PRESTO
A pathfinder Facility for a new class of PREcision physics STOrage rings

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Introduction

- The experimental activity of the JEDI Collaboration at the COSY storage rings in the past years has resulted in fundamental achievements:
  - Spin-coherence time > 1000 s
  - Spin-tune measurement with unprecedented precision $\Delta\nu_s/\nu_s \leq 10^{-10}$
  - Implementation of a spin-feedback system

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  - Milestone for the field and experimental validation of the method

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  - Milestone for the field and experimental validation of the method

- COSY will stop running in 2024

- The JEDI and CPEDM collaborations agreed upon the strategy for the next steps

Present status: CERN Yellow Report

F. Abusaif et al.: *Storage Ring to Search for Electric Dipole Moments of Charged Particles - Feasibility Study*: https://arxiv.org/abs/1912.07881.

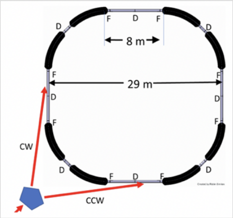
Strategy: staged approach

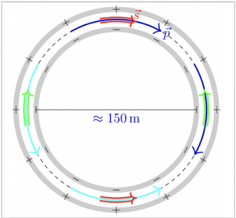
Staged approach

After finalizing Stage 1 at COSY, the necessary next step will be a prototype ring:

PRESTO

1 Precursor Experiment	2 Prototype Ring	3 All-electric Ring
dEDM proof-of-capability (orbit and polarization control; first dEDM measurement)	**pEDM proof-of-principle** (key technologies, first direct pEDM measurement)	**pEDM precision experiment** (sensitivity goal: 10^{-29} e cm)

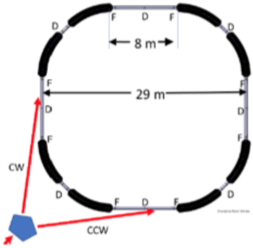




Stage 2: prototype EDM storage ring

100 m circumference

- p at 30 MeV all-electric CW-CCW beams operation
- Frozen spin including additional vertical magnetic fields



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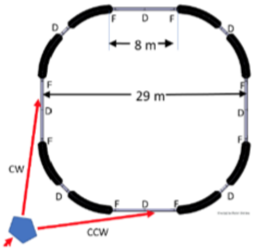


Challenges

- All electric & E-B combined deflection
- Storage time
- CW-CCW operation
  - Orbit control
  - Control of orbit difference
- Polarimetry
- Spin-coherence time
- Magnetic moment effects
- Stochastic cooling

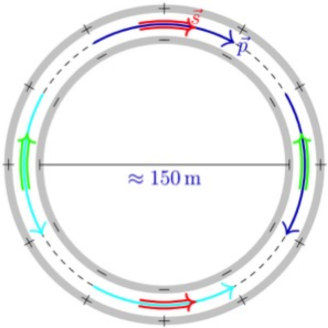
Objectives of PTR

- Study open issues.
- First direct proton EDM measurement.

Stage 3: precision EDM ring

500 m circumference (with E = 8 MV/m)

- All-electric deflection
- Magic momentum for protons (p = 707 MeV/c)



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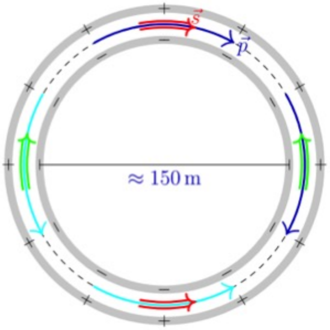

Challenges

- All-electric deflection
- Simultaneous CW/CCW beams
- Phase-space cooled beams
- Long spin coherence time ($>$ 1000 s)
- Non-destructive precision polarimetry
- Optimum orbit control
- Optimum shielding of external fields
- Control of residual B_r fields

"Holy Grail" storage ring (largest electrostatic ever conceived)

Requirements

High precision, primarily electric storage ring

- Crucial role of alignment, stability, field homogeneity and shielding from *unwanted* magnetic fields.
- High beam intensity: $N=4 \cdot 10^{10}$ per fill
- Polarized hadron beams: $P=0.8$
- Long spin coherence time: $\tau = 1000$ s
- Large electric fields: $E \sim 8$ MV/m
- Efficient polarimetry with:
  - large analyzing power: $A = 0.6$
  - high efficiency detection: eff. $= 0.005$

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Expected statistical sensitivity in 1 year of data taking:

- $\sigma_{stat} = \frac{\hbar}{\sqrt{Nf\tau}PAE} \Rightarrow \sigma_{stat} = 2.6 \times 10^{-29} e \cdot cm$
- Experimentalist's goal: provide σ_{syst} to the same level.

Systematics

Example: radial B field (B_r)

- B_r can mimic EDM (if $dE_r \approx \mu\, B_r$)
- E.g. $d = 10^{-29}$ e $\cdot$ cm, $E_r = 10$ MV/m
  - Corresponds to $B_r = \frac{dE_r}{\mu} \approx 10^{-17} T$

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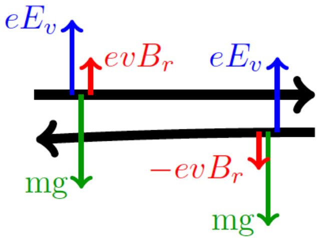
Solution

- Use of two beams running clockwise and counterclockwise
- Separation of the two beams sensitive to B_r



Research Infrastructure Concept Development:

Pathfinder facility for a new class of PREcision-physics STOrage rings ” (PRESTO)

Framework

INFRADEV-01-01-2022 - Concept Development

- Application deadline: 20.04.22
- Duration: 4 years
  - Project development: 2023-2026
- Budget: total 3 M euro
- Coordinator + 7 beneficiaries
  - INFN (Coord.) (Italy)
  - CERN
  - RWTH-Aachen (Germany)
  - GSI (Germany)
  - MPI-HD (Germany)
  - Univ. Liverpool (United Kingdom)
  - Univ. Krakow (Poland)
  - Univ. Tbilisi (Georgia)

1 - Excellence

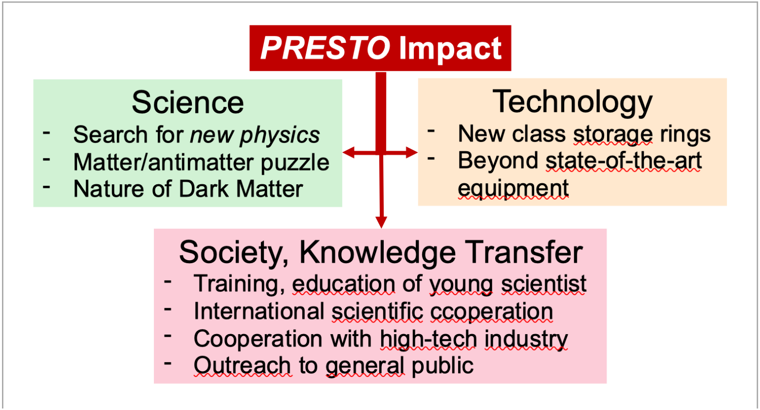
Science case

- Search for static charged particle EDMs
  - EDMs $\rightarrow$ new probes of CP-violating interactions
  - Matter-antimatter asymmetry
- Search for oscillating EDMs
  - Axion-gluon coupling
  - Dark matter search
- Sensitivity to gravitational effects

Objectives

- New class of (precision) storage rings (p: all-E; d, $^3\mathrm{He}$: comb. E/B);
- design demonstrator as:
  key performance enabler for the final precision storage ring;
- capable of providing a wealth of science already.

2 - Impact


PRESTO Impact
Science
- Search for new physics
- Matter/antimatter puzzle
- Nature of Dark Matter
Technology
- New class storage rings
- Beyond state-of-the-art equipment
Society, Knowledge Transfer
- Training, education of young scientist
- International scientific ccoperation
- Cooperation with high-tech industry
- Outreach to general public

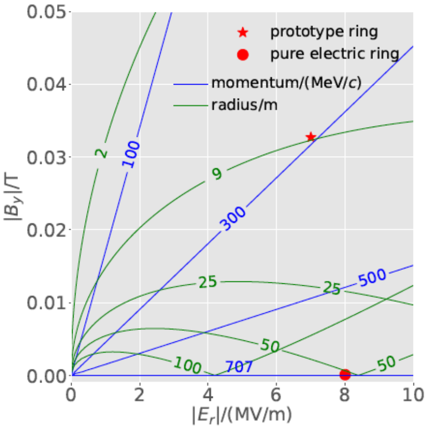
3 - Implementation

WP #	Item	PM_tot	PM detail	Institutions	Objectives
1	**Project coordination**	**15**		**INFN**	
			15	INFN	
2	**Ring design**	**48**		**CERN**	
	1. Machine lattice		18	CERN	report
			18	MPG	
	2. Beam transfer system		6	CERN	report
			6	MPG	
3	**Ring elements**	**84**		**INFN**	
	1. Electrostatic bends		24	RWTH – IAEW	report
			24	MPG	
	2. Electrostatic multipole elements		9	CERN	report
	3. Magnetic bends		12	RWTH - IAEW	report
	4. Injection hardware		9	CERN	report
	1. Vacuum system		6	INFN	report
4	**Beam diagnostics and instrumentation**	**36**		**GSI**	
	1. Beam position monitors, incl phase-space detection (Rogowski type)		6	GSI	report
	2. Beam profile restgas monitor				
	3. RF cavity		6	GSI	report
	4. Stochastic cooling		6	CERN	report
	5. Magnetic shielding		6	GSI	report
	6. Alignment and metrology of elements		6	GSI	report
			6	CERN	report
5	**Polarimetry and spin manipulation tools**	**78**		**LIV**	
	1. Beam polarimeter		48	LIV	report
			24	TSU	
	2. RF solenoid		3	GSI	report
	3. RF Wien filter		3	GSI	report
6	**Parameter control and expected performance**	**78**		**RWTH-PHIB**	
	1. Systematics investigations		6	CERN	report
	2. Spin tracking		12	RWTH-PHIB	report
	3. Error evaluation		24	JAG	report
	4. Data acquisition and management		24	TSU	report
			12	INFN	
7	**Cost estimate**	**12**		**INFN**	
			12	INFN	report
8	**Dissemination and outreach**	**36**		**JAG**	publications,
			24	JAG	meetings, talks
			12	INFN	etc.

WP Description

WP2 - Ring design

- Momentum and ring radius for proton in frozen spin condition



Two options:

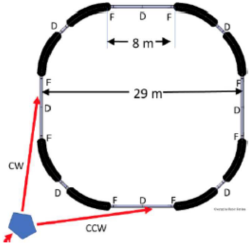
- Pure electric ring:
p = 707MeV, bending radius≈ 50 m at E=8 MV/m

⋆ combined prototype ring:
p = 300MeV, bending radius≈ 9 m at E=7 MV/m

WP2 - Ring design

PTR lattice design for protons

- p at 30 MeV all-electric CW-CCW beams operation
- p at 30 to 45 MeV frozen spin, with additional vertical B field
- relates to full scale 232.8 MeV proton EDM ring

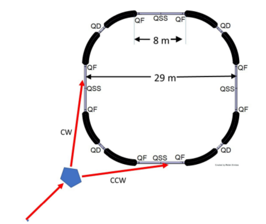


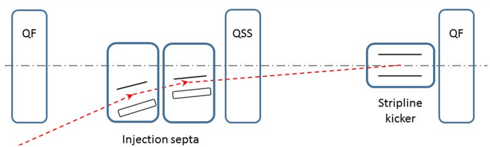
	E only	E & B frozen spin		unit
Bending radius	8.86	8.86		m
Kinetic energy	30	30	45	MeV
$\beta = v/c$	0.247	0.247	0.299	
γ (kinetic)	1.032	1.032	1.048	
Momentum	239	239	294	MeV/c
Electric field E	6.67	4.56	7.00	MV/m
Magnetic field B		0.0285	0.0327	T
rms $\epsilon_x = \epsilon_y$	1	1		π mm mrad
Transv. acc. $a_x = a_y$	> 10	> 10		π mm mrad

- Scalable modular design

WP2 - Ring design

- Beam transfer and injection
  - Development of a proper injection concept.





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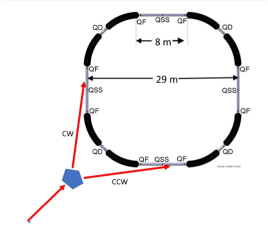
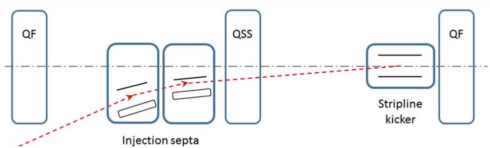
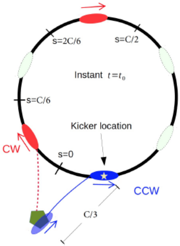
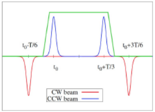




- Test at COSY: spin manipulation after injection feasible

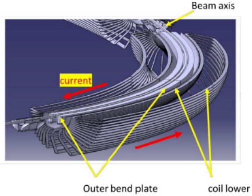




WP3 - Ring elements

Electrostatic deflectors & magnetic bends

- Concept for electrostatic deflector available
- Next step: build prototype with RWTH Aachen



		units
Electric		
electric field	7.00	MV/m
gap between plates	60	mm
plate height (straight part)	151.5	mm
plate length	6.959	m
total bending length	55.673	m
total straight length	44.800	m
bend angle per unit	(45°)	m

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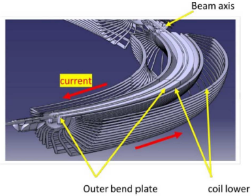

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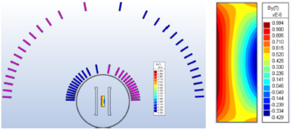
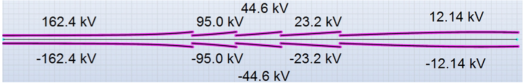
- Concept for magnetic add-on to deflector available.
- Magnetic system ($\cos\theta$) outside the vacuum tube.

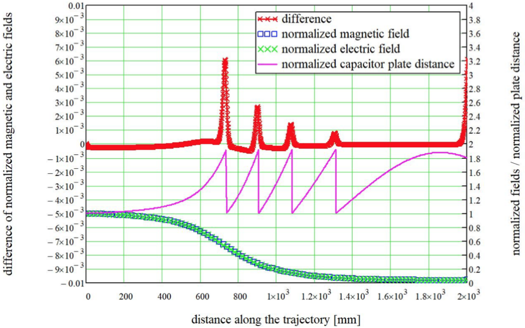


Magnetic		
magnetic field	0.0327	T
current density	5.000	A/mm^2
windings/element	60	

Matching of E and B stray fields.

- Global matching based on field integrals
- Local matching: stacking electrodes

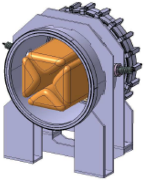


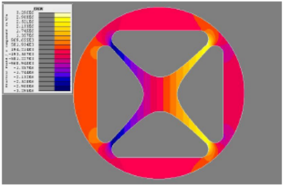


WP3 - Ring elements

Multipole elements

- Design of electrostatic elements (CERN)
- Electrostatic quadrupoles
  - aperture diameter 80mm, applied $\pm$ 20 kV.
  - Simulated design with vacuum chamber of 400mm diameter.





- PTR quadrupoles max. pole tip potential 30 kV (margin for conditioning)
  - 3D design available;
  - sextupole, octupole and higher harmonics reasonable

WP3 - Ring elements

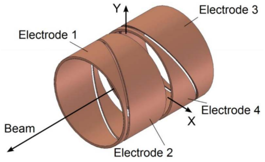
Vacuum system

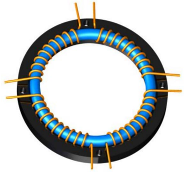
- Ring vacuum given by minimum required beam lifetime of about 1000 s.
  - N_2 pressure $< 10^{-12}$ mbar; H_2 pressure $< 5 \times 10^{-11}$ mbar.
- Stochastic cooling rate better than 5×10^{-3} mm mrad/s.
  - Validation required
- Non-vibrational system that avoids generation of magnetic fields
  - Cryogenic or NEG pumping?
- Mechanical alignment of elements inside vacuum pipe of 400 mm diameter
  - active compensation of oscillations/ground motion
- Shielding (passive versus active)

WP4 - Beam diagnostics and instrumentation

Development of compact BPM based on Rogowski coil

- Main adv.: short install. length ($\approx$ 10 cm in beam direction)





Conventional BPM

- Easy to manifacture
- Length $>$ 20 cm
- Resolution $\approx$ 100 μm

Rogowski BPM (warm)

- Excellent RF-signal response
- Length = 1 cm
- Resolution $\approx$ 1.25 μm

Advantages over conventional split-cylinder BPMs

- short insertion length: many BPMs can be installed
- inexpensive
- high sensitivity to position of bunched beams

WP4 - Beam diagnostics and instrumentation

Stochastic cooling

- Control proton beam emittance during measurements: 30 MeV to 45 MeV.
- Cooling should compensate emittance growth of 5×10^{-3} mm mrad/s.
  - Interplay between stochastic cooling and evolution of horizontally polarized ensemble of particles unknown.
  - Studies of emittance growth and spin coherence time at PTR.
- Aim: provide basic design of stochastic cooling system for PTR.

WP4 - Beam diagnostics and instrumentation

RF-cavity

- Azimuthal magnetic fields lead to spin rotations of the magnetic moment.
- Even for perfectly aligned cavity, individual particles experience horizontal magnetic fields and spin rotations into vertical and horizontal directions.
- Effect on EDM measurement suppressed
- Design of RF cavity required that minimizes unwanted spin rotations.

WP5 - Polarimetry and spin manipulation tools

Polarimetry: noise extraction

- dC (pC) scattering works with polarization errors δp/p = 10^{-6}

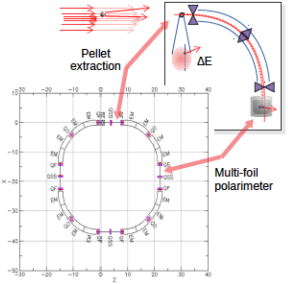
WP5 - Polarimetry and spin manipulation tools

Polarimetry: noise extraction

- dC (pC) scattering works with polarization errors $\delta p/p = 10^{-6}$

Polarimetry: sample polarimeter

- Polarization profile determination at low energies:

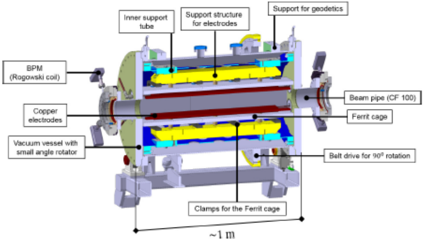


- C multifoil polarimeter based on Si-detectors with pellet extraction (Univ. of Liverpool).
- Ballistic Si pellet target for homogeneous beam sampling.
- E_{loss} of 100 keV in 50 μm pellet $\rightarrow$ track displaced by 2.5 cm behind 45^o bend.

WP5 - Polarimetry and spin manipulation tools

Spin-manipulation: longitudinal RF-solenoid

- Vertical polarisation of stored beam rotated into horizontal plane.
  - Typical ramp-up times from vertical to horizontal polarisation: 200 ms.
  - Optimize design for PTR.



Spin-manipulation: RF-Wien filter

- Applies transv. magnetic fields to spin, exerting minimal Lorentz force on beam:
  - optimize design for PTR
  - two of them needed for CW-CCW operations

WP6 - Parameter control and expected performance

Simulations

- Beam and spin-tracking simulations to scrutinise and validate concepts and ideas
- Code bench-marking on existing COSY data
- Working group established

WP7 - Cost estimate

PSR Site Options

Green Field Lab	Pre-prepared Lab	Fully-receptive Lab
No buildings available to house the EDM facility; **no** accelerator expertise; **no** experience with polarization measurements	Buildings to house the EDM facility available; accelerator expertise available; **no** polarization experience yet	Buildings to house the EDM facility available; storage ring expertise and polarization experience available
▪ Optimal facility planning from scratch	▪ Moderate additional investment cost	▪ Minimal investment cost ▪ Shortest lead time ▪ Available expertise
▪ Infrastructure (building) & facility costs largest ▪ Longest lead time ▪ Missing experience to build/run facility	▪ Some additional investments (e.g., polarized source …) required	▪ Possible compromises due to existing boundary conditions

Since Europe is leading this effort since many years (JEDI, CPEDM), it should be European host lab.

WP8 - Dissemination and outreach

Description of Work

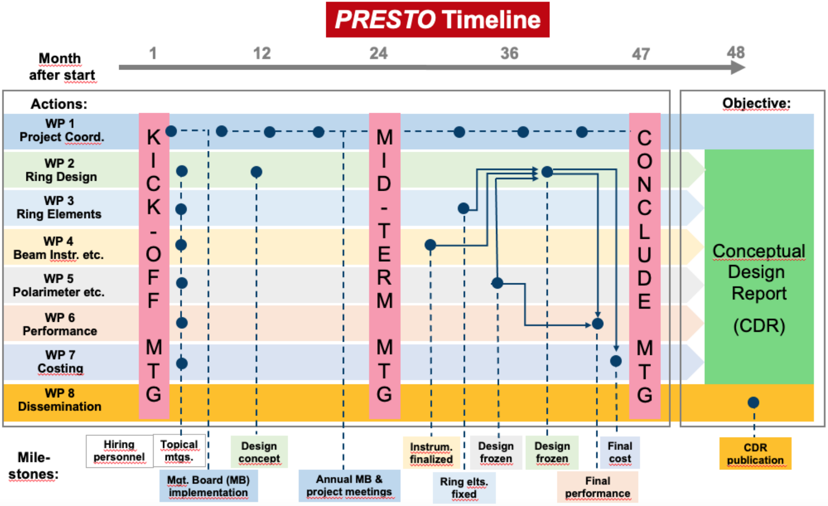
- Tools for intraconsortium communication
- Communication with the scientific community and industrial partners
- Outreach towards broad public
- Educating the coming generation

Personnel request and distribution

WP Number	WP title	Lead Participant Number	Lead Participant Short name	Person Months	Start month	End month
1	Project coordination	1	INFN	15	1	48
2	Ring design	3	CERN	48	1	48
3	Ring elements	1	INFN	84	1	48
4	Beam diagnostics and instrumentation	2	GSI	36	1	48
5	Polarimetry and spin manipulation tools	6	LIV	78	1	48
6	Parameter control and expected performance	5	RWTH	78	1	48
7	Cost estimate	1	INFN	12	1	48
8	Dissemination and outreach	7	JAG	36	1	48
				387		

Participant number & short name	WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8	Total PM participant
1 INFN	15		6			12	12	12	57
2 GSI				24	6				30
3 CERN		24	18	12		6			60
4 MPG		24	24						48
5 RWTH			36			12			48
6 LIV					48				48
7 JAG						24		24	48
8 TSU					24	24			48
	15	48	84	36	78	78	12	36	387

Timeline



PRESTO Timeline
Month after start
1
12
24
36
47
48
Actions:
Objective:
WP 1 Project Coord.
WP 2 Ring Design
WP 3 Ring Elements
WP 4 Beam Instr. etc.
WP 5 Polarimeter etc.
WP 6 Performance
WP 7 Costing
WP 8 Dissemination
KICK-OFF MTG
MID-TERM MTG
CONCLUDE MTG
Conceptual Design Report (CDR)
Mile-stones:
Hiring personnel
Topical mtgs.
Mgt. Board (MB) implementation
Design concept
Annual MB & project meetings
Instrum. finalized
Ring elts. fixed
Design frozen
Design frozen
Final performance
Final cost
CDR publication

Budget

		MM/cost	WP1		WP2		WP3		WP4		WP5		WP6		WP7		WP8	
		PostDocs	PostD		PostD		PostD		PostD		PostD		PostD		PostD		PostD	
			MM	€	MM	€	MM	€	MM	€	MM	€	MM	€	MM	€	MM	€
1	INFN	4150	15	62250		0	6	24900	0	0		0	12	49800	12	49800	12	49800
2	GSI	6872		0		0		0	24	164928	6	41232		0		0		0
3	CERN	9000		0	24	216000	18	162000	12	108000		0	6	54000		0		0
4	RWTH/IAEW	6079		0		0	36	218844		0		0		0		0		0
	RWTH/PHIB	6079		0		0		0		0		0	12	72948		0		0
	RWTH/total	6079		0	0	0	36	218844	0	0	0	0	12	72948	0	0	0	0
5	MPI/HD	7160		0	24	171840	24	171840		0		0		0		0		0
6	Liverpool	5306		0		0		0		0	48	254688		0		0		0
7	Cracow	3350		0		0		0		0		0	24	80400		0	24	80400
8	Tbilisi	1500		0		0		0		0	24	36000	24	36000		0		0
	TOTAL		15	62250	48	387840	84	577584	36	272928	78	331920	78	293148	12	49800	36	130200

SUMMARY MANPOWER				
PostD		overhead	TOTAL	
MM	€			
57	236550	59138	295688	INFN
30	206160	51540	257700	IKP/GSI
60	540000	135000	675000	CERN
36	218844	54711	273555	RWTH/IAEW
12	72948	18237	91185	RWTH/PHIB
48	291792	72948	364740	RWTH/total
48	343680	85920	429600	MPI/HD
48	254688	63672	318360	Liverpool
48	160800	40200	201000	Cracow
48	72000	18000	90000	Tbilisi
387	2105670	526418	2632088	

		SUMMARY MANPOWER			TRAVEL			WORKSHOPS/AUDIT			TOTAL OTHER			GRAND TOTAL	
		cost	over	total	cost	over	total	cost	over	total	cost	over	total	cost	total
1	INFN	236550	59138	295688	20000	5000	25000	45000	11250	56250	65000	16250	81250	301550	376938
2	GSI	206160	51540	257700	20000	5000	25000	5000	1250	6250	25000	6250	31250	231160	288950
3	CERN	540000	135000	675000	20000	5000	25000	25000	6250	31250	45000	11250	56250	585000	731250
4	RWTH/IAEW	218844	54711	273555											
	RWTH/PHIB	72948	18237	91185											
	RWTH/total	291792	72948	364740	20000	5000	25000	5000	1250	6250	25000	6250	31250	316792	395990
5	MPI/HD	343680	85920	429600	20000	5000	25000	5000	1250	6250	25000	6250	31250	368680	460850
6	Liverpool	254688	63672	318360	20000	5000	25000	5000	1250	6250	25000	6250	31250	279688	349610
7	Cracow	160800	40200	201000	20000	5000	25000	25000	6250	31250	45000	11250	56250	205800	257250
8	Tbilisi	72000	18000	90000	20000	5000	25000	15000	3750	18750	35000	8750	43750	107000	133750
	TOTAL	2105670	526418	2632088	160000	40000	275000	130000	32500	162500	290000	72500	362500	2395670	2994588