Origin and simulation of sparks in MPGD

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Overview

Simulation of sparks (Micromegas)

→ *Geant4 and origin of sparks*

→ *Open questions*

Recent spark rate measurements in beams

→ *Effect of the beam energy*

→ *Effect of the magnetic field*

Effect of a GEM foil on the spark rate

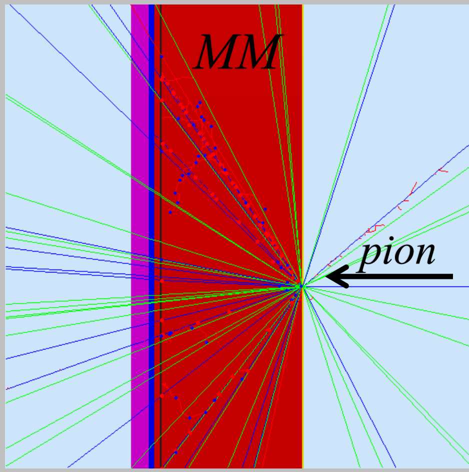
→ *Experimental observations*

→ *From Raether to a charge density limit*

→ *Comparison with data*

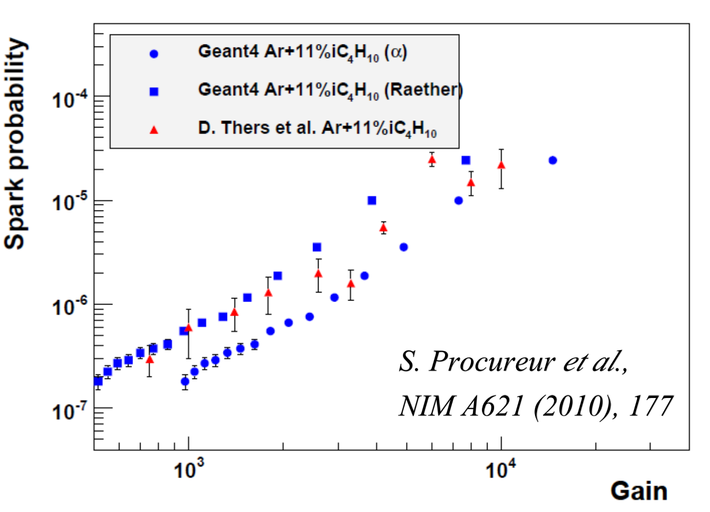
Conclusion

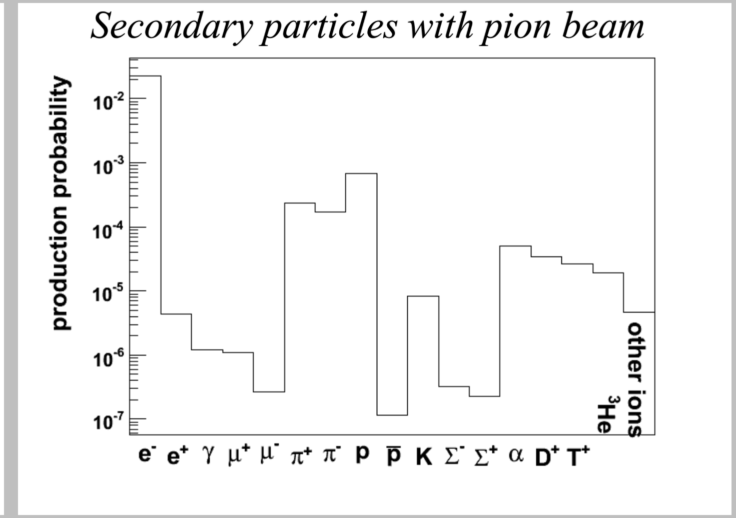
Simulation of sparks: Geant4



Sparks can be related to large energy deposits in Geant4, often originating from secondary, highly ionizing particles

=> Simple spark condition: N_{el} ~ a few 10^7 (Raether)





→ *1st simulation to reproduce « historic » data at 15 GeV/c pion beam, using $N_{el} = 2.10^7$*

→ *explained large part of the gas effect (more sparks with heavier gas)*

Open questions

1) *Behaviour of the spark rate with beam energy?*
2) *Influence of the materials in Micromegas (e.g. mesh for bulk)*
3) *Effect of a transverse and longitudinal magnetic field?*
4) *Why a GEM detector sparks less?*

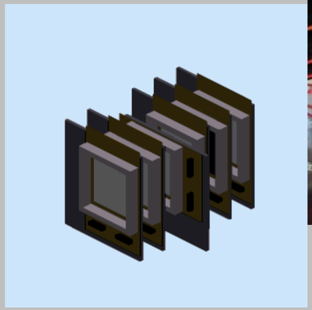
→ *To answer these questions and further validate the simulation, a series of beam tests were scheduled in the period 2009-2010:*

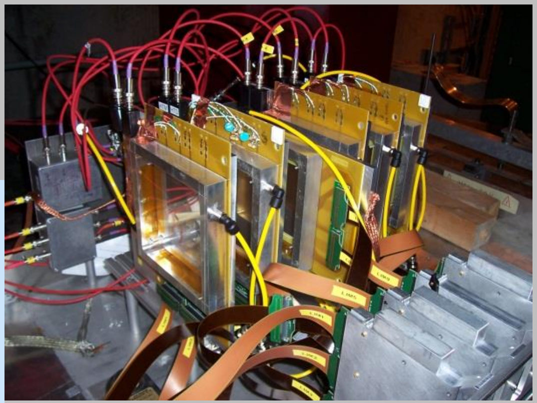
- *Oct 2009 @ CERN/SPS (RD51 beam period)*
- *July 2010 @ JLab/Hall B*
- *Aug 2010 @ CERN/PS*

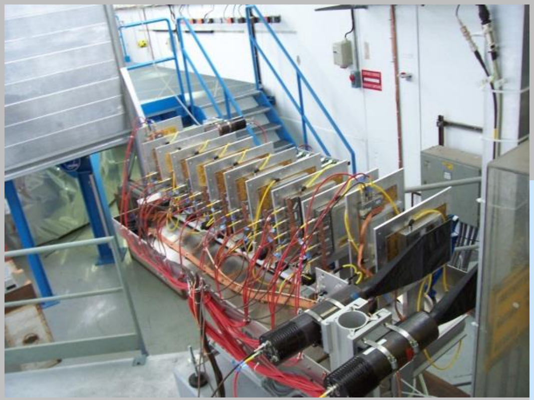
Sparks and beam energy

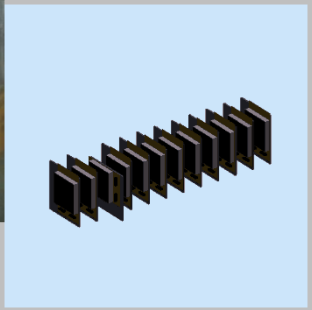
Tests @ CERN/SPS and PS

Location	CERN/SPS	CERN/PS
Date	10/2009	08/2010
Goals	Spark rate in high E beam Effect of $B_\perp$	Spark rate in low E beam Effect of a GEM foil
P_{beam}	150 GeV/c	0.2 - 3 GeV/c
Particles	π	π^+, π^-, p
Beam intensity	$\leq 10^6$ / spill	$\leq 5.10^5$ / spill
Spill	10 s every 50 s	0.4 s every 50 s
Gas	$Ar+5\%iC_4H_{10}$	$Ar+5\%iC_4H_{10}$









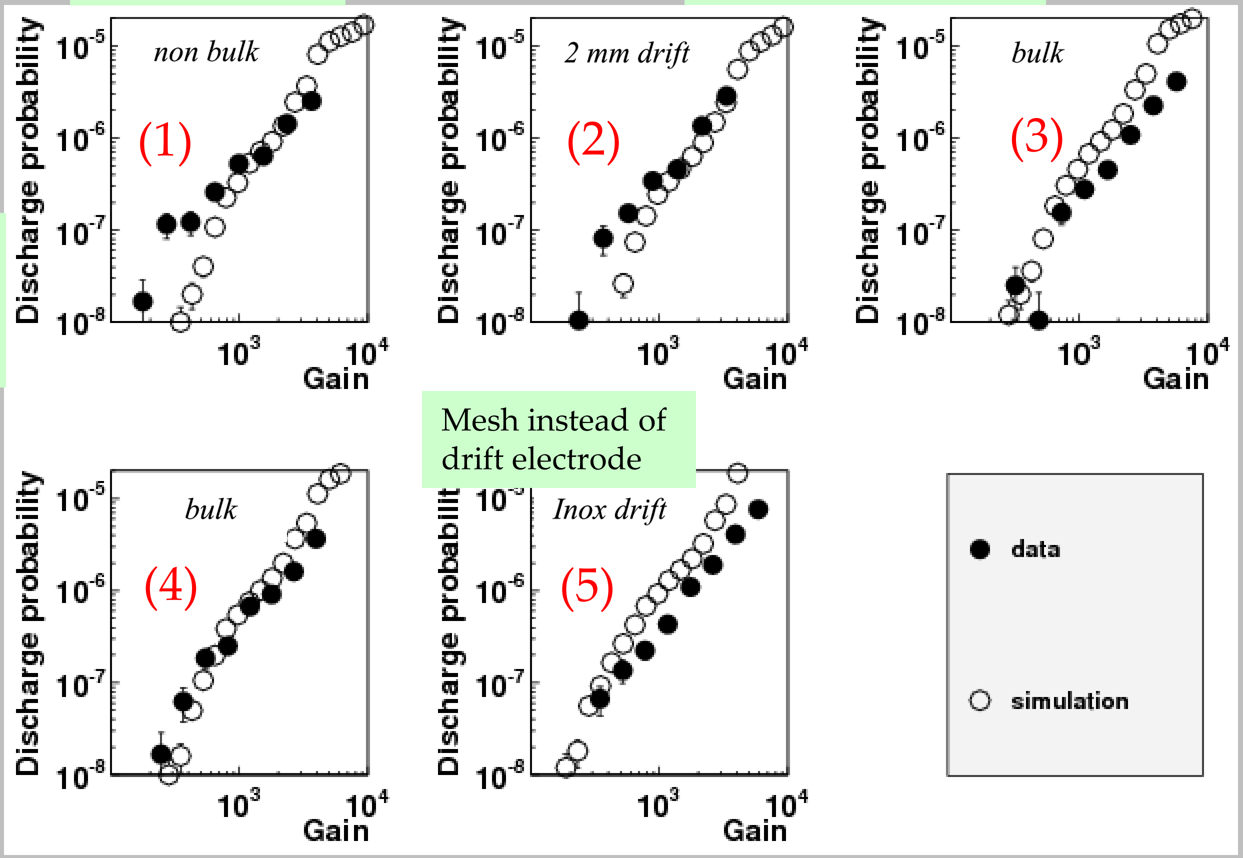
MM Tests @ SPS: results & simulation

(1): Mesh – 5 µm

(2) – (5): Mesh – 30 µm

Normalized to the total number of π

Discharge rate: ~ 10^{-7} for gain 10^3



S. Procureur *et al.*, NIM A659 (2011), 91

M.T. additions → personal responsibility

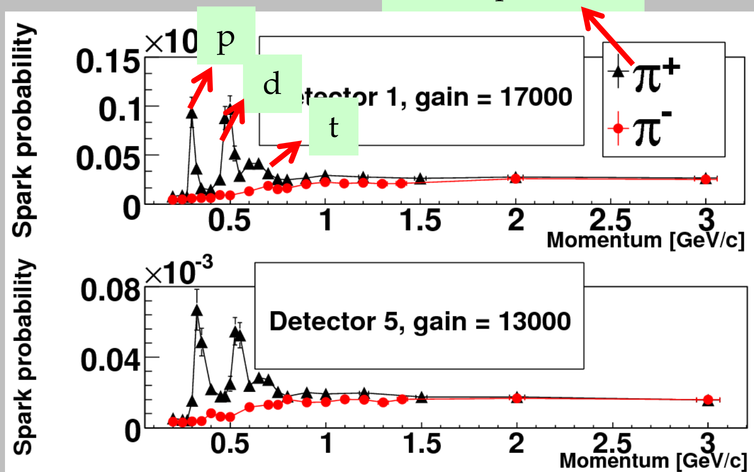
→ *no significant difference between thin and thick mesh (as predicted)*

→ *reasonable agreement with the simulation using N_{el}=2.5 10^7* → within "assumed avalanche volume: 300 x 300 µm²

=> Almost the same N_{el} to describe data at 15 and 150 GeV/c

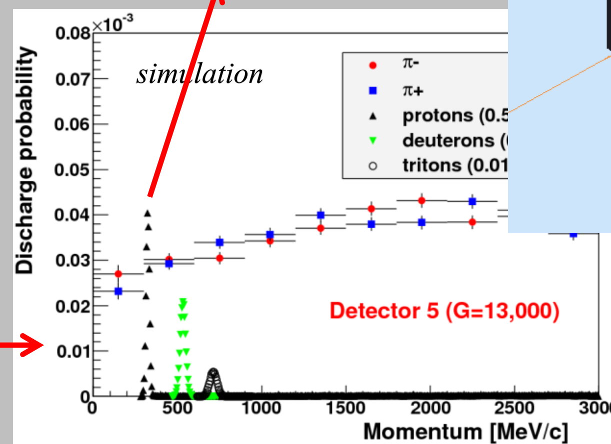
Tests @ PS: results & simulation

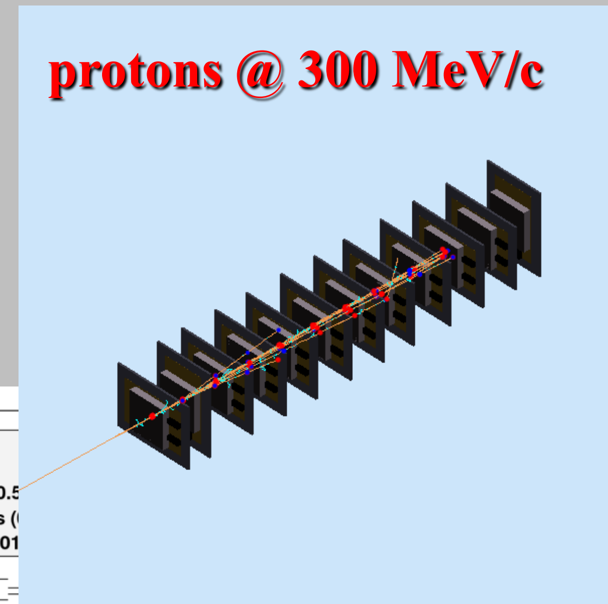
Contamination with protons



G. Charles et al., NIM A648 (2011), 174

Protons stop in the detector





Simulation is compatible with proton contamination of π+ beam: ~ 0.5% from accelerator experts

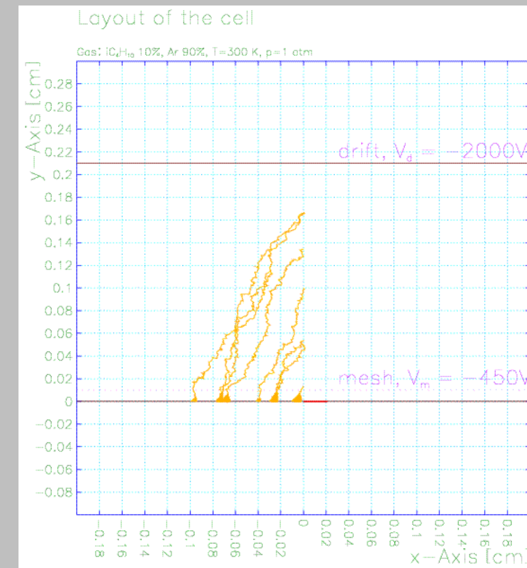
→ *explains the positions and approximate amplitudes of the peaks in the* π$^+$ *beam (proton, deuterium, tritium)*

→ *reasonable agreement with the simulation using* N_{el}*=4* 10^7

=> Similar N_{el} ***to describe data from 0.3 to 150 GeV/c***

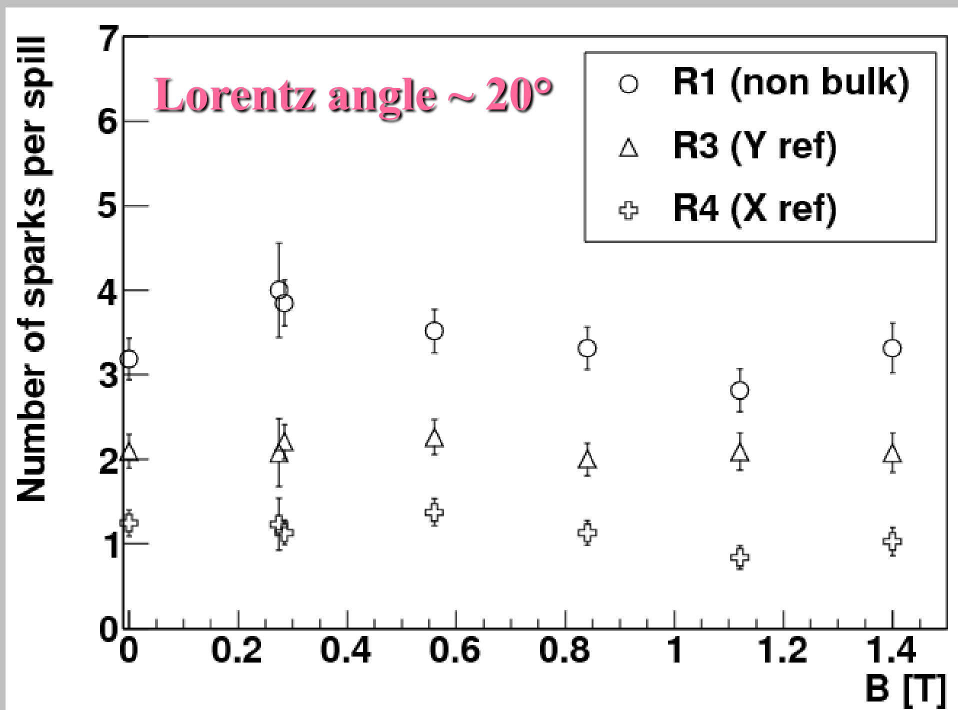
Sparks and magnetic field

B⊥E: tests at CERN/SPS



- Make use of the Goliath magnet (B up to 1.5 T)

- Naively expect spark rate reduction due to spread of charge



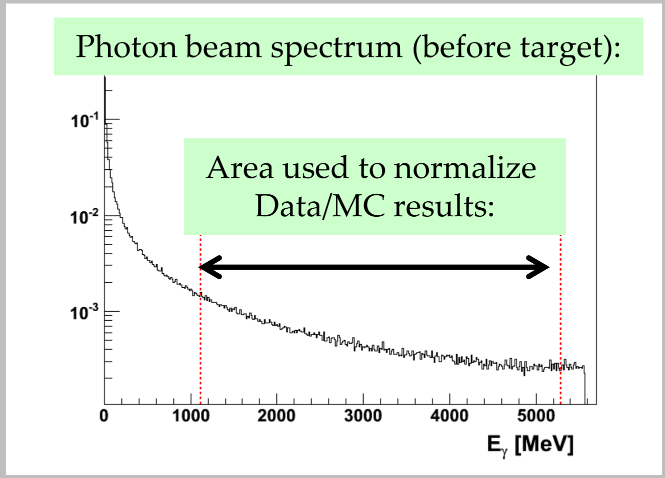
→ no significant effect of B⊥

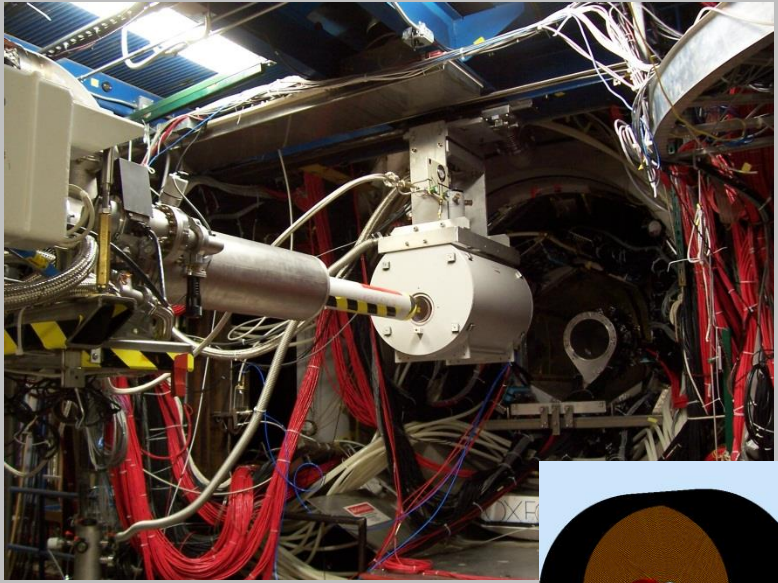
=> suggests that spark results from energy release close to the micromesh

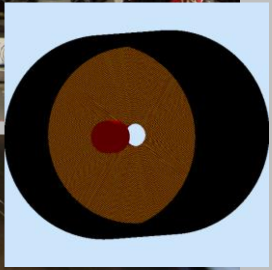
(though decrease has been indeed observed at larger Lorentz angle)

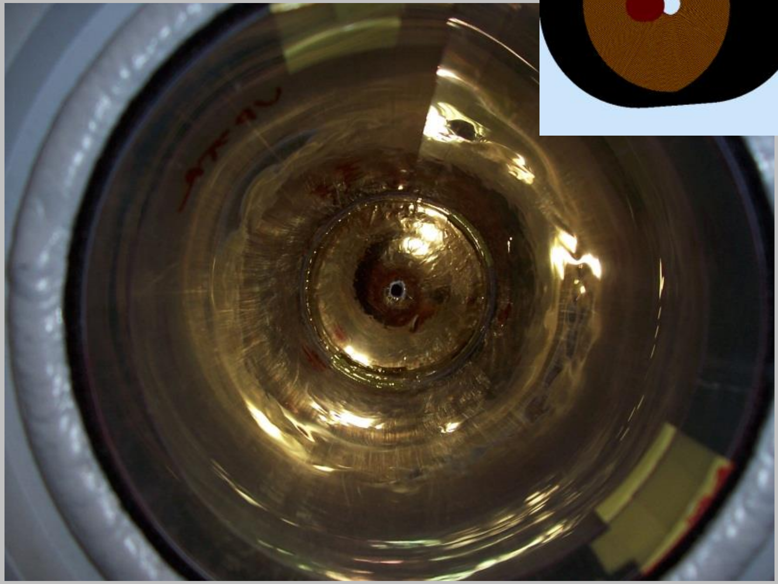
B//E: tests at JLab/Hall B

Location	JLab/Hall B
Date	08/2010
Goals	effect of $B_{//}$ effect of a GEM foil
P_{beam}	0 – 5.5 GeV/c
Particles	photons on CH_2 target
Beam intensity	≤ 2.5 10^9 / s
Spill	continuous beam
Gas	$Ar+10\%iC_4H_{10}$



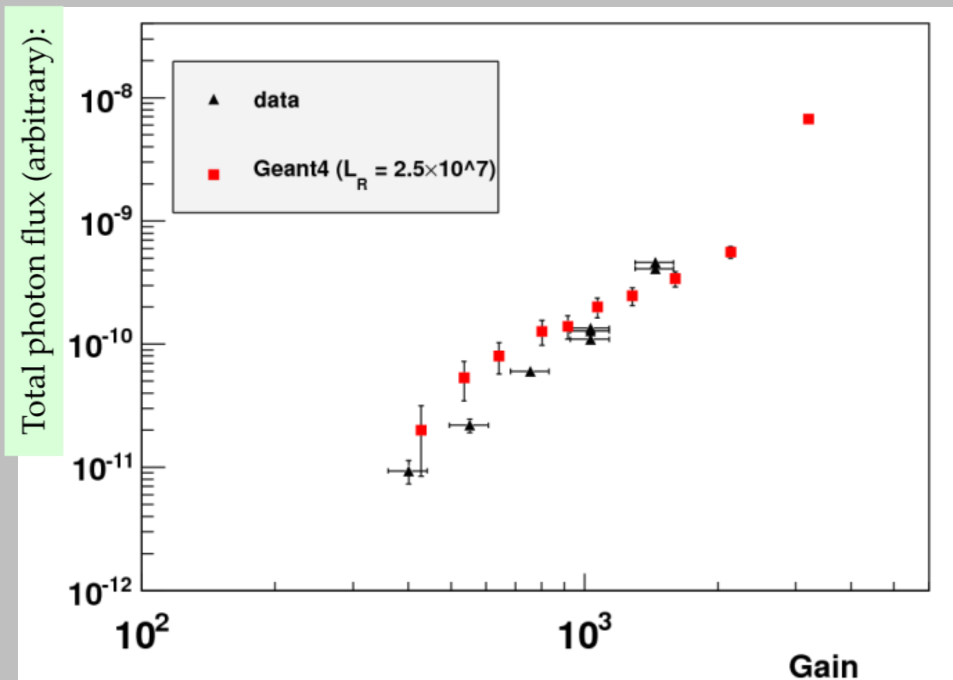




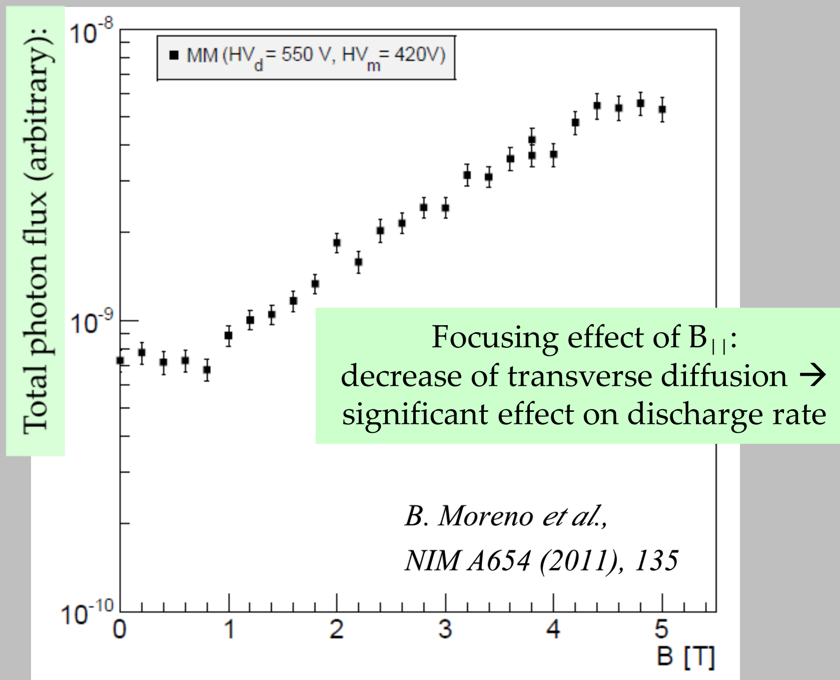


B//E: tests at JLab/Hall B

Spark rate at 0 T



Effect of the $B_{//}$ field



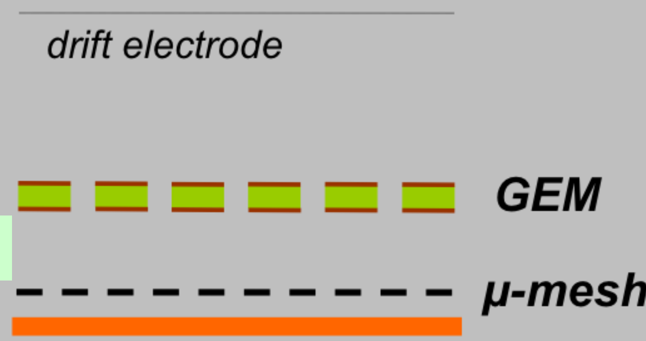
→ reasonable agreement with the simulation using N_{el}=2.5 10^7 (again)

→ spark rate increased by a factor of 10 between 0 and 5 T

⇒ Proves that transverse diffusion effect plays a role, i.e. a charge density is more relevant than a global limit « a la Raether » in our case

Effect of a GEM foil on the spark rate

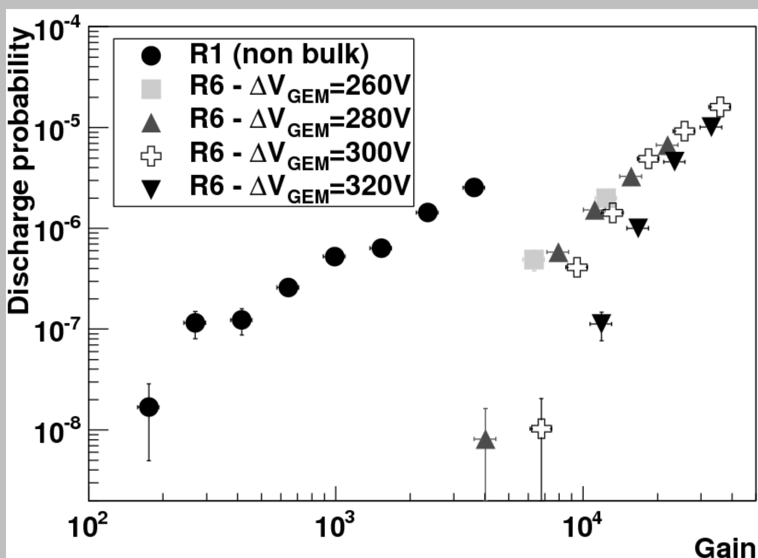
Experimental results (1/2)



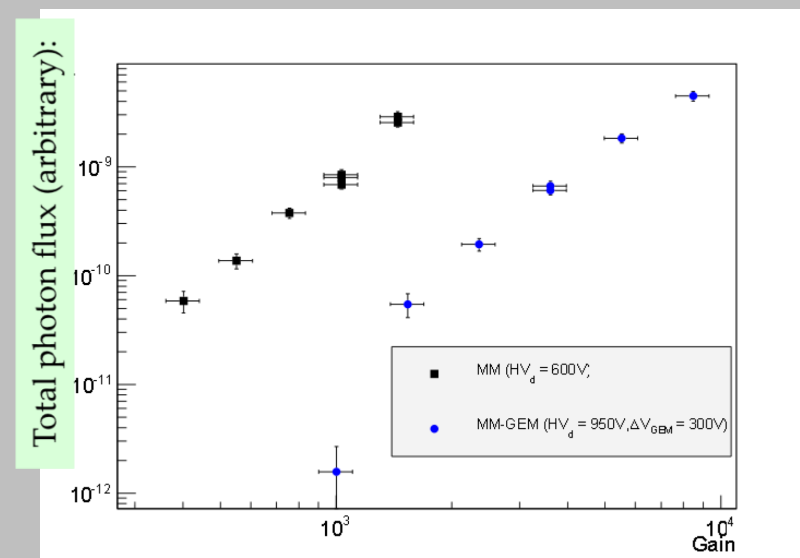
Ar/iC_4H_{10} (95:5)

1 or 2 mm

CERN/SPS



JLab/Hall B



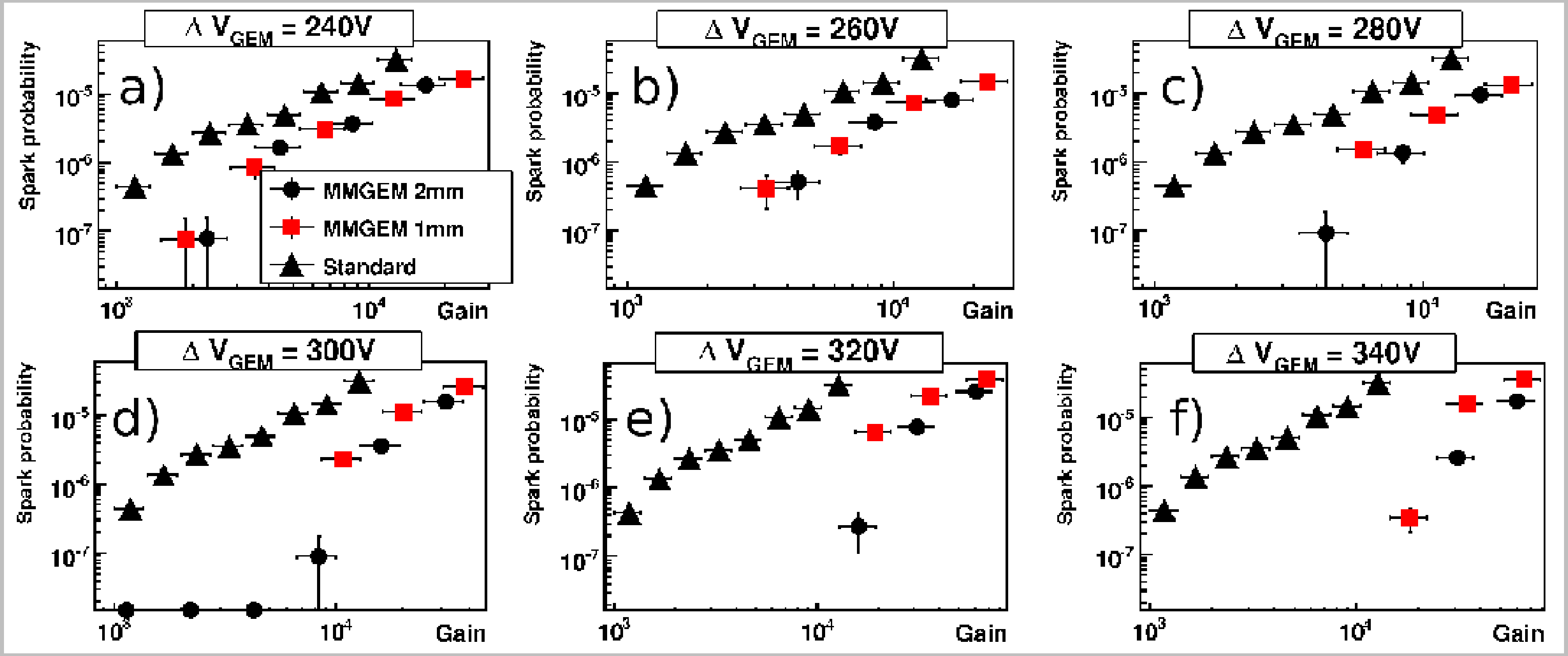
⟶ spark rate reduction by a factor of 10 to 100

⟶ reduction is largely independent on the setup (i.e. intrinsic to detector)

⟶ reduction is enhanced by using higher GEM gains

Experimental results (2/2)

Comparison between MM-GEM with 1 and 2 mm transfer gap (CERN/PS)



G. Charles et al., NIM A648 (2011), 174

→ *At small GEM gains, the transfer gap plays no role in the spark reduction*

→ *At higher GEM gains, a large transfer gap further reduces the spark rate*

Towards a charge density criteria

→ *Take into account transverse diffusion between interaction and micro-mesh*

Raether limit not adapted anymore, as originally derived for single (localized) avalanche

→ *A spark occurs when the electric field exceeds the breakdown field*

→ *The field between the electron cloud and the strip is:*

Field created by avalanche

$$E = \frac{Q}{\varepsilon S}$$

⇒ *Spark criteria should now be on the surface density $d_S = Q/S$*

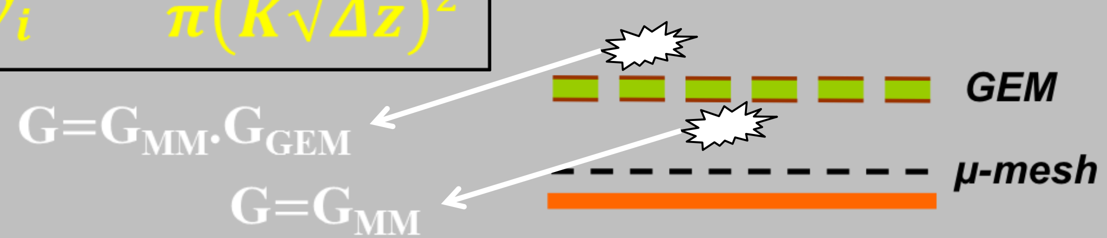
Charge density

→ *An energy deposit E_{dep} in Geant4 at a distance Δz of the anode yields:*

Charge density

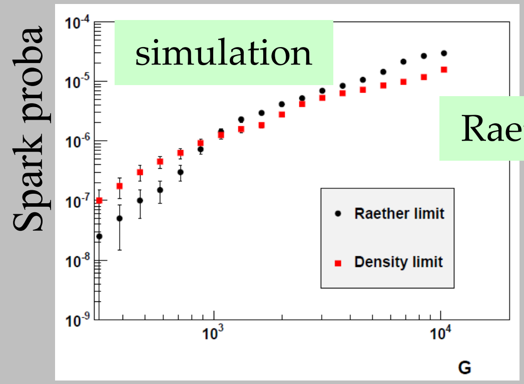
$$d_s = \frac{E_{dep}}{w_i} . G . \frac{4}{\pi\left(K\sqrt{\Delta z}\right)^2}$$

Transverse diffusion depends from z



Towards a charge density criteria

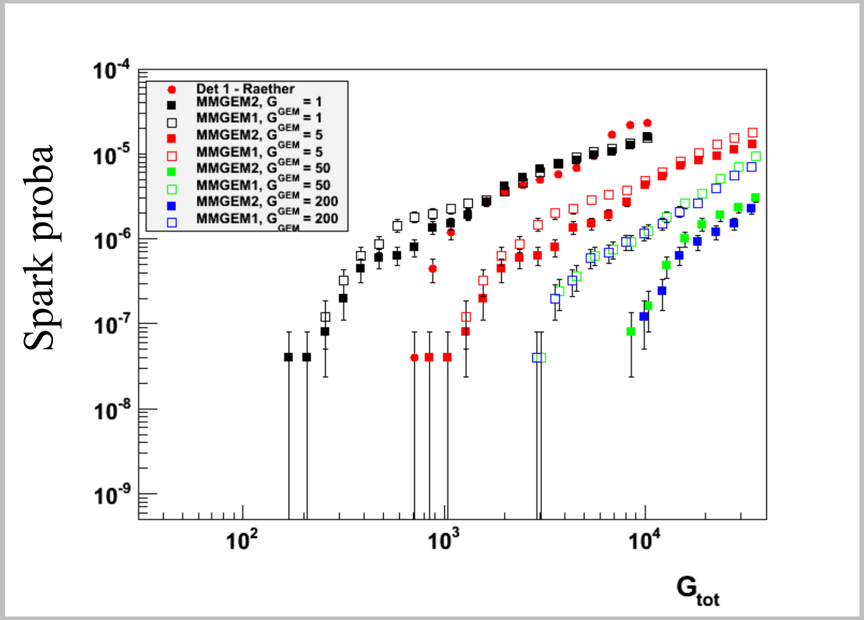
→ *Comparison of the 2 criteria (Raether and charge density) on a standard configuration*



Raether limit (2 x 10^7 electrons)

⇒ *Very similar, power law shape*

→ *Simulation of MM-GEM with different GEM gains and charge density criteria*



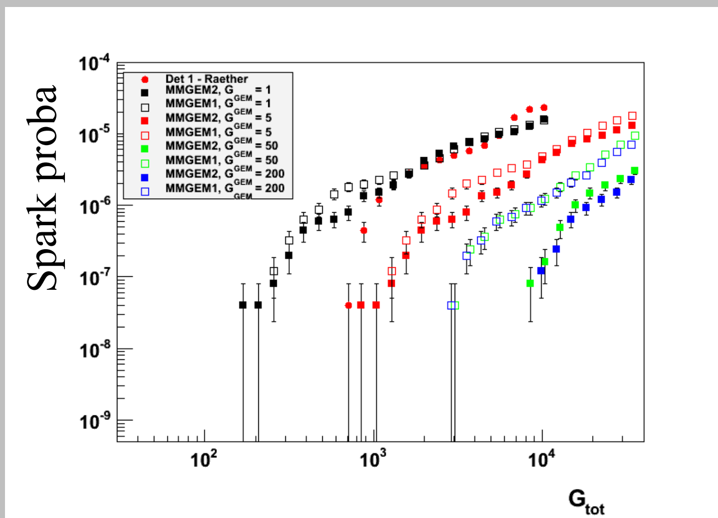
⇒ *Explains all effects seen with MM-GEM*

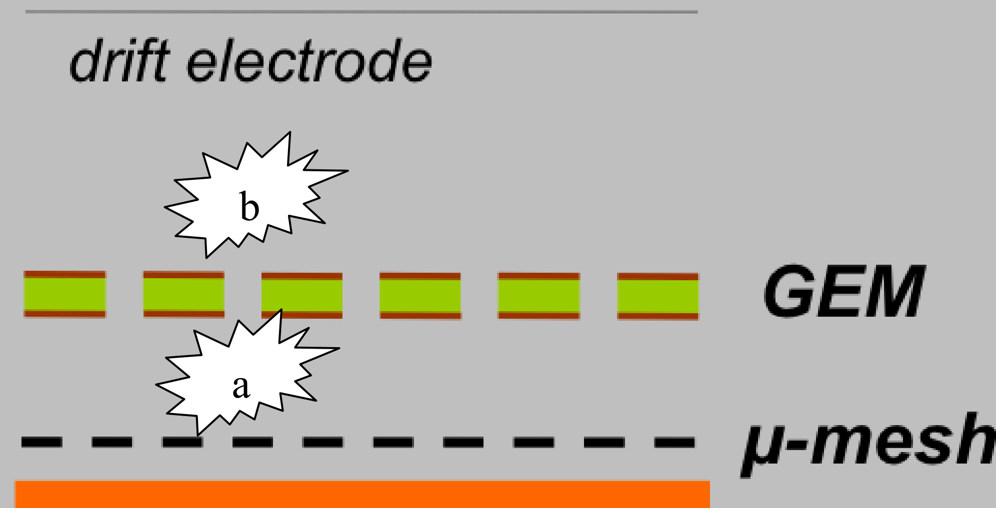
- → *Large suppression with moderate GEM gains*
- → *Effect of transfer gap only at high GEM gains*
- → *Change of slope at high GEM gains*

At higher GEM gains transfer gap plays a major role
→ it is all about the charge density

Simulation of MM-GEM

Some explanations





→ *At small GEM gains, sparks from (a) are favoured (because of transverse diffusion)*

⇒ *No difference between 1 and 2 mm transfer gap*

→ *Increasing GEM gains at fixed total gain progressively suppresses sparks from (a)*

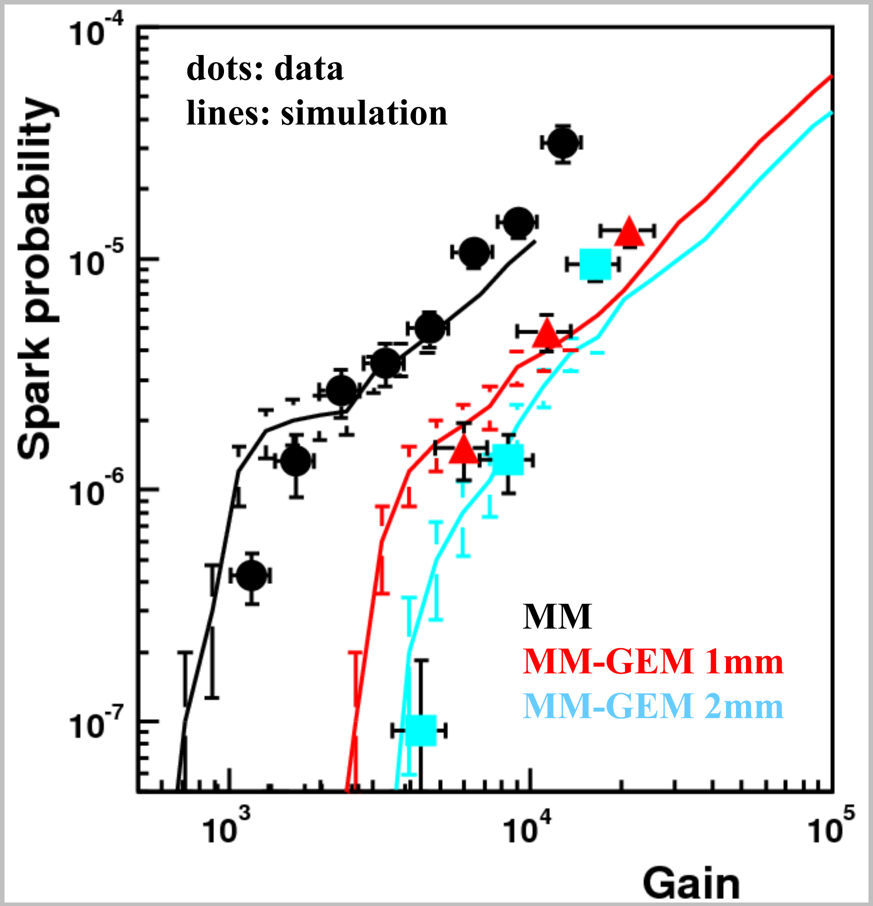
⇒ *Progressive reduction of spark rate*

→ *At high enough GEM gains, sparks from (a) are suppressed, (b) start to be dominant*

⇒ *A large transfer gap further reduces the spark rate in this regime*

Comparison with data

→ *Comparison at ΔV_{GEM} = 280 V (intermediate regime):*



→ $d_s^{lim} = 2.10^9$ *elec/mm²*

S. Procureur et al., JINST 7 C06009 (2012)

⇒ *Quantitative understanding of spark reduction with GEM foils*

Conclusion

→ *Origin of sparks with hadrons quantitatively understood in Micromegas*

⇒ ***Related to large energy deposits in the detector, often from secondaries***

⇒ ***Well compatible with Raether limit in cases where transverse diffusion effect can be neglected***

→ *Validity of the model has been checked from 0.3 to 150 GeV/c*

⇒ ***Can use Geant4 to make predictions in a given configuration***

→ *Measurements of the B effect (up to 1.5 T for* $B_{\perp}$*, 5 T for* $B_{//}$*)*

→ *Validity of the simulation extended to GEM foils by taking into account trans. diff.*

⇒ ***Spark data interpreted in terms of (surface) charge density instead of « naive » Raether limit***

⇒ ***Quantitative description of the effect of a GEM in the spark rate reduction***