

NSTAR2019

Recent results of pion and kaon photoproduction at SPring-8/LEPS

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Super Photon ring - 8 GeV

Electron storage ring

- 8 GeV electron beam
- Diameter ≈ 457 m
- RF 508 MHz
- 1-bunch spread is
within $\sigma = 12$ psec.
- Beam Current = 100 mA



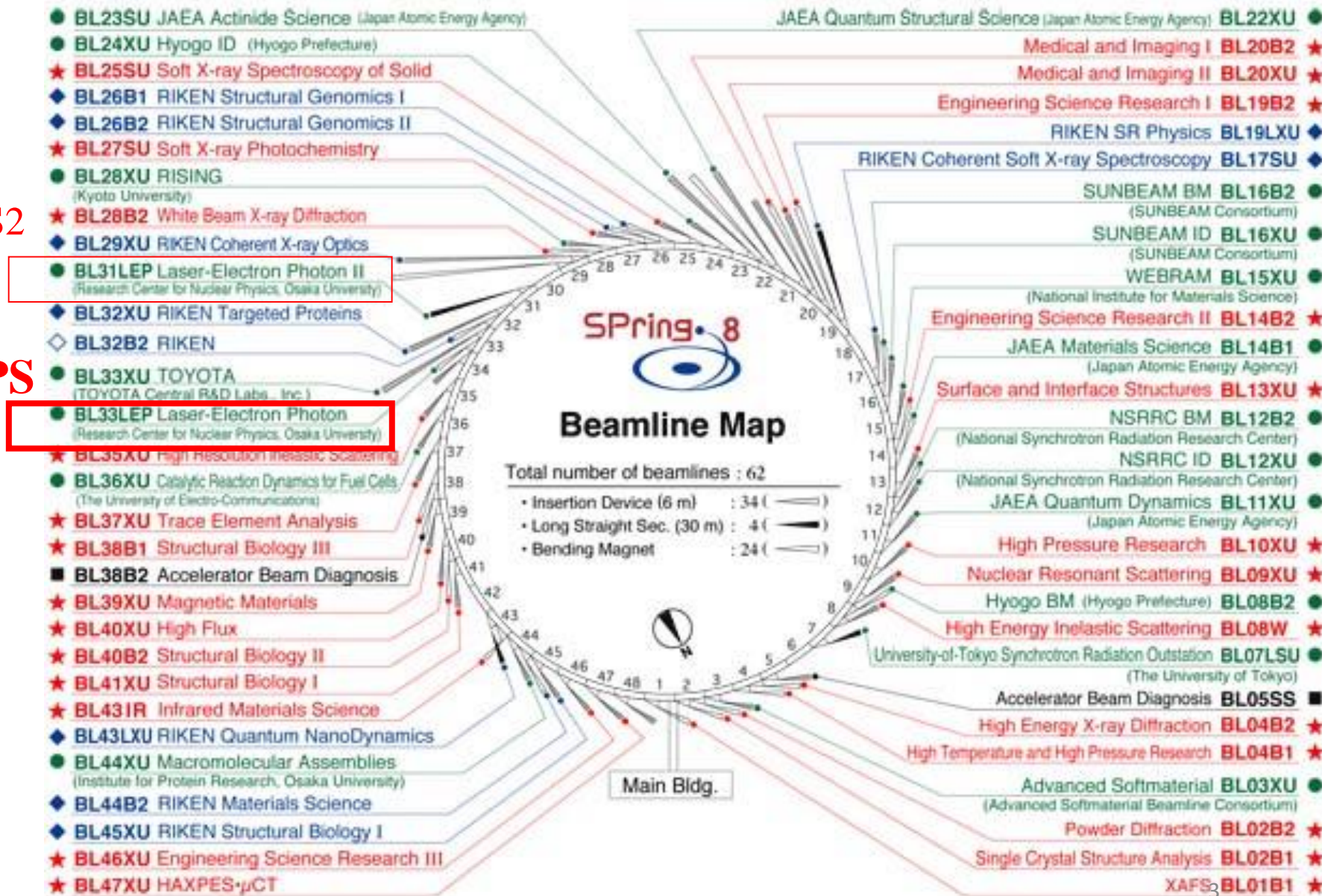
120 km distant from Osaka



SPring-8 beamline map

LEPS2

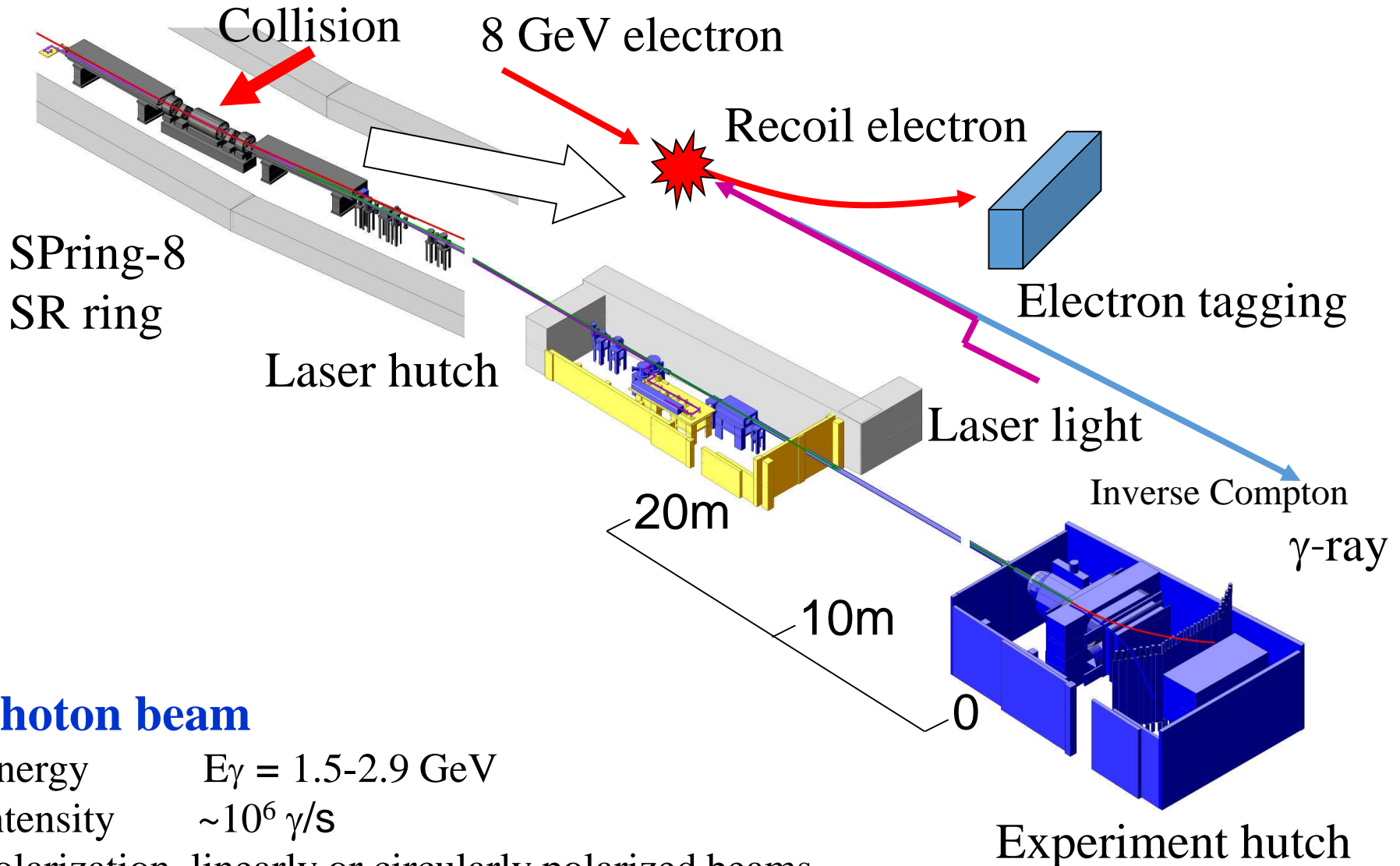
LEPS



LEPS2 new beamline constructed in 2011



LEPS facility constructed in 2000



Photon beam

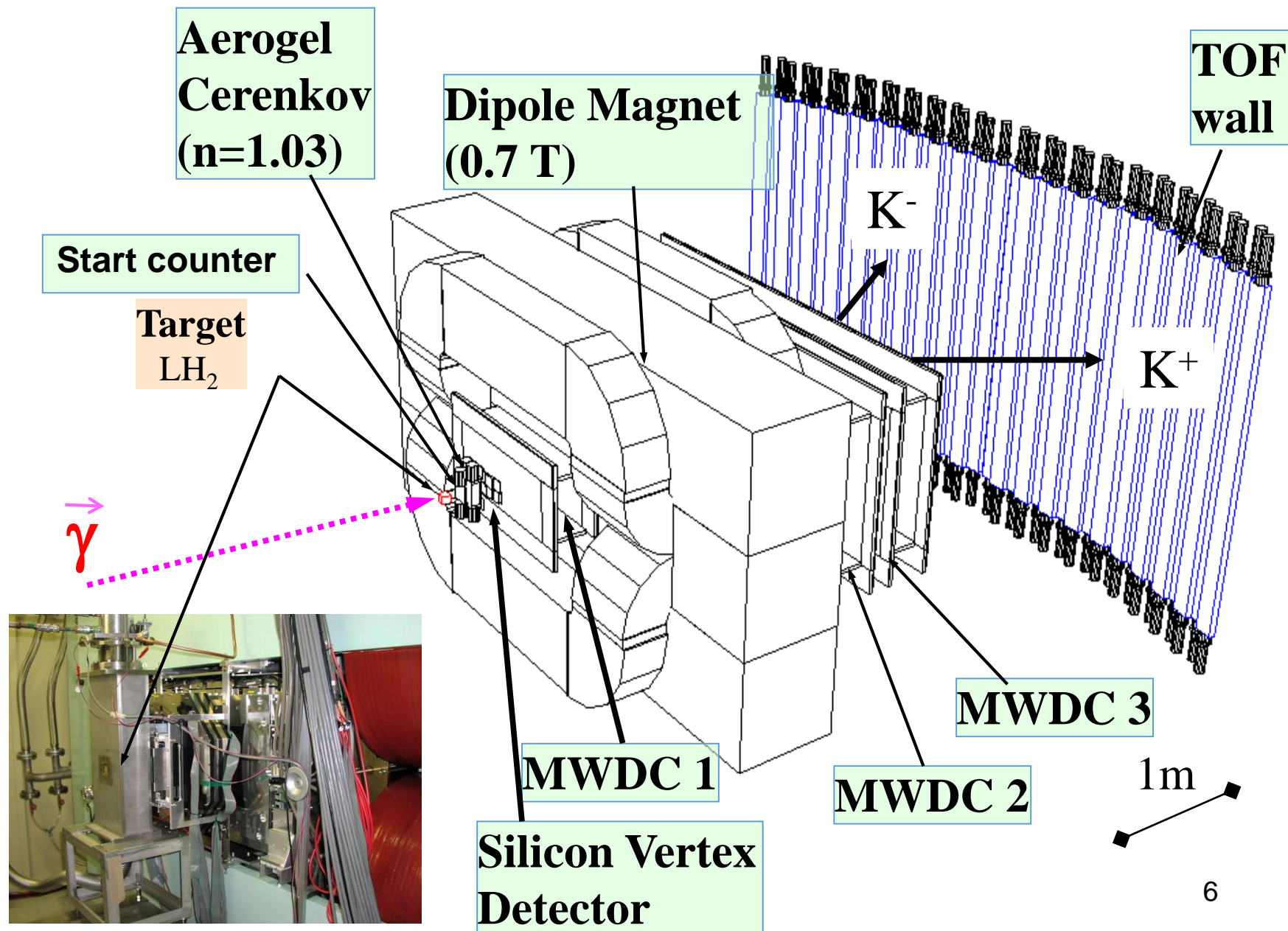
Energy $E_\gamma = 1.5\text{-}2.9\text{ GeV}$

Intensity $\sim 10^6\text{ } \gamma/\text{s}$

Polarization linearly or circularly polarized beams.

P \sim 90% at the maximum photon energy.

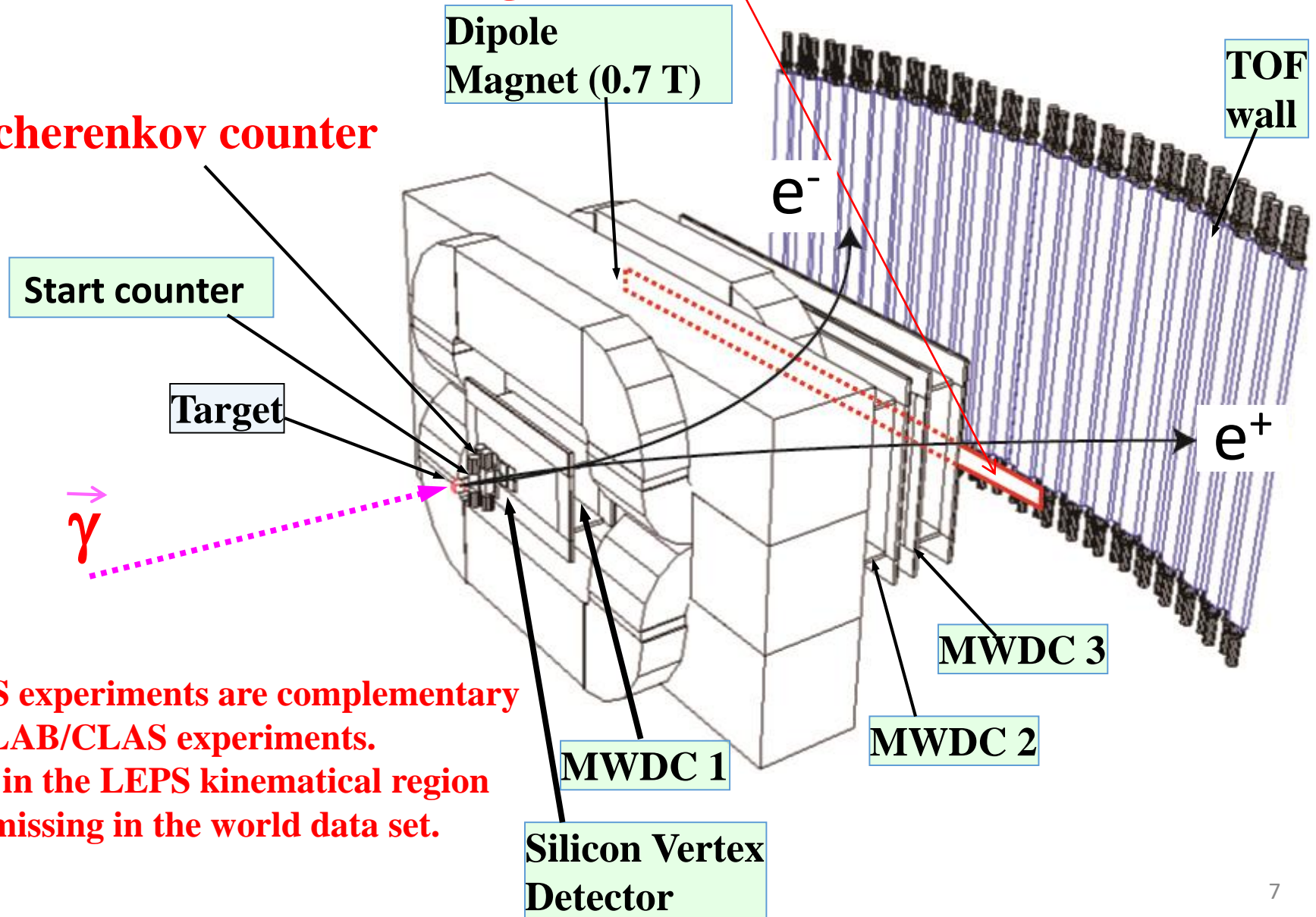
LEPS detector (optimized to detect ϕ decaying to K^+K^-)



New experimental setup for high momentum π

Plastic counter for vetoing e^+e^- was used

No cherenkov counter



LEPS experiments are complementary to JLAB/CLAS experiments. Data in the LEPS kinematical region are missing in the world data set.

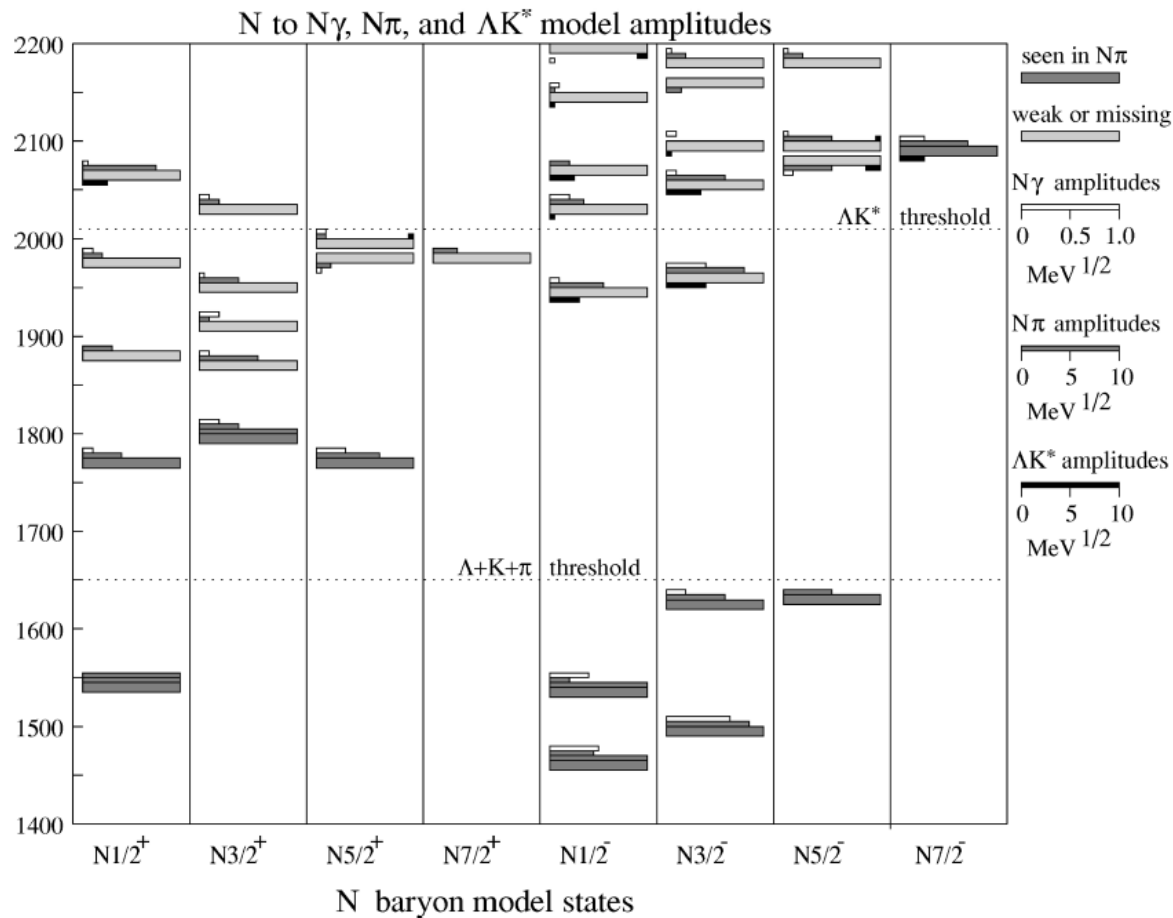
Physics objectives

One of our physics objectives is to understand how hadrons are produced.
I want to obtain unified understanding of various $q\bar{q}$ productions.

- | | |
|---|--|
| (1) $\gamma p \rightarrow \pi^+ n$ reaction | $d\bar{d}$ production in the final state |
| (2) $\gamma p \rightarrow K^+ \Lambda$ and $K^+ \Sigma^0$ reactions | $s\bar{s}$ production in the final state |
| (3) $\gamma p \rightarrow \pi^- \Delta^{++}$ reaction | $u\bar{u}$ production in the final state |
| (4) $\gamma p \rightarrow \pi^+ \Delta^0$ reaction | $d\bar{d}$ production in the final state |

Another physics objective

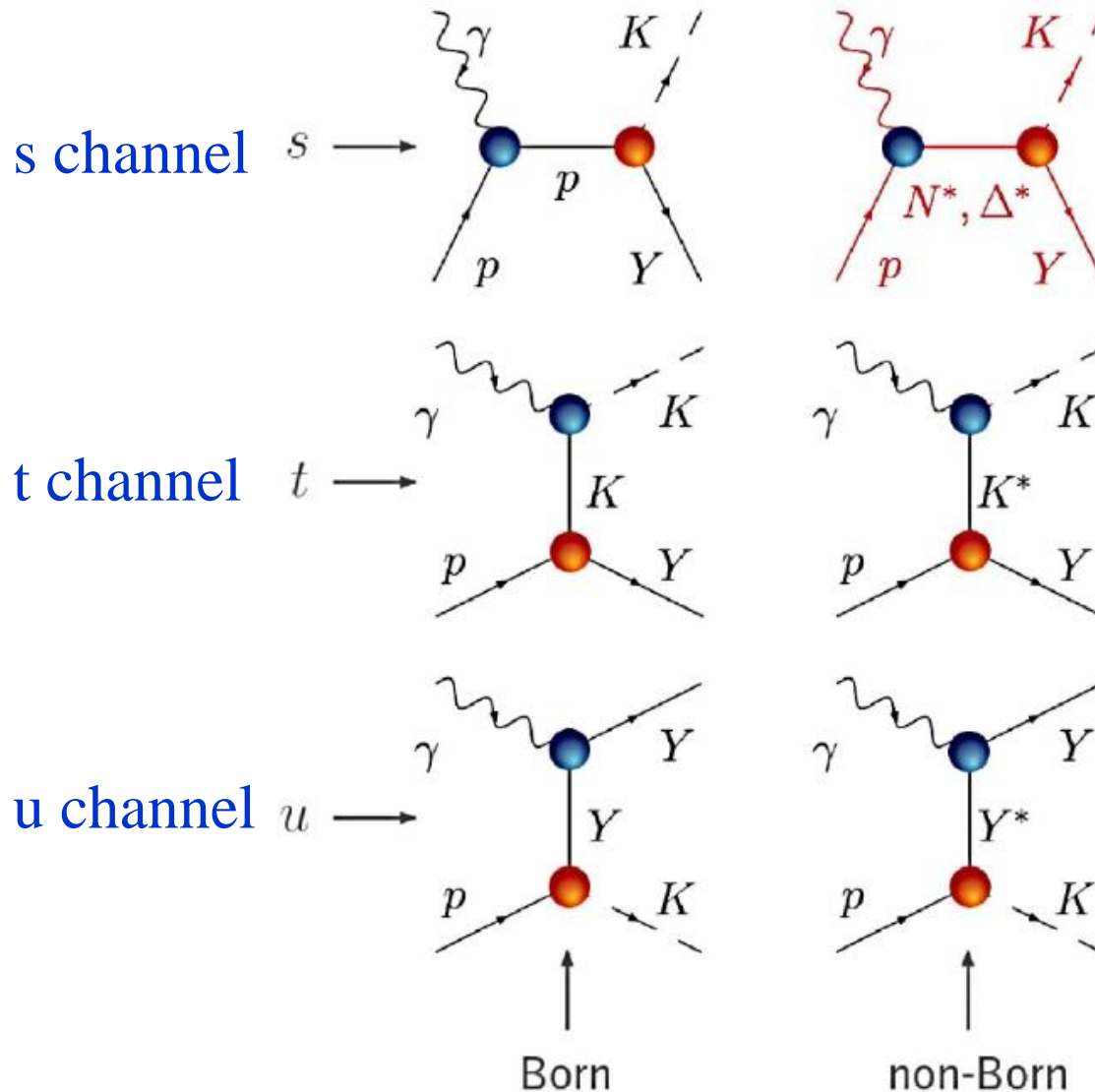
Missing nucleon resonance search



Quark models predict more nucleon resonances than observed experimentally.

Such missing nucleon resonances may be coupled to other channels than πN .

Reaction mechanisms of KY photoproduction



Strong when a meson is produced at forward angles.

Very weak

(1) $\vec{\gamma} p \rightarrow \pi^+ n$ reaction

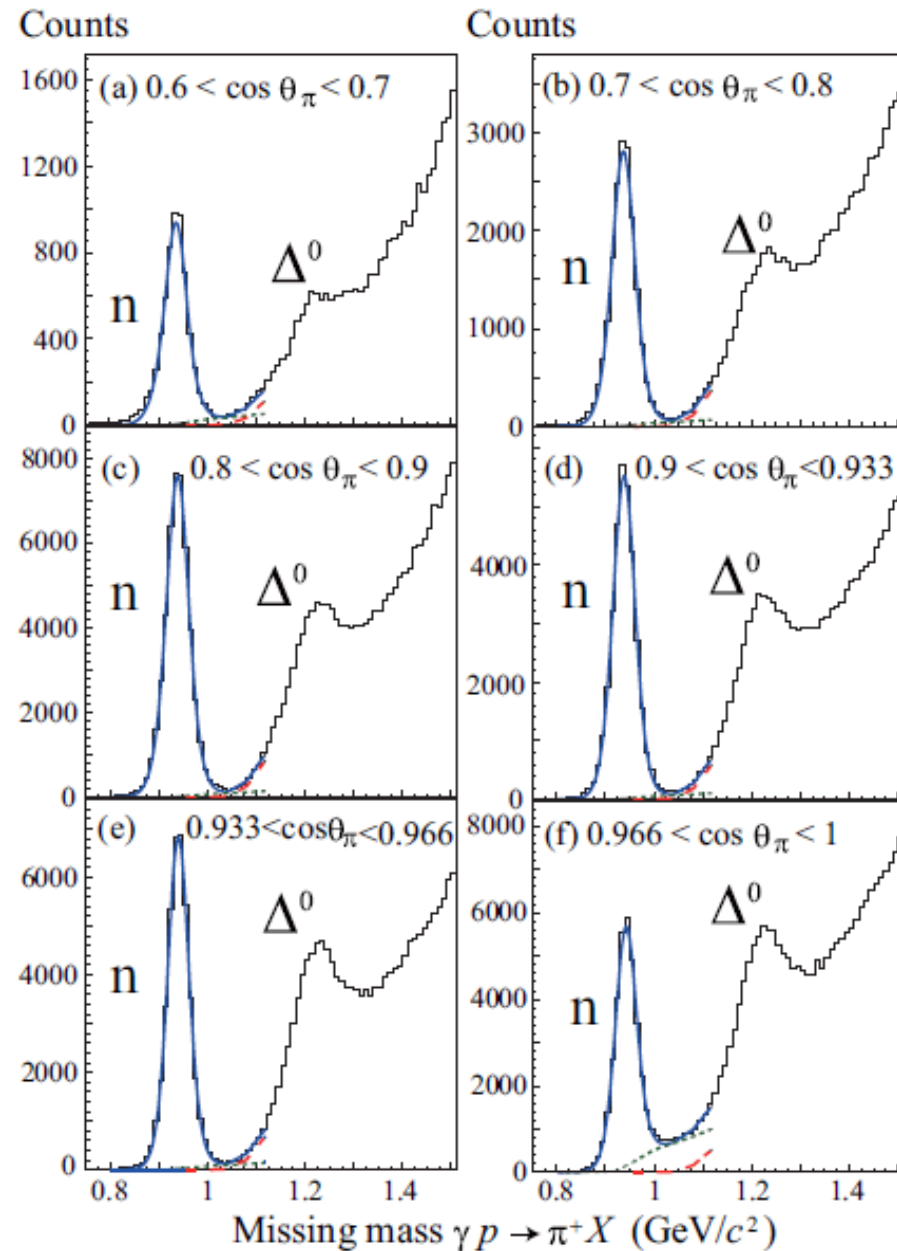
$d\bar{d}$ production

Title : Differential cross section and photon-beam asymmetry
for the $\gamma p \rightarrow \pi^+ n$ reaction at forward π^+ angles
at $E_\gamma=1.5\text{-}2.95$ GeV

Authors : H. Kohri, S.Y. Wang, S.H. Shiu, W.C. Chang, Y. Yanai et al.
LEPS Collaboration

Published in Phys. Rev. C 015205 (2018) on the 22nd of Jan.

Missing mass $p(\gamma, \pi^+)X$

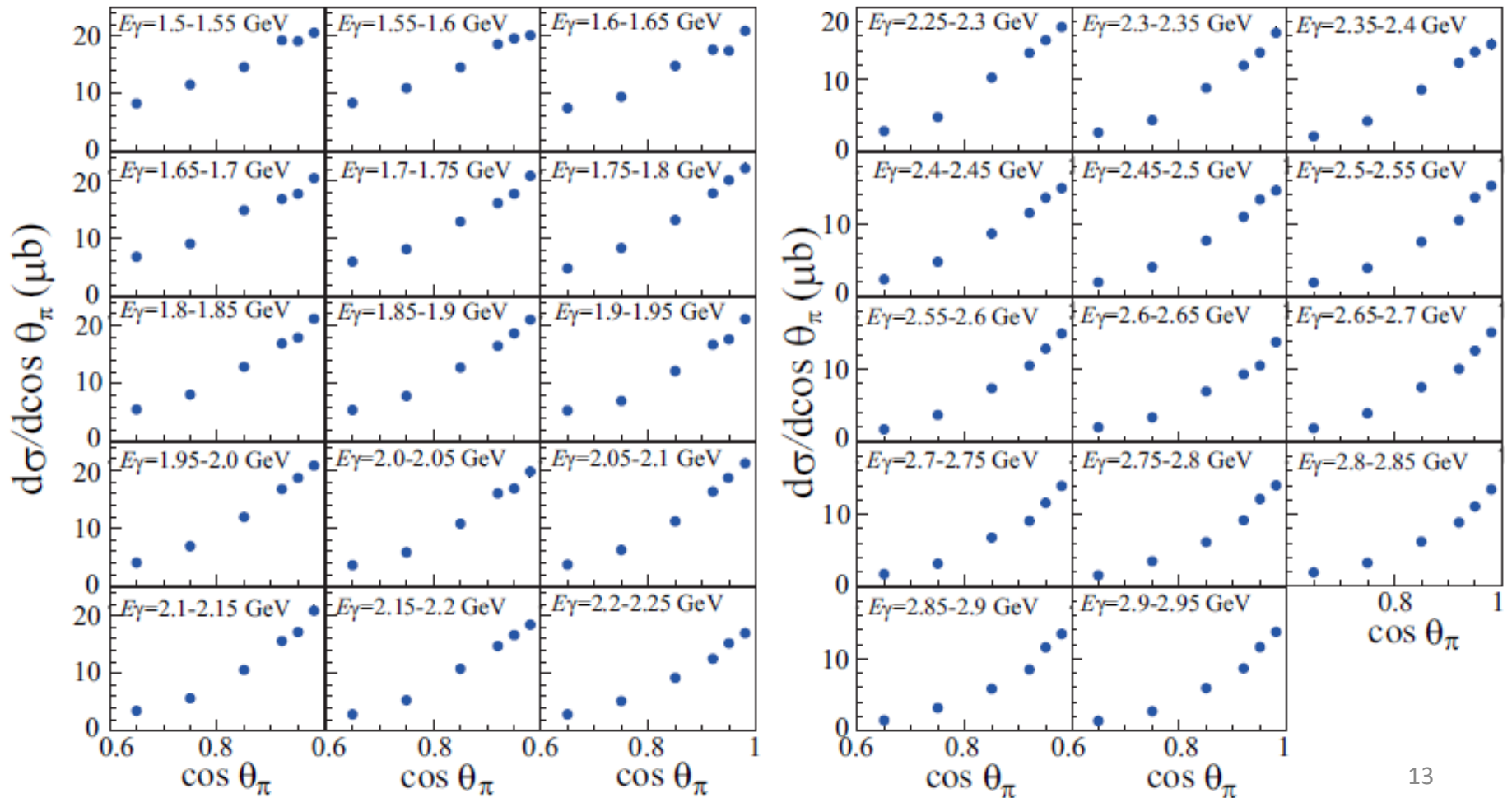


π -angle : $0.6 < \cos \theta < 1$
 E_γ range : 1.5-2.95 GeV

Neutron peaks are separately
 observed for
 $0.6 < \cos \theta < 0.966$.
 Positron mis-identification
 produces background
 between n and Δ^0 for
 $0.966 < \cos \theta < 1$.

Differential cross sections for $\gamma p \rightarrow \pi^+ n$

Forward peaking cross sections are observed.
t-channel reaction is found to be dominant.



Differential cross sections for $\gamma p \rightarrow \pi^+ n$

Cross sections decrease as E_γ increases for $0.6 < \cos\theta < 0.9$.

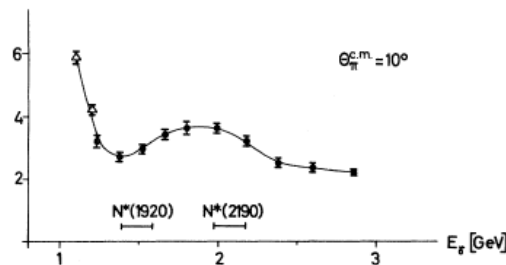
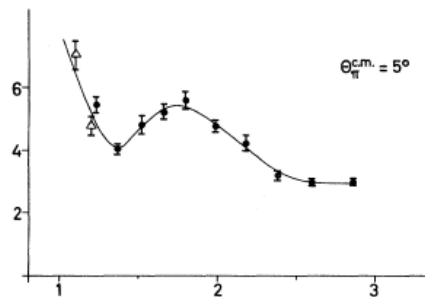
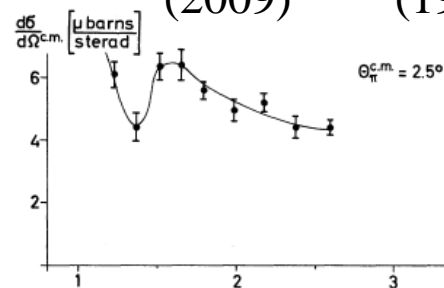
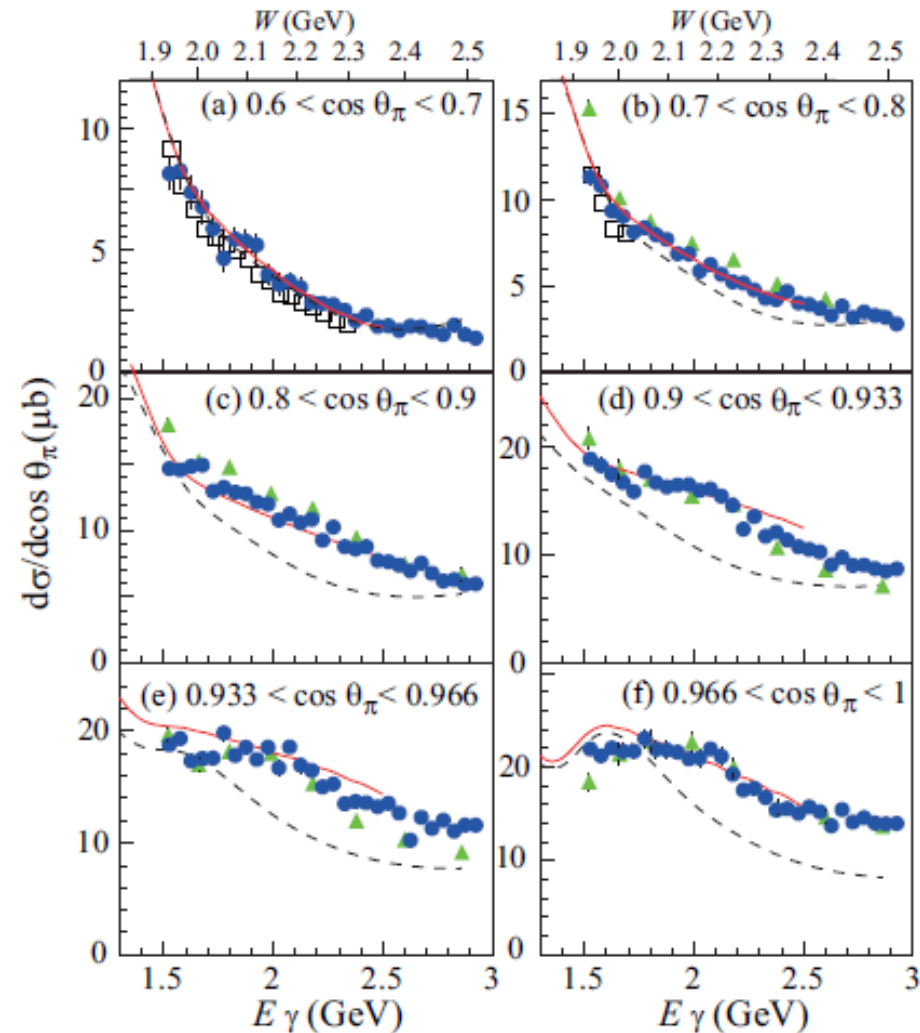
● LEPS

The energy dependence of $E_\gamma < 2.2$ GeV is different for $0.9 < \cos\theta < 1$.

This energy dependence might be due to N^* or Δ^* , as reported by the DESY group.

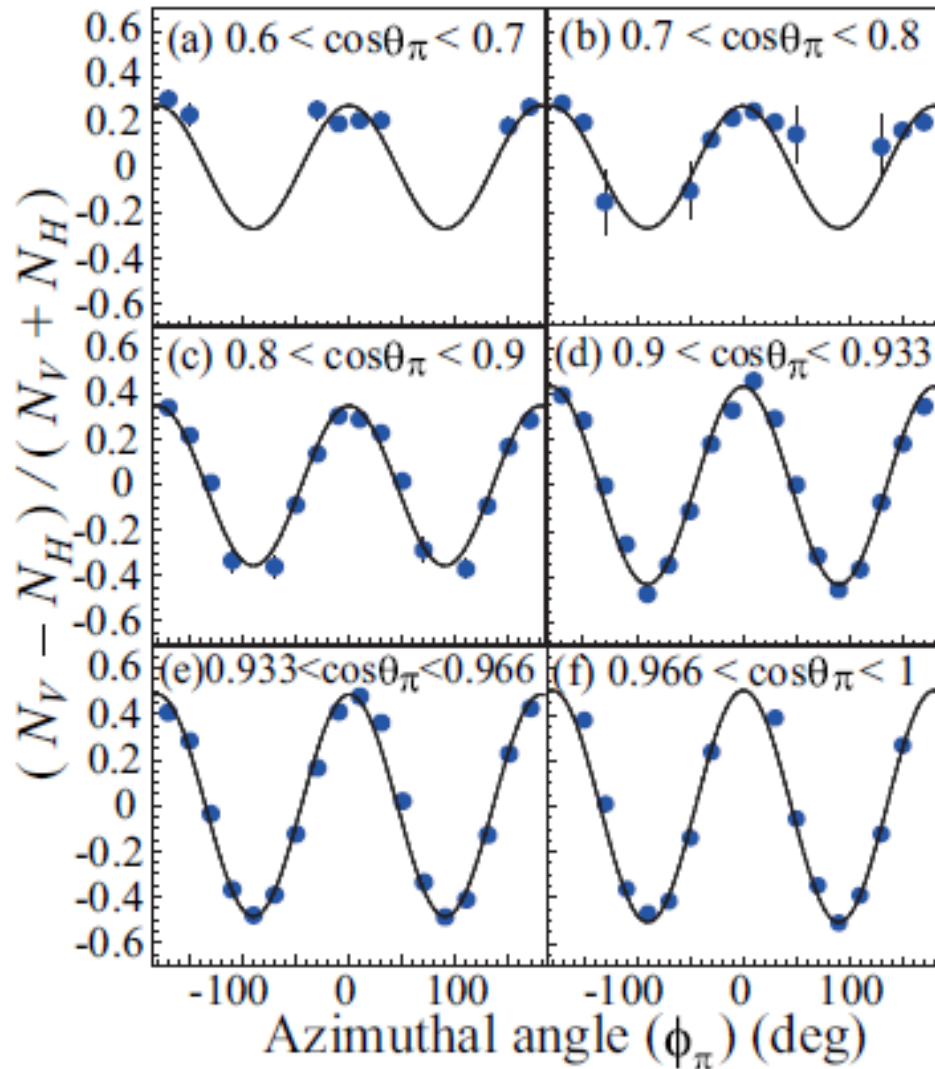
Good agreement with

CLAS(□) and DESY(▲) data.
(2009) (1966, 1967)



DESY1967 data

Ratio $(N_V - N_H) / (N_V + N_H)$



$$P_\gamma \Sigma \cos 2\phi_\pi = \frac{N_V - N_H}{N_V + N_H}$$

N_V : Yields for vertical polarization data

N_H : Yields for horizontal polarization data

P_γ : Photon polarization

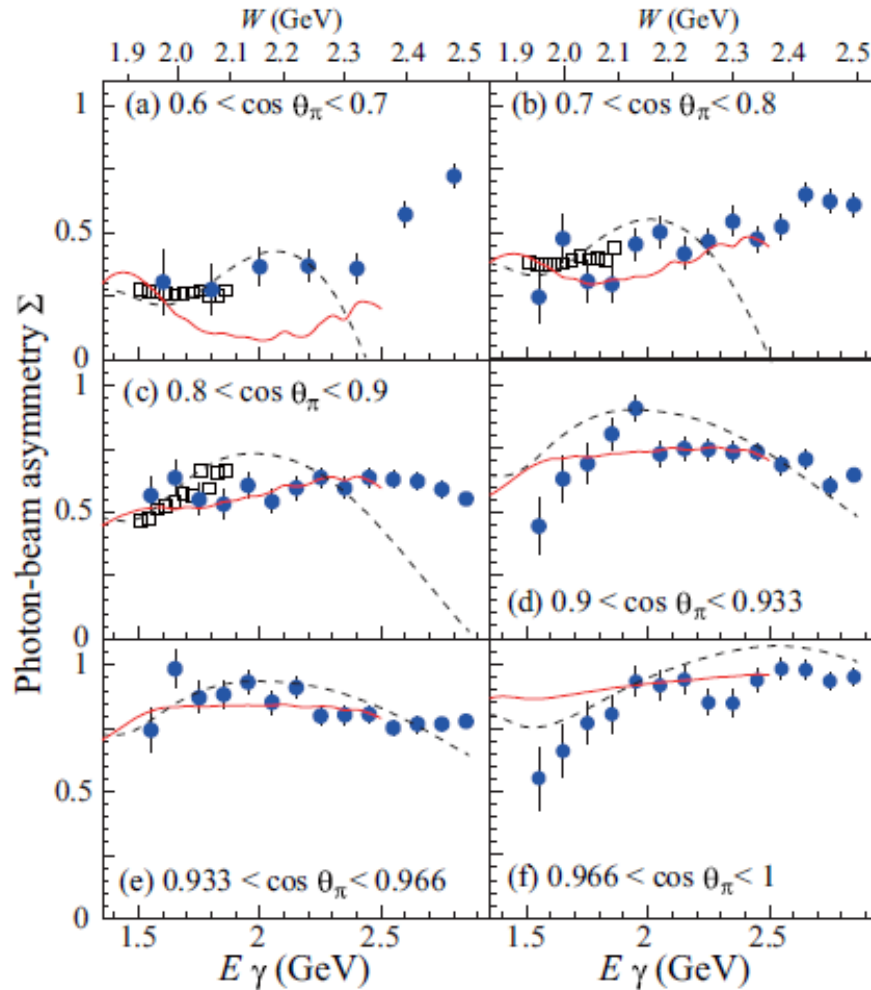
Σ : Photon-beam asymmetry

π^+ prefers to scatter at ϕ_π angles perpendicular to the polarization plane.

Photon-beam asymmetries for $\gamma p \rightarrow \pi^+ n$ are found to be positive.

Photon-beam asymmetry Σ for $\gamma p \rightarrow \pi^+ n$

● LEPS □ CLAS2013



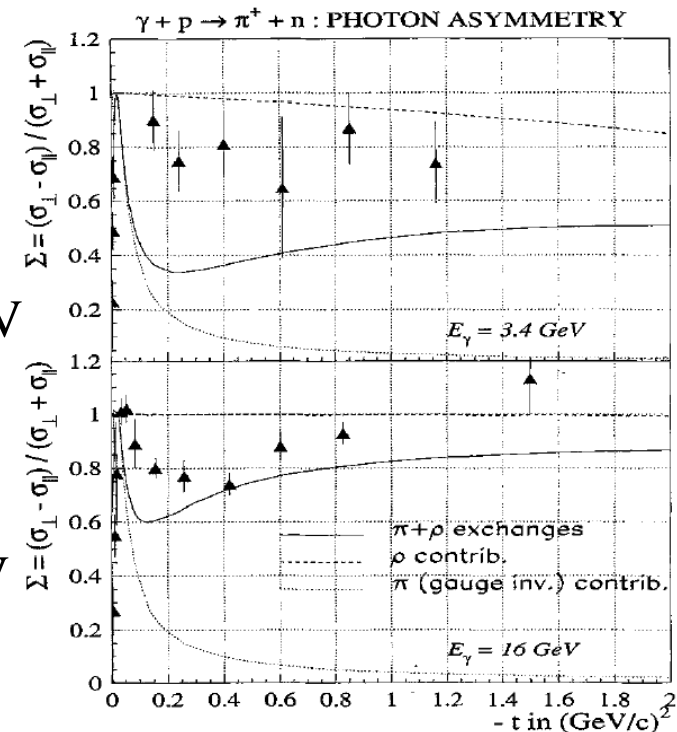
First photon-beam asymmetry data for $E_\gamma > 1.9$ GeV.

Positive asymmetries are basically explained by ρ -meson exchange in the t-channel. The asymmetries become larger as $\cos\theta$ increases.

SLAC data (1979)

$E_\gamma = 3.4$ GeV

$E_\gamma = 16$ GeV



PLB 400 (1997) 6

(2) $\vec{\gamma} p \rightarrow K^+ \Lambda$ and $K^+ \Sigma^0$ reactions $s\bar{s}$ production

Title : Photoproduction of Λ and Σ^0 hyperons off protons
with linearly polarized photons at $E_\gamma=1.5\text{-}3.0$ GeV

Authors : S.H. Shiu, H. Kohri, W.C. Chang et al.
LEPS Collaboration

Published in Phys. Rev. C 97 015208 (2018) on the 31st of Jan.

Missing mass $p(\gamma, K^+)X$

2018 data $E_\gamma = 1.5\text{--}3.0$ GeV

2006 data $E_\gamma = 1.5\text{--}2.4$ GeV

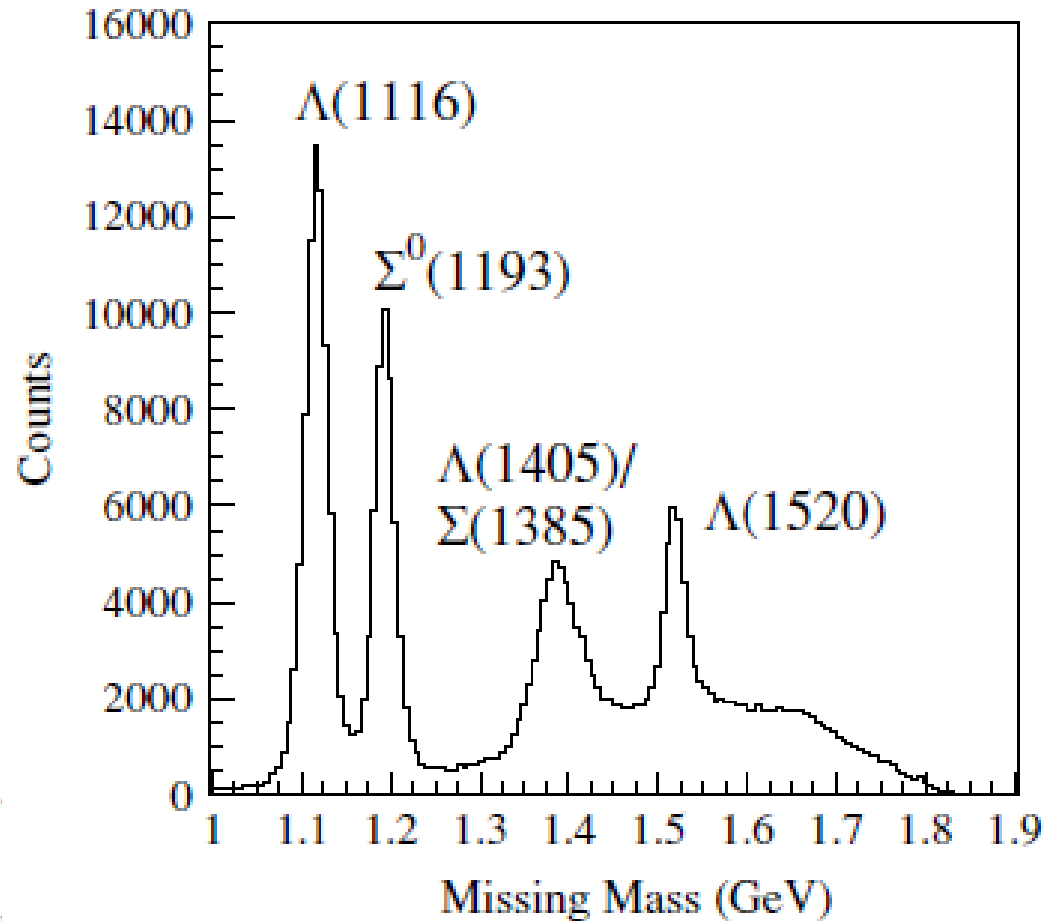
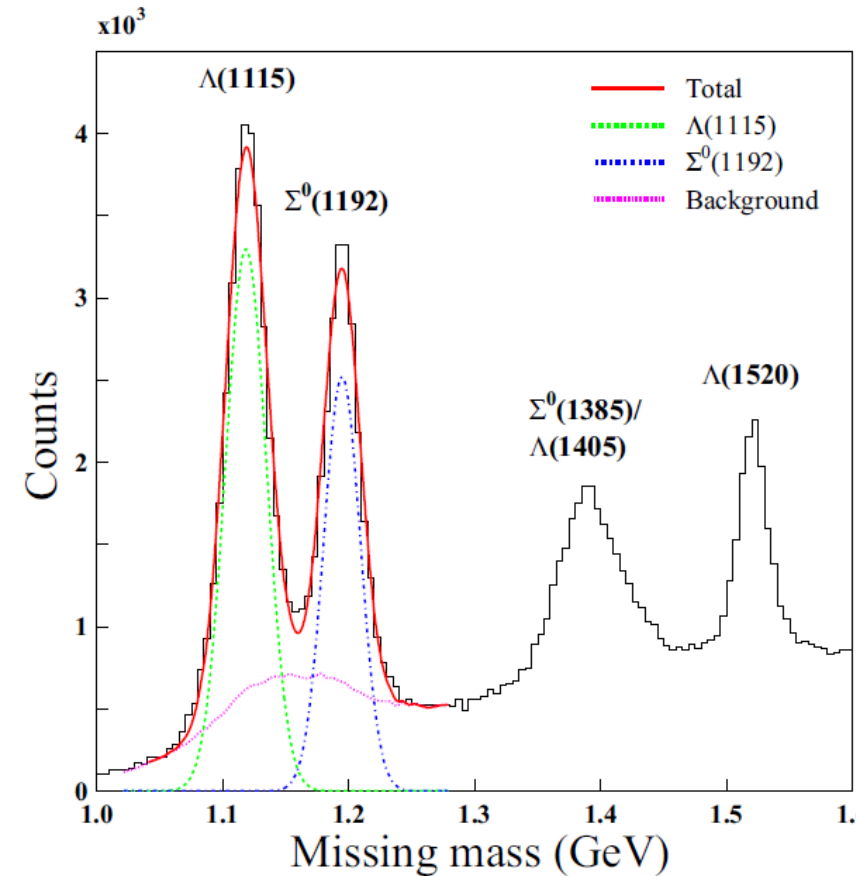
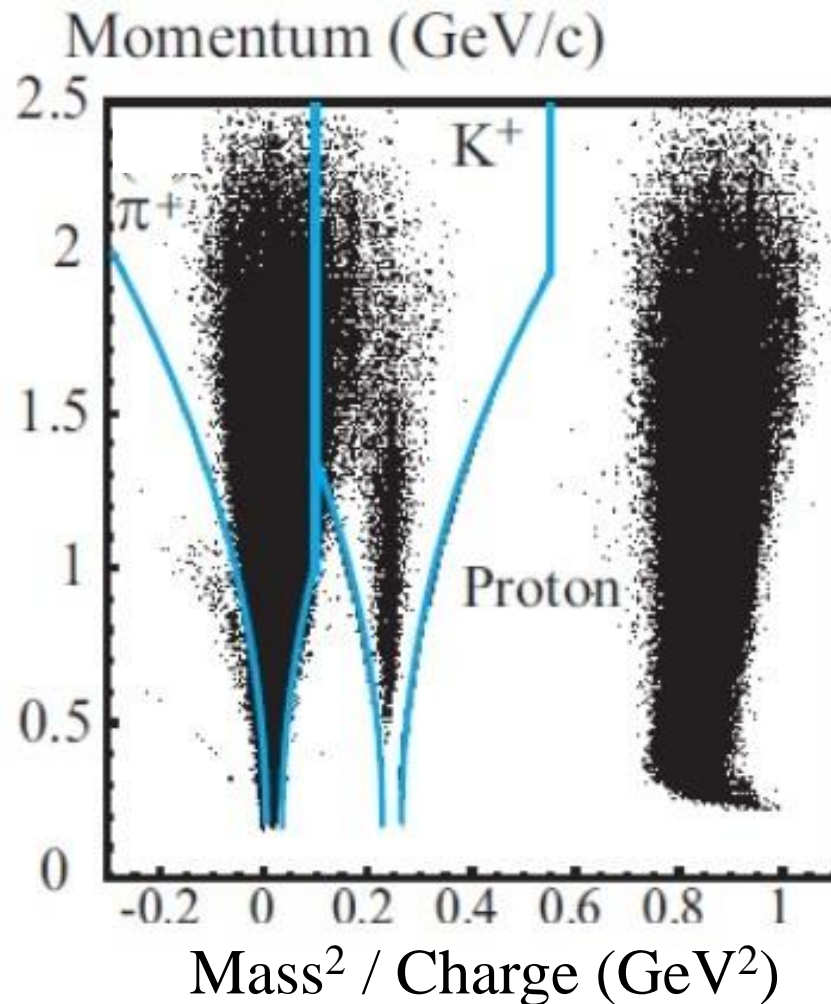


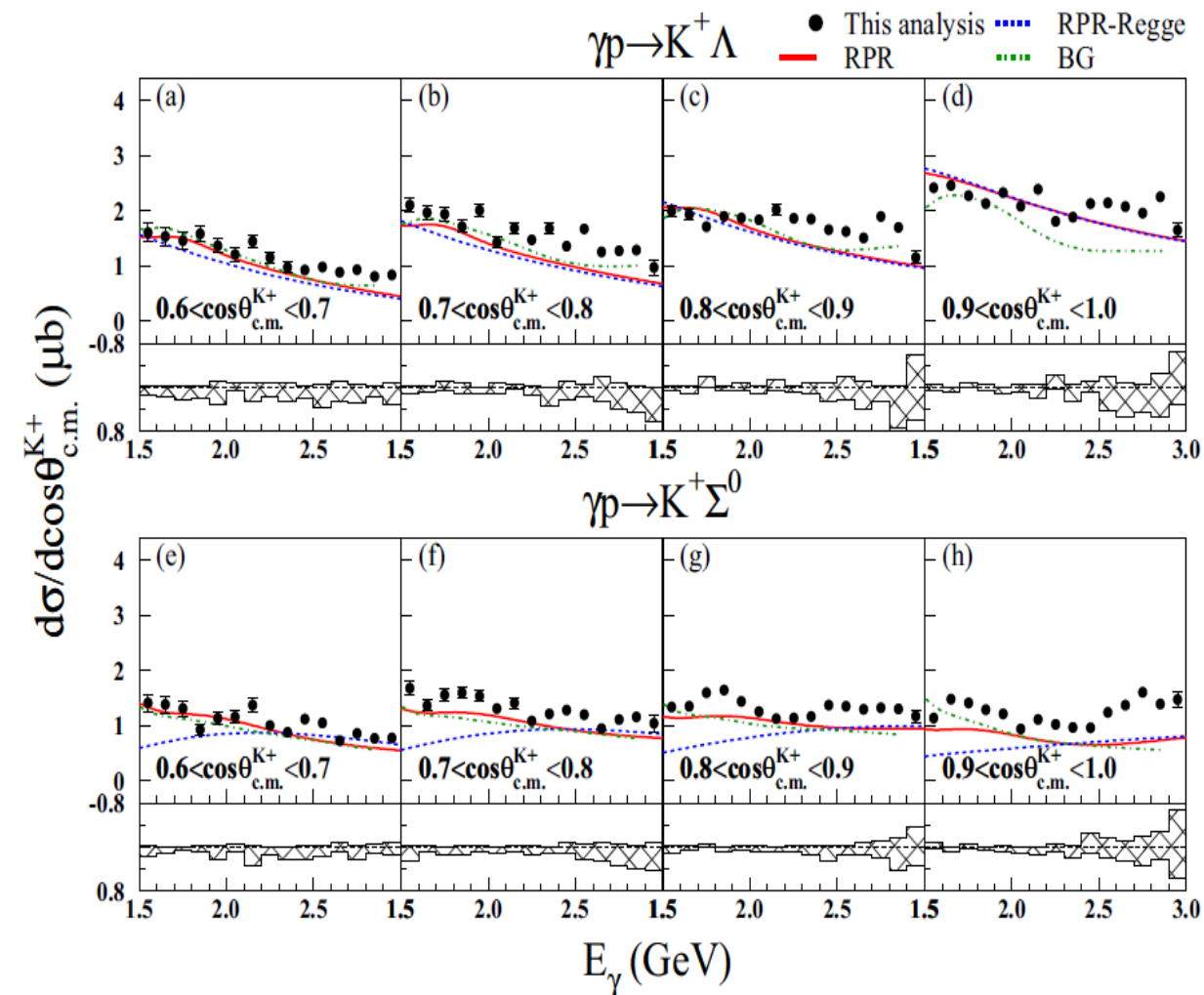
FIG. 1. Missing mass spectrum of $\gamma p \rightarrow K^+ X$ reaction: $[MM_X(\gamma p, K^+)]$ at $E_\gamma = 1.5\text{--}3.0$ GeV.

Difficulty in particle identification for high momentum K^+



The acceptance of LEPS spectrometer is limited.
The fraction of 2-track events is only 5% of all data.

Differential cross sections for $\gamma p \rightarrow K^+ \Lambda$ and $K^+ \Sigma^0$



First cross section data for LEPS at $2.4 < E_\gamma < 3 \text{ GeV}$.

$K^+ \Lambda$ cross sections are larger than $K^+ \Sigma^0$ cross sections.

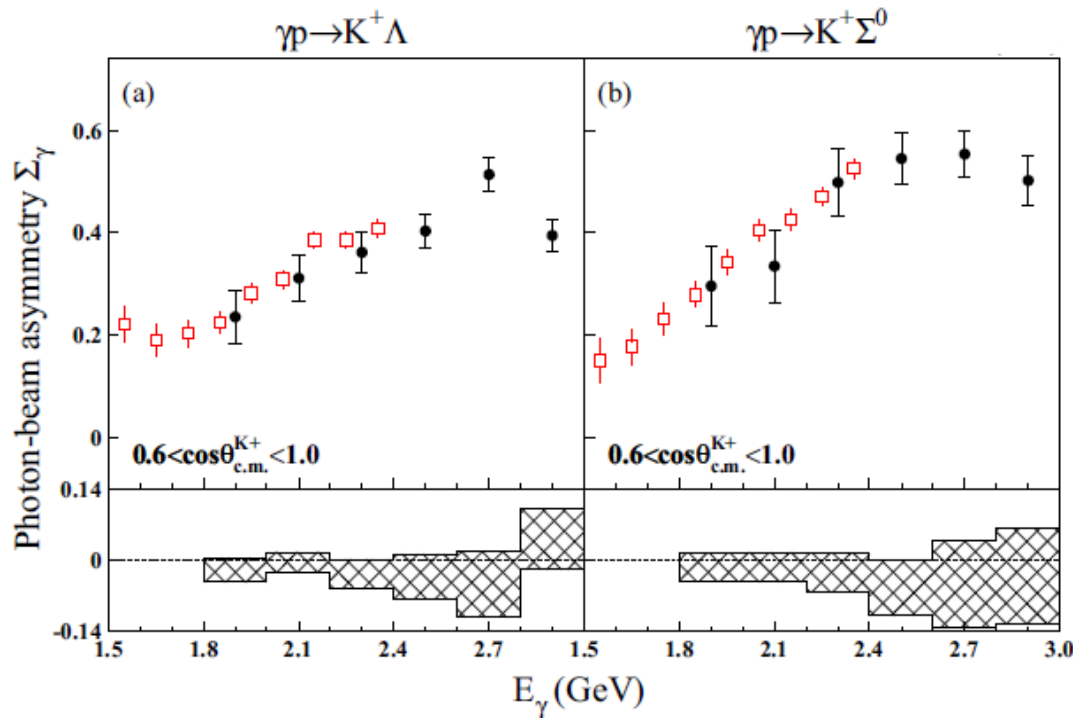
No evident structure due to N^* or Δ^* .

Photon-beam asymmetry for $K^+ \Lambda$ and $K^+ \Sigma^0$

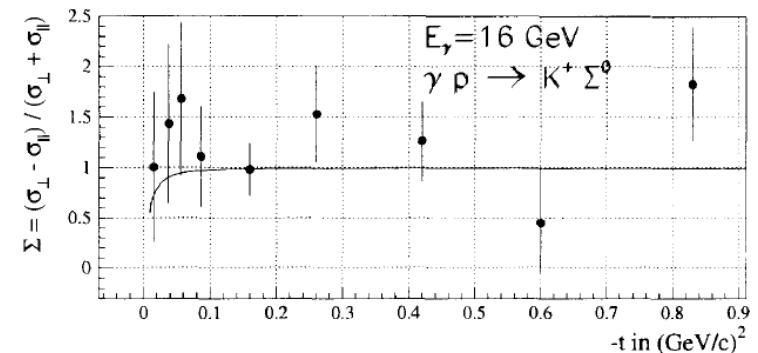
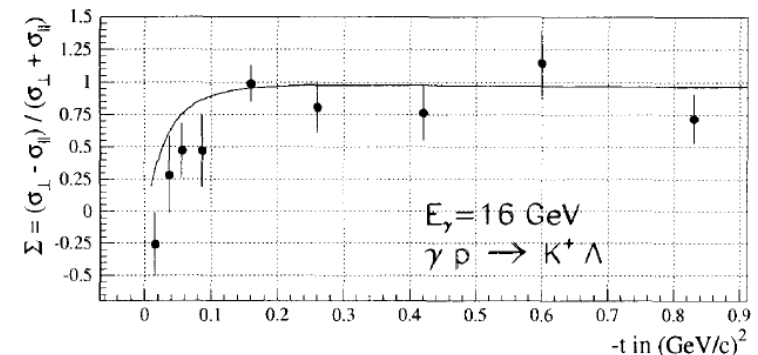
First photon-beam asymmetries data for $E_\gamma > 2.4$ GeV.

The asymmetries increase gradually as E_γ increases for both the reactions. K^* -exchange contribution becomes larger.

● LEPS2018 □ LEPS2006



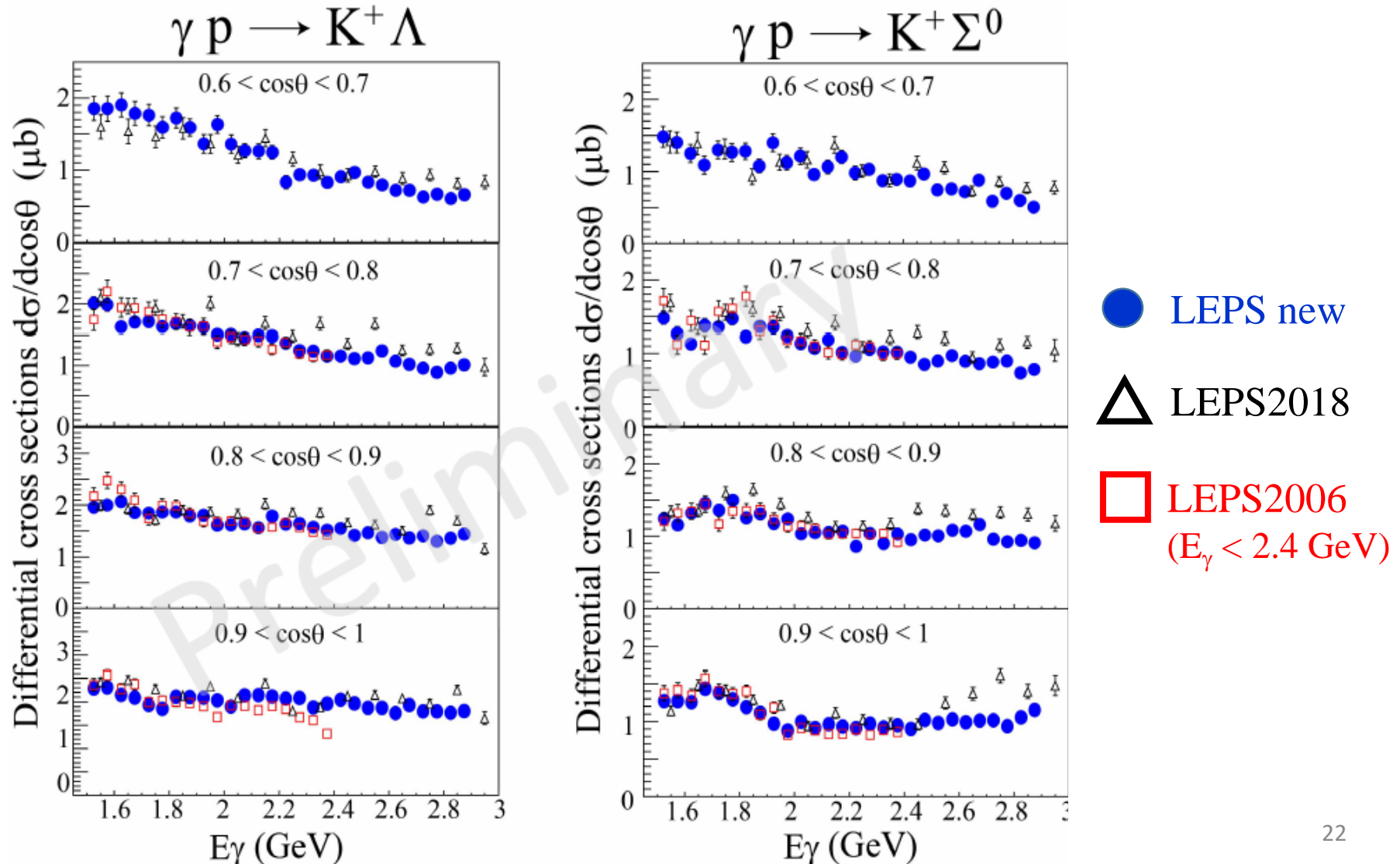
M. Guidal et al./Nuclear Physics A 627 (1997) 645–678



SLAC data
(1979)

New data with higher statistics are analyzed now

We will be able to provide more precise data in the near future.



(3) $\vec{\gamma} p \rightarrow \pi^- \Delta^{++}$ reaction

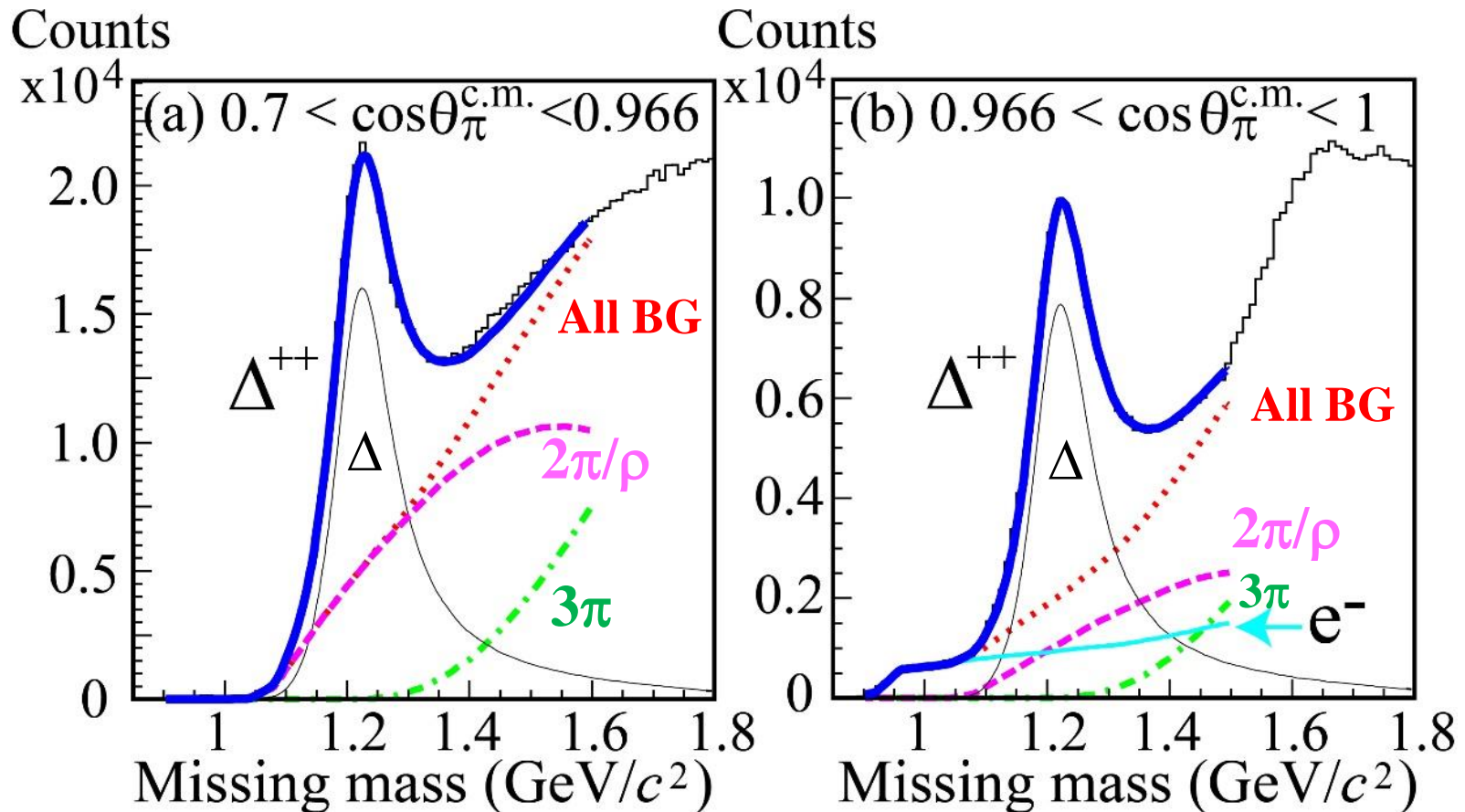
$u\bar{u}$ production

Title : Differential cross section and photon-beam asymmetry
for the $\gamma p \rightarrow \pi^- \Delta^{++}(1232)$ reaction at forward π^- angles
for $E_\gamma = 1.5\text{--}2.95$ GeV

Authors : H. Kohri, S.H. Shiu, W.C. Chang, Y. Yanai, et al.
LEPS Collaboration

Published in Phys. Rev. Lett. 120 202004 (2018)
on the 18th of May.

Missing mass $p(\gamma, \pi^-)X$

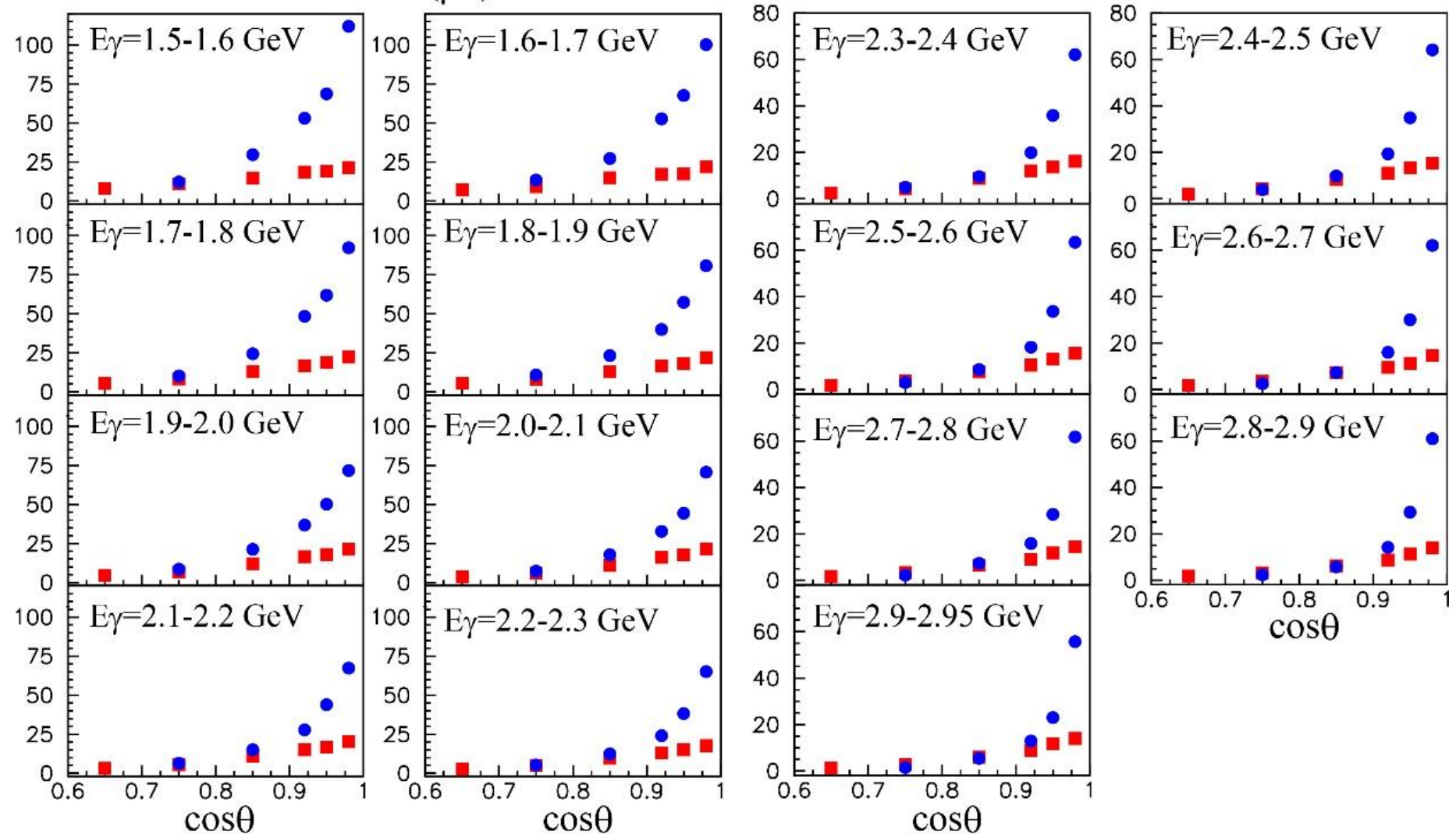


Missing mass is fitted with relativistic Breit-Wigner shape for Δ , $2\pi / \rho$, 3π , and e^- curves.

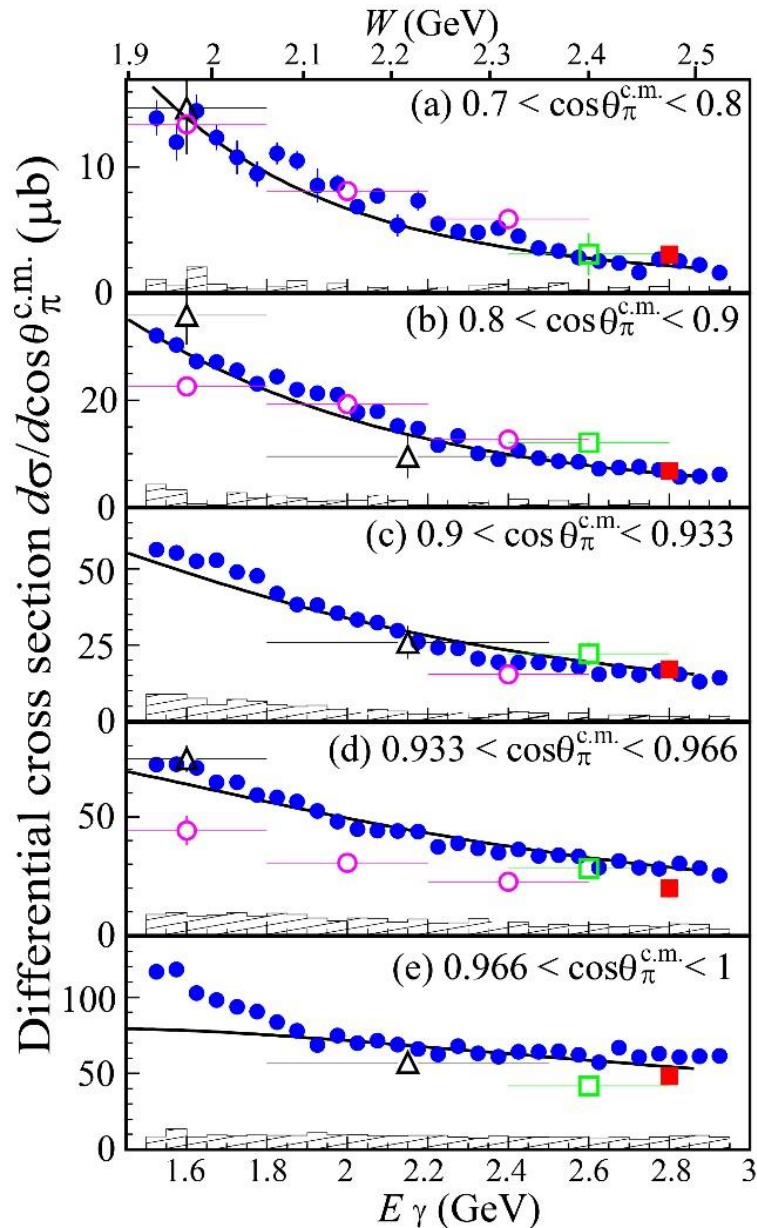
Comparison of $d\sigma/d\cos\theta$ between $\pi^- \Delta^{++}$ (●) and $\pi^+ n$ (■)

Strong forward peaking cross sections suggest t-channel reaction is dominant.

Differential Cross Section (μb)



Differential cross sections for $\gamma p \rightarrow \pi^- \Delta^{++}$



First high-statistics cross section data.
 $d\sigma/d\cos\theta$ decreases as E_{γ} increases.
 Strong forward peaking (π -exchange).

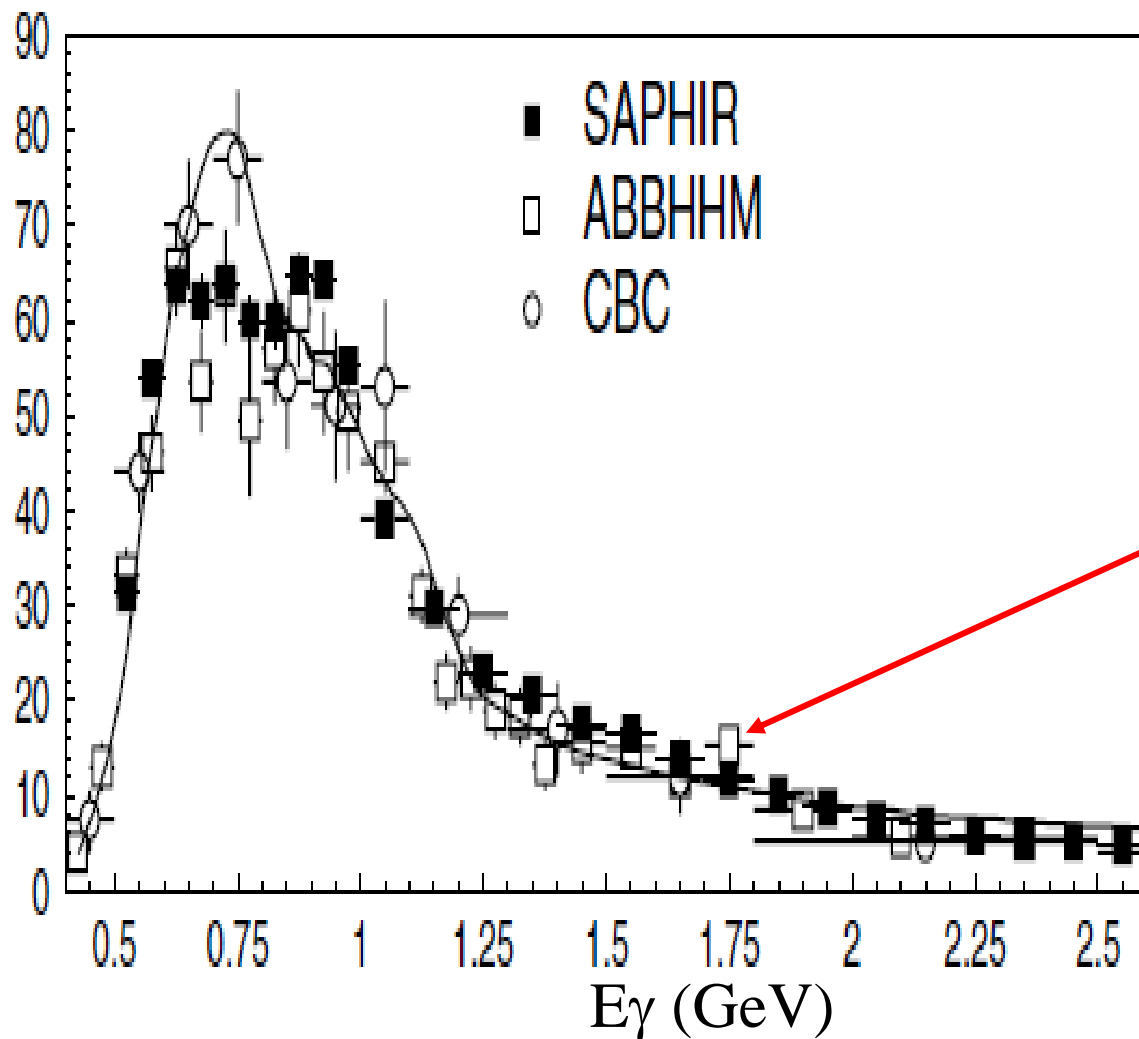
Theoretical calculations by S.i. Nam well reproduce the data.

The energy dependence of $E_{\gamma} < 1.8$ GeV cannot be reproduced for $\cos\theta > 0.9$. N^* or Δ^* ?



SAPHIR total cross sections

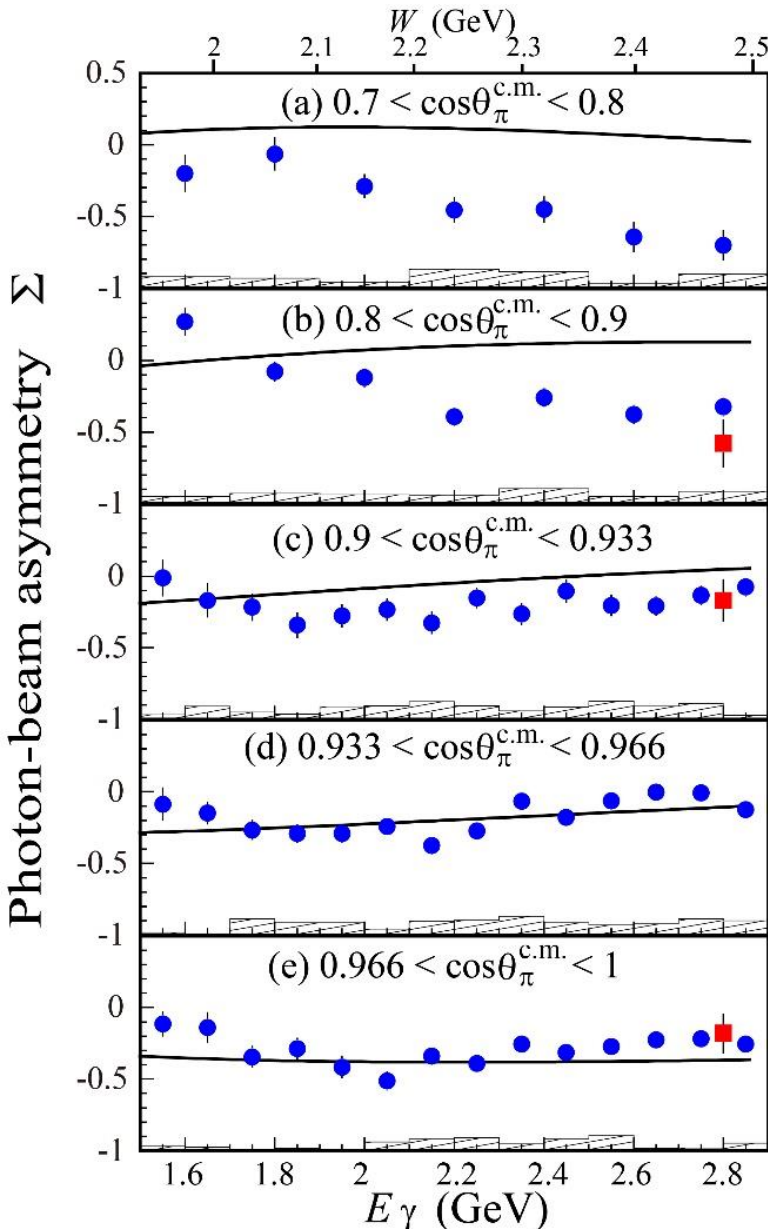
$\sigma(\mu\text{b})$



Tail of s-channel resonances
seems to continue up to
 $\sim E_\gamma = 2$ GeV

C. Wu et al. Eur. Phys. J. A 23 (2005) 317

Photon-beam asymmetry for $\gamma p \rightarrow \pi^- \Delta^{++}$



First asymmetry data for $1.5 < E_{\gamma} < 2.8$ GeV.

Asymmetries are found to be **negative** for most of LEPS kinematical regions, suggesting **π -exchange dominance**.

Theoretical calculations by S.i. Nam well reproduce negative asymmetries for $\cos\theta > 0.933$.

The calculations cannot reproduce the data for $\cos\theta < 0.9$.

Additional unnatural parity exchange is needed.



LEPS

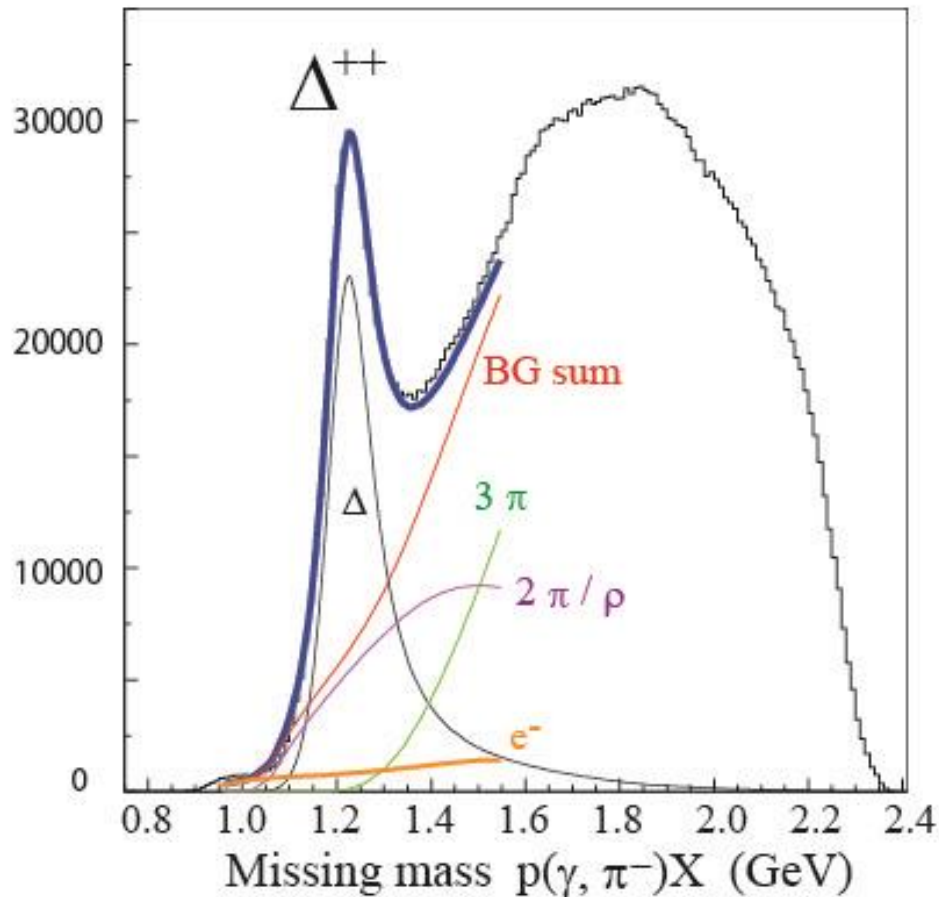


SLAC1972

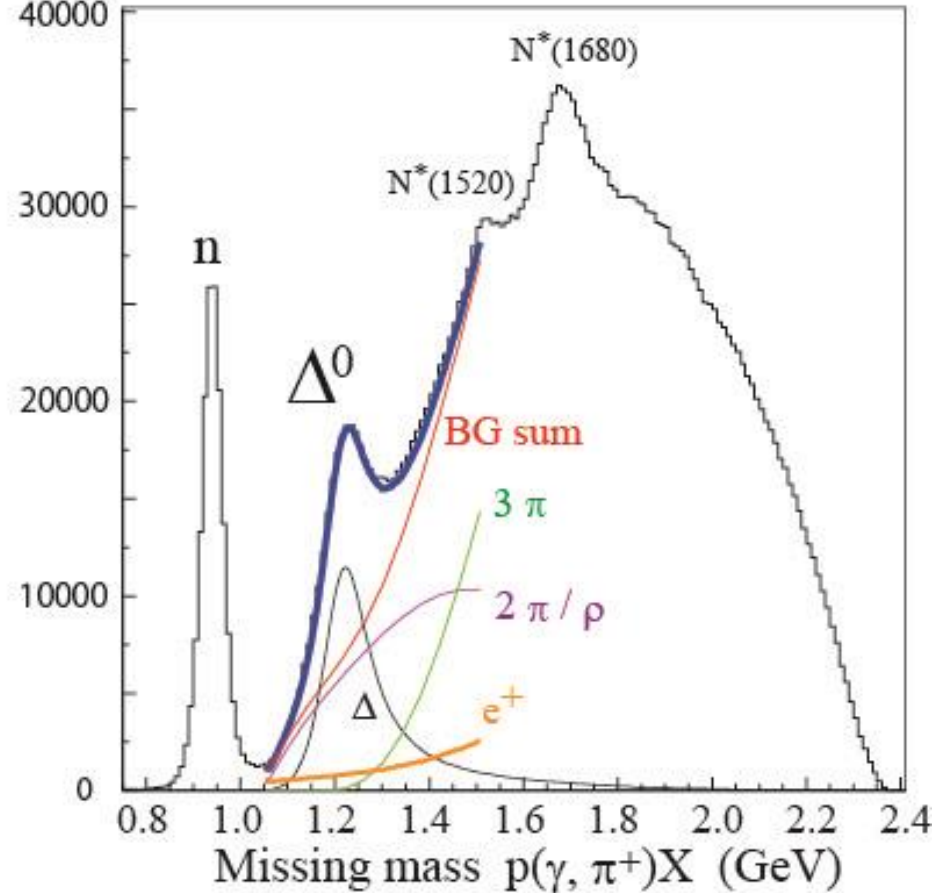
(4) $\vec{\gamma} p \rightarrow \pi^+ \Delta^0$ reaction $d\bar{d}$ production

Missing mass is fitted with relativistic Breit-Wigner shape for Δ , $2\pi / \rho$, 3π , and e^- or e^+ curves.

Counts

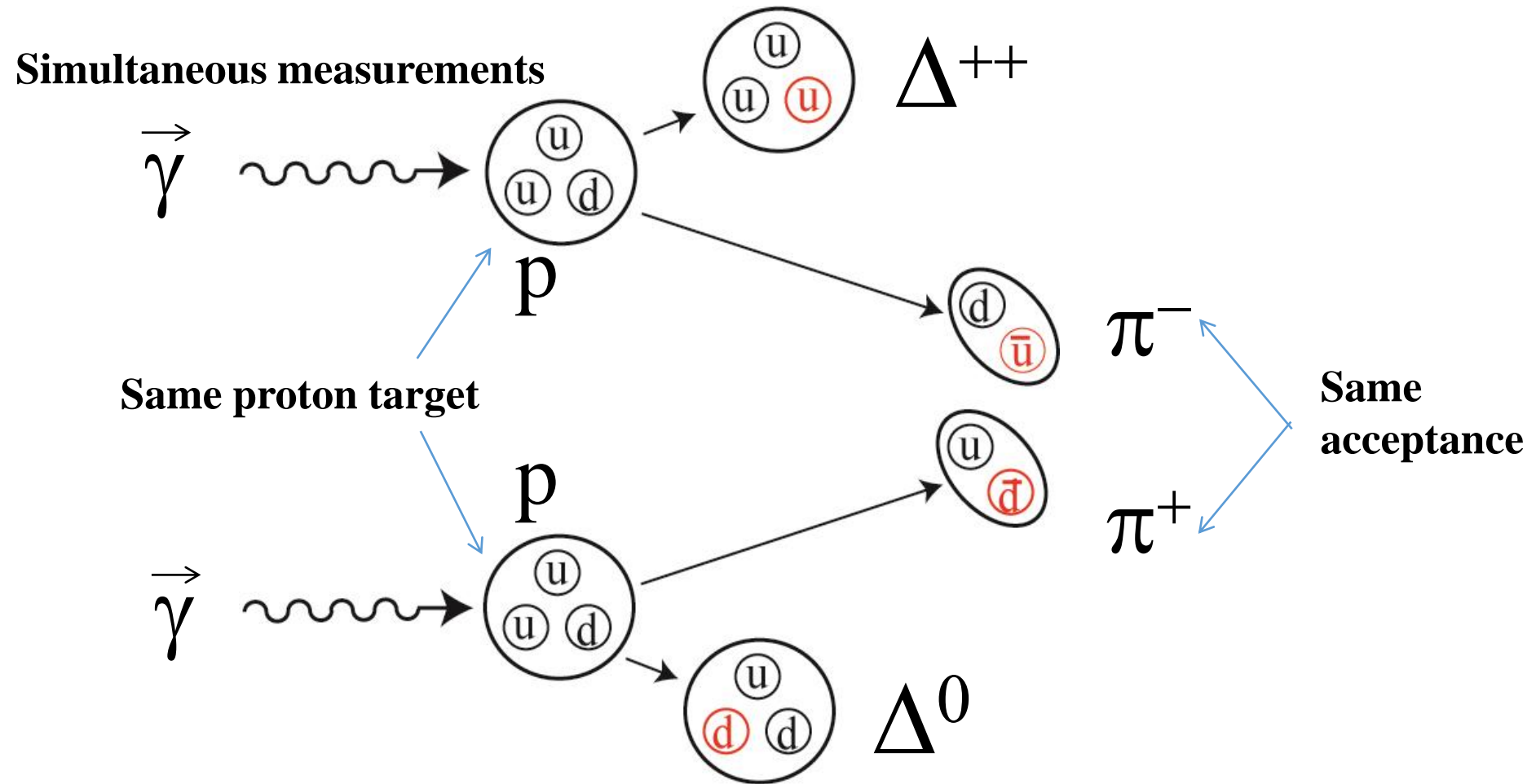


Counts



Comparison between $u\bar{u}$ and $d\bar{d}$ productions

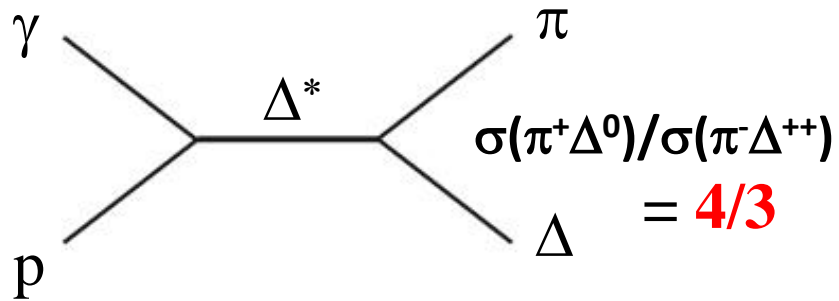
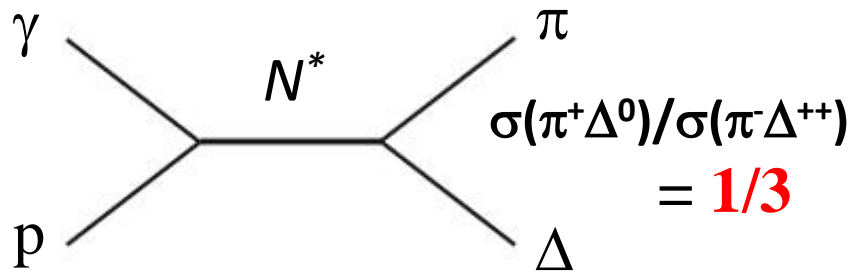
$u\bar{u}$ production is precisely compared with $d\bar{d}$ production
by the $\gamma p \rightarrow \pi^- \Delta^{++}$ and $\pi^+ \Delta^0$ reactions



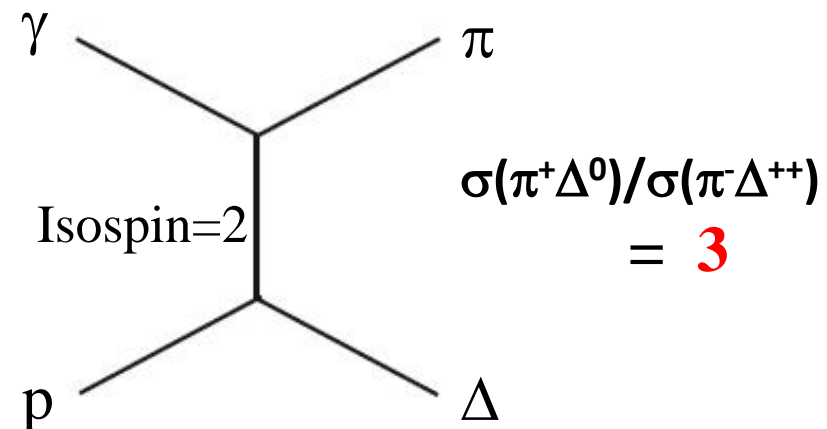
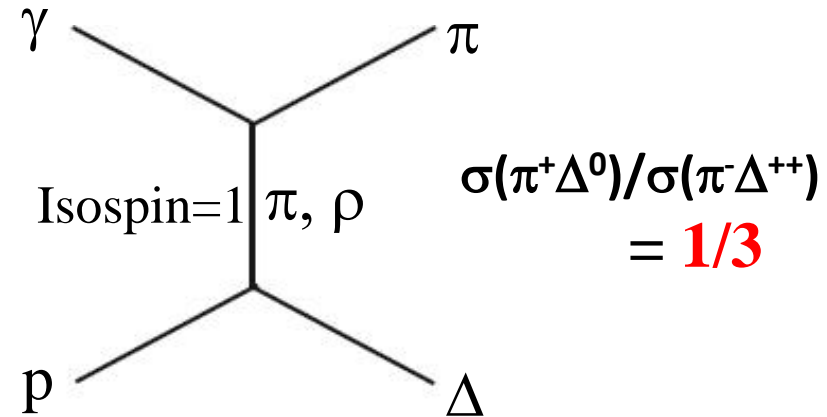
I expect this comparison would give important information
to understand how hadrons are produced.

Expected cross section ratio $\sigma(\pi^+\Delta^0)/\sigma(\pi^-\Delta^{++})$

s- channel

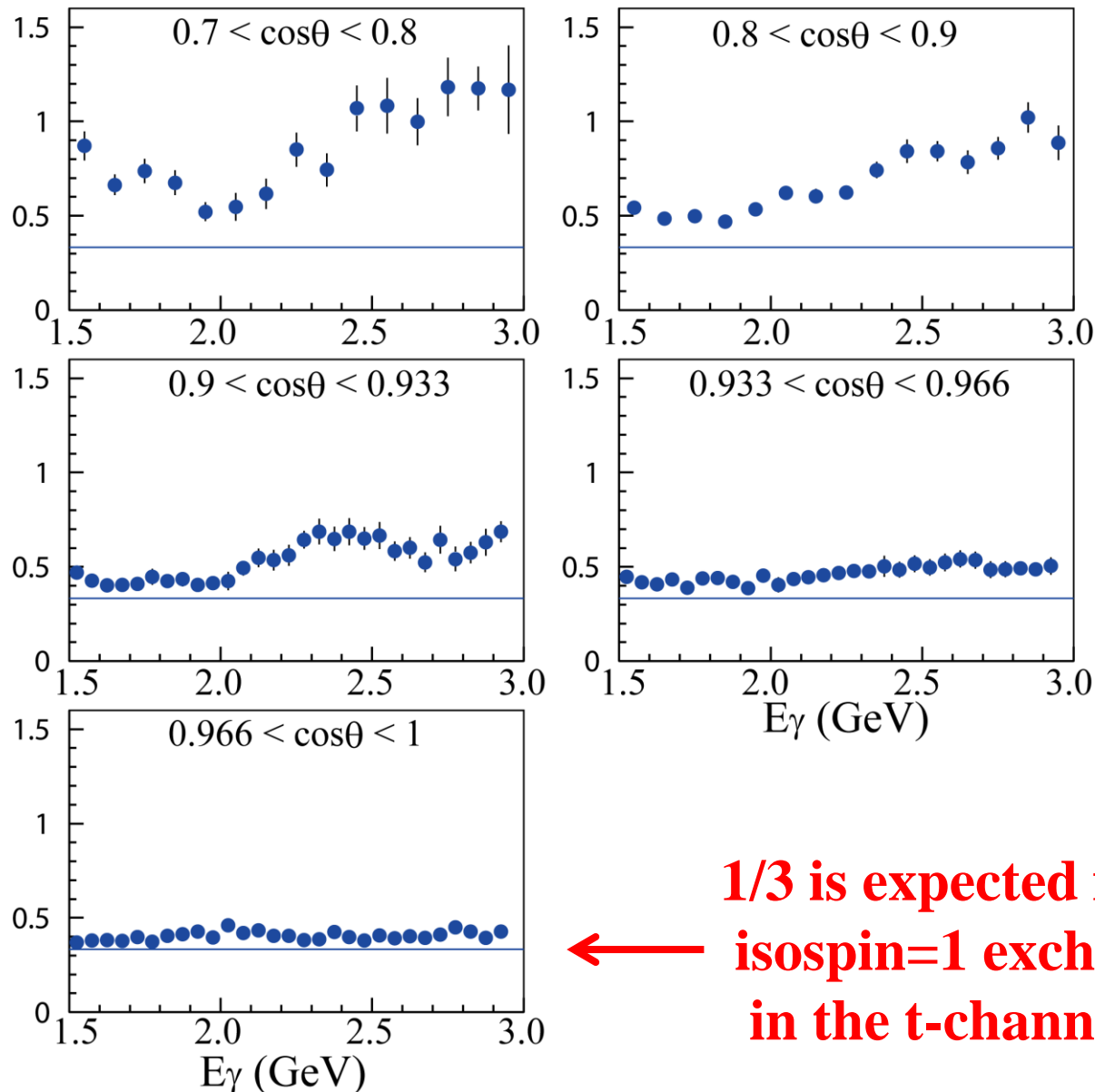


t- channel



Ratio $\sigma(\pi^+\Delta^0)/\sigma(\pi^-\Delta^{++})$

($d\bar{d}$ production / $u\bar{u}$ production)

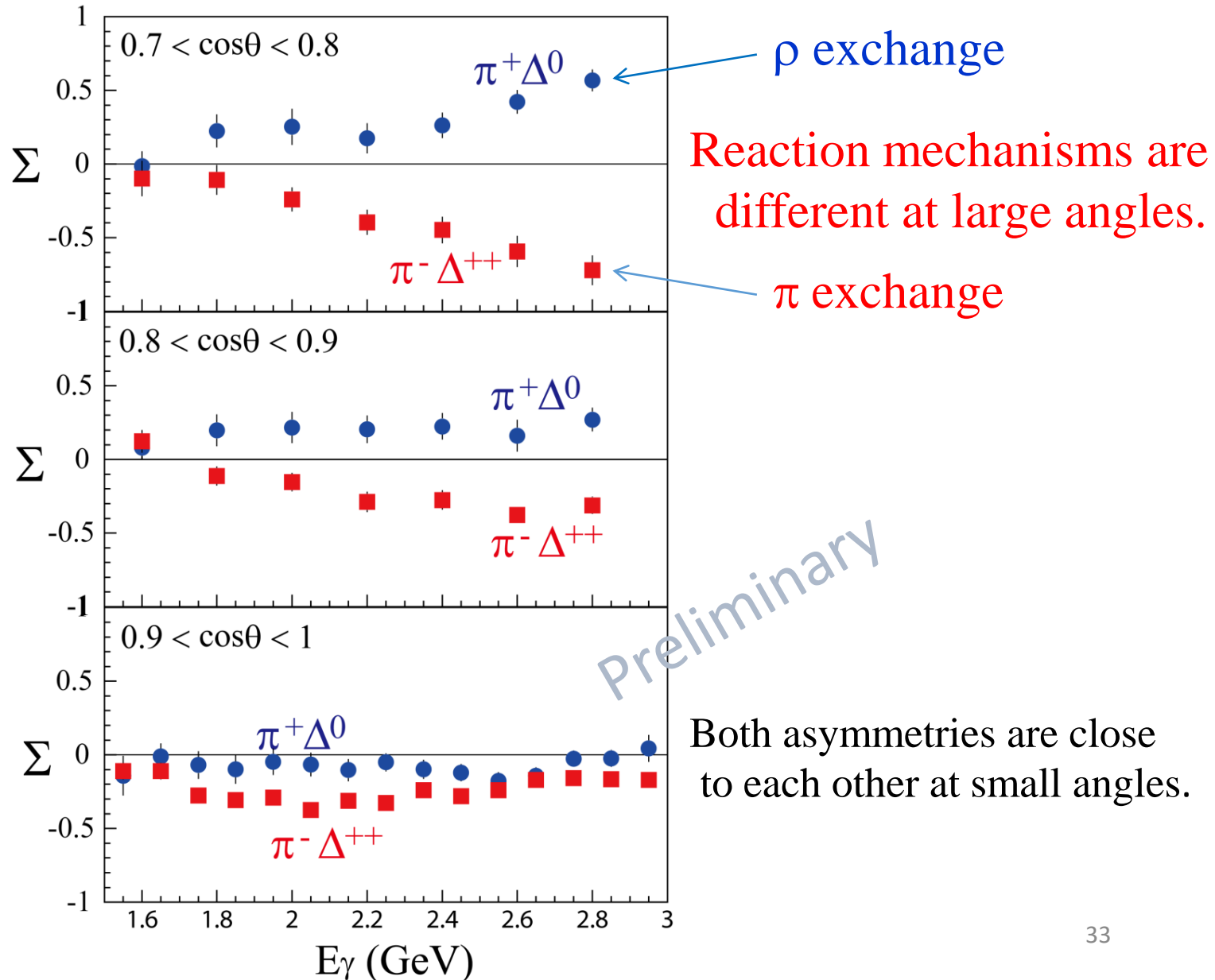


Preliminary

$d\bar{d}$ production is enhanced
or
 $u\bar{u}$ production is suppressed.

← 1/3 is expected from isospin=1 exchange in the t-channel

Photon beam asymmetry for $\gamma p \rightarrow \pi^- \Delta^{++}$ and $\gamma p \rightarrow \pi^+ \Delta^0$ reactions



Summary and future plan

We took high momentum charged pion data for the first time.
It enables us to study $u\bar{u}$, $d\bar{d}$, and $s\bar{s}$ productions and we want to obtain unified understanding of these $q\bar{q}$ productions.

- | | |
|--|--|
| (1) $\gamma p \rightarrow \pi^+ n$ reaction data
$d\bar{d}$ production | Published in Phys. Rev. C on Jan/22/2018 |
| (2) $\gamma p \rightarrow K^+ \Lambda$ and $K^+ \Sigma^0$ reaction data
$s\bar{s}$ production | Published in Phys. Rev. C on Jan/31/2018
New data are analyzed now. |
| (3) $\gamma p \rightarrow \pi^- \Delta^{++}$ reaction data
$u\bar{u}$ production | Published in Phys. Rev. Lett. on May/18/2018 |
| (4) $\gamma p \rightarrow \pi^+ \Delta^0$ reaction data.
$d\bar{d}$ production | Physics paper is prepared. |

Refrigerators for polarized HD target



Osaka RCNP
DRS

Osaka RCNP
TC1

RCNP -> SPring-8
SC



→
T=4K
B=0.2T

T=10mK
B=17 T

SPring-8
IBC

T=300mK
B=1 T



T=2K
B=1T



↓
SPring-8
TC2
T=4K B=0.2T



Status of polarized HD target

- We are developing a polarized HD target for the near future LEPS experiments using polarized photons and HD targets. We will be able to obtain much more information to understand hadron photoproduction.
- The polarization of H is **44+-1%** and the relaxation time of the H polarization is **8+-2 months**.
These performances are good enough for physics runs.
- We need skills to transport the HD target from the first cryostat to the last one.
After acquiring these skills, we will start the physics runs.
- Previously, SPring-8-II(8 GeV -> 6 GeV) planned to start in 2020. But the schedule is largely delayed.
We still have some years for taking physics data with HD.

Thank you