

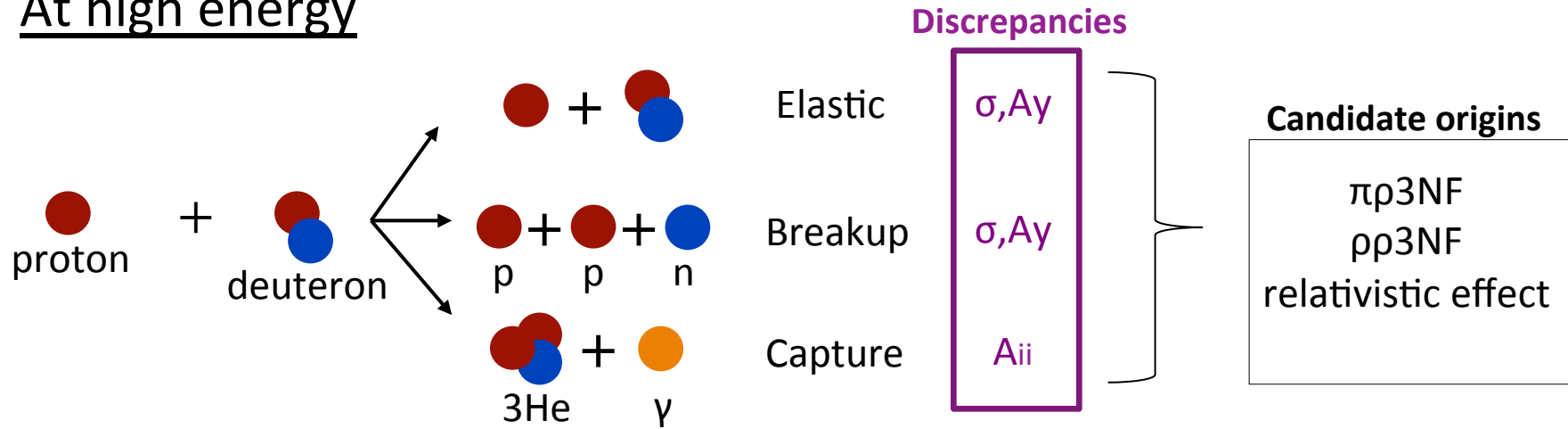
Systematic measurement of pd breakup cross section around Space Star

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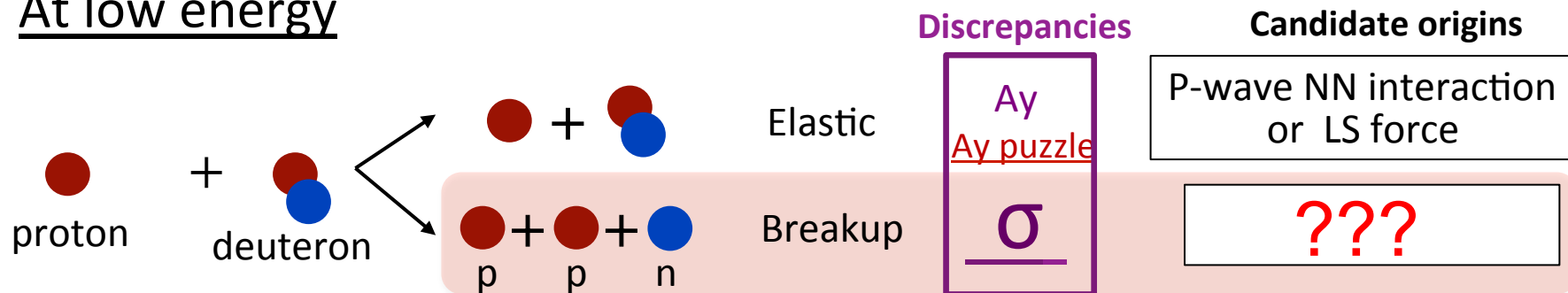
Department of Physics, Kyushu University

Remaining problems N+d reactions after $\pi\pi 3NF$ was found

- At high energy



- At low energy

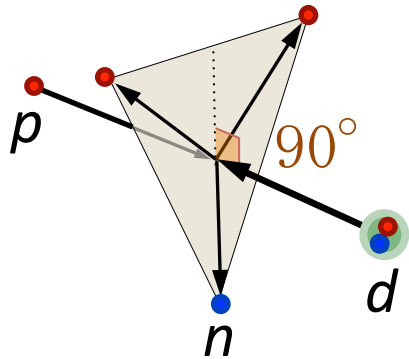


Space Star Anomaly

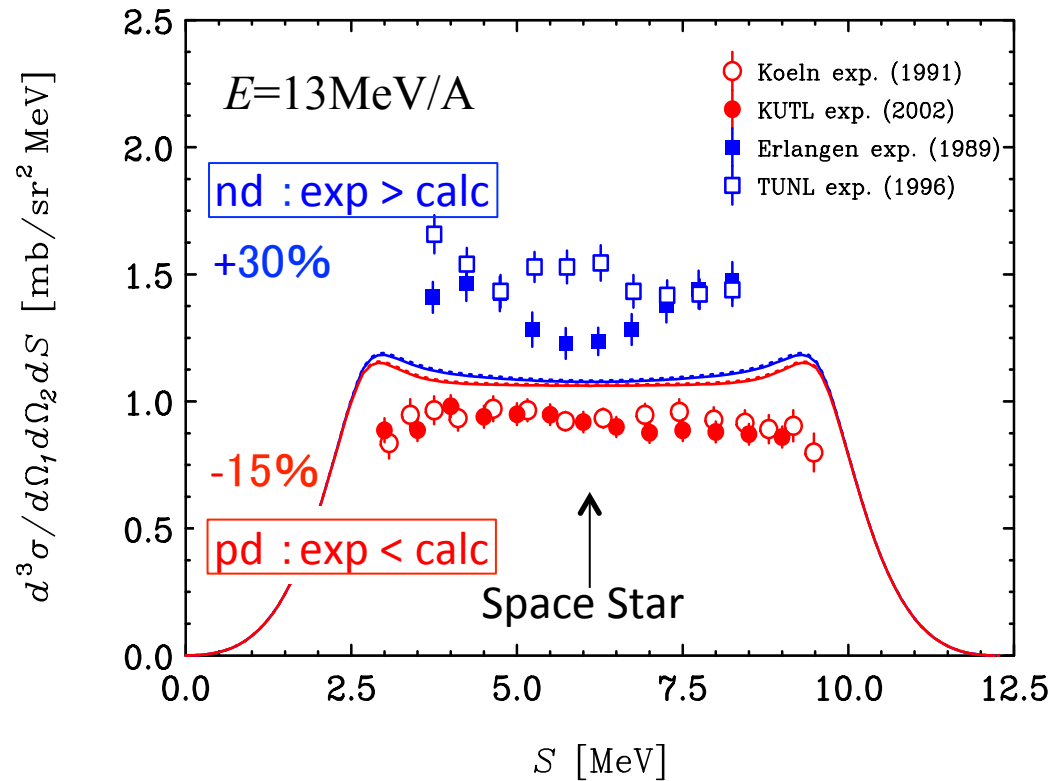
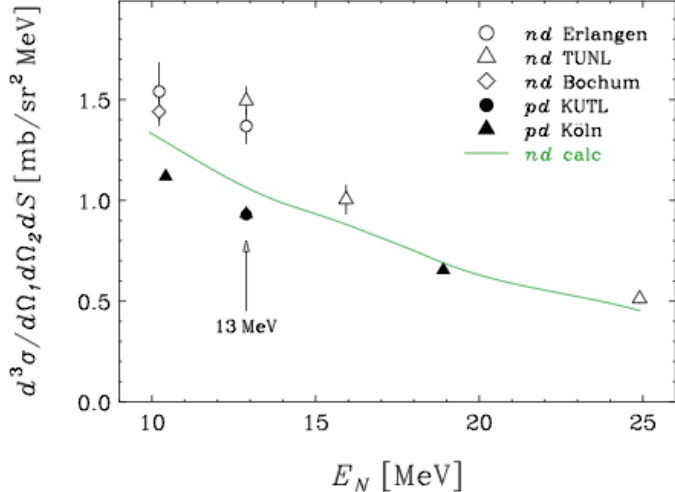
→ This study

Space Star anomaly

Space Star configuration

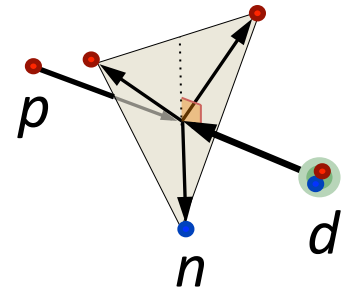


Outgoing 3-nucleons form
 1) rectangular triangle Δ
 2) Δ is perpendicular to beam axis



- : Erlangen [J. Strate et al., Nucl. Phys. A 501, 51 (1989).]
 - : TUNL [H. R. Setze et al., Phys. Lett. B 388, 229 (1996).]
 - : Koeln [G. Rauprich et al., Nucl. Phys. A 535, 313 (1991).]
 - : KUTL [T. Ishida et al., Mod. Phys. Lett. A 18, 436 (2003).]
- All calculations by A. Deluva et al.

At Space Star (SS), outgoing 3-nucleons form
1) a *rectangular triangle*, and
2) the triangle is *perpendicular* to the beam axis



Origin of SS anomaly has not been found.
There are no candidate for the origin yet.

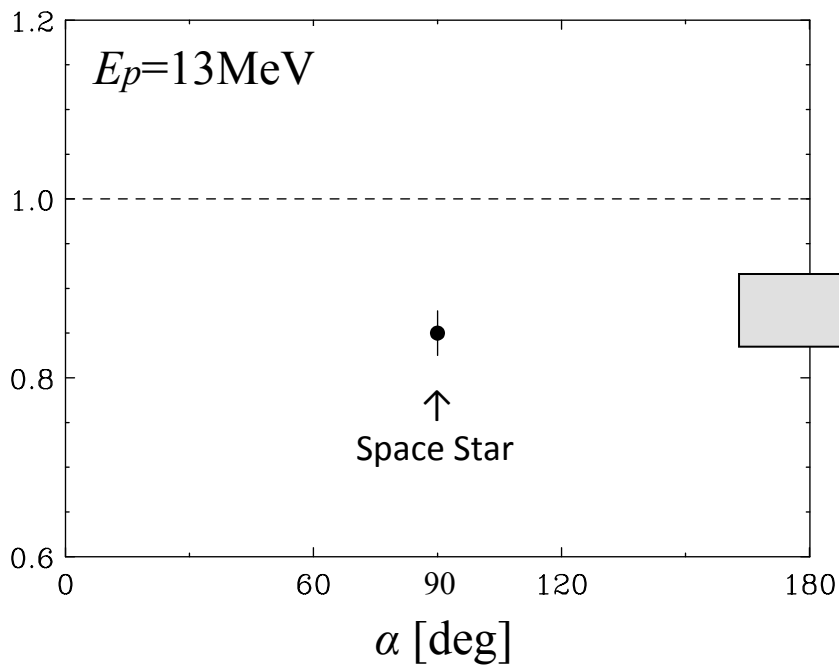
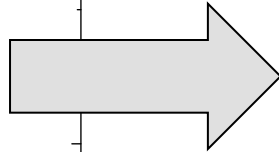
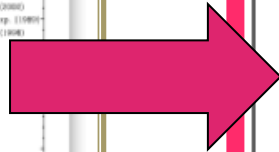
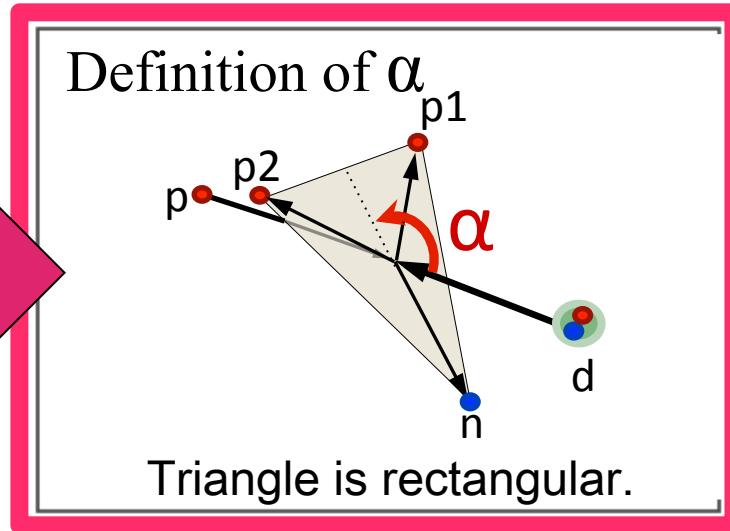
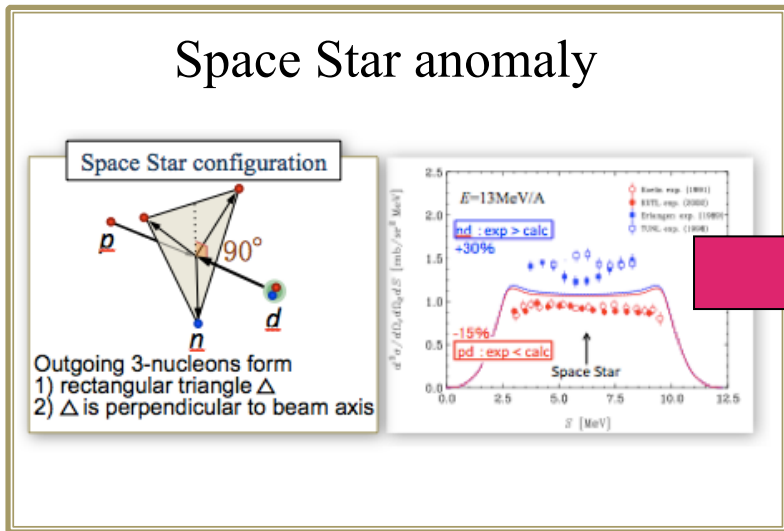
- a) $p+d$ breakup cross sections can be precisely measured.
- b) $p+d$ breakup calculation has become available since 2005 (Deltuva et al).



Systematic measurement of $p+d$ breakup cross section around Space Star

- A: Is *perpendicular condition* necessary?
- B: Is *rectangular triangle condition* necessary?
- C: How is *energy-dependence* of SS anomaly?

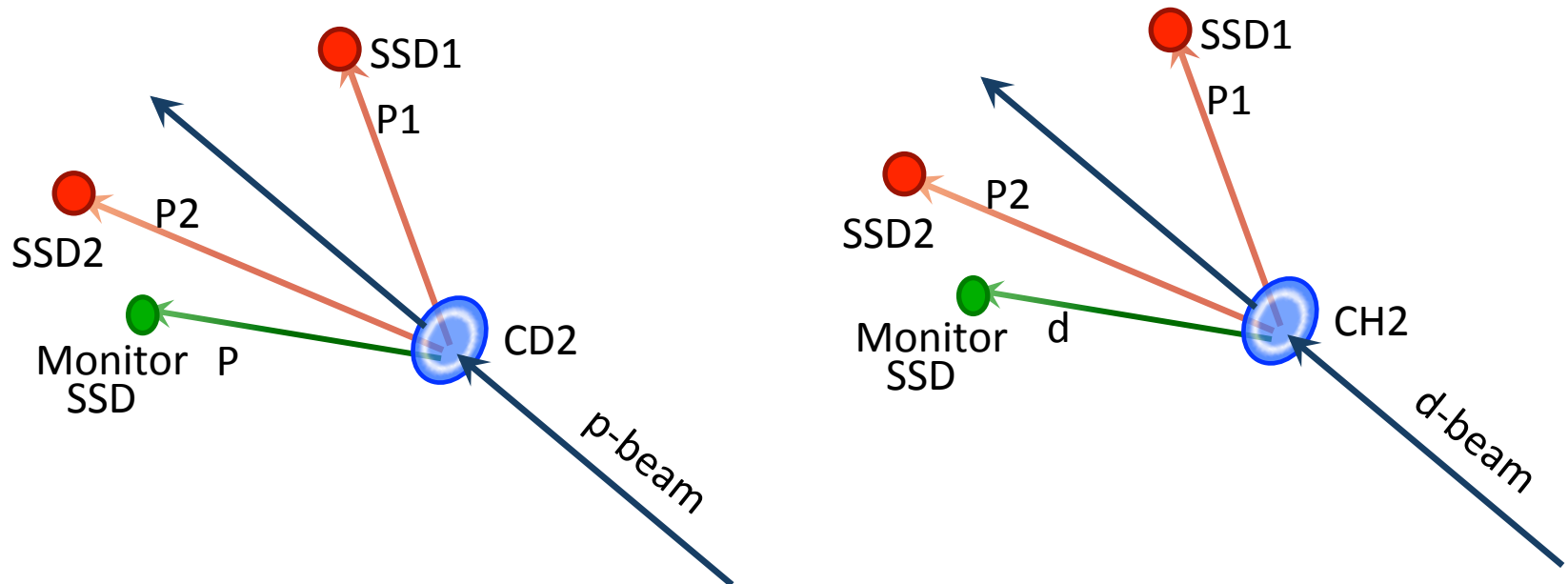
A: Is *perpendicular condition* necessary?



How is α -dependence?

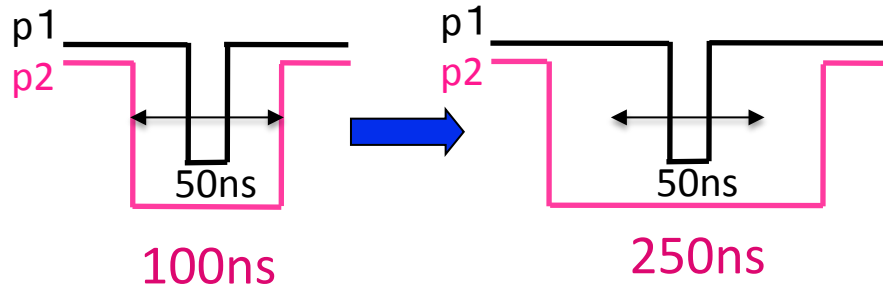
$p+d \rightarrow p_1+p_2+n$ experiment

- ☆ **Facility** : Kyushu U. Tandem Laboratory, $E_p=7.5, 9.5, 13$ MeV
Tsukuba U. Tandem Acc. Center, $E_d=19$ MeV
RCNP Osaka, $E_d=26$ MeV
- ☆ **Beam** : unpolarized p -beam or d -beam (~ 200 nA)
- ☆ **Target** : CD2 or CH2 foil (~ 0.3 mg/cm²)
- ☆ **Monitor** : using $p+d$ elastic scattering, targetxbeam was monitored

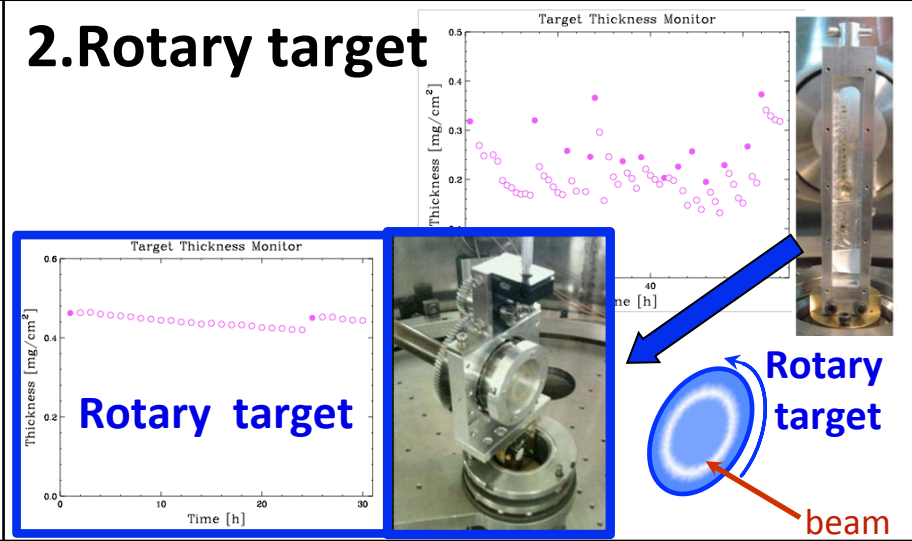


Precise measurement of absolute cross section

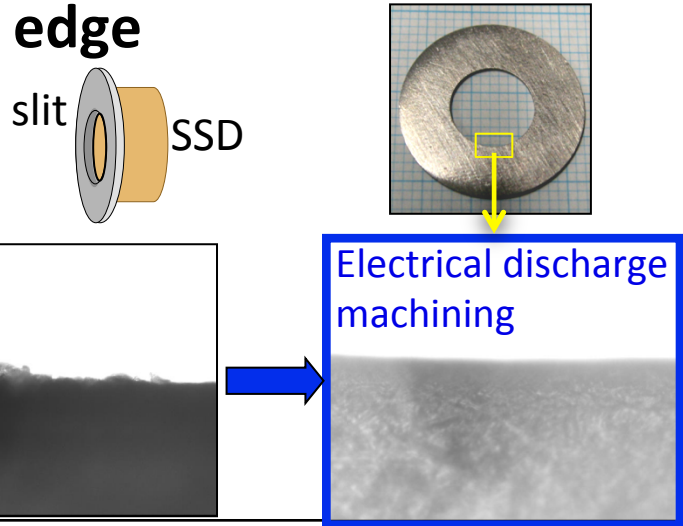
1. Coincidence time



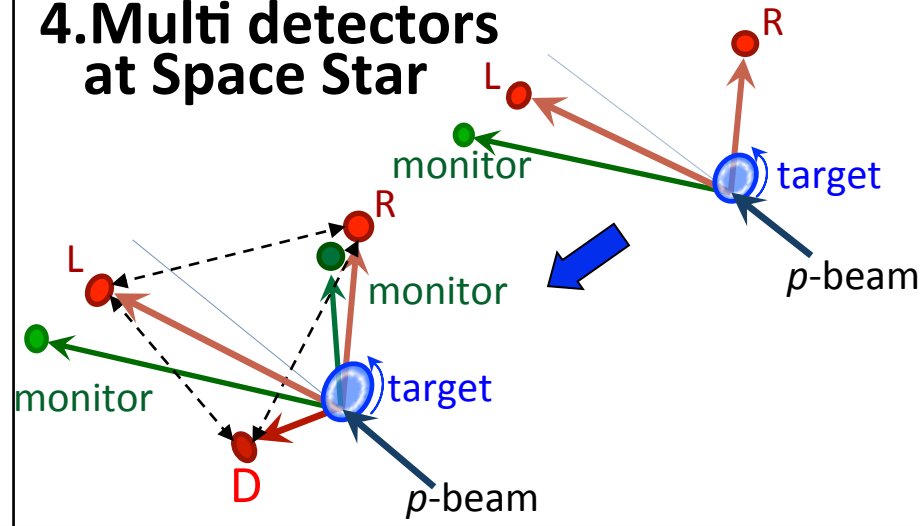
2. Rotary target



3. Slit edge



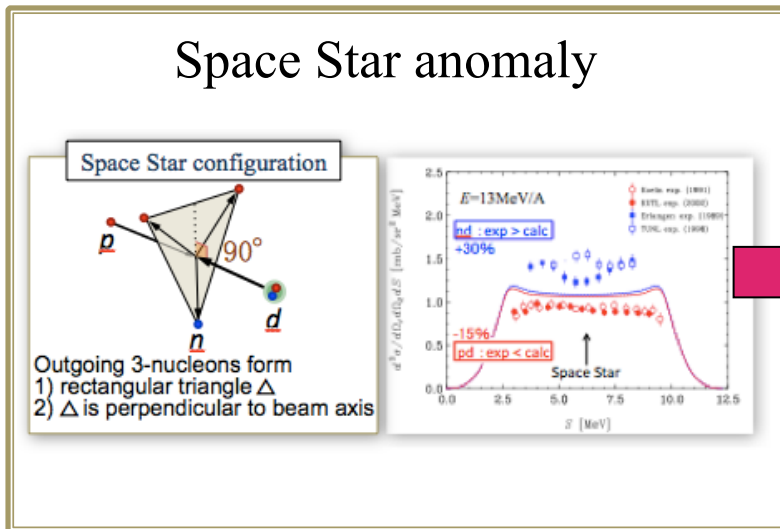
4. Multi detectors at Space Star



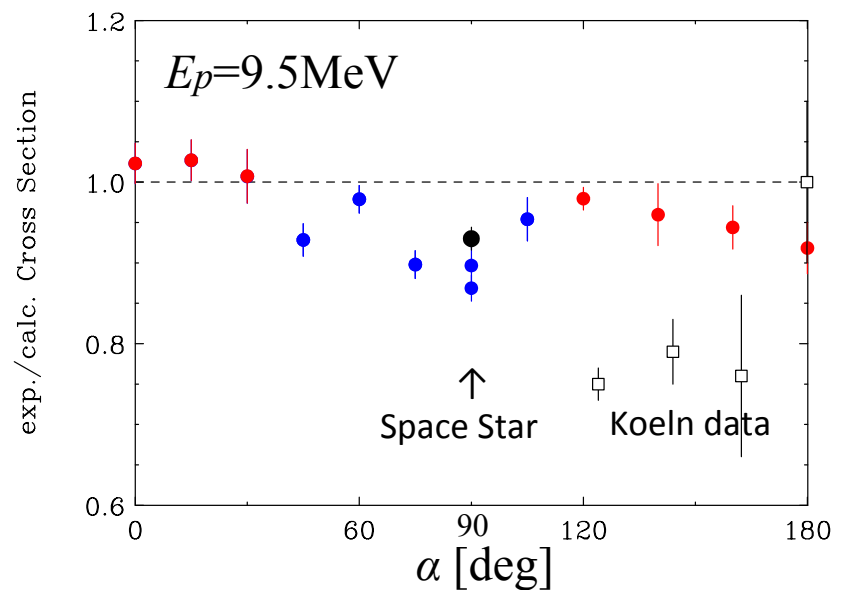
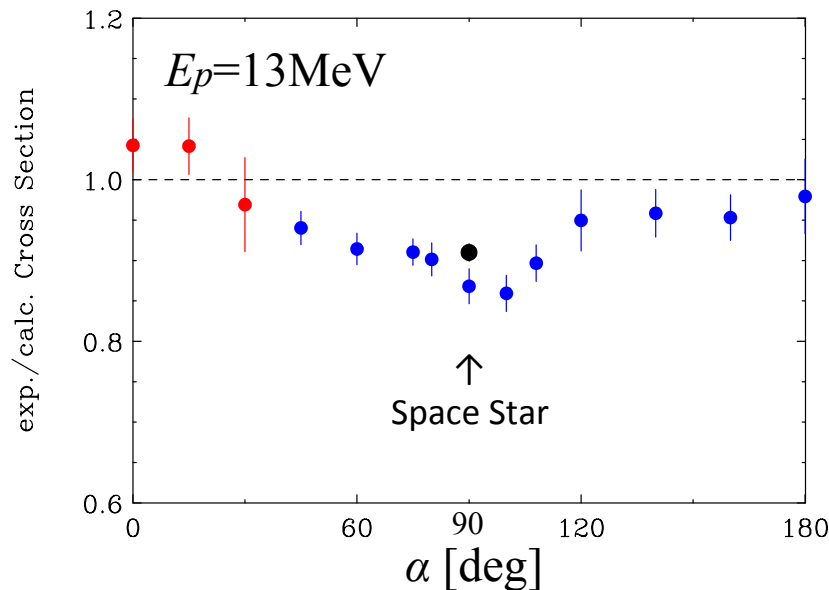
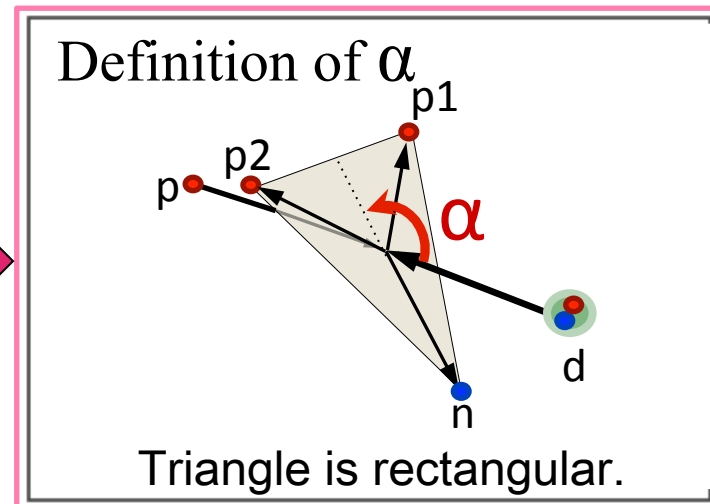
Exp data: ● Old (-), ● New(1.+2.+3.), ● New-SS(1.+2.+3.+4.)

Experimental Results for *perpendicular condition*

Space Star anomaly

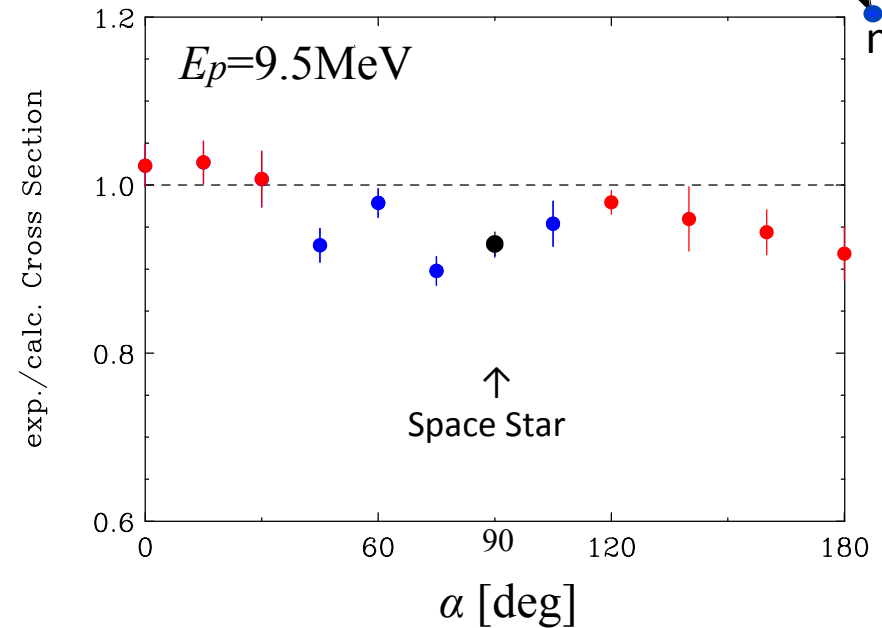
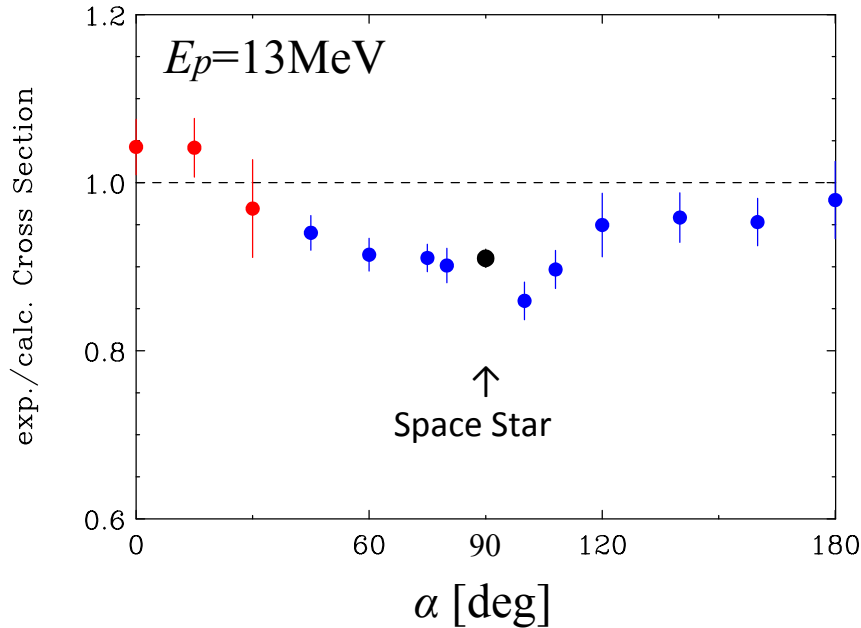
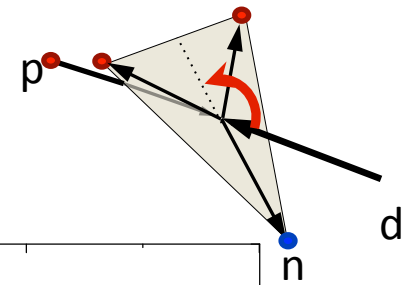


Definition of α



Exp data: ● Old (-), ● New(1.+2.+3.), ● New-SS(1.+2.+3.+4.)

A: Is *perpendicular condition* necessary?



Exp data: ● Old (-), ● New(1.+2.+3.), ● New-SS(1.+2.+3.+4.)

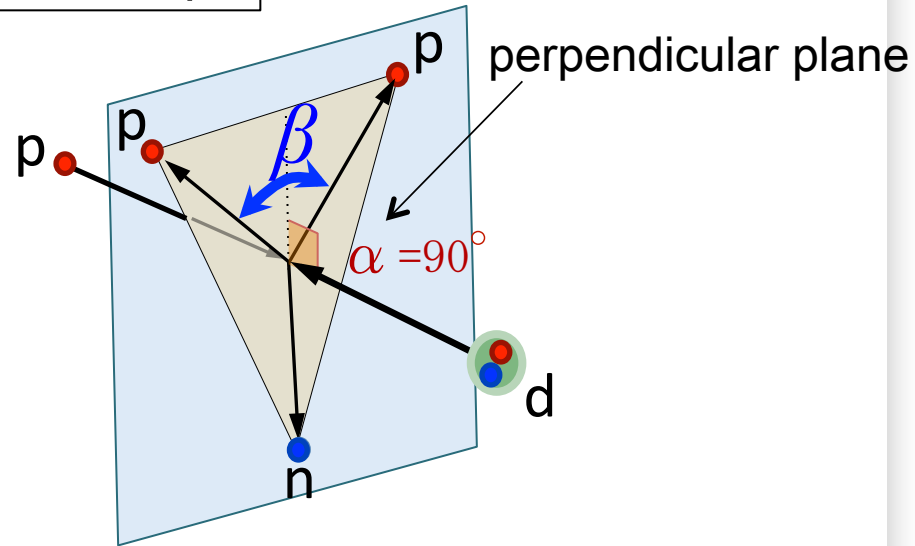
Tendency:

Anomaly becomes maximum at $\alpha = 90^\circ$ (Space Star), and Anomaly gradually decreases as α increases/decreases from 90° .

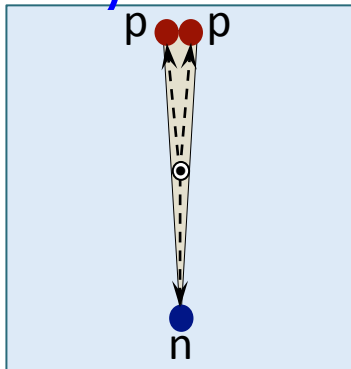
→ *perpendicular condition* is necessary!

B) Is *rectangular triangle condition* necessary?

definition of β

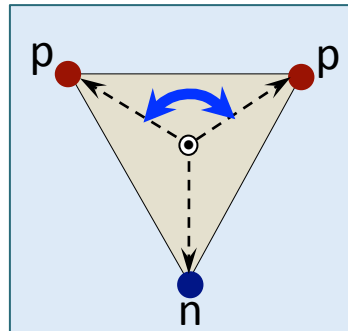


$\beta = 0^\circ$



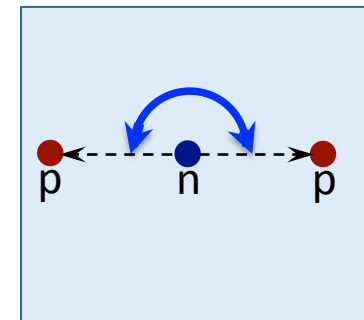
pp-FSI

$\beta = 120^\circ$



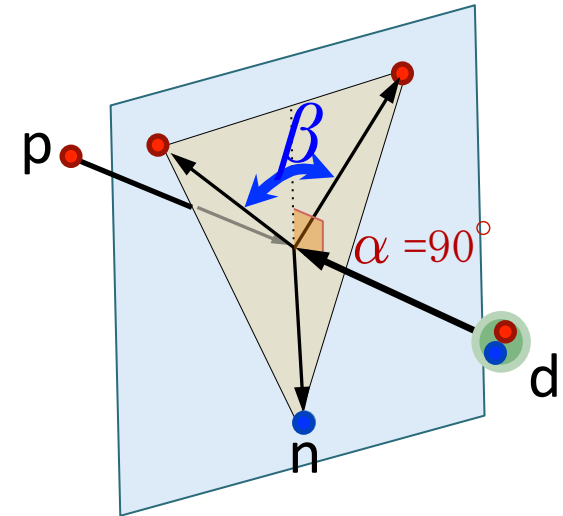
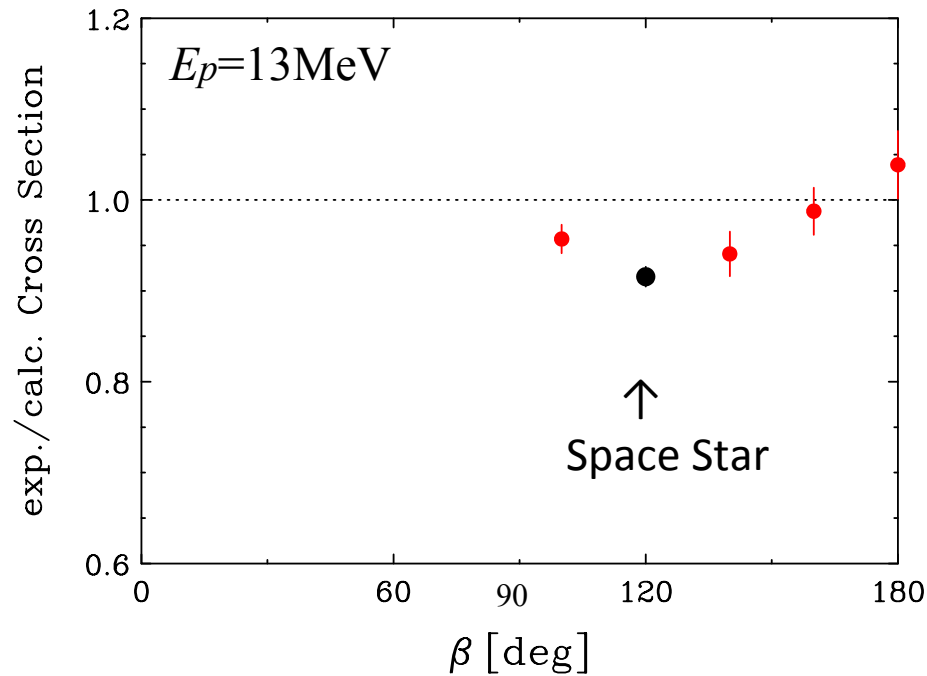
Space Star

$\beta = 180^\circ$



collinear

B: Is *rectangular triangle condition* necessary?



Exp data: ● Old (-), ● New(1.+2.+3.), ● New-SS(1.+2.+3.+4.)

Anomaly becomes maximum at $\beta = 120^\circ$ (Space Star), and Anomaly gradually decreases as β increases/decreases from 120° .

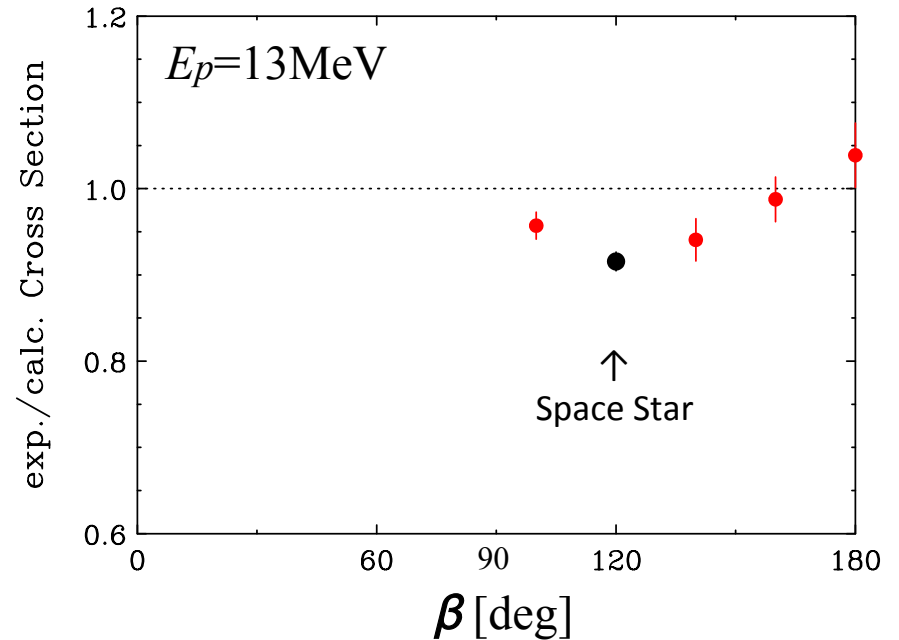
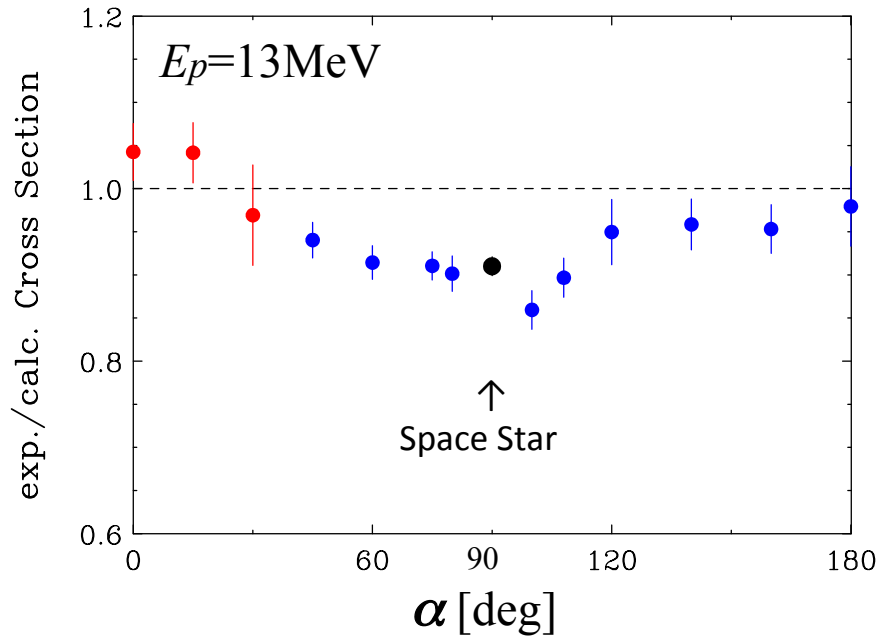
→ *rectangular triangle condition* is necessary!

A: *perpendicular condition* is necessary

B: *rectangular triangle* is necessary



A+B: *Space Star* is necessary



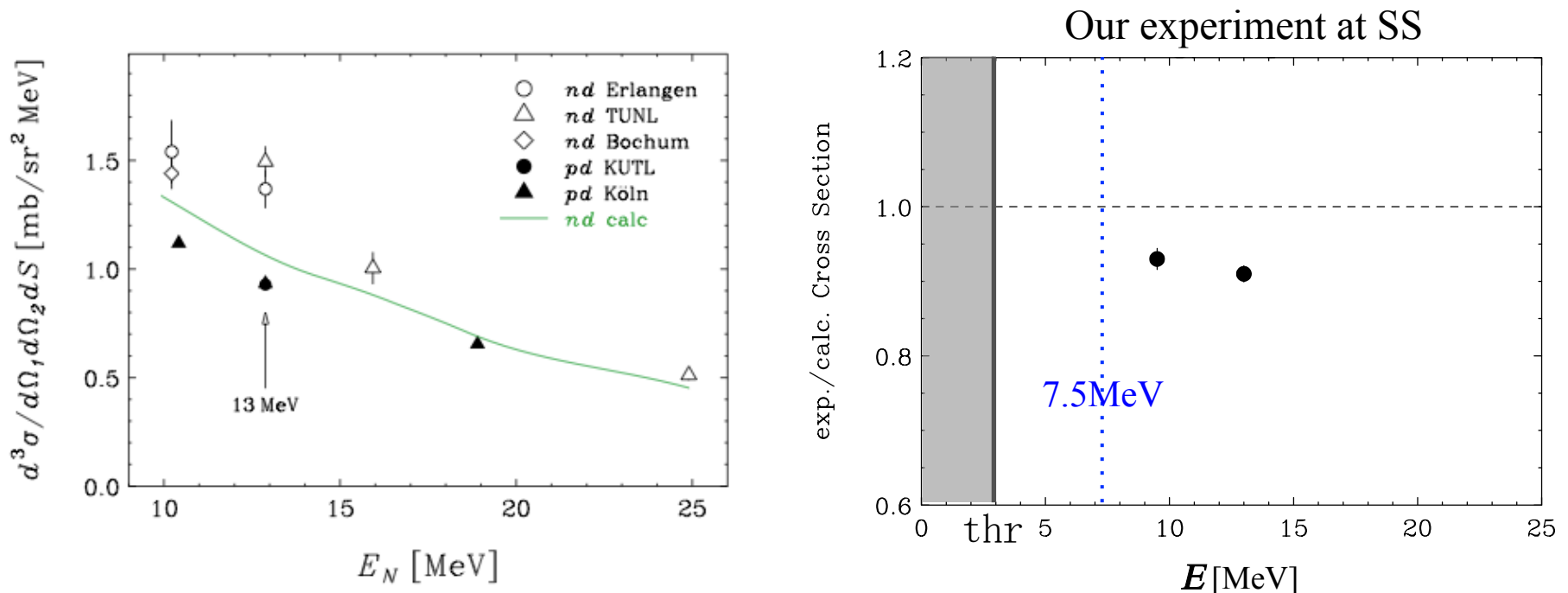
Anomaly becomes maximum at Space Star.



C) How is *E-dependence* of SS anomaly.

C) How is *E-dependence* of SS anomaly.

We have measured Space Star cross section at 9.5MeV and 13MeV.

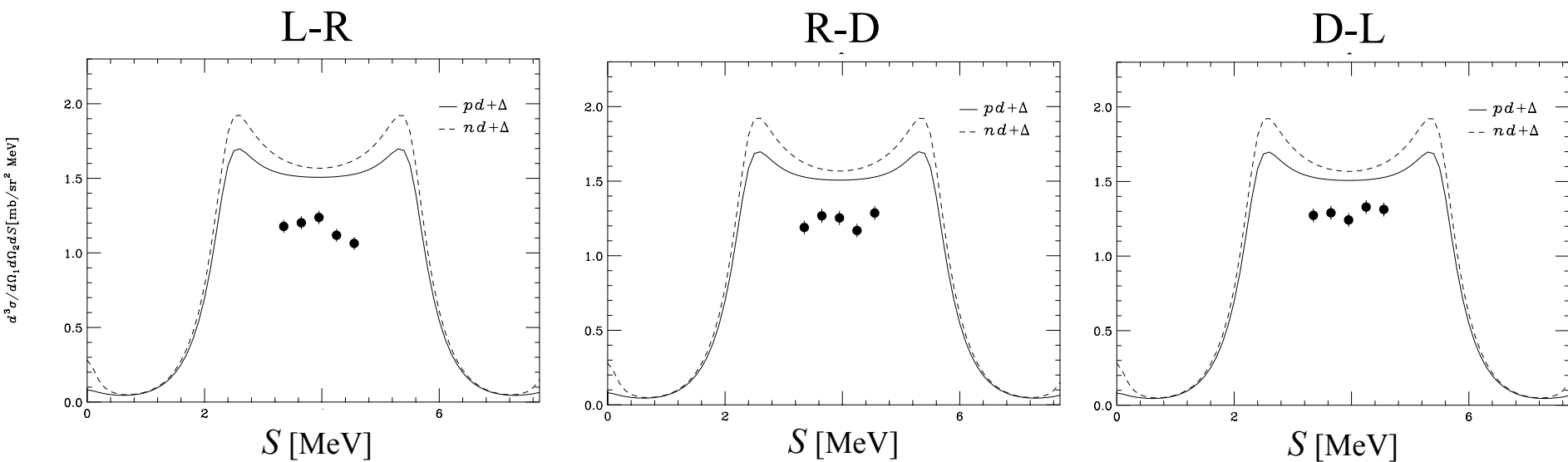


Does *pd*-breakup Space Star anomaly become maximum at 13 MeV?

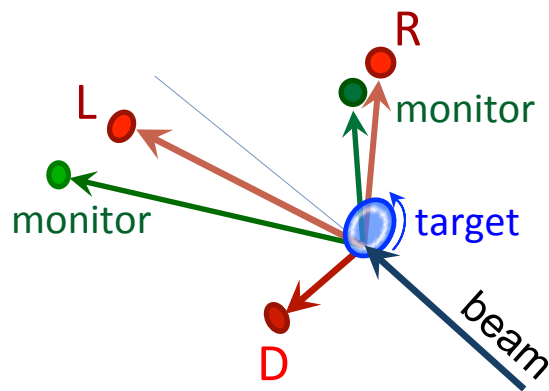
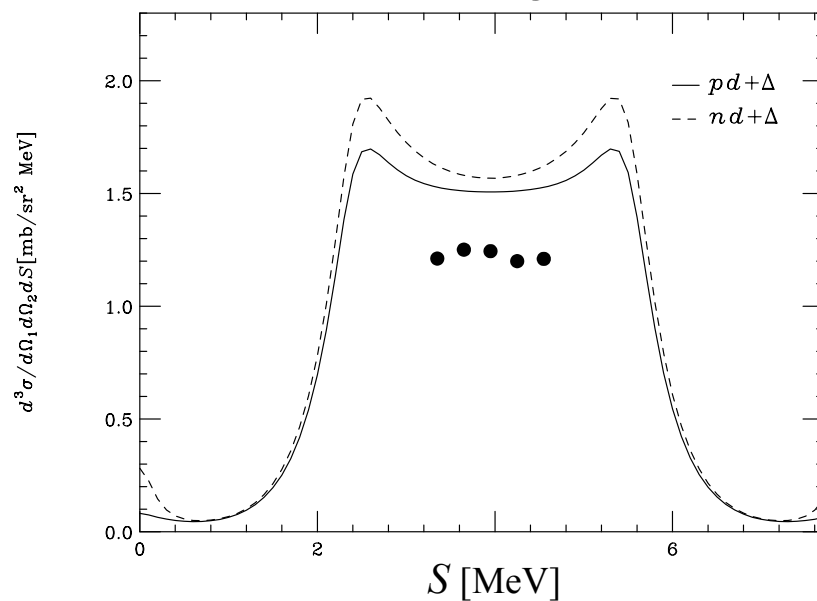


Next, we measured Space Star cross section at $E_p=7.5\text{MeV}$.

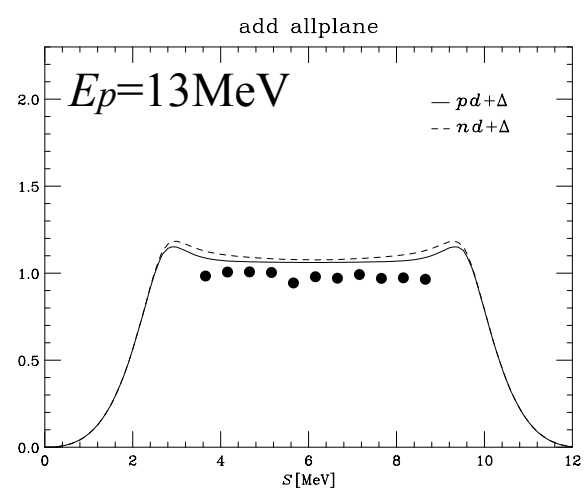
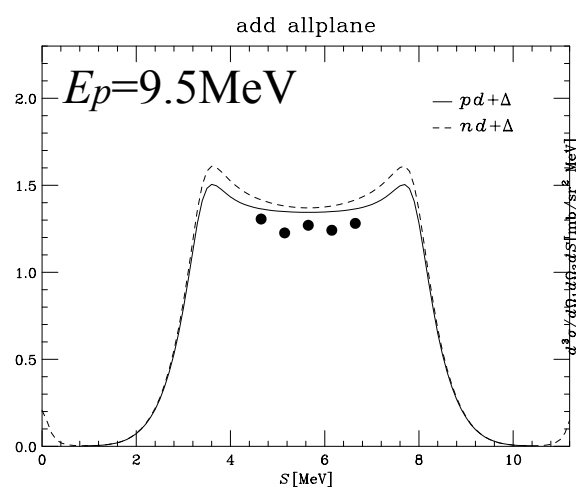
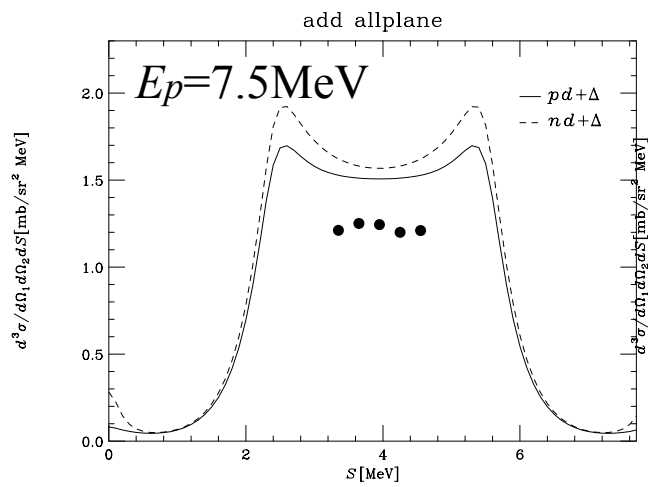
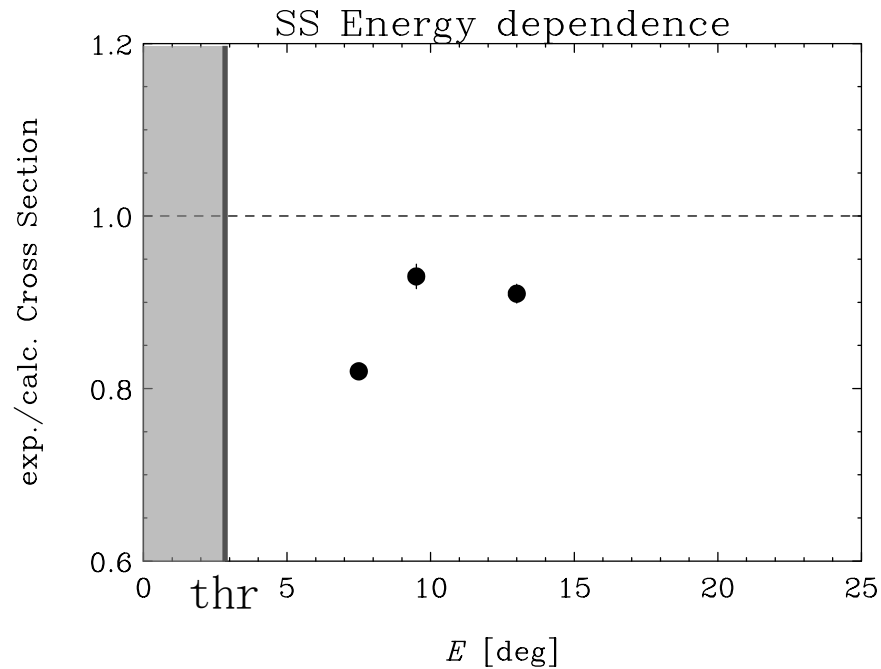
Experimental results for Space Star anomaly at $E_p = 7.5$ MeV



Average



E-dependence of Space Star anomaly

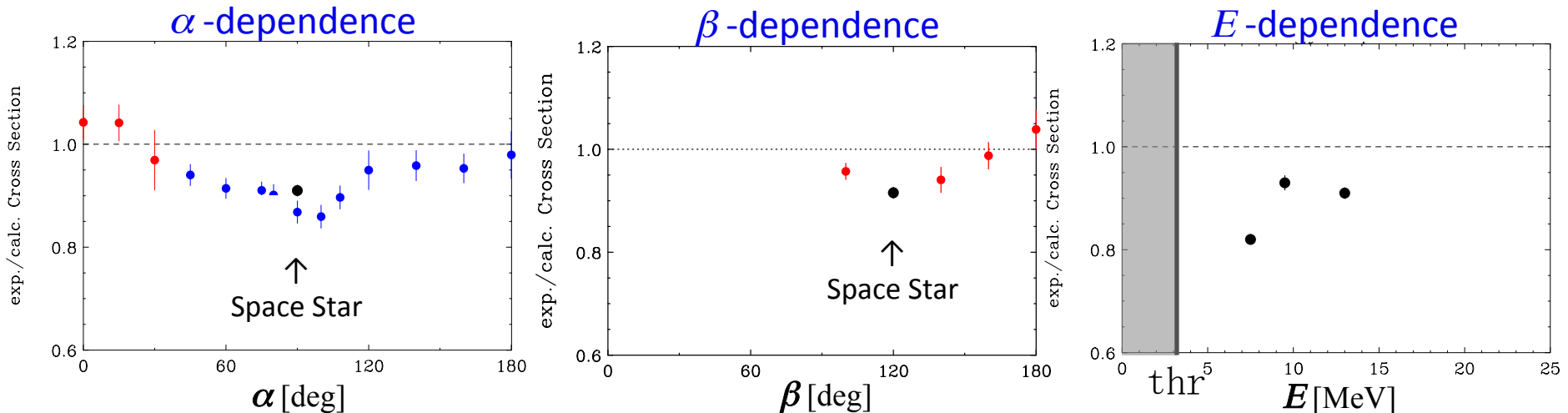


Conclusion

We systematically measured pd breakup cross section around Space Star at $E_p=13$ MeV ($E_d=26$ MeV), $E_p=9.5$ MeV ($E_d=19$ MeV), and $E_p=7.5$ MeV, to investigate cross section anomaly (pd experiment < pd calculation).

We found,

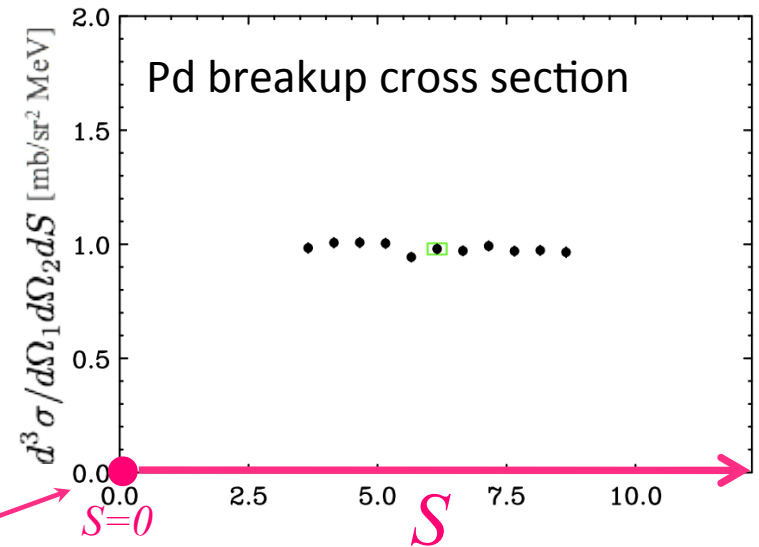
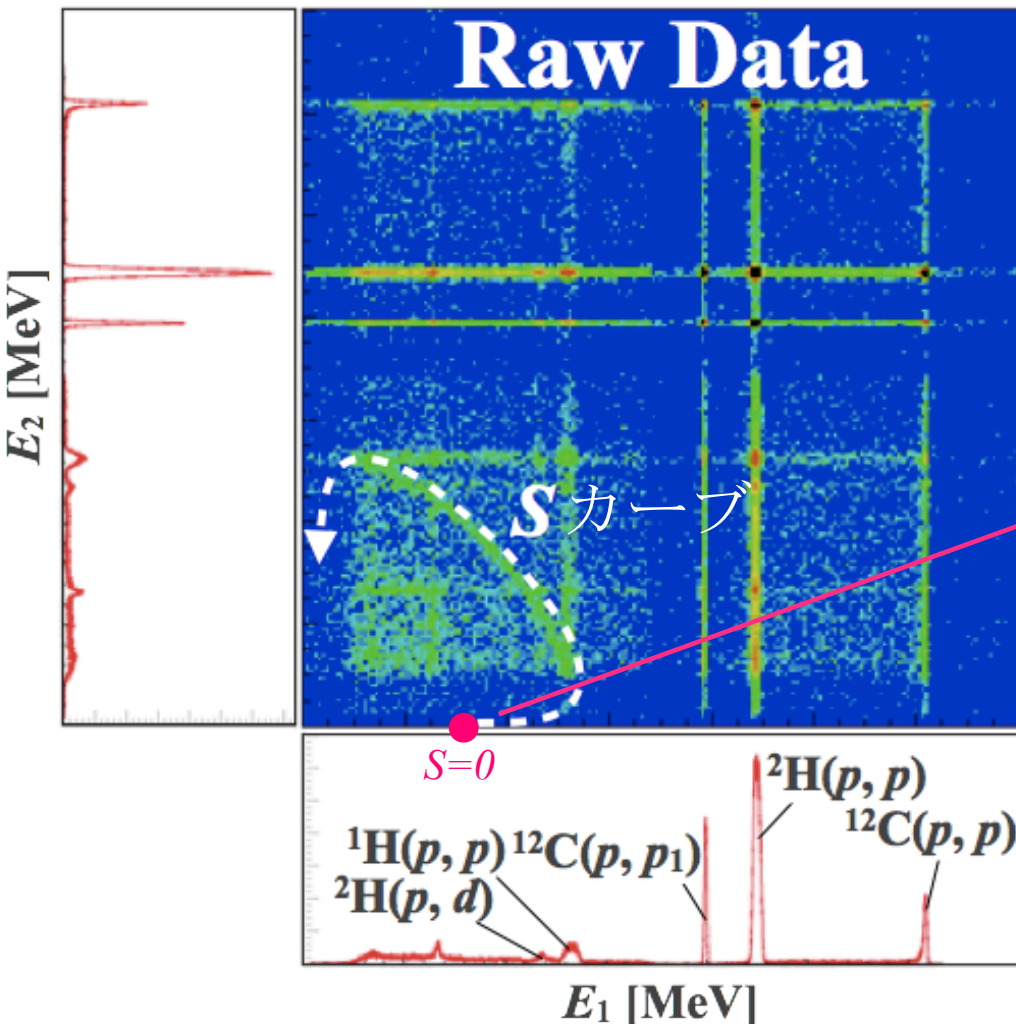
- 1) Anomaly becomes maximum at Space Star,
- 2) Anomaly slowly decreases when Space Star configuration is gradually destroyed.
- 3) pd breakup Space Star anomaly becomes large at low energy.



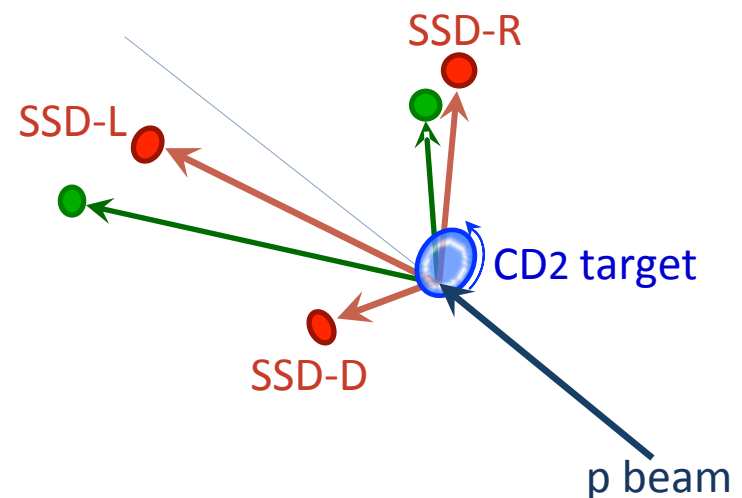
Characteristics of pd breakup Space Star Anomaly have become clear. Next step is theoretical search for the origin of Space Star anomaly.

Thank you !

From raw data to cross section

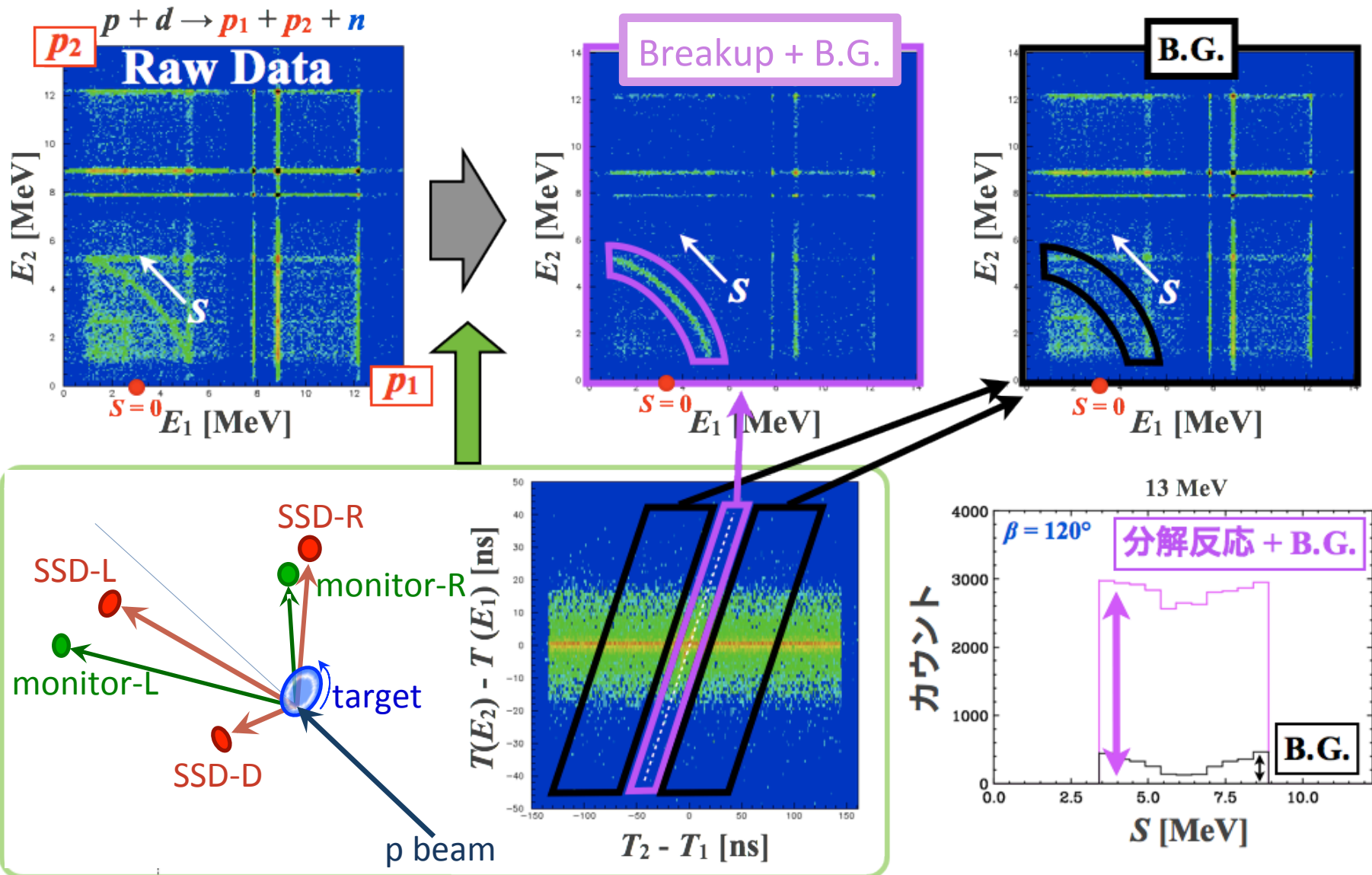


【 S : arc length from $S=0$ point】



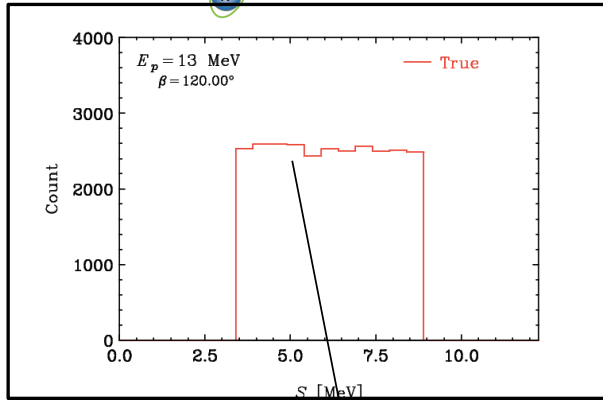
【pd breakup events appear on S curve】

B.G. removal – Time of Flight

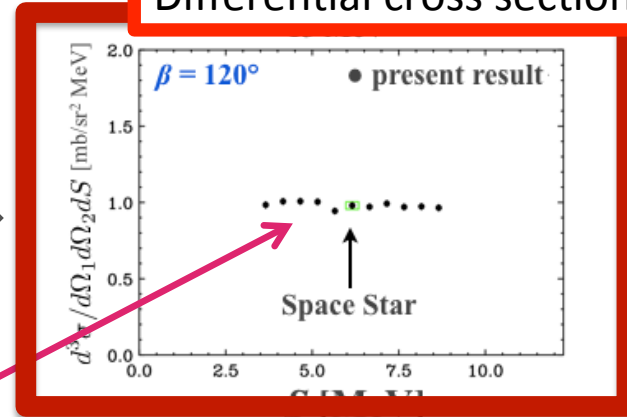


Determination of absolute cross section

Pd breakup events



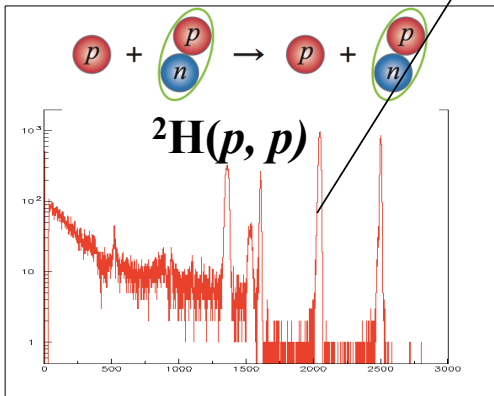
Differential cross section



$$Y_{bu} = \frac{d^3 \sigma}{d\Omega_1 d\Omega_2 \Delta S}(\theta_1, \theta_2) N_b N_t \Delta\Omega_1 \Delta\Omega_2 \Delta S$$

$$Y_{moni} = \frac{d\sigma}{d\Omega_{moni}}(\theta_{moni}) N_b N_t \Delta\Omega_{moni}$$

0.3 MeV



Past experimental data
(K.Sagara et al. (1994))

Solid angle
 $\Delta\Omega = S / r^2$
S: Slit aperture size
r: Distance (target—Detector)

Why the two experimental results disagree?

Comparison of experimental conditions		
	KUTL	Koeln
Beam	Unpolarized d -beam to measure only σ . $E_d=19$ MeV, 70 nA	Polarize d -beam to measure σ, iT_{11} and A_{yy} . $E_d=19$ MeV, 90 nA
Target	Rotating CH ₂ foil 50 mm in diameter 0.3 mg/cm ² in thickness	Rotating CH ₂ foil 20 mm in diameter? 0.65 mg/cm ² in thickness
Counting rate [in arbitrary unit]	$70\text{nA} \cdot 0.3 \text{ mg/cm}^2 \cdot 0.6\text{msr}$ 0.37	$90\text{nA} \cdot 0.65 \text{ mg/cm}^2 \cdot 0.6\text{msr}$ 1.00
Detectors	Si-SSD	Si-SSD
Solid angle for p_1 and p_2	0.60 msr	0.60 msr
Aperture for beam monitor	28.3 mm ² (6mm in diam.)	3.11mm ² (2mm in diam.)
Aperture edge	Arc-discharge cut	No information
pd breakup s evaluation	pd scattering σ used	pd scattering σ used

系統誤差の見積もり

・ σ pd 弾性散乱の微分断面積	: $\pm 1.4\%$
・ σ 検出器の立体角	
▶ モニター検出器	: $\pm 1.7\%$
▶ 本測定用検出器	: $\pm 2.1\%$
・ σ その他	: $\pm 1.0\%$
<hr/>	
・ σ 合計	: $\pm 3.2\%$

$$\frac{d^3\sigma}{d\Omega_1 d\Omega_2 dS}(\theta_1, \theta_2) = \frac{d\sigma}{d\Omega_m}(\theta_m) \frac{\Delta\Omega_m}{\Delta\Omega_1 \Delta\Omega_2 \Delta S} \frac{Y_{bu}}{Y_m}$$