3核子力と3核子反応研究の今後

九大理　相良　建至

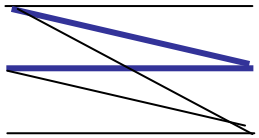
3核子系研究の歴史

FJ3核子力発見

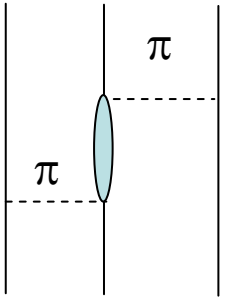
今後の3核子力研究

3核子力以外の問題

2核子力
3核子力
4核子力
....



2核子データ
3核子データ
4核子データ
....



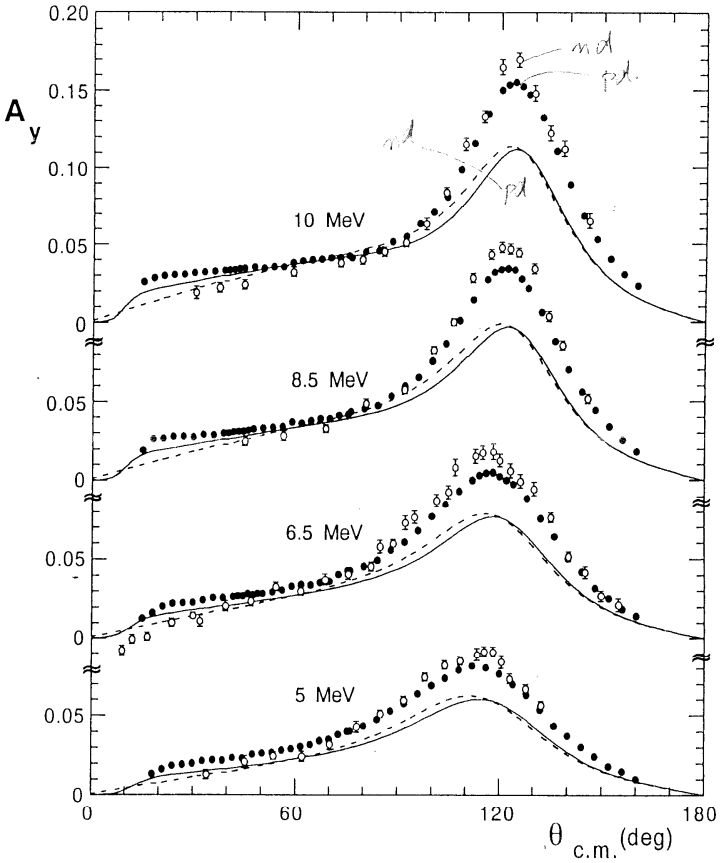
1935　湯川中間子論
1957　藤田ー宮沢3核子力　ππ3NF
1960　Faddeev eqs.
1970
1980
1985 偏極国際会議　RCNP
1986 Ay puzzle (Koike)
1994 pd cross section minimum 2-18MeV
1996 pd exp at 135 MeV at RIKEN
1997 Koike's talk at KVI (FB15)
1998　3NF calc. by Witala et al　ππ3NF found

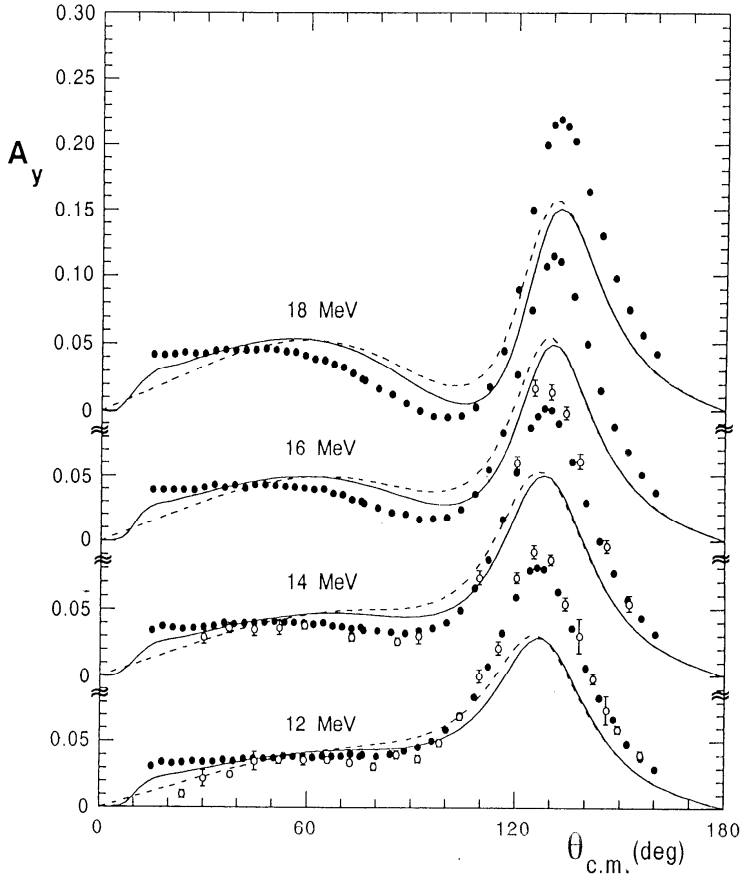
九大偏極実験開始

九大pd実験開始

search for 3NF
problems other than 3NF

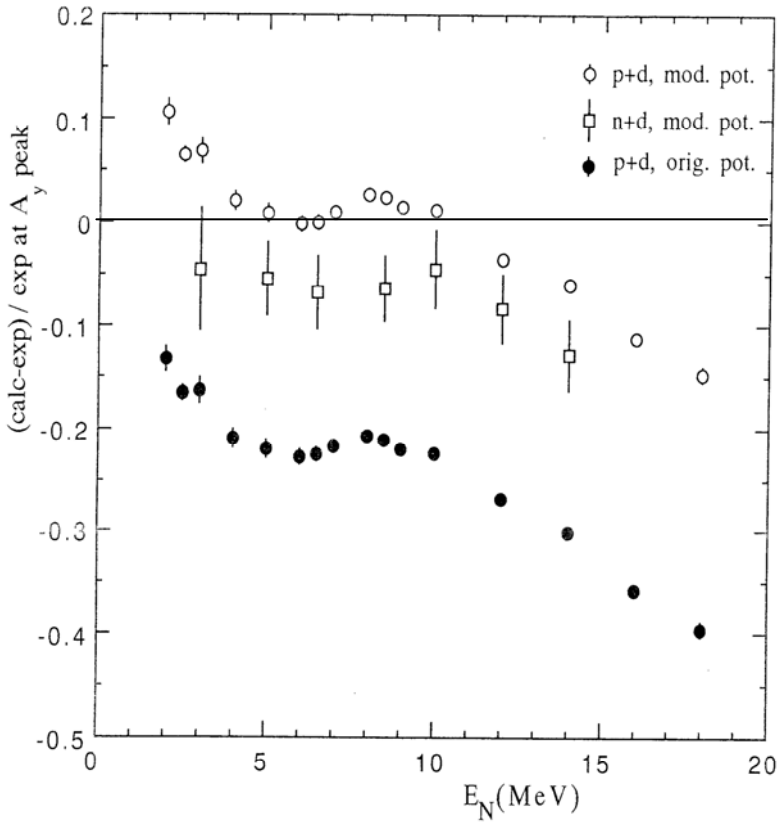
Systematic measurement of pd scattering Ay at Ep =2-18 MeV at KUTL (1994)





Ay puzzle

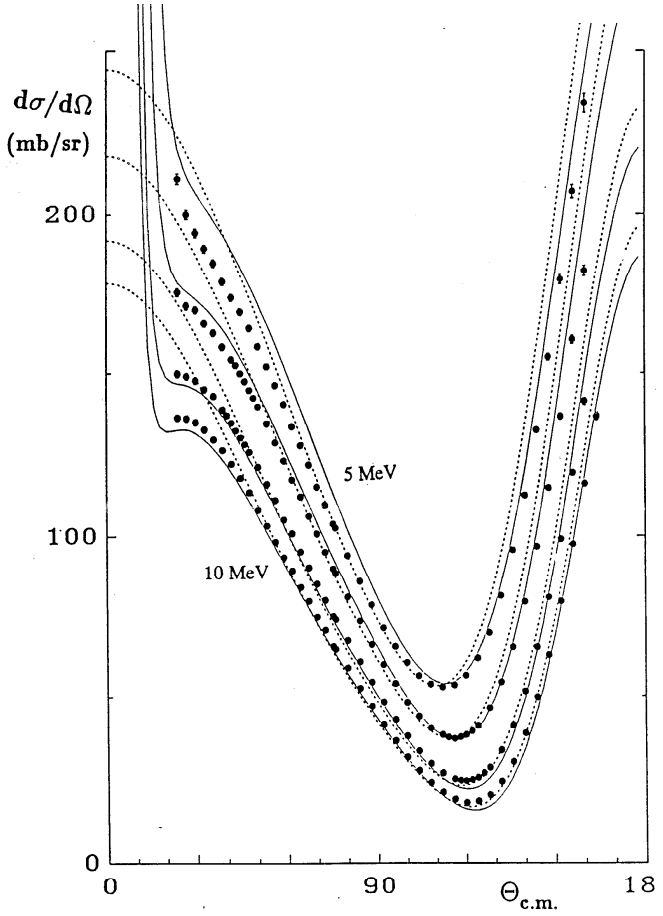
E-dependence of Ay puzzle (1994)

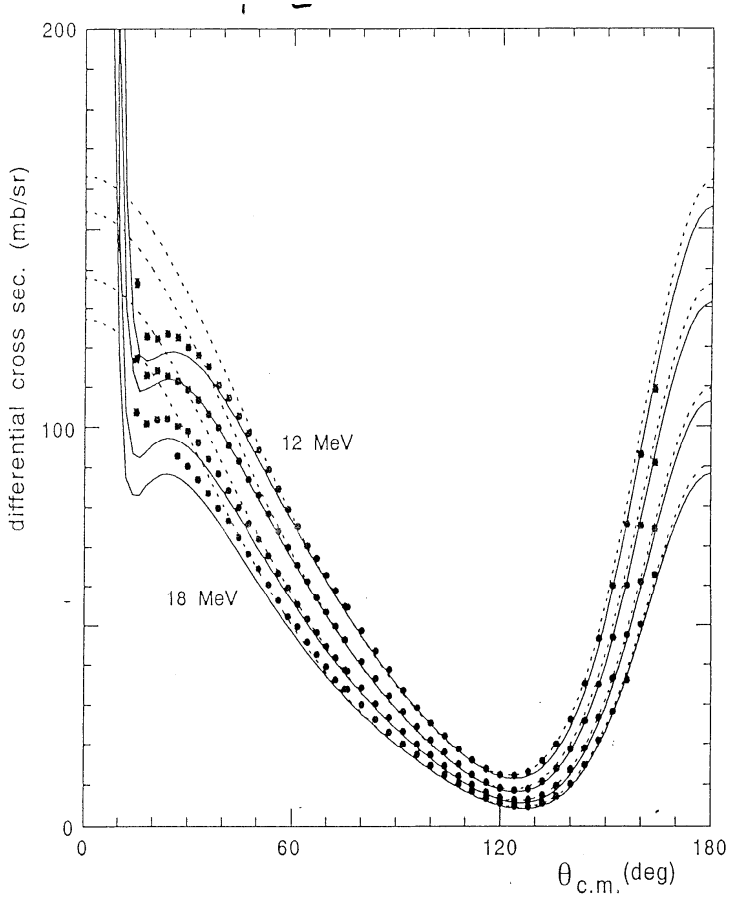


Discrepancy of
-10% ~ -40%

Ay puzzle is not related to 2π3NF.
Ay puzzle is a puzzle still now.

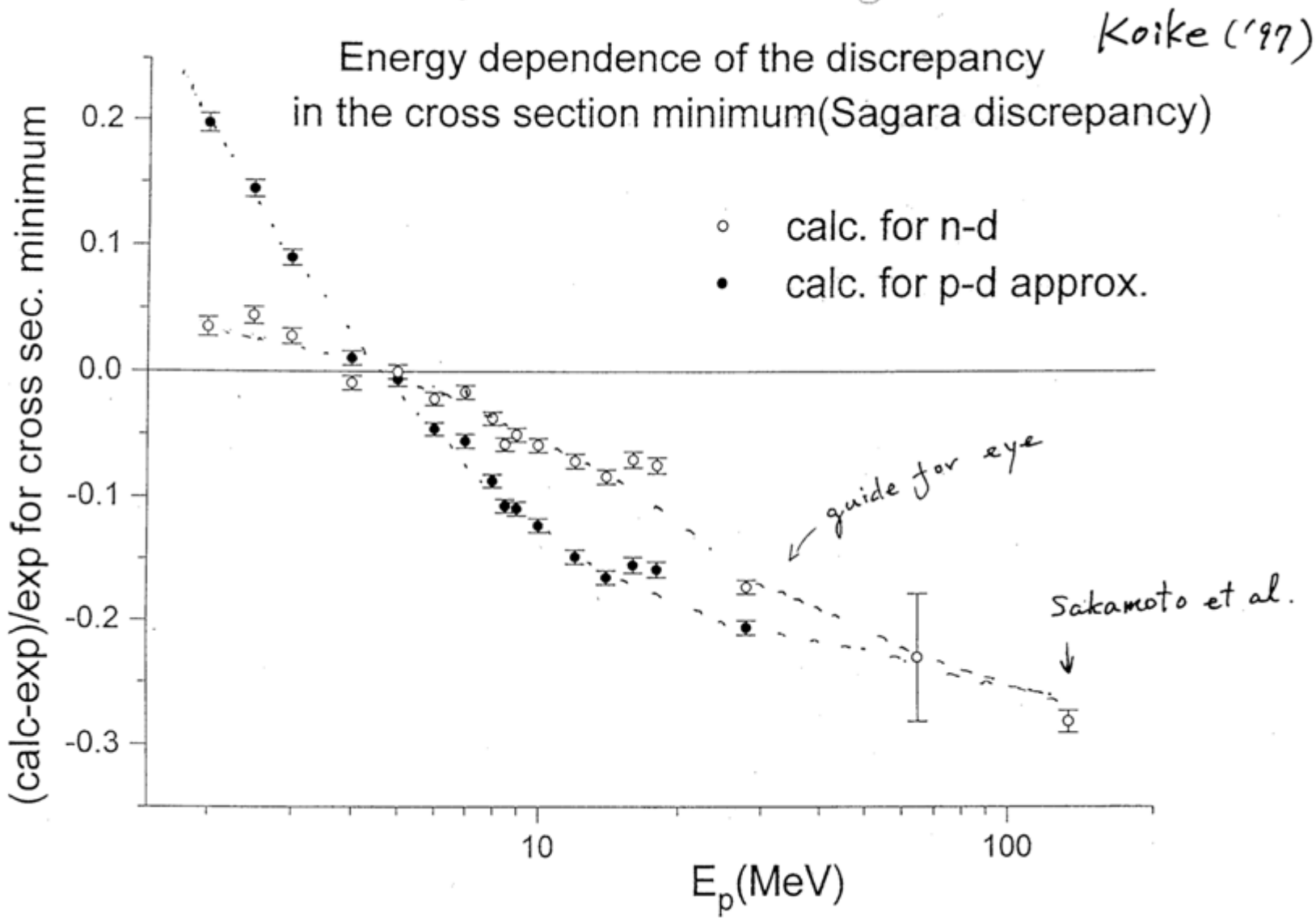
pd scattering cross section at 2-18 MeV were measured systematically (1994)





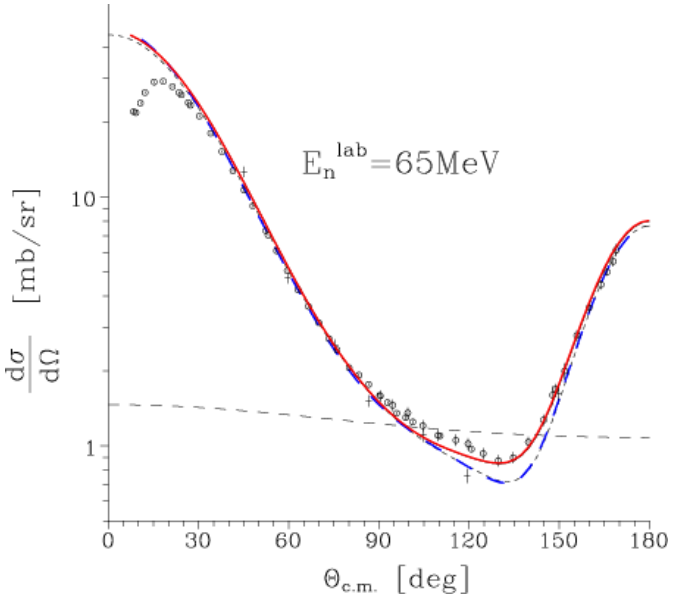
- Exp. errors < 1%.
- Data are “well” reproduced by 3N calculation.
- But, at the cross section minimum, discrepancy can be seen.

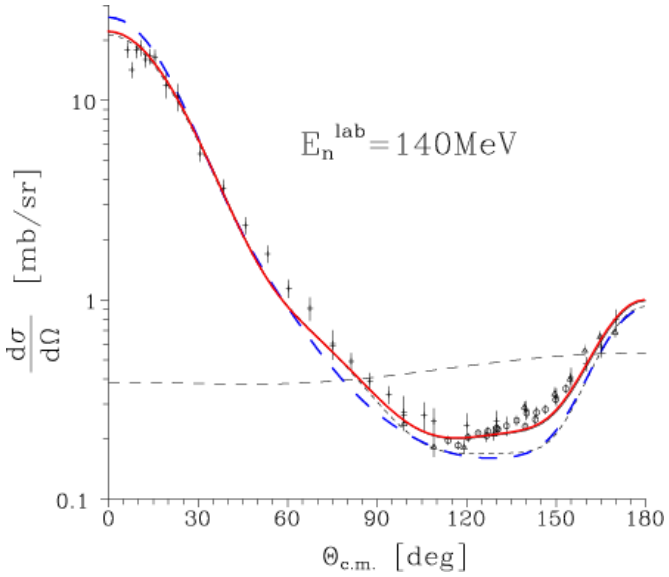
By Koike's talk at Few-Body Conf. at KVI (1997), CS minimum discrepancy was widely recognized.



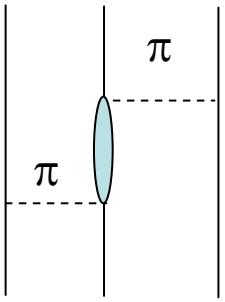
In the next year (1998),
Discrepancy at CS minimum was excellently explained by 2π3NF.
The same 2π3NF also reproduces 3N binding energy.

H.Witala et al., Phys Rev Lett. 81 1183(1998)



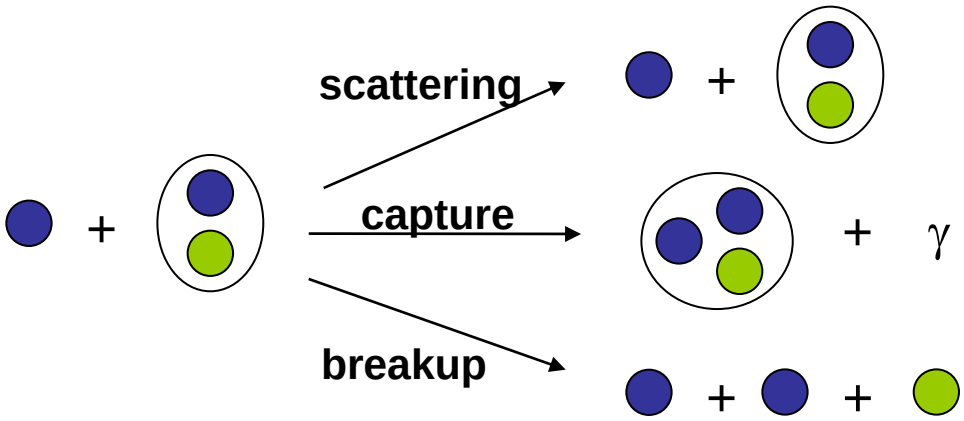


Existence of 2π3NF was found (1998),
after 41 years since Fujita-Miyazawa theory (1957).




3NF boom started

Experiments for 3NF searches

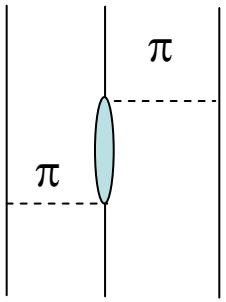


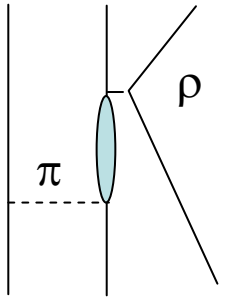
RIKEN, KVI, RCNP, IUCF, ・・

KUTL, RCNP, KVI

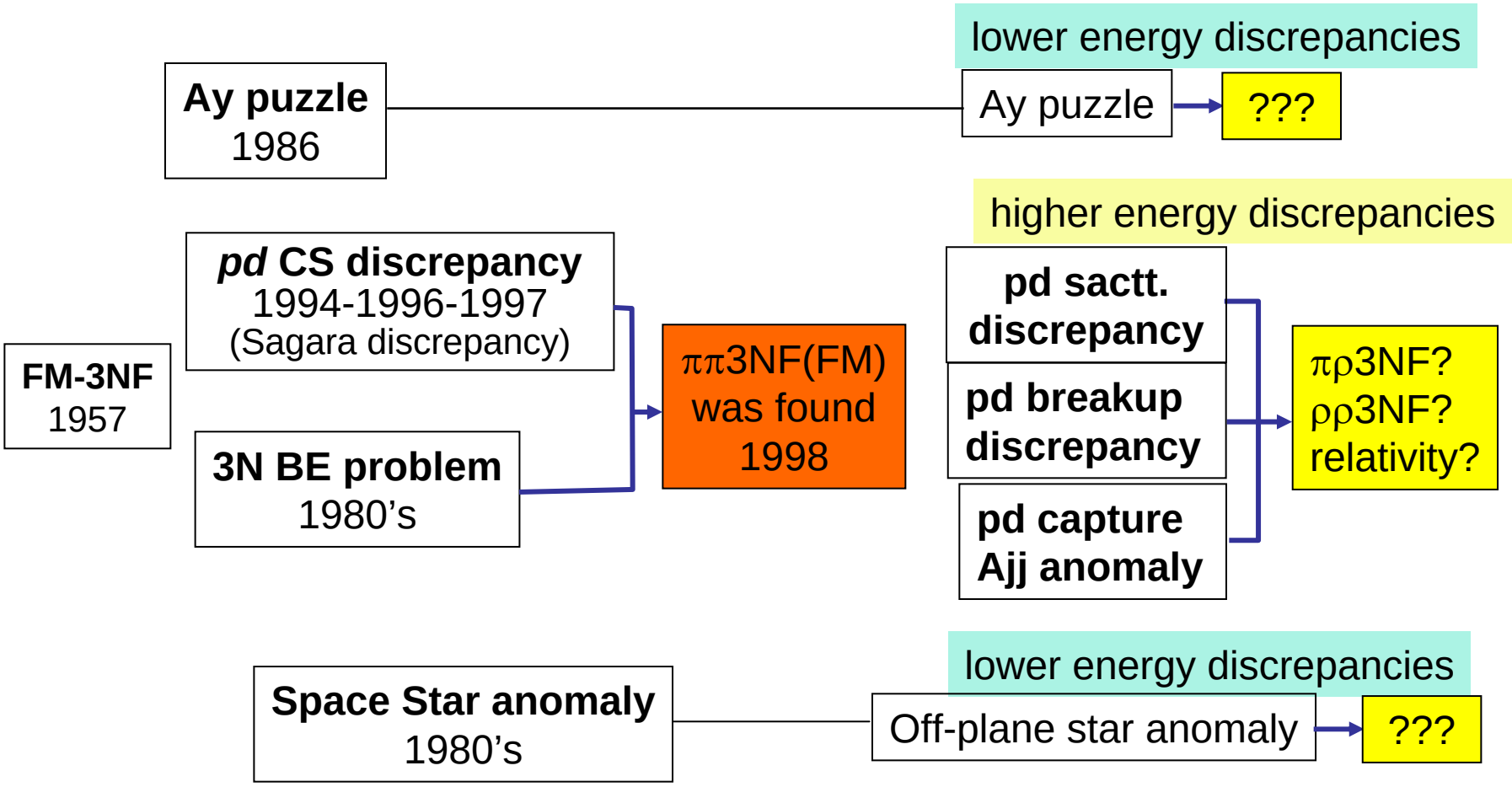
KUTL, RCNP

1) Investigation of 2π3NF
2) Search for new 3NF

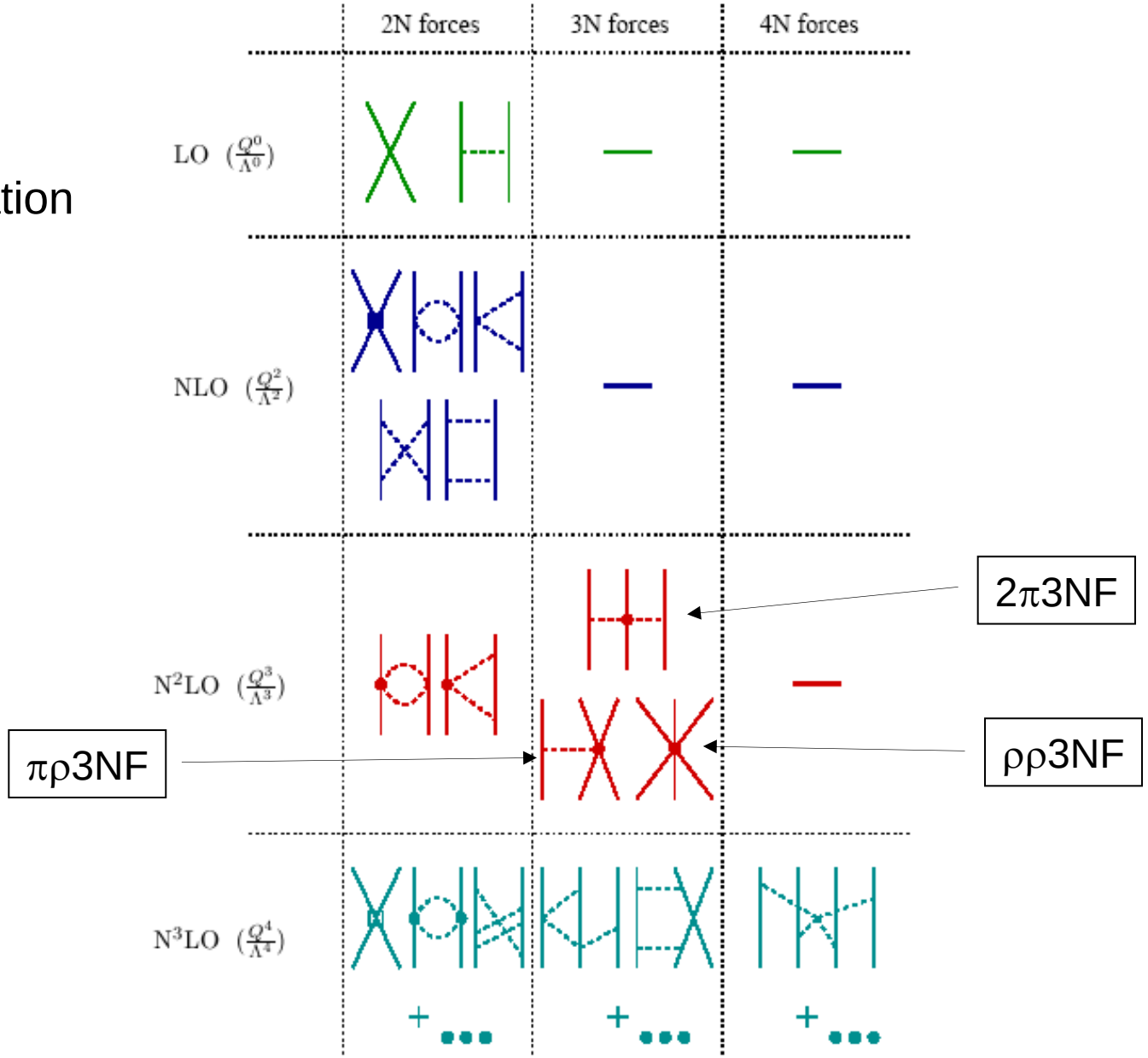




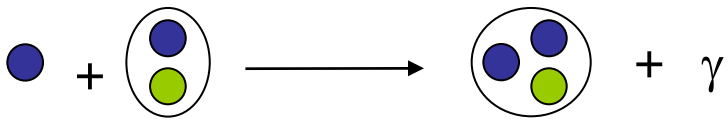
Discrepancies in 3N systems and their origins



χ–perturbation theory



Experimental setup



H($\vec{d}$,^{3}He) γ reaction

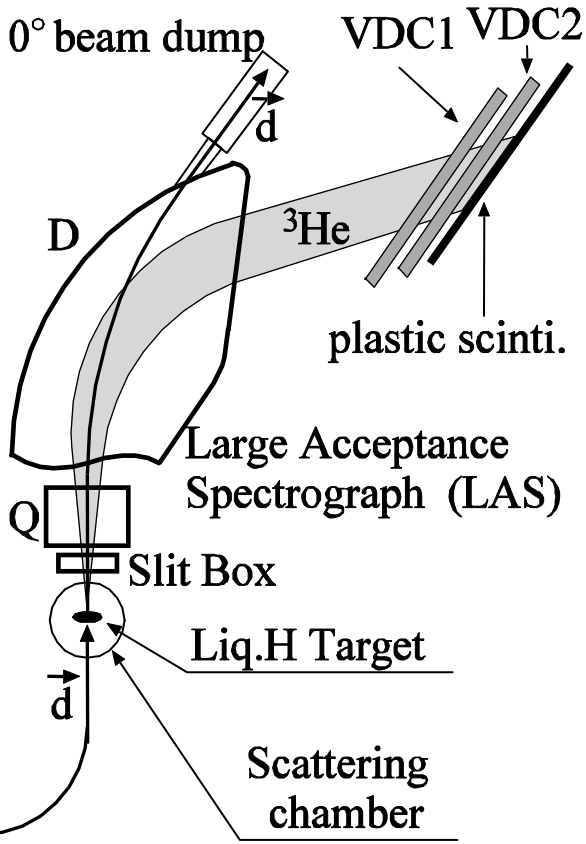
E_d= 200 MeV (15nA)

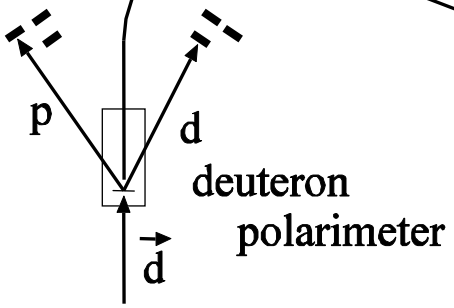
LAS 0deg : Axx (pure tensor)

LAS 3deg : Ay (pure vector)
Ayy (pure tensor)

(py=-0.5, pyy=-1.2)

Target: Liquid Hydrogen
thickness:1.5mm(11mg/cm²)

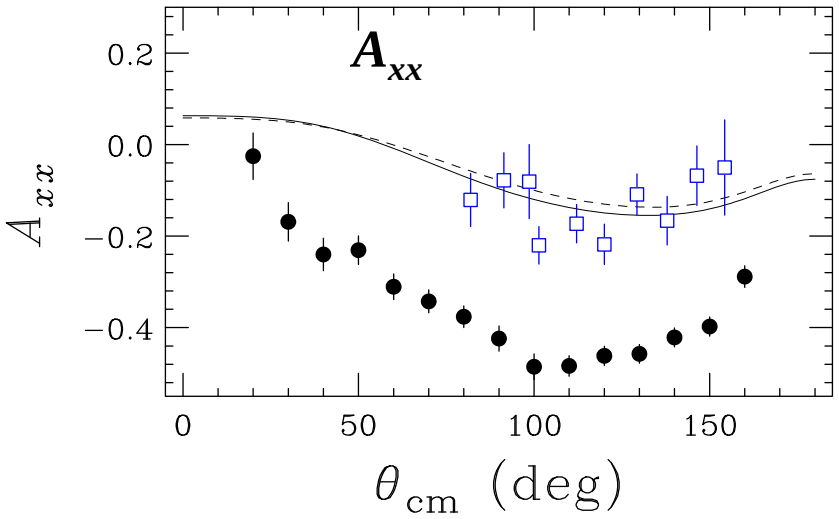


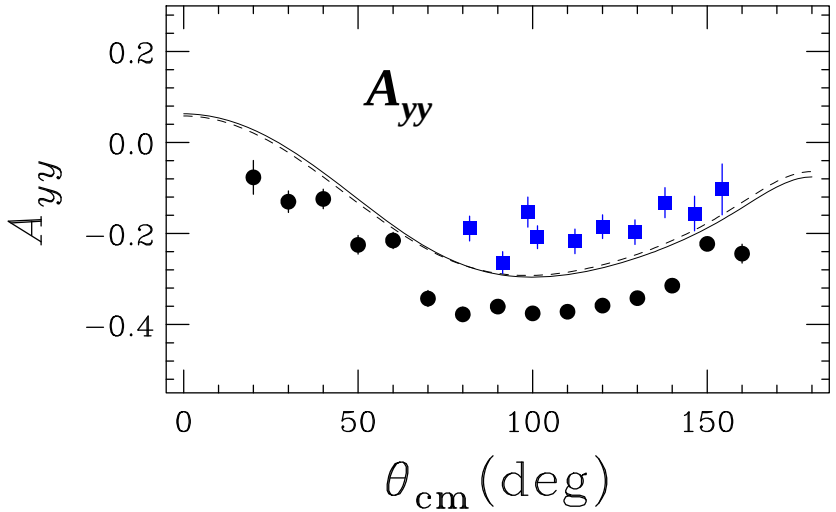


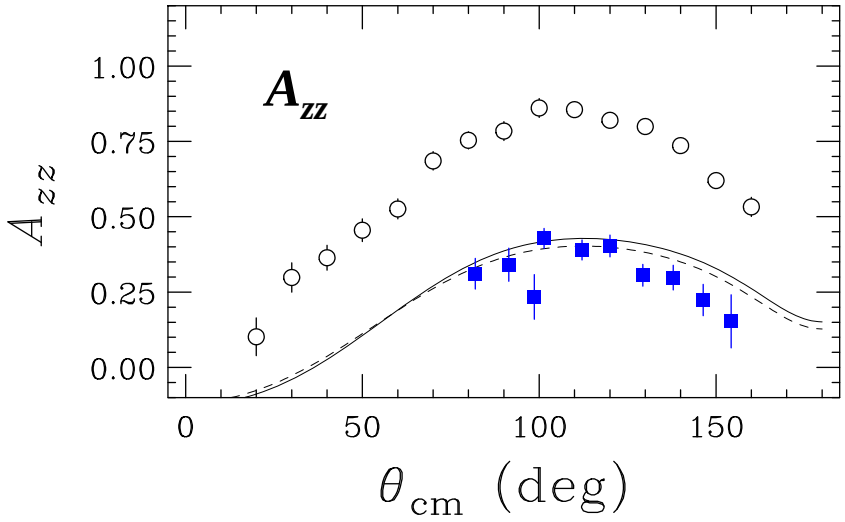
from Ring Cycrotron

RCNP WS course

Ajj of *pd*-capture were measured also at KVI, and KVI data agreed with calculations.



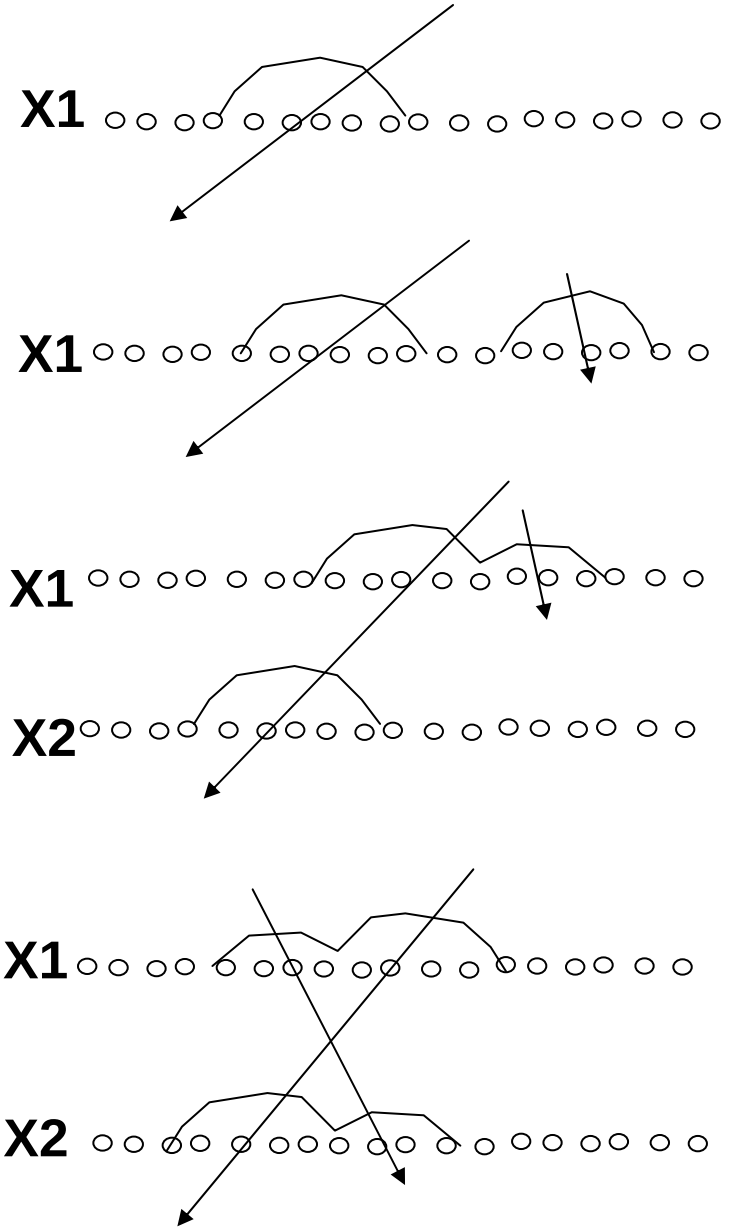




● ○ RCNP(200MeV)
■ □ KVI （180MeV)

RCNP data at 137MeV also disagreed with KVI data at 133MeV.

Detection efficiency was much improved by a multi-II method.



Single cluster **~83%**

Efficiency =.83^4 =0.48
Standard data analysis

Multiple cluster **~14%**

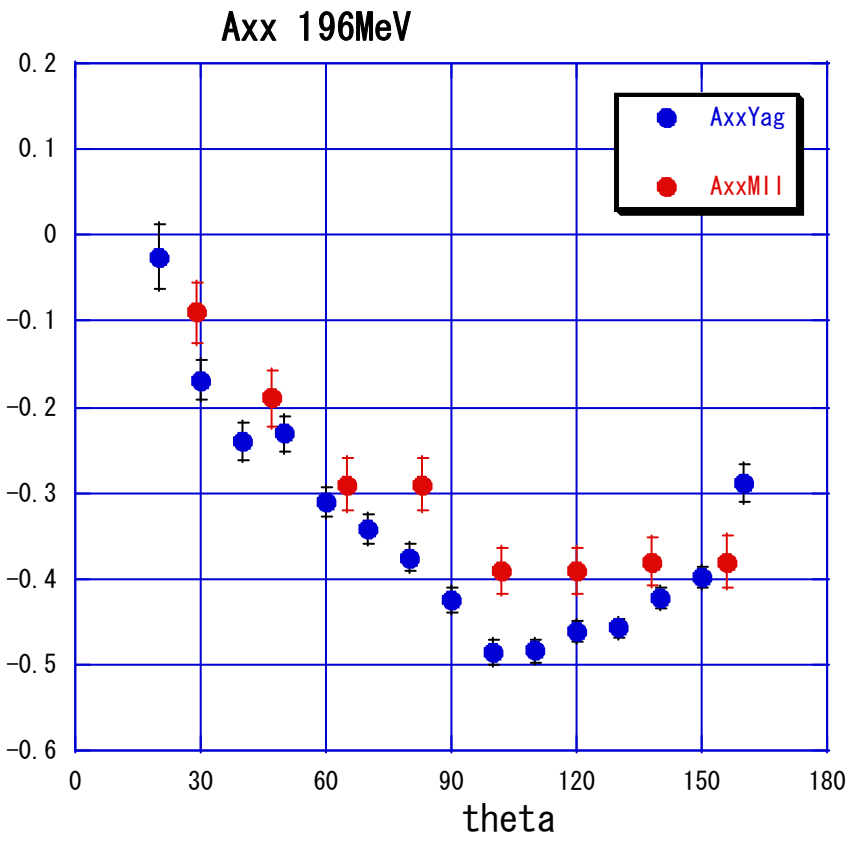
Efficiency =.97^4 =0.88

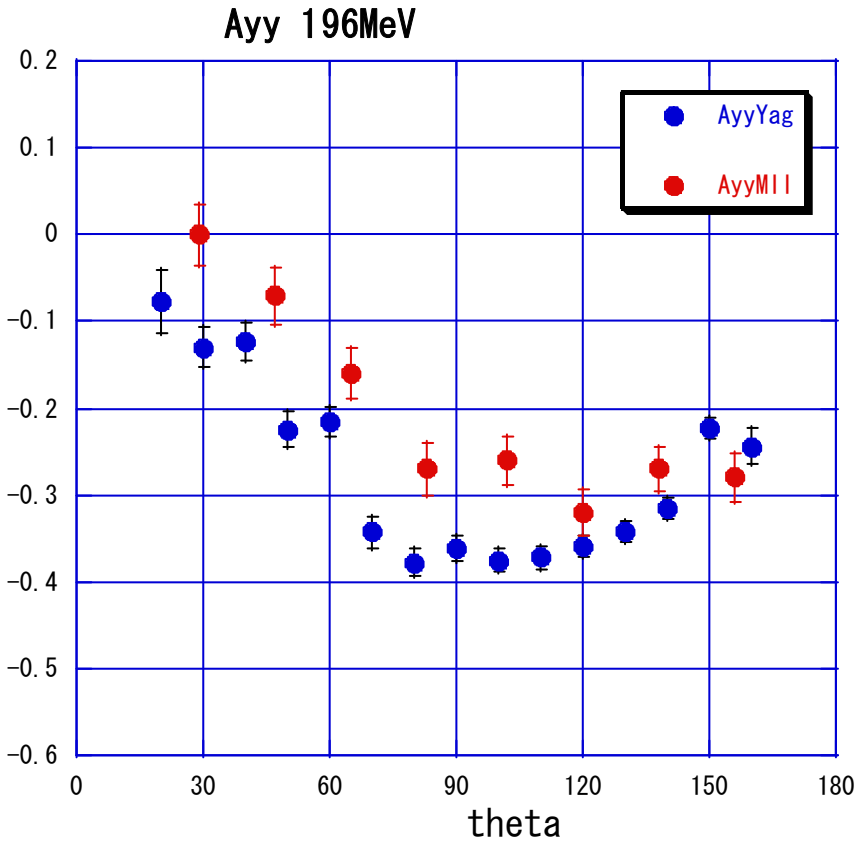
Combined cluster & single cluster
~2%

Efficiency =.99^4 =0.96
Multi-II data analysis

Combined–combined cluster
Other rays **~1%**

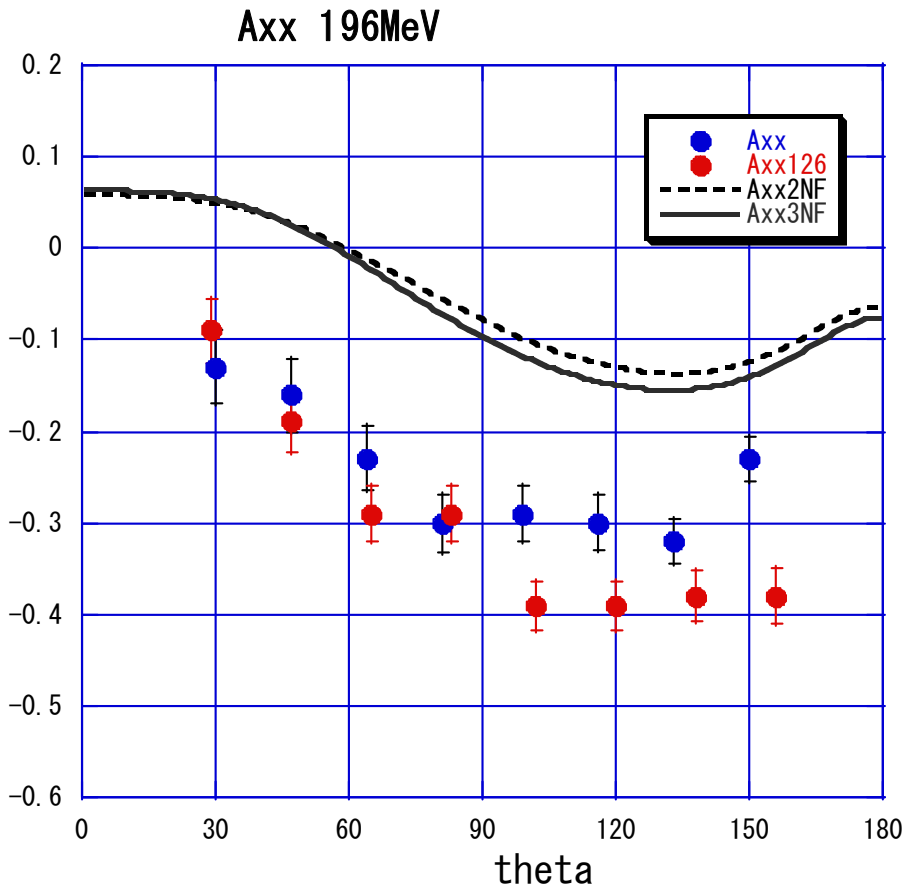
Single cluster data analysis vs.
Multi-cluster II data analysis

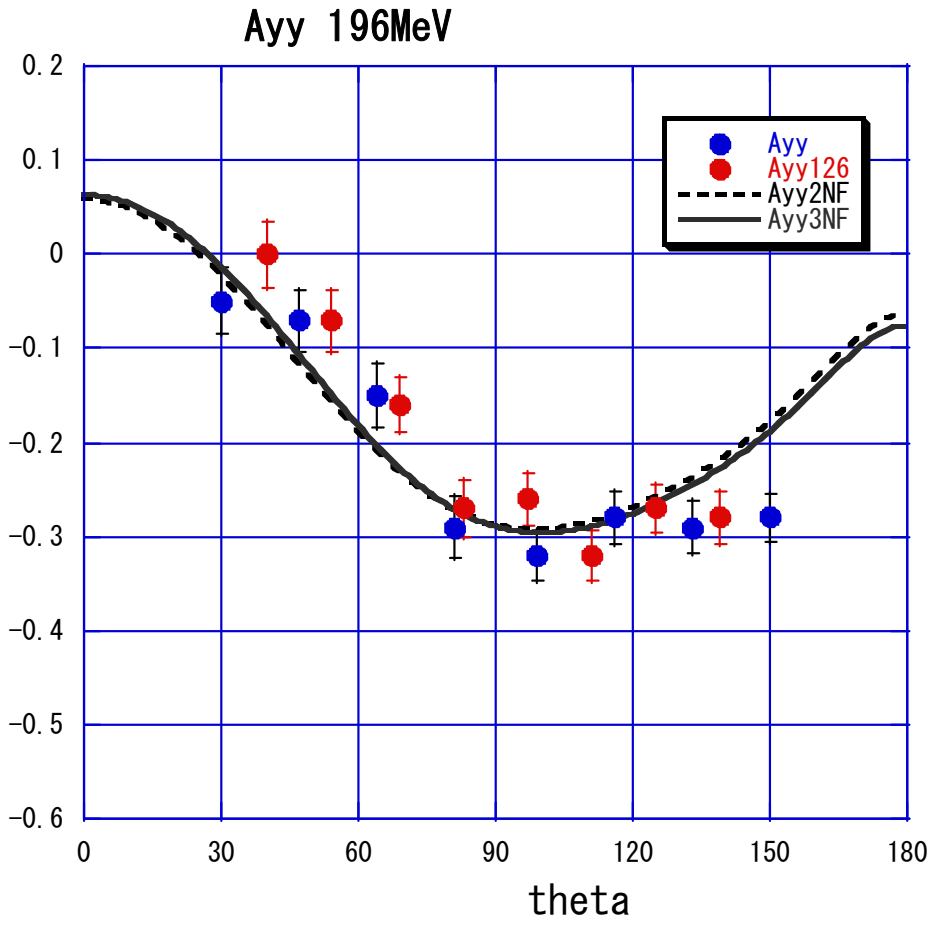


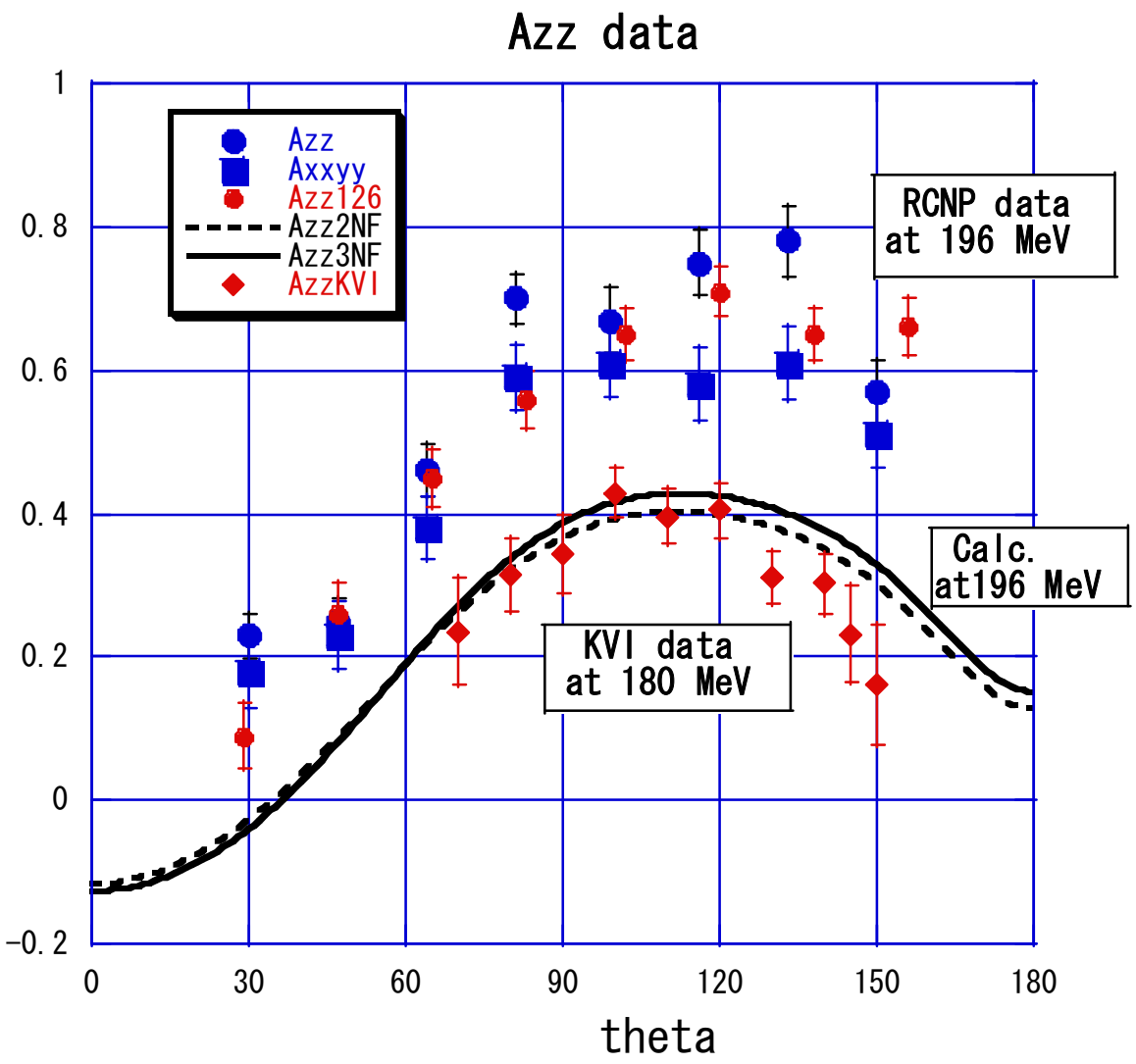


New d+p→3He+γ experiment by Tameshige et al.

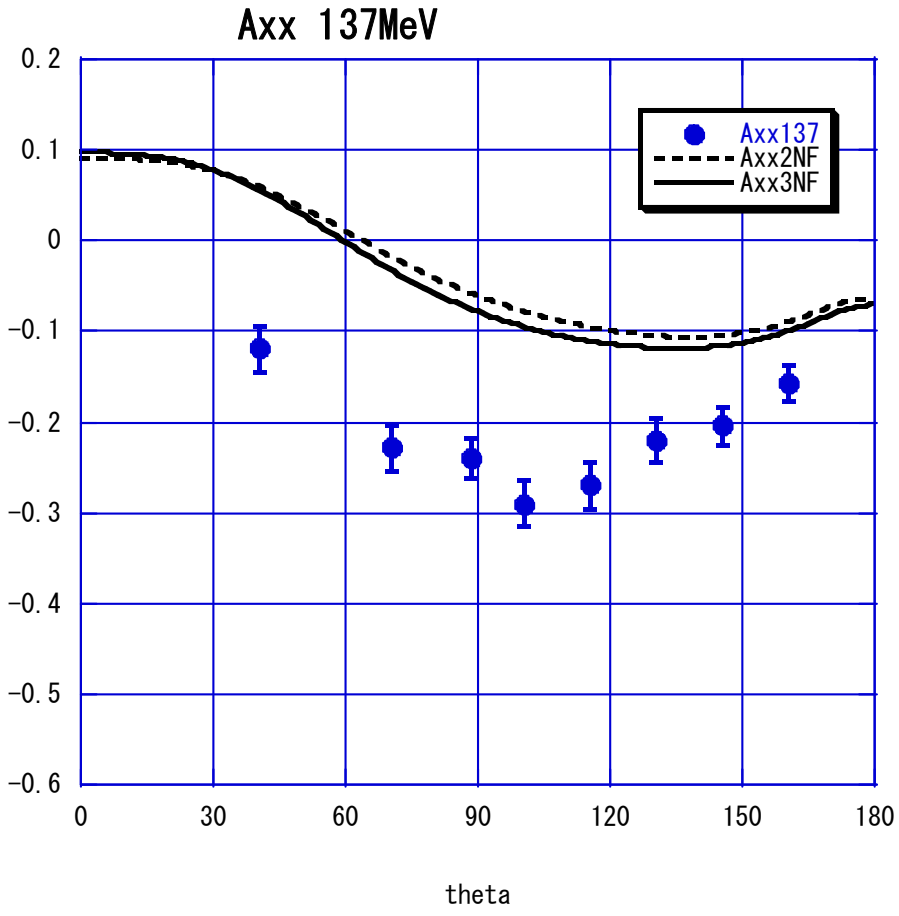
New data and previous data (Multi-II)

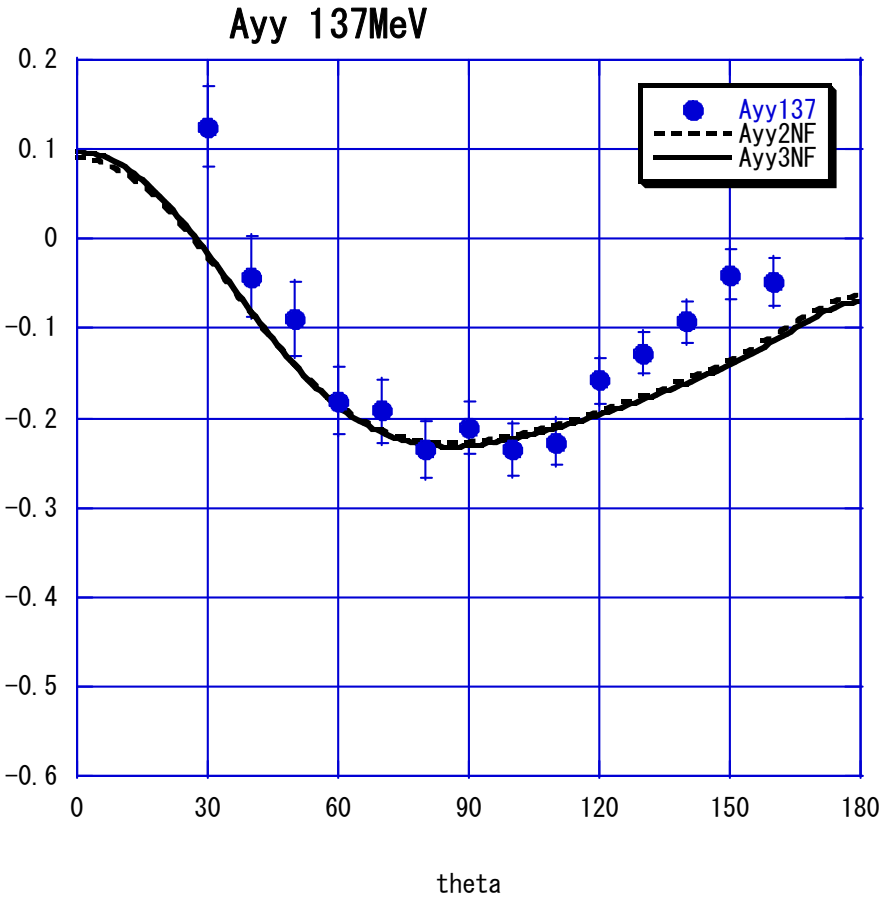




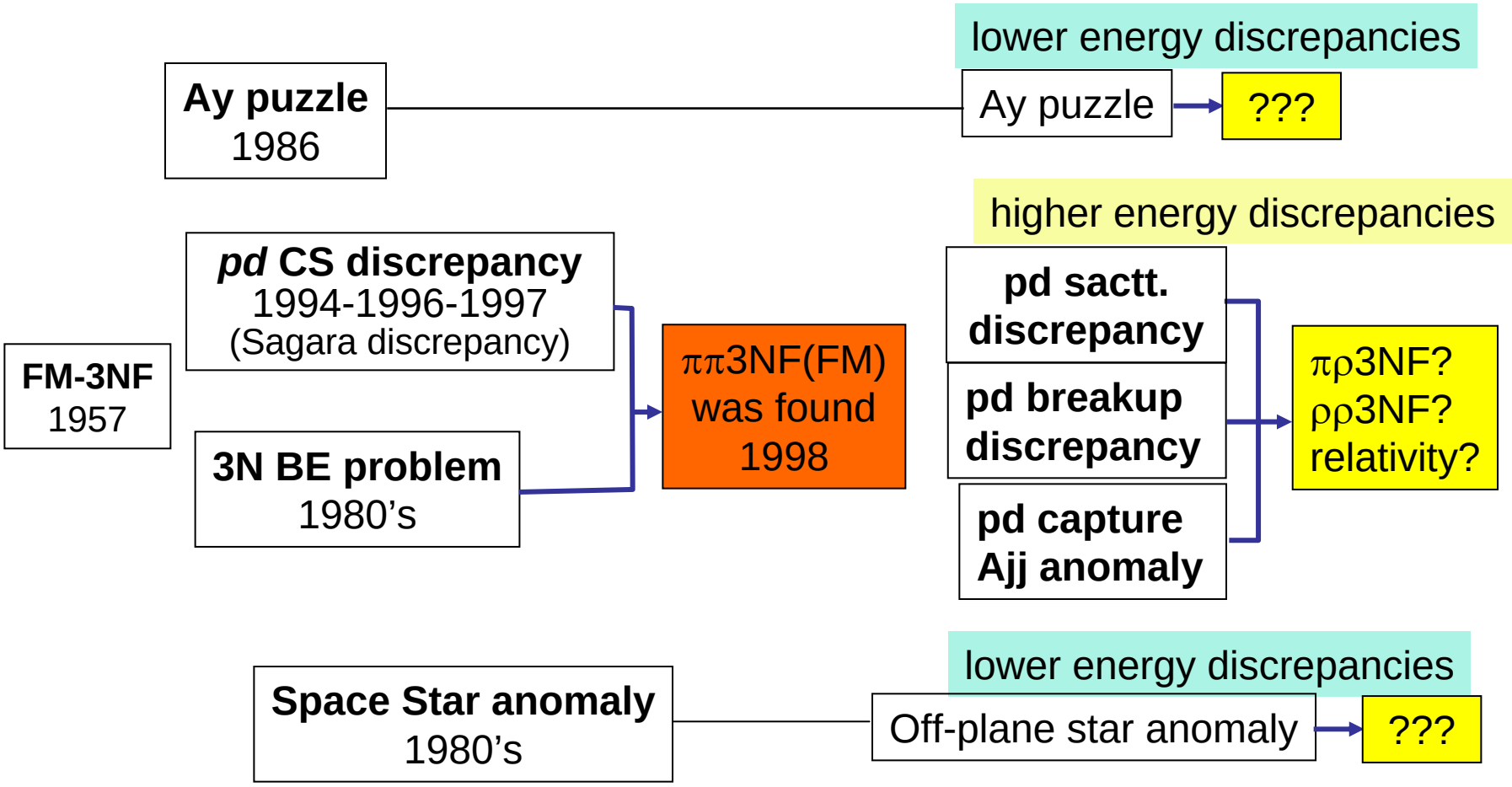

Azz data
Azz
Axxyy
Azz126
Azz2NF
Azz3NF
AzzKVI
RCNP data
at 196 MeV
Calc.
at196 MeV
KVI data
at 180 MeV
1
0.8
0.6
0.4
0.2
0
-0.2
0
30
60
90
120
150
180
theta

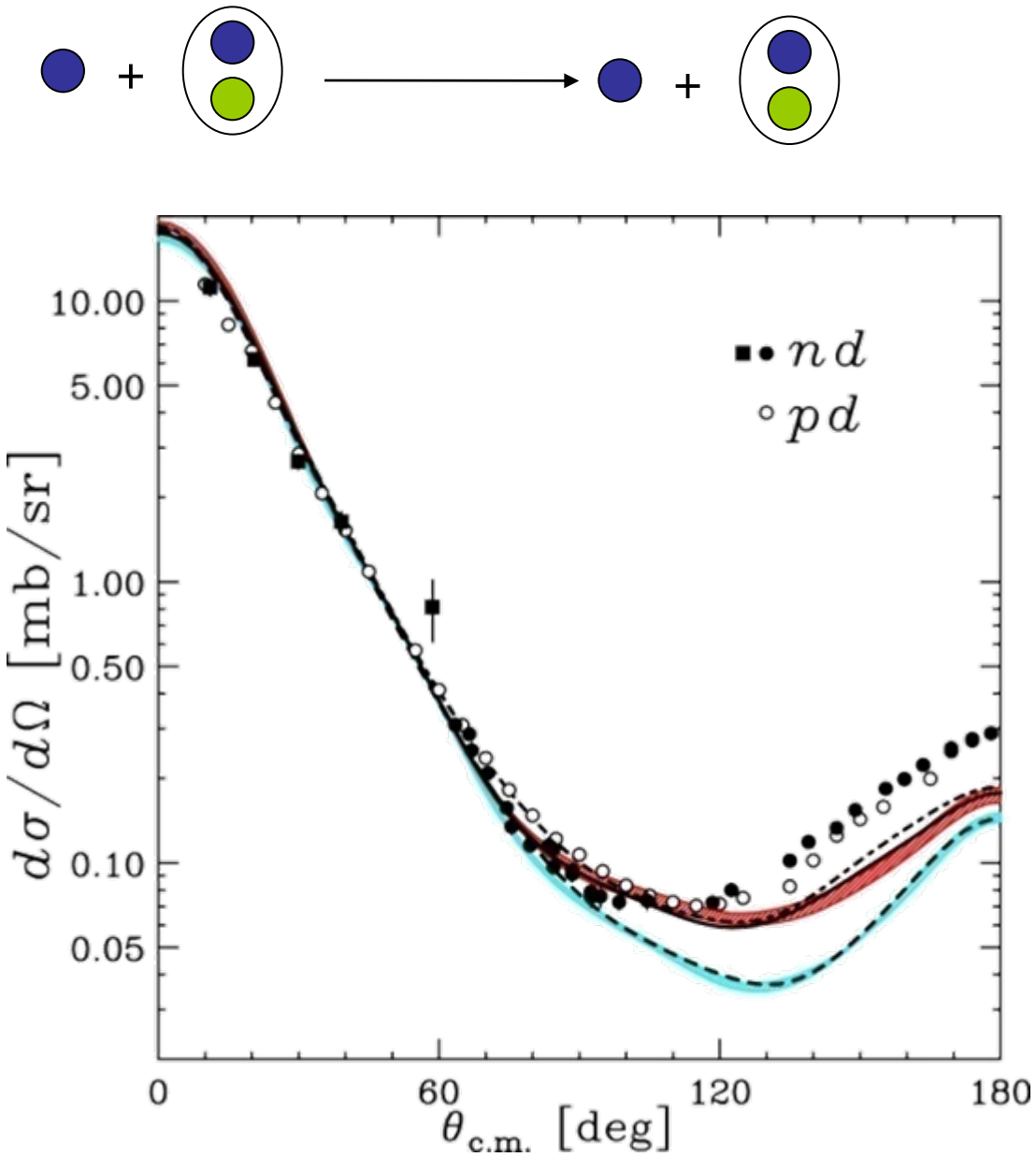
pd radiative capture at Ed = 137 MeV (multi-II analysis)

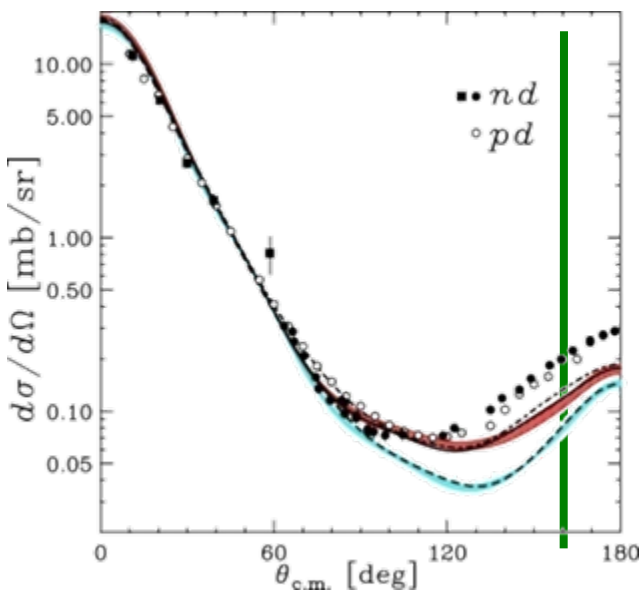




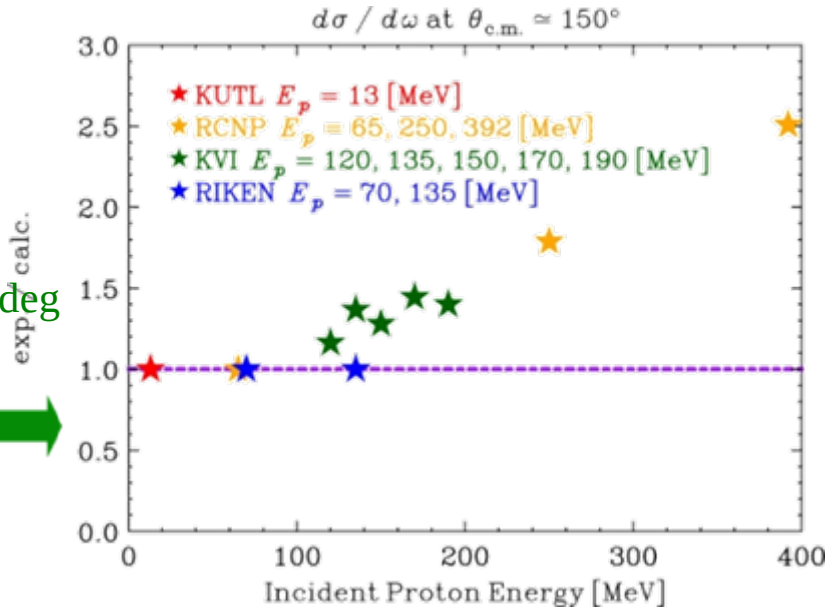
Discrepancies in 3N systems and their origins

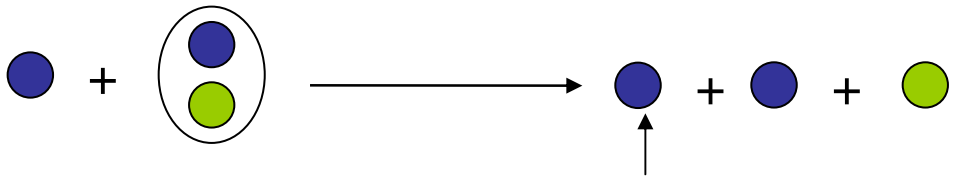



+
+
10.00
5.00
1.00
0.50
0.10
0.05
$d\sigma/d\Omega$ [mb/sr]
$n\,d$
$p\,d$
0
60
120
180
$\theta_{\rm c.m.}$ [deg]

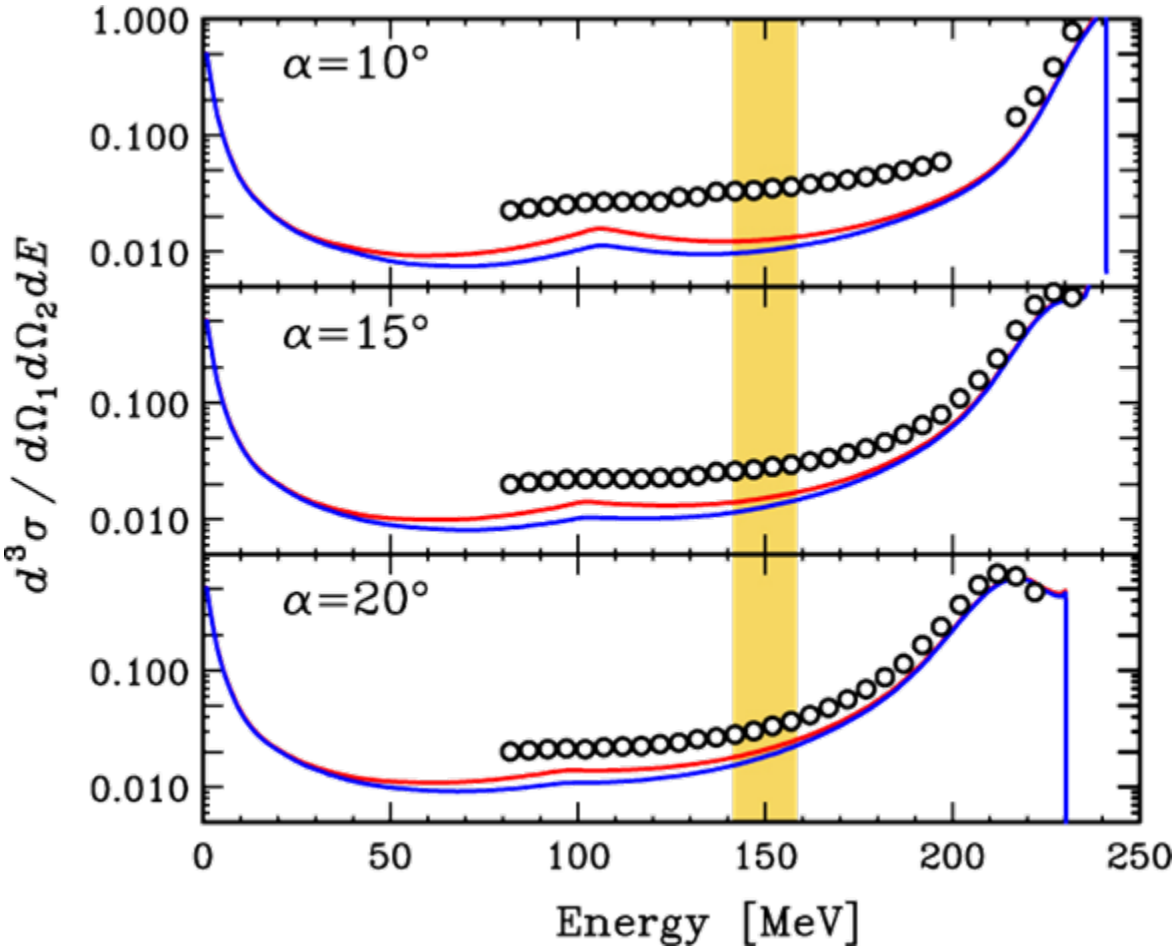


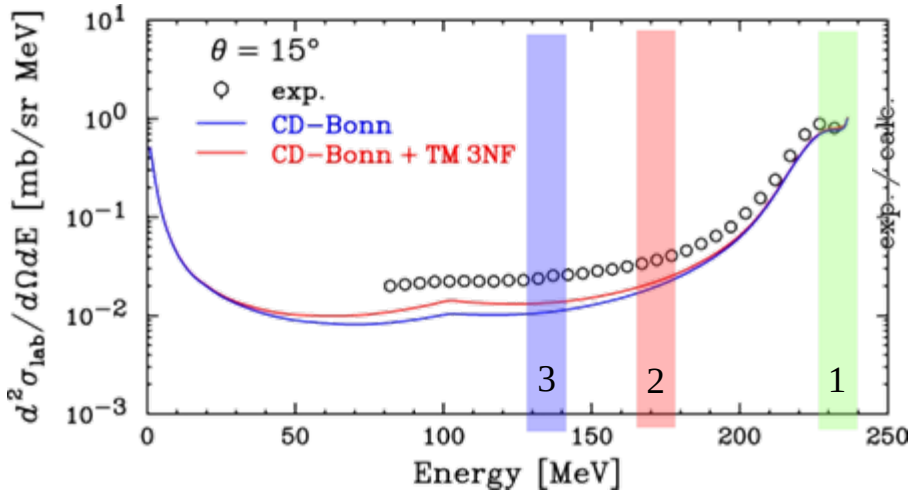
focus at 150 deg

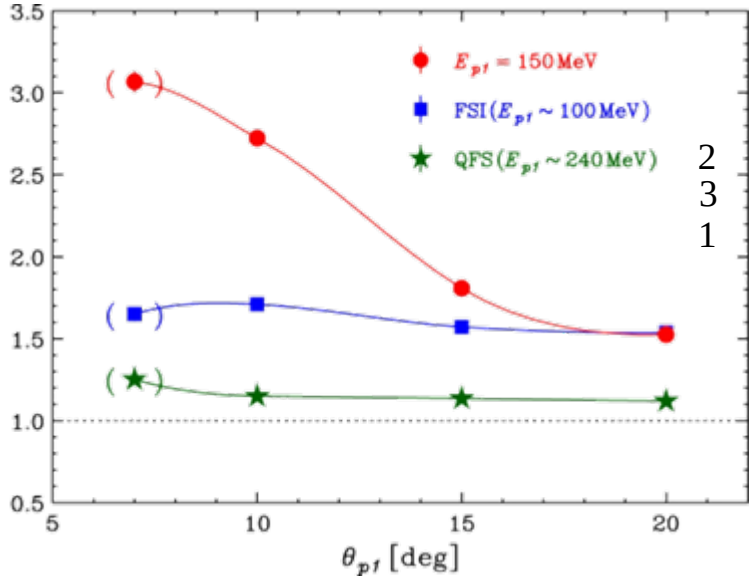


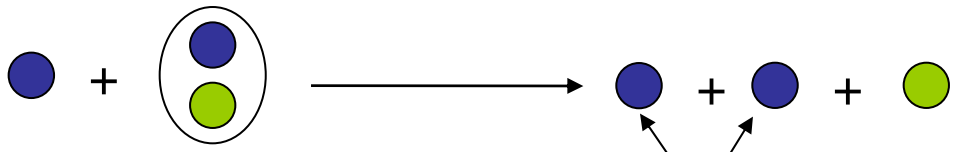


detect only one proton



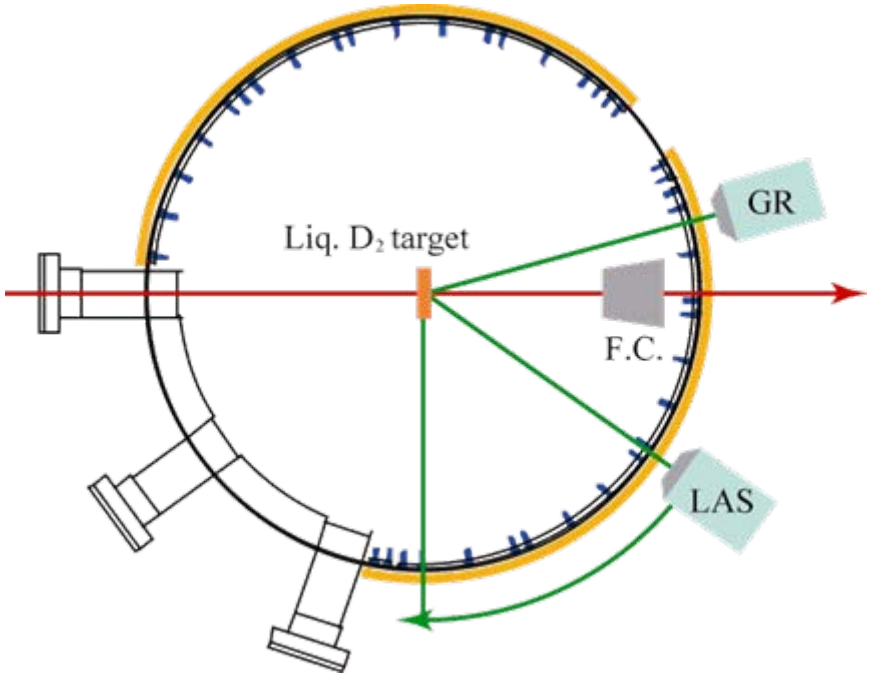

θ = 15°
exp.
CD−Bonn
CD−Bonn + TM 3NF
$d^2\sigma_{lab}/d\Omega dE$ [mb/sr MeV]
Energy [MeV]
exp. / calc.
3
2
1

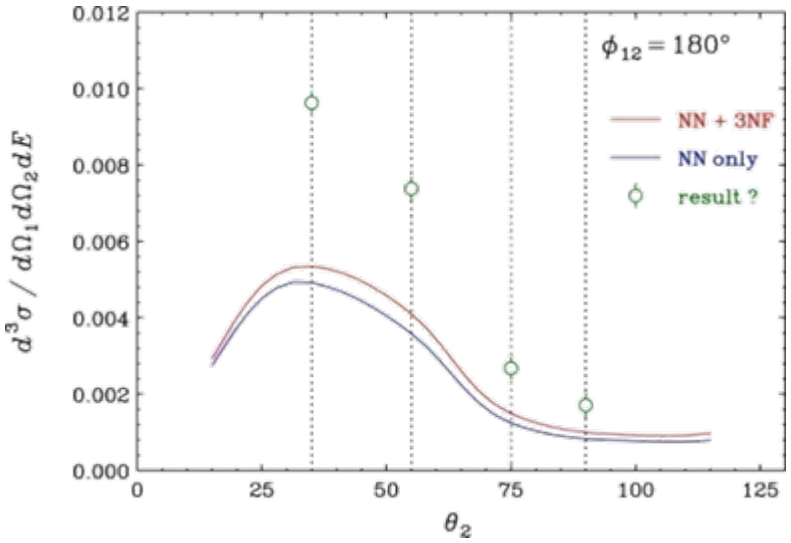

E_{pf} = 150 MeV
FSI(E_{pf} ~ 100 MeV)
QFS(E_{pf} ~ 240 MeV)
θ_{pf} [deg]
2
3
1



detect two protons

Exp. in 2009





Discrepancies in 3N systems and their origins

lower energy discrepancies

Ay puzzle 1986 — Ay puzzle → ???

higher energy discrepancies

***pd* CS discrepancy** 1994-1996-1997 (Sagara discrepancy)

FM-3NF 1957

3N BE problem 1980's

→ ππ3NF(FM) was found 1998

pd sactt. discrepancy

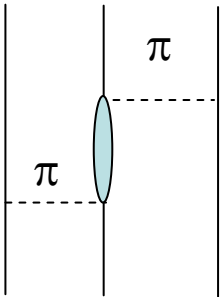
pd breakup discrepancy

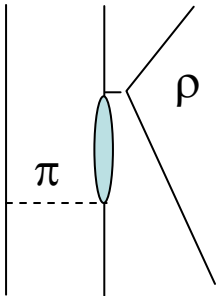
pd capture Ajj anomaly

→ πρ3NF? ρρ3NF? relativity?

lower energy discrepancies

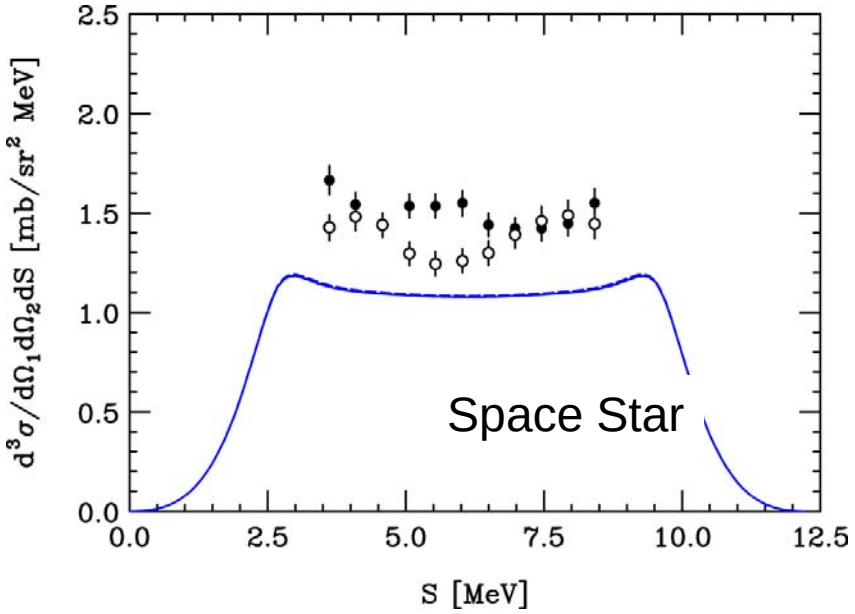
Space Star anomaly 1980's — Off-plane star anomaly → ???

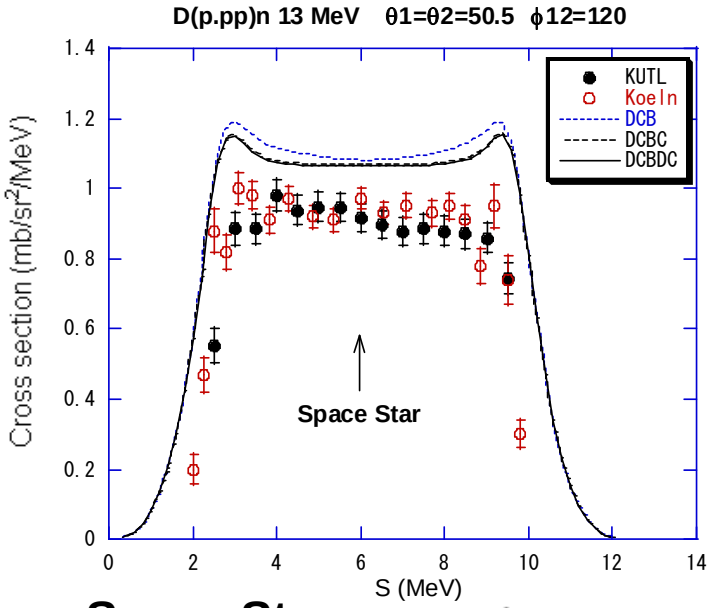




Space Star Anomaly

Space Star Anomalyはnd分解反応で発見された。



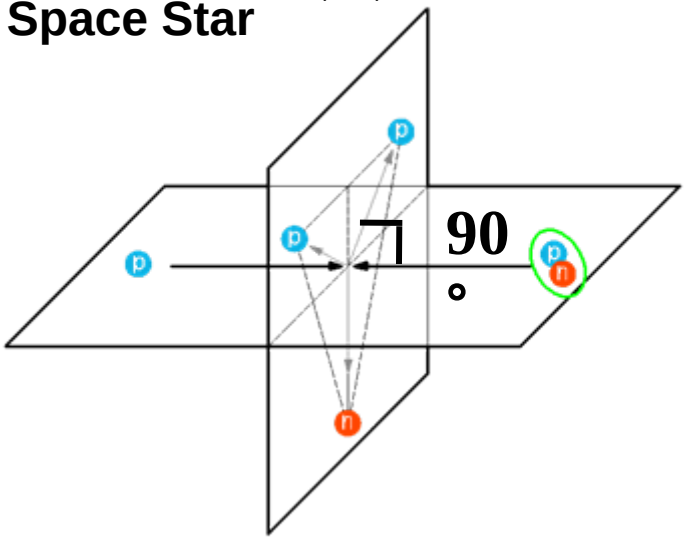


J.STRATE et al, Nucl.Phys.A501(1989)51
H.R.Setze et al, Physics Letters B388(1996)229

SSでのnd分解反応の実験値はnd計算よりも約30%大きい。

未だに原因はわかっていない。

Space Star

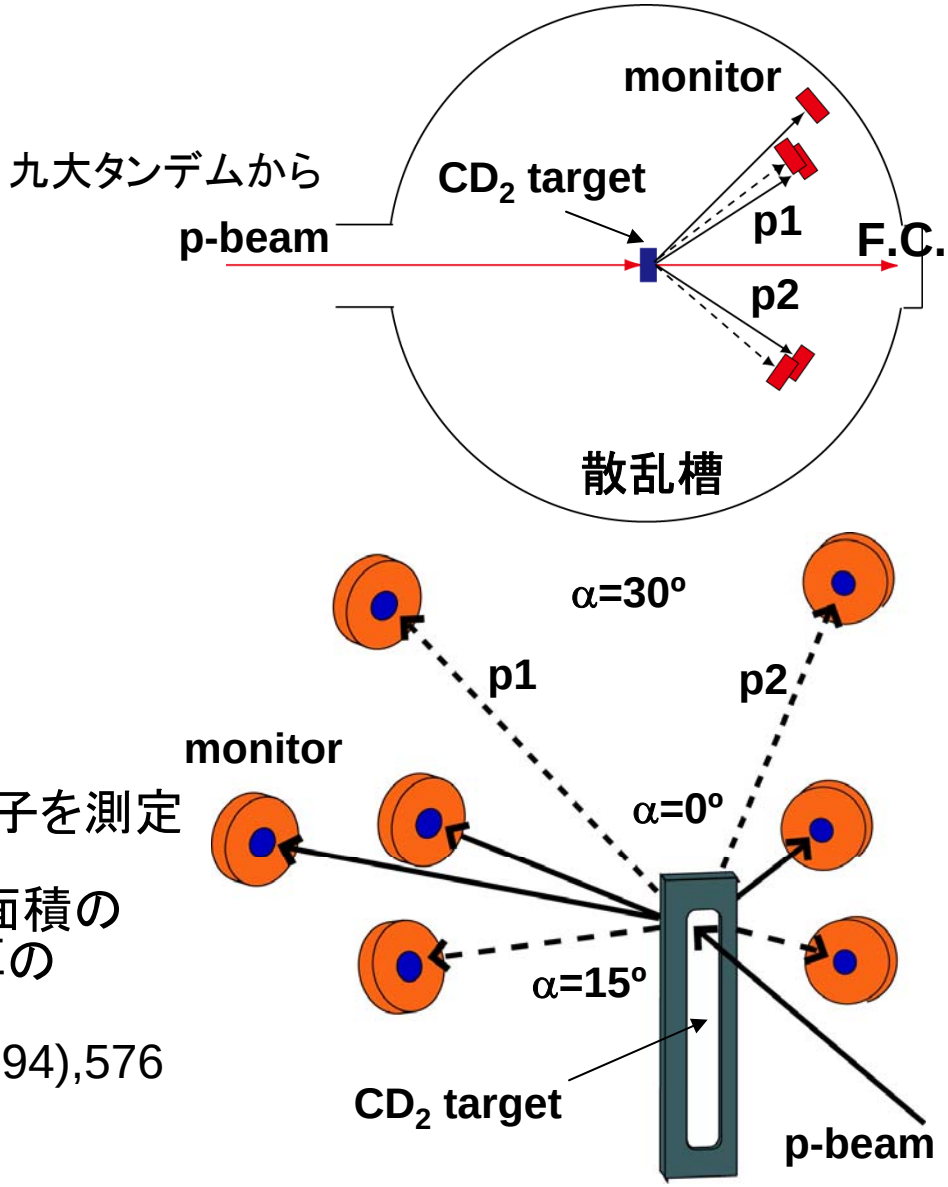


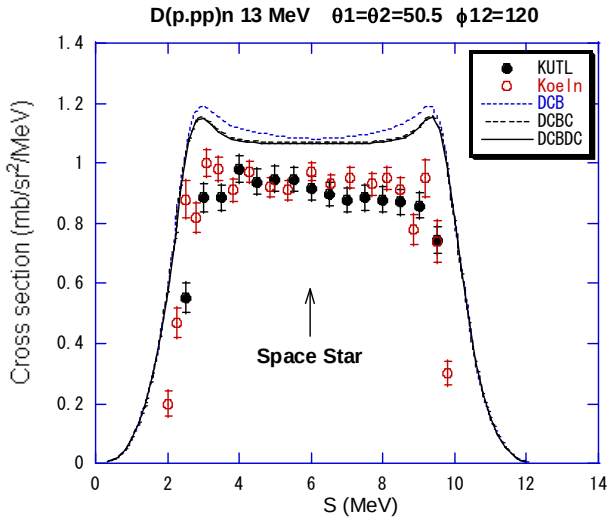
Ep=9.5MeV,13MeV D(p,pp)n Star 測定@九大

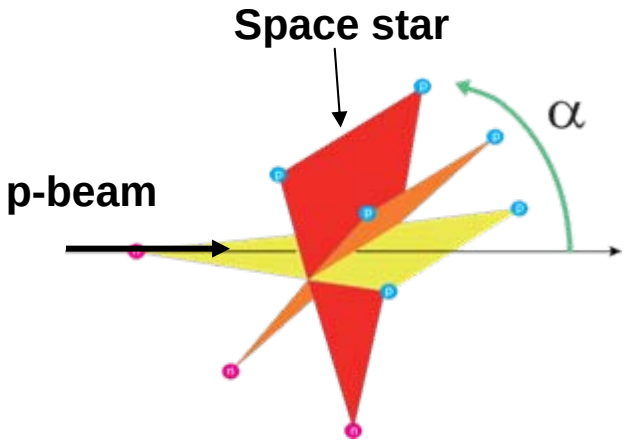
分解反応で生じる二つの陽子を
Starの条件で同時測定する。

- 測定角度:
  Ep=13MeV で α=0°~75°
  Ep=9.5MeVで α=30°~90°
- 標的:CD_2膜
  (厚さ 0.3~0.5と0.2~0.3mg/cm^2)
- 検出器:Si-SSD
- 観測量:微分断面積 $\frac{d^3\sigma}{d\Omega_1 d\Omega_2 dS}$
- モニターを用いてpd弾性散乱陽子を測定

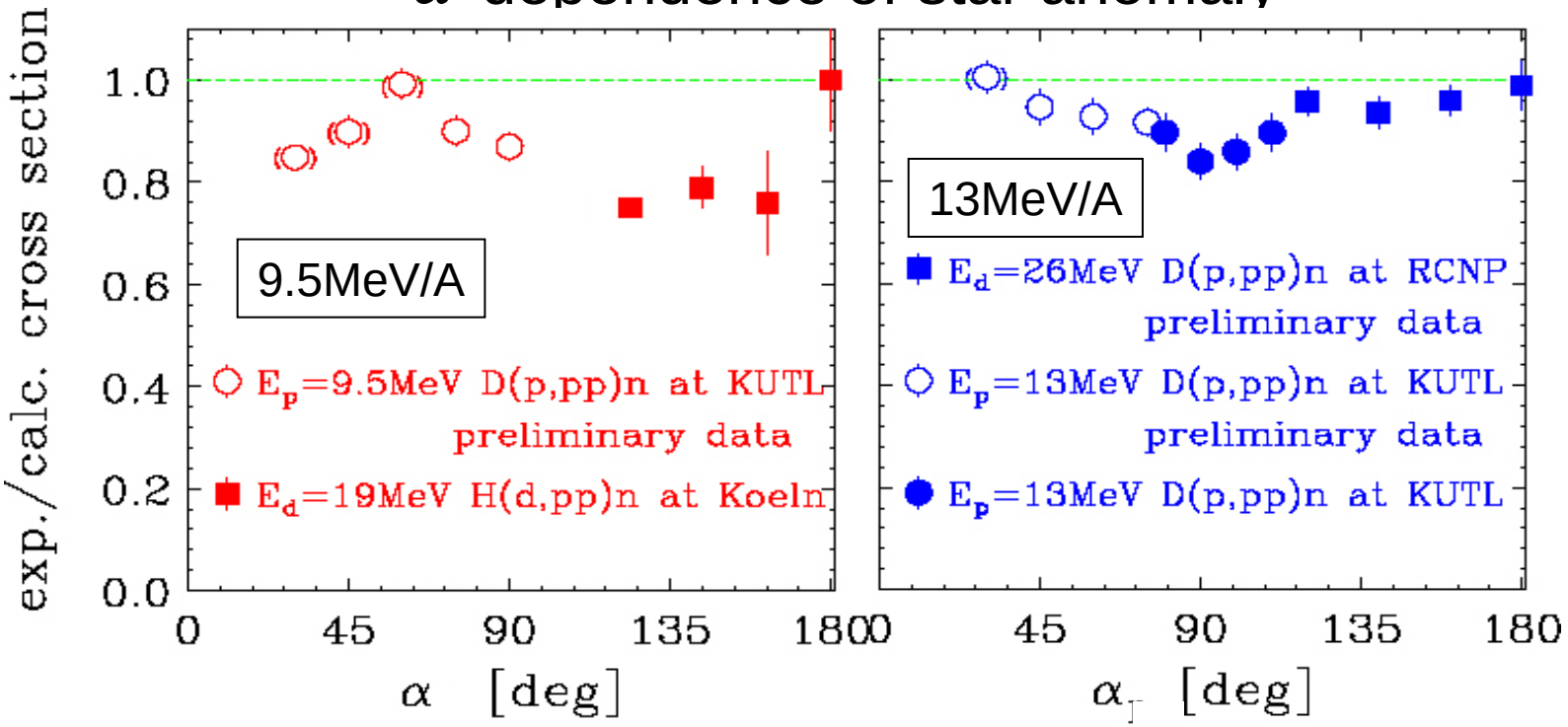
(過去に行った、D(p,p)d反応断面積の
精密測定の結果を用いて標的厚の
絶対値を測定した。)
K.Sagara et al,Phys.Rev.C**50**(1994),576







α dependence of star anomaly



Discrepancies in 3N systems and their origins