CaPiRe R&D

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Outline

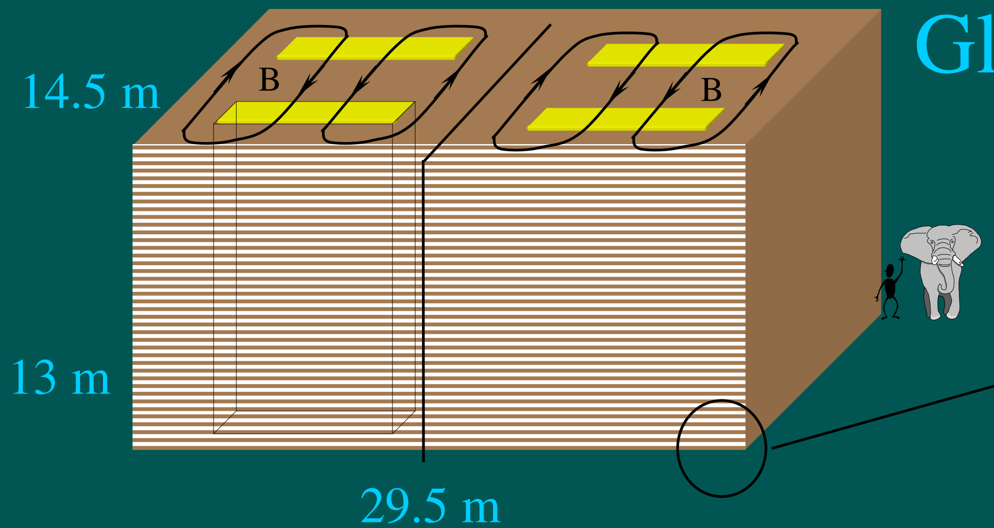
- Introduction
- RPC with glass electrodes
- The R&D programme of the CaPiRe experiment
  - Large area glass RPC prototypes
  - Rate capability measurements
  - Long term stability studies
- Conclusions and outlook

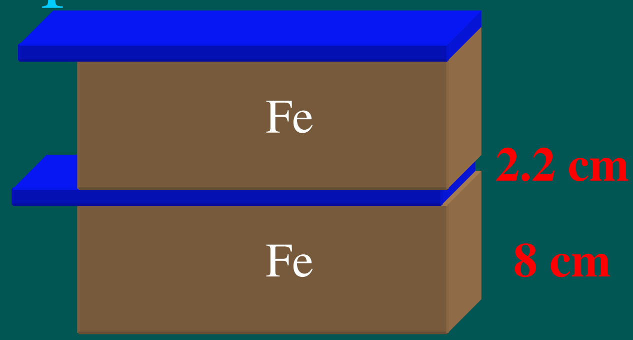
INO (Indian-based Neutrino Obs.) (MONOLITH)

Large mass 34 kton
Magnetized Fe spectrometer B = 1.3 Tesla
Time resolution ~ 1 ns (for up/down discrimination)
Space resolution ~ 1 cm (rms on X-Y coordinates)
Momentum resolution $\sigma_p/p \sim 20\%$ from track curvature for outgoing muons
~ 6% from range for stopping muons
Hadron E resolution σ_{E_h}/E_h ~ $90\%/\sqrt{E_h} \oplus 30\%$

~52000 m^2 of detector :

Glass Spark Counters





NuMI Off-Axis Detector

Detector dimensions

17m x 19m x 200m

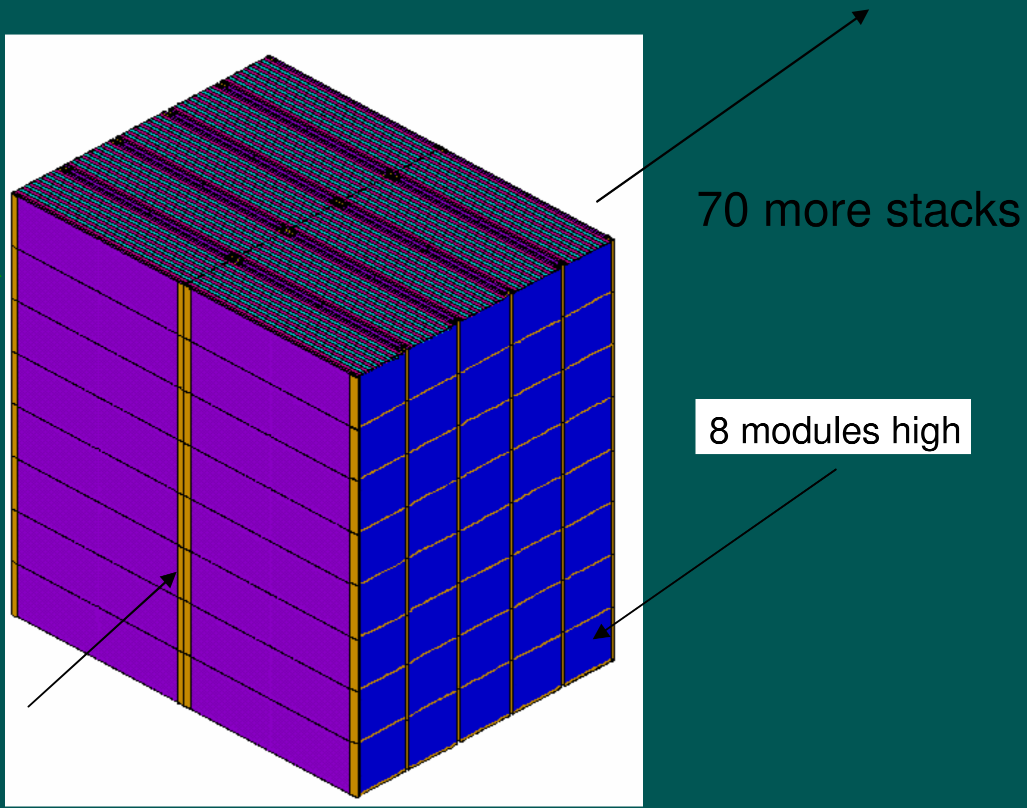
86400 RPCs

RPCs: 2.84 m x 2.43 m

≈ 600000 m^2

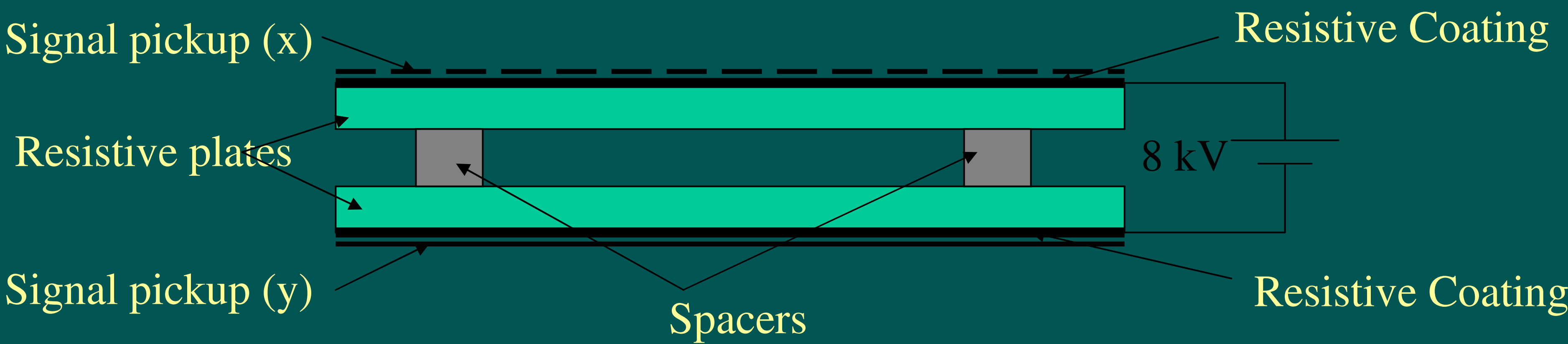
Module: 12 planes

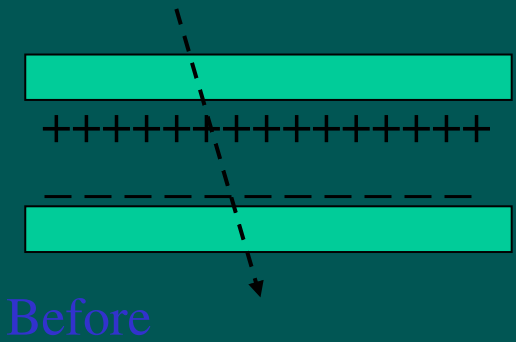
RPCs / absorber (20cm)



Modular RPC Neutrino Detector
1200 Modules

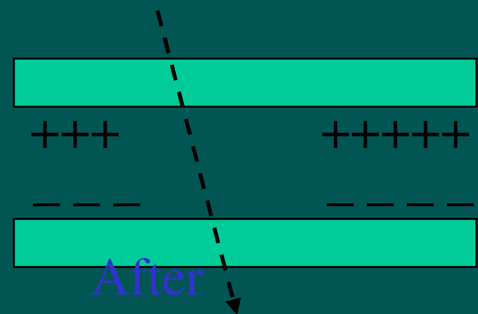
RPC Principles of Operation





A passing charged particle induces an avalanche, which develops into a spark. The discharge is quenched when all of the locally $(r \approx 0.1 \text{ cm}^2)$ available charge is consumed.

The discharged area recharges slowly through the high-resistivity glass plates.



RPC with glass electrodes

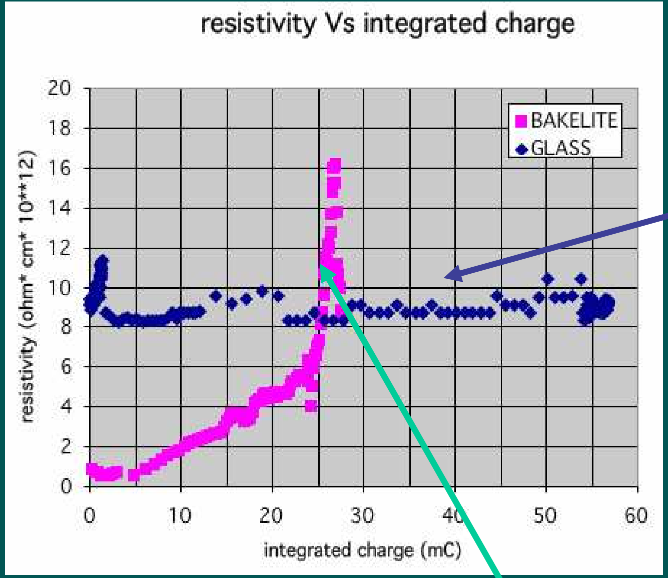
- Advantages of glass electrodes
  - high electrode planarity (*float* glass)
  - high stability of the electrode resistivity
  - Relatively inexpensive and commercially available

  - One successful application on large scale (~2000 m^2) at colliders (BELLE experiment)

- Disadvantages
  - high volume resistivity (limited rate capability)
  - absence of industrial standards for mass production

→ CaPiRe

Float Glass vs Bakelite



Float Glass

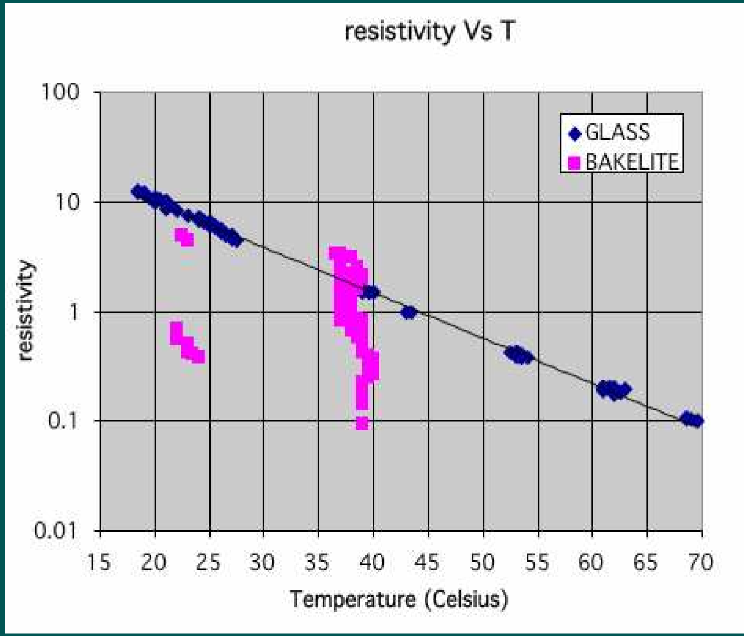
Has a stable resistivity (hopping conductivity)

$\rho = 10^{12}$-10^{13} Ωcm at room temperature

Resistivity depends only on temperature

$$\rho = \rho_{20} 10^{(T-20)/25}$$

Ageing due to the fluorine compounds like $C_2H_2F_4$



Bakelite

$\rho = 10^{10}$-10^{12} Ωcm at room temperature

resistivity increases with the integrated charge (ionic conductivity)

Need a surface treatement with linseed oil

BELLE

To reduce assembly time, extruded strips were used instead of “button-like” spacers.

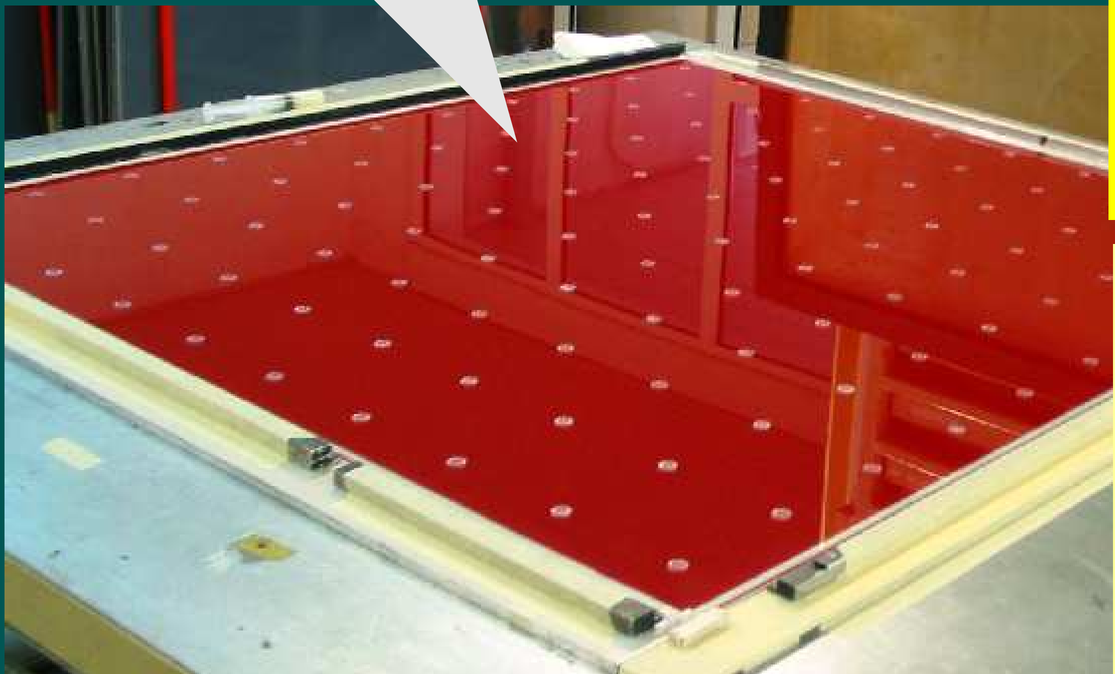
This also provided a natural “mouse maze” to ensure uniform distribution of the gas.

2000 m^2 / 2 years

CaPiRe R&D programme

- Design and engineering of large area glass RPC prototypes suitable for mass production
  - Test industrial procedures for detector assembly
  - Adoption of techniques derived from glass industry
  - Test prototypes performance and reproducibility
- Search for electrode materials and/or working conditions to aleviate the rate capability limitations of glass RPC

Silk Screen Printing



Resistive acrylic paint for electrical contacts deposited with silk screen printing technique

- Fast and reliable:
  - Up to 1000 m^2/day
  - Controllable and reproducible surface resistivity

G.C. Trinchero, A. Giuliano, P.Picchi, Nucl. Instr. and Meth. A 508 (2003) 102
M.Ambrosio et al. Nucl. Instr. and Meth. A 508 (2003) 98.

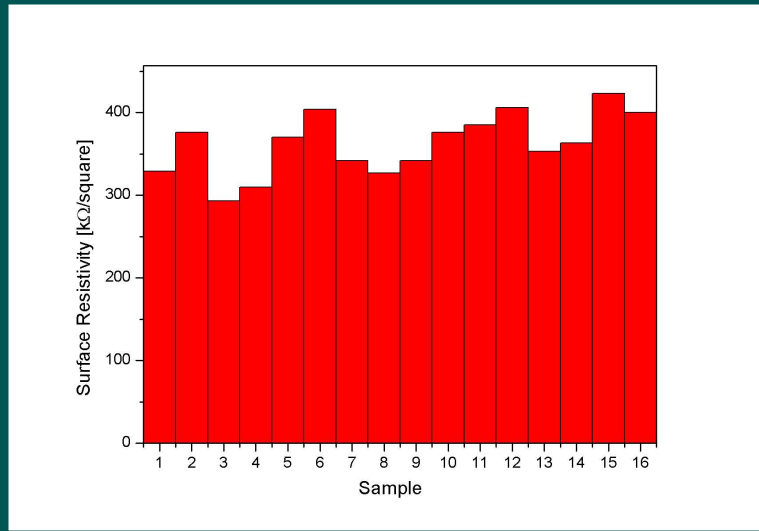
UV Silk Screen Printing

Large scale production plants
(4800/day Max 0.9x 3. m^2)

Better reliability and uniformity over entire production

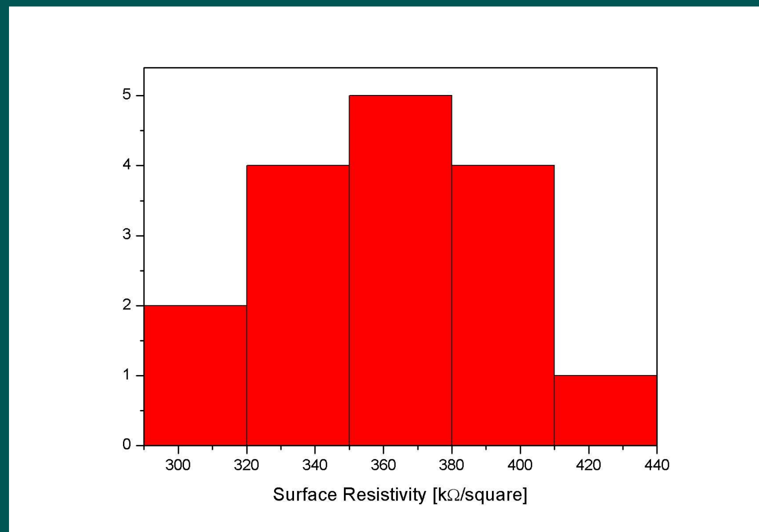
UV Silk Screen Printing: Uniformity

16	12	8	4
15	11	7	3
14	10	6	2
13	9	5	1

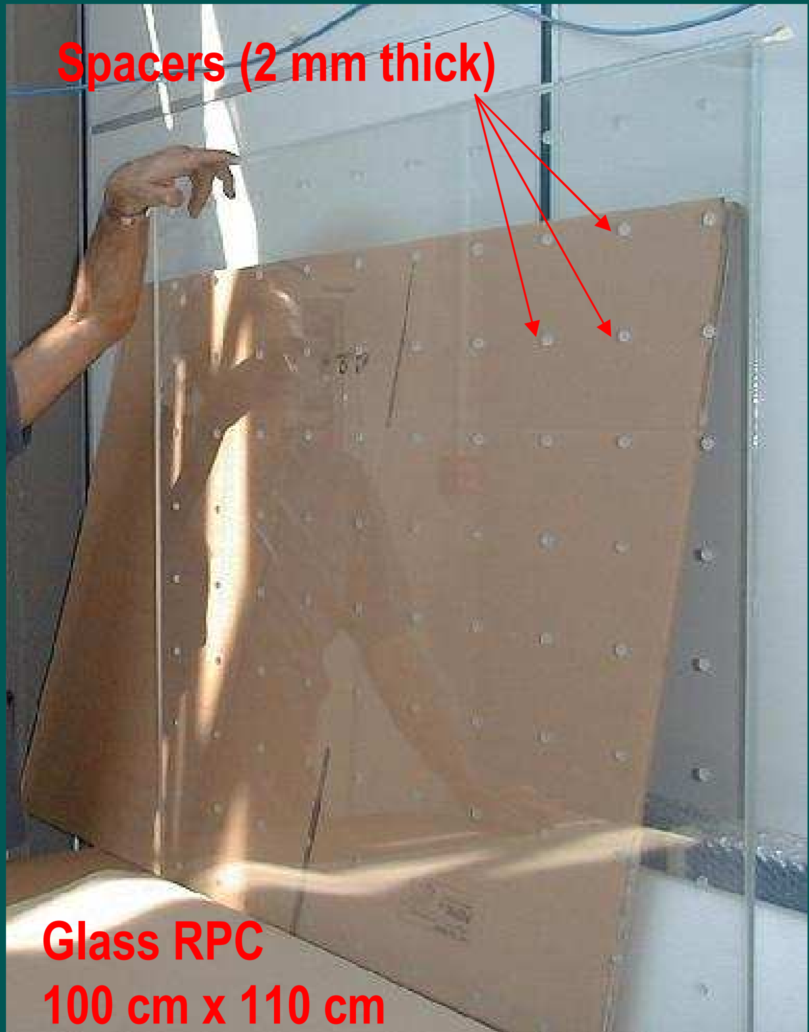


293÷406 kΩ/

σ=362 ± 37 kΩ/



Glass RPC prototypes

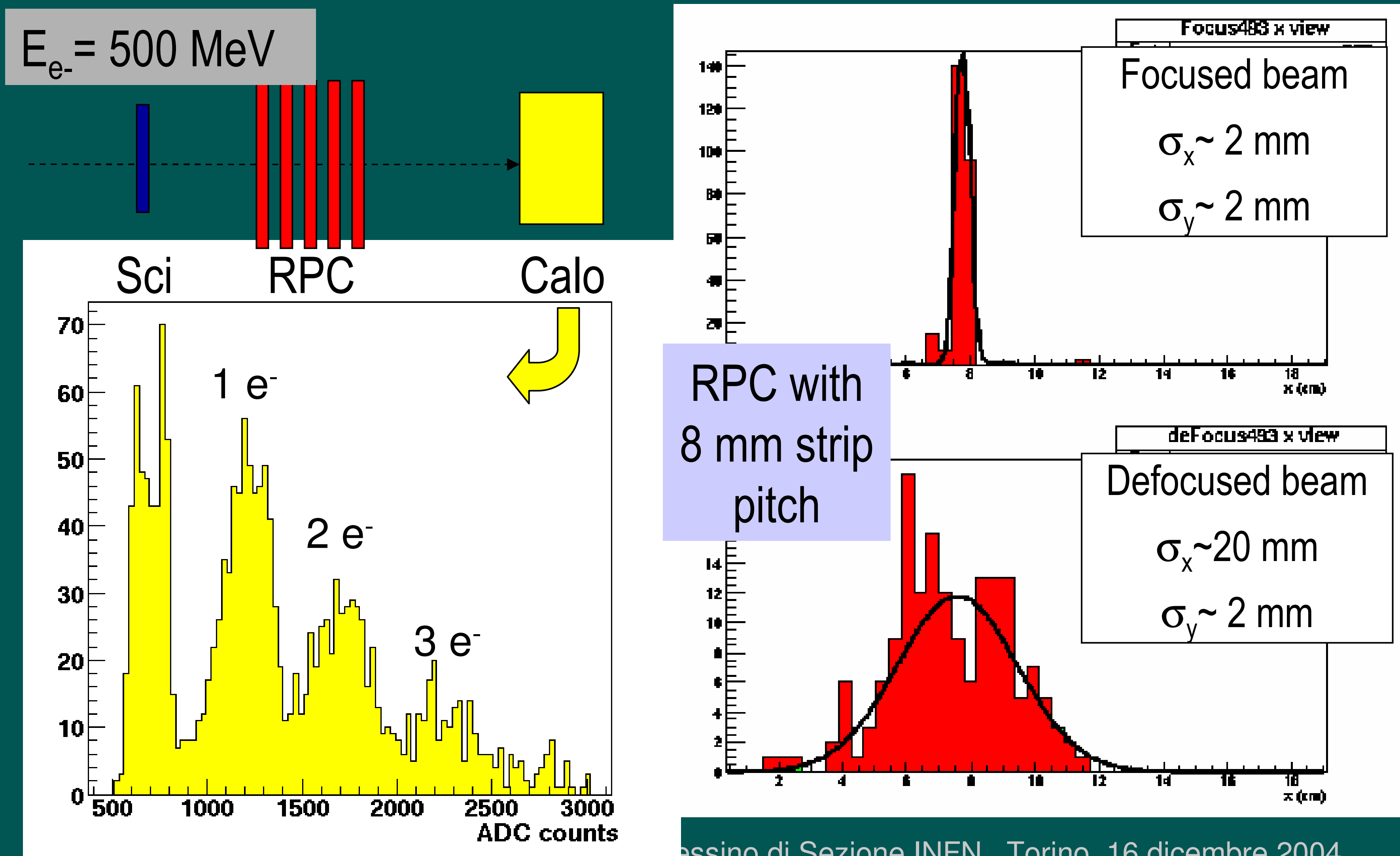


- RPC prototypes produced in collaboration with General Tecnica:
  - 100 cm x 110 cm surface
  - 2 mm gap
  - 2 mm glass (ρ_v=3÷5 x 10^{12} Ωcm @ 25 ºC)
- Assembly procedure and materials for spacers, supports and gas connectors borrowed from bakelite RPC produced by GT

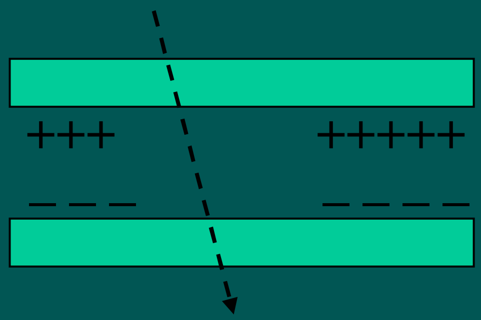
Rate capability studies

- Test Beam Facility @ LNF ideal bench for:
  - detector efficiency vs particle flux (rate capability)
  - efficiency maps
- BTF parameters:
  - e^- energy 50÷750 MeV
  - Repetition rate up to 49 Hz
  - Pulse duration 10 ns
  - Intensity $1 \div 10^{10}$ e^-/pulse

Setup at the BTF



Principles of Operation: Rate Capability



As noted, each discharge locally deadens the RPC. The recovery time is approximately

$$\tau = RC \cong \left(\frac{\rho\, l}{A}\right)\left(\frac{\kappa\varepsilon_0 A}{l}\right) = \rho\kappa\varepsilon_0$$

Numerically this is (MKS units)

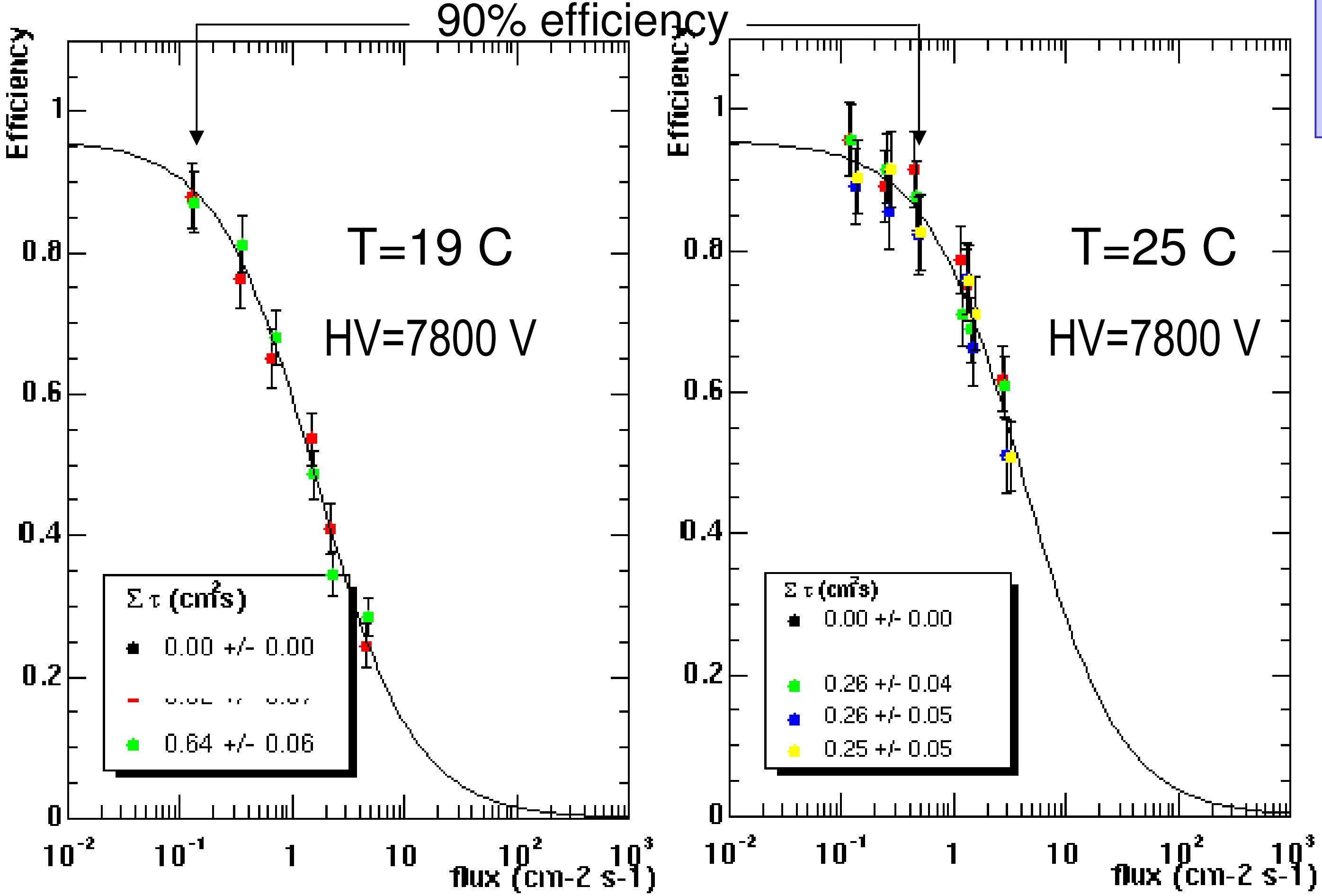
$$\tau = (5 \text{ x } 10^{10}) \text{ x } 4 \text{ x } (8.85 \text{ x } 10^{-12}) = 2 \text{ s}$$

Assuming each discharge deadens an area of $0.1\,\text{cm}^2$, rates of up to $500\,\text{Hz/m}^2$ can be handled with 1% deadtime or less.

Efficiency vs Rate I

Istituto Nazionale di Fisica Nucleare

$Ar/C_2H_2F_4/i\text{-}C_4H_{10}=48/48/4$



$$\varepsilon = \frac{\varepsilon_0}{1+\varepsilon_0 \phi \, \Sigma \tau_d}$$

$$\tau_d = -\tau \ln\left(1-\frac{V_{thresh}}{V_0}\right)$$

ε_o = intrinsic eff.

ϕ = particle flux

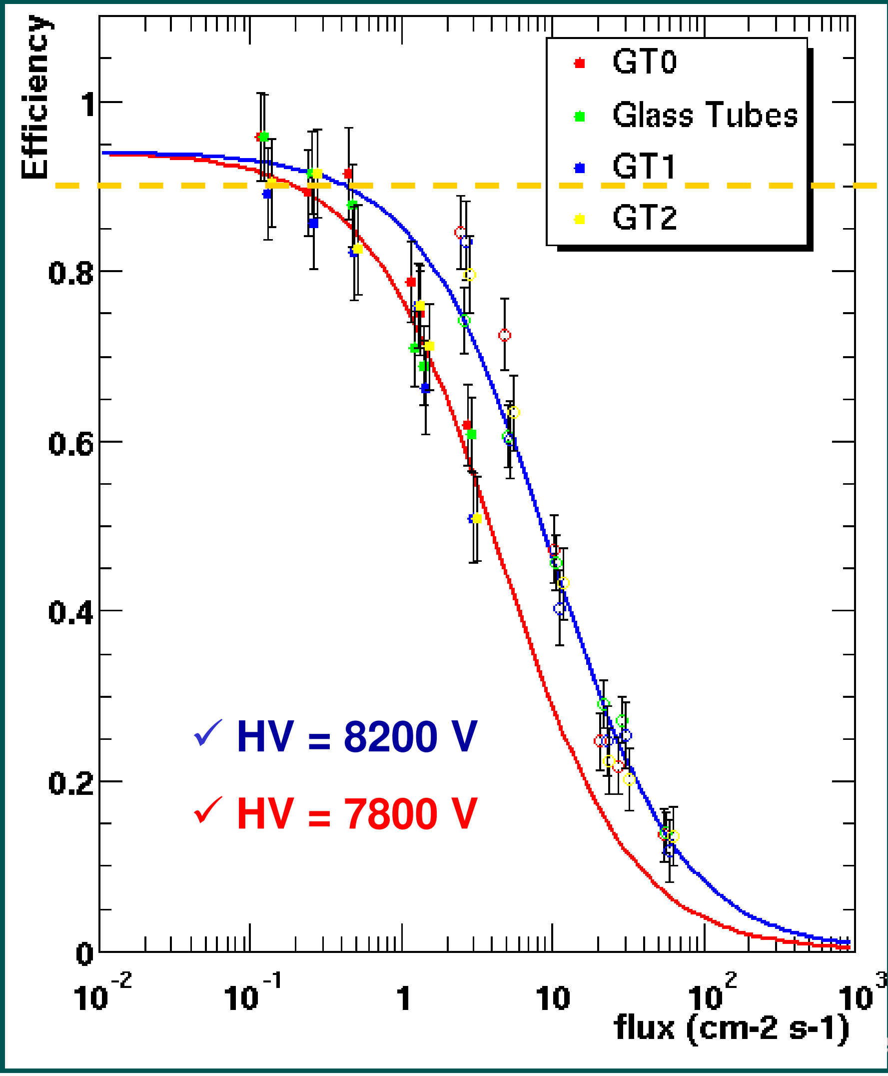
Σ = spark dim.

τ_d = dead time

$\div \rho(T_0) e^{-0.11\Delta T}$

volume resistivity

Efficiency vs Rate II

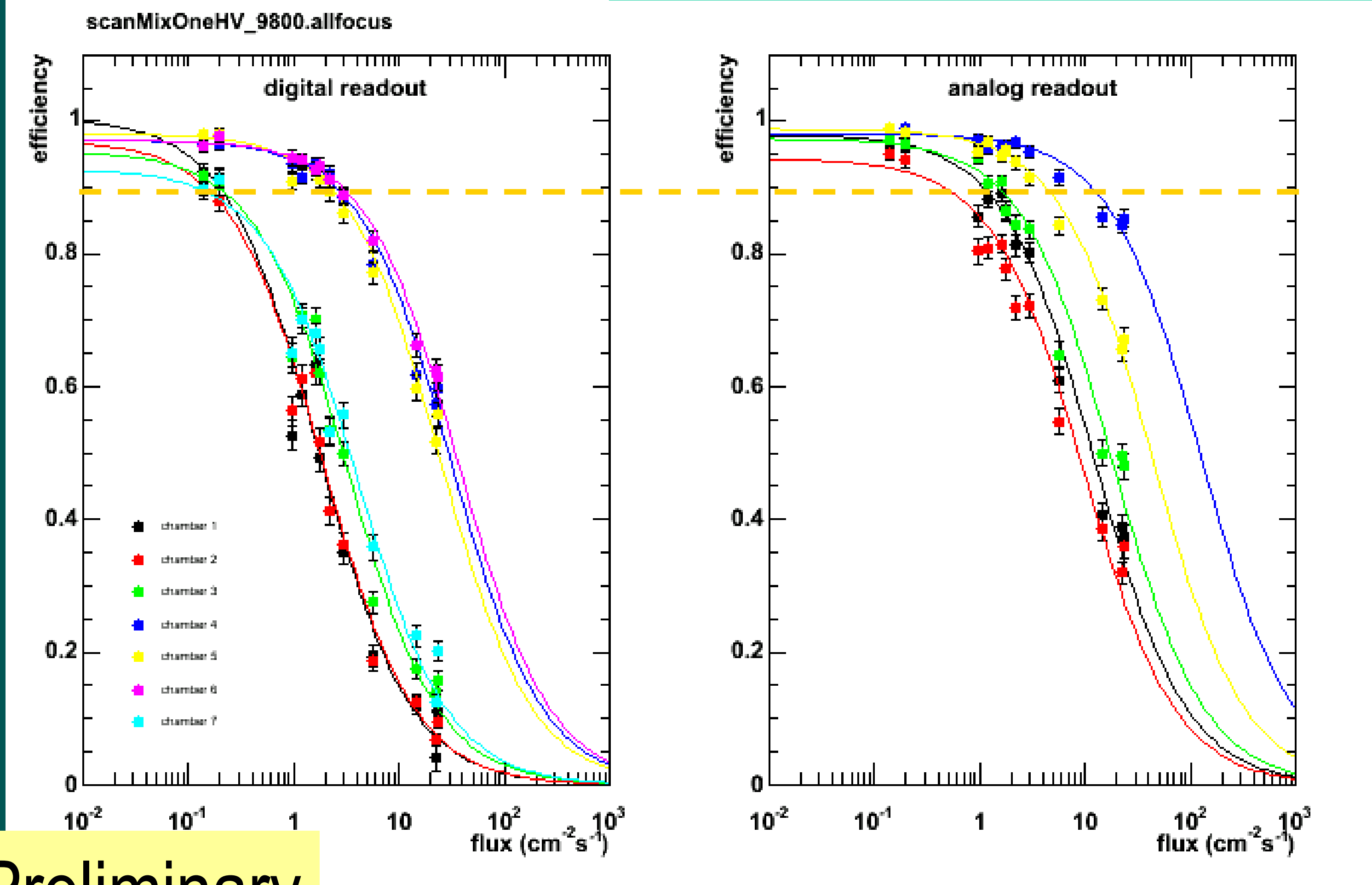


$Ar/C_2H_2F_4/i\text{-}C_4H_{10}=48/48/4$

- 90% efficiency in streamer mode at 0.5 Hz/cm^2
  - Higher voltages/temperatures increase the rate capability
- To further extend the rate capability:
  - Avalanche mode

Efficiency vs Rate (preliminary 11/2004)

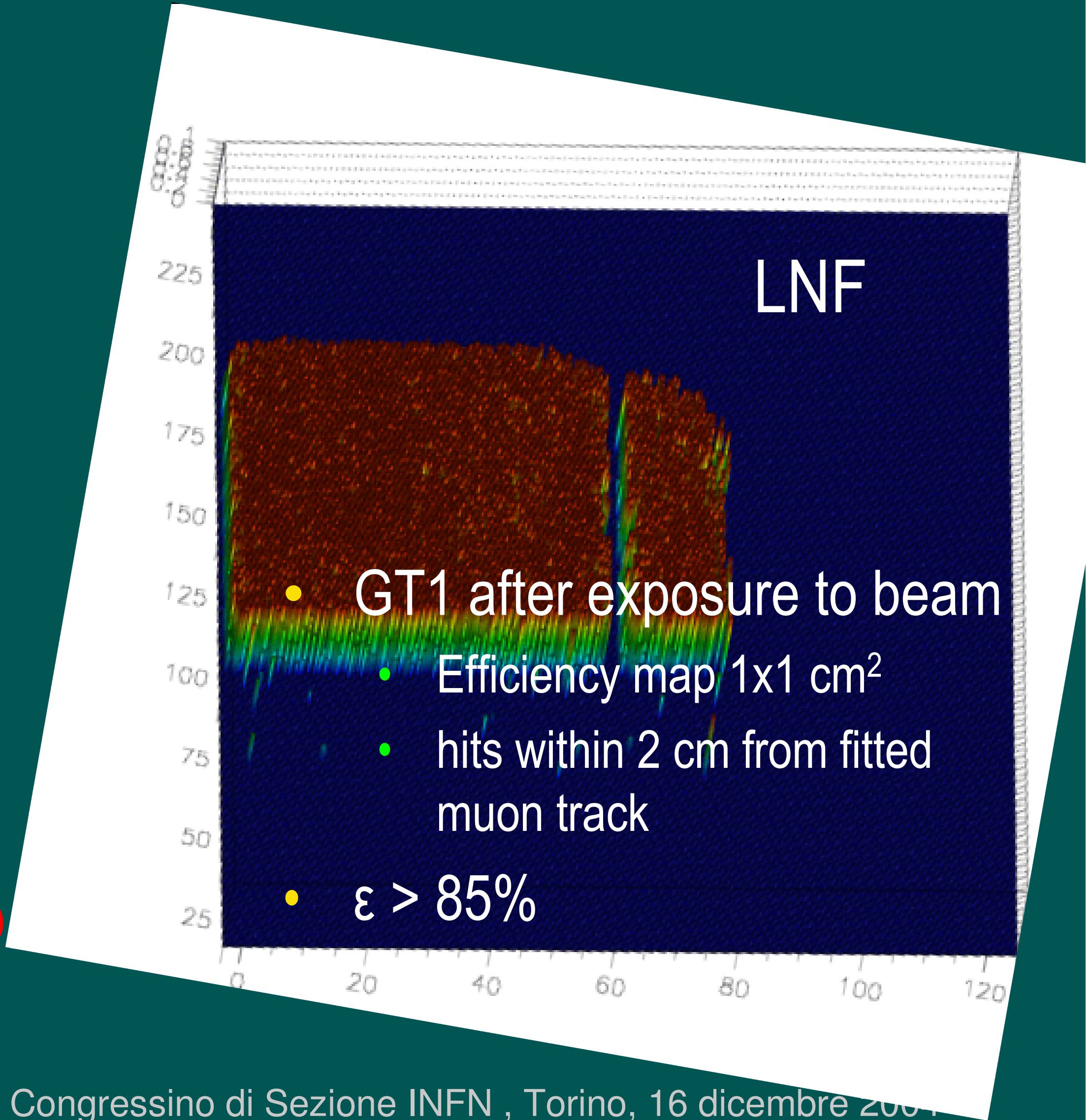
$Ar/C_2H_2F_4/i\text{-}C_4H_{10}/SF_6=14.4/80.8/4.3/0.5$



Preliminary

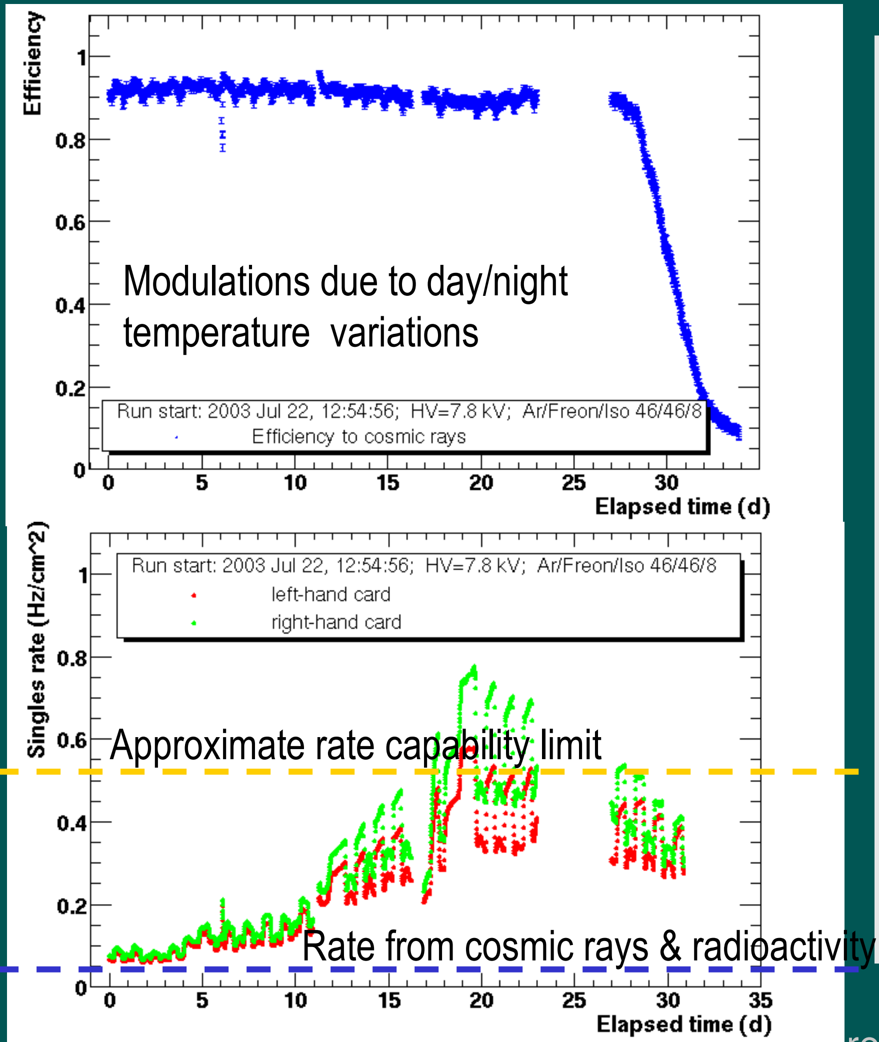
Long term (in)stability

- Continuous monitoring with cosmic rays
  - RPC arrays at LNF and Milano Bicocca
    - Efficiency and chamber noise (singles) maps
- All the chambers tested in 2003 have shown a significant efficiency drop



- GT1 after exposure to beam
  - Efficiency map 1x1 cm^2
  - hits within 2 cm from fitted muon track
- $\varepsilon > 85\%$

An example

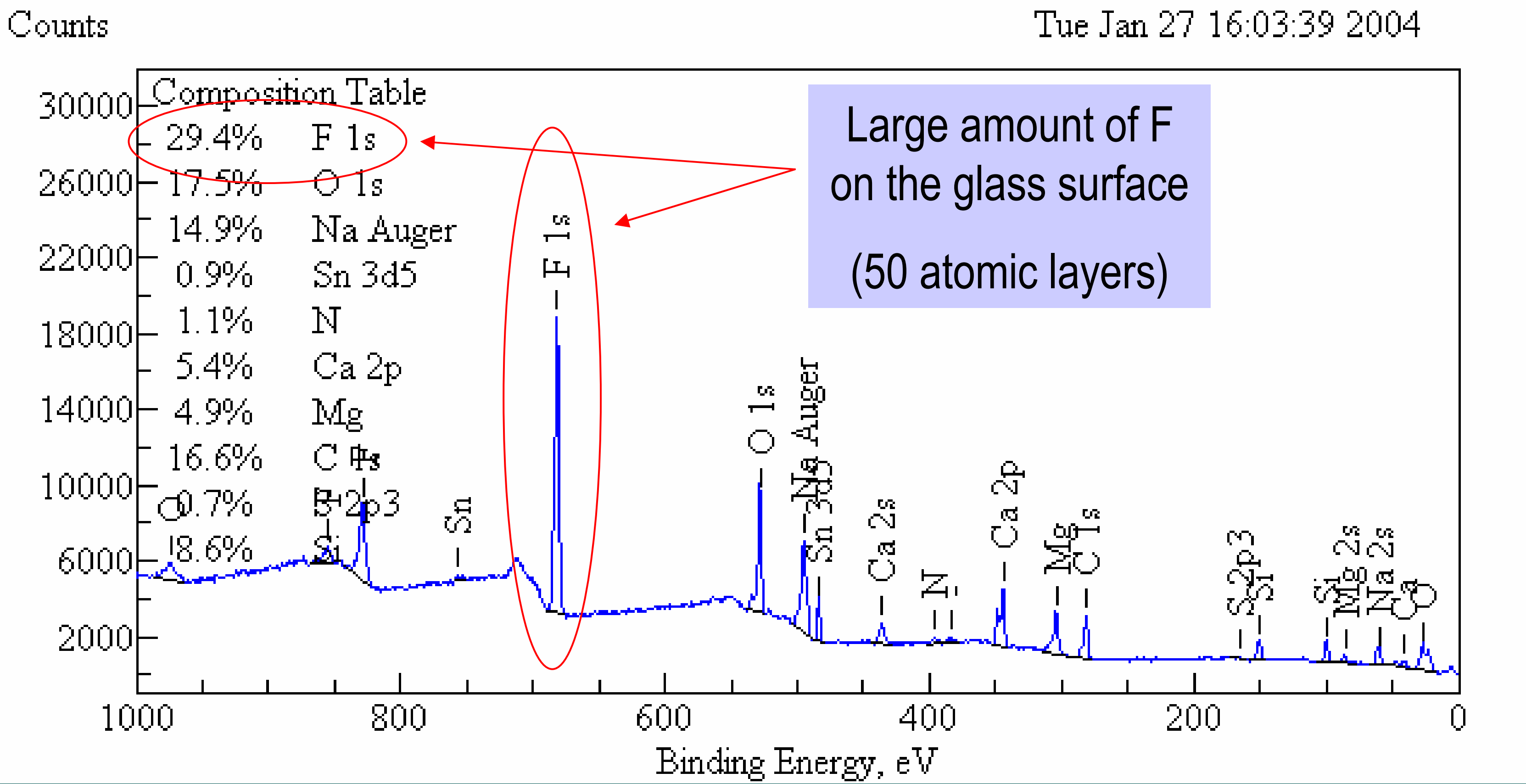


- Fast efficiency drop after a few weeks of operation
- Steady increase of the singles rate and of the RPC dark current
- Possible interpretation
  - Wet gas problem like in BELLE (overlooked)
    - sparks + Freon → HF (chemical attack of the glass surface)
    - H_2O modifies the surface conductivity
  - Water content > 200-300 ppm measured in both the set-up (permeability of plastic tubes)

Preliminary ESCA analysis of damaged electrodes

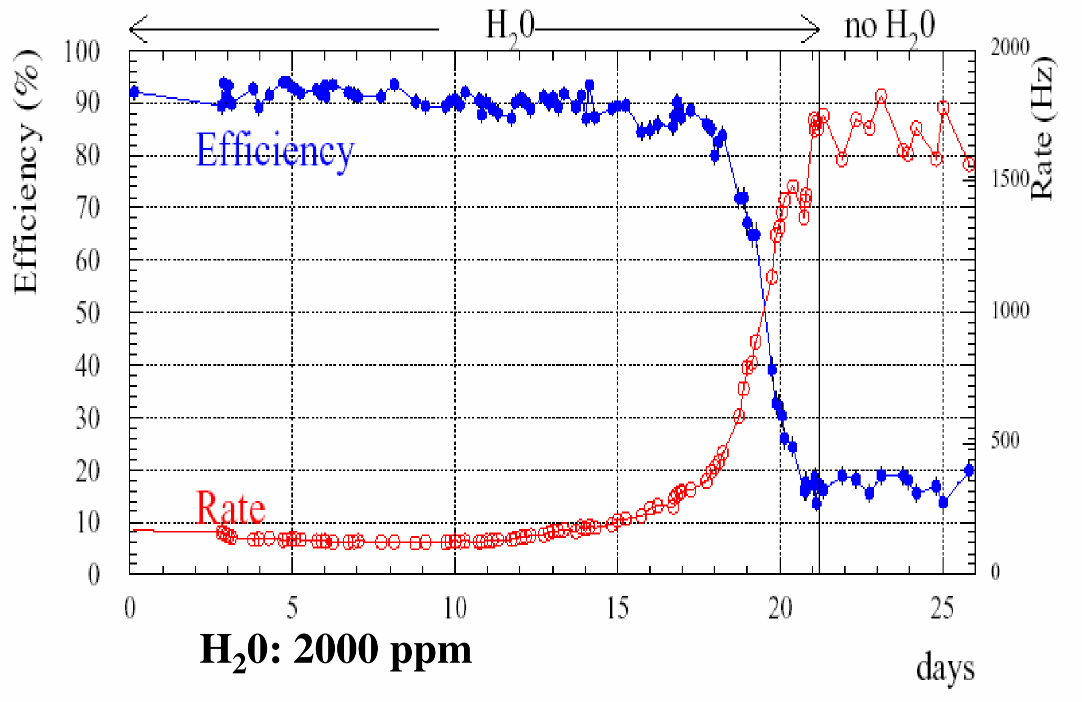
Courtesy of C.Bianchi & F.Ragaini,
Dipartimento di Chimica, Università di Milano

System Name: XI ASCII
Pass Energy: 156.51 eV
Charge Bias: 5.0 eV
Tue Jan 27 16:03:39 2004

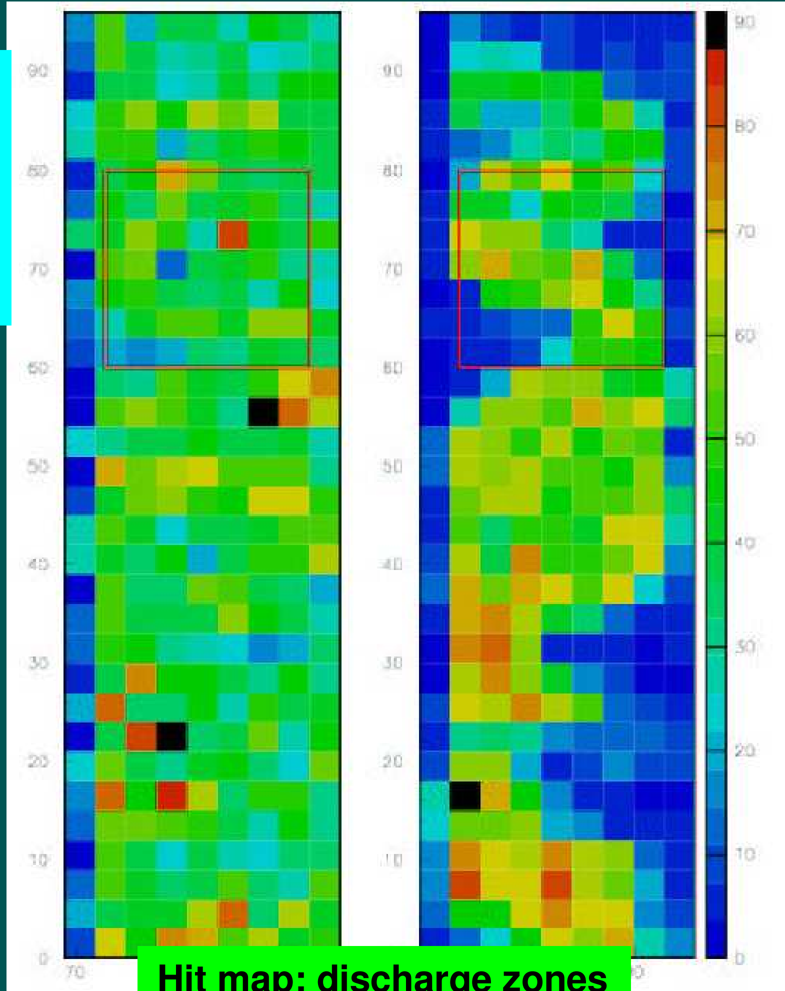


Water vapor aging

Aging measurements on glass RPC.
IEEE Trans.Nucl.Sci.50:820-824,2003
Confirms results of Belle collaborators tests:
Glass surface demaged

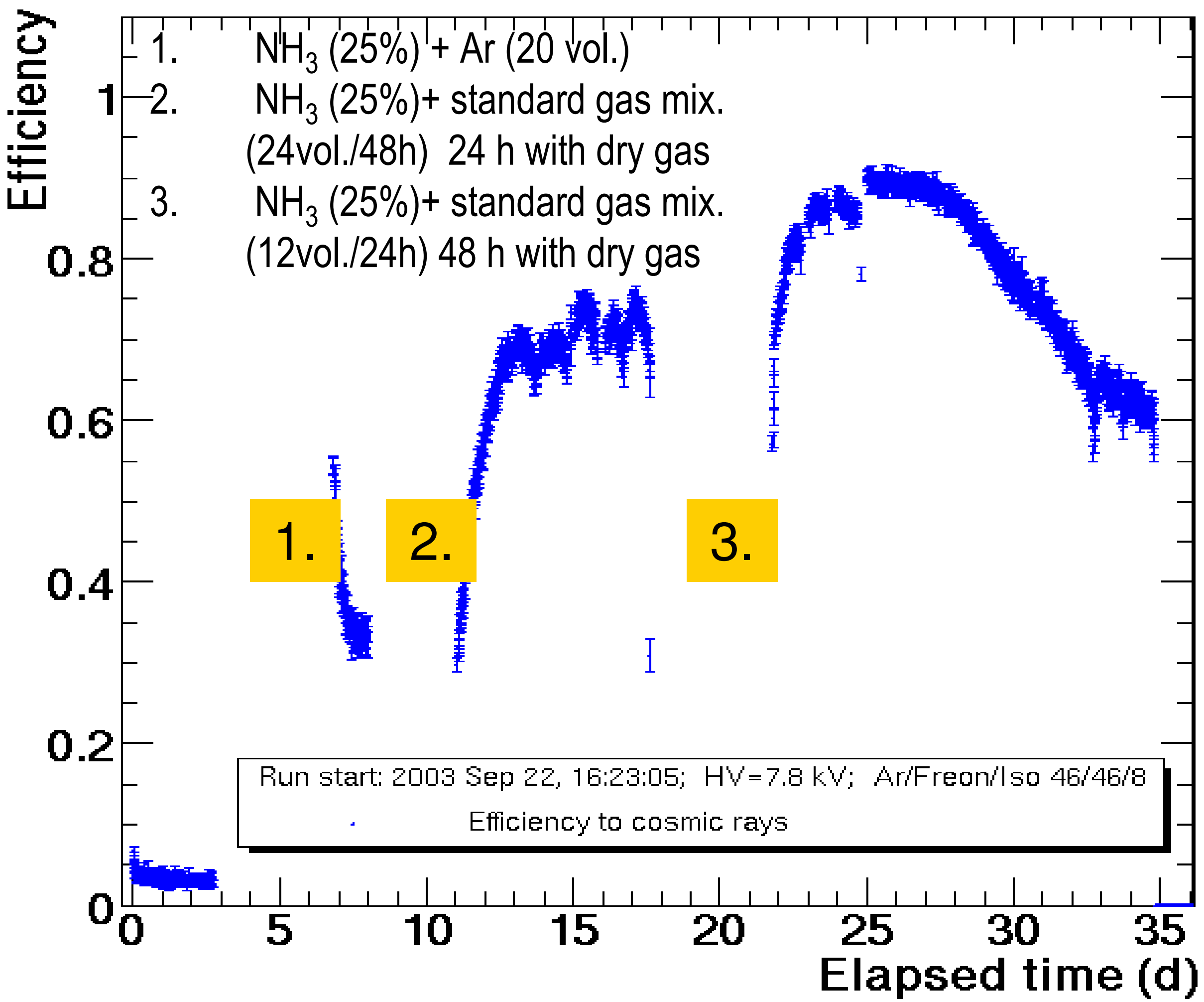


H_20: 2000 ppm



Hit map: discharge zones are located along the preferential gas flow path

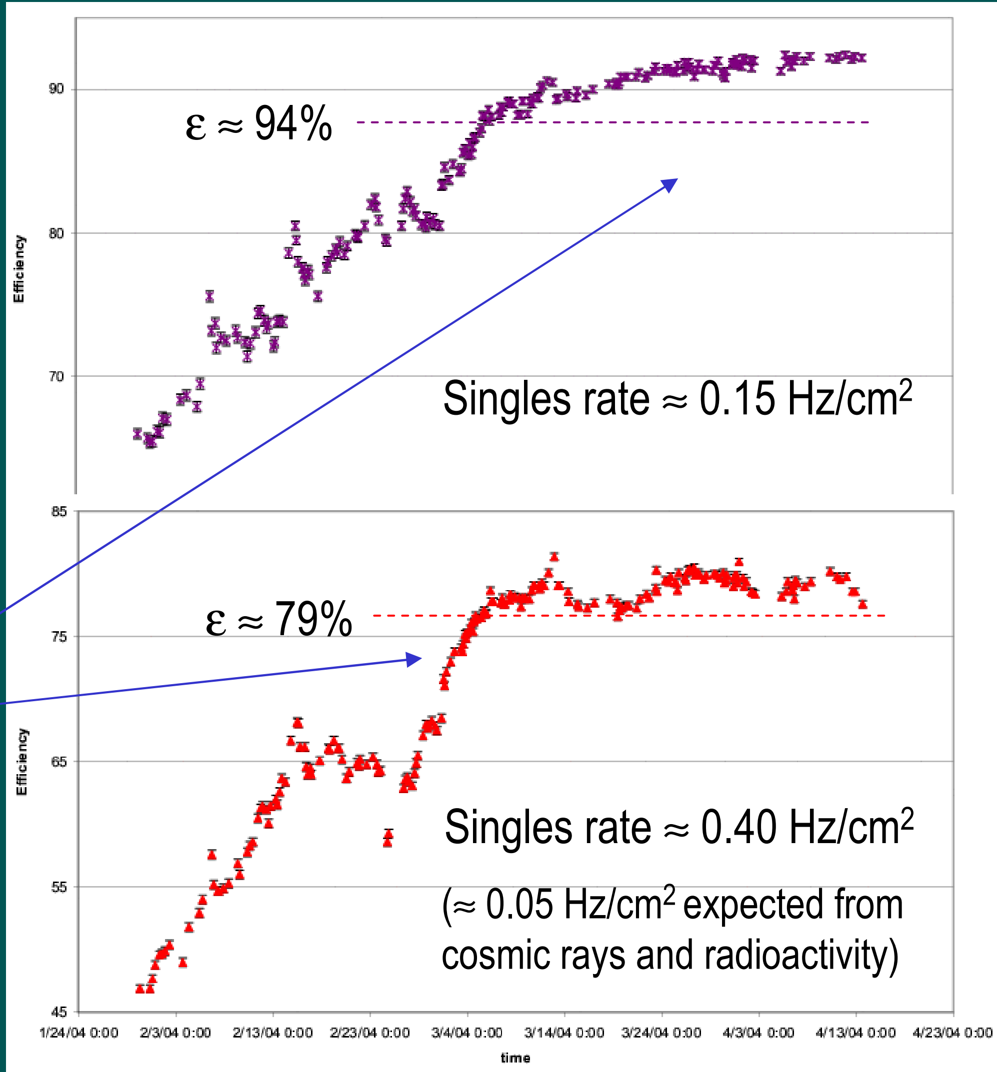
Alchemy (bubbling through ammonia)



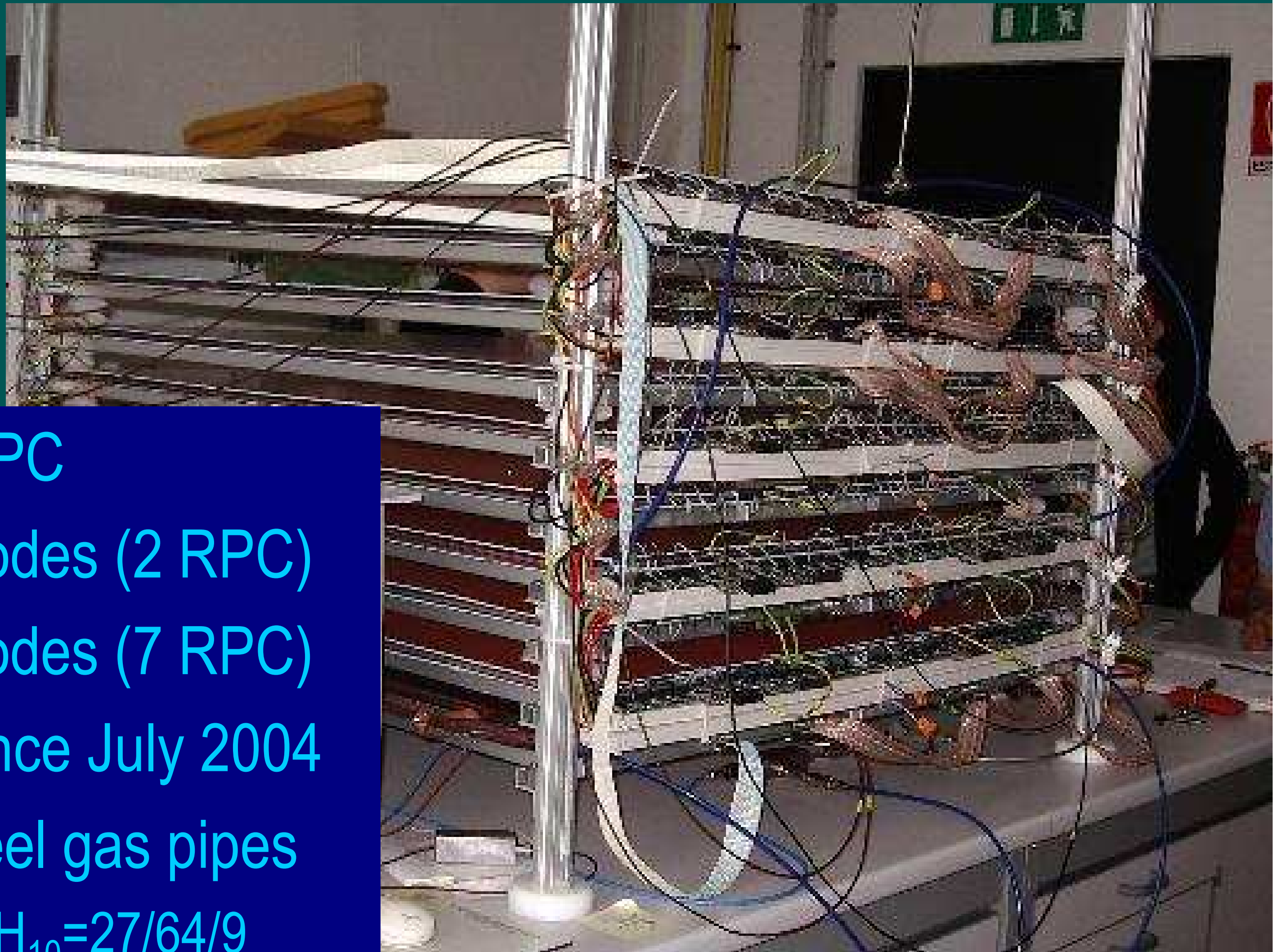
- Suggested procedure to recover loosely damaged chambers
  - H.Sakai et al. NIM A484,(2002), 153
  - C.Gustavino et al, NIM A533 (2004),116
- Successful temporary recovery of a "dead" chamber
- Need further tests
- Not for stable running

A basic solution

- Stainless steel/copper tubing
  - dry gas (H_2O<50 ppm)
- More quenched gas mix ($Ar/C_2H_2F_4/i\text{-}C_4H_{10}=27/64/9$)
  - lower charge in the spark (catalyst of HF formation)
- (Partial) recovery of damaged chambers
- New chambers under study
  → Test the chamber lifetime

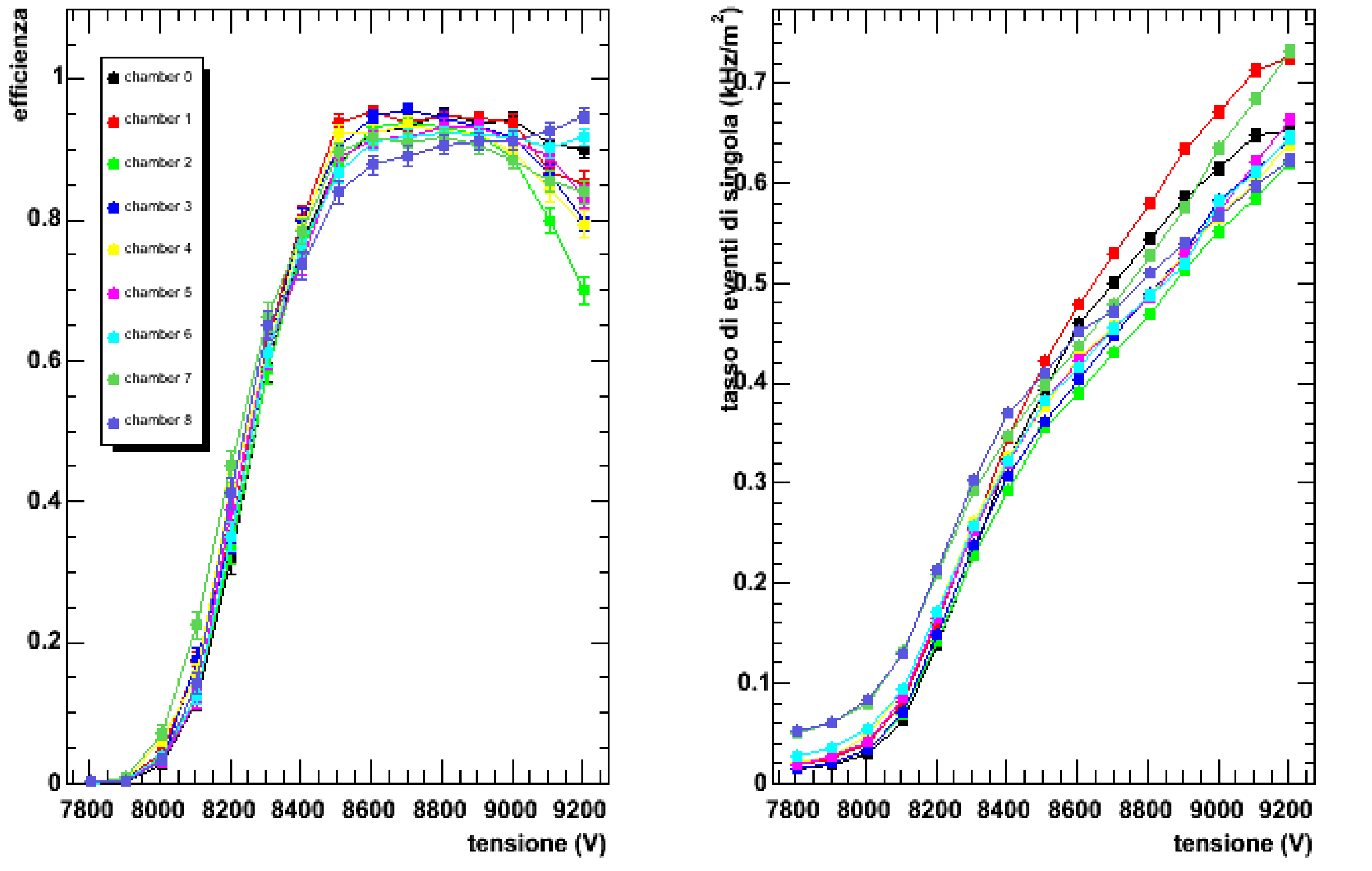


MI-Bicocca Test Facility

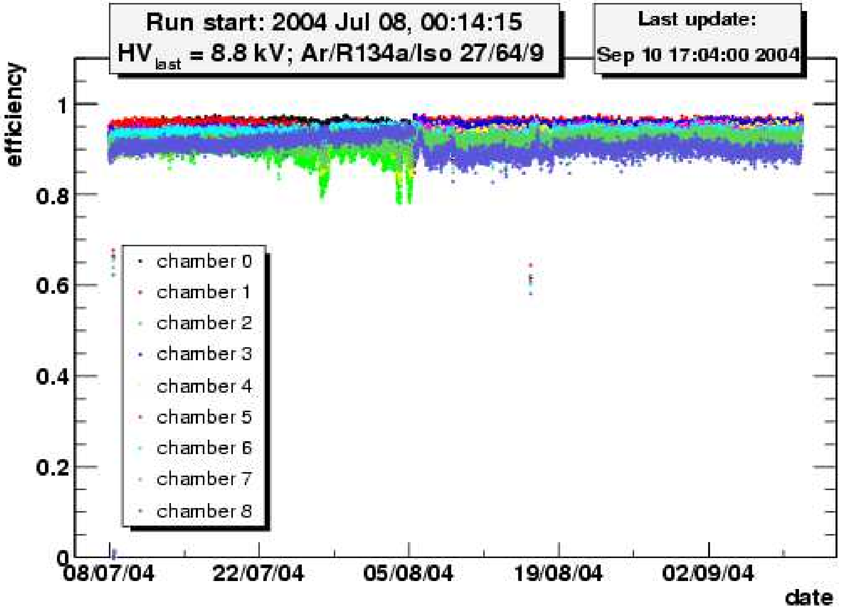


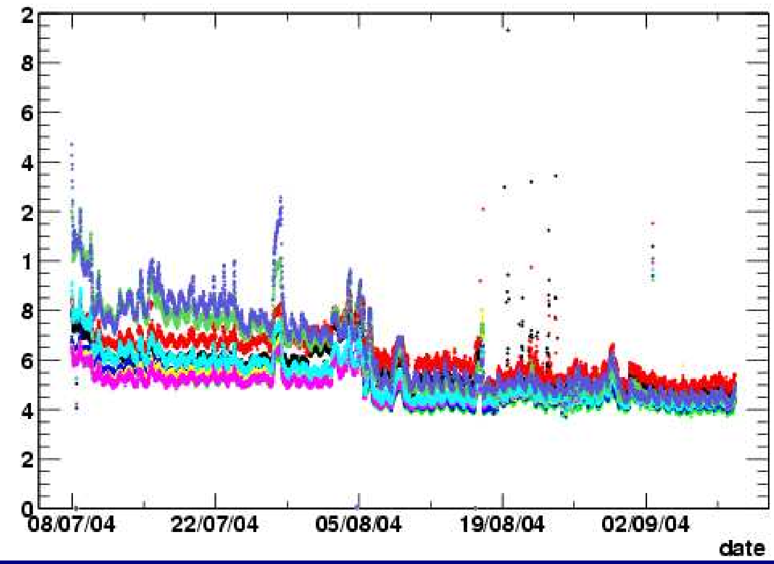
- 9 1X1 m^2 RPC
- 2 mm electrodes (2 RPC)
- 3 mm electrodes (7 RPC)
- Runnning since July 2004
- Stainless steel gas pipes
- $Ar/C_2H_2F_4/i\text{-}C_4H_{10}=27/64/9$

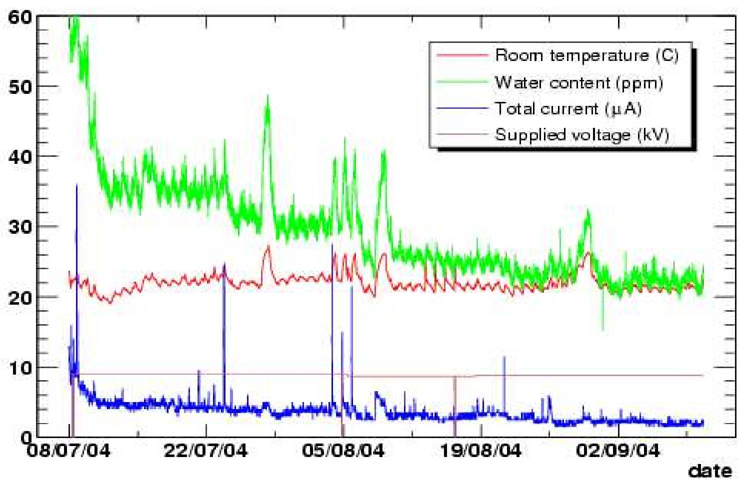
MI-Bicocca Results



MI-Bicocca Results

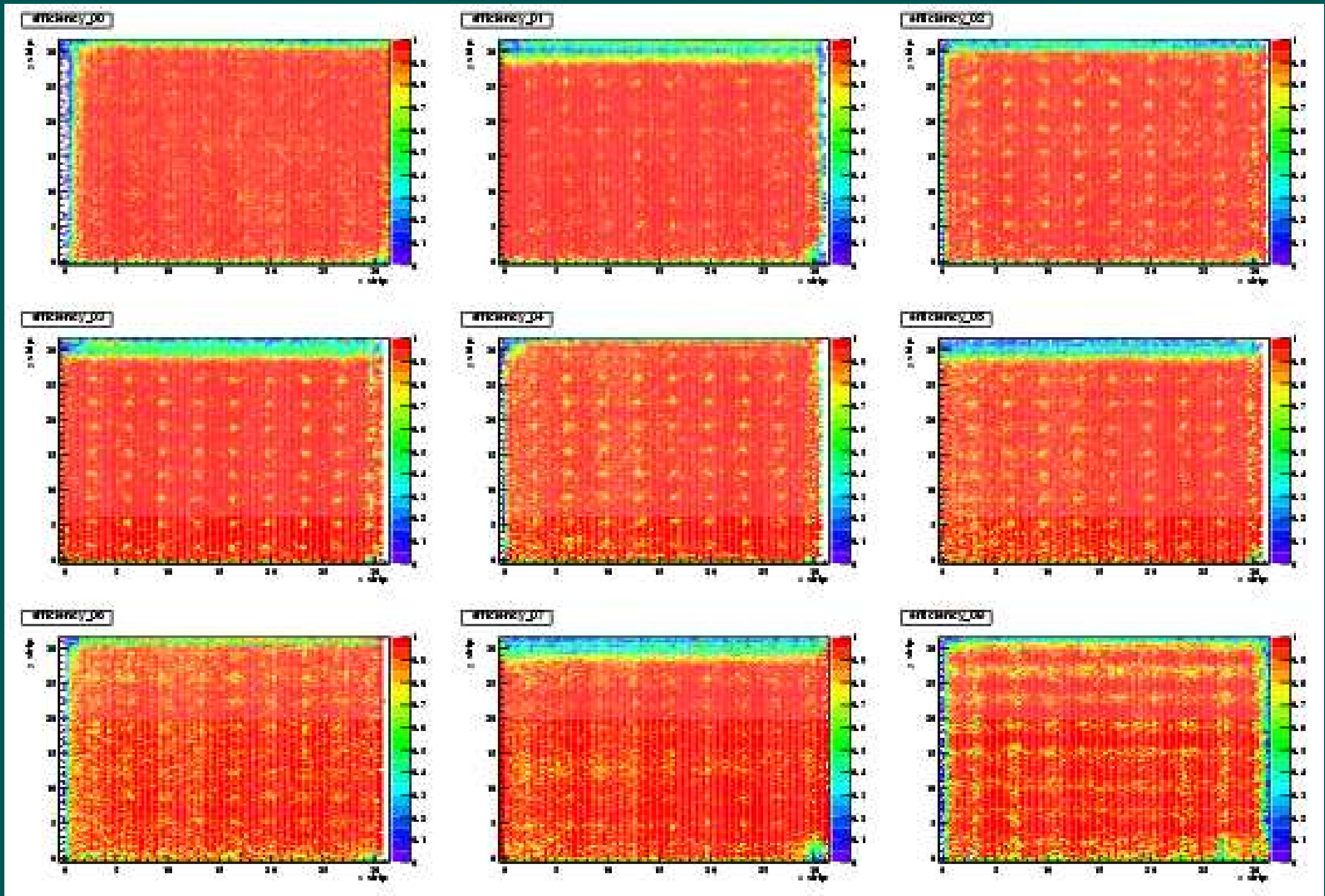






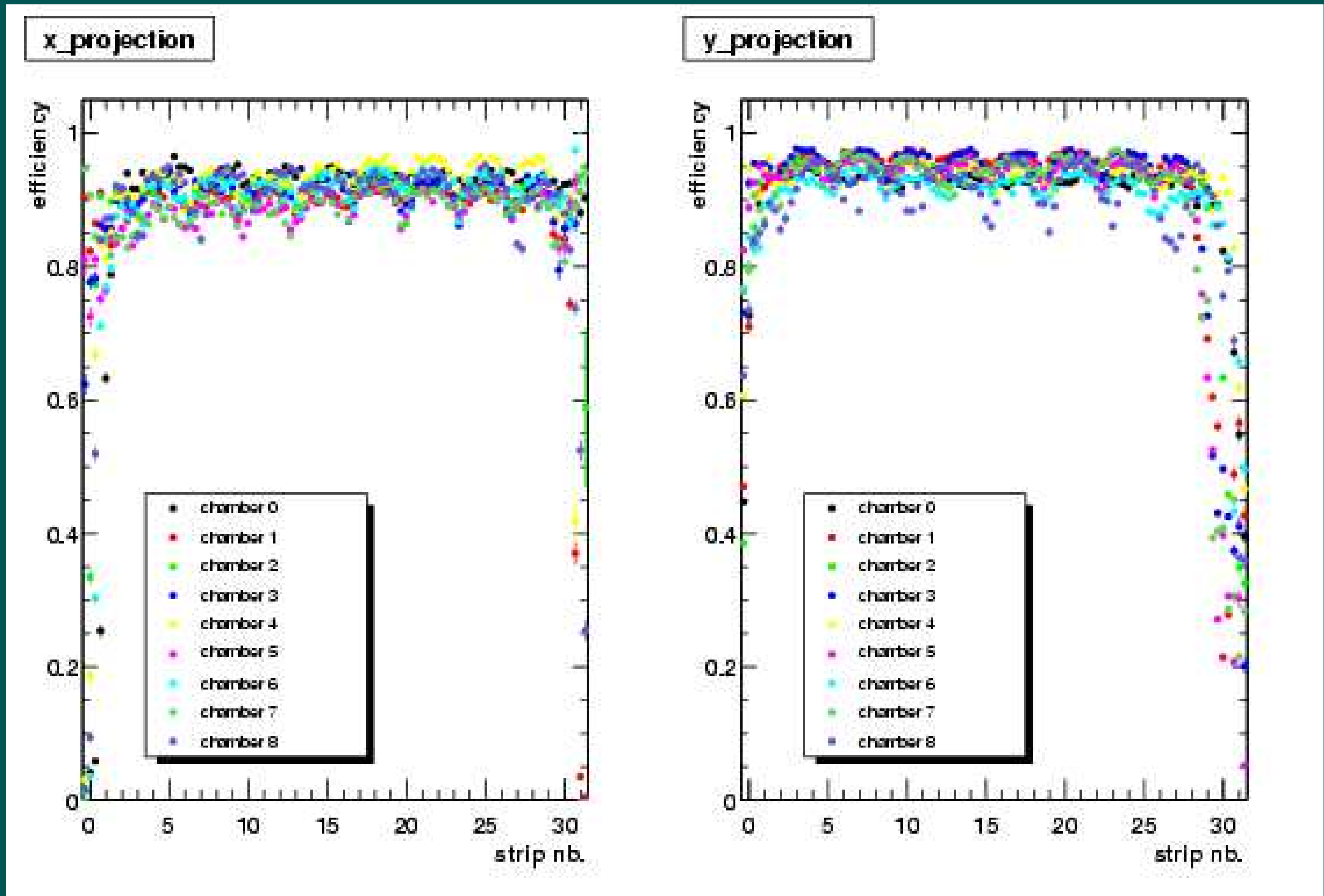
- Water content < 30 ppm
- Runnning since July 2004
- Controlled temperature
- 4+ months of continuous run
- Stable behavior

MI-Bicocca Results

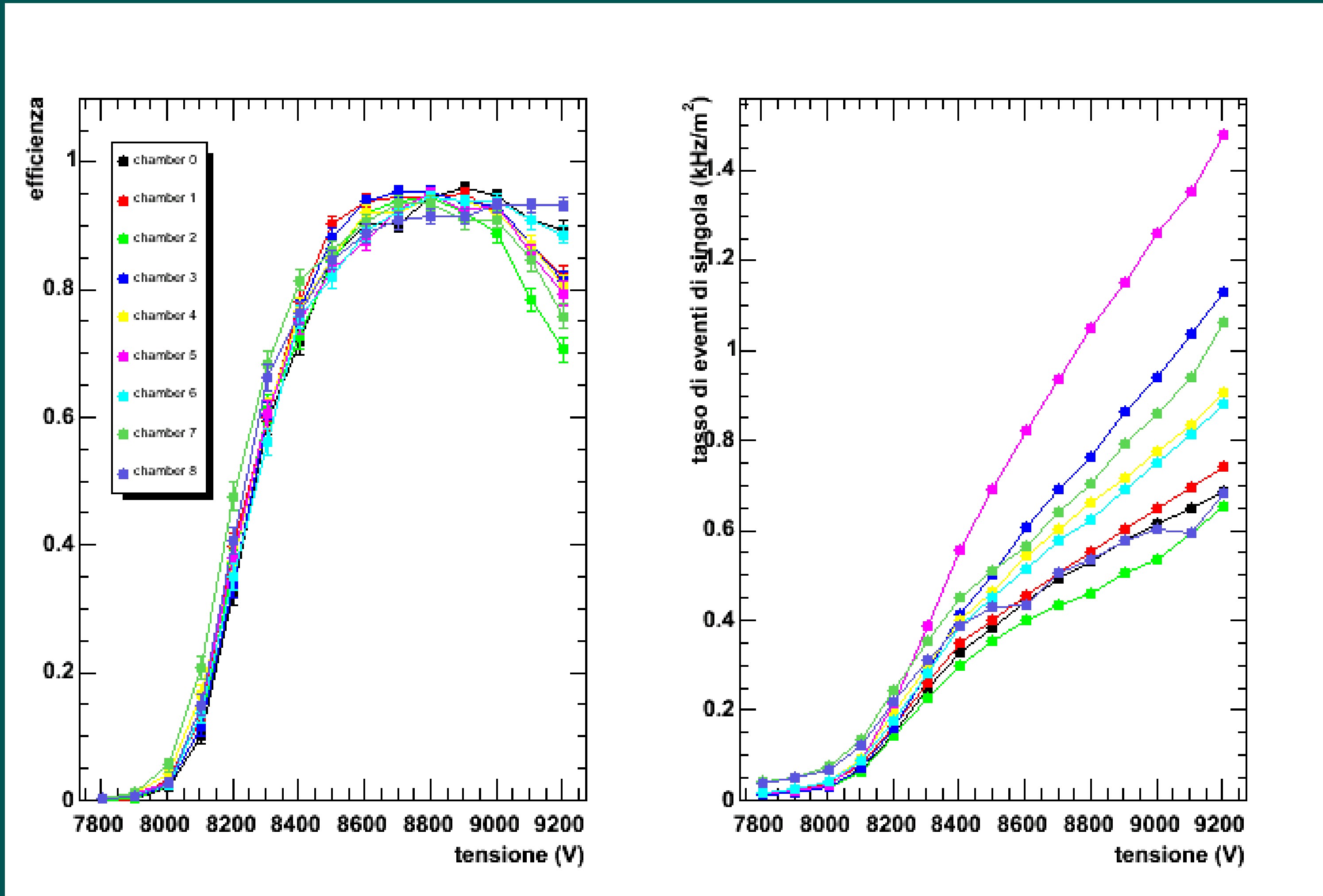


- High Statistic Efficiency map
- hits within 2 cm from fitted muon track

MI-Bicocca Results



MI-Bicocca Results



Conclusions and outlook

- Large area glass RPC prototypes have been produced in collaboration with industry
  - Good efficiency (when new)
  - Somewhat noisy
- Maximum rate capability in streamer mode around 0.5 Hz/cm^2 with commercial float glass (~3.0 Hz/cm^2 with a more quenched gas mixture)
  - Further studies are planned to extend the rate capability (avalanche mode and conductive glasses)
- Instability problems related to water contamination
  - Running with dry gas (chamber lifetime?)
  - Pre-treatements
  - Recovery procedures?