The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

1942-13

Sixth International Conference on Perspectives in Hadronic Physics

12 - 16 May 2008

Hard Photodisintegration of a proton Pair.

E. Piasetzky

Tel Aviv University
Isreal

The Abdus Salam
International Centre for Theoretical Physics

TEL AVIV UNIVERSITY

Sixth International Conference on Perspectives in Hadronic Physics

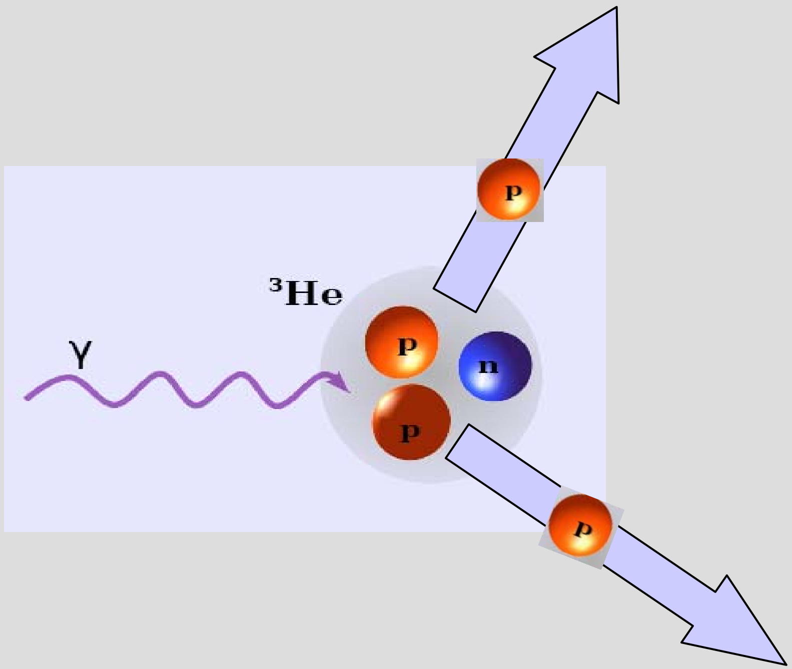
Hard Photodisintegration of a proton Pair

$$\gamma\ {}^{3}\mathrm{He} \rightarrow \mathrm{p}\,(\mathrm{high}\ \mathrm{p_t}) + \mathrm{p}\,(\mathrm{high}\ \mathrm{p_t}) + \mathrm{n(slow)}$$

E. Piasetzky

Tel Aviv University,

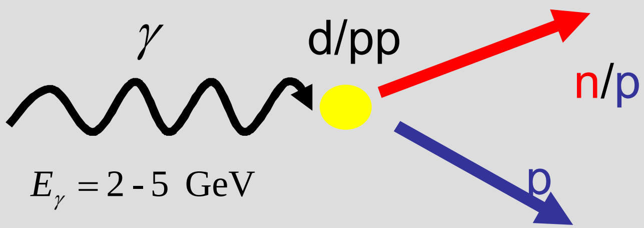
Tel Aviv, Israel

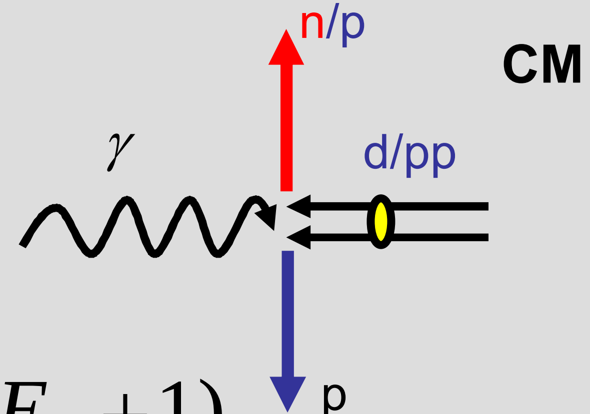


12 - 16 May 2008

(Miramare - Trieste, Italy)

Kinematics :





$$s = (p_\gamma + p_d)^2 = \mathrm{M_d}^2 + 2\,\mathrm{M_d}\,E_\gamma \approx 4(E_\gamma + 1)$$

$$t = (p_\gamma - p_N)^2 \approx \frac{\mathrm{s - M_d^2}}{2}[\cos(\theta_{cm}) - 1] \approx 2\mathrm{E}_\gamma[\cos(\theta_{cm}) - 1]$$

$$p_t = \sqrt{\frac{1}{2}E_\gamma M_d \sin^2(\theta_{cm})} \approx \sqrt{E_\gamma}\,\sin(\theta_{\mathrm{cm}})$$

FOR $\theta_{\mathrm{cm}} = 90^0$

$E_\gamma = 2$ GeV $\quad \mathrm{s} \approx 12\,\mathrm{GeV}^2, \quad \mathrm{t} = -4\,GeV^2, \quad \mathrm{p_t} \approx 1.5\,\mathrm{GeV/c}$

$E_\gamma = 5$ GeV $\quad \mathrm{s} \approx 24\,\mathrm{GeV}^2, \quad \mathrm{t} = -10\,GeV^2, \quad \mathrm{p_t} \approx 2.5\,\mathrm{GeV/c}$

photodisintegration is an efficient way to reach the hard regime.
To obtain the same s in NN scattering Pp ~ 2 Pγ.

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Leading order pQCD **underestimates** cross sections for intermediate energy photo - reactions

Deuteron elastic form factor

Farrar, Huleihel, Zhang PRL 74, 650 (1955)

FF (Q^2 = 4 GeV^2) calculation/data < 10^{-3}

Meson photoproduction

Farrar, Huleihel, Zhang NP B 349, 655 (1991)

Real Compton scattering

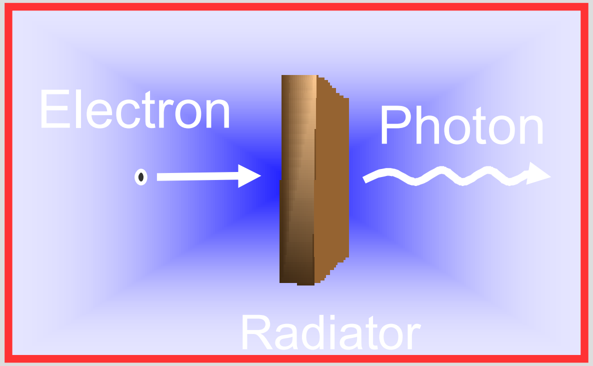
Brooks, Dixon PRD 62 114021 (2000)

(pQCD $\Rightarrow$ scaling scaling $\not\Rightarrow$ pQCD)

High – energy photodisintegration of the deuteron

$$d(\gamma, p)n$$

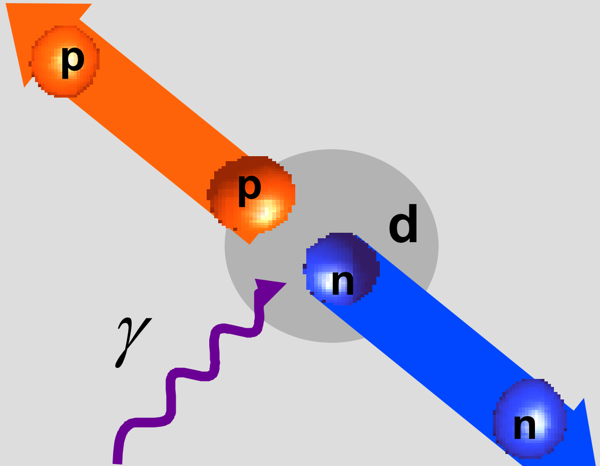
The bremsstrahlumg endpoint technique:



It is enough to measure the proton momentum vector

⇒ The incident photon energy

The recoil neutron kinematics



Assuming two-body reaction

To ensure two-body reaction the reconstructed photon energy
Is limited to the endpoint – the π mass

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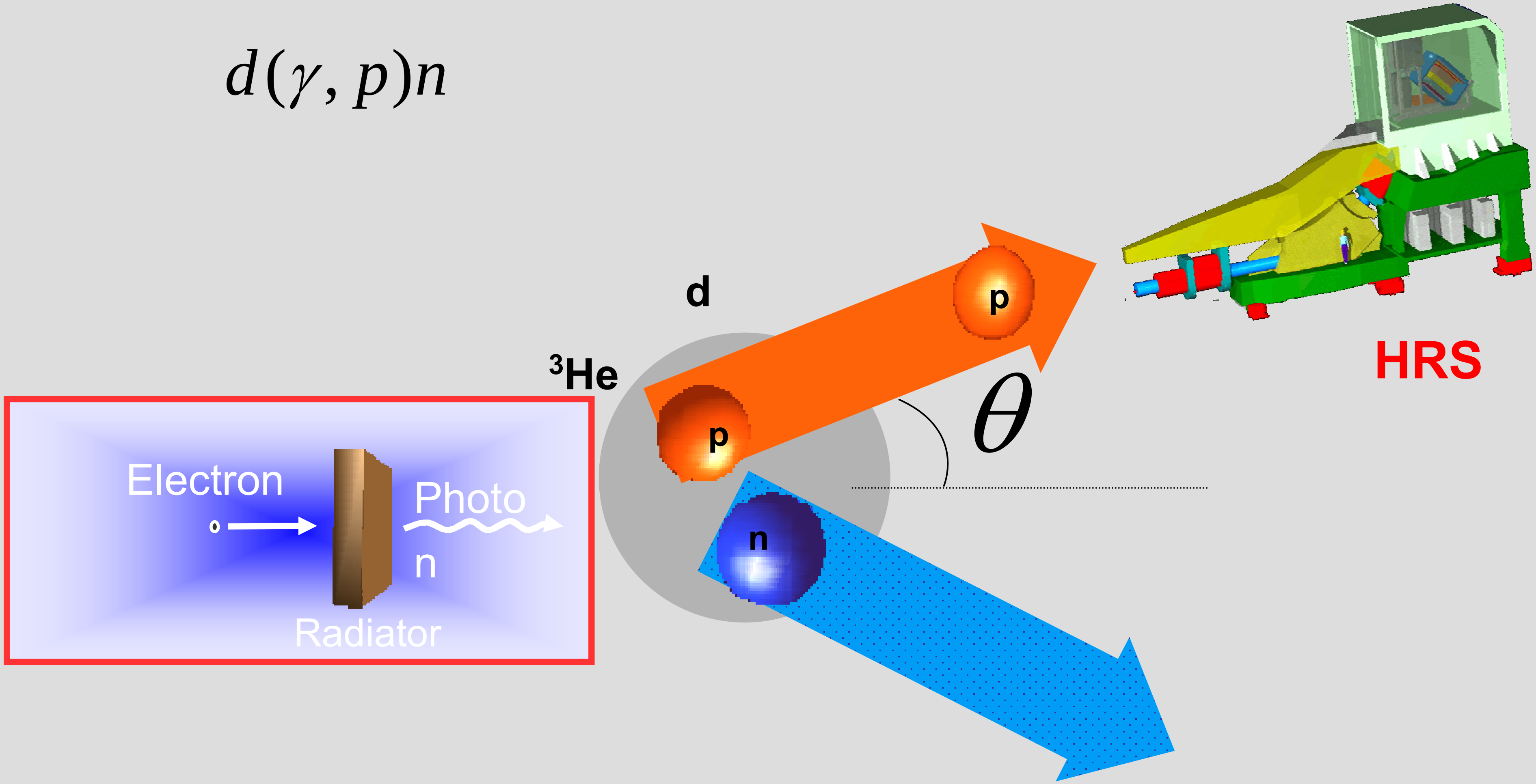
$$d(\gamma, p)n$$



Backgrounds are subtracted by “radiator out” and empty target runs

Build in quality-control – empty region beyond the endpoint

Exclusive large-momentum-transfer scattering

scaling

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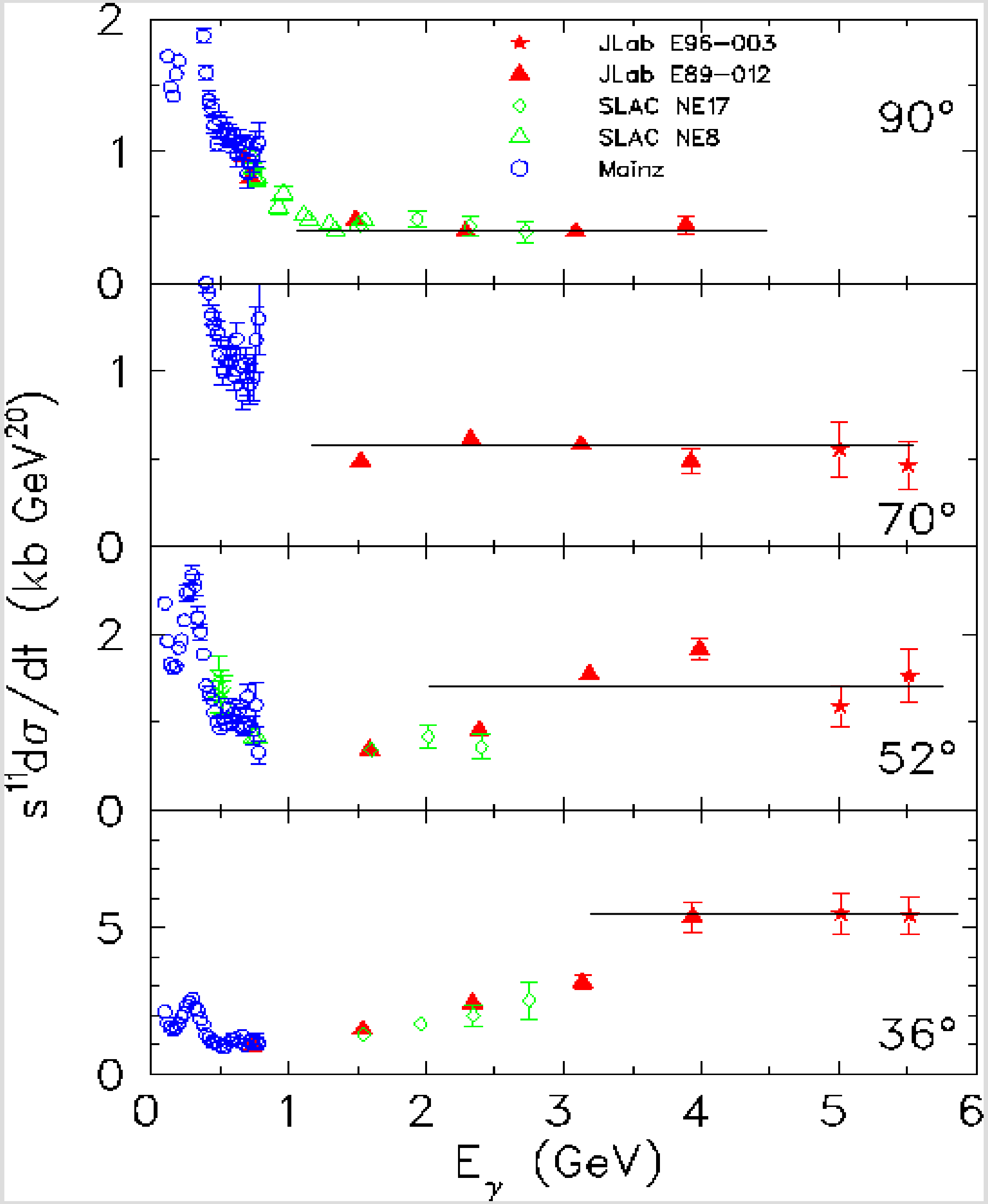
•**Dimensional (Constituents) counting rule:**

$$\frac{d\sigma}{dt}_{AB\to CD} \propto S^{-(N=n_A+n_B+n_C+n_D-2)} f\left(\tfrac{t}{s}\right)$$

For

$$\gamma\, d \to p\,(high\ p_t) + n\,(high\ p_t)$$

N = 1 + 6 + 3 + 3 – 2 = 11



Notice:

$$\frac{d\sigma}{dt}(E_\gamma = 1\,\mathrm{GeV/c}) / \frac{d\sigma}{dt}(E_\gamma = 4\,\mathrm{GeV/c}) \approx 10^4$$

Electromagnetic structure of the deuteron

R Gilman[1,2] and Franz Gross[2,3]

J. Phys. G: Nucl. Part. Phys. **28** (2002) R37–R116

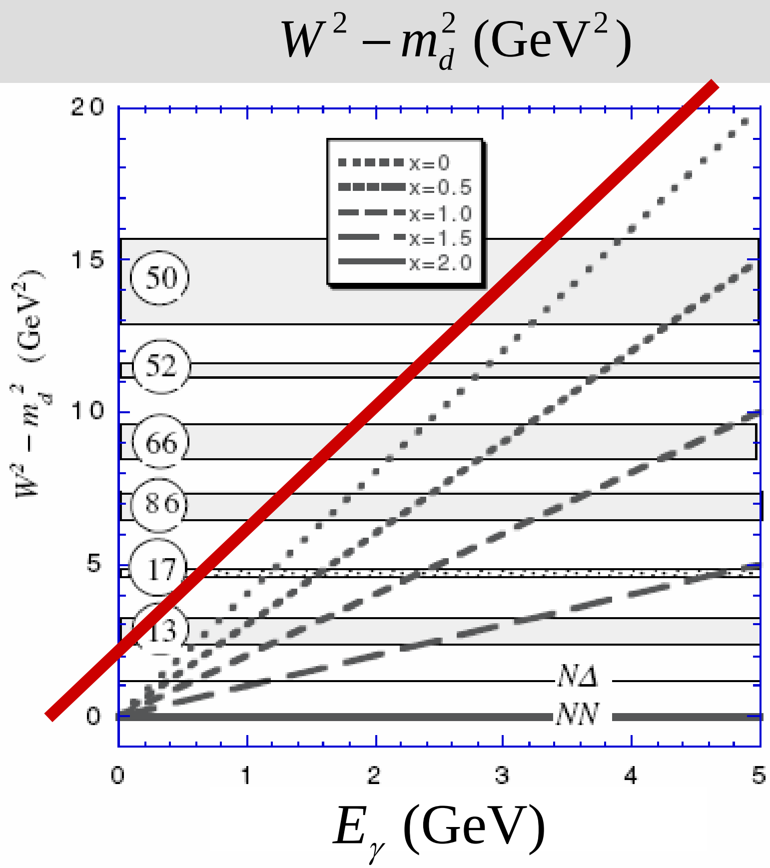


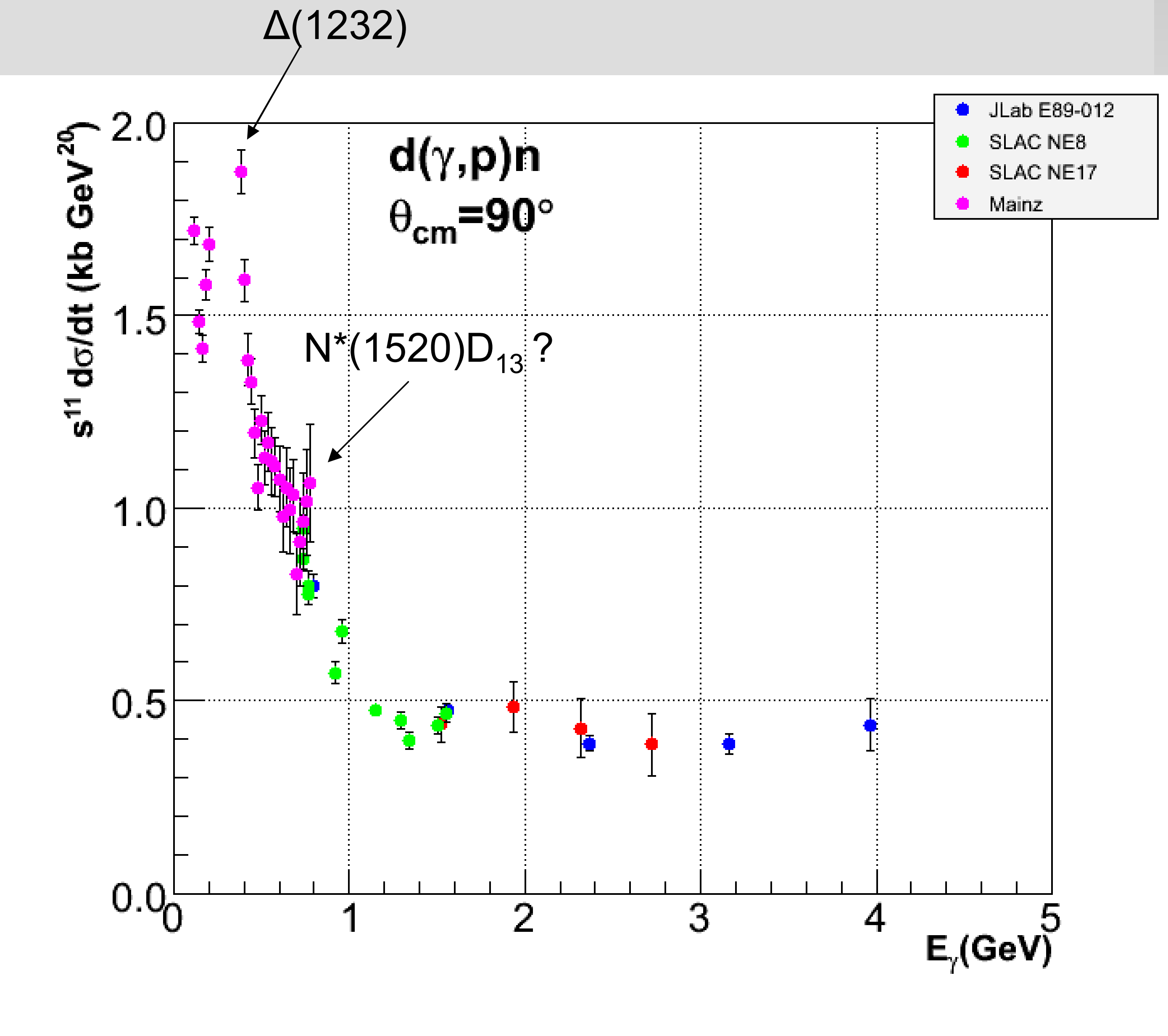
Figure 26. The variation of W^2 with the photon energy ν for various values of x, as given by equation (115). The shaded regions show the approximate thresholds for the production of bands of nucleon resonances, as discussed in the text and shown in table 7. The numbers in the small circles are the number of distinct channels in each band.

Table 6. The 24 well-established nucleon resonances listed in the *Particle Physics Booklet* [170] fall into the eight bands listed in table 7. Masses of *neighbouring* resonances in each band are less than 150 MeV apart. All of these resonances can contribute to deuteron photodisintegration for $W < 4.5$ GeV. All but N_4 and Δ_4 can contribute in all combinations, giving $13 + (13 \times 12)/2 = 91$ channels with two $I = 1/2$ particles, 45 channels with two $I = 3/2$ particles, and 117 channels with one $I = 1/2$ and one $I = 3/2$ particle. The number of additional channels contributed by N_4 and Δ_4 is shown in the table and totals 33. The total number of channels is 286.

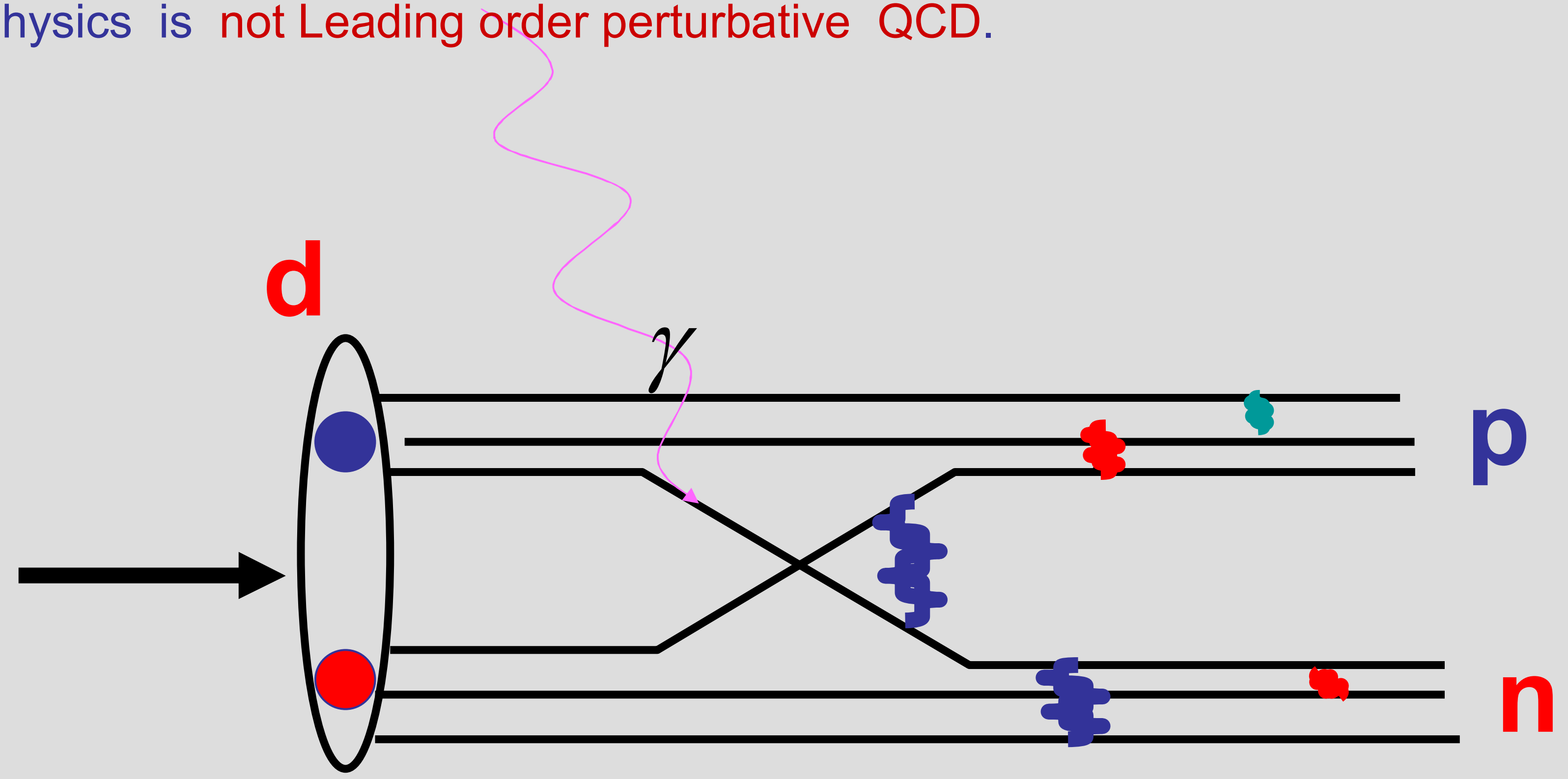
	$I = 1/2$		$I = 3/2$
N_1	$N(939)$	Δ_1	$P_{33}(1232)$
N_2	$P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$, $S_{11}(1650)$, $D_{15}(1675)$, $F_{15}(1680)$, $D_{13}(1700)$, $P_{11}(1710)$, $P_{13}(1720)$	Δ_2	$P_{33}(1600)$, $S_{31}(1620)$, $D_{33}(1700)$
N_3	$G_{17}(2190)$, $H_{19}(2220)$, $G_{19}(2250)$	Δ_3	$F_{35}(1905)$, $P_{31}(1910)$, $P_{33}(1920)$, $D_{35}(1930)$, $F_{37}(1950)$
N_4	$I_{1,11}(2600)$ 14 channels	Δ_4	$I_{3,11}(2420)$ 19 channels

Table 7. The thresholds for the production of pairs of baryon resonances also fall into eight bands. *Neighbouring* thresholds within each band are less than 150 MeV apart. These bands are shown in figure 26.

Band	Mass range	Members	Number of channels
$B_1 = NN$	1878	N_1N_1	1
$B_2 = N\Delta$	2171	$N_1\Delta_1$	1
B_3	2464–2579	$\Delta_1\Delta_1$, N_2N_2, $N_1\Delta_2$	13
B_4	2858–2872	$N_2\Delta_1$, $N_1\Delta_3$, $\Delta_1\Delta_2$	17
B_5	3155–3280	$\Delta_1\Delta_3$, N_2N_2, $N_2\Delta_2$, $\Delta_2\Delta_2$	86
B_6	3452–3652	$N_3\Delta_1$, $N_1\Delta_4$, N_1N_4, $N_2\Delta_3$, $\Delta_2\Delta_3$, $\Delta_1\Delta_4$	66
B_7	3832–3860	$N_4\Delta_1$, $\Delta_3\Delta_3$, N_2N_3, $N_3\Delta_2$,	52
B_8	4046–4440	$N_2\Delta_4$, $\Delta_2\Delta_4$, $N_3\Delta_3$, N_2N_4, Δ_2N_4, $\Delta_3\Delta_4$, N_3N_3	50


Δ(1232)
d(γ,p)n
θcm=90°
N*(1520)D13 ?
JLab E89-012
SLAC NE8
SLAC NE17
Mainz
s11 dσ/dt (kb GeV20)
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
Eγ(GeV)

The observation of the scaling indicates the onset of the quark – gluon degrees of freedom, the appropriate underlying physics is not Leading order perturbative QCD.



Millions of diagrams like this

Theoretical models:

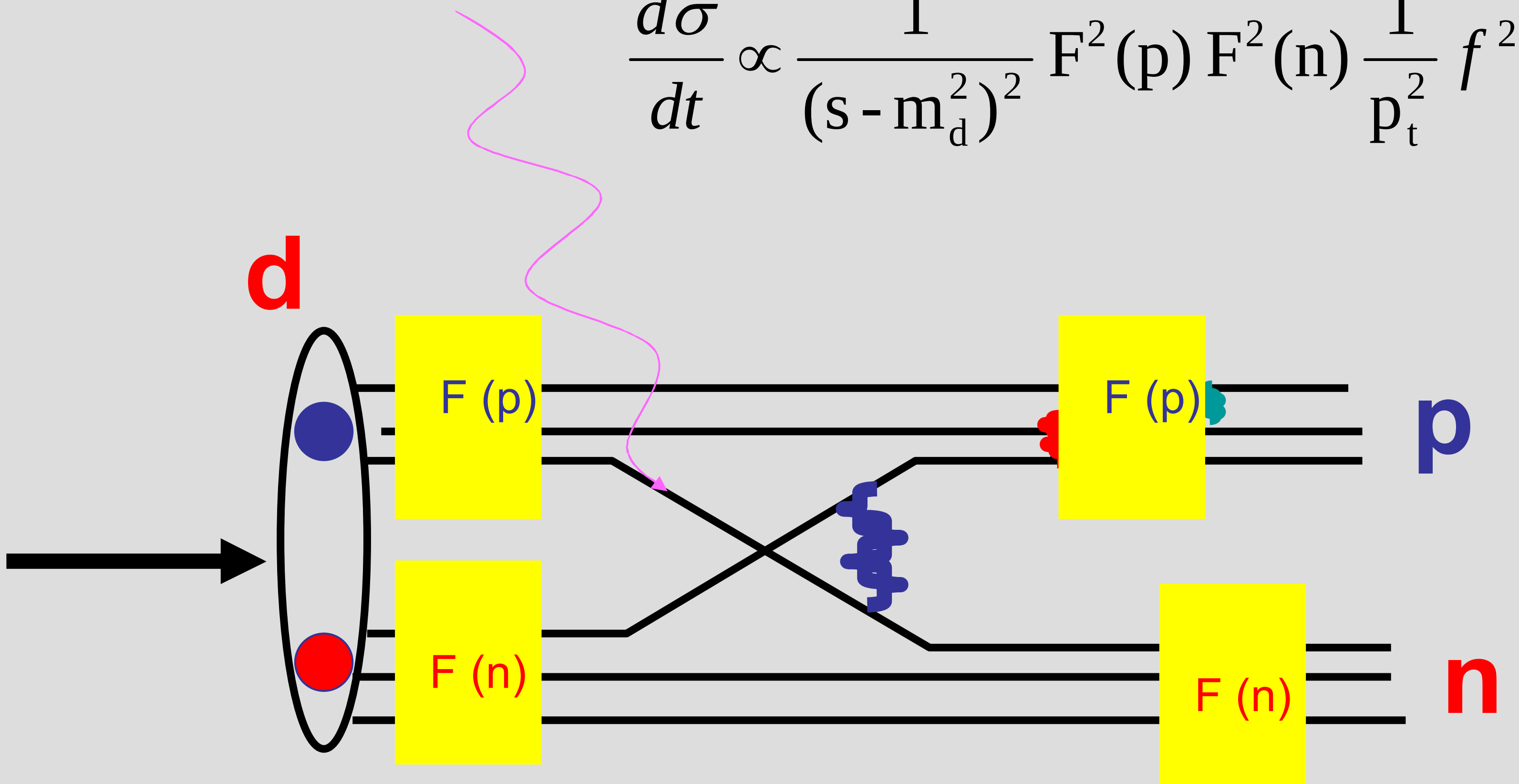
- How the photon is coupled
- How to use experimental data to replace sum over many diagrams
- What diagrams can be neglected

RNA (Reduced Nuclear Amplitude)

Brodsky , Hiller PRC 28, 475 (1983)

- ★ Experimental nucleon FF → gluon exchanges within the nucleons
- ★ Neglect diagrams with gluon exchanges between the nucleons
- ★ Photon can interacts with any quarks

$$\frac{d\sigma}{dt} \propto \frac{1}{(s - m_d^2)^2} F^2(p)\, F^2(n) \frac{1}{p_t^2} f^2(\theta_{cm})$$

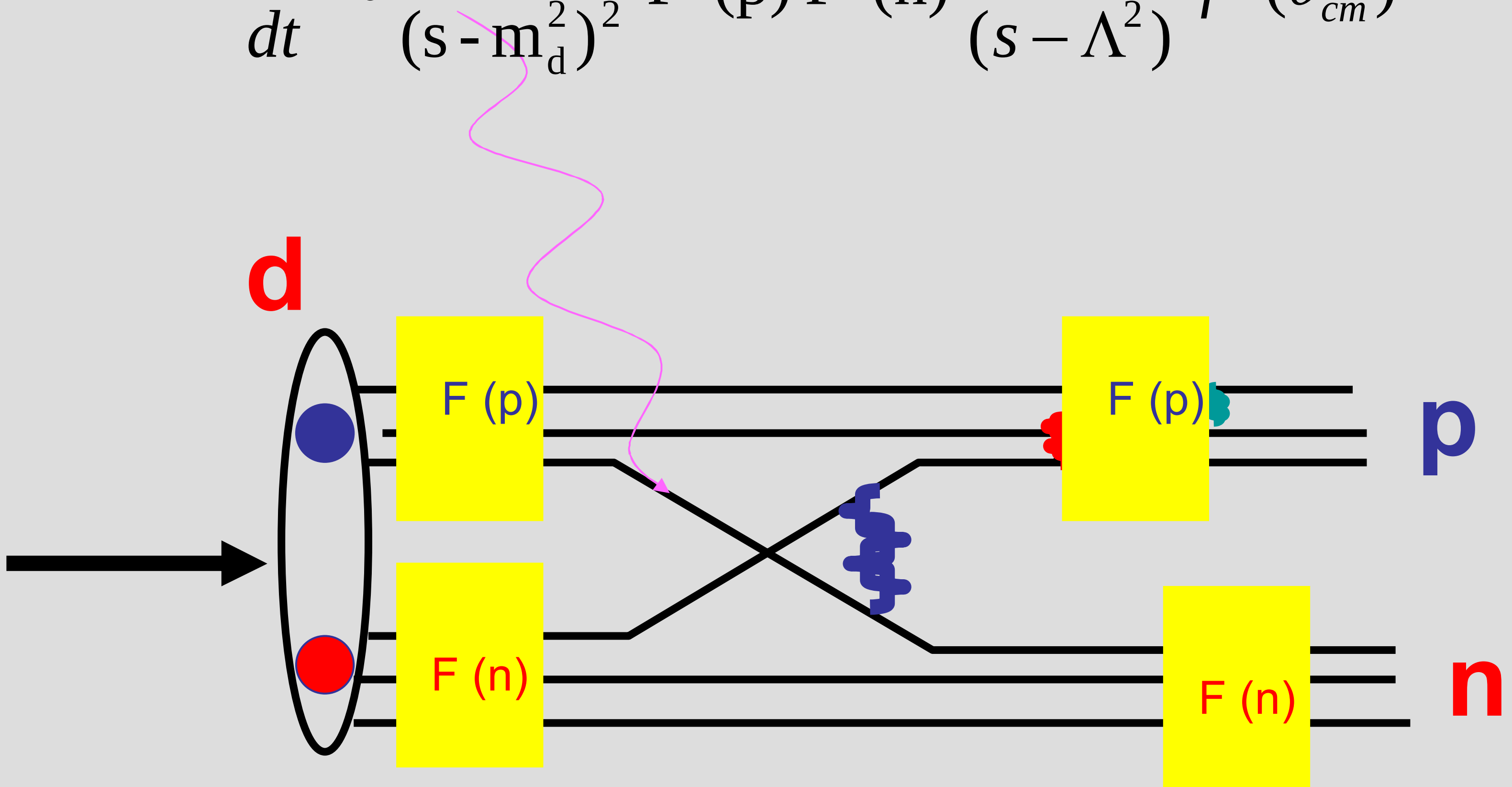


TQC (Two - Quark Coupling)

Radyushkin

- gluon exchanges within the nucleons → Experimental nucleon FF
- gluon exchanges between the nucleons → neglected
- Photon interacts with the exchange pair of quarks

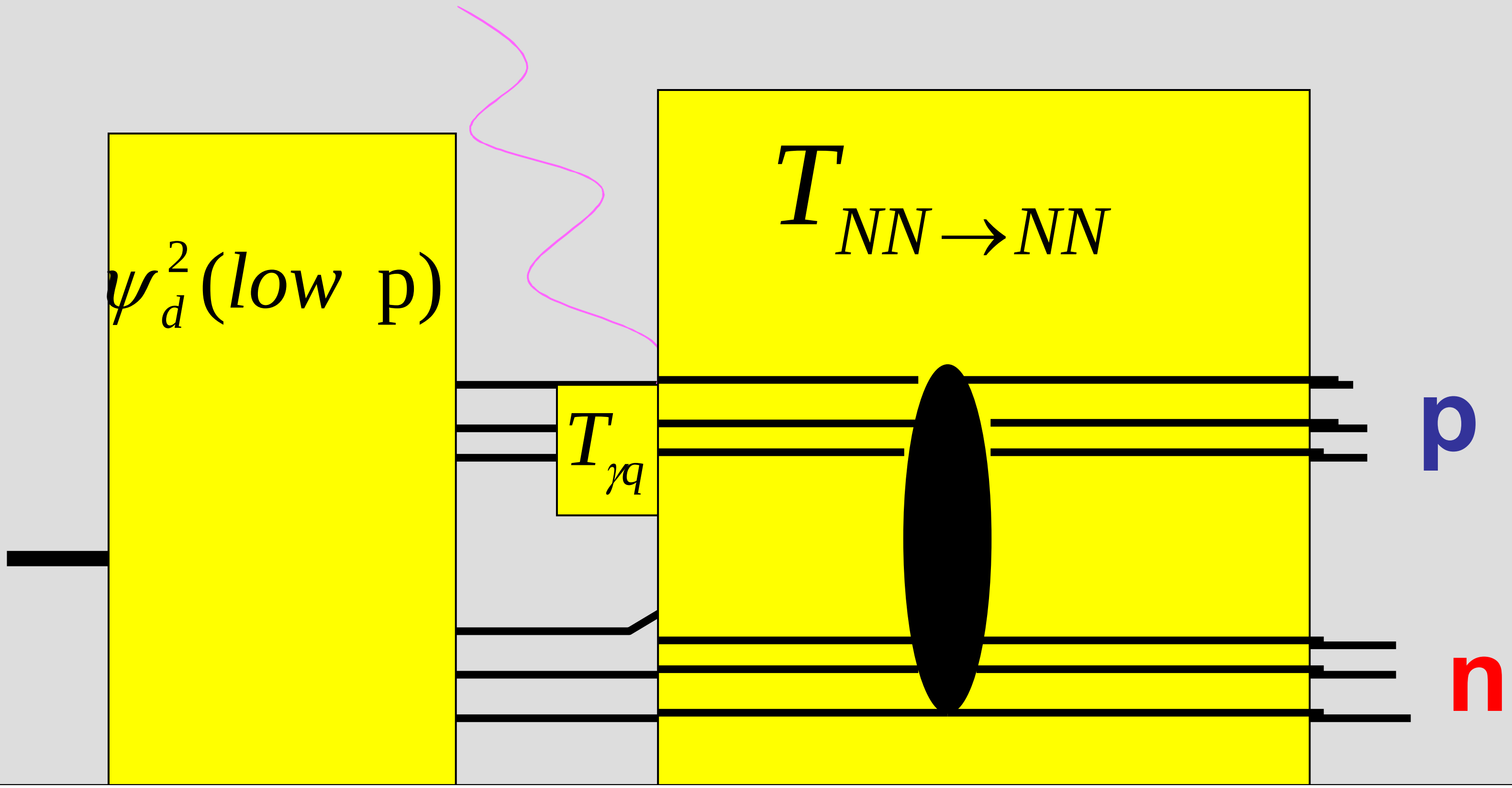
$$\frac{d\sigma}{dt} \propto \frac{1}{(\mathrm{s} - \mathrm{m}_{\mathrm{d}}^2)^2} \mathrm{F}^2(\mathrm{p})\, \mathrm{F}^2(\mathrm{n}) \frac{1}{(s - \Lambda^2)} f^2(\theta_{cm})$$



HRM (Hard rescattering Model)

Frankfurt, Miller, Sargsian, Strikman PRL 84, 3045 (2000).

- Convolution of large angle pn scattering amplitude , hard photon – quark interaction vertex, and low momentum nuclear wave function
- The pn scattering amplitude is obtained from large angle pn data

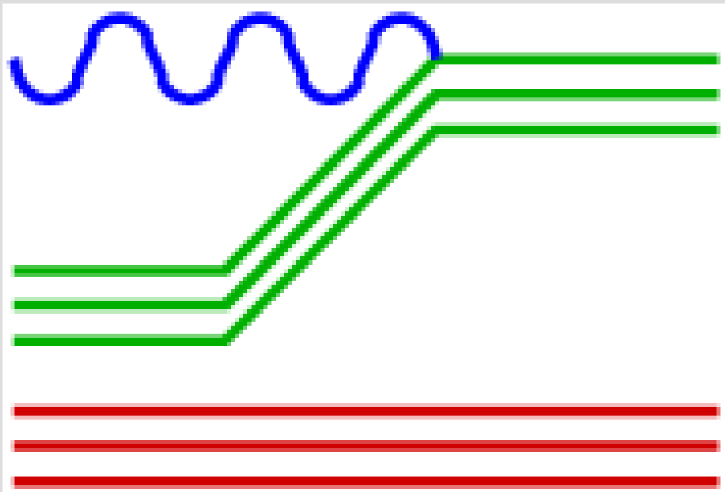


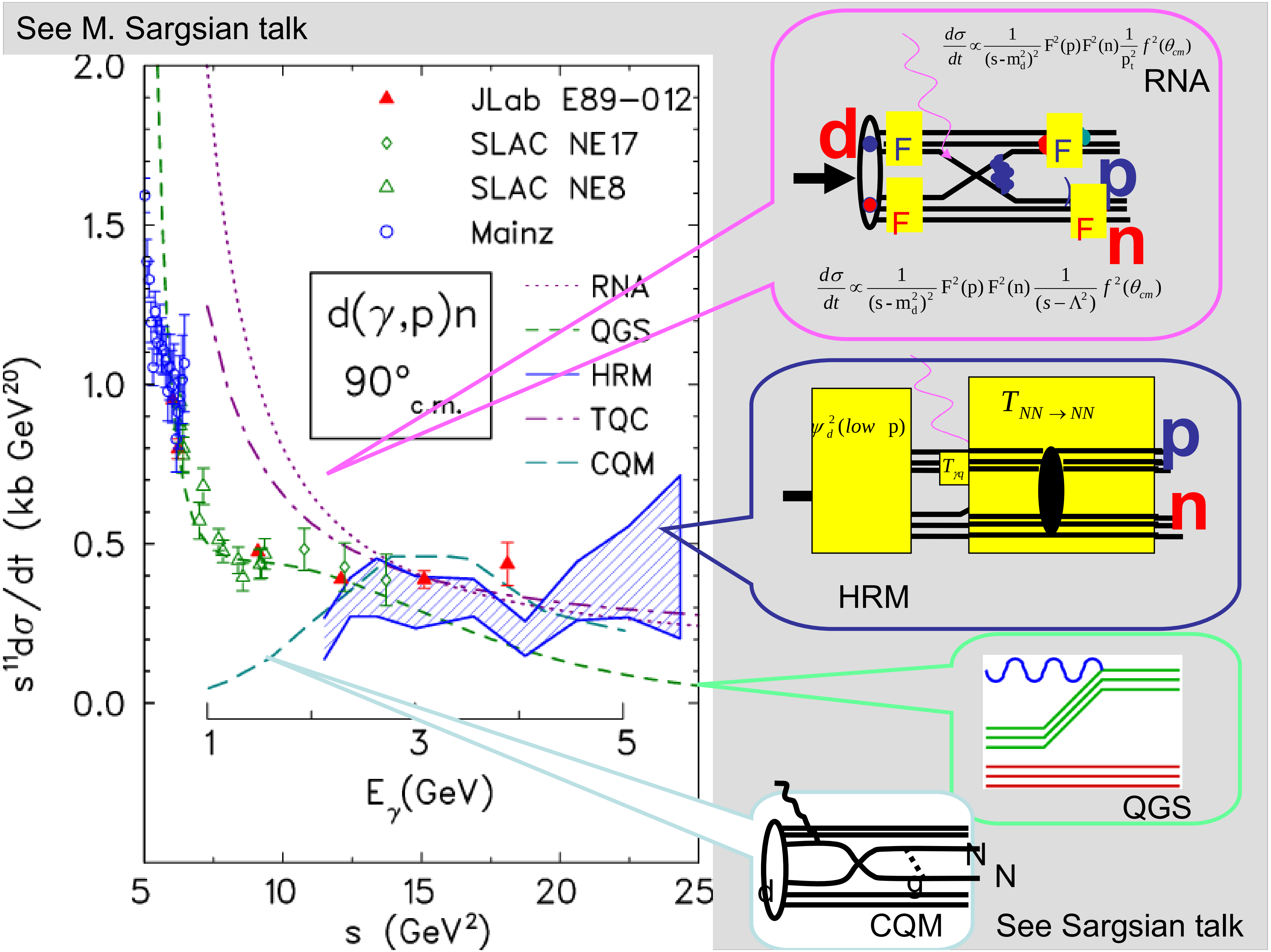
Quark – Gluon String model (QGS)

Grishina et al. EUR. J. Phys. A 10, 355 (2000)

3 q exchange with an arbitrary number of gluon exchanges

Regge theory - nonlinear trajectory





See M. Sargsian talk
d(γ,p)n
90° c.m.
JLab E89−012
SLAC NE17
SLAC NE8
Mainz
RNA
QGS
HRM
TQC
CQM
$s^{11} d\sigma/dt$ (kb GeV^{20})
s (GeV^2)
E_γ(GeV)
$\frac{d\sigma}{dt} \propto \frac{1}{(s-m_d^2)^2} F^2(p) F^2(n) \frac{1}{p_t^2} f^2(\theta_{cm})$
$\frac{d\sigma}{dt} \propto \frac{1}{(s-m_d^2)^2} F^2(p) F^2(n) \frac{1}{(s-\Lambda^2)} f^2(\theta_{cm})$
$\psi_d^2(low\ \ p)$
$T_{NN \to NN}$
$T_{\gamma q}$
See Sargsian talk

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But comparing calculations with the data do not reveal the underlying physics.

How are such large transverse - momentum nucleons produced ?

Breaking a transverse compact object formed before the absorption ?

RNA

$$\psi_d\,(\,p \approx 2\ \mathrm{GeV/c}\,)$$

Double hard scattering ?

HRM

$$\psi_d\,(\,P \leq 300\ \mathrm{MeV/c}\,)$$

Hard Photodisintegration of a proton pair

$$\gamma\ {}^{3}\mathrm{He} \rightarrow \mathrm{p}\,(\mathrm{high}\ \mathrm{p}_t) + \mathrm{p}\,(\mathrm{high}\ \mathrm{p}_t) + \mathrm{n}(\mathrm{slow})$$

What new can we learn from that?

How are such large transverse momentum nucleons produced ?

Transitions from meson exchange to quark exchange

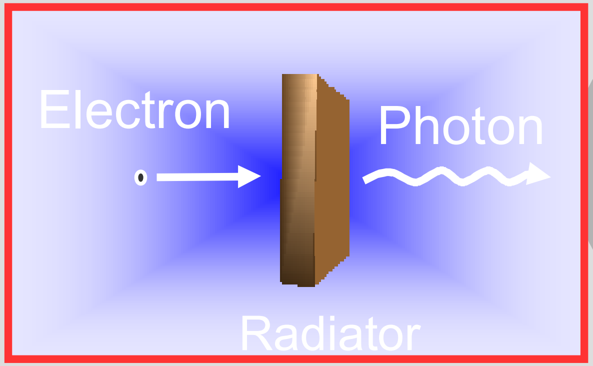
Scaling

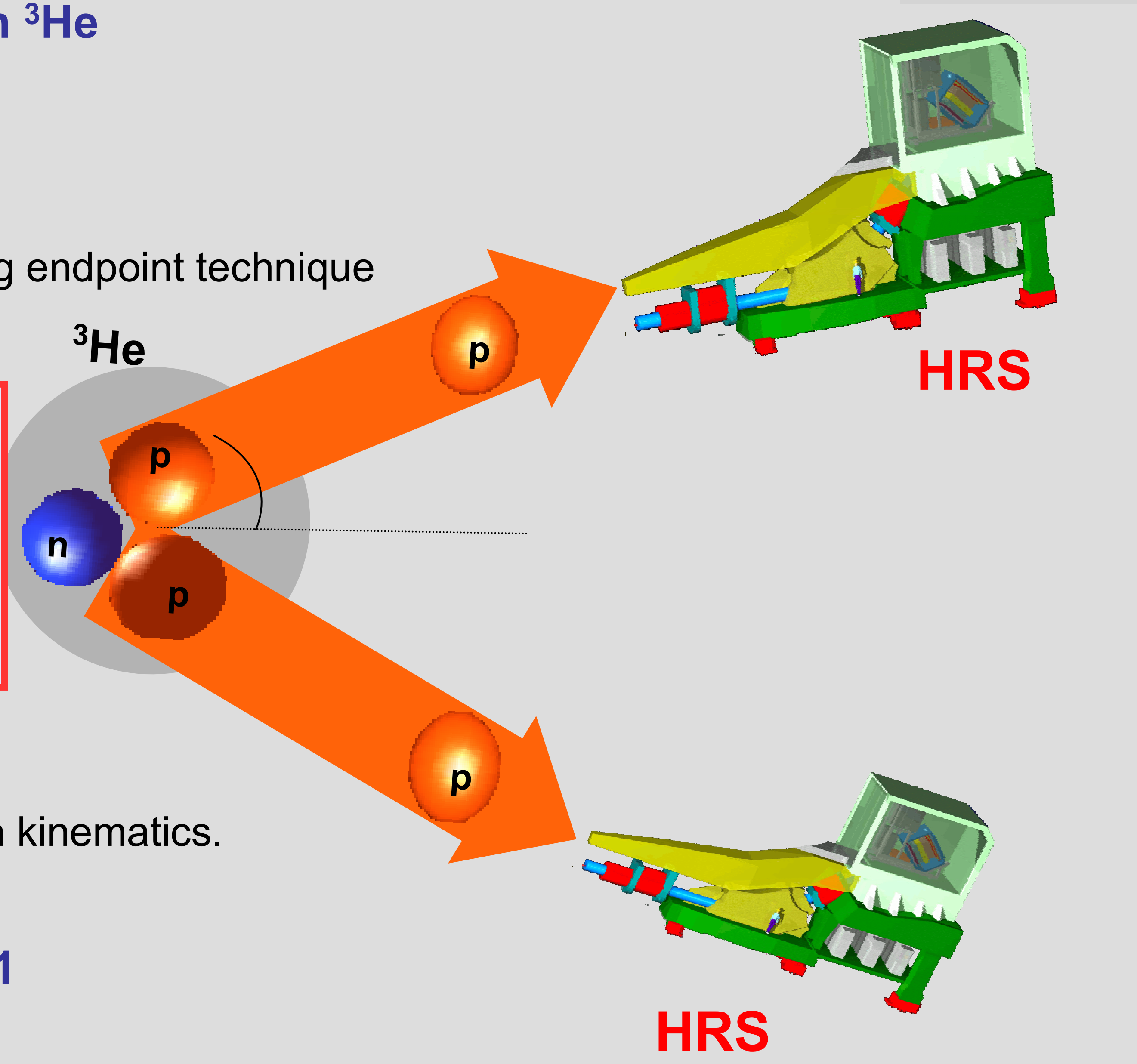
Oscillations

High – energy photodisintegration of a proton pair in ^{3}He

$$^3H_e(\gamma, pp)n$$

The bremsstrahlumg endpoint technique





$$\theta_{c.m} = 90^0$$

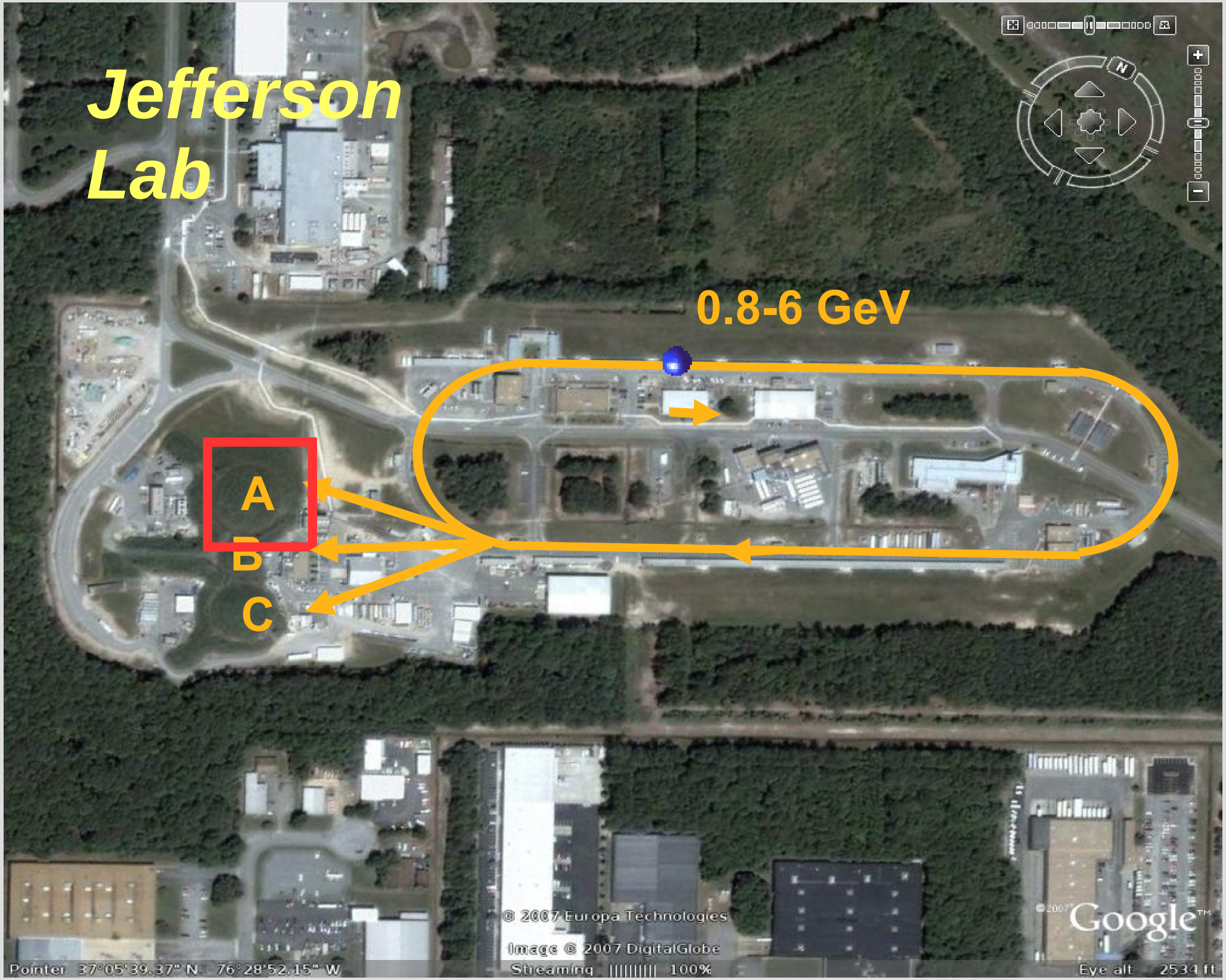
a spectator neutron kinematics.

Experiment E03-101

JLab. June 2007

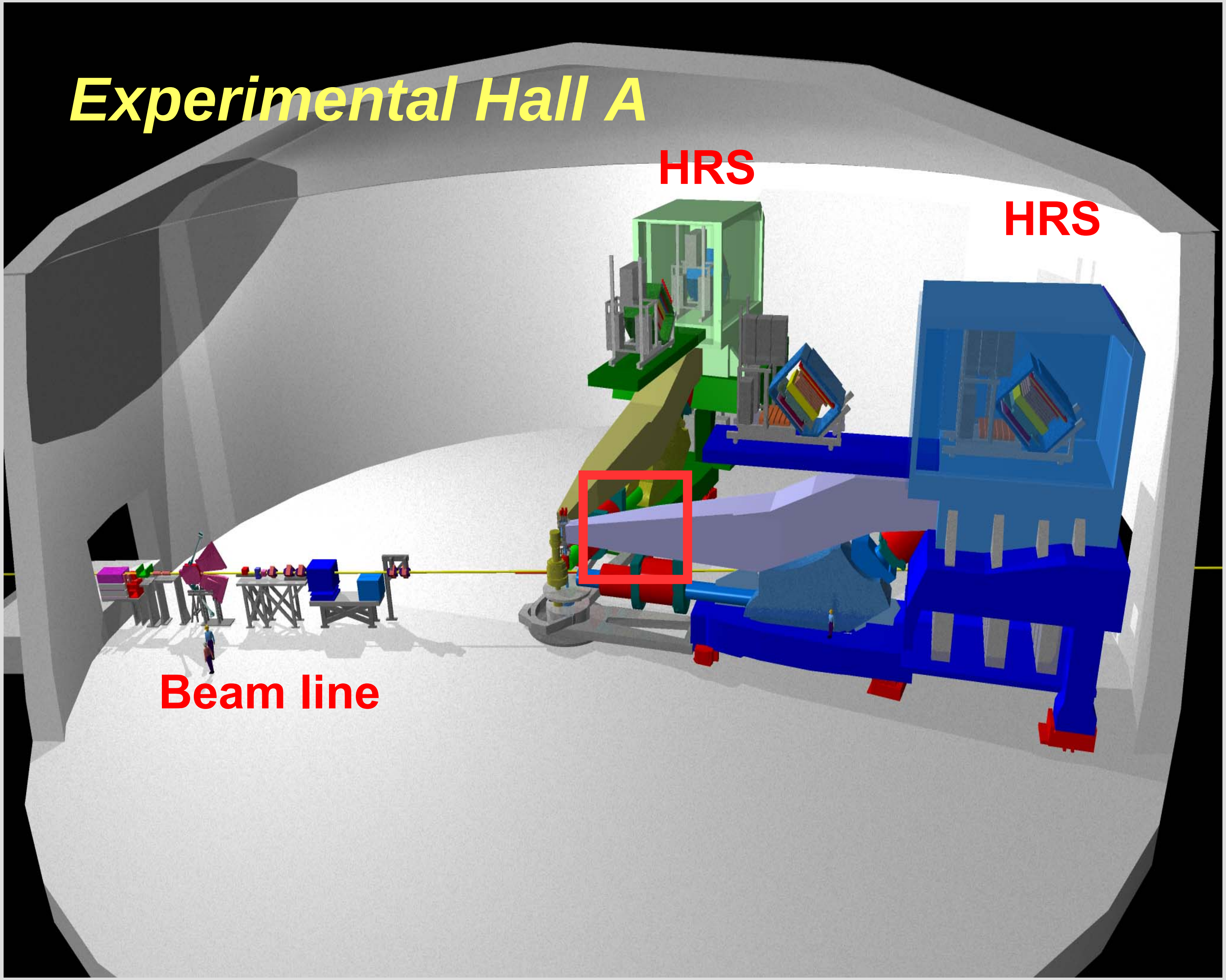
Experimental setup

Experiment E03-101



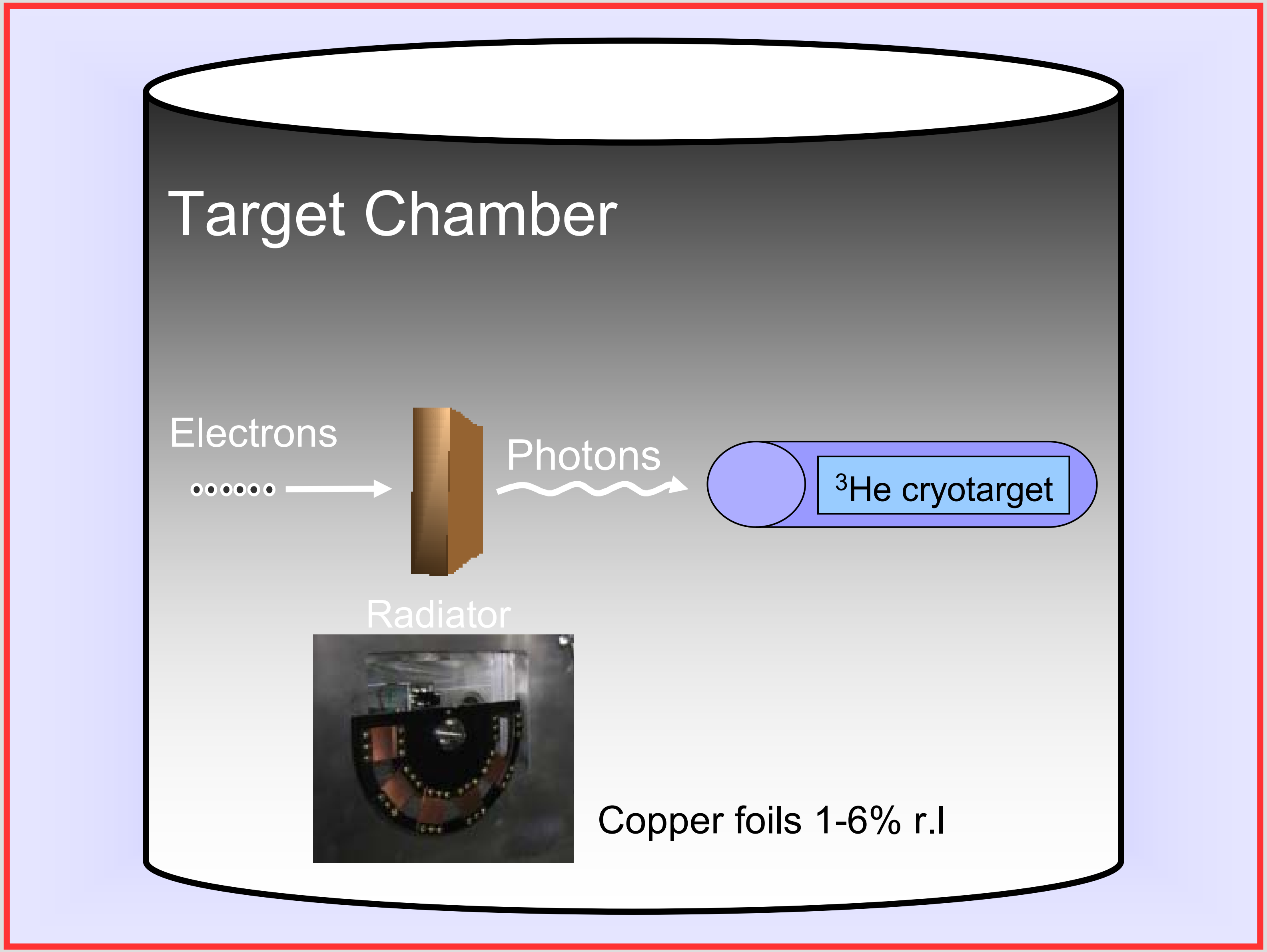
Experimental setup

Experiment E03-101

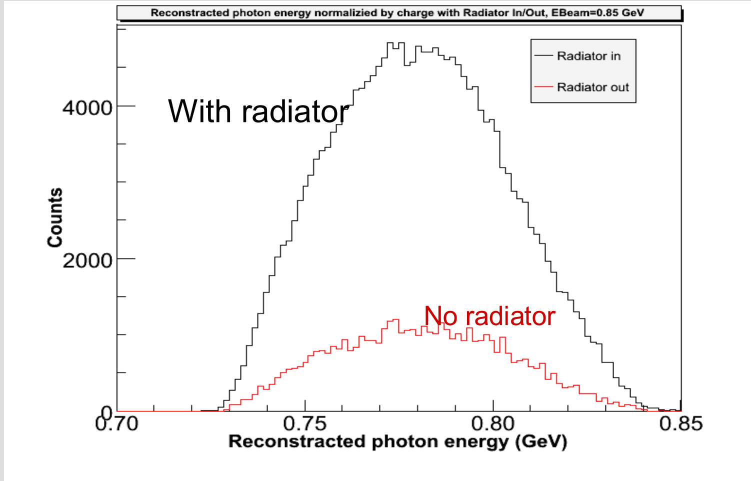


Experimental setup

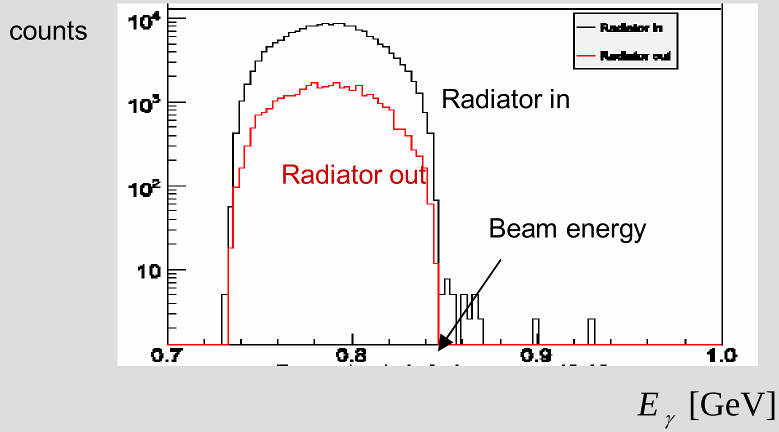
Experiment E03-101

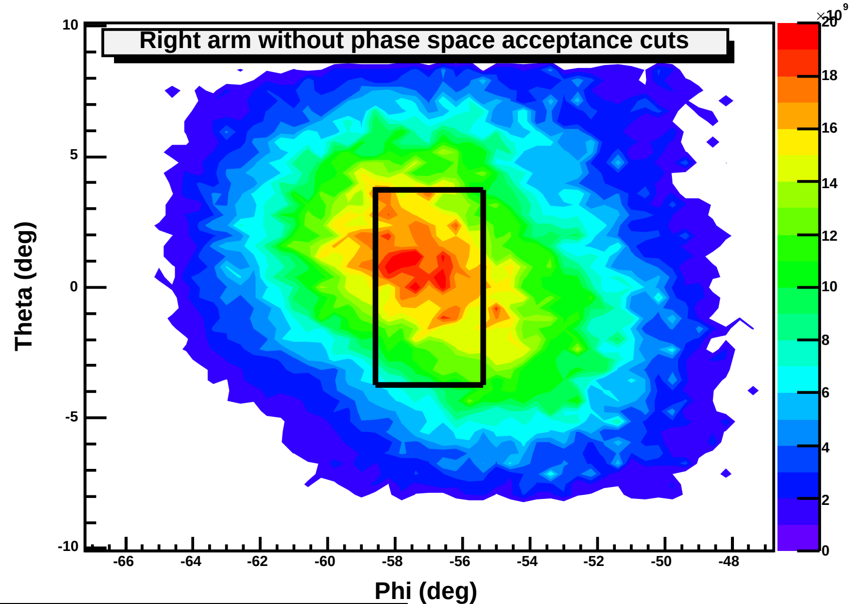


Backgrounds are subtracted by “radiator out” and empty target runs

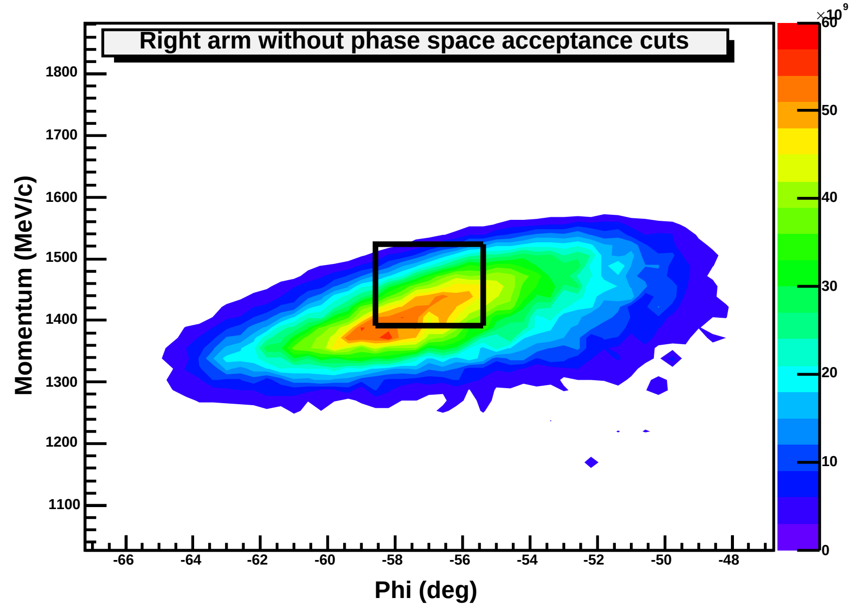


Build in quality-control – empty region beyond the endpoint





Coincidence efficiency: 8.5 %



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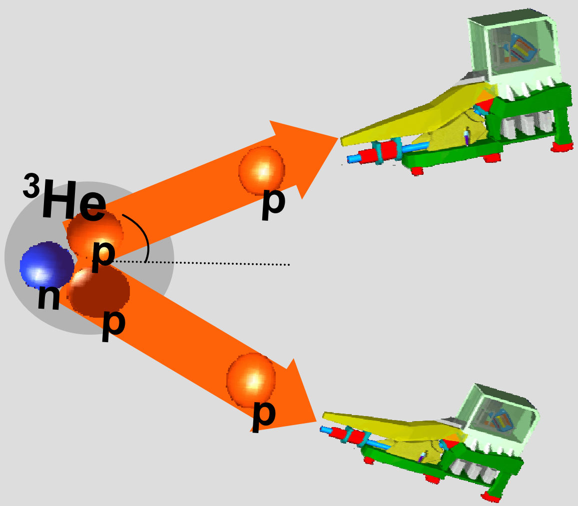
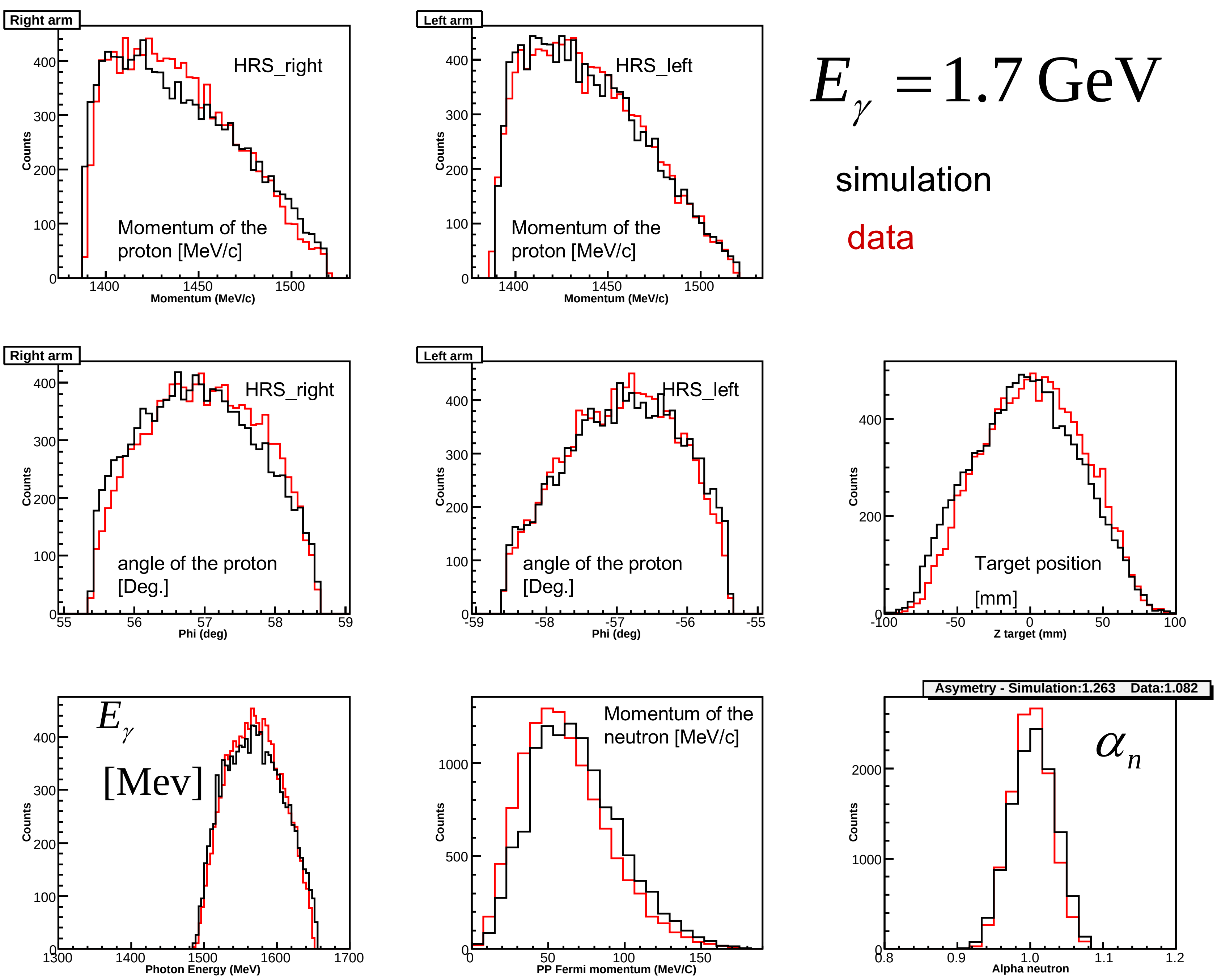
Correcting for the finite acceptance of the second spectrometer

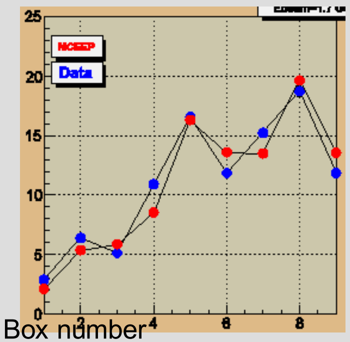


Simulation assumes photon energy distribution based on Matthews and Owens NIM 111, 157-168 (73).

Neutron momentum distribution based on ^{3}He Wave function of R. Schiavilla, et al., PRL. 98, 132501 (2007), and references therein.



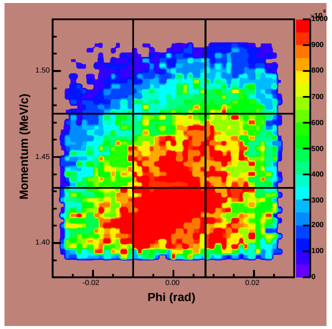
$E_\gamma = 1.7\ \mathrm{GeV}$
simulation
data
Right arm
HRS_right
Momentum of the proton [MeV/c]
Momentum (MeV/c)
Counts
Left arm
HRS_left
Momentum of the proton [MeV/c]
Momentum (MeV/c)
Counts
Right arm
HRS_right
angle of the proton [Deg.]
Phi (deg)
Counts
Left arm
HRS_left
angle of the proton [Deg.]
Phi (deg)
Counts
Target position [mm]
Z target (mm)
Counts
E_γ [Mev]
Photon Energy (MeV)
Counts
Momentum of the neutron [MeV/c]
PP Fermi momentum (MeV/C)
Counts
Asymetry - Simulation:1.263 Data:1.082
α_n
Alpha neutron
Counts



We (temporarily) assigned an extrapolation error of 15% to the data

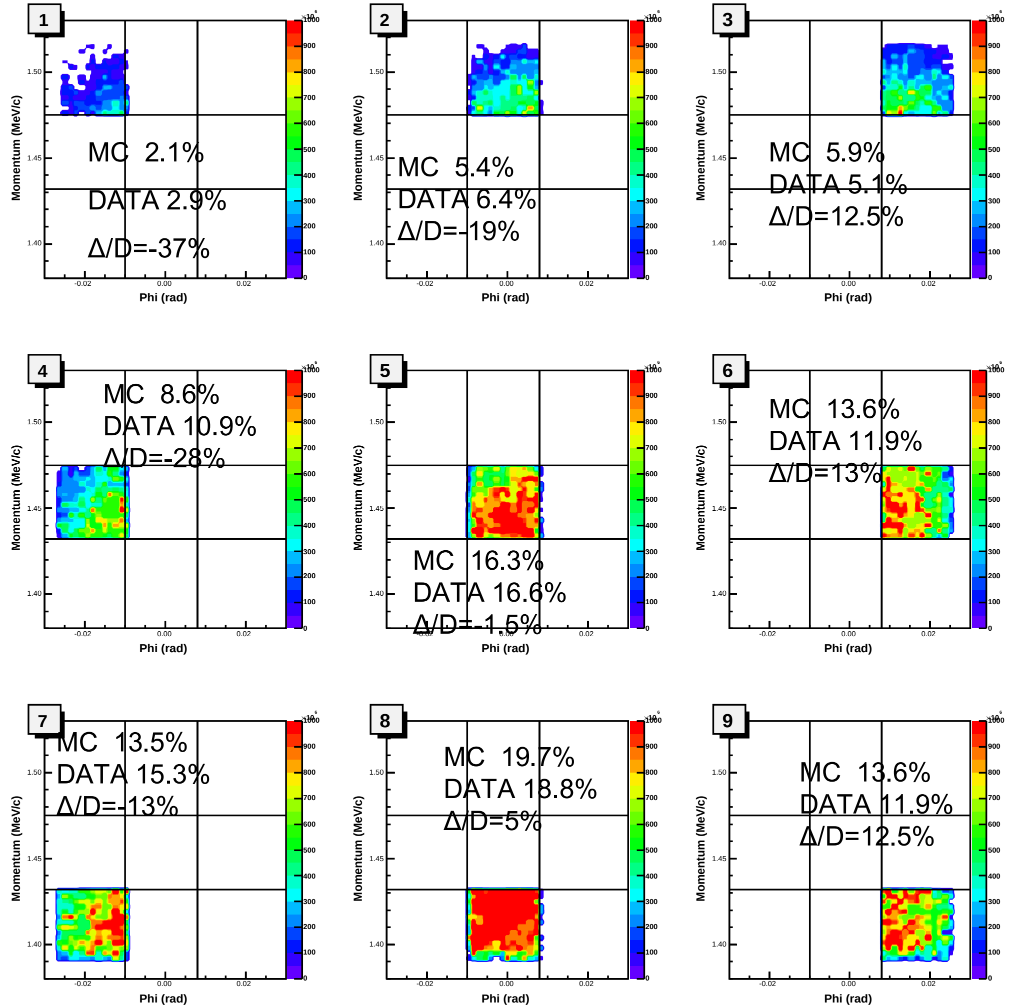
Simulation

$$E_{\gamma} = 1.7 GeV$$



MC 100%

DATA 100%



Expected Results

Magnitude of pp vs. pn hard photodisintegration

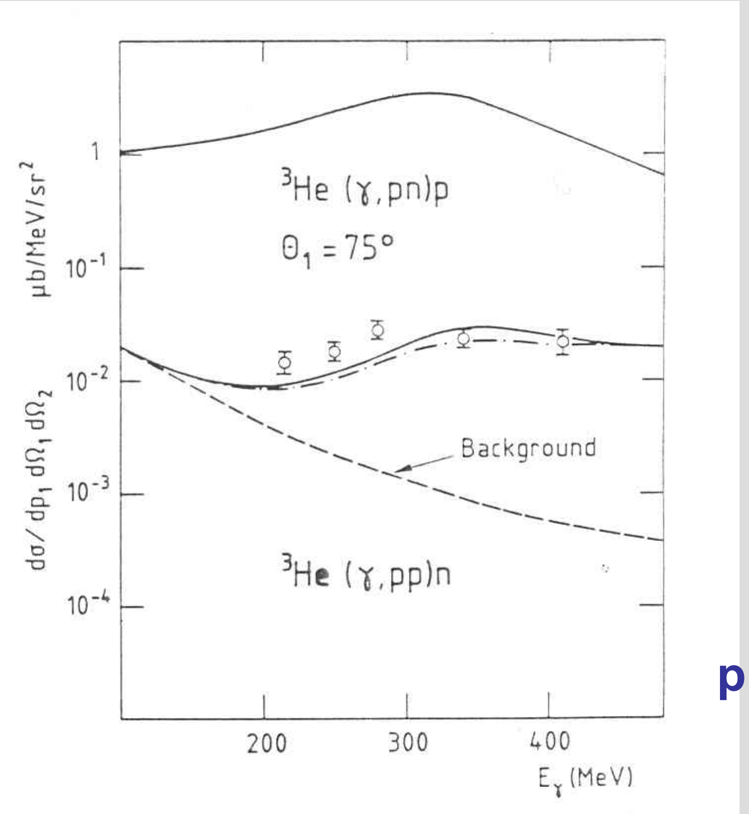
At low photon energy

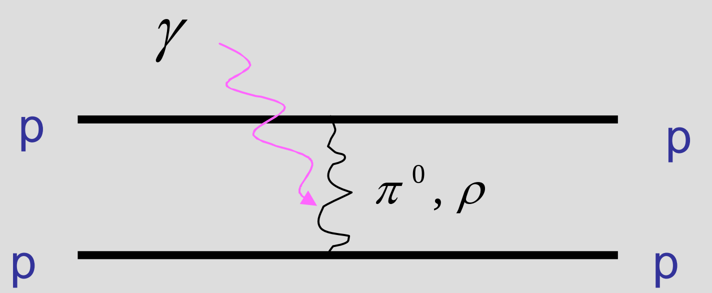
For $E_\gamma \leq 0.5\,\mathrm{GeV/c}$

$$\sigma(\gamma\ ^3He \rightarrow \mathrm{pp}) / \sigma(\gamma\ ^3He \rightarrow \mathrm{pn}) \approx 1\%$$

$$\sigma_{\gamma pp} << \sigma_{\gamma pn}$$

$$\sigma_{\gamma pp} \approx 0$$





MEC is the dominant process

pp pair : only a neutral pion can be exchanged , its coupling to the photon is weak.

Laget NP A497 (89) 391, (Saclay data).

Expected Results

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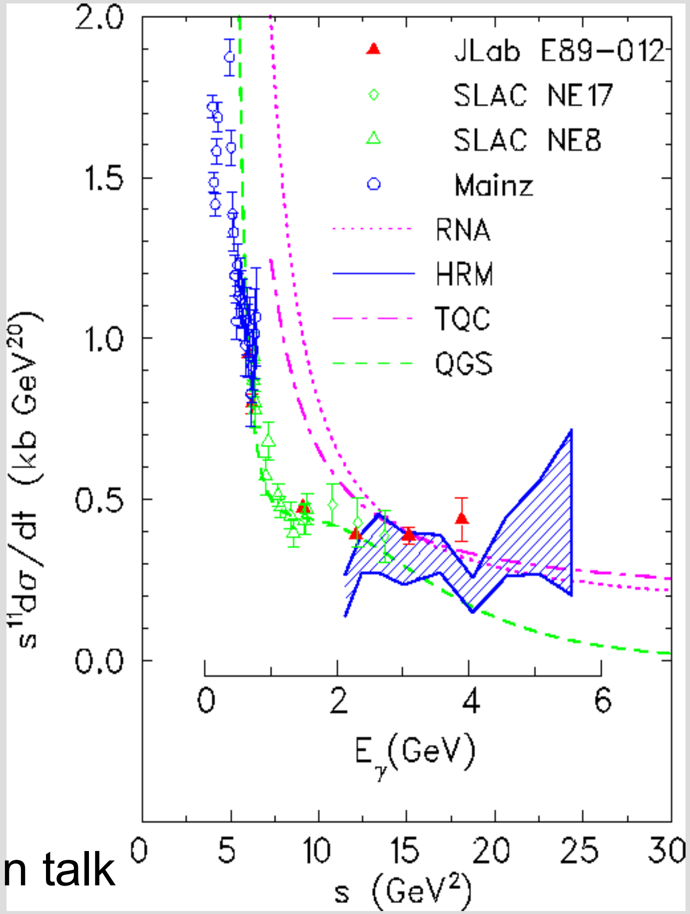
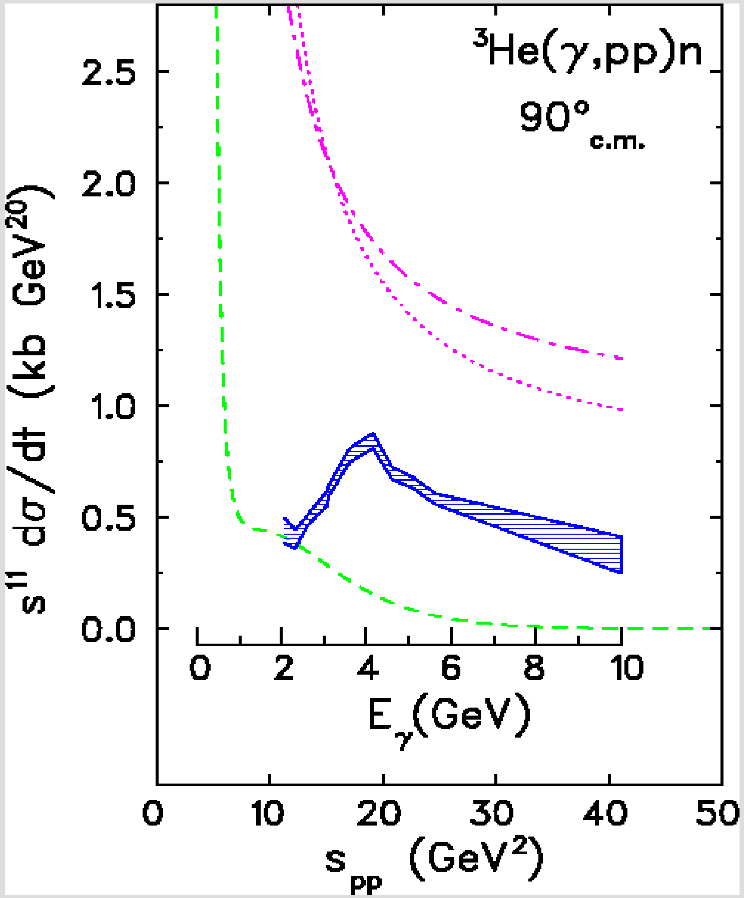
Hard photodisintegration of a proton pair in ^{3}He

S.J. Brodsky [a,b], L. Frankfurt [c], R. Gilman [b,d], J.R. Hiller [e], G.A. Miller [f], E. Piasetzky [c], M. Sargsian [g], M. Strikman [h]

Physics Letters B 578 (2004) 69–77





See
M. Sargsian talk

Normalized to deuteron

Absolute for ^{3}He

Expected Results

What are the relevant degrees of freedom ?

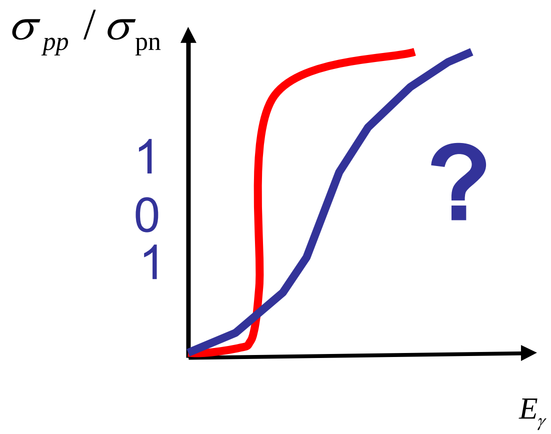
In contrast to low energy observations, nonperturbative models predict a large cross section for the pp break up.

This is an indication for quark – gluon dynamics

The exchange particles in the diproton photodisintegration reaction are:

Neutral at low energies where meson exchange dominates.

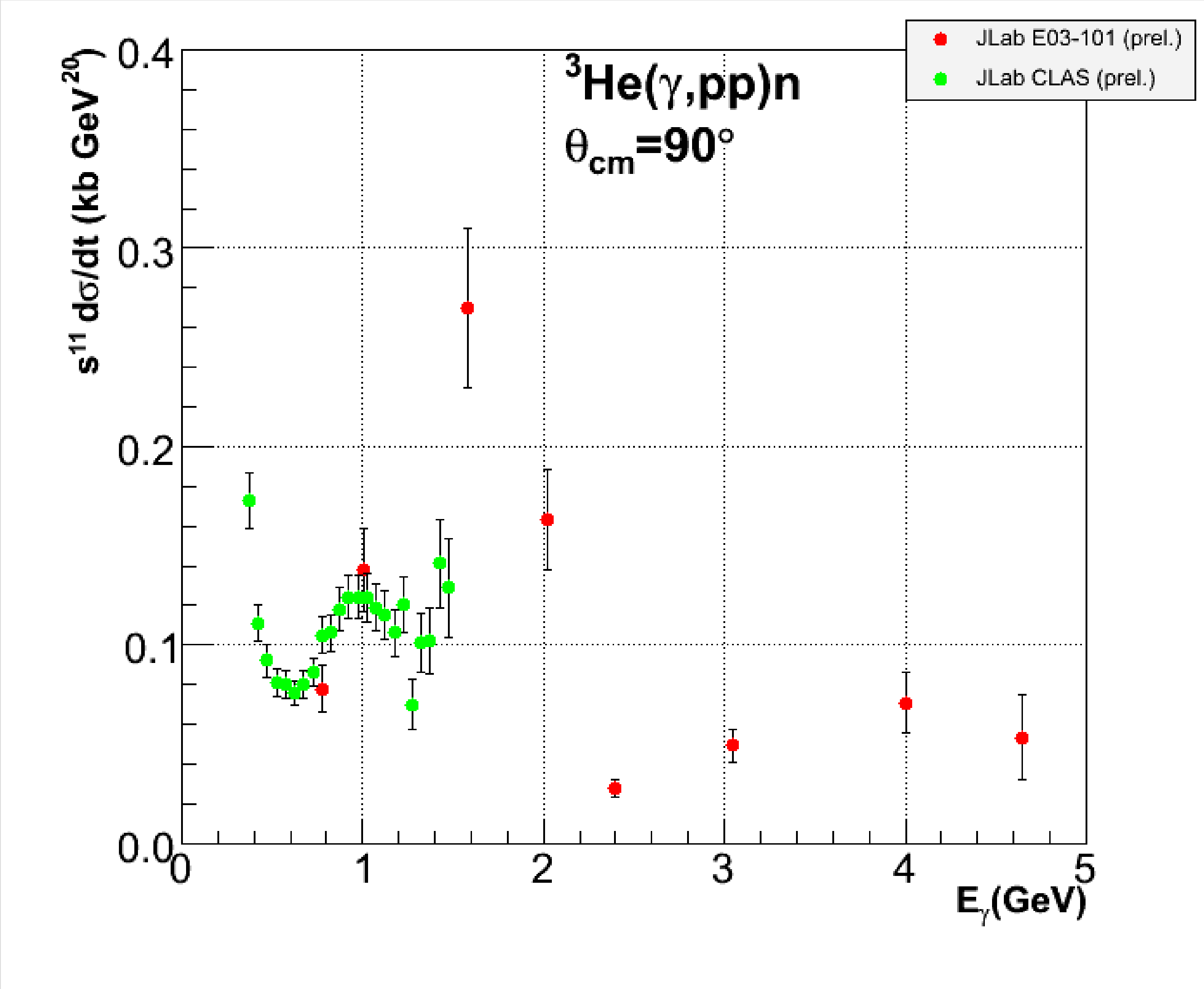
Charged at high energy where quark exchanges dominate.



The energy dependence of the pp/pn break up can map the transition

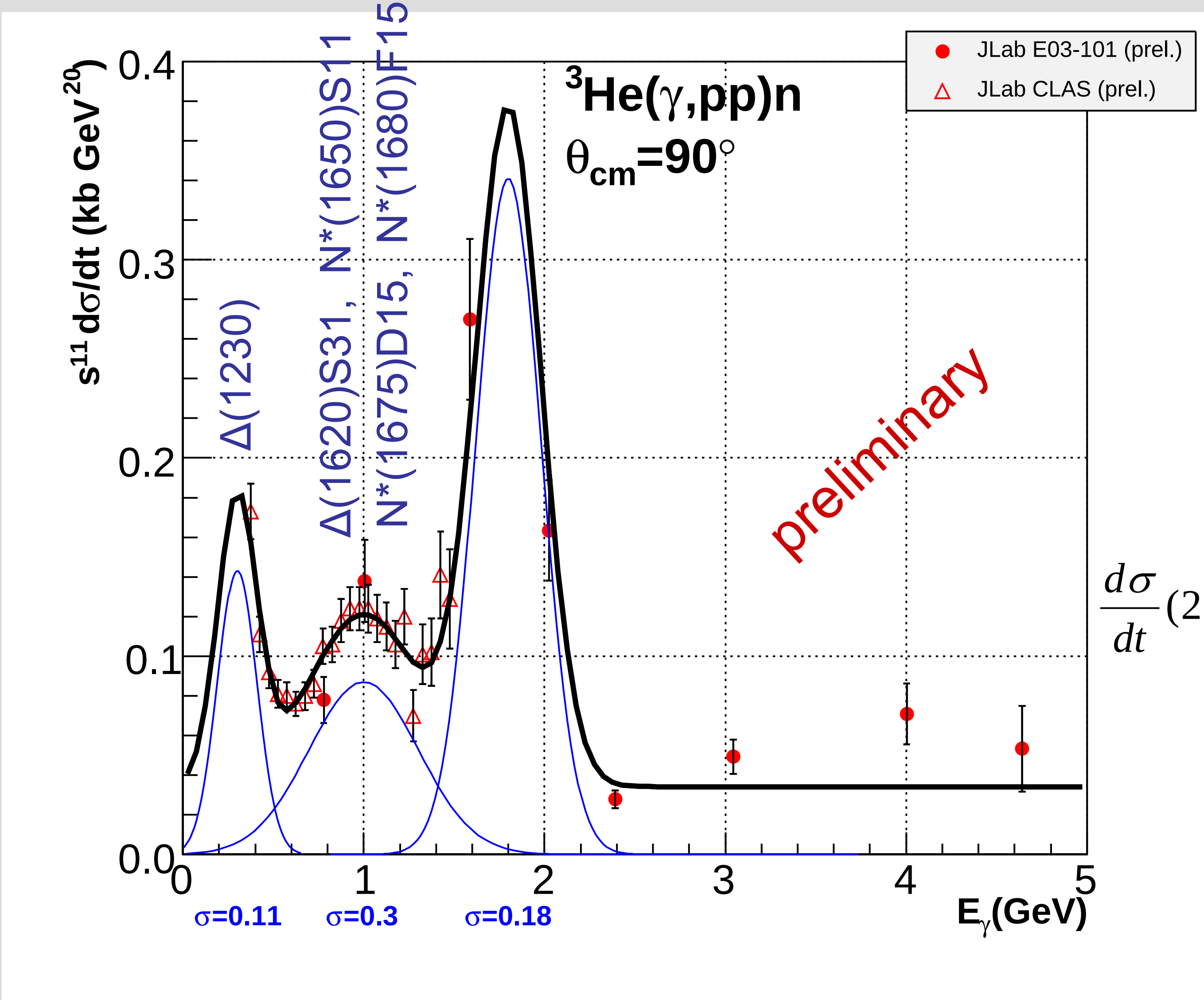
from hadronic to quark – gluon domain

Preliminary Results



The new data were normalized to the preliminary CLAS data !

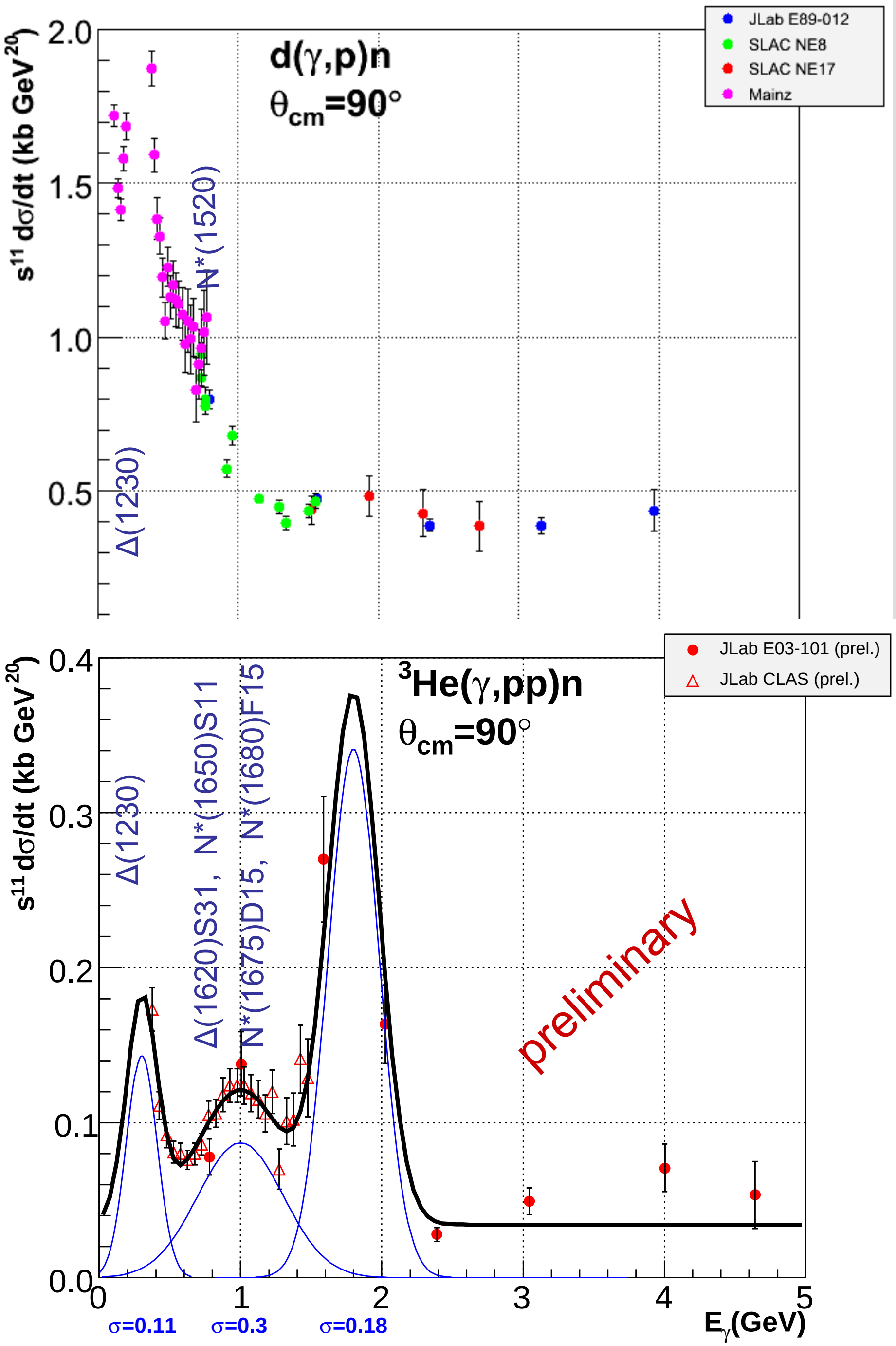
Preliminary Results



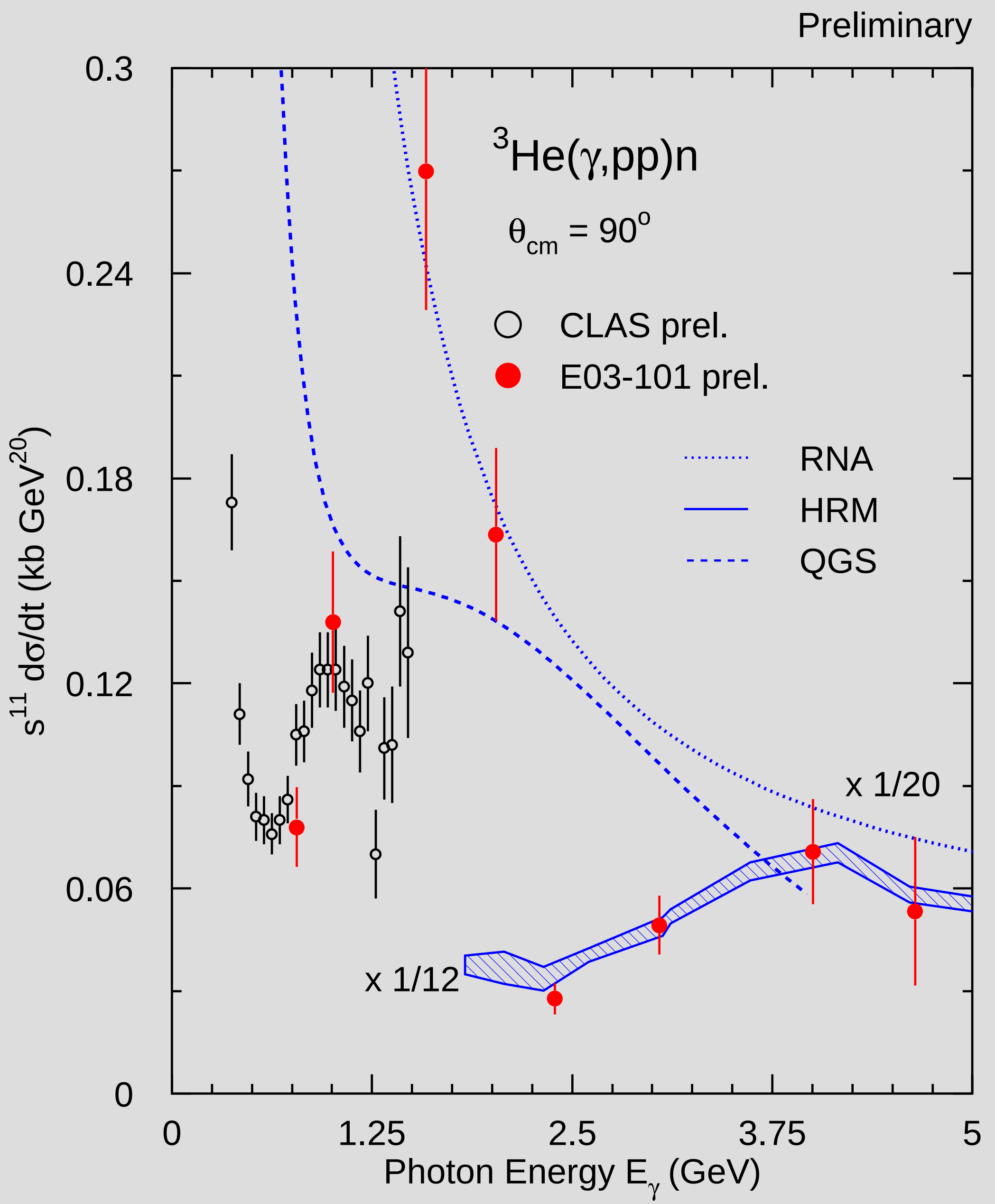
$$\frac{d\sigma}{dt}(2.5)/\frac{d\sigma}{dt}(4.5) \approx 200$$

The new data were normalized to the preliminary CLAS data !

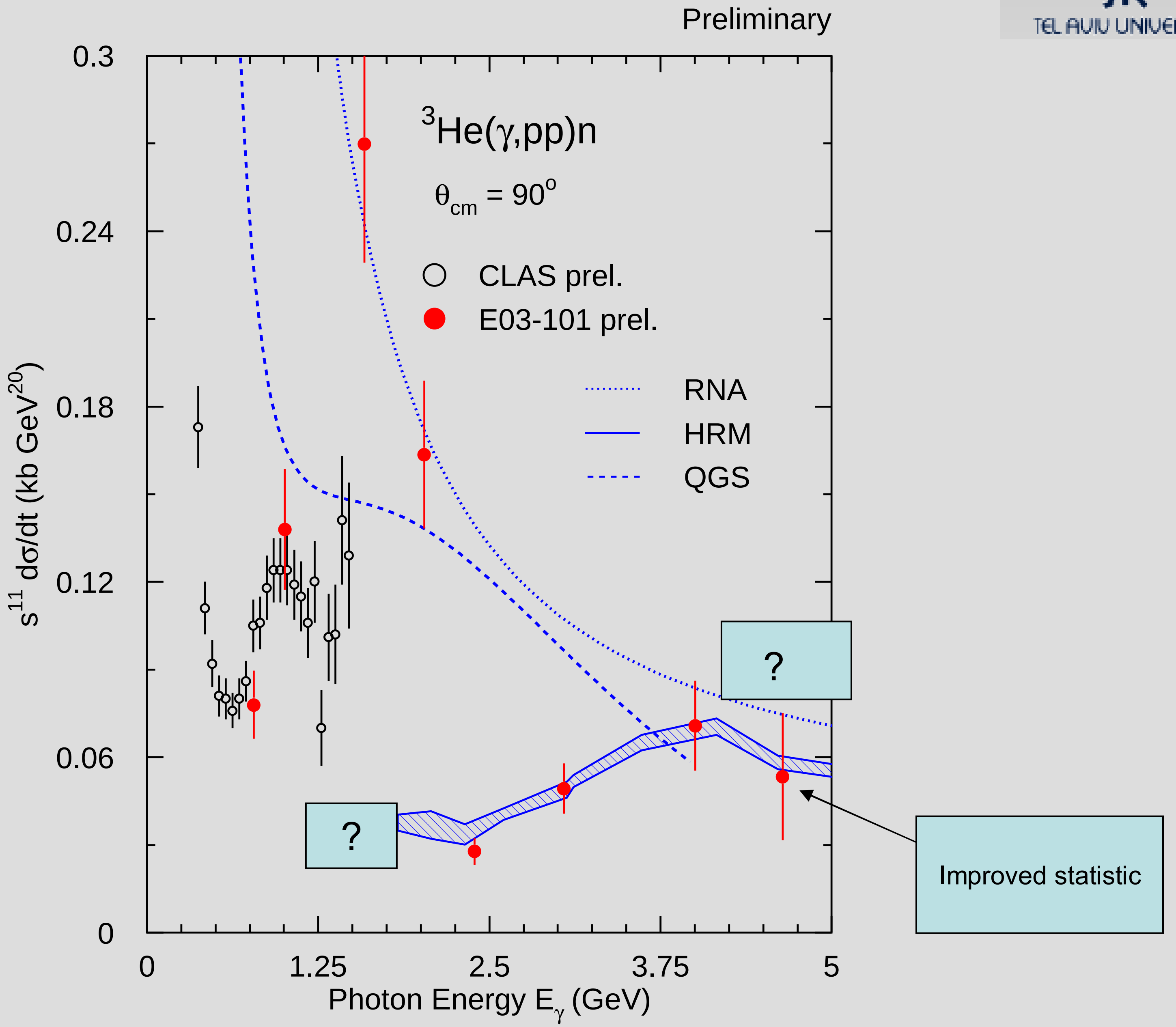
Preliminary Results



Preliminary Results



Outlook



Preliminary
0.3
0.24
0.18
0.12
0.06
0
0
1.25
2.5
3.75
5
Photon Energy E$_\gamma$ (GeV)
s^{11} dσ/dt (kb GeV^{20})
^{3}He(γ,pp)n
θ$_{cm}$ = 90^o
CLAS prel.
E03-101 prel.
RNA
HRM
QGS
?
?
Improved statistic

Outlook

We can utilize the recoil neutron to study how such large transverse- momentum nucleons are produced.

$\alpha = (E - P_Z) / m$

$$\alpha_\gamma + \alpha_{^3He} = 0 + 3 = \alpha_{p_1} + \alpha_{p_2} + \alpha_n$$

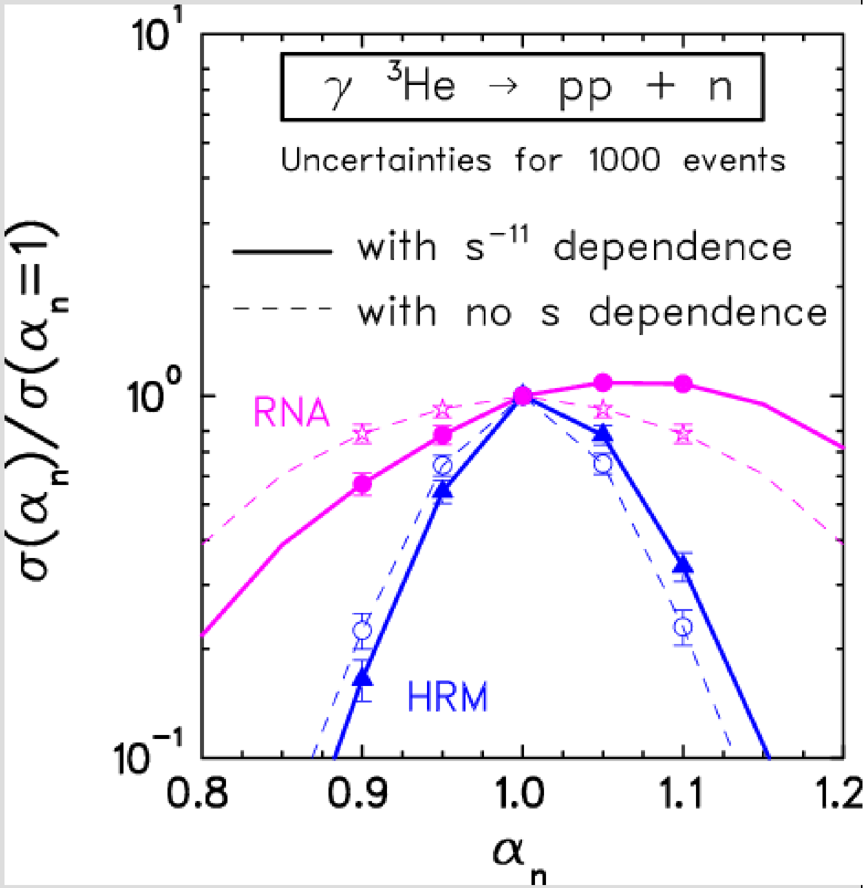
$$\Rightarrow \quad \alpha_n = 3 - \alpha_{p_1} - \alpha_{p_2}$$

Breaking a transverse compact object formed before the absorption ?

RNA $\psi_d(\,p \approx 2\,\mathrm{GeV/c}\,)$

Double hard scattering ?

HRM $\psi_d(\,P \le 300\,\mathrm{MeV/c})$



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scaling

- Verify the scaling for another hard exclusive reaction
- Extend the verification of photodisintegrartion scaling

$$\left[\frac{s(E_\gamma = 4)}{s(E_\gamma = 1)}\right]^{11} \approx 10^4 \qquad \left[\frac{s(E_\gamma = 5)}{s(E_\gamma = 1)}\right]^{11} \approx 10^5$$

- Utilize the recoil neutron to study scaling

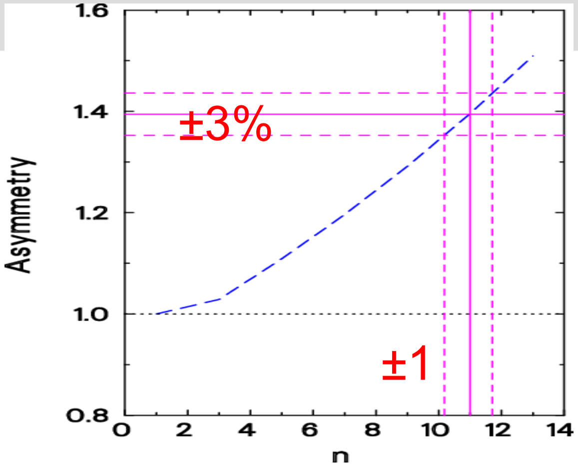
α=(E - P_Z) / m

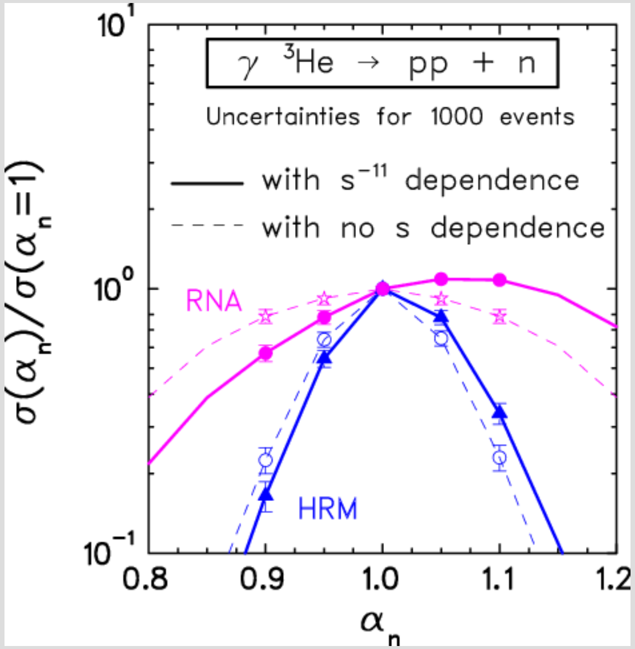
$$\alpha_\gamma + \alpha_{^3He} = 0 + 3 = \alpha_{p_1} + \alpha_{p_2} + \alpha_n \quad \Rightarrow \quad \alpha_n = 3 - \alpha_{p_1} - \alpha_{p_2}$$

$$s_{pp} \approx 2\,E_\gamma\,M_d\,\frac{3-\alpha_n}{2} + M_d^2$$

HRM, α(1-1.2) / α(0.8-1)

$$\frac{d\sigma}{dt}_{\gamma(pp)\to pp} \propto S^{-n}$$





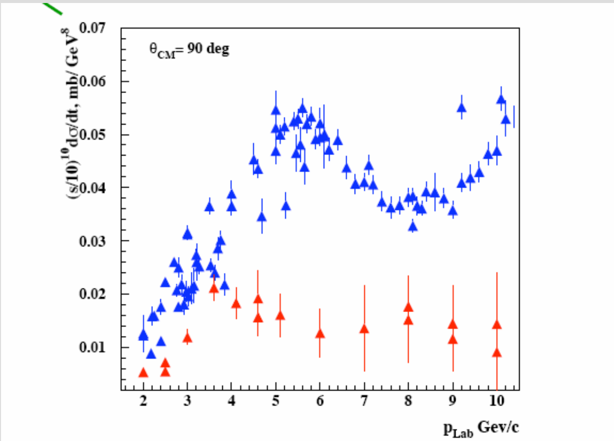
Outlook

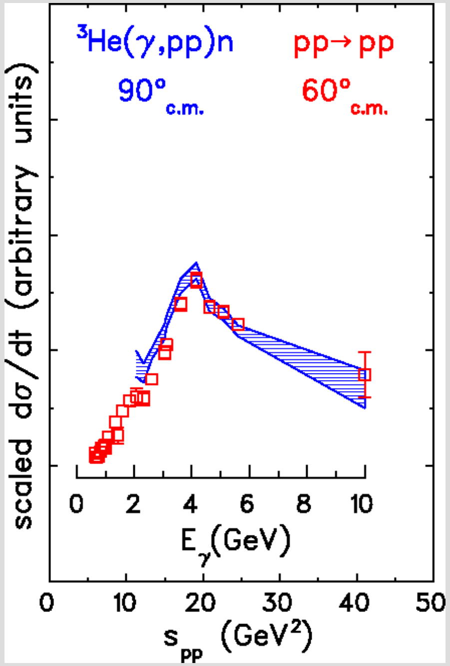
energy oscillation

If **HRM is valid** (see Sargsian talk) and photodisintegration **amplitude can be factorized**

Hard photodisintegration data can

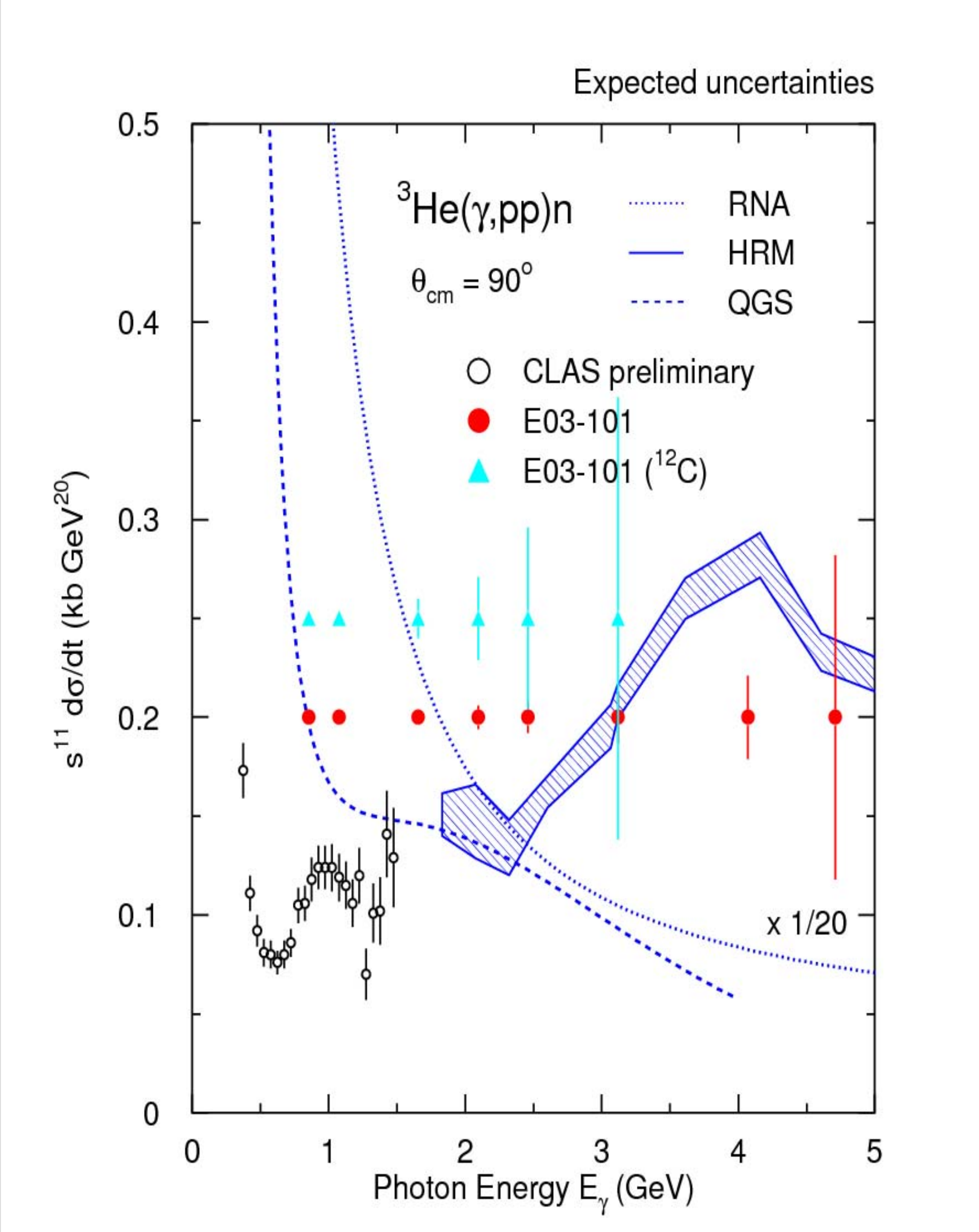
be related to NN scattering data





Outlook

We also have $^{12}C\,(\gamma,\mathrm{pp})$ data



Acknowledgment

TEL AVIV UNIVERSITY

Experiment E03-101 collaboration

Hall A / JLab.

Spokespersons: R. Gilman, E. Piasetzky

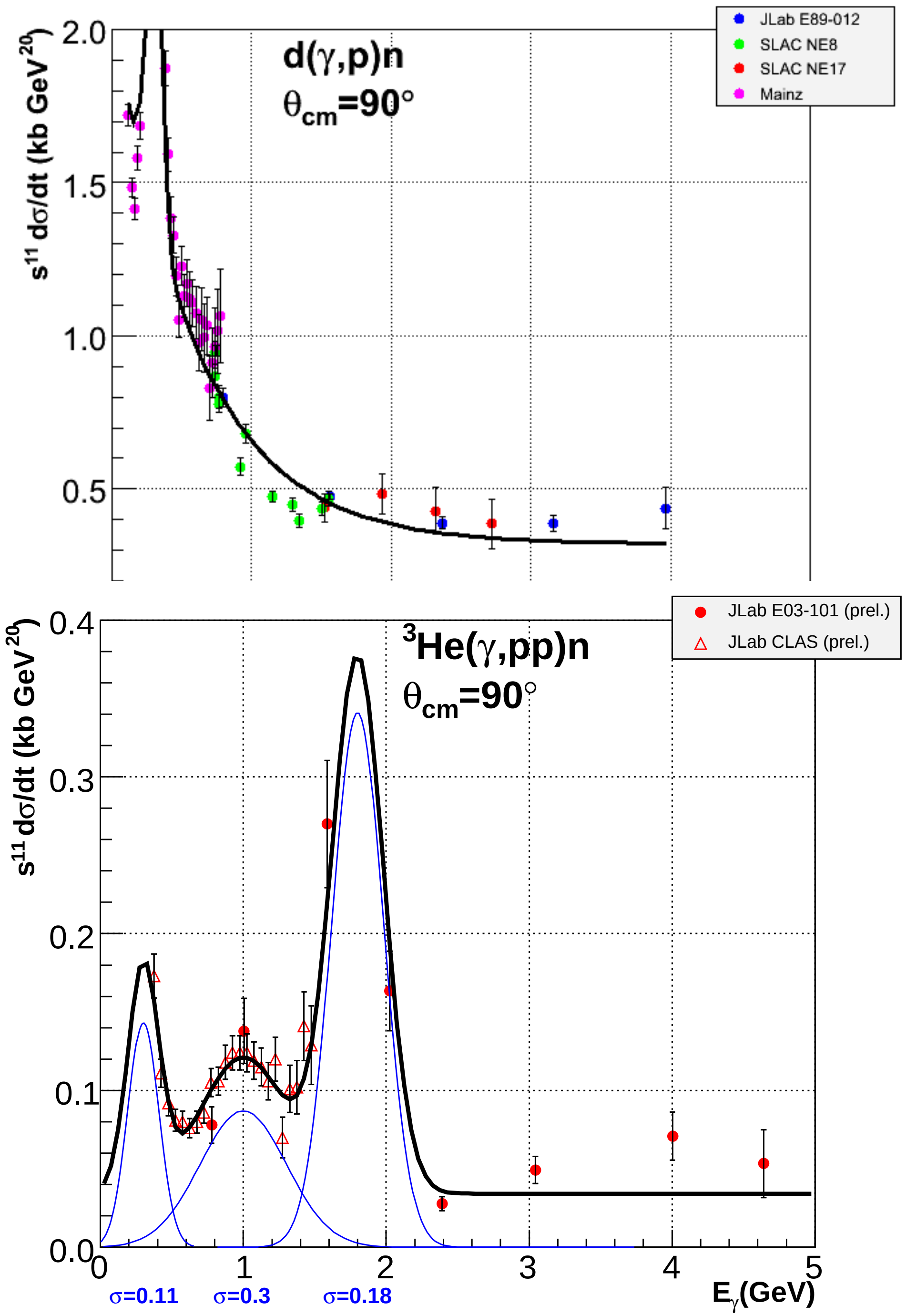
Graduate student: Ishay Pomerantz (Tel Aviv University)

Theoretical support : M. Sargsian

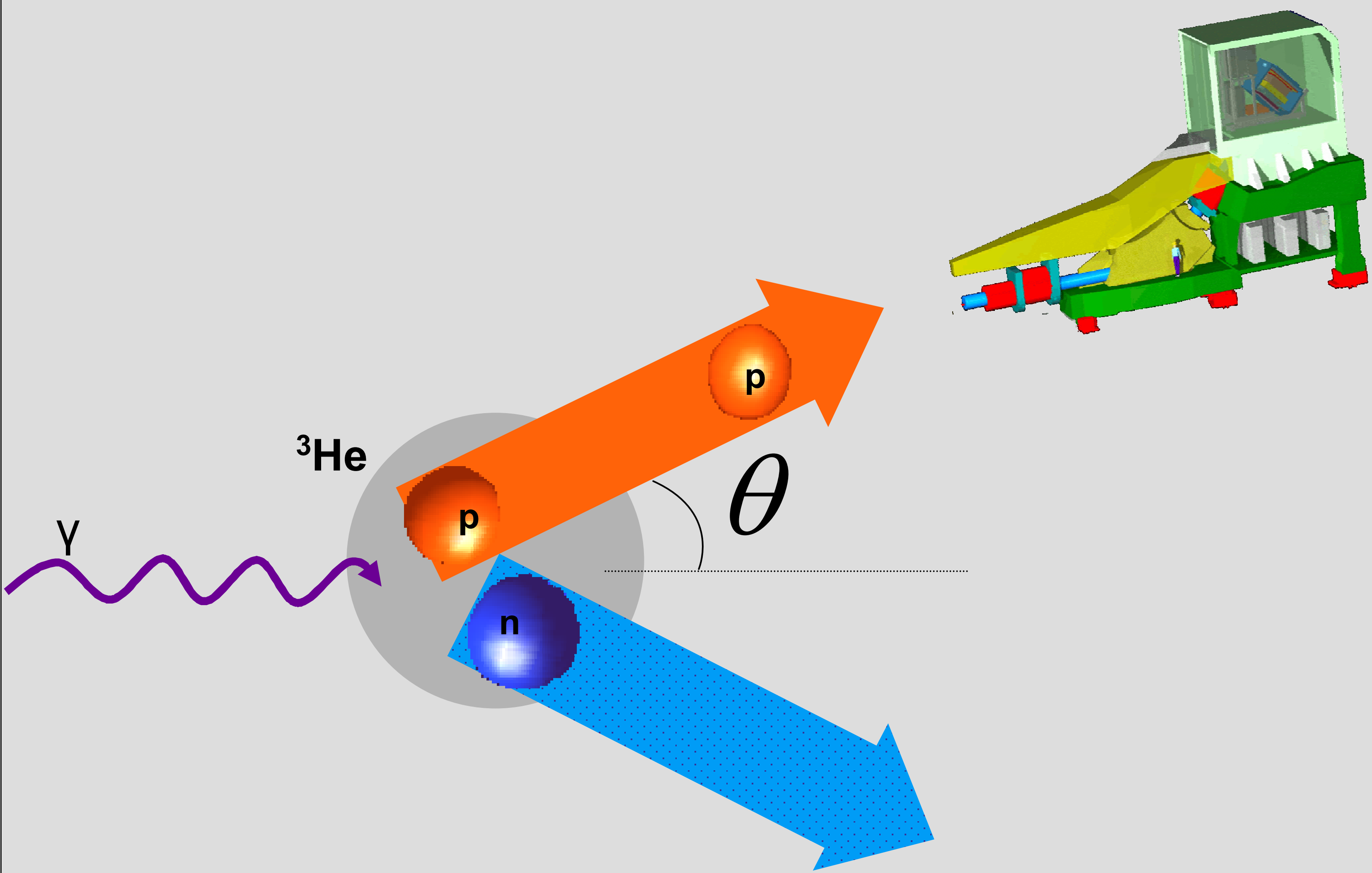
"Hard Photodisintegration of a Proton Pair in ^{3}He"

Physics Letters B 578 (2004) 69–77

Brodsky, Frankfurt, Gilman, Hiller, Miller,
Radyushkin, Piasetzky, Sargsian, Strikman

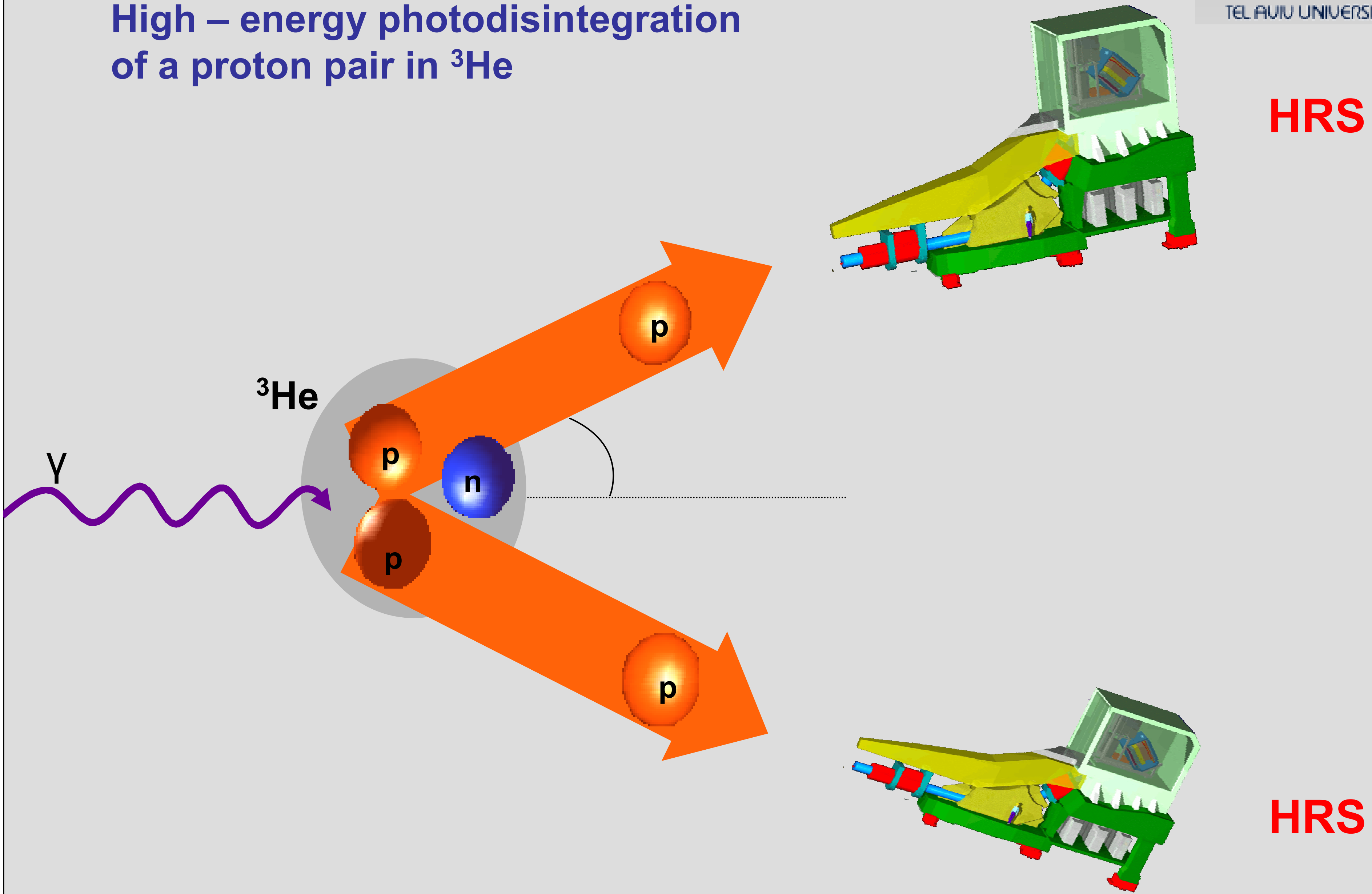


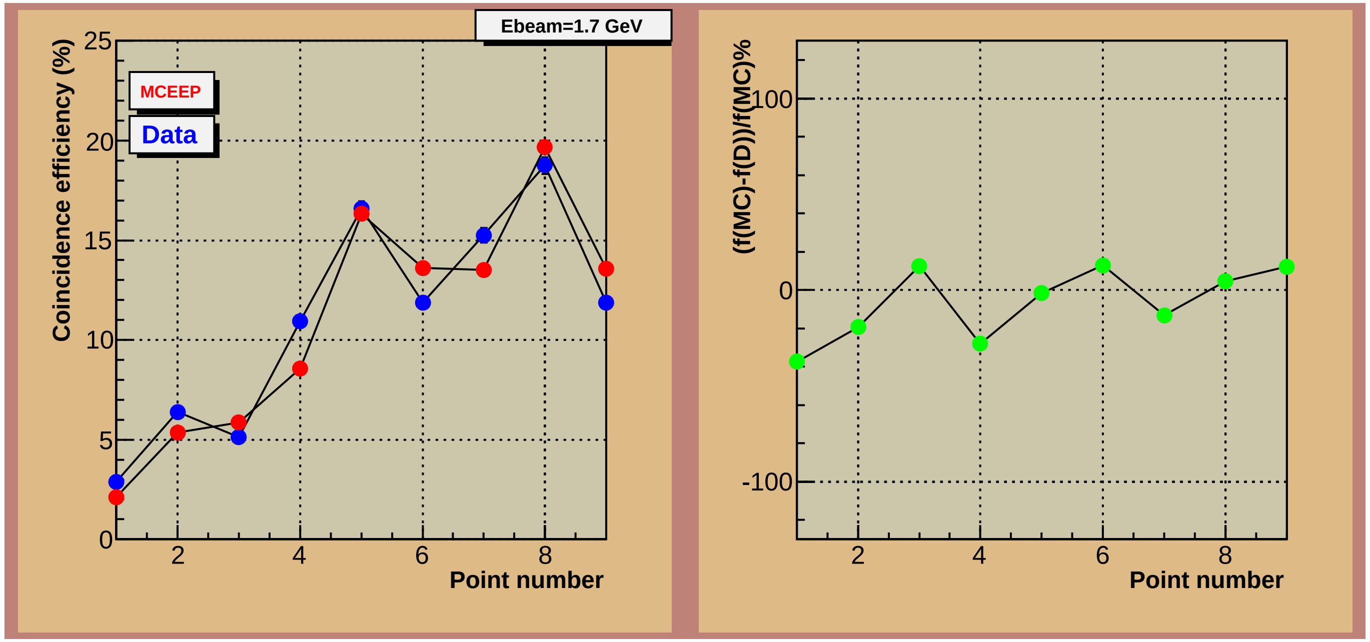
d(γ,p)n
θcm=90°
JLab E89-012
SLAC NE8
SLAC NE17
Mainz
s11 dσ/dt (kb GeV20)
2.0
1.5
1.0
0.5
3He(γ,pp)n
θcm=90°
JLab E03-101 (prel.)
JLab CLAS (prel.)
s11 dσ/dt (kb GeV20)
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
Eγ(GeV)
σ=0.11
σ=0.3
σ=0.18

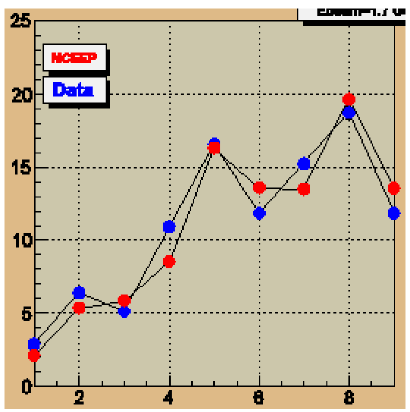


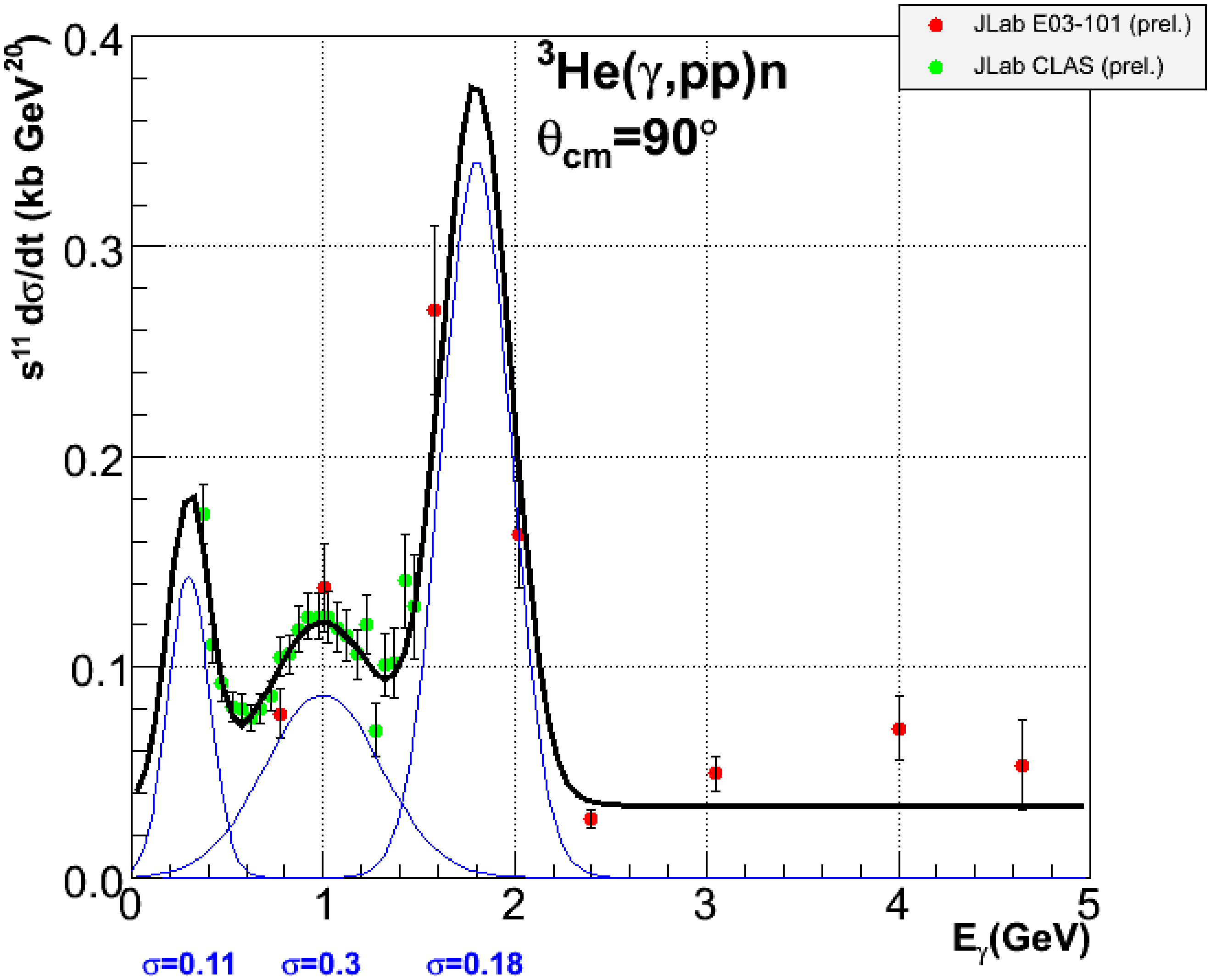
HRS
^{3}He
p
p
n
γ
θ

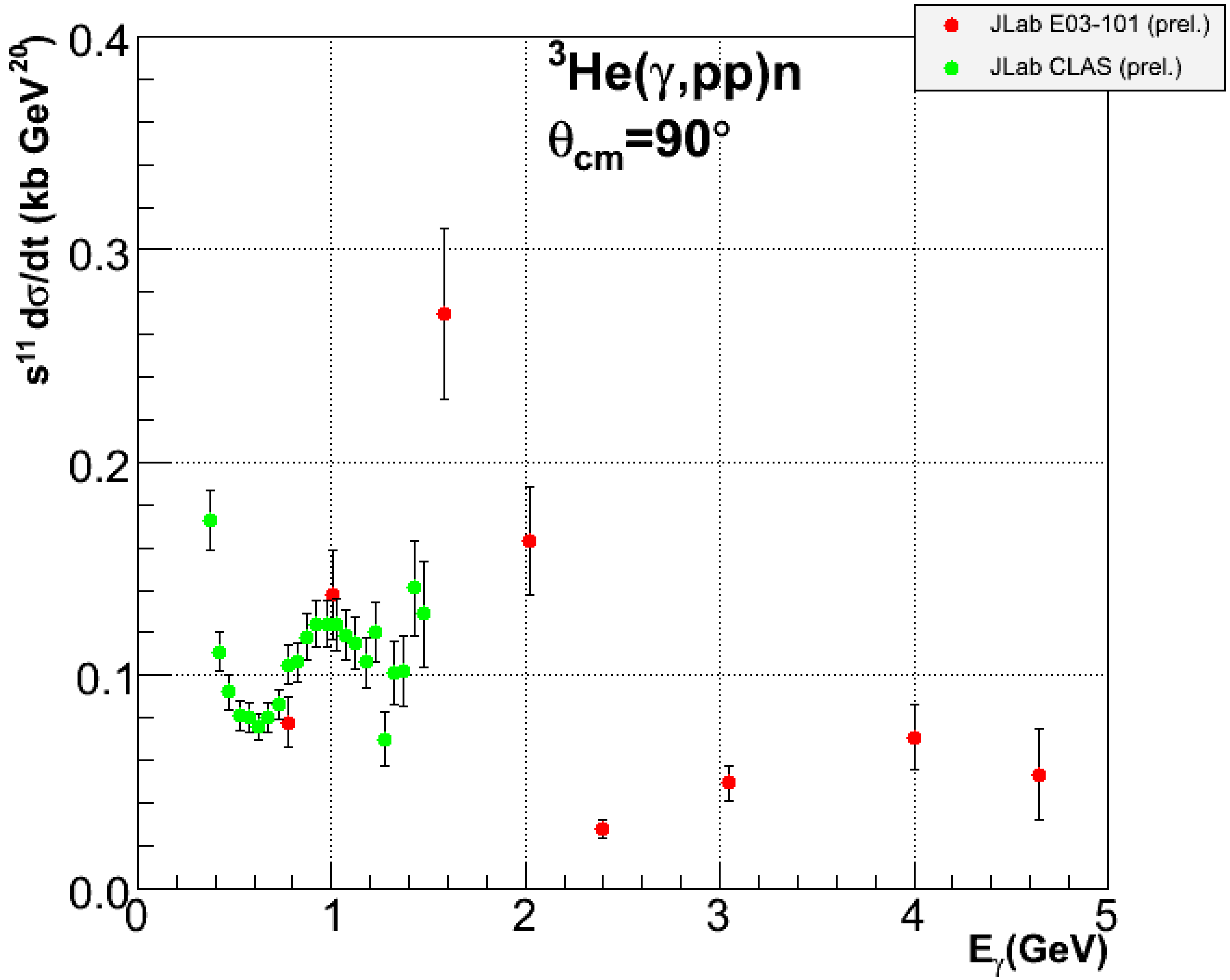
High – energy photodisintegration of a proton pair in ^3He



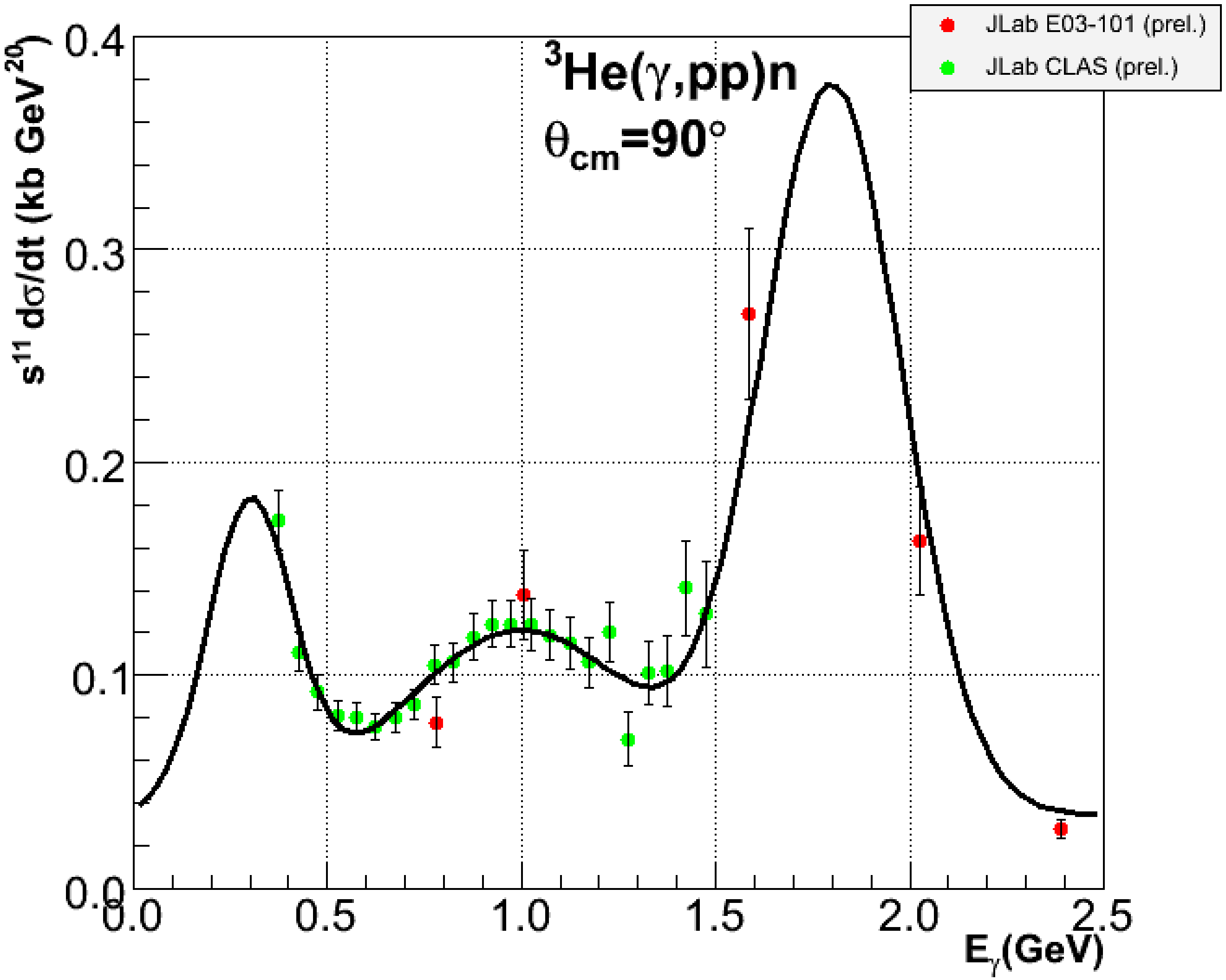

Ebeam=1.7 GeV
MCEEP
Data
Coincidence efficiency (%)
Point number
(f(MC)-f(D))/f(MC)%
Point number


MCEEP
Data

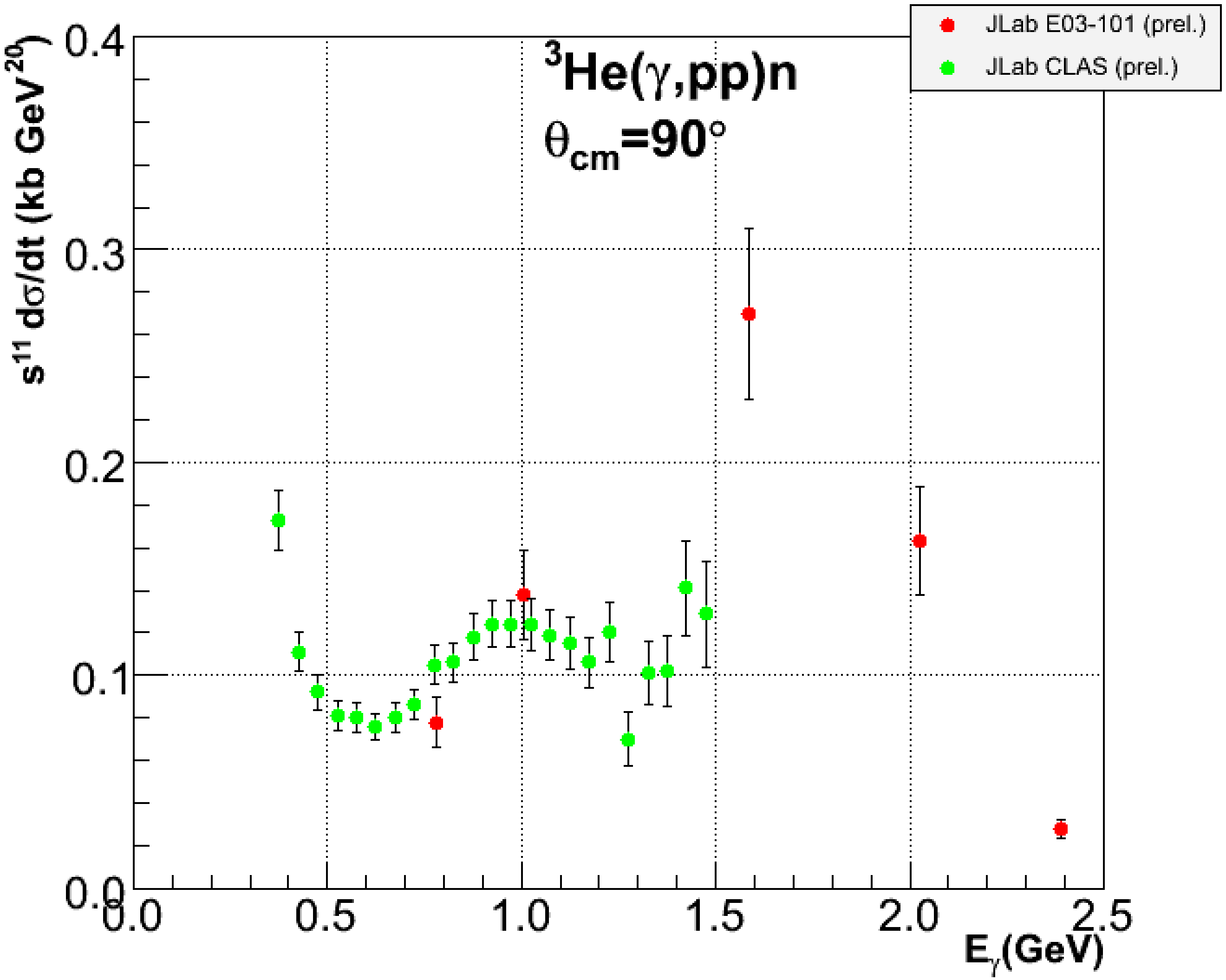

JLab E03-101 (prel.)
JLab CLAS (prel.)
$^3He(\gamma,pp)n$
$\theta_{cm}=90°$
$s^{11}\ d\sigma/dt$ (kb GeV^{20})
E_γ(GeV)
0.0
0.1
0.2
0.3
0.4
0
1
2
3
4
5
σ=0.11
σ=0.3
σ=0.18



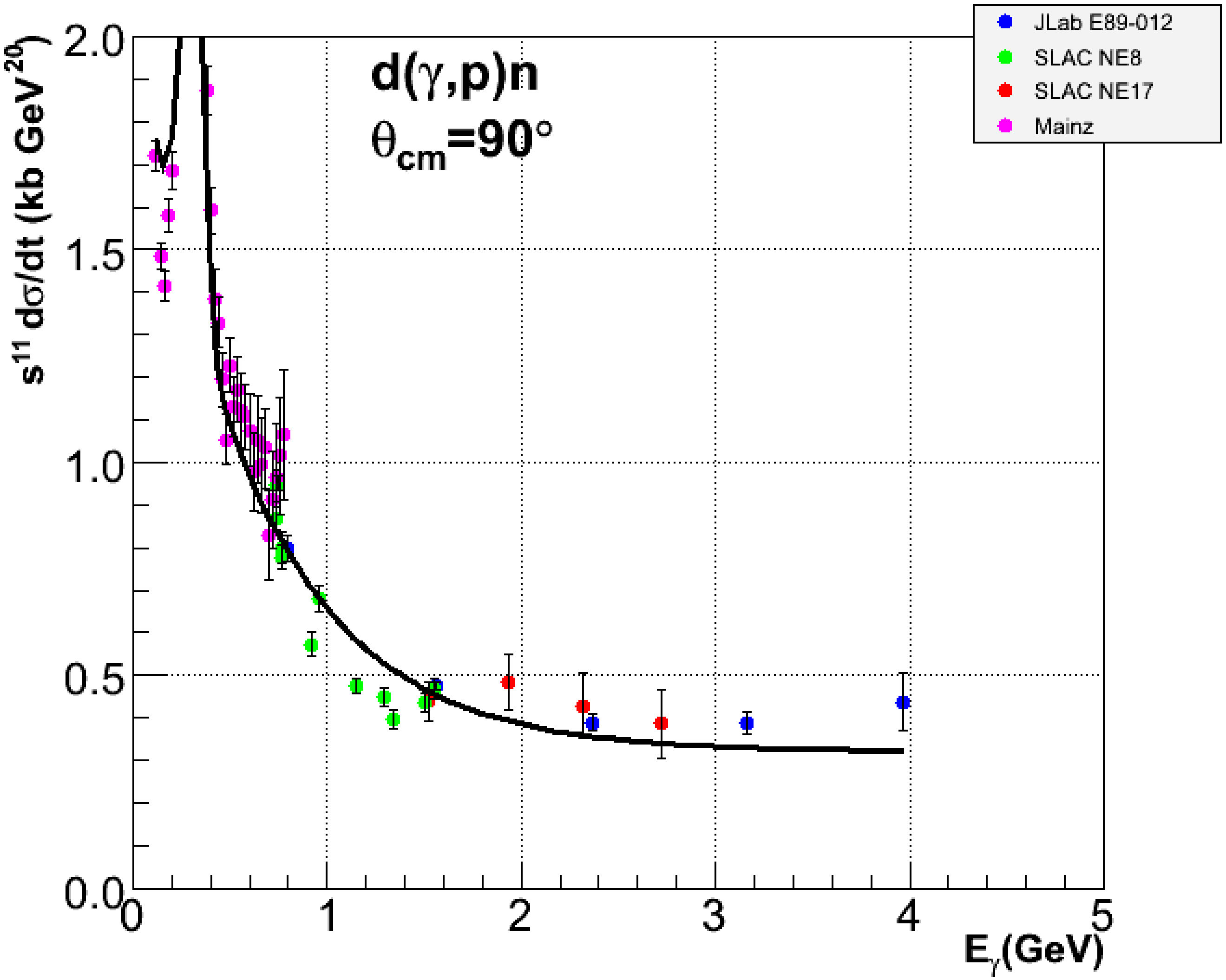
JLab E03-101 (prel.)
JLab CLAS (prel.)
3He(γ,pp)n
θcm=90°
s11 dσ/dt (kb GeV20)
0.0
0.1
0.2
0.3
0.4
0
1
2
3
4
5
Eγ(GeV)



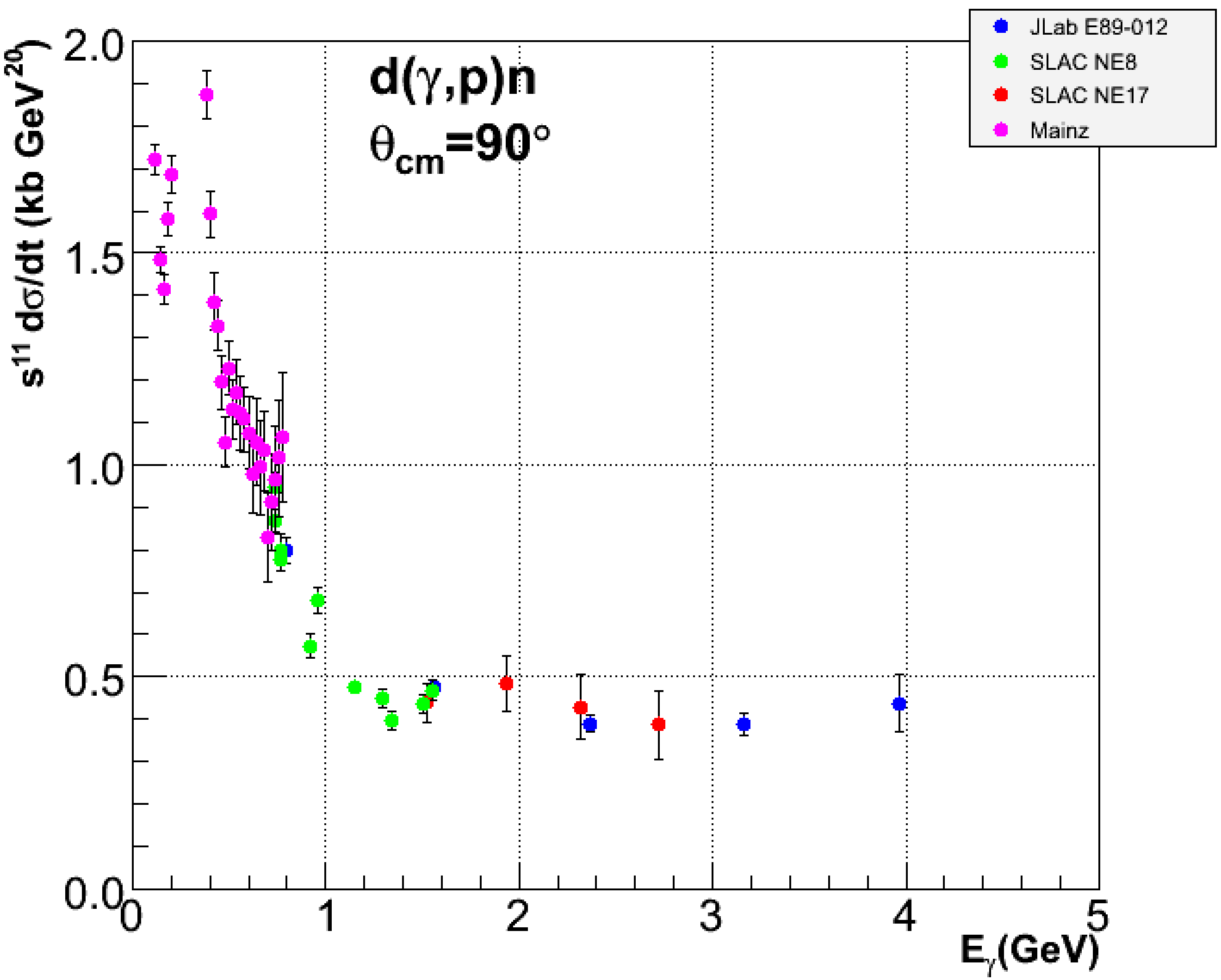
JLab E03-101 (prel.)
JLab CLAS (prel.)
3He(γ,pp)n
θcm=90°
s11 dσ/dt (kb GeV20)
0.0
0.1
0.2
0.3
0.4
0.0
0.5
1.0
1.5
2.0
2.5
Eγ(GeV)



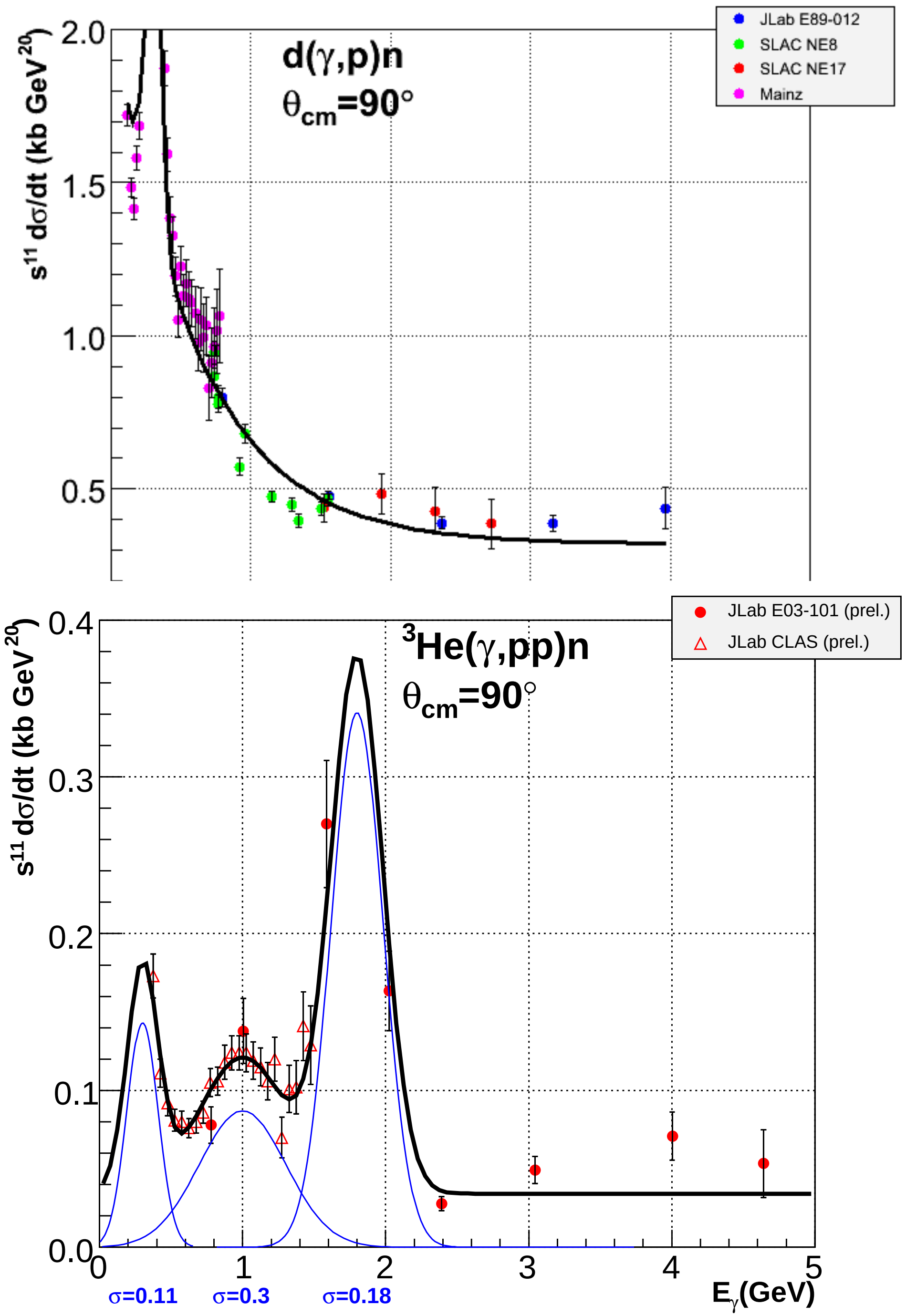
JLab E03-101 (prel.)
JLab CLAS (prel.)
$^3He(\gamma,pp)n$
$\theta_{cm}=90°$
$s^{11}\, d\sigma/dt$ (kb GeV^{20})
0.0
0.1
0.2
0.3
0.4
0.0
0.5
1.0
1.5
2.0
2.5
E_γ(GeV)



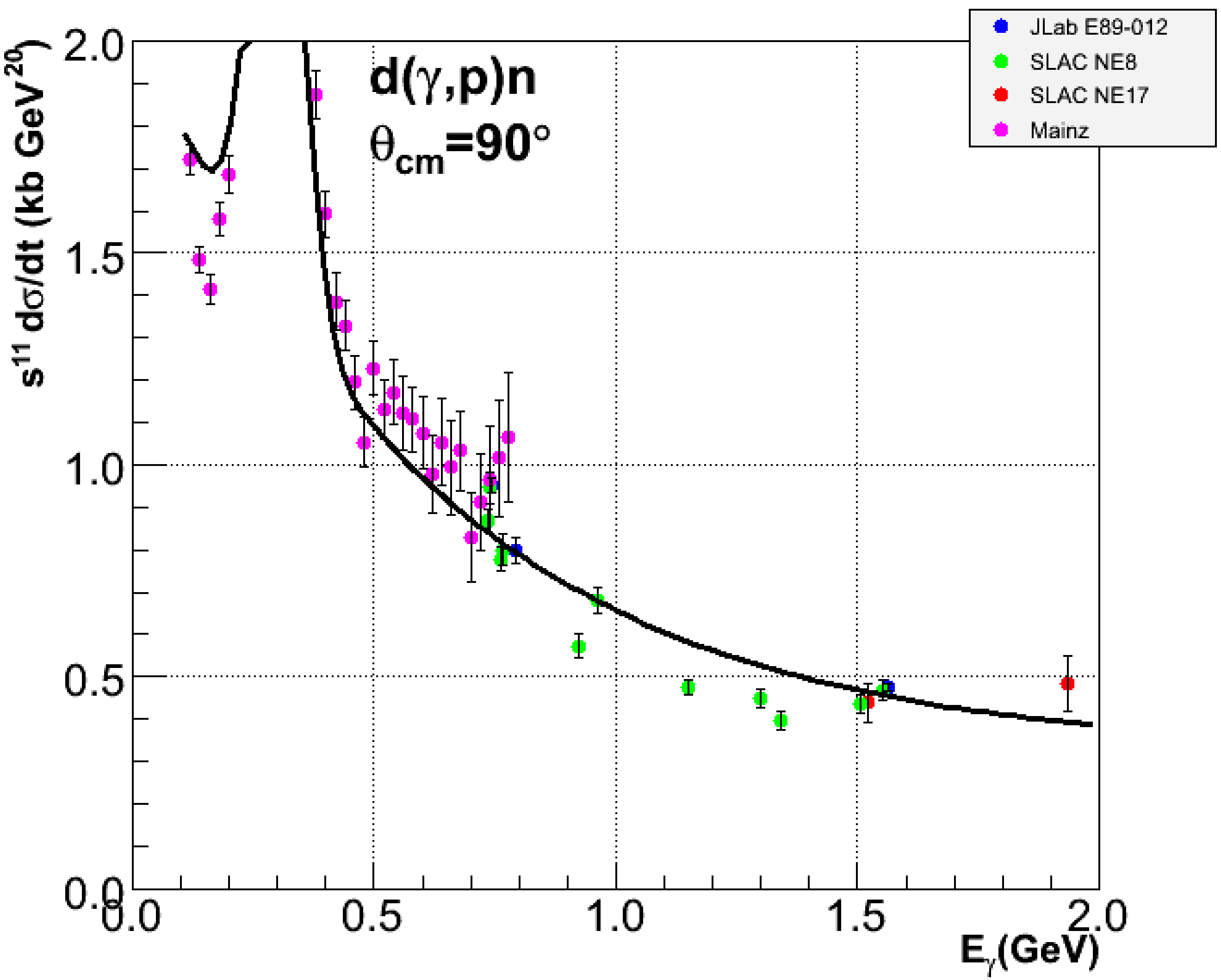
d(γ,p)n
θcm=90°
JLab E89-012
SLAC NE8
SLAC NE17
Mainz
s11 dσ/dt (kb GeV20)
Eγ(GeV)
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5



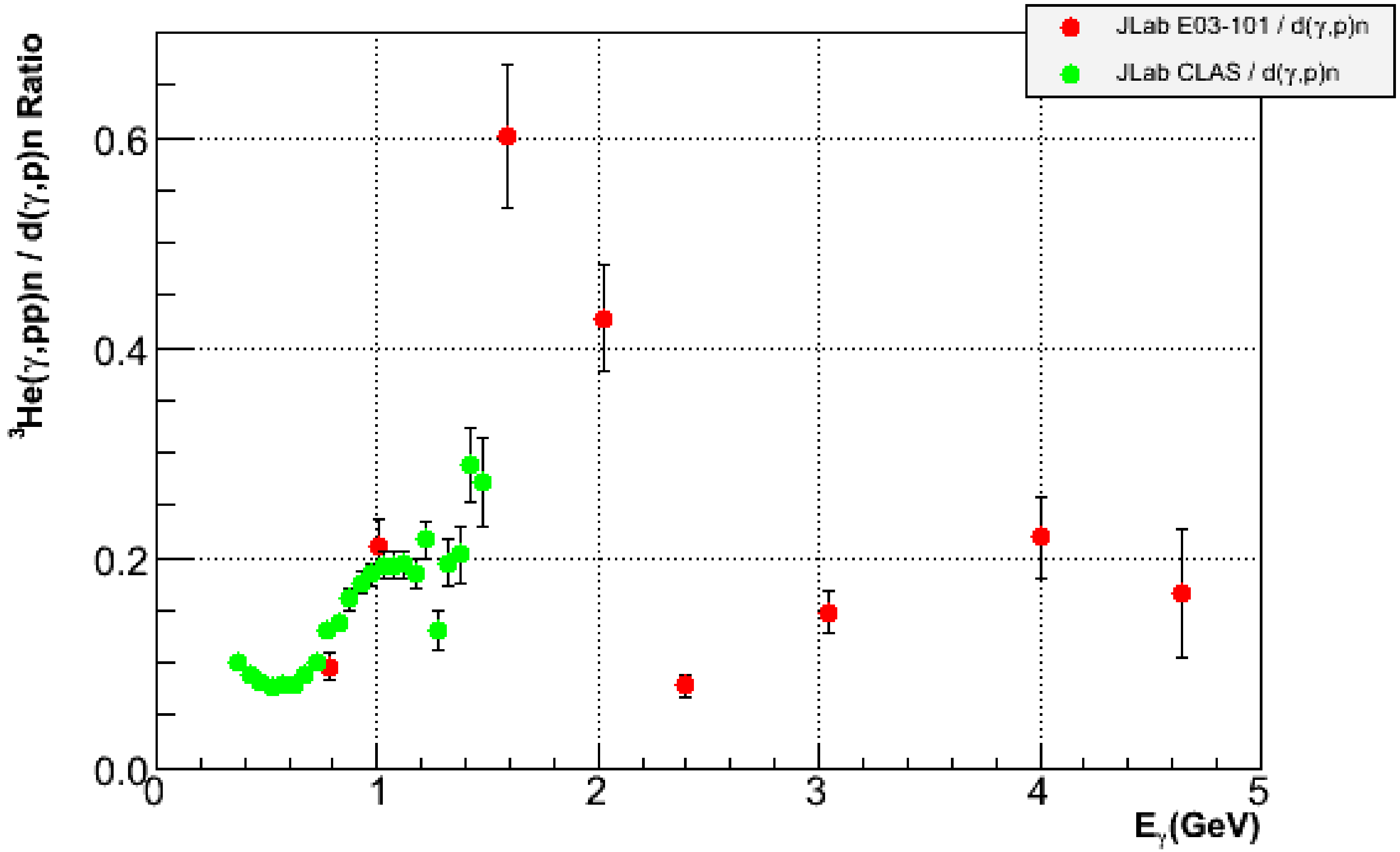
JLab E89-012
SLAC NE8
SLAC NE17
Mainz
d(γ,p)n
θcm=90°
s11 dσ/dt (kb GeV20)
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
Eγ(GeV)



d(γ,p)n
θcm=90°
JLab E89-012
SLAC NE8
SLAC NE17
Mainz
s11 dσ/dt (kb GeV20)
2.0
1.5
1.0
0.5
3He(γ,pp)n
θcm=90°
JLab E03-101 (prel.)
JLab CLAS (prel.)
s11 dσ/dt (kb GeV20)
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
Eγ(GeV)
σ=0.11
σ=0.3
σ=0.18



d(γ,p)n
θcm=90°
JLab E89-012
SLAC NE8
SLAC NE17
Mainz
s11 dσ/dt (kb GeV20)
Eγ(GeV)
0.0
0.5
1.0
1.5
2.0



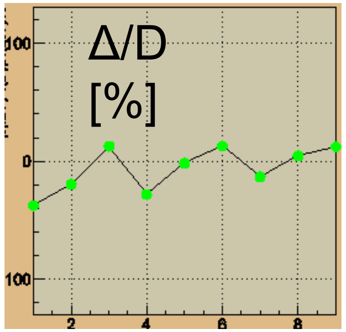
JLab E03-101 / d(γ,p)n
JLab CLAS / d(γ,p)n
^{3}He(γ,pp)n / d(γ,p)n Ratio
0.0
0.2
0.4
0.6
0
1
2
3
4
5
E_γ(GeV)

Step 1. MCEEP Randomly pick scattering angle for the first proton

Step 2. MCEEP Randomly pick photon energy [1] and neutron momentum [2]

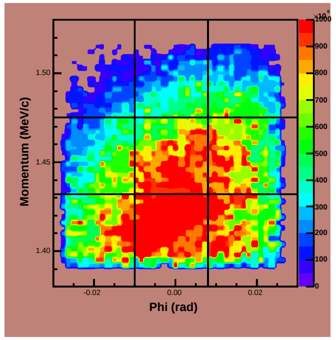
Step 3. MCEEP Calculates momentum magnitude of the first proton and the momentum of the second proton

[1] MATTHEWS AND OWENS NIM 111, 157-168 (73) [2] R. Schiavilla, et al., Phys. Rev. Lett. 98, 132501 (2007), and references therein.



Box number

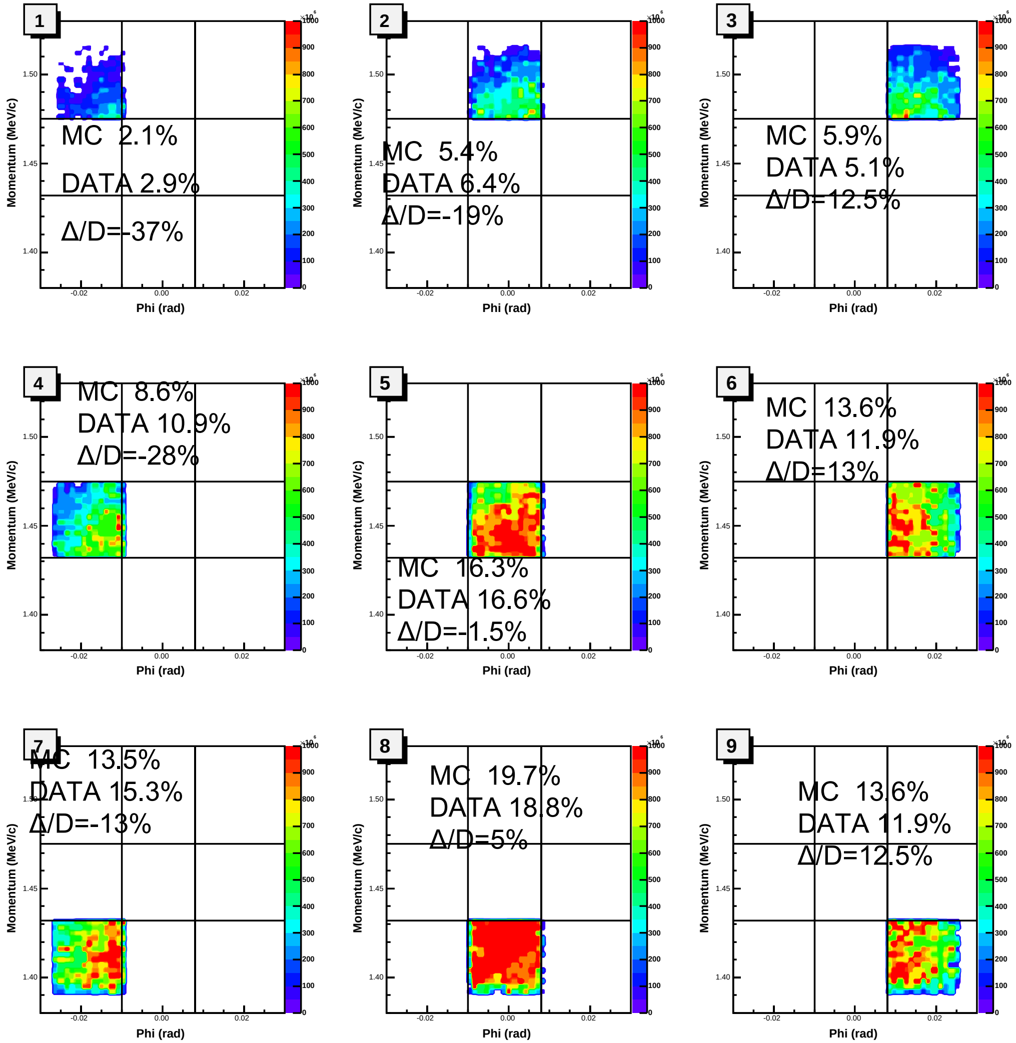
Simulation



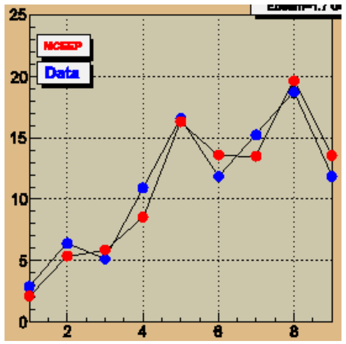
MC 100%

DATA 100%

$$E_{\gamma} = 1.7 GeV$$



MC 5.4%
DATA 6.4%
Δ/D=-19%



Box number

TEL AVIV UNIVERSITY

Hard photodisintegration of the deuteron has been extensively studied

$$\gamma\, d \rightarrow p\,(high\; p_t) + n\,(high\; p_t)$$

★ What did we learn ?

★ What are the current problems ?

HRM model The differential cross section within the HRM model is [29]:

$$\frac{d\sigma}{dt\,d^3p_n} = \left(\frac{14}{15}\right)^2 \frac{8\pi^4\alpha_{EM}}{s - M_{^3\mathrm{He}}^2} \frac{d\sigma^{pp}(s_{pp}, t_N)}{dt} \times \frac{1}{2}\left|\sum_{\mathrm{spins}} \int \Psi^{^3\mathrm{He}}(p_1, p_2, p_n)\sqrt{M_N}\frac{d^2 p_{2T}}{(2\pi)^2}\right|^2, \tag{3}$$

where $s = (P_\gamma + P_{^3\mathrm{He}})^2$, $t = (P_p - P_\gamma)$ $s_{pp} = (P_\gamma + P_{^3\mathrm{He}} - P_n)^2$, and $t_N \approx (1/2)t$. The pp elastic cross section is $d\sigma^{pp}/dt$. The momentum of the recoil neutron is p_n. In the argument of the ^{3}He nuclear wave function, $\vec{p}_1 = -\vec{p}_2 - \vec{p}_n$ and $p_{1z} \approx p_{2z} \approx -p_{nz}/2$ near 90°. The pp scattering cross section was

$$\frac{d\sigma}{dt d^3 p_n} = \left(\frac{14}{15}\right)^2 \frac{8\pi^4 \alpha_{EM}}{s - M^2_{^3\mathrm{He}}} \frac{d\sigma^{pp}(s_{pp}, t_N)}{dt} \frac{1}{2} \left| \sum_{spins} \int \Psi^{^3\mathrm{He}}(p_1, p_2, p_n) \sqrt{M_N} \frac{d^2 p_{2T}}{(2\pi)^2} \right|^2,$$

where $s = (P_\gamma + P_{^3\mathrm{He}})^2$, $t = (P_p - P_\gamma)$ $s_{pp} = (P_\gamma + P_{^3\mathrm{He}} - P_n)^2$, and $t_N = (p_a - \alpha p_{pp})^2 \approx \frac{1}{2}t$.

=1/3

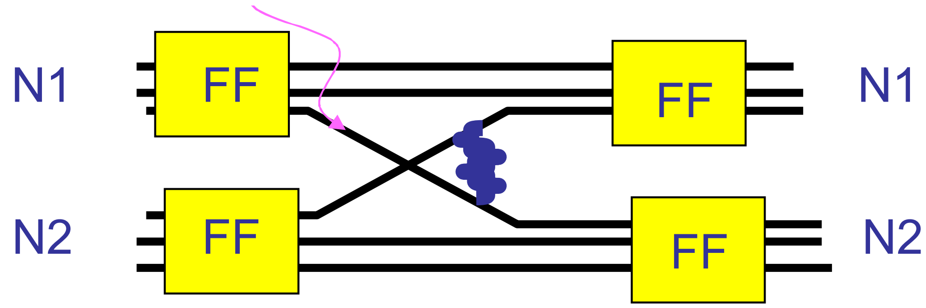
$$\frac{d\sigma}{dt d^3 p_n} = \left(\frac{14}{15}\right)^2 \frac{16\pi^4 \alpha}{S - M^2_{^3He}} \left(\frac{2c^2}{1 + 2c^2}\right) \frac{d\sigma^{pp}}{dt}(s_{pp}, t_n) \frac{S_{34}}{E_n}$$

Helicity Selection Rule

$$c = \frac{|\phi_{3,4}|}{|\phi_1|} \sim \frac{1}{2}$$

- **Photon selects nucleon in the nucleus with helicity = to its own**

$$\frac{d\sigma}{dt} \propto F^2_{N1}(-t_1)\, F^2_{N2}(-t_2)\, \frac{d\sigma}{dt}_{\text{reduced}}$$



$$\sigma_{\gamma pp} / \sigma_{\gamma pn} = (F_p / F_n)^2 \left[\left(\frac{d\sigma}{dt}\right)^{pp}_{reduced} / \left(\frac{d\sigma}{dt}\right)^{pn}_{reduced} \right]$$

$$G_E \text{ and } G_M \text{ data} \quad \Rightarrow \quad (F_p / F_n)^2 \approx (-2)^2 = 4$$

$$\sigma_{\gamma pp} / \sigma_{\gamma pn} \approx 16$$

$$\left(\frac{d\sigma}{dt}\right)^{pp}_{reduced} / \left(\frac{d\sigma}{dt}\right)^{pn}_{reduced} \approx (\text{charge ratio})^2 = 4$$

$$\frac{\sigma(\gamma\ {}^3\text{He} \to \text{pp})}{\sigma(\gamma\ \text{d} \to \text{pn})} = \frac{\int [\psi^{^3\text{He}}_{\text{pp}}]^2\ \text{p}_\text{n} \le 100\ \text{MeV/c}}{\int [\psi^d]^2} \bullet \frac{\sigma_{\gamma pp}}{\sigma_{\gamma pn}} \approx \frac{16}{3}$$

$$\approx 5$$

$$\frac{\int [\psi^{^3\text{He}}_{\text{pp}}]^2\ \text{p}_\text{n} \le 100\ \text{MeV/c}}{\int [\psi^d]^2}$$

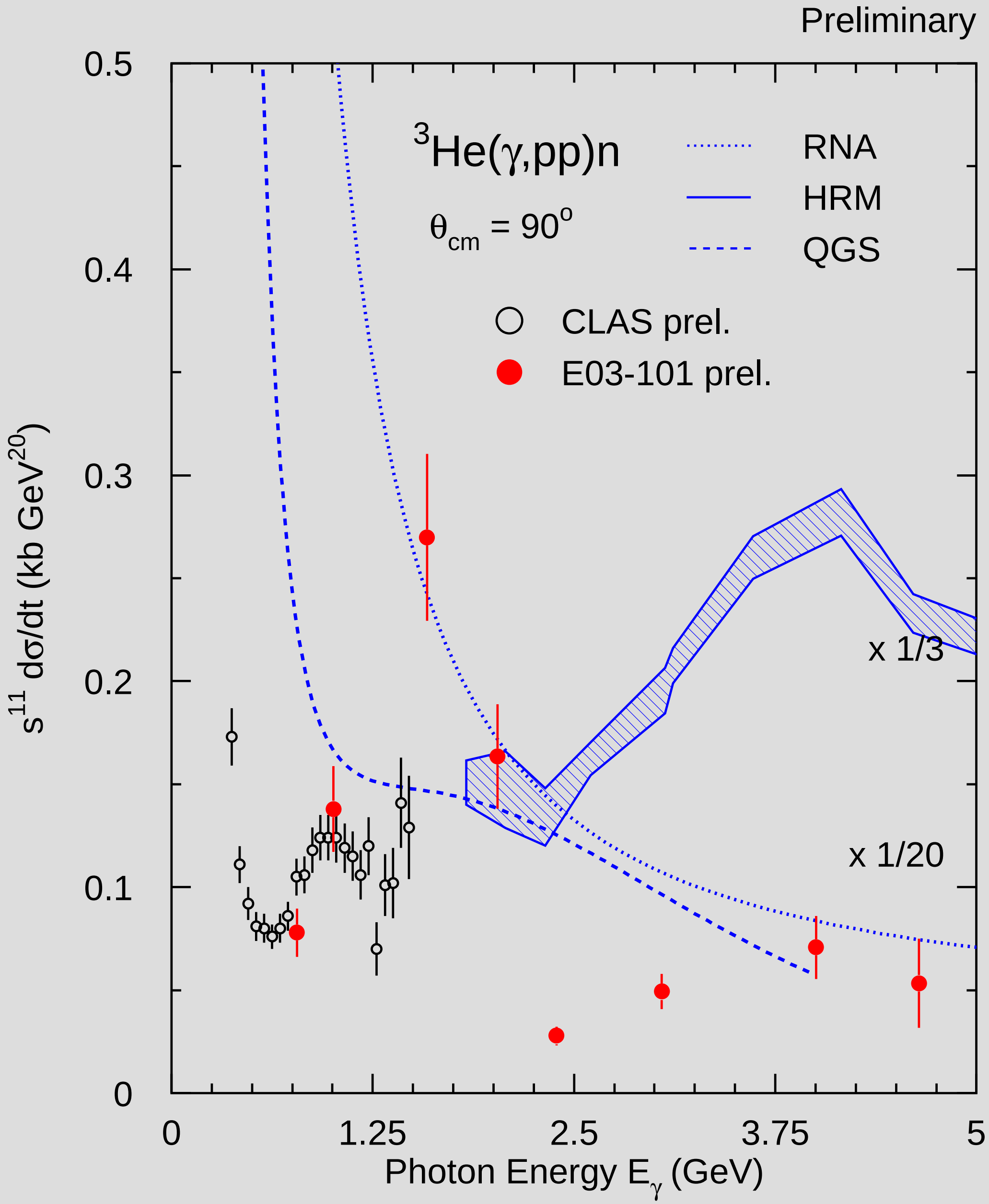
Is it SRC ? Does this talk being given in the correct section?

11:45 - 12:15	**M. Alvioli** / *Perugia, Italy* **n-p and p-p correlations in light and medium-weight nuclei**

14:00 - 14:30	**S. Gilad** / *MIT, USA* **(e,e'p) and (e,e'pp) on 12C and Nucleon-Nucleon Correlations**
14:30 - 15:00	**J. Watson** / *Kent State, USA* **Investigation of NN correlations by hadronic probes**
15:00 - 15:30	**D. Higinbotham** / *Jlab, USA* **Short-Range Structure of Nuclei**

16:45 - 17:15	**D. Day** / *UVA, USA* **Scaling and Short Range Correlations in Inclusive Electron-Nucleus Scattering at High Momentum Transfers**
17:15 - 17:45	**M. Strikman** / *Penn State, USA* **Future directions for probing two and three nucleon short-range correlations at high energies**

Preliminary Results



RNA (Reduced Nuclear Amplitude)

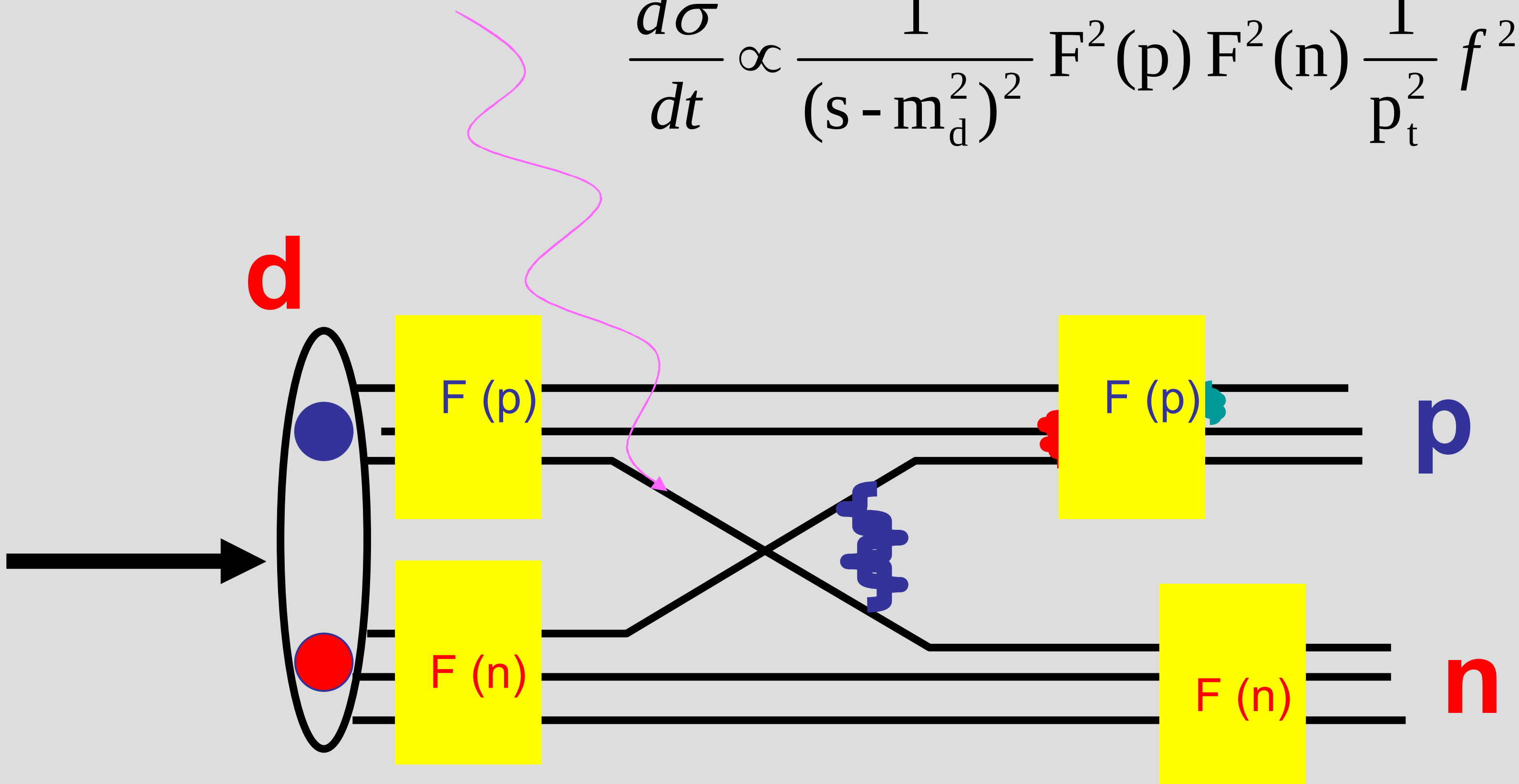
Brodsky , Hiller PRC 28, 475 (1983)

★ Experimental nucleon FF → gluon exchanges within the nucleons

★ Neglect diagrams with gluon exchanges between the nucleons

★ Photon can interacts with any quarks

$$\frac{d\sigma}{dt} \propto \frac{1}{(s - m_d^2)^2} F^2(p)\, F^2(n)\, \frac{1}{p_t^2}\, f^2(\theta_{cm})$$

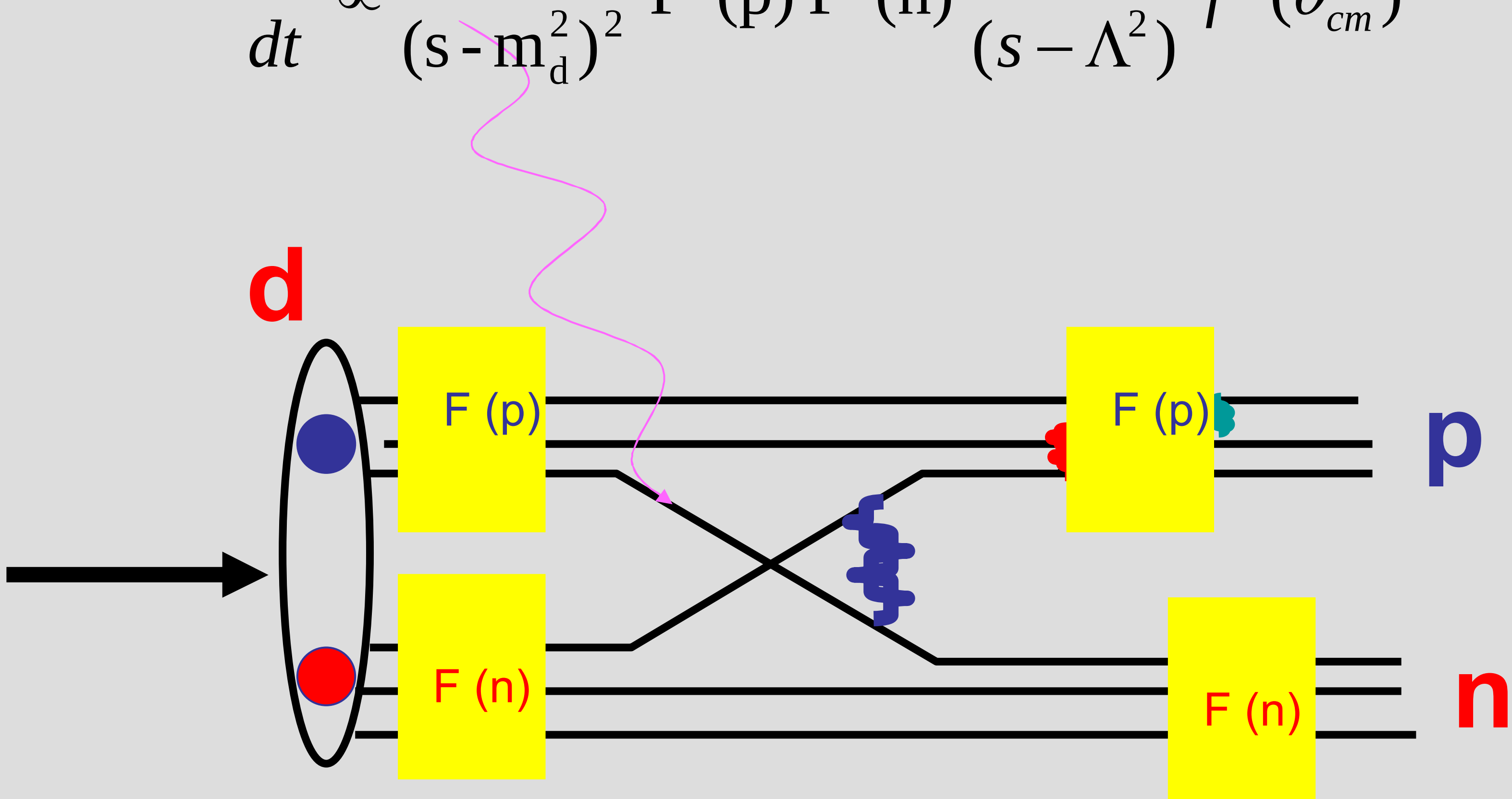


TQC (Two - Quark Coupling)

Radyushkin

- gluon exchanges within the nucleons → Experimental nucleon FF
- gluon exchanges between the nucleons → neglected
- Photon interacts with the exchange pair of quarks

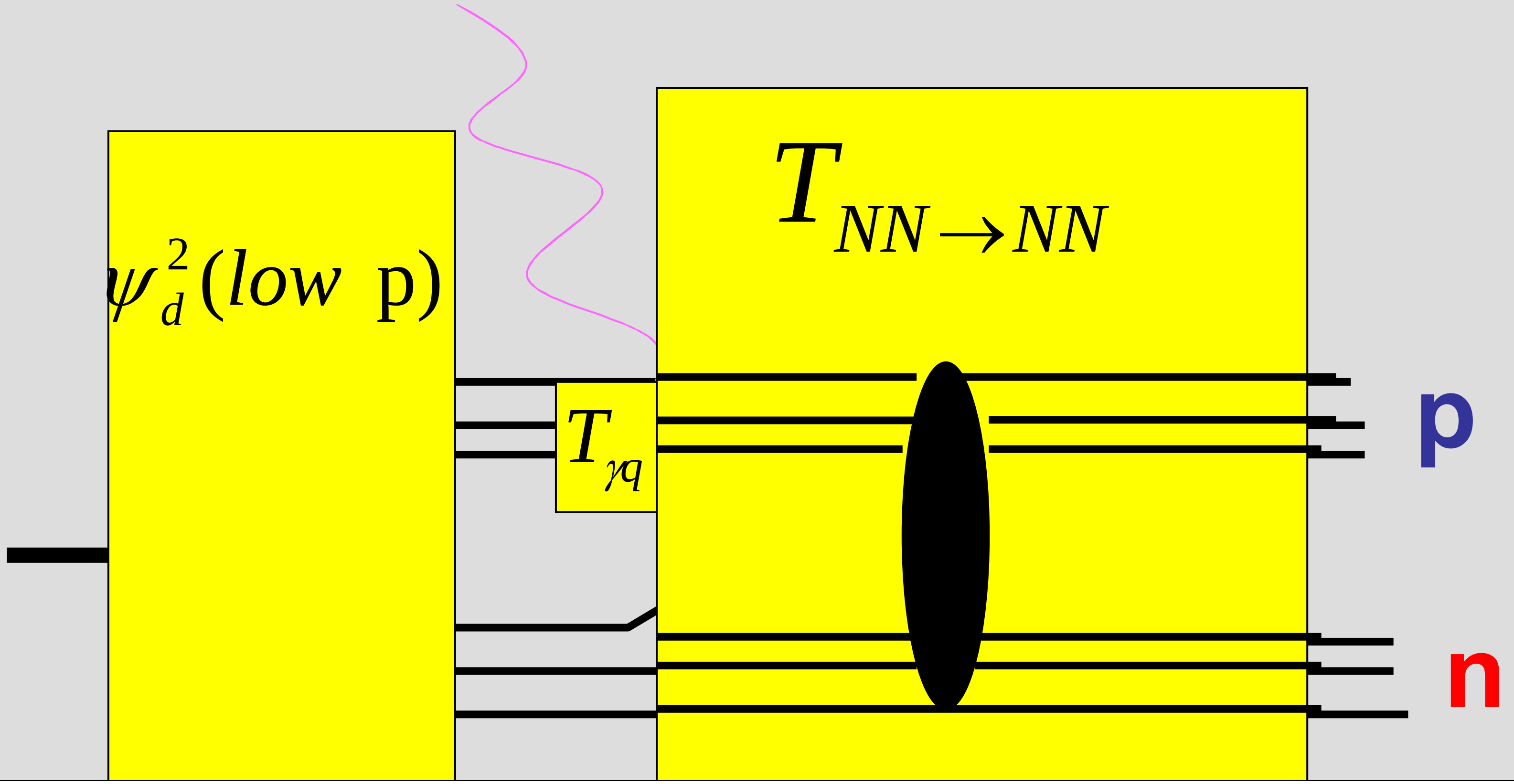
$$\frac{d\sigma}{dt} \propto \frac{1}{(s - m_d^2)^2} F^2(p)\, F^2(n) \frac{1}{(s - \Lambda^2)} f^2(\theta_{cm})$$



HRM (Hard rescattering Model)

Frankfurt, Miller, Sargsian, Strikman PRL 84, 3045 (2000).

- Convolution of large angle pn scattering amplitude , hard photon – quark interaction vertex, and low momentum nuclear wave function
- The pn scattering amplitude is obtained from large angle pn data



Quark – Gluon String model (QGS)

Grishina et al. EUR. J. Phys. A 10, 355 (2000)

3 q exchange with an arbitrary number of gluon exchanges

Regge theory - nonlinear trajectory