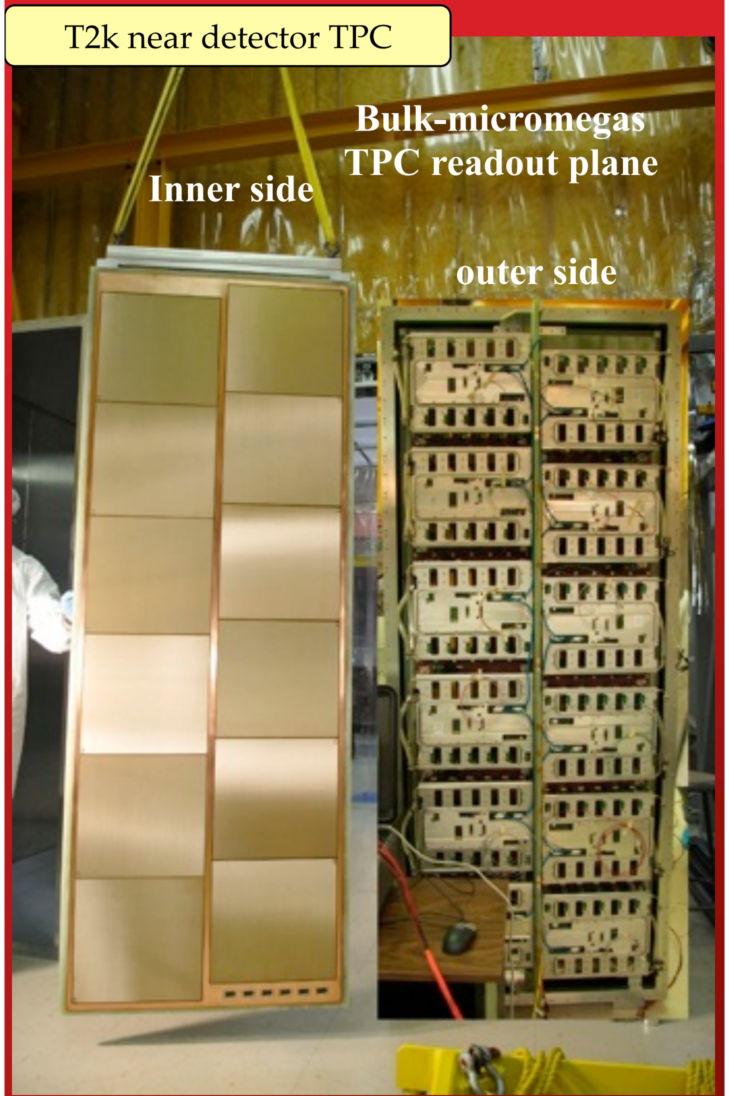
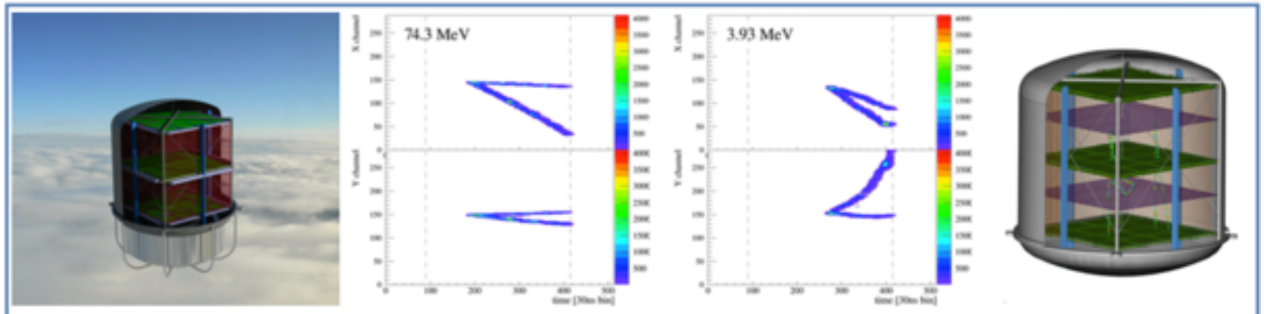
DE LA RECHERCHE À L'INDUSTRIE

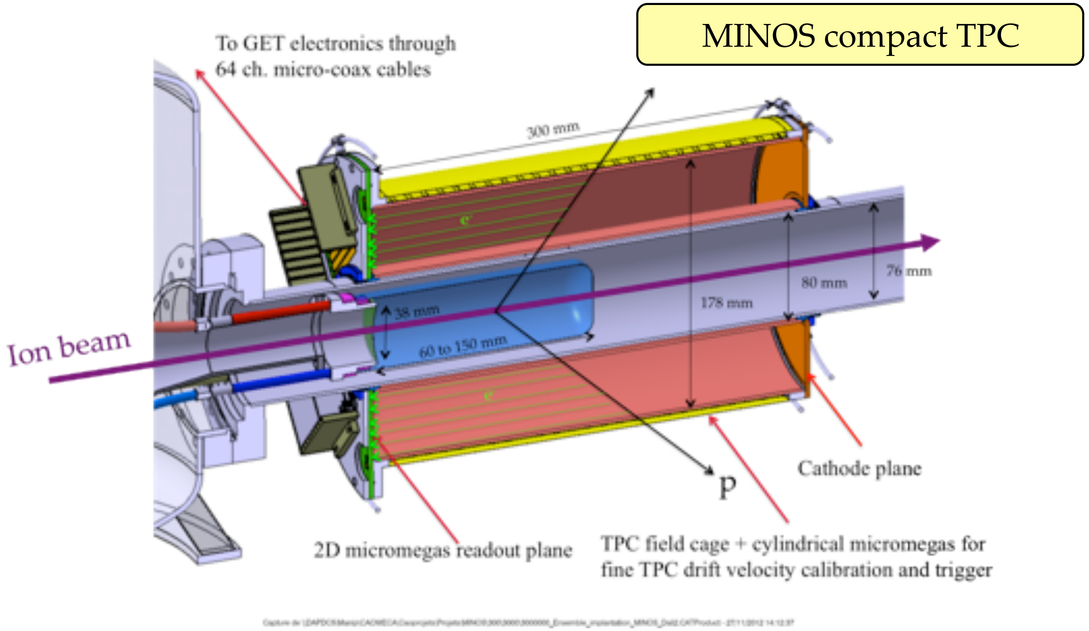




Left and right: artist's impression of the prototype instrument we are developing. Centre: (x,t) and (y,t) images of the conversions of a 74.3 MeV & 3.93 MeV photon from the BL01 polarised gamma-ray beam line of the NewSUBARU facility in the 2.1 bar argon-isobutane (95-5%) active target of the HARPO TPC prototype.

TIME PROJECTION CHAMBERS
AND ASSOCIATED ELECTRONICS

A. Delbart, D. Attié, D. Calvet, P. Colas
CEA/DSM-IRFU,
CE-Saclay, 91191 Gif-Yvette, France



Workshop on « A TPC for MeV Astrophysics »
Polytechnique, april 12th -14th , 2017

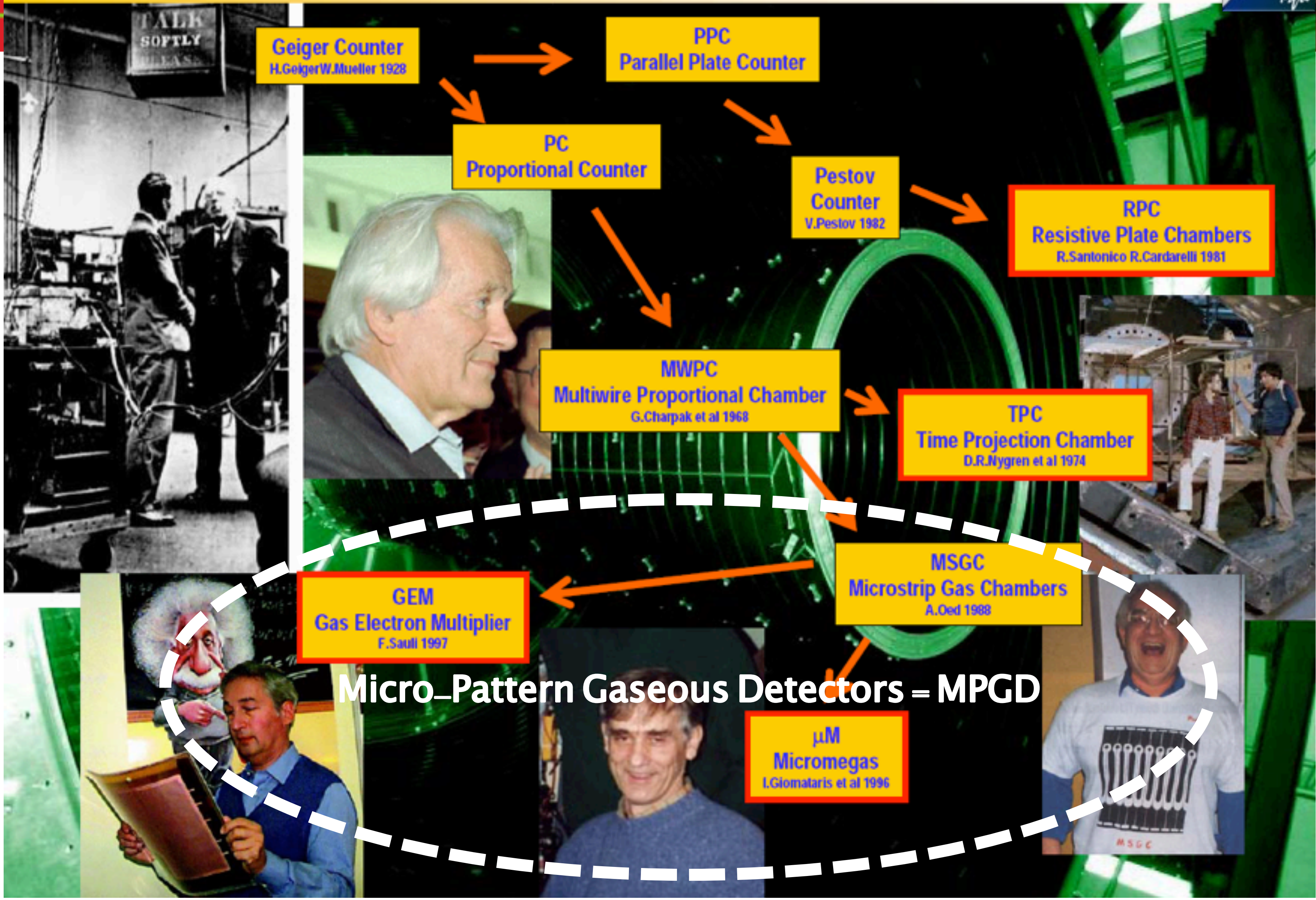
OUTLINE

- Gaseous detectors and Micro-Pattern detectors for the readout of TPCs
- Time Projection Chambers : Definitions, characteristics and terminology
- The Micromegas readout TPCs of the ND280 near detector of the T2K experiment

- Two “hot subjects” for future MPGD readout TPCs
  - ✓ dealing with ion backflow which limits high rate applications
  - ✓ dealing with narrow charge distribution which can limit spatial resolution

- The Asic For Tpc Electronic Readout (AFTER) family
- The General Electronic for Tpc (GET)

Gas Detector History

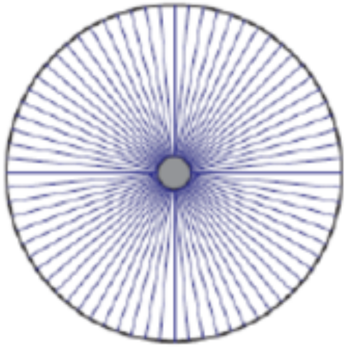


Ref : M. Titov, "Trends and Perspectives in Gaseous Detectors: Linking MPGD Technology for Future Physics Projects", CERN Detector Seminar, April 13, 2012

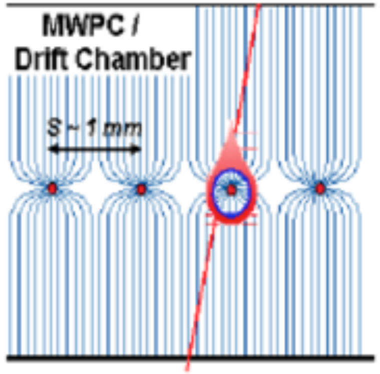
MICRO-PATTERN GASEOUS DETECTORS GALLERY

MPGD family ….

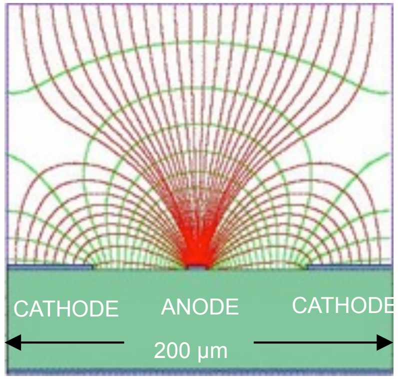
Drift tubes



Multi-Wire Proportional Chamber
MWPC (1968)

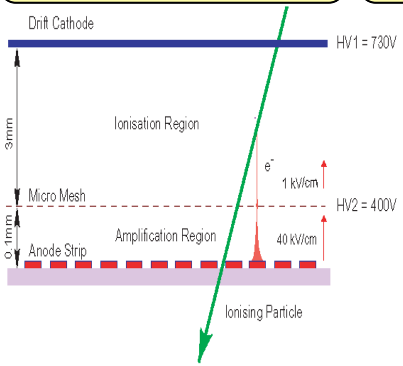


Micro-strip Gas Chamber
MSGC (1988)

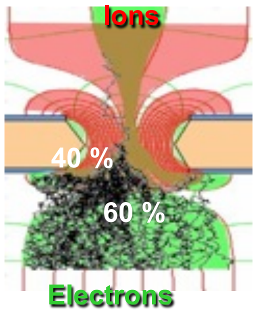


Microgap Chamber
MGC(1993)
MicroDOT chamber
MDOT S. Biagi et al., NIM A366(1995)76
Compteur A Trou
CAT F. Bartol et al., J. Phys. III France 6(1996)337
Micro PIxel Chamber
µ-PIC (2000) **Etc ……**

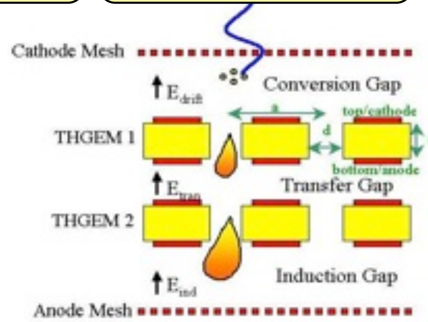
MICROMEGAS
(1996)



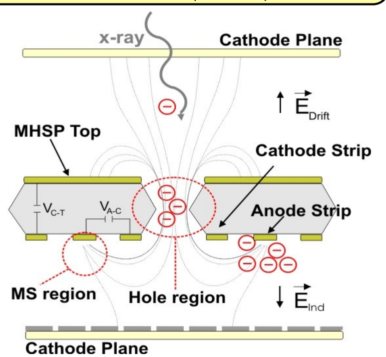
Gas Electron Multiplier
GEM (1997)



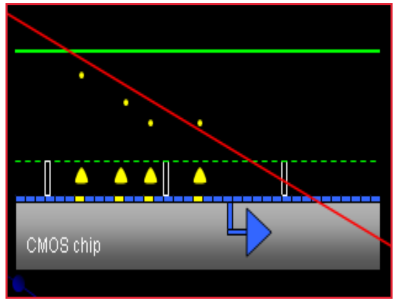
Thick GEM
THGEM (2003)

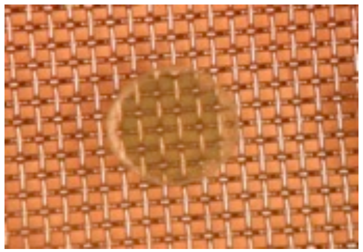


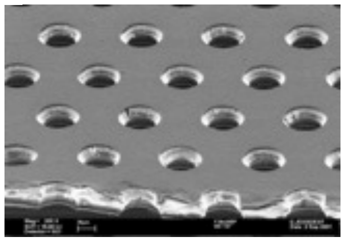
Micro Hole & Strip Plate
MHSP (2002)

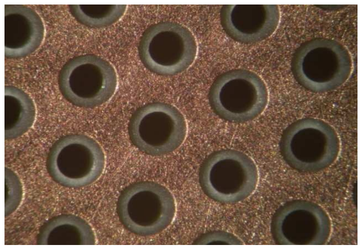


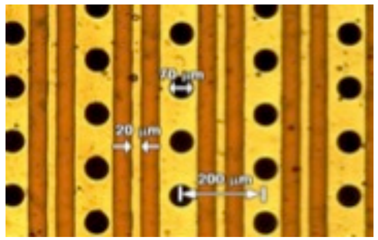
INGrid
(2005)

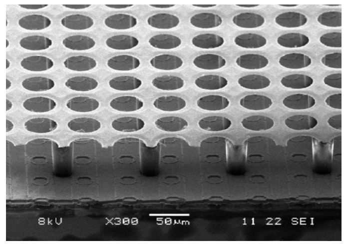










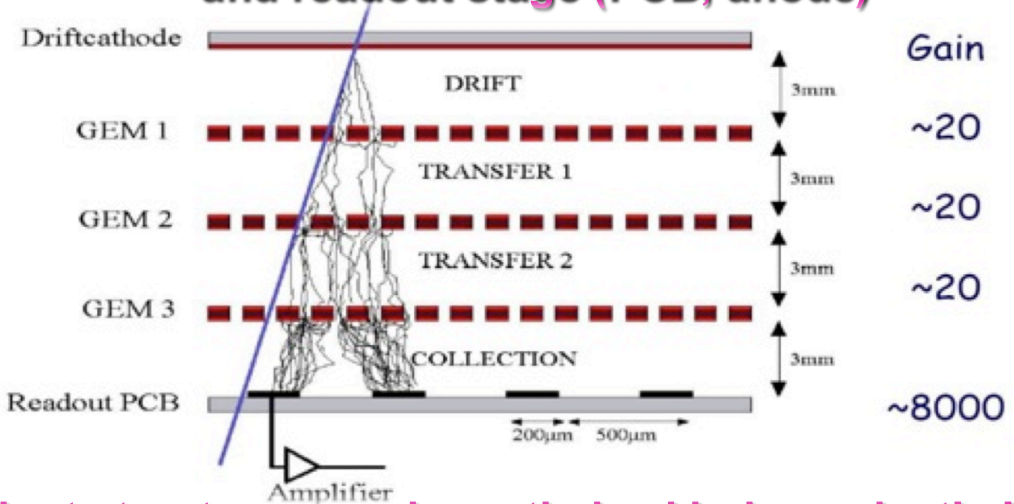


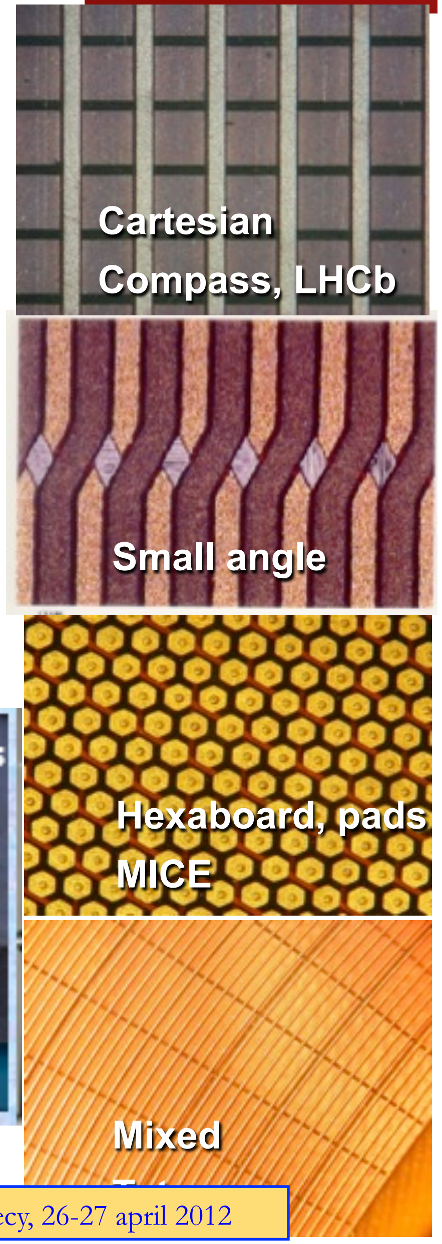
THE GAS ELECTRON MULTIPLIER GEM

F. Sauli, NIM A386(1997) 531
F. Sauli, http://www.cern.ch/GDD

5-10,000 INDEPENDENT PROPORTIONAL COUNTERS per cm^2

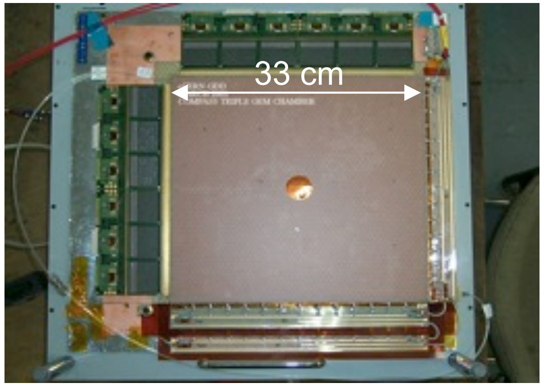
Full decoupling of amplification stage (GEM) and readout stage (PCB, anode)



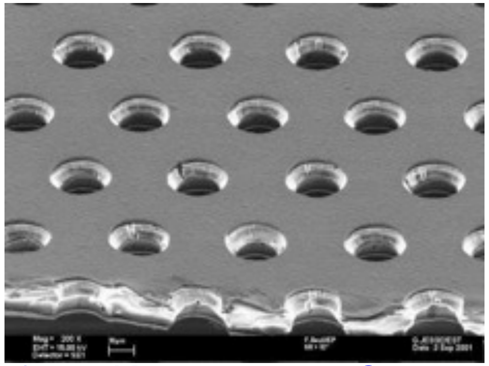


Amplification and readout structures can be optimized independently !

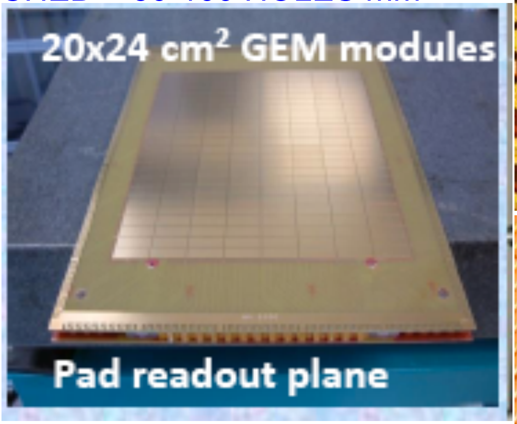
THIN METAL-COATED POLYMER FOIL CHEMICALLY ETCHED ~ 50-100 HOLES mm^2



Compass



50 µm Kapton, 5 µm Copper
70 µm holes at 140 µm pitch

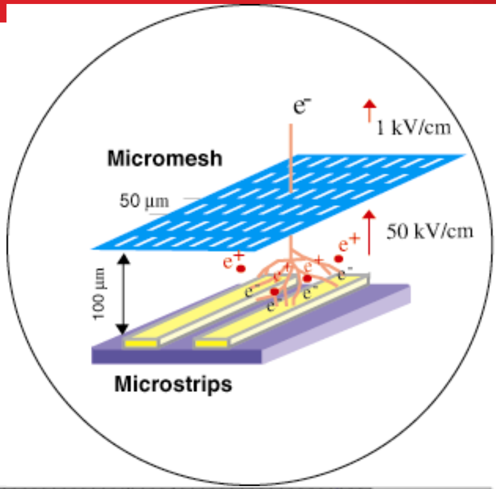


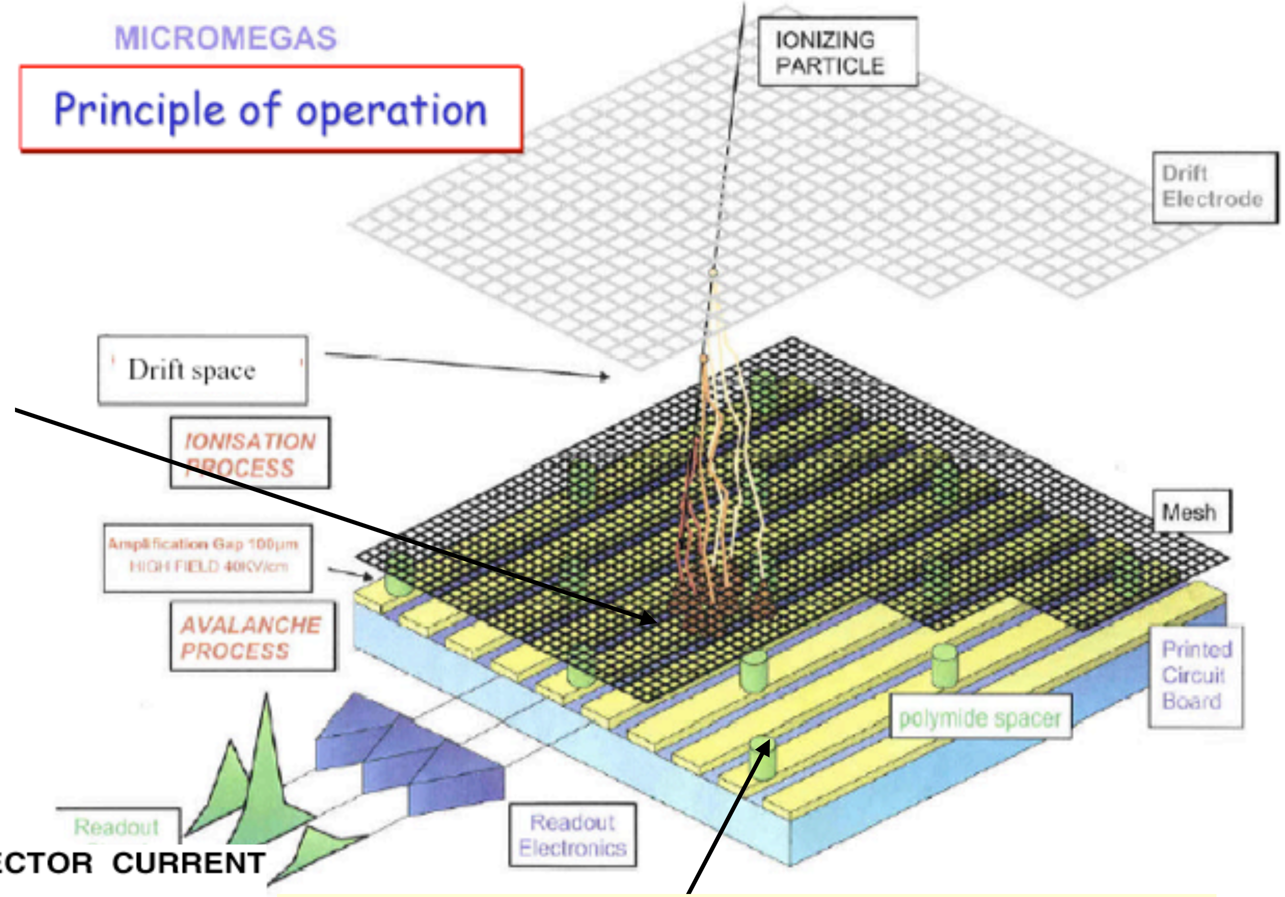
LHCb trigger

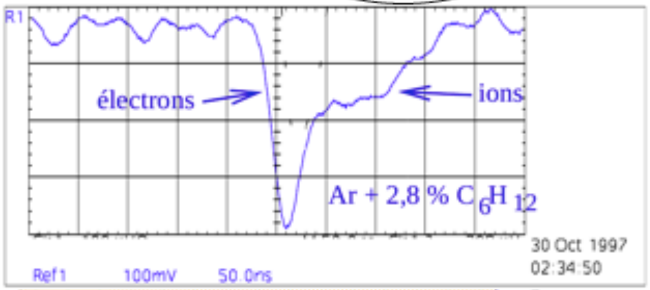
Ref : Y. Giomataris, Industry-Academia Matching Event on Micro-Pattern Gaseous Detectors, LAPP, Annecy, 26-27 april 2012

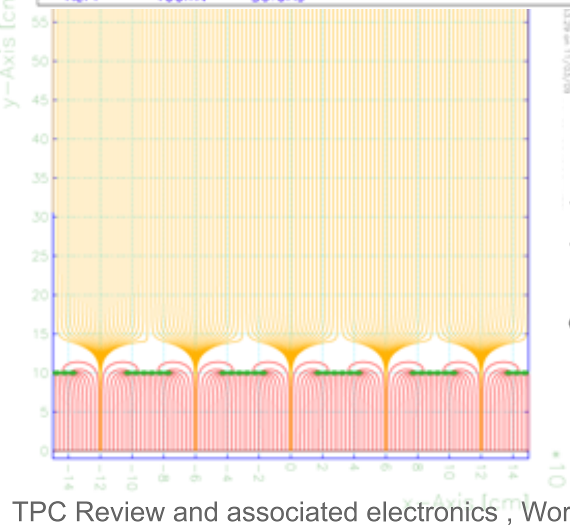
THE MICROMESH GASEOUS STRUCTURE MICROMEGAS

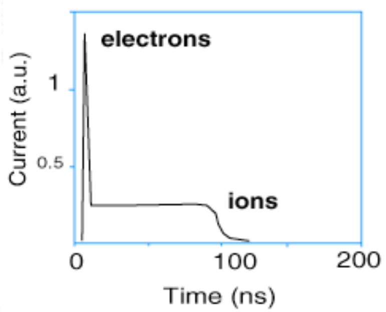
Y. Giomataris, Ph. Rebourgeard, J-P Robert and G. Charpak, NIM A376, 1996









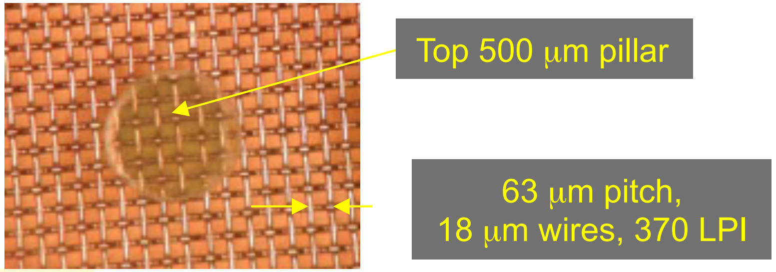


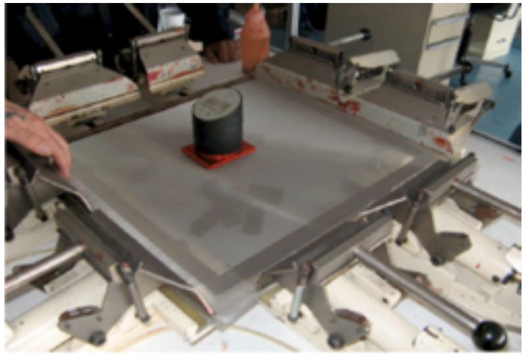
keeping the gap constant ~100 µm gap

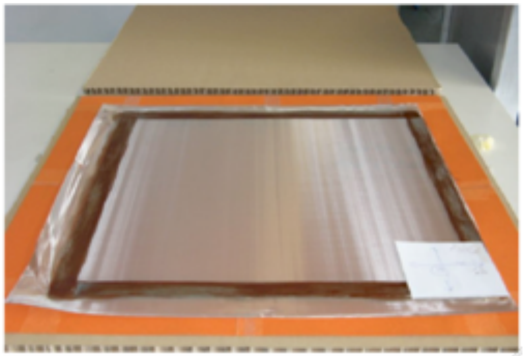
- Ni or Cu micromesh + pillars on PCB or on mesh
- « bulk » and « micro-bulk » technologies
- **Recent InGrid techniques** : mesh over Si pixel chip
- New resistive anode technologies for high rate applications (spark dead time minimization)

BULK-MICROMEGAS
PRODUCTION @ CERN, IRFU, AND IN PCB INDUSTRY

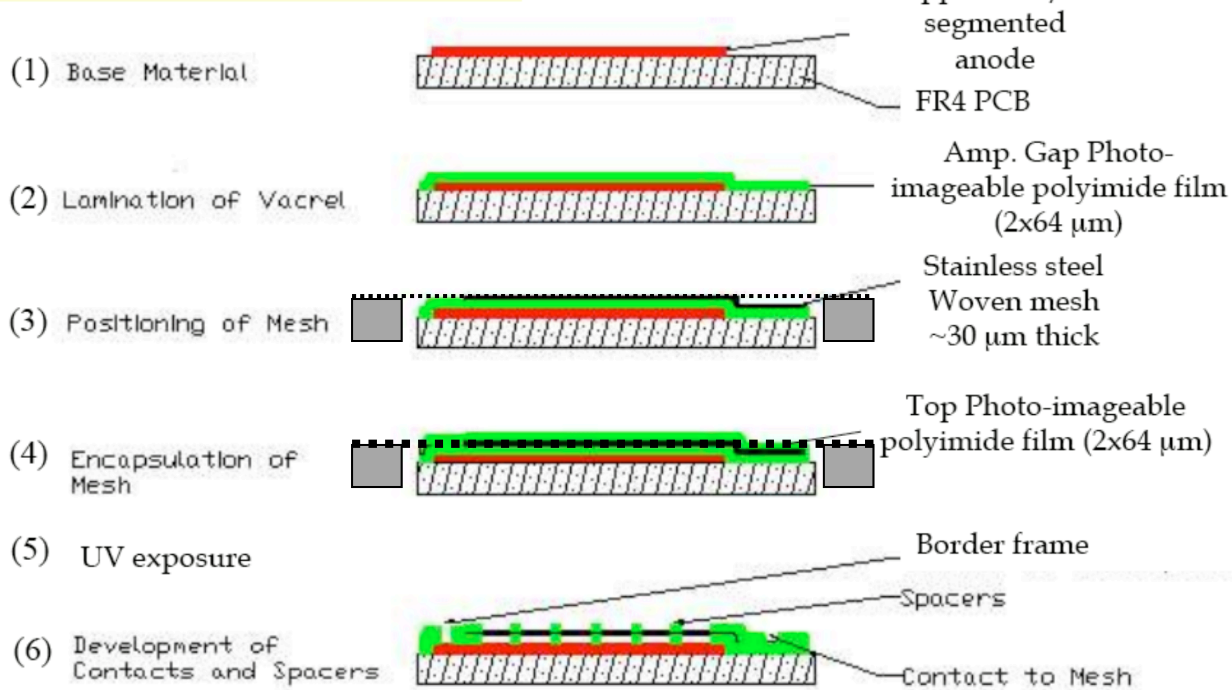
- ✓ First prototypes in 2004. CERN PCB Workshop /Irfu collaboration
- ✓ A woven micro-mesh is embedded between 2 layers of photo-imageable Pyralux PC1000 material. Amplification gap of 128 µm is standard, 64,102,196 µm, & 256 µm were done
- ✓ No frame, no mechanics → % level dead zones
- ✓ Up to 50x50 cm^2 is standard
- ✓ Robust, Industrial process (≈10 k€/m^2)







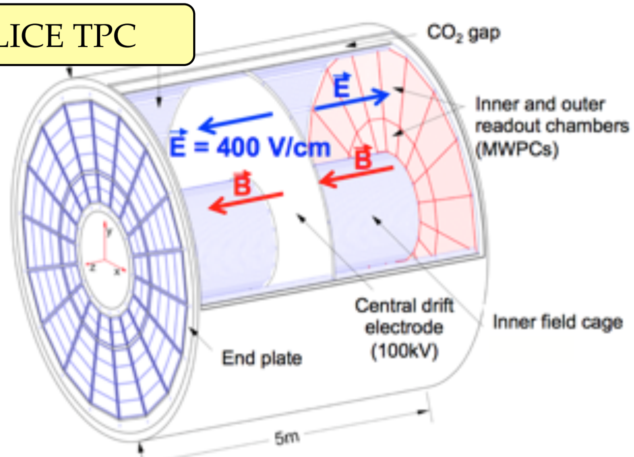
Réf : R. De Oliveira (CERN/EST-DEM-PMT)

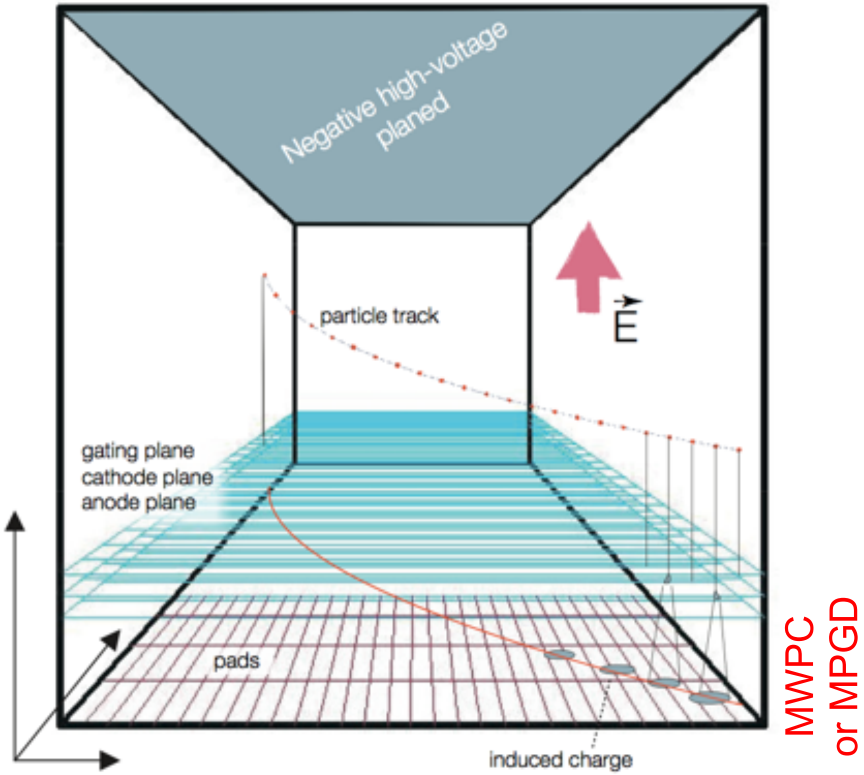


WHAT IS A TIME PROJECTION CHAMBER

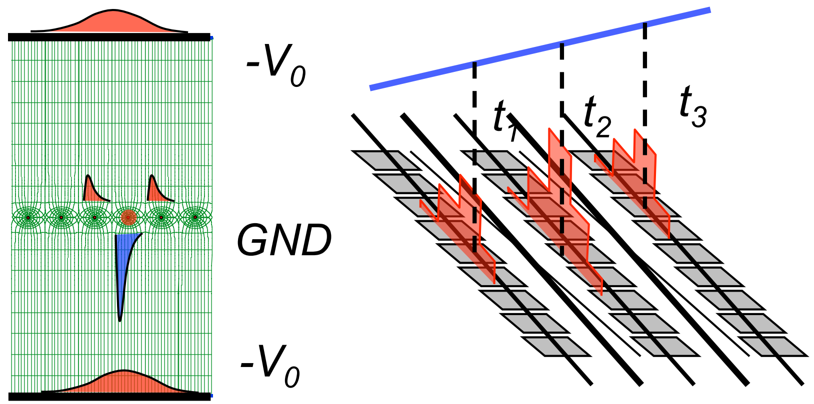
Original proposal by D. R Nygren for the PEP4 experiment (LBNL internal report, 1974)

ALICE TPC





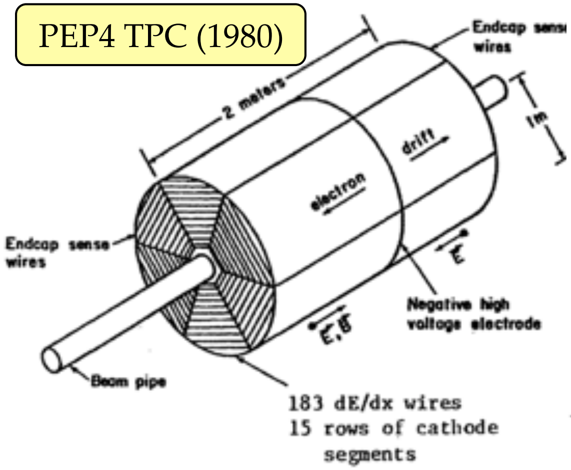
A TPC is an "Electronic Bubble Chamber" which delivers direct 3D track information for pattern recognition in high multiplicity events and particle identification over a wide momentum range



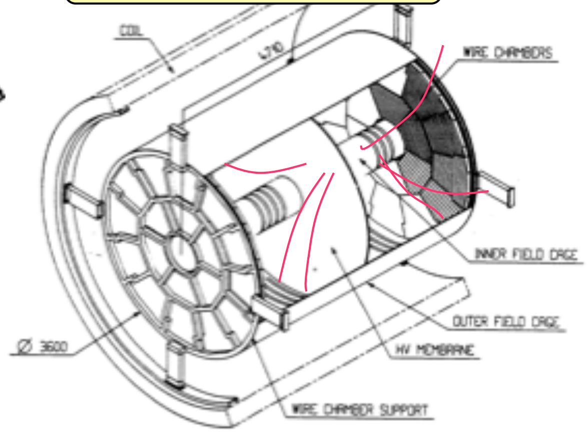
- A uniform electric field over a large volume drifts electron tracks to an end-cap position-sensitive detector.
- A magnetic field B//E deflects the tracks to measure their momentum (+ Lorentz angle =0 along drift)
- The drift time of each track segment is measured to provide the vertical coordinate Z
- The position in the XY projection is obtained by recording the induced charge profiles on the segmented readout plane after amplification
- The recorded charge provides dE/dx for particle Identification (PID).

COMPONENTS OF A TPC

PEP4 TPC (1980)

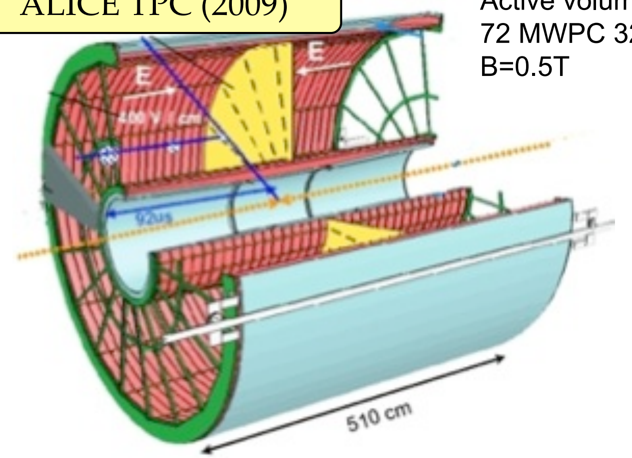


ALEPH TPC (1990)

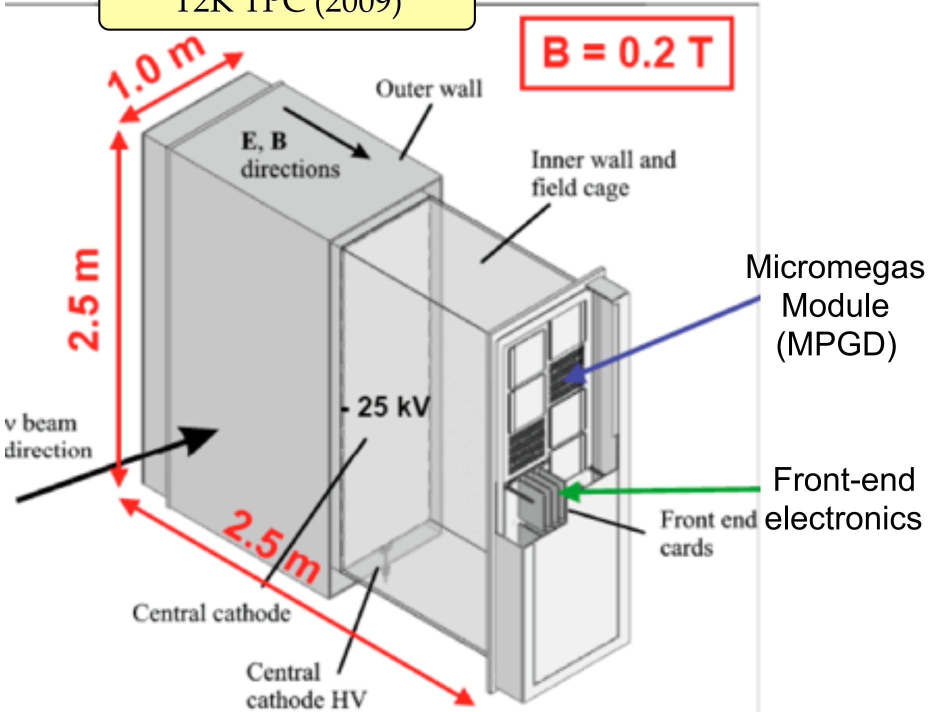


ALICE TPC (2009)

Active volume 88m^3
72 MWPC 32m^2
B=0.5T



T2K TPC (2009)



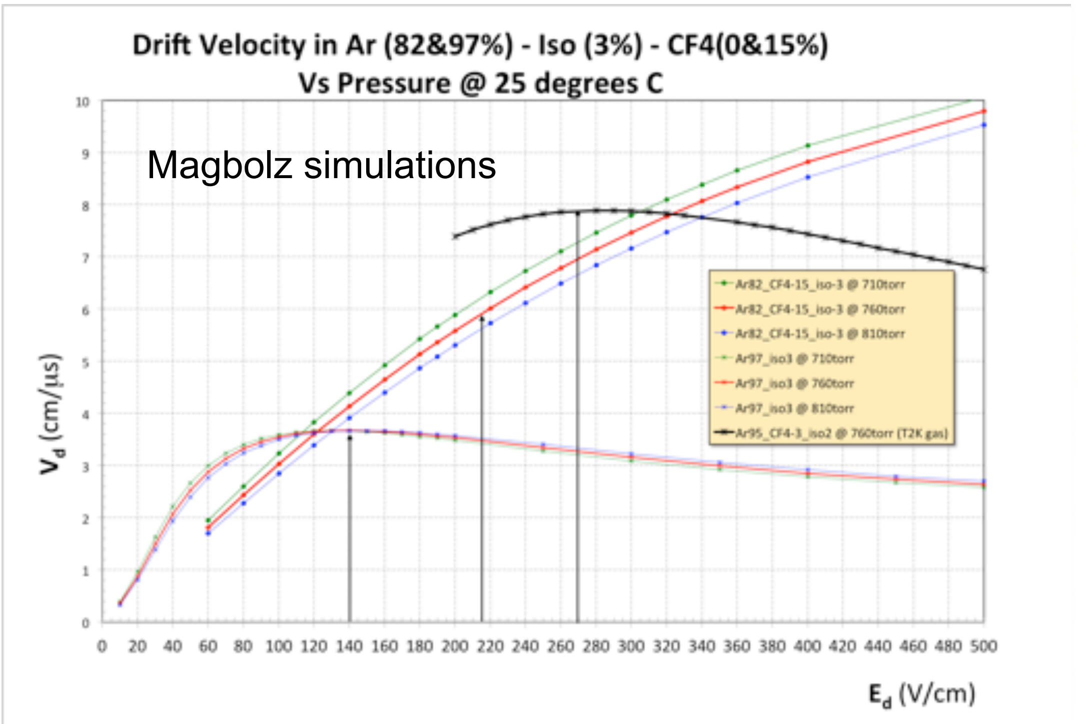
- ✓ Gas choice (Magbolz, Garfield), gas system, gas vessel
- ✓ Field cage for homogeneous electric field to provide an undeformed projection of the tracks (COMSOL)
- ✓ Magnetic field (for momentum measurement and B// E to lower diffusion of electrons)
- ✓ Readout plane with charge amplification for X–Y localization and dE/dx measurement (MWPC, MPGD)
- ✓ Gating grid to suppress the ion feedback
- ✓ Calibration system (field distorsions, gain, …)
- ✓ Readout electronics : continuous sampling of induced charge on X–Y pad plane
- ✓ Event triggering system

GAS CHOICE

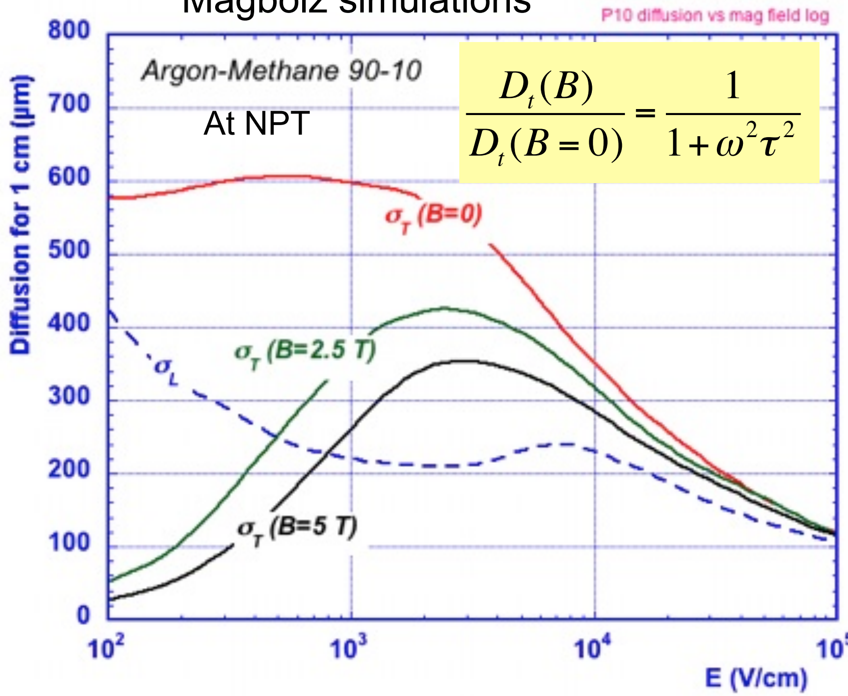
The TPC gas mixture properties have to comply with many design and operating TPC parameters :

- ✓ Electron drift velocity Vs electronics sampling frequency Vs maximum drift length
- ✓ Electron transverse diffusion Vs pad size for optimal charge sharing between adjacent pads (X,Y)
- ✓ Gas gain (electron multiplication by avalanche) in the charge amplification
- ✓ Stability of gas parameters Vs P, T, impurities, electric field, …
- ✓ Electron attachment by electronegative components or impurities (Halogenides, oxygen)

Ex: $Ar(80)/CH_4(20)$ for PEP4, $Ne(90)/CO_2(10)/N_2(5)$ for ALICE, $Ar(95)/CF_4(3)/iC_4H_{10}(2)$ for T2K



Magbolz simulations



TPC VESSEL AND ELECTRIC FIELD CAGE DESIGN

The TPC field cage has to provide a uniform electric field // to the magnetic field.

It usually has to cope with two conflicting requirements :

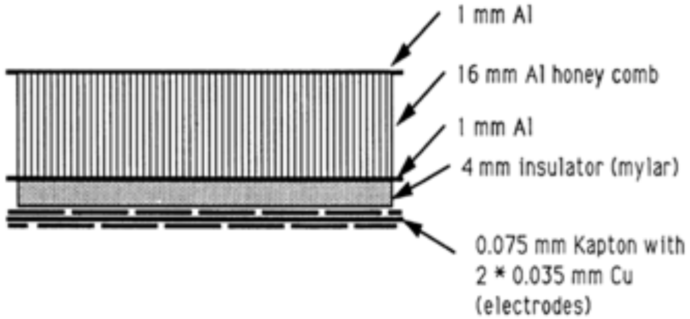
- ✓ Mechanical and electrical stability : electrodes alignment and high voltage handling
- ✓ Low radiation length materials : use of a solid or gaseous insulator (High Voltage Vs Ground)

For long term stability and minimization of ageing effects, many materials must be avoided (hydrocarbons, Si coumponds such as certain glues or adhesives)

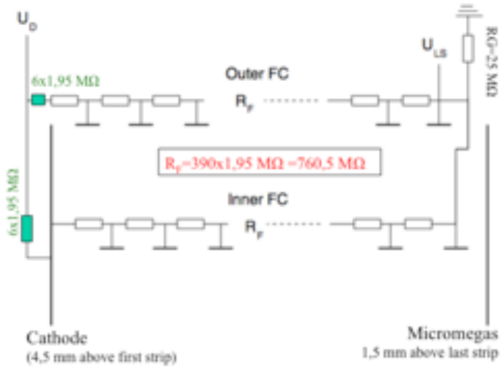
Minimization of insulating surfaces is required to avoid charging up effects

The electric field is usually defined through a linear potential degarder of a series of metallic strips interconnected with high precision resistors

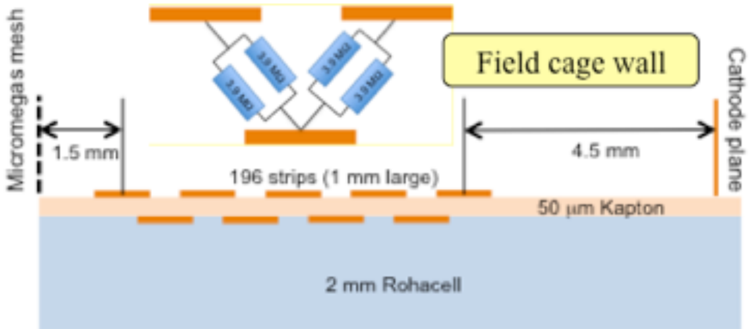
ALEPH TPC field cage cut
4,8 % radiation length



MINOS TPC high voltage setup



MINOS TPC field cage

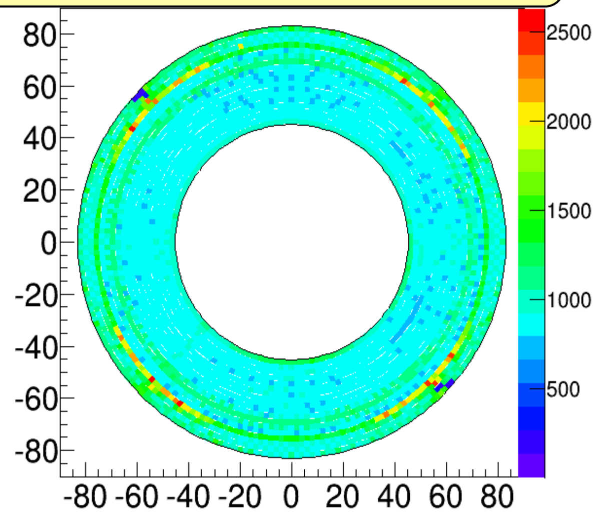


TPC CALIBRATION

Many calibration procedures may be used :

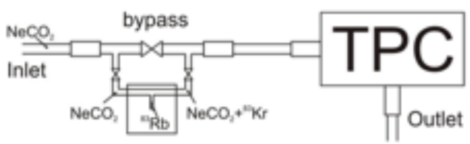
- ✓ Pulsing of grid wires (or micromegas mesh) and use of radioactive sources for dE/dx calibration
- ✓ Use of actual tracks for relative sector to sector timing or electron drift velocity calibration
- ✓ Acumulated cosmic ray events « filling » the TPC volume, to identify dead zones, and derive the electron drift velocity
- ✓ Laser beam tracks (2 photon ionization process) or photo-electrons extraction on targets for electron drift velocity calibration and tracking distorsions characterization

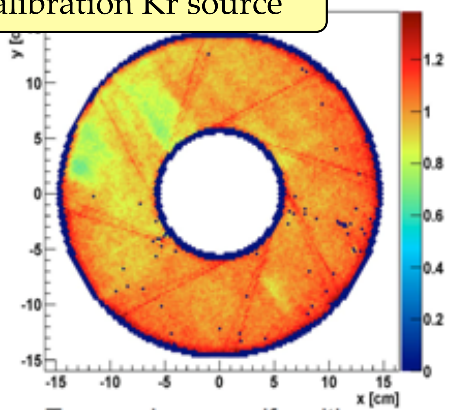
MINOS TPC : pad response to a 300 mV pulse on micromegas mesh



PANDA 3xGEM TPC : gas gain calibration Kr source

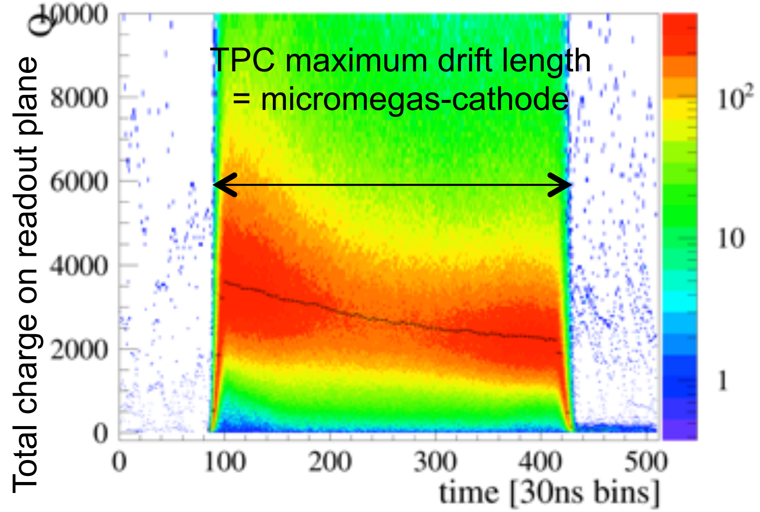
R. Arora et al., Physics Procedia 37 (2012) 491





- Trace gain non-uniformities originating from GEM stages (stresses, bending→ eff. fields), FEE etc.
- Correct the ΔE signal

HARPO TPC : electron drift velocity Form 1 h cosmic ray run



SOME MAJOR TPCS

Upgrade with MPGD readout (2015-2018)

Table 3. Characteristics and performance of some TPCs.

Parameter/Experiment	PEP4	TRIUMF	TOPAZ	AlEPH	DELPHI	STAR	ALICE[a]
Operation	1982/1984	1982/1983	1987	1989	1989	2000	2009
Inner/Outer radius (m)	0.2/1.0	~ 0.15/0.50	0.38/1.1	0.35/1.8	0.35/1.4	0.5/2.0	0.85/2.5
Max. driftlength ($L/2$) (m)	1	0.34	1.1	2.2	1.34	2.1	2.5
Magnetic field (T)	0.4/1.325	0.9	1	1.5	1.23	0.25/0.5	0.5
Gas :	Ar/CH_4	Ar/CH_4	Ar/CH_4	Ar/CH_4	Ar/CH_4	Ar/CH_4	$Ne/CO_2/N_2$
Mixture	80/20	80/20	90/10	91/9	80/20	90/10	90/ 10/ 5
Pressure (atm)	8.5	1	3.5	1	1	1	1
Drift field (kV cm^{-1} atm^{-1})	0.088	0.25	0.1	0.11	0.15	0.14	0.4
Electron drift velocity (cm μs^{-1})	5	7	5.3	5	6.69	5.45	2.7
$\omega\tau$ (see section 2.2.1.3)	0.2/0.7	2	1.5	7	5	1.15/2.3	<1
Pads: Size $w \times L$ (mm × mm)	7.5 × 7.5	(5.3–6.4) × 19	(9–11) × 12	6.2 × 30	~7 × 7	2.85 × 11.5 6.2 × 19.5	4 × 7.5 6 × 10/15
Max. no. 3D points	15—straight	12	10—linear	9 + 12—circular	16—circular	13 + 32—straight	63 + 64 + 32
dE/dx: Max. no. samples/track	183	12	175	148 + 196	192	13 + 32	63 + 64 + 32
Sample size (mm atm); w or p	4 × 8.5; wires	6.35; wires	4 × 3.5; wires	4; wires	4; wires	11.5 + 19.5; pads	7.5 + 10 + 15; pads
Gas amplification	1000	50 000		3000–5000	5000	3000/1100	20 000
Gap a–p; a–c; c–gate[b]	4; 4; 8	6	4; 4; 8	4; 4; 6	4; 4; 6	2; 2; 6/4; 4 ; 6	2; 2; 3/3; 3; 3
Pitch a–a; cathode; gate	4; 1; 1		4; 1; 1	4; 1; 2	4; 1; 1	4; 1; 1/ 4; 1; 1	2.5; 2.5; 1.5
Pulse sampling (MHz/no. samples)	10/455, CCD	only 1 digitiz., ADC	10/ 455, CCD	11/ 512, FADC	14/300, FADC	9.6/400	5–10/500–1000, ADC
Gating[c]	⩾1984 o.on tr.	⩾1983 o.on tr.	o. on tr.	synchr. cl.wo.tr	static	o.on tr.	o.on tr.
Pads, total number	15 000	7800	8200	41 000	20 000	137 000	560 000
Performance							
Δx_T (μm)-best/typ.	130–200	200/	185/230	170/200–450	180/190–280	300–600	spec:800–1100
Δx_L (μm)-best/typ.	160–260	3000	335/900	500–1700	900	500–1200	spec:1100–1250
Two-track separation (mm), T/L	20		25	15	15	8 - 13/30	
$\partial p/p^2$ $(GeV/c)^{-1}$: TPC alone; high p	0.0065		0.015	0.0012	0.005	0.006	spec:0.005
dE/dx (%) Single tracks/ in jets	2.7/4.0		4.4 /	4.4 /	5.7/7.4	7.4/7.6	spec:4.9/6.8
Comments		a in single PCs strong $E \times B$ effect	chevron pads	circular pad rows	circular pad rows	No field wires >3000 tracks	No field wires ⩽20 000 tracks

[a] Expected performance.
[b] a = anode, p = pads, c = cathode grid.
[c] o. on tr.: gate opens on trigger; cl.wo.tr. : opens before collision and closes without trigger; static : closed for ions only (see text).

H. J. Hike, "Time Projection Chambers", Repot On Progress In Physics (2010) p73-109

SOME MAJOR TPCS

MPGD readout

Table 3. Continued.

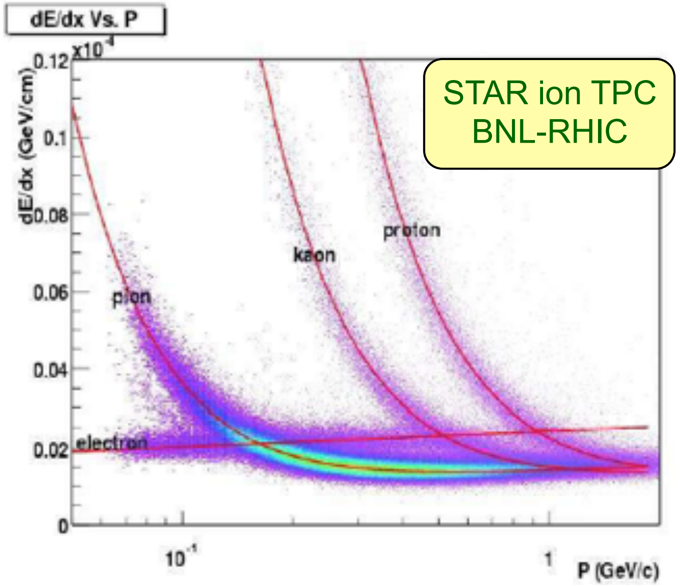
Parameter/Experiment cont.	NA35	EOS/HISS	NA49 VTX	NA49 MAIN	CERES/NA45	HARP	T2K[a]
Operation	1990	1992	1995	1995	1999	2001	2009/10
Inner/Outer radius or L/W (m)	2.4/1.25 (L/W)	1.5/0.96 (L/W)	2.5/1.5 (L/W); 2×	4/4 (L/W); 2×	0.6/1.3; $L = 2$	0.1/0.41	2.2/0.7 (H/L); 3×
Max. driftlength ($L/2$) (m)	1.12 vert.	0.75 (H)	0.67 vert.	1.1 vert.	0.7 rad.	1.6	0.9 W
Magnetic field (T)	0	1.3	1.5	0	$B_z < 0.7$; $B_r < 0.3$	0.7	0.2
Gas :	Ar/CH_4	Ar/CH_4	Ne/CO_2	$Ar/CH_4/CO_2$	Ne/CO_2	Ar/CH_4	Ar/CF4/i-C4H10
Mixture	91/ 9	90/ 10	90/10	90/ 5/5	80/ 20	91/ 9	95/ 3/ 2
Pressure (atm)	1	1	1	1	1	1	1
Drift field (kV cm^{-1} atm^{-1})	0.12	0.12	0.19	0.175	0.2-0.6	0.111	0.2
Electron drift velocity (cm μs^{-1})	5	5.5	1.3	2.3	0.7-2.4	5.2	7
$\omega\tau$ (see section 2.2.1.3)	0	0.5	1	0		3.3	0.7
Pads: size ($w \times L$, mm × mm)	5.5 × 40	8 × 12	3.5× (16 , 28)	(3.6, 5.5)×40	10 chevron	6.5 × 15	6.9 × 9.7
Max. no. 3D points	60 + 30	128	<150	90		20	72 × 3
dE/dx: Max. no. samples/track	60	128	<150	90		20	72 × 3
Sample size (mm atm); w or p	40; pads	12	16, 28	40		15	9.7
Gas amplification		3000	20 000	5000	8000	20 000	~1000
Gap a–p; a–c; c–gate[b]		4; 4; 6	3 , 2;	2,3; 3;6	3;3;6	5;5;6	0.128
Pitch a–a; cathode; gate	4; 1; 2	4; 1; 2	4; 1; 1	4; 1;1	6; 2; 2	4; 2; 2 stagg.	
Pulse sampling (MHz/no. samples)	12.5 /	10/256, SCA	/512	/ 512		10/>300, FADC	/512 SCA
Gating[c]		o. on tr.	o. on tr.	o. on tr.	o. on tr.	o.on tr.	none
Pads, total number	11 000	15 000	74 000	108 000	78 000	4000	125 000
Performance							
Δx_T (μm)-best/typ.	300–800	300	150	150	230/340	600–2400	600 (1m drift)
Δx_L (μm)-best/typ.	250–450				dr = 400/640	3.5	
Two-track separation (mm)	18	25		10			
$\partial p/p^2$ (GeV/c) $^{-1}$: TPC alone; high p		1			1	0.2/0.45–0.50	spec: <10;
dE/dx (%) : single tracks/in jets	/ 6	/ 4	<4 : VTX + Main			16	spec: <10 /
Comments	$B = 0$ only pad r.o.	only pad r.o.	Kr^m calibration only pad r.o.	up to1200 tr. only pad r.o.	Radial TPC No field wires	el. crosstalk	Micromegas r.o.

[a] Expected performance.
[b] a = anode, p = pads, c = cathode grid.
[c] o. on tr.: gate opens on trigger; cl.wo.tr. : opens before collision and closes without trigger; static : closed for ions only (see text).

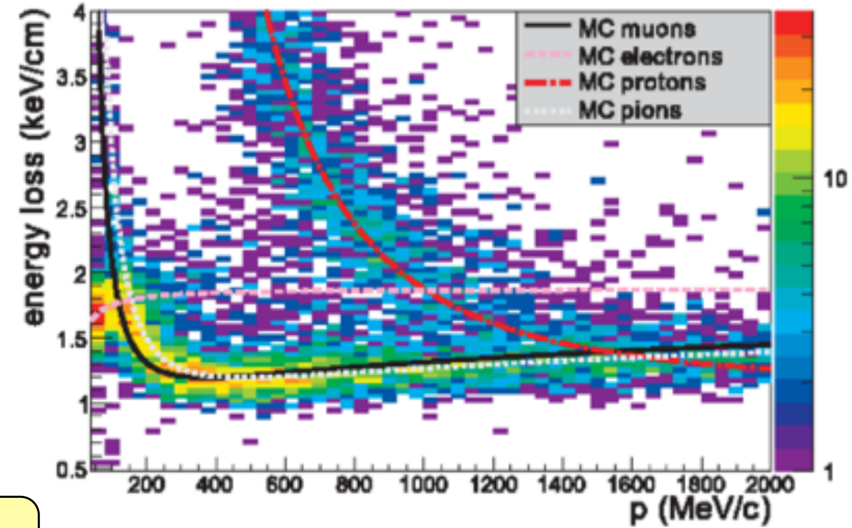
H. J. Hike, "Time Projection Chambers", Repot On Progress In Physics (2010) p73-109

SOME TPC PID PERFORMANCES

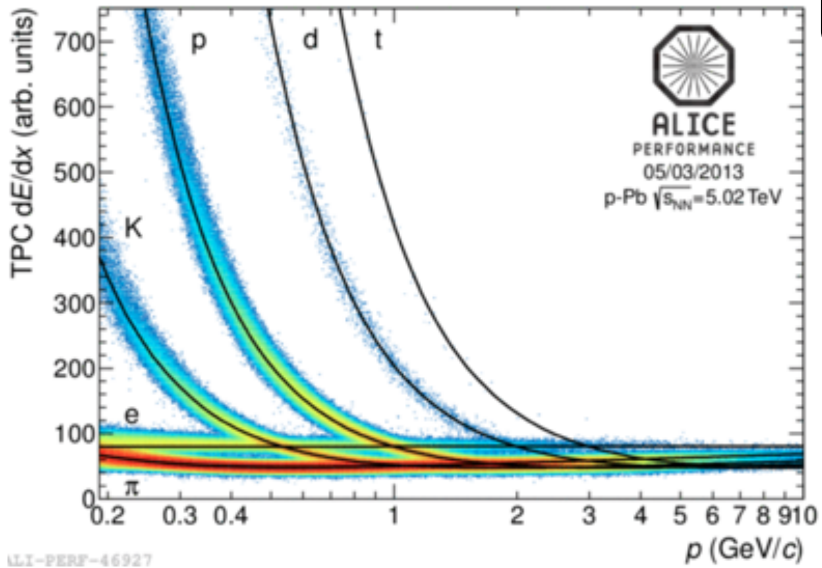
STAR ion TPC
BNL-RHIC

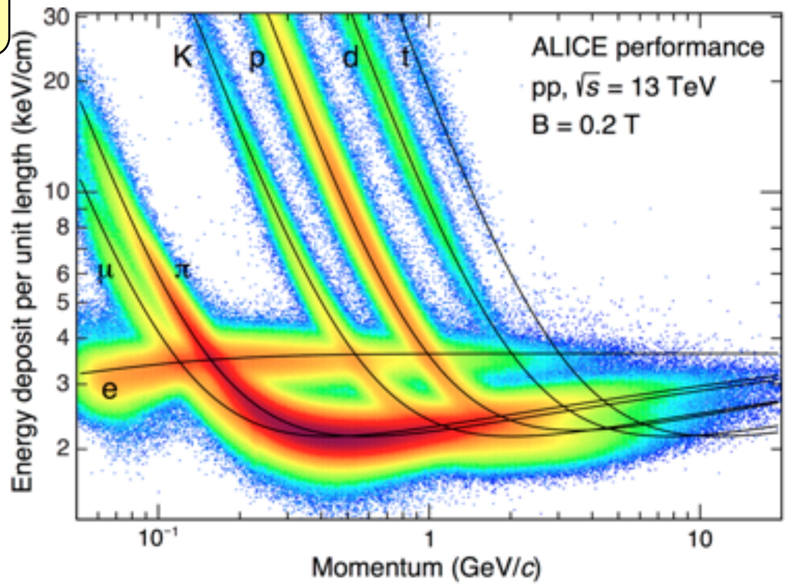


T2K/TPC : p, π^+, e^+



ALICE
TPC





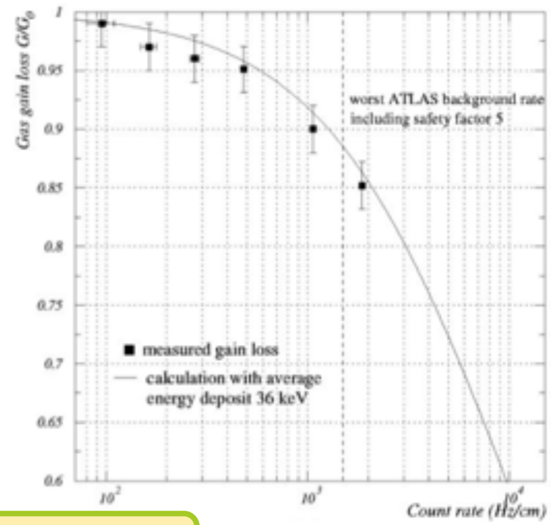
MPGD VS MWPC READOUT TPCS

MWPC readout TPC

- ✓ Rate capability in MWPC is limited to few kHz/cm^2 because of the long ion drift time and induced space charge density wich reduces the effective electric field
- ✓ ExB effect (lorenz angle) around wires induces smearing which degrades the X-Y spatial resolution
- ✓ Sector boundaries (mechanical frame dead areas + gain loss on borders) are of the order of tens of mm
- ✓ Backflow of ions in the drift volume is of the order of 10-20% without use of a gating grid.

ATLAS/MDT : 1 kHz / cm^2 → 10% gain drop

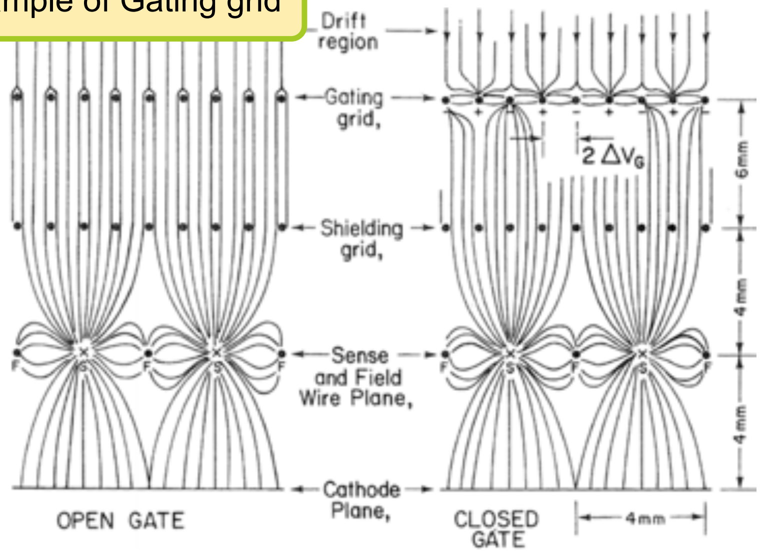
M. Aleksa et al, NIM A446 (2000) 435



MPGD readout TPC

- ✓ Rate capability of MPGD goes up to few MHz/cm^2 thanks to the fast charge signal (<100 ns in micromegas)
- ✓ ExB effects are negligible
- ✓ Sector boundaries can be minimized to less than 1 cm
- ✓ Improved robustness and ease of fabrication
- ✓ Backflow of ions can be lowered to the percent level with proper geometry and voltage operating conditions

Example of Gating grid



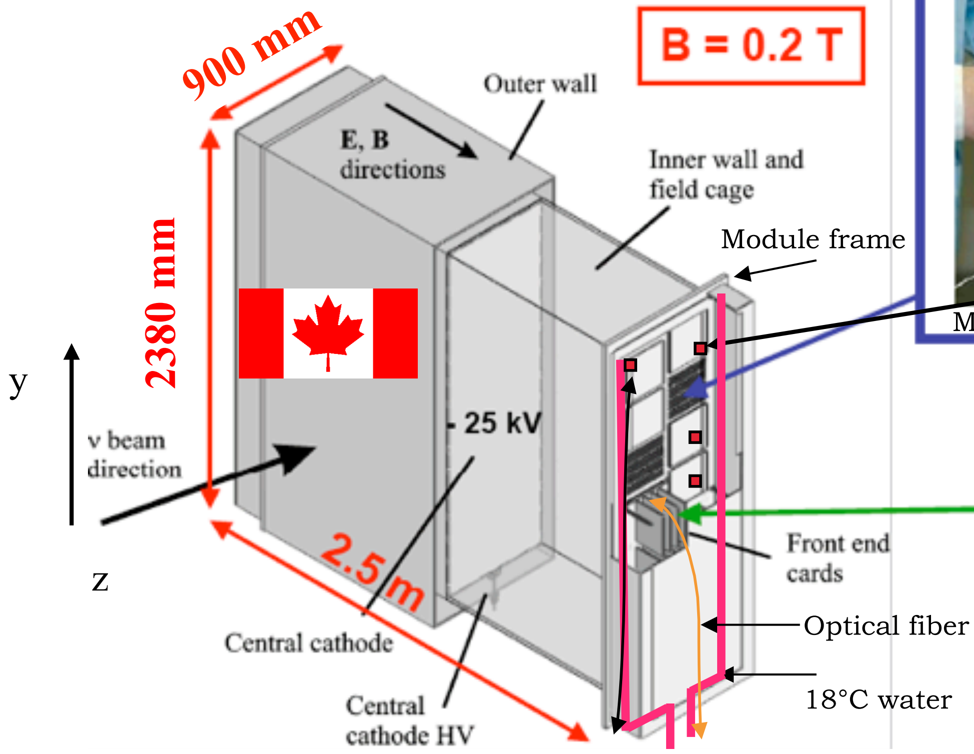
IRFU MPGDS ROADMAP

THE T2K/TPC : THE BULK-MICROMEGAS + AFTER FRONT-END ELECTRONICS READOUT

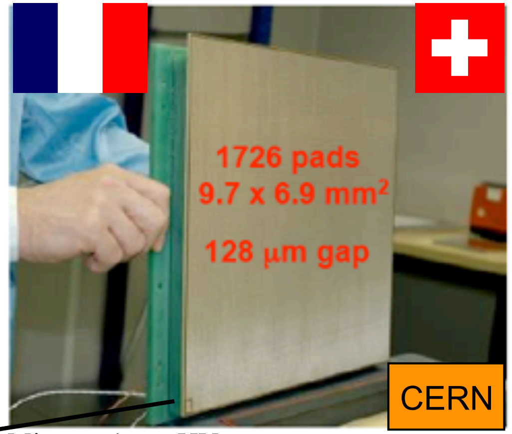
Specifications / performances

- ✓ MIP identification and momentum measurement
- ✓ Spatial resolution of 600 µm @ z=1m (Δp/p<10%)

B = 0.2 T

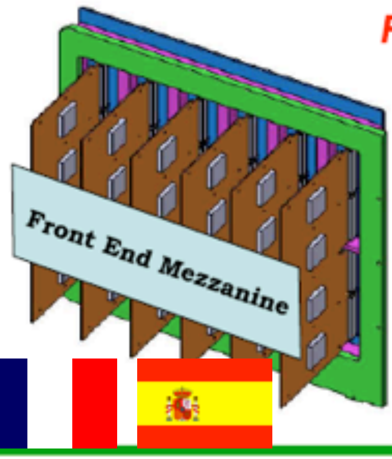


36 x 34 cm² « Bulk » MicroMegas



12 modules per Readout plane

Total of 72 modules



FEE based on the ASIC AFTER

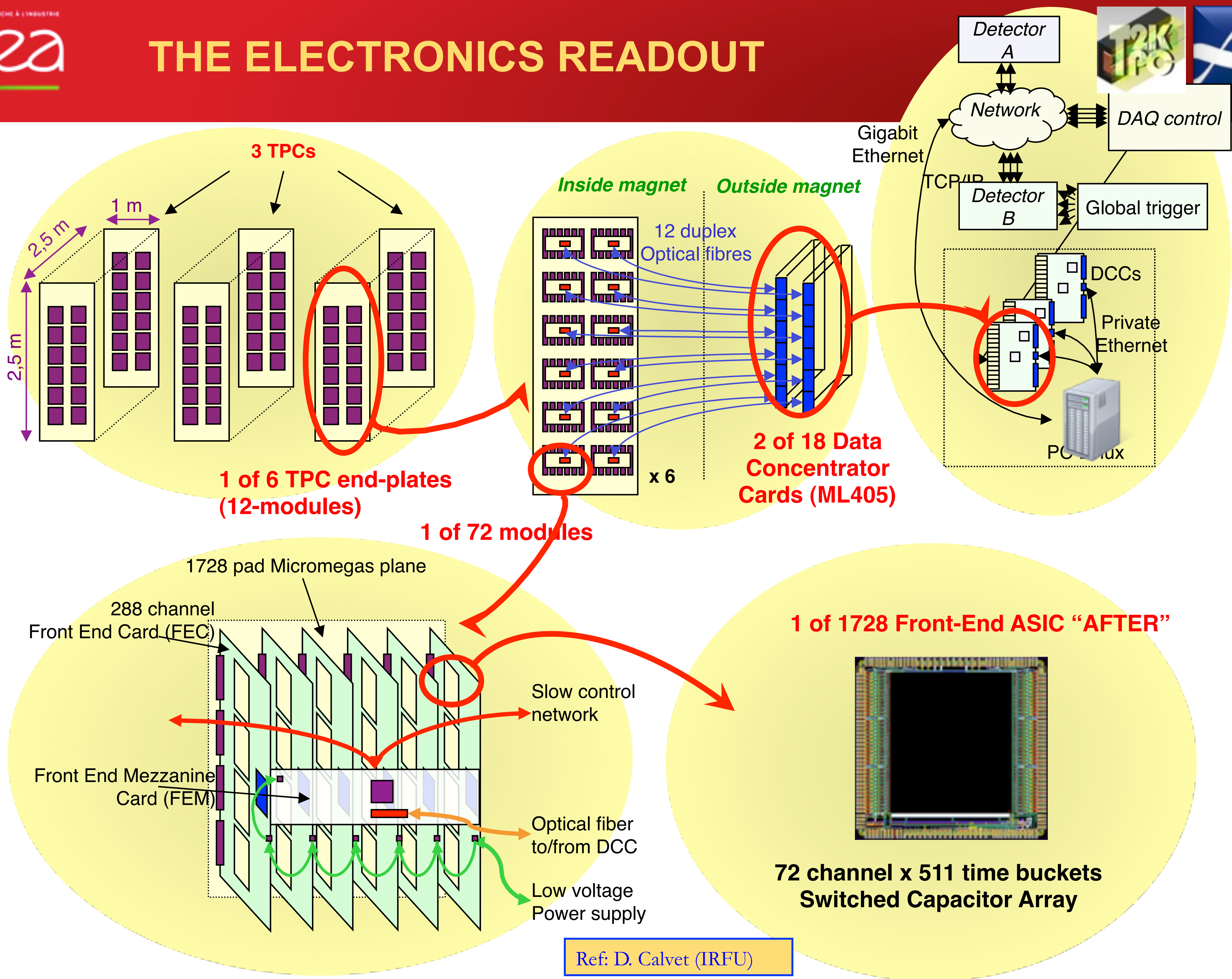
6 FECs + 1 FEM per module

Total of
1728 ASICs
432 FECs
72 FEMs

With On-detector FEE cooling mechanicals

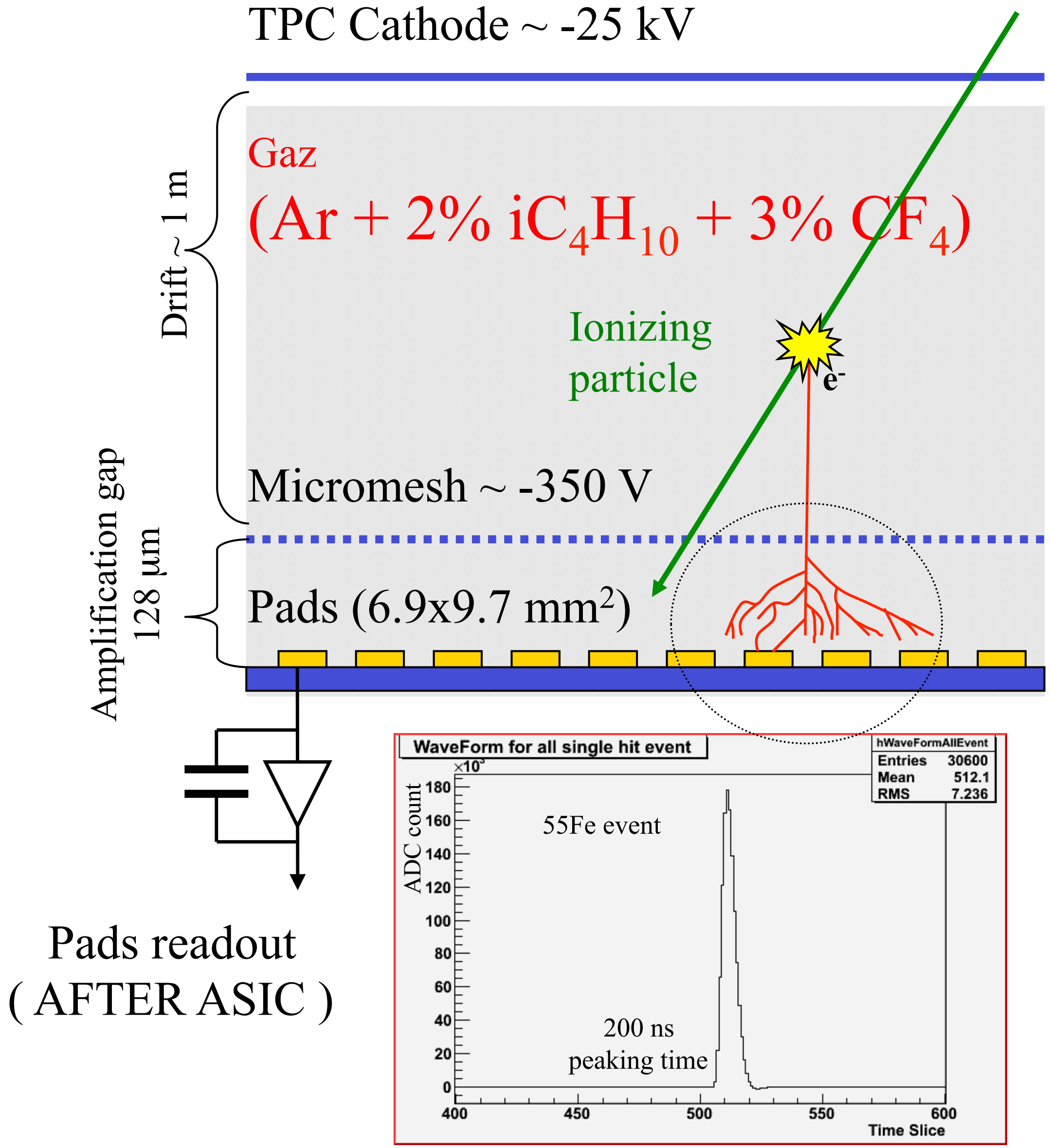
72 modules for ~9 m² active area
~120k electronic channels

THE ELECTRONICS READOUT



Ref: D. Calvet (IRFU)

THE CHOICE OF BULK-MICROMEGAS FOR T2K TPCS



1 time bin = 50 ns (20 MHz sampling freq.)

a new gas mixture

- ✓ Non-flammable
- ✓ low tr. Dif. for small B (250 µm/cm$^{1/2}$)
- ✓ operation close to the maximum drift velocity (7,5 cm/µs @ 200 V/cm)
- ✓ minimization of the effect of impurities (mainly O$_2$) : > 30m att. Length

Drawbacks of micromegas technologies with seperate mesh & anode PCB :

- "large" dead zones around active area + delicate assembly due to the mesh frame
- gain non-uniformities in corners

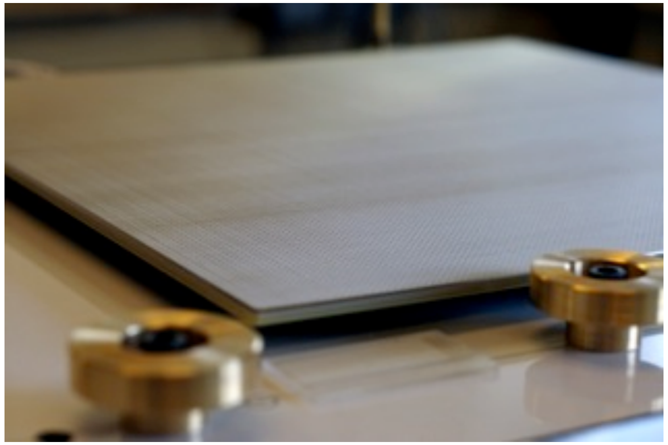
Use of bulk-micromegas technology

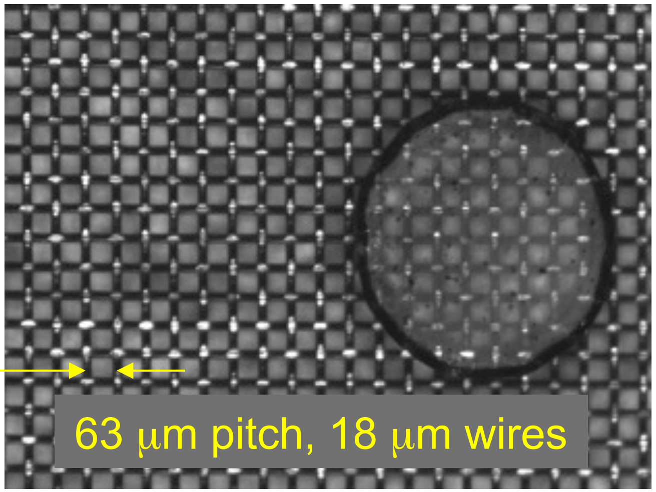
- ✓ all-in-one detector : minimized blind areas, including edges and corners
- ✓ simple design, cheap & robust
- ✓ good uniformity of performances
- ✓ Production by CERN/TS-DEM-PMT

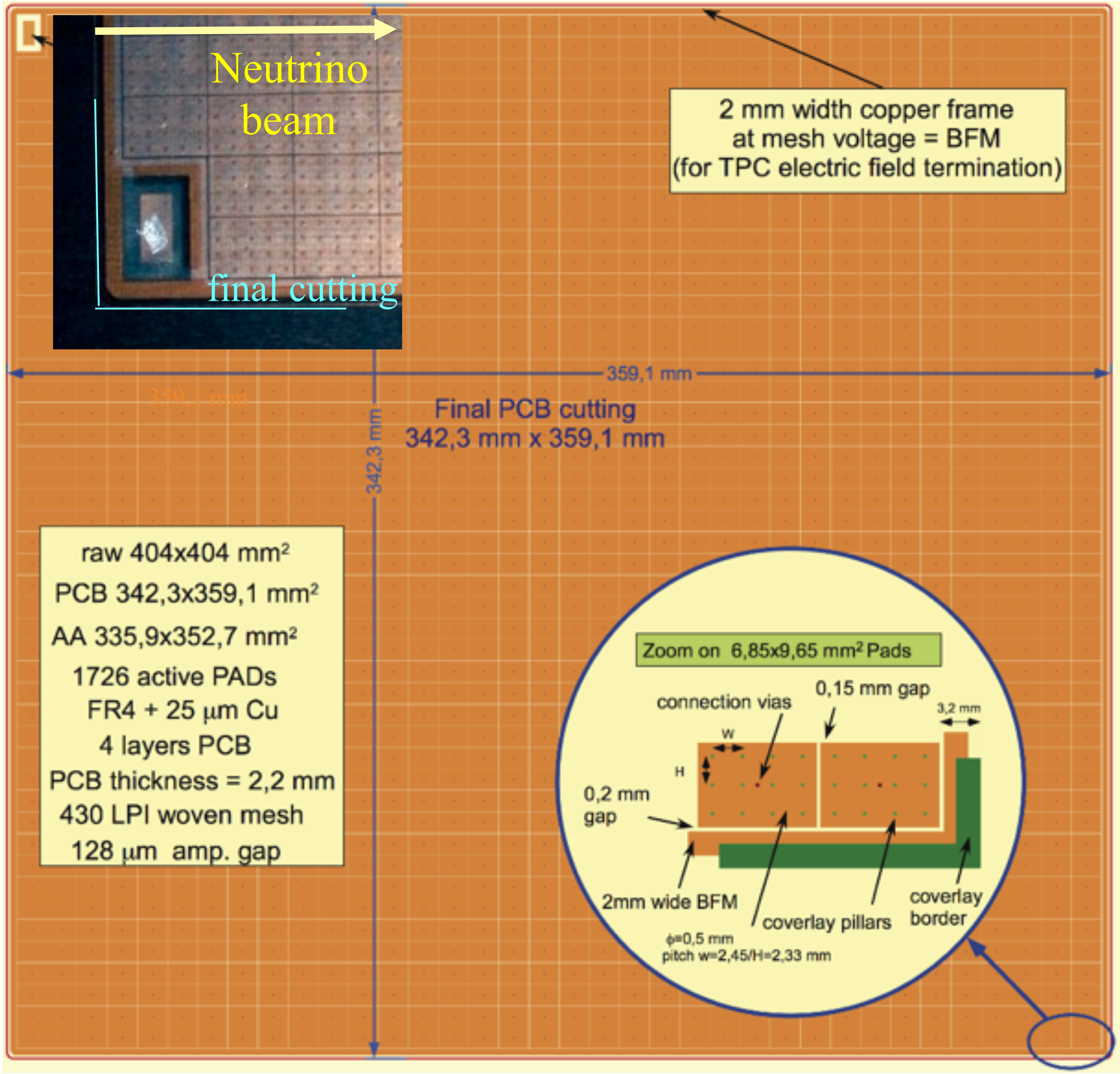
2005 HARP tests : NIM A574 (2007) 425-432

2011 T2K TPCs : NIM A637 (2011) 26-47

THE BULK-MICROMEGAS PCB



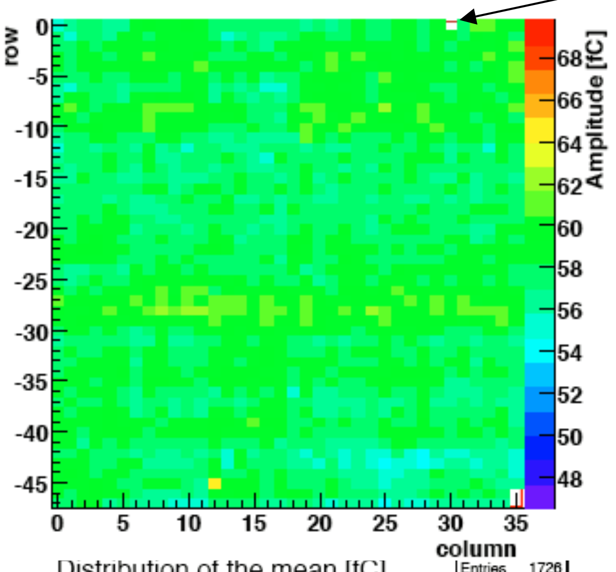


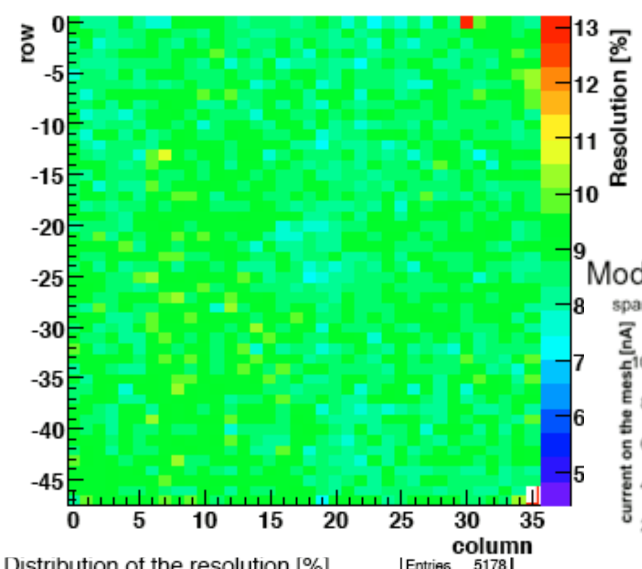


BULK-MICROMEGAS MODULE PERFORMANCES

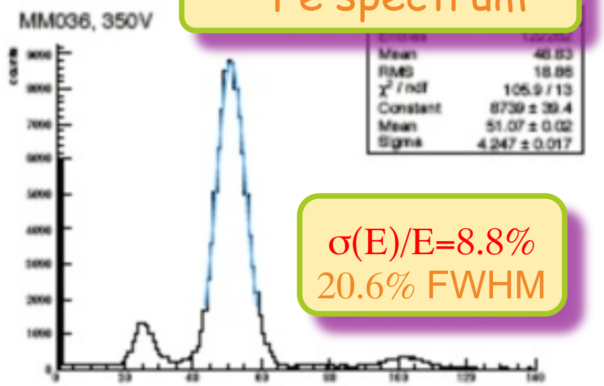
1726 pads scan @ -350 V

1 FEC dead ch.

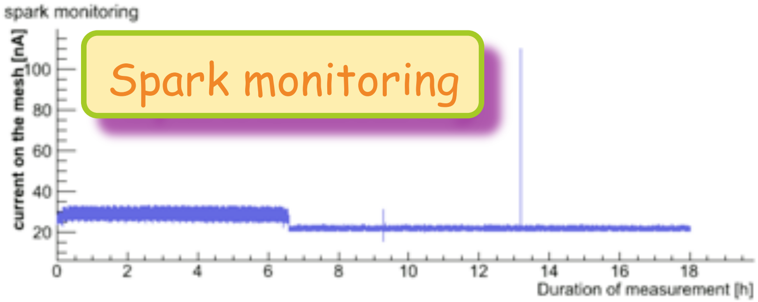




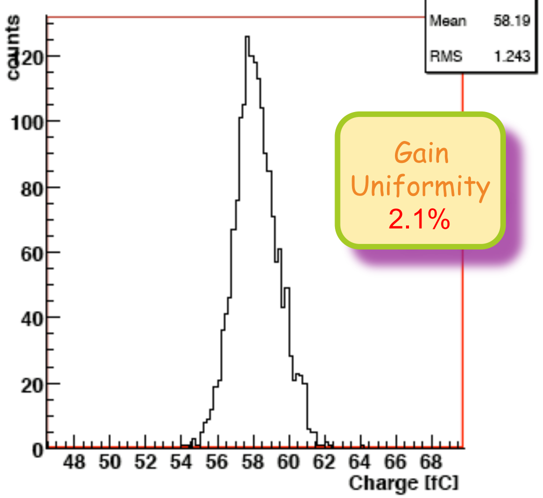
^{55}Fe spectrum



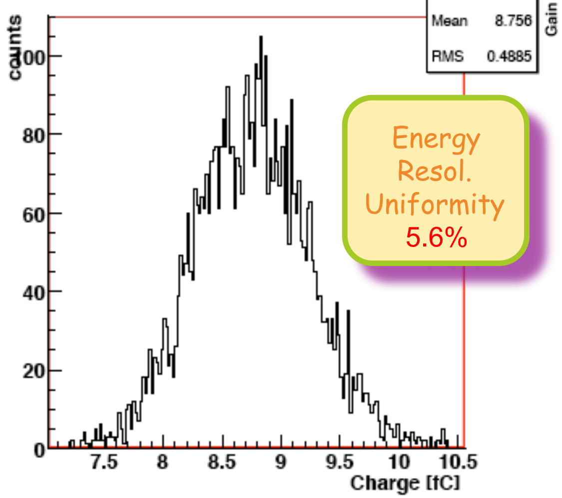
σ(E)/E=8.8%
20.6% FWHM



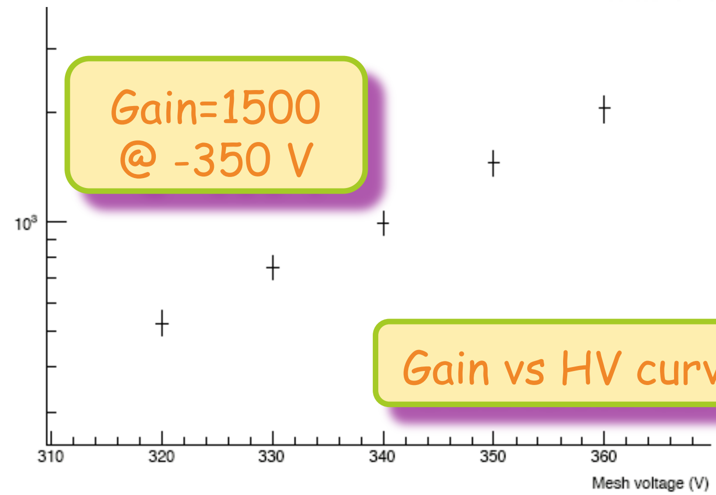
Spark monitoring



Gain Uniformity 2.1%



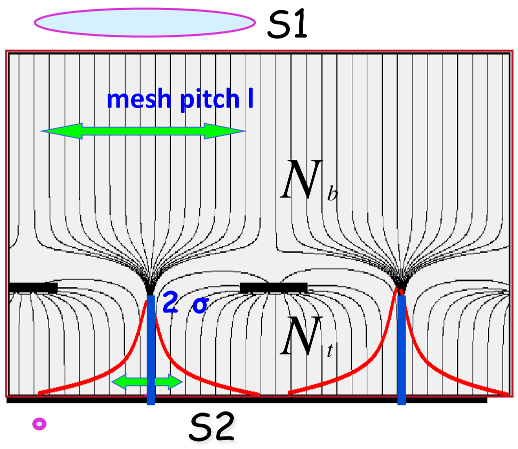
Energy Resol. Uniformity 5.6%

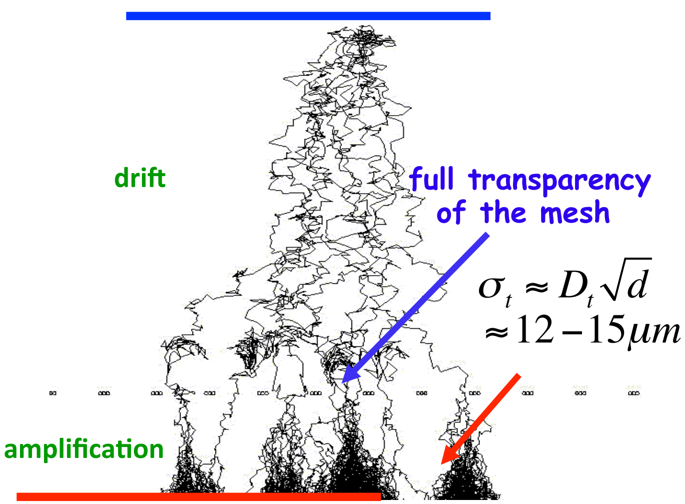


Gain=1500 @ -350 V

Gain vs HV curve

ION BACKFLOW (IBF) MINIMIZATION WITH MICROMEGAS





$\sigma_t \approx D_t\sqrt{d} \approx 12-15\mu m$

$$IBF = \frac{N_b}{N_t} \propto \left(\frac{1}{FR}\right)\left(\frac{l}{\sigma_t}\right)^2$$

$$IBF \propto \left(\frac{1}{FR}\right) \quad for \frac{\sigma_t}{l} \geq 0.5$$

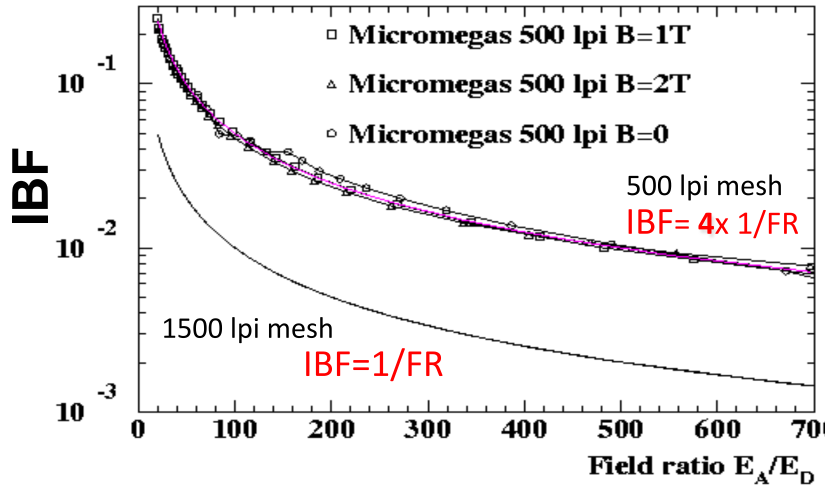
$FR = \frac{E_a}{E_d}$

$l = mesh\ pitch$

$\sigma_t \approx D_t\sqrt{d}$

D_t : e⁻ diffusion coef.

100 μm gap, 500 LPI micromegas, Ar+10%iso

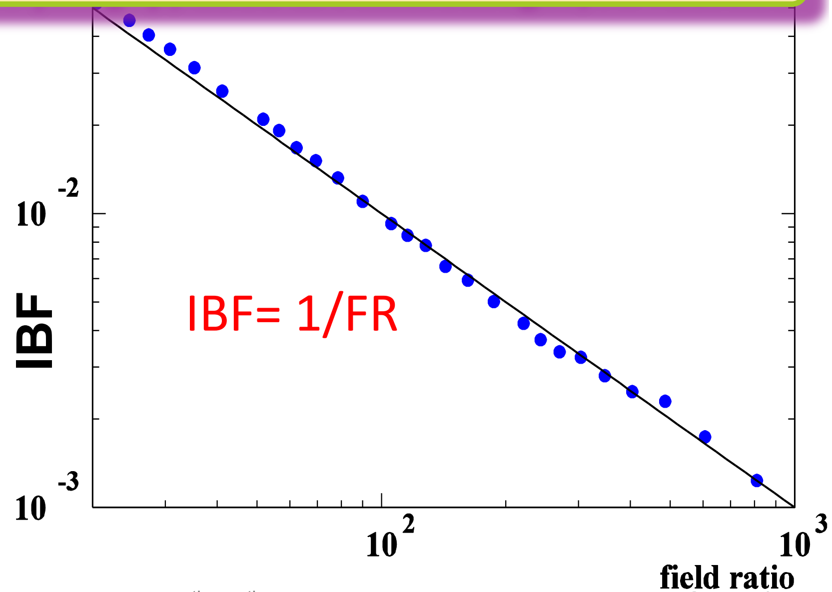


$\frac{\sigma_t}{l} \geq 0.5$

for 1000 LPI
100 μm gap

for 1500 LPI
50 μm gap

100 μm gap, 1500 LPI micromegas, Ar+10%iso

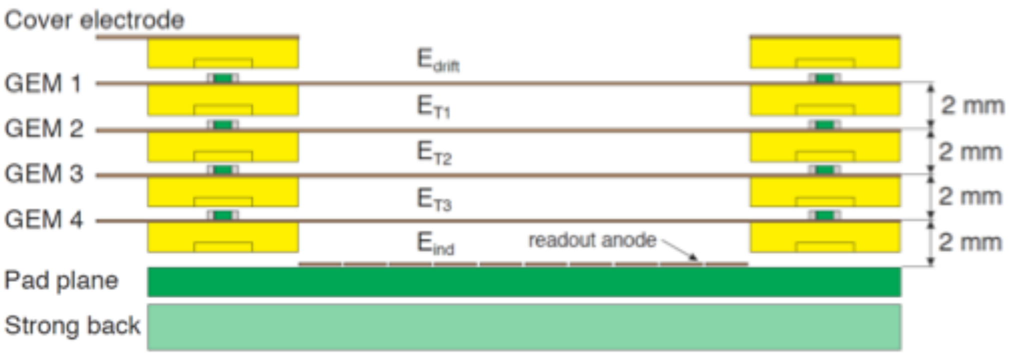


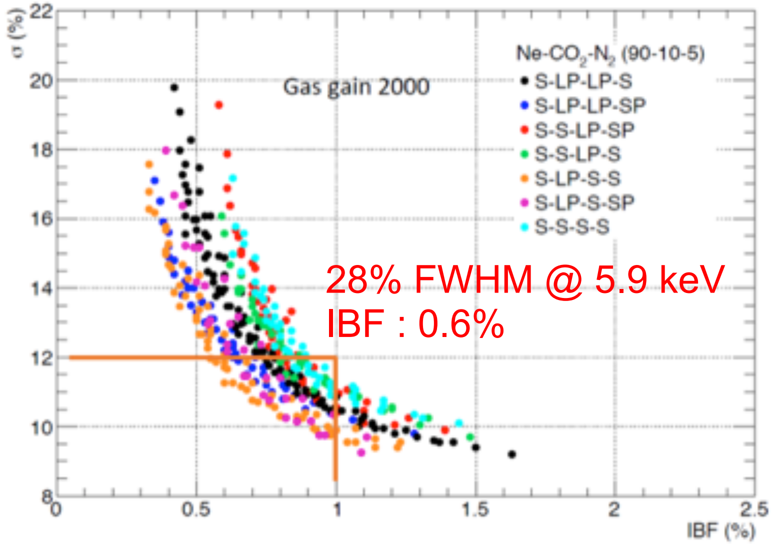
Ref: P. Colas et al., NIM A535, (2004), 226-230

ION BACKFLOW (IBF) MINIMIZATION
ALICE TPC UPGRADE : 4 GEM STACK

Difficulties

- charging-up + sagging of large GEM foils
- distorsion corrections with space charge distorsion map & track interpolation from ITS-TRS-TOF



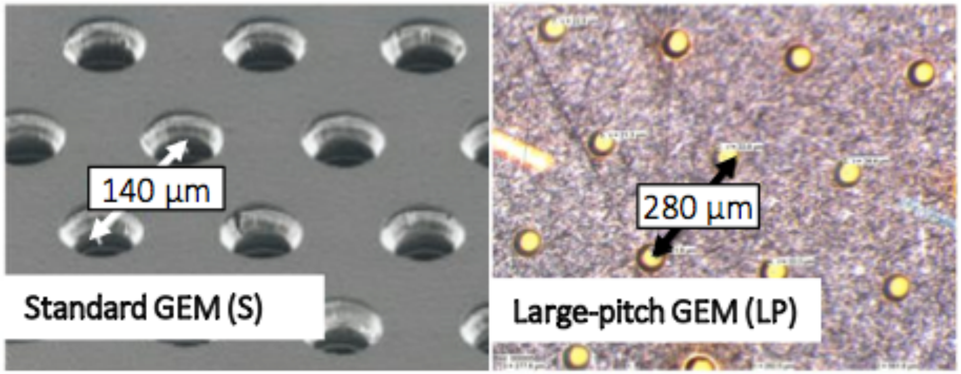


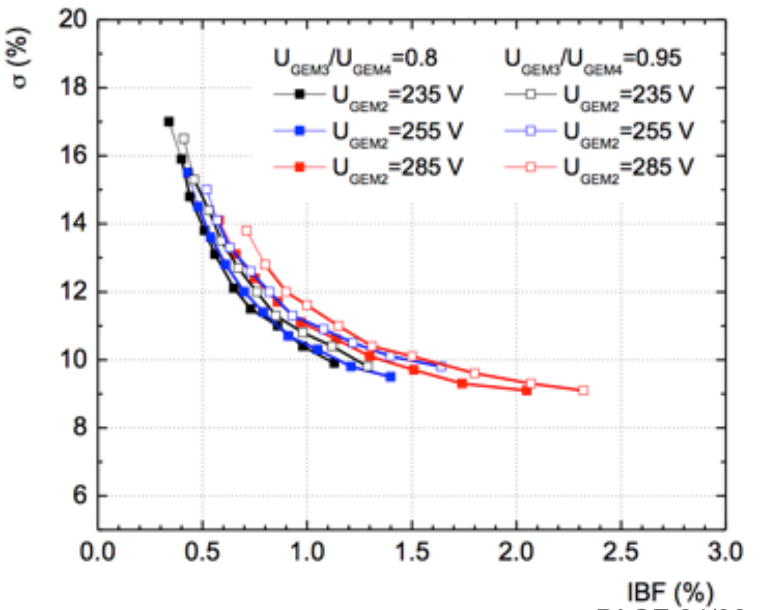
Selected S-LP-LP-S GEM stack

Some figures

8000 events pile-up at 50 kHz Pb-Pb (160 ms ion drift)

→ radial distorsions up to dr=20 cm (small r and long z)

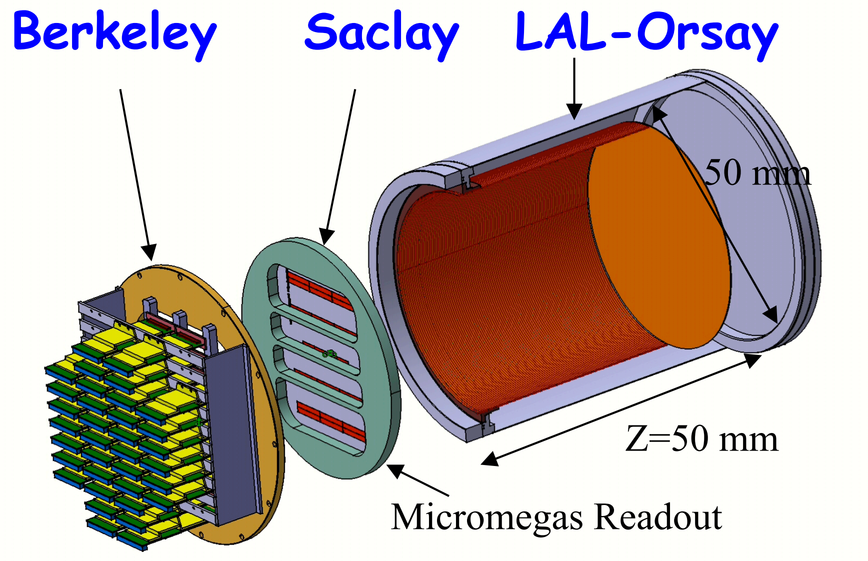




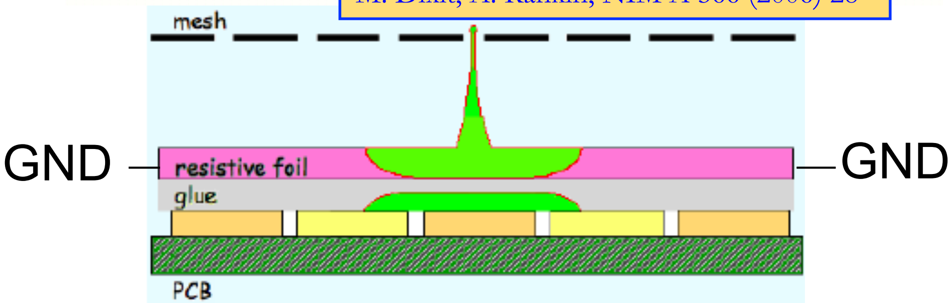
CHARGE SPREADING OVER ANODE PADS WITH A RESISTIVE FOIL (ILC/TPC R&D)

P. Colas[5], I. Giomataris[5], V. Lepeltier[4], M. Ronan[1], K. Sachs[2], T. Zerguerras[3]
1) LBNL Berkeley, 2) Carleton Univ., 3) IPN Orsay, 4) LAL Orsay, 5) DAPNIA Saclay

A prototype tested in a 2T magnet at Saclay



M. Dixit, A. Rankin, NIM A 566 (2006) 28



Various resistive coatings have been tried
Carbon-loaded Kapton (CLK) with 1 - 5 MΩ/square, resistive paste, with 10-20 MΩ/square

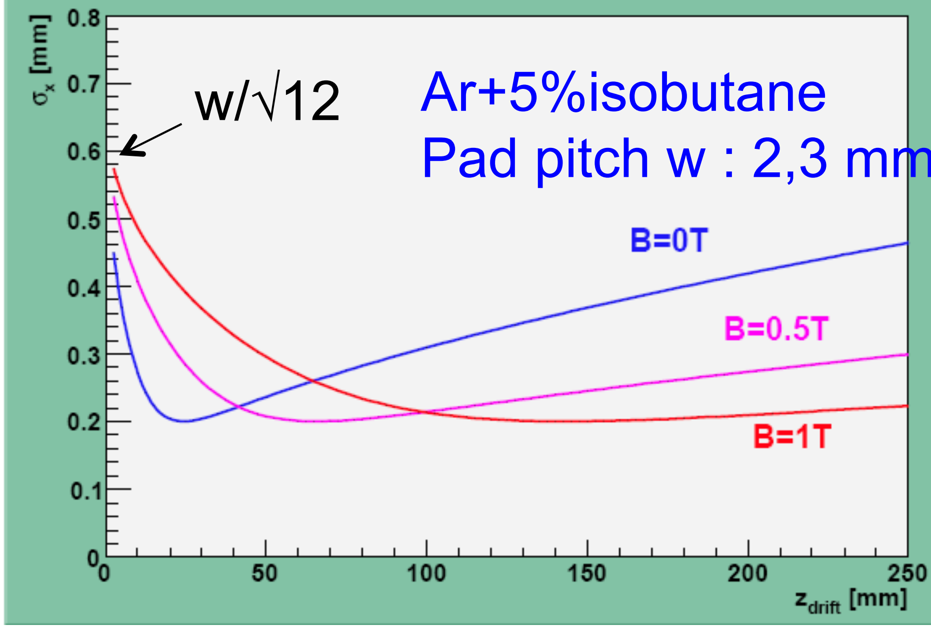
specifications

- ✓ MIP momentum resolution = 10xLEP
- ✓ High flux : space charge effect (ions feedback minimization)
- ✓ high level of 2 tracks seperation
- ✓ High magnetic field (4 Tesla)

R&D

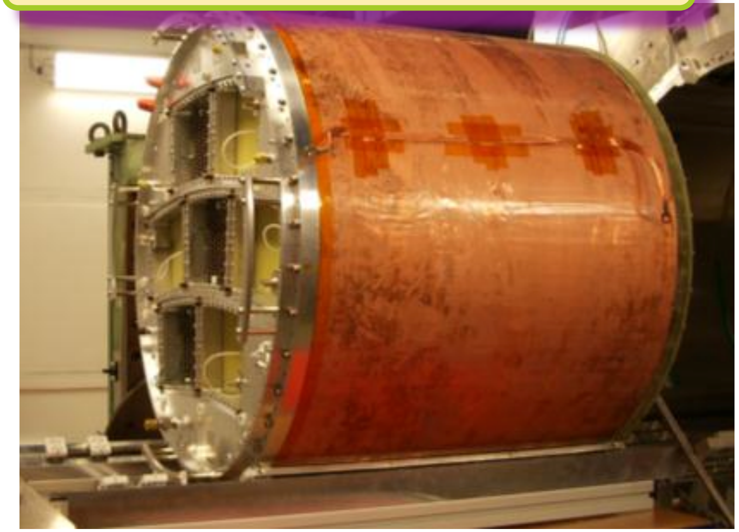
- ✓ Resistive foil to lower the space point resolution < 100 μm close to readout plane

Resolution simulations

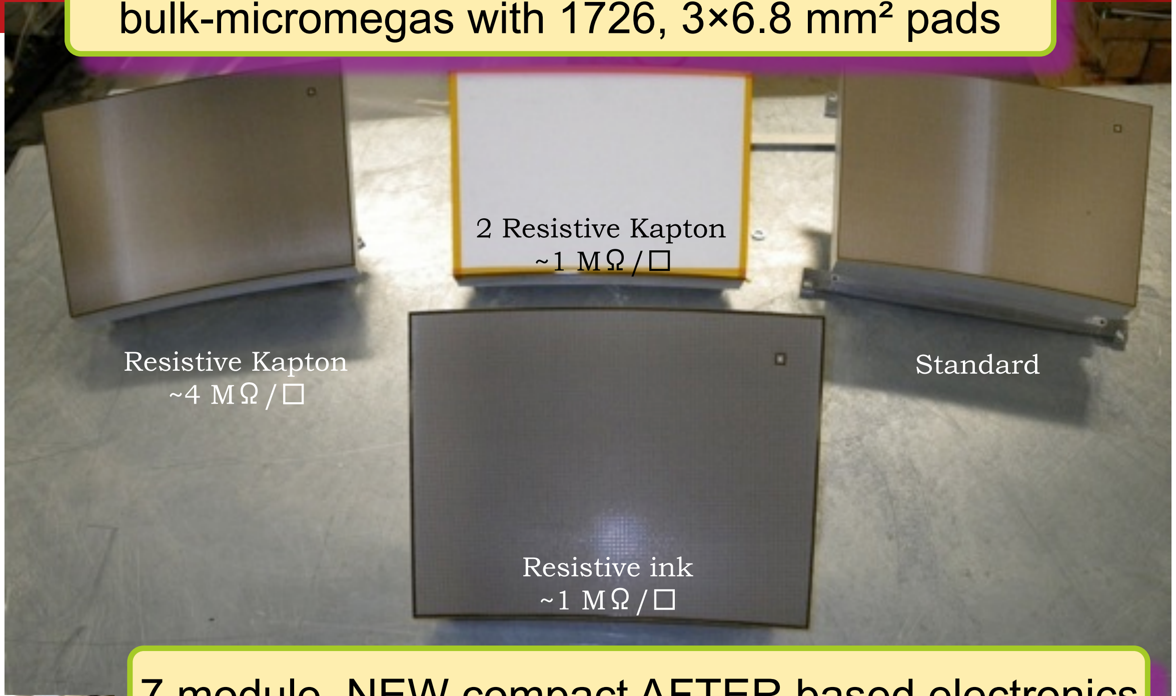


ILC/TPC : 7 MODULES SETUP IN LIC TPC PROTOTYPE

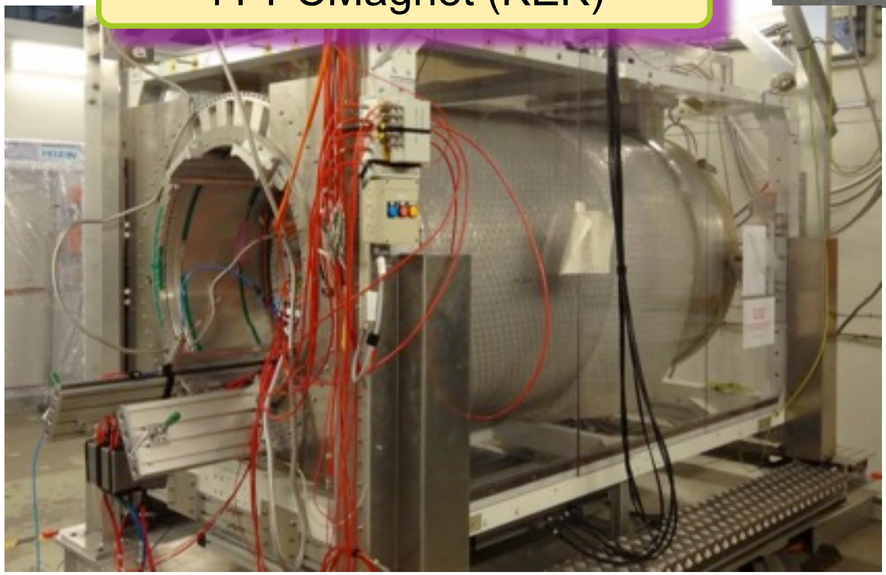
Large prototype ILC TPC (DESY)



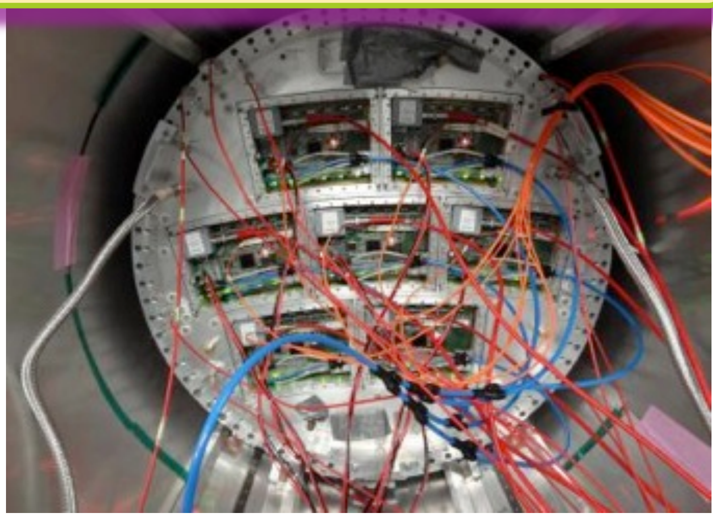
bulk-micromegas with 1726, 3×6.8 mm² pads



1T PCMagnet (KEK)



7 module, NEW compact AFTER based electronics



ILC/TPC CARBON-LOADED KAPTON RESISTIVE FOIL

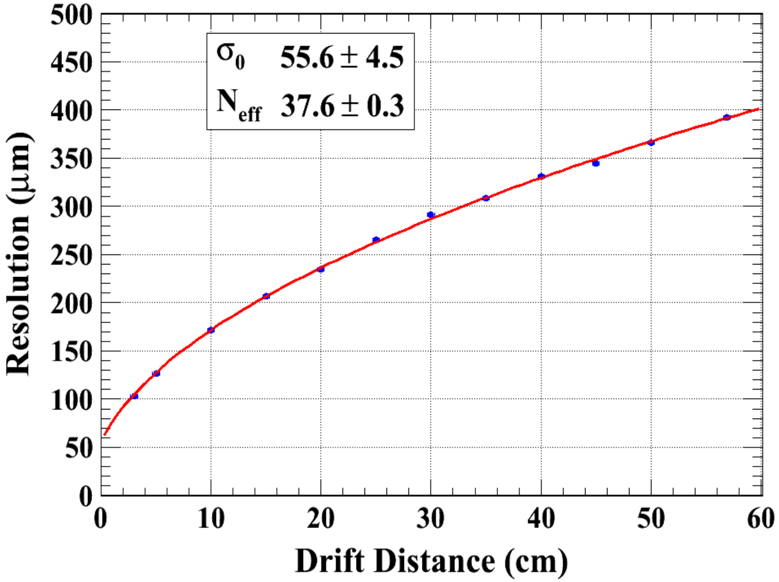
A resistive coating is glued on top of the anode plane to spread the charge over several pads thanks to a continuous RC network to improve resolution for short drift distance
Bonus : observed reduction in spark energy and sparking rate

T2K Gas: 95% Ar + 3% CF_4 + 2% Iso

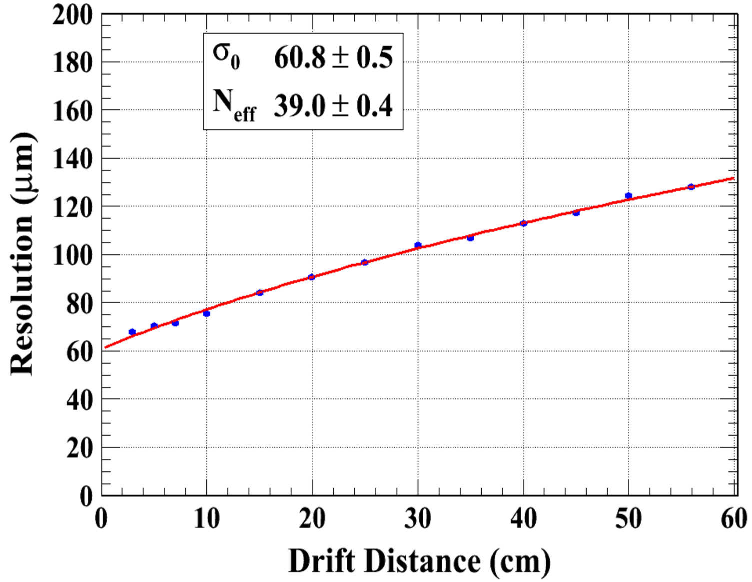
$$\sigma = \sqrt{\sigma_0^{\ 2} + \frac{C_d^2 \cdot z}{N_{eff}}}$$

σ_0 : the resolution at Z=0
N_{eff} : the effective number of electrons
C_d : diffusion constant

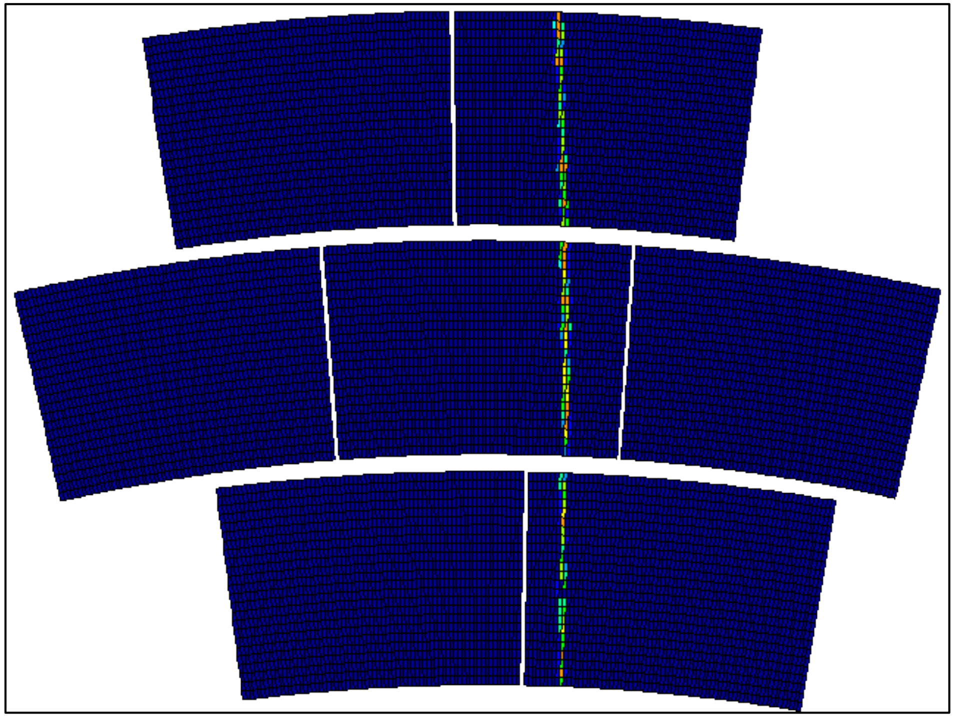
B=0 T C_d = 315.1 μm/√cm (Magboltz)



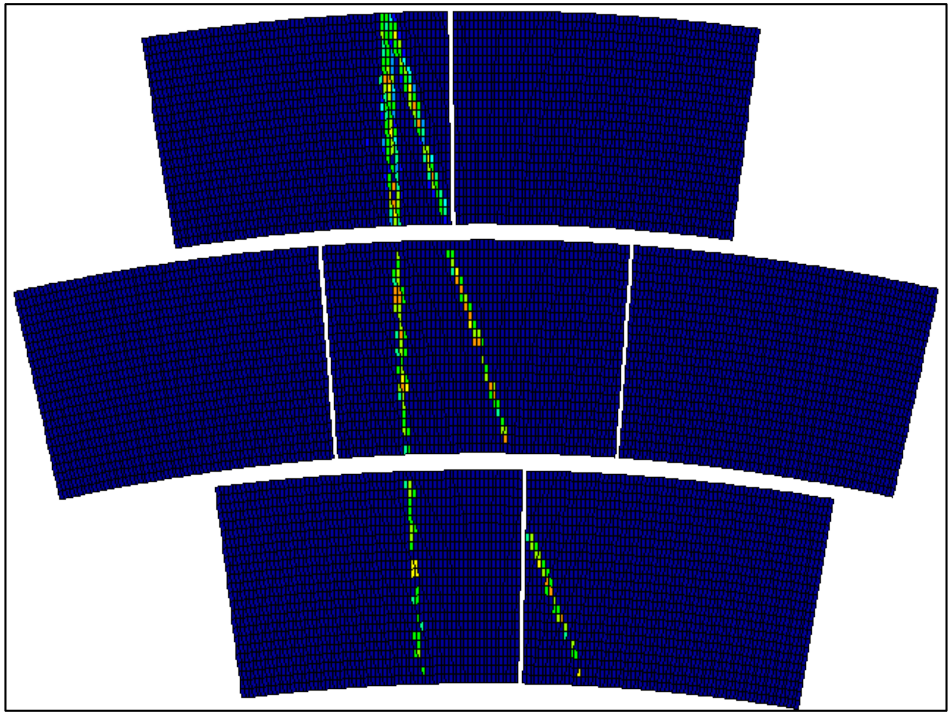
B=1 T C_d = 94.2 μm/√cm (Magboltz)



ILC/TPC : 2013 BEAM TESTS @ DESY

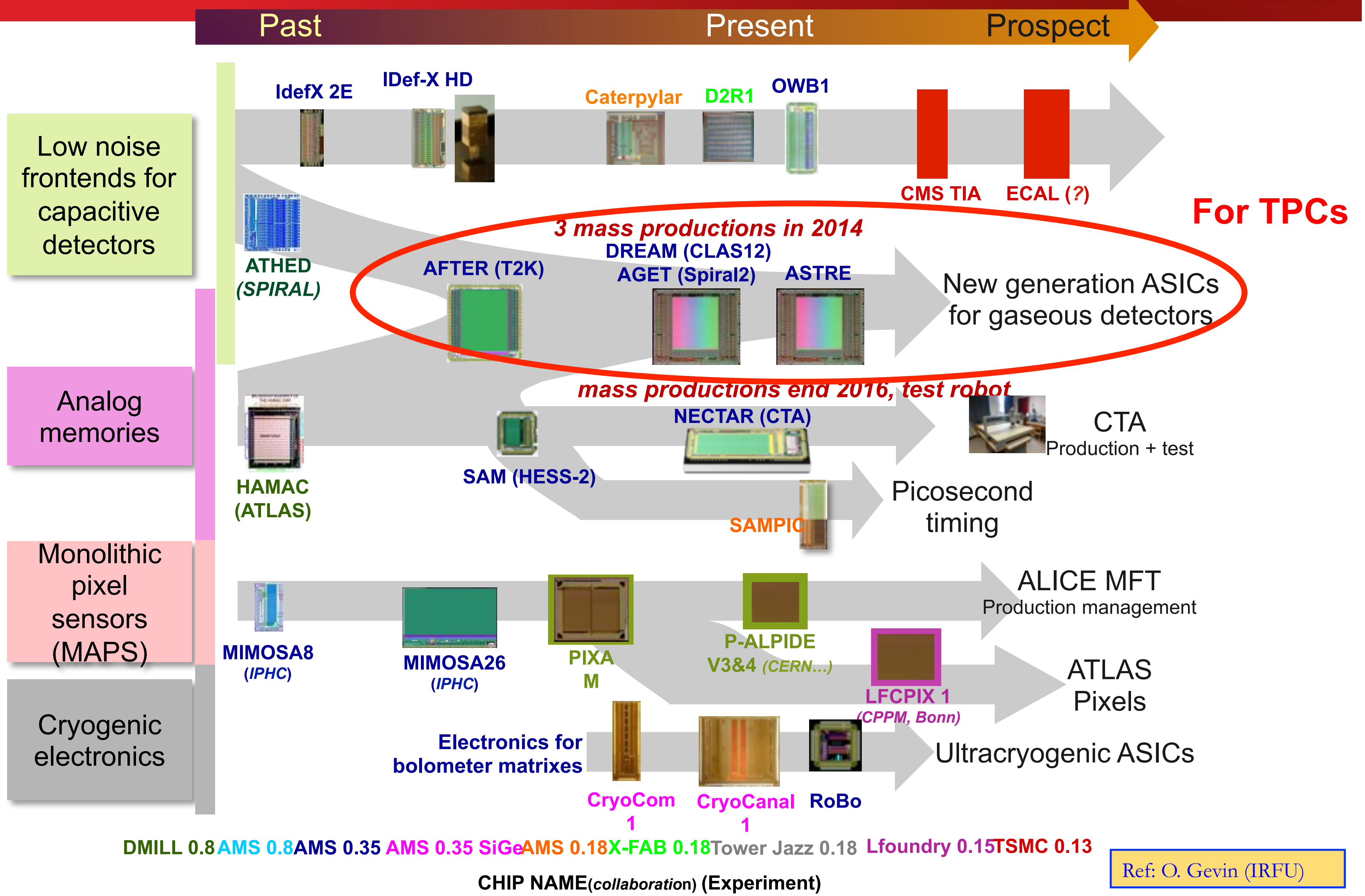


4 GeV e^- Beam

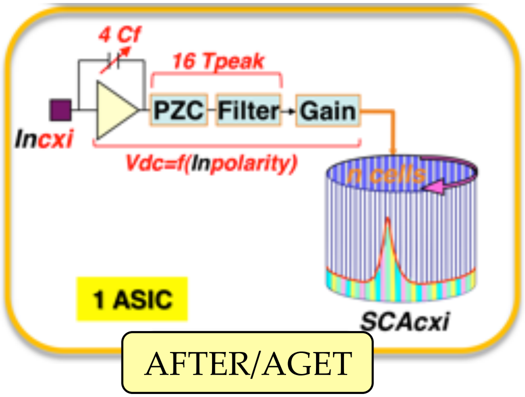


Cosmics

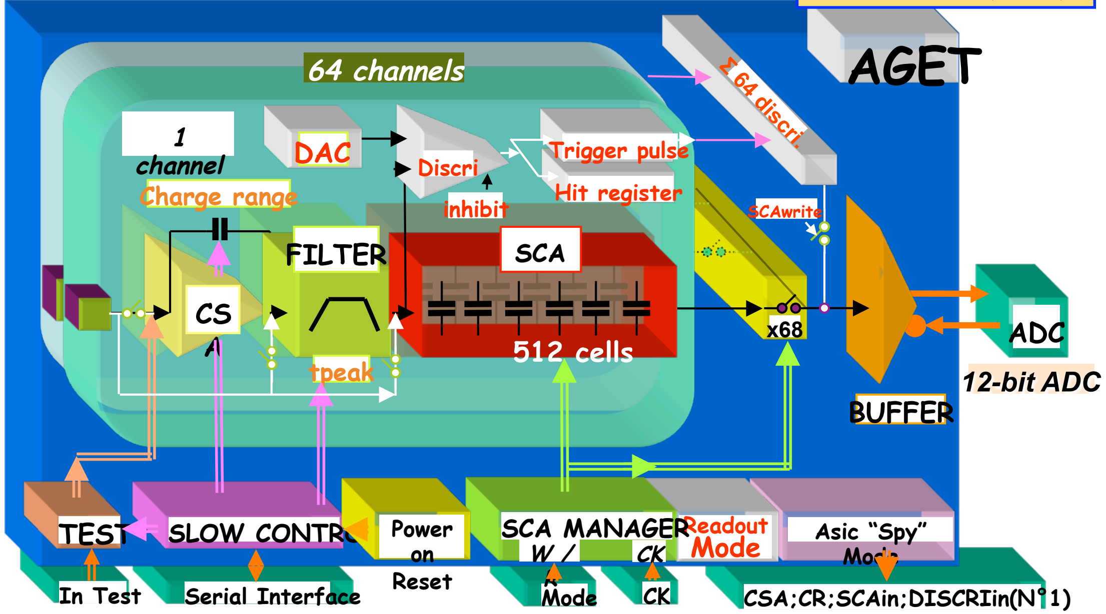
IRFU MICROELECTRONICS ROADMAP



THE AGET CHIP



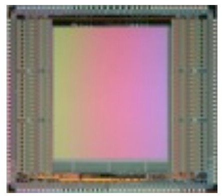
Ref: D. Calvet (IRFU)



The SCA is 512 –time bin circular buffer in which the pad signal is continuously sampled and stored at a 1-100 MHz sampling write frequency and read at 25 MHz when triggered

Sampling write frequency is chosen to adjust the captured window to the max drift time

AMS CMOS 0,35 µm
Surface: 8,5 x 7,6 mm^2



- **64 analog channels :** *CSA, Filter, SCA (512 cells), Discriminator*
- **Auto triggering :** per channel discriminator + threshold (DAC)
- **Multiplicity signal :** *analog **OR** of 64 discriminators*
- **Hit Channel register. Accessible in R/W**
- **SCA readout mode:** *all, hit or specific channels (gives lower dead-time)*
- **4 charge ranges/channel:** *120 fC; 240 fC; 1 pC;10 pC (e.g. for Silicon detectors)*
- **Input current polarity** *positive or negative, selectable by software programming*
- **Possibility to bypass the CSA:** *enter directly into the RC2 filter or SCA inputs*

THE TPC READOUT ASIC FAMILY

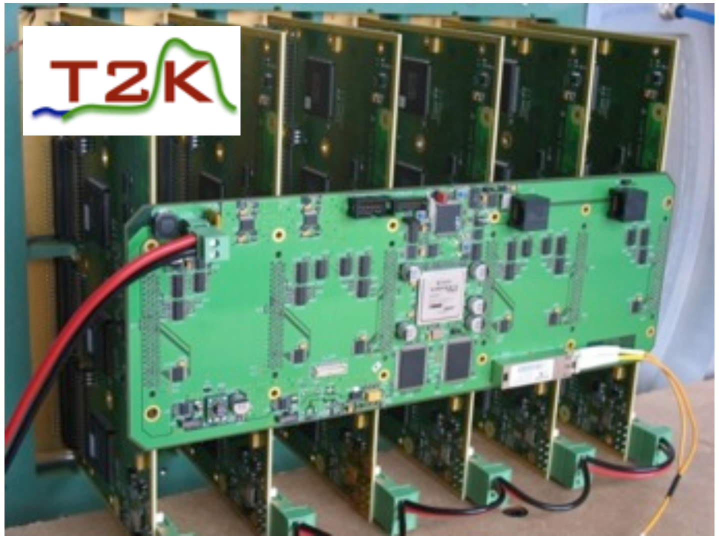
ASIC generation

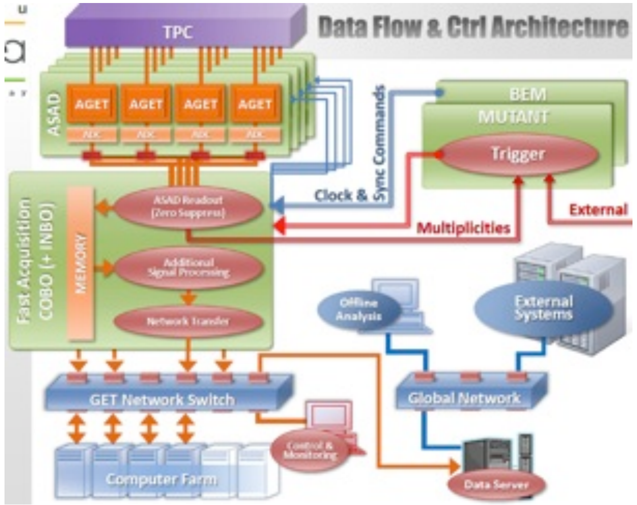
AFTER
Asic For Tpc Electronic Readout

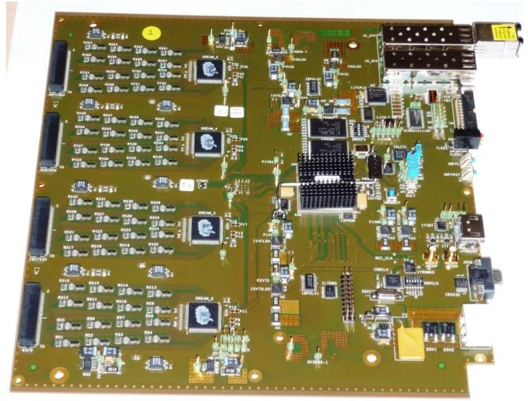
AGET
Asic for General Electronics for Tpc

DREAM
Dead timeless REadout Asic for Micromegas

2006 — **2009** — **2012**







CLAS12

- Over 150.000 channels in operation (80% in T2K neutrino experiment)
- 20 applications in physics

- Optimized for active target TPC's
- Over 22 deployments underway

- Optimized for trackers
- Target experiments: Clas12, Asacusa, Gbar, WatTo, etc.

→ Rad-hard version of AGET = ASTRE for HARPO
Asic with SCA & Trigger for detector Readout Electronics
with other improvements including multiplicity signal processing

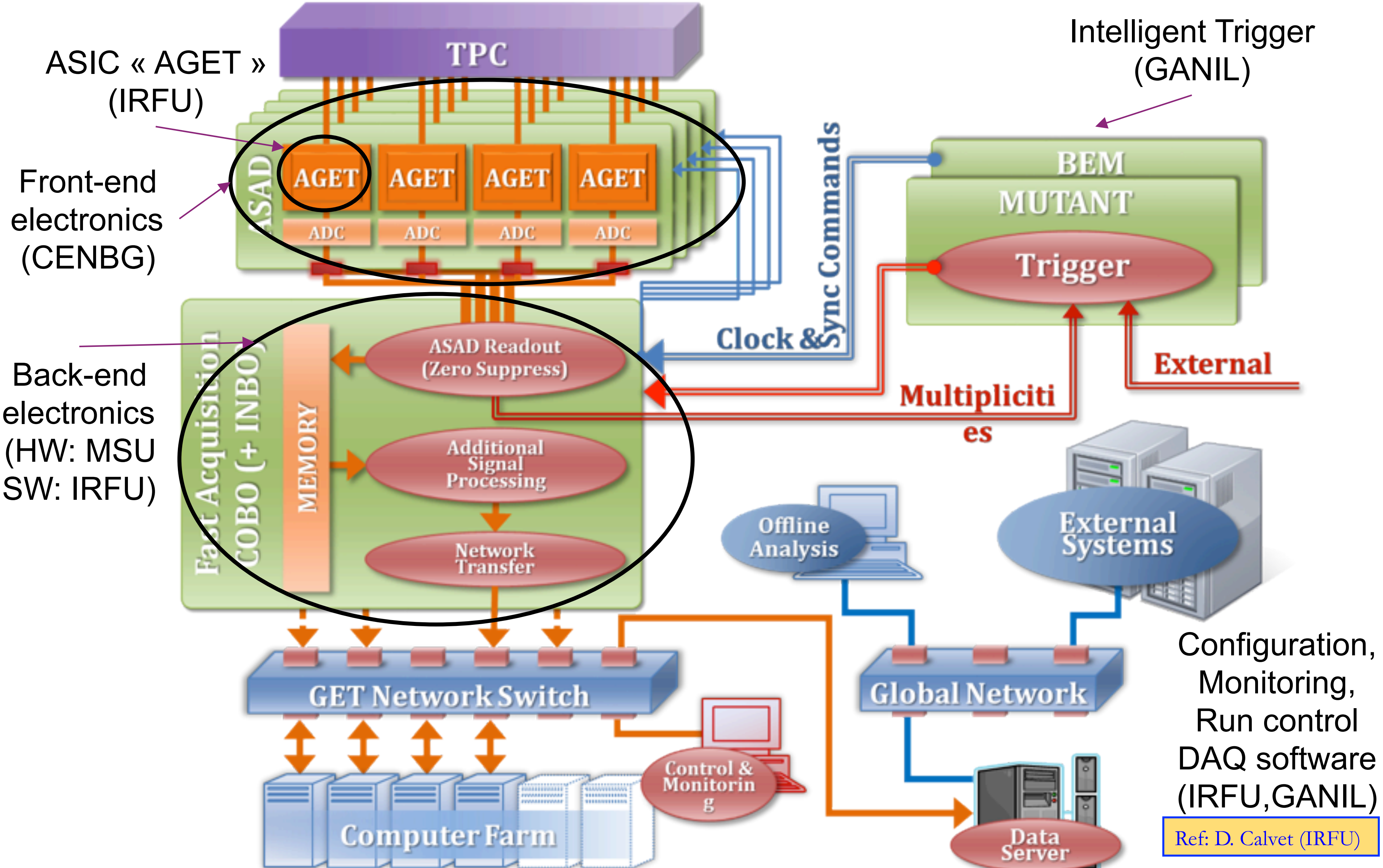
Ref: D. Calvet (IRFU)

THE IRFU TPC READOUT ASIC FAMILY

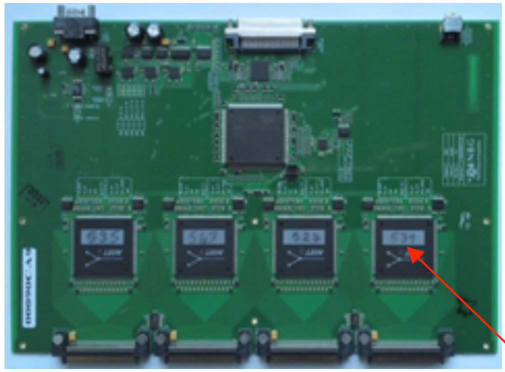
Parameter	AFTER	AGET	DREAM
Polarity of detector signal	Negative or Positive	Negative or Positive	Negative or Positive
Number of channels	72	64	64
External Preamplifier	No	Yes; access to the filter or SCA inputs	Yes; access to the filter or SCA inputs
Charge measurement			
Input dynamic range/gain	120 fC; 240 fC; 360 fC; 600 fC	120 fC; 240 fC; 1 pC; 10 pC /channel	50 fC; 100 fC; 200 fC; 600 fC /channel
Gain v.s Cdet (200pF)			
200 fC; tp = 230 ns	- 13%	- 13%	-0,9%
Sampling			
Peaking time value	100 ns to 2 µs (16 values)	50 ns to 1 µs (16 values)	50 ns to 900 ns (16 values)
Number of SCA Time bins	511	512	512
Sampling Frequency (WCk)	1 MHz to 100 MHz	1 MHz to 100 MHz	1 MHz to 50 MHz
Triggering			
Discriminator solution	No	Leading edge	Leading edge
HIT signal		OR of the 64 discri. outputs in LVDS level	OR of the 64 discri. outputs in LVDS level; 8 multiplicity levels
Threshold Range		5% or 17.5% of the dynamic range	5% or 17.5% of the dynamic range
Threshold value		(3-bit + polarity bit) common DAC + 4-bit DAC / channel	(7-bit + polarity bit) DAC common to all channels
Readout			
Readout frequency	20 MHz	25 MHz	Up to 20 MHz
Channel Readout mode	all channels	All, hit or selected	all channels
SCA cell Readout mode	all	1 to 512	Triggered columns only
Trigger rate			Up to 20kHz (4 samples read/trigger).
Counting rate	< 0.3 Hz / channel	< 1 kHz / channel	< 50 kHz / channel
Power consumption	< 10 mW / channel	< 10 mW / channel	< 10 mW / channel
Status	Production	Production	Production
Noise 120 fC; 200 ns peaking time	370 e- + 14.6 e- / pF (measured)	580 e- + 9 e- / pF (measured)	
Noise 200 fC; 200 ns peaking time	700 e- + 8.5 e- / pF (measured)		610 e- + 9 e- / pF (measured)
Electronics	T2K (AFTER + FEC + FEM) AFTER + FEC + evaluation kit AFTER + FEC + STUC AFTERSED	GET AGET + AsAd + rCoBo FEMINOS	DREAM + FEU + SSP DREAM + FEU + TCM

Ref: P. Baron (IRFU)

THE GET ELECTRONICS SYSTEM ARCHITECTURE

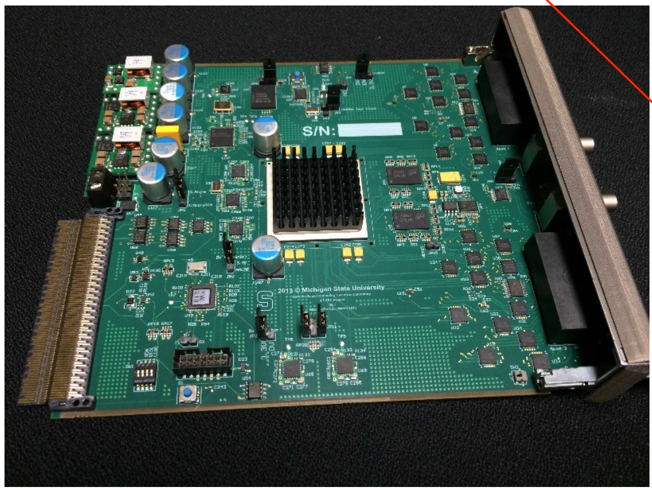


THE AGET READOUT ELECTRONICS COMPONENTS

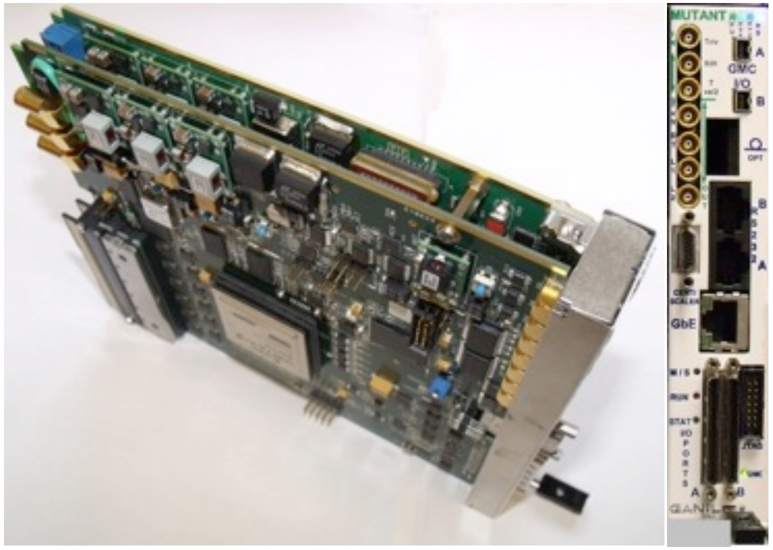


ASAD (CENBG)

- 256 channel front-end boards
- 4 AGET chips
- Optional spark protection board
- Commercially available from FED company (FRANCE)



AGET (IRFU)



Mutant (GANIL)

- Trigger and Multiplicity processing
- Controls up to 10 CoBos in a µTCA shelf (i.e. 10240 channels). Scales up to 3 µTCA shelves (i.e. 30 K channels)
- MicroTCA board
- Commercially available soon

CoBo (MSU)

- Controls 4 ASAD (i.e. 1024 channels)
- MicroTCA board
- Virtex 5 FPGA with PowerPC
- Commercially available from Vadatech company (USA)

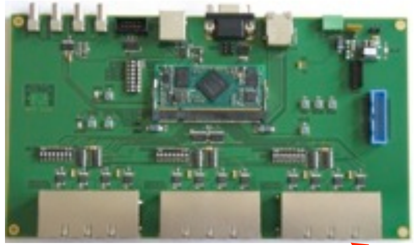
Software (GANIL - IRFU)

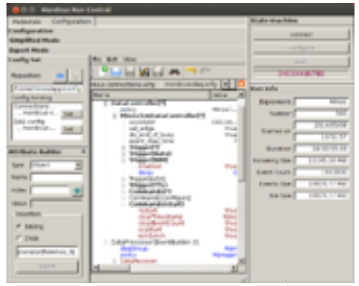
- Configuration / Run Control / Monitoring / DAQ / GUI
- “Narval” framework based option
- “Mordicus” framework based option

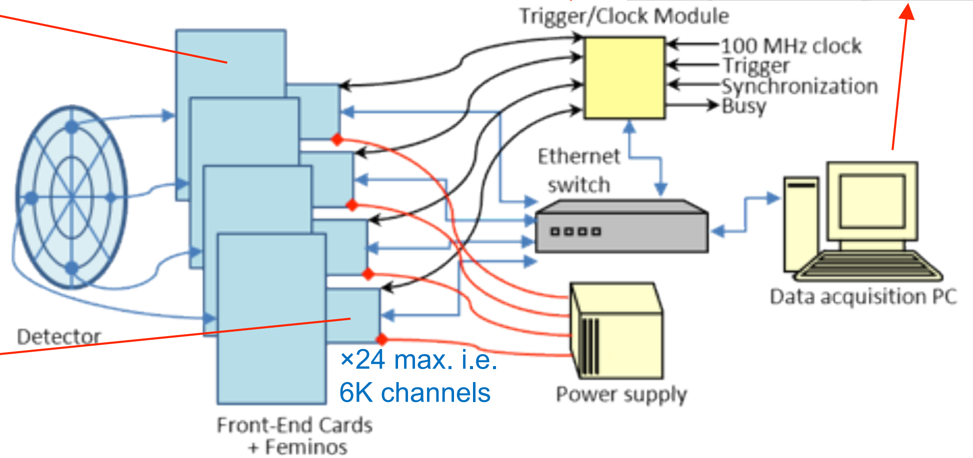
Ref: D. Calvet (IRFU)

THE FEMINOS: AN EVOLUTIVE SYSTEM COMPATIBLE WITH AFTER AND AGET

T2K FEC: 4 AFTER chips

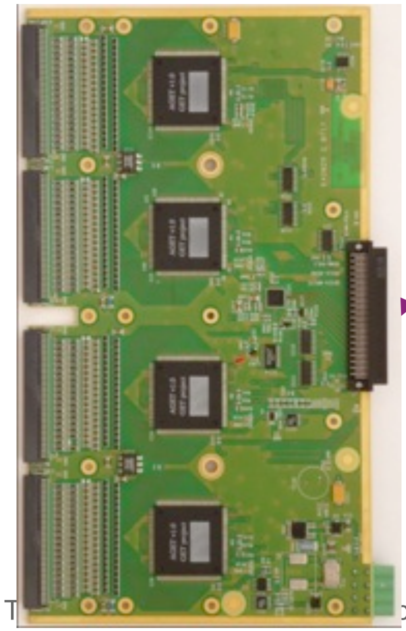






FEMINOS Board

OR



MINOS FEC: 4 AGET chips (pin-compatible with AFTER)

- Main features
  - For small to medium scale systems 6K channels
  - Close to the lowest possible dead-time of AFTER and AGET to reach high event rate
  - External trigger or basic self trigger on multiplicity
  - Low cost system in a light infrastructure

Ref: D. Calvet (IRFU)

- Consider building an improved version (e.g. more scalability) and could become a commercial product

EXAMPLE OF ADVANCED TRIGGER GENERATION USING GET READOUT ELECTRONICS

Basic One Level Self Trigger

- AGET chips send their multiplicity signal to CoBo's
- CoBo's transfer multiplicity data to Mutant
- Mutant processes multiplicity data to build a trigger signal sent to CoBo's and all AGETs
- Data from hit channels are digitized and send to CoBo's for processing and transfer to DAQ

Two Level Self Trigger

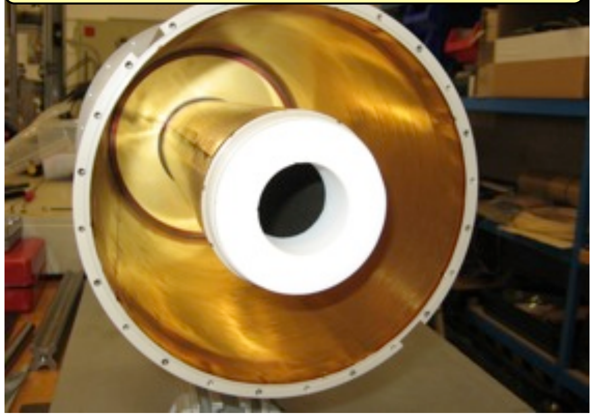
- AGET chips send their multiplicity signal to CoBo's
- CoBo's transfer multiplicity data to Mutant
- Mutant processes multiplicity data to build a L1 trigger signal sent to CoBo's and all AGETs
- The Hit Channel Register of AGET chips is read out and sent to CoBo's then Mutant
- The global channel hit pattern is analyzed by Mutant to elaborate a L2 trigger signal sent back to AGET chips via CoBo's
- Data from hit channels are digitized

→ Large flexibility of schemes and algorithms for trigger generation

→ to be used for an event trigger generation for HARPO ST3G

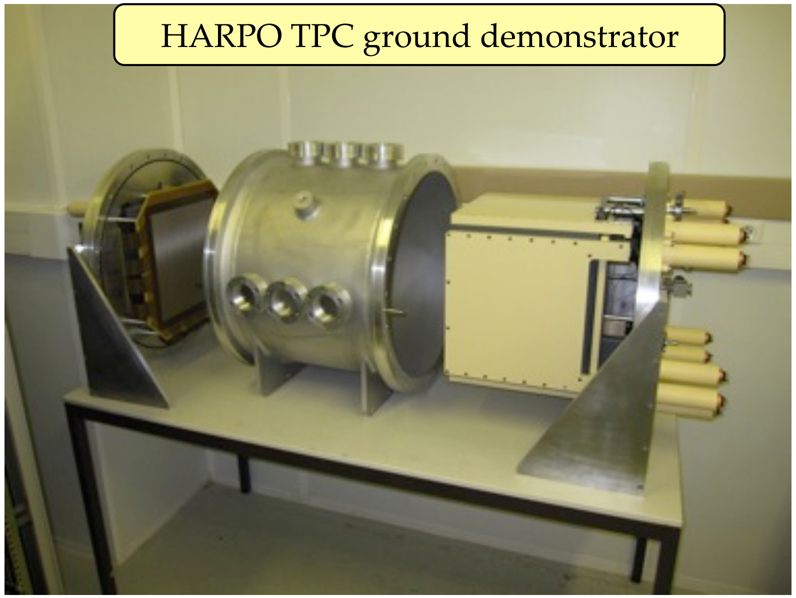
THANK YOU FOR YOUR ATTENTION !

MINOS TPC field cage

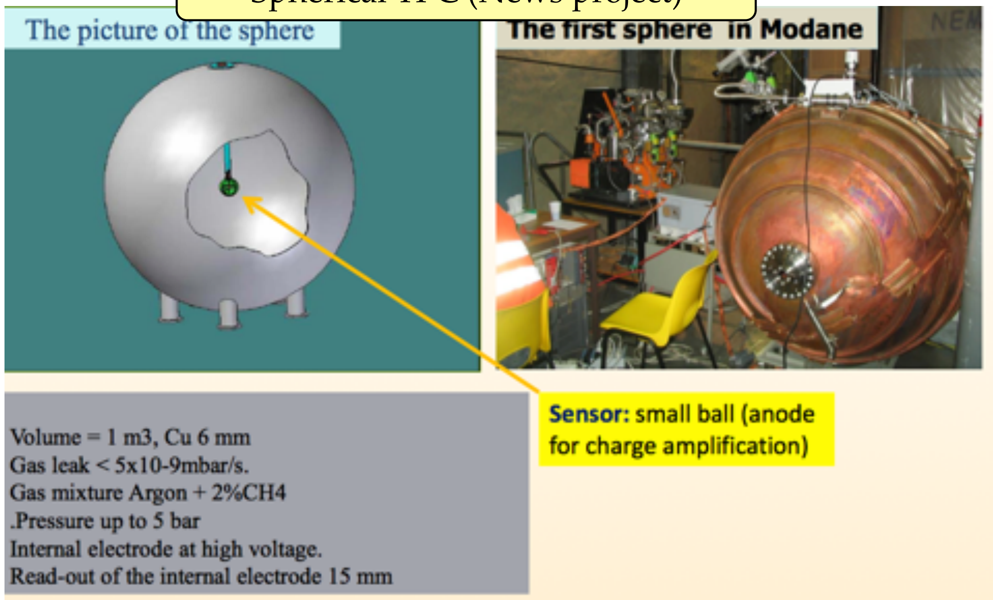


T2K TPC

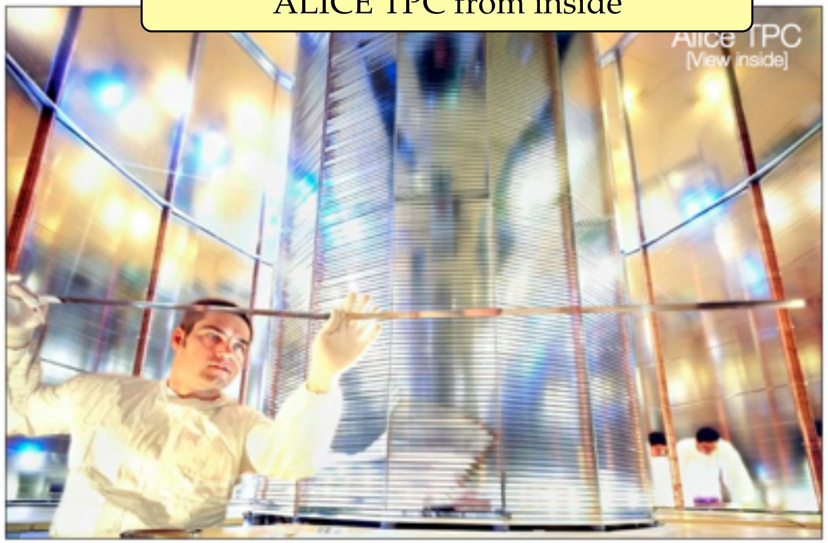
HARPO TPC ground demonstrator



Spherical TPC (News project)



ALICE TPC from inside

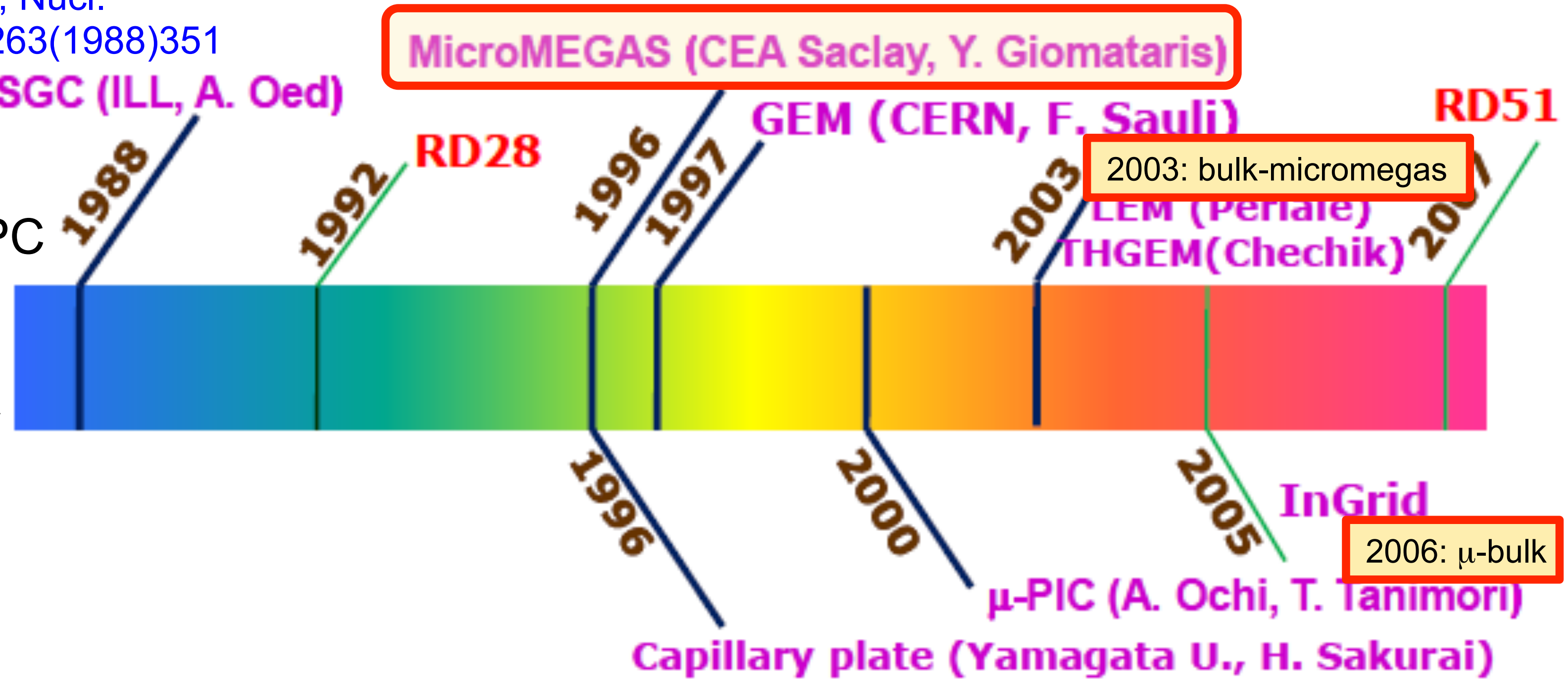


HISTORY OF MICROMEGAS TECHNOLOGIES

A. Oed, Nucl.
Instr. Meth. A263(1988)351

1968 : MWPC
G. Charpak

1978 : TPC
D. Nygren



… and the spark-resistant bulk-MICROMEGAS with resistive anode 2008-2010

From A.Ochi ADA2012@Kolkata (updated)

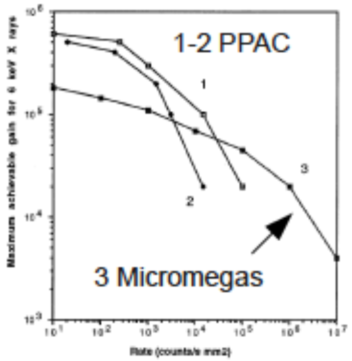
Ref : M. Titov, "Trends and Perspectives in Gaseous Detectors: Linking MPGD Technology for Future Physics Projects", CERN Detector Seminar, April 13, 2012

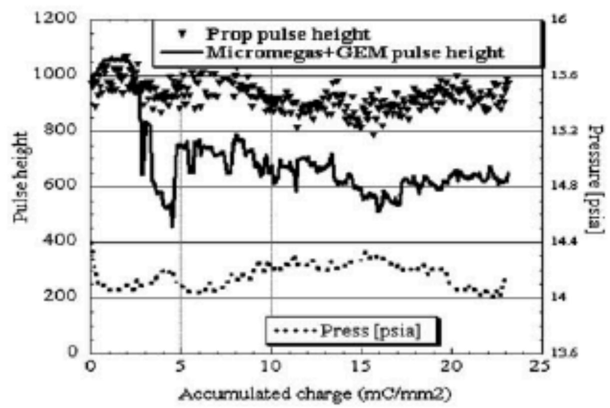
THE RD51 COLLABORATION
DEVELOPMENT OF MPGD TECHNOLOGIES

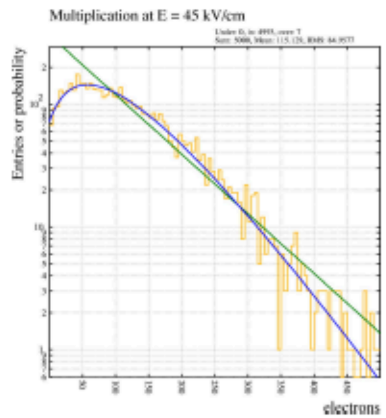
"RD51 aims at facilitating the development of advanced gas-avalanche detector technologies and associated electronic-readout systems, for applications in basic and applied research."

WG2
Characterization studies

Gas discharges	Aging	Charging-up	Gain fluctuations
Micro-defects	**Material outgasing** **Radiation hardness** Database of bad/good materials	**Dielectric charging-up** Diffusion of avalanche charge	**Single electron response** Polya VS exponential
Rather limit Max. gain VS radiation	**Gas flow/mixture** ppm Impurities	**Geometry** Influence of dielectric Shielding against avalanche charge	**Photon feedback** Second Townsend coef.
Feedback phenomena Ion impact in noble gas Photo-effect in avalanche	**Rate effects** Polymer deposits Malter effects Photo-cathode QE loss	**Gain stability** Time constants Discharges	**Penning transfers** Gain enhancement
High rate mechanisms Avalanche overlap Ion space charge at the cathode			**Electric field** Low VS High Hole edges

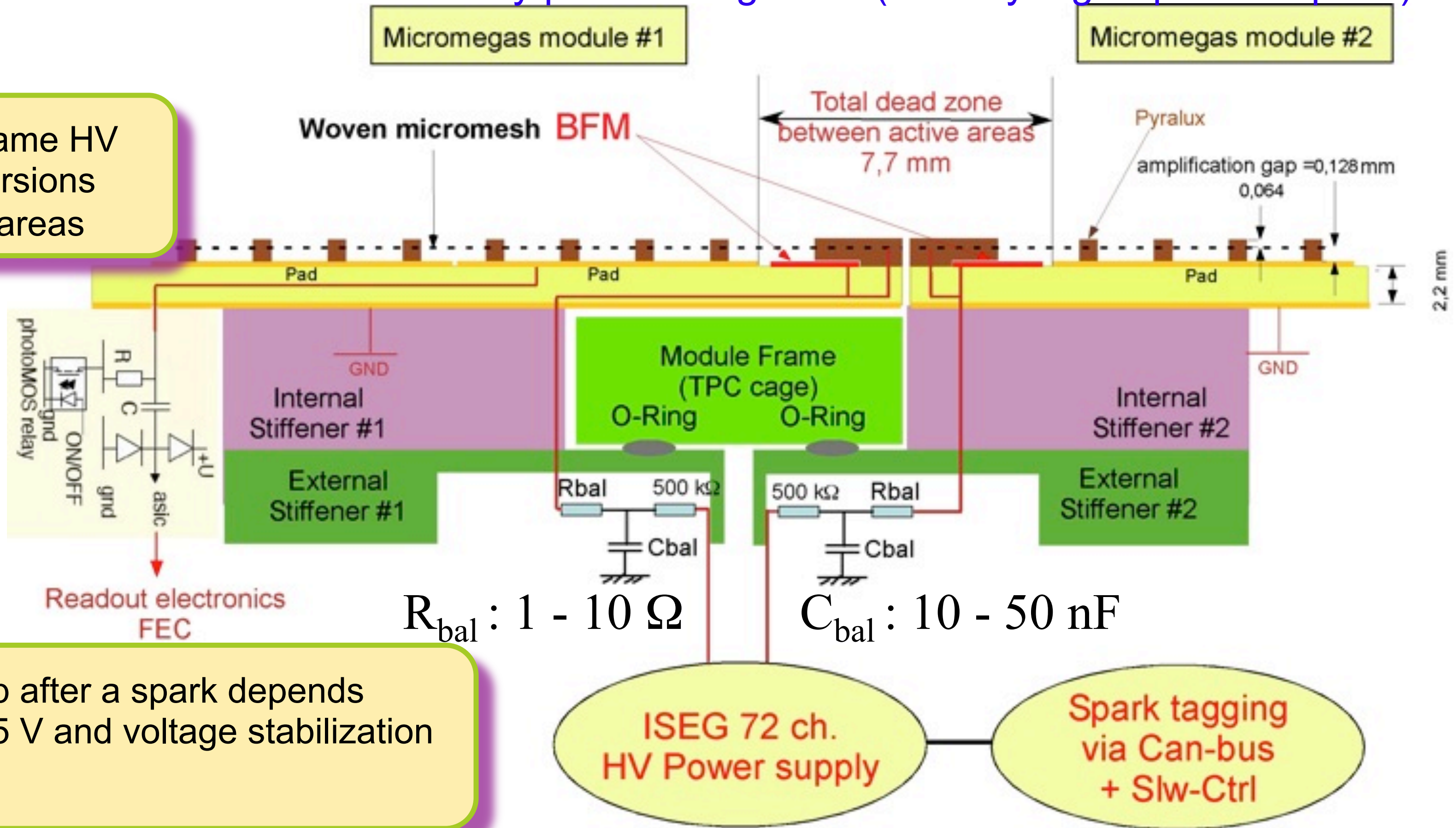






T2K/TPC : BULK-MICROMEGAS VS FIELD CAGE INTERFACE

- Minimize the electric field distorsions with precise alignment of modules' mesh & BFM polarization
- Strategies to handle failures when a spark or a permanent short-citrcuit occurs by :
  - 1/ demanding module quality selection for very low failure probability (« burn-in » in air)
  - 2/ optimized pad & mesh polarization circuit to minimize the effects of a spark
  - 3/ possible remote disconnection of faulty pads from ground (actually a group of 144 pads)



Mesh & BFM @ same HV to minimize distorsions between active areas

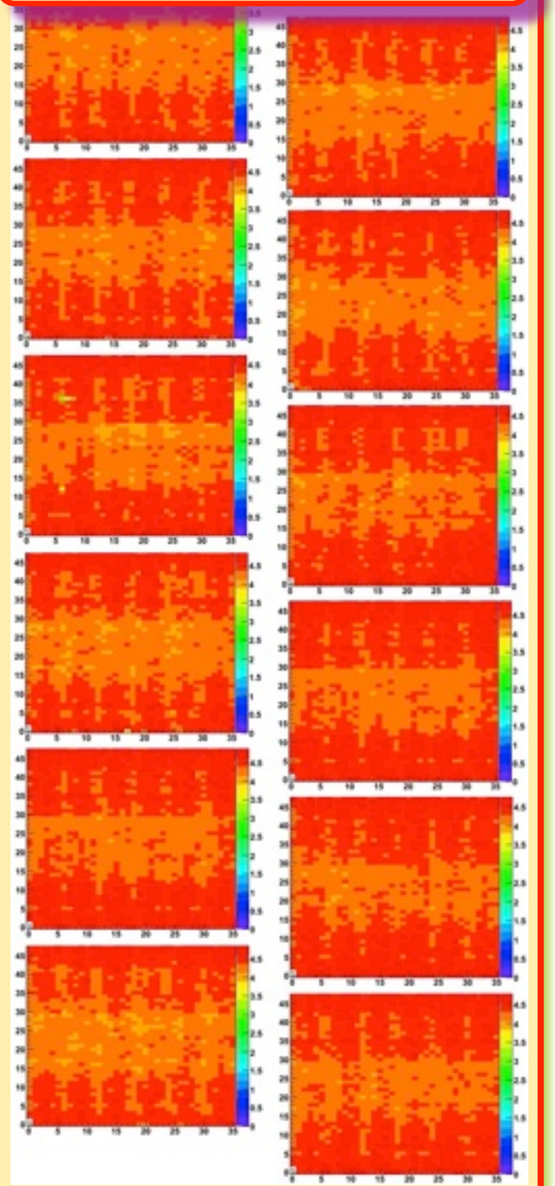
R_{bal} : 1 - 10 Ω

C_{bal} : 10 - 50 nF

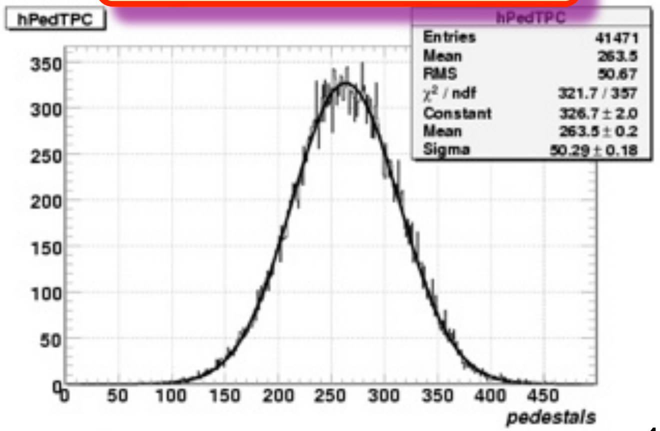
Mesh voltage drop after a spark depends on R_{bal}/C_{bal} : 1 to 5 V and voltage stabilization in 1 µs to 1 ms

T2K/TPC : PEDESTALS & RMS NOISE LEVEL OF A READOUT PLANE MEASURED ON SITE @ JPARC.

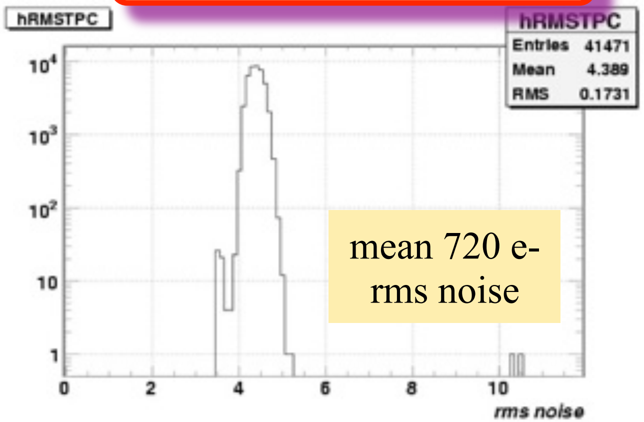
2D map of rms noise



pedestals distribution



rms noise distribution

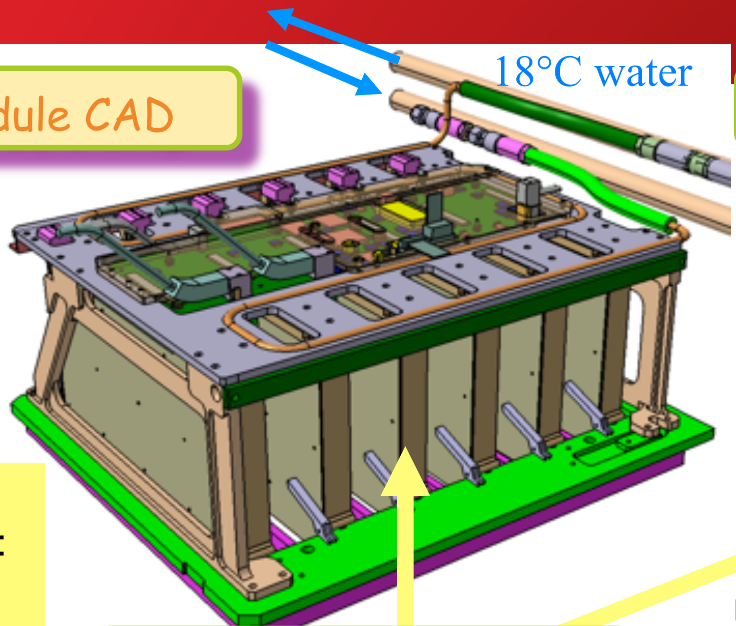


mean 720 e- rms noise

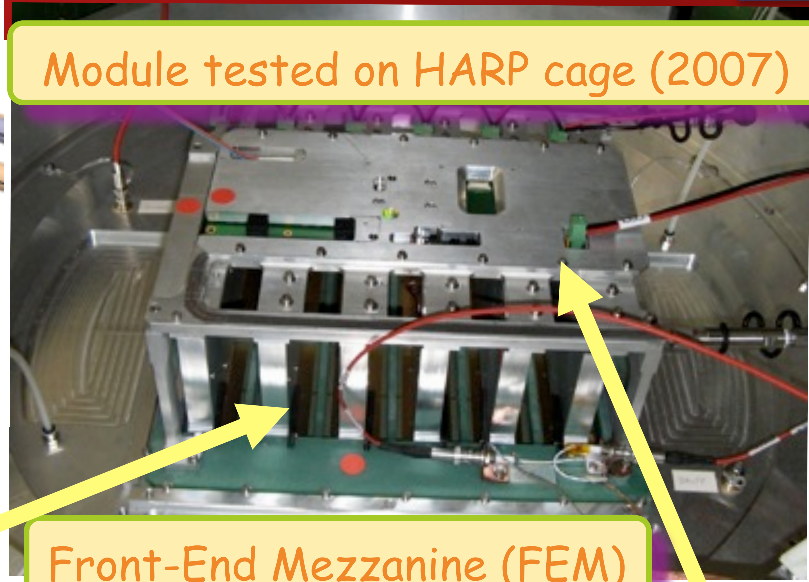
1 ADC ~ 160 e^-

T2K/TPC FRONT-END READOUT ELECTRONICS

Module CAD



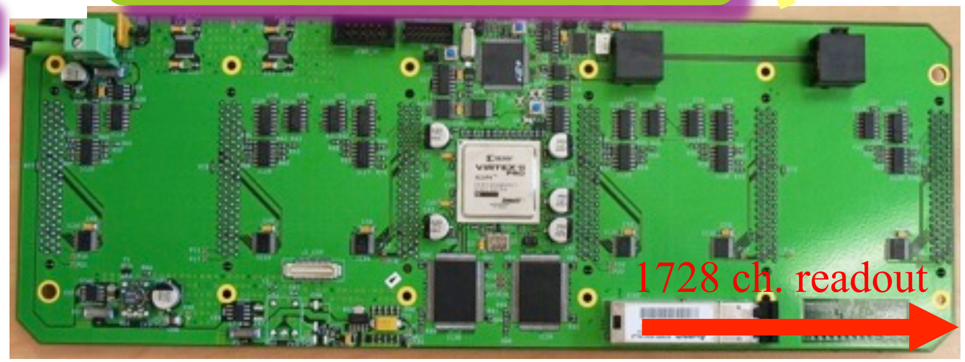
Module tested on HARP cage (2007)

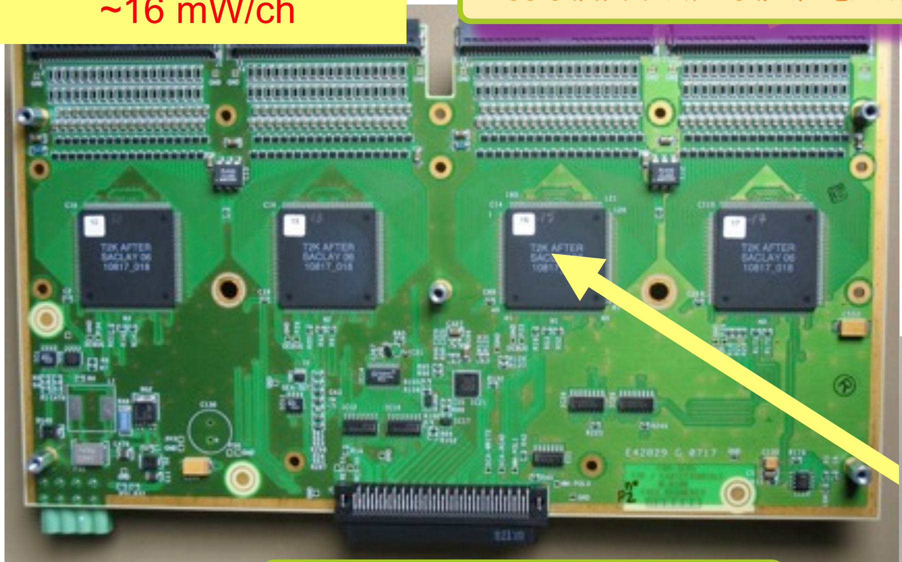


Total Cost of FEE
(ASIC+FEC+FEM) :
~2 € / ch.
Power consuption :
~16 mW/ch

288 ch. with 4x72 ch. AFTER ASICs

Front-End Mezzanine (FEM)

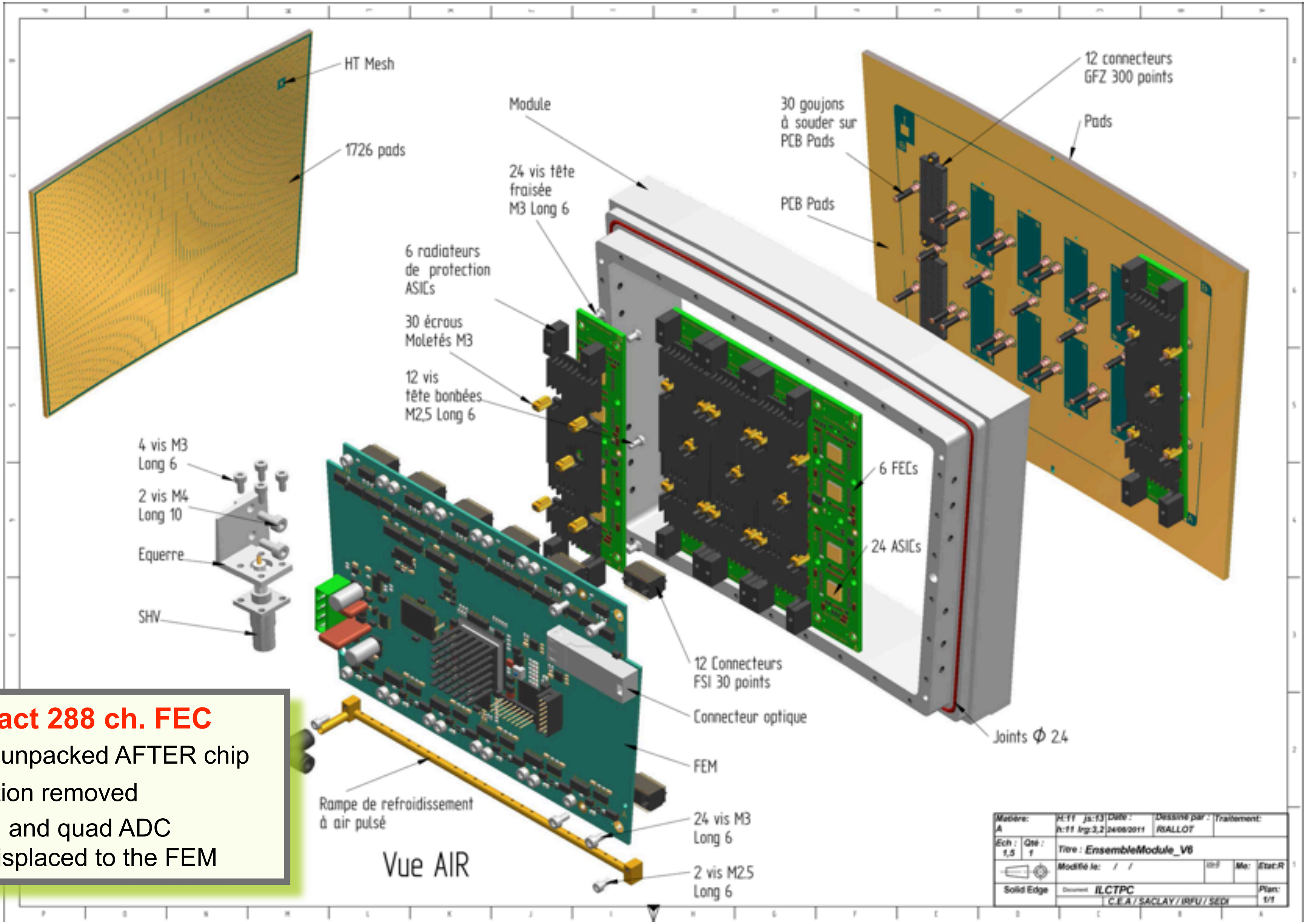




Front-End Card (FEC)

AFTER ASIC

ILC/TPC : AFTER BASED FRONT-END ELECTRONICS INTEGRATION

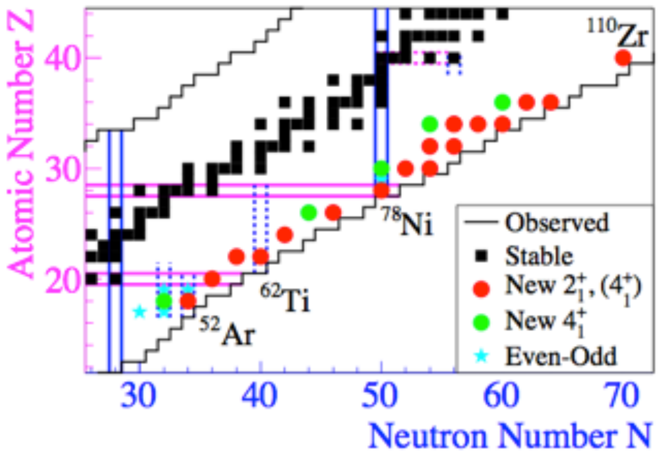


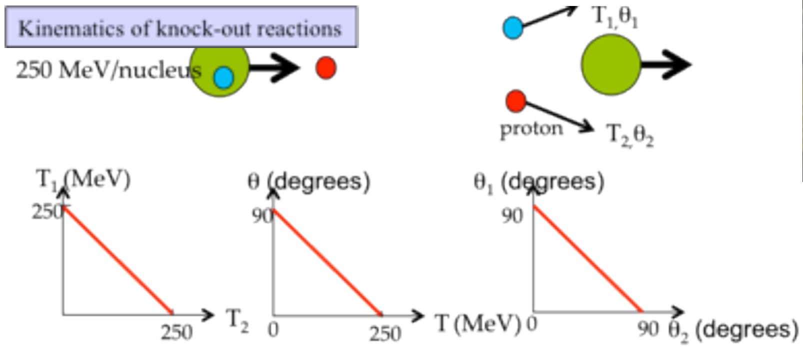
Compact 288 ch. FEC

- ✓ wire-bonded unpacked AFTER chip
- ✓ diode protection removed
- ✓ LV regulation and quad ADC removed and displaced to the FEM

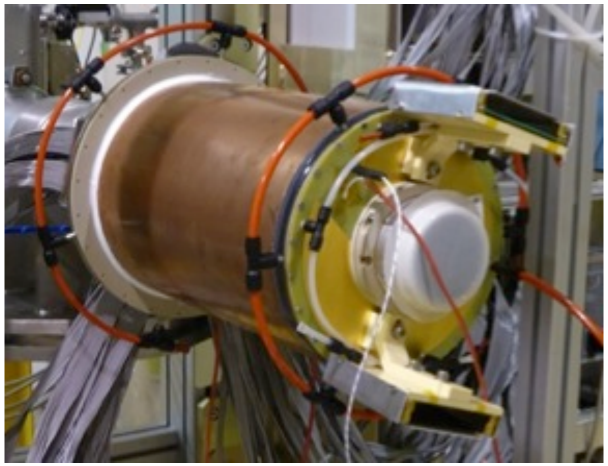
MINOS – MagIc Number Off Stability (ERC grant)

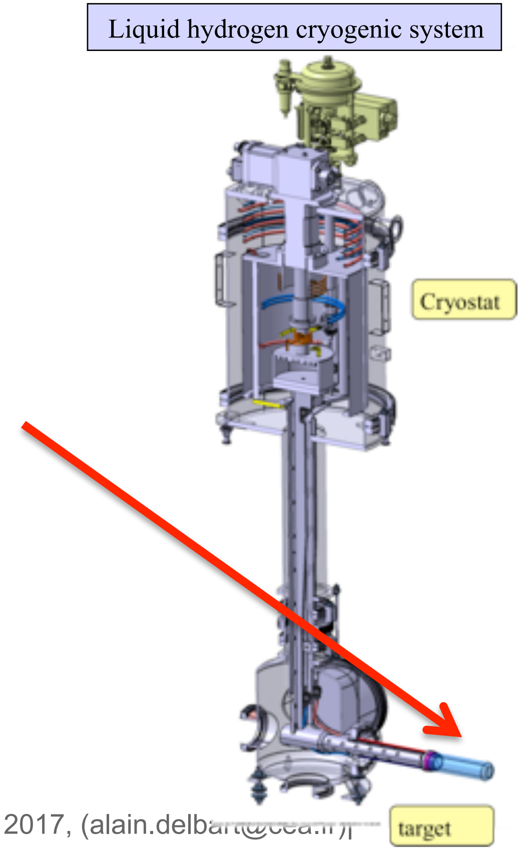
Physics motivations :
Study of the shell structure of very exotic and unstable nuclei on new generation radioactive beams
Instrumental method :
Gamma spectroscopy of knock-out reactions of radioactive nuclei impinging on a proton rich target
Innovation : Improving luminosity and preserving gamma energy resolution by coupling a thick liquid hydrogen target with a TPC to localize the vertex with 4 mm resolution and apply Doppler corrections to measured γ energies in the spectrometer (DALI2 @RIKEN or AGATA @FAIR)



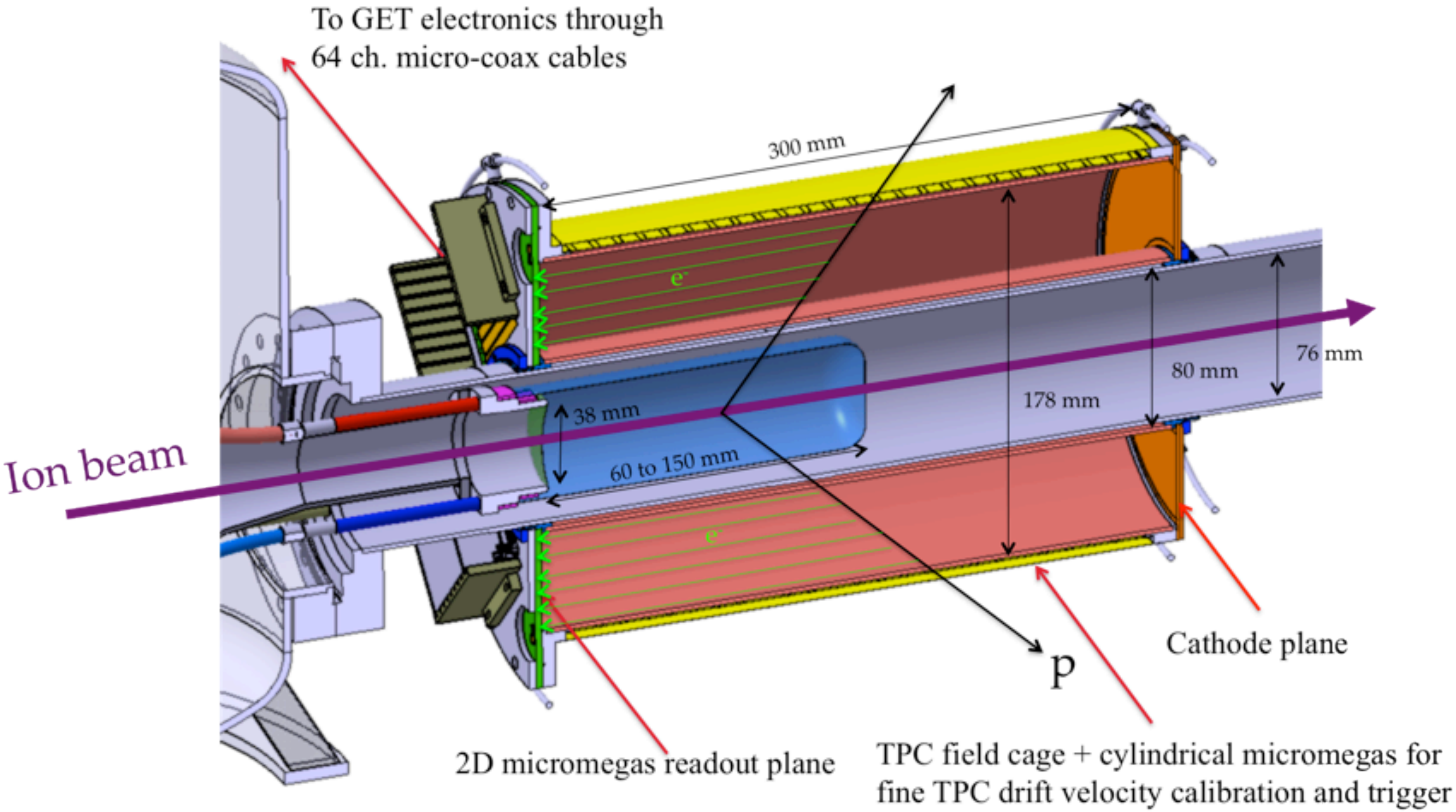


The MINOS TPC





THE MICROMEGAS READOUT TPC OF MINOS



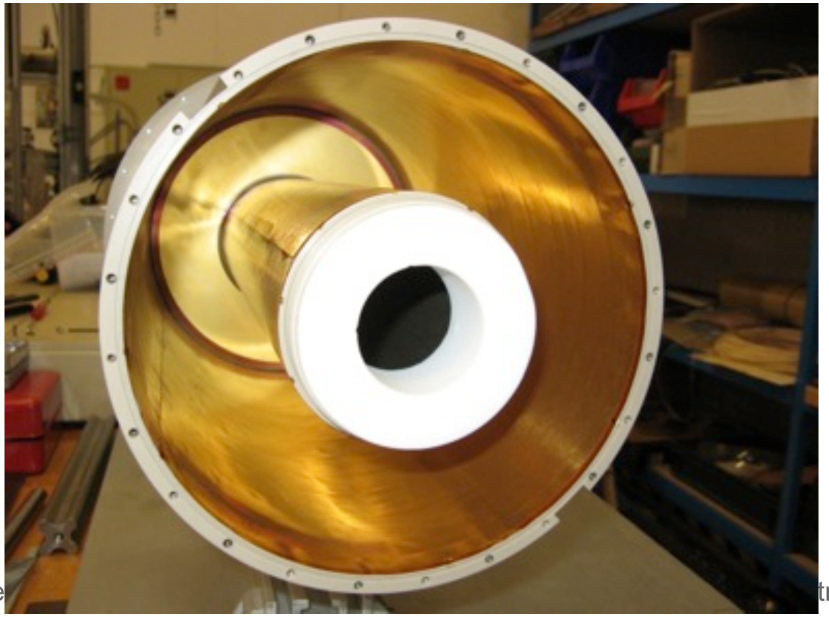
The MINOS Vertex tracker

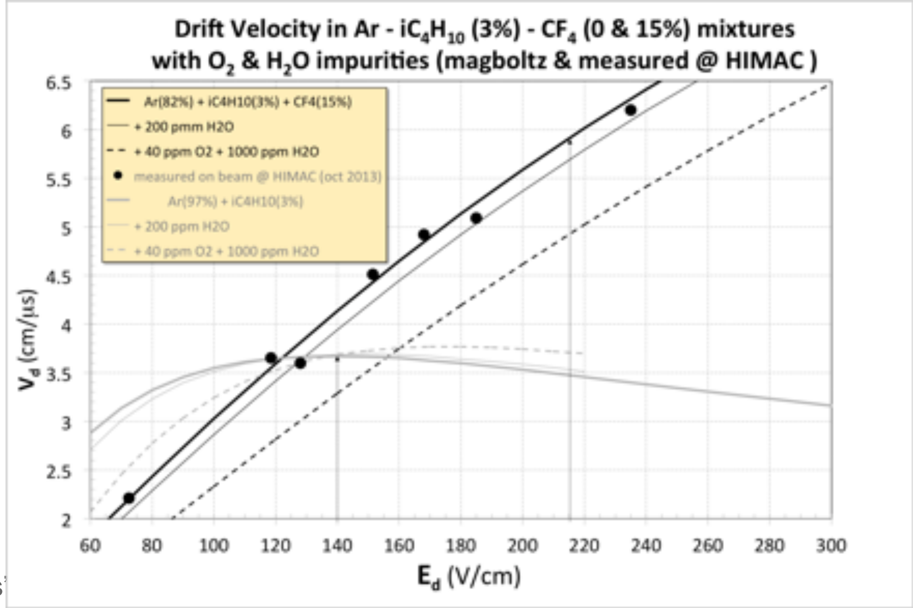
A compact cylindrical TPC readout with a bulk-micromegas pad plane and GET electronics, surrounded by a cylindrical micromegas tracker and two DSSD beam monitors (up&downstream)

TPC DESIGN AND MECHANICAL STRUCTURE

✓ A very compact and light structure made of 2 mm thick Rohacell cylinders
→ The challenge is to efficiently and accurately measure the proton tracks as soon as they exit the target (the first active pad is 7,2 mm from vacuum pipe)
✓ Solder free electrical connections between field cages and endcaps
✓ Cathode & micromegas endcaps can easily be dismounted (1 mm O-rings)
✓ Gas leaks (<0,1 l/h) are balanced with a 10 l/h gas flow to maintain H_2O & O_2 contaminations below measured 700 ppm & 40 ppm respectively
✓ 2 gas mixtures : baseline $Ar+3\%iC_4H_{10}+15\%CF_4$ & backup $Ar+3\%iC_4H_{10}$

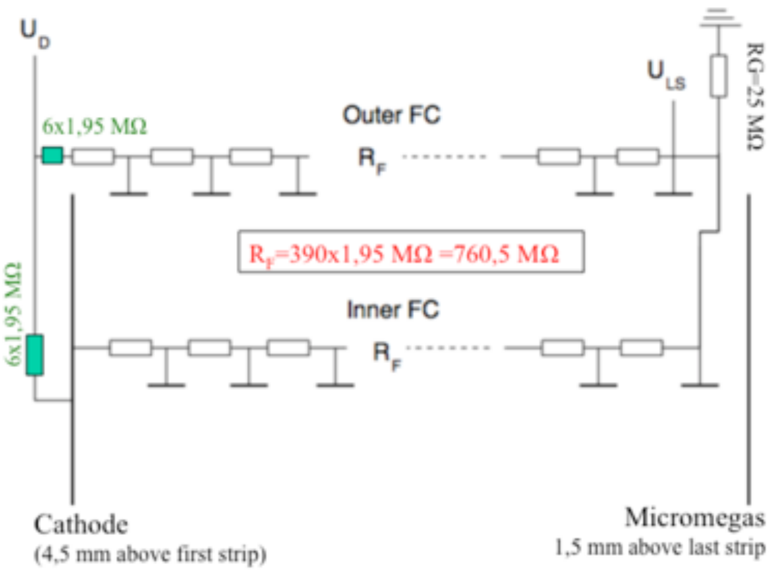
Opened TPC (cathode side)

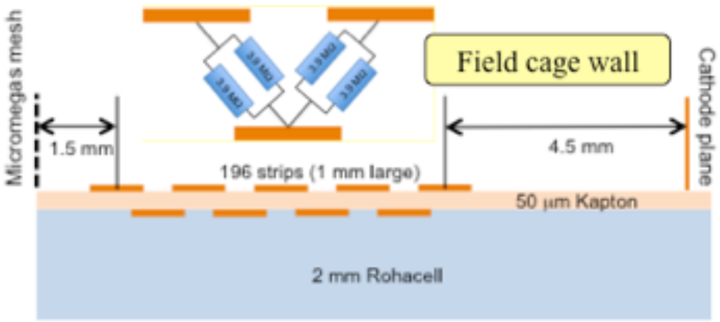




MINOS TPC FIELD CAGE

- ✓ The design is greatly inspired by the PANDA TPC electric field cage
- ✓ The drift field is defined by 196 + 195 strips, 1 mm large, printed with a 1,5 mm pitch on both side of a 50 µm thick gas tight kapton foil (made by CERN/TE-MPE-EM) glued on the internal & external Rohacell cylinders
- ✓ 2 x 3,9 MΩ (+/-1%) SMD805 resistors are soldered between 2 strip
- ✓ The 195 resistors between 2 adjacent strips are measured : a typical measure is 3889,8 kW mean value with 0,25% peak-peak dispersion
- ✓ a HV power supply is used to precisely define the last strip voltage

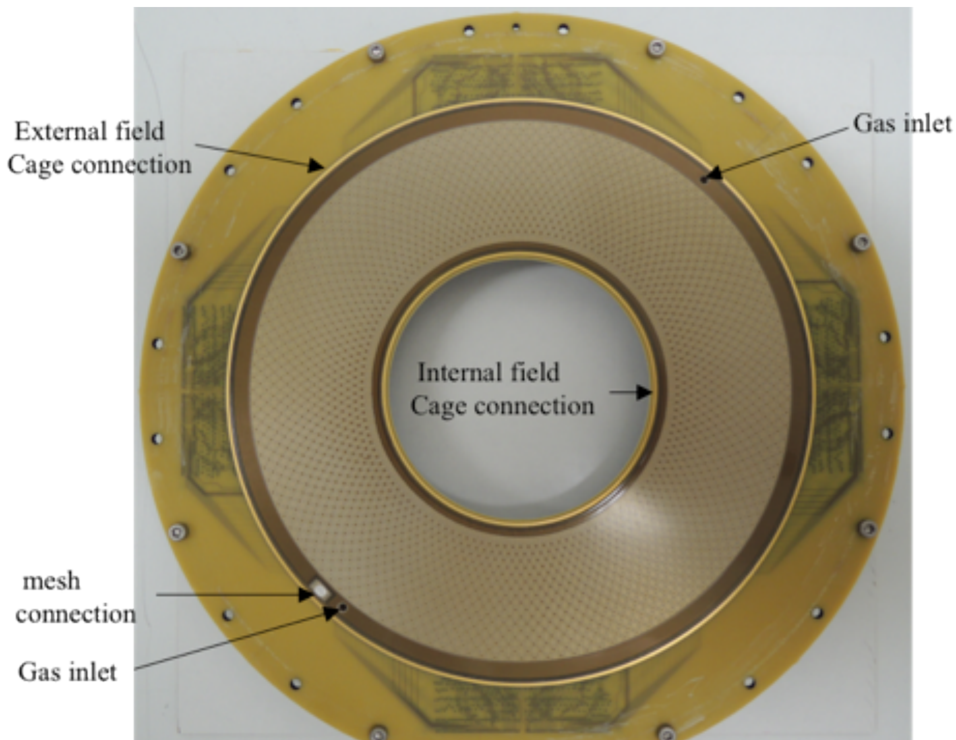




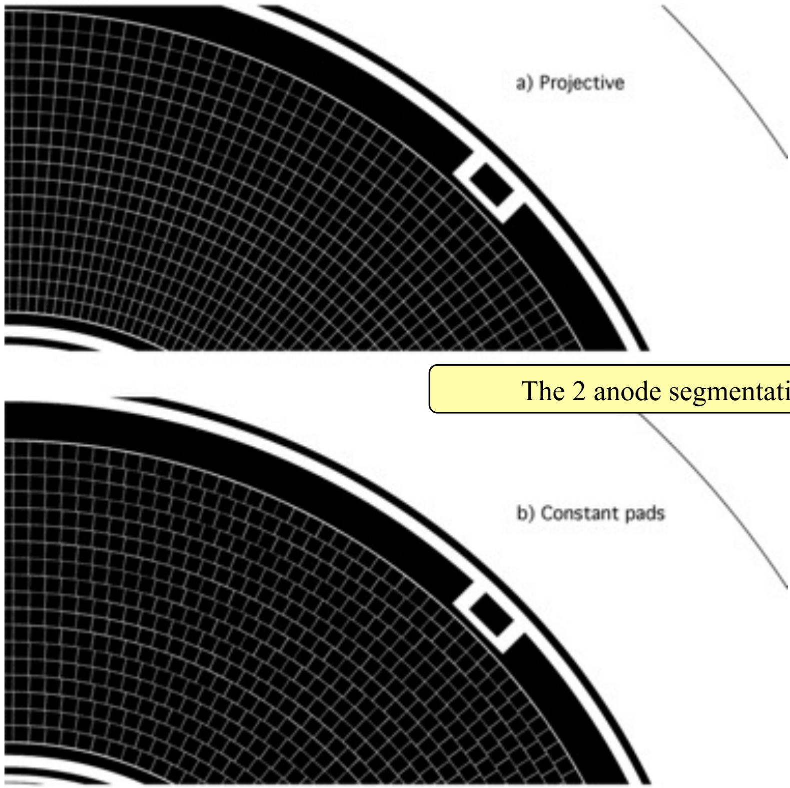
E (V/cm)	Gas	V_{drit} (cm/µs)	D_t (µm/sqrt(cm)	D_l (µm/sqrt(cm)	U_D(V)	ΔV_{strip} (V)
140	Ar+3%iso	3.67	600	348	4200	10.5
215	Ar+3%iso+15%CF4	5.8	206	200	6450	16.125

MINOS TPC MICROMEGAS READOUT PLANE

- ✓ 128 μm gap bulk-micromegas, a pillar every 2 pads (made @ Irfu)
- ✓ 2 anode plane segmentations in 18 rings of 2 x 1-2 mm^2 pads
  - ✓ « projective » : 4608 pads, 256 per ring
  - ✓ « Constant pad » : 3604 x 4 mm^2 pads,
- ✓ 12 layers PCB with more than 18000 blind vias (ELTOS, Italy)



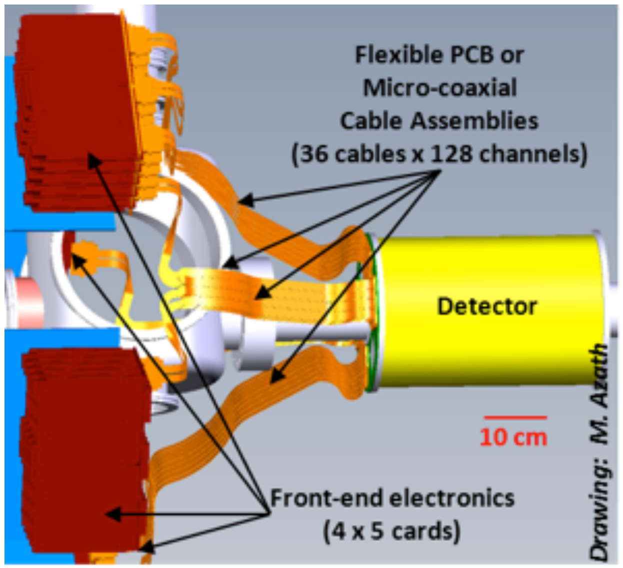
Bulk-micromegas with “Projective” anode

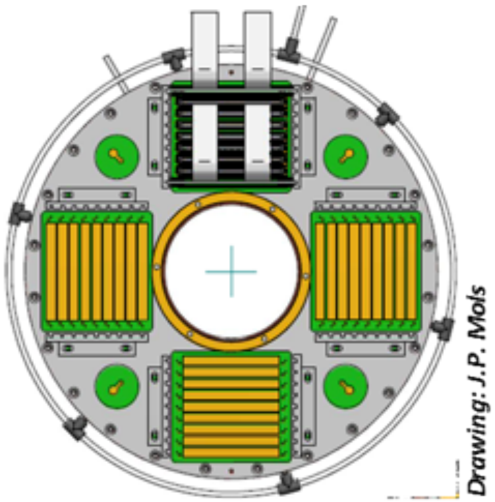


The 2 anode segmentations

THE MINOS TPC ELECTRONIC READOUT

- ✓ Use of the new 64 ch. AGET chip , with 512 time-bin SCA sampled @ 100 MHz
- ✓ New FEMINOS digital card to read a 4xAGET or 4xAFTER Front-End Card (T2K-TPC FEC)
- ✓ New TCM Trigger-Clock Module for synchronization of up to 24 FEMINOS cards
- ✓ 80 cm Hitachi FC-Band® micro-coax cables (50 pF/m)
- ✓ DAQ based on a new C++ generic "MORDICUS" framework developped for "GET" project
- ✓ Up to measured 5.5 kHz (AGET) & 600 Hz (AFTER) DAQ rates (for 6 ch. hits per chip)
- ✓ Low cost and versatile readout system for small to medium scale detectors up to 6000 channels





TPC readout plane

Ref: D. Calvet

FEMINOS card

AFTER
or GET card

MINOS TPC : FLOOR NOISE IN EXPERIMENTAL CONDITIONS

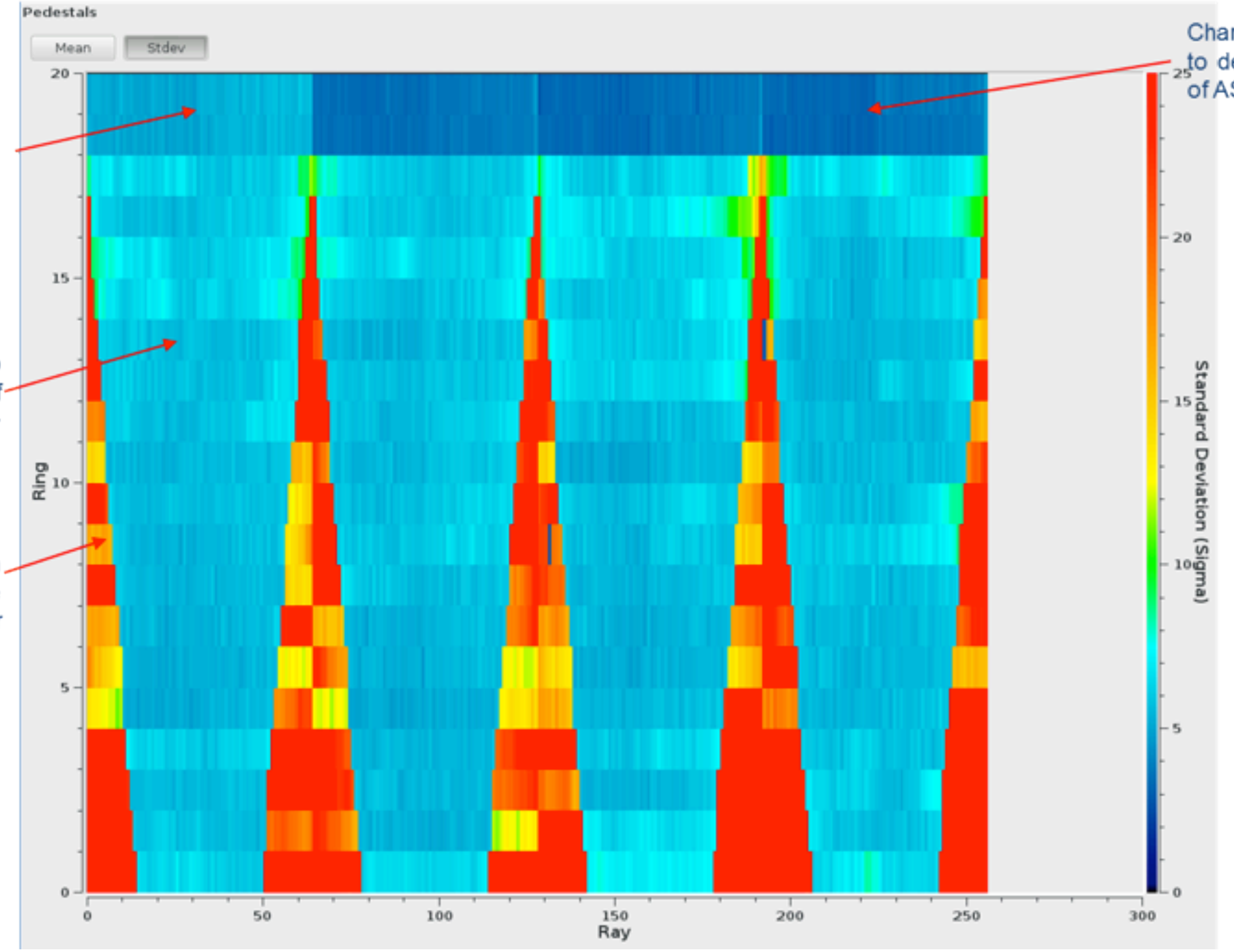
MINOS fully installed in DALI2. Constant size pad geometry TPC connected to 20 AGET-FEC-Feminos (5120 channels) via 80 cm cables.
Sampling: 50 MHz, Charge-Shaping: 120 fC-300 ns (1 ADC unit = ~185 e-)

Channels connected to cable only -> floor noise of ASIC + FEC + cable = ~1200 e-

Channels connected to TPC -> floor noise of ASIC + FEC + cable + detector = ~1400 e-

Channels grounded on constant pad size geometry – Masked for readout

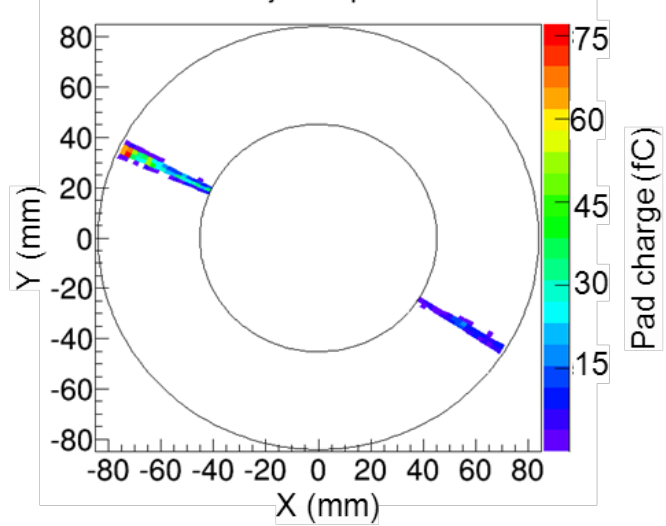
Channels not connected to detector -> floor noise of ASIC + FEC = ~800 e-



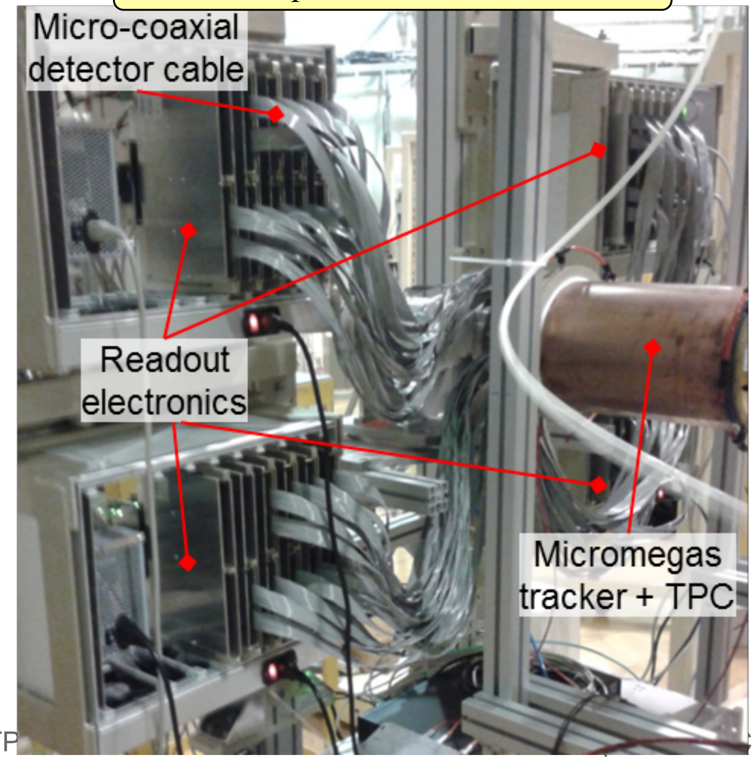
MINOS TPC ION BEAM TESTS @ NIRS-HIMAC (CHIBA, JAPAN)

- ✓ One week Data taking in october 2013
- ✓ ^{20}Ne 180 and 350 Mev/nucleon beam
- ✓ 2 x MWDCs, 300 μm resolution, for beam tracking
- ✓ Two 0,5 mm thick CH_2 or C targets were placed 124 mm apart in place of the LH_2 target
- ✓ Use of 20 x T2K-AFTER FEC cards
- ✓ The 2 gas mixtures & anode geometries were tested

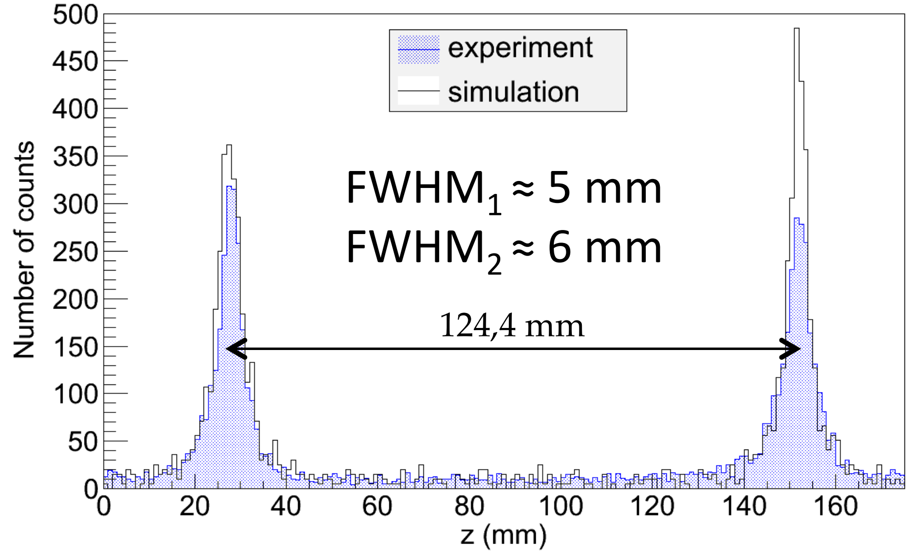
A typical (p,2p) event in the TPC



Test setup on HIMAC beam line

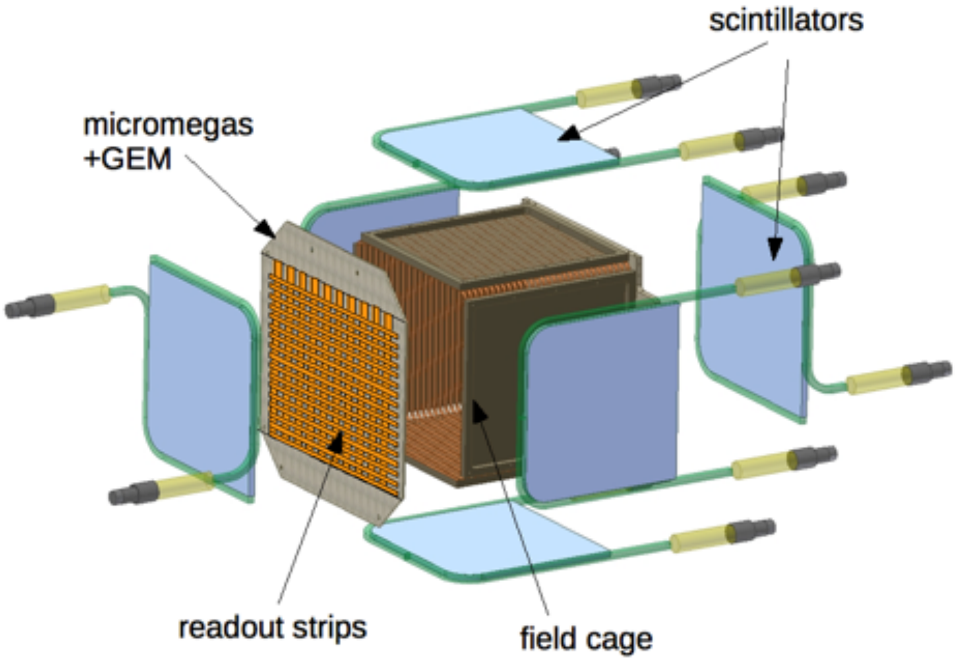


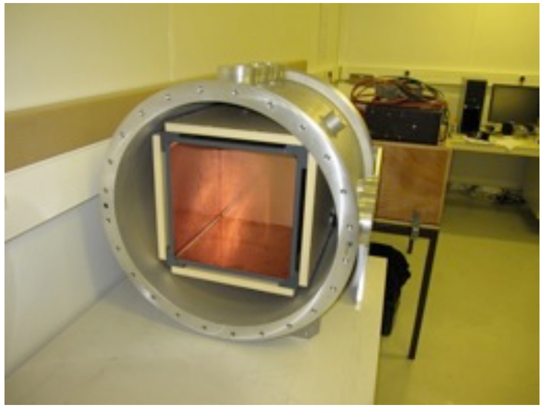
Ne beam, 350 MeV/nucleon

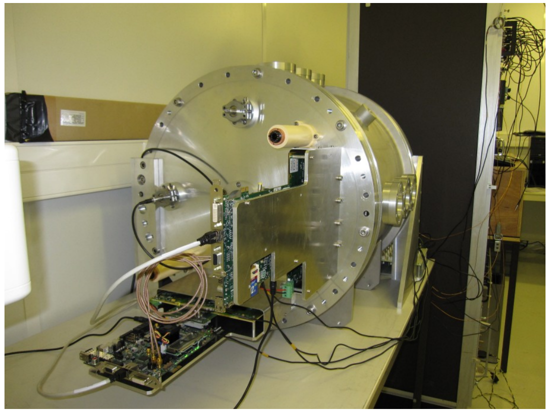


THE HARPO TPC DEMONSTRATOR

- ✓ A (30 cm)^3 TPC filled with Ar+5% iC_4H_{10}
- ✓ Can be pressurized and operated at up to 5 bars
- ✓ 6 scintillators + wavelength Shifters + PMTs
- ✓ A cubic electric field cage with 3 mm width strips spaced with a 5 mm pitch
- ✓ Charge readout with a micromegas + 2 GEMs
- ✓ Electronic readout with 2 X T2K FEC+FEMINOS
- ✓ Stable operation over a month

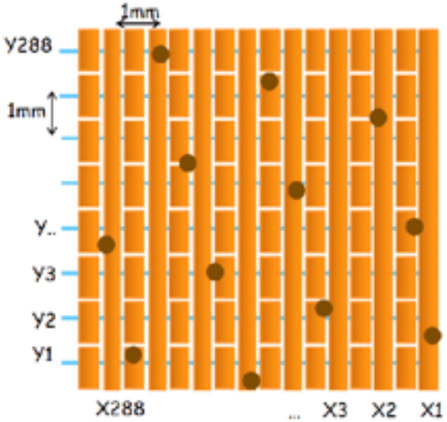


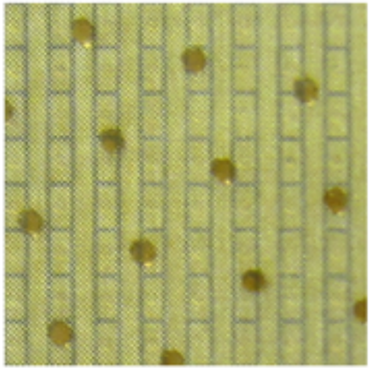


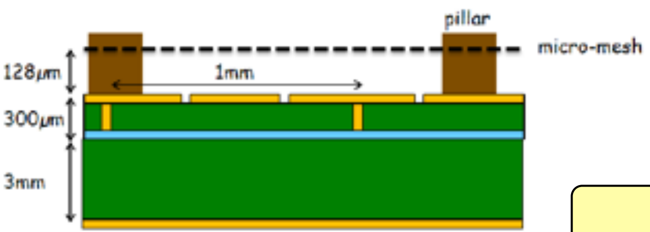


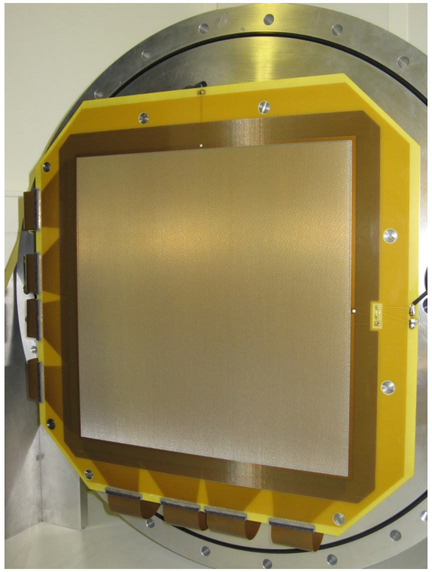
THE HARPO TPC CHARGE READOUT

The X-Y striped anode PCB + bulk-micromegas

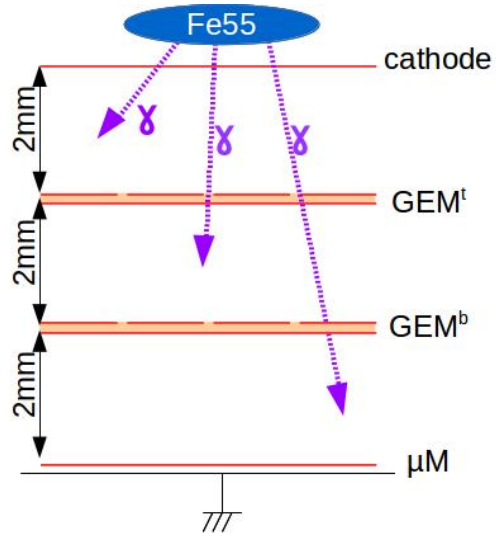




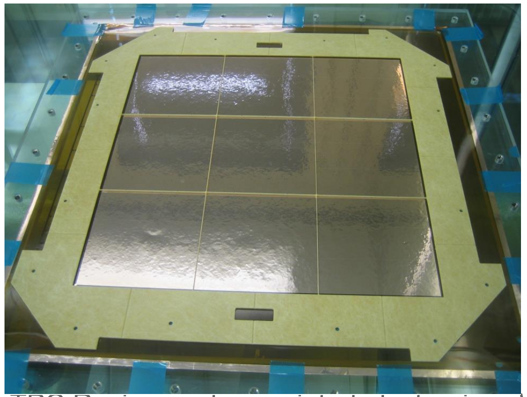




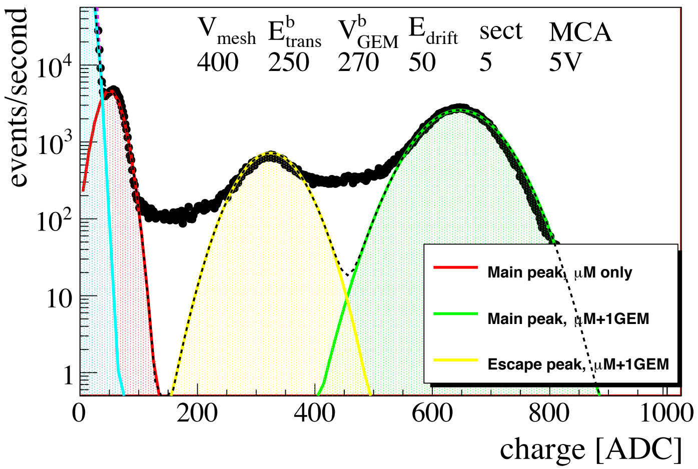
The charge readout

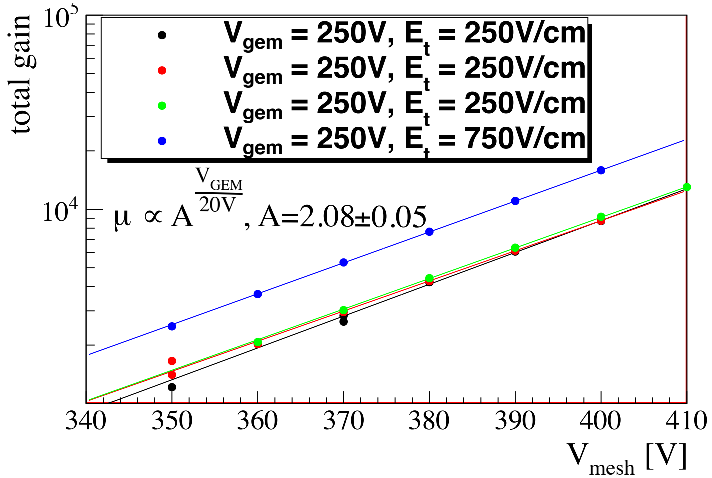


A GEM foil



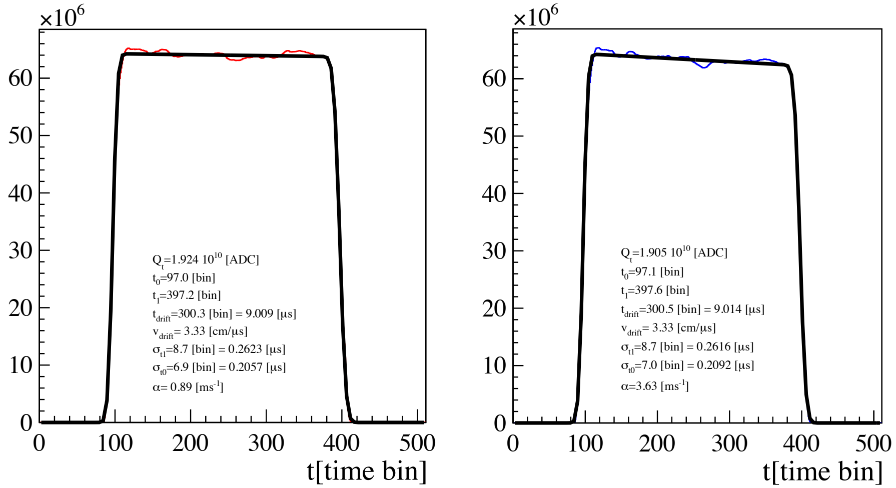
The measured gain with 55Fe X-ray source at 1 bar



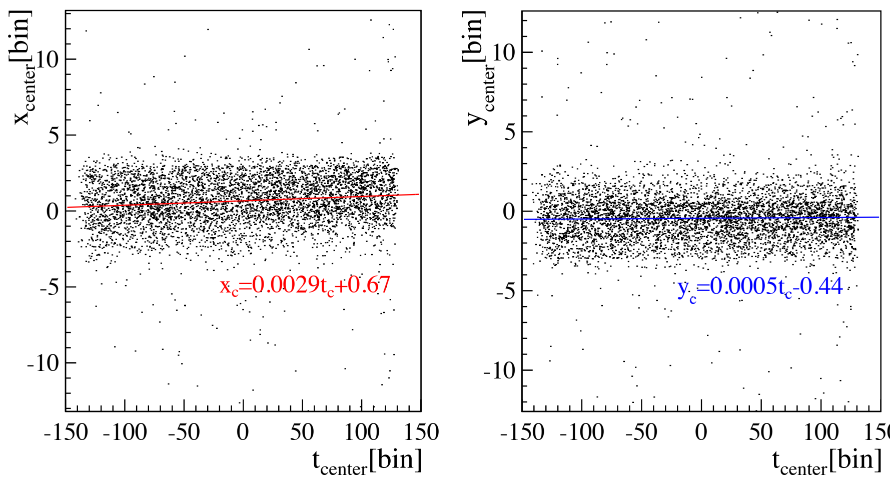


THE HARPO TPC IN γ−BEAM VALIDATION AT NewSUBARU, UNIV. OF HYOGO, JAPAN (20/10-22/11)

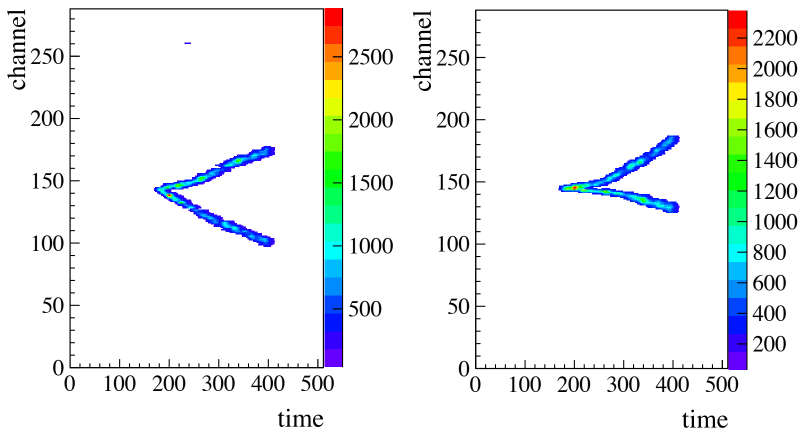
P≈1 linearly polarized γ beam, produced from on-axis collision on NdYag (1.064 μm, 2ω, 3ω), Er (1.54 μm), or CO2 (10.64 μm) laser pulses on 1.0-1.5 GeV e-, for a 2-76 MeV γ energy range. Commissioning is done, data taking is on-going



TPC calibration plot $(x,\ y)$ (z traversing tracks).



TPC alignment on collimated γ beam



Ref: D. Bernard Laboratoire Leprince-Ringuet

One γ photon converts to an e^+e^- pair in the fiducial volume of the HARPO TPC.