Σ^0 PRODUCTION WITH HADES

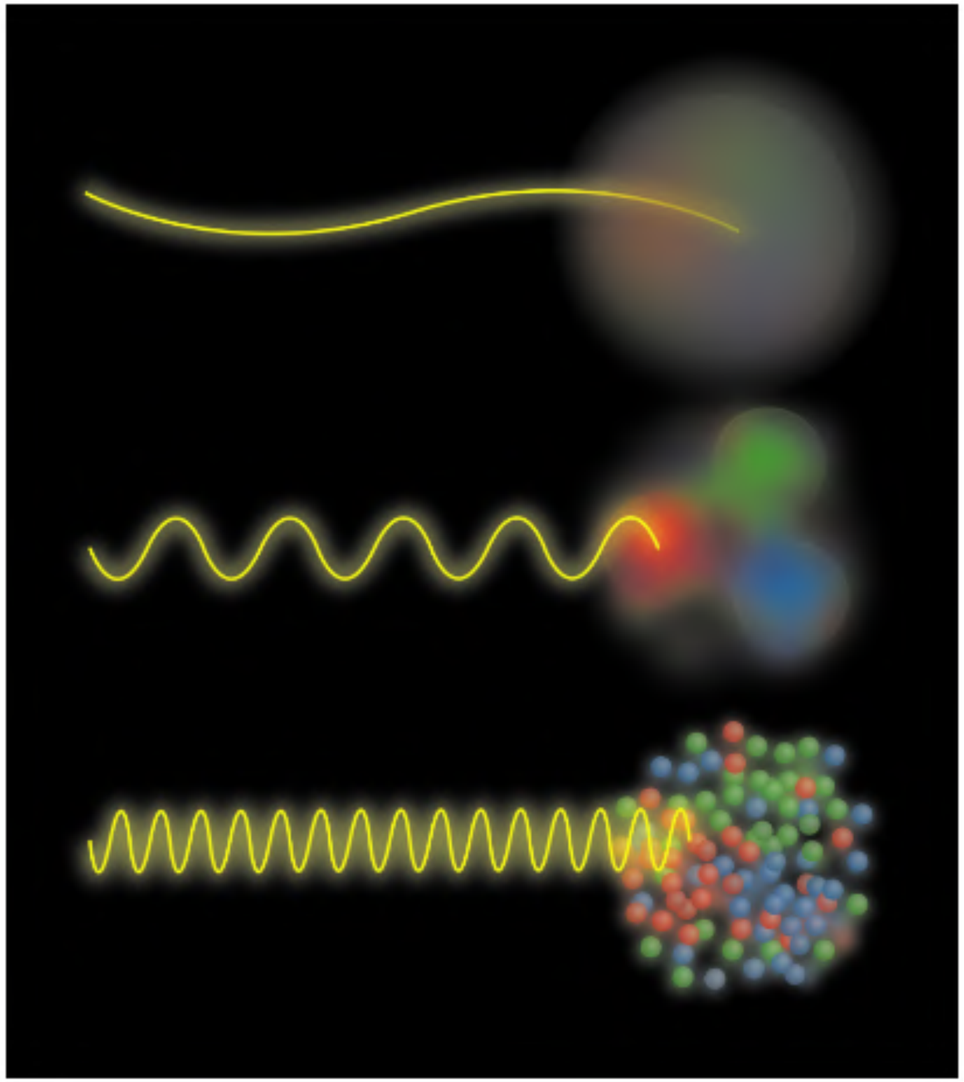
TOWARDS A GLIMPSE OF ITS DALITZ DECAY

Malin Bohman, *For the HADES Collbaboration*

MESON 2026

MOTIVATION: HADRON STRUCTURE

- Observation of electromagnetic transitions offer a powerful probe of hadronic properties.
- Hadron structure probed by virtual photon in e^- scattering.
    - Elastic case: EM form factors encode charge and magnetization distributions.
    - An approach utilized for proton radius measurements [1].
- A successful approach utilized for p, n and atomic nuclei for approx. 70 years.



[1] Phys. Rev. C **90** 015206 (2014).

WHAT IF WE ADD STRANGENESS?

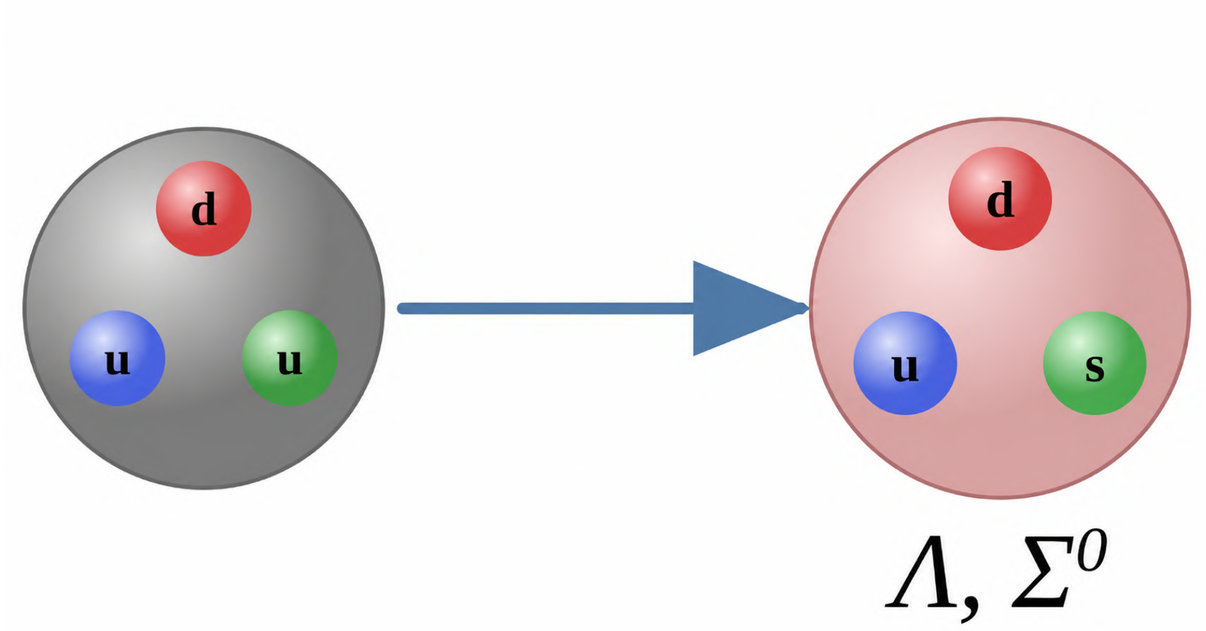
HYPERONS: SHORT-LIVED $\longrightarrow$ CONVENTIONAL e^- SCATTERING NOT FEASIBLE!

$\tau_p > 10^{34}$ years

$\tau_n \approx 15$ min

$\tau_\Lambda \sim 10^{-10}$ s

$\tau_{\Sigma^0} \sim 10^{-20}$ s



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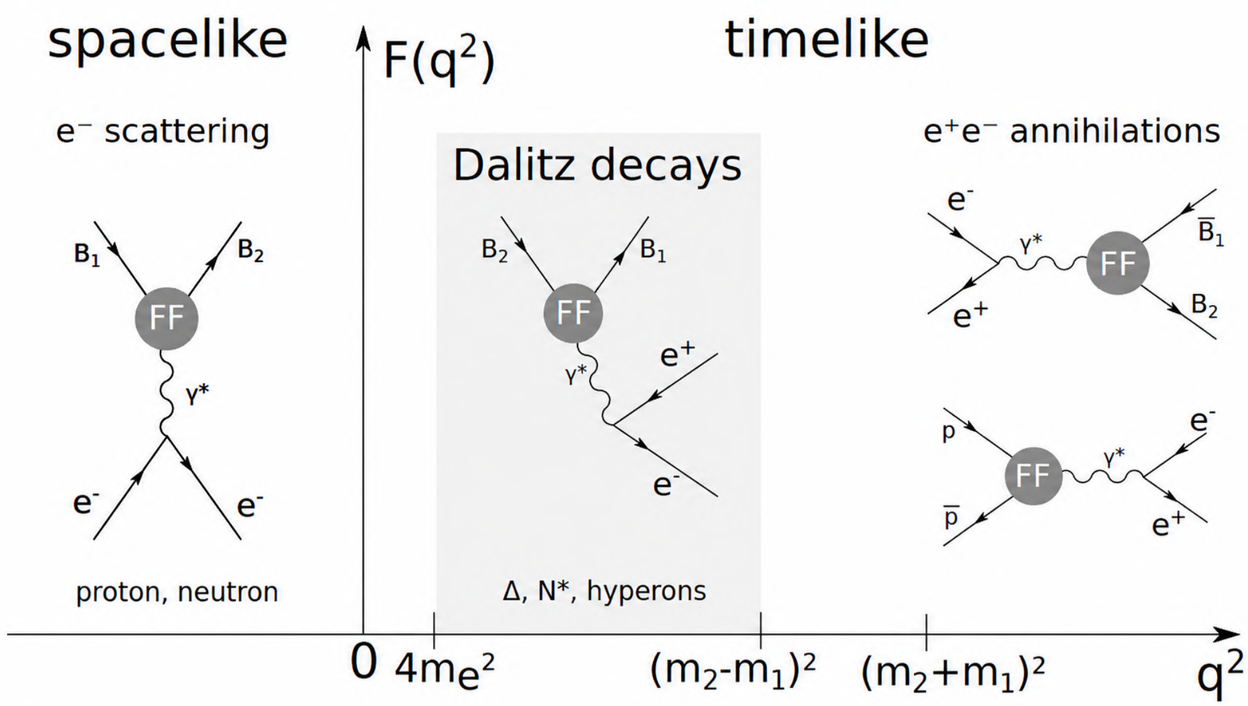
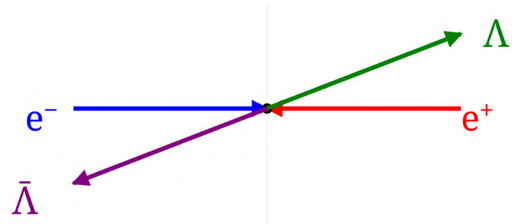
HYPERON STRUCTURE



- $q^2 < 0$ defines space-like region and $q^2 > 0$ defines the time-like.
- Space-like and time-like regimes connected via dispersion relations.
- Used in recent Λ RMS radius measurement from e^+e^- annihilation at BESIII [2].



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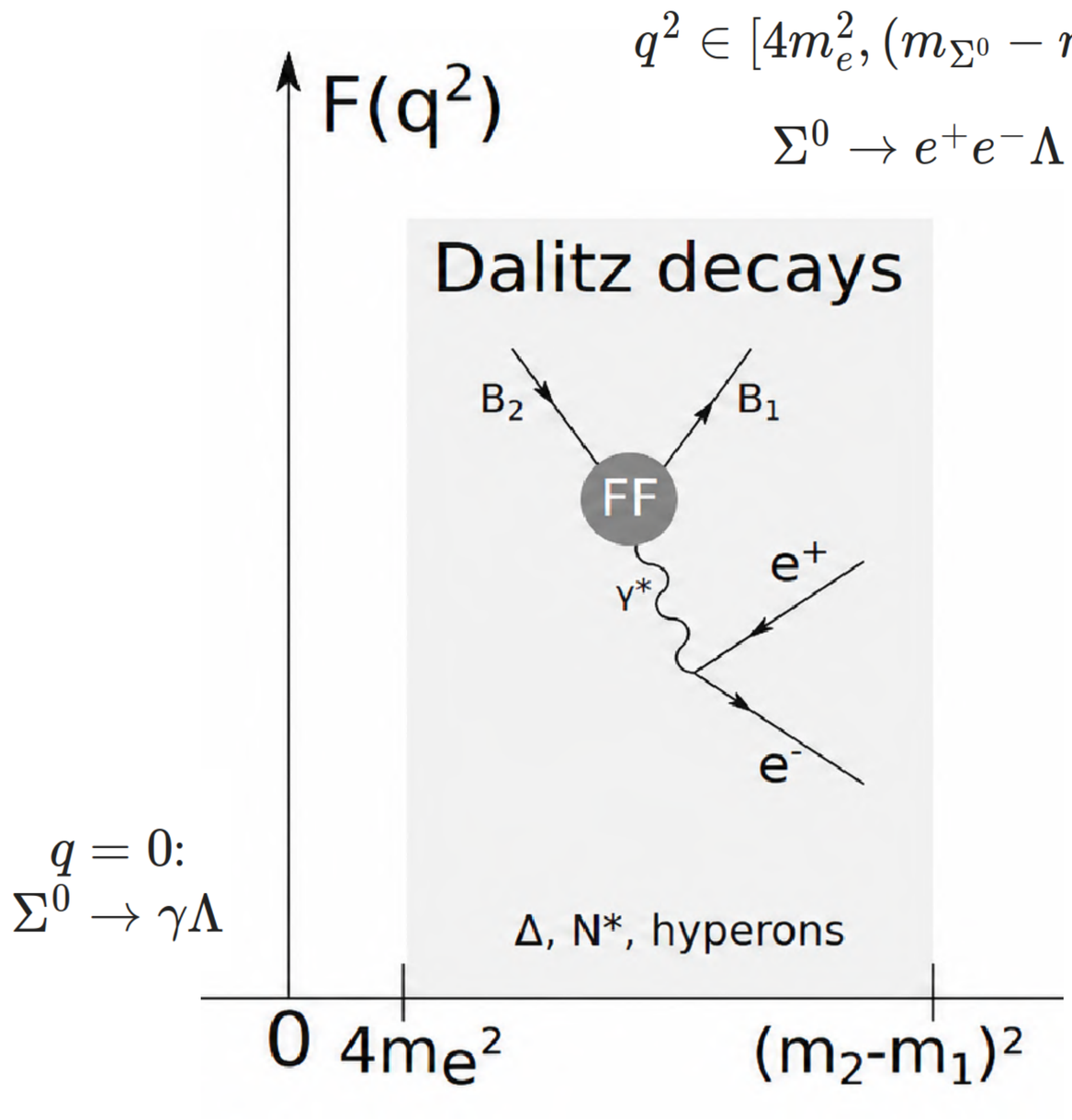
[2] BESIII: Phys. Rev. Lett. 135, 191 902 (2025)

DALITZ DECAY

- *Photon point* at $q = 0$ connects space-like and time-like regions.
- Σ^0 Dalitz decays probe the TFF in low $q^2 < (m_{\Sigma^0} - m_\Lambda)^2$ region
- Close enough to the photon point for prediction of space-like TFF [3].



[3] Eur. Phys. J. A (2017) 53(6):117

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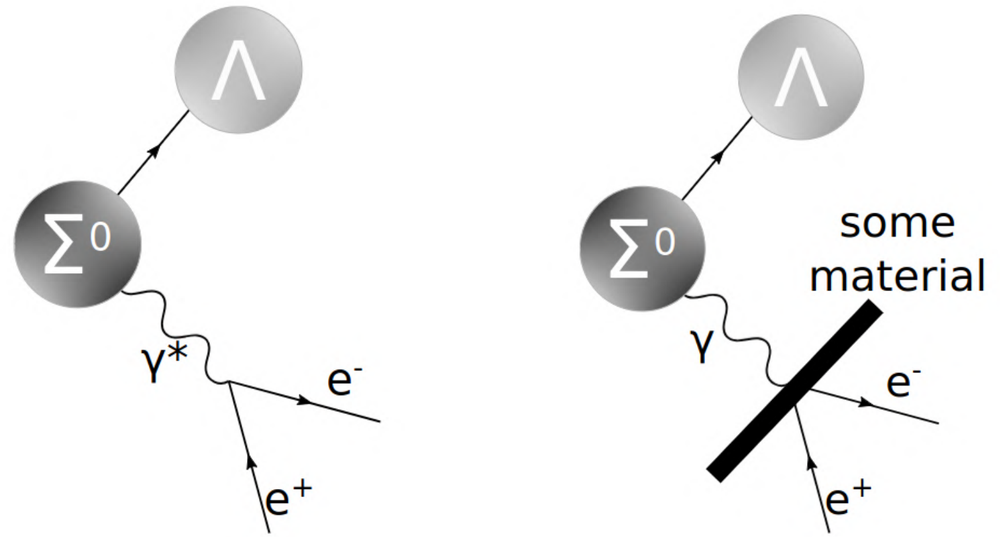
CHALLANGES OF A $\Sigma - \Lambda$ TRANSITION MEASUREMENT

The Dalitz measurement has many challenges [4]:

- *Slow* e^+e^- pairs due to small mass difference:

  $m_{\Sigma^0} - m_\Lambda \approx 77\, MeV$.
- Rare decay mode, predicted $BR \approx 0.55\%$ [5].
- *Significant* background from $\Sigma^0 \to \gamma\Lambda$ where the photon undergoes conversion:
  - Converts into $\gamma \to e^+e^-$ via pair production in the presence of some material.
  - Very similar signal to the Dalitz decay!



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[4] Rieger, J. (2026). Doctoral dissertation, Uppsala University.]. [5] Eur. Phys. J. C (2020) 80: 218.

THE HADES EXPERIMENT

A Dalitz measurement needs:

- Large data sample.
- Detection and ID of e^+e^-
- Λ reconstruction, decaying at a displaced vertex.

HADES fulfills the requirements!

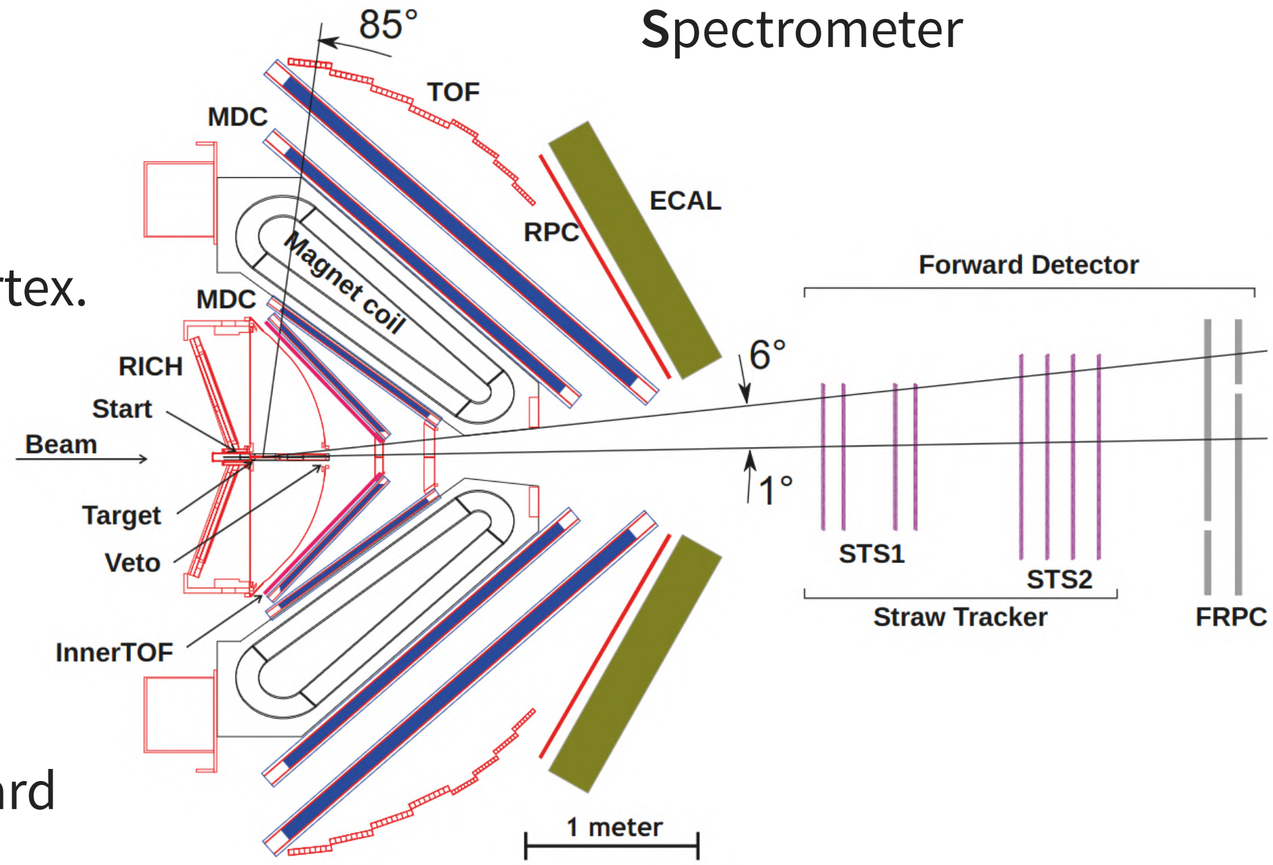
- Has achieved the only baryonic Dalitz decay measurements to date [6,7]:

  $\Delta^{++} \rightarrow pe^+e^-$ and $N^* \rightarrow pe^+e^-$

- Improved hyperon reconstruction with Forward Detector
  - Provided via the PANDA@HADES collaboration

HADES

The **H**igh **A**cceptance **D**i-**E**lectron **S**pectrometer



See talk by B. Ramstein

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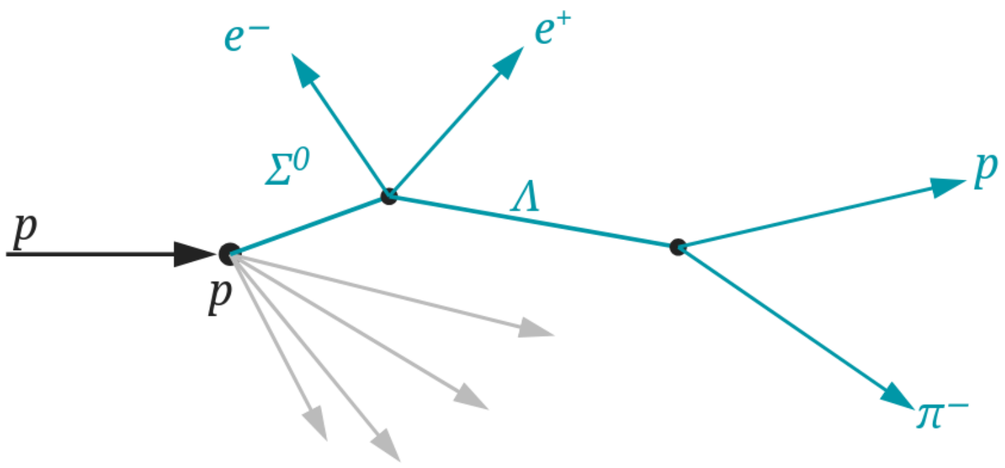
[6] Phys. Rev. C, (2017) 95:065205. [7] Phys. Lett. B 875 (2026) 140338

Σ^0 DALITZ DECAY AT HADES

Σ^0 Dalitz decay study with HADES [4] performed by

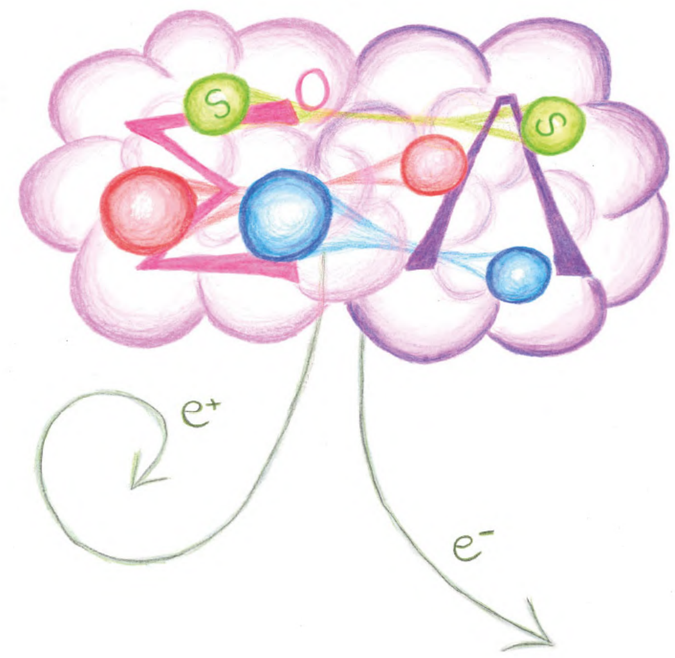
J. Rieger for:

$pp \rightarrow \Sigma^0 + X$ at $T_{beam} = 4.53\,GeV$.



Glimpse of a Hyperon Transition

How elastic proton-proton scattering and kinematic fits can contribute to the measurement of the Σ^0 Dalitz decay



Jana Rieger

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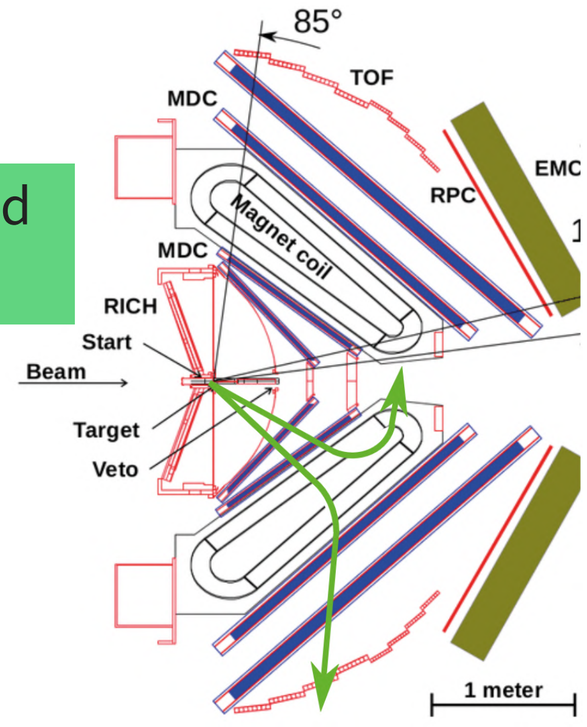
[4] Rieger, J. (2026). Doctoral dissertation, Uppsala University.

Σ^0 DALITZ DECAY AT HADES: STATUS

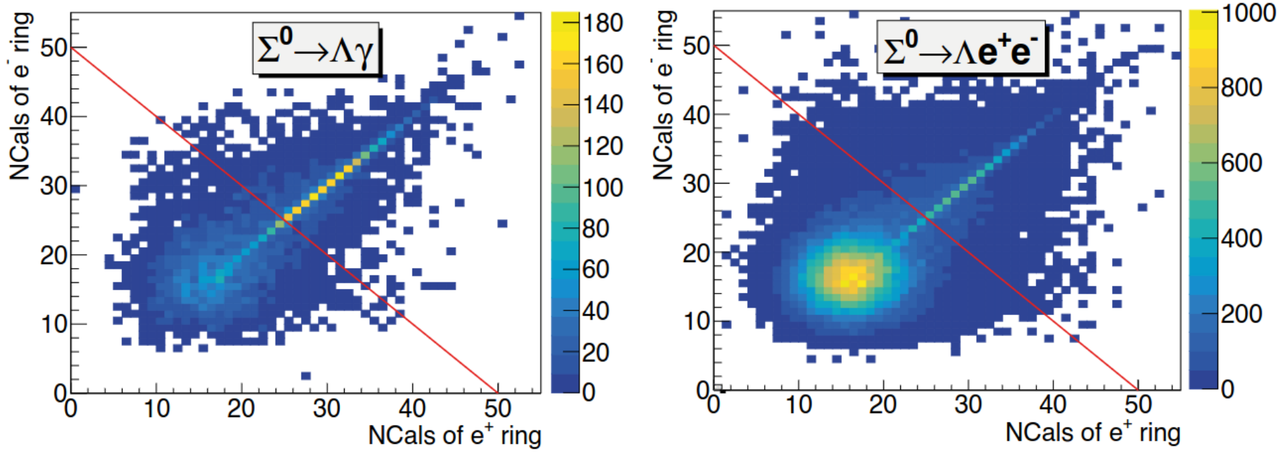
Analysis strategy in [4]:

- Novel strategy for **mini lepton tracks**:
  - Slow e^+/e^- bent out of detector.
  - Momentum reconstruction from RICH ring radius.
  - Mini tracks always used in combination with full track.
- Photon conversion rejection via proximity of RICH signatures:
  - **NCals** $\sim$ photon detector pixel hits around ring.
  - Cut on NCals(e^-) $<$ 50$-$NCals(e^+) isolates true Dalitz e^+e^- pairs.

Momentum determined from RICH.



γ conversion rejection



[4] Rieger, J. (2026). Doctoral dissertation, Uppsala University.

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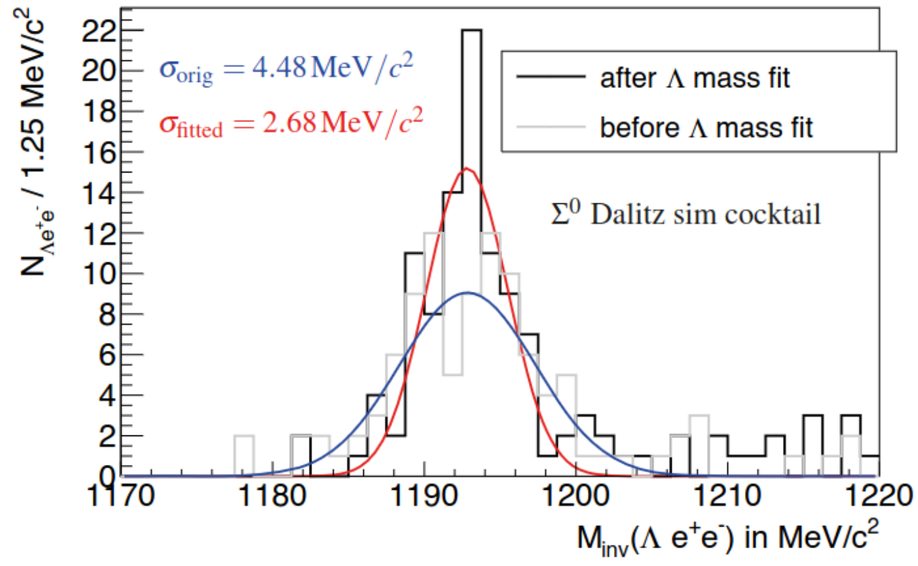
Σ^0 DALITZ DECAY AT HADES: STATUS

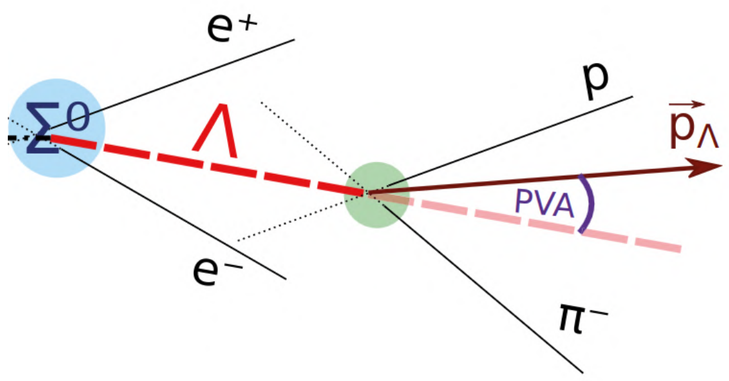
Analysis strategy in [4]:

Λ selected from kinematic refit and

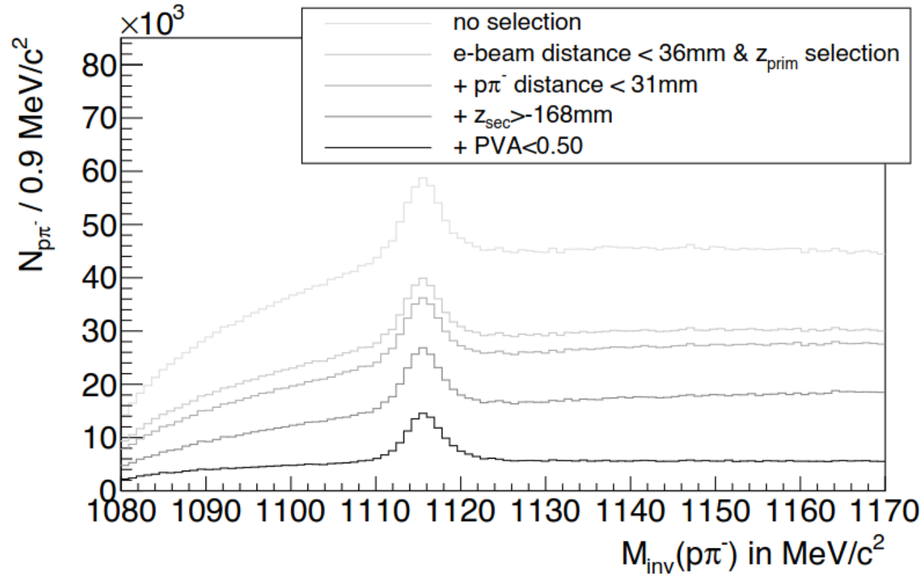
topological cuts:

- Di-lepton track distance or single lepton track distance to beamline.
- Primary vtx. z_{prim} around target region.
- If single full lepton track, prim vtx. r_{prim} cut.
- $p\pi^-$ track distance.
- Decay vtx. z_{dec} cut.
- PVA.





e^+/e^- tagged Λ candidates.



[4] Rieger, J. (2026). Doctoral dissertation, Uppsala University.

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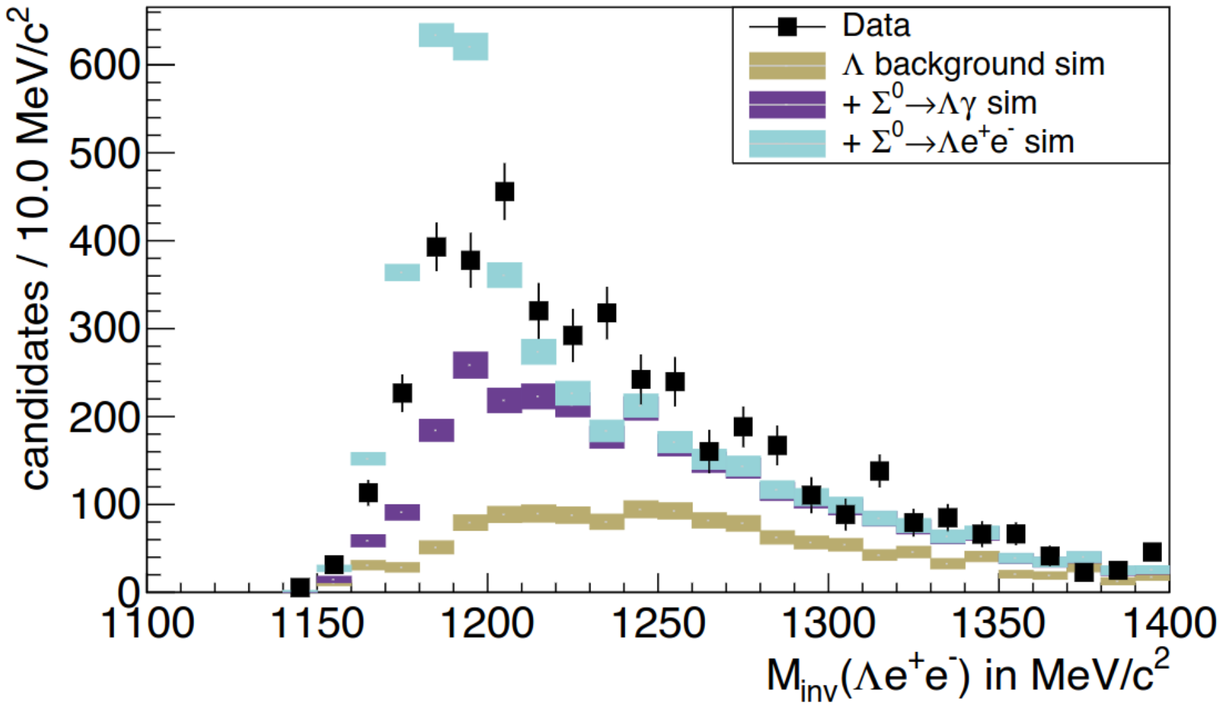
Σ^0 DALITZ DECAY AT HADES: STATUS

Σ^0 signal search in BG-subtr. $M_{inv}(\Lambda e^+ e^-)$ with full e^- and mini e^+ tracks.



CONCLUSION: Need further steps to understand both signal and background! [4]

[4] Rieger, J. (2026). Doctoral dissertation, Uppsala University.

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BACKGROUND AND EFFICENCY FROM $\Sigma^0 \to \gamma\Lambda$

STEPS TOWARDS A BR MEASUREMENT:

1. Realistic MC a crucial step to proceed with Σ^0 Dalitz decay measurements.
   - Σ^0 production at $\sim$ GeV range poorly understood [8]
   - Data necessary to tune models and achieve realistic MC generators.
2. Efficiency corrections required for both the Dalitz and radiative decay.
   - Channel specific corrections likely needed due to varying efficiencies and weights.

$$BR(\Sigma^0 \to e^+e^-\Lambda) \approx \frac{N_{prod}(\Sigma^0 \to e^+e^-\Lambda)}{N_{prod}(\Sigma^0 \to \gamma\Lambda)}$$

$$N_{prod} = \frac{N_{obs}}{\varepsilon} = \frac{N_{obs}}{\varepsilon_1 w_1 + \varepsilon_2 w_2 + \varepsilon_3 w_3 + \ldots}$$

ε = *reconstruction efficiency.*

w_i = *relative channel production rates*:

$$pp \to pK^+\Sigma^0$$

$$pp \to pK^0\pi^+\Sigma^0$$

$$pp \to pK^0\pi^0\pi^+\Sigma^0$$

$$\vdots$$

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[8] HADES: Eur. Phys. J. A (2024) 60:18.

Σ^0 PRODUCTION

GENERAL MOTIVATION

- Improve understanding of strangeness production in proton-proton collisions.
- Few measurements around relevant energy regime.

PREVIOUS Σ^0 STUDY FROM HADES pp [8]

- Detailed study of $pp \rightarrow pK^+\Sigma^0$ at $T_{beam} = 3.5\,GeV$
- Production partially constrained with contributions from both meson exchange and resonances.

Example: $pp \rightarrow N^* K \Sigma^0$

$N\pi$ / $N\pi\pi$

STATE-OF-THE-ART ESTIMATES

Produced by SMASH - a relativistic hadronic transport approach [9]

reaction	σ in μb
$p\Sigma^0K^0\pi^+$	57.7
$p\Sigma^0K^0\pi^0\pi^+$	32.1
$p\Sigma^0K^+\pi^0$	28.9
$p\Sigma^0K^+\pi^+\pi^-$	25.6
$p\Sigma^0K^+$	19.5
$p\Sigma^0K^+\pi^0\pi^0$	9.6
$n\Sigma^0K^0\pi^+\pi^+$	9.2
$n\Sigma^0K^+\pi^+$	5.0
$n\Sigma^0K^+\pi^+\pi^0$	4.8

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[8] HADES: Eur. Phys. J. A (2024) 60:18. [9] Phys. Rev. C 94, 054905 (2016) [Version 3.0]

ONGOING WORK

Study of exclusive Σ^0 production via its radiative decay mode $\Sigma^0 \rightarrow \gamma\Lambda$ with

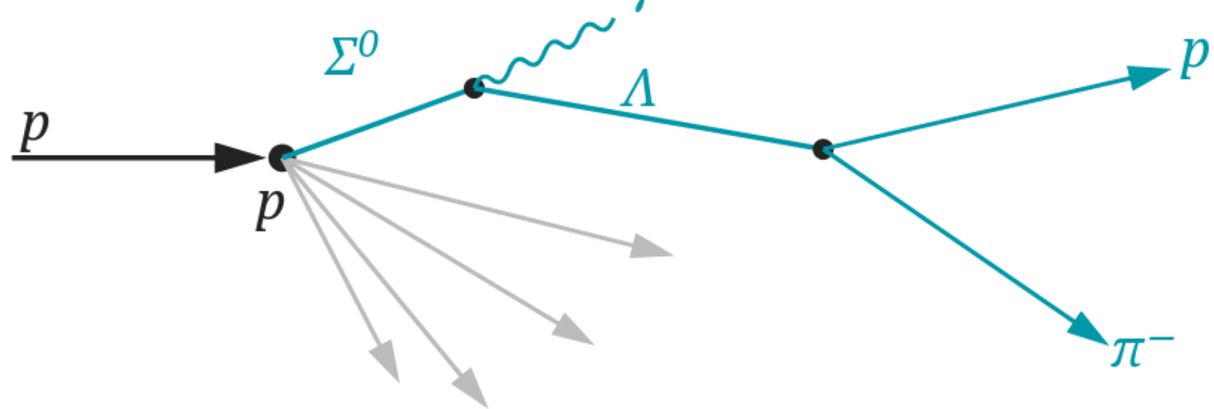
HADES pp @ $T_{beam} = 4.53\,GeV$ data.

END GOAL:

Provide the necessary ingredient for a Dalitz decay

BR at HADES in the form of:

- Data input to tune MC generators
- Background modelling
- reference channel for BR measurement.



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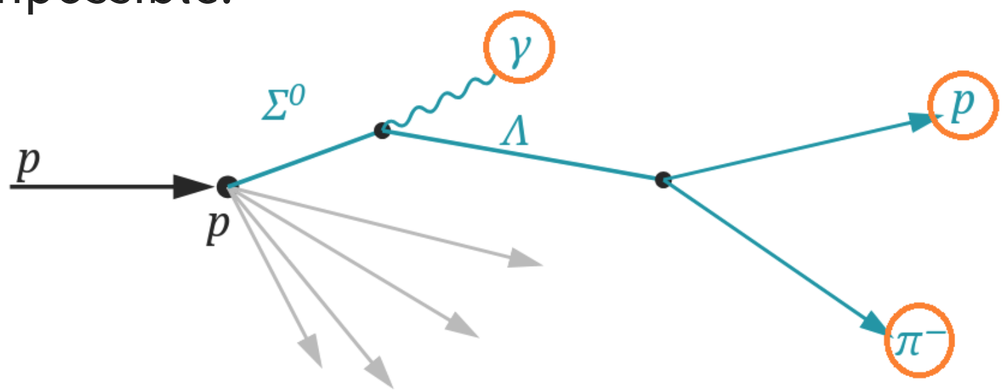
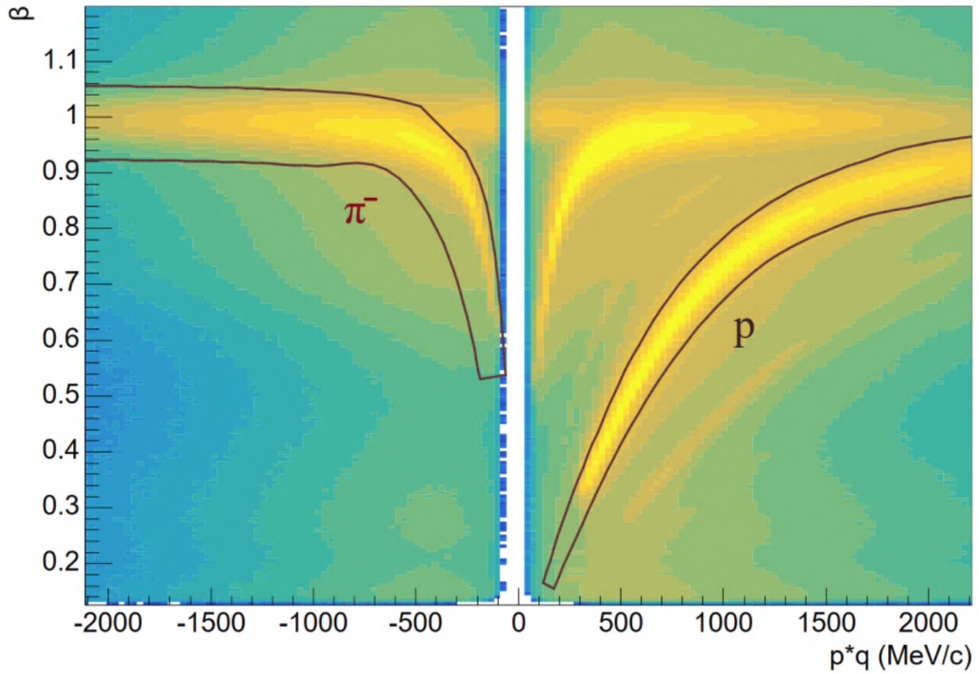
EVENT SELECTION

- Hadron identification from selected regions of β vs momentum.
- γ measured from EM Calorimeter
- Topological selection cut: event must contain p, π^- & γ for Σ^0 reconstruction.
- Event based missing mass selection on $MM(\gamma p \pi^-)$.
  - removes events where Σ^0 is kinematically impossible.





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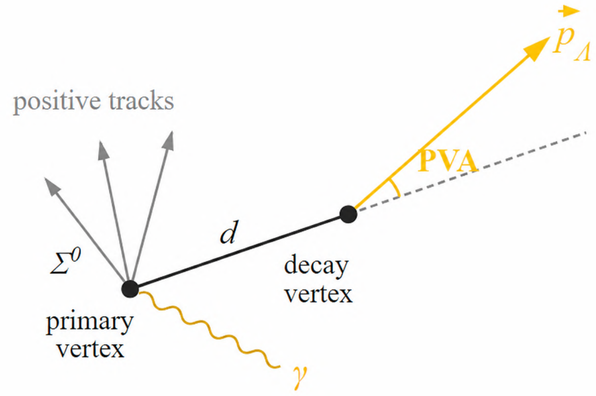
Λ SELECTION

Λ reconstruction from $p\pi^-$ and:

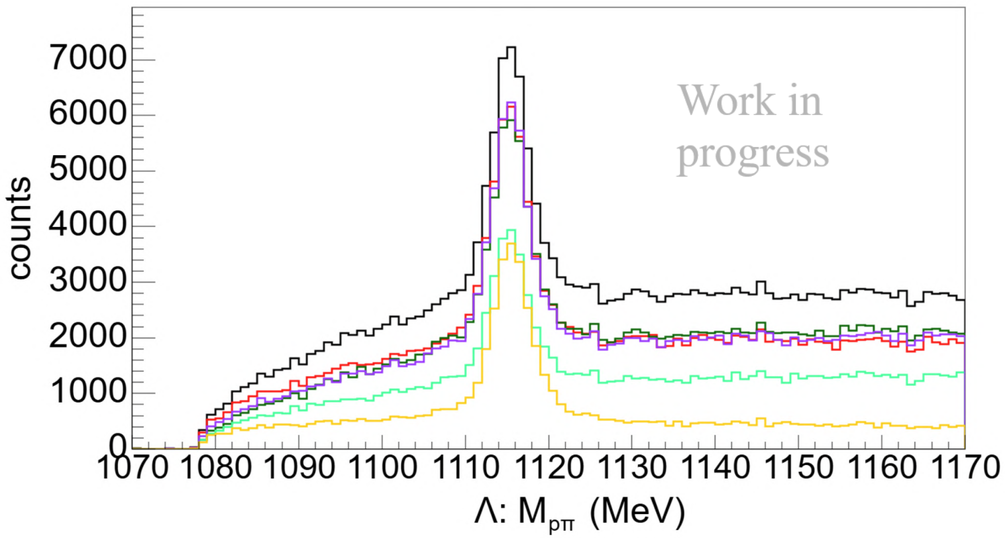
- **Decay vertex** from PoCA for p & π^- tracks.
- **Prim. vertex** from PoCA of available primary positive tracks and the reconstructed Λ-candidate track.

Selection Cuts:

- $p\pi^-$ minimum track distance.
- Prim. vertex is behind decay vertex:
  $z_{dec.vtx} - z_{prim.vtx}$.
- Prim. vertex is around the target region: $z_{prim.vtx}$.
- Pointing vector angle (PVA) is small.
- Missing mass cut: $MM(p\pi^-)$.



Effects of Λ cuts on $M_{inv}(p\pi^-)$



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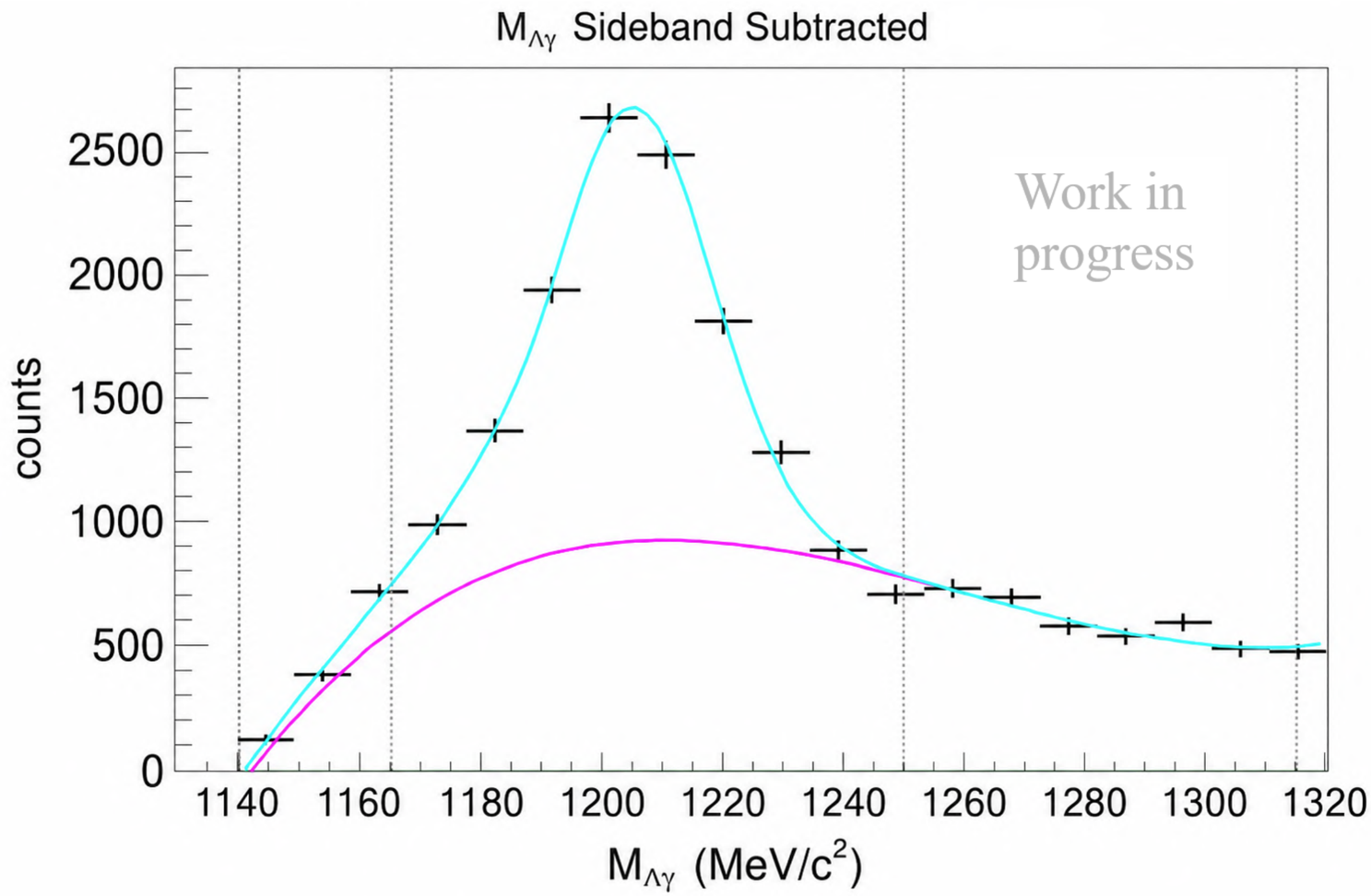
Σ^0 RECONSTRUCTION

Starting with exclusive $pp \to pK^+\Sigma^0$:

- Σ^0 reconstructed from Λ and γ tracks.
- Ambiguous separation of signal and background despite sideband subtraction.

Next step:

- Utilize kinematic refit to reduce background and improve peak resolution.



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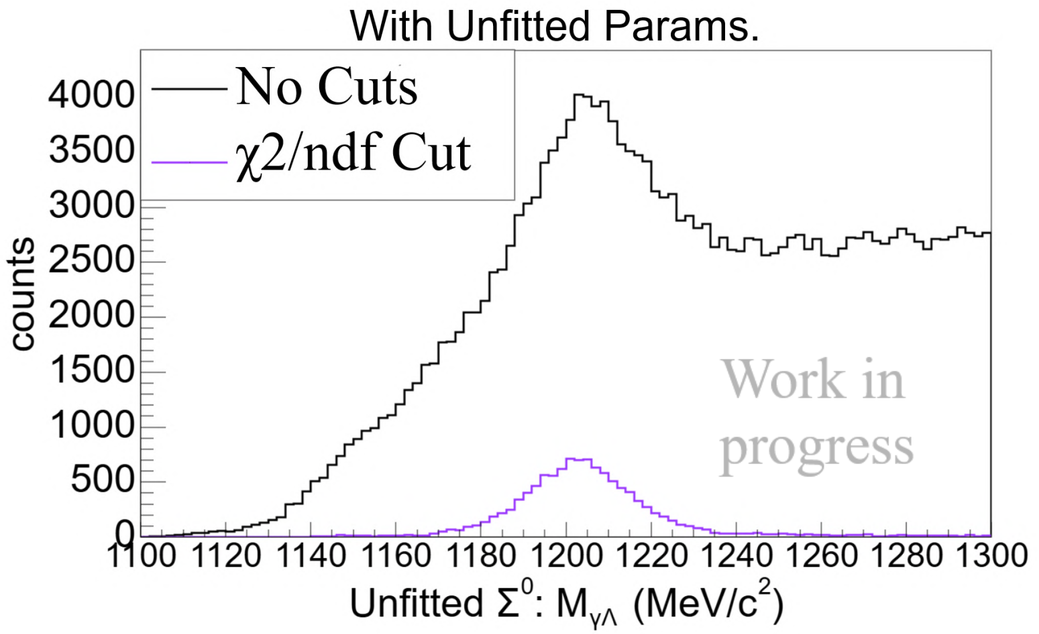
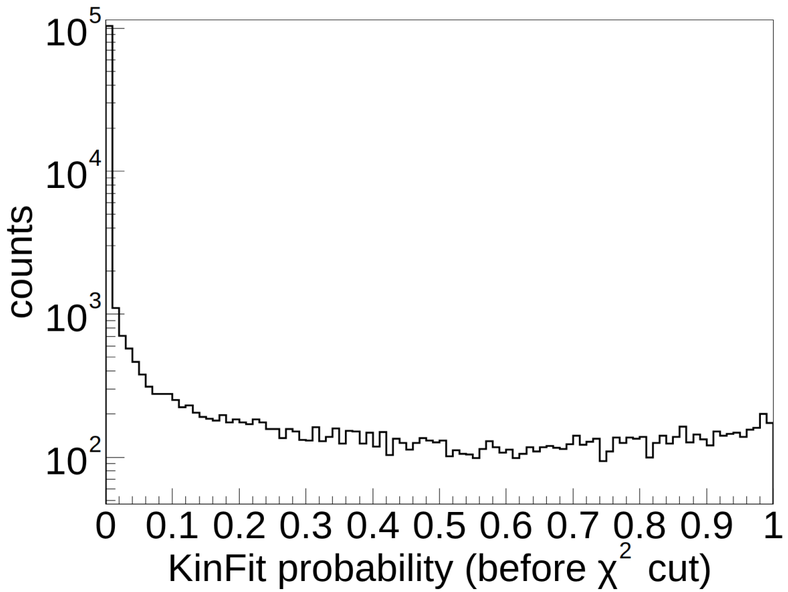
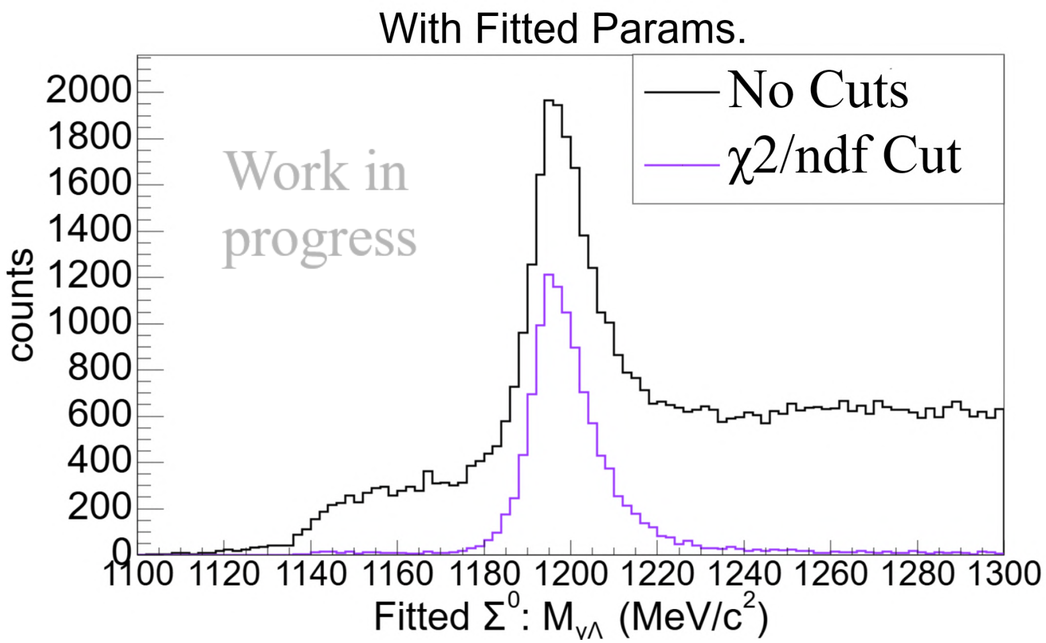
Σ^0 RECONSTRUCTION WITH KINFIT

Kinematic refit performed with the `KinFit` package [10]

- Optimizes track parameters using constrained minimization.
- FS 4-vectors constrained to initial beam+target system.
- χ^2/ndf cut: strong background reduction.







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[10] Comput. Softw. Big Sci. 8(1): 3 (2024)

A FIRST PEAK...

TOWARDS OTHER Σ^0 PRODUCTION CHANNELS

- Same event and Λ selections as presented earlier

$pp \to pK^+\pi^0\Sigma^0$,

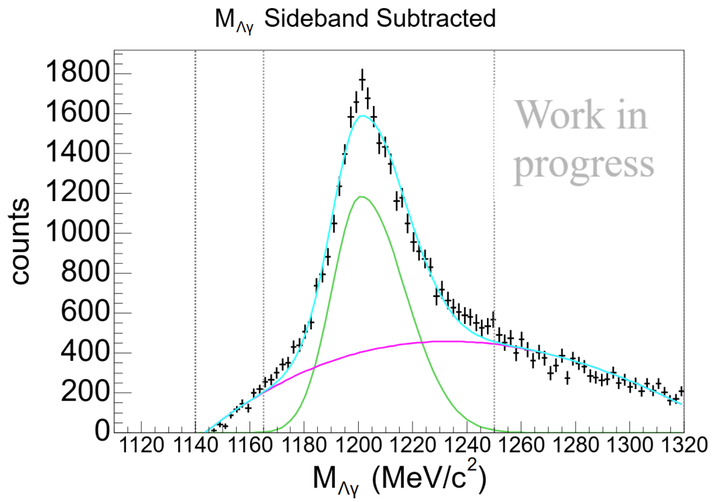
$pp \to pK^+\pi^+\pi^-\Sigma^0$:

- Exclusive selection.

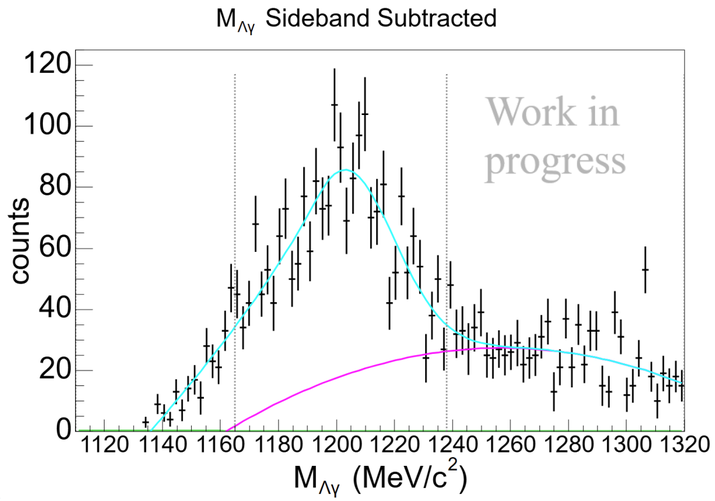
$pp \to pK^0\pi^+\Sigma^0$:

- Unmeasured K^0.
- `KinFit` with constraint on $MM = m_{K^0}$.

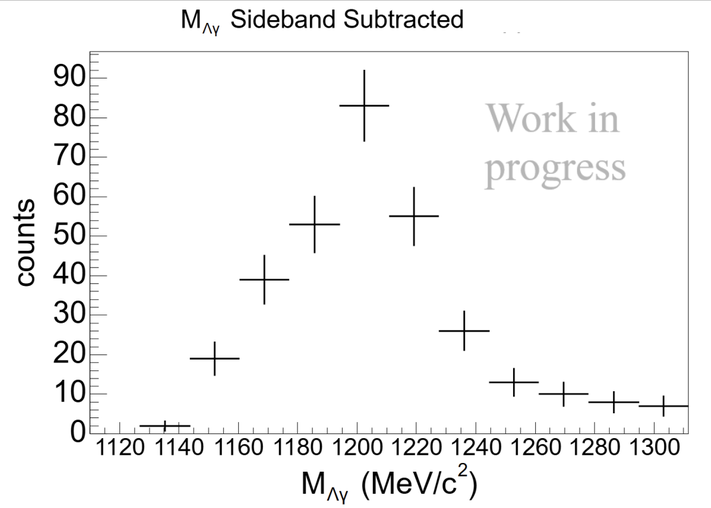
$pp \to pK^0\pi^+\Sigma^0$



$pp \to pK^+\pi^0\Sigma^0$



$pp \to pK^+\pi^+\pi^-\Sigma^0$



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OUTLOOK

The roadmap from here:

- Identify the most important Σ^0 production channels.
- Investigate the cross-section dependence on dynamic variables such as p_T, θ_{Σ^0}, psedorapidity etc.
- Perform full and parallel analyses of Σ^0 radiative decay and Dalitz decay.
- $\Sigma - \Lambda$ TFF slope measurement planned at CBM [11]

[11] arXiv:2512.15986 [hep-ex]

THANK YOU!

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Swedish Research Council

Knut and Alice Wallenberg Foundation

panda @ HADES

BACKUP

BACKUP: Σ^0 DALITZ DECAY AT HADES

MC Background Cocktails with Pluto (phase space event generator) used in [4].

channel	σ in μb	available Pluto sim	events in cocktail
$p\Lambda K^0\pi^+$	85.2	yes	$1.5 \cdot 10^8$
$p\Lambda K^+$	56.1	yes	10^8
$p\Lambda K^+\pi^0$	29.3	yes	$5.2 \cdot 10^7$
$p\Lambda K^+\pi^+\pi^-$	15.6	yes	$2.8 \cdot 10^7$
$p\Lambda K^0\pi^0\pi^+$	12.7	yes	$2.3 \cdot 10^7$
$n\Lambda K^+\pi^+$	6.6	no	0
$p\Lambda K^+\pi^0\pi^0$	2.4	no	0

reaction	σ in μb	available Pluto sim	events in cocktail
$p\Sigma^0K^0\pi^+$	57.7	yes	$16.5 \cdot 10^6$
$p\Sigma^0K^0\pi^0\pi^+$	32.1	yes	$9 \cdot 10^6$
$p\Sigma^0K^+\pi^0$	28.9	yes	$12.5 \cdot 10^6$
$p\Sigma^0K^+\pi^+\pi^-$	25.6	no	0
$p\Sigma^0K^+$	19.5	yes	$13 \cdot 10^6$
$p\Sigma^0K^+\pi^0\pi^0$	9.6	no	0
$n\Sigma^0K^0\pi^+\pi^+$	9.2	no	0
$n\Sigma^0K^+\pi^+$	5.0	yes	$4 \cdot 10^6$
$n\Sigma^0K^+\pi^+\pi^0$	4.8	no	0

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[4] Rieger, J. (2026). Doctoral dissertation, Uppsala University.