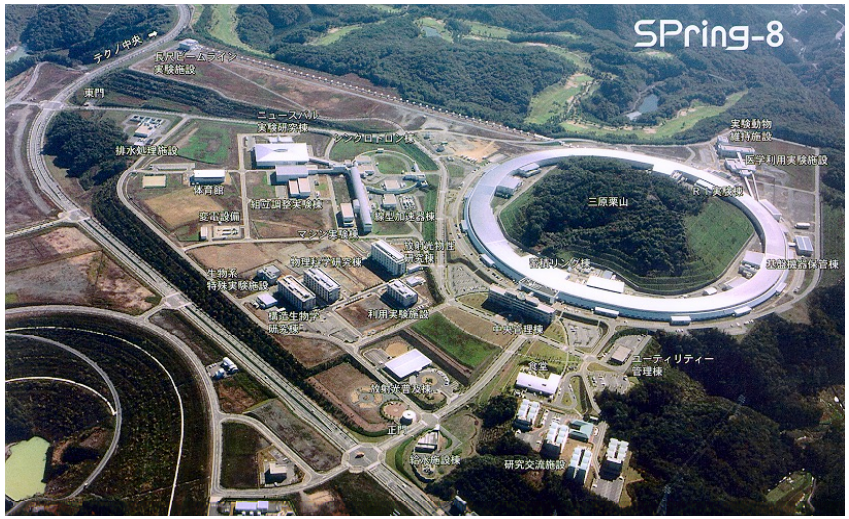
SPring-8/LEPS2 で探るクォークやハドロンのクラスター
Study quark/hadron clusters at SPring-8/LEPS2

A02班
M. Niiyama (Kyoto Sangyo U.)

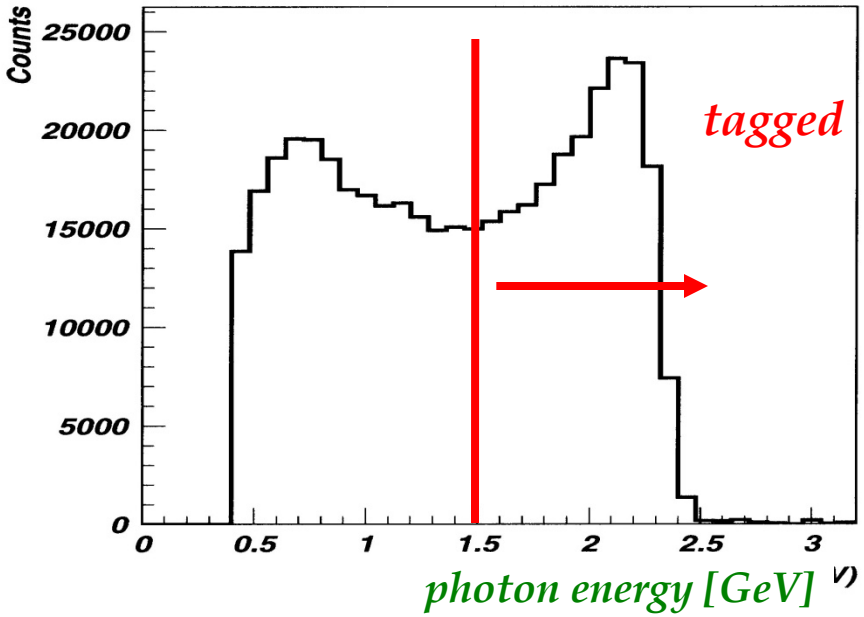
Super Photon Ring 8 GeV (SPring-8)



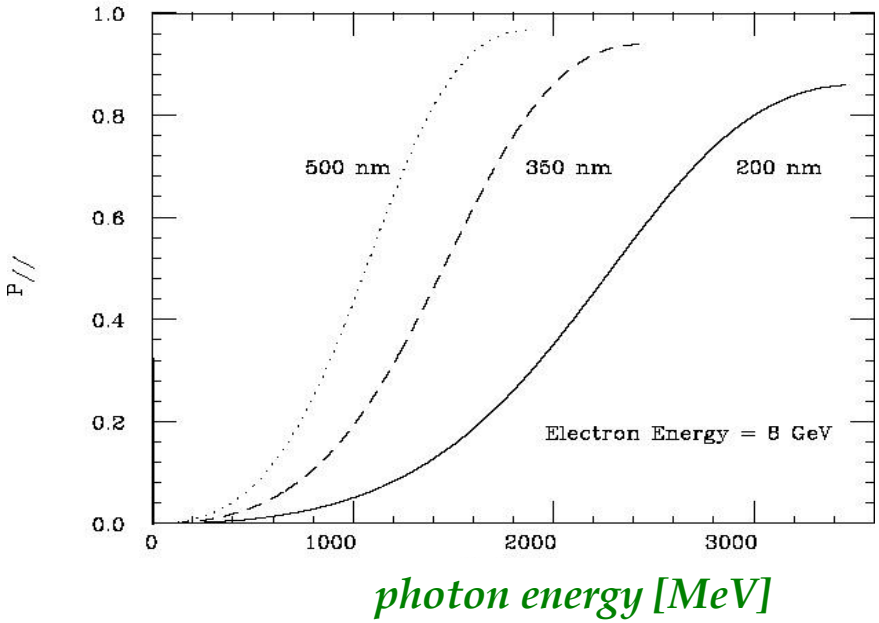
Backward-Compton Scattered Photon

- 8 GeV electrons in SPring-8
  - + 351nm Ar laser (3.5eV) 8W➔ ~ **2.4 GeV** photon
  - + 266nm Solid+BBO (4.6eV) 1W➔ ~**2.9 GeV** photon
- Laser Power ~6 W (351nm) ➔ Photon Flux ~1 Mcps (2.4 GeV)
- Eγ measured by tagging a recoil electron ➔ Eγ>1.5 GeV, **ΔEγ ~10 MeV**
- Laser linear polarization 95-100% ⇒ **Highly polarized γ beam**

PWO measurement

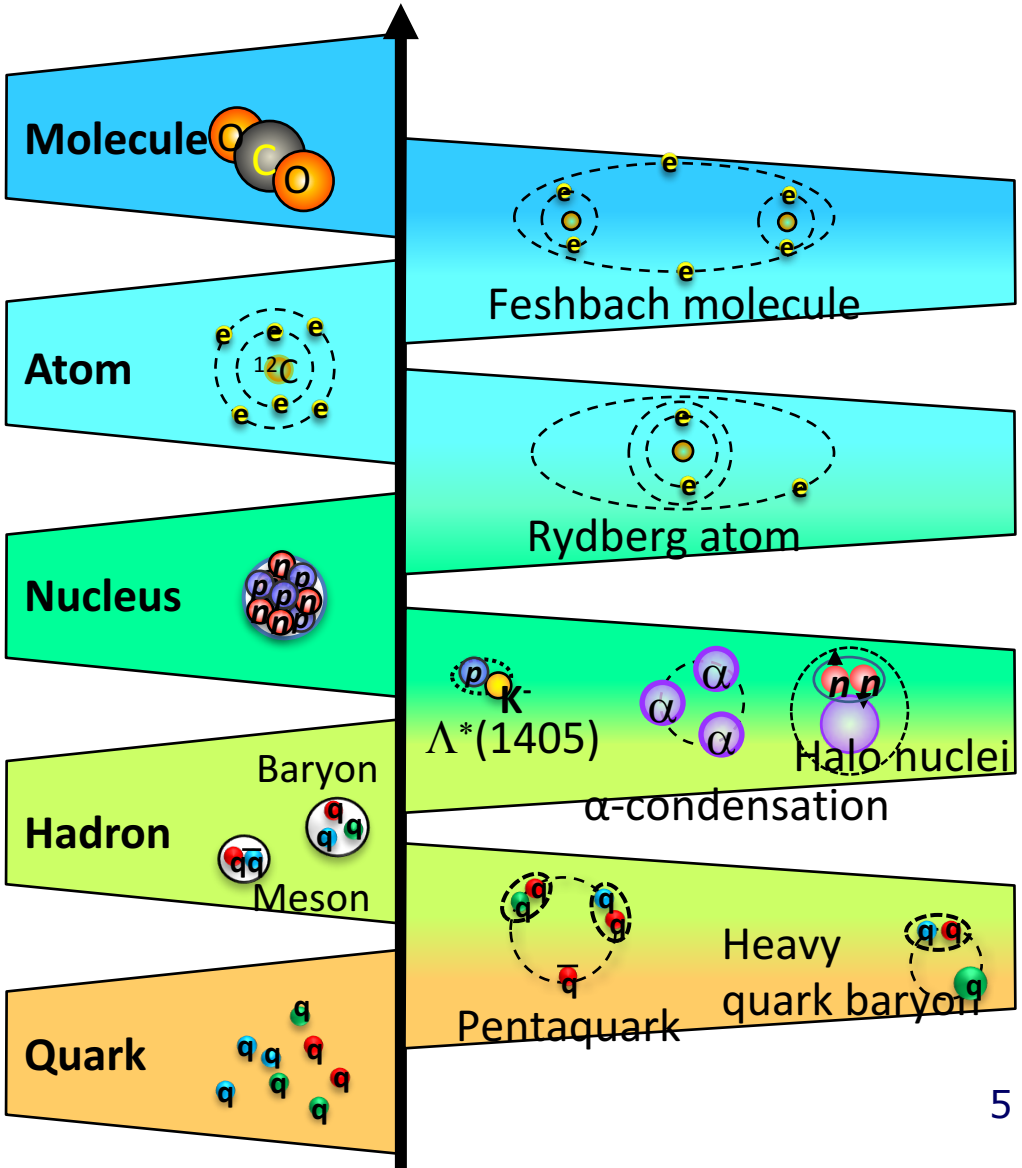


Linear Polarization of γ beam



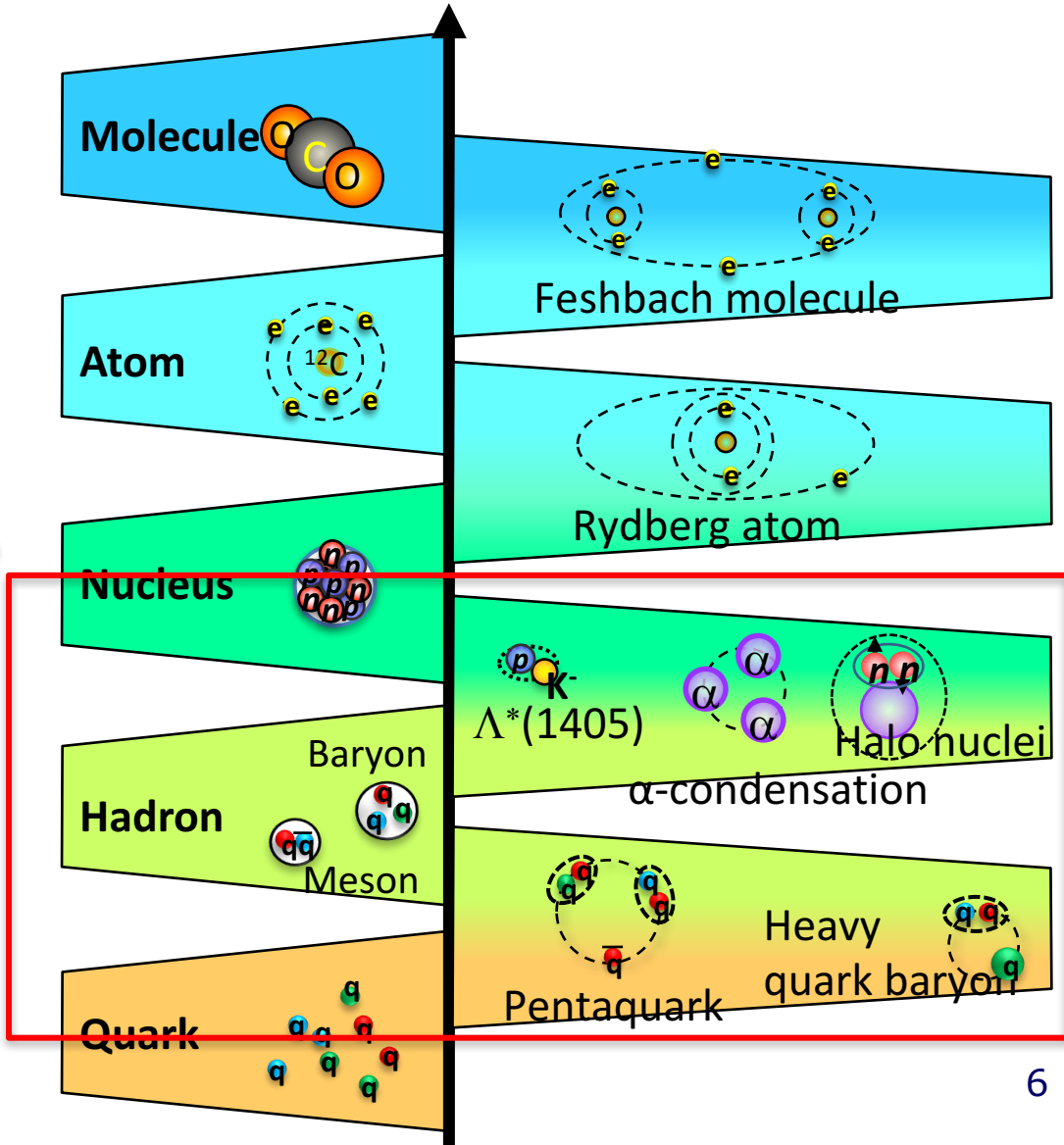
New experimental hutch

Clusters in the hadron physics



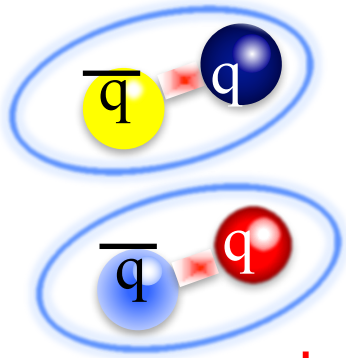
Clusters in the hadron physics

A02
Study at LEPS2

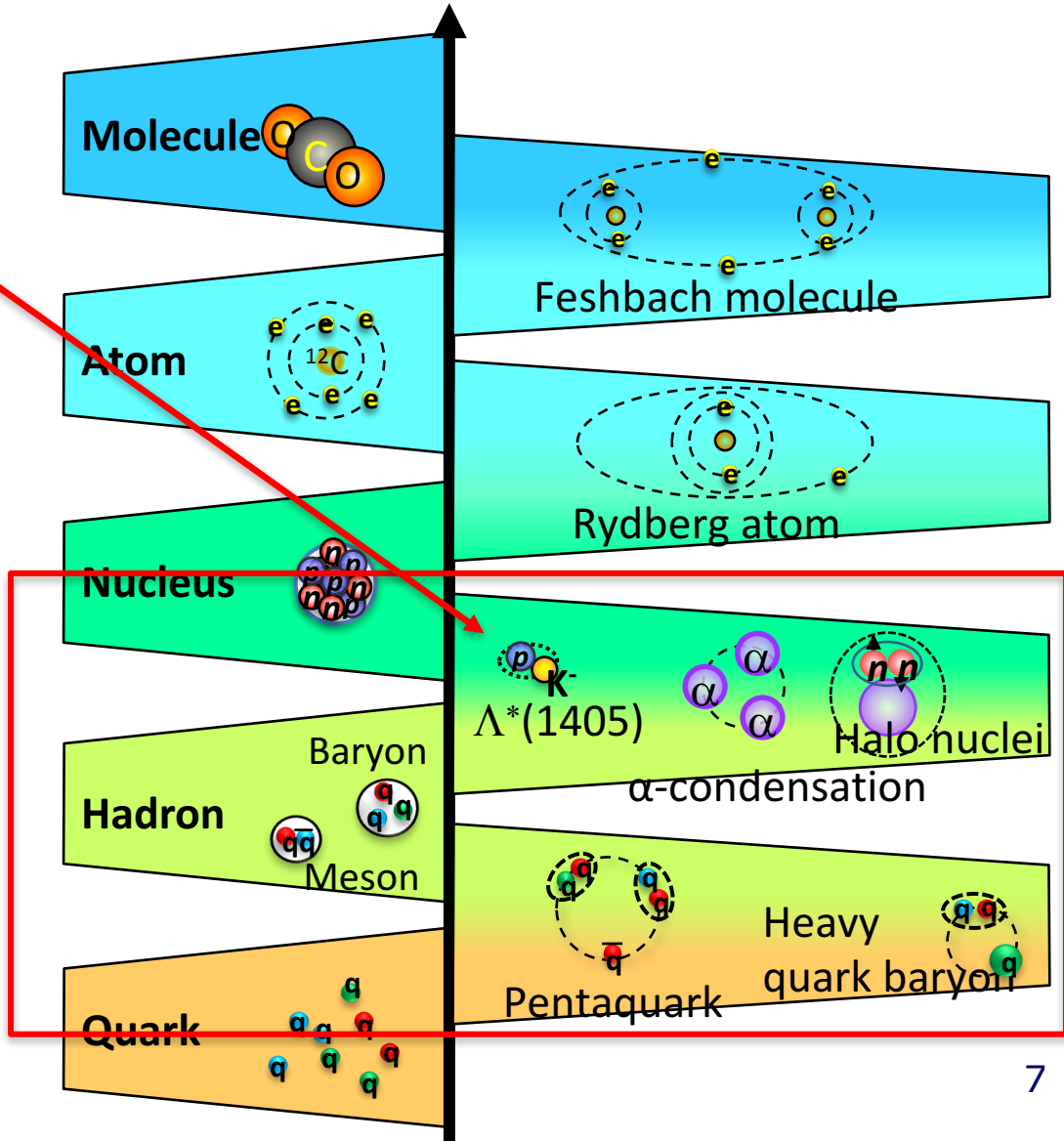


Cluster in hadron physics

- Colorless cluster
  - Hadronic molecule

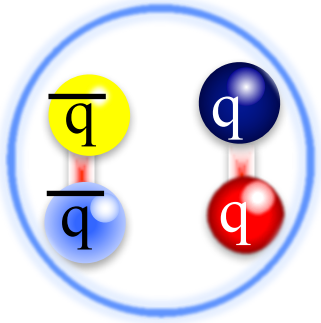


  - Meson as a building block
  - $\Lambda(1405)$
    - $\bar{K}N$
  - Kaonic nuclei



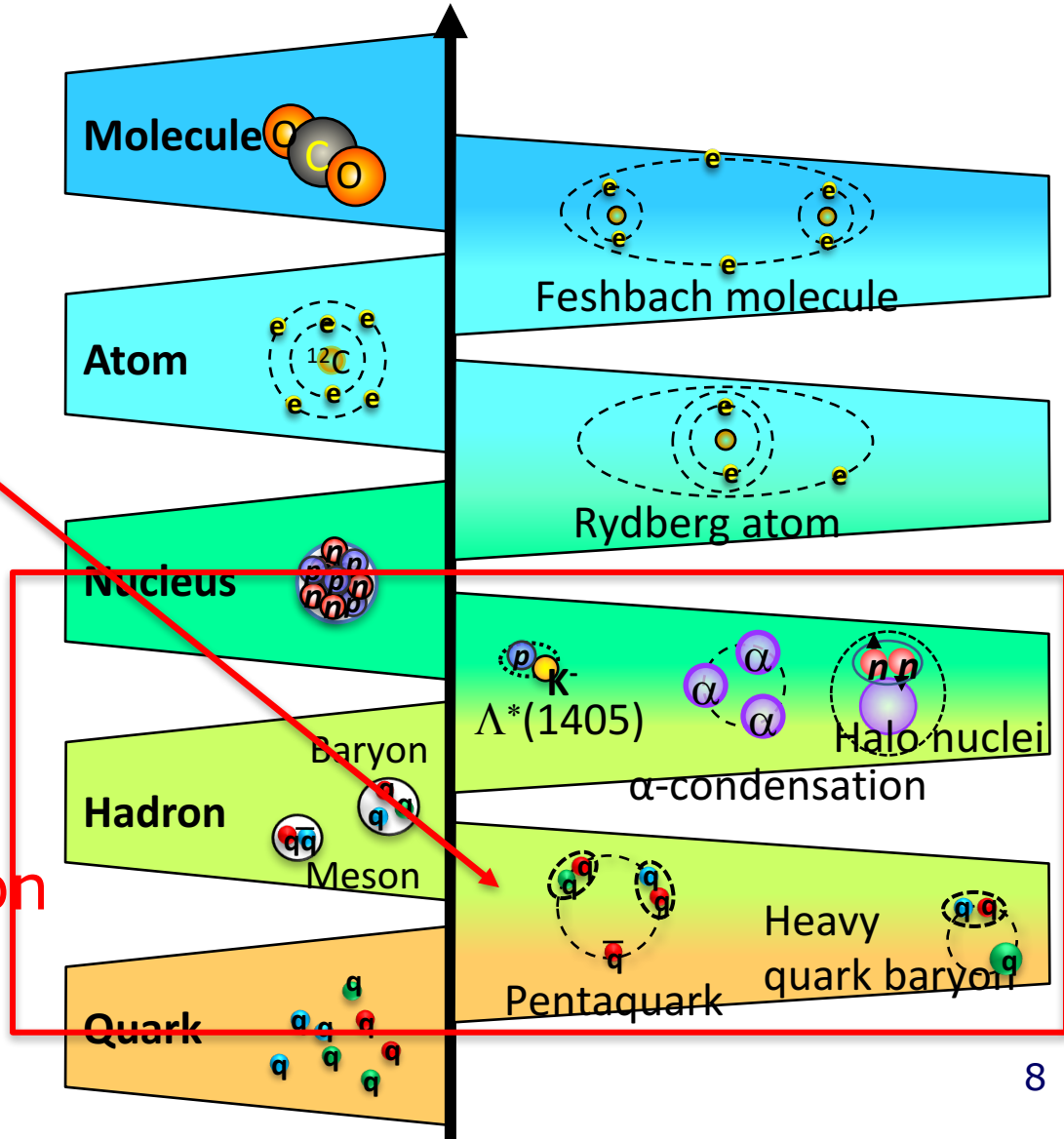
Cluster in hadron physics

- Colorless cluster
  - Hadronic molecule
- Colored cluster
  - Diquark



  - Confined in hadron

→ 4 or 5 quark hadron (exotic hadron)



Exotic hadrons

Normal hadrons

$q\bar{q}$ meson

qqq baryon

q(quark): u, d, s, c, …

Exotic hadrons

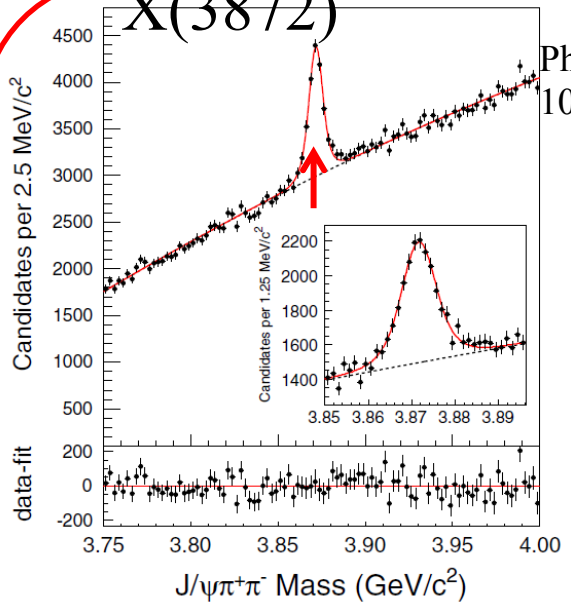
Normal hadrons

$q\bar{q}$ meson

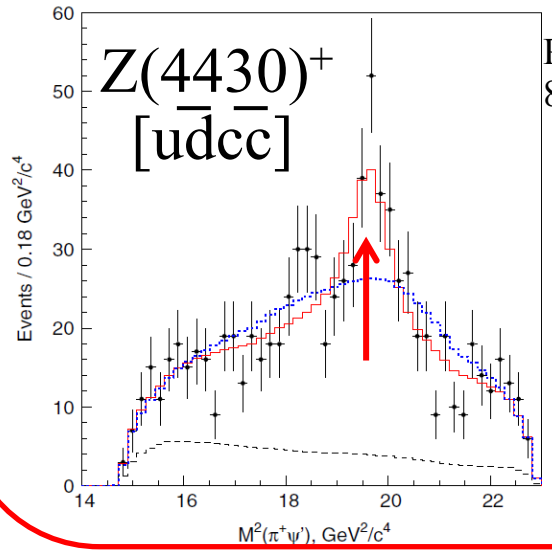
qqq baryon

q(quark) : u, d, s, c, …

4 quark



Phys. Rev. Lett. 103, 15201



Phys. Rev. D 80, 031104

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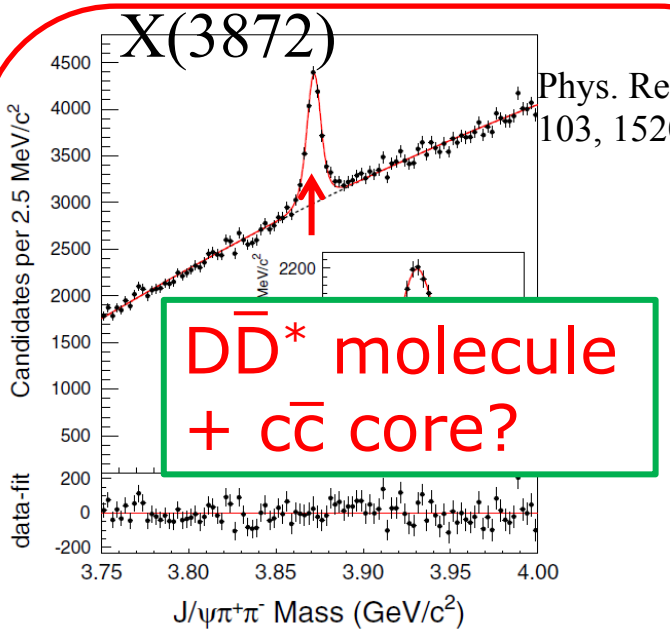
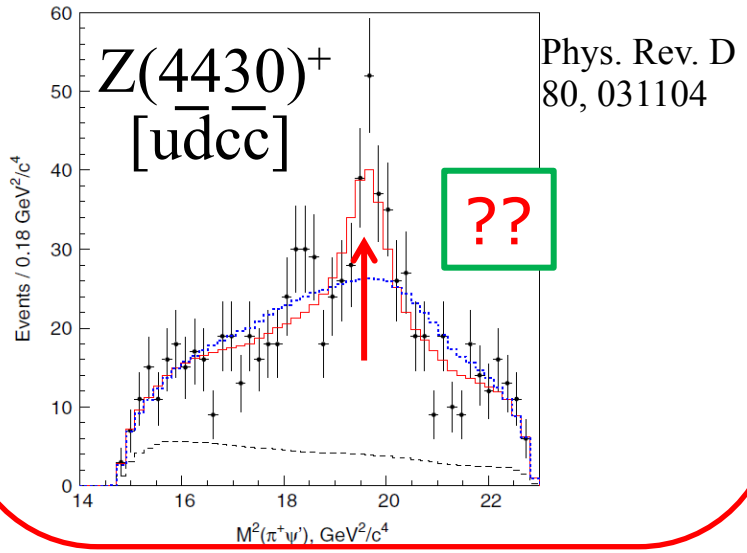
4 quark





Exotic hadrons

Normal hadrons

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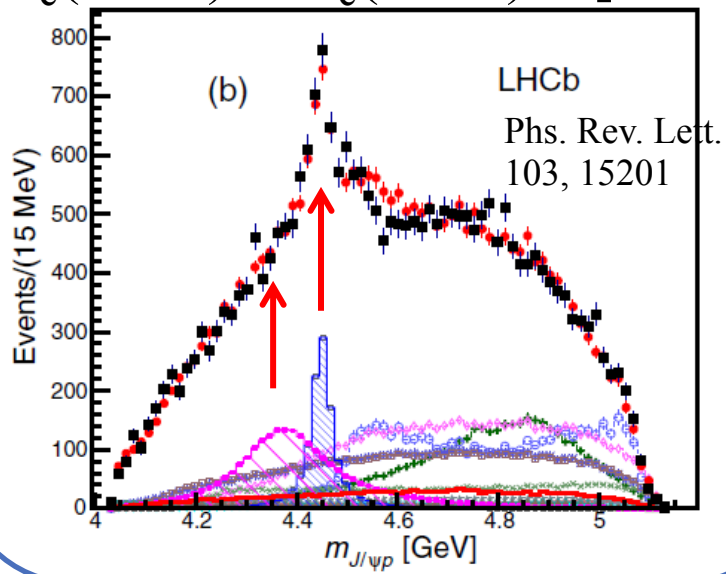
q (quark) : *u*, *d*, *s*, *c*, …

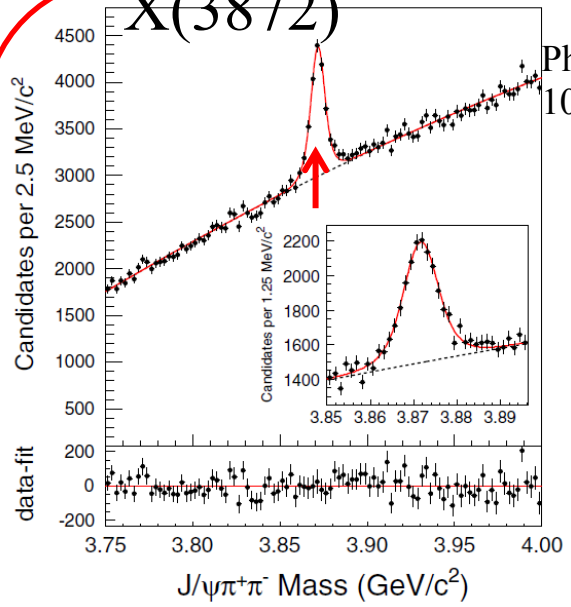
5 quark

$P_c(4380)^+$ / $P_c(4450)^+$ [uudc$\bar{c}$]



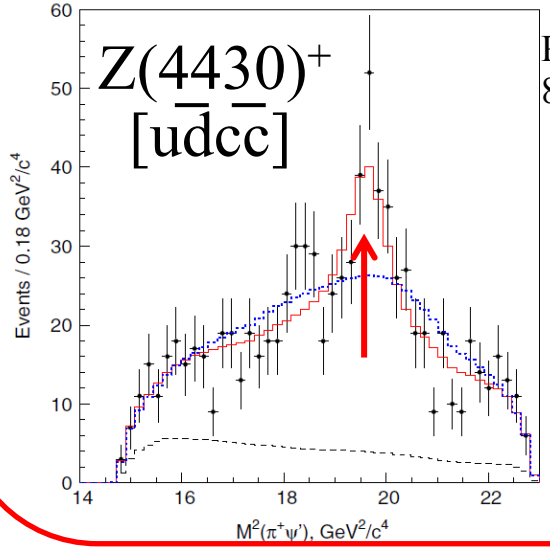
4 quark

X(3872)



Phys. Rev. Lett.
103, 15201

$Z(4430)^+$
[u$\bar{d}$c$\bar{c}$]



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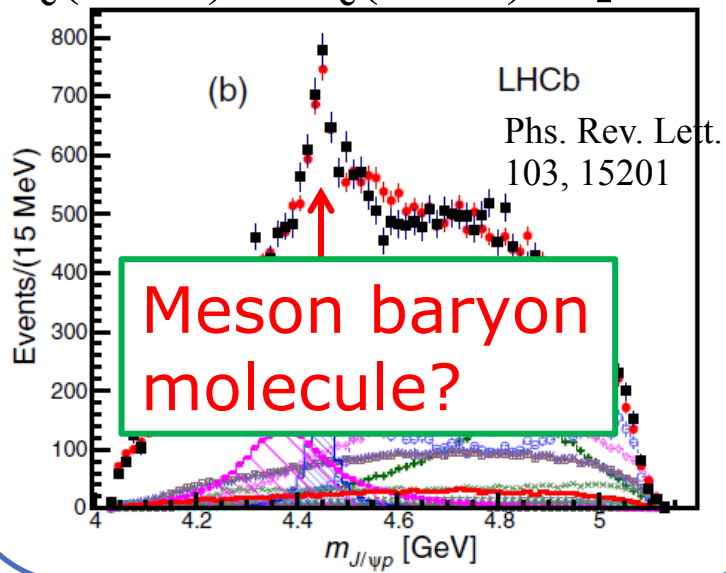
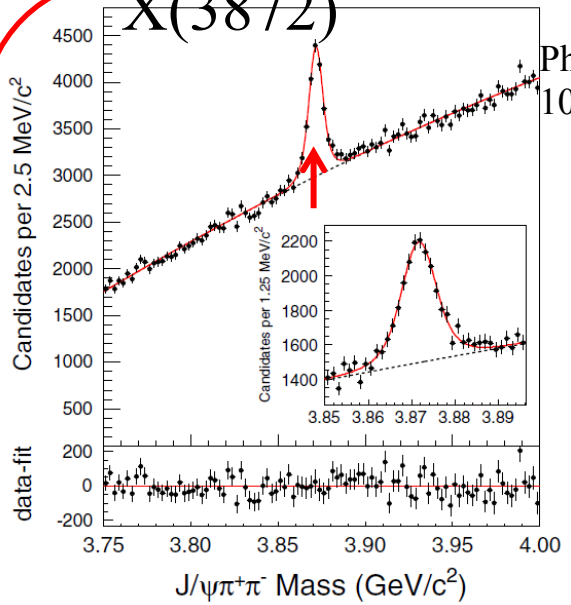
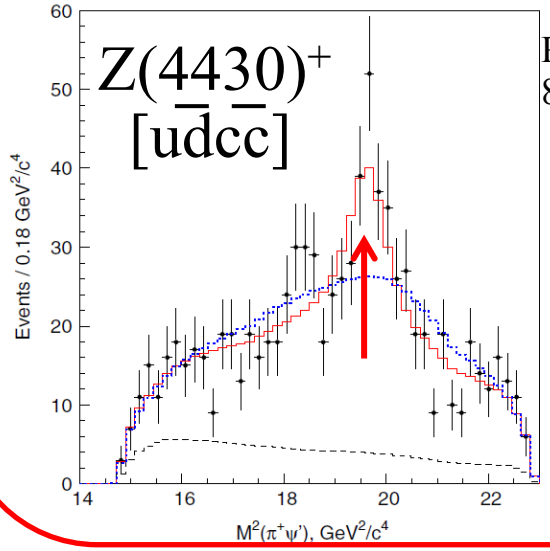


4 quark





Pentaquark Θ+

Theoretical Prediction（Z. Phys.A 359, 305(1997)）

1. Baryon with strangeness(S)=+1, charge(Q)=+1
minimal quark contents : $uud\bar{u}\bar{d}\bar{s}$

2. Light Mass: M(Θ+) ~1530 MeV

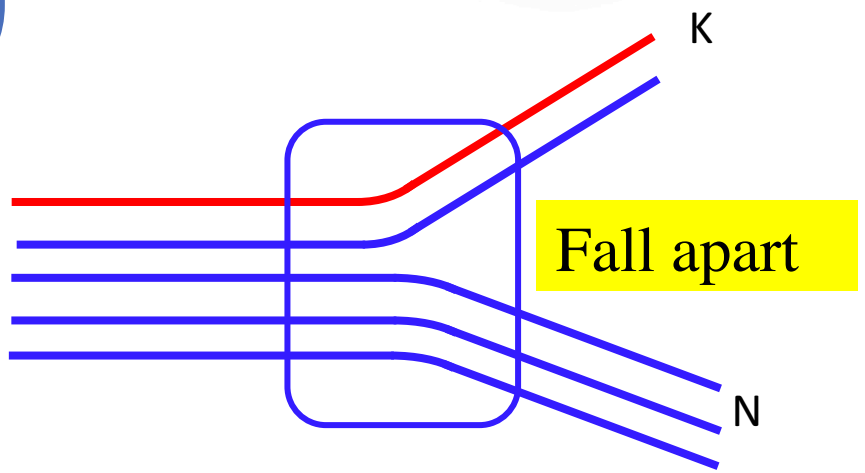
(quark model: 1700~1800 MeV)

3. Narrow Width: Γ < 1 MeV [exp.+theor.]

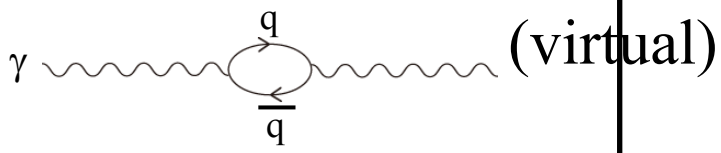
$\Theta^+ \rightarrow K^+ N$ repulsive

~~KN molecule~~

Diquark correlation?
PRL91 232003

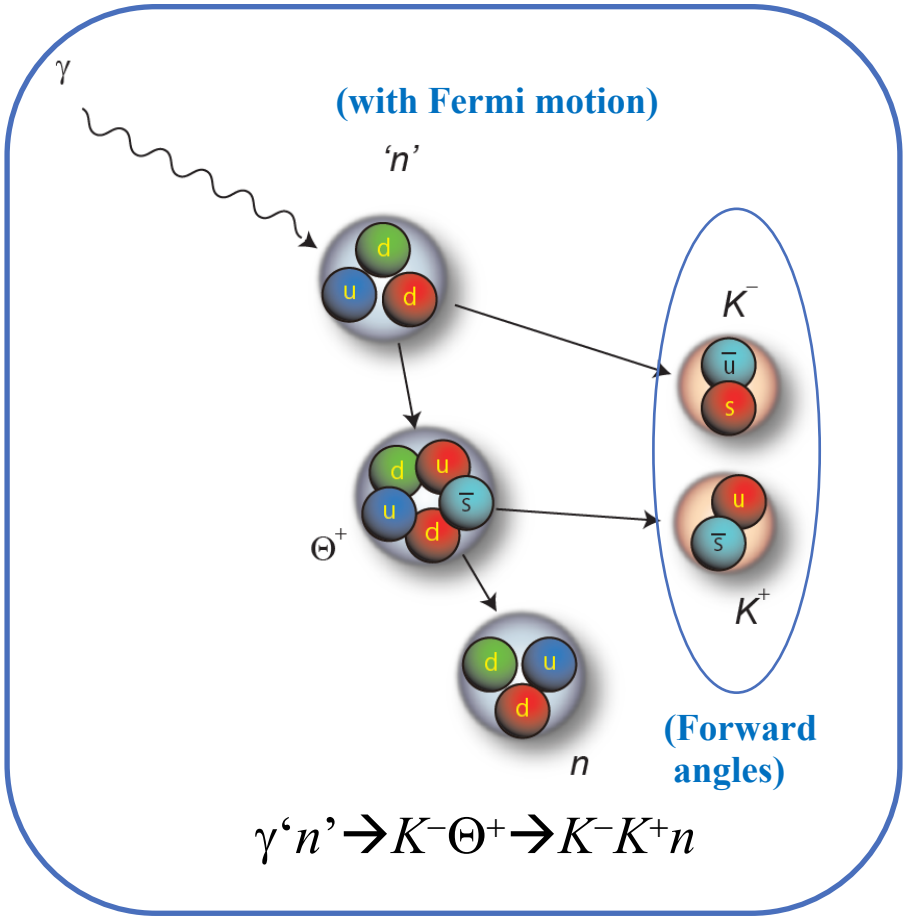


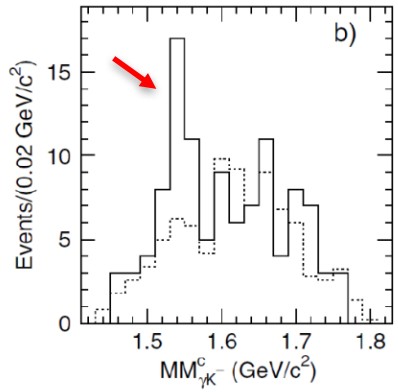
- photon beam → $s\bar{s}$ beam



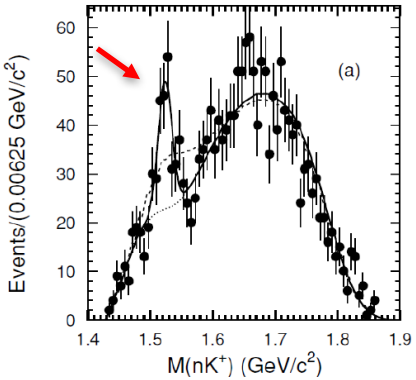
Θ^+ search at LEPS

(after correcting Fermi motion)



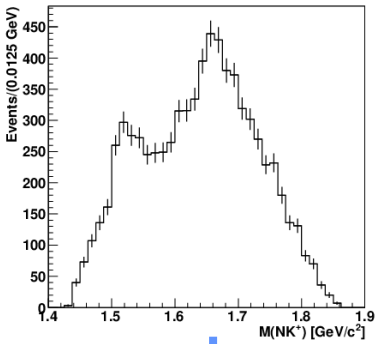


LEPS 2003
Carbon target
(PRL 91, 012002)



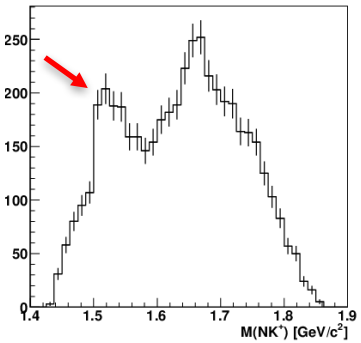
LEPS 2009
Deuteron target
(PRC 79, 025210)

Increase statistics



Partially subtract proton events

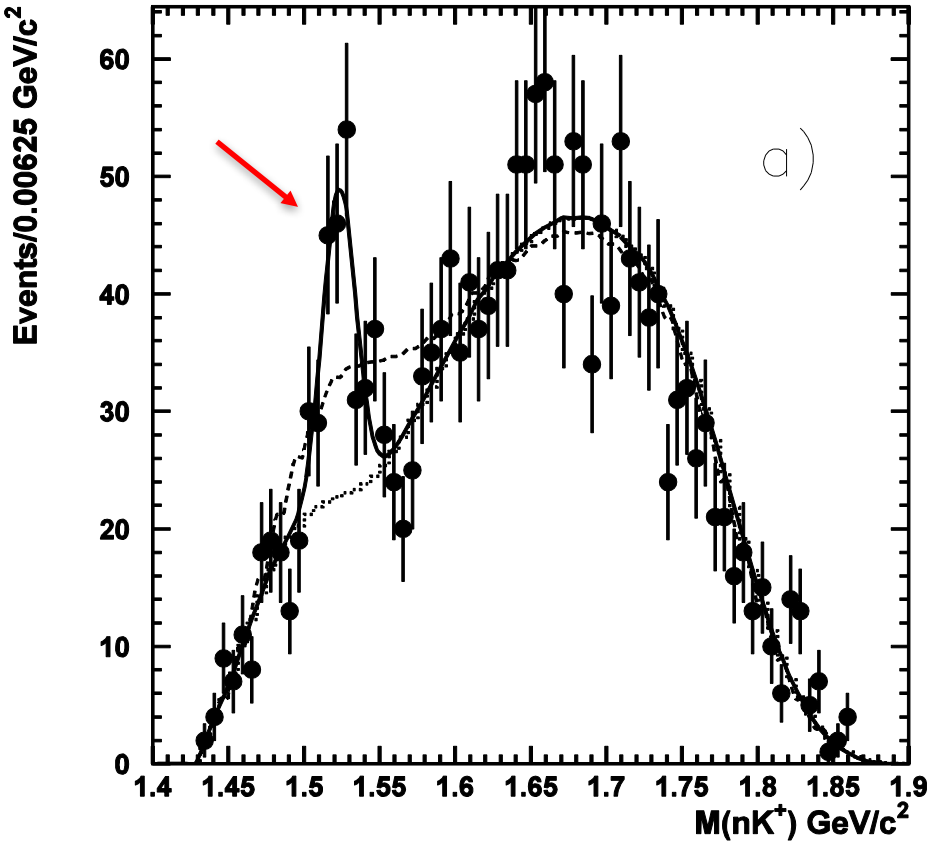
LEPS 2013
(Few Body Syst., 54,1245)



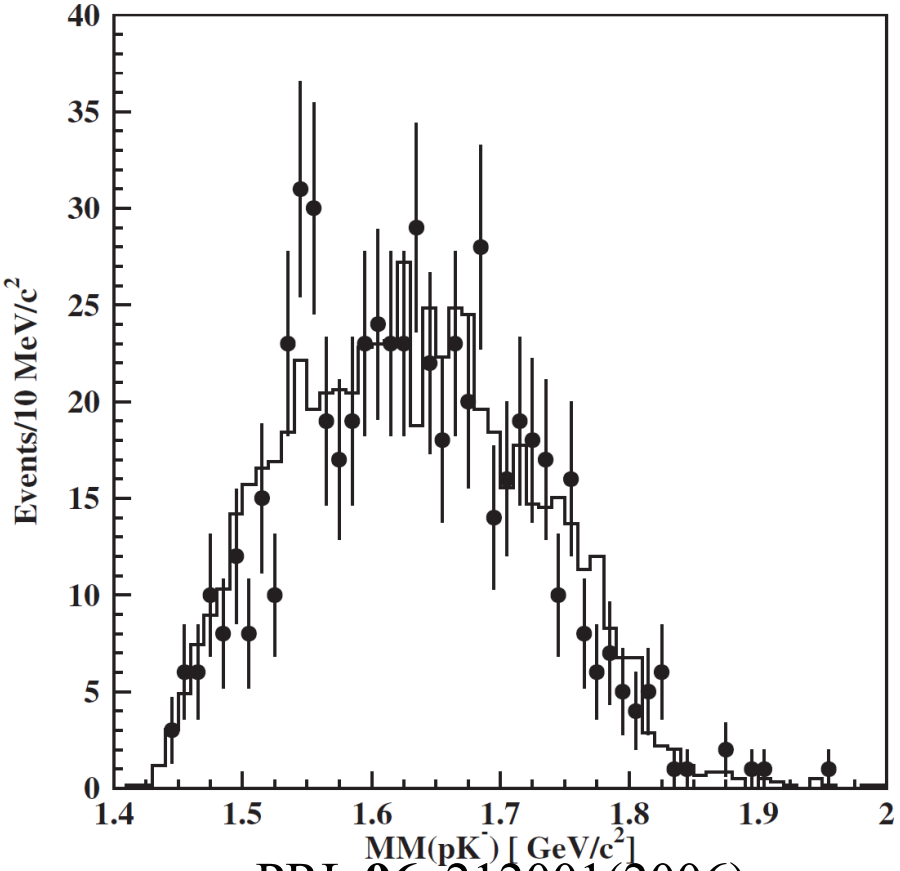
Results with higher S/N ratio will open soon!

Counter evidence from J-lab/CLAS

photon beam and deuteron target



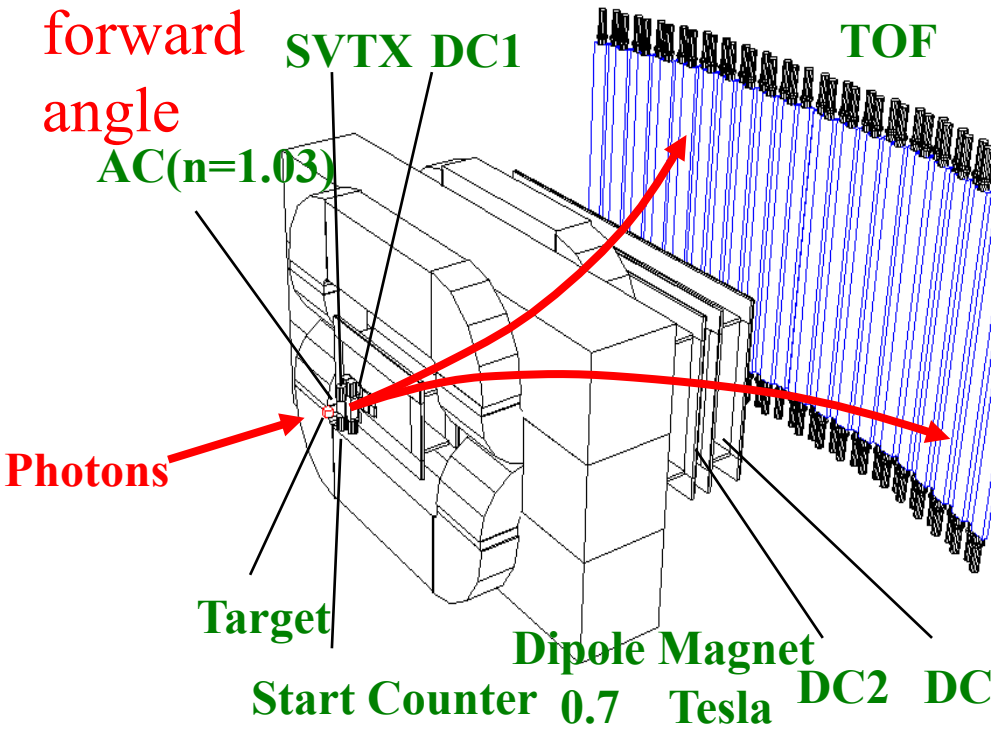
PRC **79,** 025210 (2009)



PRL **96**, 212001(2006)

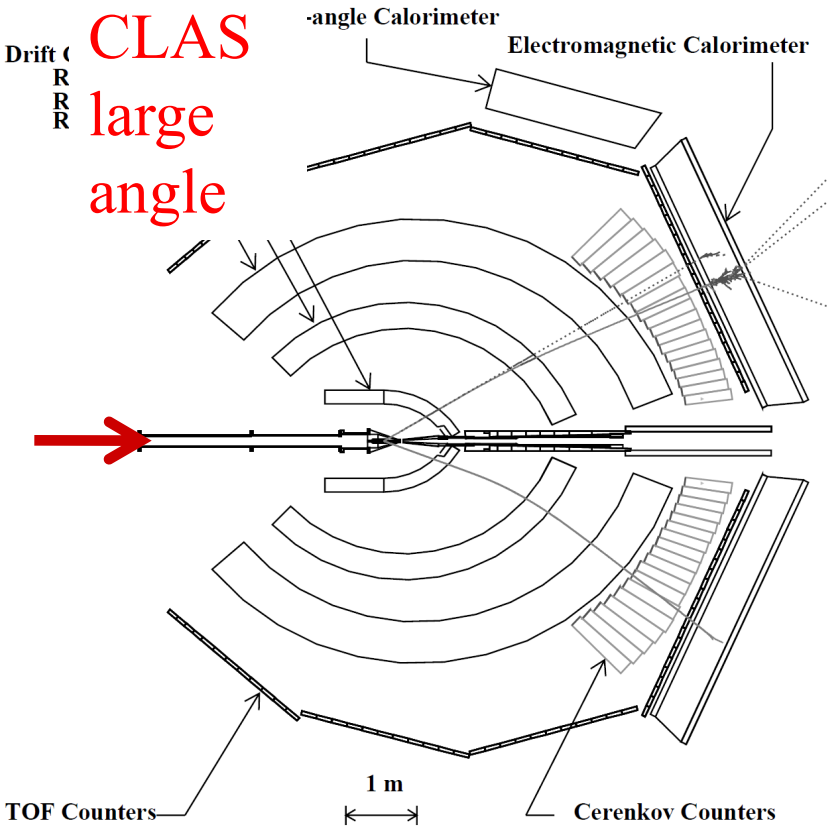
Θ^+ search at LEPS and CLAS

LEPS forward angle



PRC **79,** 025210 (2009)

CLAS large angle



PRL **96**, 212001(2006)

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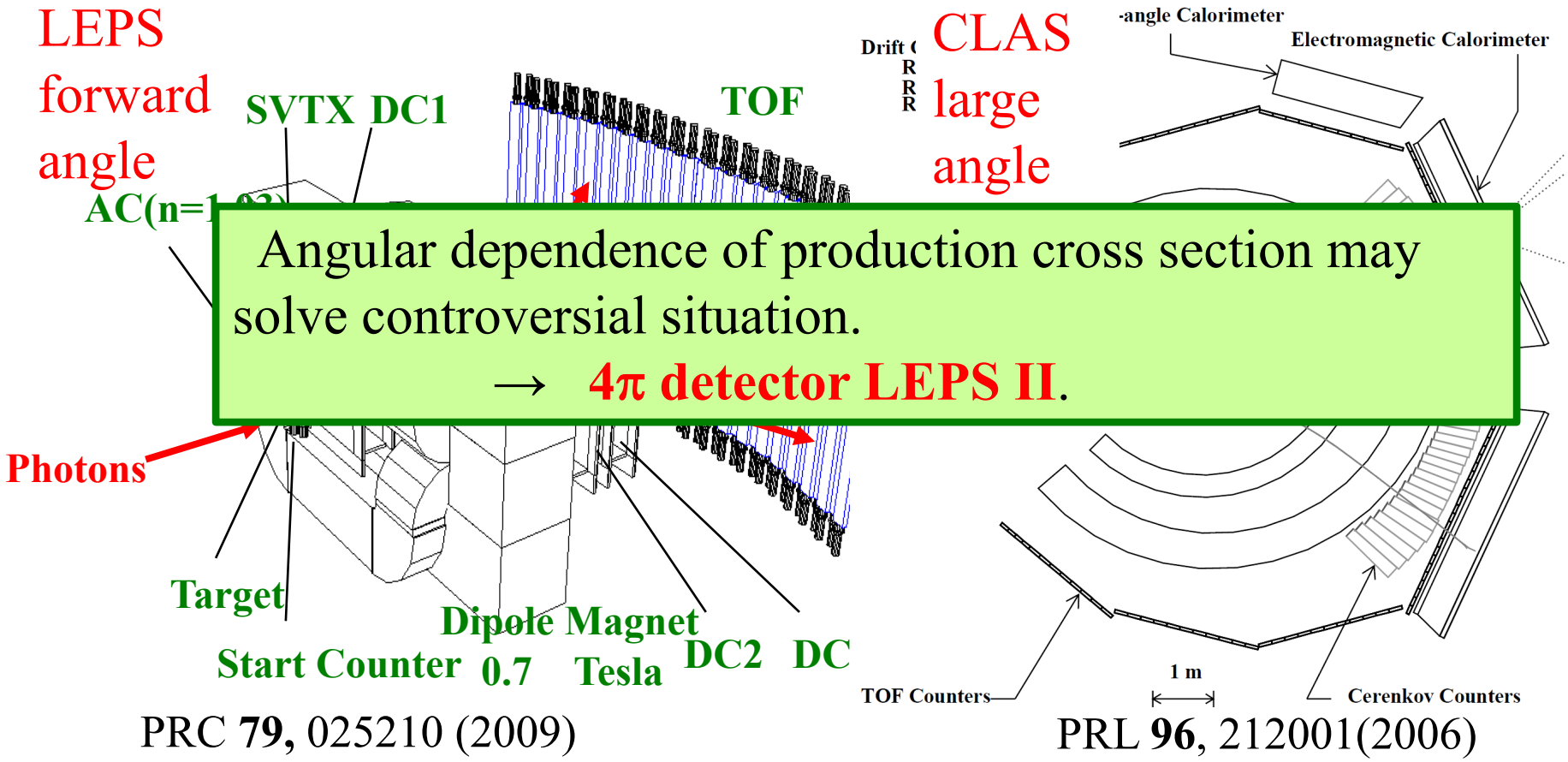


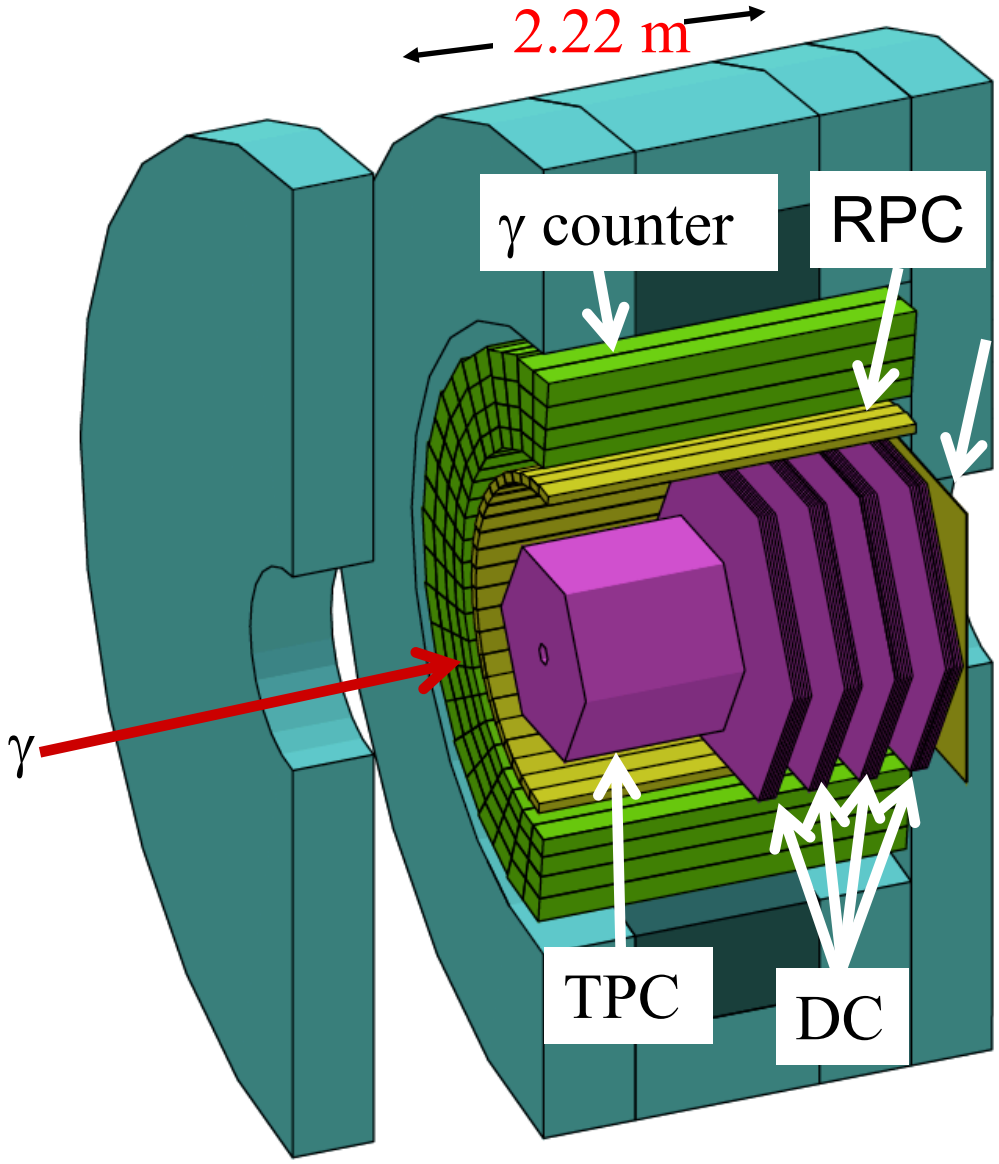
Angular dependence of production cross section may solve controversial situation.

→ **4π detector LEPS II**.

PRC **79,** 025210 (2009)

PRL **96**, 212001(2006)

Solenoid spectrometer



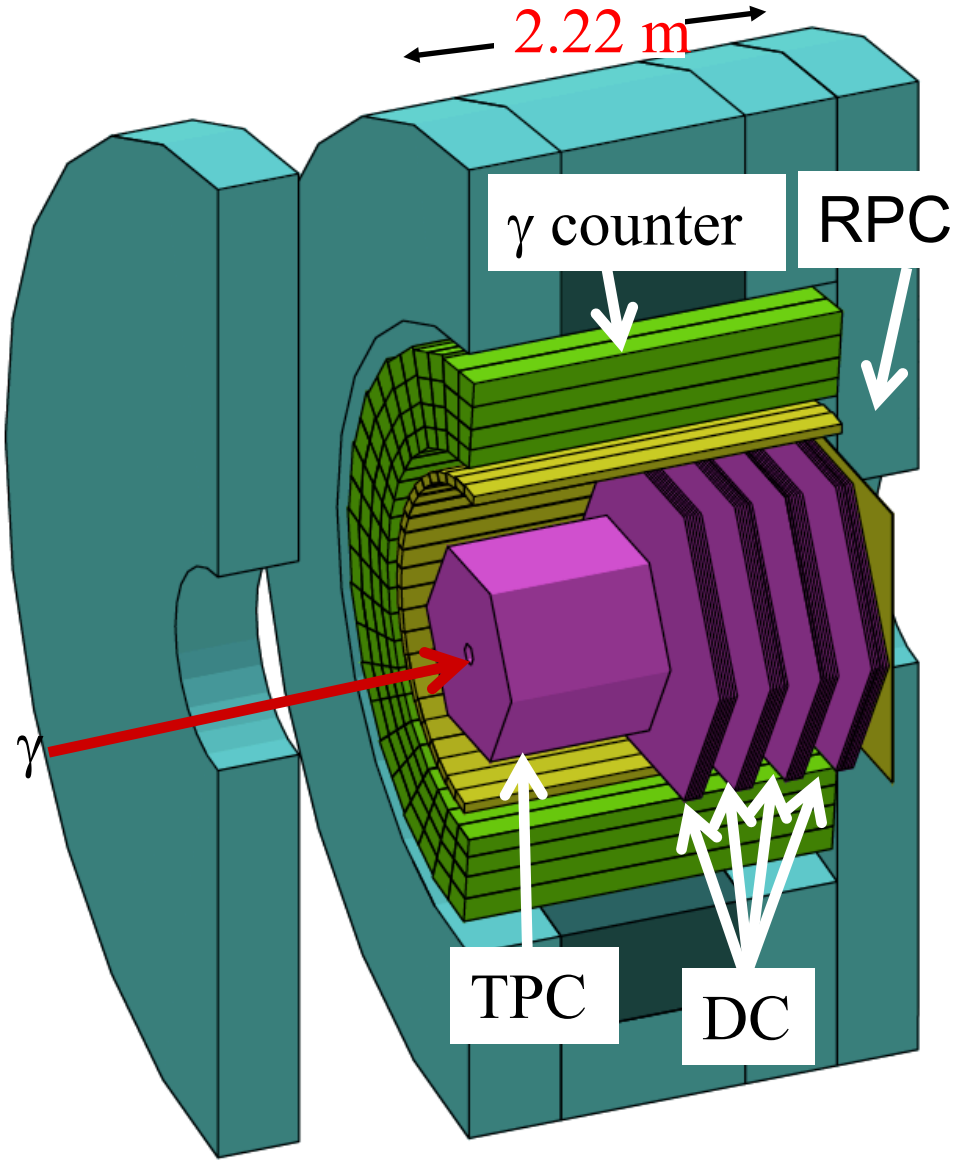
Magnet (BNL-E949)
B=1 T

$\Delta p/p \sim$ 1-5%
for $\theta > 7$ deg

detectors for
photons, charged particles

3σ K/π/p separation
< 2.7 GeV

Solenoid spectrometer



- Sideway tracker
- Time Projection Chamber (TPC)
  - R=655 mm, 24 layer
  - $\sigma_{r\varphi}$=150 μm, σ_z=2 mm
- Forward tracker
  - 4 drift chambers (DC)
  - 6 plane
  - σ_{xy}=150 μm
- Time-of-flight
  - Resistive Plate Chamber (RPC)
  - Δt=70 ps
- Aerogel Cherenkov counters
  - n=1.03, 1.05
- Barrel γ counter
  - Lead plastic sandwich 14.3X_0

Θ^+ search at LEPS and LEPS2

LEPS

Detect

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

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

Fermi-momentum correction

Invariant mass

Mass resolution 11 MeV/c²

Main background

$\gamma d \rightarrow \phi X$

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

LEPS2

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

$\Theta^+ \rightarrow K_s^0 p \rightarrow \pi^+ \pi^- p$

Detect

No Fermi-motion corr.

Invariant mass

Mass resolution 6 MeV/c²

No ϕ meson background

$\gamma d \rightarrow \Lambda(1520) K_s^0 p$

$\Lambda(1520) \rightarrow K^- p$

Θ^+ search at LEPS and LEPS2

LEPS

Detect

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

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

Fe
co

Invariant mass

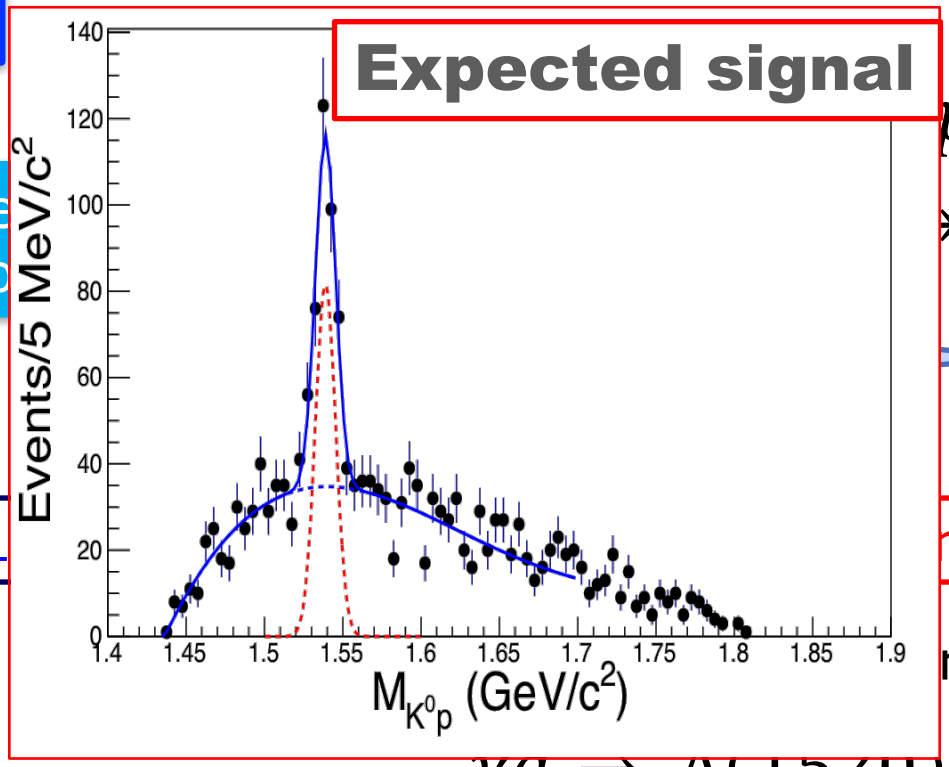
Mass resolution 11

Main background

$\gamma d \rightarrow \phi X$

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

LEPS2



p

Detect

$\rightarrow \pi^+ \pi^- p$

Invariant mass

n 6 MeV/c²

round

$\gamma d \rightarrow \Lambda(1520) K_s^0 p$

$\Lambda(1520) \rightarrow K^- p$

Θ^+ search at LEPS and LEPS2

LEPS

Detect

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

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

Fe
co

Invariant mass

Mass resolution 11

Main background

γd

LEPS2

p

Detect

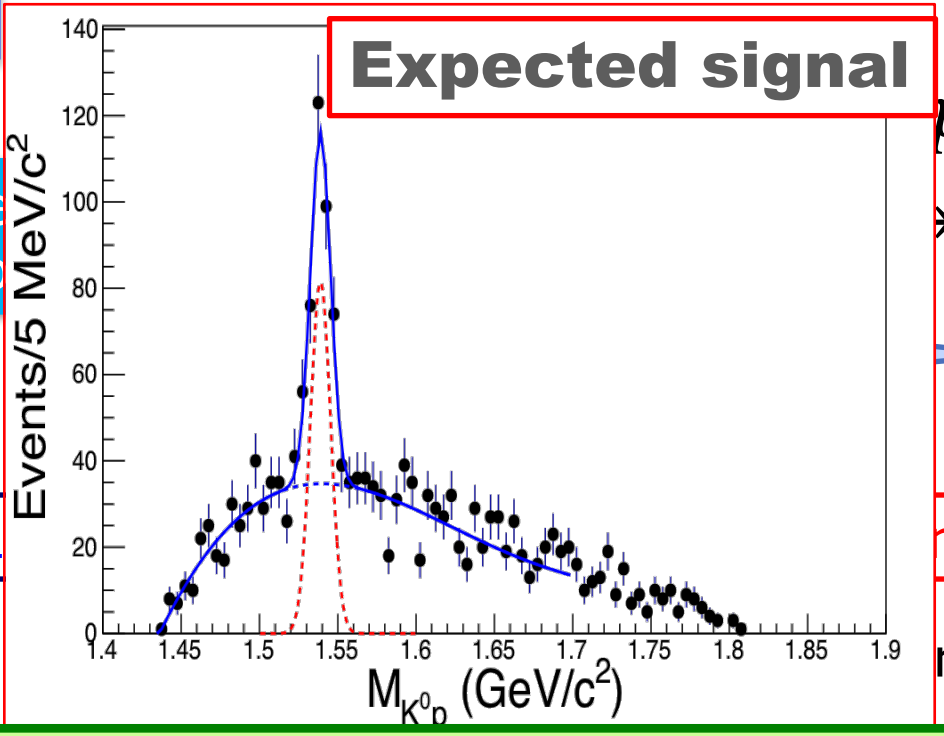
$\rightarrow \pi^+ \pi^- p$

Invariant mass

n 6 MeV/c^2

round

Expected signal



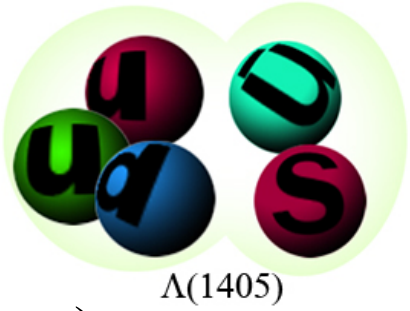
- Confirm Θ^+ in $K^0_s p$ decay mode
- Angular dependence of production rates
- KN coupling using $\gamma p \rightarrow \overline{K(890)}\ \Theta^+$ reaction

Colorless clusters

$\Lambda(1405)$
Kaonic nuclei

Λ(1405) $J^P=1/2^-$

Structure of P-wave baryons



nucleon (ud sector)

hyperon (uds sector)

$1/2^-$ N(1535)

$3/2^-$ N(1520)

η+N (1485)

$3/2^-$ Λ(1520)

s-quark

K+N (1430)

30 MeV

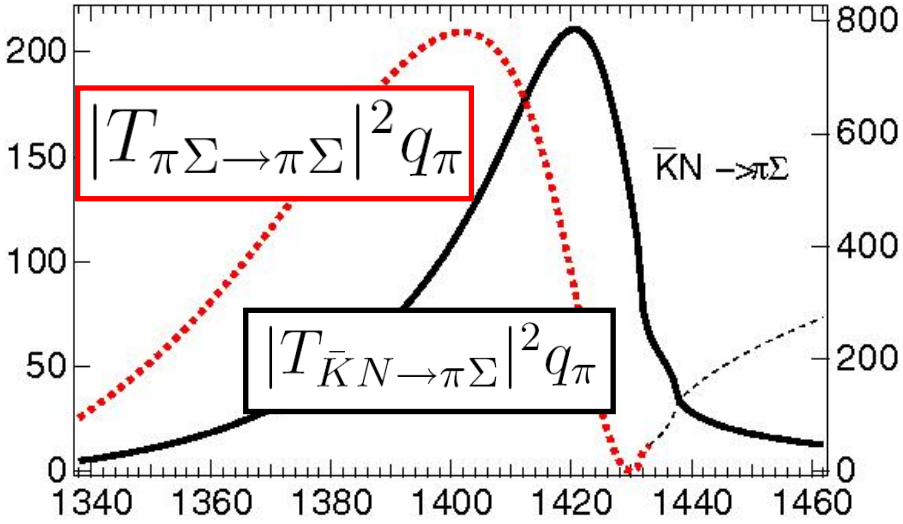
$1/2^-$ Λ(1405)

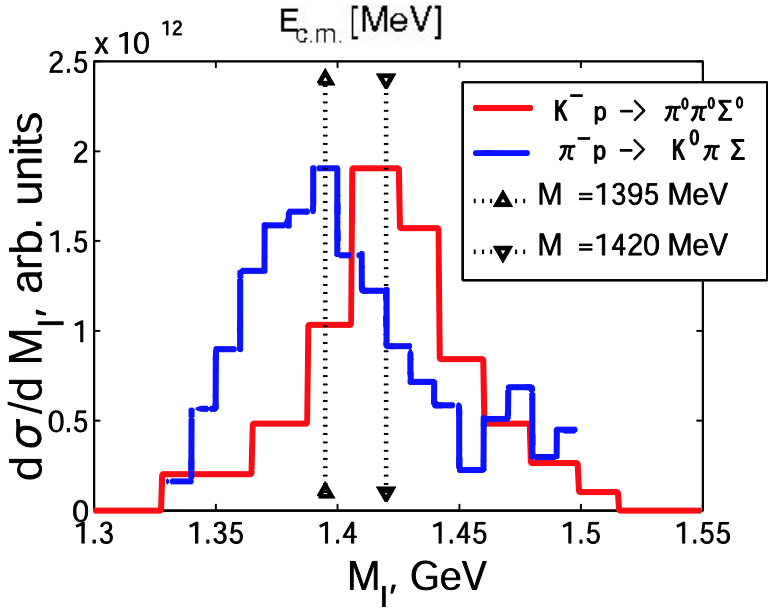
One strange-quark, but lighter than N*

Opposite sign of LS splitting

Λ(1405)

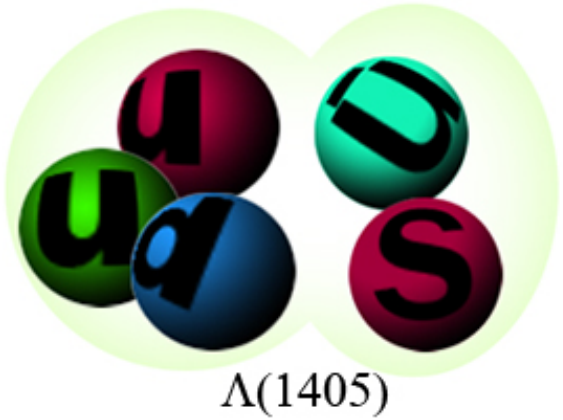
D. Jido, et al. NPA725(2003)





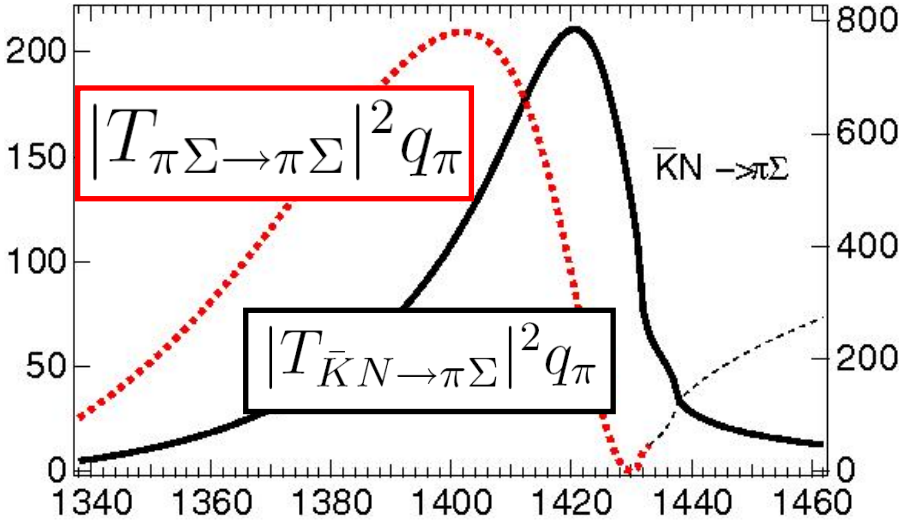
V.K. Magas, E. Oset and A. Ramos, PRL 95

- 30 MeV below $\bar{K}N$ threshold
- Hadronic molecule candidate
  - $\bar{K}N$, $\pi\Sigma$ comonents
- Two resonance poles are predicted
- Heavier mass pole couples mainly to $\bar{K}N$



Λ(1405)

D. Jido, et al. NPA725(2003)



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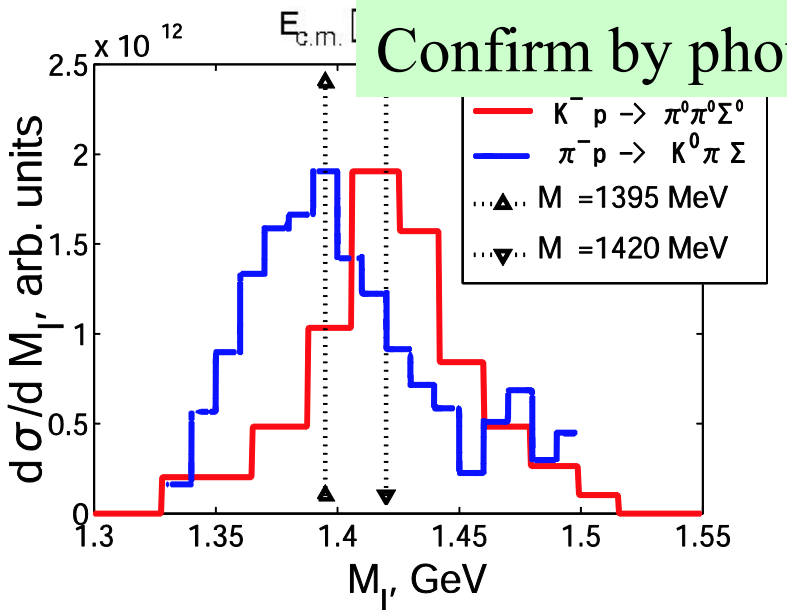
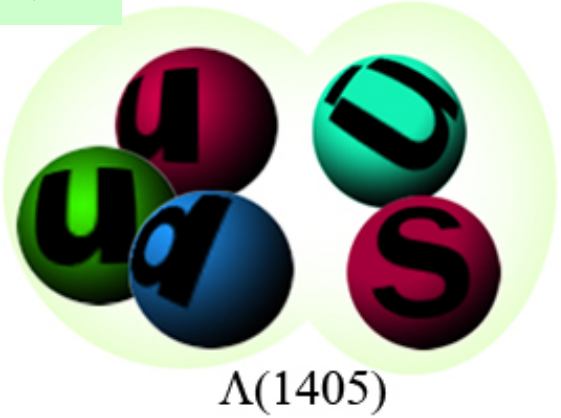
Confirm by photoproduction.

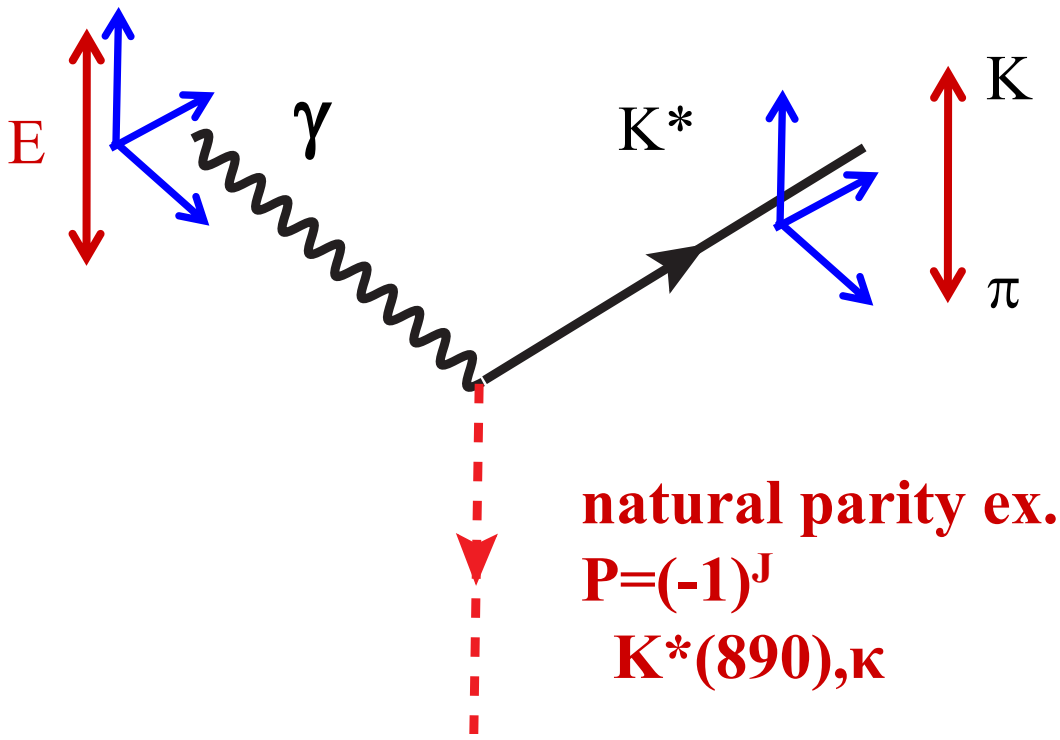




V.K. Magas, E. Oset and A. Ramos, PRL 95

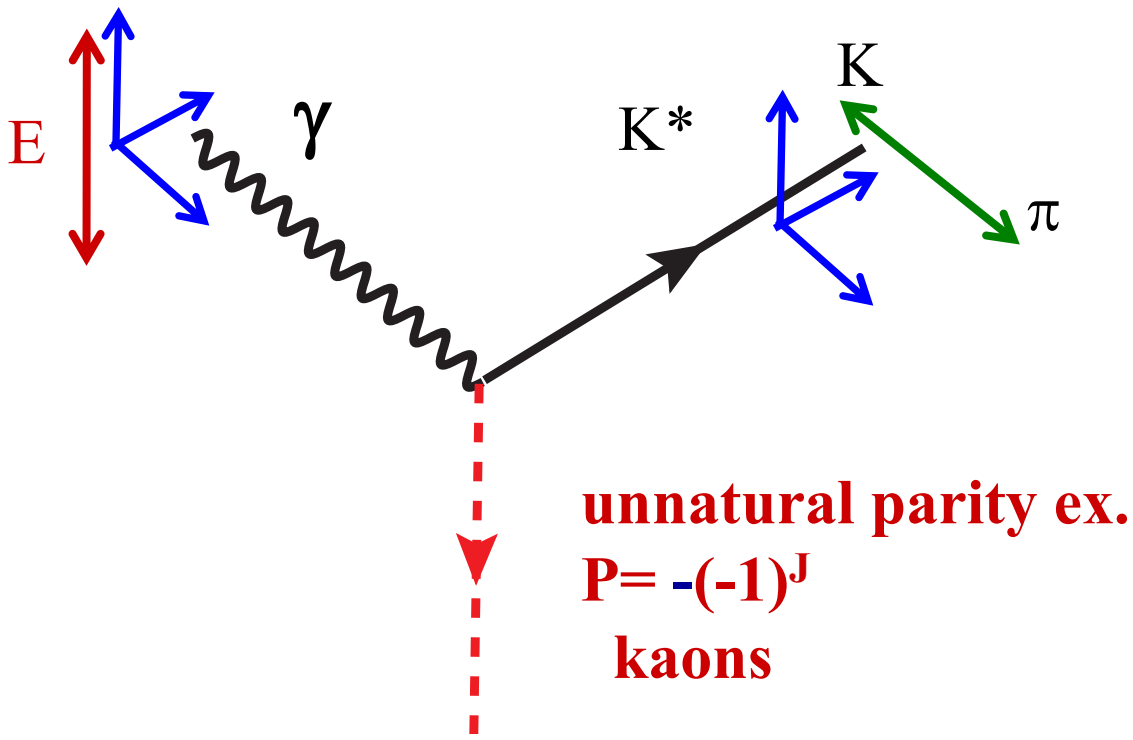
Hyperon photoproduction with K*(892)

- **Parity filter with linearly polarized photon**

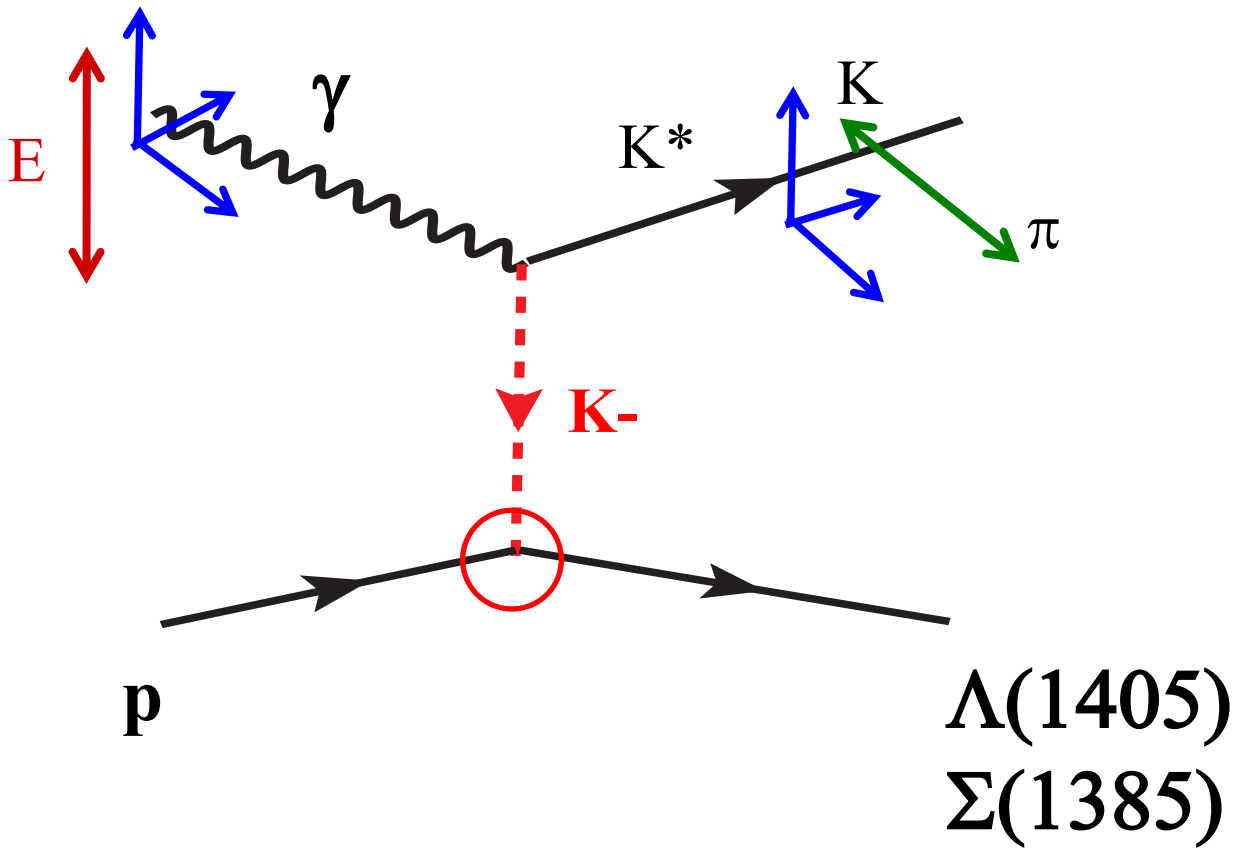


Hyperon photoproduction with K*(892)

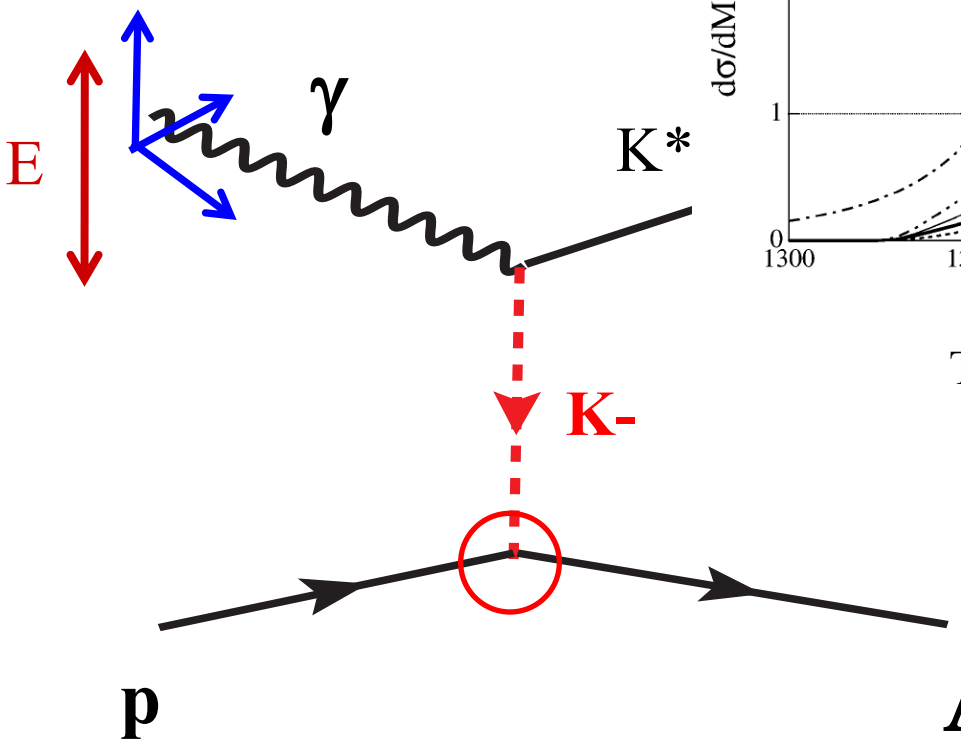
- **Parity filter with linearly polarized photon**

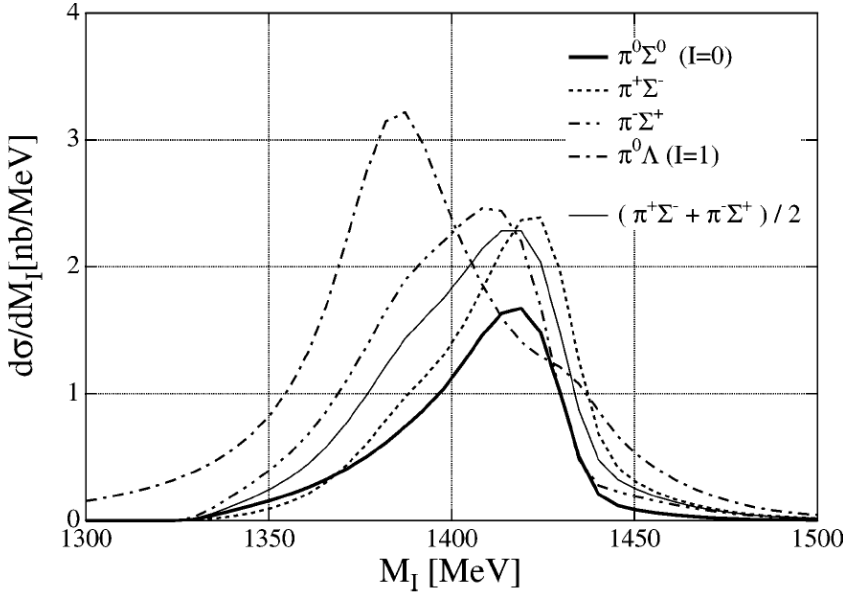


K*(890) Λ(1405) photoproduction with linearly polarized photon



K*(890) Λ(1405) photoproduction with linearly polari

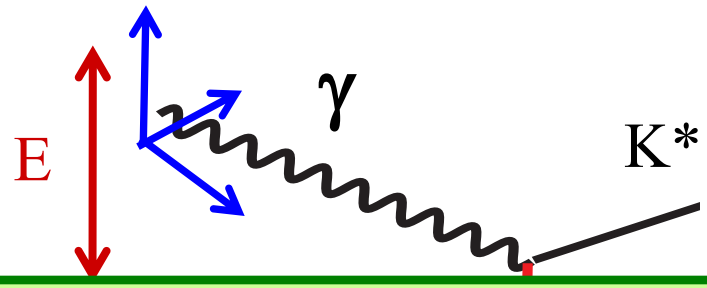


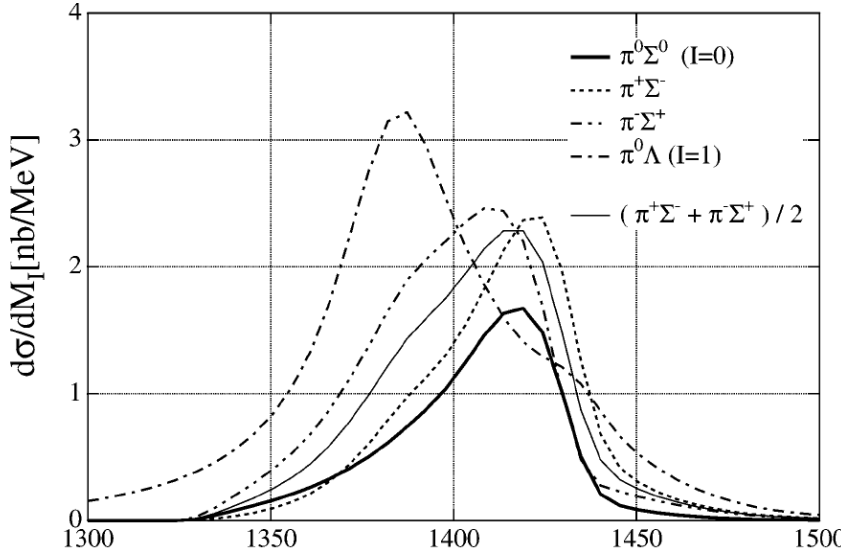


T.Hyodo et. al, PLB593

Λ(1405)
Σ(1385)

K*(890) Λ(1405) photoproduction with linearly polari





High luminosity photon beam with Eγ>2.4 GeV.

Detect $K^{*+} \rightarrow K^0_S \pi^+ \rightarrow \pi\pi\pi$

$\Lambda(1405) \rightarrow \Sigma^0\pi^0 \rightarrow \Lambda\gamma\,\gamma\gamma$

$\Sigma(1385) \rightarrow \Lambda\pi^0$

Large acceptance charged / photon detector

LB593

p

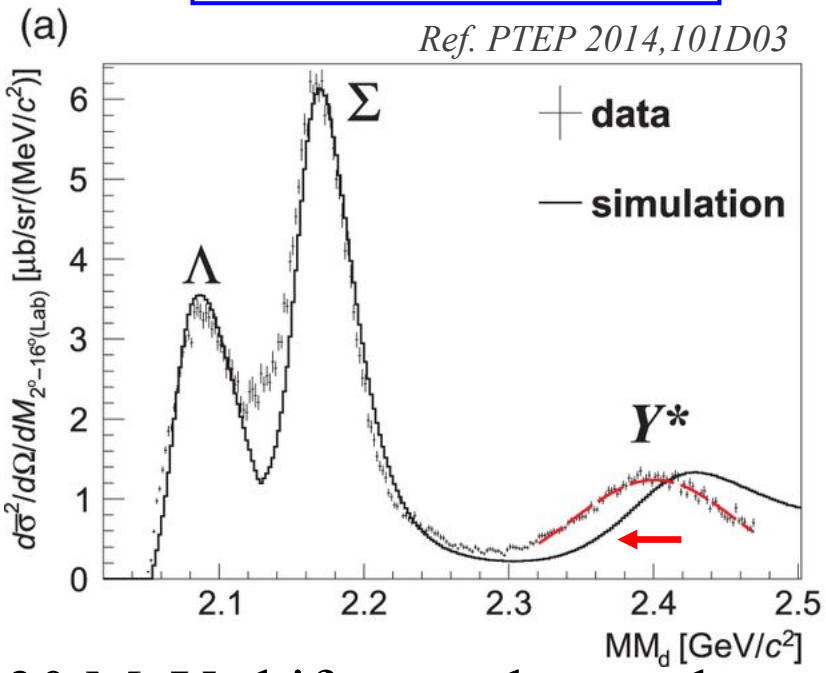
Λ(1405)

Σ(1385)

Kaonic nuclei

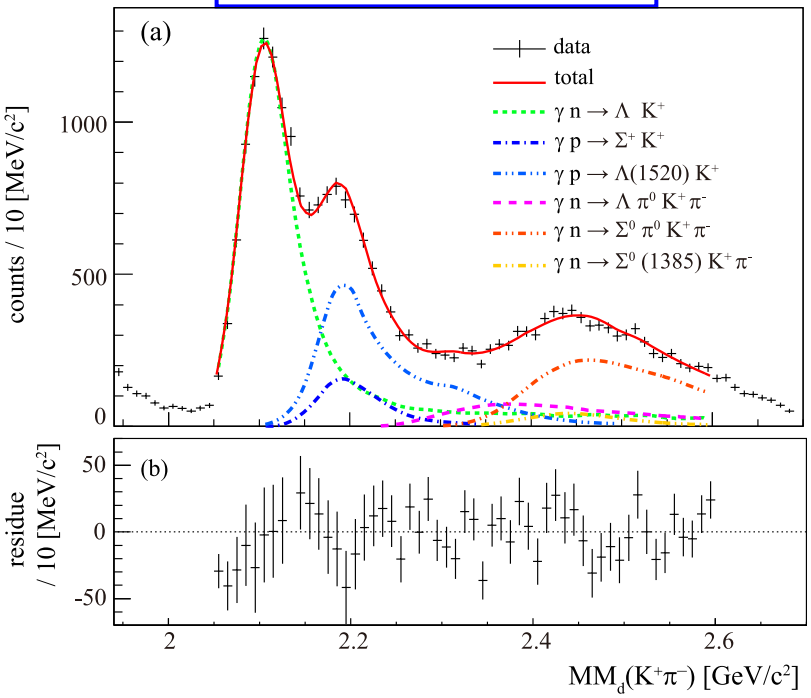
If Λ(1405) is K^{bar} N molecule, K^-pp system can be strongly bound state.

MM(K^+) *J-PARC E27*



30 MeV shift was observed in Y* region
(caused by Y*N interaction?)

MM($K^+\pi^-$) *LEPS*



no shift was observed in Y* region

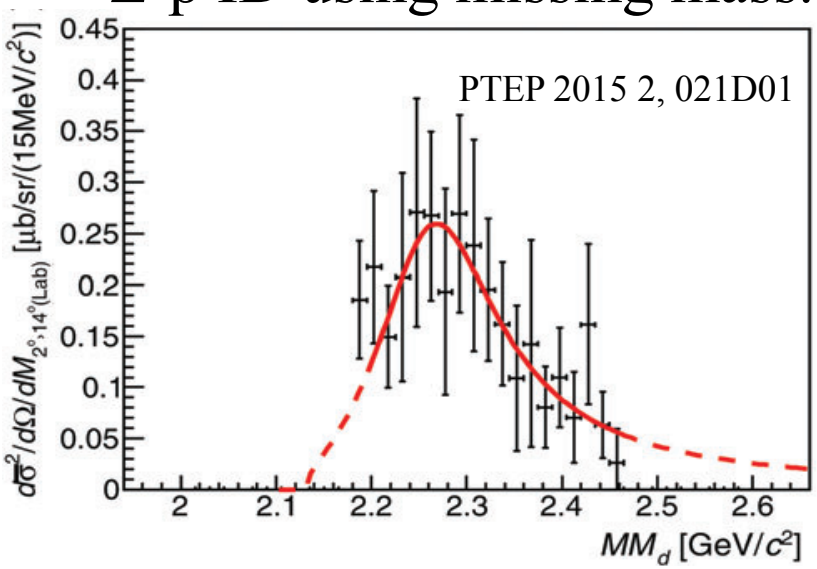
Kaonic nuclei

J-PARC E27

$d(\pi^+, K^+)X$

decay proton-tagged

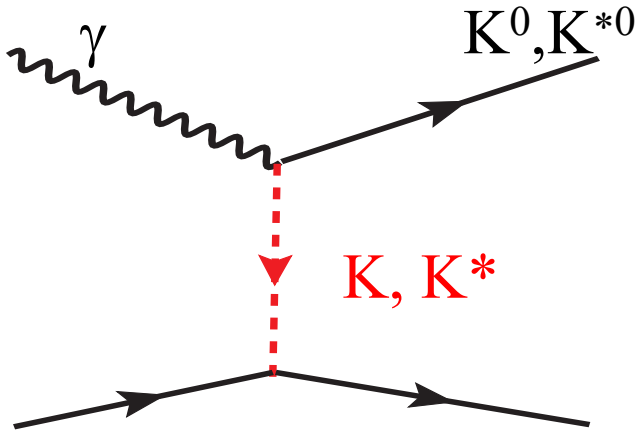
$\Sigma^0 p$ ID using missing mass.



$B.E. = 95^{+18}_{-17}{}^{+30}_{-21}$ MeV

$\Gamma = 162^{+87}_{-45}{}^{+66}_{-78}$ MeV

LEPS2



– $\gamma + d \rightarrow K^+ + \pi^- + X$

– $\gamma + d \rightarrow K_s^0 + X$

– $\gamma + d \rightarrow K^{*0} + X$

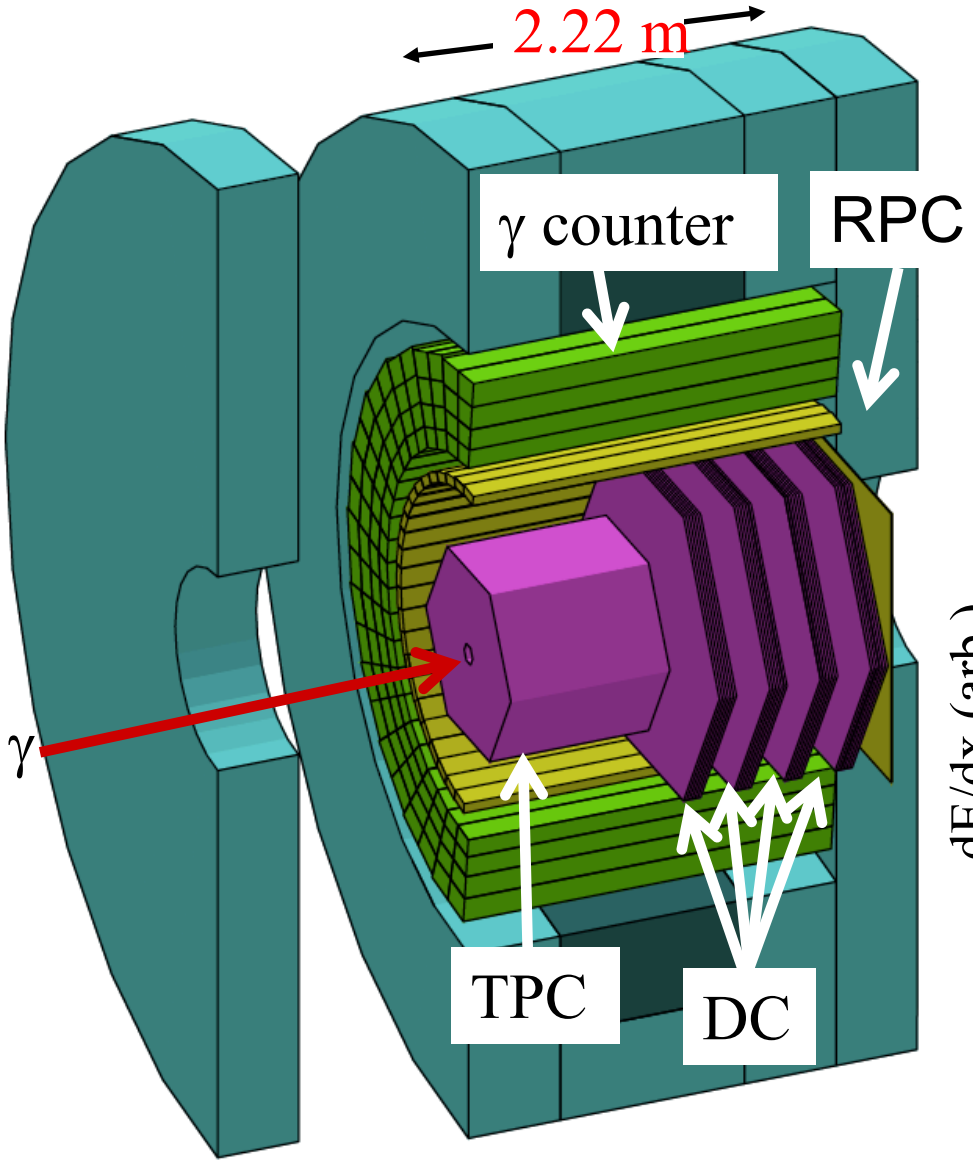
☆detect decay products

X= Λp , $\Sigma^0 p$

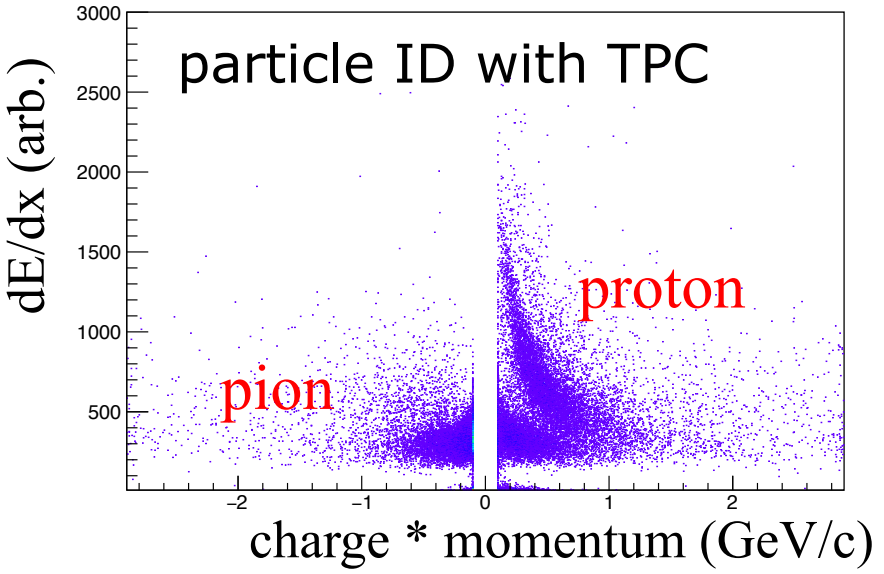
Relative B.F.

→ internal structure?

Status of detector development



- Detector commissioning started last year
- 4th drift chamber is under construction
- We aim to start physics data taking next FY!



Summary

- Colored cluster
  - Diquarks in pentaquark Θ^+
- Colorless cluster
  - $\Lambda(1405)$, Kaonic nuclei
- LEPS2 γ beam line for hadron physics.
  - **Highly polarized** photon beam up to 3 GeV with high intensity.
- **4π detector** with solenoid magnet which covers from very forward to backward
  - Simultaneous detection of Photon and charged particle.
- Commissioning run started last year
- Physics data taking ~next fiscal year.

Backup

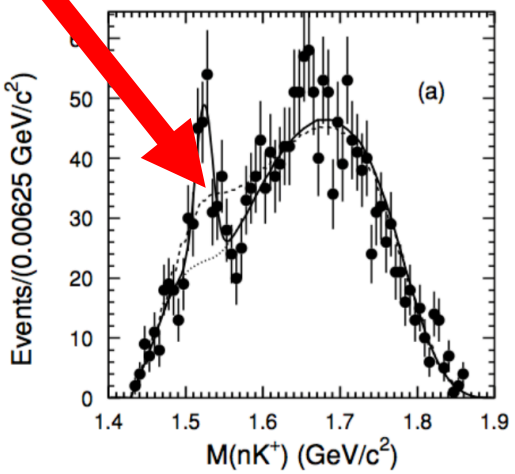
Collaboration list

- Osaka U. RCNP
  - M. Yosoi, T. Nakano, T. Hotta, S.Y. Ryu, S. Ajimura, Y. Sada, K. Mizutani, Y. Ohashi, R. Yamamoto
- Tohoku U. ELPH
  - H. Ohnishi, N. Muramatsu, A. Tokiyasu, C. Yoshida
- Kyoto U.
  - R. Kobayakawa, K. Watanabe, E. Umezaki, H. Furuta
- Gifu U.
  - M. Sumihama
- Taiwan Academia Sinica
  - W. C. Chang,
- Kyoto Sangyo U.
  - M. Niiyama

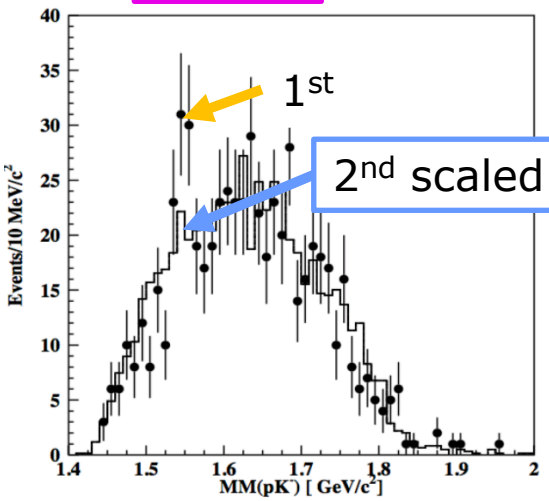
Motivation for LEPS2

ペンタクォーク (Θ)

LEPS

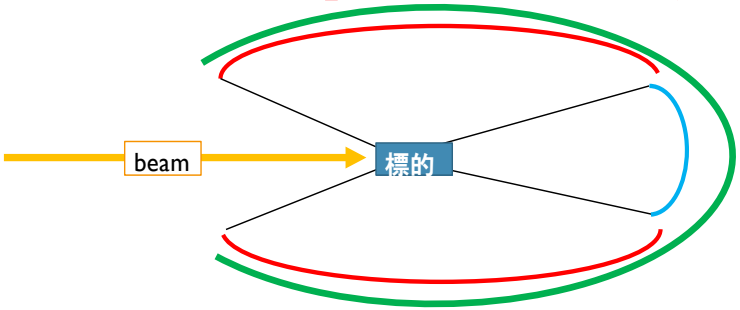


CLAS



$\gamma d \rightarrow \Theta^{+} K^{-} p$

CLAS acceptance ($20 < \theta_{lab}$)



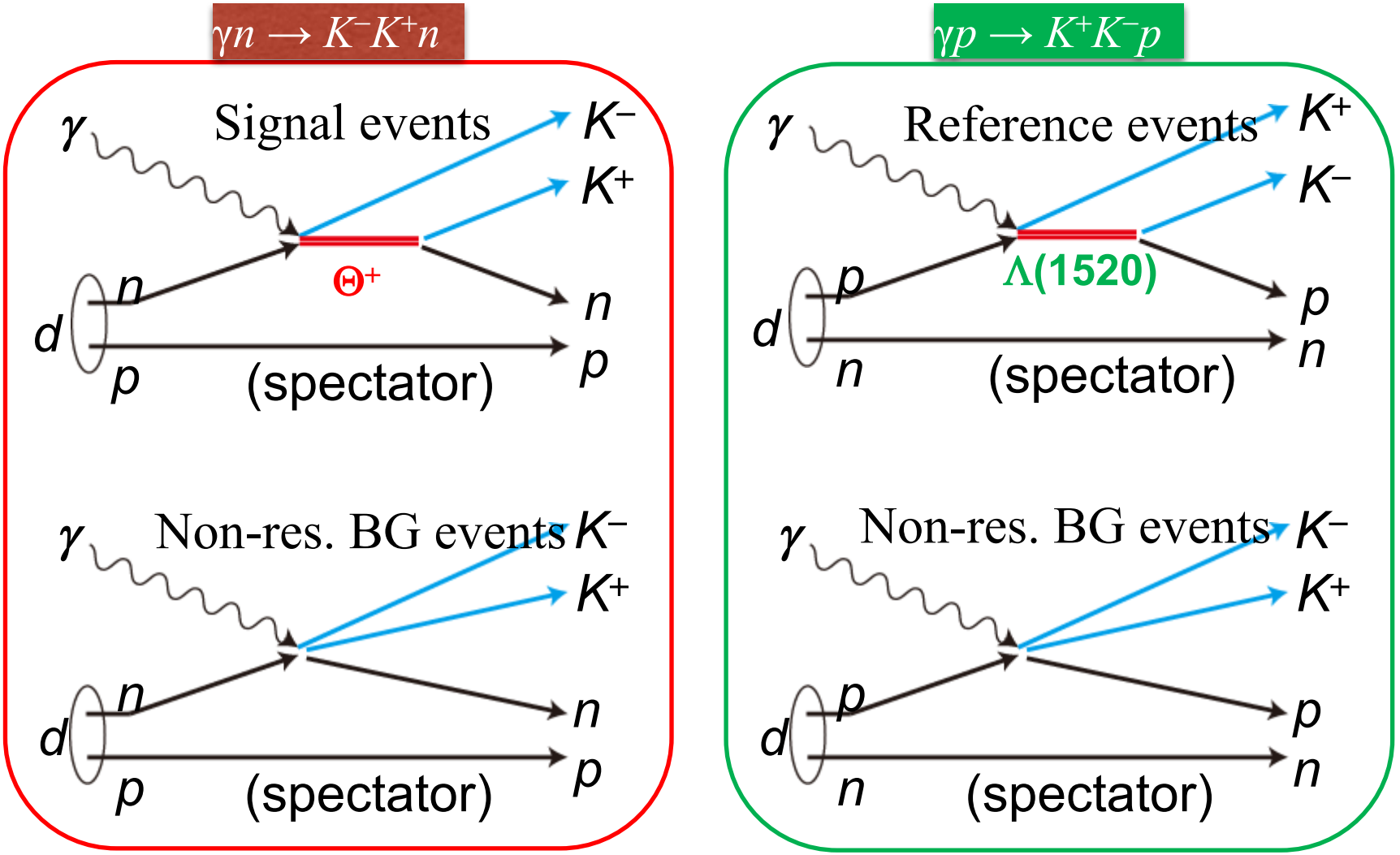
LEPS acceptance ($0 < \theta_{lab} < 20$)

LEPS2 acceptance ($7 < \theta_{lab} < 110$)

If the production rate is forward peaking, we can explain LEPS and CLAS results

→ LEPS2

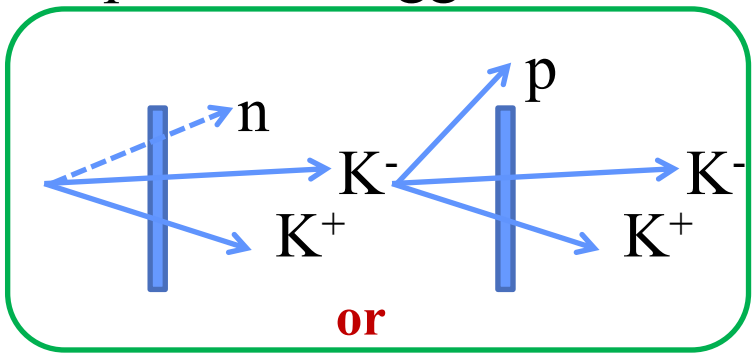
$\gamma d \rightarrow K^- \Theta^+ p \rightarrow K^- K^+ pn$ reaction



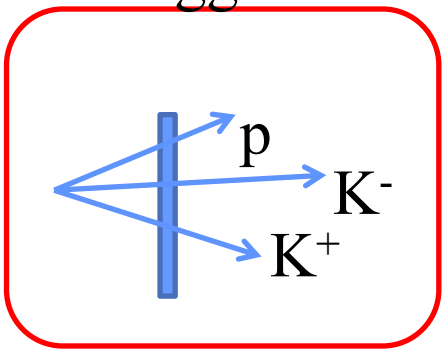
Most of ϕ events are excluded with $M(K^+K^-)$ cut.
Spectator protons can not escape from the target

2013-2014 run with large start counter

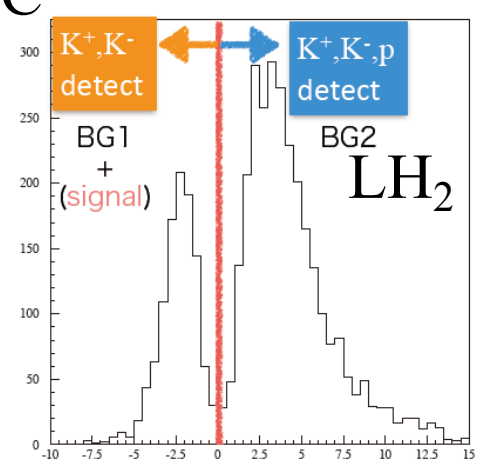
proton untagged with STC



proton tagged with STC



dE/dx in STC

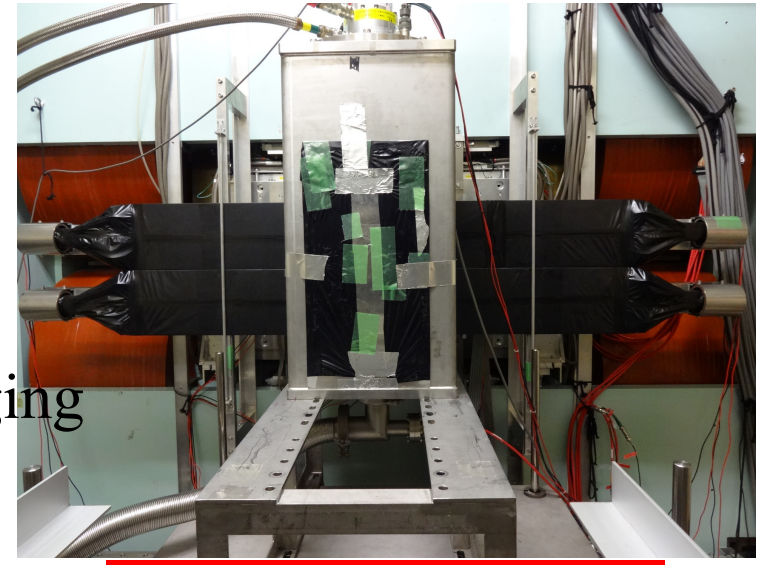


(2002 -203, 2006 – 2007)

150 mm[X] x 94 mm

Increase proton tagging efficiency

(2013 - 2014)

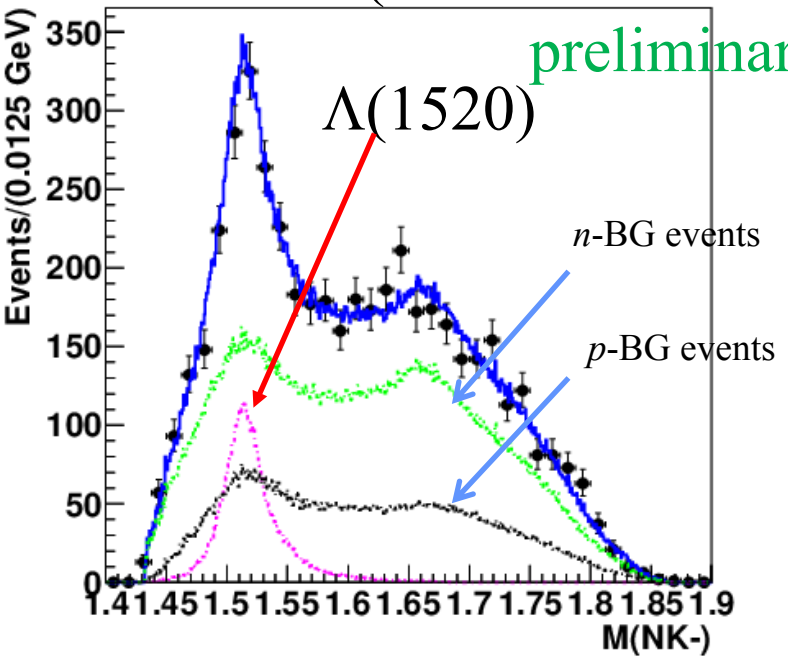


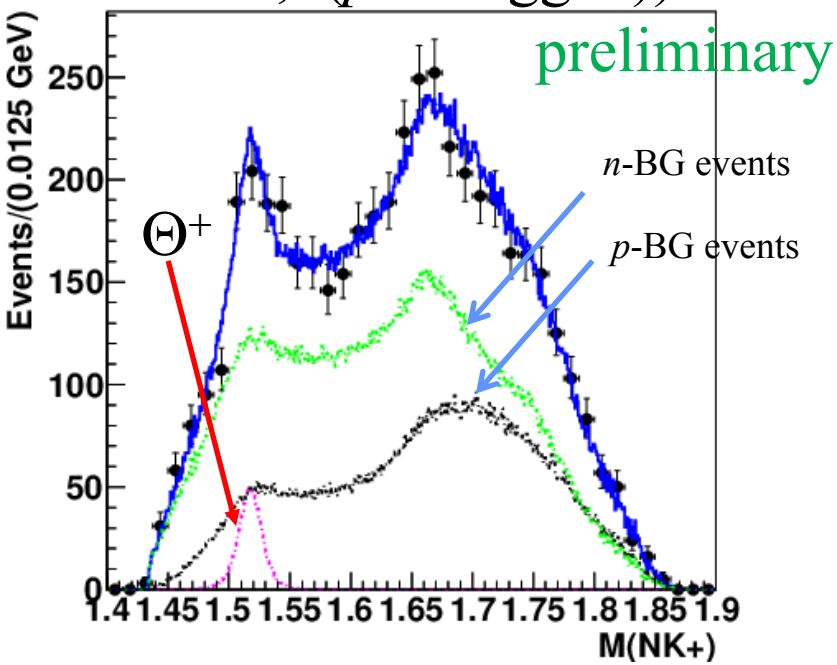
600 mm[X] x 340 mm

The present status of Θ+ analysis

- *p/n* separation has been improved with the large STC
- Simulate the mass distributions considering the possible physical processes (Θ+, Λ(1520), ϕ , non-resonant (scalar), non-resonant(vector))
- Simultaneously fit both M(NK−) and M(NK+) for *p*-untagged events
  (Λ(1520), ϕ are fixed. ← *p*-tagged events analysis)

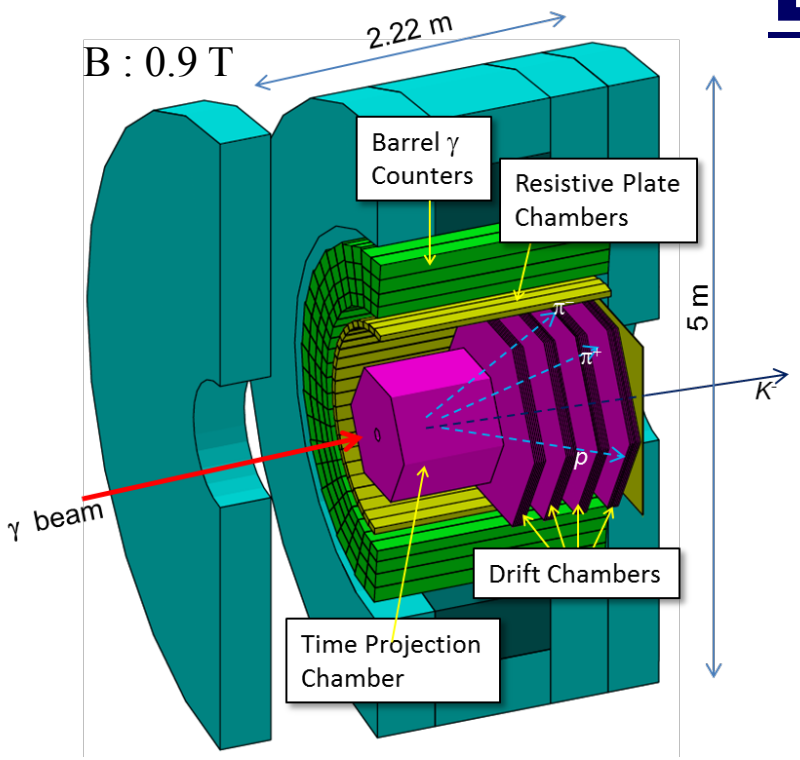
(2002-2003 & 2006-2007 data, (*p*-untagged))



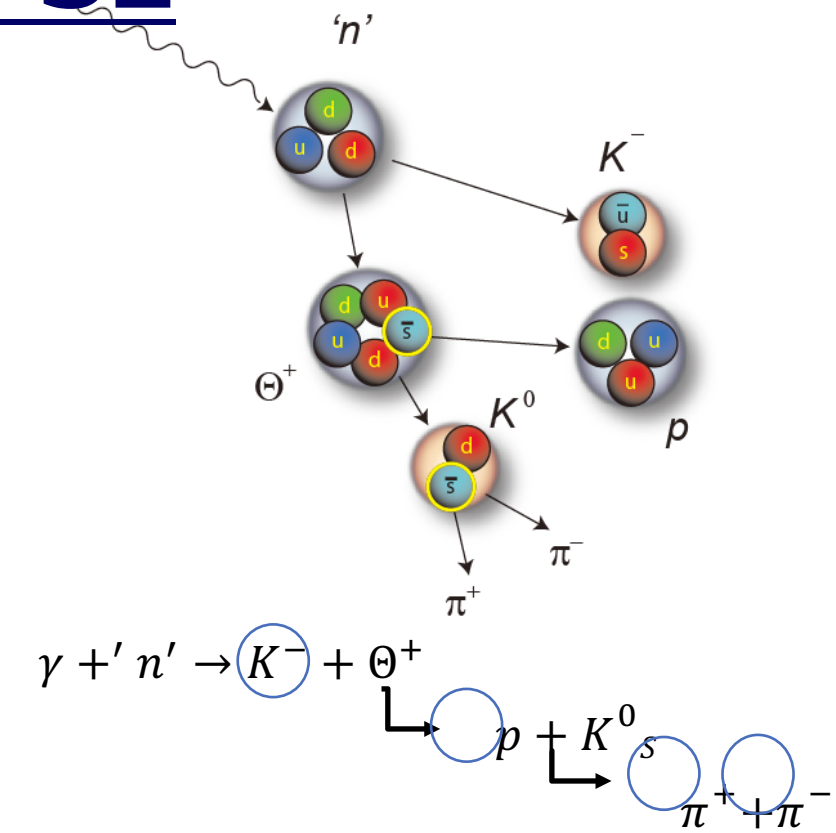


Significance of Θ+ peak : ~3 σ. 2013-2014 results will be open soon.

1st objective: Θ+ search at LEPS2



LEPS2 solenoid spectrometer



- ***No Fermi motion correction***
- ***No ϕ and non-resonant K^+K^- backg***

Mass resolution of Θ+ : ~6 MeV

(~11 MeV at LEPS)

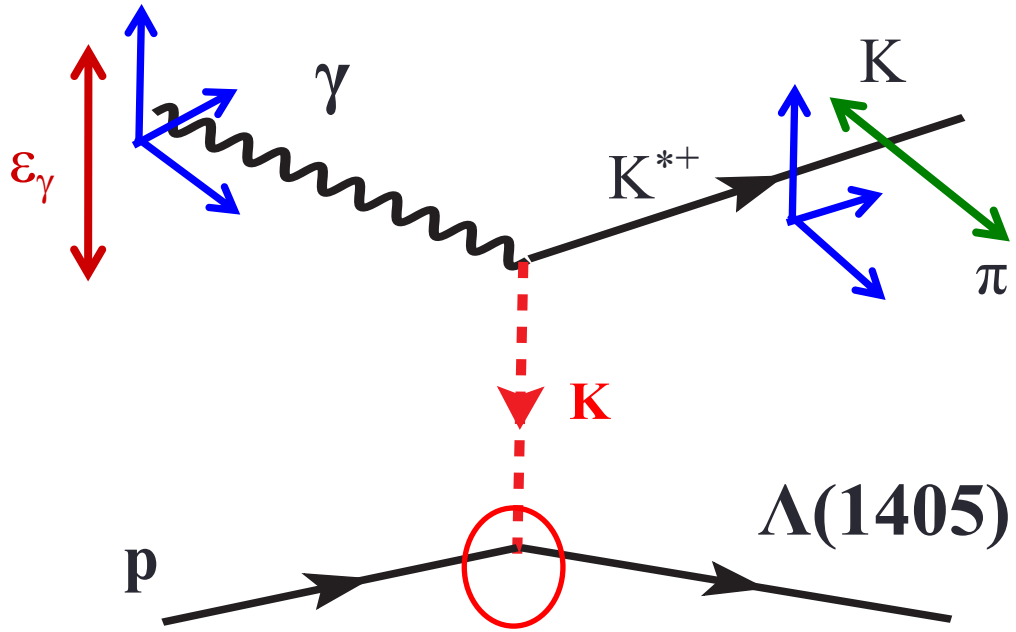
Multi-purpose large acceptance detector for fixed target exp.

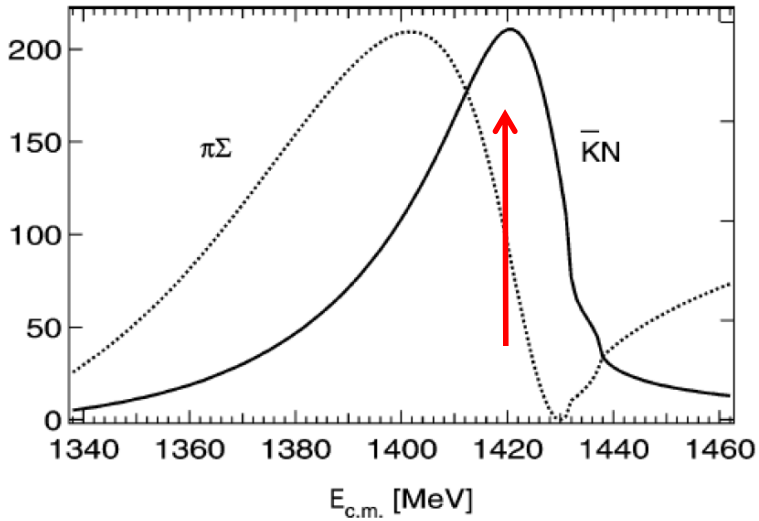
2nd: Λ(1405) with K*(892) photoproduction

$\gamma + p \rightarrow K^{*+} + \Lambda(1405)$

$\Lambda(1405) \rightarrow K^0 + \pi^+ \rightarrow \pi^+ + \pi^- + \pi^+$

Meson-baryon molecule with two poles ?





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Parity filter with linearly polarized photon

$\varepsilon_\gamma \perp K\pi$ → unnatural parity exchange (K)

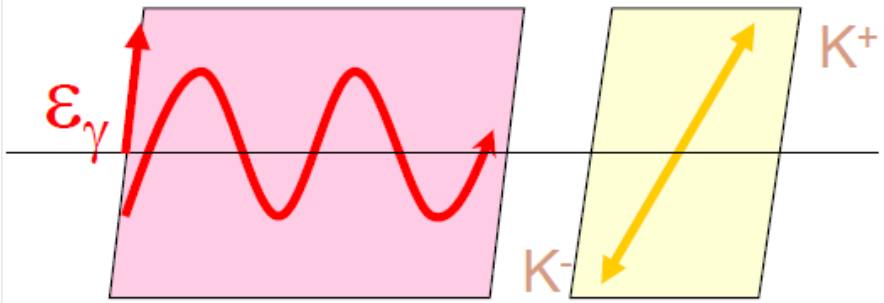
$\varepsilon_\gamma \parallel K\pi$ → natural parity exchange (K*, κ)

Measure difference of line sh

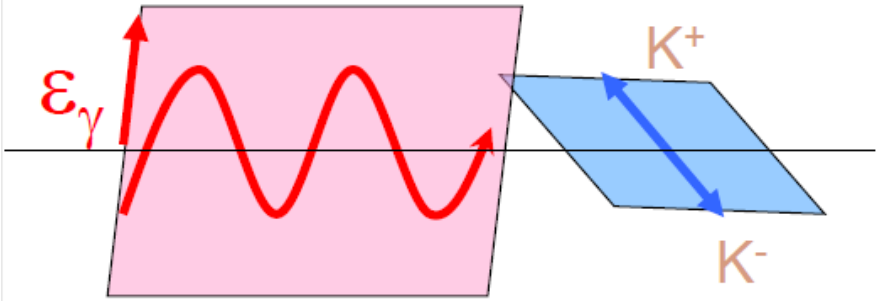
→ determine the higher pole

Parity filter w/ linearly polarized photon

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



Photon Polarization



Decay Plane $/\!/ \vec{\gamma}$

natural parity exchange $(-1)^J$

(Pomeron, 0+ glueball, scalar mesons)

Decay Plane $\perp \vec{\gamma}$

unnatural parity exchange $-(-1)^J$

(Pseudoscalar mesons π,η)

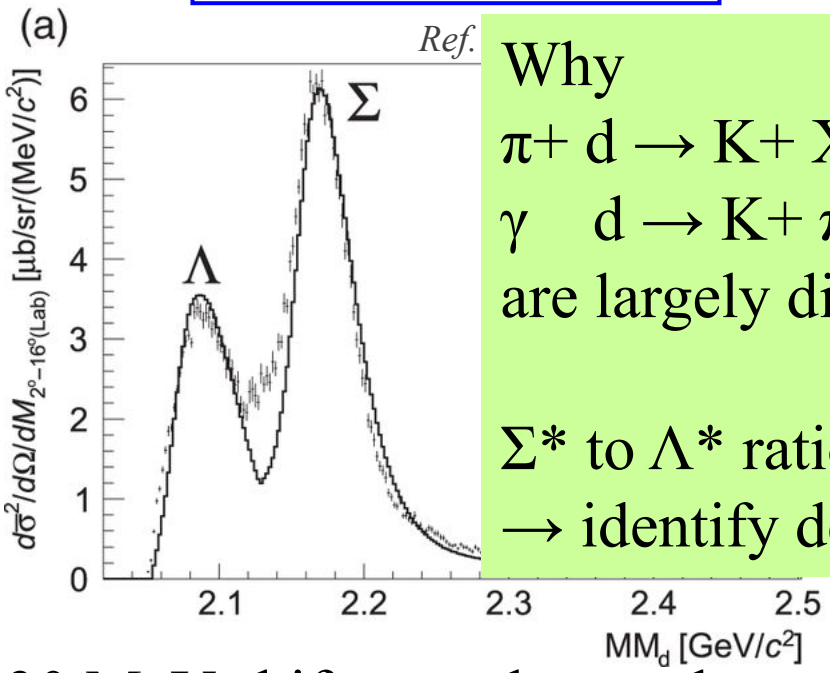
→ *Act as a parity-filter in t-channel exchange!!*

Physics motivation for LEPS2 (III)

Kaonic nuclei search

If Λ(1405) is K^{bar} N molecule, K^-pp system can be strongly bound state.

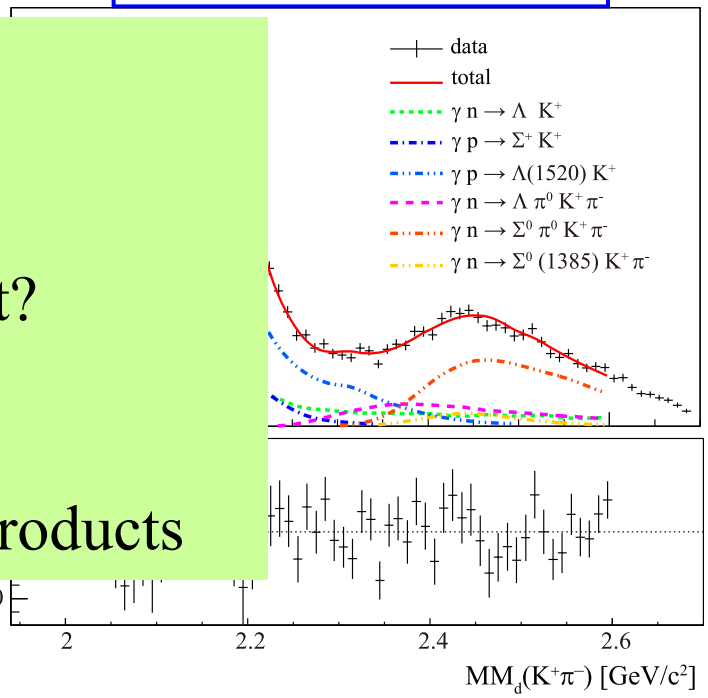
MM(K^+) *J-PARC E27*



Why
π+ d → K+ X
γ d → K+ π- X
are largely different?

Σ* to Λ* ratio?
→ identify decay products

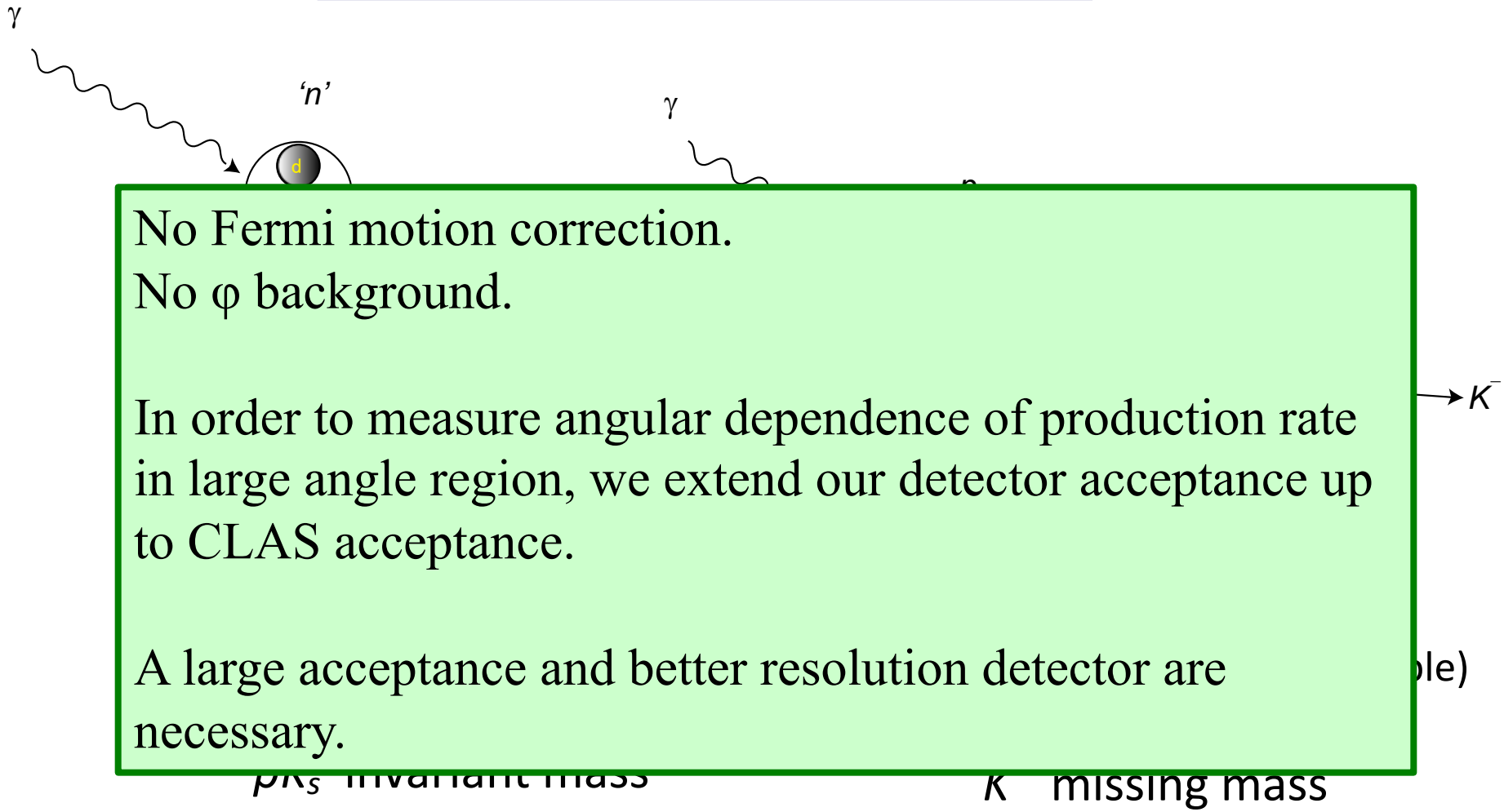
MM($K^+\pi^-$) *LEPS*



30 MeV shift was observed in Y* region
(caused by Y*N interaction?)

no shift was observed in Y* region

Θ^+ Search at LEPS2

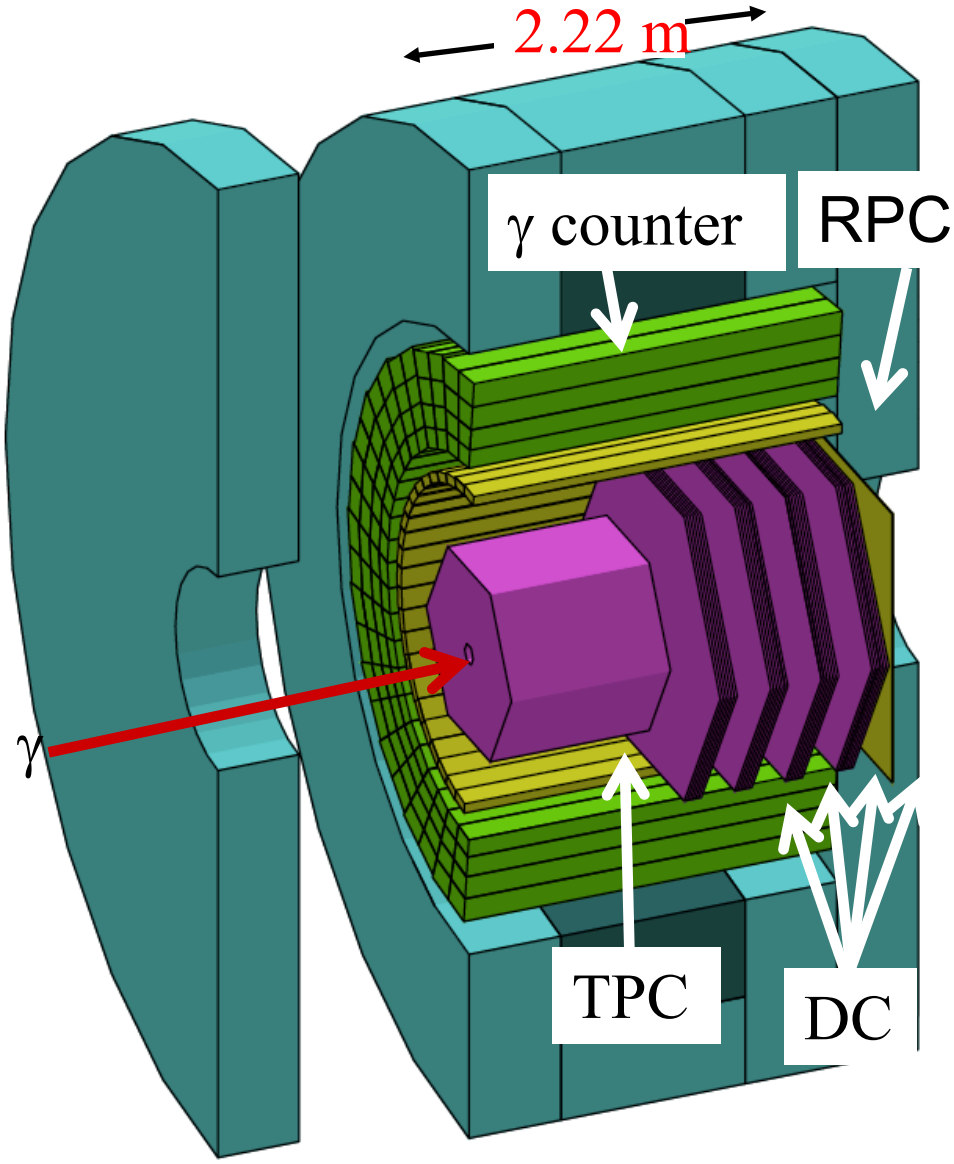


No Fermi motion correction.
No φ background.

In order to measure angular dependence of production rate in large angle region, we extend our detector acceptance up to CLAS acceptance.

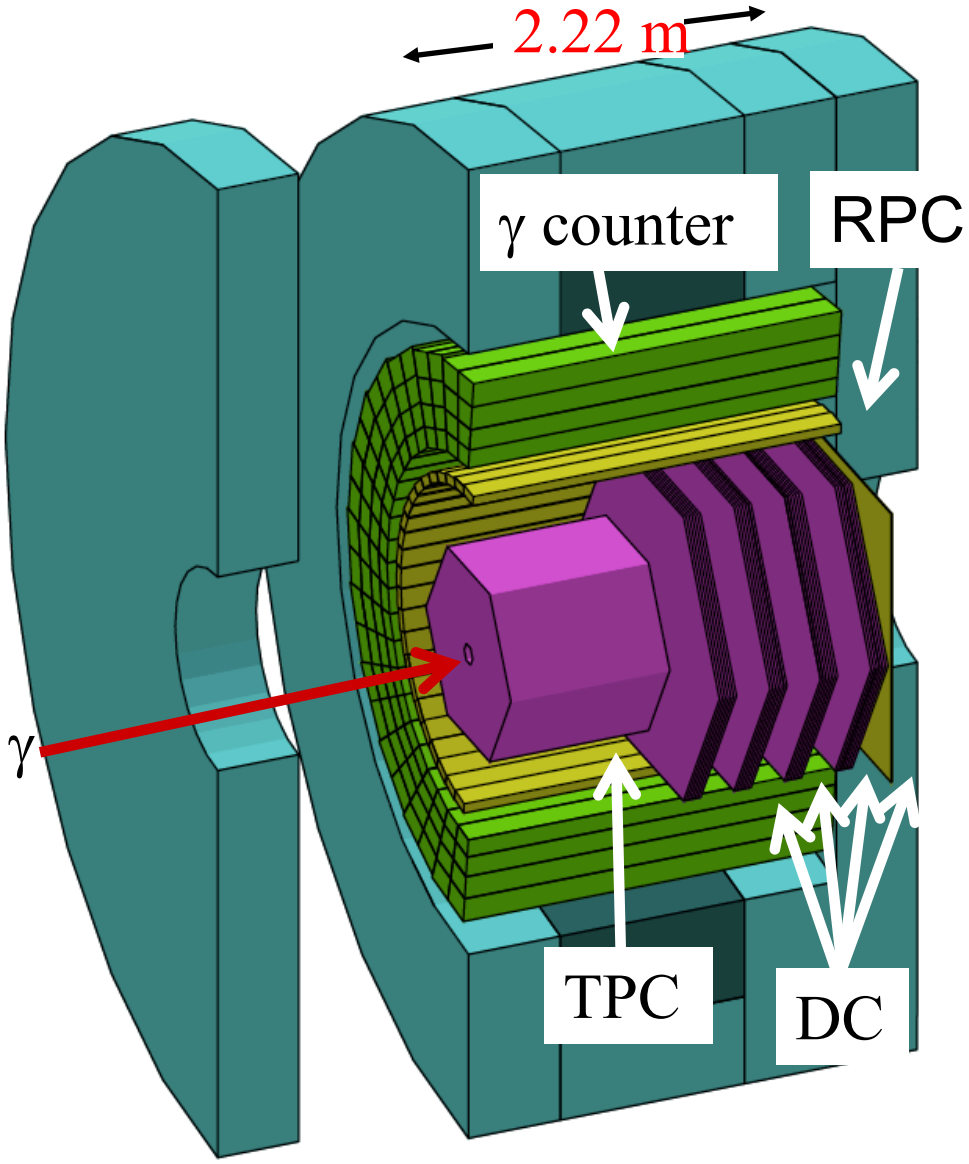
A large acceptance and better resolution detector are necessary.

Solenoid spectrometer



- Sideway tracker
- Time Projection Chamber (TPC)
  - R=655 mm, 24 layer
  - $\sigma_{r\varphi}$=150 μm, σ_z=2 mm
- Forward tracker
  - 4 drift chambers (DC)
  - 6 plane
  - σ_{xy}=150 μm
- Time-of-flight
  - Resistive Plate Chamber (RPC)
  - Δt=70 ps
- Aerogel Cherenkov counters
  - n=1.03, 1.05
- Barrel γ counter
  - Lead plastic sandwich 14.3X_0

Invariant mass resolution



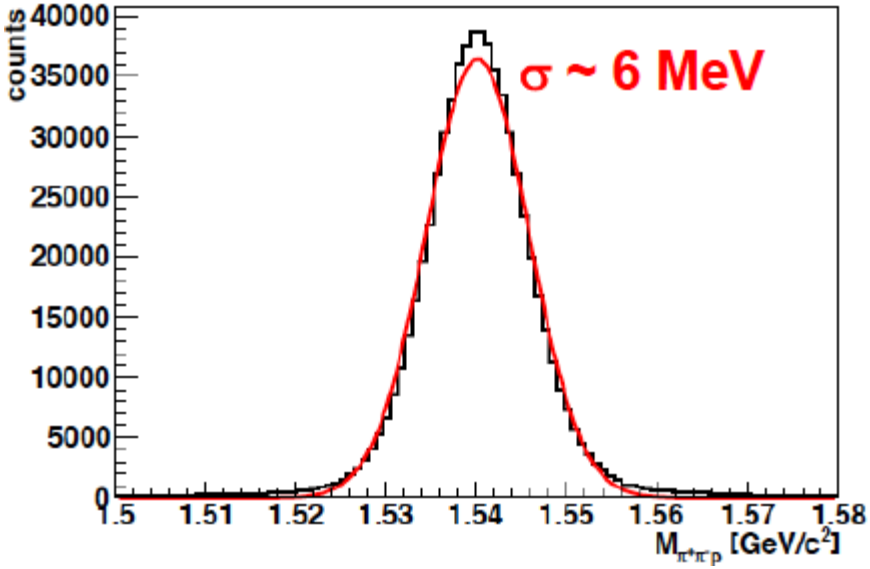
Strangeness tagging

$$\gamma + n \rightarrow K^{+} + \Theta^{+}$$

$$\rightarrow p\ K^{0}$$

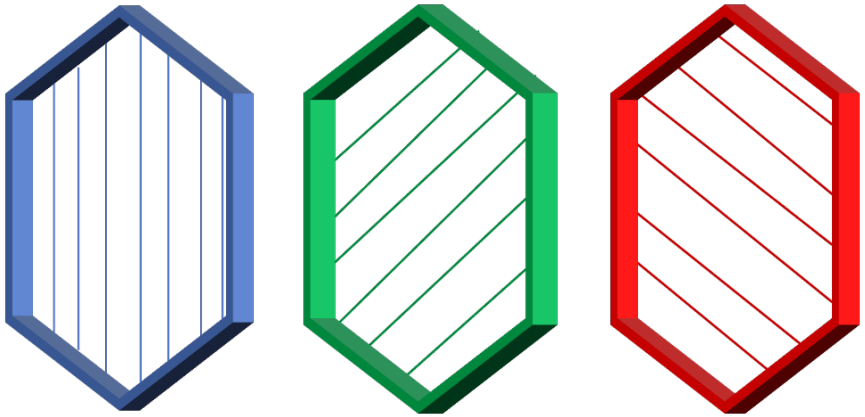
$$\rightarrow \pi^{+}\ \pi^{-}$$

Invariant Mass measurement

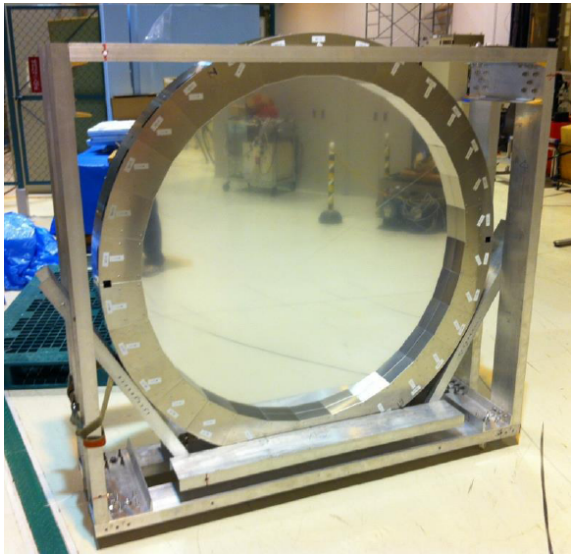


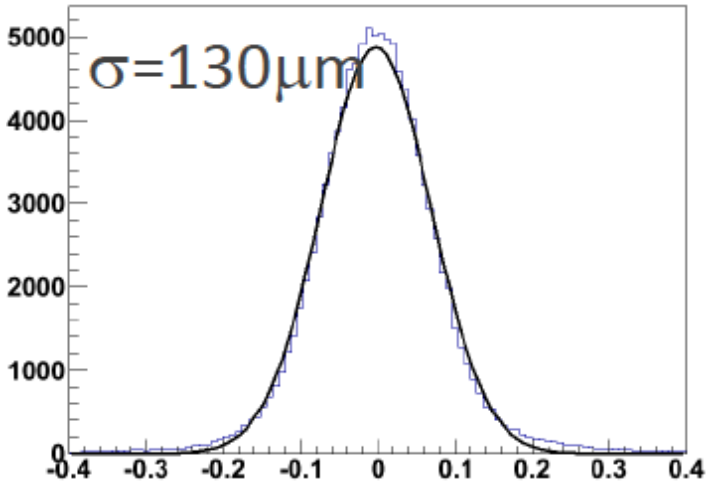
DC

XX'(0°) UU'(+60°) VV'(-60°)

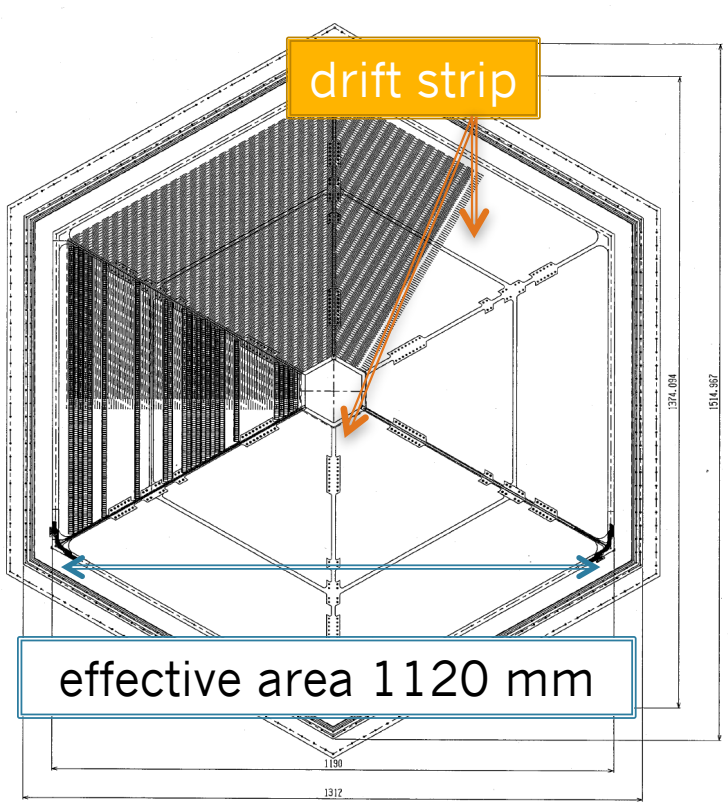


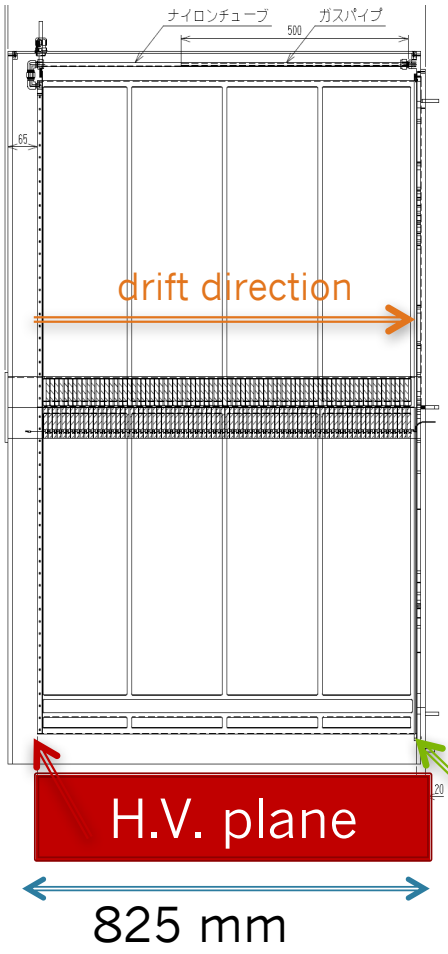
80 ch/plane x 6 = 480 ch





Specification of TPC

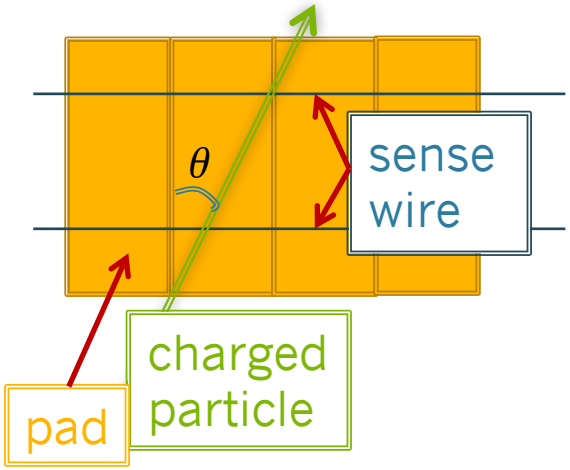




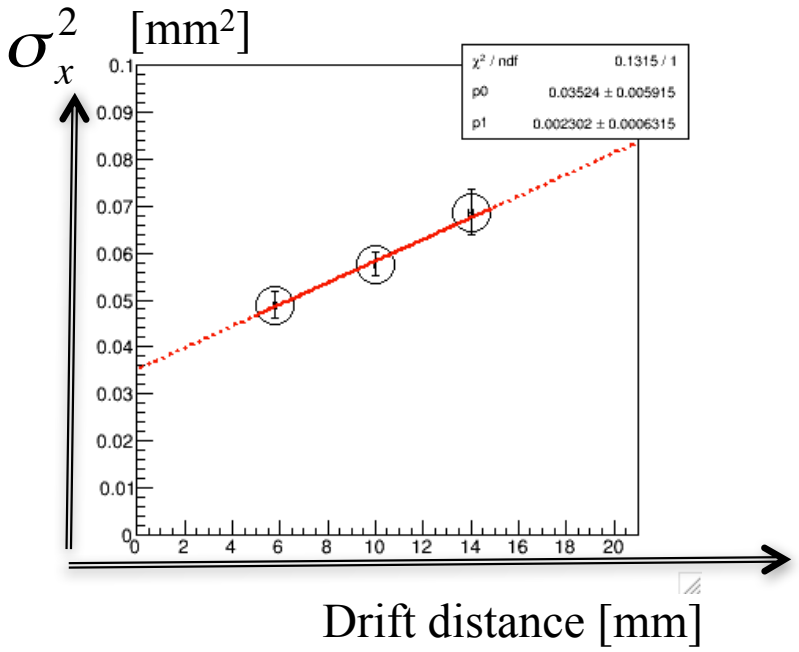
anode wire pitch
5 mm
anode-pad distance
3.5 mm
pad size
4.6 mm × 10 mm
number of pad layers
24
number of pads
10830

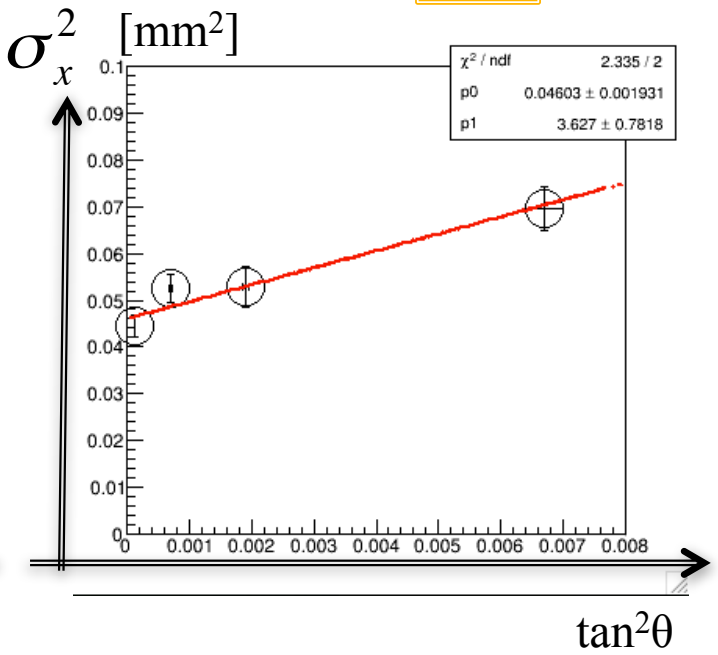
Spatial resolution of prototype TPC

- Prototype TPC with same wire-pad configurations.
- σ_x=150 μm is required to reconstruct $\Theta^+ \rightarrow K^0_s\, p$ with 6 MeV resolution.



$$\sigma_x^2 = \sigma_{0x}^2 + \sigma_{T,D}^2 \cdot L_D + \sigma_{P,W}^2 \cdot \tan^2 \theta_{T,D}^2$$





Spatial resolution of prototype TPC

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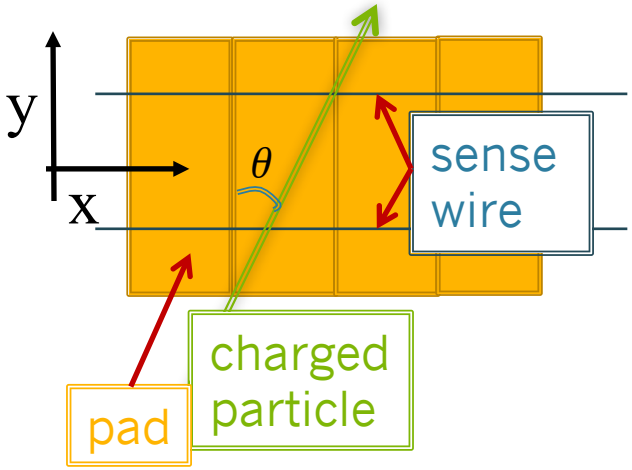
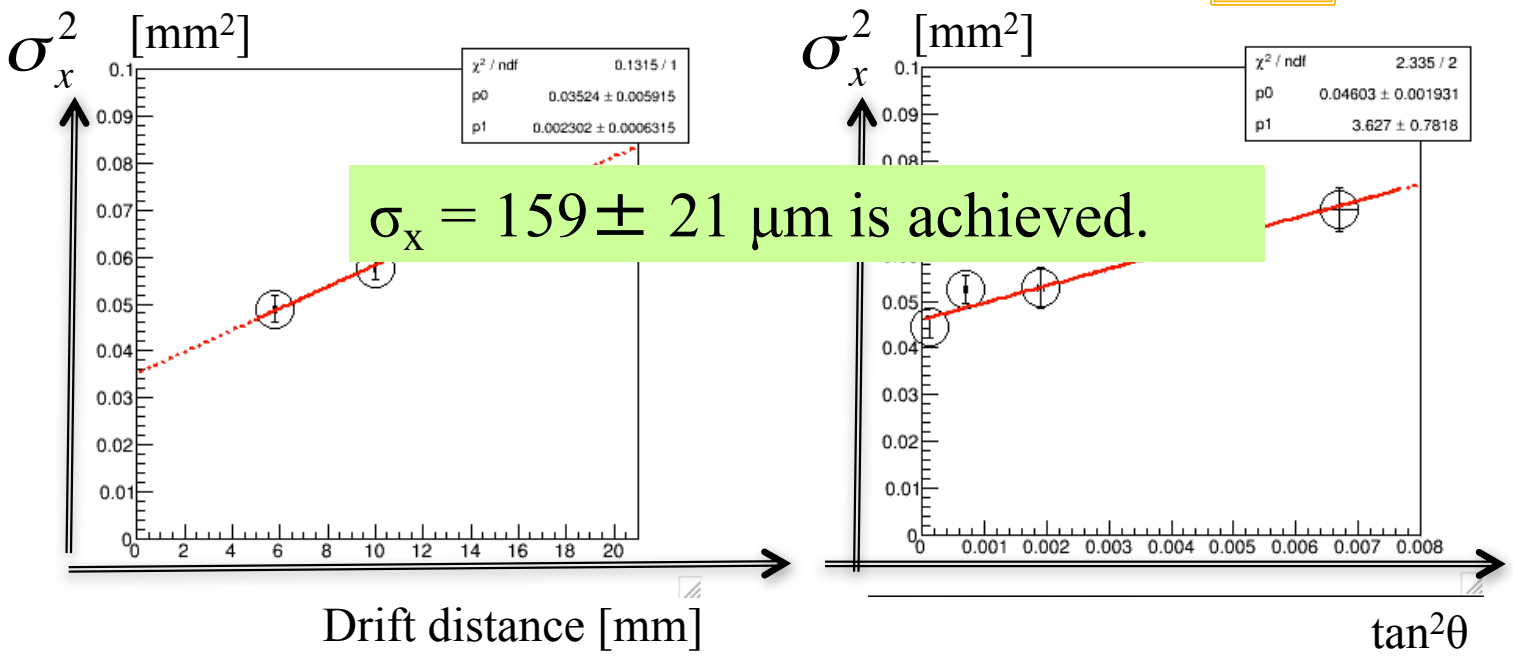


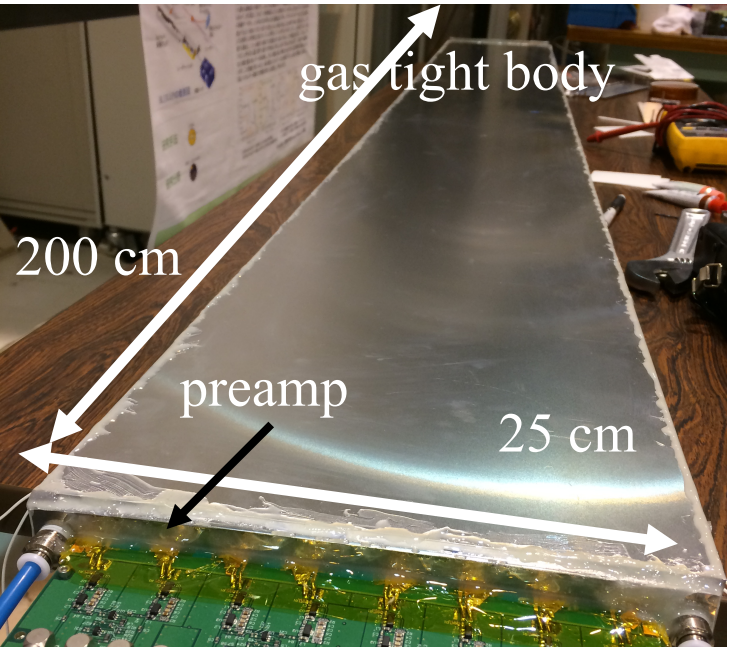
$$\sigma_x^2 = \sigma_{0x}^2 + \sigma_{T,D}^2 \cdot L_D + \sigma_{P,W}^2 \cdot \tan^2 \theta_{T,D}^2$$

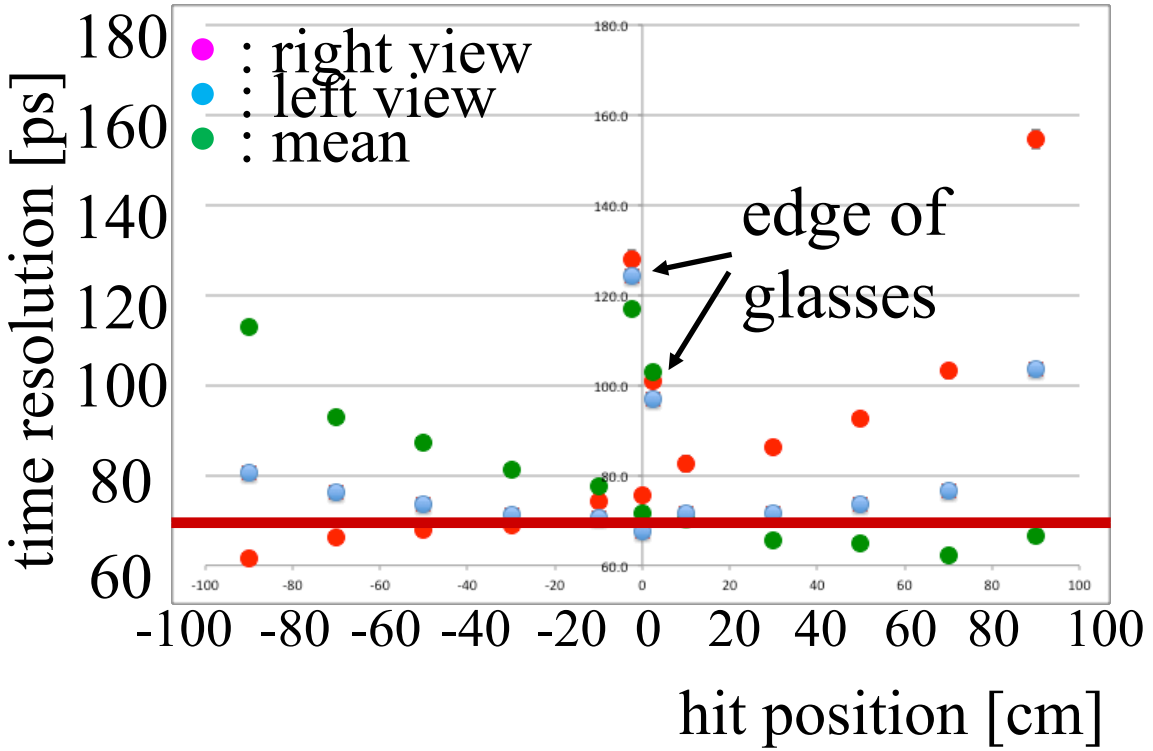


σ_x = 159± 21 μm is achieved.

2m Barrel RPC

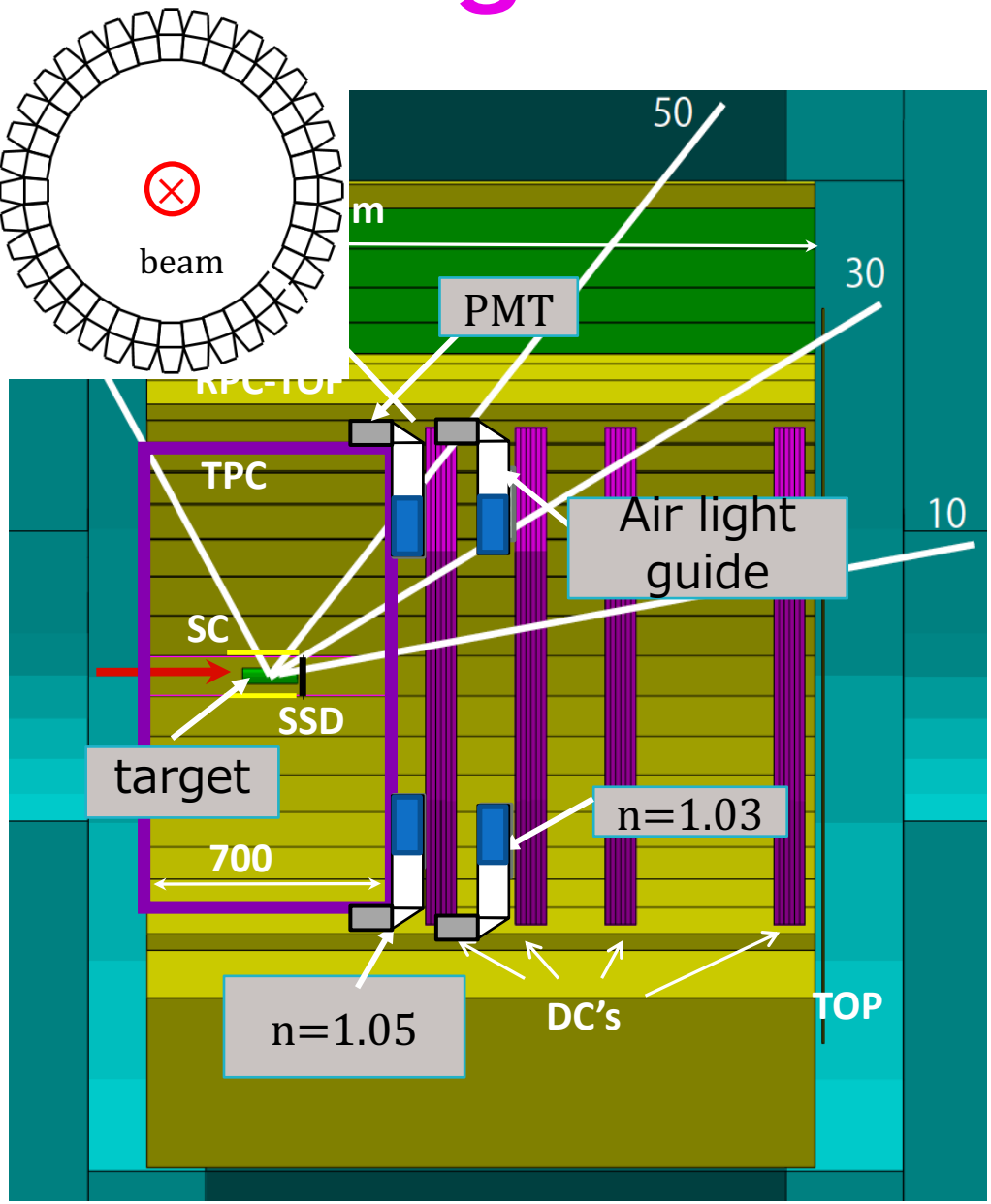
Goal: 3+3σ separation for pi/K below 1 GeV/c.
(K- associated with Theta+)
70 ps time resolution is required.



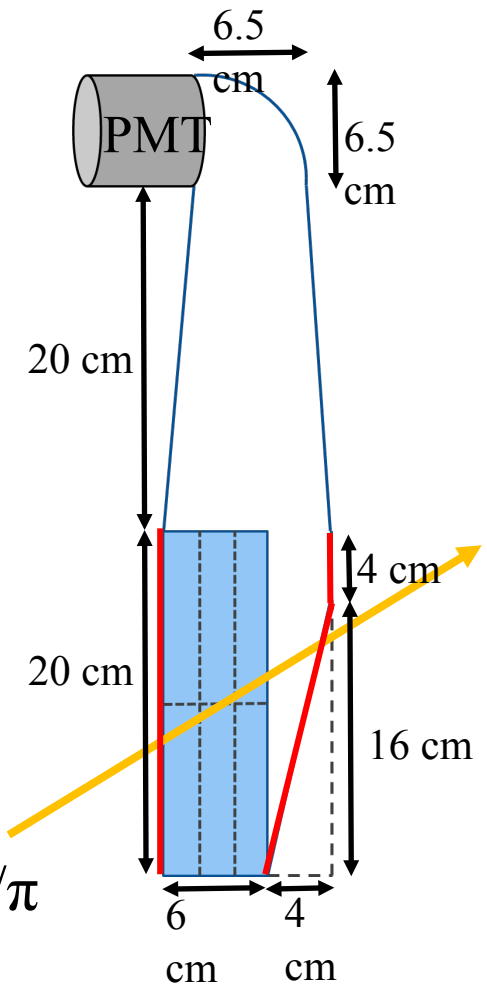


~70 ps is achieved over 2m range using near side view.

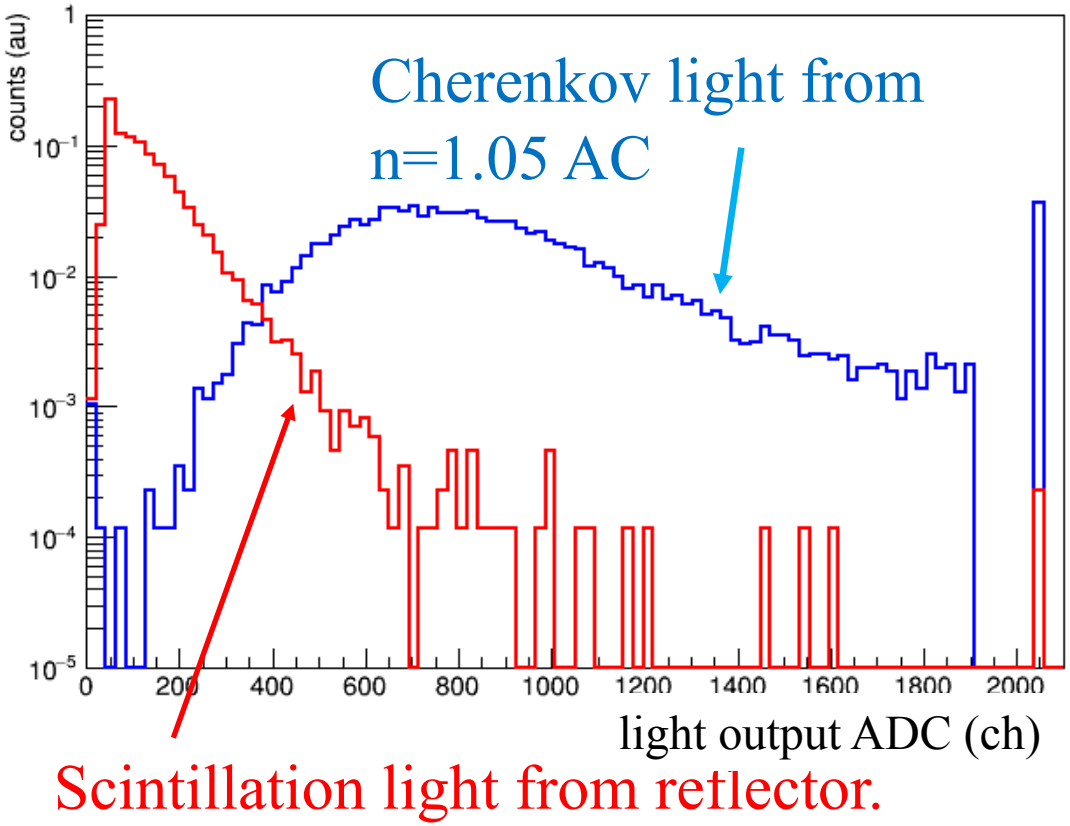
Aerogel Cherenkov counter



K/π separation above 1 GeV/c.



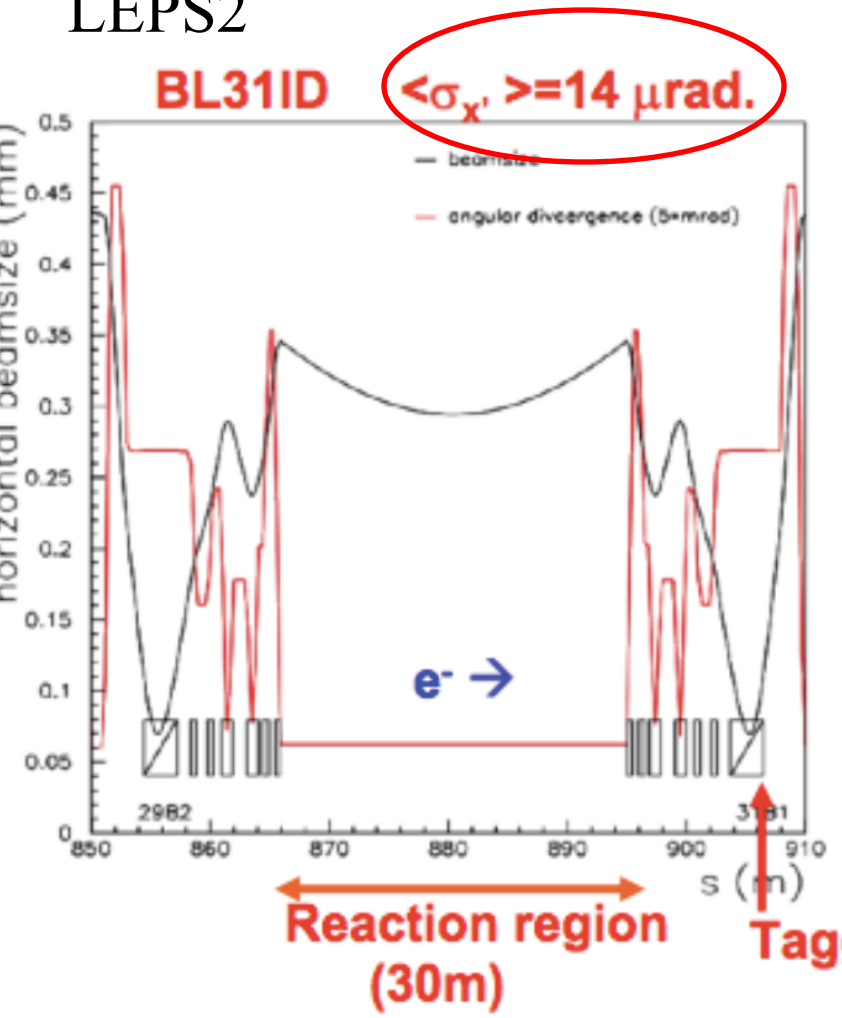
Aerogel Cherenkov counter



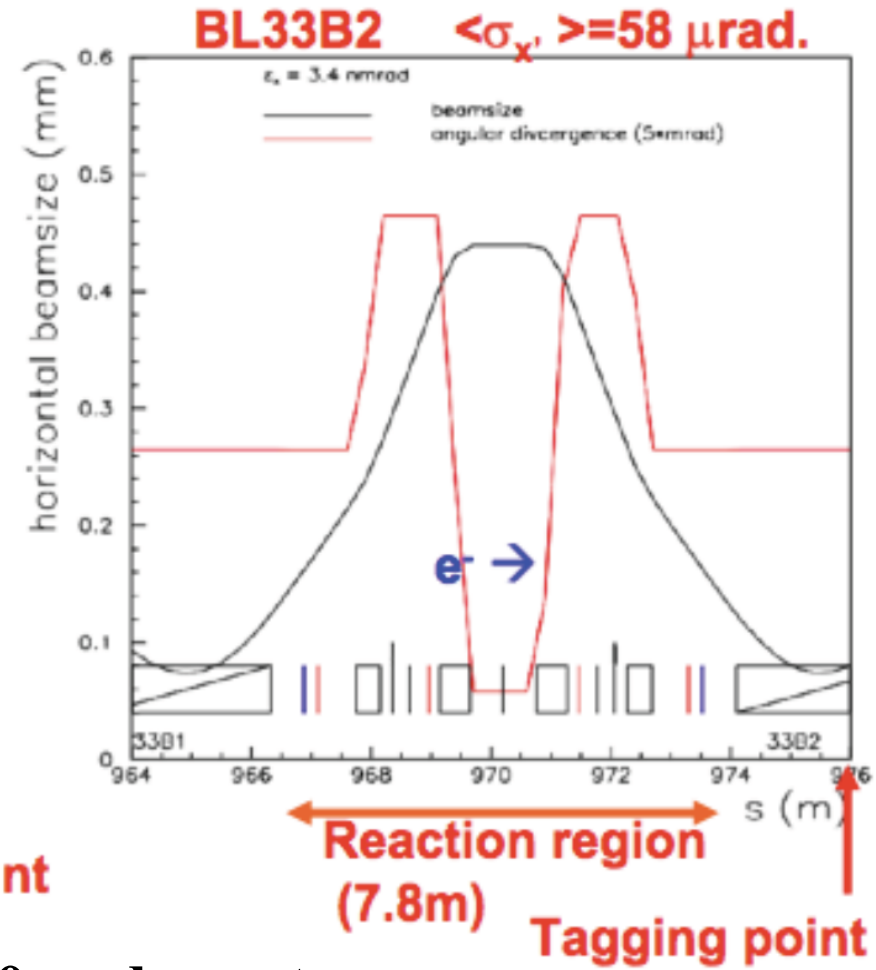
We tested with electron beam and estimate Cherenkov light from pions @ 1 GeV/c.
99.6% efficiency is achieved for pion with 3.5% over veto rate for kaon.
Test with pion beam is on-going.

Good e beam emittance in SP8

LEPS2



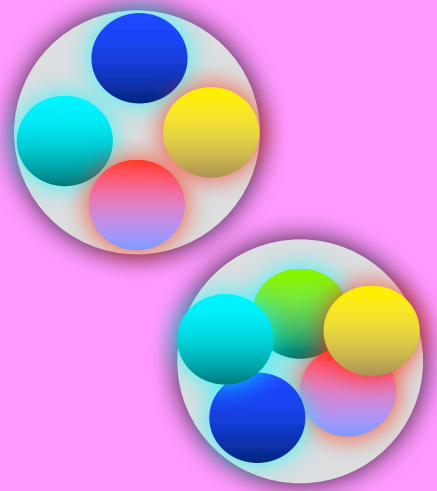
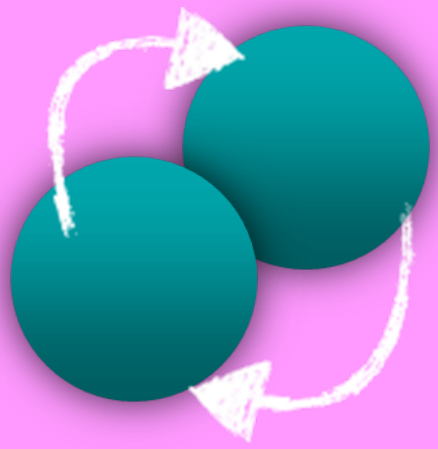
LEPS1



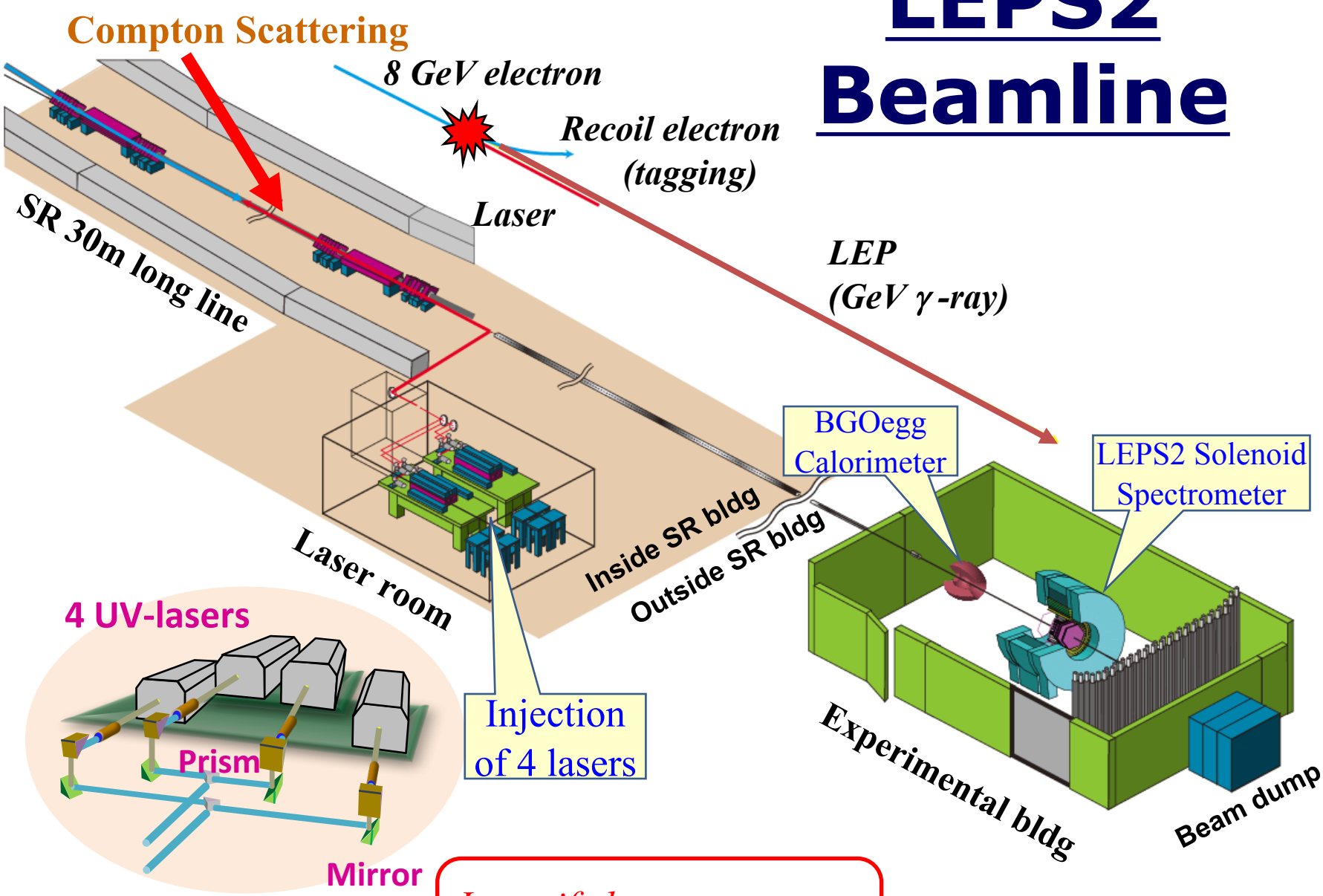
γ rays are delivered to 150 m downstream.

Beam size @ target (RMS): x ~2cm, y~1cm

Two types of exotic hadrons

	4, 5, 6 quarks in hadron Possible colored cluster	Haronic molecule Colorless cluster
		
Spatial size	Compact（<~1 fm）	Wide（~ a few fm）
Example	***Not established yet***	X(3872): $\bar{D}^{*0}\,D^{0}$

LEPS2 Beamline

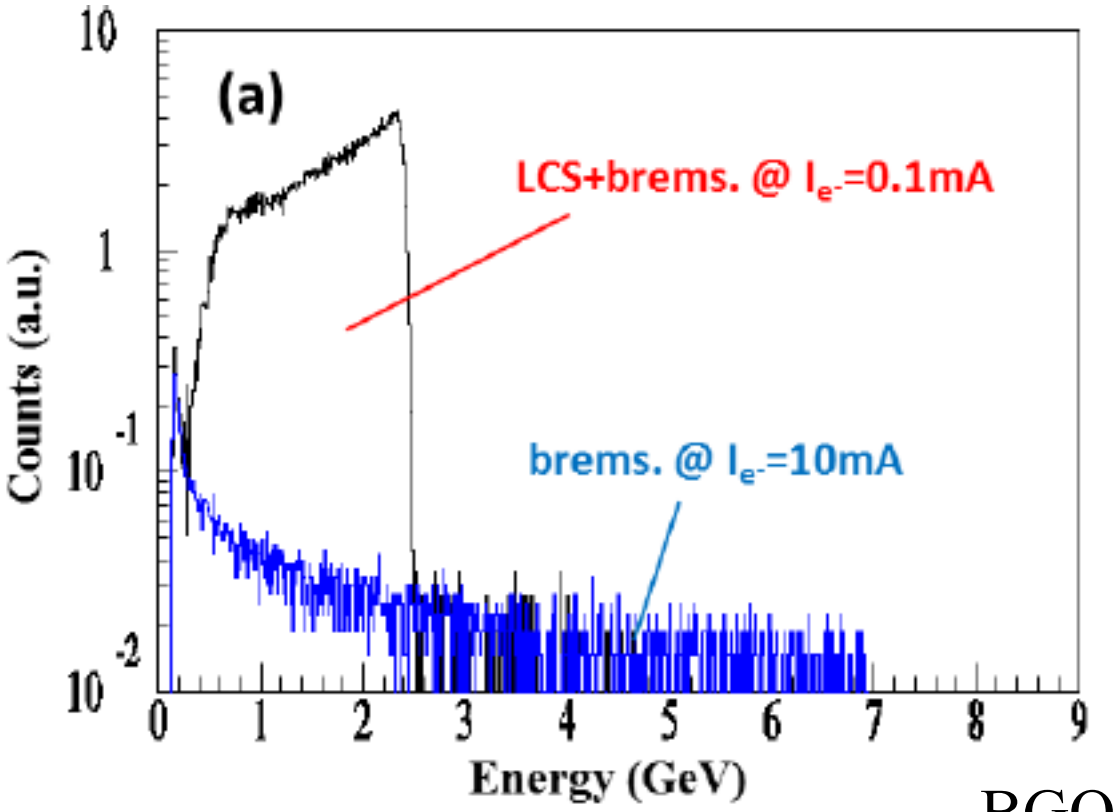


Intensify beam,
Cover large solid angle

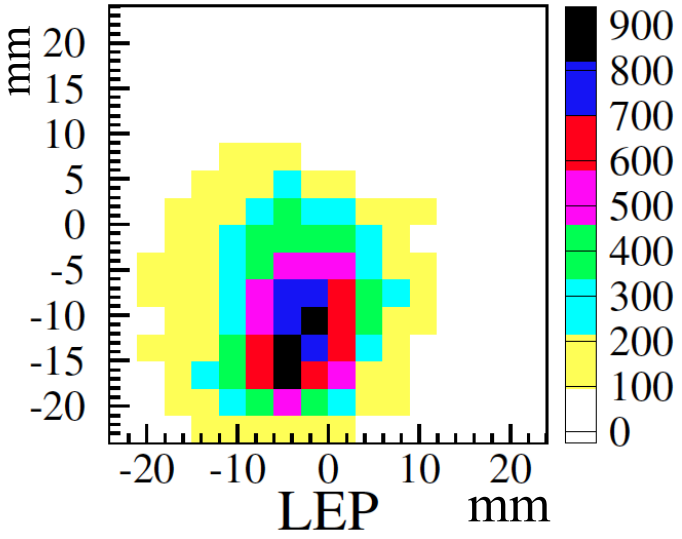
Laser injection system

◆2013.1.27 first beam
(1.5-2.4 GeV~4Mcps with a single 24W laser)

Energy spectra of photon beam



Beam size in the experimental hutch



BGOegg experiment from 2013