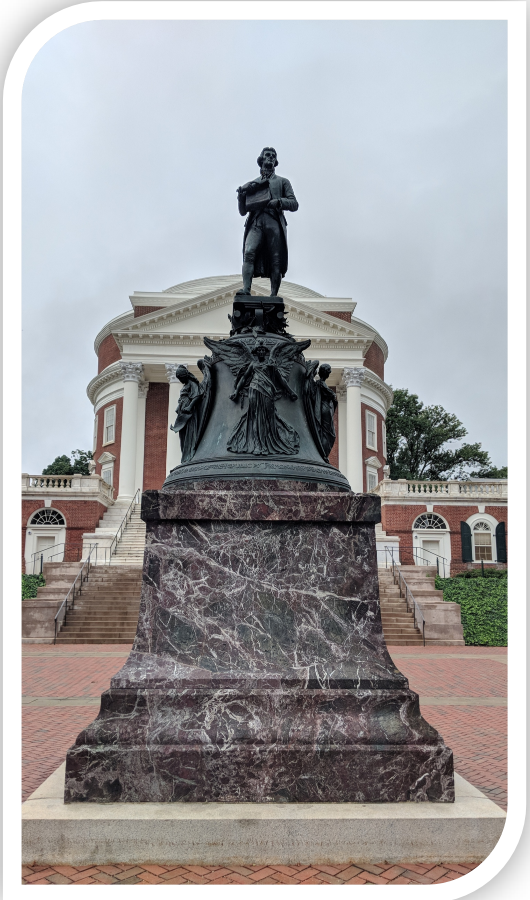
Silicon and Tracking
EIC Workshop Summary

Organizers:
L. Gonella, K. Gnanvo, and M. Posik

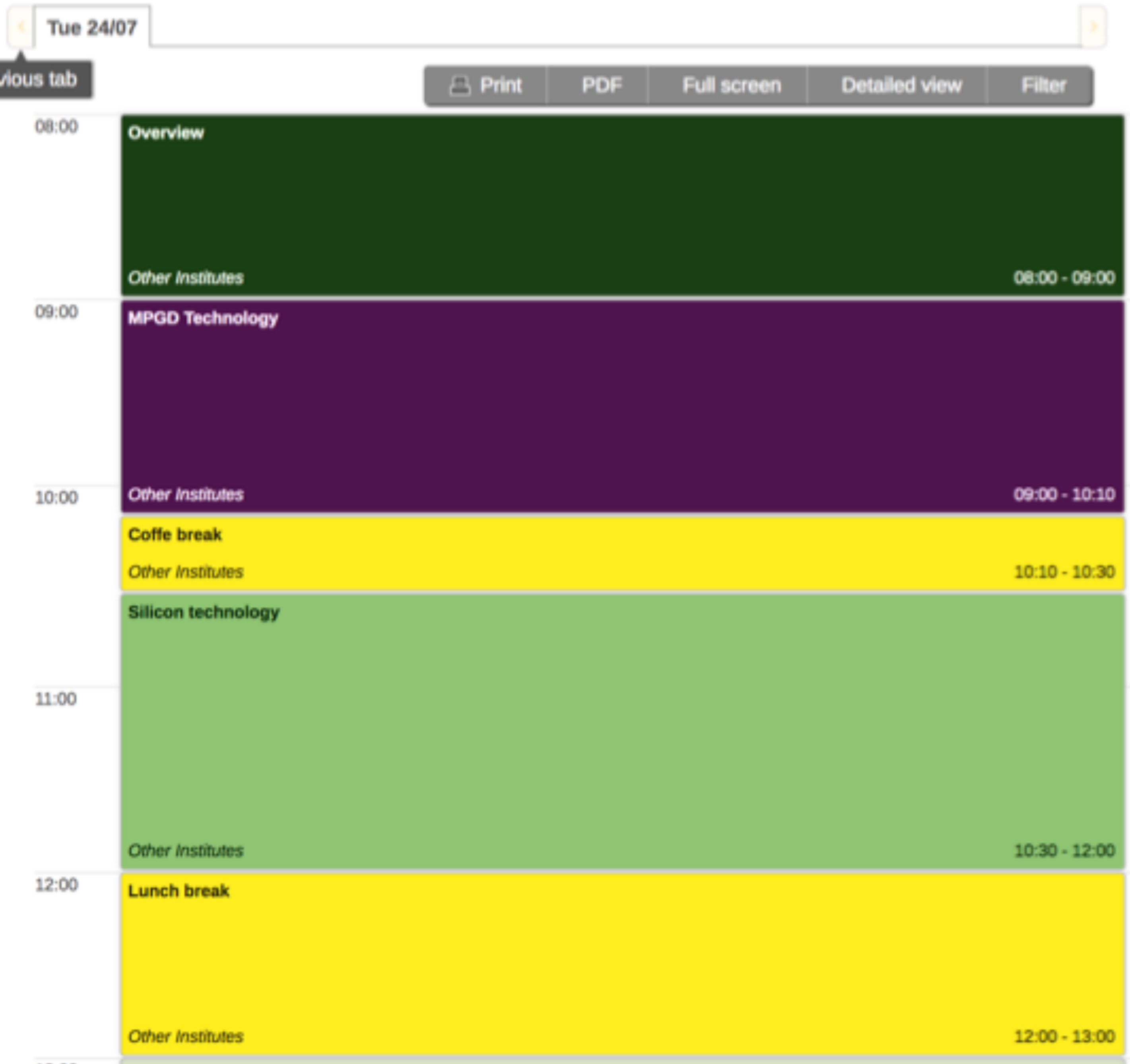
Overview

- **Details**
  - Workshop took place last week at UVa over the course of 1 day.
  - Organizers: Laura Gonella (U. of Birmingham), Kondo Gnanvo (UVa), and Matt Posik (Temple)
  - Large remote participation (> 50%)

- **Workshop Goals**
  - Look at technology
    - that is not supported by current EIC R&D effort and could be suitable for an EIC.
    - that has gained interest in other fields that have potential for EIC use.
  - Attract fields/groups/people not currently involved in EIC work.

Agenda



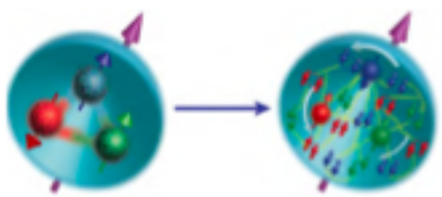
- **5 sessions covering different topics**
  - EIC Physics/R&D overview
  - MPGD
  - Silicon
  - Alternative Technologies
  - Readout Technologies

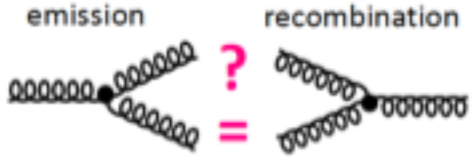
- **Workshop Site**
  - https://indico.cern.ch/event/722363/

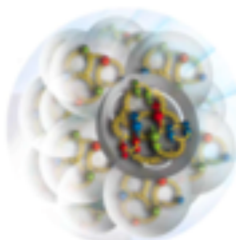
Overview

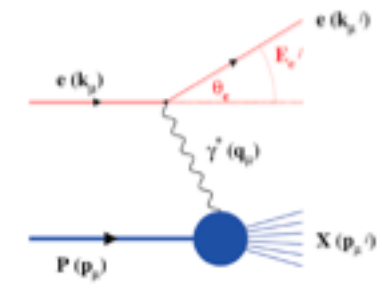
- **EIC physics/detector requirements (Salvatore Fazio)**

1. How are sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?
2. What happens to the gluon density in nuclei?
3. How does a dense nuclear environment affect the quarks and gluons, and their correlations and their interactions?



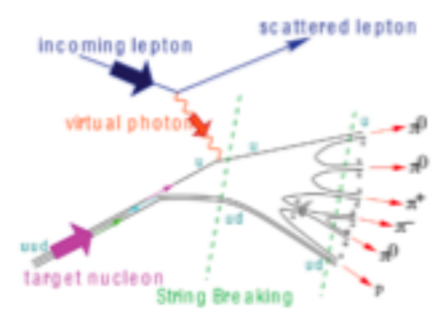






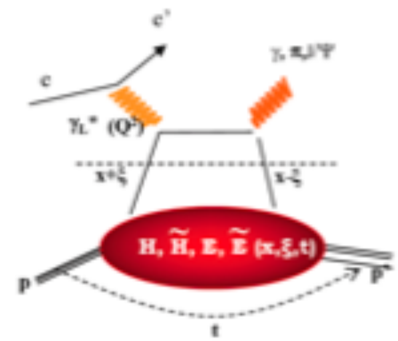
Inclusive DIS

Longitudinal motion



Semi-Inclusive DIS

Transverse momentum



Exclusive Reactions

Transverse space and momentum

EIC requirements

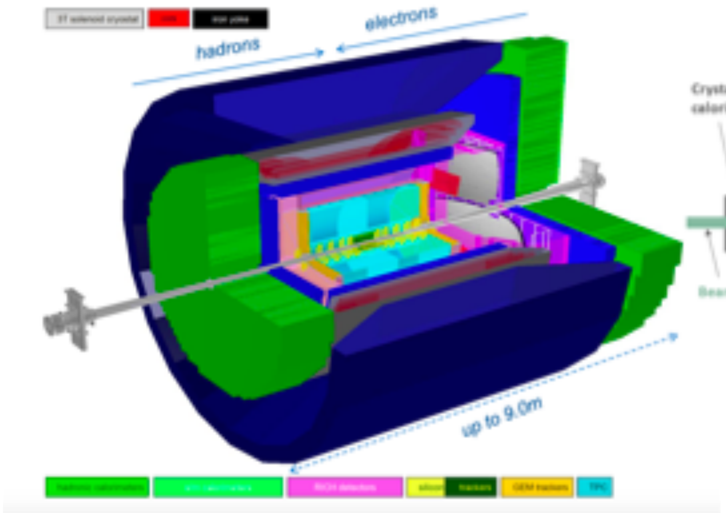
- Wide kinematic range in x and Q^2
- Polarized electron and hadron beams to access spin dependent phenomena
- High luminosity

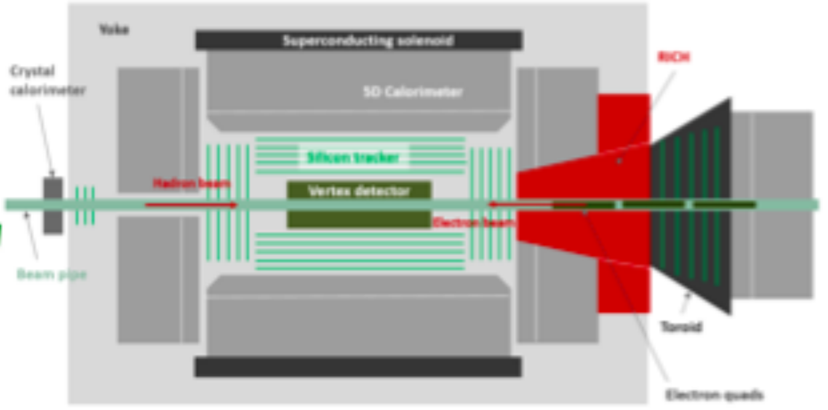
Overall detector requirements:

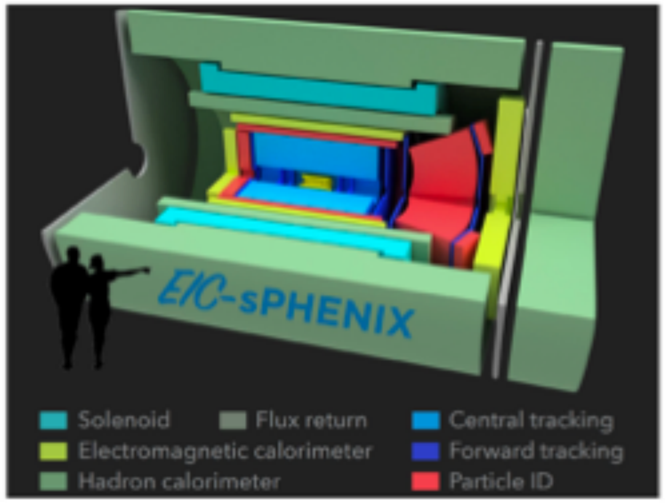
- **Large acceptance in pseudorapidity**: $-4.5 \lesssim \eta \lesssim 4.5$
- Equal coverage of tracking and EM-calorimetry
- High performance PID to separate p, K, π on track level
- High precision low mass tracking
- High control on systematic effects

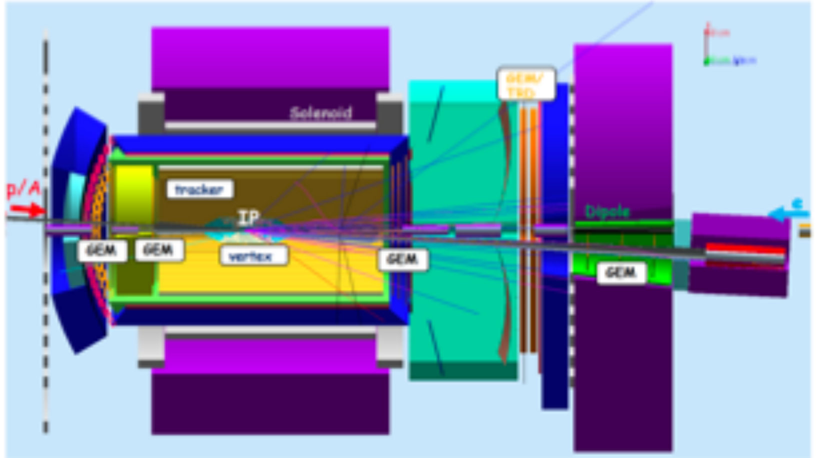
Overview

- **EIC generic detector R&D (Alexander Kiselev)**
  - TU UG meeting 17': Two general detectors
  - Many **common** features between detector concepts BeAST, ePHENIX, JLEIC, and TOPSiDE
  - Tracking R&D should move towards "**extra features**" -- GEM TRD and ps timing



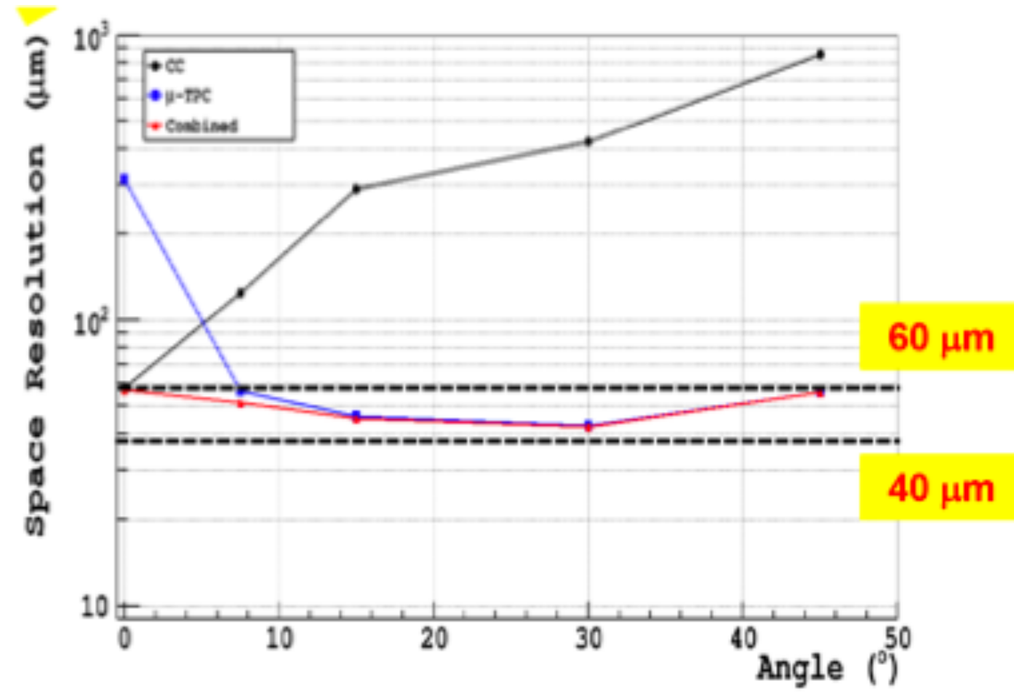




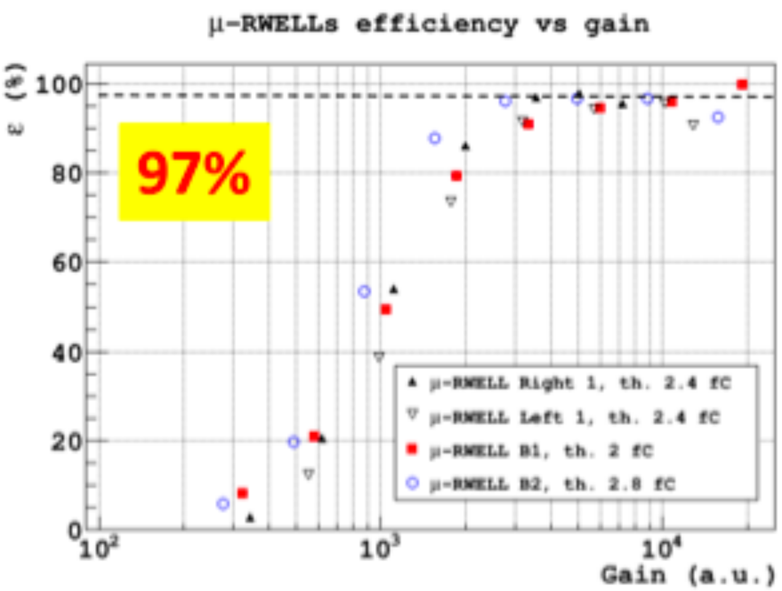


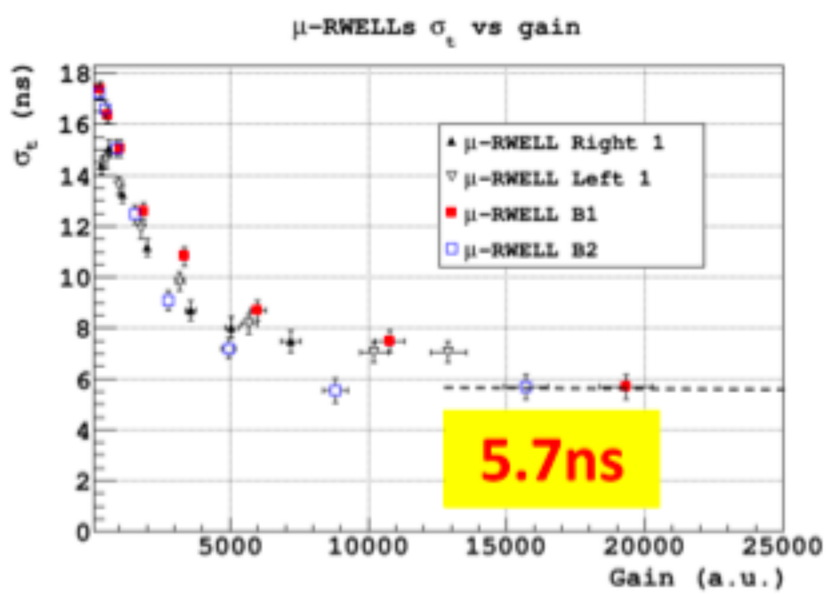
Project	Subprojects
eRD3 (forward tracking)	GEM and MM tracker (cylindrical)
eRD6 (tracking & PID)	Zig-zag readout, Cherenkov TPC, Mini TPC, GEM readout, GEM+MM TPC readout, Meta-Materials for Detection of Cherenkov Radiation, μRWELL Detectors for EIC Central Tracker, MPGDs for EIC RICH Detector
eRD16 (Forward/Backward Tracking using MAPS Detectors)	
eRD18 (Precision Central Silicon Tracking & Vertexing)	
eRD22 (GEM-TRD)	

- ***μRWELL*** **R&D (Giovanni Bencivenni)**
  - Promising technology for large planar and/or inner cylindrical trackers.
    - **Lower mass** than triple-GEM
    - Easier detector assembly
  - Extensively characterized
  - **Gas gain > 10^4**
  - Single resistive layer detectors able to **accommodate rates < 100 kHz/cm^2**
  - Promising development of **double resistive** layers for high rates (> 1MHz/cm^2)
  - Ready for technology transfer to industry

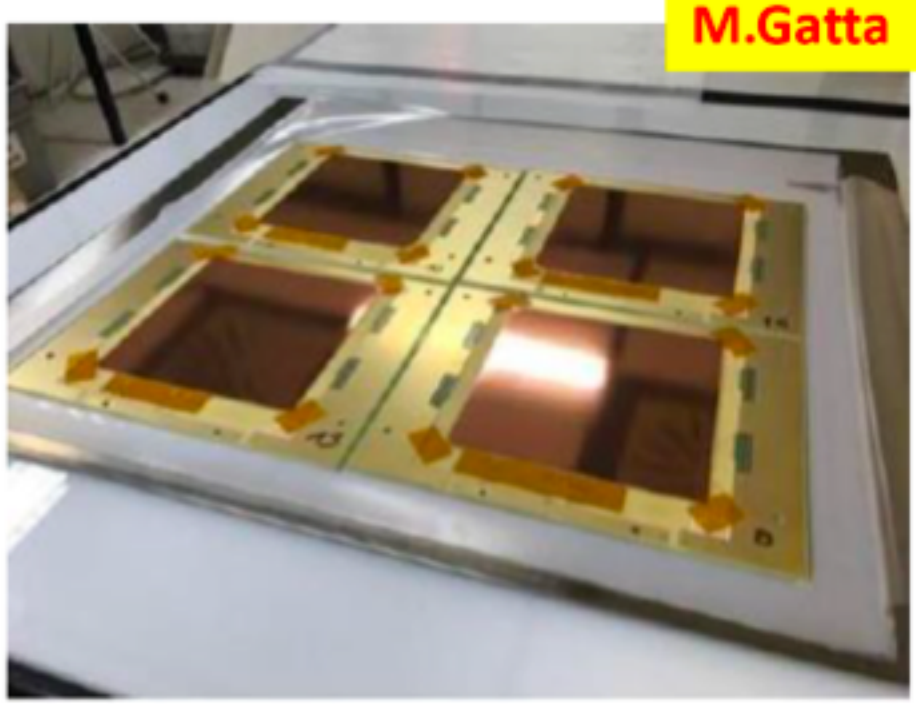


Ar/CO2/CF4 = 45/15/40





M.Gatta

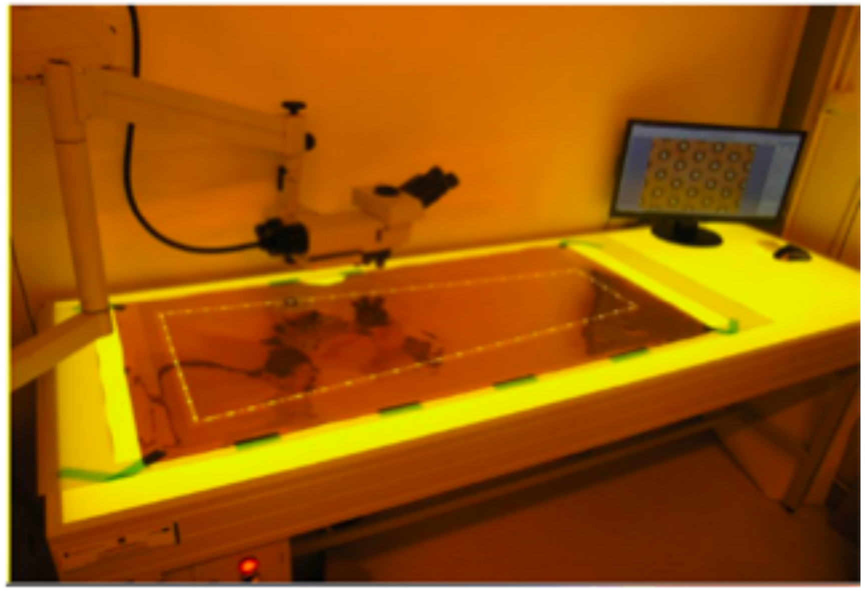


MPGD

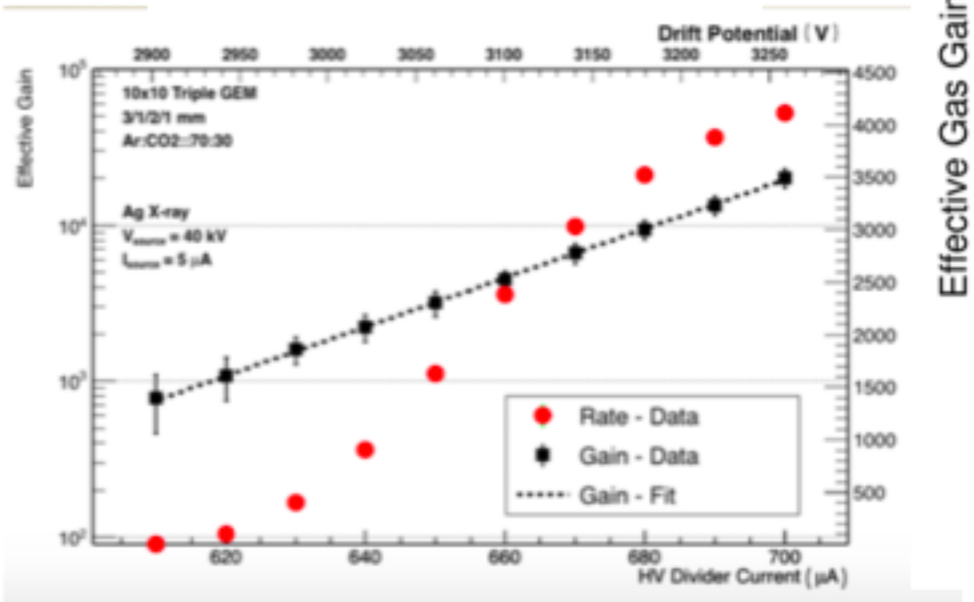
➢ Commercial GEM Development (*Inseok Yoon*)

- 3 companies working on GEM production
- Techtra
  - Polish company currently producing CERN's small GEMs
- Micropack
  - Indian company currently working on CMS upgrade GEMs
  - Use single-mask technique
  - Successfully produced foils up to 30 cm x 30 cm.
- Mecaro
  - Korean company currently working on CMS upgrade GEMs
  - Uses double-mask technique
  - Successfully produced foils up to 130 cm x 60 cm.

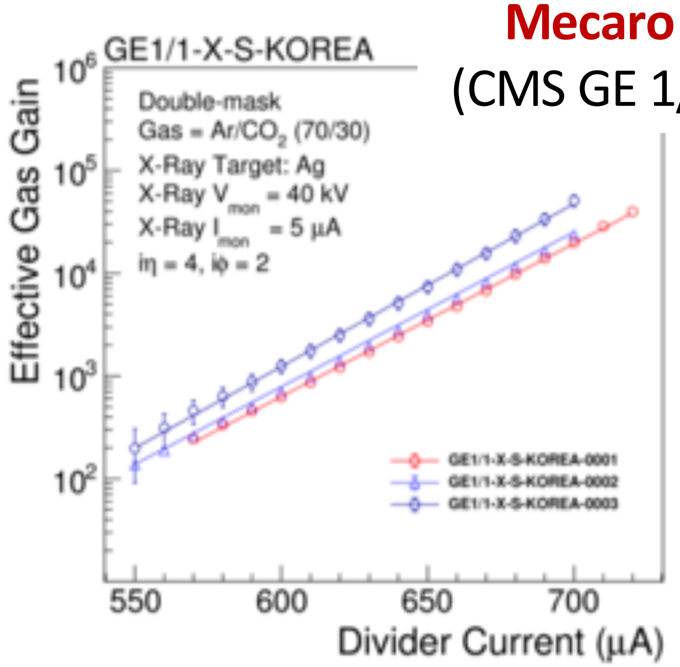
Techtra
(CMS GE 1/1)

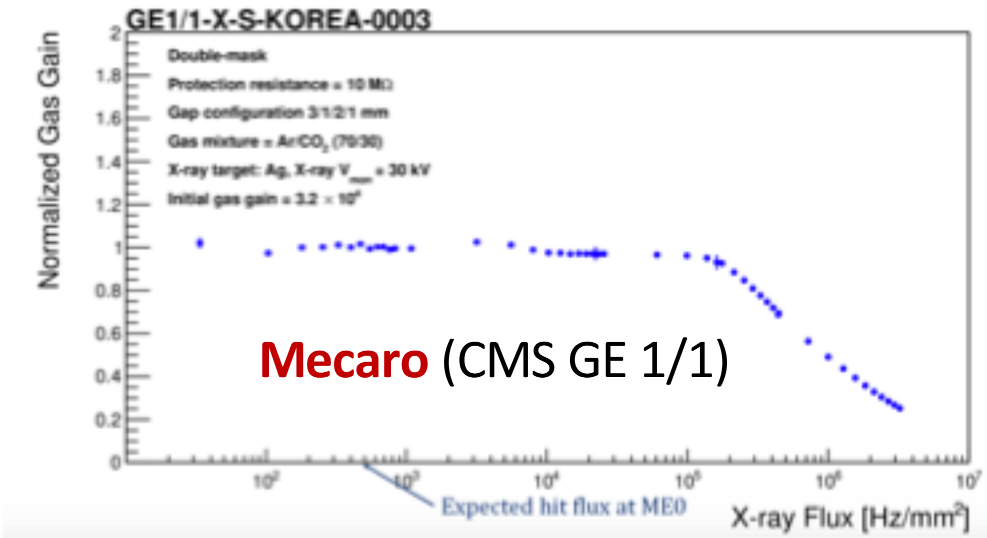


Micropack (10 cm x10 cm)



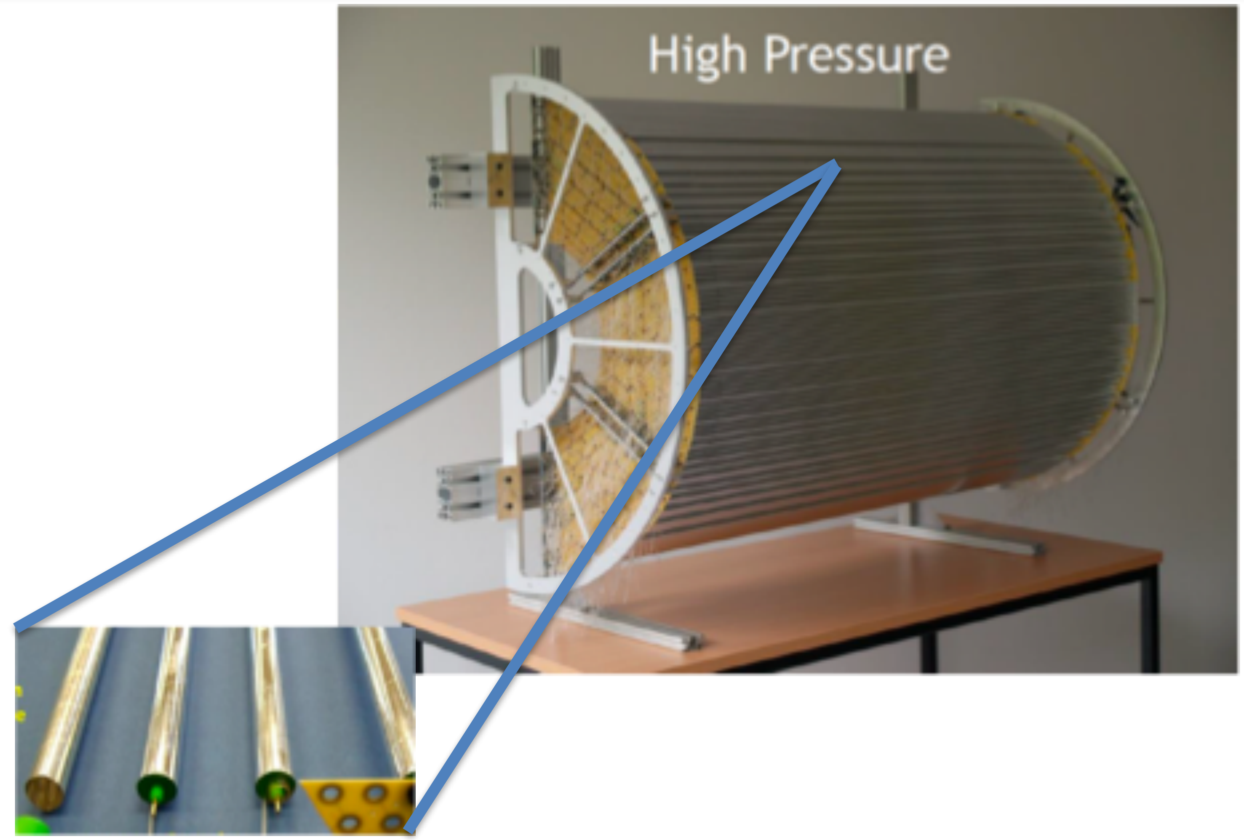
Mecaro
(CMS GE 1/1)

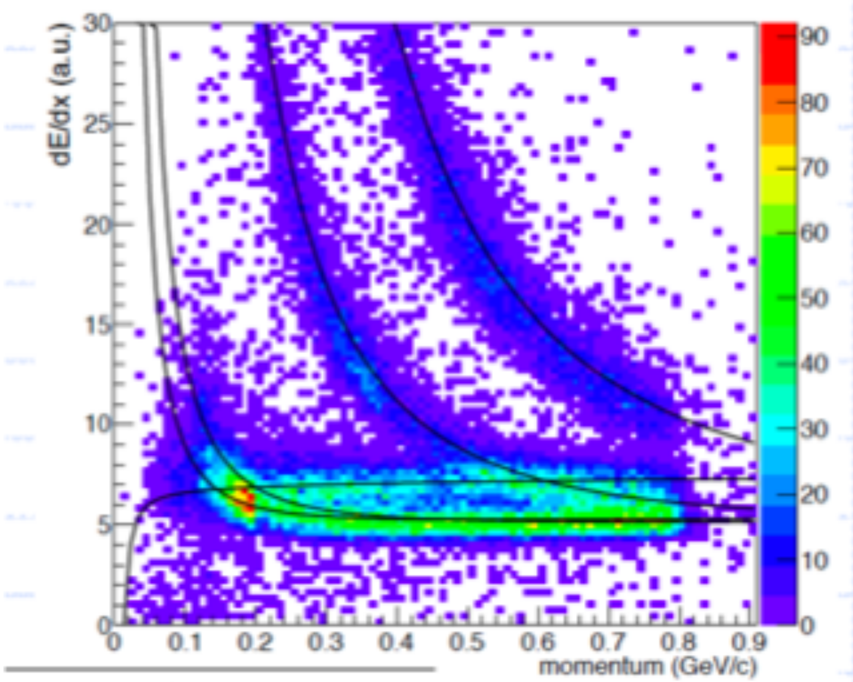




Mecaro (CMS GE 1/1)

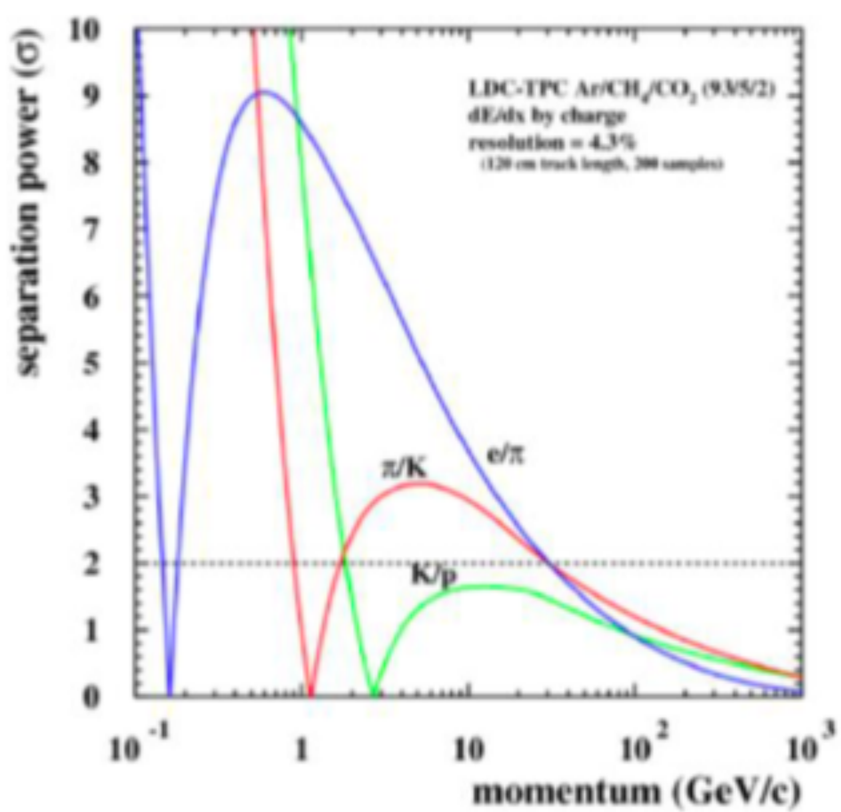
- **EIC Tracking Alternatives (TK Hemmick)**
  - We know how to do tracking at an EIC. Can we pull PID from our trackers?
  - PANDA straw tube tracker good example
    - **Low material**: $\frac{\chi}{\chi_0} \sim 1.23\%$
    - Good resolution: $\sigma_{r\phi} = 150\ \mu m, \sigma_z = 3\ mm$
    - $\boldsymbol{\frac{\sigma_E}{E} < 10\%, \frac{\sigma_p}{p} = 1 - 2\%}$
  - Gain additional separation power using cluster counting method over truncated mean in a TPC?

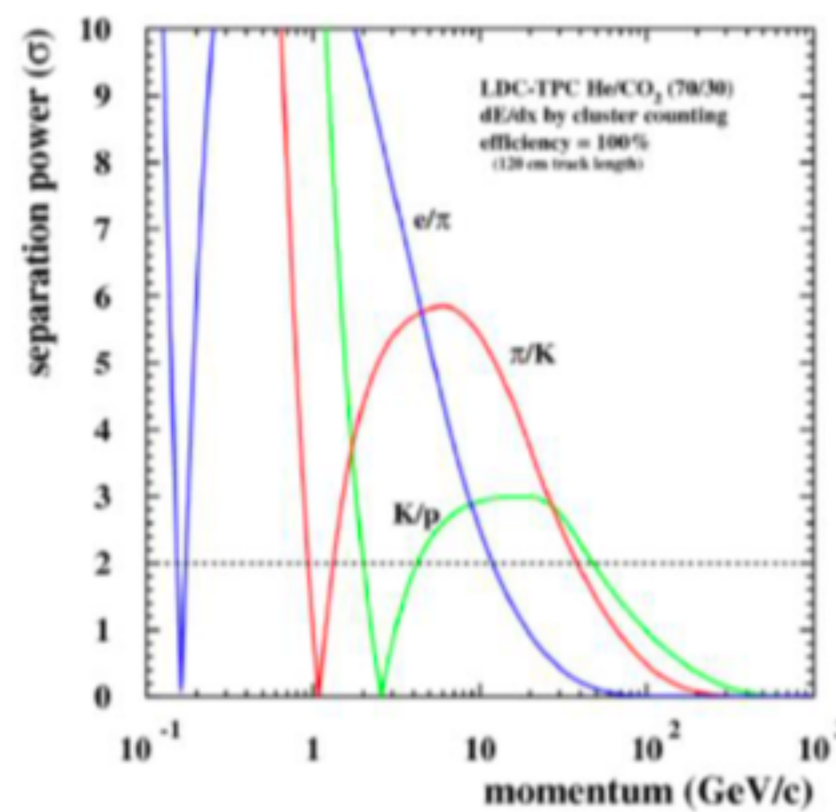




25 cm length

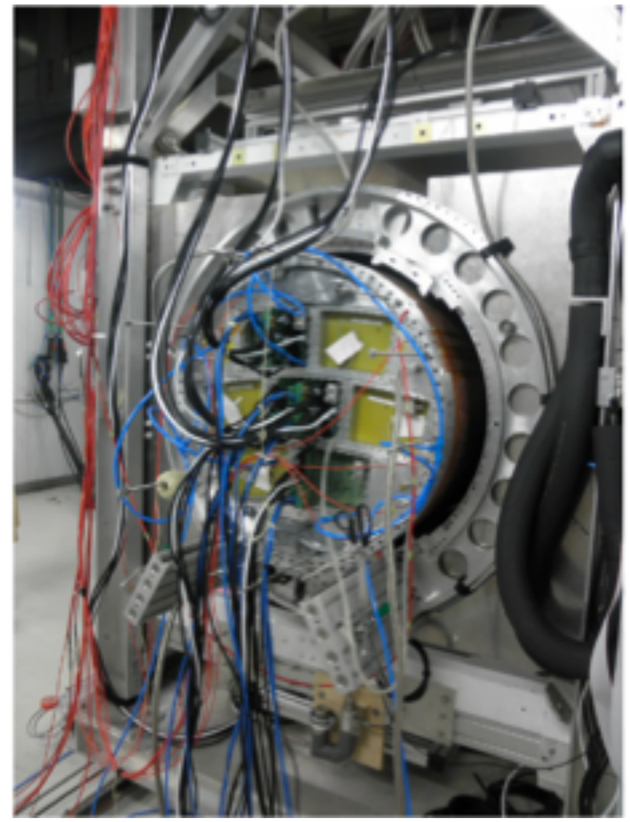
Paola Gianotti

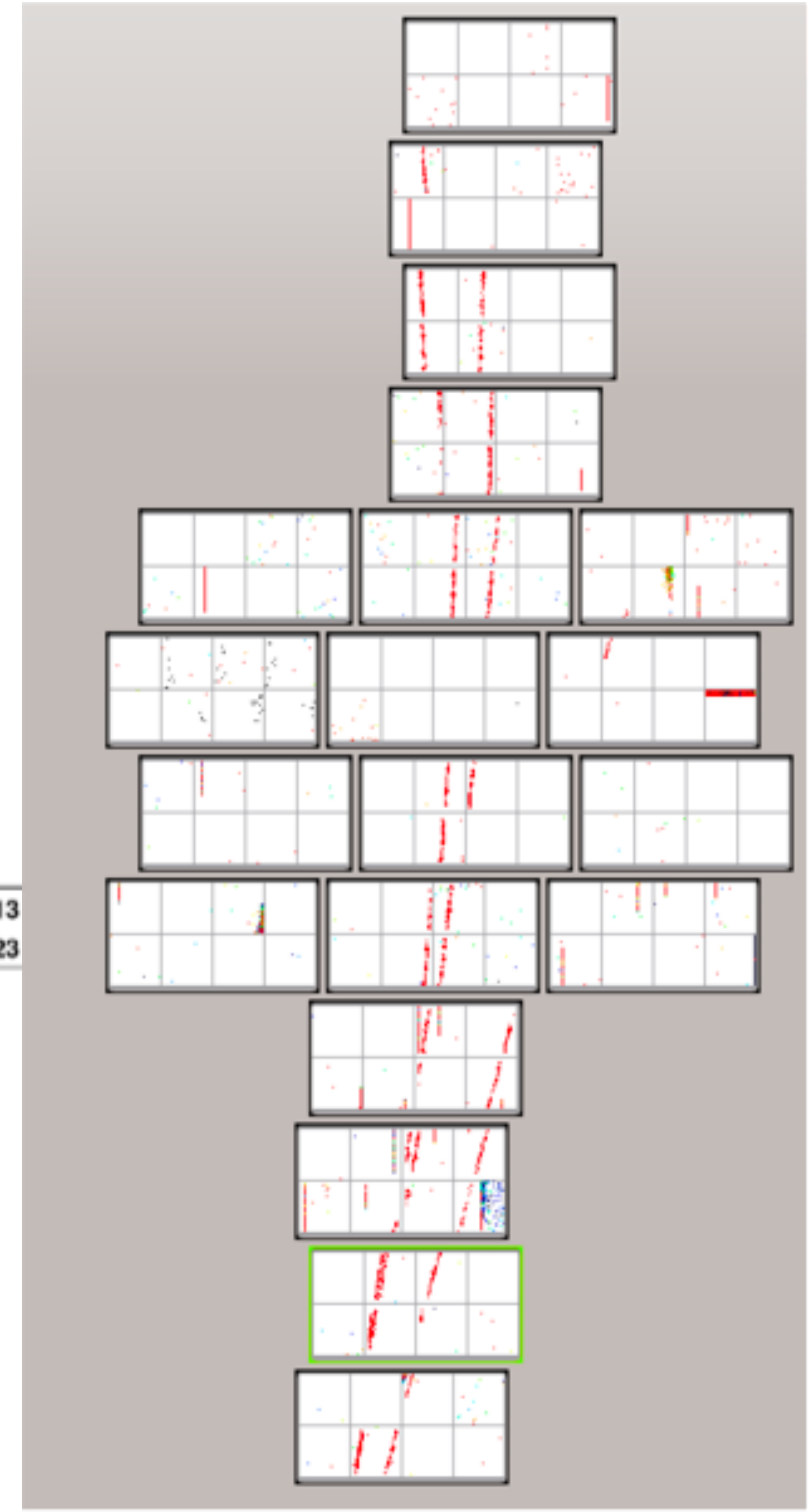


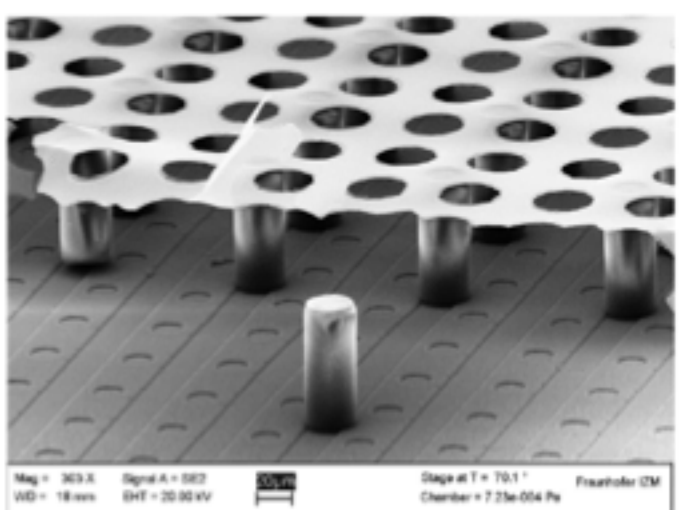


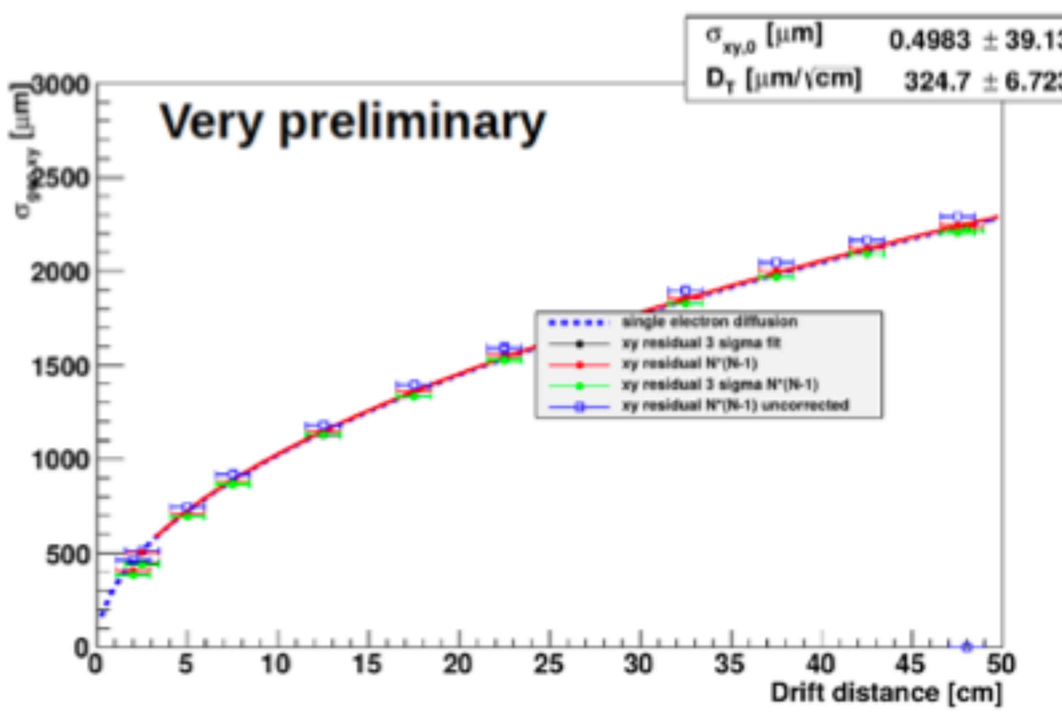
Alternative Technologies

- **GridPix (Jochen Kaminski)**
  - Good performance
    - $\frac{\sigma_E}{E} = 3.85\%$ (@ 5.9 keV)
    - Spatial resolution limited by diffusion.
    - High efficiency for single electron detection.
  - Production have advanced
    - Large systems (~160 chips) have been operated.

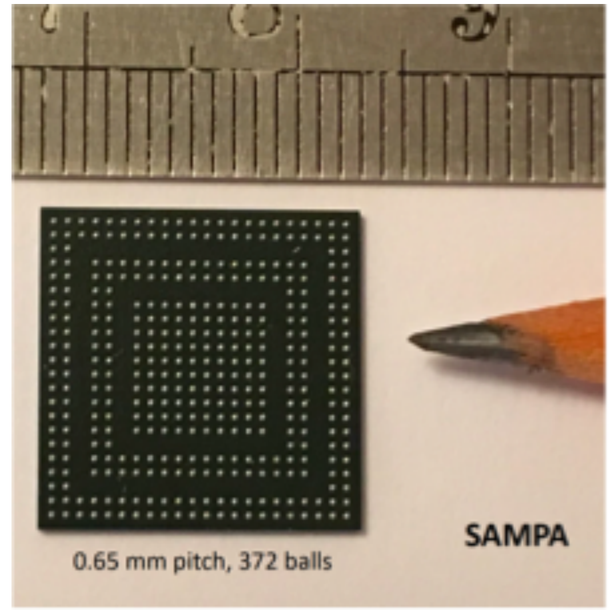


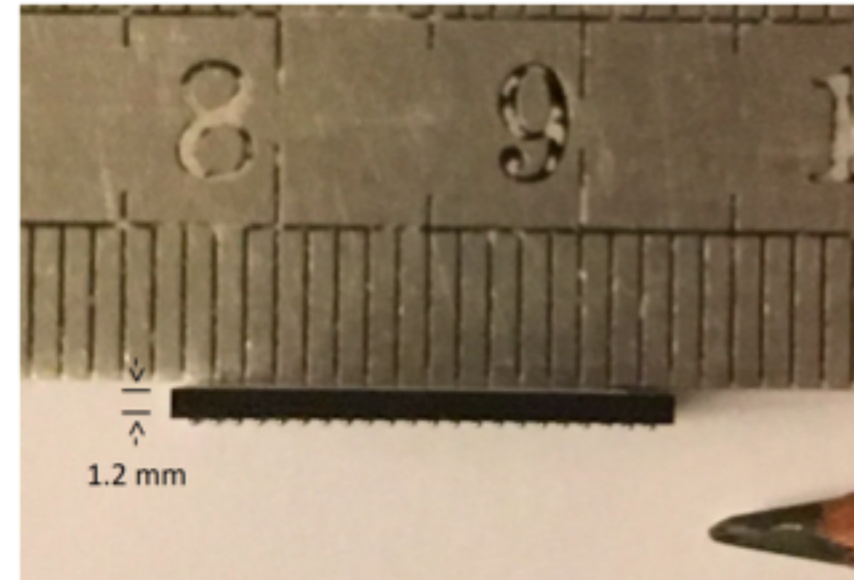


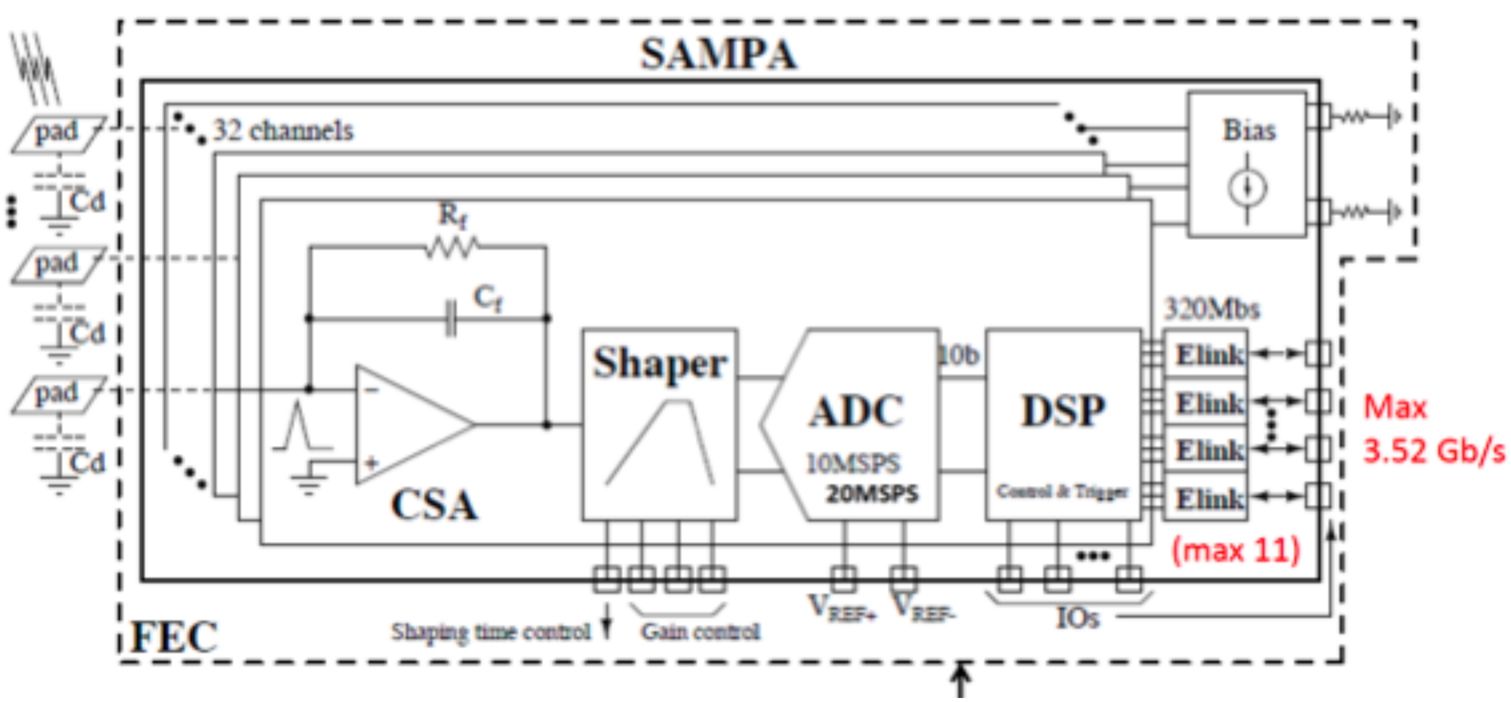




- **SAMPA ASIC (Ed Jastrzembski)**
  - ASIC developed for ALICE TPC and Muon Chamber upgrade.
  - Also chosen TPC readout for sPHENIX and STAR upgrade at RHIC.
  - Will be used in continuous readout mode for TPC.



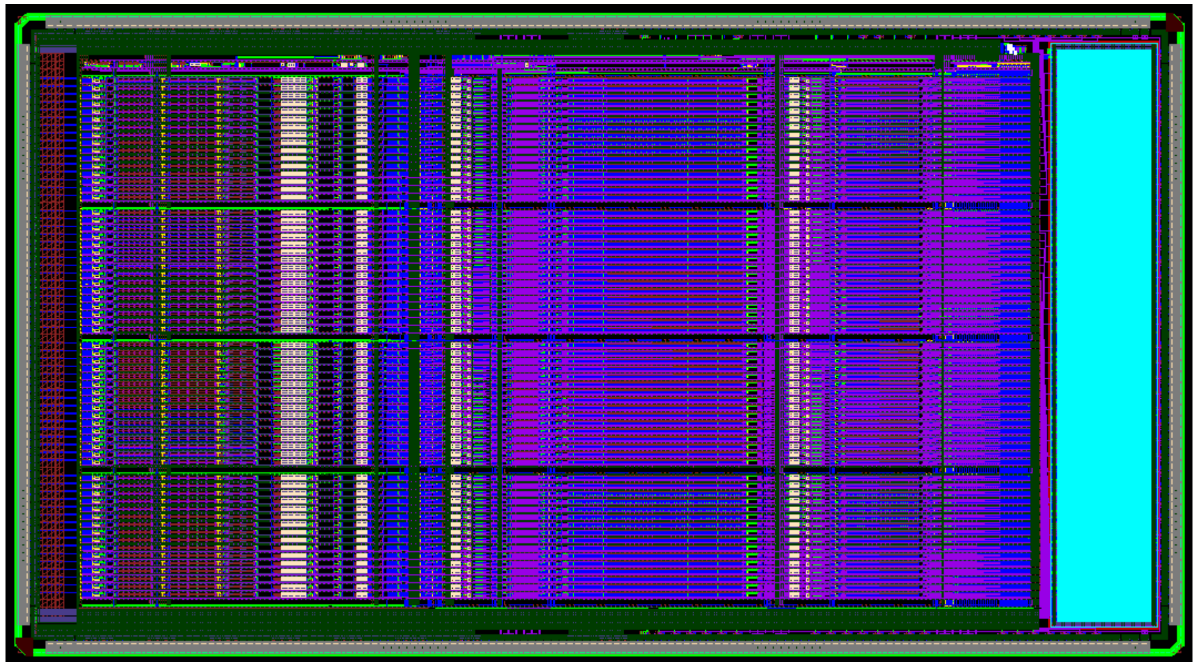


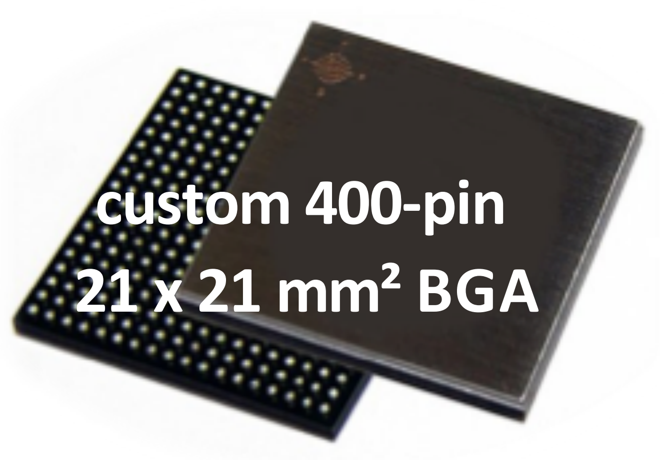


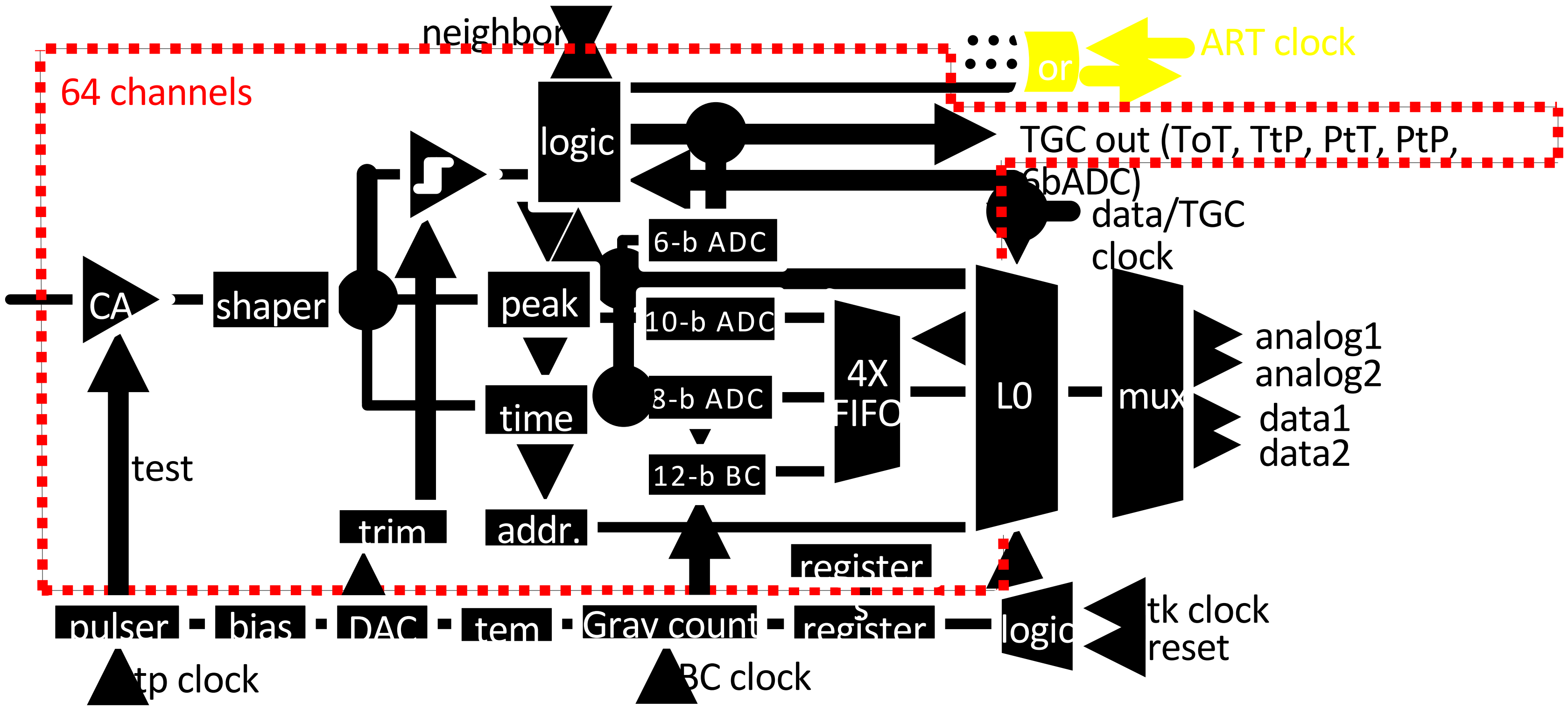
Specification	TPC	MCH
Voltage supply	1.25 V	1.25 V
Polarity	Negative	Positive
Detector capacitance (Cd)	18.5 pF	40 pF - 80 pF
Peaking time (ts)	160 ns	300 ns
Shaping order	4th	4th
Equivalent Noise Charge (ENC)	< 600e@ts=160 ns*	< 950e @ Cd=40 pF* < 1600e @ Cd=80 pF*
Linear Range	100 fC or 67 fC	500 fC
Sensitivity	20 mV/fC or 30 mV/fC	4 mV/fC
Non-Linearity (CSA + Shaper)	< 1%	< 1%
Crosstalk	< 0.3%@ts=160 ns	< 0.2%@ts=300 ns
ADC effective input range	2 Vpp	2 Vpp
ADC resolution	10-bit	10-bit
Sampling Frequency	10 (20) Msamples/s	10 Msamples/s
INL (ADC)	<0.65 LSB	<0.65 LSB
DNL (ADC)	<0.6 LSB	<0.6 LSB
ENOB (ADC)**	> 9.2-bit	> 9.2-bit
Power consumption (per channel) CSA + Shaper + ADC	< 15 mW	< 15 mW
Channels per chip	32	32

*$R_{esd} = 70\Omega$
** @ 0.5MHz, 10Msamples/s

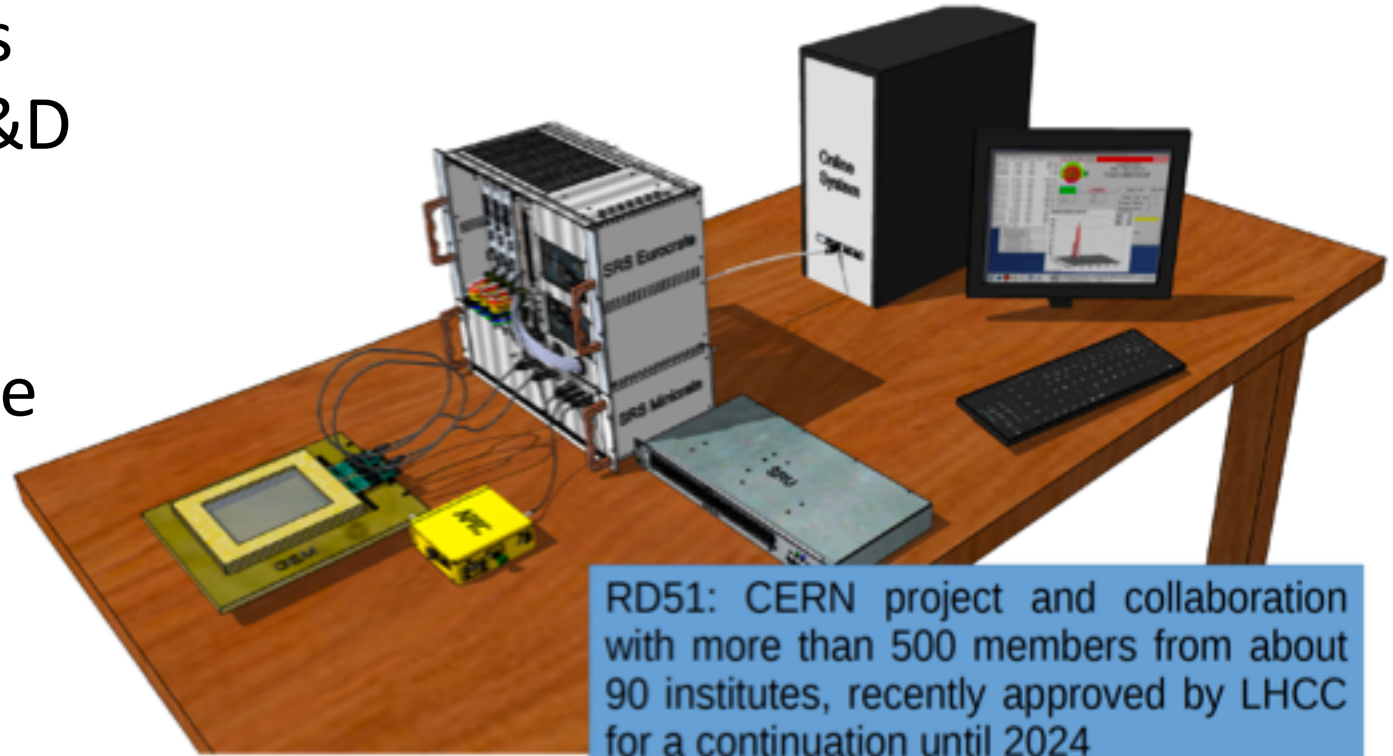
- **VMM Chip (Gianluigi De Geronimo)**
  - ASIC developed for ATLAS Muon upgrade.
  - Few pF to a few nF input capacitance.
  - Sub fC charge resolution, 2pC linear range.
  - Sub ns timing resolution, ~100 ns processing time.
  - Various measurements, readout modes and interfaces.



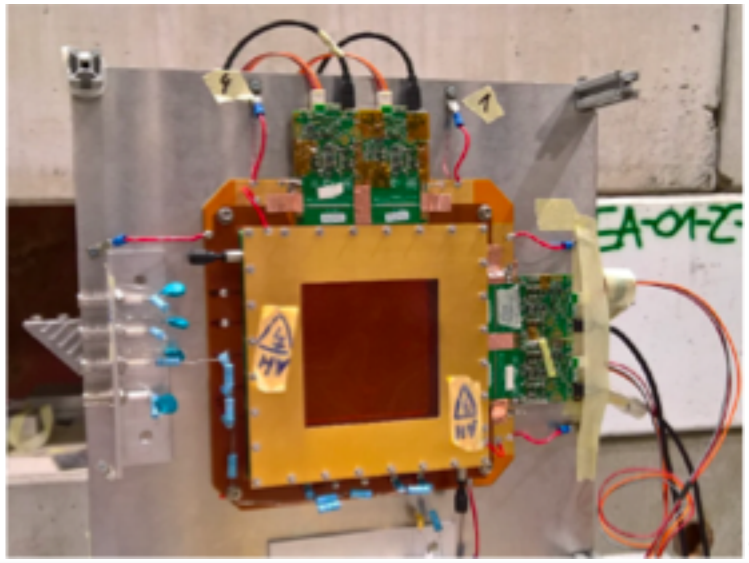


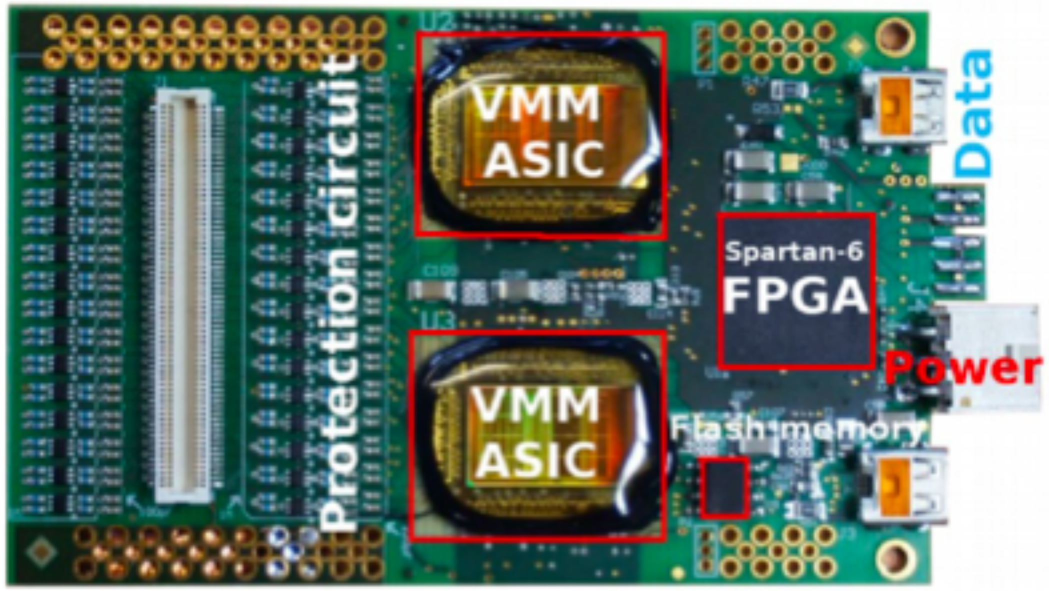


- **Scalable Readout System (SRS) (Michael Lupberger)**
  - SRS of RD51 is widely used in various MPGD applications from detector R&D to experiments.
  - Can be used with a **variety of chips**.
  - New **VMM based SRS** will replace the current APV based SRS as the RD51 readout standard.
    - Currently in prototyping phase
    - Lab and beam tests have been ongoing for the last 2 years.
    - Hardware should be available to users soon.



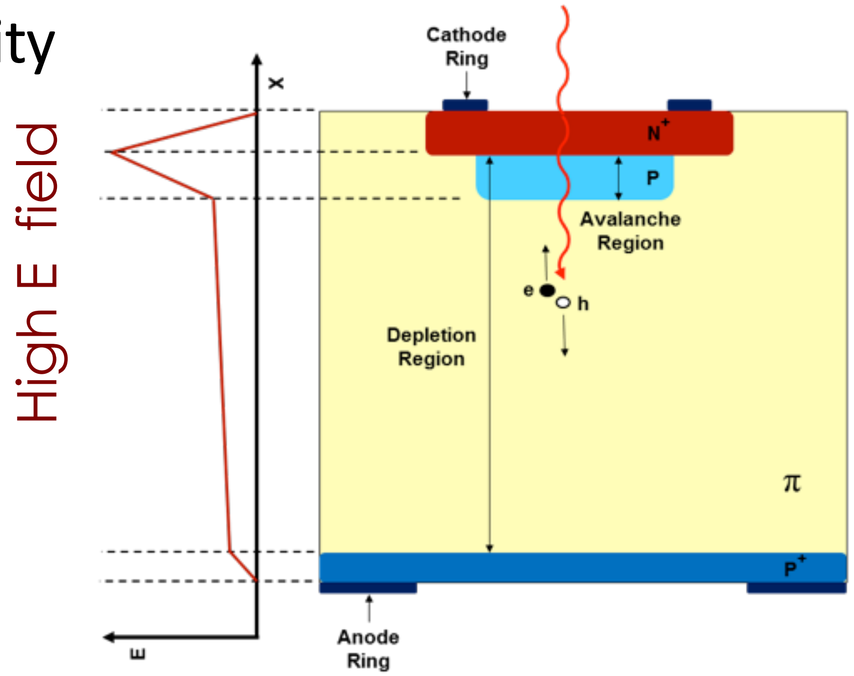
RD51: CERN project and collaboration with more than 500 members from about 90 institutes, recently approved by LHCC for a continuation until 2024

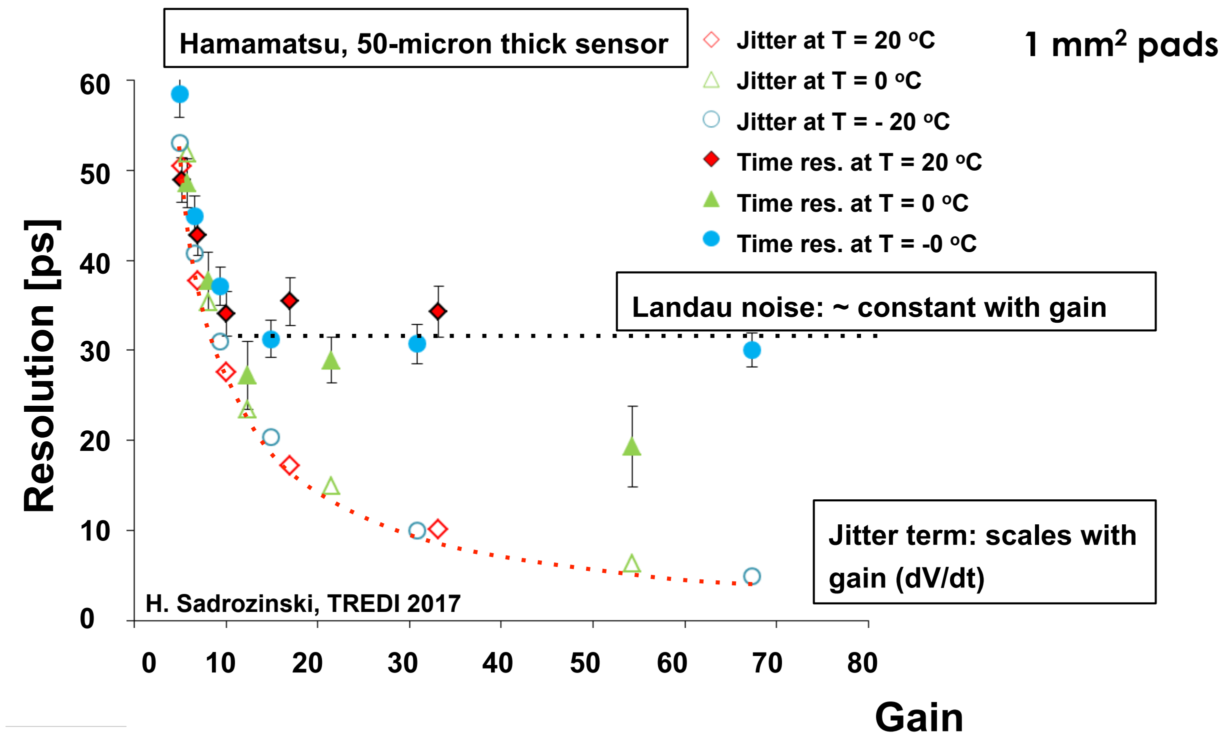




Low Gain Avalanche Diodes

- **Silicon 4D trackers (R. Arcidiacono)**
  - Addition of timing information to trackers explored for the HL-LHC to simplify pattern recognition, distinguish overlapping events, reduce trigger rates
  - Needed: thin sensor with gain, uniform E-field and drift velocity
  - The idea: add a thin layer of doping to produce low controlled multiplication (the **gain layer**) → LGAD technology sensors optimized for timing measurements

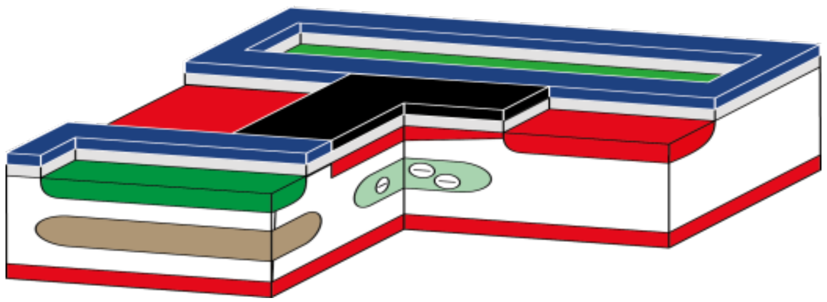




  - An example of UFSD time resolution achieved in testbeams: 30 ps (gain >= 20)
  - The ultimate time resolution limit is determined by charge non-uniformity
  - The best working point is determined by the interplay with the electronics
  - Potentially interesting for the EIC: **thin sensor with large signal** (improve spatial resolution with smaller pixels); **TOF PID in silicon tracker** (requires substantial development towards small pixels and low power readout)

➢ DEPFETs for tracking applications - state of the art (J. Ninkovic)

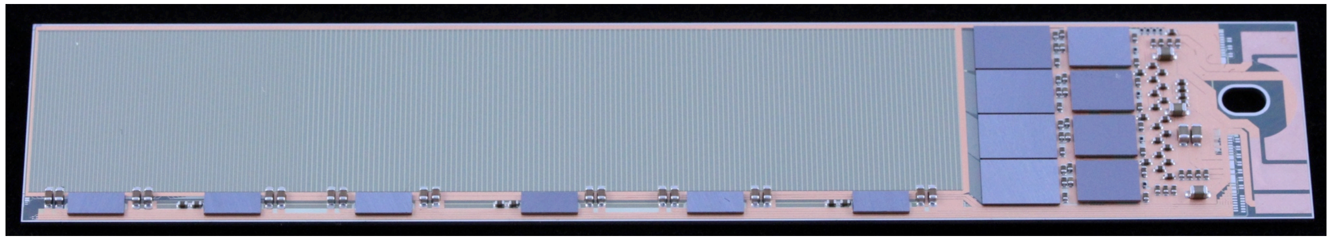
- p-MOSFET on fully depleted n-substrate
  - **Internal amplification** → large signal, even for thin devices
  - Fully depleted sensitive volume → fast signal rise time (~ns), small cluster size
  - Charge collection in "off" state, read out on demand → potentially low power device
- **Rolling shutter readout**
- Different DEPFET classes for application in many projects: **vertex**, x-ray flourescence, x-ray imaging spectroscopy, FEL radiation detection, photon science, …



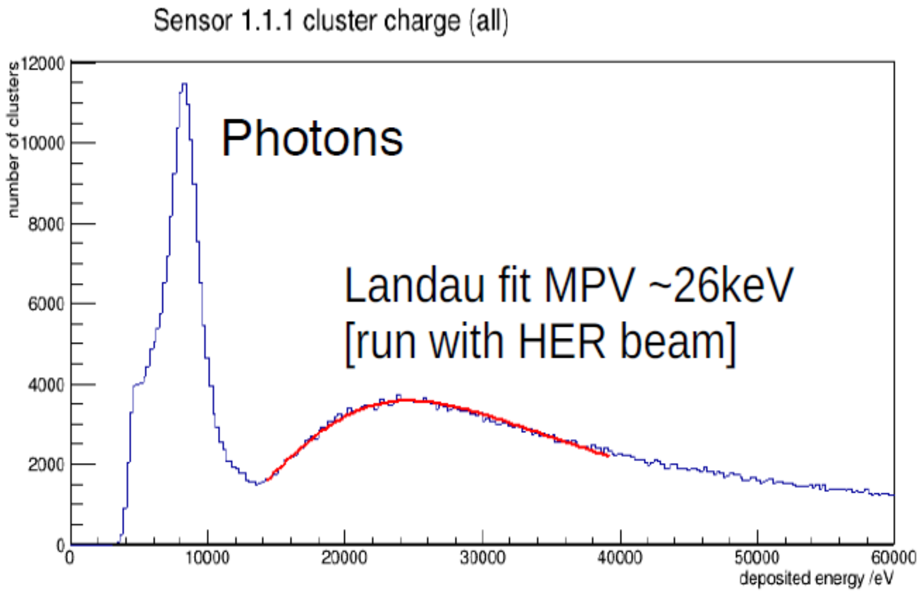
Thin & small pixel: vertex, low E electron detectors (TEM)

pixel size: 20µm…75µm
read out time per row: 25ns-100ns
Noise: ≈100 el ENC
thin detectors: 30µm…75µm → still large signal: 40nA/µm for MIP

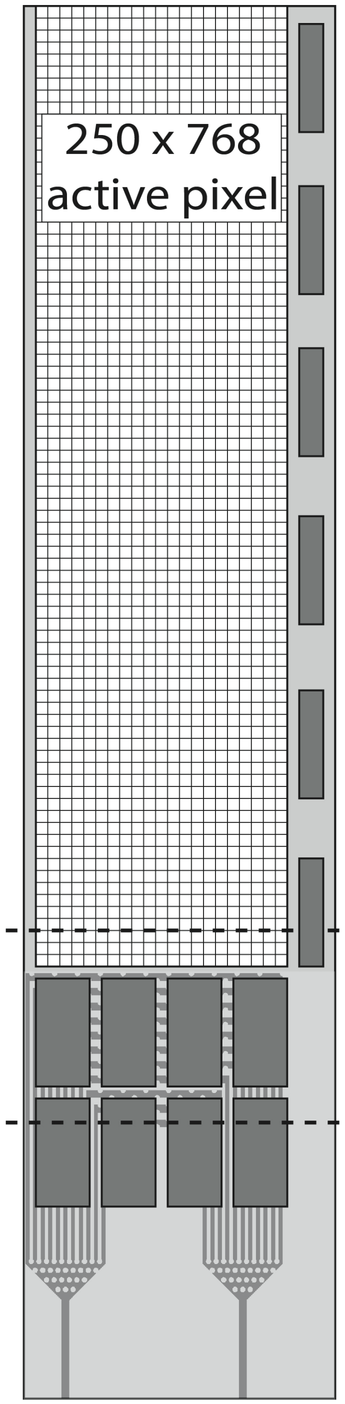
- DEPFET **all-silicon module** for Belle II

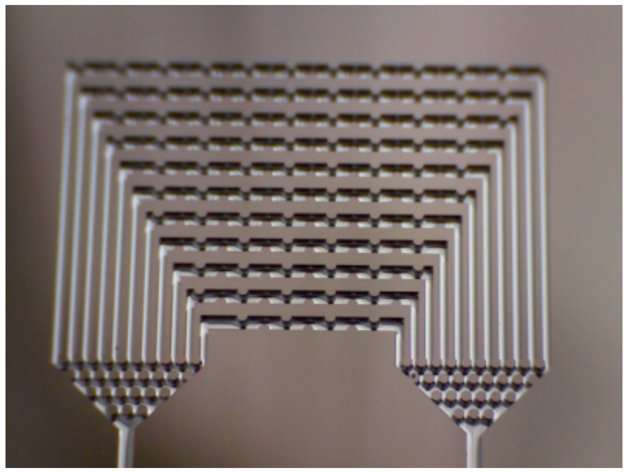


- **0.2% X/X0** per layer: 75 um thin sensor; air cooling; 4 layer low mass, rigid kapton-flex PCB

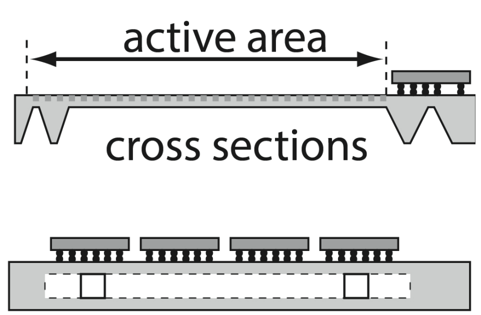


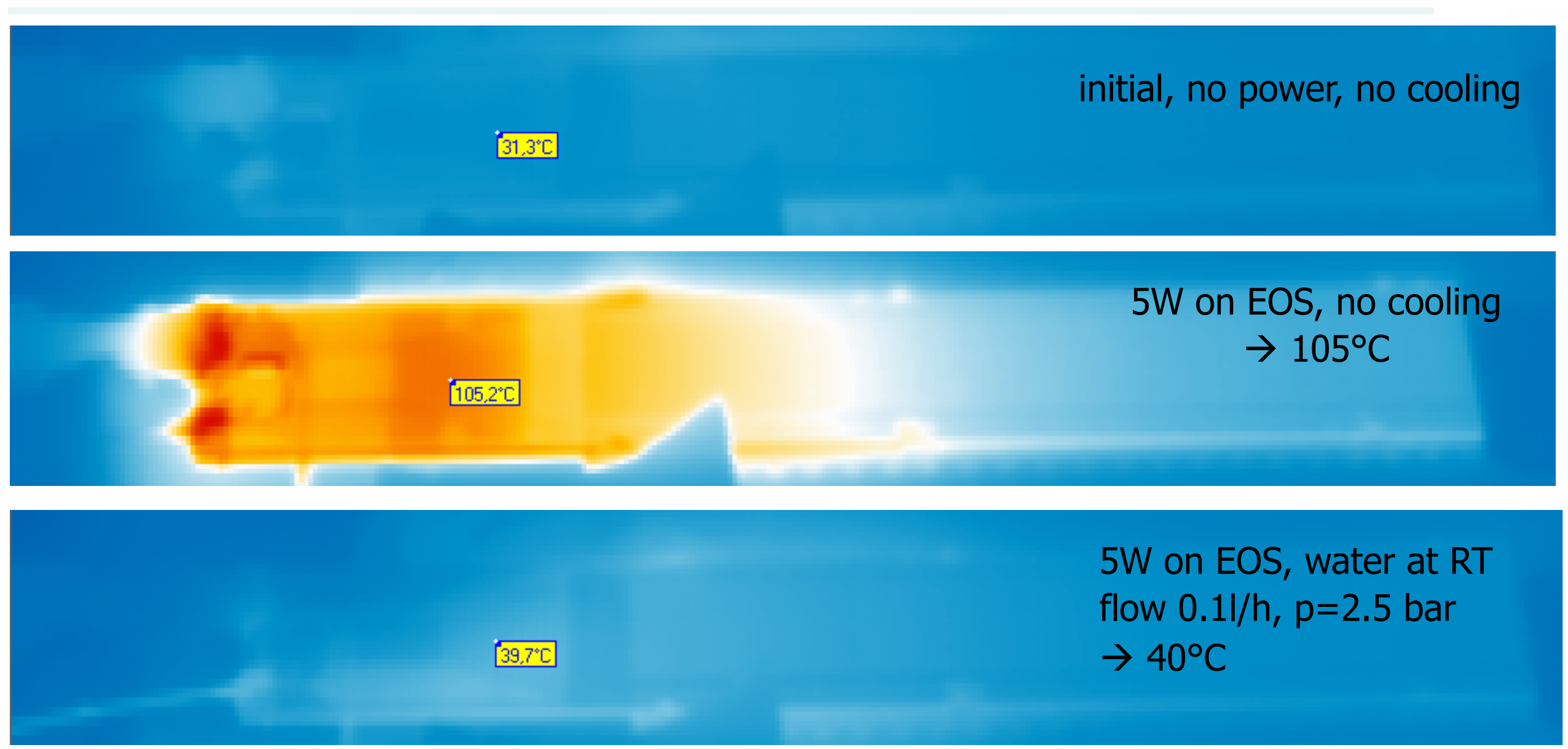
➢ DEPFETs for tracking applications - state of the art (J. Ninkovic)





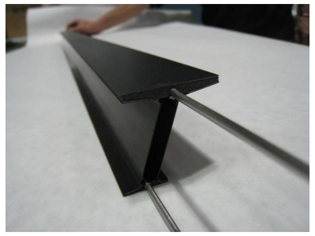
- ○ Ongoing development: **thinned all-silicon module with integrated cooling**
- ○ Channels etched in handle wafer below ASICs
- ○ Proof of principle with water as coolant shows very effective cooling performance
- ○ **Very interesting low mass cooling development for an EIC**



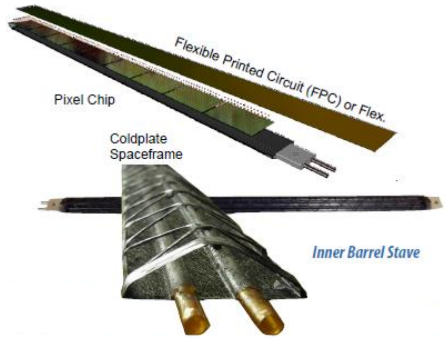


Micro-structures Si cold plate

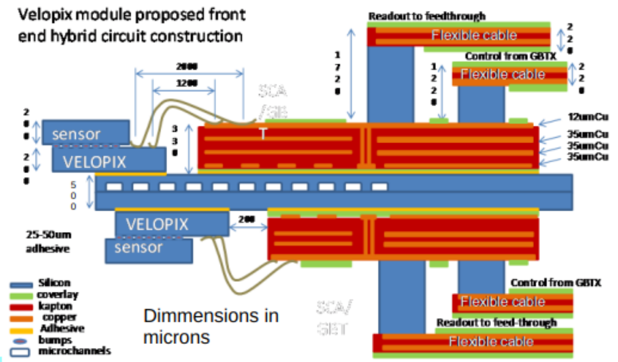
- **Micro-channel cooling (P. Petagna)**
  - Thermal management of electronics
    - Smaller technology nodes help in reducing power consumption but they also push towards implementing more functionalities, more speed, more “intelligence” in the chips, therefore increasing the power → the problem of “electronics cooling” basically stays the same
  - Design and integration of optimized support structures and thermal management solutions
  - State of the art Carbon foam structures with embedded cooling pipe (ATLAS, ALICE, CMS, Na62, STAR)
  - Aggressive evaporator design: **micro-structured Si cold plate with CO_2**
    - R&D ongoing (reliable miniaturized hydraulic connectors, fabrication technologies, boiling dynamic control)
    - **LHCb Velo** spun-off the technology and engineered the first silicon micro-structured coldplate



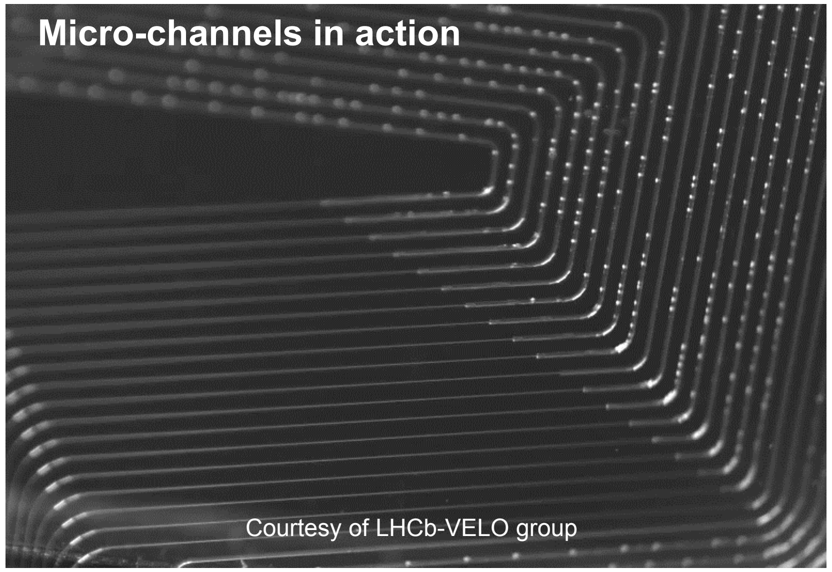
ATLAS PIXEL upgrade (study)

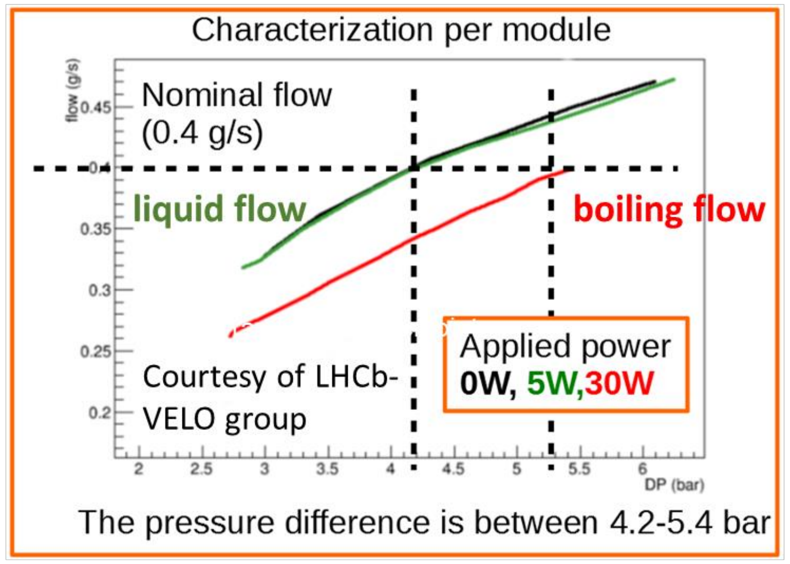


ALICE ITS upgrade



- 52 cold plates
- ~2 kW max power dissipation
- In high vacuum





Summary

- Several gas and silicon technologies were discussed
  - $\mu RWELL$, straw tubes, and INGRID
  - 4D (fast silicon), micro-channel cooling, and DEPFETs for tracking
- Three companies are currently pursuing commercial GEM development
- Ideas discussed
  - Gas trackers moving to integrate PID *i.e. GEM-TRD*
  - Using cluster counting rather than dE/dx for PID
  - Fast gas detector (ps detector) *ala* 4D silicon
  - ps MPGD for TOF

Thank You!