

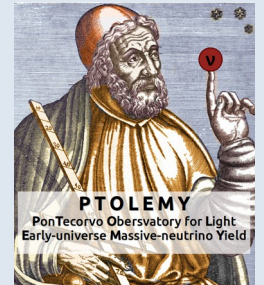
# PTOLEMY

## HV stabilization system

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and F. Virzi (*LNGS Group*)



PTOLEMY ITA Meeting  
Roma, Feb 18th 2024



# Part I

## Static voltage reference

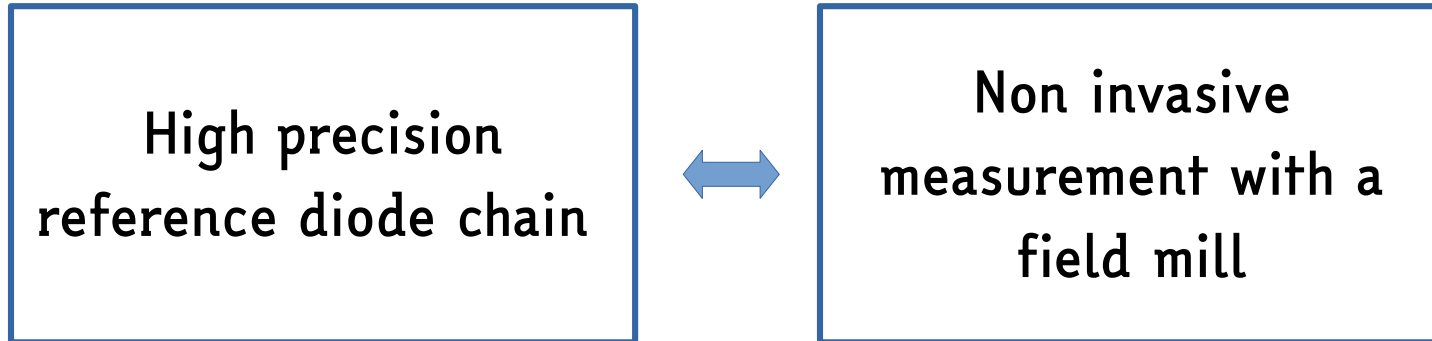
# Motivations and goals

Resolution  $\Delta E \sim \Delta V$ :

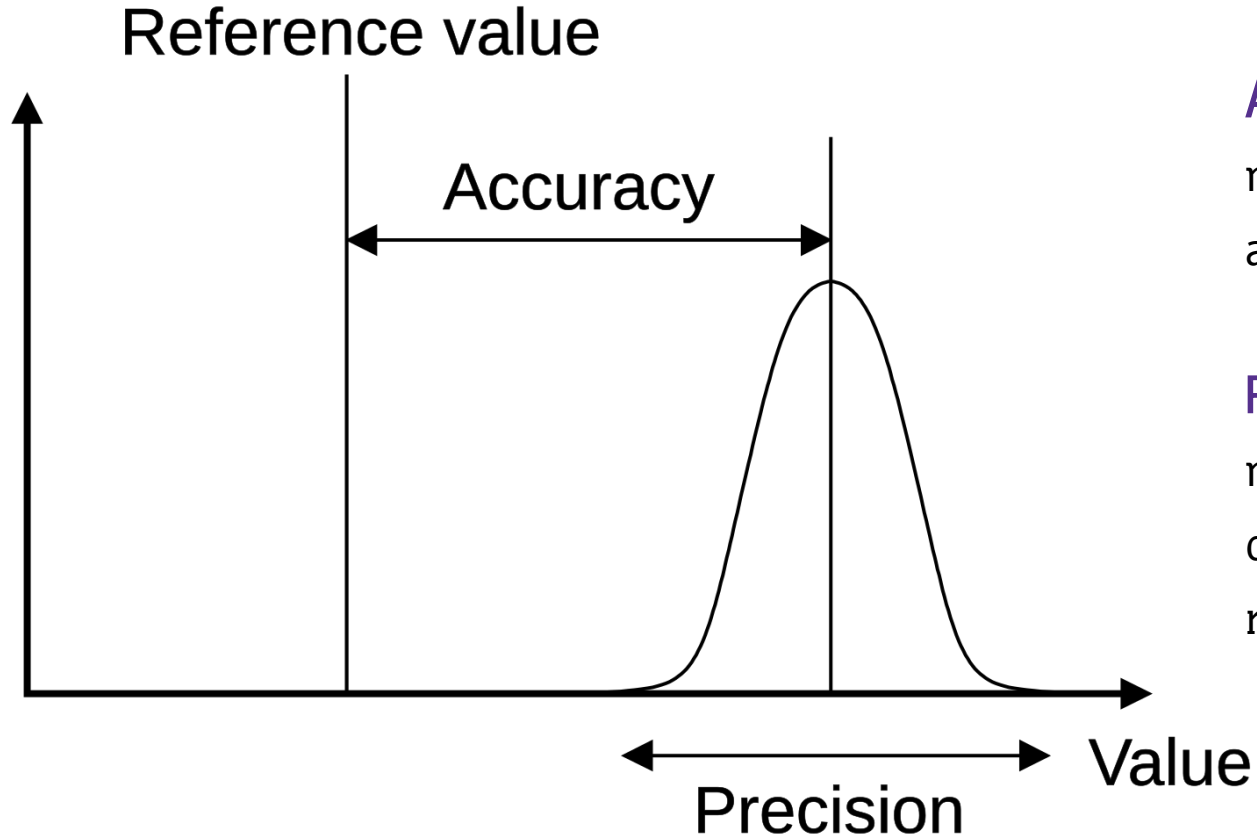
$\Delta E < 50$  mV at the tritium end point (18600 keV) (CvB)

$\Delta E < 500$  mV at the tritium end point (18600 keV) (Nu Mass)

@ 20 kV  $\rightarrow \Delta V/V \sim 2.5$  ppm



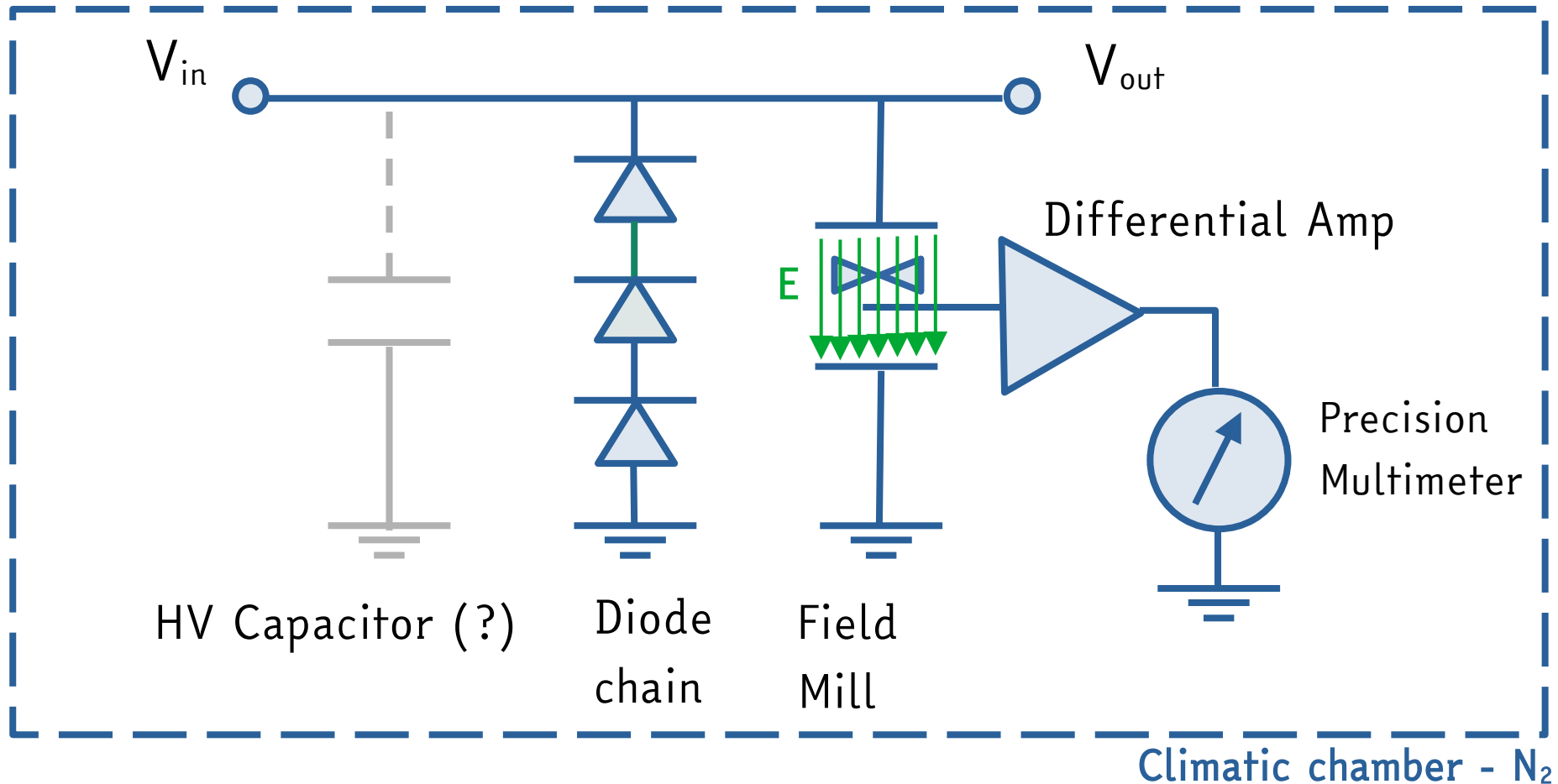
# Accuracy and Precision



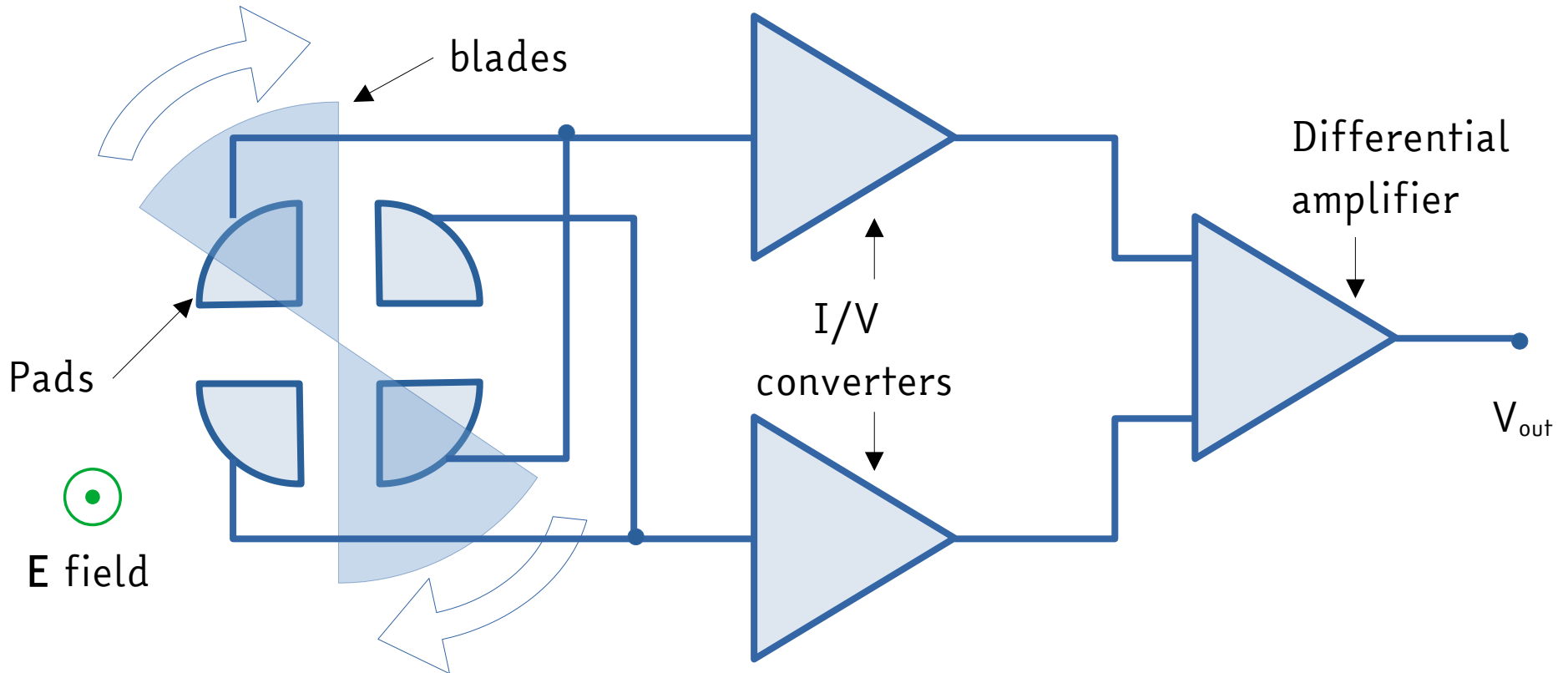
**Accuracy:** proximity of measurement results to the accepted value

**Precision:** degree to which measurements under unchanged conditions show the same results.

# Setup scheme (baseline)



# Amplification chain



# High precision reference voltage regulators (slang *diode*) - REF50xx

$$V_0 = 10V$$

$$V_{in} = 10.2 - 18 V$$

$$I_q = 0.8 \text{ mA}$$

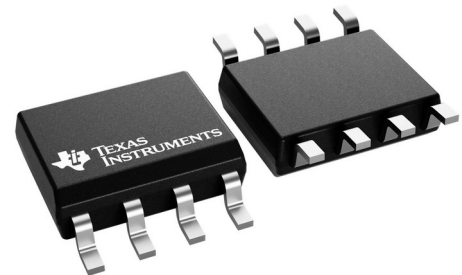
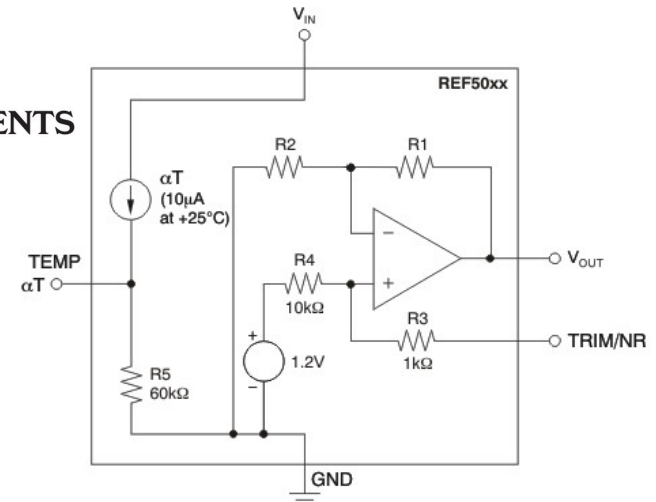
Low temperature drift: 2.5 ppm/°C

High accuracy: 0.025%

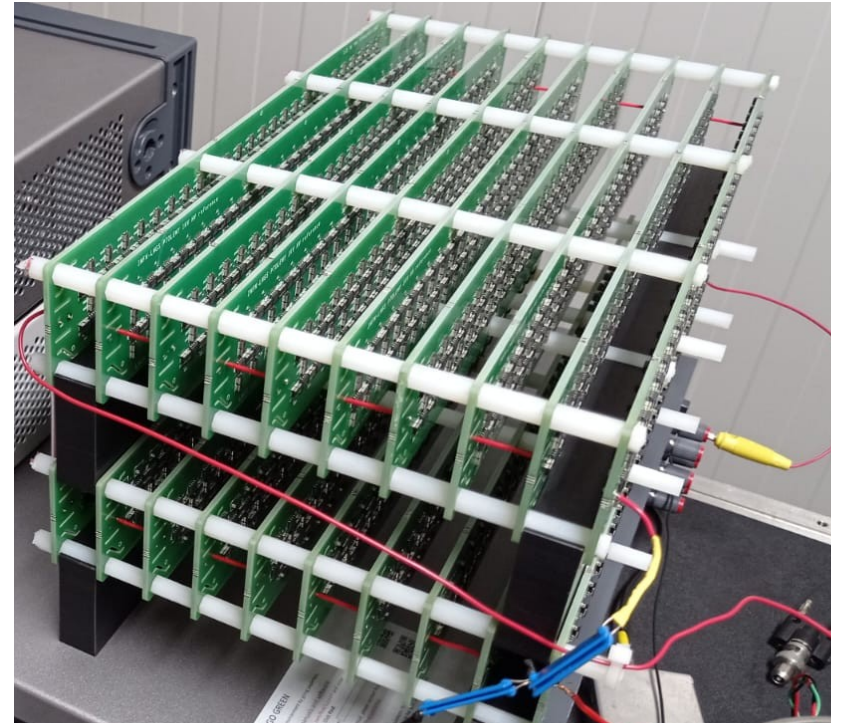
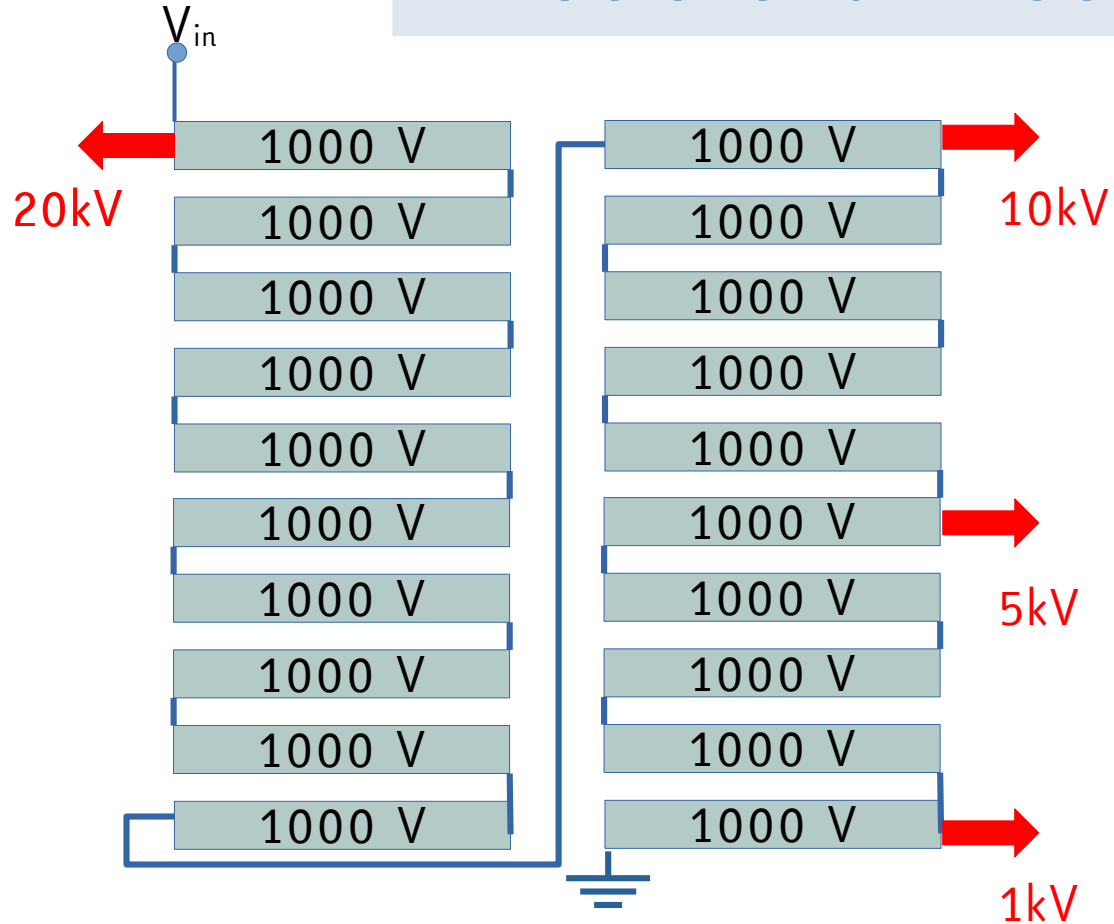
Low noise: 0.5  $\mu\text{V}_{pp}/\text{V}$

Excellent long term stability: 22 ppm/1000h

Temperature range: -40 ÷ 125°C



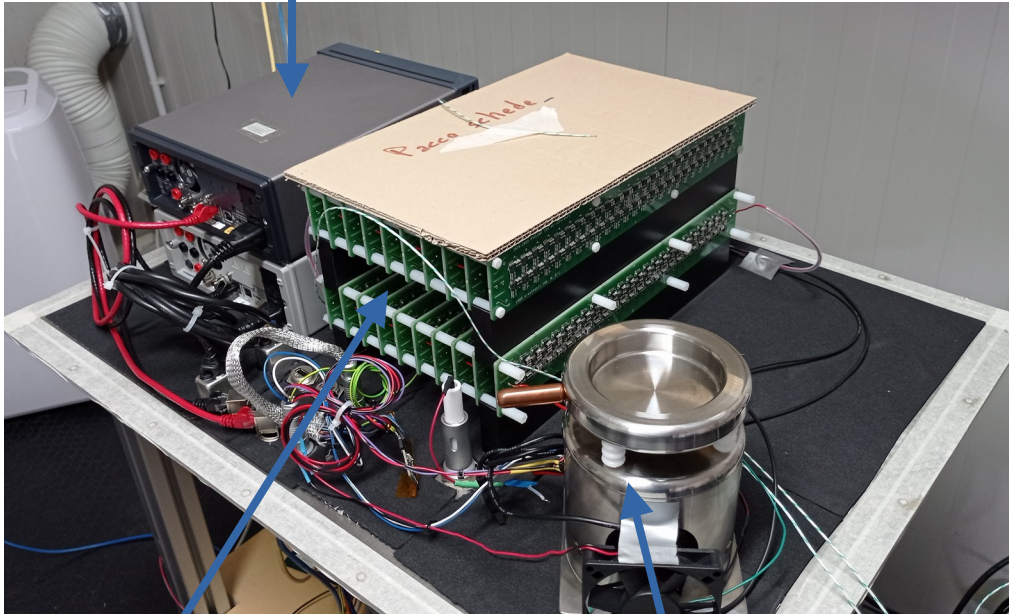
# Diode chain configuration





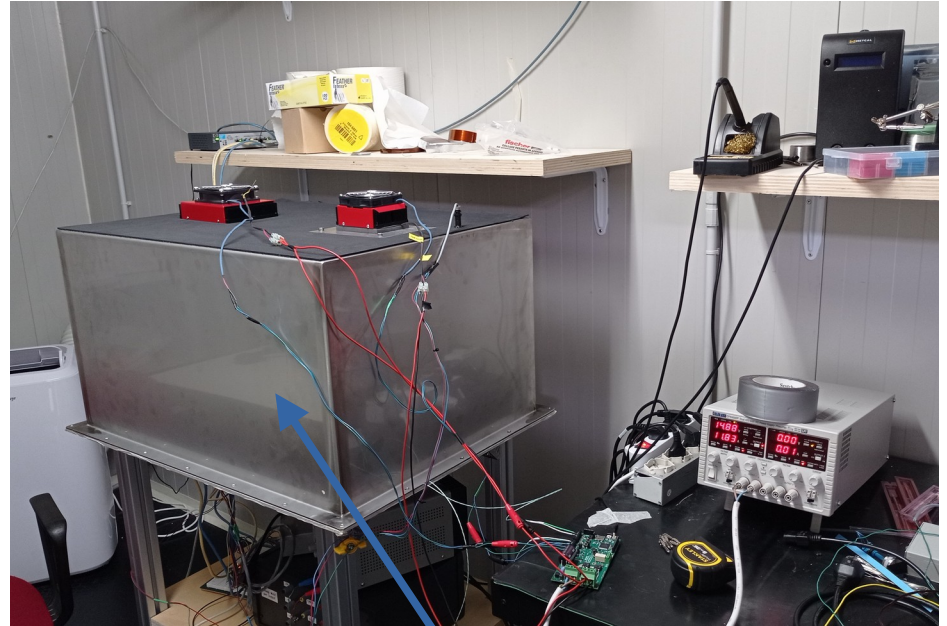
Precision  
Multimeters  
6.5 and 7.5 digits

# Old set-up



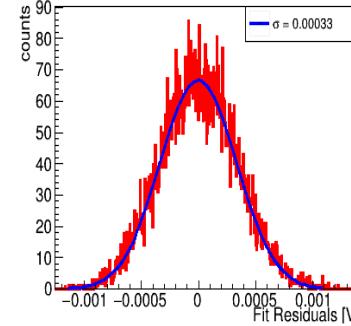
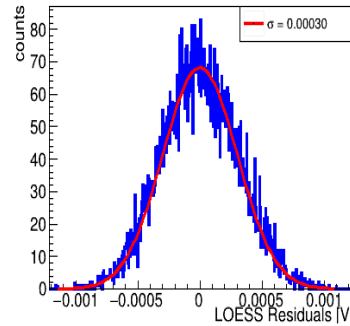
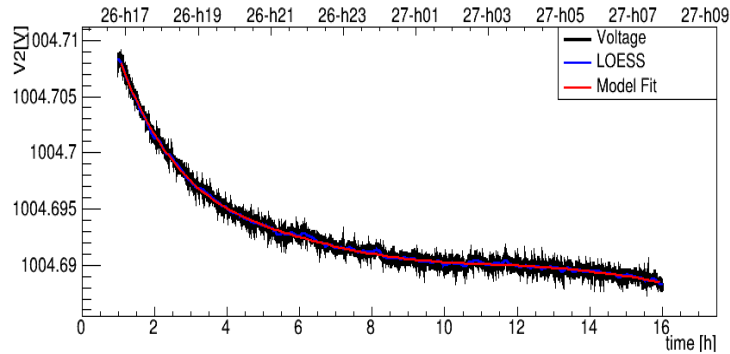
Diode chain

Field mill



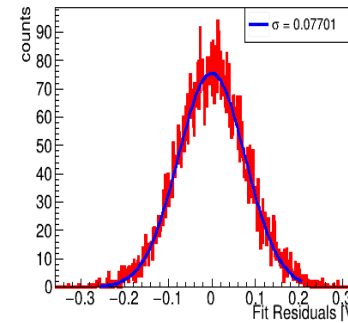
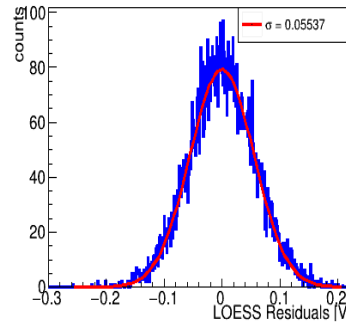
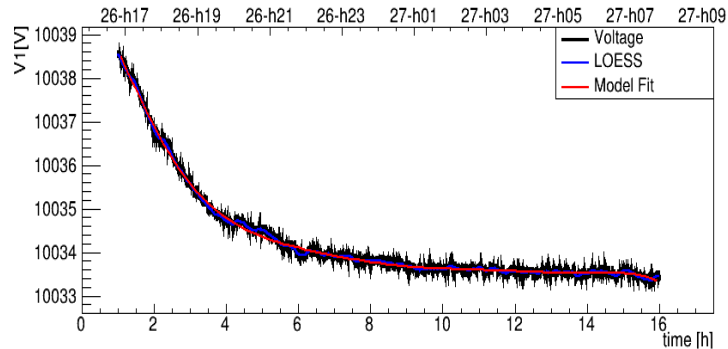
Climatic chamber

# Old results (baseline)



Single board  
(1 kV)

$$\sigma = 0.3 \text{ mV}$$



10 board series  
(10 kV)

$$\sigma = 55 \text{ mV}$$

$$\sigma(\text{intrinsic, 10kV}) = \text{sqrt}(10) \times 0.3 \sim 1 \text{ mV}$$

$$\sigma(\text{intrinsic, 20kV}) = \text{sqrt}(20) \times 0.3 \sim 1.4 \text{ mV}$$

( $\ll 55 \text{ mV} !!!$ )  
[I wish!!!]

# Where we are

Source of **systematics**:

$$\sigma_{tot}^2 = \sigma_{source}^2 + \sigma_{filter}^2(E, B) + \sigma_{RF}^2(\Delta t[7\text{meV}/\mu\text{s}]) + \sigma_{detection}^2$$

What we can reasonably say:

$$\sigma_{filter}(20\text{ kV}) \lesssim \sqrt{2}\sigma_{HV}(10\text{ kV}) \simeq 80\text{ meV}$$



Good starting poi for the mass measurement

# PTOLEMY Milestones

## Sensitivity to neutrino mass (optimistic!)

- (i) Tritium on graphene (source) [Feasible] ✓
- (ii) Filter [simulated → To be tested with the magnet] ⚠
- (iii) HV reference (Feasible) ✓
- (iv) RF detection [Close enough] ✓
- (v) Electron detection [Close enough] ✓

# New set-up

- New climatic chamber ✓
- New motor ✗⚠
- New mill blade ✓
- New motor driver ⚠
- Modified differential amplifier ⚠
- Additional precision multimeter ✓  
(8.5 digits)
- HV slow switch ✓

Make a change  
at a time!

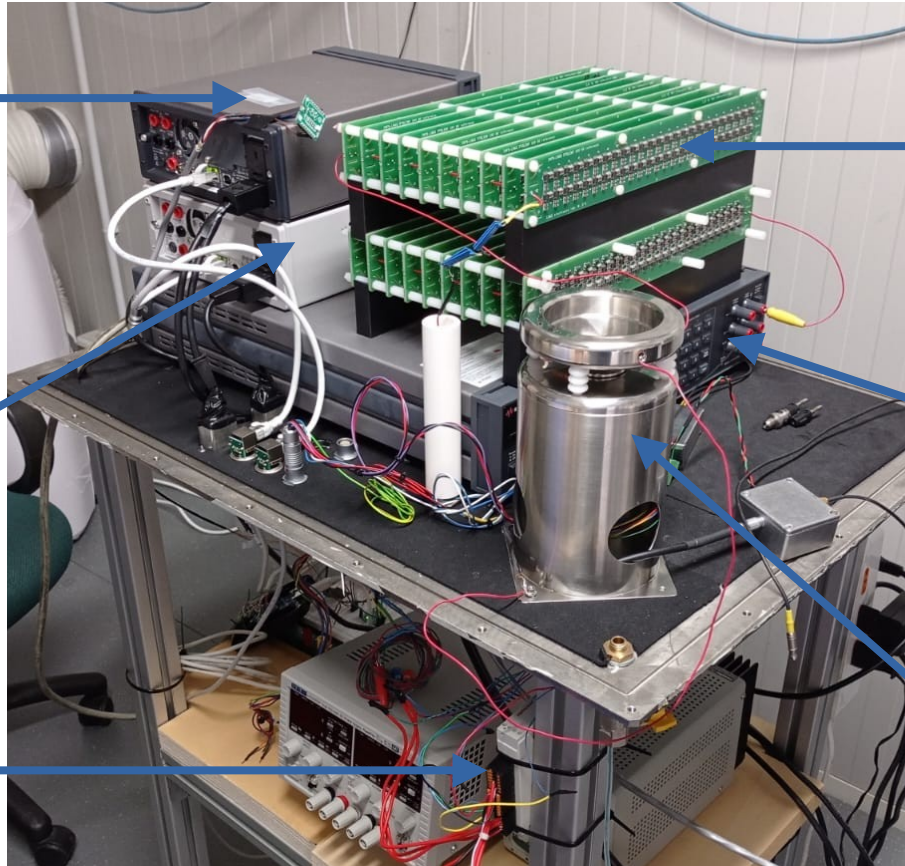


# New set-up

Multimeter  
7.5 digits  
(Field mill)

Multimeter  
6.5 digits  
Temp. board

Motor driver



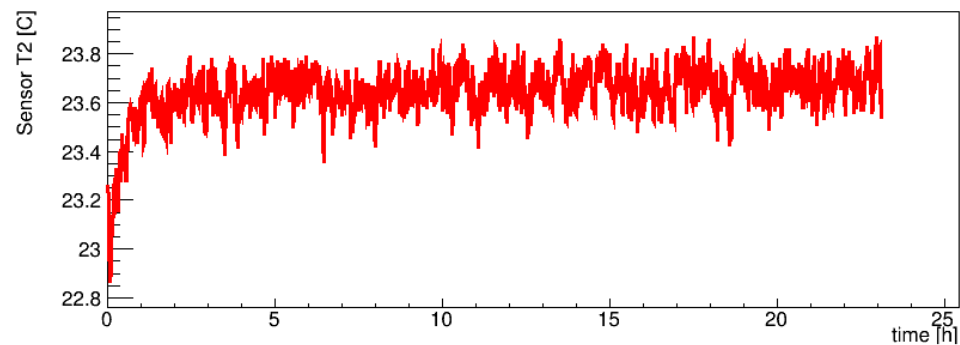
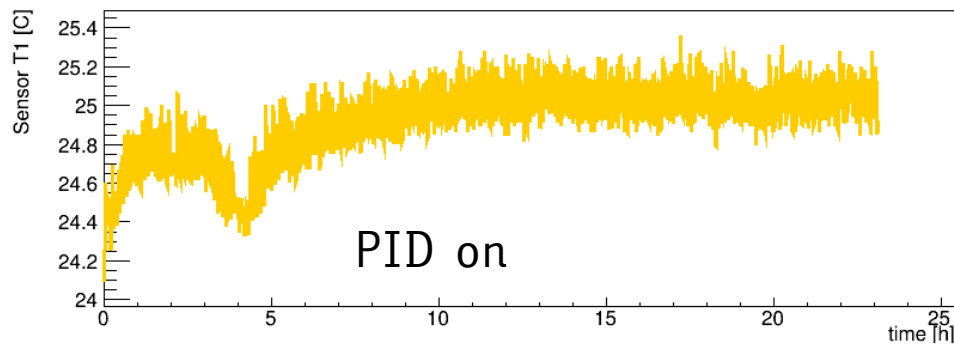
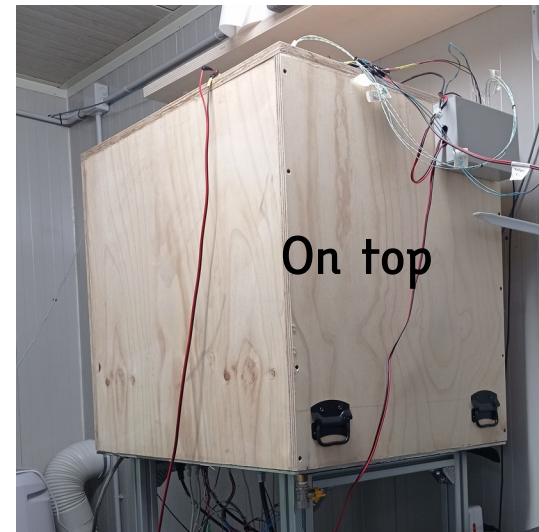
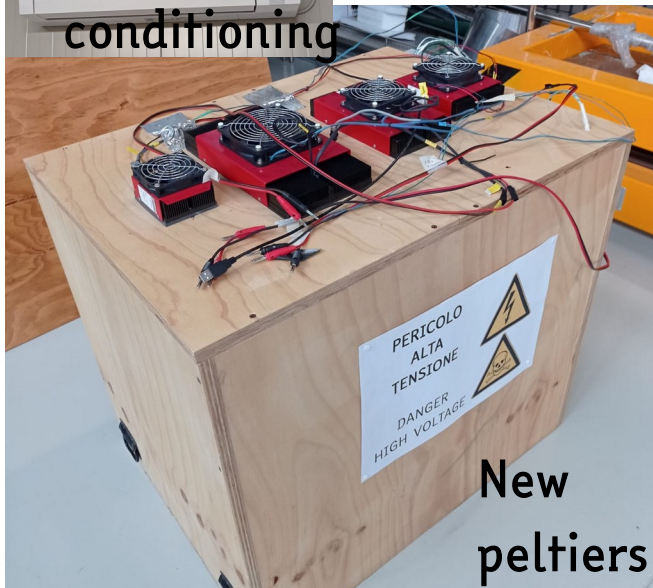
Diode  
chain

Multimeter  
8.5 digits  
(1kV board)

Field mill

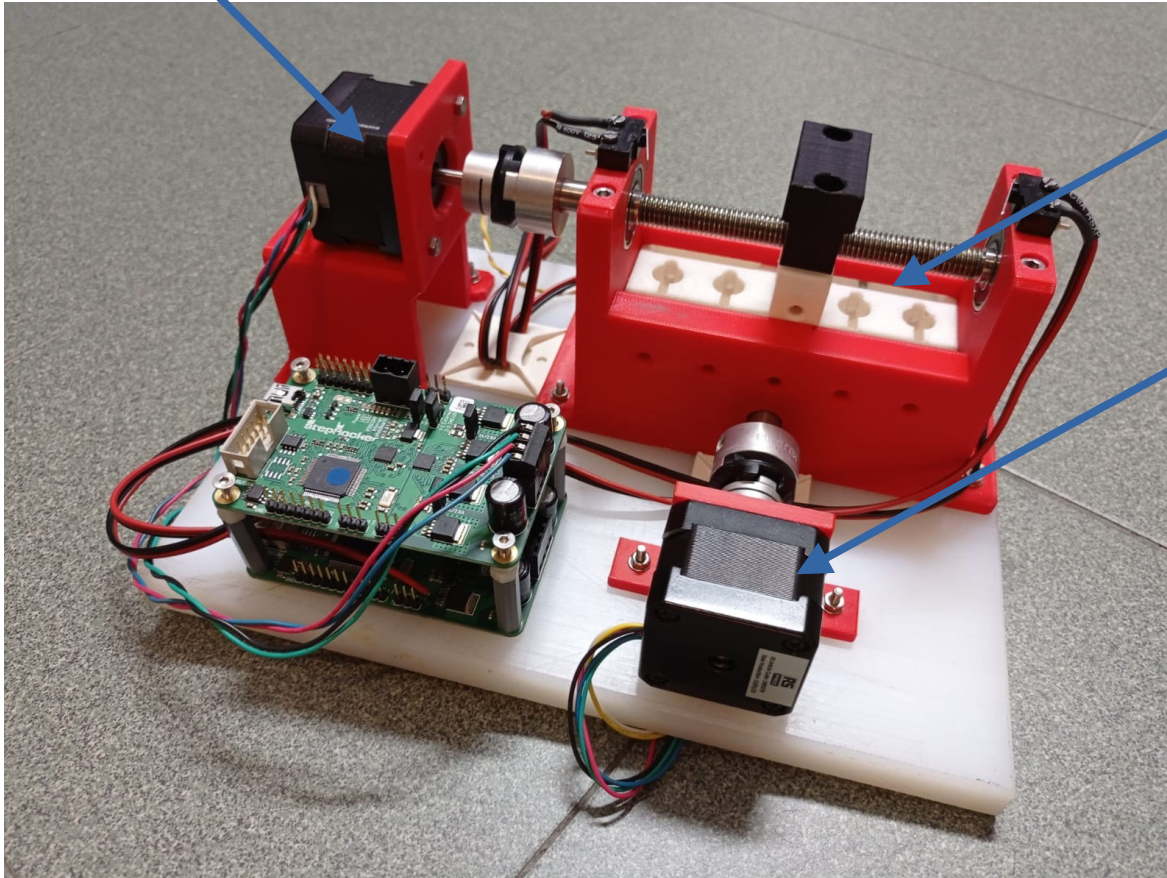
# New climatic chamber

Room  
conditioning



# HV slow switch

Horizontal  
movement



Electrode  
holes

Lateral  
movement

Switching between  
different partition of the  
diode chain without  
opening the climatic  
chamber

Ready to be tested

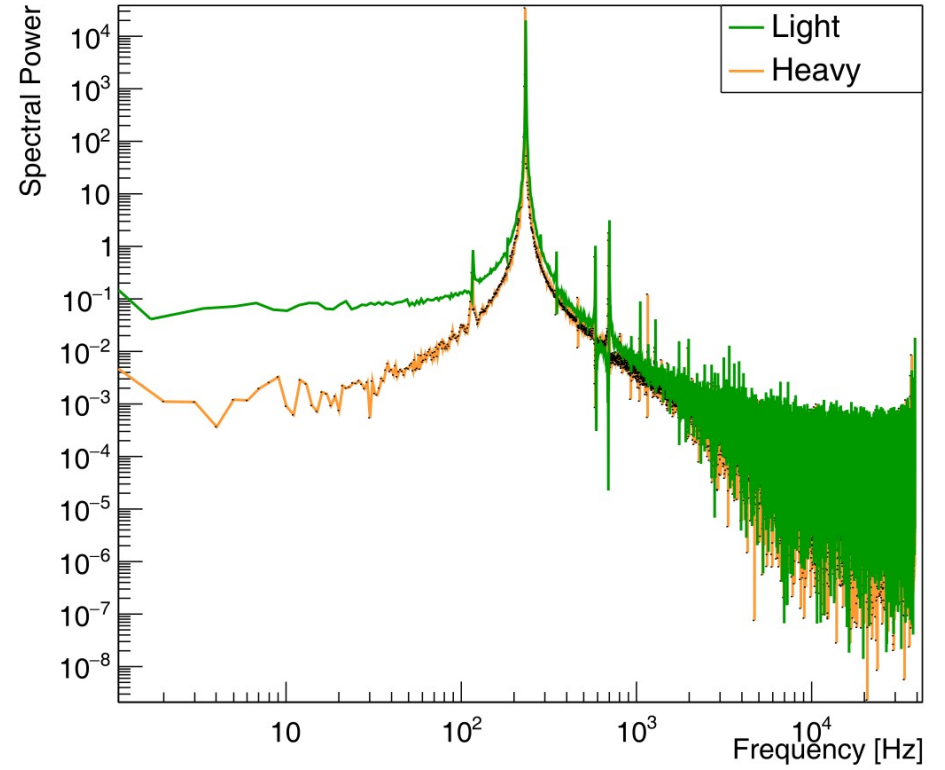


# New mill blade



New mill  
blade  
LIGHT  
(height  
adjustable)

Mechanical Spectrum



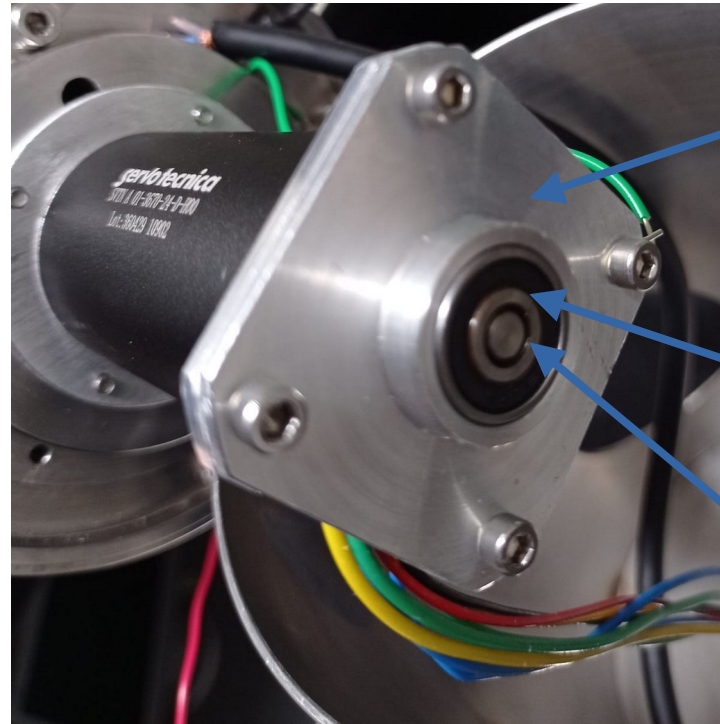
New mill  
blade  
HEAVY

High stability in frequency

# New motor



New brush-less motor



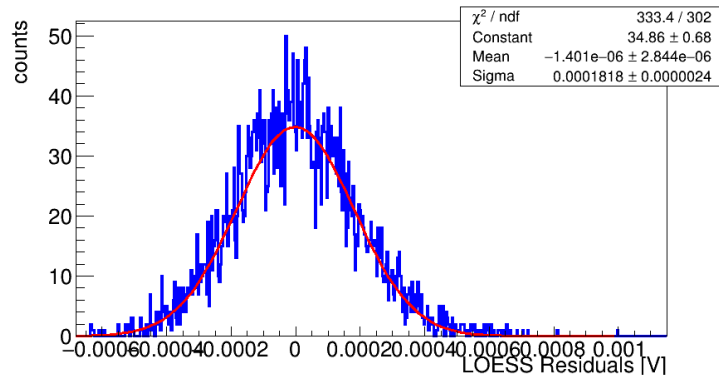
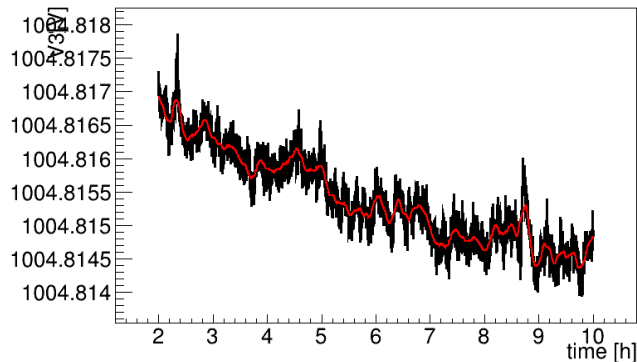
Aluminum plate

Ball bearing

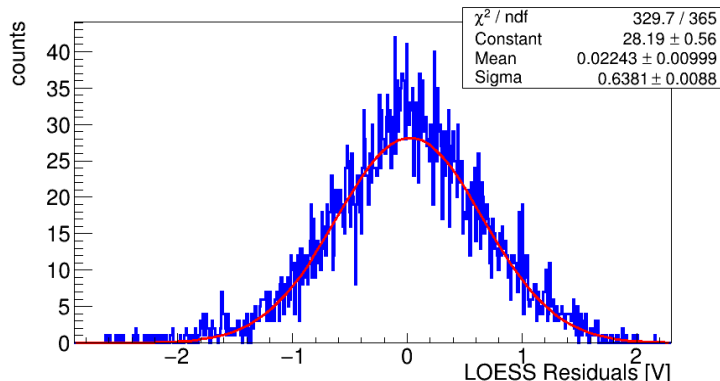
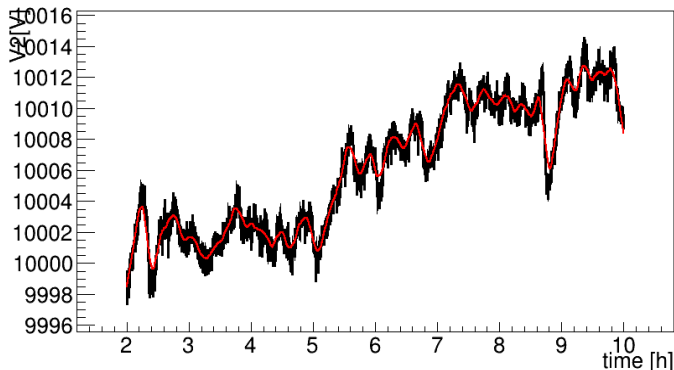
Motor axis

Grounding problem between the axis and the aluminum plate ( $> 10 \text{ k}\Omega$ ) ⚠

# New results



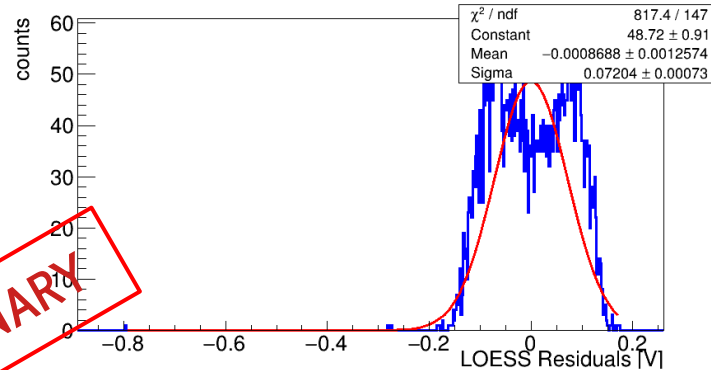
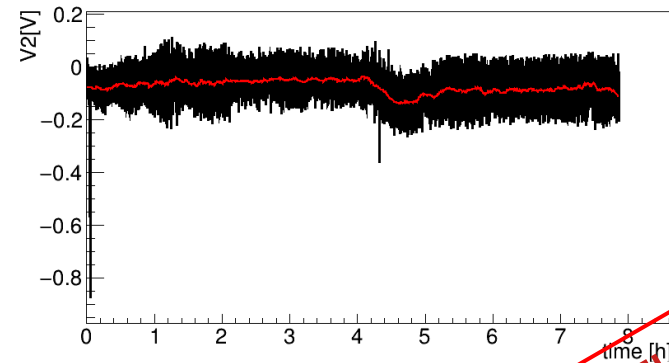
Single board  
(1 kV)  
 $\sigma = 0.18 \text{ mV}$   
**[IMPROVED]**  
 $\Delta V/V = 0.18 \text{ ppm}$



10 board series  
(10 kV)  
 $\sigma = 638 \text{ mV}$



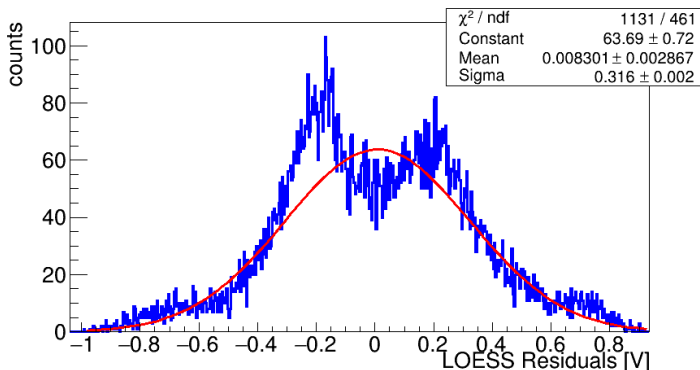
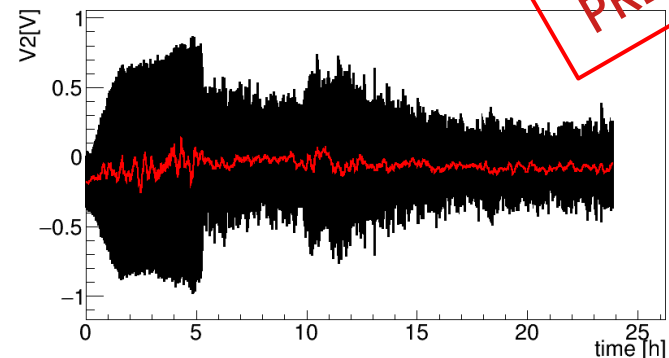
# Origin of the noise



Field mill off  
Plate grounded

$$\sigma = 72 \text{ mV (10 kV eq.)}$$

**PRELIMINARY**



Field mill on  
Plate grounded

$$\sigma = 300 \text{ mV (10kV eq.)}$$

# Next actions

- Motor **grounding** fix
- Optimization of the field mill signal **amplifier**
- Test on **mechanical stability**
- Tests with the new motor **driver**

## Publication of preliminary results [in preparation]

- 0.18 ppm precision on the single board 1kV and extrapolation at 0.8 ppm
- Preliminary 5.5 ppm on 10kV and field mill technology

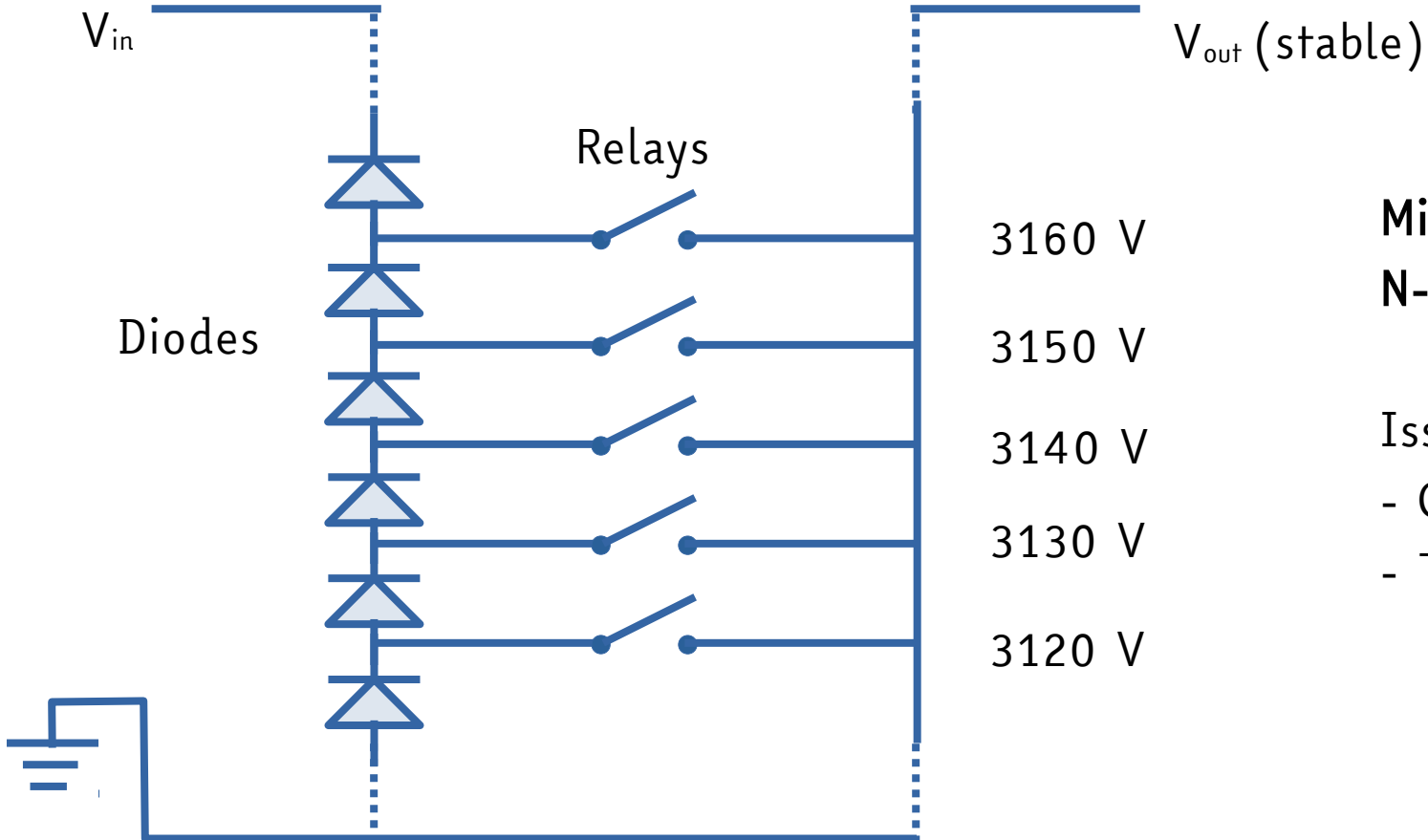
# Part. II

## Dynamic voltage reference

# Dynamic filter electrode switch

- Change the reference voltage over a **wide range** from 0 to 20 kV
- Change in a **very short time** ( $\sim 1\text{ms}$ )
- Avoid **electromagnetic noise emission**
- Avoid **leakage current** in switches
- Minimize the **reference diode divider** complexity

# Zero level switch



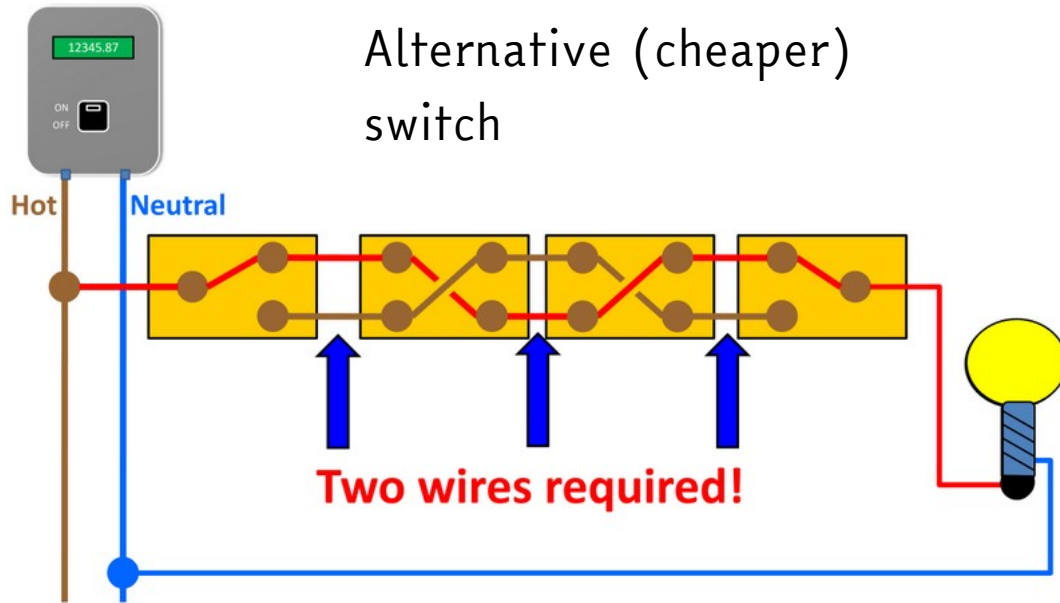
Millipede  
N-way switch

Issues:

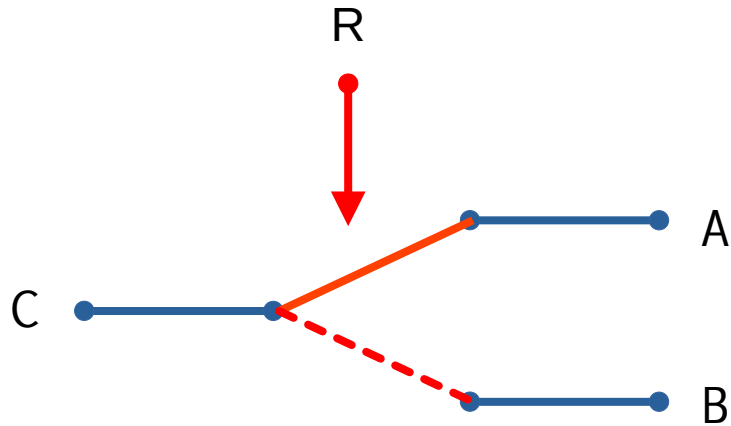
- Complex system
- Too many components



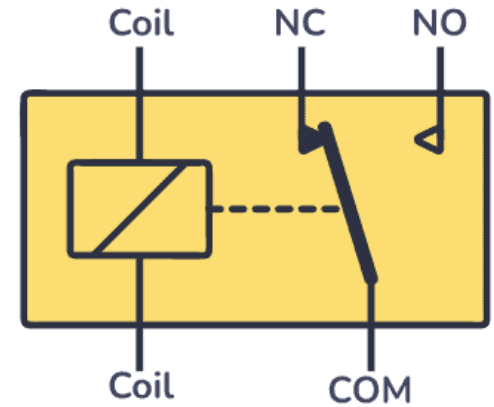
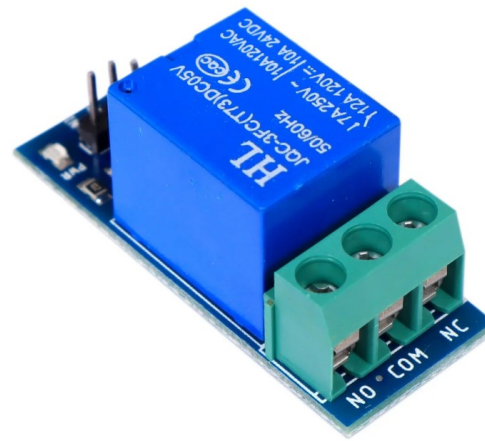
# Multiple switch problem



# Diverter (3 ways)



Three  
way  
witch

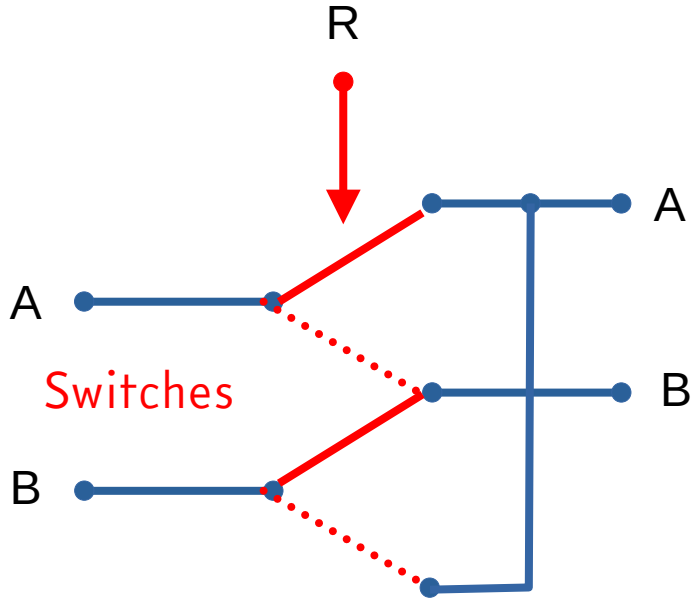


**Common coil relay**

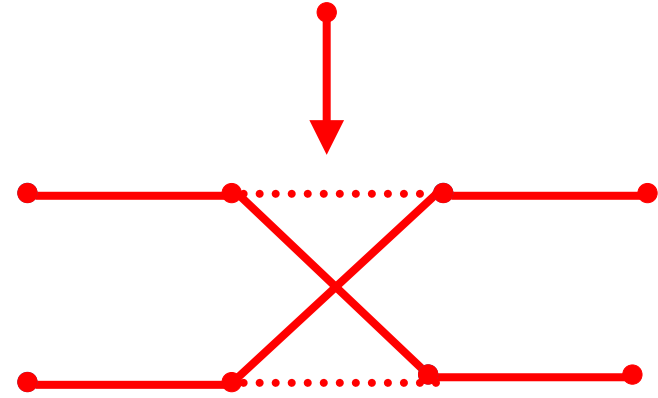
NC = normally closed

NO = Normally open

# Inverter (4 ways)



Made of two relays  
switching  
Simultaneously



Simplified scheme

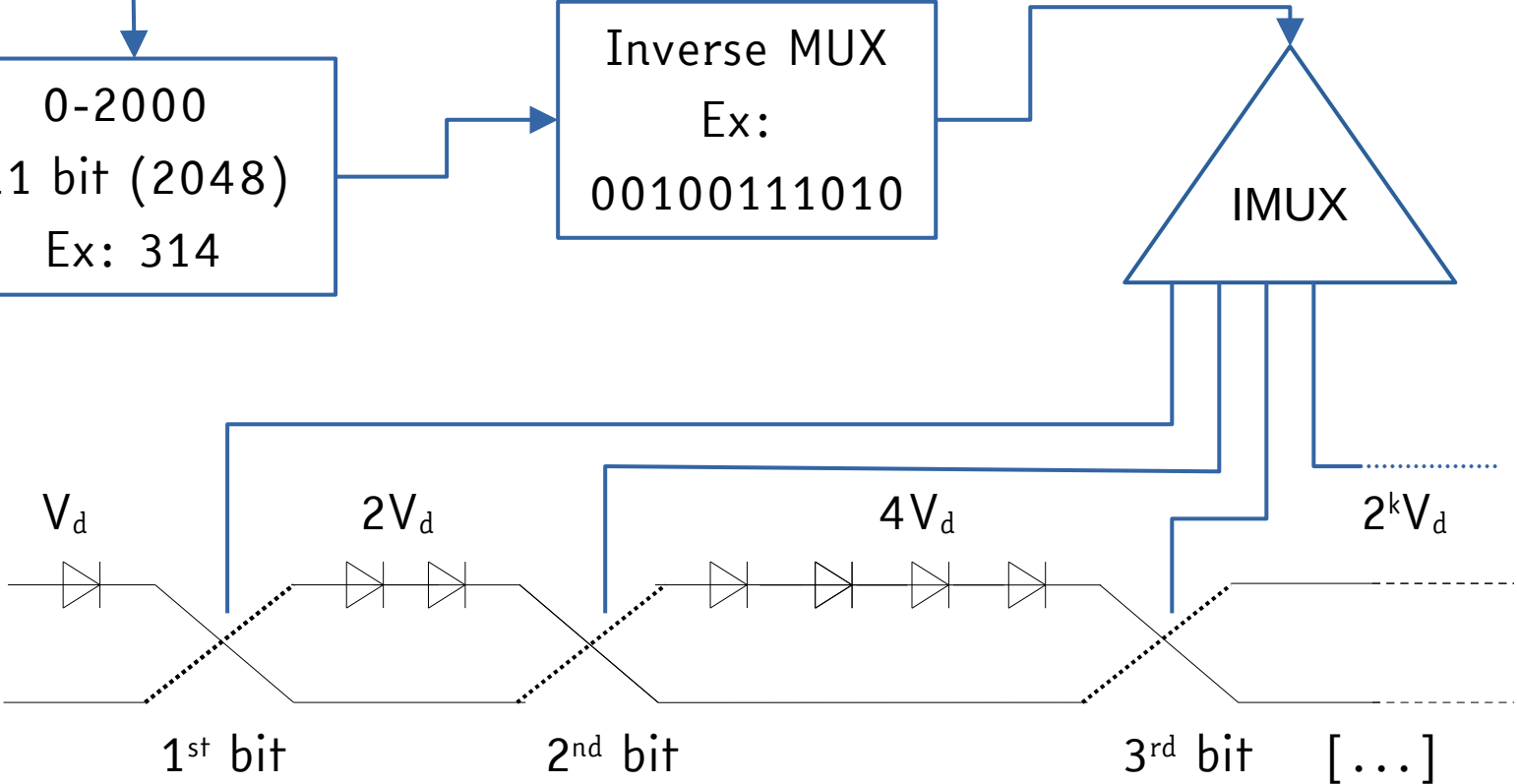
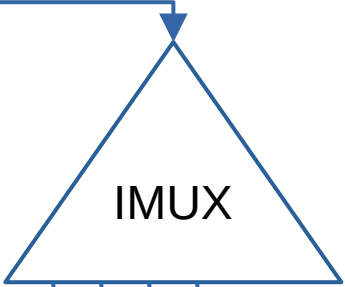
- I. parallel (direct)
- II. Crossed (inverted)

# Encoding

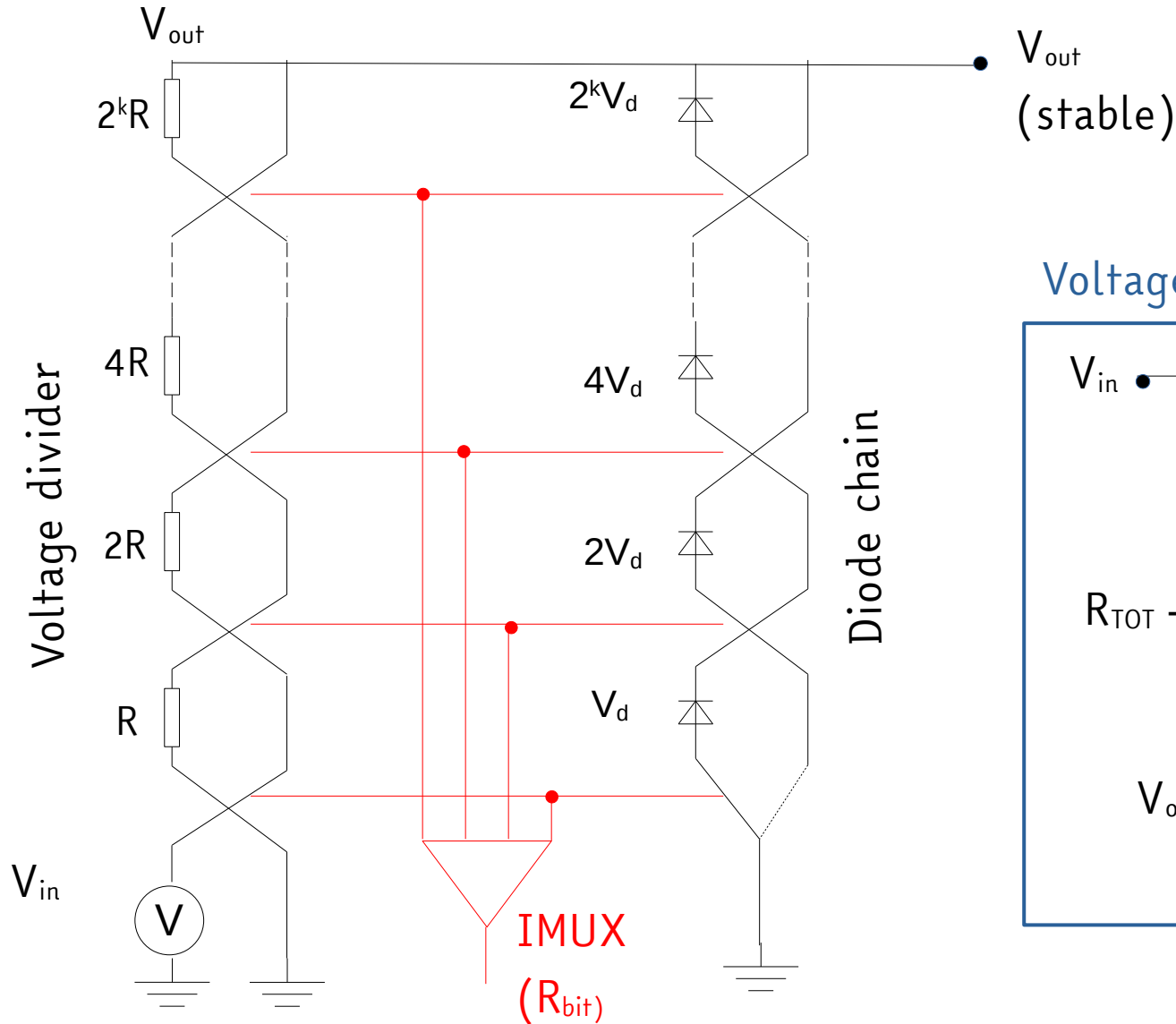
0-20000 V  
(in steps of  $V_d = 10$  V)  
Ex: 3142 V

0-2000  
11 bit (2048)  
Ex: 314

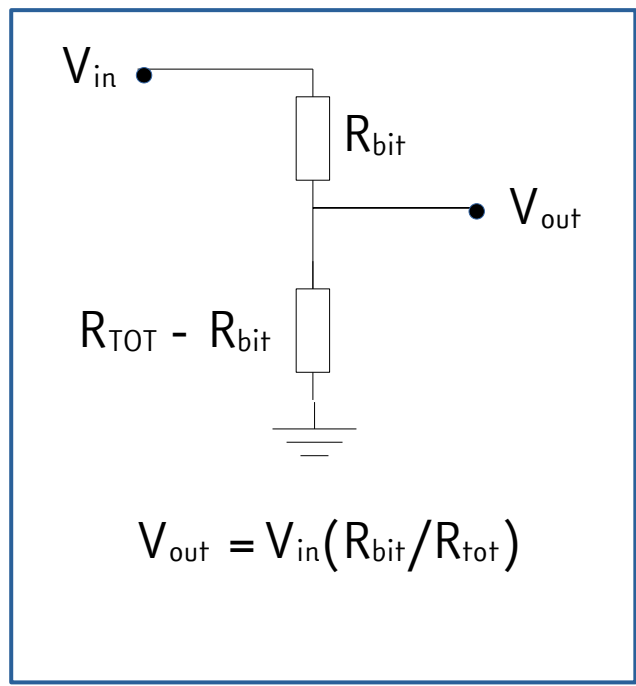
Inverse MUX  
Ex:  
00100111010



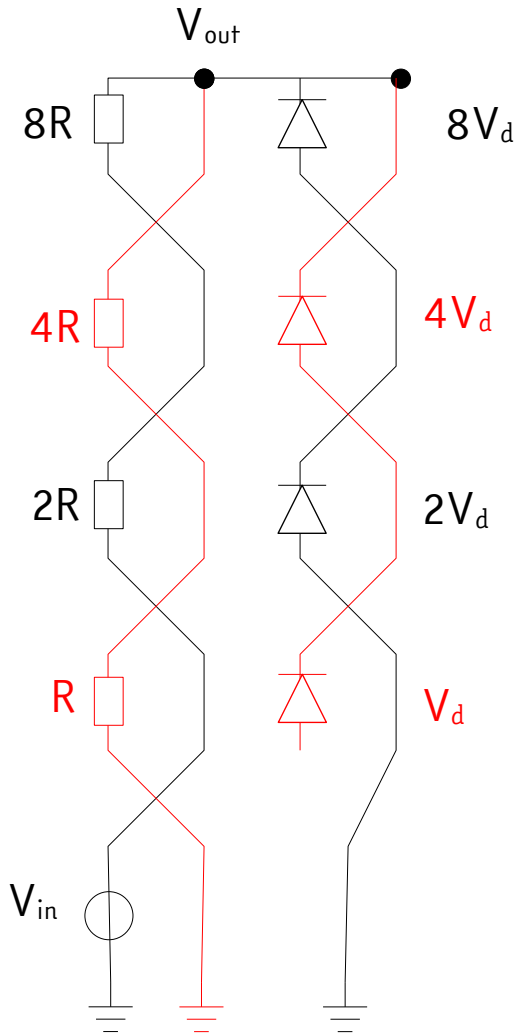
# Divider



Voltage divider equivalent



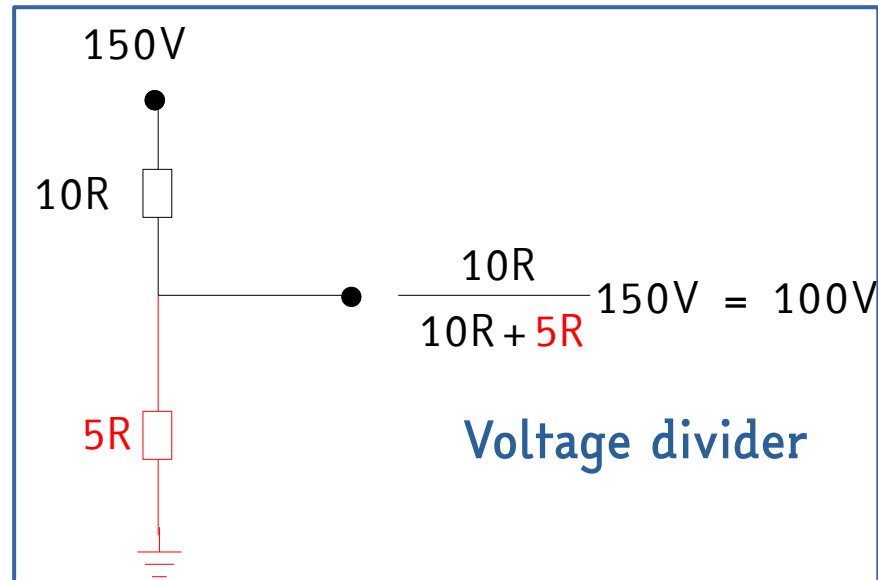
# "4 bit" example



$$1 + 2 + 4 + 8 = 15 \rightarrow V_{in} = 150 \text{ V}$$

$$\text{Ex: } V_{out} = 100 \text{ V}$$

$$100 \rightarrow N = 10 \rightarrow \text{bit} = 1010$$

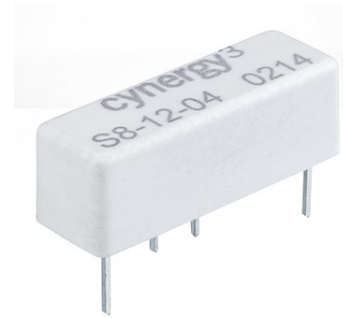
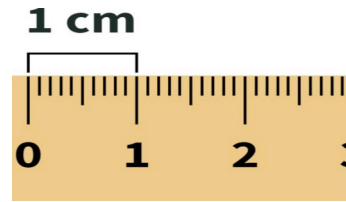
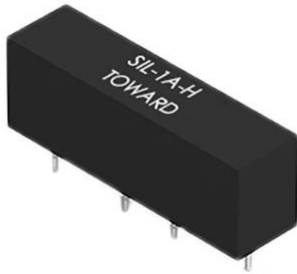


Diode Chain

$$8V_d + 2V_d \rightarrow 100 \text{ V}$$

# High Voltage Relay

On the market...



A. Low noise  
**Solid-state relay (SSR)**  
(up to 2 kV)

B. Low noise  
**Reed switch relay**  
(up to tens of kV)

# Next actions

## Problem to face

- Fast output
- Leakage current
- Electromagnetic emission
- Field mill inertia

## Test bench

- Realization of a small prototype  $< 1$  kV with SSR
- Preliminary test with precision multimeter



**Thank you very much!**