Micromegas for Rare Events:
latests developments and plans

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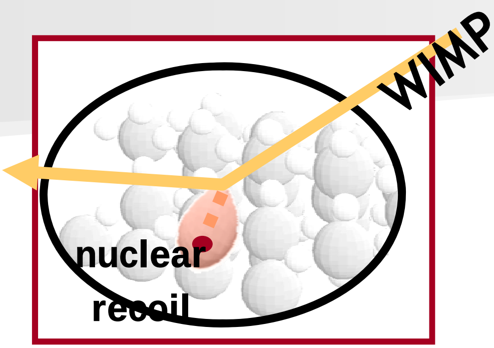
Summary:

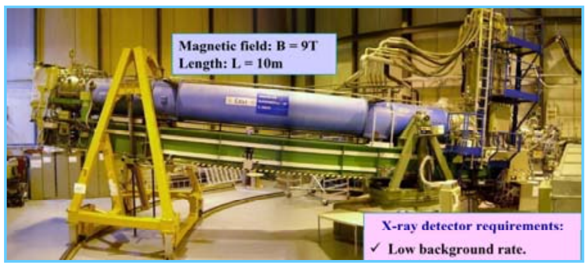
- Rare Events: WIMPs, axions and $0\nu\beta\beta$
- Micromegas in CAST
- High energy resolution in Micromegas
- NEXT: new proposal at Canfranc lab

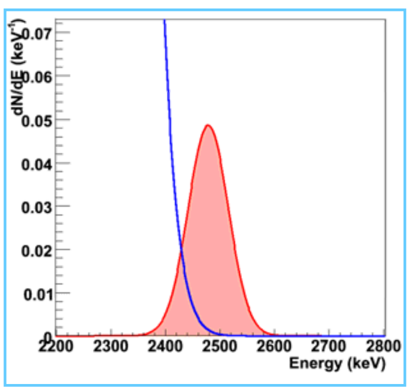
Acknowledgements:

Saclay, Athens, Zaragoza
CAST-groups
Zaragoza, Saclay, APC
NEXT groups (Zgz, Valencia, Barcelona, Saclay, Berkeley,…)

Rare Events and MPDGs







- Dark Matter WIMPs:
  - Unique signal identification by "directionality"
  - NEWAGE, DRIFT and MIMAC
- Axions from the Sun
  - Background suppression by topology
  - New Micromegas for CAST at CERN
- Double beta decay
  - Powerful topology signal identification & energy resolution
  - New initiative, NEXT, at Canfranc Underground Lab

The challenge of Rare Events

- Need for **large target masses**
- Need for **very low background** → extreme radiopurity, shielding, event discrimination.
- Need for **very good stability** of operation (very large exposures)
- **Simplicity in** operation and construction is a bonus.
- **Low threshold** (for WIMPs and axions)
- **Good energy resolution** (for DB)

All these requirements add up to a formidable challenge

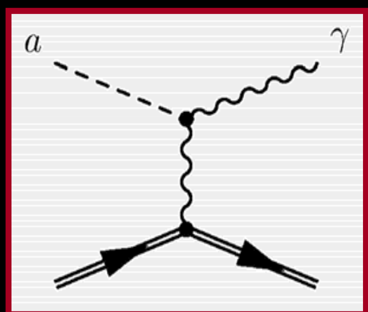
+
Construction &
Operation
underground

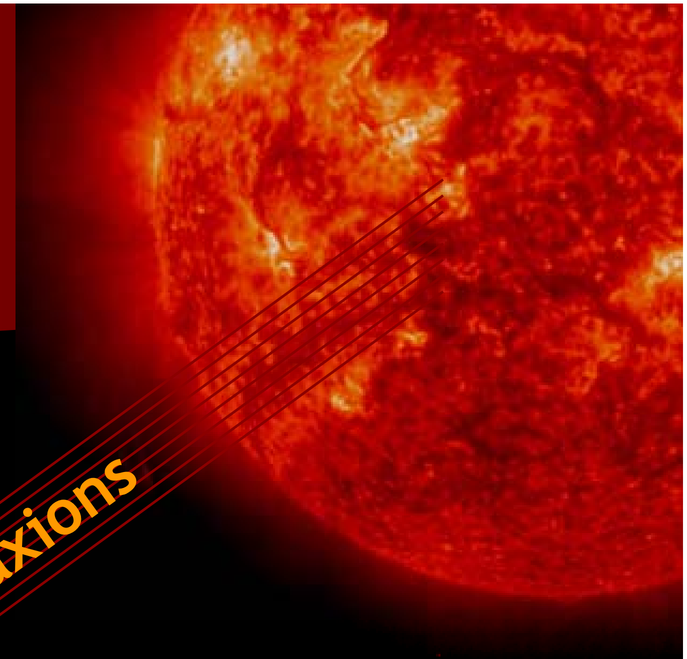
Latests advances in MPDGs, in particular, Micromegas, open the way to use gaseous detectors (TPCs) in Rare Event Searhces, facing these challenges without the traditional drawbacks of conventional TPCs.

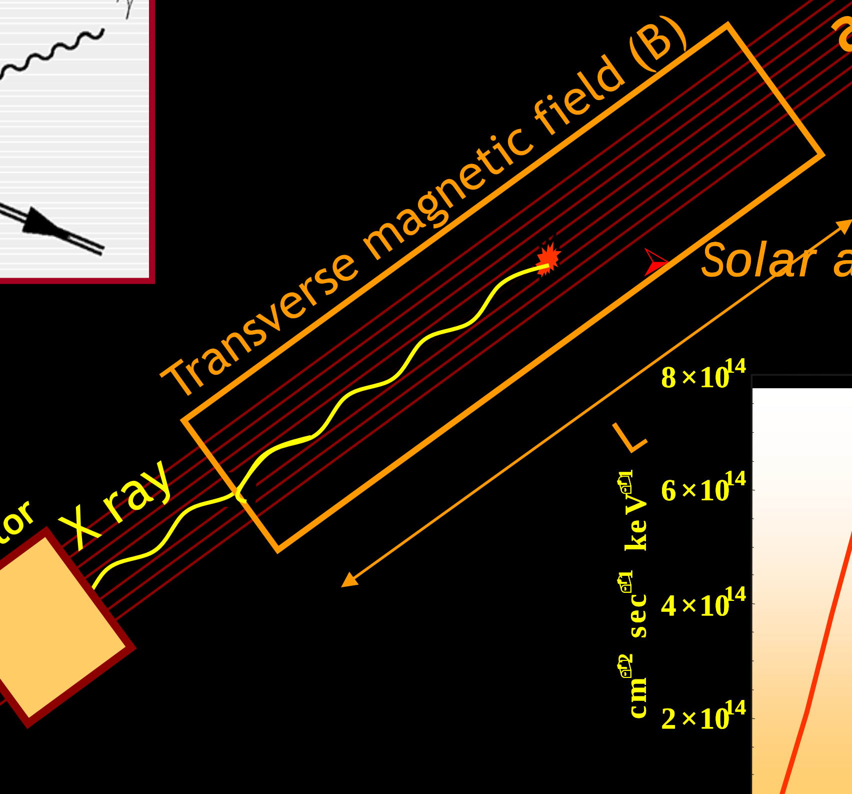
Solar Axions

- Principle of detection (**axion helioscope**)
  [Sikivie, PRL 51 (87)]

AXION PHOTON CONVERSION



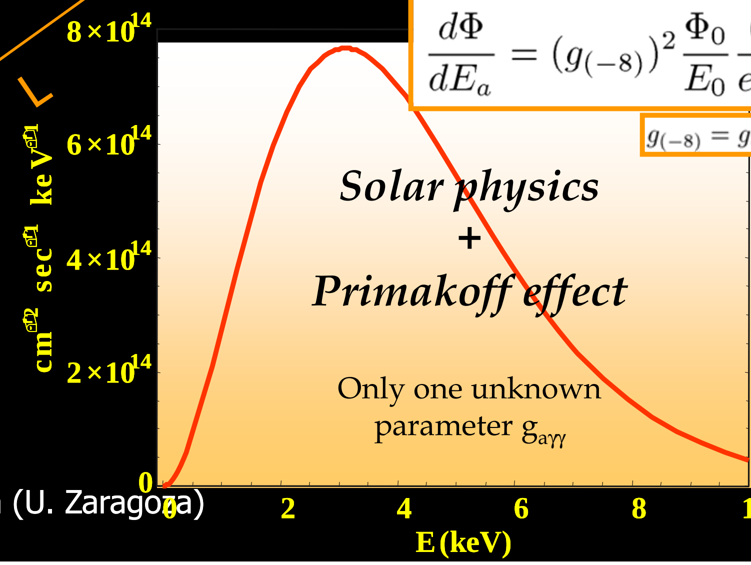




Solar axion flux *[van Bibber PRD 39 (89)]*

$$\frac{d\Phi}{dE_a} = (g_{(-8)})^2 \frac{\Phi_0}{E_0} \frac{(E_a/E_0)^3}{e^{E_a/E_0} - 1}$$

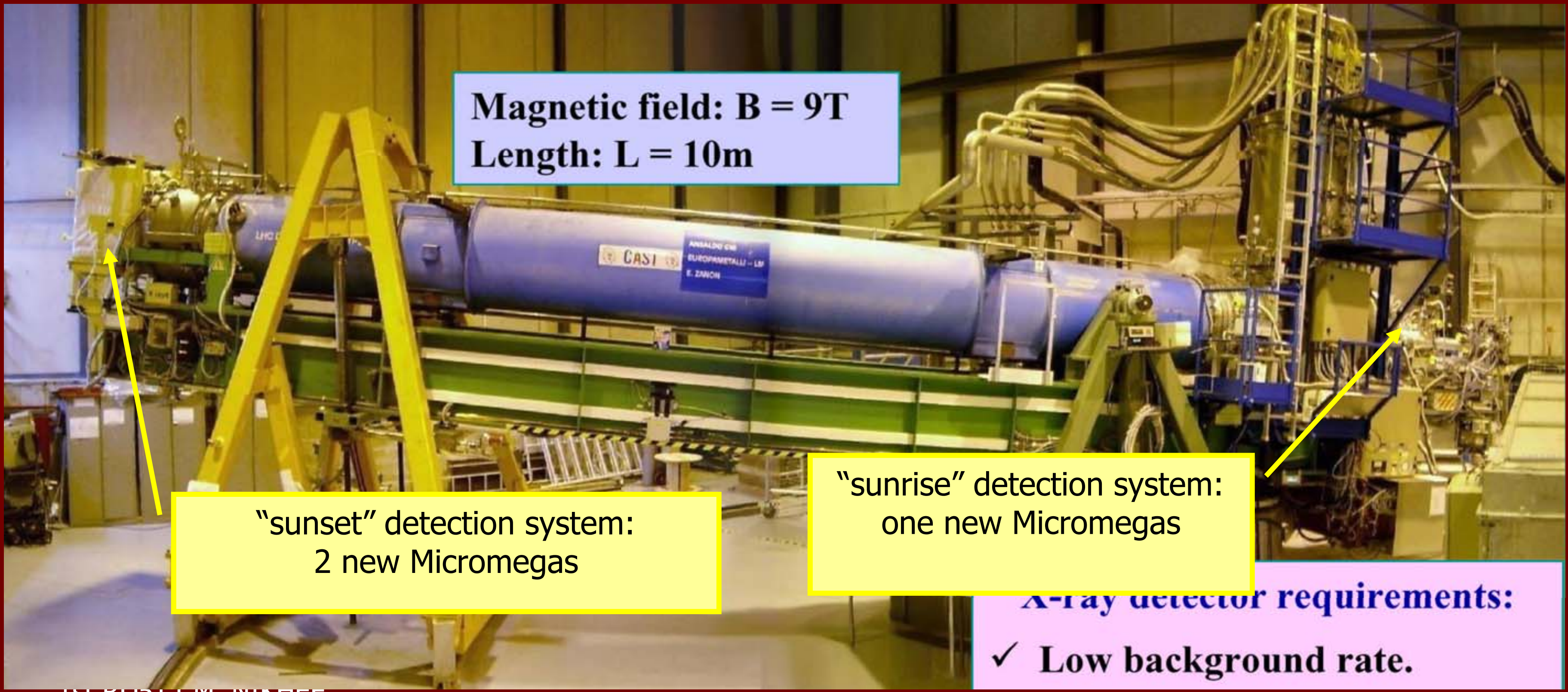
$g_{(-8)} = g_{a\gamma\gamma} \times 10^8/\mathrm{GeV}^{-1}$



51 CM, NIKHEF,

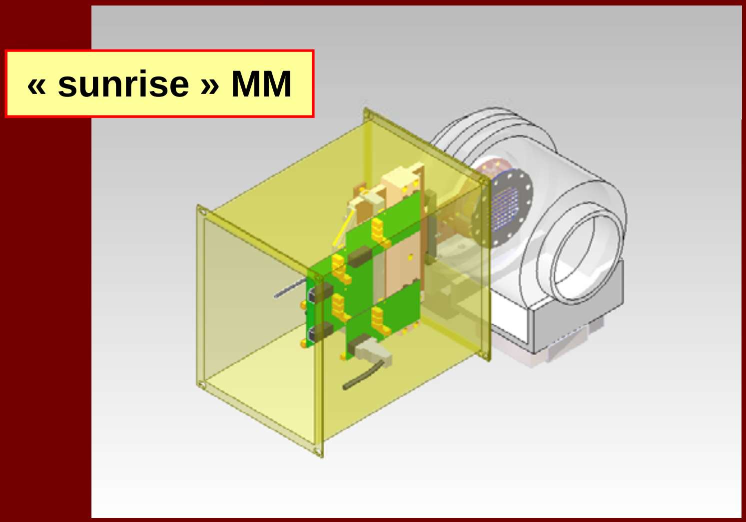
CERN Axion Solar Telescope (CAST)

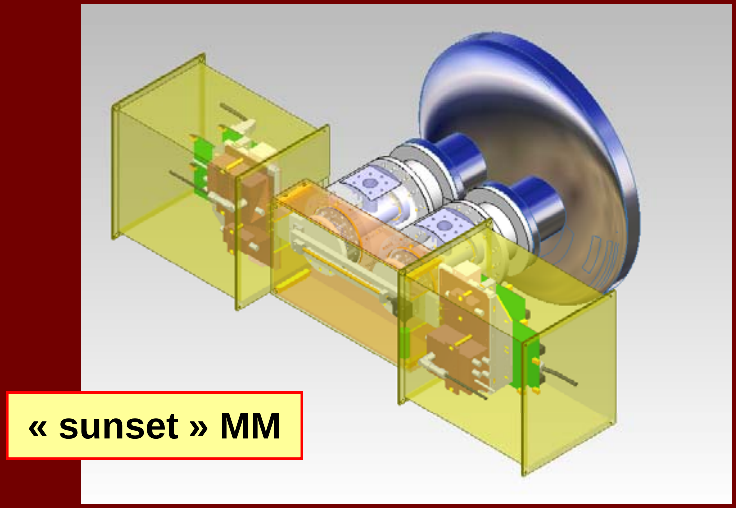
- **Decommissioned LHC test magnet (L=10m, B=9 T)**
- **Moving platform ±8°V ±40°H (to allow up to 50 days / year of alignment)**
- **4 magnet bores to look for X rays**
- **3 X rays detector prototypes being used.**
- **X ray Focusing System to increase signal/noise ratio.**



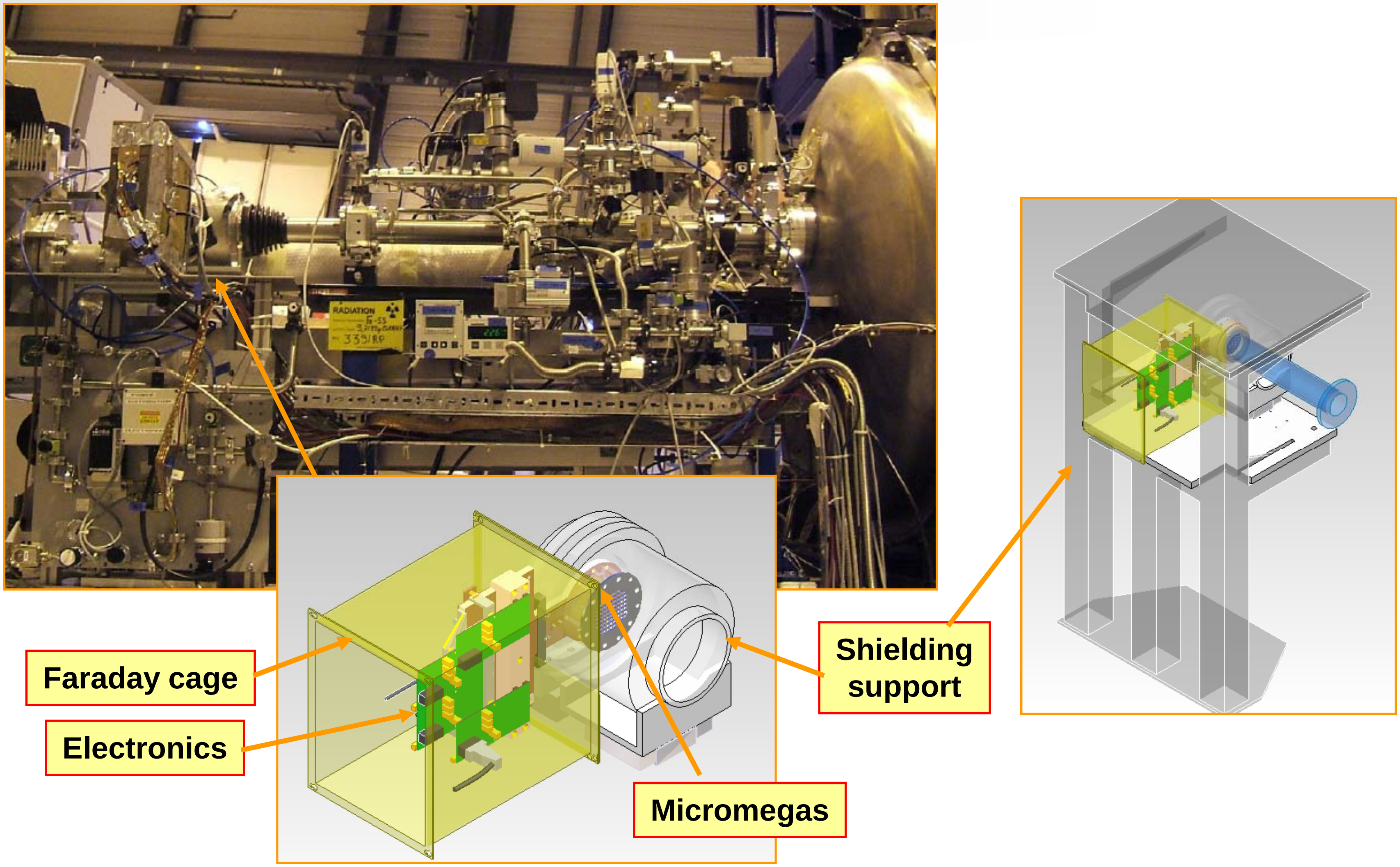
New detectors for CAST

- At the sunset side, replace conventional multiwire TPC.
- At the sunrise side, replace old un-shielded MM, with a more optimized design (very small space), able to accommodate shield and a possible X-ray focusing device.
- Higher efficiency.
- Lower background (shielding)
- Robustness



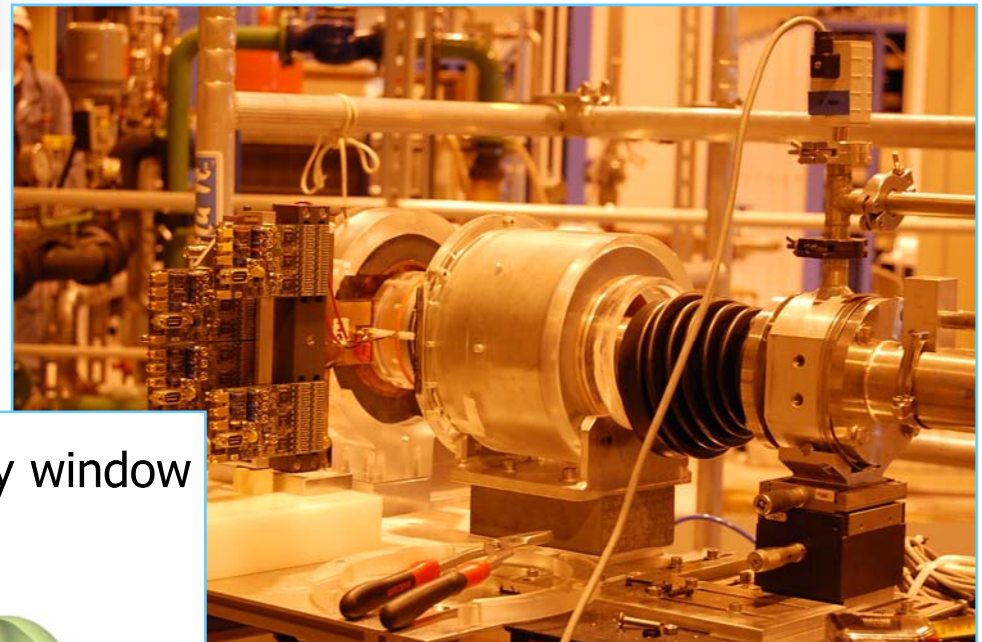


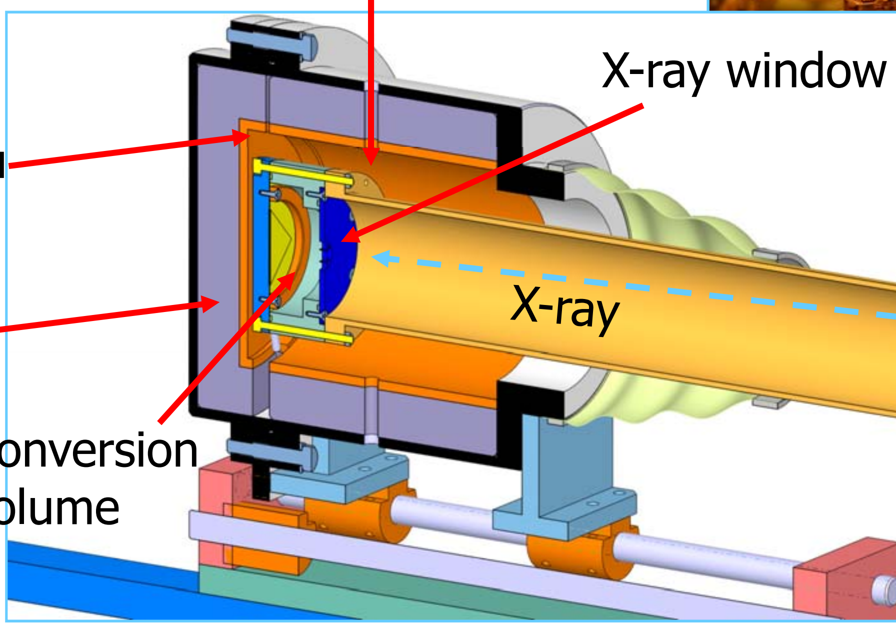
New “sunrise” CAST Micromegas



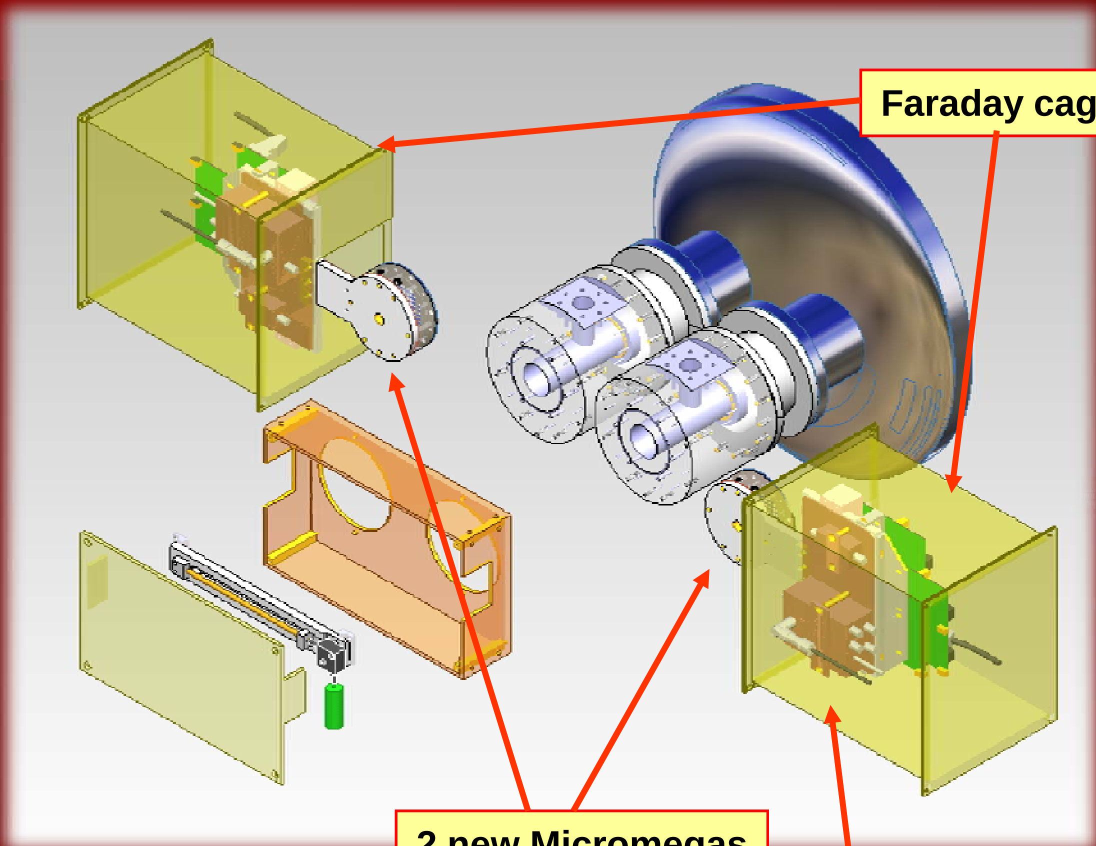
New "sunrise" CAST Micromegas

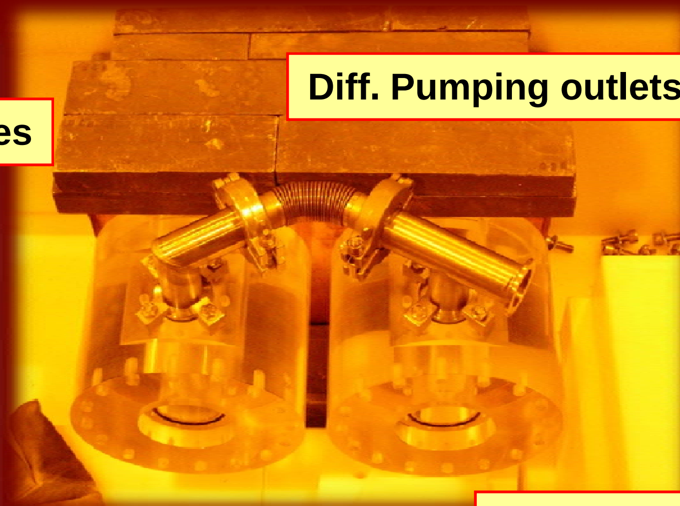
- More optimized mechanical design
- Shielding



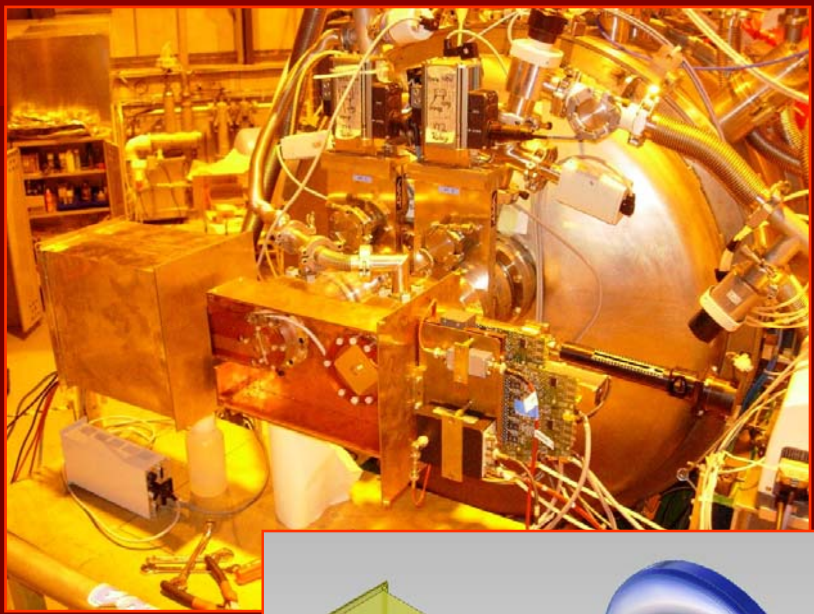


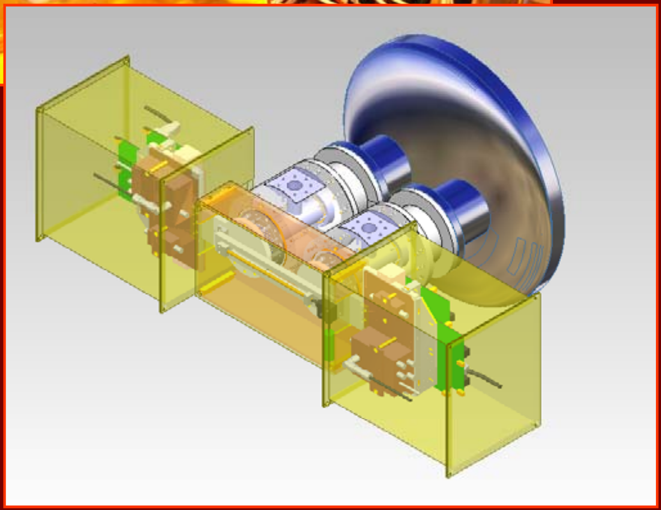
New “sunset” CAST Micromegas





New "sunset" CAST Micromegas

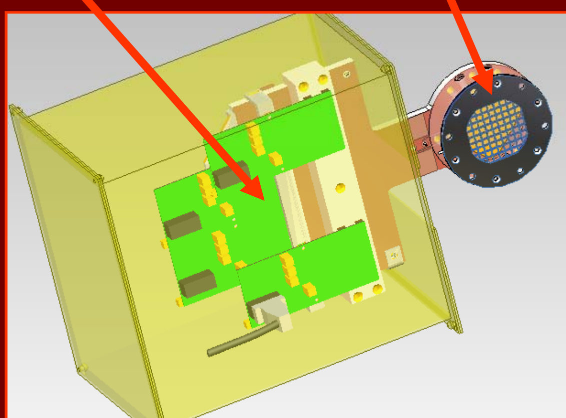


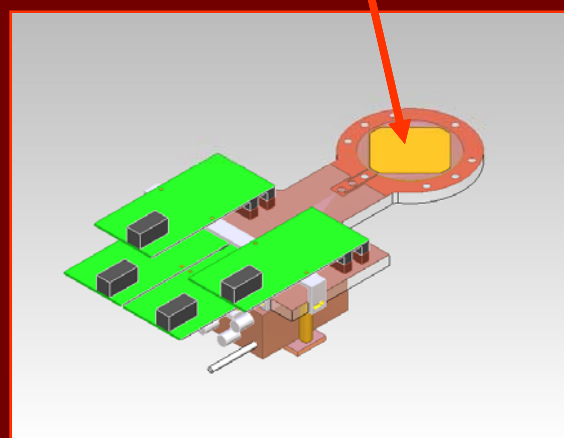


- TPC shielding and setup adapted to the new detectors…

The detectors: new design

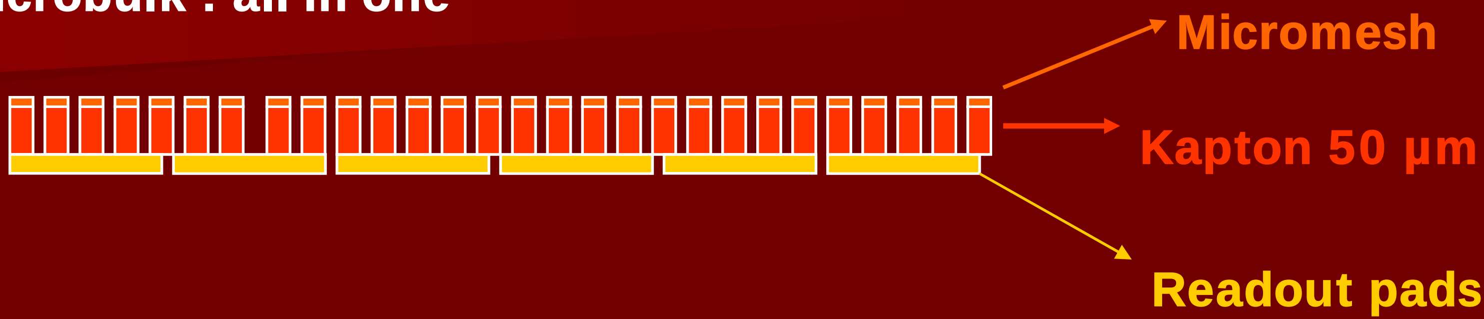
- Microbulk technology
- 106 × 106 strips, 0.5 mm pitch
- Compact construction to fit with shielding
- Very good energy resolution
- Same mechanics for both sunset and sunrise



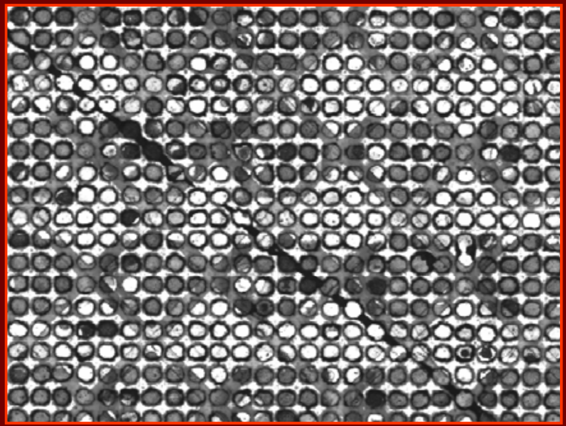


Microbulk manufacturing technique

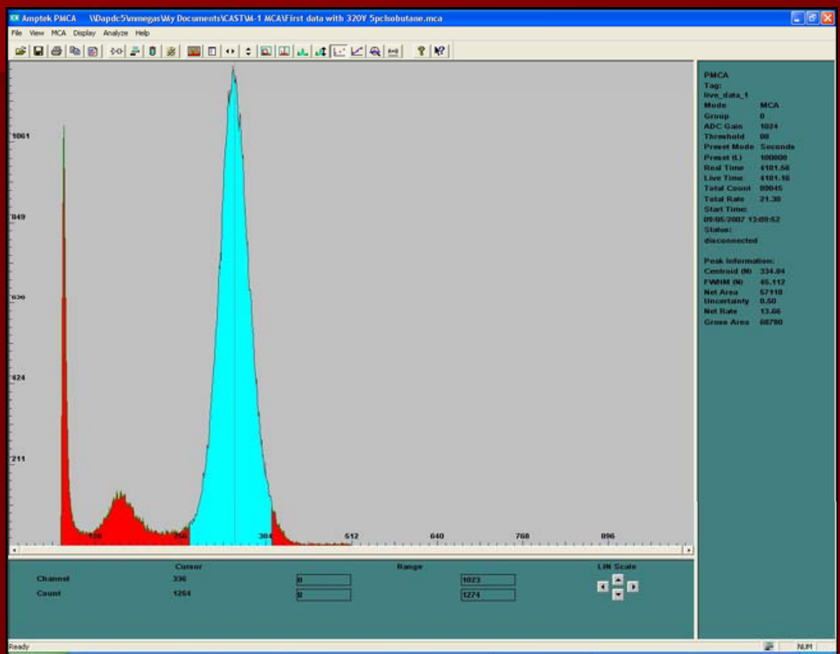
Microbulk : all in one

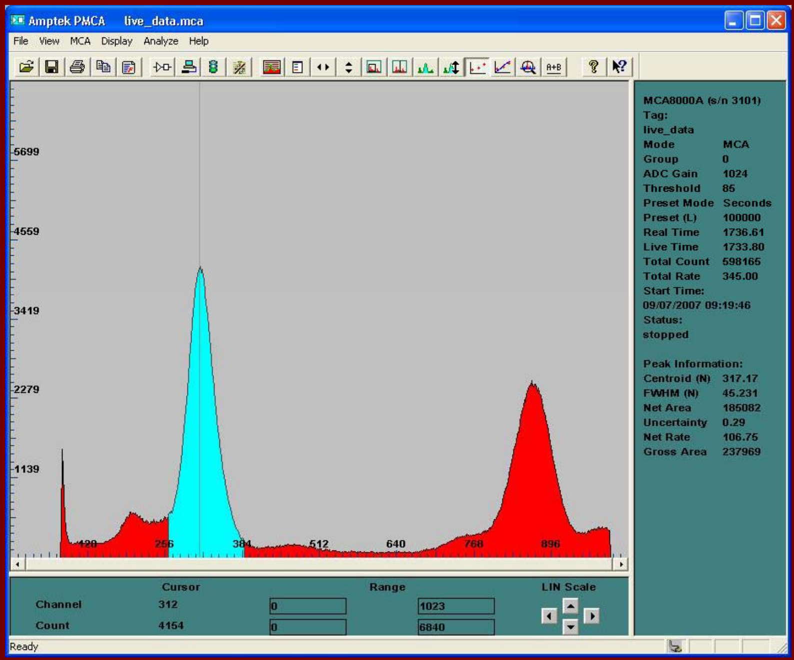


- Developed by Saclay/CERN (see Yannis´talk)
- Manufactured at Rui´s workshop at CERN
  - Better E resolution
  - Easier construction and manipulation
  - Robustness
- First time this kind of detector is used an experiment.
- Intense RD activity during 2007 to meet CAST schedule. Numerous manufacturing issues have been debugged.



First data with new detectors

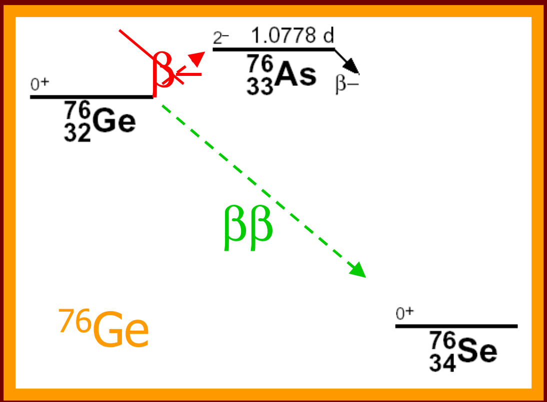




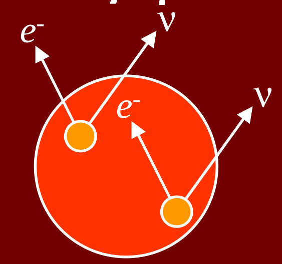
- Energy resolution:
  - @ 5.9 keV~13% FWHM
  - @ 8 keV~14% FWHM

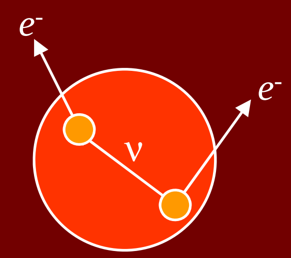
Neutrinoless Double Beta (0νββ)

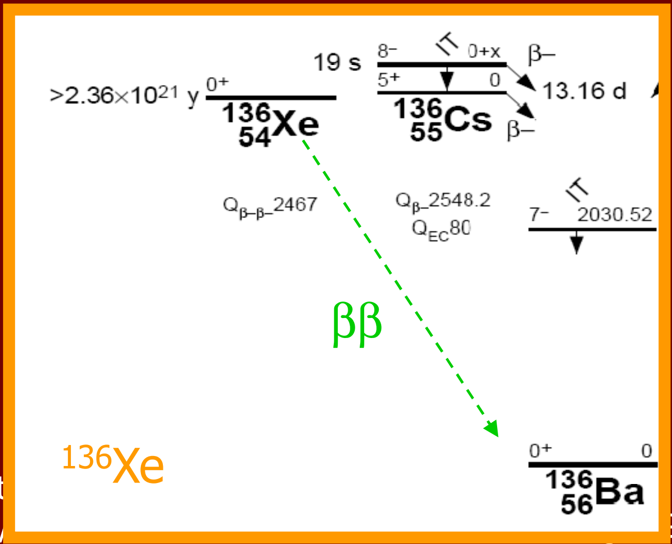
- ββ decay is relevant when the nucleus cannot decay β.



- ✓ With emission of 2 ν (2νββ). Standard process, observed in a number of isotopes.
- ✓ With no neutrino (0νββ). Only possible if neutrino is massive and Majorana. Not yet seen(*).



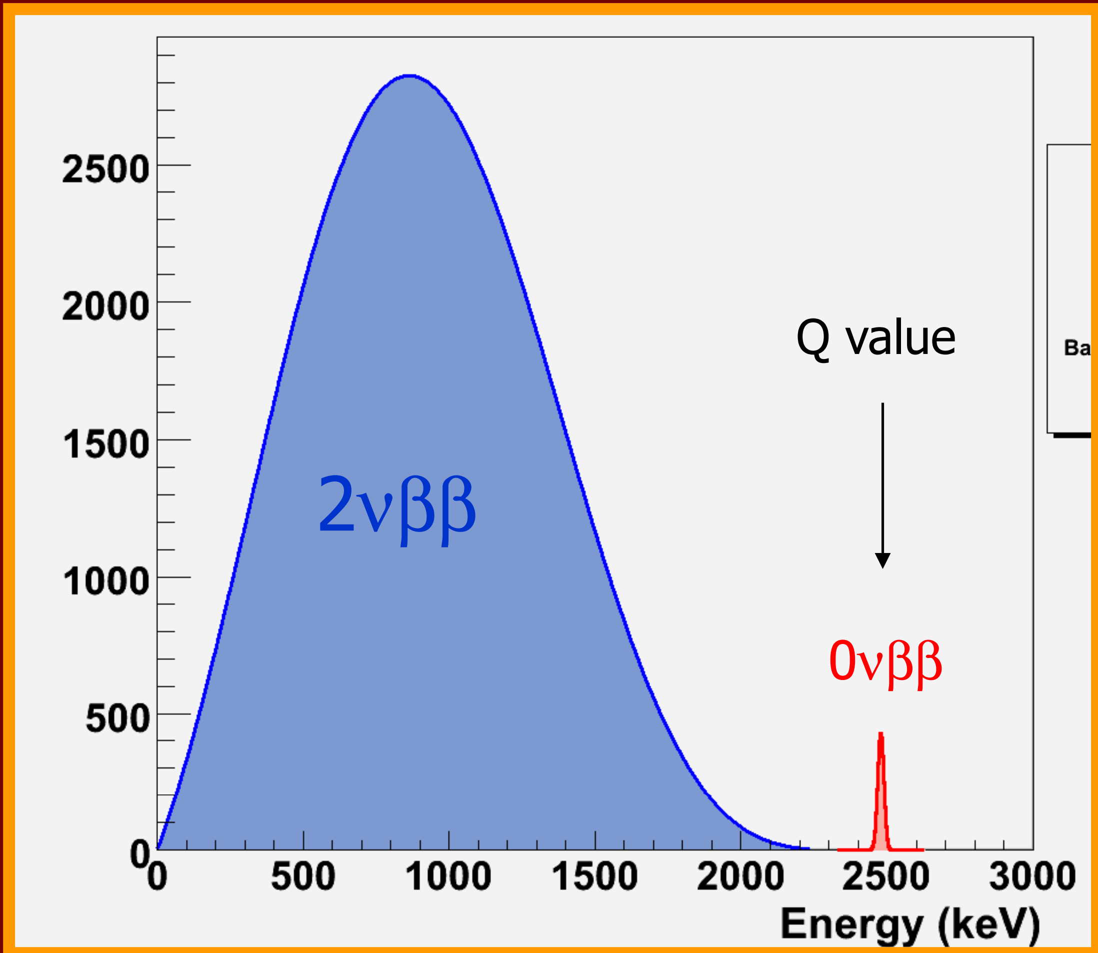


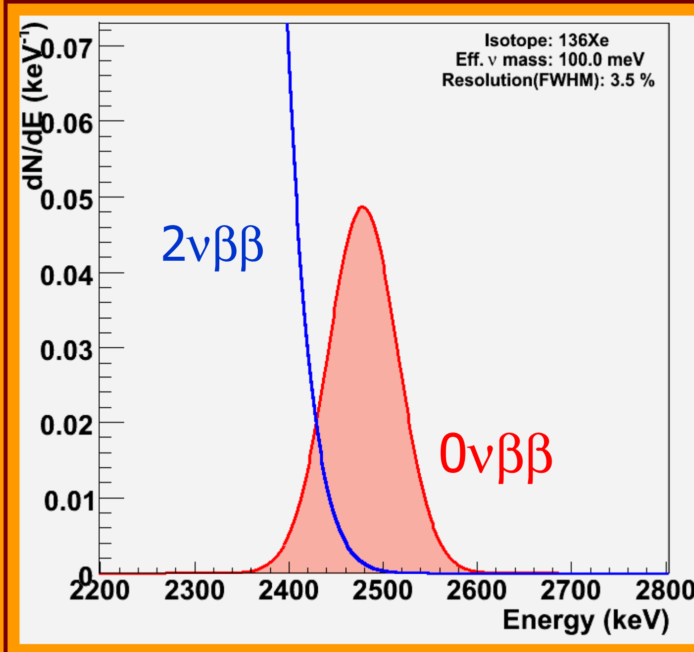


- Precious information on neutrino properties (mass scale, Majorana/Dirac nature,…)

Neutrinoless Double Beta (0νββ)

- "Visible" energy (i.e. the 2 e⁻) spectrum:

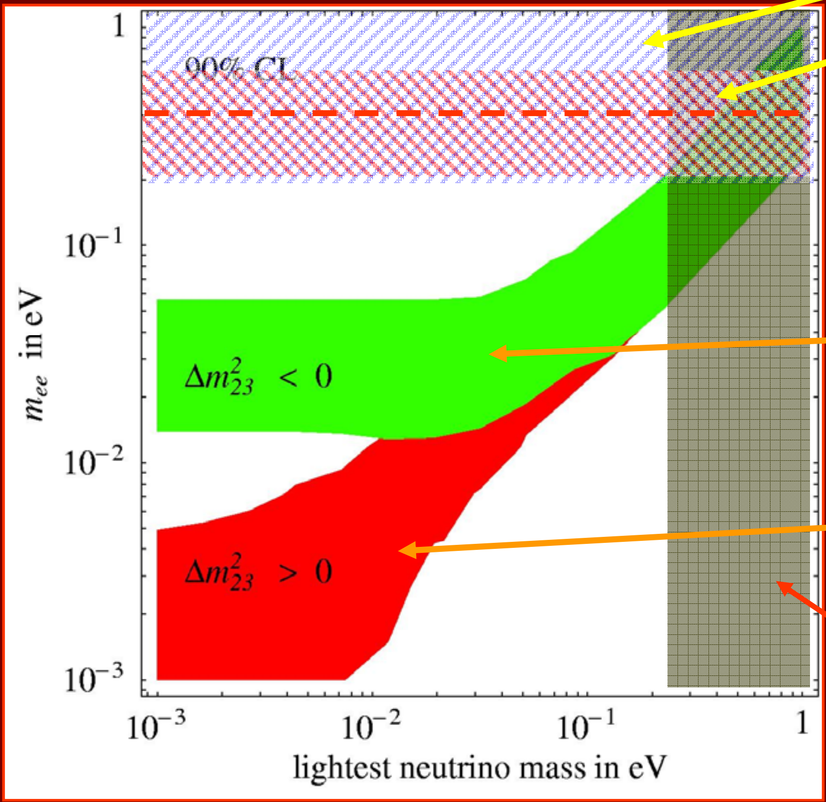




- Energy resolution very important. **Only way to distinguish between both processes**

Neutrino mass scale and 0νββ

- IGEX (^{76}Ge) $\langle m_\nu \rangle$ < 0.33 – 1.35 eV PRD65(02)092007
- NEMO-3 (^{100}Mo) $\langle m_\nu \rangle$ < 0.6 – 1.3 eV PRL95(05)182302 & talk @ TAUP07
  expected next summer < 0.3 – 0.7 eV
- CUORICINO (^{130}Te) $\langle m_\nu \rangle$ < 0.2 – 1.1 eV PRL95(05)142501



Region being explored by present experiments

Possible evidence (0.2-0.6 eV)
PLB586(04)092007

"quasi" degeneracy
$m_1 \approx m_2 \approx m_3$

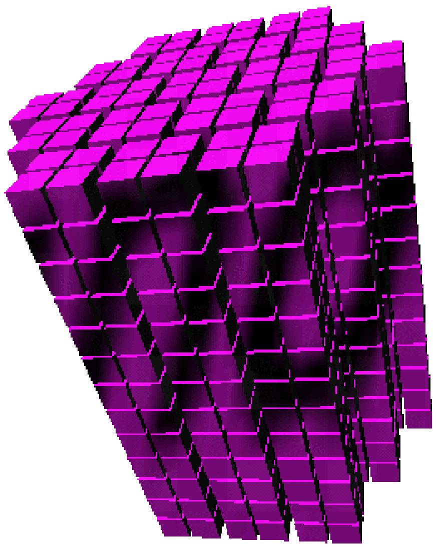
Inverse hierarchy
$\Delta m^2_{12} = \Delta m^2_{atm}$

Direct hierarchy
$\Delta m^2_{12} = \Delta m^2_{sol}$

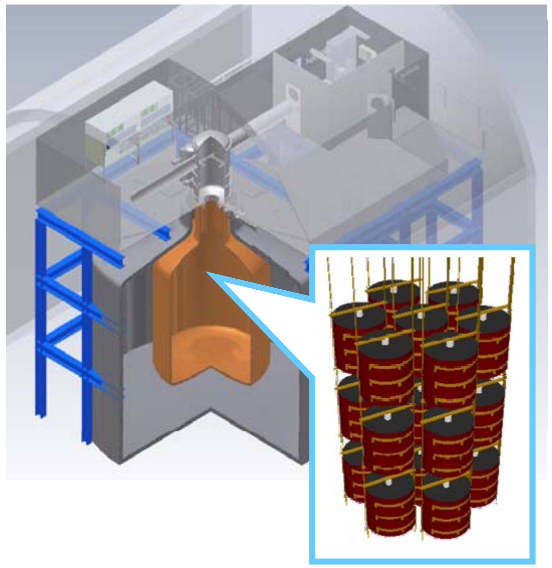
Cosmological disfavoured Region (WMAP)

Current generation ββ experiments

- Source = target
- Source ≠ target



CUORICINO/CUORE



GERDA

- •Good E resolution
- •Good scaling-up
- •BUT, modest background discri.

→strong requirements on radiopurity and shielding

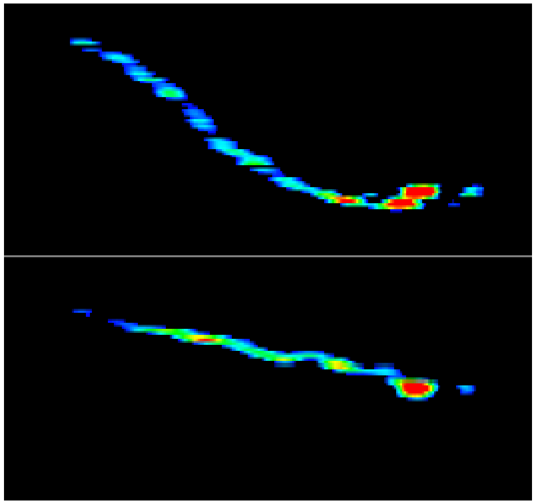
NEMO/SUPERNEMO

- •Event topology information
- •BUT, moderate energy resolution and difficult scaling up

Gas Xe TPCs for ββ?

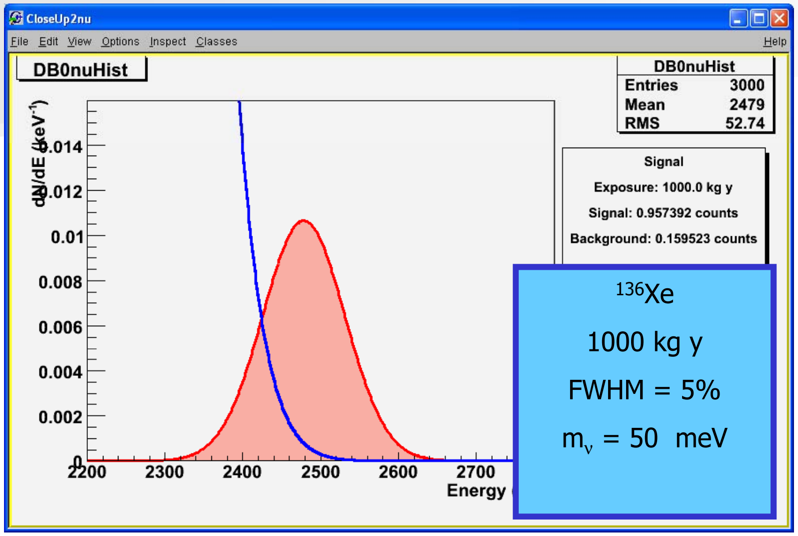
Are they competitive in the race towards ton or multiton scale exp's?

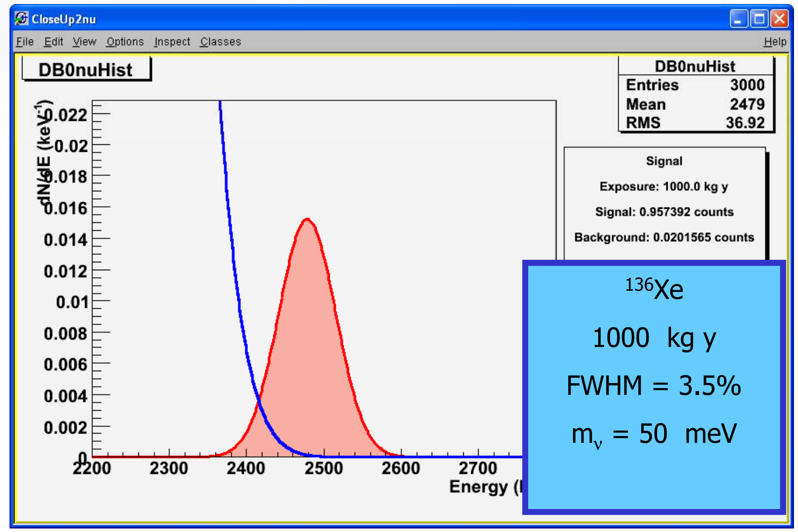
- Gas TPCs offer in principle the advantages of both previous approaches: topological signature & scaling-up
- But also:
  - Xe easy to enrich
  - No long lived isotope to activate
  - Very weak 2νββ mode (still to be measured!)
  - Single homogeneus medium (no surfaces/boundaries)
  - Ba++ taging, as proposed by EXO (R&D needed)

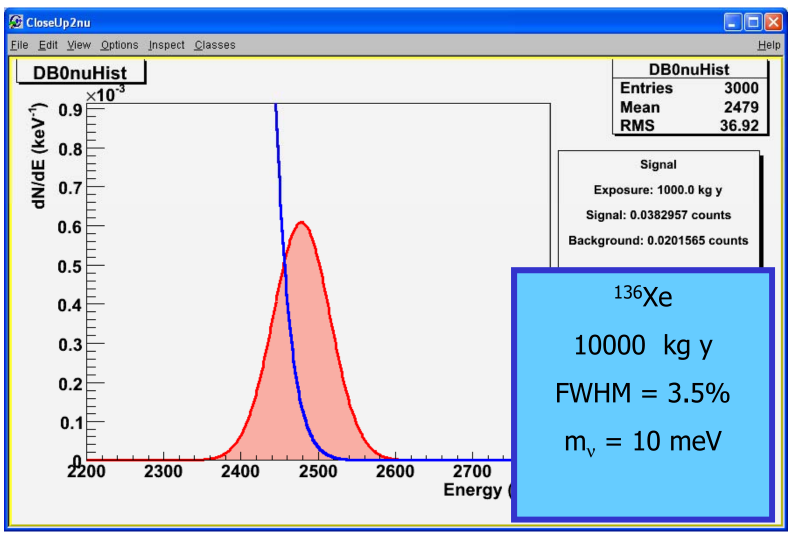


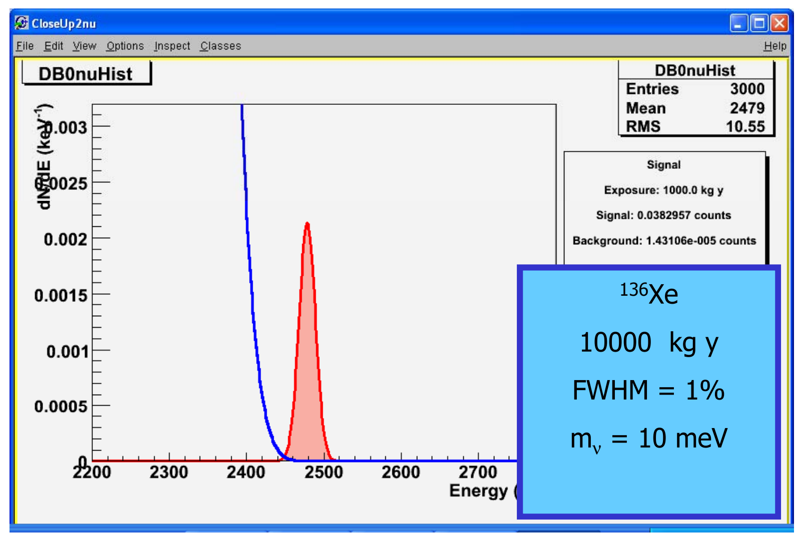
870 keV e- in the MUNU TPC

The role of E resolution @ the ton scale



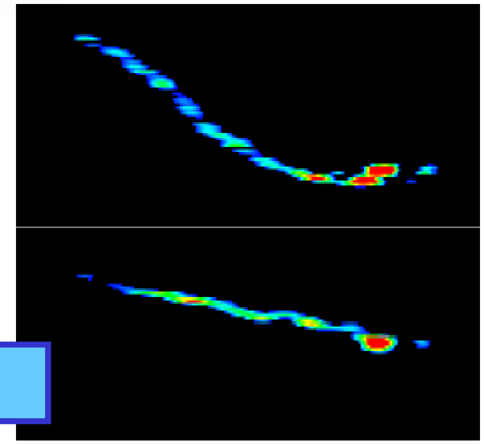


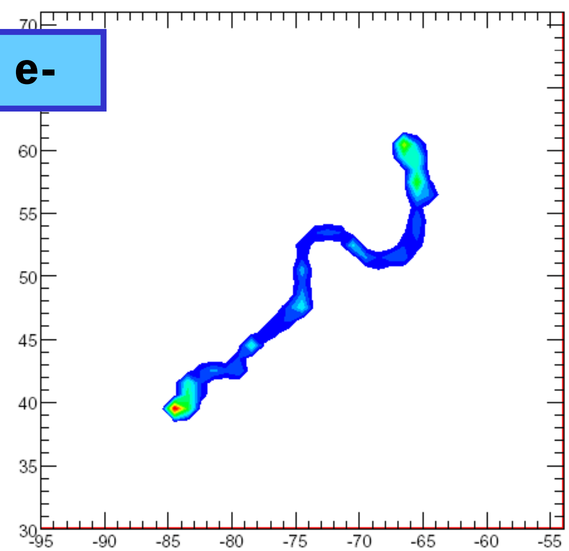




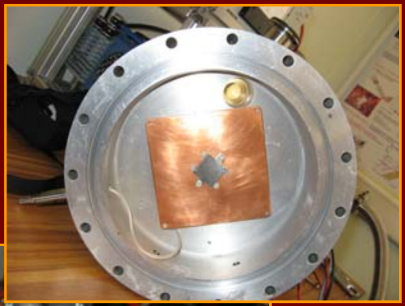
The topological signature

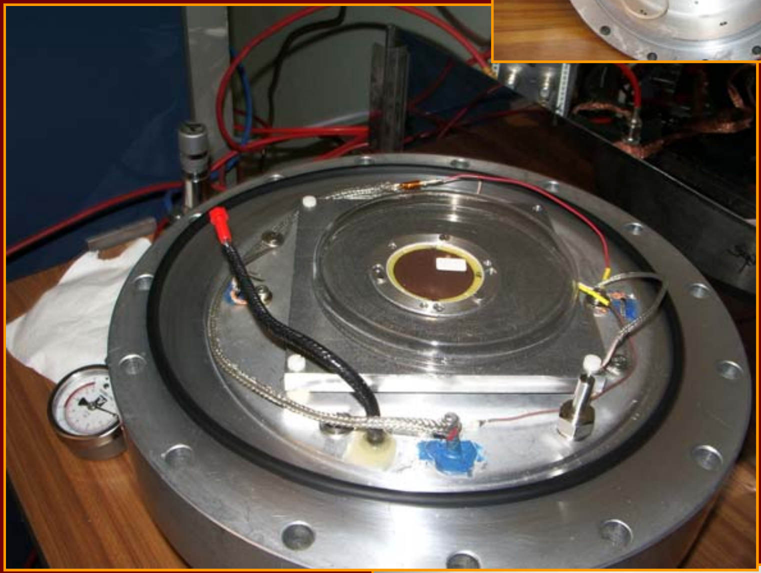
- A gas TPC have access to the "image" of the event.
- 1 e^- events and 2 e^- events have different topologies. This can be used to reject gamma background (1 e^-)
- Gothard demostrated that this can be done. They achieved a 96.5% efficiency in rejecting single e^- events. We may do better.
- **A gas TPC would have an extra handle to reduce background by a factor of at least 10^2 (most probably more?).**





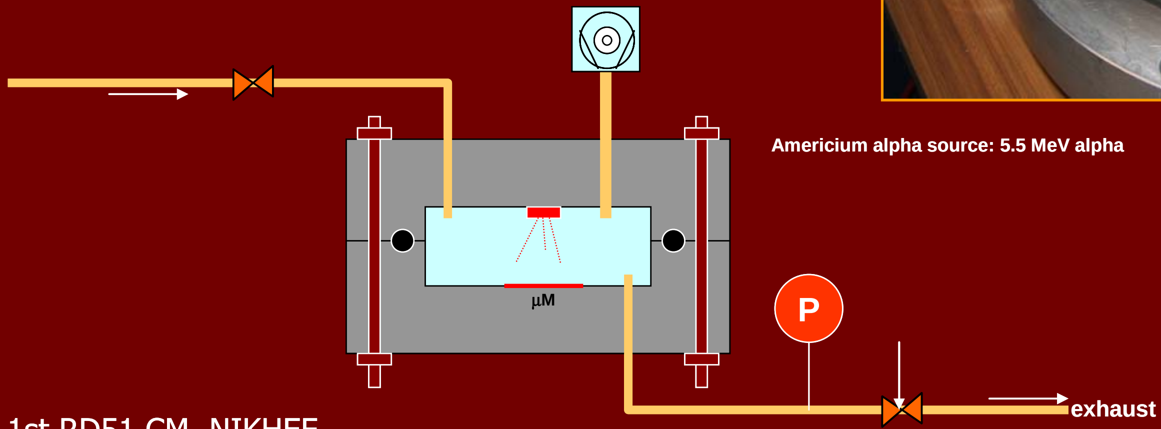
High energy resolution in Micromegas: ongoing tests





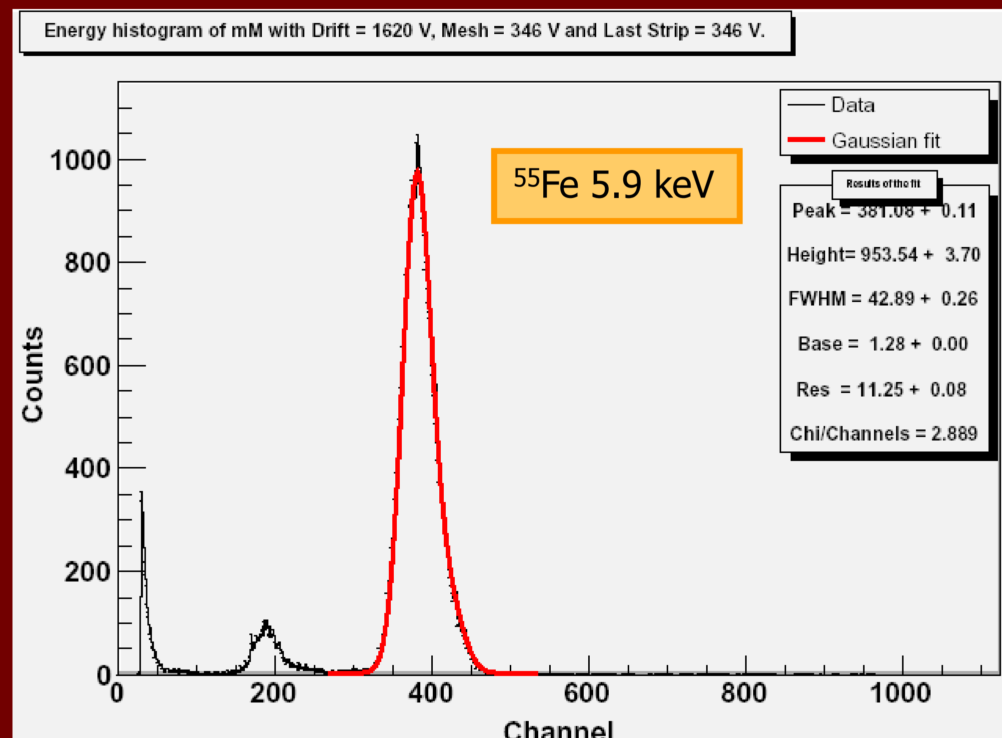
- Measurement of E resolution at high energies:
  - High pressure Ar+Isob small setup, read by new generation Micromegas readout (*microbulk*) non-pixelized anode

- Mixtures testes: Ar + Iso 2%, Ar + Iso 5%
- Pressures tested: from 1 to 5 bar



Energy resolution

- Readouts used first tested at low energy and atmosferic P
- 11% FWHM at 5.9 keV (^{55}Fe peak)



Energy resolution

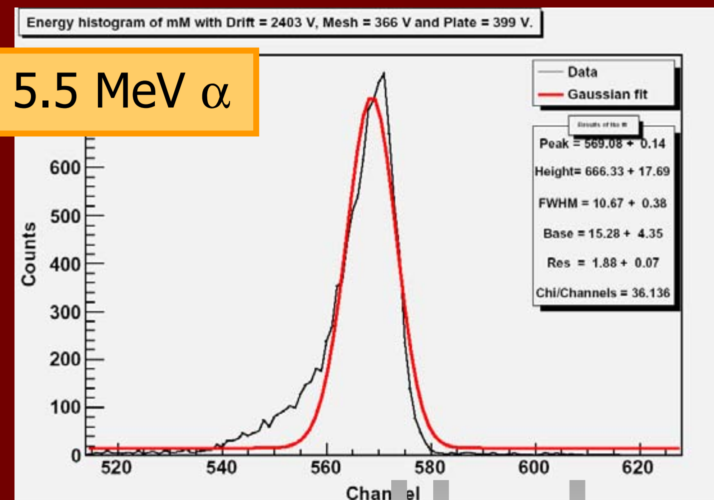
- Energy resolution tested with Am alphas source (5.5 MeV)
- Best resolution obtained:

1.5 – 2 % (FWHM)

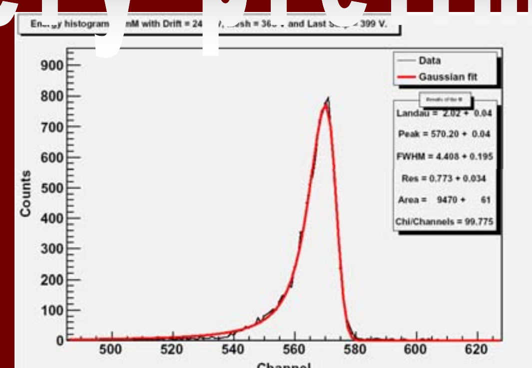
in a wide range of parameters (mesh and drift V, P, etc…)

- The **asymmetry** of the peak may indicate the presence of *external* effects (electrostatics, recombination, attachment, etc…) and that intrinsic limits are better.
- Landau deconvolution analysis indicate possible intrinsic Micromegas energy resolution of **0.7 % FWHM**.

Am 5.5 MeV α

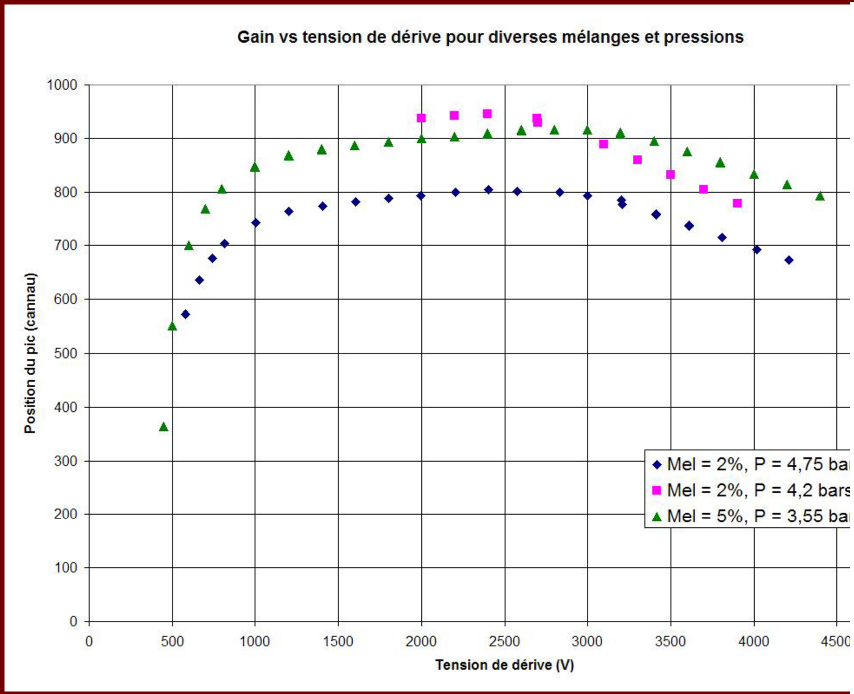


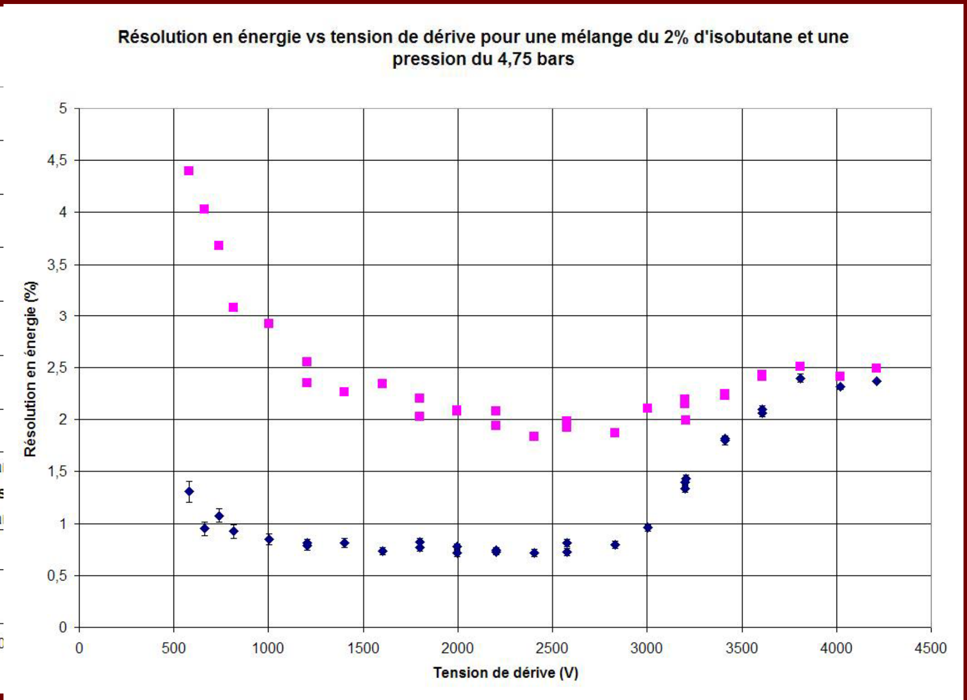
Very preliminary



Energy resolution

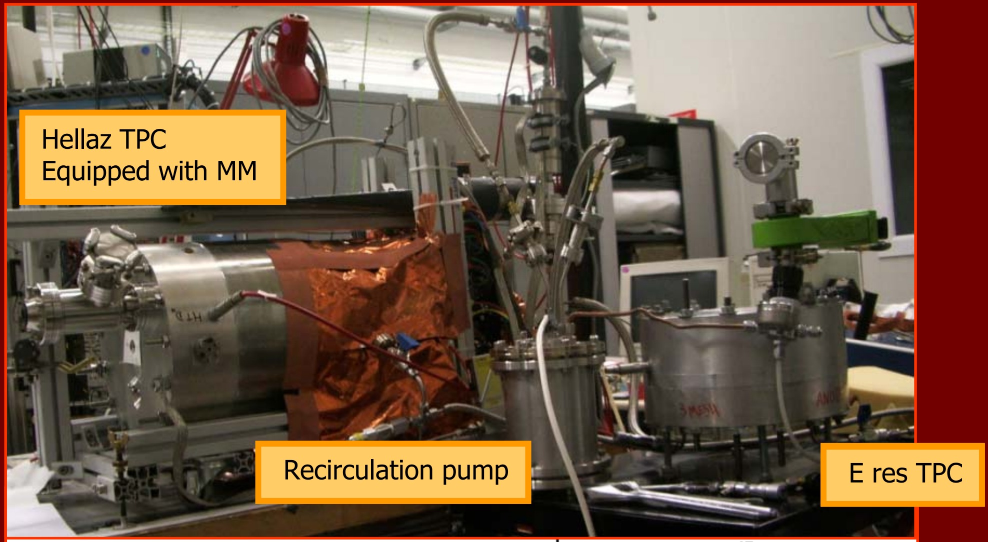
- Gain & resolution *plateau*

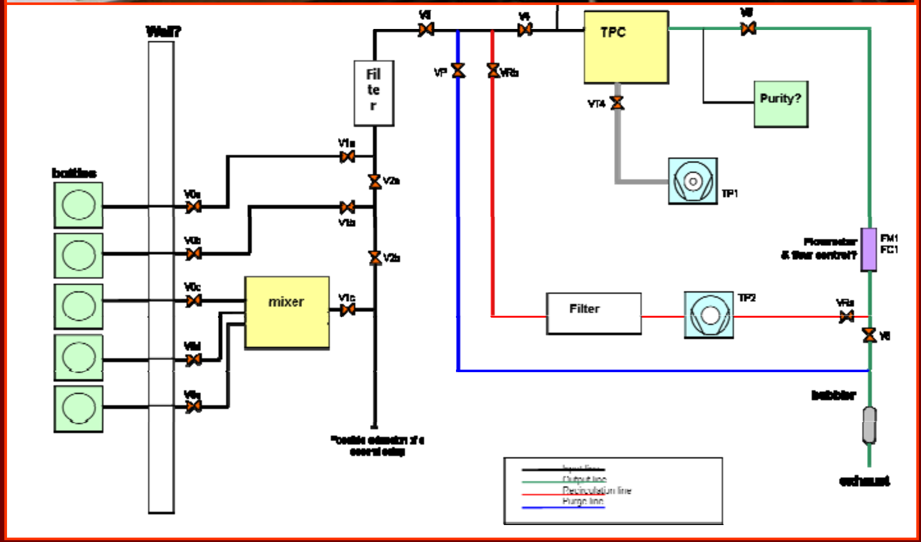




Energy resolution: next steps

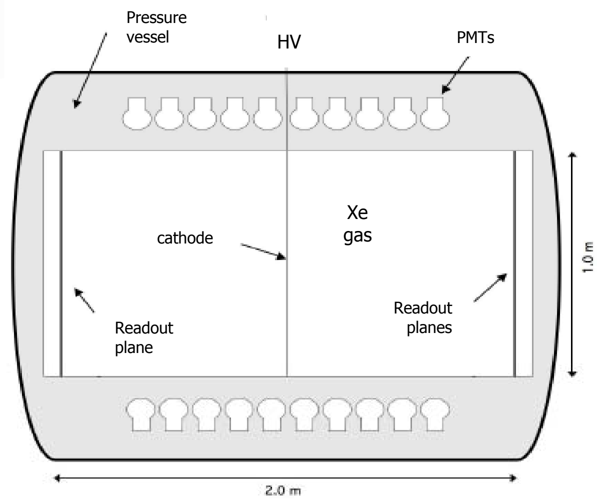
- First priority: ***same measurement in Xenon***
- Setup being upgraded for such measurement in Saclay
  - better control of purity: filtering, leaktighness, recirculation,…
  - Similar gas setup being built at Zaragoza for further R&D.
- Measurement expected to be done in the coming weeks.





New proposed experiment: NEXT

- A new initiative to build a **N**eutrino **E**xperiment with a gas **X**e **T**PC for double beta decay
- Groups involved: Barcelona, Berkeley, Saclay, Valencia, Zaragoza,…
- More collaborators are wellcome!
- Letter of Intent submitted to Canfranc Lab. Well received by the committee
- Good funding prospects.



1. Have all advantages of a Xe monolithic detector (like EXO)
2. Outdo Liquid Xe by getting topological info
3. Override tradicional limitation of gas TPCs (Gothard) by applying the latest developments on TPC readouts
4. Be a competitive option for the next (ton scale) generation of experiments

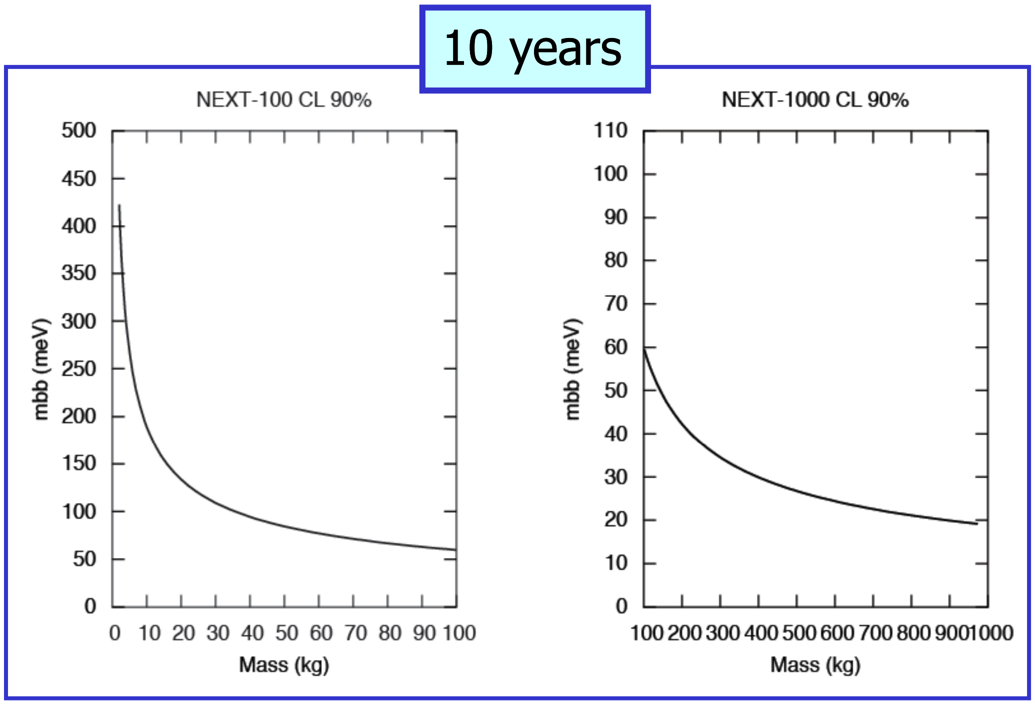
Hall A of new Canfranc Lab

NEXT

- A sensitivity down to 60 eV (for NEXT-100) and 20 eV (for NEXT-1000) is a priori reachable:

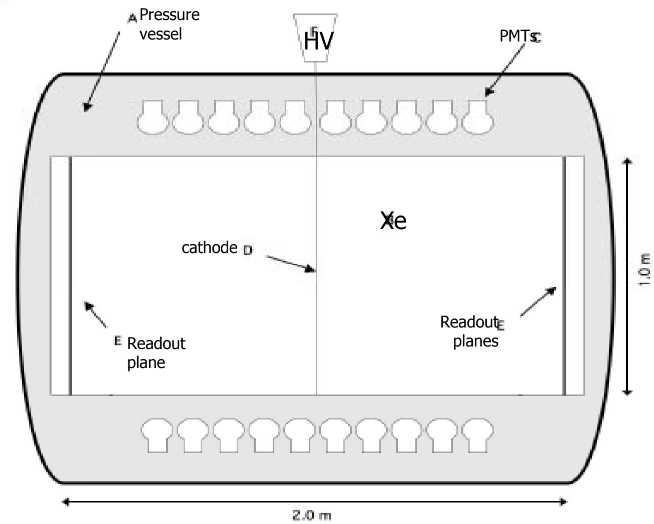
Of course, IF

- Low enough resolution is achieved (~1% FWHM)
- Low enough backgroung after topology cuts (i.e. not background limited)
- We believe this is possible after last developments on TPC
- Of course, a dedicated R&D is needed now to demonstrate these issues (as well as other technical ones)



NEXT R&D

- Energy resolution and gas mixture
  - Demonstrate in Xe
  - Role of quencher. Compromise with scintillation signal.
- T0 measurement (UV light)
- Software: simulations
  - Best use of topology information
  - Backgrounds
- Mechanics (high P issues)
- Background
  - Needed radiopurity measurement program
  - Needed shielding? Active/pasive? Selfshielding?
- Readout type and design
  - Which is best for NEXT?
  - Implications to radiopurity



Possible NEXT roadmap

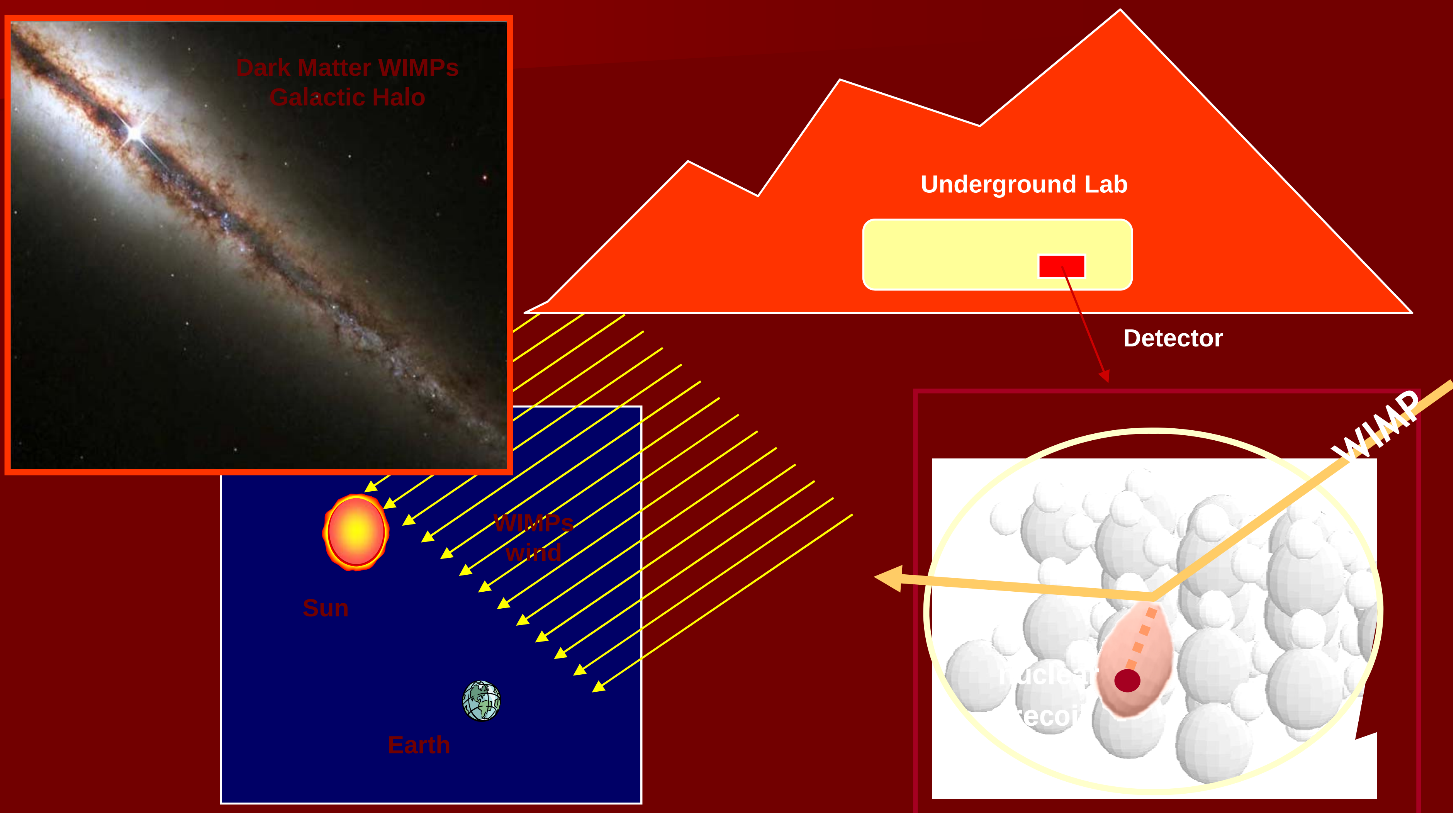
R&D phase	Medium scale detector	Large scale
■ R&D activities: – E resolution, t0, radiopurity, backgrounds, etc… ■ Small scale (<10 kg) demonstrating prototypes ■ Conceptual design of larger prototypes	■ Larger prototypes with physics interest: - 100-200 kg ■ Continued R&D for further scaling up: – Backgrounds – Ba++ tagging ?	■ Final detector (ton scale and beyond)

Conclusions

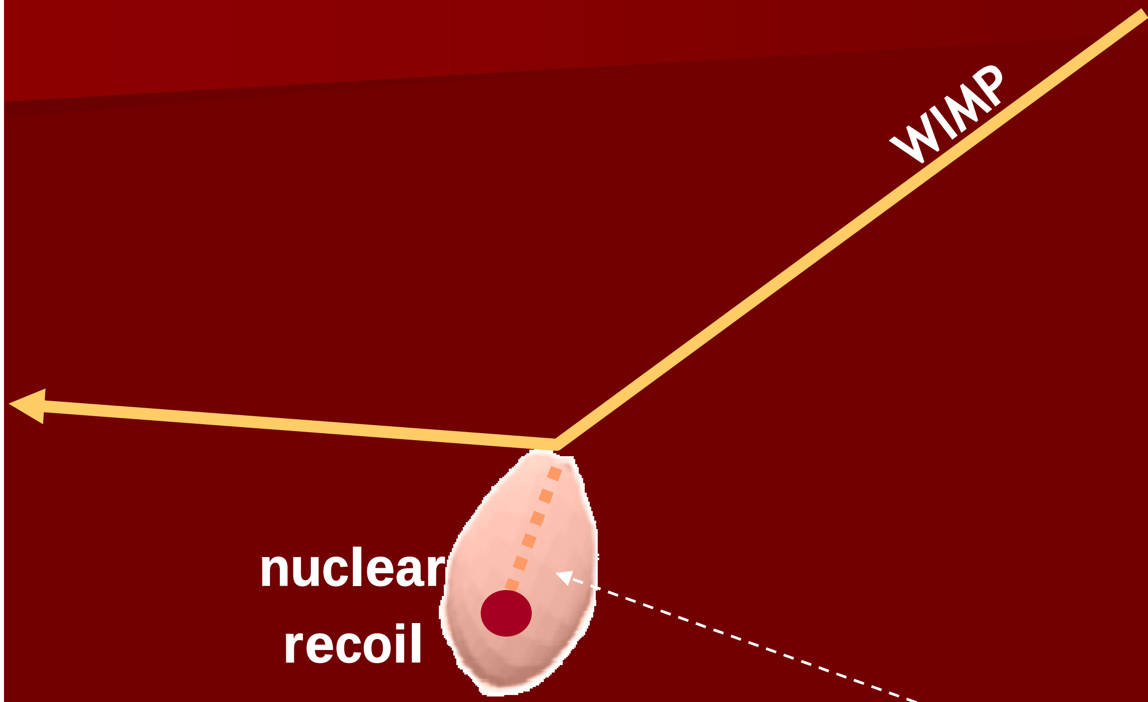
- Latest MPDG developments offer rich perspectives to Rare Event Searches. They override typical limitations of coventional TPCs.
- Micromegas in particular are actively developed and a number of initiatives in the RE field are in course or foreseen to use them.
- CAST is commissioning 3 new MM detectors, validating novel manufacturing techniques in a real experiment.
- Dedicated measurements of high energy resolution on Micromegas are giving very interesting results for their application to double beta decay experiments.
- A new initiative has born, NEXT to build a gas Xe TPC for double beta decay at Canfranc Lab.
- **Rare Events have specific development needs from MPDGs. RD51 perfect tool to accomodate such development**

Backup slides

Detection of Dark Matter WIMPs

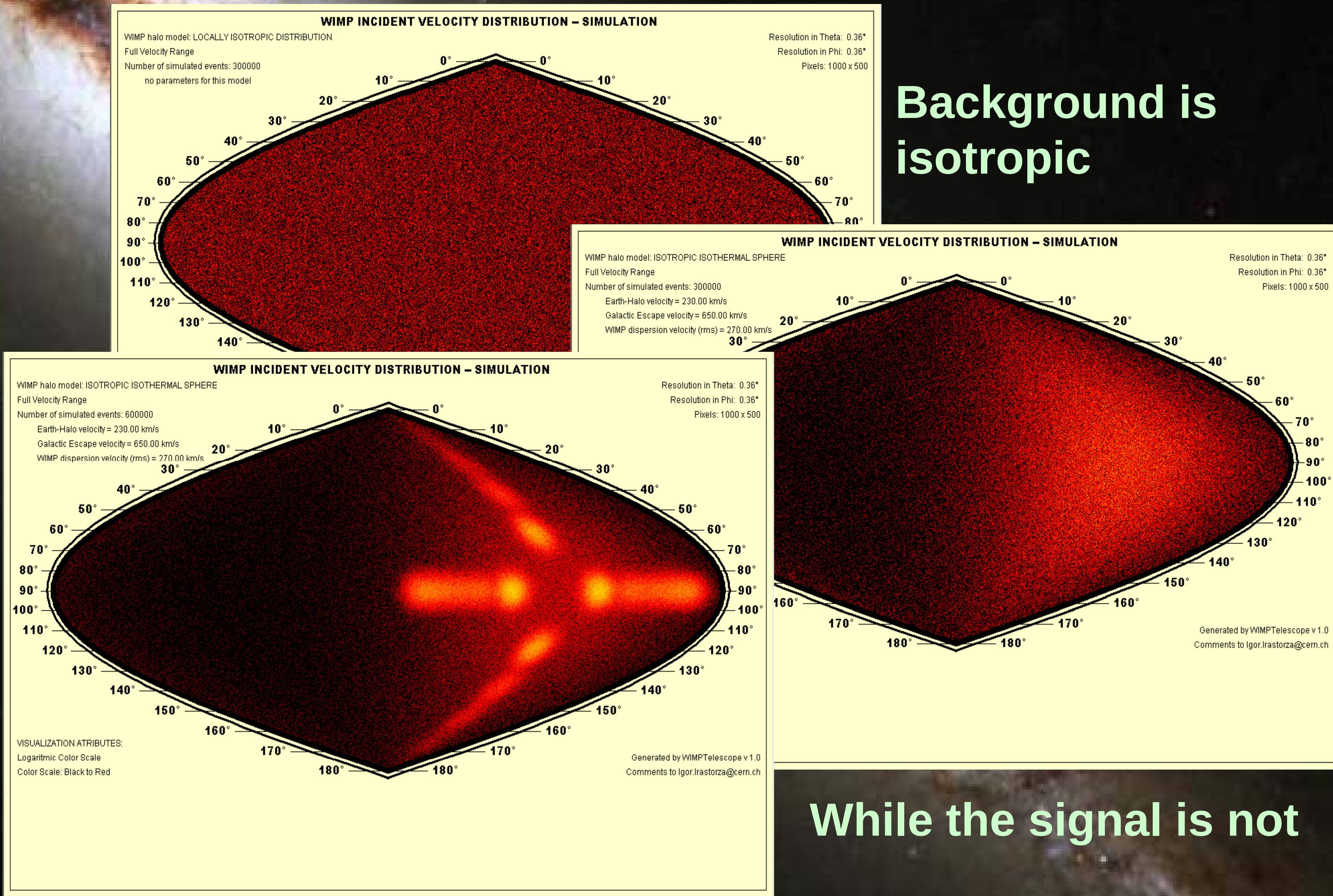


Detection of Dark Matter WIMPs



- Present leading experiments record the E deposit and discriminate between electron/nuclear recoils.
- If a WIMP is detected, it will

Directional signal

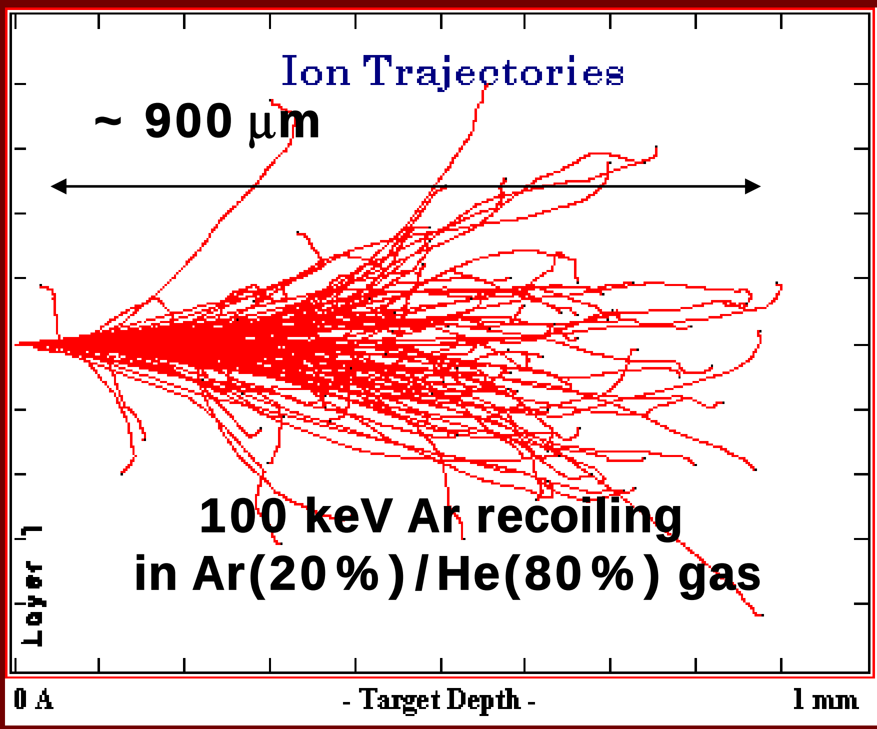


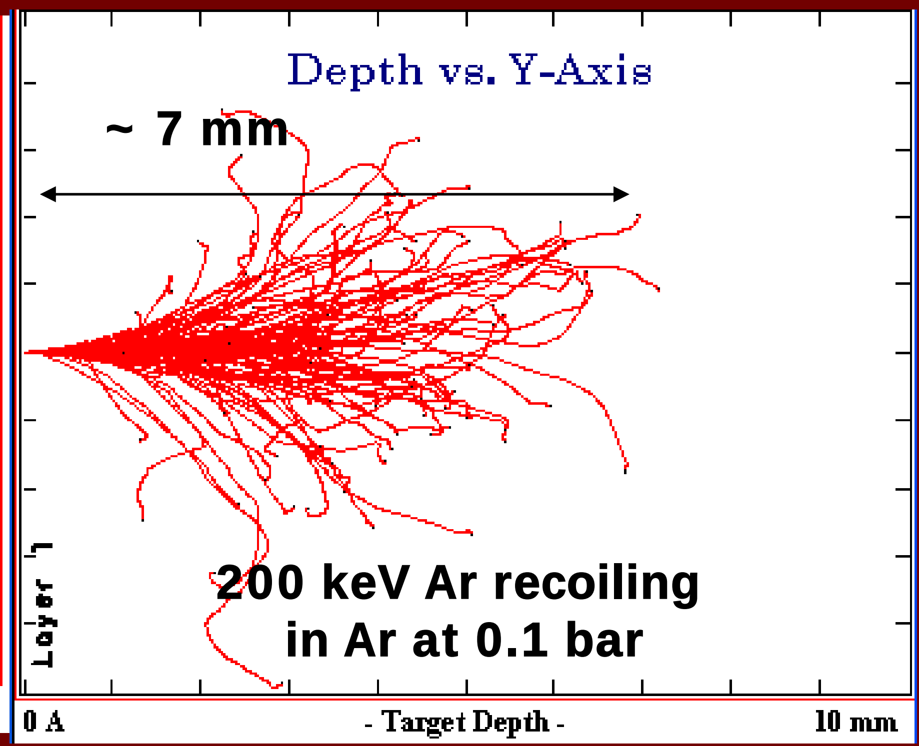
Background is isotropic

While the signal is not

But can the direction of the recoil be measured?

- Very hard technological challenge…
- In solids/liquids only 100 nm, so we go to gas…
- Some examples of n.r. tracks in gas:

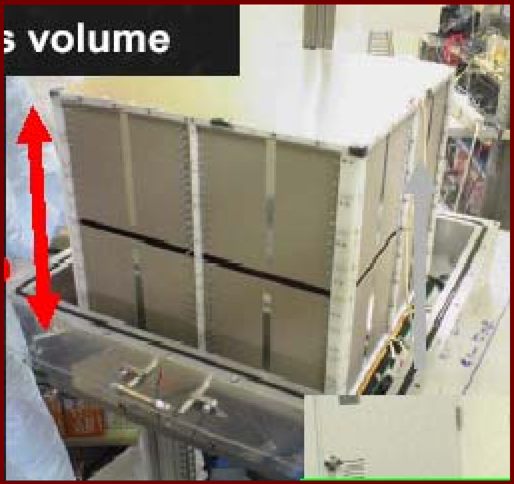




International network on directionality: CYGNUS

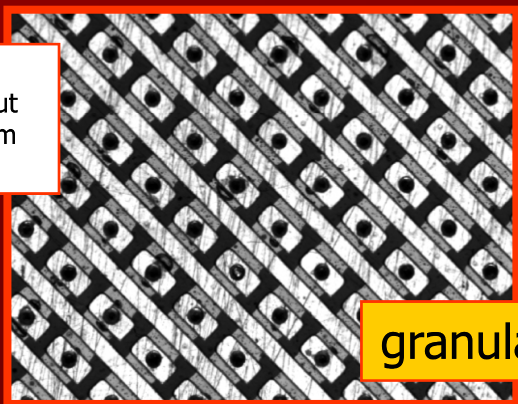
- CYGNUS: *CosmoloGY with NUclear recoilS*
- DRIFT coll, Grenoble, Saclay, Zaragoza…
- Slightly different approaches, but common interest in MPDG.

- NEWAGE experiment in Japan already using MPDGs (microdot)
- DRIFT and MIMAC experiments plan to use Micromegas

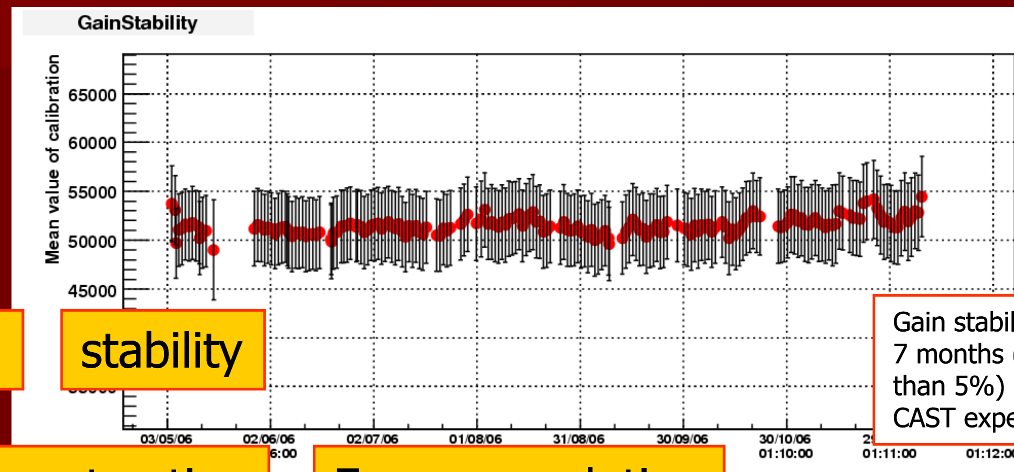


Micromegas: latest developments

CAST readout 300 µm pitch

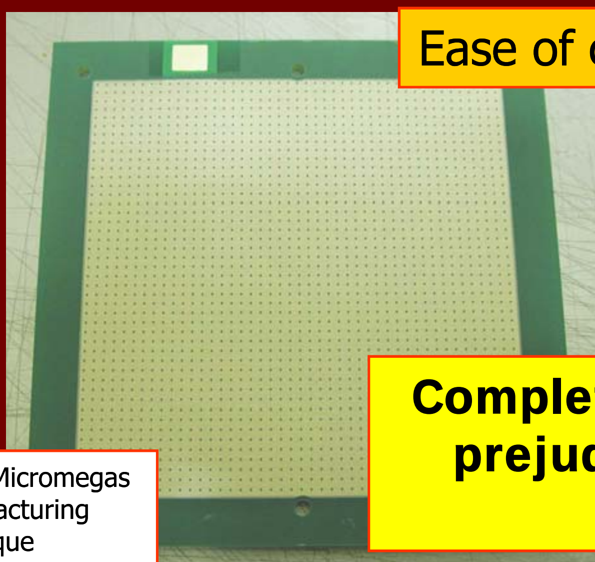


granularity



stability

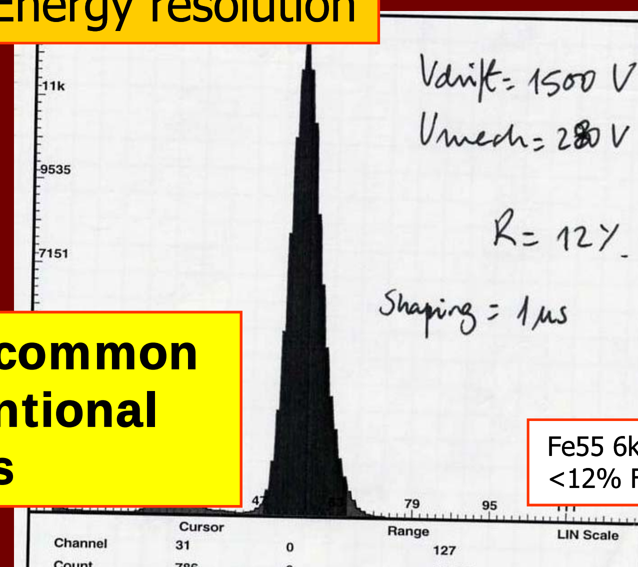
Gain stability over 7 months (less than 5%) in the CAST experiment



Ease of construction

BULK Micromegas manufacturing technique

Energy resolution



Fe55 6keV source <12% FWHM

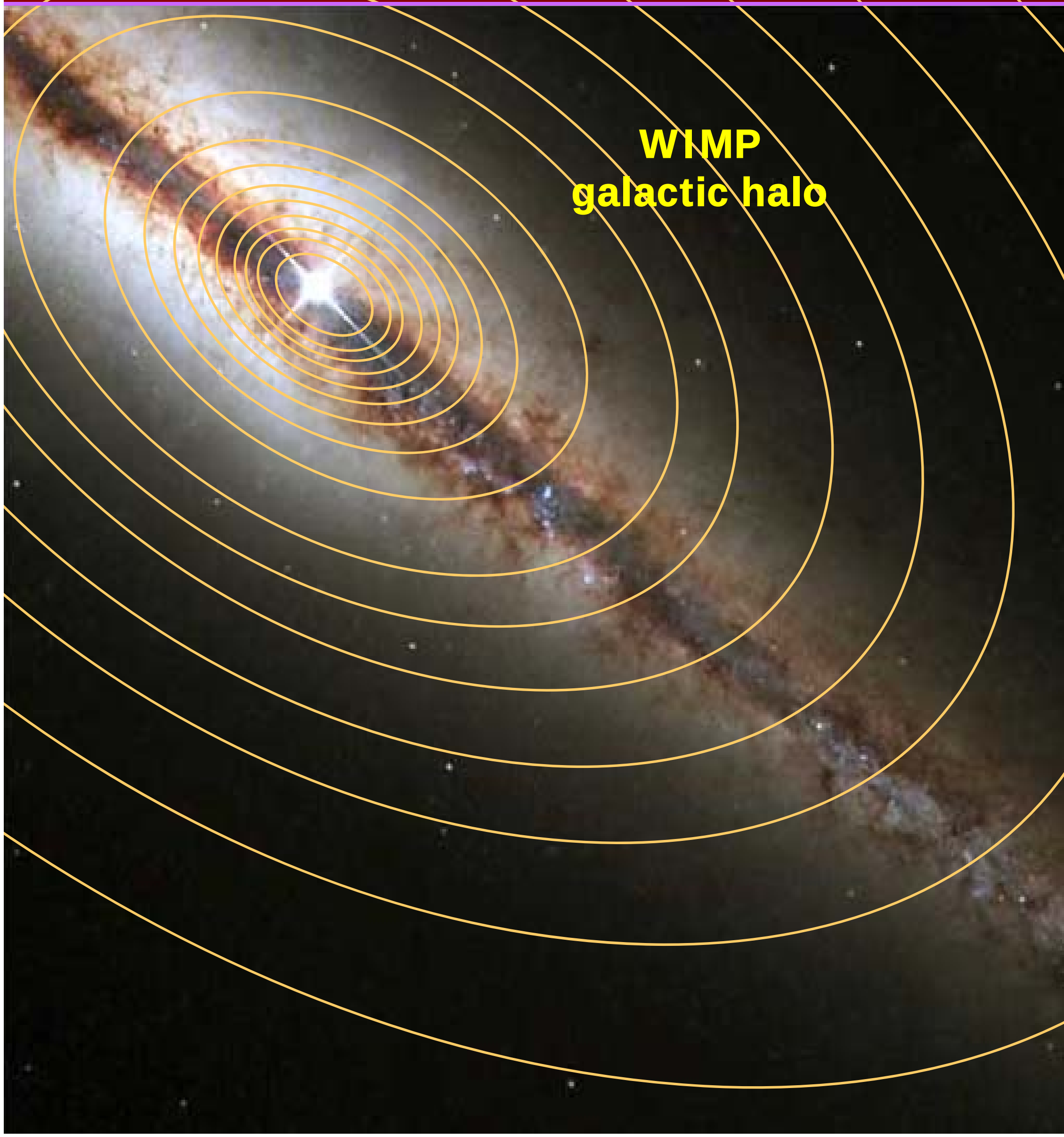
Completely overrides common prejudices on conventional multiwire TPCs

Why TPCs are not being used for RE?

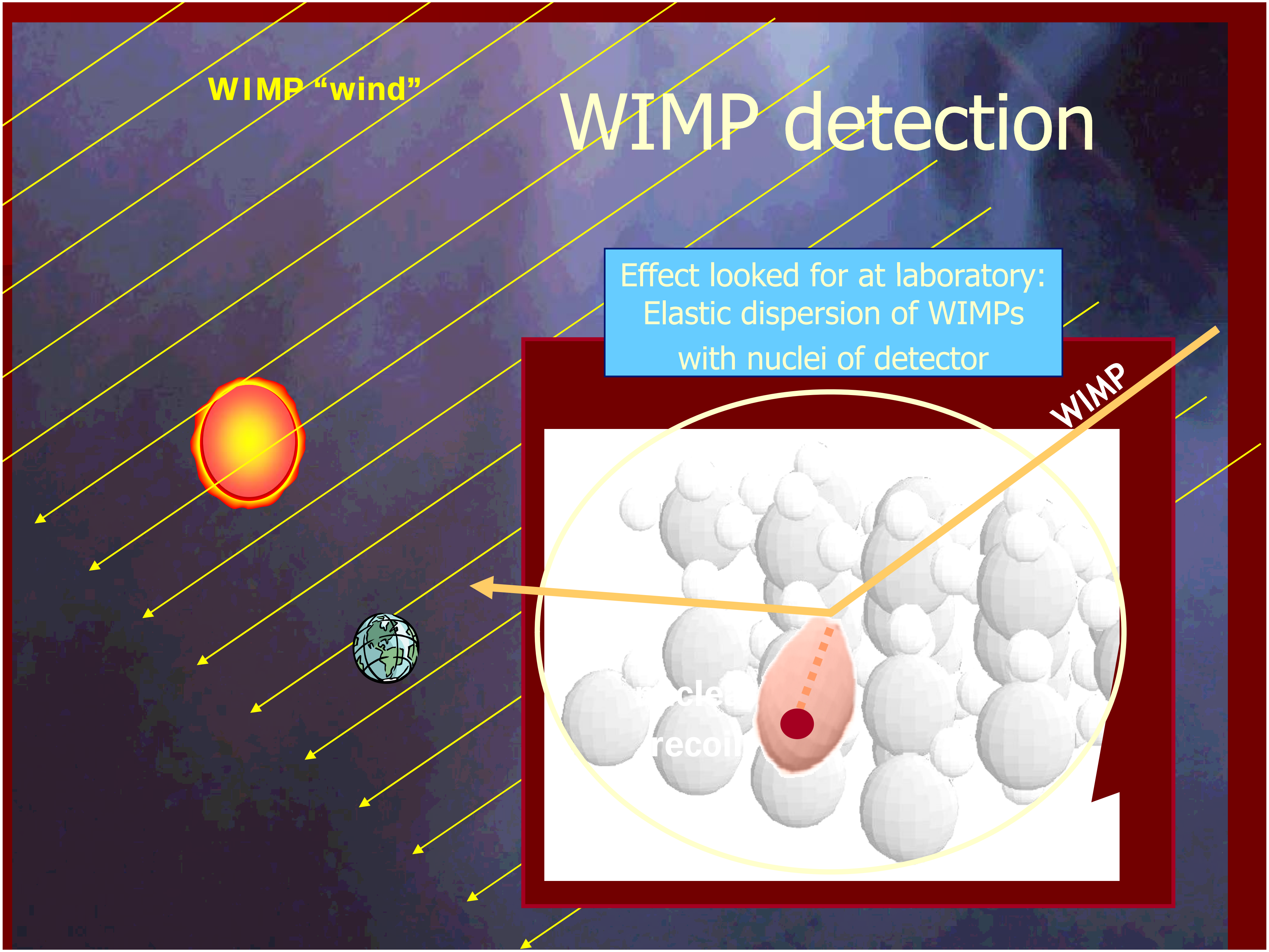
Events in gas: traditional limitations of TPCs read by wires

- TPCs are usually developed for tracking purposes, not for calorimetry.
- Bad energy resolution
  - Intrinsically (lower n of pairs that, e.g., semiconductor detector)
  - By readout effects: sum up many wires, signal extended in time, charge effects?,…
- Detector with "gain".
  - Gain very dependent on external parameters (geometrical imperfections, environmental par. P & T, gas purity)
  - Need extreme control of these parameters over time and space (if you are doing calorimetry)
- Extended events, homogeneity is an issue.
- Complex detectors: Mechanically (wire tension), Electrostatically (E field under control over large V), Acquisition (complex electronics, soft & analysis).
- Wires cannot be deployed with pitches < 1-2 mm
- It is gas! Large volumes needed for rare events searches.

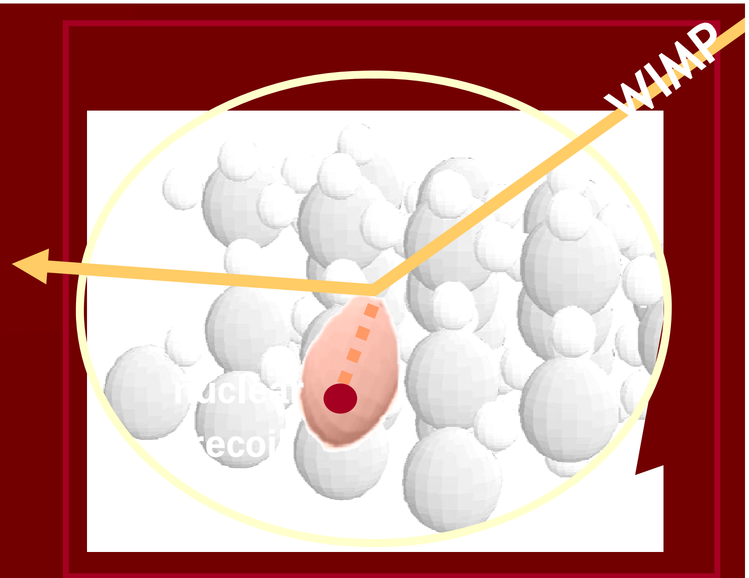
Dark Matter WIMPs detection



- 23% of the Universe is Dark Matter (comological observations)
- Galactic evidence: rotation curves of galaxies
- Cannot be baryonic matter. Cannot be neutrinos
- Beyond standard model: WIMPs or axions.
- WIMP galactic halo → it could be detected directly in underground laboratories…

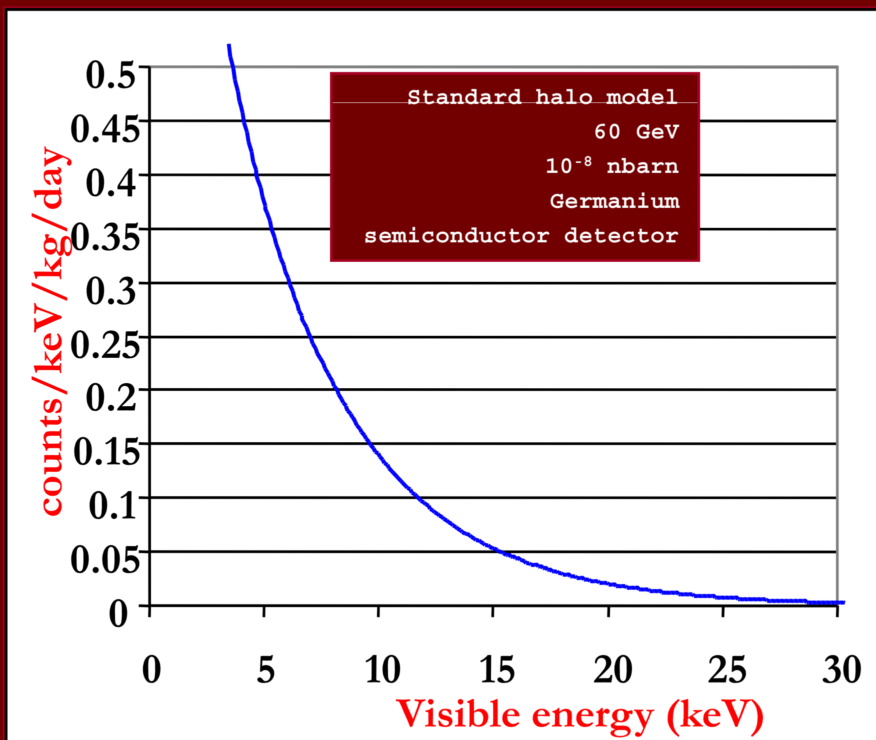

WIMP detection
WIMP “wind”
Effect looked for at laboratory:
Elastic dispersion of WIMPs
with nuclei of detector
WIMP

WIMP detection



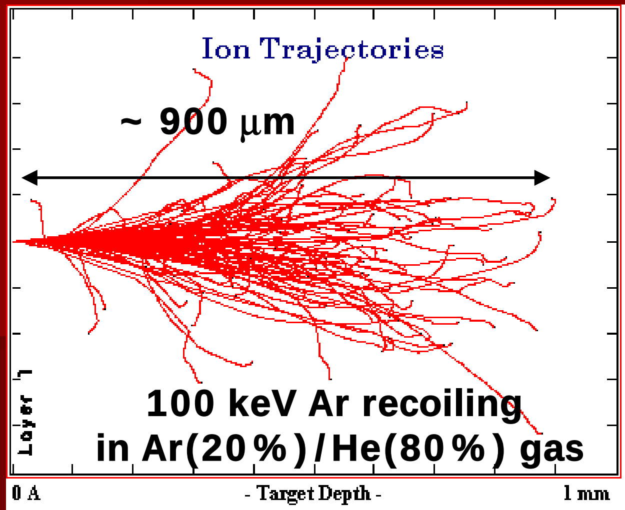
- Expected signal:

rare low energy event



Specific challenges:

- ✓Low threshold (~keV)
- ✓Reasonable resolution
- ✓Very low background at keV scale:
  - ✓Radiopurity & rejection techniques
- ✓Aim for large detector masses
- ✓Great stability over time.



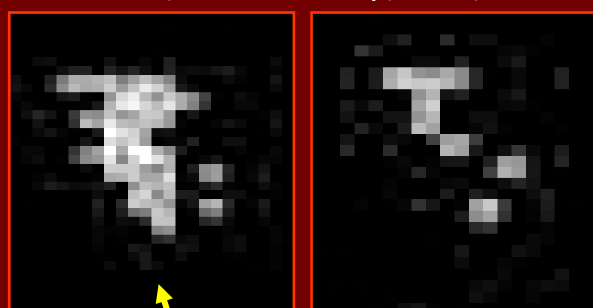
Requirements:

- Very high spatial resolution gaseous detector
- 3D imaging capabilities
- Very high granularity readout

Medipix + Micromegas

Images of 5.9 Fe55 keV photon interacting in Argon
Obtained with a Micromegas couple to a Medipix chip
v.d.Graaf, TPC workshop, Paris, dec04

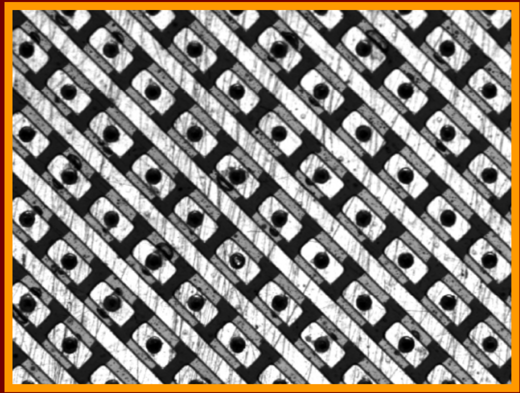
~500 µm



imagine a nucleus recoiling here

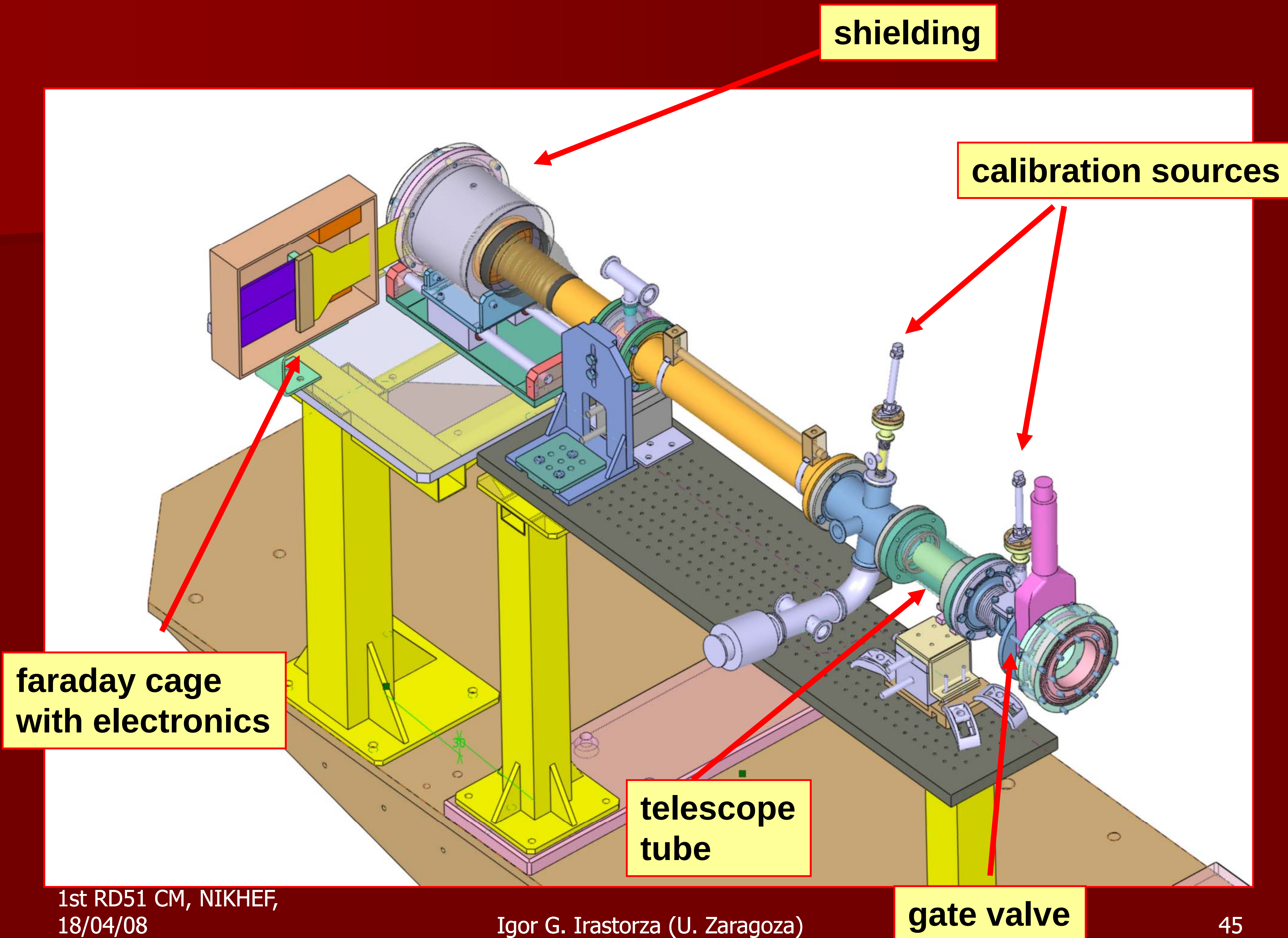
- But also, the ability to instrument large surfaces/ volumes of detector

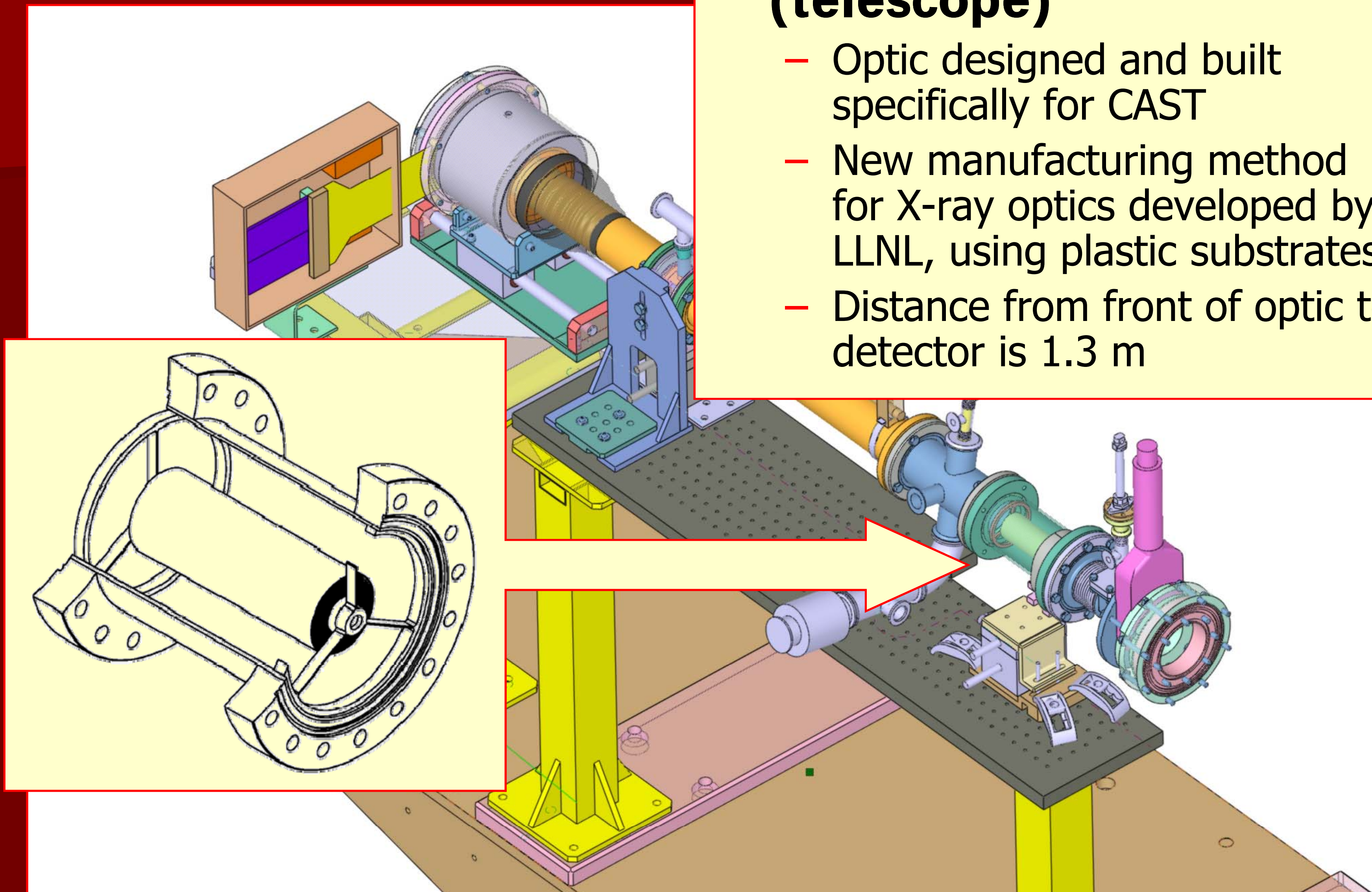
WIMPs with Micromegas in Zaragoza/Canfranc



- Latest advances show that:
  - Required granularity is achievable
  - Large surfaces are posible to instrument easily.
- Ongoing project to:
  - Detailed simulation of nuclear recoils in gas:
    - Assess methods to extract directional info.
    - Discrimination by topology
  - Assess low background issues. Apply low background know-how to adapt MM manufacturing process. (radiopurity meas., etc…)
  - Assess technical issues of MM operating undergroung → First prototype (CAST replica) already taking data in Canfranc !
  - Further: measure quenching factor and directional calibration.

- First MM in Canfranc ! First underground data being taken.

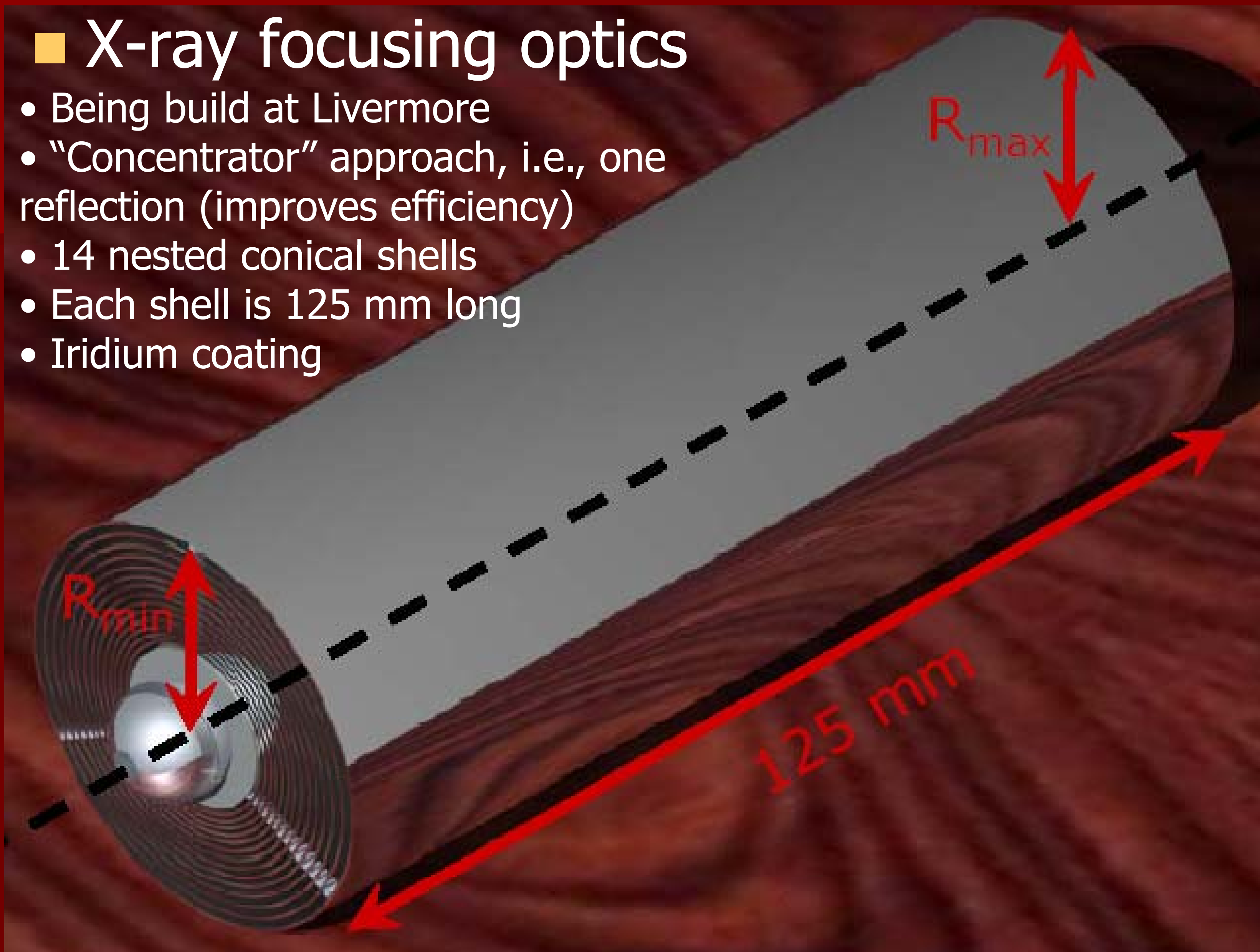

shielding
calibration sources
faraday cage
with electronics
telescope
tube
gate valve



- **X-ray focusing optics (telescope)**
  - Optic designed and built specifically for CAST
  - New manufacturing method for X-ray optics developed by LLNL, using plastic substrates.
  - Distance from front of optic to detector is 1.3 m

X-ray focusing optics

- Being build at Livermore
- "Concentrator" approach, i.e., one reflection (improves efficiency)
- 14 nested conical shells
- Each shell is 125 mm long
- Iridium coating



Why MMs **should** be used for RE?

Most traditional limitations of TPCs are overriden by recent developemnts

- No **mechanical challenge**. Standard PCB technology replaces plane of wires.
- **Spatial resolution** achievable much higher.
- Manufacturing process of **large surfaces/volumes** is much simpler, and cheaper.
- Robustness
- Impact on electronics (more freedom in readout design)

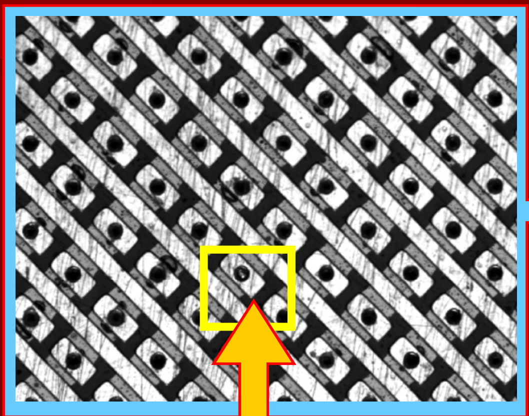
All MICROPATTERN

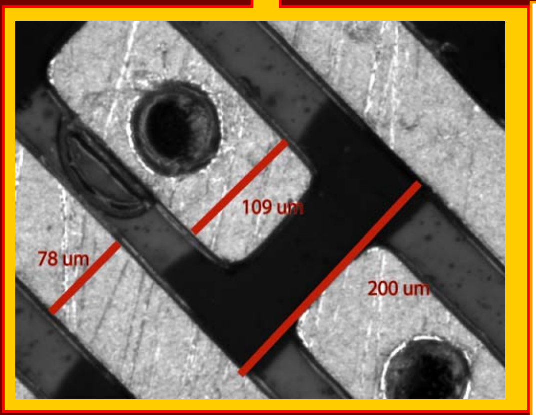
And specially:

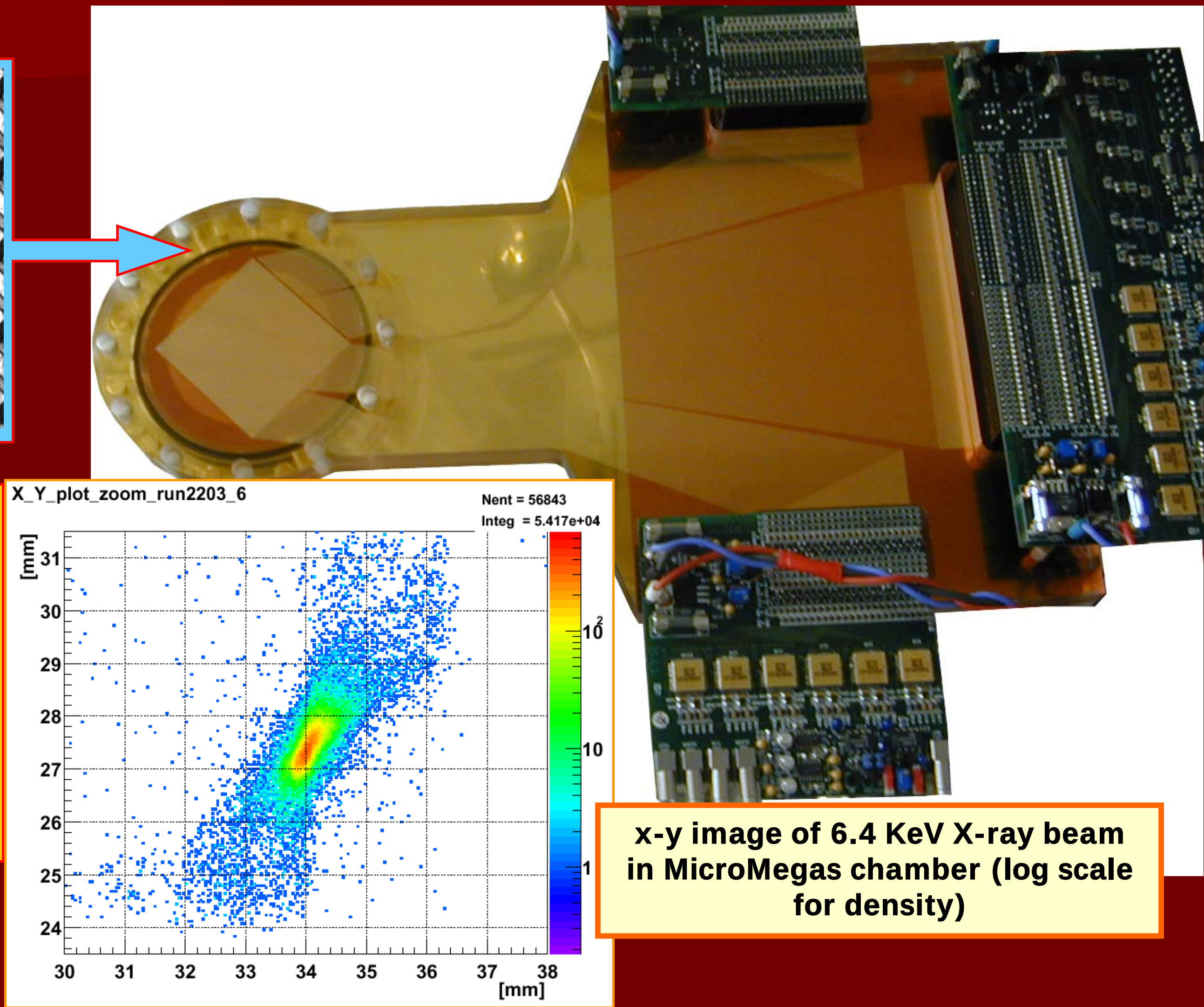
- **Energy resolution** close to the Fano limit
- **Stability and homogeneity** enhanced by special compensating effect.

Specifically MICROMEGAS

High granularity







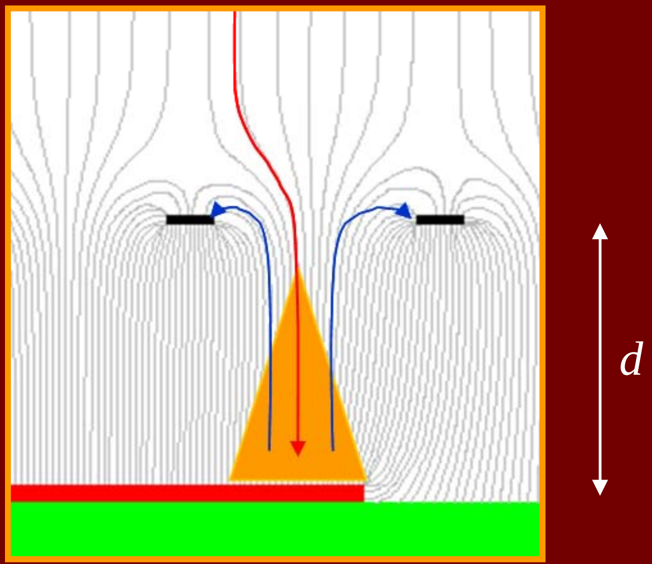
x-y image of 6.4 KeV X-ray beam in MicroMegas chamber (log scale for density)

Gain compensating effect

$$G = e^{\alpha d}$$

$$\frac{\alpha}{p} = Ae^{-Bp/E} = Ae^{-Bpd/V}$$

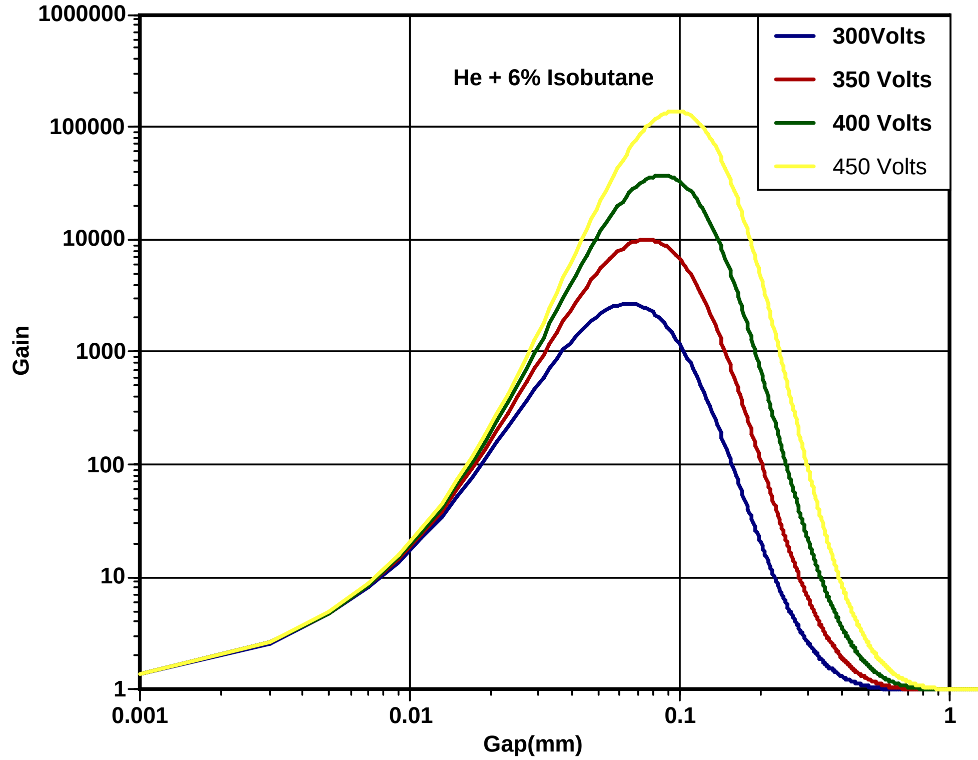
$$\delta G / G = apd(1 - Bpd / V) = apd(1 - Bp / E)$$



For $d \sim V/Bp$
gain variations are minimized

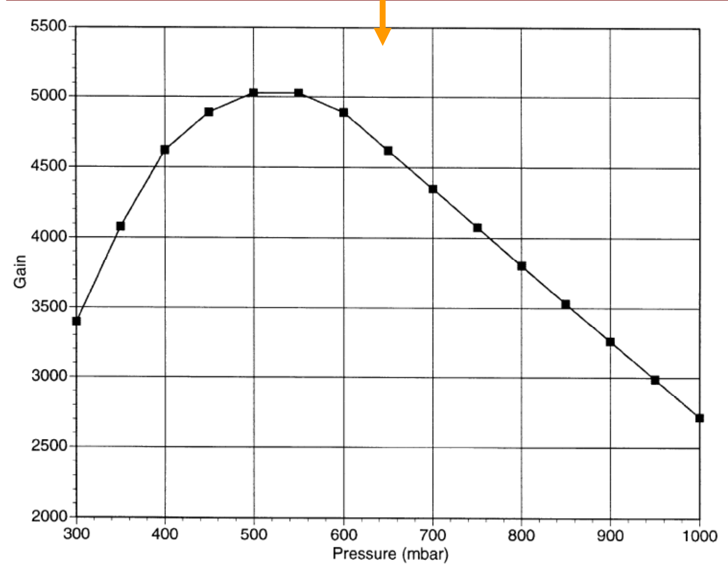
This distance corresponds to 30-100 microns
for typical MM mesh voltages

Gain compensating effect

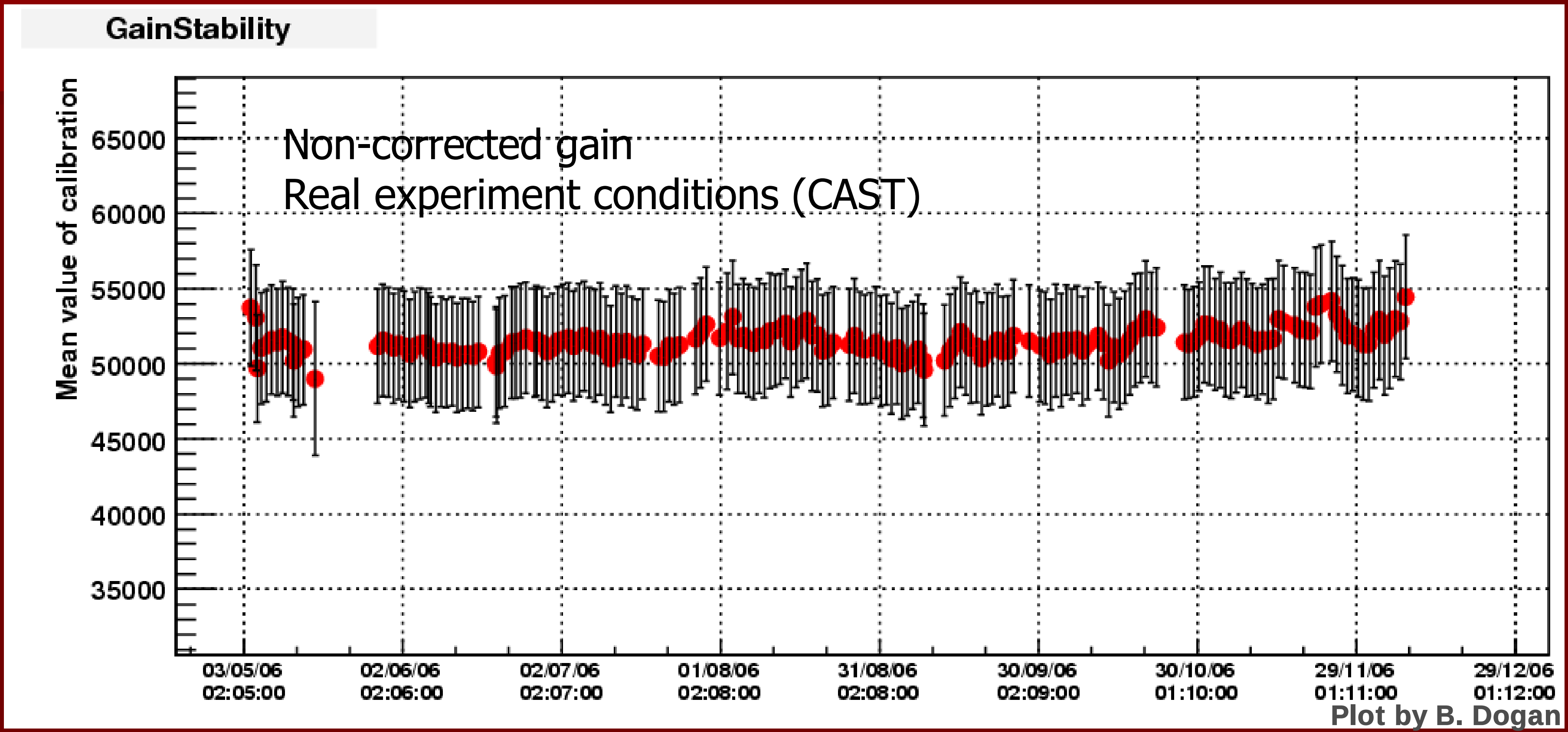


Optimum gap : 30 - 100 microns

This effect is evident also for the P-T dependences: time stability is easier

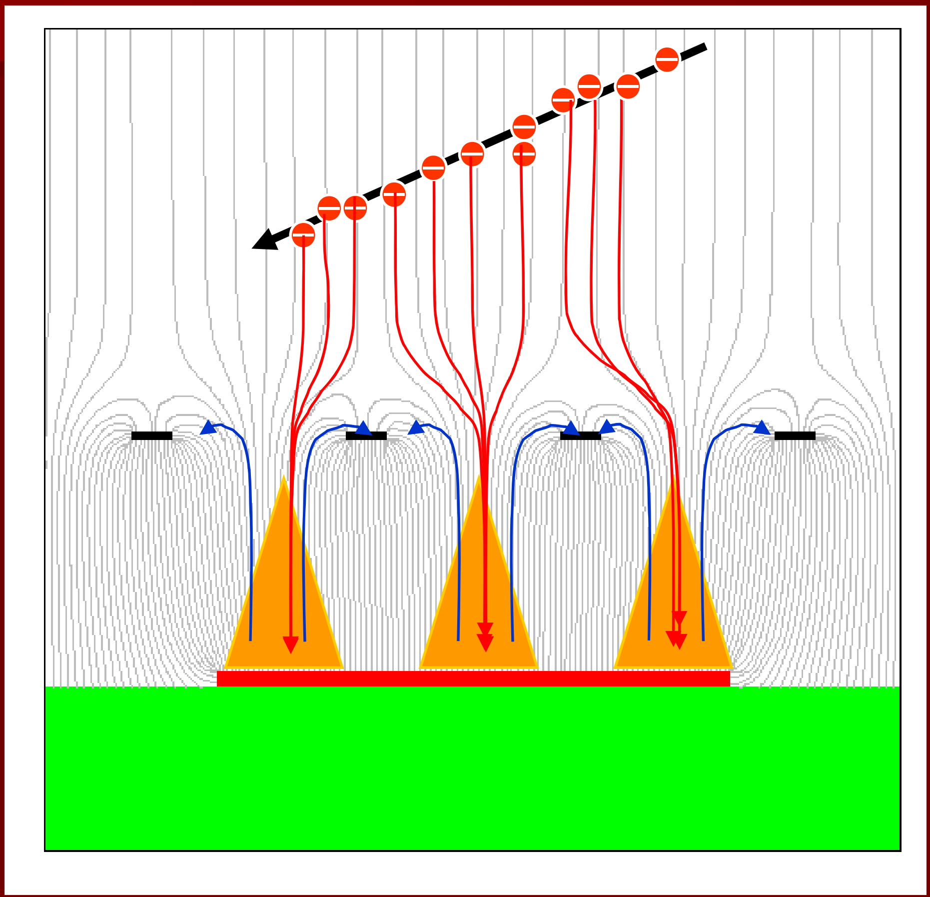


stability on time



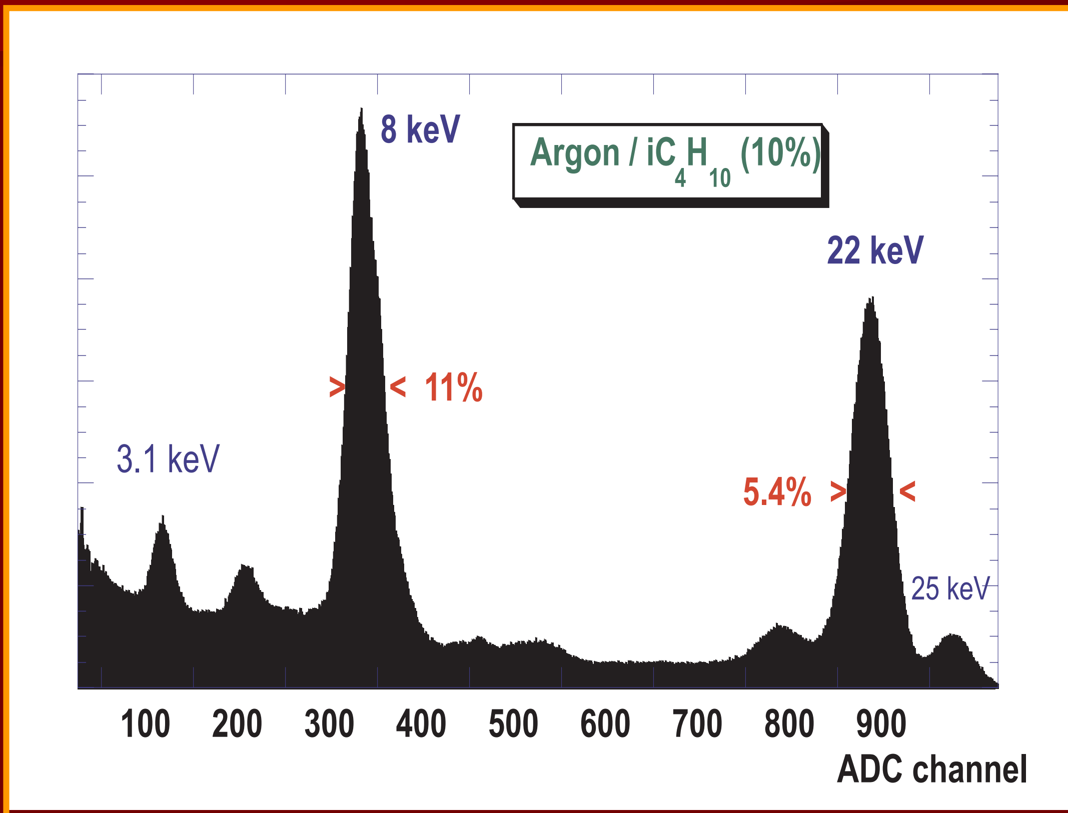
Gain evolution in 7 months almost continuous operation: well below ±5%
Excellent for gaseous detector

MM energy resolution

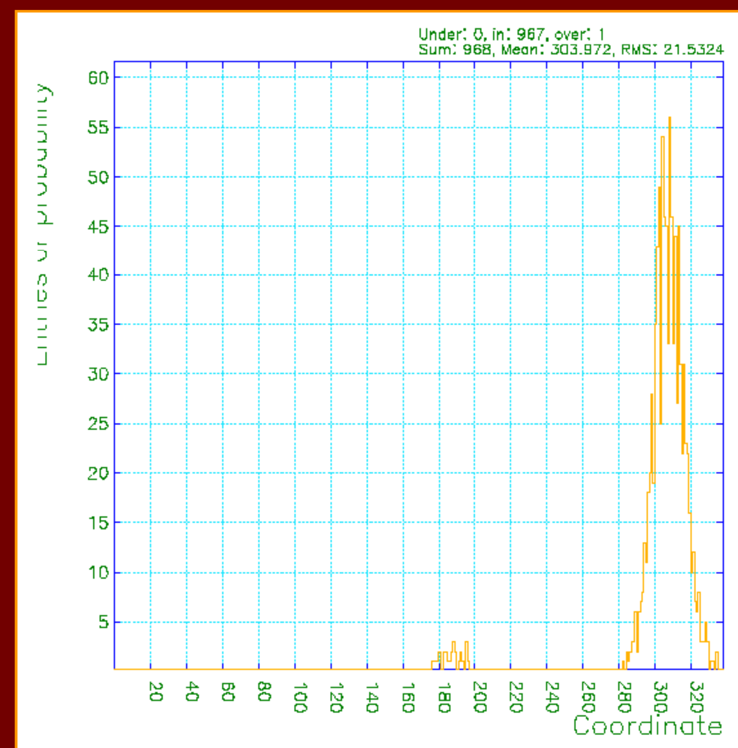


- MM is the micropattern detector with best energy resolution. Reasons inherent to the avalanche process in MM:
  - Spatial homogeneity of gain
  - Minimal loss of charge before avalanche
  - Avalanche is produced mostly in same E (transition from drift to multiplication is fast)
  - Ions are evacuated fast and efficiently. Charge effects very small

MM Energy resolution



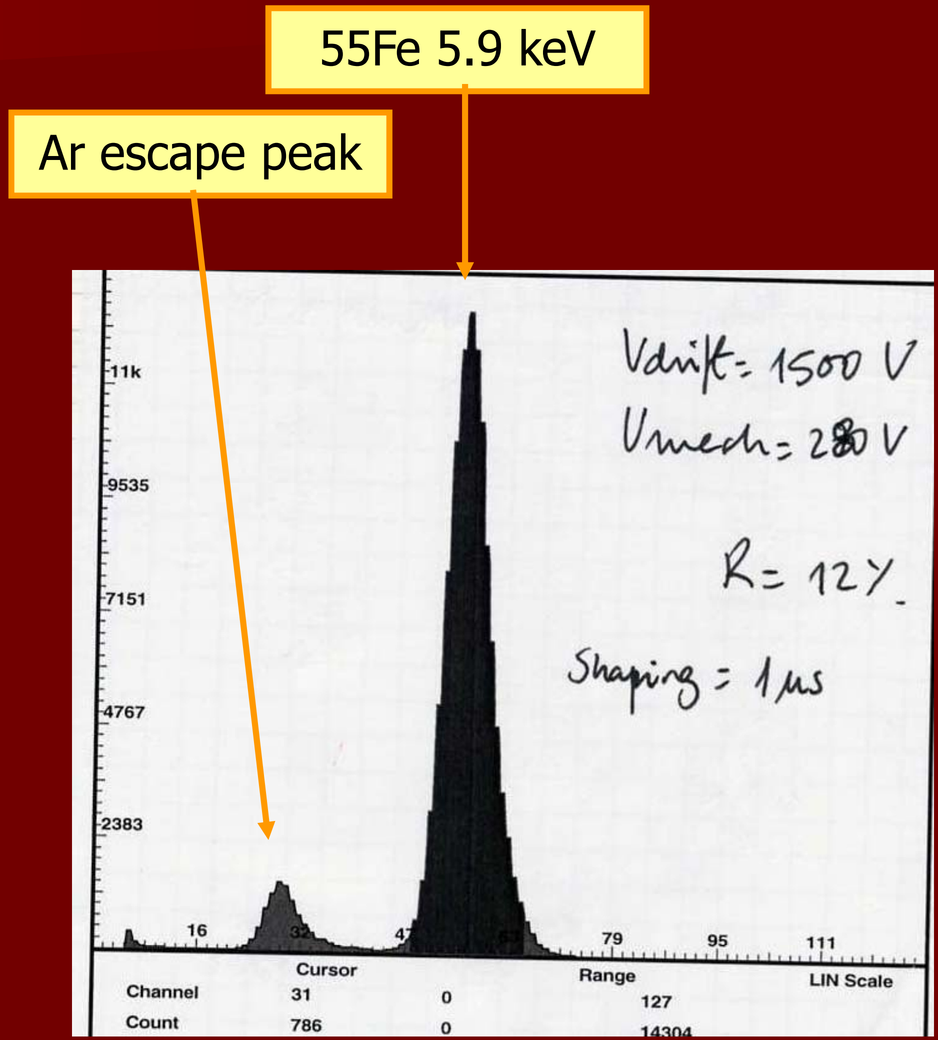
While Fano limit
at 8 keV is ~7%



MM Energy resolution

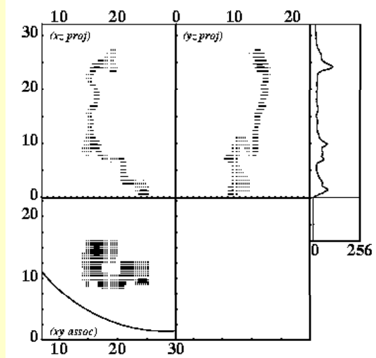
One more example:

- **CAST T detector** recently built…

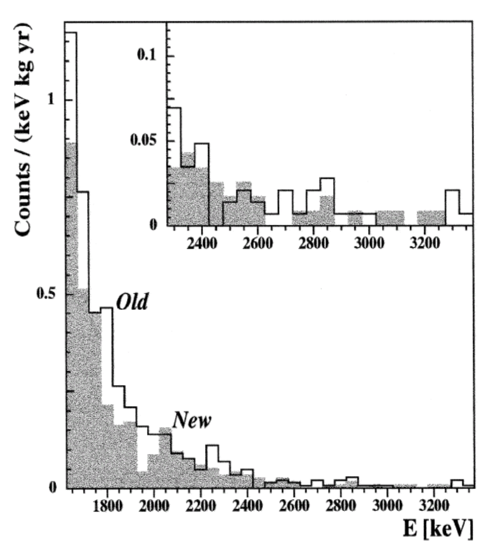


Gas Xe TPCs for ββ?

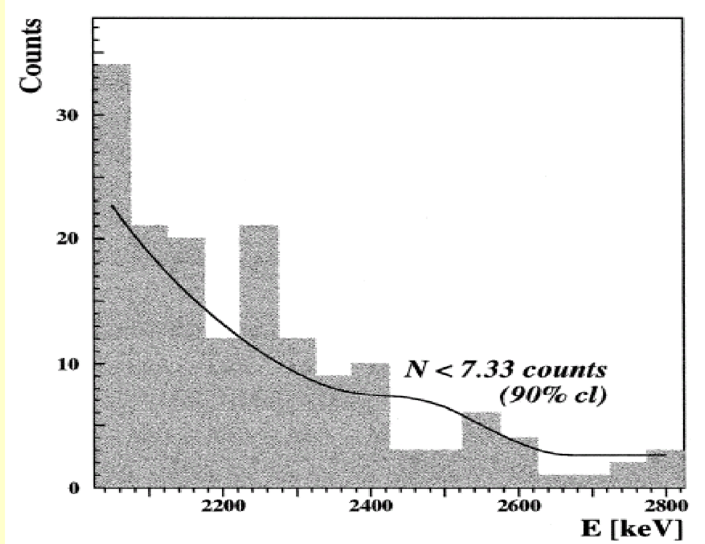
- Not presently comtemplated in present projects (EXO: liquid TPC)
  Why?:
  - Energy resolution: Fano factor, gain stability
  - homogeneity, equalization, ballistic deficit,…
  - Complex detectors. Specially for large V needed.



Typical double beta decay candidate. The x–z and y–z projections are measured, as well as the anode signal to the right. The x–y projection is reconstructed. Lengths are in cm.

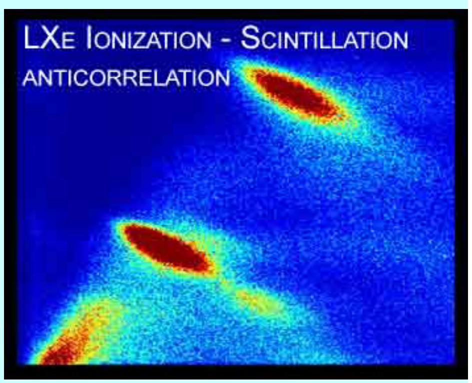


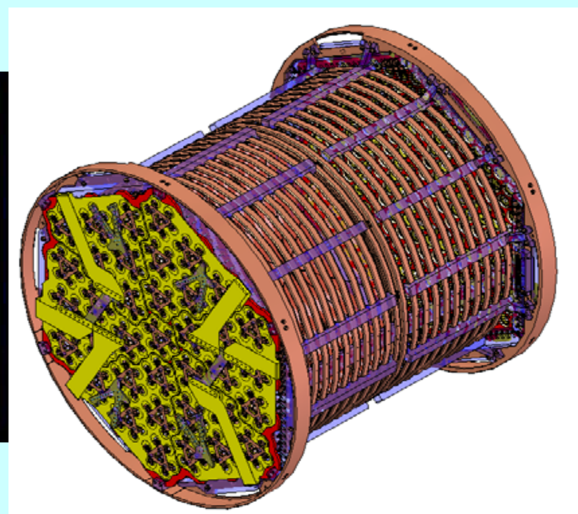
- Gothard TPC in the 90´s
  PLB 434 (98) 407
- **180 l @ 5 bar = 3.3 kg** Xe^{136}
- **6.6 % FWHM** E resolution at $Q_{\beta\beta}$
- **96.5 %** topological rejection of single e-
- Background limited (environ. gammas)
- $T_{1/2}^{0\nu} > 4.4 \times 10^{23}$ years



Liquid vs. Gas

- EXO experiment:
  - Liquid Xe TPC
  - Energy measurement by ionization + scintillation
  - No single e- identification → poor background rejection
  - R&D for Ba ion tagging in progress ($^{136}Xe \rightarrow {}^{136}Ba^{++} + 2e^-$)
  - EXO200 being built in WIPP, without Ba tagging



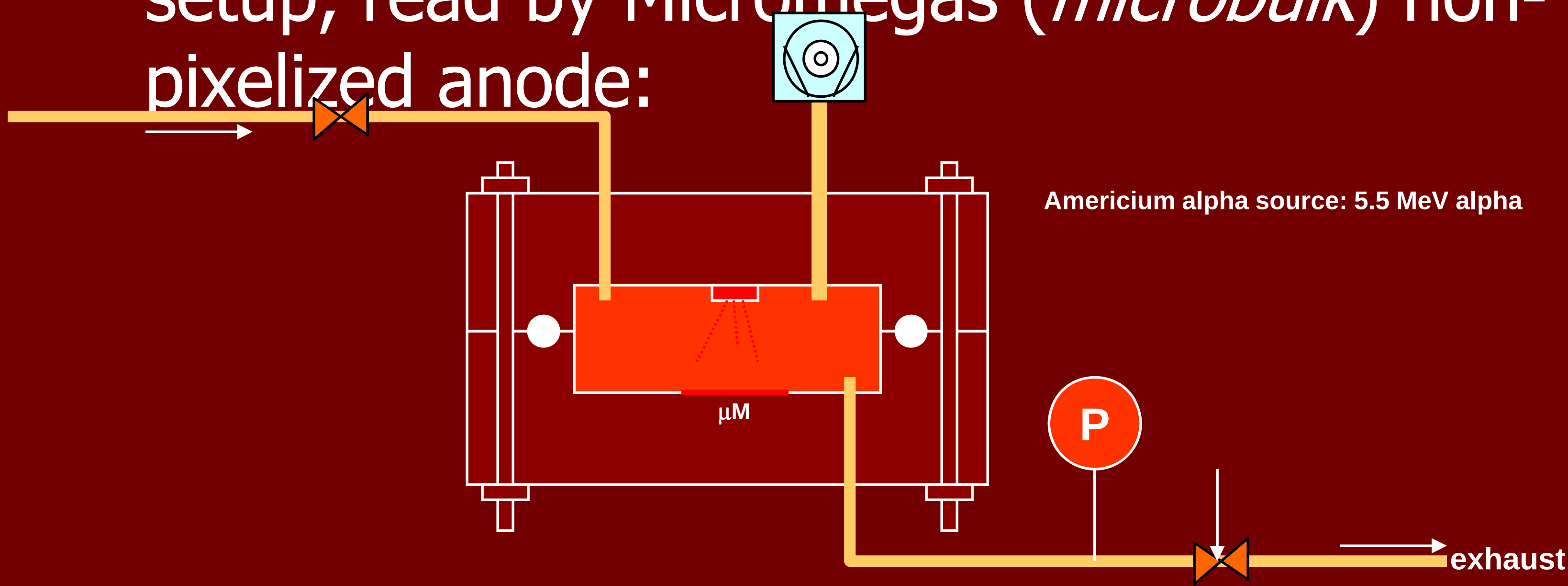


Liquid Xe		Gas Xe
✓	Scalability	✓
✓	Compact	✗
Cryogenics	Complexity	High P
✗	Topology	✓
✓	E resolution	✓

+ And Ba tagging can be done better in gas

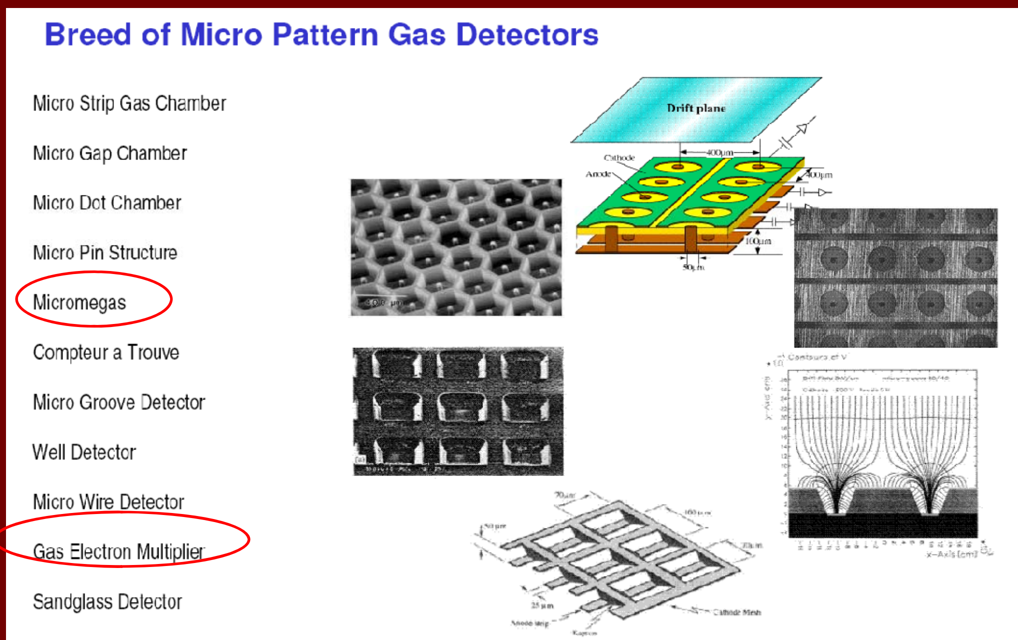
Energy resolution

- Final results of last summer tests in Argon:
  - High pressure (up to 5 bar) Ar+Isob small setup, read by Micromegas (*microbulk*) non-pixelized anode:

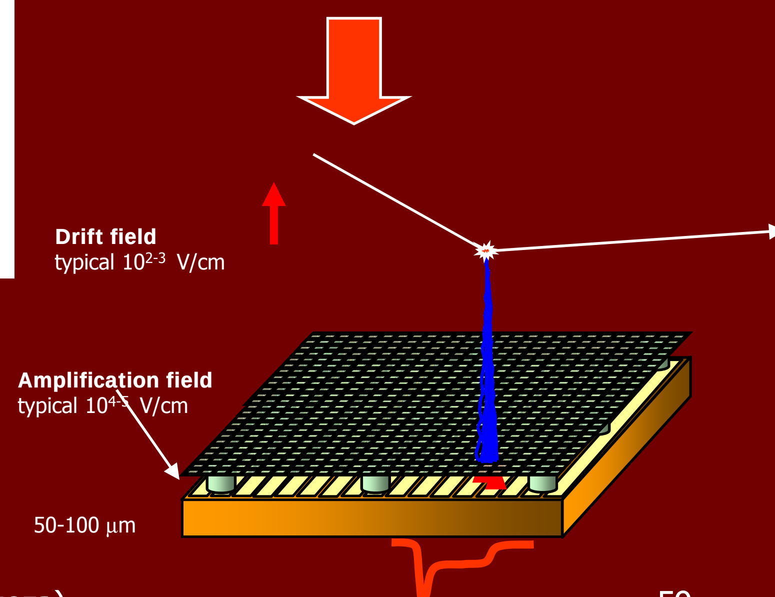


Micropattern detectors

seminal idea is atributed to Oed (88)

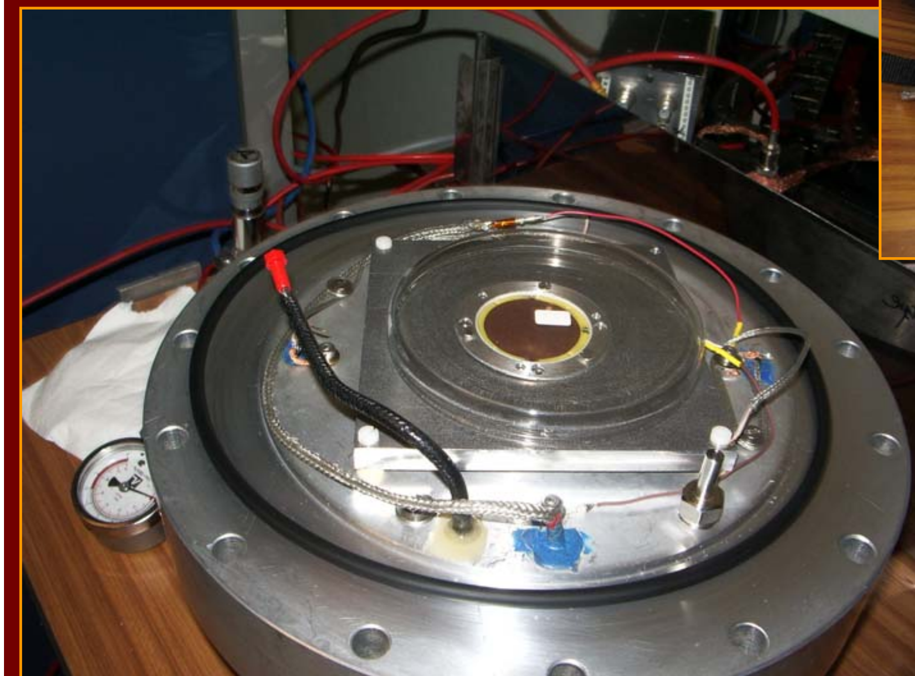


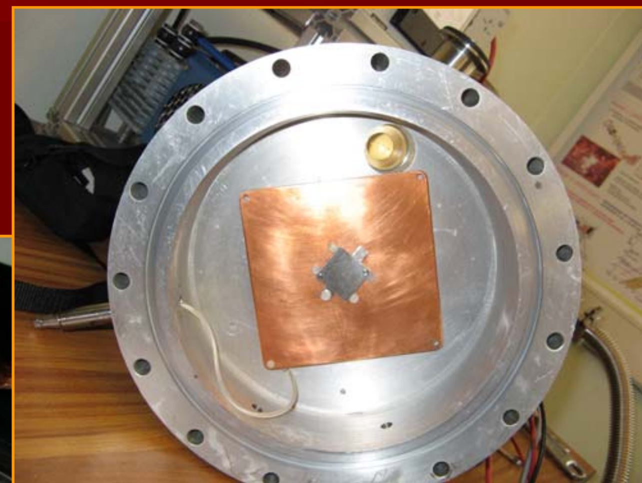
e.g. MICROMEGAS
Giomataris, Charpak (96)



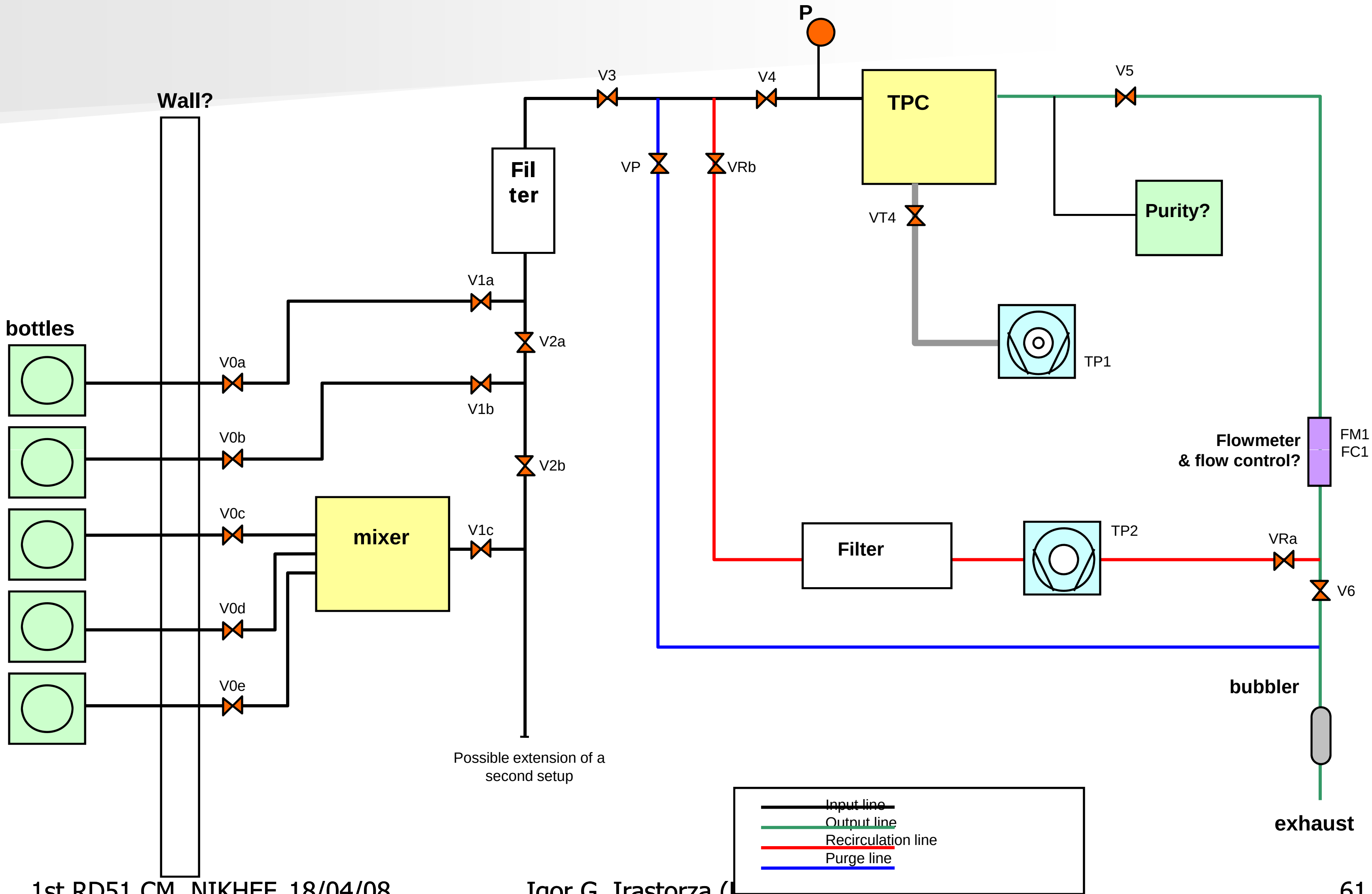
Energy resolution in Micromegas

- Setup at Saclay:



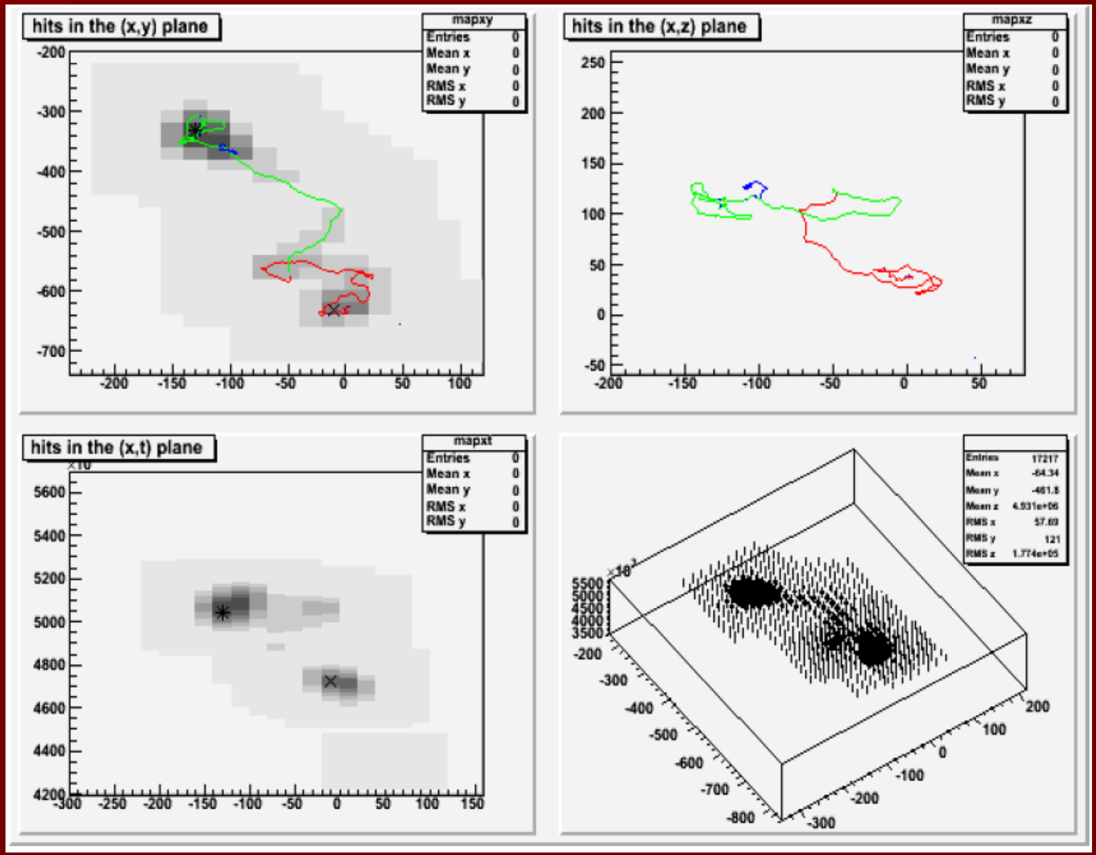


Gas System


P
Wall?
V3
V4
TPC
V5
Fil
ter
VP
VRb
VT4
Purity?
V1a
bottles
V2a
TP1
V0a
V1b
V0b
V2b
Flowmeter
& flow control?
FM1
FC1
V0c
V1c
mixer
TP2
Filter
VRa
V6
V0d
V0e
bubbler
Possible extension of a
second setup
exhaust
Input line
Output line
Recirculation line
Purge line

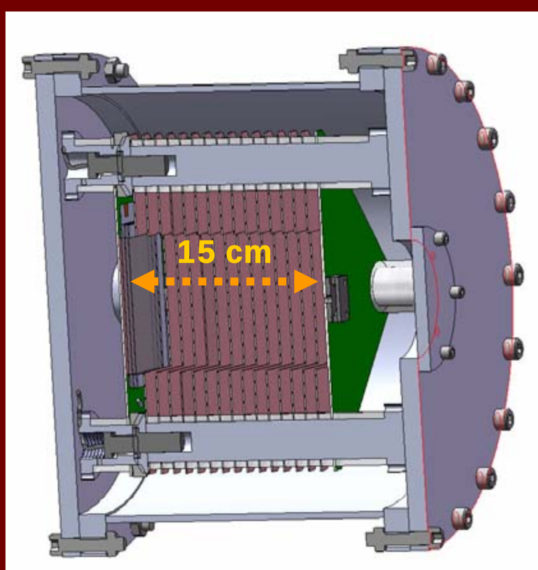
Software simulations

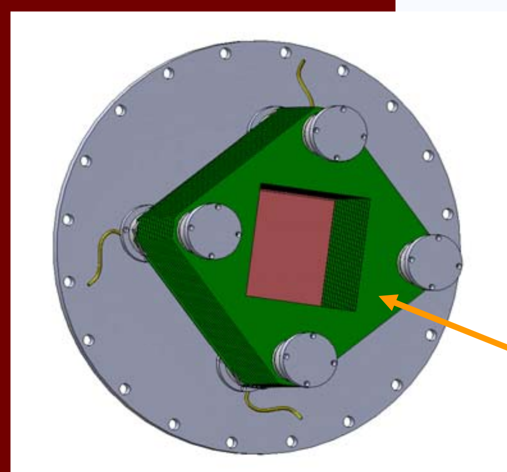
- Active work on simulation has started:
- ββ events in Xenon.
- background events.
- Pattern recognition (2 blobs)
- Background sources and background level.
- ...

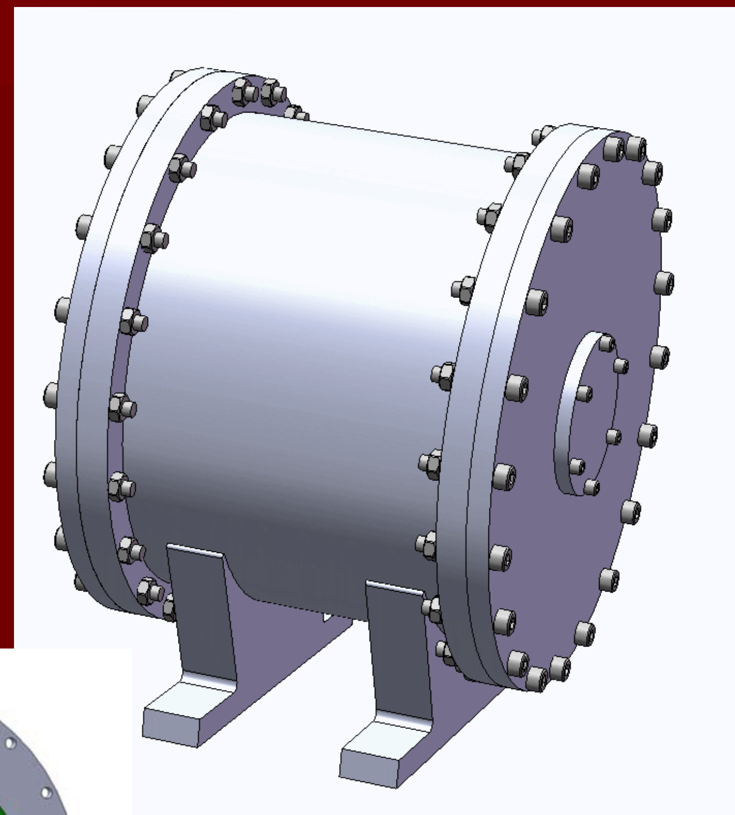


First mechanical designs

- Prototypes like this one will be specifically built for NEXT
- Design under progress
- Flexible design to accommodate different readouts







10x10 cm2 cut out

• Present background dominated by fluorescence