# Technical Challenges for RPCs

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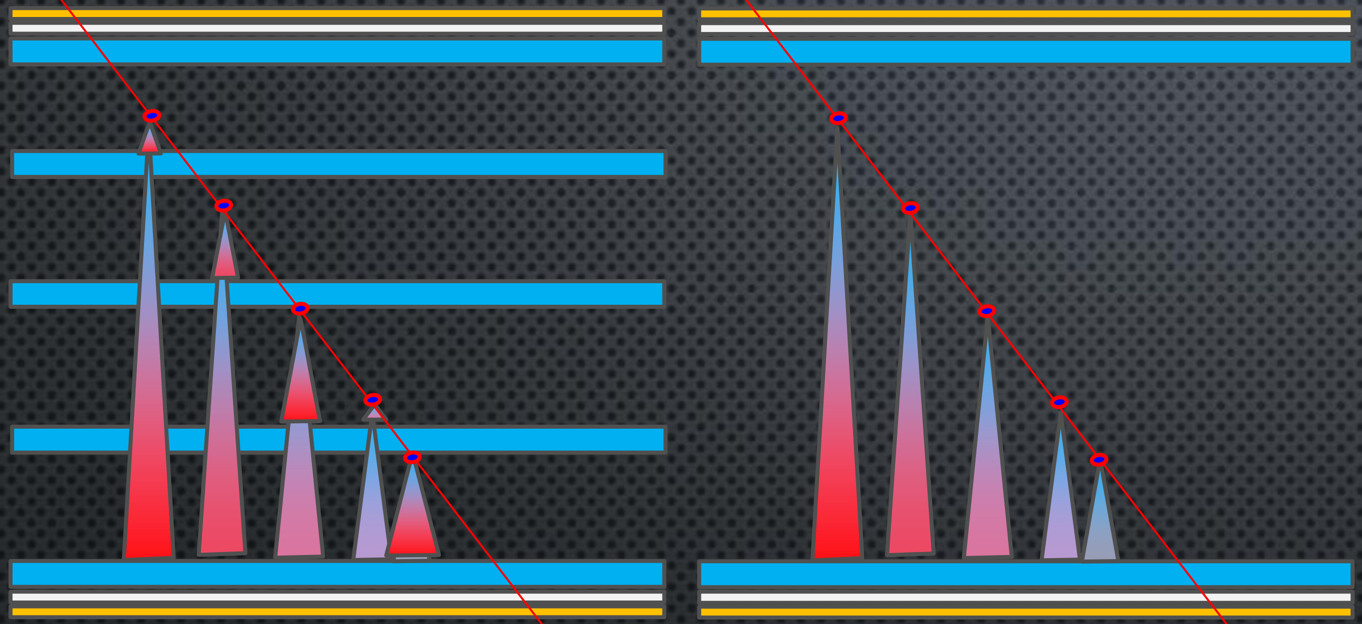
First DRD1 Collaboration Meeting, January 30 2024, CERN

Technologies: overview, limitations and perspectives

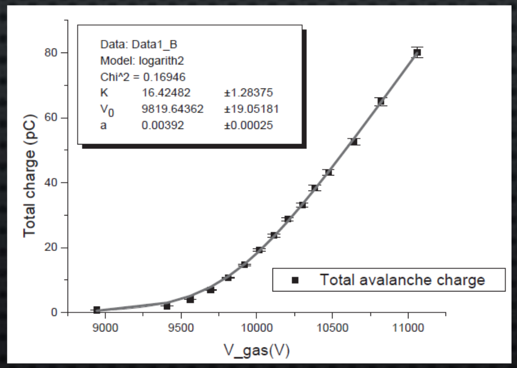
# RESISTIVE PLATE CHAMBERS AT A GLANCE



$$Q(V) = \ln\left(1 + e^{a(V-V_0)}\right)$$
$$Q(x) = \ln\left(1 + e^{\alpha x}\right)$$

Integral logistic growth

G. Aielli et al NIM A 508 (2003) 6–13

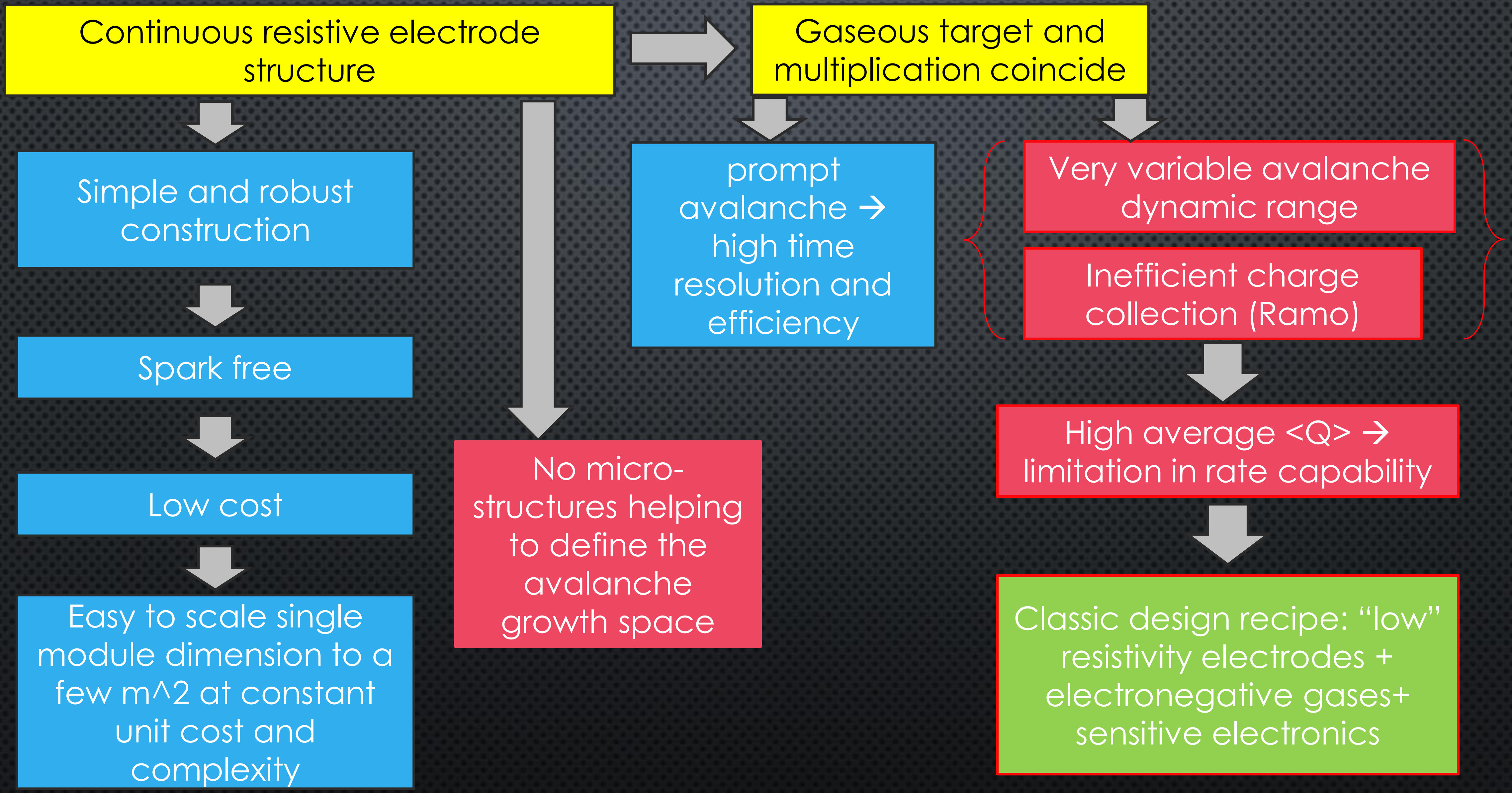



## COMMON FEATURES

- HIGH R ELECTRODES → SPARK LESS
- UNIFORM ELECTRODE → SIMPLE
- UNIFORM FIELD → PROMPT SIGNAL
- WORKING AT ATM. PRESSURE
- 0.1MM 2D LOCALIZATION
- GAS MIXTURE

| Feature | RPC vs | MRPC |
|---|---|---|
| # OF GAPS → | 1 – | 4 TO TENS |
| ρ(Ω CM) → | $5\times10^{10}$ – | $5\times10^{12}$ |
| MODULE SIZE → | 2 $M^2$ – | 0.1 $M^2$ |
| HZ/$CM^2$ → | $10^4$ – | $5\times10^2$ |
| $\sigma_t$ → | 300 PS – | 30 PS |

# RPC STRENGTH VS. WEAKNESS DIAGRAM



# PRESENT LIMITS – RATE AND LONGEVITY

## RATE CAPABILITY

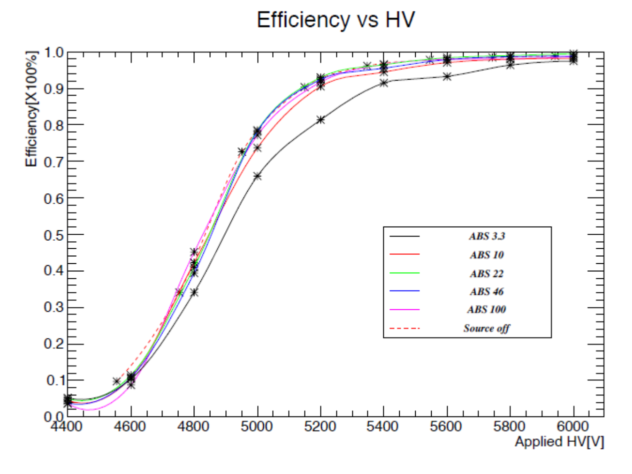
- ELECTRODE RESISTIVITY IS RESPONSIBLE FOR THE PROVERBIAL STABILITY OF RPCS
- ALSO LIMITS ITS RATE CAPABILITY BECAUSE OF THE VOLTAGE DROP
  - $\Delta V = \langle Q \rangle$ X FREQ. X R

  [Q IS THE AVERAGE CHARGE PER COUNT R IS THE TOTAL ELECTRODE RESISTANCE]

## LONGEVITY

- RPC MATERIALS ARE INSENSITIVE TO RADIATION BUT:
  - RADICALS PRODUCED IN THE DISCHARGE AFFECT THE ELECTRODE QUALITY → NOISE
  - THE AMOUNT OF CONDUCED CHARGE CAN DEPLETE THE CARRIERS AFFECTING R

State of the art




1mm gap ATLAS upgrade
Resistivity → $5*10^{10}$
Noise → 4000 e-
ABS3.3 at GIF++ → ~10 $kHz/cm^2$

- LOWERING R IMPROVES RATE CAPABILITY ONLY
  - LOWER RESISTIVITY MATERIALS
  - THINNER ELECTRODES
- ACHIEVING HIGH RATE BY BRUTE FORCE REDUCTION OF R (WITHOUT REDUCING AT THE SAME TIME THE E FIELD) MAY LEAD TO INSTABLE DETECTORS

- REDUCTION OF <Q> IMPROVES RATE CAPABILITY AND LONGEVITY AT THE SAME TIME
  - BY IMPROVING THE S/N ON THE FE ELECTRONICS
  - BY IMPROVING THE SIGNAL COLLECTION EFFICIENCY

Keeping the gas clean is the key to preserve the electrode longevity

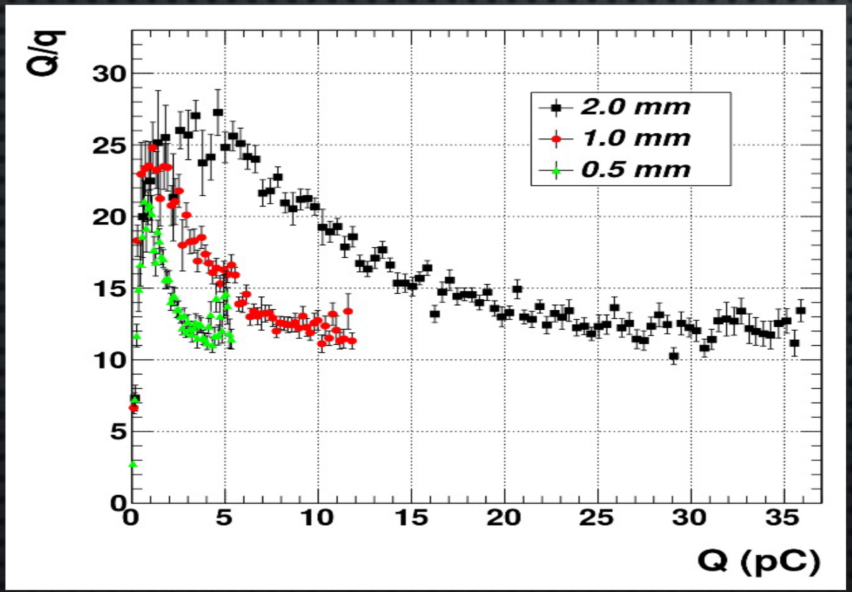
# HIGH RATE STRATEGY FOR RPCS

HL-LHC upgrade

- LIMITED BY RAMO THEOREM (~1/10 OF <Q> IS USABLE)
- LOW RESISTIVITY ELECTRODES MADE OF HPL (~$10^{10}$ Ω CM)
- SIGE FE TECH. WITH 4K E- NOISE TO REDUCE <Q>
- REACHING UP TO 10 KHZ/CM$^2$ IN PRODUCTION CHAMBERS
- SUITABLE FOR SAFE OPERATION WITH ECO-GAS MIXTURE

THIS IS THE PRICE PAID BY RPCS FOR HAVING A PROMPT AVALANCHE MULTIPLICATION → THE EXCELLENT TIME RESOLUTION IS PAID WITH A LARGER CHARGE PER COUNT

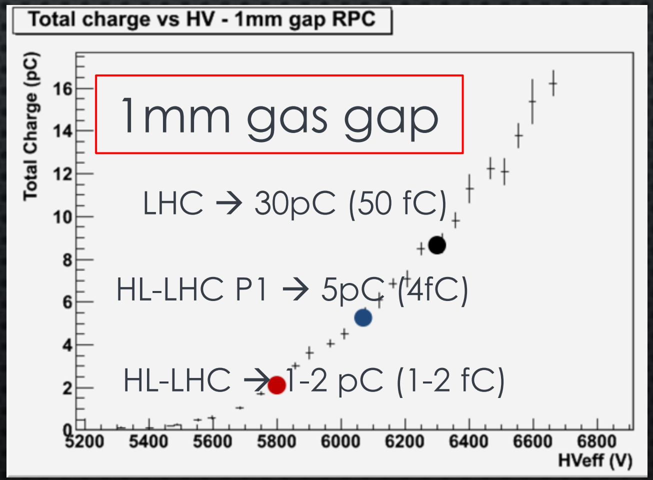
FFC TARGET → improve by a further order of magnitude by increasing S/N




Thinner gap → better Q/q (https://doi.org/10.1088/1748-0221/11/07/P07014)

Pointing out a bi-gap of 0.5 mm as ultimate classic RPC….

Last generation SiGe etero-junction technologies (fT 0.7 THz) announce a further x 10 leap in the FE → 500 e- noise reduction

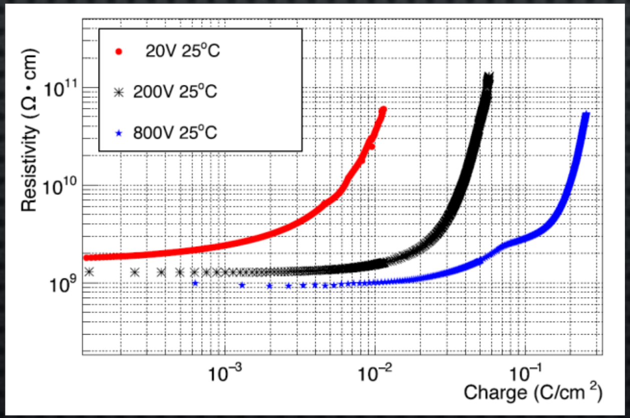



For further exploiting the electronics:

- Faster avalanche
- Very efficient grounding

# LOWER RESISTIVITY FOR HIGHER RATE (ALL RPCS)

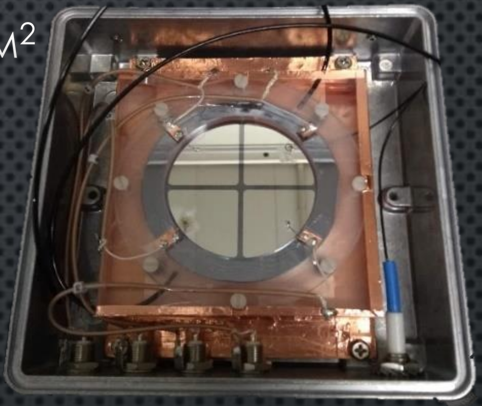
- MRPC → EXTREME EXPLOITATION OF THE DETECTOR GEOMETRY TO EXTRACT THE MOST OF <Q>
  - E.G. ALICE: 10 GAS GAPS OF 0.25MM WITH 0.4 MM ELECTRODES
- MAIN LIMITATION → THIN FLOAT GLASS LIMITED TO < 1 KHZ/CM² DUE TO $\rho \sim 10^{12}$ Ω/CM.
- NEW MATERIALS WITH LOW RESISTIVITY (DOWN TO $10^{9-10}$ Ω/CM) →(CERAMICS, PLASTICS, GLASS,…) (10.1016/J.NIMA.2006.12.027, 10.1016/J.NIMA.2010.08.076, 10.1016/J.NIMA.2020.163483, 10.1088/1748-0221/14/09/C09007, HTTP://CDS.CERN.CH/RECORD/2319919
  - CARRIER DEPLETION EFFECTS → R&D NEEDED
  - MATERIAL NON-HOMOGENEITIES FOR LARGE SIZES
  - THINNING ELECTRODES STILL POSSIBLE.
  - FORCED (NO DIFFUSION) GAS DISTRIBUTION
- LARGE MARGIN ACHIEVABLE BY LOWERING < Q >




A NEW DEVICE: SINGLE GAP SEMI-CONDUCTOR RPC

[ELECTRONIC CARRIERS CAN NOT BE DEPLETED]

- COUNTING RATE > 40 KHZ/CM²
- 0.6 MM GAAS ELECTRODES
- RESISTIVITY 1.4×10^8 ΩCM
- 1 MHZ/CM² SEEMS POSSIBLE
- ACTIVE AREA 6.25 CM²
- 10.1088/1748-0221/15/12/C12004



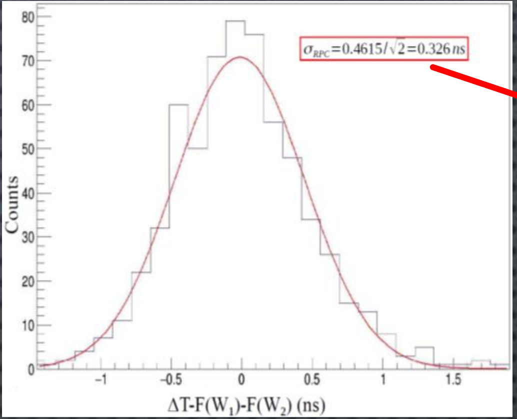


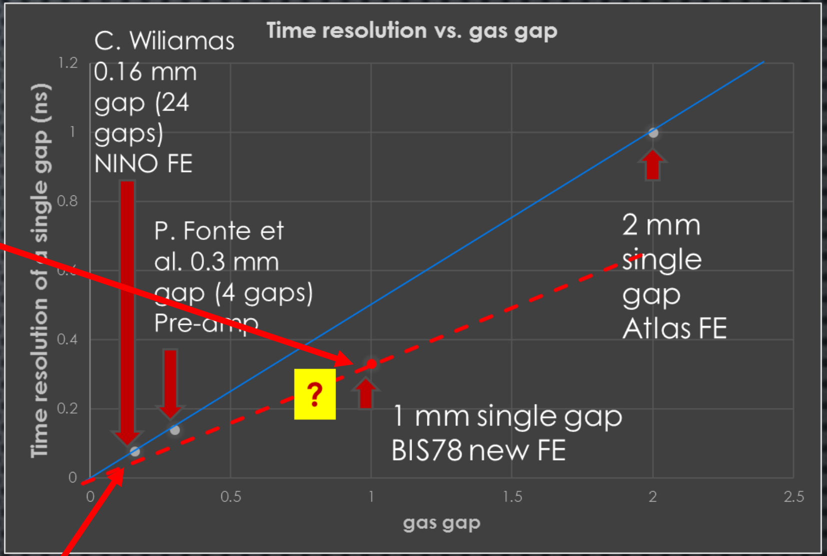

**FFC TARGET → improve by a further order of magnitude by lowering R**

# PRESENT LIMITS – TIME RESOLUTION

## TIME RESOLUTION IS ONE OF THE MAIN RPC FEATURES

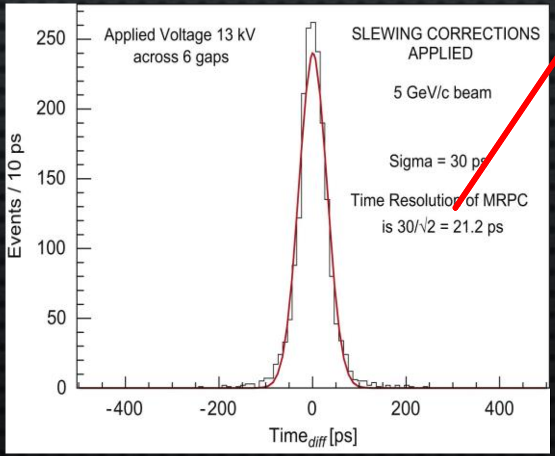
- GOLDEN STANDARDS: **MRPCs ~30 PS -- RPCs ~300 PS**
- COMPLEX PHYSICS BEHIND: CLUSTER STATISTICS, MULTIPLICATION DYNAMICS, ELECTRONIC NOISE
- EMPIRICALLY SMALLER GAS GAPS → HIGHER RESOLUTION
  - SMALLER GAS GAPS CAN BE OPERATED AT HIGHER ELECTRIC FIELD AND HAVE A FASTER MULTIPLICATION DYNAMICS COMPRESSING NOISE FLUCTUATIONS
- STILL A FEW POINTS TO BE BETTER UNDERSTOOD ON THE DETECTOR PHYSICS SIDE




## CHALLENGE: RESOLUTION BEYOND 50 PS

- WITH MORE AND THINNER GAS GAPS, E.G, 20 PS WITH 24, 0.16 MM GAPS [10.1016/J.NIMA.2008.06.013]
- THINNER ELECTRODES → HIGHER SIGNAL
- LOW NOISE HIGH RESOLUTION FEE (PICOTDC) HTTPS://KT.CERN/TECHNOLOGIES/PICOTDC



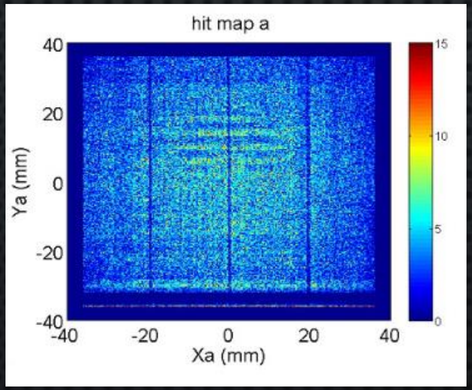

## INNOVATIVE APPROACH →

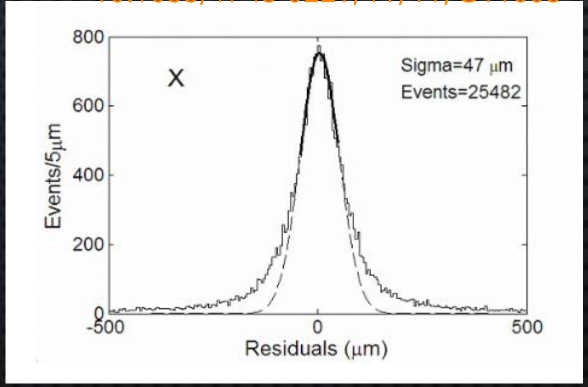
- GOING BEYOND THE GAS GAP WIDTH LAW
- EXTRACT HIDDEN INFORMATION BEYOND DISCR. AND SLEW CORRECTION
- PROMISING THE USE OF DNN TO FILTER THE COMPLEX AVALANCHE DYNAMICS → 16 PS ACHIEVED! [ARXIV:2005.03903V1 [PHYSICS.INS-DET] 8 MAY 2020]

# 2D Tracking Challenge – For All RPCs

- RPC generate signals with accurate position information → discharge cell footprint ~ 100μm$^2$ (10.1088/1748-0221/7/11/P11012)
- Same limitations of micro-pattern detectors coming from
  - the readout system precision
  - Expensive readout electronics
  - A lot of readout channels
- Efficient and innovative readout systems
- Applications: PET, muon tomography, future tracking devices

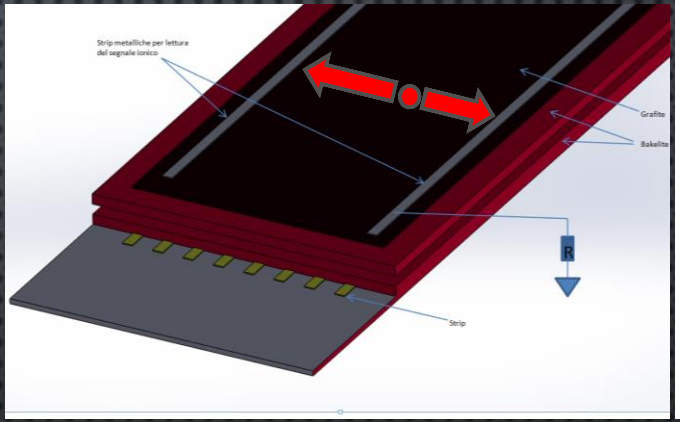
10.1088/1748-0221/11/11/C11008

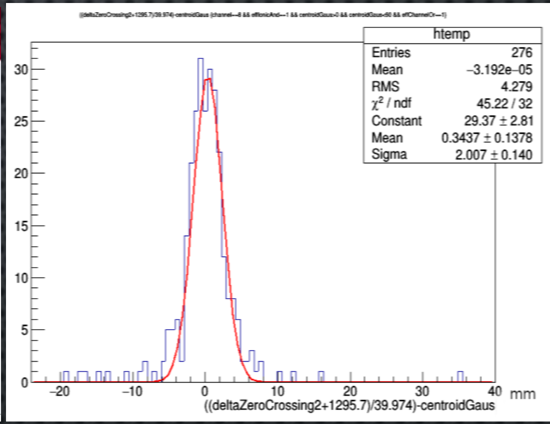



**A new Idea** → Planar drift chamber

- Measuring the impact position from the diffusion wave time walk difference on the graphite electrode



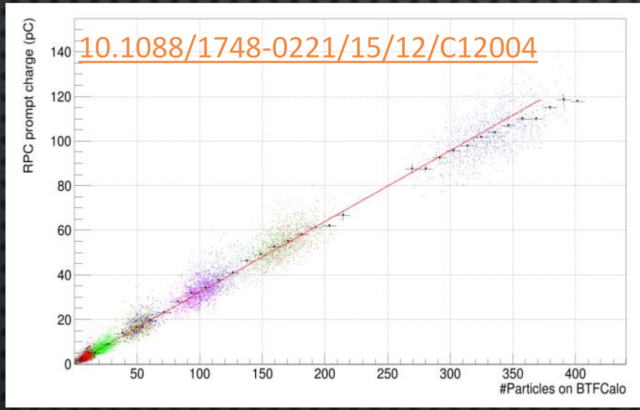




R. Cardarelli et Al. Track resolution in the RPC chamber NIM A572, vol. 1 170-172 (2007).

- Can reach sub mm precision
- Suitable for large area low rate environment (rate is limited to about 100 Hz/cm$^2$)
- Very low cost readout electronics

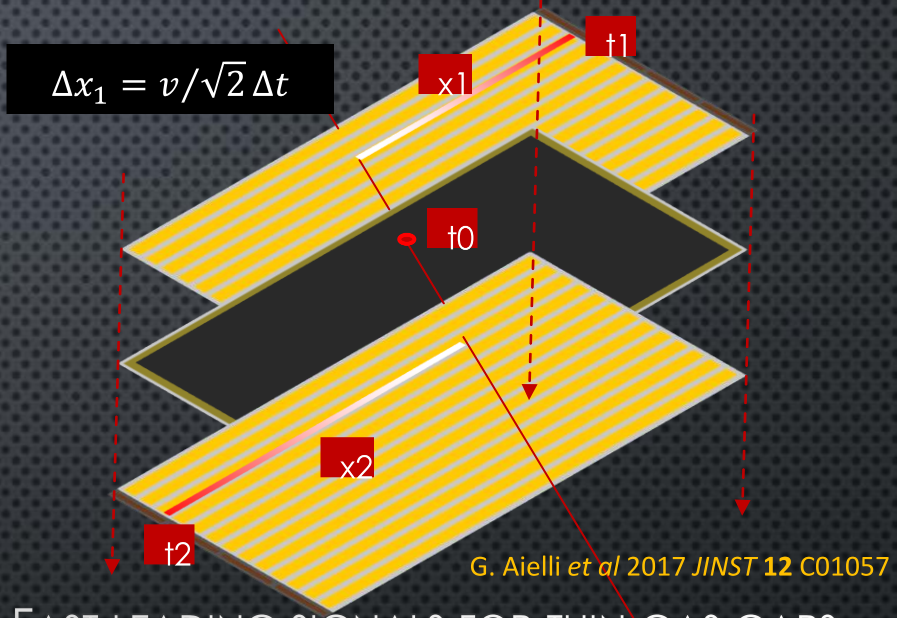
# HIGH DENSITY AND MULTI-TRACKS – FOR ALL RPCS

- NOT WELL KNOWN RPC FEATURE: THE SIGNAL AMPLITUDE IS PROPORTIONAL TO THE NUMBER OF SIMULTANEOUS TRACKS UP TO VERY HIGH DENSITY
- CONSEQUENCES FOR ANALOG CALORIMETRY
- NO DEVIATION FROM LINEARITY MEASURED UP TO 2200 SIMULTANEOUS HITS PER CM$^2$




- TIME TAGGING OF THE SHOWER: $\sigma_t/\sqrt{N}$
- N IS THE NUMBER OF SIMULTANEOUS TRACKS
- EXAMPLE FOR $\sigma_t = 0.5\, ns$ AND 100 TRACKS THE SHOWER IS TAGGED WITH 50 PS ACCURACY

CHALLENGING READOUT FOR FUTURE COLLIDERS



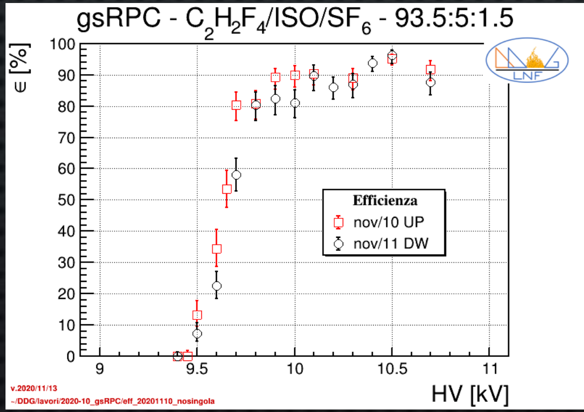

- FAST LEADING SIGNALS FOR THIN GAS GAPS
- NEW GENERATION OF INEXPENSIVE ~ 1PS TDCS
- PROPAGATION SPEED 15 CM/NS
- 100 μM PRECISION IS THE TARGET
- CAN BE REPLICATED IN 2D
- ACCURATE RECONSTRUCTION OF MULTIPLE TRACKS

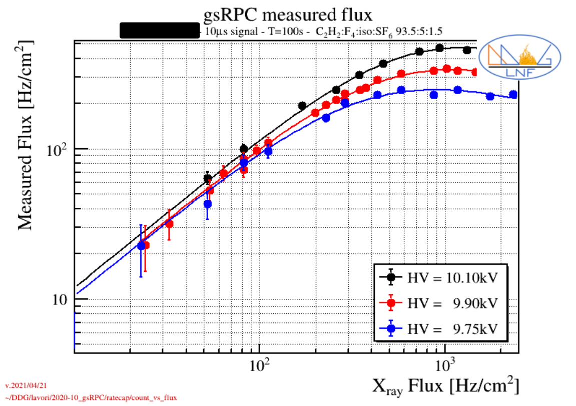
# AN INNOVATIVE CONSTRUCTION METHOD

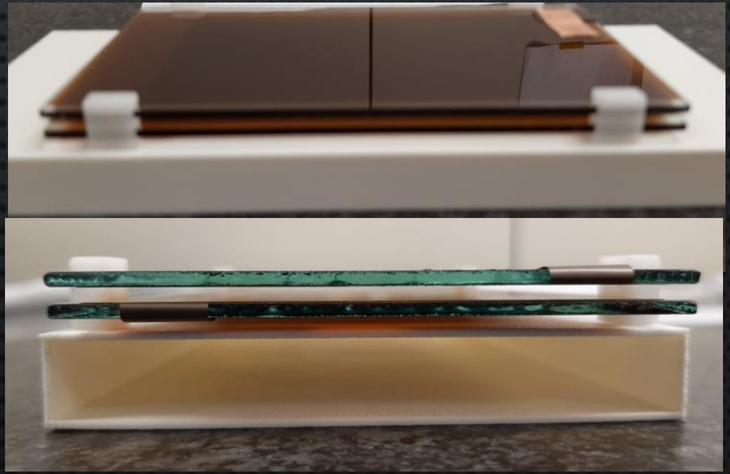
## sRPC (surface RPC)

*(1) Brevetto in Italia N. 102020000002359 (submitted to INFN 10 Sept 2019 - deposited to Ufficio Brevetti 6 Feb 2020)*
*INFN – "ELETTRODO PIANO A RESISTIVITÀ SUPERFICIALE MODULABILE E RIVELATORI BASATI SU DI ESSO."*

- Traditional resistive electrodes and their HV distribution coating (e.g. graphited HPL) is replaced by 1-10 G Ω/square DLC coating
- Technology ported from resistive MPGDs (1)
- A 2mm gas gap built and tested, shows a normal behavior
- Current is evacuated through the surface which might limit the rate
- Can achieve up to 10 kHz/cm$^2$ by implementing higher segmentation of the grounding network (as for the MPGDs)



All RPC features have been stretched in all direction except two apparently fundamental ones

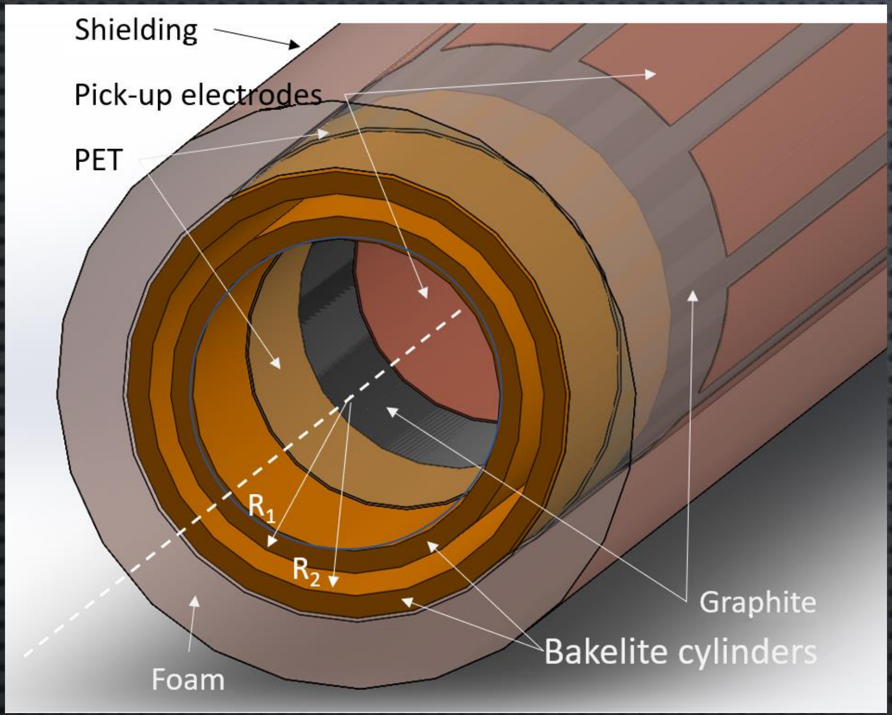
- The atmospheric pressure operation
- The electric field uniformity

# SOMETHING NEW

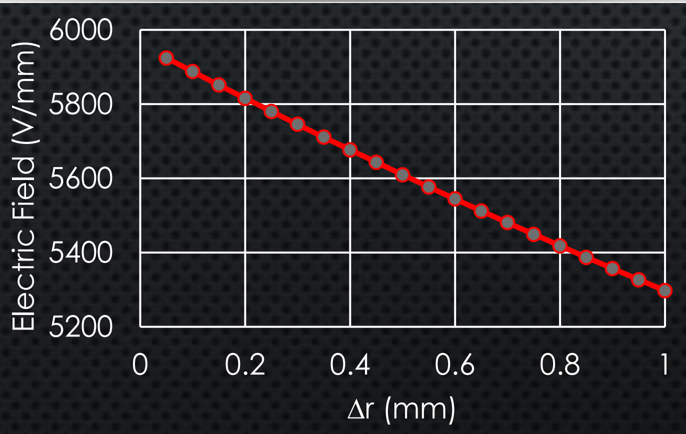
## WHAT IF ONE TRIES TO COMBINE RPCS AND PESTOV CHAMBER IN A SINGLE WARPED DEVICE?

# THE RESISTIVE CYLINDRICAL CHAMBER (RCC)

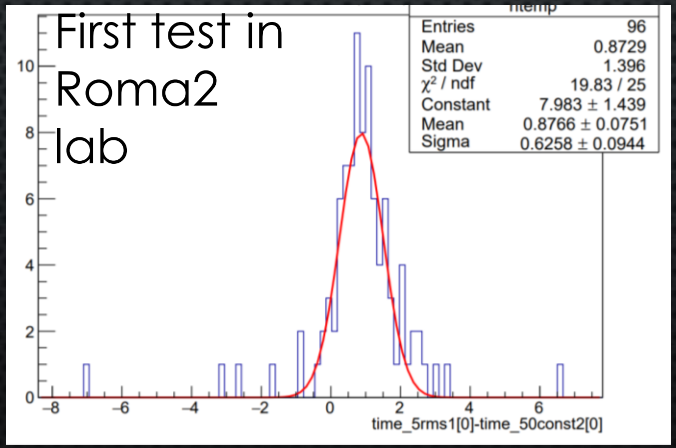
R. Cardarelli "***Future RPC developments***", RPC2020 Roma 10-14 /02/2020 proceeding on JINST

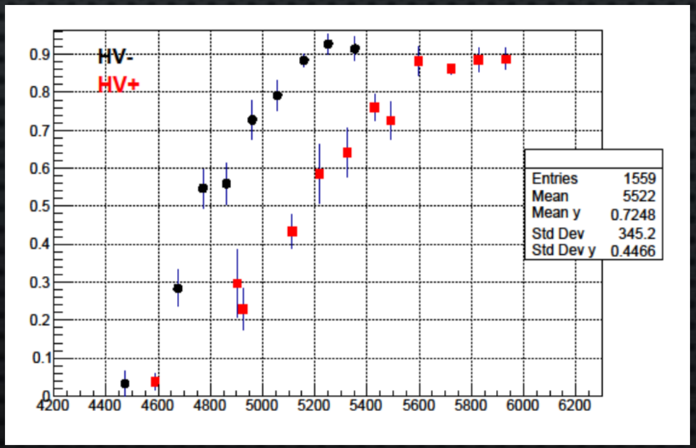



- Geometry defined by two concentric pipes spaced by a gas gap
- The radial field introduce the concept of geometrical quenching, can be tuned by playing with R1 and R2
- No need of expensive and high GWP electronegative gases to keep the avalanche stable
- No chemical driven ageing effects
- Cylindrical geometry supports high pressure operation i.e.
  - Full efficiency in a single micro gap even with light gases
  - Time resolution proportional to pressure
  - Can exploit large experience in MDT chambers…
- Aiming to a fully efficient sparkles ~5 ps resolution detector…




$$E(r) = -\frac{V}{r\log\frac{R_1}{R_2}}$$



# CONCLUSIONS

ALL VERSIONS OF RPC TECHNOLOGY HAS PROVEN IN THE LAST 30 YEARS TO BE A FUNDAMENTAL BUILDING BLOCK OF MODERN EXPERIMENTS.

THERE ARE CHALLENGES WHICH MUST BE FACED TO FULFIL FUTURE EXPERIMENTS NEEDS

- INDUSTRIAL CHALLENGE
- INEXPENSIVE GAS CHALLENGE
- APPROACHING MHZ/CM^2 RATE
- BREAKING THE WALL OF 300 PS WITH A FULLY EFFICIENT SINGLE GAS GAP
- INEXPENSIVE SPACIAL RESOLUTION CHALLENGE
- MULTIPLE TRACK SEPARATION CHALLENGE
- COUNTING HIGH DENSITY TRACKS

RPCS DEVELOPED ENORMOUSLY IN THE LAST 30 YEARS AND SHOW AN EVEN LARGER POTENTIAL