TF4 Draft Outline

Peter Krizan (Ljubljana) and Neville Harnew (Oxford)

Panel Members :

- Ichiro Adachi (KEK)
- Christian Joram (CERN)
- Eugenio Nappi (INFN Bari)
- Hans-Christian Schultz-Coulon (KIP Heidelberg)

09:00 → 09:25 **Introduction and facilities input**
Speakers: Neville Harnew (University of Oxford (GB)) , Philip Patrick Allport (University of Birmingham
Allport-Harnew-TF4-...

09:30 → 10:00 **RICH technology requirements & optical elements**
Speaker: Carmelo D'Ambrosio (CERN)
carmelo_2021_05_0...

10:10 → 10:35 **Radiator materials**
Speaker: Ichiro Adachi (KEK)
RadiatorMaterial-IA....

10:45 → 11:00 **Coffee break**

11:00 → 11:25 **DIRC technology requirements**
Speakers: Joachim Schwiening (GSI Helmholtzzentrum für Schwerionenforschung GmbH) , Jochen Sc
GmbH (DE))
20210506-ECFA-TF...

11:35 → 12:00 **Time of flight technologies**
Speaker: Roger Forty (CERN)
TOF technologies.pdf

12:10 → 12:35 **Gaseous detectors with photocathodes/ MPGDs**
Speaker: Fulvio Tessarotto (INFN Trieste)
tessarotto_ECFA_TF...

13:30 → 13:55 **MCP-PMT technologies**
Speaker: Kenji Inami (Nagoya university)
20210506MCP_ina...

14:05 → 14:30 **SiPMs technologies and timing**
Speaker: Samo Korpar (Jozef Stefan Institute (SI))
TF4-Korpar.pdf

14:40 → 15:05 **SiPMs - radiation hardness, low-temperature operation etc**
Speaker: Yuri Musienko (University of Notre Dame (US))
SiPMTs-rad-hard-ne...

15:15 → 15:30 **Coffee bre**

15:30 → 15:55 **Photomultiplier technologies**
Speaker: Razmik Mirzoyan (Max-Planck-Institute for Physics)
ECFA-Detector-R&D-...

16:05 → 16:30 **Superconducting devices overview**
Speaker: Sae Woo Nam (NIST)
TF4_Nam.pdf

16:40 → 17:05 **Overlapping technologies and summary**
Speaker: Peter Križan (Jožef Stefan Institute, Ljubljana)
ecfa2021-tf4sympo...

17:15 → 17:45 **Discussion session**

Many thanks to the symposium speakers for their essential input

DRAFT : Section of Task Force 4 Photon and Particle Identification Detectors

- \section{Brief Introduction}
  - Here a short introduction is given which includes the state-of-the-art

- \section{Main drivers from the facilities}
  - Overview of the main requirements from the facilities for the specific TF. The output of the matrix can be used here **(see over).**

- \section{Key technologies: particle identification}
- \section{Key technologies: photon detection}

Facility requirements : Particle Identification

Projects	Timescale	RICH (high and low momentum PID)	Time of flight and DIRC	RPC technologies	TRD & dE/dx
Panda/CBM (Fair/GSI)	2025	✓	✓	✓	
NA62/KLEVER/TauFV	2025	✓	✓		
ALICE	2026-27 (LS3) – 2031 (LS4)	✓	✓	✓	✓
Belle-II	2026	✓	✓		
Neutrino long baseline	2027				
LHCb	2031 (LS4)	✓	✓		
ATLAS-CMS	2031 (LS4) - 2035 (LS5)				
Non accelerator & particle astro	--				
EIC	2031	✓	✓		
ILC	2035				
CLIC	2035				
FCC-ee	2040	✓	✓		✓
Muon-collider	> 2045				
FCC-hh	> 2050				

* Table layout: with thanks to Didier Contardo

Facility requirements : Photon Detectors

Projects	Timescale	SiPM technology	MCP-PMT technology	Large diameter PMT technology	Scintillating fibres & new scintillating materials	CCDs & superconducting devices
Panda/CBM (Fair/GSI)	2025	✓	✓			
NA62/KLEVER/TauFV	2025	✓	✓			
ALICE	2026-27 (LS3) – 2031 (LS4)	✓	✓			
Belle-II	2026		✓			
Neutrino long baseline	2027	✓		✓	✓	
LHCb	2031 (LS4)	✓	✓		✓	
ATLAS-CMS	2031 (LS4) - 2035 (LS5)	✓				
Non accelerator & particle astro	--	✓		✓	✓	✓
EIC	2031	✓	✓		✓	
ILC	2035	✓			✓	
CLIC	2035	✓			✓	
FCC-ee	2040	✓	✓		✓	
Muon-collider	> 2045	✓				
FCC-hh	> 2050	✓				

* Table layout: with thanks to Didier Contardo

RICH technologies

- \subsection{RICH detectors}
  - RICH design
    - Timing crucial to the new generation of RICHes
    - Design of RICH detectors with a total length shorter than a meter.
    - Pressurizing noble gases to several bars
    - Design of a very compact RICH detector working in the far UV (VUV) region
    - The design of lightweight mirrors
  - Photon detectors
    - With a high photon detection efficiency large area single photon detectors capable of sustaining high counting rates, a total ionizing dose up to a few Mrad, a high granularity, timing resolution of the order of few tens of ps
  - Radiator materials
    - Gas : Alternative to fluorocarbons
    - Liquid
    - Solid, Crystal, Aerogel
    - Meta-materials, such as photonic crystals, capable to match the refractive indices needed to identify particles at high momentum.

DIRC Technologies

- \subsection{DIRC detectors}
  - Introduction
    - Short intro on DIRC principle, time of propagation.
    - Advantages
    - Disadvantages (not so suitable at high energy machines)
    - Future applications, e.g. Panda, Belle-II EIC, Gluex
  - Future R&D
    - R&D to make DIRC readout more compact, expand momentum reach, use for endcap. Focusing design, emphasizing spatial resolution.
    - Exploring mitigation of RICH resolution terms: chromatic dispersion, multiple scattering.
    - Quartz technology, surface quality ((sub)nm surface roughness, current cost driver), lower price.
    - State of the art timing is also important (O(10)ps binning)
    - Photon Detection - Fast timing performance essential (ps level). SiPMs, MCP-PMTs. Photon detector granularity. Radiation tolerance, low noise, photon sensitivity.

- \subsection{TOF detectors}

TOF Technologies

- Introduction
  - Short intro on ToF principle;
  - Advantages
  - Disadvantages :TOF falls fast, provides only complimentary PID for high energy machines.
  - Synergy with calorimeter, timing layers, 4-D tracking silicon detectors
  - List of future applications, , e.g. Panda/CBM, Na62/TauLV, ALICE, Long Baseline, LHCb, ATLAS/CMS, EIC, FCC ...
- ToF methods
  - Scintillators
  - Gaseous detectors: Multigap RPCs, micro pattern gas detectors. Picosecond development
  - Silicon detectors (overlap with FT3) :Low gain avalanche diodes (LGADs)
  - Large area MCPs : LAPPDs. Instrumenting large area surfaces
  - Cherenkov (DIRC)-based detectors eg. TORCH detector
- Future R\&D challenges
  - State of the art timing ASIC compulsory (O(10)ps binning)
  - Quartz technology (as for DIRC),
  - Photon Detection - Fast timing performance essential (ps level). SiPMs, MCP-PMTs LGADs.
  - Timing (clock) distribution R&D essential.

\subsection{PID with dE/dx, TRD}

(with references to the TF1 chapter)

PID with dE/dx, TRD

dE/dx resolution around 5% is routinely reached, in excellent conditions and with accurate calibration. Possible improvements

- dE/dx resolution ~ 5.4% $(LP)^{-0.37}$ with L length in m, P pressure in bar; the interest in the P term is renewed where excellent PID is needed together with a large mass of the gas (TPC-as-a-target). R&D topics: suitable gas mixtures for high-P operation, light pressure-containment vessels.
- Cluster counting: dN_{cl}/dx resolution is potentially better than dE/dx (by a factor of 2). Cluster counting requires fast electronics and sophisticated counting algorithms, or alternative readout methods. It has the potential of being less dependent on other parameters. Cluster counting in time, cluster counting in space; R&D topics: wave-form sampling FEE with FPGA processing, 2D micropattern read-out.

TRD: employed in several experiments, ATLAS, ALICE, AMS, CBM, EIC

- Gas TRDs a mature instrument for PID at high energies. Due to the overlapping of the TR signal with the ionization, a precise knowledge (and simulation) of dE/dx is a must.
- GEMs are making their way in the technique
- An attempt has been made to improve cluster counting by means of a GridPix. Some improvement is possible, although not drastic. Potential improvement may be reached by differentiating the response to X-ray photons and to particle ionization→ Extensive R&D required!
- TRD imaging (e.g., with Timepix3)? (for hadron PID at very high energies)

Vacuum based photodetectors

\subsection{Vacuum based photodetectors}

- Micro-channel plate detectors (MCP-PMTs)
  - Cost of devices/unit area needs to be reduced. Gain 10^6 – 10^7. To improve: rate limitation around 10^5 /cm2. Improvements (QE, CE, lifetime, rate) to come. Granularity needs to be tunable for DIRC/TOF applications. Also to improve - operation at lower gain to reduce integrated charge: readout electronics essential. LAPPD pixelated readout.
- Photo-multipliers (including large areas)
- Multianode (MaPMTs)
- Hybrid avalanche photon detectors (HAPDs)
- Hybrid HPDs
- Others? PMT with a-Si based MCP. Tynode: CMOS pixel chip with transition dynodes on top. (H.v.d. Graaf). VSiPMT (Barbato)

- \subsection{Gas based photodetectors}

Gas based photodetectors

Introduction

- Gaseous Photon Detector (GPD) features
- Requirements for using GPDs at future facilities

Develop GPD based on Micro Pattern Gaseous Detector (MPGD) structures

- with enhanced capability to reduce the negative effects of positive-ion back flow and photon feedback caused by the charge multiplication process in the gas. The goal is to improve the photocathode lifetime and the intrinsic GPD amplification gain (high single photoelectron detection efficiency) and operating speed.

Search for UV sensitive materials more radiation-hard and chemically inert than CsI.

- Carbon based photocathodes

Develop GPDs with time resolution in the few ps range.

- The PICOSEC-Micromegas Detector Development

Gas based photodetectors

- \subsection{Gas based photodetectors}

Develop compact GPD systems with integrated electronics for imaging applications

- InGrid - Micromegas integrated in a Timepix

R&Ds for alternative hydrocarbon-free gas mixtures

GPDs for cryogenic applications, 4π coverage for detecting the scintillation light produced in the noble liquids

- Detection of both scintillator light and ionization

Very challenging extension to the visible spectral range.

Semiconductor photodetectors

- \subsection{Semiconductor photodetectors}

Introduction

- short intro on SiPM principle; parameter correlation use case and list of (future)
- applications in particle physics advantages and disadvantages (w.r.t. to PMTs)
- recent performance improvements (intro only) short list of what still needs research (more details below) [e.g. timing, radiation tolerance, low backgrounds ...]

Basic SPAD Technologies

- Analog vs. Digital, Custom vs. CMOS
- Active vs. Passive

- \subsection{Semiconductor photodetectors}

Semiconductor photodetectors

Recent Developments and Future Challenges

- Photon Detection Efficiency (IR, V, UV) [different needs for different areas]
- Cell size, dynamic range, fill factor ...
- Fast timing performance
- Noise, cross talk, after-pulsing [single pixel r/o; hybrid vs. CMOS]
- Temperature dependence
- Radiation Hardness
- Cryogenic performance [large area arrays; ganging]
- r/o Electronics

Concluding Remarks

- Connected areas (scintillators; radiators, micro-lenses; integration)

- \subsection{Superconducting photodetectors}

Superconducting photodetectors

Single photon detection technologies with superconductors

Superconducting detectors for UV-midIR photons

- TES: Transition Edge Sensor
- SNSPD: Superconducting Nanowire Single Photon Detector
- MKID: Microwave Kinetic Inductance Detector

Example: nanowire detectors for dark matter detection; dark photons

Work in progress relevant to HEP applications

Novel optical materials for fiber trackers

- \subsection{Novel optical materials for fiber trackers}

Scintillating fibres:

- A cost-effective way of instrumenting large areas for charged particle tracking at relatively low material budget. With the availability of small-pitch SiPM arrays, high resolutions are possible (LHCb SciFi tracker upgrade)

Further advances in the technology, e.g. for a second upgrade of the tracker envisaged for the High-Luminosity LHC:

- Optimize photo-sensor and optical fibers need to be optimised for a higher light yield, allowing for smaller diameters and thus higher precision and improved radiation tolerance.

Open issues:

- Radiation tolerance, speed, emission spectrum

Innovative materials: Nanostructured-Organo-silicon-Luminophores (NOL) scintillators:

- Exhibit stronger and faster light output than presently achieved.
- Decay time: NOL fibres are almost a factor 2 (6) faster than the best blue (green) standard fibres, which makes them very interesting for time critical applications
- Radiation hardness (X-rays to a dose of 1 kGy): damage is as expected on a level comparable to reference fibres

Promising results but clearly more R&D needed

Concluding sections

- \section{Observations}
  - This section covers comments on community, cross-cutting issues, more global points with neighbouring fields and interactions with industry,

- \section{Recommendations}
  - This section covers unmet needs for short, medium and long-term R\&D and organisational model for future R\&DA bulleted list or subsections of the needs could be included.