Closing PD24

Fabrice Retiere (TRIUMF)

We respectfully acknowledges the Sḵwx̱wú7mesh Úxwumixw (Squamish), səl̓ilw̓ətaʔɬ (Tsleil-Waututh) and xʷməθkʷəy̓əm (Musqueam) peoples on whose traditional, unceded territories the Vancouver campus resides.

Special thanks

- The International Advisory Committee for helping make the workshop happen
- Darren Grant (SFU) and the Simon Fraser University team for all the behind the scene work
- The abstract review team led by Paolo Agnes (Gran Sasso Science Institute)
- All the pictures by Paolo Organtini (Princeton Univ.)
- Maria Adriana Sabia (TRIUMF, Sapienza) for managing the agenda, the tour,...
- M. Walzcak (Gran Sasso Science Institute) with help from Seraphim Koulosousas (Royal Holloway University London) for the audio/video
- Everyone from the TRIUMF team to help on short notice
- And Giacomo Gallina (TRIUMF, Princeton Univ., Co-Chair) for everything else

Many thanks to all attendees

Discovery, accelerated

Posters

- I was very impressed by the quality of the posters
- This is the sign of a healthy community!

The need for single photon detectors is stronger than ever

Many contributions. Sorry for not citing names

- ”Standard model” particle physics – now and in the future
  - From CMS, from HPD to “rad-hard” SiPMs
  - Electron-Ion Collider + ALICE, Quantum Chromo-Dynamics with many SiPMs
  - LHCB low light fast timing. Playing out the SiPM – MCP competition
  - Future colliders, conceptual stage development, rad hard and high performance
  - Low energy applications continue to bring new challenge, e.g. Liquid Xenon calorimeter for MEG
- Neutrino and dark matter
  - It is exciting to see JUNO about to turn on. HyperK is around the corner and sometime soon DUNE
  - New concepts for very large area detectors, Dichroicon, ASIC,… Digital Hybrid Photo-detector?
  - Noble liquid detectors drive need for Vacuum UV light detection, with low power dissipation even in HV floating condition (nEXO, DarkSide, DUNE)
- Astronomy, neutrinos, cosmic ray, gamma ray
  - In-space astronomy and new camera type
  - No air-shower and neutrino astronomy contribution at this workshop but I am expecting, we will hear back
- Many non-subatomic physics application
  - Medical imaging, neutron detection,…

SiPM radiation damage

- The current status – Y. Musienko
  - Performances degrade a lot
    - Dark noise is the main issue
  - Detector with large signals can survive. M. Wayne
  - Annealing helps
  - Hamamatsu's SiPM appear to sustain radiation damage a bit better than FBK's
- The path forward. A. Gola et al.
  - Lowering the gain – lowering the maximum electric field
    - Reduce dark noise
  - Lowering the temperature. E. Rivera et al.
    - Dark noise start lower
  - Focusing the light with lenses

PMT & MCP – what is new?

- PMT – when low dark noise is required and timing is moderately demanding
  - Comprehensive overview talk by S. Qian
  - JUNO + HyperK are in the commissioning/construction phase – quite a few talks and posters
  - Next? Neutrino astronomy (P-ONE, IceCUBE, Km3Net?)
- MCP – when low dark noise and fast timing is required
  - MCP + Anode + electronics integration is major effort – T. Conneely, L. Ma
  - Timing achieve in the 10-20ps Single Photon Timing Resolution

Electronics – new ASICs

- Analog Photon Processor for PMT – J.Klein
- Wide range of development at Fermilab and many other labs – P. Rubinov
- LightPix for large number of channels – S. Greenberg
- CAEN + WEEROC and others providing complete solutions – M. Locatelli

Optics and photonics

- Dichroicon – Josh Klein (Penn)
- Macro lenses – Guido Haefeli (EPLF)
- Meta lenses – (M. Garcia Peris, U. Manchester - poster)
- “Photonic” communication by modulating light - James Sinclair (SLAC) and Paul Rubinov (Fermilab)
- My view: with advent of simulation software and photonic fabs, it is a field that will expand

New material for photo-detection

- Selenium – compelling for UV and can be adjusted for visible
- GaN – focus on UV and VUV
- GaN photo-cathode for HPD
- Diamond as a scintillator

SiPM – Many new development with still not well understood feature

- Progress showed by Hamamatsu, FBK and RayQuant
- Question marks
  - Burst
  - Efficiency in liquid Xenon – T.Iwamoto
  - Temperature dependence of efficiency – S. Borden (poster)
- Advancing models
  - Photon detection efficiency modeling. Austin de Ste Croix
  - Timing response. Seraphim Kolousousas

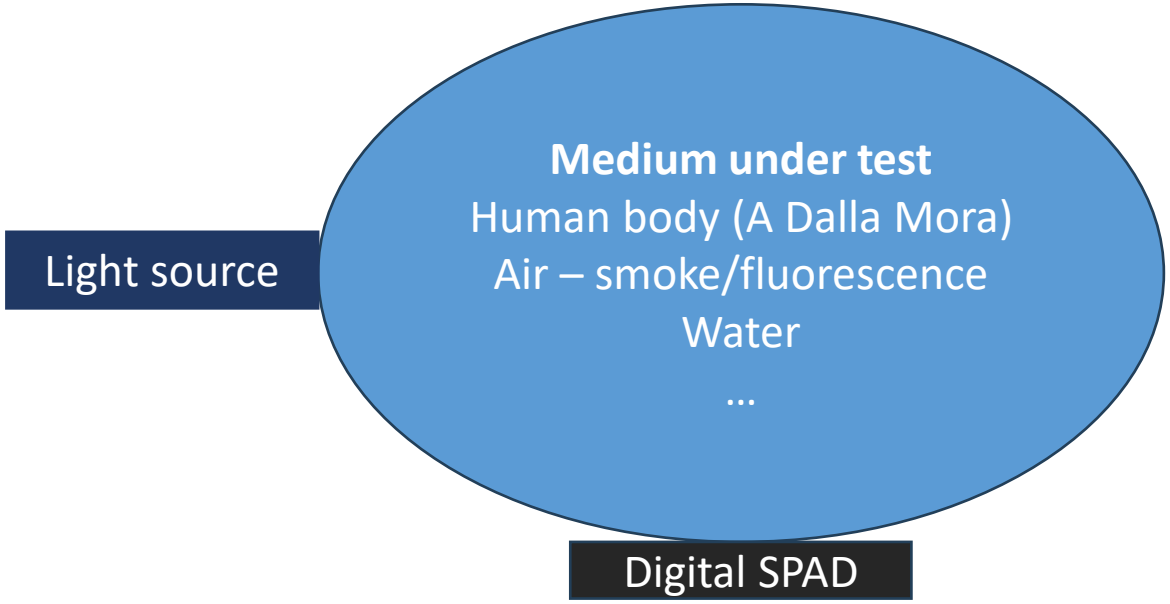
Digital SiPMs

- Peter Fischer showed that monolithic digital SiPM can deliver high performances. But where to make them?
  - Lfoundry / Sparc is most common – N. D'ascenzo, R. Dolenek, RayQuant
  - Global foundry in the US – P. Rubinov
  - Fraunhofer IMS has lowest dark noise but being phased out – P. Fischer
  - Other unknown options: TSMC (Taiwan), AMS (Austria), X-fab (Germany), STMicroelectronics + some in China
  - We should compare the various options
- Is 3D/2.5D a best way forward?
  - Great progress at Sherbrooke (G. Lessard) and FBK (A. Gola)
  - Separate SPAD chip for CMOS chip but require chip to chip integration
  - Single Photon timing resolution for single SPADs about 20ps

Towards PD26

- Prediction 1. digital SiPMs will be used in SAP applications at the next PD in 2026
  - Digital SiPMs will make most analog SiPM obsolete by 2030
  - At least for the group that can pool resources to custom design chip for each application
- Prediction 2. digital SiPM will overtake MCP for SPTR
  - Unless MCP integrated on silicon succeed
- Prediction 3. digital Hybrid Photo-Detector will get to the proof of concept stage
- Prediction 4. There will be a full session about photonic and non-linear optics (3D AR structures,…)

Towards PD26 – For digital SPAD lovers…



There is a wealth of opportunities

- Customize digital SPAD for requirement
- Embed light source
- Use entangled photons?
- Find new applications…

Look towards PD26 and PD27

- The International Advisory Committee met at lunch time. Addition of new members:
  - Shiva Abbaszadeh (UC Santa Cruz, RDC2, new materials)
  - Nicola D'ascenzo (Huazhong University of Science, China, digital SiPM, medical imaging)
  - Massimiliano Fiorini (INFN Ferrara, DRD4, BSI SiPM, MCP)
  - Roxanne Guenette (U. Manchester, DRD2, noble liquid)
  - Guido Haefeli (EPFL Lausanne, SiPM for tracker, LHCB)
  - Josh Klein (U. Pennsylvania, PMT, neutrino)
- We agreed to organize PD26 and PD27 assuming that NDIP happens in France in 2025 (to be confirmed)
- We received several proposals for next PD. We are proposing to have PD26 in Italy (venue to be selected) and PD27 tentatively in China organized by IHEP. We look forward to JUNO results after 2 years of operation!

Farewell

And enjoy the TRIUMF tour tomorrow morning

You will see: TRIUMF general, VERA, MIEL, PMT Testing Facility, Neutron spectrometer proto