Spin effects in the interaction of antiprotons with the deuteron at low and intermediate energies

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MOTIVATION

*** Preparation of an intense beam of polarized antiprotons (PAX)**

V. Barone et al., arXiv:hep-ex/0505054.

pbar-1H scattering in rings /F. Rathmann et al. PRL 94 (2005) 014801/

p-1H scattering at 23 MeV FILTEX, F.Rathmann et al. PRL 71 (1993) 1379
49 MeV, COSY, W. Augustinyak et al. PLB 718 (2012) 64

Other possibilities - polarized deuterium targets :
Yu.N. Uzikov and J. Haidenbauer, PRC 79 (2009) 024617;
PRC 87 (2013) 054003; PRC 88 (2013) 0227001
S. Salnikov NPA 874 (2012) 98
- or polarized 3He target
Yu.N. U., J. Haidenbauer, B. Prmantaeyva , PRC (2011)

* Spin dependence of the elementary anti-*p* *N* amplitudes

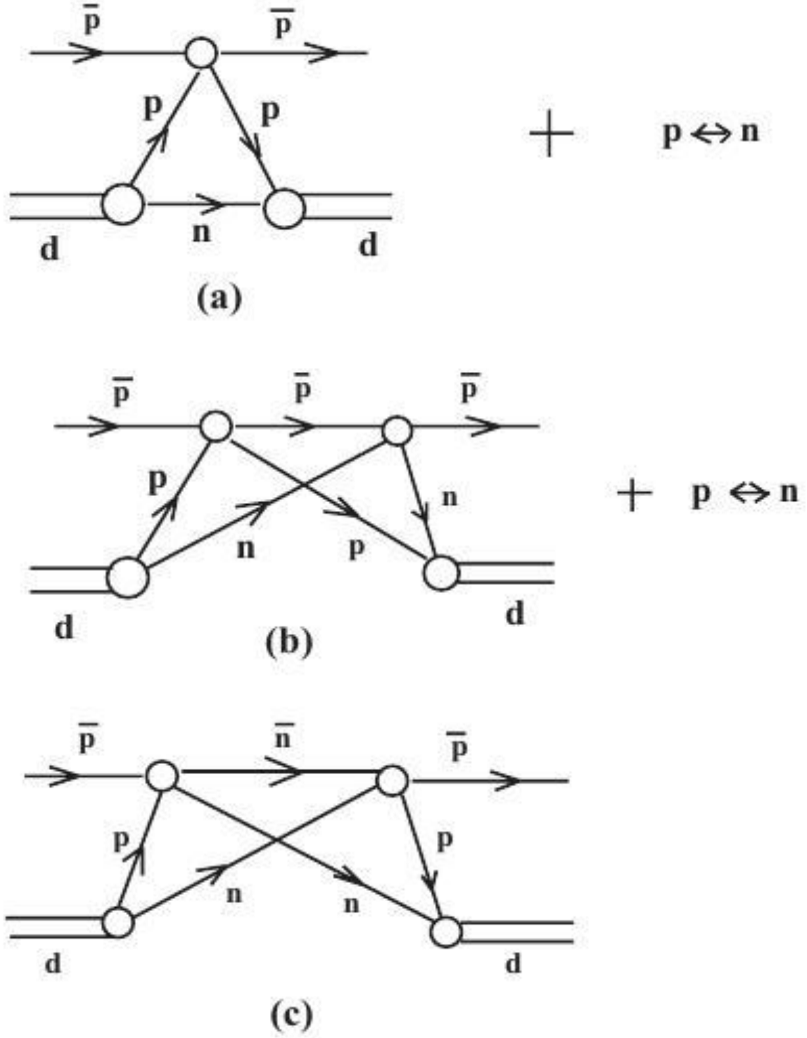
Nbar *N* interaction model developed by the Juelich Group

T. Hippchen, J. Haidenbauer, K. Holinde, V. Mull,
PRC 44, 1323 (1991)
Models A and D (differ by treatment of annihilation)

Recent partial-wave analysis of antip p- data
D. Zhou, R.G.E. Timmermans, Phys. Rev. C 86, 044003 (2012)

* pbar-d dynamics -> Glauber model

pd elastic scattering: M.N. Platonova, V.I. Kukulin,
PRC **81,014004 (2010)**
-> apdated for pbar d scattering : Yu.N. U.
J.Haidenbauer, PRC 87, 054003 (2013)



$$
\begin{aligned}
\hat{M}(\mathbf{q},\mathbf{s}) \\
&= \exp\left(\frac{1}{2} i\mathbf{q}\cdot\mathbf{s}\right) M_{\bar{p}p}(\mathbf{q}) + \exp\left(-\frac{1}{2} i\mathbf{q}\cdot\mathbf{s}\right) M_{\bar{p}n}(\mathbf{q}) \\
&\quad + \frac{i}{2\pi^{3/2}} \int \exp(i\mathbf{q}'\cdot\mathbf{s})[M_{\bar{p}p}(\mathbf{q}_1)M_{\bar{p}n}(\mathbf{q}_2) \\
&\quad + M_{\bar{p}n}(\mathbf{q}_1)M_{\bar{p}p}(\mathbf{q}_2) - M_{\bar{p}p\to\bar{n}n}(\mathbf{q}_1)M_{\bar{n}n\to\bar{p}p}(\mathbf{q}_2)]d^2\mathbf{q}'.
\end{aligned}
$$

$$
\begin{aligned}
M_{\bar{p}N} &= A_N + (C_N \boldsymbol{\sigma}_1 + C'_N \boldsymbol{\sigma}_2) \cdot \hat{\mathbf{n}} + B_N (\boldsymbol{\sigma}_1 \cdot \hat{\mathbf{k}})(\boldsymbol{\sigma}_2 \cdot \hat{\mathbf{k}}) \\
&+ (G_N - H_N)(\boldsymbol{\sigma}_1 \cdot \hat{\mathbf{n}})(\boldsymbol{\sigma}_2 \cdot \hat{\mathbf{n}}) + (G_N + H_N)(\boldsymbol{\sigma}_1 \cdot \hat{\mathbf{q}})(\boldsymbol{\sigma}_2 \cdot \hat{\mathbf{q}})
\end{aligned}
$$

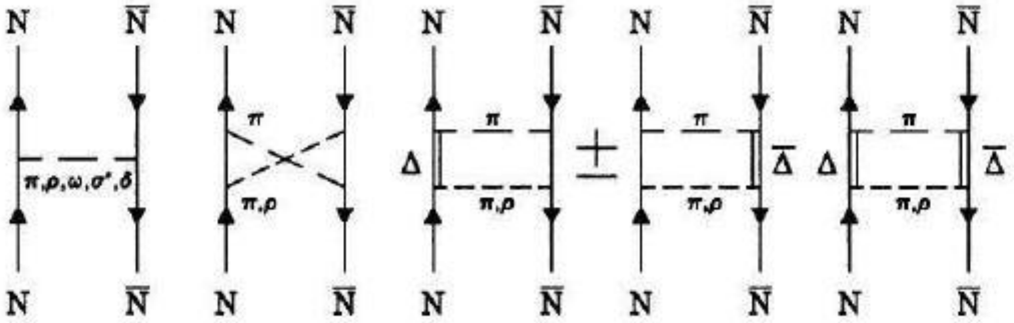
The unit vectors are defined by $\hat{\mathbf{k}} = (\mathbf{k}_i + \mathbf{k}_f)/|\mathbf{k}_i + \mathbf{k}_f|$, $\hat{\mathbf{q}} = (\mathbf{k}_i - \mathbf{k}_f)/|\mathbf{k}_i - \mathbf{k}_f|$, and $\hat{\mathbf{n}} = [\hat{\mathbf{k}} \times \hat{\mathbf{q}}]$, where $\mathbf{k}_i$ ($\mathbf{k}_f$) denotes the momentum of the incident (outgoing)

The Jülich $\bar{N}N$ model

I) V_{el}

starting point: Bonn *NN* potential

(R. Machleidt, K. Holinde, C. Elster, Phys. Rep. 149 (1986) 1)



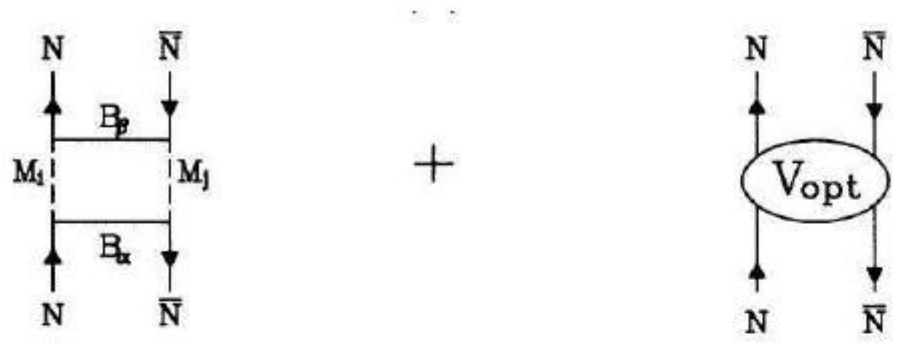
G-parity transform

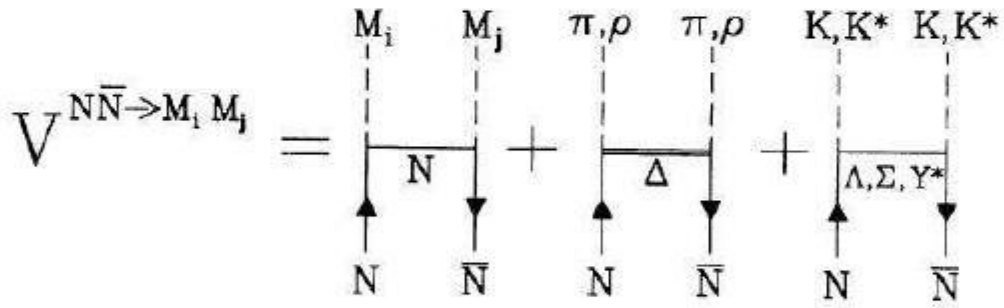
well defined over whole range

no modification of short-range part is required

The Jülich $\bar{N}N$ model

- microscopic annihilation model (for 2-meson channels) (D)



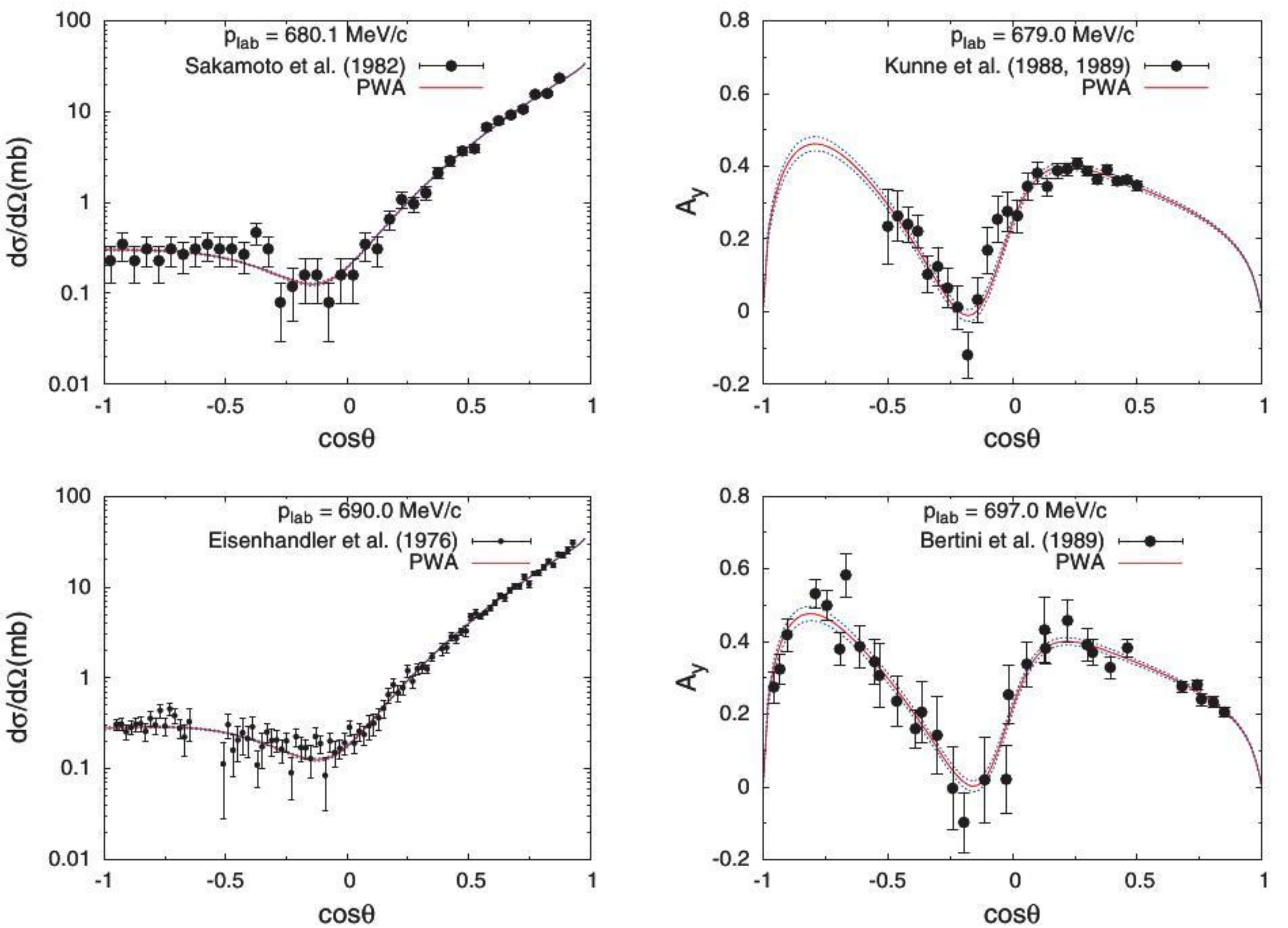


$$M_{i,j} = \pi, \eta, \rho, \omega, f_0, a_0, f_1, a_1, f_2, a_2$$

- T. Hippchen et al., PRC 44 (1991) 1323; V. Mull et al., PRC 44 (1991) 1337
- V. Mull & K. Holinde, PRC 51 (1995) 2360

$\overline{p}p \rightarrow \overline{p}p$

PHYSICAL REVIEW C **86**, 044003 (2012)



ZT

Optical theorem:

$$\mathrm{Im}\,\frac{\mathrm{Tr}(\hat{\rho}_i \hat{F}(0))}{\mathrm{Tr}\hat{\rho}_i} = \frac{k_{\bar{p}d}}{4\pi}\sigma_i$$

M.P. Rekalo et al. Few -Bod. Syst (1998):

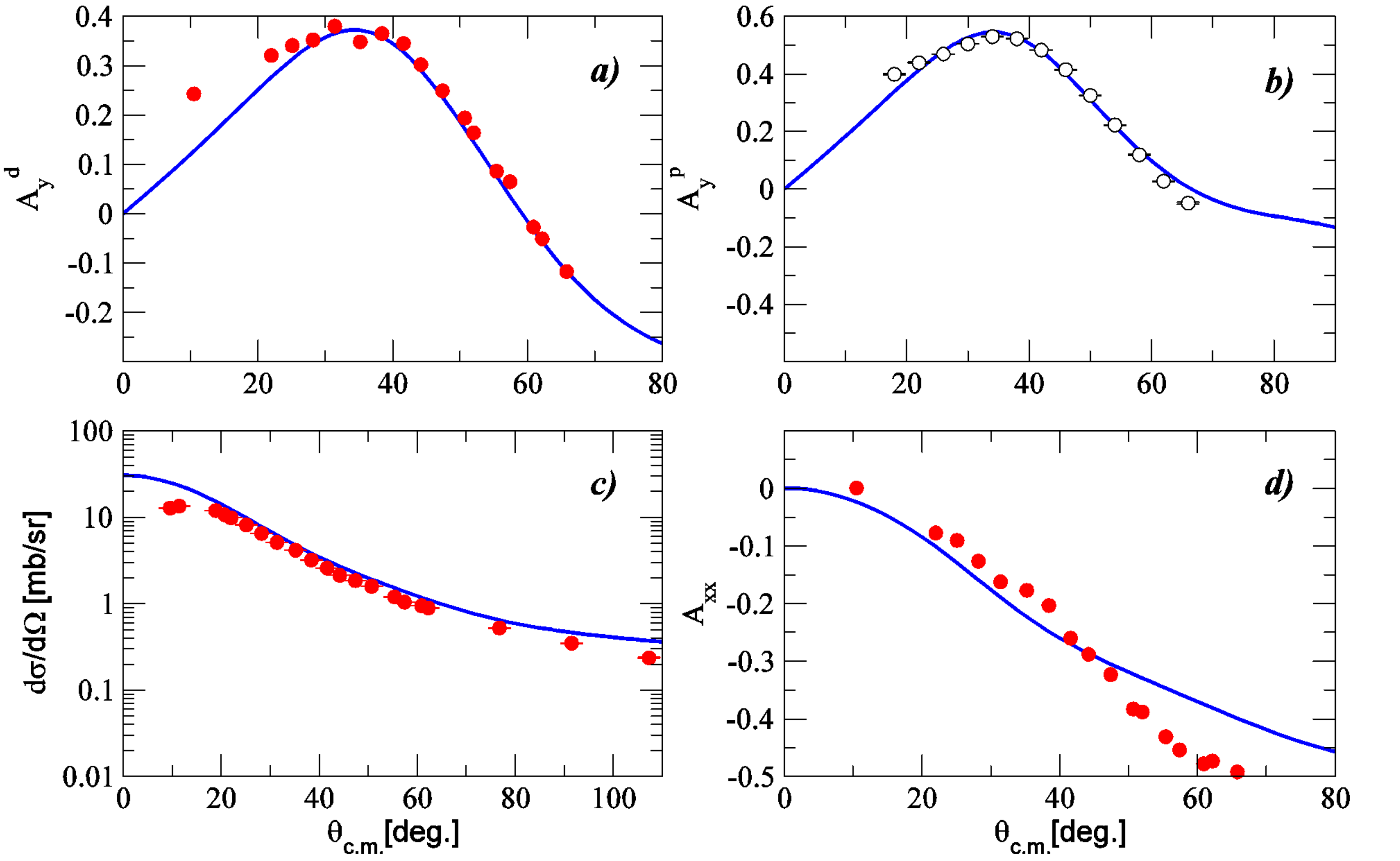
$$\hat{F}_{\alpha\beta}(0) = g_1\delta_{\alpha\beta} + (g_2 - g_1)m_\alpha m_\beta + i g_3\hat{\sigma}_i\epsilon_{\alpha\beta i} + i(g_4 - g_3)\hat{\sigma}_i m_i m_j \epsilon_{\alpha\beta j},$$

The total $\bar{p}d$ cross section is defined by [11]

$$\sigma = \sigma_0 + \sigma_1 \mathbf{P}^{\bar{p}} \cdot \mathbf{P}^d + \sigma_2(\mathbf{P}^{\bar{p}} \cdot \hat{\mathbf{k}})(\mathbf{P}^d \cdot \hat{\mathbf{k}}) + \sigma_3 P_{zz}, \quad (1)$$

TEST calculation: pd elastic scattering at 135 MeV (Yu.N. U., J. Haidenbauer , arxive 1212.2761)

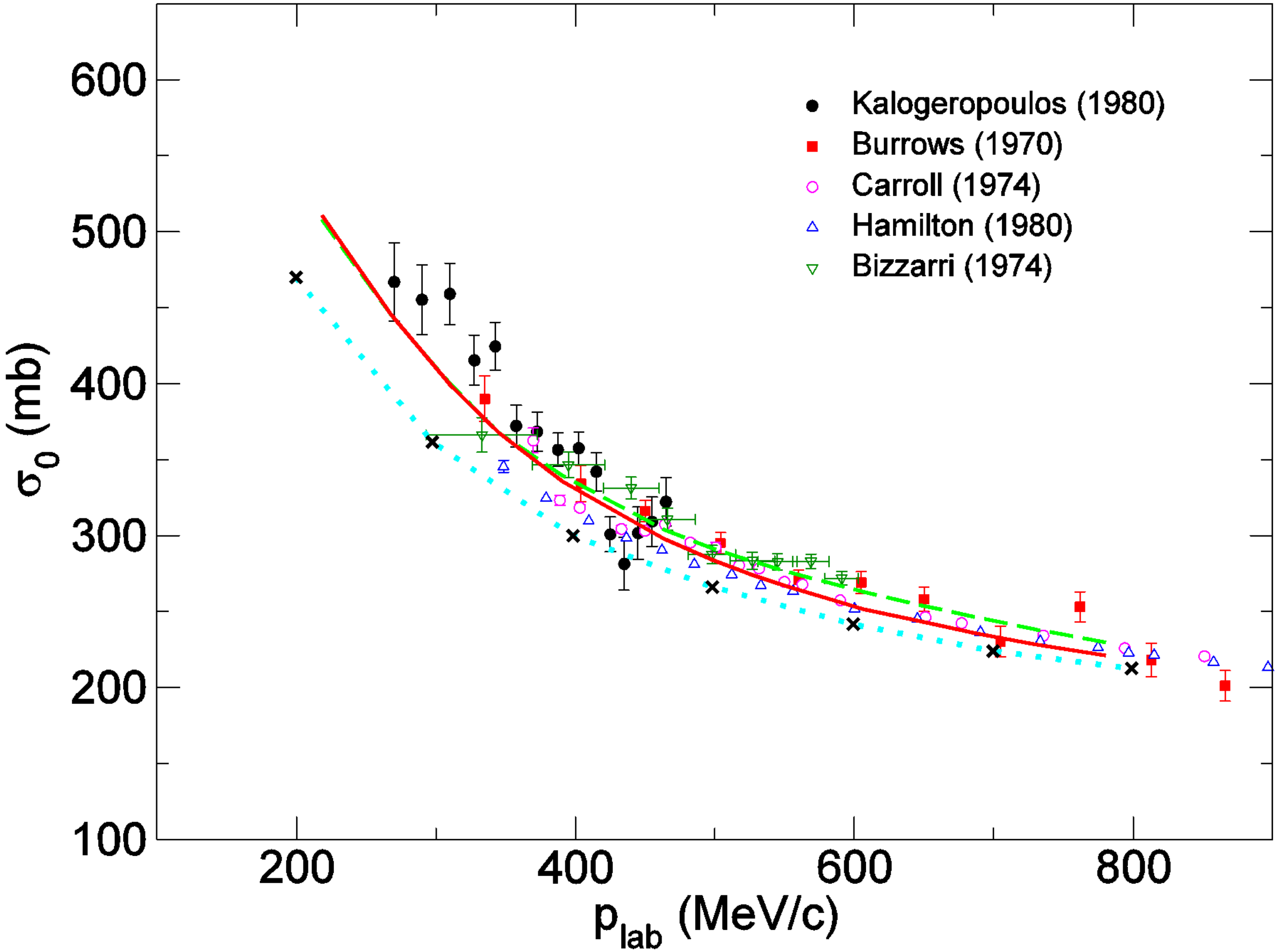
data :K. Sekiguchi et al. (2002) ; B. von Przewoski et al (2006)

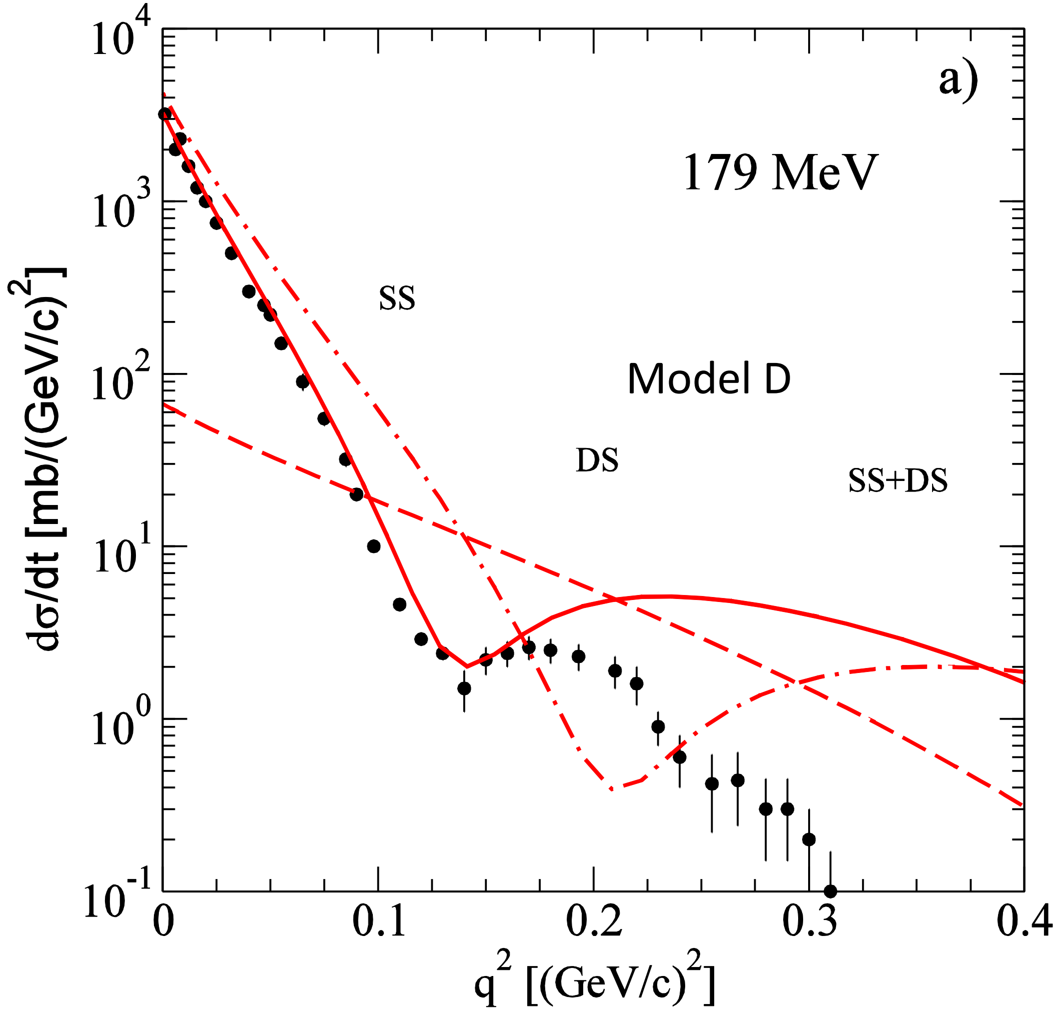


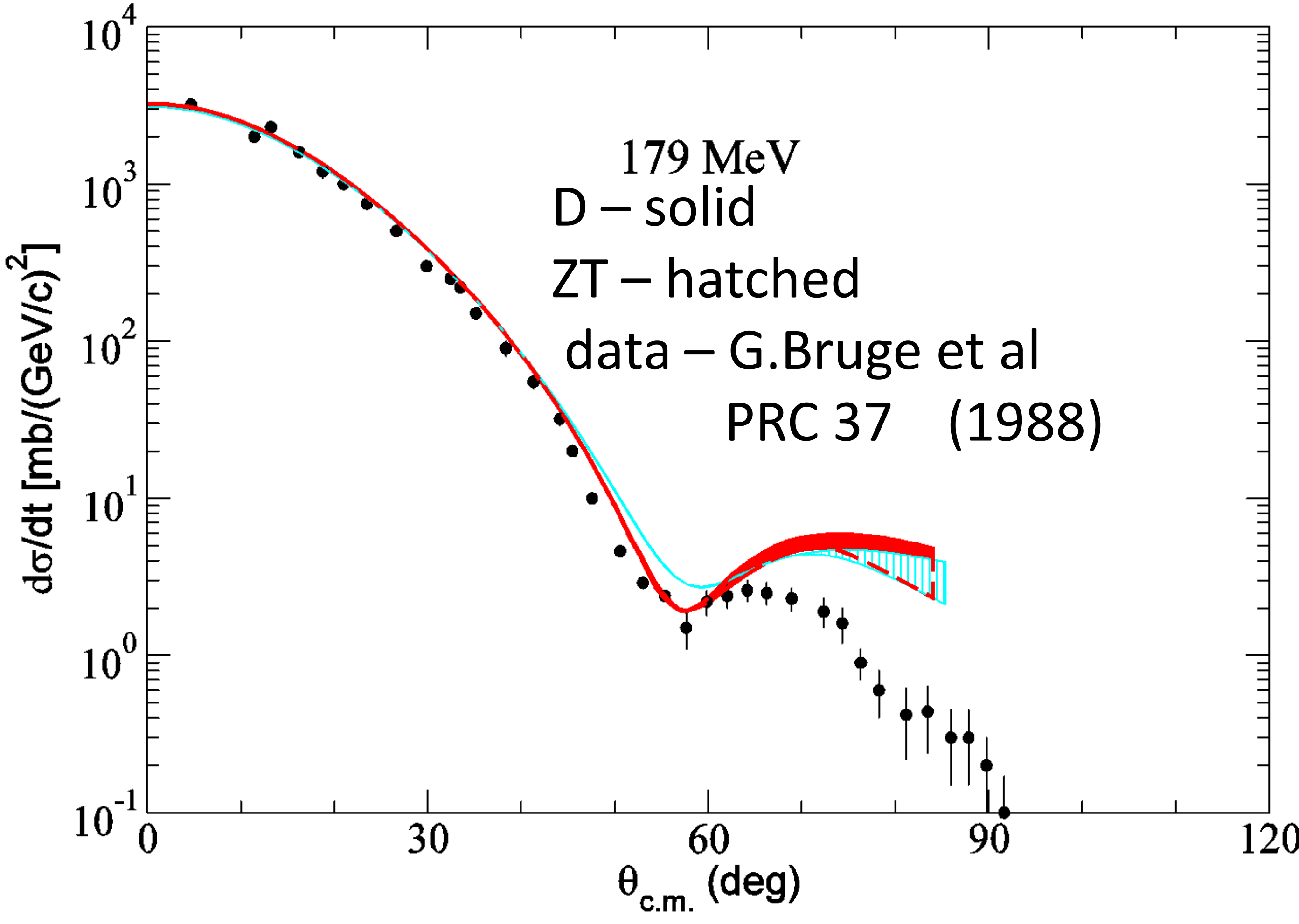
Total unpolarized pbar -d cross section

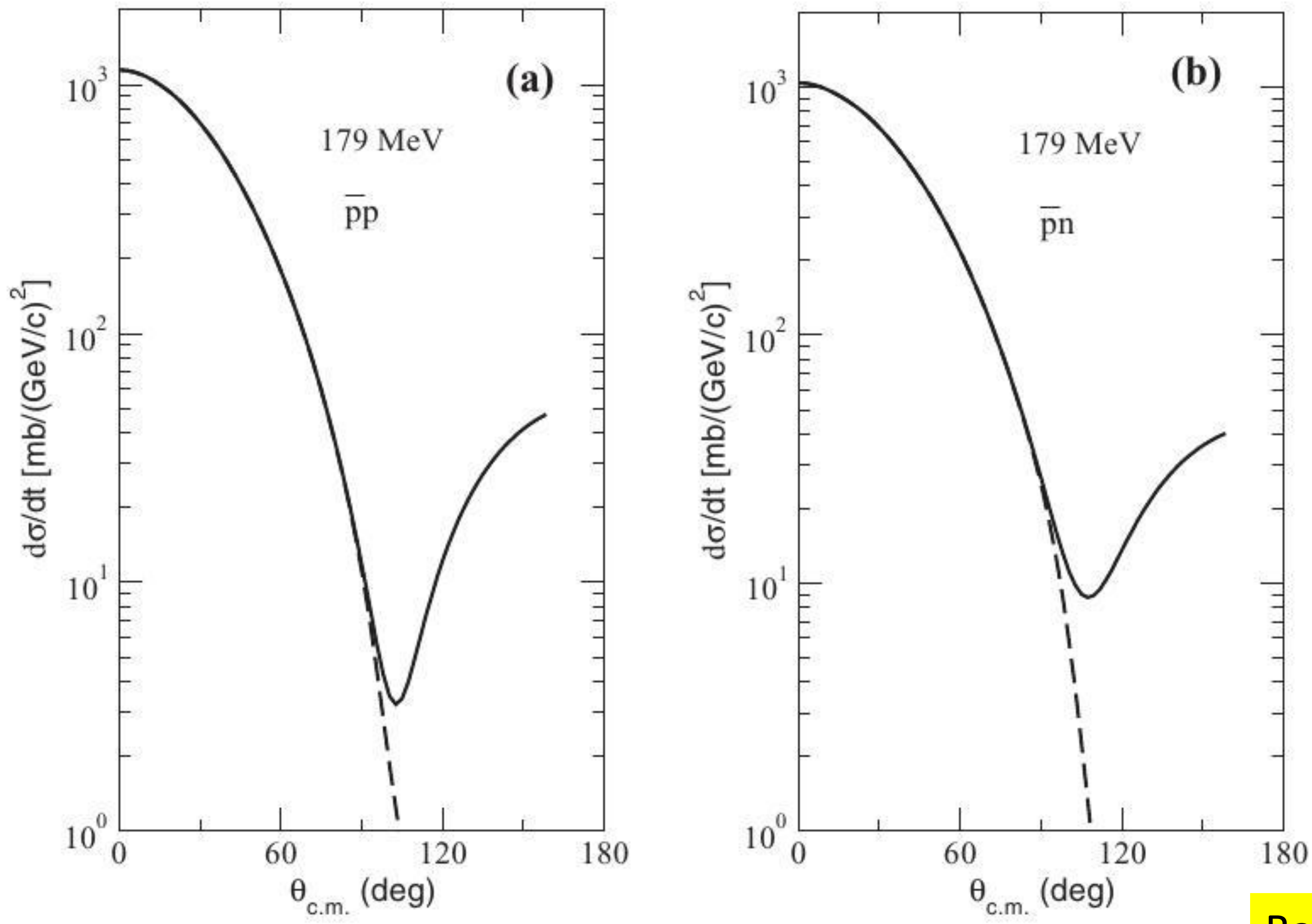
Yu.N.Uzikov, J. Haidenbauer, PRC 88 (2013) 027001

dotted – ZT
red – D
green - A

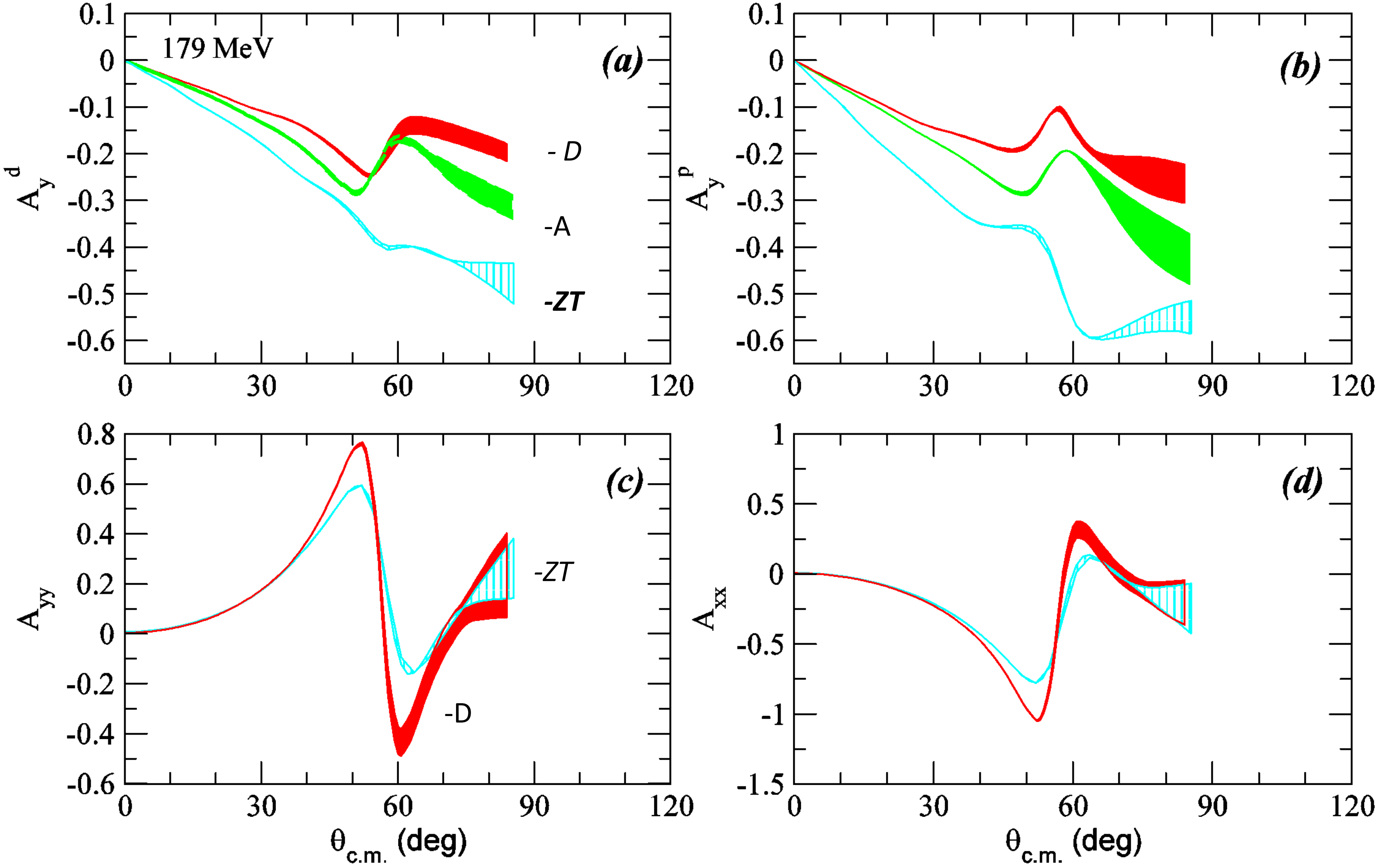


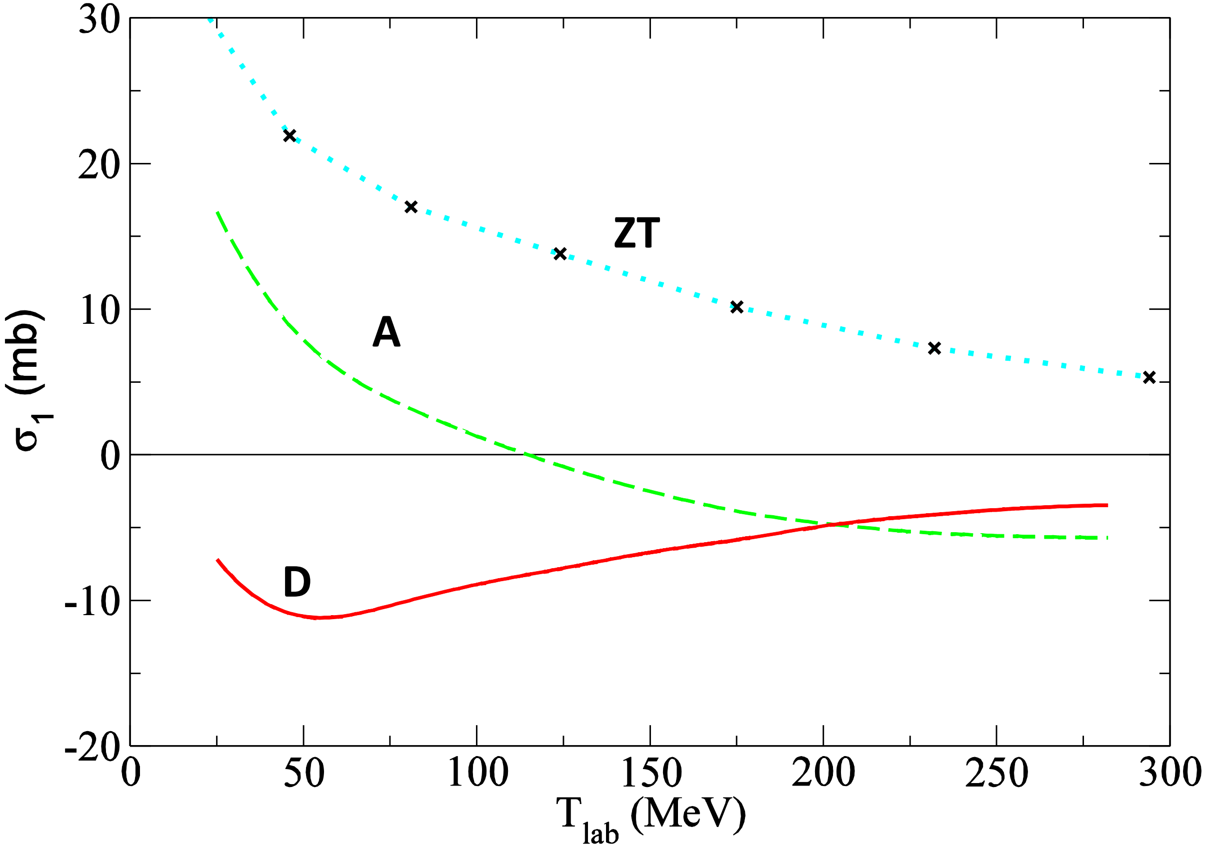

a)
179 MeV
SS
Model D
DS
SS+DS
dσ/dt [mb/(GeV/c)^2]
q^2 [(GeV/c)^2]

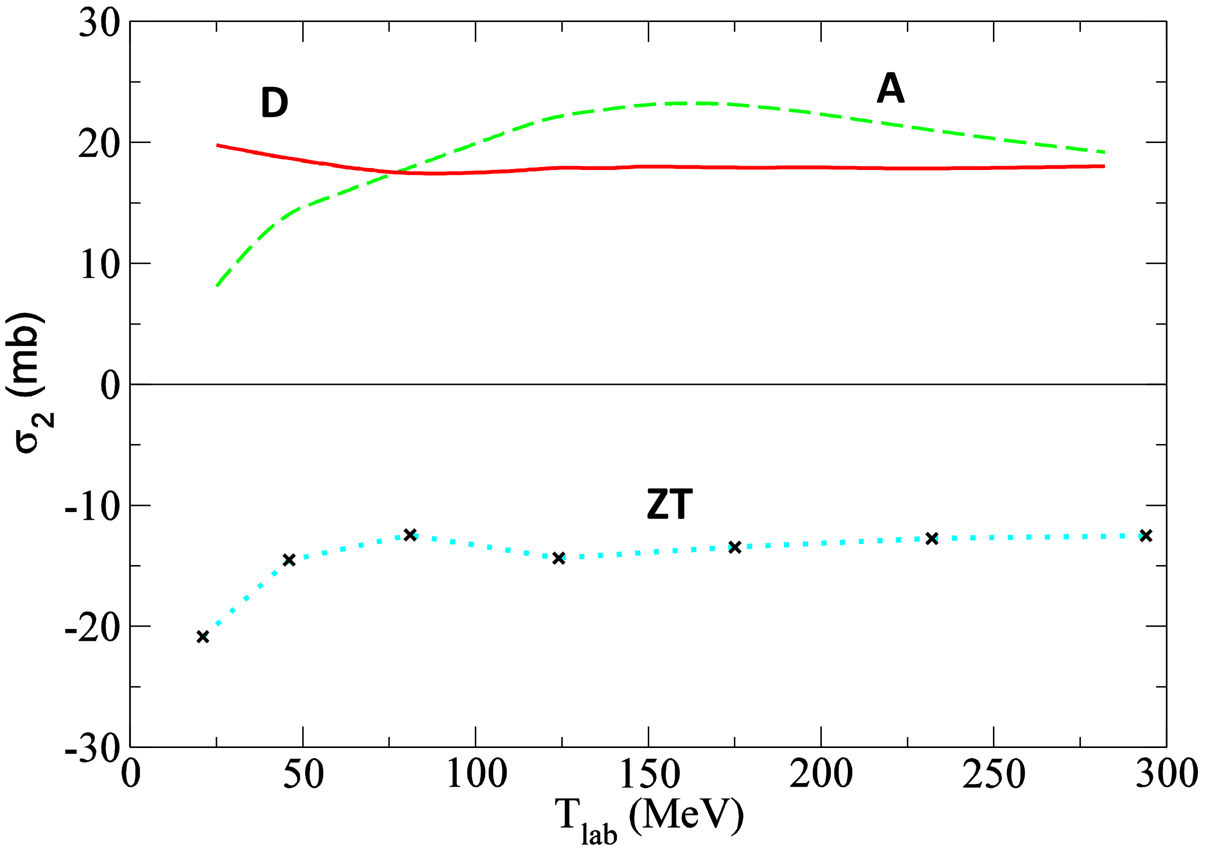

179 MeV
D – solid
ZT – hatched
data – G.Bruge et al
PRC 37 (1988)
dσ/dt [mb/(GeV/c)^2]
θ_c.m. (deg)



Backward tail and cut off


179 MeV
(a)
(b)
(c)
(d)
- D
-A
-ZT
-ZT
-D
A_y^d
A_y^p
A_{yy}
A_{xx}
$\theta_{c.m.}$ (deg)
$\theta_{c.m.}$ (deg)

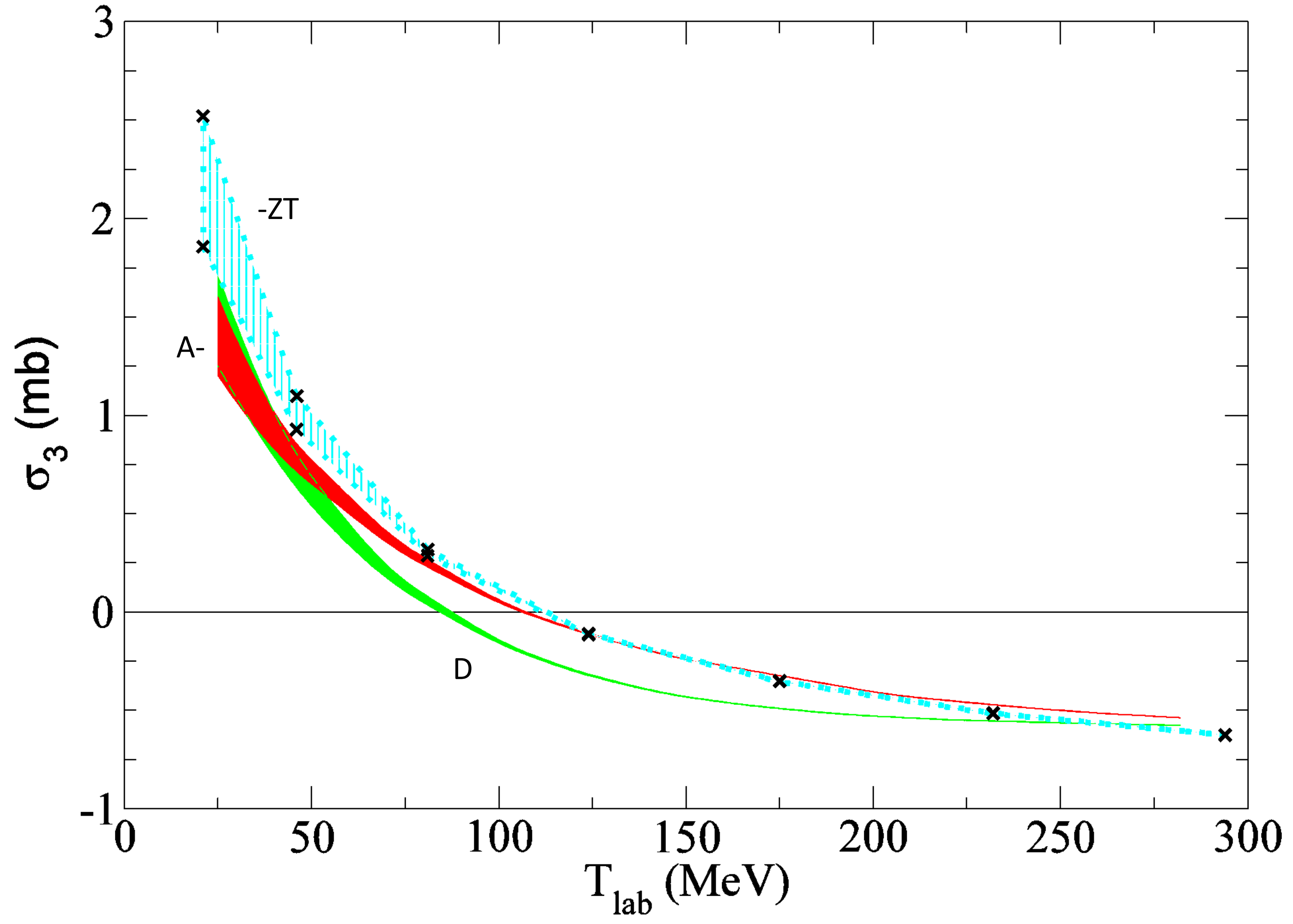




$$P_{\bar{p}}(t_0) = -2P_T\frac{\sigma_1}{\sigma_0}, \text{ if } \boldsymbol{\zeta}\cdot\hat{\mathbf{k}} = 0,$$

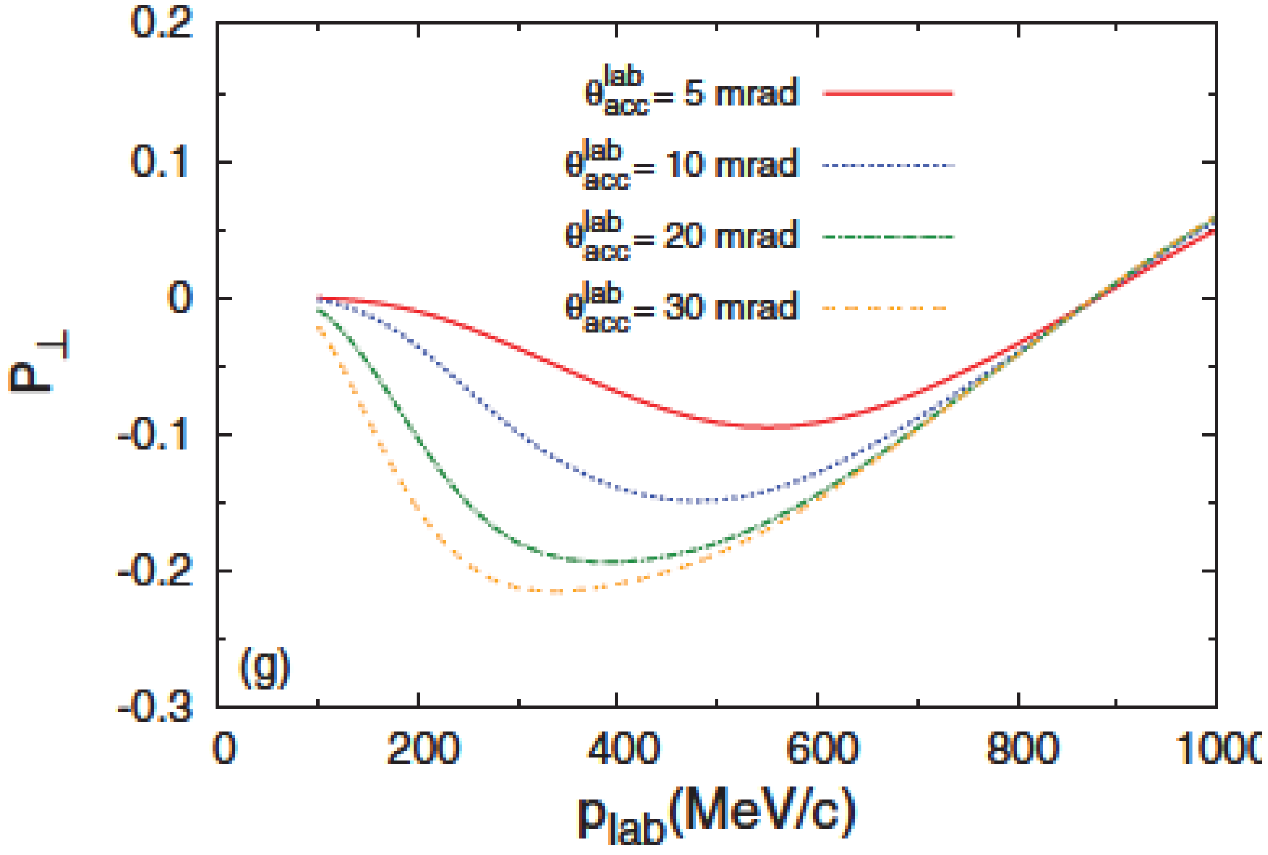
$$P_{\bar{p}}(t_0) = -2P_T\frac{\sigma_1+\sigma_2}{\sigma_0}, \text{ if } |\boldsymbol{\zeta}\cdot\hat{\mathbf{k}}| = 1\,, \qquad (2)$$

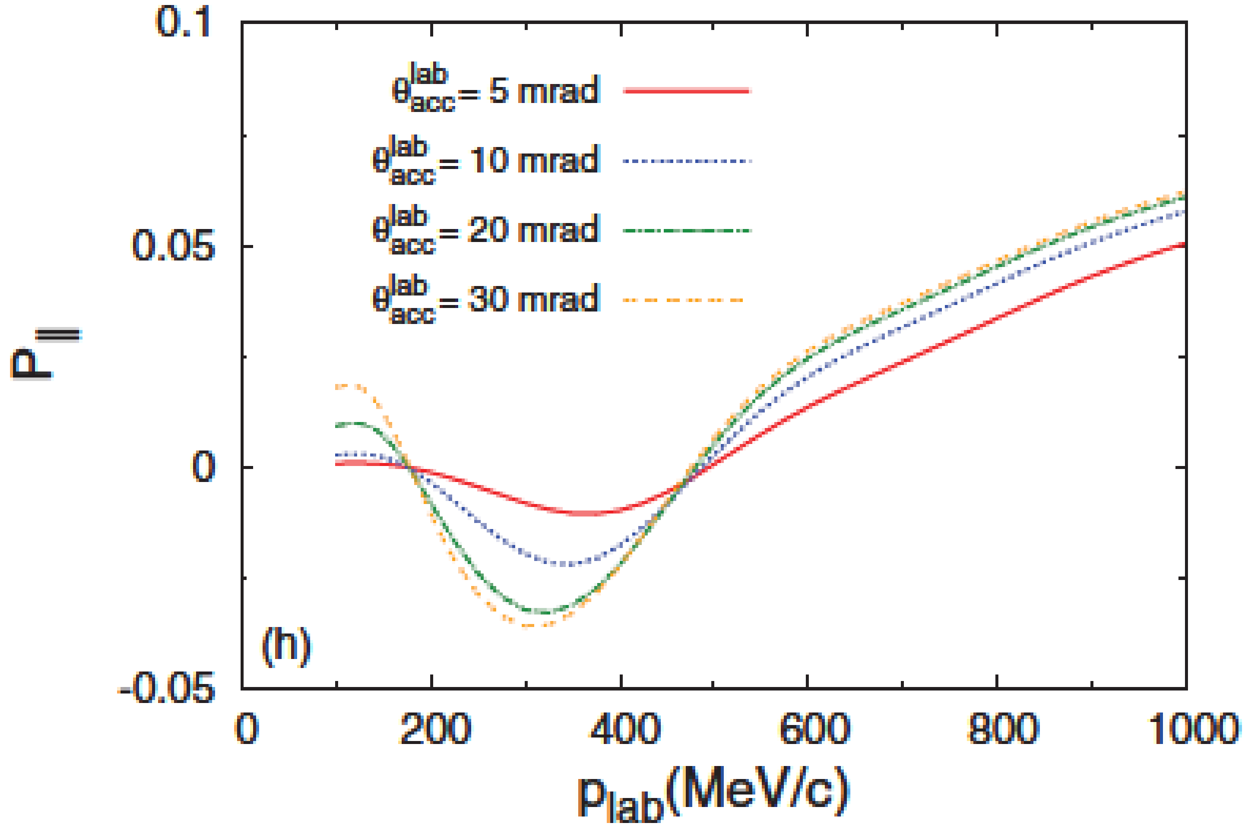
V.F. Dmitriev, A. Milstein, S. Salnikov, PLB 690 (2010) 427



3
2
1
0
-1
0
50
100
150
200
250
300
σ_3 (mb)
T_{lab} (MeV)
-ZT
A-
D

D.Zhou, R..G.E. Timmermans, PRC 87 (2013) 054005 $\bar{p}p \rightarrow \bar{p}p$





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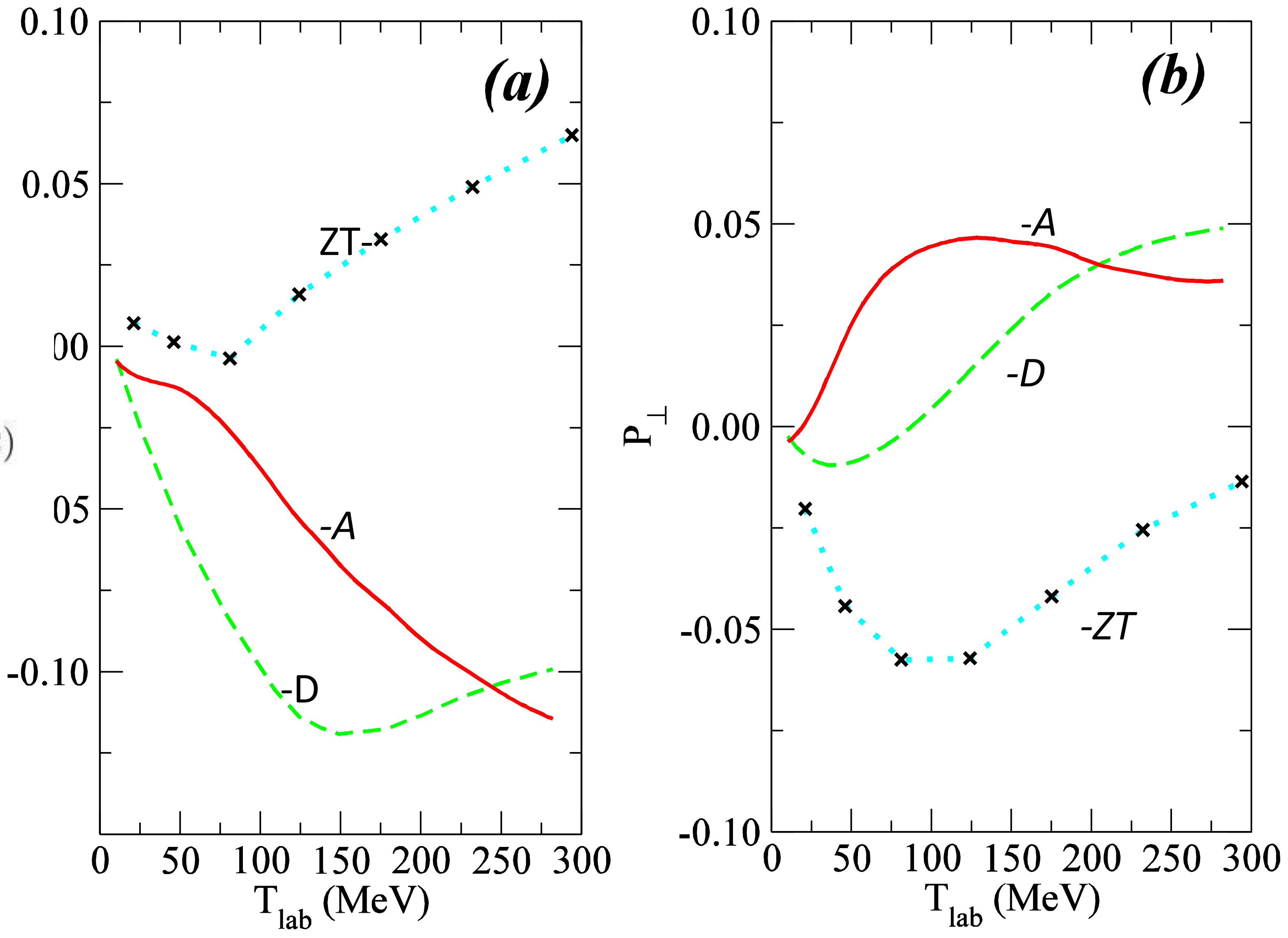

SUMMARY

- Glauber theory is applied to pbar-d scattering accounting for SS and DS mechanisms
- Full spin structure of elementary pbar-N amplitudes is included
- Amplitudes from the Juelich Nbar N model and from recent model-independent analysis by Zhou-Timmermans are employed
- Integrated cross sections and spin observables A_y, A_{xx}, A_{yy} are calculated
- Polarization efficiency for antiprotons in rings is calculated at 50-300 MeV
- Agreement with measured total cross section and with diff. cross section at 179 MeV
- Polarization efficiency for a deuterium target is comparable to 1H target
- Need more pbar d data ! AD at CERN or at FAIR in Darmstadt ?