Session Summary: SPS Upgrade

Gianluigi Arduini, CERN, AB/ABP

5th October 2007

Acknowledgements: All the Speakers for their excellent talks

SPS upgrade session

SPS challenges	E. Shaposhnikova
SPS impedance	E. Métral
Experimental studies on SPS e-cloud	G. Rumolo
SPS chamber upgrade: coatings	S. Calatroni, M.Taborelli
Clearing electrodes	T. Kroyer
Pulsed magnet options	L. Bottura

Motivation (2/2)

Maximum intensities in the SPS: achievements and future needs

		SPS record at 450 GeV	LHC request at 450 GeV	PS2 offer at 50 GeV/c
Bunch intensity	10^{11}	1.2	1.7/5.5*	3.6/7.2**
Total intensity	10^{13}	3.5(5.3***)	9.2	12.0
Beam current (RF)	A	1.5	3.5	4.6

* 10% beam loss assumed for PS-SPS and SPS-LHC beam transfer

** Intensity for 25/50 ns bunch spacing

*** CNGS beam at 400 GeV with 5 ns spacing and full ring

Likely not acceptable for high intensity operation

⇒ SPS upgrade is necessary

E. Shaposhnikova

Known intensity limitations in the SPS

Single bunch intensity

- space charge
- TMCI (transverse mode coupling instability)

Multi-bunch effects (total intensity)

- e-cloud
- coupled bunch instabilities at injection and high energy
- beam loss
- beam loading in the 200 MHz and 800 MHz RF systems
- heating of machine elements (e.g. MKE kickers)

E. Shaposhnikova

What needs to be studied?

Summary (1/2)

The LHC upgrade scenario with 50 ns bunch spacing is very challenging for the SPS. Nevertheless

- The increased injection energy with PS2 (≥ 50 GeV) should help to overcome single bunch limitations (space charge and TMCI)
- Increased longitudinal emittance at injection (≥ 0.6 eVs) should cure multi-bunch effects and TMCI (completely)
- To accelerate "50 ns" beam with large longitudinal emittance the RF system of the SPS should be seriously upgraded: doubling of power plant with R&D for its most critical elements.
- Vertical e-cloud instability is a "bottle-neck" → the SPS vacuum chamber upgrade should be studied
- SPS impedance control is essential for any future intensity increase

Experimental verification of the simulations and scaling laws is needed

…and reduction to solve the problem of kicker heating and further increase the margin for single bunch instabilities (μ-wave?)

E. Shaposhnikova

Required HW modifications

E. Shaposhnikova

Summary (2/2)

What was not discussed but not forgotten:

- Injection kicker at 50 GeV/c
- Beam control:
  - longitudinal feedback, feedforward and damper
  - transverse feedback/damper
- Beam dump
- Beam instrumentation
- The 200 MHz capture RF system in the LHC

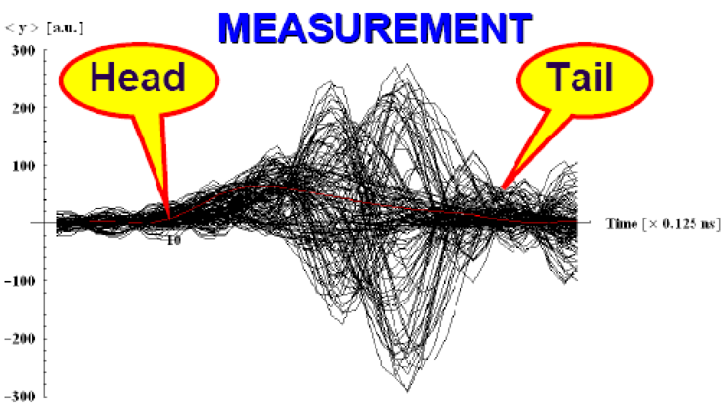
$\Longrightarrow$ The SPS must be significantly improved to match all other upgrades in the accelerator chain! - Any good ideas?

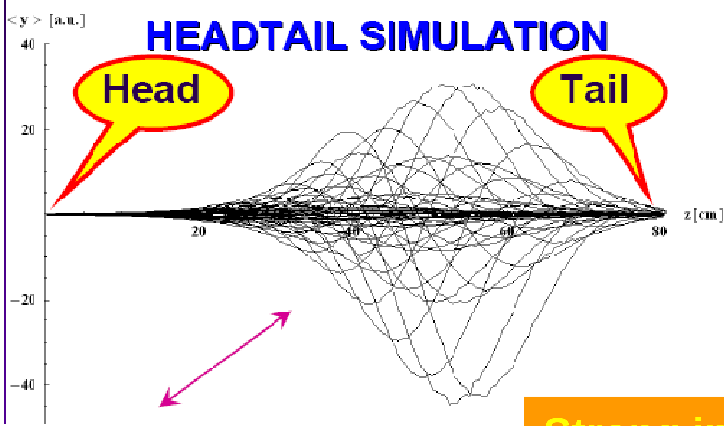
The need of a collimation system required to protect the machine for high intensity operation is likely required

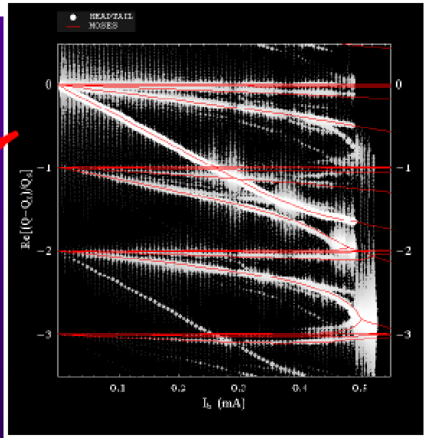
P+M is required for design and construction

Impedance

FAST VERTICAL SINGLE-BUNCH INSTABILITY AT INJECTION IN 2003 (3/3)







See B. Salvant's talk (BB impedance)

Strong indication of TMCI in the SPS. $N_{b\ th}$~1.7×10^{11} p (ultimate) for nominal ε_L

Next steps:

- Measure mode coupling
- Improve impedance model

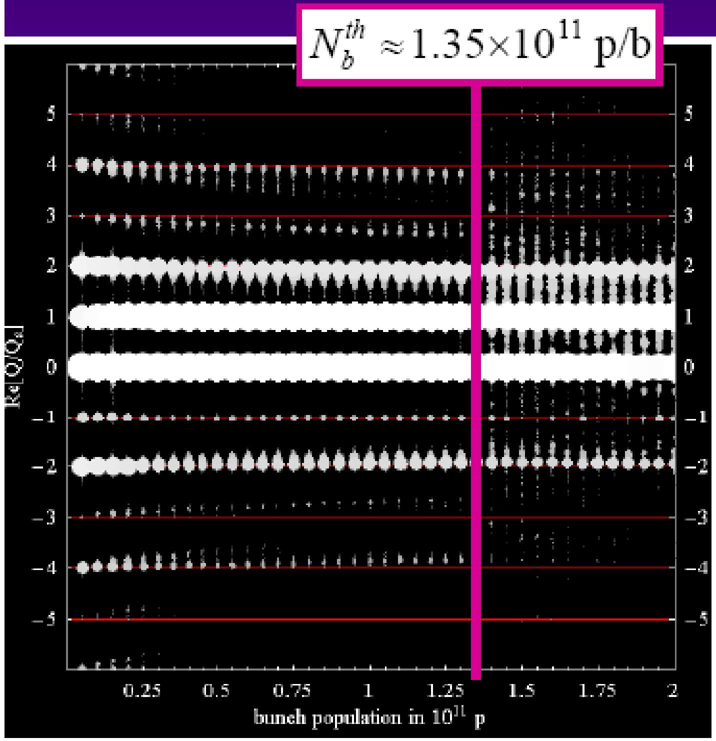
Elias Métral, CARE-HHH-APD BEAM'07, CERN, 05/10/07 7/28

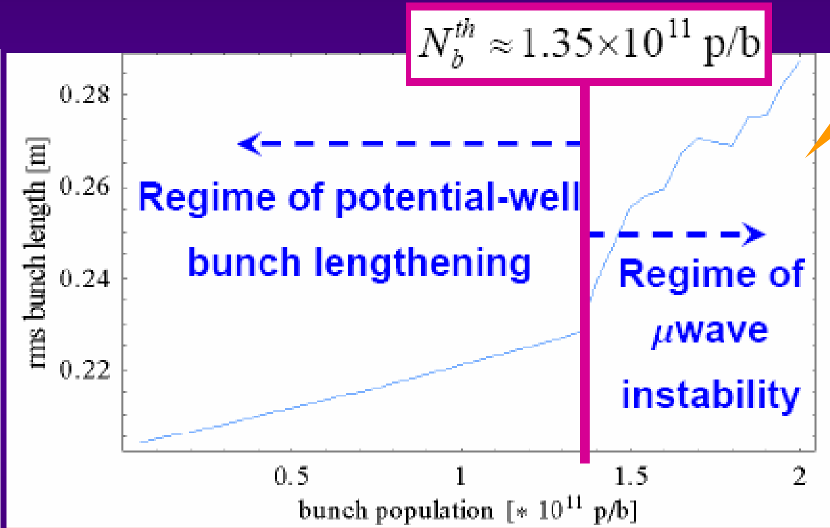
E. Métral

Impedance

HEADTAIL SIMULATION IN THE LONGITUDINAL PLANE (1/3)

f_r = 1 GHz
Q = 1
$(Z_l / p)_{f=0} = j \times 10\ \Omega$





Could it be a problem even for larger ε_L ?

Next steps:

- Improve impedance model
- Measure mode coupling?

E. Métral

Impedance

CONCLUSION

- Transverse analytical estimates and measurements of the low frequency inductive effective impedance are in good agreement over the last years (relative values)
- Transverse analytical estimates and measurements of the head-tail growth/decay rates are also in good agreement over the last years (relative values)
- All the kickers can only explain ~ 50% of the longitudinal and transverse impedances ⟹ Continue the investigation (in addition to the kickers, we looked at the 108 BPMH, 108 BPMV, ~ 1000 pumping ports, the 4 TW 200 MHz cavities, TIDVG: See Appendices)
- 1 major issue in our understanding: Why the longitudinal effective impedance measured in 2007 is ~ 40% higher than in 2006, whereas a reduction was foreseen???

Elias Métral, CARE-HHH-APD BEAM'07, CERN, 05/10/07

Therefore we need to continue the effort of Z reduction of the kickers With a more radical solution (LHC-type)?. We still "miss" ~50% of Z_{tr}

Could be compatible with an underestimate of the measured impedance in 2006.

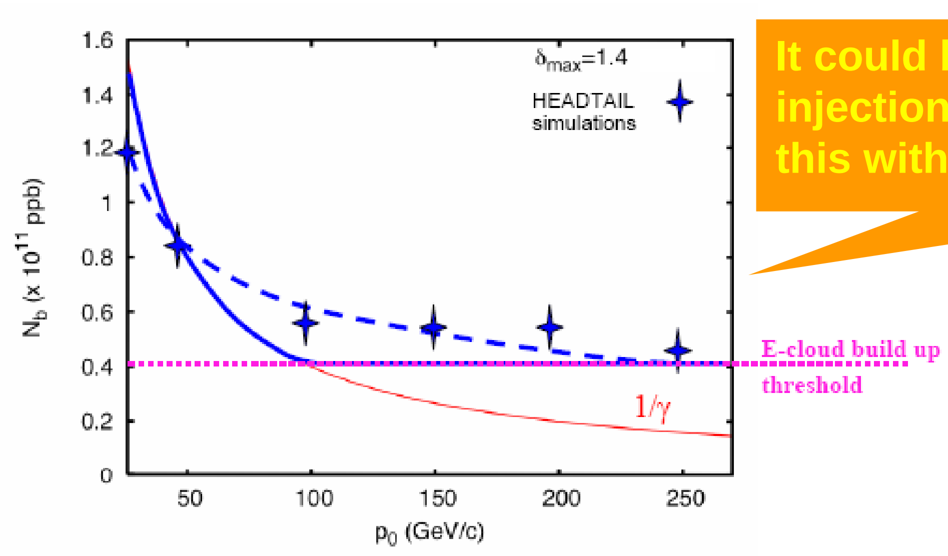
E. Métral

V-Electron cloud instability

G. Rumolo

AB-ABP/LHC Injector Synchrotrons Section

HEADTAIL PREDICTION USING MODEL WITH SELF-CONSISTENT E-CLOUD



It could become worse going to higher injection energy (PS2). We need to confirm this with measurements!!!

For δ_{max}=1.4 the instability threshold decreases with γ up to ~100 GeV/c, then it levels off at the value of the build up threshold

→ Conservation of longitudinal emittance, bunch length and normalized transverse emittances.

→ Bunch always matched to the bucket !

Pessimistic assumption for the upgrade: ε_L > 0.6 eV.s

CERN, 05.10.2007 Giovanni Rumolo

V-Electron cloud instability

G. Rumolo

PRELIMINARY – STUDY & ANALYSIS ONGOING

SUMMARY OF THE OBSERVATIONS

- The electron cloud has been observed in the SPS with the e-cloud monitor
  - At 26 GeV/c with a bunch shortening voltage bump or enhanced by untrapped coasting beam
  - Clear signal at higher energies (shorter bunch, smaller transverse sizes)
- The LHC beam is **vertically unstable** in the SPS at
  - **26 GeV/c** for $Q'_V \sim 0\text{-}2$ (with 1 to 3 batches)
  - **37 GeV/c** for $Q'_V \sim 3.3$ (with 1 batch)
  - **55 GeV/c** for $Q'_V \sim 4$ (with 1 to 3 batches)
- In most cases we observed that only the tail of the bunch train(s) is affected by the instability.
- Pattern of the instability along the bunch train seems to point to a coupled bunch instability (with possible single bunch effects) at 26 and 55 GeV/c. At 37 GeV/c this is not evident.

⇒ Correlation between the observed instability and the e-cloud is not straightforward, we would like to assess it by observing a dependence of the instability threshold on the beam transverse size!

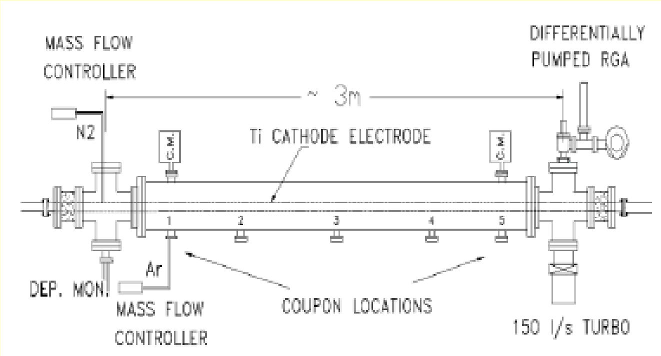
Scaling with energy and qualitative behaviour seem to exclude instability mechanisms other then e-cloud and are qualitatively consistent with the simulations.

Uncorrelated dipole motion at the end of the batch observed at 37 GeV/c, to be analyzed at 55 GeV/c

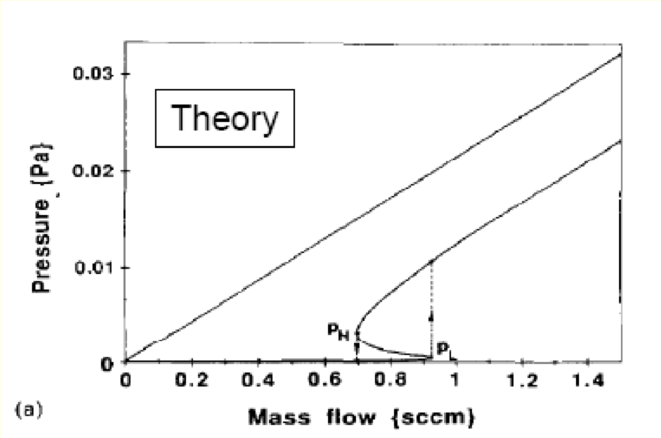
Need of completing the analysis and possibly to conduct additional experiments

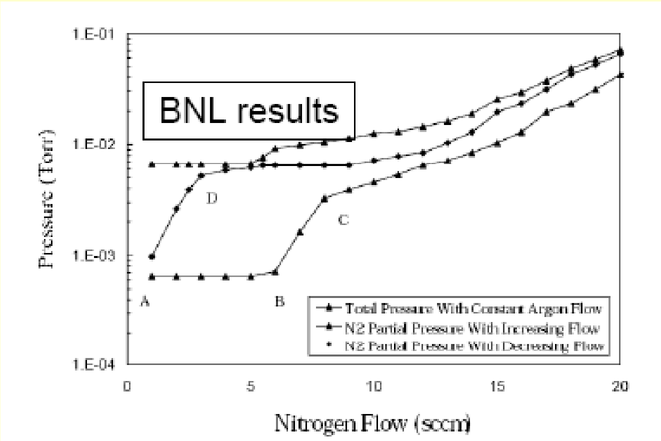
Cures for EC: Coatings

Composition control: experience from BNL



- Ti_1N_1 regarded as the best for reducing SEY
- "Gold" colour (smooth surface, "D" operating point) provides higher SEY/lower outgassing than "brown" colour (rougher surface, "C" operating point)
- Composition control along length and cross section considered as the most difficult practical aspect

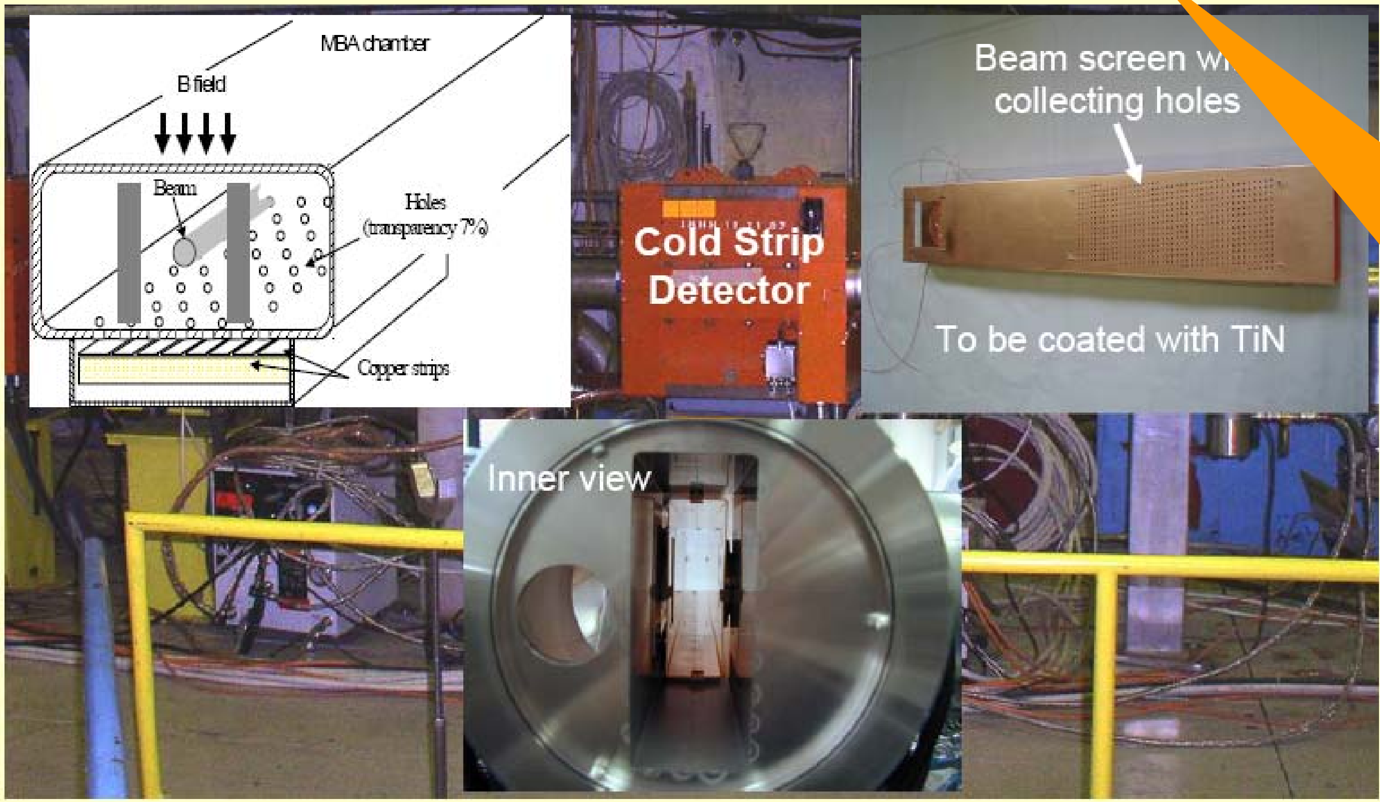




S. Calatroni

Cures for EC: Coatings

Proposed test at CERN SPS: The CSD detector



From: J. M. Jimenez

Sergio Calatroni TS/MME 5

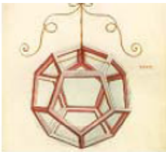
Tests with beam in the machine environment is necessary to qualify the coating as EC killer. These studies will be beneficial also for the PS2 upgrade!

S. Calatroni

Cures for EC: Coatings

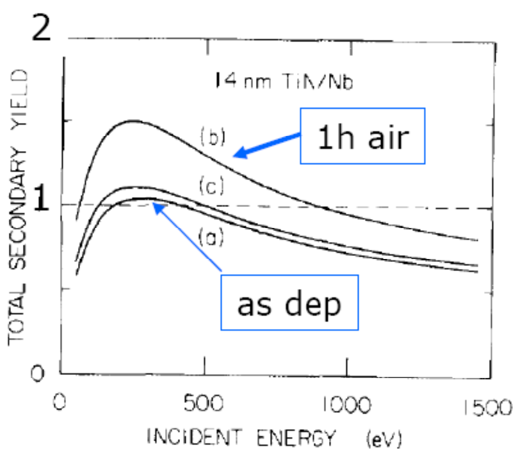
M. Taborelli

Compare air exposed TiN versus copper

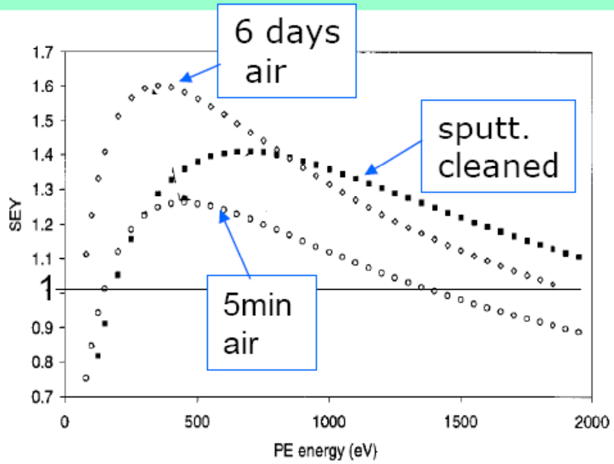


As deposited TiN is potentially better since it has a **δmax = 0.9-1.1** ; clean copper has 1.3

Upon air exposure the TiN yield increases to δ**max** = 1.5-2.5 ; for copper δmax =1.6-2.6



(E.L.Garwin et al. 1987)



(Bojko, Henrist, Hilleret, Scheuerlein, 2000)

M.Taborelli, BEAM 07

Cures for EC: Coatings

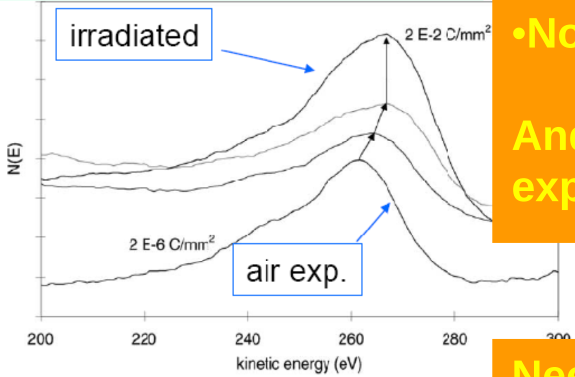
M. Taborelli

Some carbon is bad.......and some is good: conditioning

After air exposure and conditioning by e-bombardment (typically 10^{-3}C/mm^2) the δ**max of TiN decreases to 1-1.2** ; and for copper to **1.2-1.3**

Conditioning means:
-- particle stimulated desorption (H, CO..) and cleaning of the surface: is not highly material specific
--**graphitization** of the adsorbed hydrocarbons and increase of the carbon coverage

Change of CKLL Auger upon irradiation of air exp. Cu
(Scheuerlein, Taborelli, 2002, similar results in XPS by Kato 2005)



-an alternative to TiN would be a **graphite-like layer!**
(by sputtering, CVD, e-bombardment.......)

What do we need ("user" point of view):
- **Low SEY w/o baking and with limited conditioning after venting to air for several days**
- **Minimum effect on machine impedance**
- **Radiation resistant**
- **No "ageing"**

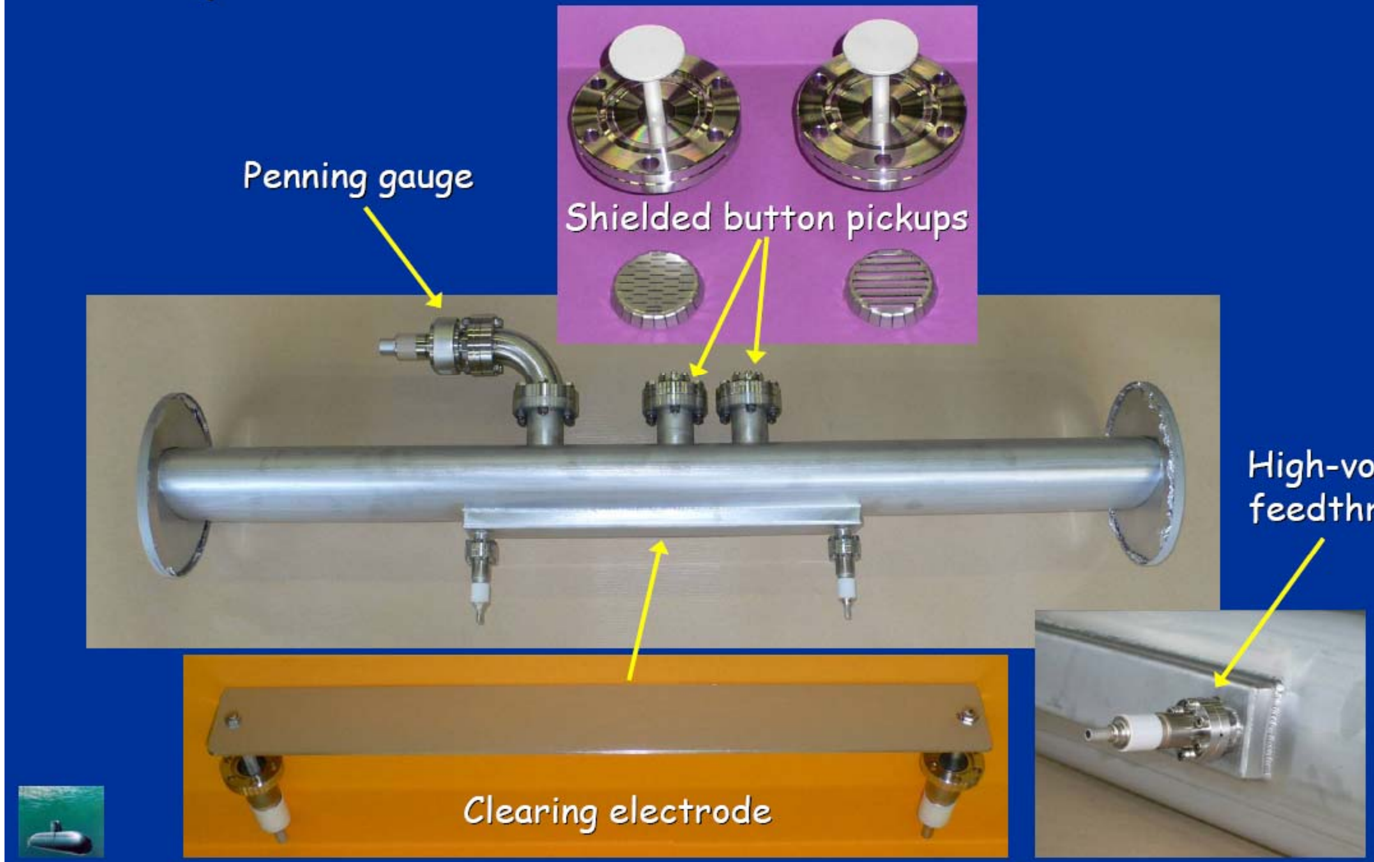
And this must be proven experimentally in beam operation

Need to study alternative coatings in the laboratory. Financial support is needed.

Cures for EC: Clearing Electrodes

T. Kroyer

Components of the PS electron cloud setup



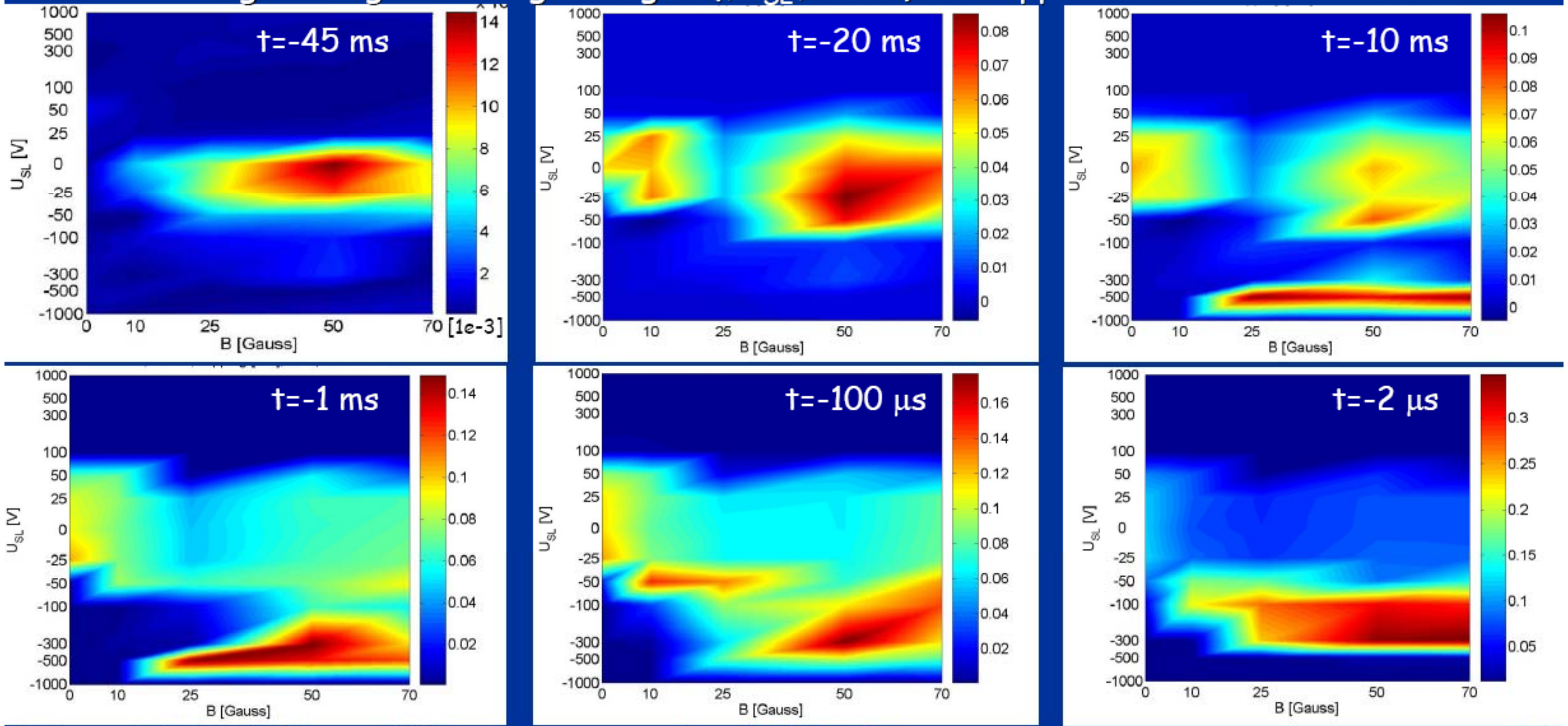
T. Kroyer, E. Mahner, F. Caspers, CERN — Beam'07, Oct. 2007 — 6

Cures for EC: Clearing Electrodes

T. Kroyer

Islands with surviving EC

- EC signal from shielded PU1 plotted at different times before ejection
- Build-up starts earlier with magnetic field; Islands with large EC appear in the parameter space.
- For large enough clearing voltages ($|U_{SL}|$> 1 kV) EC suppression was found in all cases



T. Kroyer, E. Mahner, F. Caspers, CERN

Beam'07, Oct. 2007

11

Cures for EC: Clearing Electrodes

T. Kroyer

Conclusion

- Clearing electrodes have been used in several machines for ion and electron cleaning
- In the PS electron cloud cleaning was achieved with a 40 cm long stripline electrode biased at ~1 kV
- The challenge is to apply such electrodes over longer section of a machine, which exacerbates impedance and other issues
- A highly resistive coating has a low longitudinal and transverse impedance; in practice resistive layers an enamel, alumina or other dielectrics can be used
- There is ongoing work on the practical implementation of such electrodes

To be proven!

testing the deposition of enamel strips inside a beam pipe...

Did not pass "mechanical test" during the session!!!

T. Kroyer, E. Mahner, F. Caspers, CERN

Beam'07, Oct. 2007

SPS+ SC magnets

L. Bottura

Magnet design parameters as from ECOMAG-05 and LUMI-06

	PS2+a	PS2+b	SPS+a	SPS+b
Injection energy [GeV]	4	4	**50**	75
Extraction energy [GeV]	**50**	75	**1000**	1000
Injection field [T]	0.144	0.144	**0.225**	0.337
Maximum field [T]	1.8	2.7	**4.5**	4.5
Maximum ramp-rate [T/s]	1.6	2.5	1.43	1.39
Ramp time [s]	1.1	1.1	3	3
Dipole magnetic length [m]	3	3	6	6
Number of dipoles [-]	200	200	750	750
Number of cycles [Mcycles]	60	60	1	1

PS2 reference

The choice of energy in PS2 makes the nominal SPS+ **very difficult** (**low injection field, field swing by a factor 20**)

Highly non linear behaviour due to the low injection field. For comparison 0.54 T in the LHC

SC magnets for the LHC injectors

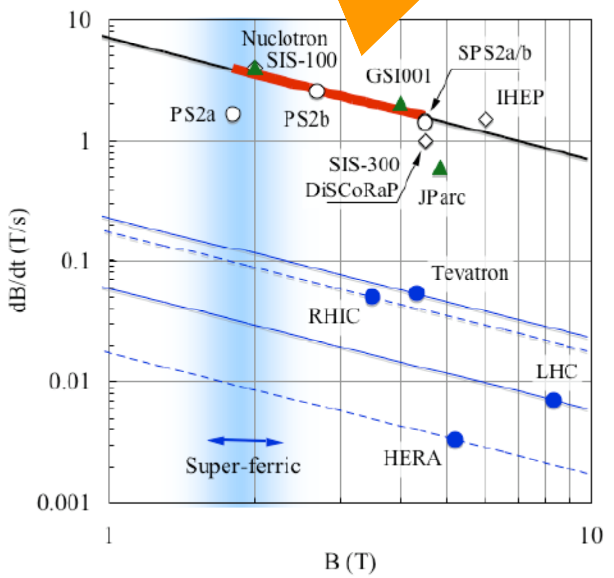
L. Bottura

Comments - 2

Several EU initiatives for the study of a SC fast-ramped magnets. No CERN involvement

Power per unit volume

- Magnets of equal *difficulty* can be realised taking as objective $\Pi \approx$ constant



- *It so happens* that PS2+b **has the same** Π as SPS+
  - PS2+b:
    - B_{max}=2.7 T, $(dB/dt)_{max}$=2.5 T/s
  - SPS+a:
    - B_{max}=4.5 T, $(dB/dt)_{max}$=1.4 T/s

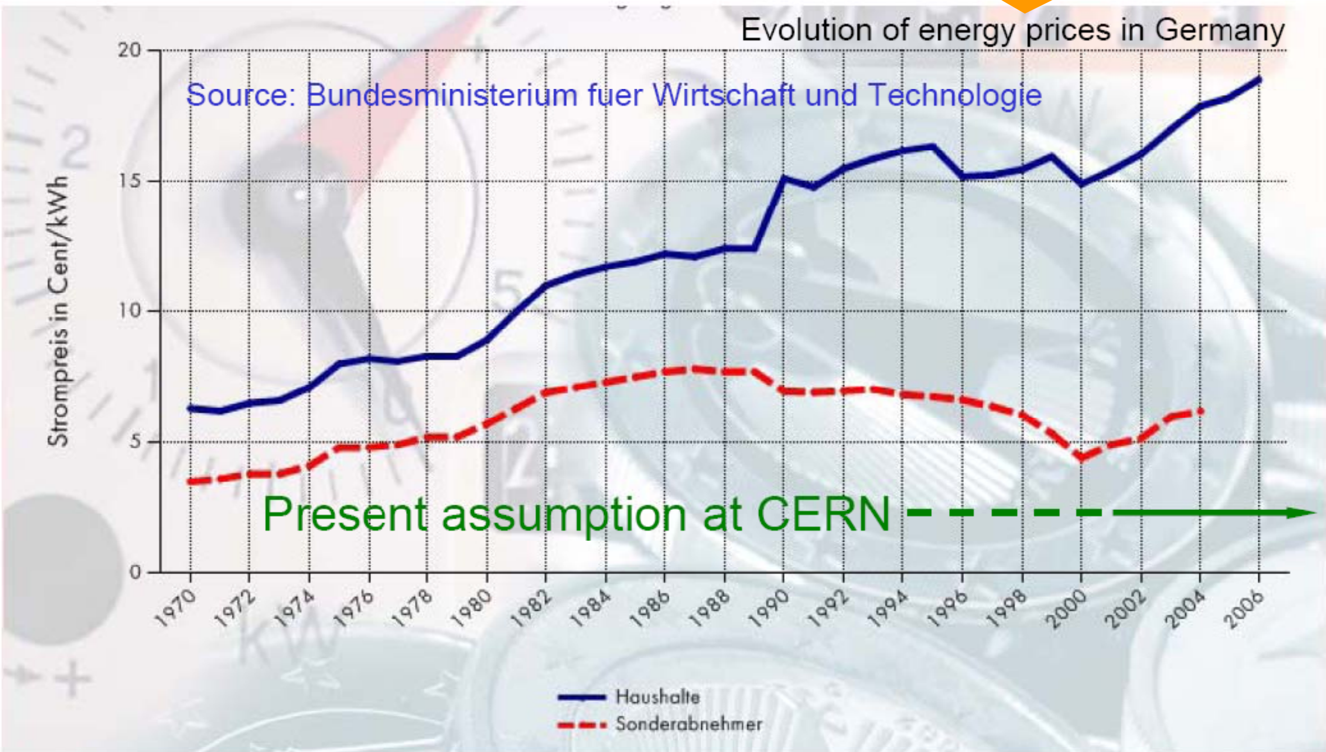
- A technology demonstrator with B_{max}=2.7 T, $(dB/dt)_{max}$=2.5 T/s would provide the proof of principle for **both** a superconducting SPS **and a** superconducting option for PS2

SC magnets for the LHC injectors

L. Bottura

Prices of electricity

Operational costs (over a few decades) should not be forgotten in the comparison of NC and SC options



L. Bottura

Conclusions

- There is consensus in the community of experts that **all issues** specific to fast-ramped superconducting magnets **can be addressed and solved** by
  - Adapted design solutions: phenomena are well known, engineering tools exist
  - Material R&D: within reach
- Focus should be put on a technology demonstration magnet, that proves **low-loss, robust and reliable** performance
  - Purchase wire
  - Produce cable
  - Wind coils
  - Test magnet models
- This technology would provide valuable **input and potential savings for PS2** that **cannot be discarded**

Some conclusions?

- The LHC will profit of the pre-injector upgrade **only if** a significant upgrade of the SPS is implemented
- Transfer of beams with larger longitudinal emittance is necessary ➔ RF system need a major upgrade (together with a few other systems – I am wondering what will be left of the present SPS…..)
- Vertical electron cloud instability could be worse at higher injection energy:
  - Need to confirm with experimental results ASAP
  - In parallel investigate with experiments in the lab and in the machine:
    - Possible coatings
    - Clearing electrodes
    - Grooves (?)
  - Some seed activities have been launched but they need to be fed (P+M)
- The hunt for unwanted sources of impedance has just been started but it needs to be strengthened

Some Conclusions?

- SPS+ magnets have comparable difficulty as other fast pulsed SC magnets (….and PS2+ - 50 and 75 GeV options)
- Operational costs should not be forgotten in the comparison of NC and SC options for PS2