ELENA Project

Status, Conclusions from the ELENA Review, Planning and Budget …

C. Carli for the ELENA Team

ADUC/ELENA Meeting, 14th January 2014

- Technical Design Report
- General Project Review (technical)
- Some technical Topics (recent progress, discussed after review, not covered elsewhere …)
  - Lattice Studies
  - Electron Cooler
  - Magnets
- Status of the Annex Building 393
- External Contributions to the ELENA Project
- Summary and Outlook

Technical Design Report TDR

- Aim
  - Describe the machine we intend to build to fix ideas and make sure we all speak the "same language"
  - Important step to make sure that plans from different groups are consistent
  - Afterwards, proper follow-up of (small?) design changes mandatory (usage of Engineering Change Requests ECR)
- Status
  - All chapters received
  - Thanks everybody for the effort to write their parts, thanks to the editor (N. Chohan) for pushing and putting everything together
  - Proofreading (get section, figure, table .. numbers correct, polishing of english …) underway, resulting document expected this month
  - Only (hopefully) minor changes afterwards
- Final published document is expected in spring as CERN yellow report

Project Review

see: https://indico.cern.ch/conferenceDisplay.py?confId=268237

ELENA Project Review

from Monday, 14 October 2013 at **09:00** to Tuesday, 15 October 2013 at **18:00** (Europe/Zurich)
at **CERN (31-3-004 - IT Amphitheatre)**

Manage

Description The Extra Low Energy Antiproton ring (ELENA) is a CERN project aiming at constructing a small ~30 m circumference synchrotron equipped with an electron cooler to further decelerate antiprotons injected from the Antiproton Decelerator AD at a kinetic energy of 5.3 MeV down to 100 keV. At present, most experiments receive the beam directly from the AD at an energy of 5.3 MeV and further slow down antiprotons to ~5keV using foils and then trap them. ELENA will decelerate antiprotons and in addition cool them with electron cooling. With thinner foils required to reach an energy suitable for the trapping, the efficiency can be increased by one to two orders of magnitude. Furthermore, the intensity available per AD cycle lasting about 100 s will be distributed into several bunches allowing the experiments to take beam over longer periods.

Review Committee:
V.Lebedev (FNAL, chair), M.Benedikt (CERN), M.Chanel (CERN-retired), S.Gilardoni (CERN), M.Grieser (Max Planck Institute for Nuclear Physics, Heidelberg), S. Møller (Aarhus Univ)

Charge:
The ELENA project and technical design will be presented with emphasis an possibly critical aspects like electron cooling at very low energies, beam instrumentation for low intensities, the design of long electrostatic transfer lines transferring the beam from the extraction to experiments and the construction of magnets for very low magnetic fields. The review board members will provide feedback with their opinion on the feasibility of the project and possible advice for improvements and further studies helps us improving the project. In particular:

- Are possible limitations and performance to be expected properly analyzed and adequately addressed?
- Is the technical design sound and likely to meet the expected performance?
- Have any possibly overlooked issues or showstoppers been identified?

The review panel will give a presentation with preliminary conclusions at the end of the second day of the review and, later, produce a report, summarizing the recommendations and findings.

Material: Transparents

Report from Review Committee
General Comments

- General Comments (from the Committee)
  - The review committee would like to support the construction of low energy antiproton ring ELENA
  - We find it greatly supportive for the CERN program with low energy antiprotons as well as an interesting project in the accelerator physics
  - We would like to thank all presenters for good and coherent presentations
- This means (… although not stated explicitly)
  - Basic design is sound and no showstoppers or very critical issues identified
  - Mandate to go on with the machine described for the implementation phase
  - We will build a machine very close to what has been described during the review and in the TDR draft
- However, many recommendations for improvements and studies
  - List of (most) recommendations (re-ordered ..) with planned actions from our side in spare slides
  - Some recommendations in next slides on selected technical topics

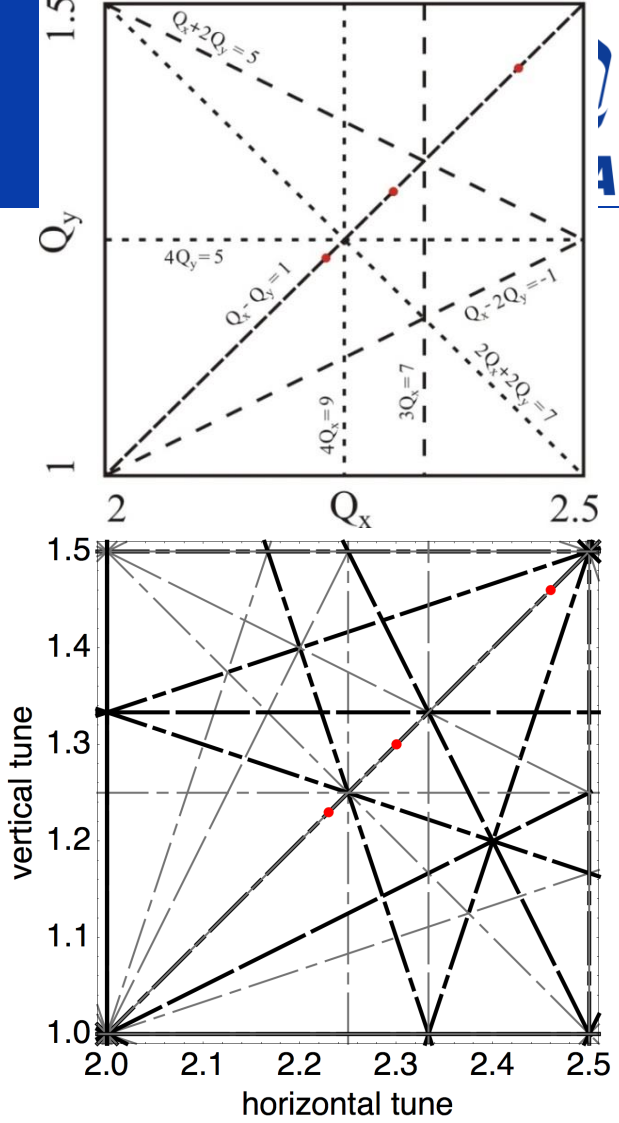
Lattice Tunability Studies

Work by and materiel taken from doc's by P. Belochitskii

- Motivation:
  - Review committee: 4th order resonances close to working point excited by space charge
  - Understand tunability – working points reachable with "reasonable" machine optics
- Results
  - Two more (bare machine without space charge) working points investigated – with space charge tunes are lowered
  - Reasonable tuning range found
  - Many discussions on impact of smaller acceptance with "low WP" and need to enlarge apertures
  - Magnet apertures kept as defined for magnet design

Q_x / Q_y	$\beta_x/\beta_y/D_x$, m (cooler)	$\beta_x/\beta_y/D_x$, m (max)	K1, m^{-2}	K2, m^{-2}	α
2.23 / 1.23	3.1/2.1/1.5	15.0/9.3/1.7	1.9/-0.53/0.62	32/-56	0.241
2.30 / 1.30	2.1/2.2/1.5	11.8/6.6/1.7	2.3/-1.2/0.72	24/-45	0.255
2.46 / 1.46	1.2/1.9/1.5	110.2/4.8/1.7	2.9/-2.4/0.95	17/-34	0.264

Some lattice properties with the three WPs studied

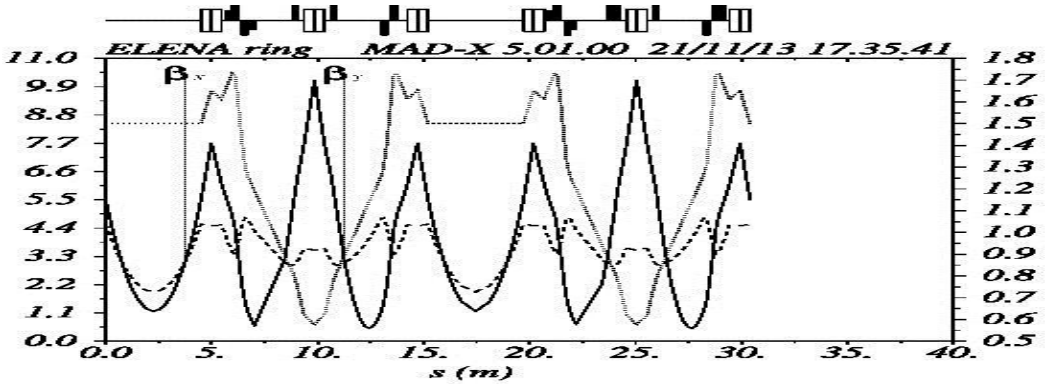


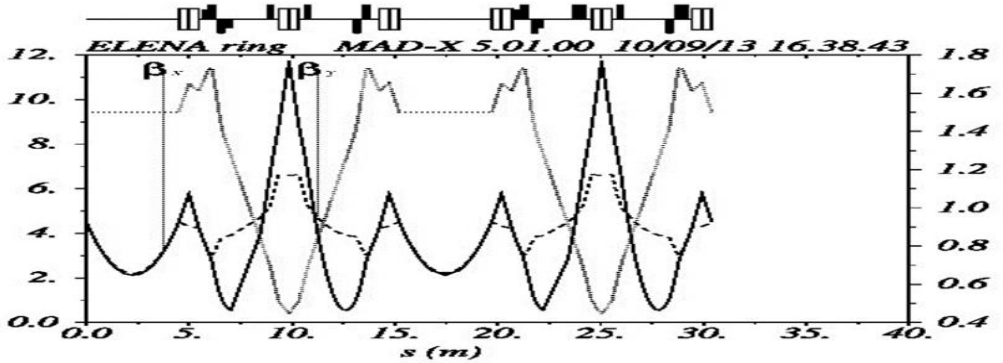
Tune diagrams up to 4th order with working points studied in detail and:

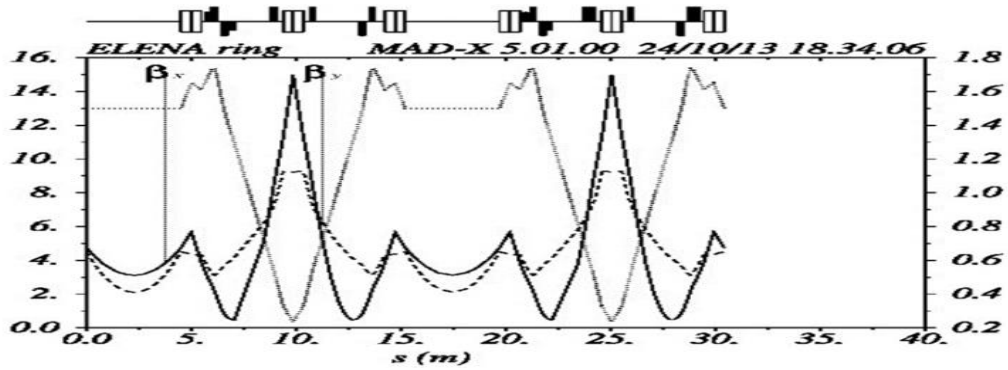
- resonances expected to be the main limitation and
- all resonances

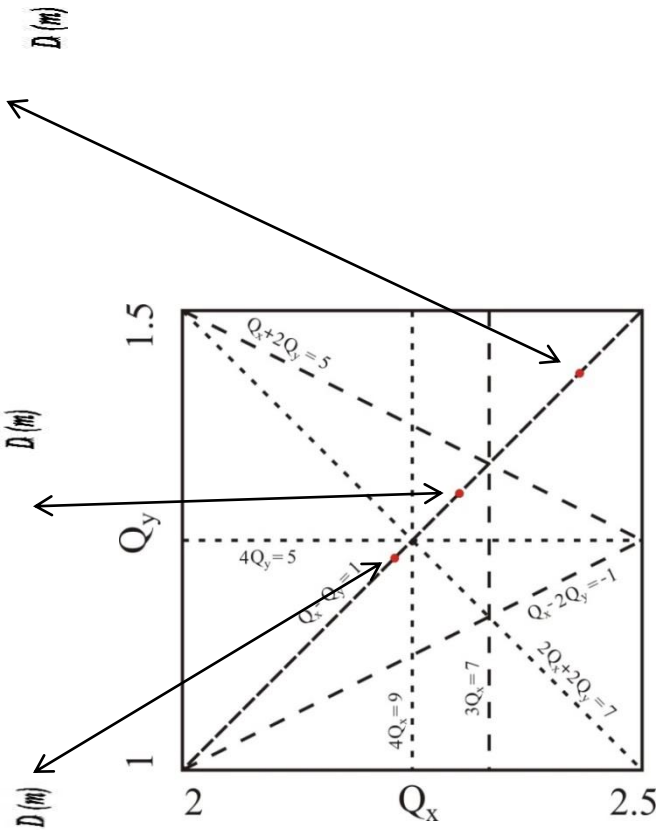
Lattice Tunability Studies

Based on work by P. Belochitskii







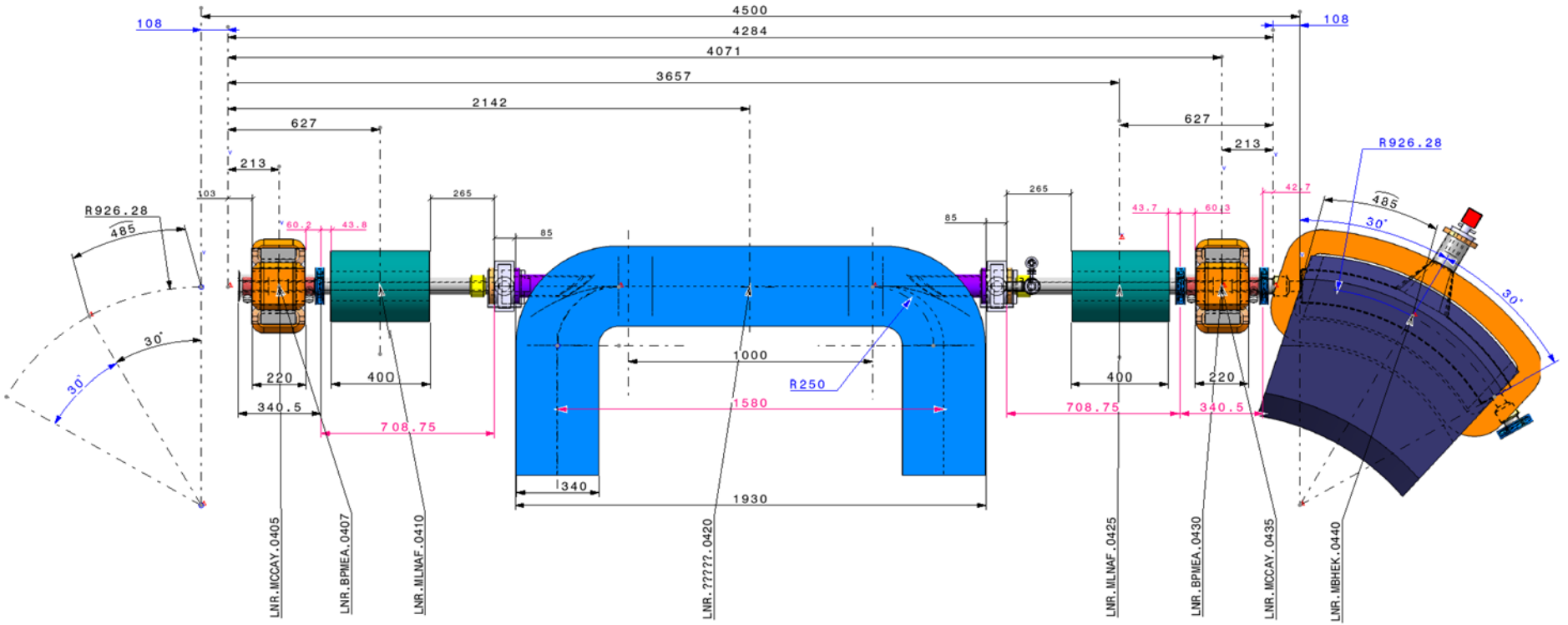


Tune diagram with working points studied in detail

Electron Cooler

(Slides by G. Tranquille)

Compact cooler!



Must fit in Section 4 incl. solenoid compensators and correctors.

~ 2 meters available for the electron cooler.

Space constraints also necessitate 90°bends (toroids, i.e. bent solenoids) on relatively small radius (25 cm)

Electron Cooler Parameters

Momentum (MeV/c)	35	13.7
β	0.037	0.015
Electron beam energy (eV)	355	55
Electron current (mA)	5	2
Electron beam density (m^{-3})	1.38×10^{12}	1.41×10^{12}
Bgun (G)	1000	
Bdrift (G)	100	
Expansion factor	10	
Cathode radius (mm)	8	
Electron beam radius (mm)	25	
Twiss parameters (m)	$\beta_h \approx 2$, $\beta_v \approx 2$, $D \approx 1.5$	

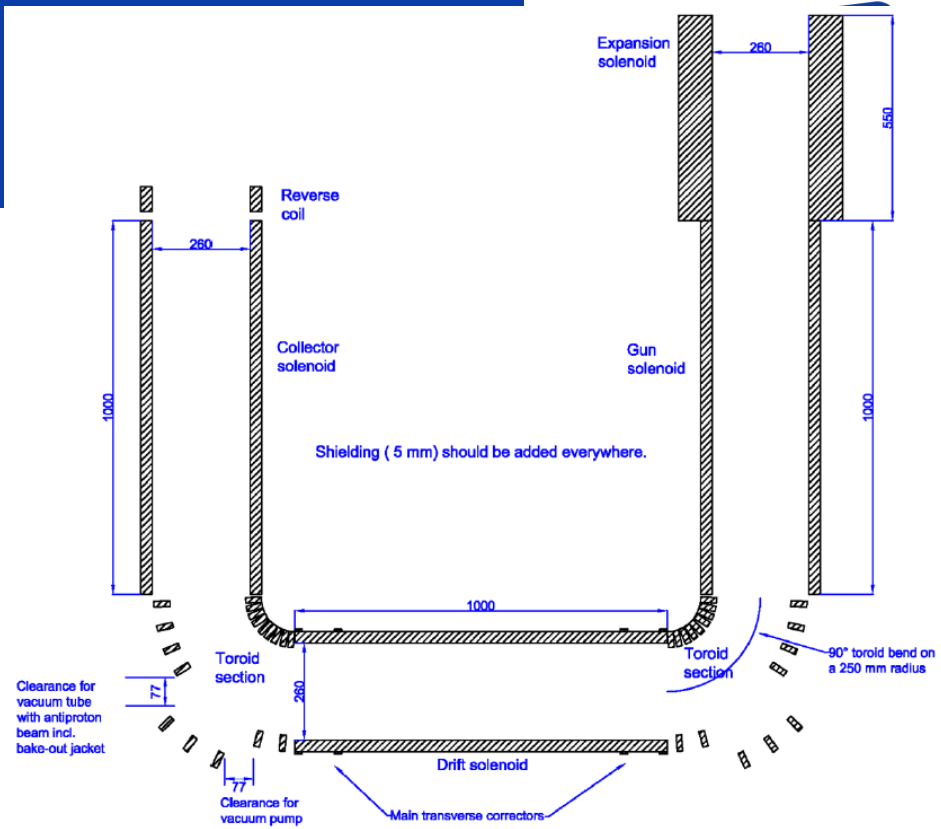
Electron Cooler

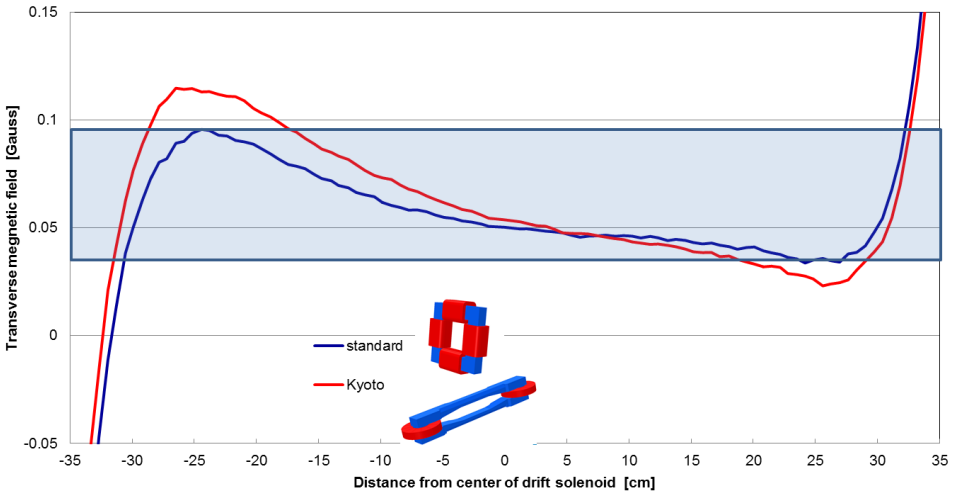
(Slides by G. Tranquille)

The Magnetic System

- Main cooler solenoid
- Gun solenoid
- Collector solenoid
- Expansion solenoid
- Reverse coil at collector
- 2 x Toroid section consisting of 9 racetrack coils each
- Various corrector coils to ensure good field quality
- Orbit correctors
- Solenoid compensators

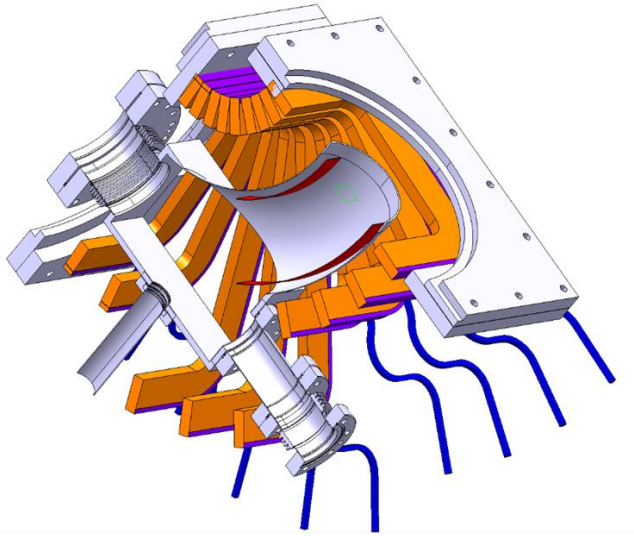
- 1m solenoid for drift, gun and collector solenoids
  - Common spare
  - Reduce influence of expansion solenoid

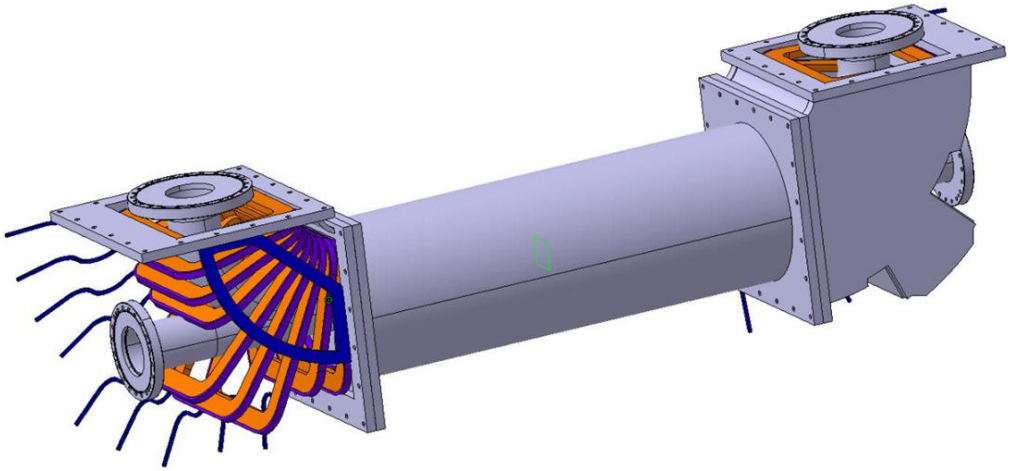




The Vacuum System

- Vacuum system will be XHV compatible
  - 316 LN NEG coated vacuum chambers
  - ST707 NEG cartridges at gun exit and collector entrance
  - CF flanges, sliver coated seals
  - Hydroformed bellows
  - NEXTorr pumps (collector and 2 toroid chambers)
  - System bakeable at 300°C for 24 hours
  - Bakeout jackets
- Whole mechanical structure to be tilted by 90°
  - Support with rails to slide out gun/collector solenoids





Status

Abandon construction of cooler by Toshiba.

Vacuum system to be designed by CERN.

Market survey for the “Design, manufacture, testing and delivery of the magnetic and vacuum components of an electron cooler for the ELENA ring” (IT-3995/BE/ELENA) initiated:

- Invitation to Tender scheduled for second quarter 2014.
- Specification drawings of the vacuum system to be prepared by EN/MME and BE/BI for April 2014 (80% of the job already done). Will be part of IoT.
- If 750 kCHF < cost < 1 MCHF go to Finance Committee in June 2014.

18 months estimated for design, manufacture, testing and delivery for the system.

- Leaves only a few months for installation on ELENA!!!!!!

Magnets: Overview of Work Package

Slides provided by D. Schoerling

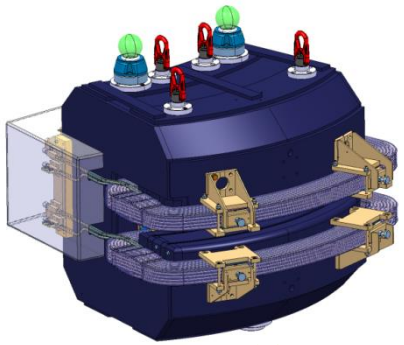
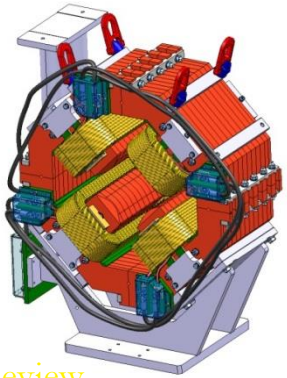
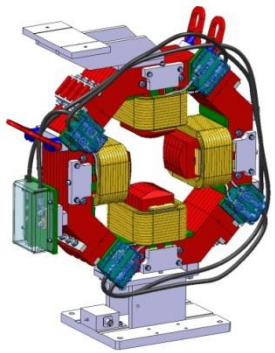
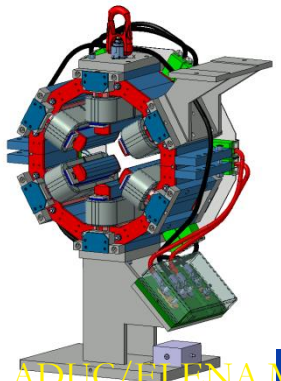
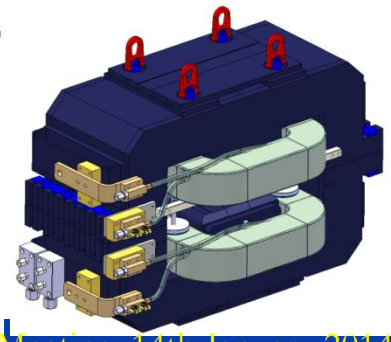
Findings of the review committee: The design of the magnets is in a good shape. The chosen magnetic material is good to minimize the remnant field.

Recommendations from the review committee

- The low pole field asks for studying dilution in all magnets, not just in dipoles. The machine operation and the reproducibility could be greatly improved.
- ¼ of the strength of the corrector strength is sufficient (WP Beam Dynamic confirmed that around ½ of the strength is sufficient).

Actions taken by the WP Magnets

- Designs of quadrupole and sextupole changed to make dilution of the magnetic material possible
- Three quadrupole prototypes are being built in-house at CERN to study and better understand the effects of remnant fields in the quadrupole magnets (status: coils are finished and yoke production is started)
- Corrector magnet re-designed as air-core magnets to take advantage of the relaxed field strength requirements. By using this design no remnant field in the corrector magnets will be present.

Magnets: Design of ELENA H/V Correctors

Slides provided by D. Schoerling

Initial requirement

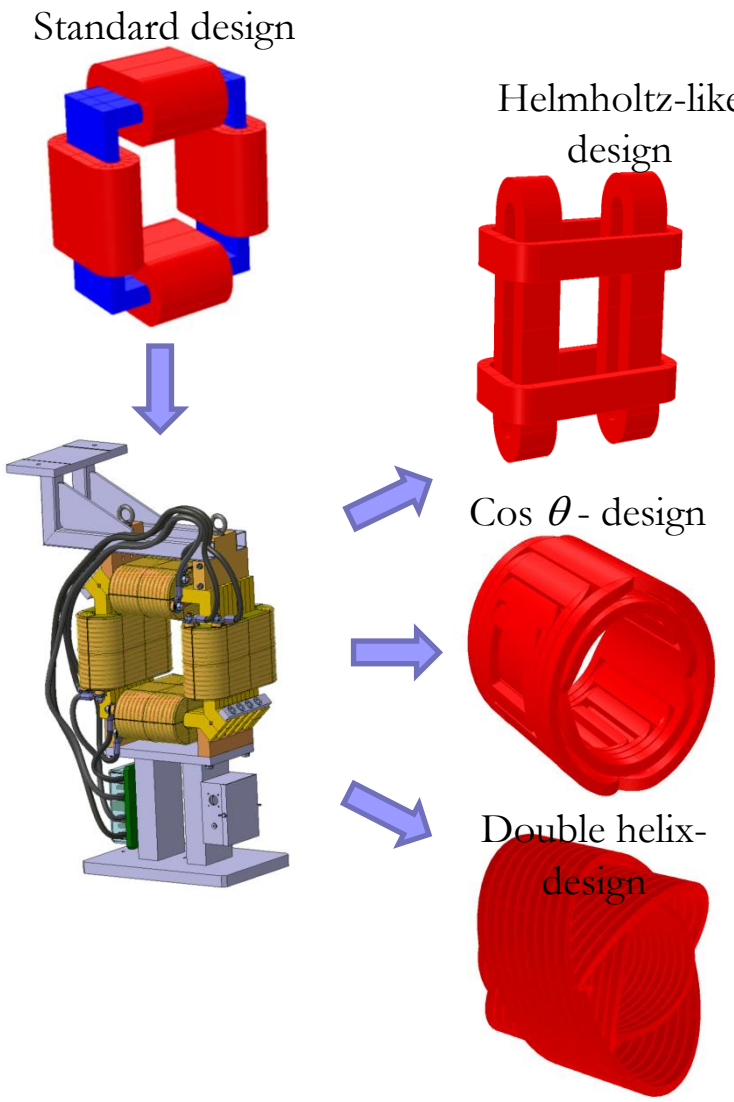
- Iron-based design completed including mechanical design for corrector magnets with a field strength of 60 Gm.

Comments from the review committee

- Reduction of required field strength to 25 Gm and risk of remnant field asked for studying air-core corrector designs

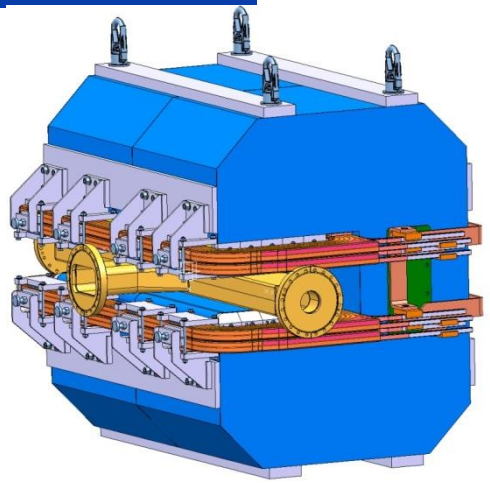
Actions taken by the WP Magnets

- Different possible designs (cos θ-, double helix and Helmholtz-like design) are studied.
- If all requirements are taken into account (power converter, vacuum, available space, etc.) the cos θ design seems most promising but requires further study to find an easy winding scheme and a feasible indirect cooling scheme.



Magnets: ELENA Dipole Prototype

Slides provided by D. Schoerling



Challenge

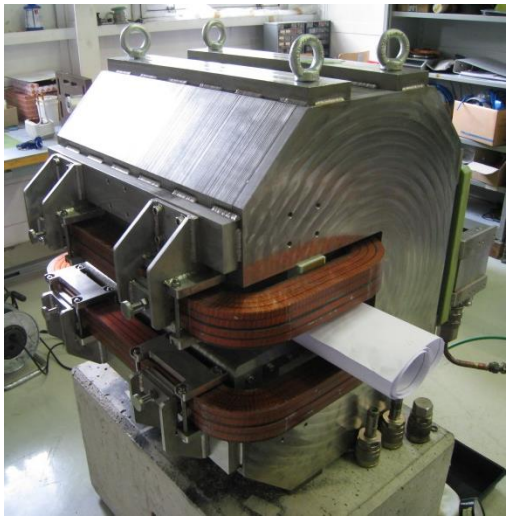
- Excellent and repeatable field quality is requested at very low field.

Solution

- Selection of high permeability electrical steel M270-50 A HP.
- Dilution of electrical steel with non-magnetic stainless steel to increase the magnetic induction in the iron and avoid working in the highly nonlinear area of the BH-curve.

Prototype

- Manufacturing methods were studied.
- Magnetic measurements are performed to show that the magnet is within requirements.



See ATS report CERN-ACC-2013-0261. - 2013. - 34 p.

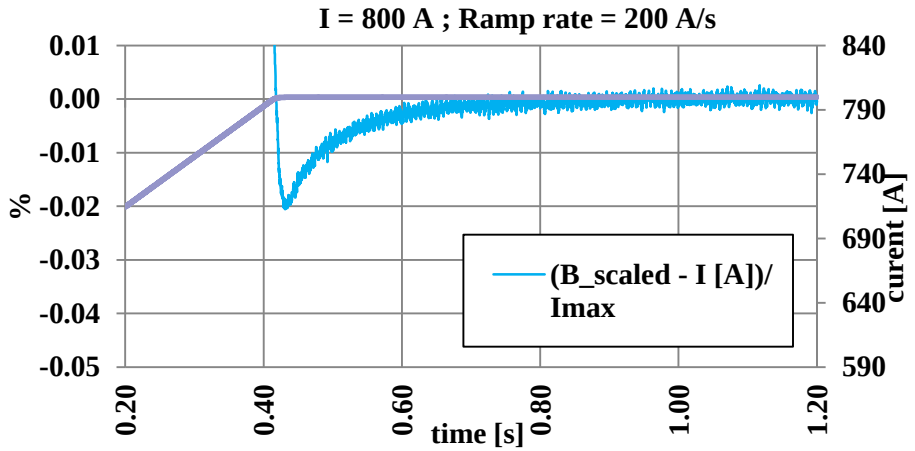
Magnets: ELENA Dipole Prototype Measurement

Slides provided by D. Schoerling

- After one pre-cycle the field is extremely repeatable (better than 10^{-5}).
- The remanent field at zero excitation is below 1 mT after having excited the magnet at nominal field.
- After around 0.1 s the integrated field is stable in the 10^{-4} level (similar time constant expected in the final magnet).
- Field homogeneity is as expected. However, further investigation is required with a rotating coil measurement system to better study the variation of the sextupole component. Preliminary measurements show that the magnet is at the limit with a variation of 2.8±2 units for different field values (expected variation <1 unit, requested variation <4 units).

The preliminary measurement results show excellent results close to the simulation results presented in the ATS report CERN-ACC-2013-0261. - 2013. - 34 p.

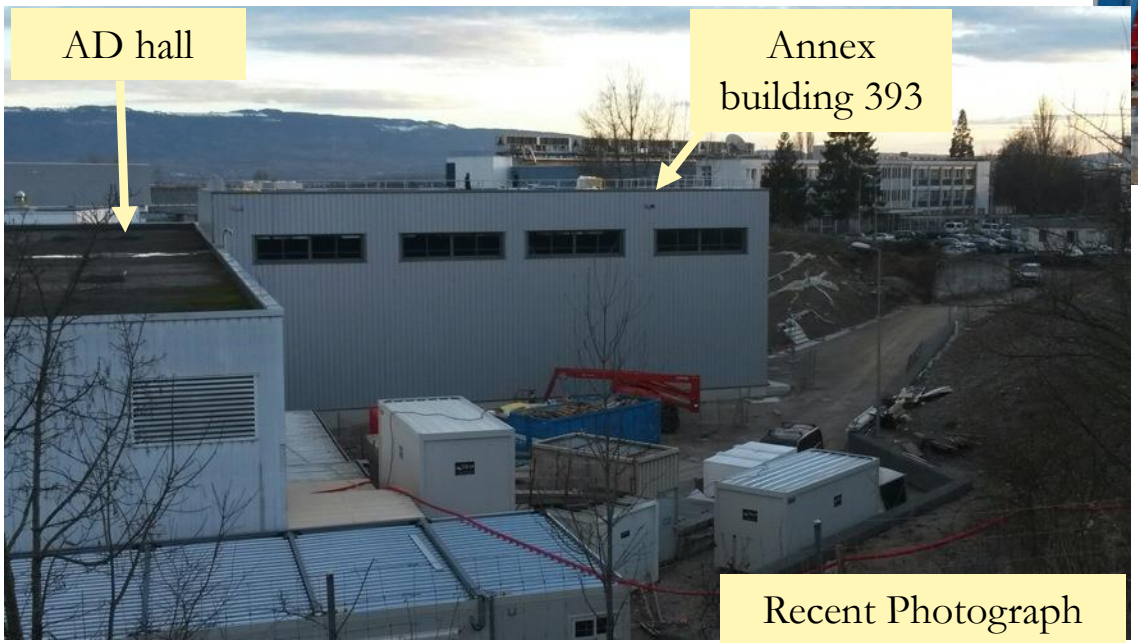
	Current [A]	B [T]	dB/B [10^{-4}]
	0		
Cycle 1	100	0.051399	/
	900	0.411017	/
Cycle 2	100	0.052770	259.8
	900	0.411045	0.7
Cycle 3	100	0.052770	0.0
	900	0.411044	0.0
Cycle 4	100	0.052770	0.0
	900	0.411044	0.0



Construction of Annex Building 393

- Construction of building close to completion
  - Delivery expected in February (ahead of schedule)
- To be followed by Infrastructure Installation (CV, electrical distribution, access system, crane …)
- Needed for installation of kicker equipment from late autumn 2014

Situation end of September 2013



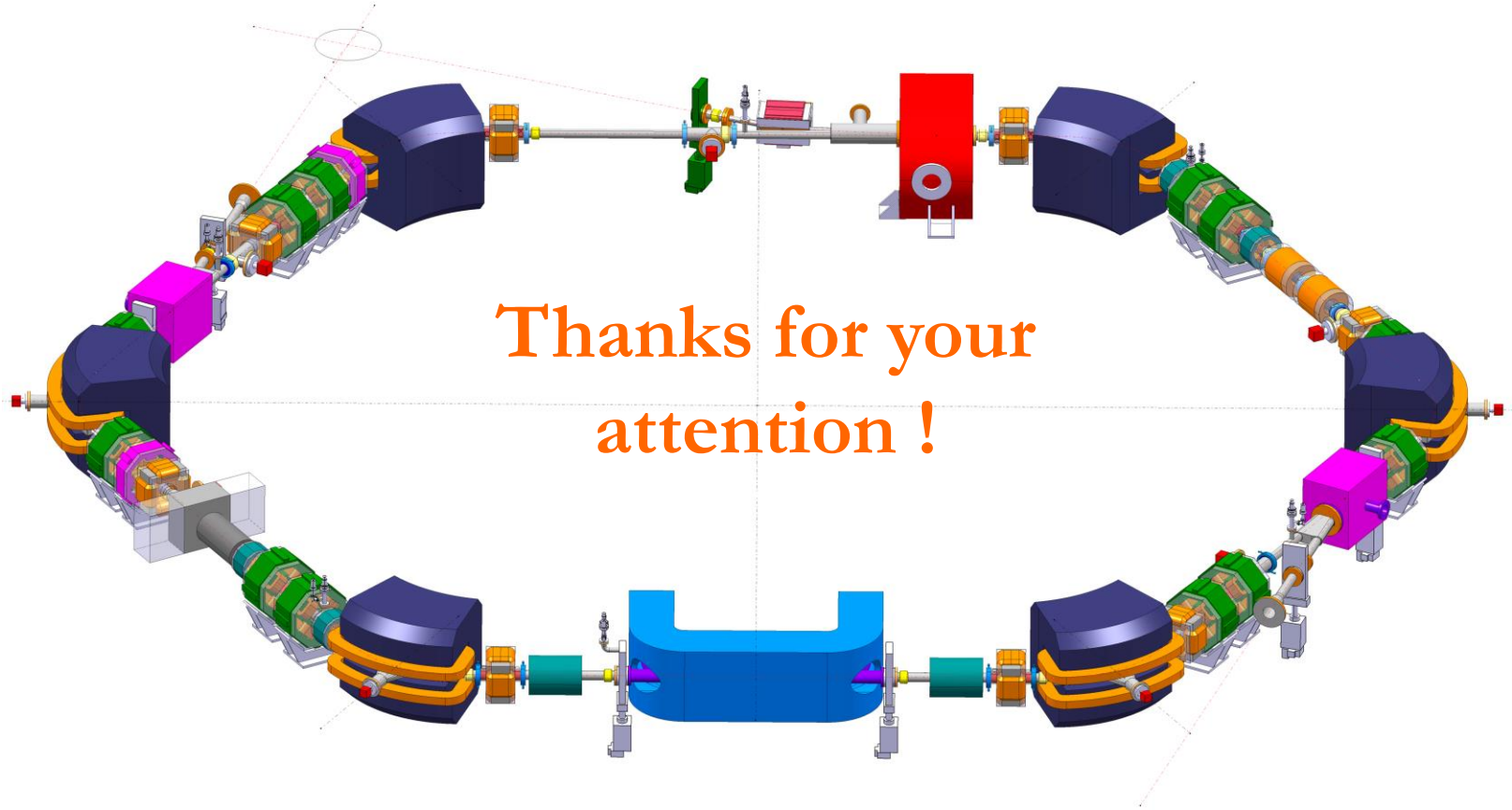
Recent Photograph

Status of external Contributions

- **Univ. Tokyo and MPQ-MPI**:
  - Profile monitors for lines
  - Other contributions to be discussed after decision (our side) that cooler construction in house
  - Manpower to work on electrostatic transfer lines (devices), electron cooling ..
- **Cockcroft Institute & Univ's and Swansea University:**
  - Started working on beam dynamics and physics related subjects
  - Plans for more work with enlarged team (team with full time postdocs and doctoral students)
- **Denmark:** Funds (580 kCHF, thanks!!!) for the construction of the bending magnets transferred to CERN in autumn 2013
- **IKP-FZ Julich:**
  - Work on external source for commissioning going on - contacts with transfer lines and integration.
- **Univ. Brescia:**
  - 25 kEuros transferred and 25 kEuros to be transferred soon
  - Collaboration on electronics design for position Pick-Ups
- **RIKEN (since last ADUC)**
  - Manpower (student) discussed last autumn
- **TRIUMF:** Help for design of electrostatic transfer lines
- **Hemholtz Institute Mainz:** Construction of supports – agreement to construct "jacks" for support and precise alignment of heavy bending magnets last autumn, others items may follow
- **Manne-Siegbahn Laboratory:** Plans to help with ELENA commissioning

Summary and Outlook

- Outcome of Review
  - Basic ELENA machine design presented is sound and expected to meet the requirements
  - No overlooked showstoppers identified
  - Several interesting recommendations and suggestions for further improvements
- Machine to be built is known
  - .. it is the machine described at the review and in the TDR, which had evolved since the feasibility study and project approval
  - Some (hopefully small) modifications to be expected
    - As a result of the recommendations from the review and problems encountered
- Ongoing now and outlook
  - Completion of TDR – draft from proofreading expected this month
  - Revision of budgets and planning
    - Collecting input from Work Package holders
    - Setting up of an EVM structure for project follow-up
  - Construction, installation, commissioning …
  - First 100 keV beam for experiments from ELENA expected during 2nd half of in 2017



Thanks for your attention !

Report from Review Committee

Recommendations and actions to take them into account

- Optics, longitudinal and transverse Dynamics
  - Recommendation: revise working point to avoid 4th order resonances excited by direct space charge
    - ➡ Comment: understanding before review was that working point will be found empirically "somewhere close to" $Q_x = 2.3$ and $Q_x = 1.3$
    - ➡ Action: optics solutions for lower (q = 0.23) and higher (q = 0.46) fractional tunes have already been investigated since, consequences on aperture under discussion (avoid increasing magnet apertures!!) .. better understanding of lattice tunability obtained
  - Recommendation: 6D tracking with electron cooler (effect of non-linearities experienced by circulating antiproton beam under the "toroid" of the electron cooler)
    - ➡ Comment: had been planned since discussions with one of the reviewers (M. Grieser) at the Cool workshop in June (very important and high priority!)
    - ➡ Action: to be done when a field map of the cooler (with orbit correction) is available
  - Recommendation: evaluation and, if possible, measurement of impedances of every element, even though collective instabilities expected not to be an issue
    - ➡ Comment and action: started well before review with PhD student and help from ABP/ICE
  - Recommendation: double harmonic RF system to mitigate direct transverse space charge effects
    - ➡ Comment: plan to keep low level RF system flexible for implementation later (with large bandwidth cavity foreseen anyhow no impact on other hardware to be constructed)
  - Recommendation: evaluate effect of (switch mode) power converter noise on beam (blow-up)
    - ➡ Comment & action: important and tricky problem … to be discussed with priority

Report from Review Committee

Recommendations and actions to take them into account

- Possible issues related to very low magnetic fields, closed orbit studies
  - Recommendation: magnetic stray field measurement in AD hall at ELENA position
    - ➡ Comment: has been done long ago with AD pulsing, crane moving … not presented at review due to lack of time
  - Recommendation: simulations of closed orbit with random errors
    - ➡ Comment: simulations with expected field in AD hall (only earth magnetic field) presented at the review (orbit distortions and their correction)
    - ➡ Action: simulations with random magnet (alignment) errors as soon as time permits
  - Recommendation: Evaluate effect of supercycle operation and remanence effects
    - ➡ Comment: planned to (i) execute repetitive hysteresis cycles (always ramp currents up and down to the same reference currents) and (ii) to quantify hysteresis effects during magnetic field measurement campaigns
  - Recommendation: "Thinning" (mixing of magnetic and stainless steel laminations) not only for bending magnets, but also quadrupoles etc. for field quality and mitigation of remanence
    - ➡ Action: magnet experts (i) launched ordering of different prototype quadrupole yokes for systematic studies and (ii) proposed and study orbit correctors without yoke
  - Recommendation: revise ring orbit corrector strengths (reduction by a factor ≈4)
    - ➡ Action: Strength reduced by factor 2.4 (to keep compatibility with bumps around the electron cooler) makes it easier to adopt yoke free magnets (see above)

Report from Review Committee

Recommendations and actions to take them into account

- Electron Cooling
  - Comment: electron cooling of antiprotons in ELENA is expected "not to be a problem" …e.g. extrapolating from measurements with $^{31}P^{+}$ beams (same relativistic β) at TSR
  - Comment: details of electron collector, clearing electrodes (removing ions otherwise trapped in electron beam) and position pick-ups not presented
    - ➡ Comment: pick-ups under study now and clearing electrodes were foreseen anyhow
  - Comment: design of cooler (magnetic system) behind of what was done for ring magnets
    - ➡ Comment & action: lengthy discussion with Toshiba without result; meeting on 8th November organized by BI with agreement to (i) launch a market survey and (ii) discuss vacuum system between BI and design office
  - Recommendation: reduce size of electron beam to simplify gun design
    - ➡ Comment & action: reduction of electron current considered by team working on cooler
  - Recommendation: A proof of accuracy of BetaCool should be done (using AD and TSR data)
    - ➡ Comment & action: effort based on LEIR and AD data will continue
  - Further recommendation: effect of "toroids" on antiproton dynamics, IPM
    - ➡ Comment: see other topics under which these recommendation were made as well
- Vacuum system
  - Recommendation: valves on both sides of injection kicker
    - ➡ Action: valve to be added upstream of the kicker, downstream very difficult
  - Recommendation: design of vacuum of cooler with differential pumping for gun & collector

Report from Review Committee

Recommendations and actions to take them into account

- Instrumentation
  - Recommendation: "micro-wire" profile monitors in injection line as well
    - ➡ Comment & action: excellent proposal, details (where, number ..) to be discussed
  - Recommendation: "micro-wire" profile monitor be of interest for ring with kicked beam?
    - ➡ Comment: Extracted beam can be measured with first monitor in extraction line
  - Ionization Profile Monitor in ring, ~1 s integration time & pressure bump (by factor 10)
    - ➡ Comment: excellent news if IPMs are really feasible (had been foreseen, but then abandoned) as little transverse diagnostics (only destructive scraper) is available in ring
    - ➡ Action: to be studied by a fellow
  - Recommendation: position pick-ups in electron cooler
    - ➡ Comment: has been discussed before, feasibility under study (works well at other machines)
- Transfer (extraction) lines
  - Recommendation: Full tracking simulation trough complete line/sensitivity to errors
    - ➡ Comment: tracking studies through complete line planned as external contribution by the Cockcroft institute
  - Recommendation: review (momentum) acceptance
    - ➡ Comment & action: surprise! … conservative margins will be better documented
  - Recommendation: shielding studies for lines passing close to experiments
    - ➡ Comment: partly done, plan for simple tests (field inside shielded tubes)