$\Lambda\Lambda$ reconstruction from pp@ $\sqrt{s}$=3.46 GeV

Update for CS estimates and systematics

HADES Analysis Meeting, Darmstadt

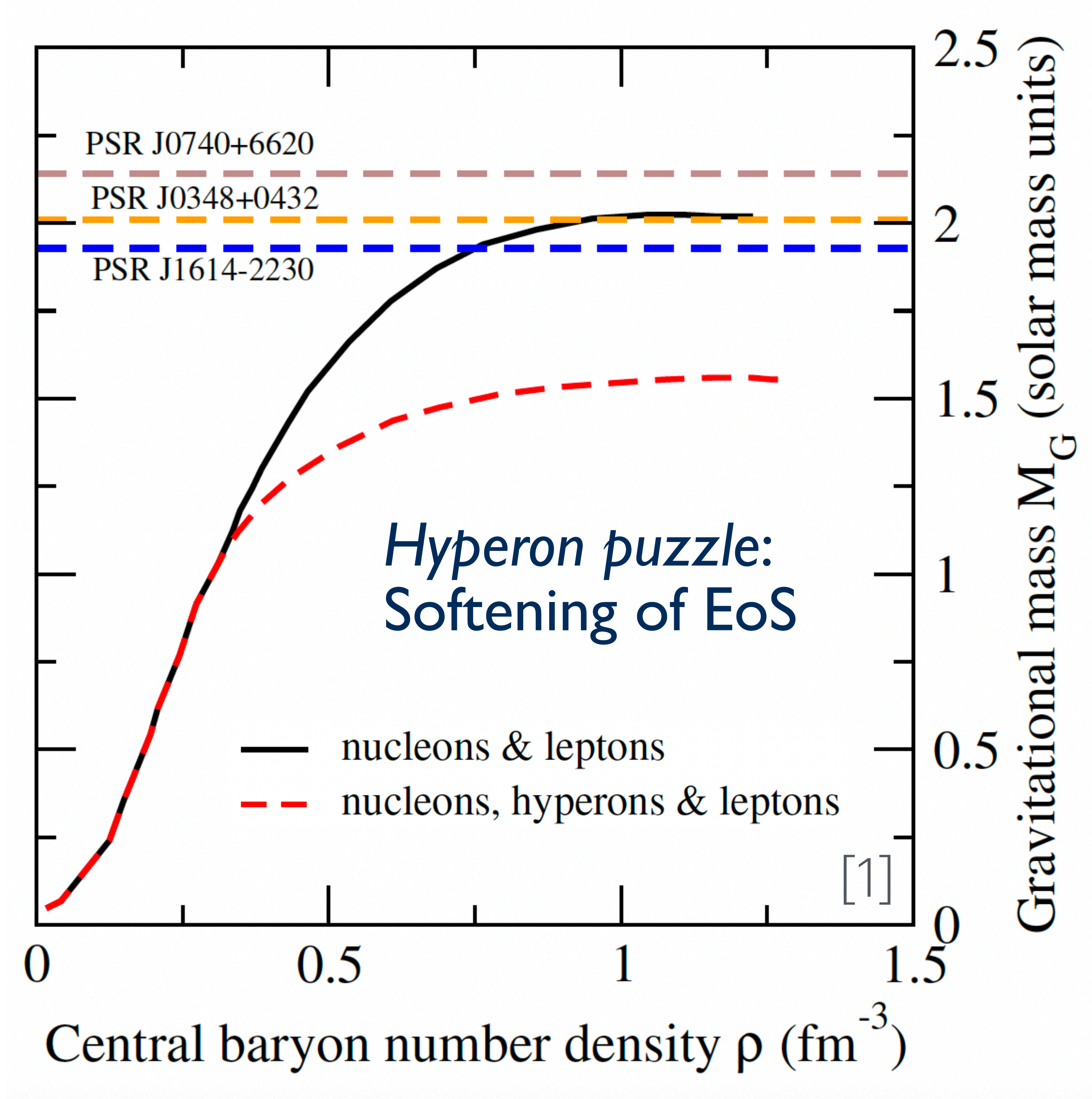
June 23, 2026

G. Appagere

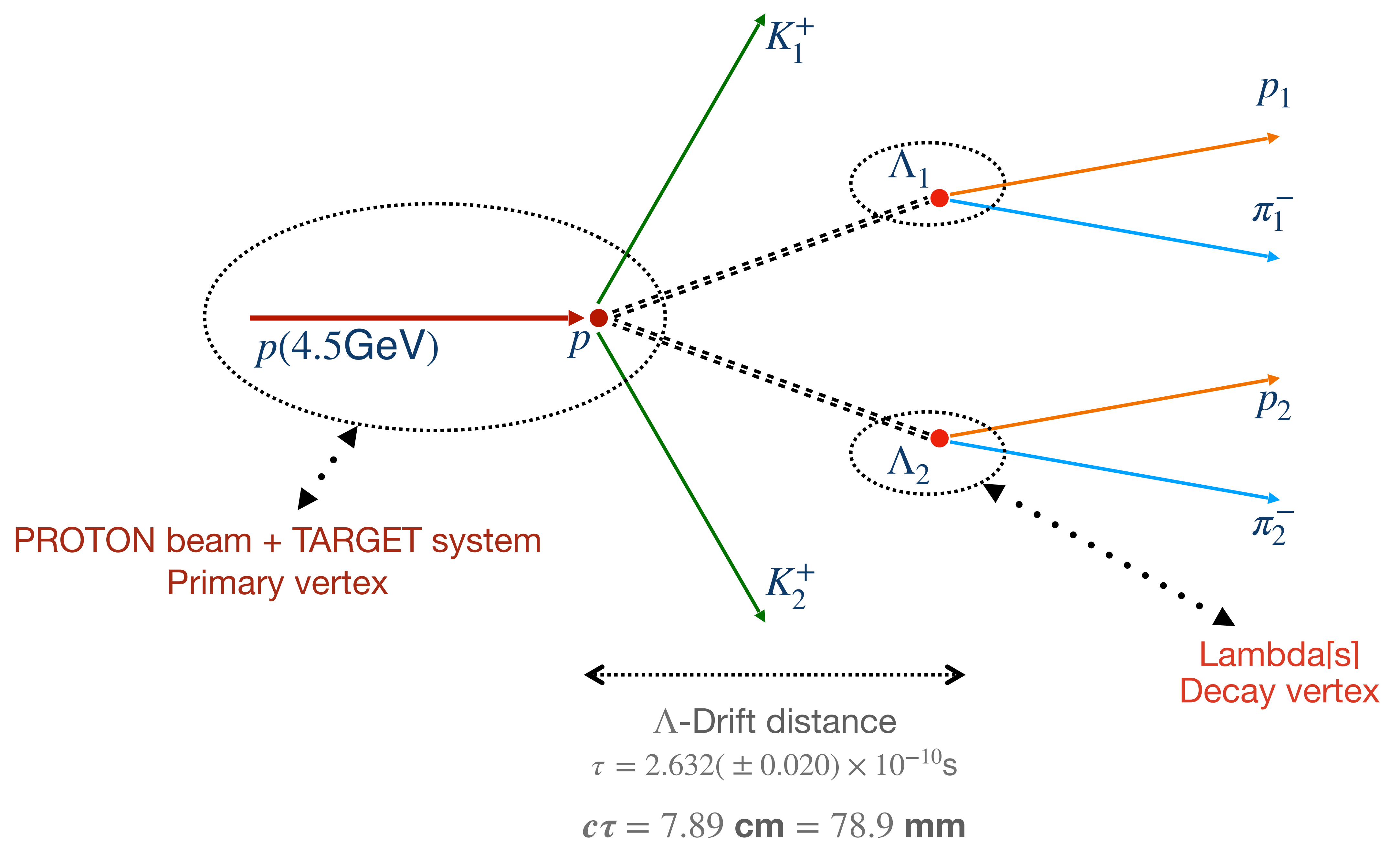
Outline

Motivation: Neutron stars and $\Lambda\Lambda$ studies

- Conditions (energy, pressure, temperature) inside *neutron stars* are favourable for *strangeness* production: *Hyperonization*



- Λ-Λ interaction studies at low rel. momentum *may* help solve the Hyperon puzzle



Event selection conditions

Inclusive : $p(4.5)p \mapsto p\pi^- p\pi^- + X$

Semi-exclusive : $p(4.5)p \mapsto p\pi^- p\pi^- + K^+ + X$

Exclusive : $p(4.5)p \mapsto p\pi^- p\pi^- + K^+K^+$

- Complex reaction topology with 6 final states with 2 displaced vertices
- p (4.5 GeV) $p \rightarrow \Lambda\Lambda + K^+K^+$ ($\sqrt{s_{pp}} = 3.46$ GeV) $\rightarrow$ Excess kinetic energy (T) of 0.24 GeV (CoM)

[1] Plot: I. Vidana, Generic model with and without hyperons

Analysis stages

Exp. duration: 28 days (Feb22)
Data size ≈ 155 Tb
DSTs = gen03
Luminosity: ≈ 5.66 ± 0.26 pb^{-1}

Broad Selections/Corrections

`kIsUsed` Flag
Beam tilt correction
Energy loss correction

S0 Particle Identification (PID) (MIN 4 Tracks)

- p, π^-, K^+, π^+ using relative-ToF method

S1 First-selection of the data

- Missing Mass selection with $pp \mapsto p\pi^- p\pi^- + X$: M_X > 0 MeV/c²
- To suppress Kapton Window tracks

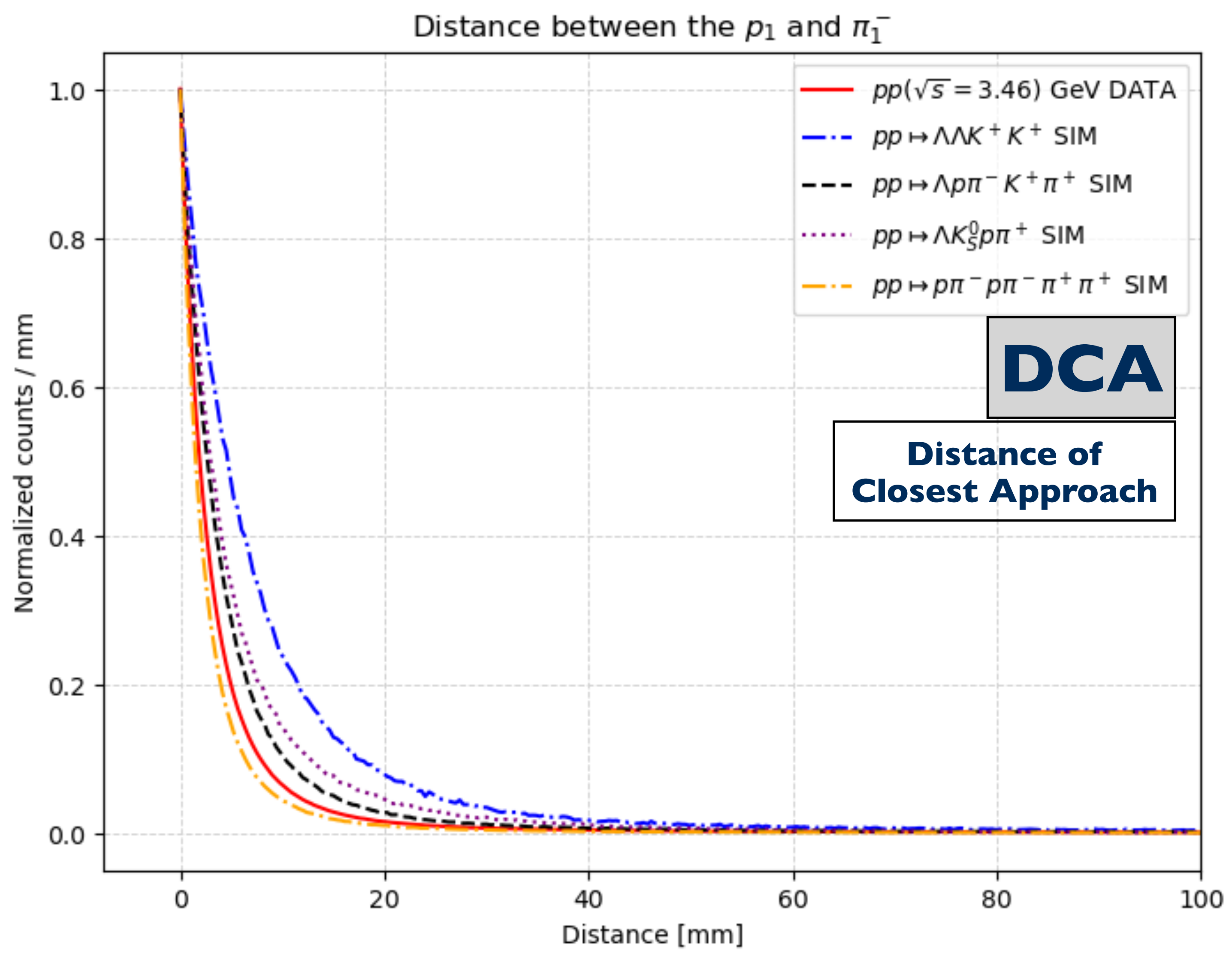
S2 Lambda reconstruction and selection

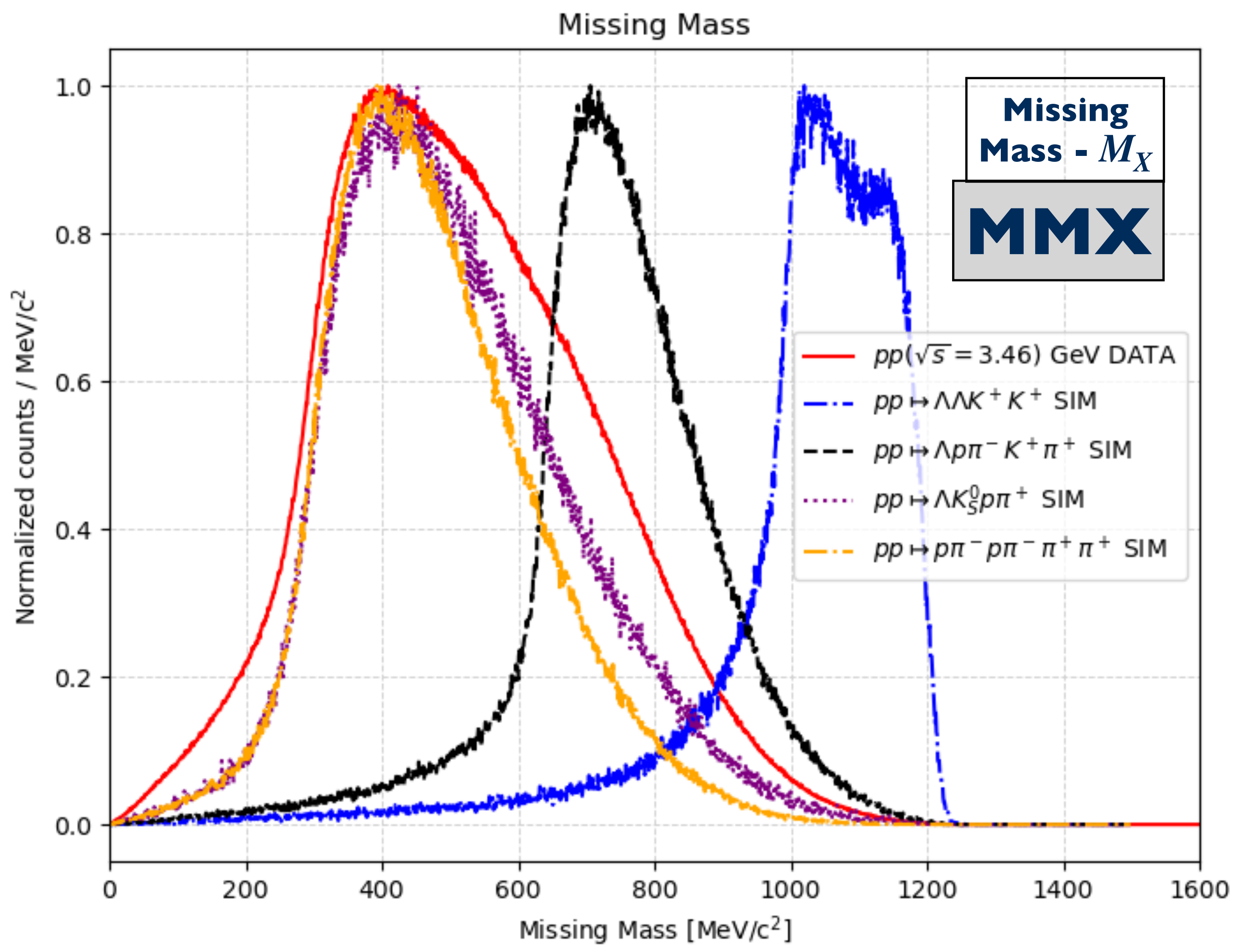
- $\Lambda\Lambda$ candidate selection with Physics cut-based
- Randomisation of Lambda candidate assignment as Λ_1 or Λ_2

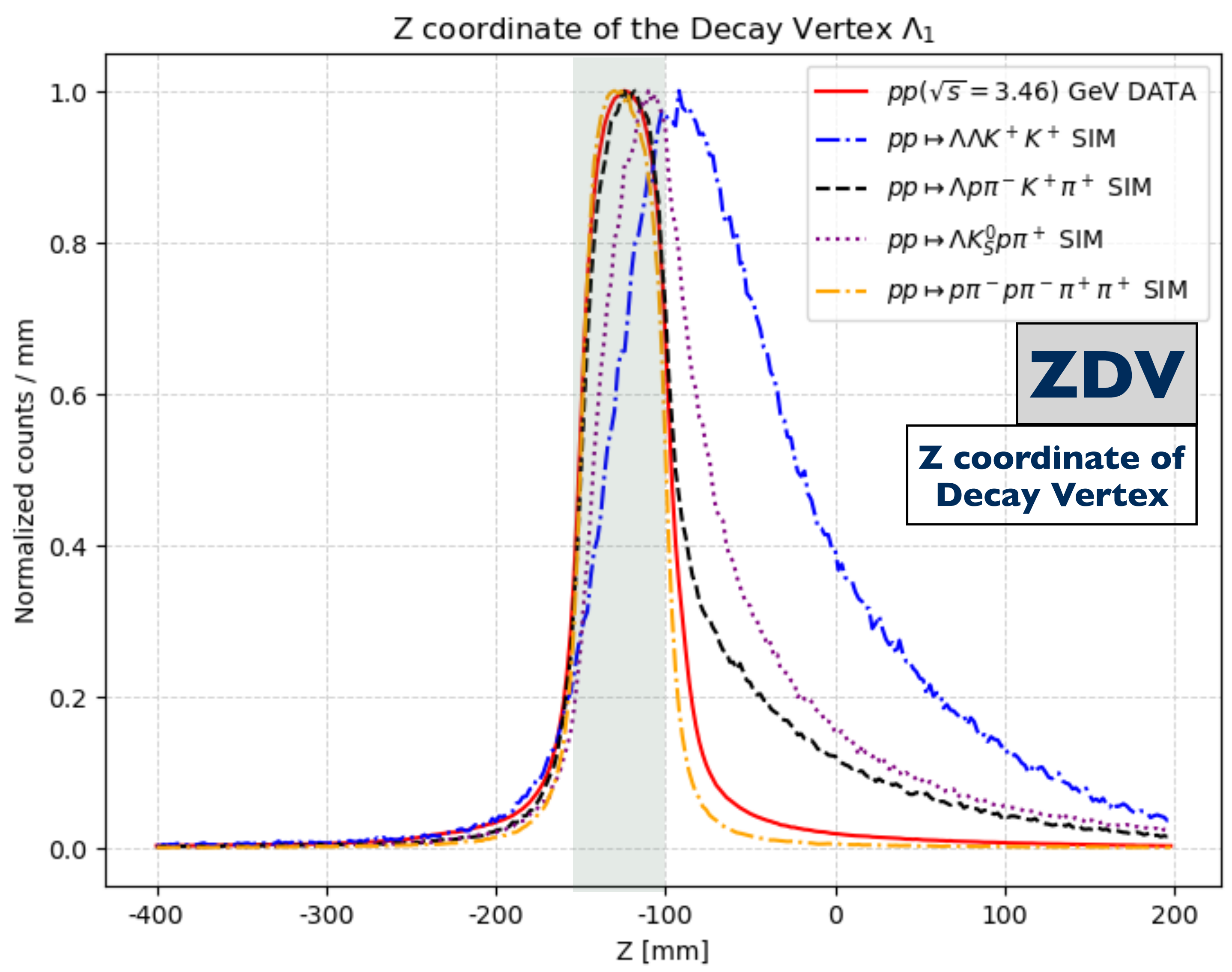
S3 Optimising the cuts to suppress background

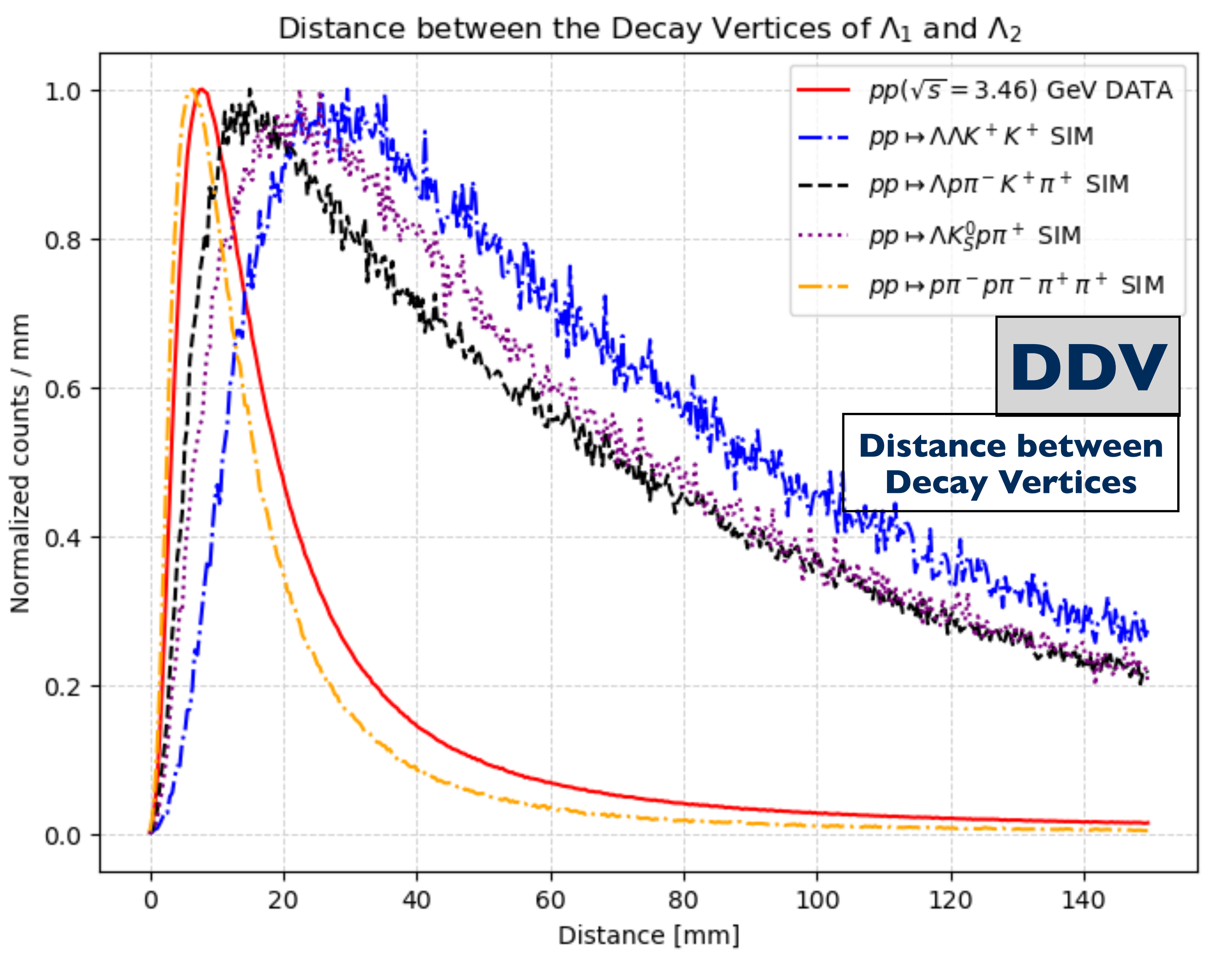
Details in the backup (S0–S2)

Stages-S3: Optimization









Physics channels

A. $pp \mapsto \Lambda[p\pi^-]\,\Lambda[p\pi^-] + X-; X \mapsto K^+, K^+$:

Λ-Λ Signal

SIG: $pp \mapsto \Lambda\Lambda K^+K^+$

B. $pp \mapsto \Lambda\, p\pi^- + X$:

Single-Λ + uncorrelated

OLBG: $pp \mapsto \Lambda p\pi^- K^+\pi^+$

KSBG: $pp \mapsto \Lambda K^0_S p\pi^+$

C. $pp \mapsto p\pi^- p\pi^- + X;\ X \mapsto \pi^+\pi^+$:

Pure non-resonant channel

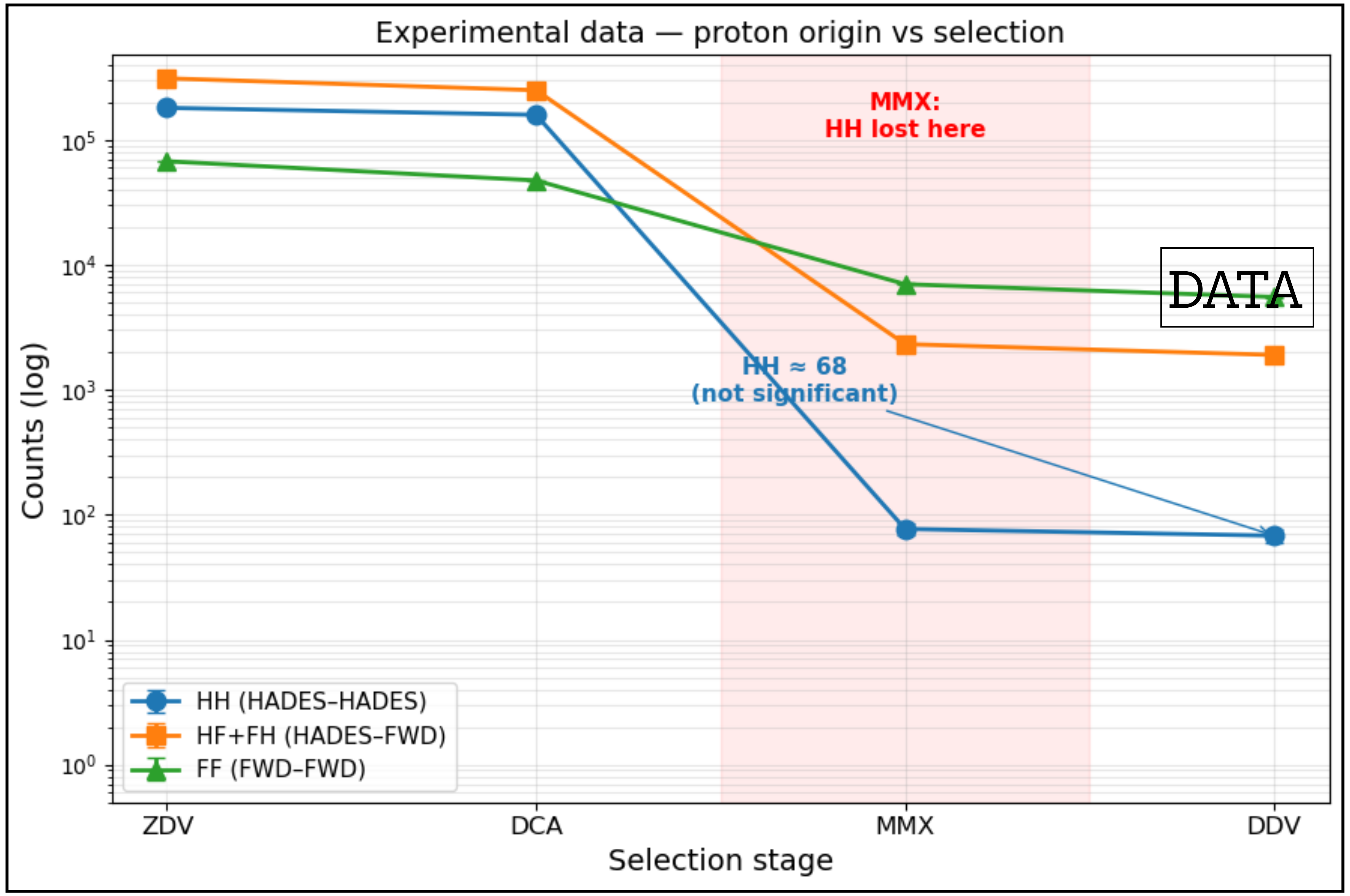
NRBG: $pp \mapsto p\pi^- p\pi^- \pi^+\pi^+$

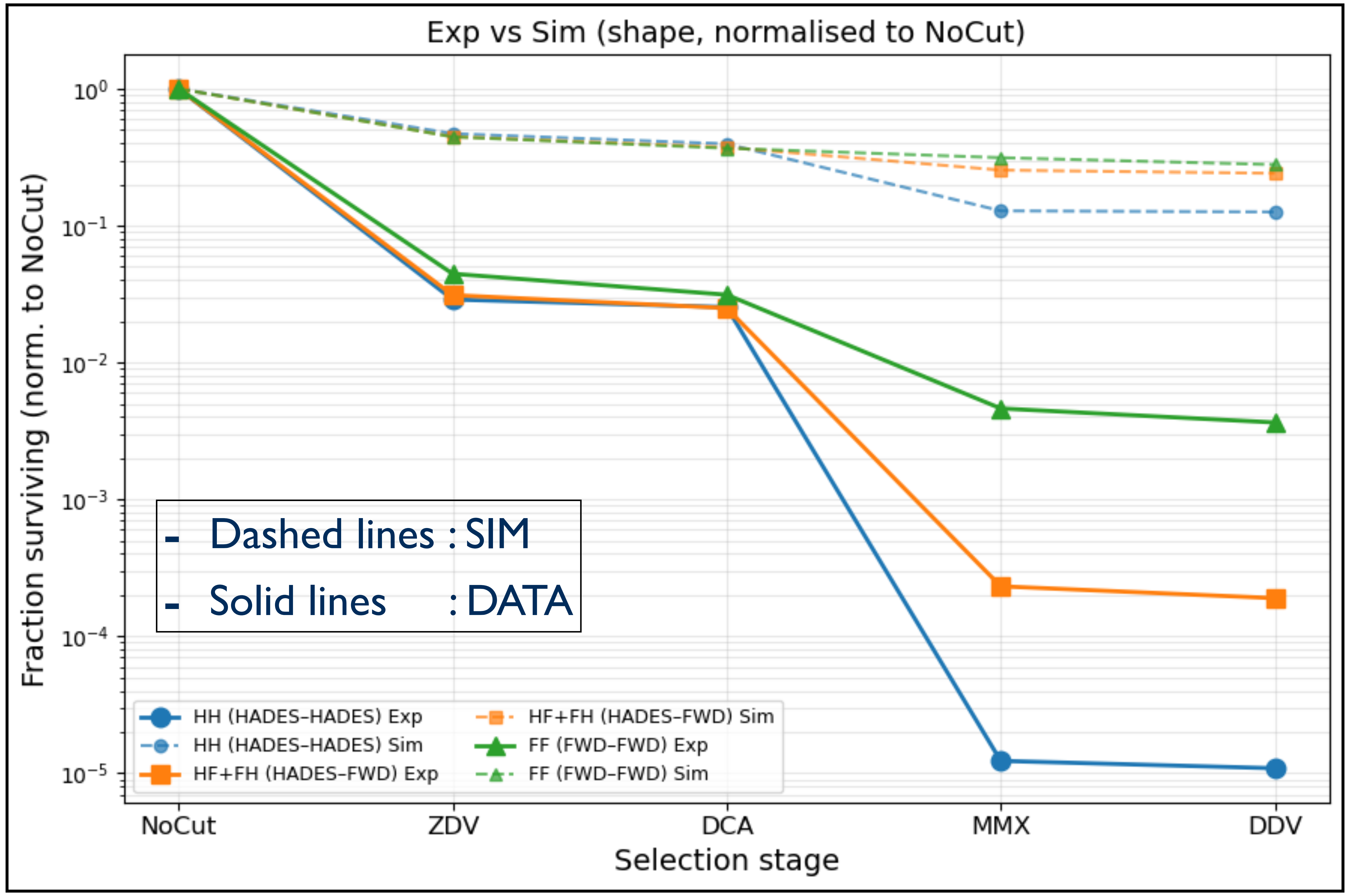
Pion Plus Veto (PPV), π^+ tracks as **VETO** to suppress BG channels

The PPV keeps most of the signal (97%) but rejects only part of the backgrounds

Proton Statistics

- HH: p of both Λ candidates are in HADES
- HF: p of at least one Λ candidate is in HADES
- FF: p of both Λ candidates are in FWD





- Missing Mass selection (MMX) is where we lose much of the HH events
- HH events aren't statistically significant enough to extract counts (on the order of 10 events)
- **Simulations show MMX selection is not removing Signal events**

Choosing a figure of merit (FOM)

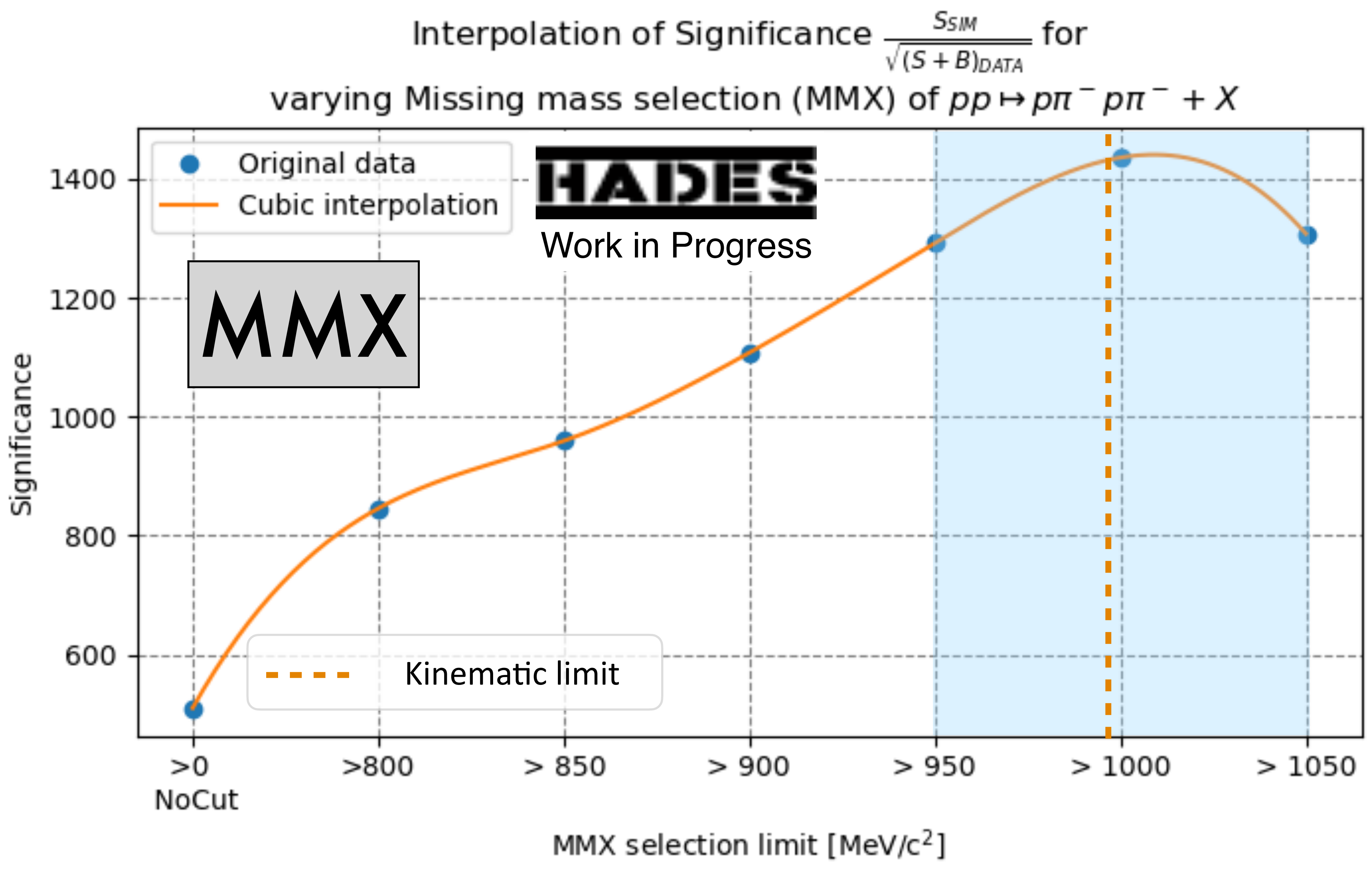
- We define a metric to optimize selections by maximizing statistical sensitivity
- We define the figure of merit (FOM) as the significance

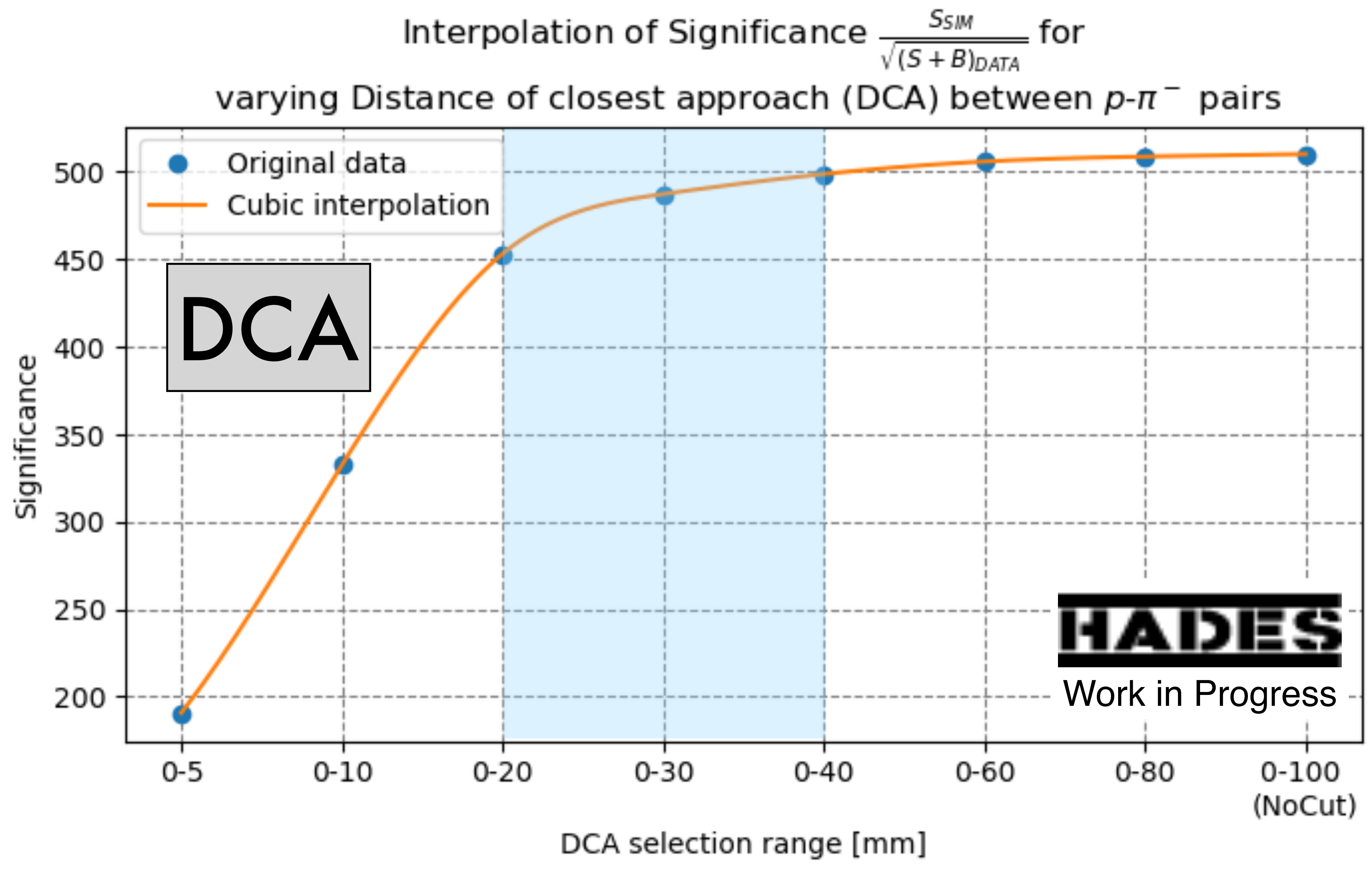
$$\text{FOM} = \frac{S_{\text{SIM}}}{\sqrt{(S+B)_{\text{DATA}}}}$$, where S_{SIM} is the simulated **signal** (LL) count

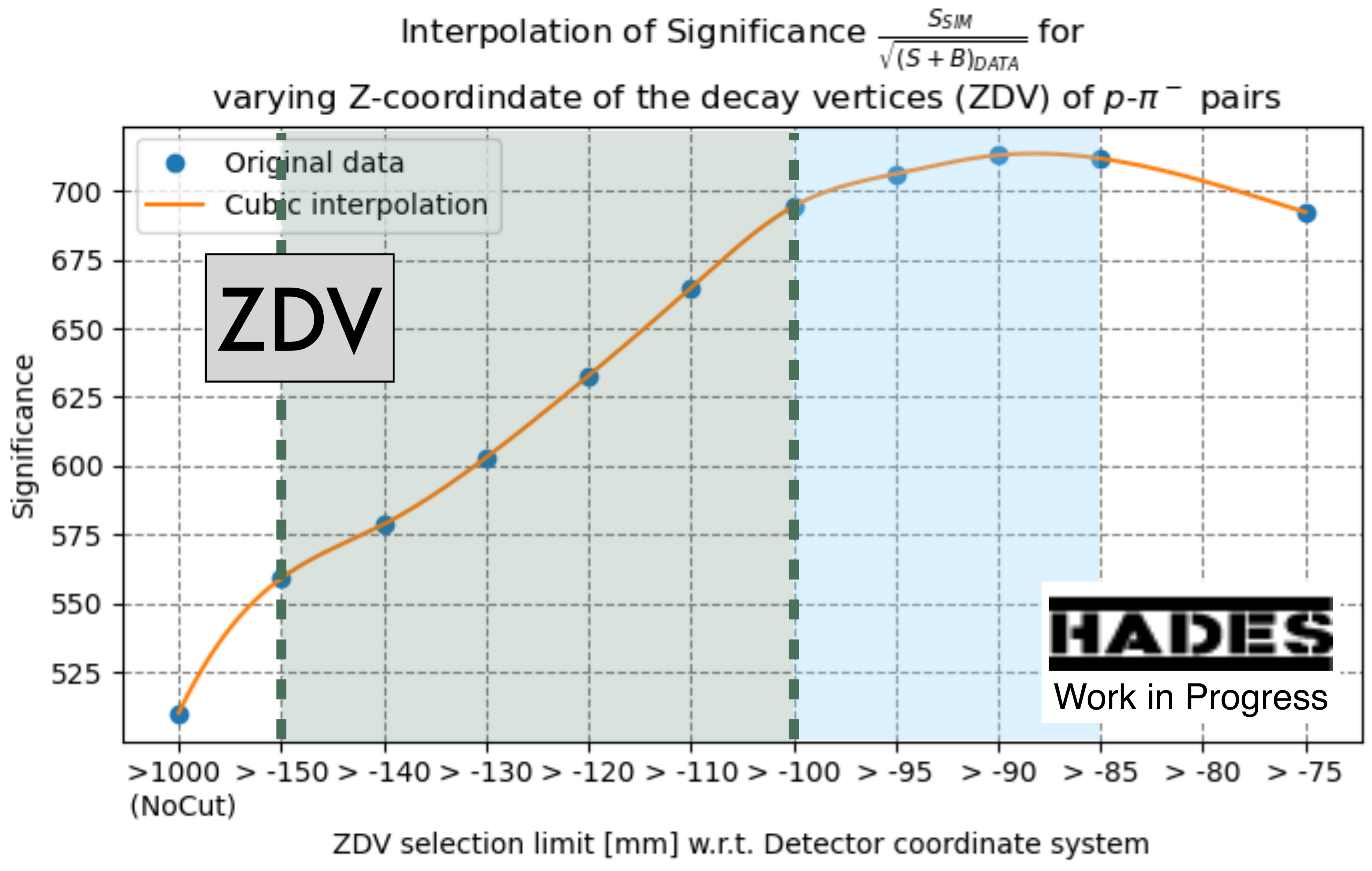
- The denominator quantifies the Poisson uncertainty of the **total** observed count $(S+B)_{\text{DATA}}$ in the data
- A larger ratio indicates better to resolve signal in the observed data

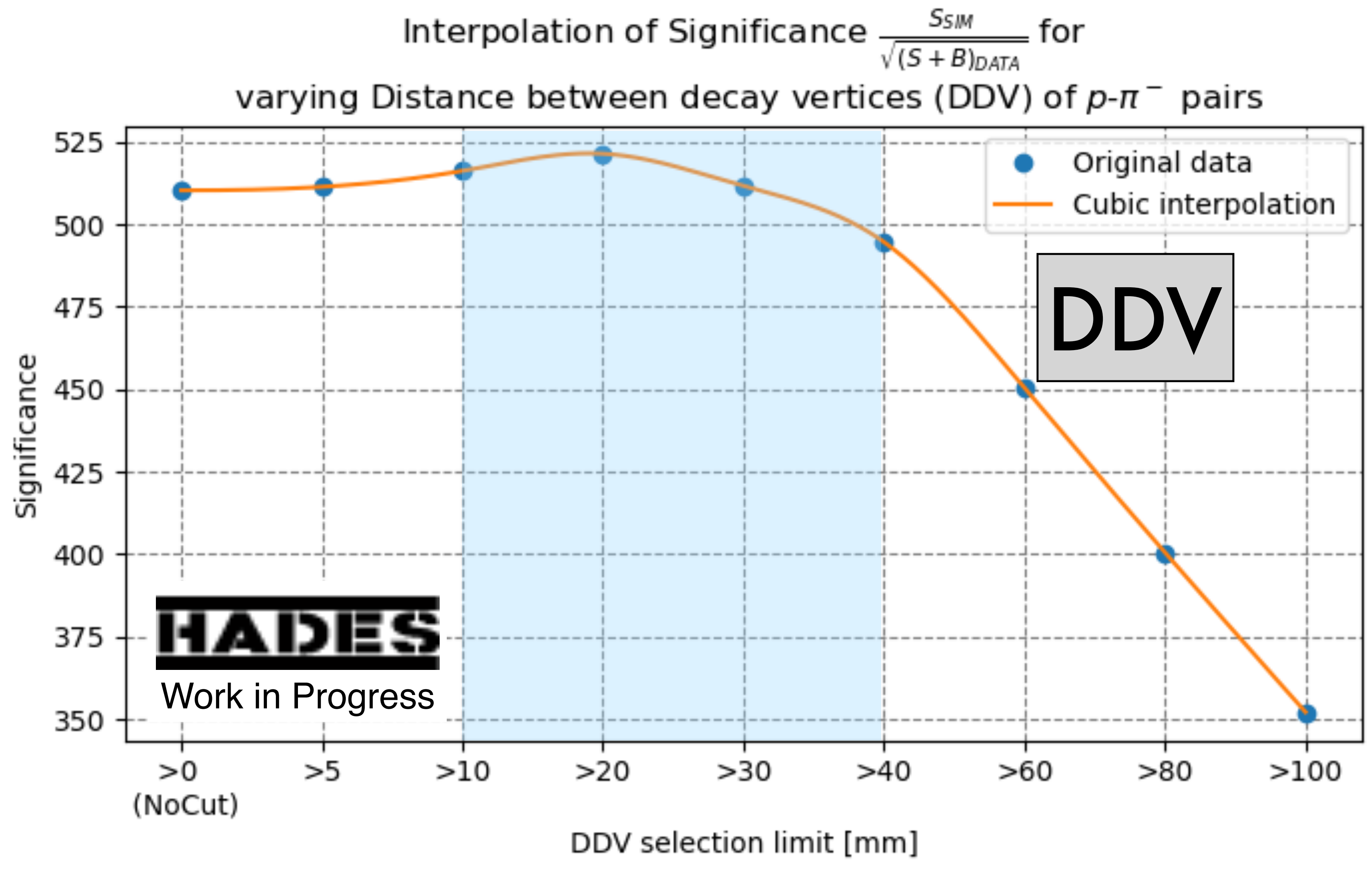
$$\text{Invariant mass range: } 1100\,\text{MeV}/c^2 \leq M_{\Lambda_1}, M_{\Lambda_2} \leq 1130\,\text{MeV}/c^2$$

Variation of FoM (cubic interpolation)





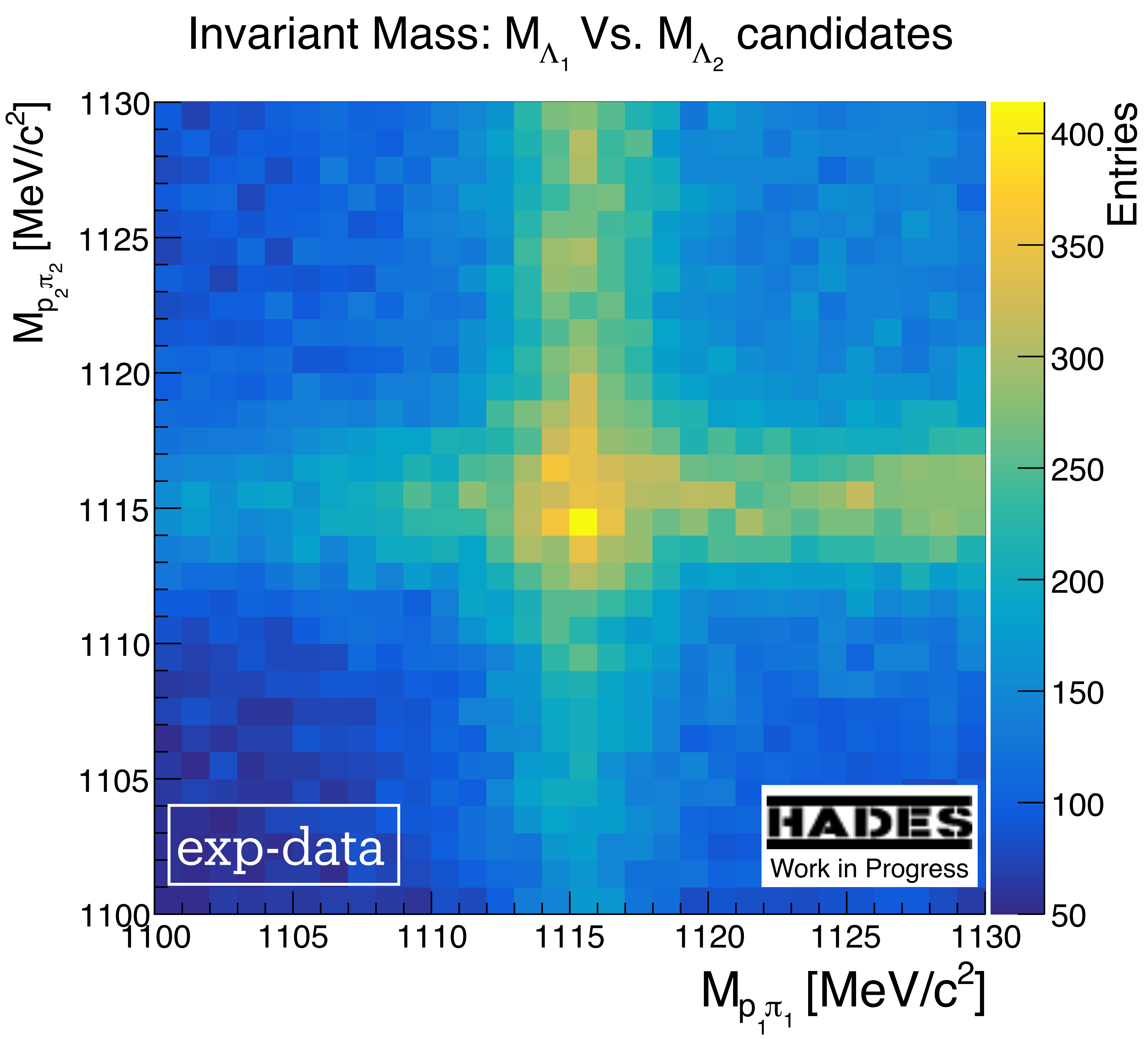




The table of FOM and Efficiency

					Data counts after IMX Cut	Simulations channel counts after IMX Cut: S_MC		FOM:	FOM *Efficiency	% Loss in due to the CUTs		Efficiency
MMCut (MeV/c^2)	DCA (mm) (<XX)	ZDV (mm) (>XX)	DDV (mm) (>XX)	PPV	Total Counts (S + B)	Signal: LL (100 M)	TRUE LL Counts	[S_MC/Sqrt(S + B)]		In DATA	In SIM	In SIM
>950	40	-100	30	(==)0	1973	79565	62940	**1791,26**	**1,43**	98,57	57,95	0,080
>950	40	-95	10	(==)0	2186	88404	70198	**1890,81**	**1,67**	98,41	53,28	0,088
>950	40	-95	20	(==)0	1902	82376	65387	**1888,84**	**1,56**	98,62	56,46	0,082
>950	40	-95	30	(==)0	1650	73363	58165	**1806,07**	**1,32**	98,80	61,23	0,073
>950	40	-90	10	(==)0	1752	80809	64238	**1930,60**	**1,56**	98,73	57,29	0,081
>950	40	-90	20	(==)0	1573	75451	59955	**1902,39**	**1,44**	98,86	60,12	0,075
>950	40	-90	30	(==)0	1375	67239	53368	**1813,30**	**1,22**	99,00	64,46	0,067
>976	20	-100	10	(==)0	1700	79638	66182	**1931,51**	**1,54**	98,76	57,91	0,080
>976	20	-100	20	(==)0	1425	73795	61398	**1954,88**	**1,44**	98,96	61,00	0,074
>976	20	-100	30	(==)0	1190	65392	54497	**1895,62**	**1,24**	99,13	65,44	0,065
>976	20	-95	10	(==)0	1337	73251	61052	**2003,31**	**1,47**	99,03	61,28	0,073
>976	20	-95	20	(==)0	1151	67963	56711	**2003,25**	**1,36**	99,16	64,08	0,068
>976	20	-95	30	(==)0	979	60216	50321	**1924,51**	**1,16**	99,29	68,17	0,060
>976	20	-90	10	(==)0	1077	66862	55829	**2037,38**	**1,36**	99,22	64,66	0,067
>976	20	-90	20	(==)0	931	62170	51973	**2037,54**	**1,27**	99,32	67,14	0,062
>976	20	-90	30	(==)0	797	55101	46133	**1951,78**	**1,08**	99,42	70,88	0,055
>976	30	-100	10	(==)0	2017	89555	72909	**1994,05**	**1,79**	98,53	52,67	0,090
>976	30	-100	20	(==)0	1710	83187	67747	**2011,67**	**1,67**	98,76	56,03	0,083
>976	30	-100	30	(==)0	1447	73900	60211	**1942,72**	**1,44**	98,95	60,94	0,074
>976	30	-95	10	(==)0	1609	82400	67265	**2054,23**	**1,69**	98,83	56,45	0,082
>976	30	-95	20	(==)0	1395	76628	62578	**2051,64**	**1,57**	98,99	59,50	0,077
>976	30	-95	30	(==)0	1202	68083	55606	**1963,75**	**1,34**	99,13	64,02	0,068
>976	30	-90	10	(==)0	1322	75277	61528	**2070,36**	**1,56**	99,04	60,21	0,075
>976	30	-90	20	(==)0	1150	70145	57356	**2068,46**	**1,45**	99,16	62,93	0,070
>976	30	-90	30	(==)0	997	62356	50999	**1974,83**	**1,23**	99,28	67,04	0,062
>976	40	-100	10	(==)0	2213	93350	74957	**1984,37**	1,85	98,39	50,66	0,093
>976	40	-100	20	(==)0	1890	86839	69711	**1997,49**	**1,73**	98,63	54,10	0,087
>976	40	-100	30	(==)0	1609	77285	62005	**1926,71**	**1,49**	98,83	59,15	0,077
>976	40	-95	10	(==)0	1785	85951	69178	**2034,38**	**1,75**	98,70	54,57	0,086
>976	40	-95	20	(==)0	1556	80045	64413	**2029,22**	**1,62**	98,87	57,69	0,080
>976	40	-95	30	(==)0	1347	71253	57284	**1941,42**	**1,38**	99,02	62,34	0,071

Λ-Λ Signal Estimate from the Data



Physics channels

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Λ-Λ Signal

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C. $pp \mapsto p\pi^- p\pi^- + X;\ X \mapsto \pi^+\pi^+$:

Pure non-resonant channel

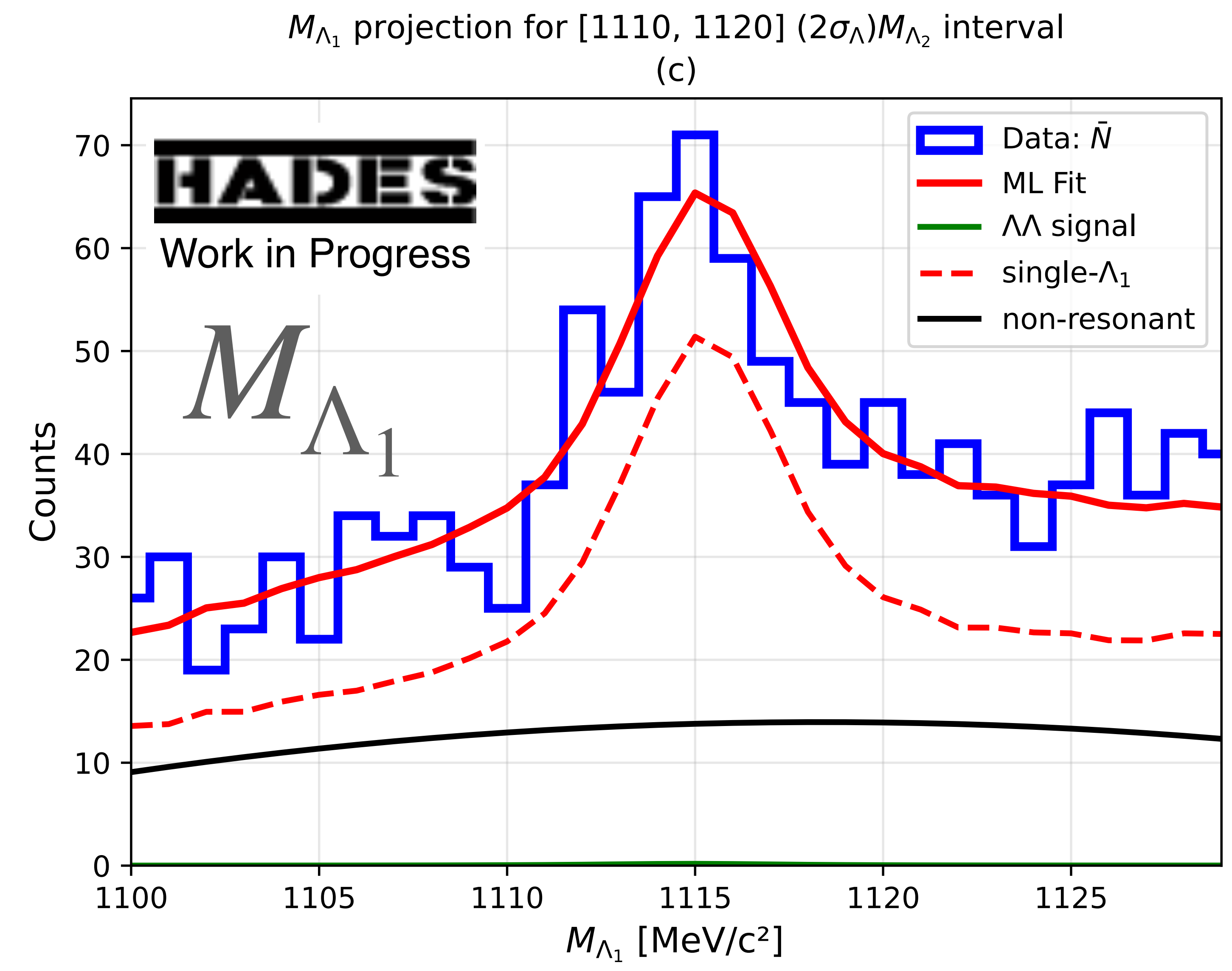
NRBG: $pp \mapsto p\pi^- p\pi^- \pi^+\pi^+$

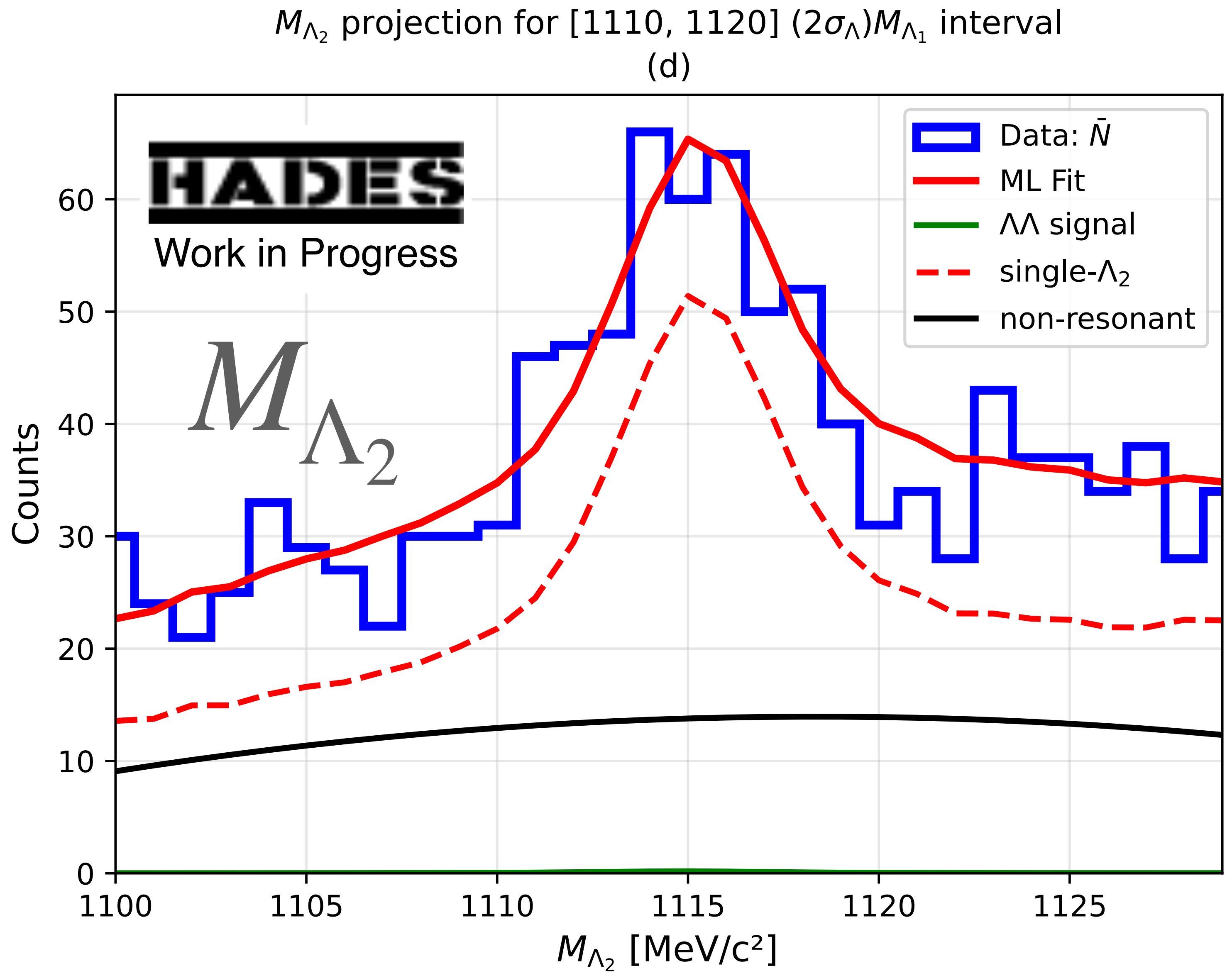
Maximum Likelihood Fit Model

$$\text{model} = \boldsymbol{A}\cdot \text{LL}_{SIM} + \boldsymbol{B_0}\cdot \text{OLBG}_{SIM} + \boldsymbol{B_1}\cdot \text{KSBG}_{SIM} + \text{NRBG}$$

$$\text{NRBG} = \boldsymbol{C_0} + \boldsymbol{C_1}\cdot(M_{\Lambda_1} + M_{\Lambda_2}) + \boldsymbol{C_2}\cdot(M^2_{\Lambda_1} + M^2_{\Lambda_2}) + \boldsymbol{C_3}\cdot(M_{\Lambda_1}\cdot M_{\Lambda_2})$$

Λ-Λ Cross-Section Estimation





MMX = 976 MeV/c^2, ZDV = -100 mm, DDV = 10 mm, DCA = 40 mm

ML Fit of the optimal selected data

NDF = 894, NLN = 988.08

A ($N_{\Lambda\Lambda}$)	B = ($B0 + B1$)	C0	C1	C2	C3
2 ± 60	1256 ± 108	1139 ± 151	80 ± 33	-177 ± 85	66 ± 25

$$\sigma_{\Lambda\Lambda} = \frac{N_{\Lambda\Lambda}}{L \cdot \epsilon_{AR}}$$

L = 5.66 ± 0.26 pb^{-1}

ϵ_{AR} = 0.093%

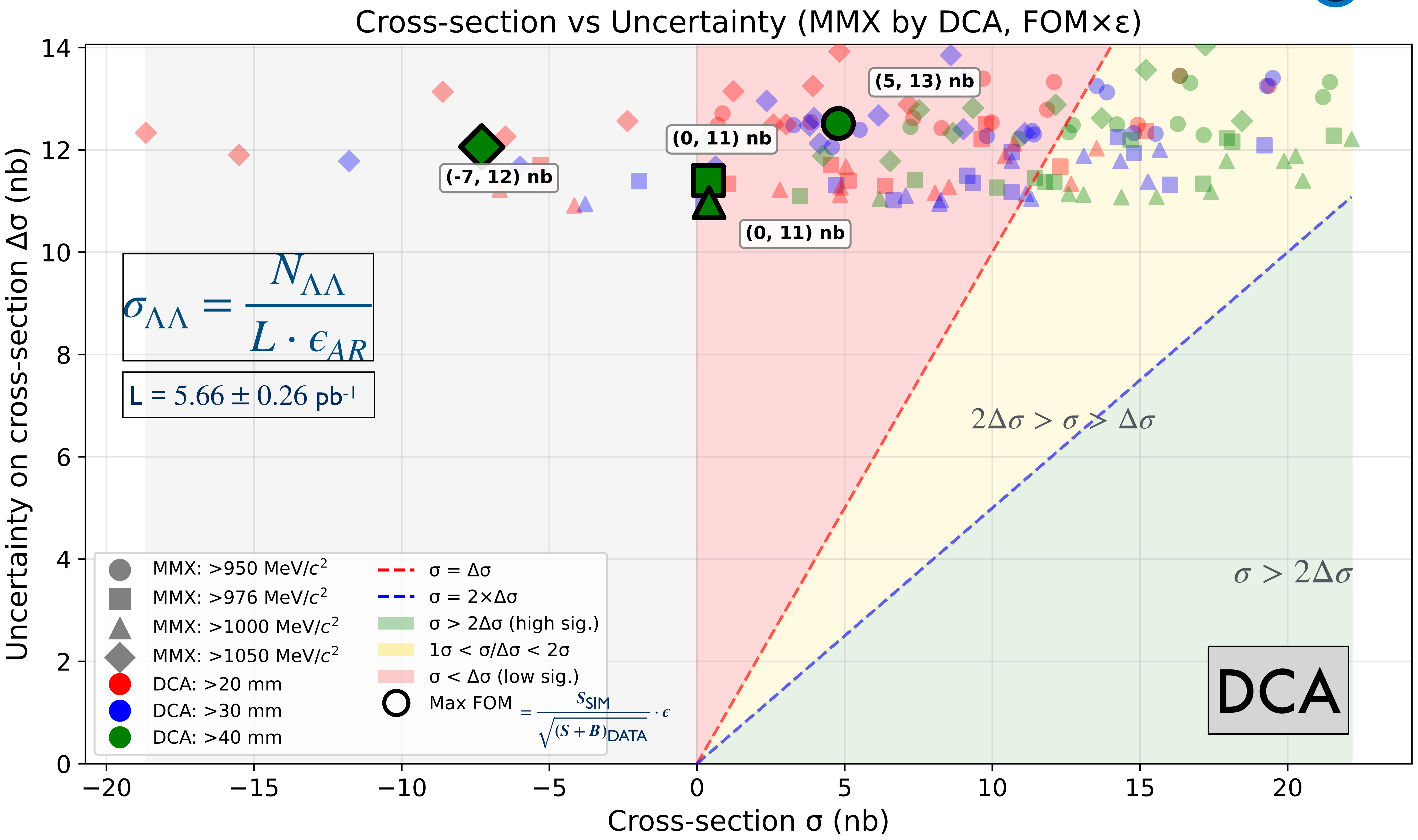
- Upper limit for the Λ-Λ cross-section is estimated at 95% confidence level : **19 nb**

- The cross-section for $pp \mapsto \Xi^- K^+ K^+ p$ was measured to be 7 ± 5 μb at $\sqrt{s_{pp}}$ = 4.54 GeV [Holmgren et. al, 1967] and is extrapolated to be 350 ± 230 nb at $\sqrt{s_{pp}}$ = 3.46 GeV. [1]

[1] Production and electromagnetic decay of hyperons: a feasibility study with HADES as a phase-0 experiment at FAIR

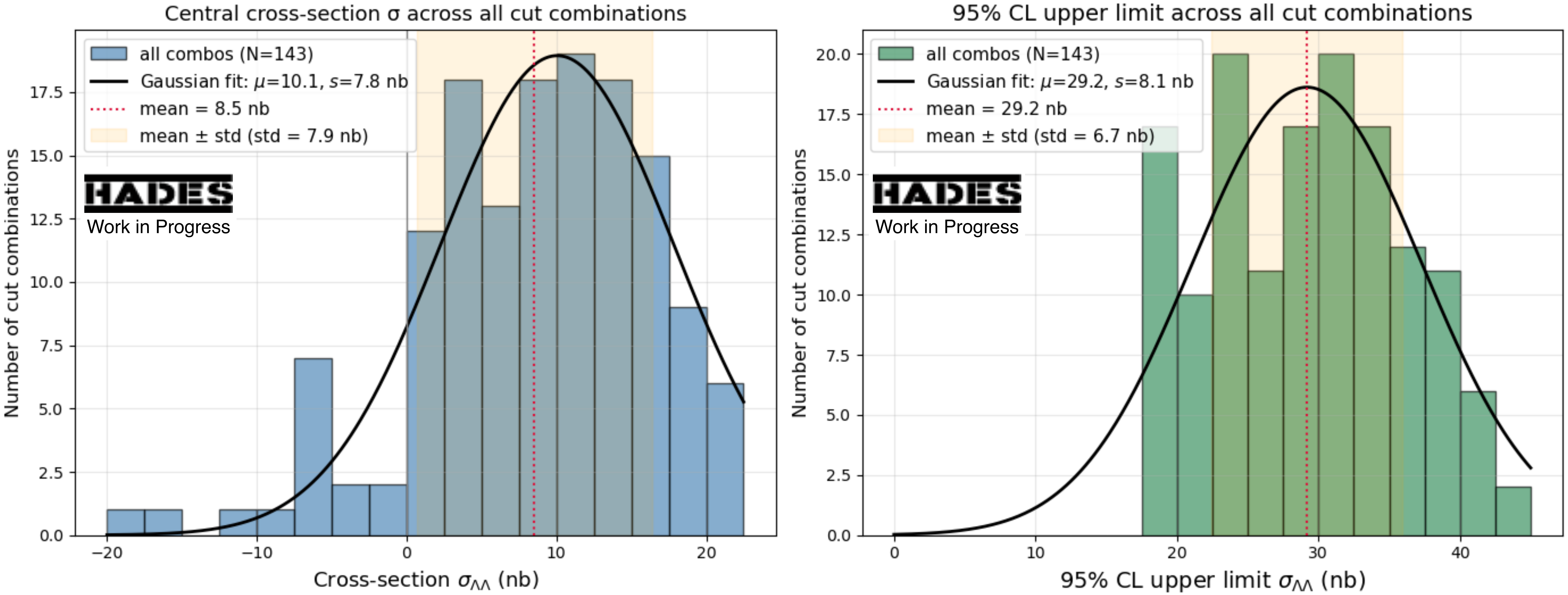
SYSTEMATICS

CS variation in the parameter space



- The MMX selection parameter is shown in shapes while the selection in the parameter DCA values are indicated with colours.
- The circled BOLD markers indicate the selection combination for which the FOM has a maximum for each MMX.
- **Results show that no selection parameters indicate >2 st. dev**

Systematic Uncertainty



- The luminosity enters the cross-section purely as a global normalisation: $\frac{\Delta\sigma_L}{\sigma} = \frac{\Delta L}{L} = \frac{0.26}{5.66} \approx 4.6\,\%$
- Systematics: cut variation +/-7 nb (dominant) and luminosity +/-0.9 nb (4.6%), added in quadrature $\mapsto$ **+/-7 nb**

Result: $\sigma_{\Lambda\Lambda}$(95% Confidence level, Upper limit) = $\mathbf{19 \pm 7}$(sys) **nb**; (Based on the Optimal selection)
Luminosity is a fully-correlated normalisation, quoted separately from the cut systematic

SINGLE-Λ CS

Single-Λ Cross-section

Goal: To independently validate the ML Fit model with the similar selection as that of $\Lambda\Lambda$

- **Strategy**: Make two exclusive missing mass selections in the $pp \mapsto \Lambda[p\pi^-]\Lambda[p\pi^-] + X$ (DATA)
- MMX $\in (600, \infty)$ MeV$/c^2$ makes **OLBG** (ΛK^+) significant. $m_{K^+} + m_{\pi^+} = 633.2$ MeV$/c^2$
- MMX $\in (280, 600)$ MeV$/c^2$ expected to contain only **KSBG** (ΛK^0_S) reactions, $2\,m_{\pi^\pm} = 279.1 \approx 280$ MeV$/c^2$
- Both windows may also contain other same-final-state channels (primarily Σ^0 production)

OLBG: $pp \mapsto p\pi^- p\pi^- + \mathrm{X}, \mathrm{X} = K^+\pi^+$

KSBG: $pp \mapsto p\pi^- p\pi^- + \mathrm{X}, \mathrm{X} = \pi^+\pi^-$

Key assumption: Identical final state $(2p, 2\pi^-)$ $\Rightarrow$ same selection as $\Lambda\Lambda \Rightarrow$ we assume the same efficiency for all these similar channels (including Σ^0)

The two MM cuts simply select / deselect KSBG vs OLBG

Single-Λ Cross-section

$$\text{Model} \; = A \cdot LL + B \; + \left(C_0 + C_1(M_1 + M_2) + C_2(M_1^2 + M_2^2) + C_3 M_1 M_2\right)$$

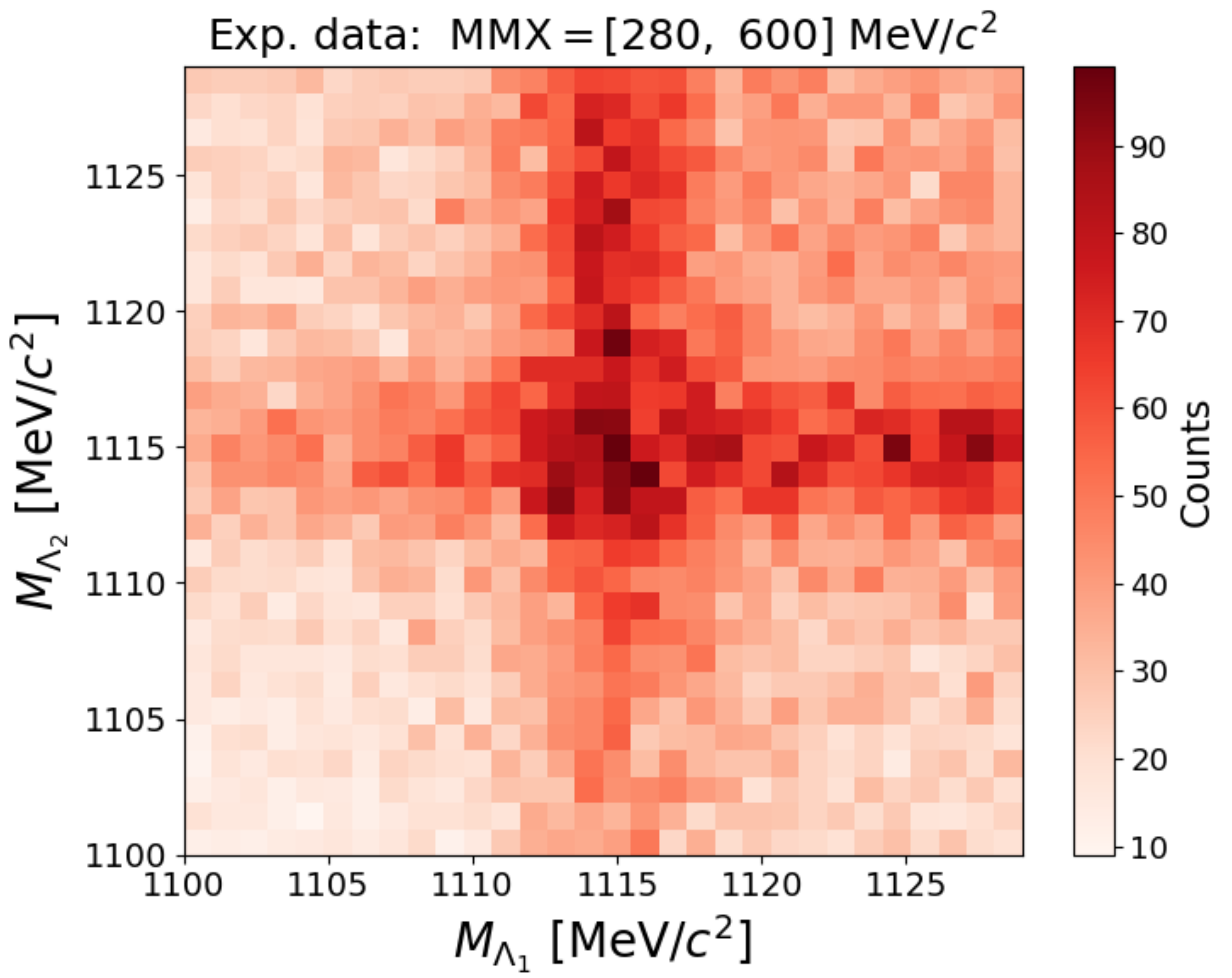
- Fit B and C and keep $A = 0.$
- Solve for the contribution of the two channels: $\boldsymbol{a}$ (KSBG) and $\boldsymbol{b}$ (OLBG). N is the simulated number of events corresponding to the two channels for the two missing mass selections (for 10^8 events).

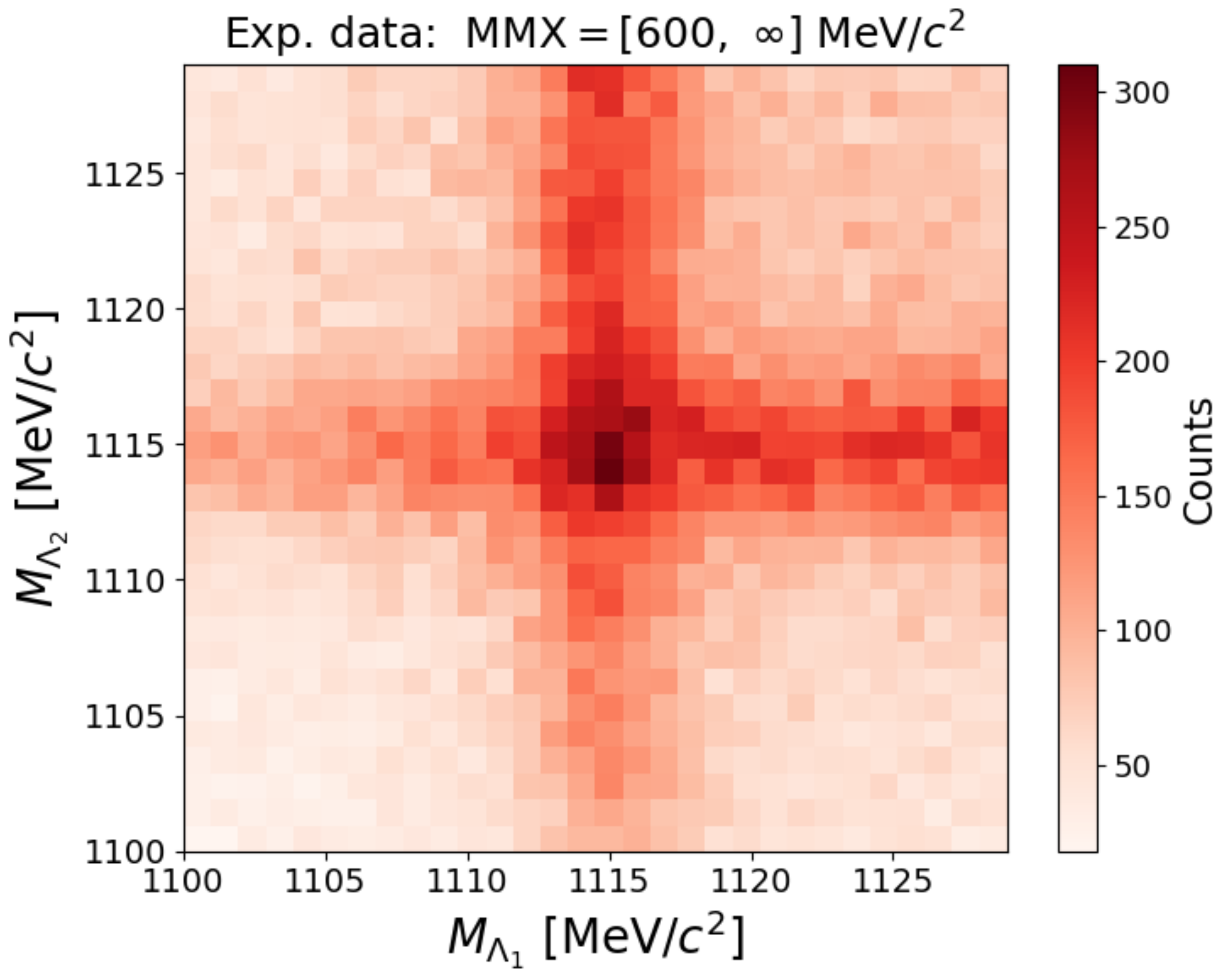
$$\begin{pmatrix} N_{280\text{-}600}^{KSBG} & N_{280\text{-}600}^{OLBG} \\ N_{600\text{-}\infty}^{KSBG} & N_{600\text{-}\infty}^{OLBG} \end{pmatrix} \begin{pmatrix} a \\ b \end{pmatrix} = \begin{pmatrix} B_{280\text{-}600} \\ B_{600\text{-}\infty} \end{pmatrix}$$

- Cross-section: $\sigma_{\text{KSBG}} = \dfrac{\boldsymbol{a}\, N_{\text{sim}}^{\text{gen}}}{L_{\text{int}}}, \qquad N_{\text{sim}}^{\text{gen}} = 10^8, \;\; L_{\text{int}} = 5.66 \text{ pb}^{-1}$
- Errors in B are propagated through the inverse system: $\text{Cov}(a,b) = A^{-1}\,\text{Cov}(B)\,(A^{-1})^{\text{T}}$

Channel		Estimated Cross-section: $\sigma_{\Lambda x}$ (ub)	Extrapolated CS (Phase0 Paper): $\sigma_{(\Lambda+\Sigma)x}$ (ub)
OLBG	$pp \mapsto \Lambda p \pi^- K^+ \pi^+$	13 ± 0.3	21+2
KSBG	$pp \mapsto \Lambda K_S^0 p \pi^+$	14 ± 0.5	30+9

The estimated $\sigma_{\Lambda X}$ sit just below the $(\Lambda + \Sigma)$X predictions:
Yet same order of magnitude → model validated.





Summary and Outlook

- Systematic, FoM-based (significance) optimization of selections from signal simulation + experimental data
- ΛΛ signal extracted via a simulation-based 2D maximum-likelihood fit:
  model = A·LL + B·(OLBG+KSBG) + NRBG(poly)
- Updated σ_ΛΛ: 95% CL upper limit = **19 ± 7(sys) nb** at the optimal selection (MMX=976, DCA=40, ZDV=−100, DDV=10)
- Systematic uncertainty quantified: cut variation ±7 nb (dominant) ⊕ luminosity 4.6%
- Stable across the cut scan, no selection deviates by > 2Δσ; goodness-of-fit (NLN ≈ NDF) indicates good fit performance
- New: Independent single-Λ CS cross-check (KSBG, OLBG) via two exclusive MMX windows validates the ML-fit model: $\sigma_{\Lambda X}$ same order as the $\sigma_{(\Lambda+\Sigma)X}$ predictions

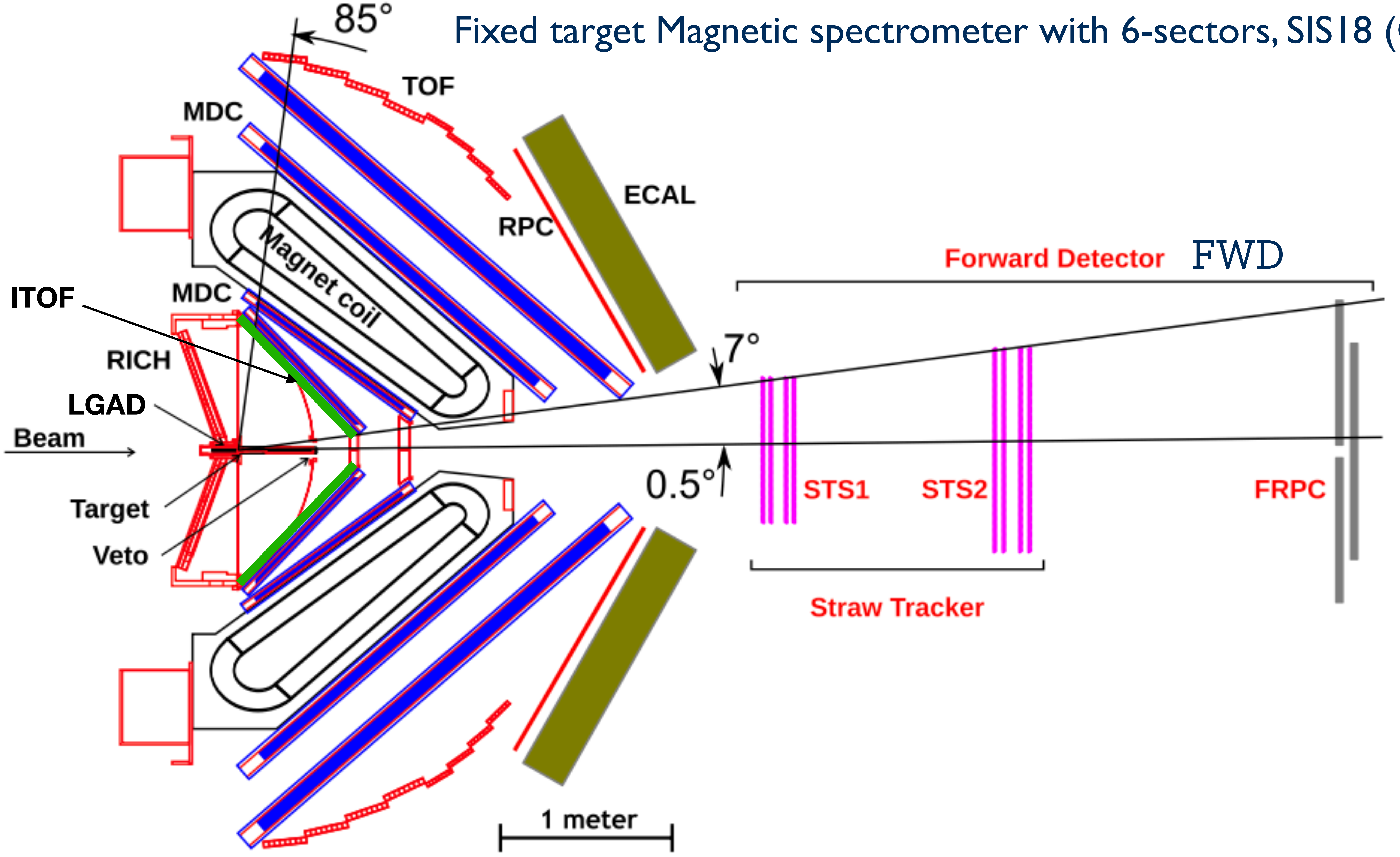
- $S1$ missing-mass systematics via the Empty-Target dataset, extrapolated to the full (with-target) sample and systematics from the **PID**
- Evaluate systematics separately for HH / HF / FF Λ-candidate topologies.
- **Analysis Note** with the detailed description of the methodology and tools deployed.

APPENDIX

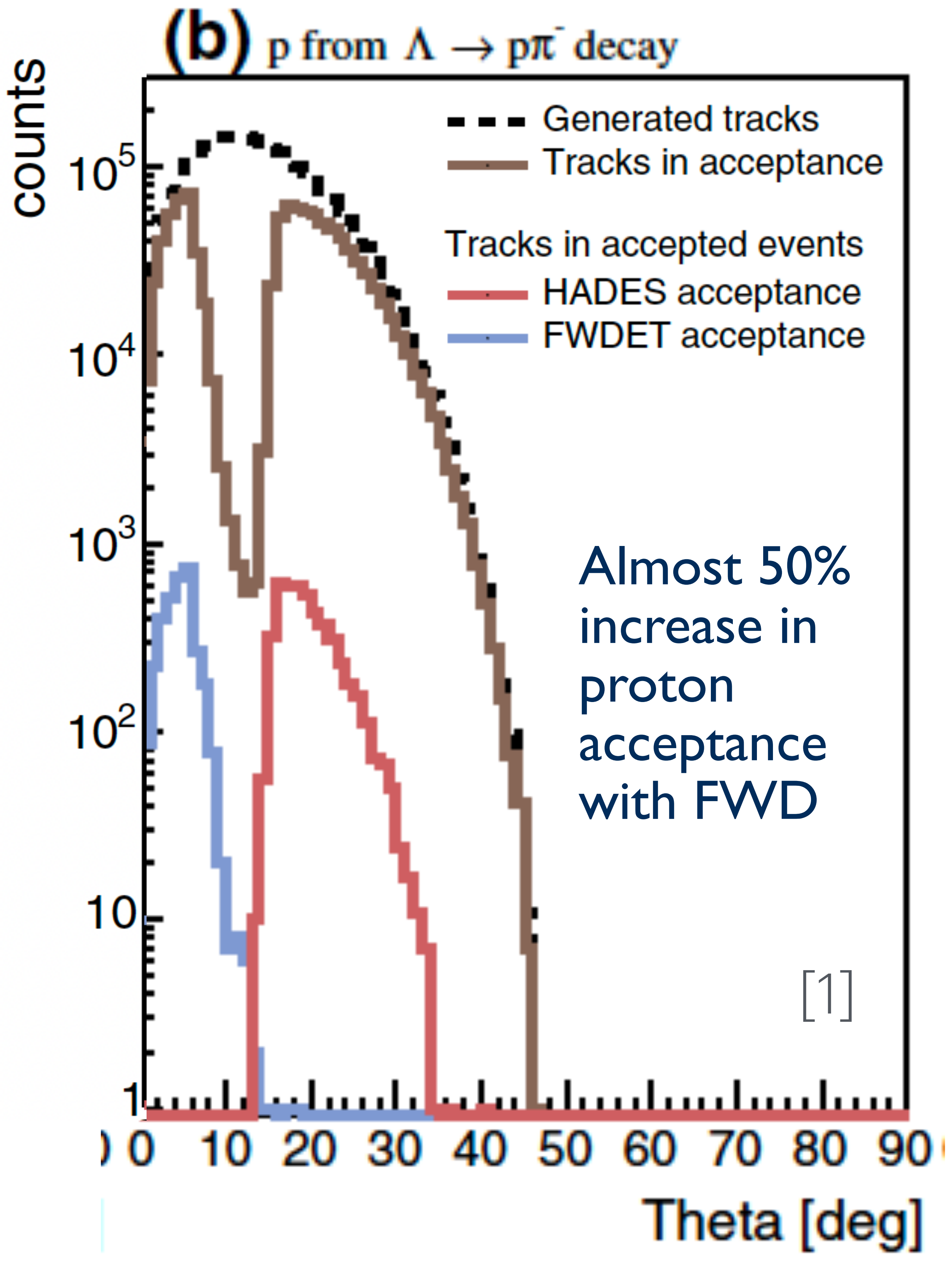
HADES (+ PANDA) detector

High **A**cceptance **D**i-**E**lectron **S**pectrometer

Fixed target Magnetic spectrometer with 6-sectors, SIS18 (GSI, Germany)



Cross-sectional sketch of the HADES spectrometer

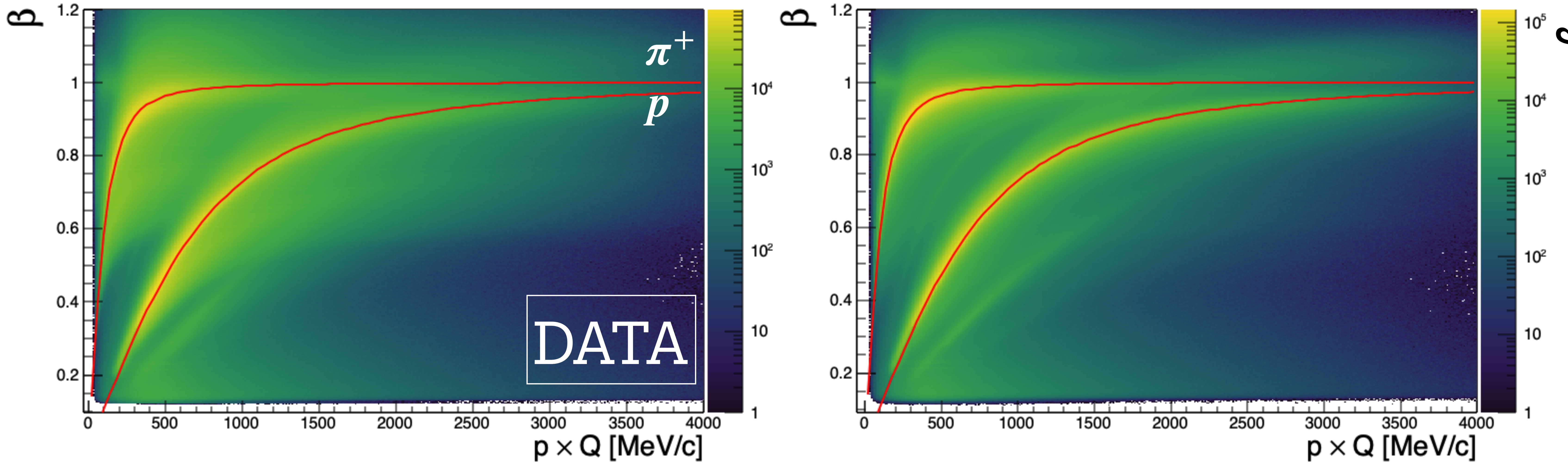


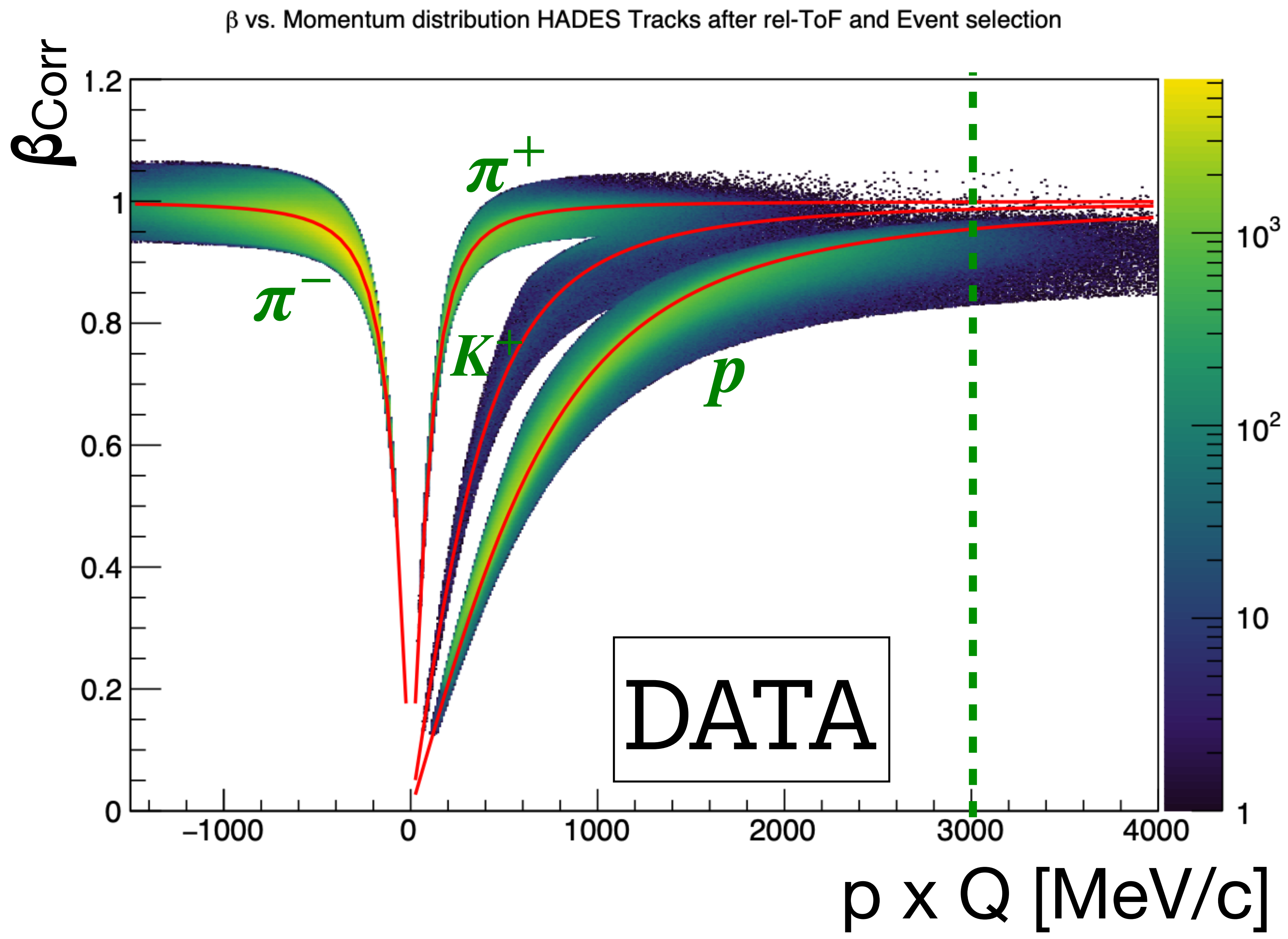
Almost 50% increase in proton acceptance with FWD

[1] Production and electromagnetic decay of hyperons: a feasibility study with HADES as a phase-0 experiment at FAIR

Stage-SO: PID (β vs. P)

Measured TOF



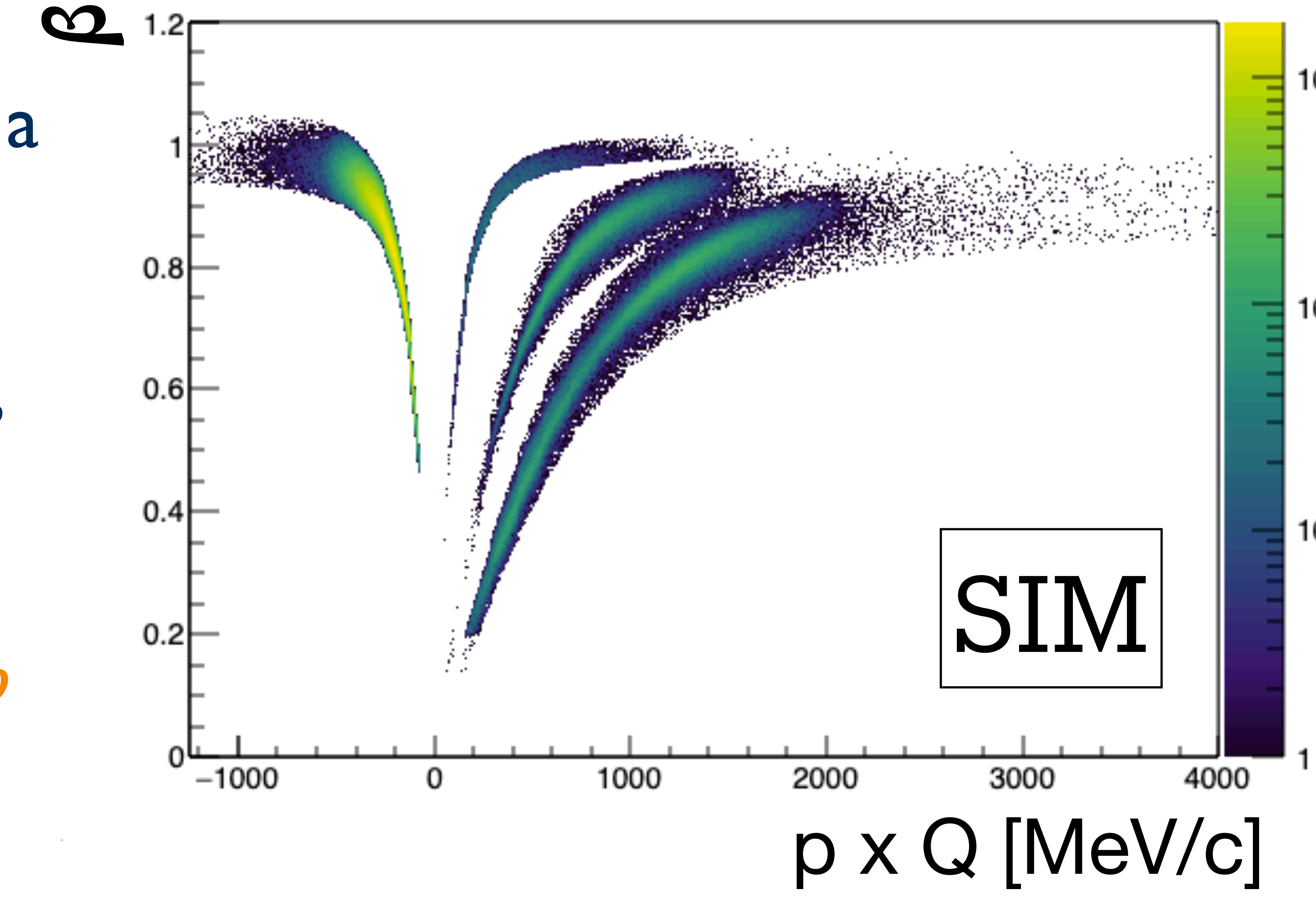


Relative ToF Correction

1. Graphical cuts around the π^- region
2. Selection on π^- tracks, $\Delta t_{\pi^-} \leq 2\text{ns}$
   - Where, $\left|\Delta t_{\pi^-}\right| = t_{meas_{\pi}^-} - t_{th_{\pi}^-}$
3. Tof correction to positive tracks:
   - $t_{\text{corr}_{p/K^+}} = t_{\text{meas}_{p/K^+}} - \Delta t_{\pi^-}$

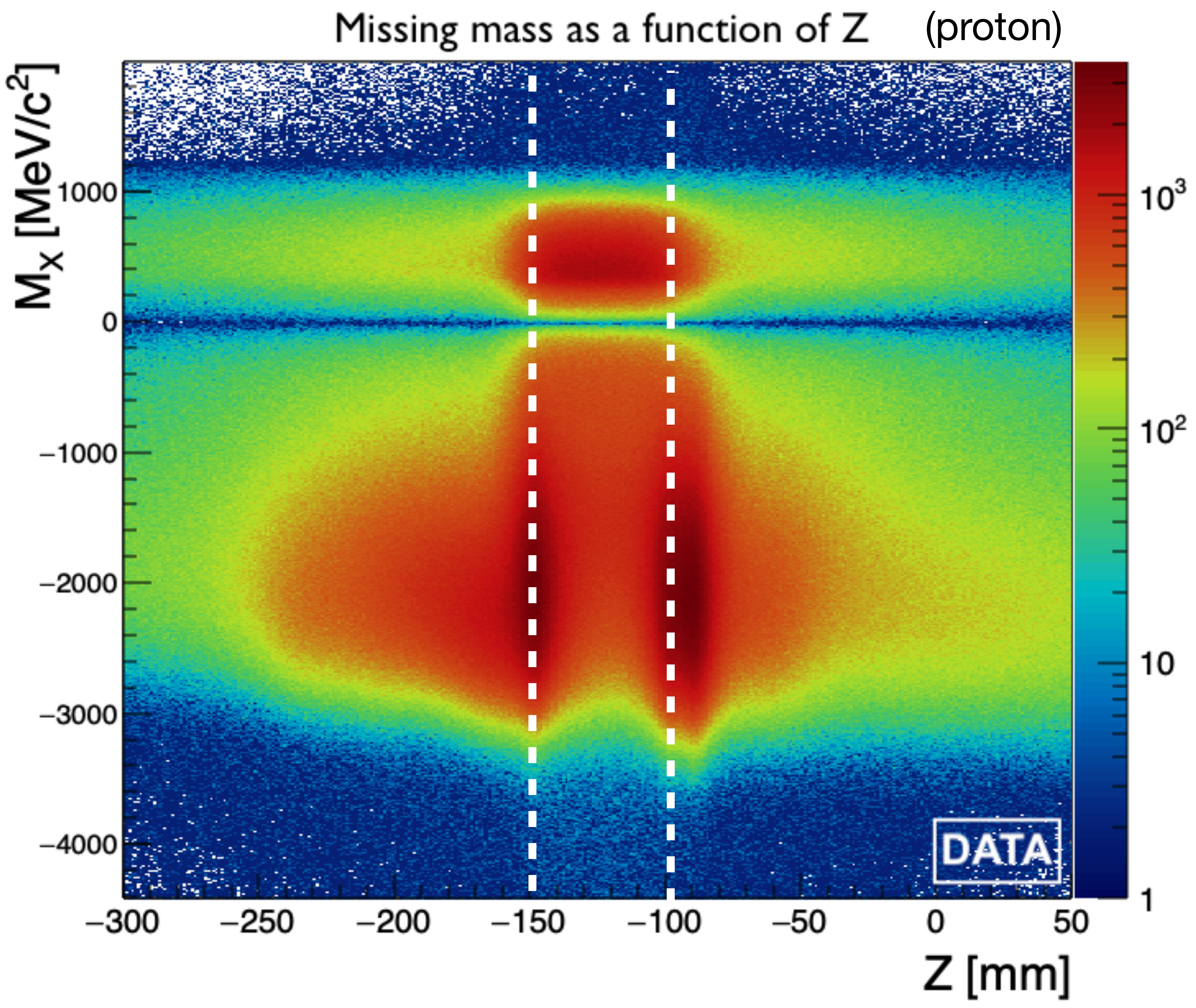
Positive Track selection

1. Selecting p, π^- and K^+ tracks within a threshold shown below:
2. $|\Delta t_{corr_p}| \leq 15\% \cdot t_{\exp_p}$, $|\Delta t_{corr_{K^+}}| \leq 10\% \cdot t_{\exp_{K^+}}$, $|\Delta t_{corr_{\pi^+}}| \leq 5\% \cdot t_{\exp_{\pi^+}}$
3. All FWD tracks are assumed to be p

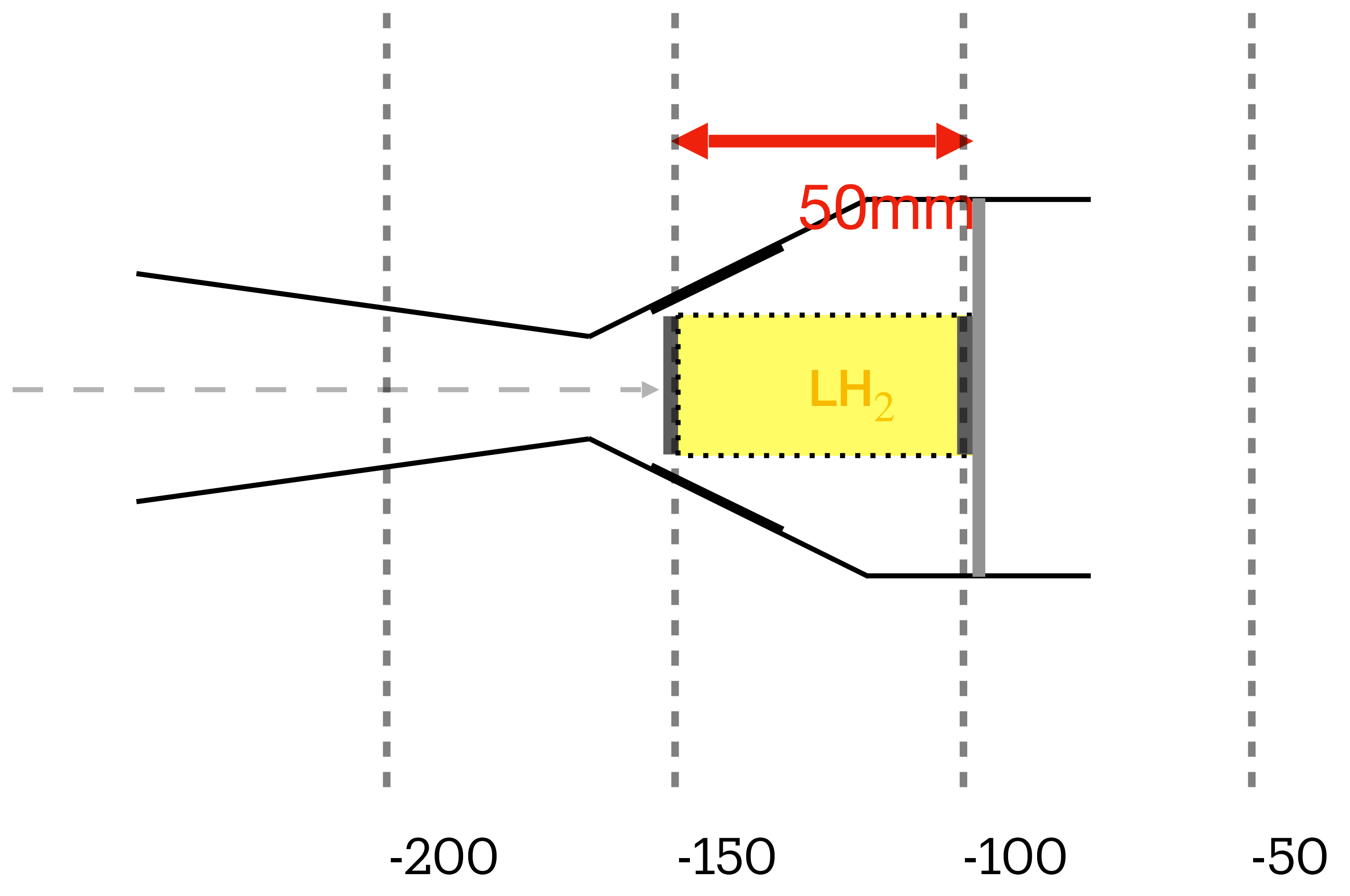


Stage-S1: First selection

$$p(4.5)p \rightarrow p_1\pi_1^- p_2\pi_2^- + X$$



- Missing Mass (M_X) selection is applied with p(4.5 GeV)p system for the inclusive tracks
- $M_X < 0$ corresponds to $M_X^2 < 0$:
  - Concentrated to the Kapton encaps
- $M_X > 0$:
  - Interactions in the LH_2 cell



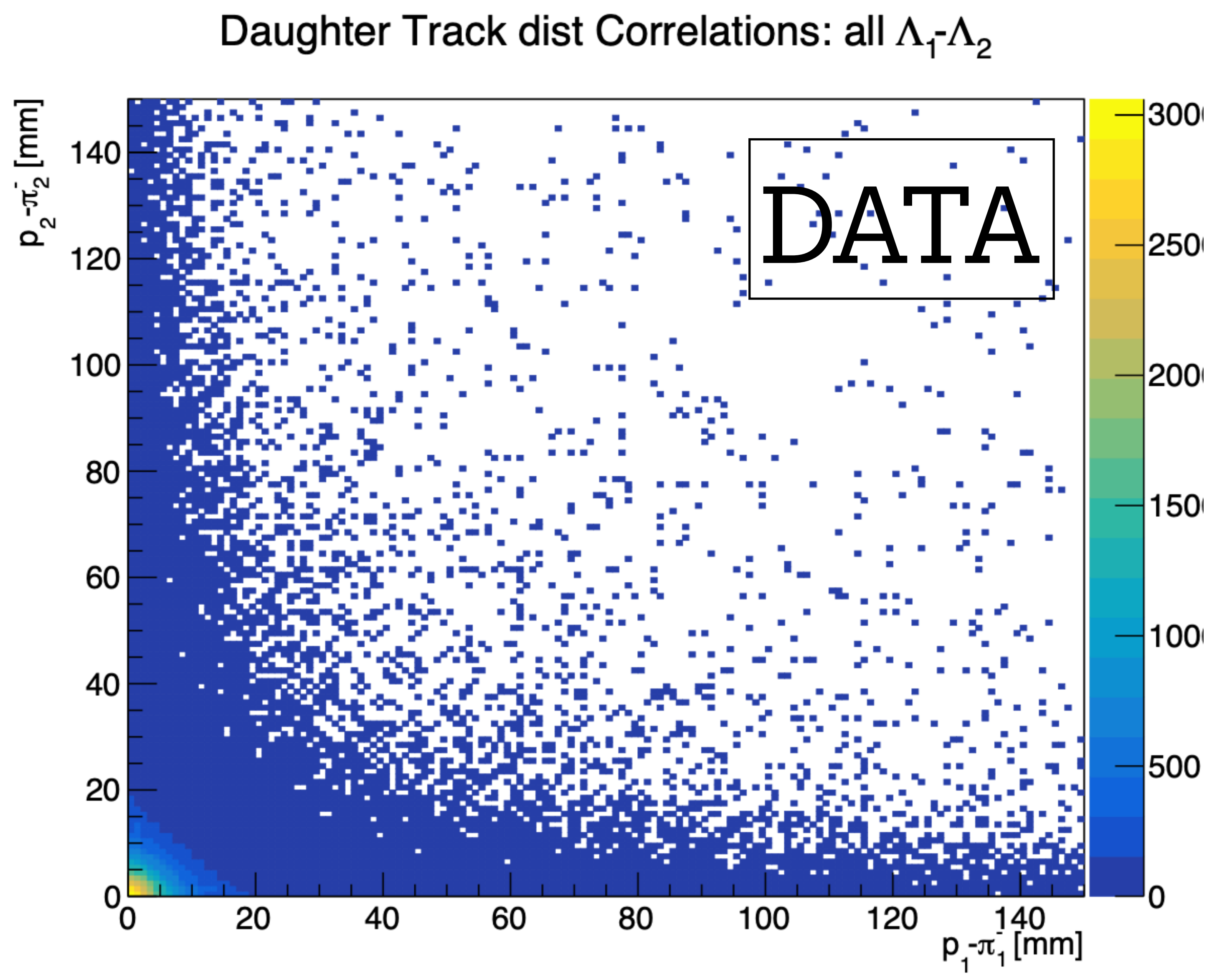
Stages-S2: Λ-Λ candidates

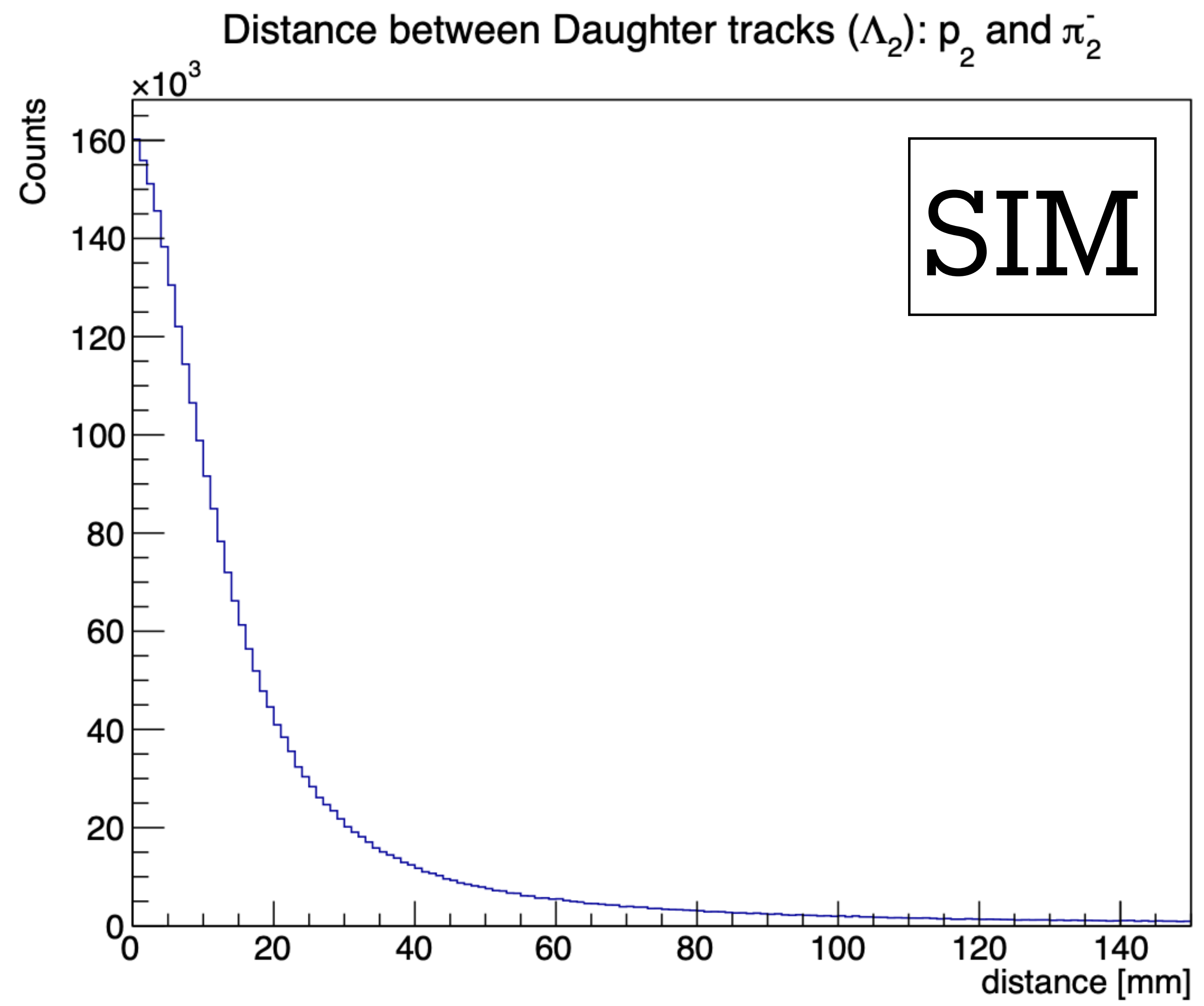
S2

Lambda reconstruction and selection

- Select only 2 sets of proton and pions for 2 Λ candidates
- Condition used
- $d_{p_i\pi_i} < 100$ mm $i \in 1,2$
- Select combination with smallest $d_{res} = d_{p_1\pi_1} * d_{p_2\pi_2}$

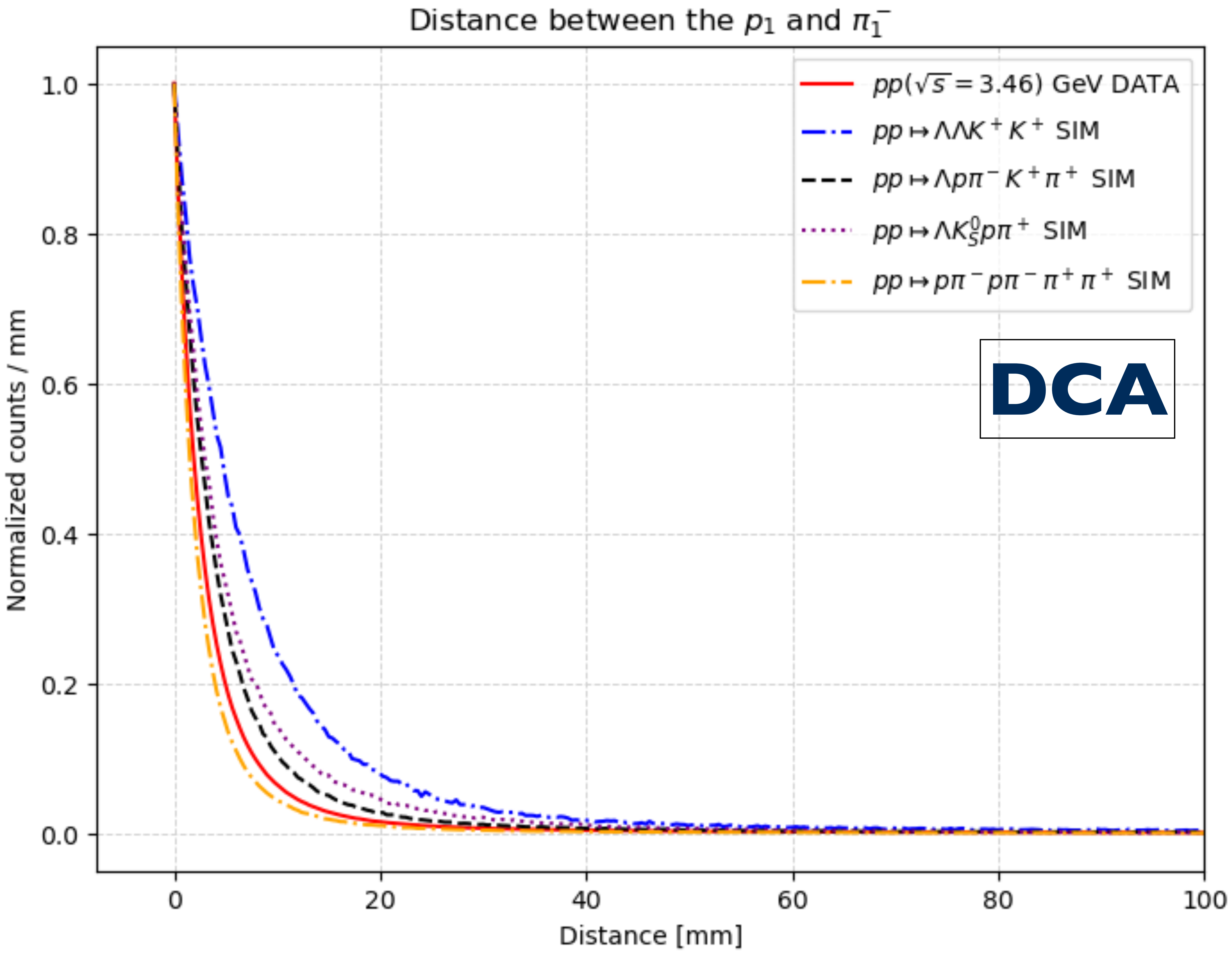
Simulations show that the d_{res} criteria is not removing Signal events





Stages-S3: Optimization

Distance of Closest Approach (DCA)



Physics channels

A. $pp \mapsto \Lambda[p\pi^-]\,\Lambda[p\pi^-] + X - ; X \mapsto K^+, K^+ :$

Λ-Λ Signal

SIG: $pp \mapsto \Lambda\Lambda K^+K^+$

B. $pp \mapsto \Lambda\, p\pi^- + X$:

Single-Λ + uncorrelated

OLBG: $pp \mapsto \Lambda p\pi^- K^+\pi^+$

KSBG: $pp \mapsto \Lambda K_S^0 p\pi^+$

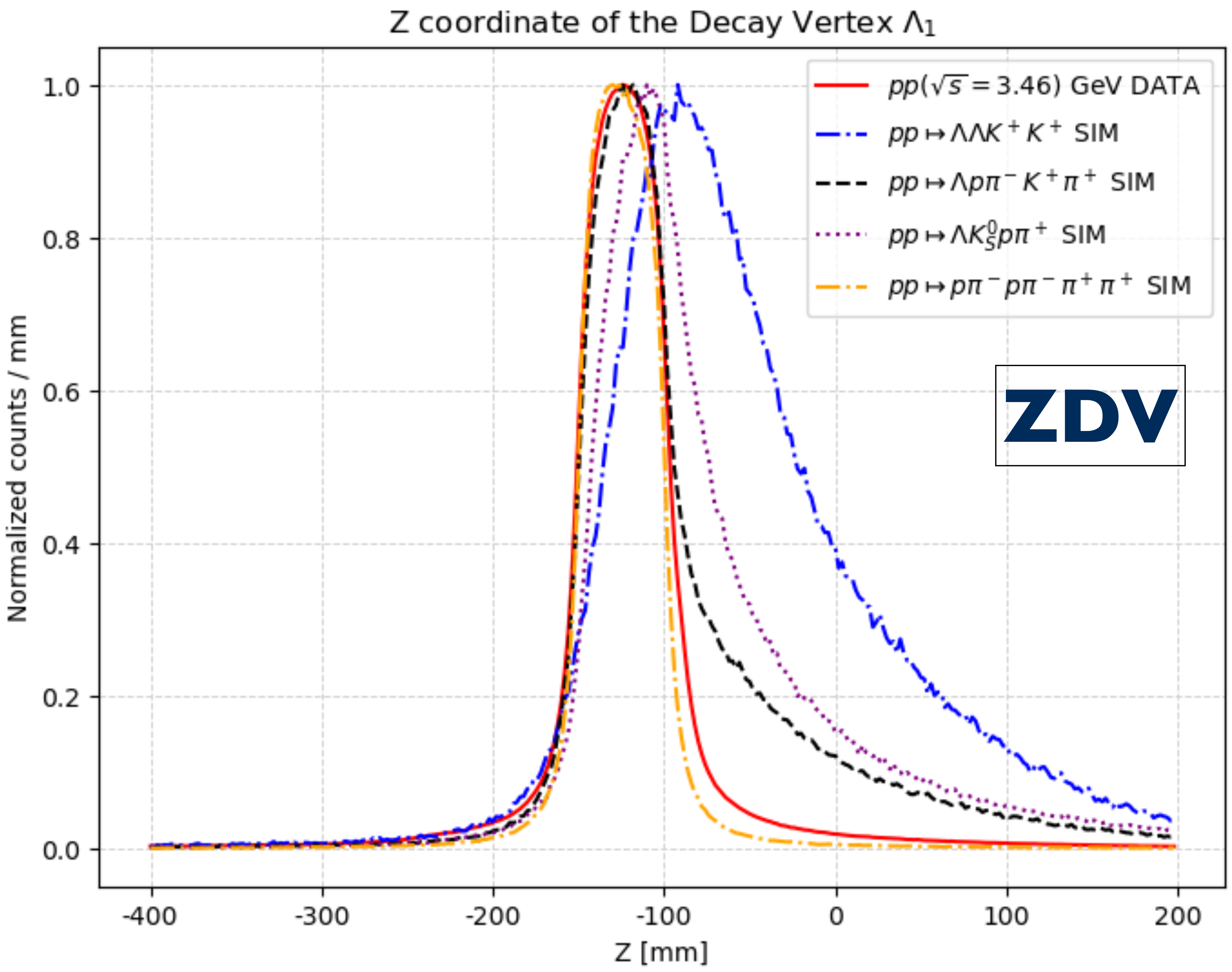
C. $pp \mapsto p\pi^- p\pi^- + X;\ X \mapsto \pi^+\pi^+ :$

Pure non-resonant channel

NRBG: $pp \mapsto p\pi^- p\pi^- \pi^+\pi^+$

Stages-S3: Optimization

Z coordinate of Decay Vertex (ZDV)



Physics channels

A. $pp \mapsto \Lambda[p\pi^-]\,\Lambda[p\pi^-] + X - ; X \mapsto K^+, K^+$:

Λ-Λ Signal

SIG: $pp \mapsto \Lambda\Lambda K^+K^+$

B. $pp \mapsto \Lambda\, p\pi^- + X$:

Single-Λ + uncorrelated

OLBG: $pp \mapsto \Lambda p\pi^- K^+\pi^+$

KSBG: $pp \mapsto \Lambda K_S^0 p\pi^+$

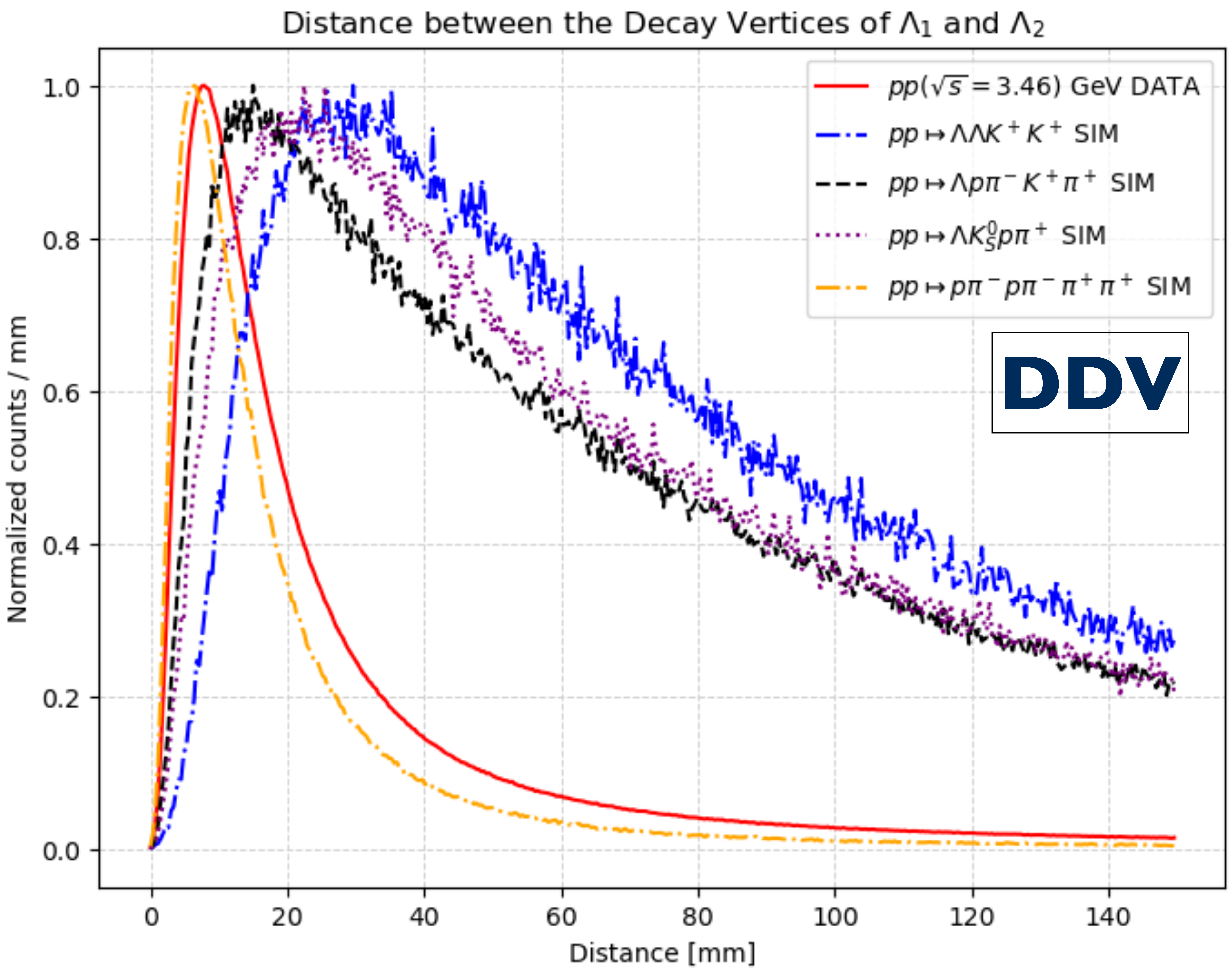
C. $pp \mapsto p\pi^-\, p\pi^- + X;\; X \mapsto \pi^+\pi^+$:

Pure non-resonant channel

NRBG: $pp \mapsto p\pi^- p\pi^- \pi^+\pi^+$

Stages-S3: Optimization

Distance between Decay Vertices (DDV)



Physics channels

A. $pp \mapsto \Lambda[p\pi^-]\,\Lambda[p\pi^-] + X - ; X \mapsto K^+, K^+$:

Λ-Λ Signal

SIG: $pp \mapsto \Lambda\Lambda K^+K^+$

B. $pp \mapsto \Lambda\, p\pi^- + X$:

Single-Λ + uncorrelated

OLBG: $pp \mapsto \Lambda p\pi^- K^+\pi^+$

KSBG: $pp \mapsto \Lambda K^0_S p\pi^+$

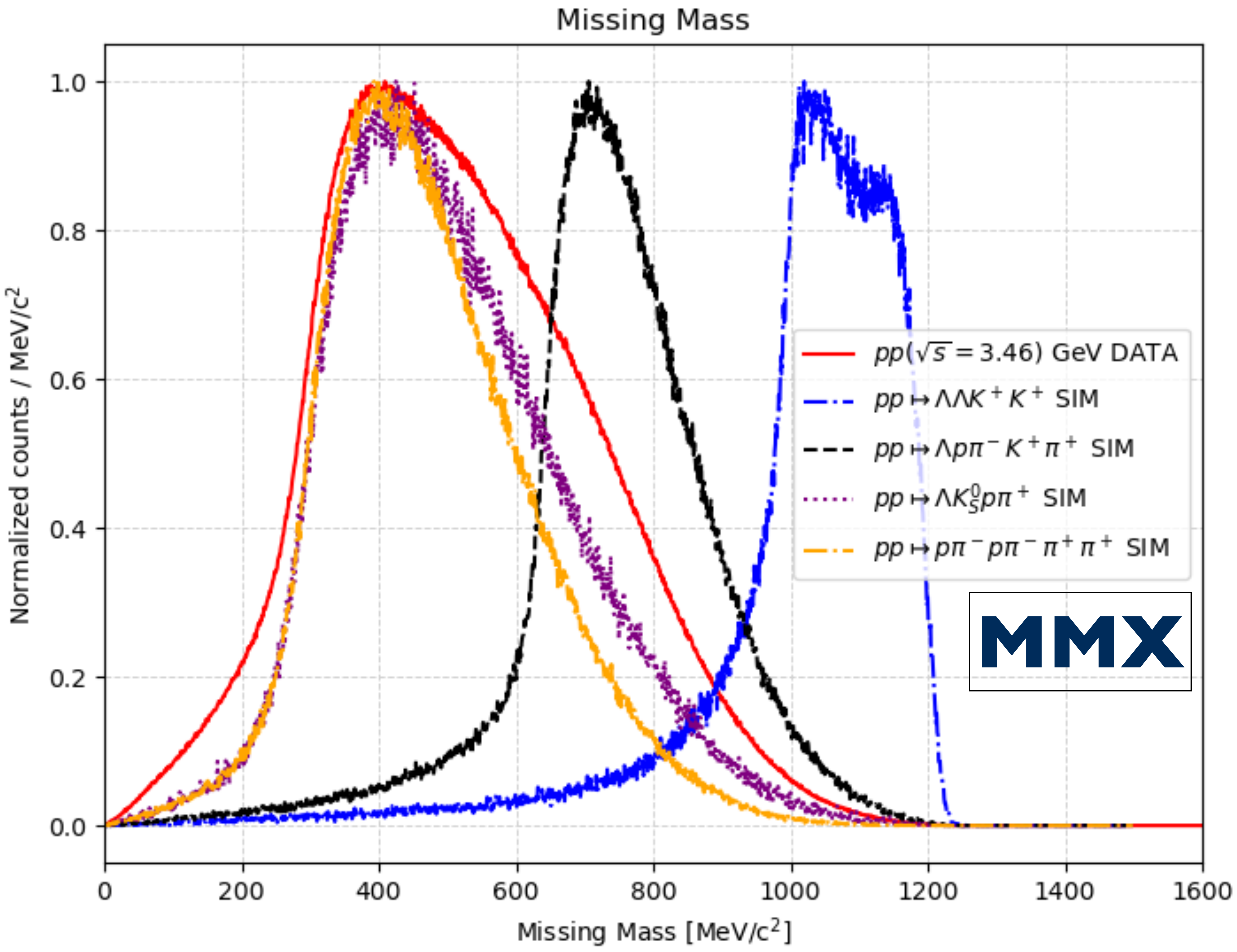
C. $pp \mapsto p\pi^-\,p\pi^- + X;\ X \mapsto \pi^+\pi^+$:

Pure non-resonant channel

NRBG: $pp \mapsto p\pi^- p\pi^- \pi^+\pi^+$

Stages-S3: Optimization

Missing Mass - M_X cut on $pp \mapsto \Lambda\Lambda + X$ (MMX)



Physics channels

A. $pp \mapsto \Lambda[p\pi^-]\,\Lambda[p\pi^-] + X - ; X \mapsto K^+, K^+$:

Λ-Λ Signal

SIG: $pp \mapsto \Lambda\Lambda K^+K^+$

B. $pp \mapsto \Lambda\, p\pi^- + X$:

Single-Λ + uncorrelated

OLBG: $pp \mapsto \Lambda p\pi^- K^+\pi^+$

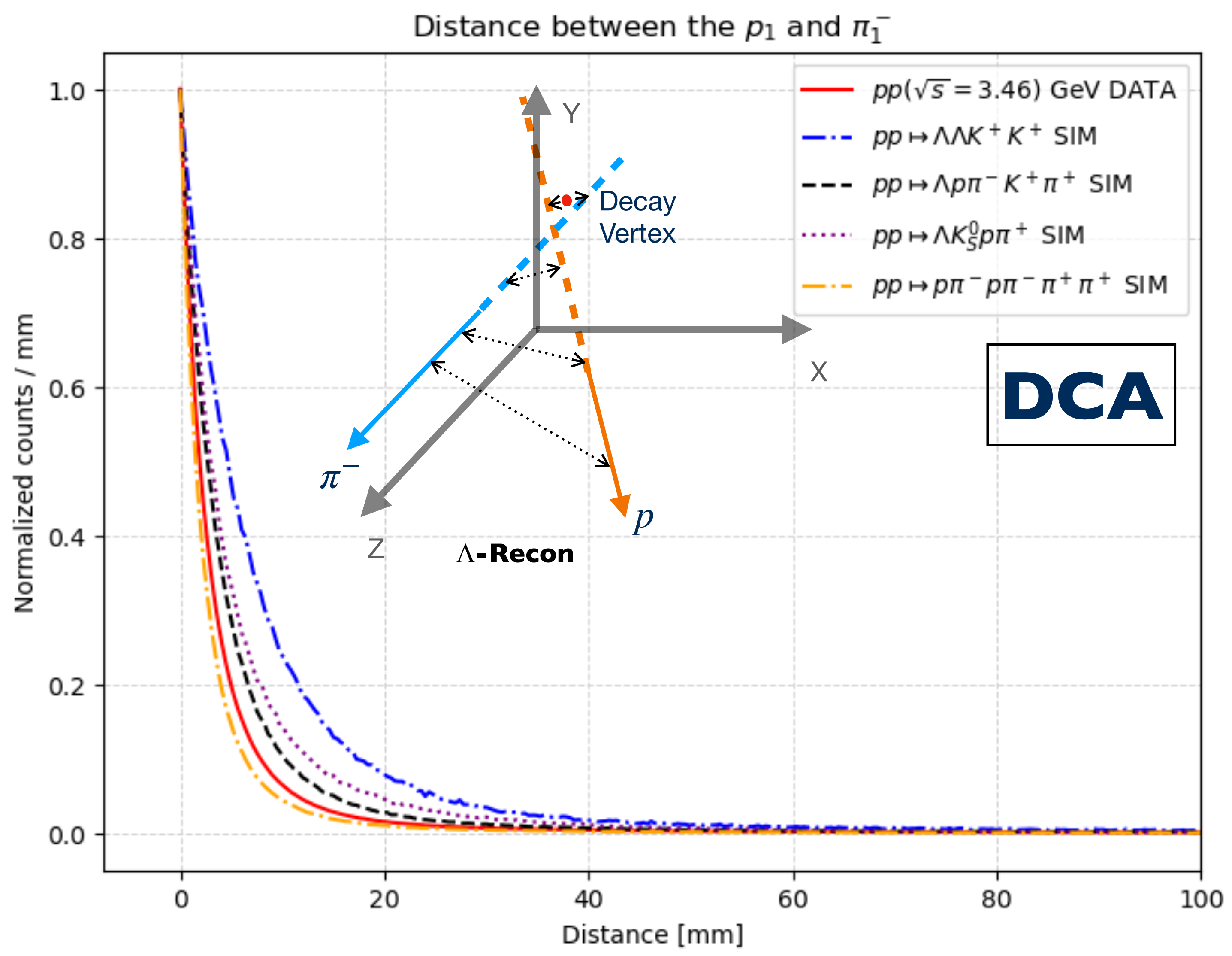
KSBG: $pp \mapsto \Lambda K_S^0 p\pi^+$

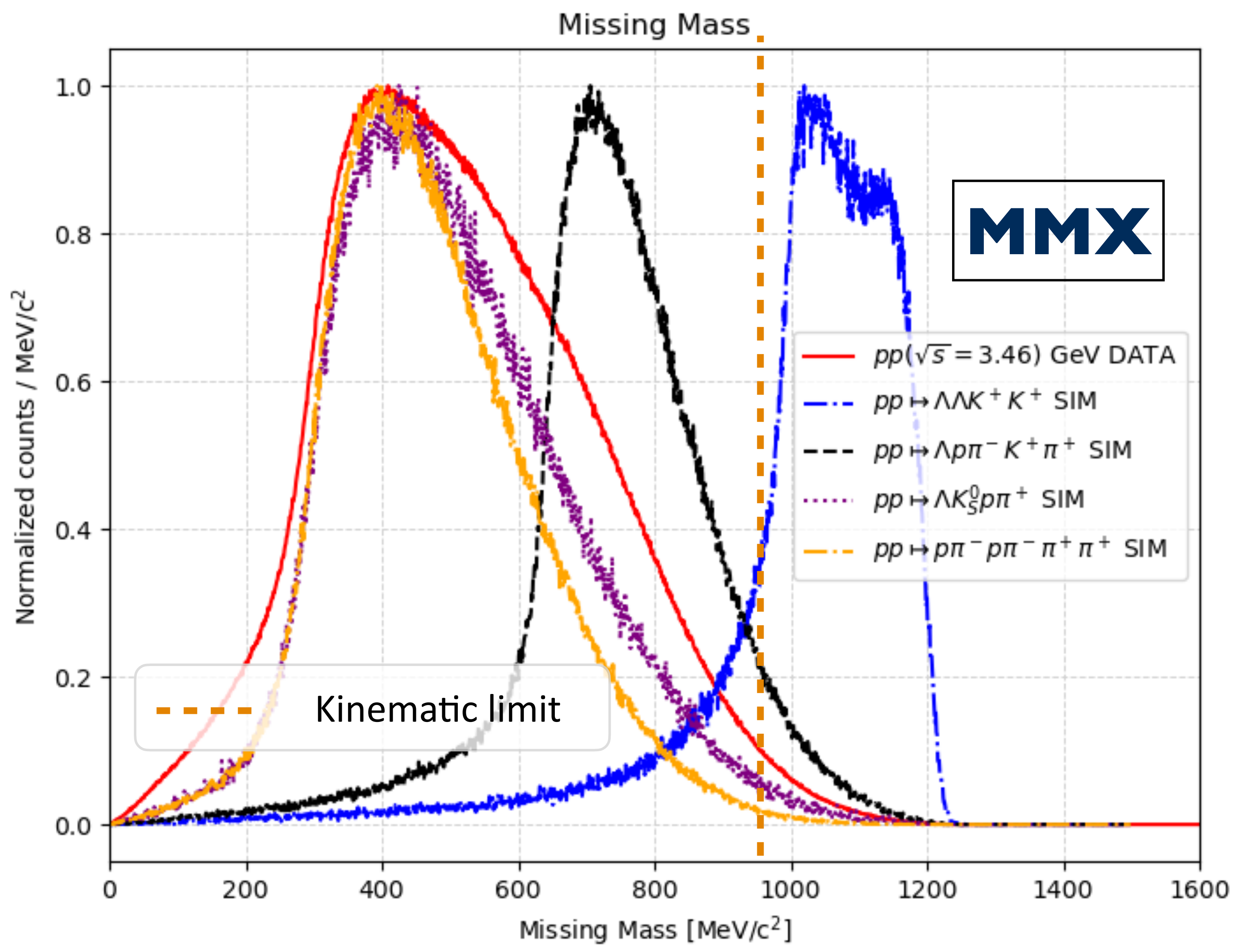
C. $pp \mapsto p\pi^- p\pi^- + X;\ X \mapsto \pi^+\pi^+$:

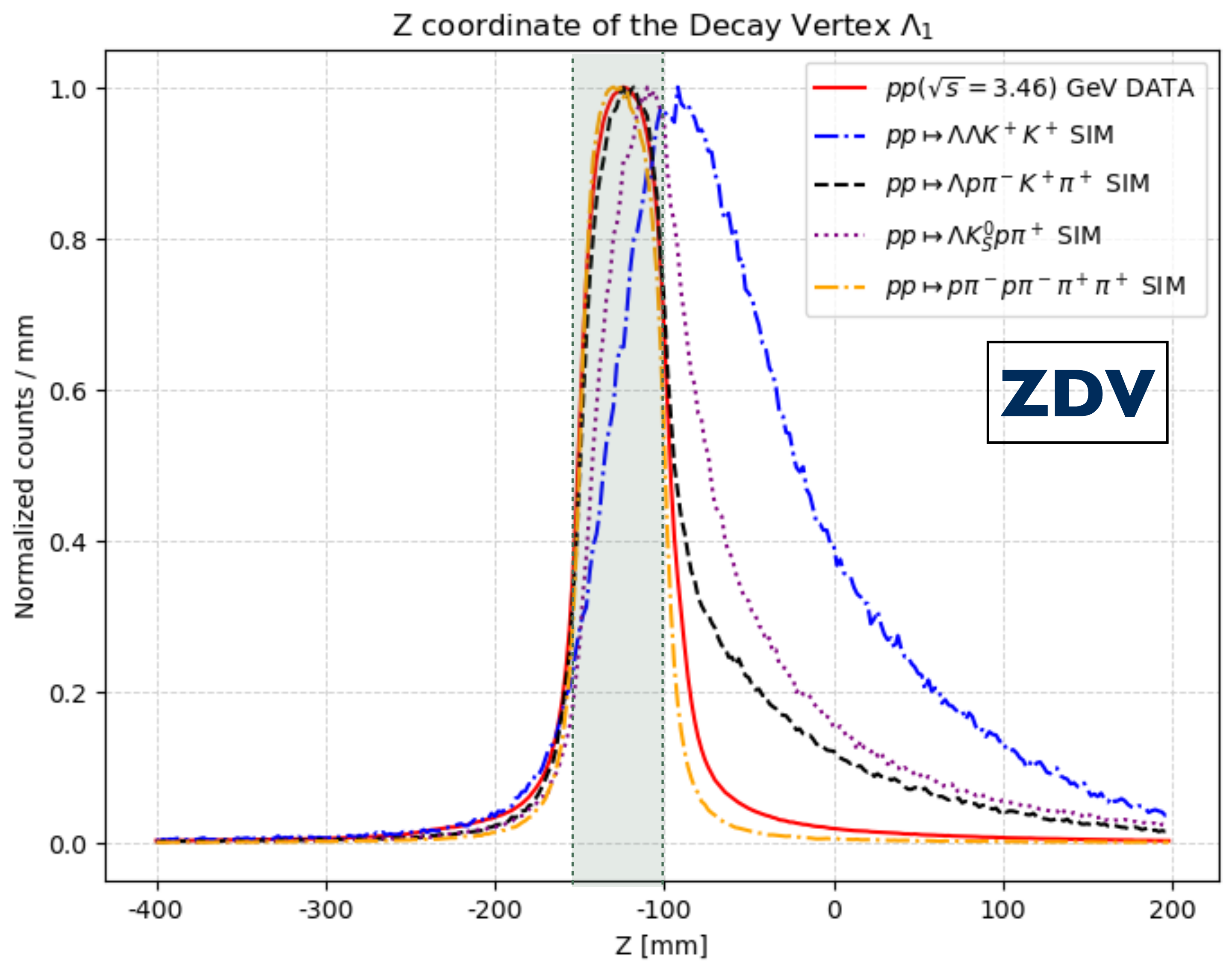
Pure non-resonant channel

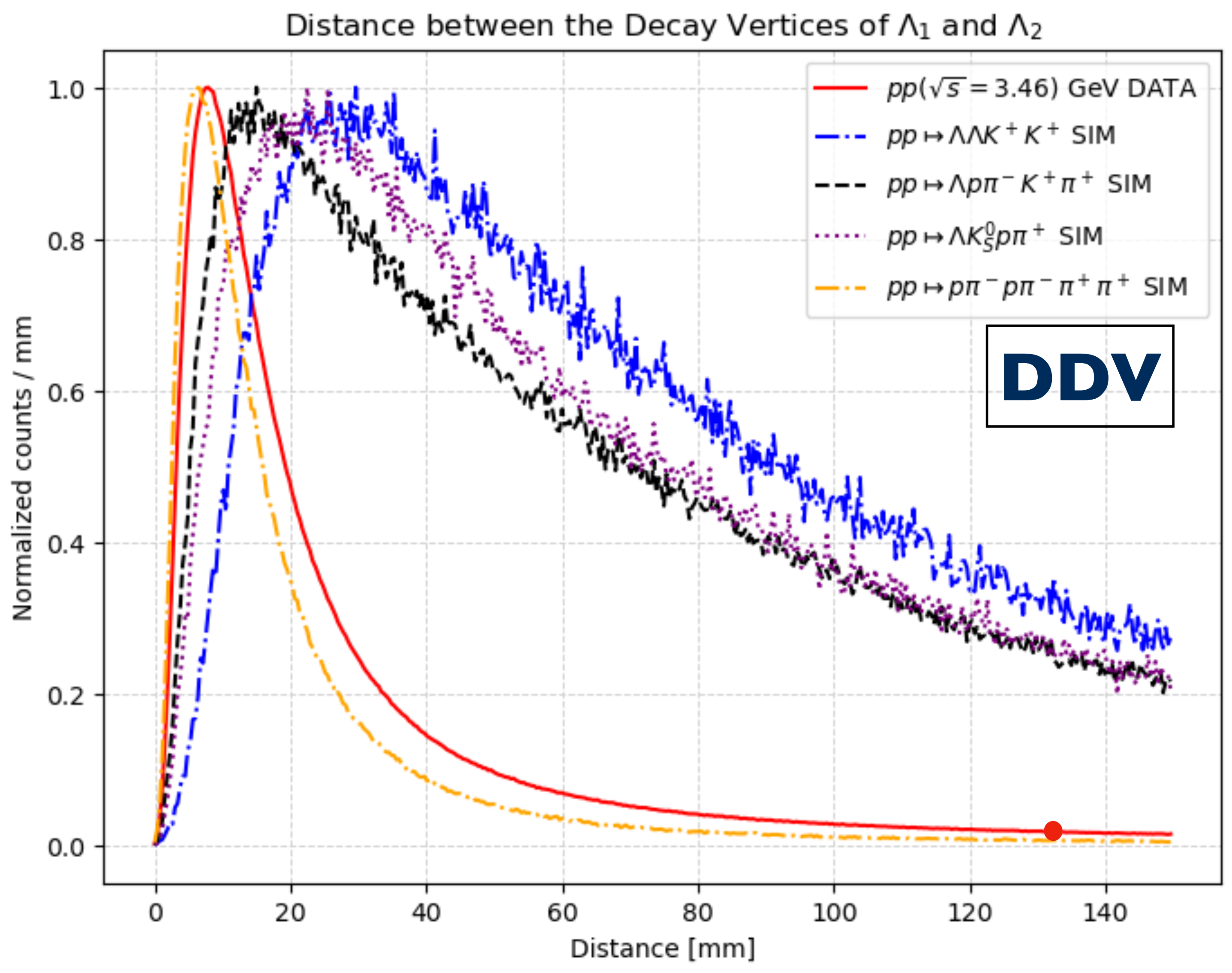
NRBG: $pp \mapsto p\pi^- p\pi^- \pi^+\pi^+$

Stages-S3: Optimization









Physical channels

A. $pp \mapsto \Lambda[p\pi^-]\,\Lambda[p\pi^-] + X - ; X \mapsto K^+, K^+$:

Λ-Λ Signal

SIG: $pp \mapsto \Lambda\Lambda K^+K^+$

B. $pp \mapsto \Lambda\, p\pi^- + X$:

Single-Λ + uncorrelated

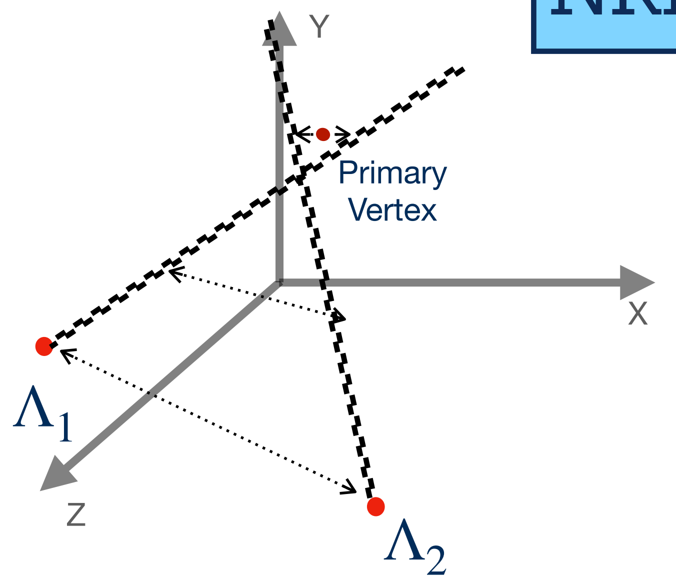
OLBG: $pp \mapsto \Lambda p\pi^- K^+\pi^+$

KSBG: $pp \mapsto \Lambda K_S^0 p\pi^+$

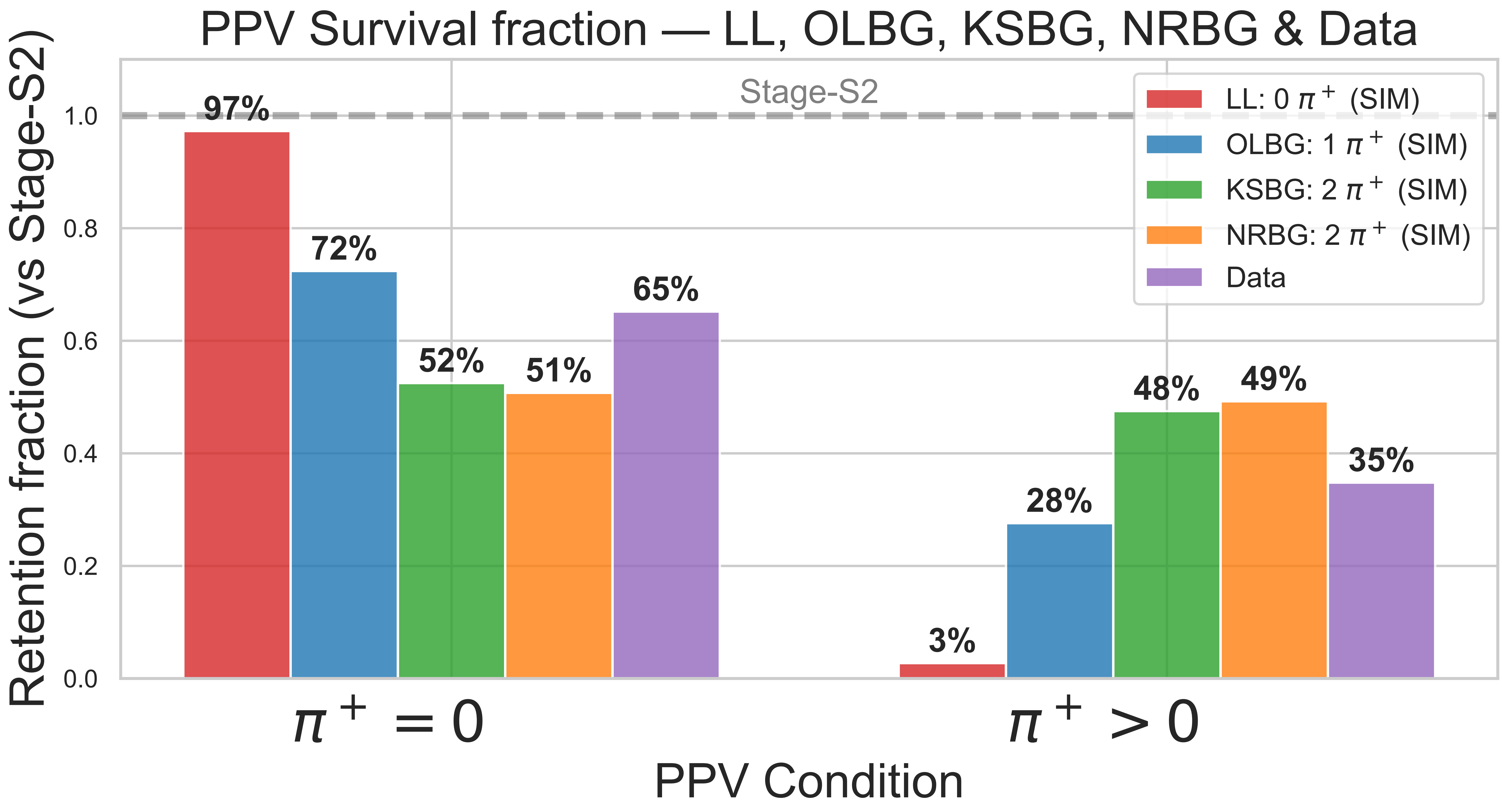
C. $pp \mapsto p\pi^-\, p\pi^- + X;\ X \mapsto \pi^+\pi^+$:

Pure non-resonant channel

NRBG: $pp \mapsto p\pi^- p\pi^- \pi^+\pi^+$



Positive Pion Veto (PPV) Effectiveness



- The PPV keeps most of the signal but rejects only part of the backgrounds.
- Effectiveness is a function of π^+ counts in the background channels.

Physics channels

A. $pp \mapsto \Lambda[p\pi^-]\,\Lambda[p\pi^-] + X - ; X \mapsto K^+, K^+ :$

Λ-Λ Signal

SIG: $pp \mapsto \Lambda\Lambda K^+K^+$: $0\,\pi^+$

B. $pp \mapsto \Lambda\, p\pi^- + X$:

Single-Λ + uncorrelated

OLBG: $pp \mapsto \Lambda p\pi^- K^+\pi^+$: $1\,\pi^+$

KSBG: $pp \mapsto \Lambda K_S^0 p\pi^+$: $2\,\pi^+$

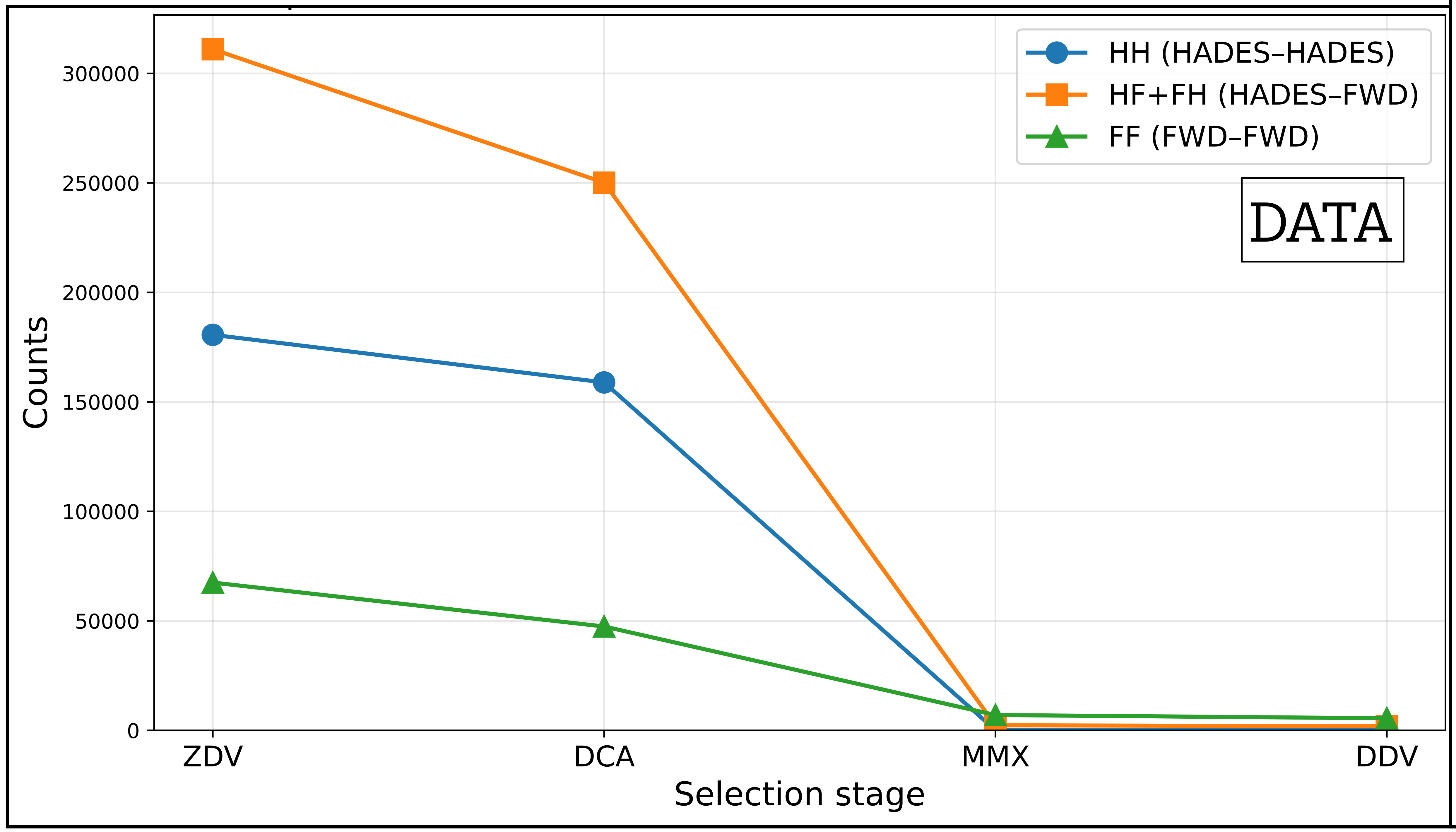
C. $pp \mapsto p\pi^- p\pi^- + X;\; X \mapsto \pi^+\pi^+ :$

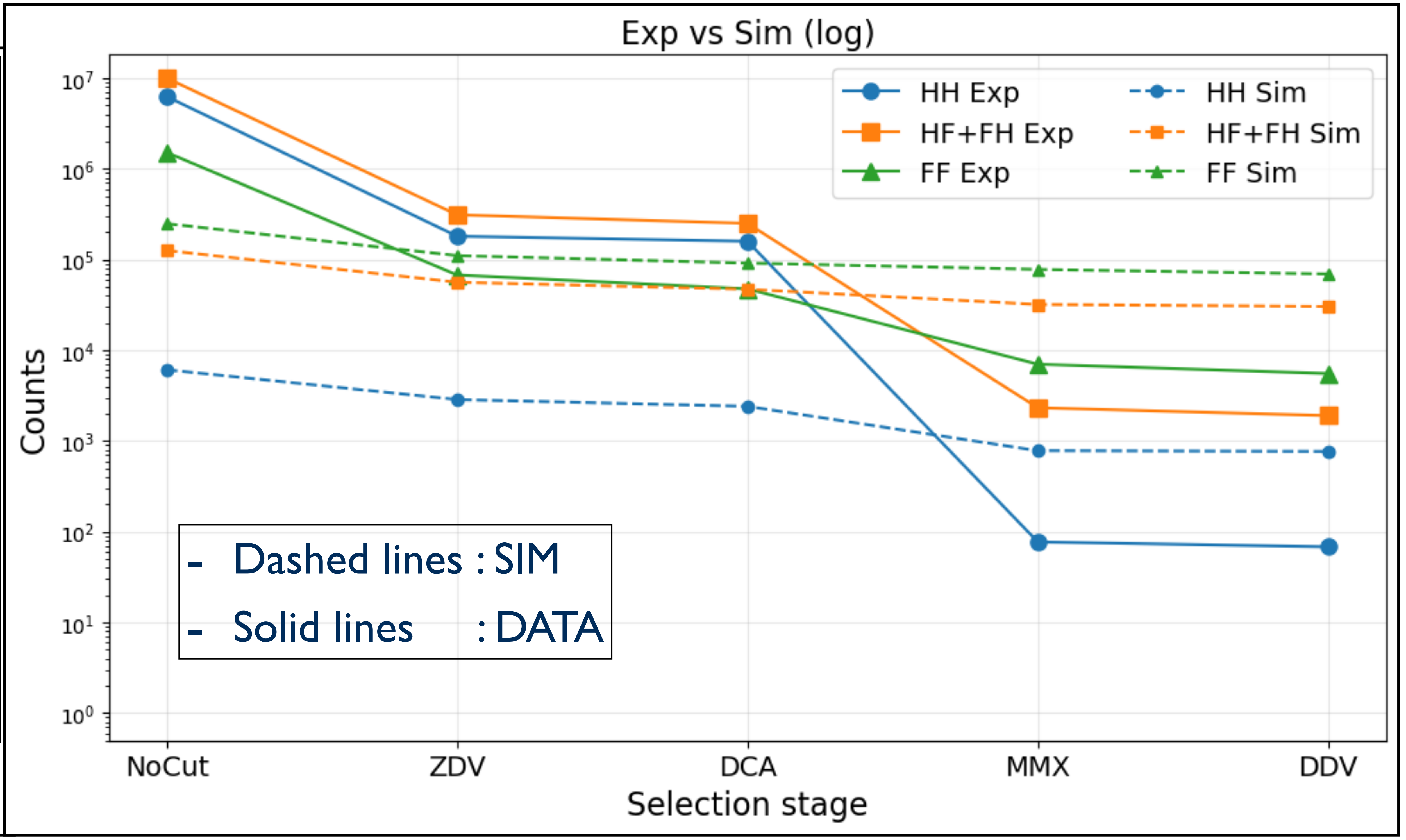
Pure non-resonant channel

NRBG: $pp \mapsto p\pi^- p\pi^- \pi^+\pi^+$: $2\,\pi^+$

Proton Statistics

- HH: p of both Λ candidates are in HADES
- HF: p of at least one Λ candidate is in HADES
- FF: p of both Λ candidates are in FWD





- Missing Mass selection (MMX) is where we lose much of the HH events
- HH events aren't statistically significant enough to extract counts (on the order of 10 events)
- **Simulations show MMX selection is not removing Signal events**

Systematic analysis with FoM

MM (MeV/c²) Incl.	DCA (mm)	ZDV (mm) :- Coordinate value	DDV (mm)	PPV (#) Pion Plus Veto
> 800	5	> -150	> 5	(=) 0
> 850	0 - 10	> -140	> 10	(>) 0
> 900	0 - 20	> -130	> 20	
> 950	0 - 30	> -120	> 30	
> 1000	0 - 40	> -110	> 40	
	0 - 60	> -100	> 60	
	0 - 80	> -95	> 80	
	0 - 100	> -90	> 100	
		> -85		
		> -80		
		> -75		

+

Invariant mass range: $1100\,\mathrm{MeV}/c^2 \leq M_{\Lambda_1}, M_{\Lambda_1} \leq 1130\,\mathrm{MeV}/c^2$

Systematic analysis with FoM

MM (MeV/c^2) Incl.
> 800
> 850
> 900
> 950
> 976
> 1000
> 1050

DCA (mm)
5
0 - 10
0 - 20
0 - 30
0 - 40
0 - 60
0 - 80
0 - 100

ZDV (mm) :- Coordinate value
> -150
> -140
> -130
> -120
> -110
> -100
> -95
> -90
> -85
> -80
> -75

DDV (mm)
> 5
> 10
> 20
> 30
> 40
> 60
> 80
> 100

PPV (#) Pion Plus Veto
(=) 0
(>) 0

+

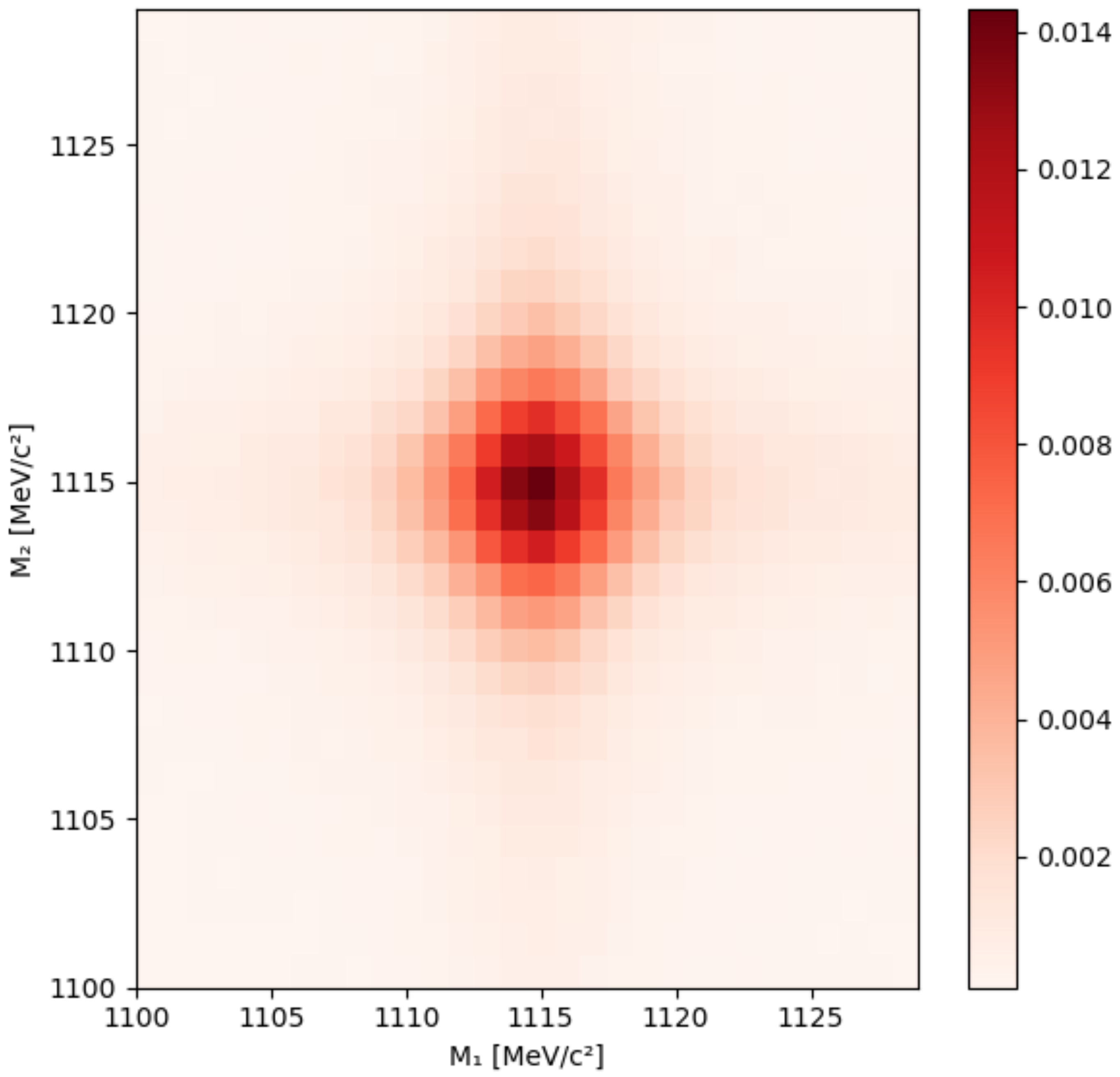
Invariant mass selection: $1100\,\mathrm{MeV}/c^2 \leq M_{\Lambda_1}, M_{\Lambda_1} \leq 1130\,\mathrm{MeV}/c^2$

Maximum Likelihood Fit Model

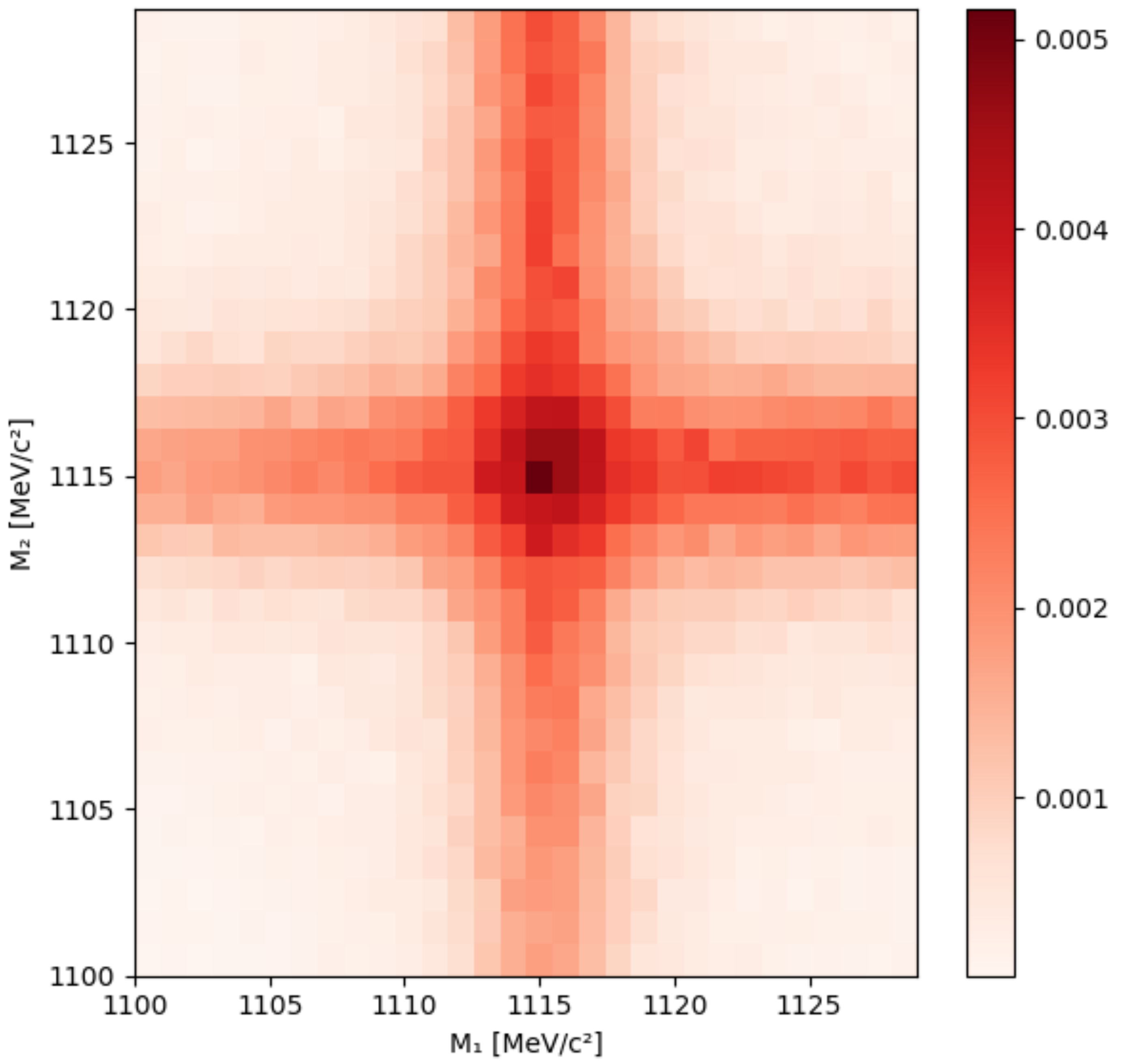
$$model = \boldsymbol{A} \cdot LL_{SIM} + \boldsymbol{B_0} \cdot OLBG_{SIM} + \boldsymbol{B_1} \cdot KSBG_{SIM} + NRBG$$

$$NRBG = \boldsymbol{C_0} + \boldsymbol{C_1} \cdot (M_{\Lambda_1} + M_{\Lambda_2}) + \boldsymbol{C_2} \cdot (M_{\Lambda_1}^2 + M_{\Lambda_2}^2) + \boldsymbol{C_3} \cdot (M_{\Lambda_1} \cdot M_{\Lambda_2})$$

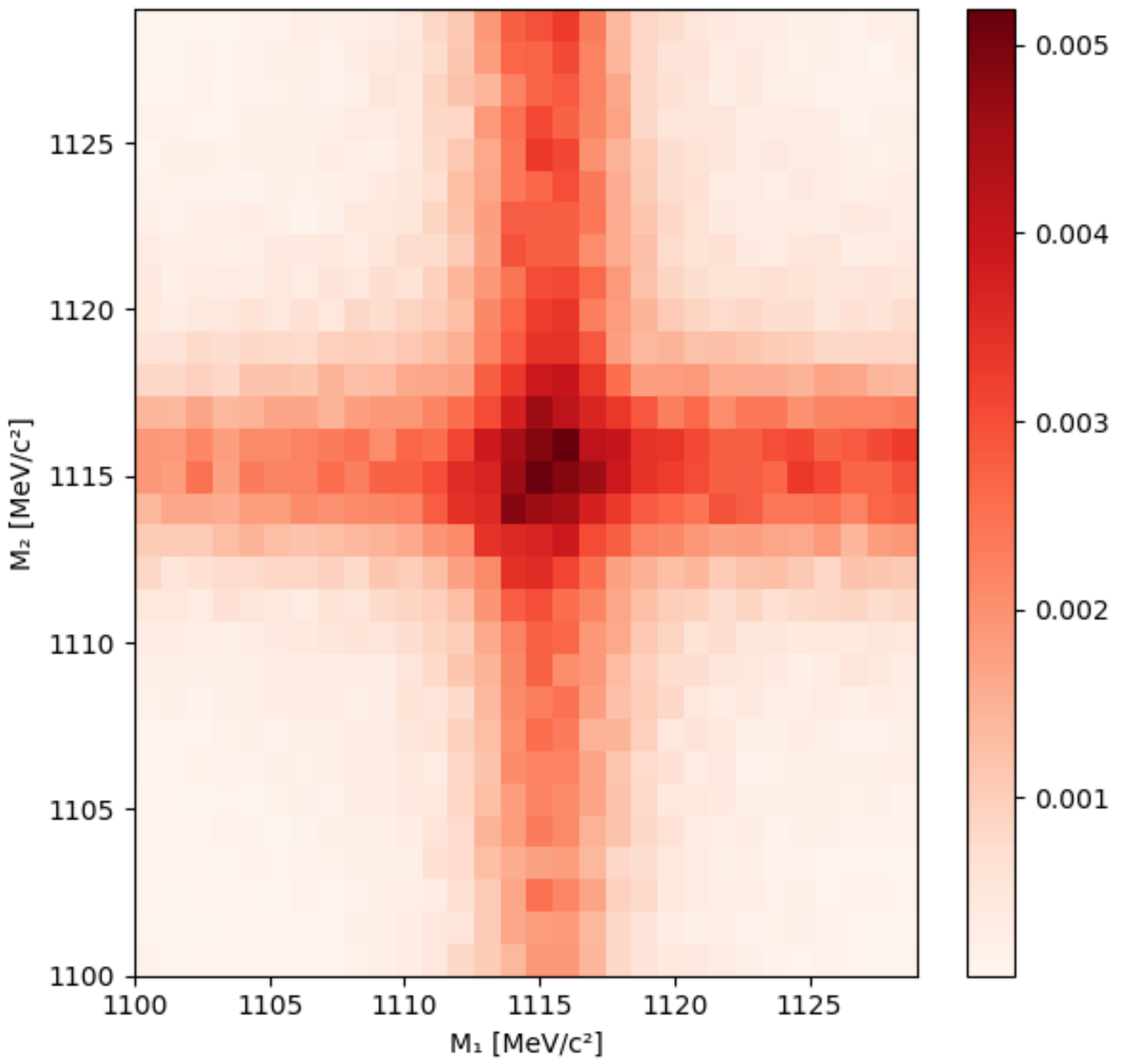
LL: $pp \mapsto \Lambda\Lambda K^+K^+$



OLBG: $pp \mapsto \Lambda p\pi^- K^+\pi^+$



KSBG: $pp \mapsto \Lambda K_S^0 p\pi^+$



ML Fit Representation with Data

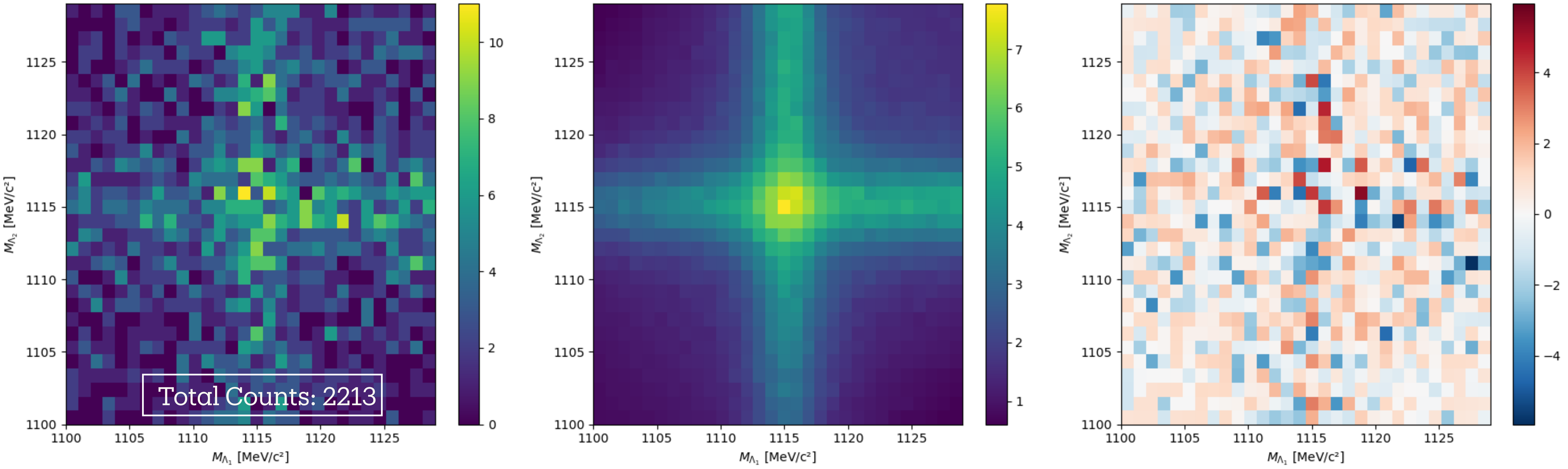
For the optimal parameters:

MMX = 976 MeV/c^2, ZDV = -100 mm, DDV = 10 mm, DCA = 40 mm

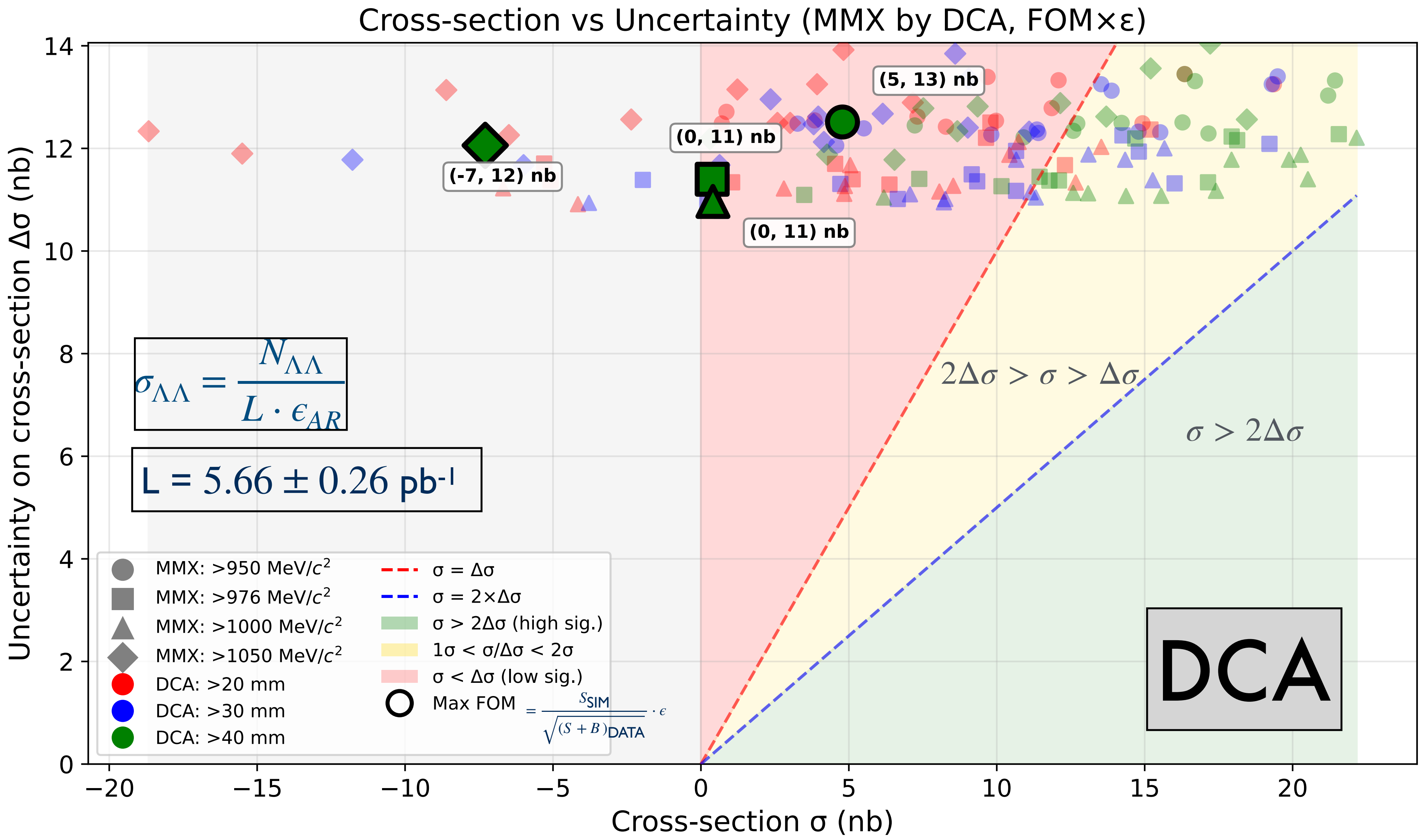
M_{Λ_1} vs. M_{Λ_2} Data (Before Fit)

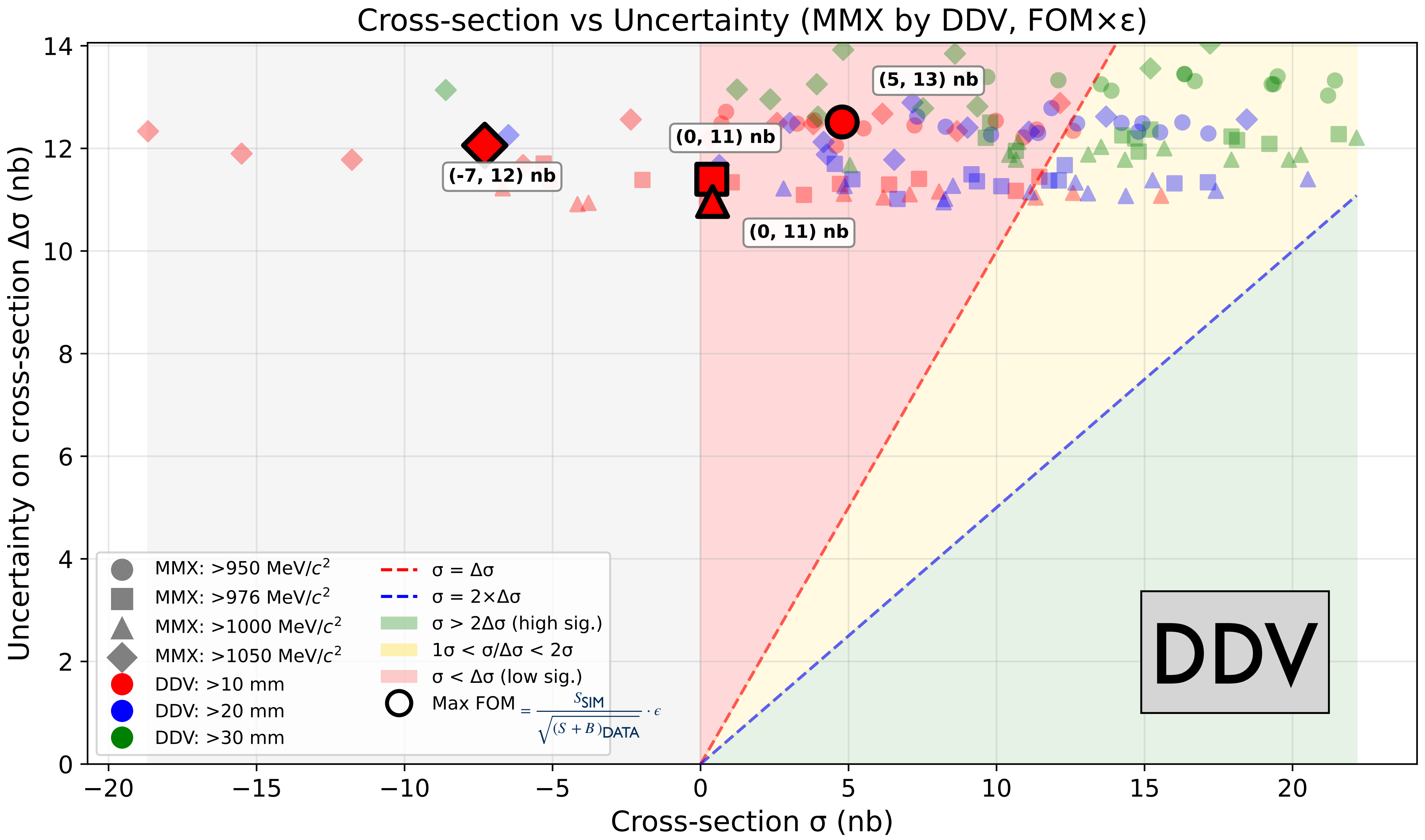
M_{Λ_1} vs. M_{Λ_2} Data representation with Fitted param

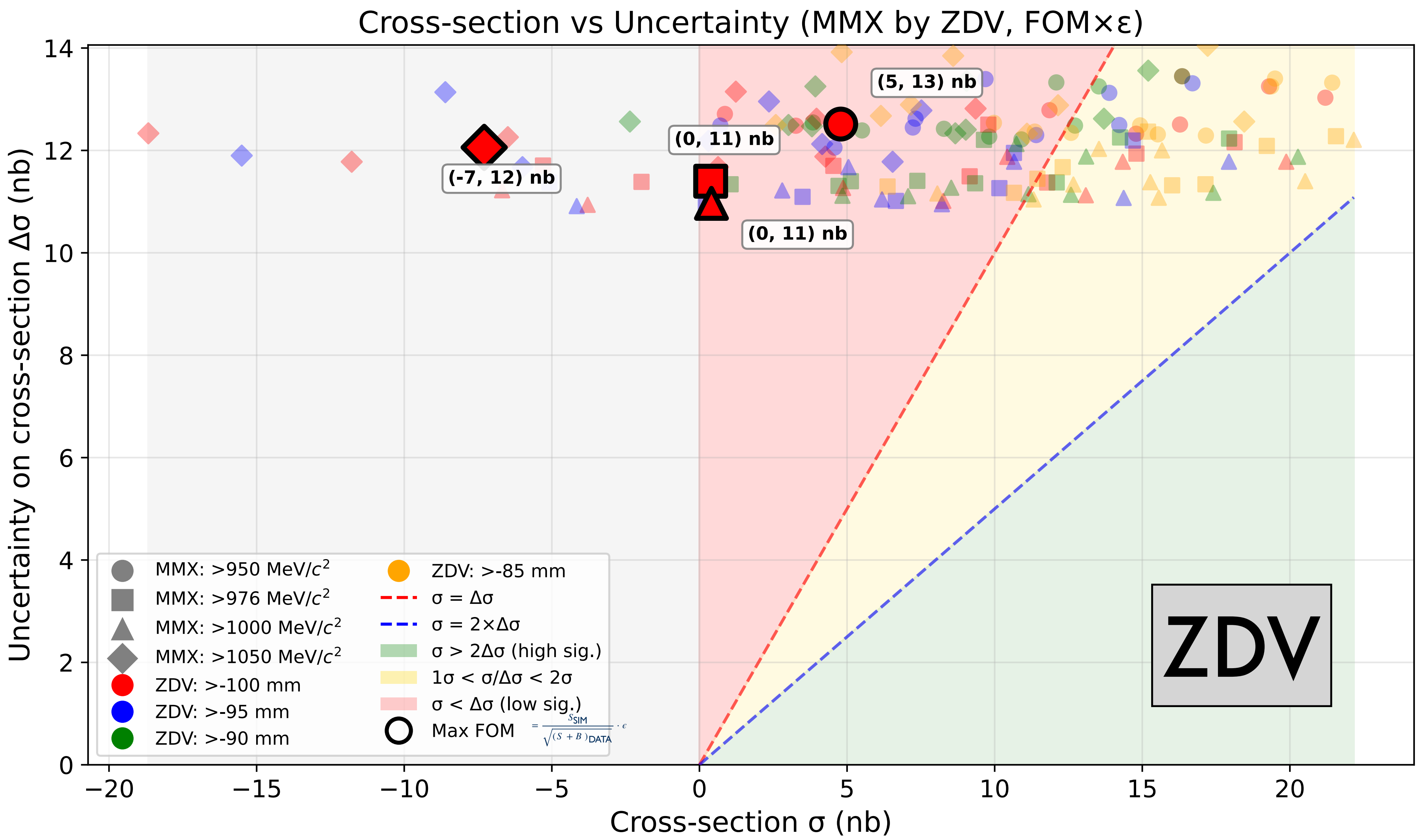
M_{Λ_1} vs. M_{Λ_2} Difference



CS variation in the parameter space

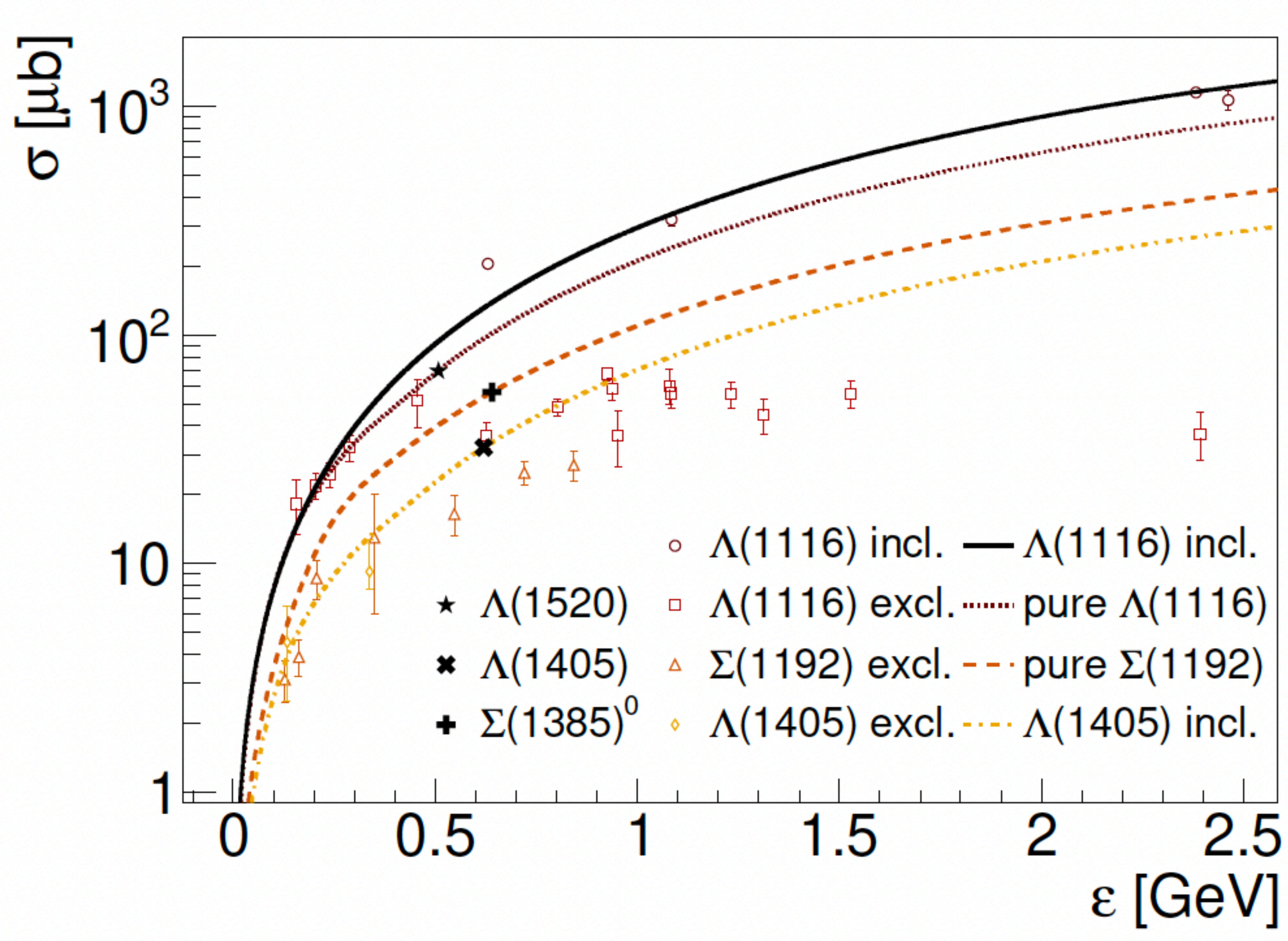






- The MMX selection parameter is shown in shapes while the selection in the shown parameter (DCA, DDV or ZDV) are indicated with colours.
- The circled markers indicate the selection combination for which the FOM has a maximum for each MMX.
- **Results show that no selection parameters indicate >2 st. dev**

Cross-section extrapolation:



Hyperon production cross-section as a function of excess energy $\epsilon = \sqrt{s} - \sqrt{s_{th}}$

Threshold energy for inclusive Λ production is $\sqrt{s_{th}}$ = 2.55 GeV

The interpolation function denoted by the solid line is:

$$\sigma_{pp\mapsto\Lambda X} = 47.97\epsilon + 292.6\epsilon^2 - 45.36\epsilon^3$$

This estimate for the Ξ^- production cross-section is based on the ratio:

$$\frac{\sigma_{\Xi^- X}}{\sigma_{(\Lambda+\Sigma^0)X}}$$

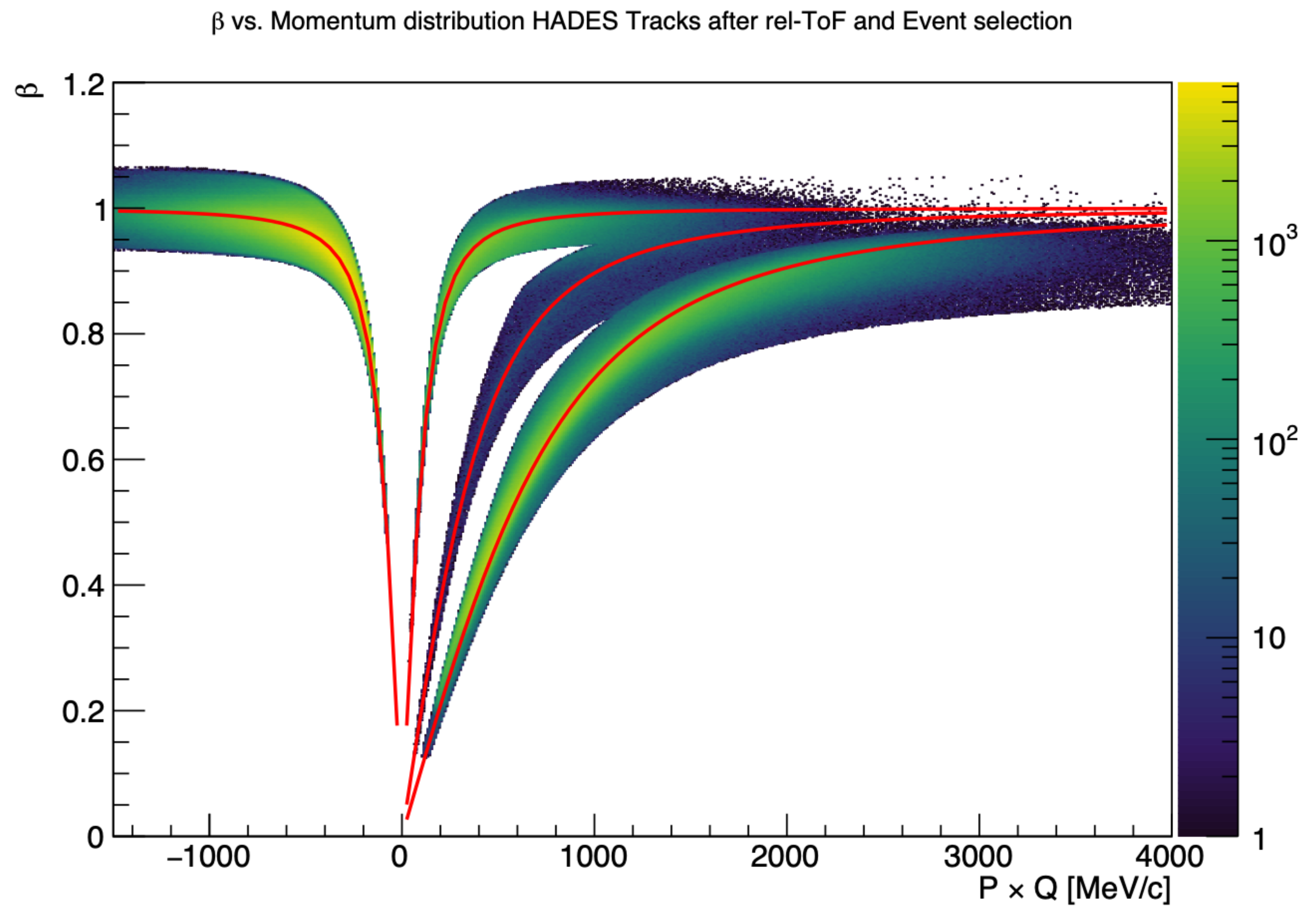
Cross-section extrapolation ($\Lambda + X$):

Table 3. List of background channels used in the benchmark simulations. See Section 3.1 for details. The "Reaction Group" column denotes the reaction in Table 1 for which the given channel is used.

	Channel	σ (μb)	Reaction Group
1	$pp\pi^+\pi^-\pi^0$	1840	AB
2	$p\pi^+\pi^-\ \Delta^+$	2760	B
3	$pn\pi^+\pi^+\pi^-\pi^0$	300	B
4	$p\pi^+\pi^+\pi^-\Delta^0$	450	B
5	$pp\pi^+\pi^-\pi^0\pi^0$	300	AB
6	$p\Lambda K^+$	54.5	A
7	$p\Lambda K^+\pi^+\pi^-$	20	A
8	$p\Sigma^0K^+$	23.5	A
9	$p\Sigma^0K^+\pi^0$	20	A
10	$p\Sigma^0K^+\pi^+\pi^-$	2	A
11	$p\Lambda K^+\pi^0$	43	AB
12	$\Delta^+K^+\Lambda$	64	B
13	$n\Lambda K^+\pi^+\pi^0$	20	B
14	$\Delta^0\pi^+K^+\Lambda$	30	B
15	$p\Lambda K^+\pi^0\pi^0$	10	B
16	$p\Lambda K^+\pi^0\pi^0\pi^0$	7	B
17	$p\Sigma^0K^0_S\pi^+$	9	BC
18	$pp\pi^+\pi^+\pi^-\pi^-$	227	CD
19	$p\Lambda K^0_S\pi^+$	30	CD
20	$p\Lambda K^+\pi^+\pi^-$	21	CD
21	$n\Lambda K^0_S\pi^+\pi^+$	10	C
22	$ppK^0_SK^0_S$	1.6	CD

Notes regarding Systematics

- How to deal with systematics from PID ?
  - Perform analysis with wider/shrunk selections on π^-, p, K^+ and π^+.
  - Wider selection $\Longrightarrow$ Longer / shorter
  - Do one separate TOF detectors: RPC, TOF and FRPC



- Systematics for stage-S1 with MM selection, one can perform the same analysis on Empty Target dataset and extrapolate the numbers for Full dataset (with Target).
  - Hope we would be left with some finite (MM > 0) events with Empty target data.
- Systematics would have to performed separately for HH, HF and FF type of Λ-Λ candidates ?!?.

To the big table again.....

MMX = 976 MeV/c^2, ZDV = -100 mm, DDV = 10 mm, DCA = 40 mm

After all the selection cuts: Invariant mass (IMX) cut is applied on the Lambda_1 vs. Lambda_2 correlation mass histogram between: **1100 MeV/c^2 to 1130 MeV/c^2** i.e. **30 MeV/c^2**

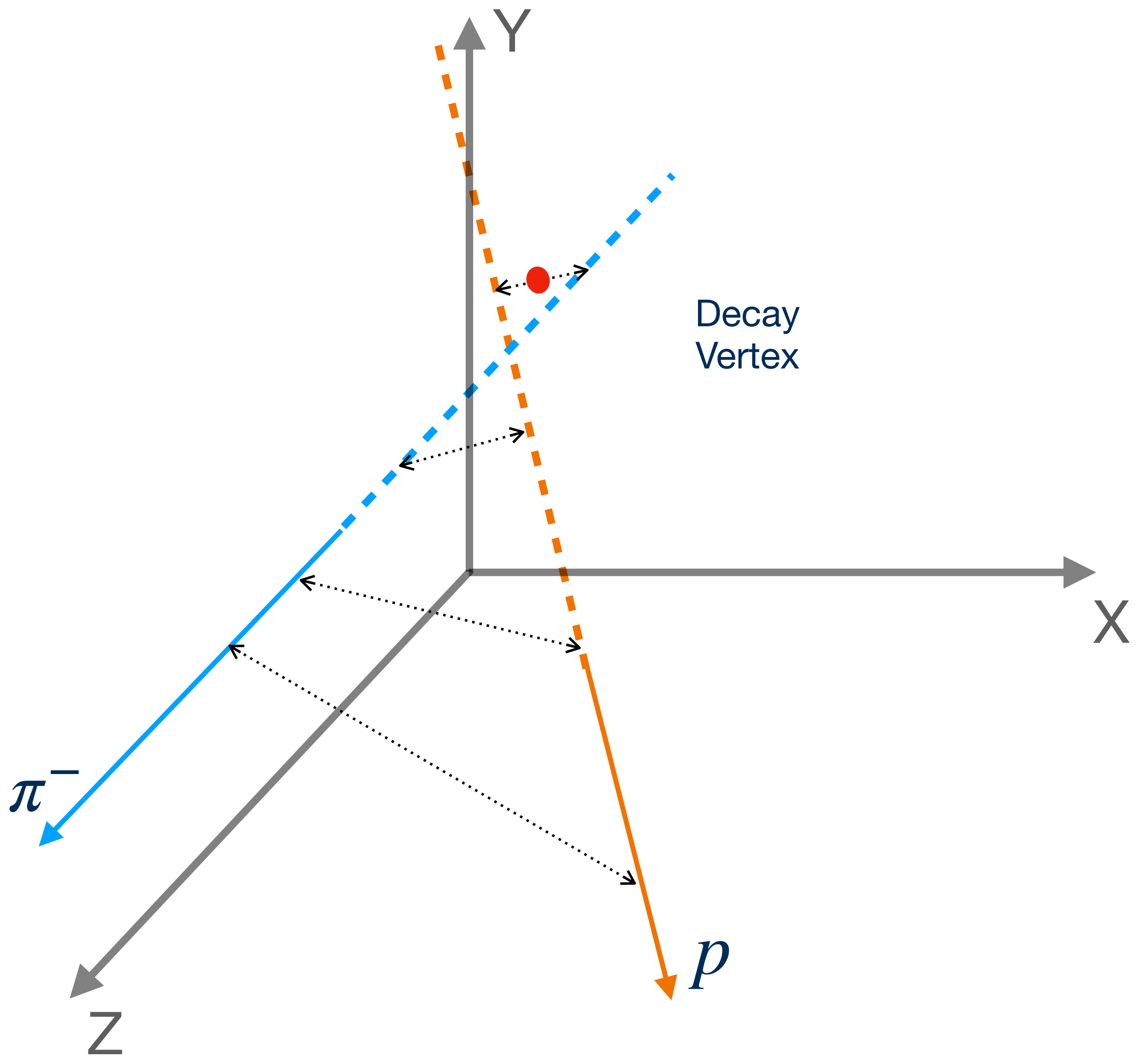
DATA (NoCut)	SIM (Recon) (NoCut)
137534	189203

					Data counts after IMX Cut	**Simulations channel counts after IMX Cut: S_MC**				**Significance:**	**% Loss in due to the CUTs**	
MMCut (MeV/c^2)	**DCA (mm) (<XX)**	**ZDV (mm) (>XX)**	**DDV (mm) (>XX)**	**PPV**	**Total Counts (S + B)**	**OL BG (100 M)**	**NR BG (97 M)**	**Signal: LL (100 M)**	**TRUE LL Counts**	**[S_MC/Sqrt(S + B)]**	**In DATA**	**In SIM**
>950	20	-100	10	(==)0	2078			81741	67107	**1793,1523**	98,49	56,80
>950	20	-100	20	(==)0	1740			75780	62278	**1816,6864**	98,73	59,95
>950	20	-100	30	(==)0	1456			67165	55288	**1760,2013**	98,94	64,50
>950	20	-95	10	(==)0	1633			75198	61922	**1860,8578**	98,81	60,26
>950	20	-95	20	(==)0	1399			69801	57539	**1866,1768**	98,98	63,11
>950	20	-95	30	(==)0	1184			61860	51066	**1797,7697**	99,14	67,30
>950	20	-90	10	(==)0	1308			68645	56644	**1898,0386**	99,05	63,72
>950	20	-90	20	(==)0	1128			63858	52749	**1901,3443**	99,18	66,25
>950	20	-90	30	(==)0	966			56614	46829	**1821,5256**	99,30	70,08
>950	30	-100	10	(==)0	2468			92016	73953	**1852,2123**	98,21	51,37
>950	30	-100	20	(==)0	2091			85520	68742	**1870,2113**	98,48	54,80
>950	30	-100	30	(==)0	1776			76001	61107	**1803,4239**	98,71	59,83
>950	30	-95	10	(==)0	1974			84676	68247	**1905,8414**	98,56	55,25
>950	30	-95	20	(==)0	1706			78785	63514	**1907,4538**	98,76	58,36
>950	30	-95	30	(==)0	1476			70028	56450	**1822,7560**	98,93	62,99
>950	30	-90	10	(==)0	1616			77358	62442	**1924,3522**	98,83	59,11
>950	30	-90	20	(==)0	1404			72124	58229	**1924,8472**	98,98	61,88
>950	30	-90	30	(==)0	1221			64147	51787	**1835,7711**	99,11	66,10
>950	40	-100	10	(==)0	2706			96003	76042	**1845,5291**	98,03	49,26
>950	40	-100	20	(==)0	2312			89361	70747	**1858,4638**	98,32	52,77
>950	40	-100	30	(==)0	1973			79565	62940	**1791,2596**	98,57	57,95

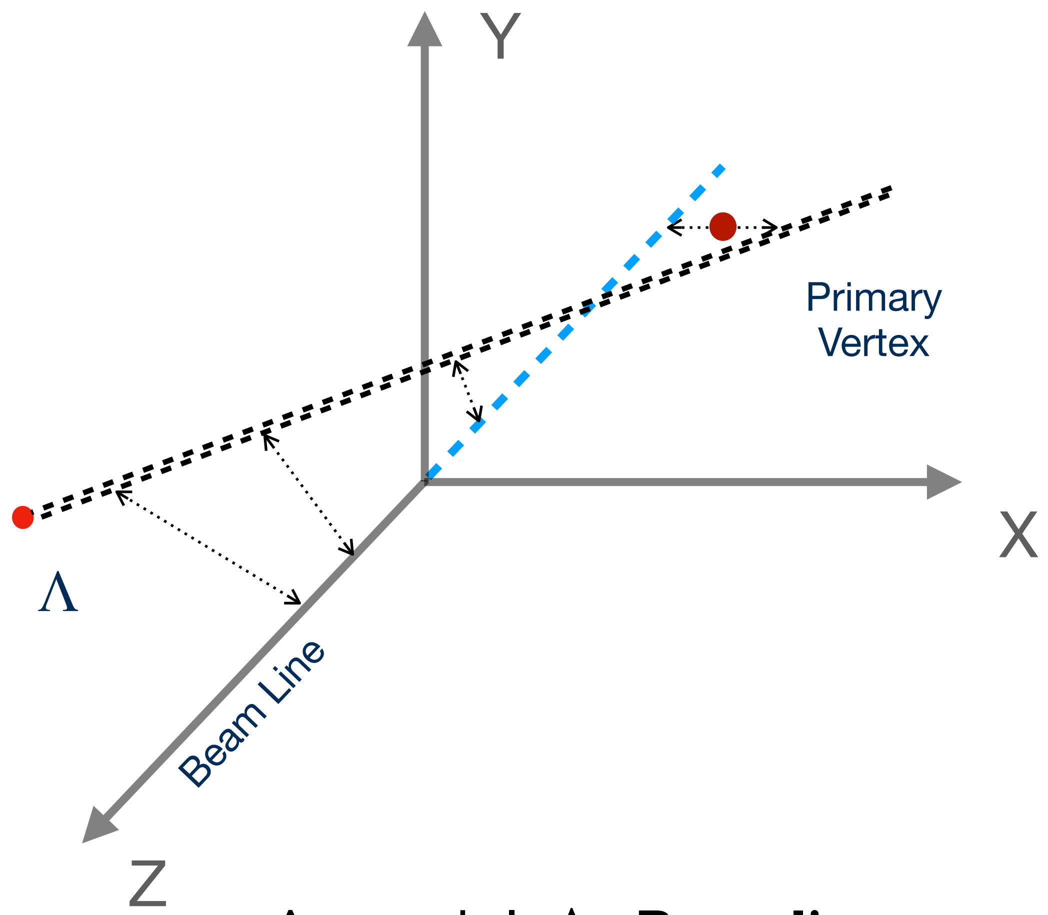
π^+ Reconstruction efficiency: NRBG

```
Total Events analysed:                                                          1000000
Total number of [Exclusive] Events select:                                          0
Total 2p pi HF counts:                                                              0
Total number of Tracks [HADES, Forward]:                                            [4146360, 415639]
Total number of final state particles [p(Prim + Dec), pi-, pi+, K+]:                     [514517(514517+0), 0, 815997, 0]
Total number of final state particles in Forward Track [p(Prim + Dec), pi-, pi+, K+]:   [245322(218012+0), 0, 63052, 0]
Final State Tracks
HADES
Number of primary protons                                                          514517 51.4517%
Number of decay protons                                                            0 0%
Number of pionMinus Lambda(s)                                                      0 0%
Number of pionPlus Primary                                                         815997 40.7998%
Number of kaons                                                                    0 0%
Forward
Number of primary protons                                                          218012 21.8012%
Number of decay protons                                                            0 0%
Number of pionMinus Lambda(s)                                                      0 0%
Number of pionPlus Primary                                                         63052 3.1526%
Number of kaons                                                                    0 0%
```

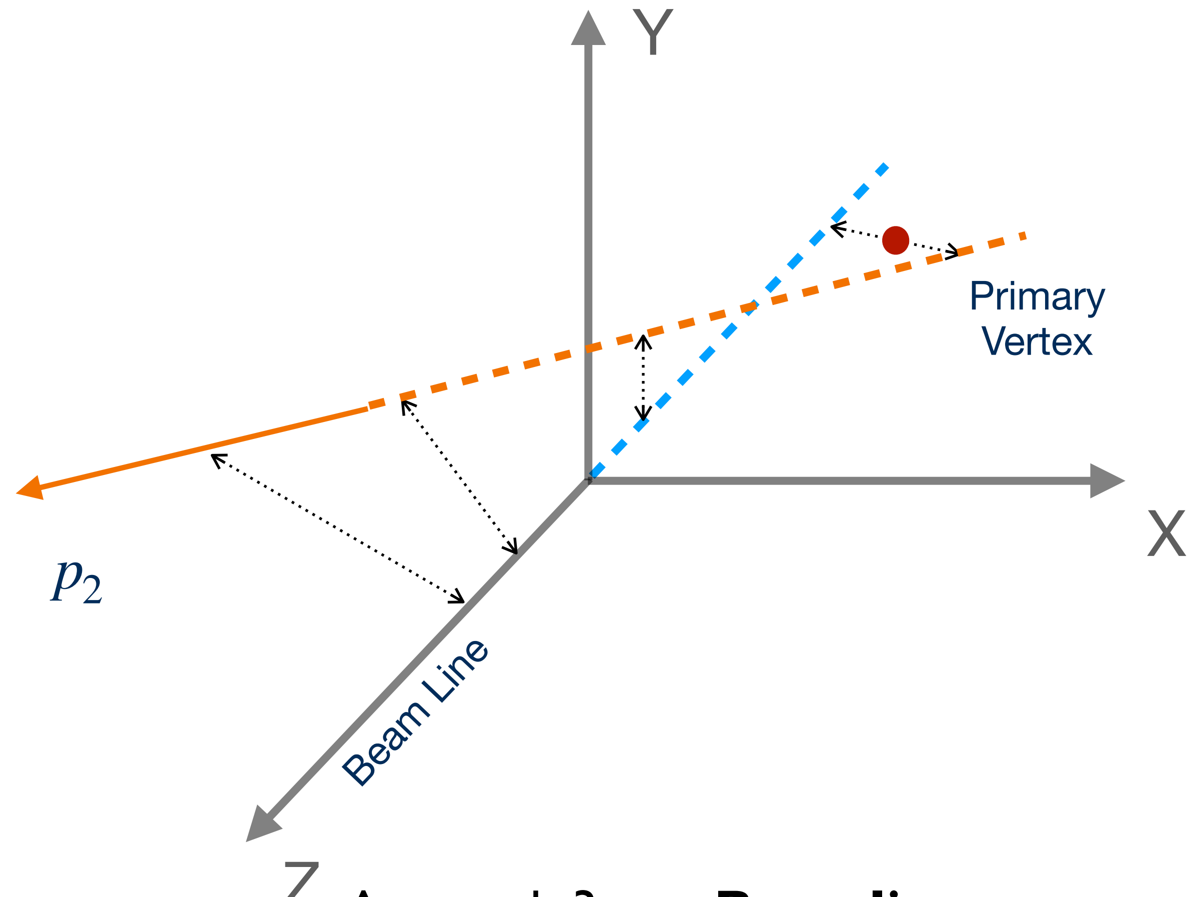
Decay and primary Vtx reconstruction



Λ-Reconstruction

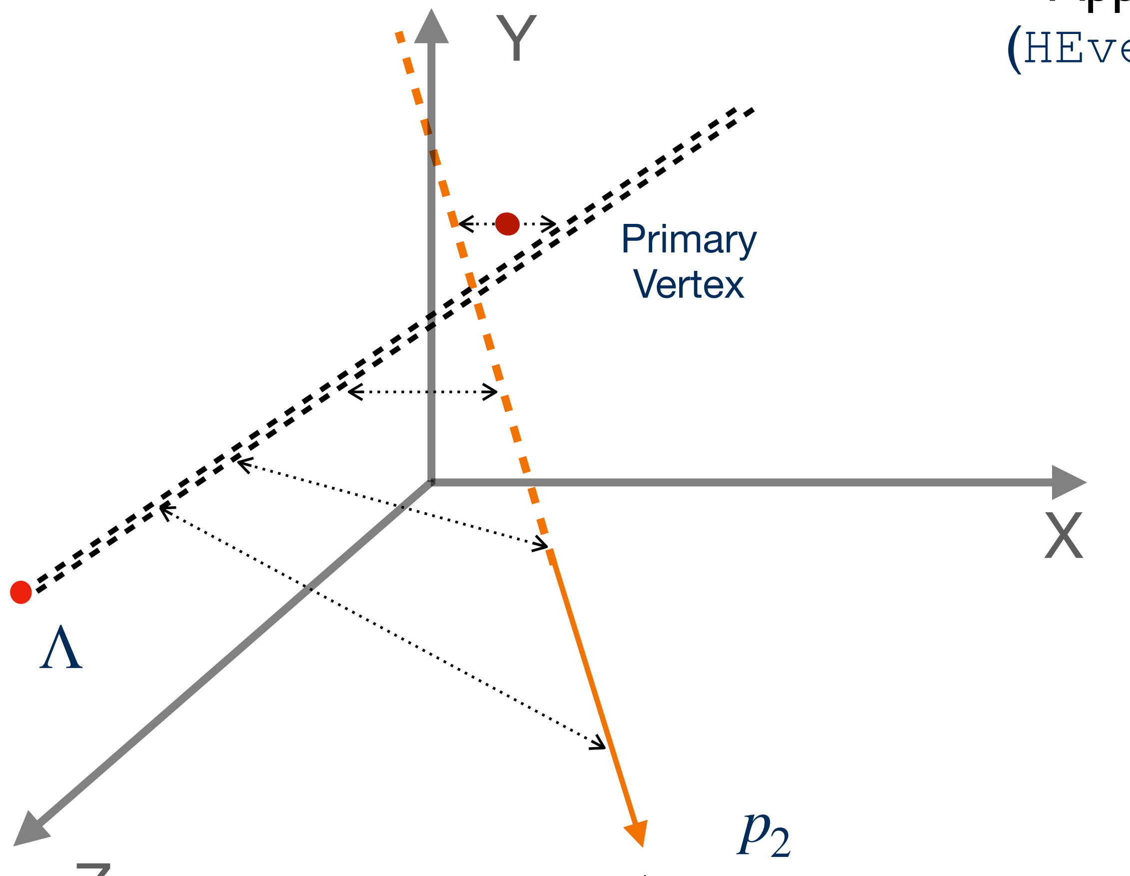


Approach 1: **Λ- Beamline**

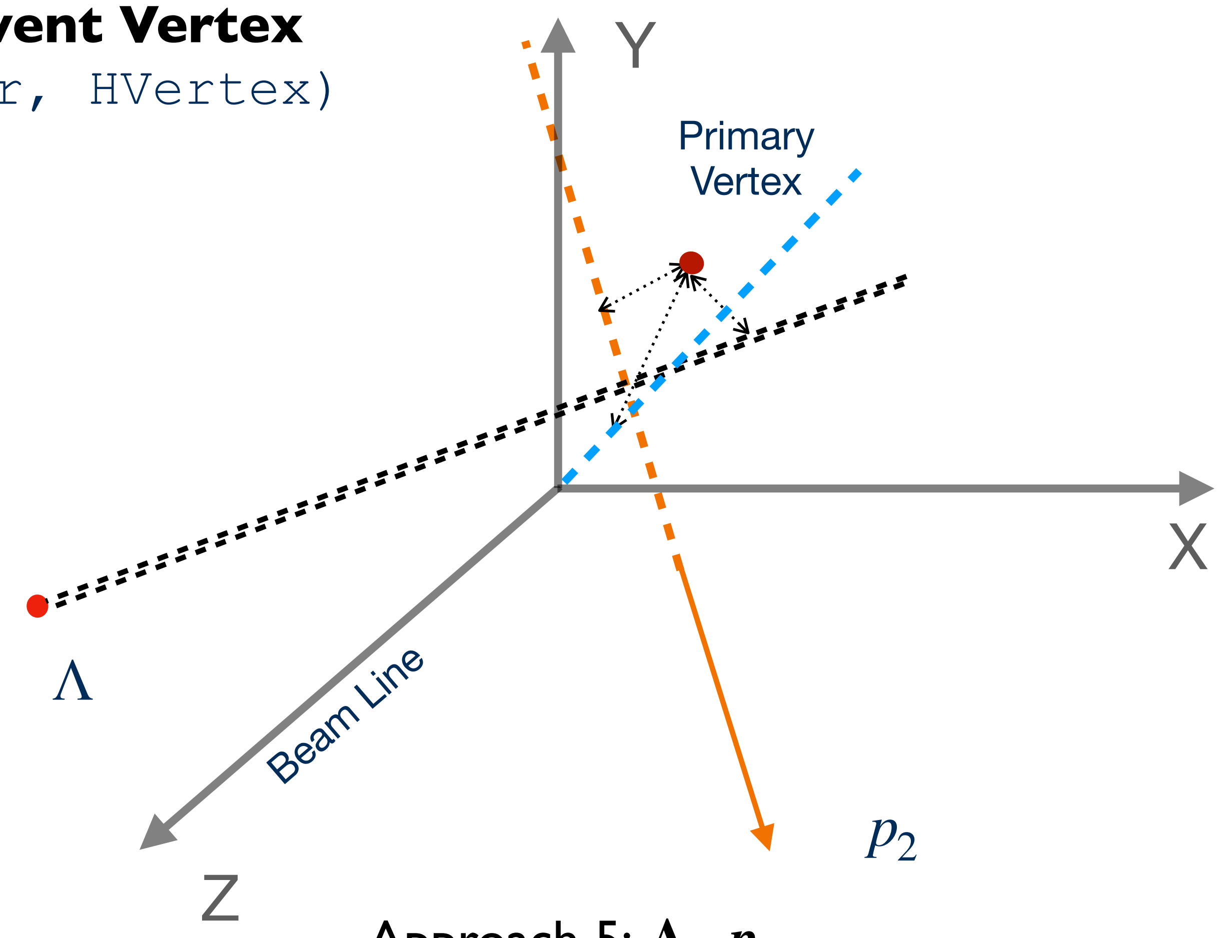


Approach 3: p_2**- Beamline**

Approach 2: **Event Vertex**
(`HEventHeader, HVertex`)



Approach 4: **Λ-** p_2



Approach 5: **Λ-** p_2
-Beamline

- `KinFit` demands Estimating Primary Vertex to reconstruct the Neutral candidate
- The requirement is to estimate the **Direction (θ, ϕ)** of the Neutral candidate**,** here **Λ**
- Specific to the topology of the channel, multiple approaches can be applied to reconstruct Primary vertex (Event vertex)