

Simulations for hyperon decays with HADES

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Paris 24 V 2018

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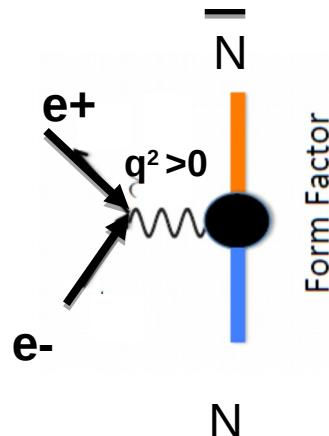


1. A motivation for hyperons' studies.
2. HADES detector and its upgrades
3. $\Lambda(1520)$ – cross section's estimation for signal and background reactions
4. $\Lambda(1520)$ - results of a simulation
5. Ξ^- – cross section's estimation for signal and background reactions
6. Ξ^- – analysis and cuts' optimization

Hyperons' spectroscopy

HADES

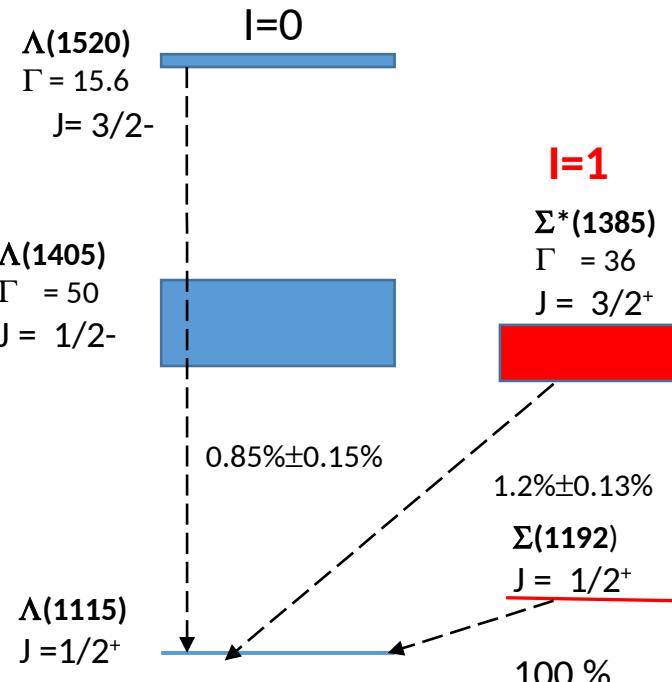
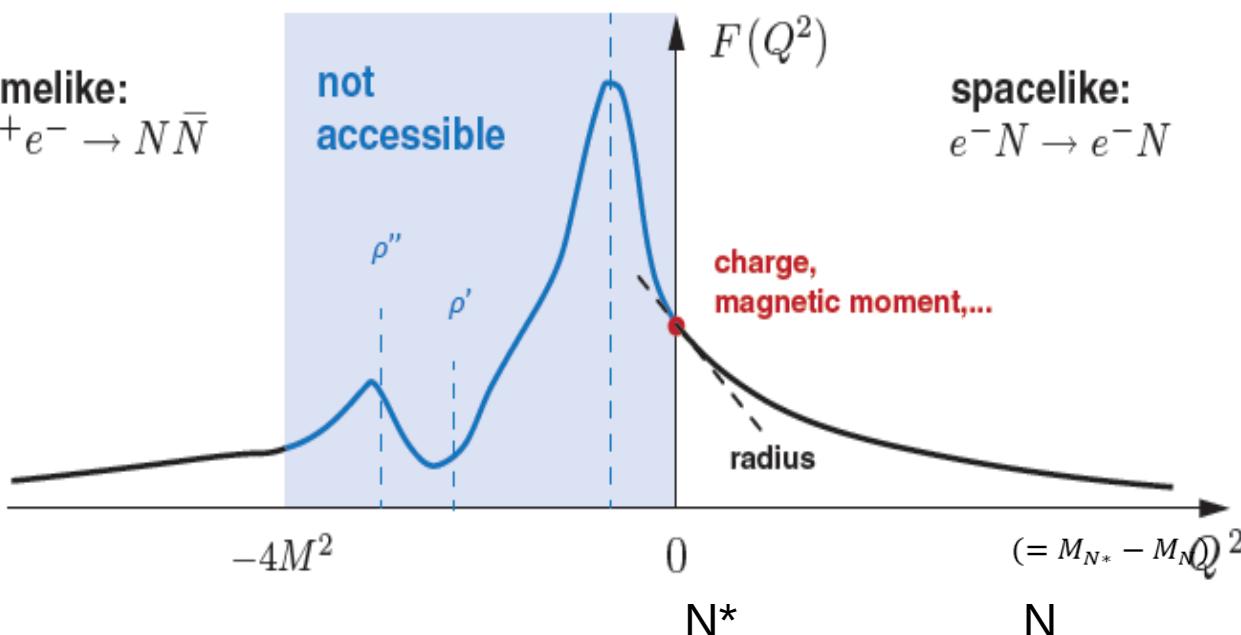
annihilation experiments



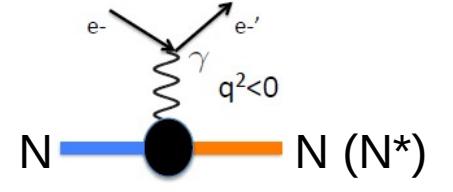
timelike:
 $e^+e^- \rightarrow N\bar{N}$



G. Eichmann

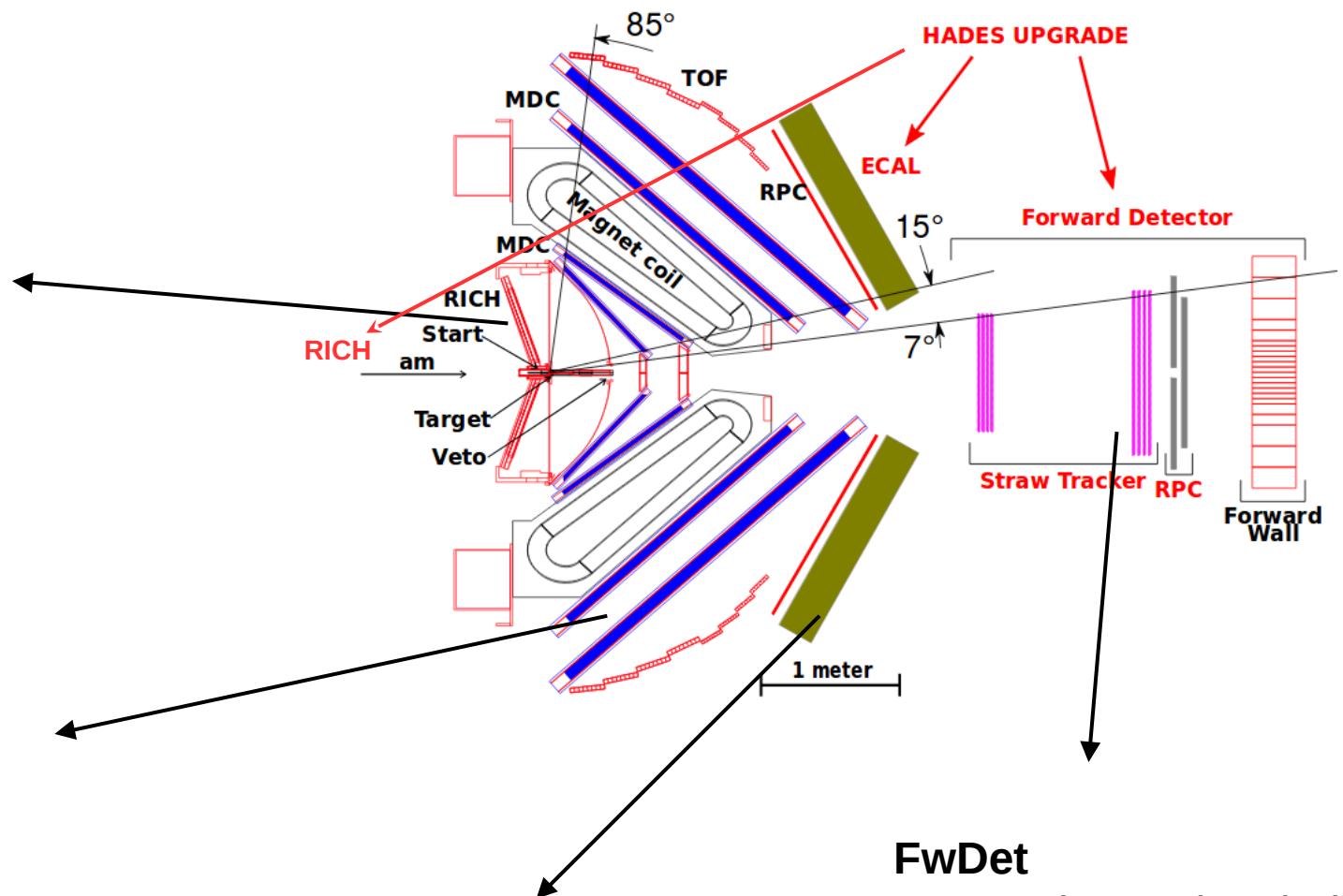


e- scattering experiments



Form Factor, helicity amplitudes,...

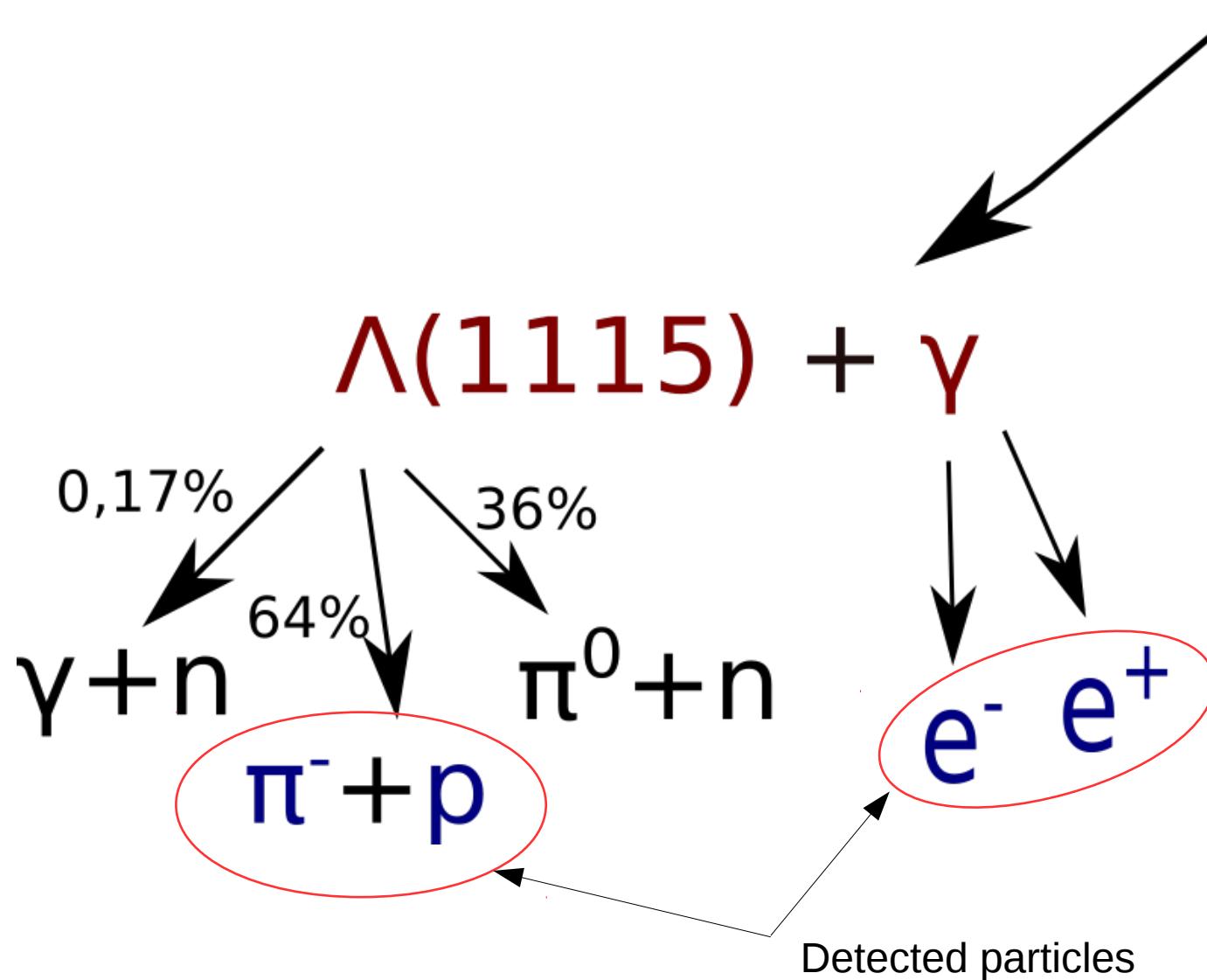
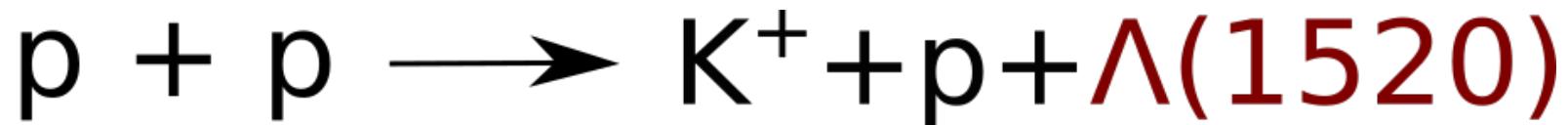
Ring Imaging Cherenkov detector.
Provides information about flight direction and allows to identify leptons



Mulit-wire drift chamber
Tracking detector installed in magnetic field.
Provides information about momentum and TOF

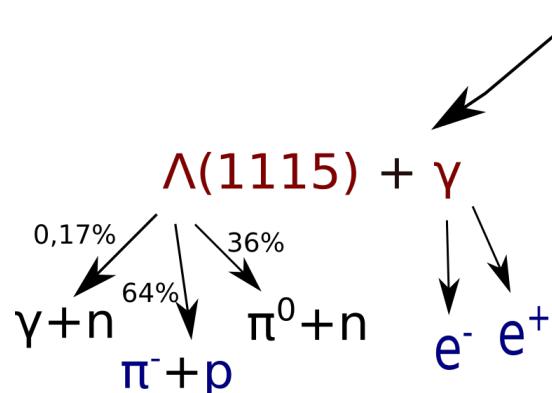
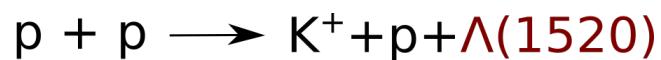
New **calorimeter** has replaced pre-shower detector. It should provide information about full energy for leptons and gammas

FwDet
Straw tube tracker, built in Cracow and Juelich. It provides information about directions and TOF.



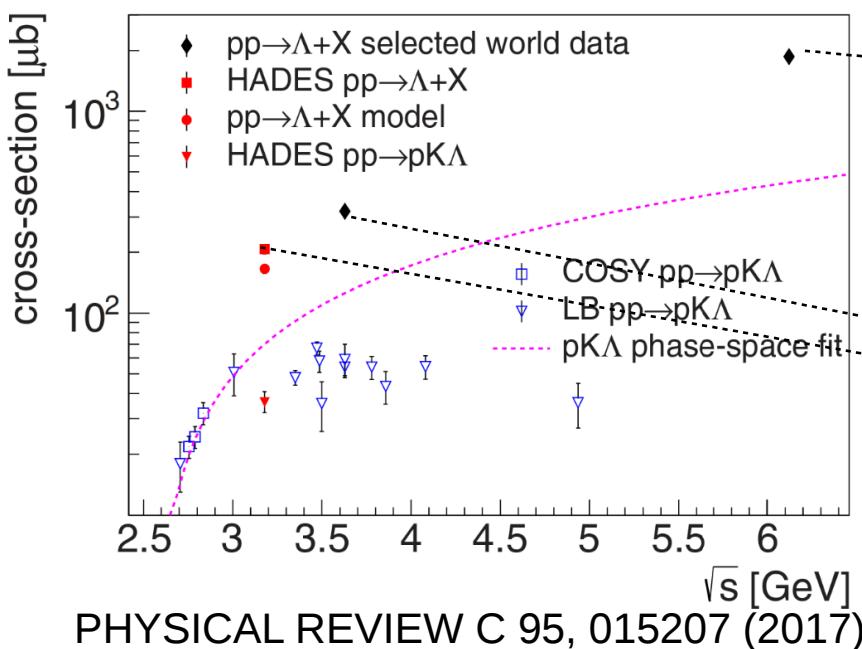
$\Lambda(1520)$ inclusive cross section

HADES

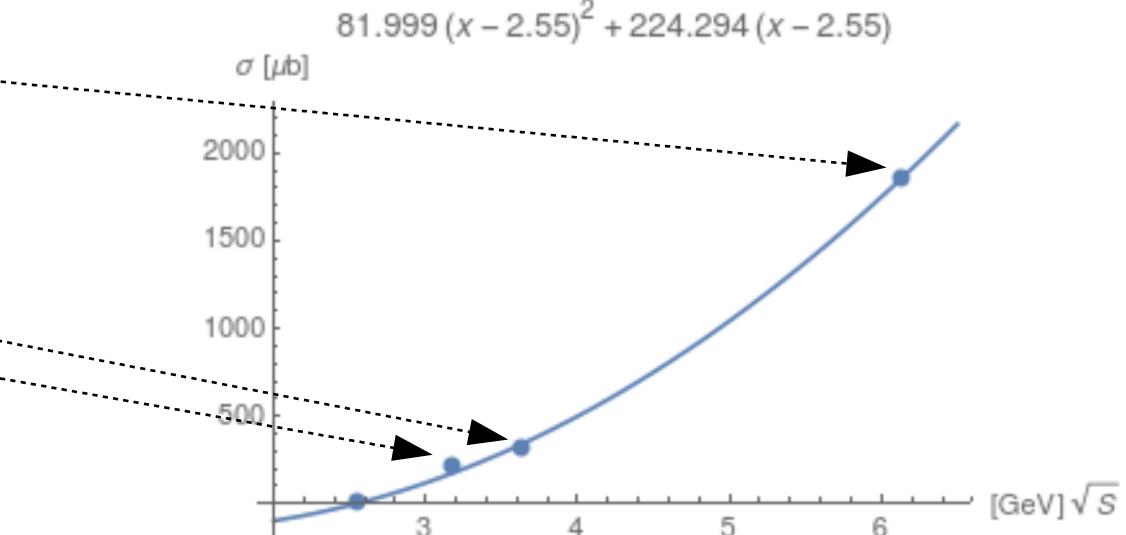


$$\sqrt{S_{\Lambda(1115)}} = m_p + m_K + m_\Lambda = 2.55 \text{ GeV}.$$

$$\sqrt{S_{\Lambda(1520)}} = m_p + m_K + m_\Lambda = 2.95 \text{ GeV}.$$



PHYSICAL REVIEW C 95, 015207 (2017)

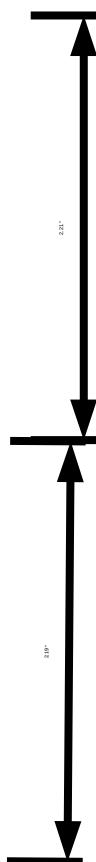


$E_k = 4.5 \text{ GeV}$ ($\sqrt{s} = 3.46 \text{ GeV}$) is 0.51 GeV over production threshold for $\Lambda(1520)$, what corresponds to $\Lambda(1115)$ production at $\sqrt{s} = 3.06 \text{ GeV}$. The cross section for this energy is equal 130 μb

Full list of simulated channels

HADES

Decay channel	Cross-section [μb]
$p \Lambda (1520) [e^+e^-\Lambda] K^+$	130
$p p \pi^+ \pi^- \pi^0$	1840
$p p \pi^+ \pi^- \pi^0 \pi^0$	300
$p p \pi^+ \pi^- \pi^0 \pi^0 \pi^0$	100
$p n \pi^+ \pi^+ \pi^- \pi^0$	300
$p \Lambda K^+ \pi^0$	43
$p \Lambda K^+ \pi^0 \pi^0$	10
$n \Lambda K^+ \pi^+ \pi^0$	20
$p \Lambda K^+ \pi^0 \pi^0 \pi^0$	7
$p \Lambda (1520) K^+$	3% of signal reaction (130)



Multi pion production
(BR: $\pi^0 \rightarrow e^+e^-\gamma = 1.17\%$).

Λ + di-lepton source

Strategy of analysis

HADES

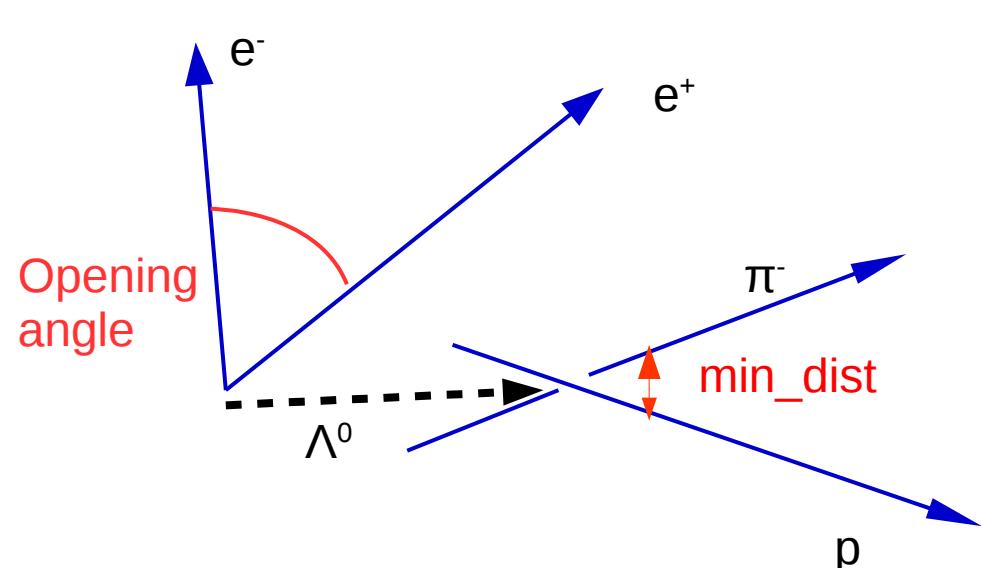
HADES-FwDet

1. Combine all tracks from FwDet and π^- candidates from HADES.
2. Calculate minimal distance between FwDet track and π^- .
3. Reject all pairs distant from each other for more than **10 mm**.
4. Assume that track in FWDet is a proton and calculate invariant mass for π^- -proton pair.



HADES-HADES

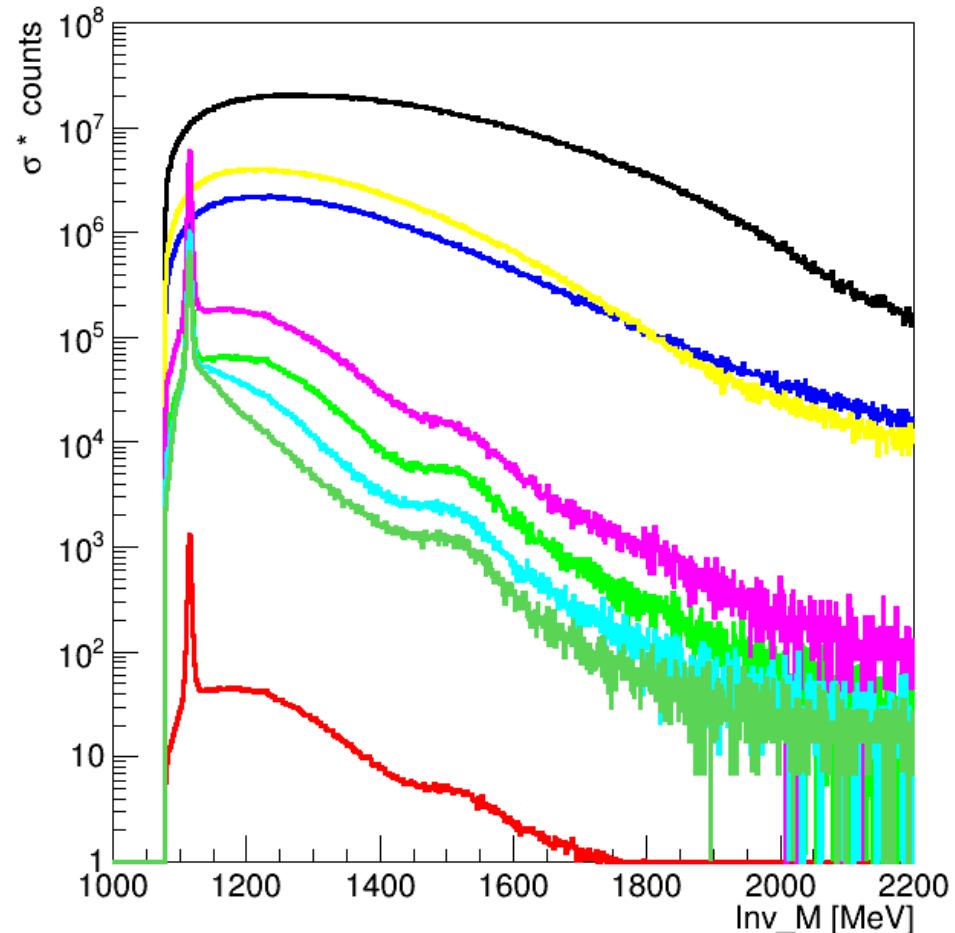
1. Combine all proton and π^- candidates from HADES.
2. Calculate minimal distance between proton and π^- track.
3. Reject all pairs distant from each other for more than **10 mm**.



5. Reject all events out of **$\Lambda(1115)$ mass window (1115-1125 MeV)**
6. **Z coordinate of reconstructed Lambda vertex displaced from target.**
7. Reconstruct di-lepton pair and calculate its invariant mass.
8. Opening angle > 5 deg and di-lepton mass $> \pi^0$
9. Sum di-lepton and $\Lambda(1115)$ 4-vector.

$\Lambda(1115)$ reconstruction

HADES

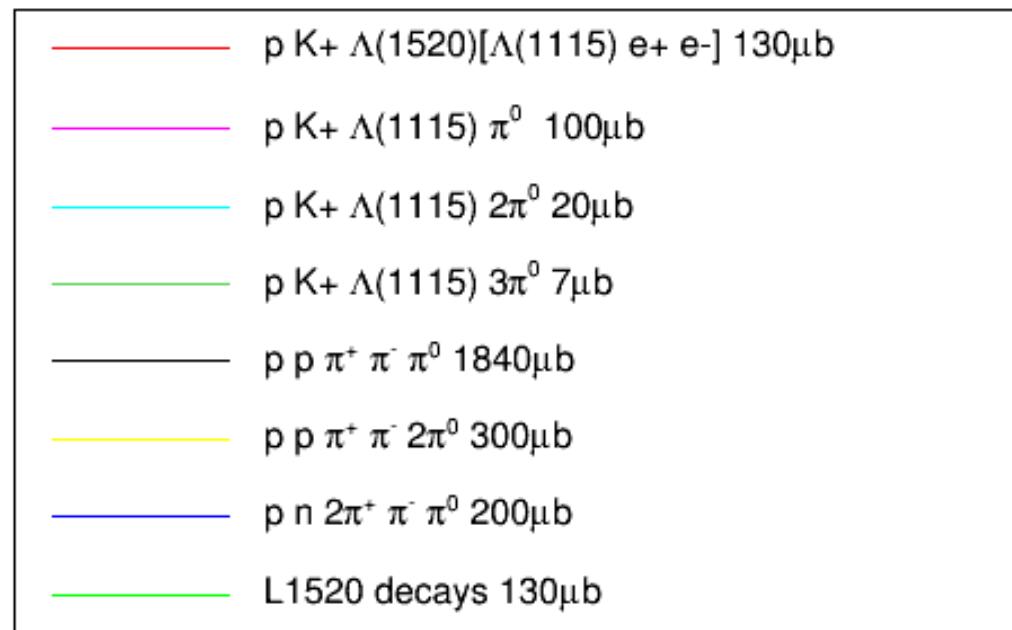
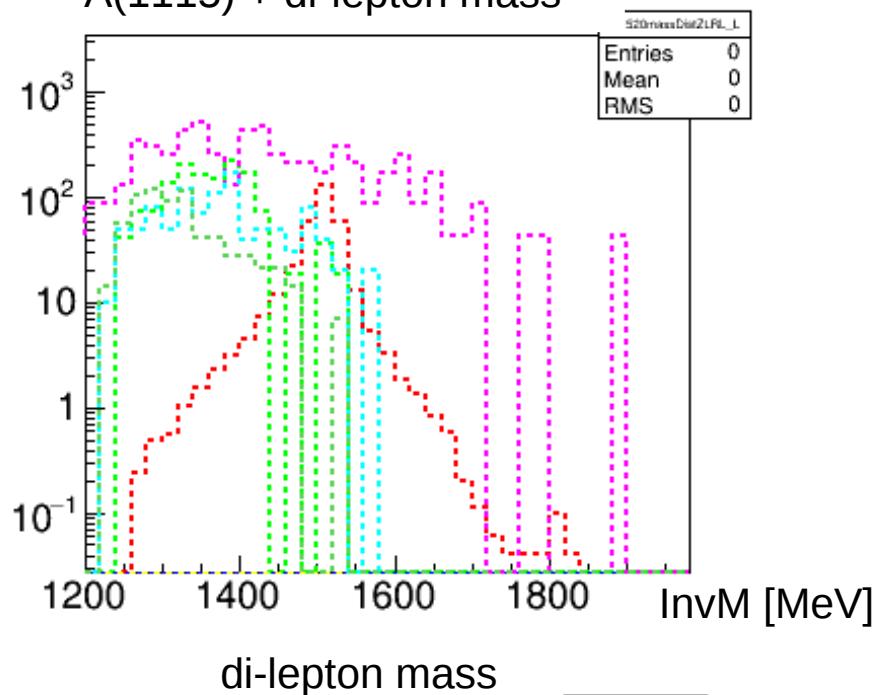


- p K+ $\Lambda(1520)[\Lambda(1115) e^+ e^-]$ $130\mu\text{b}$
- p K+ $\Lambda(1115) \pi^0$ $100\mu\text{b}$
- p K+ $\Lambda(1115) 2\pi^0$ $20\mu\text{b}$
- p K+ $\Lambda(1115) 3\pi^0$ $7\mu\text{b}$
- p p $\pi^+ \pi^- \pi^0$ $1840\mu\text{b}$
- p p $\pi^+ \pi^- 2\pi^0$ $300\mu\text{b}$
- p n $2\pi^+ \pi^- \pi^0$ $200\mu\text{b}$
- L1520 decays $130\mu\text{b}$

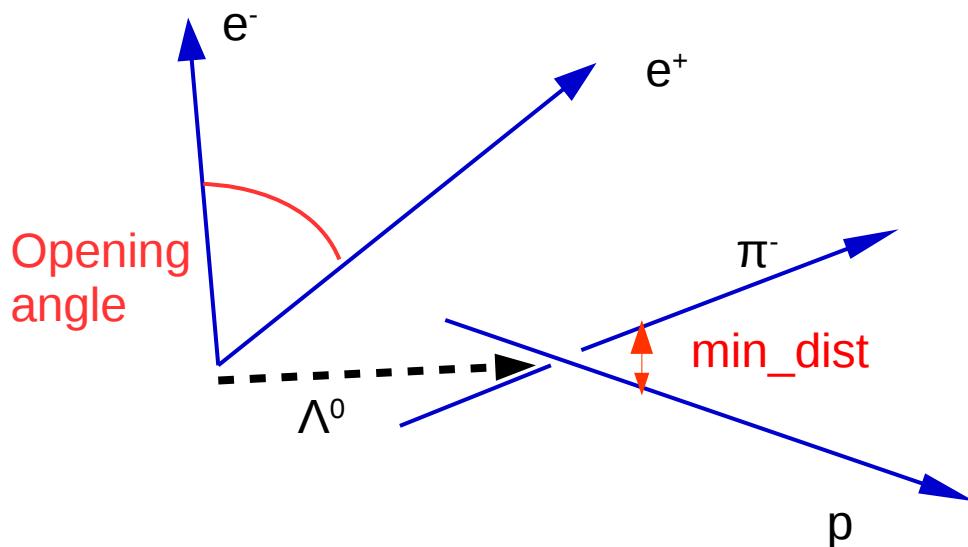
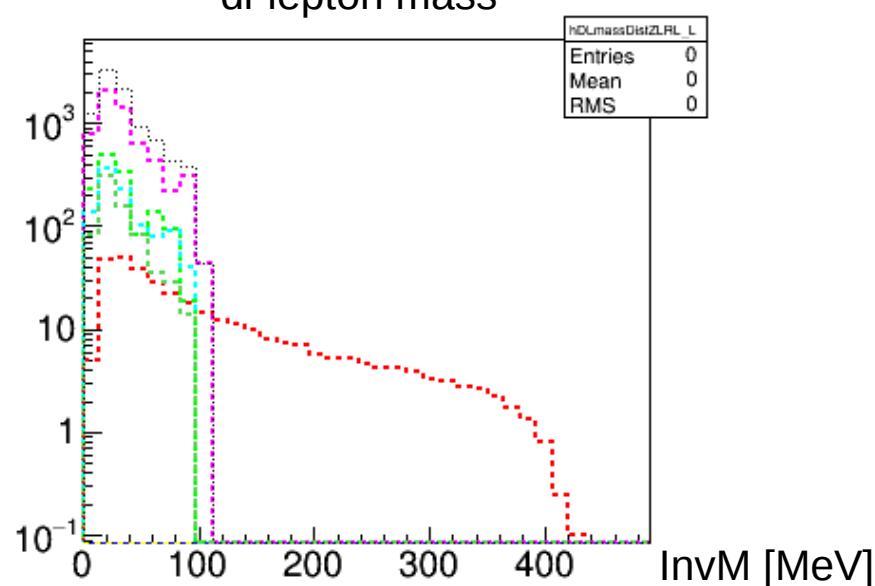
Results for signal reaction

HADES

$\Lambda(1115) + \text{di-lepton mass}$



di-lepton mass

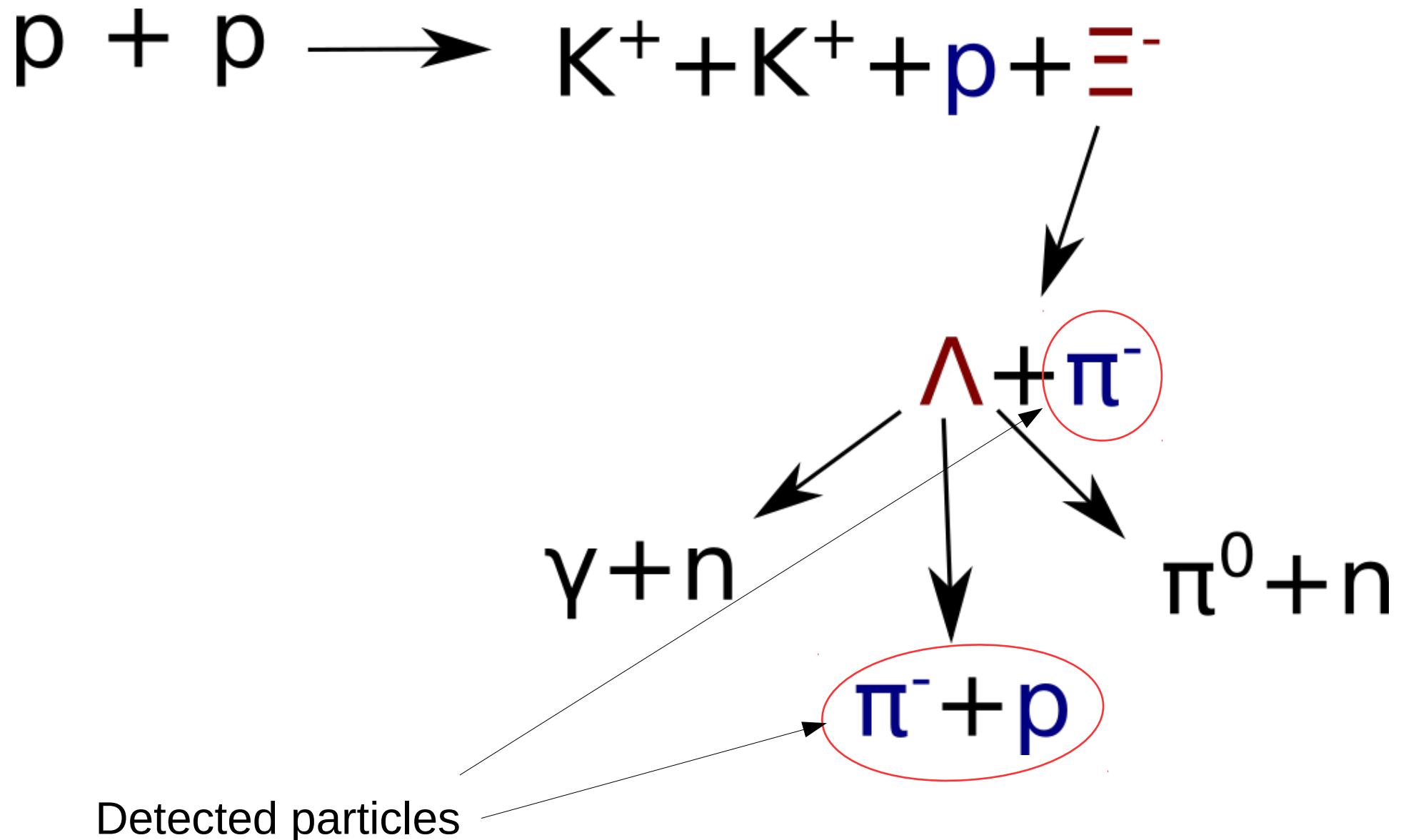


- › Beam rate 10^8 part/s
- › Target density $2 \times 10^{23} \text{ cm}^{-2}$
- › Luminosity $2 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$
- › Beam duty cycle: 50%
- › Trigger dead time: 50%

$$\sigma_{\Lambda(1520)} = 130 \mu b \cdot 0.5 = 650 nb$$

$$BR_{\Lambda(1520) \rightarrow \Lambda e^+ e^-} = 7.8 \cdot 10^{-5}$$

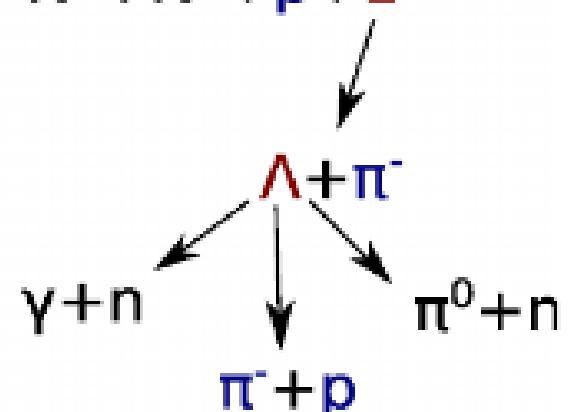
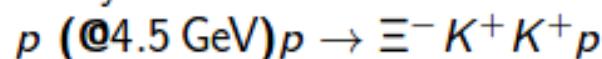
- › Expected count rate 2.5×10^{-4} part/s
- › For 4 weeks of beam $\approx 613 \Lambda(1520)$ detected



Cascade – production & background

HADES

Analysed reaction:



Particle ID:

- ▶ π^- — only pions from Hades, Geant ID
- ▶ p — all in FwDet is proton

Preliminary analysis for the most contributing background channels:

no.	reaction	cross-section [μb]
0.	$\Xi^- K^+ K^+ p$	4.8
1.	$pp2\pi^-2\pi^+$	600
2.	$p\Lambda K_s^0\pi^+$	100
3.	$p\Lambda K^+\pi^+\pi^-$	30
4.	$n\Lambda K_s^02\pi^+$	30
5.	$p\Sigma^0 K_s^0\pi^+$	20
6.	$pp2K_s^0$	20

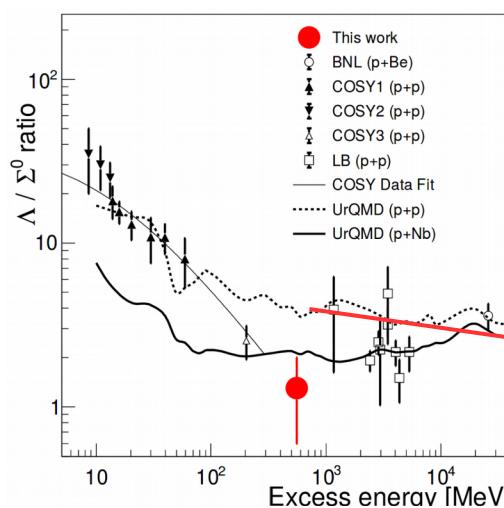
$$\Lambda \rightarrow p\pi^-$$

$$\Sigma^0 \rightarrow \Lambda\gamma$$

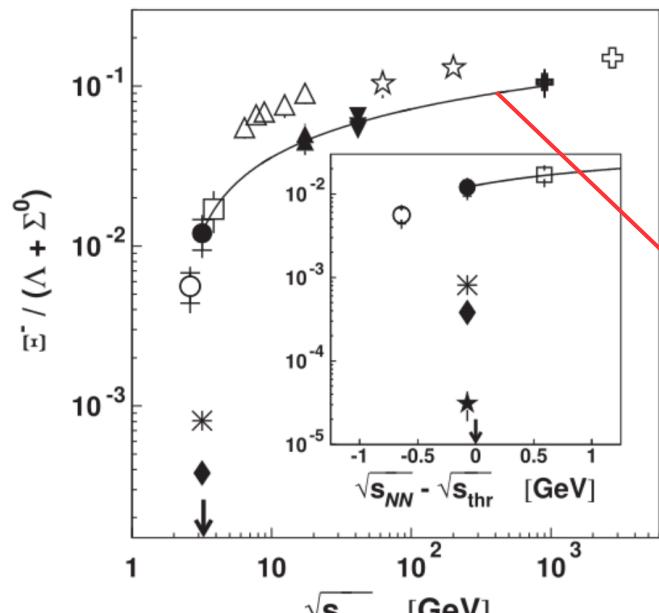
$$K_s^0 \rightarrow \pi^+\pi^-$$

Cascade – cross section

HADES



" Σ^0 production in proton nucleus collisions near threshold" Physics Letters B, 2018



PRL 114, 212301 (2015)

$p p \rightarrow \Lambda$ Anything

6.000	0.32000	0.02000
12.000	1.15400	0.02000
12.400	1.07000	0.11000

(Cross section units: 10^{-27} cm^2)

Eisner, NPB123,361-77
Fesefeldt, NPB147,317-79
Jaeger, PRD11,1756-75

Landolt-Börnstein - Group I Elementary Particles, Nuclei and Atoms

$$\frac{\sigma \Lambda^0}{\sigma \Sigma^0} \underset{E_k = 4.5 \text{ GeV}}{=} 3.5,$$

$$\sigma_{\text{E}} \approx 4.8 \mu b$$

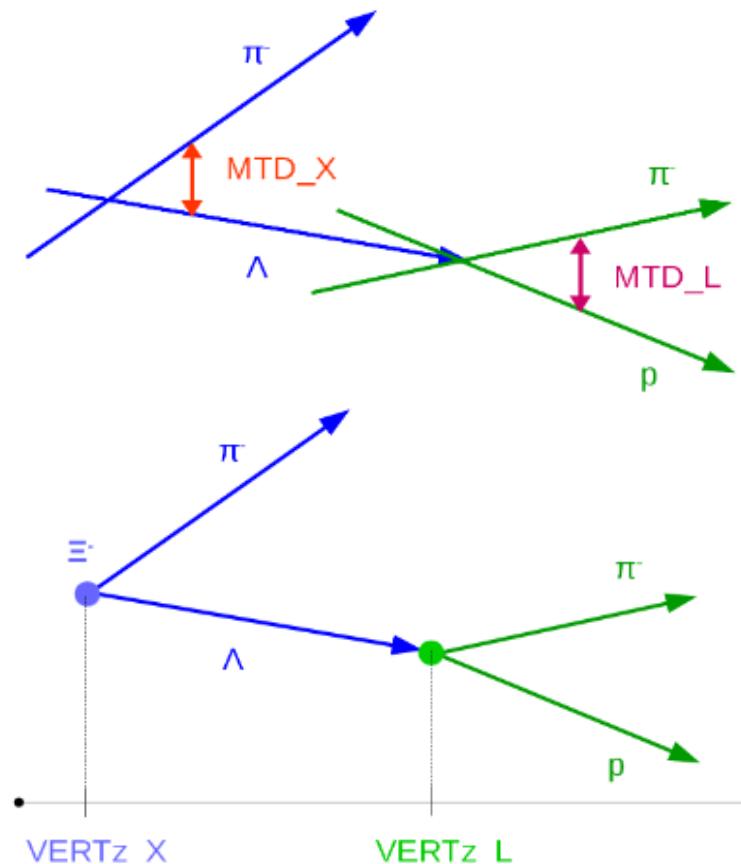
$$\frac{\Xi}{\Lambda + \Sigma^0} \underset{E_k = 4.5 \text{ GeV}}{=} 0.0141.$$

$$\frac{\Xi}{\Lambda + \Sigma^0} = 0.44 \left(1 - \left(\frac{2.2 \text{ GeV}}{\sqrt{s_{NN}}} \right)^{0.027} \right)^{0.780}.$$

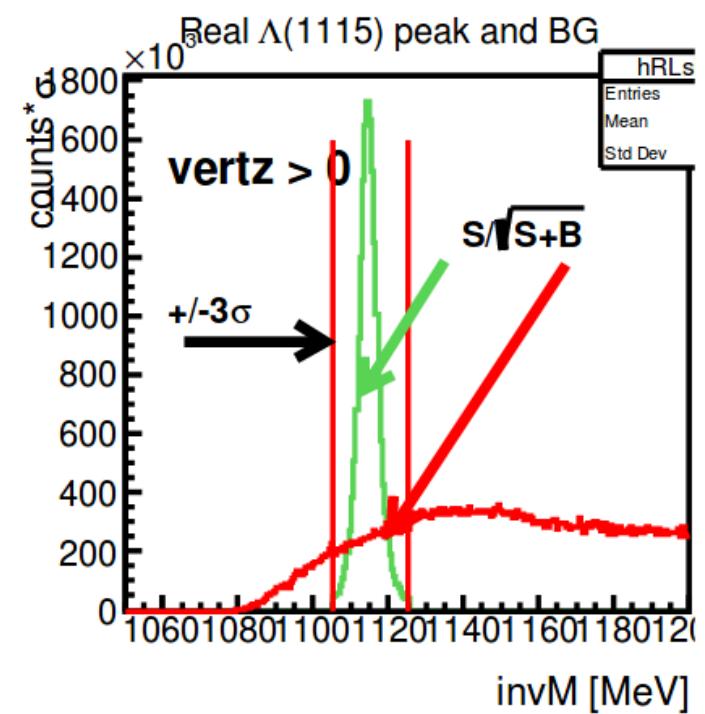
Cuts

HADES

- ▶ minimum tracks distance between p and π^- (**MTD_L**)
- ▶ distance between primary vertex and z coord. of the Λ decay vertex (**VERTz_L**)
- ▶ mass of Λ candidate (**MassL** $\in [1105\text{--}1125]\text{MeV}$)
- ▶ minimum tracks distance between Λ and another π^- (**MTD_X**)
- ▶ distance between primary vertex and z coord. of the Ξ^- decay vertex (**VERTz_X**)

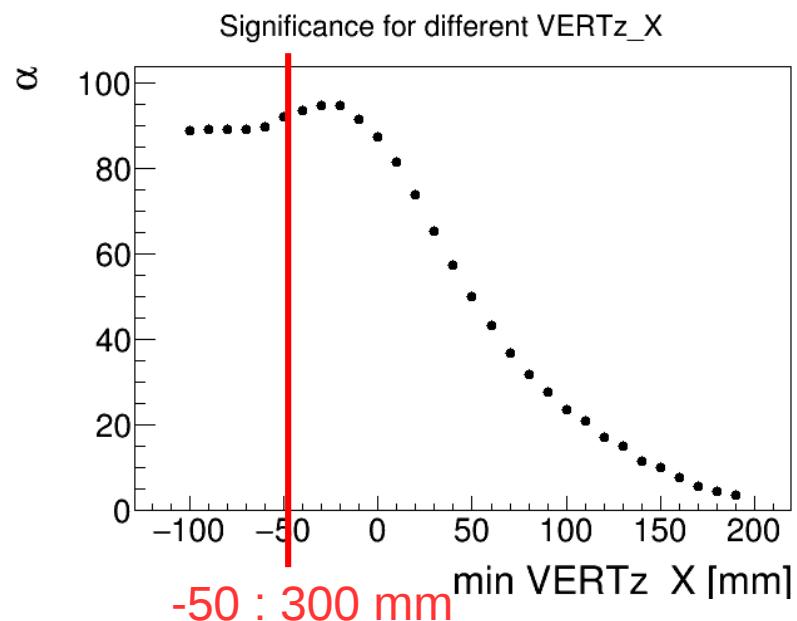
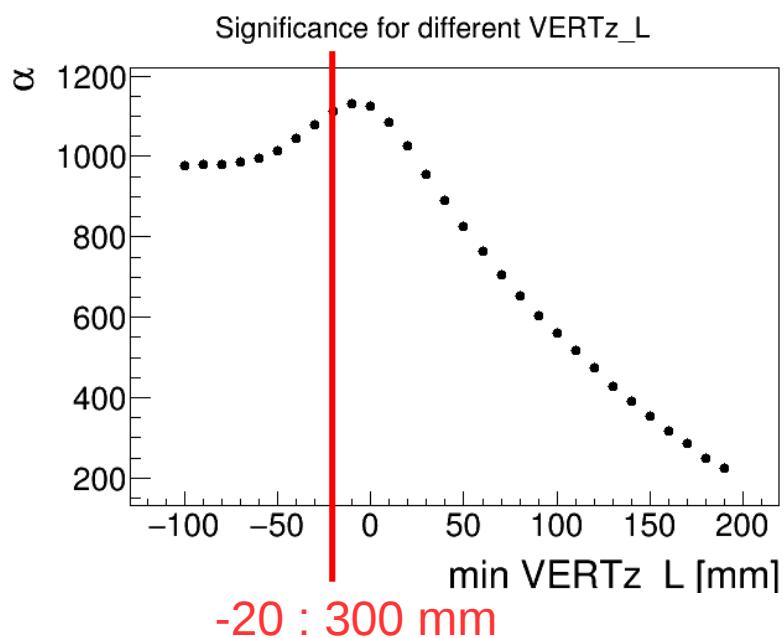
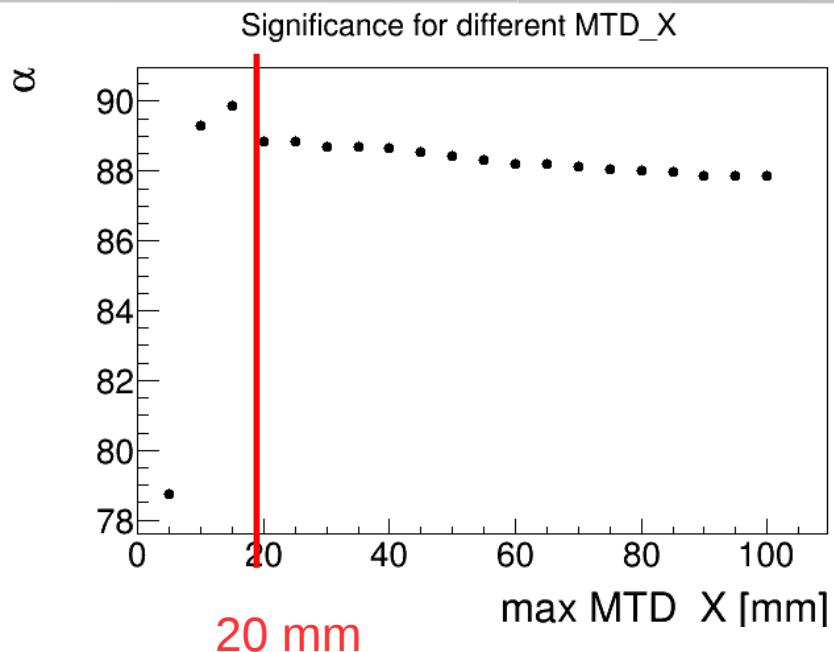
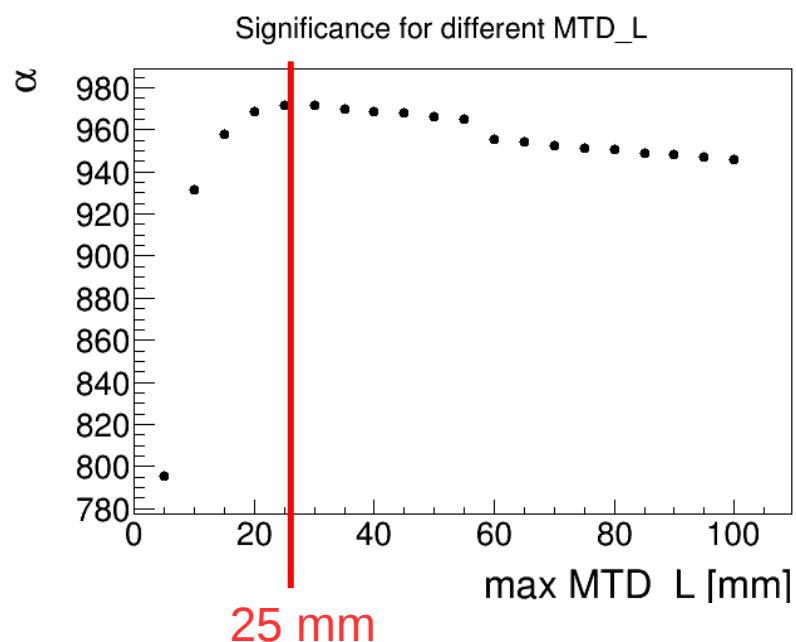


$$\text{significance} \quad \alpha = \frac{S}{\sqrt{(S+B)}}$$



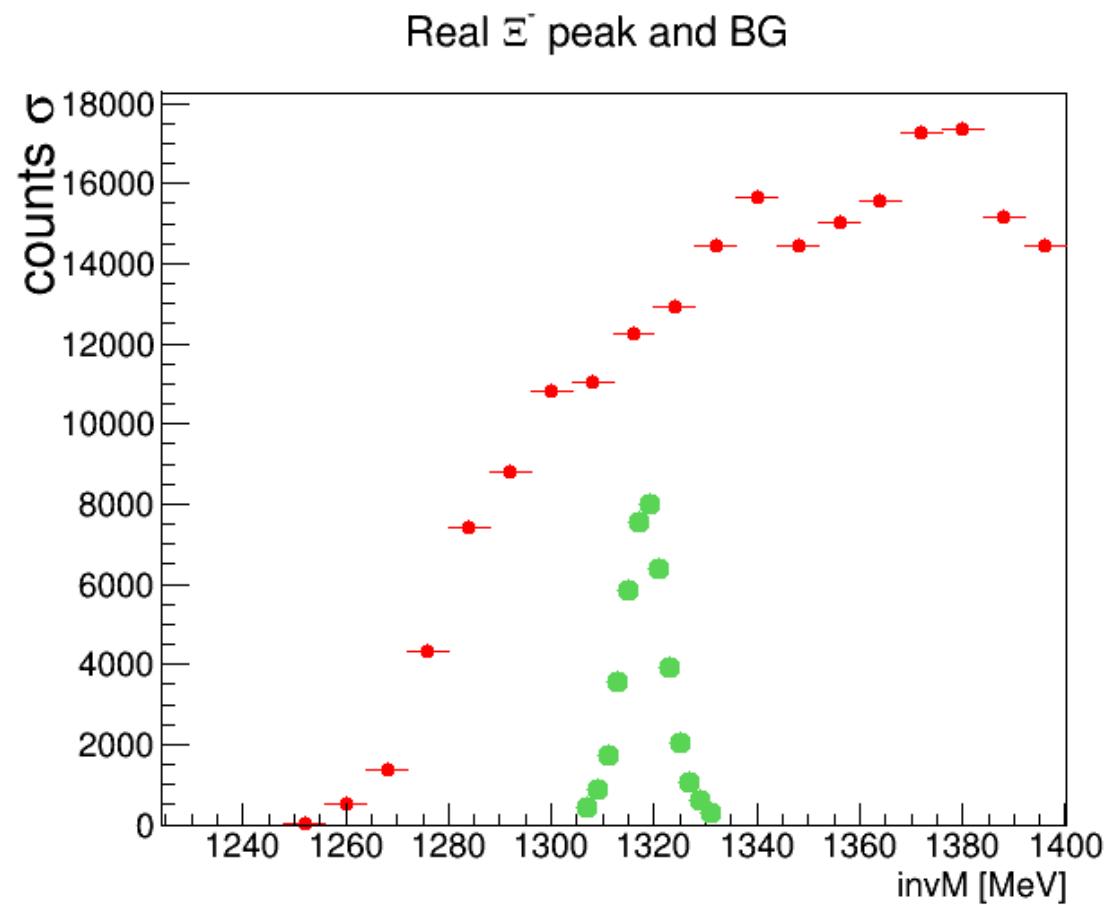
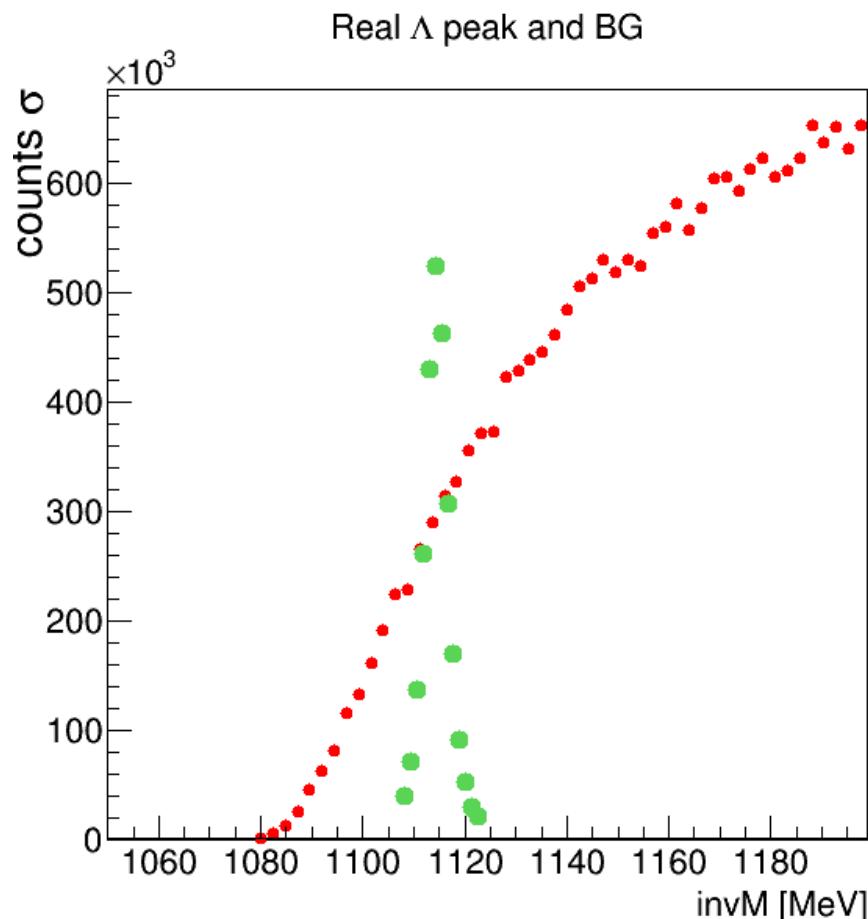
Cuts optimization

HADES



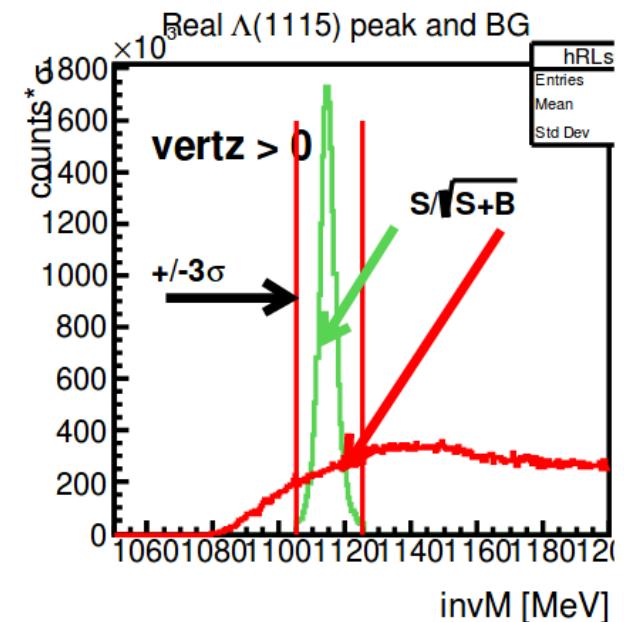
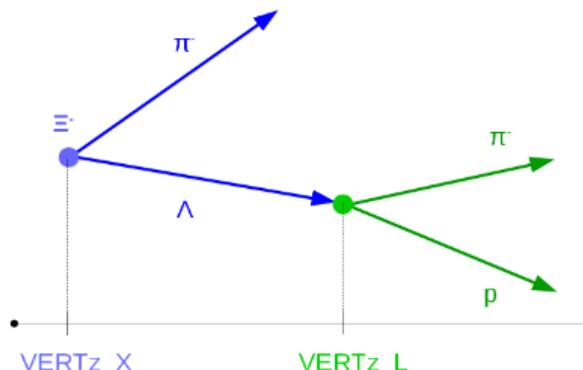
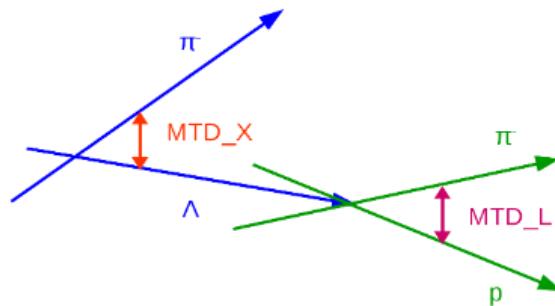
Cuts operationalization: final-results

HADES



Cuts operationalization: final-results

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number of simulated events in each channel: 1M

In the table:

- ▶ S — integral of the signal peak (green in previous histograms)
- ▶ B — integral of the BG (red in previous histograms) in the range of the signal peak
- ▶ S/B — signal-to-background ratio
- ▶ $\alpha = \frac{S}{\sqrt{S + B}}$ — significance

	LambdaNoCuts	MTD_L	VERTz_L	massL	Xi	MTD_X	VERTz_X
S:	2795032	2700048	2615254	2613456	44433	43742	42484
B:	7097518	5344390	4173199	4174967	545970	197798	175303
S/B:	0.394	0.505	0.627	0.626	0.081	0.221	0.242
$\frac{S}{\sqrt{S + B}}$	888.7	952.0	1003.8	1003.1	12.0	89.0	91.0

- Beam rate = 10^8 part/s
 - Target density $\rho = 2 \cdot 10^{23} \text{ cm}^{-2}$
 - Total cross-section $\sigma_{tot} = 4.8 \mu b$
- > $\approx \frac{3600 \text{ particle}}{\text{hour}}$

Additionally:

- Expected beam duty cycle $\approx 50\%$ → To produce 1M of Ξ ≈ 11 h
- Trigger dead time $\approx 50\%$

- ✓ The most prominent background channels included
- ✓ The analysis strategy for $\Lambda(1520)$ and Ξ tested
- ✓ Cuts optimization for cascade prepared

- ✗ Complete $\Lambda(1520)$ analysis including CB
- ✗ Simulate Σ^0 channel
- ✗ Compare our simulation with HADES Λ data
- ✗ Find Λ e+e- in pp+p Nb (8 weeks data) @3.5 GeV data using improved lepton identification method

Thank you for your
attention!

Backup

How to read table?

HADES

b) Reaction with Λ and di-lepton source (BR: $\pi^0 \rightarrow e^+e^-\gamma = 1.17\%$).

no	reaction	cross-section	source	p[GeV/c]	$p_{thr}[\text{GeV}/c]$	L-B No.
1	$p \Lambda K^+ \pi^0$	$43 \mu b$	[3]	5.4	2.74	83
2	$n \Lambda K^+ \pi^+ \pi^0$	$20 \mu b$				
3	$p \Lambda K^+ 2\pi^0$	$10 \mu b$				
4	$p \Lambda K^0 \pi^+ 2\pi^0$	$7 \mu b$				
5	$p \Lambda K^0 \pi^+ \pi^0$	$17 \mu b$	[3]	5.5	3.182	78
6	$p \Lambda K^+ 3\pi^0$	$7 \mu b$				
7	$p \Lambda \pi^+ \pi^0 \pi^- K^+$	$14.2 \mu b$	[3]	6.92	3.62	77
8	$p K^+ \Lambda(1520) \rightarrow \Lambda 2\pi^0$	BR $\approx 3\%$	calculated from C-G coefficients for decay into two pions			
	total:					

Color code:

proton's momentum
5.4-5.5 GeV/c

momentum between
5.6 and 8 GeV/c

data for higher
momentum, or no
data

c) Reaction with Σ^0 (BR: $\Sigma^0 \rightarrow \Lambda e^+e^- = 5 \cdot 10^{-3}$, $\Sigma^0 \rightarrow \gamma \Lambda^0 \approx 100\%$)

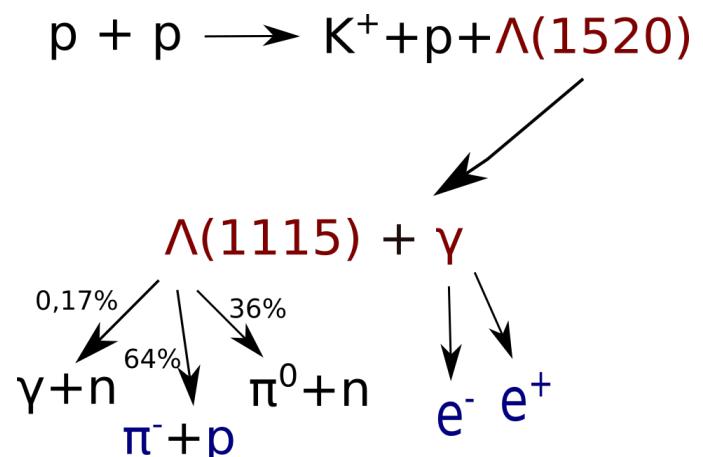
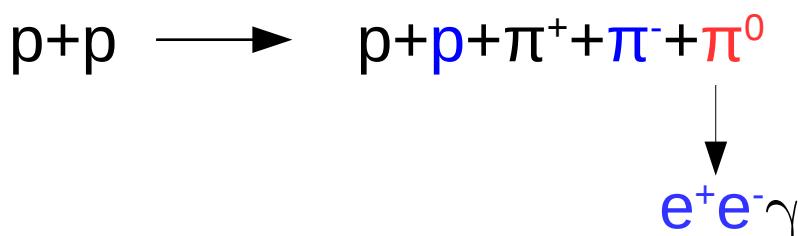
no	reaction	cross-section	source	p[GeV/c]	$p_{thr}[\text{GeV}/c]$	L-B No.
1	$p \Sigma^0 K^+ \pi^0$	$18 \mu b$	similar to reaction no 4			
2	$p \Sigma^0 K^+$	$27 \mu b$	[3]	5.4	2.67	108
3	$p \Sigma^0 K^+ \pi^+ \pi^-$	$13.7 \mu b$	[3]	6.92	3.43	106
4	$p \Sigma^0 K^0 \pi^+$	$18 \mu b$	[3]	5.4	3.00	107
	total:	$45 \mu b$				

**Bold text – channels
treated as important**

$\Lambda(1520)$ – background I

channels with neutral pions + pair proton-pion

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π^0 Dalitz decay ($\pi^0 \rightarrow e^+ e^- \gamma = 1.17\%$)

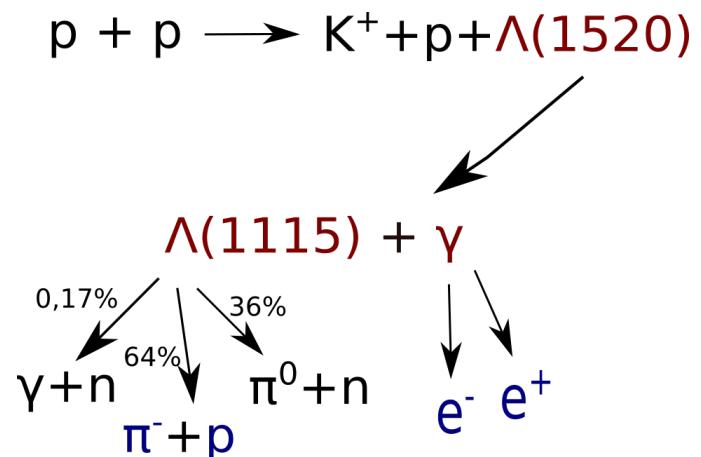
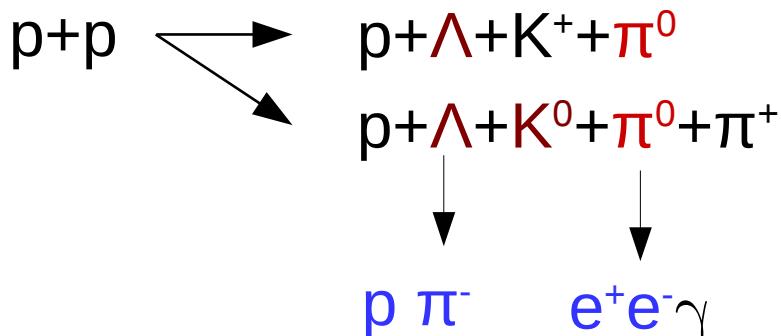
no	reaction	cross-section	source	p[GeV/c]	p_{thr} [GeV/c]	L-B No.
1	pp $\pi^+ \pi^- \pi^0$	1.84 mb	[3]	5.5	1.60	169
2	pp $\pi^+ \pi^- 2\pi^0$	0.3 mb	similar to reaction no 5			
3	pp $\pi^+ \pi^- 3\pi^0$	0.1 mb				
4	pn $2\pi^+ \pi^- \pi^0$	0.3 mb				
5	pp $2\pi^+ 2\pi^- \pi^0$	$88.0 \mu b$	[3]	5.5	2.41	179
6	pp $3\pi^+ 3\pi^- \pi^0$	$20 \mu b$	[3]	8.80	3.26	185
total:		2.24 mb				

no	reaction	cross-section	source	p[GeV/c]	p_{thr} [GeV/c]	L-B No.
1	pp $2\pi^+ 2\pi^-$	$227 \mu b$	[3]	5.50	2.016	182
2	pp $2\pi^+ 2\pi^- \pi^0$	$88 \mu b$	[3]	5.5	2.41	179
3	pn $3\pi^+ 2\pi^-$	$98 \mu b$	[3]	5.5	2.428	130
total:		$325 \mu b$				

$\Lambda(1520)$ background II

reaction with $\Lambda(1115)$ + di-lepton source

HADES

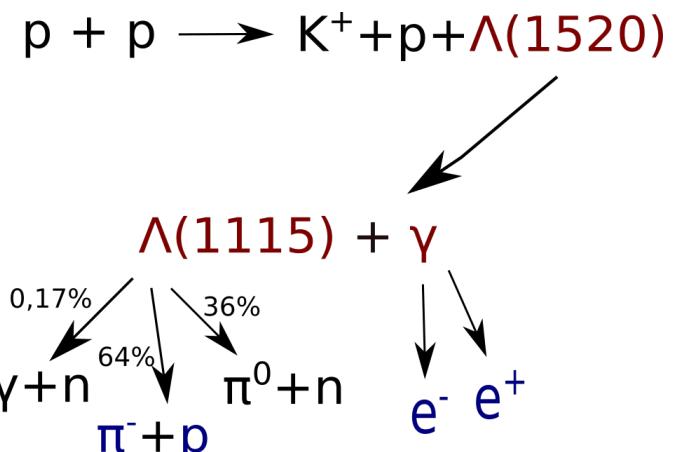
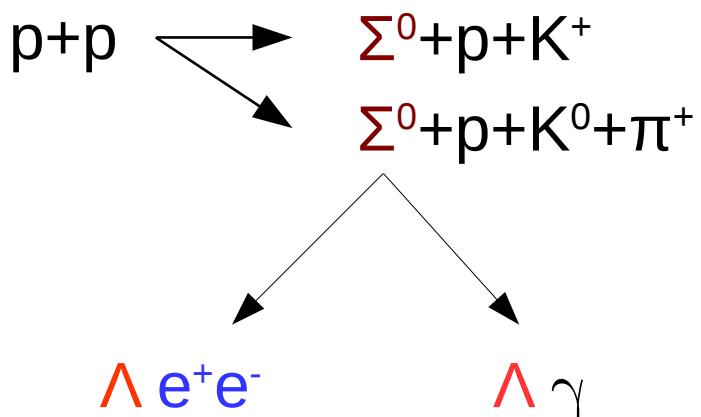


Reaction with Λ and di-lepton source (BR: $\pi^0 \rightarrow e^+ e^- \gamma = 1.17\%$).

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8	$p K^+ \Lambda(1520) \rightarrow \Lambda 2\pi^0$	$BR \approx 3\%$	calculated from C-G coefficients for decay into two pions			
	total:					

$\Lambda(1520) - \Sigma^0$ production

HADES

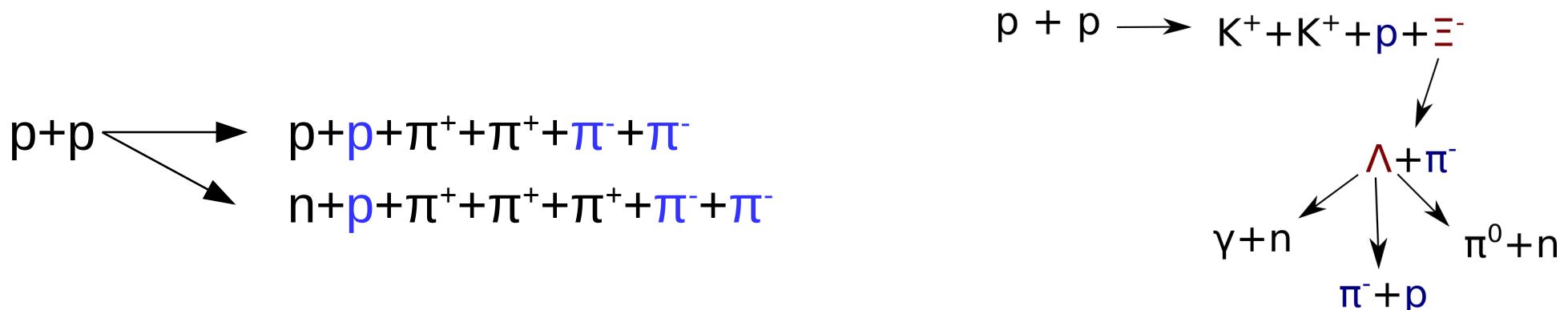


Reaction with Σ^0 (BR: $\Sigma^0 \rightarrow \Lambda e^+ e^- = 5 \cdot 10^{-3}$, $\Sigma^0 \rightarrow \gamma \Lambda^0 \approx 100\%$)

no	reaction	cross-section	source	p[GeV/c]	p_{thr} [GeV/c]	L-B No.
1	$p \Sigma^0 K^+ \pi^0$	$18 \mu b$	similar to reaction no 4			
2	$p \Sigma^0 K^+$	$27 \mu b$	[3]	5.4	2.67	108
3	$p \Sigma^0 K^+ \pi^+ \pi^-$	$13.7 \mu b$	[3]	6.92	3.43	106
4	$p \Sigma^0 K^0 \pi^+$	$18 \mu b$	[3]	5.4	3.00	107
	total:	$45 \mu b$				

Cascade – multi pion production

HADES

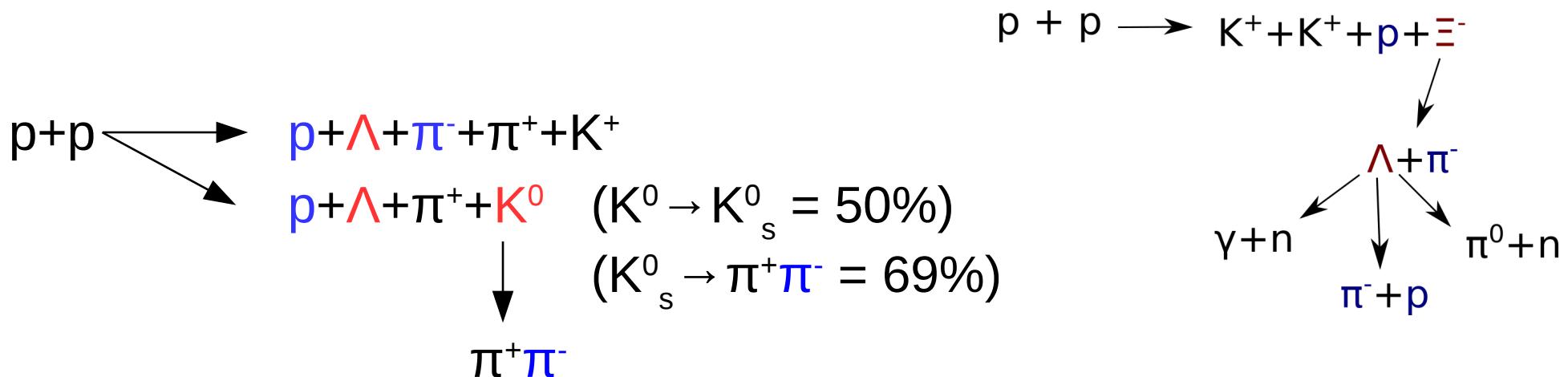


Two π^- production

no	reaction	cross-section	source	p[GeV/c]	p_{thr} [GeV/c]	L-B No.
1	pp $2\pi^+ 2\pi^-$	$227 \mu b$	[3]	5.50	2.016	182
2	pp $2\pi^+ 2\pi^- \pi^0$	$88 \mu b$	[3]	5.5	2.41	179
3	pn $3\pi^+ 2\pi^-$	$98 \mu b$	[3]	5.5	2.428	130
	total:	$325 \mu b$				

Cascade – Λ with additional π^-

HADES

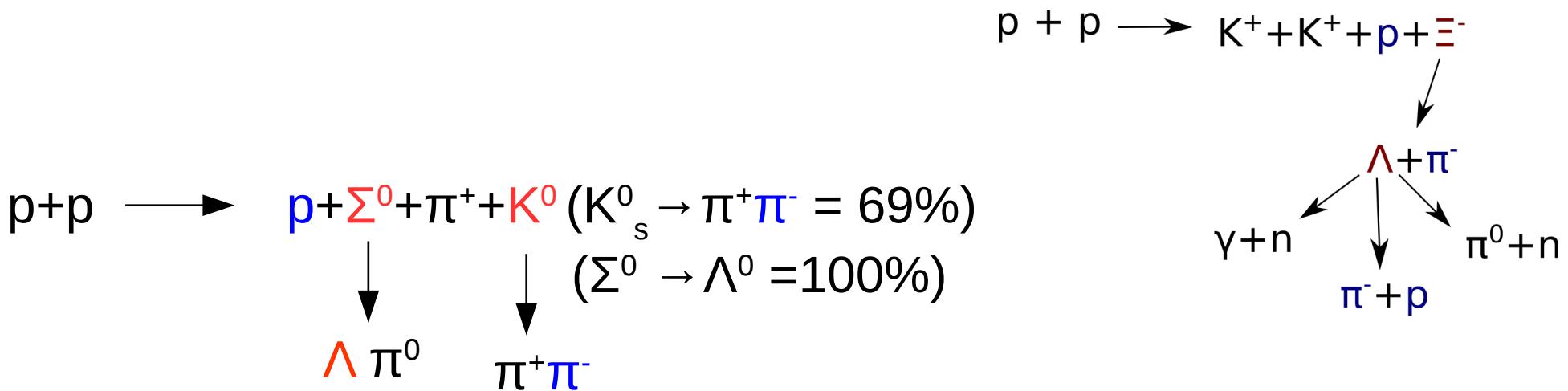


Λ production associated with π^-

no	reaction	cross-section	source	$p[\text{GeV}/c]$	$p_{thr}[\text{GeV}/c]$	L-B No.
1	$p \Lambda K^0 \pi^+$	$60 \mu b$	[3]	5.4	2.766	80
2	$p \Lambda K^0 \pi^+ \pi^0$	$17 \mu b$	[3]	5.5	3.182	78
3	$n \Lambda K^0 2\pi^+$	$29.6 \mu b$	[3]	6.920	3.204	88
4	$p \Lambda \pi^+ \pi^0 \pi^- K^+$	$14.2 \mu b$	[3]	6.92	3.62	77
5	$p \Lambda \pi^+ \pi^- K^+$	$21.3 \mu b$	[3]	5.5	3.19	79
6	$p \Lambda 2\pi^+ \pi^- \pi^0 K^0$	$34.0 \mu b$	[3]	10	4.10	81
7	$p \Lambda 2\pi^+ \pi^- K^0$	$6.2 \mu b$	[3]	6.92	3.65	82
8	$n \Lambda 2\pi^+ \pi^- K^+$	$10.1 \mu b$	[3]	6.92	3.64	87
9	$n \Lambda 3\pi^+ \pi^- K^0$	$13.0 \mu b$	[3]	10	4.12	89
total:		$98 \mu b$				

Cascade – Σ with π

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Σ^0 production associated with π^- (BR: $\Sigma^0 \rightarrow \Lambda^0 \approx 100\%$, BR: $K_s^0 \rightarrow \pi^+ \pi^- = 69.20\%$)

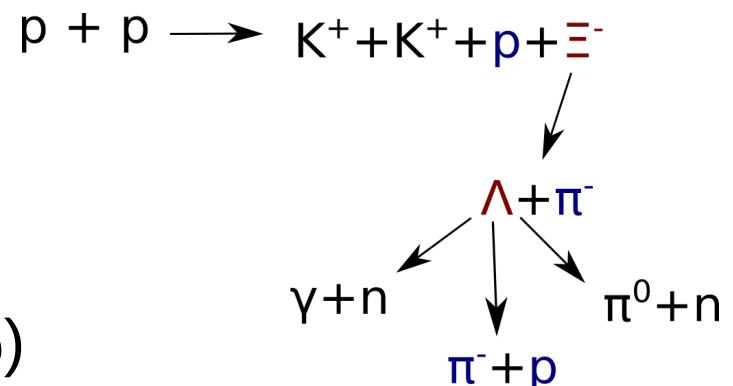
no	reaction	cross-section	source	p[GeV/c]	p_{thr} [GeV/c]	L-B No.
1	$p \Sigma K^0 \pi^+$	$18\mu b$	[3]	5.4	2.998	107
2	$p \Sigma \pi^+ \pi^- K^+$	$13.7\mu b$	[3]	6.92	3.43	106
3	$n \Sigma K^0 2\pi^+$	$6.6\mu b$	ratio between b.1 and b.3 reaction			
	total:	$18\mu b$				

1	p $\Lambda K^0 \pi^+$	60 μb	[3]	5.4	2.766	80
2	p $\Lambda K^0 \pi^+ \pi^0$	17 μb	[3]	5.5	3.182	78
3	n $\Lambda K^0 2\pi^+$	29.6 μb	[3]	6.920	3.204	88

Cascade – K^0 production

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$$p + p \longrightarrow p + p + K^0 + K^0 \quad (K^0 \rightarrow K_s^0 = 50\%) \\ (K_s^0 \rightarrow \pi^+ \pi^- = 69\%)$$



K^0 production (BR: $K_s^0 \rightarrow \pi^+ \pi^- = 69.20\%$)

no	reaction	cross-section	source	p[GeV/c]	p_{thr} [GeV/c]	L-B No.
1	$\Sigma^+ p \pi^+ \pi^- K^0$	$10.5 \mu b$	[3]	6.92	3.43	96
2	$n p \pi^+ \pi^- K^0 K^+$	$5.4 \mu b$	[3]	6.92	4.24	125
3	$n p 2 \pi^+ \pi^- 2 K^0$	$36.0 \mu b$	[3]	10	4.75	128
4	$2 p 2 \pi^+ \pi^- 2 K^0$	$6.3 \mu b$	[3]	7.87	4.25	175
5	$2 p \pi^- K^0 K^+$	$16 \mu b$	[3]	6.92	3.77	195
6	$2 p 2 K^0$	$6.4 \mu b$	[3]	5.5	3.32	201
7	$n p \pi^+ 2 K^0$	$15.7 \mu b$	[3]	6.92	3.78	126
	total:	0				

List of all simulated channels

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Decay channel	Cross-section [μb]
p p $\pi^+ \pi^+ \pi^- \pi^-$	227
p $\Lambda K^0 \pi^+$	60
p $\Lambda K^+ \pi^+ \pi^-$	21,3
n $\Lambda K^0 \pi^+ \pi^+$	29,6
p p $K^0 K^0$	6.4
p $\Sigma^0 K^0 \pi^+$	18