1 June 2017

EDM BRAINSTORM

Work package	Comments	Contributors	Coordination
Science case	• Up to date physics case for EDM • EDM landscape • Motivation for CP-EDM • Critical synthesis of storage ring systematics - can the experiment be done at the required sensivity?	KAIST/FZJ/CERN	Frederic Taubert (CERN) Themis Bowcock (Liverpool) In liason with Joerg Jaeckel (BSM WG lead)
Ring design	• All electric lattice • E/B lattice • Beam and spin dynamics • RF cavities		Yannis Semertzidis (CAPP/IBS & KAIST)
Beam control	• Cooling • Feedbacks		Joerg Pretz (FZJ)
Beam preparation	• Source, acceleration, injection, • Spin manipulation	FZJ/CERN	Beam delivery: Christian Carli (CERN) Spin manipulation NN (FZJ)
Ring components (1)	• RF, • Vacuum…	CERN	NN (CERN)
Ring components (2)	• Shielding, • Electrostatic deflectors, • ExB deflectors • Beam instrumentation (BPMs, SQUIDS…), • Beam and spin manipulators	KAIST/FZJ/CERN	Frank Rathmann
Polarimetry	• Proton • Deutron • Targets • Systematic errors	FZJ	Edward Stephenson (Indiana U.)
Systematics	• Magnetic fields • Alignment • Electric fields • CW/CCW effects	KAIST/FZJ/CERN	Yannis Semertzidis (CAPP/IBS & KAIST)
Siting at CERN	• Site • Civil engineering • Cost	CERN	Mike Lamont (CERN)

KICKOFF

Polarized proton beam preparation for injection into the EDM storage ring at CERN

- Gianluigi Arduini
- Alessandra Lombardi
- Christian Carli
- Jacques Lettry
- Themis Bowcock
- Anatoli Zelenski

Meeting after kick-off

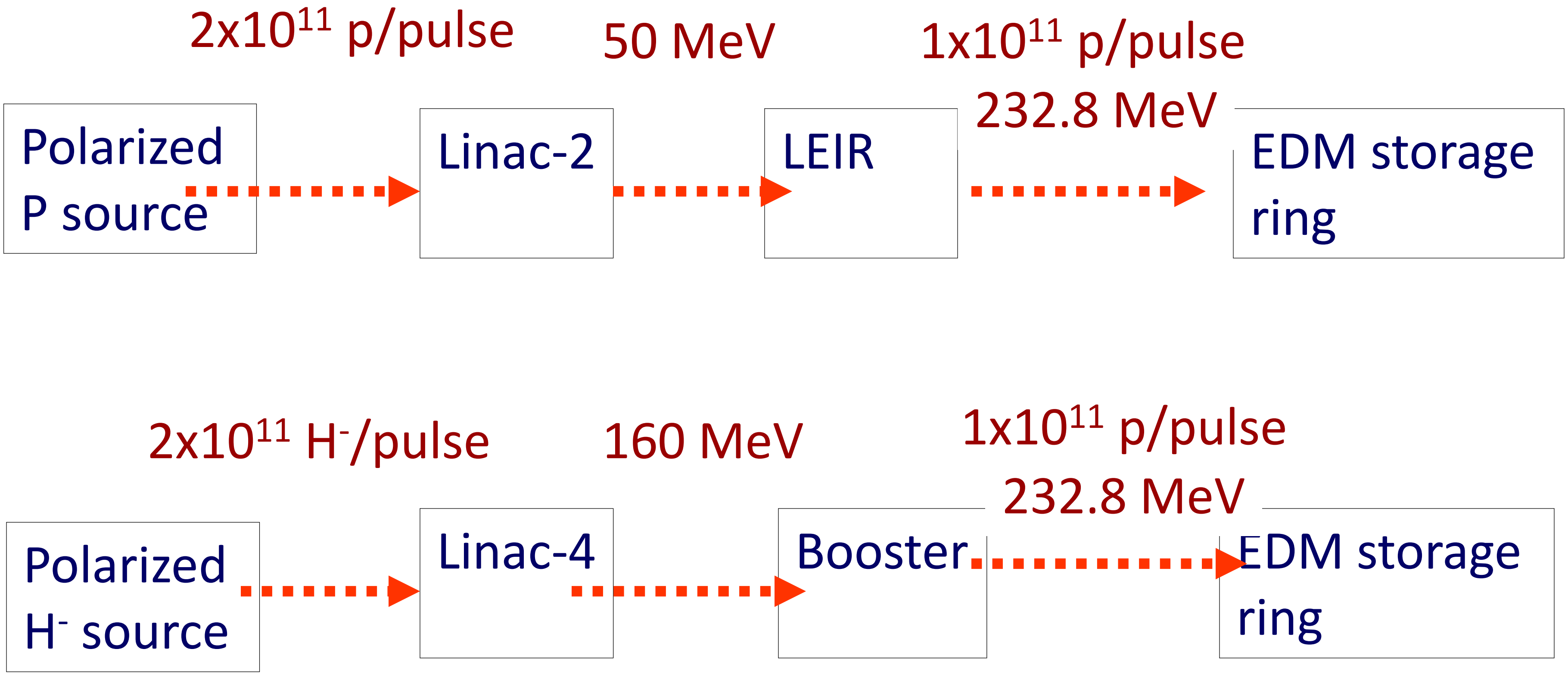
- Full energy 232.8 MeV longitudinally polarized proton injection into the EDM storage ring

p = 0.7 GeV/c, v/c = 0.6, KE = 233 MeV

Source?

- Characteristics
  - current, pulse duration, emittance
- Ion type (s)
- BNL re-use?
- Ballpark cost for transfer or construction
- Infrastructure requirements

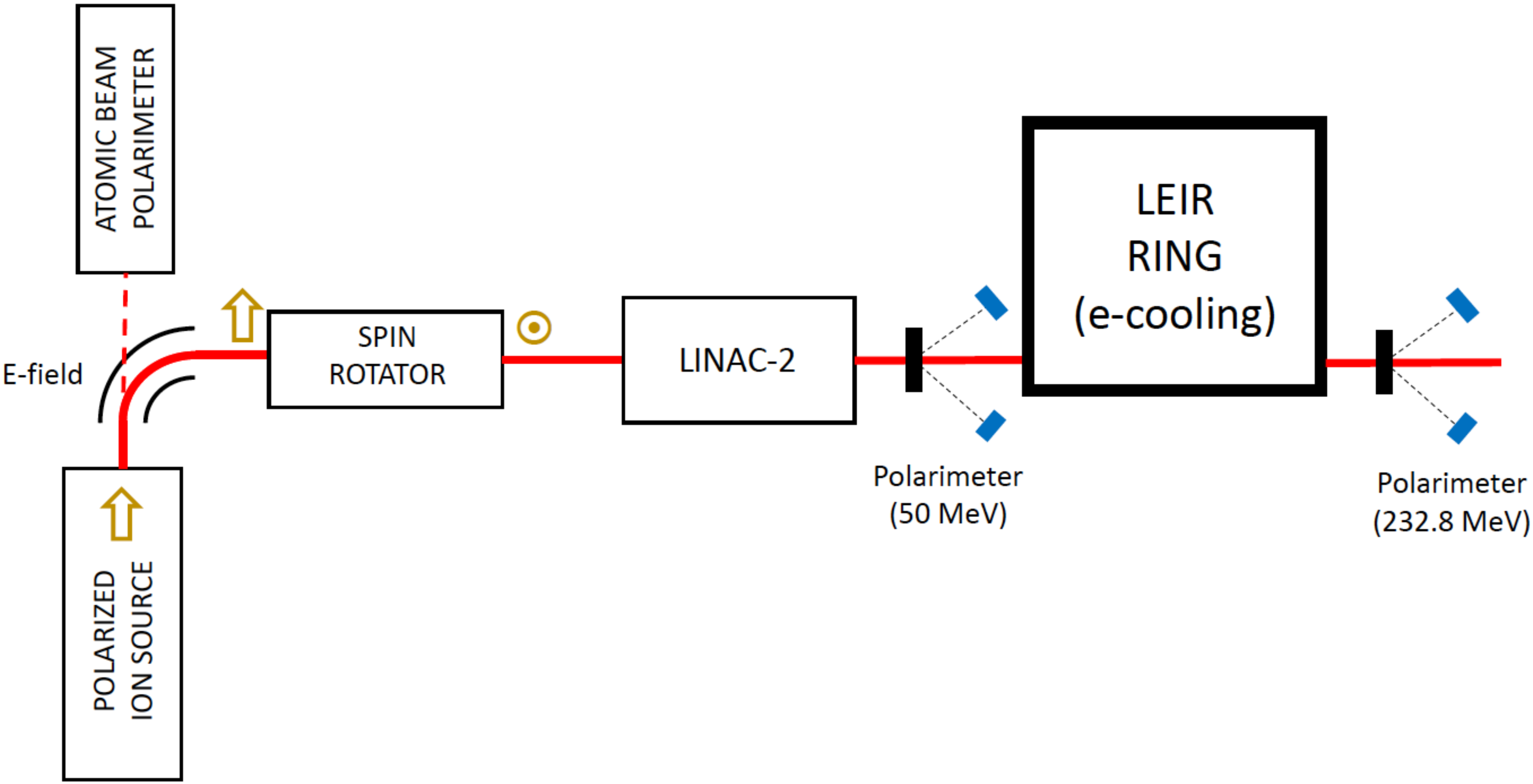
Accelerator chain options



Vertical polarization direction adjusted in the LEBT and maintained vertical along the accelerator chain and HEBT lines. Aligned to longitudinal just before injection into the storage ring.

Options

	+	-
Linac2-LEIR	Dedicated linac Electron cooling	Age of Linac2
Linac3-LEIR	Extant Electron cooling	Two sources Competition with ions
Linac4-PBS	Extant	Heavy competition No electron cooling Two sources for Linac4
Linac4++	H- to full energy	Cost, real estate, switching Two sources for Linac4
Green field Linac to 233 MeV	Designed for purpose	Cost
New linac in Linac2 tunnel	Dedicated linac Electron cooling Nice new linac	Cost



Courtesy Ed Stephenson

Common

- Polarized ion source produces atomic beam for (Breit-Rabi) polarimeter, protons for beam line. Pulse is a few hundred micro-seconds long.
- At keV energies, electric field rotates proton beam without changing polarization direction.
- Rotate polarization into vertical direction so that it will survive LEIR.
- Linac provides energy (50 MeV) for LEIR injection.
- After acceleration, check polarization by scattering from carbon or deuterium.
- Send into LEIR, electron cool for a tight bunch. Raise energy to 232.8 MeV. This involves crossing the $G\gamma=2$ imperfection resonance, which should be done quickly. We should check for other machine resonances.
- Polarimeter after LEIR confirms that polarization has survived. This uses carbon scattering and can be the calibration measurement for the polarization. Consider thicker target with holes (50% transmitting) for “flash” calibration in single integrated pulse.

Courtesy Ed Stephenson

Vertical injection into EDM ring

- Bending magnet connects to both CW and CCW injection on separate fills.
- Beams must be in tight bunches, or else the rotation into the horizontal plane will leave behind residual parts of the beam with unacceptably large normal components. Harmonic = 2.
- RF solenoid runs at beam revolution frequency and is matched so that peak of oscillating field matches time of bunch crossing through solenoid.
- Two bunches for each beam will have opposite polarization. Then each must be split to get higher harmonic for experiment with mixing with opposite polarization.

Courtesy Ed Stephenson

Horizontal injection into EDM ring

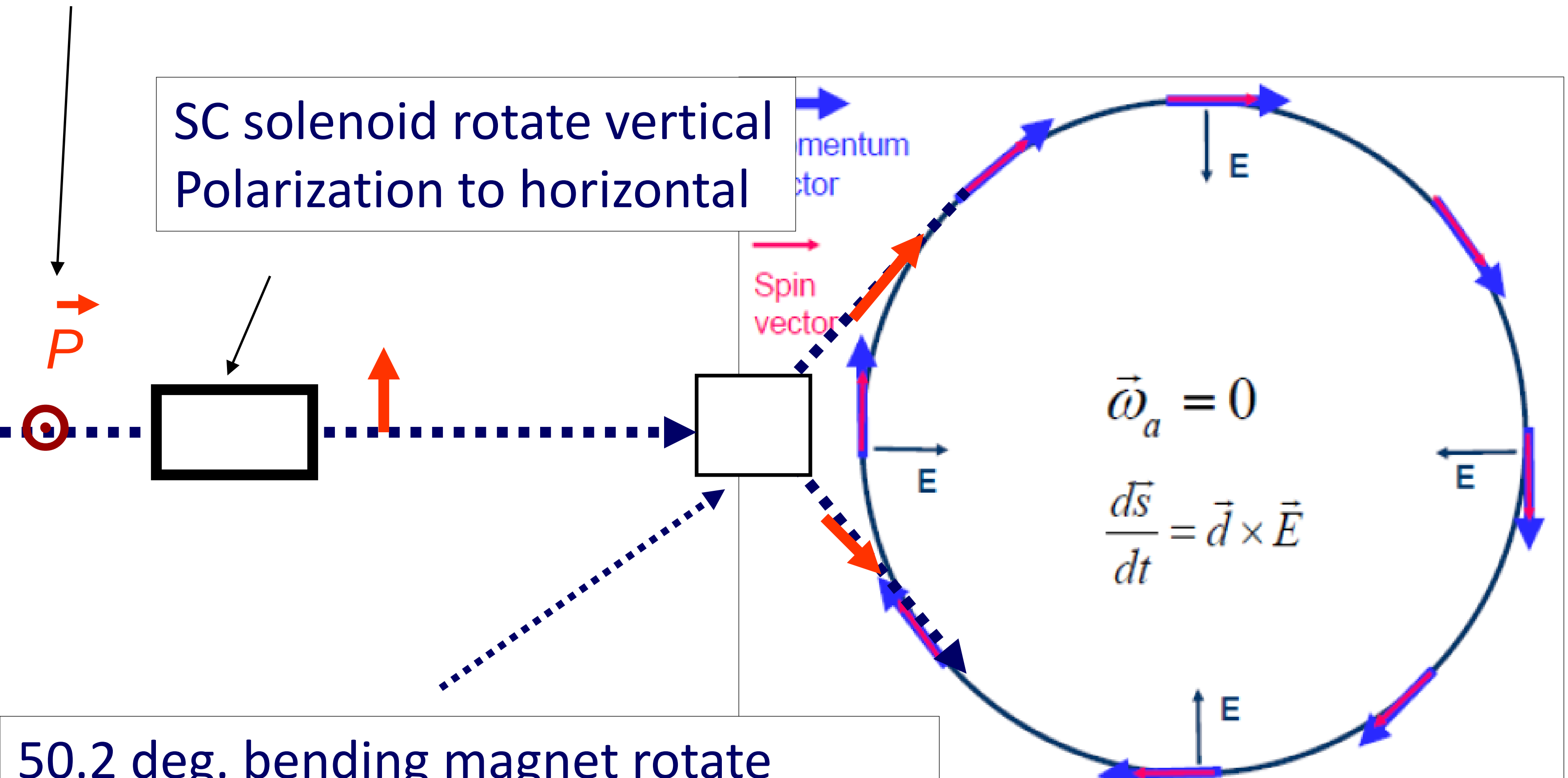
- Solenoid rotates polarization into horizontal plane. Fine adjustment cancels vertical components in EDM ring.
- CW and CCW must be done with polarizations in the same direction, otherwise we cannot later align the two beams for frozen spin condition separately. Maintaining the same direction also sets up CCW as the time reversed experiment.
- Bunch structure in EDM ring is arbitrary. Polarization cannot be reversed on single fill, so opposite polarization state requires separate fill.

Courtesy Ed Stephenson

Injection of longitudinally polarized proton beam

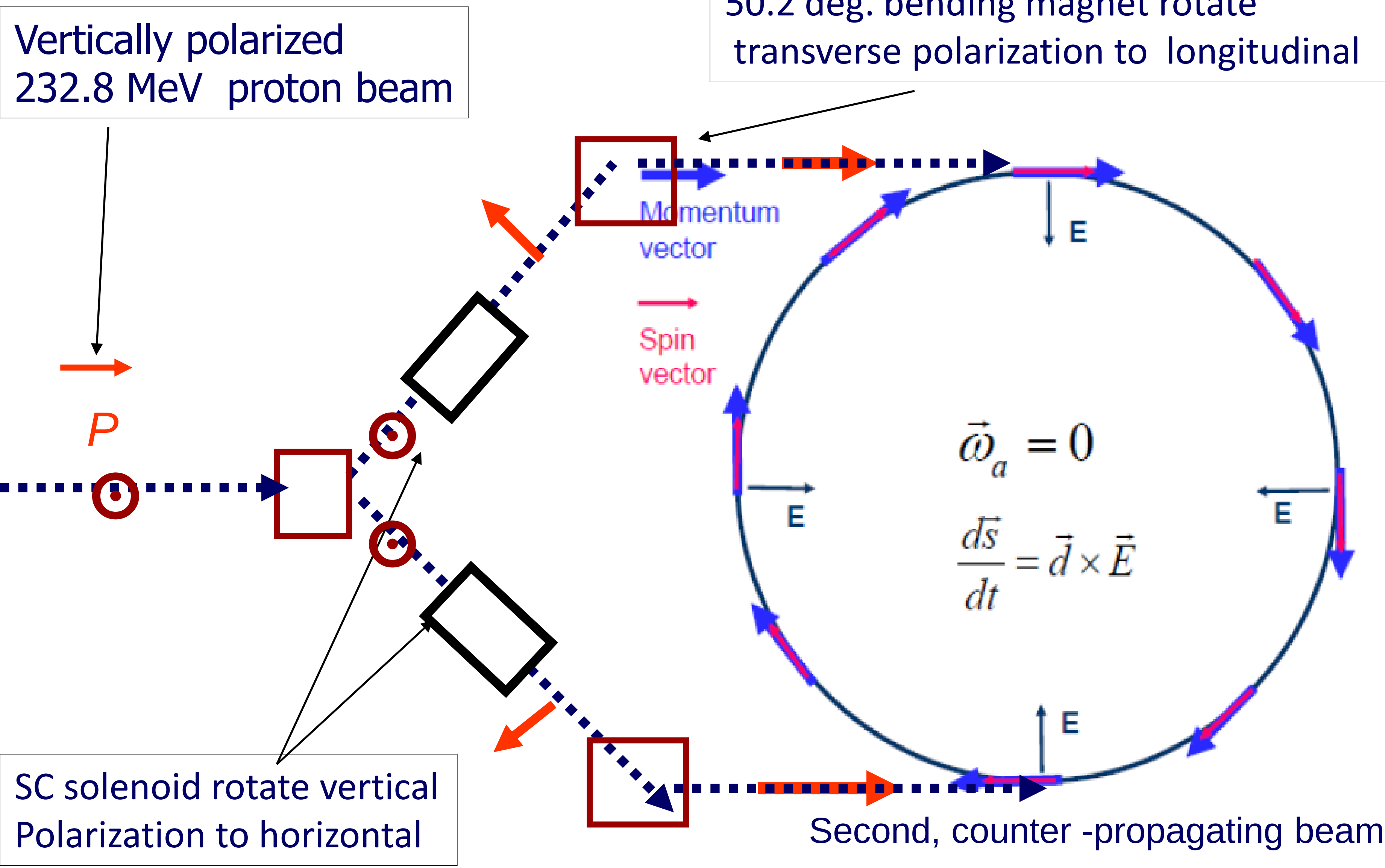
Vertically polarized
232.8 MeV proton beam

SC solenoid rotate vertical
Polarization to horizontal



50.2 deg. bending magnet rotate
transverse polarization to longitudinal

Symmetrical beam injection



Ring – basic requirements

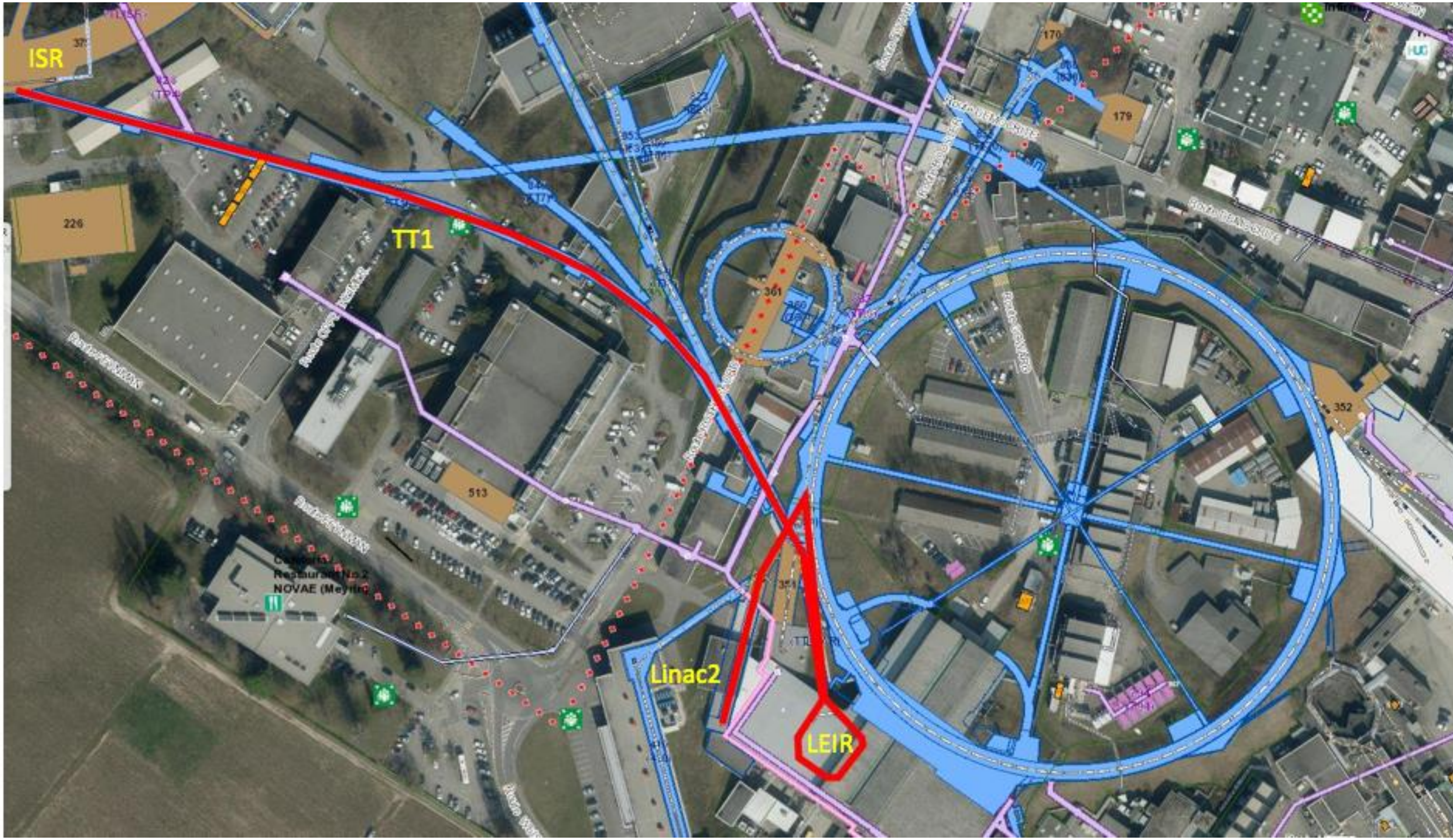
- Given the timescale (5 – 10 years) of the experiment we do not need sophisticated ancillary buildings
- There is no radiation hazard from this beam so shielding can be minimal
- Consider cut-and-fill as well as pure on-surface solutions.
- The vibration isolation and the temperature control are modest and the degree to which these need to be done depends largely on cost. For example the similar g-2 experiment at BNL operated with +/- 10 ˚ C.
- The cross-section of the storage ring including shielding is approx. $1m^2$
  - does not need huge power supplies or cryogenics. Cryo-cool but do not need super conducting magnets
  - access needs to be on 2 or 3 "sides" of the storage ring.

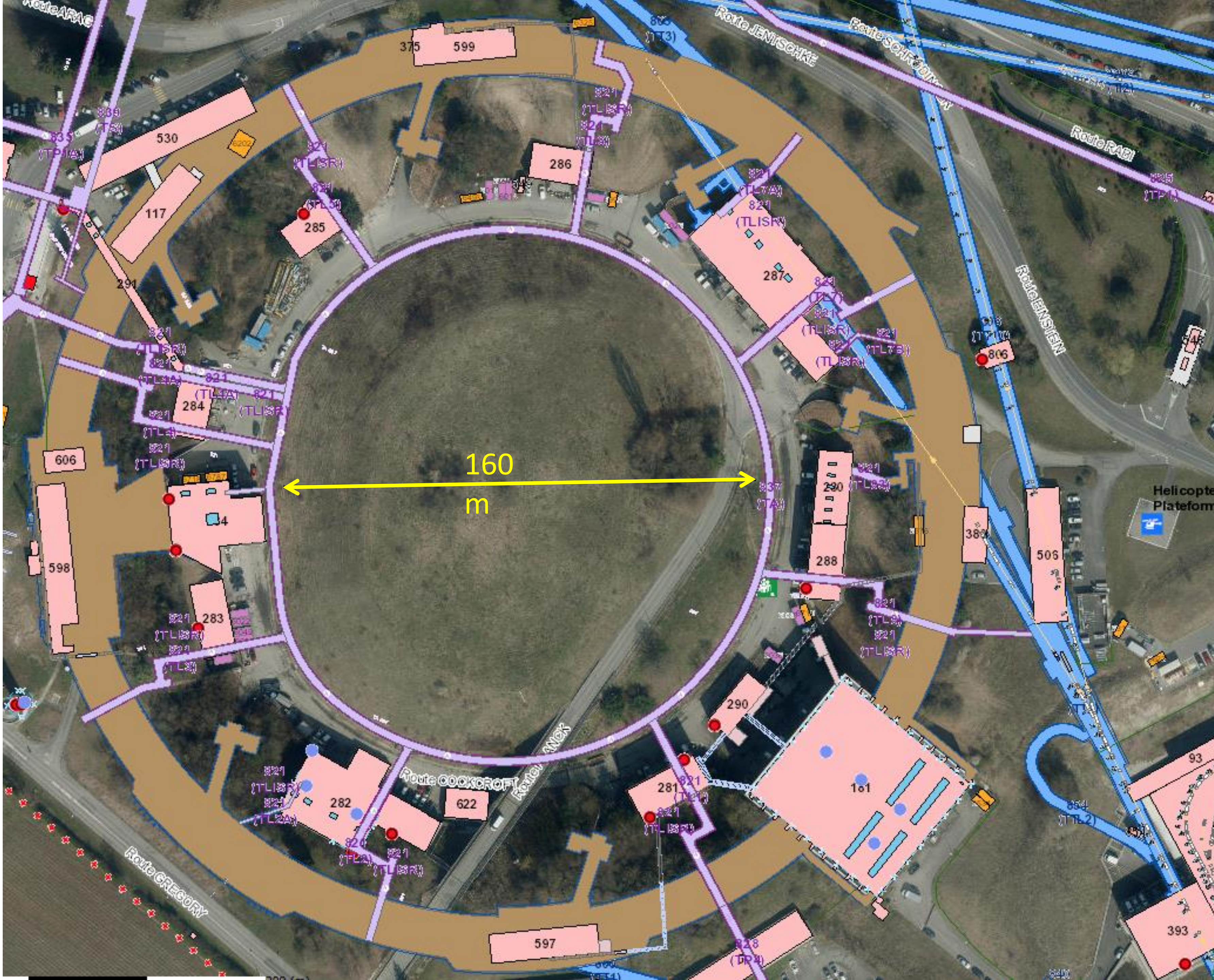
	Min	Optimal	Max	
Experiment lifetime	3years	4 years	5years	
Ancillary Buildings	Temporary accommodation e.g. trailers OK			
Experimental Size	~ 50 active physicist and engineers. Expect 10-15 on site			
Average Ring radius	40m	~70m	150m	
Circumference	250 m	440 m	940 m	
Stability (Thermal)	~0.1°C	~1°C	~10°C	
Deflectors & Shielding Cross-section	$0.9m^2$	$1m^2$	$1.1m^2$	
Vacuum	10^{-9} mb/l/s	10^{-11} mb/l/s		
Injection Clockwise and counterclockwise for simultaneous operation n	0.5×10^{11}	10^{11} total Both beams	2×10^{11} total	
Electrostatic Deflectors	150 kV @ 2cm plate separation	150 kV +/- @ 3cm plate separation	75kV	
Beam energy		T = 233 MeV 700 MeV/c		
Vibration Isolation @ 100 Hz		O(100um)		

c/o Yannis, Themis

Site?

- “green” field in middle of the ISR real estate
  - Worry about existing infrastructure
  - But transfer lines to ISR in place
- Use existing ring – ISR, PS?
  - ISR - longer running time, full (!) of mildly radioactive waste
- Green field site (Prevessin, say)
- Any other brown-field sites at CERN?


ISR
TT1
226
513
361
351
352
179
170
Linac2
LEIR

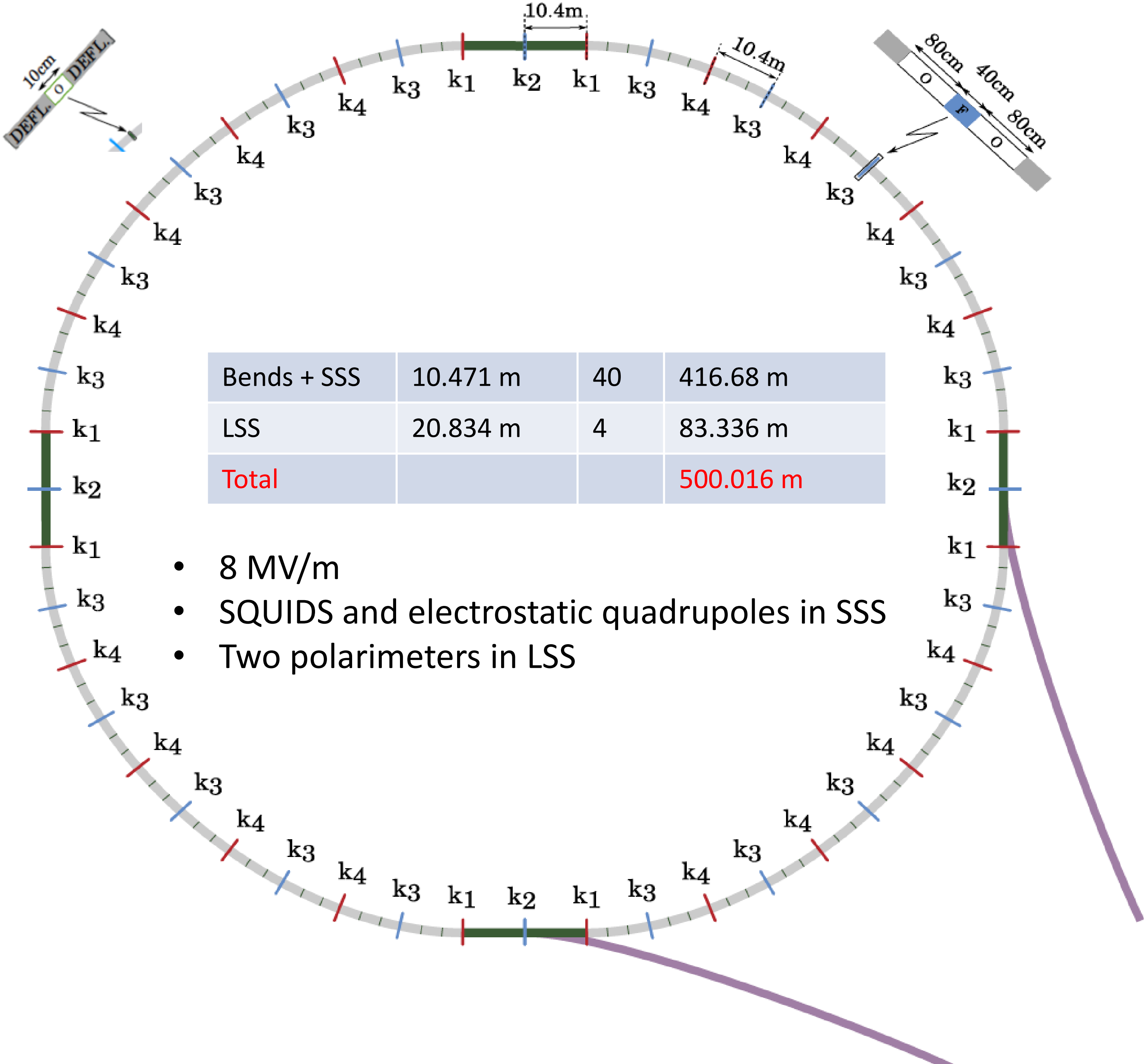


160
m
Route JENTSCHKE
Route RABI
Route EINSTEIN
Route COCKCROFT
Route GREGORY
Helicopter
Plateform
375
599
530
117
286
285
287
291
284
606
598
283
290
288
380
506
806
290
281
161
282
622
597
393
93

CE Requirements

- Need input (possibly from BNL study)
  - Tunnel cross-section, volumes
  - Required stability
  - Services (CV, EL, CRYO …)
  - Shielding (RP, EL…)
  - Access, safety
- The best way to get the process going is to start doing some layout drawings
  - it looks a bit tricky though in the ISR area with all the existing technical galleries

- Preliminary civil engineering study: ~50 kCHF approved
- John Osborne has asked member of CE draughting team (Raul) to have a look



Bends + SSS	10.471 m	40	416.68 m
LSS	20.834 m	4	83.336 m
Total			500.016 m

- 8 MV/m
- SQUIDS and electrostatic quadrupoles in SSS
- Two polarimeters in LSS

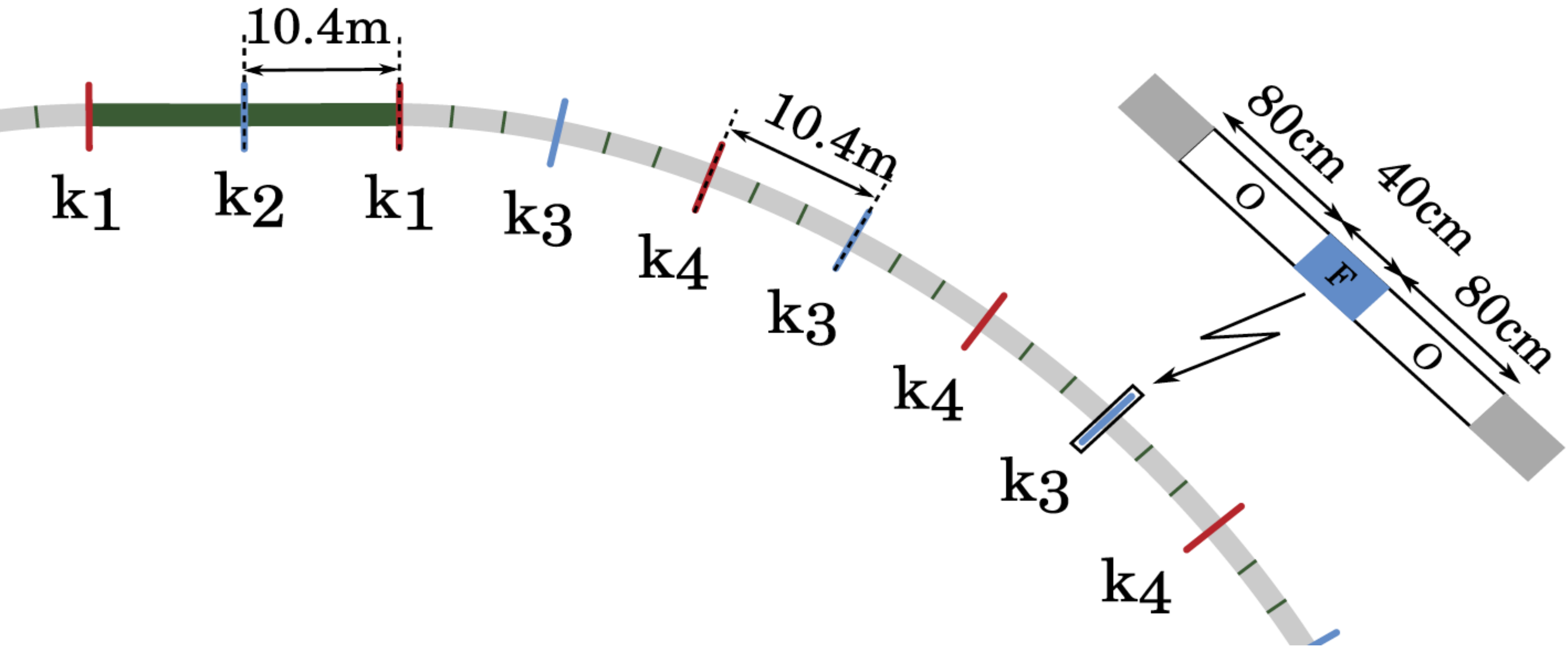

10.4m
10.4m
80cm
40cm
80cm
O
F
O
k1
k2
k1
k3
k4
k3
k4
k3
k4

TABLE II. Ring and beam parameters of the proton EDM experiment. Proton beam parameters refer to each storage direction.

Bending radius, R_0	52.3 m
Electrode spacing, d	3 cm
Electrode height	20 cm
Deflector shape	cylindrical
Radial E-field, E_0	8 MV/m
Number of straight sections	40
Straight section lengths	2.7389 m, 20.834 m
Polarimeter sections	2
Injection sections	2
SQUID-based magnetometer sections	36
Total circumference, C	500 m
Harmonic number h, RF frequency	100, 35.878 MHz
RF voltage, synchrotron tune Q_s	6 kV, 0.0066
Particles per bunch	2.5×10^8
Maximum momentum spread, $(dp/p)_{\max}$	4.6×10^{-4}
Horizontal beta function, $\beta_{x,\max}$	47 m
Vertical beta function, $\beta_{y,\max}$	216 m
Horizontal dispersion function, $D_{x,\max}$	29.5 m
Horizontal tune, Q_x	2.42
Vertical tune, Q_y	0.44
Vertical emittance, ϵ_{Vmax}	17 mm mrad
Horizontal emittance, ϵ_{Hmax}	3.2 mm mrad
Slip-factor, $\eta = \alpha - 1/\gamma^2$	–0.192

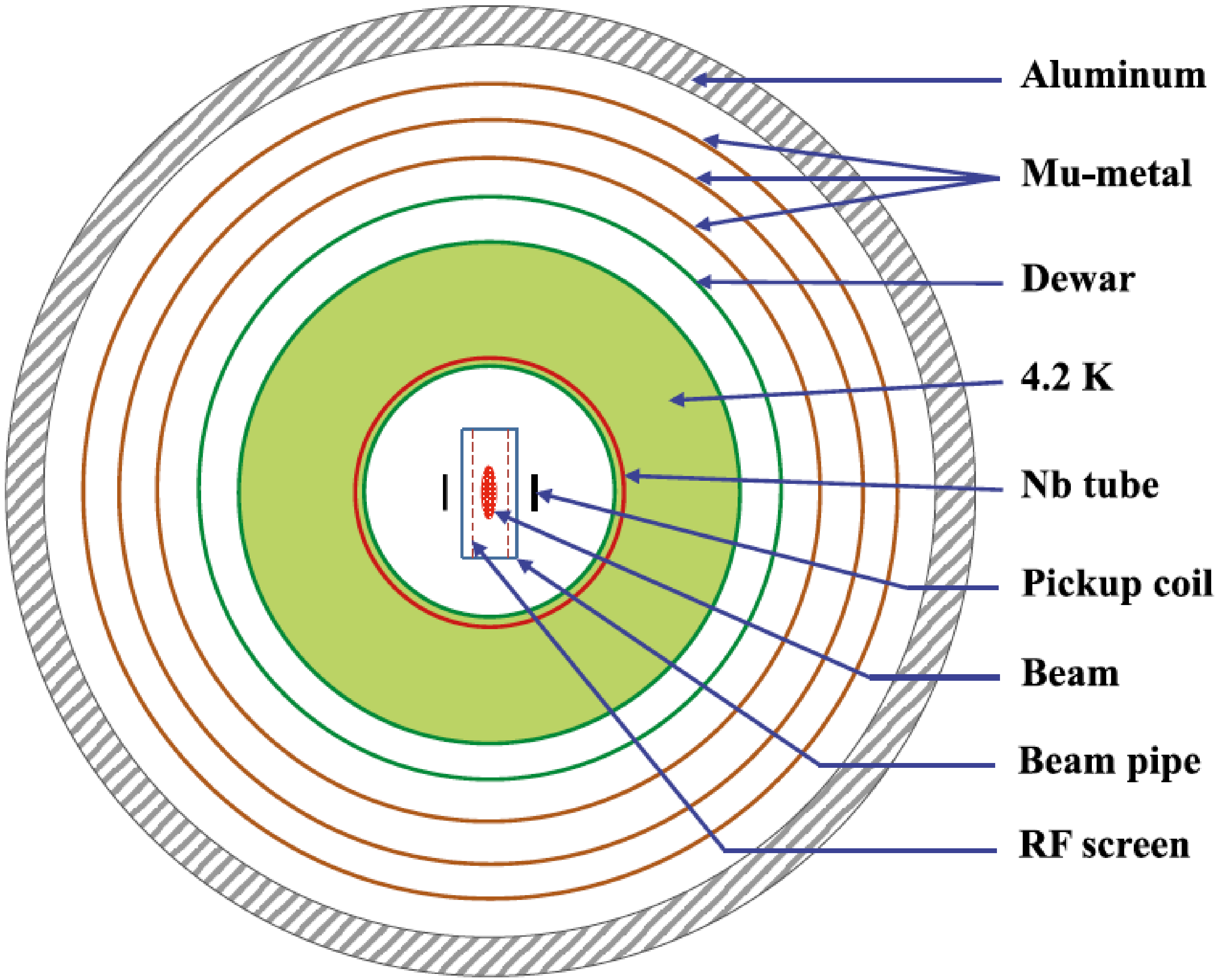
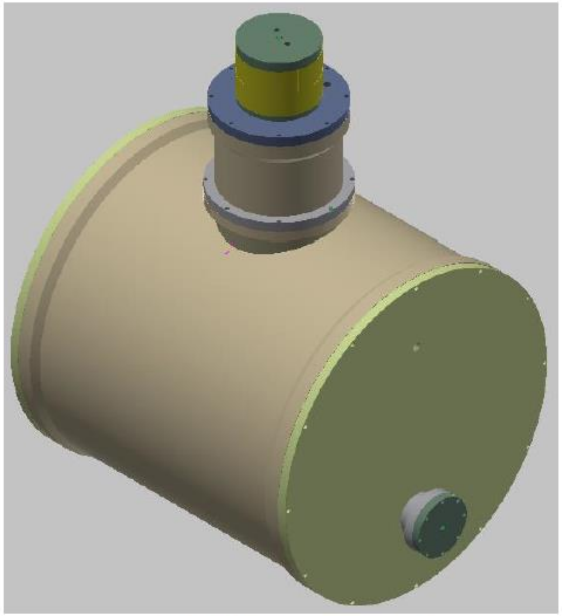
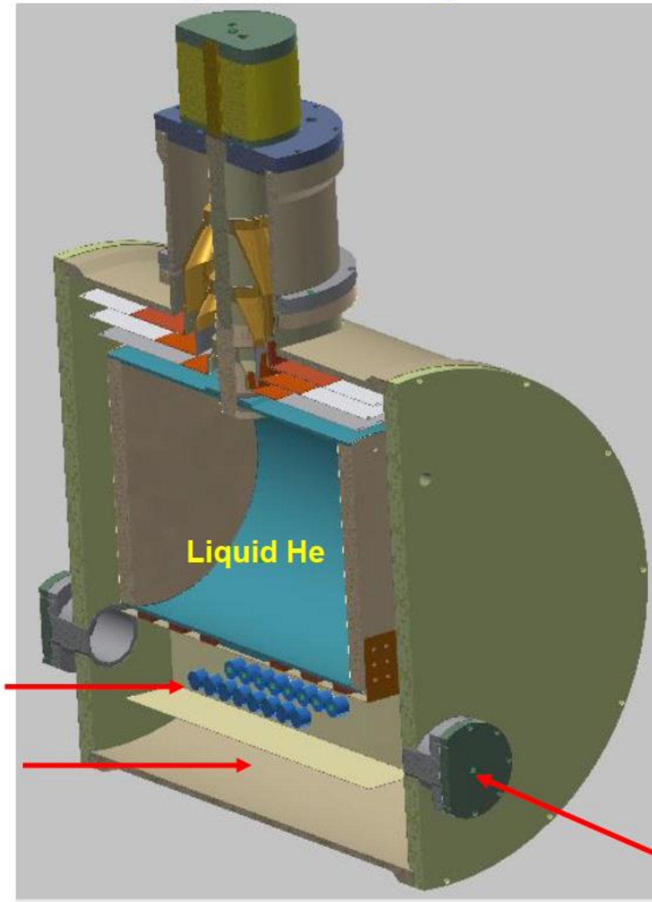


FIG. 4. A schematic of a possible SQUID BPM station, not to scale. The system is shielded with a superconducting Nb tube, Al tube for RF-shield, and several mu-metal layers. The beam-pipe dimensions are $3 \times 20\ \mathrm{cm}^2$, while the outer diameter of the Al RF-shield is of the order of 1 m.

G2 Beam Position Monitoring: Concept





CAPP
Center for Axion and Precision Physics Research

KRISS

How real could we get? Could we come up with a ball-park cost?

Electrostatic deflectors

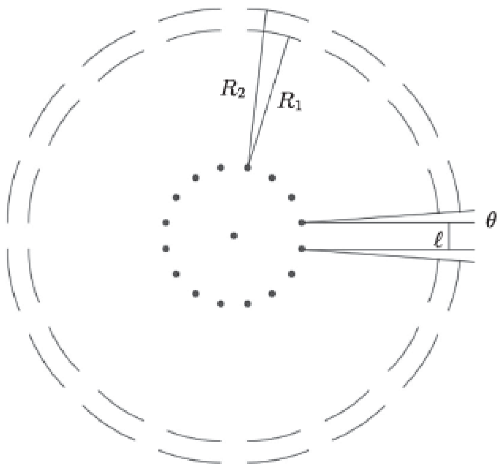


FIG. 6. The Proton EDM storage ring geometry. The ring consists of 16 sections of concentric cylindrical deflectors separated by some distance ℓ. Each section spans $2\pi/16 - 2\theta$ radians. The fringe effects occur near the ends of the deflectors.

Electrostatic separator from FermiLab

2013: Transfer of separator unit with equipment from FermiLab to Jülich

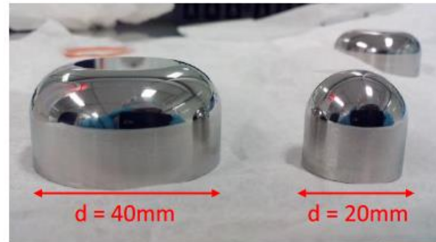
Tevatron electrostatic separators are routinely used at 6 MV/m with 1 spark/year

- 1.5 mm hydrogen free stainless steel with surface polishing
- 2500 mm long and 200 mm wide
- 4 separate parts

Electrostatic deflector development ongoing at RWTH Aachen
(electrode materials, surface treatments…)

Outlook

- ☑ UHV test stand (with baking - $1 \cdot 10^{-10}$ mbar)
- ☑ Electronic
- ☑ Electrodes
- ☑ Epoxy and fibre
- ☐ Field strength measurement with laser
- ☐ Large scale deflectors



May the electrical force be with us!

JEDI collaboration : **J**ülich **E**lectric **D**ipole Moment **I**nvestigations

What's the question for us? Could we assume the technology is mastered and ask how much would 40 2.5 m exquisitely engineered deflectors and associated infrastructure cost What would the installation look like (HV supplies, cables etc.)? Plus quads!

Systems 1/2

Given the layout, will need to run through… requirements, sketch implementation, estimate cost…

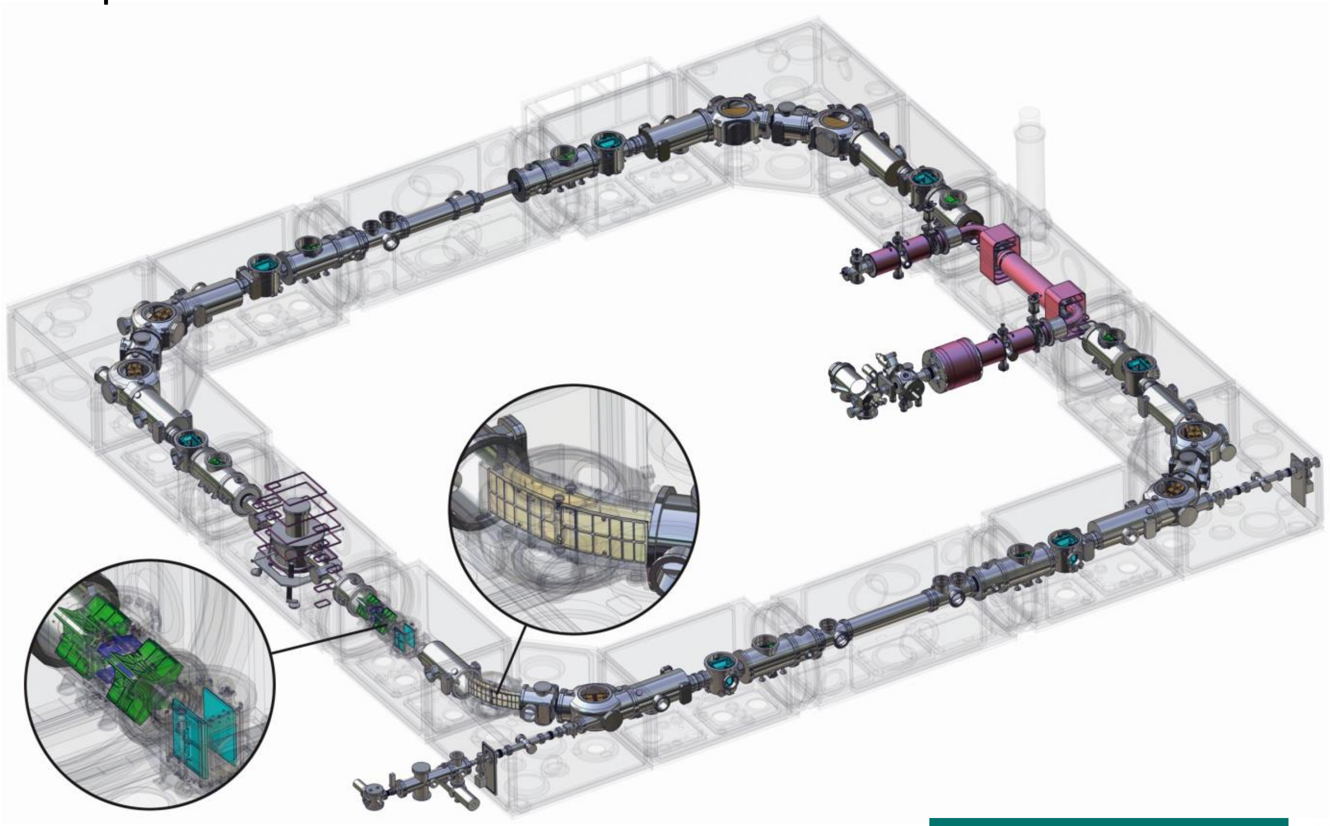
System	Group	Proposed contact
Source	ABP	Jacques Lettry
Acceleration	ABP	Christian Carli
Transfer line	ABP	Christian Carli
Injection layout	ABP	Christian Carli
Injection system	ABT	Jan Borburgh?
Deflectors	ABT	Jan Borburgh
Power supplies	EPC	
RF	RF	Olivier Brunner Steffen Doebert
Beam instrumentation including magnetometers	BI	Rhodri Jones/Ray Veness
Vacuum	VSC	Ray?
Magnetic shielding		Off-site for input?

Systems 2/2

System	Group	Contact
Cryogenics	CRG	
Cooling and ventilation	CV	
Electrical systems	EL	
Survey	SU	
Integration	ACE	
Beam intercepting devices	STI	Not at this stage
Controls	CO	Not at this stage
Interlocks	MPE	Not at this stage
Radiation protection/safety	HSE	Not at this stage?
Transport	HE	Not at this stage

The CSR consists of an experimental vacuum system kept below 10 K by integrated pumping units working at 2 K. Two radiation shields at 40 and 80 K house the experimental vacuum chambers. An outer vacuum system acting as a cryostat provides an insulation vacuum of 10^{-6} mbar.

The purely electrostatic storage ring with a circumference of 35 m is composed of four 90^o-bending corners and four field free straight sections for beam diagnostics and experimental setups.



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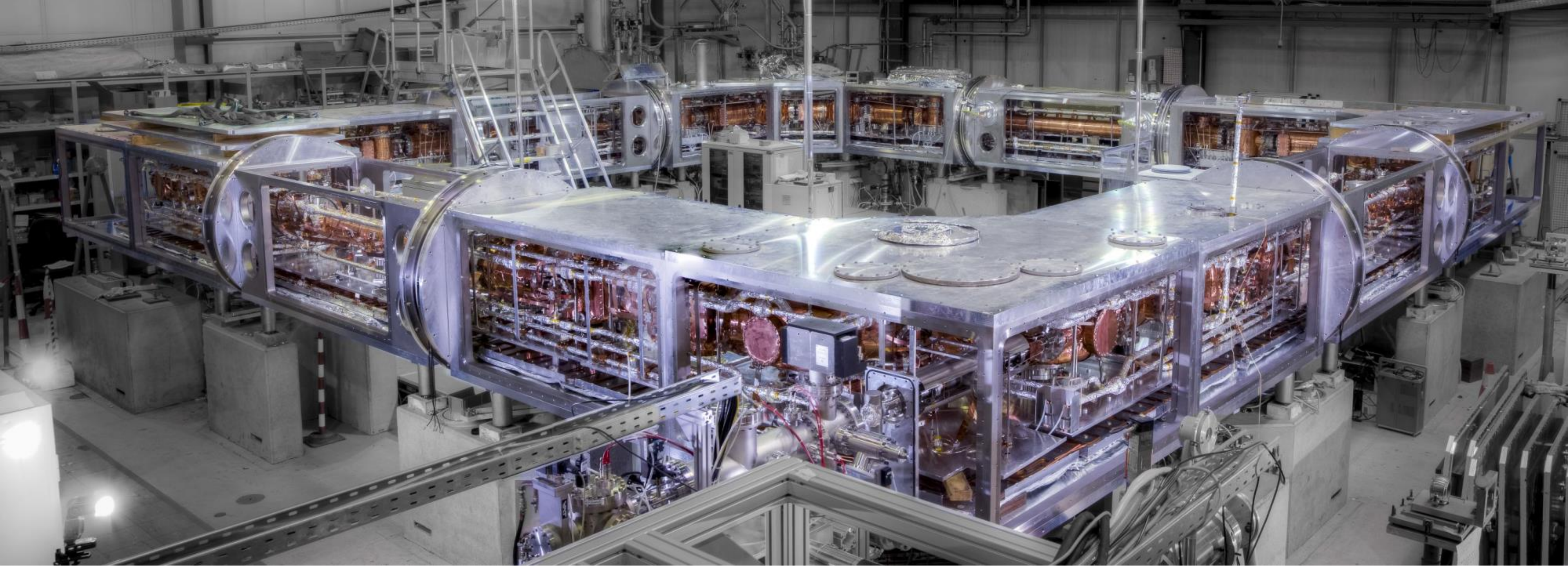
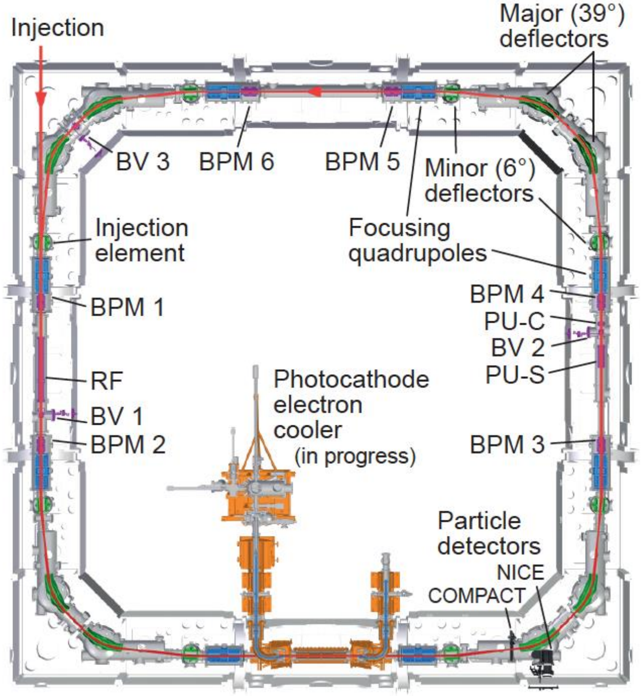
UNIVERSITY OF HEIDELBERG




Injection
Major (39°)
deflectors
BV 3
BPM 6
BPM 5
Minor (6°)
deflectors
Focusing
quadrupoles
Injection
element
BPM 1
BPM 4
PU-C
BV 2
PU-S
RF
Photocathode
electron
cooler
(in progress)
BV 1
BPM 2
BPM 3
Particle
detectors
NICE
COMPACT

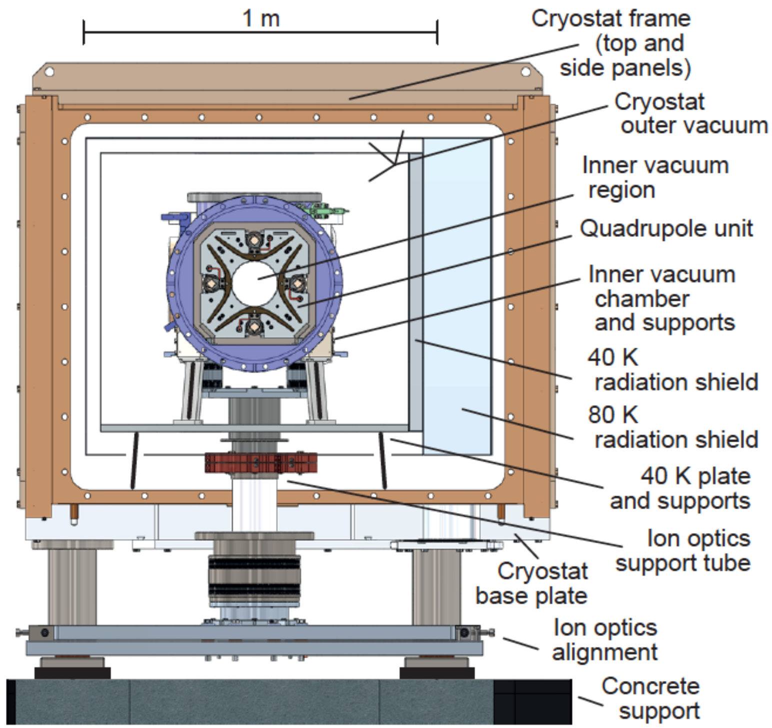


FIG. 9. Sectional view of the CSR cryostat structure, looking against ion-beam direction into a corner section. The 40 K and 80 K shields open up to the right to accomodate the bend. The elements behind the quadrupole and the super-insulation are not shown.

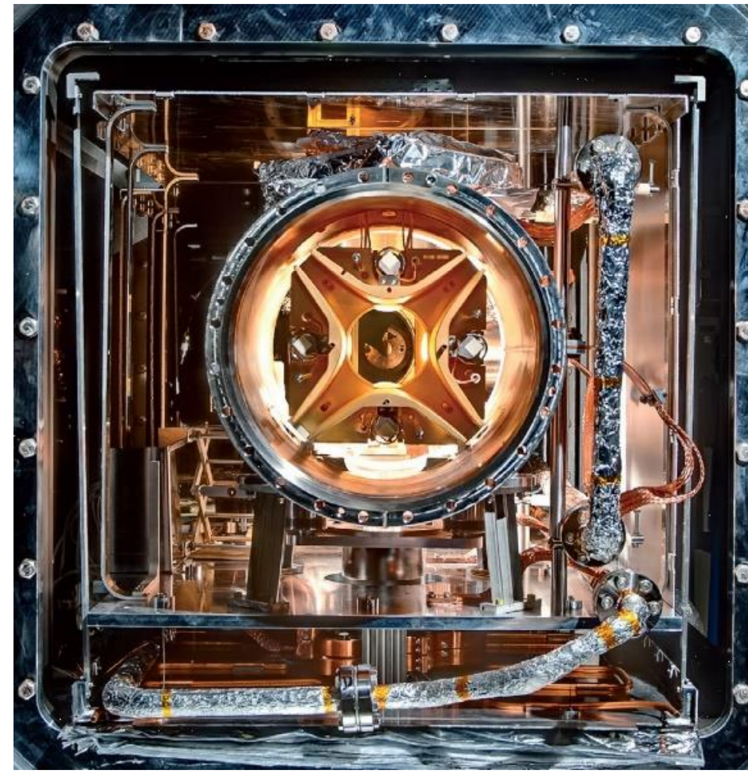


Figure 2: Photograph of electrostatic quadrupole at Heidelberg and the magnetic shielding. The cross-section is approx. 1m² as proposed for pEDM,

What next?

- CE
  - Drawings, sketch space requirements, services…
- Source, beam delivery, injection
  - Develop options
  - Explore transfer options to ISR site ring (input to CE)
- Key technology – go and pick brains – what’s out there…
  - Shielding
  - Electrostatic deflectors
  - Beam instrumentation (BPMs, SQUIDS...)
- Other systems – establish hard requirements..
  - RF, vacuum..