Hadron physics at LEPS/ LEPS II and Belle

M. Niiyama (Kyoto U.)

Contents

- LEPS
  - coherent φ-meson photoproduction from ^{4}He.
- LEPS2
  - beam asymmetry (Σ) for η-meson photoproduction.
- Belle
  - production rates of hyperons and charmed baryons from e^+e^- annihilation near $\Upsilon(4S)$.

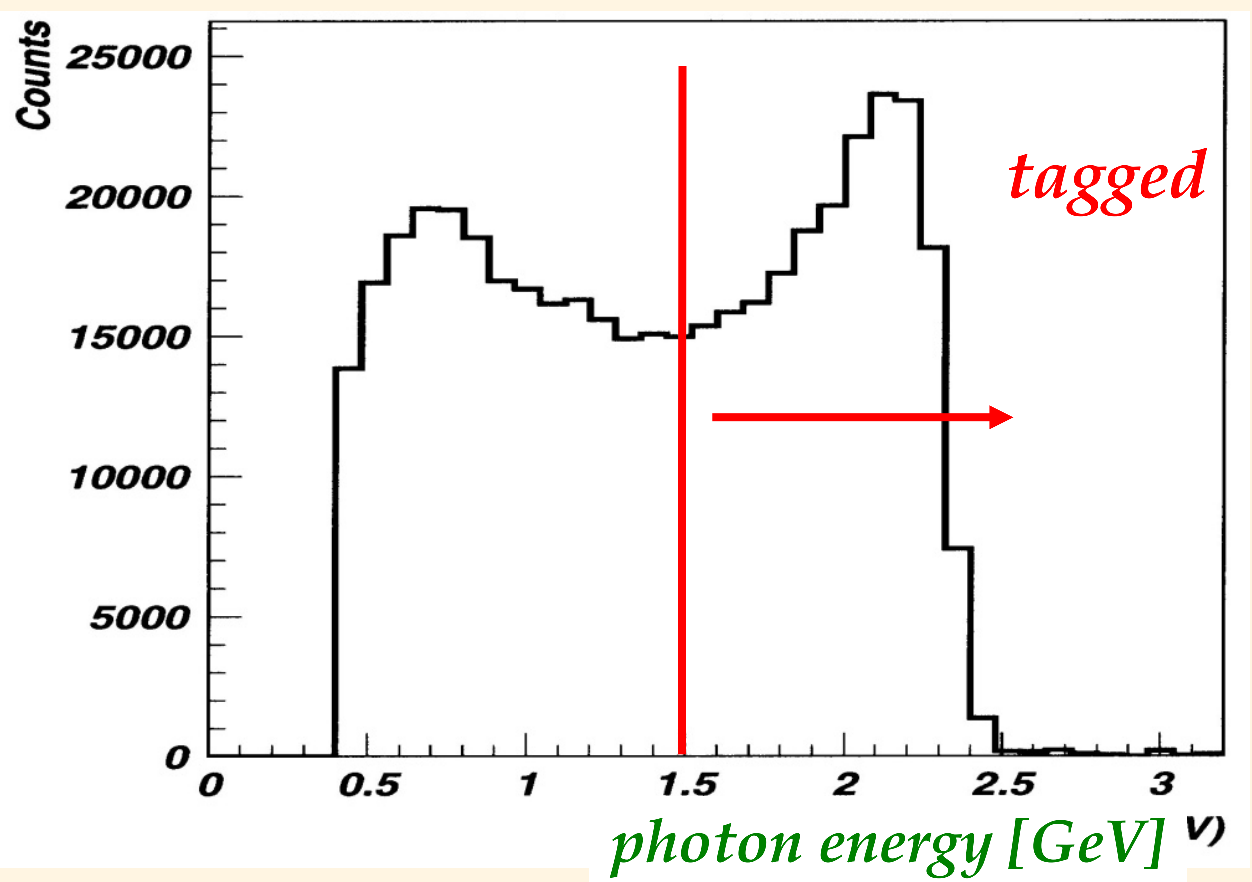
LEPS

Coherent φ-meson photoproduction from ^4He

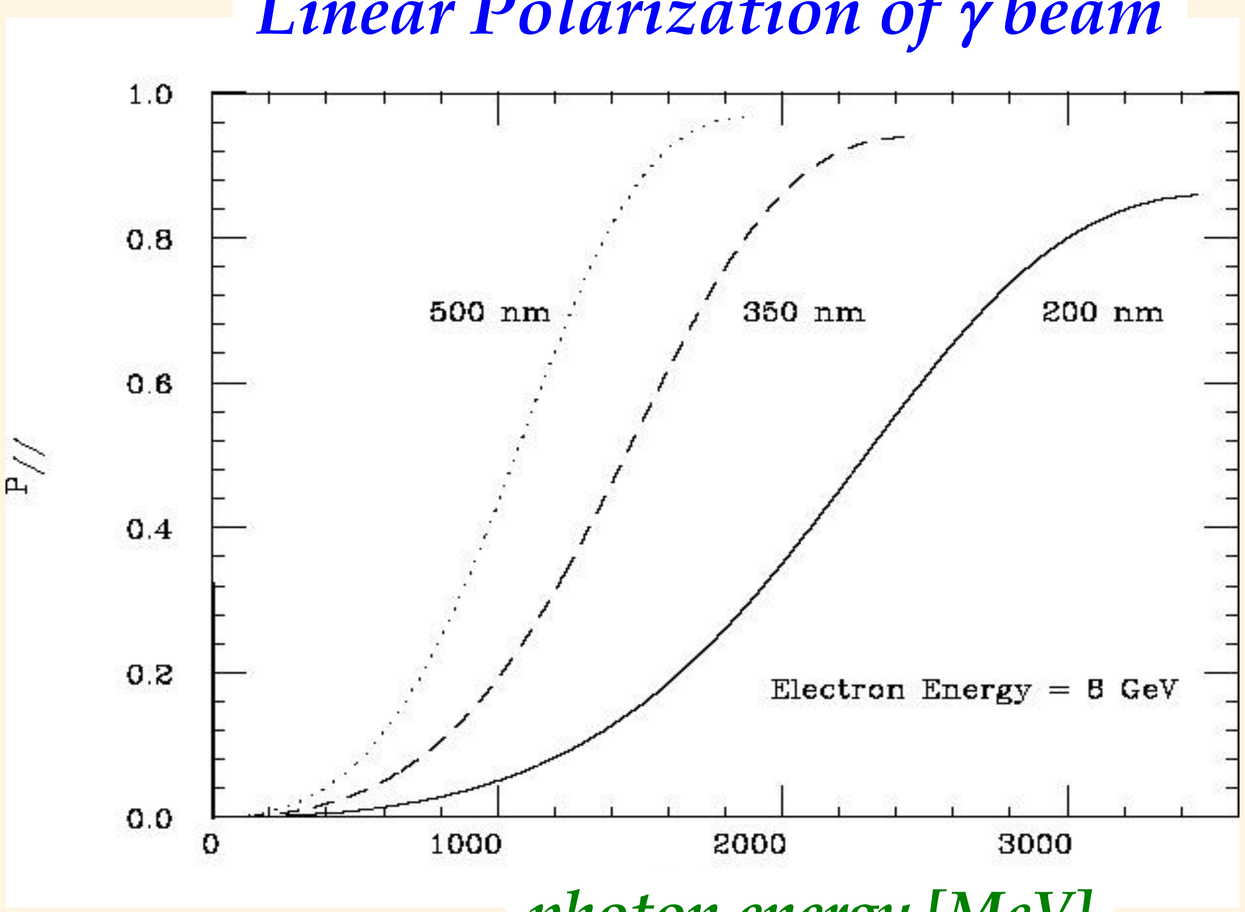
LEPS facility

- Backward Compton scattering of laser photons with 8 GeV electrons in SPring-8
  - 351nm Ar laser (3.5eV) 8W ~ 2.4 GeV photon
  - 266nm Solid+BBO (4.6eV) 1W ~3.0 GeV photon
- Laser Power ~6 W (351nm) Photon Flux ~1 Mcps (2.4 GeV)
- E_γ measured by tagging a recoil electron E_γ >1.5 GeV, ΔE_γ ~10 MeV
- Laser linear polarization 95-100% ⇒ Highly polarized beam

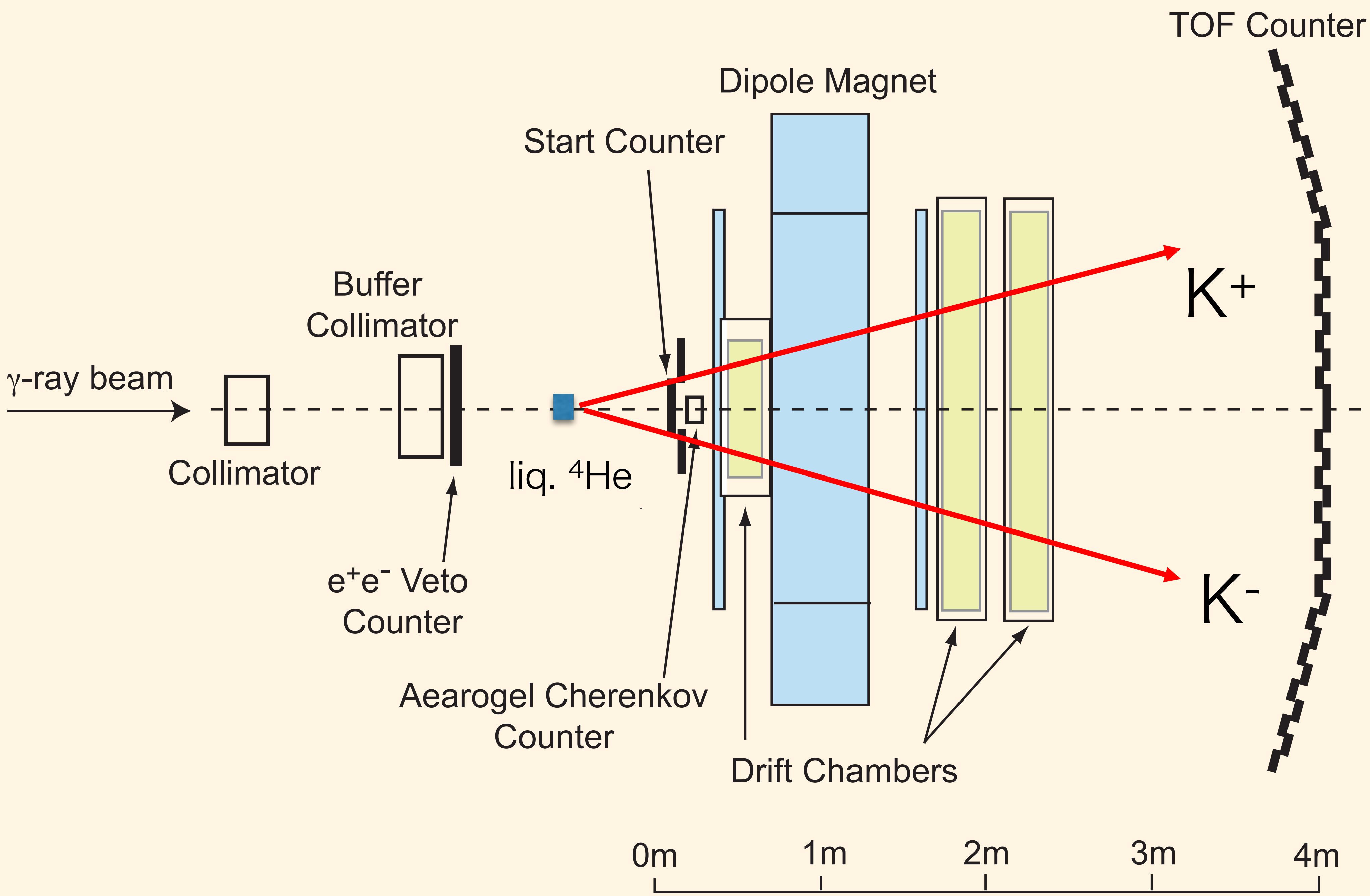
PWO measurement



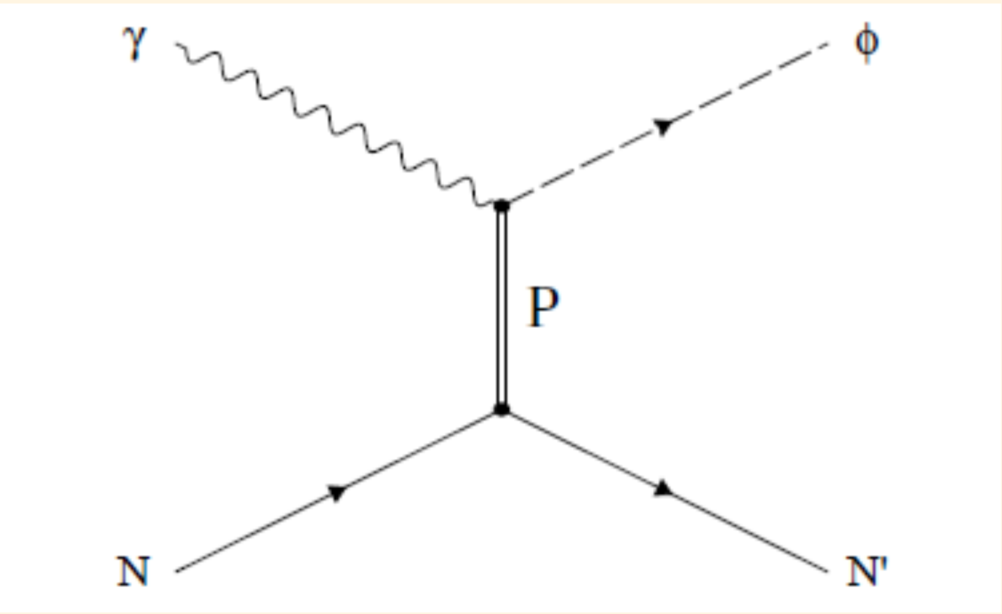
Linear Polarization of γ beam

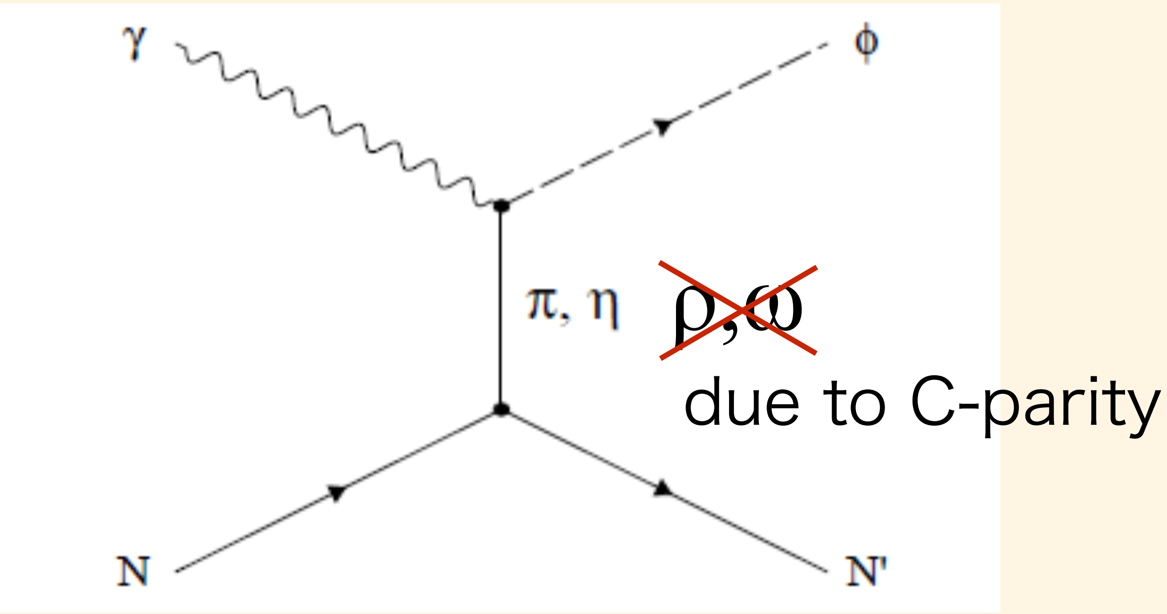


Experimental setup



Motivation (I): why φ?





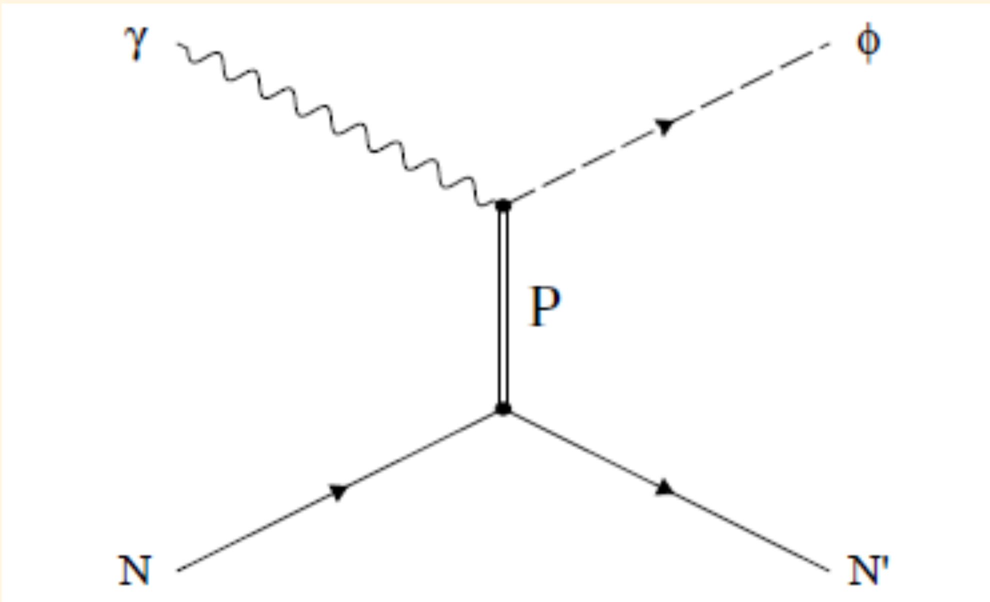
Pomeron exchange:

- Dominant process at high energies
- Not well understood at low energies
- Natural-parity
- Multi-gluon dynamics

Pseudo-scaler meson exchange:

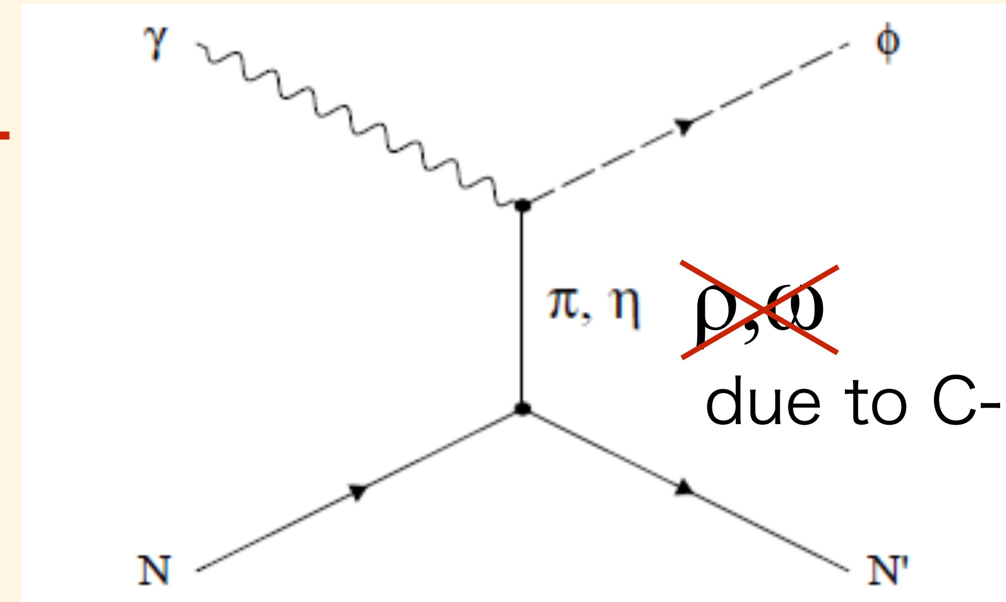
- Dominant process at low energies
- Well established process
- Unnatural-parity
- π, η meson exchange

Motivation (I): why φ?



$\varphi \sim s\bar{s}$

>>



Pomeron exchange:

- Dominant process at high energies
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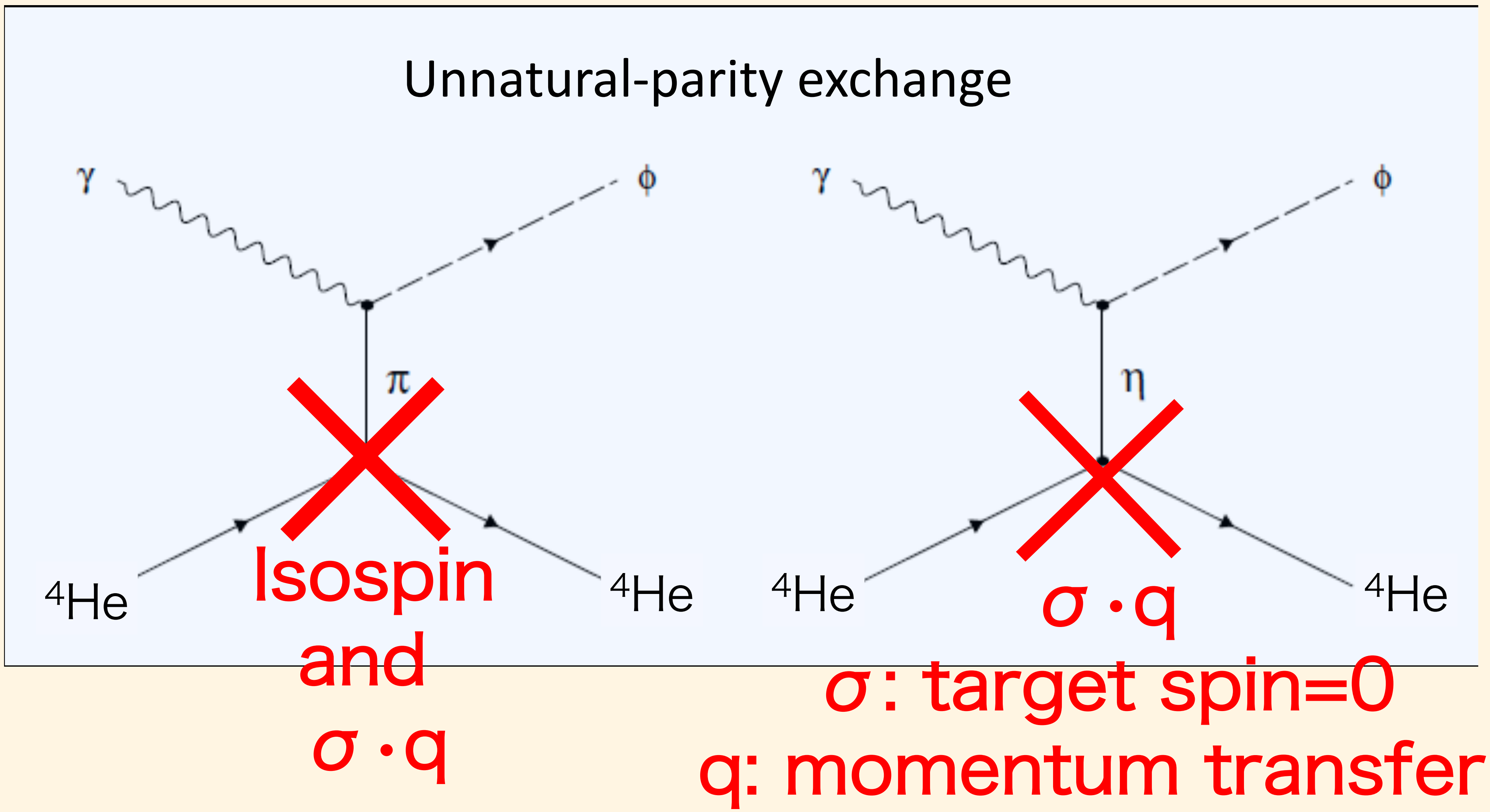
Pseudo-scaler meson exchange:

- Dominant process at low energies
- Well established process
- Unnatural-parity
- π, η meson exchange

Motivation (II): why ^{4}He?



- Pseudo scalar meson exchange is forbidden.
- Pomeron (or gluonic) dynamics appears directly.

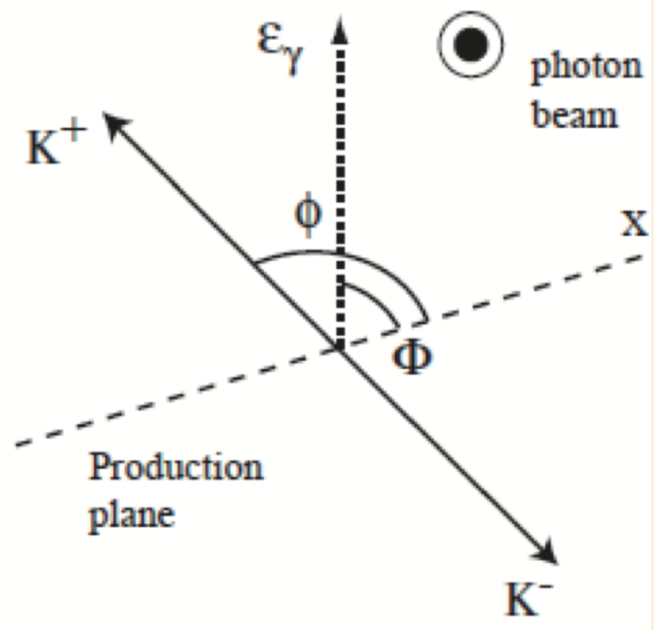
Motivation (III): why photon beam?

- Spin density matrix elements (SDME)

$$\rho^0_{\lambda\lambda'} = \frac{1}{N}\sum_{\alpha,\lambda_\gamma} I_{\alpha;\lambda,\lambda_\gamma} I^\dagger_{\alpha;\lambda',\lambda_\gamma},$$
$$\rho^1_{\lambda\lambda'} = \frac{1}{N}\sum_{\alpha,\lambda_\gamma} I_{\alpha;\lambda,-\lambda_\gamma} I^\dagger_{\alpha;\lambda',\lambda_\gamma}$$

$\alpha,\lambda,\lambda_\gamma$: helicities of nucleon, meson, photon

- Decay angular distributions in GJ frame



$$W(\cos\Theta) = N_1\{(1-\rho^0_{00})\sin^2\Theta + \rho^0_{00}\cos^2\Theta\}$$

Spin single-flip or non-flip

$$W(\Phi) = N_2(1 - 2\mathrm{Re}\rho^0_{1-1}\cos 2\Phi)$$

Interference of helicity double-flip and non-flip

Pomeron exchange amplitude Titov and Lee, PRC67,065205

$$I^P_{fi} \sim -\underbrace{\delta_{\lambda_\phi\lambda_\gamma}\bar{u}_f \not{k} u_i}_{\text{non-flip}} + \delta_{\lambda_\phi 0} k_\gamma \bar{u}_f \not{\varepsilon}_{\lambda_\gamma} u_i + \underbrace{\sqrt{2}\lambda_\gamma p_x \frac{k\cdot q}{2p\cdot k - k\cdot q}\bar{u}_f \not{\varepsilon}^*_{\lambda_\phi} u_i}_{\text{double-flip}}$$

u: nucleon w.f.
k, p_x : photon mom.
nucleon momentum in x

$$W(\Phi-\Psi) = N_3\{1 + 2P_\gamma\bar{\rho}^1_{1-1}\cos 2(\Phi-\Psi)\}$$

Parity of exchanged particle in t-channel

Motivation (III): why photon beam?

- For helicity-conserving processes, parity asymmetry is

$$\rho^1_{1\,-1} = -\mathrm{Im}\rho^2_{1\,-1} \qquad \rho^1_{1\,-1} = \frac{1}{2}\frac{|I_0^N|^2 - |I_0^U|^2}{|I_0^N|^2 + |I_0^U|^2}$$

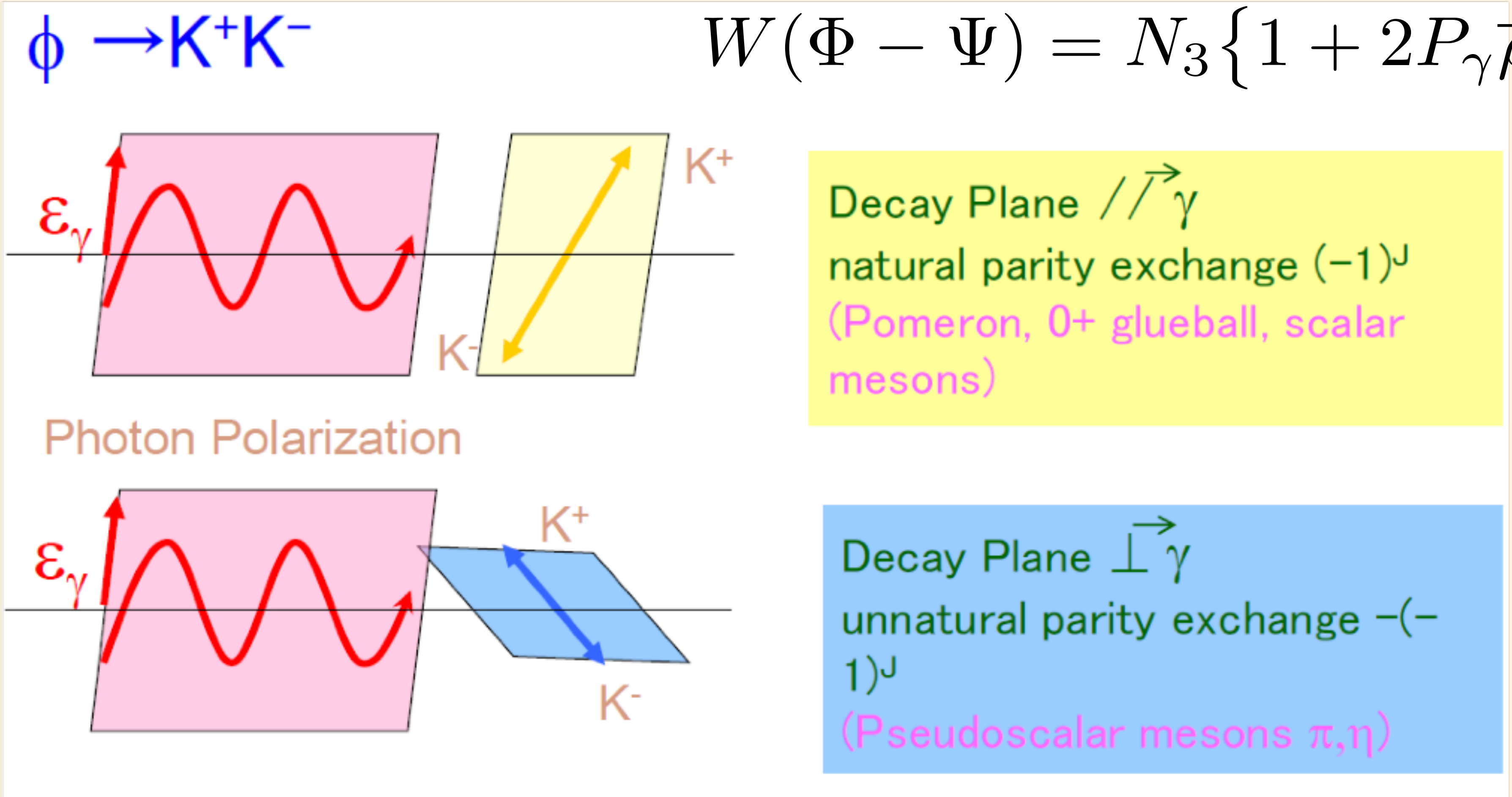
Natural (unnatural) parity exchange amplitudes

✓ Pure natural-parity exchange: $(\rho^1_{1-1} - Im\rho^2_{1-1})/2 = +0.5$

✓ Pure unnatural-parity exchange: $(\rho^1_{1-1} - Im\rho^2_{1-1})/2 = -0.5$

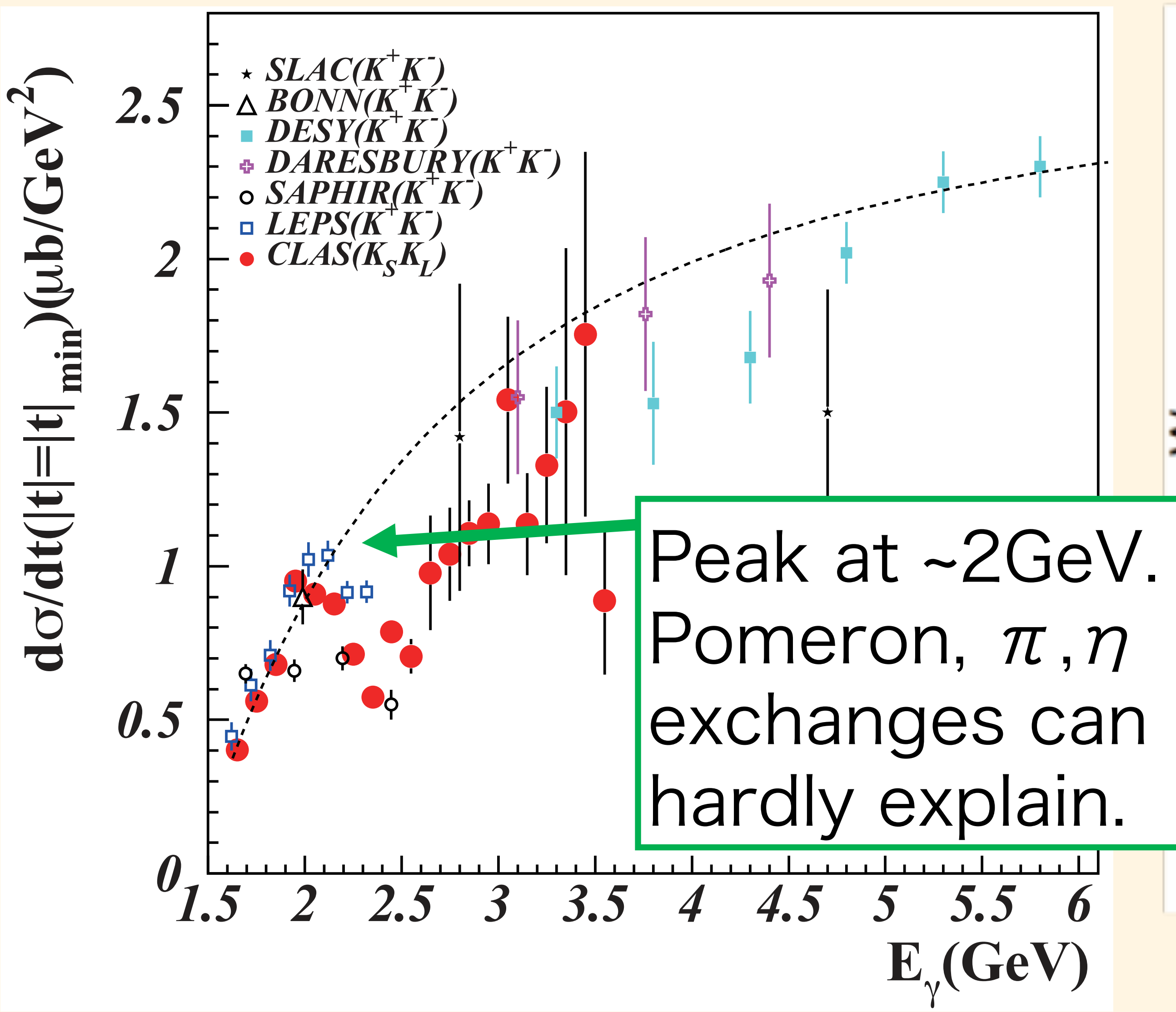
Parity filter for t-channel reaction

$$W(\Phi - \Psi) = N_3\{1 + 2P_\gamma \bar{\rho}^1_{1-1}\cos 2(\Phi - \Psi)\}$$

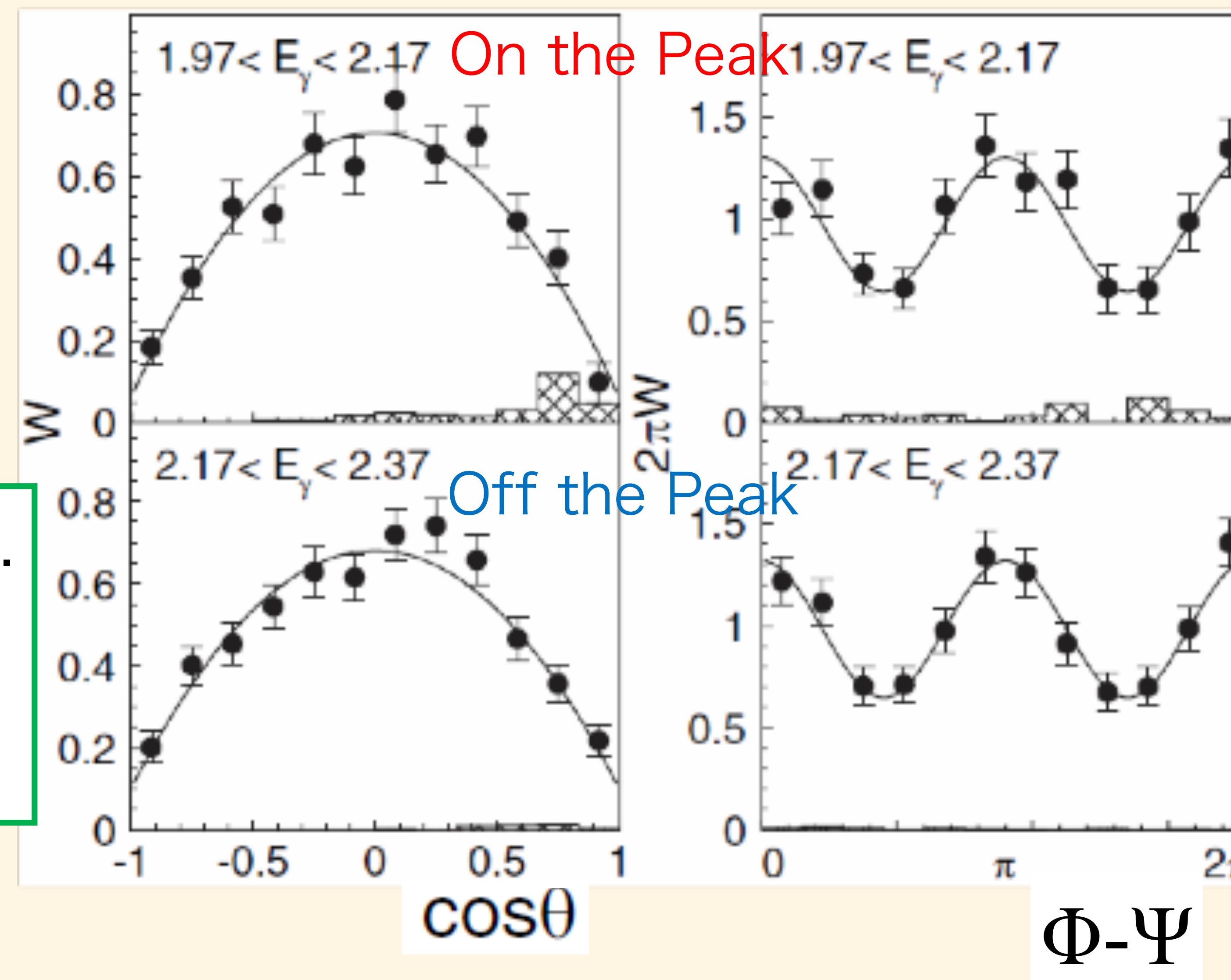


Previous measurements (I) $\gamma\, p \rightarrow \varphi\, p$

CLAS, PRC89, 055206 (2014)



LEPS, PRL 95, 182001 (2005)

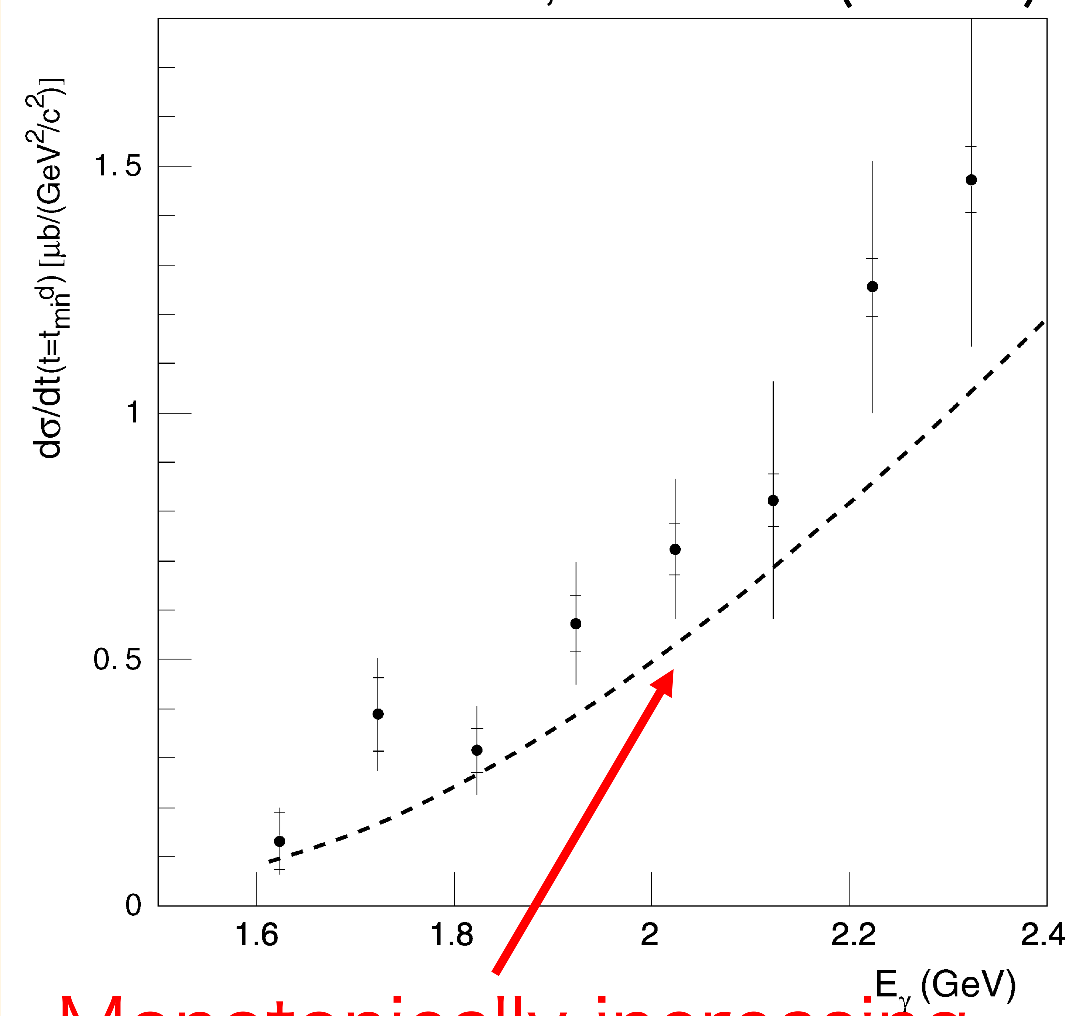


- $W(\cos\theta) \rightarrow \rho^0_{00} \rightarrow$ No helicity single-flip.
- $\rho^1_{1\text{-}1} \sim 0.2 \rightarrow N/(N+UN) \sim 0.7 \rightarrow$ Strong natural parity exchange (no energy dependence).

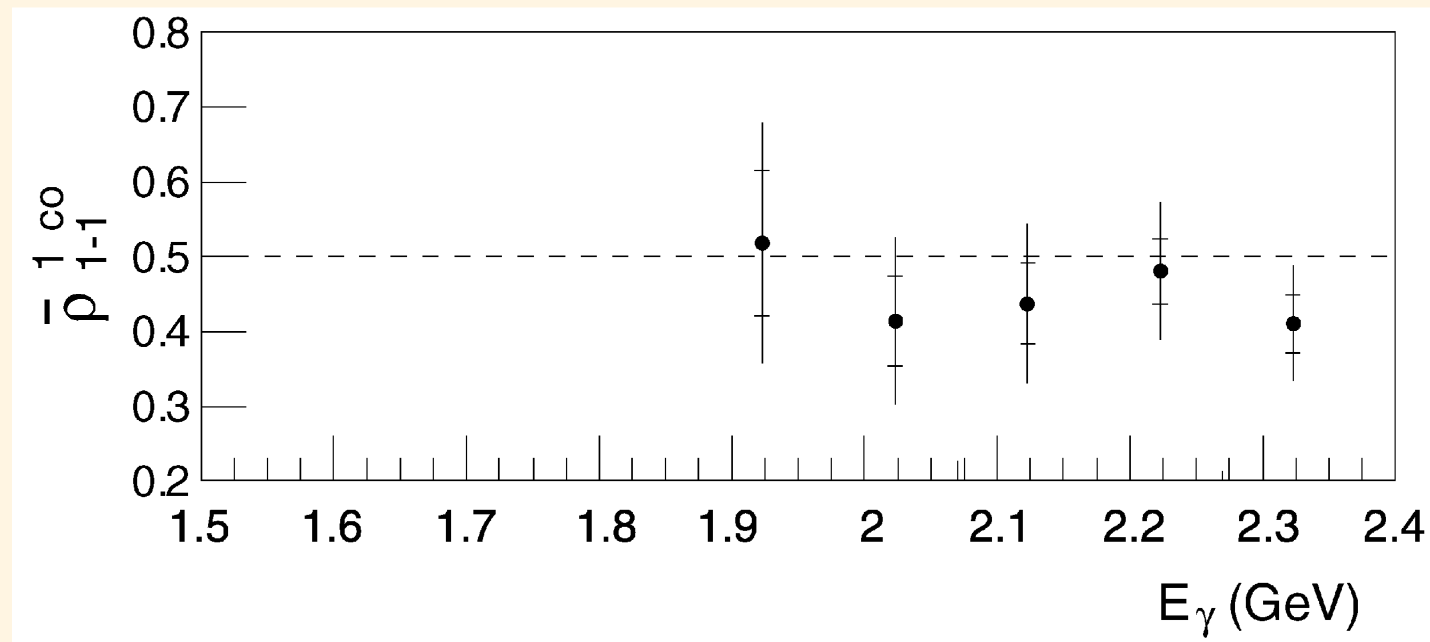
Previous measurements (II) $\gamma\, D \rightarrow \varphi\, D$

Note: pion exchange is forbidden due to isospin conservation.

LEPS, PLB658(2008)

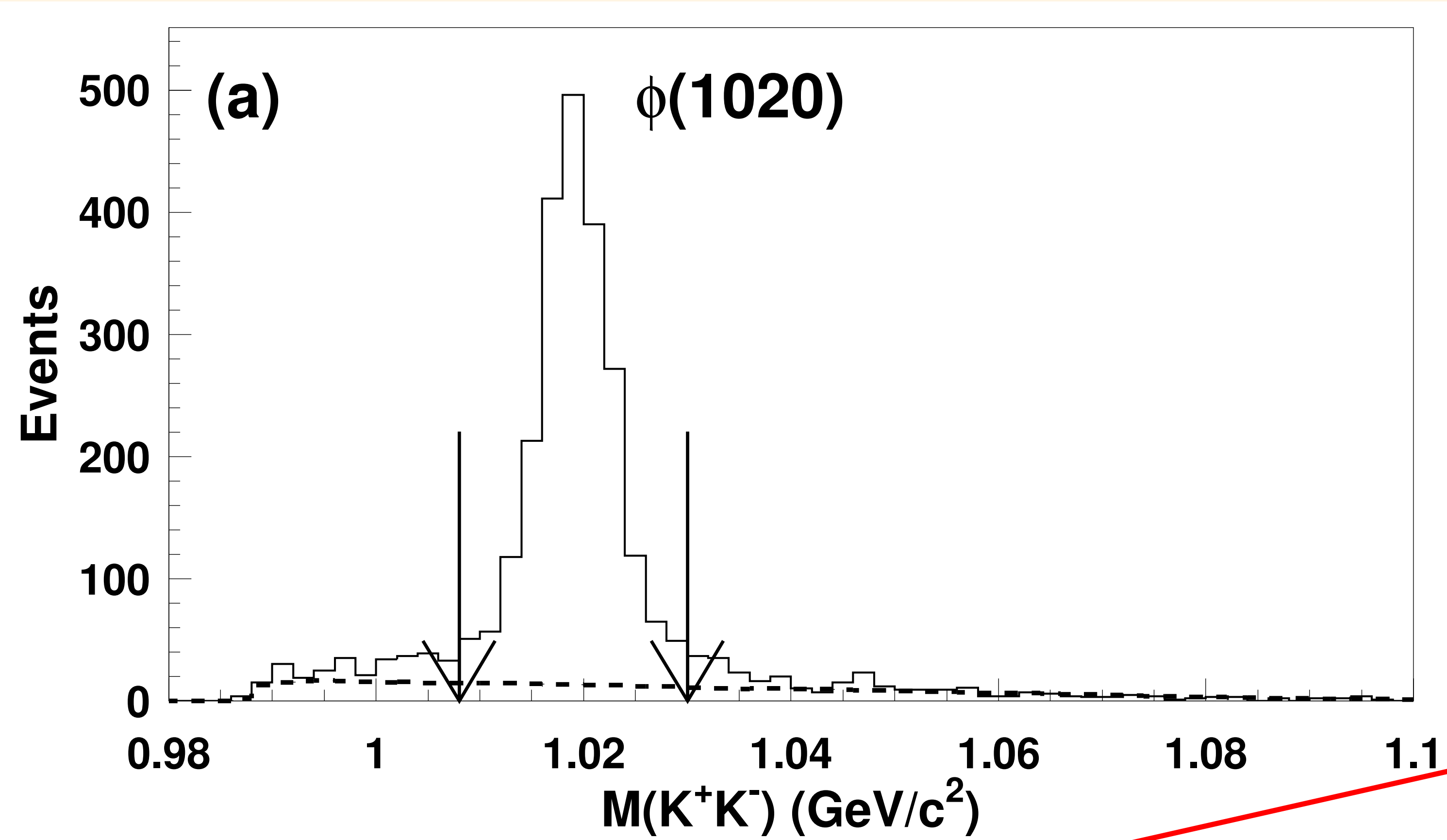


Monotonically increasing.
Pomeron, η exchange model underestimates the data.



SDM elements exhibit that helicity-conserving and natural process dominate.

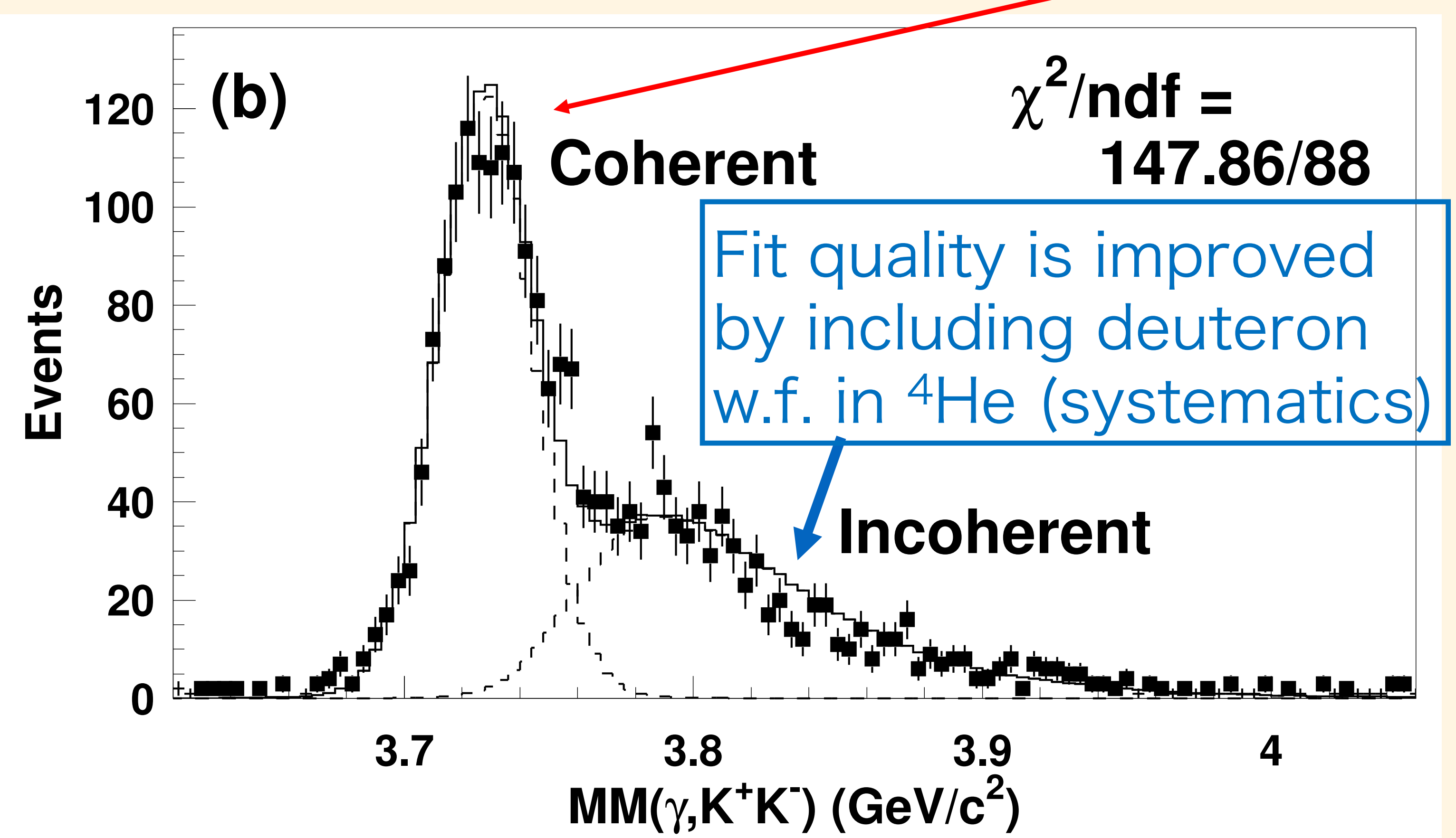
φ-meson from ^{4}He analysis



To obtain yields, fit $M(K^+K^-)$ with MC spectra of

- $\varphi \to K^+K^-$
- Non-resonant K^+K^-N
- $\Lambda(1520) \to K^-p$

Clear peak of coherent events in MM!



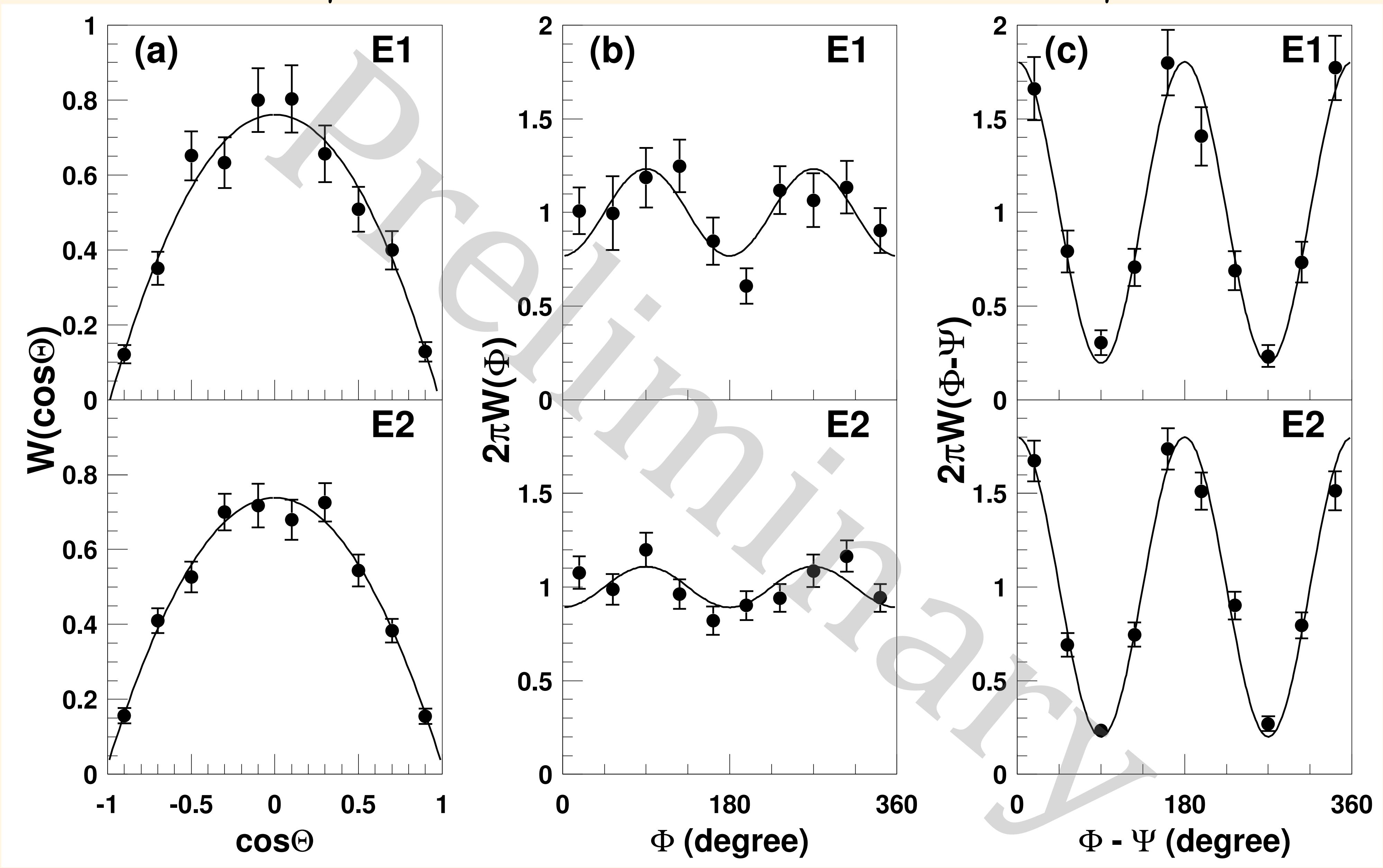
Fit quality is improved by including deuteron w.f. in ^{4}He (systematics)

To determine fraction of coherent events, fit $MM(K^+K^-)$ with MC spectra of

- Coherent φ
- Incoherent φ
  - Off-shell corr.
  - s-dep of x-section

Angular distributions

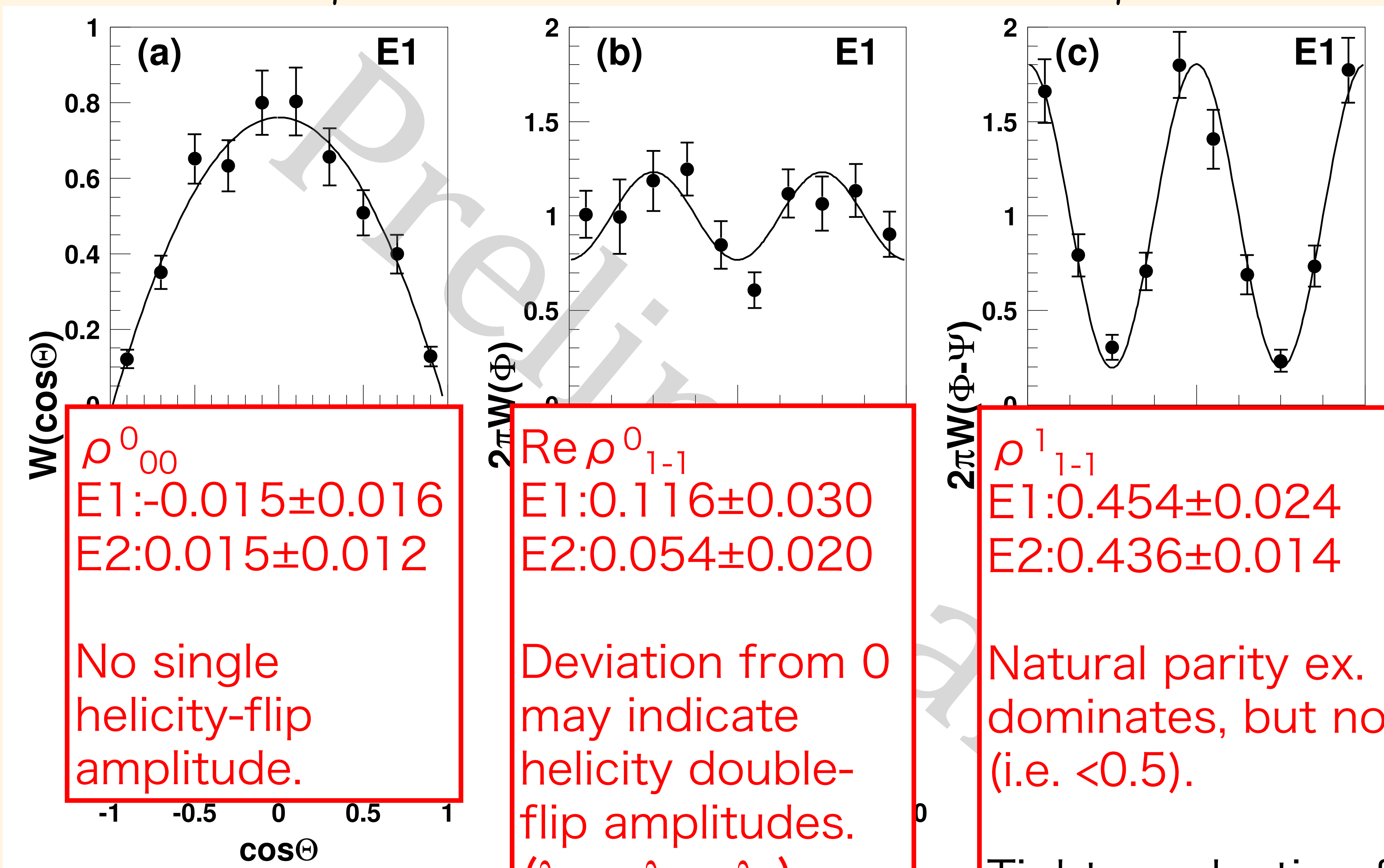
E1: $1.985<E_\gamma<2.185$ GeV,   E2: $2.185<E_\gamma<2.385$ GeV



$$W(\cos\Theta) = N_1\{(1-\rho^0_{00})\sin^2\Theta + \rho^0_{00}\cos^2\Theta\}$$
$$W(\Phi) = N_2(1 - 2\mathrm{Re}\rho^0_{1-1}\cos 2\Phi)$$
$$W(\Phi-\Psi) = N_3\{1 + 2P_\gamma\bar{\rho}^1_{1-1}\cos 2(\Phi-\Psi)\}$$

Decay angular distributions

E1: 1.985<E_γ<2.185 GeV,   E2: 2.185<E_γ<2.385 GeV



ρ^0_{00}
E1:-0.015±0.016
E2:0.015±0.012

No single helicity-flip amplitude.

Re ρ^0_{1-1}
E1:0.116±0.030
E2:0.054±0.020

Deviation from 0 may indicate helicity double-flip amplitudes. ($\lambda_\gamma \rightarrow \lambda_\varphi = -\lambda_\gamma$)

Titov and Lee, PRC67,065205

ρ^1_{1-1}
E1:0.454±0.024
E2:0.436±0.014

Natural parity ex. dominates, but not fully. (i.e. <0.5).

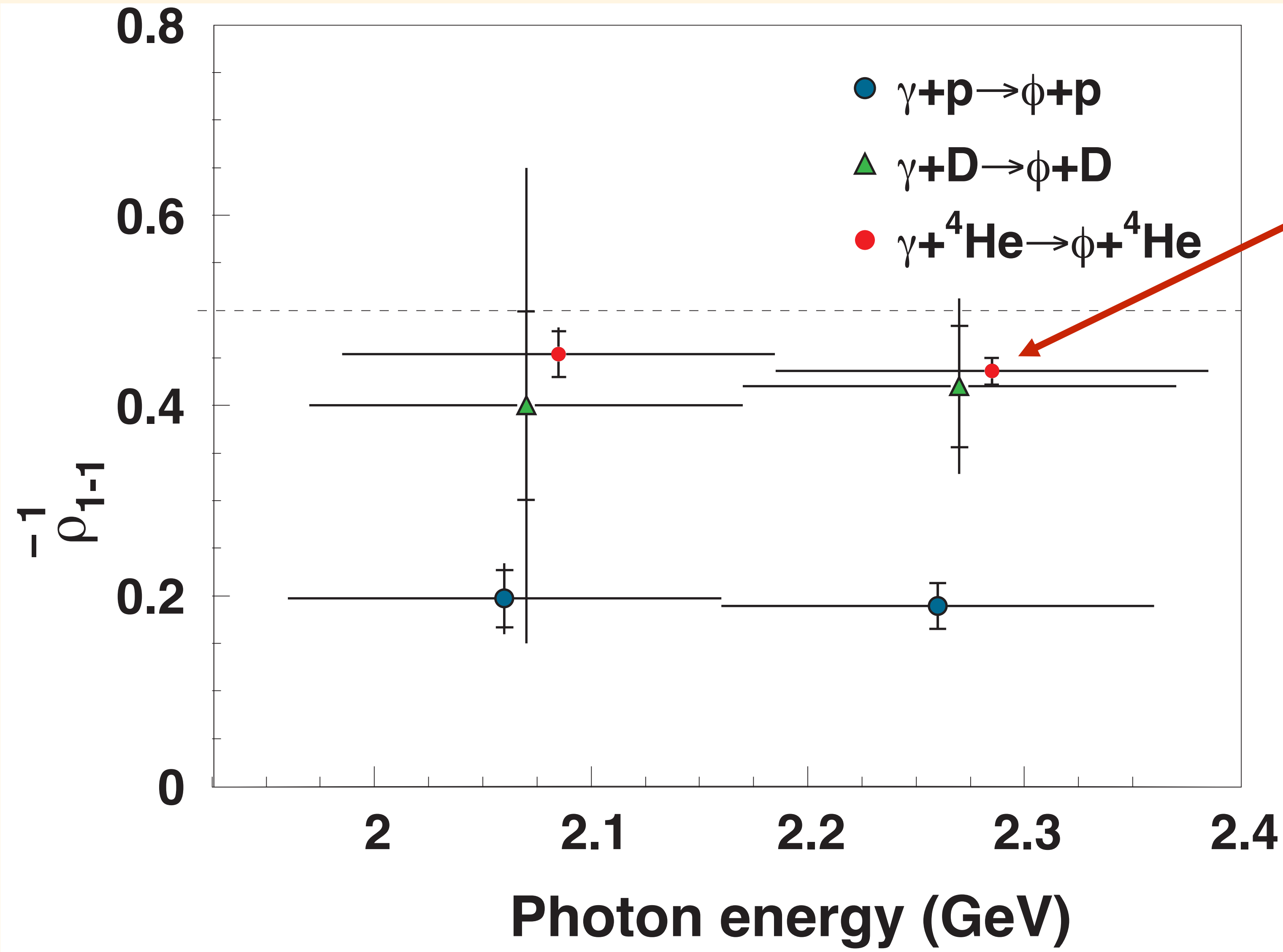
Tighter selection for coherent events gives same result.

$W(\cos\Theta) = N_1 \ldots \Theta$

$W(\Phi) = N_2(1 \ldots 2\Phi)$

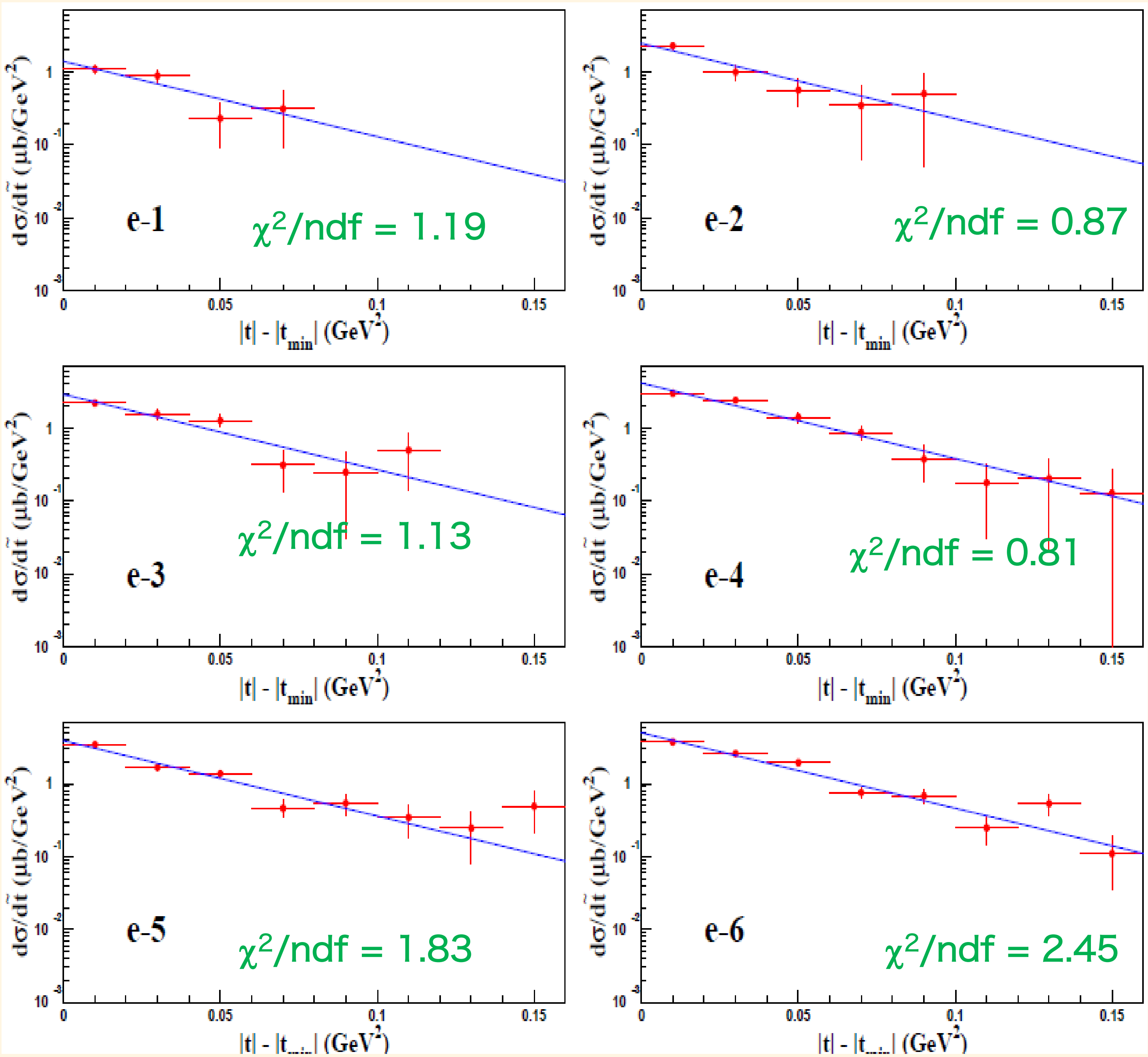
$$W(\Phi - \Psi) = N_3\{1 + 2P_\gamma \bar{\rho}^1_{1-1} \cos 2(\Phi - \Psi)\}$$

Comparison of SDME with p, d data



- Natural parity exchange
  Pomeron exchange dominates.
- 10~13% deviation from pure natural parity exchange
  - A) Contribution of unnatural parity exchange? (f_1,$J^{PC}=1^{++}$)? Due to the heavy mass, it is expected to be suppressed…
  - B) Violation of the assumption of helicity-conservation?
- Non zero ρ^0_{1-1} also indicates spin-double-flip amplitude (PRC67,065205)
- Exchange of tensor particle?
- Theoretical inputs and advices are welcome!

Results of the $d\sigma/d\tilde{t}$ measurements

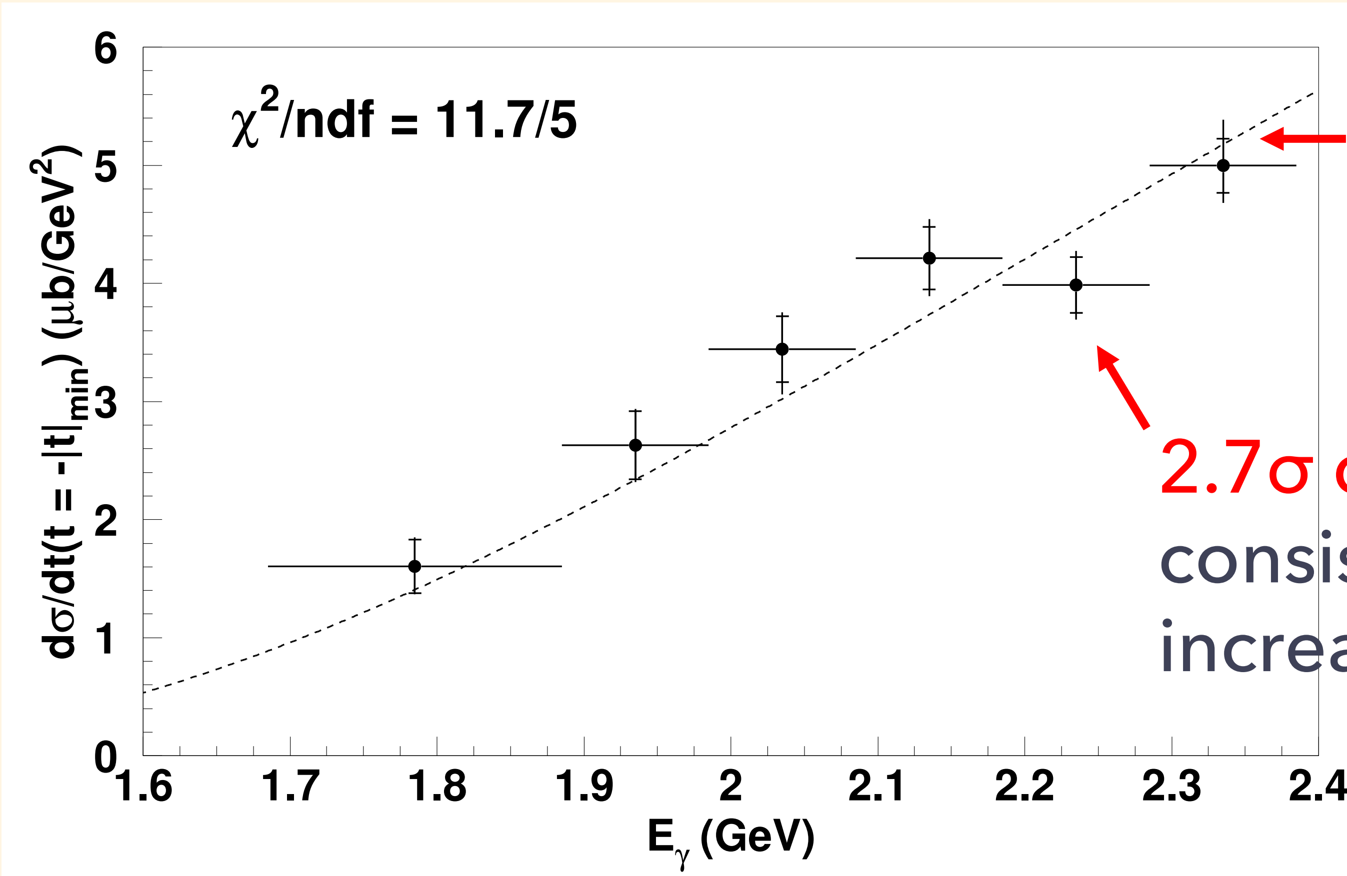


- No significant energy dependence was observed.
- $\frac{d\sigma}{d\tilde{t}} = N_0 \exp(-b\tilde{t})$
- Weighted mean of the t-slope

  23.81 ± 0.95 (stat.)$^{+5.15}_{-0.00}$ (syst.)

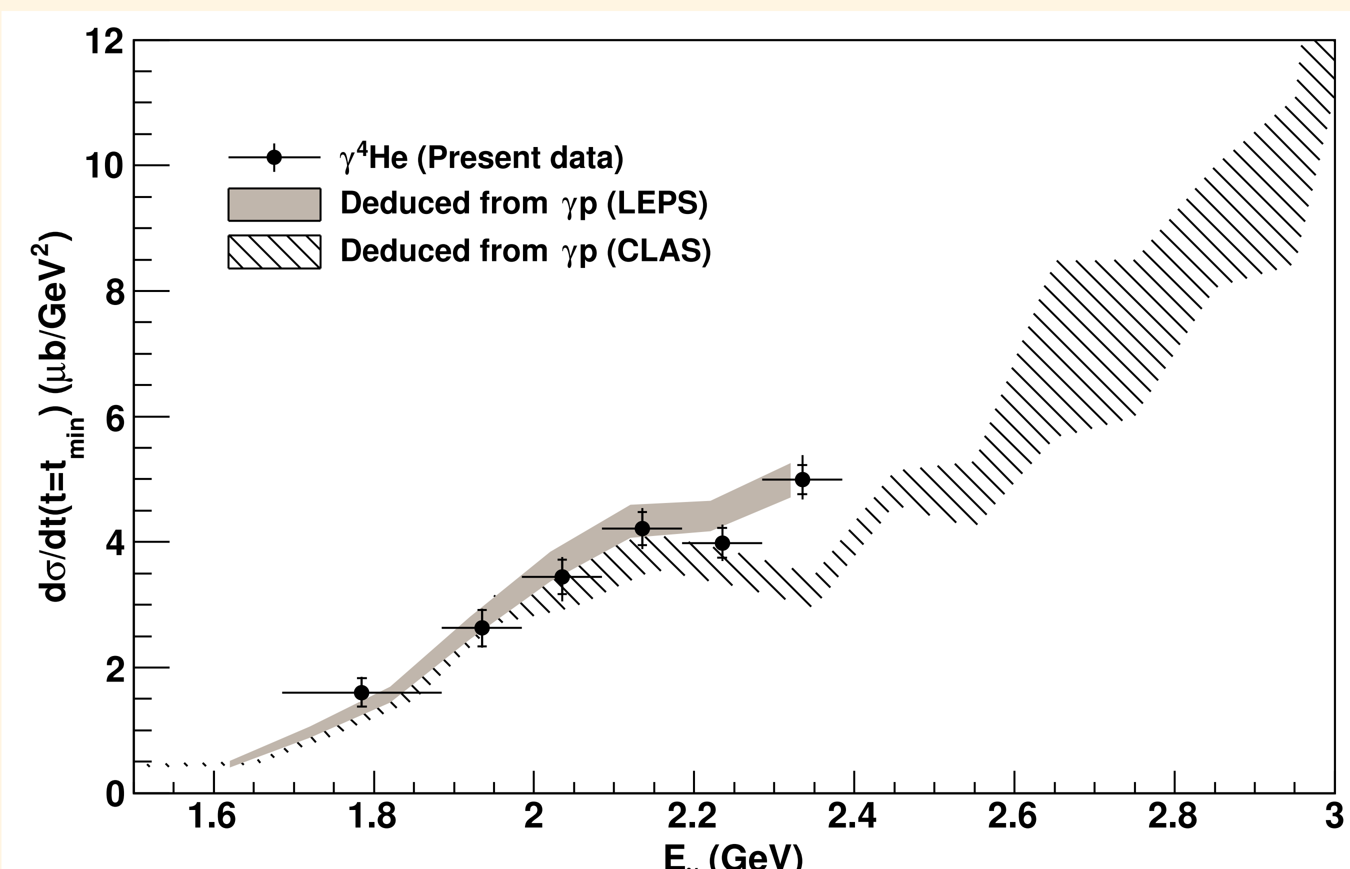
→ Consistent with $b(\gamma p \to \phi p)$ + b(Form Factor) = 3.3 + 22 = 25.3 (GeV^{-2}).

dσ/dt at t_{min}



Fitted curve assuming constant T-matrix (proportional to phase volume), strength is the fit parameter.

2.7σ deviation is observed but consistent with monotonic increasing in overall.



Comparison with proton data using ^{4}He form factor.

$$\frac{d\sigma}{dt}^{\gamma^4\mathrm{He}} = 16Z(t)\frac{d\sigma}{dt}^{\gamma N:I,J=0}$$

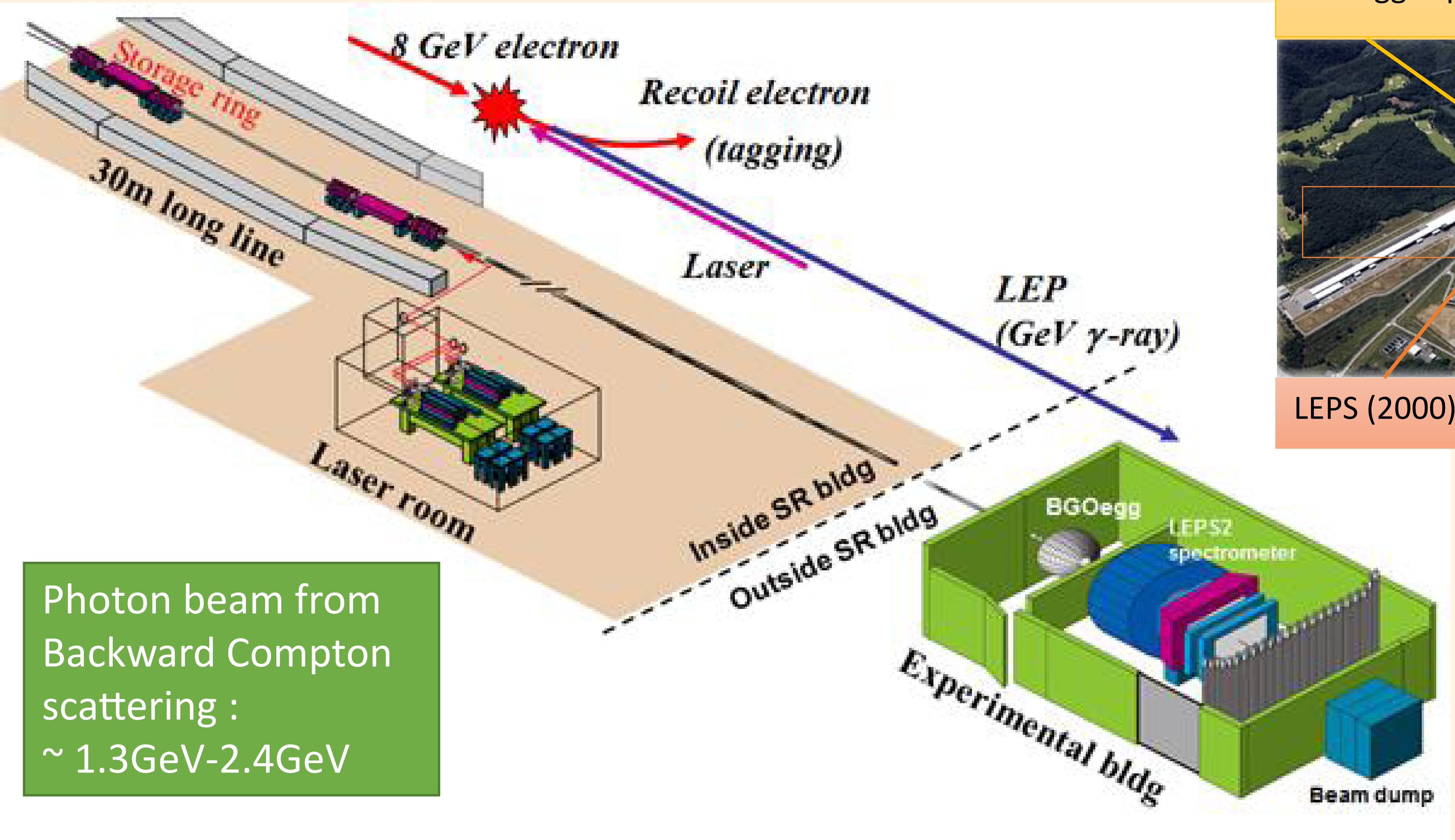
$t = t_{min}^{4He}$ (^{4}He at rest)

The peak structure of proton data seems smeared by ^{4}He form factor.

LEPS II

Beam asymmetry (Σ) for η-meson photoproduction

LEPS II facility



Photon beam from Backward Compton scattering :
~ 1.3GeV-2.4GeV

LEPS2 (2013)
BGOegg experiment (2014)

LEPS (2000)

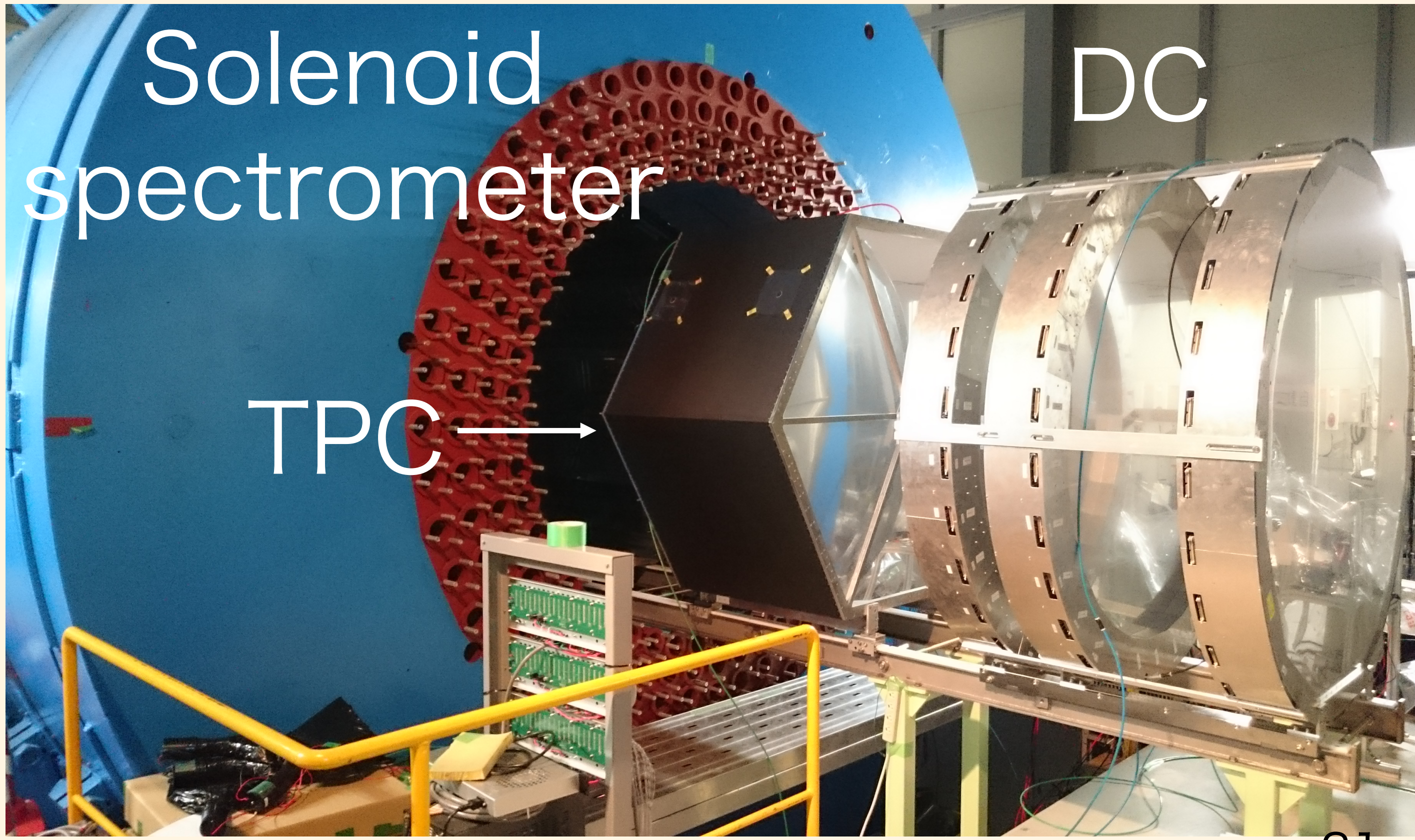
Experimental setups @ LEPS II

BGOegg setup

- BGOegg E.M. Calorimeter
  - 1320 BGO crystals
  - polar angle 24-146 degrees
- Drift chamber (DC), forward time of flight (TOF) counters
- Physics data taking from 2014.
- η-meson measurement in this talk

Solenoid spectrometer

- 0.9 T solenoid magnet
- Time Projection Chamber, DC, TOF counters, barrel photon counters.
- First commissioning run in 2016.

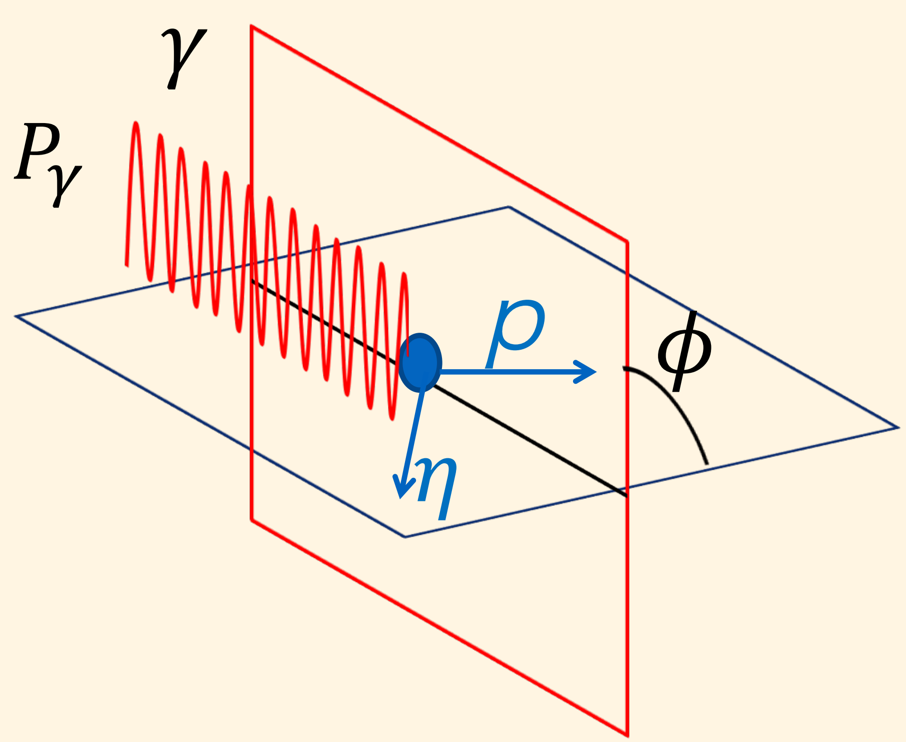


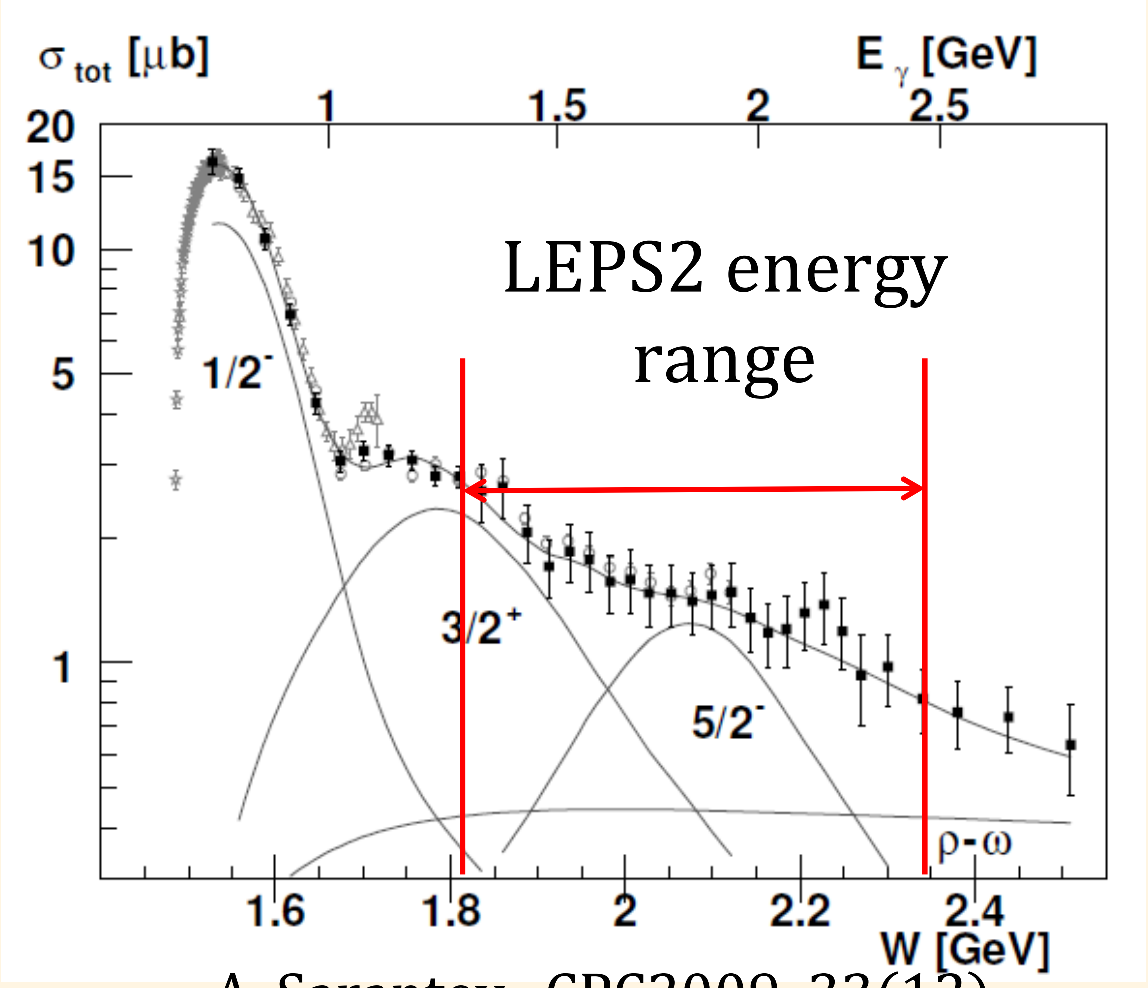
Motivation

η meson photoproduction

- Isospin = 0 → No coupling with Δ
- large strangeness component
  - Stronger coupling of N* to η than to pion may reveal strangeness content in N*. (ex. N(1535))

Beam asymmetry (Σ) helps to separate various N* contributions.





A. Sarantev , CPC2009, 33(12)

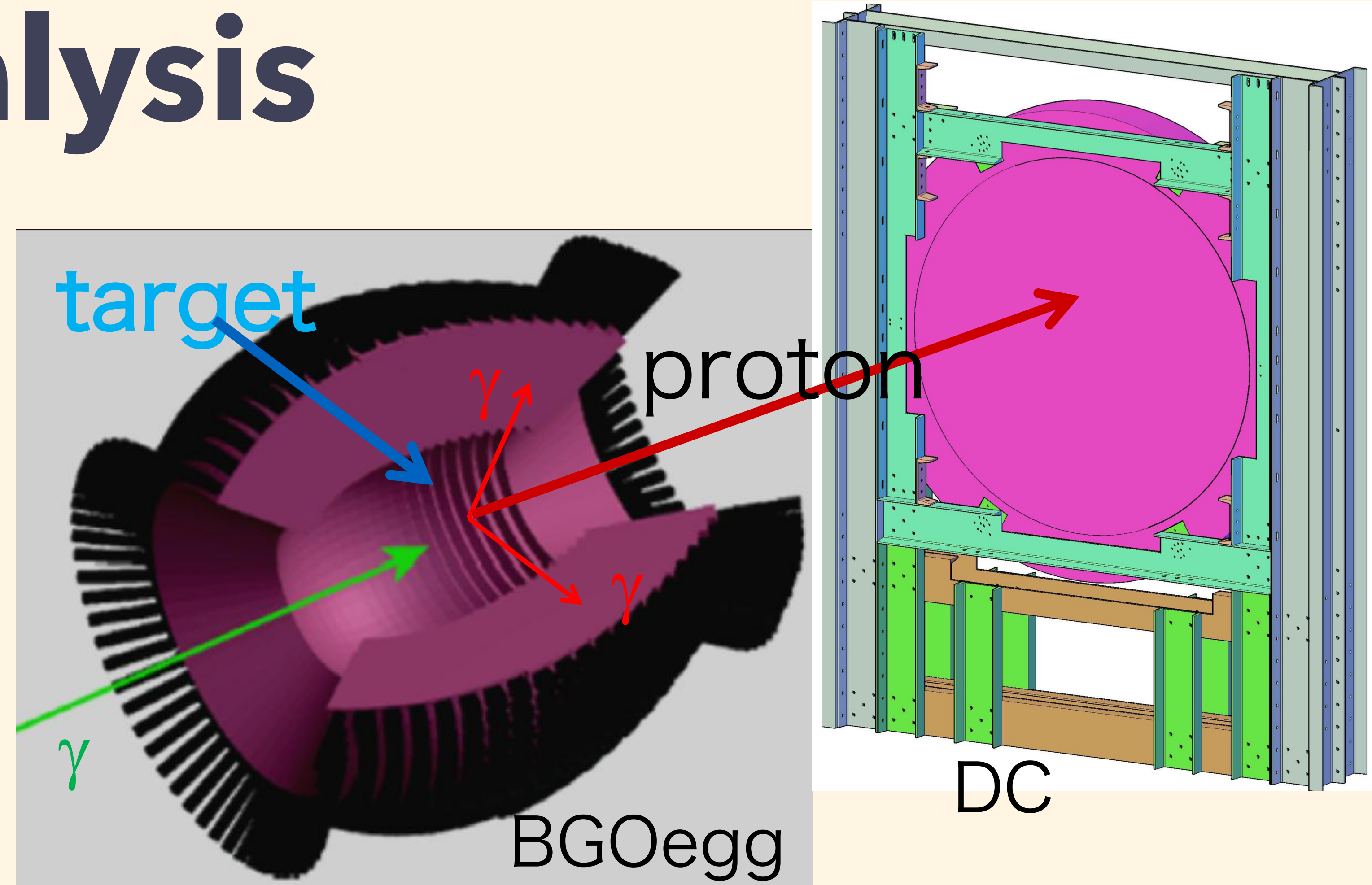
Setup and analysis

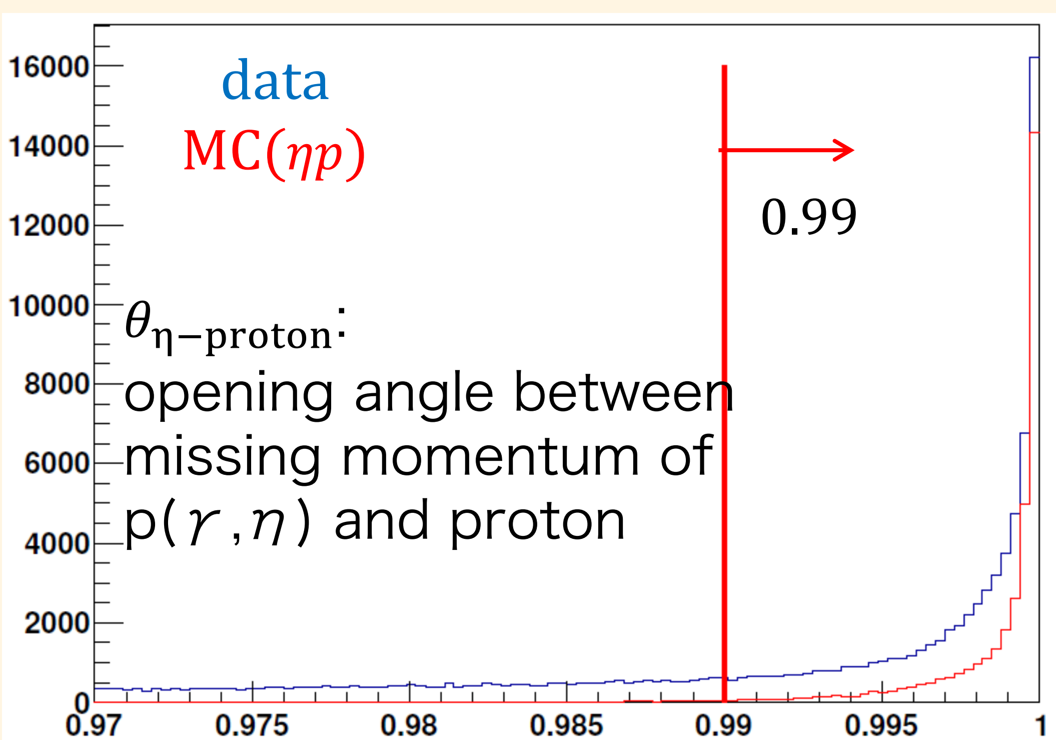
$$\gamma p \to \eta p$$

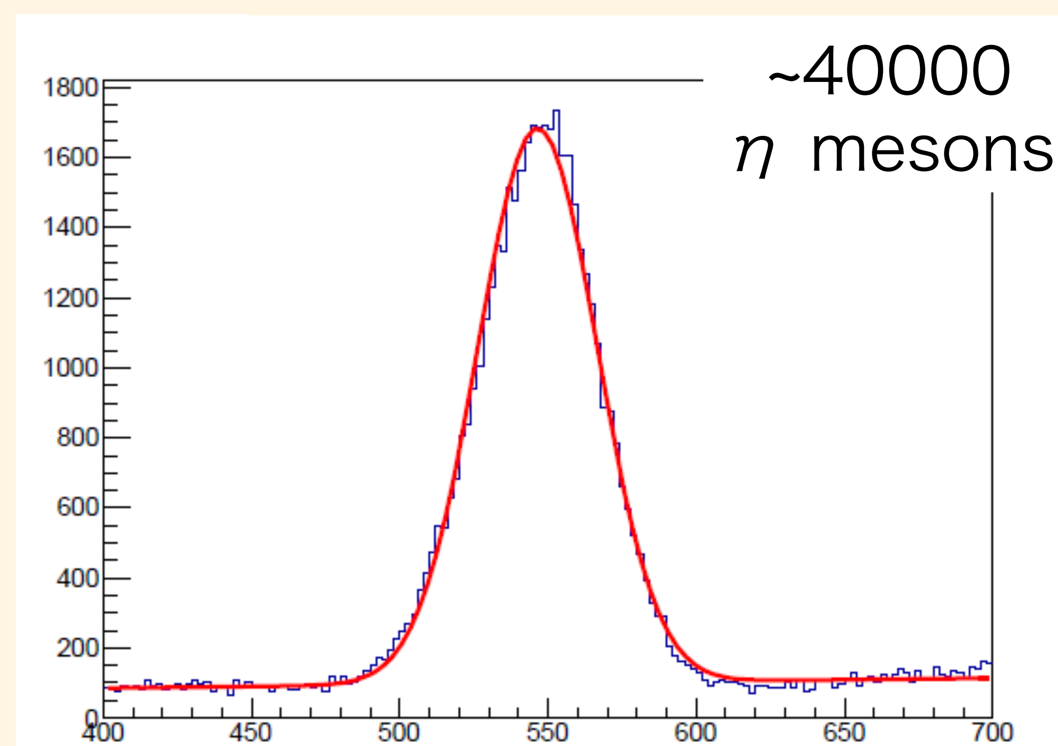
$$\to \gamma \; \gamma \; p$$

BGOegg (γ, γ)

BGOegg or DC (p)



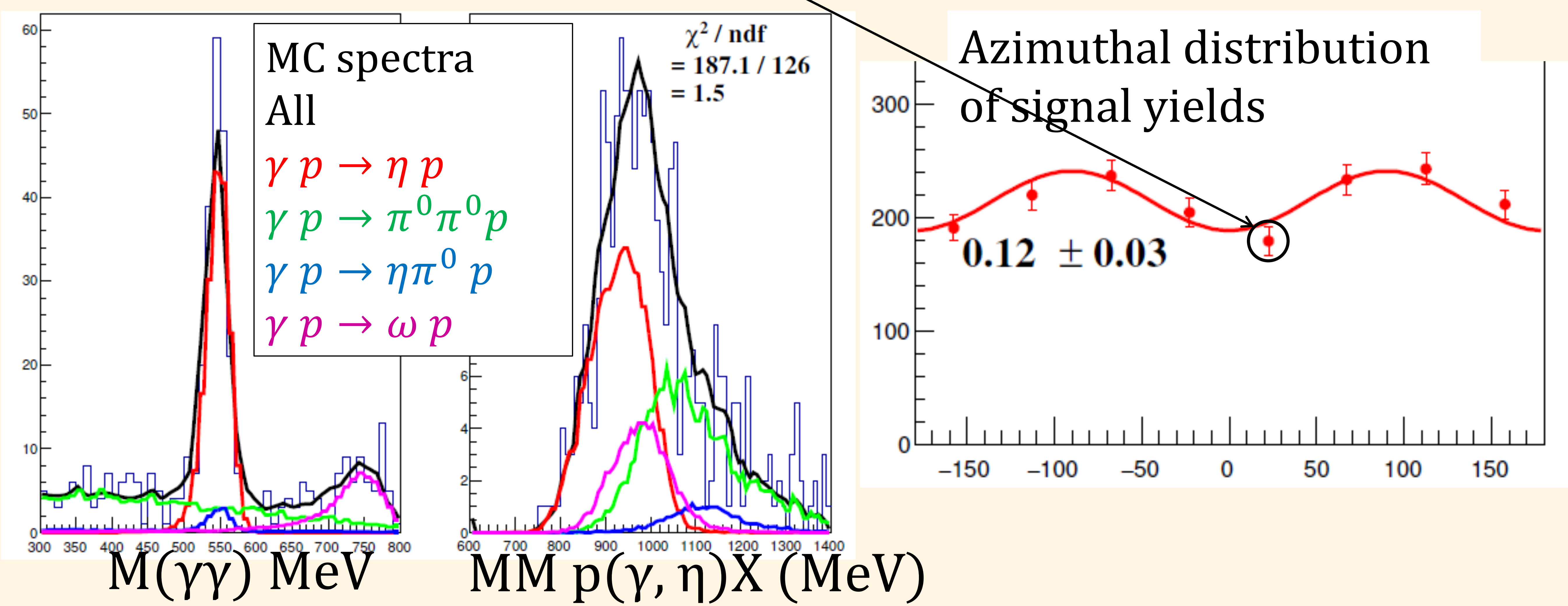




M(γγ) MeV

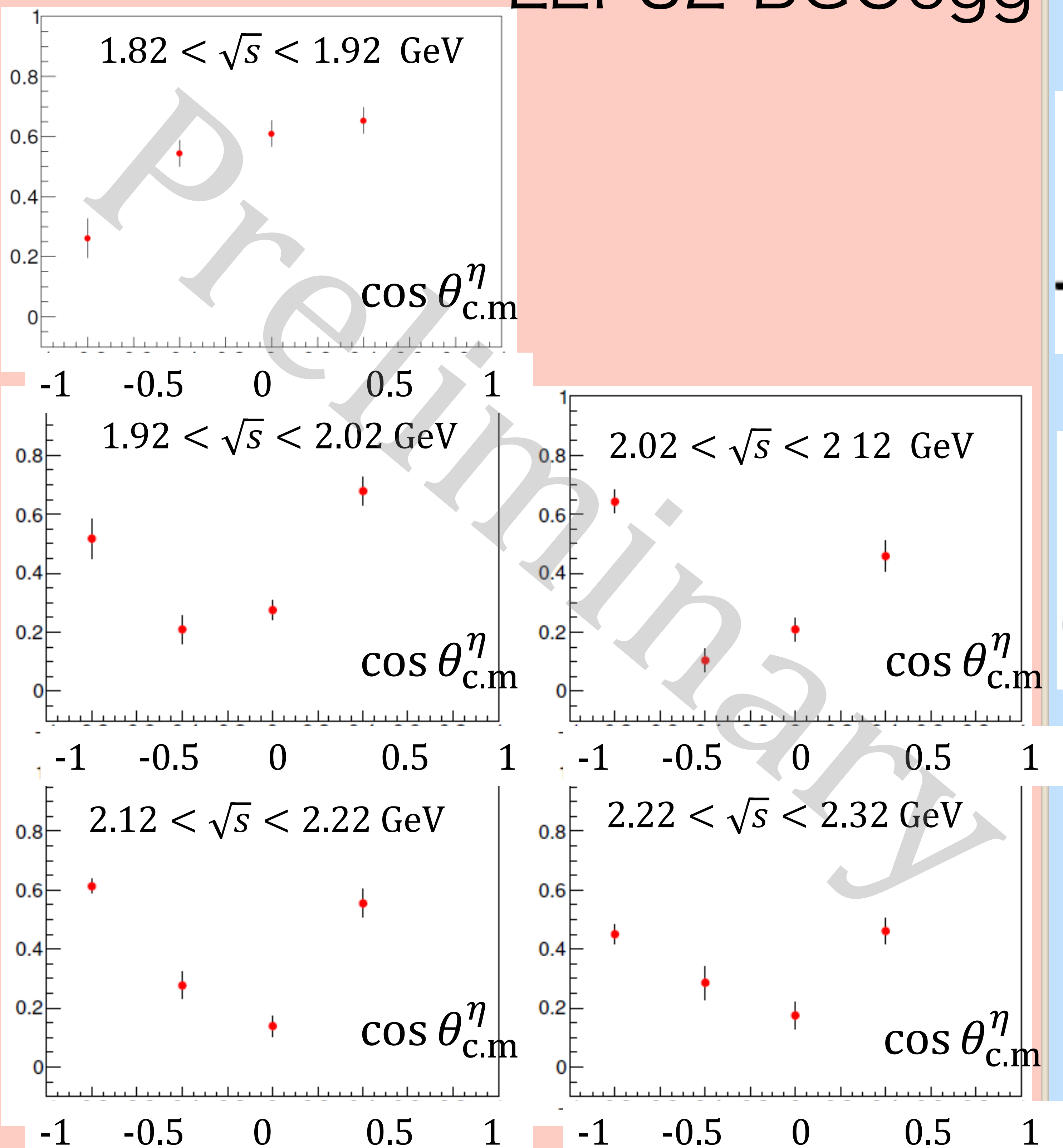
Analysis for yield estimation

$1.82 < \sqrt{s} < 1.92$, $-1 < \cos\theta^{\eta}_{c.m} < -0.6$
$0<\varphi<45$



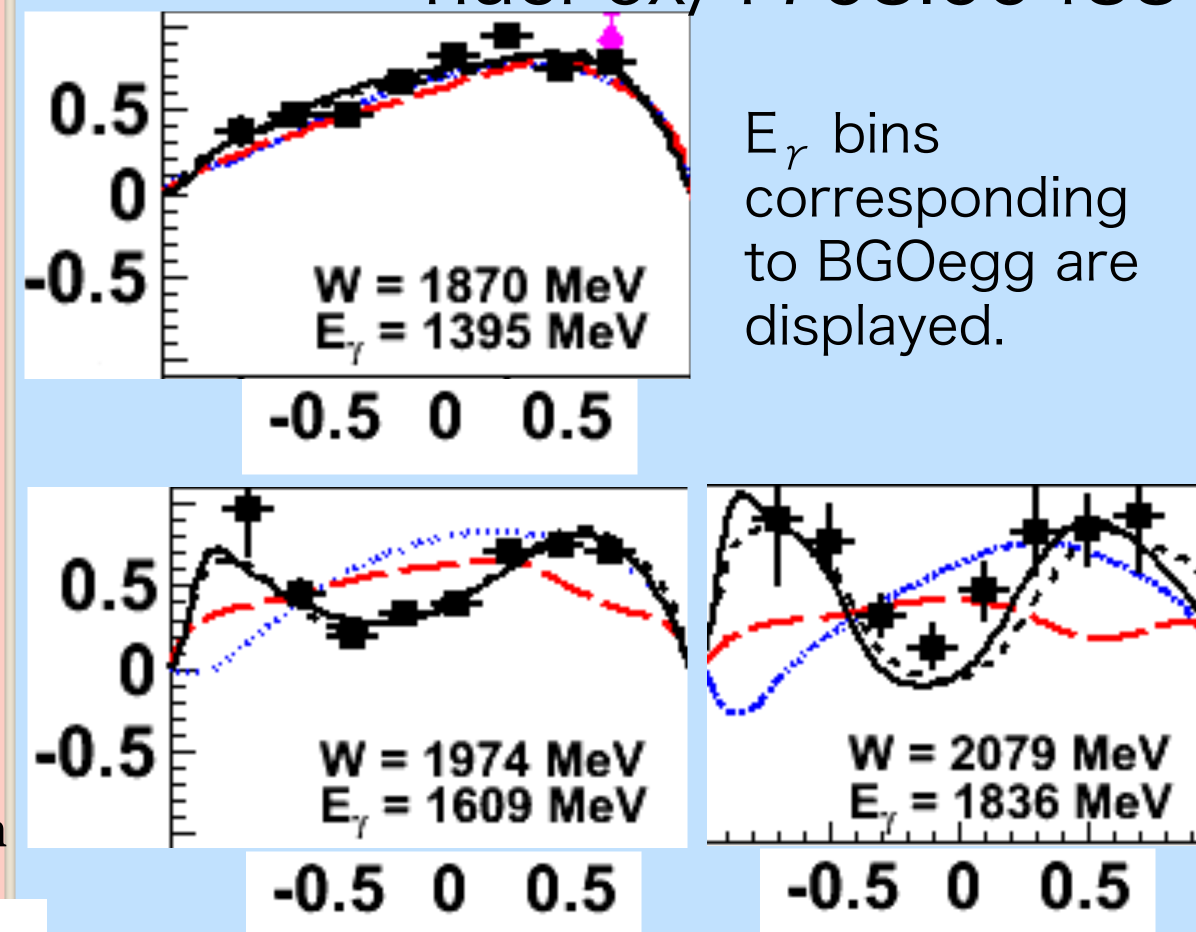
Preliminary results

LEPS2 BGOegg



J-Lab CLAS

nucl-ex/1703.00433



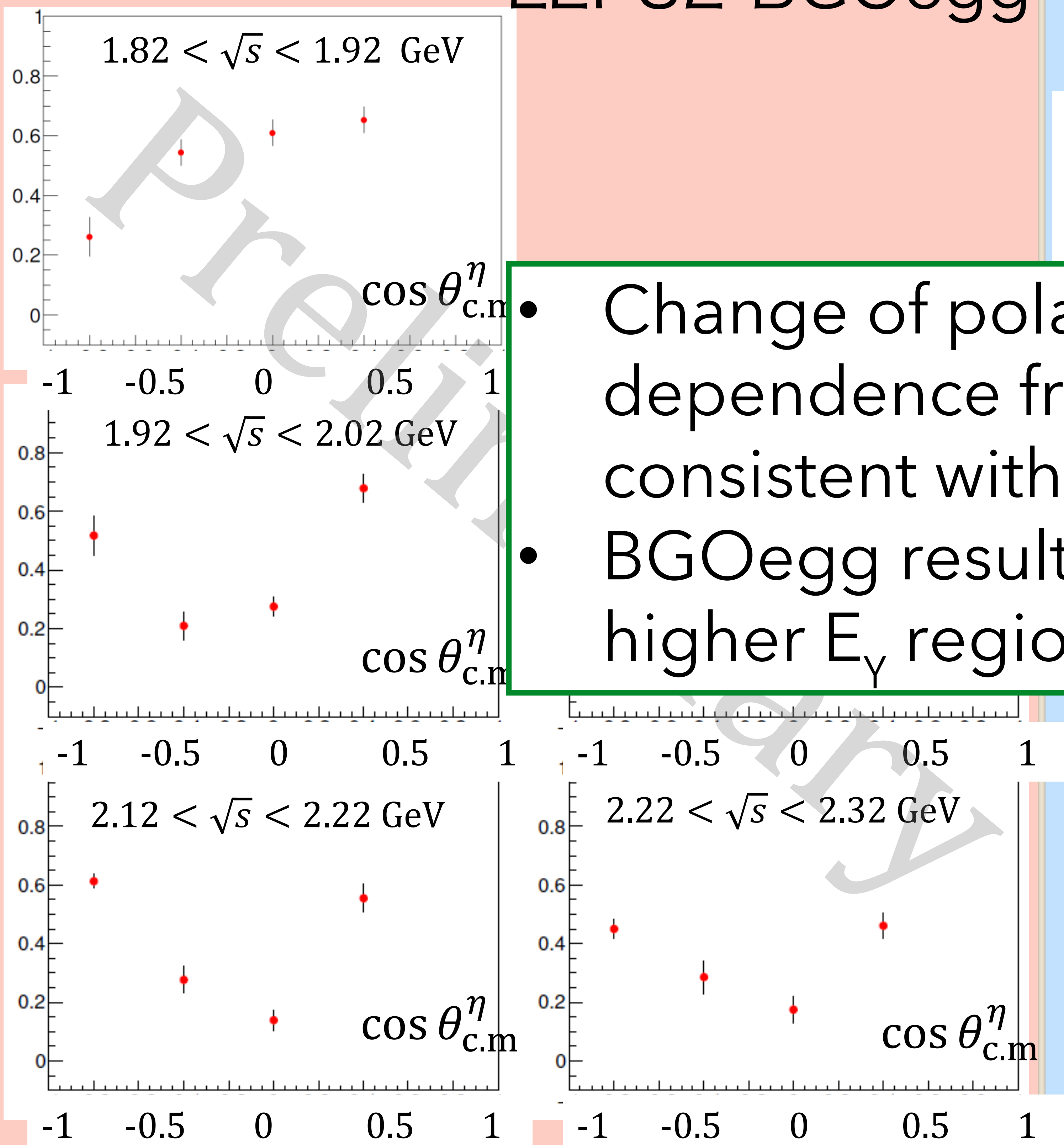
E_γ bins corresponding to BGOegg are displayed.

SAID
ETA-MAID
Julich-Bonn (solid)
Julich-Bonn w/o N(1900) (dashed)

Supporting N(1895)1/2⁻, N(1900)3/2⁺, N(2100)1/2⁺, N(2120)3/2⁻

Preliminary results

LEPS2 BGOegg



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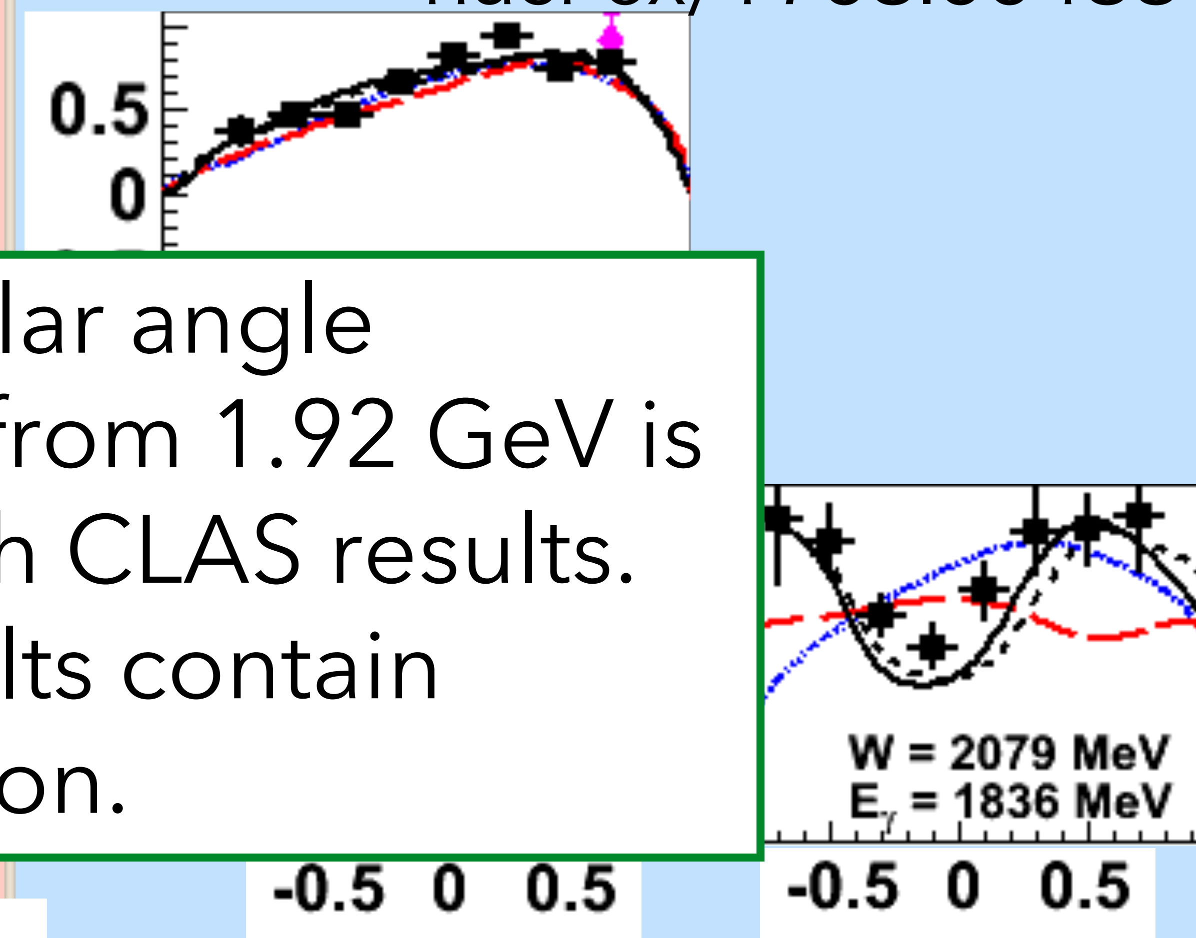


SAID
ETA-MAID
Julich-Bonn (solid)
Julich-Bonn w/o N(1900) (dashed)

Supporting N(1895)1/2⁻, N(1900)3/2⁺, N(2100)1/2⁺, N(2120)3/2⁻

- Change of polar angle dependence from 1.92 GeV is consistent with CLAS results.
- BGOegg results contain higher E_γ region.

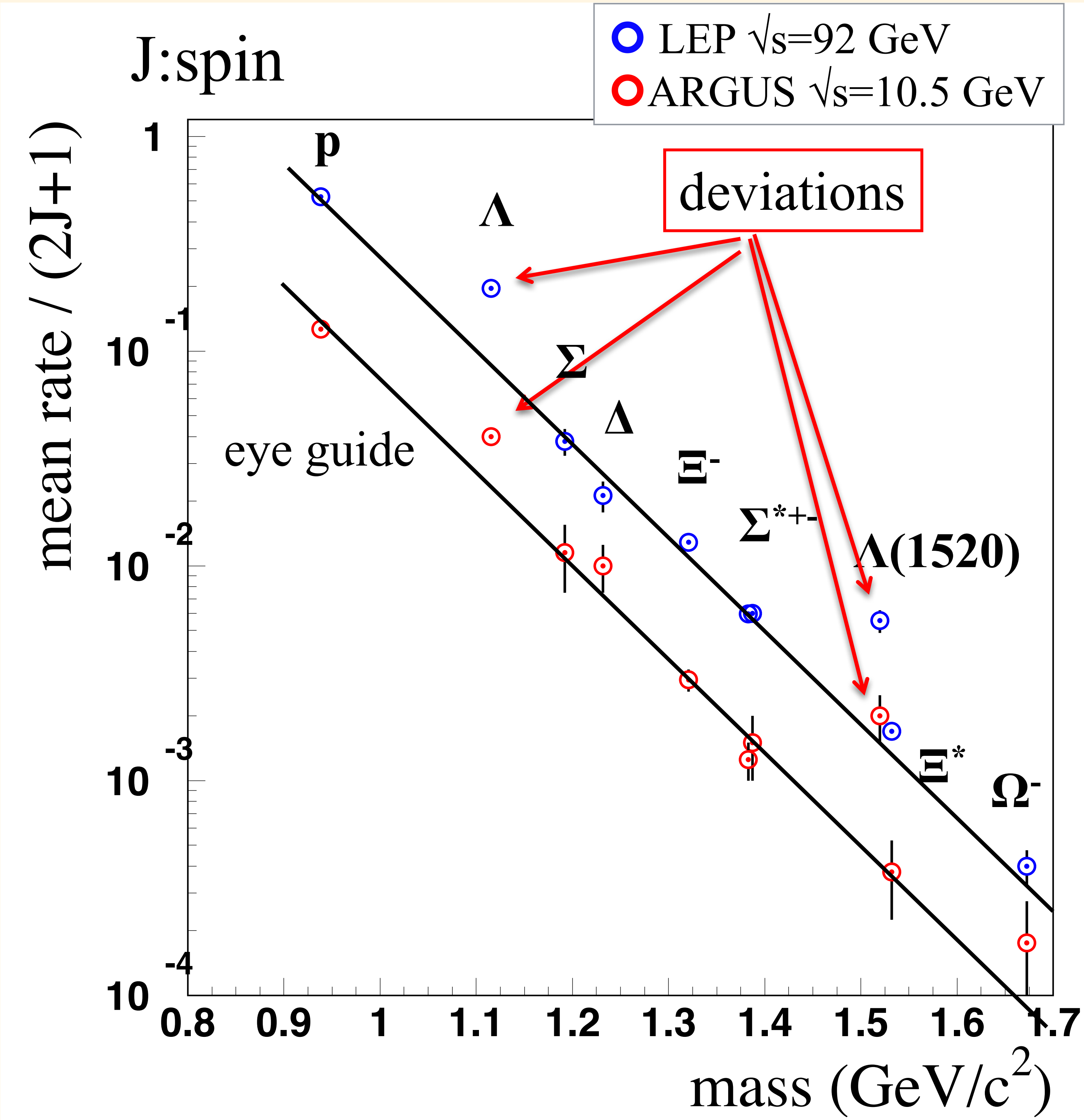
Belle

Production rates of hyperons and charmed baryons from e^+e^- annihilation near $\Upsilon(4S)$

Baryon production rates in e^+e^- collision

- $e^+e^- \rightarrow \gamma^* \rightarrow qq \rightarrow$ Haronization
  - ex) $e^+e^- \rightarrow \gamma^* \rightarrow \Lambda$ + anything
    - not $e^+e^- \rightarrow \gamma^* \rightarrow \Lambda$ + anti-Λ
- $$\frac{\sigma}{\sigma_{had}(2J+1)} \propto \exp(-\alpha m_{had})$$
  - Relativistic-string model

    S.B. Chun, PLB 308(1993)153
  - Diquark is important to explain high baryon rates
- Higher rates for Λ and $\Lambda(1520)$ in ARGUS and LEP.
  - Feed down is subtracted?
  - Large error in ARGUS results.
- J=0, light (ud) diquark in Λ?
  - R.L. Jaffe, Phys.Rept.409,1 (2005)
  - A. Selem, F. Wilczek, hep-ph/0602128



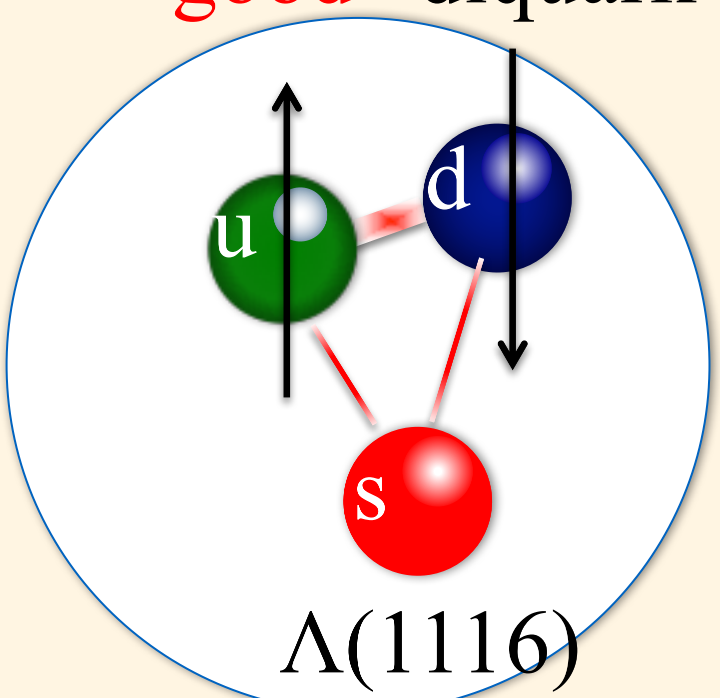
Diquark structure in hadrons

- Color magnetic interaction
  - Strong attraction in spin 0 flavor 0 channel
    - "Good" diquark

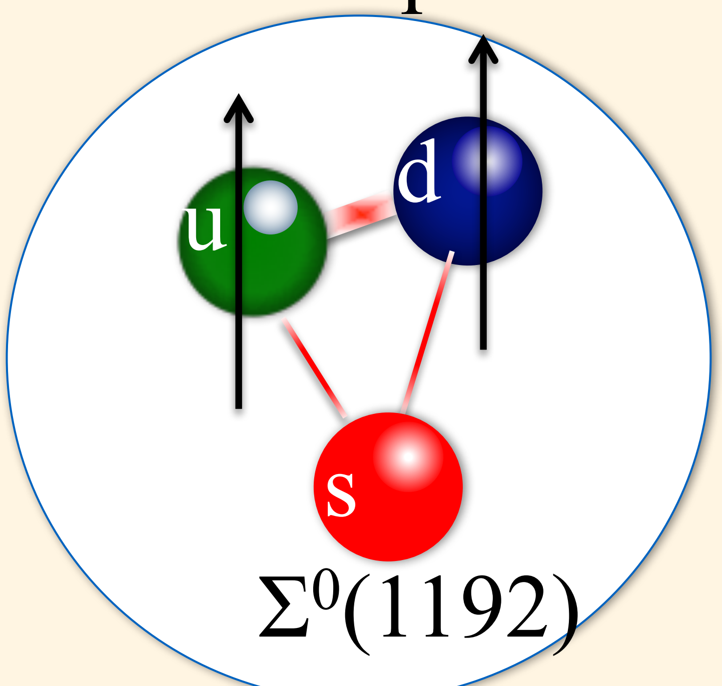
$$\frac{\alpha}{m_i m_j}\frac{\lambda^a(i)}{2}\frac{\lambda^a(j)}{2}\vec{\sigma}(i)\cdot\vec{\sigma}(j)$$

- Structure of Λ, Σ hyperons

S=0 [ud]
"good" diquark



S=1 [ud]
"bad" diquark



Diquark structure in hadrons

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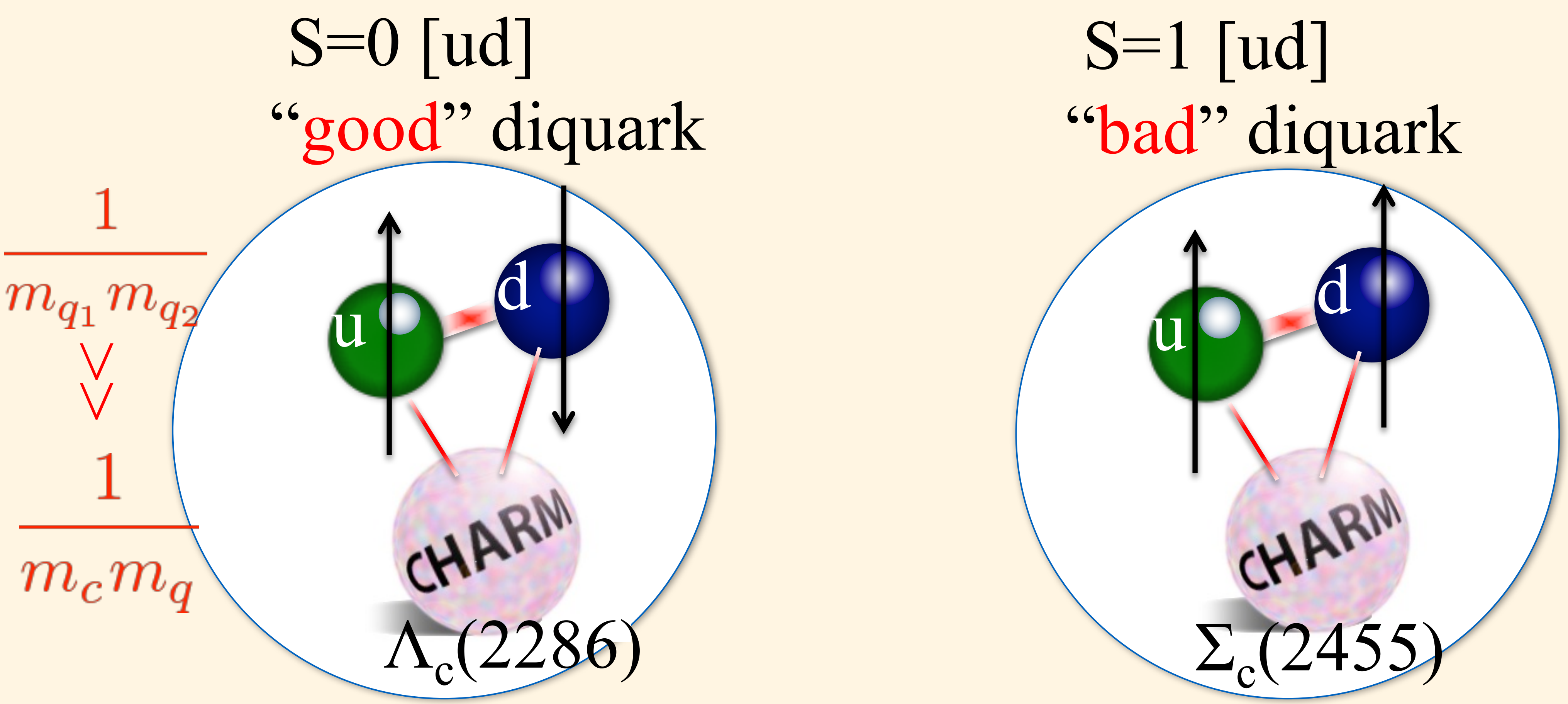
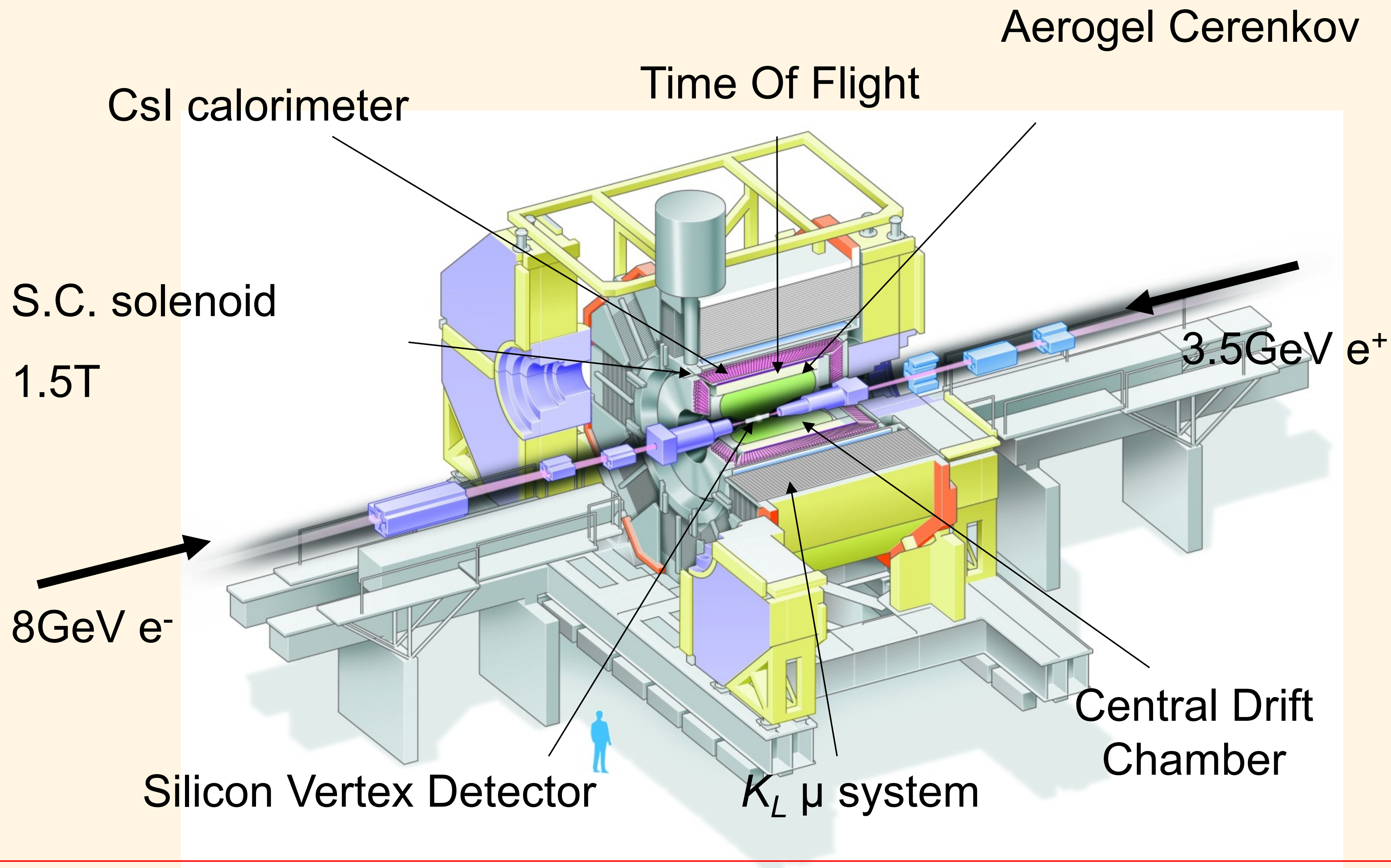
$$\frac{\alpha}{m_i m_j}\frac{\lambda^a(i)}{2}\frac{\lambda^a(j)}{2}\vec{\sigma}(i)\cdot\vec{\sigma}(j)$$

- Structure of Λ_c, Σ_c baryons



Belle data

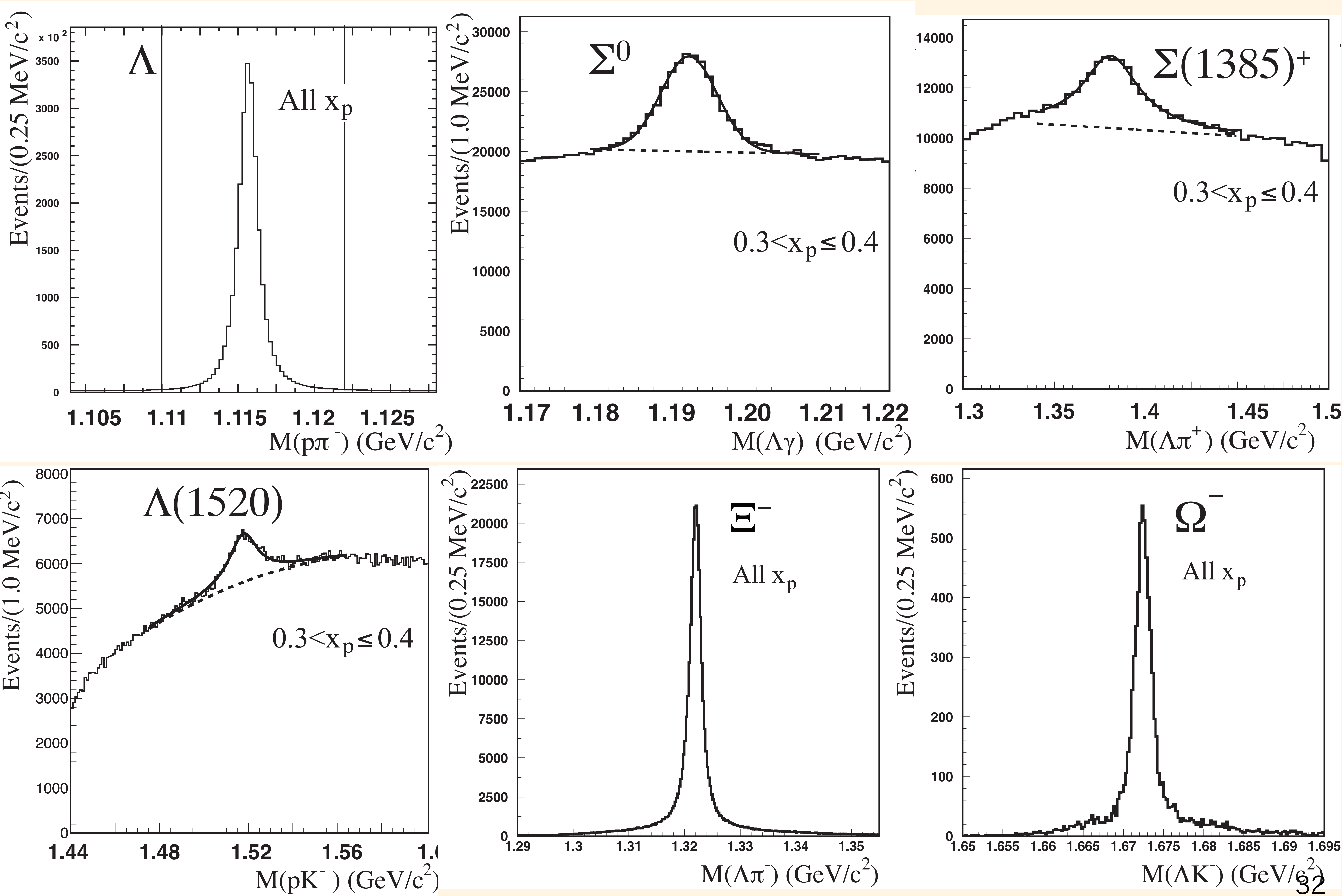


Integrated luminosity

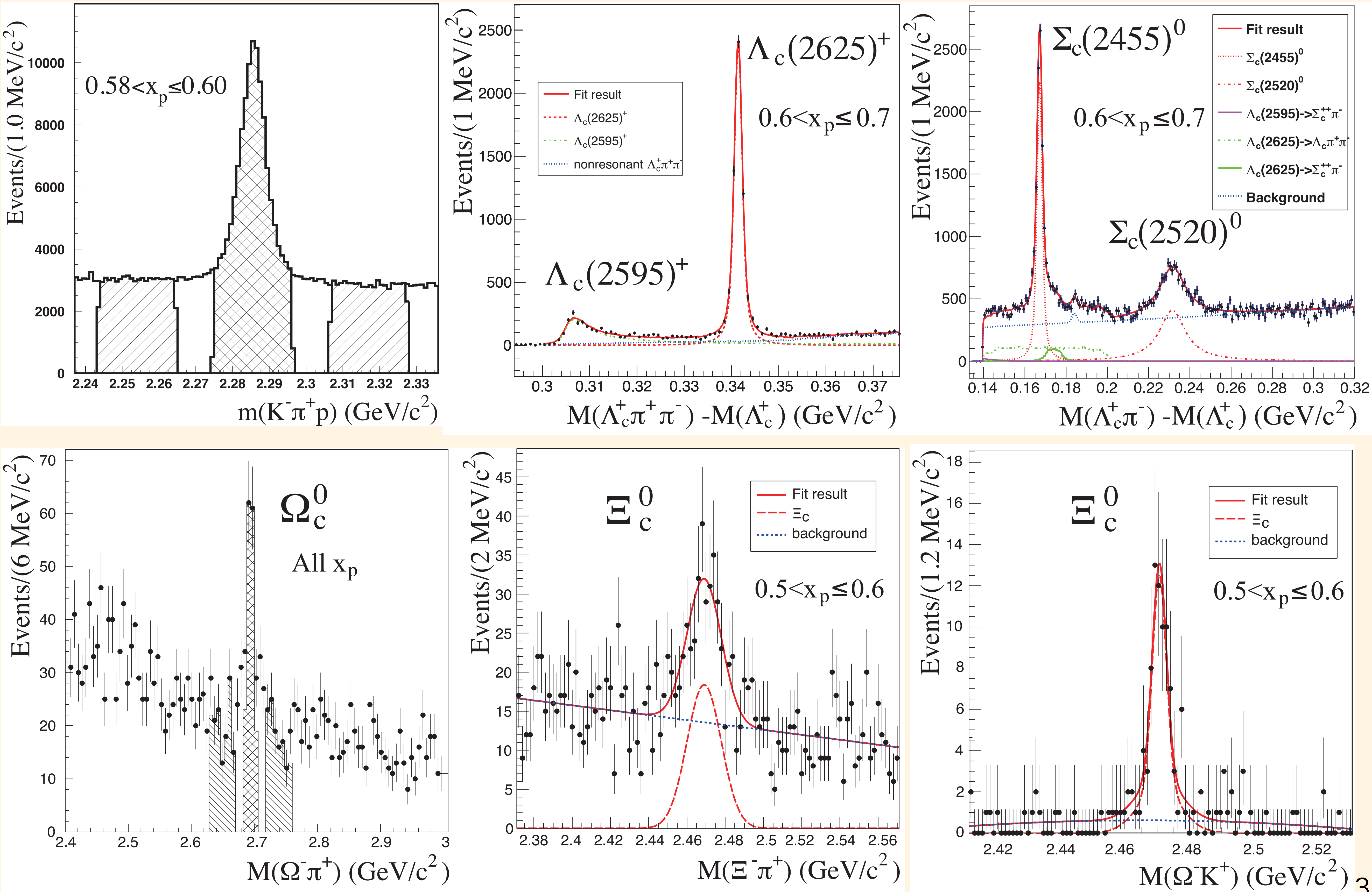
: 562. fb^{-1} @ on Υ(4S) resonance data for charmed baryons
($\sqrt{s}$ =10.58 GeV)

: 79.3 fb^{-1} @ continuum data for hyperons, charmed baryons
($\sqrt{s}$ =10.52 GeV)

Mass spectra for hyperons

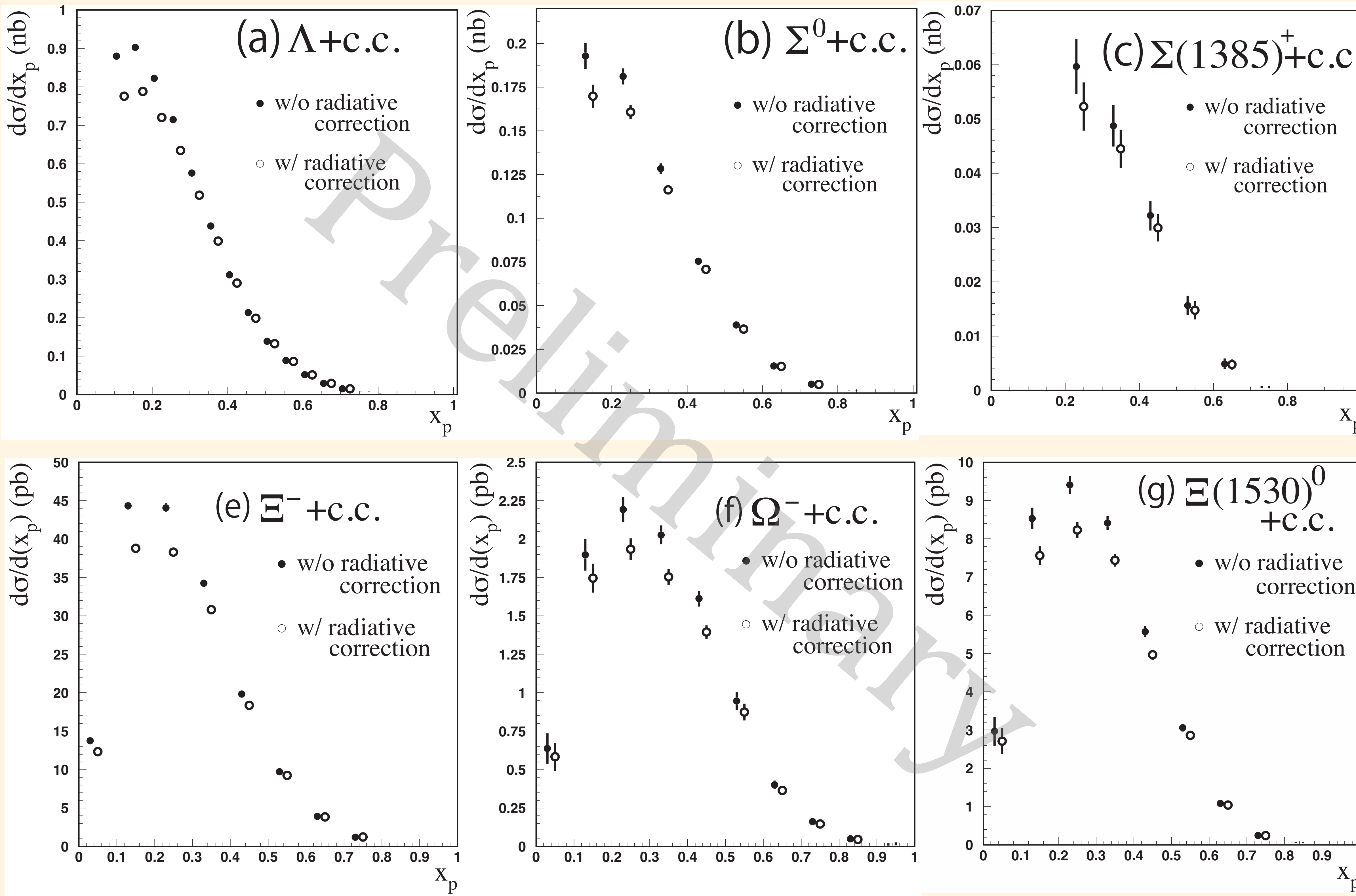


Mass spectra for charmed baryons



“Inclusive” cross sections vs. x_p

“Inclusive” cross sections (including feed-down) are obtained as a function of hadron scaled momentum (x_p). $x_p = p/\sqrt{s/4 - M^2}$ (M, p : mass and CM momentum)



Error bar represent statistical fluctuation of real and MC data

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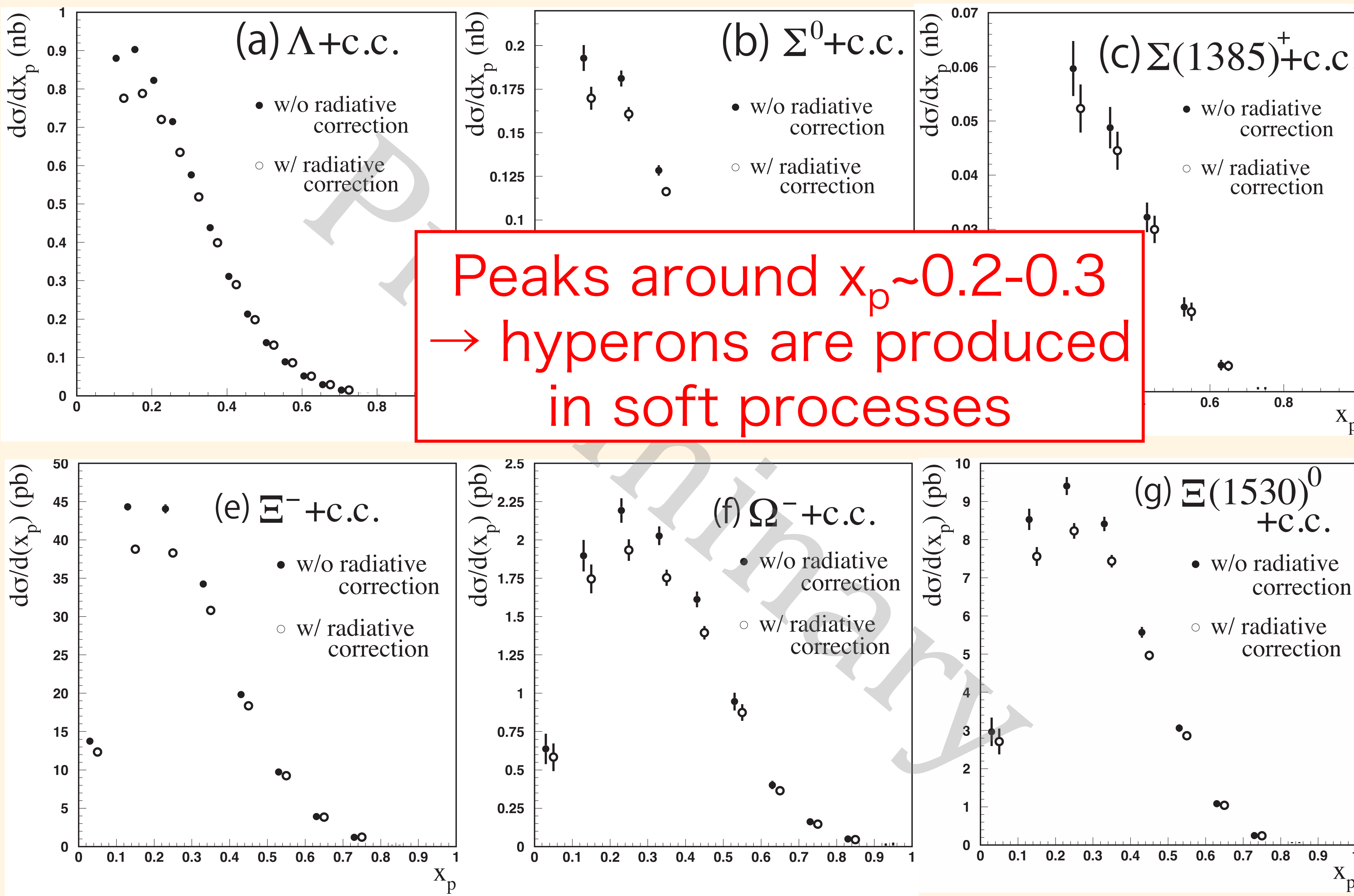
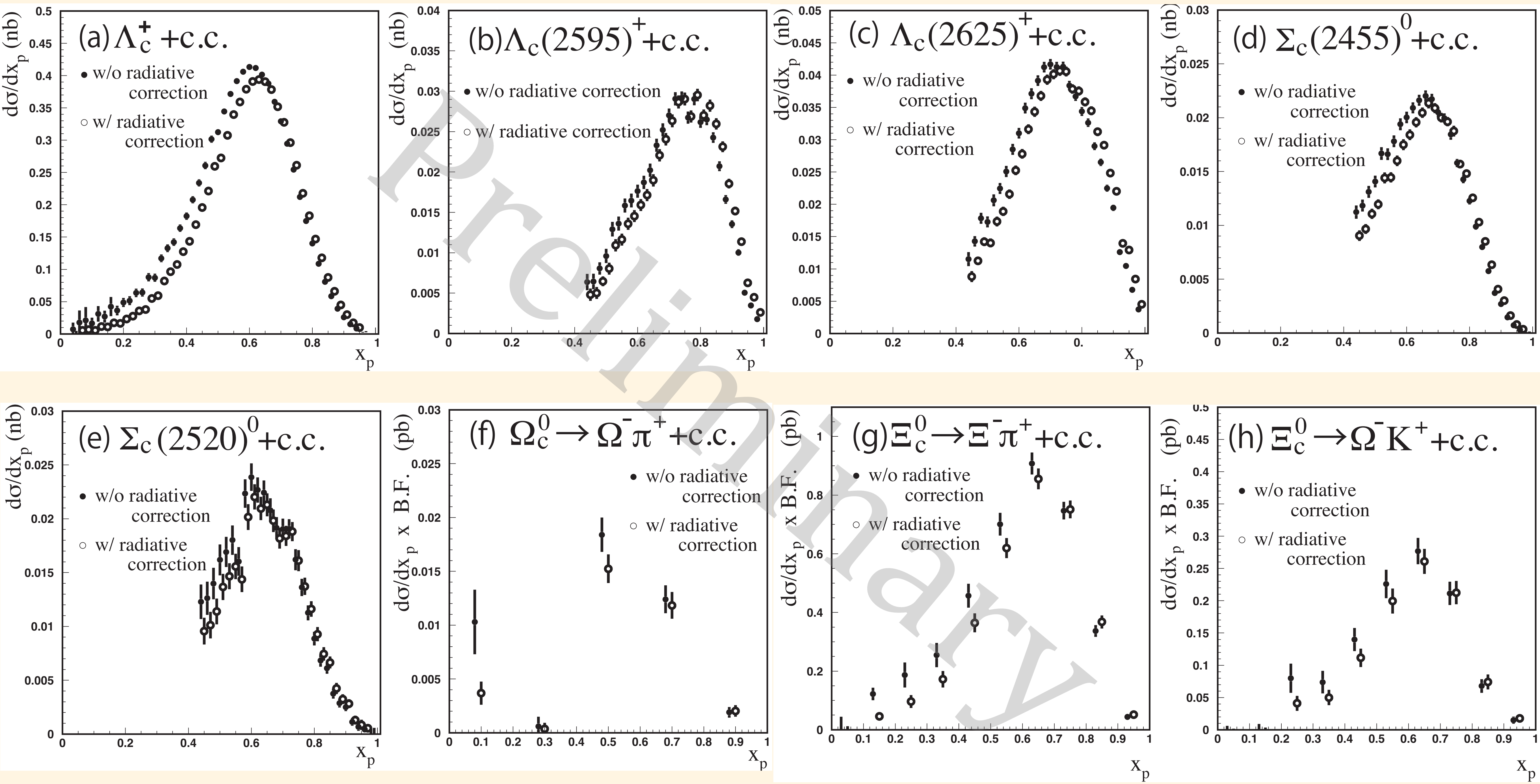


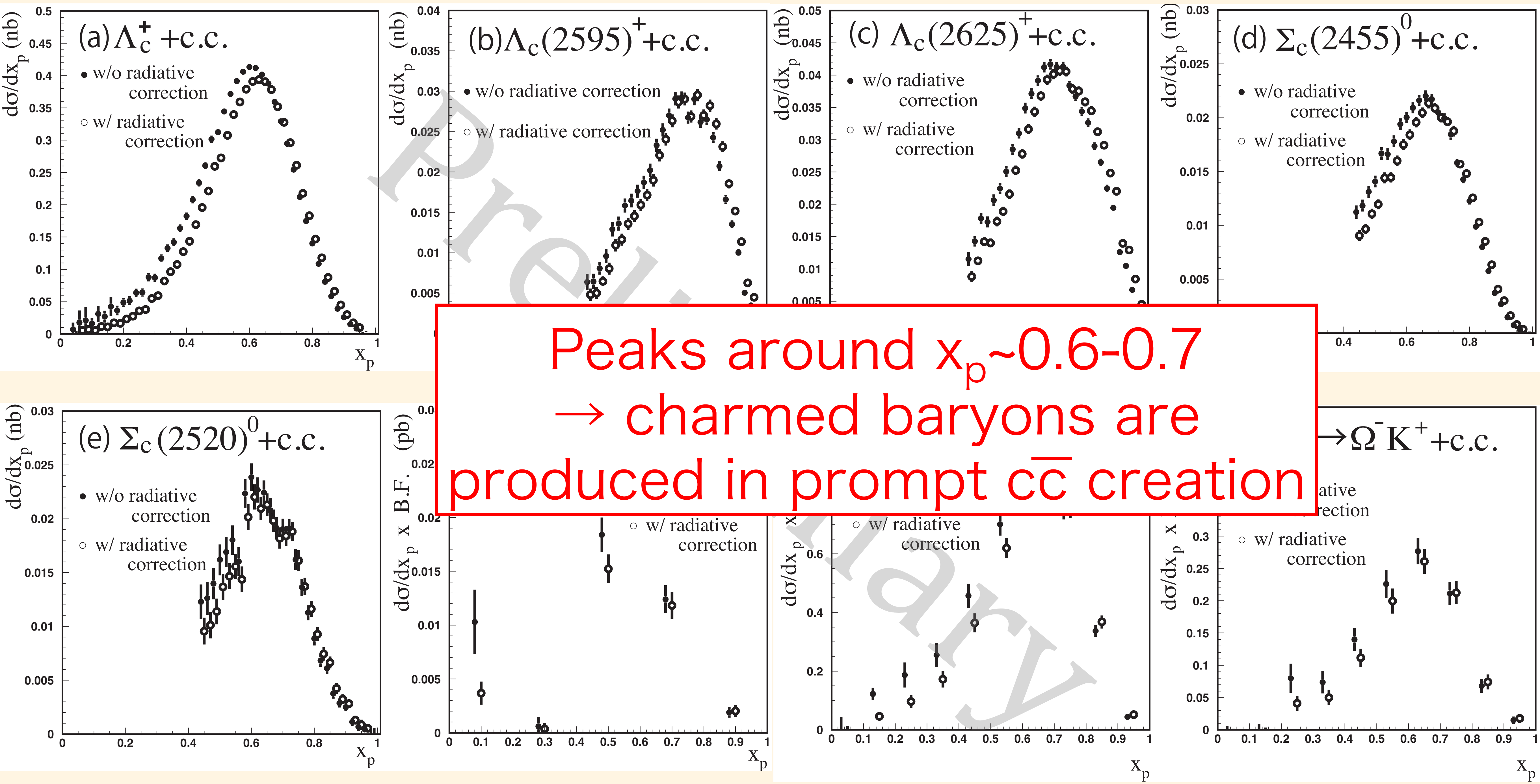
Peaks around x_p~0.2-0.3
→ hyperons are produced in soft processes

Error bar represent statistical fluctuation of real and MC data

"Inclusive" cross sections vs. x_p



"Inclusive" cross sections vs. x_p

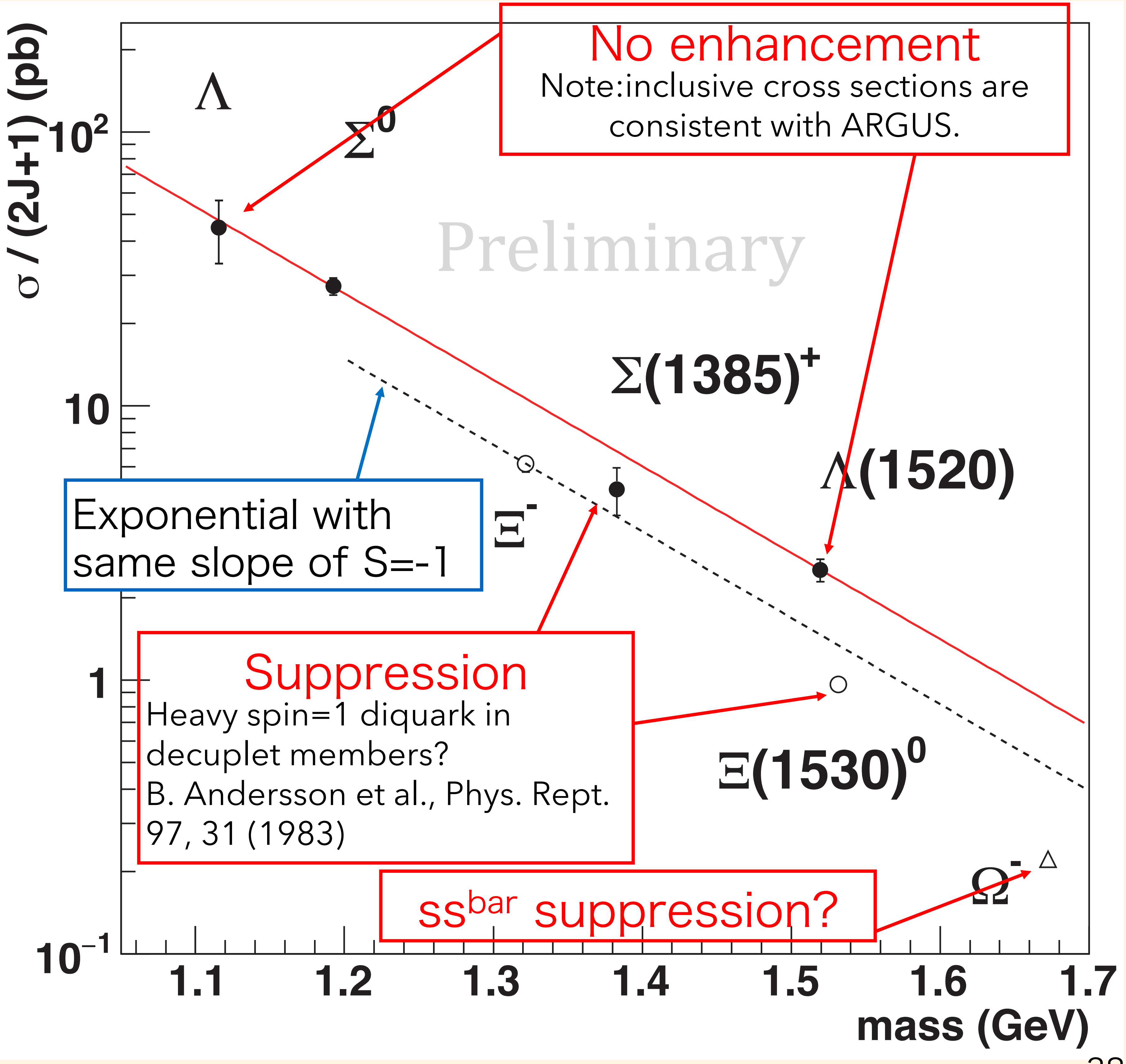


Peaks around x_p~0.6-0.7

→ charmed baryons are produced in prompt $c\bar{c}$ creation

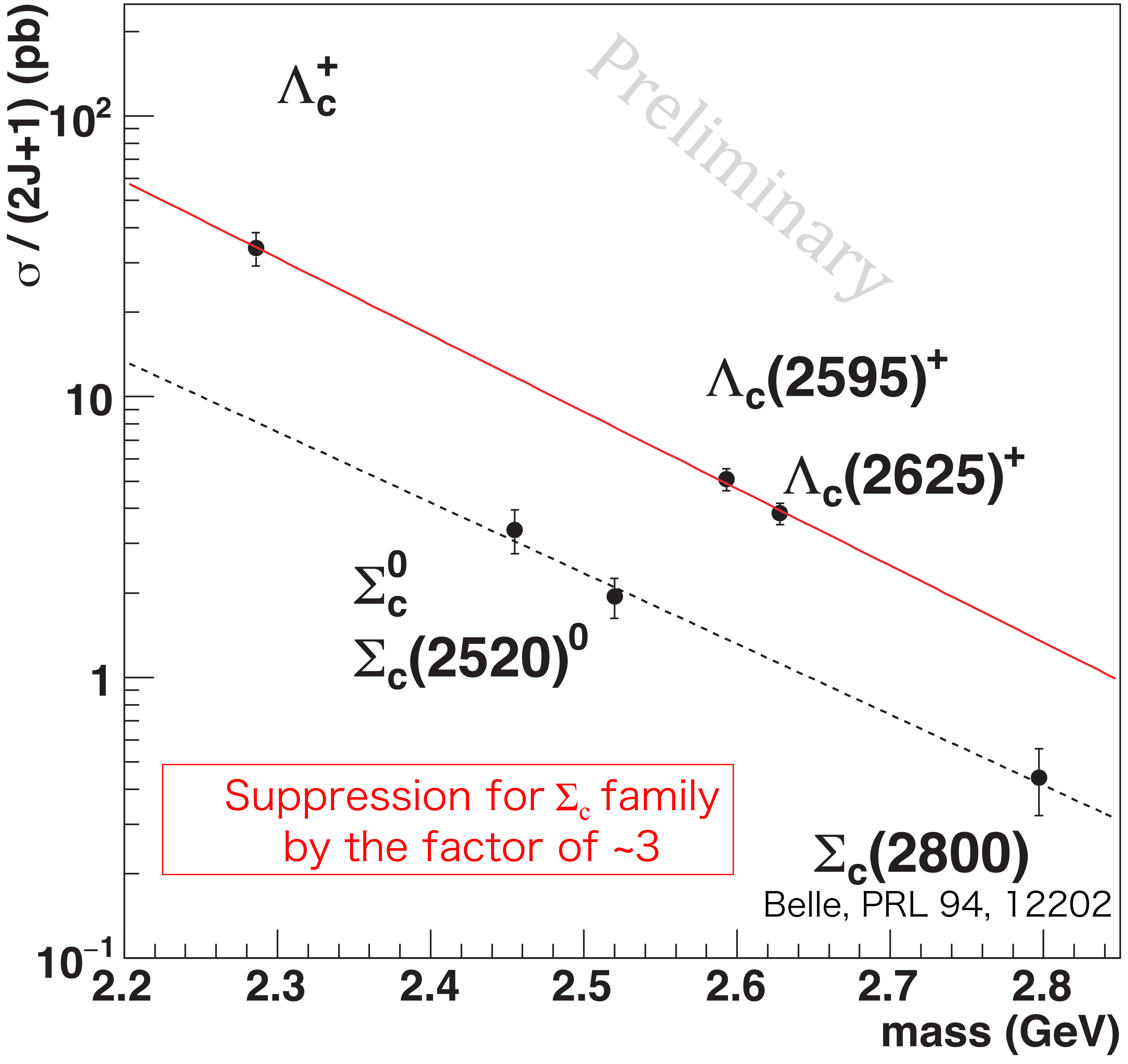
Results of hyperons

- Subtract feed down from heavier states;
  - 68% of inclusive Λ
  - 17% of inclusive Σ^0
  - 25% of inclusive Λ(1520)
  - 8% of inclusive $\Sigma(1385)^+$
  - 24% of inclusive Ξ^-



Results of charmed baryons

- Subtract feed-down
  - 52% of inclusive Λ_c^+
  - 16% of inclusive Σ_c^0



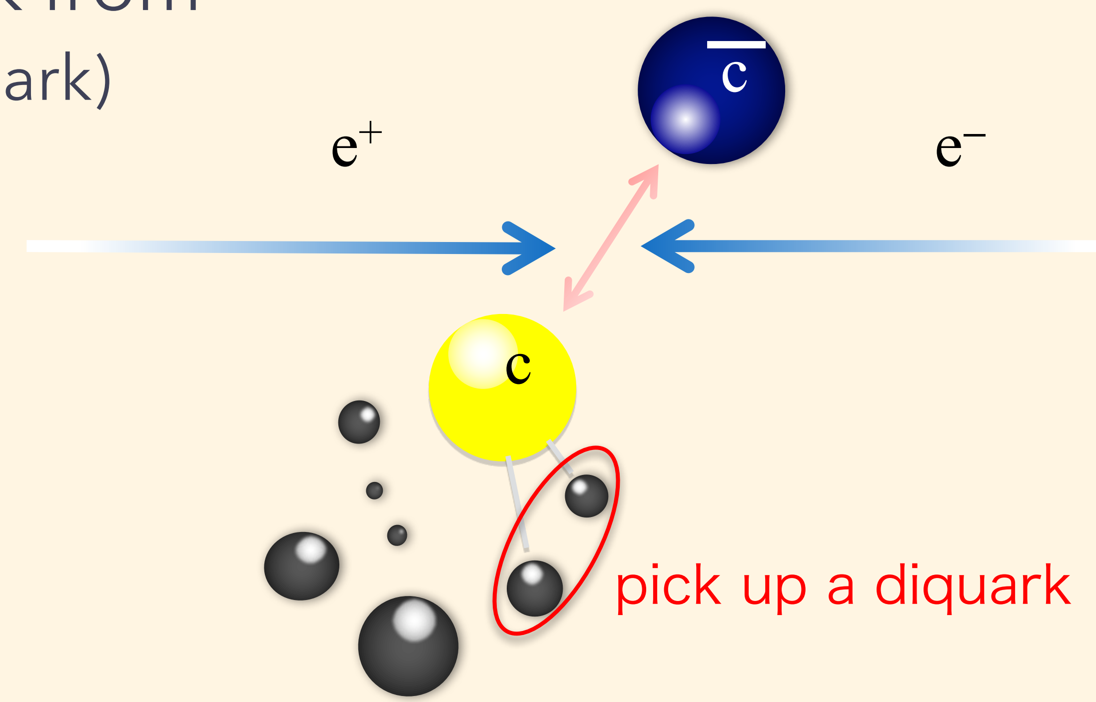
Results of charmed baryons

- Assuming that a c-quark picks up a diquark from vacuum, ("tunnel effect" of diquark and anti-diquark)

$$\sigma \propto \exp(-\pi\mu^2/\kappa)$$

μ: diquark mass
κ: gluonic string tension

B. Andersson et al., Phys. Scripta. 32, 574 (1985)



Mass difference of spin-1 and 0 diquarks

$$m(ud_1)^2 - m(ud_0)^2$$
$$= (8.2 \pm 0.8) \times 10^4 \ (\mathrm{MeV}/c^2)^2$$

ref. $490^2 - 420^2 = 6.4 \times 10^4 \ (\mathrm{MeV}/c^2)^2$

B. Andersson et al., Phys. Rept. 97, 31 (1983)

slightly larger but consistent with diquark masses in reference

- Support diquark structure in ground and low-lying Λ_c, Σ_c baryons T. Yoshida et al., PRD92 114029 (2015)
- Production rates can be a tool to study the structure of hadrons
  - Key issue: comparing various baryons and find something unexpected (probably same for time-like form factor study: comparison of Λ,Σ,Λ(1405)…)

Summary

- LEPS: coherent φ-meson photoproduction from ^{4}He
  - Isospin=0 and spin=0 target→No pseudo-scaler exchange
  - SDM elements exhibit
    - no helicity single-filp amplitude,
    - natural parity exchange dominance,
    - 10-13% discrepancies from full natural parity ex. may suggest **axial-vector ex.** or **double-helicity-flip amplitude (ex. of tensor object)**
  - E_γ dependence of dσ/dt at $t=t_{min}$ show monotonic increase
    - 2.7σ deviation near E_γ =2.2 GeV
- LEPS2: beam asymmetry (Σ) for η-meson
  - Energy range up to √s=2.32 GeV
  - **Polar angular distribution changes from √s=1.92 GeV,**
- Belle: production rates of hyperons and charmed baryons
  - Clear exponential dependence on baryon masses
  - No enhancements for Λ, Λ(1520)
  - **Suppression of decuplet hyperons and Σ_c family**
  - **Suggesting diquark structure in ground and low-lying Λ_c, Σ_c**