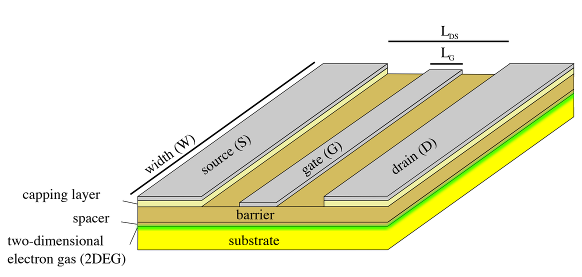
"Noise Model of cryogenic High Electron Mobility Transistor, Low threshold and high discrimination Ge cryogenic detector for Coherent Elastic Neutrino Nucleus Scattering and low mass Dark Matter" (#373)

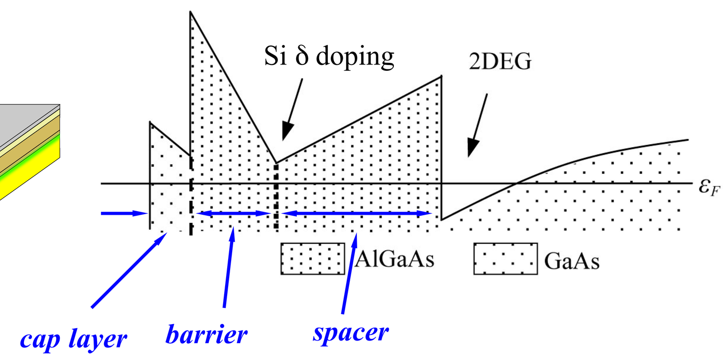
MILANO 22-26 JULY 2019 LTD 18 LOW TEMPERATURE DETECTORS

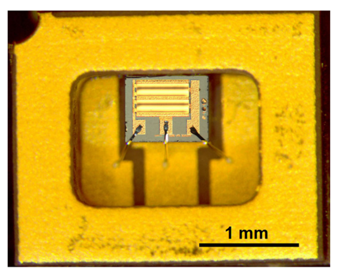
A. Juillard[1], J. Billard[1], D. Chaize[1], J-B Filippini[1], D. Misiak[1], L. Vagneron[1], Q. Dong[2], A. Cavanna[2], C. Ulysse[2], Y. Jin[2], X. de la Broise[3], A. Bounab[3], C. Nones[3], A. Phipps[4]

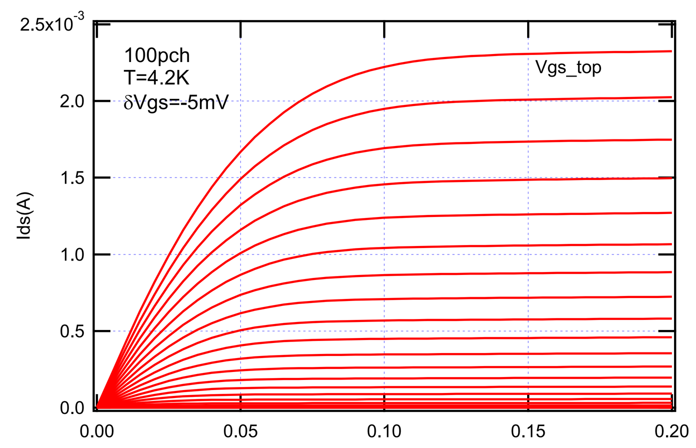
[1] *Univ Lyon, Université Lyon 1, CNRS/IN2P3, IPN-Lyon, F-69622, Villeurbanne, France*
[2] *C2N, CNRS, Univ. Paris-Sud, Univ. Paris-Saclay, 91120 Palaiseau, France*
[3] *IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France*
[4] *Department of Physics, Stanford University, Stanford, CA 94305, USA*

HEMT developed at CNRS/C2N









V_{ds} (mV)	I_{ds} (mA)	g_m (mS)	A_v (*)
100	1	36.9	8.1
100	0.5	26.7	6.2
100	0.28	17.3	4.6
100	0.1	9.55	2.7

* measured w/ R_{drain} = 300 Ω and common source amplifier.

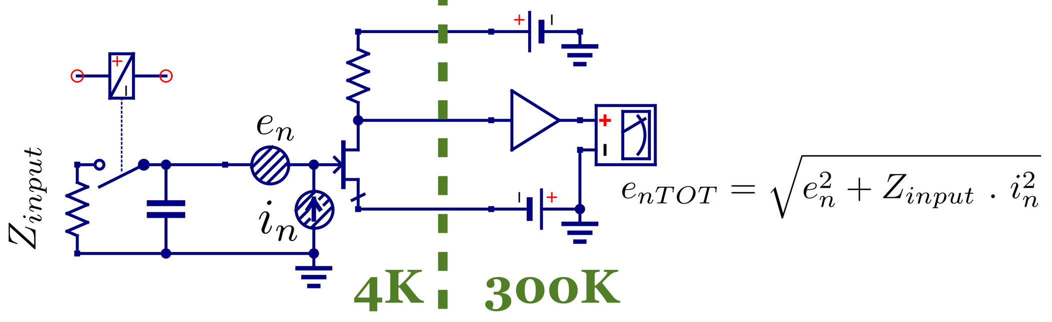
AlGaAs/GaAs hetero-junction, Energy band diagram.

The investigated **HEMTs are based on an AlGaAs/GaAs hetero-structure** grown by MBE (Molecular Beam Epitaxy). It consists of a GaAs buffer layer, a 20 nm AlGaAs spacer layer (thicker than for commercial HEMT), a Si δ-doping layer, a 15 nm undoped AlGaAs barrier layer, and a 6 nm undoped GaAs cap layer.

I_{ds}-V_{ds} characteristics of a 100 pF C_{gs} HEMT @ 4.2K

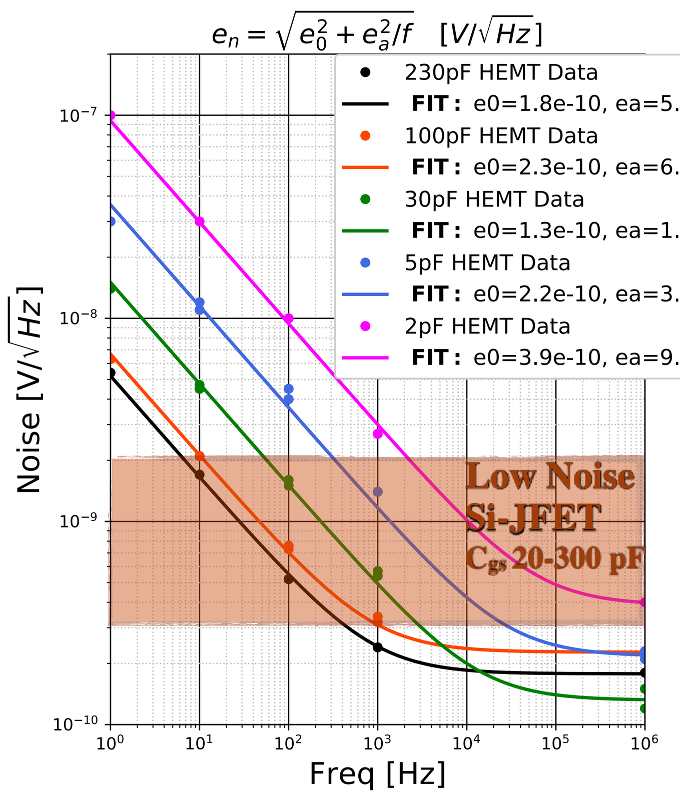
- High transconductance can be obtained with typical **power dissipation < 100 µW**
- Characteristics unchanged at T < 4K and noise improves a bit
- **HEMT can be placed close to the detector : low cabling capacitance**

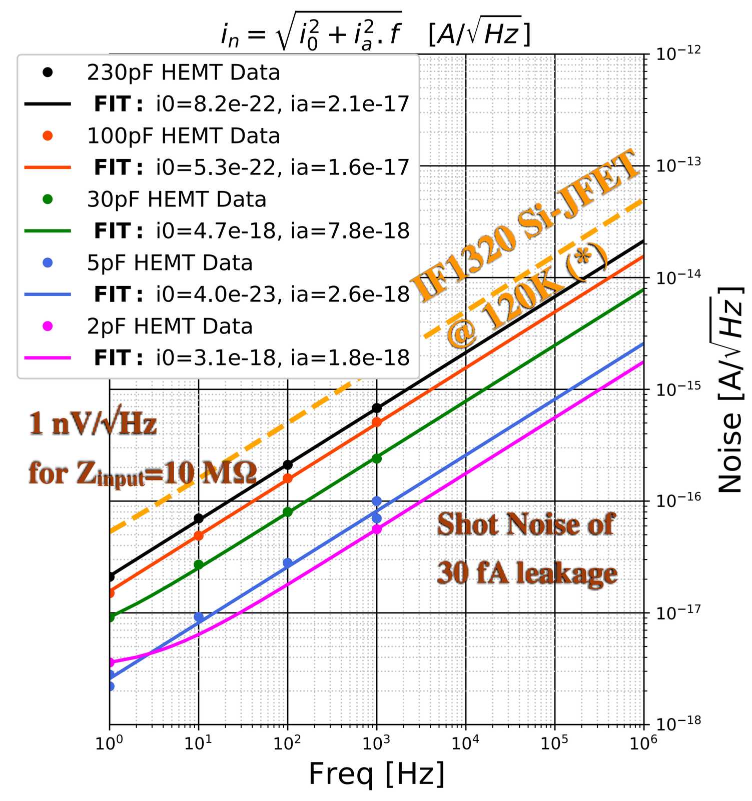
HEMT Noise : measurements and model @ 4K and 100 µW



- Both **Voltage Noise e_n and Current Noise i_n** measured
- Switching from a low R input to a pure capacitive coupling
- 5 HEMT geometries tested (C_{gs} : 2 → 230 pF)

Q. Dong et al. Appl. Phys. Lett. **105**, 013504 (2014)
Y. Jin et al. IEEE ICSICT2014 ***DOI:*** 10.1109/ICSICT.2014.7021379

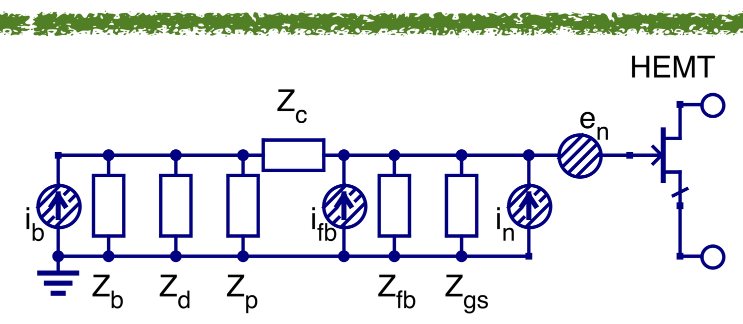




- Main features of C2N HEMT @ 4K are their **ultra low Current Noise i_n**
- **10 times lower than low noise Si-JFET** (such as InterFet IF1320 working at 120 K C_{gs} = 15 pF)
- **Voltage Noise e_n < 0.3 nV/√Hz** for F > 1 kHz and high C_{gs}

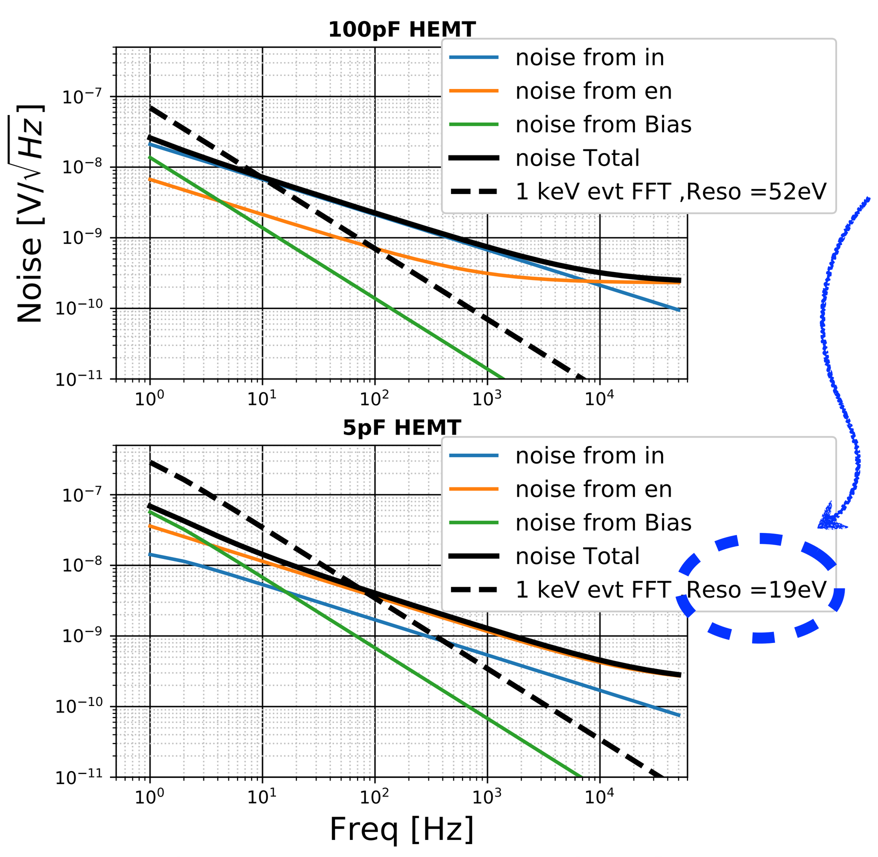
(*) InterFET IF1320 noise @ 120K:
B. Censier et al. J Low Temp Phys (2012) 167:645–651

Detector + HEMT Noise Model



- **Additional noise sources easily calculated** considering :
  - **bias** and **feedback** noises
  - bias, detector, parasitic (incl. cabling), feedback and gate-source HEMT **impedances**
- Feedback noise can be cancelled with an active reset
- Bias noise can be limited to thermal noise of Rbias
- Thermal noise of heat sensor (Ge-NTD) should be added for heat resolution
- Knowing the heat and ionization signals FFT, rms **baseline resolution are given by:**

$$\sigma_E^2 = \left(4\int_{f_{min}}^{f_{max}} \frac{|s(f)|^2}{J(f)} df\right)^{-1} \rightarrow \left(4\sum_{f_{min}}^{f_{max}} \frac{|s(f)|^2}{J(f)} \Delta f\right)^{-1}$$



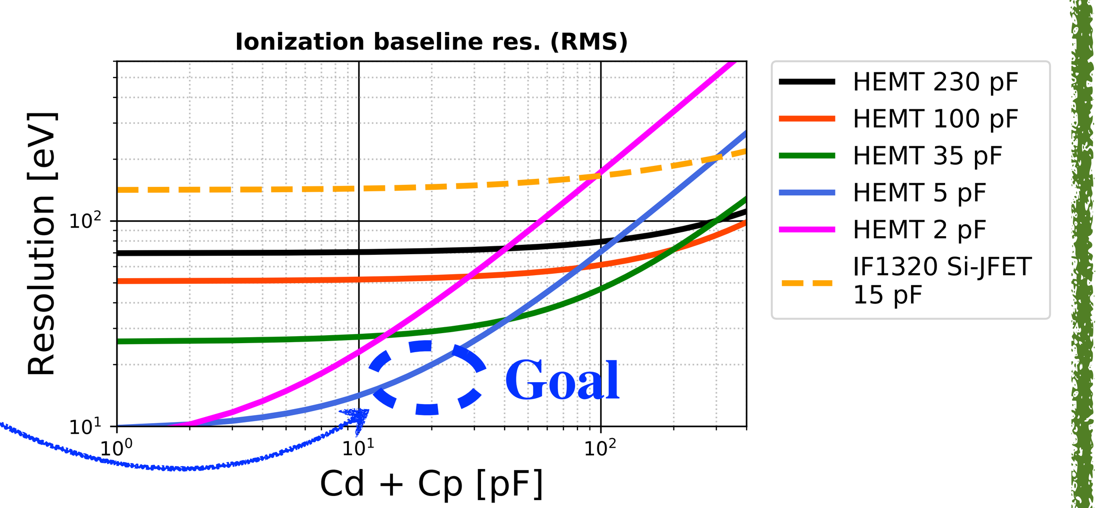
Noises and rms resolution for

- $C_d + C_p$ = **20 pF**
- 100 pF and 5 pF HEMT
- R_{bias} = 10 GΩ @ 20mK

Ionization

20 eVee rms resolution reachable w/

- **$C_d + C_p$ = 20 pF**
- **5 pF HEMT**
- R_{bias} = 10 GΩ @ 20mK



Heat

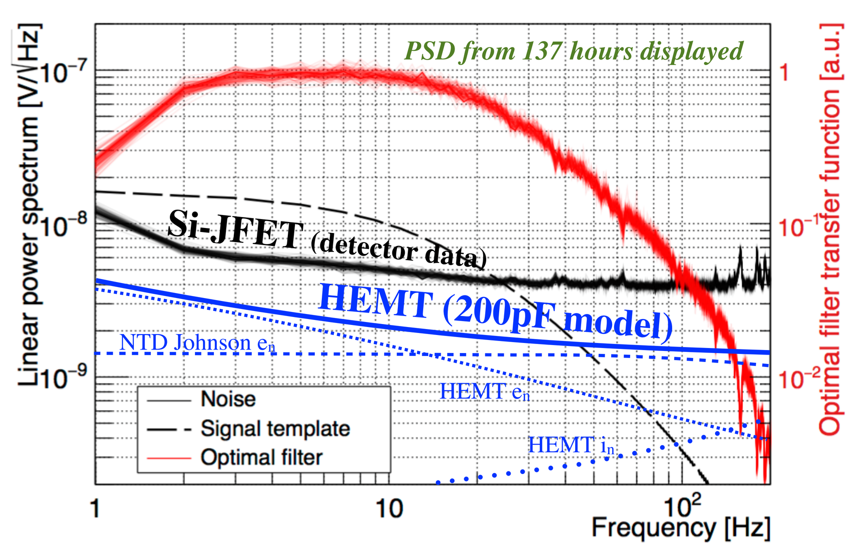
- **18 eV rms resolution reached already** on optimized 34 g Ge detector **with Si-JFET**

E. Armengaud et al. (EDELWEISS Collab.) Phys. Rev. D 99, 082003

- limited by Si-JFET i_n noise

10 eV rms resolution reachable w/

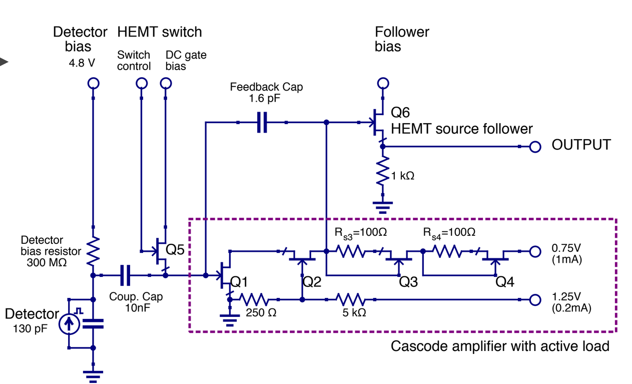
- **100 or 200pF HEMT**



Cold Amplifier schemes investigated

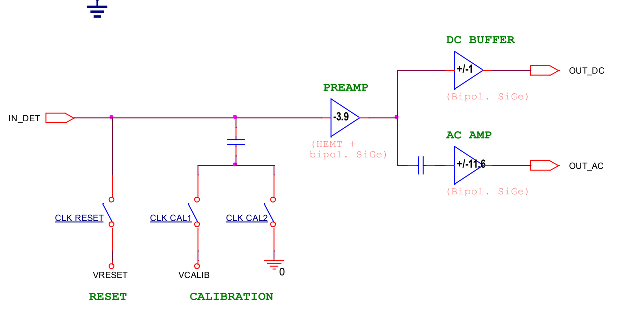
- **Full HEMT-based cryogenic amplifier**
  - Tested on a 240 g, 130 pF CDMS-II Ge cryogenic detector @ 40 mK
  - **91 eVee ionization baseline measured with 100pF HEMT** (100 eVee expected by our Model)

A.Phipps et al. https://doi.org/10.1016/j.nima.2019.06.022 *arXiv:1611.09712*



- **Hybrid HEMT + SiGe / MOS ASICs** (in production).
  - Technology demonstrated in various application

X. de la Broise et al. NIMA 787 (2015) 51–54 , NIMA 787 (2015) 64-67



- **Follower HEMT input + low noise 300 K Electronics**
  - adaptation of the EDELWEISS-III charge readout scheme

B. Censier et al. J Low Temp Phys (2012) 167:645–651

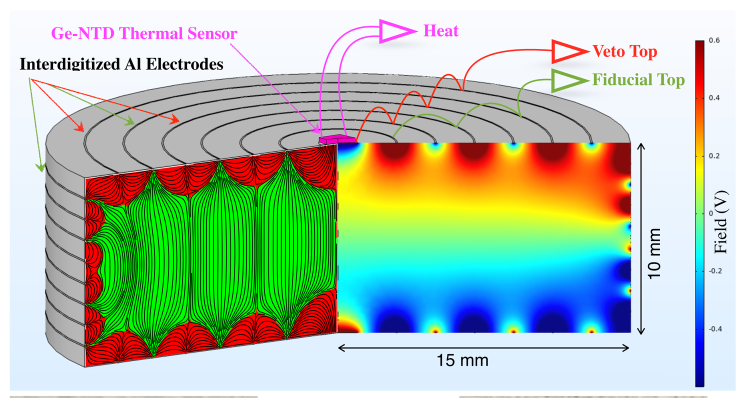
Low Capacitance Ge Detector

Electrostatic Simulation ongoing on the electrodes geometry :

- Keep the efficient **FID** (Full Interdigitized Detector) **geometry** used by EDELWEISS to **reject surface event**

E. Armengaud et al. (EDELWEISS Collab.) 2017 JINST 12 P08010

- Optimize for smaller Ge detector
- 34 g (Φ20 h20) and 38 g (Φ30 h10)
- **20 pF total capacitance budget**
- Very low capacitance cabling needed



34 g (Φ20 h20) Ge FID detector

38 g (Φ30 h10) Ge FID detector (plane surface before lithography)

CONCLUSION

- **10 eV Heat and 20 eVee Ionisation baseline resolution (rms) feasible according to our model on ~ 35 g / 20 pF Ge cryogenic detector**
- Allows for **low threshold nuclear recoils sensitivity and high background rejection** for Sub-GeV WIMPs and MeV neutrinos.
- Low Capacitance Cabling to be designed (kapton, vacuum coaxial cables)
- 1 kg of detector will be produced for the **RICOCHET** experiment (CENNS) and **EDELWEISS-SubGeV** (Low Mass Dark Matter)