

RECONSTRUCTION OF Σ^0 HYPERONS AND π^0 MESONS USING PHOTON CONVERSIONS IN NA61/SHINE

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- 1 Physics motivation and background
- 2 Experimental setup and data sample
- 3 Analysis strategy: conversions and reconstruction
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Basic facts

- ▶ Strange baryon, quark content uds .
- ▶ Member of the Σ isotriplet ($\Sigma^-, \Sigma^0, \Sigma^+$).
- ▶ Electromagnetic decay $\Sigma^0 \rightarrow \Lambda\gamma$ (BR $\approx 100\%$, decay essentially at the primary vertex).
- ▶ Small mass splitting $M_{\Sigma^0} - M_{\Lambda} \approx 77$ MeV \Rightarrow very soft photon in the Σ^0 rest frame.

Why we care

- ▶ Provides an isospin-sensitive probe of strangeness production in the baryon sector.
- ▶ A dedicated Σ^0 measurement can also help quantify possible electromagnetic $\Sigma^0 \rightarrow \Lambda\gamma$ contributions in inclusive Λ samples.

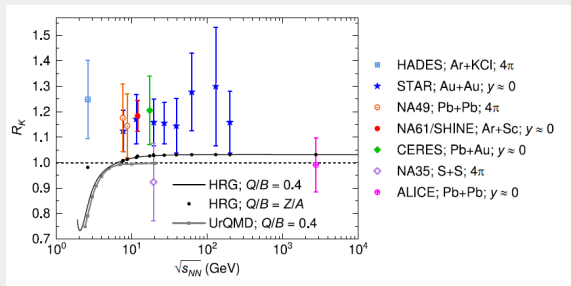


Figure 1: NA61/SHINE kaon isospin observable $R_K = (K^+ + K^-)/(2K_S^0)$ from *Nature Communications* **16**, 2849 (2025).

Meson vs baryon

Together with the kaon isospin observable (above), this probes consistency of strange mesons vs strange baryons.

- ▶ Strange baryons with the same quark content uds split into two isospin families: $\Lambda(uds)$ is an **isosinglet** ($\mathbf{I} = \mathbf{0}$), while $\Sigma(uds)$ forms an **isotriplet** ($\mathbf{I} = \mathbf{1}$).
- ▶ The observable Σ^0/Λ compares $I = 1$ vs $I = 0$ strange-baryon production under identical conditions and is sensitive to hadronisation, statistical/thermal expectations and resonance feed-down.
- ▶ **This contribution:** method and performance study in MC for $\pi^0 \rightarrow \gamma\gamma$ and $\Sigma^0 \rightarrow \Lambda\gamma$ reconstruction using conversion photons ($\gamma \rightarrow e^+e^-$) in NA61/SHINE geometry (baseline for later optimisation and data).
- ▶ **Additional motivation:** if a robust $\pi^0 \rightarrow \gamma\gamma$ measurement via conversions becomes feasible, it can be confronted with published charged-pion multiplicities (π^\pm) to build a **charged-to-neutral** observable in the pion sector (requires dedicated matching of energy, acceptance and phase space).

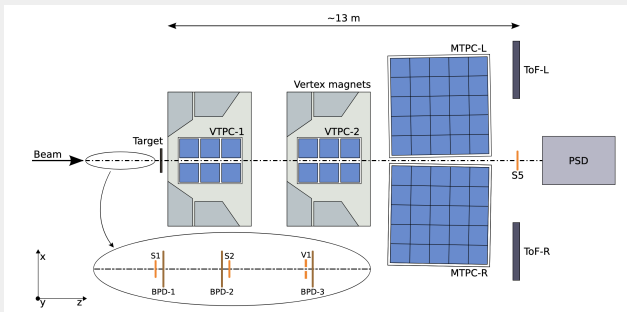


Figure 2: NA61/SHINE detector layout at the CERN SPS.

Experiment

- ▶ Fixed-target spectrometer at the CERN SPS.
- ▶ Large-acceptance TPCs + TOF and forward calorimeters.
- ▶ Good momentum and dE/dx resolution for charged hadrons and electrons.

SPS energy range (NA61/SHINE)

- ▶ Ion beams: $\sim 13\text{--}158A \text{ GeV}/c$
($\sqrt{s_{NN}} \approx 5\text{--}17 \text{ GeV}$).

Data sample

- ▶ Ar+Sc at $75A \text{ GeV}/c$ (2015 run).

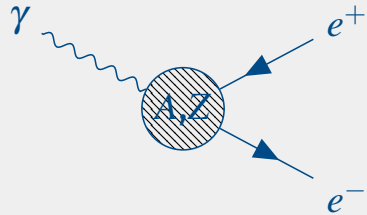
PHOTON CONVERSIONS: KINEMATICS AND TOPOLOGY

Kinematics of $\gamma \rightarrow e^+e^-$

- ▶ Bethe–Heitler process in the Coulomb field of a nucleus:

$$\gamma + Z \rightarrow e^+ + e^- + Z.$$

- ▶ The pair is highly collimated: $\theta_{ee} \sim m_e/E_\gamma \ll 1$.
- ▶ Ideal invariant mass: $M_{e^+e^-} \approx 0$, smeared by tracking resolution and bremsstrahlung.
- ▶ The e^+e^- form a V^0 -like secondary vertex displaced from the primary interaction point.
- ▶ In NA61/SHINE, converter materials include the target region, beam pipe and other holding structures.



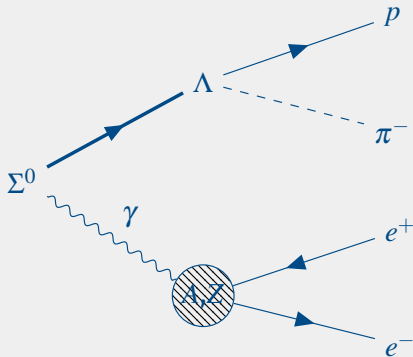
Experimental handle

- ▶ Very low $M_{e^+e^-}$ and small opening angle.
- ▶ V^0 topology allows background suppression using e.g. Armenteros–Podolanski cuts.

RECONSTRUCTION STRATEGY: FULL DECAY CHAIN

We reconstruct the chain

$$\Sigma^0 \rightarrow \Lambda \gamma, \quad \Lambda \rightarrow p \pi^-, \quad \gamma \rightarrow e^+ e^- \text{ (in material).}$$



- ▶ Step 1: reconstruct a clean $\Lambda \rightarrow p\pi^-$ sample.
- ▶ Step 2: reconstruct conversion photons $\gamma \rightarrow e^+e^-$ as very low-mass V^0 candidates.
- ▶ Step 3: associate each Λ with conversion photons and look for a peak in $M_{\Lambda\gamma}$ around the Σ^0 mass.

Conversion vertices image the detector material and validate our reconstruction.

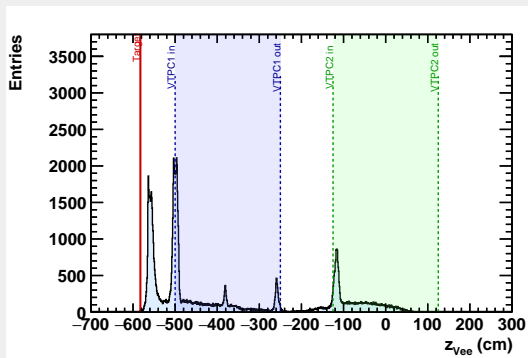


Figure 3: Longitudinal distribution of e^+e^- conversion vertices along the beam direction. VTPC entrance/exit windows and target region are clearly visible.

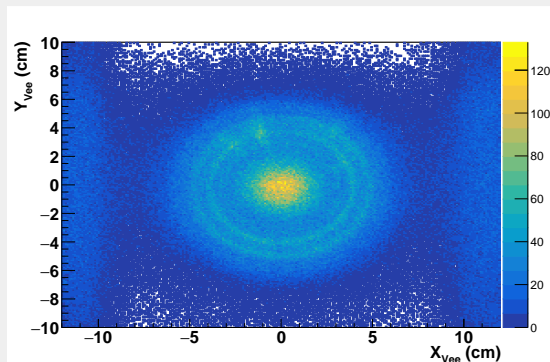


Figure 4: Transverse (XY) distribution of conversion vertices, showing the beam pipe and surrounding structures.

Both peaks are recovered with the nominal working point in MC.

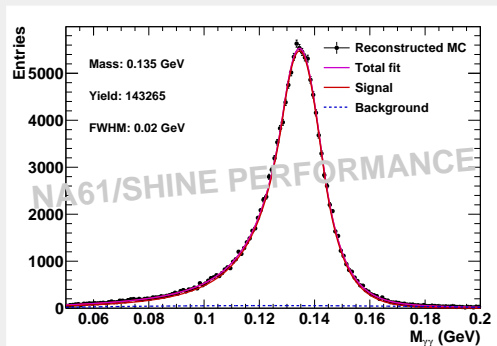


Figure 5: $\pi^0 \rightarrow \gamma\gamma$ in MC reconstructed via photon conversions.

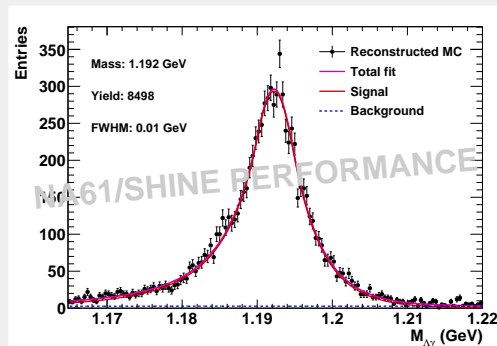


Figure 6: $\Sigma^0 \rightarrow \Lambda\gamma$ reconstructed from MC simulations.

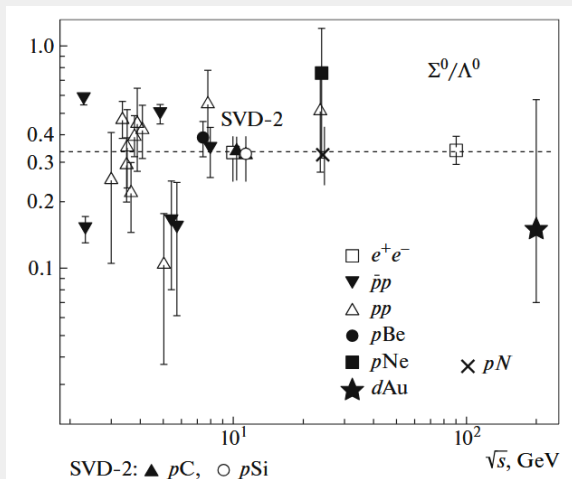


Figure 7: Existing measurements of Σ^0/Λ vs collision energy and system. Figure from Vorobiev et al. (SVD-2), *Phys. Atom. Nucl.* 84 (2021).

Context

- ▶ Low-energy fixed-target data and high-energy collider measurements exist, but there is a gap in the SPS energy range and there are no A+A data.
- ▶ NA61/SHINE Ar+Sc @ 75A GeV/c will provide a new point in this plot.

Where we are (analysis status)

- ▶ Photon conversion reconstruction using e^+e^- vertices.
- ▶ Reconstruction of $\pi^0 \rightarrow \gamma\gamma$ and full $\Sigma^0 \rightarrow \Lambda\gamma \rightarrow (p\pi^-)(e^+e^-)$ chain implemented in Ar+Sc @ 75A GeV/c MC.
- ▶ *Internal, not-yet-released preliminary studies on data are promising: the π^0 peak is visible and Σ^0 signal extraction via fits appears within reach, pending final optimisation and systematics.*

Where we go next

- ▶ Optimise the selection using MC, then apply to data and extract the first quantitative Σ^0 yield in a well-defined kinematic window.
- ▶ Perform systematic scans and estimate uncertainties.
- ▶ Compare the emerging Σ^0/Λ ratio with model expectations and existing world data.

Thank you for your attention!

Questions and discussion welcome.

Backup slides

WHY USE A “1/3” BASELINE FOR Σ^0/Λ ?



- ▶ **Isospin structure** of strange baryons (uds):
 - Λ : isosinglet, $I = 0 \Rightarrow$ one state (Λ).
 - Σ : isotriplet, $I = 1 \Rightarrow$ three states ($\Sigma^+, \Sigma^0, \Sigma^-$).
- ▶ Isospin symmetry only constrains the *relative yields inside* the Σ triplet:

$$N(\Sigma^+) \simeq N(\Sigma^0) \simeq N(\Sigma^-) \Rightarrow N(\Sigma^0) \approx \frac{1}{3}N(\Sigma_{\text{tot}}).$$

It does **not** fix $N(\Sigma_{\text{tot}})/N(\Lambda)$.

- ▶ The overall balance Σ_{tot} vs Λ comes from the dynamics (thermal weights, masses, resonance feed-down, hadronisation).
- ▶ Thermal / HRG calculations and event generators tuned to SPS-like conditions typically give Σ^0/Λ of order a few $\times 0.1$ (setup-dependent).
- ▶ In this sense “1/3” is used here as a convenient *naive, model-guided baseline*.

Why use Armenteros for $\gamma \rightarrow e^+e^-$?

- ▶ For any V^0 candidate we form:

$$\alpha_{\text{Arm}} = \frac{p_L^+ - p_L^-}{p_L^+ + p_L^-}, \quad p_T^{\text{Arm}} = p_T(\text{daughter w.r.t. } V^0)$$

- ▶ **Conversions ($\gamma \rightarrow e^+e^-$):**

- Daughters share momentum almost symmetrically $\Rightarrow \alpha_{\text{Arm}} \approx 0$.
- Tiny intrinsic transverse momentum $\Rightarrow p_T^{\text{Arm}}$ is very small.

- ▶ **Hadronic V^0 ($K_S^0 \rightarrow \pi^+\pi^-$, $\Lambda \rightarrow p\pi^-$):**

- Finite Q-value \Rightarrow larger p_T^{Arm} .
- Asymmetric momentum sharing \Rightarrow larger $|\alpha_{\text{Arm}}|$.

- ▶ **Practical gain:** an ellipse cut around the photon band at $\alpha_{\text{Arm}} \simeq 0$, low p_T^{Arm}

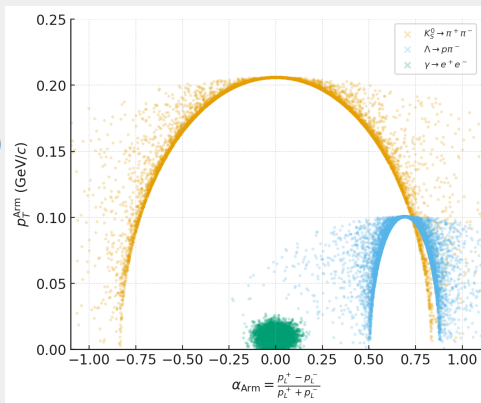


Figure 8: Armenteros-Podolanski plot in Ar+Sc @ 75 A GeV/c: bottom band = $\gamma \rightarrow e^+e^-$, top/right cluster = Λ , symmetric arcs = K_S^0 . Ellipse selects the photon band.

CONVERSION RECONSTRUCTION STABILITY VS z_{V0}

To validate the conversion selection, we check the e^+e^- invariant mass spectrum in different longitudinal regions (z_{V0}).

