Study of (anti)deuteron production at SPS energies

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OUTLINE

- Motivation
- NA49 Experiment
- Data analysis
- Results:
  - pT-spectra and rapidity distributions of (anti)nuclei
  - centrality dependence of the cluster yields
  - combined analysis of anti-p and anti-d (coalescence)
- Summary

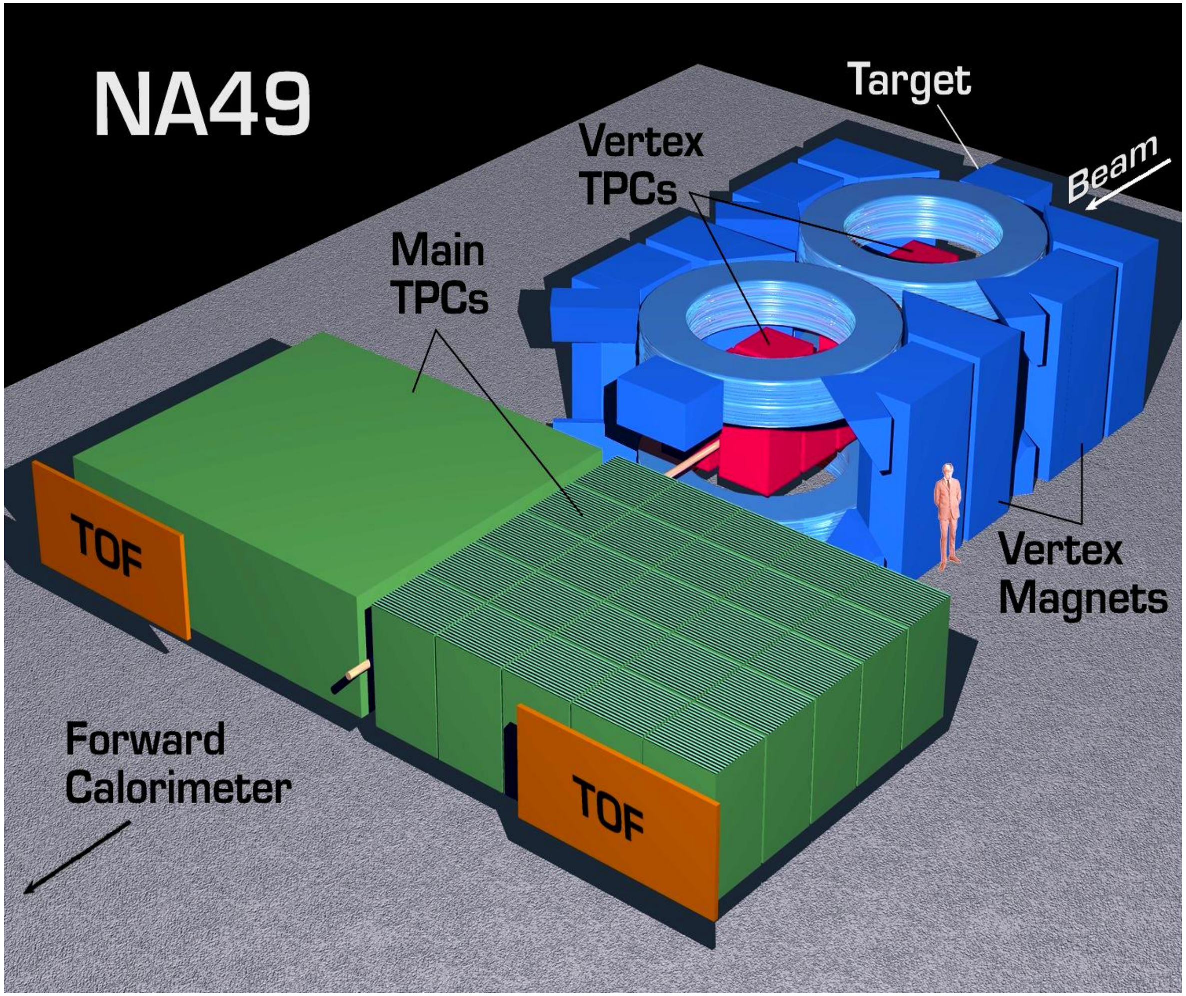
Motivation

- Anti-matter is produced in the course collision
(no contribution from spectators)

- Enhanced antimatter production in A+A (relative to p+p) was predicted as a signature of QGP

- Provide information on collision dynamics (namely):
space-time evolution of the created fireball ,
effective participant source volume,
freeze-out nucleon density distribution,
momentum-space correlations,
effects of annihilation and break up in the dense matter.

The NA49 Apparatus



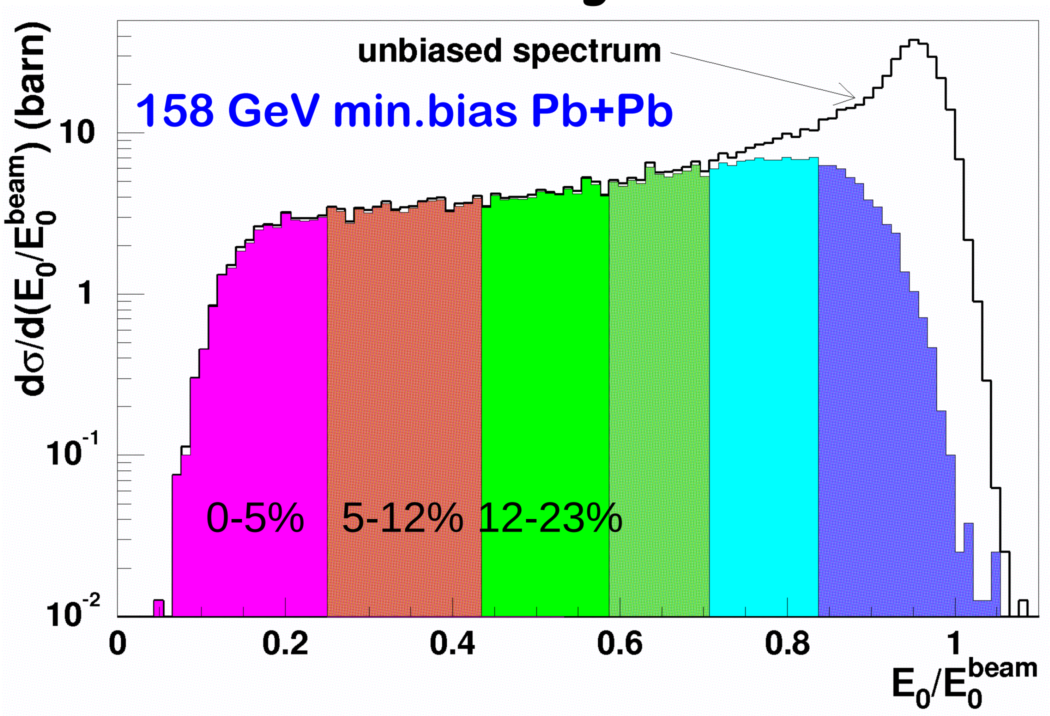
Large acceptance:
full forward
hemisphere

Tracking: 4 TPC,
$\delta p/p^2 = 3\ 10^{-5}\ (\mathrm{GeV}/c)^{-1}$

Particle ID:
dE/dx : $\sigma_E/E \cong 4\%$
TOF: $\sigma \cong 60$ ps

Centrality selection: ZDC

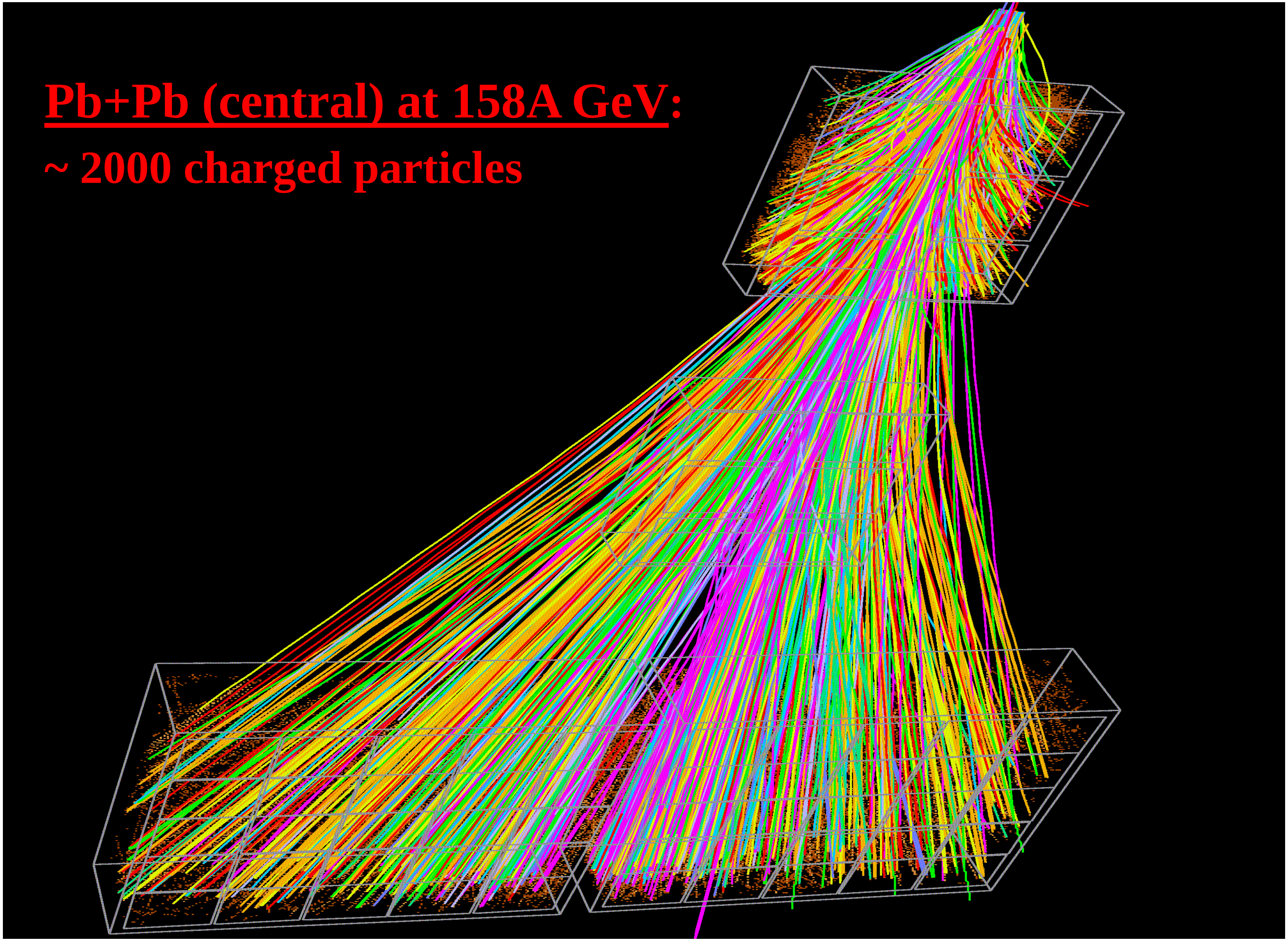
Centrality determination in NA49



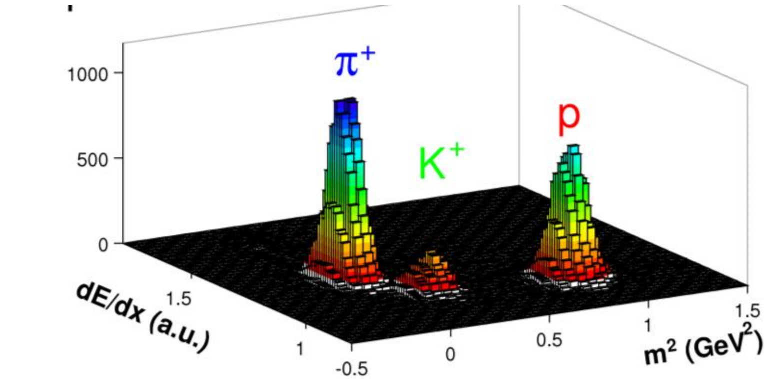
- Centrality (in %) = $\sigma_{trig}/\sigma_{total}$
- Off-line selection by windows in the measured ZDC spectrum
- For a given bin, all the relevant numbers (i.e. N_{wound} N_{part}, b) are derived from models

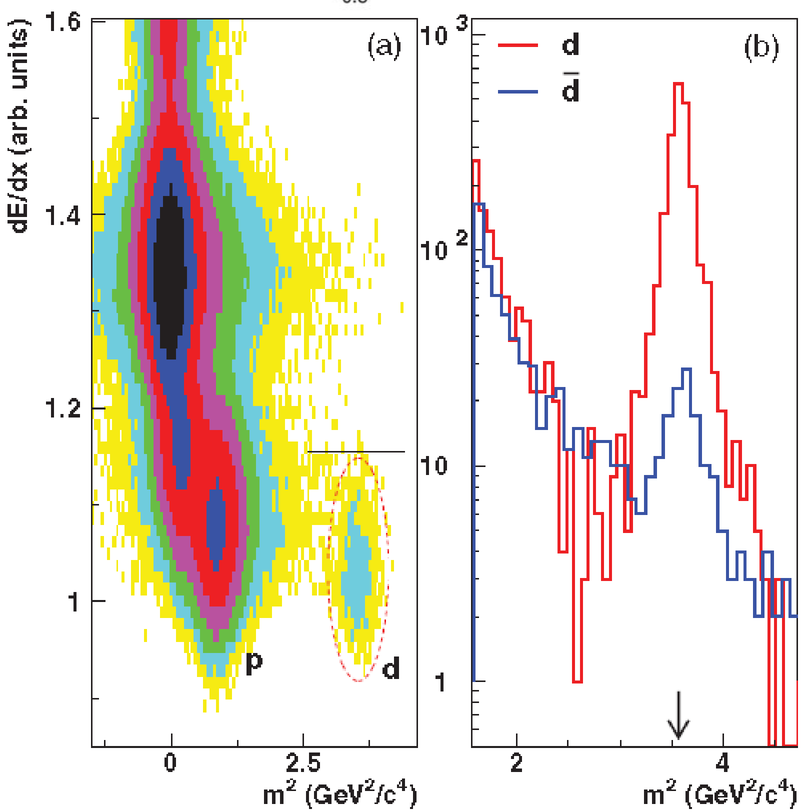
TABLE I. Summary of the data sets used in the analysis. The number of events employed are given together with the fraction of the total cross-section (in percent) and corresponding average number of wounded nucleons $\langle N_W \rangle$ per event derived from the VENUS model.

Centrality	$\langle N_W \rangle$	N_{events}
0–23.5%	265	2.40×10^6
0–12.5%	315	1.24×10^6
12.5–23.5%	211	1.16×10^6


Pb+Pb (central) at 158A GeV:
~ 2000 charged particles

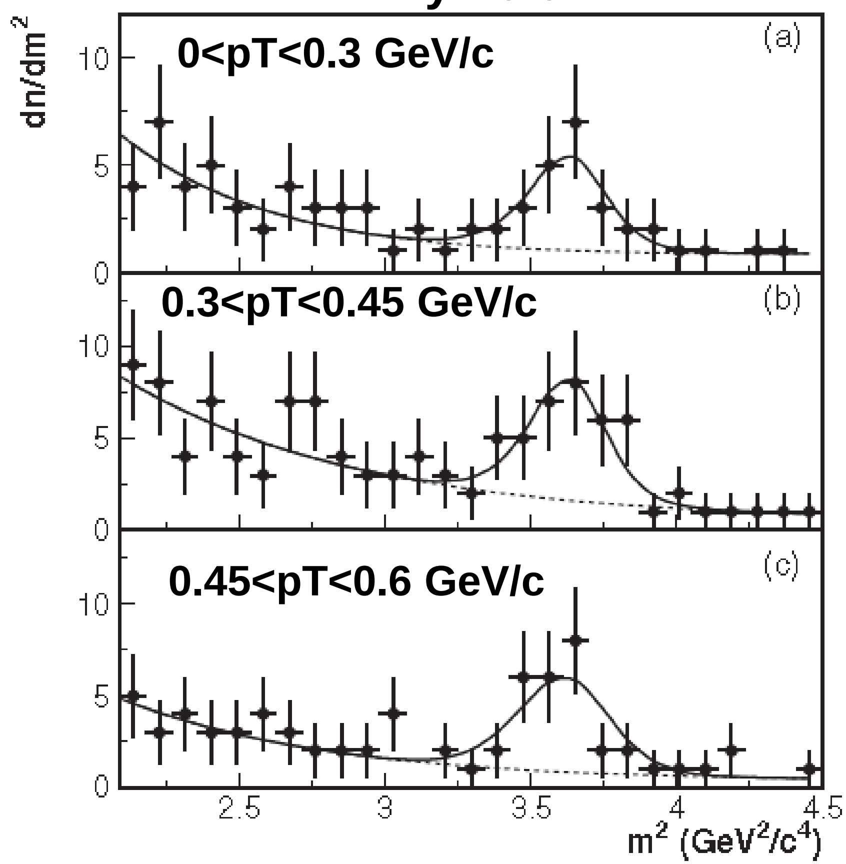
Particle ID in NA49 (dE/dx + TOF)





PID: dE/dx from TPCs+TOF
in (p-pT) bins
Dbars: dE/dx + track quality cuts applied
. $dE/dx < dE/dx_{BB}(d) + k\sigma(d)$

-1.2<y<-0.6



Analysis: yeilds

The invariant differential yield for each bin in (y,p_t) evaluated as:

$$\left(\frac{1}{\sigma_{trig}}\right) E\frac{d^3\sigma}{d^3p} = \frac{1}{2\pi}\frac{1}{p_t}\frac{d^2N}{dp_t dy} = \frac{1}{2\pi}\frac{(N - n_{bkg.})\cdot <\varepsilon> \cdot <a>}{N_{trig.}\cdot \Delta y \cdot \Delta p_t \cdot <p_t>}$$

$N_{trig.}$ - number of events
N – number of counts in $m^2(dE/dx)$ – window
n_{bkg} – number of background counts
$<\varepsilon>$ – overall correction factor (TOF and PID efficiencies)
$<a>$ – geometrical acceptance correction

Raw particle spectra are also corrected for losses due to applied cuts and contamination of decay products of hyperons and resonances (Λ, Σ, K^0)

Corrections:

- Overall efficiency (including quality cuts) > 60%,,
- feeddown corrections for (anti)protons (20-30%)

Systematic errors (clusters):

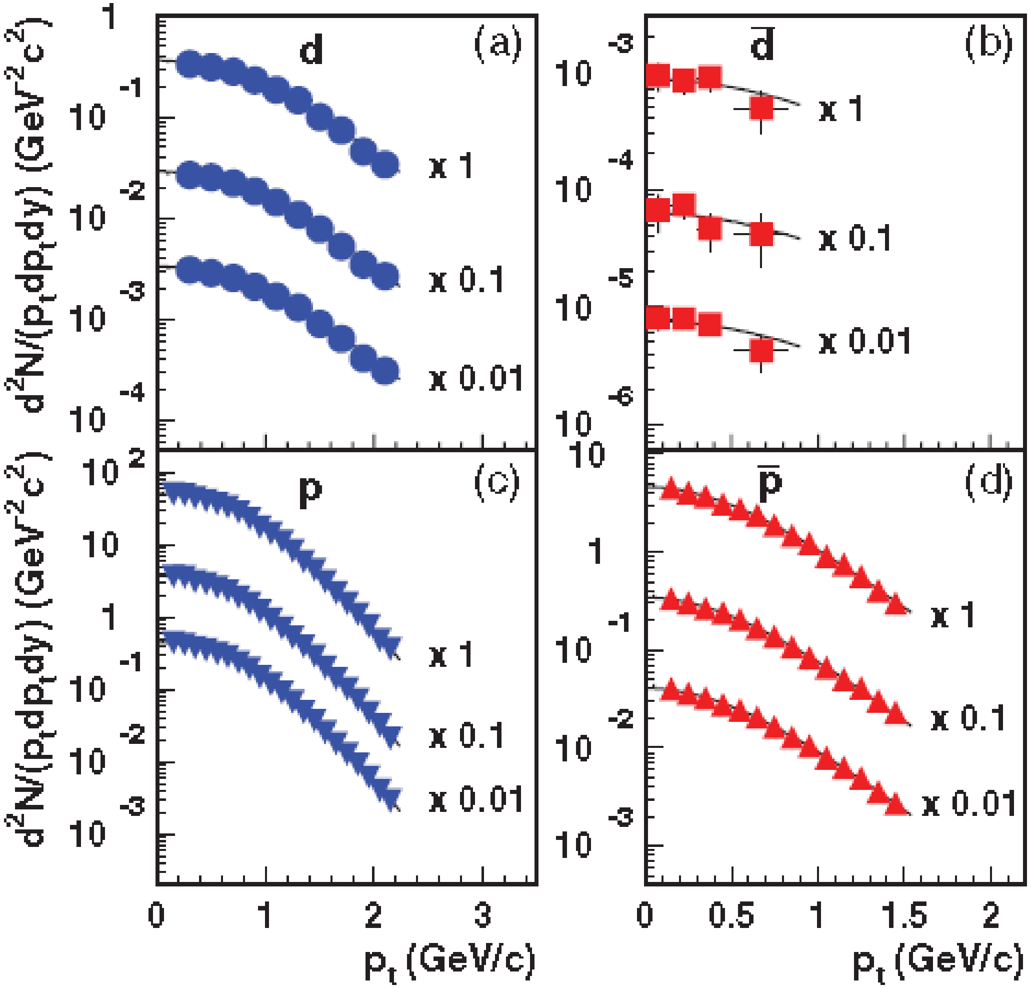
Spectra ~20% (dbar) and 10^ (d)
Coalescence – 20-30%

Details: Phys. Rev. C69, 024902 (2004); Phys. Rev. C73, 044910 (2006); Phys. Rev. C77, 024903 (2008); Phys. Rev. C85, 04 4913(2012)

Results

Results: pT-spectra of (anti)d and (anti)p

$$\frac{1}{p_t}\frac{d^2N}{dp_t dy} = \frac{dN/dy}{T(m+T)}\exp\left(-\frac{m_t - m}{T}\right), \qquad (2)$$



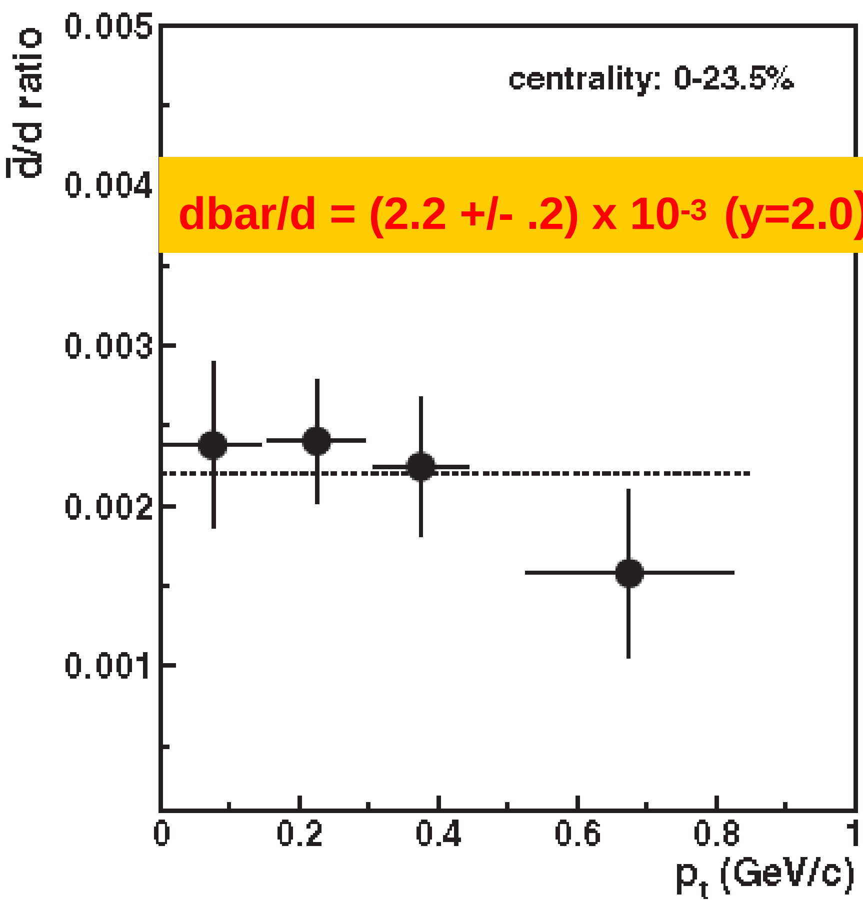
- Data for (from top to bottom) 0-12.5%, 12-23^, 0-23% central
- Thermal fit function used
- Spectra of clusters (Td ~ 400 MeV) are harder than those of nucleons (Tp ~ 300 MeV) resulting from strong collective transverse flow

$T_{eff} = T_{thermal} + m\langle v\rangle$

Results: comparing spectra of d and dbar

- Microscopic transport model predict modification of the anti-baryon spectra in dense matter due to annihilation (*M.Bleicher et al, J. Phys G 25, 1859 (1999)*)
- The (predicted) effect is larger at mid-rapidity and low-pT
- NA49 data: modifications were not observed in (anti)p and (anti)Λ at the top SPS

C. Alt et al (NA49 Coll.) Phys. Rev. C 73, 044910 (2006)
C. Anticic et al (NA49 Coll.) Phys. Rev. C 80, 034906 (2009)



dbar/d = (2.2 +/- .2) x 10^{-3} (y=2.0)

- No difference in the shapes of the spectra between d and dbar up to pT=0.9 GeV/c
- No Indication of extra reduction of the dbar yield due to annihilation

In the thermal model (TM):

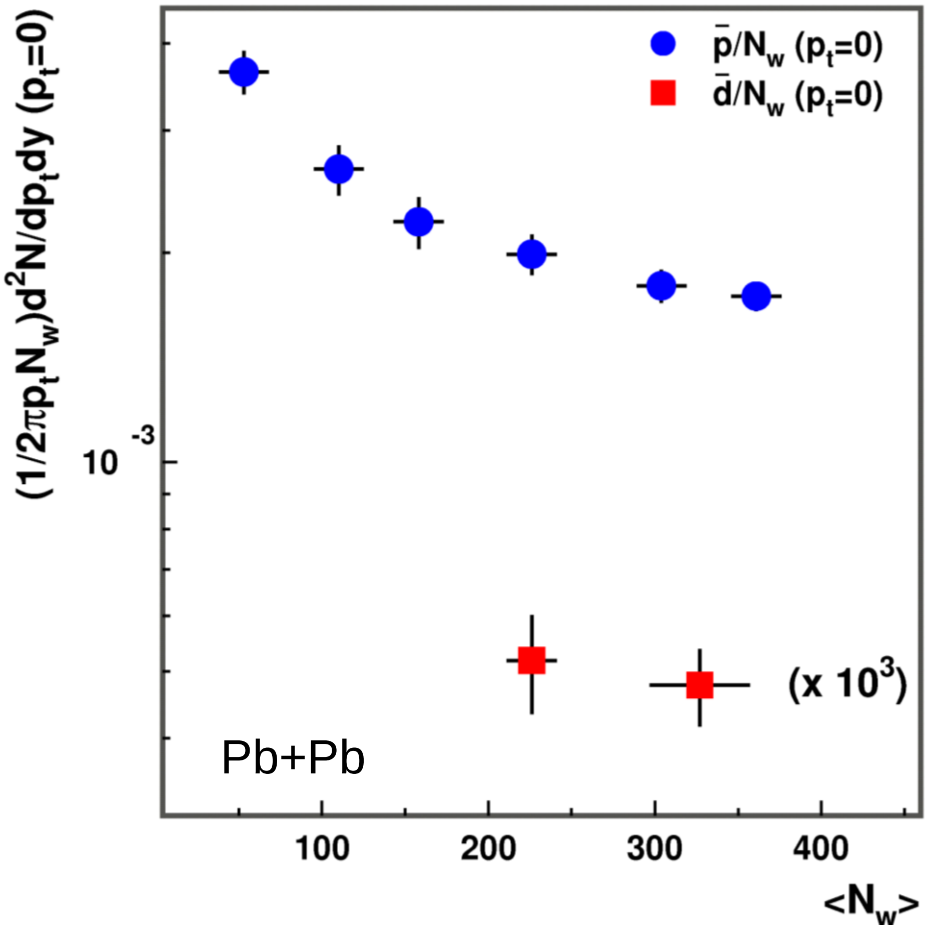
dbar/d ~ $\exp(-4\mu_B/T)$

At SPS μ_B~250 MeV, T_{ch} ~ 160 MeV

So, dbar/d ~ 1.9 x 10^{-3} agrees to the NA49 measurements

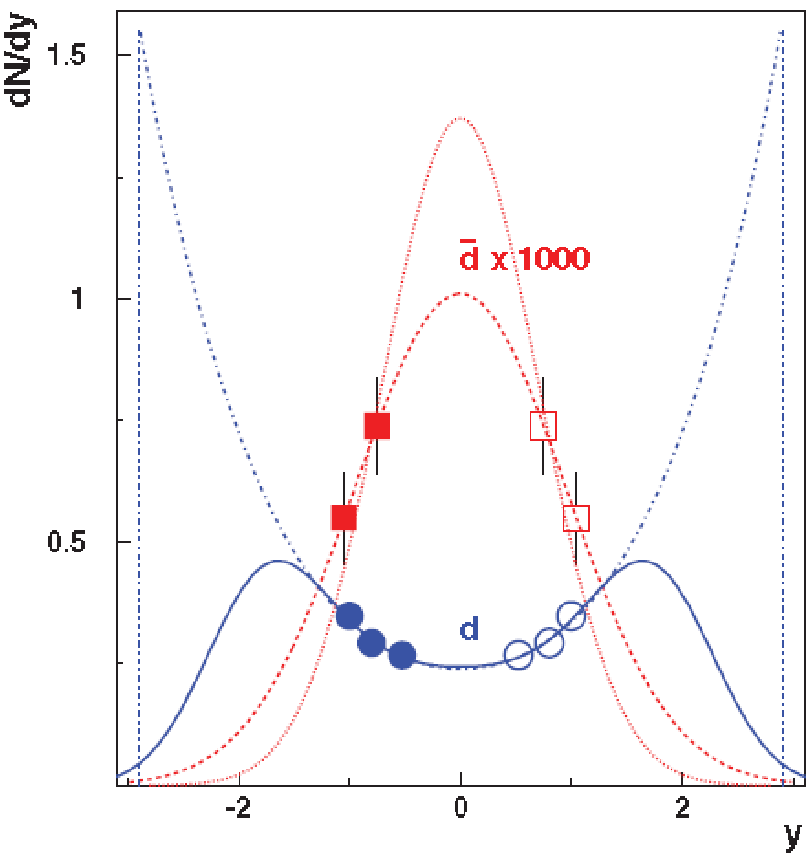
Results: centrality dependence of yields

pbars: NA49, PRC 73, 044910 (2006)



- The yield (normalized to N_w) drops with centrality
- dbars reproduce the trend of pbars in mid-central Pb+Pb

Results: (anti)d yields versus rapidity



- **Distinct shapes of the rapidity spectra for d and dbar: can be traced back to those of constituents**
- **Shapes are motivated by a coalescence approach**
- **Estimates for total yields agreed within 40% to the predictions of the hadron gas modes**

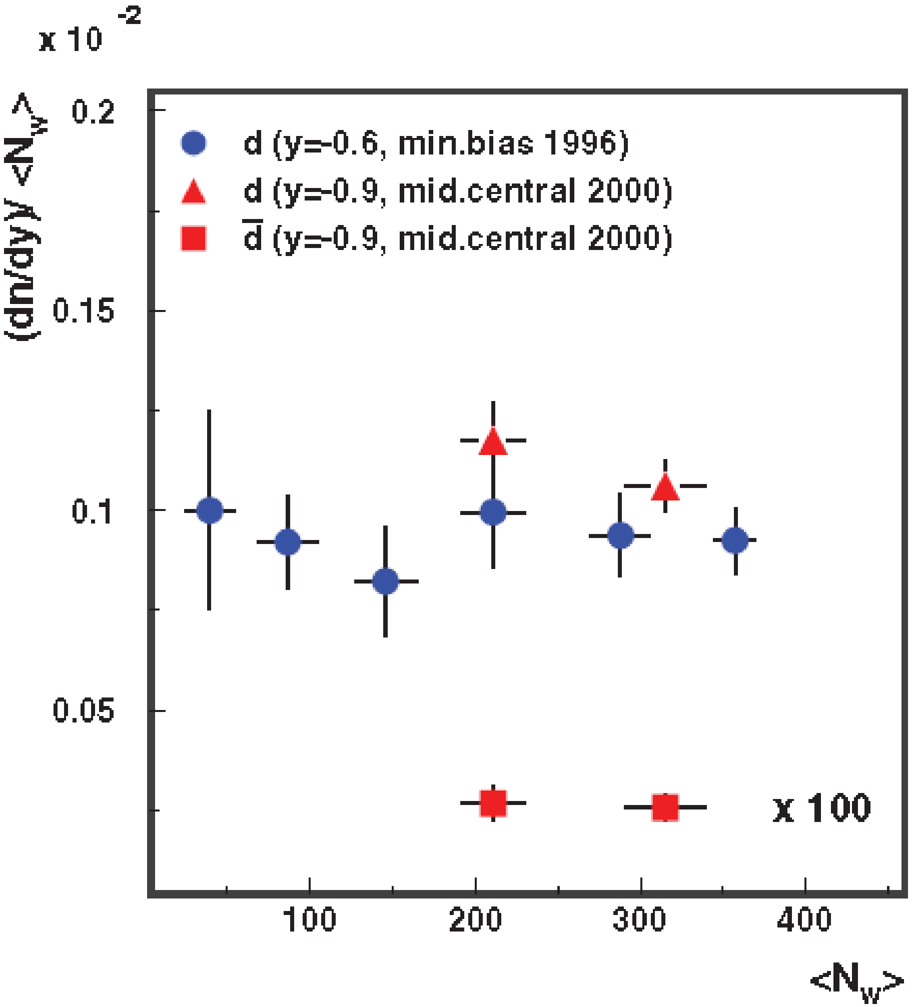
TABLE II. dN/dy for d and $\overline{d}$ obtained from fits with Eq. (2) in centrality selected Pb + Pb collisions at 158A GeV in the rapidity interval $-1.2 < y < -0.6$. Errors are statistical only.

Centrality	Deuterons	Antideuterons
0–12.5%	0.33 ± 0.02	$(8.1 \pm 1.1) \times 10^{-4}$
12.5–23.5%	0.25 ± 0.02	$(5.6 \pm 1.0) \times 10^{-4}$
0–23.5%	0.3 ± 0.01	$(6.9 \pm 1.0) \times 10^{-4}$

- **4π yields (fits): d - 3.5 +/- 0.4 (1.75 +/- .18), dbar: 2.4 x 10^{-3}**
- **Hadron Gas Model predicts**: 2.5 (d) and 4.6 × 10^{-3} in the 5% central Pb+Pb
- The agreement is within 40% (after a proper scaling for centrality)

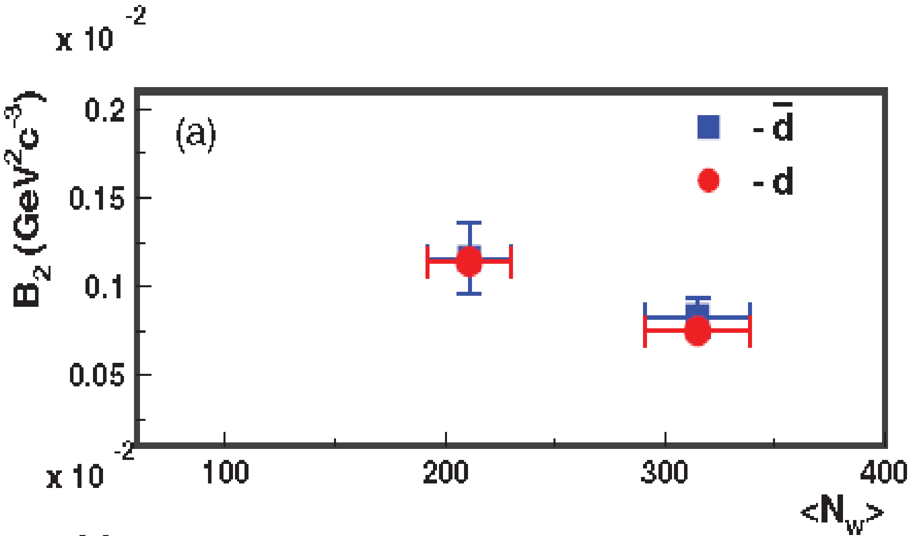
Results: centrality dependence of (anti)d yields

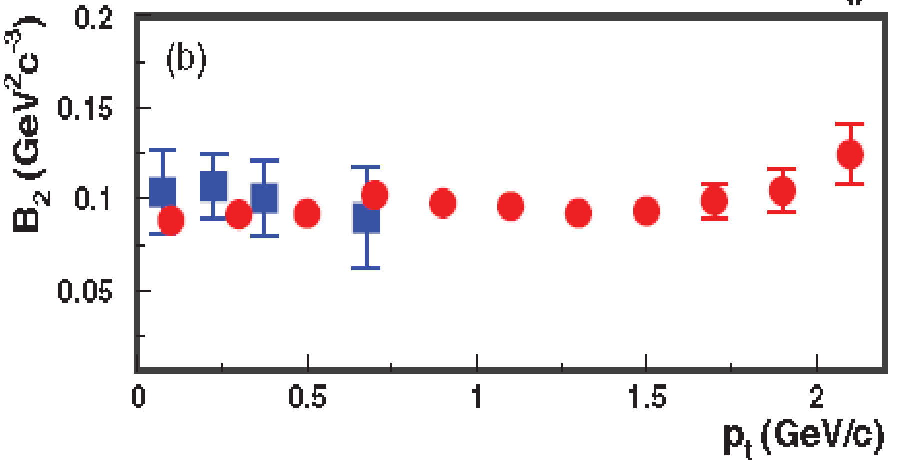
Data for min.bias Pb+Pb*:*
C. Anticic et al (NA49 Coll.) Phys. Rev. C 69, 024902 (2004)



- **Weak centrality dependence for (anti)d in Pb+Pb at 158A GeV**
- **May indicate a some degree of saturation in density distribution for (anti)nucleons at the top SPS**

Results: Coalescence





$$E_d \frac{d^3N_d}{dp_d^3} = B_2 \left(E_p \frac{d^3N_p}{dp_p^3} \right)^2, \qquad p_d = 2 \cdot p_p$$

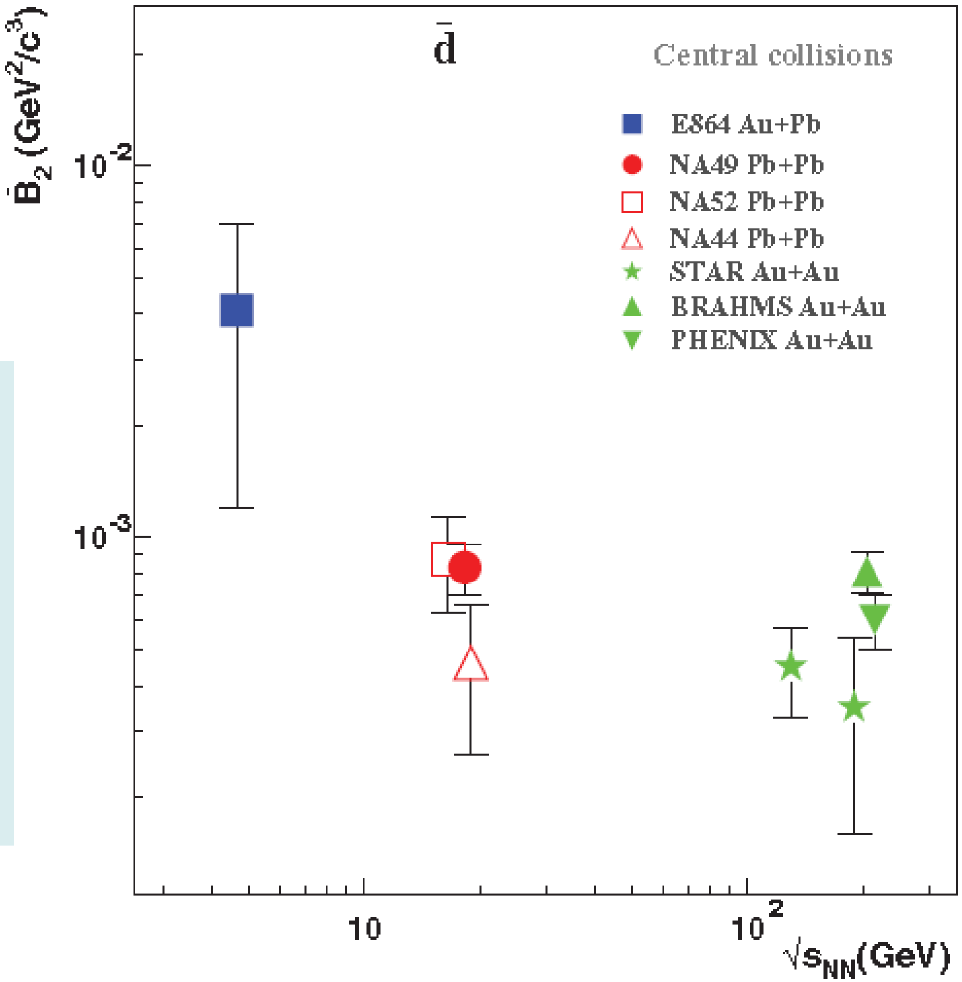
- **Cluster yields are related to those of nucleons through the B_A coefficient which depends on details of formation mechanism and reaction dynamics**
- **B_2 parameters for d and dbar agree within errors → coalescence volumes are similar for cluters and anticlusters**
- **Strong centrality dependence indicates increase of the source size in more central collisions**

Results: Coalescence (2)

B_2 is related to the size of the particle emission source:

$$B_2 \cong 1/V_{eff}$$

- **No substantial decrease of the coalescence parameter for anti-d from SPS to RHIC**
- **The transverse size of the emitting source at kinetic freeze-out depends only weakly on the collisions energy in this domain**



SUMMARY

- Measurements of (anti)deuterons in 23% central at 158A GeV are presented
- Shapes of pT-distributions for d and dbar are similar up to pT = 0.9 GeV/c. dbar/d ratio agrees to thermal model predictions and weakly depends on centrality
- Freezeout (coalescence) volumes for (anti)clusters change gradually from SPS to RHIC

The NA49 collaboration

C. Alt[9], T. Anticic[21], B. Baatar[8],D. Barna[4], J. Bartke[6], L. Betev[10], H. Białkowska[19], C. Blume[9], B. Boimska[19], M. Botje[1], J. Bracinik[3], R. Bramm[9], P. Bunčić[10], V. Cerny[3], P. Christakoglou[2], O. Chvala[14], J.G. Cramer[16], P. Csató[4], P. Dinkelaker[9], V. Eckardt[13], D. Flierl[9], Z. Fodor[4], P. Foka[7], V. Friese[7], J. Gál[4], M. Gaździcki[9,11], V. Genchev[18], G. Georgopoulos[2], E. Gładysz[6], K. Grebieszkow[20], S. Hegyi[4], C. Höhne[7], K. Kadija[21], A. Karev[13], M. Kliemant[9], S. Kniege[9], V.I. Kolesnikov[8], E. Kornas[6], R. Korus[11], M. Kowalski[6], I. Kraus[7], M. Kreps[3], M. van Leeuwen[1], P. Lévai[4], L. Litov[17], B. Lungwitz[9], M. Makariev[17], A.I. Malakhov[8], M. Mateev[17], G.L. Melkumov[8], M. Mitrovski[9], J. Molnár[4], St. Mrówczyński[11], V. Nicolic[21], G. Pálla[4], A.D. Panagiotou[2], D. Panayotov[17], A. Petridis[2], M. Pikna[3], D. Prindle[16], F. Pühlhofer[12], R. Renfordt[9], C. Roland[5], G. Roland[5], M. Rybczyński[11], A. Rybicki[6,10], A. Sandoval[7], N. Schmitz[13], T. Schuster[9], P. Seyboth[13], F. Siklér[4], B. Sitar[3], E. Skrzypczak[20], G. Stefanek[11], R. Stock[9], H. Ströbele[9], T. Susa[21], I. Szentpétery[4], J. Sziklai[4], P. Szymanski[10,19], V. Trubnikov[19], D. Varga[4,10], M. Vassiliou[2], G.I. Veres[4,5], G. Vesztergombi[4], D. Vranić[7], A. Wetzler[9], Z. Włodarczyk[11] I.K. Yoo[15], J. Zimányi[4]

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Thank you
for your attention!