Heavy stable particle production at HERA

Takahiro Matsumoto / KEK

On behalf of H1 and ZEUS collaborations

Measurement of (anti)deuteron and (anti)proton production in DIS at HERA

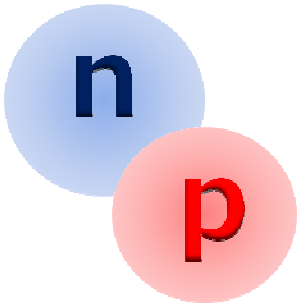
DESY 07-070, accepted by Nuclear Physics B

Measurement of Anti-Deuteron Photoproduction and a Search for Heavy Stable Charged Particles at HERA

DESY 04-032, European Physical Journal C36 (2004) 413

The 11th International Conference Baryons '07

Deuteron : Introduction



- Loosely bound state of proton and neutron
  - $\Delta E = M_p + M_n - M_d \sim 2.2$ MeV
- Deuteron production :
  - coalescence is expected : p + n → d
    - fireball → freeze out stage (overlap of wave function between p and n)
  - production scheme is not implemented in current Monte Carlo (because not through standard hadronization of quarks and gluons)
- Still few measurements in elementary particle collisions :
  - Antideuterons were observed in e^+e^- → Υ(1S,2S) (ARGUS, CLEO)
  - However, ~5-10 smaller yields in e^+e^- → qq (OPAL, ALEPH)
- Motivation of the analysis at HERA :
  - To understand the production mechanism further by investigating another processes (ep photoproduction and DIS)

Coalescence model

- $d\sigma_d \propto d\sigma_p\, d\sigma_n \sim (d\sigma_p)^2$

$$\frac{E_d}{\sigma_{tot}}\frac{d^3\sigma_d}{dp_d^3} = B_2\left(\frac{E_p}{\sigma_{tot}}\frac{d^3\sigma_p}{dp_p^3}\right)^2$$

B_2 : coalescence parameter

$\propto$ 1/(freeze out volume)

pp, pA, AA collision → both d and $\bar{d}$ were measured

If B_2 is same between particle and antiparticle → $\bar{d}/d = (\bar{p}/p)^2$

ex.) Recent measurement in Au + Au (PHENIX)

PRL (2005) 12303

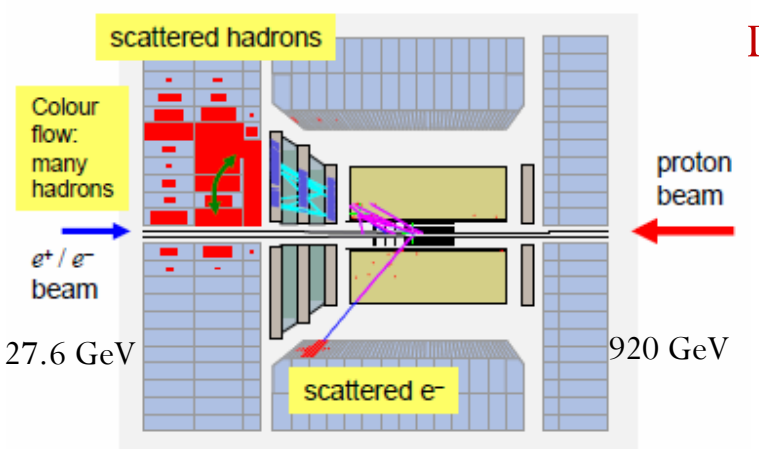
$\bar{d}/d = 0.47 \pm 0.03$

$\bar{p}/p = 0.73 \pm 0.01$

→ support $\bar{d}/d = (\bar{p}/p)^2$

Baryon asymmetry is useful to evaluate the coalescence model

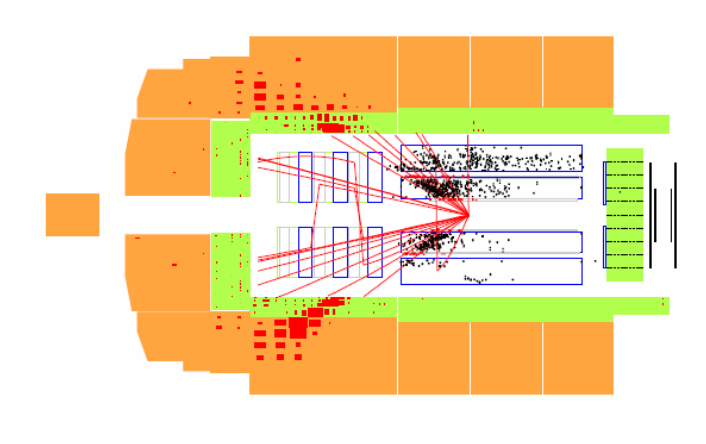
Search for (anti)deuterons at HERA



Deep Inelastic Scattering (DIS)

- L = 120/pb (HERA-I)
- $Q^2 > 1$ GeV^2

New measurements!



ep Photoproduction

- L = 5.5/pb (HERA-I)
- Scattered electron in the positron tagger (not visible in the central detector)
  → $Q^2 < 10^{-2}$ GeV^2
- $\langle W_{\gamma p} \rangle$ = 200 GeV

- Both analyses use momentum and dE/dx of charged particles measured in the central tracking detector (CTD)

Analyses strategies

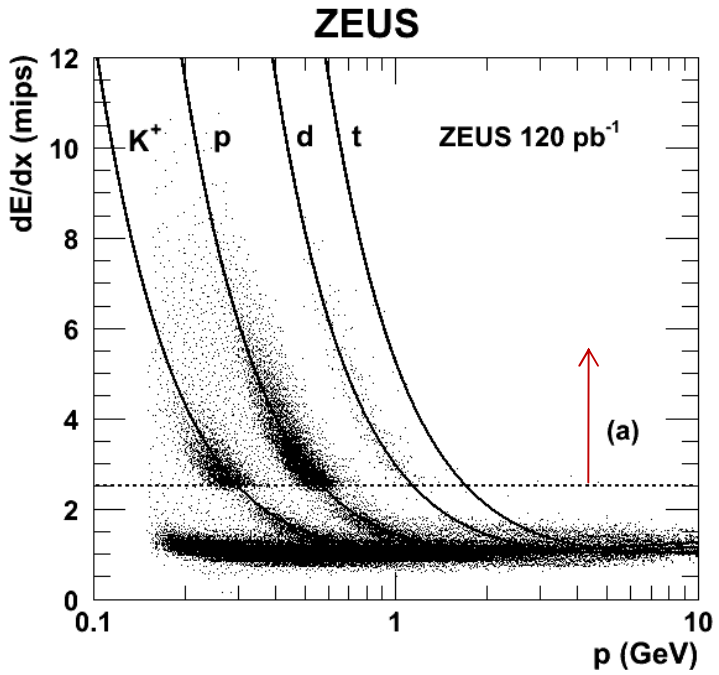
- Photoproduction : H1
  - Measurements for antideuterons
  - Deuterons → suffered from beam gas backgrounds
- Deep Inelastic scattering : ZEUS
  - Also investigate deuterons (for baryon asymmetry)
    - Idea for deuterons :
      - Requirement of scattered electron in DIS
        - Strong suppression of beam-gas events
      - Comparison of HERA-I and HERA-II data
      - HERA-II : 3 times radiation length (0.03 X_0) inner CTD due to Silicon vertex detector: Can be used to understand the effect of material backgrounds on the deuteron rate.

Measurements :

cross sections, coalescence parameter B_2, production ratios

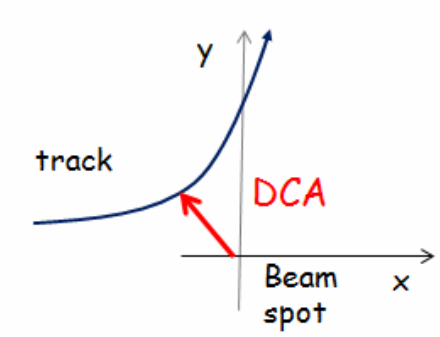
Particles selection

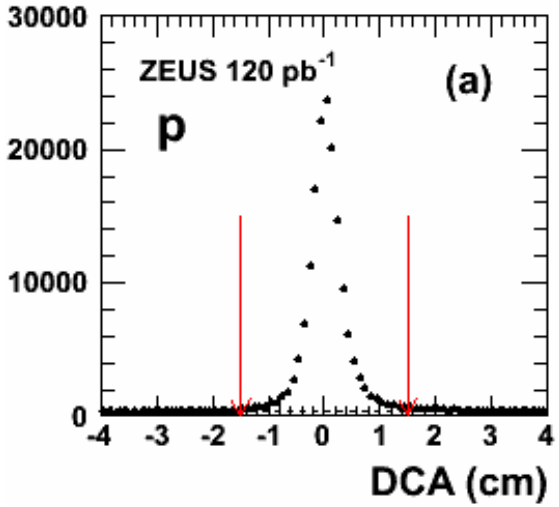
- $0.3 < p_T/M < 0.7$
- $|y|$(rapidity) < 0.4
- dE/dx(mips)>2.5

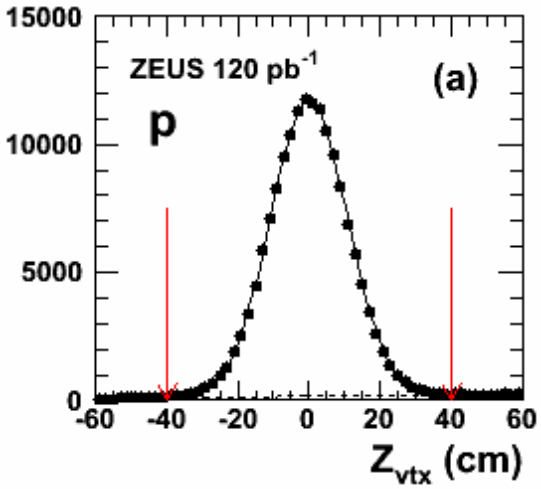


- Also require tracks near interaction point

→ DCA, Z_{vtx} (+ $\Delta Z = Z_{trk} - Z_{vtx}$ for ZEUS)







* Similar selections for H1

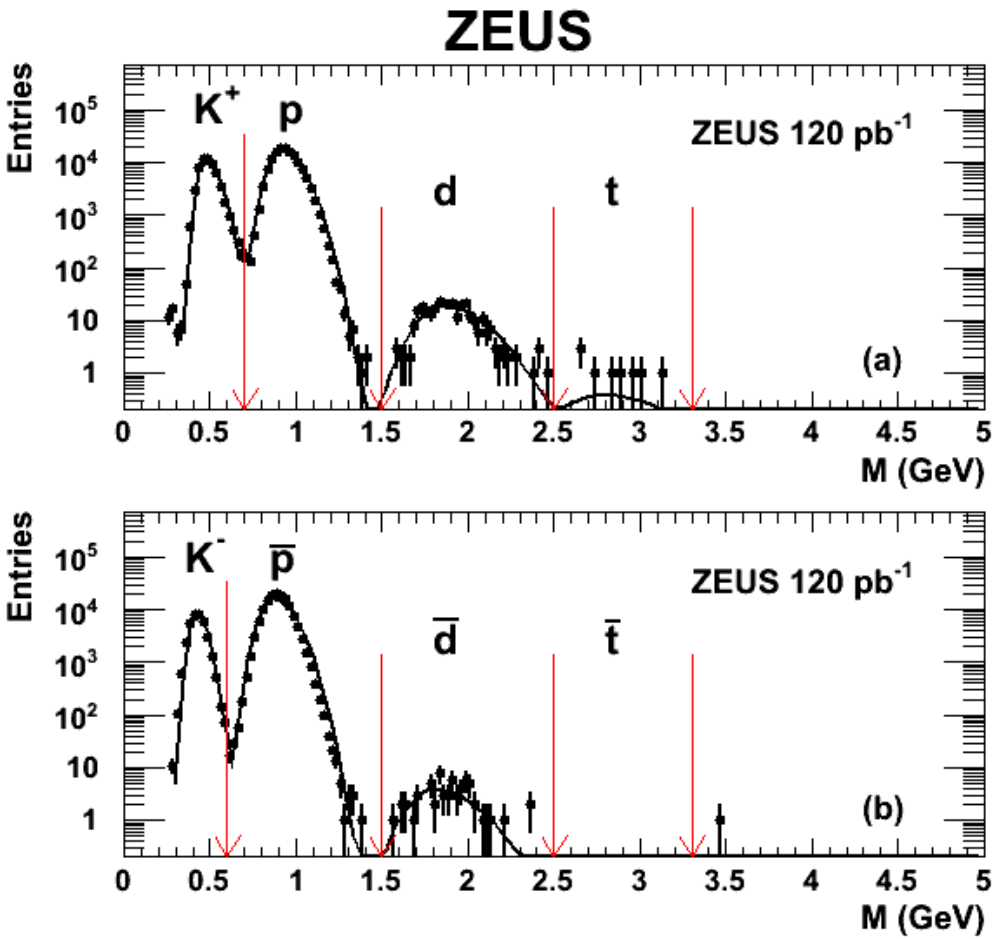
Mass

- Analytically obtained from momentum and dE/dx

- $\Delta M = +7/-11\%$
  → Particle species are well separated

Candidates in DIS :

d	306
$\bar{d}$	62
p	1.61×10^5
$\bar{p}$	1.66×10^5



c.f. H1 observed 45 antideuterons in photoproduction

New stable particles heavier than triton :
→ not observed

Reconstructed efficiencies

* ZEUS

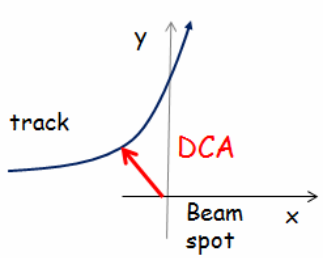
- Tracking efficiency
  - p and d : $\varepsilon \sim 0.95$, p : $\varepsilon \sim 0.9$ (from MC)
  - Antideuteron: not-implemented in MC
    - assumed $\varepsilon(\bar{d}) = \varepsilon(d) * \varepsilon(\bar{p})/\varepsilon(p) \sim 0.9$
      - Effect of absorption loss of d : roughly estimated from $\bar{p}$
        - $\sigma_{inel}(\bar{p}) \gg \sigma_{inel}(n)$ at low mom. → $\sigma_{inel}(\bar{d}) \sim \sigma_{inel}(\bar{p})$
      - Also $\varepsilon(\bar{d})$ was validated with few models

* Similar tracking efficiencies for H1

- Efficiency of dE/dx cut
  - Evaluated from (anti)proton sample from Λ decay (also use MC for confirmation)
  - ~ 70% in average
    - Smaller eff. for high p_T due to threshold cuts on dE/dx

The difference of yields between deuteron and antideuteron in DIS
→ Cannot be explained from reconstructed efficiencies
→ How about Backgrounds?

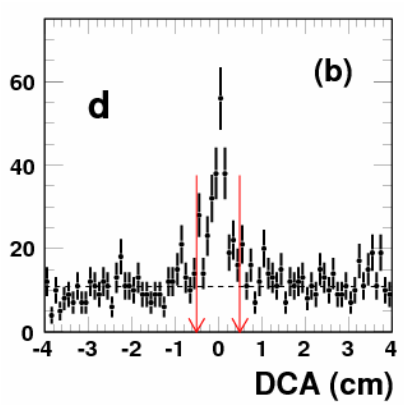
Backgrounds : secondary interactions

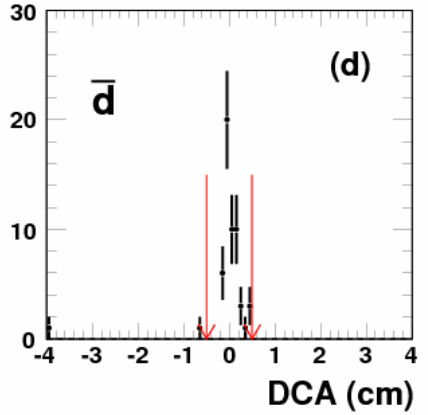


- Tracks from primary interaction :
  - peaks at DCA ~ 0
- Tracks with secondary interaction (with detector material)
  - spread over DCA

→ Backgrounds are subtracted using sideband events

ZEUS (DIS)



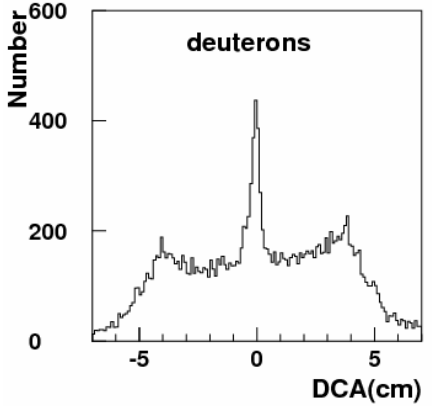


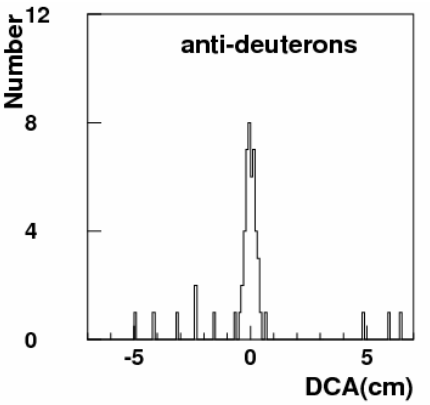
$d_{fit} = 177 \pm 17$ $\bar{d}_{fit} = 53 \pm 7$

Biases of deuteron yields in DIS: ~ 30%

- Pickup process : p+n → d (one nucleon from material)
  - Expectation from previous exp.
  - DCA width of deuteron will be significantly large r with this interaction
- N+N → d + π (one nucleon from material)
  - Track multiplicity for events with d cand.
  - Distance of track between d cand. and another charged tracks
- Comparison between HERA-I and HERA-II
  - Consistent $d/\bar{d}$ ratio

H1 (photoproduction)





Backgrounds : Beam-gas

- Physics events: clean peaks at $Z_{vtx} = 0$
- Beam-gas : spread over Z_{vtx}

Beam-gas events also have peaks at DCA ~ 0

→ Utilize Z_{vtx} to understand beam-gas events

DIS events :

- Almost background free for d (<20%)
- Higher tail in Z_{vtx} → consistent with events containing secondary tracks

Photoproduction events :

- Large contributions from beam-gas

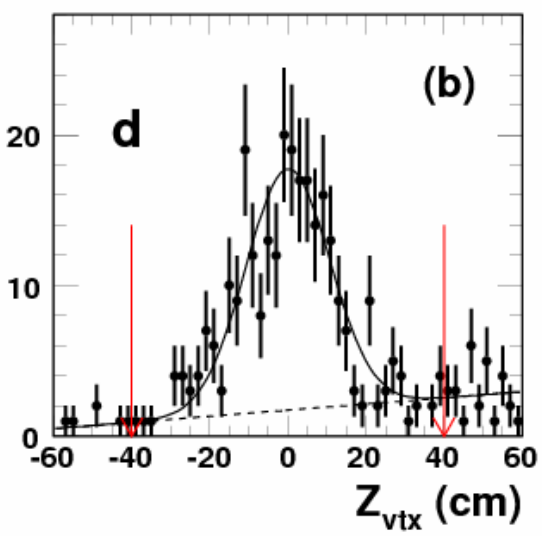
Events from photoproduction :

→ Estimated from events with forward/backward calorimeter hits (C11)

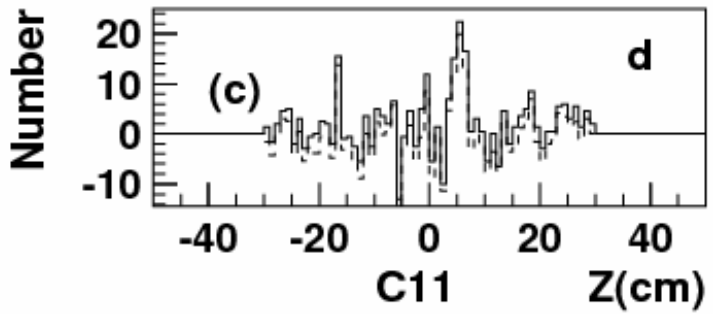
(dominated by photoproduction)

→ Large uncertainties, no physics results for d

ZEUS (DIS)



H1 (photoproduction)

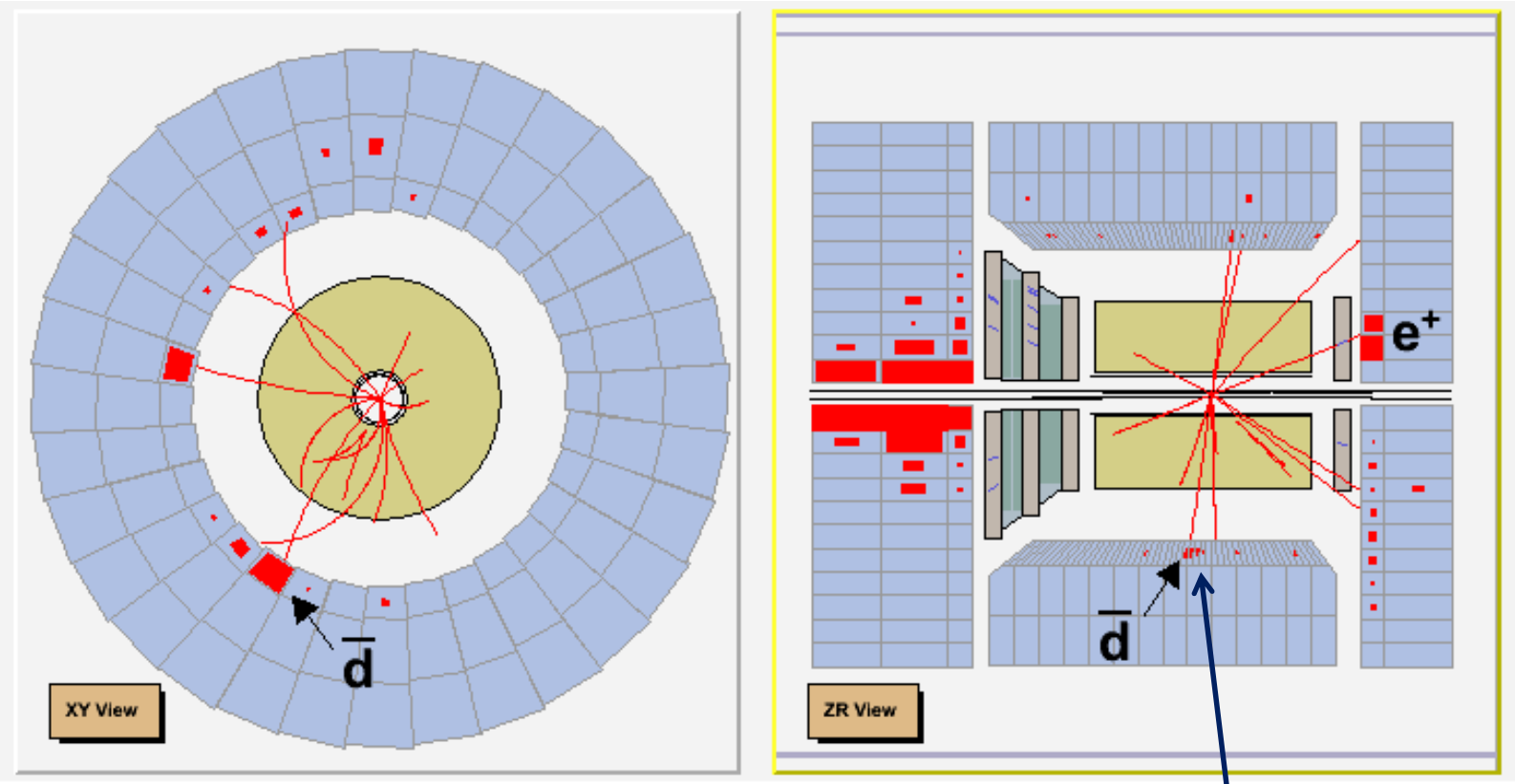


* Subtracted Backgrounds estimated by DCA

Antideuteron candidate in DIS

$Q^2 = 45.5\ \mathrm{GeV}^2$

$E_e' = 14.1\ \mathrm{GeV}$

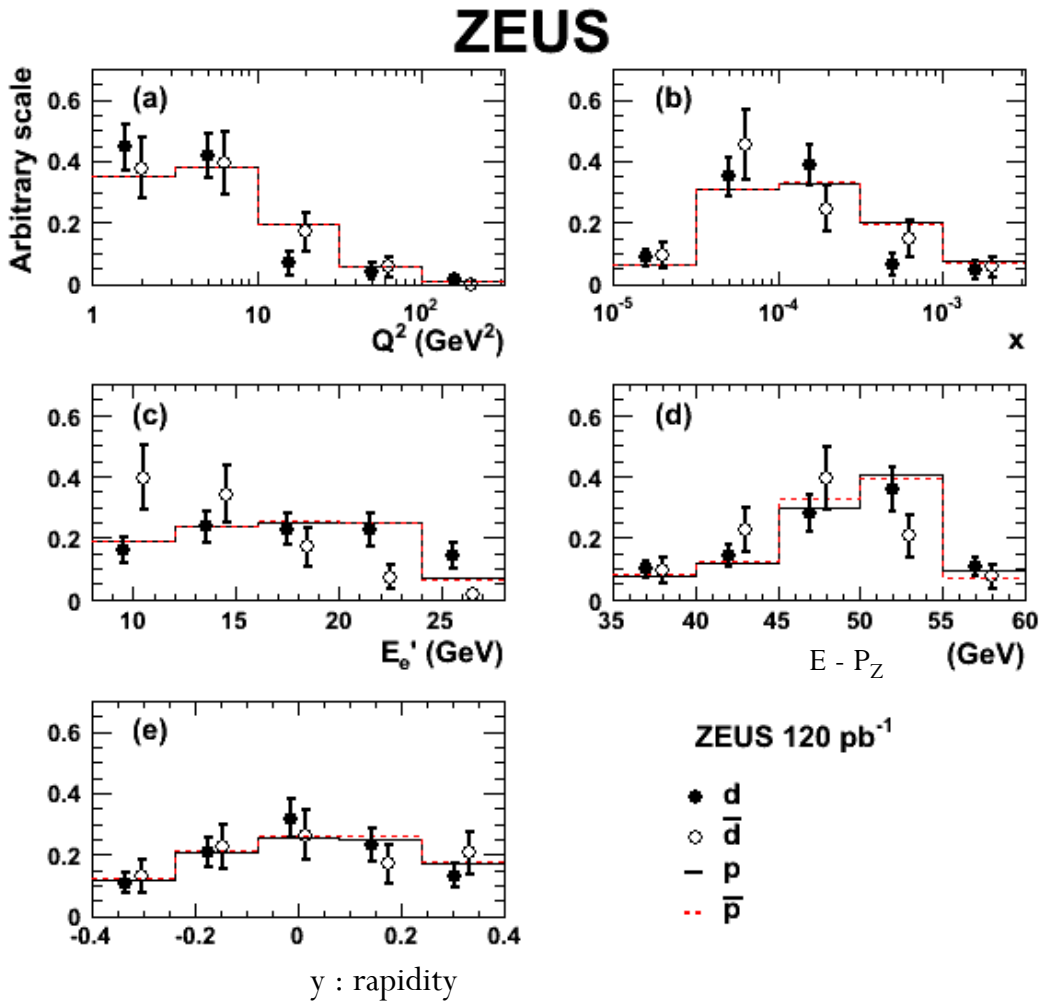


- Candidate track :
  - P = 1.1 GeV, DCA = -0.09 cm
  - dE/dx (mips) = 2.7

$E_{CAL} = 3.2\ \mathrm{GeV}$

Consistent with $\bar{d}$ annihilation

Distributions of (anti)deuterons and (anti)protons in DIS



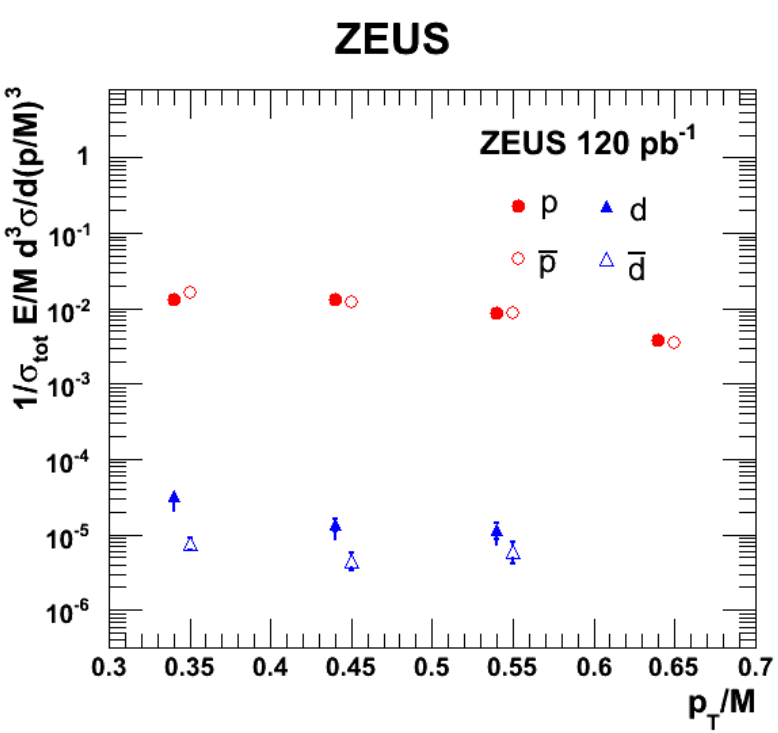
- Events with d are consistent with $\bar{p}$ and p in DIS
- Some small differences for $\bar{d}$ candidates (E_e', $E - P_Z$)

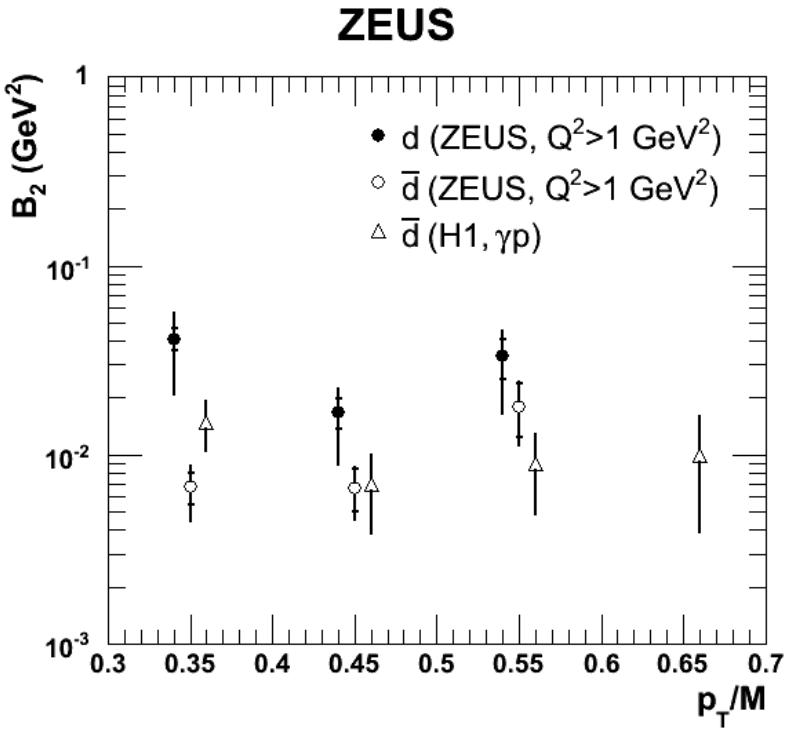
Cross sections and B_2

- Deuteron yields suppressed by 1000 (relative to protons)
- Good agreements of B_2 between DIS and photoproduction
- Deuteron yield is systematically larger than antideuteron

$$\frac{E_d}{\sigma_{tot}}\frac{\mathrm{d}^3\sigma_d}{\mathrm{d}p_d^3} = B_2\left(\frac{E_p}{\sigma_{tot}}\frac{\mathrm{d}^3\sigma_p}{\mathrm{d}p_p^3}\right)^2$$

$$B_2 = M_p^4\, M_d^{-2}\, R^2(d/p)\left(\frac{\gamma_d}{\sigma_{tot}}\frac{\mathrm{d}^3\sigma_d}{\mathrm{d}(p_d/M_d)^3}\right)^{-1}$$





- For (anti)protons, subtracted the events from Λ decay (~20%)

B_2, comparisons

B_2 in DIS (unit: 10^{-2} GeV^{-2})

$B_2(d) = 3.32 \pm 0.34\ ^{+1.13}_{-1.55}$

$B_2(\bar{d}) = 0.89 \pm 0.14\ ^{+0.19}_{-0.20}$

Consistent with photoproduction , pp, pA, Υ(1,2S)

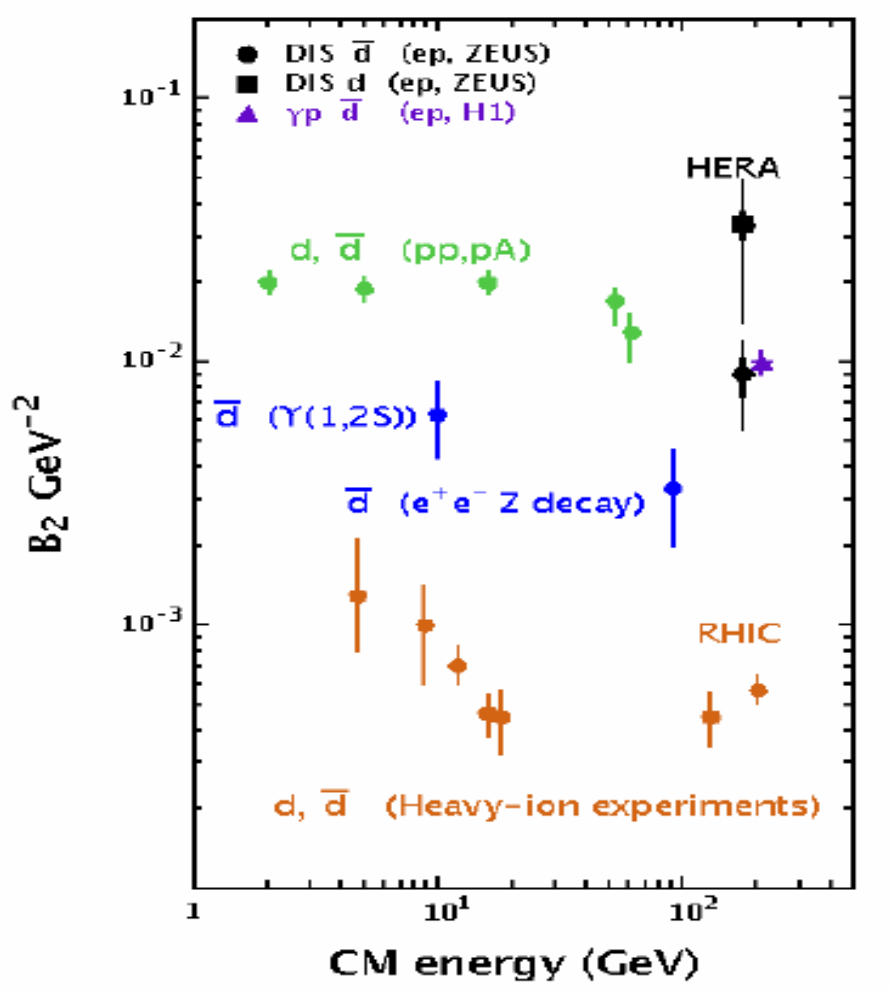
Significantly smaller B_2 in AA

→ larger source size

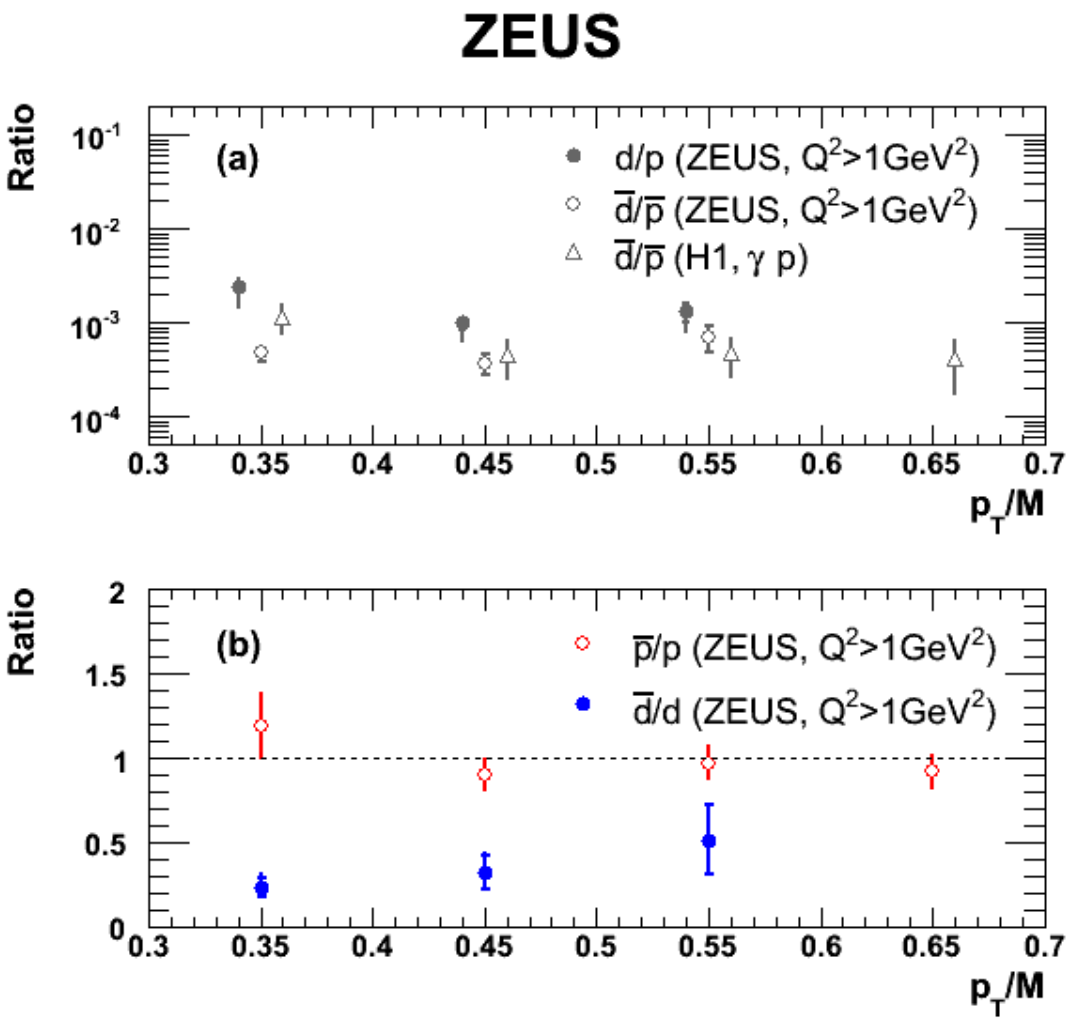
* $B_2 \sim 1 / V$ (freeze out volume)

Significantly smaller B_2 in e^+e^- →Z

→ Not well known. The only model for G.Gustafson & J. Hakkinen fails



Ratios



- $\bar{d}/p$ ratio ~ 5x 10^{-4}
  - Consistent between DIS and photoproduction
- New results on ratios in DIS $\bar{p}/p$, $\bar{d}/d$

Averaged values:

- $\bar{p}/p = 1.05 \pm 0.15$
- $\bar{d}/d = 0.31 \pm {}^{0.12}_{0.08} < 1$

Dose not support prediction from coalescence model

$$\bar{d}/d = (\bar{p}/p)^2$$

Open questions :

- Consistency with other experimental results?
- Any theoretical interpretation?

Conclusions

- H1 and ZEUS provide (anti)deuteron measurements with newer processes in ep collision :
  - Antideuteron production in photoproduction : H1
  - (Anti)deuteron production in DIS : ZEUS
    → first measurements of d in elementary particle collisions
- Deuteron rates :
  - Three orders of magnitude suppressed compared to protons
  - Studied also in terms of coalescence model
    - B_2 is consistent between photoproduction and DIS
    - B_2 at HERA is compatible with pp, pA collisions, but significantly larger than heavy ion collision and e^+e^-
- Baryon asymmetries in DIS :
  - $\bar{p}/p$: consistent with 1
  - $\bar{d}/d$: ~ 0.3
    - Does not support prediction from coalescence model, $(\bar{p}/p)^2$
    - Further investigations from experimental and theoretical side will be useful for the better understanding