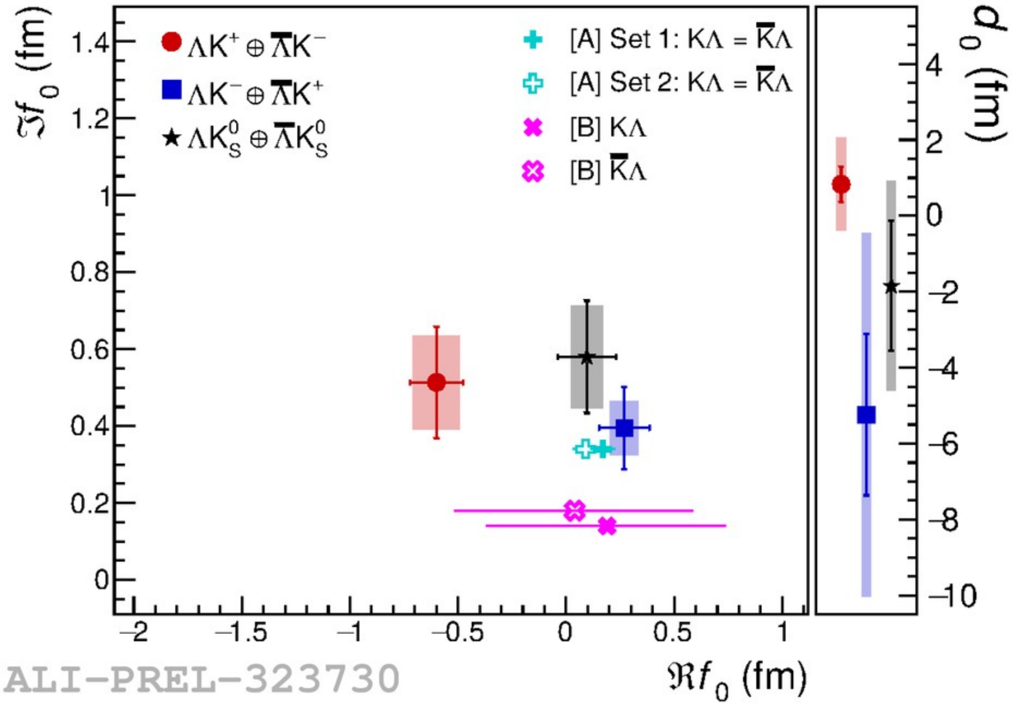
Results: CFs with Fits

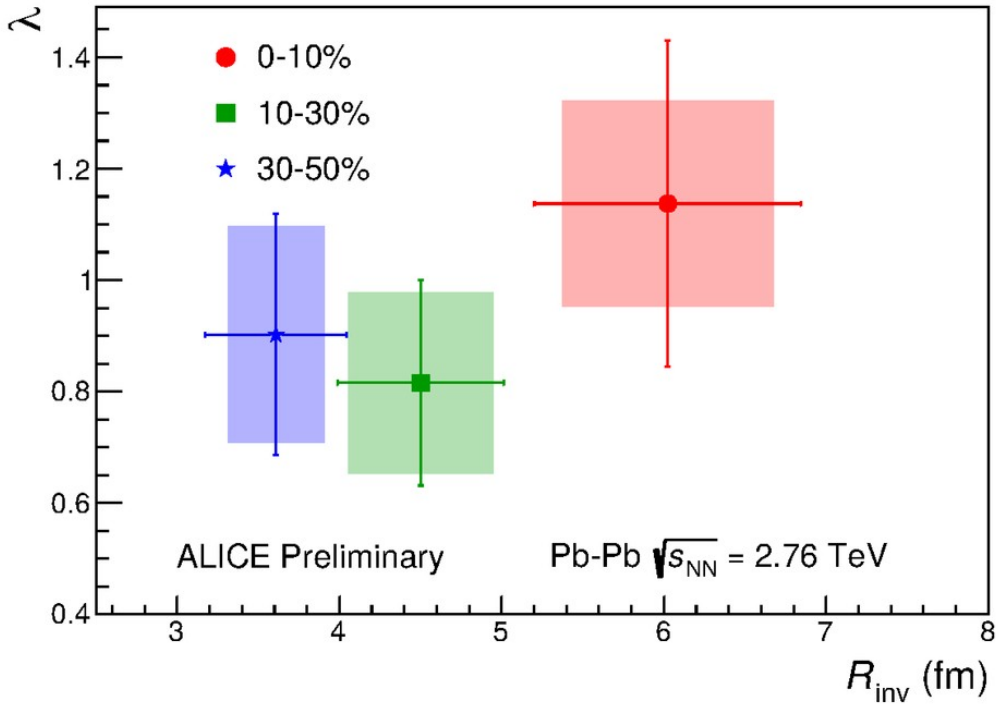
- All analyses fit simultaneously across all centralities
  - For each centrality *R* and λ_{Fit} shared among all systems
  - Unique set of scattering parameters for each ΛK charge combination (ΛK^+, ΛK^-, ΛK^0_S)
- Residual contributions from resonance feed-down included
- Non-femtoscopic background and momentum resolution corrections applied



Results: Fit Parameters

- $\Re f_0$ is **positive** for **ΛK^-** and **ΛK^0_s** → **attractive** strong interaction
- $\Re f_0$ is **negative** for **ΛK^+** → **repulsive** strong interaction

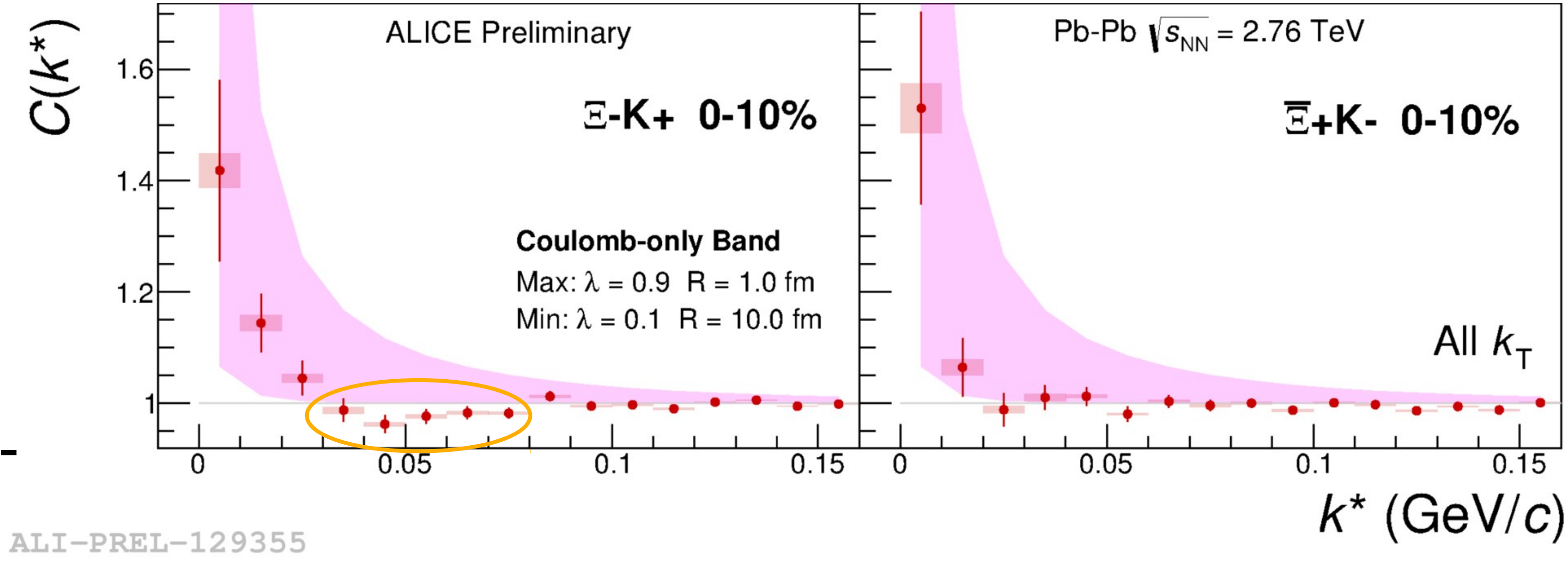


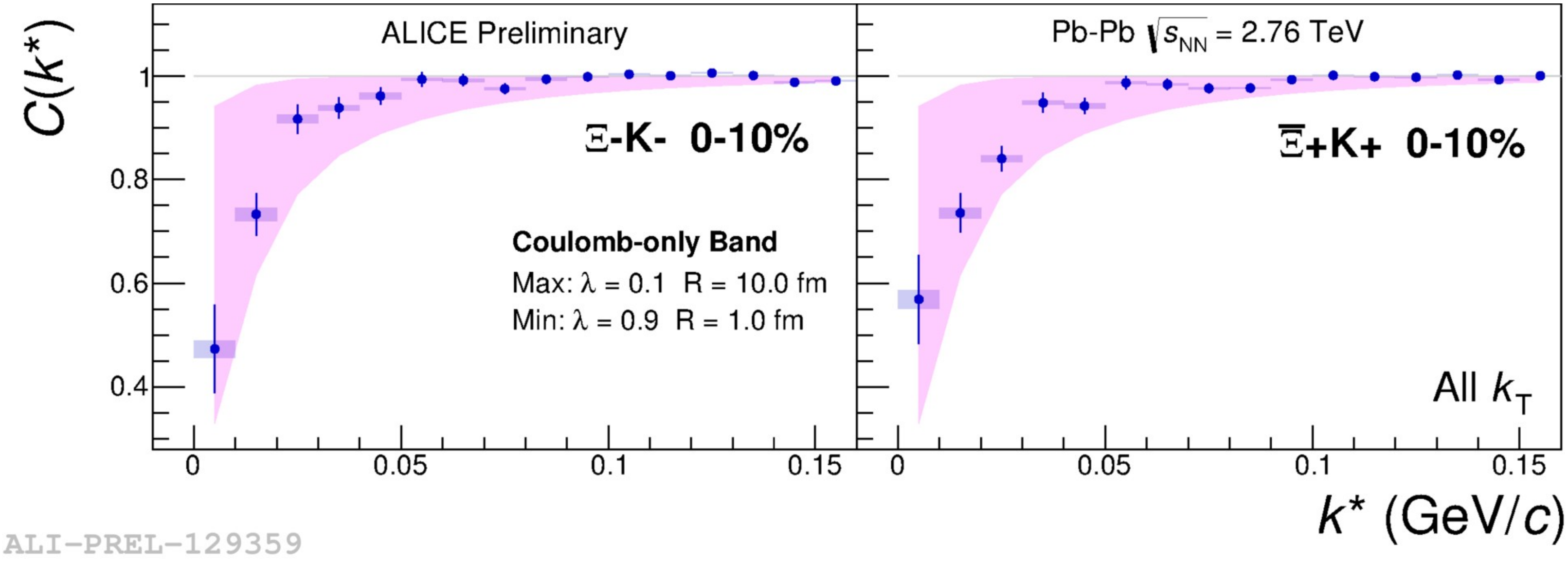


$\Xi^{-}K^{\pm}$ Analysis

$\Xi^{-}K^{\pm}$ Data vs. Coulomb Only

- **Magenta** = Coulomb-only band
  - Spanned by two Coulomb-only CFs
- $\Xi^{-}K^{+}$ cannot be described with only Coulomb
  - Strong force showing?



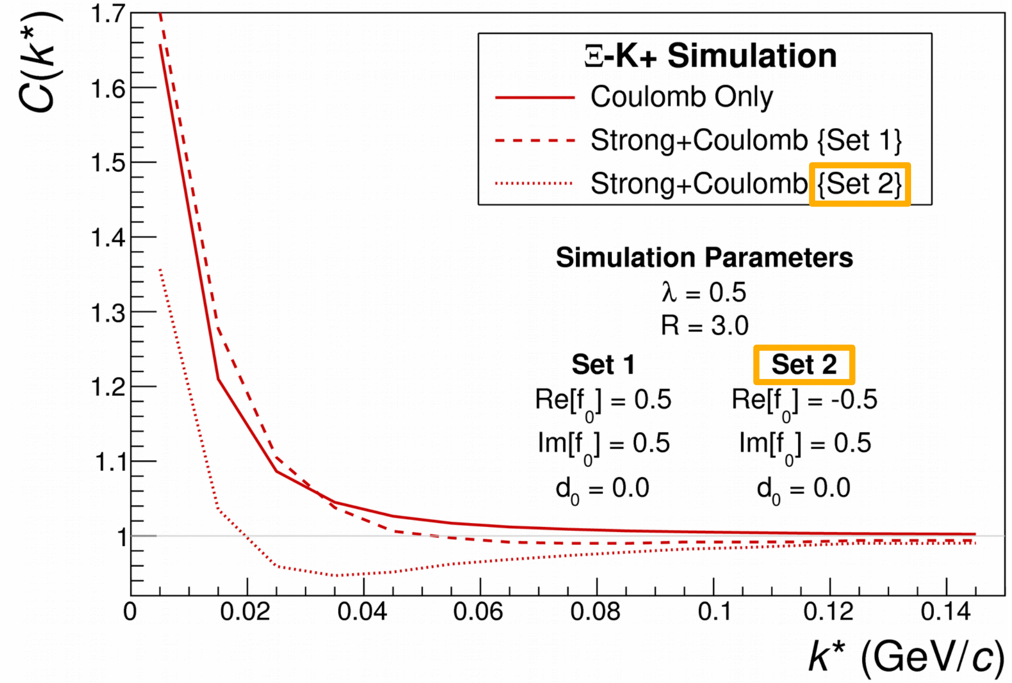


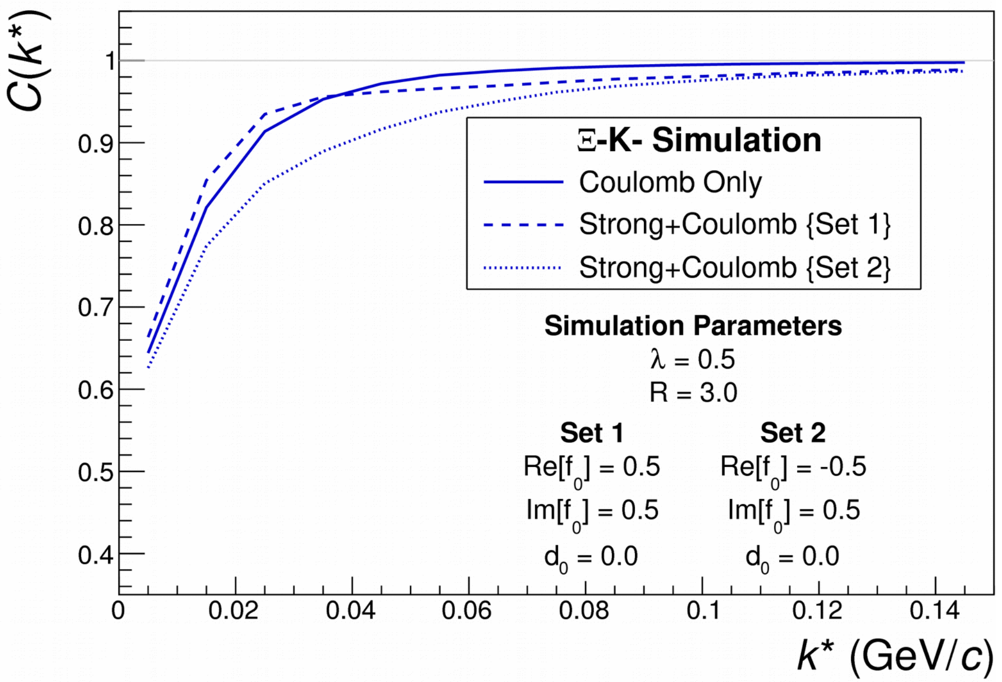
Outlook

- Inclusion of strong and Coulomb interactions
  - No nice analytic form
  - Must integrate by hand

$$\Psi_{\mathbf{k}^*}(\mathbf{r}^*) = e^{i\delta_c}\sqrt{A_c(\eta)}\left[e^{-i\mathbf{k}^*\cdot\mathbf{r}^*}F(-i\eta,1,i\xi)+f_c(k^*)\frac{\tilde{G}(\rho,\eta)}{r^*}\right]$$

$$f_c(k^*) = \left[\frac{1}{f_0}+\frac{1}{2}d_0k^{*2}-\frac{2}{a_c}h(\eta)-ik^*A_c(\eta)\right]^{-1}$$





Summary

- ΛK femtoscopic analysis presented for Pb-Pb collisions at 2.76 TeV
  - First measurement of ΛK scattering parameters
  - Pair emission source radii extracted for 0-10%, 10-30%, and 30-50% centralities
- $\Xi^{-}K^{\pm}$ femtoscopic analysis introduced for Pb-Pb collisions at 2.76 TeV
  - Goal to help explain striking difference in ΛK^{+} and ΛK^{-} correlations observed at low k^{*}
  - A Coulomb-only fit cannot describe the data

Thank you

References

[1] S. Akkelin and Y. Sinyukov, “The HBT-interferometry of expanding sources,” *Physics Letters* **B356** (1995) 525 – 530.

[2] S. E. Koonin, “Proton Pictures of High-Energy Nuclear Collisions,” *Phys. Lett.* **B70** (1977) 43–47.

[3] S. Pratt, T. Csorgo, and J. Zimanyi, “Detailed predictions for two pion correlations in ultrarelativistic heavy ion collisions,” *Phys. Rev.* **C42** (1990) 2646–2652.

[4] R. Lednicky and V. L. Lyuboshits, “Final State Interaction Effect on Pairing Correlations Between Particles with Small Relative Momenta,” *Sov. J. Nucl. Phys.* **35** (1982) 770.

[5] A. Kisiel, H. Zbroszczyk, and M. Szymaski, “Extracting baryon-antibaryon strong interaction potentials from p$\bar{\Lambda}$ femtoscopic correlation functions,” *Phys. Rev.* **C89** no. 5, (2014) 054916, `arXiv:1403.0433 [nucl-th]`.

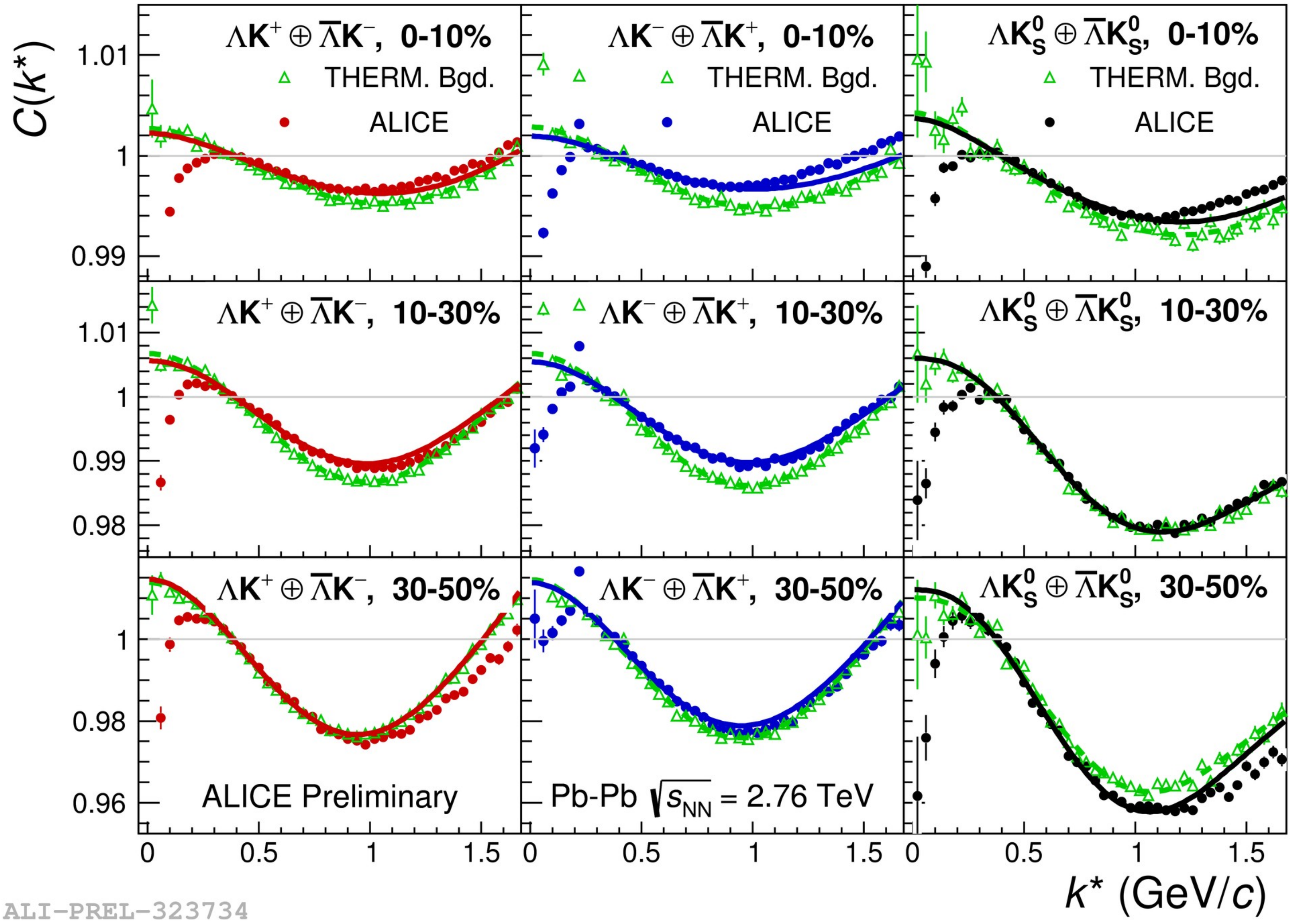
[6] A. Kisiel, “Non-identical particle correlation analysis in the presence of non-femtoscopic correlations,” *Acta Physica Polonica B* **48** (04, 2017) 717.

[7] A. Kisiel, “Non-identical particle correlation analysis in the presence of non-femtoscopic correlations,” *XII Workshop on Particle Correlations and Femtoscopy*, 12-16 June 2017, Nikhef, Amsterdam, The Netherlands. Conference Talk.

[8] M. A. Lisa, S. Pratt, R. Soltz, and U. Wiedemann, “Femtoscopy in relativistic heavy ion collisions,” *Ann. Rev. Nucl. Part. Sci.* **55** (2005) 357–402, `arXiv:nucl-ex/0505014 [nucl-ex]`.

BACKUP

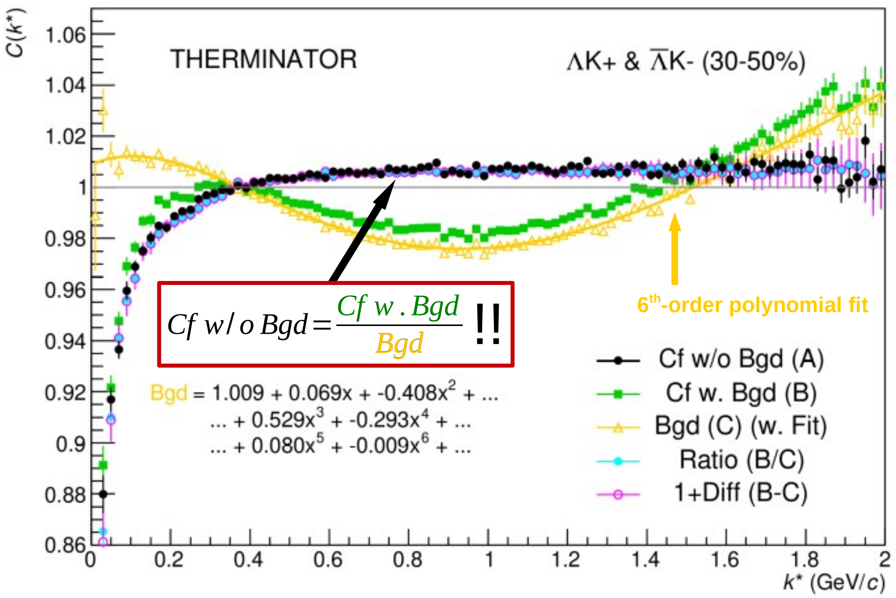
Non-femtoscopic Background



THERMINATOR 2 Background

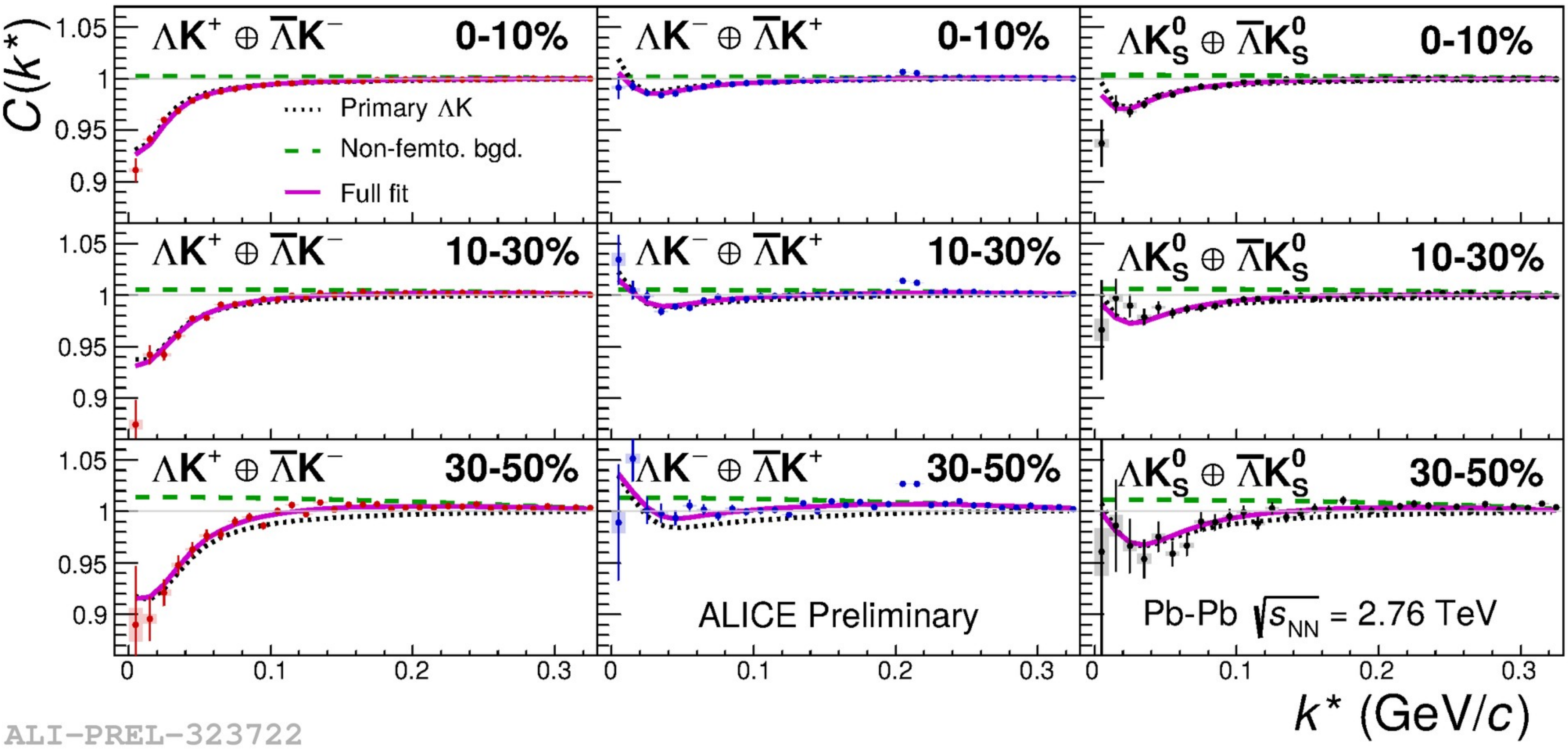
- THERMINATOR 2: THERMal heavy IoN geneATOR 2
  - Statistical hadronization in relativistic heavy-ion collisions
  - Any freeze-out hypersurface + expansion velocity field can be implemented
- Demonstrates background is scale factor

$$Cf\ w/o\ Bgd = \frac{Cf\ w.Bgd}{Bgd} \Rightarrow Cf_{th} = \frac{Cf_{exp}}{F_{Bgd}} \Rightarrow Cf_{exp} = Cf_{th} \cdot F_{Bgd}$$



Simulation Only:
Interaction achieved by assuming scattering parameters, and weighting the numerators in the simulation

Results: CFs with Fits



m_T Scaling of Radii

- Expect asymmetry μ_{out} in the outward direction
- Hydrodynamic response on higher m_T particles
  - confines them to smaller homogeneity regions
  - pushes them further in the out direction
- Within 1D model used, a non-zero μ_{out} induces larger extracted source radii

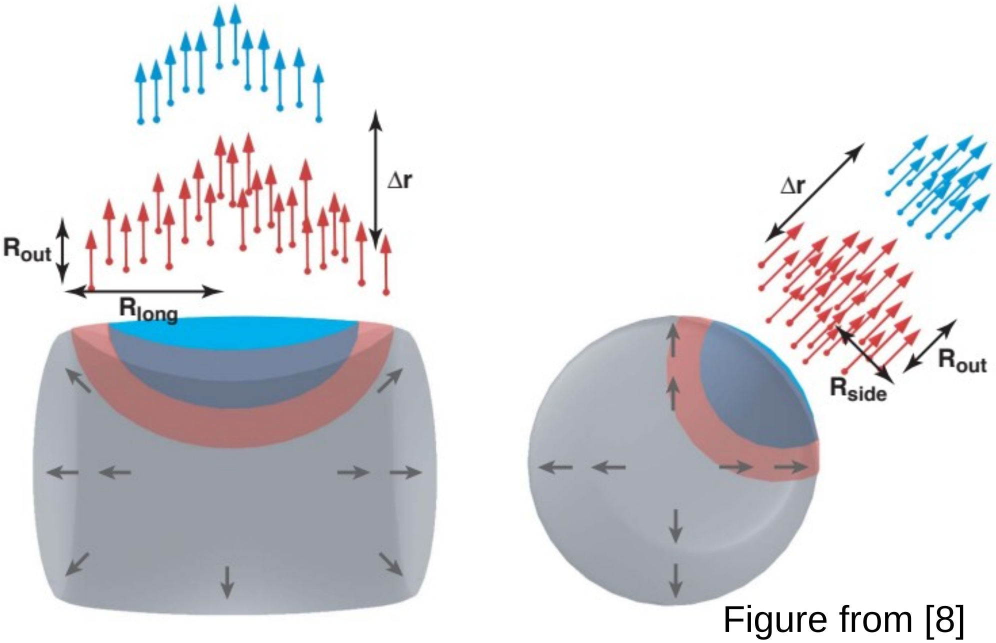


Figure from [8]

$$S_{ab}(\mathbf{r}) \propto \exp\left(-\frac{[r_{out}-(\mu_{a,out}-\mu_{b,out})]^2}{2(R^2_{a,out}+R^2_{b,out})}\right)\times\dots$$
$$\times\exp\left(-\frac{r^2_{side}}{2(R^2_{a,side}+R^2_{b,side})}\right)\times\dots$$
$$\times\exp\left(-\frac{r^2_{long}}{2(R^2_{a,long}+R^2_{b,long})}\right)$$

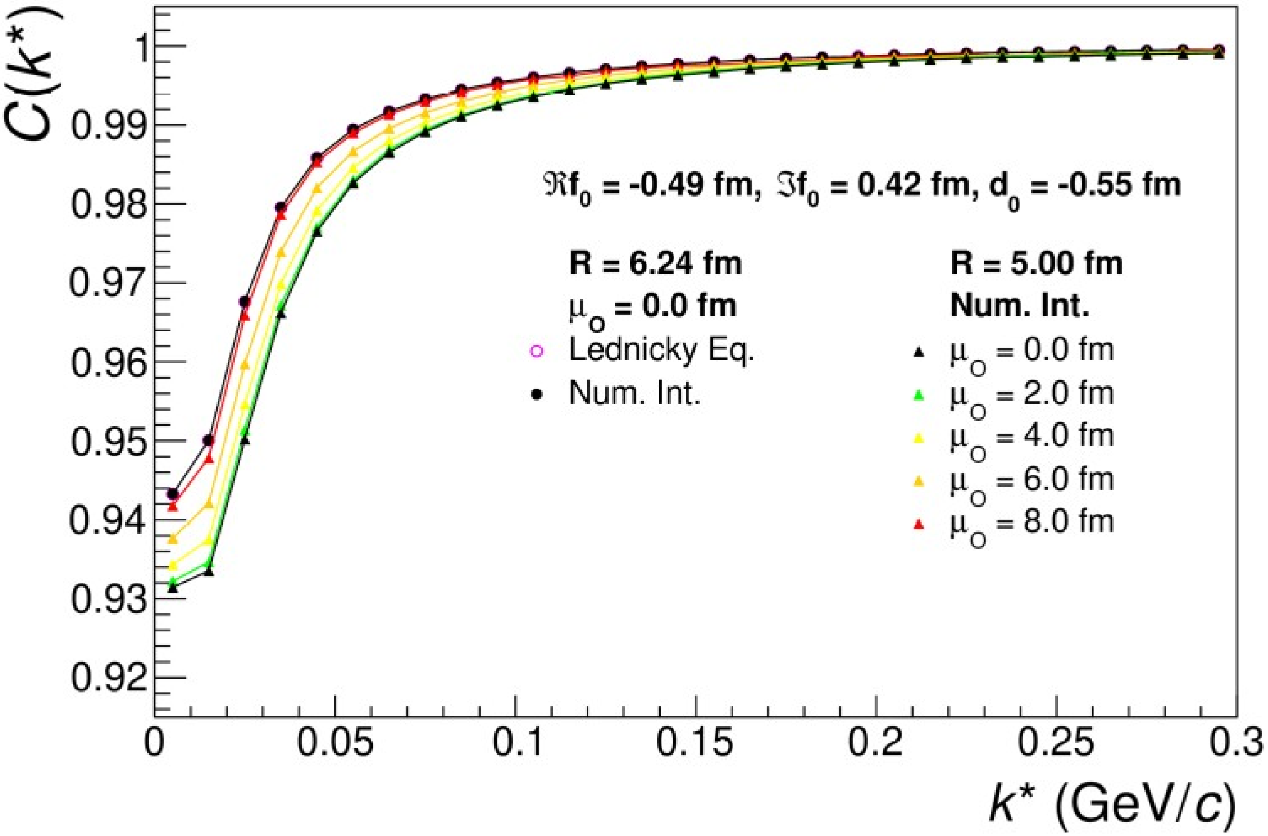
Numerical Integration

- Numerically integrate Koonin-Pratt equation
  - Allows for offset μ_{out} to be implemented
- Increasing μ_{out} makes source appear larger

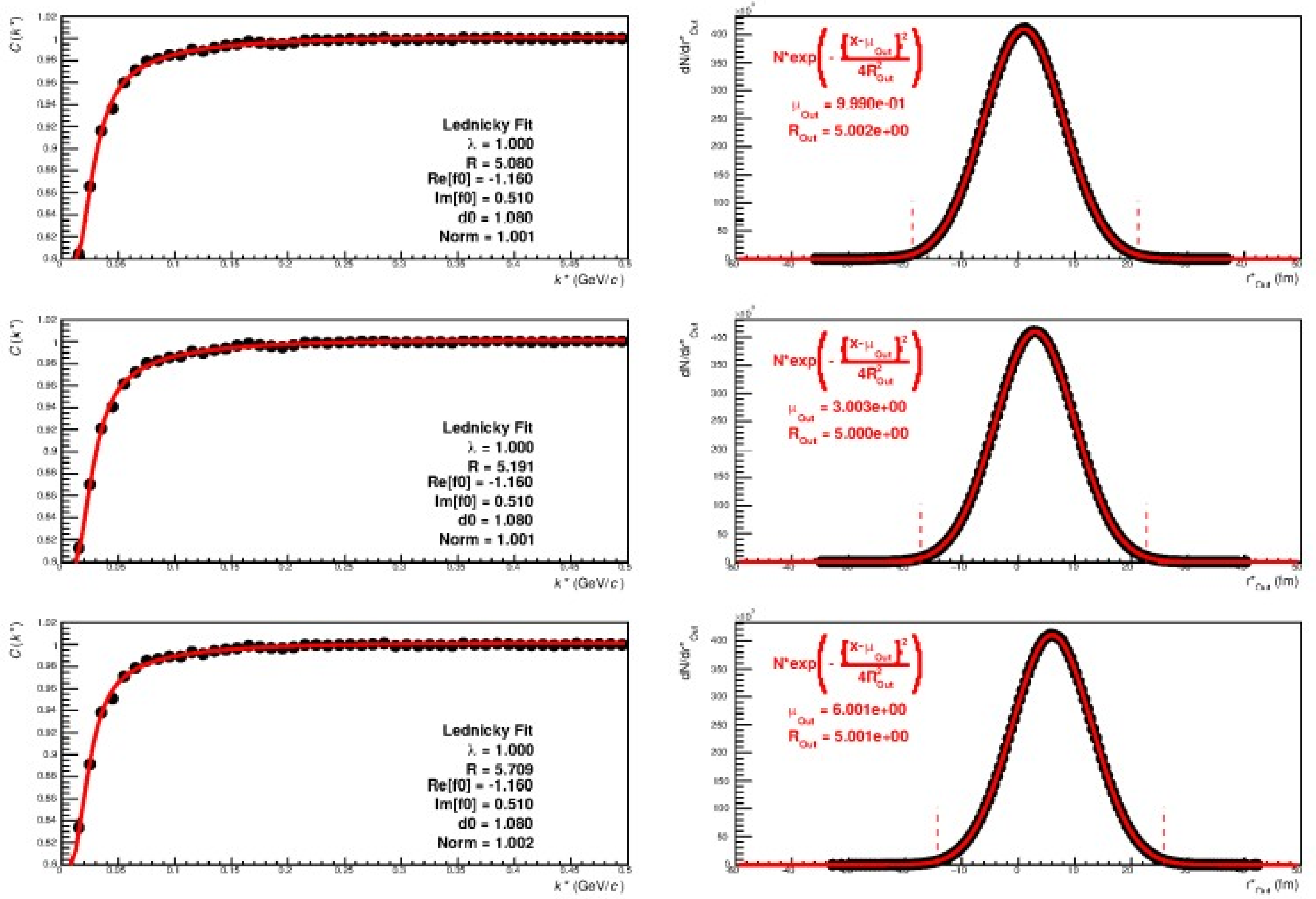
$$C(\mathbf{P},\mathbf{k}^*) = \int S_{\mathbf{P}}(\mathbf{r}^*)|\Psi(\mathbf{k}^*,\mathbf{r}^*)|^2 d^3\mathbf{r}^*$$

$$\Psi(k^*,x^*) = e^{-i\boldsymbol{k}^*\cdot\boldsymbol{x}^*} + f(k^*)\frac{e^{ik^*x^*}}{x^*}$$

$$S_{ab}(\mathbf{r}) \propto \prod_{i=\mathrm{o,s,l}} \exp\left(-\frac{[r_i-(\mu_{a,i}-\mu_{b,i})]^2}{2(R_{a,i}^2+R_{b,i}^2)}\right)$$



Shifts with THERM. 2



Strong + Coulomb

$$\Psi_{\mathbf{k}^*}(\mathbf{r}^*) = e^{i\delta_c}\sqrt{A_c(\eta)}\left[e^{-i\mathbf{k}^*\cdot\mathbf{r}^*}F(-i\eta,1,i\xi) + f_c(k^*)\frac{\tilde{G}(\rho,\eta)}{r^*}\right]$$

$$f_c(k^*) = \left[\frac{1}{f_0} + \frac{1}{2}d_0 k^{*2} - \frac{2}{a_c}h(\eta) - ik^* A_c(\eta)\right]^{-1}$$

$$h(\eta) = 0.5[\psi(i\eta) + \psi(-i\eta) - \ln(\eta^2)]$$

$$\psi(z) = \Gamma'(z)/\Gamma(z)$$

δ_c = Coulomb s-wave phase shift

$A_c(\eta)$ = Coulomb penetration factor

$\tilde{G} = \sqrt{A_c}(G_0 + iF_0)$

F_0 (G_0) = regular (singular) s-wave Coulomb functions

$$\rho = k^* r^*$$

$$\eta = (k^* a_c)^{-1}$$

$$\xi = \mathbf{k}^*\cdot\mathbf{r}^* + k^* r^*$$

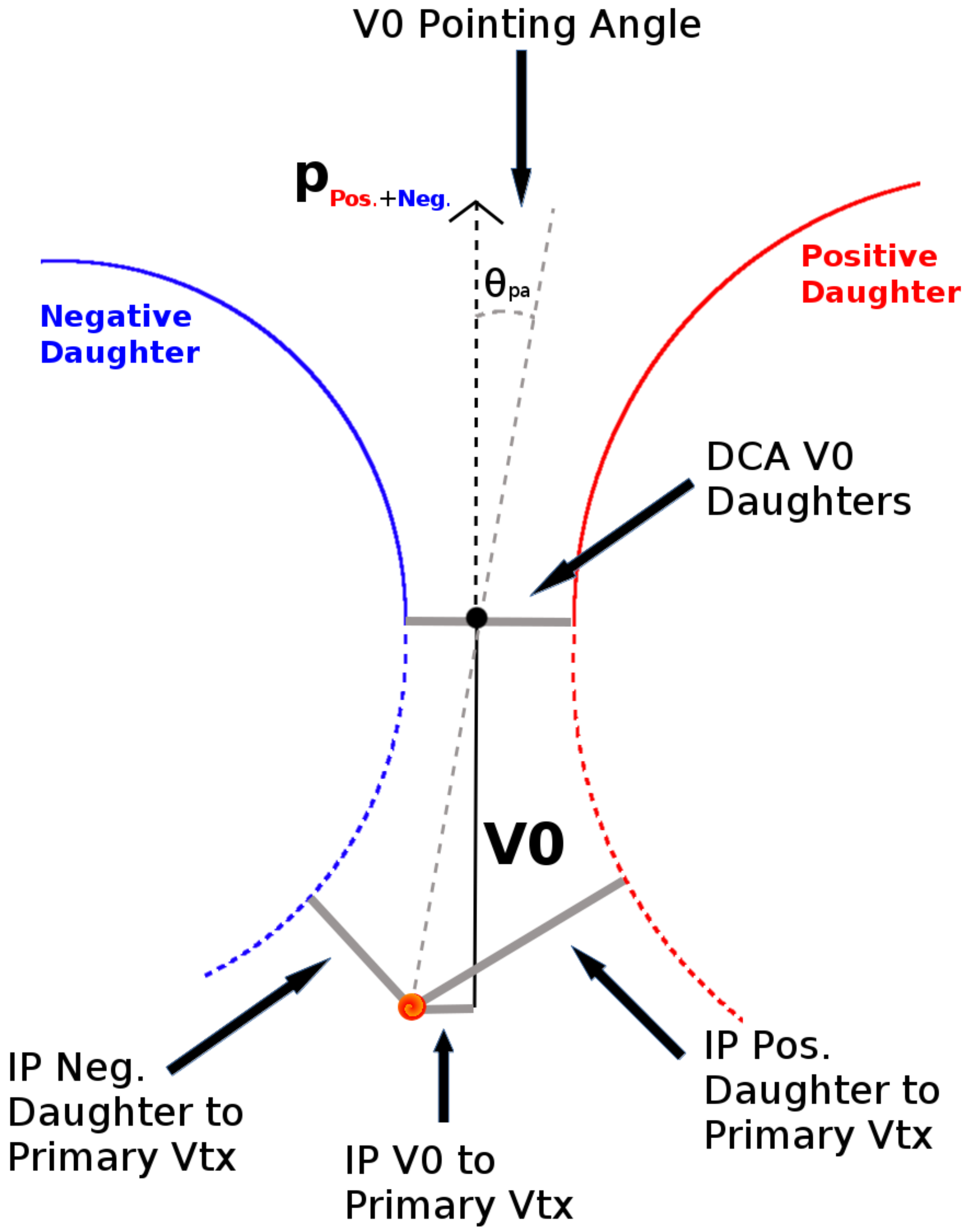
$$= \rho(1+\cos\theta^*)$$

$$a_c = (\mu z_1 z_2 e^2)^{-1}$$

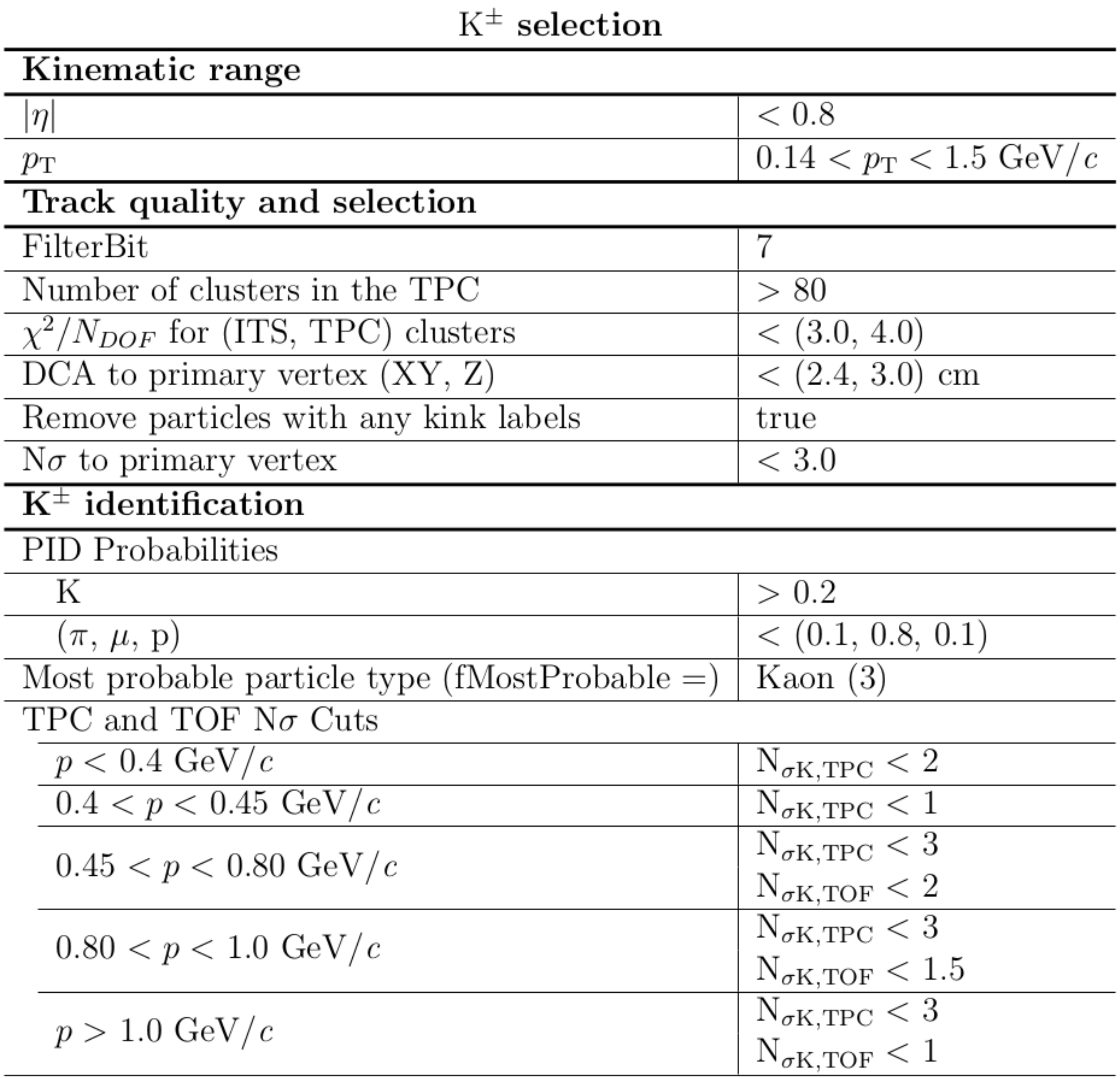
Analysis Details

Analysis Overview

- Charged tracks identified with TPC and TOF detectors
  - Purity $K^{\pm} \approx 97\%$
- Neutral V0s identified from decay products
  - $\Lambda \rightarrow p\pi^{-}$ (Purity ≈ 95%)
  - $K^{0}_{S} \rightarrow \pi^{+}\pi^{-}$ (Purity ≈ 98%)
- Misidentification cuts
  - Remove K^{0}_{S} contamination in $\Lambda(\overline{\Lambda})$ and vice versa
- V0 shared daughter cut
- Pair cuts
  - Shared daughter
  - Average separation
    - V0 Daughter-V0 Daughter (ΛK^{0}_{S})
    - V0 Daughter-Track ($\Lambda K^{\pm}$)



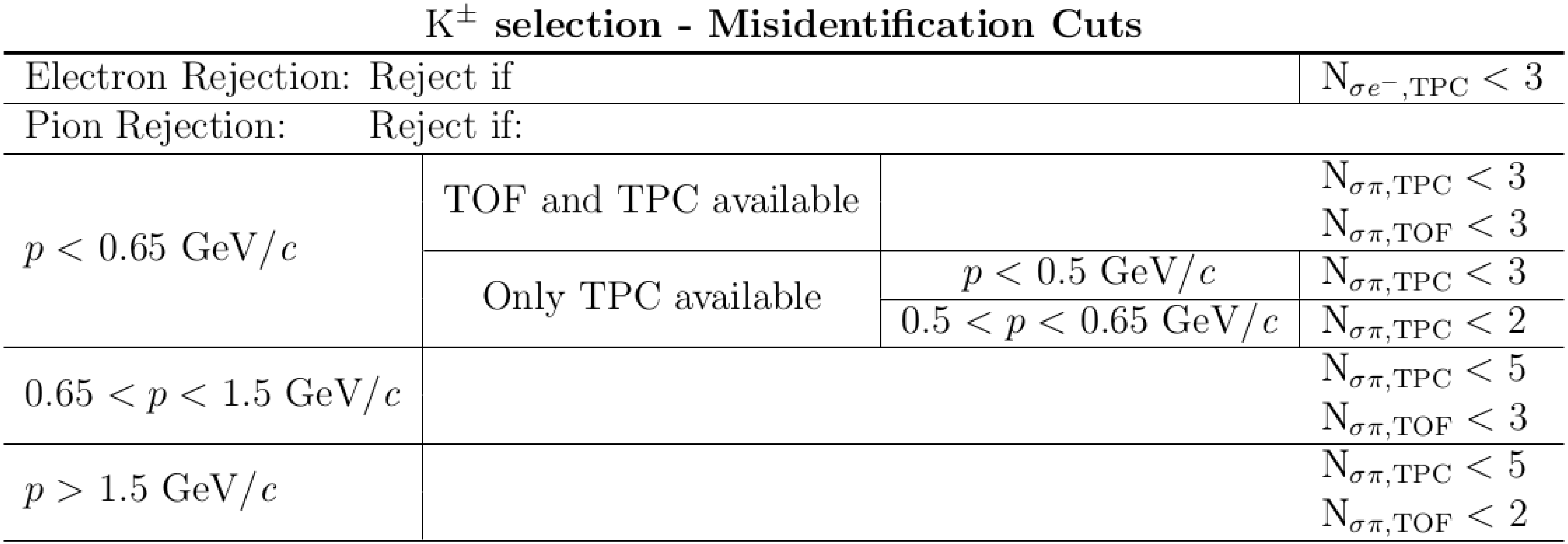
$K^{\pm}$ Selection



$K^{\pm}$ selection

Kinematic range	
$\|\eta\|$	< 0.8
p_{T}	$0.14 < p_{\mathrm{T}} < 1.5$ GeV/c
Track quality and selection	
FilterBit	7
Number of clusters in the TPC	> 80
χ^2/N_{DOF} for (ITS, TPC) clusters	$< (3.0, 4.0)$
DCA to primary vertex (XY, Z)	$< (2.4, 3.0)$ cm
Remove particles with any kink labels	true
Nσ to primary vertex	< 3.0
$K^{\pm}$ identification	
PID Probabilities	
K	> 0.2
(π, μ, p)	$< (0.1, 0.8, 0.1)$
Most probable particle type (fMostProbable =)	Kaon (3)
TPC and TOF Nσ Cuts	
$p < 0.4$ GeV/c	$\mathrm{N}_{\sigma\mathrm{K,TPC}} < 2$
$0.4 < p < 0.45$ GeV/c	$\mathrm{N}_{\sigma\mathrm{K,TPC}} < 1$
$0.45 < p < 0.80$ GeV/c	$\mathrm{N}_{\sigma\mathrm{K,TPC}} < 3$ $\mathrm{N}_{\sigma\mathrm{K,TOF}} < 2$
$0.80 < p < 1.0$ GeV/c	$\mathrm{N}_{\sigma\mathrm{K,TPC}} < 3$ $\mathrm{N}_{\sigma\mathrm{K,TOF}} < 1.5$
$p > 1.0$ GeV/c	$\mathrm{N}_{\sigma\mathrm{K,TPC}} < 3$ $\mathrm{N}_{\sigma\mathrm{K,TOF}} < 1$

K± Misidentification Cuts



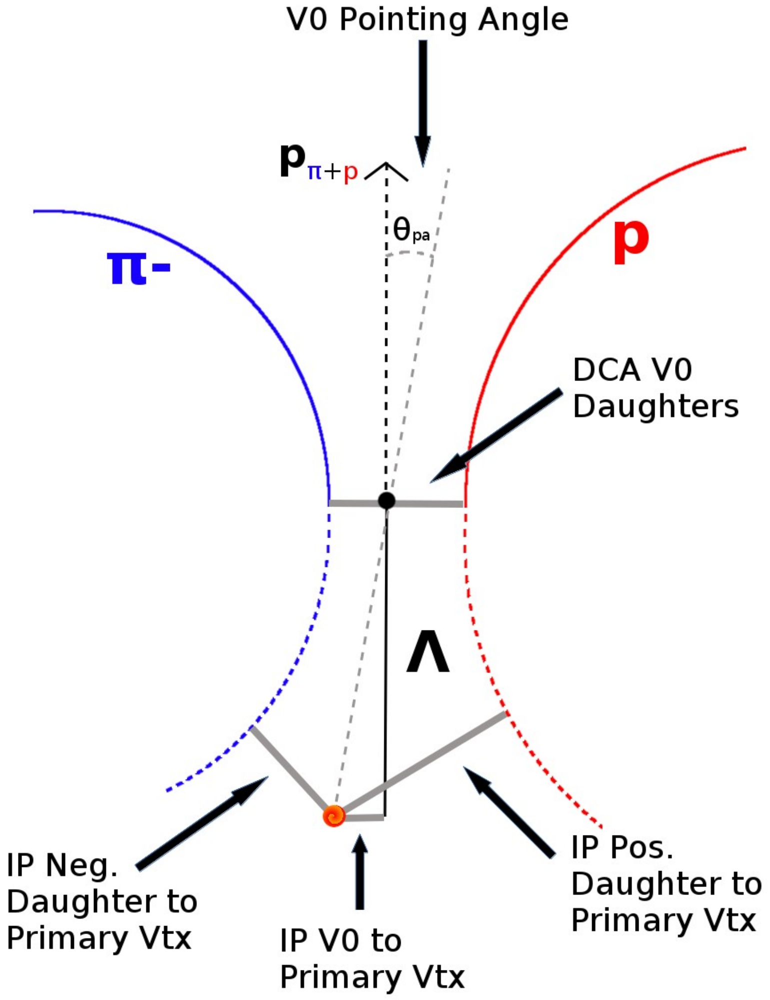
K± selection - Misidentification Cuts

Electron Rejection: Reject if			$\mathrm{N}_{\sigma e^-,\mathrm{TPC}} < 3$
Pion Rejection: Reject if:			
$p < 0.65$ GeV/c	TOF and TPC available		$\mathrm{N}_{\sigma\pi,\mathrm{TPC}} < 3$ $\mathrm{N}_{\sigma\pi,\mathrm{TOF}} < 3$
	Only TPC available	$p < 0.5$ GeV/c	$\mathrm{N}_{\sigma\pi,\mathrm{TPC}} < 3$
		$0.5 < p < 0.65$ GeV/c	$\mathrm{N}_{\sigma\pi,\mathrm{TPC}} < 2$
$0.65 < p < 1.5$ GeV/c			$\mathrm{N}_{\sigma\pi,\mathrm{TPC}} < 5$ $\mathrm{N}_{\sigma\pi,\mathrm{TOF}} < 3$
$p > 1.5$ GeV/c			$\mathrm{N}_{\sigma\pi,\mathrm{TPC}} < 5$ $\mathrm{N}_{\sigma\pi,\mathrm{TOF}} < 2$

$\Lambda(\bar{\Lambda})$ Reconstruction

$\Lambda \rightarrow p\pi^- \; (\bar{\Lambda} \rightarrow \bar{p}\pi^+)$

- $c\tau$ = 7.9 cm
- Branching ratio ~ 64%
- **Purity(Λ) ~ Purity($\bar{\Lambda}$) ~ 95%**

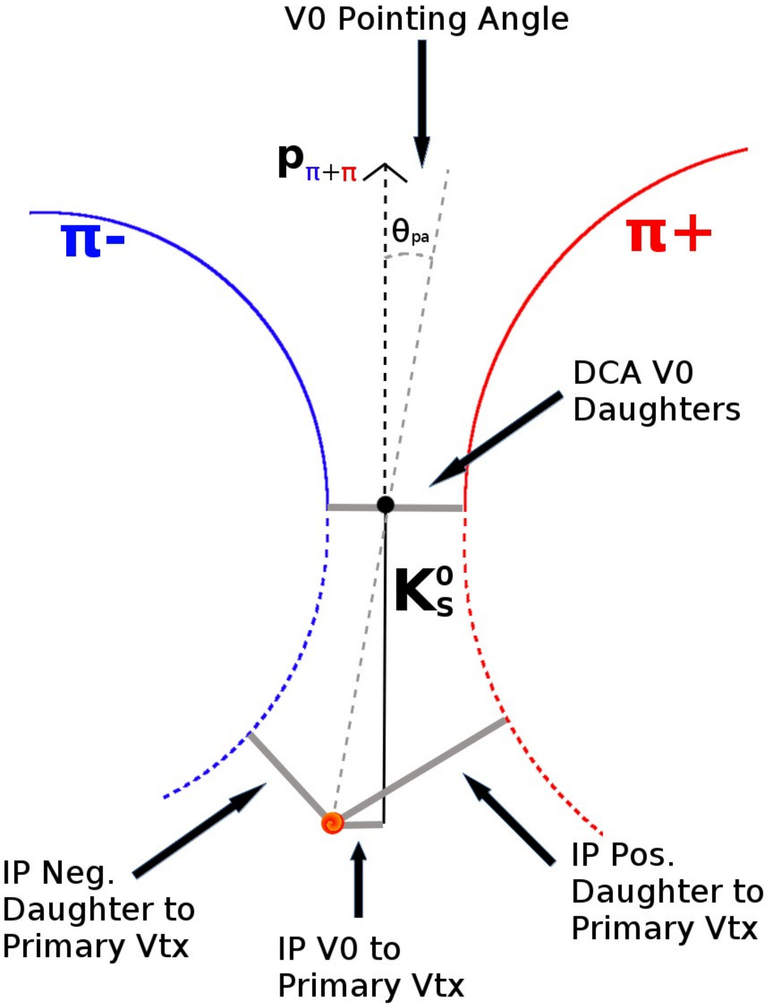


Λ reconstruction		
$\lvert\eta\rvert$		< 0.8
p_{T}		> 0.4 GeV/c
$\lvert m_{\mathrm{inv}} - m_{\mathrm{PDG}}\rvert$		< 3.8 MeV
DCA to prim. vertex		< 0.5 cm
Cosine of pointing angle		> 0.9993
OnFlyStatus		false
Decay Length		< 60 cm
Shared Daughter Cut		true
Misidentification Cut		true
Daughter Cuts (π and p)		
$\lvert\eta\rvert$		< 0.8
Number of clusters in the TPC		> 80
Daughter status		kTPCrefit
DCA πp Daughters		< 0.4 cm
π-specific cuts		
p_{T}		> 0.16 GeV/c
DCA to prim vertex		> 0.3 cm
TPC and TOF Nσ Cuts		
$p < 0.5$ GeV/c		$N\sigma_{\mathrm{TPC}} < 3$
$p > 0.5$ GeV/c	if TOF & TPC available	$N\sigma_{\mathrm{TPC}} < 3$ & $N\sigma_{\mathrm{TOF}} < 3$
	else	$N\sigma_{\mathrm{TOF}} < 3$
p-specific cuts		
p_{T}		$> 0.5(p)$ $[0.3(\bar{p})]$ GeV/c
DCA to prim vertex		> 0.1 cm
TPC and TOF Nσ Cuts		
$p < 0.8$ GeV/c		$N\sigma_{\mathrm{TPC}} < 3$
$p > 0.8$ GeV/c	if TOF & TPC available	$N\sigma_{\mathrm{TPC}} < 3$ & $N\sigma_{\mathrm{TOF}} < 3$
	else	$N\sigma_{\mathrm{TOF}} < 3$

K^0_S Reconstruction

$K^0_s \rightarrow \pi^+\pi^-$

- $c\tau$ = 2.7 cm (15 m for K^0_L)
- Branching ration ~ 70%
- **Purity(K^0_S) ~ 98%**



K^0_S reconstruction		
$\lvert\eta\rvert$		< 0.8
p_T		> 0.2 GeV/c
$m_{PDG} - 13.677$ MeV $< m_{\mathrm{inv}} < m_{\mathrm{PDG}} + 2.0323$ MeV		
DCA to prim. vertex		< 0.3 cm
Cosine of pointing angle		> 0.9993
OnFlyStatus		false
Decay Length		< 30 cm
Shared Daughter Cut		true
Misidentification Cut		true
$\pi^\pm$ Daughter Cuts		
$\lvert\eta\rvert$		< 0.8
Number of clusters in TPC		> 80
Daughter Status		kTPCrefit
DCA $\pi^+\pi^-$ Daughters		< 0.3 cm
p_T		> 0.15 GeV/c
DCA to prim vertex		> 0.3 cm
TPC and TOF $N\sigma$ Cuts		
$p < 0.5$ GeV/c		$N\sigma_{\mathrm{TPC}} < 3$
$p > 0.5$ GeV/c	if TOF & TPC available	$N\sigma_{\mathrm{TPC}} < 3$ & $N\sigma_{\mathrm{TOF}} < 3$
	else	$N\sigma_{\mathrm{TOF}} < 3$

Misidentification Cuts: V0s

- Remove K^0_S contamination from $\Lambda(\overline{\Lambda})$ sample
  - Reject candidate if all of the following are satisfied (essentially, reject if candidate would pass as K^0):
    - $\left|m_{inv,K^0_s\,Hypothesis} - m_{PDG,K^0_S}\right| < 9.0\,MeV/c^2$
    - Pos. and neg. daughters pass π cuts from K^0_S reconstruction
    - $\left|m_{inv,K^0_s\,Hypothesis} - m_{PDG,K^0_S}\right| < \left|m_{inv,\Lambda(\overline{\Lambda})\,Hypothesis} - m_{PDG,\Lambda(\overline{\Lambda})}\right|$
- Remove $\Lambda(\overline{\Lambda})$ contamination from K^0_s sample
  - Similar to Λ procedure above, reject if:
    - $\left|m_{inv,\Lambda(\overline{\Lambda})\,Hypothesis} - m_{PDG,\Lambda(\overline{\Lambda})}\right| < 9.0\,MeV/c^2$
    - Pos. daughter passes p+(π+) cut from $\Lambda(\overline{\Lambda})$ reconstruction
    - Neg. daughter passes π-($\overline{\text{p}}$-) cut from $\Lambda(\overline{\Lambda})$ reconstruction
    - $\left|m_{inv,\Lambda(\overline{\Lambda})\,Hypothesis} - m_{PDG,\Lambda(\overline{\Lambda})}\right| < \left|m_{inv,K^0_s\,Hypothesis} - m_{PDG,K^0_S}\right|$

Pair Cuts: ΛK

- Shared daughter cut for pairs
  - V0-V0 Pairs (i.e. ΛK^0_S analyses)
    - Remove all pairs which share a daughter
    - Ex. Λ and K^0_S particles which share a π^- daughter are excluded
  - V0-Track Pairs (i.e. $\Lambda K^\pm$ analyses)
    - Remove pairs if $K^\pm$ track is also used as V0 daughter
    - Only occurs if, for instance, $K^\pm$ is misidentified as π or p in the V0 reconstruction

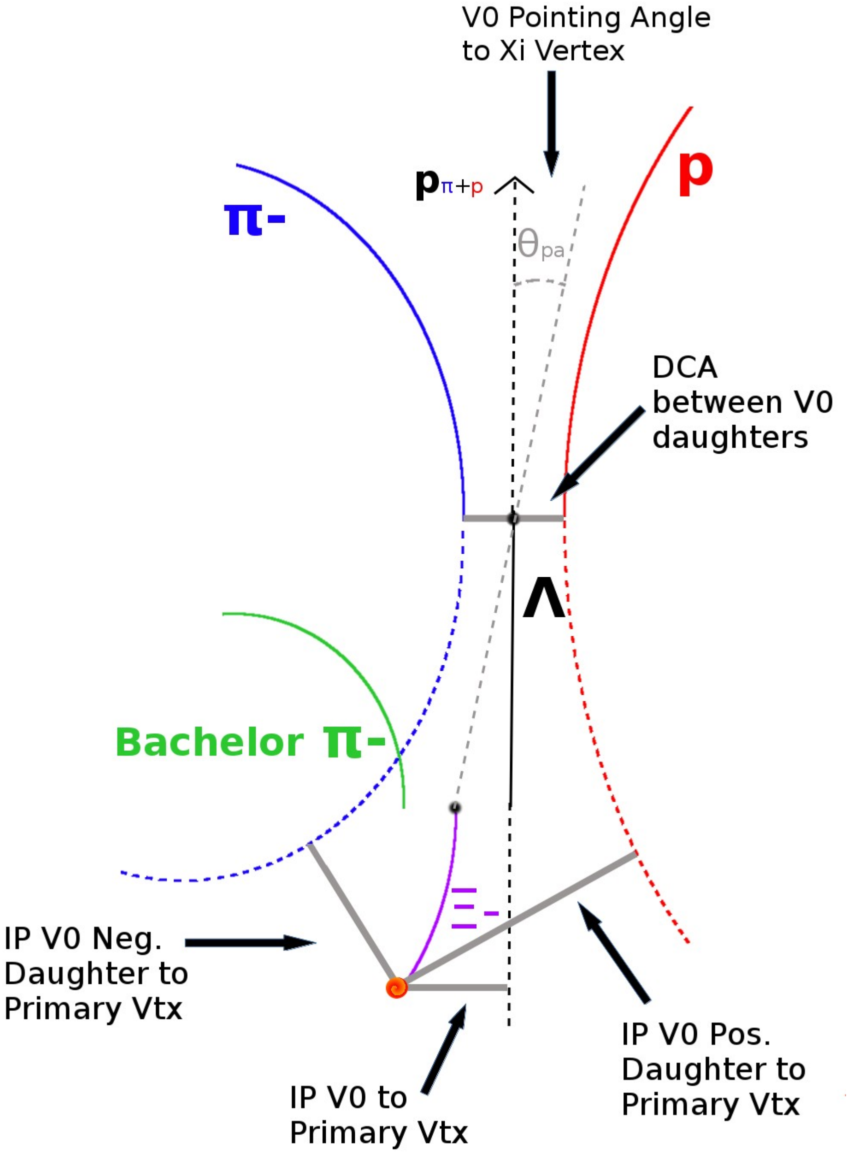
- Average separation cuts
  - ΛK^0_S
    - $\overline{\Delta r} > 6.0$ cm for like sign daughters
    - No requirement, unlike signs
  - $\Lambda K^\pm$
    - $\overline{\Delta r} > 8.0$ cm for like sign daughter and track
    - No requirement, unlike signs

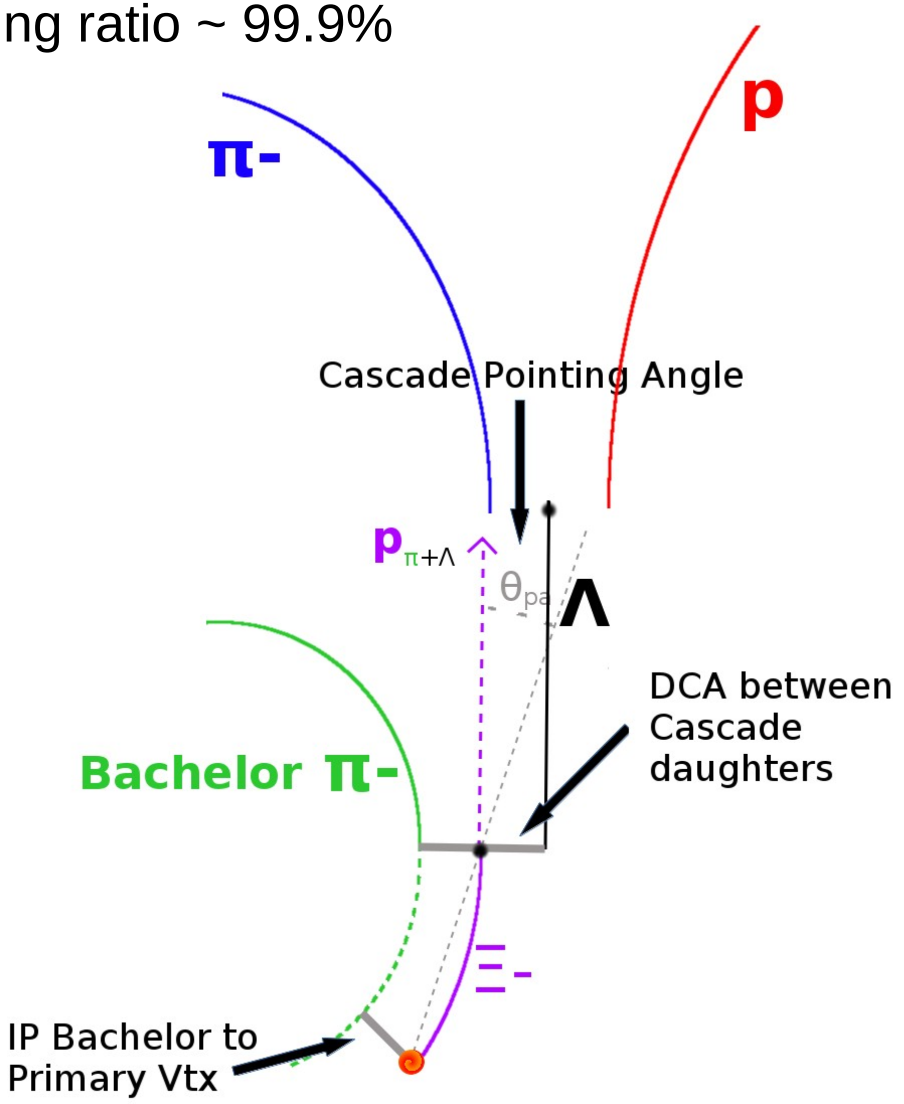
Ξ^- Reconstruction

$\Xi^- \rightarrow \Lambda\pi^- \; (\overline{\Xi}^+ \rightarrow \overline{\Lambda}\pi^+)$

- $c\tau$ = 4.9 cm
- Branching ratio ~ 99.9%

Purity(Ξ^-) ~ 90%
Purity($\overline{\Xi}^+$) ~ 92%





Ξ^- Reconstruction

<table>
<tr><th colspan="3">Ξ reconstruction</th></tr>
<tr><td colspan="2">$|\eta|$</td><td>< 0.8</td></tr>
<tr><td colspan="2">p_T</td><td>> 0.8 GeV/c</td></tr>
<tr><td colspan="2">$|m_{\text{inv}} - m_{\text{PDG}}|$</td><td>$< 3.0$ MeV</td></tr>
<tr><td colspan="2">DCA to prim. vertex</td><td>< 0.3 cm</td></tr>
<tr><td colspan="2">Cosine of pointing angle</td><td>> 0.9992</td></tr>
<tr><th colspan="3">Λ daughter cuts</th></tr>
<tr><td colspan="2">DCA to prim. vertex</td><td>> 0.2 cm</td></tr>
<tr><td colspan="2">Cosine of pointing angle</td><td>> 0.0</td></tr>
<tr><td colspan="2">Cosine of pointing angle to Ξ decay vertex</td><td>> 0.9993</td></tr>
<tr><td colspan="2">OnFlyStatus</td><td>false</td></tr>
<tr><td colspan="3">All other Λ and corresponding (π and p) daughter cuts are same as in primary Λ selection</td></tr>
<tr><th colspan="3">Bachelor π cuts</th></tr>
<tr><td colspan="2">$|\eta|$</td><td>< 0.8</td></tr>
<tr><td colspan="2">p_T</td><td>> 0.0 GeV/c</td></tr>
<tr><td colspan="2">DCA to prim. vertex</td><td>> 0.1 cm</td></tr>
<tr><td colspan="2">Number of clusters in the TPC</td><td>> 70</td></tr>
<tr><td colspan="2">Daughter status</td><td>kTPCrefit</td></tr>
<tr><td colspan="3">TPC and TOF Nσ Cuts</td></tr>
<tr><td colspan="2">$p < 0.5$ GeV/c</td><td>$N\sigma_{\text{TPC}} < 3$</td></tr>
<tr><td rowspan="2">$p > 0.5$ GeV/c</td><td>if TOF & TPC available</td><td>$N\sigma_{\text{TPC}} < 3$ & $N\sigma_{\text{TOF}} < 3$</td></tr>
<tr><td>else</td><td>$N\sigma_{\text{TOF}} < 3$</td></tr>
</table>

Pair Cuts: $\Xi^{-}K^{\pm}$

- Pair fails if
  - $K^{\pm}$ is a (misidentified) daughter of the Ξ^{-}
  - Bachelor π is also a daughter of the Λ
- Ξ shared daughter cut
  - Iterates through Ξ collection to ensure no daughter is used by more than one Ξ
- Average separation cut for all daughters
  - $\overline{\Delta r} > 8.0$ cm for daughters of Ξ^{-} and $K^{\pm}$ sharing the same charge
  - No requirement for unlike-charges

THERM. 2: Playing with flow

- Study how different anisotropic flow affects background
- THERM. 2 model includes flow effects in standard implementation (left)
- Introduce strong artificial anisotropic flow signals for more controlled study (right)
  - Sample emission angles from: $P(\phi)=\frac{1}{2}[1+\cos(n\phi)]$
- Flow signal killed by randomizing emission