RD51, status and perspectives

6th International Conference on Micro Pattern Gaseous Detectors

5-10th May 2019

M. Chefdeville, LAPP, Annecy

Introduction & overview

- I of course regreted to have accepted this talk
  - How to put together such wealth of results?
  - Previous reviews were both exhaustive and inspiring (M. Titov, E. Oliveri)!

- In 2010, I was given the chance to talk on the collaboration behalf

`→ Looking back`

- As a physicist working at LHCb

`→ Imminent Run III of LHC`

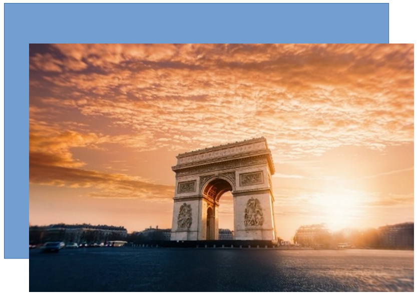
- Highlights of recent developments

`→ Resistive detectors, timing`

Looking back

- 5^{th} symposium on TPC for Low Energy Rare Event detection, 2010
- RD51, a world-wide collaboration for the development of Micro Pattern Gas Detectors

2010



2012

2014

2016

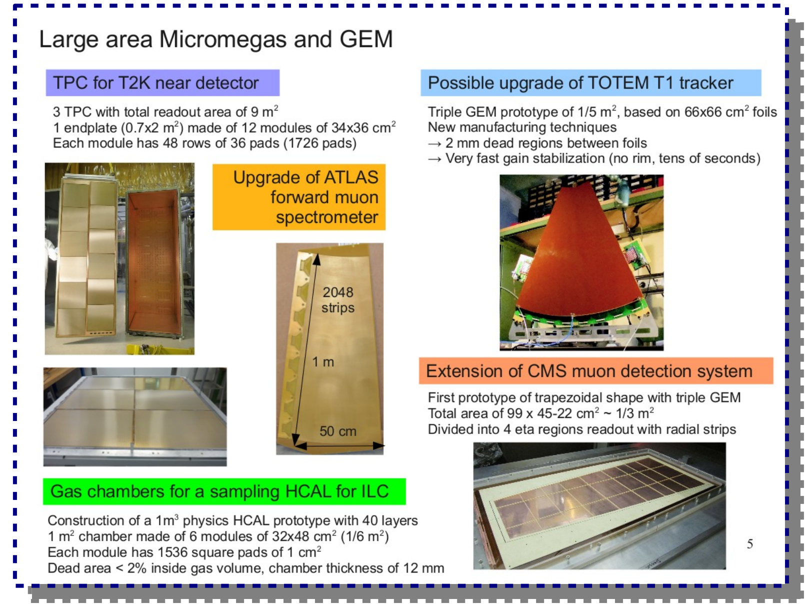
2018

Large area in 2010

- **At that time, a selection:**

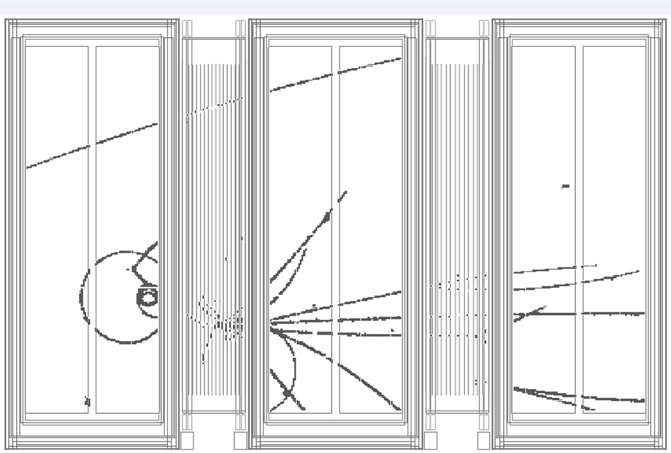
  Commisionning of T2K std-uM TPC
  Big readout board for MAMMA
  Trapezoidal shaped GEM for CMS
  Upgrade of TOTEM GEMs
  M2 uM prototype for ILC calorimetry
  ILC TPC: LP, octopuce...

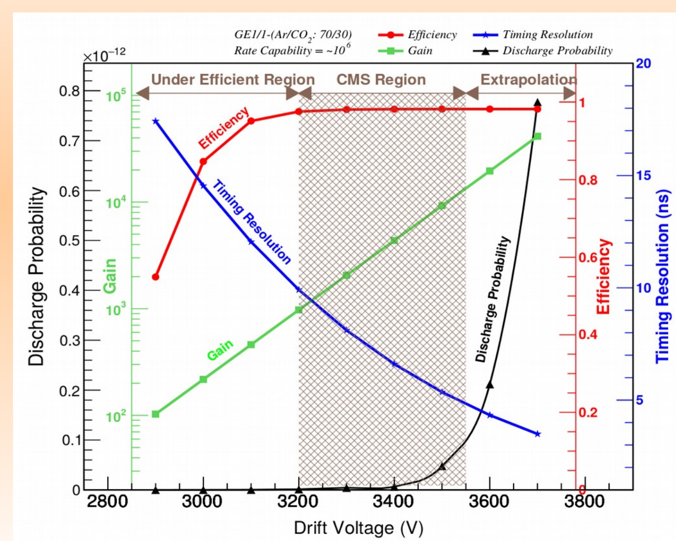
- **Today: data taking completed or ready for data taking or ready for future experiments**



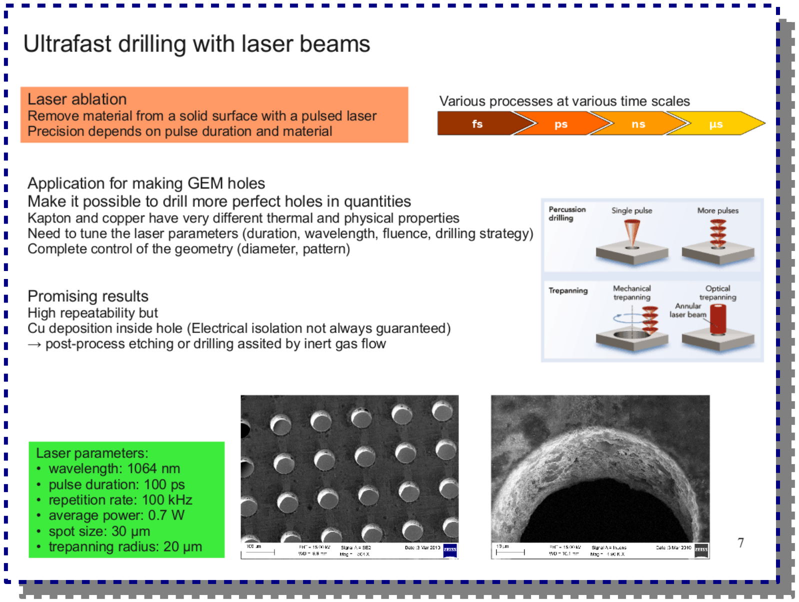
arXiv:1903.02186 The design of these chambers is finalized, and the installation is foreseen during the LS2 starting at the beginning of 2019.

arXiv:1111.4426 All three TPCS were [...] operational during the first T2K physics run [...] and the second one.



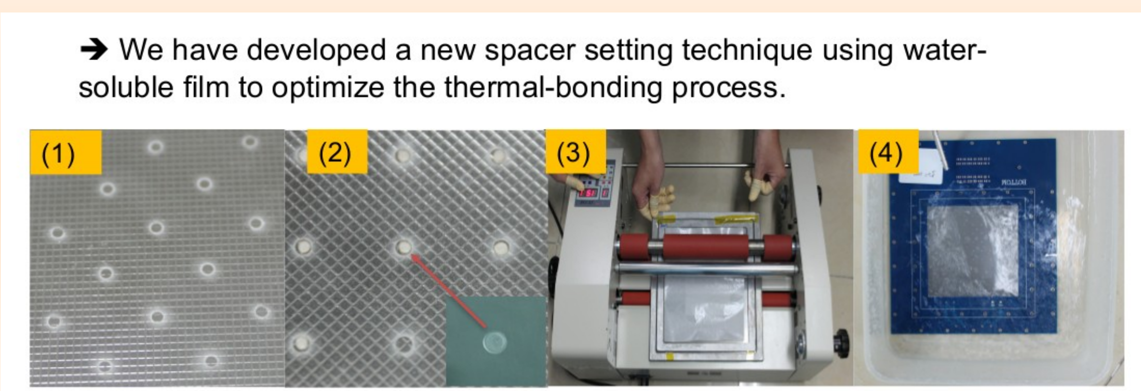


mpgd Structures in 2010

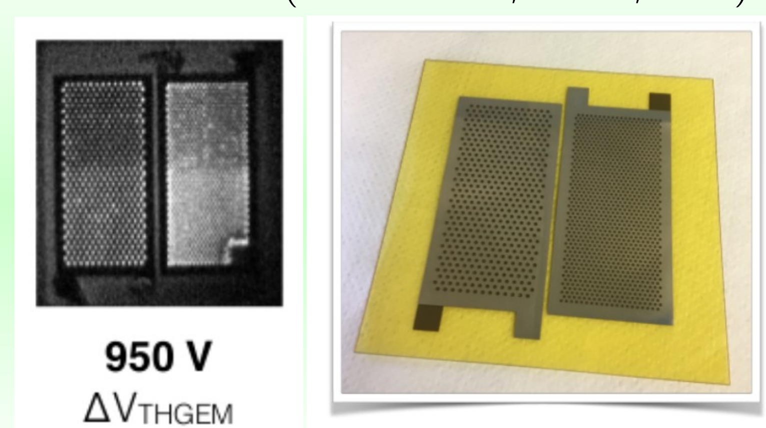


- Bulk uM & double-mask GEM
- At that time:
  - Single-mask GEMs
  - THGEM, RTHGEM, uBulk
  - Laser-drilled foils
- The rise of resistive (cf. later)
- Still new ideas

Thermal bonding (J. Liui et al., USTC, 2018)



3D inkjet printing of functional detector structures (F. Brunbauer, CERN, 2018)



Production in 2010

Production of MPGD

Objective
Development of cost effective technologies and industrialization

Today, CERN workshop is the unique MPGD production facility
Generic R&D, production of detector components, quality control

Future upgrade of the workshop has been approved by CERN management
New equipement to fabricate larger area detectors
Requests for SLHC experiments

In parallel, steps toward technological transfer to industrial partners for mass production are taken
GEM : New Flex (Korea), Tech-ETCH (USA), Scienergy (Japan)
Micromegas : CIRE (France), SOMACIS (Italy), Triangle labs (USA)

Detector technology	Currently produced	Future requirements
	cm * cm	cm * cm
GEM	40 * 40	50 * 50
GEM, single mask	70 * 40	200 * 50
THGEM	70 * 50	200 * 100
RTHGEM, serial graphics	20 * 10	100 * 50
Micromegas, bulk	150 * 50	200 * 100
Micromegas, microbulk	10 * 10	30 * 30
MHSP (Micro-Hole and Strip Plate)	3 * 3	10 * 10

8

Building 107: “a safe space for chemicals”
(Feb. 2018 CERN news link)

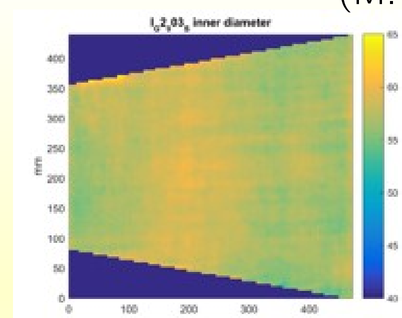
ALICE, TPC read-out, ~ 500 m^2 of GEM foils
ATLAS, small wheels, 1200 m^2 to be instrumented
CMS, GE1/1 forward detectors, 250 m^2 of GEM foils
COMPASS RICH, 4.5 m^2 to be instrumented, single photon detection

- Was mostly CERN-centered
- New workshop → new capabilities

  2x1m^2 Bulk uM & 2x0.5m^2 GEM
- Transfer to industry happened (had to)

  Strong interplay with CERN
  → importance of QA tests

QA of ALICE GEMs: Uniformity, spark detection system
(M. Ball et al.,HISKP, 2017)



Physics phenomena

- **Focused on:**

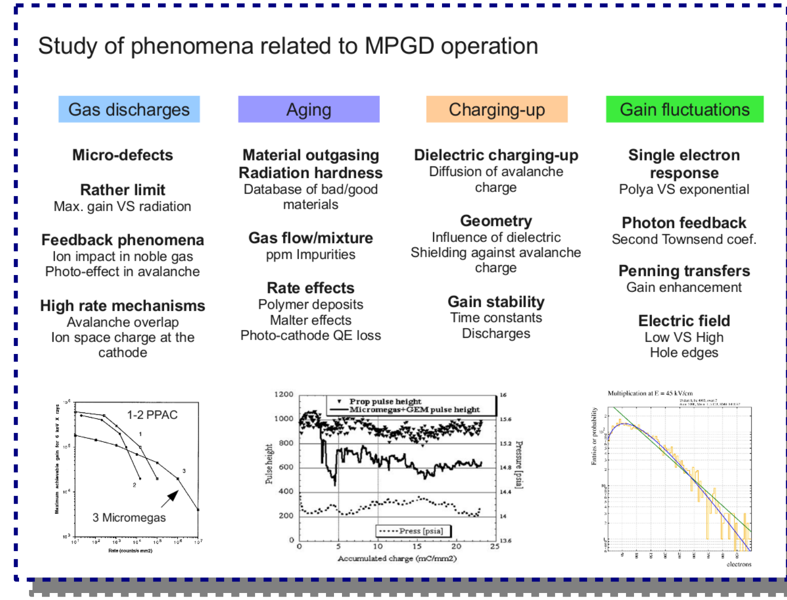
  Sparks – Aging – Charge-up – Fluctuations

- **No change really but much progress**

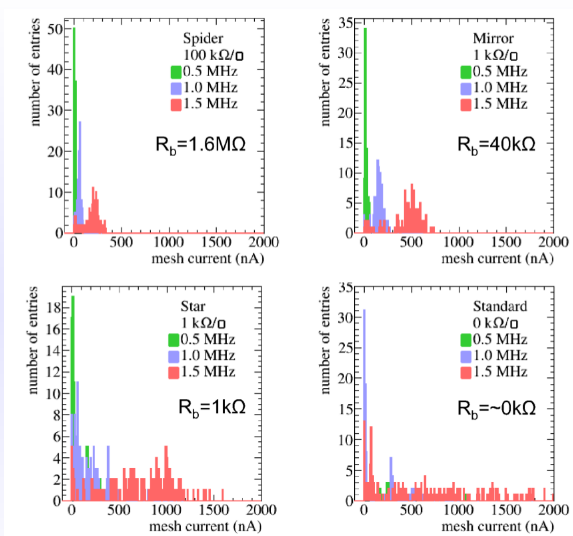
  Several studies @ GIF of techno for LHC upgrades

  Spark: region of stability known (still largely empirical)

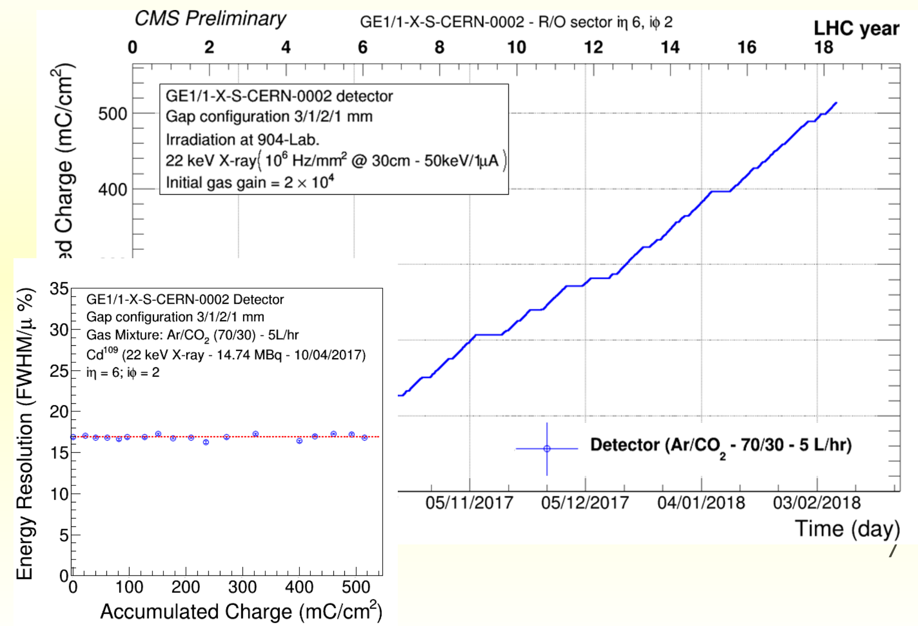
  Growing interest for timing (cf later)



CMS GEM 18 years of ME0 operation @ HL-LHC
(F. Fallavollita et al, 2018)



uM SDHCAL Mesh current through embedded-R
(Chefdeville et al., 2015)



Simulation in 2010

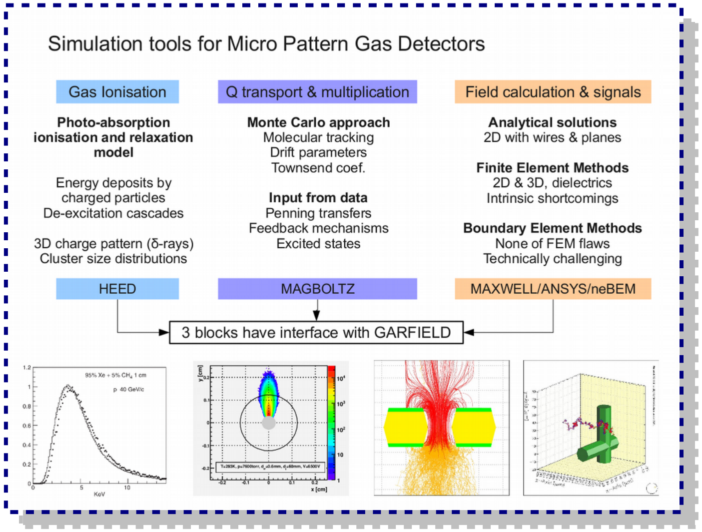
- **Focused on:**

  Ionisation – Transport – Field solver & signals

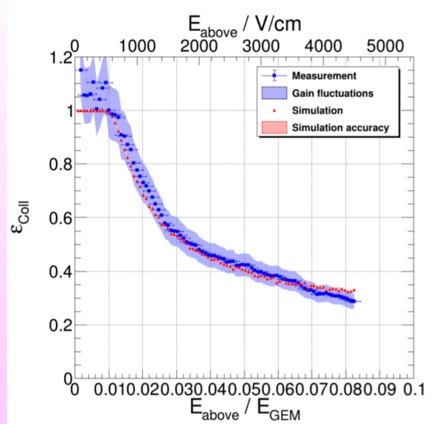
- **Maintained & improved tools**

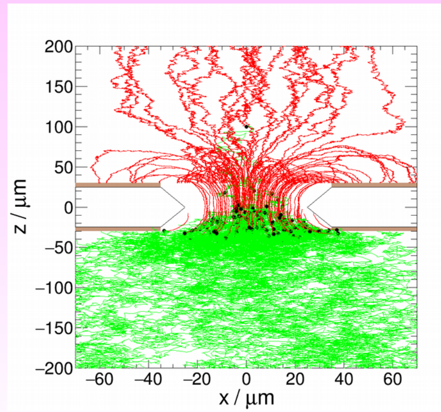
  Complete set of programs with interfaces (Magboltz-Heed-Garfield-Geant4-Field solvers.
  Long-term use → Garfield C++.

  Microscopic tracking, hydrodynamic model
  → Can model transparency, charge-up, streamer dvp^t

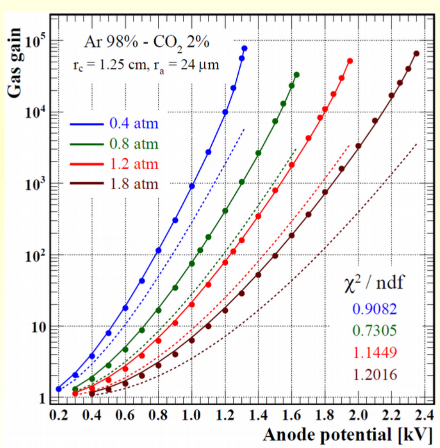


MultiGEM (J. Ottnad, 2018)





Penning & γ-feedback (O. Sahin, 2018)



Precursor & streamer (P. Fonte, 2018)

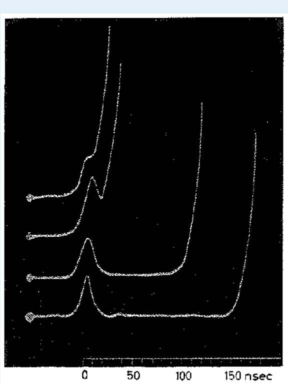
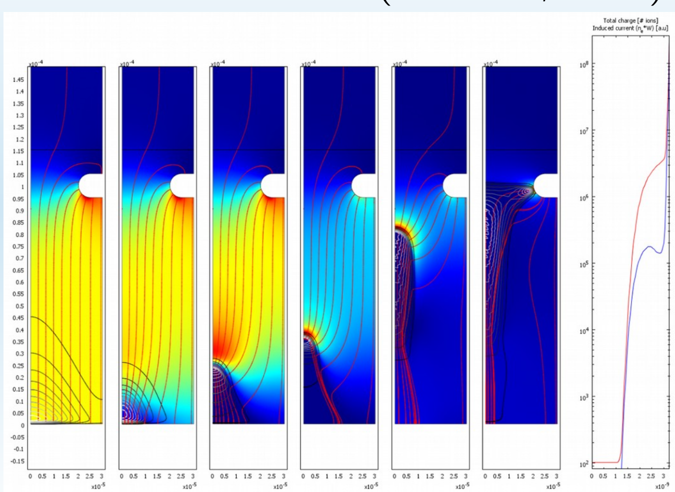
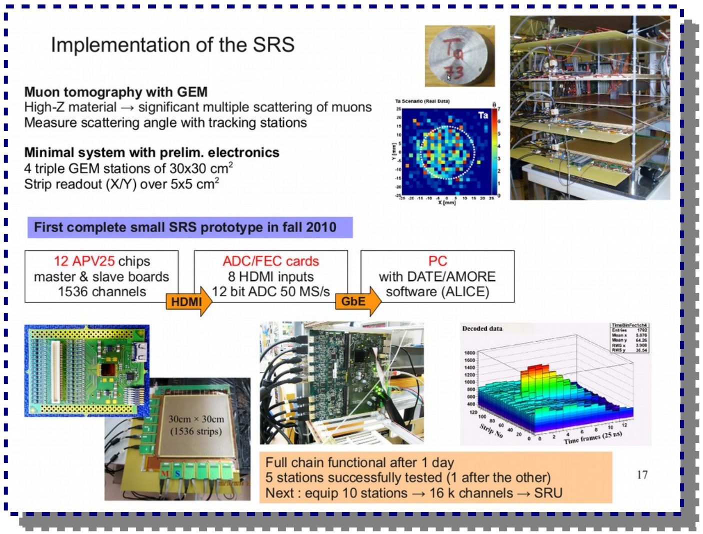


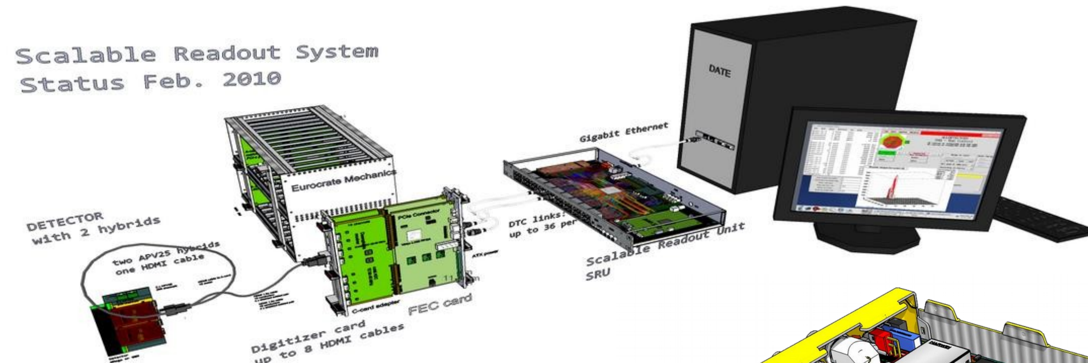
Figure 5.14. Current oscillograms of static breakdown in methylal. Optical method. $E/p = 64{\cdot}4$, $pd = 230$ Torr cm, $d = 0{\cdot}8$ cm, $T_- = 90$ nsec $RC = 5$ nsec[38]



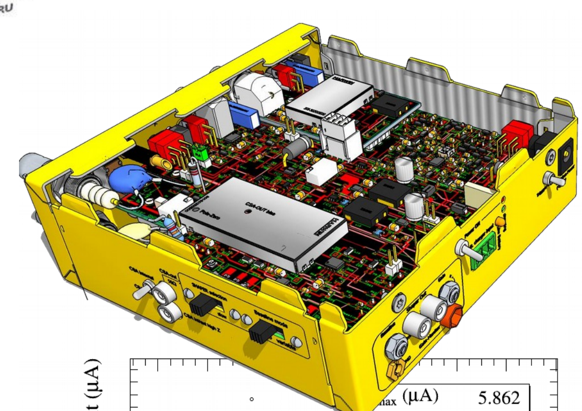
SRS in 2010



Scalable Readout System (SRS)



APIC
H. Muller 2018

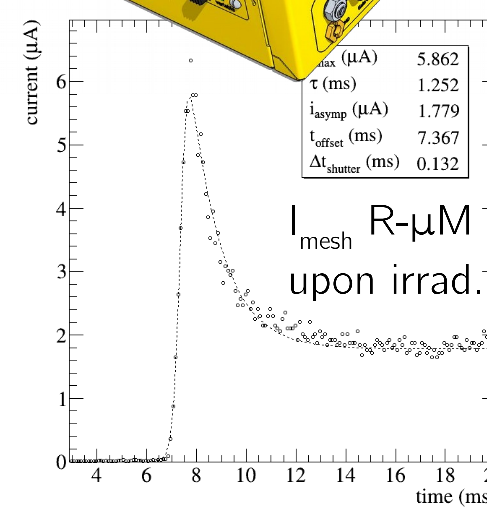


- First implementation around 2010
- Since then, quite successfull:

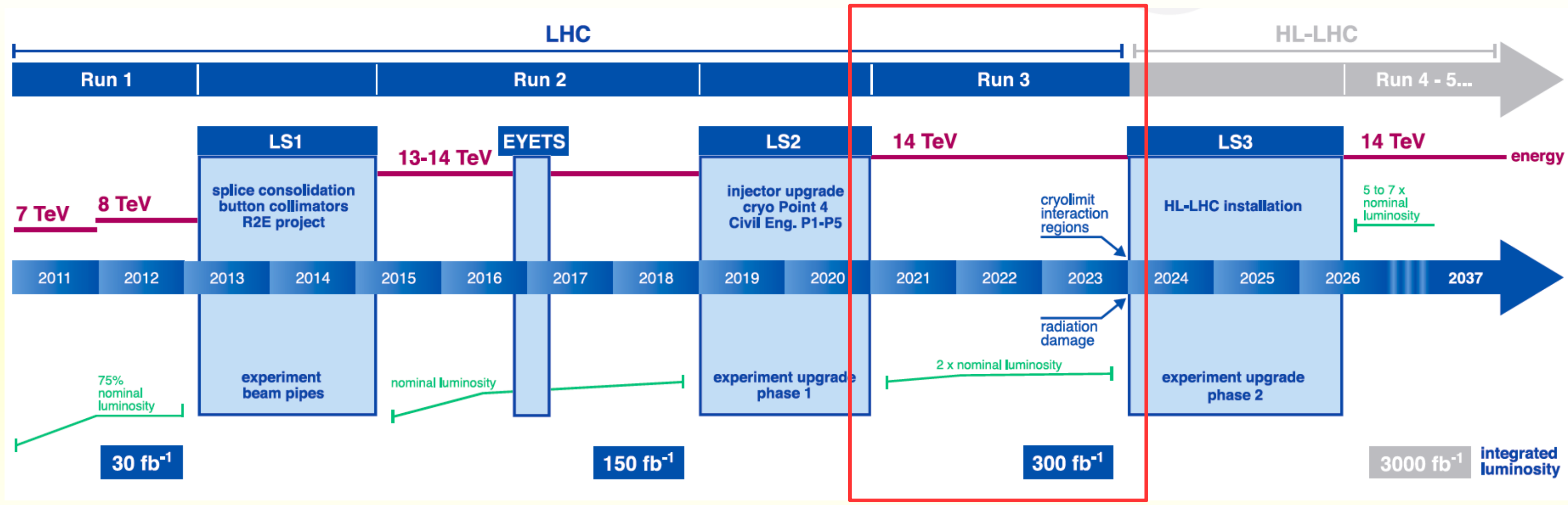
  >100 small systems (critical for TB) + interface to APV & VMM

  In-house prod. stopped → direct SPS sales > 2017
- Service electronics in GDD lab: versatile tools

  APIC is a pre-amplifier, dual shaper and dual polarity trigger discri.
  FemtoMeter box (I was happy to find it), LED pulser coming soon



Imminent Run III



- `Now preparing last Run (III, lumix2) before high-luminosity LHC`

  → MPGDs moving LHC experiments. This is now!!!

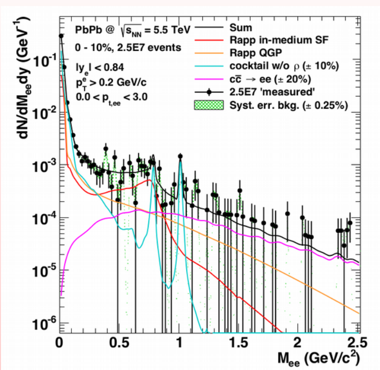
- `Major machine upgrade @ LS3 (2024-26) (lumix5-7)`

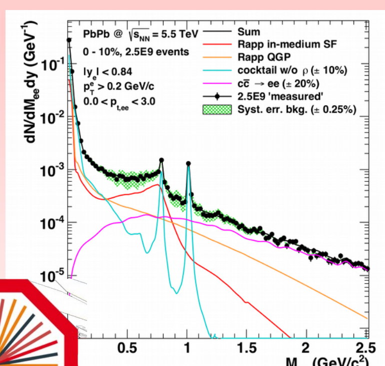
  New focus quadrupoles, lumi levelling @ IPs, crab cavities, new collimators, more compact dipoles to free space, renovated accelerator chain (new linac, improved Booster...)

  → introduction of new detector technologies to mitigate pile-up

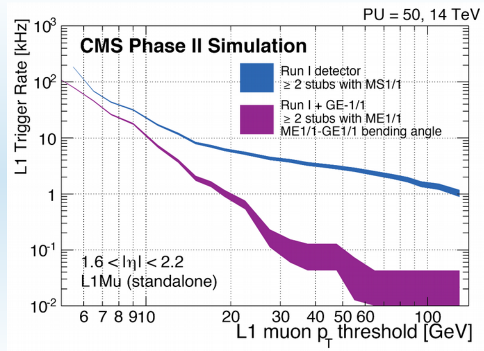
LHC detector upgrades

CERN-LHCC-2013-020
ALICE-TDR-016



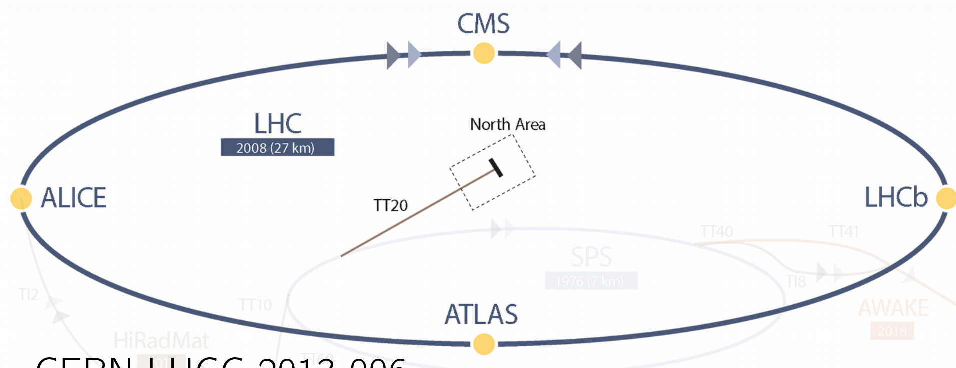


ALICE

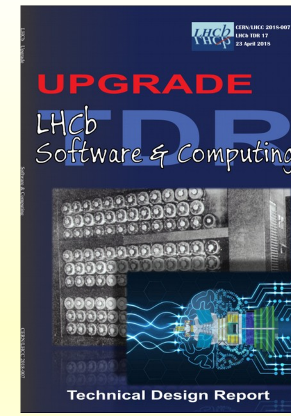


CMS

CERN-LHCC-2015-012
CMS-TDR-013

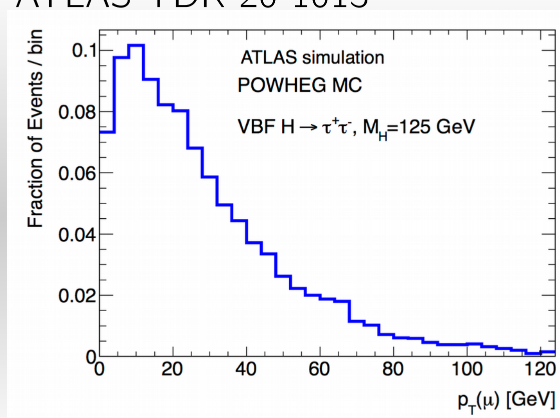


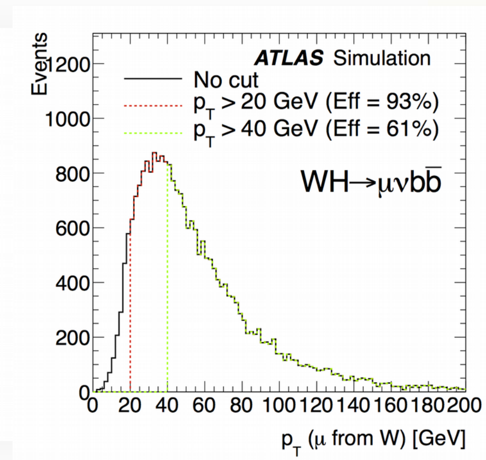
CERN-LHCC-2018-007
LHCb-TDR-017



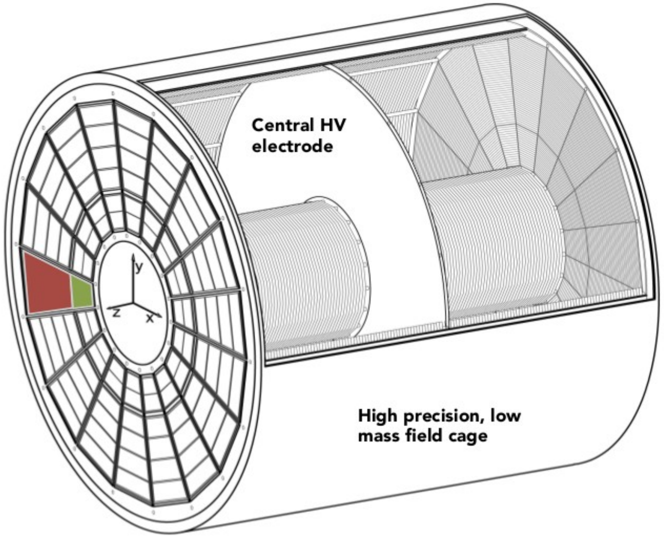
LHCb

CERN LHCC-2013-006
ATLAS-TDR-20-1013





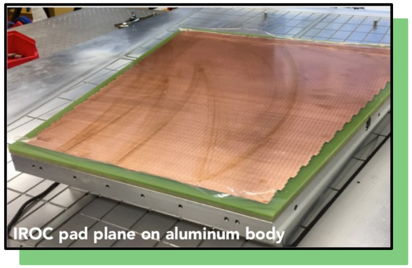
ALICE TPC

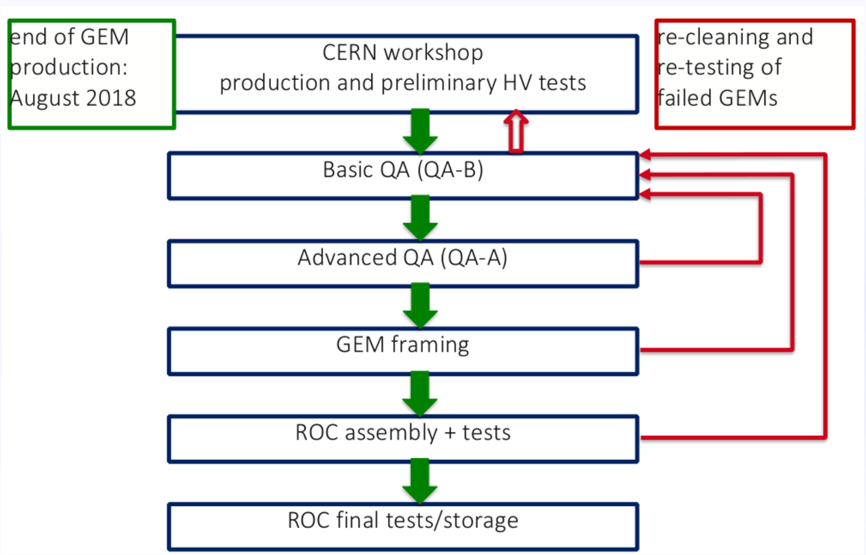


- **Continuous readout in Run 3 to maximise physics (Pb-Pb rate x100)**

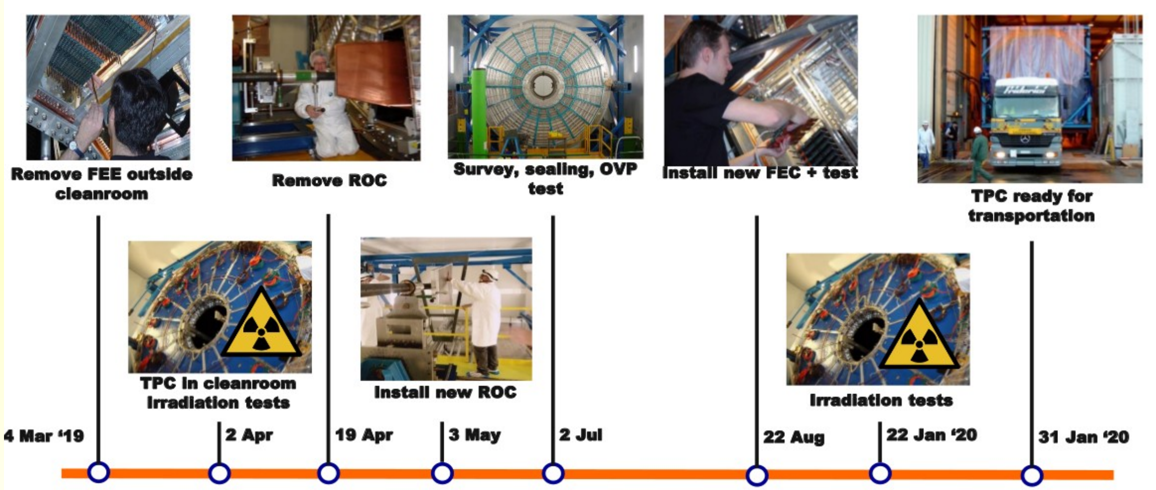
  Overlapping events → Replace MWPC & gate by GEMs
  Operate @ low gain (2.10^3) & low IBF + new FE
  Extensive R&D → 4 GEMs (mix 2 hole pitches, 90 deg tilt)

- **About 700 foils, stringent QA tests, 90% yield**
- **Foil production @ CERN, ROC assembly in 3 sites**





Schedule: installation of new ROC in May!



CMS forward μ-trigger

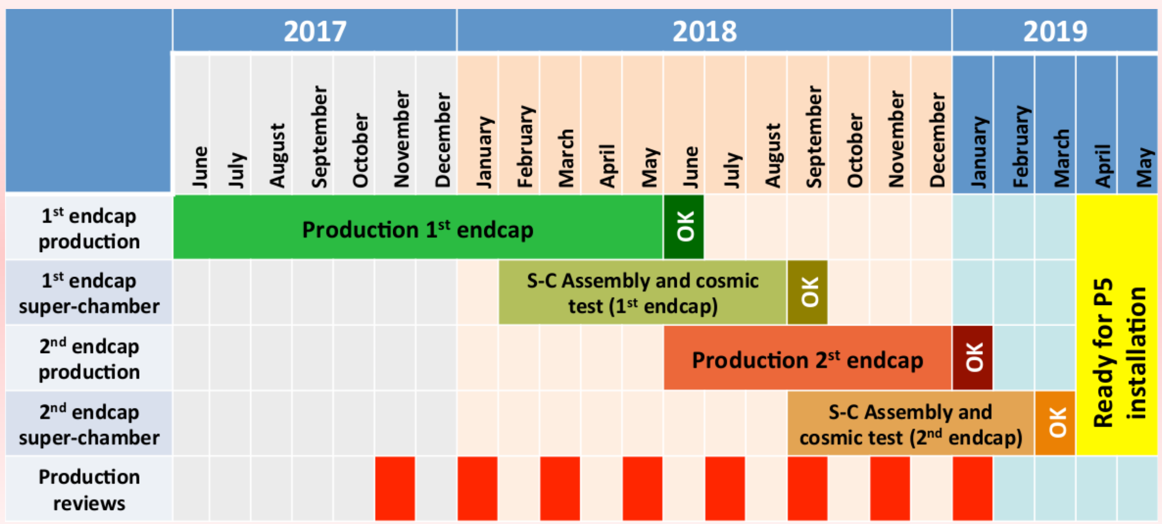
- `Improve triggering capability @ high η`

  Add redundancy (CSC) + lower trigger rate @ same threshold
  For Run 3: 2 wheels of GEMs @ 5-6 m from IP (GE1/1)
  HL-LHC: gain knowledge & add more chambers (GE2/1 & ME0)

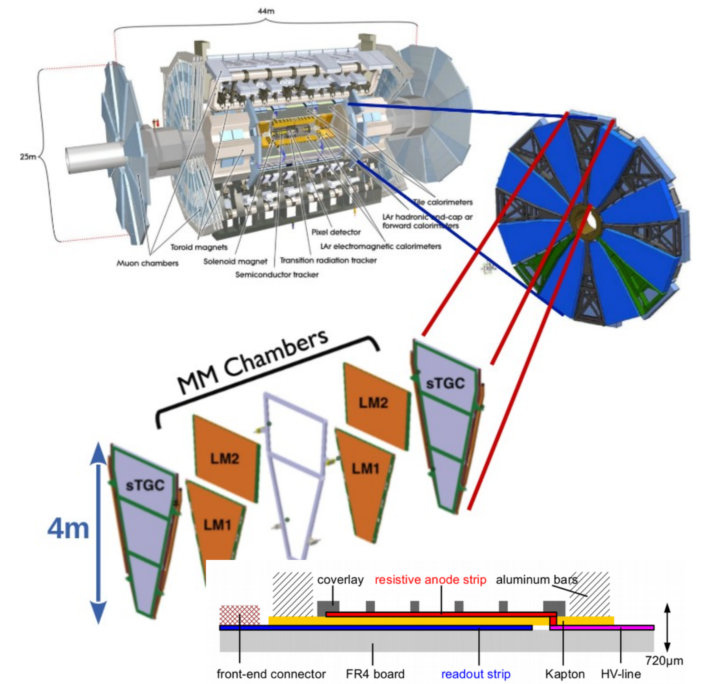
- `36 staggered triple-GEM chambers / endcap`
  → 5 years of design maturation & detailed characterisation (TB, in-situ tests during YETS)

- `Production load distributed btw. CMS institutes` (2y training program)

Schedule: as of Feb. 2018...



ATLAS μ-Wheel

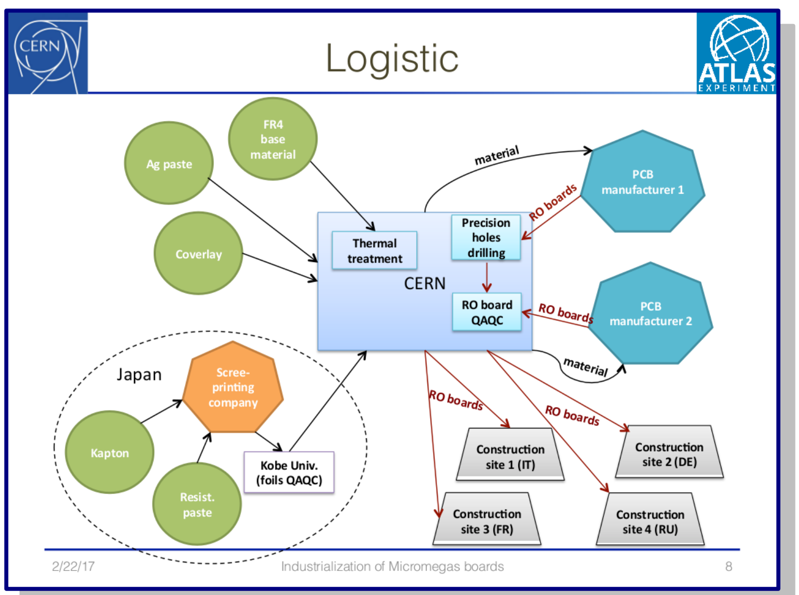


- `Improve triggering capability in endcap`

  Reduce trigger rate (15 kHz/cm^2, 90% fake)
  + maintain P_T resolution @ higher lumi (improved tracking)
  → 2 quadruplets Micromegas between 2 quadruplets sTGC

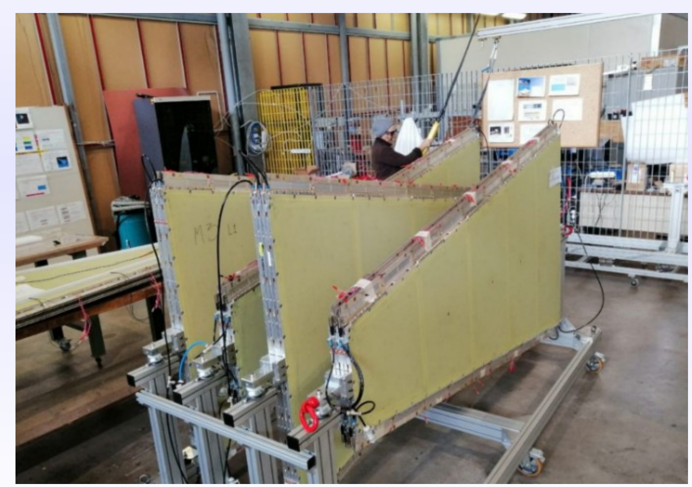
- `Most challenging project`

  10 m diameter wheel (1200 m^2), 2176 boards (32 different shapes), Resistive detector!
  Mechanical precision – high Q production of the R-boards – stability against discharges.
  Several issues recently solved.



P. Iengo 2017

`2019`: All sites ramped up production.
First quads @ integration site at CERN.



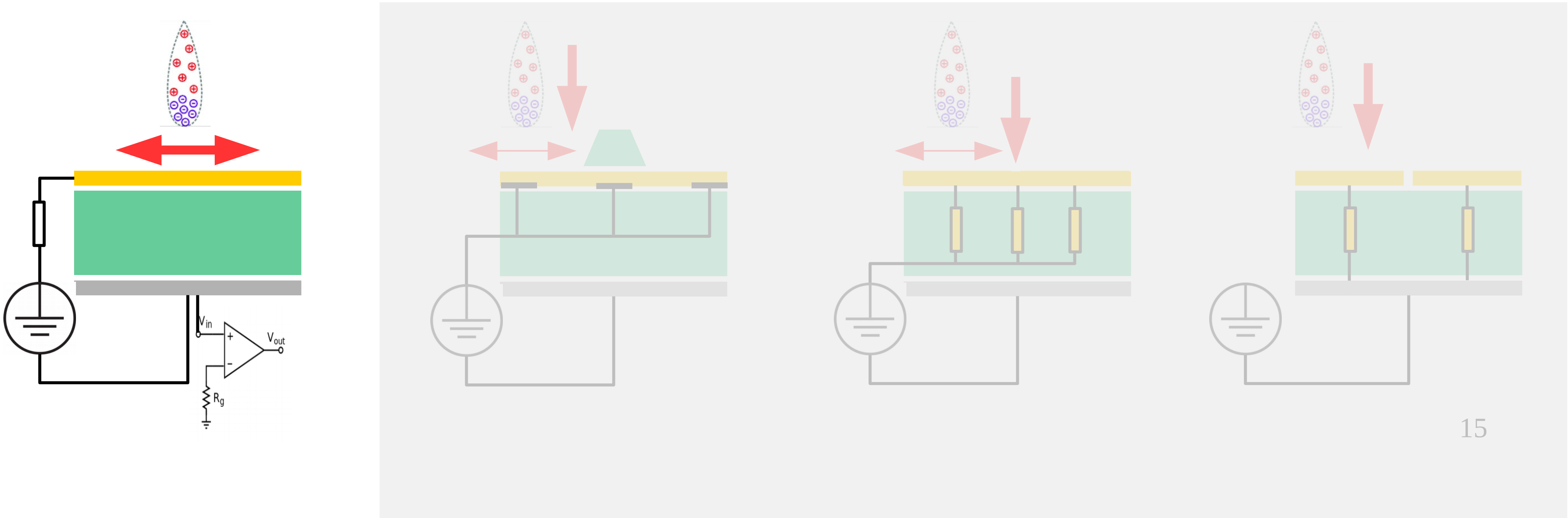
Resistive MPGD

- **Resistive electrodes** Charge spread (σ_x), local charge-up (no spark but rate effects)
- **Simplest (and first) implementation**

  Continuous layer C-coupled to anode and grounded on edges of active region

  → fine up to moderate particle rates / unit area. Used for ATLAS, LC-TPC, μRWELL.
- For higher rates: reduce R by e.g. shortening the path to ground

  → several options (keeping some R btw avalanche spot & ground in case of short with mesh)



The path to ground

- **Resistive electrodes** Charge spread (σ_x), local charge-up (no spark but rate effects)
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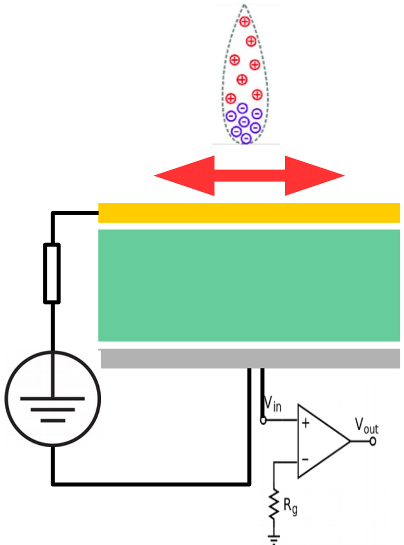
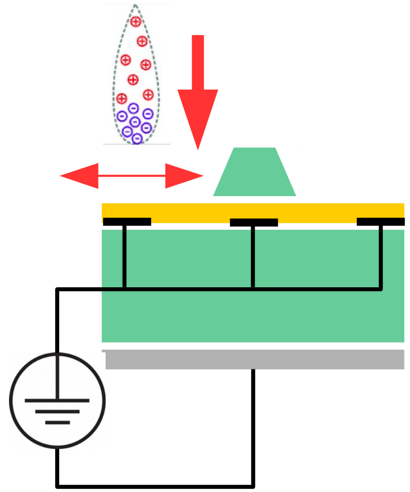
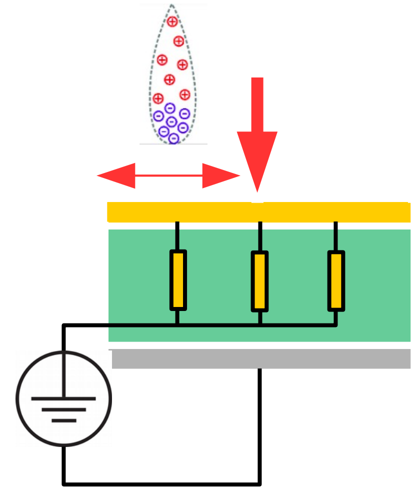
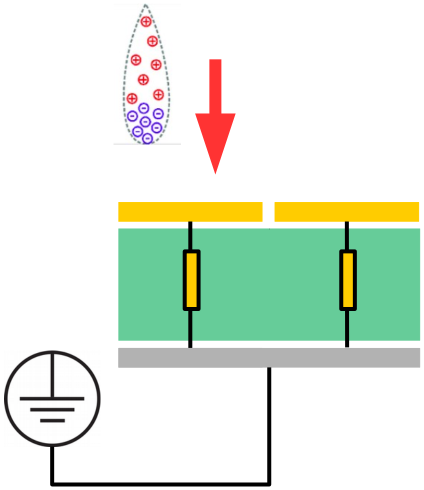




Metalic strips. µRWELL SG
(Hide critical spots)



Embedded R layer or grid
µRWELL RG, R-µM



Segmented pads
No spread → any R!

In practice, the μRWELL

- **Current resitive designs driven by**

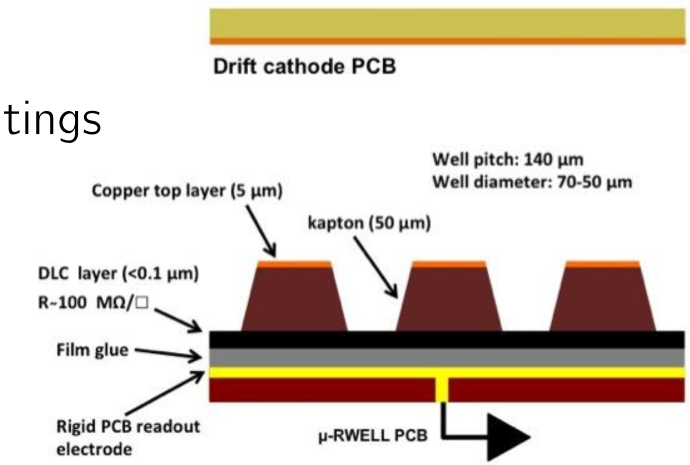
  Construction simplicity - Fast Q evacuation - Reliable R-coatings

- **Smart choice is the μRWELL**

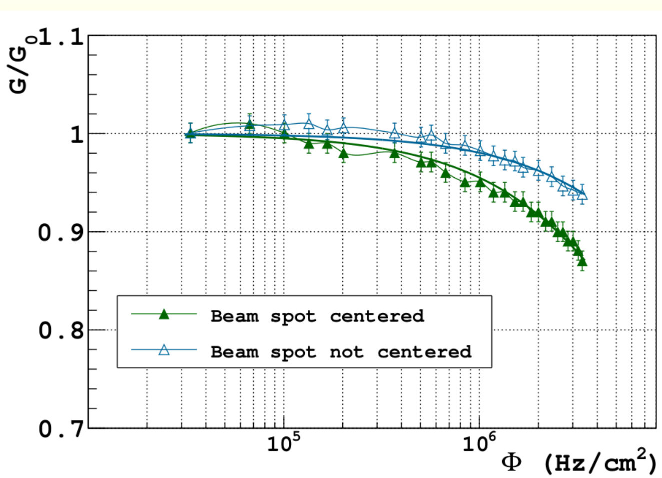
  Kapton foil with Cu & DLC coatings + insulator + PCB

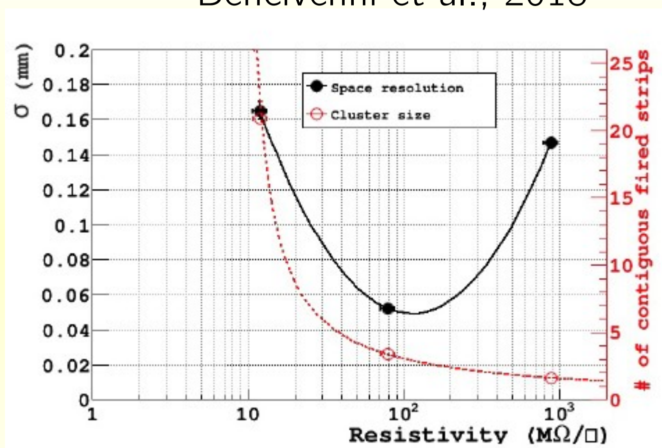
  Surface-R of 100 MΩ/sq for best x-resolution (50 μm)
  Gas gain ($>10^4$) in Ar/CO_2, good ΔE/E (10% @ 5.9 keV)
  Flux limit ~ 100 kHz/cm^2 @ G=2.10^3, position-dependent

  Industry-friendly



Bencivenni et al., 2018





1.9x1.2 m^2
(GE2/1) μ-RWELL
(ELTOS)

Higher rates (planar)

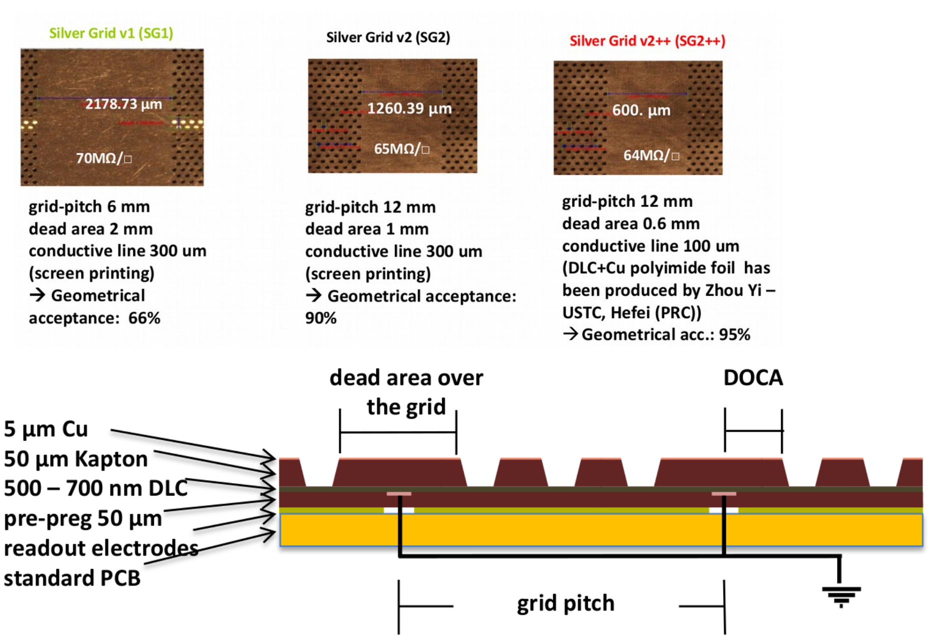
- **Rate capability**

  Measured in the lab on given position with no activity around.
  Real life (uniform illumination): should be worse as surface charges pile up $\rightarrow \Delta V(x,y)$

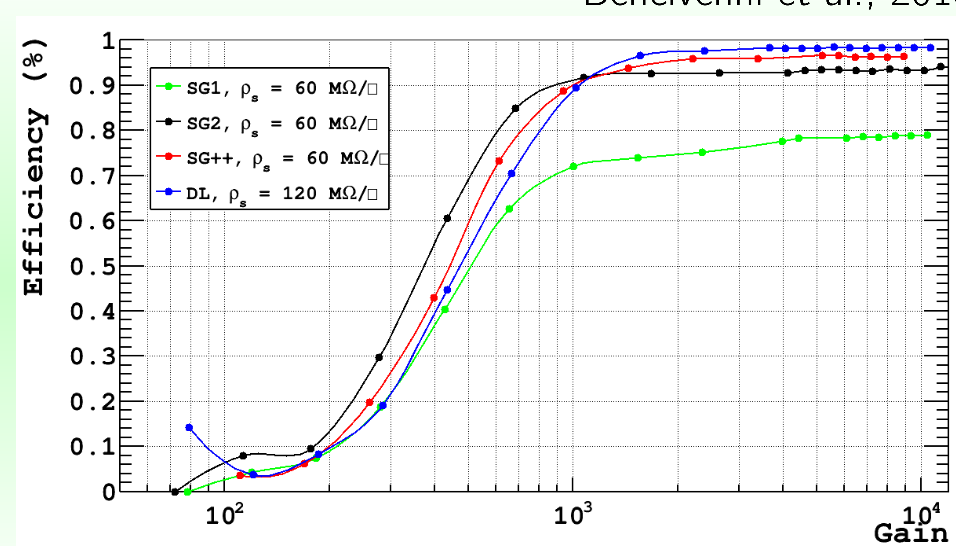
- **Planar charge collection with conductive electrodes**

  Conductive strips printed onto DLC and grounded at the edges of the active area
  - masked region around strips to avoid instabilities: as small as 5% dead zone achieved!
  - lower effective resistance: higher rate capability expected

  Next: resistive strips to elliminate dead zones or conductive dashed-strips



Bencivenni et al., 2018



Higher rates (vertical)

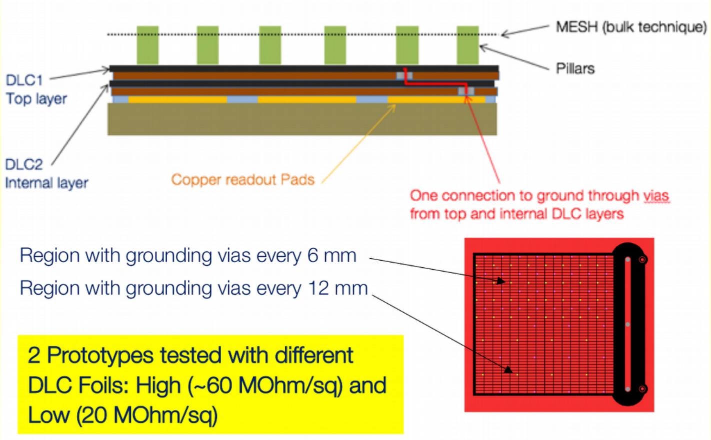
- **Rate capability**

Measured in the lab on given position with no activity around.
Should be worse with uniform illumination as surface charges pile up → $\Delta V(x,y)$

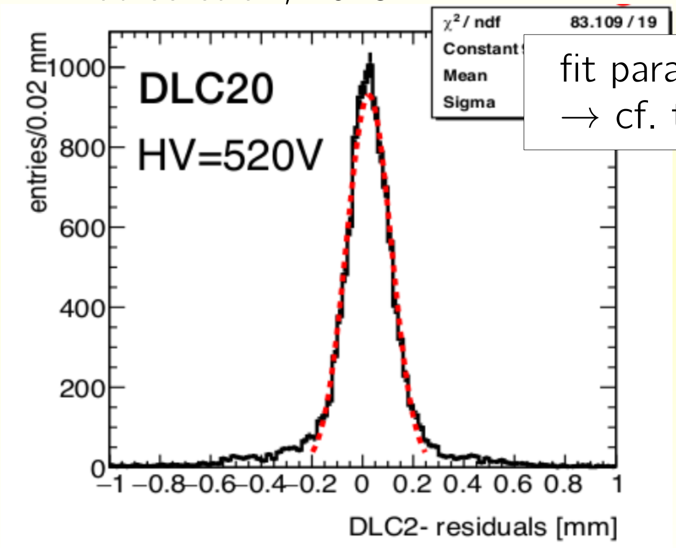
- **Vertical charge collection**

Sandwhich of insulating and resistive layers connected through conductive vias
Pioneered by COMPASS group with small mm^2-sized pads

2 flavours: continuous top R-surface (R_S tuned for σ_x) with µM or µRWELL (2018 TB)
Or segmented (R_S tuned to spark limit) with µM: MHz/mm^2 but $p/\sqrt{12}$ spatial resolution



M. Iodice et al., 2018



fit param?
→ cf. talk

Higher rates (vertical)

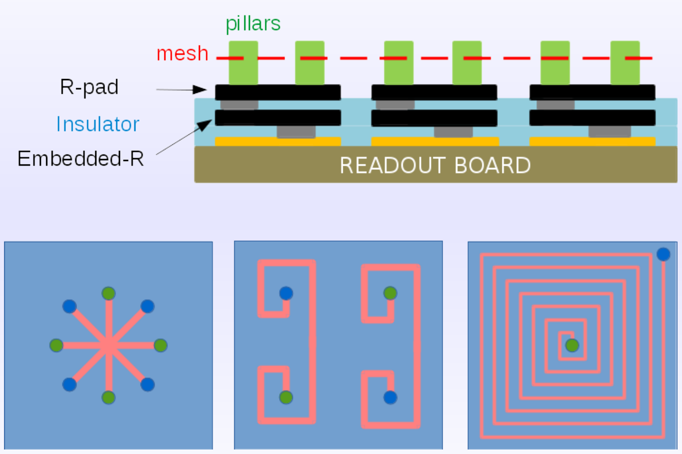
- **Rate capability**

  Measured in the lab on given position with no activity around.
  Should be worse with uniform illumination as surface charges pile up $\rightarrow \Delta V(x,y)$

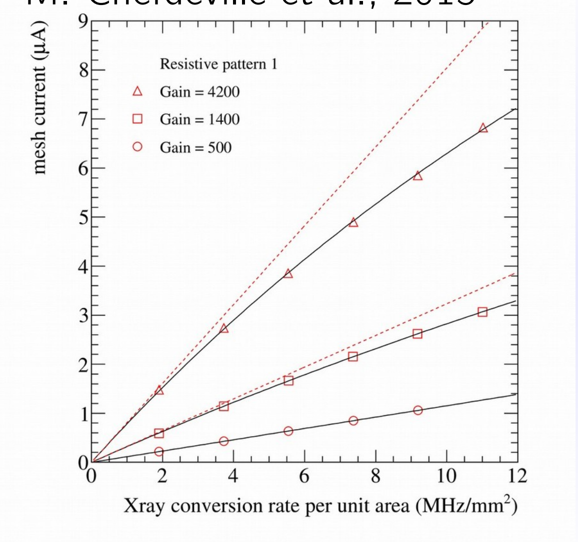
- **Vertical charge collection**

  Sandwhich of insulating and resistive layers connected through conductive vias
  Pioneered by COMPASS group with small mm^2-sized pads

  2 flavours: continuous top R-surface (R_S tuned for σ_x) with µM or µRWELL (2018 TB)
  Or segmented (R_S tuned to spark limit) with µM: MHz/mm^2 but $p/\sqrt{12}$ spatial resolution



M. Chefdeville et al., 2015



Improved Timing @ HL-LHC

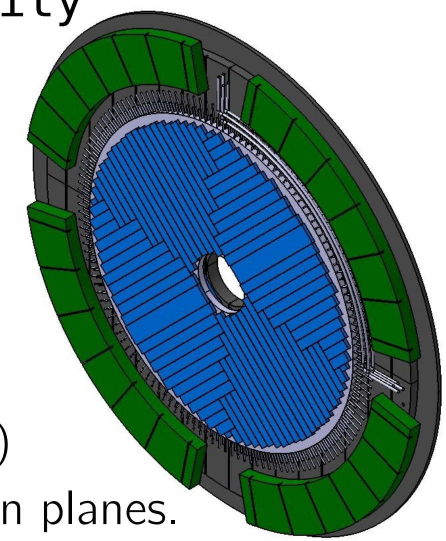
- **The challenge of pile-up @ 5-fold increased luminosity**

  200 pp col. / BX with σ_z = 50 mm (<d> = 0.6 mm) and σ_t = 180 ps

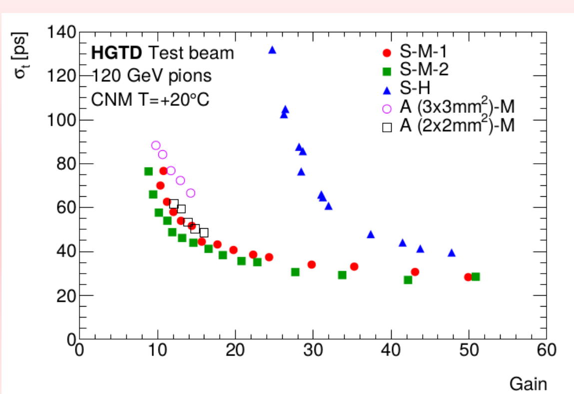
- **Mitigated** by associating tracks (& calo clusters) to PVs
  → associate time to a PV by time-stamping the track(s)

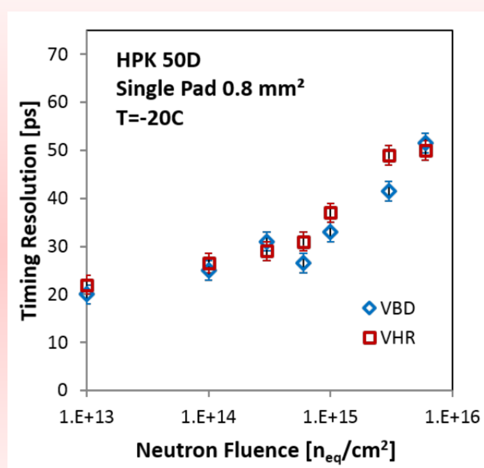
- **ATLAS High Granularity Timing Detector (HGTD)**

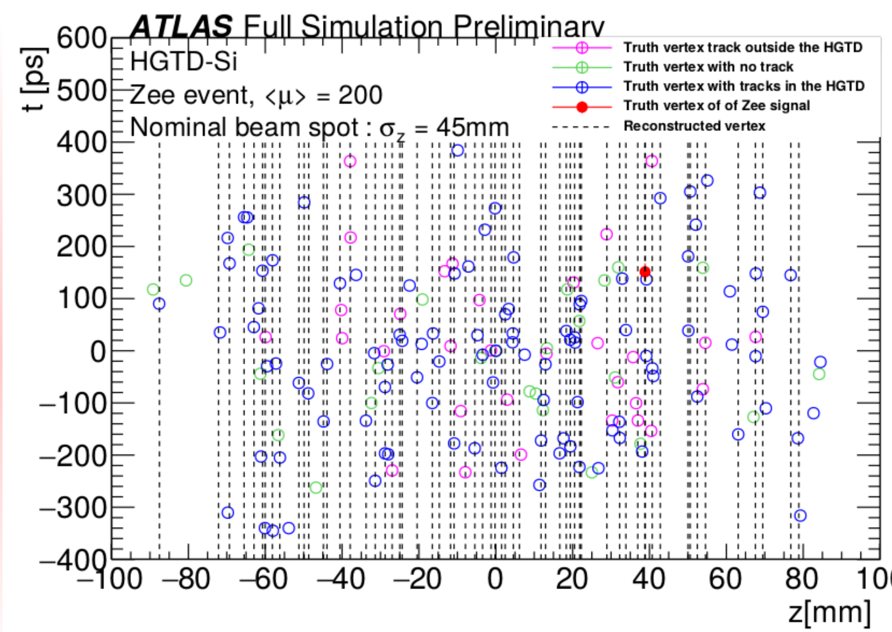
  Si Low Gain APD (σ_t of 30 ps) - 1.3x1.3 mm^2 pixels (<10% occupancy)
  Wheel inner/outer radius of 1.2-6.4 m. Covering |η| = 2.4-4. 3 detection planes.
  → Similar performance in forward & central regions



ATL-LARG-PROC-2018-003







Timing with gas

- **Standard MPGDs show moderate time resolution for MIPs**

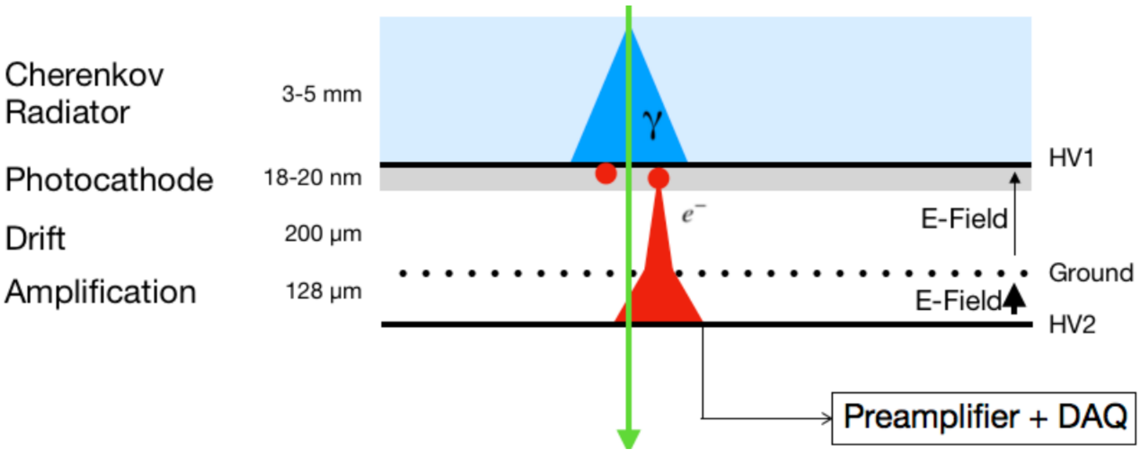
  Poisson-like statistic of primary ionisation (in gas: ns-range)

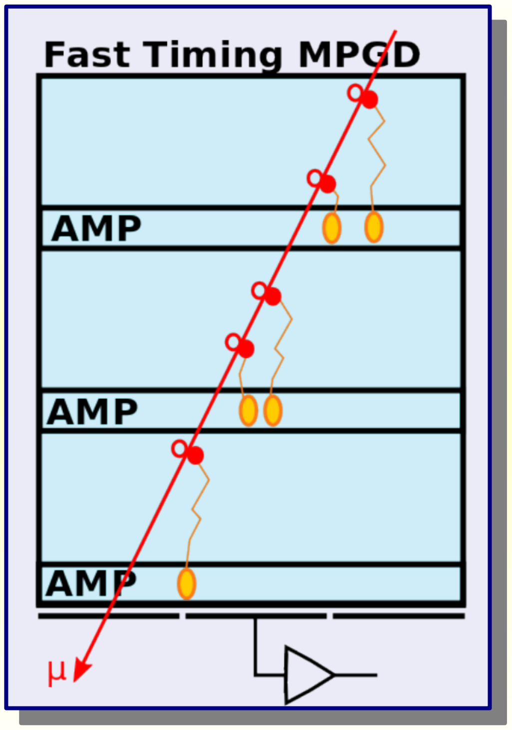
- **Split drift region in several layers (MRPC-like)**

  Fast Timing Mpgd. using resistive stages → all layers contribute to induced signal → σ_t/N

- **Remove primary fluctuations**

  Have all ionisation at a fixed distance from the anode
  → longitudinal diffusion-limited resolution (modulo PE stat)
  Acheived with radiator & photo-cathode: picosec project.





picoSec

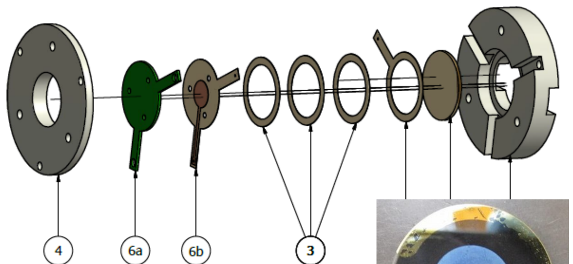
- **Growing interest since 2014**

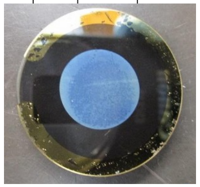
  Participation from several institutes
  Flagship RD51 project: touches all WG

- **Performance & simulation**

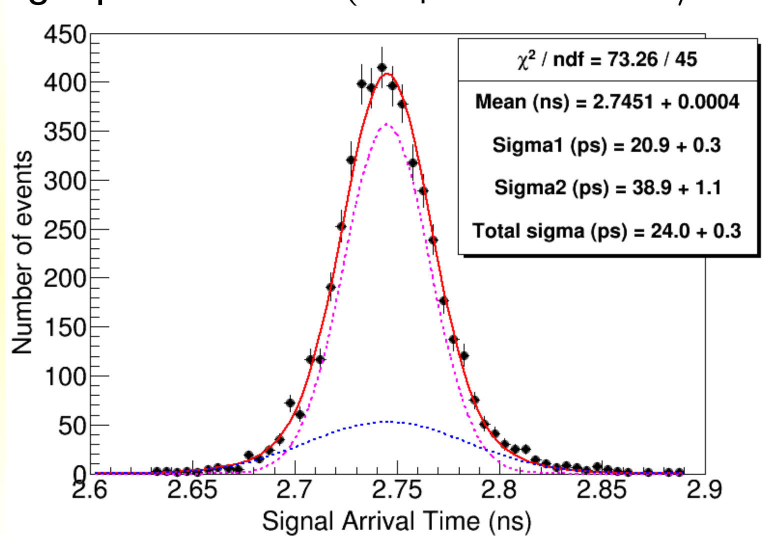
  Arrival time & resolution: waveform analysis & (x,t) corrections
  Garfield++, understand laser & TB data, validate corrections

- **Beam tests & electronics** ($T_{ref.}$, amplifier & digitiser)

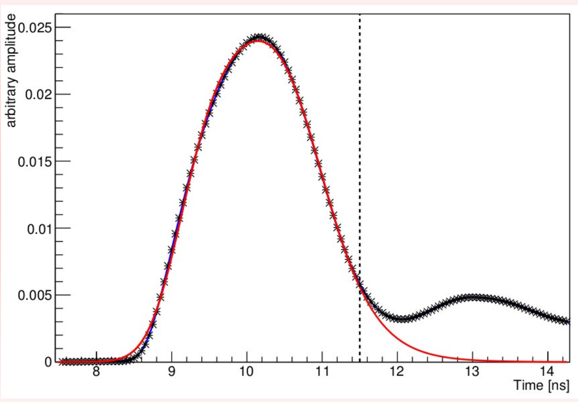


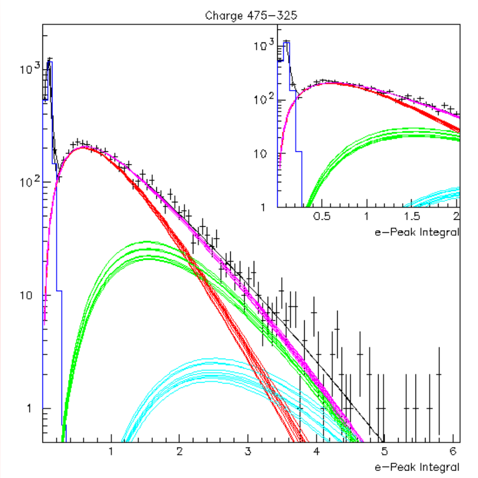


Single pad with CsI (24 ps with 10 PE/muon)

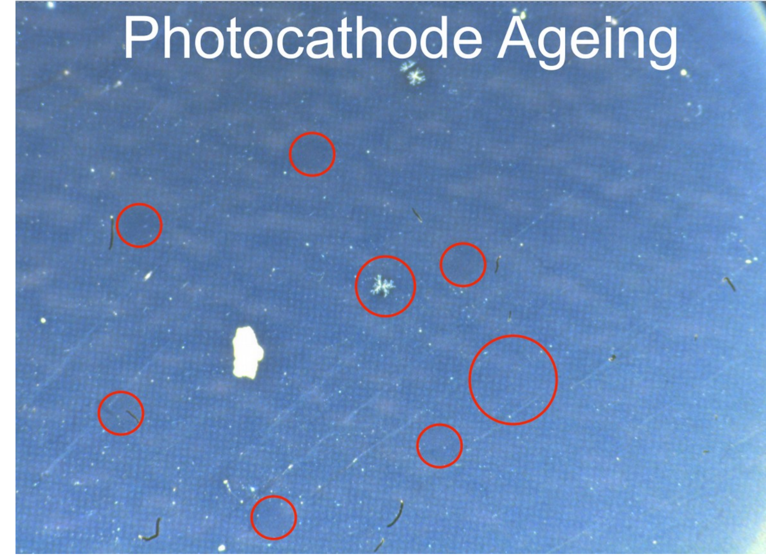


Inputs to simulation





picoSec



- New materials: (CsI,) metal, DLC

  Rad. harder photocathodes with high PE yield?

- New structures tested:

  Reduce large ion backflow ('bad' field ratio): double mesh

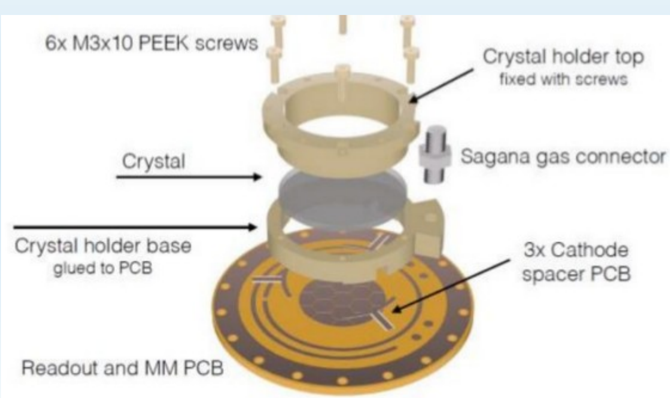
  Improved stability: R-bulk, floating strips

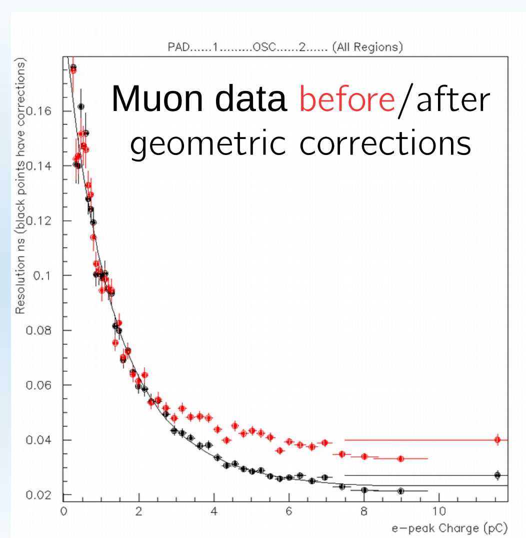
  Scaling up: Multipad: 36 mm diameter (19 pads). Cerenkov cone can overlap with more than 1 pad

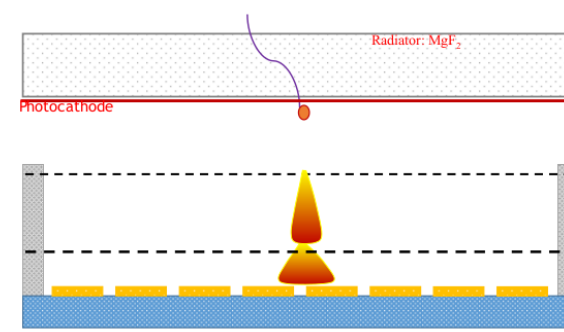
Thickness of DLC film (nm)	Npe/per muon	Detection efficiency for muons
1	Bad	Bad
2.5	3.7	97%
5	3.4	94%
7.5	2.2	70%
10	1.7	68%
5 nm Cr + 18 nm CsI	7.4	100%

Combine pads + x-corrections

Restore full signal & <25 ps reso







Outlook

- **Legacy of the MSGC**

  Much alive field of research today!

  These slides are modestly dedicated to the memory of a pioneer A. Oed.

- **Personal choice to emphasize HEP @ LHC**

  Obvisouly restricts discussion while phase-space embraced by MPGD is so much larger

  Apologies for skipping all over exciting developments (HCAL, RICH, TPC, neutrinos, DM...)

  Next speakers will fortunately correct this bias

- **I of course regreted to have accepted this talk…**

  I hope you don't.

Welcome to France

Welcome to La Rochelle

And enjoy the conference!