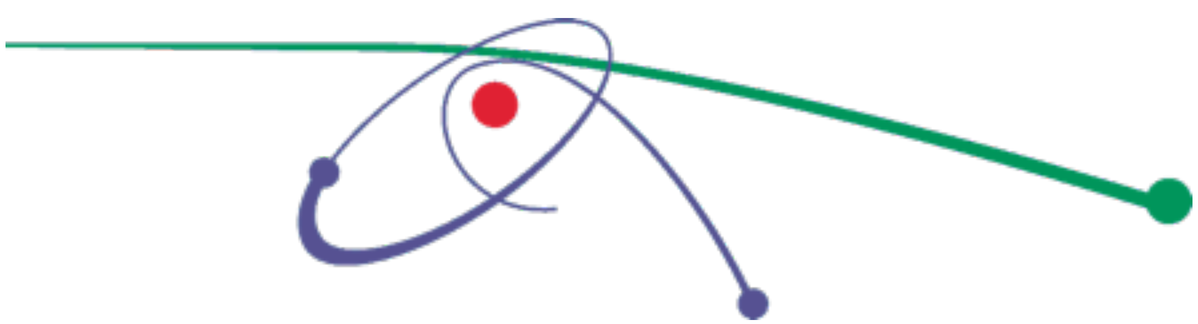
Beam instrumentation for low energy transfer lines

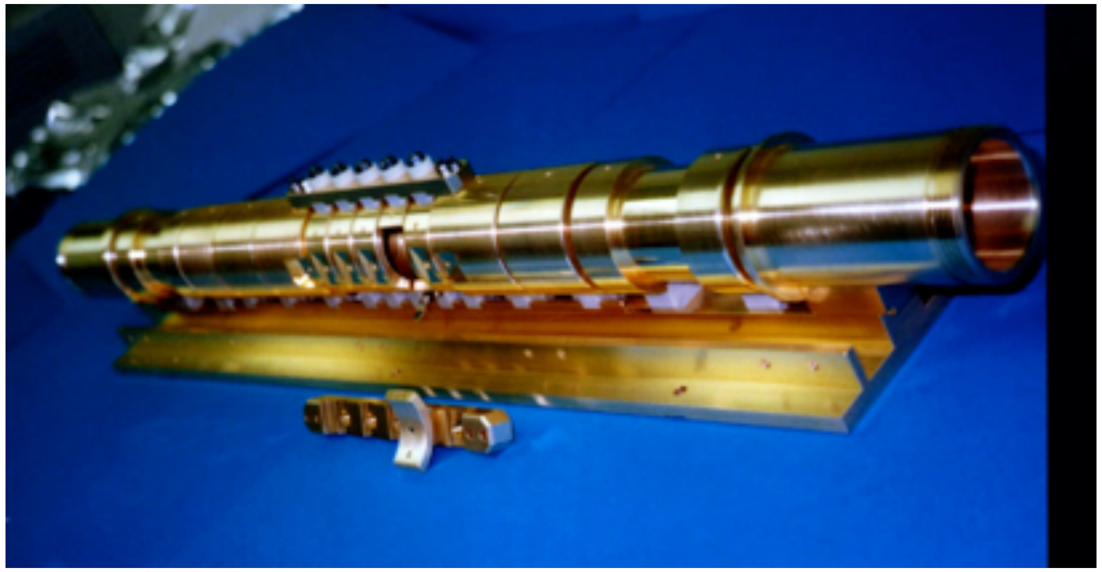
Masaki Hori
Max Planck Institute for Quantum Optics, Garching, Germany

email: Masaki.Hori@mpq.mpg.de

Experience with antiproton beams in the following energy regions

- **5 MeV** -- AD pulsed beam, LEAR slow extraction beam
- **10-130 keV** -- RFQD pulsed beam
- **0.5-10 kV** -- Trap extracted pulsed / slow-extracted beam
- **< 1 eV** -- Antihydrogen



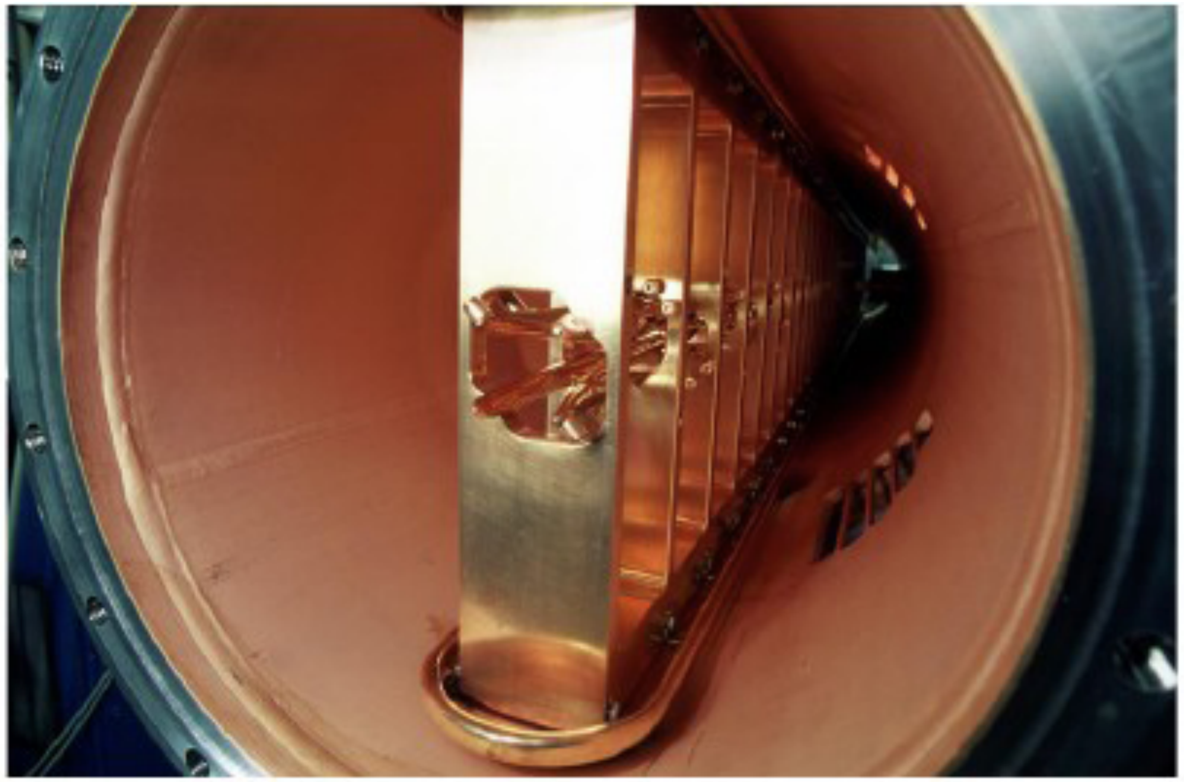


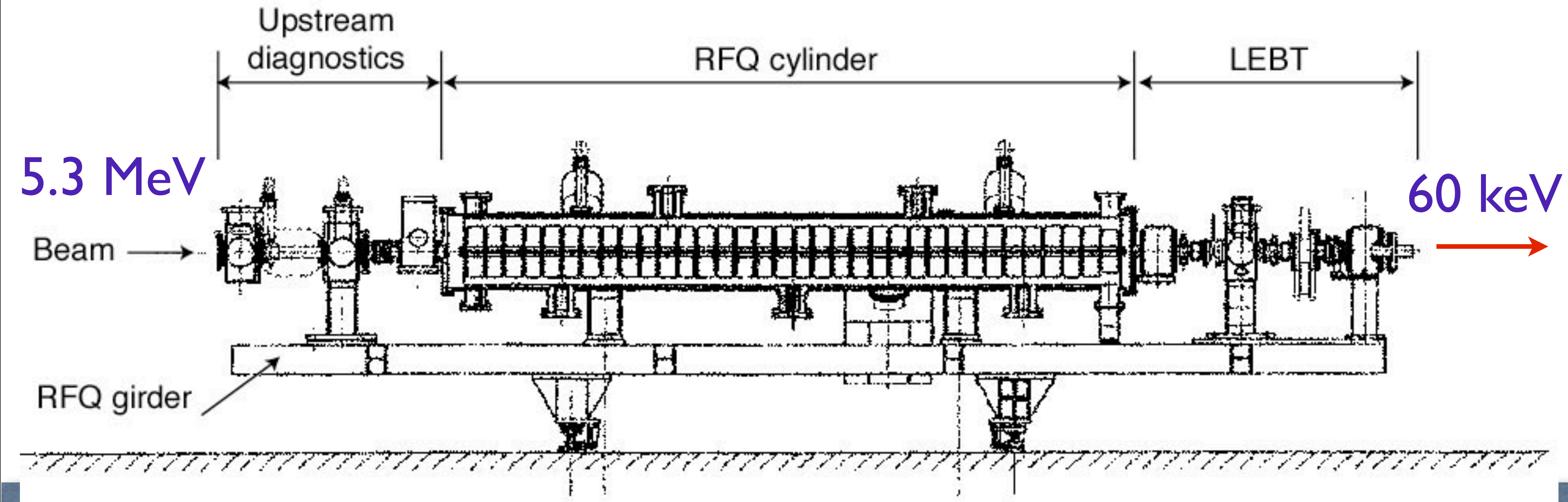
"Musashi" trap

Radiofrequency Quadrupole Decelerator

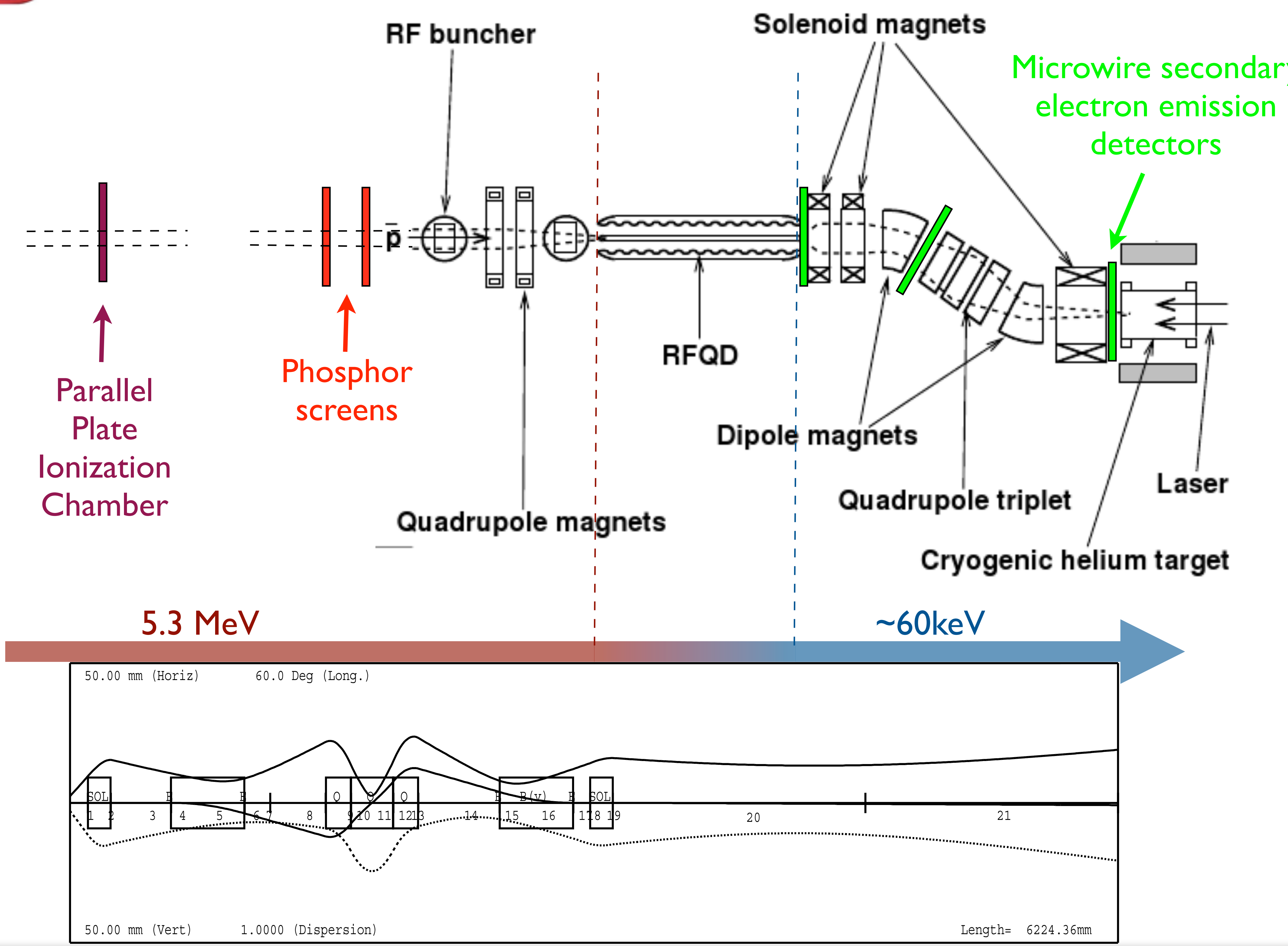
Slows down antiprotons to E<100 keV.
Delivers >7 million antiprotons every 100 s.
Beam emittance > 100 pi mm mrad,
Energy spread > 10 keV.

10-100-fold improvement of many parameters with new ELENA machine.





The RFQD and the low-energy beam transport



Measuring antiproton beams

Beam profile and intensity measurements of MeV - GeV antiproton beams were extensively studied in the 1970's to 90's at FNAL and CERN

MWPC's, flying wires, residual gas ionization detectors, Schottky pickups, scintillation and phosphor screens, intensified cameras, parallel plate ionization and avalanche detectors.

keV to eV beams were studied at AD+RFQD 2000-2011.

Secondary electron emission detectors, microchannel plates, delay line anodes, pixel detectors, Cherenkov counters, Faraday cups, scintillation/phosphor screens.

"Pros" and "Cons" are pretty well-understood

Problematic behavior of antiprotons in detectors

When antiprotons strike an object and annihilates, an “explosion” of particles create a very large background consisting of:

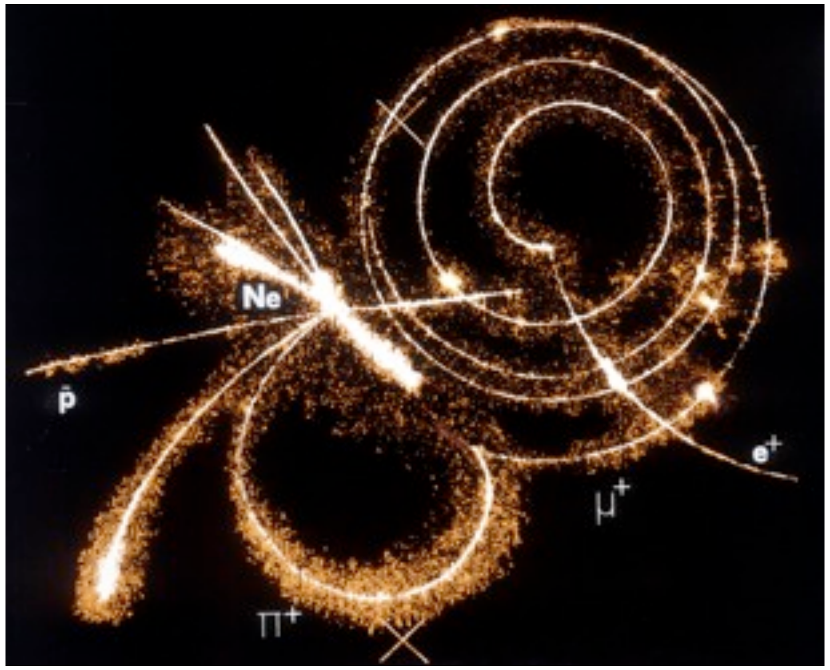
1): Around 3 charged, minimum-ionizing pions / antiproton.

2): Recoiling nuclear fragments of energy MeV.

3): X-rays (from atoms) and Gamma rays (pi0 decays).

4): Slow neutrons.

5): Several tens of internal Auger electrons.



Problem when measuring antiproton beam profiles:

Signal from the energy loss of 100-keV antiprotons is **small.**

Background from energy deposition of particles 1)-5) are **large.**

The detector has to be insensitive to all the above background particles.....

Special design constraints of detectors for ELENA

Strong magnetic field and low temperature and UHV: some detectors work in B>1 Tesla, T<5-77 K and P<10^{-10} mbar.

Low maintenance: few adjustment parameters, don't need specialists to maintain it, if possible avoid detector gases and components that wear out.

Common use: detection of 10-200 keV antiproton beams

Continuity: Parts available after 10-15 years of use in the facility.

Low cost: 20-30 kEuro per detector including vacuum chamber, software, manpower costs, etc.

Proposal for ELENA detectors

Microwire secondary electron emission detectors

Located in various (30?) positions of the beamline, to semi-non-destructively measure the beam profile with 1-2 mm spatial resolution. Currently ASACUSA has 4 monitors.

Cherenkov detectors

Located at 1-2 positions to measure the timing profile.

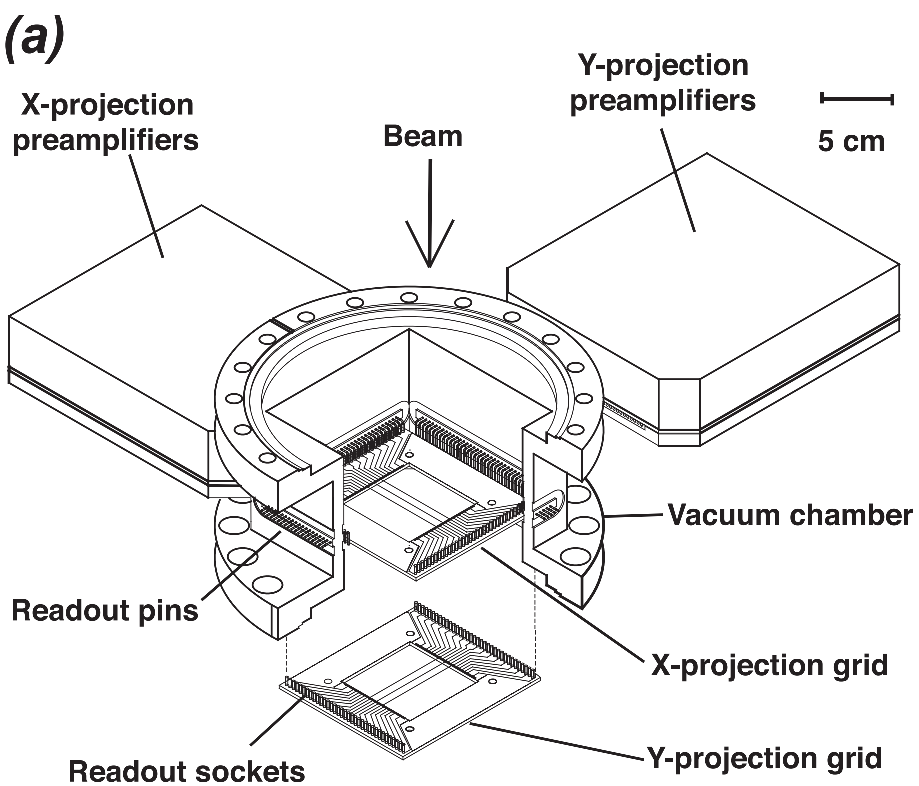
Aluminium activation measurements

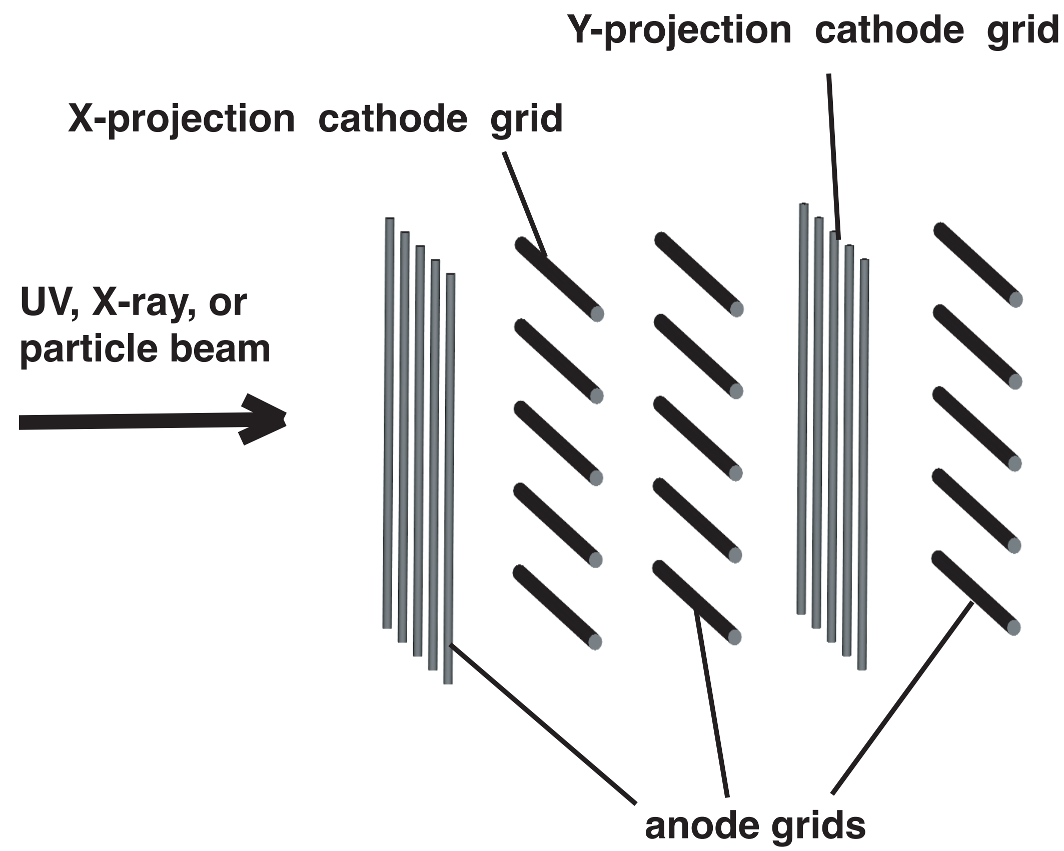
Located at the target position, to calibrate the absolute number of antiprotons arriving at the experiment. One-time measurement during commissioning phase only. Used in AD in the past.

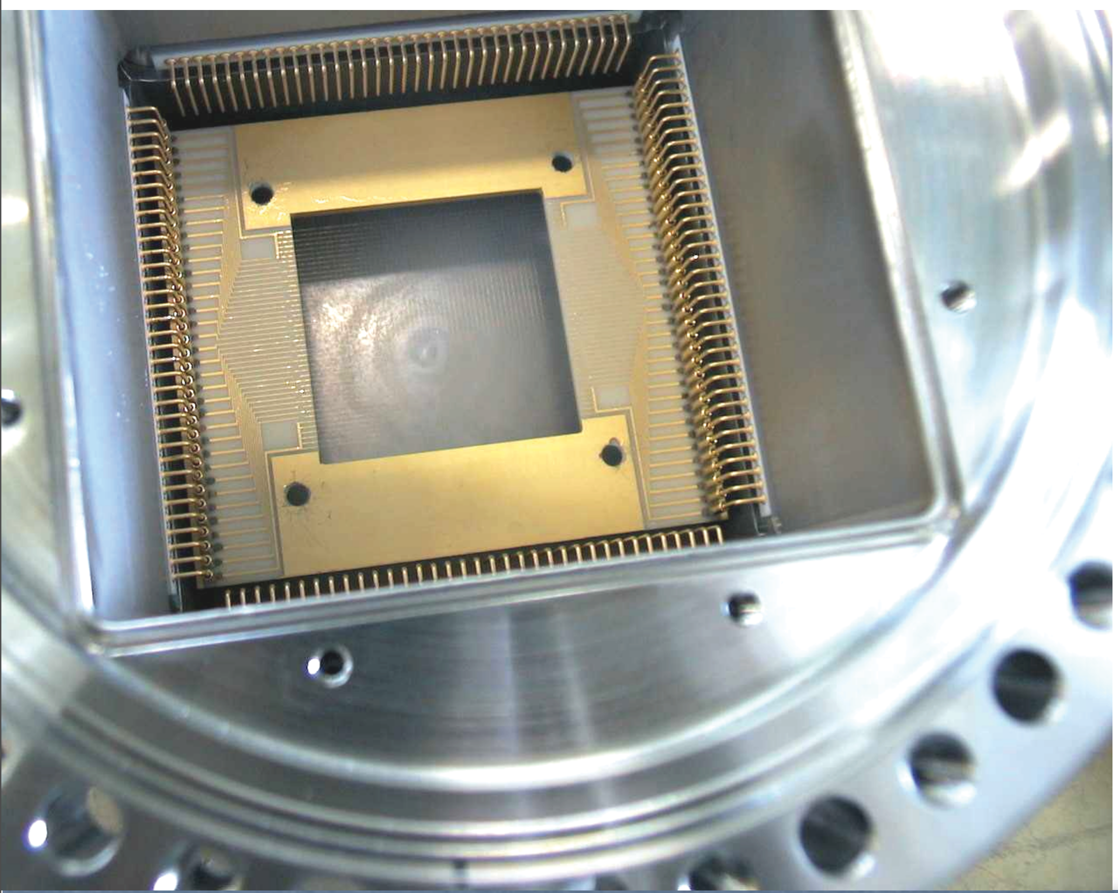
Beam transformer

Not our contribution, but already standard at AD.

Microwire secondary electron emission chamber







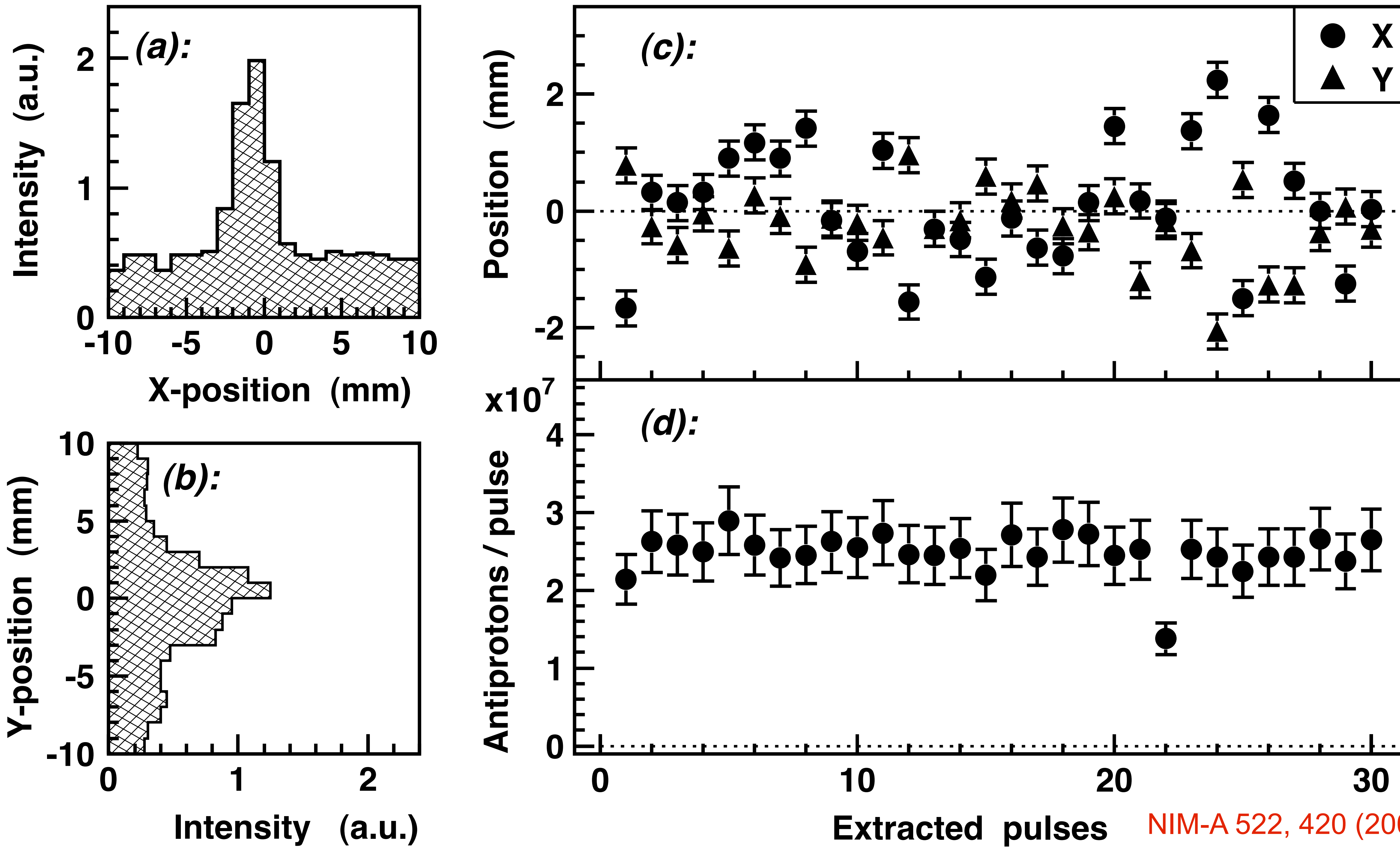
Gold-sputtered tungsten wires or carbon filaments diameter 5-30 um placed in UHV.

Wires intercept 1-3% of the beam. 97-99% travel through without being affected.

Secondary electrons detected by charge-sensitive preamplifiers.

RSI 76, 113303 (2005), M. Hori

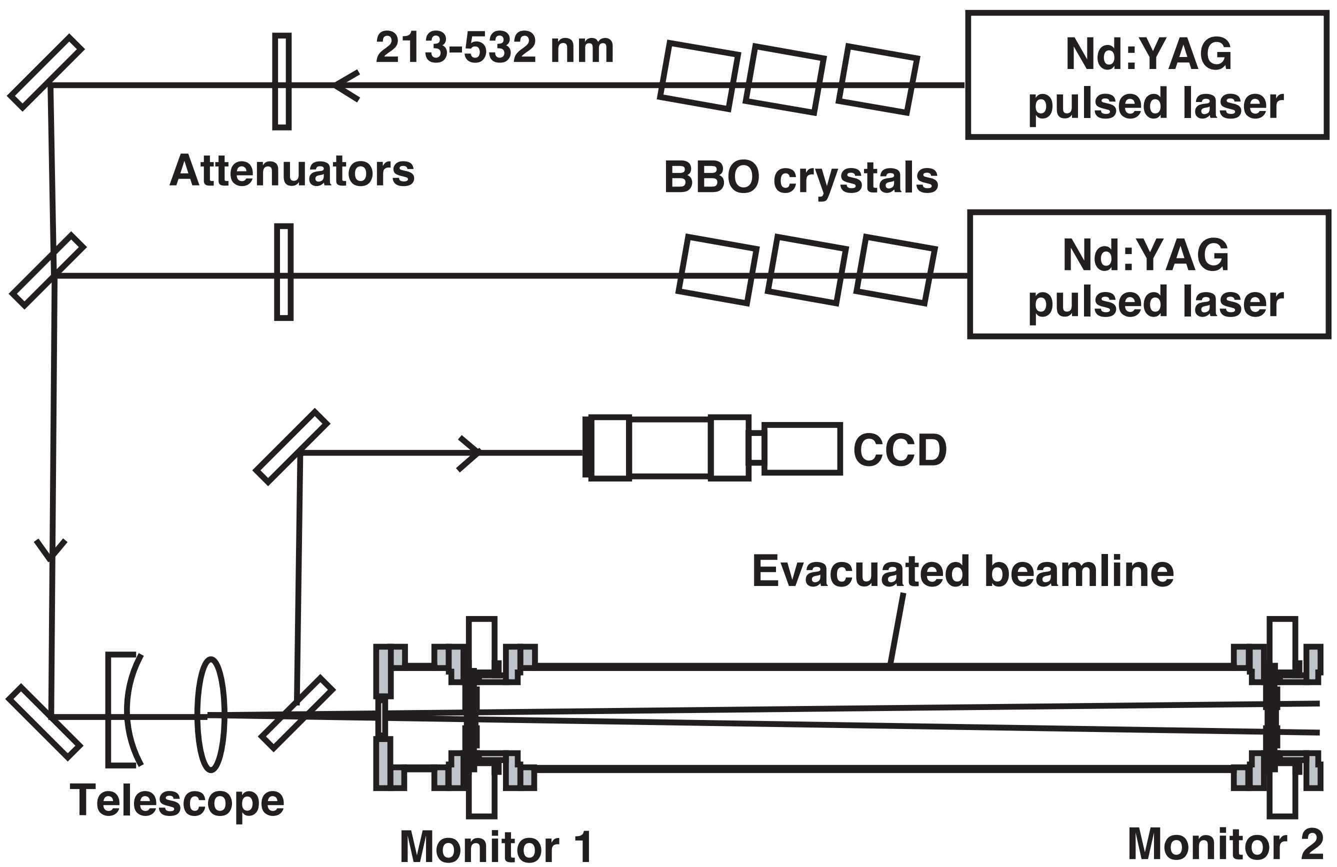
Beam profile and intensity measurements at AD

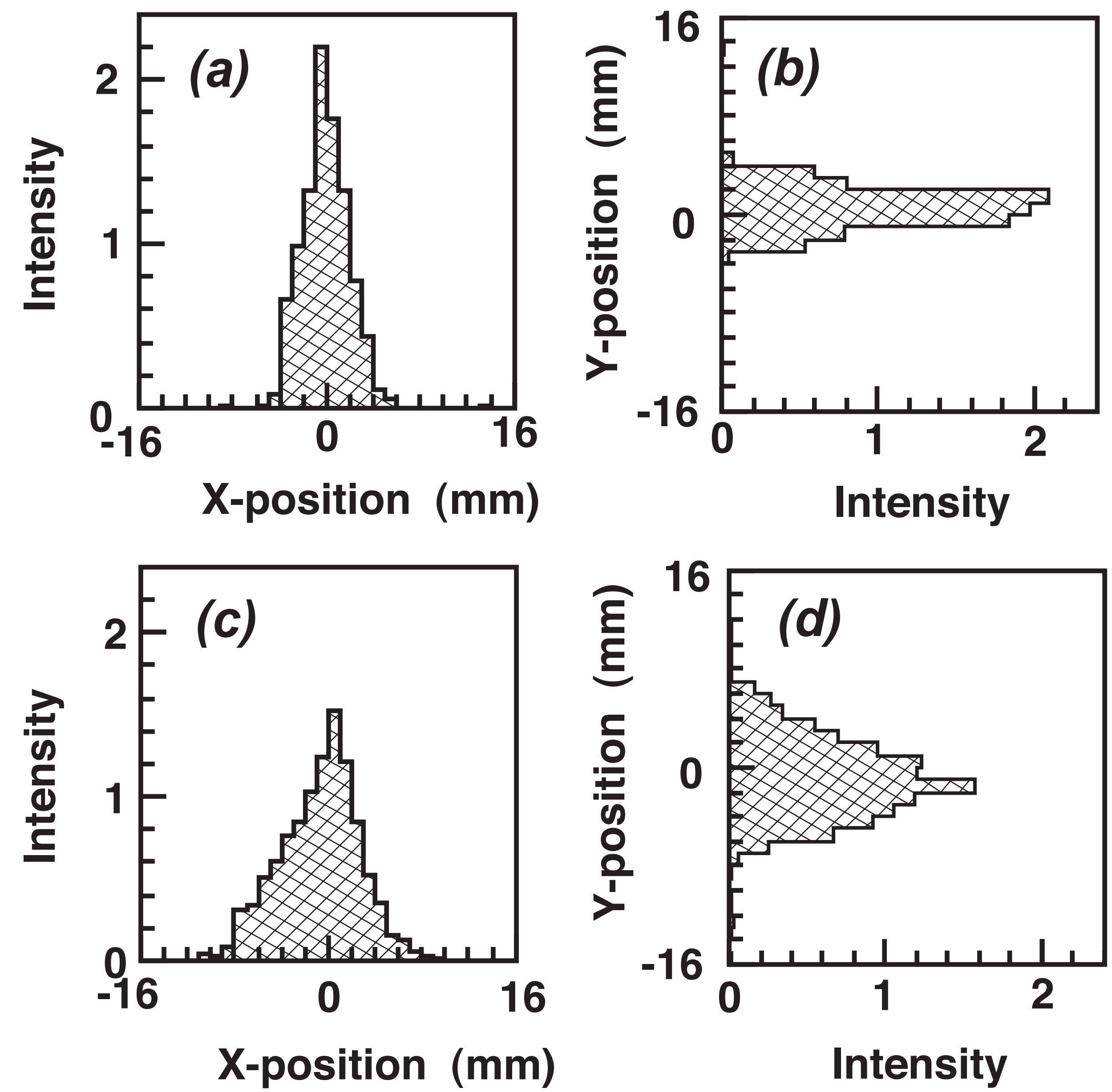


NIM-A 522, 420 (2004) M. Hori

Clear profiles can be observed using the detection of secondary electron emission 1×10^6-2×10^7 antiprotons/pulse.

Simultaneous measurements at multiple points



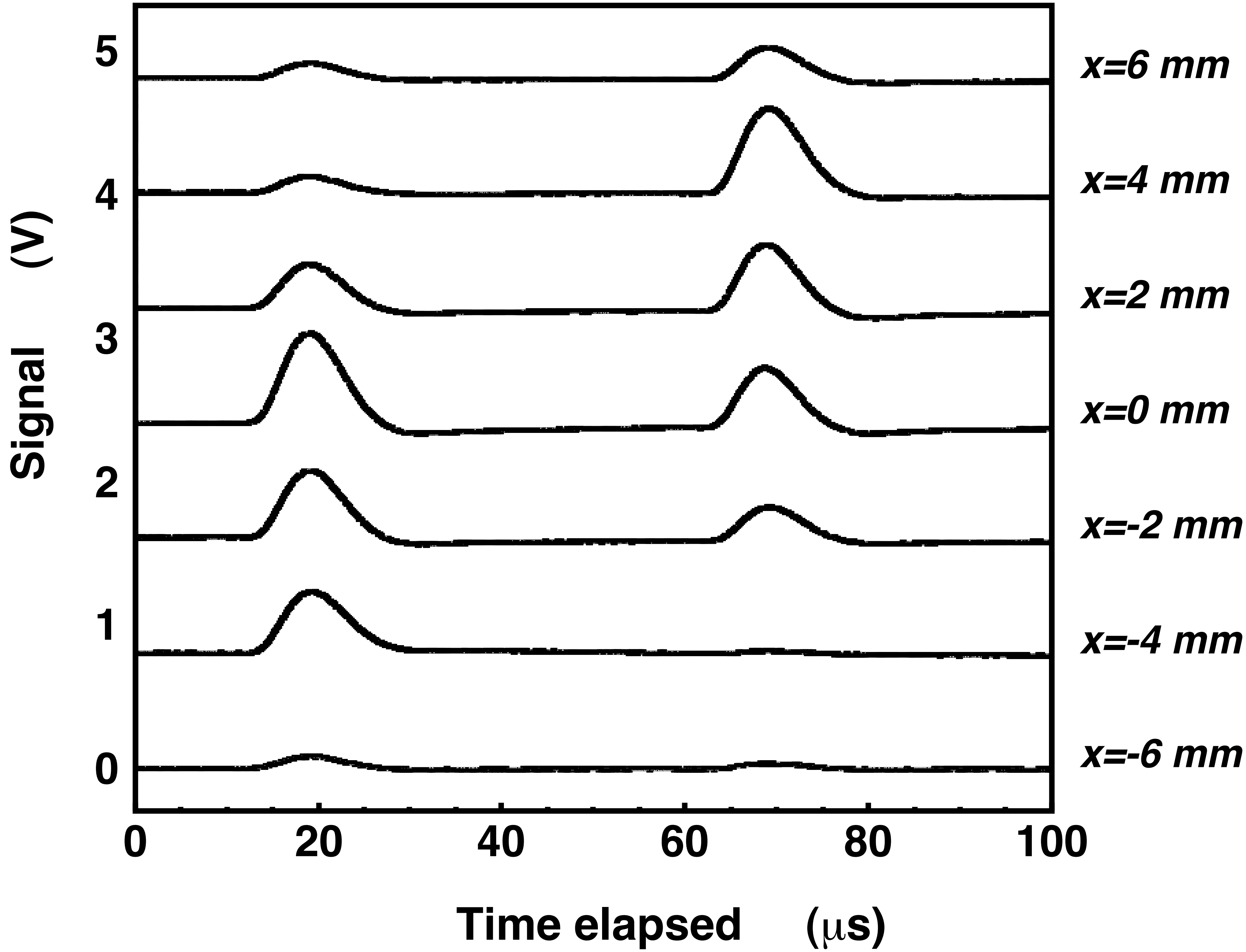


Single-shot measurement of beam profile at several point along beamline.

Enables rapid determination of beam emittance, beam tuning.

RSI 76, 113303 (2005), M. Hori

Time/space-resolved measurement

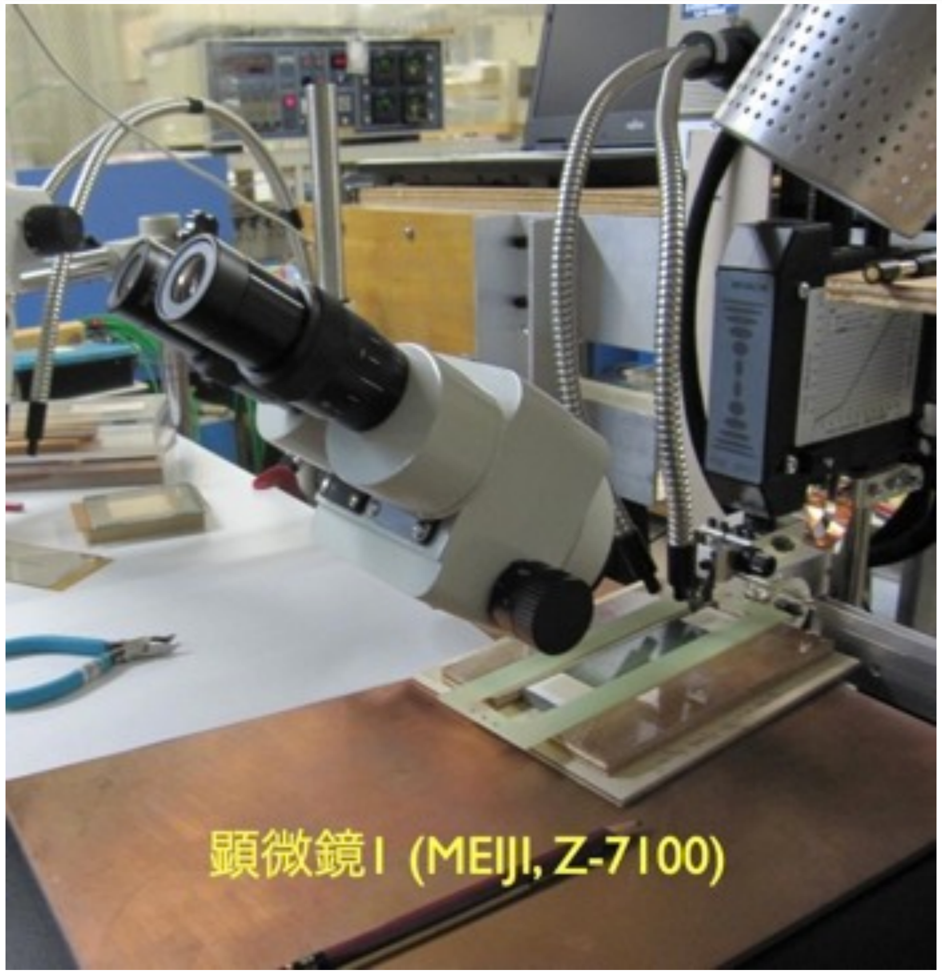


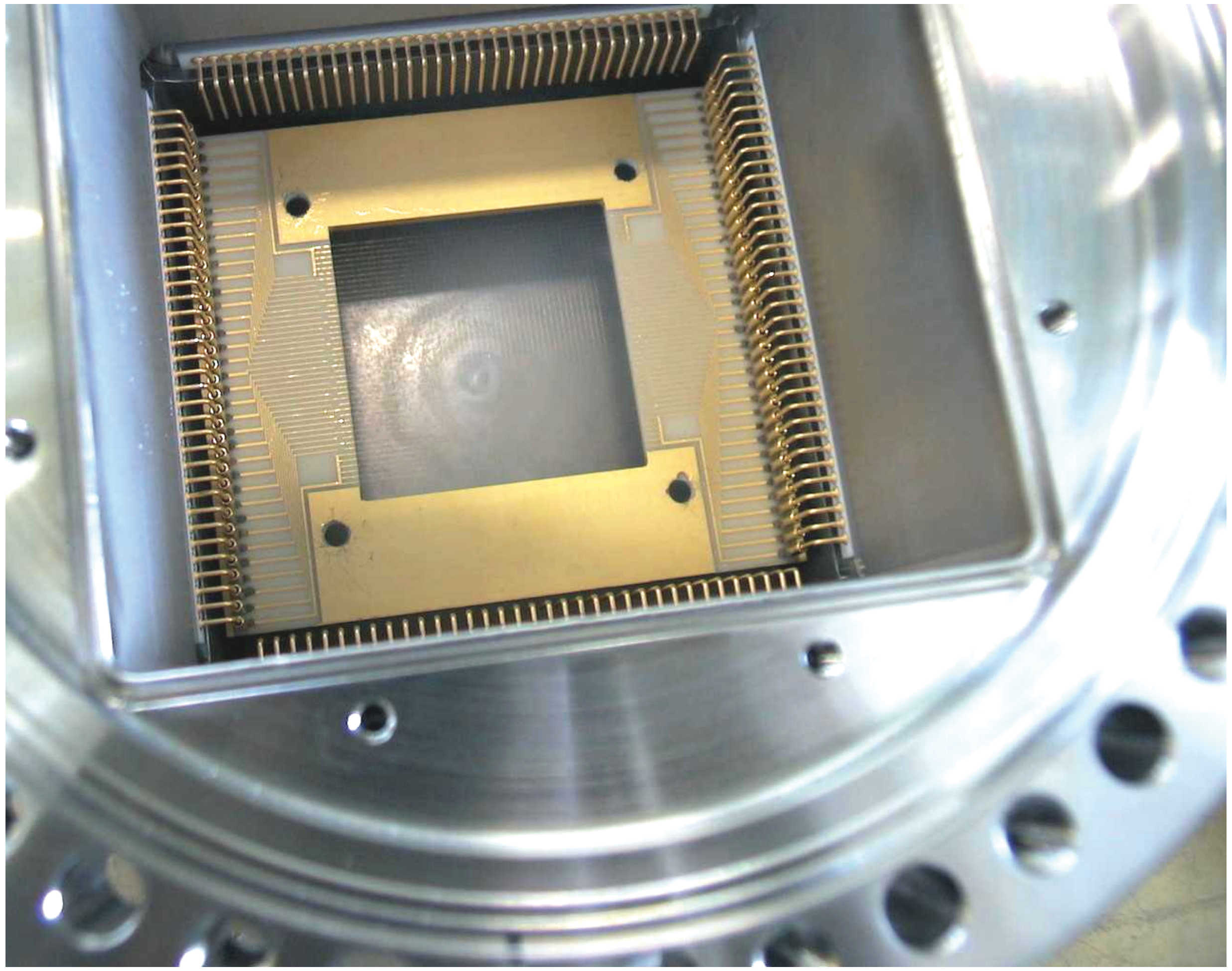
Proposed specifications

Spatial resolution:	1-2 mm
Active area:	30 x 30 - 60 x 60 mm
Minimum intensity:	10^5-10^6 antiprotons/pulse
Maximum intensity:	10^8 antiprotons/pulse
Compatible energy:	10-200 keV
In/out mechanism:	
Thickness including mechanics:	100 mm
Pressure compatibility:	$<10^{-10}$ mb
Temperature:	10-400 K
Readout/control:	Interface into PS control system

No gas needed, no high voltage (50V) needed, good for safety, etc.

Wirebonding of electrodes





Machinable ceramic board 2 mm (UHV compatible)

Thick film printing of 6-um-thick gold layers at 850 degrees C

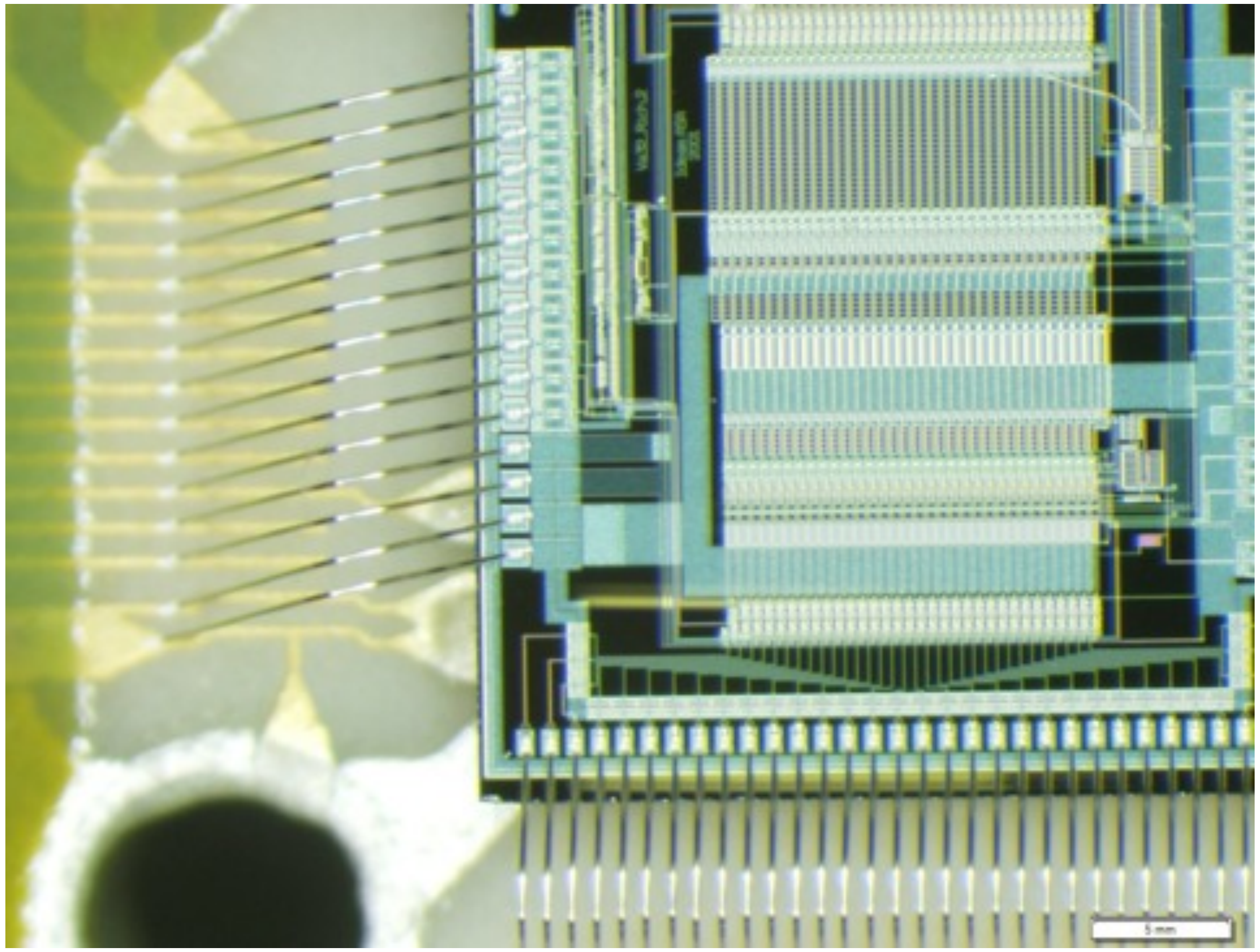
Wirebonding by thermal welding using tungsten two-prong electrodes

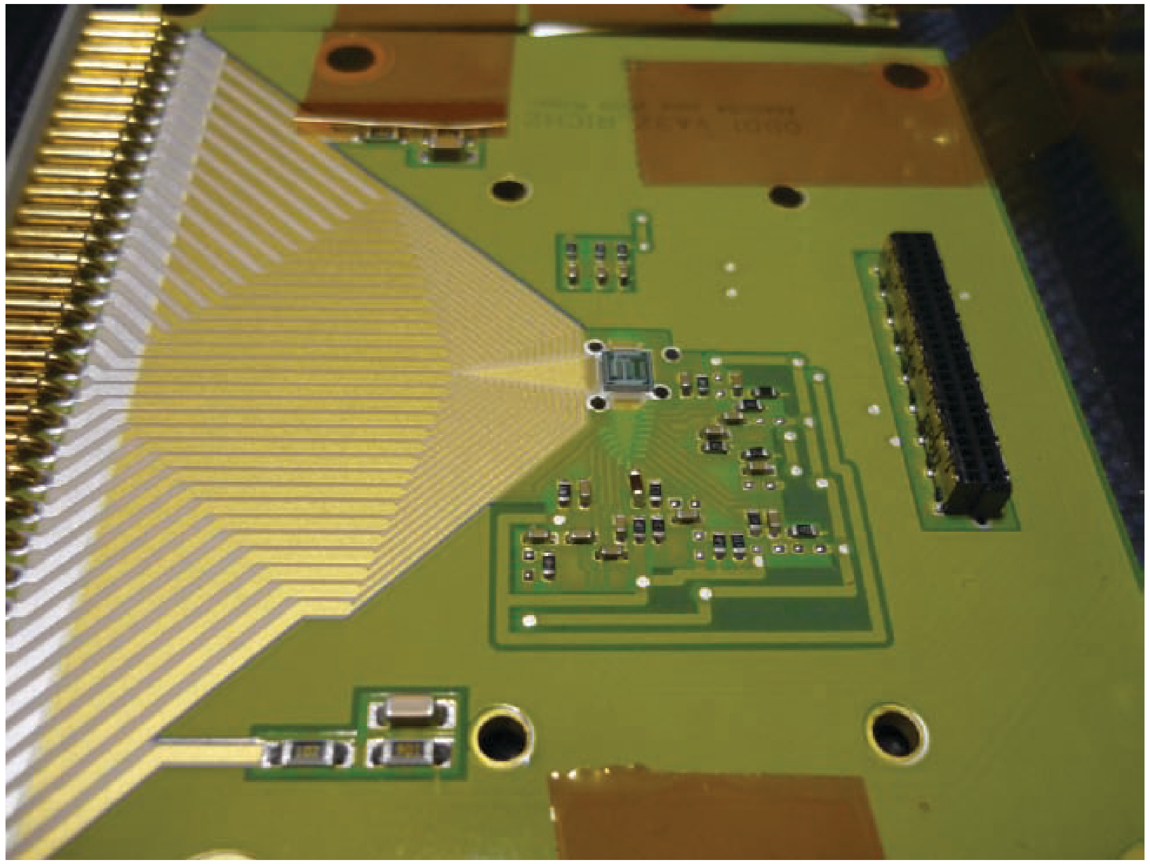
Wire diameter 5-40 um

Pitch (spatial resolution) 0.25-2 mm

Better microscope, XY stage, welding tip on servo motor.

Readout preamplifier by ASIC





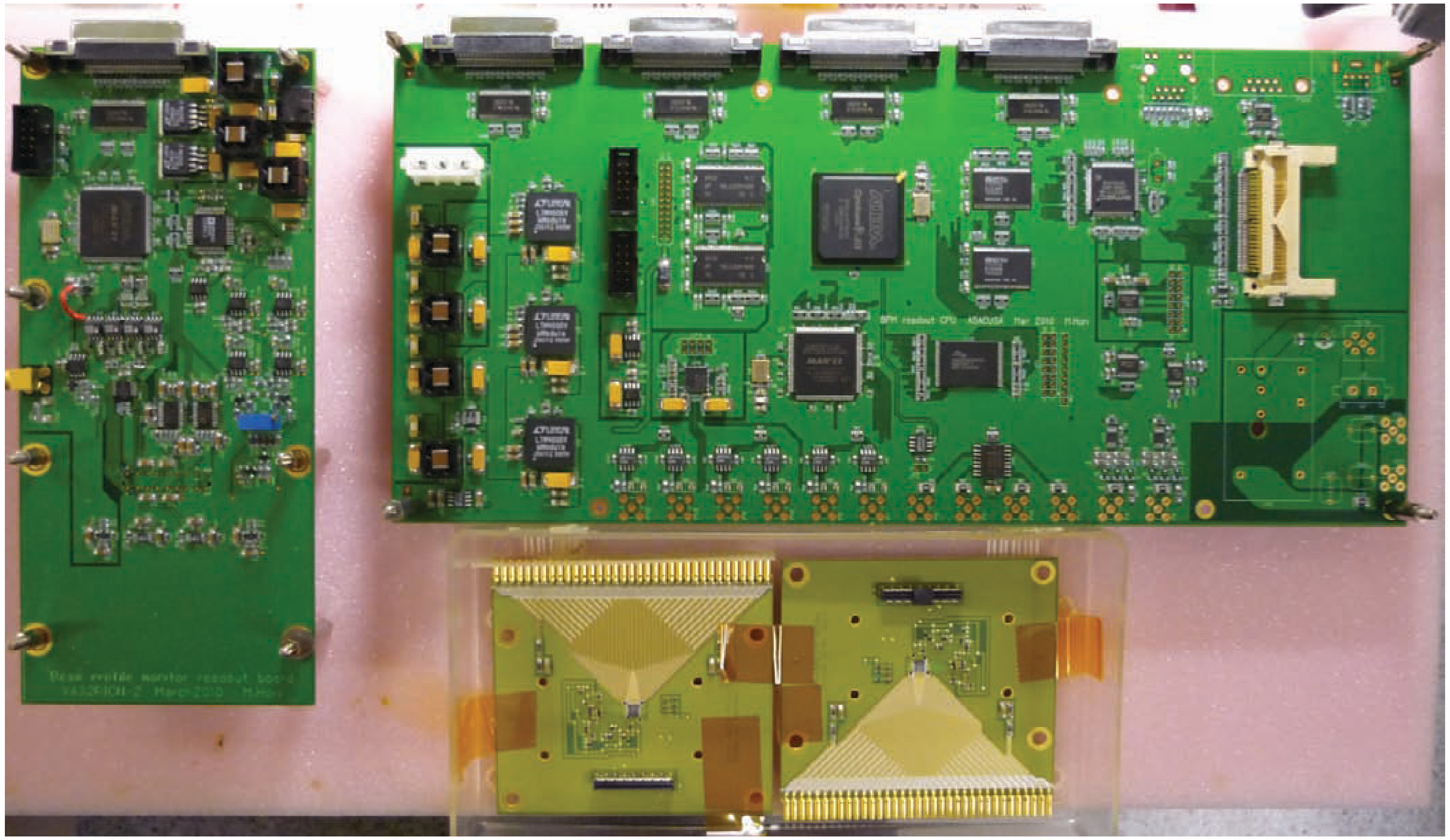
Application-specific integrated circuit (ASIC) charge-sensitive amplifier 64 ch

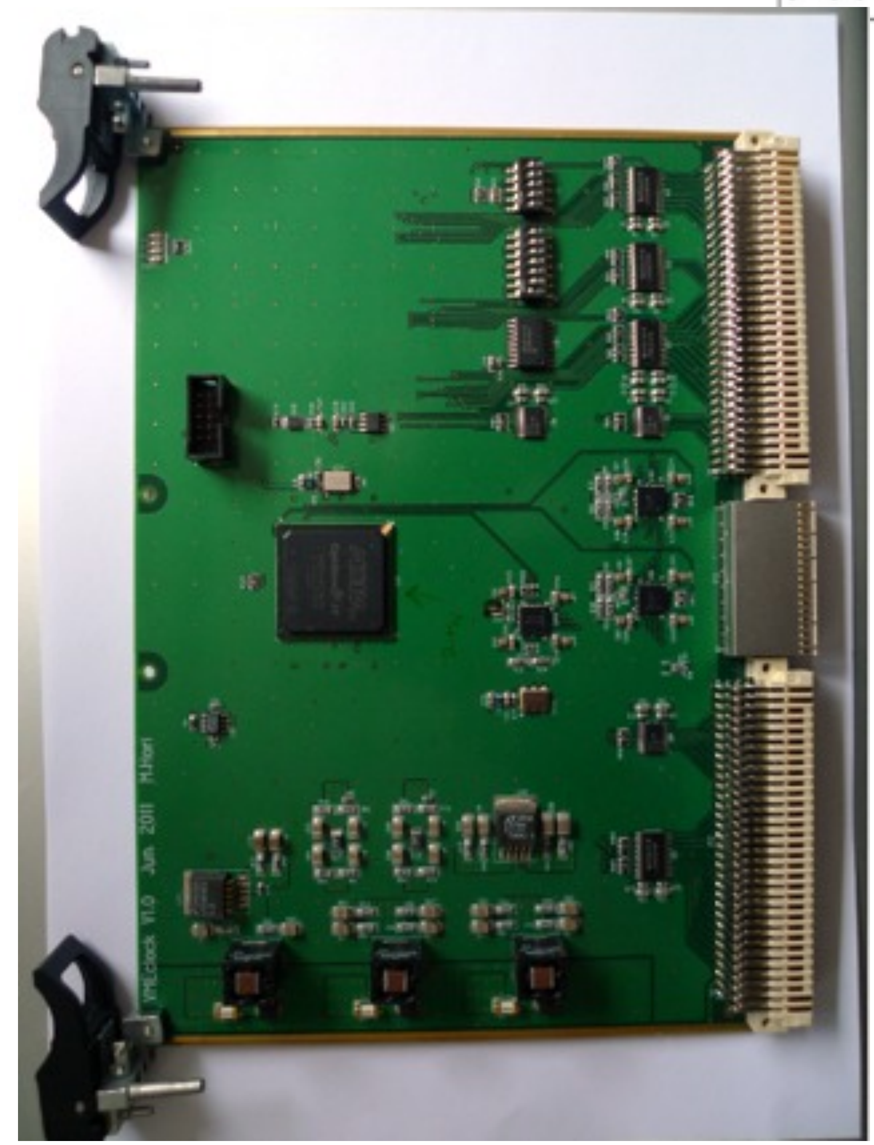
Ceramic hybrid for low leak current, 4 layers

Aluminium wedge-bonding between ASIC and hybrid board, by CERN workshop

Low cost, high integration

Backend electronics and readout software





ASIC hybrid board → Local repeater board → Ethernet cable (30-50 m)

→ Backend VME board → Standard VME64x-based CERN PS control system

Detectors self-trigger when antiprotons pass through them

Conclusions

Secondary electron emission chamber:

- Works with 100-keV RFQD beam.
- Spatial resolution 1-2 mm.
- UHV compatible $p<10^{-10}$ mb.
- Single-pass, multi-point measurement.
- Compatible with cryogenic T<50 K temperatures.
- 0.1 - 3 T magnetic field (good with Penning traps).
- Tokyo/MPQ can in principle provide 30 detectors (incl. manpower + funding)

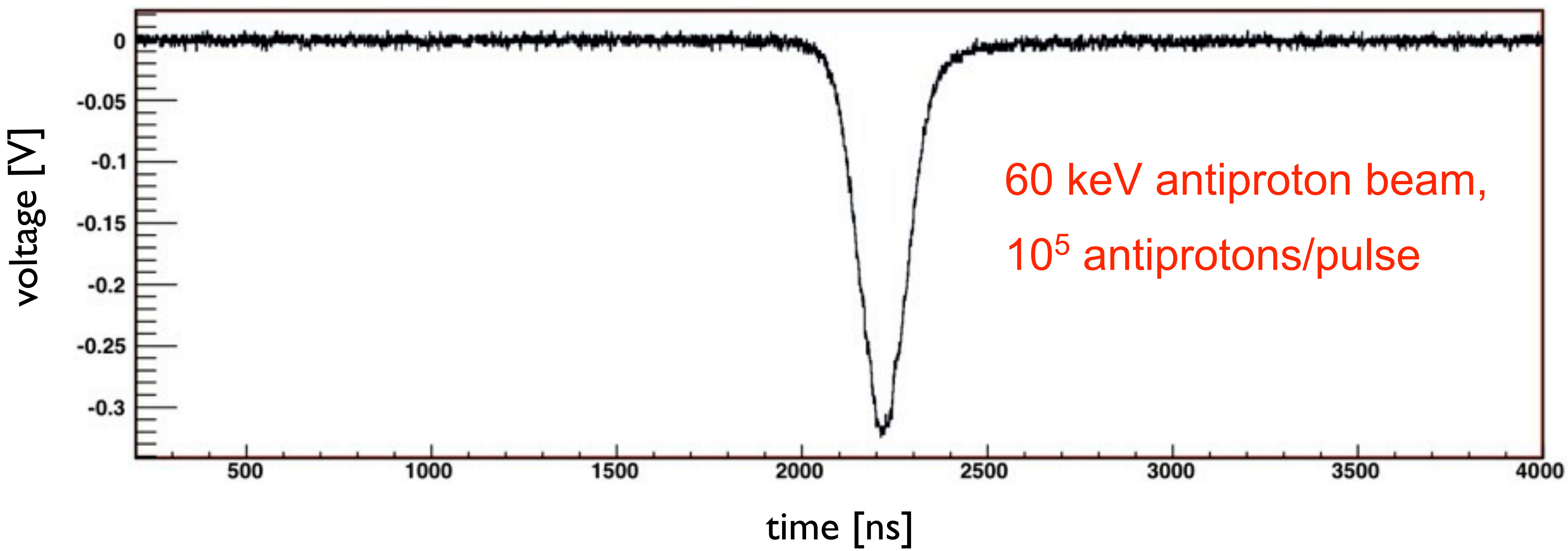
10 years of operations at AD with 4 monitors:

- 1 failure every 3 years (wire breaking).
- Local repair at CERN (within 1 day) using wire welder.

Issues:

- Need tight integration into electrostatic beamlines.
- Building 30+ boxes for so many experiments may be a pain......

Cherenkov detector for timing profile measurements



Timing and relative intensity profile measurement

300-mm long Lucite plastic radiator + photomuliplier placed next to beamline

Timing resolution: 5 ns

Minimum intensity: 10^2-10^4 antiprotons/pulse

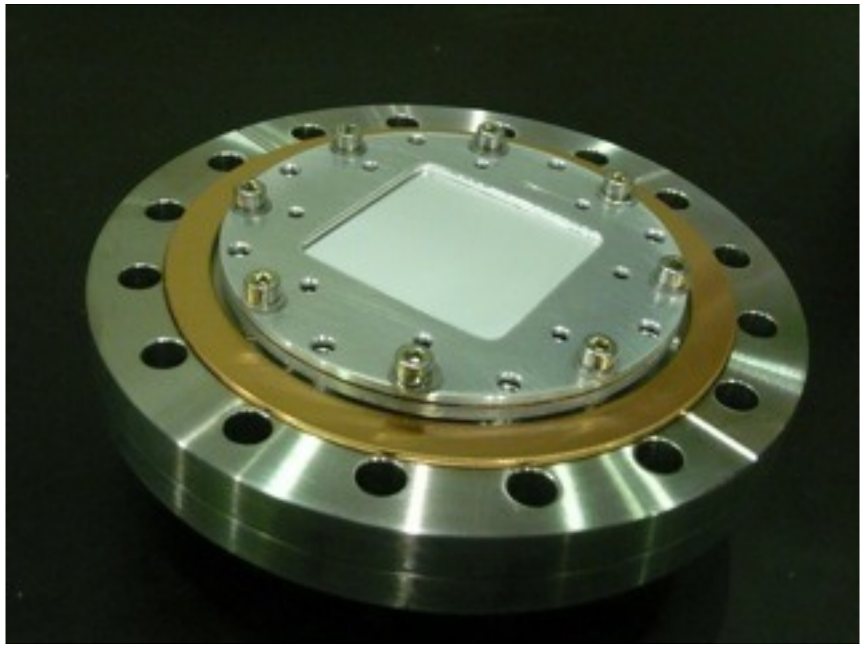
Maximum intensity: 10^9 antiprotons/pulse (tested at LEAR)

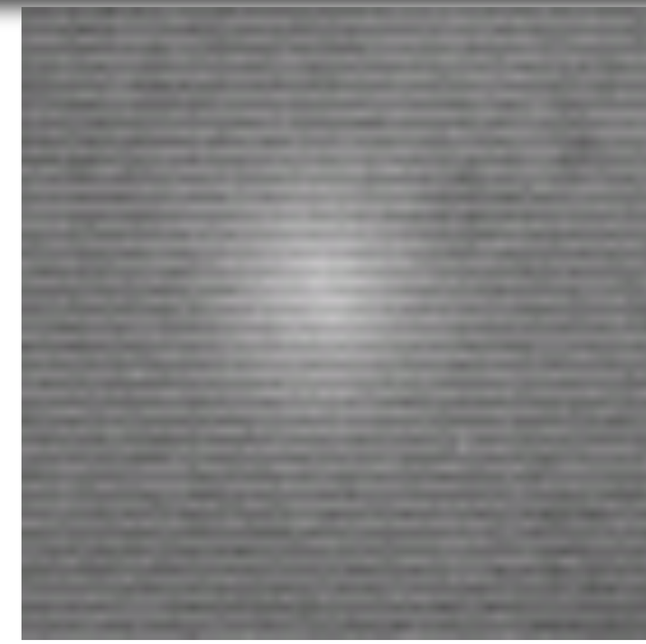
“Several” detectors in ELENA?

Other candidate detectors

Not “recommended” by us, but Wolfgang asked me to review them......

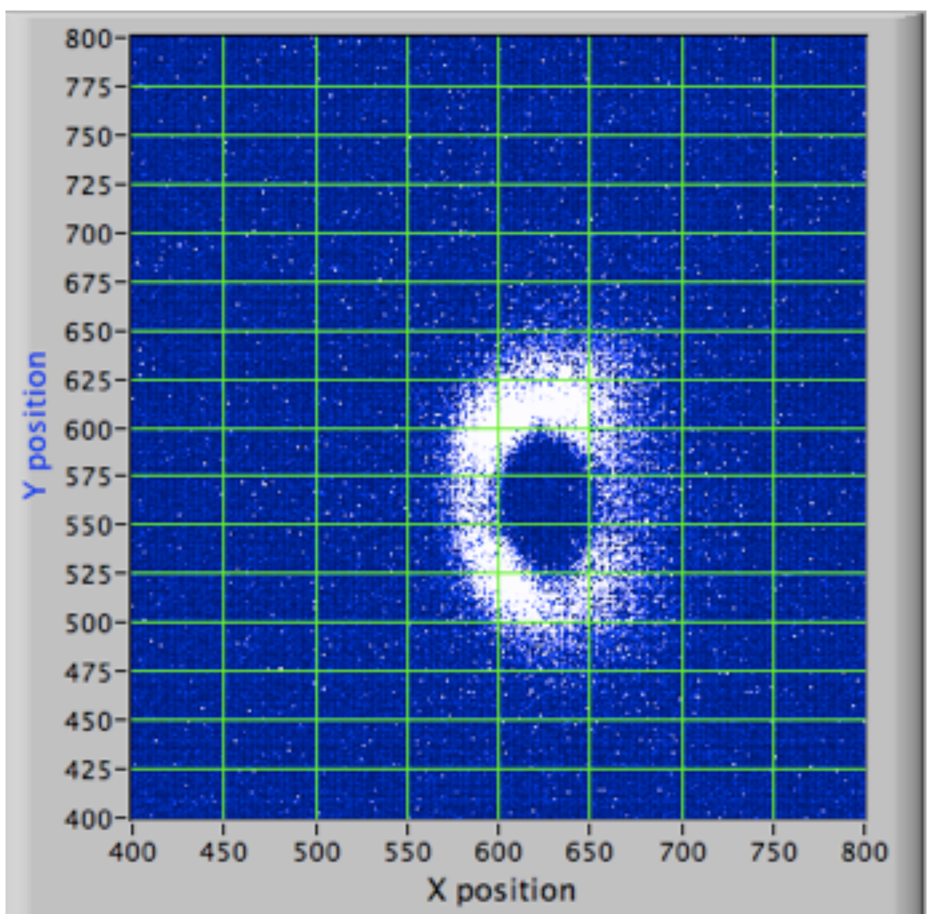
Phosphor screens, MCP's.





Allow antiprotons to strike a scintillator or phosphor plate and look at the light using a CCD camera.

Tested for 5 MeV, 100 keV, and 100 eV beams in the past.

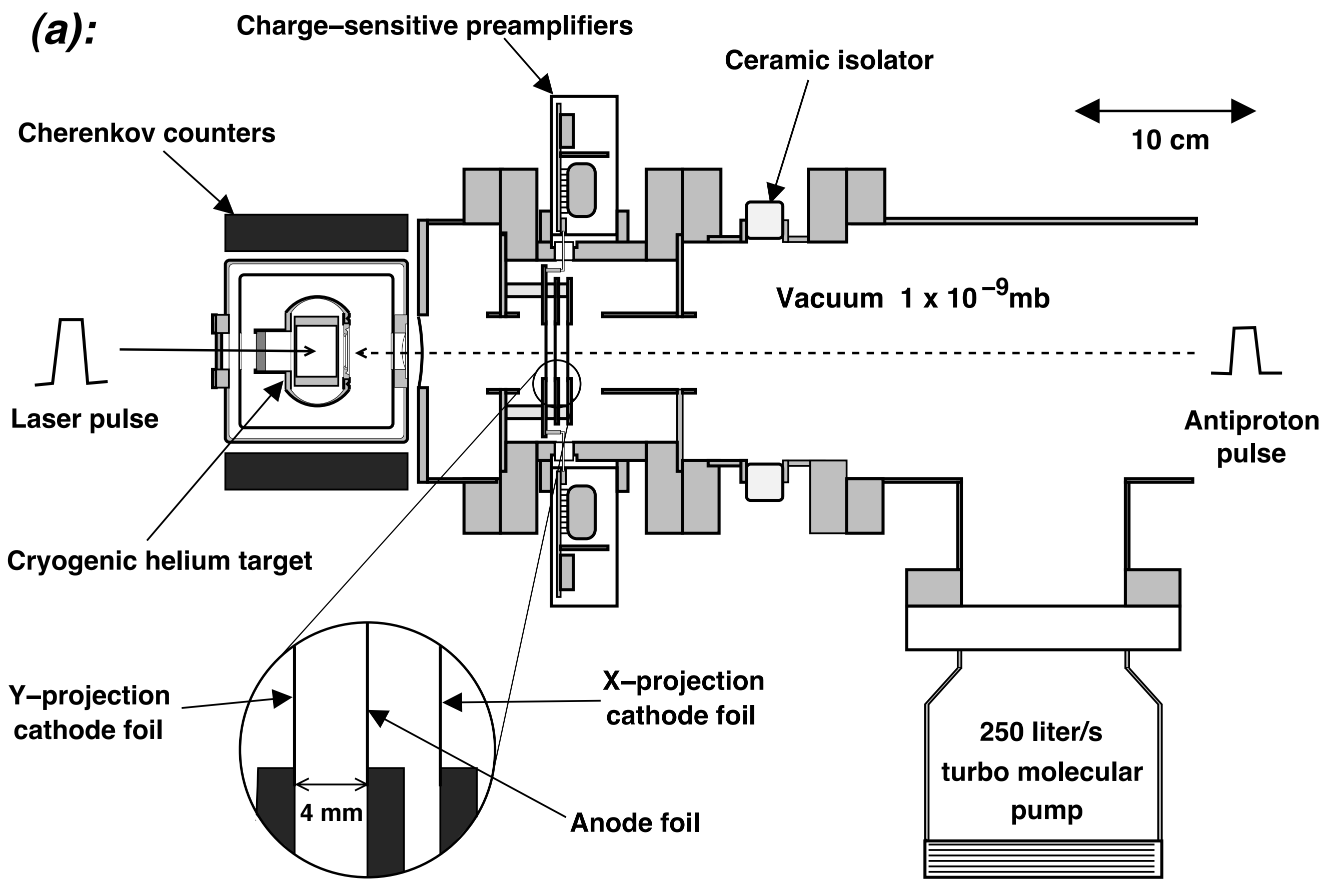


Often difficult to accurately determine beam size and intensity for pulsed beams (smearing, multiple reflections inside plate).

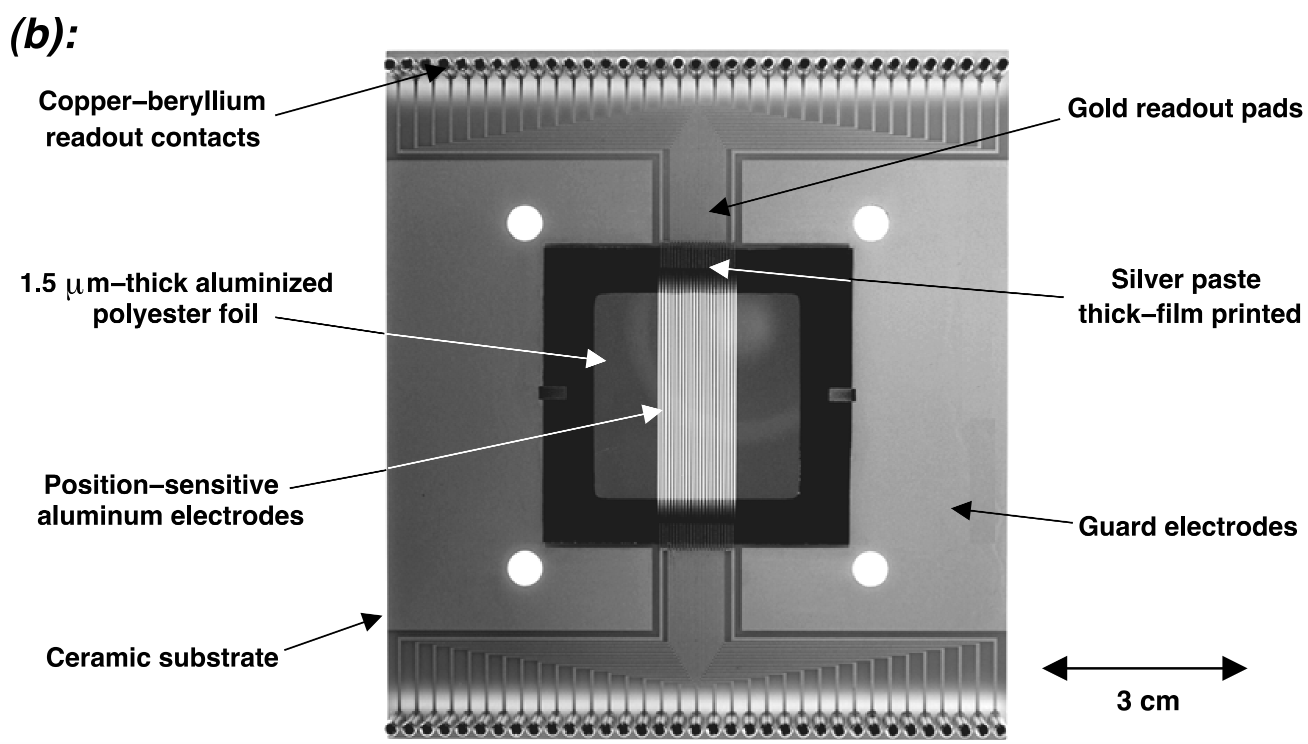
Sees background pions, heavy ions, etc. Can get confusing since upstream pions can produce a signal even when no pbar hits the detector directly.

Parallel plate secondary electron emission chamber

(a):



(b):



Foil electrodes instead of wire electrodes, see secondary electron emission

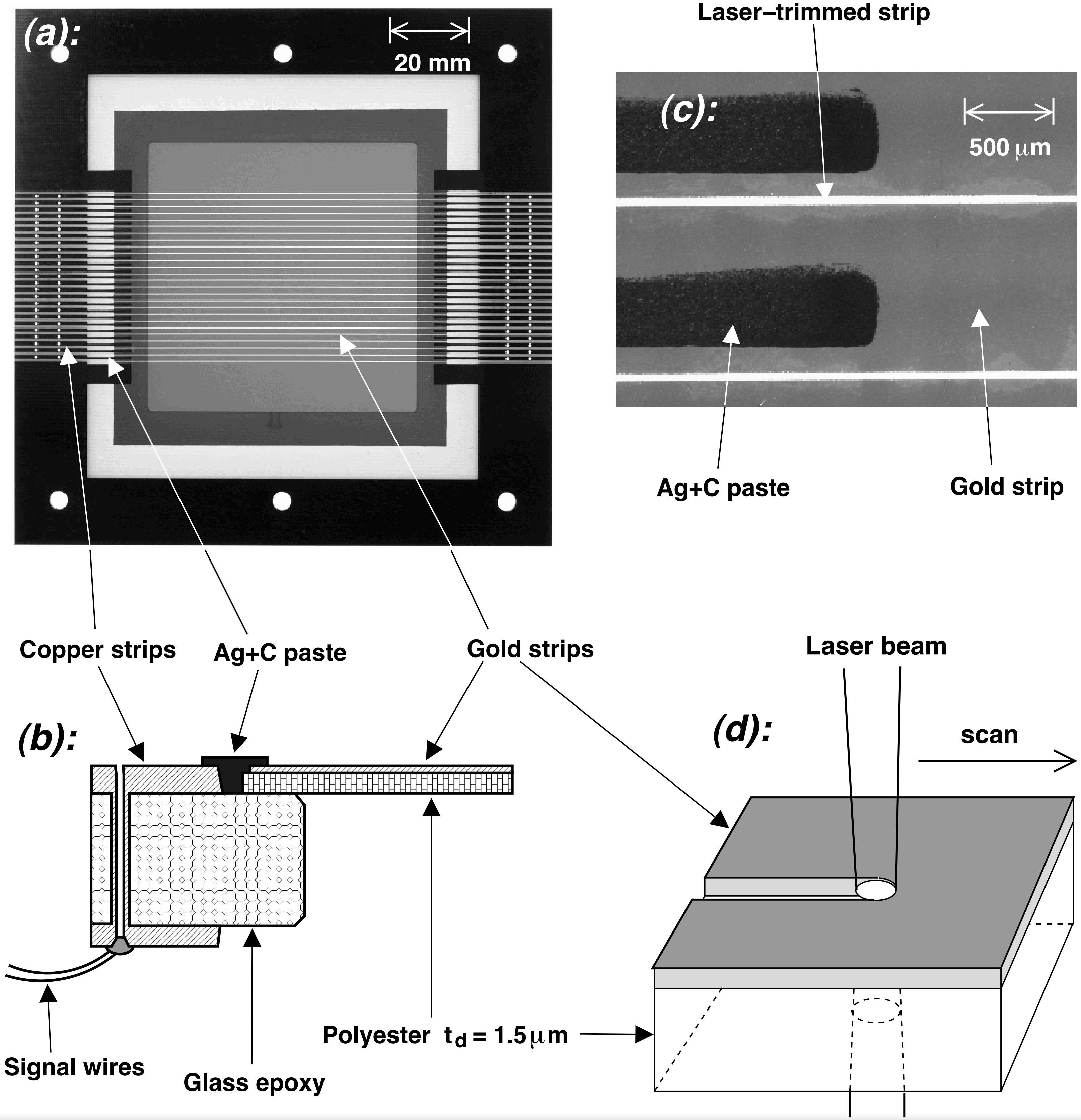
100-keV antiprotons stop in 2 um of plastic.

Large multiple scattering and range straggling induced in the beam.

Used for entrance of Penning trap, but very delicate, often breaks.

NIM-A 522, 420 (2004) M. Hori

<2 micron thick electrodes made by laser trimming



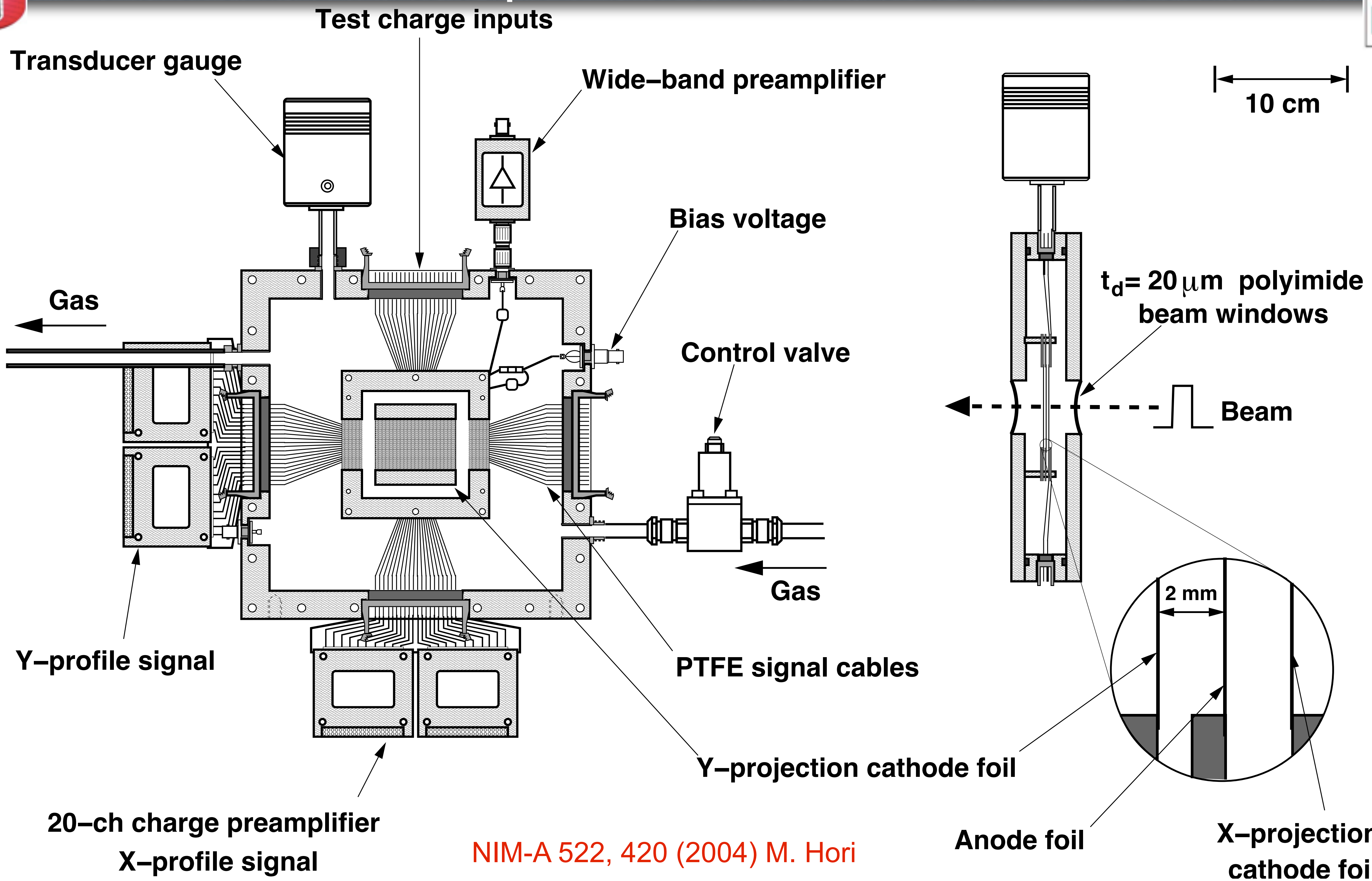
Aluminized or gold-sputtered polyester or Mylar foils.

Cutting of 80-um wide strips in metal layer using Nd:YAG or excimer nanosecond laser trimmer.

Transparent Mylar or polyester foils are left intact.

NIM-A 522, 420 (2004) M. Hori

Parallel plate ionization chamber



NIM-A 522, 420 (2004) M. Hori

Gas chambers - beams stop in entrance foil and cannot be used.

Other detectors

Faraday cup

- Provides "relative" measurement, since pions, Auger electrons carry out charge.
- Al activation measurement is superior in terms of absolute measurement.

Silicon detectors

- 100-keV antiprotons stop in dead layer of most commercial silicon detectors.

Huge stream of charged pions often saturate silicon diode (remember, LHC uses silicon detectors to measure pions).