Fast Advanced Scintillator Timing
COST ACTION TD1401

C. Piemonte
Broadcom Inc., Regensburg, Germany
On behalf of FAST Action

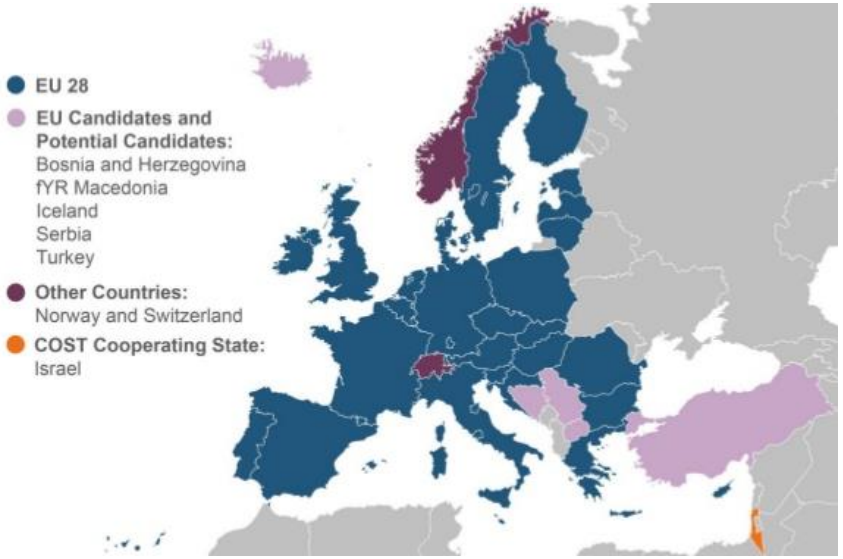
cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

COST Actions

What is COST?

- European international framework for Cooperation in Science & Technology (est. 1971)
- Based on networks called **COST Actions**
- Regular call: next one: 29/11/2018

36 Countries



COST Objectives:

- Accelerate breakthrough scientific developments via collaboration
- Strengthen Europe's research and innovation capacities
- Build capacity by connecting high-quality scientific networks
- Provide networking for Early Stage Researchers & monitor gender balance
- Address societal questions: connect policy makers, regulatory bodies and decision makers

COST is supported by the EU RTD Framework Programme

ESF provides the COST Office through a European Commission contract

Objectives of the FAST Action
COST Action TD1401

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, photo-detectors, electronics
- Facilitate the increase of competitiveness of European industry and 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

Website: http://fast-cost.web.cern.ch/fast-cost/

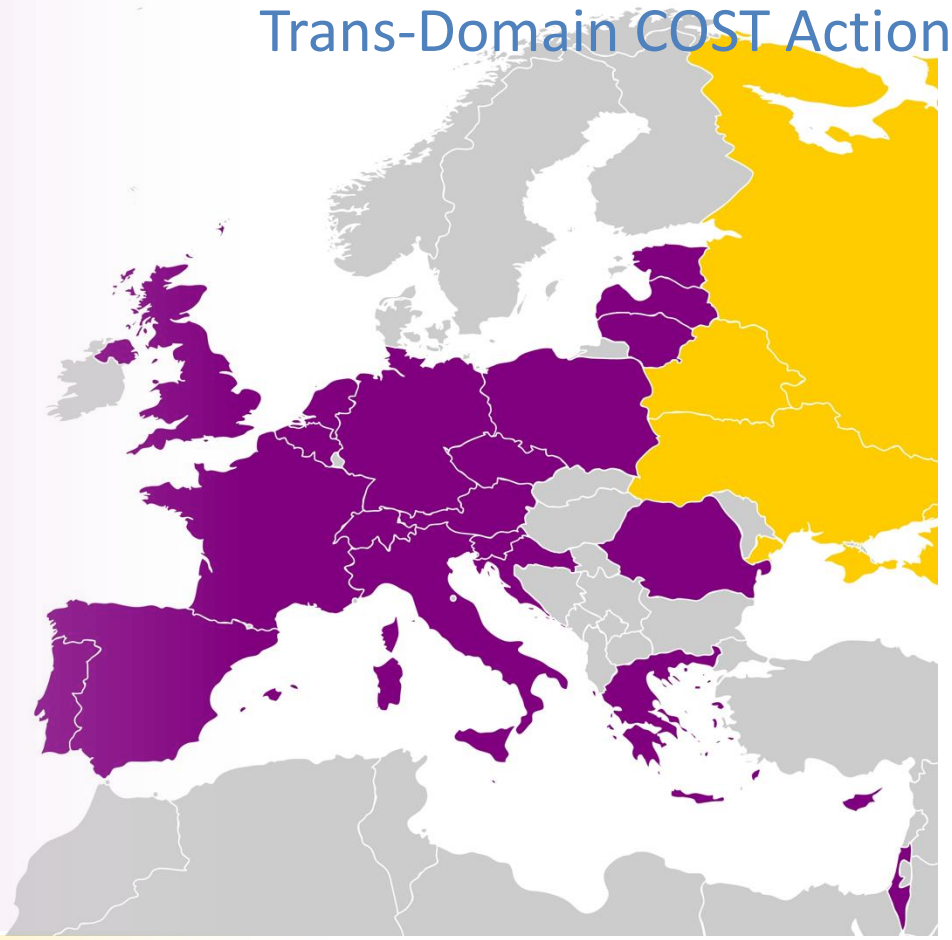
FAST Participant countries

(21 COST and 4 Near Neighbours countries)

Trans-Domain COST Action

COST countries

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



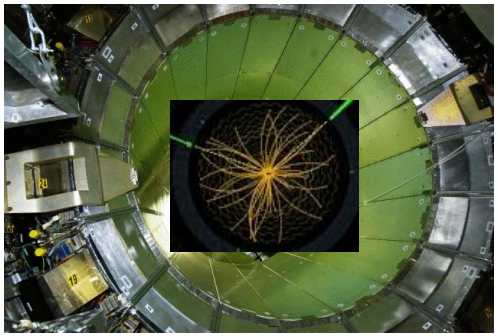
COST Near Neighbour Countries

- Armenia (1 institute)
- Belarus (1 institute)
- Ukraine (1 institute)
- Russian Federation (5 institutes)

59 institutes/industries participating

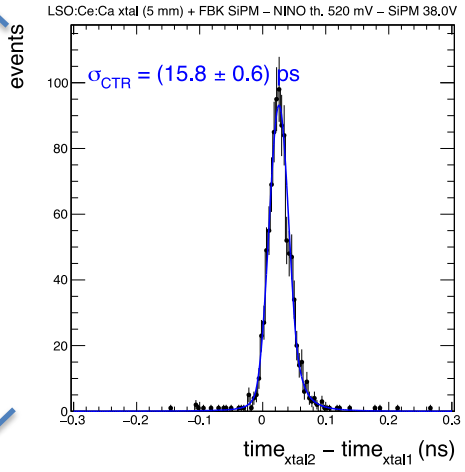
November 2014 – November 2018

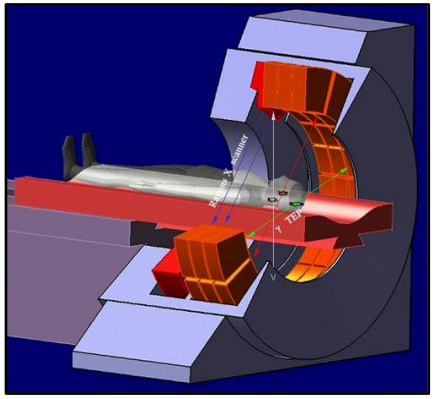
Potential Beneficiaries from FAST Advanced Scintillator Timing



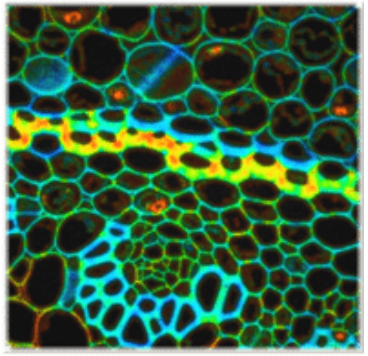
Fundamental science

Precise timing

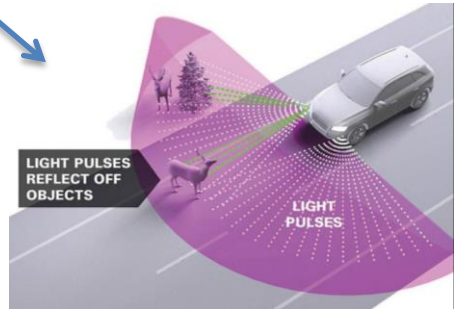




Medical Imaging



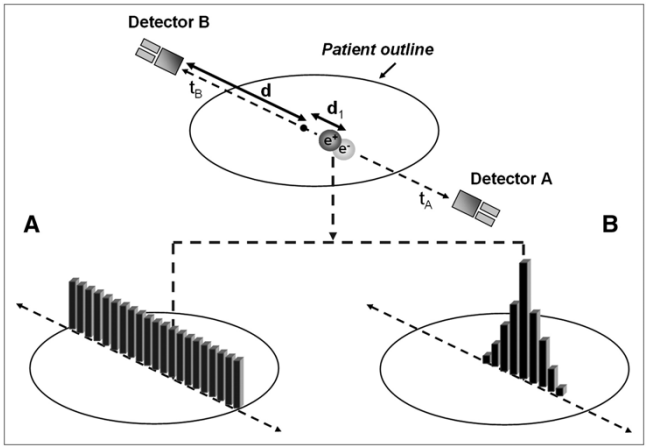
FLIM: Fluorescence Lifetime Imaging Microscopy

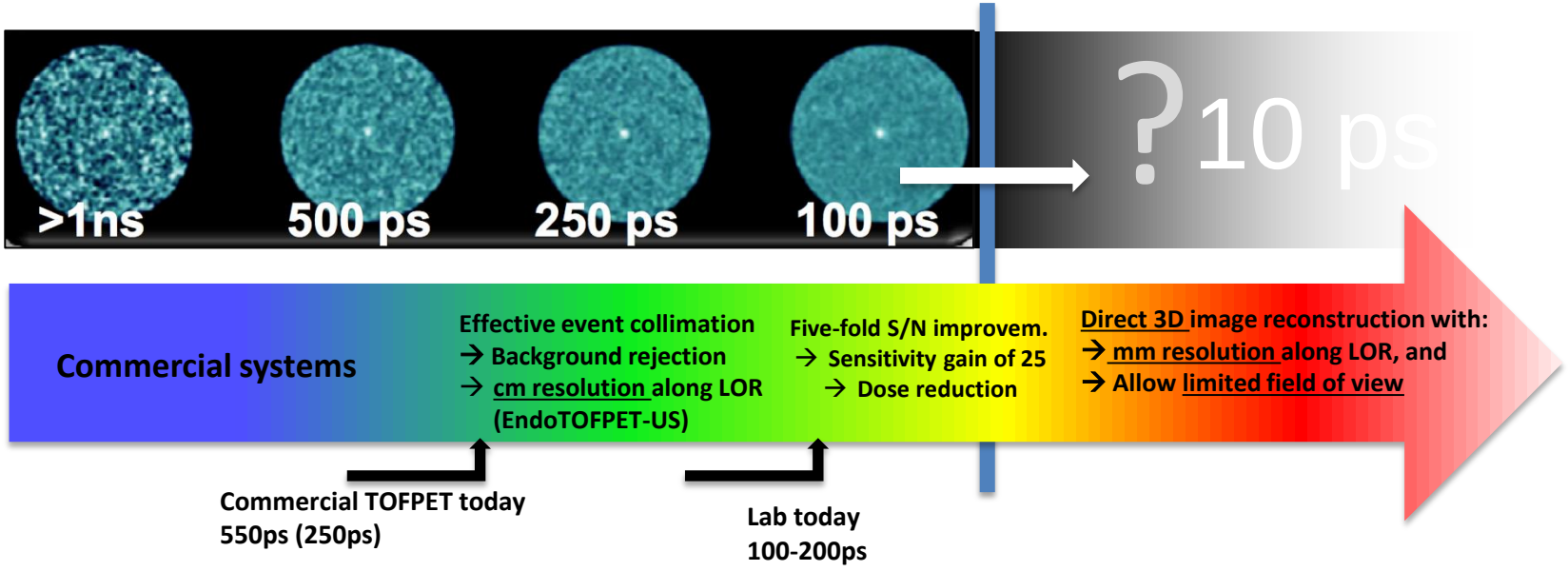


Lidar

Why FAST is important in PET imaging?

- In vivo: More precise, less invasive, more compact systems
- In vitro: Faster analysis of disease biomarkers
- Ultimately: Pave the way into precision medicine





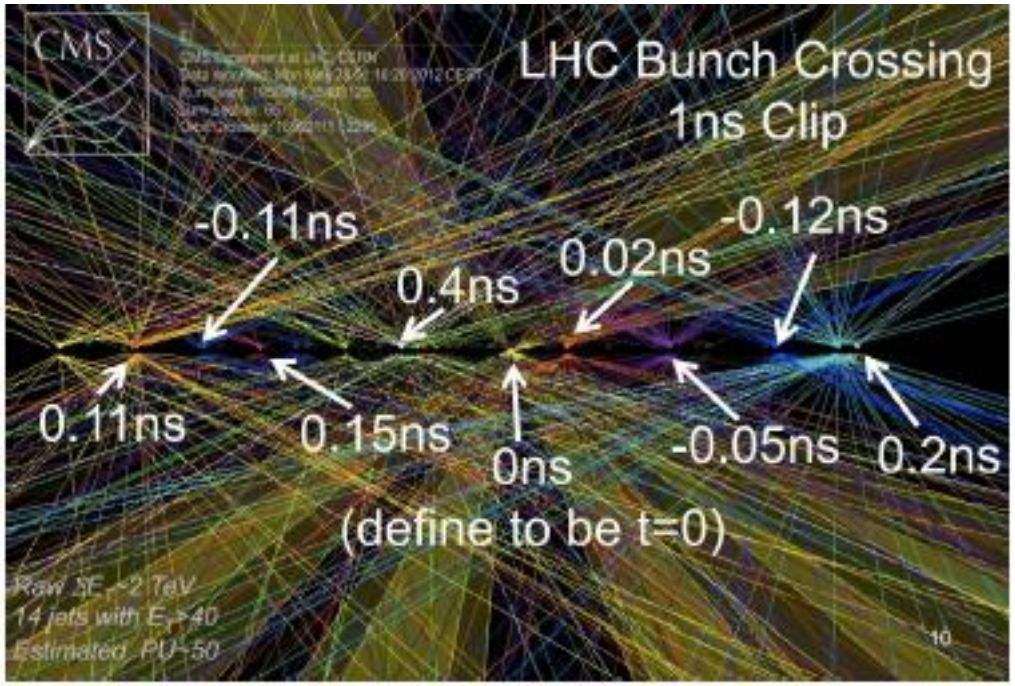
Why FAST is important in HEP

Search for rare events implies high luminosity accelerators

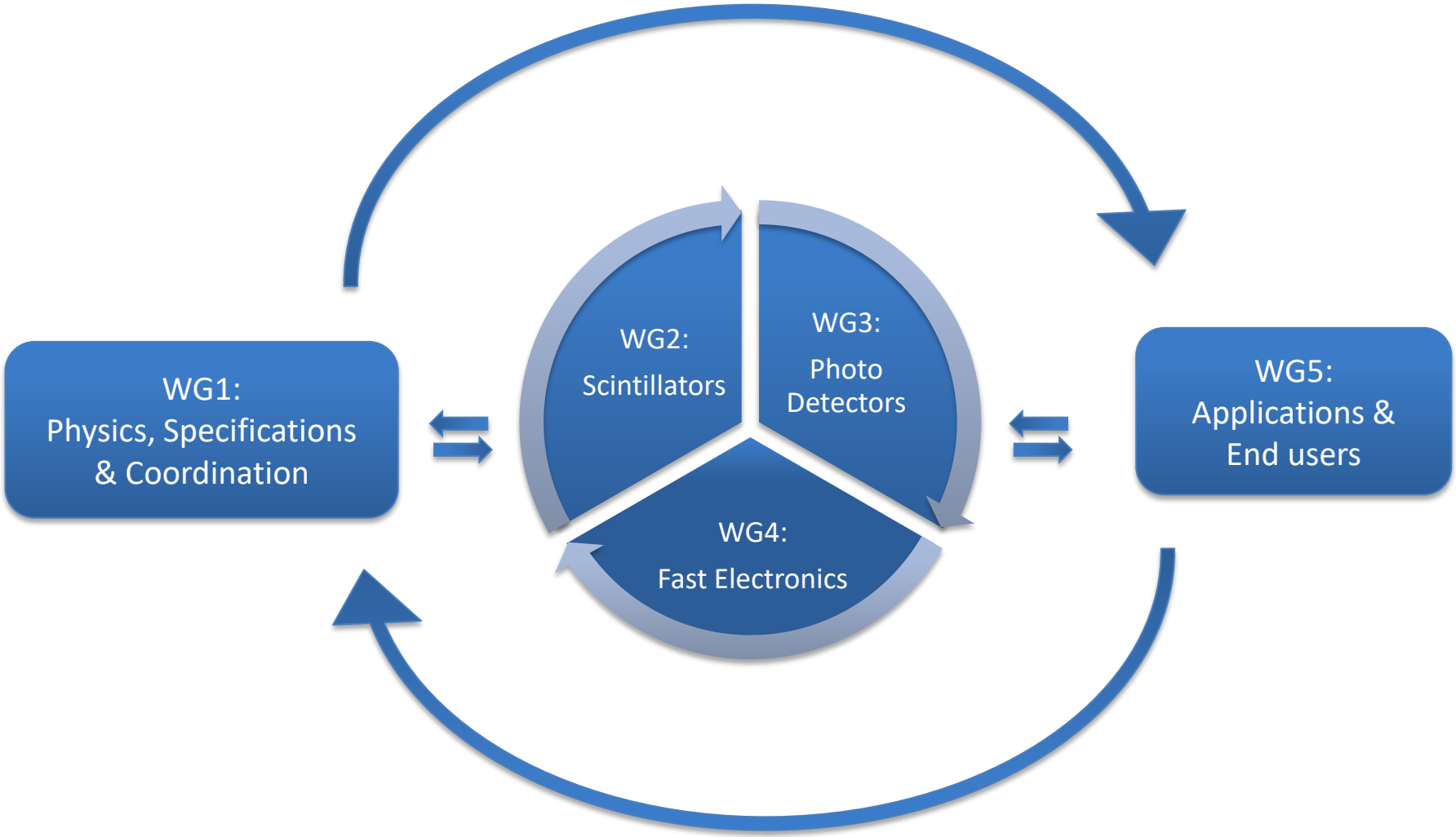
→ Rate problems;

→ Pileup of >140 collision events per bunch crossing at *High Luminosity-LHC;*

→ Pileup mitigation via TOF requires TOF resolution < 50ps.



Organization in 5 Working Groups (WG)



Exchanges through meetings, short term scientific missions, workshops, projects

Organization in 5 Working Groups (WG)

Chair: Etiennette Auffray (CERN); Vice Chair: Marco Paganoni

WG 1: Physics, Specifications & Supervision

Leader: Paul Lecoq; Deputy: Dennis Schaart

WG 2: Scintillators

Leader: Martin Nikl; Deputy: Christophe Dujardin

WG 3: Photodetectors

Leader: Claudio Piemonte; Deputy: Eduardo Charbon

WG 4: Electronics

Leader: Joao Varela; Deputy: Christian Morel

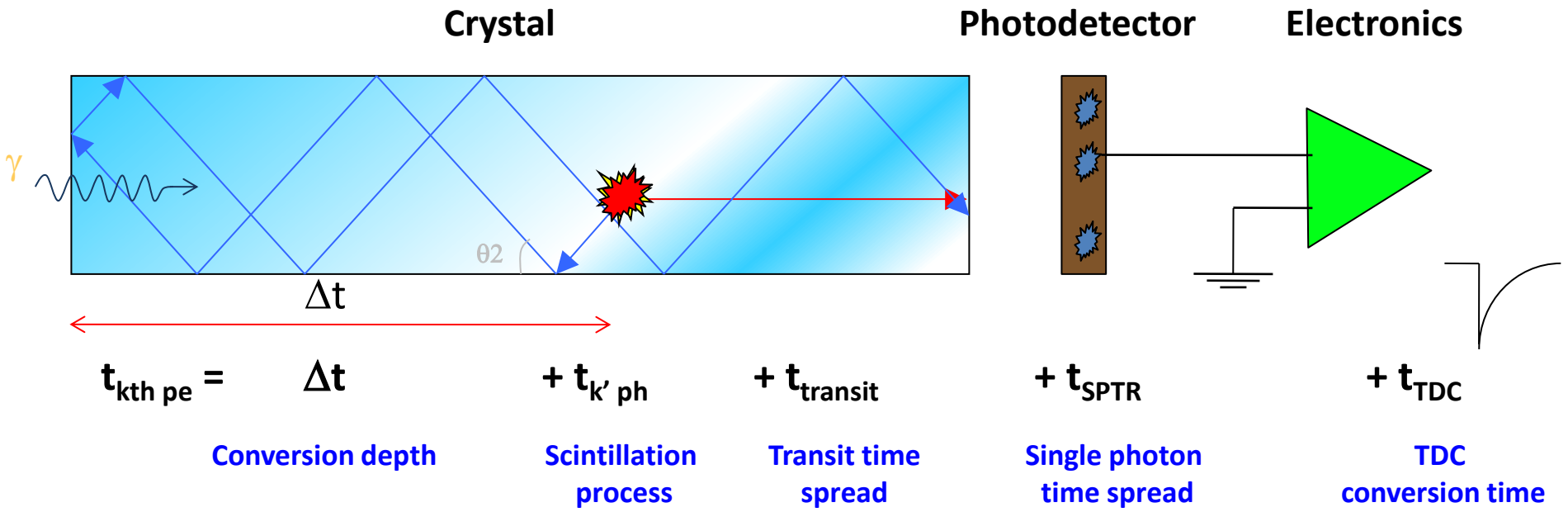
WG 5: Applications

Leader: Pedro Almeida; Deputy: Stefaan Tavernier

WG1:
Physics, Specifications & Supervision

Objectives:

- Detector chain modelling and optimization
- Design the roadmap for coincidence timing resolution towards 10ps
- Interact with each working group (WG) and follow up progress



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

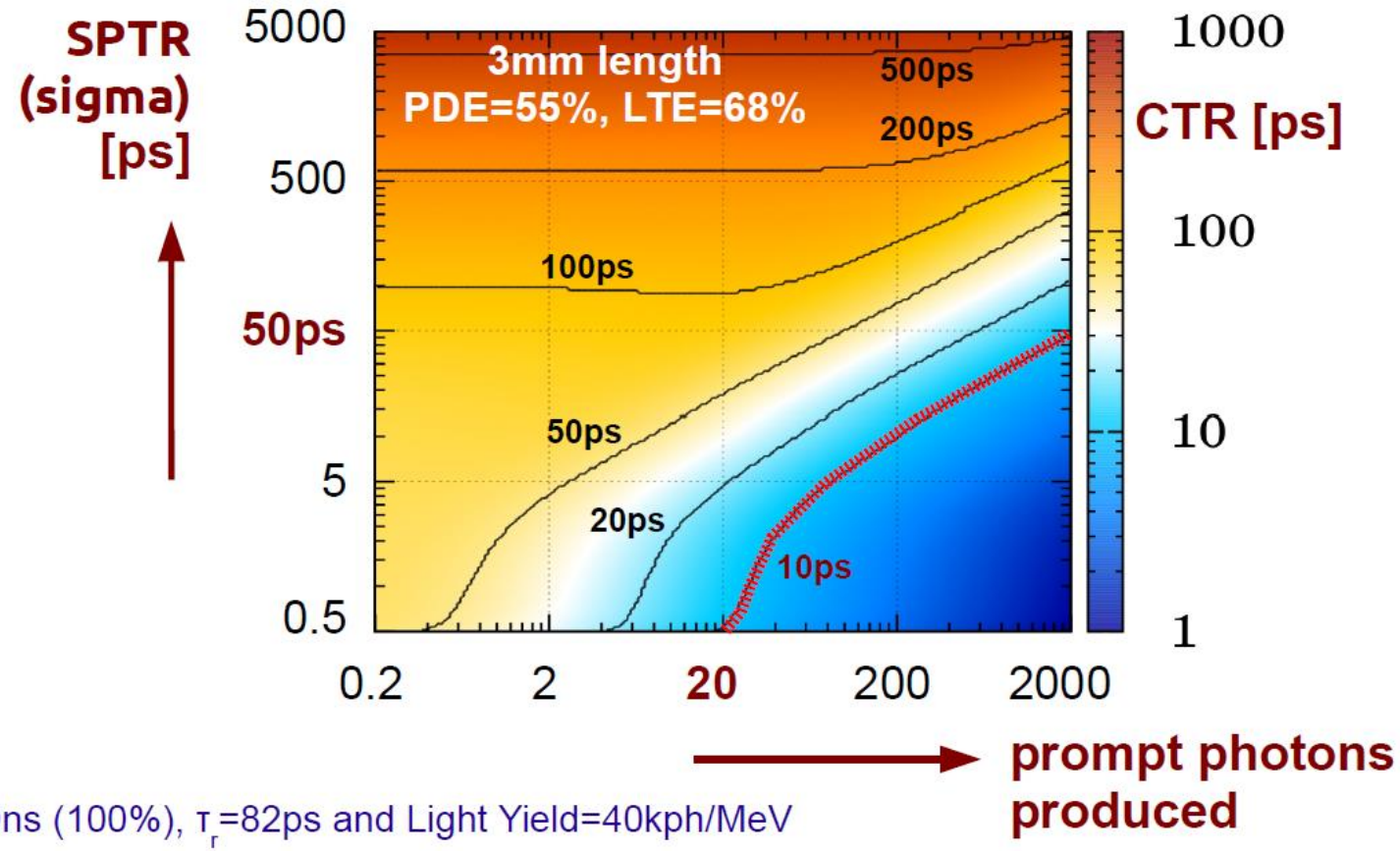
Conversion depth	Scintillation process	Transit time spread	Single photon time spread	TDC conversion time

Understand key limiting factors of timing resolution & Propose routes towards 10ps

Prompt photons

S. Gundacker, PhD Thesis.

Cramer-Rao lower bound calculations including photon transfer time spread (PTS) and light transfer efficiency (LTE) of a **2x2x3mm³ LYSO:Ce crystal**.

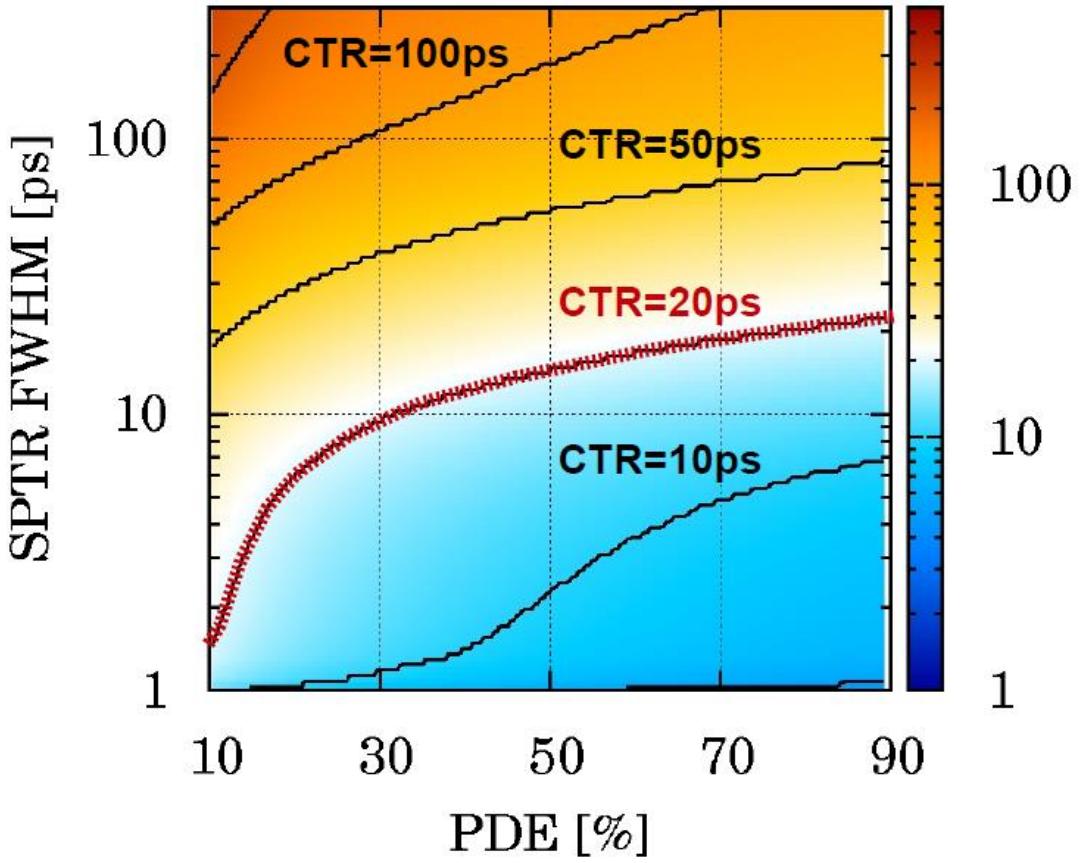


τ_d=40ns (100%), τ_r=82ps and Light Yield=40kph/MeV

Good SPTR

S. Gundacker, PhD Thesis.

Crámer Rao calculations including photon transfer time spread (PTS) and light transfer efficiency (LTE) of a **2x2x3mm³ LYSO:Ce crystal** with **30 prompt photons produced** (Cherenkov + hot intraband).



scintillator parameters:

rise time:
τ_r=80 ps

decay time:
τ_d=40 ns

light yield:
LY=40 000 ph/MeV

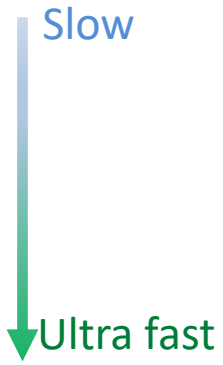
wrapped in Teflon,
coupled with glue n=1.42

WG2:Scintillators

Objectives

- Define & understand key parameters for scintillators with best timing
- How fast inorganic and semiconductor scintillators can be?
- Develop ideas/exploit properties of materials for better possible timing resolution
- What light producing modes prior to standard light generation exist?

- **Study of emission types:**
  - Excitonic emission (STE, excitations of anion complexes)
  - Emission of activators (Ce, Pr, …)
  - **Crossluminescence**
  - **Quantum confinement driven luminescence**
  - **Hot intraband luminescence (HIL)**
  - **Cherenkov radiation**



- **Study of Light transport and collection**
  - R&D on innovative ways to transport the light
  - R&D on increase light collection surface treatment, photonic crystals, light guide

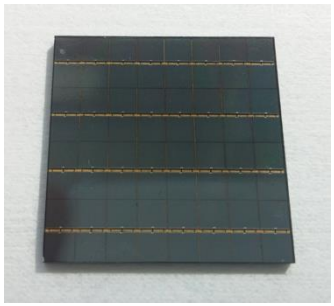
WG3: Photodetectors

Objectives

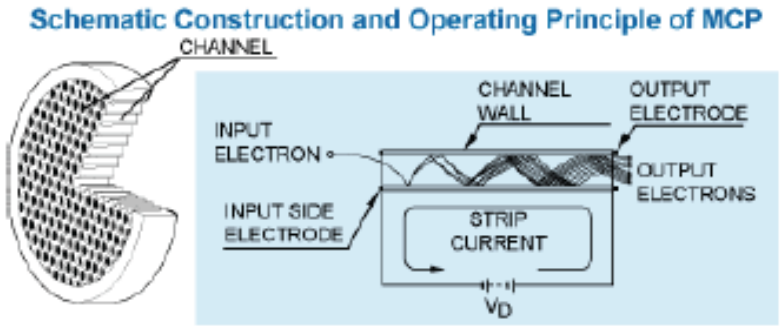
- Define key parameters for best timing performance
- Investigate the timing of different detector technologies
- Cooperate with industry to reassure feasibility of ideas

Competing technologies

PMT



SiPM



MCP

Photodetector workshops

- Prague, April 2015
- Corsica, May 2015
  < Aachen, Sept. 2015 (industrial)
- Trento, March 2016
  < Strasbourg, Nov. 2016 (industrial)
- Lisbon, January 2017
- Lubljana, January 2018

Sensor technologies

	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

Cost, market competition,…

Possible improvments?

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

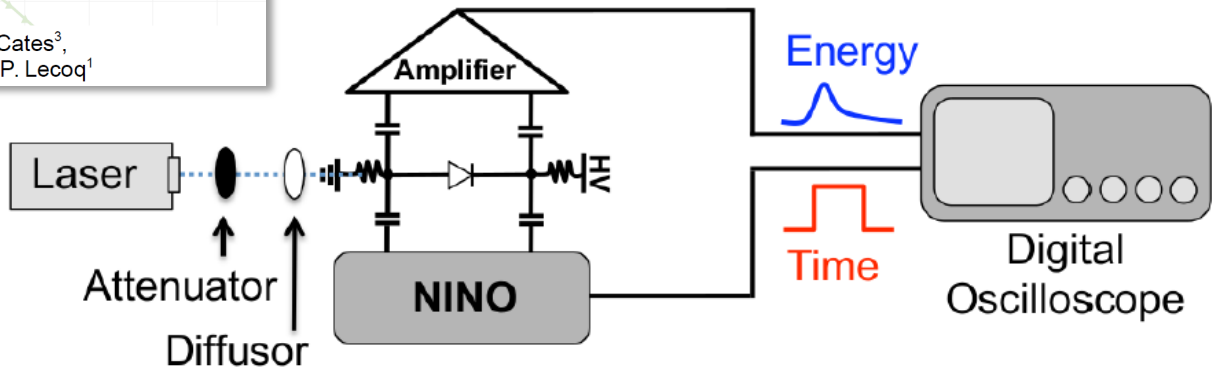
3D integration :
SPAD/SiPM custom technology
+
high-end electronics

* depending on market and Si foundry involvement

SiPM SPTR investigation

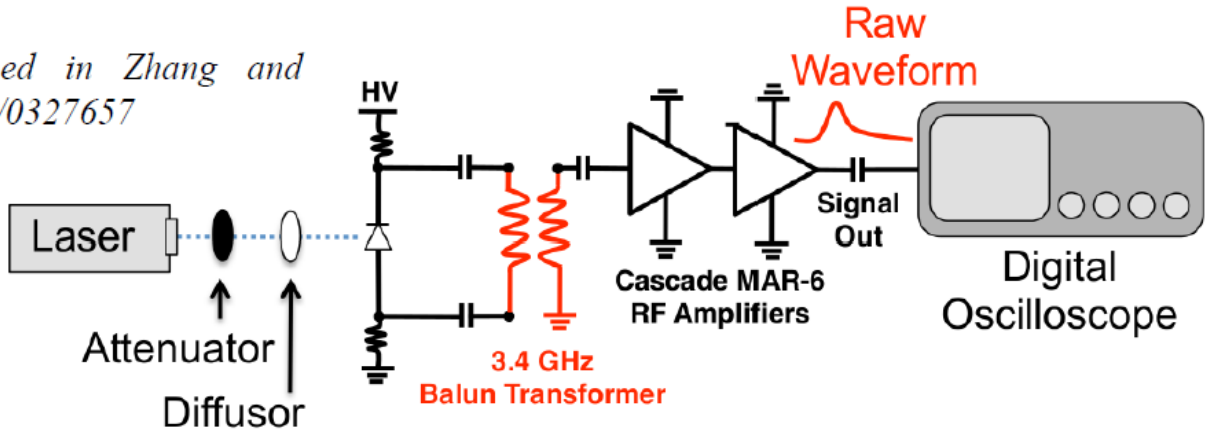
Single Photon Time Resolution (SPTR) improvement

S. Gundacker[1,2], J.W. Cates[3], E. Auffray[1], S. Levin[3] and P. Lecoq[1]



Passive Compensation Circuit:

Inspired by method outlined in Zhang and Schmand US Patent: US2016/0327657



Improvment of SPAD SPTR

Single Photon Time Resolution (SPTR) improvement

S. Gundacker[1,2], J.W. Cates[3], E. Auffray[1], S. Levin[3] and P. Lecoq[1]

Sensor	NINO (FWHM)	passive comp. (FWHM)	without laser 42ps (FWHM)
single masked SPAD (30µm)	52 ps	-	<30 ps
FBK NUV 40µm SPAD	75 ps	74 ps	61 ps
FBK NUV 1x1mm² (40µm)	94 ps	75 ps	62 ps
FBK NUV 3x3mm² (40µm)	175 ps	100 ps	91 ps
FBK NUV-HD 4x4mm² (40µm)	**113 ps**	**90 ps**	**80 ps**
HPK S13360 3x3mm² (50µm)	220 ps	144 ps	138 ps
SensL J 3x3mm² (35µm)	290 ps	150 ps	144 ps

WG4: Electronics

Objectives

- Define Key parameters required for time precision
- Design novel ASICs based on proposed specifications of the action
- Coordinate a joint characterisation of prototype devices

Several ASICs for SIPM are now available:

- analog: amplifiers, amplifier+discriminators
  NINO, FlexTOT, FastIC
- analog-digital: amplifier, discriminators, ADC, TDC
  PETA, PETIROC, STIC, TOFPET1, TOFPET2,

Similar results obtained for SPTR and CTR (FWHM)

SPTR for small SiPMs(1x1 mm2): 100 ps
SPTR for large SiPMs(3x3 mm2): 200 ps
CTR for small crystals (2x2x3 mm) around 100 ps
CTR for large (realistic) crystals (2x2x20 mm) around 200 ps

WG5: applications

Objectives

- Identify target applications
- Discuss & evaluate requirements of end users with respect to timing

Possible applications of FAST detection chains

Medical Imaging: TOF-PET, Single-photon X-ray
Biological Imaging: Live Imaging, ballistic imaging, multi-thread flow cytometry, imaging in the mesoscale, laparoscopic applications
Security: Terrestrial border control of large volumes.
LiDAR applications: High-precision remote sensing
High Energy Physics: HLLHC experiment upgrade, Cerenkov Imaging

For all these applications we have established contacts

Conclusion

- FAST Action has created and fostered a multidisciplinary expert network on fast timing detectors: system, scintillator, sensor and electronics.

- FAST is successfully contributing in the understanding of the full detection chain and the key parameters for fast timing resolution through:
  → researcher exchange;
  → thematic workshops;
  → discussions;
  → promoting projects;
  → promoting relation with industry.

10ps time resolution: Our next Challenge!

Contact details

Web page :

Website: http://fast-cost.web.cern.ch/fast-cost/

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