HHH High Energy High Intensity Hadron Beams

http://care-hhh.web.cern.ch/care-hhh/

CARE

HHH Highlight Talk

Active Techniques to Mitigate the Electron-Cloud Effects in Proton Machines

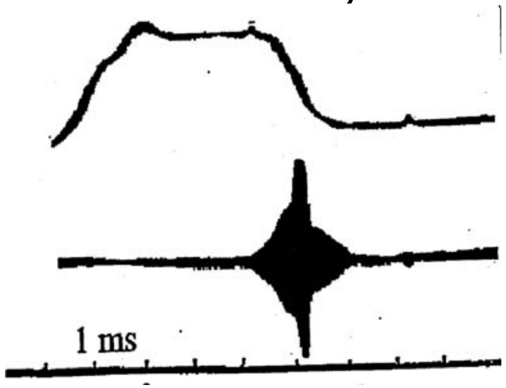
Frank Zimmermann, CERN

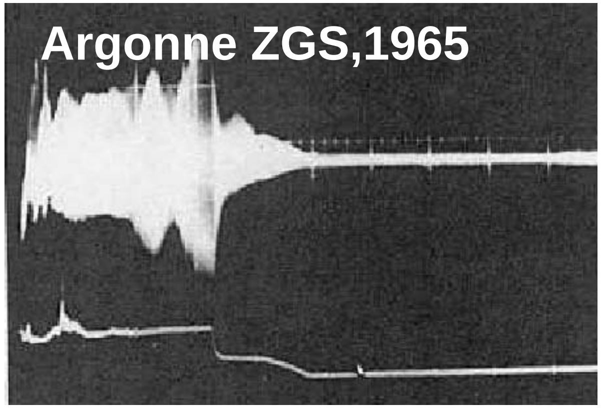
electron-cloud effects

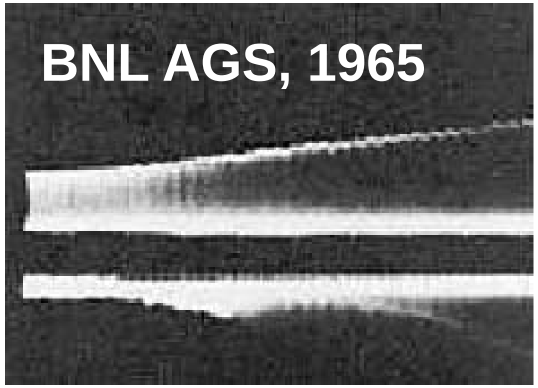
- **pressure rise**
  - → interlock, background, beam loss
- **heat load**
  - → quench of s.c. magnets
- **coherent tune shift**
  - → loss of Landau damping, instabilities
- **single and multi-bunch instabilities**
  - → beam loss, emittance growth
- **incoherent tune shift, nonlinear field**
  - → poor lifetime, emittance growth

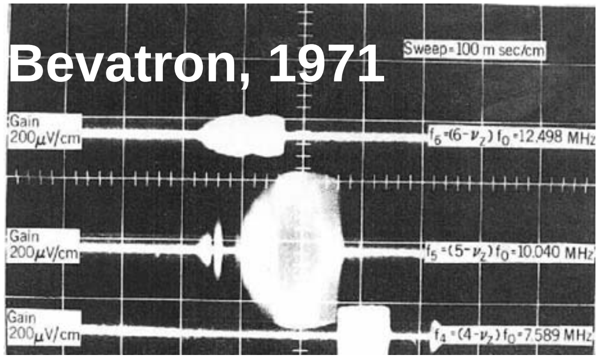
electron-cloud effects seen at almost all p (& e+) accelerators

INP Novosibirsk, 1965

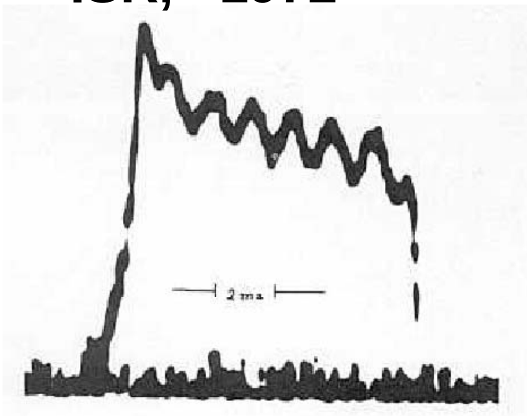




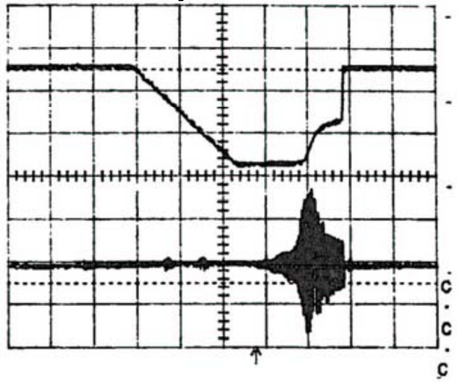




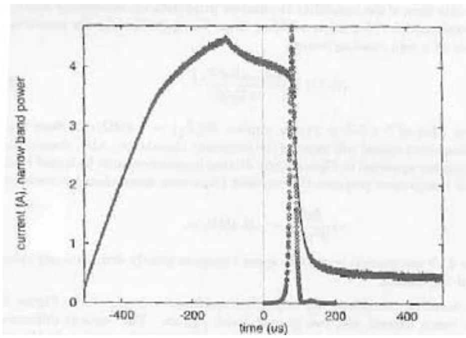
ISR, ~1972



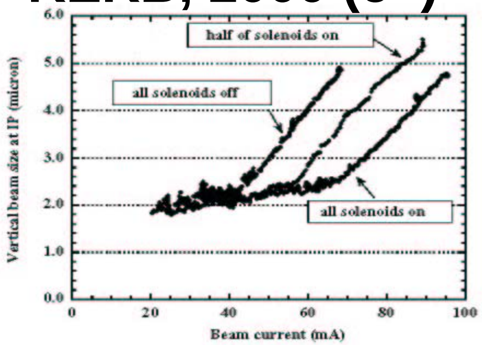
PSR, 1988



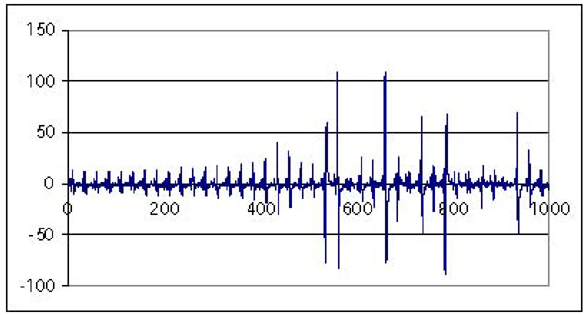
AGS Booster, 1998/99



KEKB, 2000 (e+)



CERN SPS, 2000



origin of electrons

- **ionization of residual gas**

  vacuum pressure

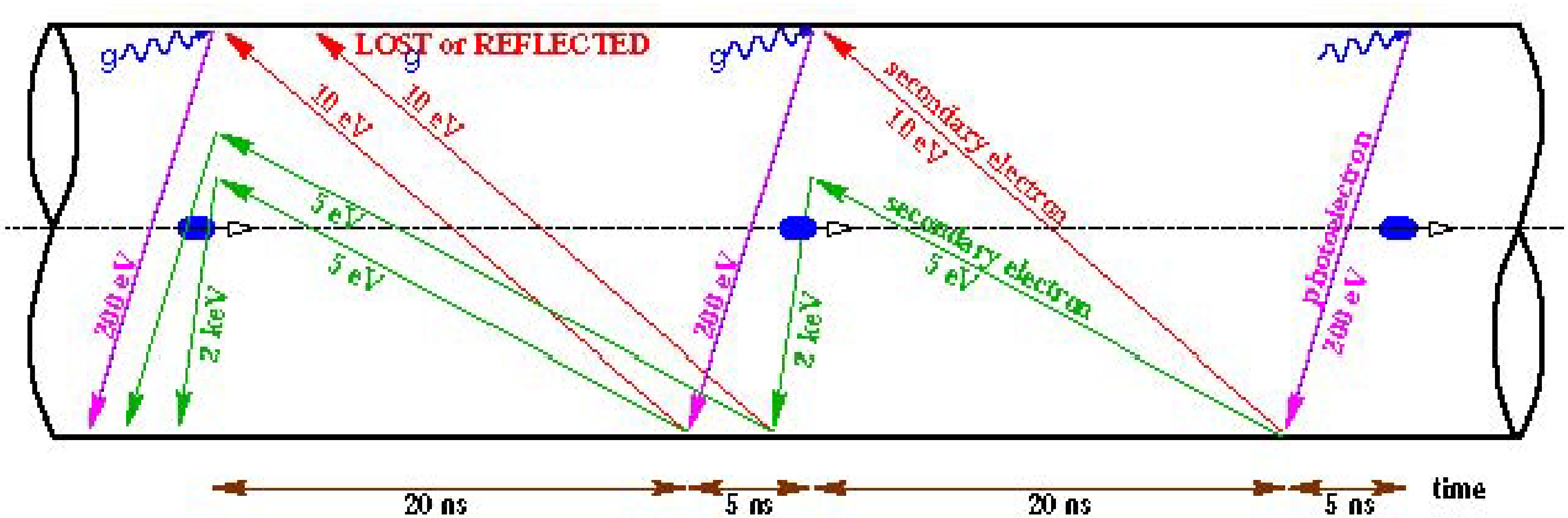
- **photoemission from synchrotron radiation**

  spatial distribution of primary and reflected photons, photon reflectivity, photoemission yield

- **avalanche build up of secondary e- via acceleration in the beam field**

  secondary emission yield, surface conditions, conditioning,….

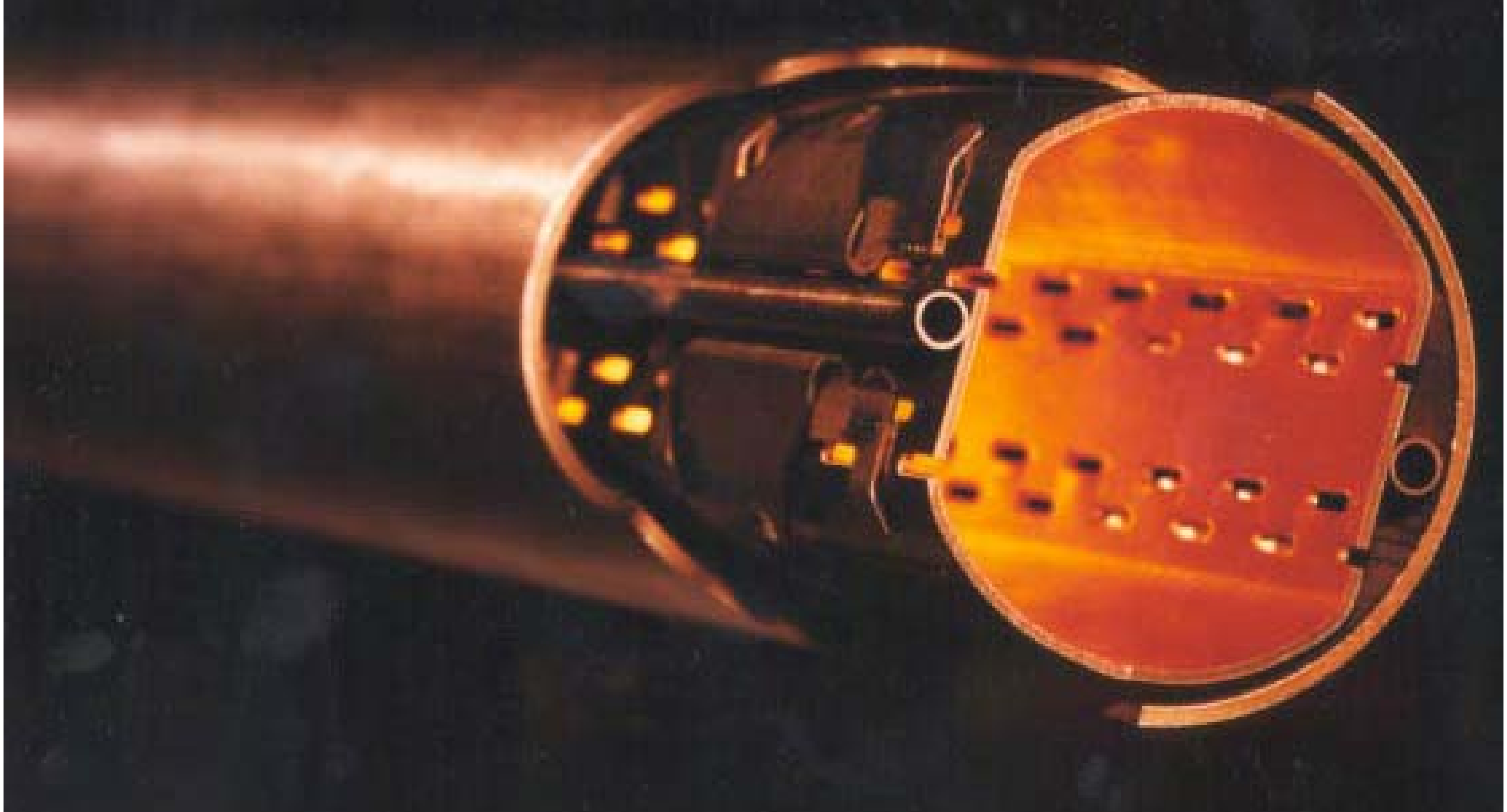
electron cloud in the LHC



schematic of e- cloud build up in the arc beam pipe, due to **photoemission** and **secondary emission**

[F. Ruggiero]

LHC cold vacuum chamber



4-20 K beam screen inside cold bore; pumping slot

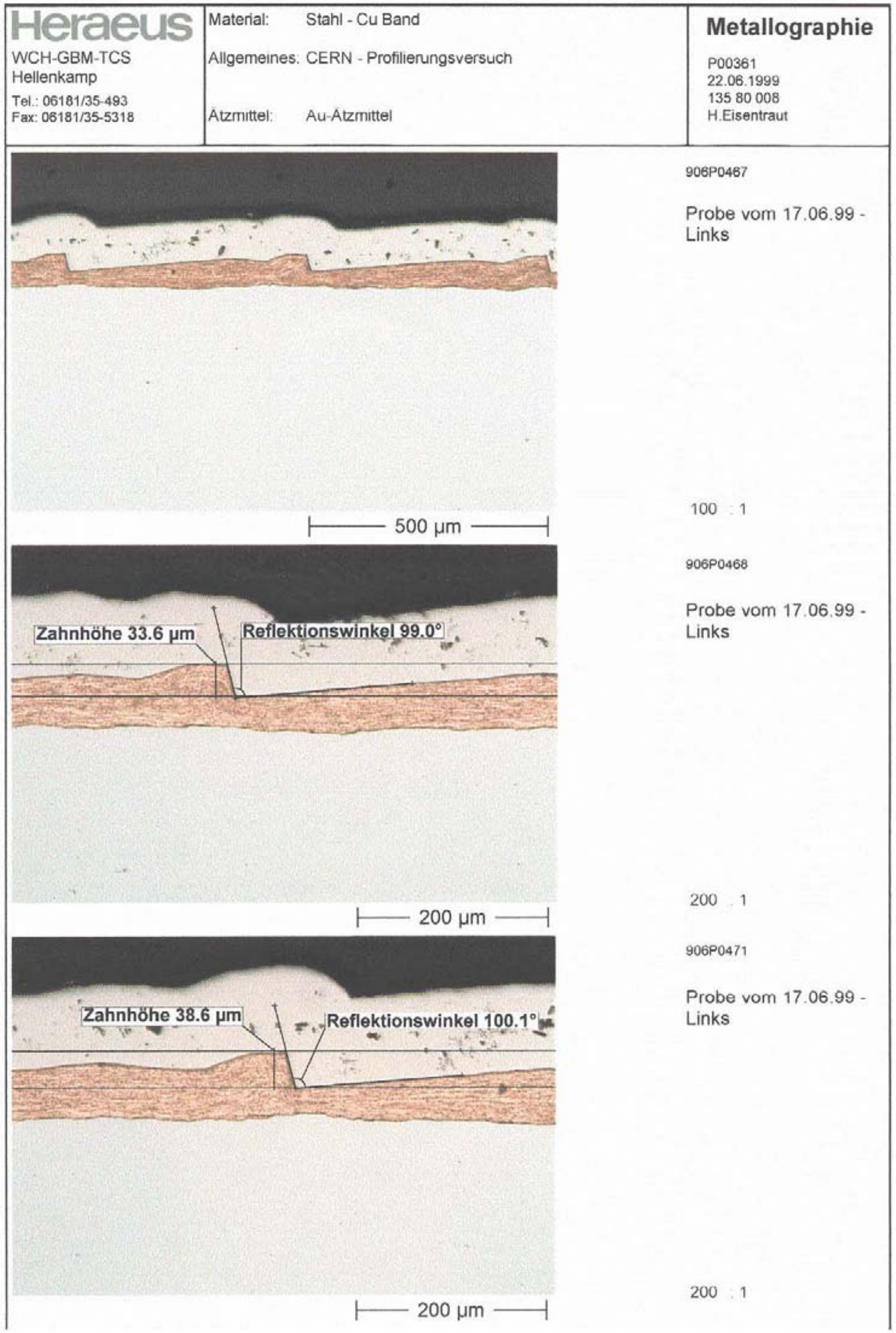
LHC strategy against electron cloud ~1997-2002

1) **warm sections** (20% of circumference) **coated by <u>TiZrV getter</u>** developed at CERN; low secondary emission; if cloud occurs, ionization by electrons (high cross section ~400 Mbarn) aids in pumping & pressure will even improve

2) outer wall of **beam screen** (at 4-20 K, inside 1.9-K cold bore) will have a **<u>sawtooth surface</u>** (30 μm over 500 μm) to reduce photon reflectivity to ~2% so that photoelectrons are only emitted from outer wall & confined by dipole field

3) **pumping slots** in beam screen are **<u>shielded</u>** to prevent electron impact on cold magnet bore

4) rely on <u>surface conditioning</u> ('scrubbing'); commissioning strategy; as a last resort doubling or tripling bunch spacing suppresses e-cloud heat load



sawtooth structure stamped on LHC beam screen

→ reduced photon reflectivity

→ only 2% of photons reflected such that they hit top or bottom of beam screen

courtesy I. Collins, 1999

“beyond LHC” - situation early 2007

- HHH LUMI’06 workshop Valencia showed e-cloud may be severe problem for new LHC injectors (PS2, SPS w PS2)
- Fritz Caspers proposed solution: “e-cloud killler” based on enamel coating; established contacts in Germany
- Warner Bruns (EUROTeV) wrote new e- code “Faktor2” & found novel cure: slots
- CARE-HHH & CARE-ELAN supportive
- wide resonance from community

→ ***ECL2 mini-workshop, 1-2 March 2007***

HHH

APD
Accelerator Physics and synchrotron Design

CARE

CERN, 1-2 March 2007

ECL2

CERN

EUROTeV

ELAN

care-hhh.web.cern.ch/CARE-HHH/ECL2

Joint CARE-HHH-APD, CARE-ELAN and EUROTEV-WP3 mini-Workshop on Electron Cloud Clearing

Electron Cloud Effects and Technological Consequences

Organizing committee: **F. Caspers (CERN), O. Malyshev (ASTeC/Cockcroft), M. Pivi (SLAC), W. Scandale (CERN), D. Schulte (CERN), R. Wanzenberg (DESY), F. Zimmermann (CERN)**

ECL2 participants

- total: 35
- 16 from CERN (4 AB/ABP, 1 AB/OP, 7 AB/RF, 2 AT-VAC, 2 TS)
- 3 from German enamel industry
- 4 from US (BNL, Cornell, LBNL & SLAC)
- 1 from KEK
- 11 from European research institutes and universities (Astec, LNF, DESY, ANKA, Rostock, CELLS, U.Sannio, ESRF)

CERN-AB-2007-064-ABP

CARE-Conf-07-007-HHH
CARE/ELAN document-2007-006
EUROTEV-Report-2007-060

20 August 2007

Joint CARE-ELAN, CARE-HHH-APD, and EUROTEV-WP3
Workshop on

Electron Cloud Clearing

- Electron Cloud Effects and Technological Consequences

"ECL2"

CERN, Geneva, Switzerland, 1 - 2 March, 2007

PROCEEDINGS

Editors :
F. Caspers
W. Scandale
D. Schulte
F. Zimmermann

GENEVA
2007

ECL2 proceedings

CARE-HHH Conf
CARE/ELAN doc
EUROTeV report
CERN-AB report

ECL2: solutions against electron cloud

- TiN coating (P. Chiggiato + team, Y. Suetsugu)
- Ti ZrV NEG coating (P. Chiggiato, Y. Suetsugu)
- grooved surfaces (M. Pivi, M. Palmer)
- conventional clearing electrodes
  (A. Poncet, M. Zobov)
- **enamel electrodes** (F. Caspers) ***New!***
- **slotted vacuum chamber** (W. Bruns) ***New!***
- **electrete inserts** (F. Caspers) *New!*

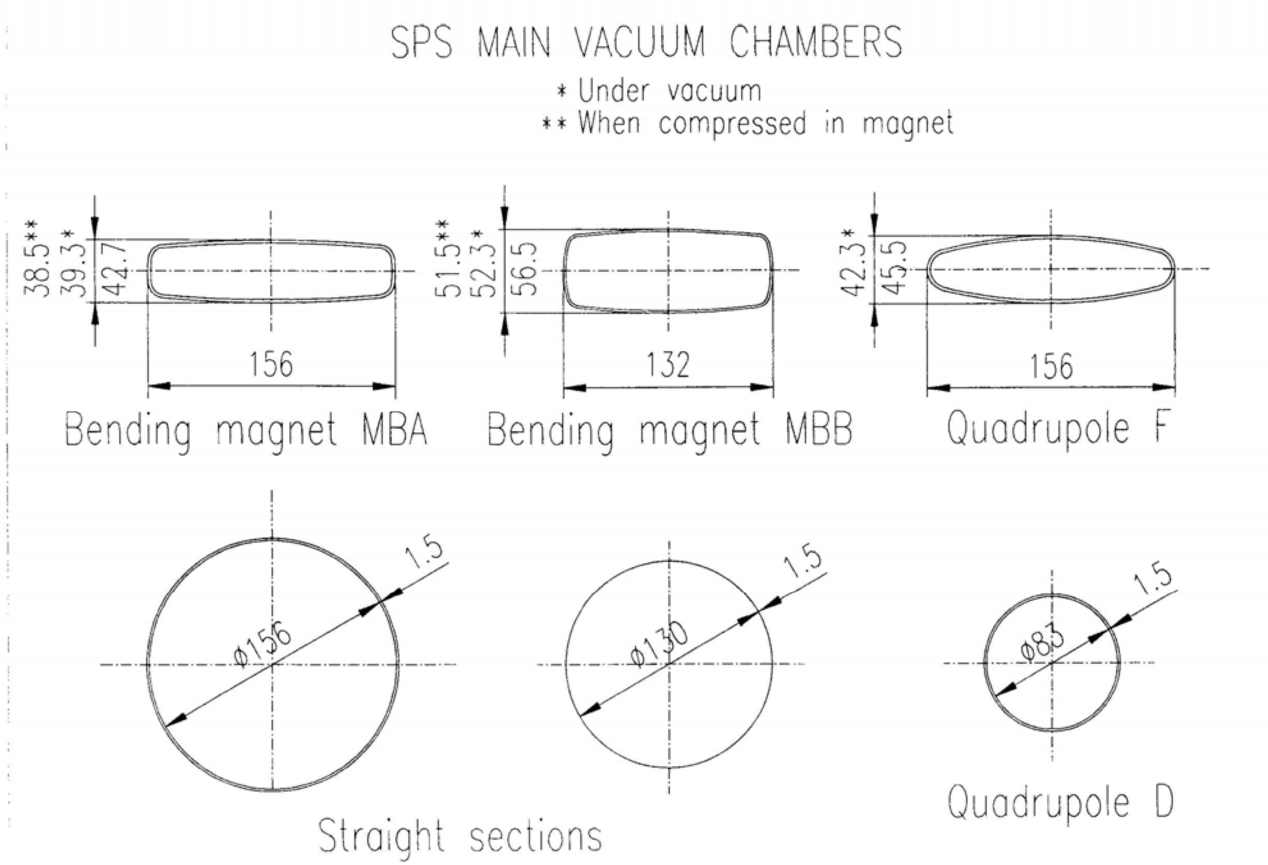
issues: modeling, prototypes, beam experiments, suppression efficiency, impedance, vacuum issues, implications & cost

TiN coating & graphite:

infrastructure for **TiN coating** exists at CERN;

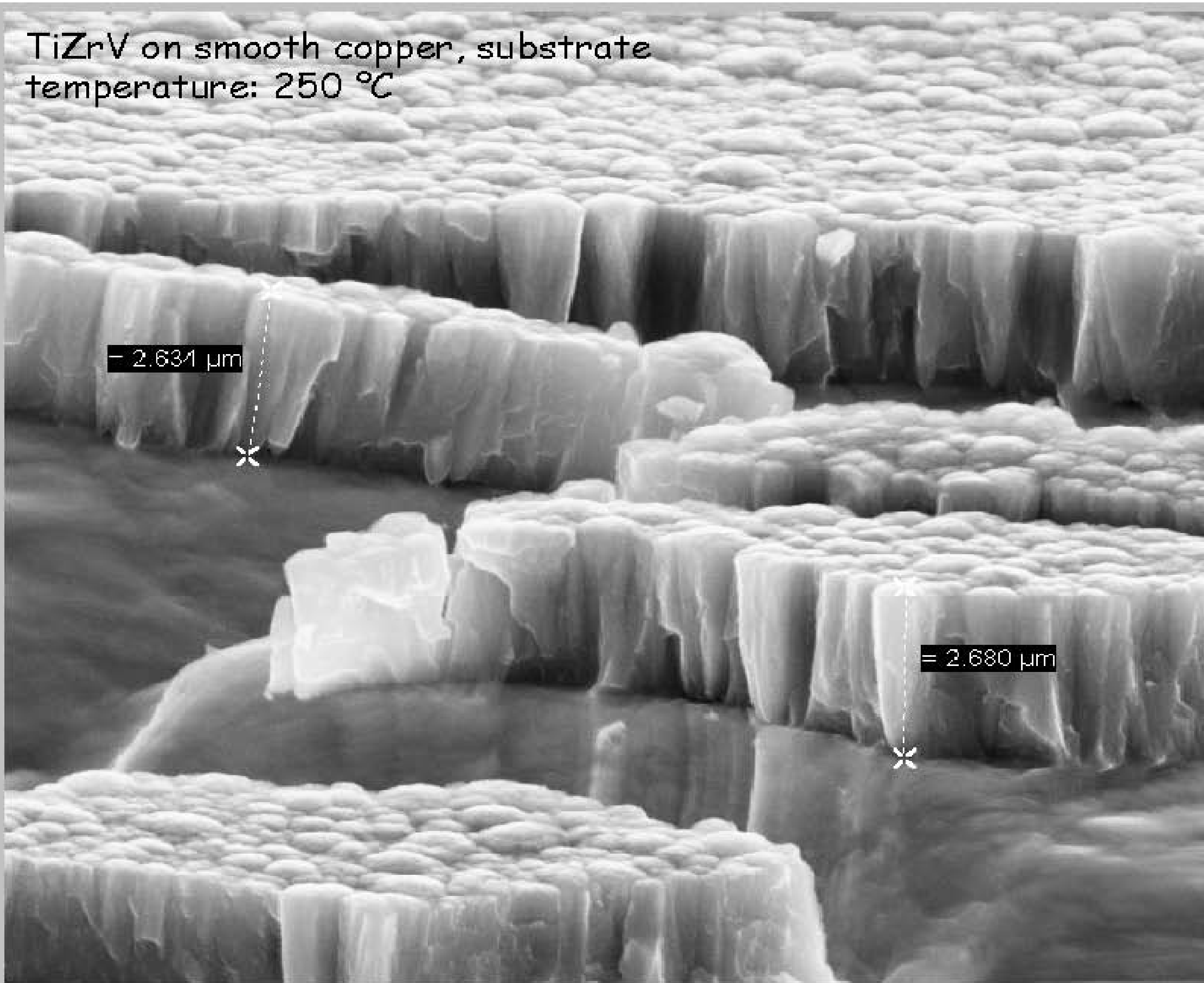
planned testing of coated liners in SPS;

alternative approach: **graphite layer**

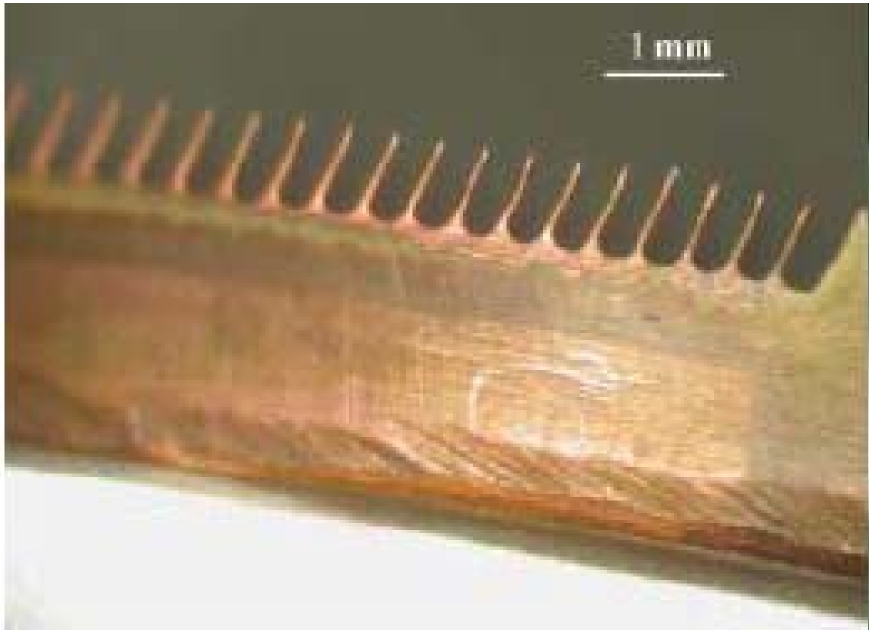


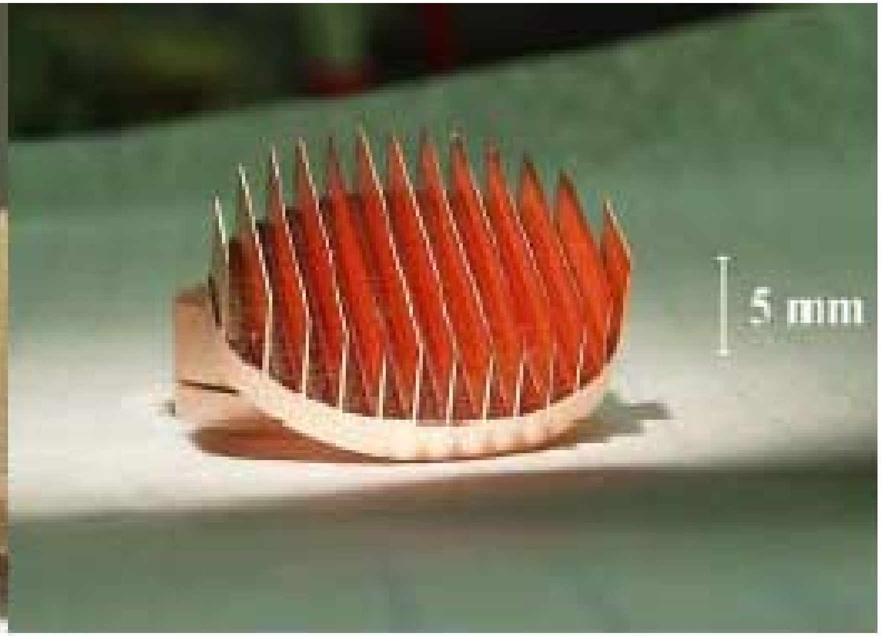
LHC NEG coating (P. Chiggiato, ECL2)

NEG coating on Cu substrate at 250 ^{o}C (P. Chiggiato, ECL2)



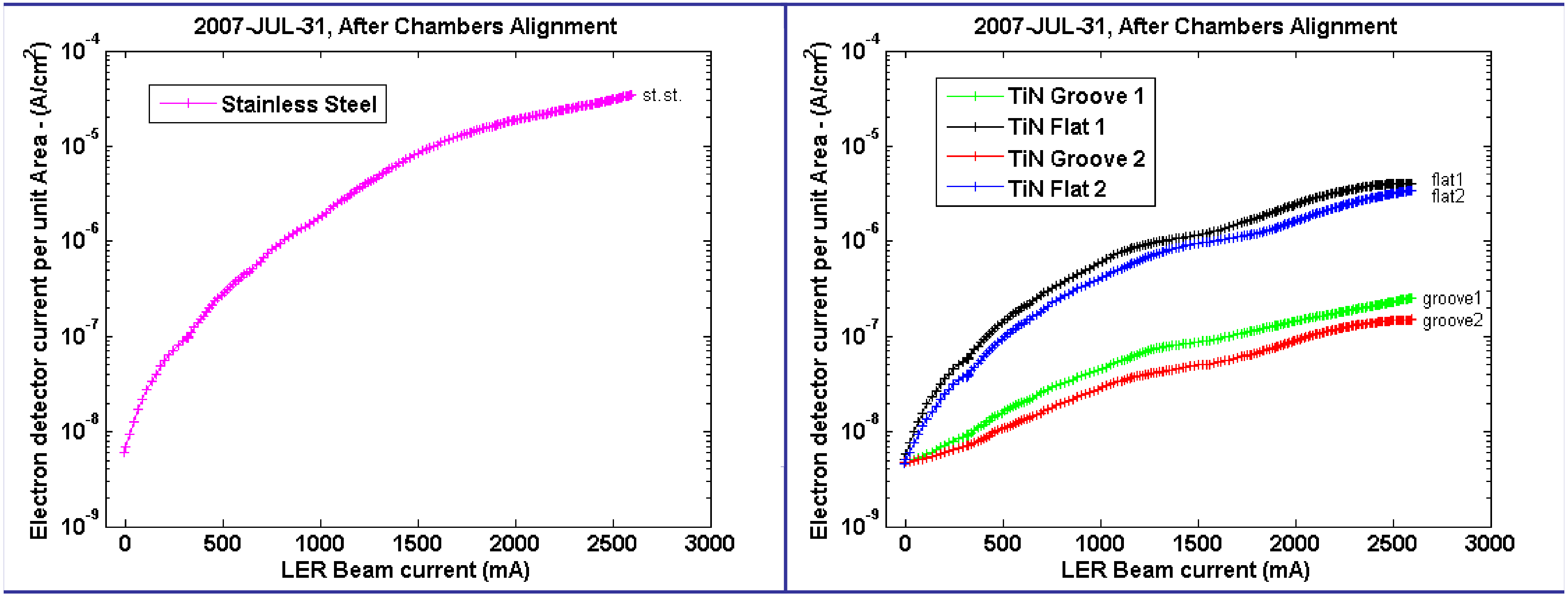
“grooves” (M. Pivi et al, SLAC, ECL2)





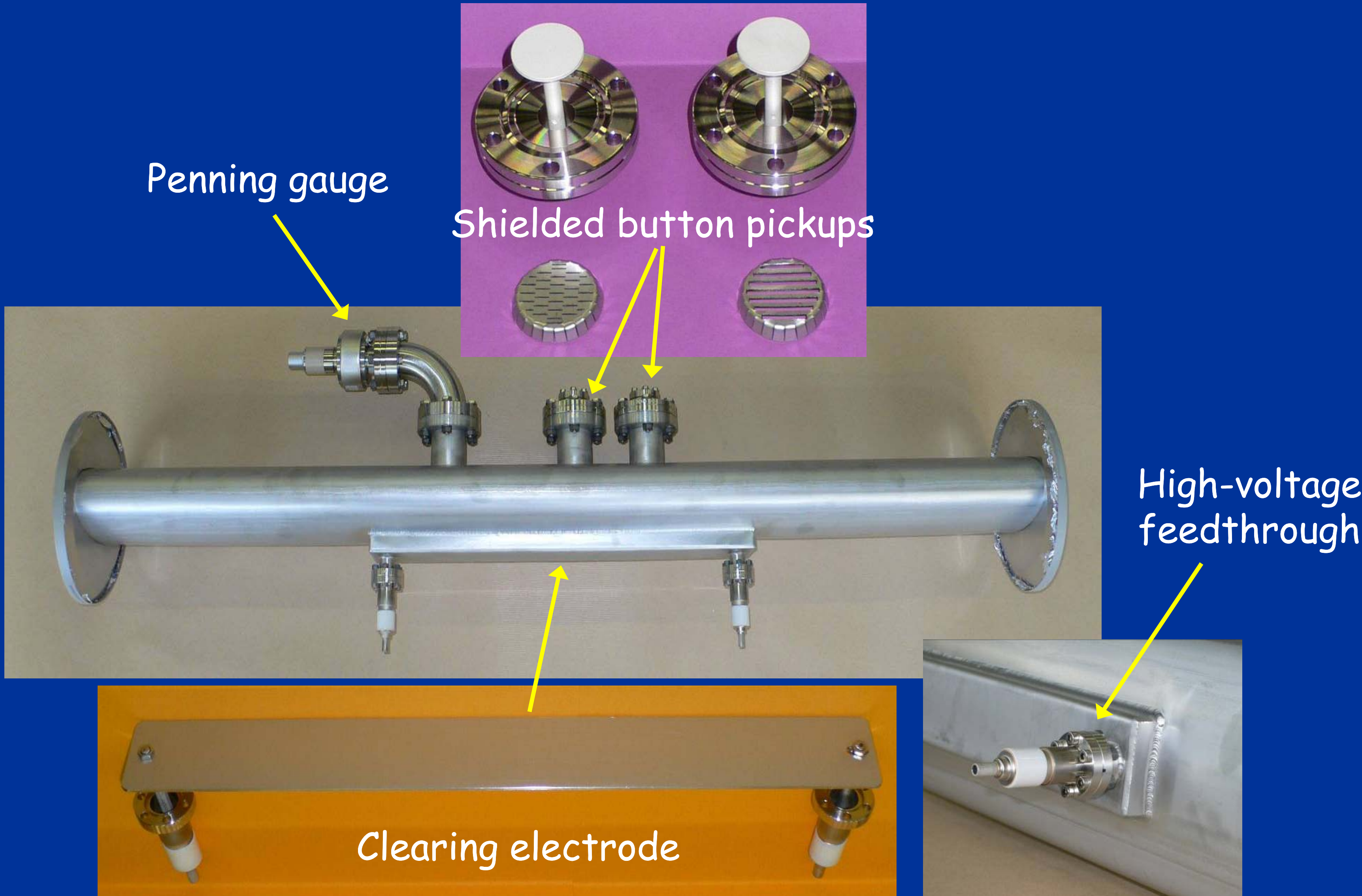
PEP-II tests w. grooved & coated chambers (2007)

- field-free region, 2 chambers with rectangular groove profiles, and 2 regular "flat" or smooth chambers
- same inner diameter, all chambers coated with TiN!



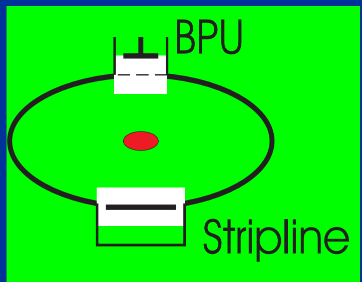
electron signal: grooved TiN-chambers « smooth TiN-chambers « regular stainless steel chamber (M. Pivi)

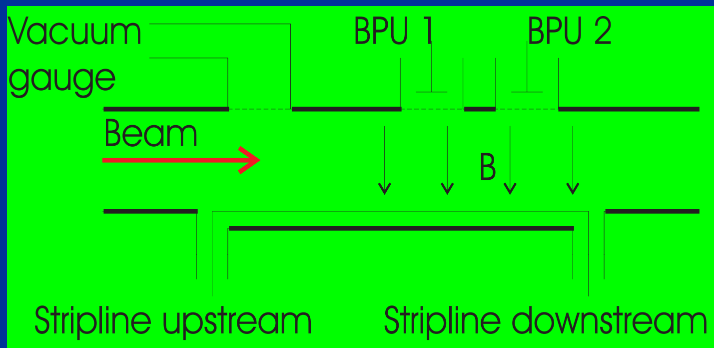
PS e- clearing electrode (2007)



PS e- cloud test bench (2007)

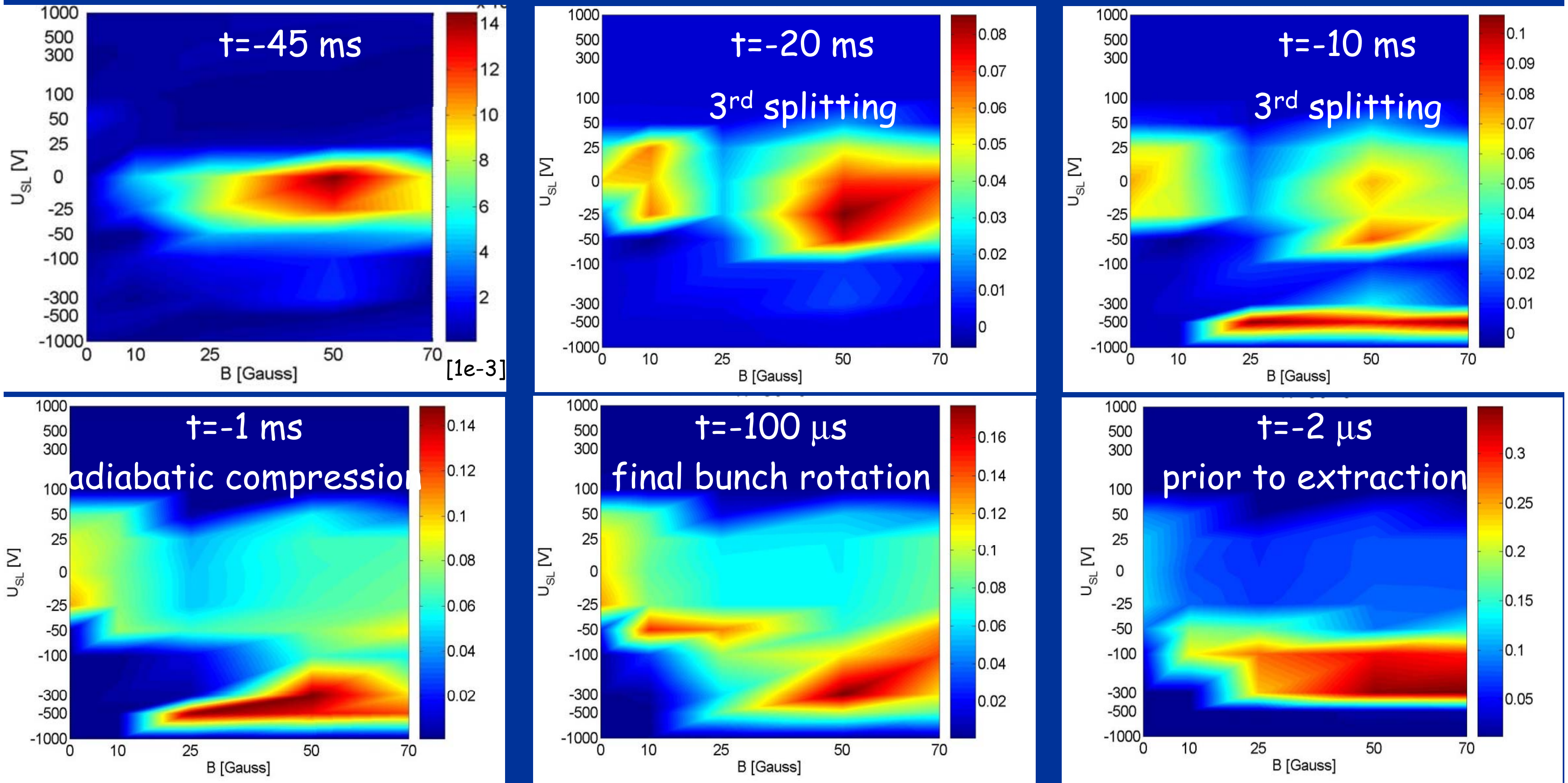
- PS elliptical vacuum chamber with dimensions 1050 x 146 x 70 mm.
- Special antechamber for clearing electrode without aperture reduction.
- Material: stainless steel 316 LN





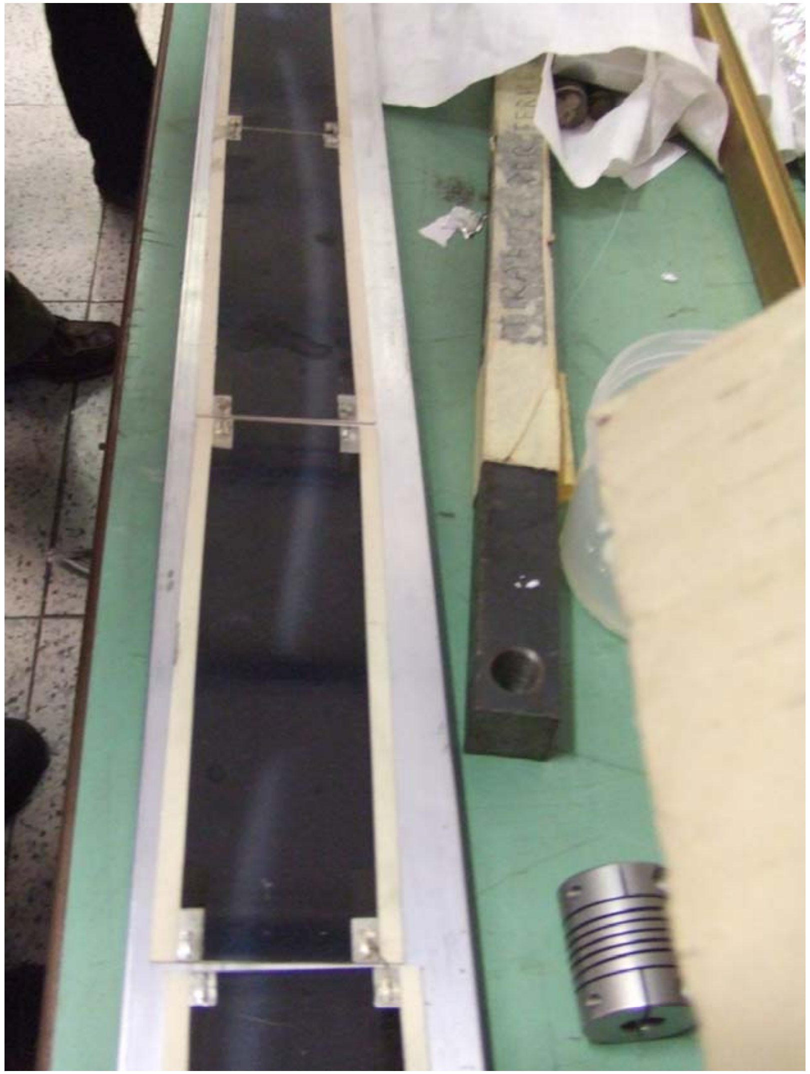
2007 PS results: "islands" w. surviving EC

- e- signal plotted at different times before ejection
- e- build-up earlier with magnetic field; e- "islands"
- for large clearing voltages (|U|> 1 kV) e- are suppressed



T. Kroyer, E. Mahner, F. Caspers, CARE-HHH BEAM'07

conventional “invisible” clearing electrode at DAFNE - major impedance! - now removed from the ring



F. Zimmermann, ECL2; M. Zobov, ECL2

“e- cloud killer” prototyped by Texas A&M

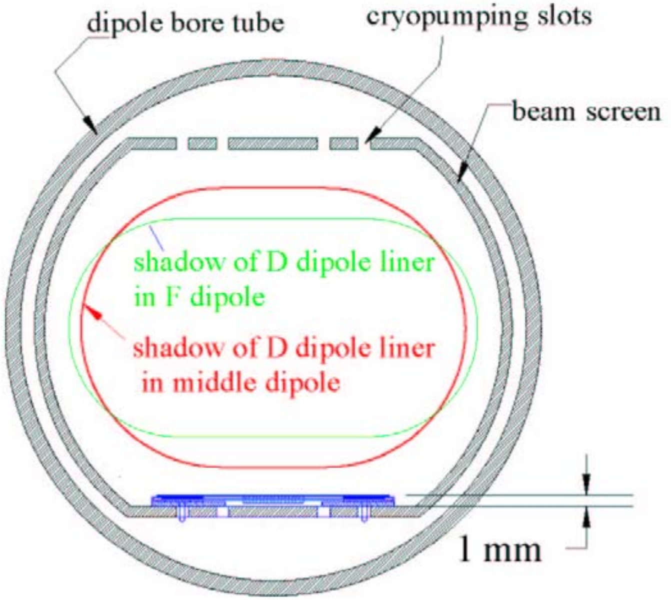


Figure 1. ECE electrode assembly (blue) on base of beam screen. Shadows of the beam screen from the D dipole are shown at the F dipole (green) and middle dipole (red).

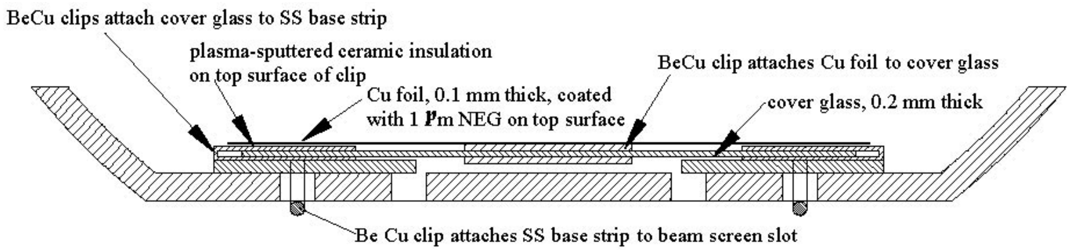


Figure 2. Detail of ECE electrode assembly.

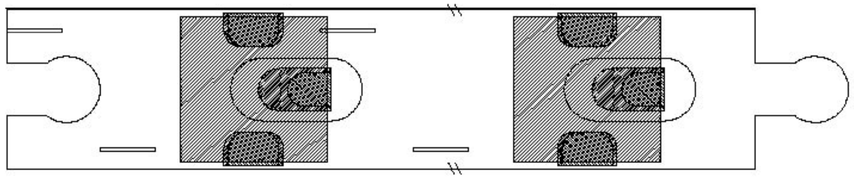


Figure 3. Plan view of a segment of the ECE electrode, showing attachement of Cu electrode to SS skid.

NEG-coated 100-µm copper-foil electrode with 100-V bias voltage; insulation by 0.2 mm cover glass

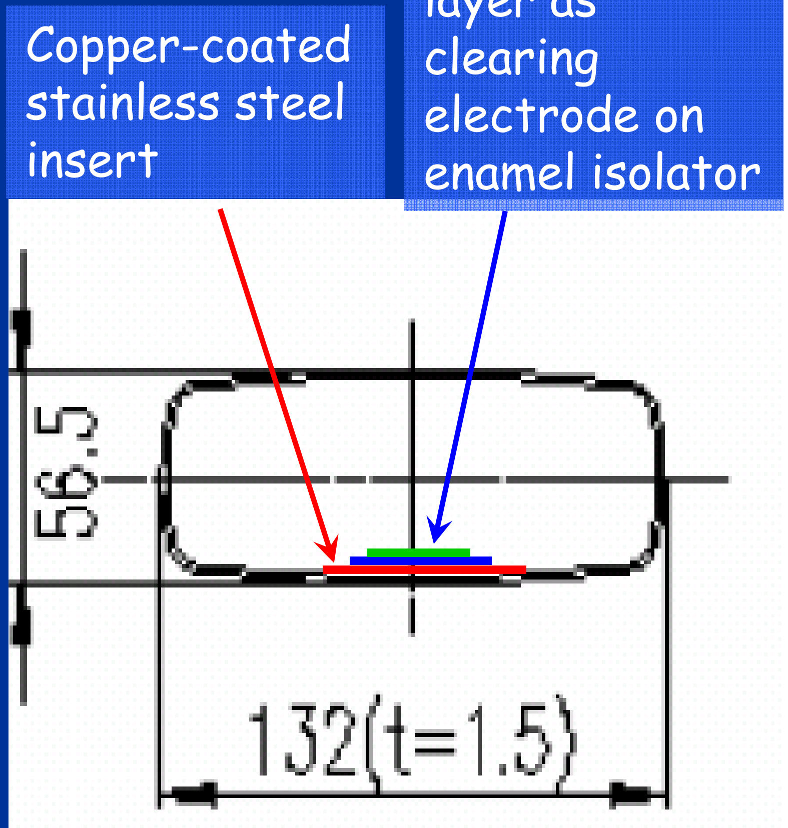
P. McIntyre et al, PAC2005

enamel coating – the new “e- cloud killer”

(F. Caspers, F.-J. Behler, P. Hellmold, J. Wendel, ECL2)

proposed enamel solution for SPS: a strip insert

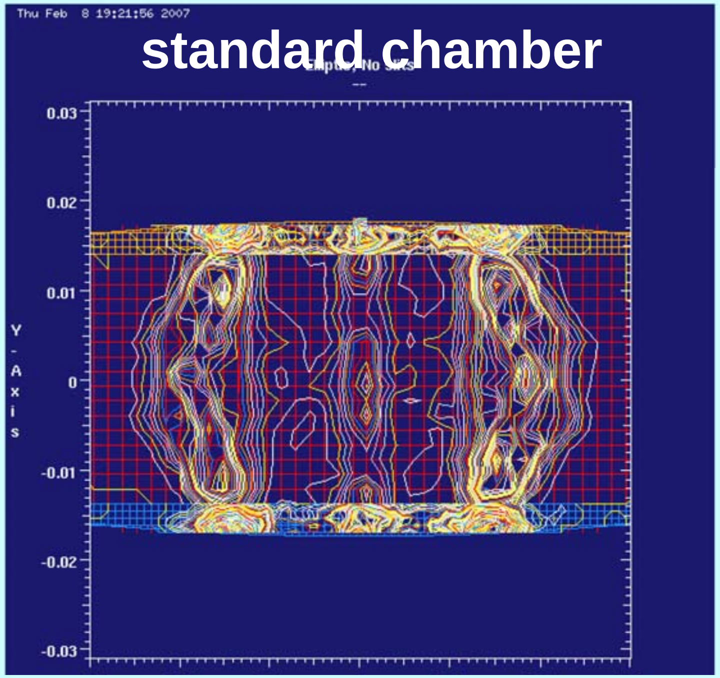
- 0.5 mm stainless steel sheet
- copper coating
- ~20 mm wide and ~0.1 mm thick enamel strip
- on top ~15 μm highly resistive thick film layer acting as "invisible" clearing electrode
- spot-welded to beam pipe

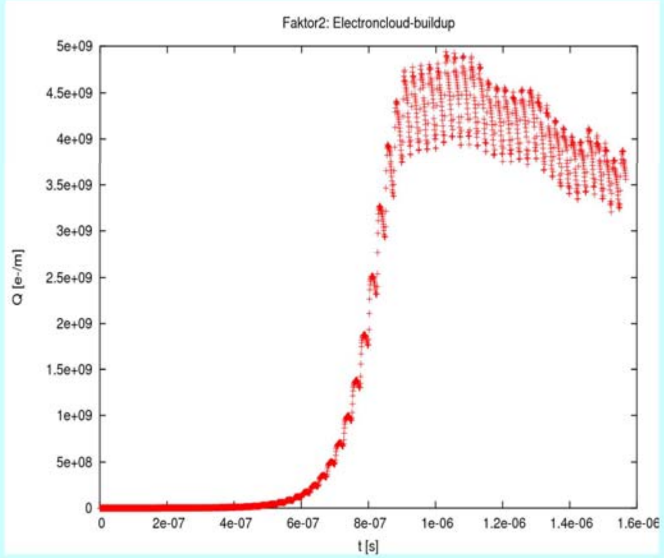


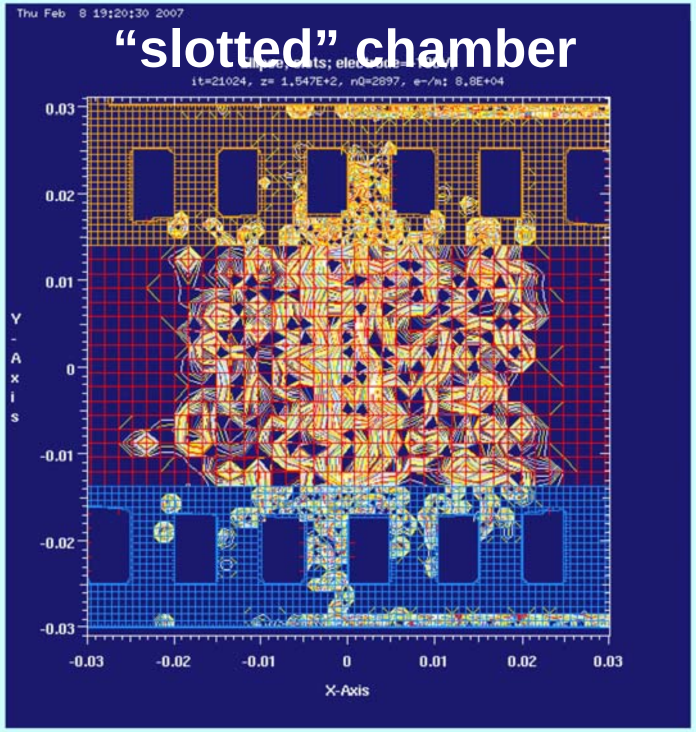
“slotted” surface

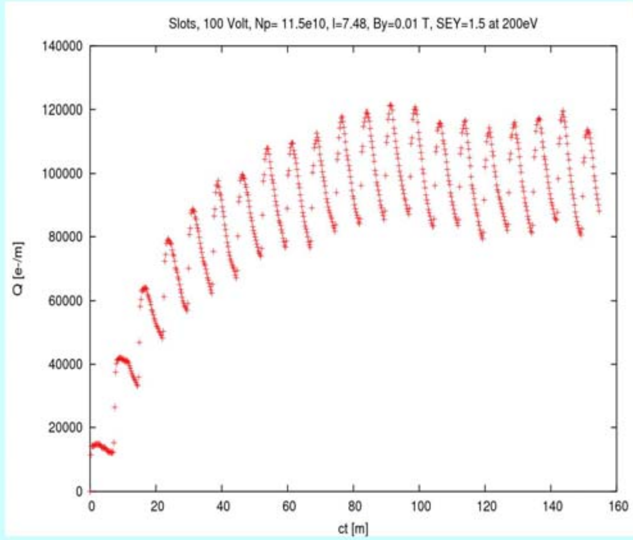
grid-like structure **shields beam fields at the wall**

this effect may explain why ISIS never observed e-cloud









W. Bruns, ECL2

electretes

- another solution proposed by Fritz Caspers at ECL2
- electrete = **permanently charged material**, e.g. teflon subjected to e- bombardment during production
- either permanent electric field is **sustained over several years**, or **self-charging by the beam field**
- may allow **in-situ upgrade** of LHC and SPS!

ECL2: pros and cons – electrodes vs NEG

clearing electrode	NEG
install once	regular activation needed
never demonstrated??	demonstrated in many machines
for ions: shaking + clearing helpful	good for vacuum
efficient for ISR coasting beam e-	long-term stability?
impedance?	

possible solutions for new LHC injectors

PS2	SPS with PS2
slotted chamber enamel electrodes electrete insert NEG coating	NEG coating TiN coating in-situ grooves electrete insert enamel inserts

possible solutions for new LHC injectors

PS2	SPS with PS2
slotted chamber	NEG coating
enamel electrodes	**TiN coating**
electrete insert	in-situ grooves
NEG coating	electrete insert
	enamel inserts

entirely new machine

aperture constraints in existing magnets

summary

- numerous technological concepts for suppressing e-cloud build up
- enamel clearing electrodes and slotted chambers: novel promising concepts
- TiN and NEG coating: still considered
- additional constraints retrofitting an existing accelerator like the SPS
- electrode clearing effect explored at PS
- studies for PS2 & enhanced SPS vacuum chambers progress at high momentum

appendix

- open questions from ECL2
- SEY conditioning effect

open questions from ECL2

- **modeling of electron cloud & e- emission**
  - **effect of beam field, magnetic field**, and ions
  - many **questions on grooves**
  - **surface** parameters (e.g. Cu-st.st. difference)
- **enamel**
  - **SEY and PEY, impedance, stability**
  - study suppression efficiency
  - can enamel coating fit into SPS chamber?
- **air baked Cu, radical injection, permanent el. fields**
- **in-situ grooving?**
- **NEG, TiN – long term stability, self-activation, heat**

surface physics of secondary emission yield (SEY)

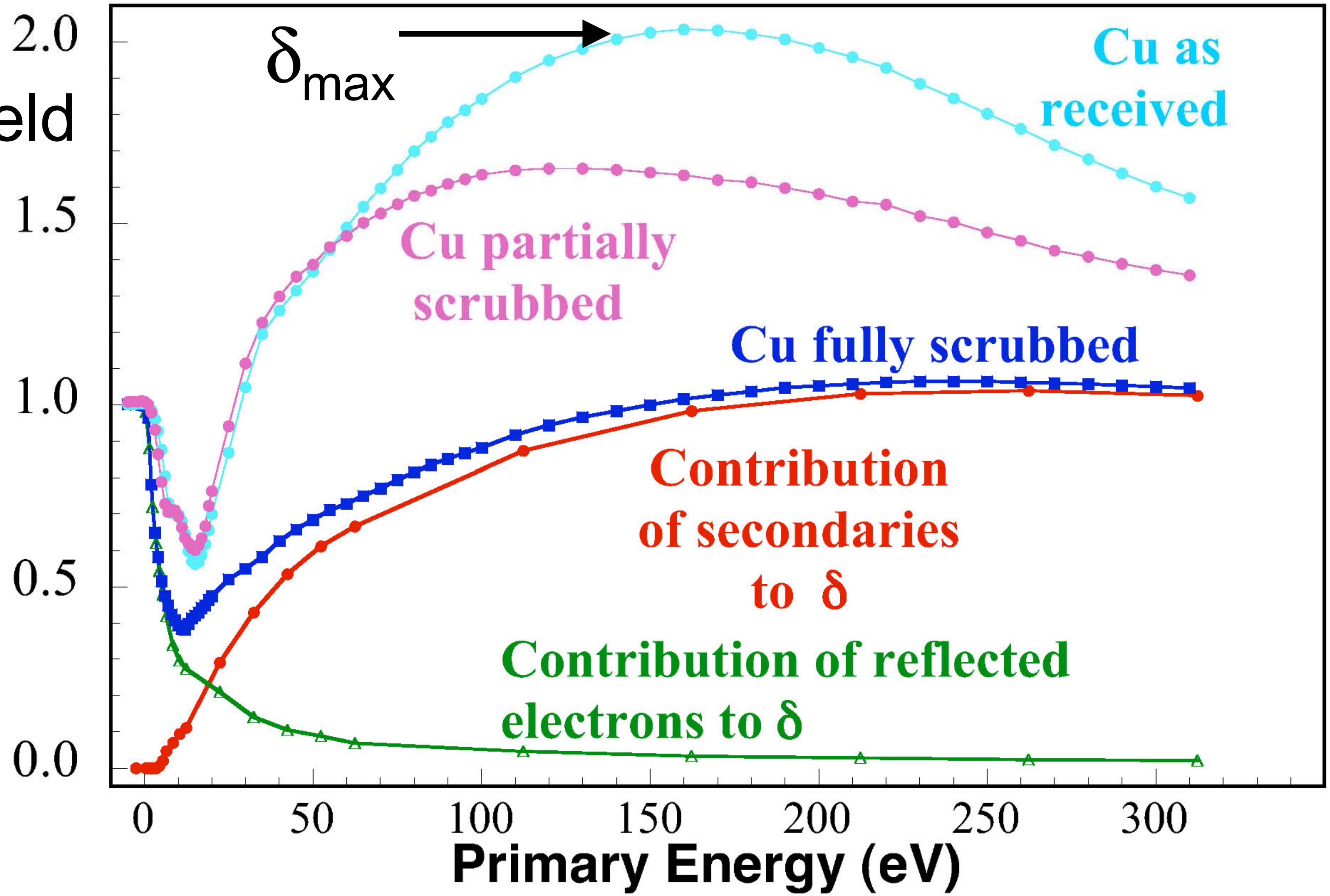
- important role of **surface hydrocarbons**
- after limited air exposure and **(re-)conditioning by e-bombardment** (typically 10^{-3}C/mm^2) maximum SEY of TiN decreases to 1-1.2 ; and for copper to 1.2-1.3
- two phenomena contribute to conditioning:

- particle stimulated **desorption** (H, CO..) and surface cleaning

- **graphitization** of adsorbed hydrocarbons

R. Cimino, I. Collins et al, Phys.Rev.Lett.93:014801,2004

secondary e- yield



probability of elastic electron reflection may approach 1 for zero incident energy and is ~independent of δ^*_{max}