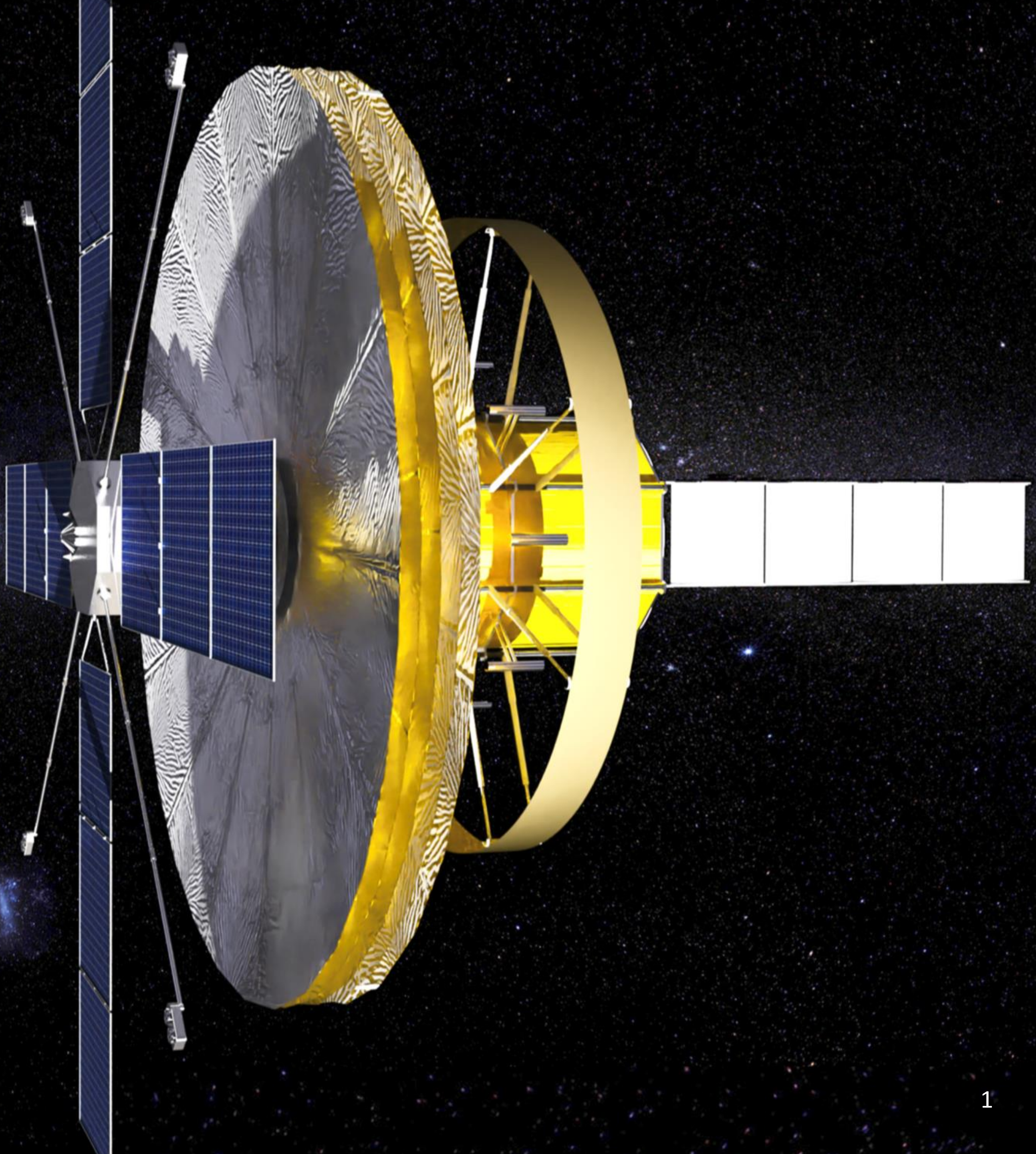
Cryogenic Tests of Time of Flight and Scintillating Fiber Tracker Prototypes for the AMS-100 Experiment



Thomas Kirn

C. H. Chung, J. Deiters, D. Fehr, W. Karpinski, D. Louis,

Th. Oeser, S. Schael, Th. Siedenburg, M. Wlochal

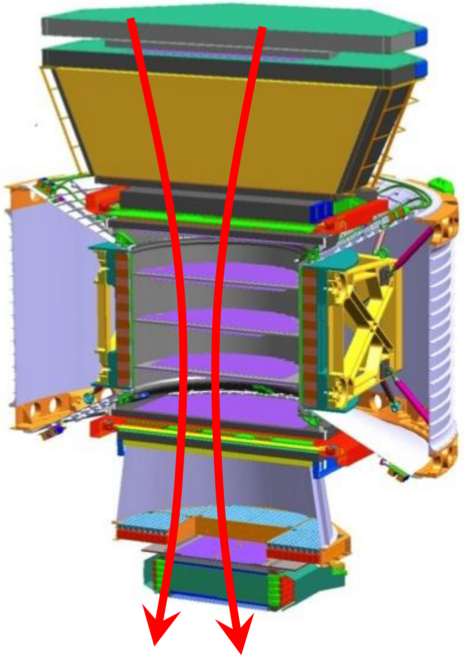
I.PI I. Physikalisches Institut | RWTH AACHEN UNIVERSITY

presented at 17th Vienna Conference on Instrumentation,

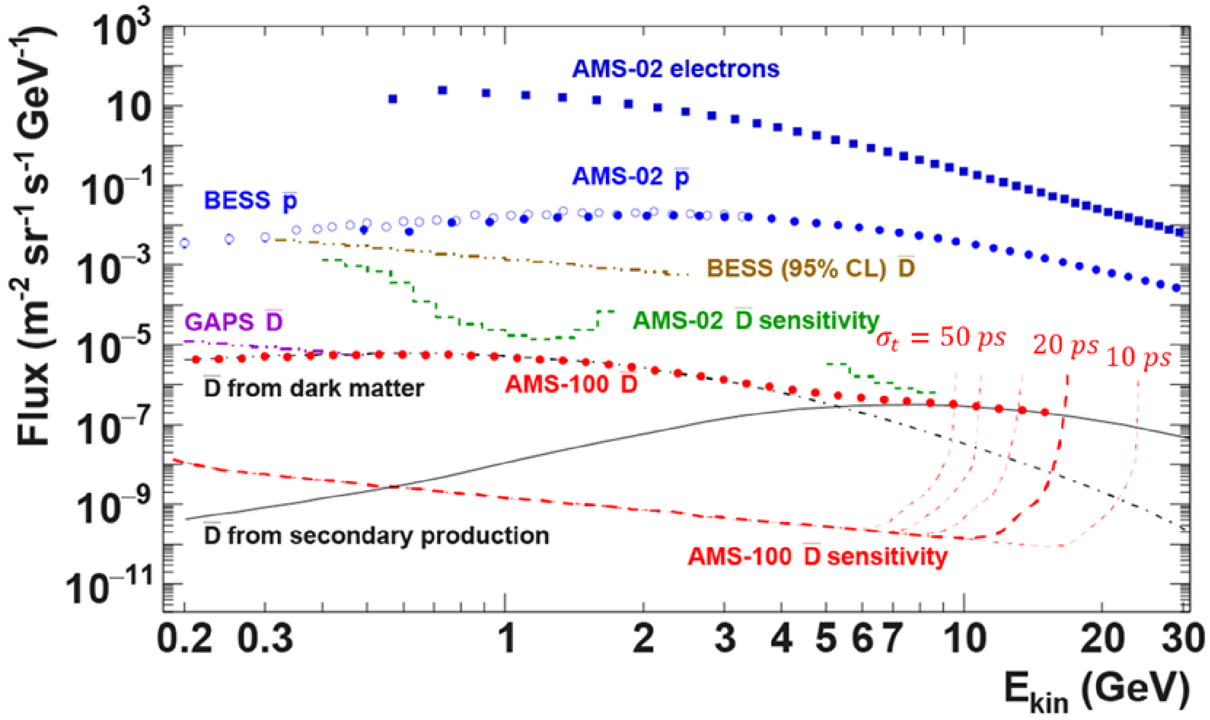
19th February, Vienna

New Physics in Cosmic Rays? AMS-100

AMS-02

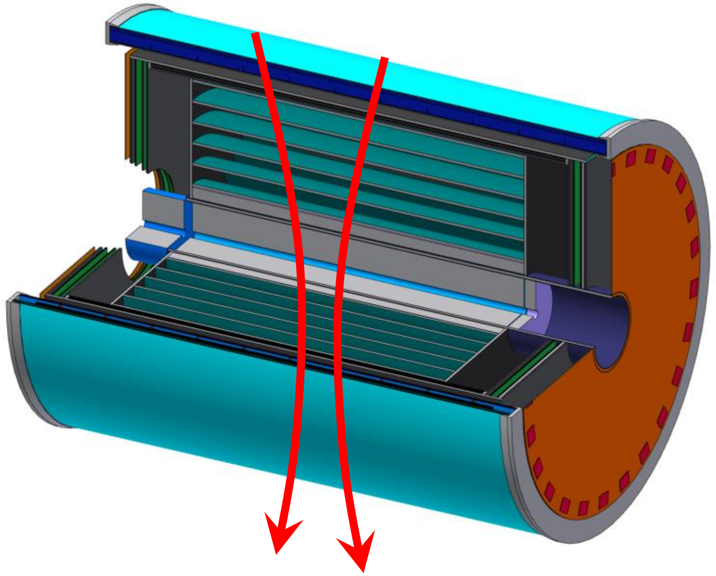


Operating on the ISS since May 2011
Weight: 7 t
Permanent Magnet: B = 0.15 T
Acceptance: 0.1 m^2sr
MDR: 2 TV
Calorimeter: 17 X_0, 1.7λ
Detected Cosmic Ray Events: >240 Billion



Anti-Deuterons: sensitive probe for New Physics in Cosmic Rays
→ Need spectrometer with higher acceptance than AMS-02: **AMS-100**

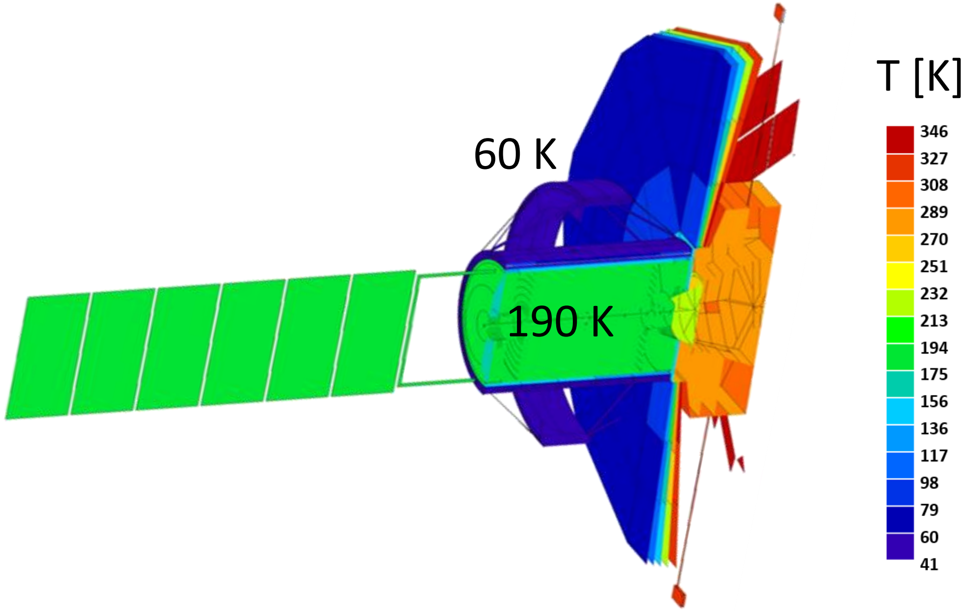
AMS-100

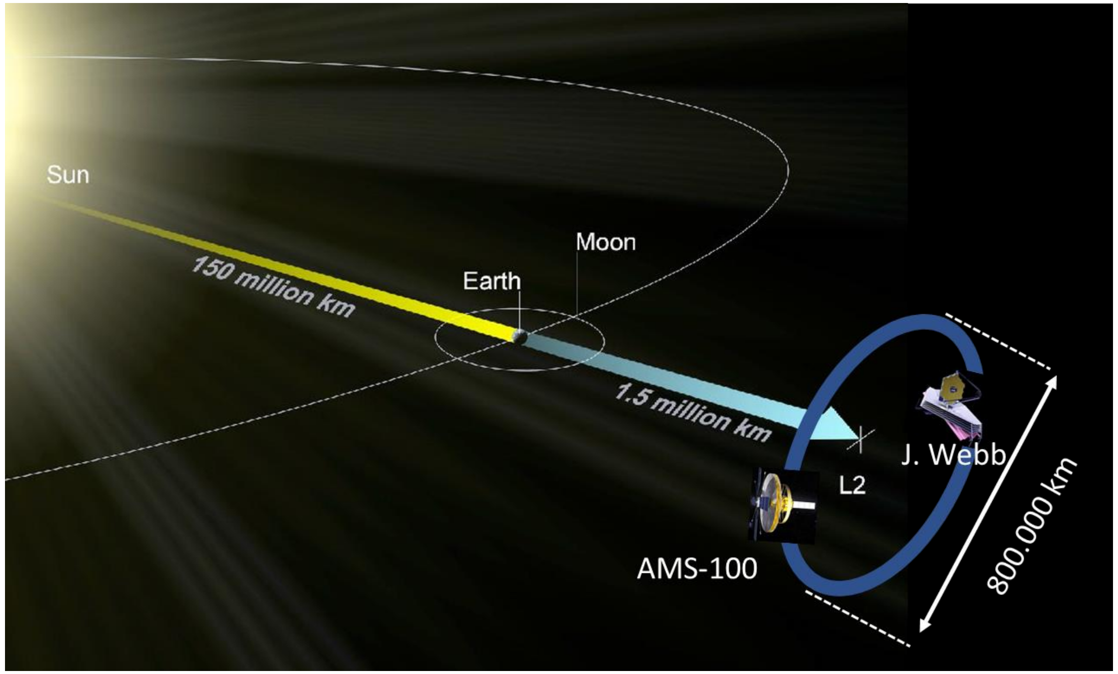


Weight: 40 t
Thin HTS Solenoid: B = 0.5 T
Acceptance: 100 m^2sr
MDR: >50 TV
Calorimeter: 70 X_0, 4λ

AMS-100: Cosmic Ray Physics at Lagrange Point 2

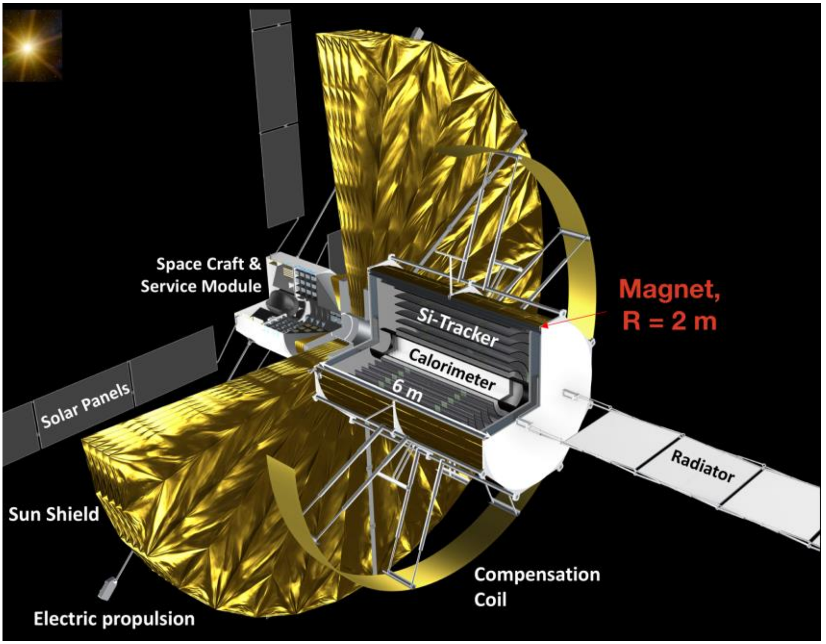
- AMS-100 operated at Sun-Earth Lagrange Point 2 and passively cooled with a sun shield
  - Subdetectors at **190 K** in switched-on state
  - Subdetectors at **100 K** in switched-off state



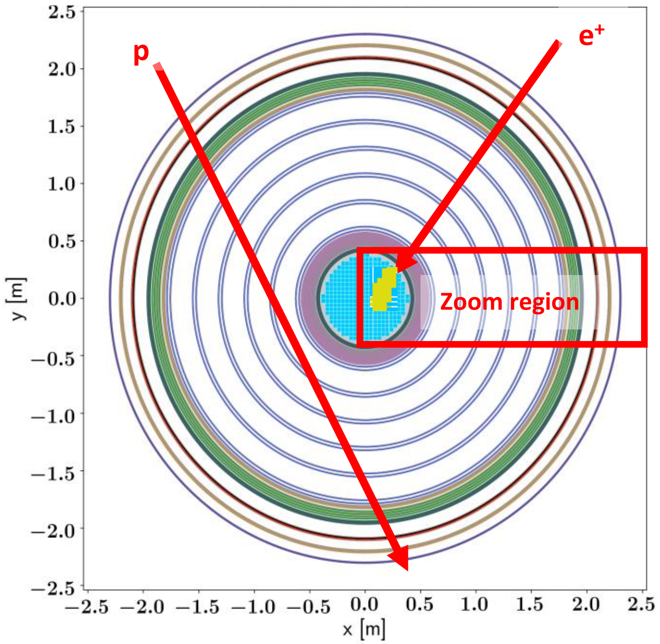


⟶ System tests required under operating conditions at L2:
- Survival at 100 K
- Operation at 190 K
- Operation in vacuum

AMS-100 Detector

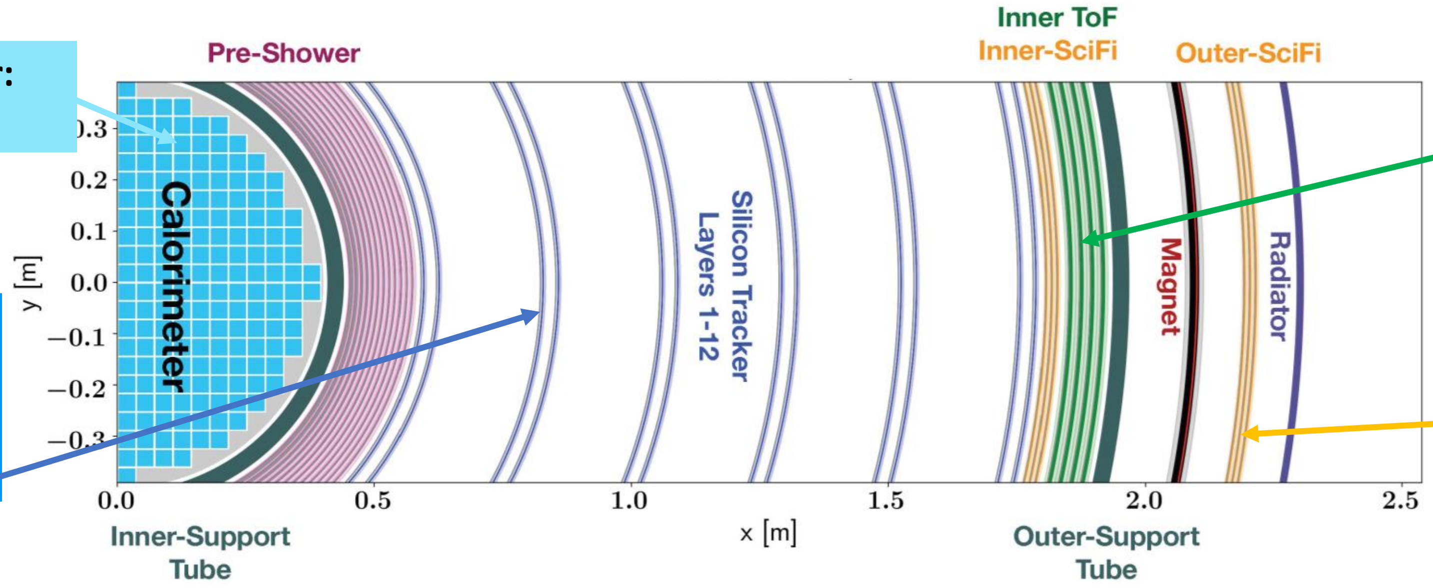


Weight:	40 t
Thin HTS Solenoid :	B = 0.5 T
Acceptance:	100 m^2sr
MDR:	>50 TV
Calorimeter:	70 X_0, 4λ
Power Consumption:	15 kW
Incoming Particle Rate:	2 MHz
Number Readout Channels:	8 Million
Mission Flight Time:	10 years



Calorimeter & Pre-Shower:
Measurement of E and Z

Silicon-Tracker
Measurement of R and Z
2 x 12 Space Points,
5µm resolution.

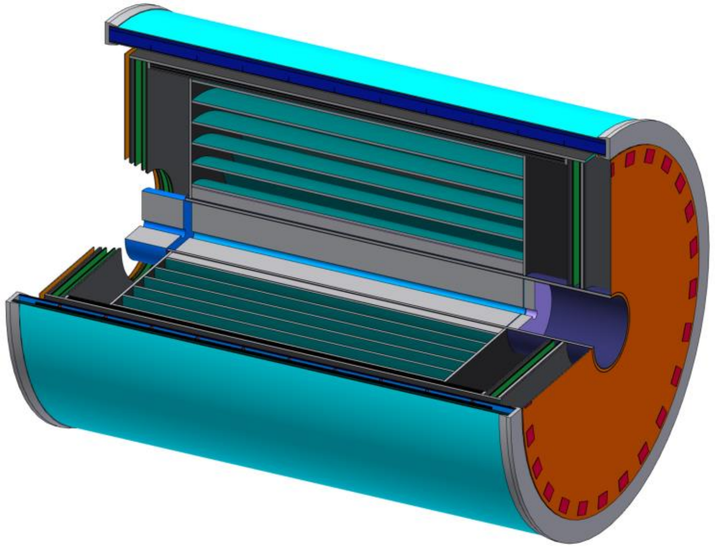


ToF
Measurement of β=P/E and Z
2 x 4 Measurements,
≈20 ps resolution.

SciFi-Tracker
Measurement of R and Z
2 x 6 Measurements,
40µm resolution.

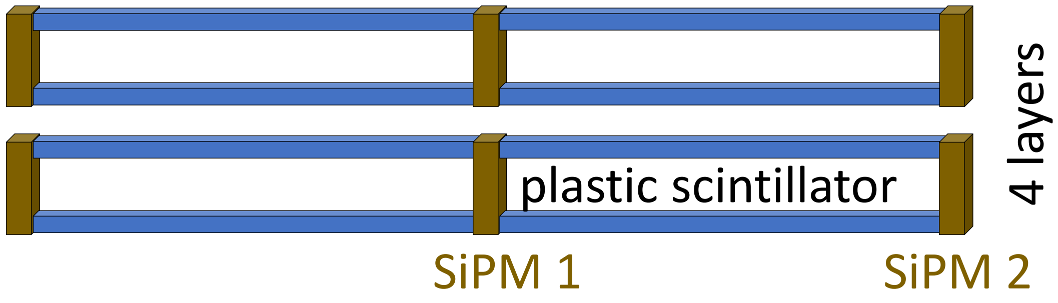
S.Schael et al., https://arxiv.org/pdf/1907.04168.pdf, Nucl. Instrum. Methods Phys. Res. Sect. A 2019, 944, 162561

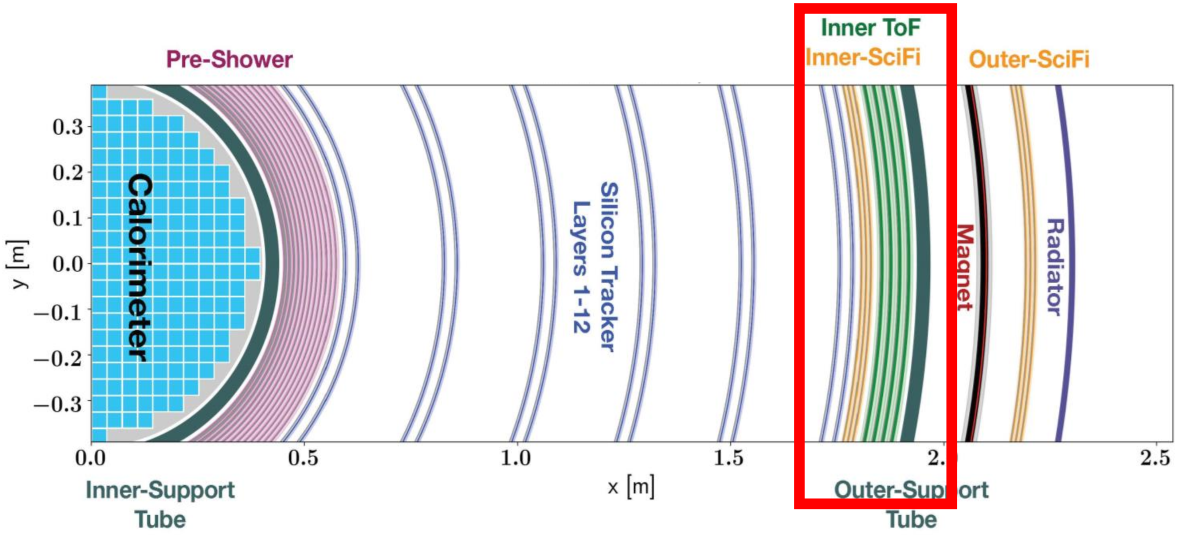
AMS-100: Time of Flight System (ToF)



- ToF provides the trigger and measures $\beta = v/c$
- Z measurements from the signal height
- Desired ToF Single Counter time resolution: 20 ps
- Current ToF prototypes: ~ 40 ps

Operation principle of AMS-100 ToF:





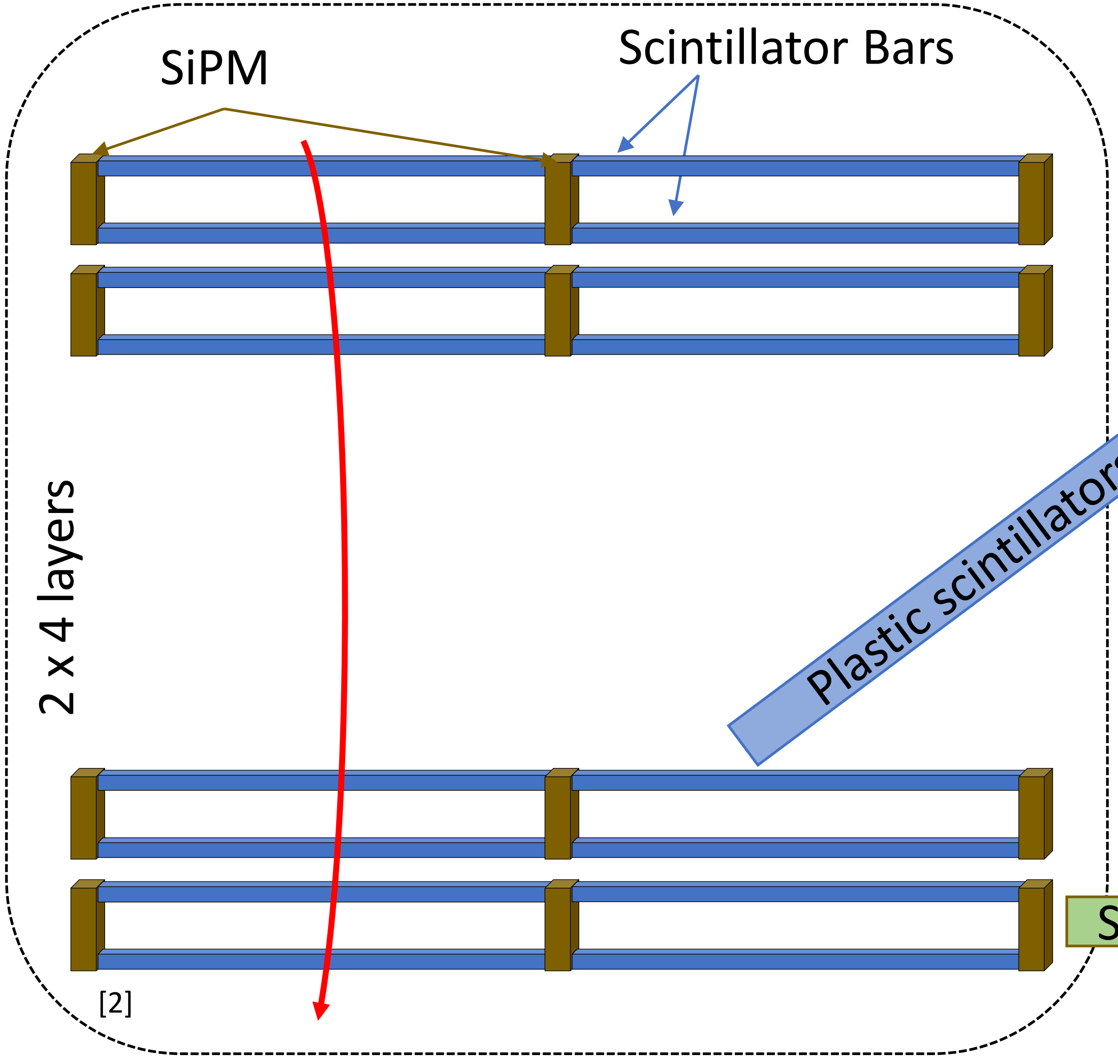
- Scintillator rods with SiPMs operating at 200 K
  - Scintillator dimensions 90 x 25 x 6 mm^3
- Similar to the PANDA Barrel TOF

  ⟶ Reached 50ps resolution, but matching factor ≈ 0.25

→ full coverage of the frontface of scintillators, k=1

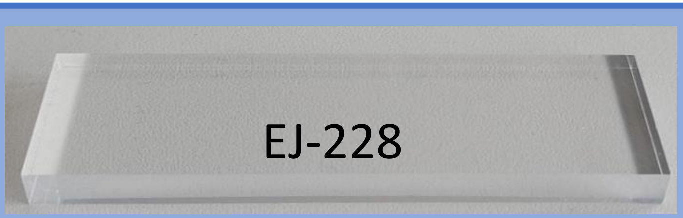
→ serial connection of SiPM cells ⟶ reduce C $_{\text{SiPM}}$

AMS-100: Time of Flight System (ToF)

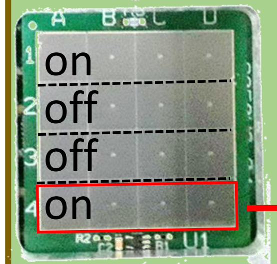


Plastic scintillators

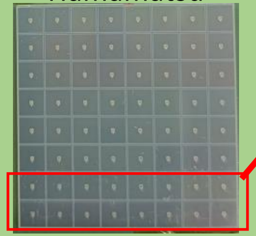
SiPMs



Single Scintillator Size = 6 mm × 25 mm × 90 mm
Matching-Factor $k \approx 1.0$
Peak emission at 391 nm

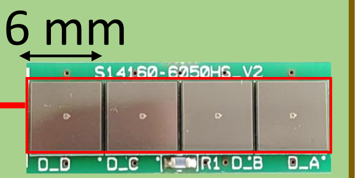


S14161-6050HS-04
Hamamatsu

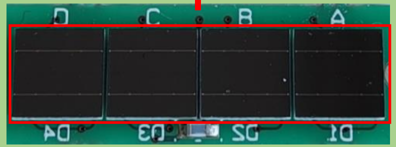


S14161-3050HS-08
Hamamatsu

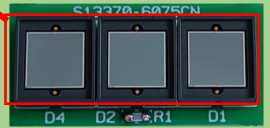
Hybrid connection:
SiPM signals are summed
up and fed into one channel
Peak Sensitivity
(450nm, PDE=50%)



S14160-6050HS
Hamamatsu

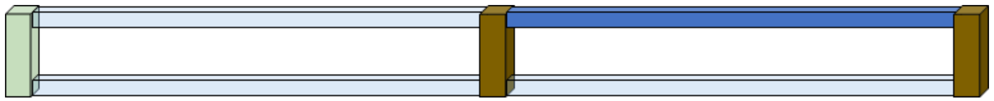


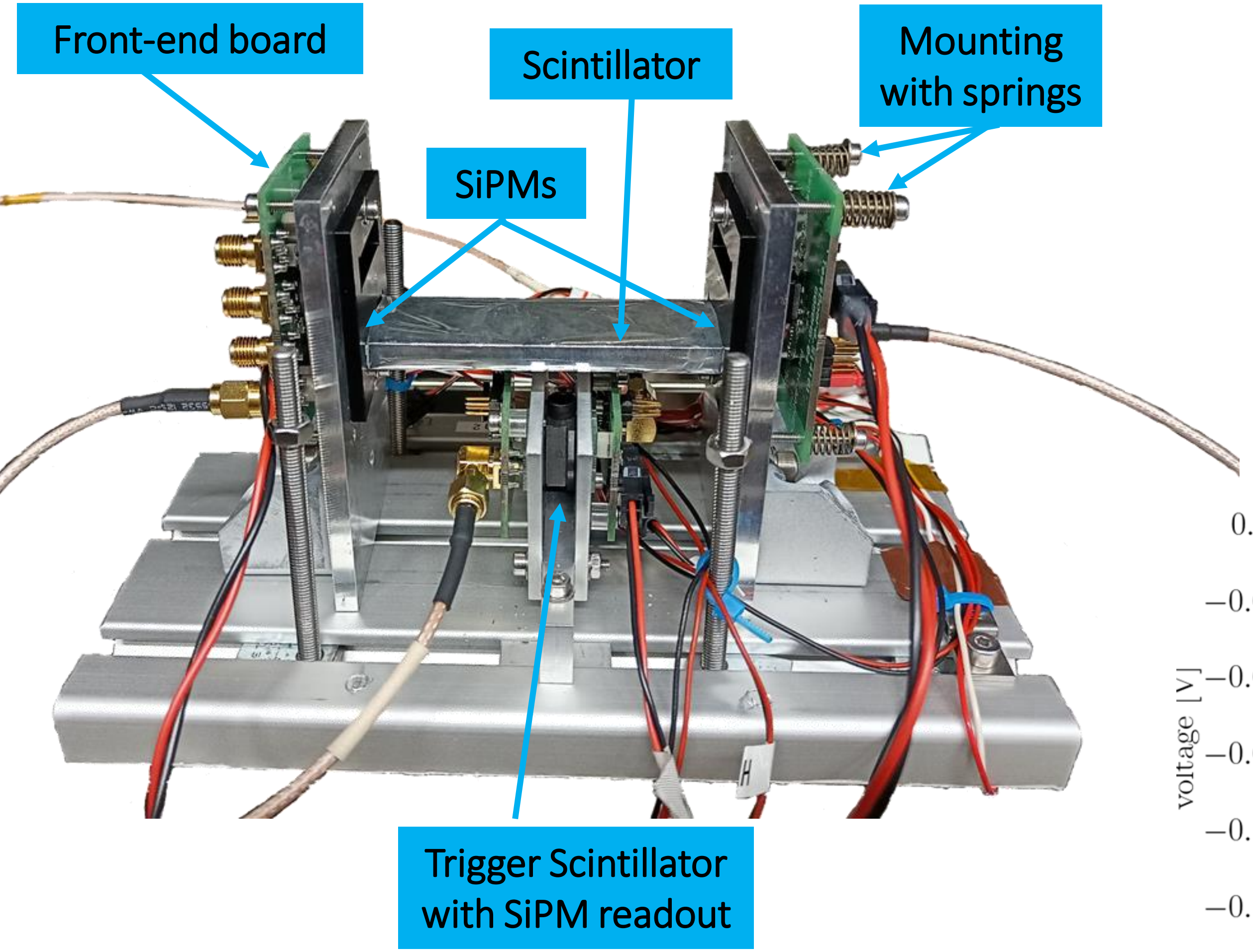
AFBR-S4N66C013
Ketek/Broadcom



S13370-6075CN
Hamamatsu
$k \approx 0.7$

AMS-100: ToF Prototypes





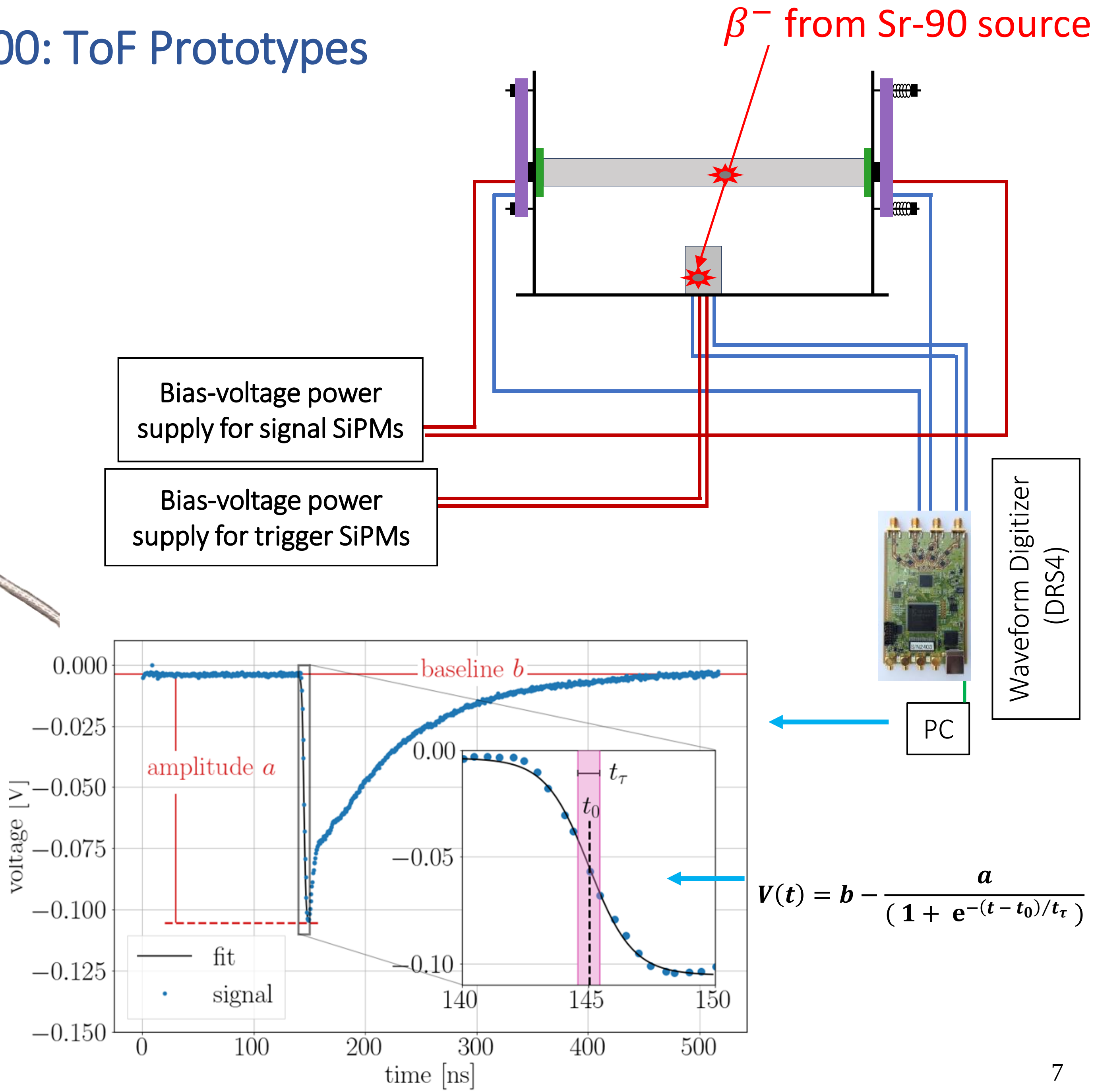
Front-end board

Scintillator

Mounting with springs

SiPMs

Trigger Scintillator with SiPM readout



β^- from Sr-90 source

Bias-voltage power supply for signal SiPMs

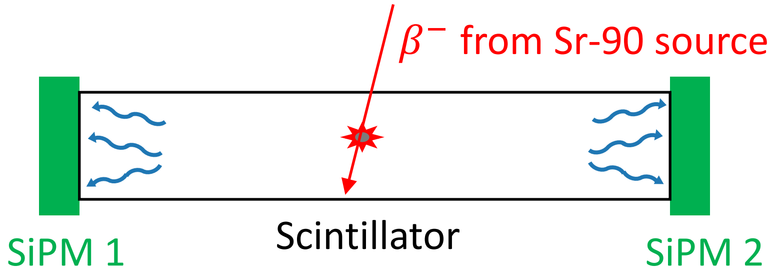
Bias-voltage power supply for trigger SiPMs

Waveform Digitizer (DRS4)

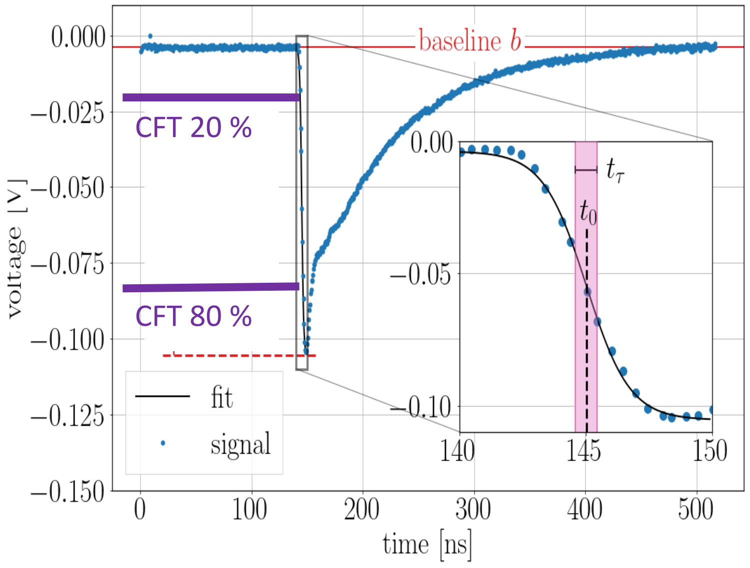
PC

$$V(t) = b - \frac{a}{(1 + e^{-(t-t_0)/t_\tau})}$$

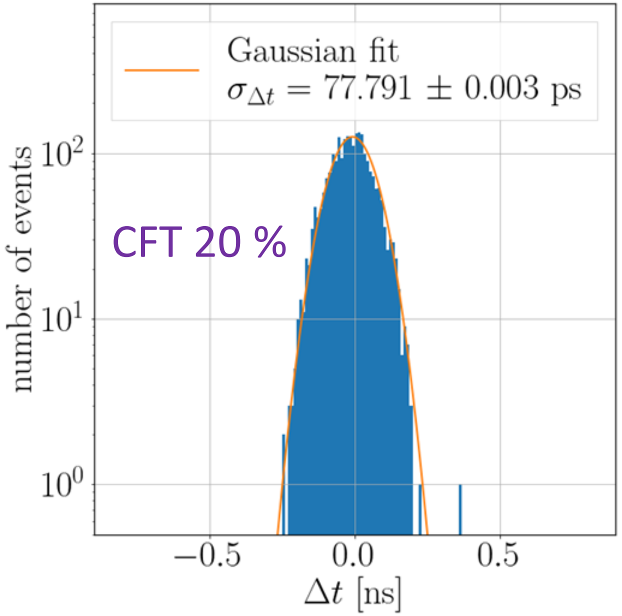
AMS-100: ToF Prototypes:



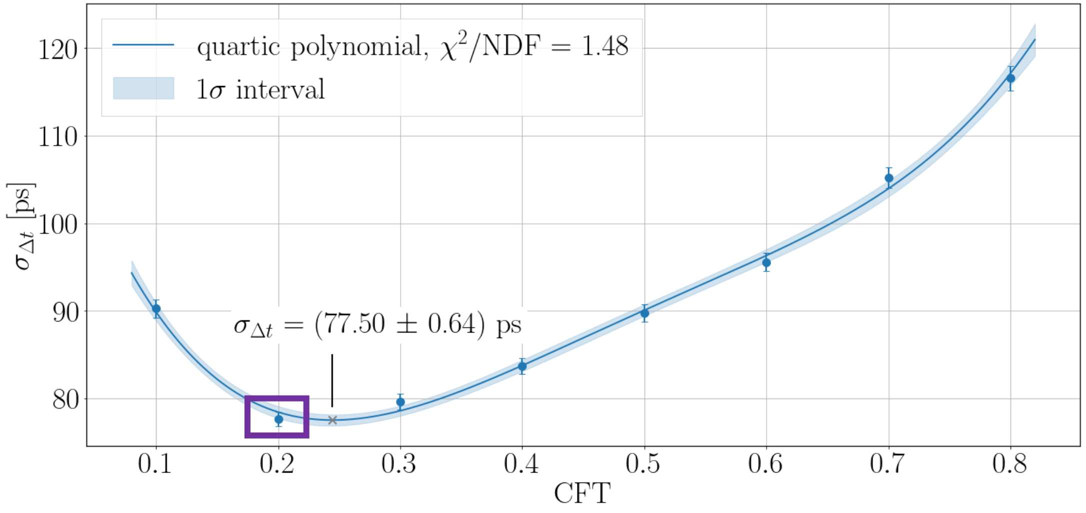
Teststand optimized for time resolution measurement



$$\Delta t = t_1 - t_2$$



Coincidence Time Resolution (CTR, $\sigma_{\Delta t}$)
For triggered MIP-particles: $\sigma_{\Delta t}$ = 77.5 ps



Coincidence time resolution: $\sigma_{\Delta t} = \sqrt{\sigma_{t_1}^2 + \sigma_{t_2}^2} = \sqrt{\sigma_{\text{SiPM}}^2 + \frac{\sigma_{\text{scinti}}^2}{k} + \sigma_{\text{elec}}^2}$

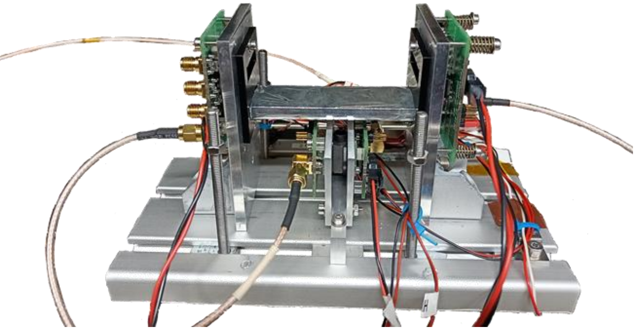
$\sigma_{\text{elec}} \propto \frac{t_\tau}{a} \cdot \text{noise}$

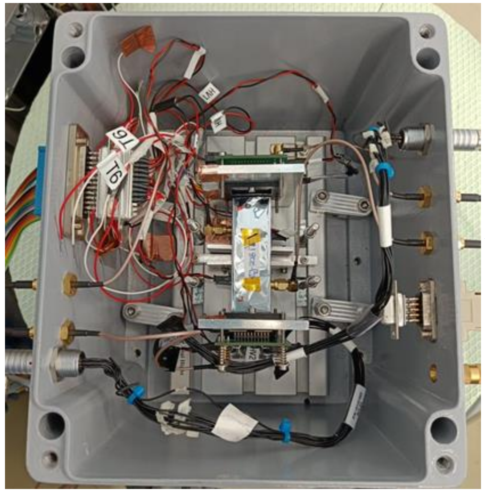
$t = \frac{t_1 + t_2}{2}$

Single counter time resolution: $\sigma_t = \frac{\sqrt{\sigma_{t_1}^2 + \sigma_{t_2}^2}}{2} = \frac{\sigma_{\Delta t}}{2}$

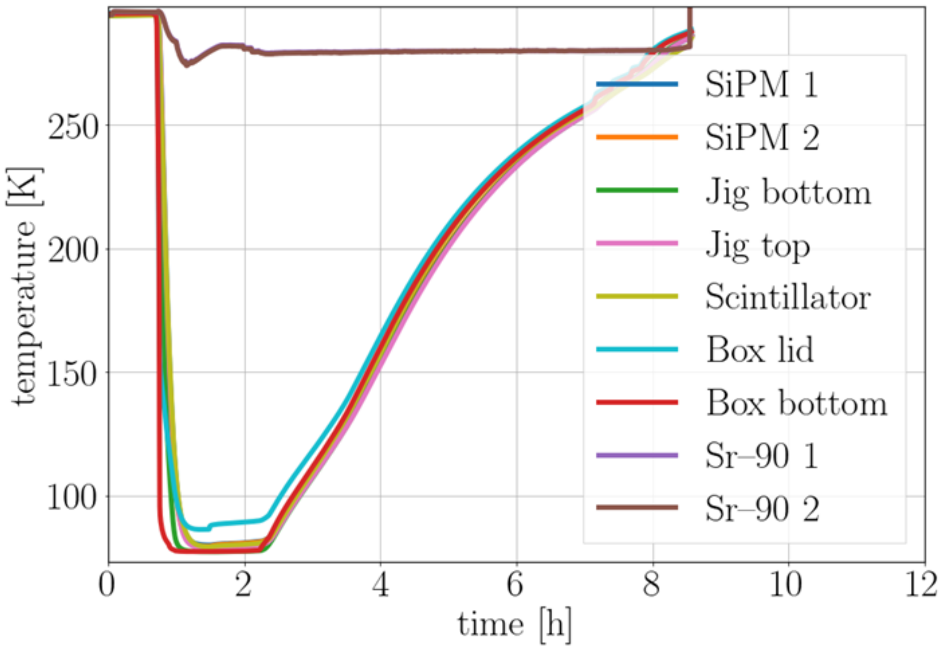
$\sigma_t = (38.8 \pm 0.3)\ ps$

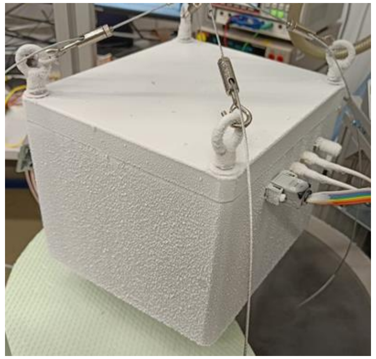
AMS-100: ToF Prototypes: System Test at low temperatures





Cryotank: 294 K to 77 K



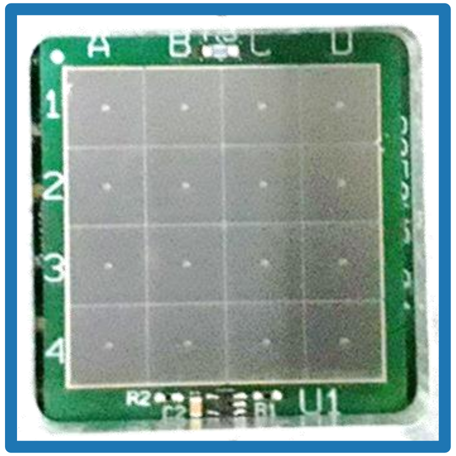


- ToF prototype in air-tight box submerged in liquid nitrogen
- Radioactive source heated (only specified up to 233 K)
- 9 temperature sensors in the box
- Flushing with dry air to avoid condensation and ice
- Bias-voltage corrected for temperature, so the over-voltage is constant!

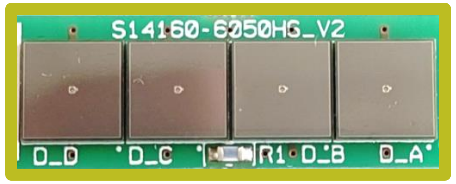
AMS-100: ToF Prototypes: Signal Shape vs Temperature: Slow Decay Time

Poly-Si quench resistor

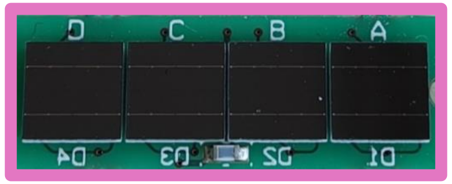
S14161-6050HS-04



S14160-6050HS



AFBR-S4N66C013



k **= 90 %**

Metal quench resistor

S13370-6075CN

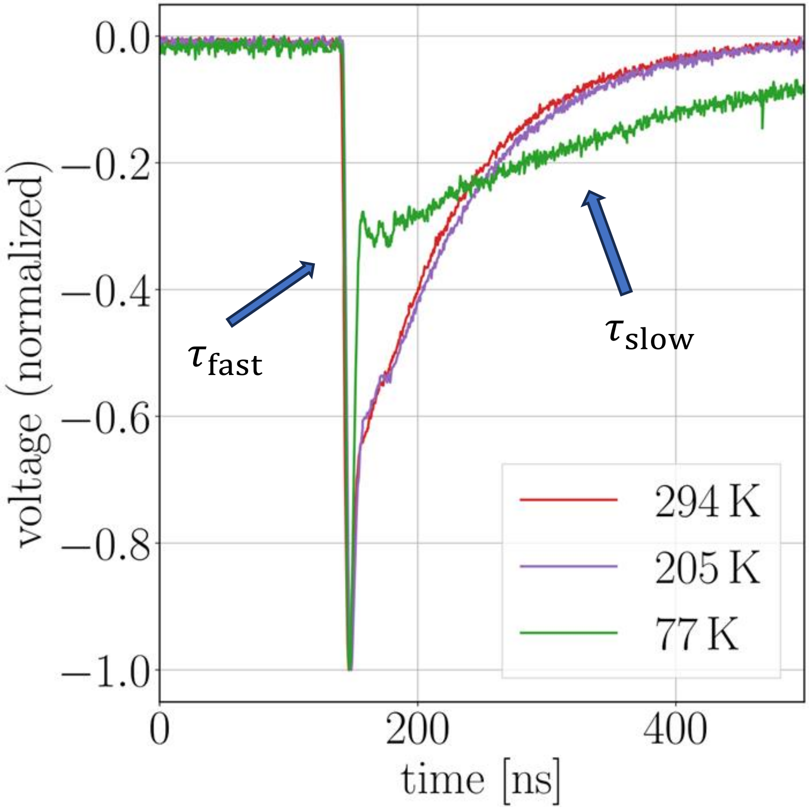
k **= 70 %**

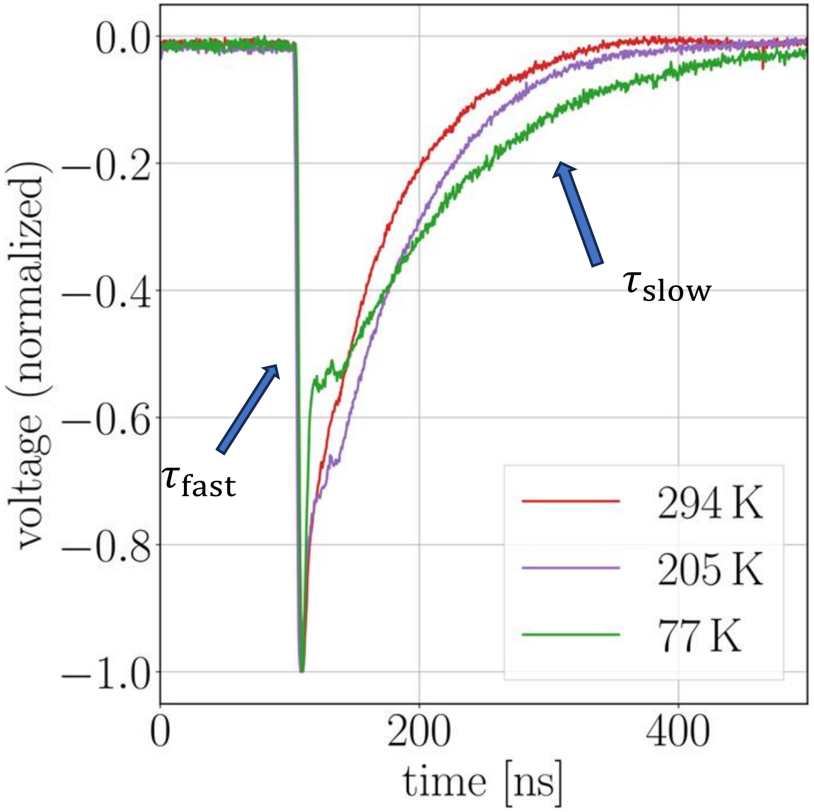
$$\tau_{\text{fast}} = R_{\text{load}} C_{\text{tot}}$$

$$\tau_{\text{slow}} = R_{\text{q}}(C_{\text{q}} + C_{\text{d}})$$

Poly-Si quench resistor

$$\tau_{\text{slow}} \propto a + b\sqrt{T} \cdot e^{c/T}$$

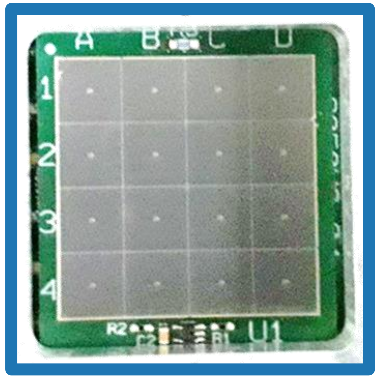




AMS-100: ToF Prototypes: Signal Shape vs Temperature: Slow Decay Time

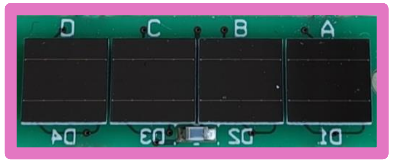
Poly-Si quench resistor

S14161-6050HS-04

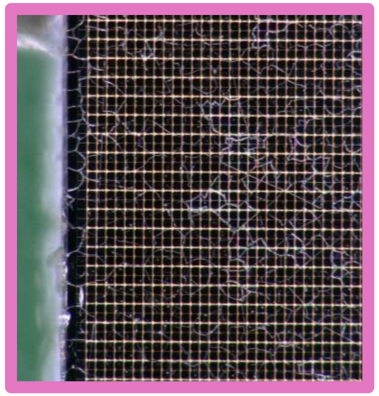


S14160-6050HS

AFBR-S4N66C013

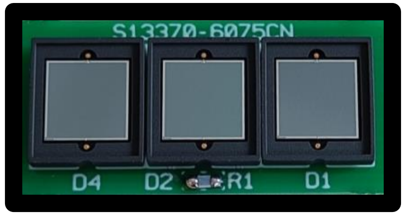


***k* = 90 %**



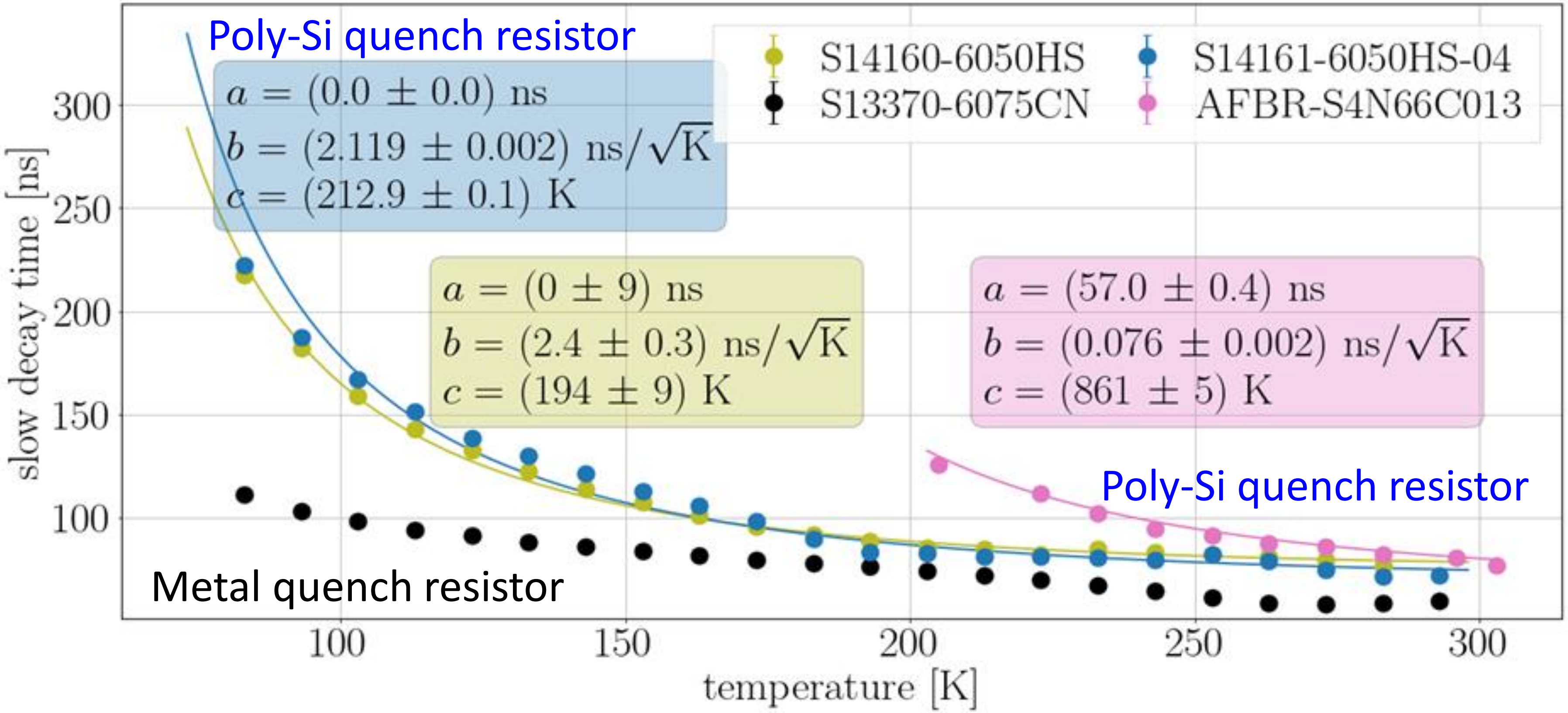
Metal quench resistor

S13370-6075CN



***k* = 70 %**

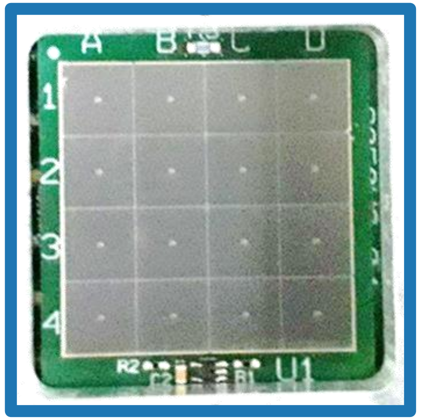
$$\tau_{\text{slow}} \propto a + b\sqrt{T}\cdot e^{c/T}$$



AMS-100: ToF Prototypes: Signal Shape vs Temperature: Time Resolution

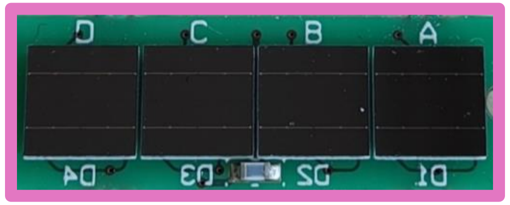
Poly-Si quench resistor

S14161-6050HS-04



S14160-6050HS *k* = 90 %

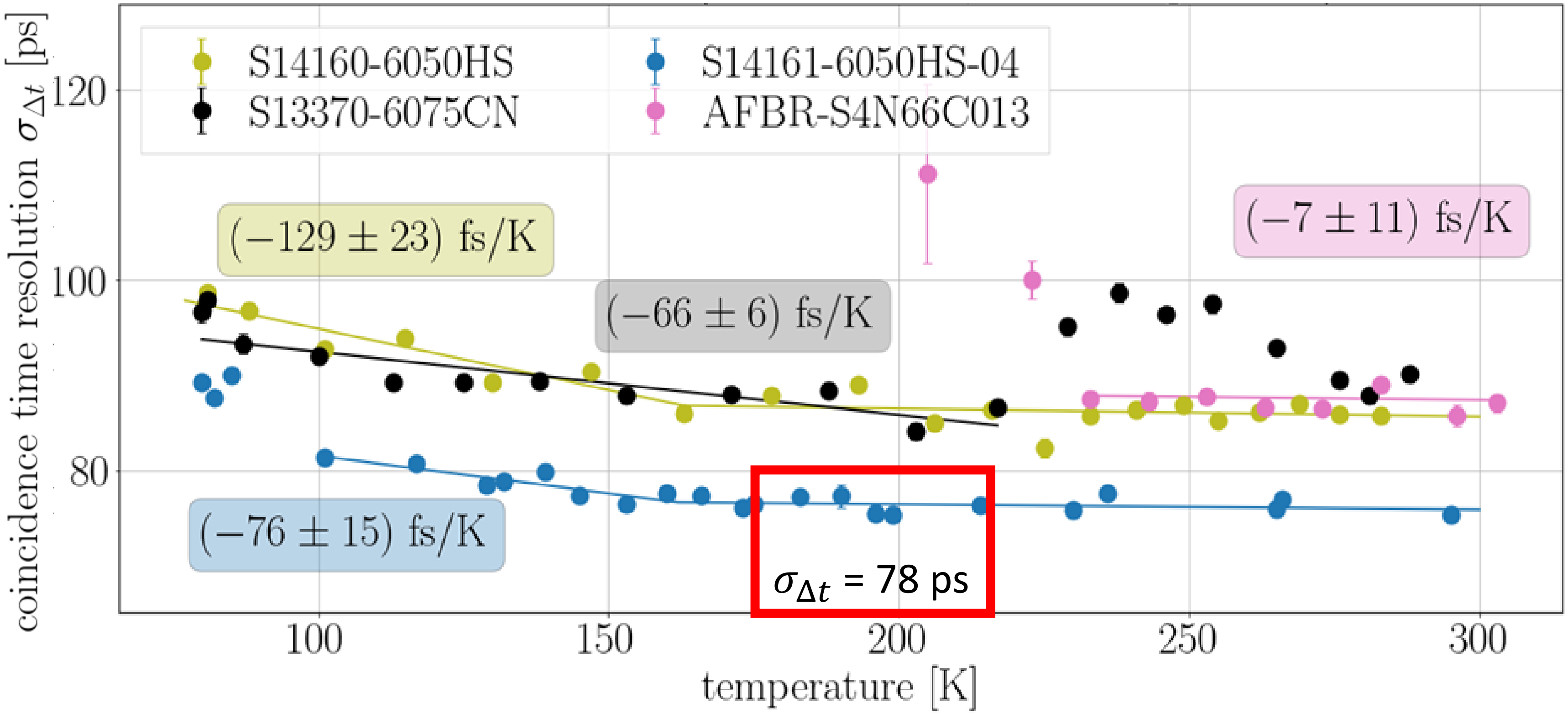
AFBR-S4N66C013



- ToF Prototypes can be operated at 77 K
- σ_t increases at low temperatures
- at 190 K:
  - S14160-6050 HS: $\sigma_t = 43$ ps
  - S14161-6050HS-04: $\sigma_t = \mathbf{39}$ ps

Metal quench resistor

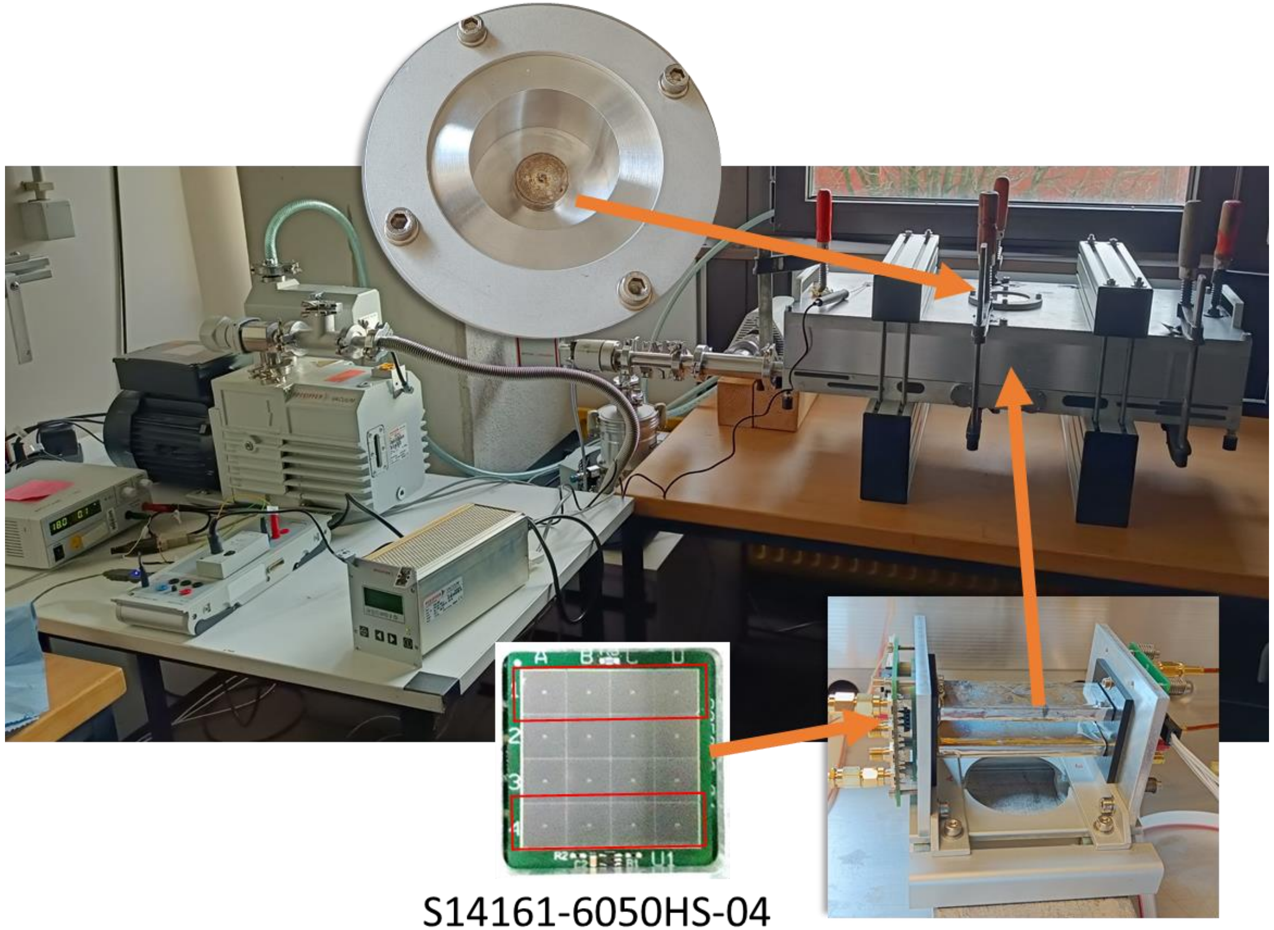
S13370-6075CN *k* = 70 %



$\sigma_{\Delta t}$ = 78 ps

AMS-100: ToF Prototypes: System Test in Vacuum

Teststand not optimized for time resolution measurement

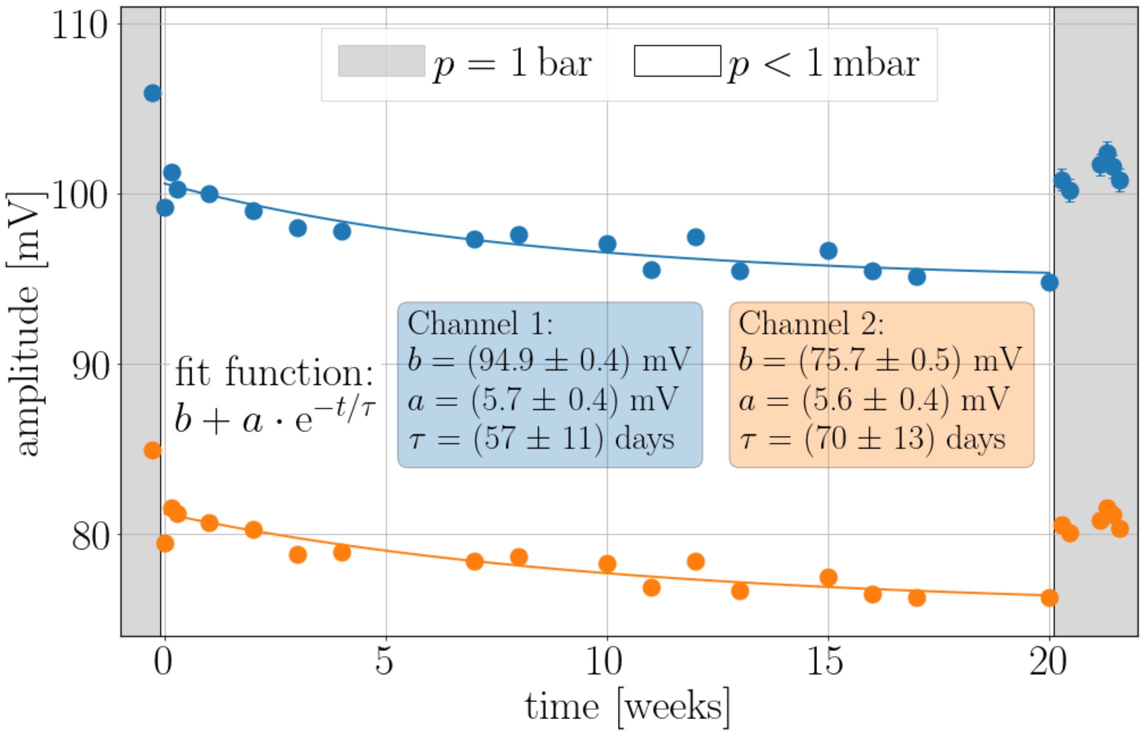


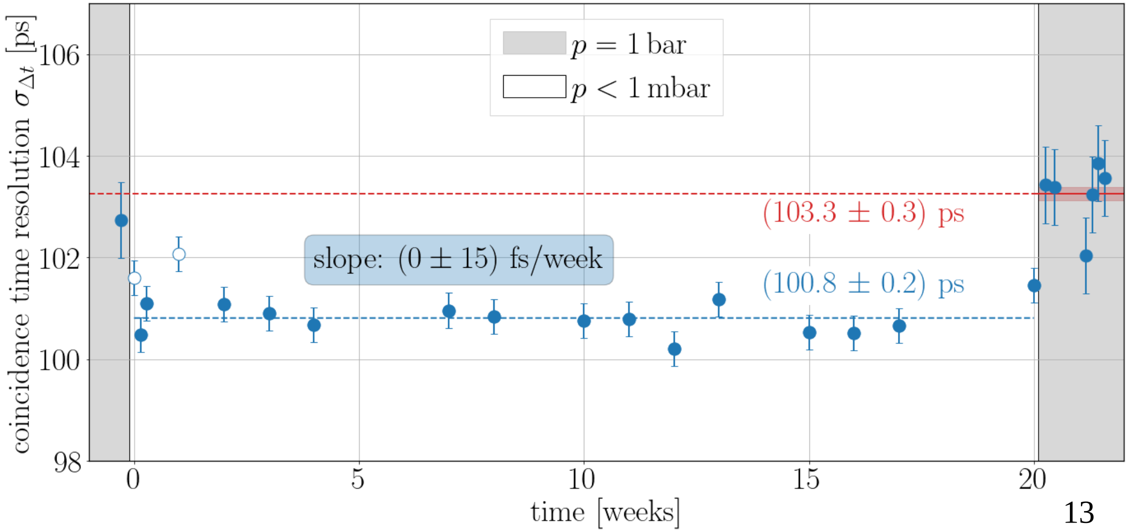
S14161-6050HS-04

Prototype can be operated in vacuum

amplitude loss of ~ 5 % over first weeks due to outgassing of H_2O and O_2

no degradation in time resolution



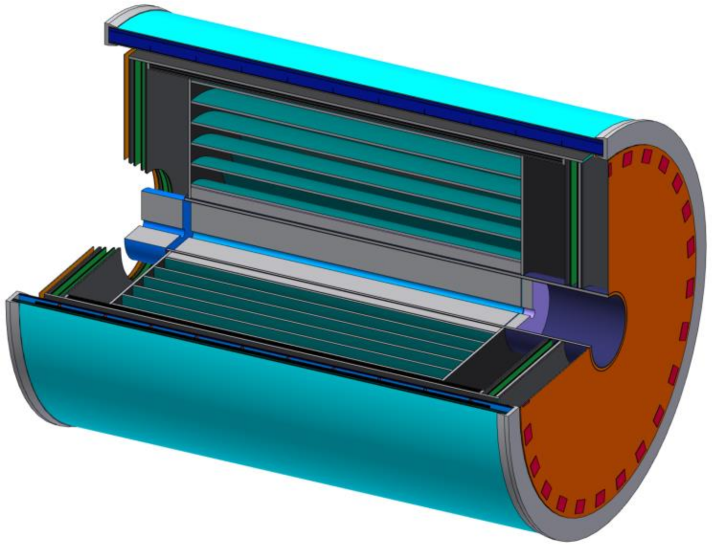


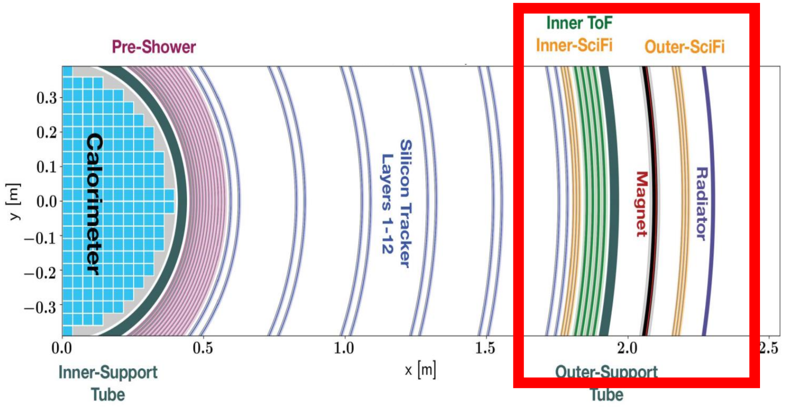
AMS-100: Scintillating Fiber Tracker (SciFi)

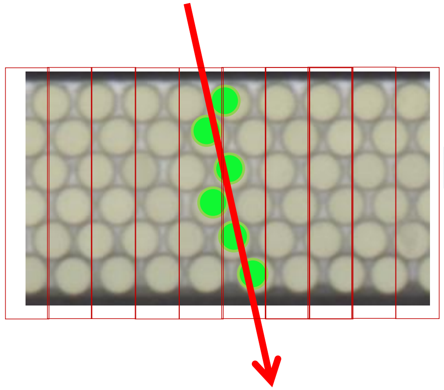
First & Fast Measurement of R and Z; MDR: 3TV

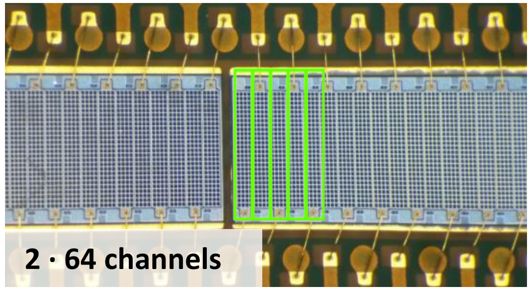
Provides 2x6 Measurements with 40 µm resolution

(using fiber mats made out of 6 layers of 250µm thick fibers)

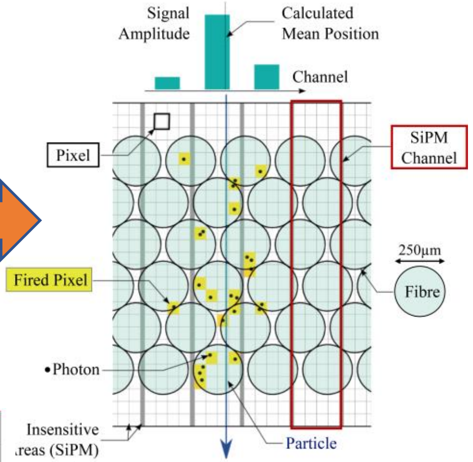


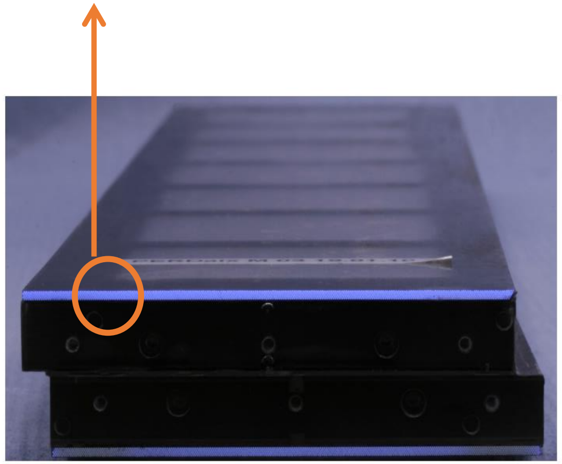


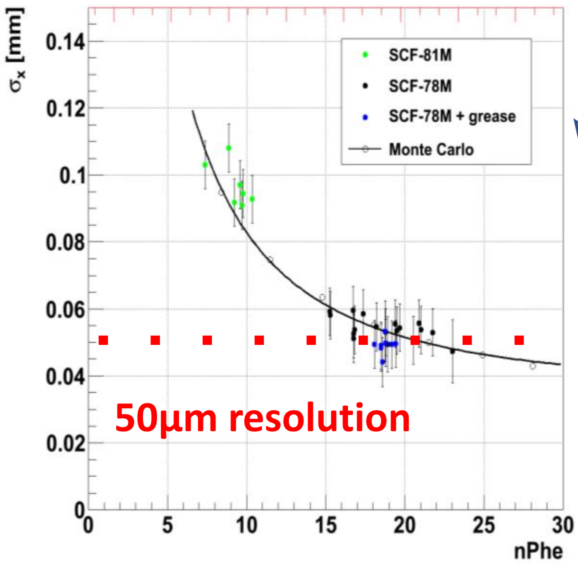




2 · 64 channels





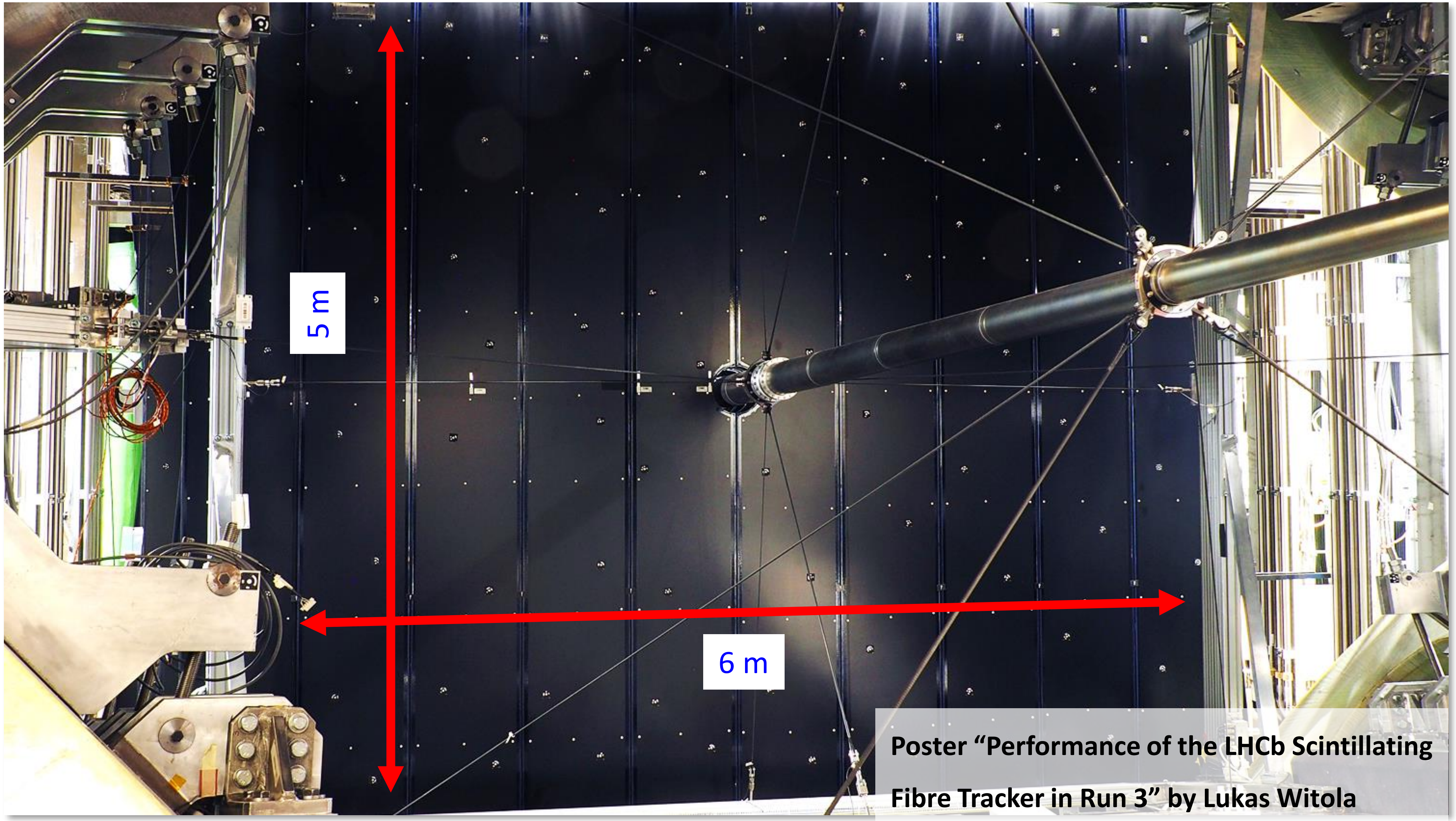


50µm resolution

AMS-100: Scintillating Fiber Tracker (SciFi)

LHCb-SciFi-Tracker:

10,000 km of fibres ⟶ 1152 SciFi mats ⟶ 144 Modules ⟶ 12 Stations ⟶ 340 m² total area

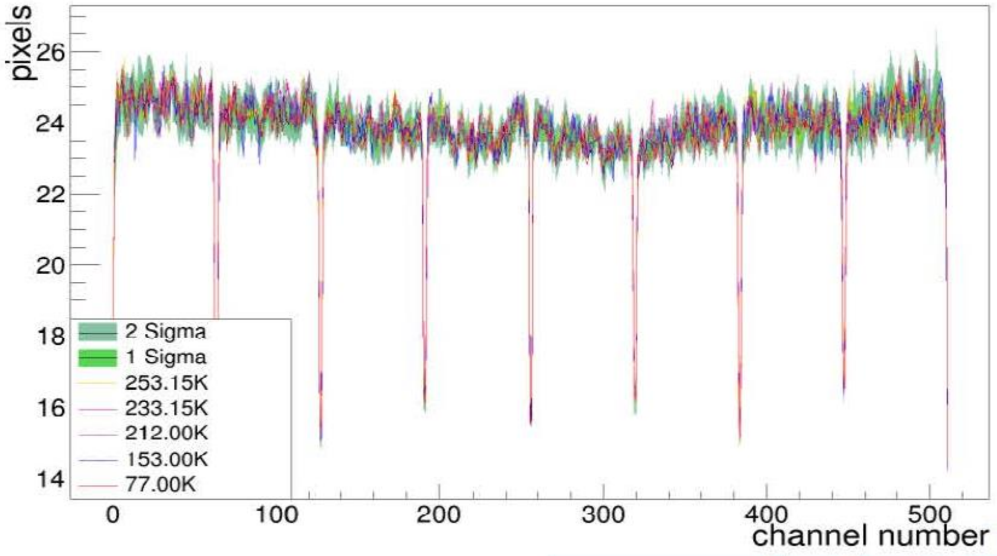


Poster "Performance of the LHCb Scintillating Fibre Tracker in Run 3" by Lukas Witola

AMS-100: Scintillating Fiber Tracker (SciFi)

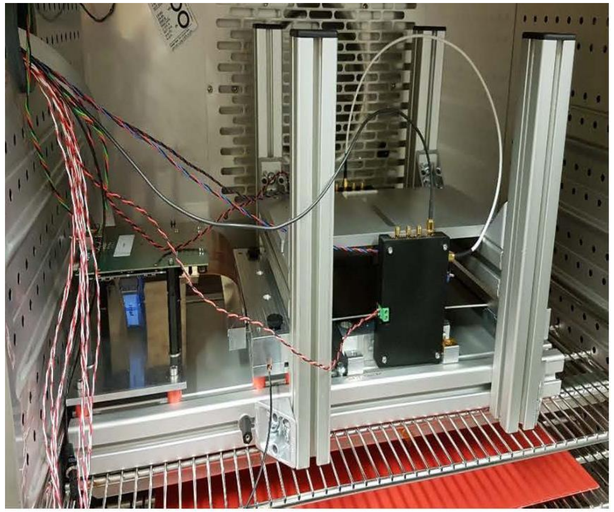
6 Layers SciFi-Mat (0.25mm Fibers) @ temperature range 77 K - 253K

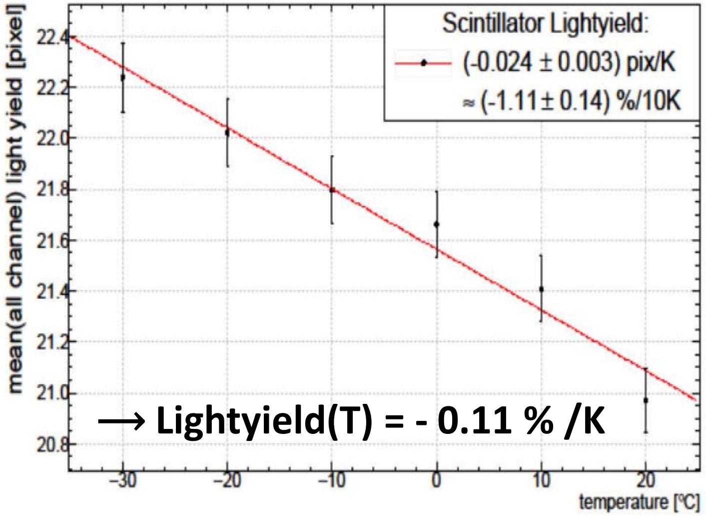
Light yield before and after cryogenic temperatures



⟶ no significant changes in performance

Light yield of 6 Layers SciFi-Mat with 250µm fibers measured at lower temperatures



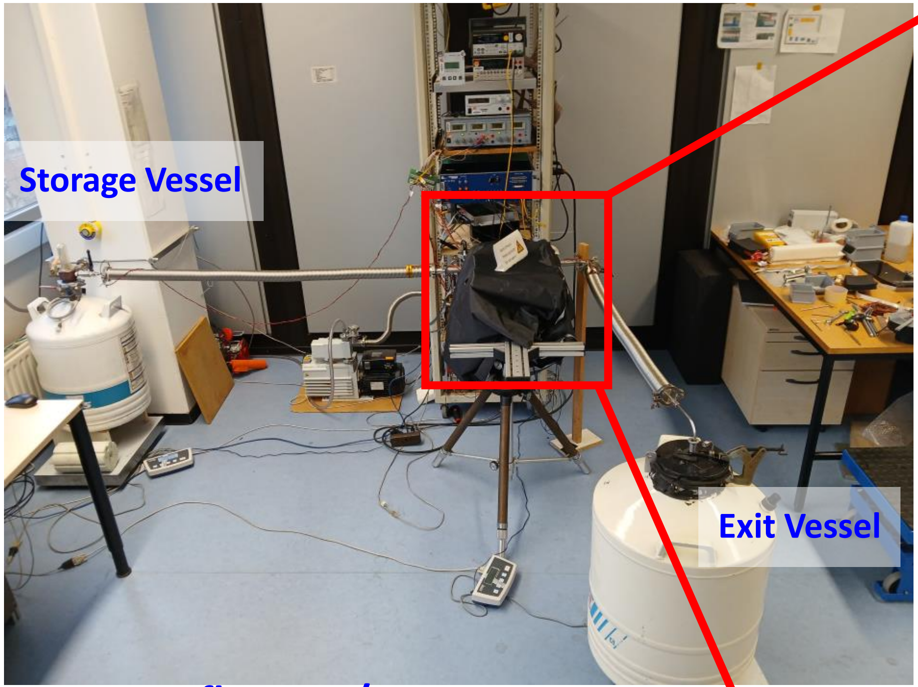


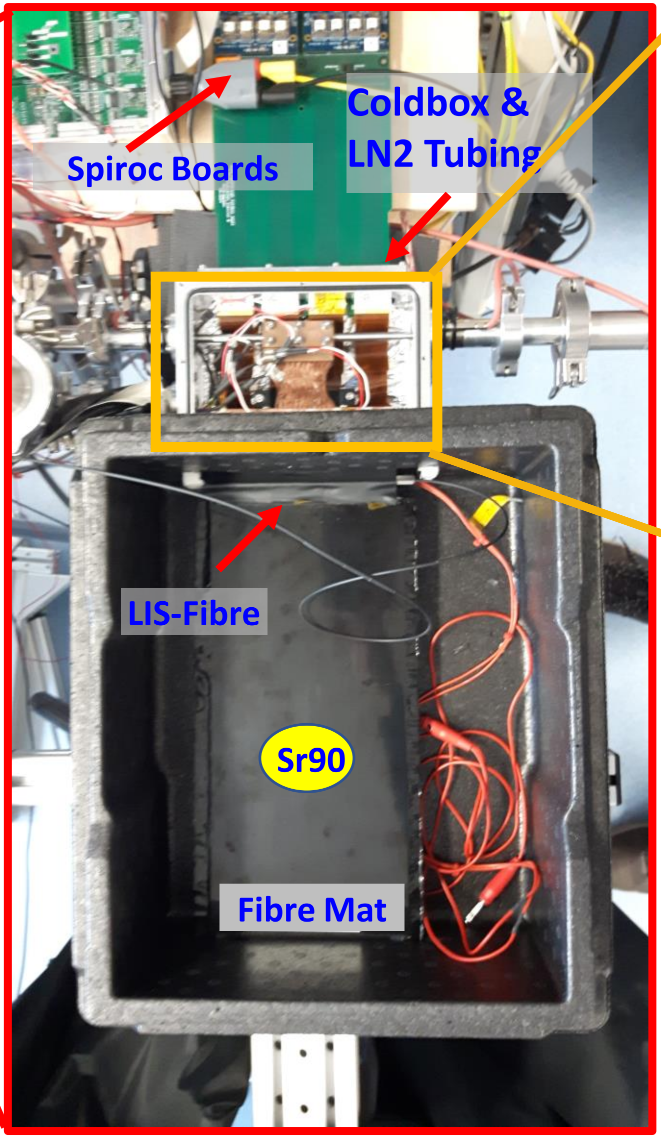
⟶ Lightyield(T) = - 0.11 % /K

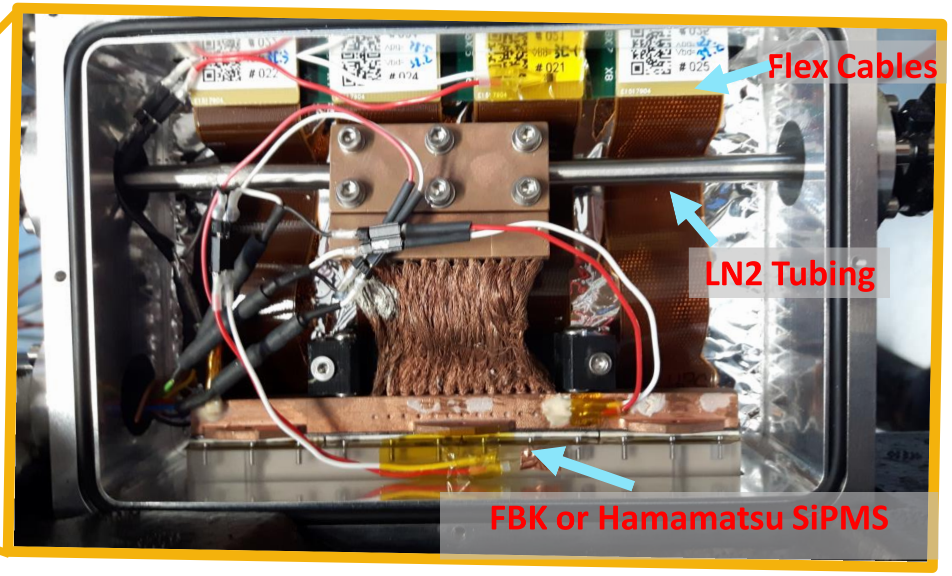
Light yield of fibre mat
@ cryogenic temperatures to be done

SciFi tracker R&D for AMS-100 and LHCb Upgrade II

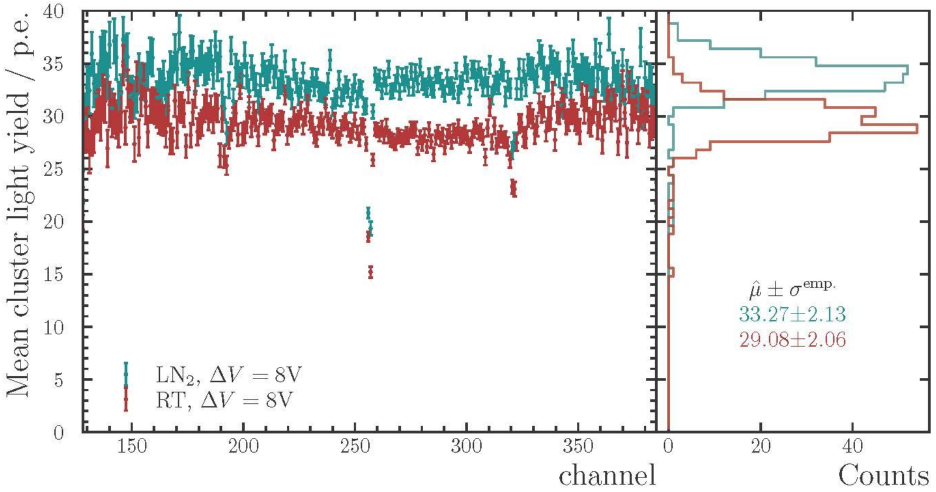
Teststand for the readout of cryogenic cooled SiPMs optical connected to SciFi fiber mat







- LN2 flow: 2g/s
- Pressure: 2• 10^{-5} mbar
- No ice formation
- Increase in light yield by 14% @ 108K, @same overvoltage

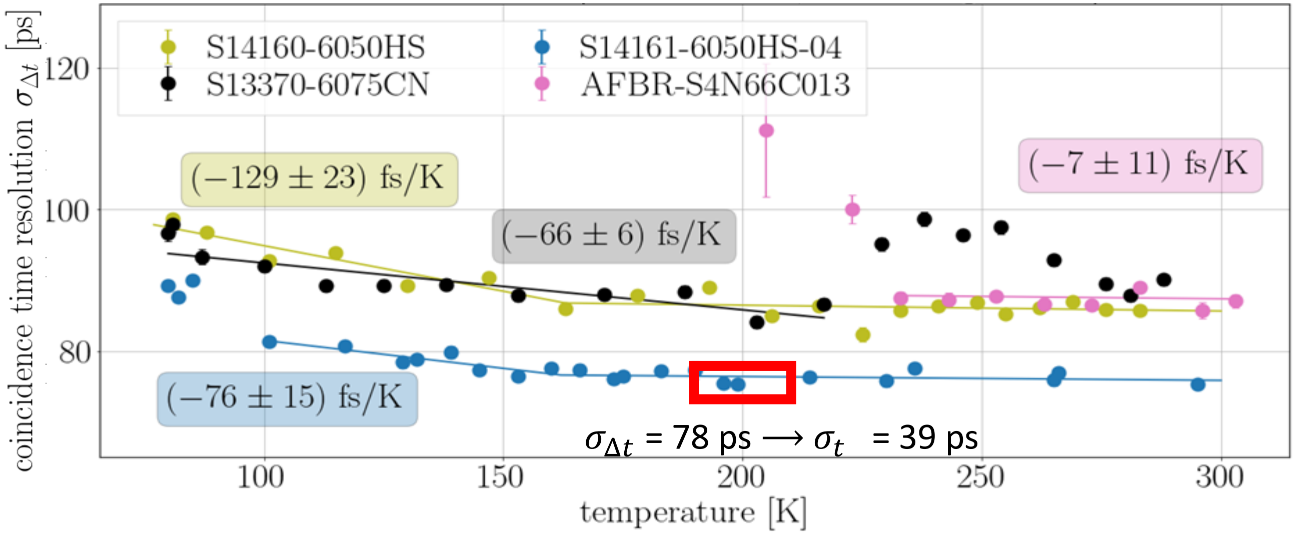


I. Physikalisches Institut

Summary & Outlook

- AMS-100 ToF prototypes (EJ-228 and S14161-6050HS-04) currently achievable minimal time resolution at 190K:

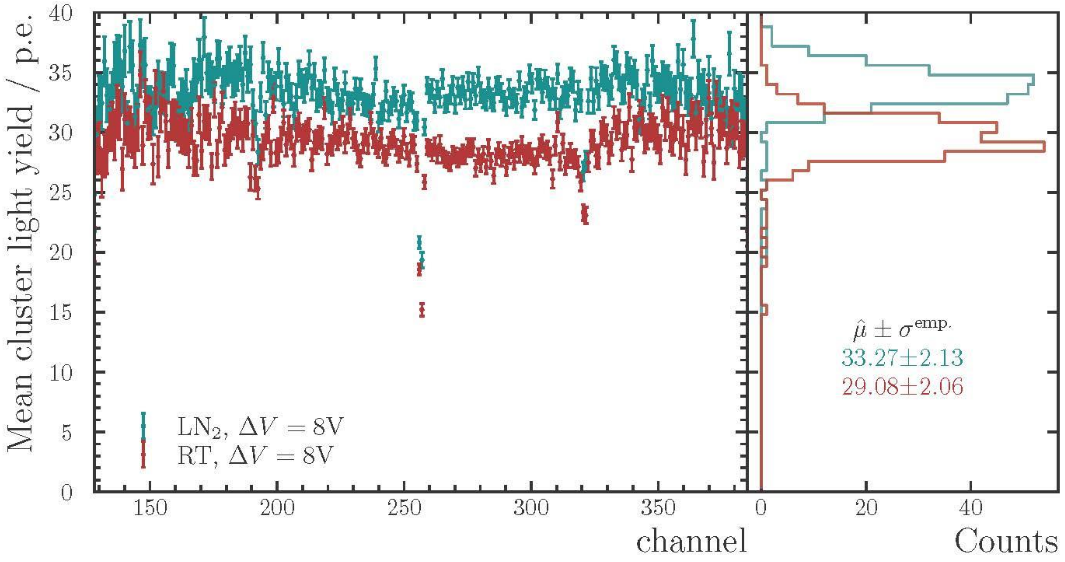
  σ_t = 39 ps
- Test scintillator materials (EJ and BC) and optimize scintillator geometry (width and thickness) to reach design single counter time resolution of 20 ps



$\sigma_{\Delta t}$ = 78 ps ⟶ σ_t = 39 ps

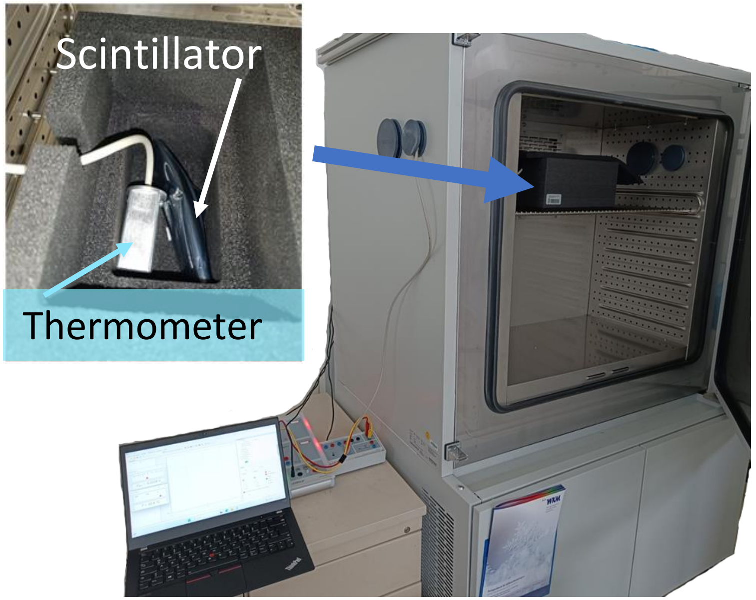
- SciFi: R&D for AMS-100 and LHCb upgrade II:

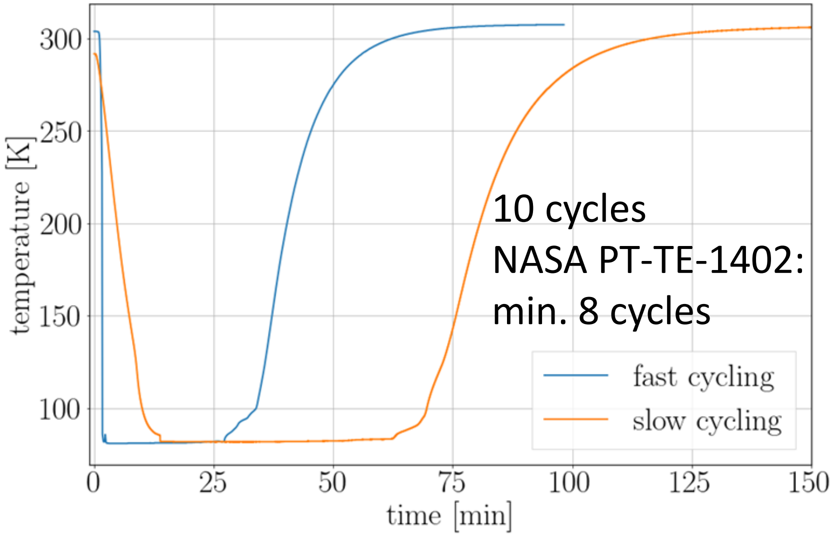
  Light yield increased for lower temperatures (14% @ 108 K)



Backup

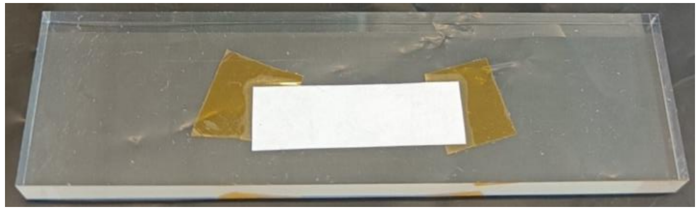
AMS-100: ToF Prototypes: Scintillator thermocycling





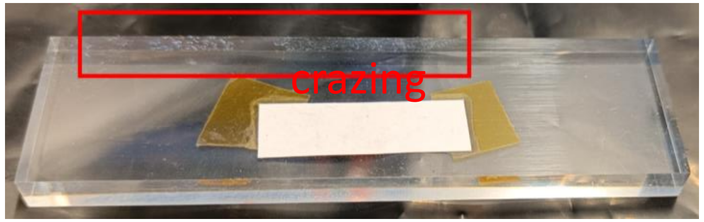
10 cycles
NASA PT-TE-1402:
min. 8 cycles

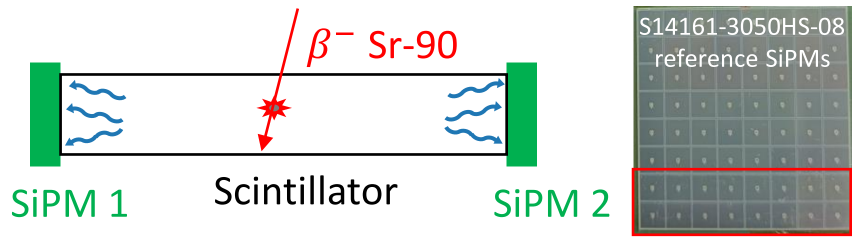
Before cycling

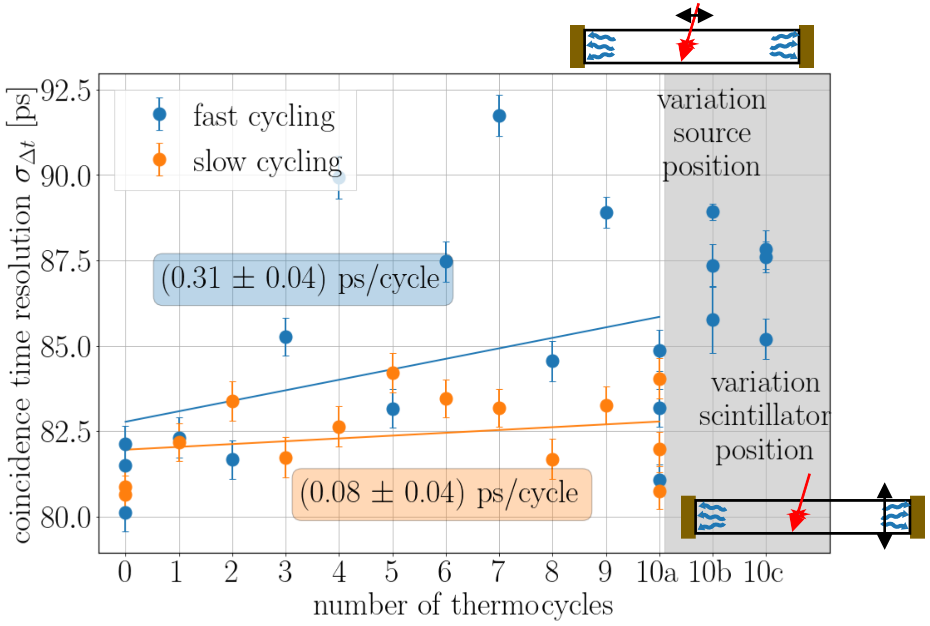


After fast cycling

After slow cycling

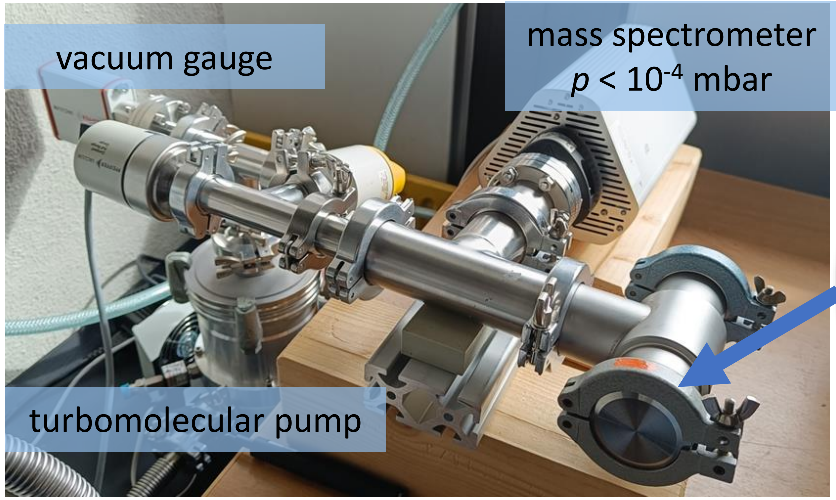






EJ-228 can be thermocycled,
elevated temperatures lead to crazing

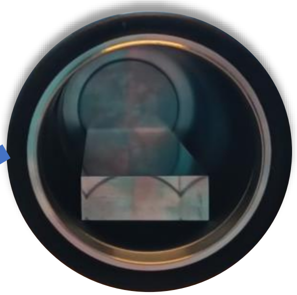
AMS-100: ToF Prototypes: Scintillator in Vacuum



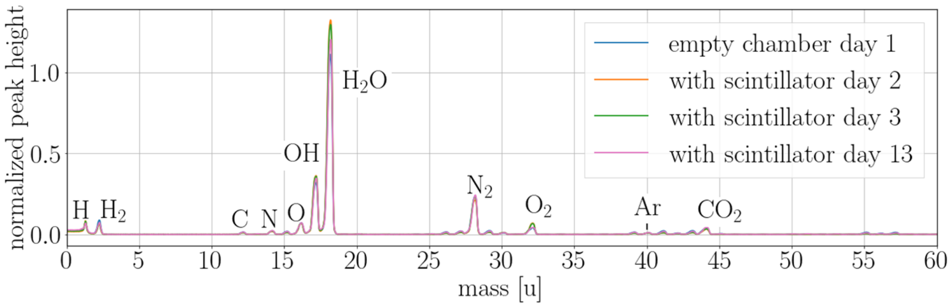
vacuum gauge

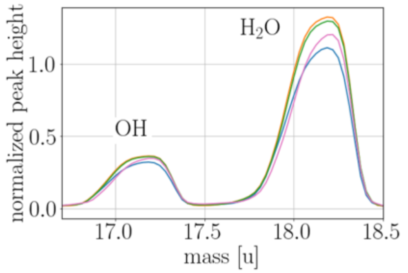
mass spectrometer
$p < 10^{-4}$ mbar

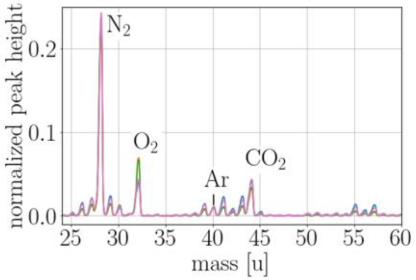
turbomolecular pump



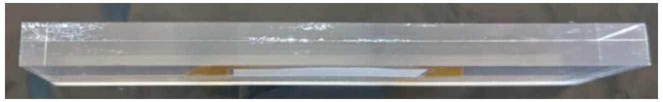
Mass Spectroscopy





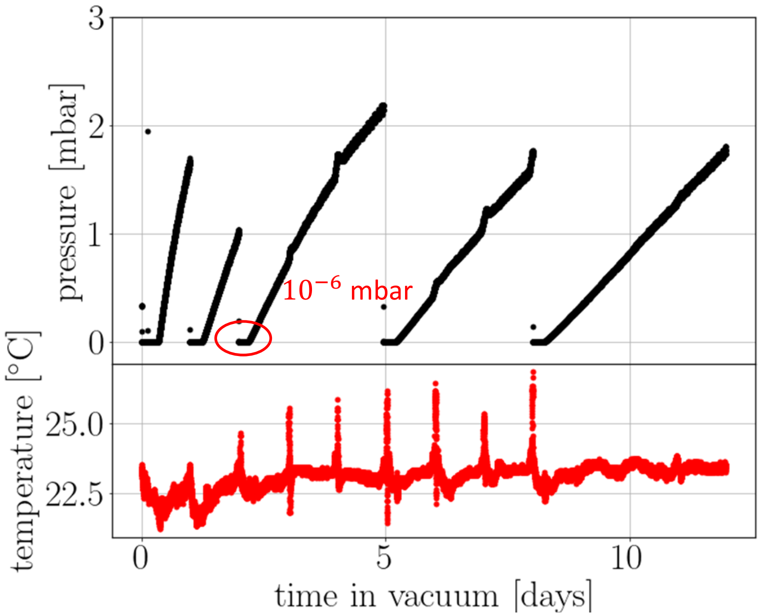


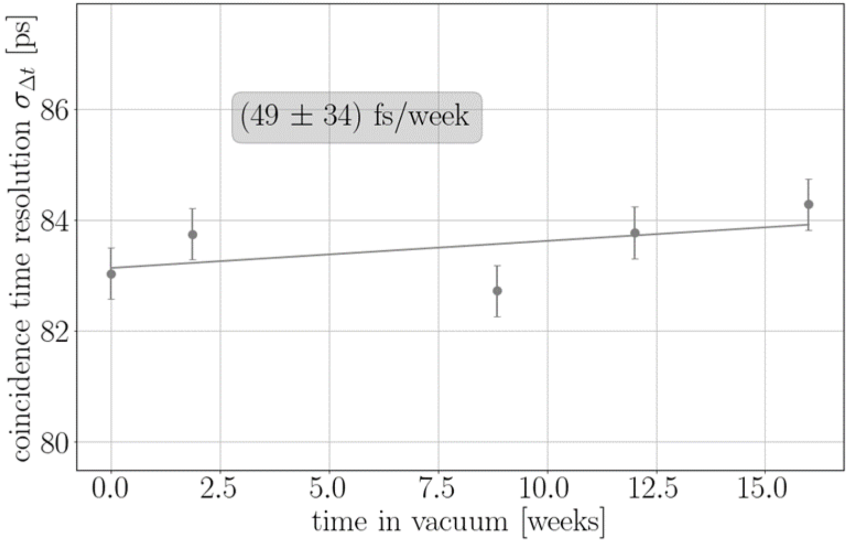
Before vacuum storage



After 16 weeks in vacuum

H_2O and O_2 gas out of voids between polymer chains

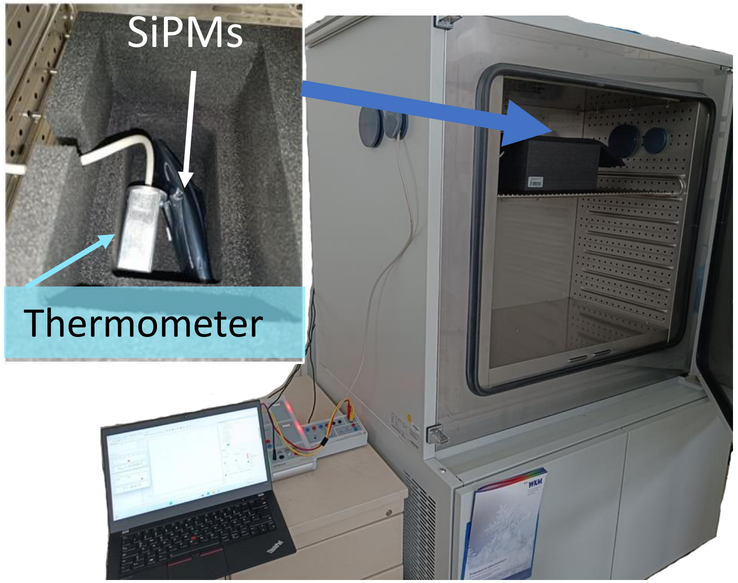


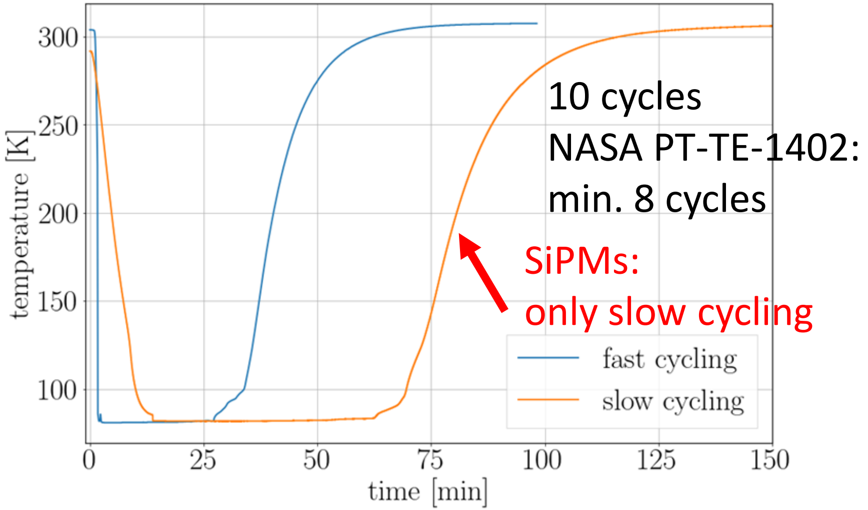


EJ-228 can be stored in vacuum
BUT: frequent pressure changes increase crazing

AMS-100: ToF Prototypes: SiPMs thermocycling

S14160-6050HS

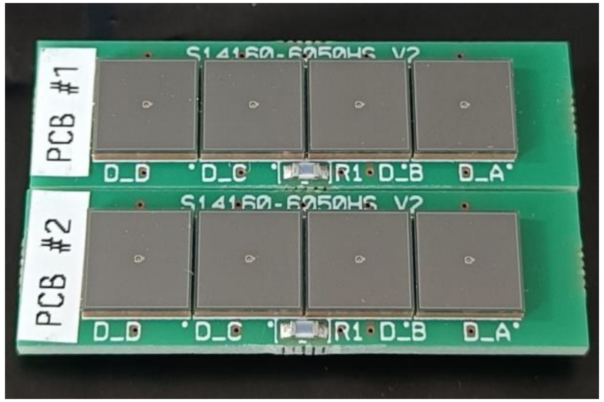




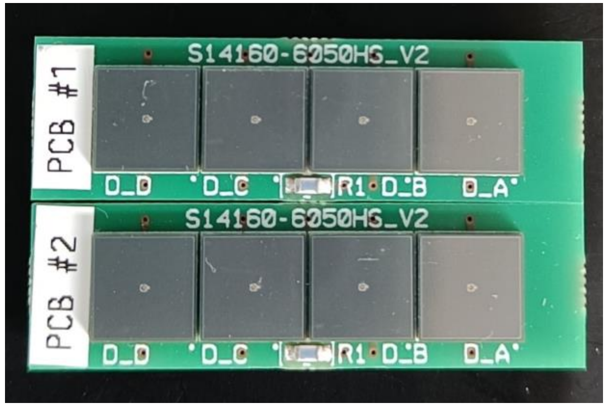
10 cycles
NASA PT-TE-1402:
min. 8 cycles

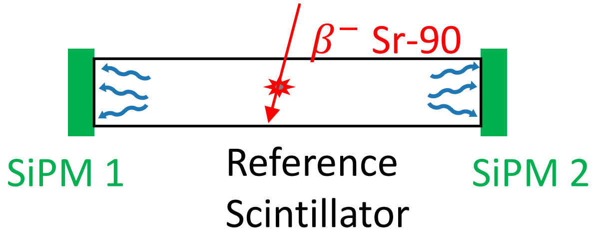
SiPMs:
only slow cycling

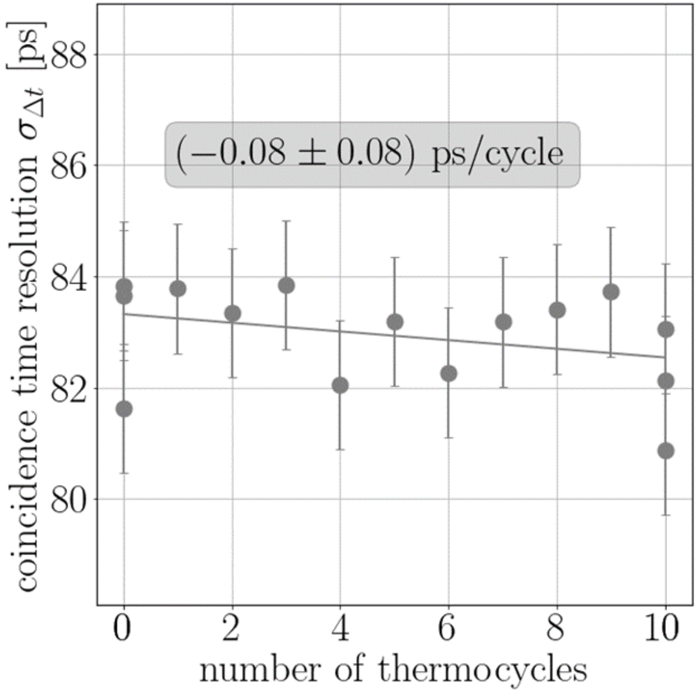
Before cycling



After slow cycling





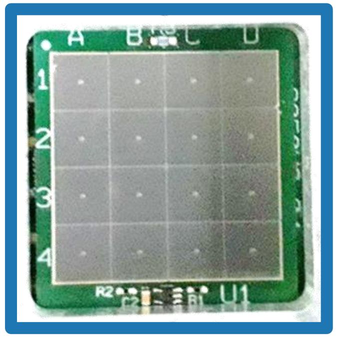


S14160-6050HS can be thermocycled without any change in performance

AMS-100: ToF Prototypes: Signal Shape vs Temperature: Amplitude

Poly-Si quench resistor

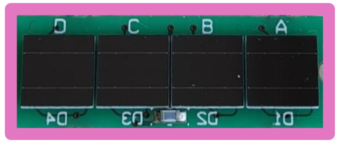
S14161-6050HS-04



S14160-6050HS

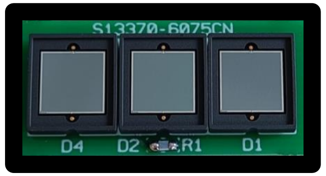
k = 90 %

AFBR-S4N66C013



Metal quench resistor

S13370-6075CN

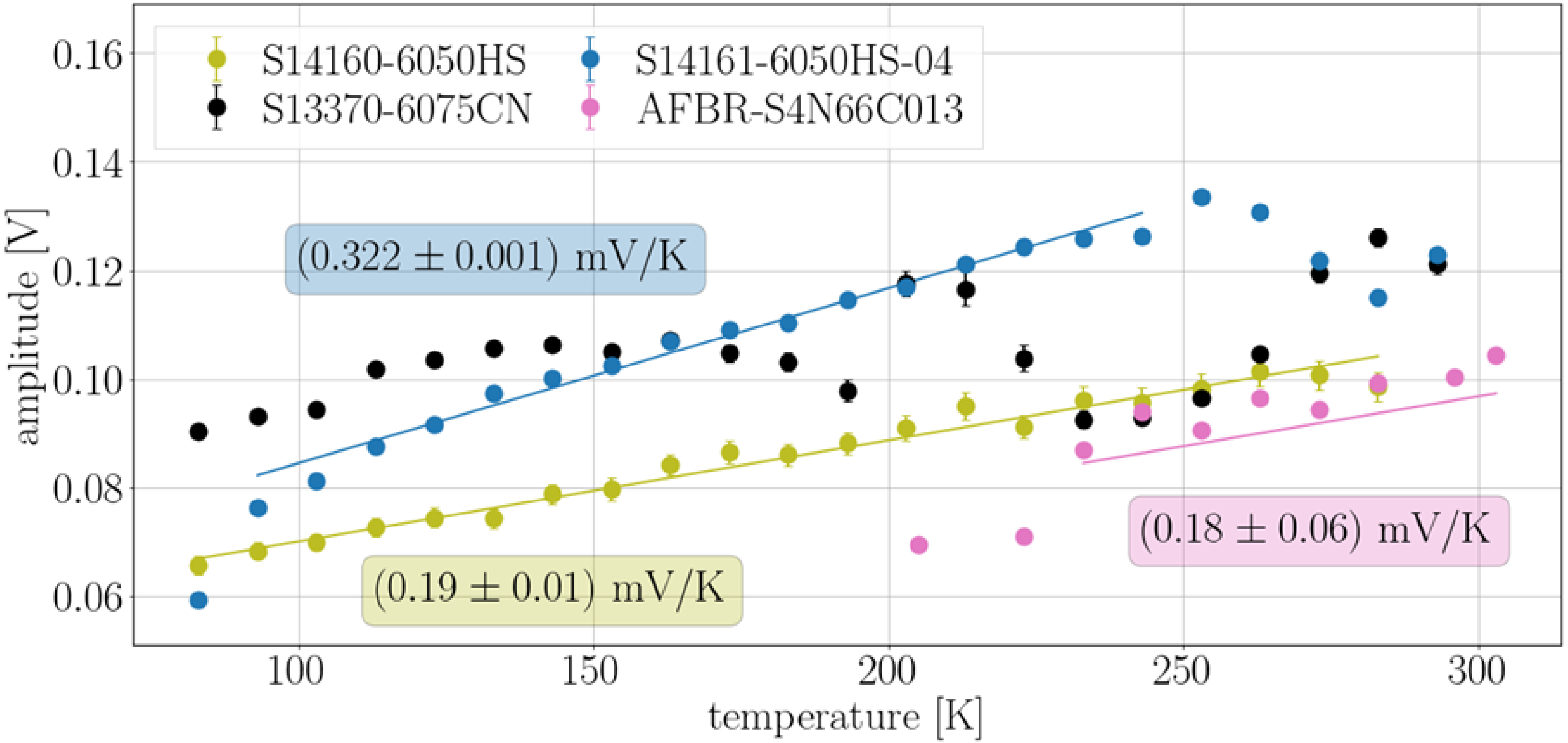


k = 70 %

$$V_{\text{max}} \propto R_{\text{load}} \cdot \left(\frac{Q_{\text{fast}}}{\tau_{\text{fast}}} + \frac{Q_{\text{slow}}}{\tau_{\text{slow}}}\right)$$

Higher τ_{slow}

→ reduced amplitude



SciFi tracker R&D for AMS-100 and LHCb Upgrade II

Thermal Simulation of the coldbox (cryogenic cooled SiPMs optical connected to SciFi fiber mat)