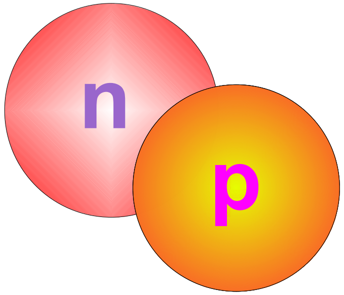
Deuteron and antideuteron production in DIS at HERA

S.Chekanov
(DESY/ANL)
on behalf of the ZEUS Collaboration

DIS07, Munich, Germany
April 2007

.. Deuterons? What do we know about them?

- **Deuteron (d):**
  - nucleus of deuterium
  - multiquark particle with one proton and one neutron



(anti)Deuterons in elementary particle collisions

- **$p + n \to d$ due to overlap of wave functions in the final state $\sim \langle \varphi_{pn} | \varphi_d \rangle$**
  - p and n should be close in space and momentum
- **Cannot be produced by the standard hadronisation of quarks and gluons**
  - not even implemented in the current Monte Carlo models
- **$\bar{d}$ yield in $e^+ e^- \to q\bar{q}$ is factor ~5-10 smaller than in Upsilon production**
  (studies by ARGUS, OPAL, ALEPH, CLEO)
- **Observation of $\bar{d}$ in ep photoproduction (H1)**
- **No measurements of d:**
  - beam-gas, beam-wall & secondary interactions have to be understood

The coalescence model

- **Active topic for pp, pA, AA collisions and cosmic-ray studies:**
  - **pp, pA, AA: both d and $\bar{d}$ were measured**
  - **Explore nuclei production in the early universe**
  - **Created during "freeze-out" stage of fireball via coalescence:**

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

Coalescence parameter: $\mathbf{B_2 \sim p_0^3\,\gamma \sim r(n/p) / R^3}$

R – source radius

r(n/p) – ratio of neutrons to protons yields (depends on the beam and target nuclei)

- if B_2 is the same for particles and antiparticles: $\bar{d}/d = (\bar{p}/p)^2$

- test the coalescence model by reconstructing $\bar{d}$/d

Recent measurement: Au+Au — $\bar{d}/d = 0.47 \pm 0.03$

PHENIX Coll. PRL (2005) 122302 — $\bar{p}/p = 0.73 \pm 0.01$

Also by ISR (1973-1978), British-Scandin.(1978), E858 (1992), E864(2000), NA44 (1995), BRAHMS (2006) Collab...

Motivation

Possible connection with pentaquarks (PQ)?

- as PQ, d is multiquark state
- PQ may be explained using the coalescence model as well? (Karliner&Webber, 2004)
- PQ candidates where not found in e^+e^- where d production is suppressed compared to proton-initiated processes

Deuterons in DIS?

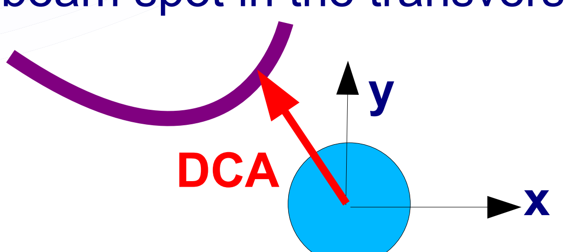
- $\bar{d}$ and d have not been observed so far
- Both d and $\bar{d}$ could be reconstructed under <u>clean experimental conditions</u>
  - detection of scattered electron reduces beam-gas contributions
- huge event sample with unbiased hadronic-final state selection

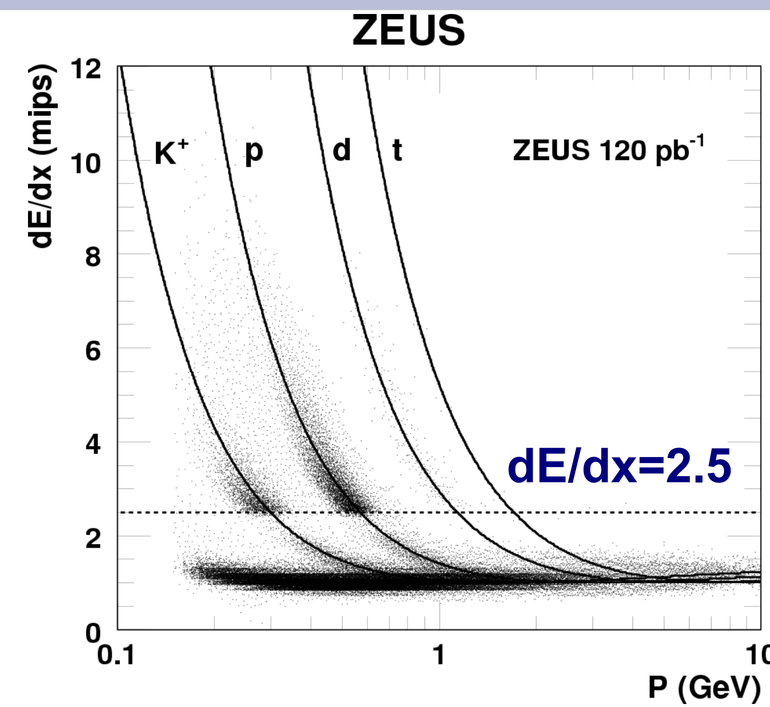
Look at baryon-antibaryon asymmetry in production yields:

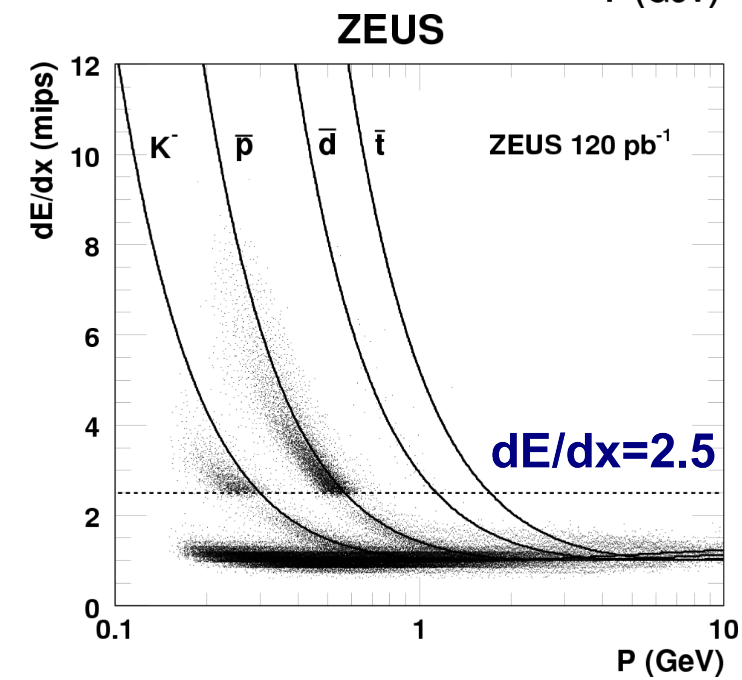
- Asymmetry in ep is expected for final-state protons due to several effects
  - valence quark contribution (<2-4%)
  - baryon-number transfer by gluons (< 8%) (Kopeliovich&Povh, 1997)
- Asymmetry strength affected by baryons from quark and gluon fragmentation
- What about "compound" particles which are not contaminated by the standard fragmentation?

Data selection and reconstruction

- **Event selection and kinematic range**
  - 120 pb^{-1}. HERAI data
  - E_e>8.5 GeV
  - $|Z_{vtx}|$<50 cm $X_{vtx}^2 + Y_{vtx}^2 < 1$ cm
  - Q^2>1 GeV^2 ($\langle Q^2 \rangle$ ~10 GeV^2)
  - number of primary track >3
  - P_T(tracks)>150 MeV
  - all good quality tracks (>3 CTD super-layers)
  - dE/dx for particle identification
  - events with at least one track for dE/dx>2.5
  - 0.3 < p_T/M<0.7 and central rapidity $|\Delta y|$<0.4
- **Primary tracks are selected using statistical background subtraction in 2 variables:**
  - **ΔZ** - distance from track helix to Z_{vtx} in Z
  - **DCA** - distance of closest approach of the track to the beam spot in the transverse plane







Data selection and reconstruction

- **Mass reconstruction:**
  - Use dE/dx Bethe-Bloch formula
  - scan mass where differences from the Bethe-Bloch expectations are minimal
- **Small shift for positive and negative tracks**

  (expected due to CTD structure)
- **Mass resolution:ΔM/M = +7-11 %**

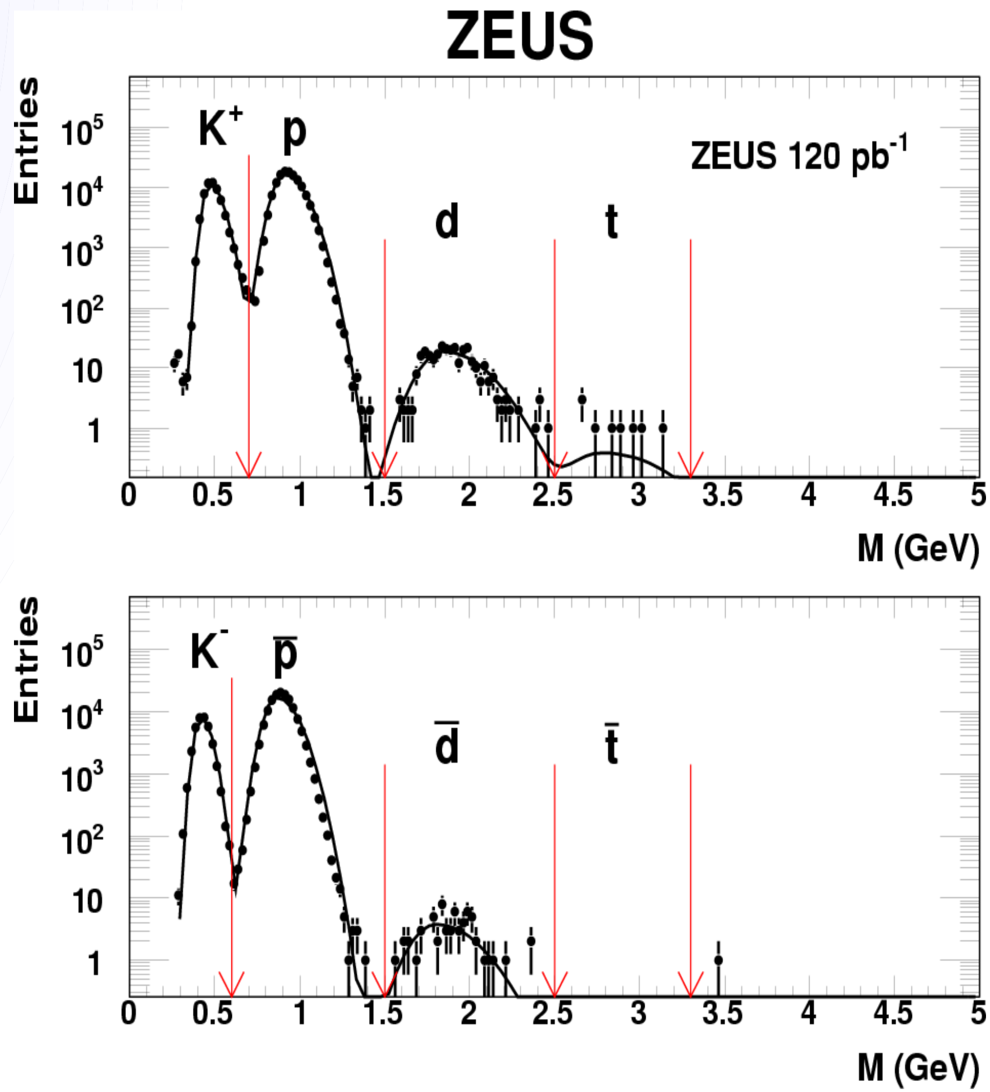
Mass requirements for candidates:

- **p : 0.7 (0.6) < M < 1.5 GeV**
- **d : 1.5 < M < 2.5 GeV**
- **t : 2.5 < M < 3.3 GeV**

Numbers of candidates:

d:	**309**
$\bar{d}$	**62**
p:	**1.61×10^5**
$\bar{p}$:	**1.66×10^5**

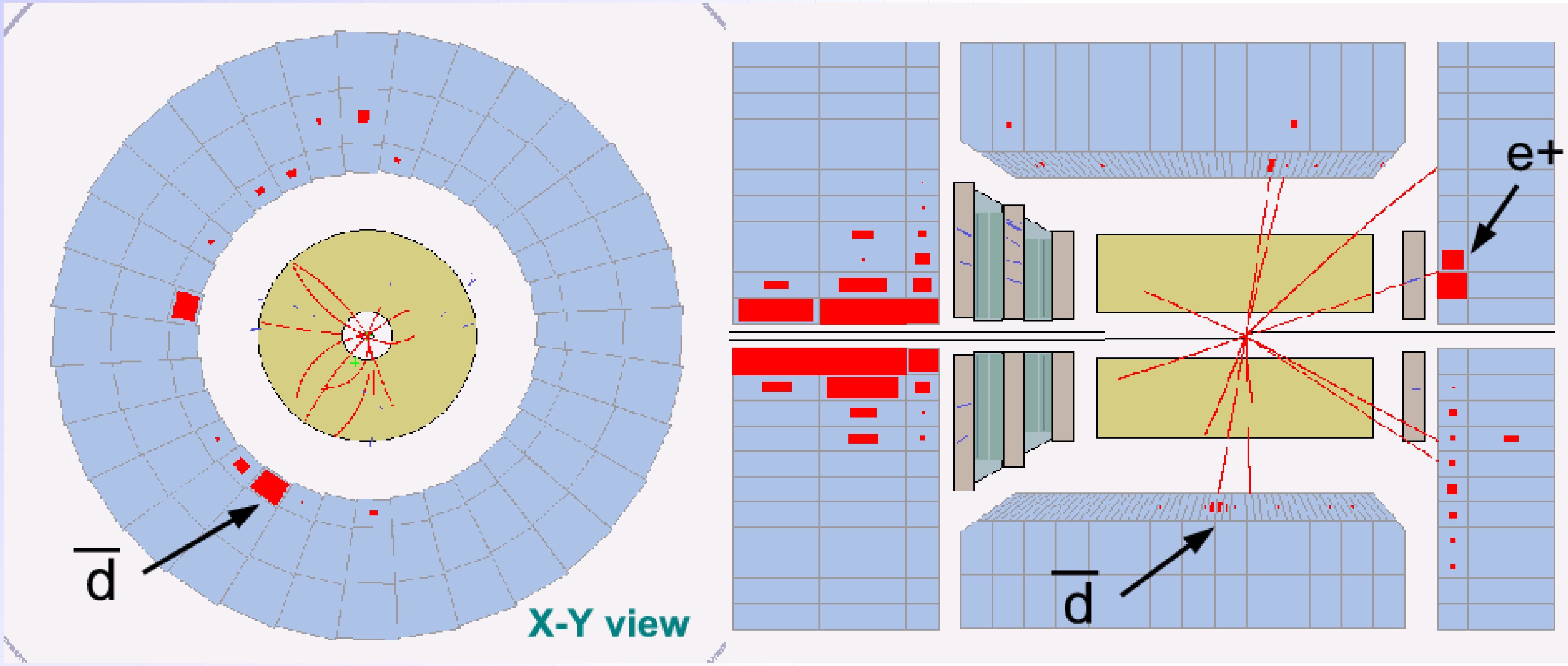
more $\bar{p}$ than p
due to CTD efficiency



Final identification of primary particles is based on ΔZ and DCA distributions

No (anti)deuteron candidates are found in the current region of the Breit frame (analogous to a single hemisphere of e+e-)
No contradiction with low rate of $\bar{d}$ in e+e-

DIS event with antideuteron



First observation of $\bar{d}$ in DIS
$\bar{d}$ annihilates on the surface of CAL

Q^2 = 45.5 GeV^2
E_e = 14.1 GeV
12 primary tracks
p =1.1 GeV
dE/dx=2.7 mips
E_{CAL} = 3.2 GeV
DCA=-0.09 cm

ZEUS interaction region:
- Beam-pipe: Al
  D=324 mm.
  thickness=1.5 mm
- CTD inner wall:
  2 Al skins with thickness 0.7 mm

Small amount of inactive material compared to other experiments (~0.03X0)

Identification of particles from ep

Clear peaks for ΔZ & DCA distributions due to primary ep particles

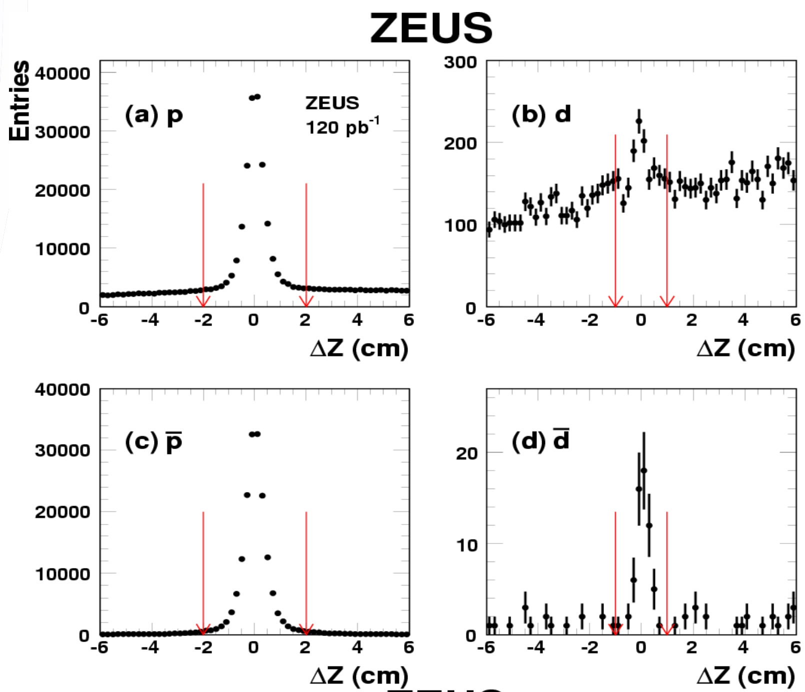
- dE/dx mass cuts to identify particles
- |ΔZ|<2(1) cm for p (d) to reduce background
- DCA (best resolution!) background subtraction to reconstruct primary particles

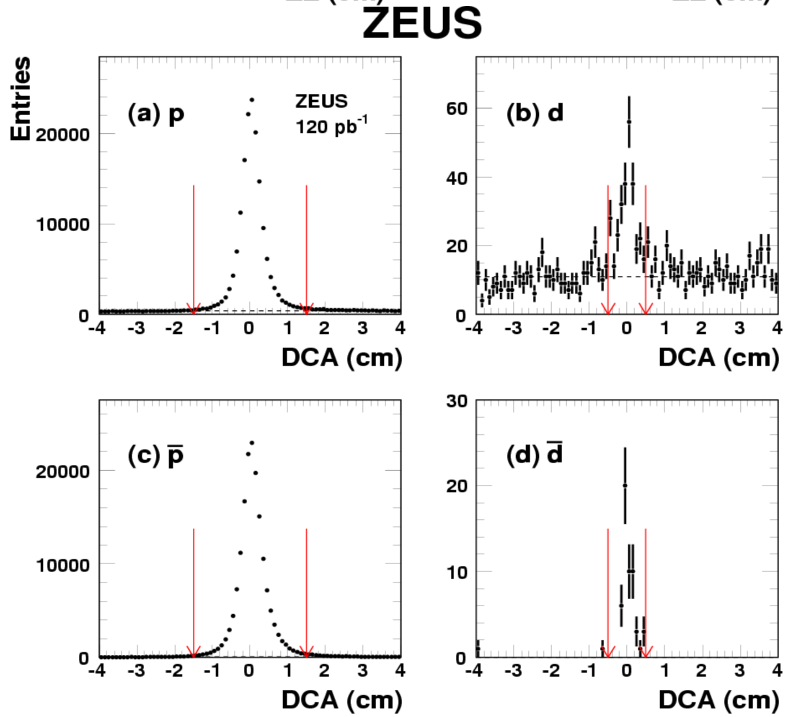
Tracking efficiency:

- d implemented in MC
- For p and d using MC: ε~0.95; For $\bar{p}$: ε~0.90
- For $\bar{d}$: ε($\bar{d}$)~ ε(d)ε($\bar{p}$) / ε(p)~0.9
  - GEANT/GHEISHA does not treat $\bar{d}$!
- Validate using few models for inelastic nuclear cross section
- Annihilation of $\bar{d}$ was found to be small (<5%):
  - beam-pipe + CTD inner wall: ~3%X0

dE/dx efficiency:

- ~ 70% in average
- estimated using Λ→pπ and MC (as a cross check)
- MC was used to confirm

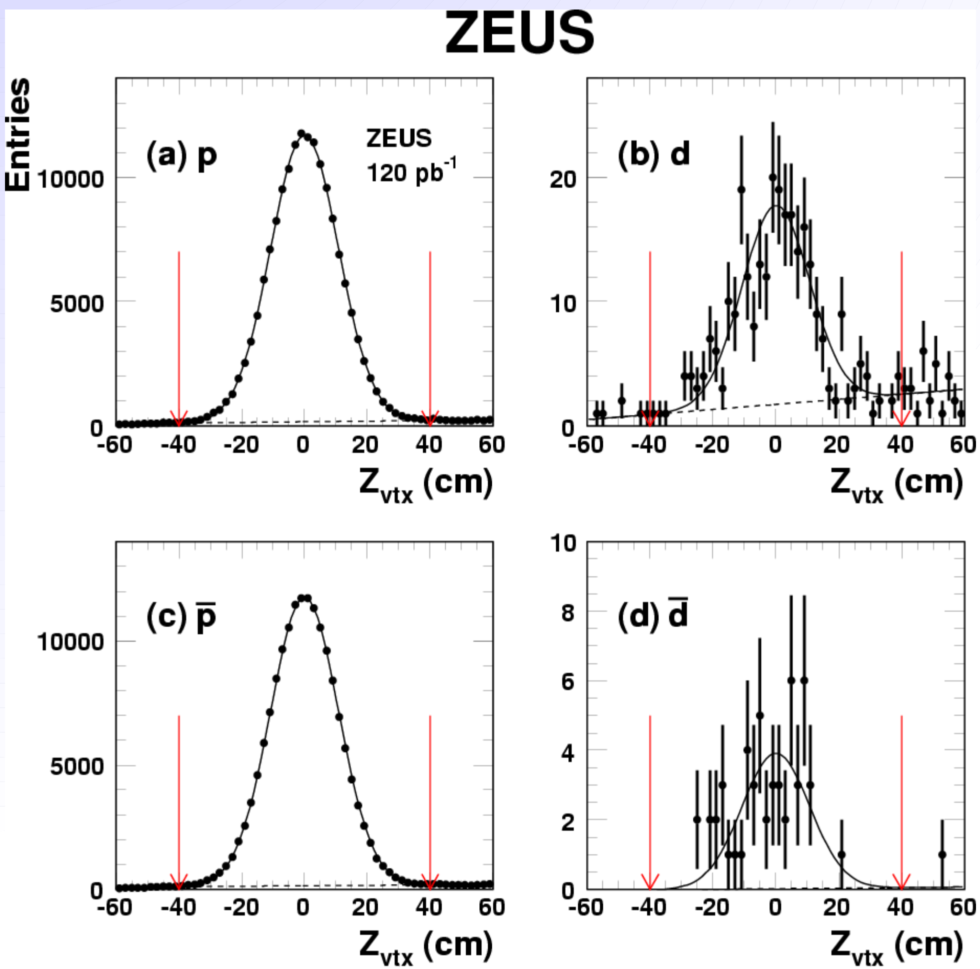


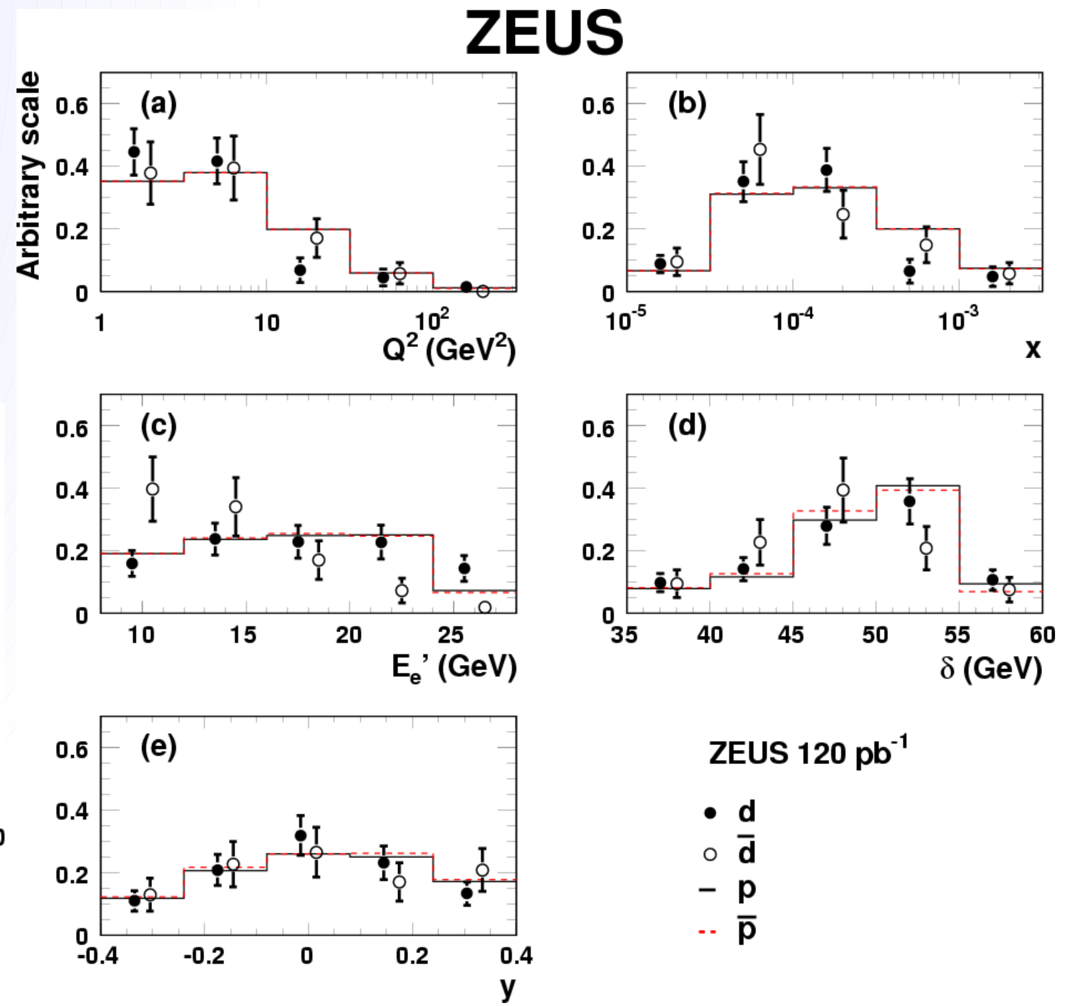


Identification of particles from ep

Clear peaks for Z_{vtx} distribution
Almost background free

Small background for Z_{vtx} consistent with being contribution from:
- secondary interactions (from MC studies)
- electron-gas events?





Events with d are consistent with being DIS events (with p and $\bar{p}$)

Some small difference for $\bar{d}$ compared to proton sample

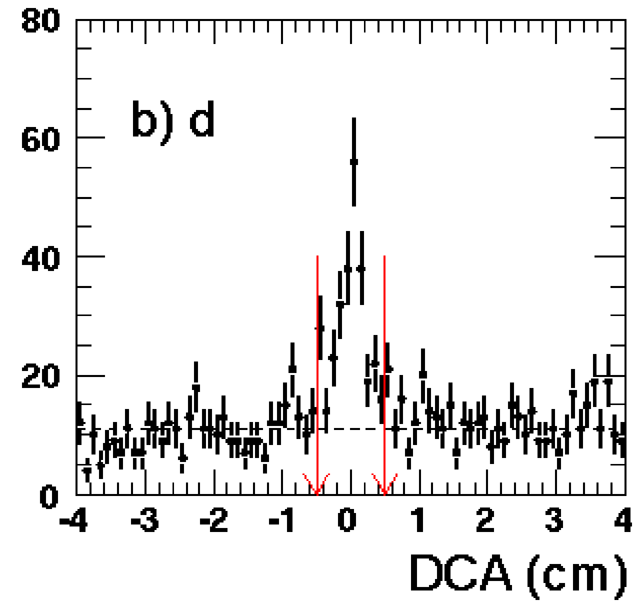
Studies of background processes

Difference between the production yields of $\bar{d}$ and d after the DCA background subtraction is difficult to explain by the tracking efficiency

Possible background sources:

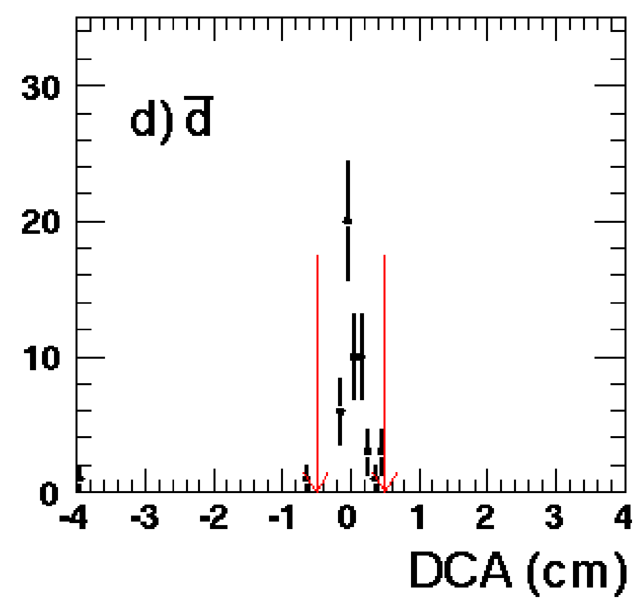
- beam-gas interactions

- secondary interactions of particles from ep



Beam-gas (eA,pA) & beam-wall interactions

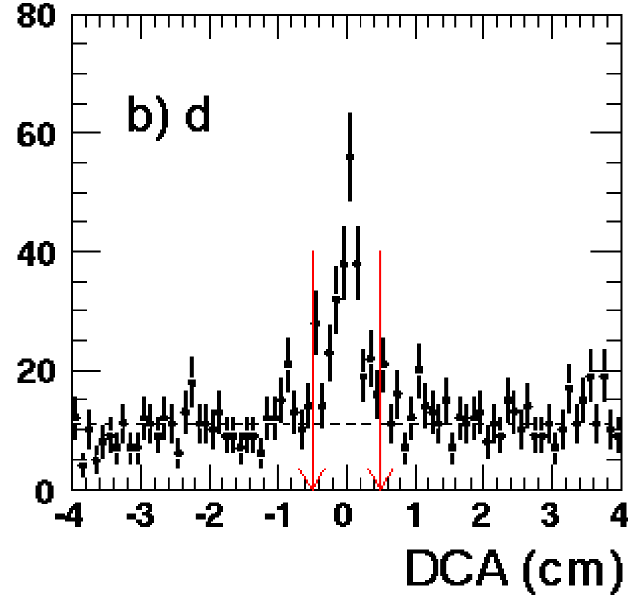
- Expected to be negligible for DIS
- All DIS distributions for d looks as expected
- Beam-wall events are removed using cut on transverse component of the primary vertex
- Events were visually analysed using an event display
- Beam-gas events were studied for non-colliding bunches
  - No peak for Z_{vtx}=0

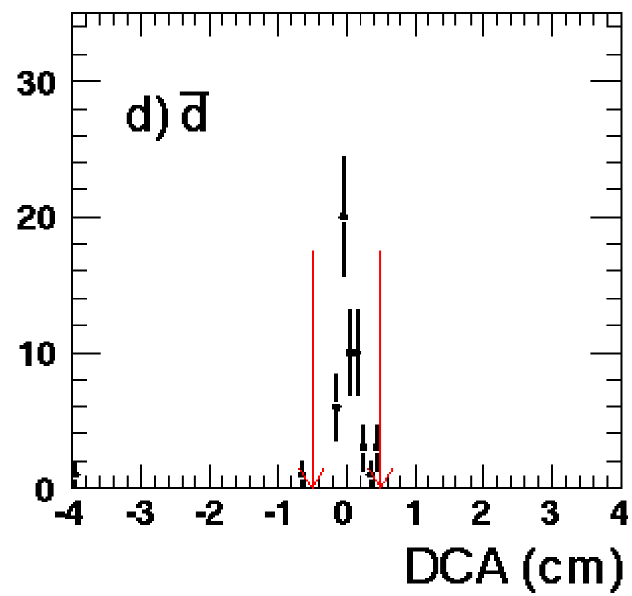


Studies of background processes

Secondary interactions on material

- MC (GEANT) does not show any peak at $\Delta Z=0$ and DCA=0 for secondary d and p
- DCA widths for d and $\bar{d}$ are statistically consistent.
- DCA width for d is also consistent with that for p ($\bar{p}$)
- Pickup processes $p+n \rightarrow d$ (one nucleon from material) were studied from previous experiments:
  - DCA is expected to be significantly wider
  - absolute rate is difficult to verify
- $N+N \rightarrow d + \pi$ (one nucleon from material)
  - No enhancements for:
    - track multiplicity compared to $\bar{d}$ events
    - tracks close to d
- HERAII data analysed with a larger amount of inactive material in from of the CTD
  - consistent $\bar{d}$/d ratio with HERAI was found





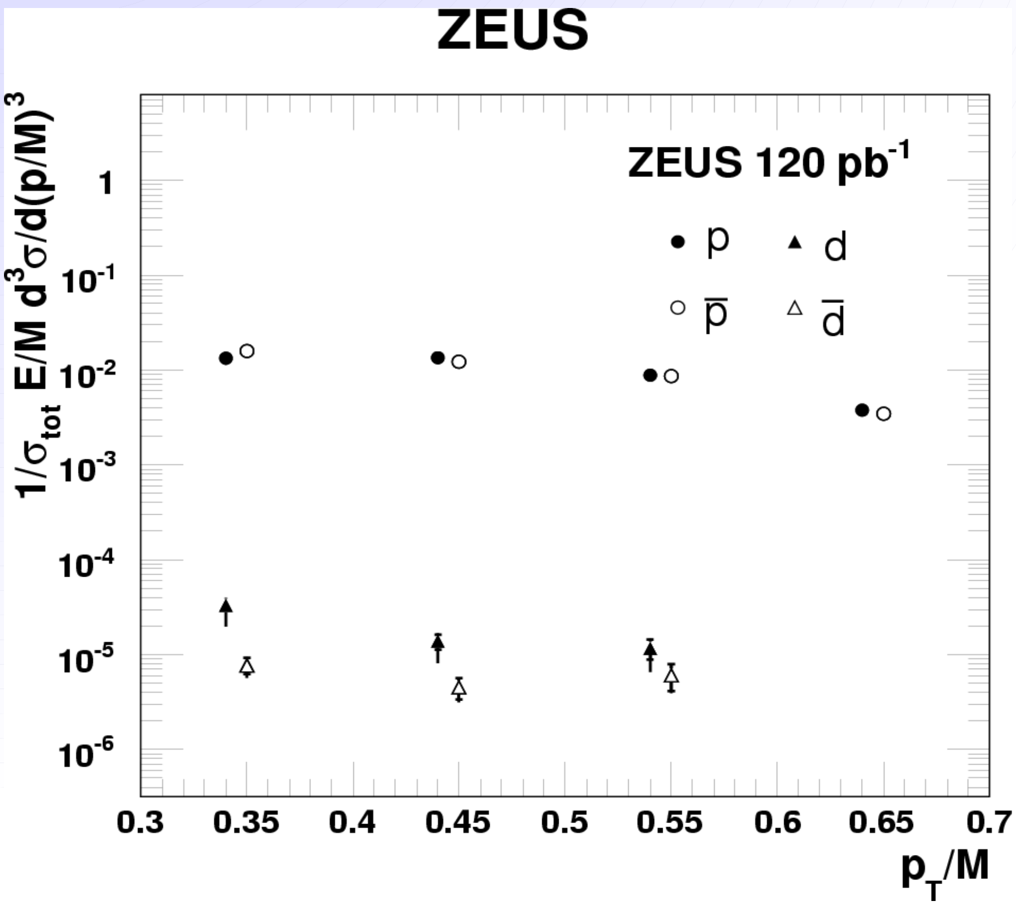
No experimental evidence for d originating from secondary/beam-gas interactions found

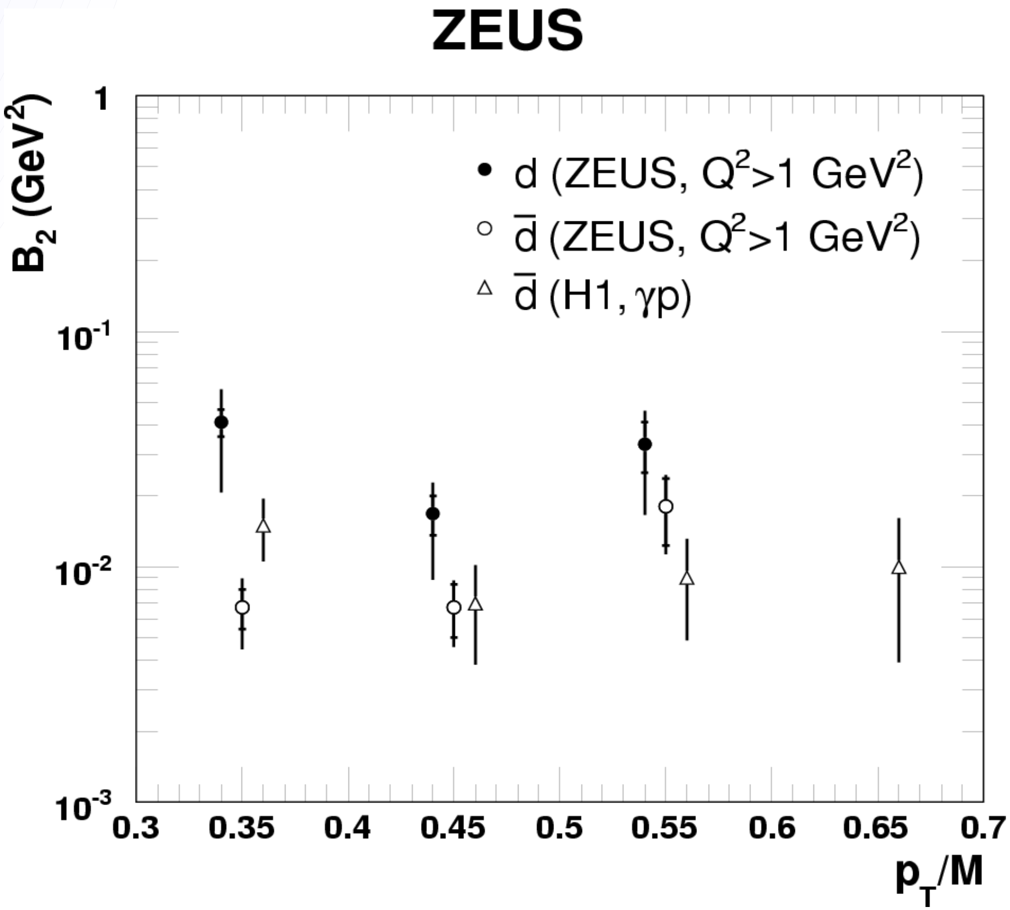
Reconstruction of cross sections and B_2

- **Deuteron yield suppressed by a factor of about 1000 (relative to protons)**
- **Good agreement for B_2 between DIS and photoproduction (H1)**
- **Some systematic difference in the production rate of d and $\bar{d}$**

$$\frac{E_d}{\sigma}\frac{d^3\sigma_d}{dp_d^3} = B_2 \left(\frac{E_p}{\sigma}\frac{d^3\sigma_p}{d(p_d/2)^3}\right)^2$$

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





Summary of B_2

$B_2 \sim r(n/p)/R^3$

R – source radius
r(n/p) – ratio of neutrons to protons

B_2 in DIS and photoproduction are consistent

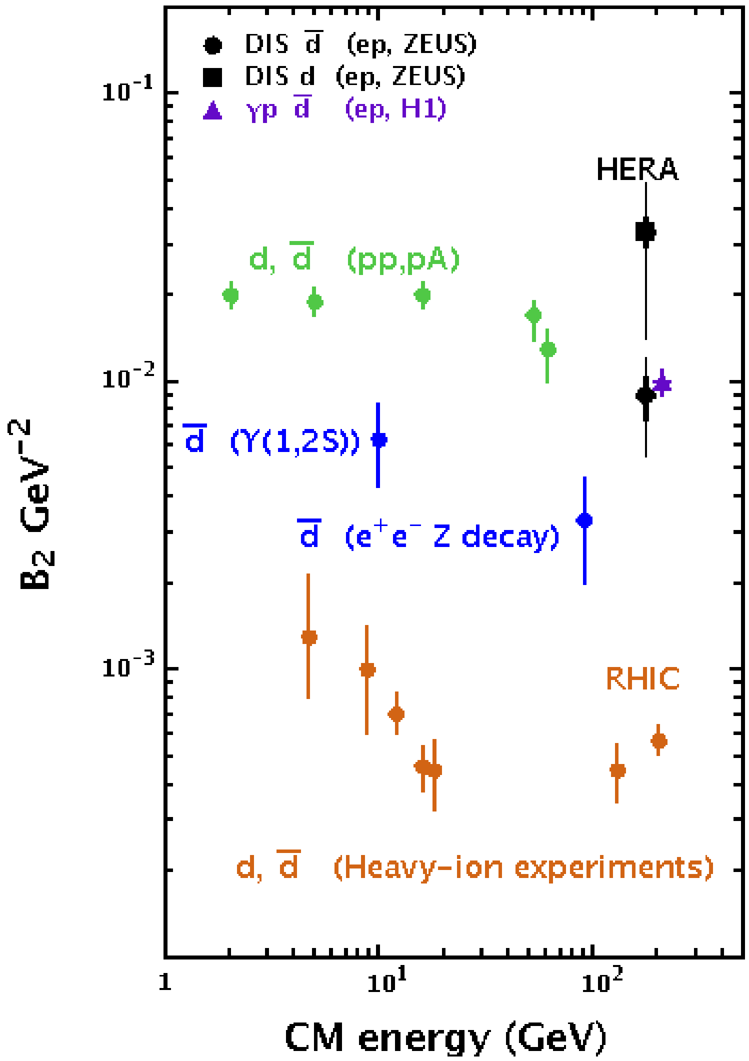
B_2 in ep is significantly larger than in heavy-ion collisions and $e^+e^- \to q\bar{q}$

→ **Smaller source radius**

Assuming the coalescence model:

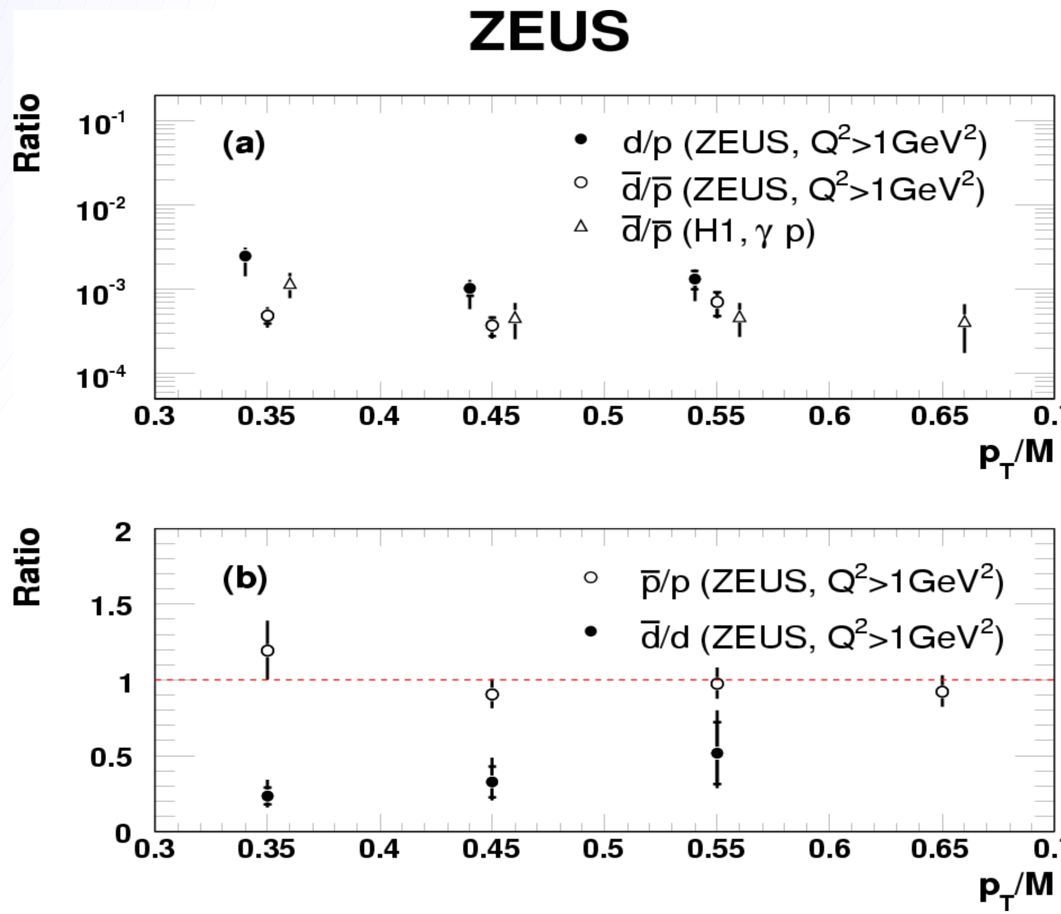
- indication for a smaller source radius for d compared to $\bar{d}$?
- or.. r(n/p) is larger than $r(\bar{n}/\bar{p})$?

B_2 world data



Ratios

- **Look at particle/antiparticle yields directly**
  - Remember: for the coalescence model: $\bar{d}/d=(\bar{p}/p)^2$ **(*)**
- **Good agreement between $\bar{p}$ and p yields for $0.3<p_T/M<0.7$**
- **Systematic difference in yields between d and $\bar{d}$**



- **For many heavy-ion and pp experiments, the rate of d is indeed higher than that for $\bar{d}$, but agrees with (*)**
- **Assuming that background processes do not produce a peak at DCA=0 → $\bar{d}/d<1$**
  - **does not support (*)**
- **Open questions:**
  - Does this contradict other measurements?
  - Does this contradict theoretical expectations?

$\bar{d}$ bar /d < 1 contradicts to what we know?

Experimental situation:

- **No d measurement in collisions with elementary particles:**
  - ARGUS (e+e-). No DCA available, only $\bar{d}$ can be measured
    Phys.Lett. B236 (1990) 102
  - ALEPH (e+e-). DCA too complicated without a clear background level (spallations?)
    Phys.Lett. B639 (2006) 16
  - OPAL did not find antideuterons. Sets a limit.
  - H1 (γp). No deuteron measurement due "background" (beam-gas?)
    Eur. Phys. J C36 (2004) 413
  - CLEO (e+e-). No deuteron measurement, only checks for "consistency"
    hep-ex/0612019
- **All other measurements done in heavy-ion and pp, pA:**
  - **all indicate $\bar{d}$/d<1, but usually consistent with $(\bar{p} / p)^2$**

Theoretical remarks:

- **No theory for deuteron production from "first principles"**
- **Open questions for the coalescence model:**
  - B_2 for e+e- is a factor ~5-10 suppressed compared to hadronic and photonic collisions (including the present result)
  - The only model for elementary collisions (G.Gustafson & J.Hakkinen) fails

Conclusions

- **First observation of $d(\bar{d})$ in DIS**
- **First measurement of d in collisions with elementary particles**
- **Rates are three orders of magnitude suppressed relative to protons**
  - consistent with the world measurements
  - ~5-10 times higher compared to e+e-
- **Yield of p is consistent with that for $\bar{p}$ for $0.3<p_T/M<0.7$**
  - ~12% experimental uncertainty
  - difficult to verify models predicting 4-8% p-$\bar{p}$ asymmetry
- **Rate of d is ~3 times larger than that for $\bar{d}$**
  - no evidence for d originating from secondary/beam-gas interactions found
- **Production rates were studied in terms of the coalescence model:**
  - invariant cross sections and B_2 are consistent with results in photoproduction (H1)
  - significantly smaller production volume compare to AA