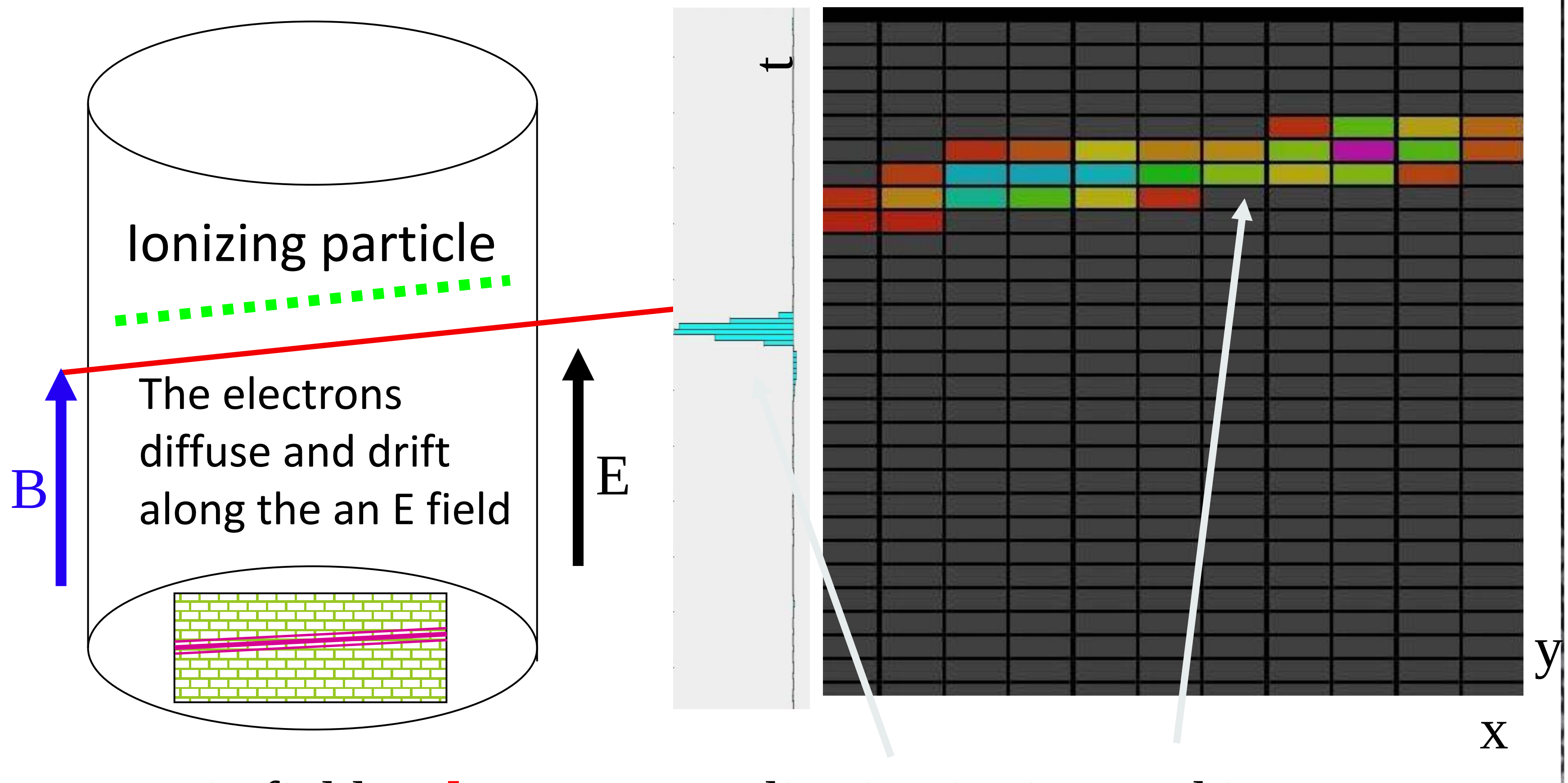
"MPGDs for TPC readouts at the Energy, Intensity and Cosmic Frontiers

Paul Colas, CEA/Irfu Saclay

electrons are separated from ions



Ionizing particle

The electrons diffuse and drift along the an E field

A magnetic field **reduces** diffusion

Localisation in time and in x-y

Principle of operation and advantages

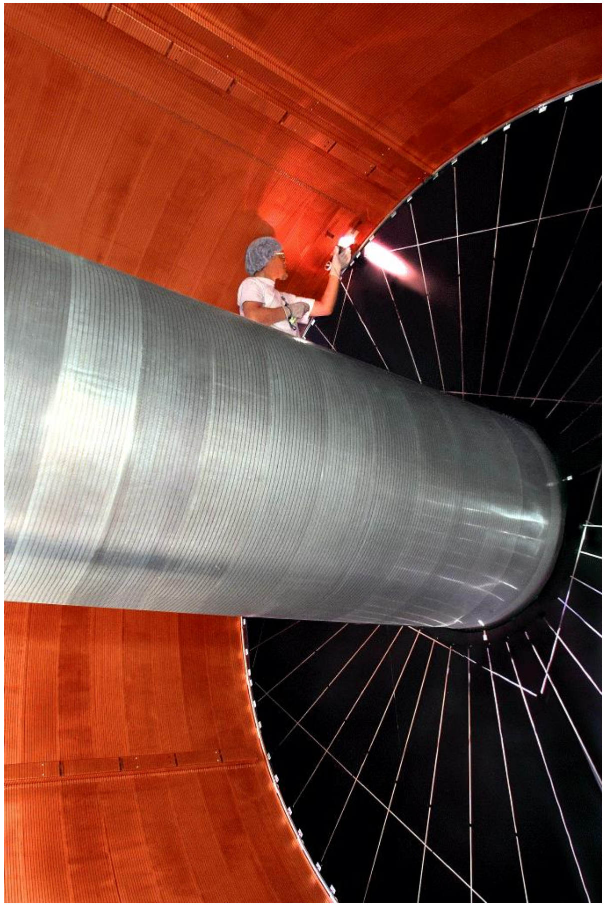
There is nothing cheaper than gas as active medium.

There is nothing lighter than gas (at atmospheric pressure).

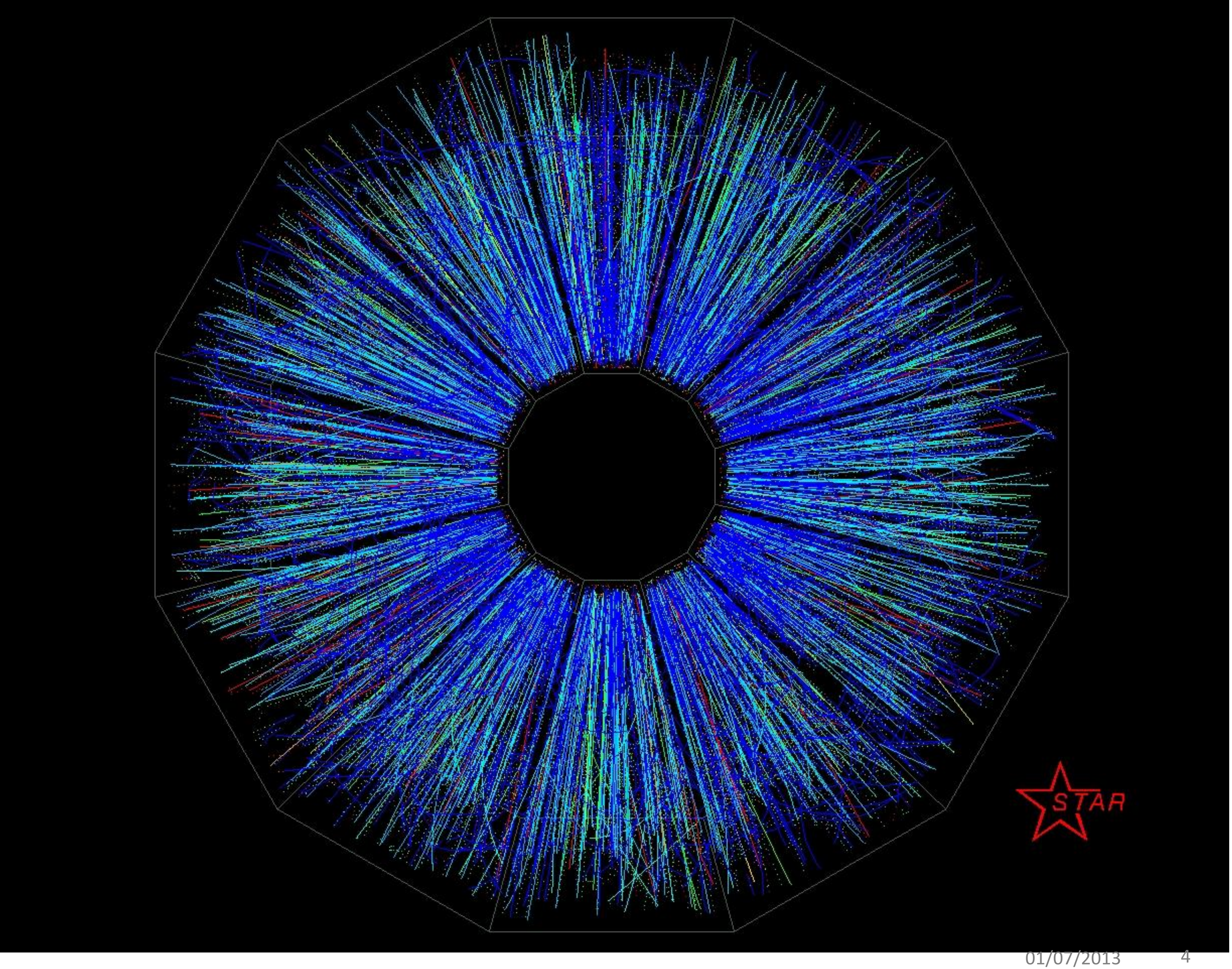
A TPC allows a continuous tracking in 3D at a very low material budget, and at a very low cost (by ‘voxel’)

It can thus handle very high multiplicities.
The gas itself can be a target for some experiments (nuclear physics, dark matter search).

dE/dx measurement provides non-destructive charged particle identification in a wide momentum range.



STAR heavy ion TPC


STAR

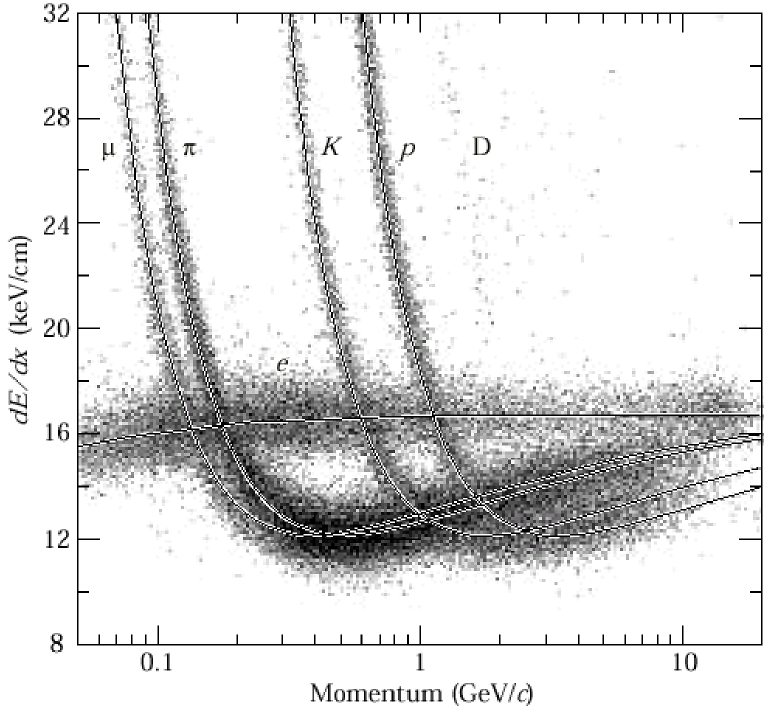


Figure 25.3: PEP4/9-TPC dE/dx measurements (185 samples @8.5 atm Ar-CH_4 80–20%) in multihadron events. The electrons

TPCs are very versatile

They can detect x-rays, high energy low-ionizing particles, highly ionizing ions, nuclear recoils… (10 talks at this conference are on TPCs)

Gas choice and pressure are according to applications (velocity, diffusion, radiopurity, multiple scattering…).

Very wide range of operation conditions: from a few e-/pad to 5000 e-/cm for ions and 60000 for liquid Argon.

Many wire-chamber TPCs have been very successful after David Nygren's TPC 2γ and Hargrove's Carleton TPC:

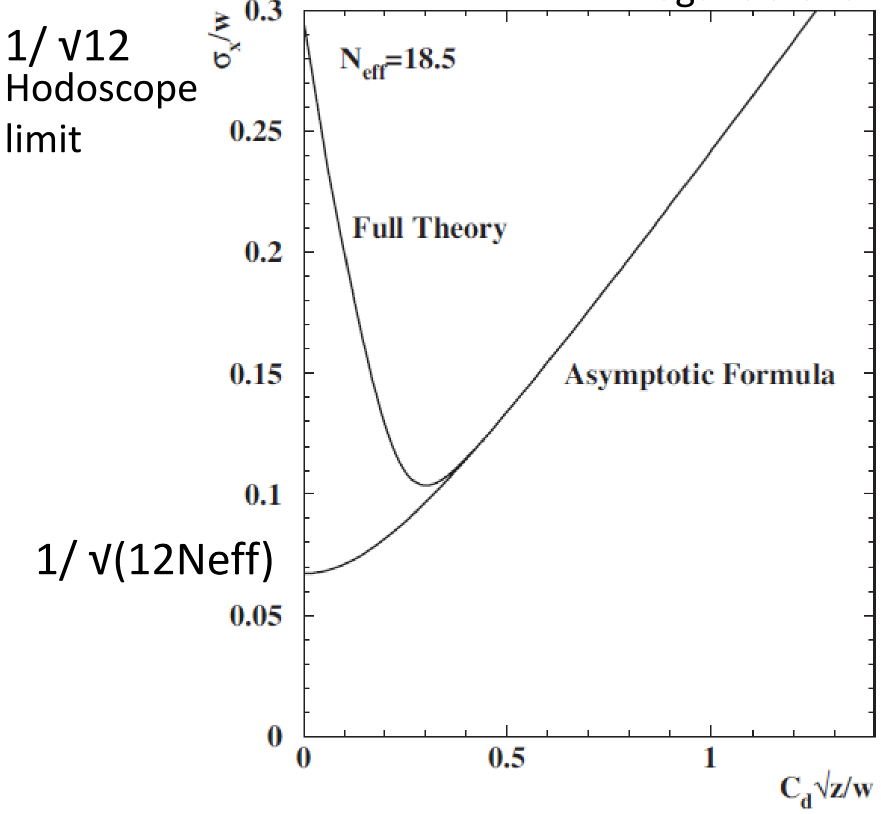
DELPHI and ALEPH at LEP, STAR at RHIC, ALICE at LHC…

But the trend is now to use Micropattern TPCs:
Easier to manufacture small pads
No need for strong frames
Fast and efficient ion collection
Natural ion feed-back suppression O(1%) rather than 20-30%

Micropattern TPCs

There is a complete theory of the resolution in MPGD TPCs (see Ryo Yonamine's talk). In GEM/THGEM TPCs, the diffusion in the amplification device provides enough diffusion for charge sharing between neighbouring pads, for pad widths about 1mm.

D. Arrogancia et al.

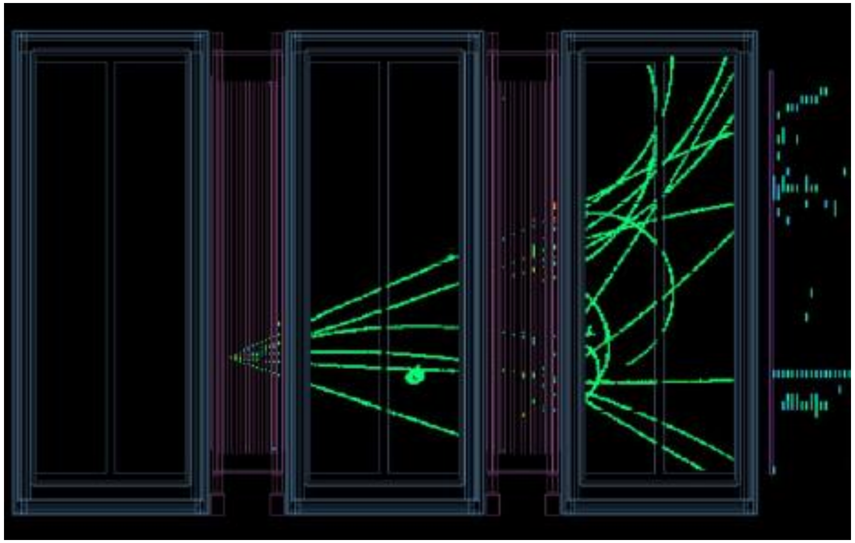


Spatial resolution

Neff includes ionization statistics and gain fluctuation effects

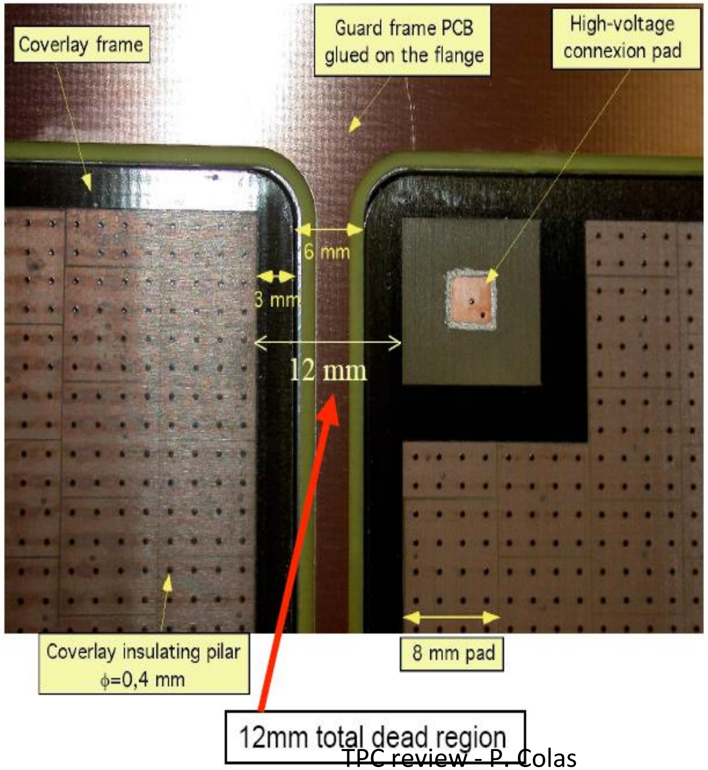
The T2K/ND280 Micromegas TPC

3 Large TPCs, 72/80 modules 40x40 cm^2



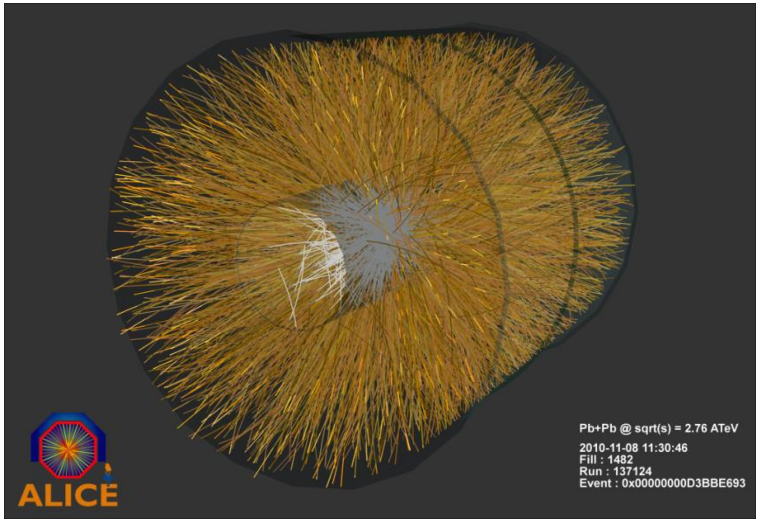
Four years of smooth running with ‘Bulk’ technology. Dead areas kept to minimum by avoiding frames

dE/dx essential at separating e/μ/π

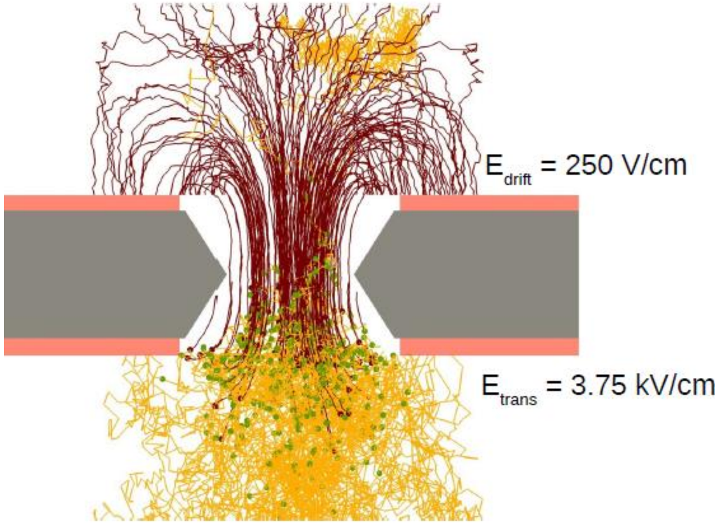


GEM upgrade of ALICE TPC

See Markus Ball's talk



Stability issues are under scrutiny

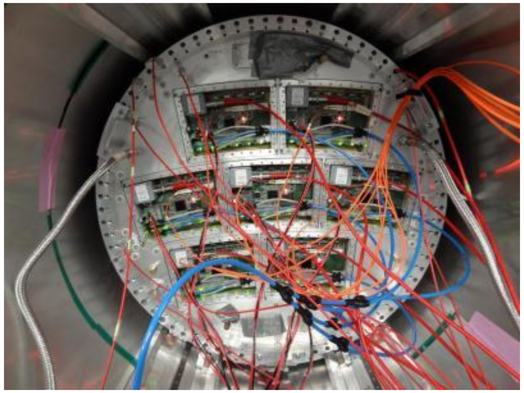


ILC R&D

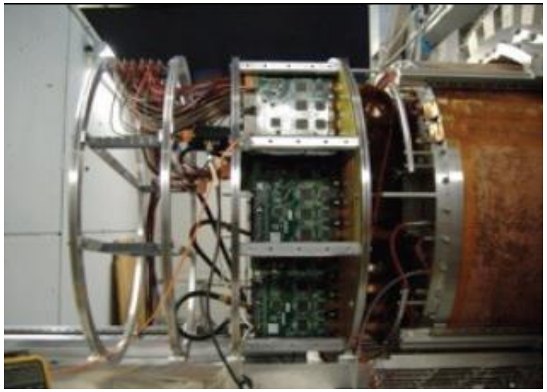
Several Micro-Pattern Gaseous Detectors types of readout modules are studied

Readout		**Pad Size**	**Electronics**	**Groups**
MPGDs	Micromegas (Resistive anode)	(~ 3 × 7 mm^2 Pad)	AFTER	Saclay-Carleton
	Double GEMs (Laser-etched)	(~ 1 × 6 mm^2 Pad)	ALTRO	Asia
	Triple GEMs (wet-etched)			Desy

Micromegas (test with 7 modules) 25% X°



GEM (test with 3 modules)

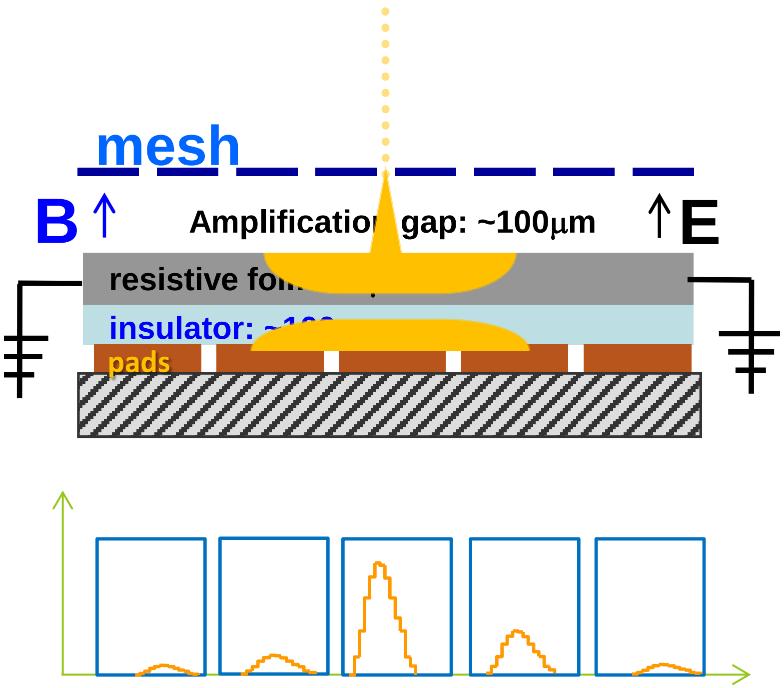


Micromegas with Resistive Anode

Pad width limits MPGD TPC resolution

Charge dispersion technique

with a resistive anode



Equation for surface charge density function on the 2D continuous RC network:

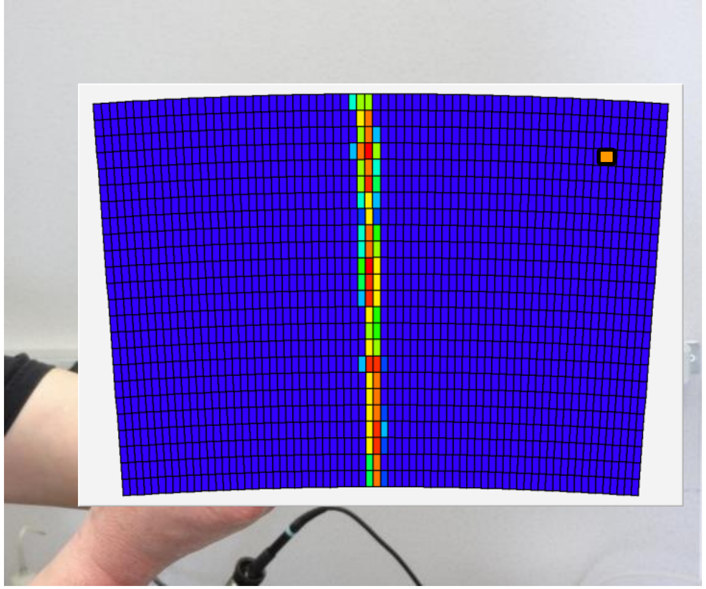
$$\frac{\partial \rho}{\partial t} = \frac{1}{RC}\left(\frac{\partial^2 \rho}{\partial r^2} + \frac{1}{r}\frac{\partial \rho}{\partial r}\right)$$

$$\Longrightarrow \rho(r,t) = \frac{RC}{2t} exp\left(\frac{-r^2 RC}{4t}\right)$$

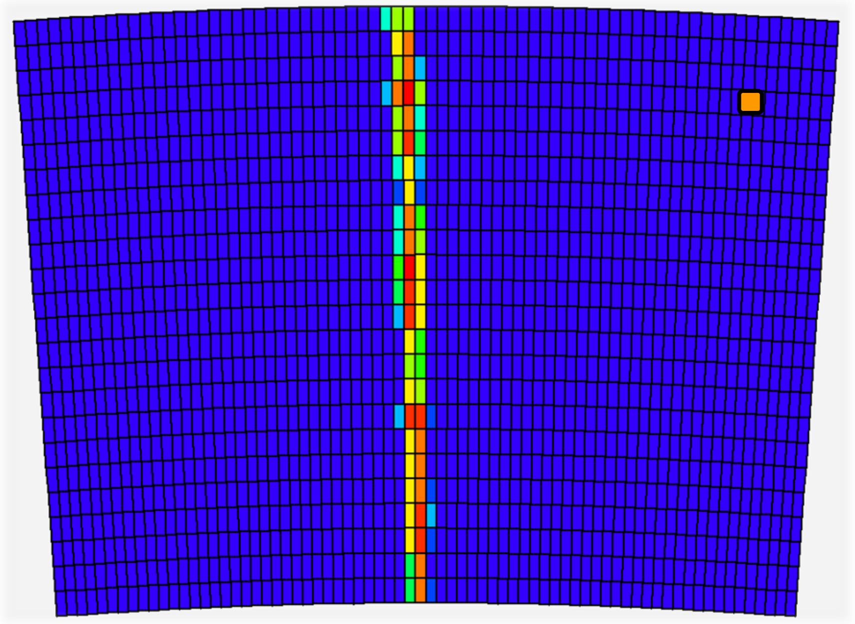
$\rho(r,t)$: the surface charge density
R: the surface resistivity of the resistive layer
C: the capacitance per unit area.

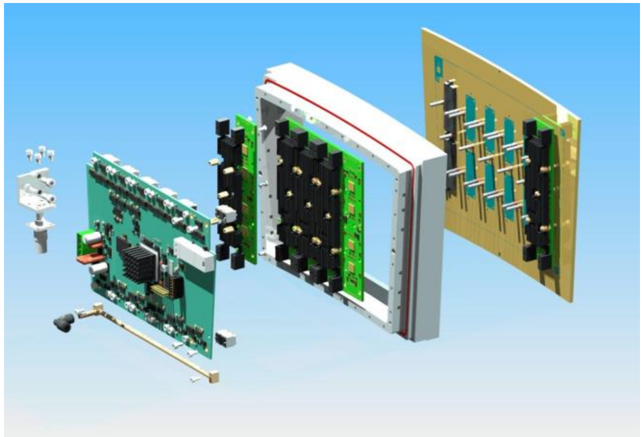
Resistive foil also provides
anti-spark protection

Micromegas module



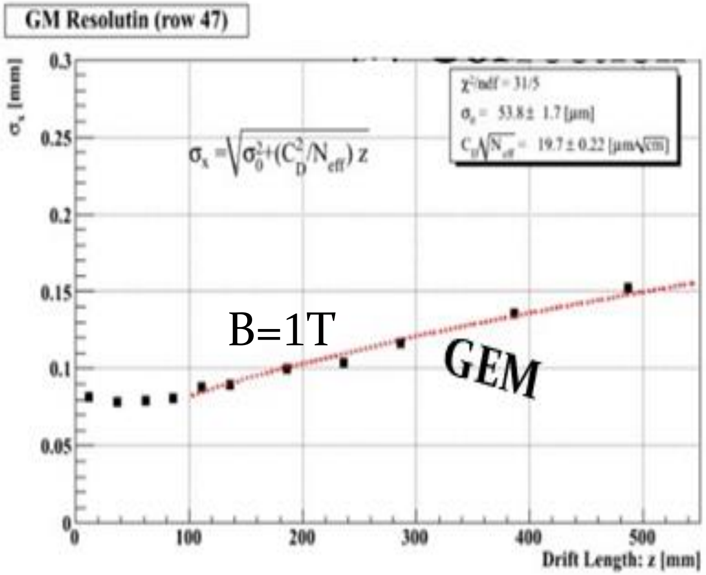
- **Module size: 22 cm × 17 cm**
- **24 rows × 72 columns**
- **Readout: 1726 Pads**
- **Pad size: ~3 mm × 7 mm**
- **7 miniaturized electronics flat behind the modules**

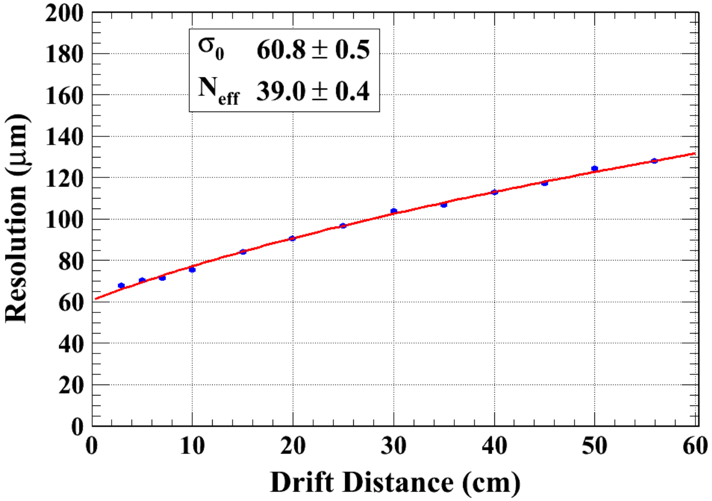




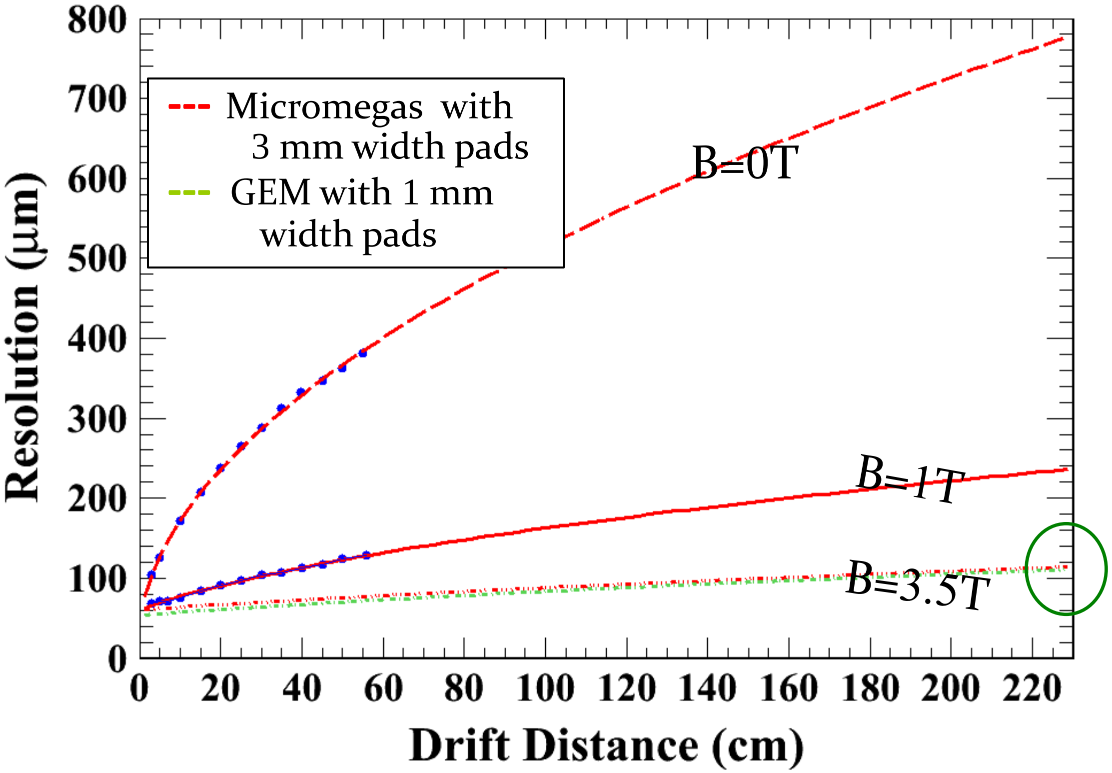
$$\sigma = \sqrt{\sigma_0^{\;2} + \frac{C_d^2 \cdot z}{N_{eff}}}$$

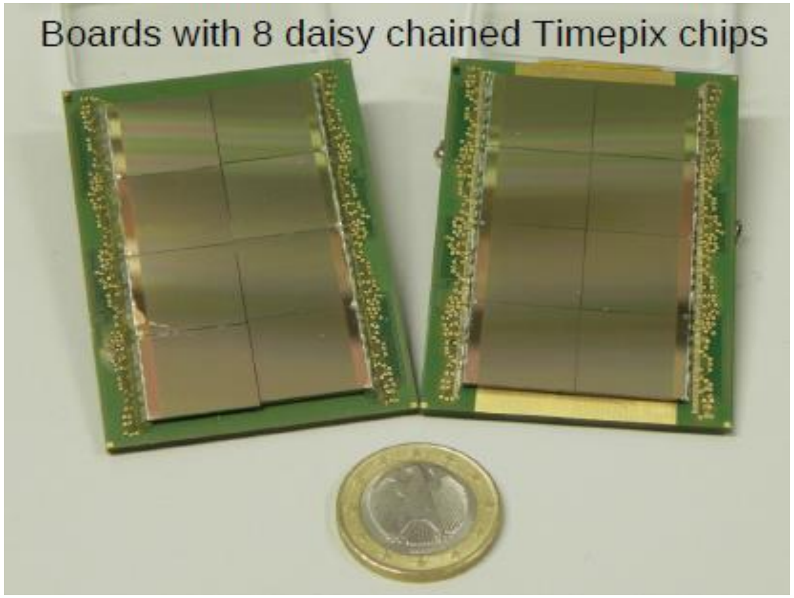
Extrapolation of the spatial resolution



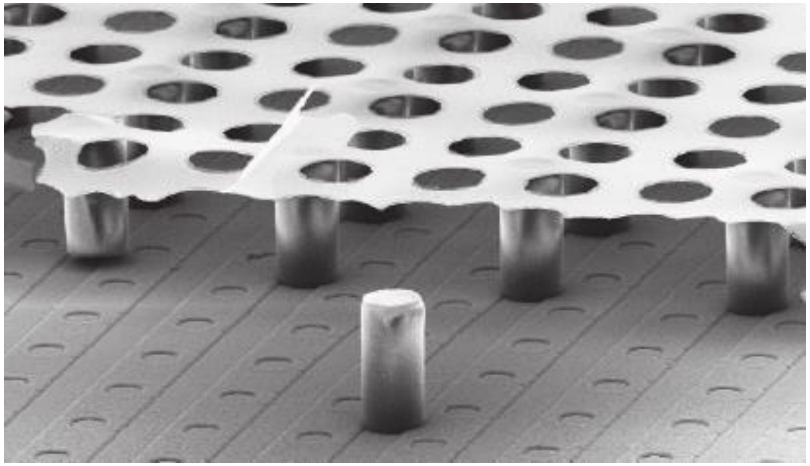


Extrapolate to 2.3m & B=3.5T





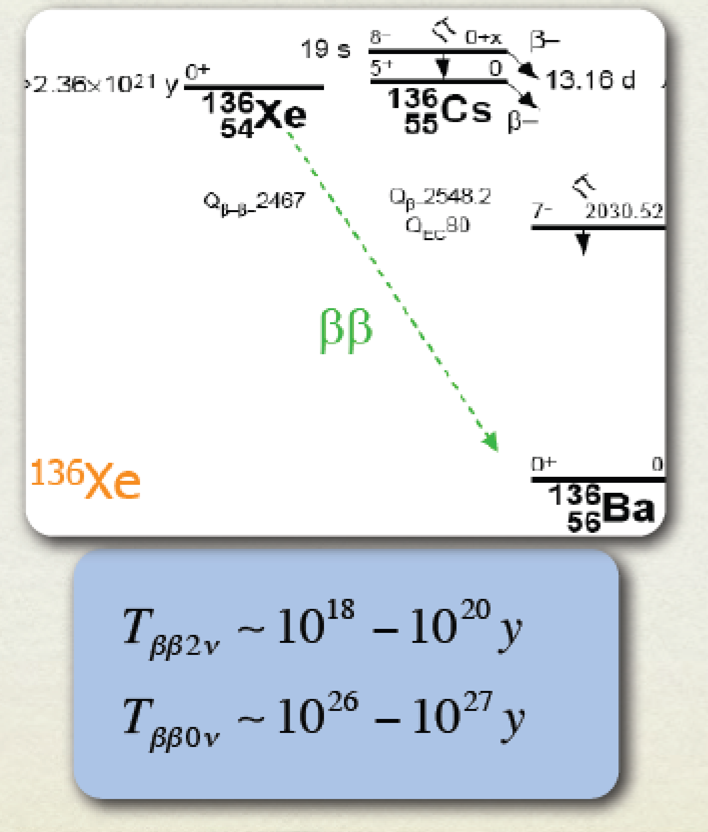
Concept in 2002 by Michael Hauschild: detect single electrons. Realized in 2004 by Jan Timmermans, H. Van der Graaf, PC, et al. (see Michael Lupberger's talk)



The Digital TPC

Use the pads of a pixel chip (TimePix for instance, with 55µ pads) as collecting anode for a Micromegas TPC.

Applications to axion search, LC TPC, dark matter search

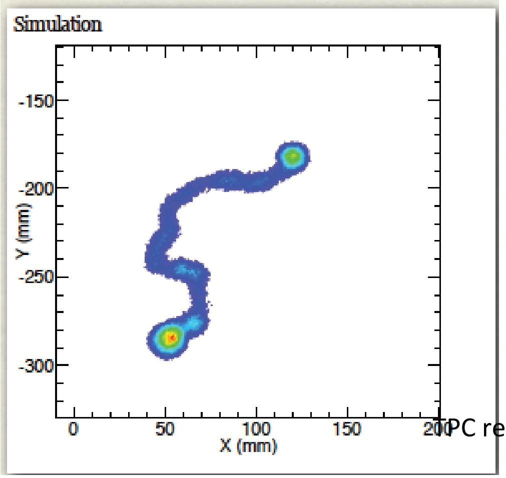


$$T_{\beta\beta 2\nu} \sim 10^{18} - 10^{20}\,y$$

$$T_{\beta\beta 0\nu} \sim 10^{26} - 10^{27}\,y$$

Neutrinoless double beta decay

- NEXT TPC : High pressure enriched xenon : spaghetti + 2 meat balls + energy resolution



Enriched Xenon Observatory

- **EXO-200**
  - 200 kg TPC of LXe 80% enriched in isotope 136;
  - ^{136}Xe double beta decay;
  - Limit on ^{136}Xe $0\beta\nu\nu$ decay $T_{½}(0\nu) > 1.2\cdot10^{24}$ [1].
- **EXO-full**
  - a ton scale experiment (1-10tons);
  - ^{136}Xe $0\beta\nu\nu$
  - m_{ν} in the inverted hierarchy region.

Double beta decay: High pressure gas TPC (Bern)

Enriched Xenon Observatory

EO

for double beta decay

Advantages of Xe

•background rejection with Barium tagging.

•Xe $2\nu\beta\beta$ decay still to be observed

DARK MATTER SEARCH

Principle : bounce nuclei and detect their ionization and/or light

In large volumes, neutrons interact several times, allowing background rejection.

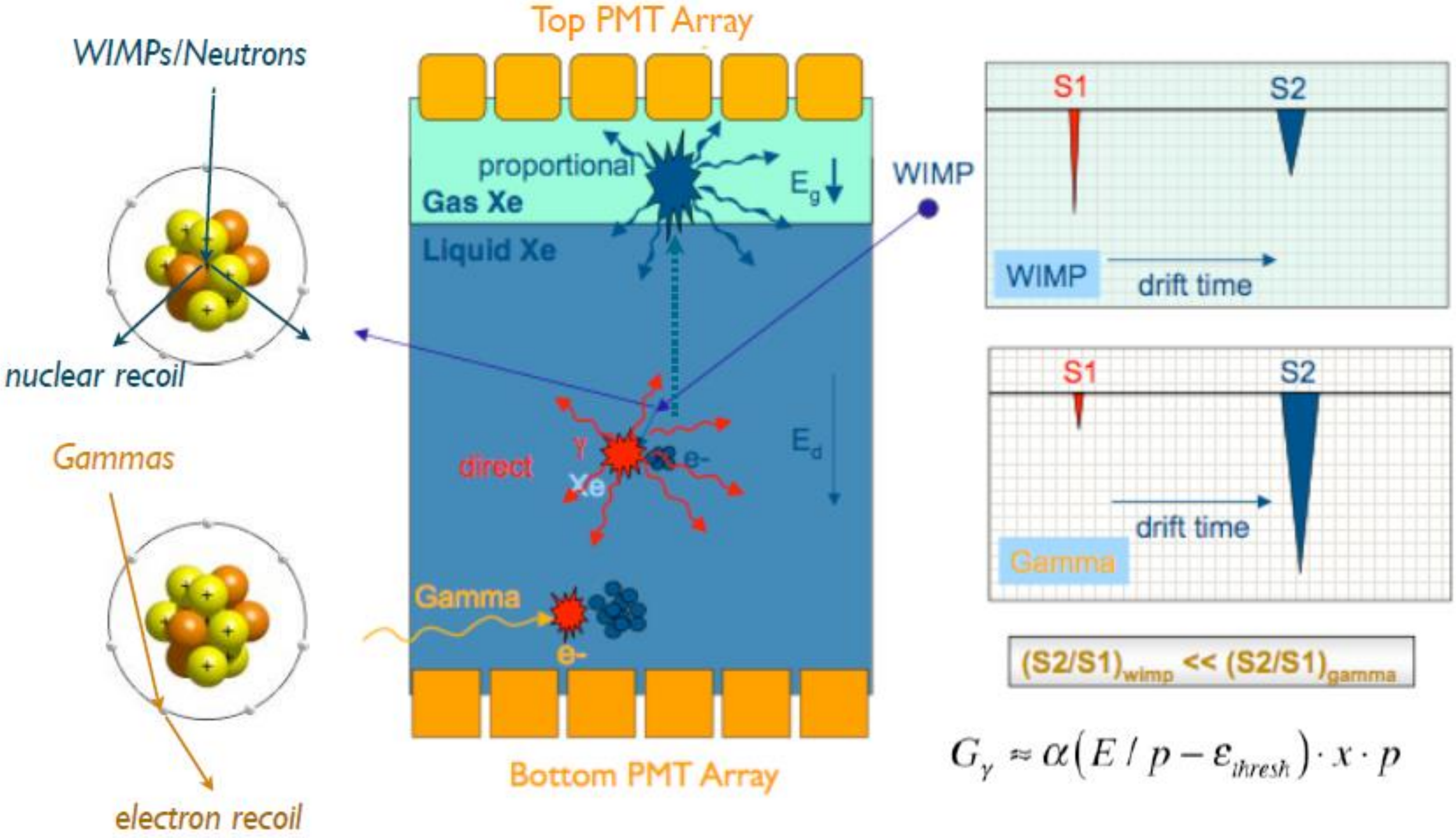
MIMAC : low-pressure gas TPC for directional search

2-phase liquid xenon TPC

In large volumes, neutrons interact several times, allowing background rejection.

DARK MATTER SEARCH

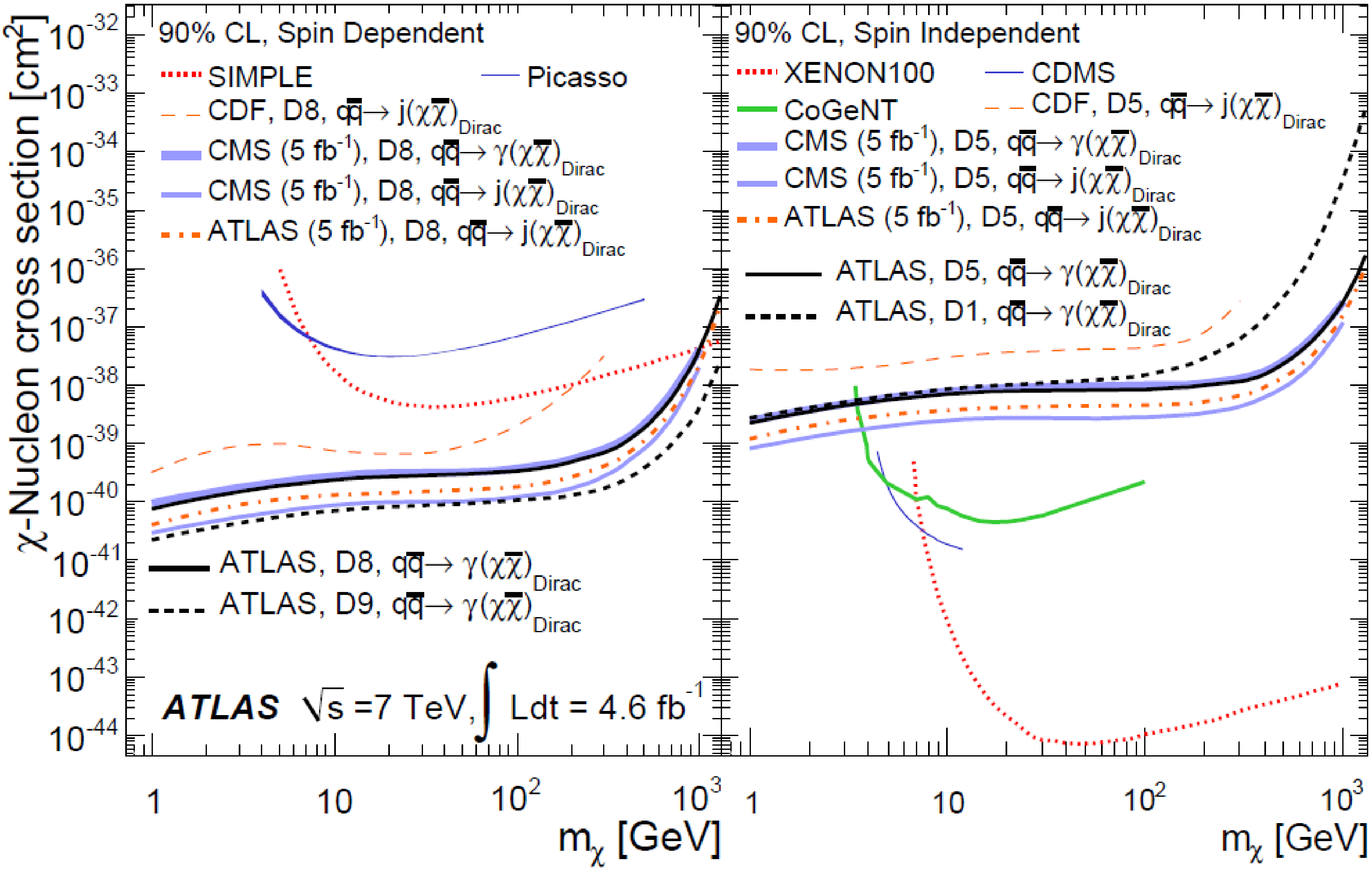
The XENON two-phase TPC concept



$(S2/S1)_{wimp} << (S2/S1)_{gamma}$

$$G_\gamma \approx \alpha\left(E/p - \varepsilon_{thresh}\right)\cdot x \cdot p$$

$$\alpha_{LXe} = 70\ \gamma/kV \quad \varepsilon^{LXe}_{thresh} = 1.3kV/cm/atm$$


χ-Nucleon cross section [cm²]
90% CL, Spin Dependent
SIMPLE
Picasso
CDF, D8, qq̄→ j(χχ̄)Dirac
CMS (5 fb-1), D8, qq̄→ γ(χχ̄)Dirac
CMS (5 fb-1), D8, qq̄→ j(χχ̄)Dirac
ATLAS (5 fb-1), D8, qq̄→ j(χχ̄)Dirac
ATLAS, D8, qq̄→ γ(χχ̄)Dirac
ATLAS, D9, qq̄→ γ(χχ̄)Dirac
ATLAS √s =7 TeV, ∫ Ldt = 4.6 fb-1
90% CL, Spin Independent
XENON100
CDMS
CoGeNT
CDF, D5, qq̄→ j(χχ̄)Dirac
CMS (5 fb-1), D5, qq̄→ γ(χχ̄)Dirac
CMS (5 fb-1), D5, qq̄→ j(χχ̄)Dirac
ATLAS (5 fb-1), D5, qq̄→ j(χχ̄)Dirac
ATLAS, D5, qq̄→ γ(χχ̄)Dirac
ATLAS, D1, qq̄→ γ(χχ̄)Dirac
10-32
10-33
10-34
10-35
10-36
10-37
10-38
10-39
10-40
10-41
10-42
10-43
10-44
1
10
10²
10³
mχ [GeV]
1
10
10²
10³
mχ [GeV]

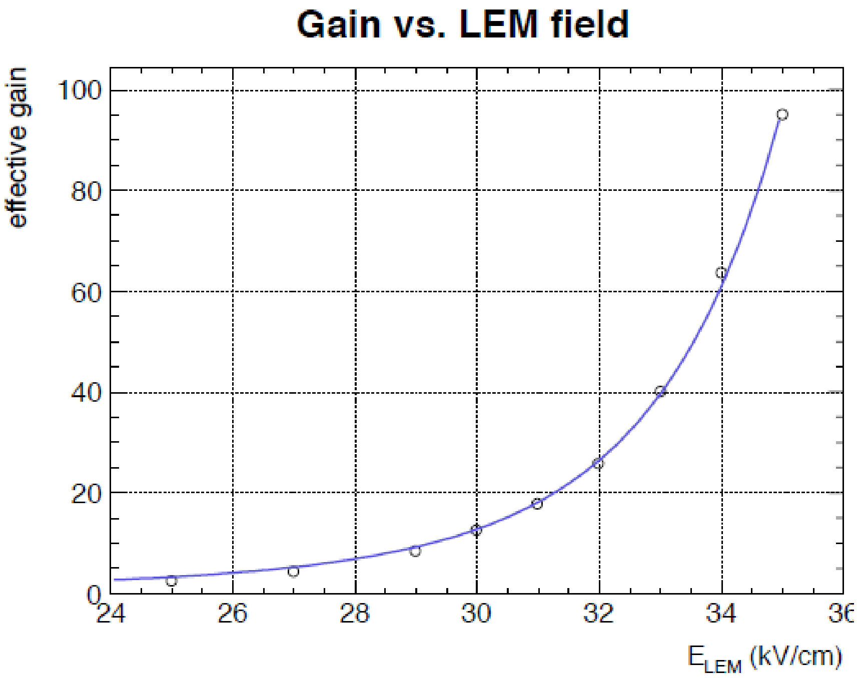
liquid noble gas TPC

GLACIER

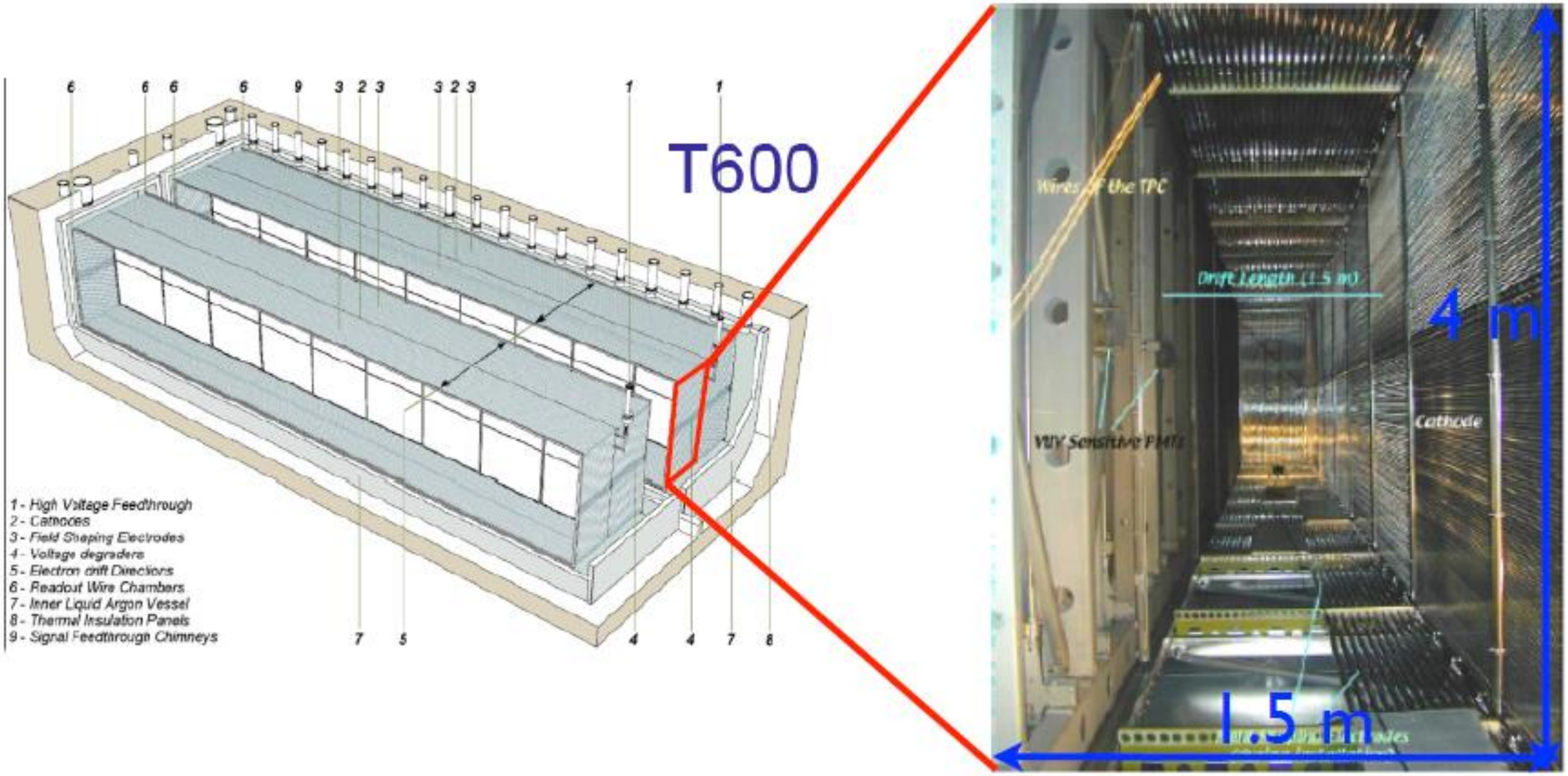
LBNE

PANDA-X

Xe-100

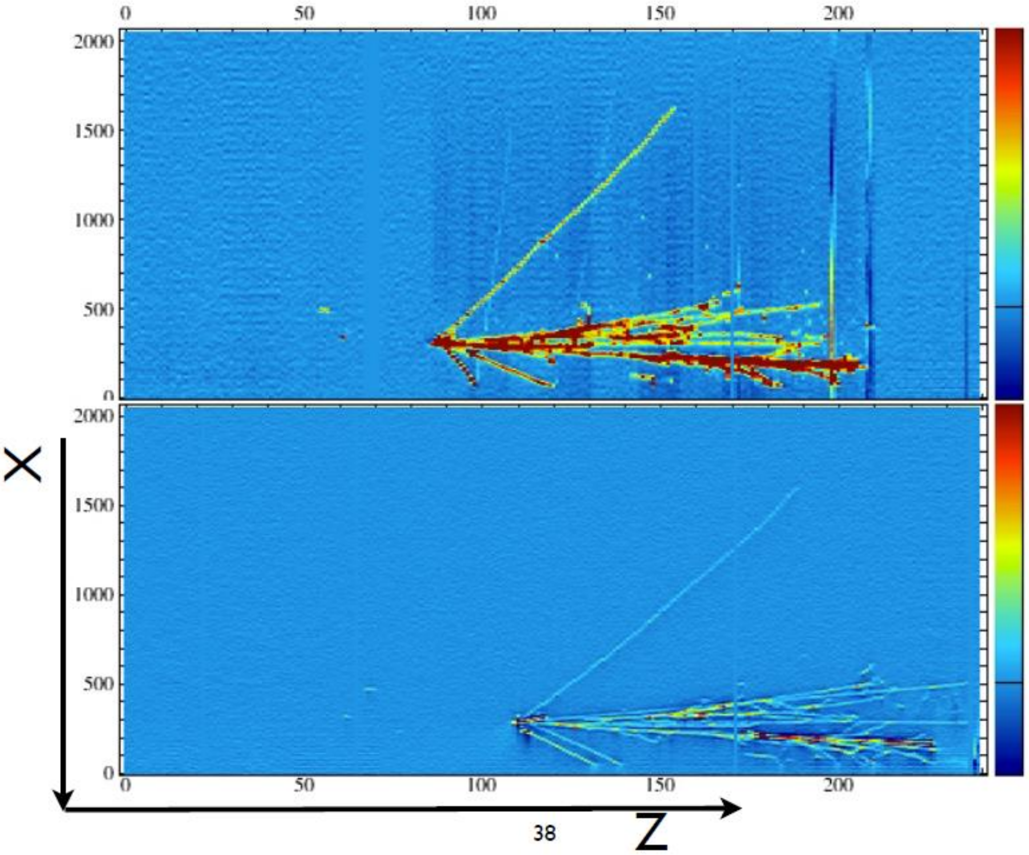


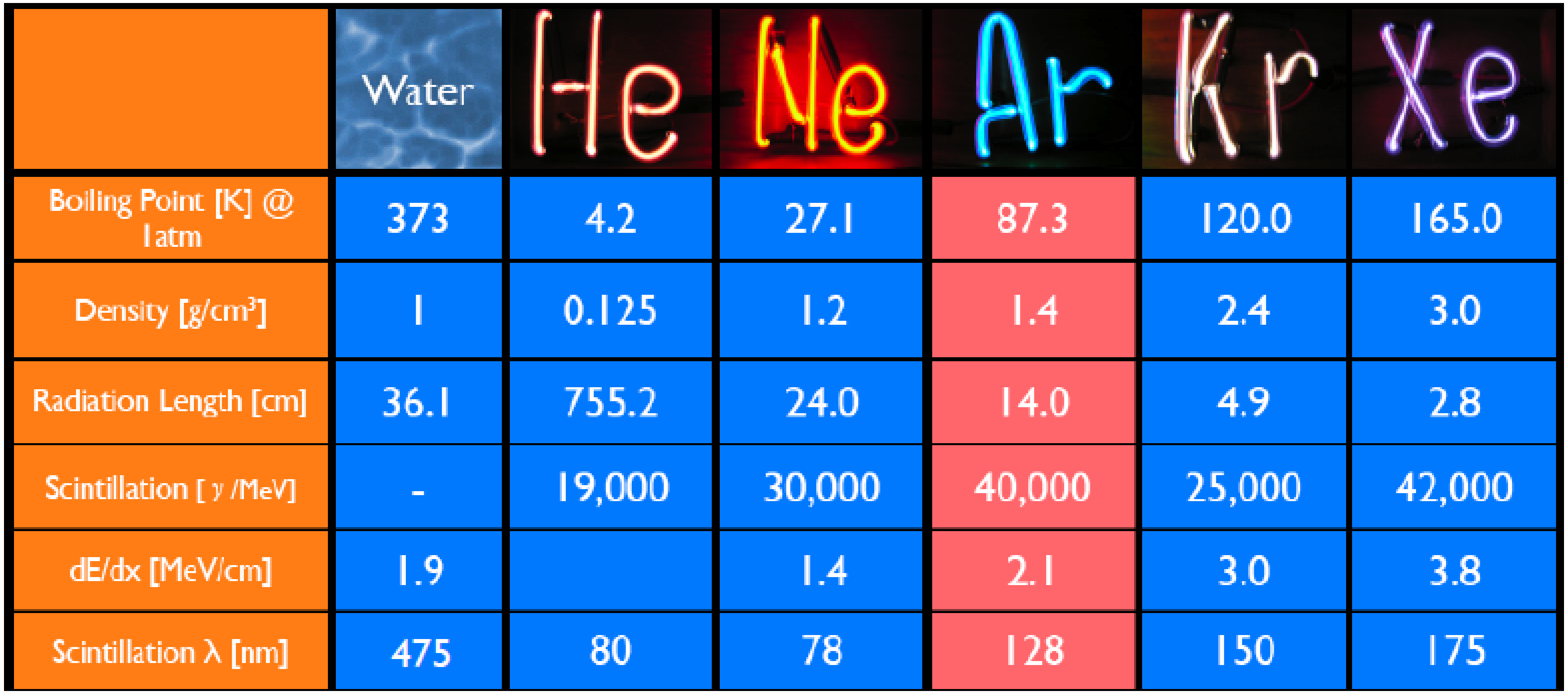
ICARUS



- First large liquid argon detector
- Culmination of 20 years of effort - 50 L → 3 t →300 t
- Provided solid foundation for future efforts

Neutrinos in ArgoNeuT



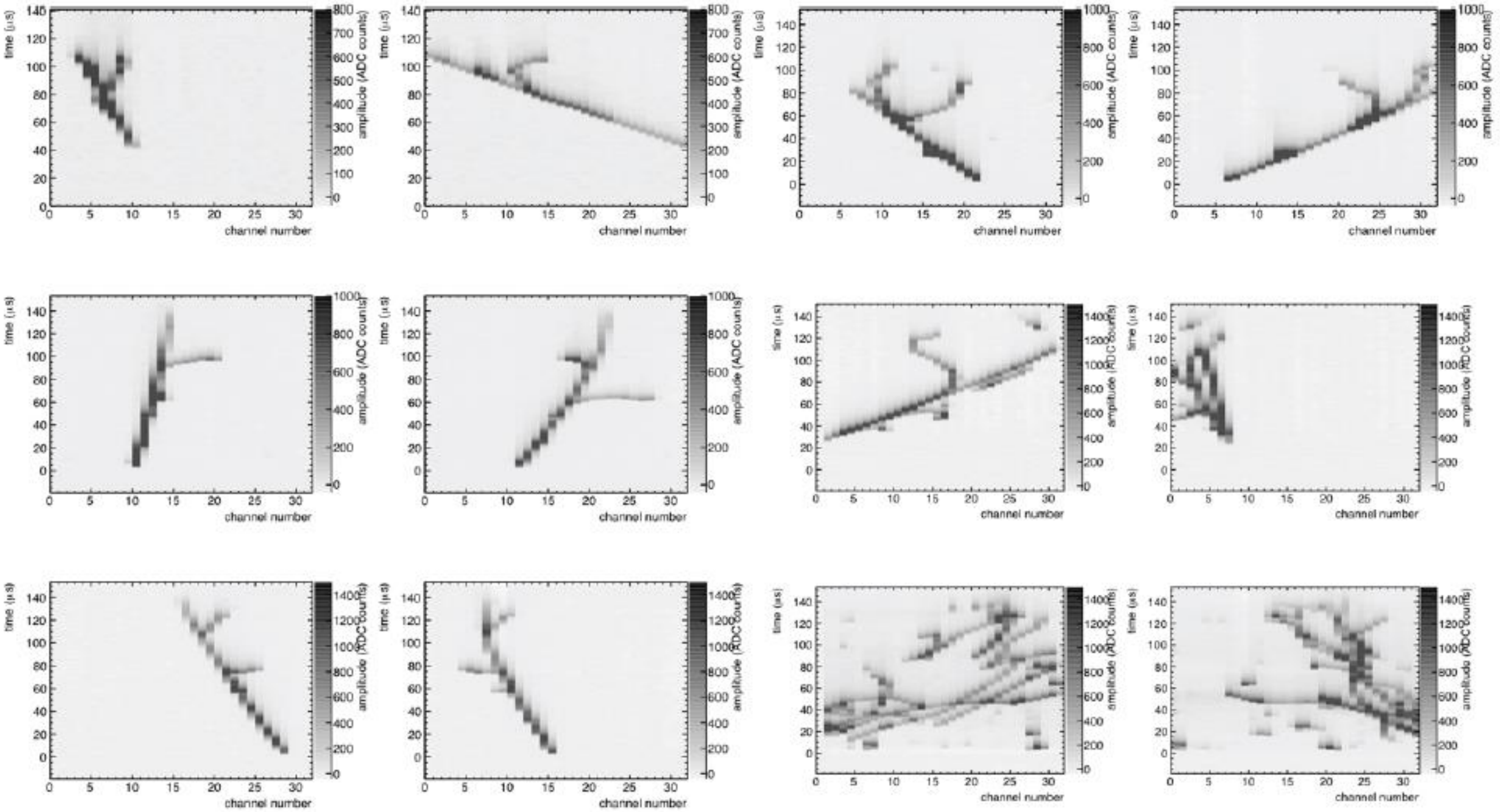


	Water	He	Ne	Ar	Kr	Xe
Boiling Point [K] @ 1atm	373	4.2	27.1	87.3	120.0	165.0
Density [g/cm^3]	1	0.125	1.2	1.4	2.4	3.0
Radiation Length [cm]	36.1	755.2	24.0	14.0	4.9	2.8
Scintillation [γ /MeV]	-	19,000	30,000	40,000	25,000	42,000
dE/dx [MeV/cm]	1.9		1.4	2.1	3.0	3.8
Scintillation λ [nm]	475	80	78	128	150	175

R&D for GLACIER (A. Rubbia et al.) : LEMs

(Similar results with Micromegas)

gain ~30



D. Lussi, RD51 mini-week (April 2013)

LOW MASS DARK MATTER SEARCH

The spherical TPC with ball amplification allows the range below 10 GeV to be studied, with nitrogen and He gases (Macro-Pattern Gaseous Detector)

CONCLUSION

Since almost 40 years of existence, the concept of TPC plays an important role in Particle Physics and Nuclear Physics.

It got a new blood in the recent years thanks to the introduction of MPGD readouts and various inventions.

It is now used in various fields of research a the Energy, Intensity and Cosmic frontiers.