Fast Advanced Scintillator Timing

A COST TDP ACTION

TD1401

E. Auffray, Chair of FAST Action
CERN, Geneva, Switzerland

cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

What is Cost Organization?

COST is the oldest and widest European intergovernmental framework for Cooperation in Science and Technology (1971)

It complements the activities of the EU Framework Programmes, constituting a "bridge" towards the scientific communities of different countries.

It also aims to increase the mobility of researchers across Europe and fosters the establishment of scientific excellence in nine key domains:
(Biomedicine and Molecular Biosciences, Food and Agriculture, Forests, their Products and Services, Materials, Physics and Nanosciences, Chemistry and Molecular Sciences and Technologies, Earth System Science and Environmental Management, Information and Communication Technologies, Transport and Urban Development,Individuals, Societies, Cultures and Health, **Trans Domain**)

COST enables break-through scientific developments leading to new concepts and products and thereby contributes to strengthen Europe's research and innovation capacities.

It is a unique means for European researchers to jointly develop their own ideas and new initiatives across all scientific disciplines through trans-European networking of nationality funded research activities

What is a COST Action?

Pan-European, bottom-up science and technology networks open to researchers, industry and policy stakeholders

Duration 4 years.
Minimum 5 COST member countries

COST supports:
Meetings, Conferences, Workshops, Short-term scientific exchanges, Training schools, Publications & dissemination activities

COST does not fund projects

COST has been supporting the networking of research activities across all 35 Member Countries and beyond for over 40 years

Currently there are 328 running Actions networking around 30 000 researchers per year, worldwide.

Objectives of the FAST Action

FAST Action is a multidisciplinary network that brings together European experts from academia and industry to ultimately achieve scintillator-based detectors with timing precision of better than 100ps, in particular to enable significant breakthroughs in diagnostic medicine and high luminosity particle physics..

- Establish the ultimate achievable limits for fast timing for scintillators, photodetectors, electronics
- Facilitate the increase of competitiveness of European industry;
  provide input for future market applications
- Provide training opportunities for a new generation of scientific experts to strengthen their background in the field of fast timing detectors

Added Value of this COST Action

- Enhanced synergies between partners through long term collaboration Building
- Access to network of experts and knowledge for partners
- Increased prospects for innovation in fast timing photodetection
- Opportunities for new European research projects
- Availability of a new generation of scientists with interdisciplinary expertise

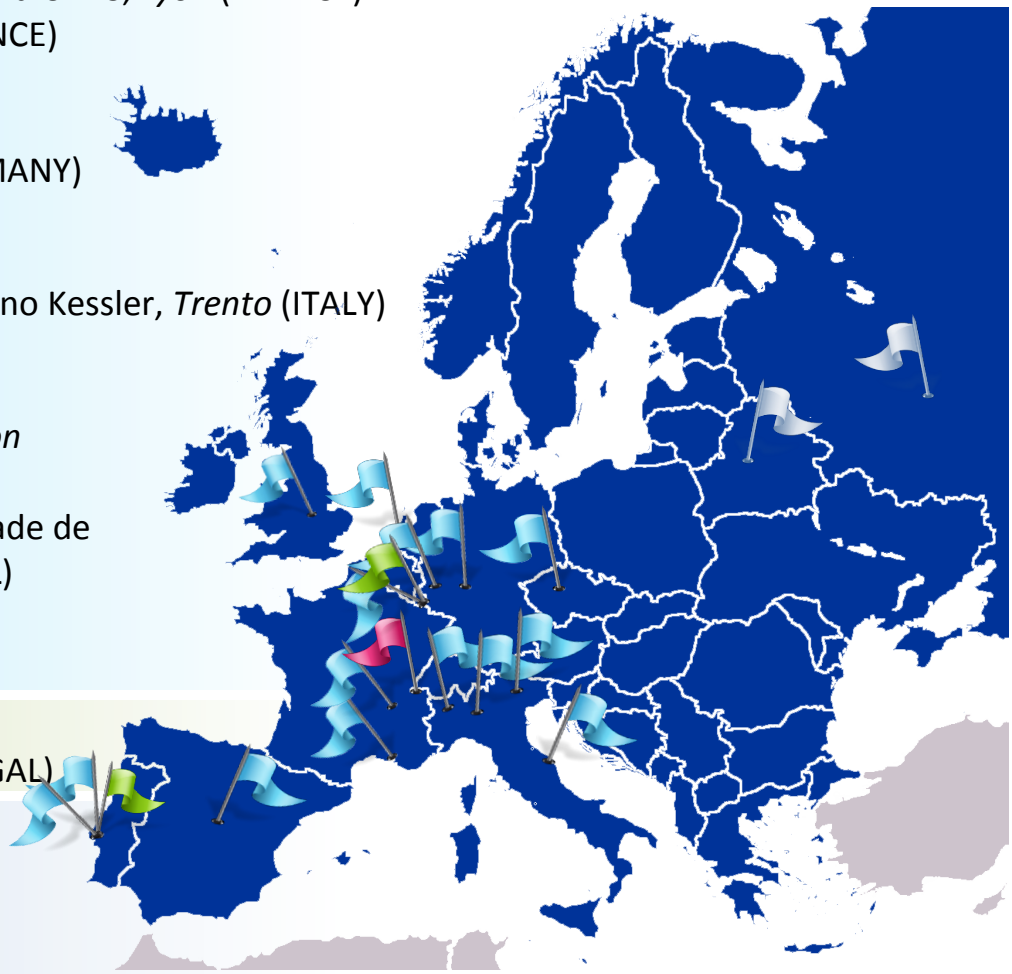
List of 18 Proposers
(9 Cost Countries & 2 NNC, 2 companies)

- **CERN**, *Geneva* (SWITZERLAND)

- **Institute of Physics**, Academy of Sciences of the Czech Republic, *Prague* (CZECH REPUBLIC)
- **Institut Lumière Matière**, University Claude Bernard and CNRS, *Lyon* (FRANCE)
- **Centre de Physiques des Particules** de *Marseille* (FRANCE)
- **Forschungszentrum Julich** GmbH, *Julich* (GERMANY)
- **Justus-Liebig-University**, *Giessen* (GERMANY)
- **Aachen University of Applied Sciences**, *Aachen* (GERMANY)
- **Università Politecnica delle Marche**, *Ancona* (ITALY)
- **University of Milano-Bicocca**, *Milano* (ITALY)
- **Center for Materials & Microsystems**, Fondazione Bruno Kessler, *Trento* (ITALY)
- **INFN** *Torino* (ITALY)
- **Delft University of Technology**, *Delft* (NETHERLANDS)
- **LIP Laboratory of Instrumentation and Particles**, *Lisbon* (PORTUGAL)
- **Instituto de Biofísica e Engenharia Biomédica**, Faculdade de Ciências da Universidade de Lisboa, *Lisbon* (PORTUGAL)
- **CIEMAT**, *Madrid* (SPAIN)
- **University College**, *London* (UNITED KINGDOM)

- **Philips Technologie GmbH**, *Aachen* (GERMANY)
- **PETsys medical PET imaging systems**, *Lisbon* (PORTUGAL)

- **Research Institute for Nuclear Problems**, *Minsk* (BELARUS)
- **Lomonosov Moscow State University**, *Moscow* (RUSSIAN FEDERATION)



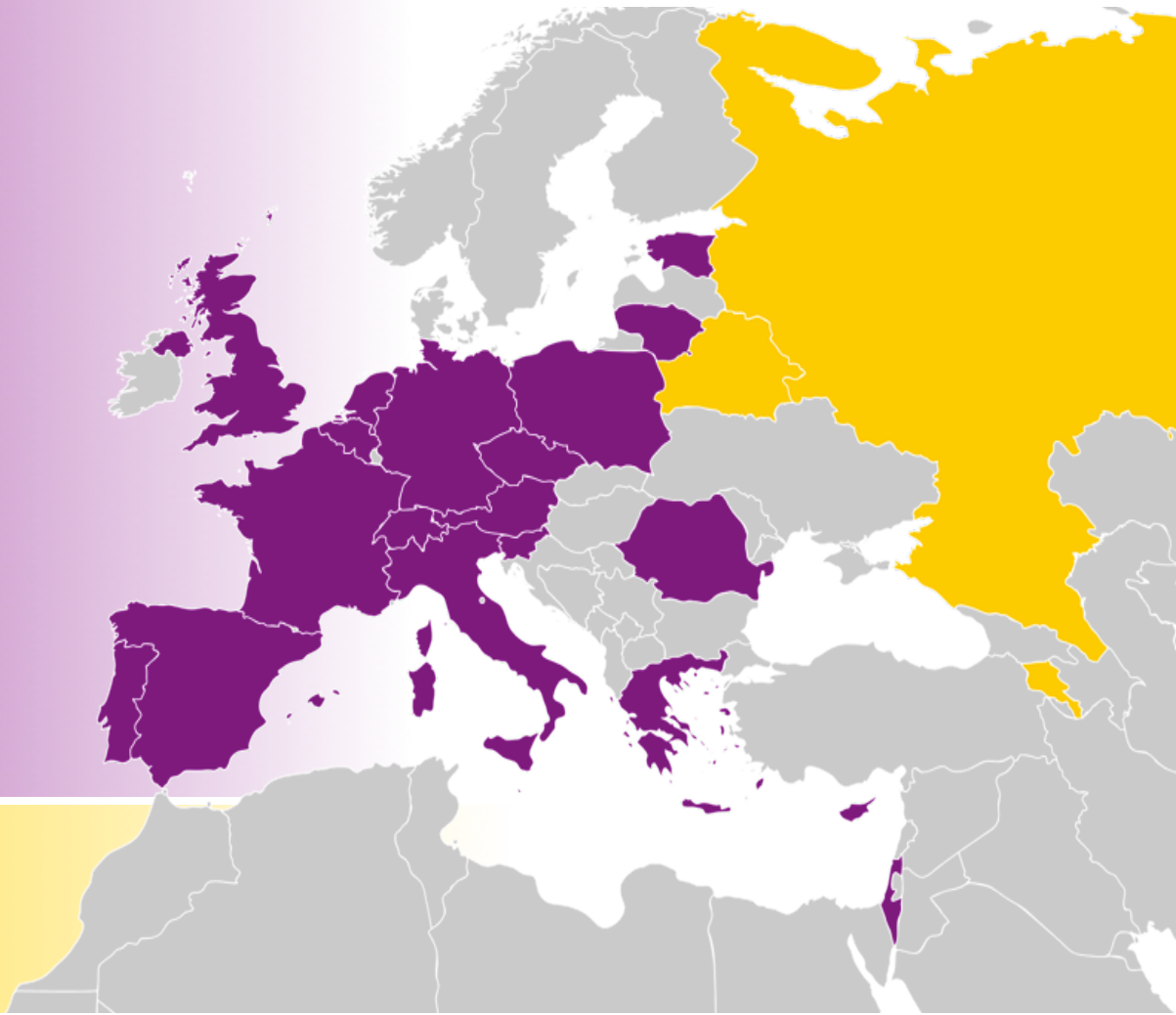
Today participating countries
(19 COST and 3 Near Neighbour)

COST countries

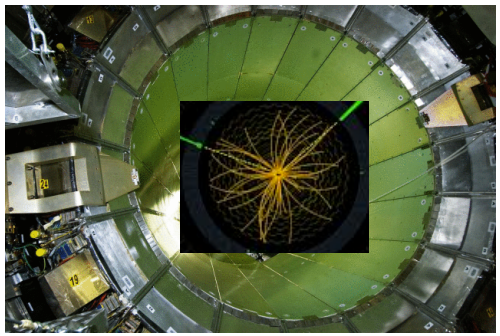
- Austria
- Belgium
- Cyprus
- Czech Republic
- Estonia
- France
- Germany
- Greece
- Israel
- Italy
- Lithuania
- Netherlands
- Poland
- Portugal
- Romani
- Slovenia
- Spain
- Switzerland
- United Kingdom

COST Near Neighbour Countries

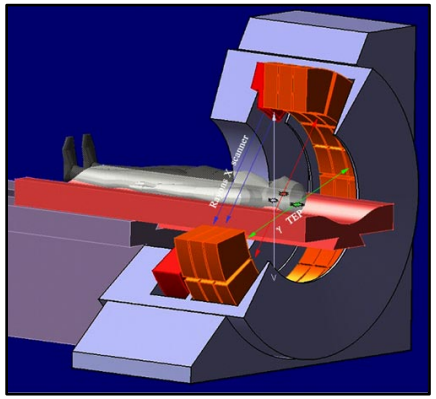
- Belarus
- Russian Federation
- Armenia



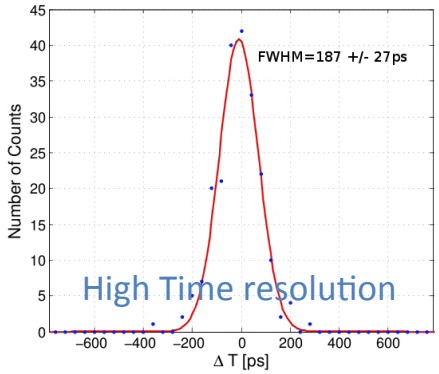
Areas Benefitting From High Time Resolution

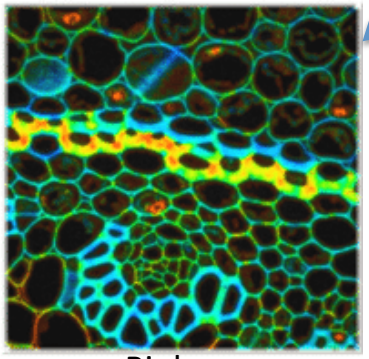


Fundamental science



Medical Imaging



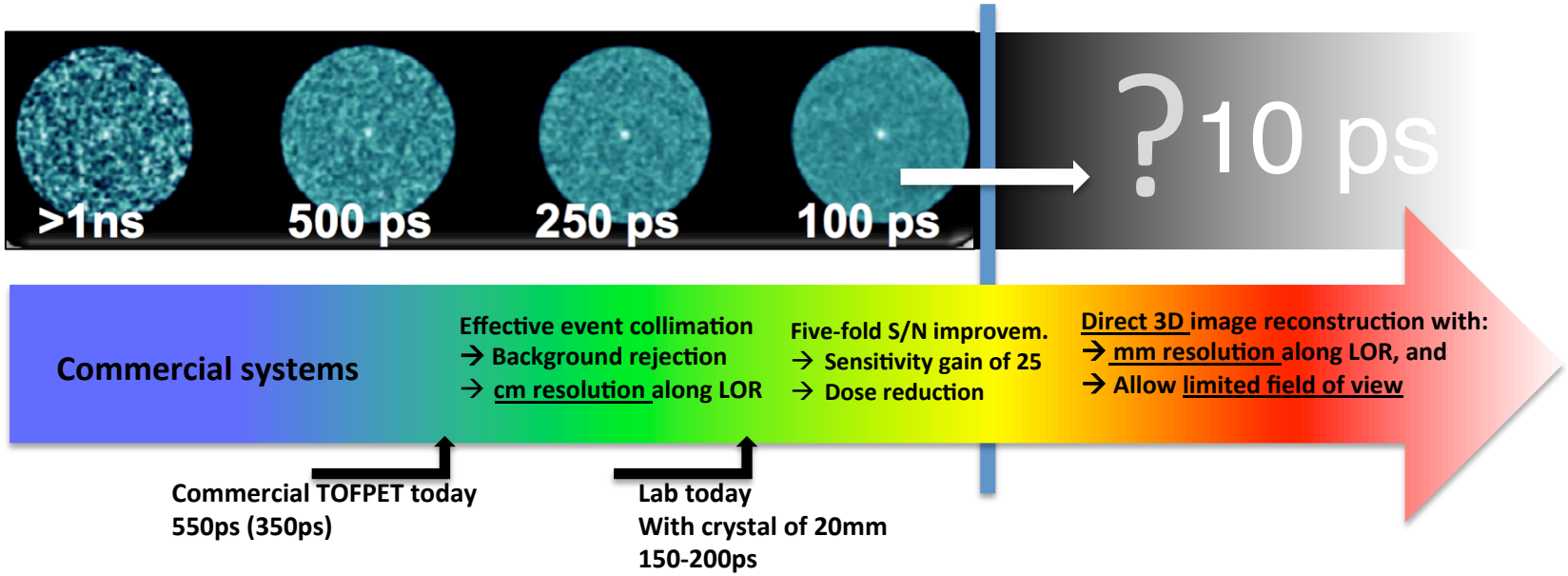


Biology

Other applications

Scientific Goals: *PET, a new frontier*

The Merits of Time of Flight in PET (TOF-PET):

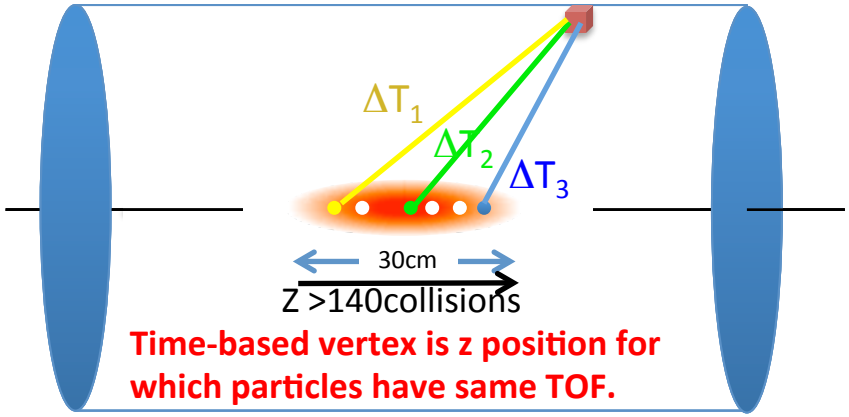


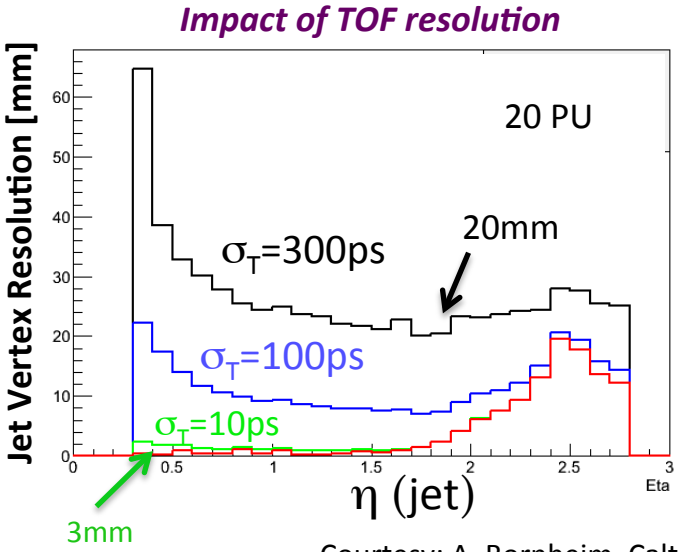
Scientific Goals: *HEP, a new frontier*

Search for rare events implies high luminosity accelerators

- → Rate problems;
- → Pileup of >140 collision events per bunch crossing at *High Luminosity-LHC;*
- → Pileup mitigation via TOF requires TOF resolution < 50ps.

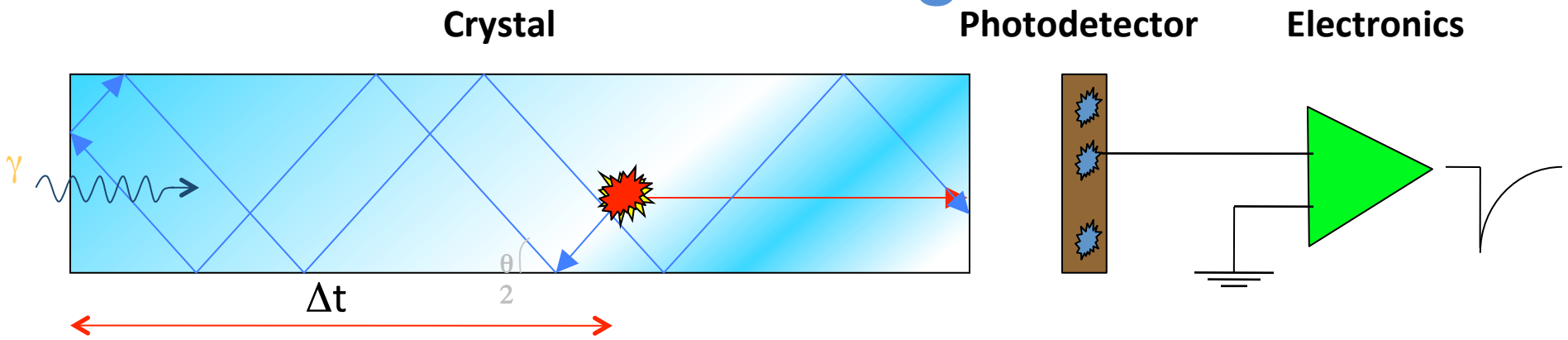
Benchmark: Express TOF pileup mitigation performance in terms of di-jet vertex resolution:





Courtesy: A. Bornheim, Caltech, U.S.A.

The Photodetection Chain challenges



$t_{kth\ pe} = \Delta t + t_{k'\ ph} + t_{transit} + t_{SPTR} + t_{TDC}$

Conversion depth	Scintillation process	Transit time jitter	Single photon time spread	TDC conversion time

WG 2

Scintillator R & D

- Particule Interaction
- Light generation
- Light transport
- Light transfer
- Light collection

WG 3

Photodetector R & D

- Reduce SPTR and DCR
- Increase fill factor (PDE)
- Digital SiPM
- MCP for PET & HEP

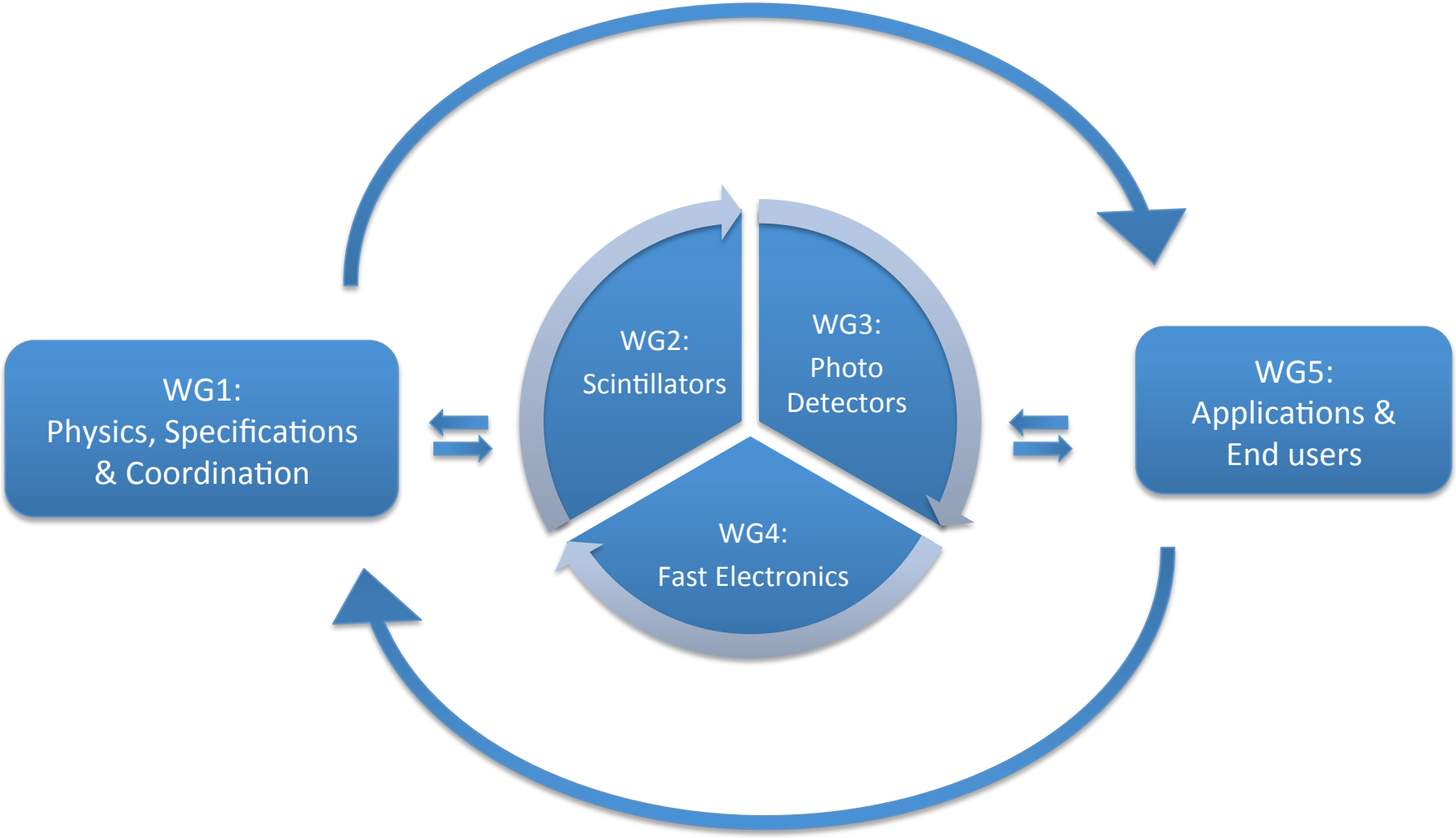
WG 4

Electronics R & D

- TDC < 10ps bins
- Monolithic architecture
- High bandwidth
- Low noise
- Massive parallel data
- High number of channels

⇒ **Challenge: Understanding key factors of timing resolution**
Proposing routes toward 10ps

Working groups interaction



Exchanges through meetings, STSM, workshops, projects

WG leaders

- **WG 1: Physics, Specifications & Coordination**:
  - WG Leader: Paul Lecoq
  - Vice WG leader: Denis Schaart
- **WG 2: Scintillators**
  - WG Leader: Martin Nikl
  - Vice WG leader: Christophe Dujardin
- **WG 3: Photodetectors**
  - WG Leader: Claudio Piemonte
  - Vice WG leader: Eduardo Charbon
- **WG4: Electronics**
  - WG Leader: Joao Varela
  - Vice WG leader: Christian Morel
- **WG5: Applications**
  - WG Leader: Pedro Almeida
  - Vice WG leader: Stefaan Tavernier

WG1 Objectives

Define the technical and physical specifications/parameters of the project and determine the roadmap for achieving the Action's objectives of time coincidence resolution below 100ps

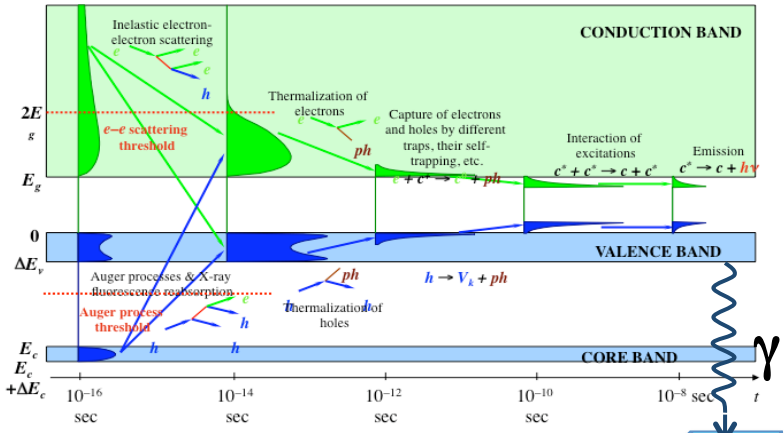
WG2 Scintillation: Objectives

- **Define and understand the key parameters of scintillators to obtain the best timing properties:**
  a) Fundamental understanding of scintillation mechanism
  b) Light production, light reabsorption, light transport and light collection
- **Propose and study the processes beyond the classical scintillation mechanism and useful for fast timing:**
  - Cherenkov radiation
  - Intraband luminescence
  - Absorption of free charge carriers
  - Other processes occuring in the stage of hot carrier existence
  - Quantum size effect in nanomorphological materials – quantum wells and dots

Limits to Scintillator Time Resolution

1) The scintillation mechanism

- Light yield;
- Rise time;
- Decay time.



A. Vasil'ev, SCINT2001 proceedings, NIMA 486 (2002) 367

2) The light transport in the crystal

- Time spread related to different light propagation modes

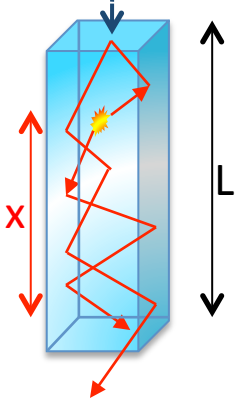
3) The light extraction efficiency

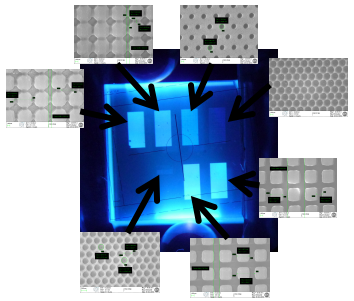
- Light Yield → Light Output;
- Impact on photostatistics;
- Weights the distribution of light propagation modes.

Δt_{max} = 71 ps for x = L

Δt_{max} = 384 ps for x = 0

(L = 20mm





Different emission processes with different speed

- Excitonic emission (STE, excitations of anion complexes)
- Emission of activators (Ce, Pr, …)
- Emission of quantum dots
- Crossluminescence
- Intraband hot luminescence
- Cherenkov radiation

Slow

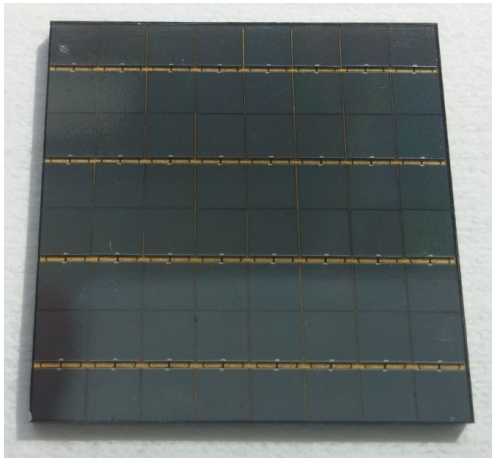
Short

WG3 Photodetectors: Objectives

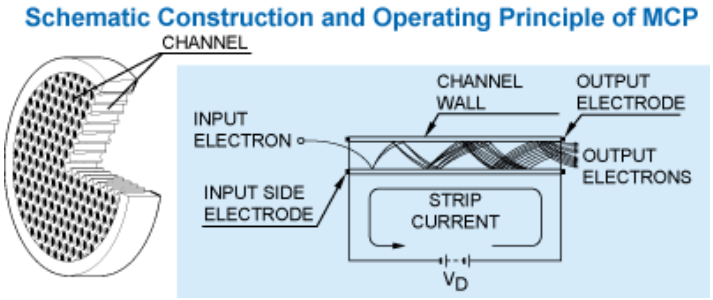
- Understand the key parameters of current and future photodetectors for the best time resolution and shall consequently propose technological approaches
- Investigate the different existing state-of-the-art photodetection technologies and evaluate their merits and disadvantages with main emphasis on timing
- Establish Industrial cooperation to evaluate feasibility of proposed ideas and methods

Many existing technologies

PMT



SiPM



MCP

Else?

Today State of Art

	PMT*	SPAD	aSiPM	dSiPM	MCP
PDE	35% (blue)	70% (green)	~45% (blue)	~25% (blue)	35%
SPTR	200ps	20ps	200ps (3x3mm2)	180ps	20ps
Gain	1e8	1e6	1e6	-	1e6
DCR	<100 Hz/cm2	10Hz 100um	100 kHz/mm2	>1M Hz/mm2	<100 Hz/cm2
ENF	1.1	1.0x	1.1	?	1.05
Radiation hardness	Good	lower	lower	lower	Good
Reliability/Life	Good	Good	Good	Good	moderate
magnetic field tolerance	bad	Good	Good	Good	moderate
Temperature sensitivity	Good	Good	Good	Good	Good

Possible improvements

	PMT	SPAD	aSiPM	dSiPM *	MCP
PDE	**45%**	70/80%	**60-70%**		**45%**
SPTR	100ps	10ps	<200ps (?)		
Gain	1e6	1e6	1e6		
DCR	100Hz	100Hz	**~10kHz/ mm2**		
ENF	1.05	1.0x	1.1		1.05
Size					200x200mm^2

New approach:

3D integration :
SPAD/SiPM custom technology
+
high-end electronics

Fast Action could help to study the limits

WG4 electronics: Objectives

- Understand the key parameters and microelectronics technologies required for good time resolution;
- Study possible electronics architectures;
- Evaluation of currently existing state-of-the-art-electronics for TOFPET by joint characterization of prototype;

Motivations

The development of electronics with picosecond time resolution is challenging

- ASIC design
- system level.

Front-end systems with

- very large bandwidth
- very low noise
- very low-power

Various architecture options are being investigated:

- low level discrimination and fast TDCs
- high frequency ADC sampling
- no solution will fit it all

Several chips are currently developed for fast timing

1. Omega Group in Paris: FLC_SiPM, MAROC, SPIROC
2. BASIC – Bari/Pisa
3. SPIDER – Siena/Pisa/Oslo
4. RAPSODI – Krakow
5. DRS4 – PSI
6. Flext Tot- Madrid/Barcelona
7. Nino CERN
8. PETA – Heidelberg
9. TOFPET Asic – Lisbon
10. STiC – Heidelberg

} Both developed in the frame of the Endo-TOFPET-US project (FP7 grant

Fast Action network will help to evaluate performance of the different ASICs between different groups through STSM

WG5 Applications: Objectives

The WG5 will assemble all partners with expertise in the various relevant research domains and experience in applications where FAST timing is important.

- **Identify target applications in, e.g. HEP, TOF-PET, FLIM, and others**
- **Discuss and evaluate the requirements of potential end users w.r.t. timing.**

Possible applications of FAST detection chains:

- Medical Imaging
- Biological Imaging
- Security
- LiDAR applications (remote sensing)
- Industrial non-destructive quality control in production chains
- Others ?

=> **Discussion of Tomorrow meeting**

COST Policy

- Favor participation of inclusiveness countries
- Involve ESR (≤ 8 years PhD)
- Encourage gender balance
- Encourage International collaboration
- Involve industrial
- Dissemination and outreach

FAST Coordinators

- **STSM (short term scientific missions) organization**:
  - George Loudos
- **ESR involvement**
  - Maria Georgiou (F, ESR)
- **Industrial contact**
  - Karl Ziemons
- **Outreach/dissemination coordinator**
  - Harry Tsoumpas (ESR)

Industry Involvement

FAST is far more than an academic exercise …

- R&D on fast scintillators and photo detection provide the baseline technologies for many applications in different fields
- Main technology development streams in FAST are application driven
- Large synergy benefits through sharing of knowledge and experts by carrying out R&D in international collaborations

Combining FAST R&D with industry expertise in pre-commercial developments can significantly enhance the market prospects of jointly developed solutions

In joining FAST collaborative R&D, partners from industry benefit from:

- Reduced costs of basic technology development and expertise building through access to public funded knowledge and expertise
- a wide network of experts active in many different technology domains
- Access to intellectual property of results generated throughout FAST

Agenda of today

09:00 - 09:30 Welcome and overview of the 1st Industrial FAST Workshop
(Karl Ziemons & Vice Chancellor Prof. Baumann, FH Aachen University of Applied Sciences)
09:30 - 10:00 Introduction of the COST project FAST
(Etiennette Auffray Hillemanns, CERN)
10:00 - 10:30 Overview of possible Applications
(Pedro Almeida, Instituto de Biofísica e Engenharia Biomédica - Universidade de Lisboa /
Stefaan Tavernier, Vrije Universiteit Brussel)
10:30 - 11:00 Coffee break
11:00 - 13:00 Industrial & Academic Presentation - Photo detection & read out electronics
11:00 **Hamamatsu Photonics Deutschland GmbH** *25'*
Speaker: Simon Kempf
11:30 **Philips Digital Photon Counting** *25'*
Speaker: Torsten Solf
12:00 **FBK** *25'*
Speaker: Claudio Piemonte
12:30 **KETEK** GmbH *25'*
Speaker: Werner Hartinger

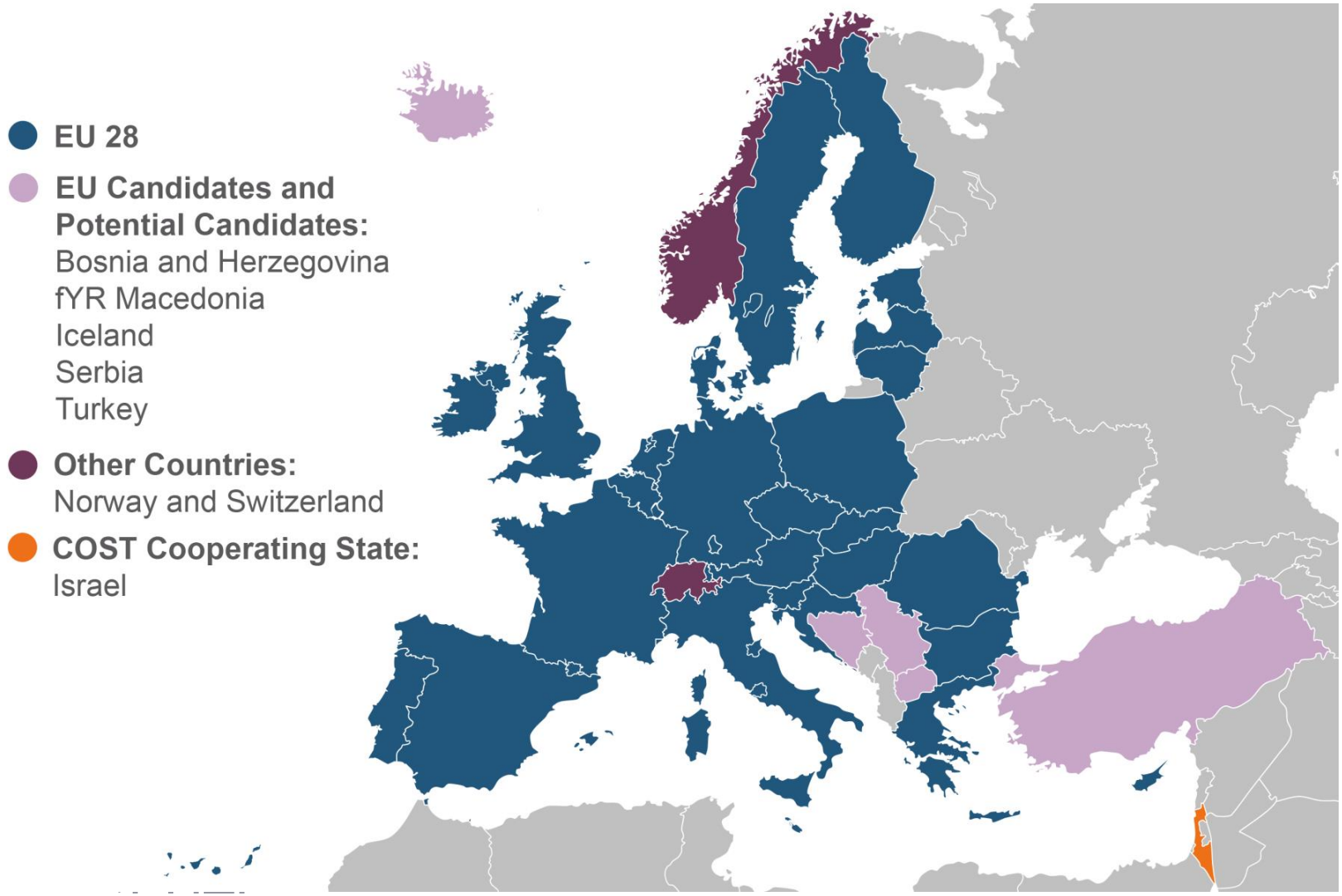
13:00 - 14:00 Lunch break
14:00 - 15:00 Poster presentation by young researchers
15:00 - 17:00 Industrial & Academic Presentation - Medical and Biological Applications
15:00 **Siemens Health Care** *30'*
Speaker: Matthias Schmand
15:30 **GE Global Research** *30'*
Speaker: Sergei Dolinsky
16:00 **EMBL***30'*
Speaker: Yuri belyaev
16:30 - 17:00 Coffee break
17:00 - 18:00 Round table
(Industrial Needs and Shares of Intellectual Properties) ***45'***
19:45 - 22:45 Come Together Diner @ Ratskeller, Aachen City Hall

Agenda of tomorrow WG5 meeting

9h00m - Welcome and Introduction
Overview of potential FAST timing applications
S. Tavernier – V.U.B (Belgium) & P. Almeida - IBEB, FCUL, Univ. Lisboa (Portugal)
9h20m – **Applications to Biology**
Yury Belyaev , EMBL, Heidelberg (Germany)
9h45m - Discussion
9h55m – **Applications to 3D imaging**
Hans Ingelberts, V.U.B. (Belgium)
10h20m – Discussion.
10h30m – **Applications to Cerenkov radiation detection**
Samo Korpar, Jozef Stefan Institute, Ljubljana - (Slovenia)
10h55m – **Development of the high efficient Cherenkov detector of 511 keV gamma with high resolution in time at IRFU"**
Viatcheslav Sharvy – CEA (France)
11h05m – Discussion.
11h15m – **Applications to new generation sensors**
Torsten Wagner, FH Aachen (Germany)
11h40m – General Discussion.
12h10m – **Closing.**

backup

35 COST Countries

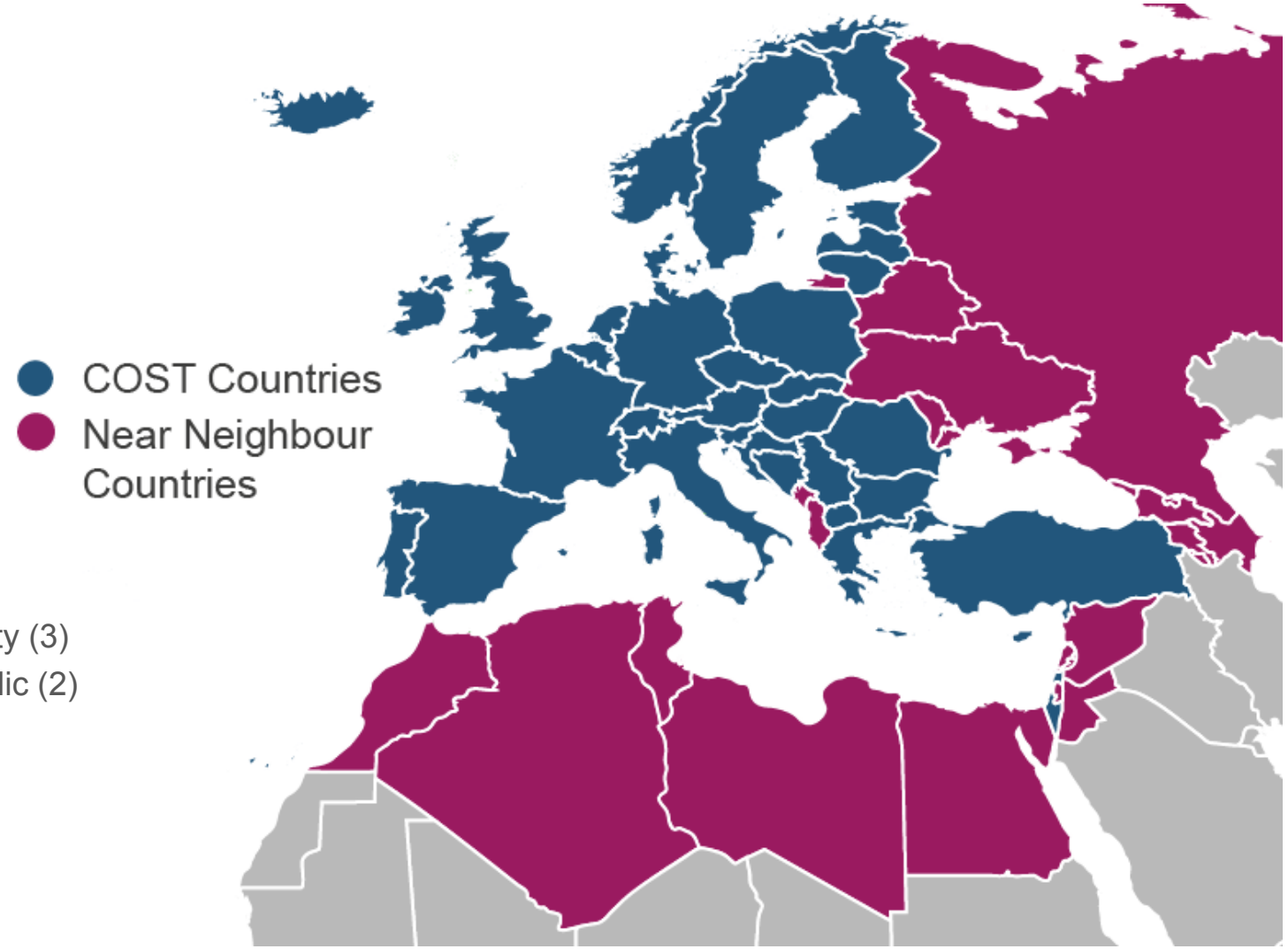


COST Near Neighbour Countries

206 participations in running COST Actions across 17 countries

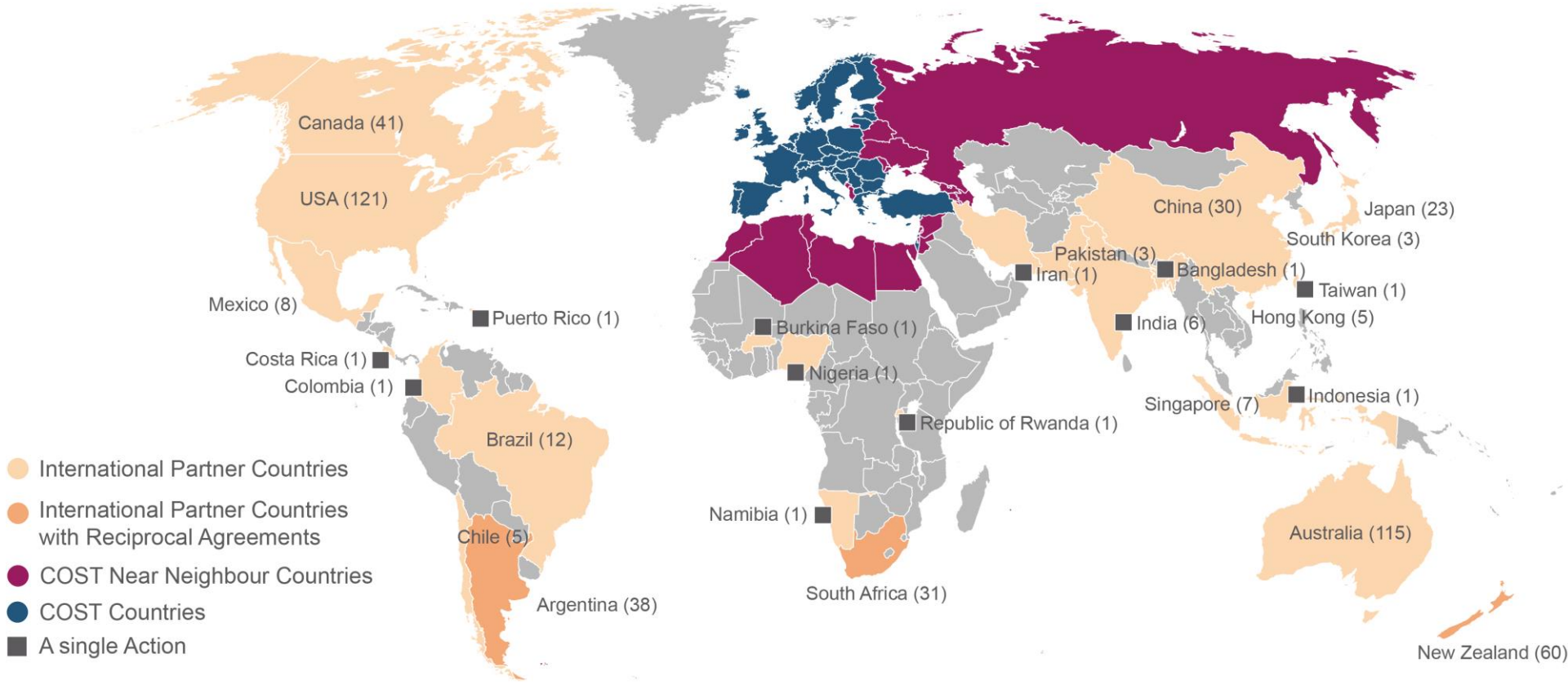
- **Albania (15)**
- Algeria (7)
- Armenia (8)
- Azerbaijan (5)
- Belarus (6)
- Egypt (7)
- Georgia (5)
- Jordan (2)
- Lebanon (5)
- **Moldova (5)**
- **Montenegro (12)**
- Morocco (13)
- Palestinian Authority (3)
- Syrian Arab Republic (2)
- Russia (51)
- Tunisia (14)
- **Ukraine (46)**

March 2014 data



International Partner Countries

519 participations in running Actions across 27 countries



March 2014 data