GeV photon beam experiments at the SPring-8 laser-backscattering facility

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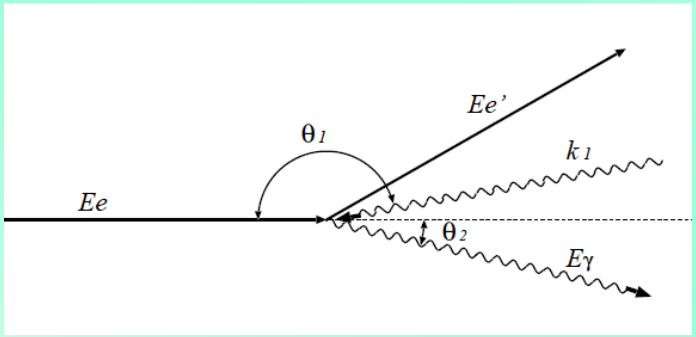
for the LEPS collaboration

- Introduction
- LEPS (Laser-Electron Photon at SPring-8) facility
- Some experimental results using the forward spectrometer
  - photon beam asymmetry for the K^+ photoproduction
  - ϕ meson photoproduction
  - search for pentaquark Θ^+
- Present status and future prospect

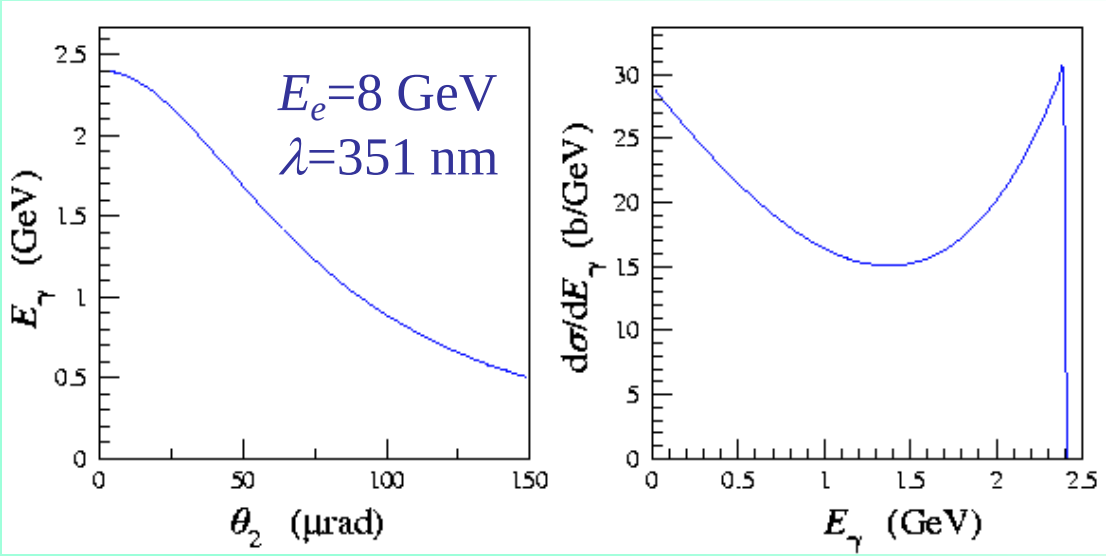
Characteristics of BCS photons

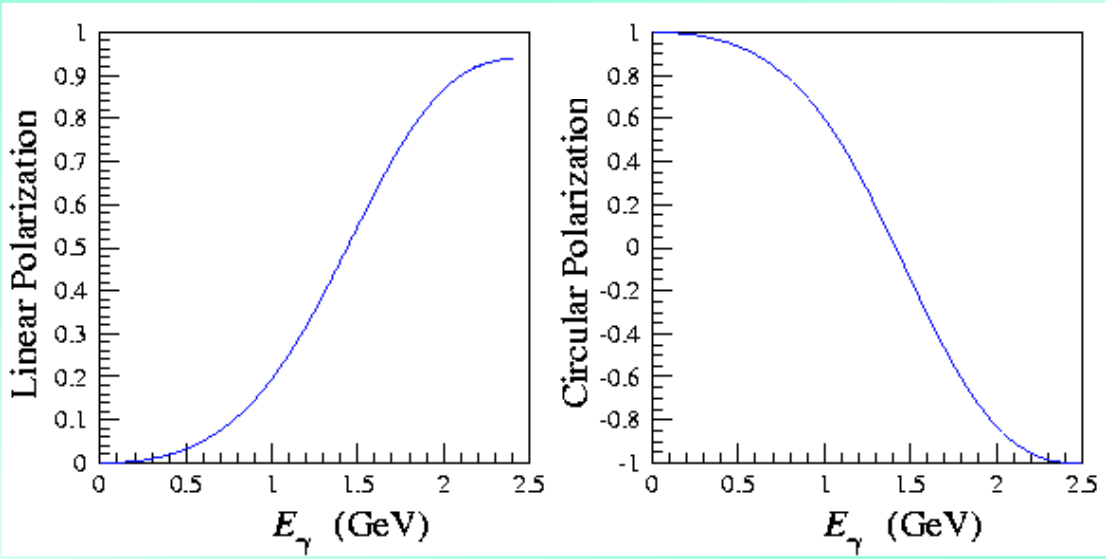
(BCS:Backward Compton Scattering)



- rather flat energy distribution with small spreading

  (Unlike the Bremsstrahlung, where low energy photons are dominated, ~1/E_γ)
- high linear- or circular-polarization
- photon energy can be tagged by recoil electron





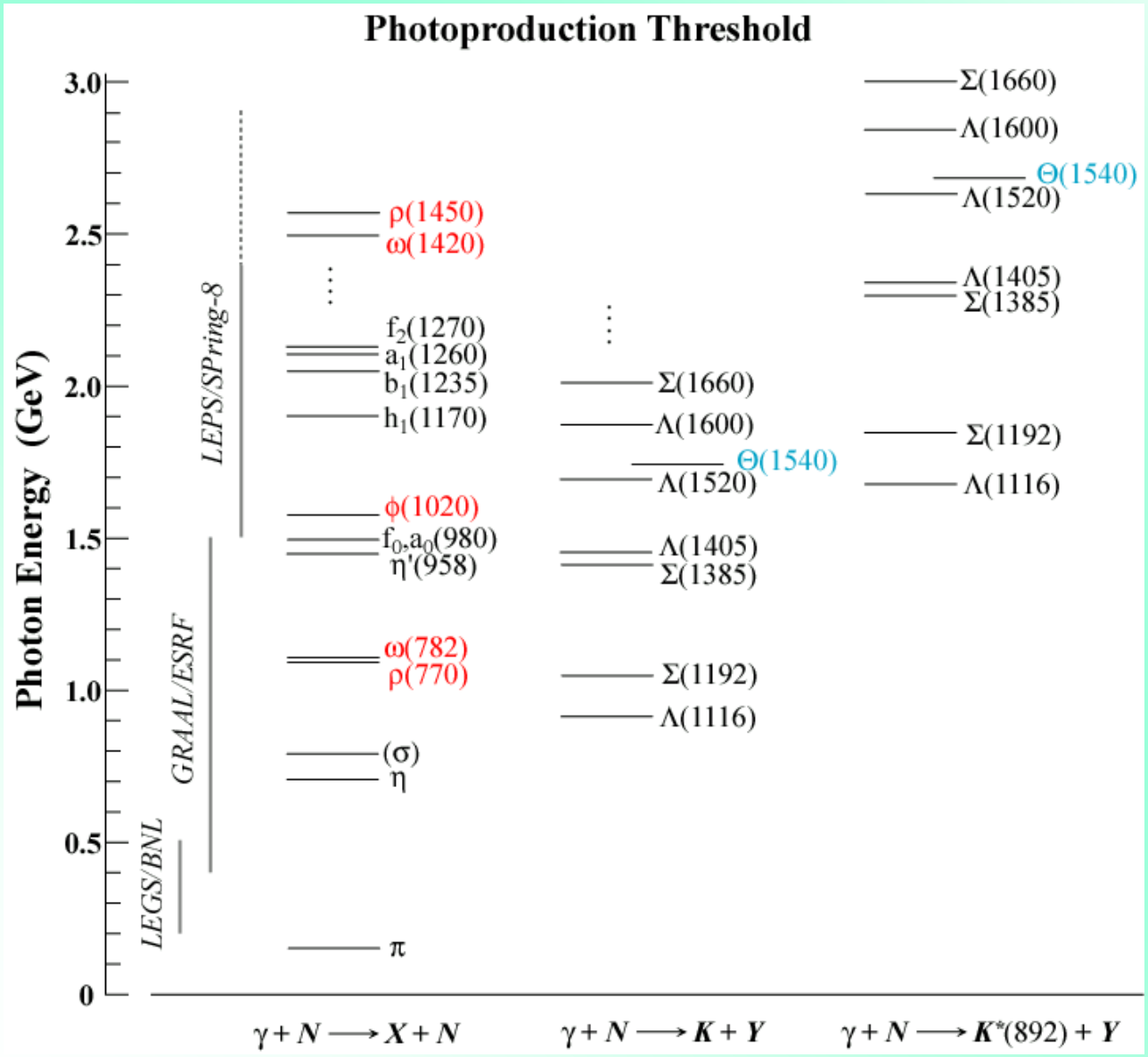
Synchrotron Radiation Rings with laser-backscattering facilities

LEGS@NSLS/BNL
2.8 GeV

GRAAL@ESRF 6 GeV

LEPS@SPring-8 8GeV ~100mA

With LEPS, what can be aimed at ?



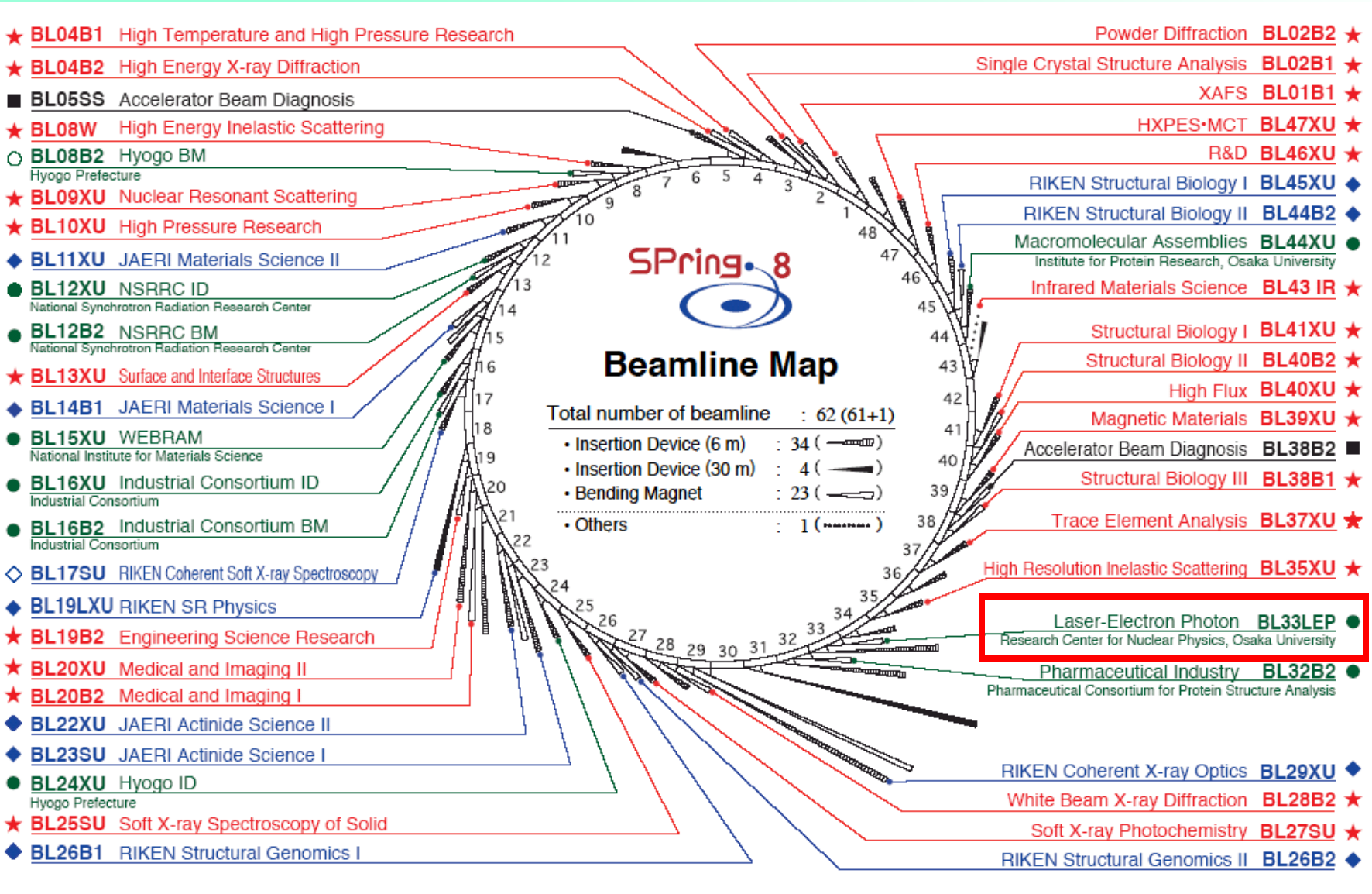
Threshold region of $\phi(s\bar{s})$ meson and hyperon resonances

Key words :

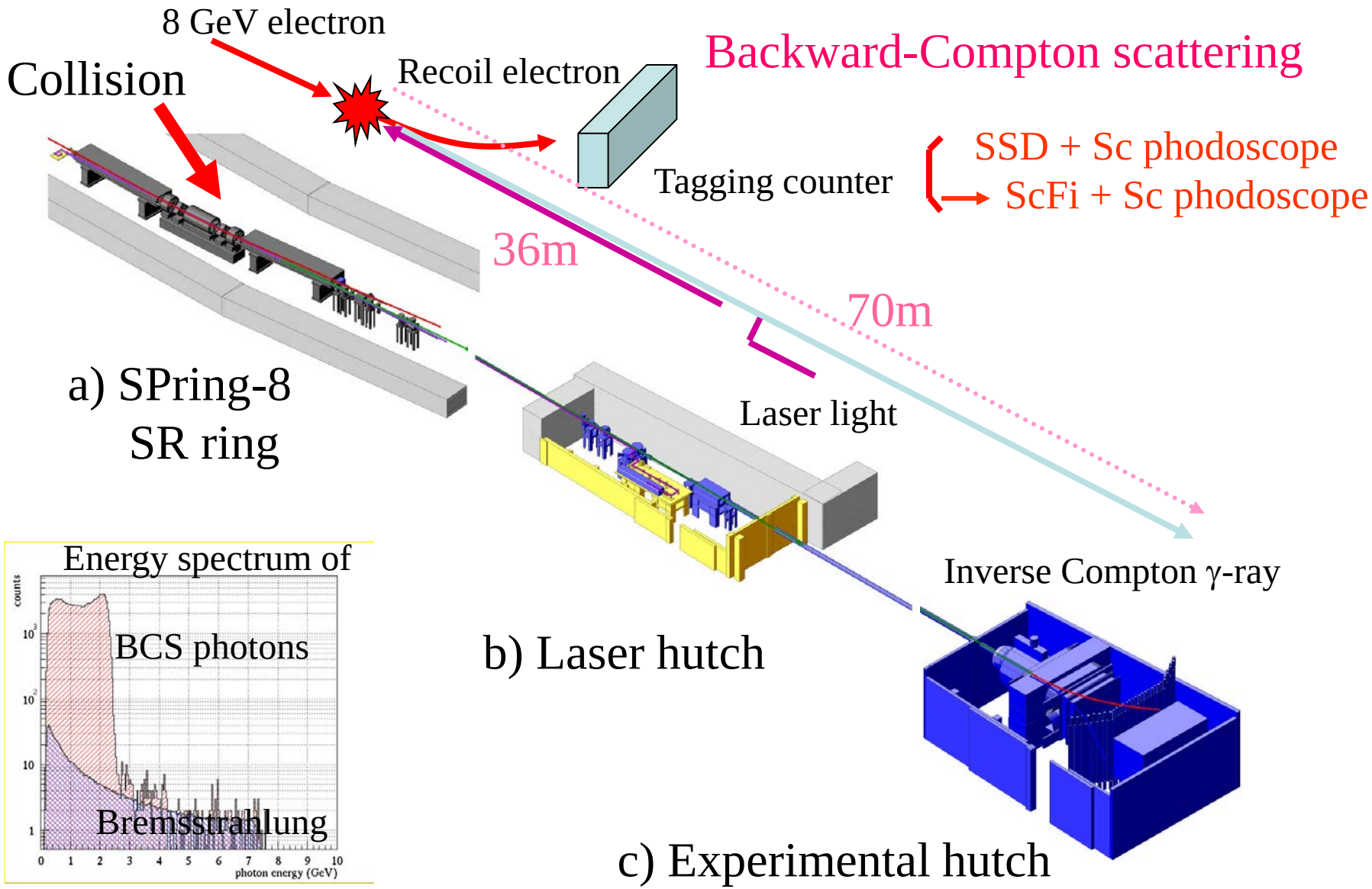
1. **Forward angle measurement including 0 deg.**
2. **Polarization observables**
3. **Strangeness**

LEPS facility

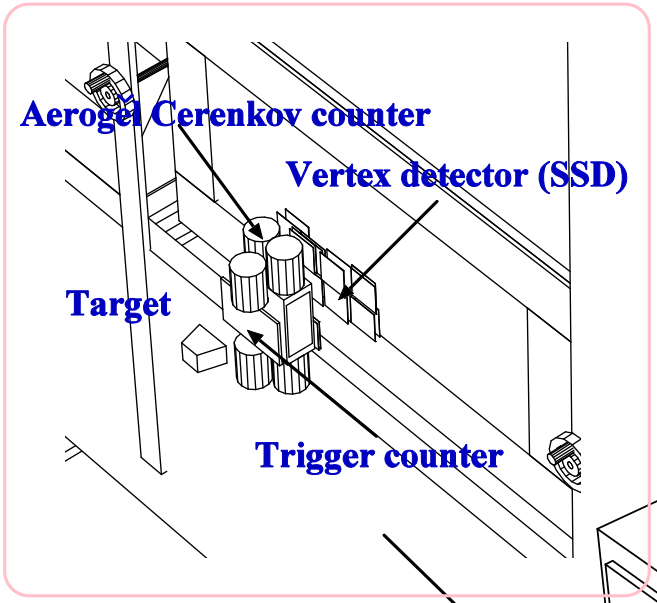
Beam line map of Spring-8

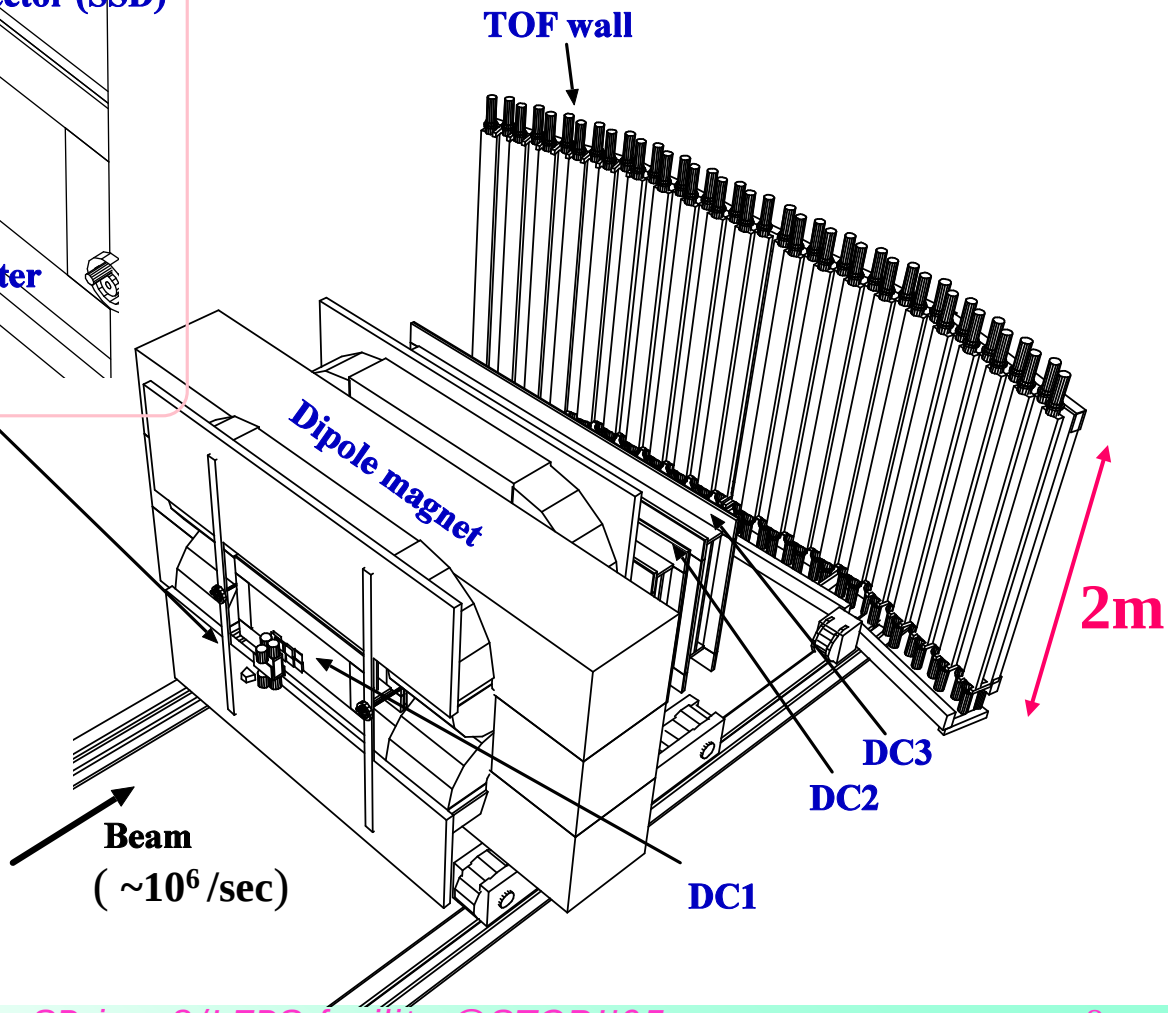


Schematic view of the LEPS facility



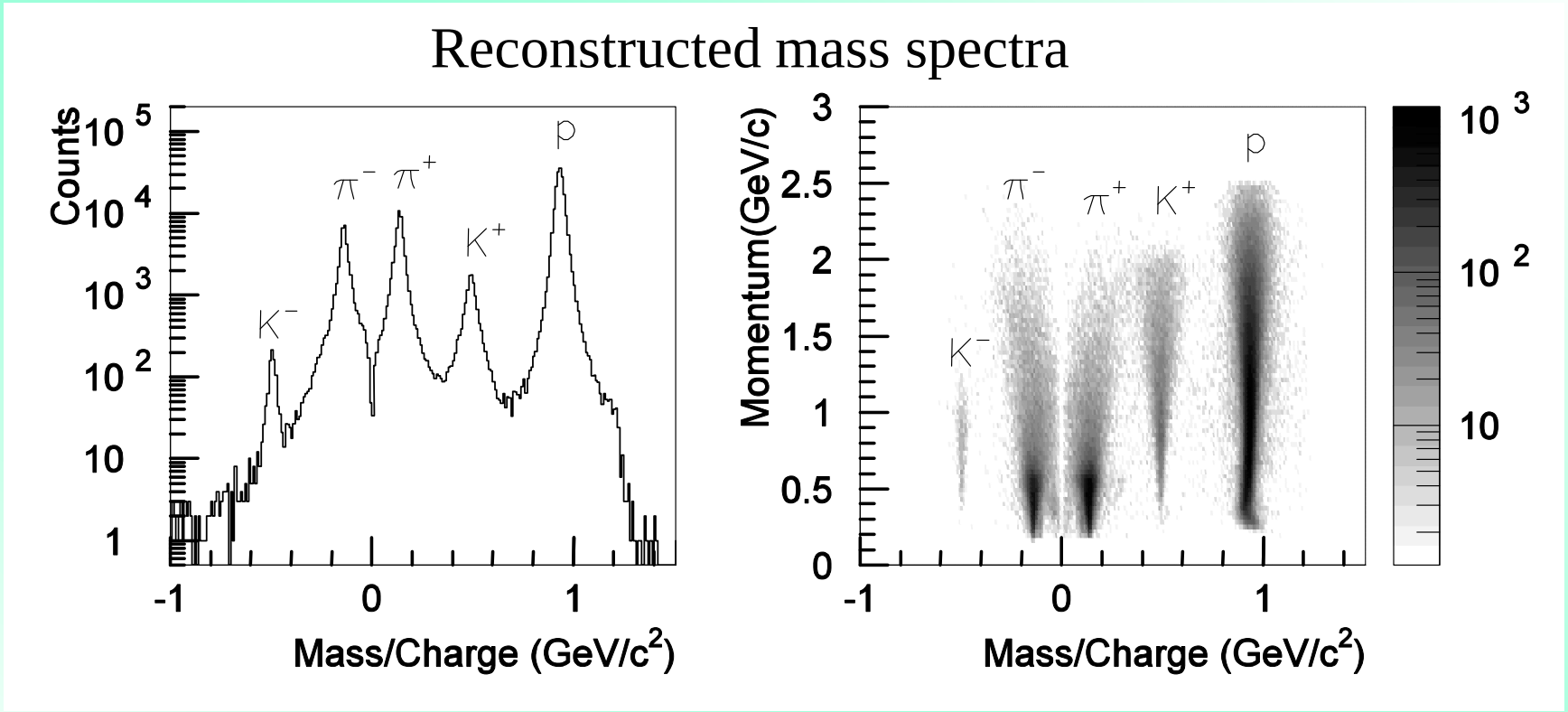
LEPS forward spectrometer





- Target LH_2, LD_2, etc.
- AC index = 1.03
  to reject e^+e^- pairs
- SSD 120μm pitch
- DCs σ ~ 200 μm
- Magnet 135 x 55 cm^2,
  (35° x 15°)
  B = 0.7T

Particle identification



- TOF : RF signal - TOF wall, Δt = 120 ps
- Momentum : SSD, DCs, Tracking

  Δp ~ 6 MeV/c for 1 GeV/c K

Other detectors : 1. EM calorimeter for $\pi^0 \rightarrow 2\gamma$, $\eta \rightarrow 2\gamma$

- **Main detector**

  Lead scintillating fiber

  252 modules

- Covered solid angle

  2.08π (str)

  θ : 30° ~ 100°

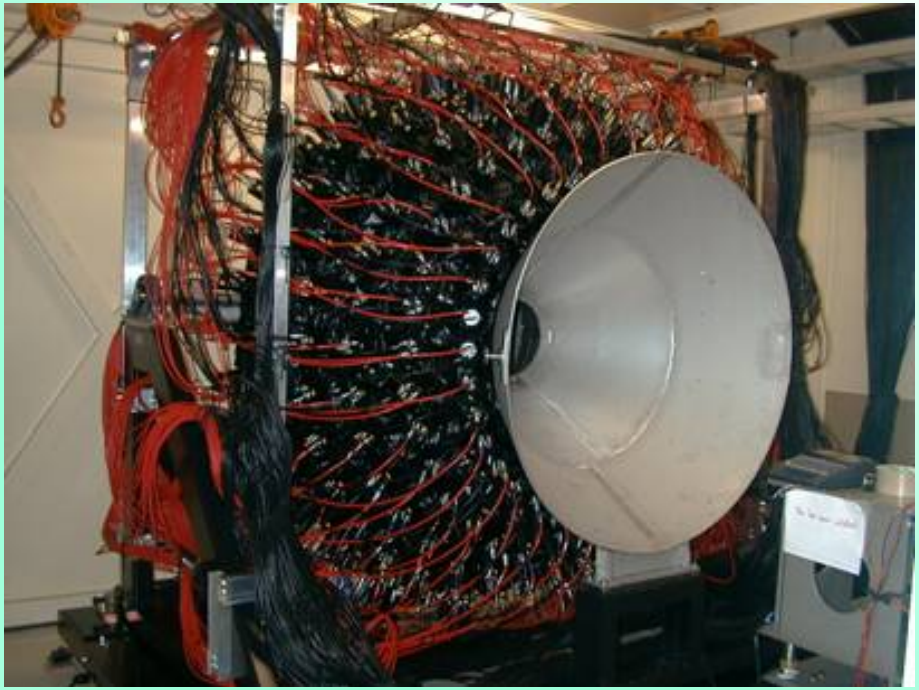
  ϕ : 0° ~ 360°

- Length of each module

  22cm (13.7 X_0)

- Angular interval (segment)

  10 degree

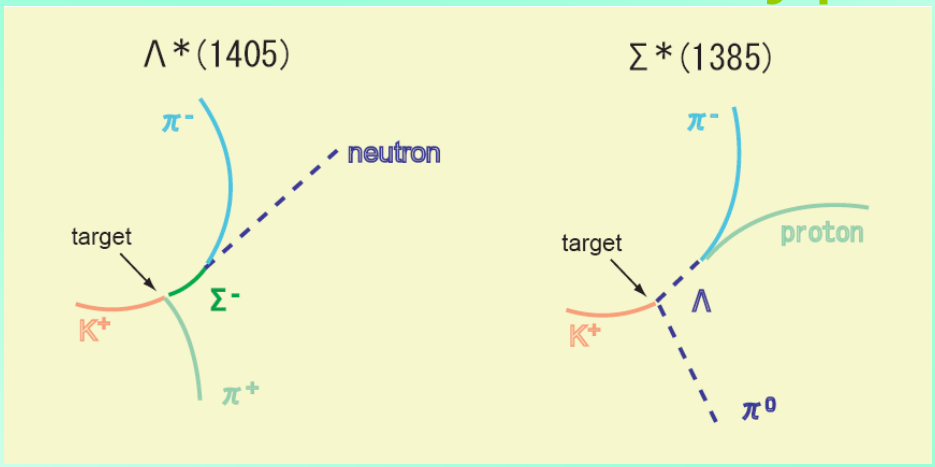


- Energy resolution

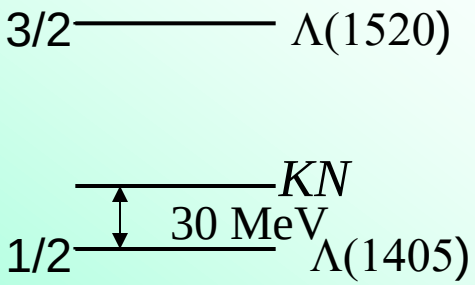
$$\frac{\sigma_E}{E} = \sqrt{\left(\frac{5.2 \pm 0.1\%}{\sqrt{E}}\right)^2 + (4.4 \pm 0.2\%)^2}$$

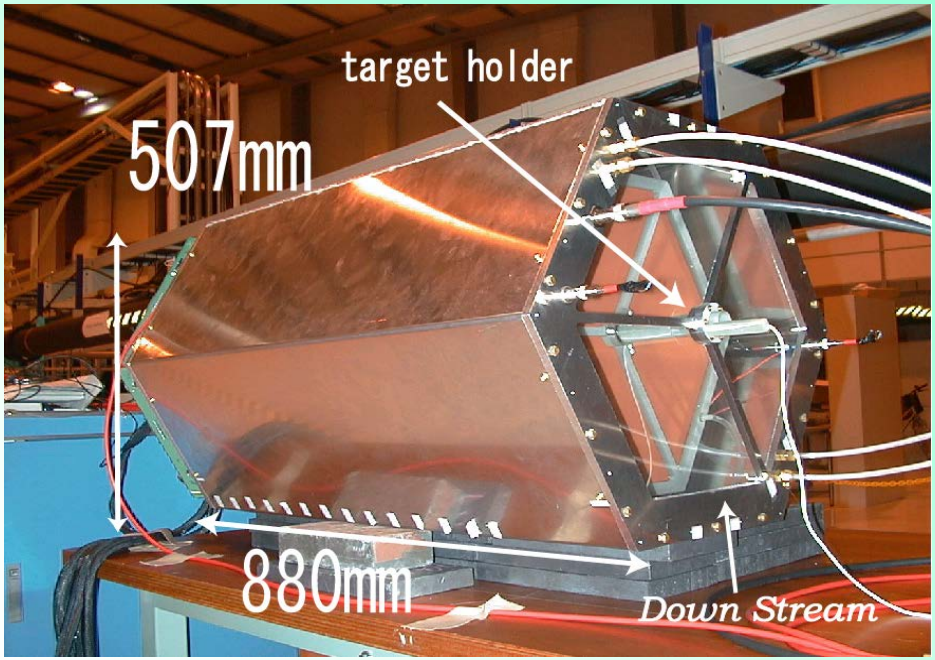
(6.8% for 1 GeV photon)

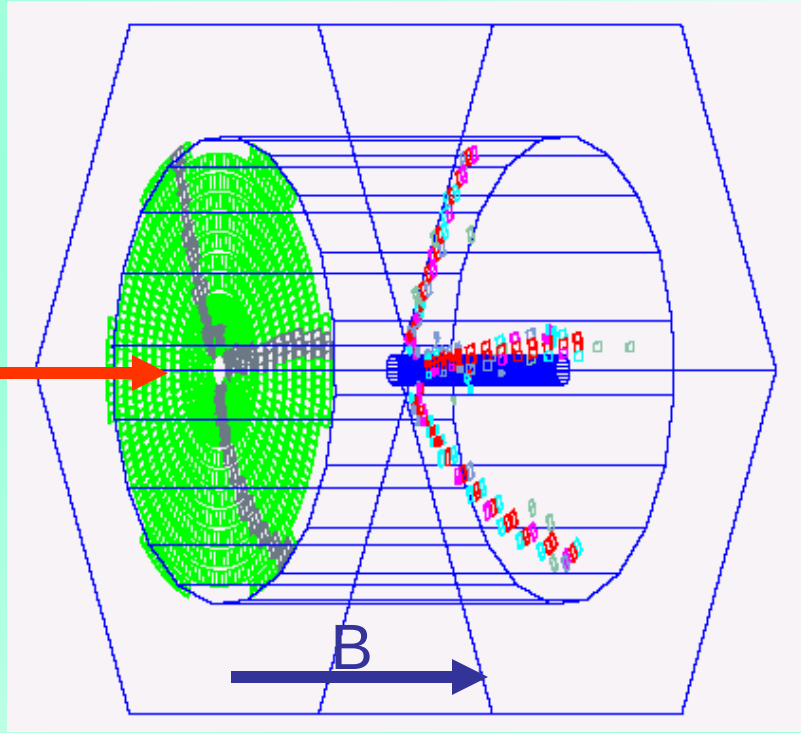
Other detectors : 2. TPC for Hyperon Resonances



Λ(1405) :
3-quark state
or
KN bound state ?





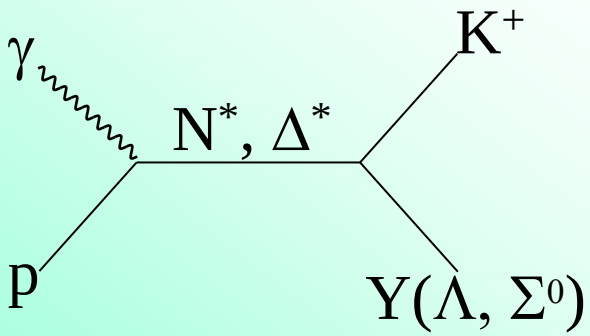


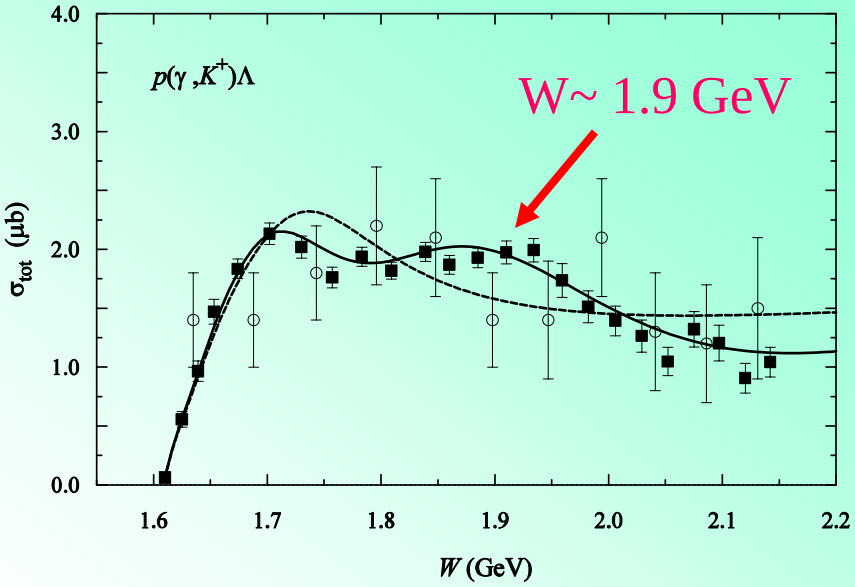
Photon beam asymmetry for the $p(\gamma,K^+)\Lambda$ and $p(\gamma,K^+)\Sigma^0$ reactions

R.G.T. Zegers et al. PRL29,092001

Missing resonances N^* and Δ^*

- Knowledge of N* and D* is essential to understand the internal structure of baryons.
- Many nucleon resonannces predicted by quark models are still missing.
- So far, πN channel → $K\Lambda$ or $K\Sigma$ channel





- **SAPHIR data**

→ **$D_{13}(1895)$ resonance ?**

without D_{13}

with D_{13}

Recent CLAS data show more than one resonance !

Description of *K* photoproduction

tree-level effective-Lagrangian approach

Ambiguities

- Choice of included resonances
- Coupling constant
- Hadronic form factors
- Treatment of background terms

Need more study to fix parameters.

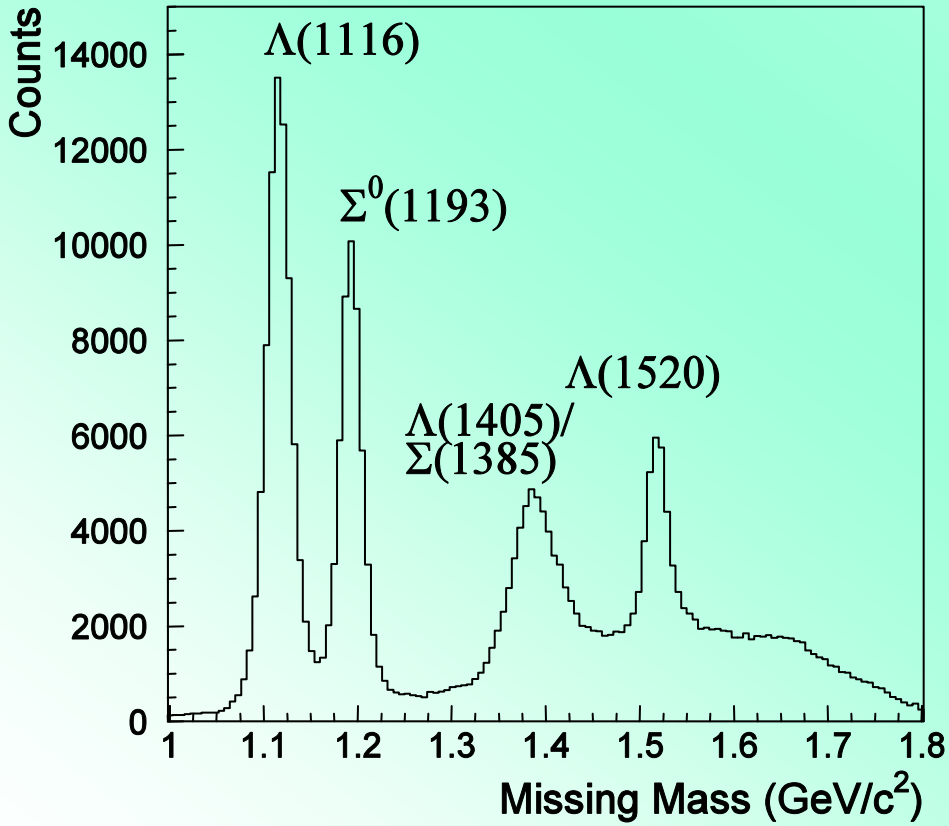
- should be cautious to define conclusions with cross sections only

- Additional observables are useful for further studies.
- There are the data of cross sections and recoil polarizations from SAPHIR and CLAS collaborations.
- Photon beam asymmetry is one of the good candidates.

Missing mass spectrum and photon beam asymmetry Σ

Λ and Σ^0 events

2σ cuts : contamination < 2%

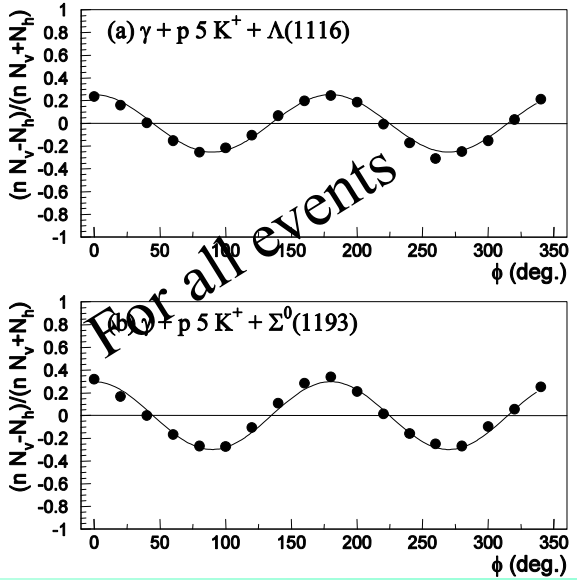


$$\frac{N_v - N_h}{N_v + N_h} = \Sigma\, P_\gamma \cos(2\phi)$$

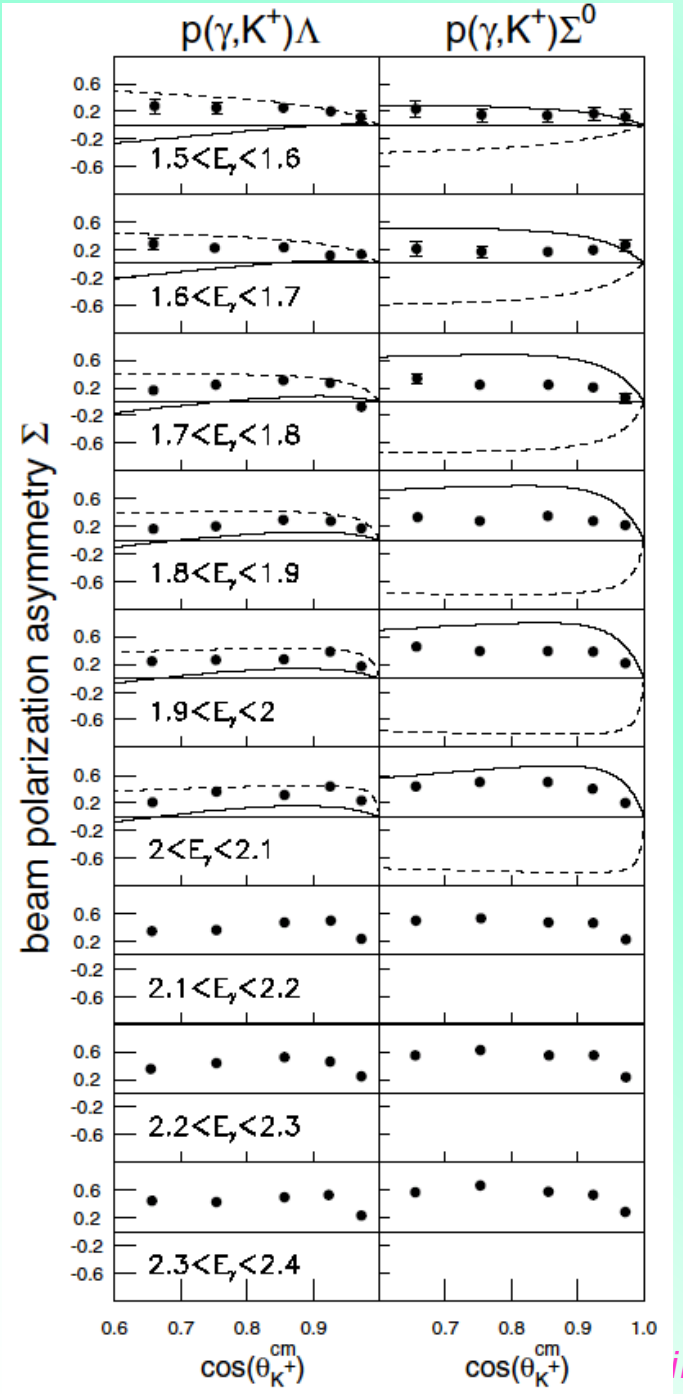
$N_{v(h)}$: normalized yield of K^+ photoproduction for vertical (horizontal) pol.

ϕ : K^+ azimuthal angle

P_γ : Polarization of photon



Experimental Results and comparison with model calculations



Data : positive sign
become large as E_γ

——— Janssen et al.
PRC65, 015201, PRC66,035202

..... Mart & Bennhold
PRC61, 012201
(with D_{13})

Currently no models reproduce our data consistently.

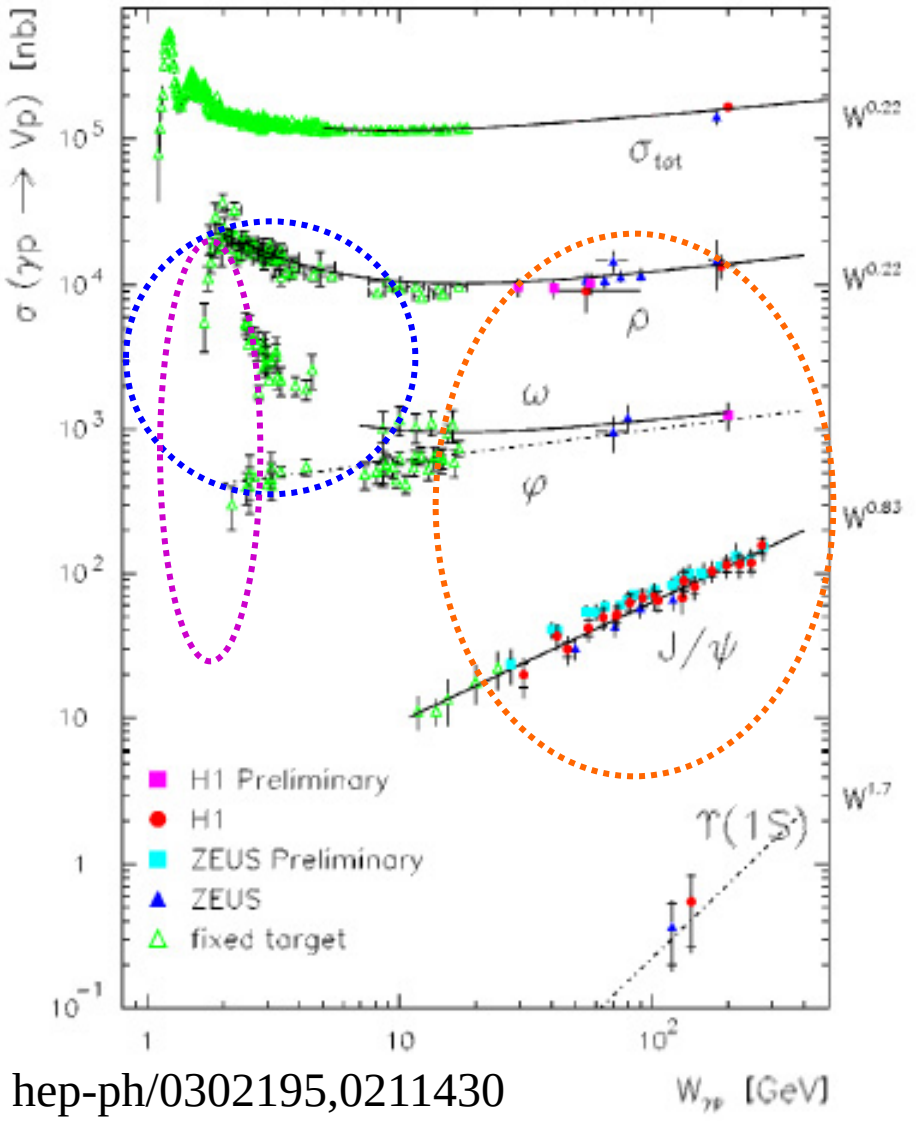
→ Strong conclusions for D_{13} etc., are very premature.

ϕ meson photoproduction on protons near threshold

cf.) ϕ photoproduction from Li, C, Al, and Cu has also been measured

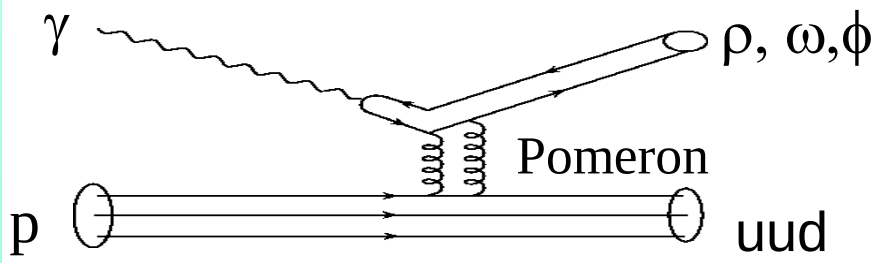
→ study modification of ϕ in the nuclear medium (T. Ishikawa et al. PLB608, 215)

Vector meson photoproduction

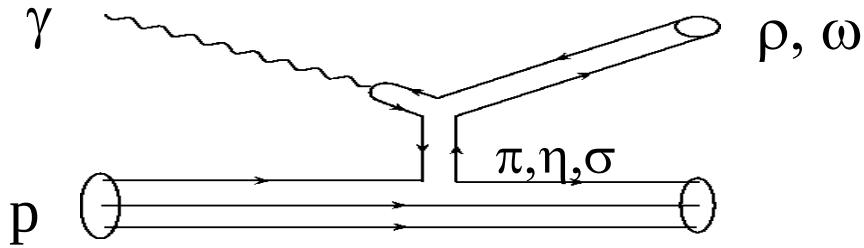


hep-ph/0302195,0211430

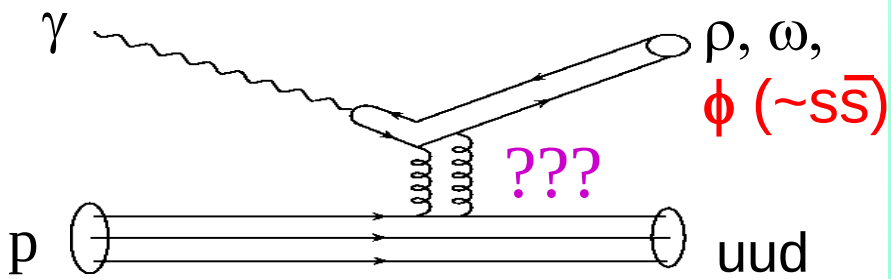
Pomeron exchange



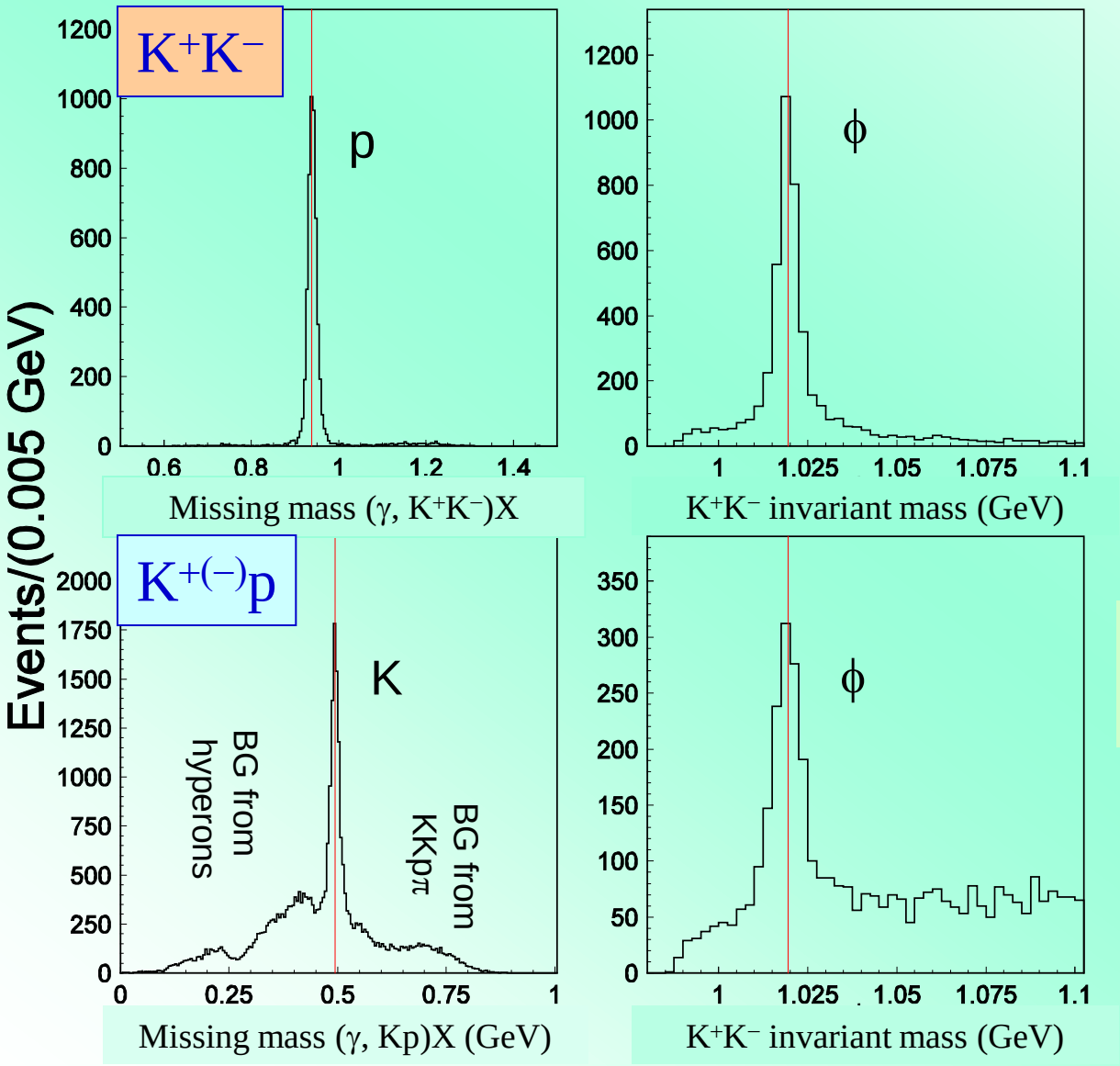
Meson exchange



Glueball exchange ??



K^+K^- invariant mass distributions



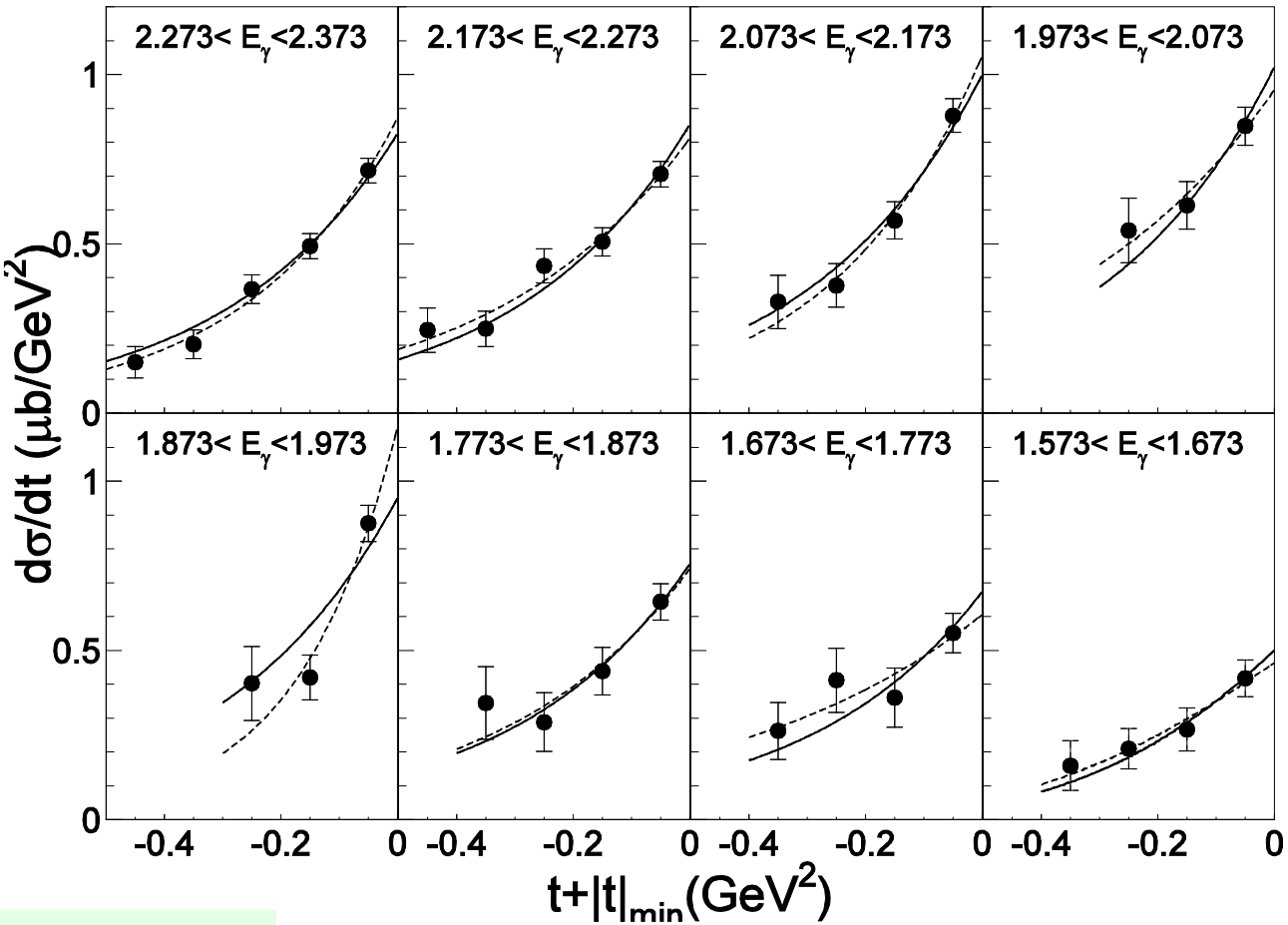
Missing mass resolution
σ=10 MeV
Invariant mass resolution
σ=2-3 MeV

Selection of K^+K^-p final state:
3 σ cut in missing mass

ϕ selection cut:
$|M_{KK}-1.019| < 10$ MeV

BG subtraction by using weighted MC which fits to the real data.

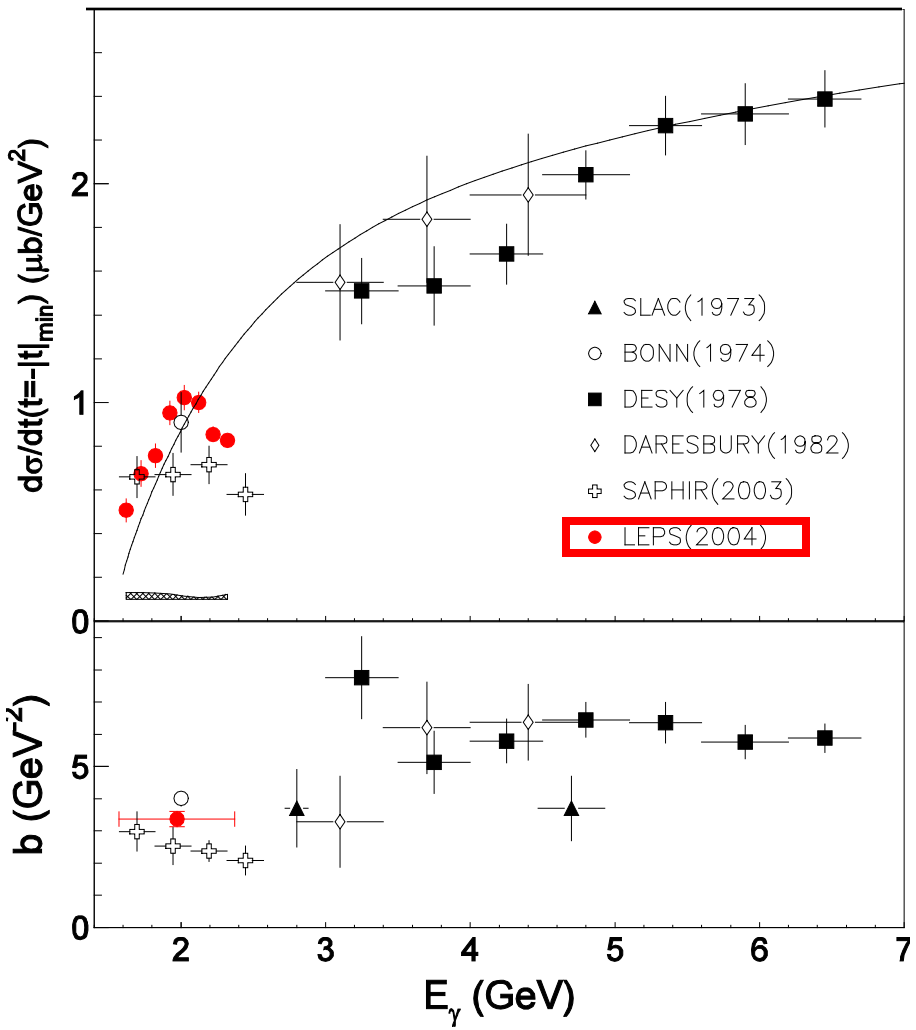
Differential cross sections



$$\frac{d\sigma}{dt} = \left(\frac{d\sigma}{dt}\right)_{t=-|t|_{min}} \exp\left(b\left(t+|t|_{min}\right)\right)$$

Solid : fit with E_γ independent slope
Dashed : fit with E_γ dependent slope

Differential cross section at $t=-|t|_{min}$



$$\frac{d\sigma}{dt} = \left(\frac{d\sigma}{dt}\right)_{t=-|t|_{min}} \exp\left(b\left(t+|t|_{min}\right)\right)$$

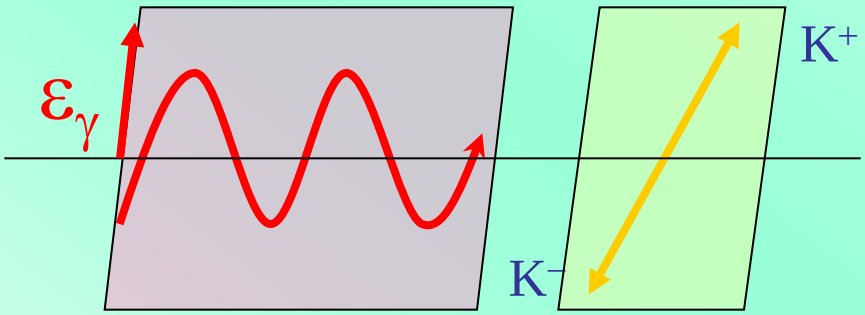
Curve : Pomeron + Pseudo scalar exchange model
(A. Titov et. al, PRC 67, 065205)

A peaking structure is seen in $d\sigma/dt$ near E_γ=2 GeV, which has not been explained by model calculation.

Smaller t-slope near threshold.

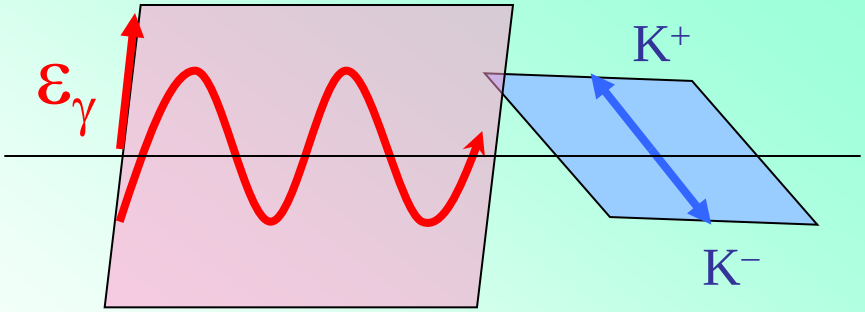
Decay polarization observables with linearly polarized photon

$\phi \rightarrow K^+K^-$



Decay Plane // $\vec{\gamma}$
natural parity exchange $(-1)^J$
(Pomeron, 0^+ glueball,
Scalar mesons)

Photon Polarization

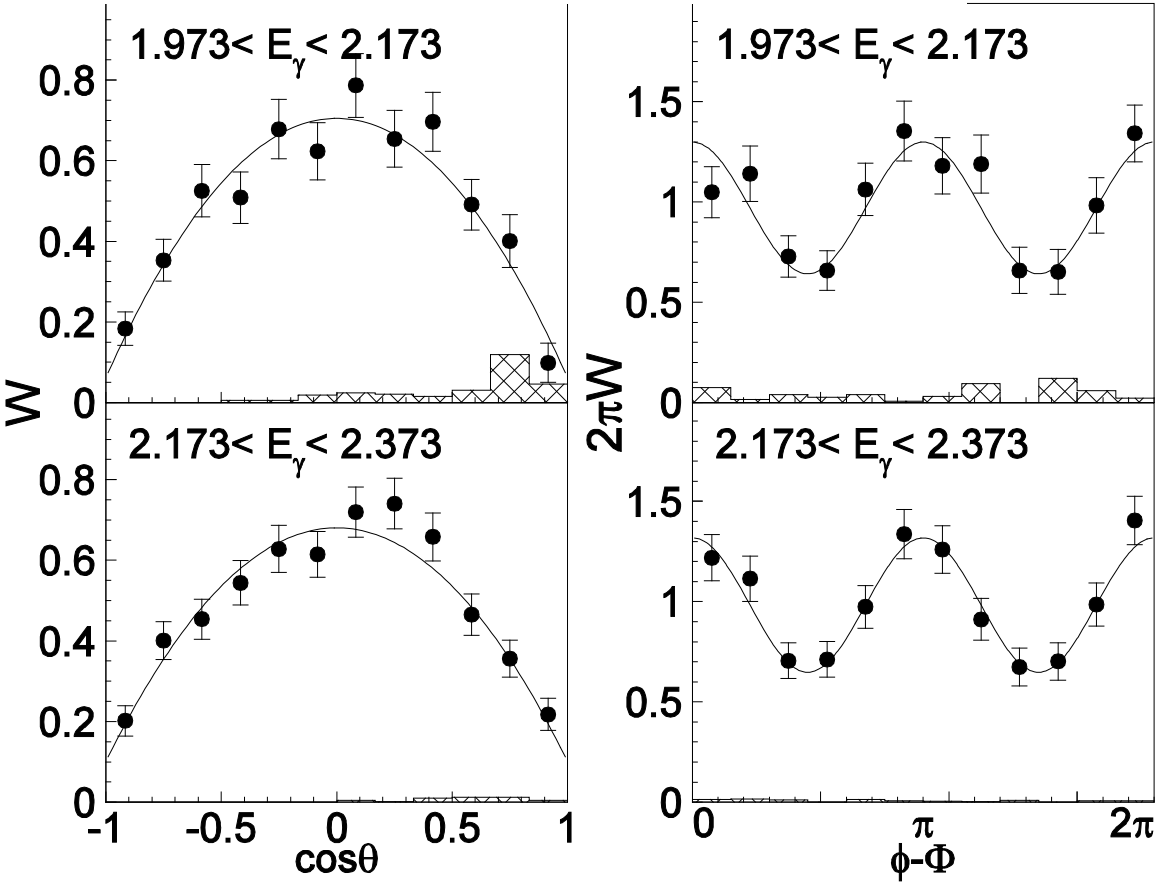


Decay Plane $\perp \vec{\gamma}$
unnatural parity exchange $-(-1)^J$
(Pseudoscalar mesons π,η)

Decay angular distribution of ϕ meson → **Relative contributions from natural, unnatural parity exchanges (U/UN)**

Decay angular distribution

Forward angles; $-0.2 < t+|t|_{min} < 0$ GeV^2



around the peak region of the cross section

above the peak region

~2 GeV peak :
mainly natural parity exchange
Need more data above 2.4 GeV

- W ~ $\sin^2\theta$: Helicity-conserving process is dominant.
- Natural parity exchange is dominant. (no energy dependence)

Search for pentaquark Θ^+

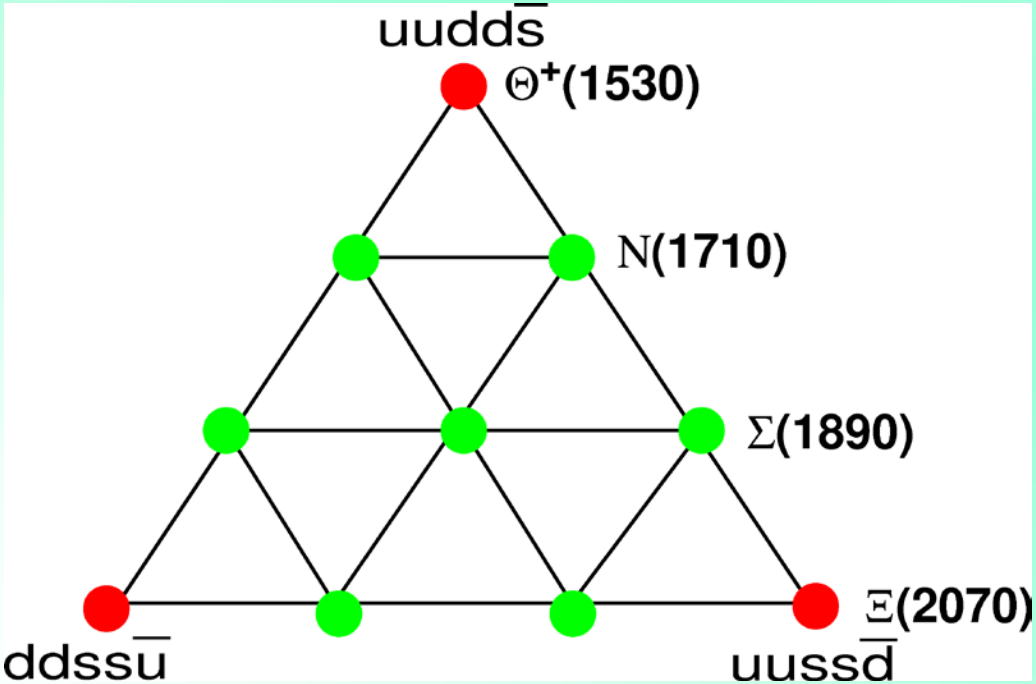
What are pentaquarks ?

- **Minimum quark content : 5 quarks** $qqqq\bar{q}$
- **Quantum numbers of "Exotic" pentaquarks : not 3-quark**

Theoretical Prediction of Θ^+

D. Diakonov, V. Petrov, and M. Polyakov, Z. Phys. A 359 (1997) 305

(Chiral Soliton Model)



$M = [1890\text{-}180*Y]$ MeV

- **Exotic: $S = +1$**
- **Low mass: 1530 MeV**
- **Narrow width: ~ 15 MeV**
- **$J^\pi = 1/2^+$**

First evidence of Θ^+ from LEPS

$\gamma n \rightarrow \Theta^+ K^- \rightarrow K^+ K^- n$

M = 1.54±0.01 GeV
Γ < 25 MeV
Gaussian significance 4.6σ

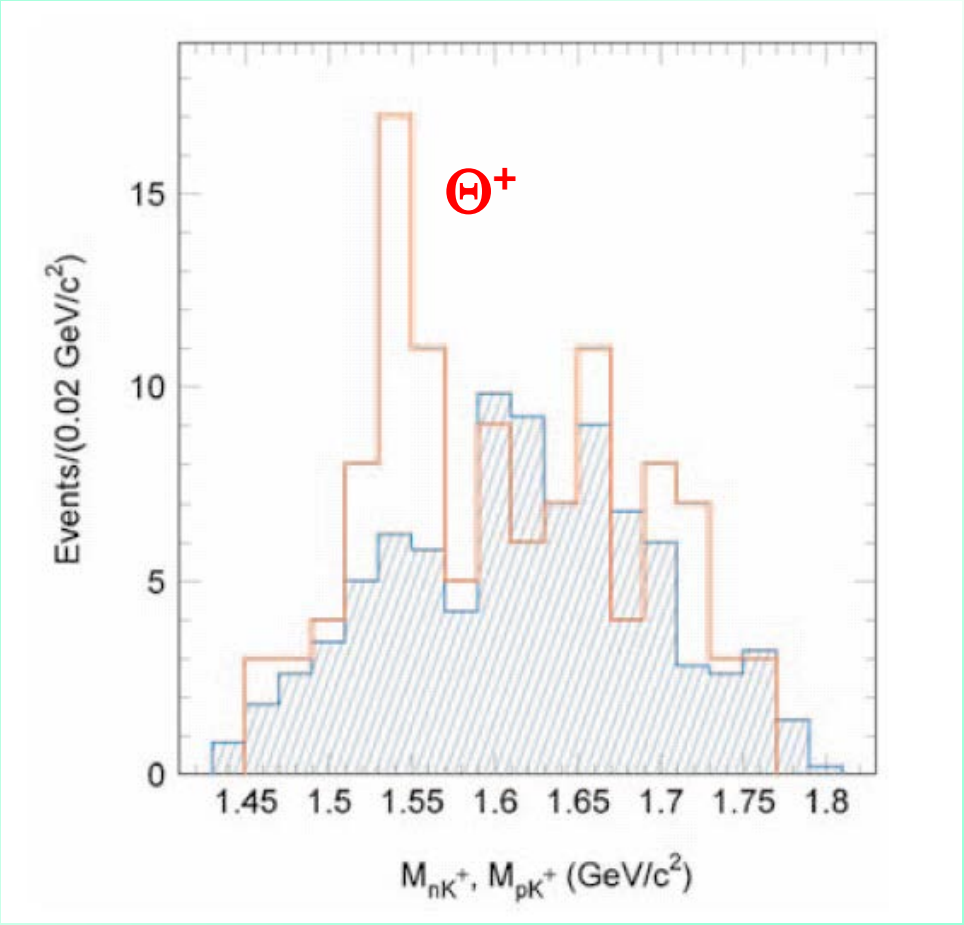
Target: neutron in Carbon nucleus

Background level is estimated by a fit in a mass region above 1.59 GeV.

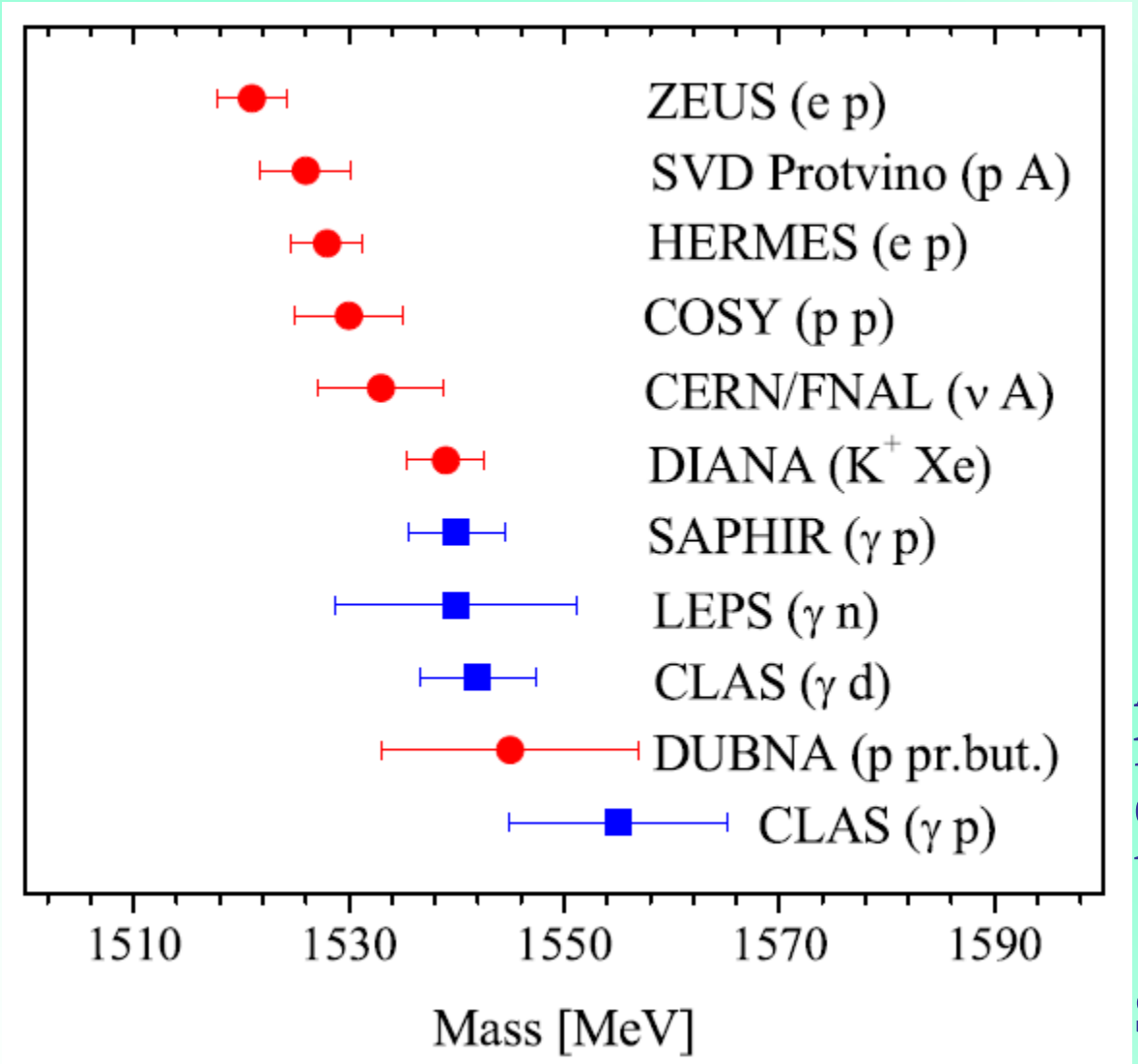
Assumption:

- **Background is from non-resonant K^+K^- production off the neutron/nucleus**
- **… is nearly identical to non-resonant K^+K^- production off the proton**

T. Nakano et al., PRL91, 012002



Positive results



Final state:

$K^+ + n$

$K_s + p$

$(K_s + \overline{p})$

A few % difference from zero, but ~20% difference from the KN threshold.

Statistics is not enough.

Negative results

- **Many negative results have been reported with good statistics from high energy facilities.**

  (HERA-B, HyperCP, CDF, BaBar, LEP, Belle, …)

- **New CLAS data for $\gamma p \rightarrow K_s \Theta^+$ has shown no peak !**

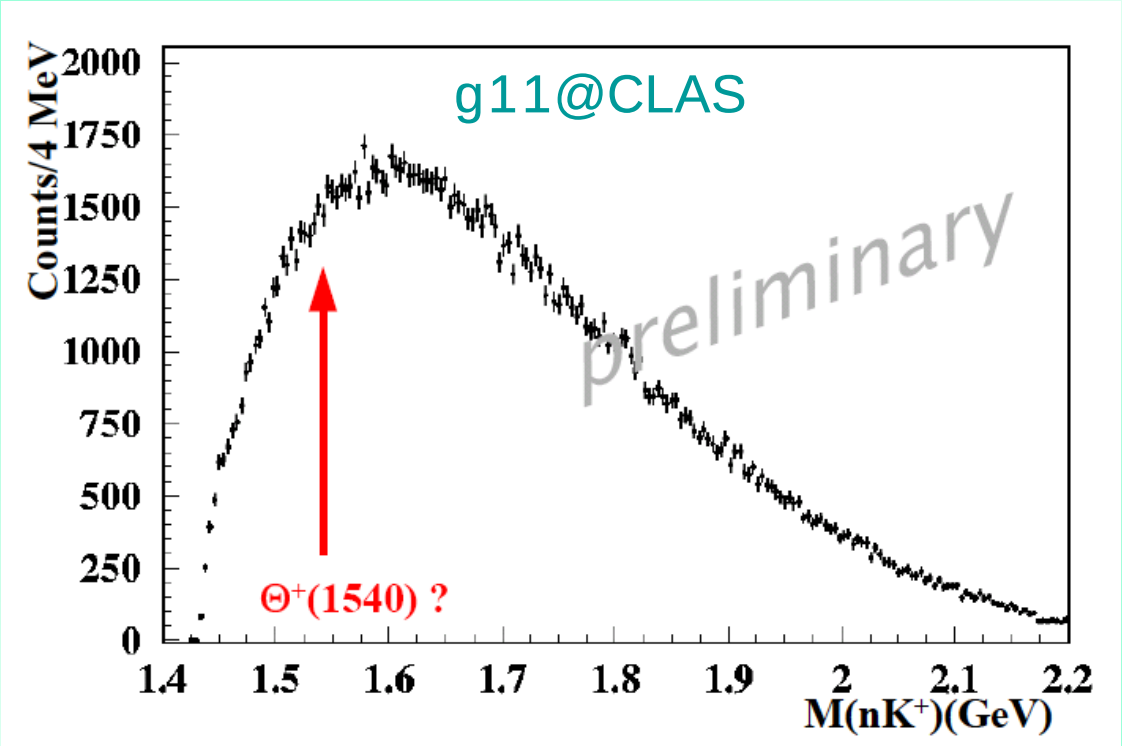
  (April APS meeting)

Cross section

$\sigma(\gamma p \rightarrow \Theta^+ K_s)$

< 1-4 nb

Inconsistent with SAPHIR data

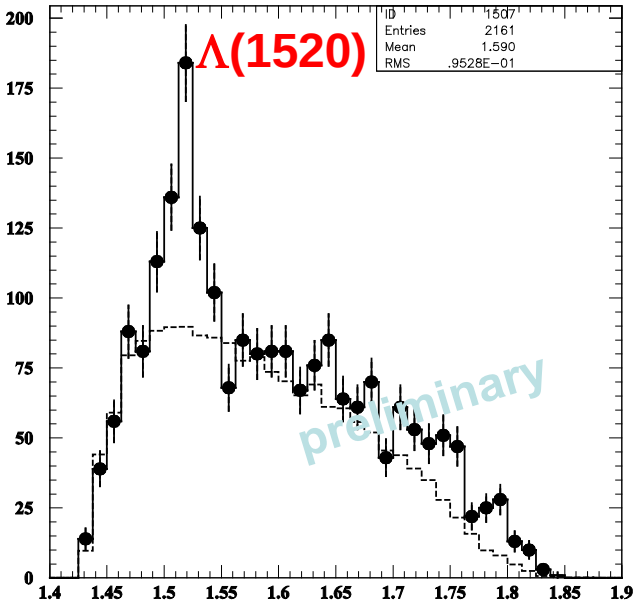


LEPS new search for Θ^+
1. $\gamma n \rightarrow \Theta^+ K^- \rightarrow K^+ K^- n$ in deuteron

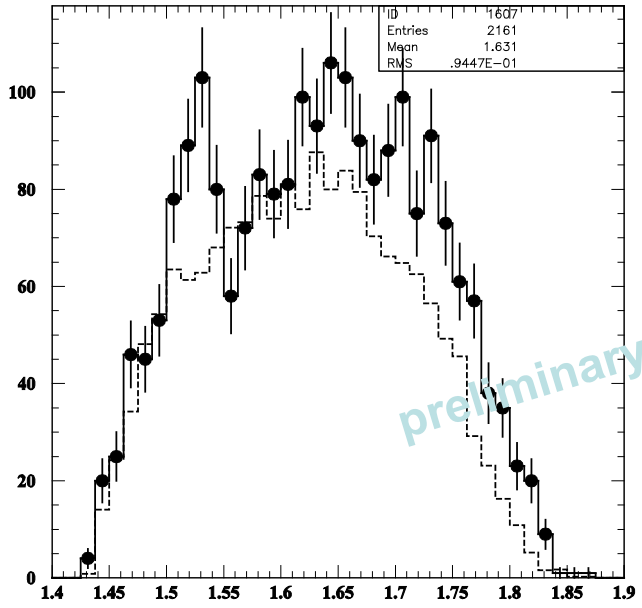
LEPS new LH_2/LD_2 data (Oct. 2002 – Jun, 2003)

- **Fermi motion is corrected to get the missing mass spectra**
- **ϕ exclusion cut is essential**
- **Background is estimated by mixed events**

$\gamma p \rightarrow K^+ K^- p$



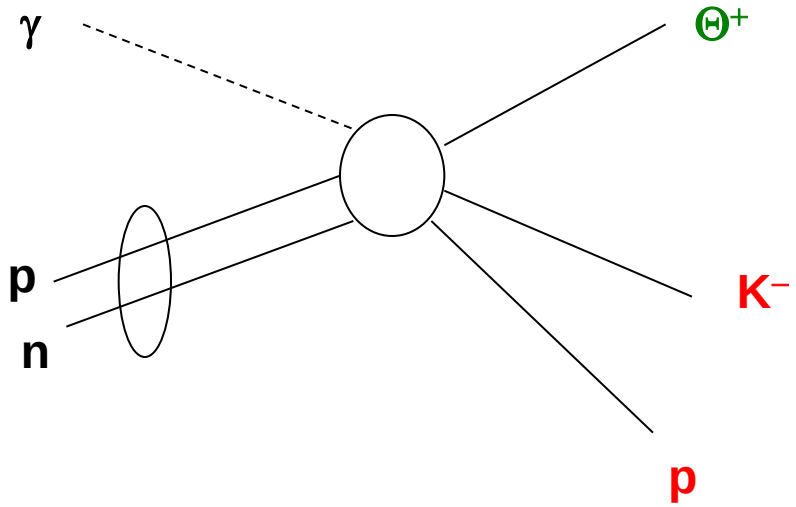
$\gamma n \rightarrow K^+ K^- n$

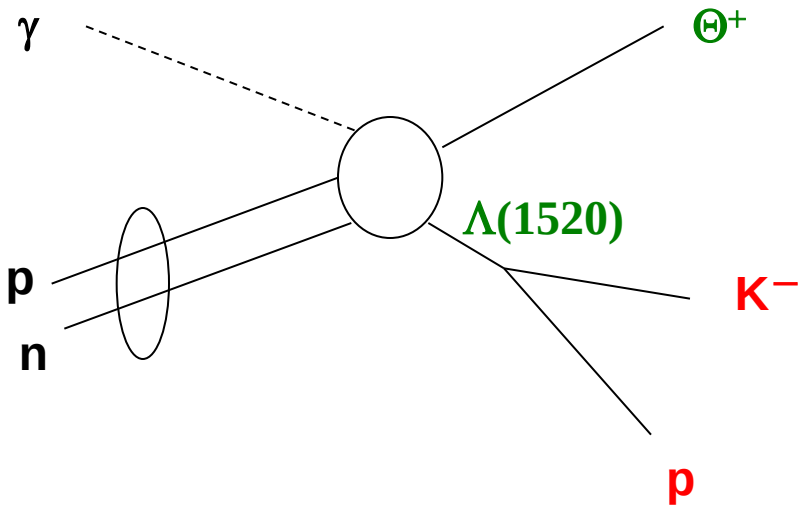


LEPS new search for Θ^+
2. $\gamma d \rightarrow \Lambda(1520)\Theta^+ \rightarrow K^- p\ \Theta^+$

Θ^+ is identified by $K^- p$ missing mass from deuteron.

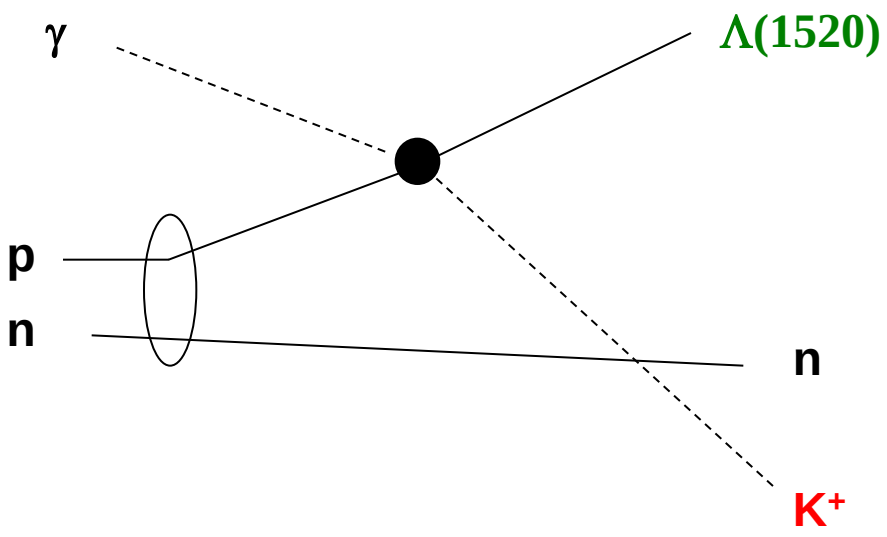
→ No Fermi correction is needed.



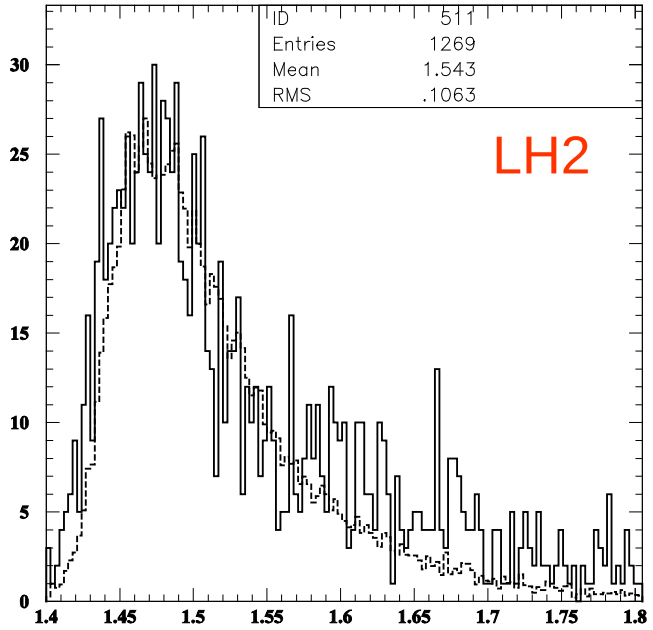


Major background process

- Quasi free Λ(1520) production must be the major background.
- **The effect can be estimated from the LH_2 data**

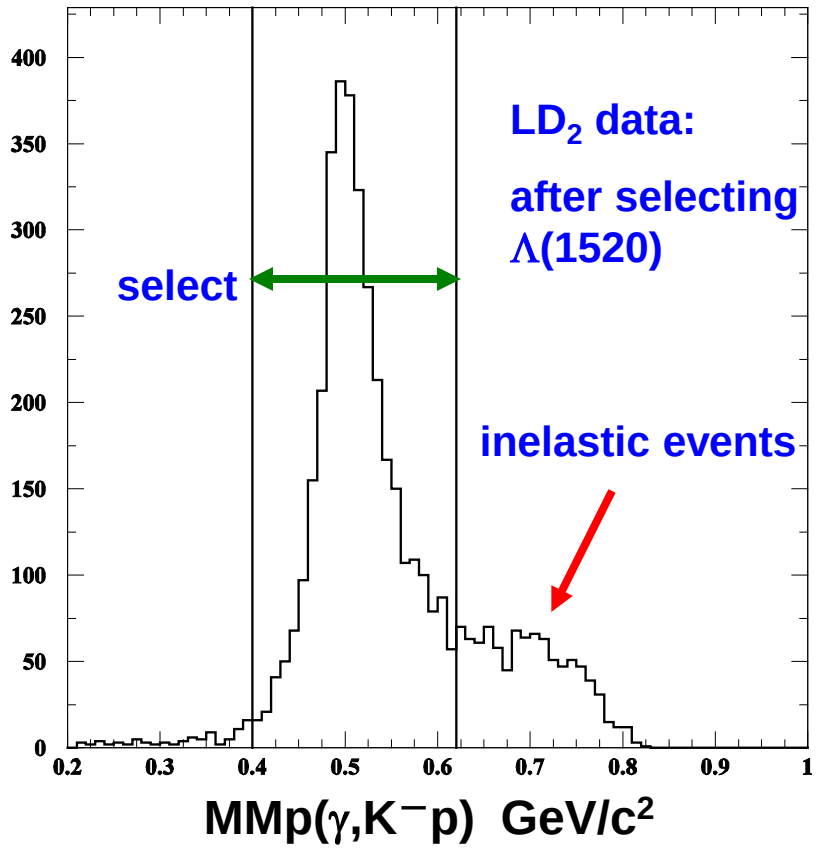


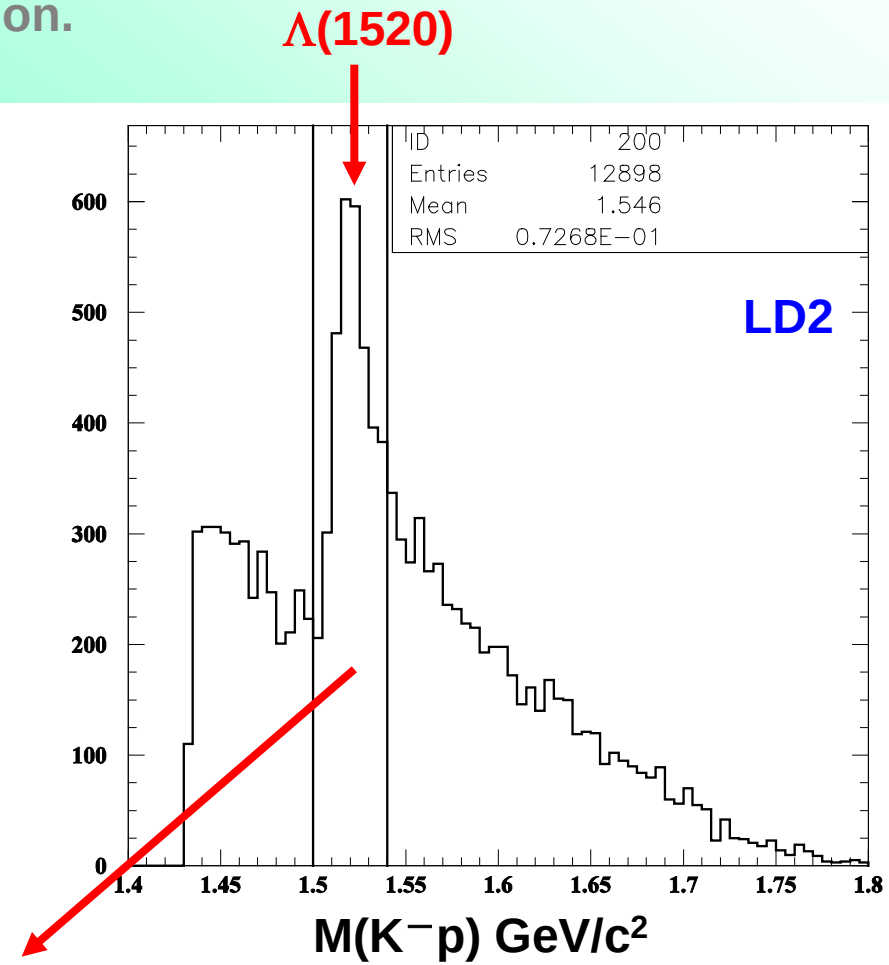
LH2 distribution: comparison with MC



Event selection

K mass is smeared by Fermi motion.
(assumed proton at rest)

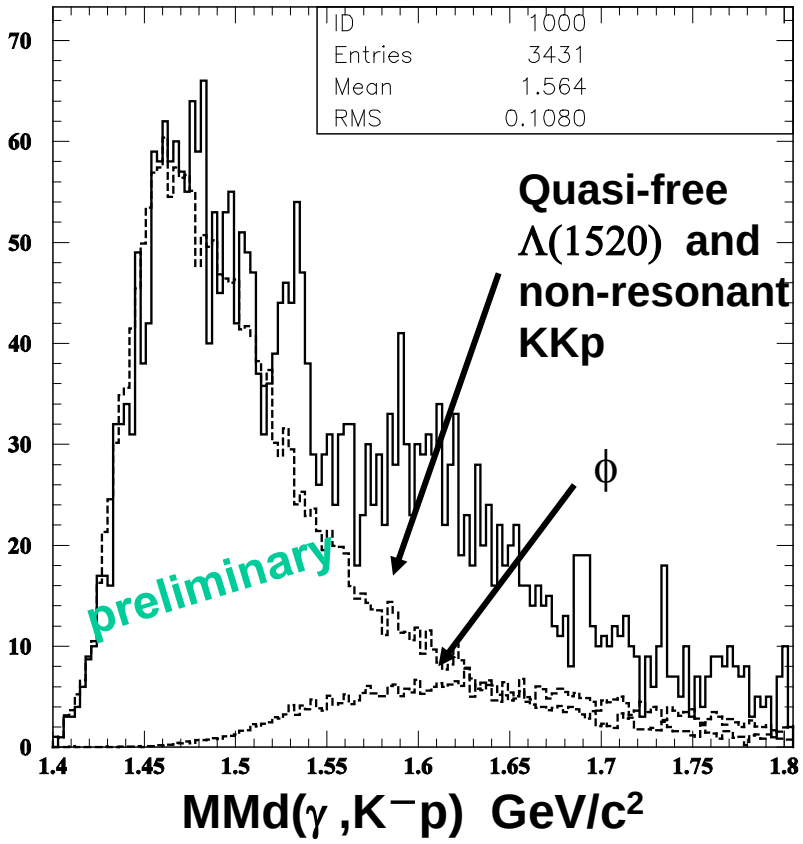


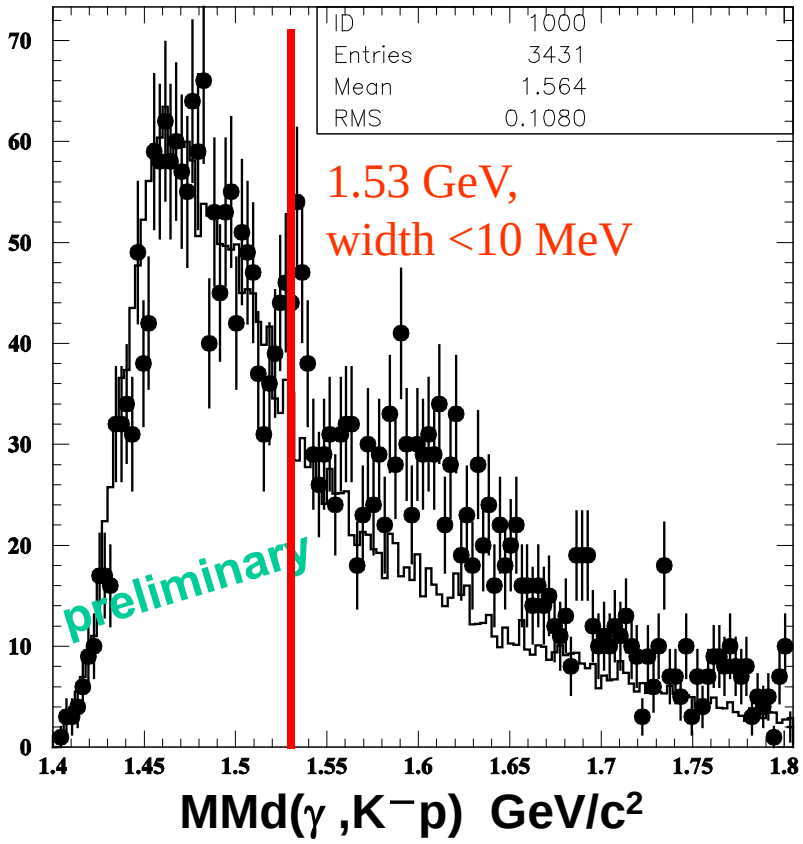


Select Λ(1520) in 1.50–1.54 GeV/c^2

⇒ calculate K$^-$ p missing mass

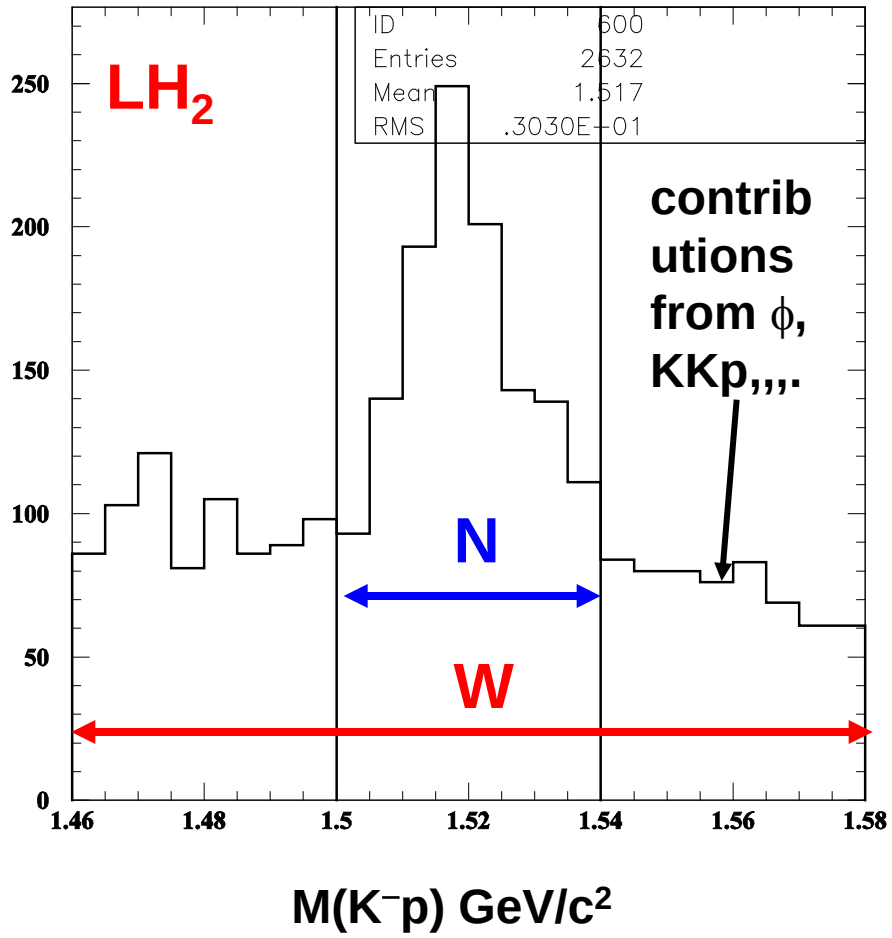
K^-p missing mass for $\Lambda(1520)$ production from deuteron





Extracting Λ(1520) contribution

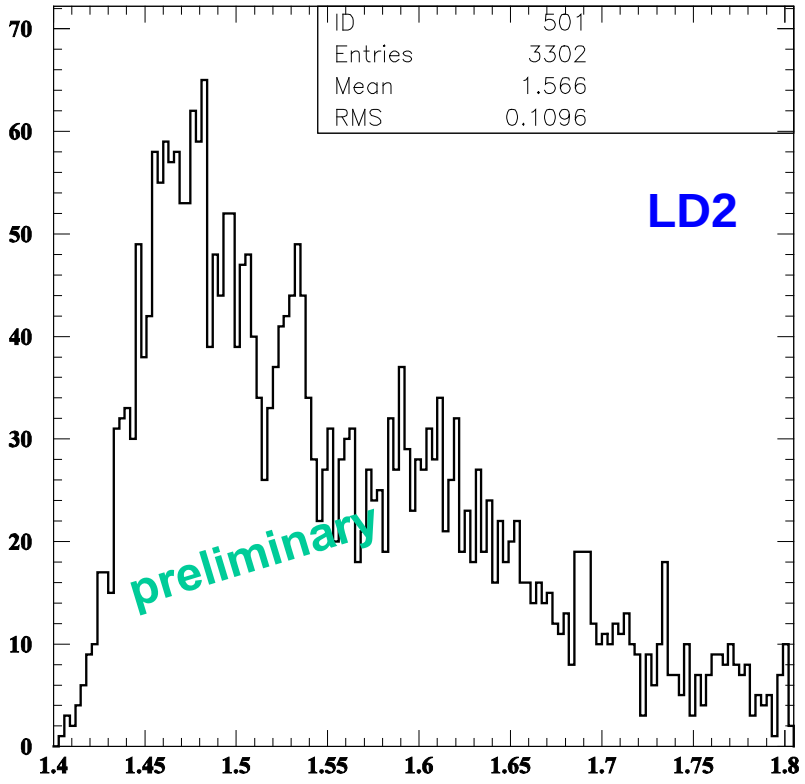
$$\Lambda(1520) = 1.5 \times N - 0.5 \times W$$

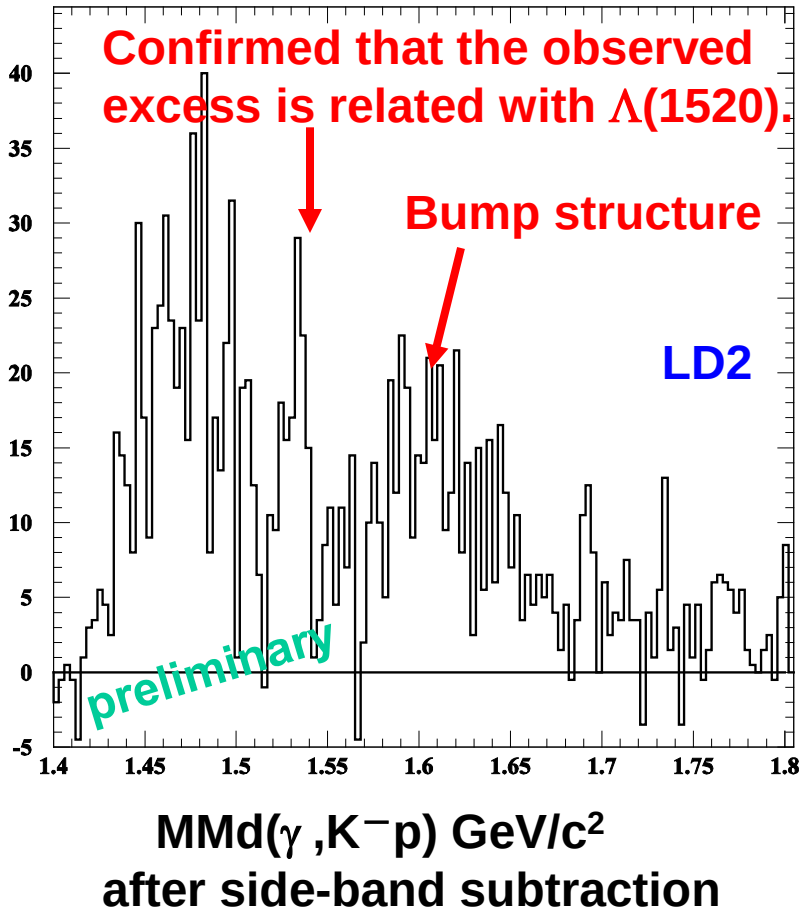


γ p → φ p reaction and non-resonant KKp production can contribute in the signal region. But they do not make a peak in K^-p invariant mass.

Λ(1520) contribution can extracted by sideband subtraction method.

Side-band subtraction in K^-p missing mass





Summary

- LEPS@Spring-8 has been in operation since 2000 for the study of the nuclear and particle physics.
- From the first LH_2 run with the forward spectrometer
  - photon beam asymmetry Σ of K^+ photoproduction
    → polarization observables are strong tools to pin down the missing baryon resonances.
  - ϕ photoproduction near the threshold
    → found peaking structure around $E\gamma$=2 GeV, new mechanism ? → more study (LD_2, $E\gamma$ upgrade)
  - Θ^+ was first discovered in $n(\gamma,K^-)$ mode for n in the carbon of the trigger counter
- New LH_2/LD_2 exp. Re-observed Θ^+ peak in two ways $n(\gamma,K^-)$ mode (n in d), and $d(\gamma,\Lambda(1520))$ mode

Present status and prospect

- ϕ photoproduction from nuclear target (Li,C,Al,Cu)

  data taking completed in 2001, already published

- $p(\gamma,K_s)$ experiment with gas cherenkov counter

  data taking completed in 2002

- Experiment using the EM calorimeter with nuclear target (CH_2,C,etc)

  data taking completed in 2003

- Hyperon resonance study with TPC and spectrometer for nuclear target (CH_2,C,Cu)

  data taking completed in 2004

- Energy upgraded : 2.4 GeV → 2.9 GeV

  now going on for the nuclear target

- LH_2/LD_2 + TPC(new) + 2.9 GeV γ

  will start after this summer

LEPS collaboration

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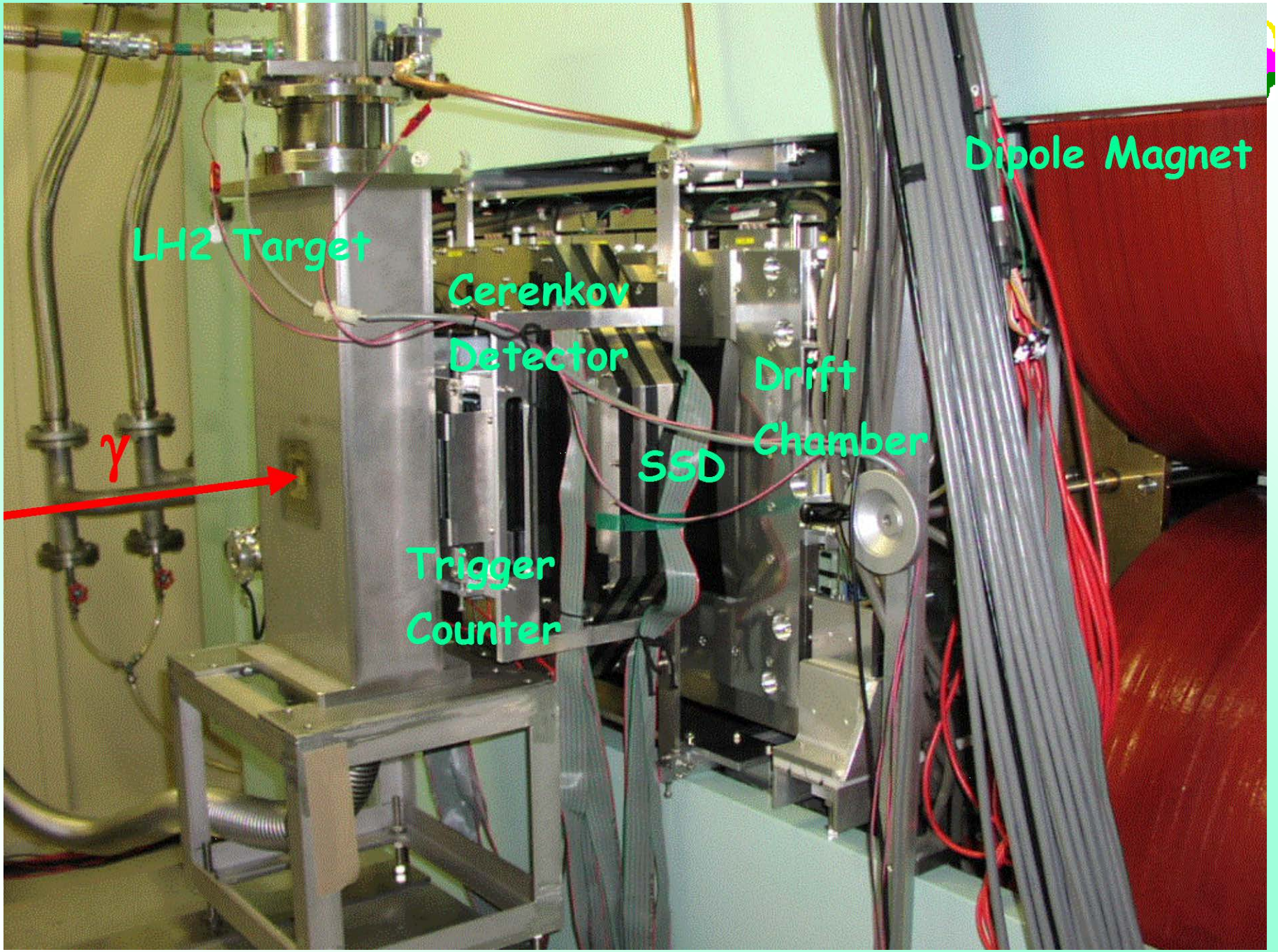
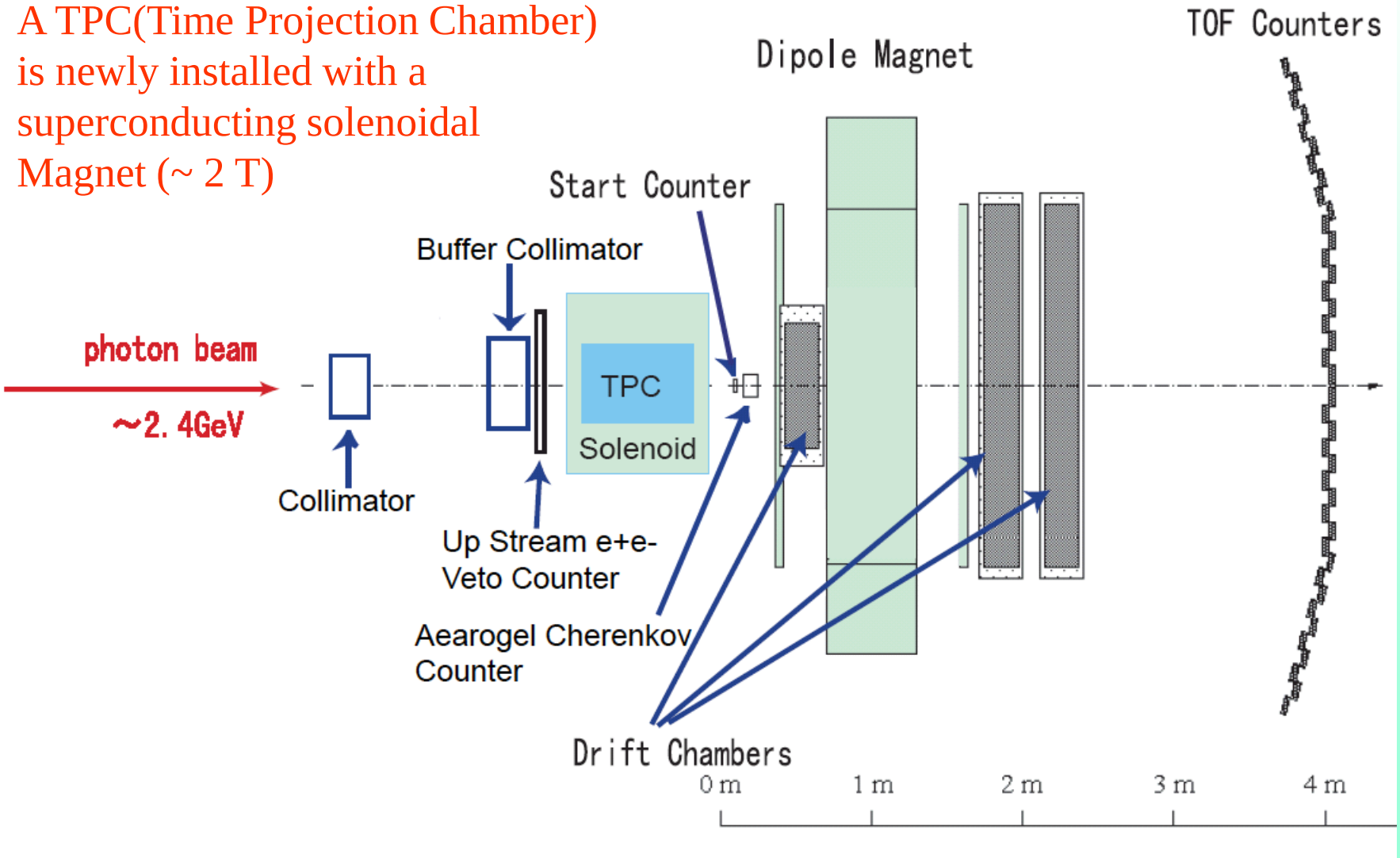
Backup slides


Dipole Magnet
LH2 Target
Cerenkov
Detector
Drift
Chamber
γ
SSD
Trigger
Counter

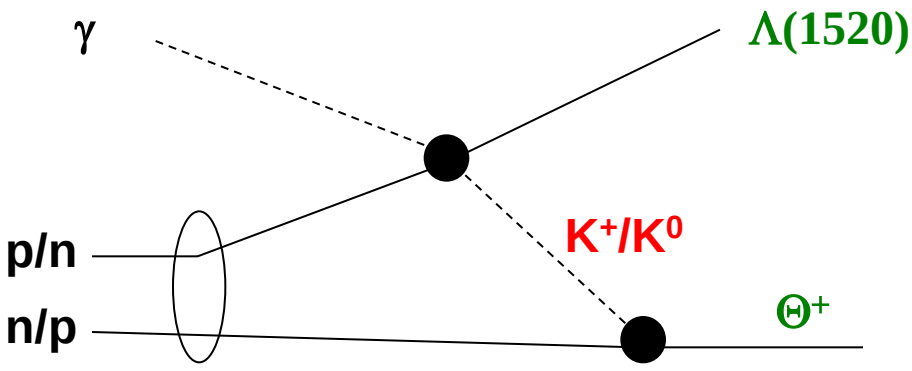
Recent experimental setup with TPC

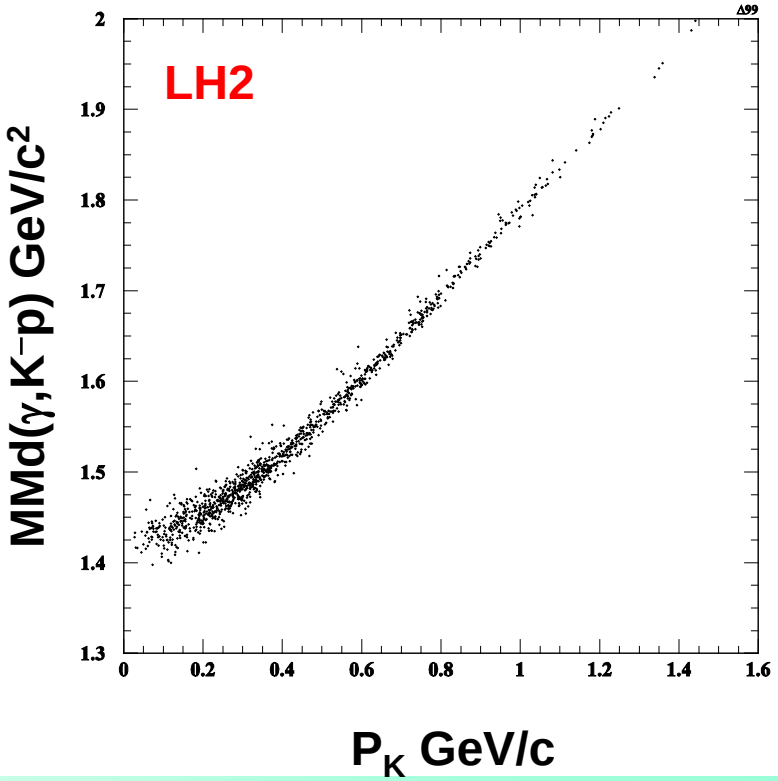
A TPC(Time Projection Chamber) is newly installed with a superconducting solenoidal Magnet (~ 2 T)



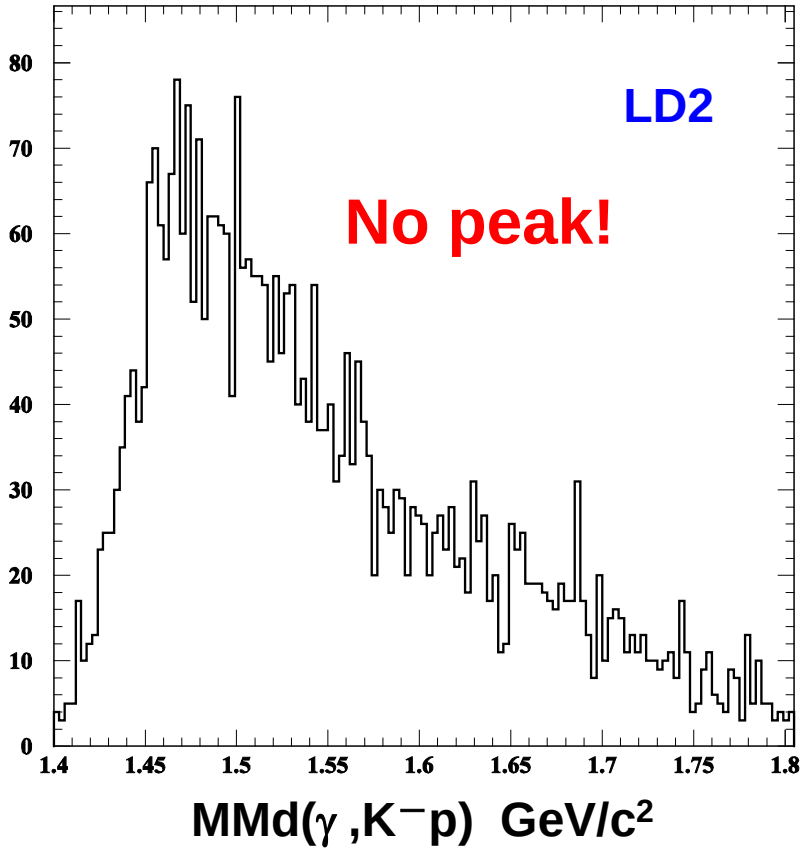
A possible reaction mechanism

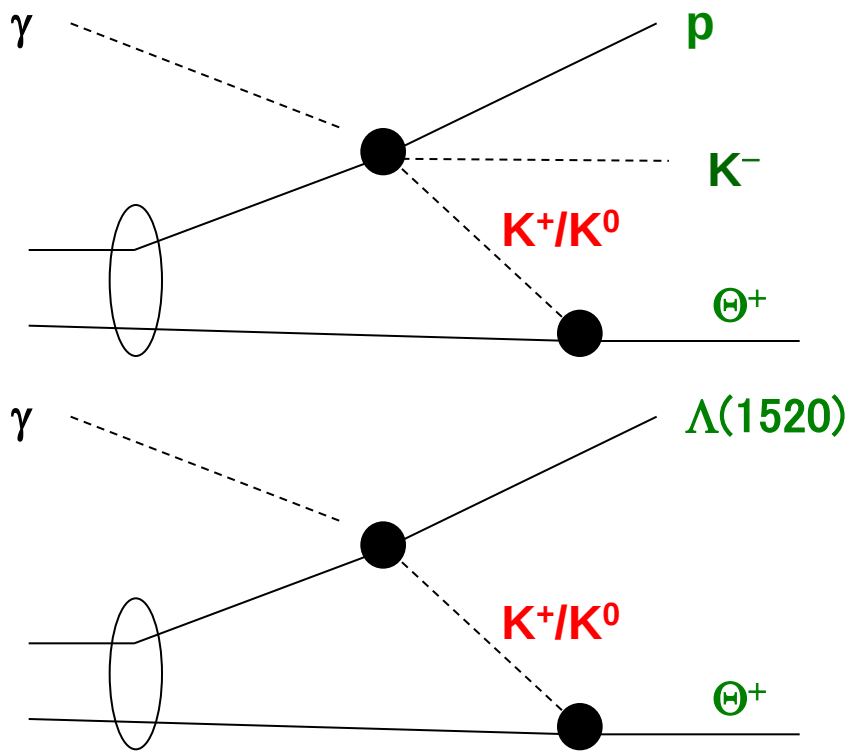
- Θ^+ can be produced by re-scattering of K^+.
- K momentum spectrum is soft for forward going $\Lambda(1520)$.





K^-p missing mass in sideband regions





A. Titov estimated it is small. →

Θ^+ formation cross-section by simple kaon re-scattering should be small.