Applications of the LGAD in the Luminosity Measurement of LHC

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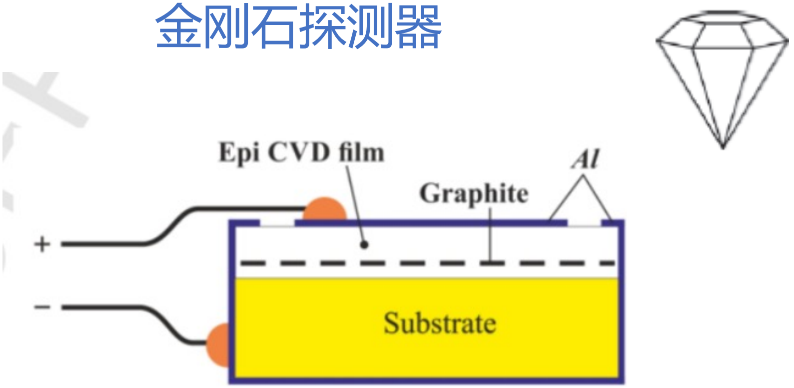
Motivation

- **Luminosity measurement:**

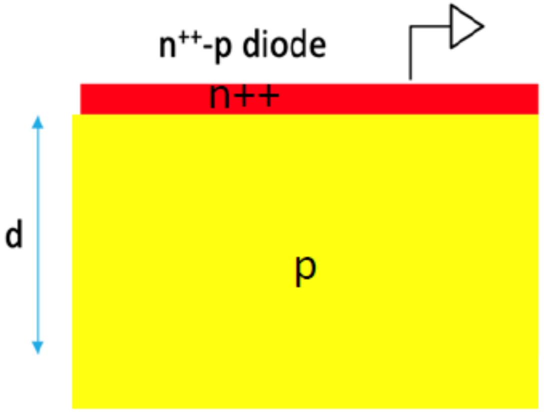
The uncertainty of the Luminosity measurement could be limited with 1% in the HL-LHC operation (LHC is 2%) very challenging!

- **束流测试对探测器的要求：抗辐照，好的线性度等**
- **LHC使用的探测器：金刚石探测器、 PiN 硅探测器 （抗辐照性能差！）**

金刚石探测器



PiN 硅探测器



The Performance of Diamond Detector

- **经过LHC run1和run2 的实践发现，金刚石探测器辐照稳定性差，极大影响了亮度测试，影响物理目标的实现。**
  - 单晶金刚石探测器在很少的辐照之后，收集电荷低->高电压工作->突然的breakdown
  - 多晶金刚石探测器，信号幅度低，探测效率低
  - 辐照后线性度变差

LHC run2，金刚石探测器线性度表现差

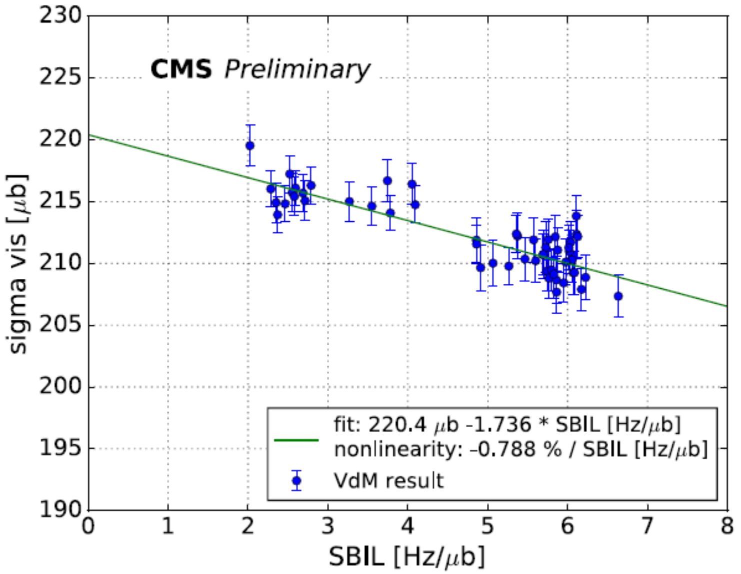
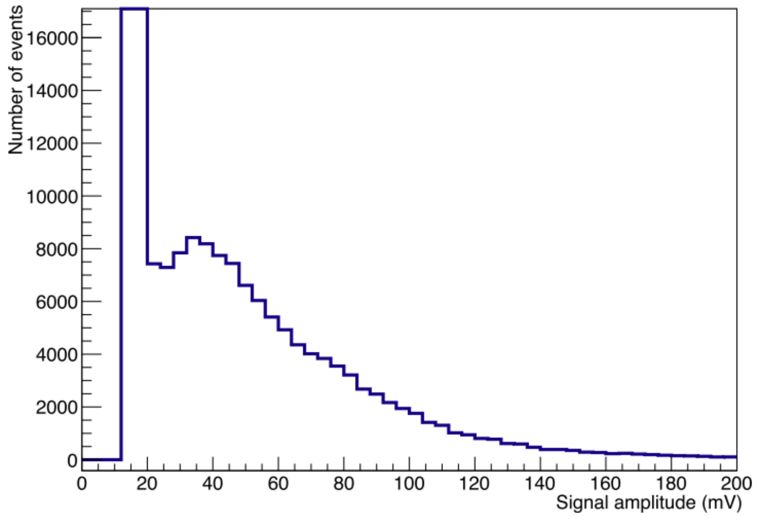


Fig. 2. σ_{vis} as function of single bunch instantaneous luminosity for pCVD diamond based luminosity.

Moritz Guthof f2019, NIMA

图 LHC run2，多晶金刚石探测器束流测试中多晶金刚石探测器在偏压1000V时的信号幅度谱。与噪音峰很接近，探测效率变低



超快硅传感器与金刚石传感器对比

- **金刚石探测器：**超快时间分辨，抗辐照，信号小
- **超快硅传感器：**超快时间分辨，抗辐照（2.5e15 neq/cm2，更换方便），信号大
- **普通PIN硅探测器：**
  - 线性度好、但辐照后噪音过大，暗电流增加明显

ATLAS使用超快硅传感器进行亮度测试

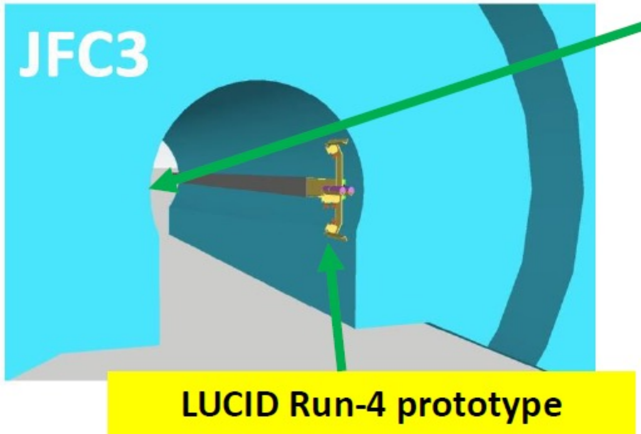
2022年初，ATLAS实验已经决定在未来亮度探测器升级中使用超快硅传感器

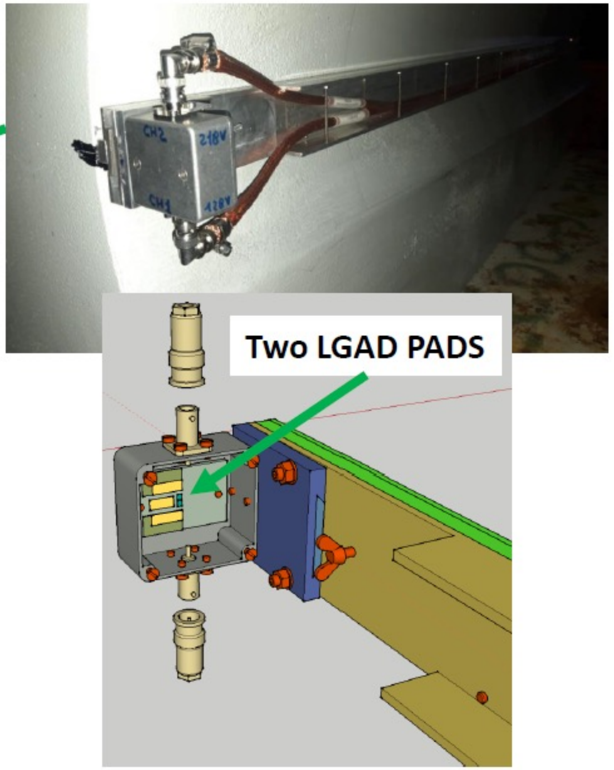
超快硅传感器在ATLAS探测器的JFC3上的束流监测实验，其线性度和响应均表现优异

BMA (Beam Monitor of ATLAS)

- Two LGAD pads (1.7 mm^2) installed this year on Feb. 22 in JFC3 side C as Run-4 lumi monitor prototypes.
- Innovative detector readout scheme.

Good thermal contact with the JFC3.
NO COOLING NEEDED!





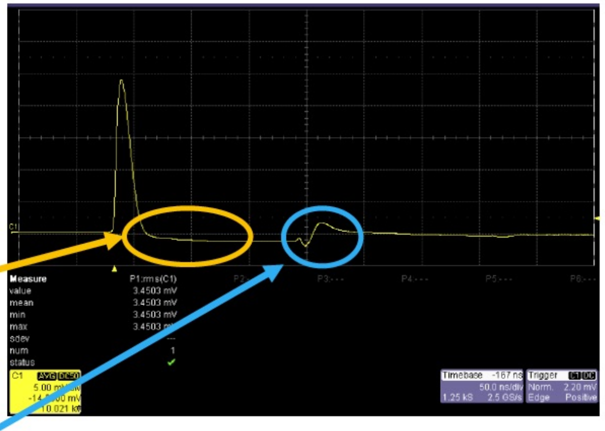
In the original proposal the installation of a standard CERN RP 90 Sr source for routinely calibrations is foreseen (NOT ADDED IN THIS FIRST VERSION).

G. Avoni etal,at
ATLAS open EB2022

Raw Signal Measured in run3 at ATLAS

It Does ! (After being installed on JFC3)

- Noise threshold: 4-4.5 mV (~0.7 mV rms)
    - The threshold was ~50 mV in the pilot beam run
- Signal average amplitude ~ 25 mV
- S/N ~ 35
- PZ compensation (still not fully optimized): signal duration ~ 30 ns !!!
- Cable reflection visible: can be cured with RLC signal adapter
    - RC working on this



```
Measure    P1:rms(C1)   P2:---   P3:---   P4:---   P5:---   P6:---
value      3.4503 mV
mean       3.4503 mV
min        3.4503 mV
max        3.4503 mV
sdev       ---
num        1
status     ✓
```

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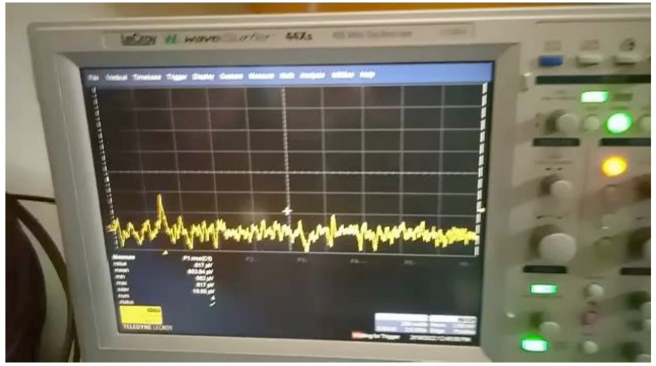
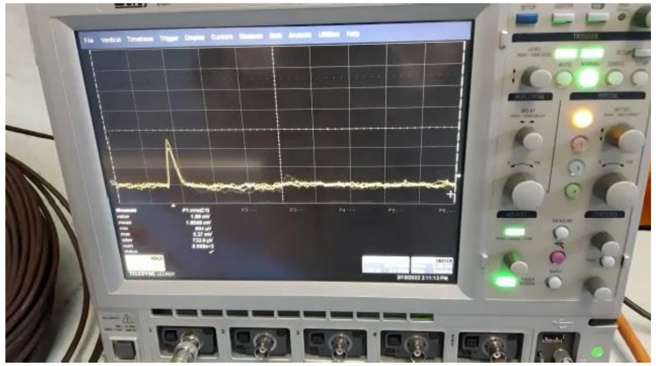


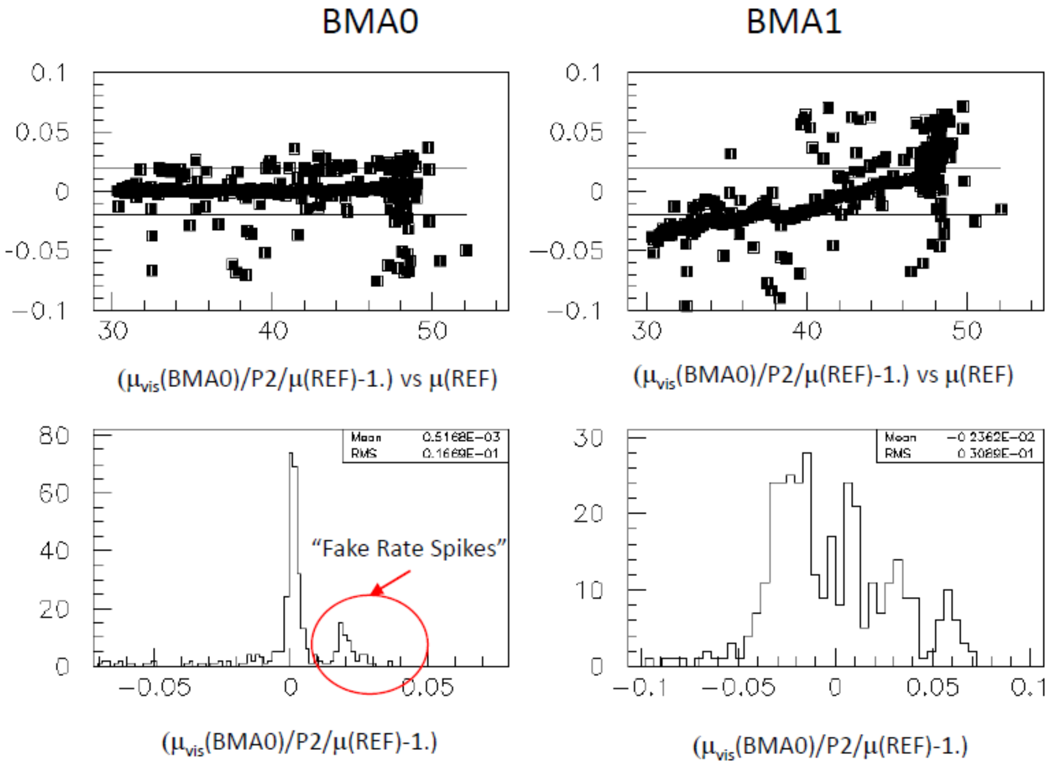


Clic on the pictures above:
two short movies of the
full setup working taken
in the final installation without and
with 90 Sr source

HPK LGAD sensor for the test

BMA to μ-corrected LUCID ratio in one fill

- One of the last run taken before the LHC stop at the end of August with a total delivered luminosity of ~0.5/fb.
  - Many fluctuations due to the “fake rate spikes” (a problem in the CTP FW discovered at the end of August. Seems to be solved inspecting data in LHCf run)
- **BMA0: it seems that it does not suffer from μ-dependent effects**
  - **No “migration effect”.**
  - **Negligible gain variations within long high-lumi run**
  - **To be confirmed with Tracks.**
- **However, this conclusion does not hold for BMA1.**



RUN 431906, L_{int}=0.49/fb

BMA0 with LGAD1 showed good performance of the luminosity measurement!

Conclusion

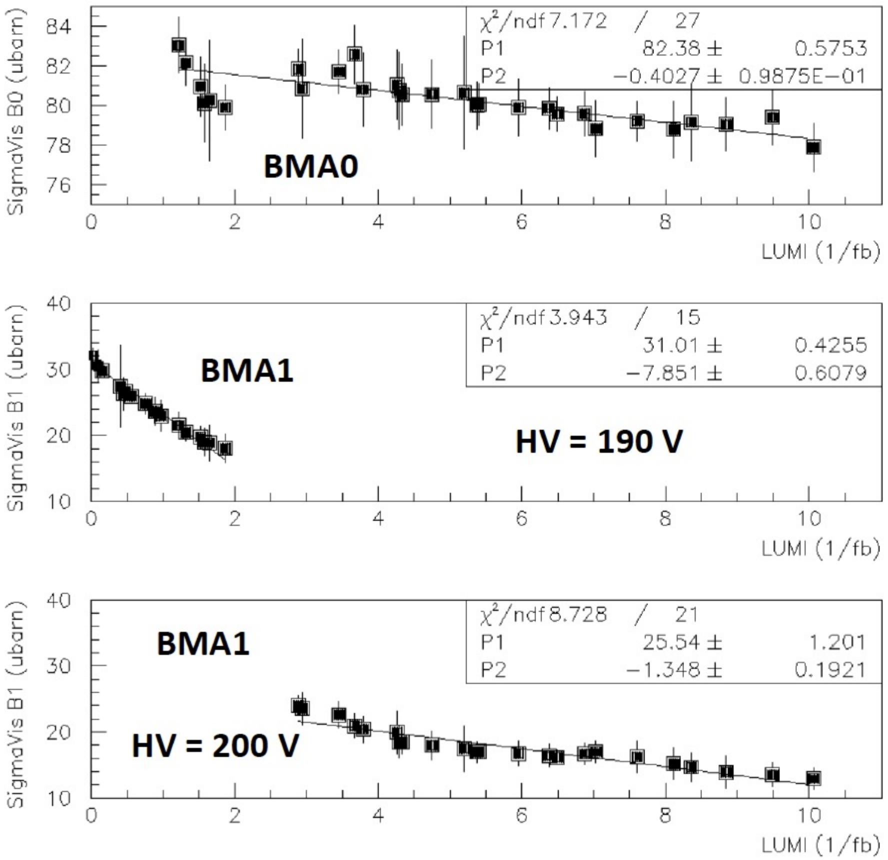
- **2022年初，ATLAS实验已经决定在未来亮度探测器升级中使用超快硅传感器**
  - 强辐射环境下(在等效中子辐照达2.5e15 n_{eq}/cm^2)，线性度好，信号大
  - 相较于**金刚石**，**成本低**、**信噪比高**、**生产批量化**的优势，可覆盖大面积探测，进一步提高测试精度
  - 相较PIN构的硅探测器，具有**电容小**、**电荷收集高及抗辐照性能优**

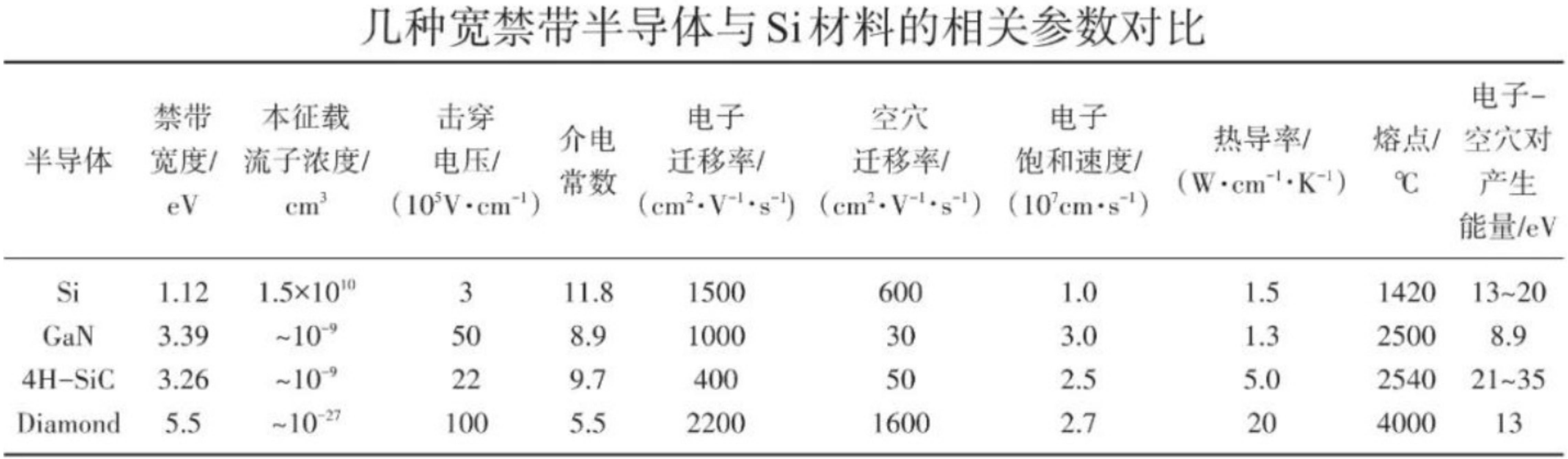
Thanks for your attention!

- **Back up**

BMA gain loss rates

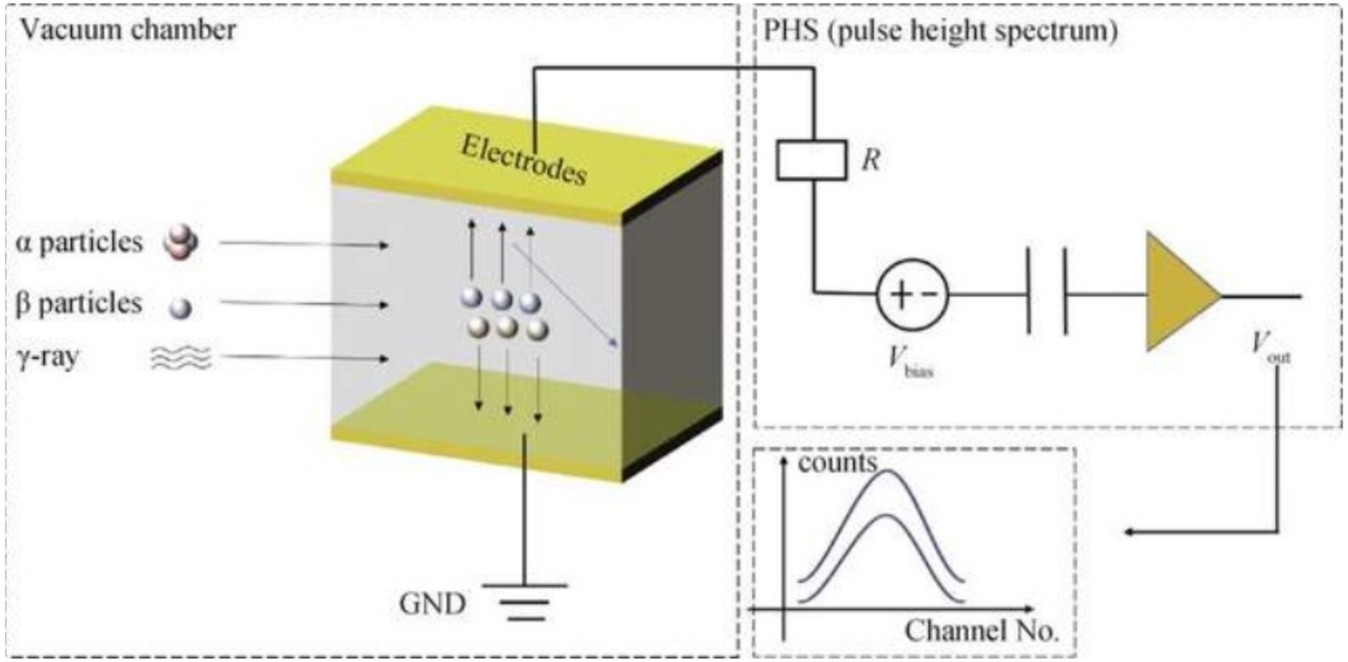
- The gain of BMA0 and BMA1 change with the integrated luminosity.
  - BMA0: 1% gain variation each 2/fb
  - BMA1: 1% gain variation each 0.2/fb (after HV change from 190 V to 200 V).
- Gain stability studies indicate that BMA0 has a better performance as luminosity monitor compared to BMA1
- Gain correction in the future
  - Use a 90Sr source
    - The present design already would allow this, but to get RP allowance is difficult
  - Change trigger threshold
    - Will be possible using LUCROD
  - Use more rad hard devices
    - Probably a carbon diffused LGAD pad can be already installed for 2023



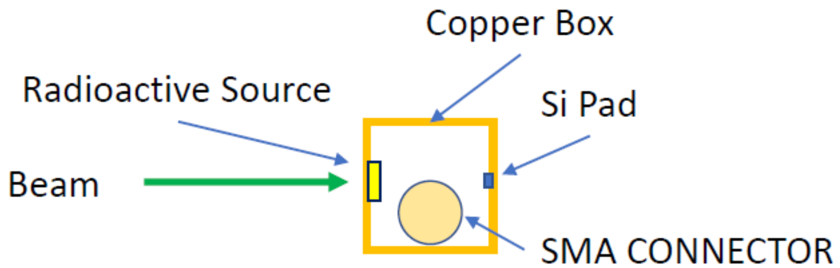


几种宽禁带半导体与Si材料的相关参数对比

半导体	禁带宽度/eV	本征载流子浓度/cm^3	击穿电压/$(10^5\mathrm{V}\cdot\mathrm{cm}^{-1})$	介电常数	电子迁移率/$(\mathrm{cm}^2\cdot\mathrm{V}^{-1}\cdot\mathrm{s}^{-1})$	空穴迁移率/$(\mathrm{cm}^2\cdot\mathrm{V}^{-1}\cdot\mathrm{s}^{-1})$	电子饱和速度/$(10^7\mathrm{cm}\cdot\mathrm{s}^{-1})$	热导率/$(\mathrm{W}\cdot\mathrm{cm}^{-1}\cdot\mathrm{K}^{-1})$	熔点/℃	电子-空穴对产生能量/eV
Si	1.12	1.5×10^{10}	3	11.8	1500	600	1.0	1.5	1420	13~20
GaN	3.39	$\sim10^{-9}$	50	8.9	1000	30	3.0	1.3	2500	8.9
4H-SiC	3.26	$\sim10^{-9}$	22	9.7	400	50	2.5	5.0	2540	21~35
Diamond	5.5	$\sim10^{-27}$	100	5.5	2200	1600	2.7	20	4000	13


Vacuum chamber
PHS (pulse height spectrum)
Electrodes
R
α particles
β particles
γ-ray
V_{bias}
V_{out}
GND
counts
Channel No.

- **Cooling down of the detector (is it needed?)**
  - The fast shaping of the amplifier will cut off most of the low freq noise (Bias resistor and leakage current)
  - Thermal runaway?



Box Dimensions: 2x2x2 cm3

Fix the BOX in good thermal contact to JFC3 (ideal heat reservoir):

Room temperature guaranteed without cooling !

No thermal runaway!

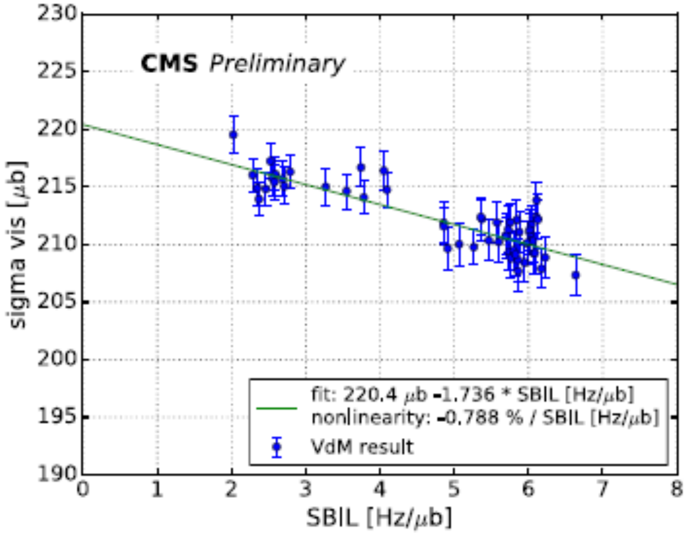


Fig. 2. σ_{vis} as function of single bunch instantaneous luminosity for pCVD diamond based luminosity.

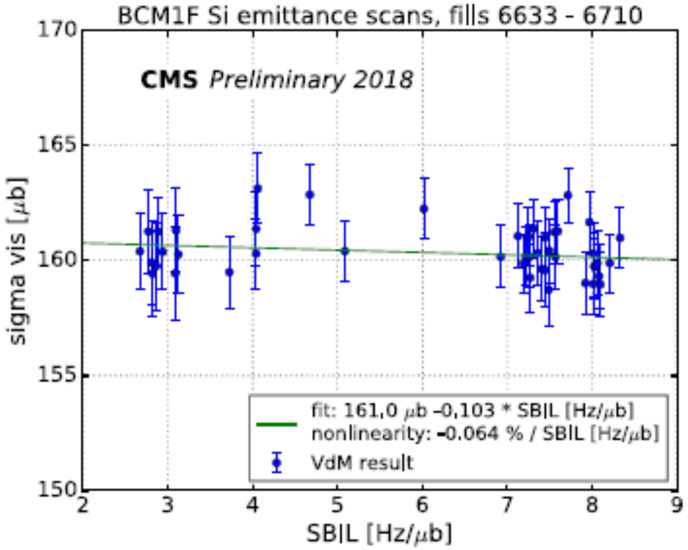


Fig. 3. σ_{vis} as function of single bunch instantaneous luminosity for silicon diode based luminosity.