Search for the $N\Delta$ resonance in the $\gamma d \rightarrow d\pi^+\pi^-$ reaction
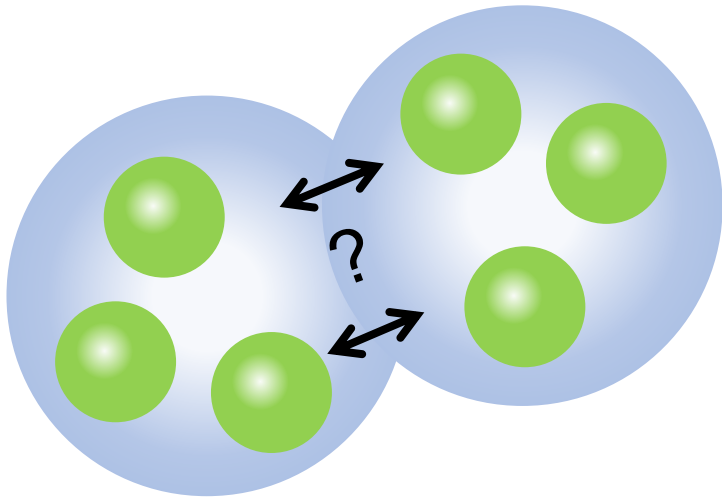
Yuichi Toyama

B7SD2011

Contents

Yuichi Toyama

Introduction

- Dibaryon
- D_{12}
- Old measurement of the $\gamma d \to d\pi^+\pi^-$ reaction
- Goal of this study

What is "dibaryon" ?

Predicted 2-baryon states without strangeness

$\mathcal{D}_{IS}$	$\mathcal{D}_{01}$	$\mathcal{D}_{10}$	$\mathcal{D}_{12}$	$\mathcal{D}_{21}$	$\mathcal{D}_{03}$	$\mathcal{D}_{30}$
BB	NN	NN	NΔ	NΔ	$\Delta\Delta$	$\Delta\Delta$
Mass formula	A	A	A+6B	A+6B	A+10B	A+10B
Approx. mass	1878	1878	2160	2160	2348	2348

Molecule state of 2 baryons?
Compact 6 quarks state?

Deuteron
$^3S_1$

Virtual state
(pp, nn, np)
$^1S_0$

WASA/CELSIUS,
WASA at COSY
d*(2380)

$$M = A + B\left(I(I+1) + S(S+1) - 2\right)$$

A = 1878 MeV
B = 47 MeV

F.J. Dyson and N.H. Xuong, PRL 13 (1964) 815

D_{IS}

isospin

spin

What is "dibaryon"?

?

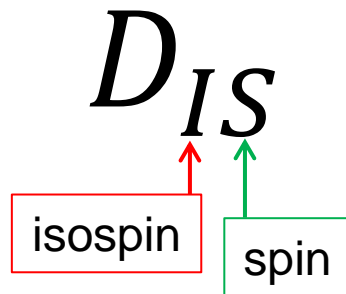Molecule state of 2 baryons
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Predicted 2-baryon states without strangeness

$\mathcal{D}_{IS}$	$\mathcal{D}_{01}$	$\mathcal{D}_{10}$	$\mathcal{D}_{12}$	$\mathcal{D}_{21}$	$\mathcal{D}_{03}$	$\mathcal{D}_{30}$
BB	NN	NN	NΔ	NΔ	$\Delta\Delta$	$\Delta\Delta$
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WASA/CELSIUS,
WASA at COSY
d*(2380)

pn $\longrightarrow$ d$\pi^0\pi^0$

σ [mb]

d$\pi\pi$ threshold

PRL106, 242602 (2011)
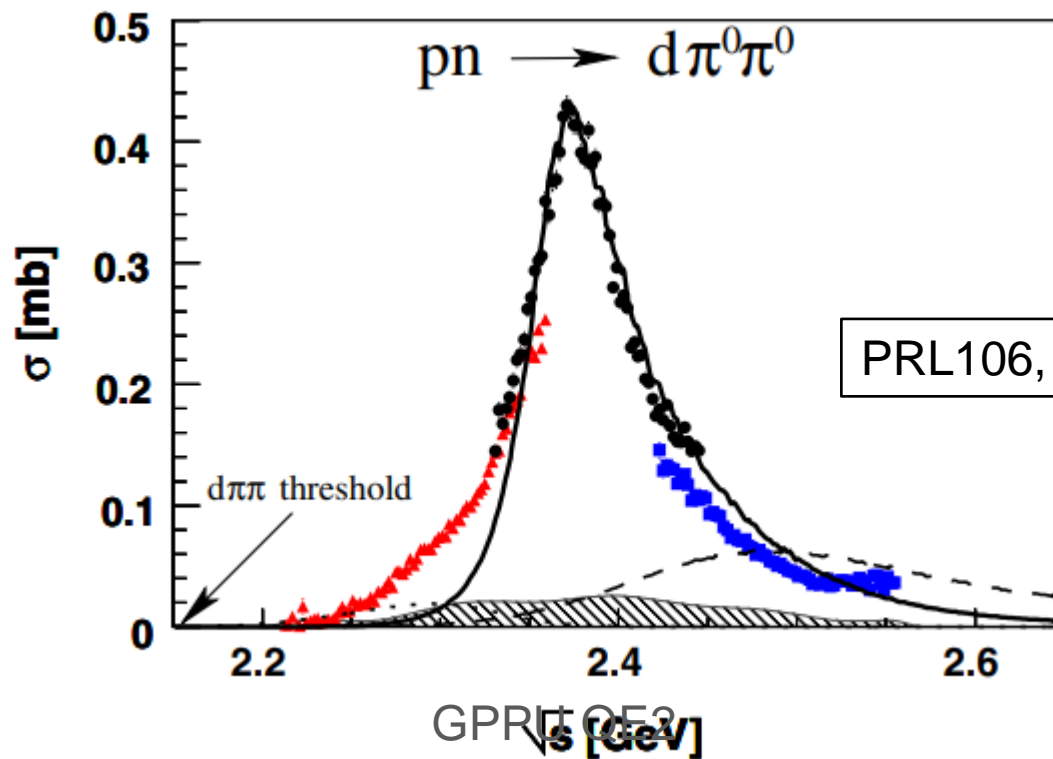
$\sqrt{s}$ [GeV]

GPRU QE?

Yuichi Toyama

What is "dibaryon" ?

Molecule state of 2 baryons?
Compact 6 quarks state?
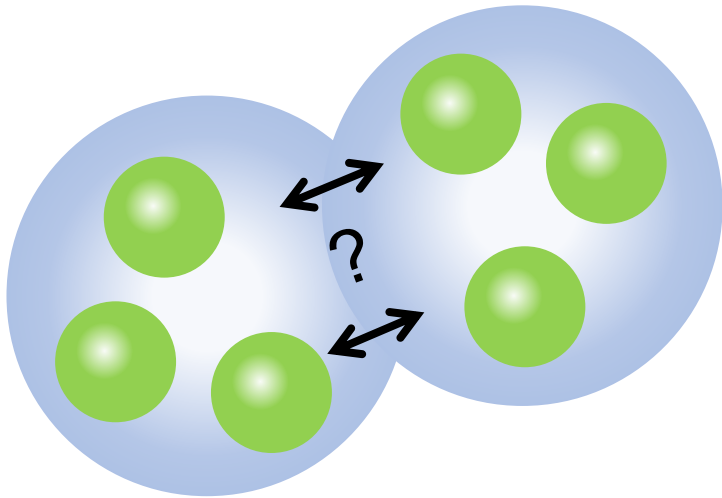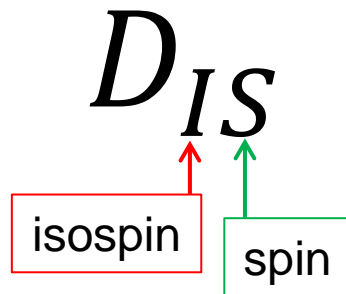
Predicted 2-baryon states without strangeness

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BB	NN	NN	NΔ	NΔ	ΔΔ	ΔΔ
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Deuteron
$^3S_1$

Virtual state
(pp, nn, np)
$^1S_0$

WASA/CELSIUS,
WASA at COSY
d*(2380)

$$D_{IS}$$

isospin   spin

$$M = A + B\,(I(I+1) + S(S+1) - 2)$$
A = 1878 MeV
B = 47 MeV
F.J. Dyson and N.H. Xuong, PRL 13 (1964) 815

Previous studies of D_{12}

- Experiment
  - B.S. Neganov, L.B. Parfenov, JETP7, 528 (1958).
  - $\pi d \to pp$ scattering PWA: R. Arndt *et al.*, PRC48, 1926 (1993).
  - $\pi d \to \pi d$ scattering PWA: R. Arndt *et al.*, PRC50, 1796 (1994).
  - Coupling channel including pp scattering: C.H. Oh *et al.*, PRC56, 635 (1997).

- Theory
  - Bag model: P.J. Mulders, A.T. Aerts, J.J. de Swart, Phys. Rev. D 21 (1980) 2653.
  - Bag model + π cloud correction: P.J. Mulders, A.W. Thomas, J. Phys. G 9 (1983) 1159.
  - πNN three-body Faddeev: A. Gal, H. Garcilazo, Nucl. Phys. A 928 (2014) 73.
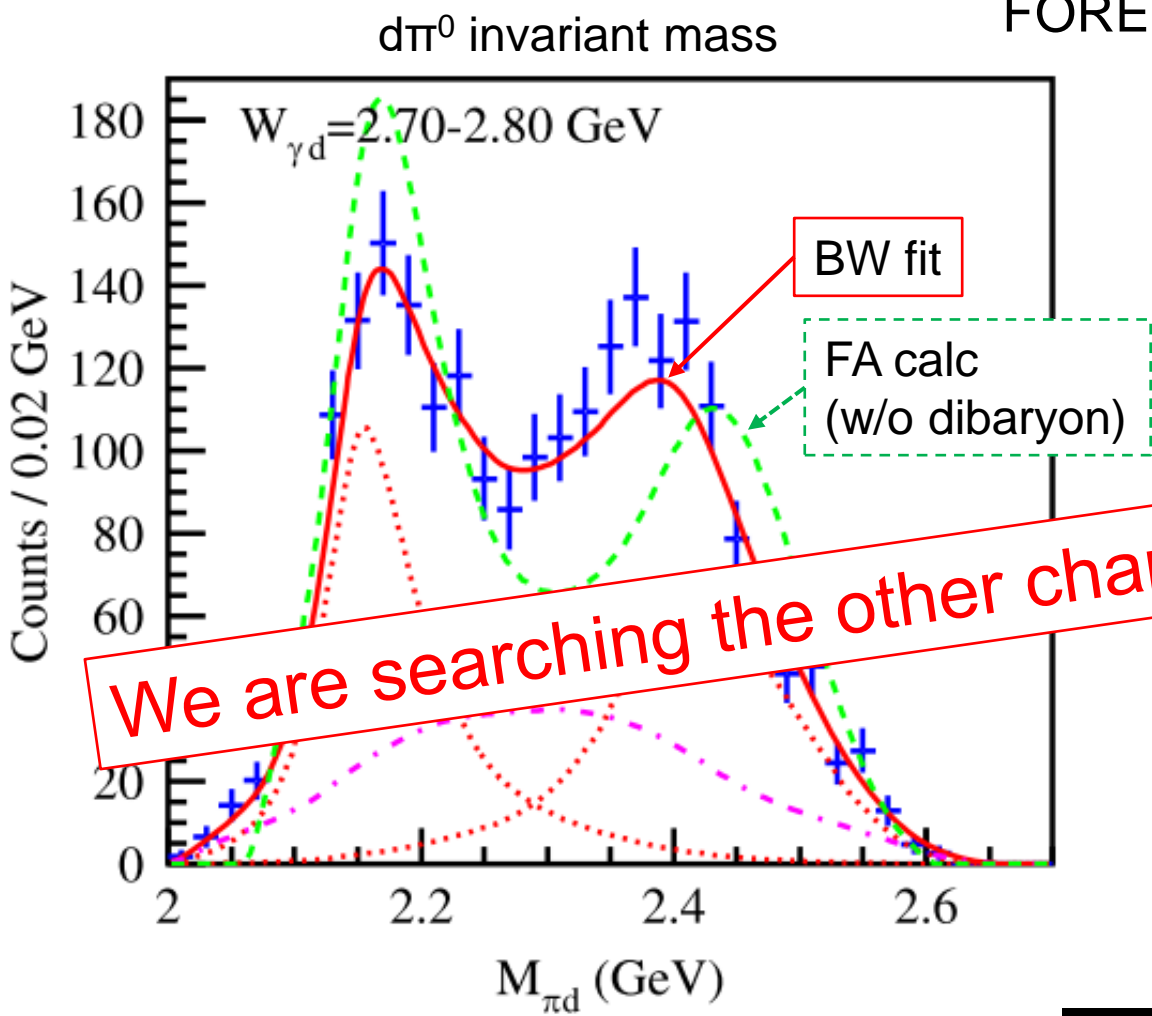 - NN scattering including intermediate dibaryon: M.N. Platonova, V.I. Kukulin, Nucl. Phys. A 946 (2016) 117.

However, D$_{12}$ was a still questionable state.

i.e. kinematical effect or true resonance? (PLB112(1982)17 etc.)

Recent experimental data of photoproduction
T. Ishikawa et al., PLB789, 413 (2019)

$$\gamma d \rightarrow d\pi^0\pi^0$$
FOREST, ELPH

dπ^0 invariant mass

M = 2.14$\pm$ 0.01 GeV
Γ = 0.09$\pm$0.01 GeV
J^P = 1$^+$, 2$^+$, or 3$^-$

- 3 isoscaler dibaryon, 1 isovector dibaryon
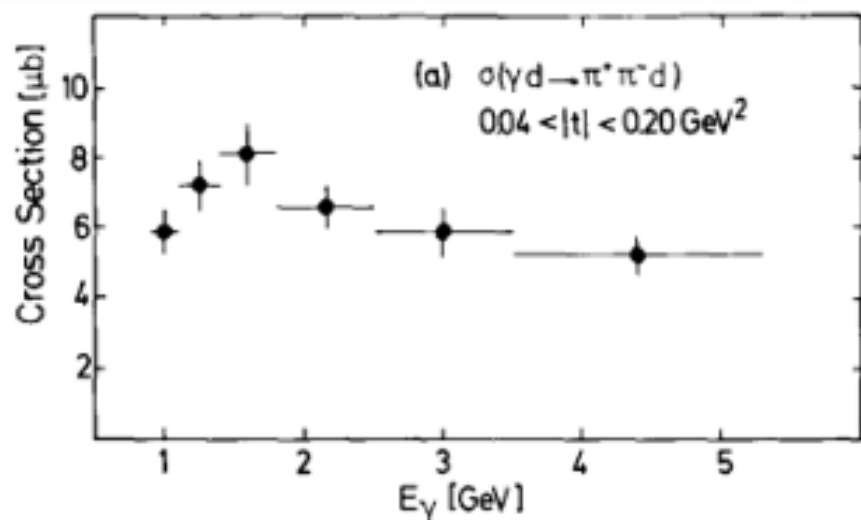- Isovector dibaryon as a decay product of isoscaler dibaryons

BW fit
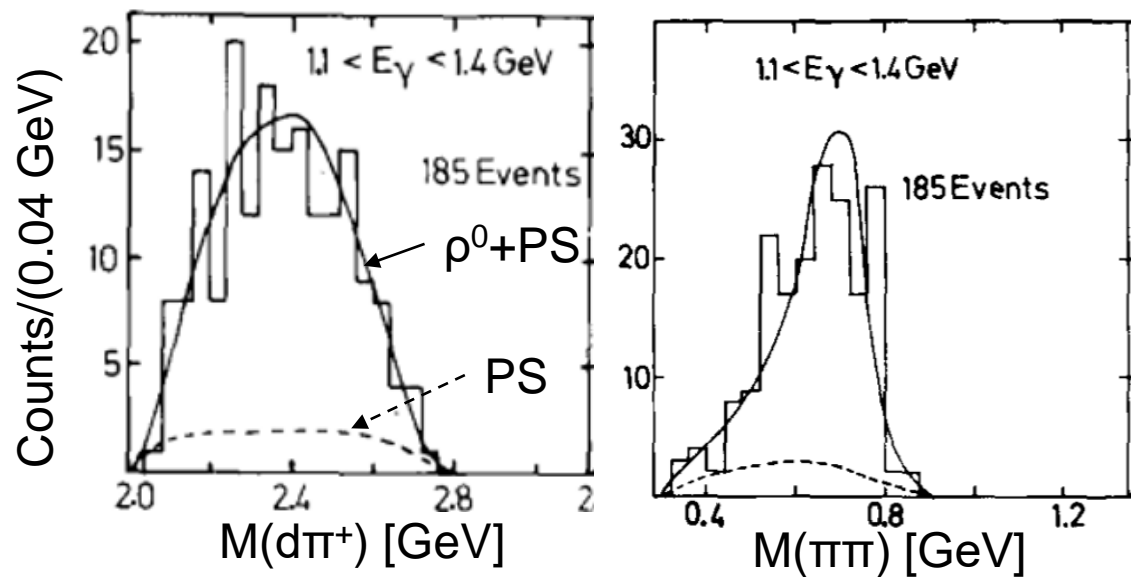
FA calc
(w/o dibaryon)

They suggested

$$\gamma d \rightarrow R_{IS} \rightarrow D_{12}\pi^0 \rightarrow d\pi^0\pi^0$$

We are searching the other charge state ($d\pi^\pm$) by the $\gamma d \rightarrow d\pi^+\pi^-$

Old measurement of the $\gamma d \rightarrow d\pi^+\pi^-$ reaction

Benz *et al.*, NPB79 (1974) 10.

Old bubble chamber experiment

- Higher E_γ (1.1< E_γ<5.3 GeV)
- Limited statistics
- Limited t region (**0.04<|t|<0.20 GeV²**, lower d momentum ($mom_d \lesssim 0.4$ GeV/*c*))
- **No peak structure in dπ invariant mass**
  - ρ^0 and PS dist. reproduce the data
- Differential cross section dσ/dt of ρ^0 production

- Total cross section ~6μb (E_γ~1 GeV)

Goal of this study

・Study of a possible dibaryon state, especially *NΔ* dibaryon via the $\gamma d \rightarrow d\pi^+\pi^-$ reaction.

・ Mass & Width

・ Deuteron angular distribution

・The cross section measurement of the $\gamma d \rightarrow d\pi^+\pi^-$ reaction.

・ First measurement in this kinematic region (energy and mom$_d$)
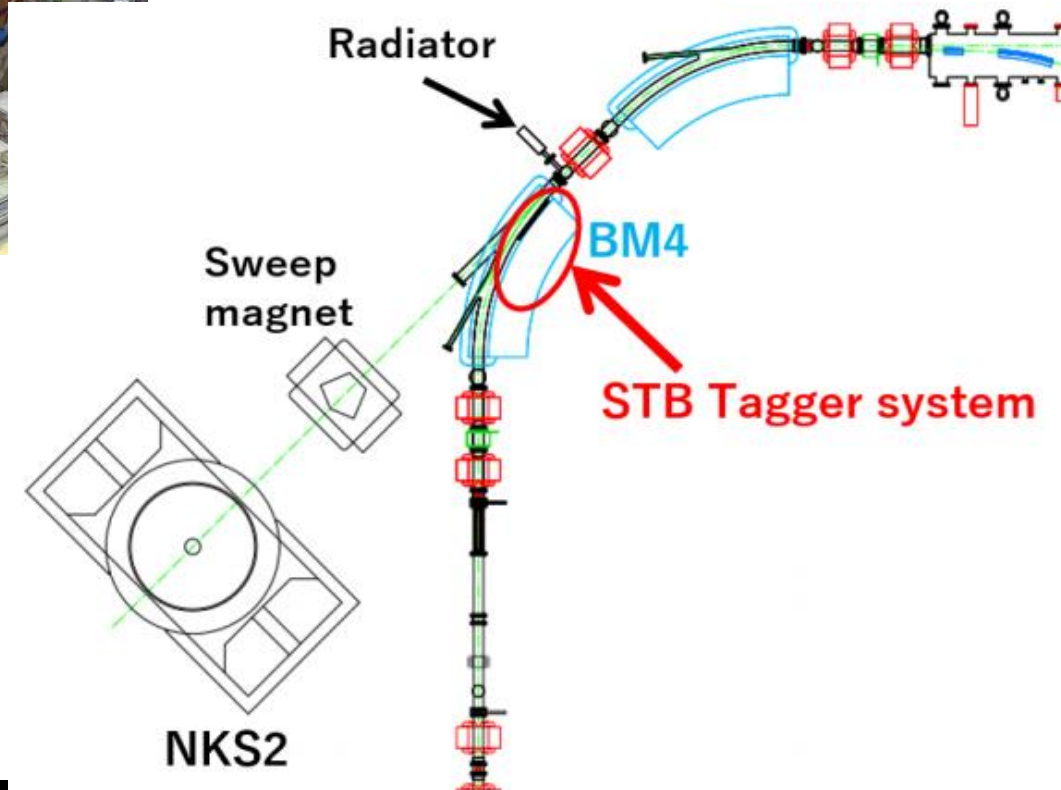
Yuichi Toyama

Experiment   Oct. 2010

- Research Center for ELectron PHoton Science（ELPH）
- Neutral Kaon Spectrometer 2 (NKS2)

Research Center for ELectron PHoton Science (ELPH)

https://www.lns.tohoku.ac.jp/

- Location: Sendai, Japan
- Electron Synchrotron
  - Internal target system for γ beam [1]

[1] H. Yamazaki *et al.*, Nucl. Instr. and Meth. A 536 (2005) 70.

Experimental condition (2010 NKS2)	
Injection Beam energy	150 MeV
Ring top energy	1.2 GeV
Gamma beam energy	0.78—1.08 GeV

Radiator

Sweep magnet

BM4

STB Tagger system

NKS2

Neutral Kaon Spectrometer 2 (NKS2)
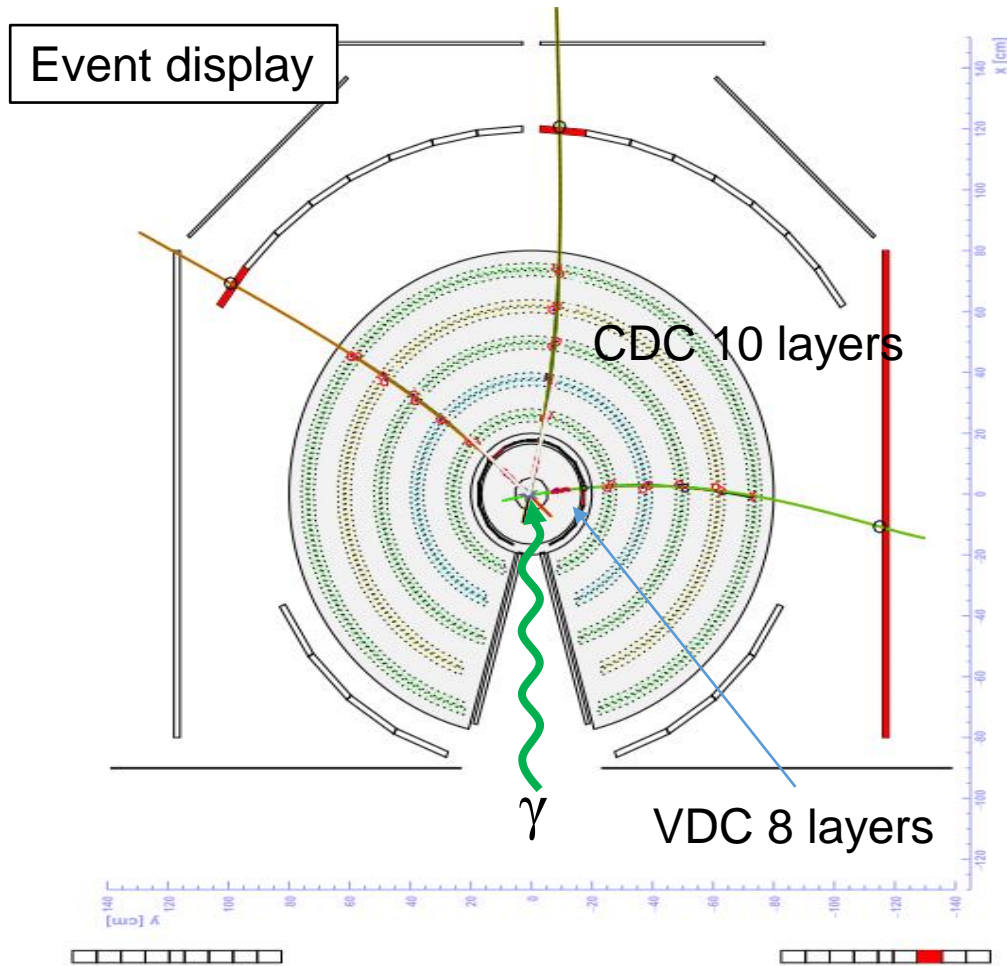
- $\gamma d \to d\pi^+\pi^-$
- Data taken in Oct. 2010
- E_γ = 0.78−1.08 GeV
- liq. D target (516 mg/cm^2)
- N_γ = 3 x 10^{12}

- Dipole magnet : B ~ 0.42 T, R = 0.8 m
- Hodoscopes (IH and OH): TOF measurement
- MWDC's (CDC and VDC) : Tracking for momentum and vertex finding
- EV: e$^+$e$^-$ rejection
- Geometrical acceptance: ~1 π sr

Neutral Kaon Spectrometer 2 (NKS2)

Event display

CDC 10 layers

π

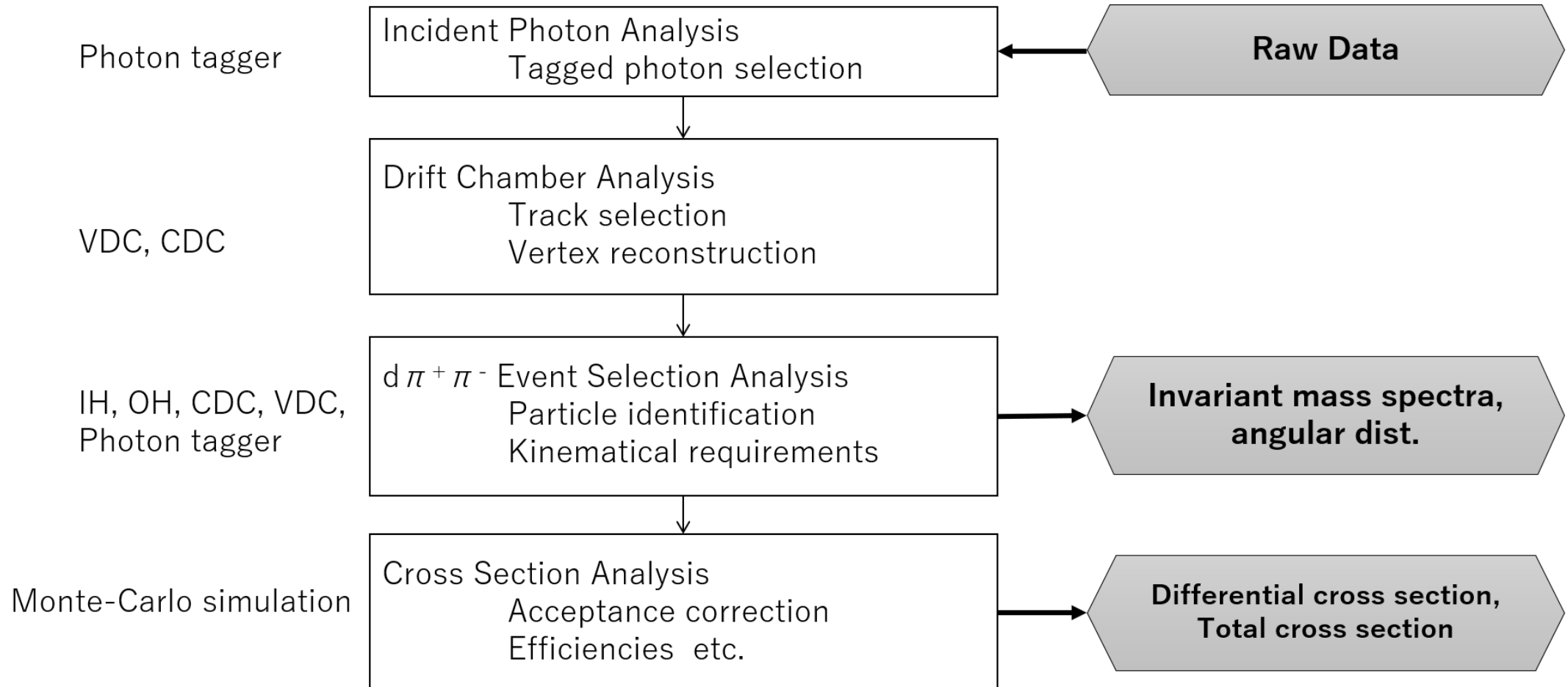γ

VDC 8 layers

γ beam

1 m

20 cm

Target

Beam
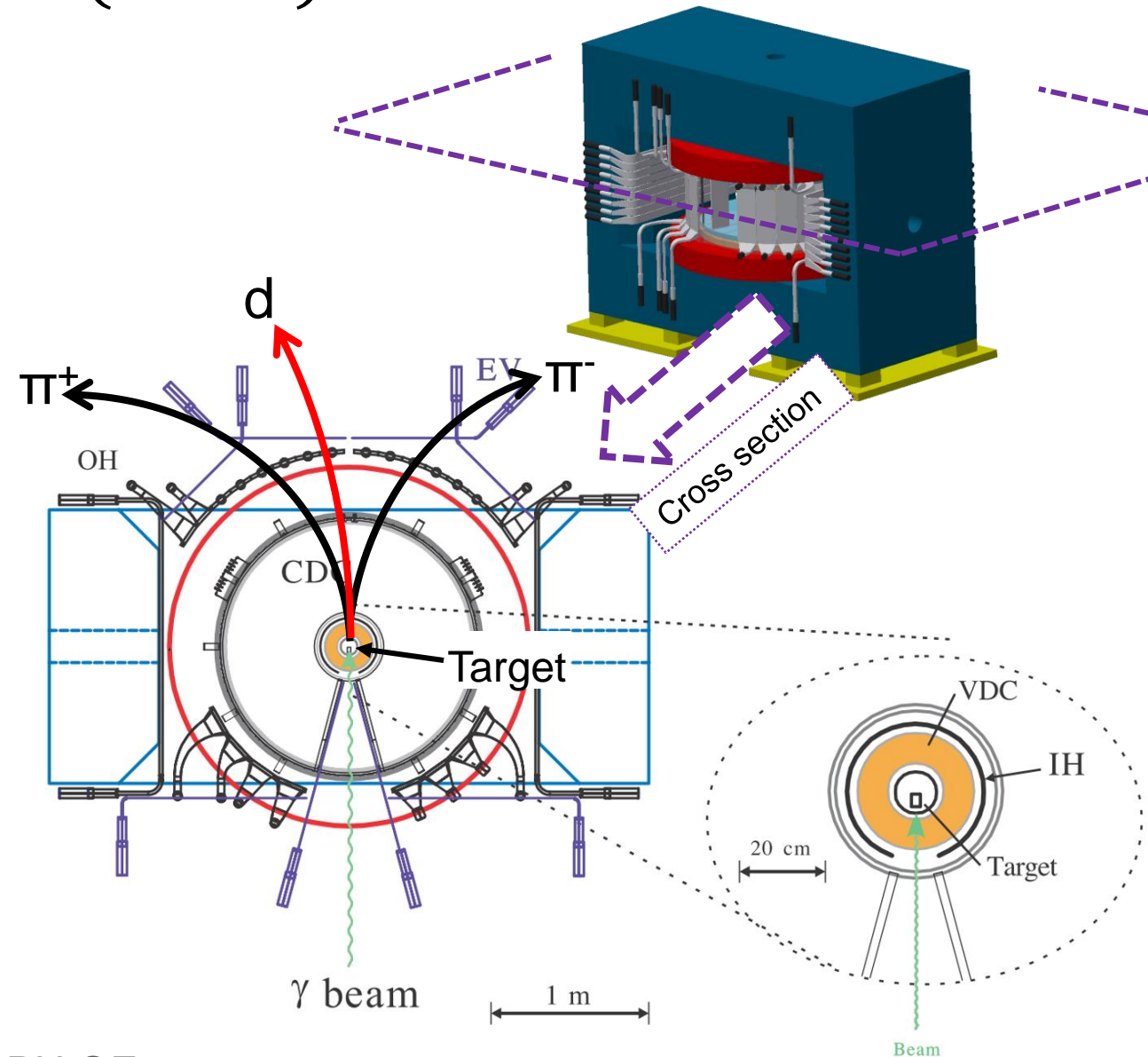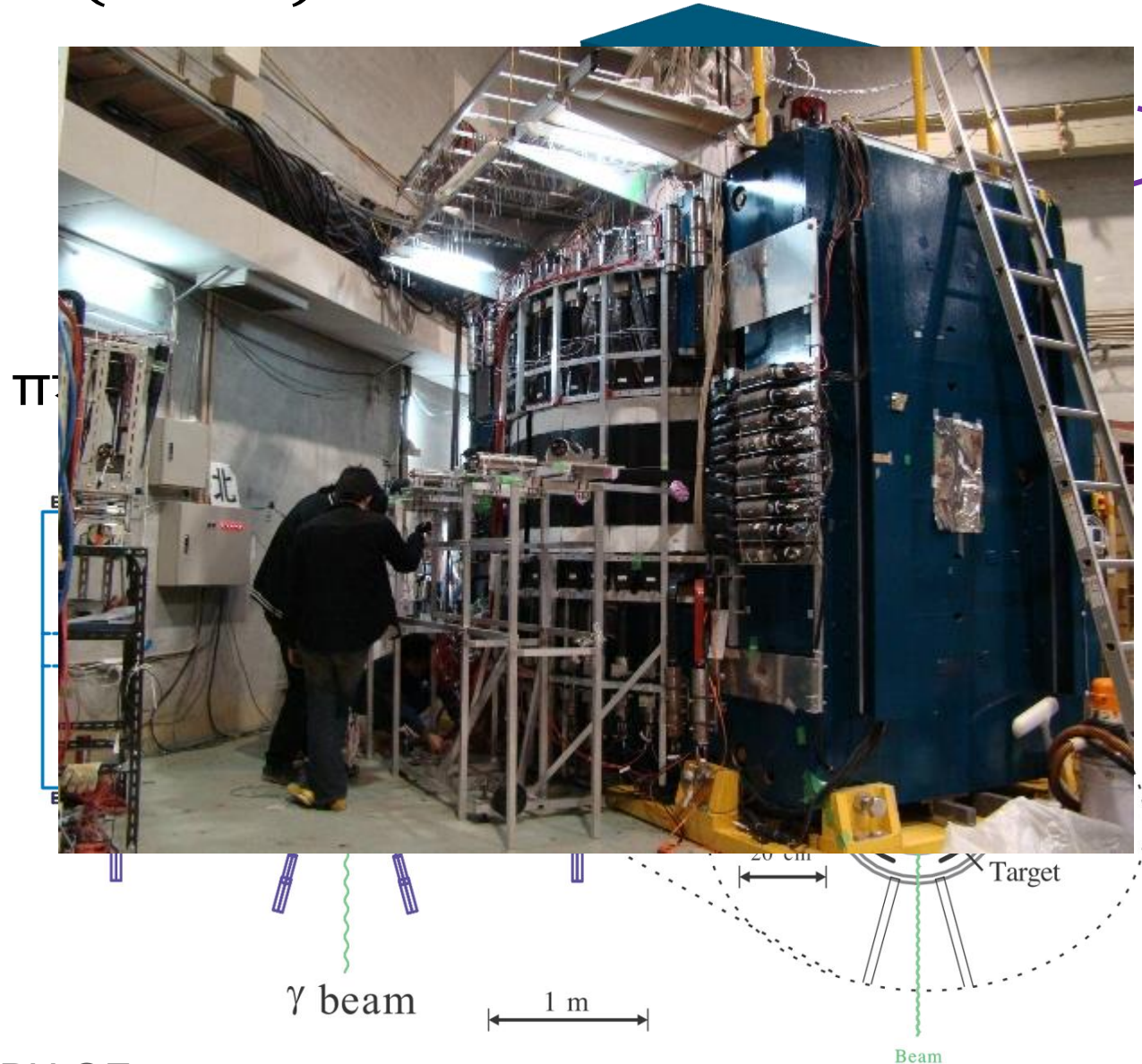
Analysis & Results

- Incident photon analysis
- Drift chamber analysis
- Selection of the $\gamma \to d\pi^+\pi^-$ reaction events
- Invariant mass & $\cos\theta_d$ distributions
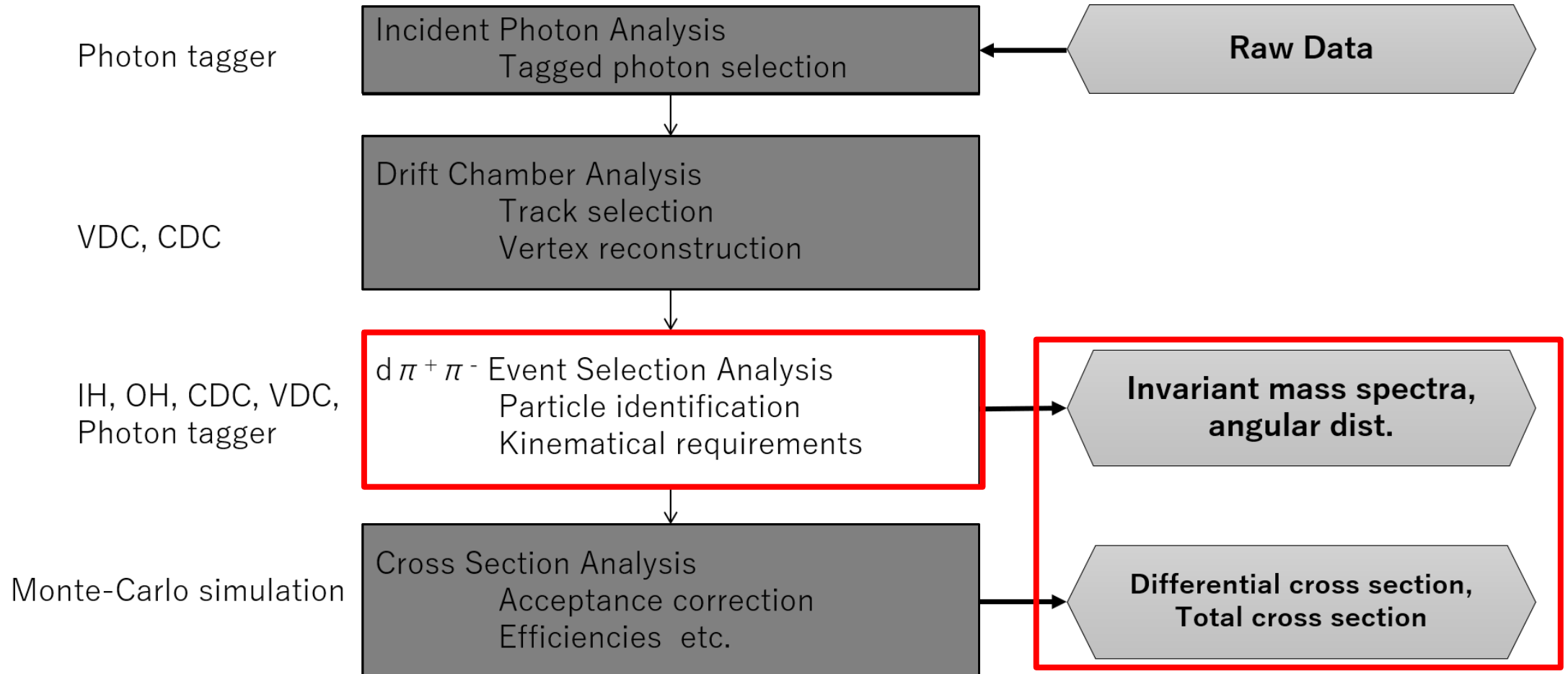- Acceptance estimation of NKS2
- Cross section

Analysis procedure

Goal: $\sigma_{CS} = \dfrac{N_{ev}}{N_{Target} \cdot N_{\gamma} \cdot \eta_{acpt} \cdot \epsilon_{DAQ}}$

Photon tagger

Incident Photon Analysis
    Tagged photon selection

Raw Data

VDC, CDC

Drift Chamber Analysis
    Track selection
    Vertex reconstruction

IH, OH, CDC, VDC, Photon tagger

d$\pi^{+}\pi^{-}$ Event Selection Analysis
    Particle identification
    Kinematical requirements

Invariant mass spectra, angular dist.

Monte-Carlo simulation

Cross Section Analysis
    Acceptance correction
    Efficiencies etc.

Differential cross section, Total cross section

Analysis procedure

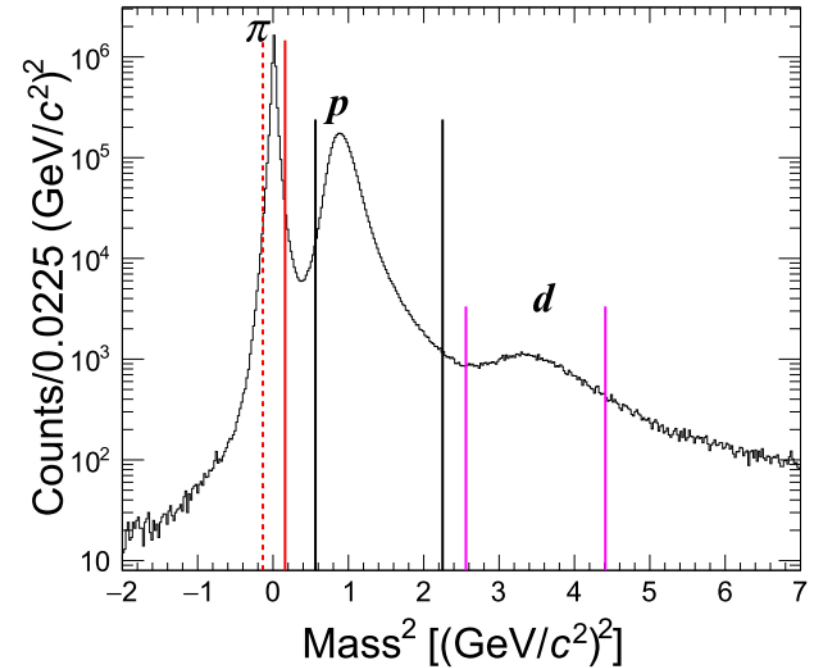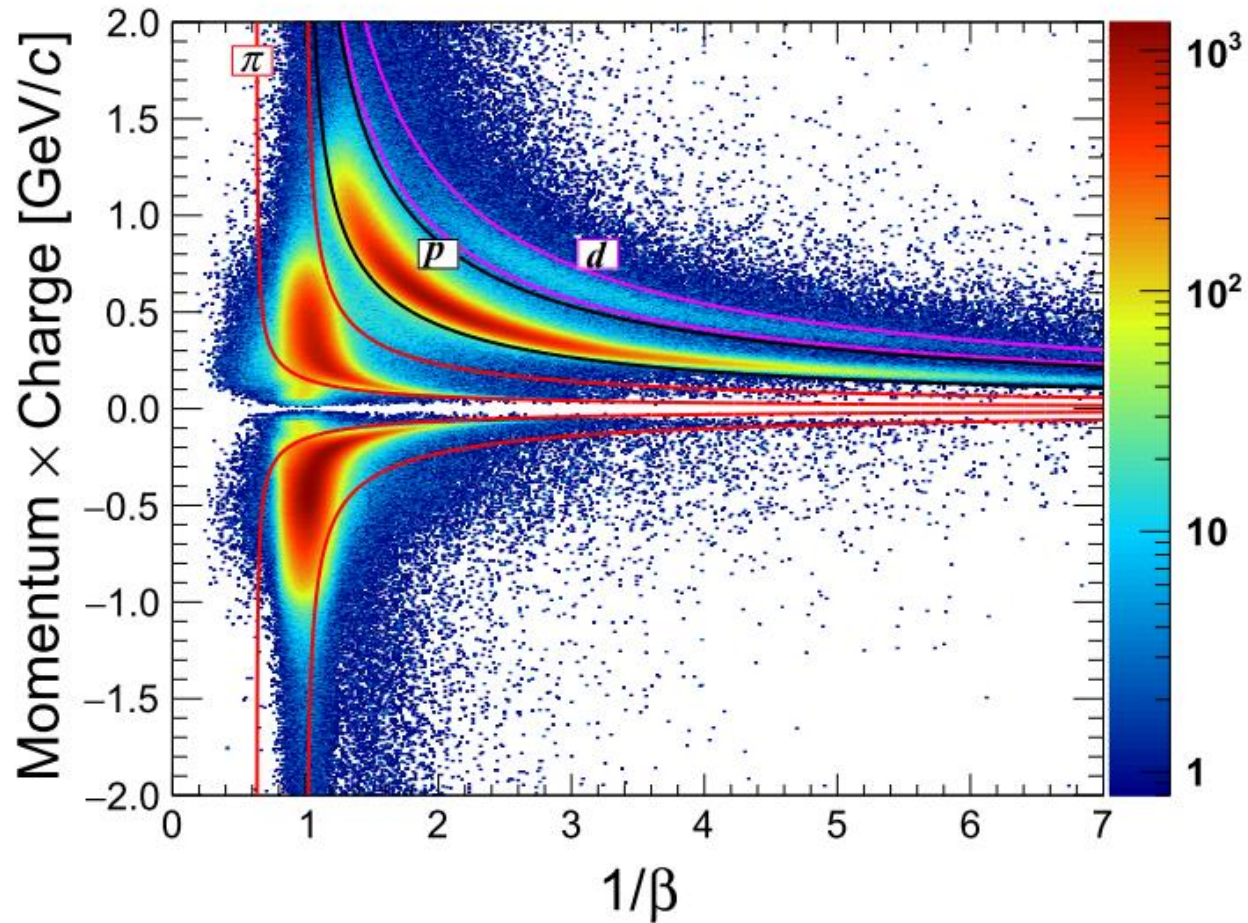Goal: $\sigma_{CS} = \dfrac{N_{ev}}{N_{Target} \cdot N_\gamma \cdot \eta_{acpt} \cdot \epsilon_{DAQ}}$

Photon tagger

Incident Photon Analysis
  Tagged photon selection

Raw Data

VDC, CDC

Drift Chamber Analysis
  Track selection
  Vertex reconstruction

IH, OH, CDC, VDC,
Photon tagger

$d\,\pi^+\pi^-$ Event Selection Analysis
  Particle identification
  Kinematical requirements

**Invariant mass spectra,
angular dist.**

Monte-Carlo simulation

Cross Section Analysis
  Acceptance correction
  Efficiencies etc.

**Differential cross section,
Total cross section**
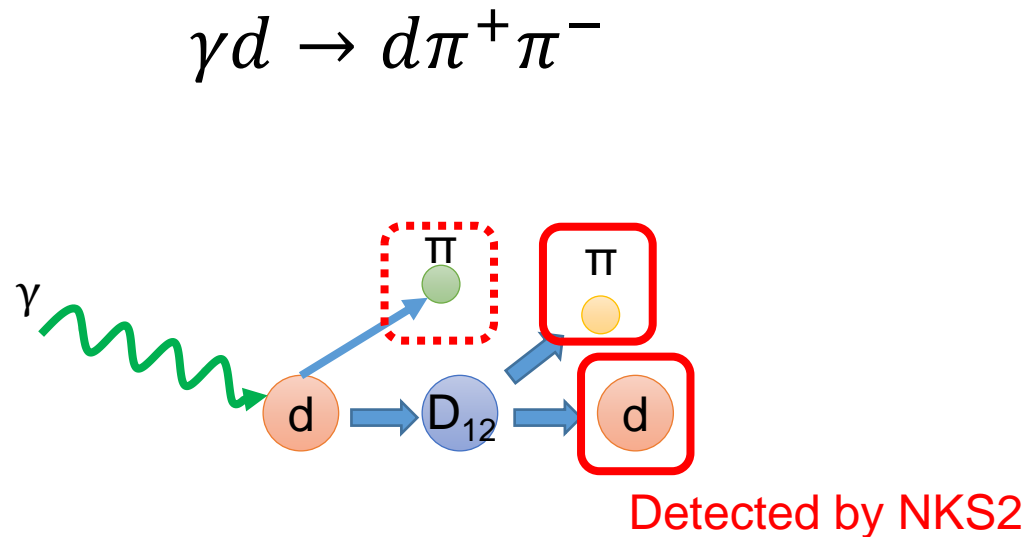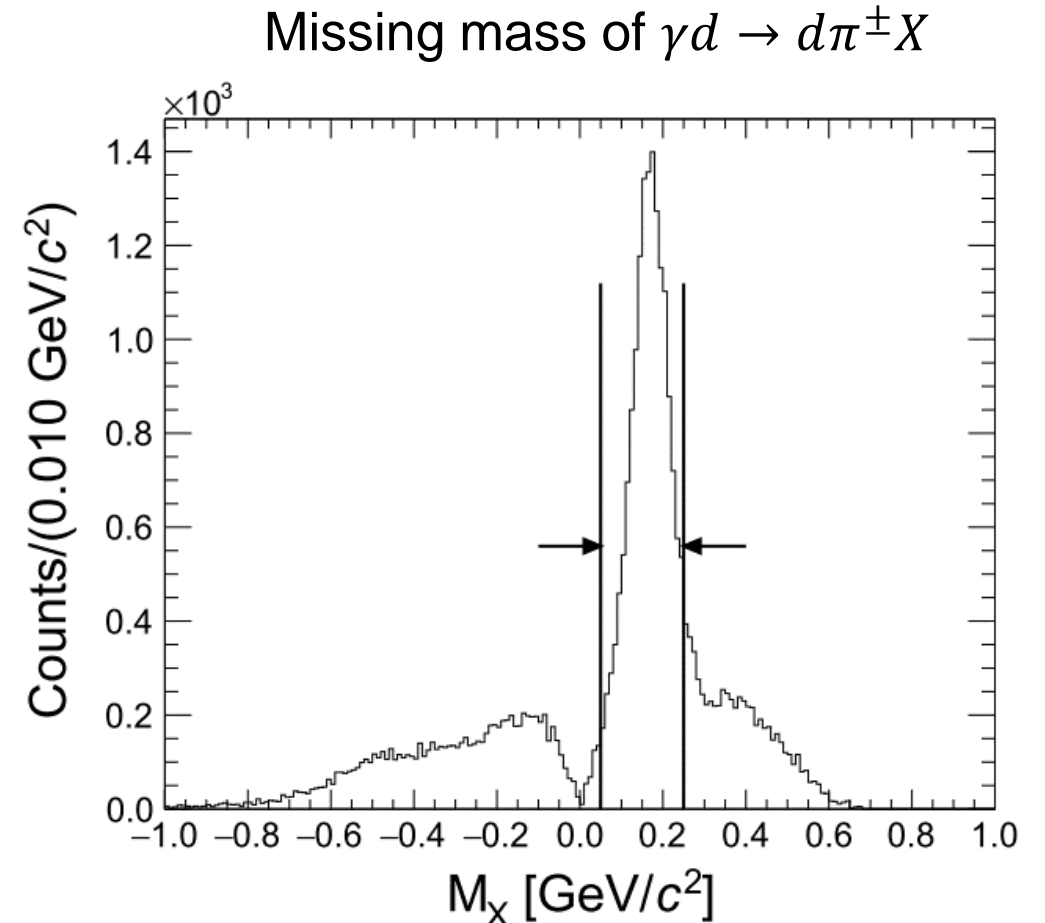
Particle identification

- Momentum and ToF between IH & OH
- π, p, d separation
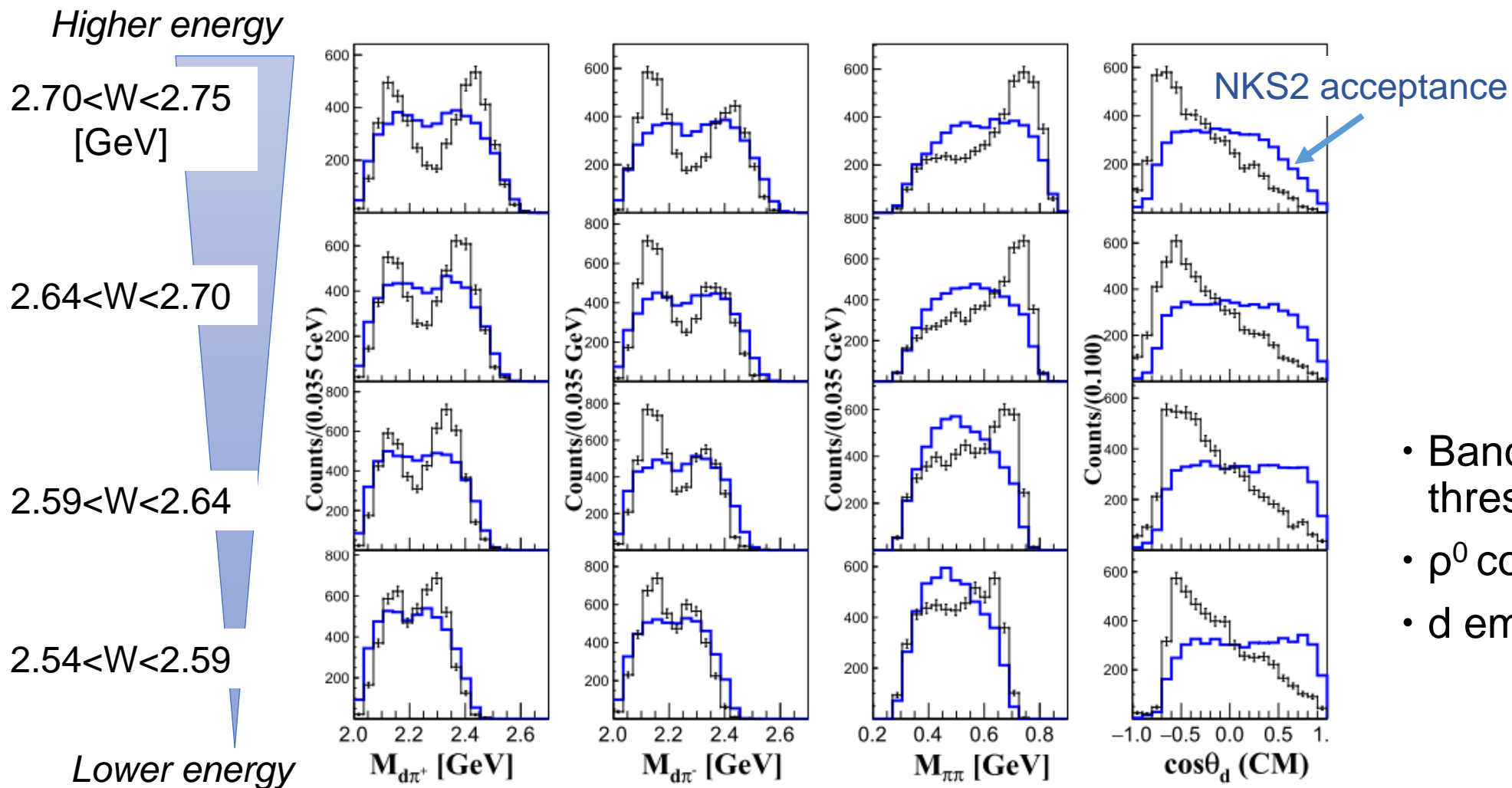
- Additional info. (dE/dx in IH) for d selection

Missing mass

$$\gamma d \rightarrow d\pi^+ \pi^-$$

Detected by NKS2

- 2-track analysis
  - Detect 2 charged particles, dπ+ or dπ-
  - Missing mass for π+/-

Missing mass of $\gamma d \rightarrow d\pi^{\pm}X$

Invariant mass & cosθ$_d$ distributions

Higher energy

2.70<W<2.75 [GeV]

2.64<W<2.70

2.59<W<2.64

2.54<W<2.59

Lower energy

NKS2 acceptance

- Band structure below NΔ threshold in M$_{d\pi}$
- ρ^0 contribution in M$_{\pi\pi}$ ~0.7
- d emitted backward
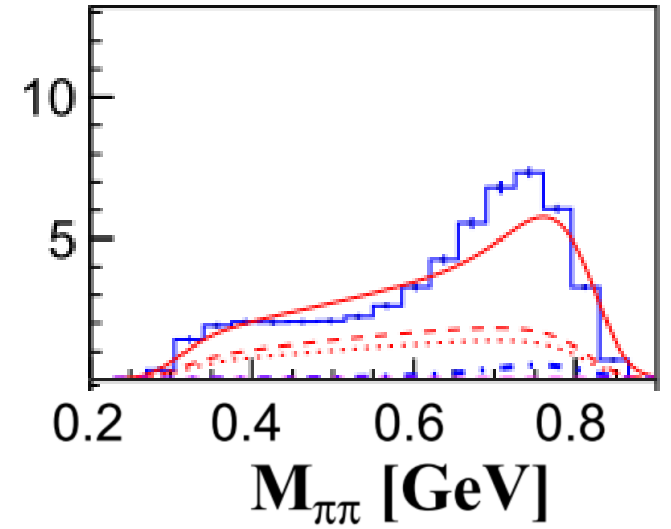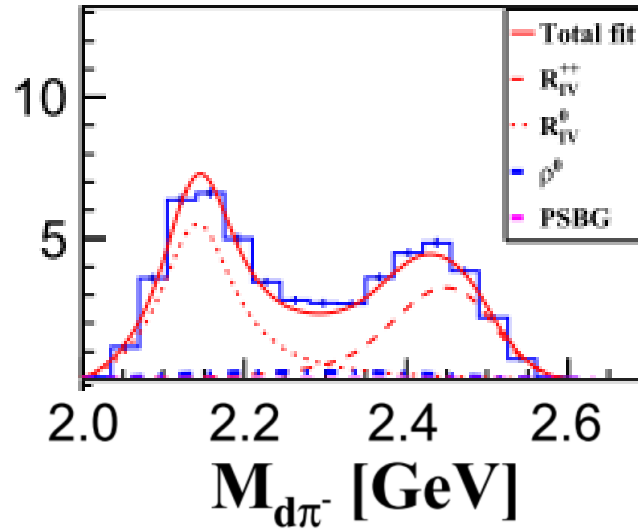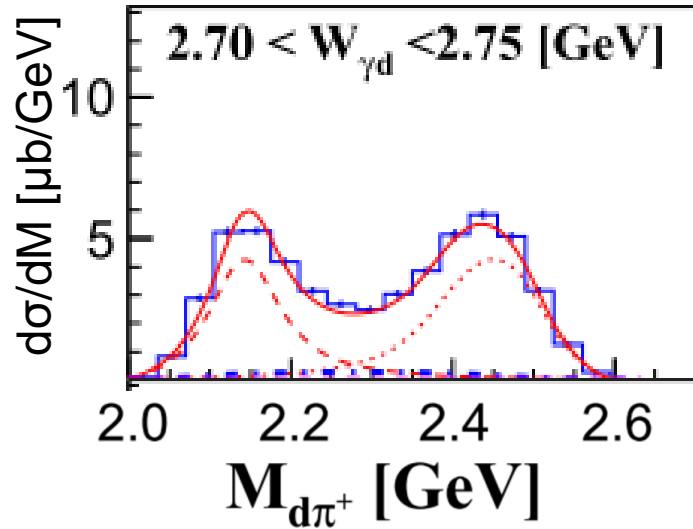
Total cross section
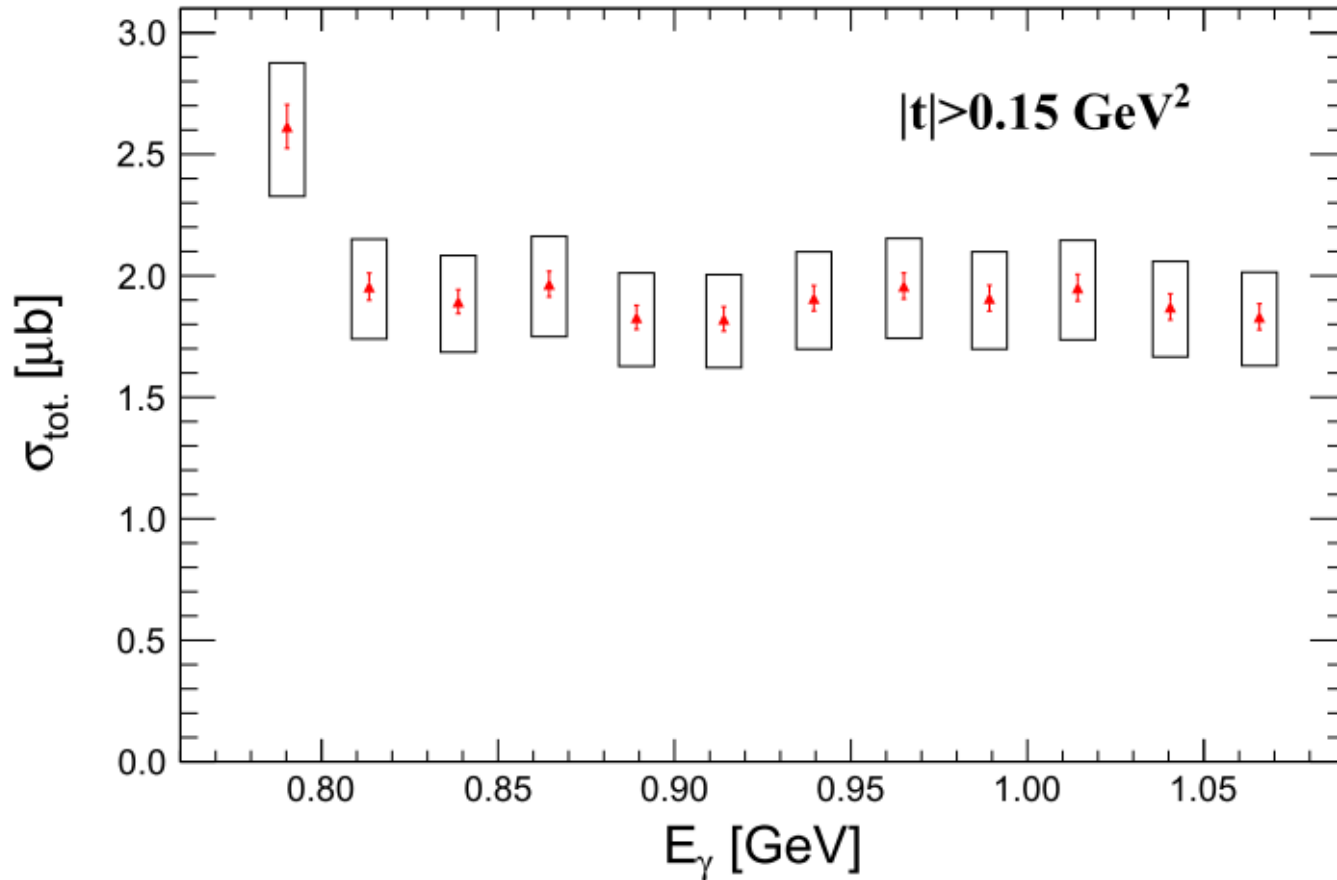
- No significant structure
  - ~2 μb
  - Syst. error ~8%

- |t|=0.15 GeV^2 ⇒ p$_d$~350 MeV/c
  - Out of NKS2 acceptance due to the energy loss

$$t = (P_\gamma - P_{\pi\pi})^2$$

BW1(dπ⁺)   BW2(dπ⁻)   BW3(ππ)

$$N\left(m_{d\pi^+}\right) = \int_{m_{\pi\pi}} \int_{m_{d\pi^-}} \left(\left| \alpha A^{R_{IV}^{++}}_{M_{++},\Gamma_{++}}\left(m_{d\pi^+}\right) + \beta A^{R_{IV}^{0}}_{M_0,\Gamma_0}\left(m_{d\pi^-}\right) + \gamma A^{\rho}_{M_{\rho},\Gamma_{\rho}}\left(m_{\pi\pi}\right) \right|^2 + C \right)$$

$$\cdot V_{PS}\left(m_{d\pi^+}, m_{d\pi^-}, m_{\pi\pi}\right) dm_{d\pi^-} dm_{\pi\pi}$$

BW: $A_{M,\Gamma}(m) = \left(M^2 - m^2 + iM\Gamma\right)^{-1}$

Phase space

- (3 Breit-Wigner + PS background) ⊗ Det. Resolution
  - Mass & Width of ρ⁰ were fixed at 0.77 and 0.15 GeV

BW1(dπ⁺) BW2(dπ⁻) BW3(ππ)

$$N\left(m_{d\pi^+}\right) = \int_{m_{\pi\pi}} \int_{m_{d\pi^-}} \left(\left| \alpha A^{R_{IV}^{++}}_{M_{++},\Gamma_{++}} \left(m_{d\pi^+}\right) + \beta A^{R_{IV}^{0}}_{M_0,\Gamma_0} \left(m_{d\pi^-}\right) + \gamma A^{\rho}_{M_\rho,\Gamma_\rho} \left(m_{\pi\pi}\right) \right|^2 + C \right)$$

$$\cdot V_{PS}\left(m_{d\pi^+}, m_{d\pi^-}, m_{\pi\pi}\right) dm_{d\pi^-} dm_{\pi\pi}$$

BW: $A_{M,\Gamma}(m) = \left(M^2 - m^2 + iM\Gamma\right)^{-1}$

Phase space

- (3 Breit-Wigner + PS background) ⊗ Det. Resolution
  - Mass & Width of ρ^0 were fixed at 0.77 and 0.15 GeV

$$N(m_{d\pi^+}) = \int_{m_{\pi\pi}} \int_{m_{d\pi^-}} \left(\left| \alpha A^{R_{IV}^{++}}_{M_{++},\Gamma_{++}}(m_{d\pi^+}) + \beta A^{R_{IV}^{0}}_{M_0,\Gamma_0}(m_{d\pi^-}) + \gamma A^{\rho}_{M_\rho,\Gamma_\rho}(m_{\pi\pi}) \right|^2 + C \right) V_{PS}(m_{d\pi^+}, m_{d\pi^-}, m_{\pi\pi}) \, dm_{d\pi^-} dm_{\pi\pi}$$

BW1(dπ⁺) BW2(dπ⁻) BW3(ππ)

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Phase space

- (3 Breit-Wigner + PS background) ⊗ Det. Resolution
  - Mass & Width of ρ⁰ were fixed at 0.77 and 0.15 GeV

Differential cross sections (dσ/dM)

BW1 BW2 BW3
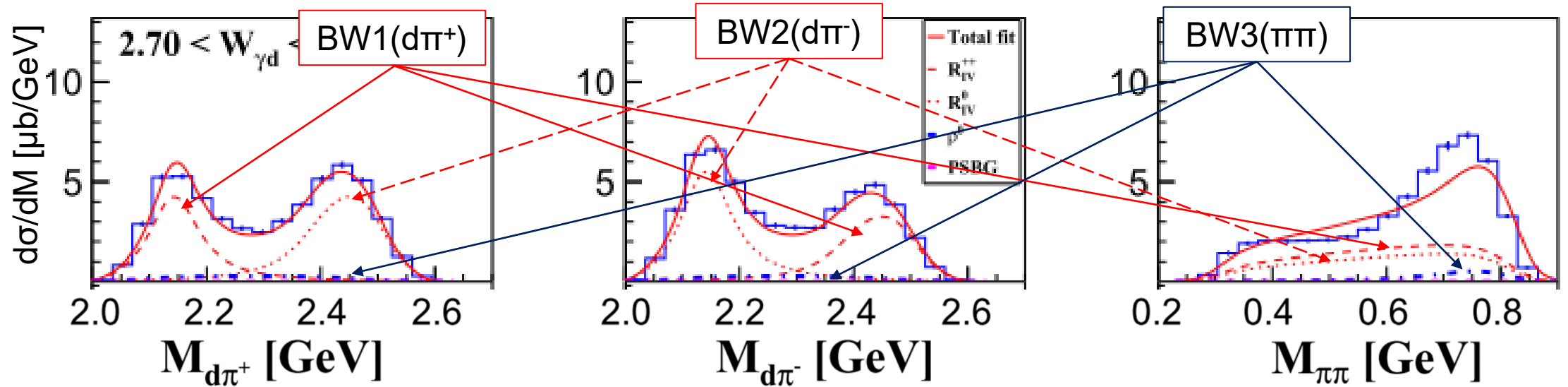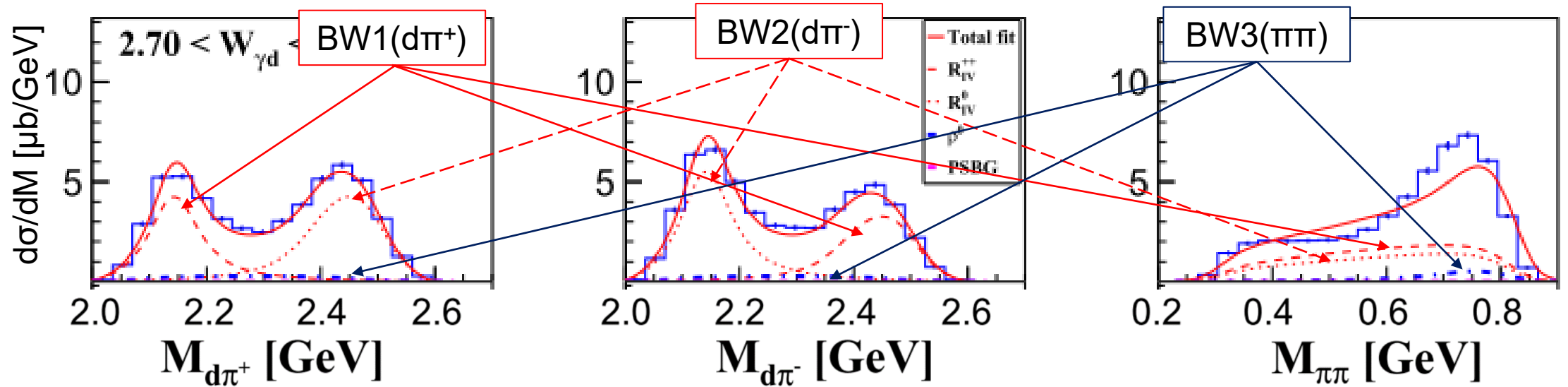
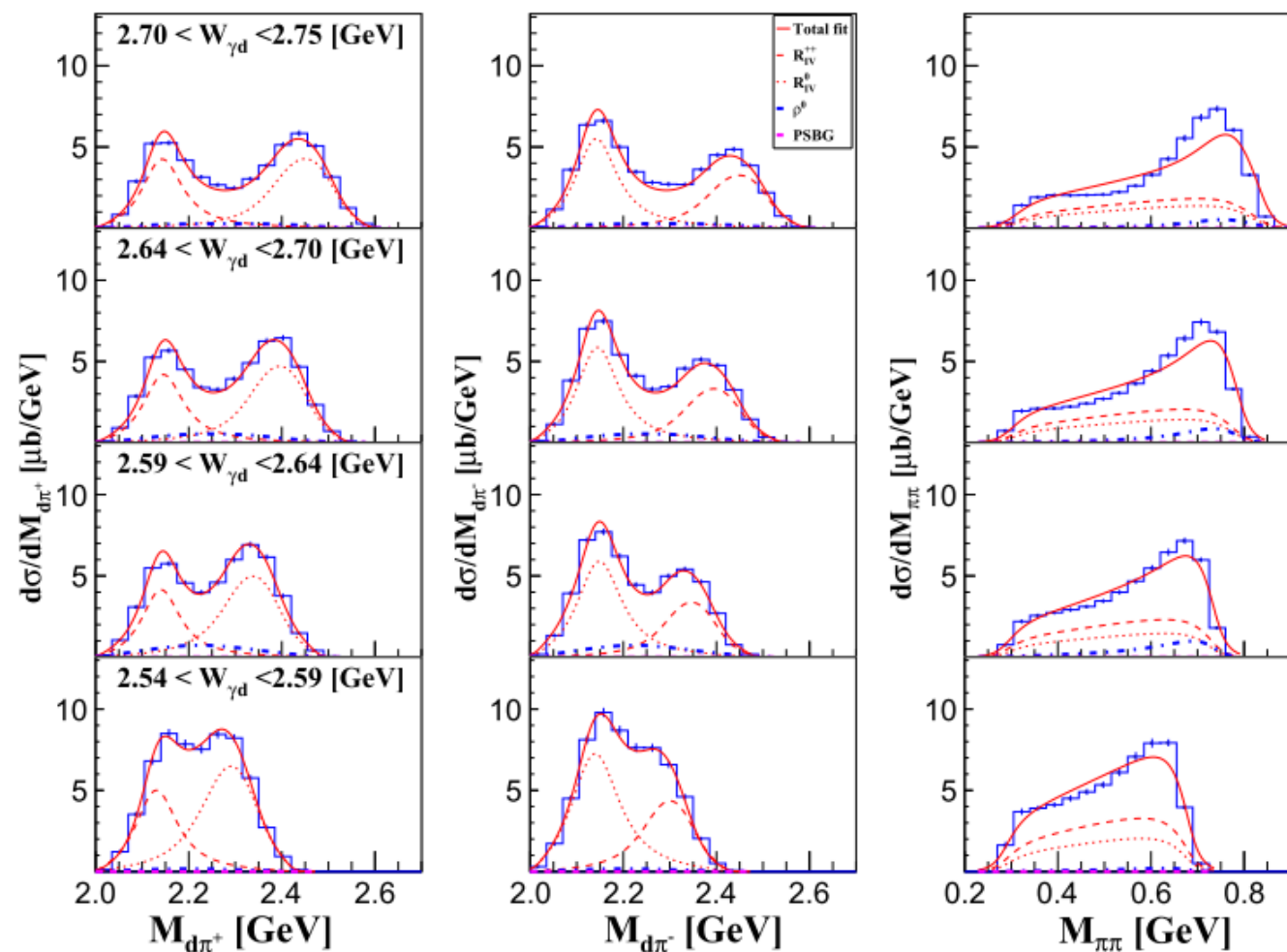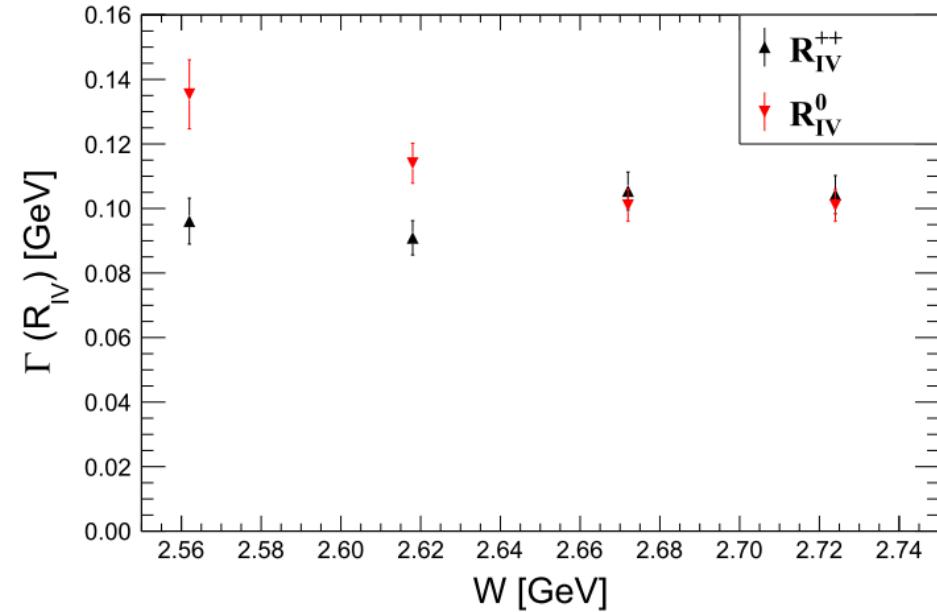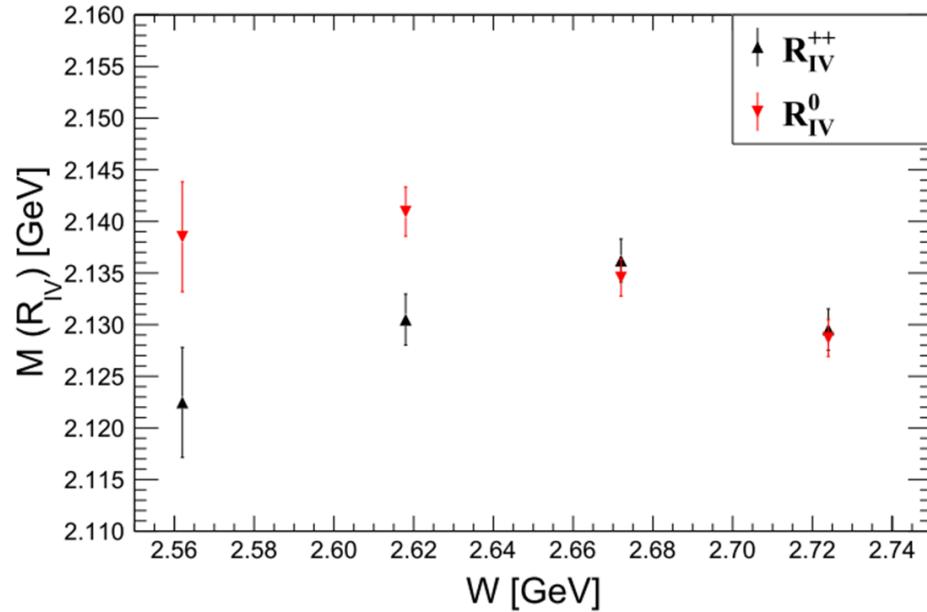$$N(m_{d\pi^+}) = \int_{m_{\pi\pi}} \int_{m_{d\pi^-}} \left(\left| \alpha A^{R_{IV}^{++}}_{M_{++},\Gamma_{++}}(m_{d\pi^+}) + \beta A^{R_{IV}^0}_{M_0,\Gamma_0}(m_{d\pi^-}) + \gamma A^{\rho}_{M_\rho,\Gamma_\rho}(m_{\pi\pi}) \right|^2 + C \right)$$

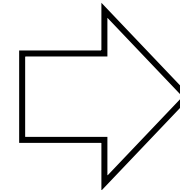$$\cdot V_{PS}(m_{d\pi^+}, m_{d\pi^-}, m_{\pi\pi}) \, dm_{d\pi^-} dm_{\pi\pi}$$

Phase space

BW: $A_{M,\Gamma}(m) = \left(M^2 - m^2 + iM\Gamma \right)^{-1}$

- (3 Breit-Wigner + PS background)⊗Resolution
  - Mass & Width of ρ^0 were fixed at 0.77 and 0.15 GeV

Mass & Width of the dπ resonances

- Weighted average of higher energy points
  - M=2.1329±0.0008 (stat.)±0.0085 (syst.) GeV
  - Γ =0.1033±0.0021 (stat.)±0.0092 (syst.) GeV
- Systematic errors of fitting
  - standard deviation of the all points
  - ρ^0 free fitting result
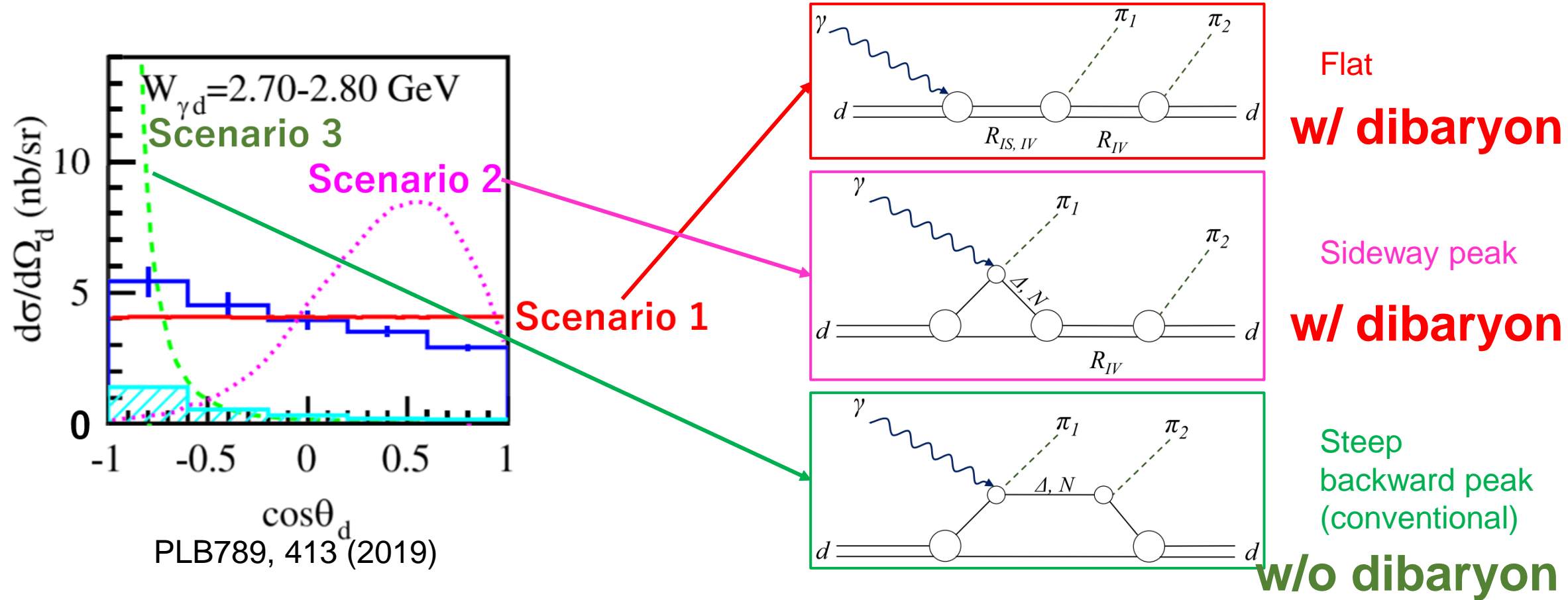
Lower than NΔ threshold (~2.17 GeV)
Narrower than single Δ width (~0.12 GeV)

Consistent with D_{12} (z=+1) from FOREST
(M=2.140±0.011 GeV, Γ=0.091±0.011 GeV)

$z = +2, 0$ states of D_{12}?

Discussions

- Possible scenarios for 2π production and deuteron emission angle distribution
- Comparison with the Previous Measurement (NPB79 (1974) 10.)

$W_{\gamma d} = 2.70\text{-}2.80$ GeV

Scenario 3

Scenario 2

Scenario 1

$\frac{d\sigma}{d\Omega_d}$ (nb/sr)

cosθ_d

PLB789, 413 (2019)

Flat

w/ dibaryon

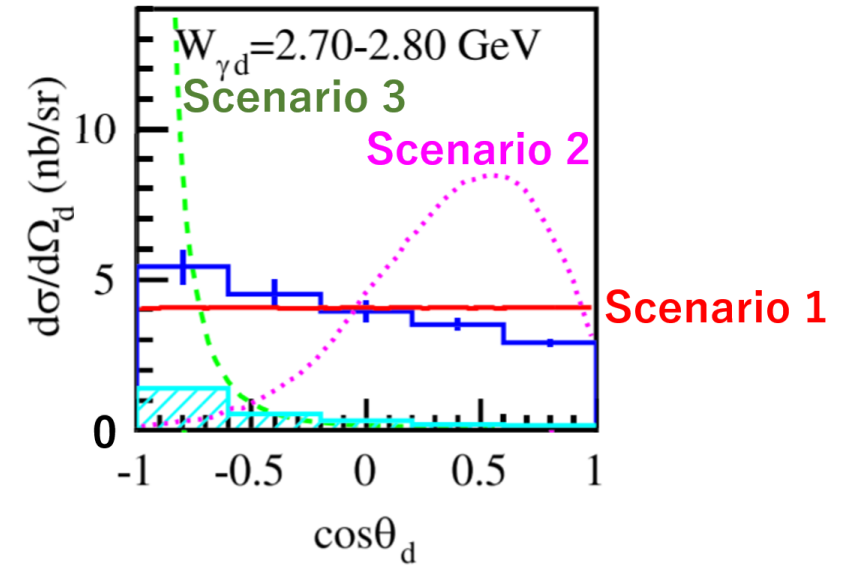Sideway peak

w/ dibaryon

Steep backward peak (conventional)

w/o dibaryon

These are separatable by cosθ_d (γd CM frame) distribution

if no isovector dibaryon (conventional), cosθ_d strong backward peak

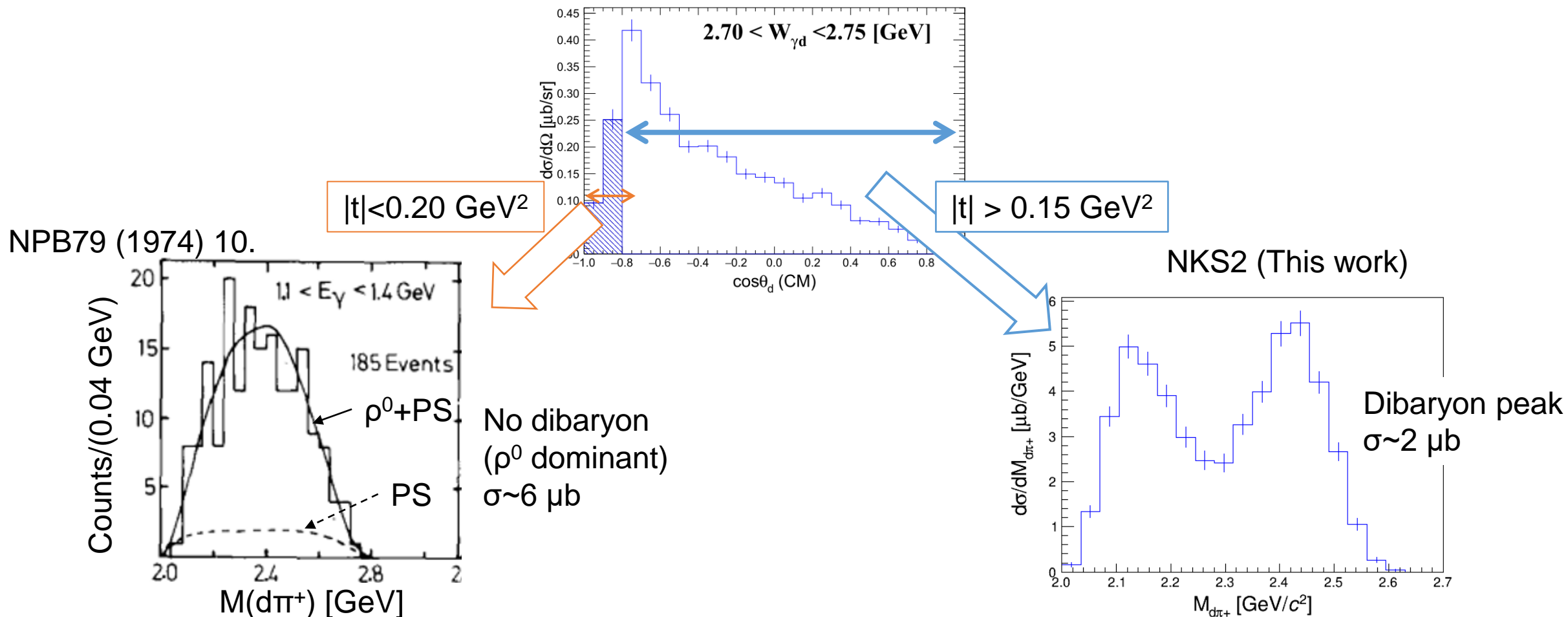$$\text{Possible scenarios for } 2\pi \text{ production and } \cos\theta_d \text{ distribution}$$

PLB789, 413 (2019)

d backward   d forward
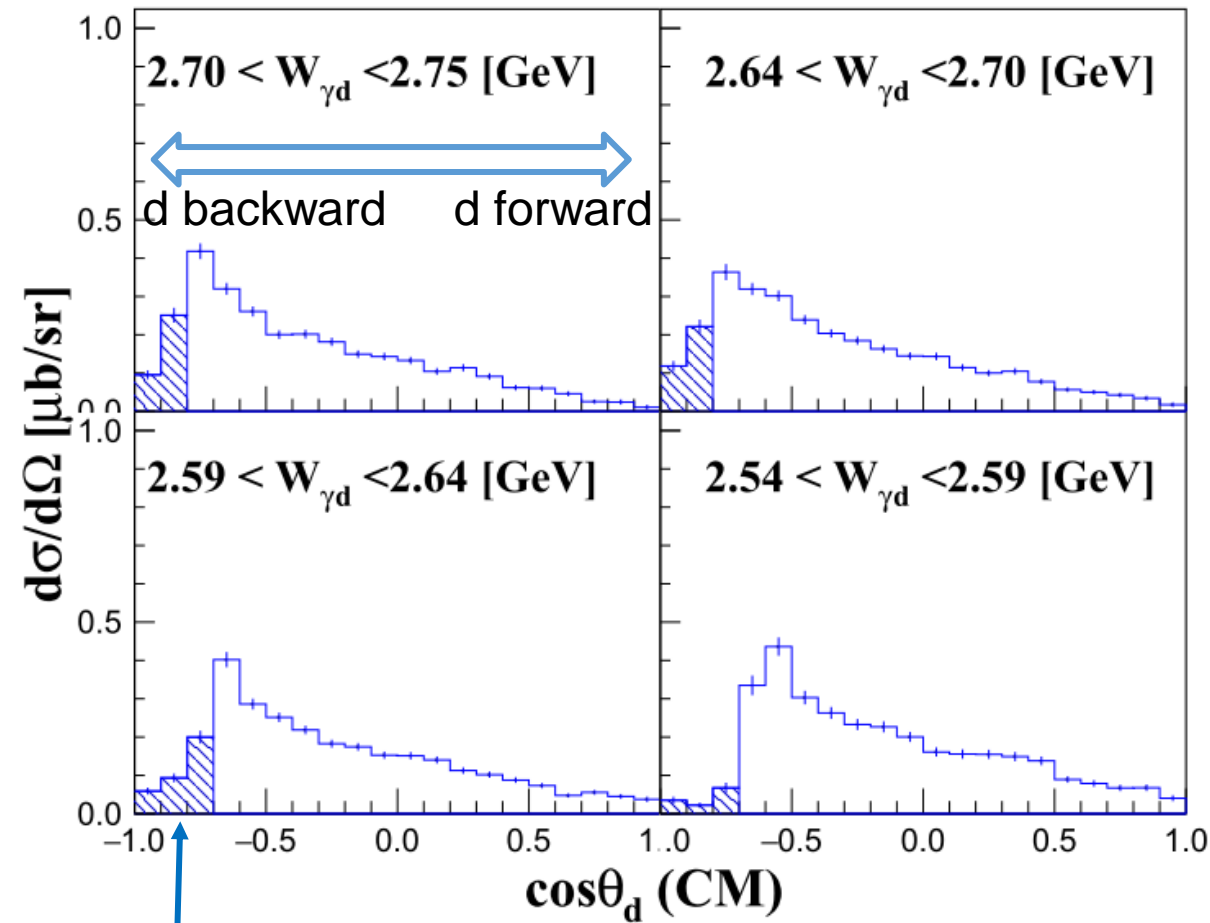
$|t| < 0.15\,\mathrm{GeV}^2$
(almost no sensitivity)

W_{\gamma d}=2.70-2.80 GeV
Scenario 3
Scenario 2
Scenario 1

- Backward enhanced structure

  in |t|>0.15 GeV² region

  - But not so steep peak
  - Can not be explained by Senario3 only

- dσ/dΩ > 0.1 μb/sr in cosθd > 0 ⇒
  unconventional process (i.e. Dibaryon)

Yuichi Toyama

Comparison with the Previous Measurement (NPB79 (1974) 10.)

2.70 < $W_{\gamma d}$ < 2.75 [GeV]

$d\sigma/d\Omega$ [μb/sr]

$\cos\theta_d$ (CM)

|t|<0.20 GeV²

|t| > 0.15 GeV²

NPB79 (1974) 10.

1.1 < E_γ < 1.4 GeV

185 Events

Counts/(0.04 GeV)

ρ^0+PS

PS

M(dπ^+) [GeV]

No dibaryon
(ρ^0 dominant)
σ~6 μb

NKS2 (This work)

$d\sigma/dM_{d\pi+}$ [μb/GeV]

$M_{d\pi+}$ [GeV/c^2]

Dibaryon peak
σ~2 μb

Our kinematic region sensed unconventional process.

Summary & Conclusion

- The first measurement of the cross section of the $\gamma d \to d\pi^+\pi^-$ reaction in |t|>0.15 GeV^2 region
  - E_γ : 0.78—1.08 GeV
  - Total cross section: ~2μb (almost flat)

- Isovector resonance structure (R_{IV}) in dπ$^{+/-}$ invariant mass
  - M=2.1329±0.0008 (stat.)±0.0085 (syst.) GeV $_{< M_N+M_\Delta \sim 2.17\ GeV}$
  - Γ =0.1033±0.0021 (stat.)±0.0092 (syst.) GeV $_{< \Gamma_\Delta \sim 0.12\ GeV}$
    - Consistent with FOREST (M=2.14±0.01, Γ=0.09±0.01 GeV)
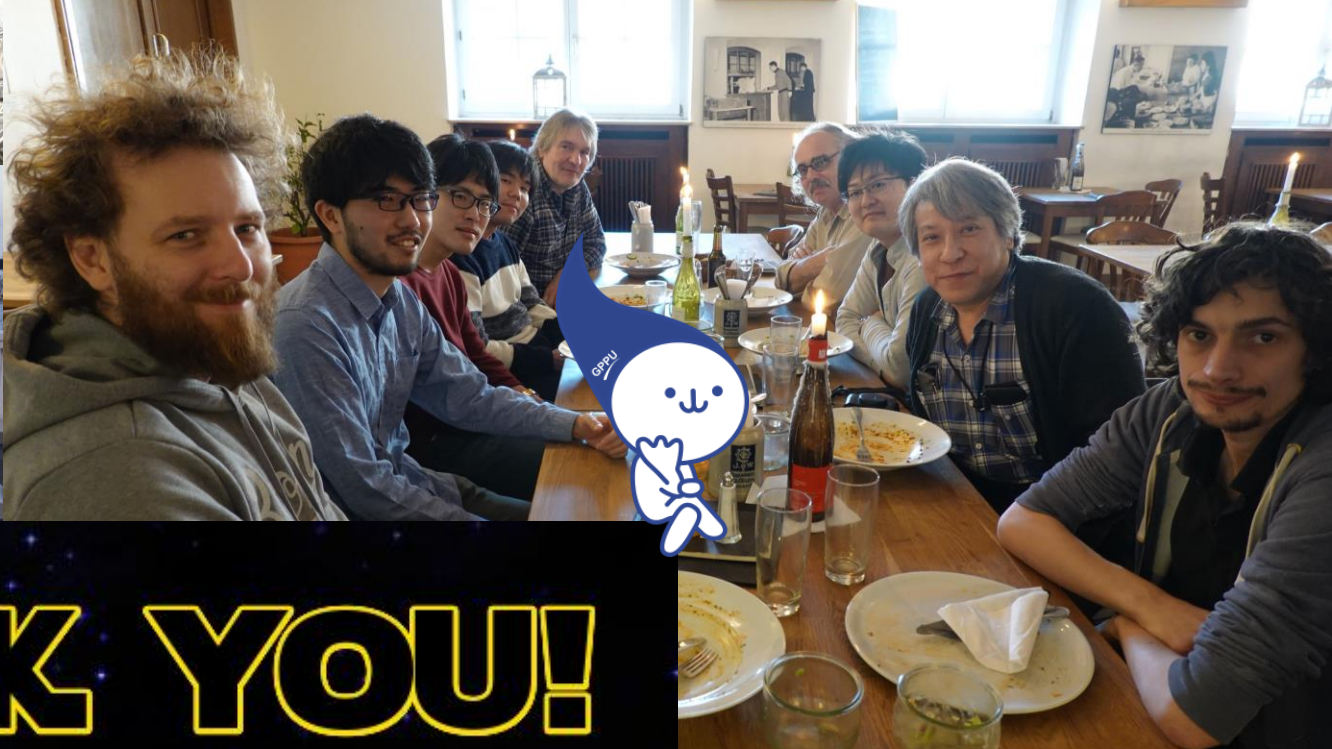 - z=+2, 0 state of D_{12}

Memories of GPPU…
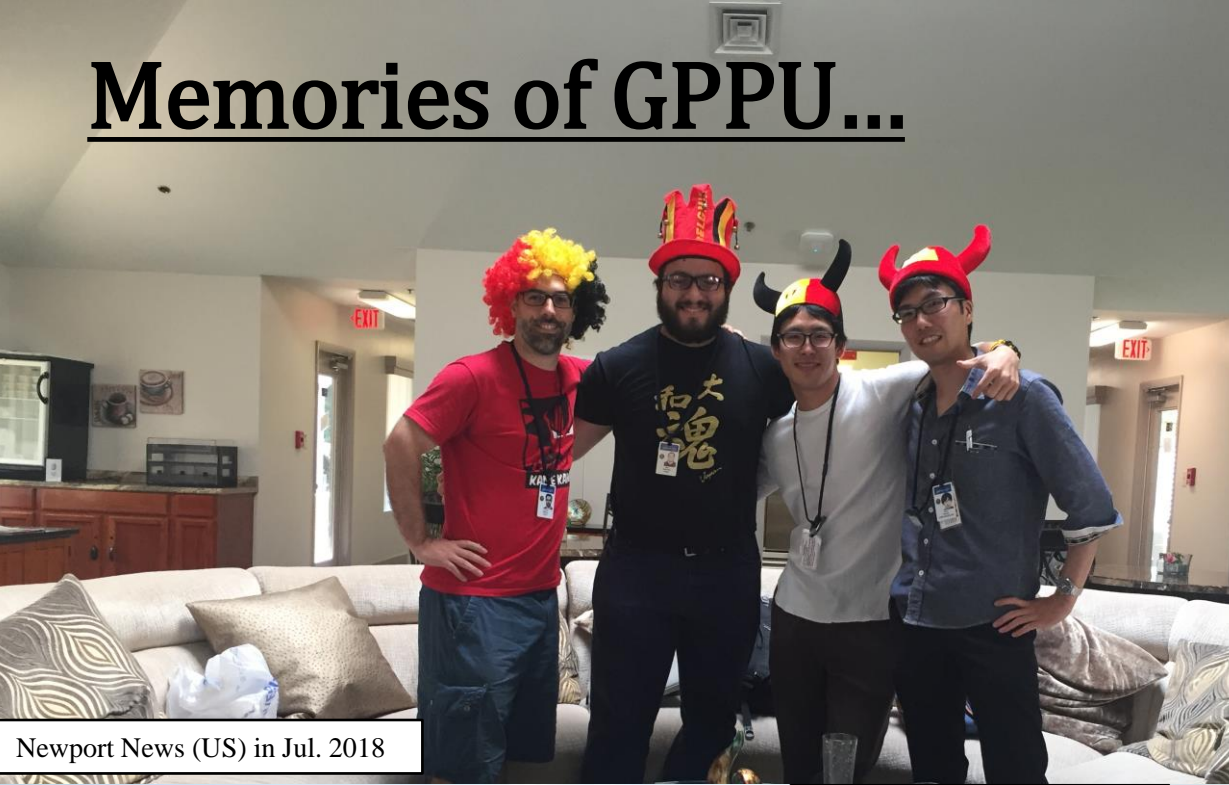
Newport News (US) in Jul. 2018

Sendai (JP) in Feb. 2020

Portsmouth (US) in Jul. 2018

2022/2/8

THANK YOU!

Mainz (GE) in Feb. 2019

Outlook

- Spin and Parity of R_{IV}
  - decay angular distribution analysis

- Measurement of Deuteron with Lower Momentum
  - d ID by only VDC

- Measurement of and with Higher Incident Photon Energy
  - By-product of the $\gamma d \rightarrow d\pi^+\pi^-\pi^0$ measurement (η'd nuclei search)