



BESIII

Study of Baryon Interaction $\bar{n}n(\bar{p}p) \rightarrow \bar{p}p$ and Baryon Transition $\Xi^0 \rightarrow \gamma \Sigma^0$ at BESIII

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Mid Term Report

Oct. 14, 2026

Outline

- Introduction
- Interaction — $\bar{n}n \rightarrow \bar{p}p$ and $\bar{p}p \rightarrow \bar{p}p$
- Transition — hyperon radiative decay $\Xi^0 \rightarrow \Sigma^0 \gamma$
- Summary and prospects

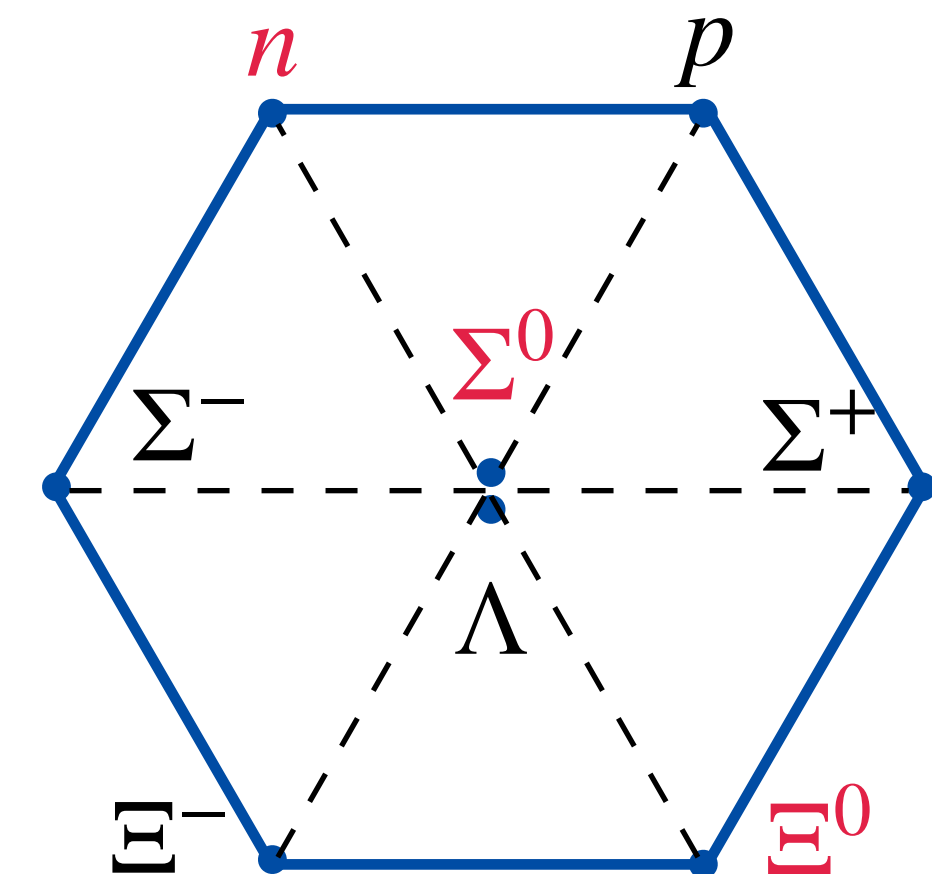
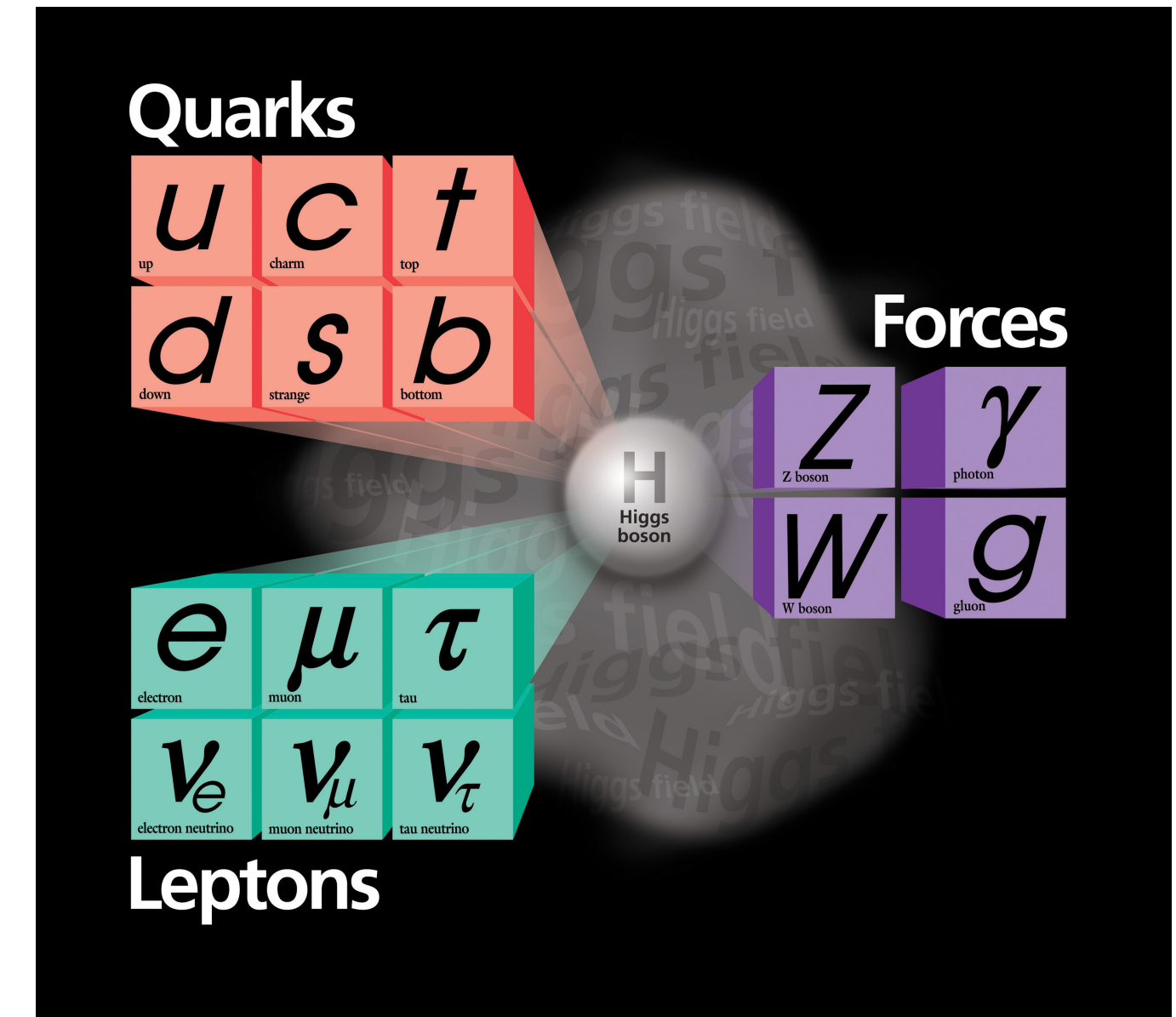
Introduction

Standard Model and QCD

- Standard Model has achieved remarkable success
- QCD governed the Baryon properties
- non-pQCD at low energies remains challenging

Two experimental perspectives

- **Transition:** tag Ξ^0 from J/ψ and reconstruct $\Xi^0 \rightarrow \Sigma^0 \gamma$
- **Interaction:** tag $\bar{n}$ and $\bar{p}$ from J/ψ decay and study $\bar{n}n \rightarrow \bar{p}p, \bar{p}p \rightarrow \bar{p}p$



$$n : udd, \quad \Sigma^0 : uds, \quad \Xi^0 : uss \quad 3$$

BEPCII and BESIII



Tagged baryon samples

10 billion J/ψ decays

$$\mathcal{B}(J/\psi \rightarrow \Xi^0 \bar{\Xi}^0) \sim (1.17 \pm 0.04) \times 10^{-3}$$

$$\mathcal{B}(J/\psi \rightarrow p \bar{n} \pi^-) \sim (2.12 \pm 0.09) \times 10^{-3}$$

$$\mathcal{B}(J/\psi \rightarrow p \bar{p} \pi^- \pi^+) \sim (6.0 \pm 0.5) \times 10^{-3}$$

EMC

Resolution at 1 GeV

Barrel: 2.5%

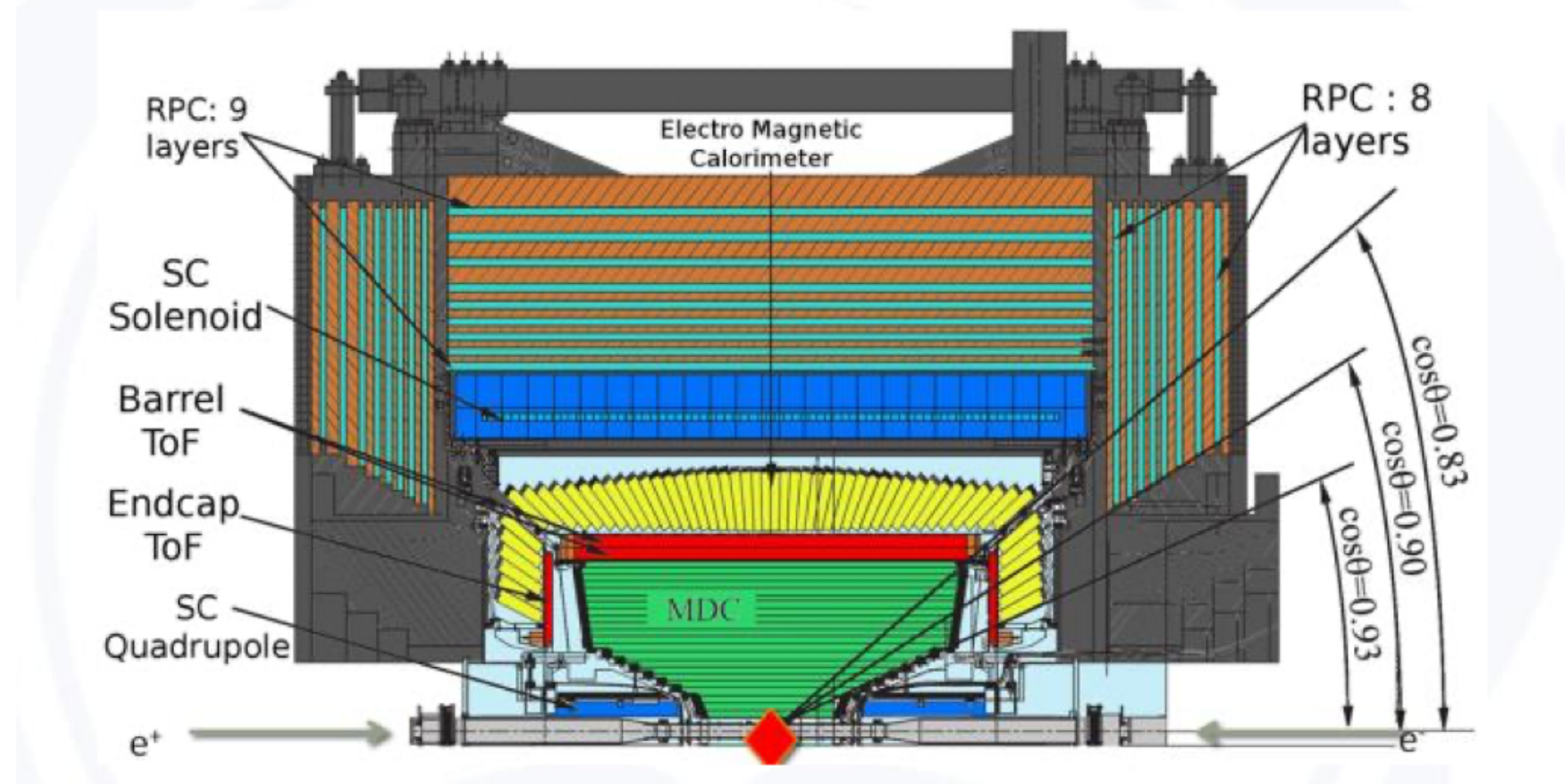
Endcaps: 5.0%

MUC

RPC readout

9 barrel layers

8 endcap layers



MDC

$$\sigma_{xy} = 130 \mu\text{m}$$

$$dE/dx \sim 6 \%$$

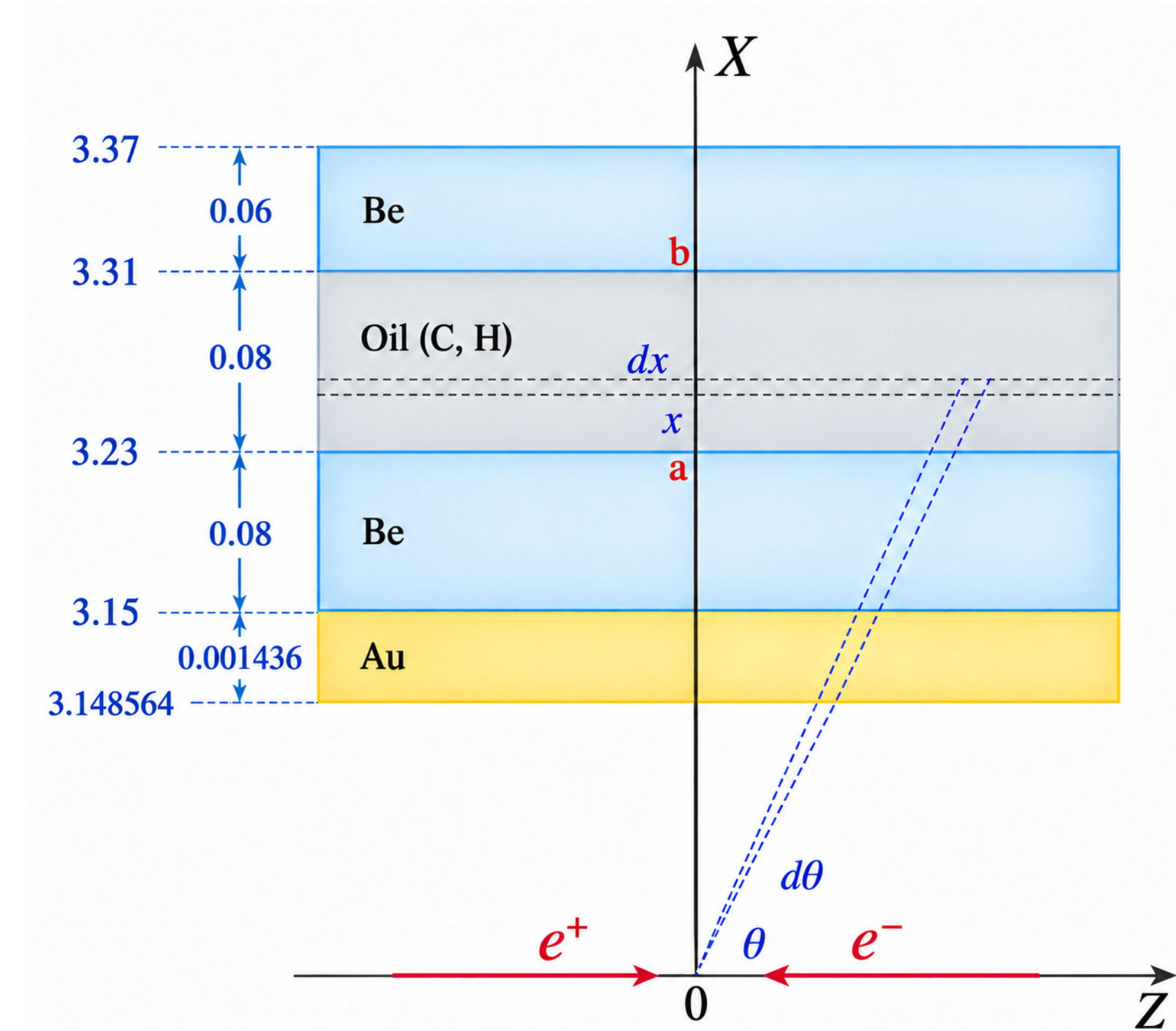
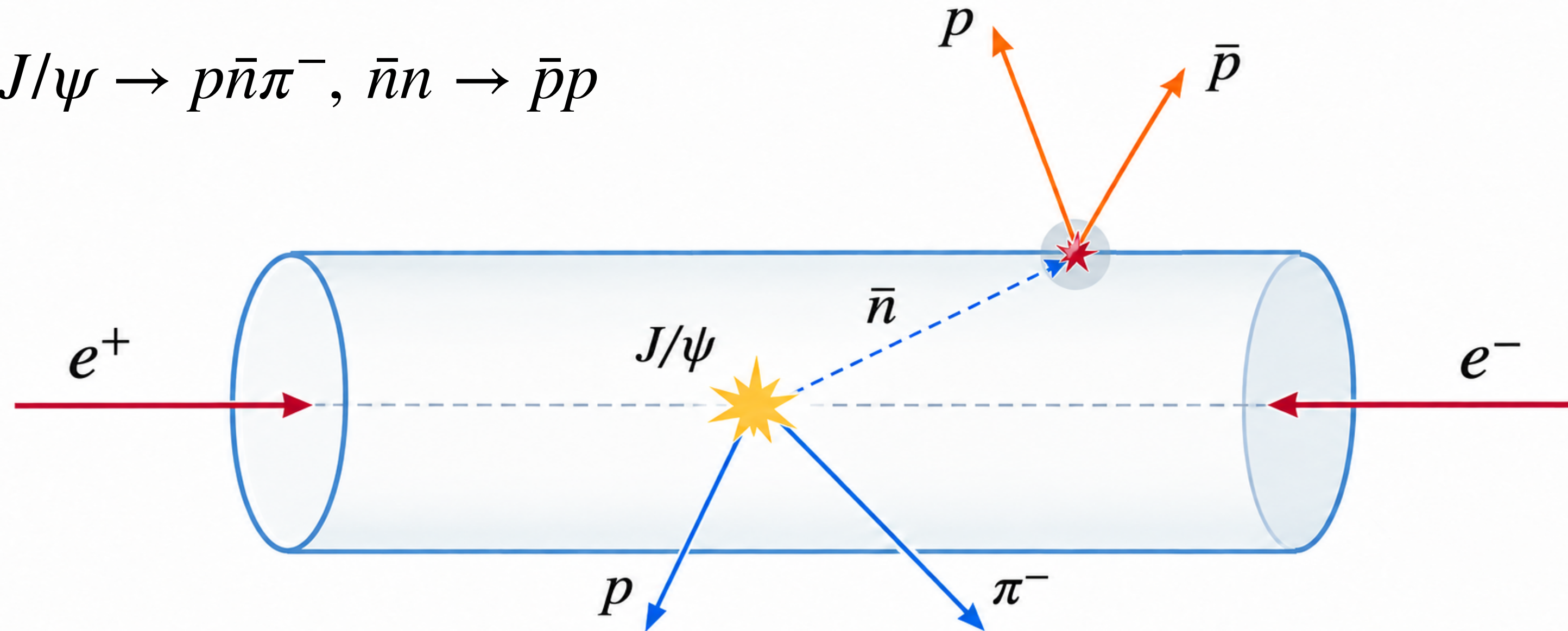
TOF

Barrel: 68 ps

Endcaps: 60 ps

Interaction — $\bar{n}n \rightarrow \bar{p}p$ & $\bar{p}p \rightarrow \bar{p}p$

$$J/\psi \rightarrow p\bar{n}\pi^-, \bar{n}n \rightarrow \bar{p}p$$

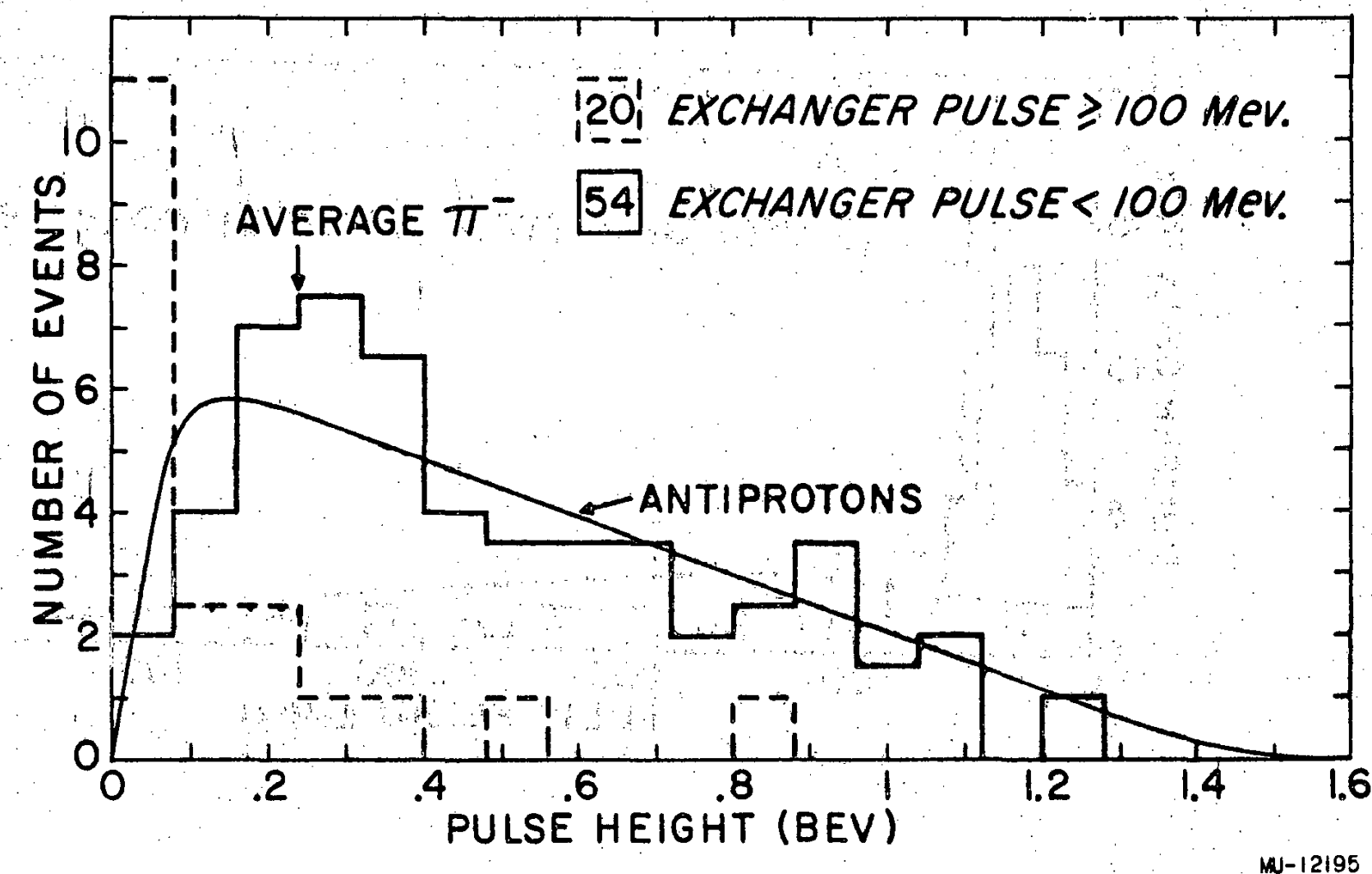


Interaction — Why charge exchange?

Discovery of the antineutron

- 1956: discovery through charge exchange

$$\bar{p}p \rightarrow \bar{n}n$$



Isospin amplitudes

- For $\bar{N}N$ system $I = 0$ or 1

$$T(\bar{p}p \rightarrow \bar{p}p) = \frac{T_0 + T_1}{2}$$

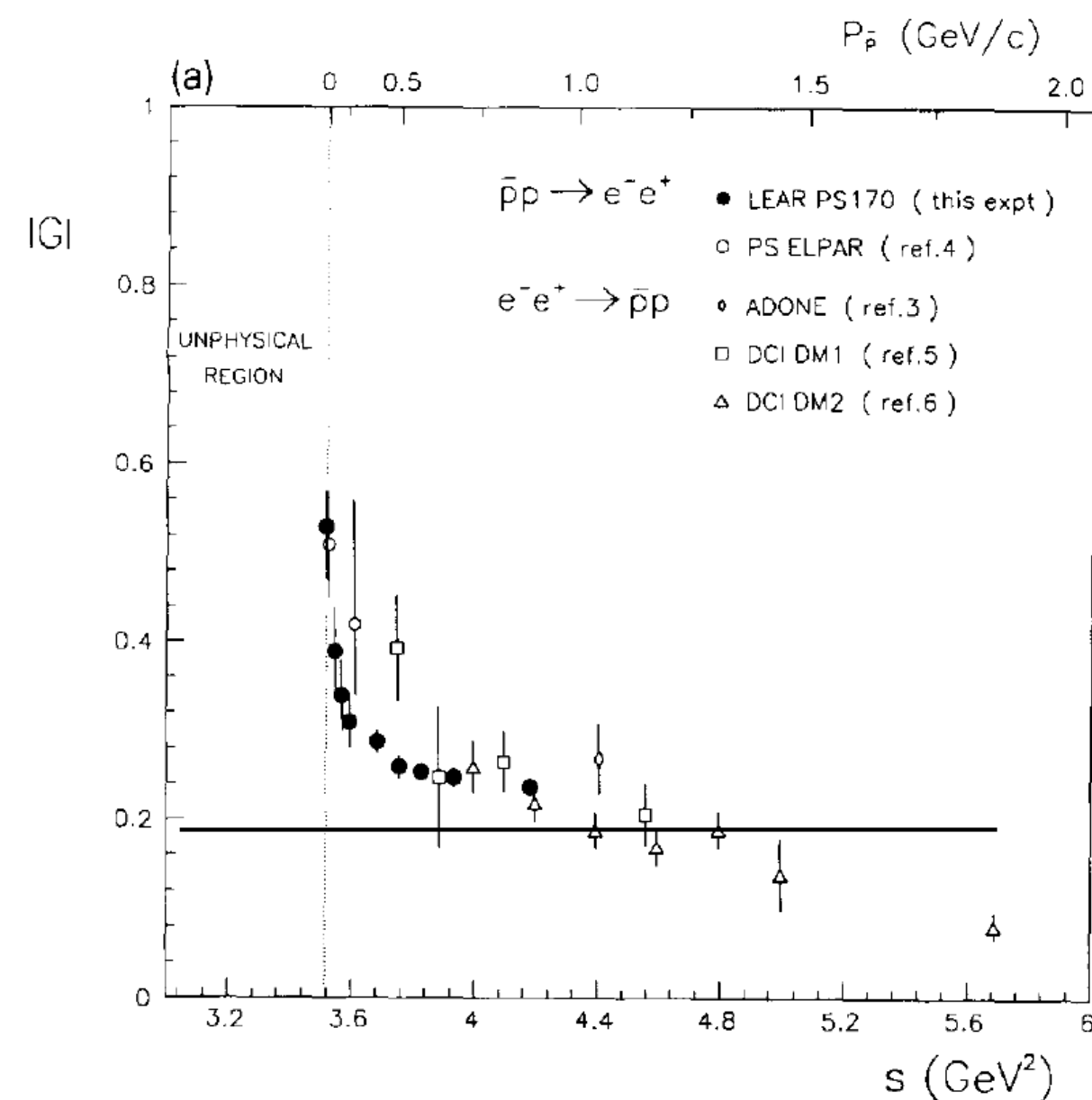
$$T(\bar{n}n \rightarrow \bar{p}p) = \frac{T_0 - T_1}{2}$$

- Complementary isospin constraints

Interaction — Near-threshold structure

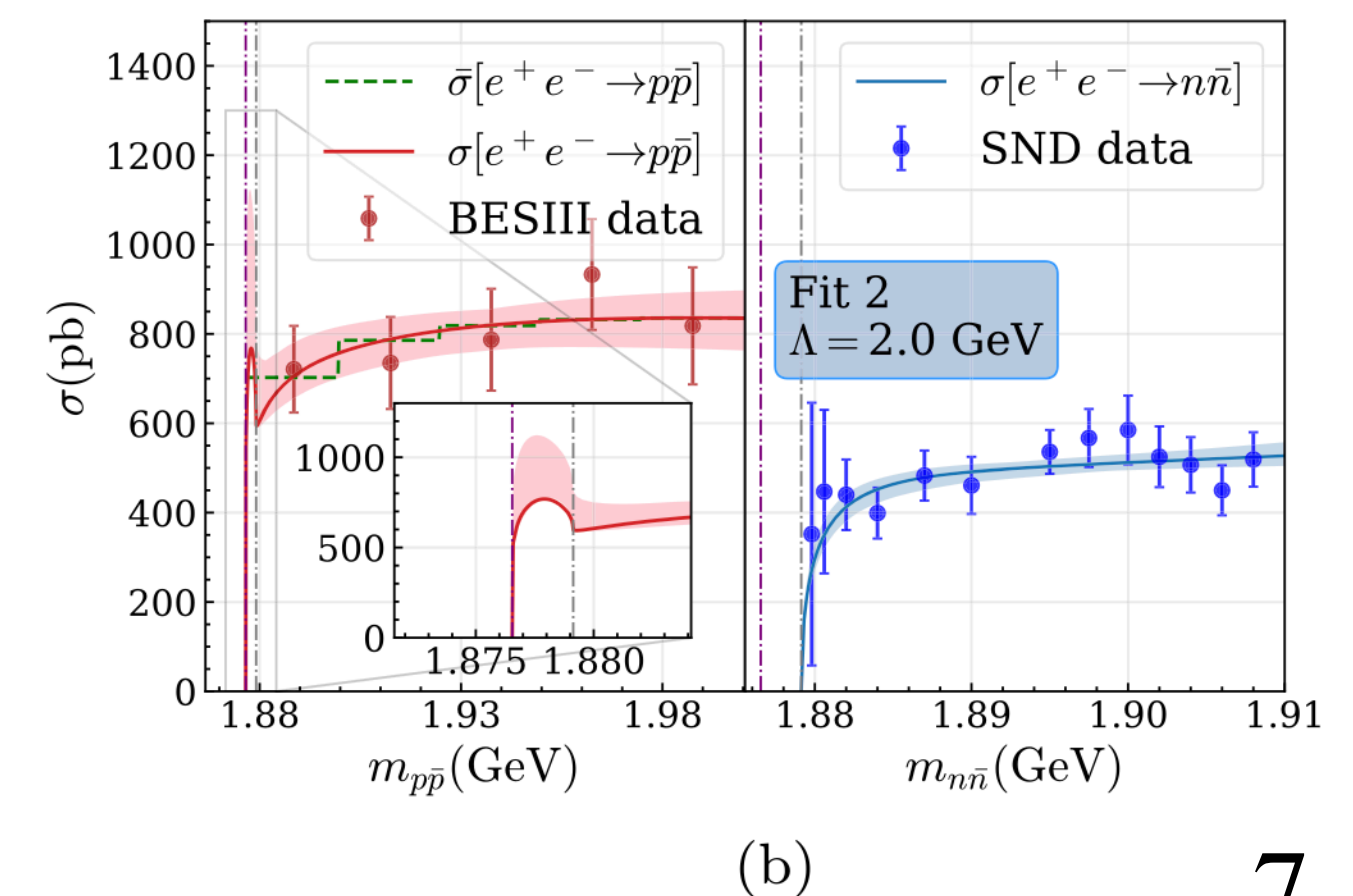
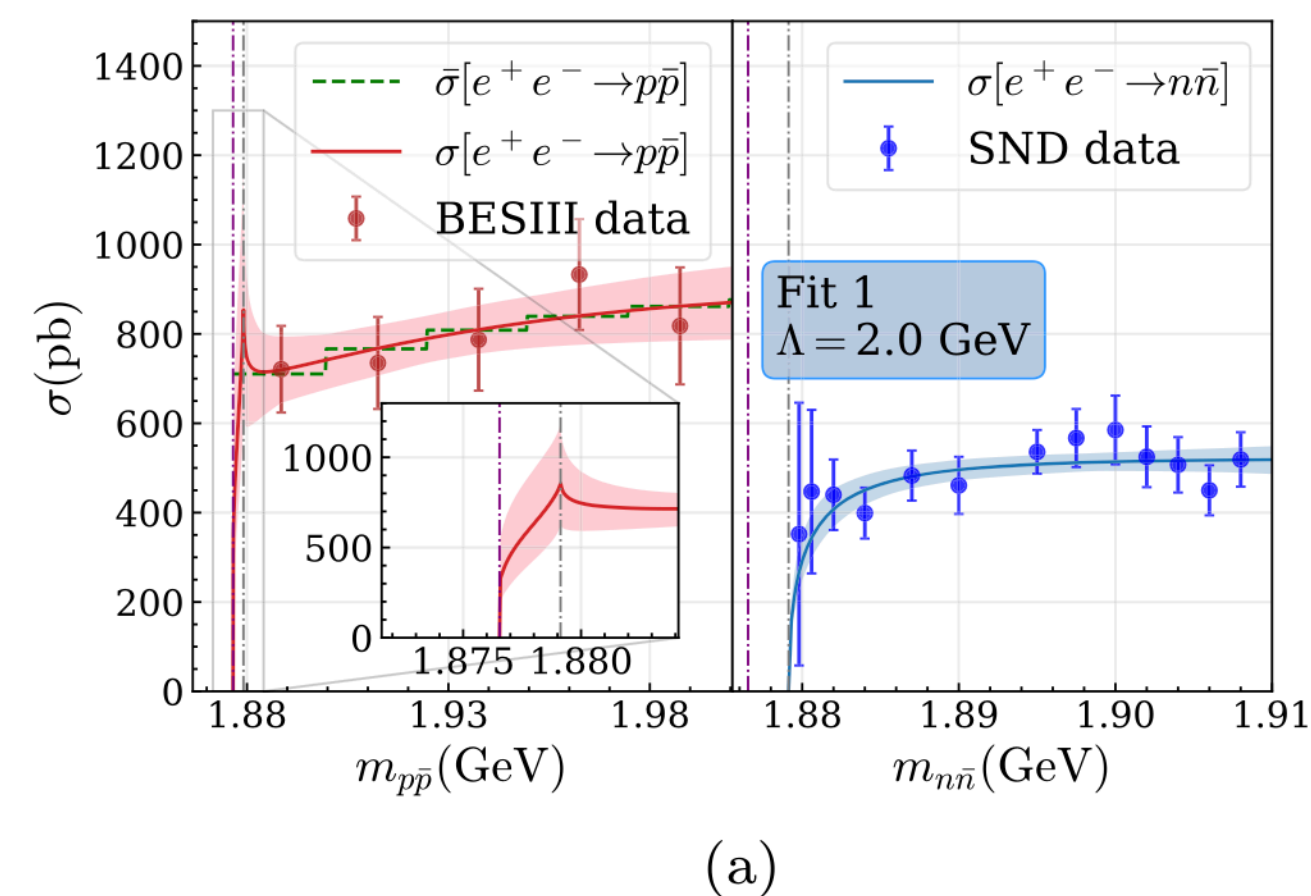
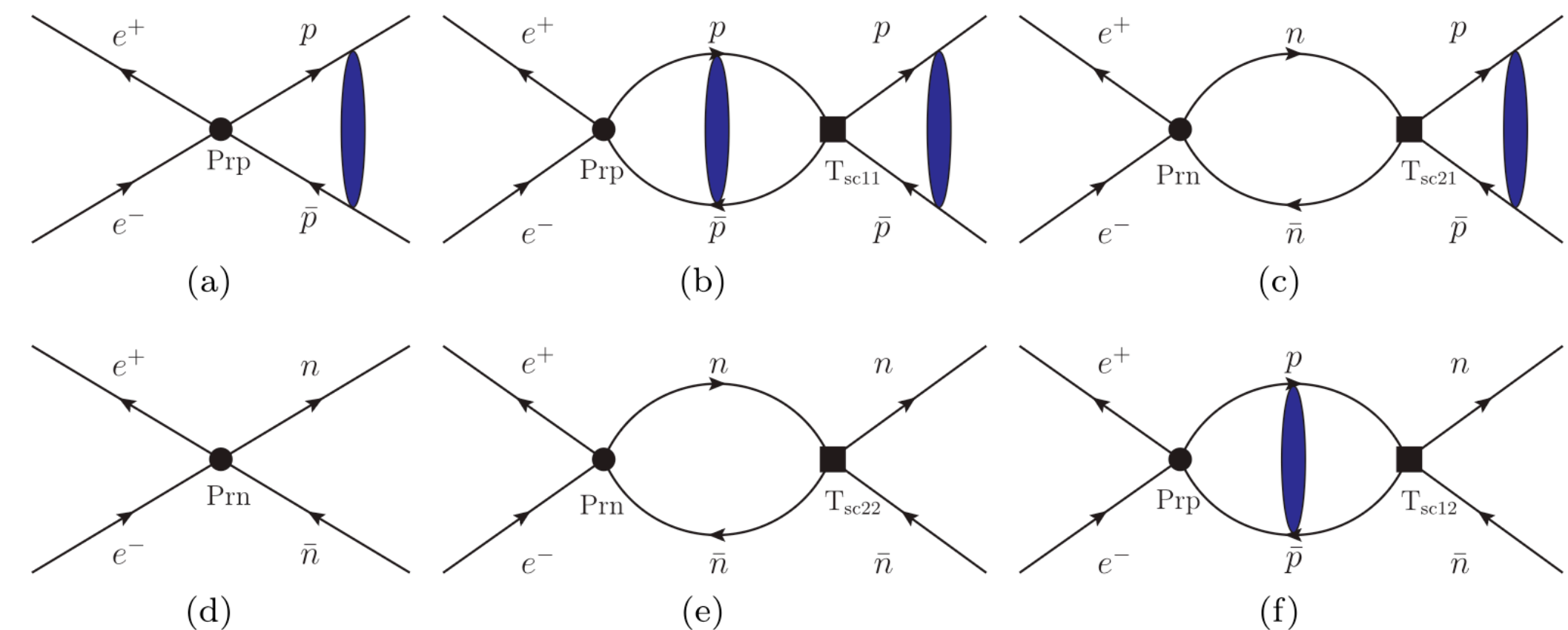
Threshold enhancement

- PS170 (1991–1994)
- Steep near-threshold form factor
- Observed in several hadron decays and e^+e^- annihilations (include $e^+e^- \rightarrow \bar{n}n$)



Coupled-channel FSI

- CEX coupling

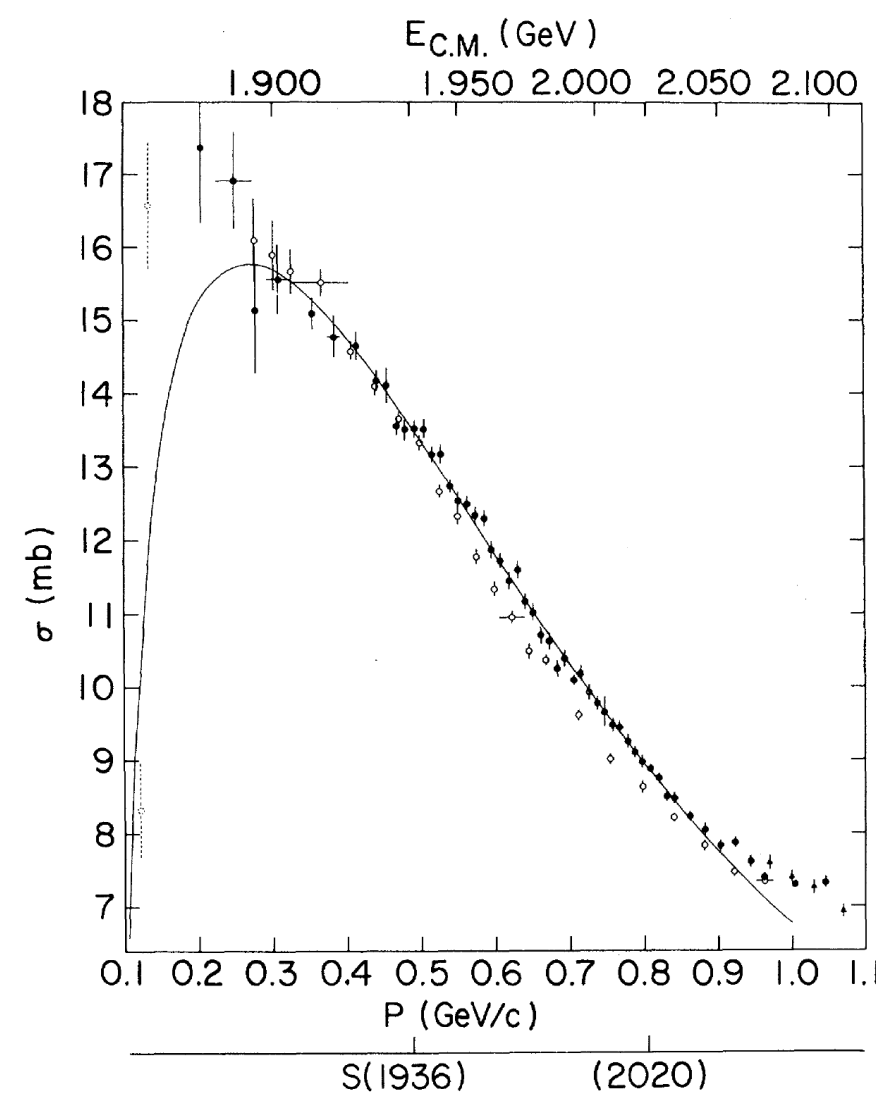


Interaction — Existing charge-exchange data

Experimental results

- No direct measurement for $\bar{n}n \rightarrow \bar{p}p$
- Convert $\bar{p}p \rightarrow \bar{n}n$ results

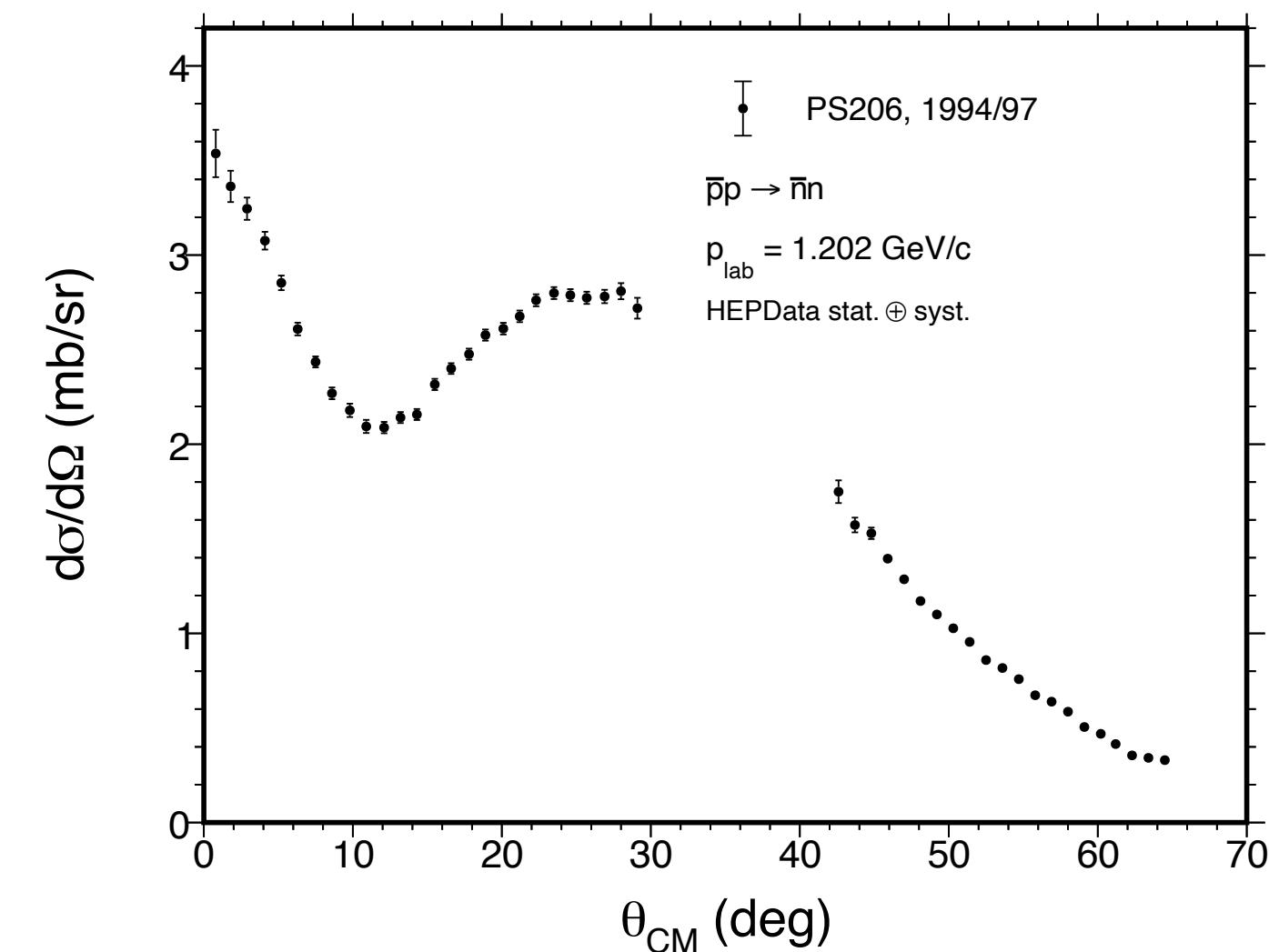
BNL AGS — Hamilton 1980



Integrated cross section

Beam momentum: 0.119–1.046 GeV/c

CERN LEAR — PS206



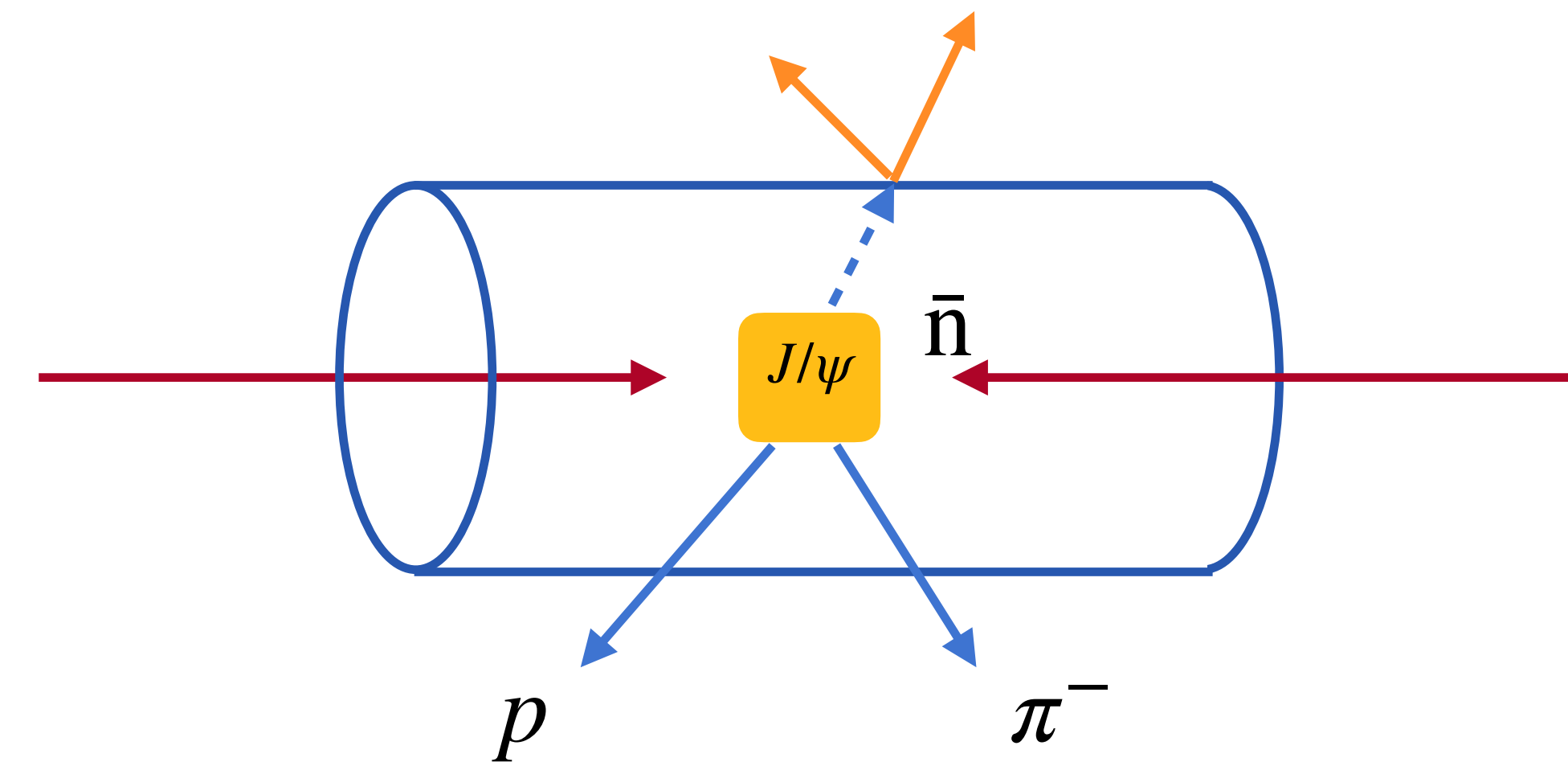
Corrected differential cross section

Forward peak and dip–bump structure

Interaction — Measurement strategy

Analysis strategies

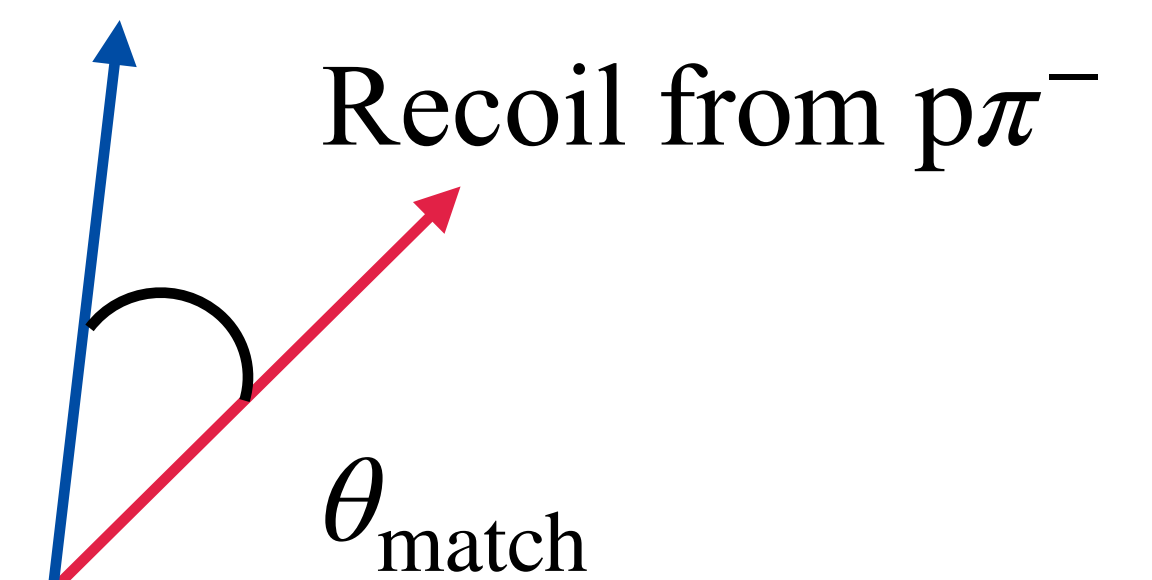
- Select $J/\psi \rightarrow p\pi^-\bar{n}$
- Prompt tracks: $V_r < 0.5$ cm , $|V_z| < 5$ cm
- Interaction tracks: $0.5 < V_r < 10$ cm , $|V_z| < 30$ cm
- Vertex match: $\theta_{\text{match}} < 10^\circ$
- Exactly one additional proton and one antiproton



Beam-pipe region (cm)

$$V_r < 5, |V_z| < 10$$

IP to Vertex



Interaction — Measurement strategy

Calculation of cross section

- reaction rate: $P = n_{\text{H}} \ell \sigma$

n_{H} : hydrogen number density, ℓ : path of $\bar{p}$ within oil

- number of incident $\bar{p}$: $N_{\text{inc}} = N_{\text{tag}} / \epsilon_{\text{tag}}$
- number of reaction events: $N_{\text{sig}} = N_{\text{inc}} n_{\text{H}} \bar{\ell} \cdot \sigma \cdot \epsilon_{\text{sig}}$

$$\rightarrow N_{\text{sig}} = N_{\text{tag}} n_{\text{H}} \bar{\ell} \sigma \frac{\epsilon_{\text{sig}}}{\epsilon_{\text{tag}}} = \mathcal{L}_{\text{H}}^{\text{tag}} \cdot \sigma \cdot \frac{\epsilon_{\text{sig}}}{\epsilon_{\text{tag}}}$$

$$\rightarrow \sigma = \frac{N_{\text{sig}} / \epsilon_{\text{sig}}}{\mathcal{L}_{\text{H}}^{\text{tag}} / \epsilon_{\text{tag}}} = \frac{N_{\text{sig}} / \epsilon_{\text{sig}}}{\mathcal{L}_{\text{H}}^{\text{eff}}}$$

- effective luminosity: $\mathcal{L}_{\text{H}}^{\text{eff}} = \mathcal{L}_{\text{H}}^{\text{tag}} / \epsilon_{\text{tag}} = \sum_{j=1}^{N_{\text{tag}}} \frac{n_{\text{H}} \ell_j}{\epsilon_{\text{tag}}(p_{\bar{p},j})}$

$$n_{\text{H}} = \rho_{\text{oil}} w_{\text{H}} N_{\text{A}} / M_{\text{H}}, \quad \ell_j = \frac{r_{\text{out}} - r_{\text{in}}}{\sin \theta_j}$$

Differential cross section

$$\left(\frac{d\sigma}{dx} \right) |_k = \frac{N_{\text{sig},k} / \epsilon_{\text{sig},k}}{\Delta x \mathcal{L}_{\text{H}}^{\text{eff}}}$$

- k : q^2 or $\cos \theta$ bin;
- ϵ_{tag} : from weighted PHSP MC
- ϵ_{sig} : from interaction MC

Interaction — MC generation

Efficiency estimation

$$\sigma = \frac{N_{\text{sig}}/\epsilon_{\text{sig}}}{\mathcal{L}_{\text{H}}^{\text{tag}}/\epsilon_{\text{tag}}} = \frac{N_{\text{sig}}/\epsilon_{\text{sig}}}{\mathcal{L}_{\text{H}}^{\text{eff}}}$$

- estimation of efficiency is important

But:

- Geant4 version at BOSS is **outdated**
- existing virtual particle method is **questionable**

Our strategy

input $\bar{n}$ momentum from PWA

standalone G4 simulation

keep events with final state of interest

transfer information to BOSS

kinematic reweighing



Interaction — MC generation

Develop ManualGenerator

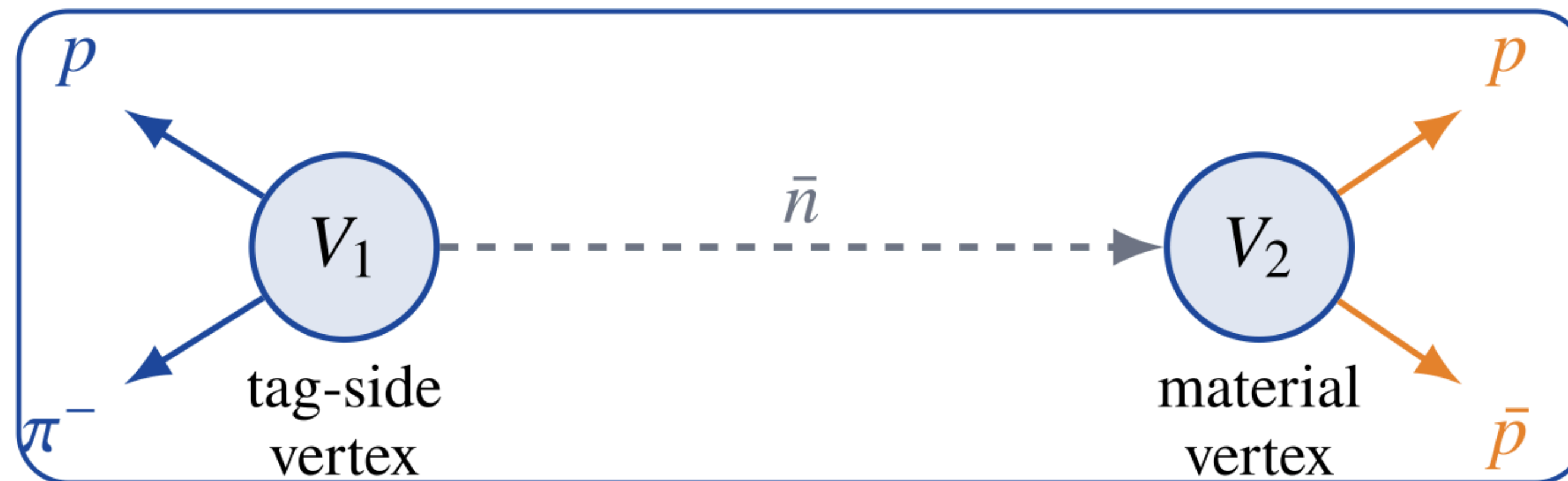
- Input each track with exact four-momenta & space-time coordinates:

(PID, p_x , p_y , p_z , E , x , y , z , t)

Modify G4Svc package

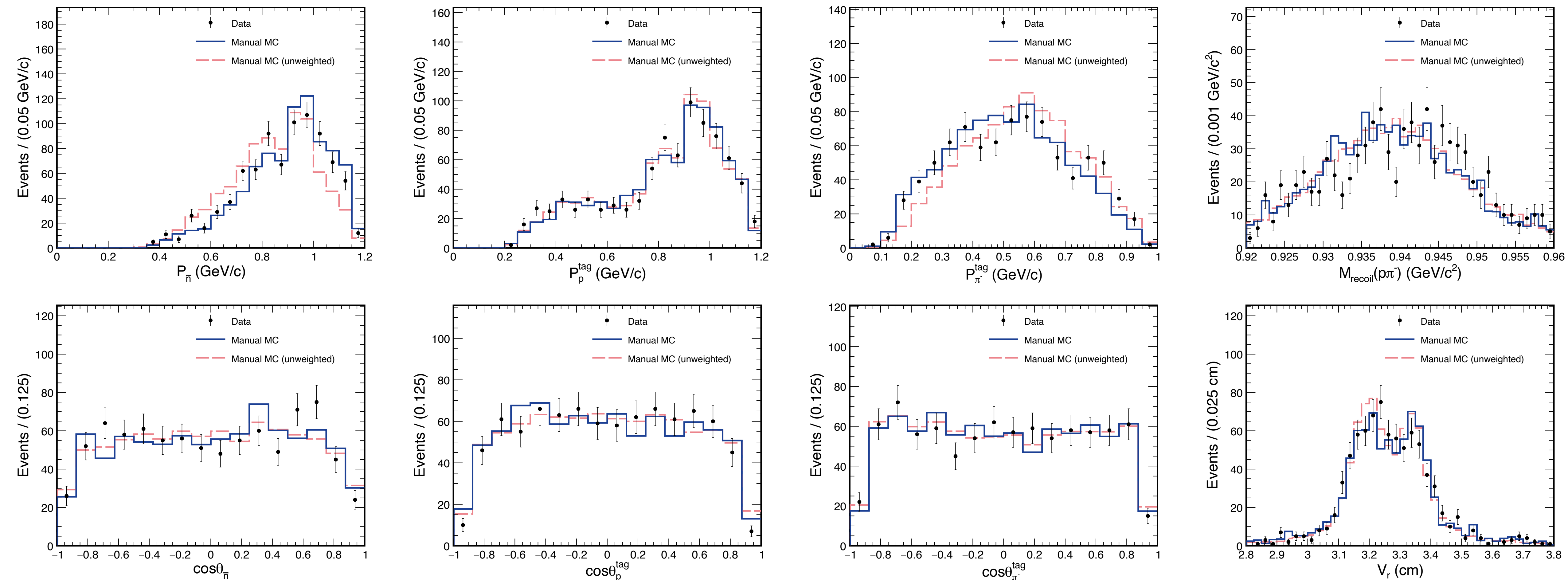
- Enable it to preserve multiple vertices in detector simulation

Two-vertex event input



Interaction — Kinematic distributions (1)

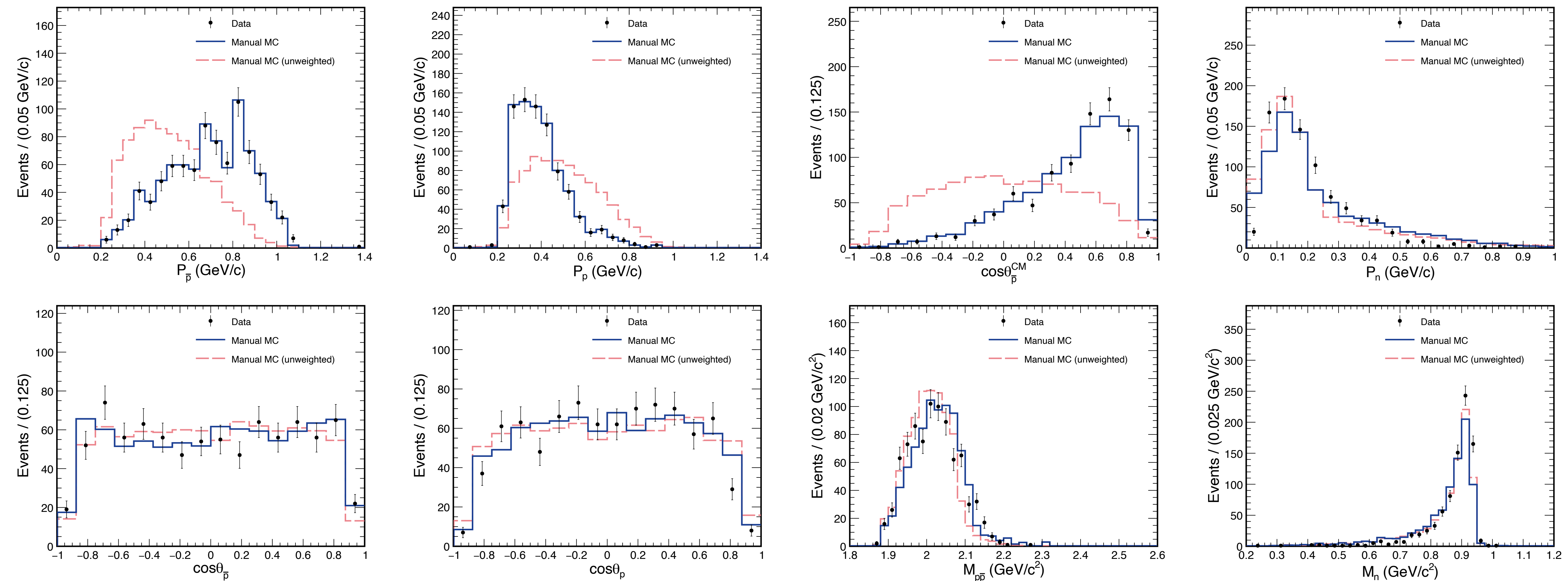
Data and 2D-weighted MC in the selected material-interaction sample



MC normalized to Data in each displayed range

Interaction — Kinematic distributions (2)

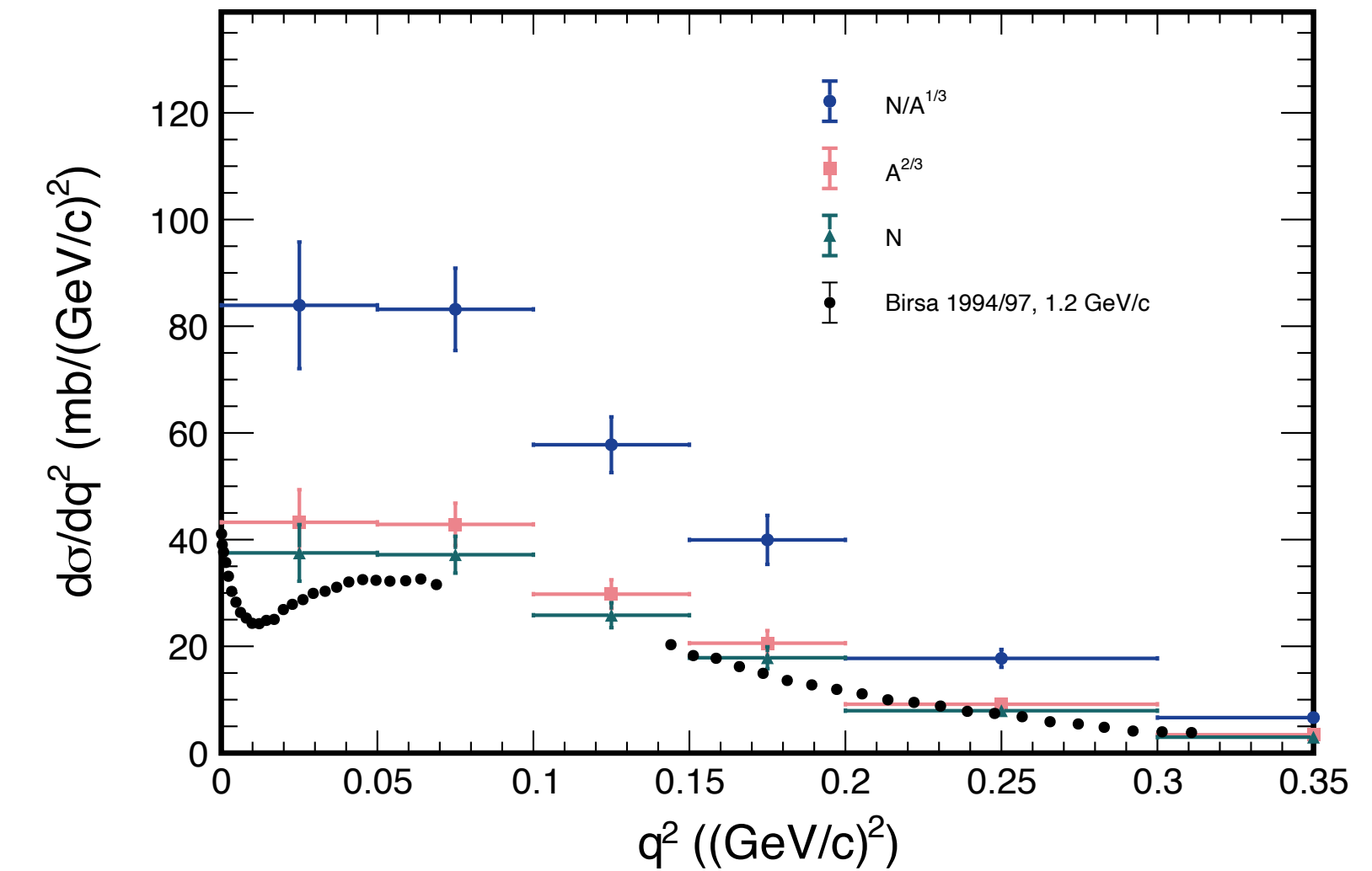
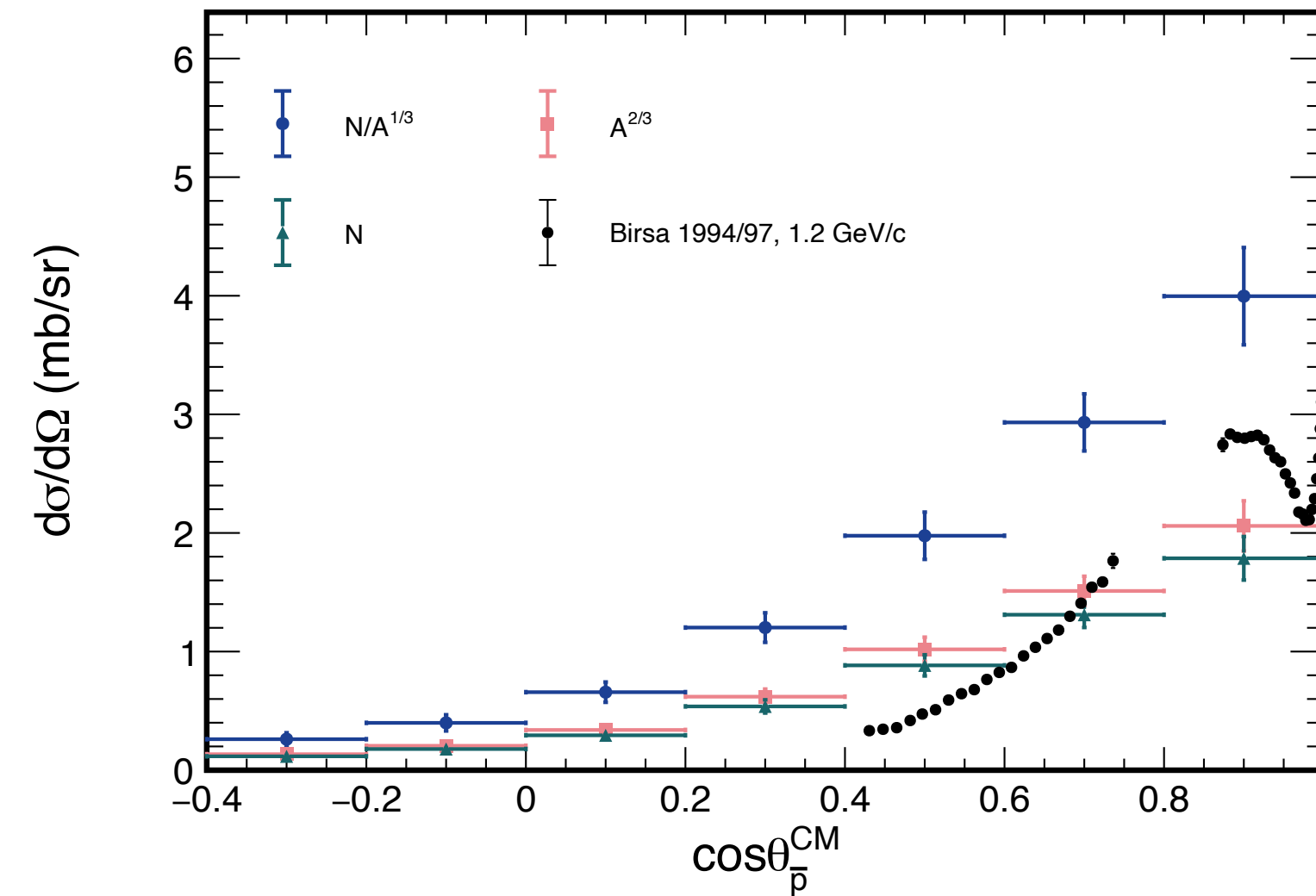
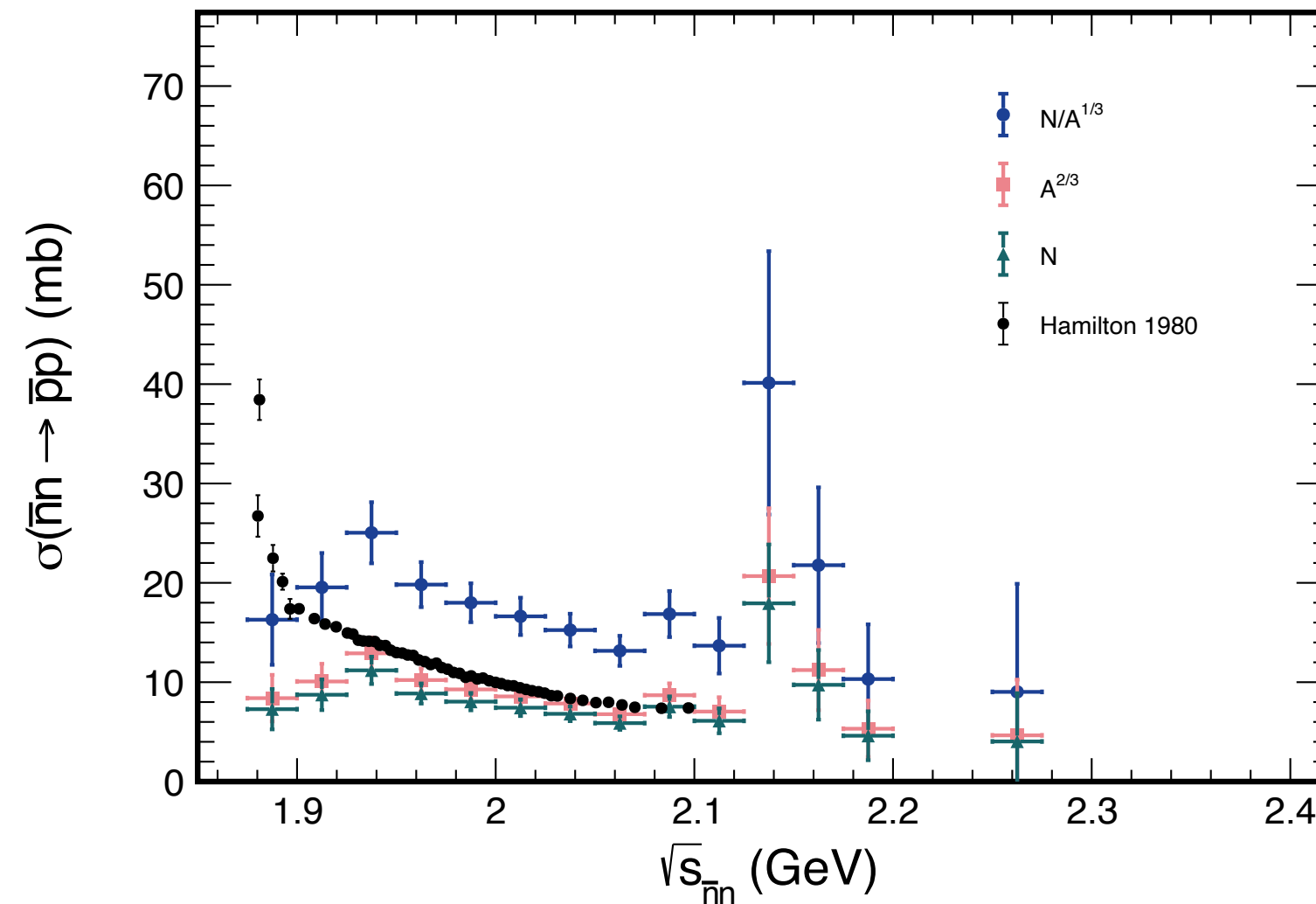
Data and 2D-weighted MC in the selected material-interaction sample



MC normalized to Data in each displayed range

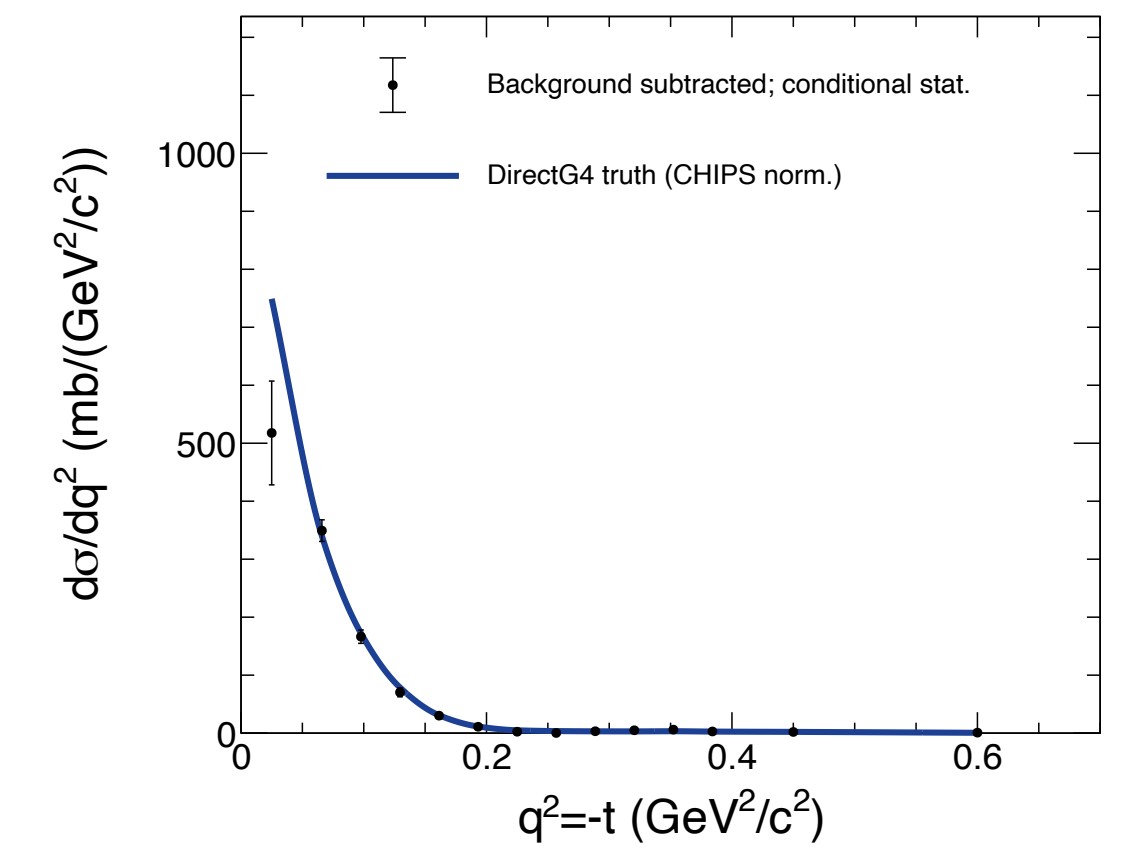
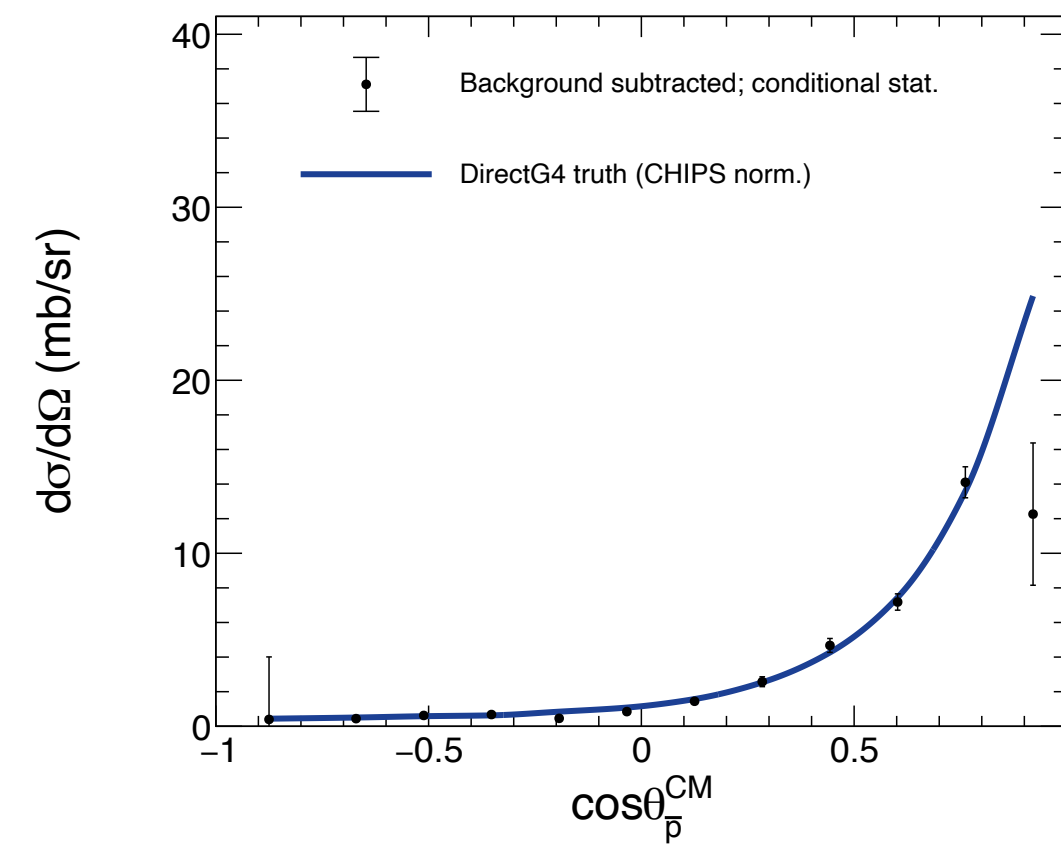
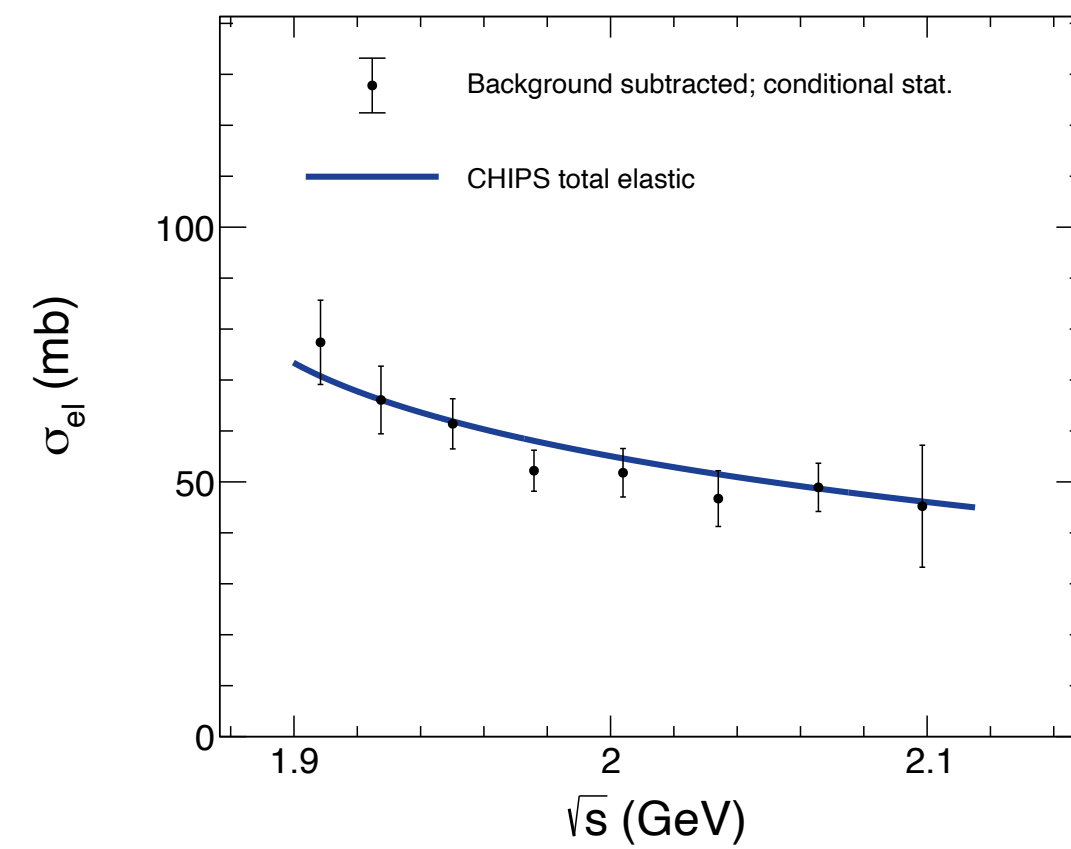
Interaction — Results

- Forward antiprotons retain a strong correlation with the incident direction
- The distribution is concentrated at small momentum transfer



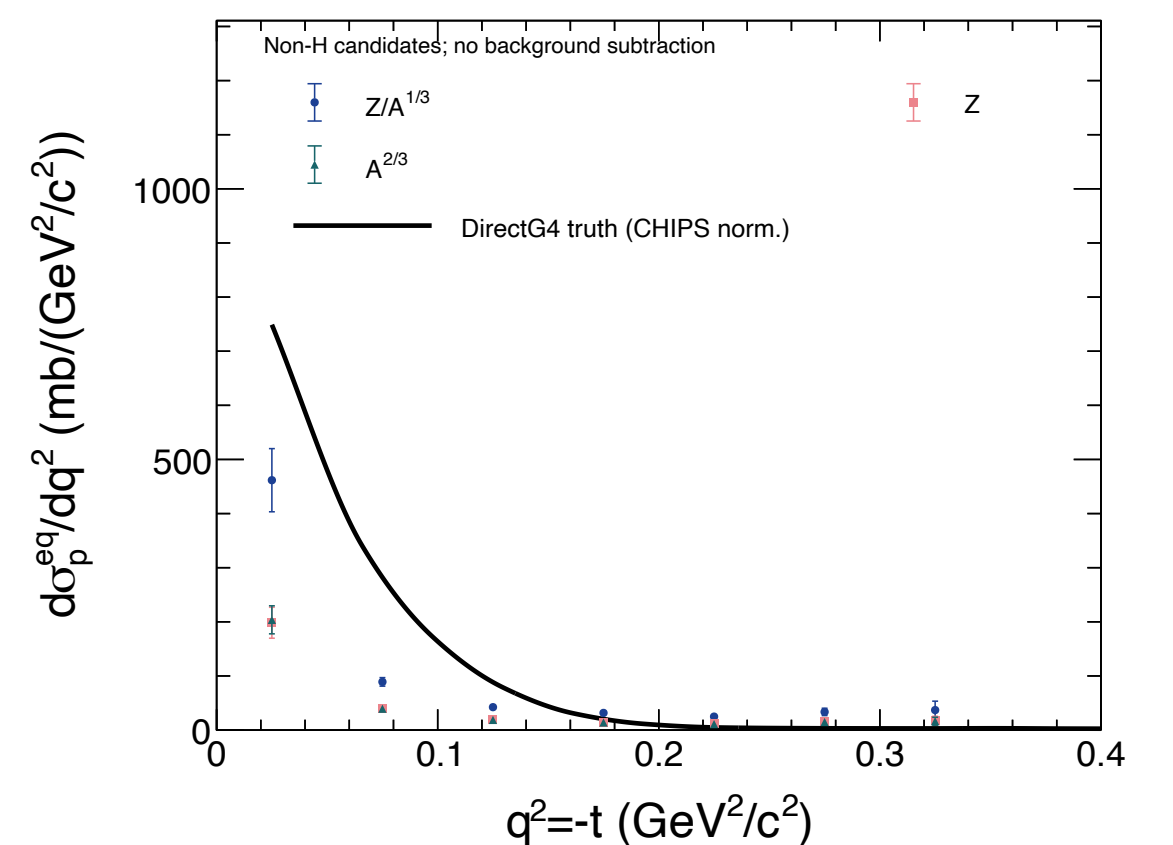
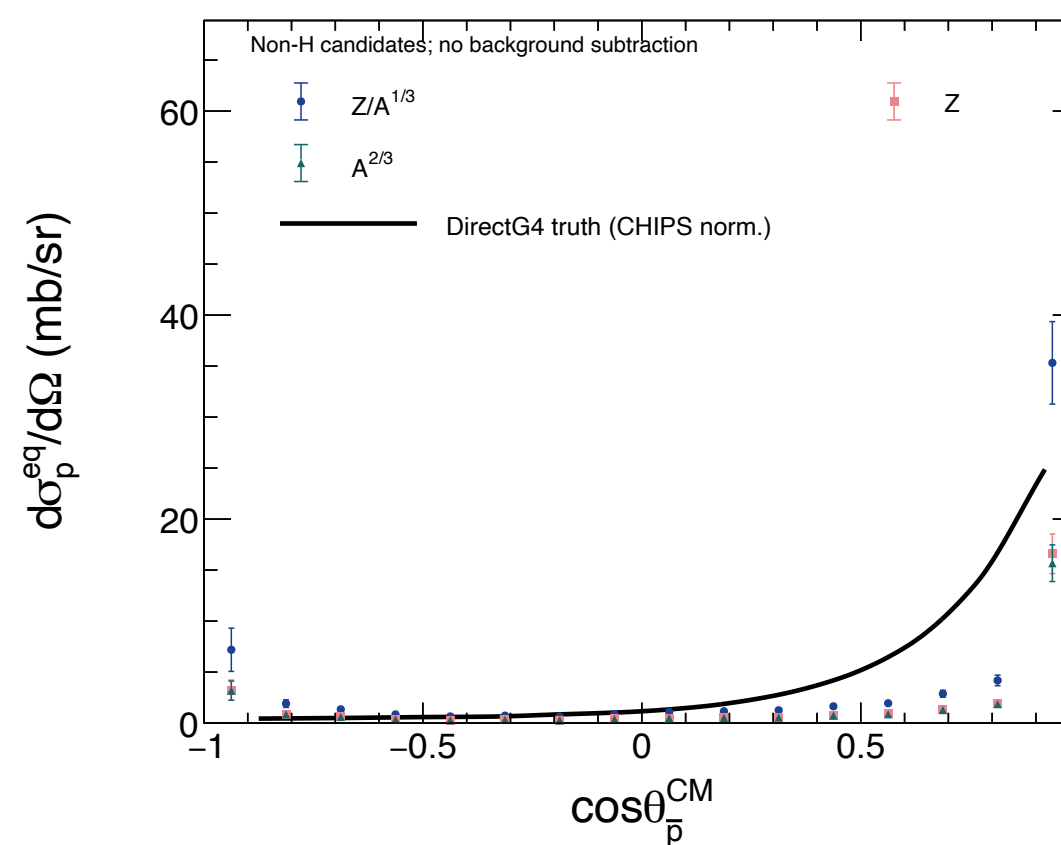
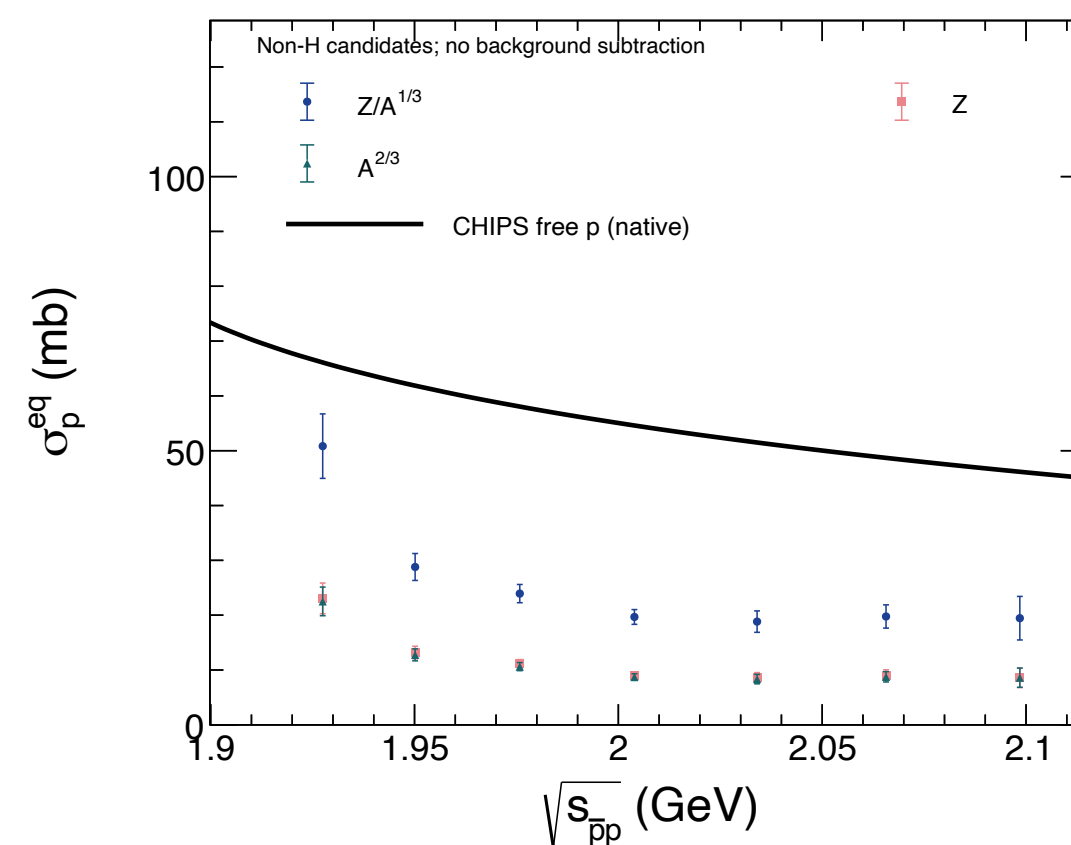
Interaction — Antiproton validation

H-like

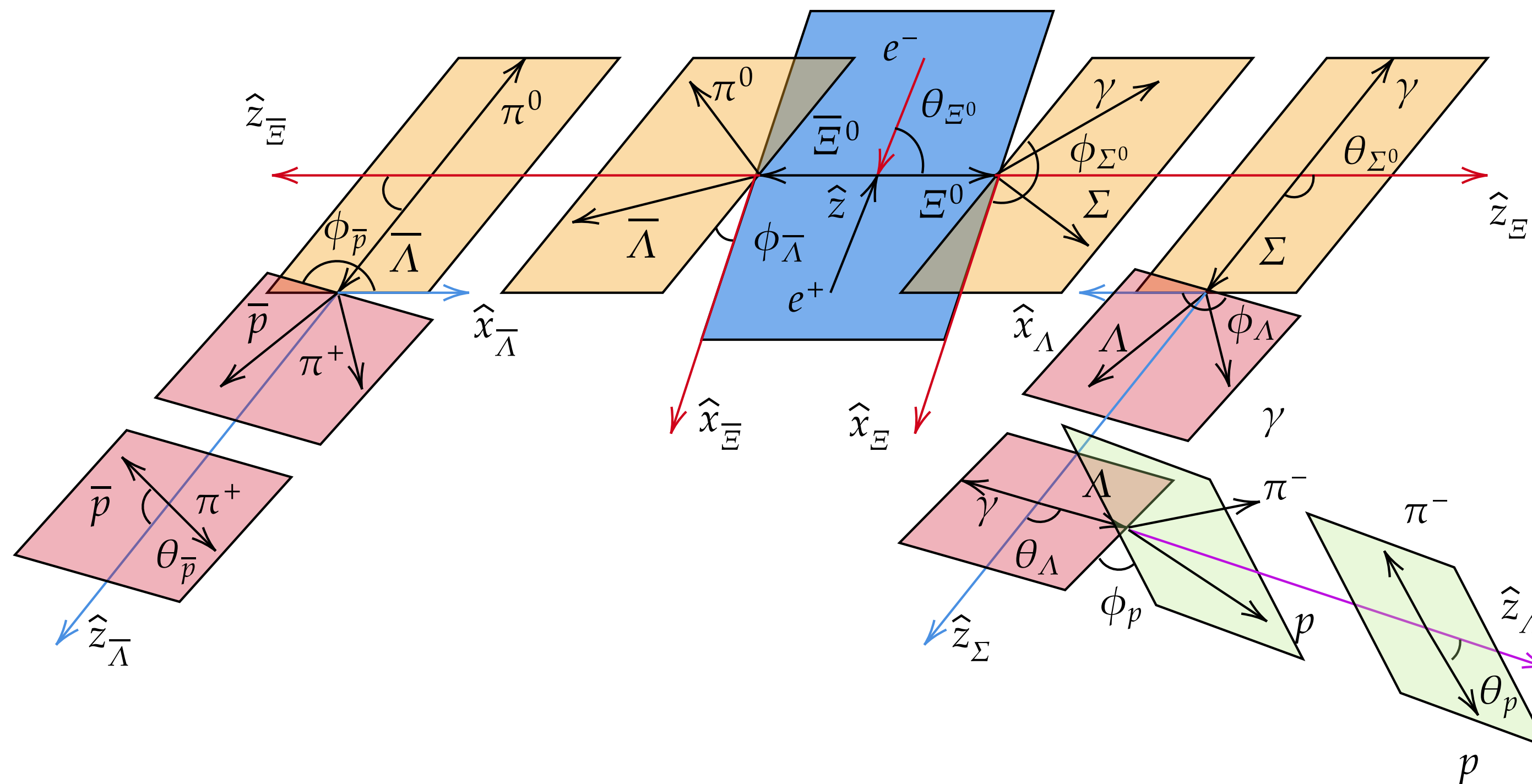


Non-H

free-proton-equivalent candidates using three different assumptions



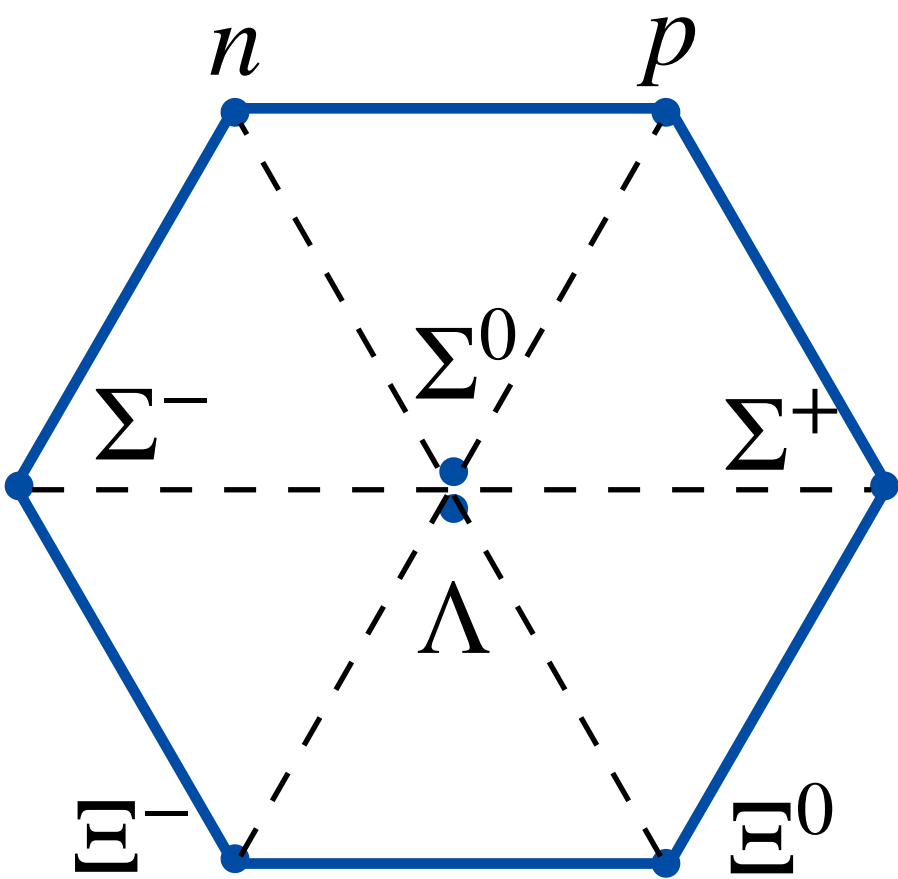
Transition — Hyperon radiative decay $\Xi^0 \rightarrow \Sigma^0 \gamma$



Transition — Introduction

Hara theorem puzzle

- In the under SU(3) limit $\alpha(\Sigma^+ \rightarrow p\gamma) = 0$
- A **large negative** asymmetry has been observed Berkeley, KEK, Fermilab and BESIII



$$\alpha = \frac{2\text{Re}(ab^*)}{|a|^2 + |b|^2}$$

6 HWRD: $s \rightarrow d\gamma$

Phenomenological models

Decay	$\Lambda \rightarrow \gamma n$	$\Sigma^+ \rightarrow \gamma p$	$\Xi^0 \rightarrow \gamma \Lambda$	$\Xi^0 \rightarrow \gamma \Sigma^0$	$\Xi^- \rightarrow \gamma \Sigma^-$
Branching fraction, $\mathcal{B}$, in units of $\times 10^{-3}$					
VMD	0.77	0.72	1.02	4.42	0.16
NRCQM	1.83 ± 0.96	1.06 ± 0.59	0.96 ± 0.32	9.75 ± 4.18	—
ChPT	1.45	16	1.17	1.14	—
Pole model(I)	0.16 ± 0.06	0.75 ± 0.3	0.72 ± 0.42	2.6 ± 1.2	0.04
Pole model(II)	0.62	1.15	3.0	7.2	—
PDG18	1.75 ± 0.15	1.23 ± 0.05	1.17 ± 0.07	3.33 ± 0.10	0.127
BESIII	0.832 ± 0.07	0.996 ± 0.028	1.347 ± 0.085	this work	—
Decay asymmetry parameter, α_γ					
VMD	-0.93	-0.67	-0.97	-0.92	0.89
NRCQM	-0.67 ± 0.06	-0.58 ± 0.06	0.72 ± 0.11	0.33 ± 0.036	—
ChPT	-0.19	-0.49	0.46	0.15	0.84
Pole model(I)	0.91	-0.92	0.07	-0.75	0
Pole model(II)	-0.49	-0.80	-0.78	-0.96	—
PDG18	—	-0.76 ± 0.08	-0.70 ± 0.07	-0.69 ± 0.06	—
BESIII	-0.16 ± 0.11	-0.652 ± 0.059	-0.741 ± 0.065	this work	—

Transition — Introduction

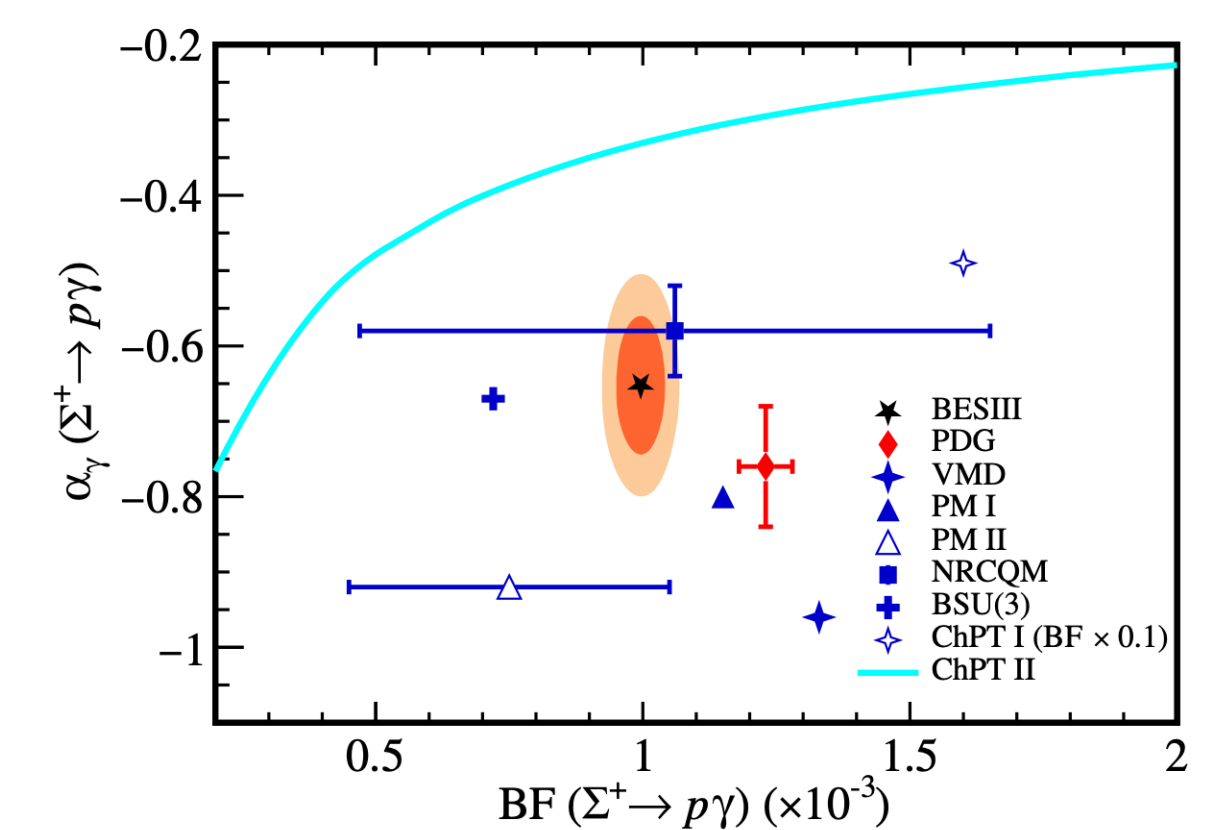
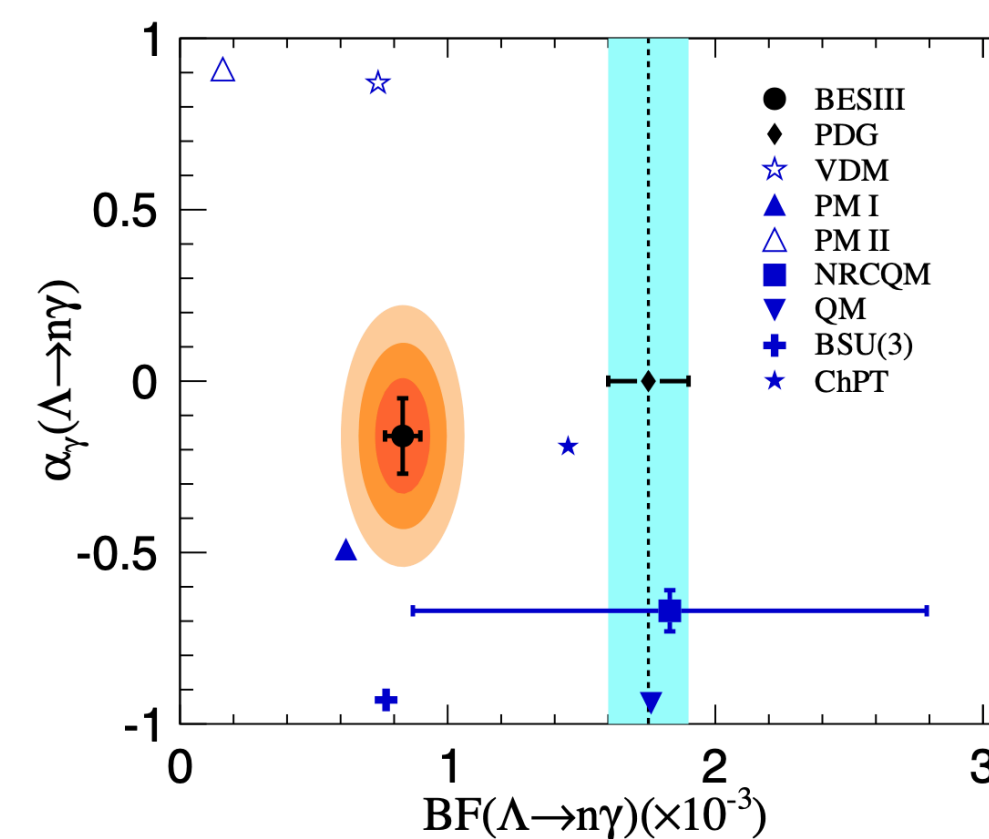
Why $\Xi^0 \rightarrow \Sigma^0 \gamma$

- Independent measurement at an e^+e^- collider
- Absolute branching fractions for both charge-conjugate channels
- Updated input for $\alpha(\Lambda \rightarrow p\pi^-)$
- Comparison with $\Xi^0 \rightarrow \Lambda \gamma$ probes hyperon structure

Experiment	Branch fraction ($\times 10^{-3}$)	Decay asymmetry parameter	Events
1989 SPEC	$3.56 \pm 0.42 \pm 0.10$	$+0.20 \pm 0.32 \pm 0.05$	85
2000 NA48	$3.16 \pm 0.76 \pm 0.32$	-	17
2001 KTeV	$3.34 \pm 0.05 \pm 0.09$	$-0.63 \pm 0.08 \pm 0.05$	4045
2010 NA48	-	$-0.729 \pm 0.030 \pm 0.076$	15 k
2010 NA48(c.c. channel)	-	$+0.786 \pm 0.104_{stat}$	1404

Advantages of BESIII

- 10 billion J/ψ decays
- Spin information from hyperon pairs
- Measurements of $\Lambda \rightarrow n\gamma$, $\Sigma^+ \rightarrow p\gamma$



Transition — Analysis strategy

Double tag

- Measure the absolute branching fraction
- Partially cancel shared tag-side uncertainties

$$\mathcal{B}(\Xi^0 \rightarrow \gamma \Sigma^0) = \frac{N_{\text{DT}} \epsilon_{\text{ST}}}{N_{\text{ST}} \epsilon_{\text{DT}}} \times \frac{1}{\mathcal{B}(\Sigma^0 \rightarrow \Lambda \gamma) \mathcal{B}(\Lambda \rightarrow p \pi^-)}$$

Decay asymmetry

$$\mathcal{W} = \sum_{\mu, \nu=0}^3 C_{\mu\nu} \sum_{\mu', \nu', \rho=0}^3 b_{\mu\mu'}^{\Xi} a_{\nu\nu'}^{\bar{\Xi}} b_{\mu'\rho}^{\Sigma} a_{\nu'\rho}^{\bar{\Lambda}} a_{\rho 0}^{\Lambda}$$

$$\mathcal{L} = \prod_{i=1}^N \frac{\mathcal{W}(\xi, \alpha_{\gamma})_i \epsilon(\xi)_i}{C}$$

$$C_{\mu\nu} = \begin{pmatrix} 1 + \alpha_{\psi} \cos^2 \theta_{\Xi^0} & 0 & \beta_{\psi} \sin \theta_{\Xi^0} \cos \theta_{\Xi^0} & 0 \\ 0 & \sin^2 \theta_{\Xi^0} & 0 & \gamma_{\psi} \sin \theta_{\Xi^0} \cos \theta_{\Xi^0} \\ -\beta_{\psi} \sin \theta_{\Xi^0} \cos \theta_{\Xi^0} & 0 & \alpha_{\psi} \sin^2 \theta_{\Xi^0} & 0 \\ 0 & -\gamma_{\psi} \sin \theta_{\Xi^0} \cos \theta_{\Xi^0} & 0 & -(\alpha_{\psi} + \cos^2 \theta_{\Xi^0}) \end{pmatrix}$$

$$a_{\mu\mu'} = \begin{pmatrix} 1 & 0 & 0 & \alpha \\ \alpha \cos \phi \sin \theta & \gamma \cos \phi \cos \theta - \beta \sin \phi & -\beta \cos \phi \cos \theta - \gamma \sin \phi & \cos \phi \sin \theta \\ \alpha \sin \phi \sin \theta & \beta \cos \phi + \gamma \cos \theta \sin \phi & \gamma \cos \phi - \beta \cos \theta \sin \phi & \sin \phi \sin \theta \\ \alpha \cos \theta & -\gamma \sin \theta & \beta \sin \theta & \cos \theta \end{pmatrix}$$

$$b_{\nu\nu'} = \begin{pmatrix} 1 & 0 & 0 & -\alpha_{\gamma} \\ \alpha_{\gamma} \cos \phi \sin \theta & 0 & 0 & -\cos \phi \sin \theta \\ \alpha_{\gamma} \sin \theta \sin \phi & 0 & 0 & -\sin \theta \sin \phi \\ \alpha_{\gamma} \cos \theta & 0 & 0 & -\cos \theta \end{pmatrix}$$

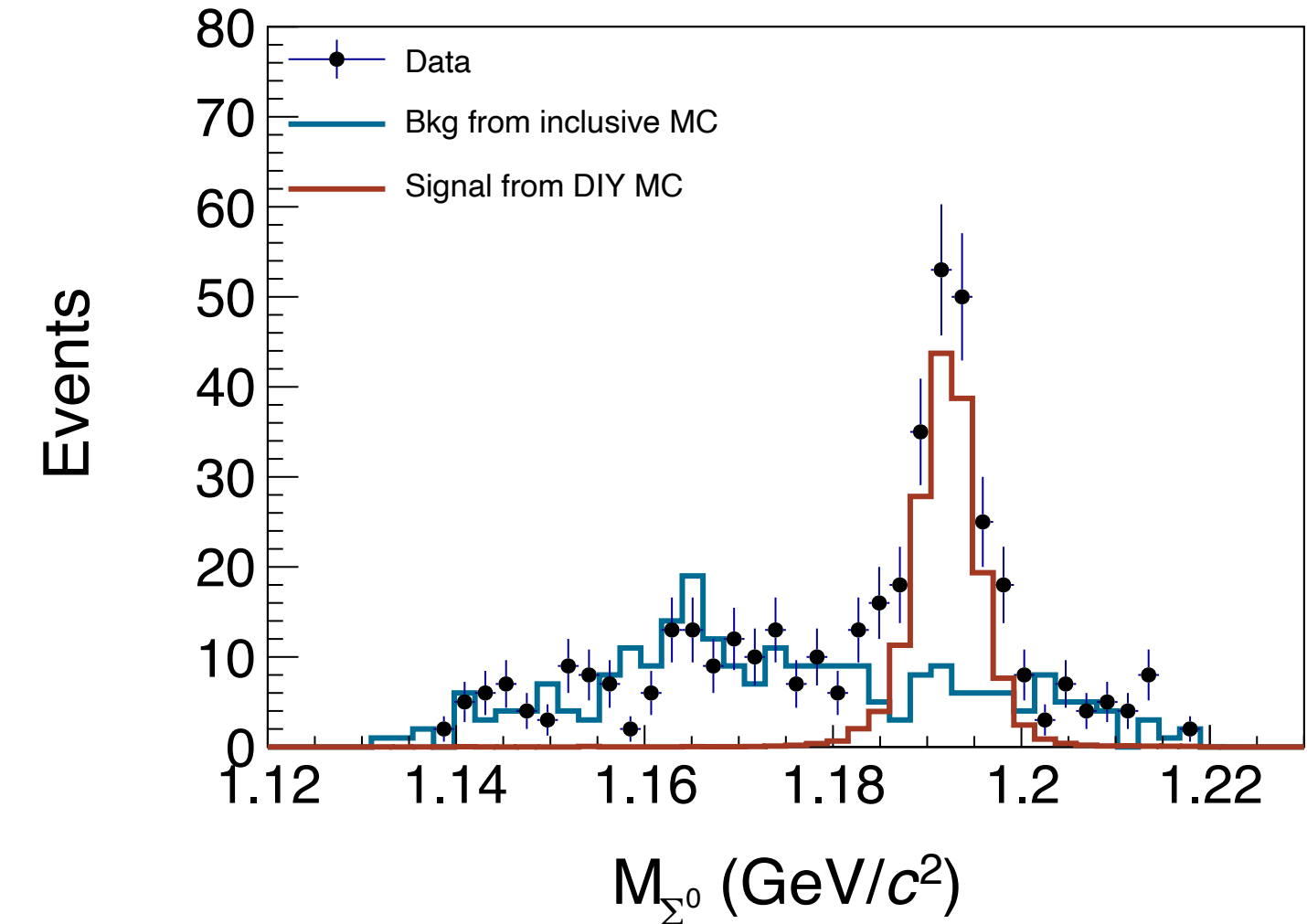
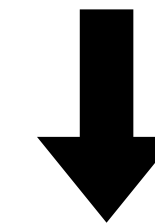
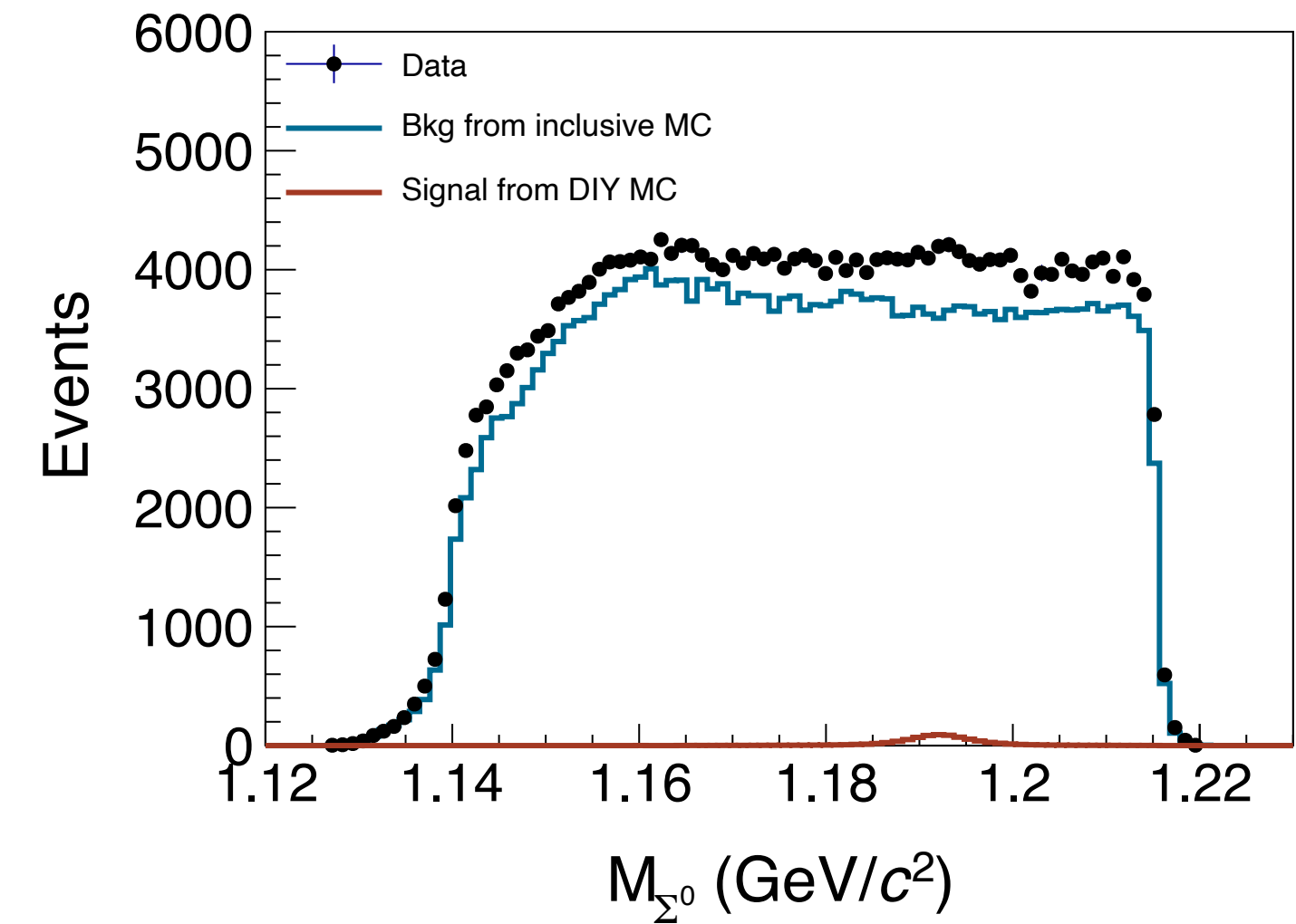
Transition — Background suppression

Dominant background

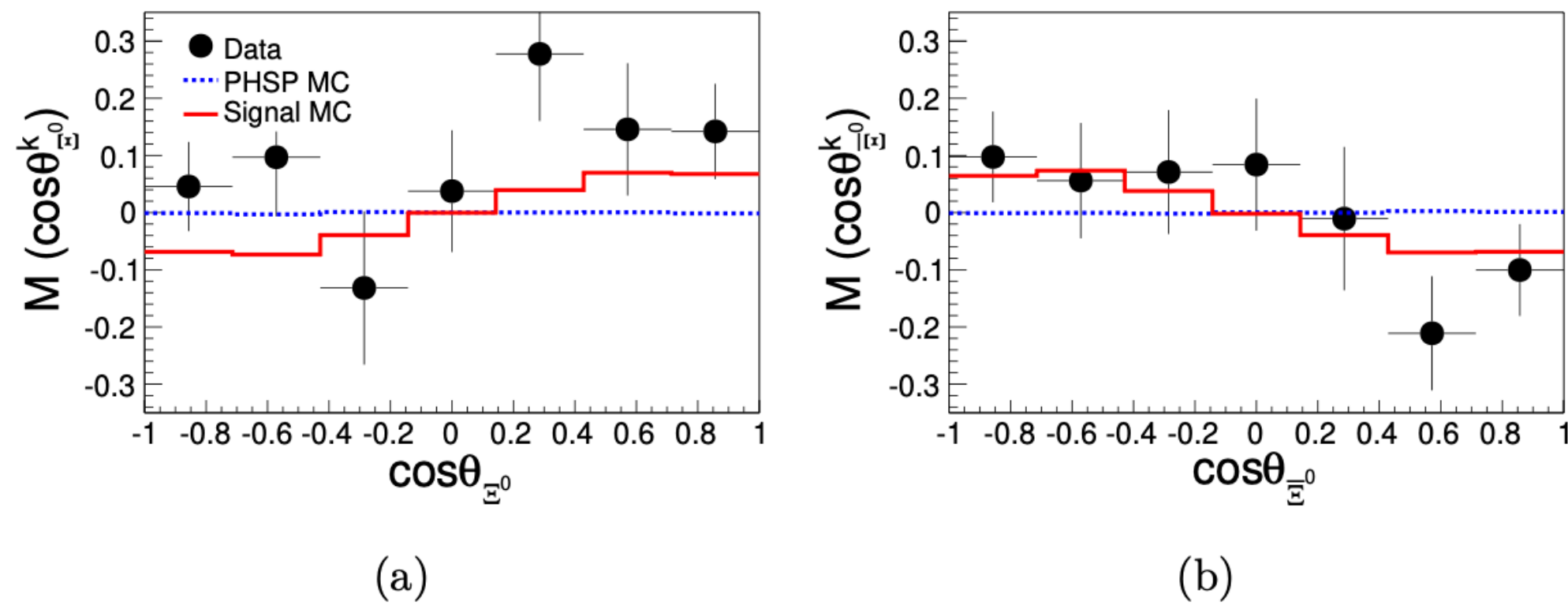
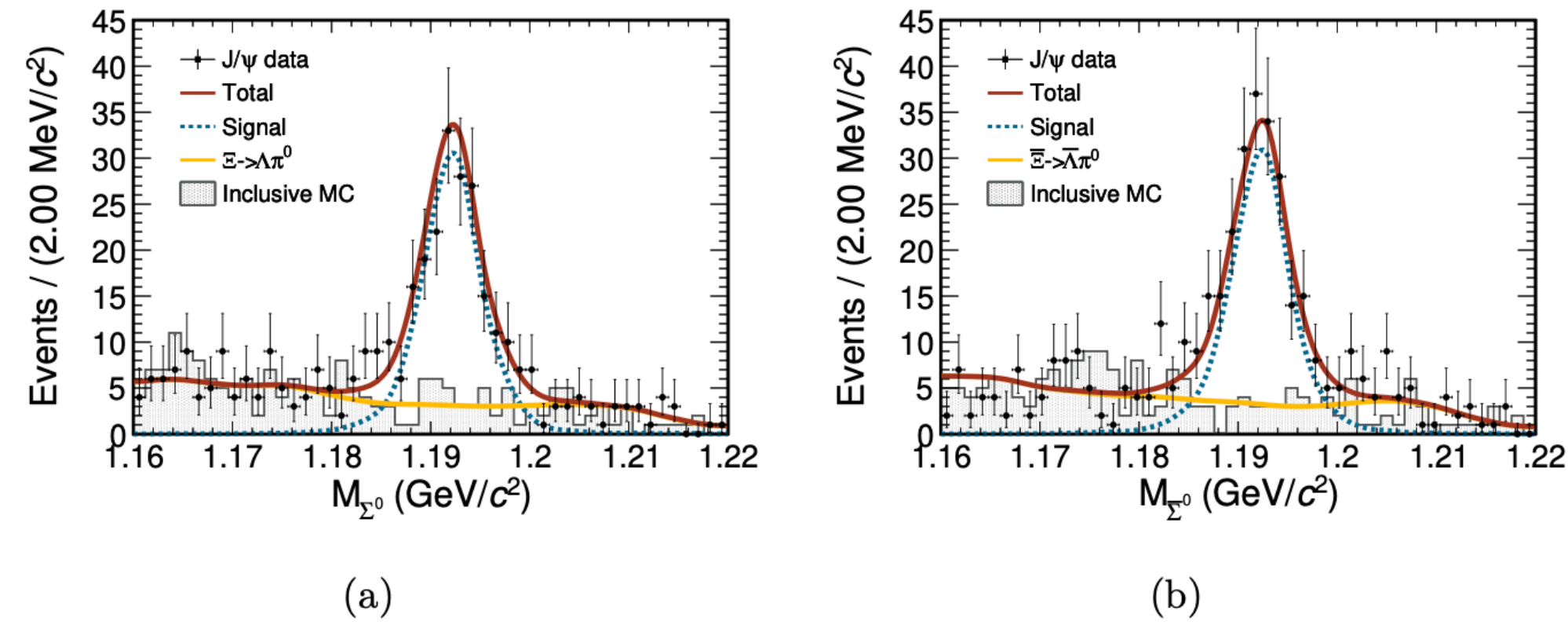
- $J/\psi \rightarrow \Xi^0 \bar{\Xi}^0 \rightarrow \Lambda \pi^0 \bar{\Lambda} \pi^0$
- $J/\psi \rightarrow \Sigma^{*0} \bar{\Sigma}^{*0}, J/\psi \rightarrow \Sigma^0 \bar{\Sigma}^{*0}, J/\psi \rightarrow \pi^0 \Sigma^0 \bar{\Sigma}^0$

Further selection

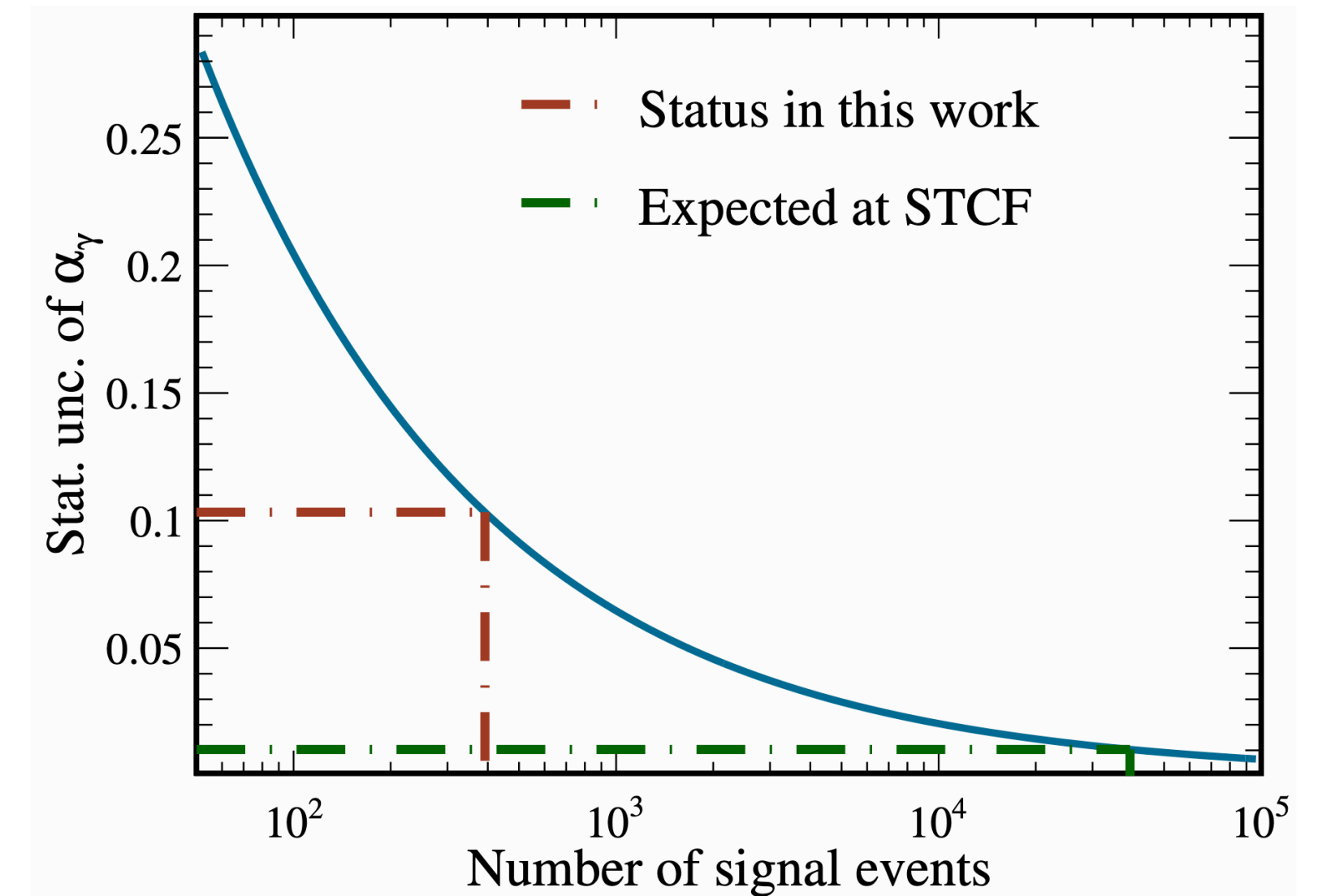
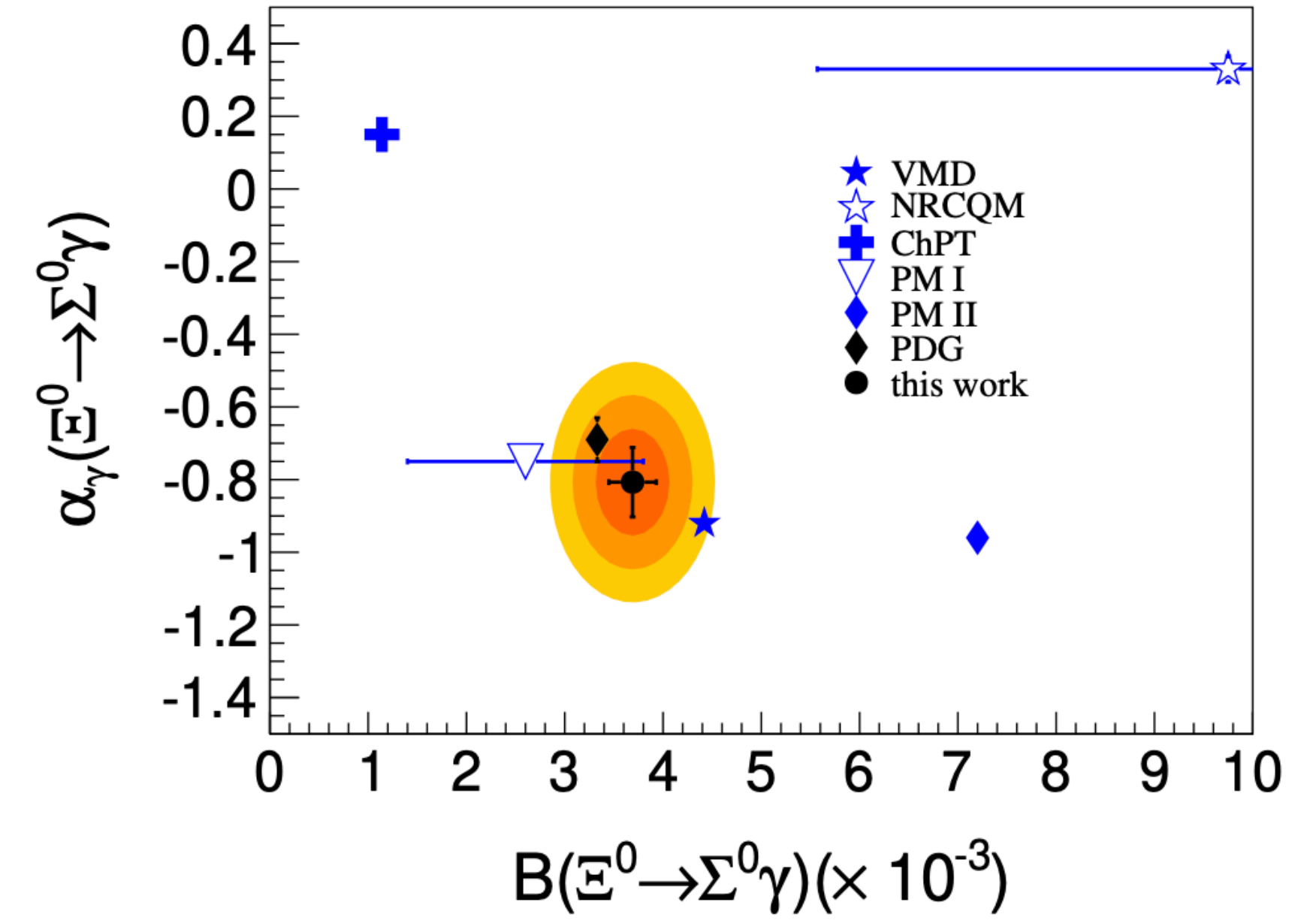
- $|L/\sigma_L| > 2.0$
- $M_{\gamma\gamma} < 88 \text{ MeV}$ or $M_{\gamma\gamma} > 162 \text{ MeV}$ & $\chi^2_{7C} < 50$



Transition — Results



Decay	$\mathcal{B} (\times 10^{-3})$	α_γ
$\Xi^0 \rightarrow \gamma \Sigma^0$	$3.33 \pm 0.29_{\text{stat.}} \pm 0.11_{\text{syst.}}$	$-0.693 \pm 0.139_{\text{stat.}} \pm 0.013_{\text{syst.}}$
$\Xi^0 \rightarrow \gamma \bar{\Sigma}^0$	$4.00 \pm 0.32_{\text{stat.}} \pm 0.11_{\text{syst.}}$	$0.956 \pm 0.139_{\text{stat.}} \pm 0.014_{\text{syst.}}$
Combined	$3.66 \pm 0.21_{\text{stat.}} \pm 0.10_{\text{syst.}}$	$-0.807 \pm 0.095_{\text{stat.}} \pm 0.011_{\text{syst.}}$



Summary and prospects

Interaction

- $\bar{n}n \rightarrow \bar{p}p$
calculated preliminary differential cross-section
analysis memo is in preparation
- $\bar{p}p \rightarrow \bar{p}p$
obtained differential cross-section for H-like and non-H target
study the nuclear effect further

Transition

- $\Xi^0 \rightarrow \Sigma^0 \gamma$
measured absolute branching fraction and decay asymmetry
results are published

Reported at plenary session

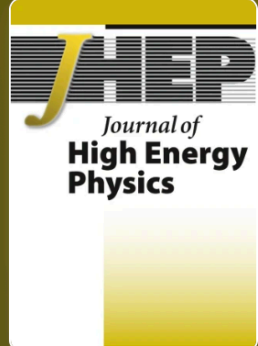
2:00 PM → 3:40 PM		Light hadron plenary (Chair: Ulrich Wiedner)	📍 Ruby Grand Ballroom
		Conveners: Isabella Garzia (高能所), Shuangshi Fang (IHEP), Wenbin QIAN (University of Chinese Academy of Sciences)	
2:00 PM	PWA of $\chi_{cJ} \rightarrow \phi KK$	Speaker: Xiaoting Chen (高能所)	🕒 15m
	PWAphiKK.pdf		
2:20 PM	CTPWA and $J/\psi \rightarrow K^+ K^- \eta$	Speaker: Benhou Xiang (IHEP)	🕒 15m
	PWAJpsi2KKeta.pdf		
2:40 PM	Study of charge exchange process $n\bar{n}$ to $p\bar{p}$ at BESIII	Speakers: Jiajun Tang, 嘉骏 唐 (中国科学技术大学)	🕒 15m 📄
	nbar_summer_slide...		

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Measurement of the hyperon weak radiative decay $\Xi^0 \rightarrow \gamma \Sigma^0$ at BESIII

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Thanks