Identification of the Key Areas for the TIARA R&D Program

P. Pierini

For the WP4

T.Garvey (PSI), D. Schulte (CERN), B. Launé (CNRS), L. Lilje (DESY), O. Napoly (CEA), D. Obradors (CIEMAT), P.Pierini (INFN), B. Skoczen (IFJ PAN), S. Smith (STFC), C. Omet (GSI), V. Zieman (UU)

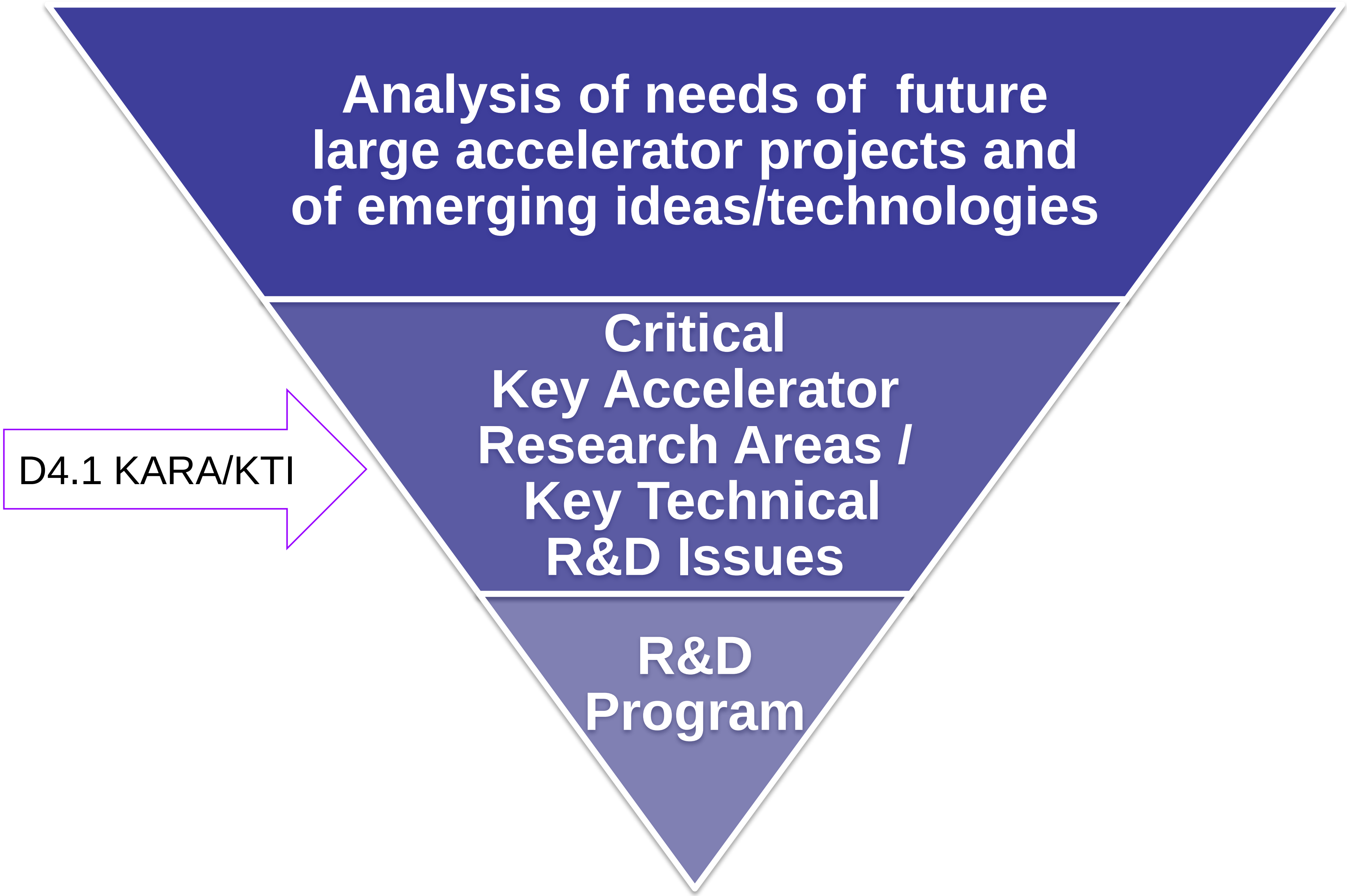
WP4

- «Coordination» workpackage dealing with
  - Joint R&D Programming
    - Overall status presented on Thursday

- This Work Package is primarily devoted to
  - identify the critical technical issues in the field of accelerator science
  - to define a joint **R&D Programme** to be carried out with the European distributed accelerator R&D infrastructure, proposed by TIARA

- Interaction with other Coordination WP3
  - Accelerator R&D Infrastructures

Key Area Identification



List KARA/KTI

ESGARD survey in 2010 among the 37 EuCARD partners

+

Extended within WP4 members (assisted by colleagues from our home institutions)

→

Collected broad areas needing R&D, with potential impact on community

- HEP/Nuclear
- technical requirements for accelerators as drivers of “analytical” facilities (Neutron Sources, FELs, Ultimate light sources, …)

D4.1: 46 pages

Test infrastructure and Accelerator Research Area

DELIVERABLE

General Report on Key Issues

By the WP4 Members:

Terence Garvey (PSI),
Jean-Pierre Koutchouk (CERN), **WP Deputy**
Bernard Launé (CNRS),
Lutz Lilje (DESY),
Olivier Napoly (CEA),
Diego Obradors (CIEMAT),
Paolo Pierini (INFN), **WP Leader**
Blazej Skoczen (IFJ PAN),
Susan Smith (STFC),
Peter Spiller (GSI), **WP Deputy**
Volker Ziemann (Uppsala University)

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- Issued December 2011, after approval of GC
  - Base for WP4 Joint R&D Programme
  - Mapping R&D items/Projects

Domain	Projects / KARA	ESFRI Project List										
		XFEL	FAIR	ESS	LHC Upgrades (HL-HE)	Linear Colliders (ILC, CLIC)	Flavour Factories (SuperB)	Neutrino Factories Muon Colliders	High Intensity Hadron Facilities (Eurisol, ADS/MYRRHA, IFMIF)	3rd Generation radiation sources	4th Generation radiation sources, FEL, ERL	5th Generation radiation sources
Accelerator Components	Sources and Injectors	x	x	x	x	x	x	x	x	x	x	
	RF Structures	x	x	x	x	x	x	x	x		x	
	RF Systems	x		x		x	x		x		x	
	SC Magnets		x		x	x	x	x				
	Conventional NC Magnet Systems		x			x				x	x	x
	Diagnostic and Instrumentation	x	x	x	x	x	x	x	x	x	x	x
	Targetry		x	x	x	x		x	x			
	Radiation Issues		x	x	x	x		x	x			
Accelerator Technologies	Electronics and Software	x	x	x	x	x	x	x	x	x	x	x
	UHV	x	x	x	x	x	x	x	x	x	x	x
	RF Sources	x	x	x	x	x	x	x	x	x	x	x
	Cryogenics	x	x	x	x	x		x	x			
	Alignment and Stabilization	x	x	x	x	x	x	x	x	x	x	x
Accelerator Concepts	Accelerator Design		x	x		x	x	x	x			x
	Beam Dynamics		x	x	x		x	x	x			x
	FEL Processes	x									x	x
	Beam Cooling		x					x				
	New Techniques for High Gradient Acceleration					x						x
	Medical and Industrial Accelerators	N/A										

Cannot condense all in 20 m! Outline...

1. Accelerator Components

2. Accelerator Technologies

3. Accelerator Concepts

1. Accelerator Components

- Sources and Injectors
- RF structures
- SC magnets
- Conventional NC magnets
- Diagnostics and instrumentation
- Targetry
- Radiation issues

For each of these Key Areas, a further level (Key Technical Issues) is provided, with a ½-1 page description

Sources/Injectors - Issues

- Crucial elements for achievement of beam quality and intensity for all facilities under investigation
- R&D needed to progress the state of the art in
  - High brightness e- photoinjectors
  - High intensity ion and proton injectors
  - High polarisation e- and e+ sources
  - RFQ design and development
  - Hollow beam generation
  - Beam funneling schemes

Sources/Injectors - PhotoInj

- High brightness e- photoinjectors
  - Ultra low emittance/high intensity e- beams needed for FELs and ERLs
  - Drive laser and cathode technology issues
  - Explore CW high intensity frontier (SC guns)
  - Consolidate the design of bunch compression stages using high harmonic schemes, non magnetic compression, and laser heaters to mitigate instabilities (NC and SC versions)
  - Low emittance/ultra-short pulses at high rep rates are needed for future 4° gen light sources, e.g. for molecular dynamics at high resolution and single shot chrystallography

Sources/Injectors – Proton/Ion

- Heavy Ion and Proton Injectors
  - High intensity beams for heavy ion complexes (FAIR) and high intensity ion beams (IFMIF)
    - ECRIS at high frequency still need R&D
    - Other sources (MEVVA/CHORDIS/MUCIS) may deliver higher ion intensities at low charge states and low duty cycle
    - Neutralized beam transport in LEBT and efficient acceleration in CH structures need to be demonstrated
  - High intensity proton injectors (ESS, EURISOL, MYRRHA,...)
    - ECR with better RF coupling and plasma diagnostics and control are under development
    - Transport and matching to RFQ in a LEBT is also a challenge for simulation methods

Sources/Injectors – Sources

- Highly Polarised e- and e+ Sources
  - For linear colliders (independent from ML technology)
    - Either from conversion of polarized photons produced in helical undulators by high energy e- beams or based on Compton sources
      - Both require intensive R&D in most components (lasers, rings, capture RF structures, conversion targets, ...)
  - Essential for the physics program of SuperB
    - Polarized injector and control of polarization in the complex
- Hollow Beams
  - Based on Tevatron program, their use would allow to extend conventional collimation systems beyond the limits foreseen by tolerable losses
    - Concept proven, but alignment and control of beam profile and intensity is to be demonstrated

Sources/Injectors – Injectors...

- RFQ Development
  - Key component in low energy chains for proton and ion facilities (ESS, IFMIF, MYRRHA/ADS, RIBs, ...)
  - Specialized devices tailored for specific applications (especially at increasing design intensities) still present significant challenges in the realization and operation
    - tight tolerance budgets during brazing of long sections
    - handling of substantial heat loads for CW structures
- Beam Funneling
  - As a mean to double beam current for extremely high currents (e.g. «industrial scale» ADS waste transmuter)

RF Structures: Gradient

- Both NC and SC RF structures demand higher gradient than state of art in a reliable way
  - CLIC towards 100 MV/m at low breakdown rates
  - C-Band and X-Band structures for moderate gradients as XFEL drivers (SwissFEL, FERMI, SPARC, but also SuperB)
  - SC structures for electrons need to stabilize high yields at the highest gradients (approaching limiting mechanisms) (XFEL, ESS, EURISOL, ILC, ...)
- Several issues are common:
  - Surface preparation, cleaning, industrialization
  - Cross breeding opportunity between separated communities

RF Structures - SC

- SC technology for «low beta» still not matched to state-of-the-art of electron cavities (SPIRAL2, ESS, EURISOL, MYRRHA, ...)
  - Margin for bridging the communities and closing the perfomance gap, on the way...
- Ancillaries for high power operation
  - SC power couplers at high average power, high duty cycle or even CW operation are needed (ESS, ADS, ERLs, ...)
  - HOM antennas and couplers (and theory...)
- Beyond Nb limits (> 45 MV/m)
  - High Tc, multilayer shielding, need to move from samples to realistic RF structure prototypes

RF Structures - Various

- Crab Cavities for crab crossing in colliders (HL-LHC, LCs)
  - NC and SC variants, with many R&D issues to solve concerning feasibility (HOM control, LLRF, engineered solutions, ...)
- 6D Muon beam cooling
  - Low frequency SC structures at 200 MHz challenge the Nb sputter technology
  - NC structures challenged by high gradients in strong magnetic fields
- Variable low-frequency resonators
  - New materials for MA loader RF structures

SC Magnets - Field

- NbTi technology close to max theoretical performances
  - R&D necessary on material and technologies for the 20 T range and beyond in a staged approach
    - Nb_3Sn as an intermediate R&D path to access the 15 T range
      - Already used in NMR magnets and selected for ITER
      - Accelerator magnets have more stringent requirements in term of coil dimensions/positioning and control of magnetization, to achieve the necessary field quality
        - » Specific R&D technological effort
    - 20 T magnets for HE-LHC could be then reached by a combination of Nb_3Sn and HT superconductors (HTS)
      - Ongoing R&D since FP6-NED and FP7-EUCARD-HFM
    - 2G HTS cables (e.g. YBCO) promising for 30 T range

SC Magnets – Fast Cycling

- Fast Cycling SC magnets are needed for
  - More compact and energy-saving injector chains
    - CERN SPS requires 70 MW, a SC version would require about 20 MW
  - High repetition rate synchrotrons for intense ion beams (e.g. FAIR)
- R&D for this needs to be focussed on
  - development of low loss cables
  - handling and minimization of eddy currents and hysteresis losses in the magnet structure

SC Magnets – Eng. Challenges

- The integrated design of high field magnets is an extreme engineering challenge in several aspects:
  - Production of compact (85-90%) HTS cables capable of carrying 10 kA under high stresses
  - Restraining of e.m. Forces with compact structures
  - Dealing with huge stored energies (up to 100 GJ)
  - Superconductor «grading» (different conductors in same coil)
  - Radiation resistant materials for coils and structure
  - Improved He cooling to remove heat in thick coils
    - Especially for higher energy and luminosities
  - Engineering of fast cycling magnets (5-6 T, 1-4 T/s)

SC Magnets - Other

- Cryogen-fee magnet systems for accelerators
  - Targeting medical, industrial or security applications
- High field short period SC undulator magnets
  - E.g. Compact damping ring for LC
- High field small magnets with rare earth pole tips
  - E.g. To provide high luminosity for muon colliders

Conventional NC Magnets

- Though a well-estabilished technology, new requirements come from light sources and compact accelerators
  - Compact magnets for small facilities
  - Radiation resistant magnets
    - Mitigate synchrotron radiation damage
  - Insertion devices
    - E.g. Short period, In-vacuum ondulators
  - Fast kickers
    - For injection and extraction in complexes, with individual bunch selection from train for damping rings or beamlines
  - Compact, large aperture FFAG magnets
  - Transparent injection schemes for Top-Up
    - Tight tolerance/stability to preserve stored beam

Diagnostics and Instrumentation

- Area of constant evolution/improvement, driven by ever increasing demand of resolution, bandwidth, dynamic range, stability
  - BPM developements
    - Needed for ultimate light sources and high energy colliders
      - Better resolution for orbit correction, beam based alignemnt, feedback systems and single/multi bunch motion control
    - New ideas (e.g. Hom-BPMs)
  - Size and emittance monitors (long/transv)
    - E.g. High resolution laserwire systems, sub-ps length by electro-optical methods, otr monitors, ...
    - Intense Proton/ion beams require non-invasive non-interceptive techniques to guarantee low beam losses and no activation
    - RIBs need sensitive diagnostics for low currents

Targetry

Several hadron projects have severe demands in this area to deal with the large beam power

- LHC upgrades, ESS, ADS, FAIR, EURISOL

- High power targets for secondary beams
  - Thick/thin, low/high Z, pulsed/cw: depending on application, but all with many peculiar engineering challenges
- Radiation damage investigation by PIE
  - Experimental assessments needed (STIP, Hiradmat)
- Monte Carlo Codes Validation
  - Benchmark with experiments needed
- Crystal channeling for beam collimation

Radiation issues

Radiation protection aspects for high beam power facilities

- Prompt irradiation and radioactivity estimations
  - Need new tools for simulation to increase accuracy in low secondary production yelds and investigate regions not covered by nuclear data libraries
    - Benchmarking
- Collimation schemes to reduce(concentrate) activation
  - Halo collimation systems/Multiple stage collimators
- Compact shielding
  - Important for medical applications, where materials and techniques for improved shielding of neutron/gamma radiation may help deployment in H

2. Accelerator Technologies

There is more than just components, facilities need a complex technological infrastructure for operation. R&D is needed and beneficial, e.g.:

- Electronics/Software
  - Cost Driver. Trend is standardization (e.g. uTCA)
- Vacuum
- RF power sources and systems
  - Energy efficiency (large operation cost driver!)
- Cryogenics
  - Again energy efficiency
    - especially when COP is low! 1W@2K =750 W@RT
- Alignment/stabilization schemes

3. Accelerator Concepts

Last group of Key Accelerator Research Areas, covering design issues for future facilities or promising technologies, not yet implemented in facilities

- Accelerator Design
- Beam Dynamics
- FEL processes
- Beam cooling
- New high gradient acceleration techniques
- Medical/Industrial accelerators

Machine Design

- Design for Reliability and Availability
  - Important for analytical facilities (users), but a common concern to all machines
  - For ADS: «nuclear» context requires formal RAM assessements from the early design stages
- Losses and machine protection at high power
- Simple and compact application accelerators
- Energy efficiency and storage
  - Develop new concepts for the development of energy efficient accelerators, e.g. recovering the large amount of power which is routinely removed by the cooling circuits

Beam Dynamics

Pushing limits of computational tools for simulation and prediction of the achievement of

- High luminosity in circular and linar colliders
- High energies for hadron colliders, in regimes where synchrotron radiation and damping becomes relevant
- High beam stabilities
- Beam emittances for «ultimate» rings
- Low loss acceleration of high intensity hadron beams
- Plasma acceleration schemes
- Novel fast acceleration systems for unstable particles

Need of **new concepts** for

optics / beam manipulation / beam correction

...

Plus many other specific critical technical issues that are (briefly) described in WP4 deliverable and that need collaborative R&D efforts to find solutions for the future project needs

Cannot be all listed in a talk

Concluding message

- The Key Area Deliverable is out
- Base for the **TIARA Joint R&D Programme**
  - Space for improvement until end of TIARA-PP, we are only halfway through it
- You are encouraged to flip through it/read it, send feedback and proposal for improvements to WP4
  - Contribute to the process!