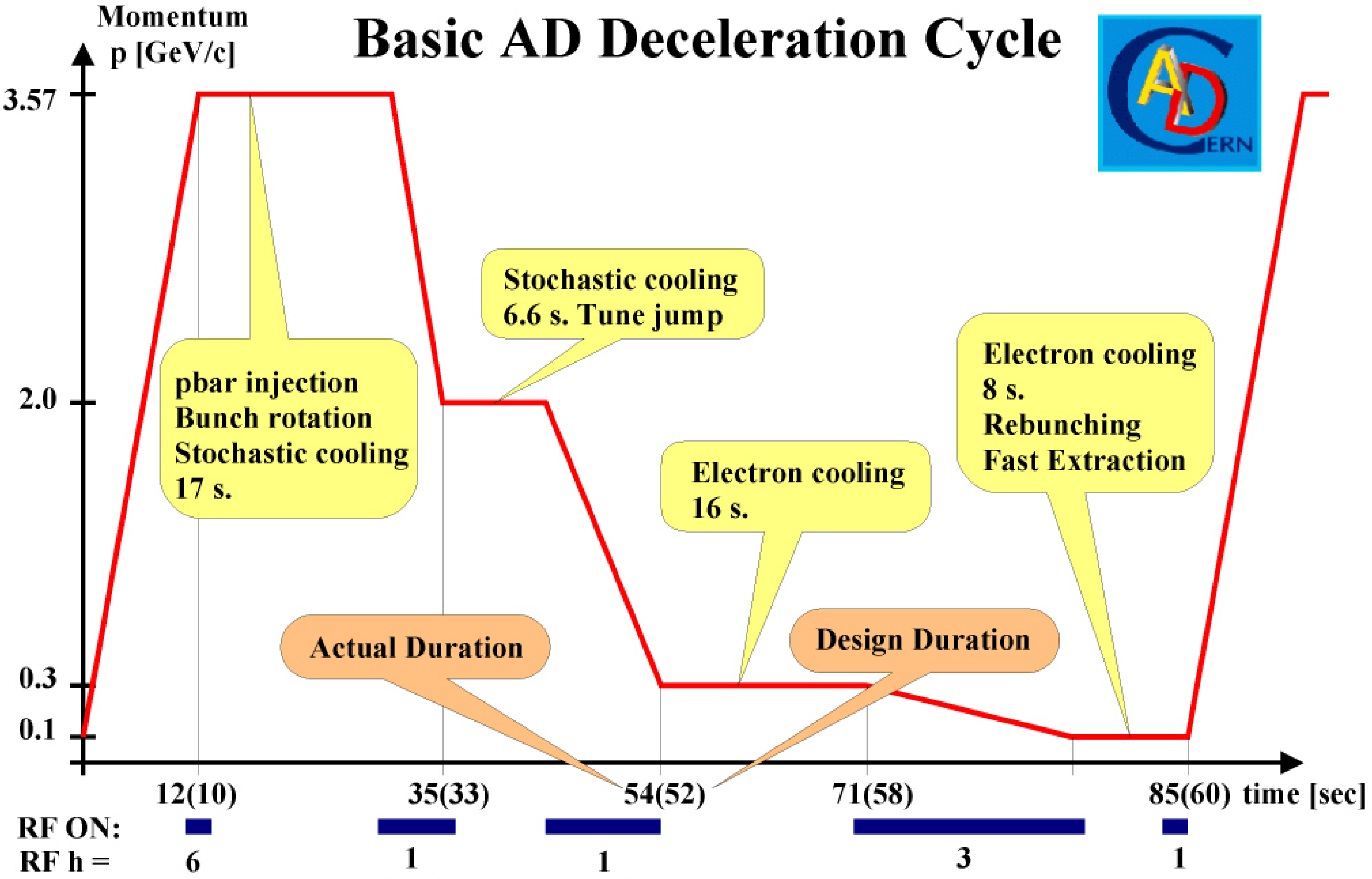
Extra Low Energy Antiproton Ring (ELENA) for antiproton deceleration after the AD

Pavel Belochitskii for the AD team

On behalf of the AD users community

Villars, 26 September 2004

Basic AD Deceleration Cycle



pbar injection
Bunch rotation
Stochastic cooling
17 s.

Stochastic cooling
6.6 s. Tune jump

Electron cooling
16 s.

Electron cooling
8 s.
Rebunching
Fast Extraction

Actual Duration

Design Duration

Beam bunched for deceleration (RF ON), debunched for cooling

28/08/00 FP
27/11/02 Rev.

Beam from AD: 3 10^7 antiprotons per cycle at energy 5.3 MeV

with transverse emittances 1 to 2 π mm mrad.

How antiprotons are decelerated further today:

- Experiments with antihydrogen program (ATHENA and ATRAP) use degraders to slow 5.3 MeV beam further down: poor efficiency due to adiabatic blow up and due to scattering in degrader.
- ASACUSA uses RFQD for antiproton deceleration down to around 100 keV kinetic energy. Due to absence of cooling beam deceleration in RFQD is accompanied by adiabatic blow up (factor 7 in each plane) which causes significant reduction in trapping efficiency.

How do we gain in intensity with extra deceleration and cooling ?

- Small ring to decelerate antiproton beam down to 100 keV and cool by electron beam to high density will be used
- Emittances of beam passing through a degrader will be much smaller than now due to electron cooling and a much thinner degrader (100 keV beam instead of 5.3 MeV) => two orders of magnitude gain in intensity is expected for ATHENA and ATRAP.
- Due to cooling, beam emittances after deceleration in ELENA will be much smaller than after RFQD => one order of magnitude gain in intensity is expected for ASACUSA.
- Kinetic energy 100 keV is close to optimal both from the point of view of beam intensity, momentum spread and separation of transfer line and trap vacuum.

Requirements to ELENA:

- Compact machine* located inside of AD Hall with minimum of reshuffle.
- Energy range from 5.3 MeV (AD extraction energy) down to 100 keV.
- Equipped with electron cooler to make beam phase space smaller in about two orders of magnitude with respect what we have today
- Machine assembling and commissioning has to be done without disturbing current AD operation.

* A similar ring for decelerating antiprotons from LEAR was proposed by H.Herr in 1982.

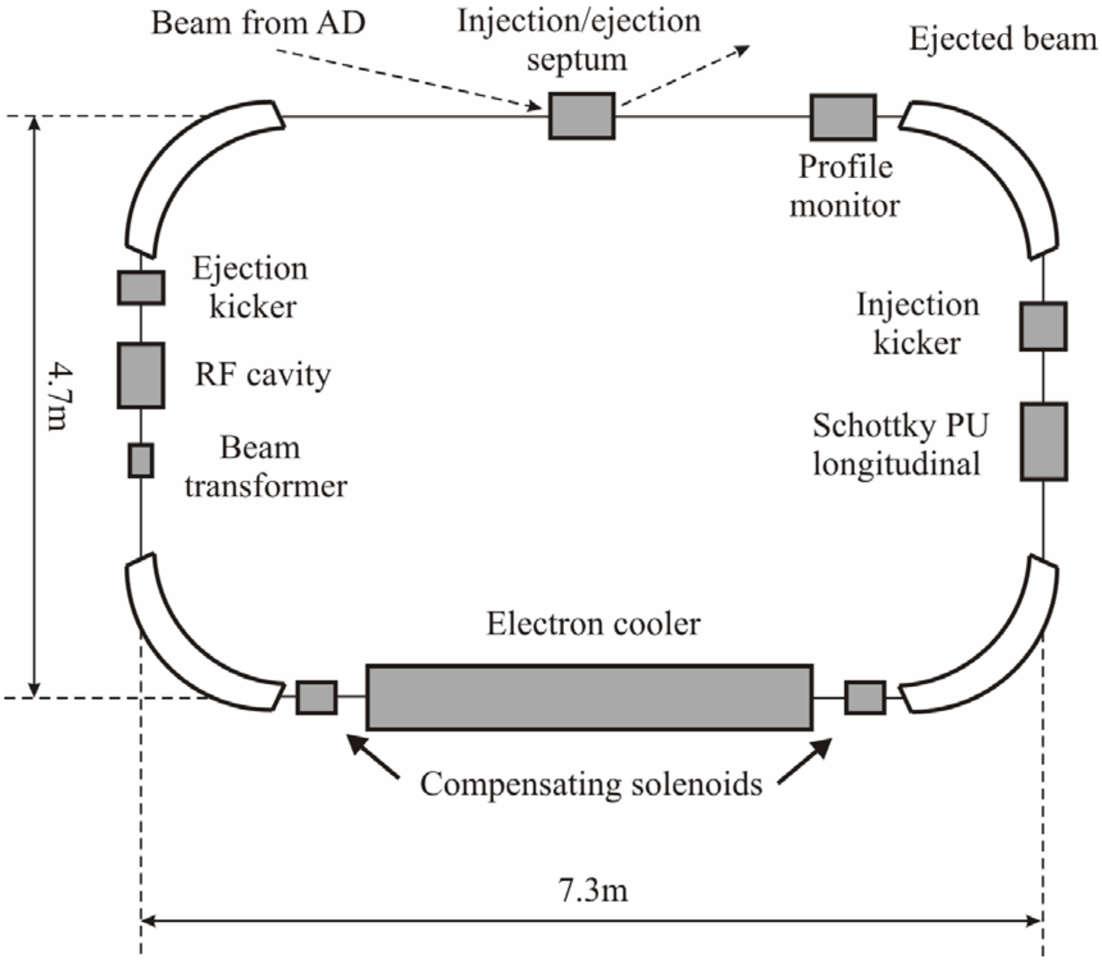
Requirements to ring configuration:

- One long straight section for electron cooler.
- One long straight section for beam injection and extraction.
- One or two straight sections for other equipment (RF, diagnostics etc.)

Electron cooler for ELENA:

- 1 m cooling length.
- Careful electron cooler design which provides low transverse temperatures of electron beam at very low energies needed for fast cooling.

ELENA schematic layout



Lattice considerations:

- Beam focusing is achieved by proper choice of edge angle of the dipoles. Economical solution for saving cost and space: neither gradient magnets, nor quadrupoles needed!
- Big area in tune diagram should be available for tune excursion caused by space charge. Conservative estimate for coherent tune shift $\Delta Q = 0.10$ was accepted which is based on CERN Booster, PS and AD experience.
- Tunes $Q_x=1.45$, $Q_y=1.43$ (with similar non-integer parts as in the AD) fit requirements.
- Choice of tunes together with required straight section length defines machine circumference about 22m.

Intensity limitation due to space charge

The incoherent tune shift

$$\Delta Q_{x,y} \propto \frac{N_b}{\varepsilon_{x,y}\beta^2\gamma^3 B_b}.$$

Here $\varepsilon_{x,y}$ is beam emittance, N_b is a number of particles in a bunch, β and γ are relativistic factors, B_b is bunching factor given by the ratio of bunch length and machine circumference.

The limitation is more severe:

- At low energies
- For bunched beam
- For a machine with big circumference in the case when the bunch length is fixed by other constraints (e.g. trap experiments)

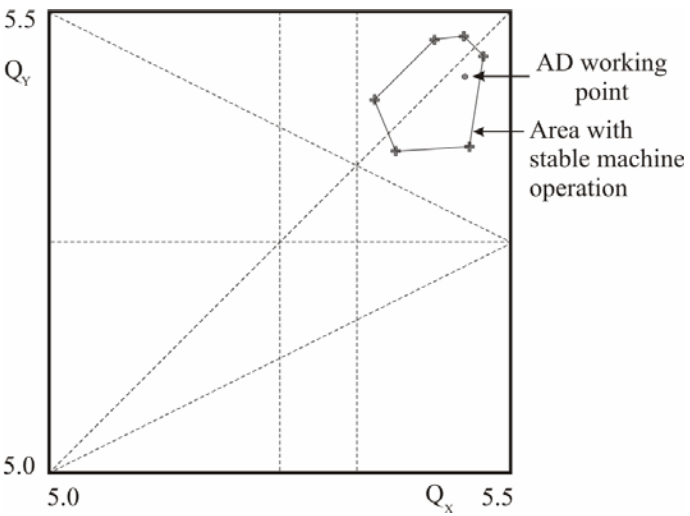
Intensity limitation due to space charge (continued)

Examples:

- AD case, 3 10^7 antiprotons in extracted beam, bunched beam 100 ns long, $\varepsilon_{x,y}=1\ \pi$ mm mrad => ΔQx,y=-0.073.
- ELENA case, 1.5 10^7 antiprotons at the end of deceleration (50% deceleration efficiency assumed), bunched beam occupies 1/3 of ring circumference, $\varepsilon_{x,y}=10\ \pi$ mm mrad => ΔQx,y=-0.01 => no problems during deceleration.
- ELENA case, 1.5 10^7 antiprotons in extracted beam, bunched beam 300 ns long, $\varepsilon_{x,y}=5\ \pi$ mm mrad => ΔQx,y=-0.10 => our choice of beam parameters at 100 keV.

How we define limit on tune excursion?

- MD studies in AD for investigation of the beam stable area in tune diagram.
- Machine is stable when tunes are inside of polygon. Beam is lost when tunes approach 5.5 (2nd order resonance) and 5.33 (3rd order resonance).



CERN Booster experience: tune excursion of 0.4 is possible for a short time with careful compensation resonance driving terms. CERN PS experience: tune excursion of 0.2 is possible with similar precautions.

Lifetime considerations:

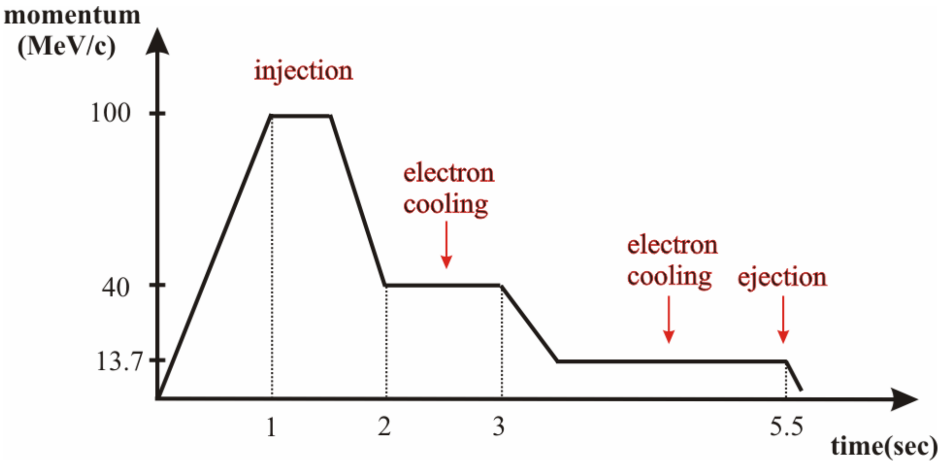
- Intrabeam scattering (IBS) is important at very low energies in a short bunch with small emittances. With reasonable choice of beam parameters (1.5 10^7 particles, emittances 5π mm mrad and $\Delta p/p=10^{-3}$) emittance rising times for coasting beam are more than 1 minute. For bunched beam 1.3m long they are of order of 1 second.
- Residual gas scattering produces beam blow up 0.5π mm mrad/s at energy 100 keV and pressure 3 10^{-12} Torr.
- electron cooling at 100 keV will be strong enough to fight successfully with intrabeam and residual gas scattering.
- for fast extraction, the beam blow up is limited by the time of beam bunching and bunch rotation (if needed), which takes few hundreds msec.

ELENA main parameters

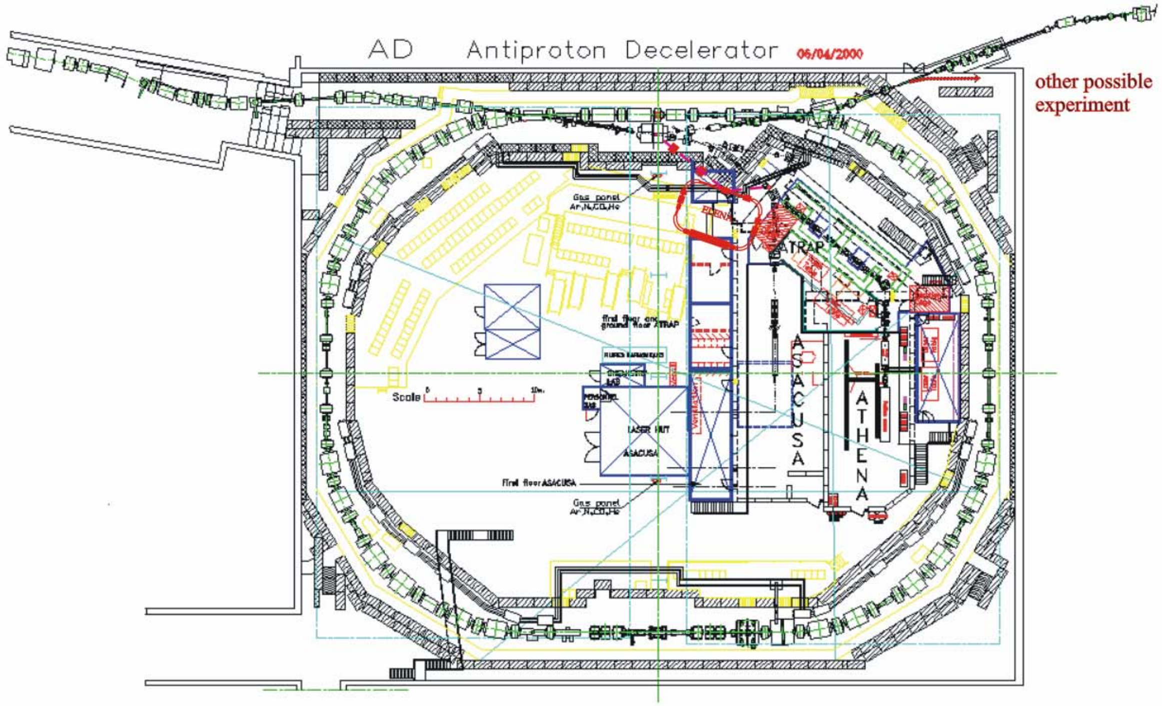
Energy, MeV	5.3 – 0.1
Circumference, m	21.9
Working point	1.45 / 1.43
Emittances at 100 keV, π mm mrad	5 / 5
Intensity limitation by space charge	$1.3\ 10^{7}$
Average antiproton flux, 1/sec	$1.5\ 10^{5}$
Maximal incoherent tune shift	0.10
Bunch length at 100 keV, m / ns	1.3 / 300
Required vacuum* for $\Delta\varepsilon=0.5\pi$ mm mrad/s,Torr	$3\ 10^{-12}$
IBS blow up times for bunched beam* ($\varepsilon_{x,y}=5\pi$ mm mrad, $\Delta p/p=1\ 10^{-3}$), s	1.1 / -9.1 / 0.85
* No electron cooling is assumed	

Schematic view of ELENA cycle

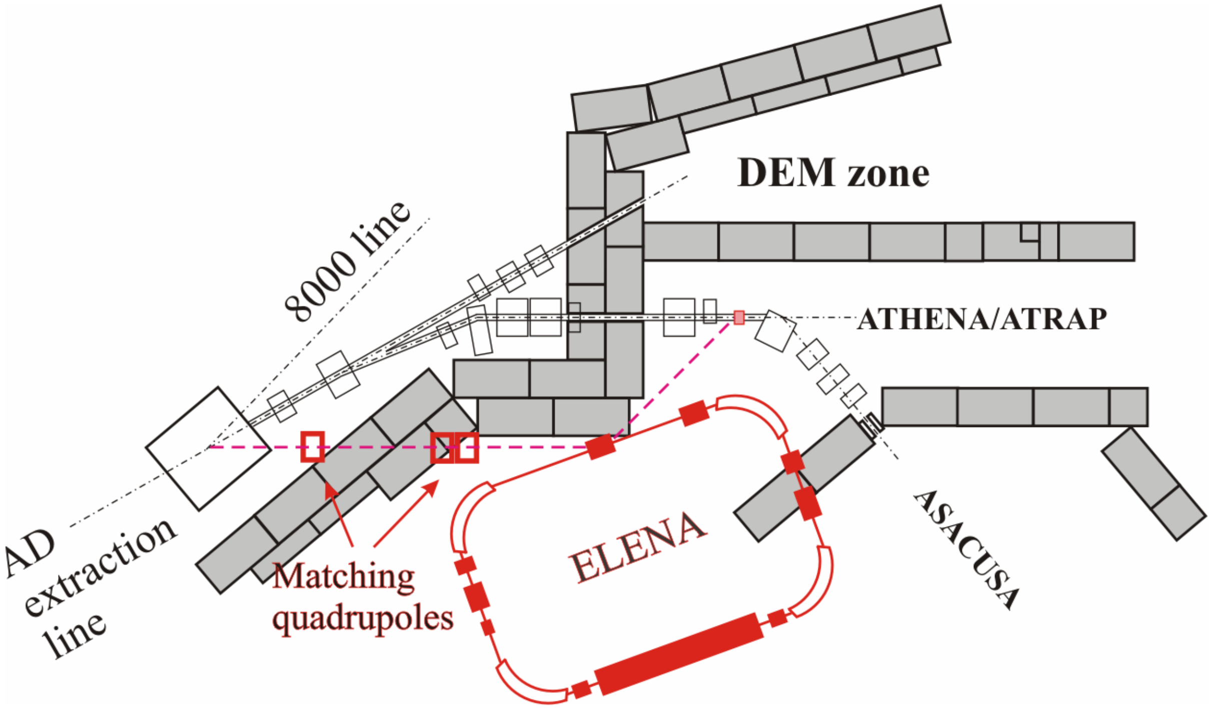
- No electron cooling is performed at injection energy: beam is cooled already in AD. After injection beam is decelerated immediately.
- One intermediate cooling (at 40 MeV/c probably) is needed to avoid beam losses



AD Hall with ELENA



ELENA layout in AD Hall



What has to be done to locate ELENA in AD Hall:

- Shielding rearrangement.
- Water distribution circuits rearrangement.
- One of the barracks on the ground floor has to be moved.
- Small part of ASACUSA experimental area needed (no real problems for physicists are created).
- Part of injection line between BMZ8000 and ELENA must be prepared, including 2 or 3 quadrupoles for matching lattice functions and beam position diagnostics.
- Bending magnet BMZ8000 (may be) needs some clockwise rotation to bend beam from AD ejection line to ELENA injection line.
- Weak bending magnet in ELENA ejection line needed. It brings beam back to existing transfer line.

Conclusions

- A small machine for decelerations and cooling of antiprotons after AD to lower energies around 100 keV is feasible.
- One to two orders of magnitude more antiprotons can be available for physics.
- Main challenges for the low energy decelerator like ultra low vacuum, beam diagnostics and effective electron cooling can be solved, using experience of AD and member-state laboratories where similar low energy ion machines are operational (ASTRID, Aarhus; CRYring, Stockholm).
- The machine can be located inside of the AD Hall with only minor modifications and reshuffling of the present installation.
- Machine assembling and commissioning can be done without disturbing current AD operation.