

Search for Hidden-Strangeness Pentaquark State in γd Reactions



Shintaro Tanaka

Research Center for Nuclear Physics, Univ. Osaka

stanaka@rcnp.osaka-u.ac.jp



NSTAR 2026



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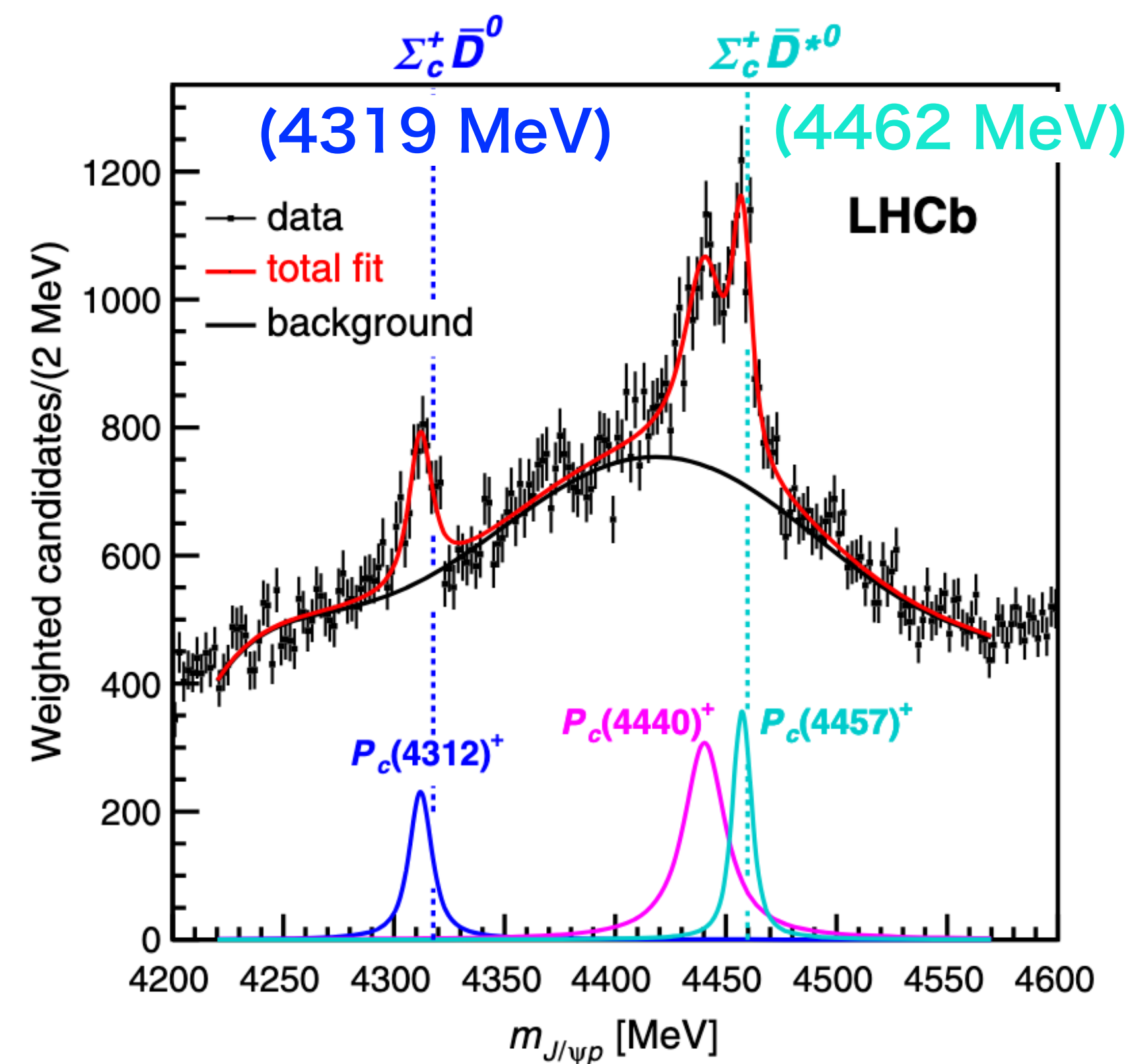
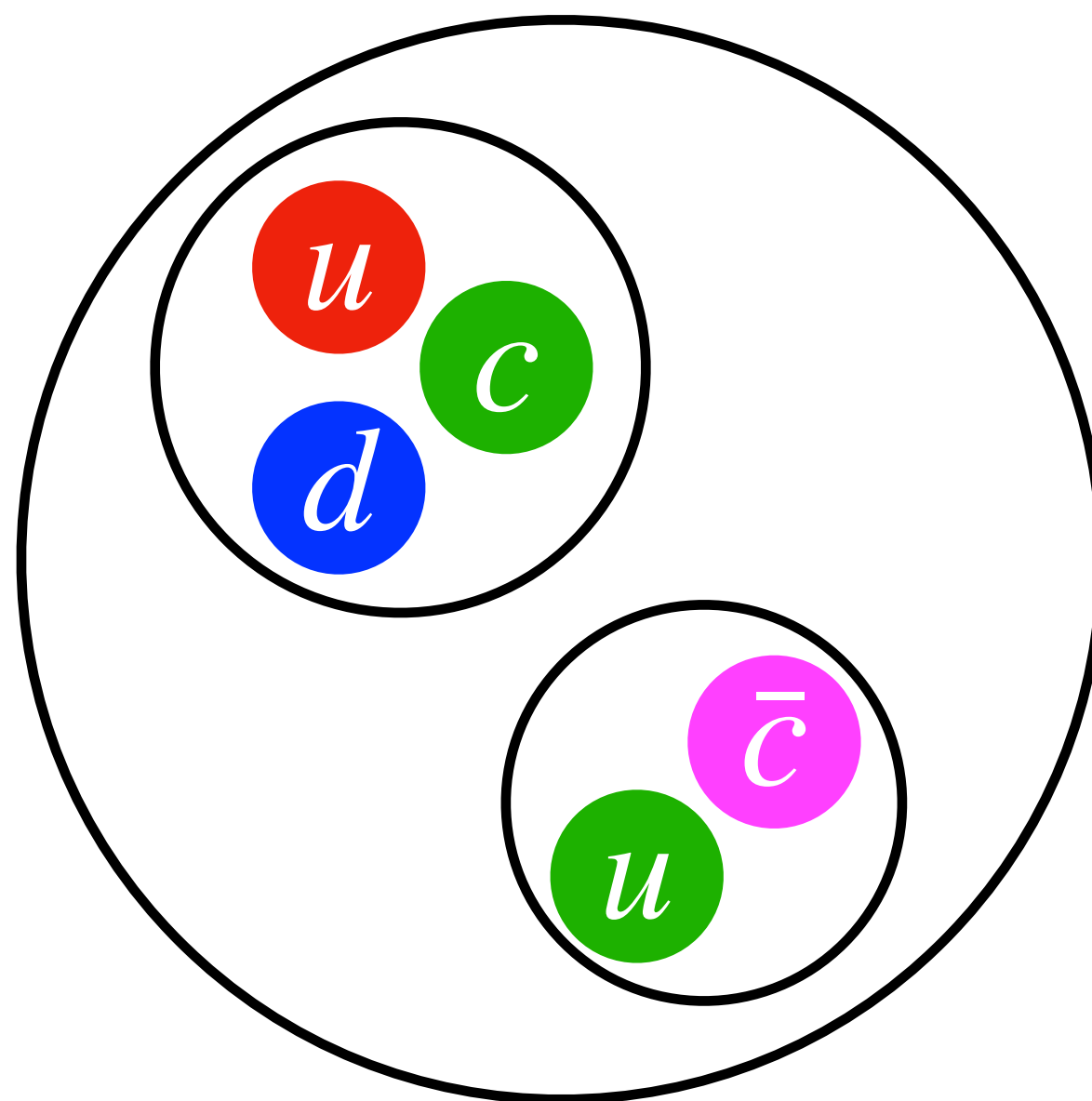
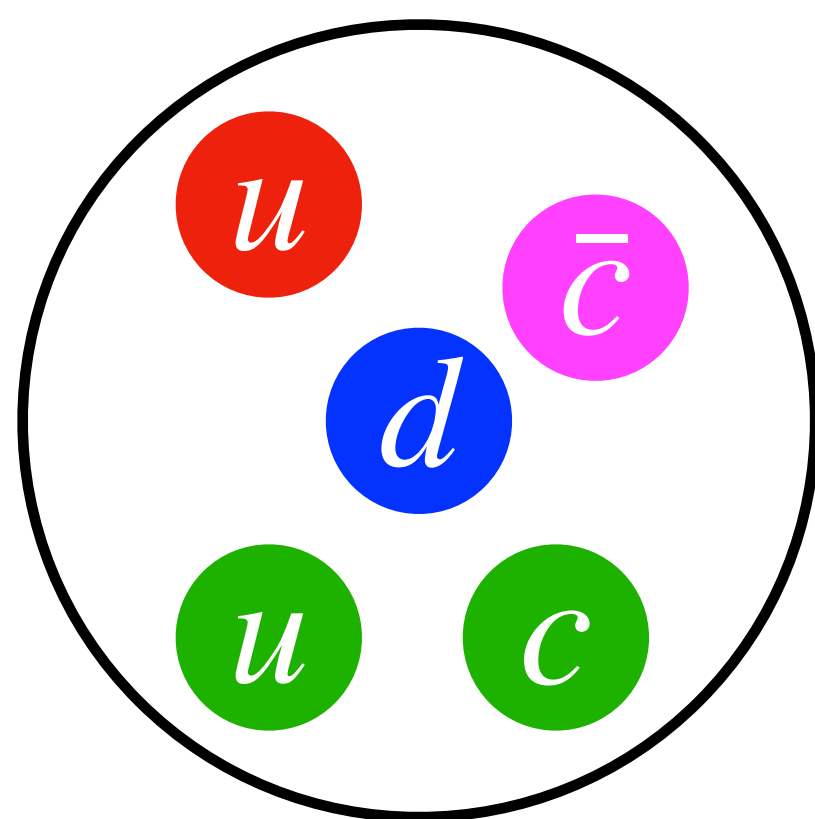
Introduction: P_c pentaquark states

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The LHCb experiment has reported the discovery of several hidden-charm pentaquark candidates $P_c(uudc\bar{c})$ using $\Lambda_b^0 \rightarrow \mathbf{J}/\psi \mathbf{p} K^-$ decay.

The P_c states are located in the vicinity of $\bar{D}^0 \Sigma_c^+$ and $\bar{D}^{*0} \Sigma_c^+$ threshold (a few MeV below).

R. Aaij *et al.* (LHCb Collaboration),
PRL**122**, no.22, 222001, (2019)





Introduction: Strangeness Sector P_c candidates 4

An analogous state to P_c in the strangeness sector,

$P_s(uuds\bar{s})$ **states**, may exist.

	Charm sector	Strangeness sector
States	$P_c(4380), P_c(4450)$	$N^*(1875), N^*(2120)$
Spin-parity	$3/2^-$	$3/2^-$
Closed-flavour channel	$J/\psi N$	ϕN
Open-flavour channel	$\bar{D}^{(*)}\Sigma_c^{(*)}, \bar{D}^{(*)}\Lambda_c^{(*)}$	$K^{(*)}\Sigma^{(*)}, K^{(*)}\Lambda^{(*)}$

Slides in Jude's talk in HADRON2025

P_s states may be observed in the ϕN and $K^{(*)}Y^{(*)}$ channels

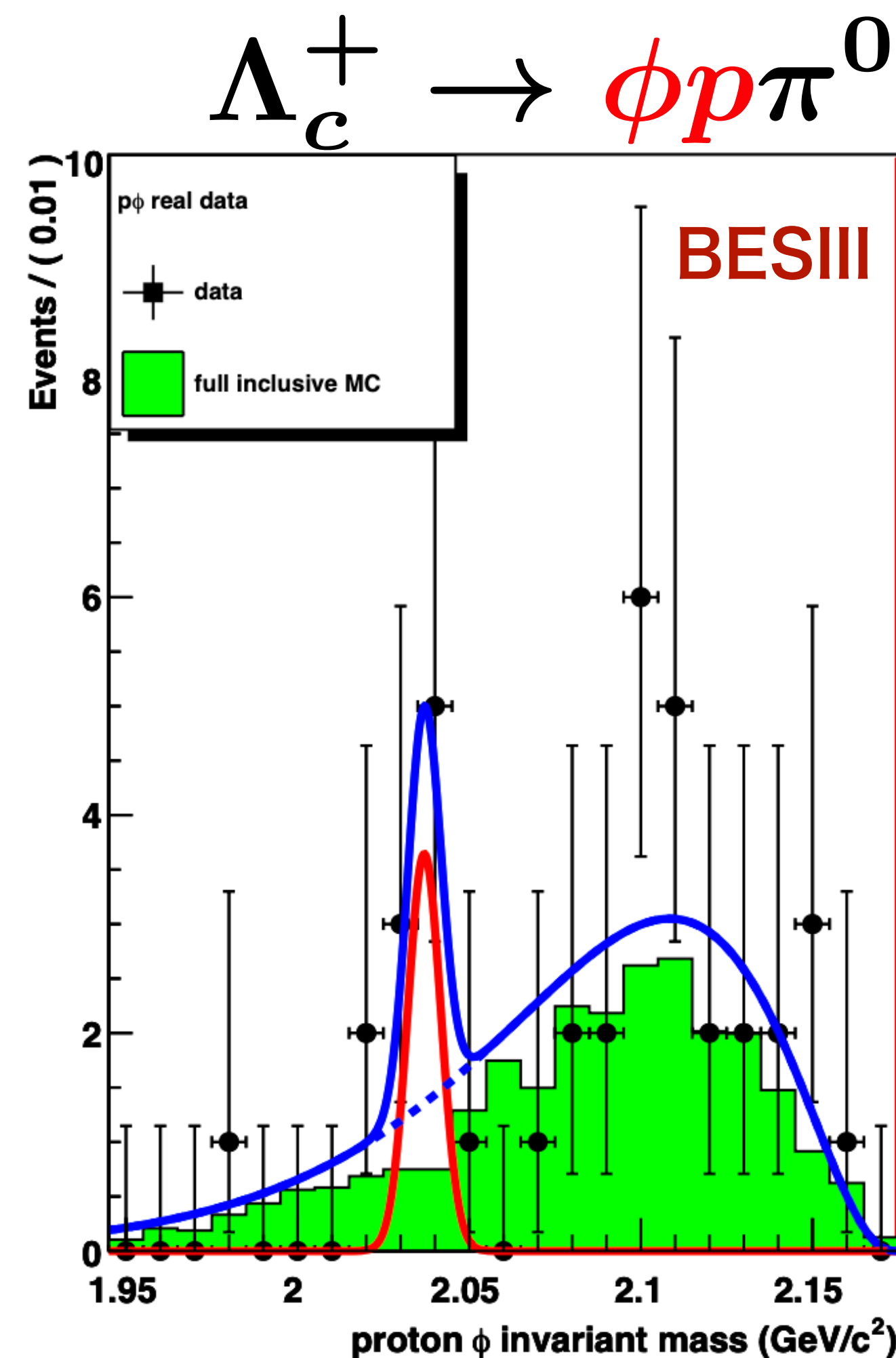
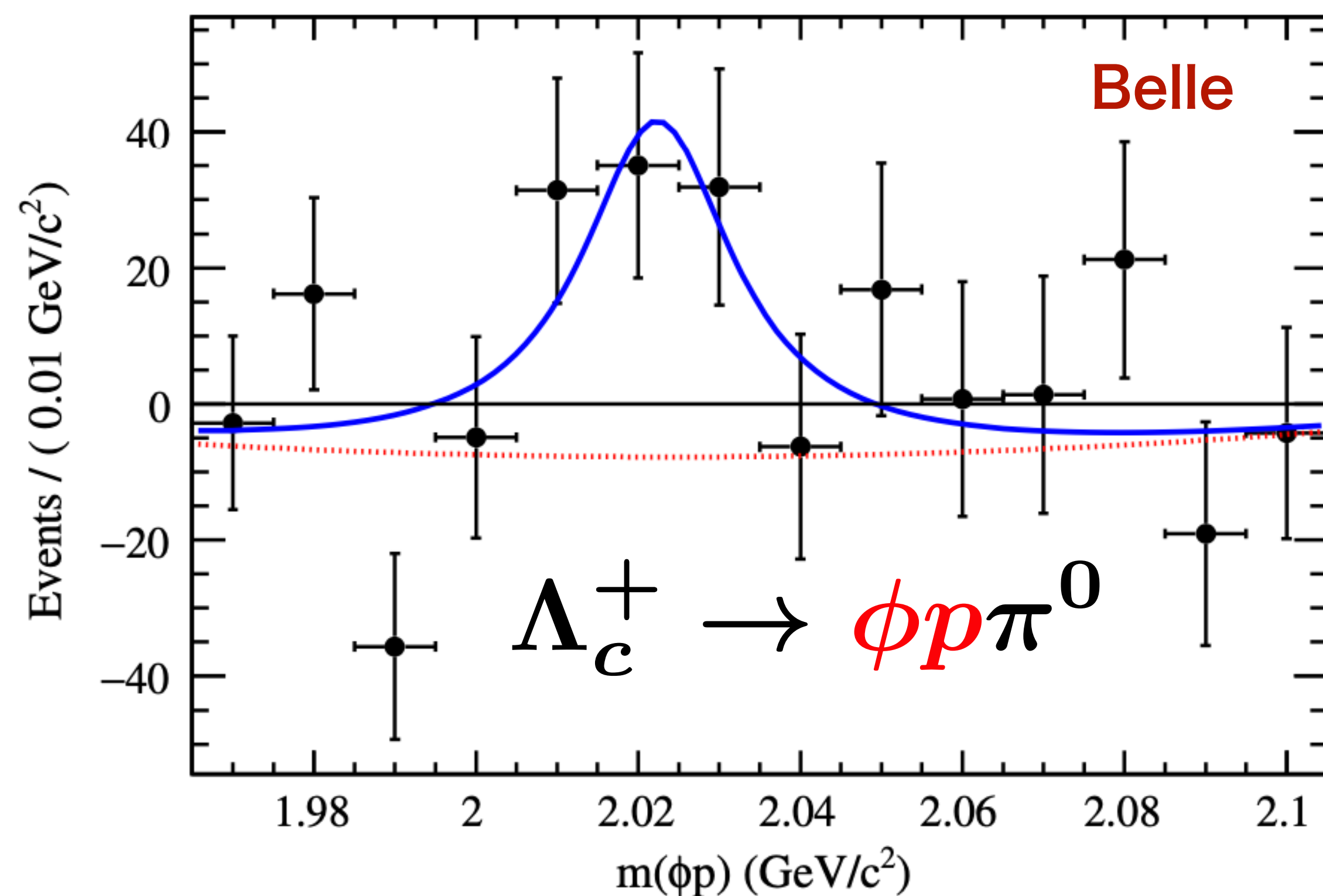


Hints for the existence of a P_s state

5

These spectra may indicate possible P_s states.

B. Pal *et al.* (Belle Collaboration),
PRD96, 051002(R) (2017)



G. Mezzadri,
PhD Thesis,
U. Ferrara (2017)

We search of this P_s state in the $\gamma d \rightarrow \phi p n$ reaction.



SPring-8

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Super Photon ring-8 GeV

@ Hyogo, Japan

SPring-8 is in beautiful nature.

Circumference: 1436 m

LEPS beamline
(2000 - 2020)

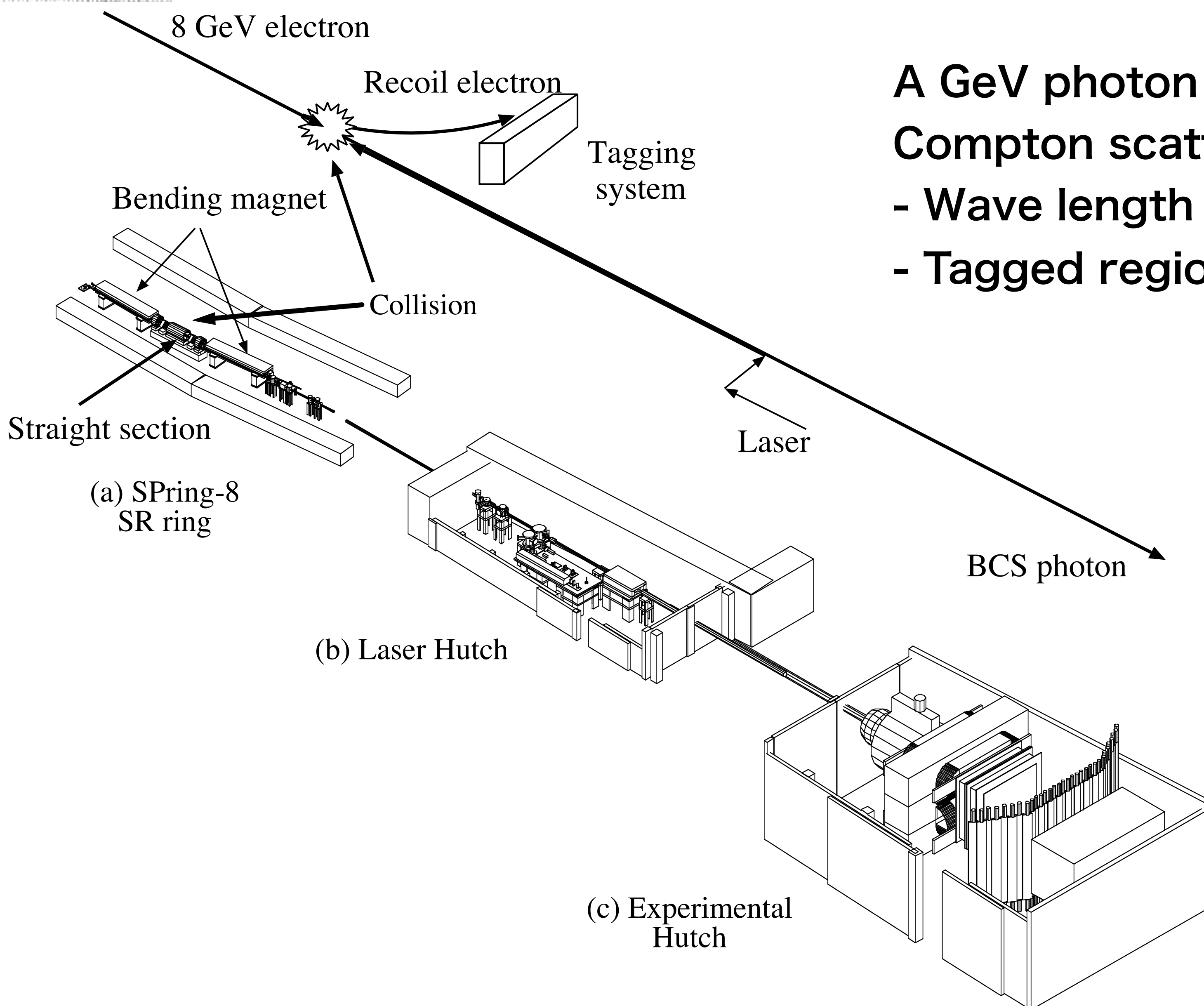
8 GeV e^-

SPring-8 Web site



SPring-8/LEPS Experiment

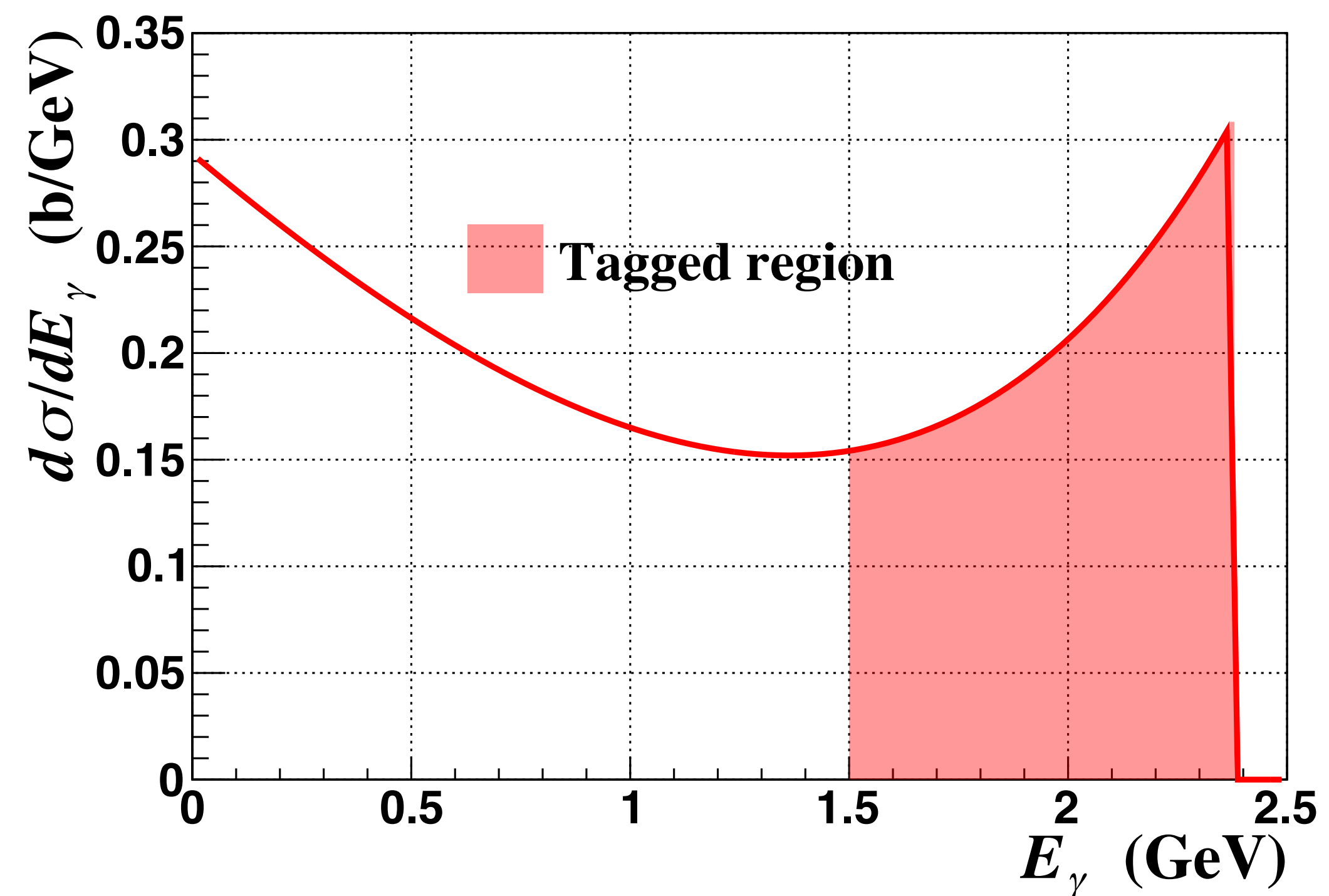
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A GeV photon beam is generated using laser-induced Compton scattering from circulating electrons.

- Wave length of Laser: 355 nm

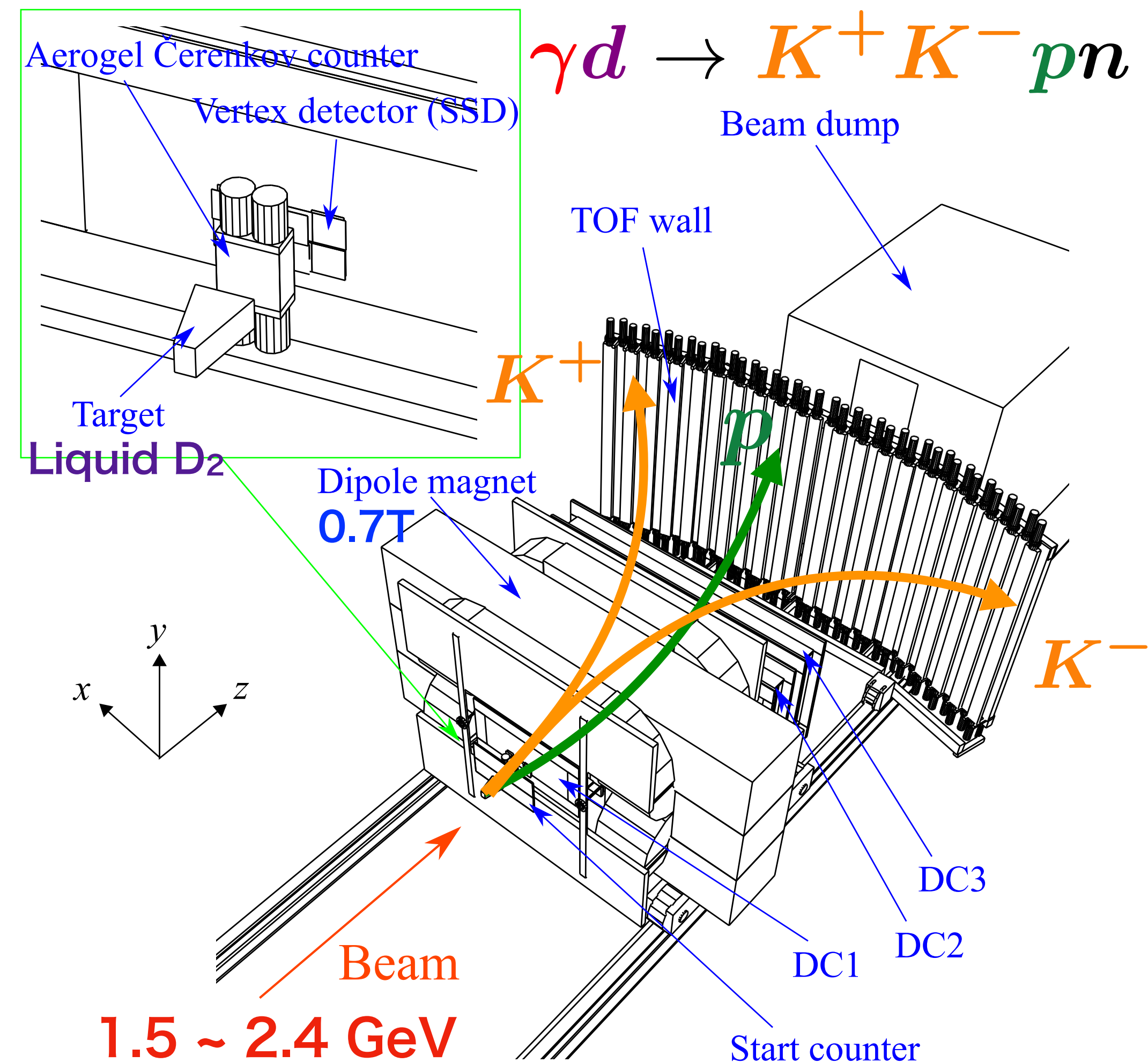
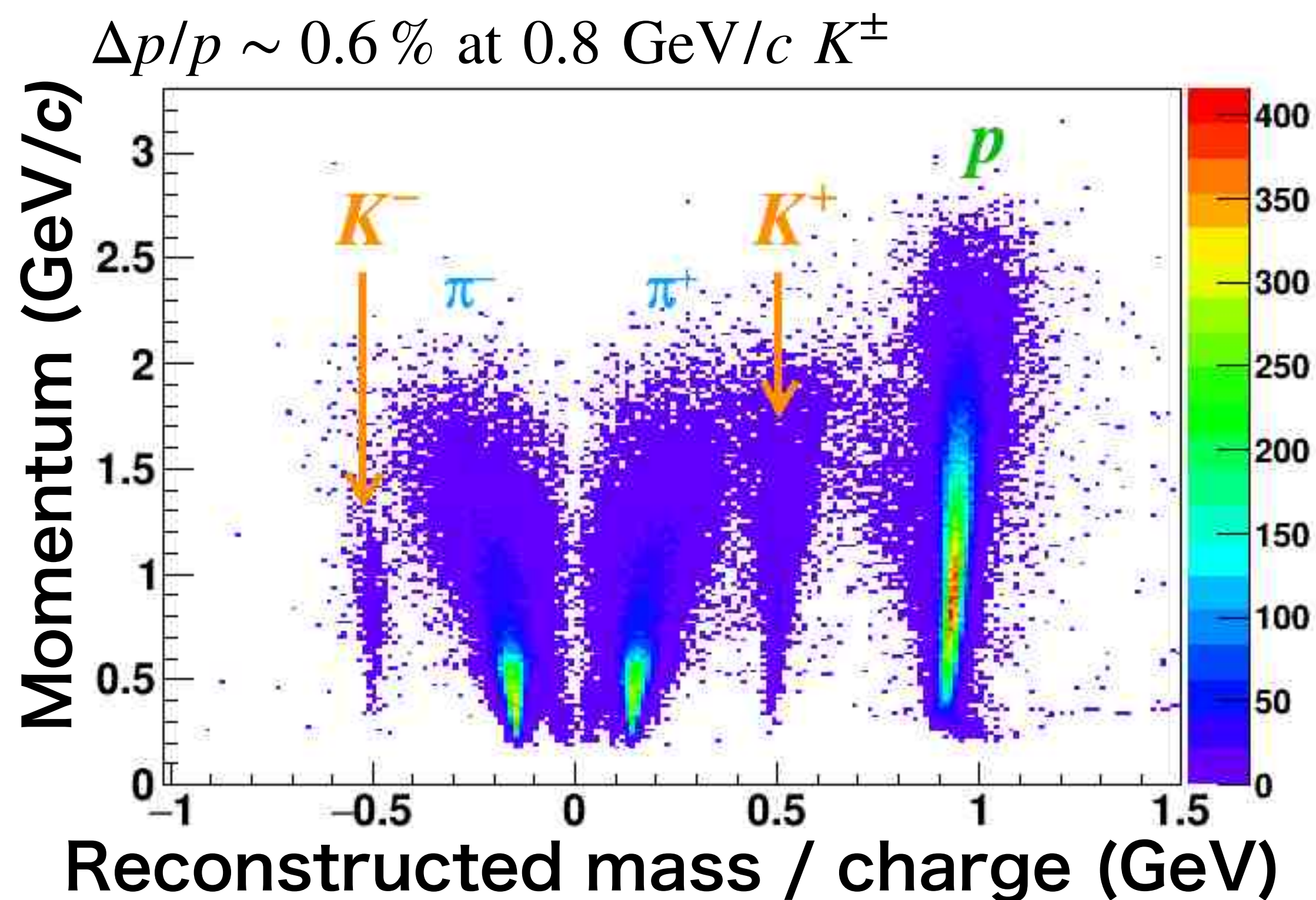
- Tagged region: $E_\gamma > 1.5$ GeV





Forward Magnetic Spectrometer 8

- The liquid-deuterium target is irradiated with the photon beam.
- K^+ , K^- (decay products from ϕ meson) and protons were detected.
- Geometrical acceptance :
 $\pm 20^\circ$ (horizontal), $\pm 10^\circ$ (vertical)
- Momentum resolution

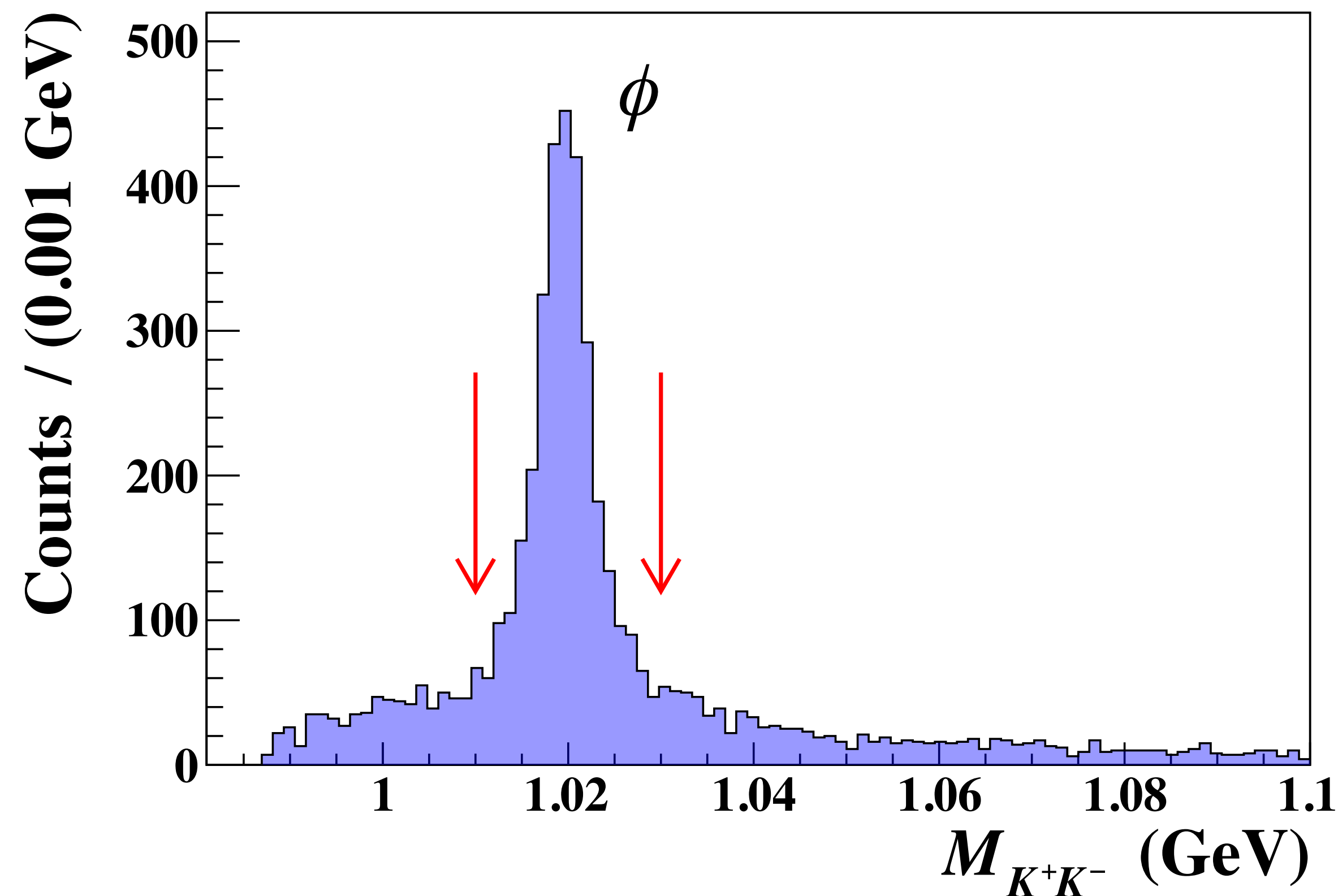
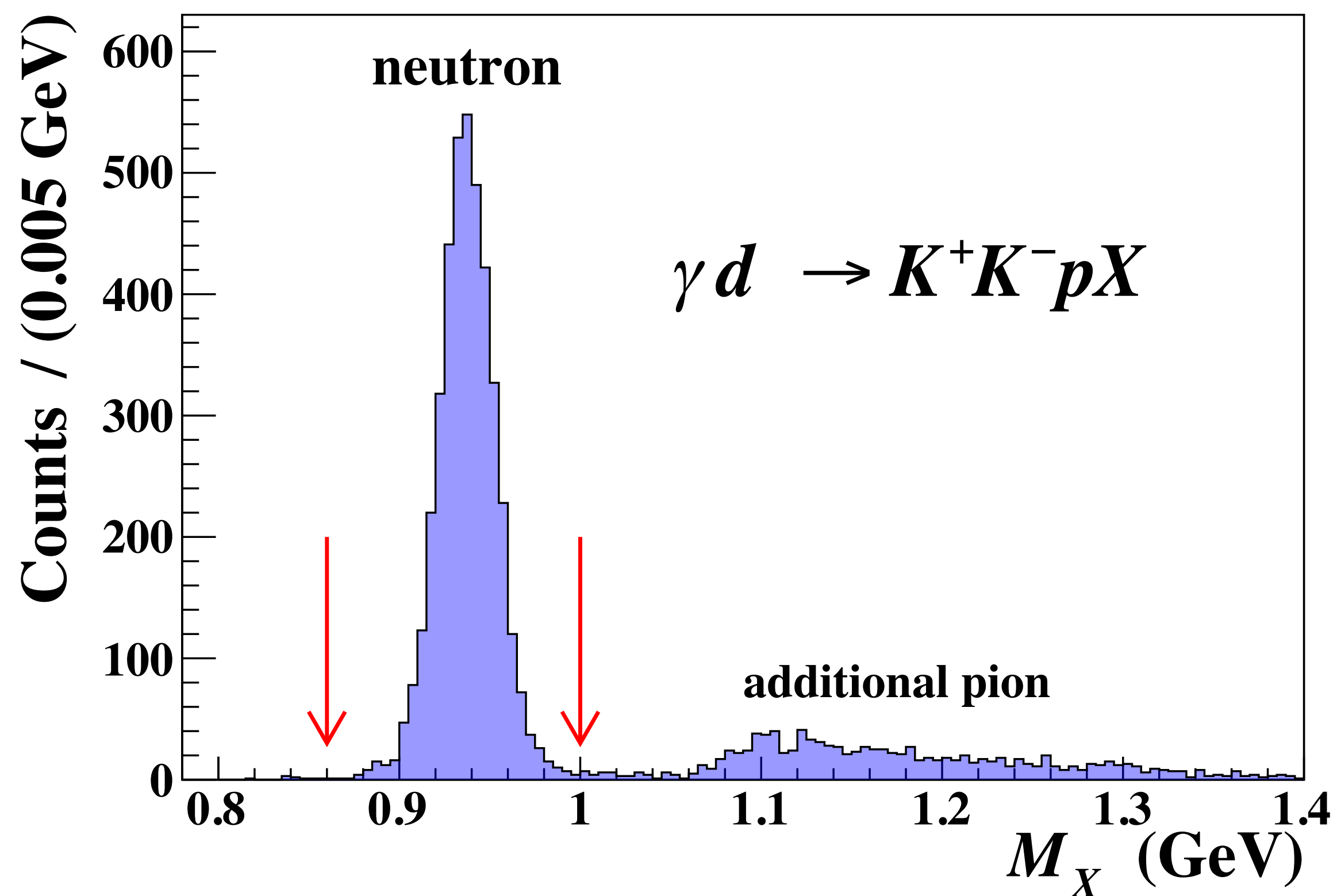
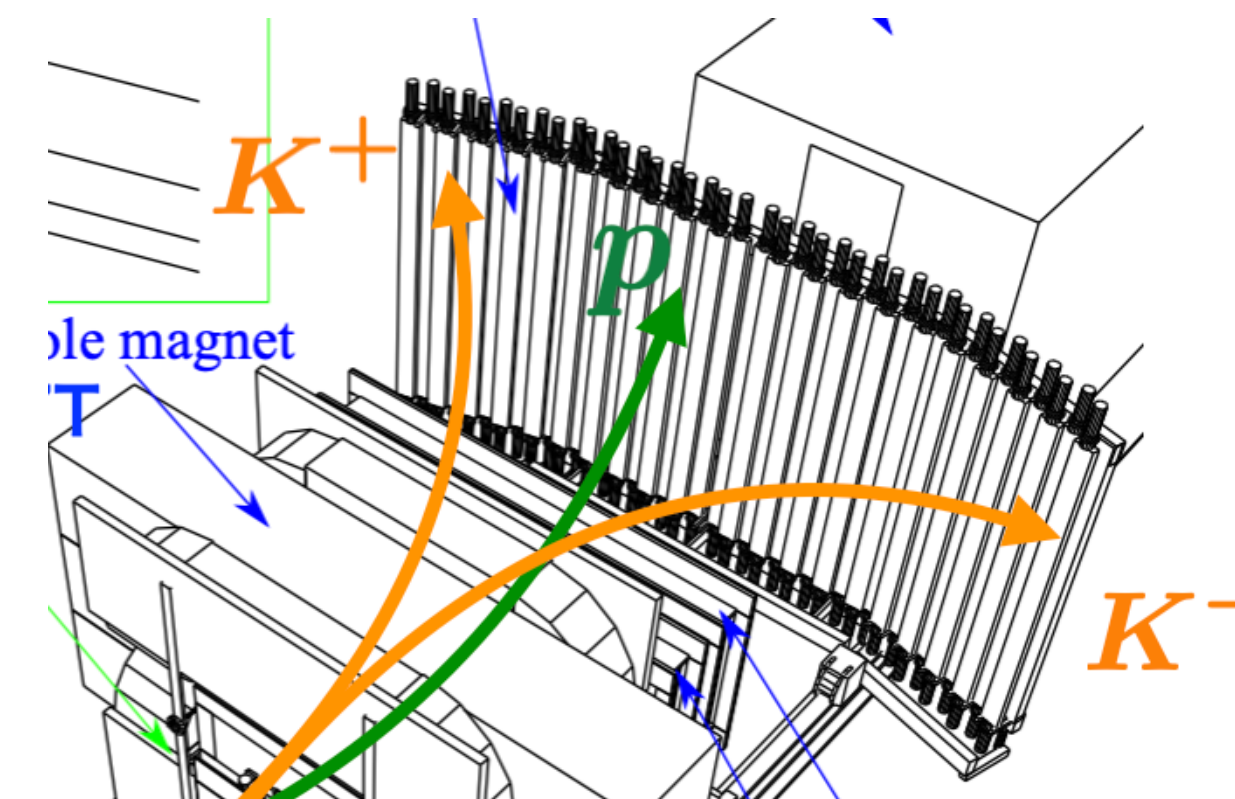




Event Selection for $\gamma d \rightarrow \phi p n$ Reaction

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- $\gamma d \rightarrow K^+ K^- p n$ events are selected by using missing mass for the $d(\gamma, K^+ K^- p)X$ reaction.
- ϕ -produced events are identified by using $K^+ K^-$ invariant mass.



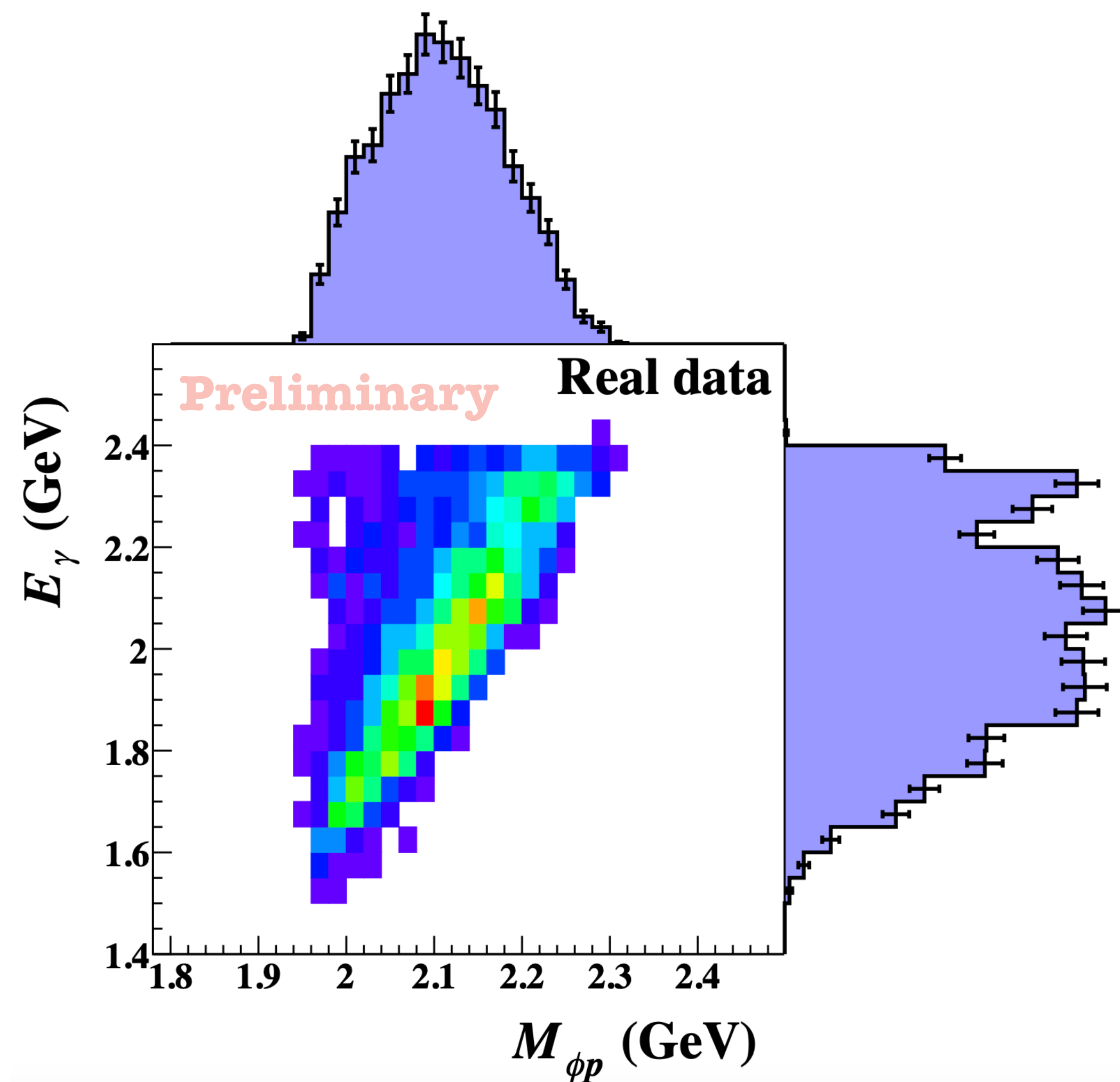
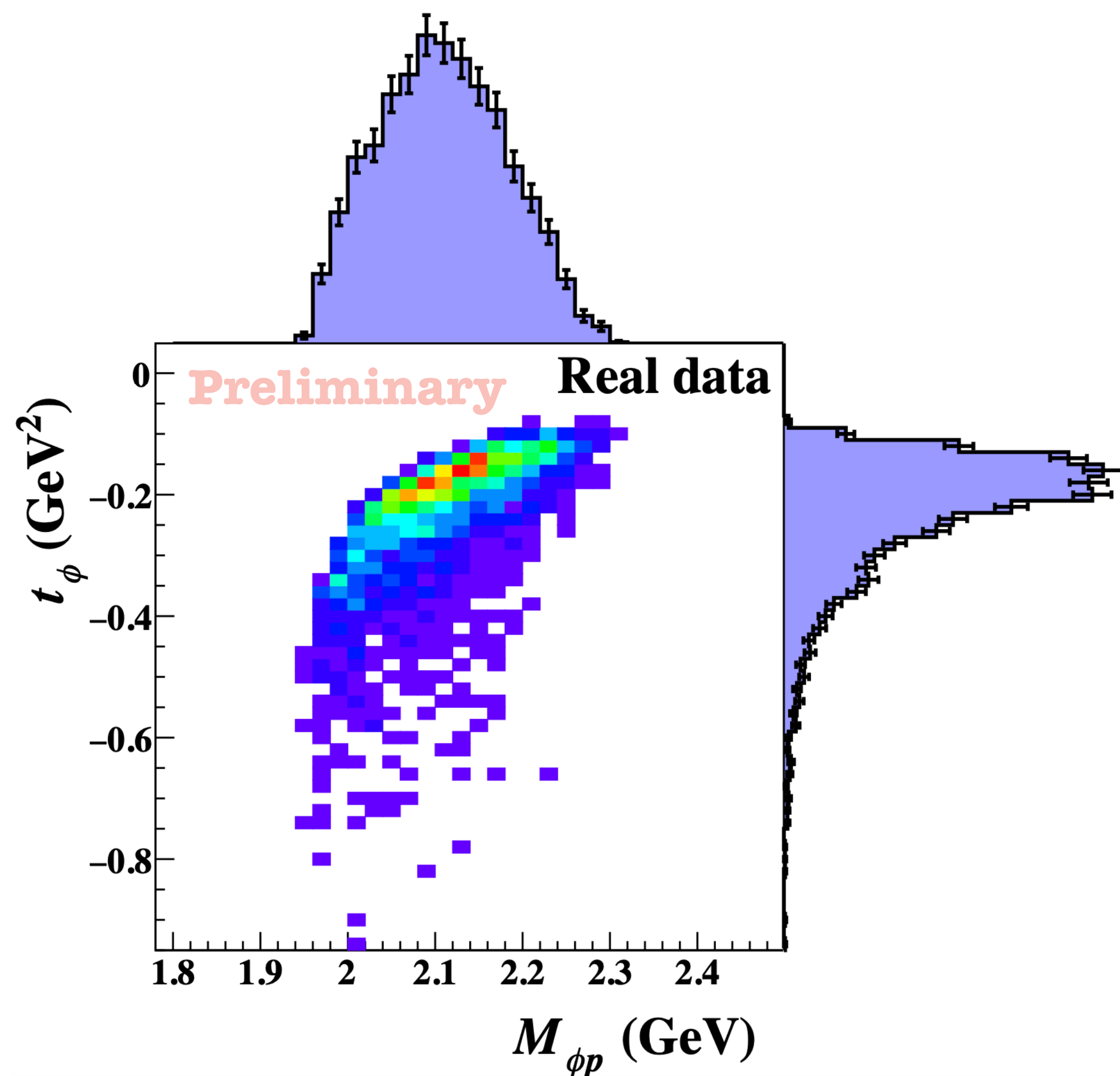


ϕp Invariant Mass Spectrum

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Dominance of ϕ -meson production at
small $|t_\phi| \equiv |(p_\gamma - p_\phi)^2|$

Correlation between $M_{\phi p}$ and E_γ





Towards an understanding of mass spectra 11

The following reactions are considered:

- **quasi-free** $\gamma' p' \rightarrow \phi p \rightarrow K^+ K^- p$

cross section, decay angular distribution of $\phi \rightarrow K^+ K^-$

- **quasi-free** $\gamma' p' \rightarrow K^+ \Lambda(1520) \rightarrow K^+ K^- p$

cross section, decay angular distribution of $\Lambda(1520) \rightarrow K^- p$

- **quasi-free, non resonant** $\gamma' p' \rightarrow K^+ K^- p$

uniformly generated in the phase space

Fermi motion of target nucleon

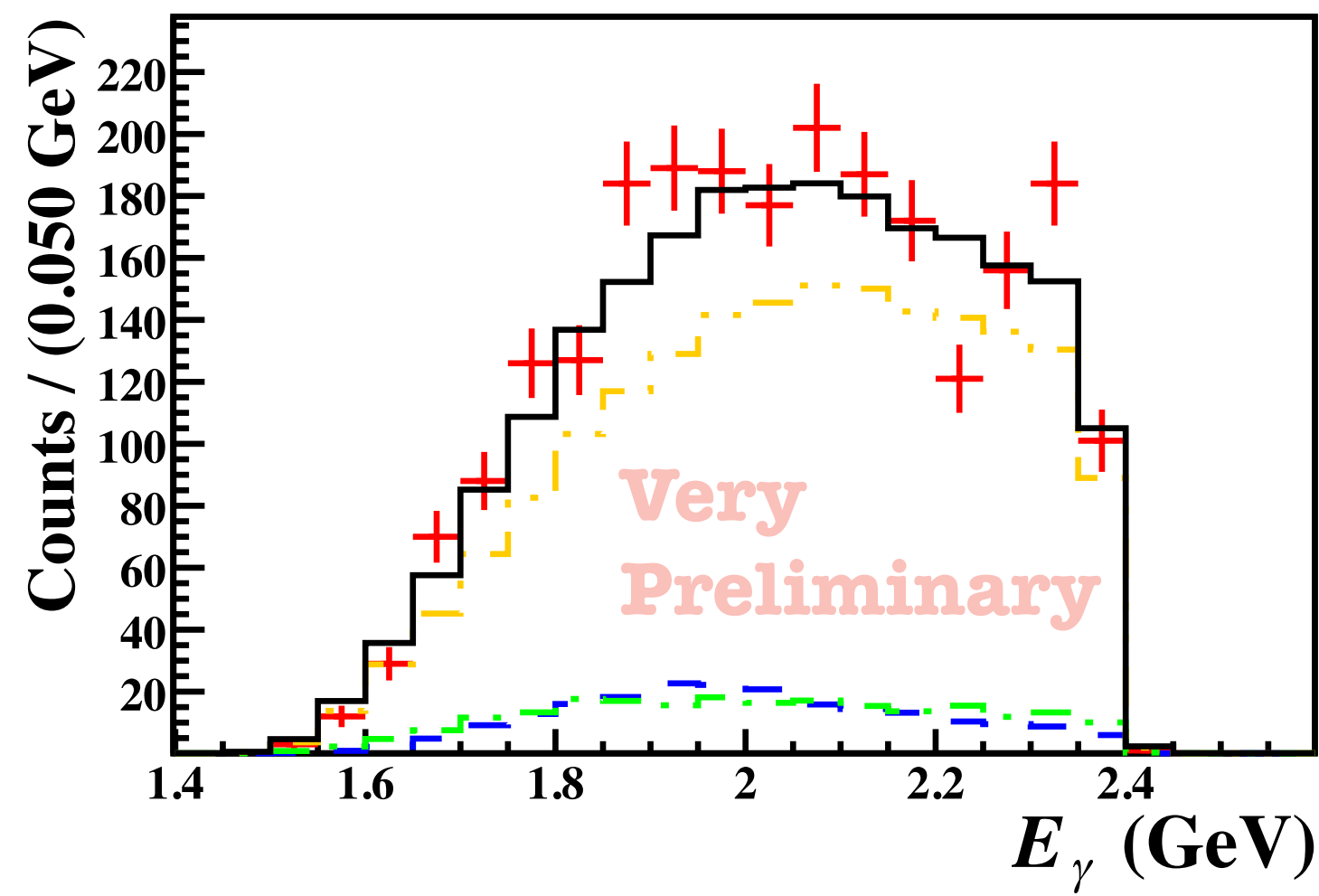
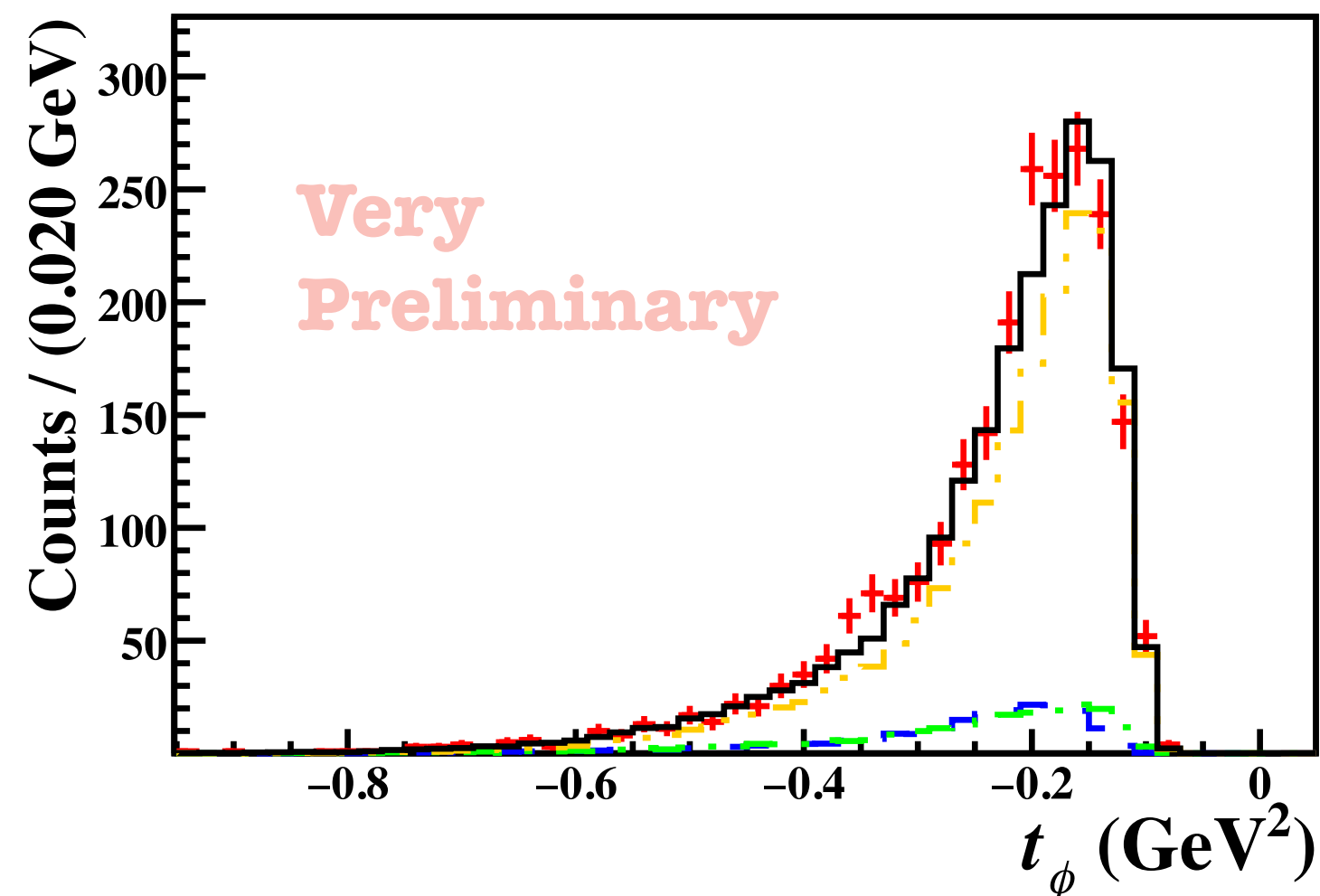
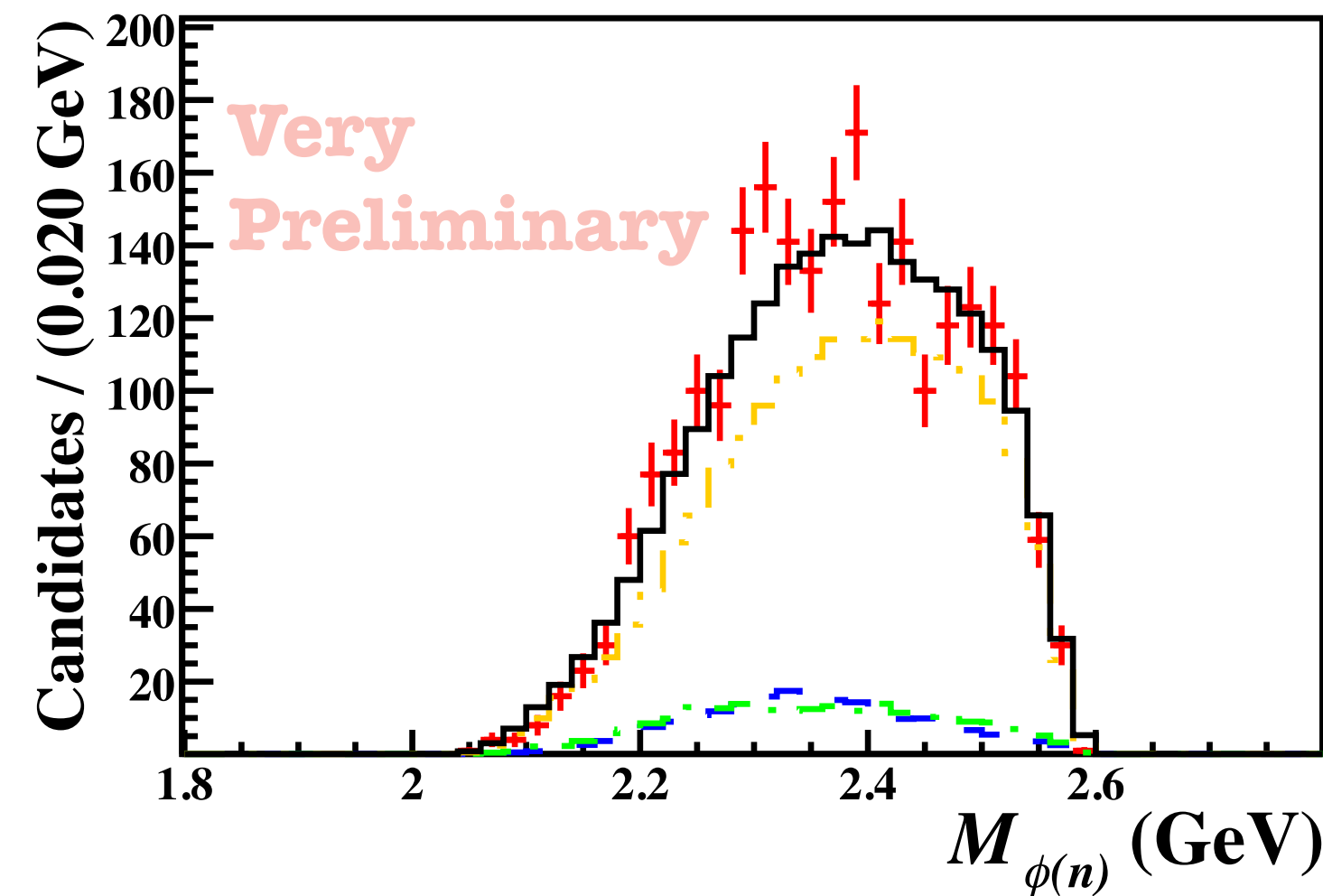
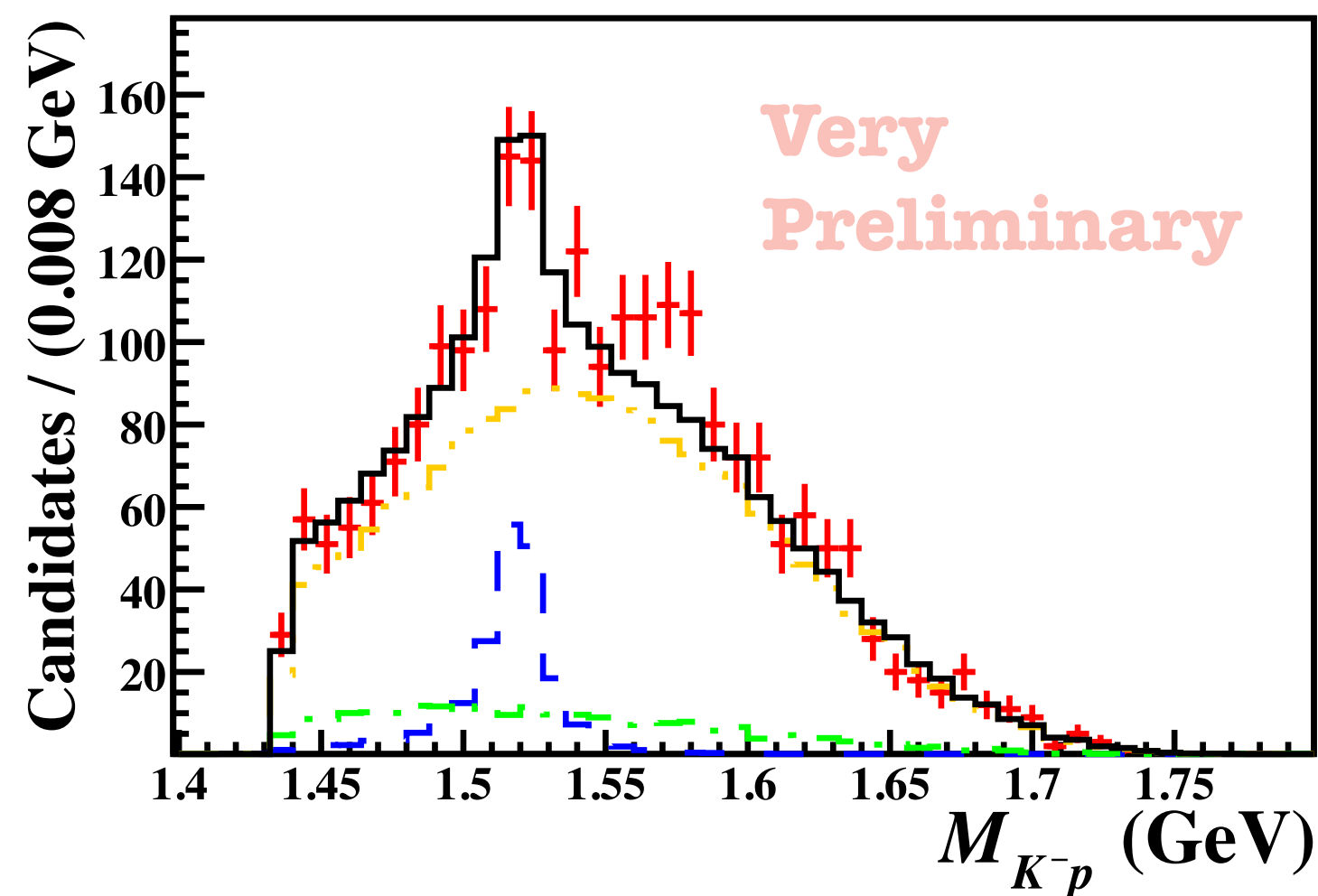
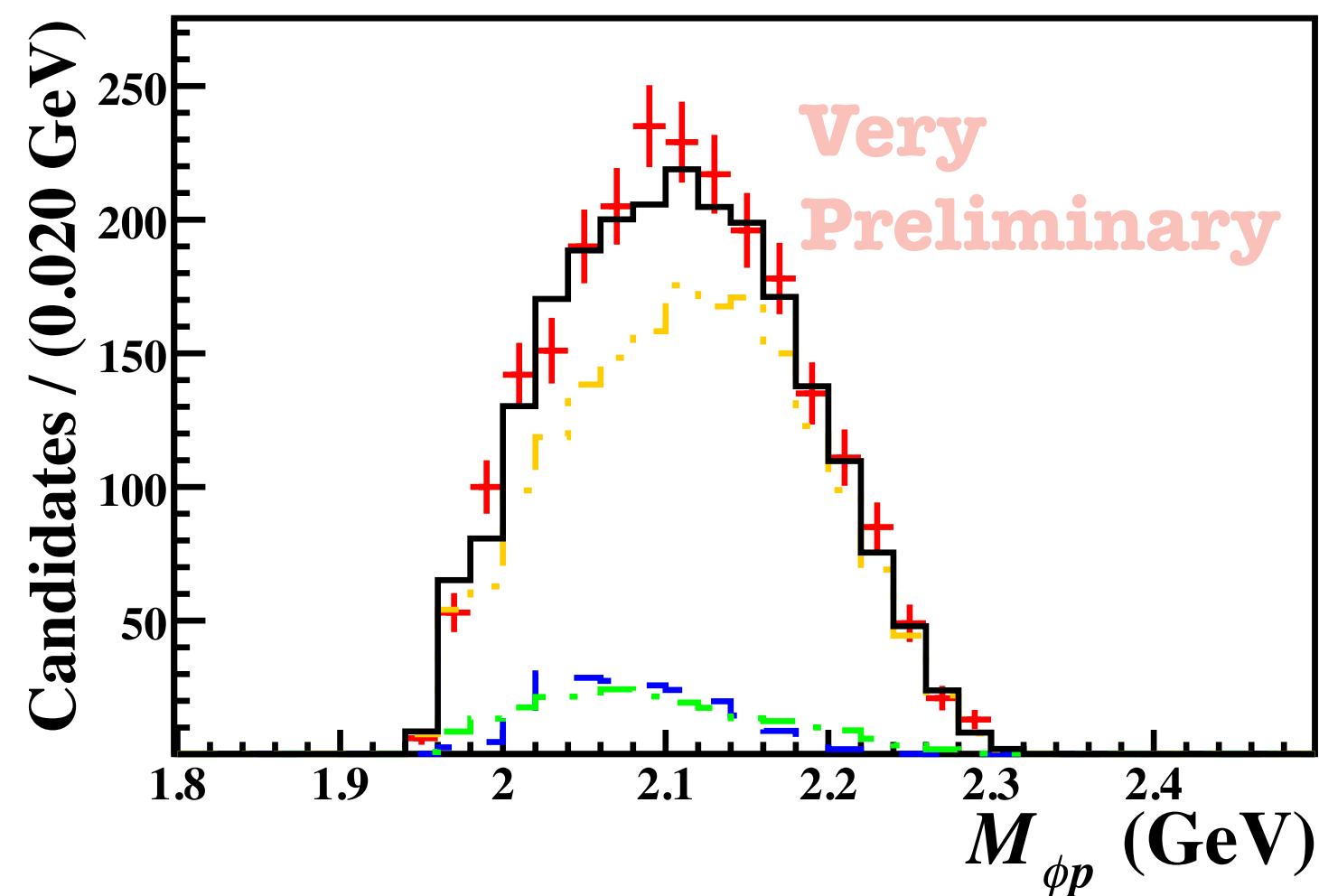
- Argonne V18 potential (<https://www.phy.anl.gov/theory/research/av18/>)

- Binding energy assigned to the participant proton



Preliminary result of simultaneous fit 12

We performed a simultaneous fit: $M_{\phi p}$, $M_{K^- p}$, $M_{\phi(n)}$, t_ϕ , E_γ .



Data

QF $\gamma p \rightarrow K^+ \Lambda(1520)$

QF $\gamma p \rightarrow K^+ K^- p$ (non reso.)

QF $\gamma p \rightarrow \phi p$

Simulation total



Discussion of $M_{\phi p}$

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- $M_{\phi p}$ distribution described by known reactions
- Small predicted partial decay width of $P_s(2080)$ into ϕN channel
- Prospects for a P_s search in the $K^*\Sigma$ channel with the LEPs2 Solenoid experiment

channel width	
ρN	5.66
ωN	1.33
ϕN	1.92
$K^* \Lambda$	6.64
$K^* \Sigma$	49.97

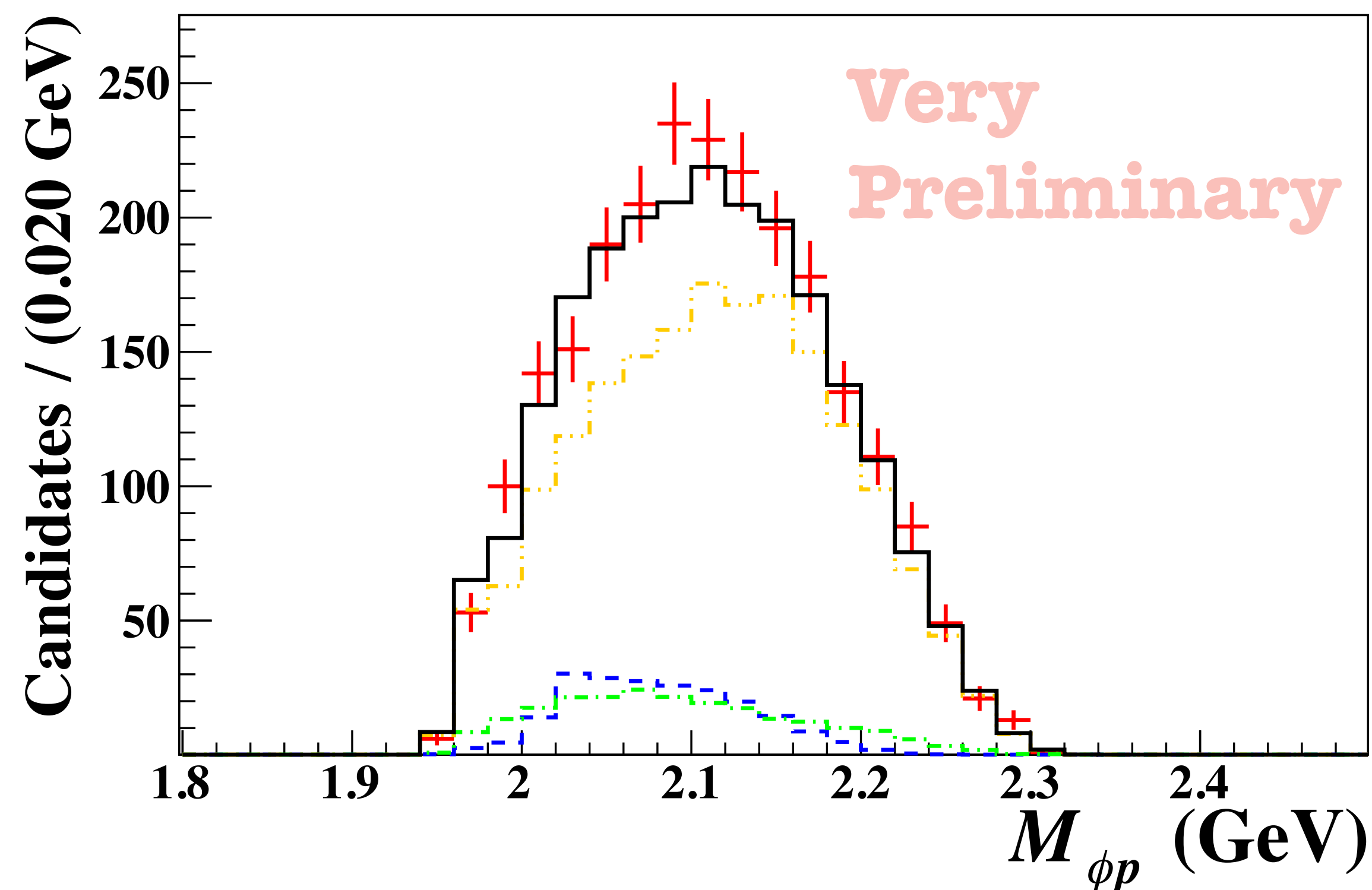
Data

QF $\gamma p \rightarrow K^+ \Lambda(1520)$

QF $\gamma p \rightarrow K^+ K^- p$ (non reso.)

QF $\gamma p \rightarrow \phi p$

Simulation total





Summary

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- A hidden-strangeness pentaquark state P_s , expected as a strangeness partner of P_c , has been hinted at in the ϕp subsystem.
- We searched for the P_s state using the $\gamma d \rightarrow \phi p n$ reaction with data taken at the SPring-8/LEPS experiment.
- The ϕp invariant mass spectrum can be described by known reactions.
- We may also be able to search for P_s in the $K^* \Sigma$ decay mode at the SPring-8/LEPS2 Solenoid experiment. (B. Agatão *et al.*, PRD 111, no.11, 116013 (2025))

Thank you!



backup

15

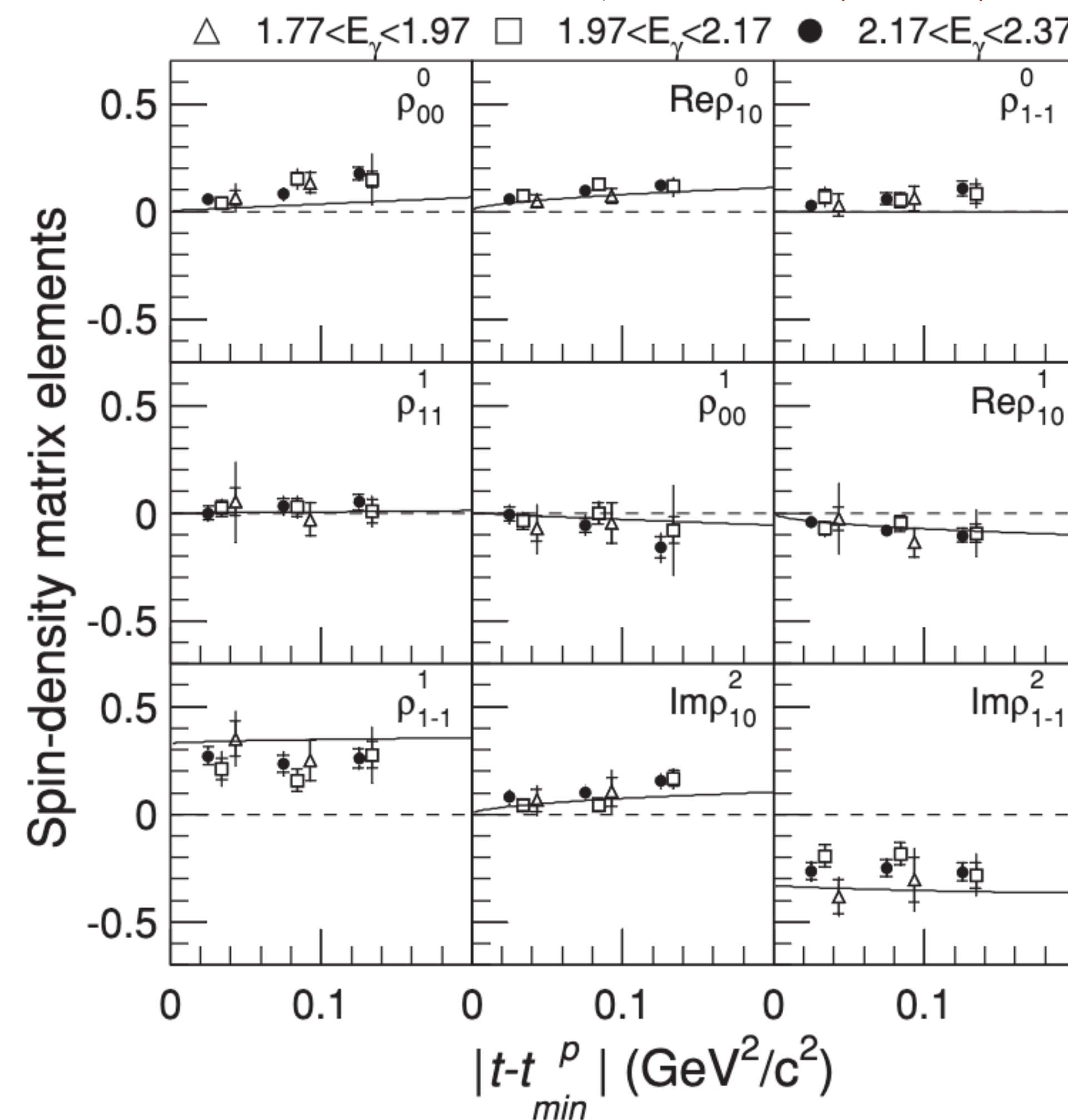
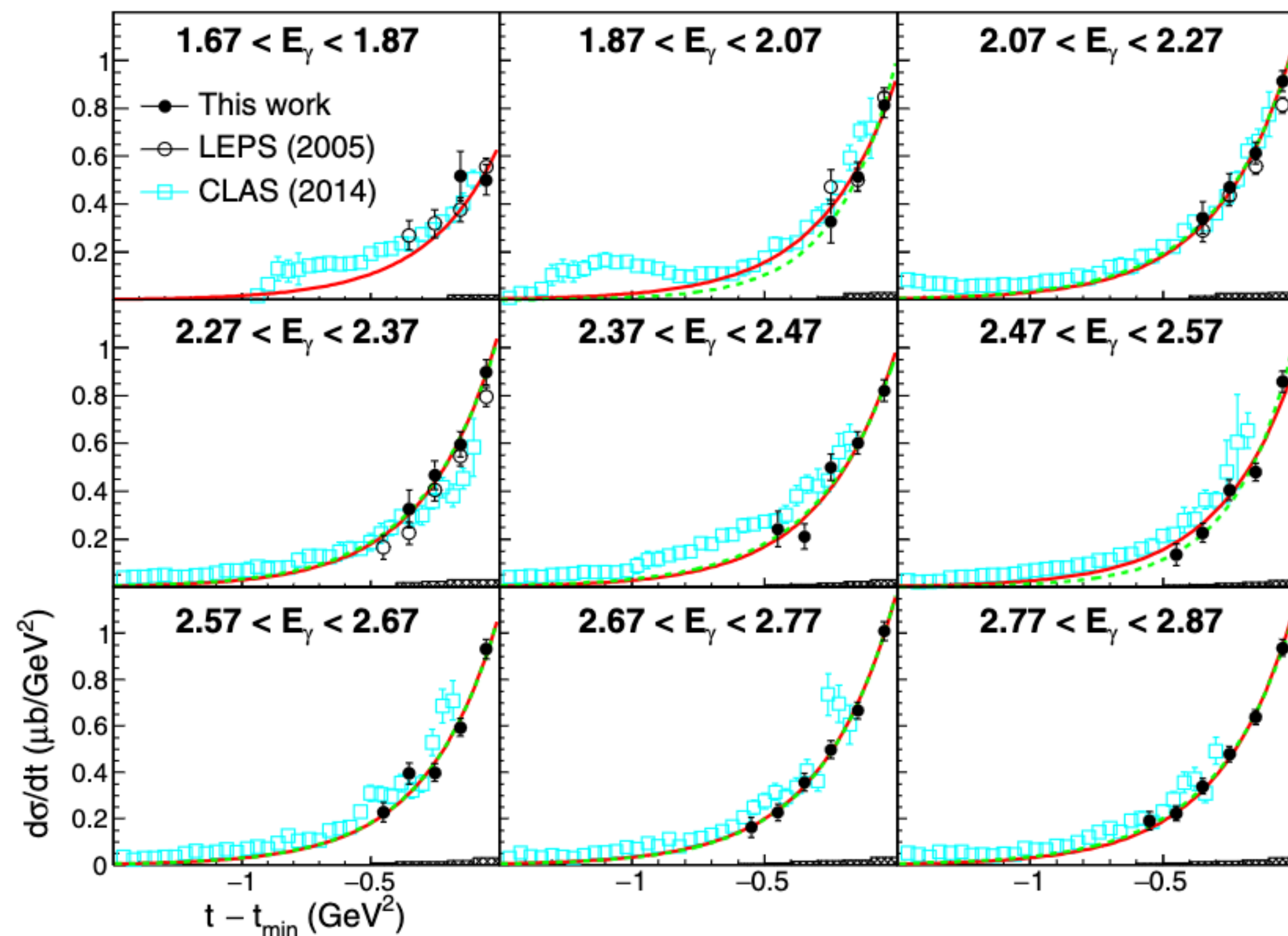


Generation of the $\gamma p \rightarrow \phi p$ reaction 16

The production cross section and the $\phi \rightarrow K^+ K^-$ decay angular distribution (SDMEs) were implemented.

K. Mizutani *et al.*, (LEPS Coll.), PRC96, 062201(R) (2017)

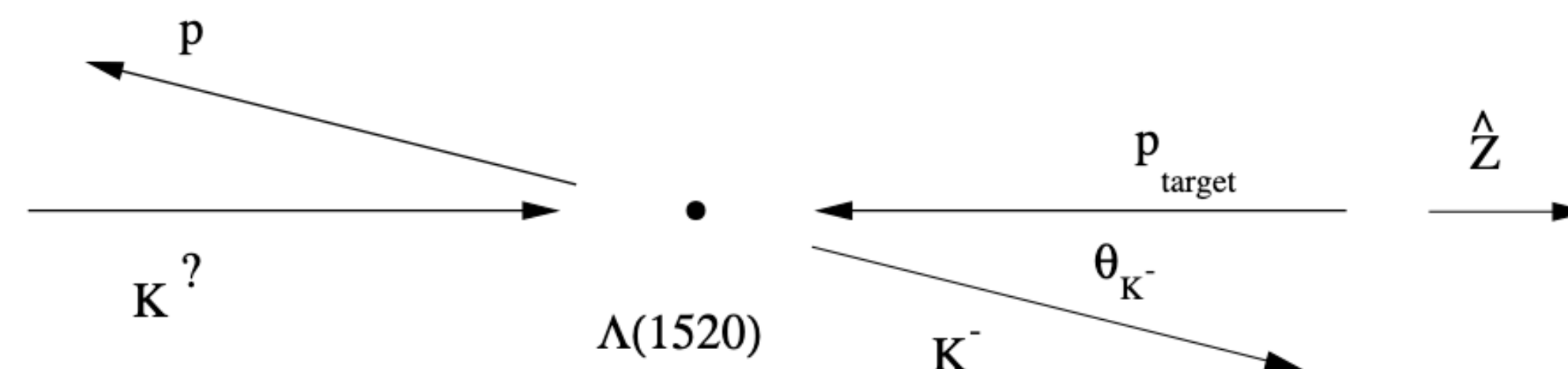
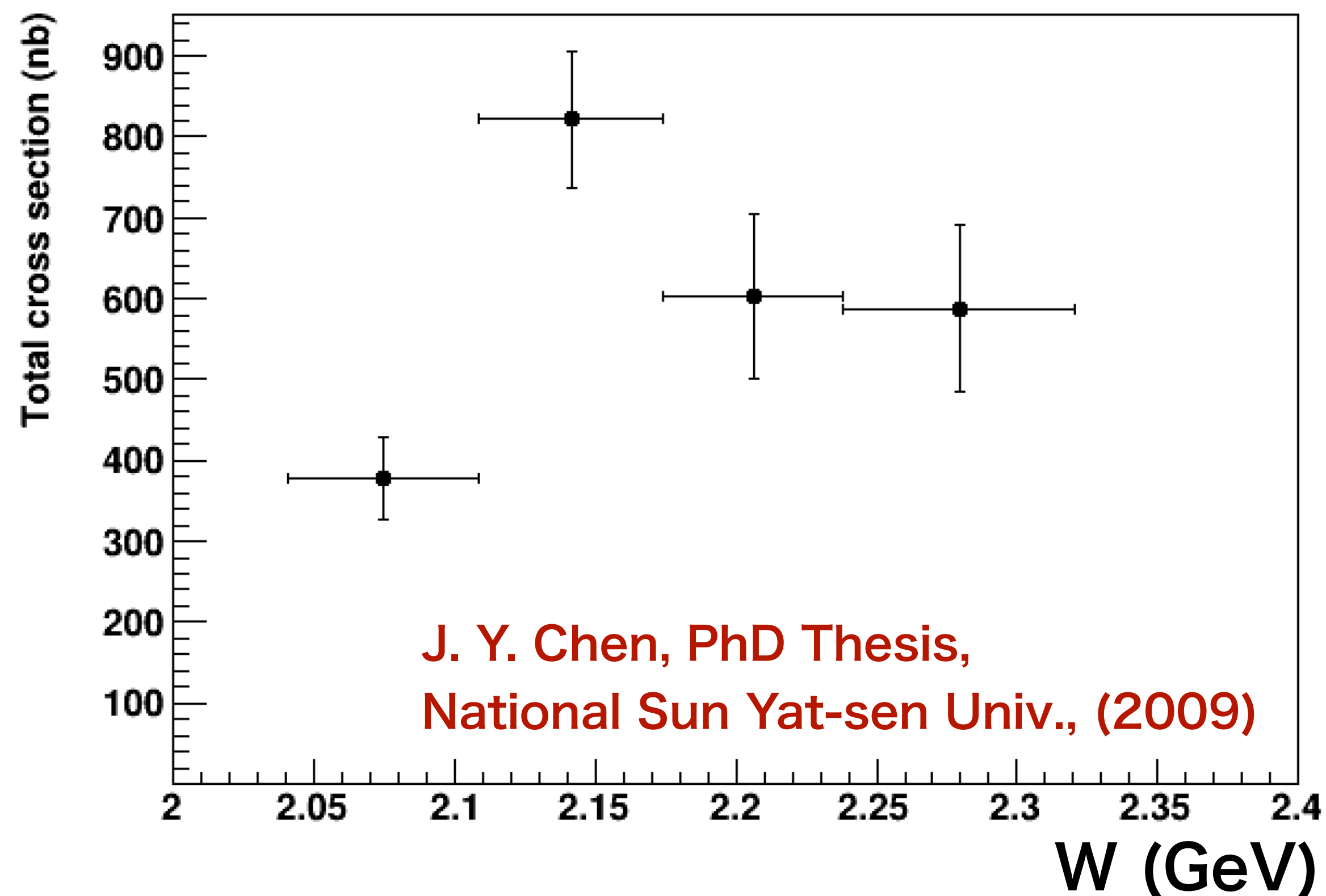
W. C. Chang *et al.*, (LEPS Coll.),
PRC82, 015205 (2010)





Generation of the $\gamma p \rightarrow K^+ \Lambda(1520)$ reaction 17

The production cross section and the $\Lambda(1520) \rightarrow K^- p$ decay angular distribution (K^- polar angle distributions in the t -ch. helicity frame of $\Lambda(1520)$, **N. Muramatsu *et al.* (LEPS Coll.), PRL 103, 012001 (2009)**) were implemented.



S. P. Barrow *et al.* (CLAS Coll.) Phys. Rev. C 64, 044601 (2001)

FIG. 7. The definition of the t -channel helicity frame angle θ_{K^-} .

$$\frac{dN}{d \cos \theta_{K^-}} = \alpha \sin^2 \theta_{K^-} + (1 - \alpha) \left(\frac{1}{3} + \cos^2 \theta_{K^-} \right)$$

$S_z = \pm 3/2$
 K^* exch.

$S_z = \pm 1/2$, K exch.

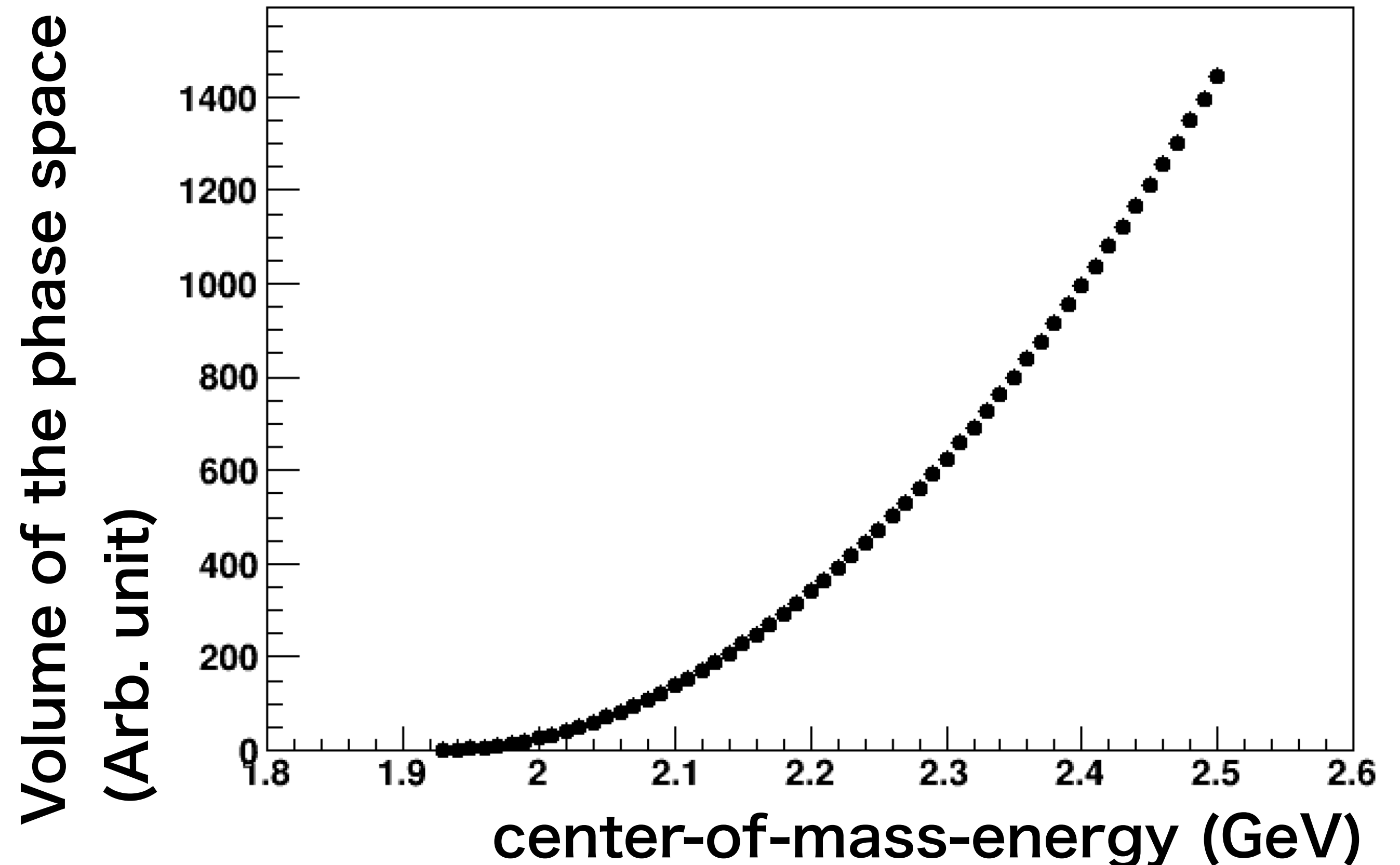
α : parameter



Generation of the $\gamma p \rightarrow K^+ K^- p$ (non reso.) reaction 18

The quasi-free $\gamma p \rightarrow K^+ K^- p$ (non resonant) events are uniformly generated in the phase space.

The production cross section was assumed to follow the center-of-mass-energy dependence of the phase-space volume.





Discussion about M_{K^-p}

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Is an excess around 1.58 GeV
the $\Sigma(1580)$?

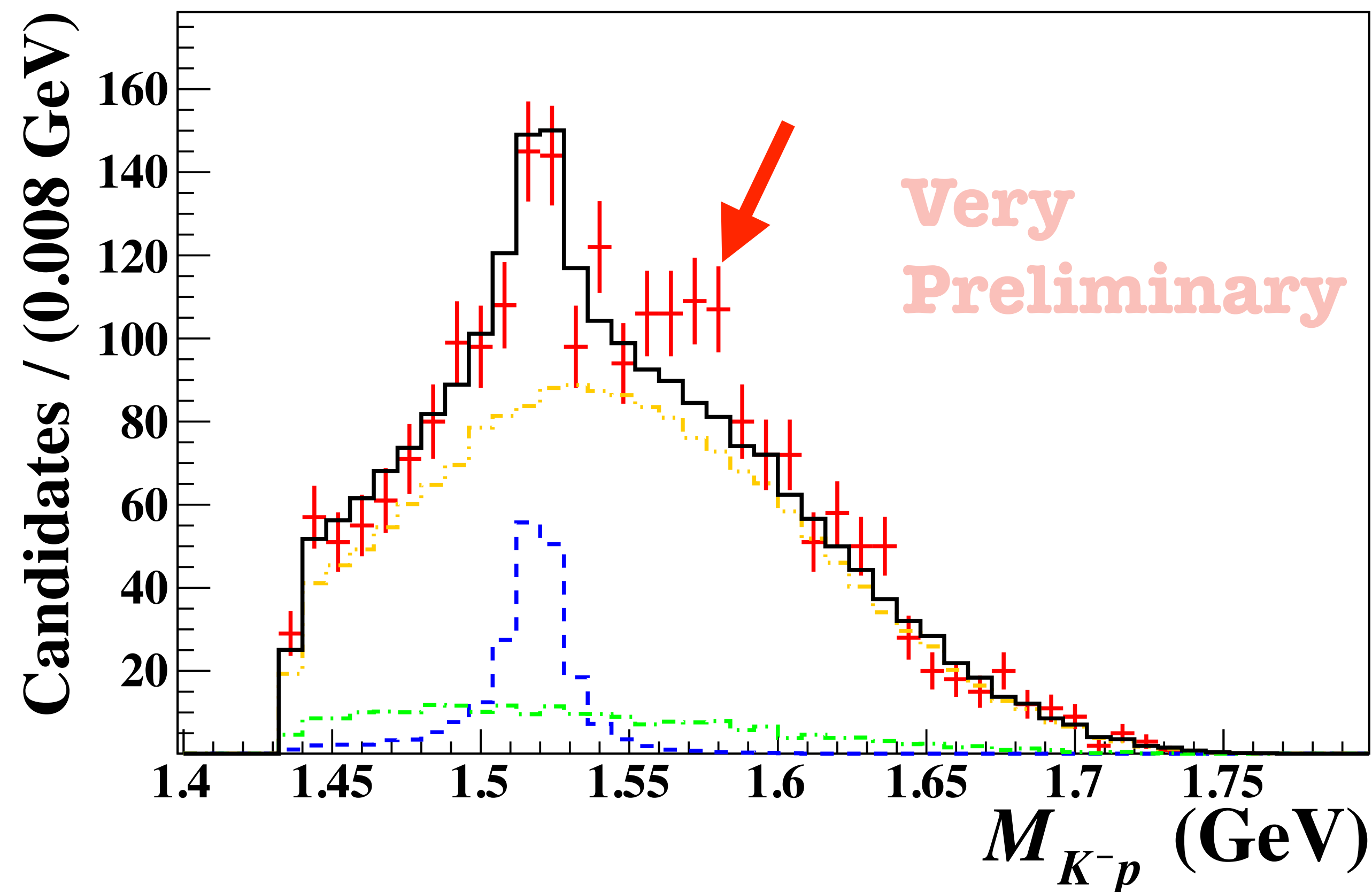
Data

QF $\gamma p \rightarrow K^+ \Lambda(1520)$

QF $\gamma p \rightarrow K^+ K^- p$ (non reso.)

QF $\gamma p \rightarrow \phi p$

Simulation total





Σ(1580)

20

$\Sigma(1580) \qquad I(J^P) = 1(3/2^-)$

Seen in the isospin-1 $\bar{K}N$ cross section at BNL (LI 1973, CARROLL 1976) and in a partial-wave analysis of $K^- p \rightarrow \Lambda\pi^0$ for c.m. energies 1560–1600 MeV by LITCHFIELD 1974. LITCHFIELD 1974 finds $J^P = 3/2^-$. Not seen by ENGLER 1978, CAMERON 1978C, OLMSTED 2004, nor by PRAKHOV 2004. Neither ZHANG 2013A nor SARANTSEV 2019 see any evidence for this state.

Σ(1580) MASS

~1580 MeV

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
≈ 1580	OUR ESTIMATE		
1583 ±4	¹ CARROLL 1976	DPWA	Isospin-1 total σ
1582 ±4	² LITCHFIELD 1974	DPWA	$K^- p \rightarrow \Lambda\pi^0$

- ¹ CARROLL 1976 sees a total-cross-section bump with $(J+1/2) \Gamma_{\text{el}} / \Gamma_{\text{total}} = 0.06$.
- ² The main effect observed by LITCHFIELD 1974 is in the $\Lambda\pi$ final state; the $\bar{K}N$ and $\Sigma\pi$ couplings are estimated from a multichannel fit including total-cross-section data of LI 1973.

References ^

CARROLL	1976	PRL 37 806	Structures in K^- Nucleon Total Cross Sections below 1.1 GeV/c
LITCHFIELD	1974	PL 51B 509	Spin-Parity of the Σ(1580)

Σ(1580) WIDTH

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
15	¹ CARROLL 1976	DPWA	Isospin-1 total σ
11 ±4	² LITCHFIELD 1974	DPWA	$K^- p \rightarrow \Lambda\pi^0$

- ¹ CARROLL 1976 sees a total-cross-section bump with $(J+1/2) \Gamma_{\text{el}} / \Gamma_{\text{total}} = 0.06$.
- ² The main effect observed by LITCHFIELD 1974 is in the $\Lambda\pi$ final state; the $\bar{K}N$ and $\Sigma\pi$ couplings are estimated from a multichannel fit including total-cross-section data of LI 1973.