



# *Picosecond timing and BSM*



## *searches for Long-Lived Particles*

*FAST-2023 - Elba*

1 – Few ps timing (test-beam):

Quartz pads/bars/fibers+MCP (sizes 3 -10cm)

$\sigma_t \approx 10 \text{ ps}/30 \text{ ps}/25 \text{ ps}$  (typical resolutions)

2 – R&D on fibers with hi-tech industry partners

3 – Search for BSM LLP in LHC forward regions



Aldo Penzo, 30 May 2023





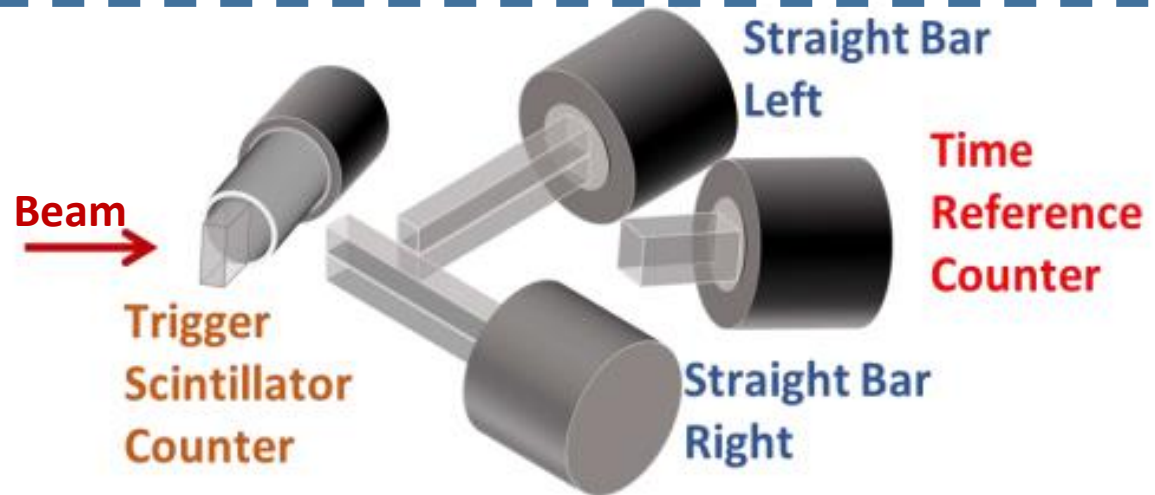
# Time Reference System (TRS)



TRS consist of three quartz Cherenkov counters

Essential contributions:

- B. Kaynak
- S. Ozkorucuklu)



Apparatus: Quartz Bars and Block + MCP (KATOD)

- 2 (identical) Slant (45°) Bars (SBL-R)
- 1 Head-on Block (0°) Time Reference Counter (TRC)

Measuring simultaneously ToF between each pair of the 3 counters, in hypothesis of independent measurements (no covariance):

$$\sigma_{12}^2 = (\sigma_1^2 + \sigma_2^2) \quad ; \quad \sigma_{13}^2 = (\sigma_1^2 + \sigma_3^2) \quad ; \quad \sigma_{23}^2 = (\sigma_2^2 + \sigma_3^2)$$

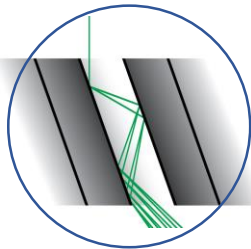
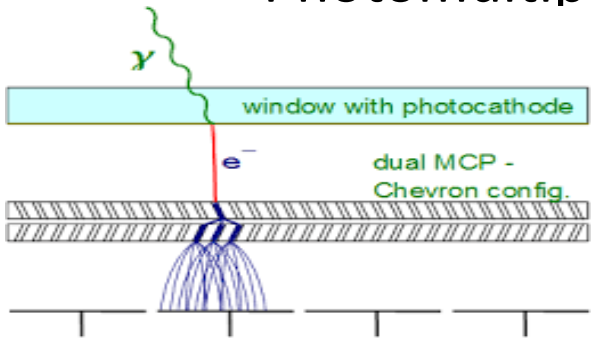
time resolution for each counter can be obtained.



Important contributions by V. Samoylenko (Protvino)



# Micro Channel Plate Photomultipliers



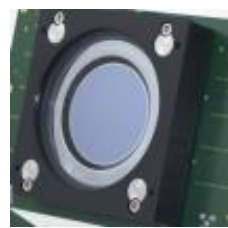
Hamamatsu



Photonis



Photek



**KATOD UFK-5G-2D:**  
 2-stage MCP 0.3 mm thick 6  $\mu\text{m}$  pores at 6 $^\circ$   
 Gain  $>10^6$  and dark current  $< 1$  nA  
 Window : 1.2mm thick glass US-49  
 Transit time spread (TTS  $\approx 30$  ps RMS)



## Photomultiplier Tube UFK-5G-2D

### General

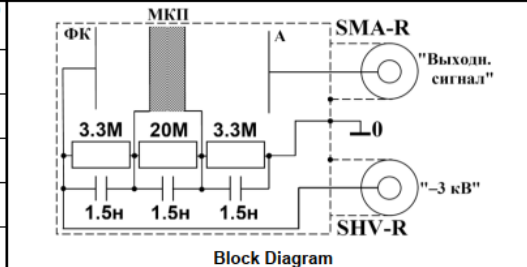
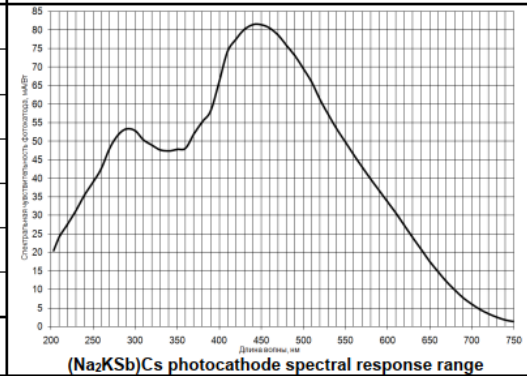
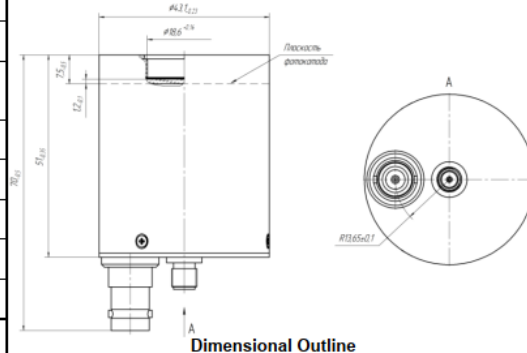
Input Window Material	glass US-49
Photocathode Material	(Na <sub>2</sub> KSb)Cs
Effective Photocathode Diameter, mm	18
Housing Material	Metal
Connector Types anode output power supply	SMA-R SHV-R
Intensification System	microchannel
MCP quantity	2
Diameter, mm	43,1
Length, mm	70
Weight, g	< 100

### Electrical Characteristics

Spectral response range, nm	200-750
Radiant photocathode sensitivity at $\lambda=450$ nm, mA/W	> 70
Gain	1-10 <sup>6</sup>
Dark Current at gain 1-10 <sup>6</sup> , A	< 1-10 <sup>-9</sup>
Max anode current, nA	300
Supply Voltage, kV	< 3,1 negative
Divider Resistance, MOhm	26,5

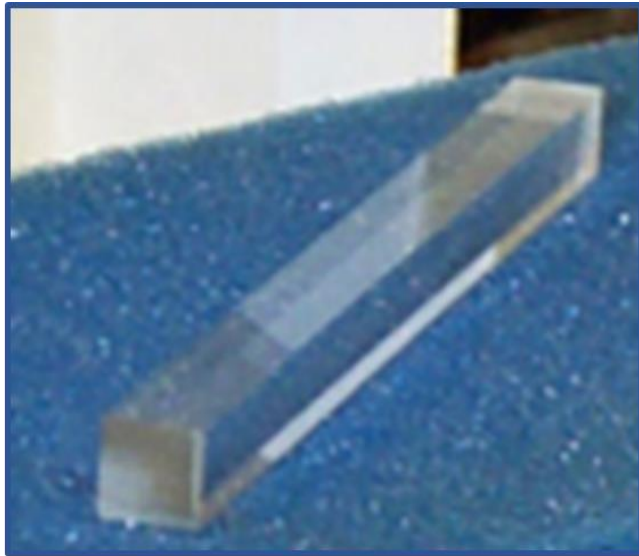
### Operational Conditions

Sinusoidal Vibration	within frequency range 1-500 Hz acceleration amplitude 5g
Multiple Shock	15g, (2÷15) ms
Single Shock	300g, 1 ms
Operational temperature	$\pm 50$ °C
Transportation temperature	+ 70, - 60 °C
Reliability: MTTF, h	10 000



# Quartz (Fused Silica) Radiators

Block is KU-1 (Russian Standard) used for TRC  
 (UV transparency, high radiation hardness and absence of fluorescence)  
 Bars produced by Specialty Glass Products (USA) used for SB counters.



Speciality Glass Products (USA)



KU-1 (Russian Standard)



MOLEX-Polymicro fiber bundle (JTFLH600630950)

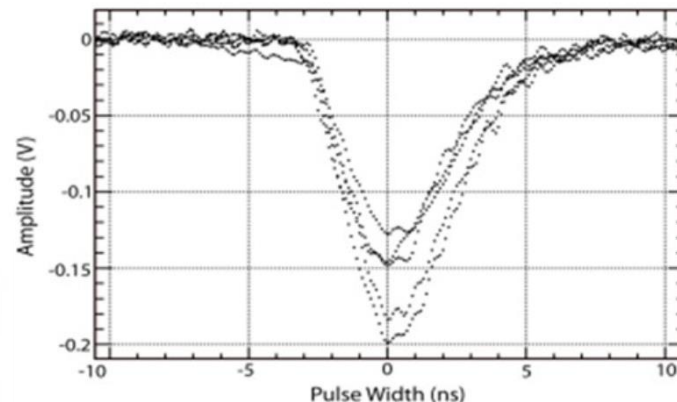
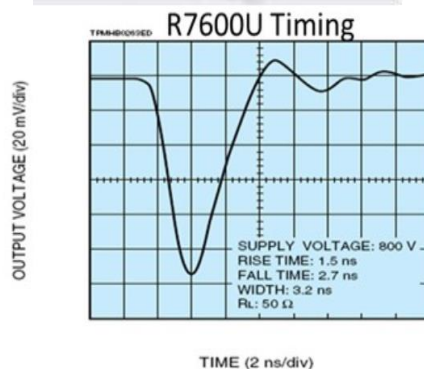
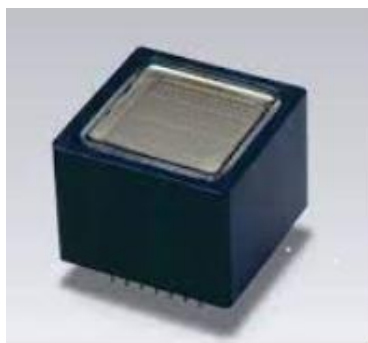
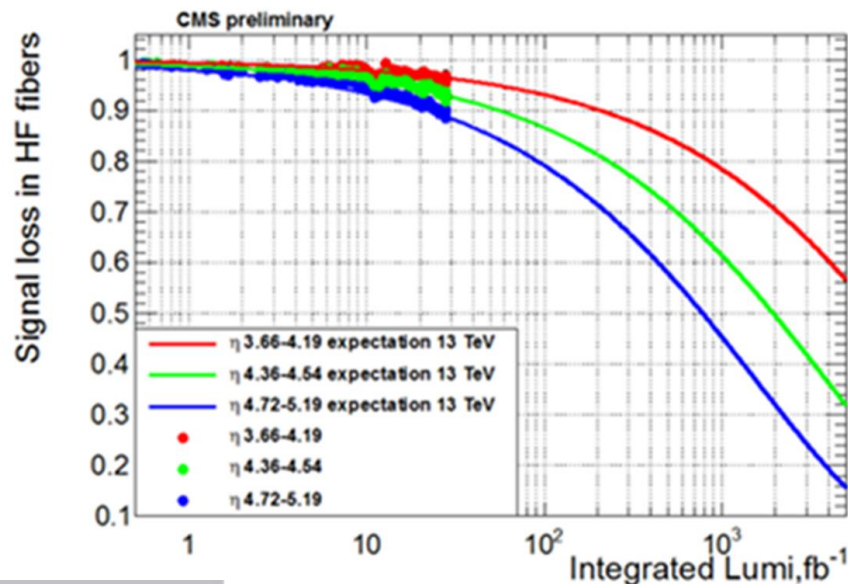


...also longer (165-145-35 cm)



Reconditioning Pre-Production HF Prototype (HF-PPP) for tests with new PMT (HPK R7600-M4) and MCP-PMT

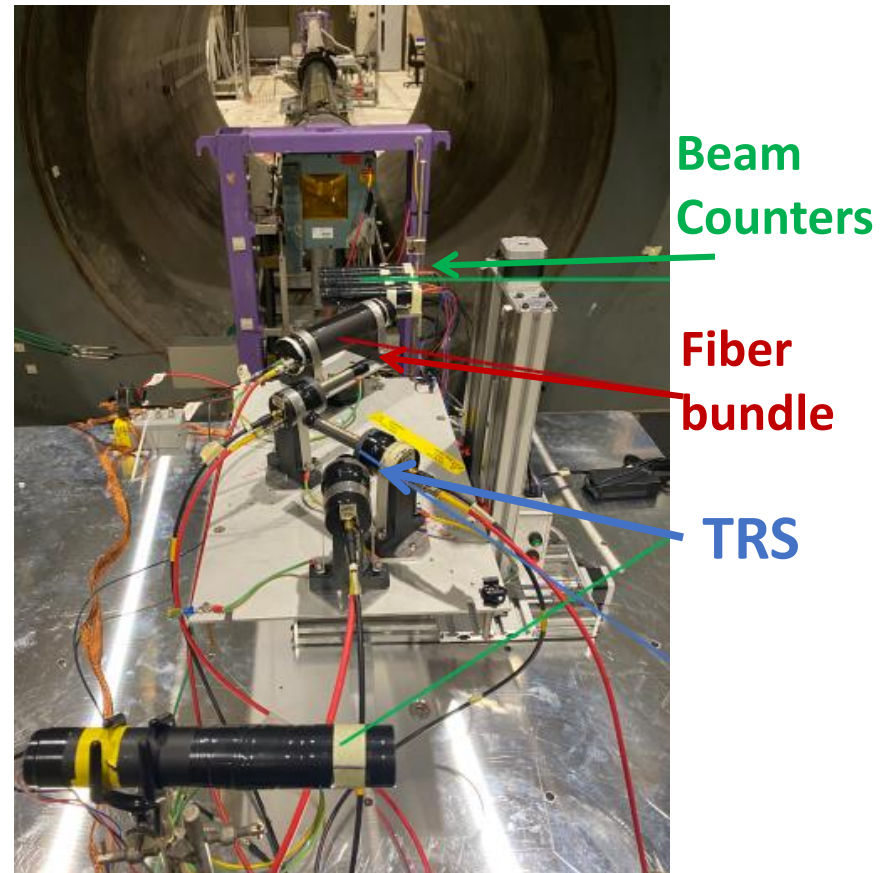
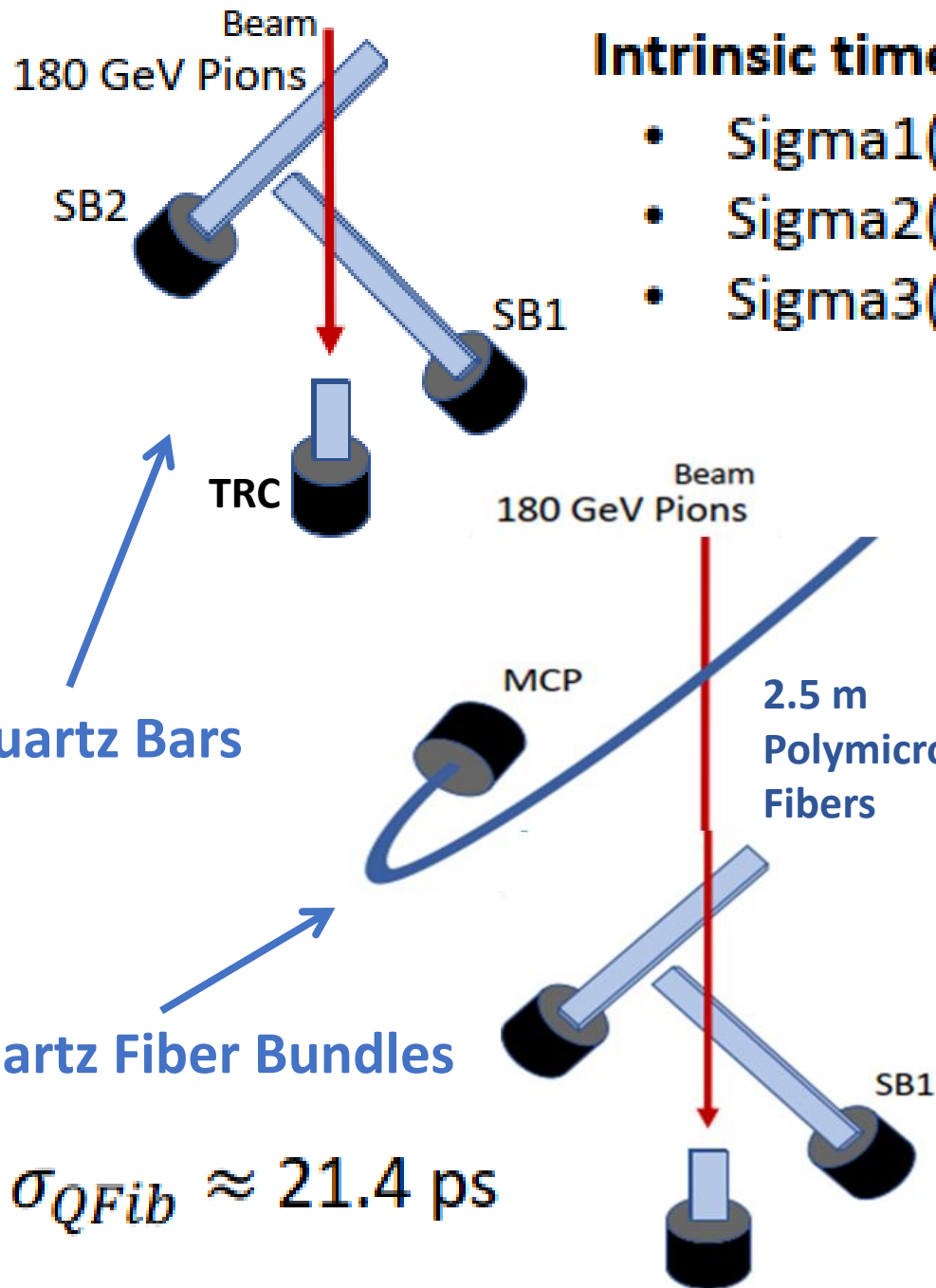
## HF Fibers' Longevity



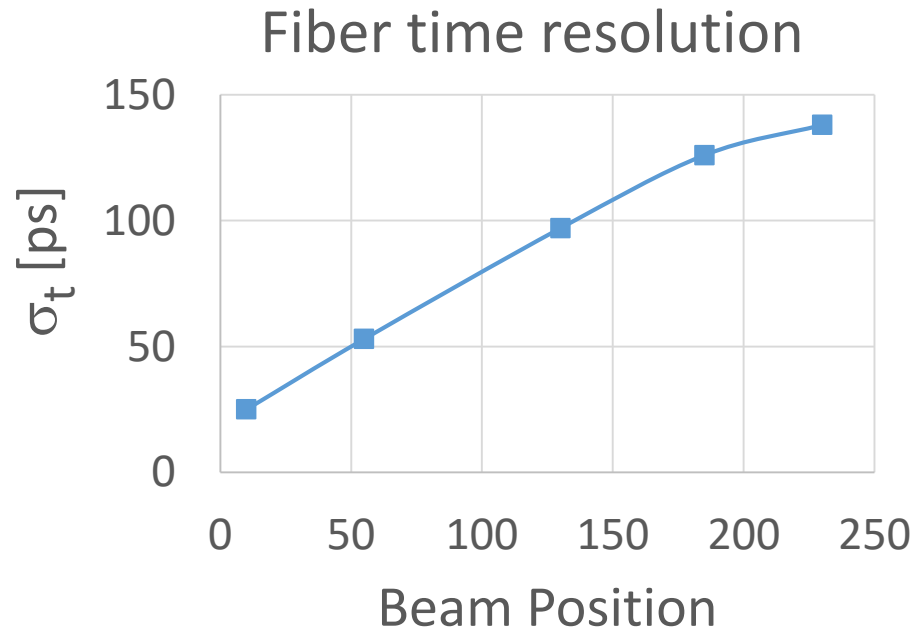
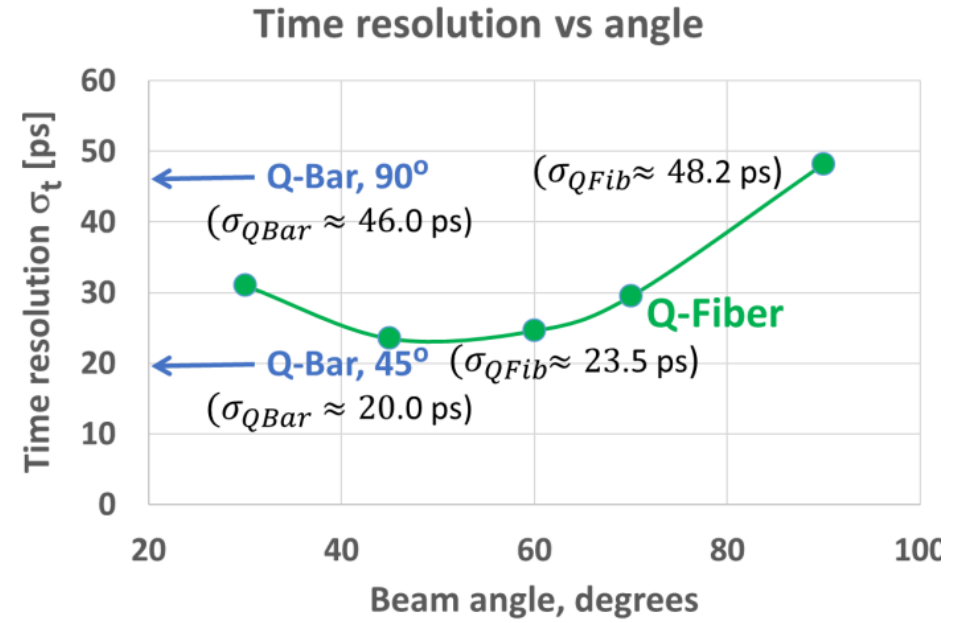
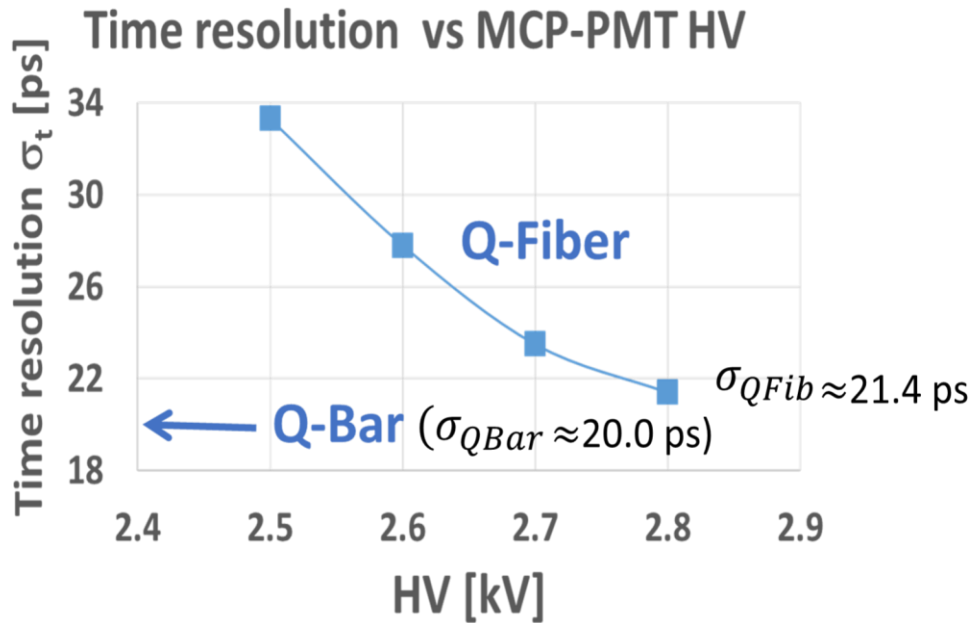
HF Signal

## Intrinsic time resolutions

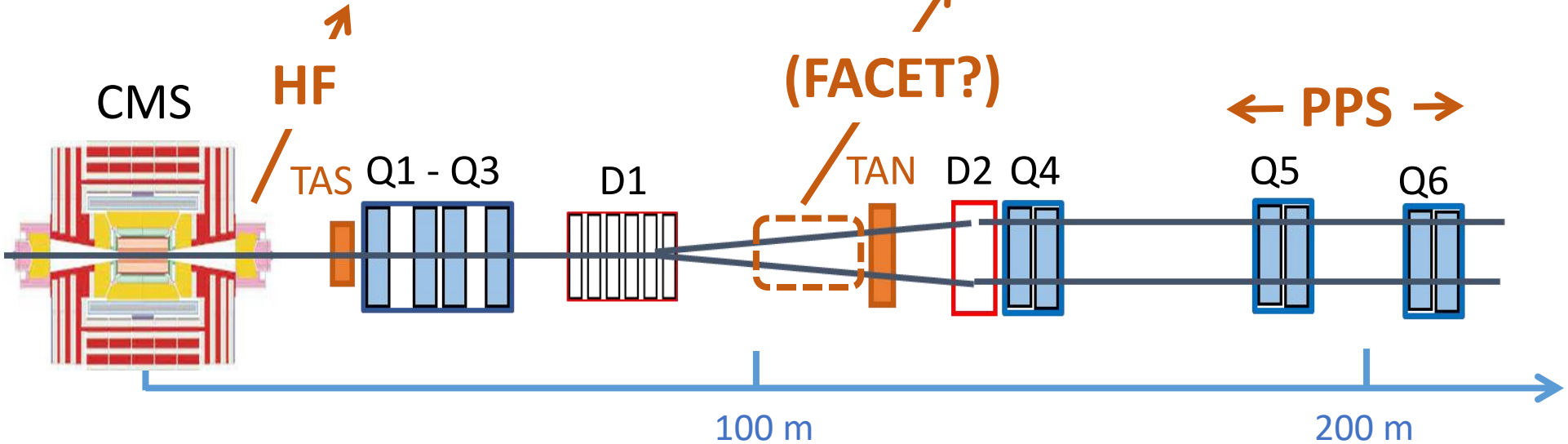
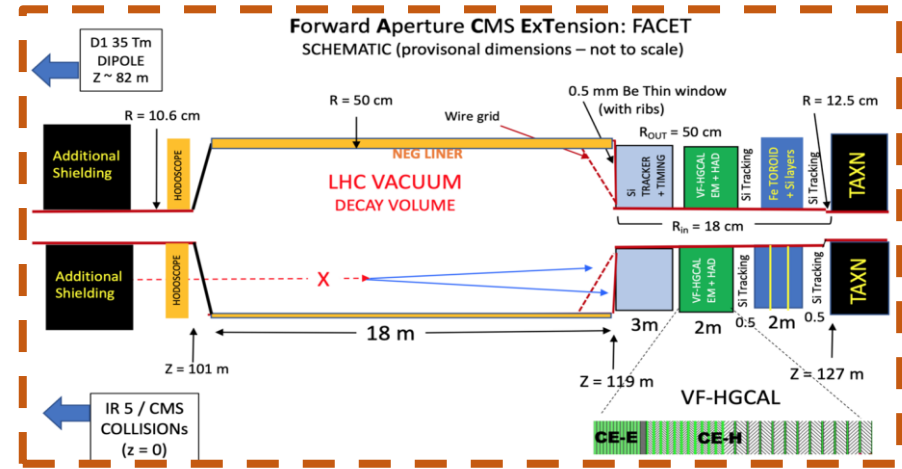
- $\text{Sigma1}(\text{TRC}) \rightarrow 7.14 \pm 2.19 \text{ ps}$
- $\text{Sigma2}(\text{SB1}) \rightarrow 19.44 \pm 0.80 \text{ ps}$
- $\text{Sigma3}(\text{SB2}) \rightarrow 22.65 \pm 0.72 \text{ ps}$



# Q- Fibers



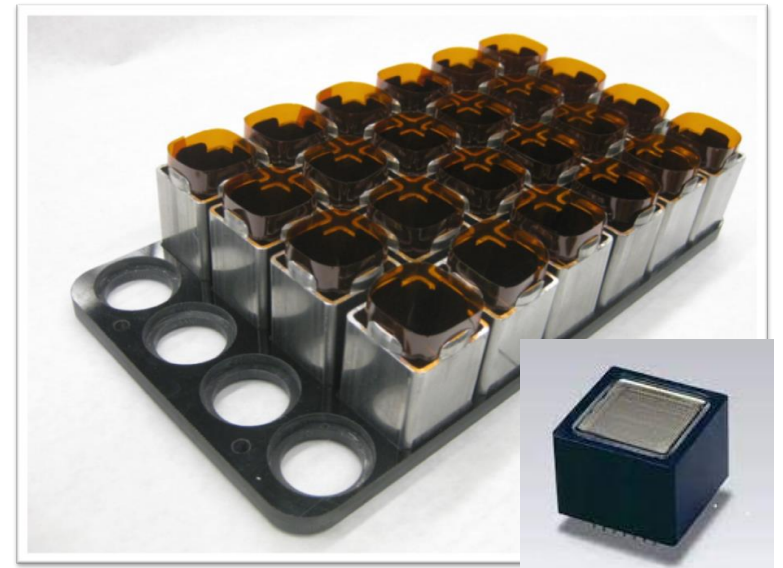
# CMS Forward Region



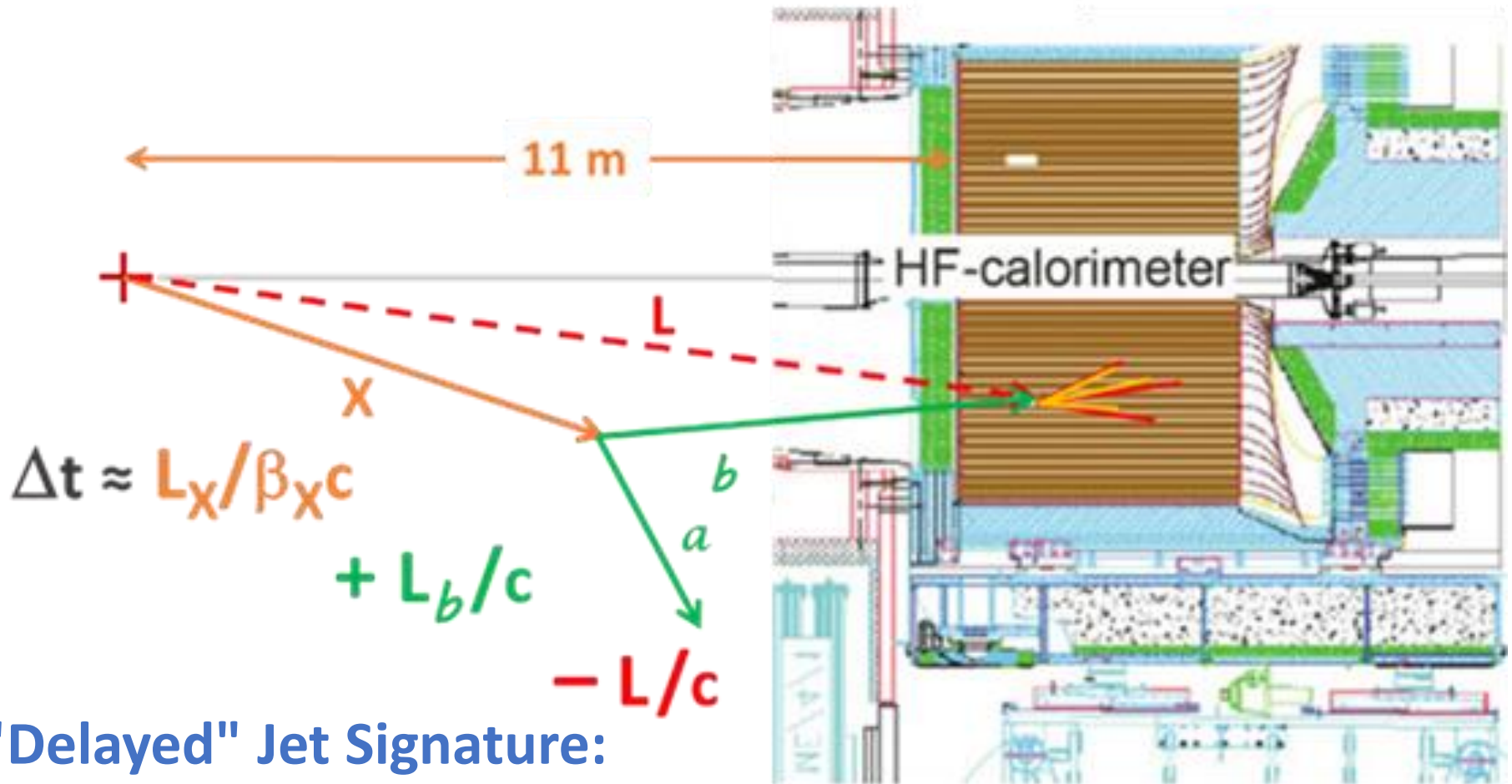


## Quartz Fiber Calorimeters in forward region ( $3 < \eta < 5$ )

- ~ 250 tons iron absorber ( $8.8 \lambda_I$ )
- ~ 1000 km quartz fibers (0.8mm diam)
- ~ 2000 PMT read-out
- 36 wedges azimuthally; 18 rings radially



Long Lived Particle (LLP)  $X \rightarrow a+b \rightarrow \text{jet}$



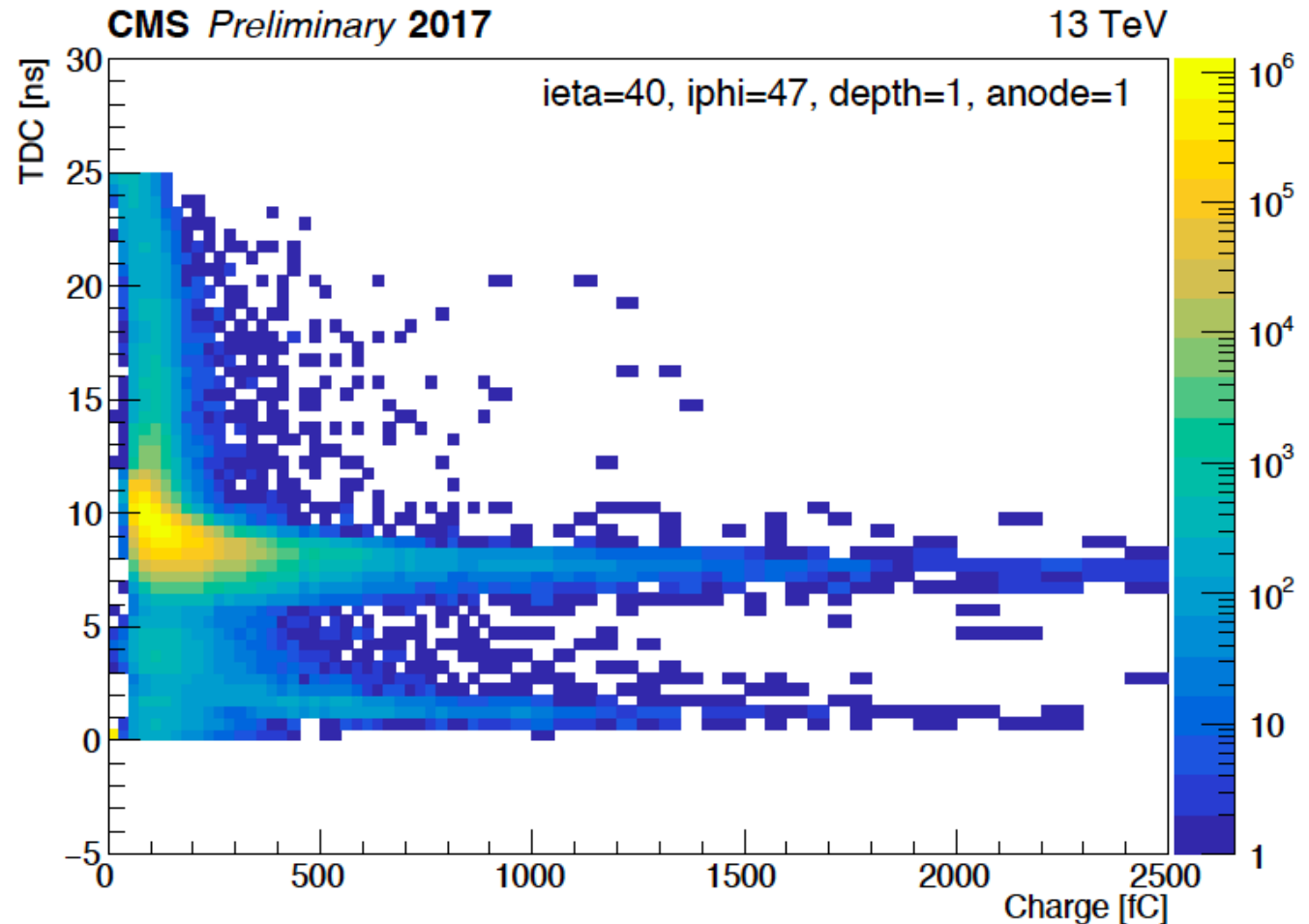
"Delayed" Jet Signature:

Jia Liu, Zhen Liu, Lian-Tao Wang, Long-lived particles at the LHC: catching them in time, Phys. Rev. Lett. 122, 131801 (2019)

[In CMS HCAL (barrel): C. Tully et al. , HCAL Trigger for LLPs]

# Small time differences help a lot!

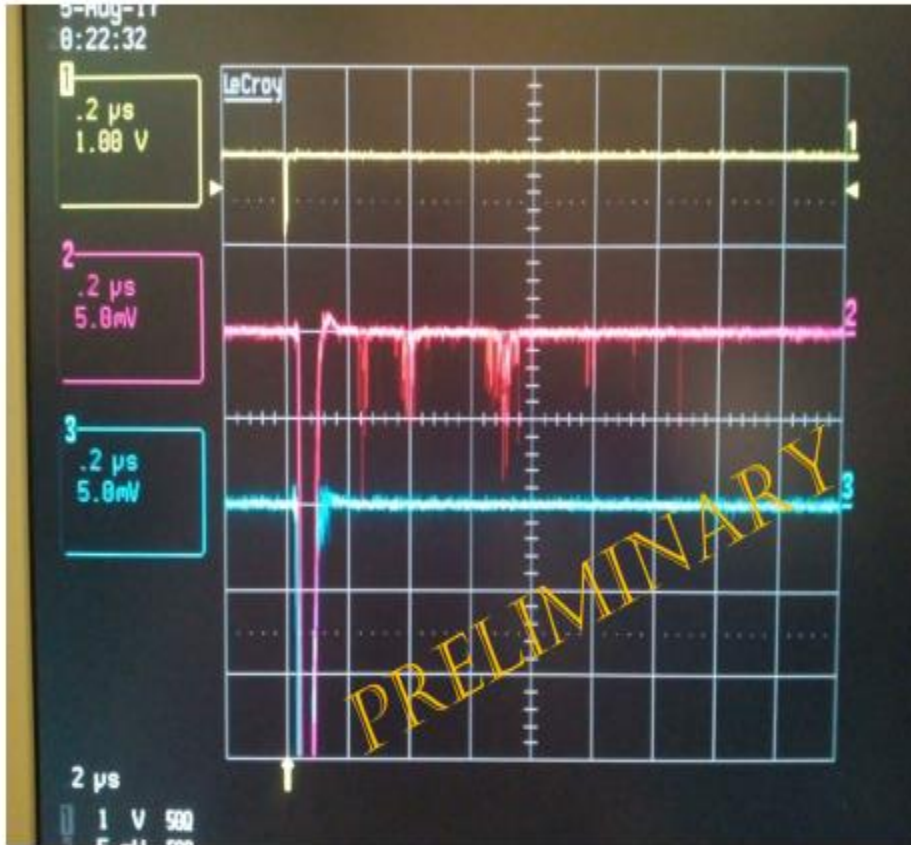
Particles hitting the HF PMTs, produce large pulses from Cherenkov in PMT windows



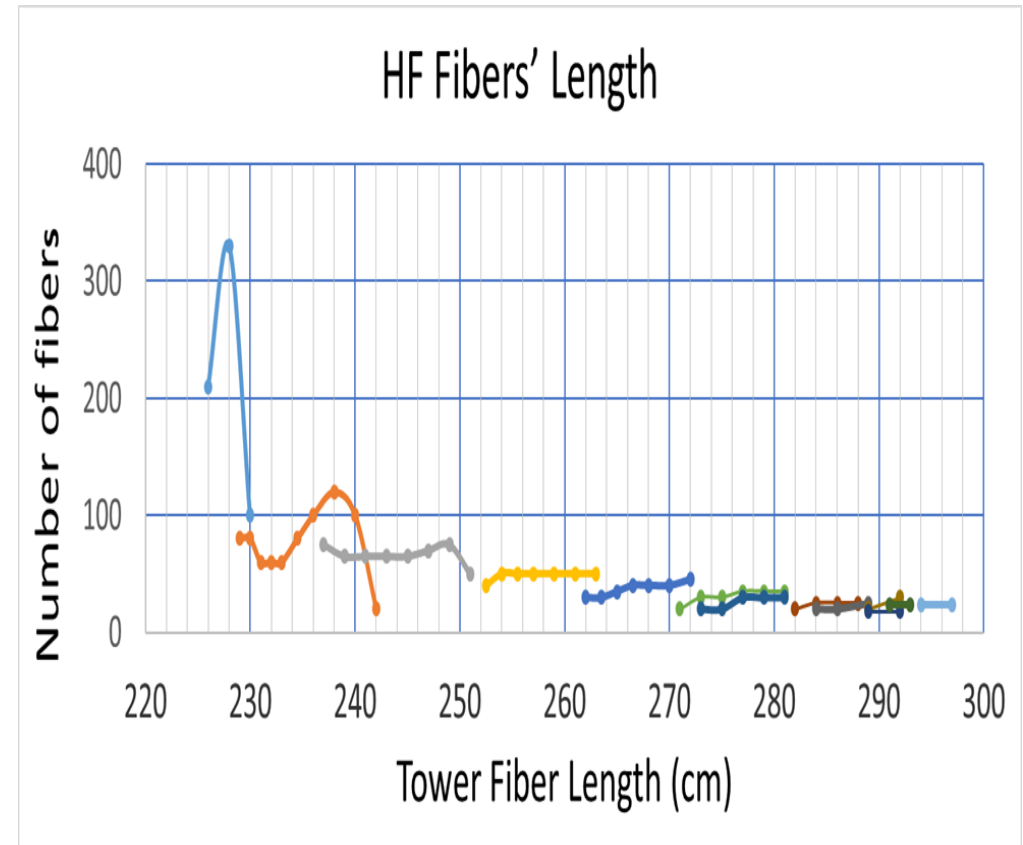
Time as measured by TDC vs anode charge in a given HF channel (ieta=40, iphi=47, depth=1). The contribution with low time values of  $<5$  ns originate from particles directly hitting the PMT. Hits from collision particles populate timing values of around 8 ns

# Beware of afterpulses... ... and fiber length differences!

Afterpulses in R7525 and R7600 PMTs



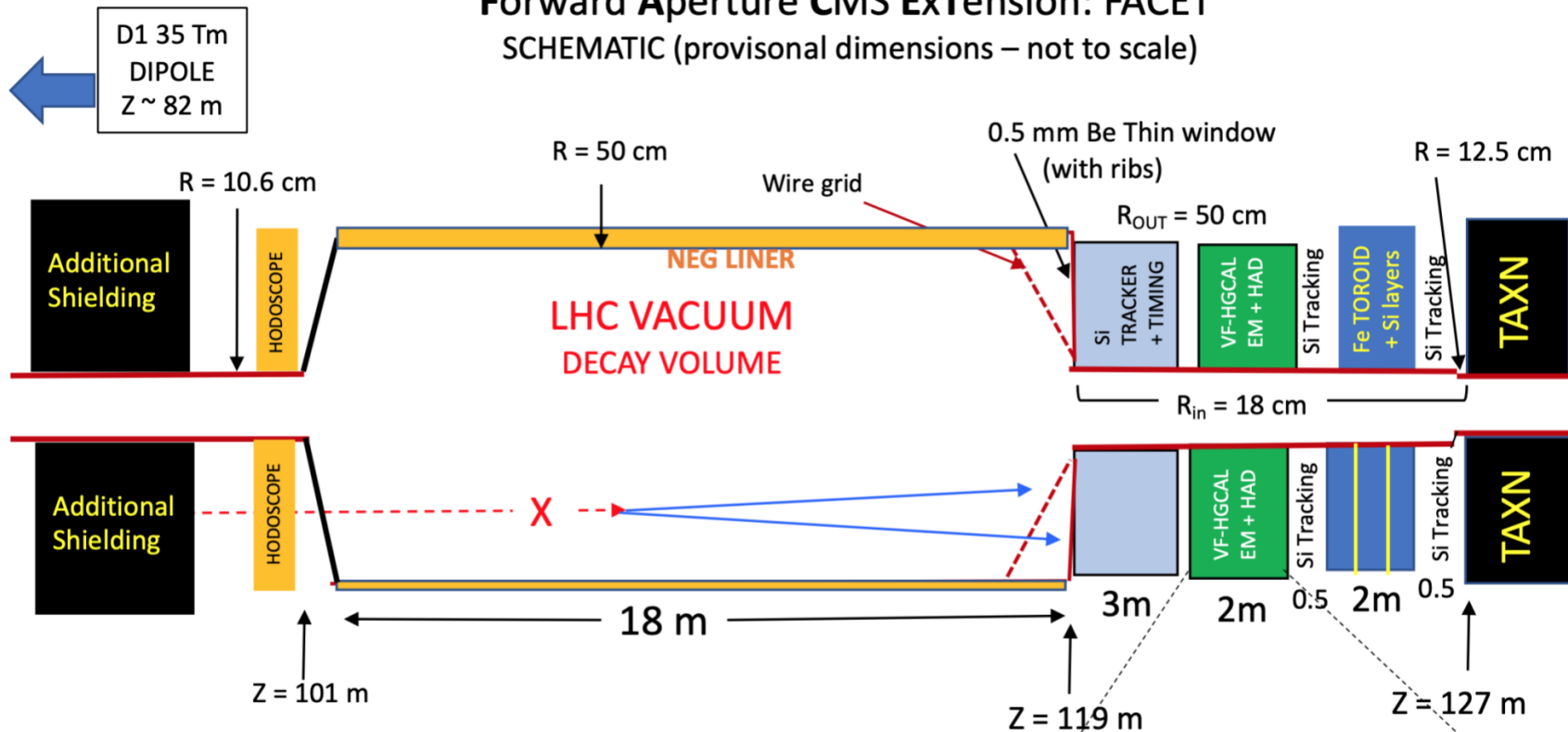
R7525 (magenta) : bands of afterpulses;  
R7600 (blue) : no special pattern....



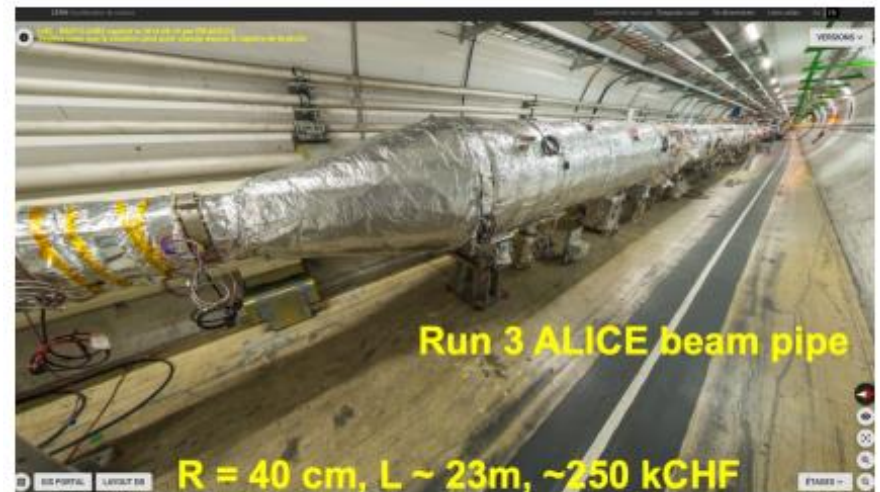
Can be corrected tower-to-tower,  
but not inside one tower!



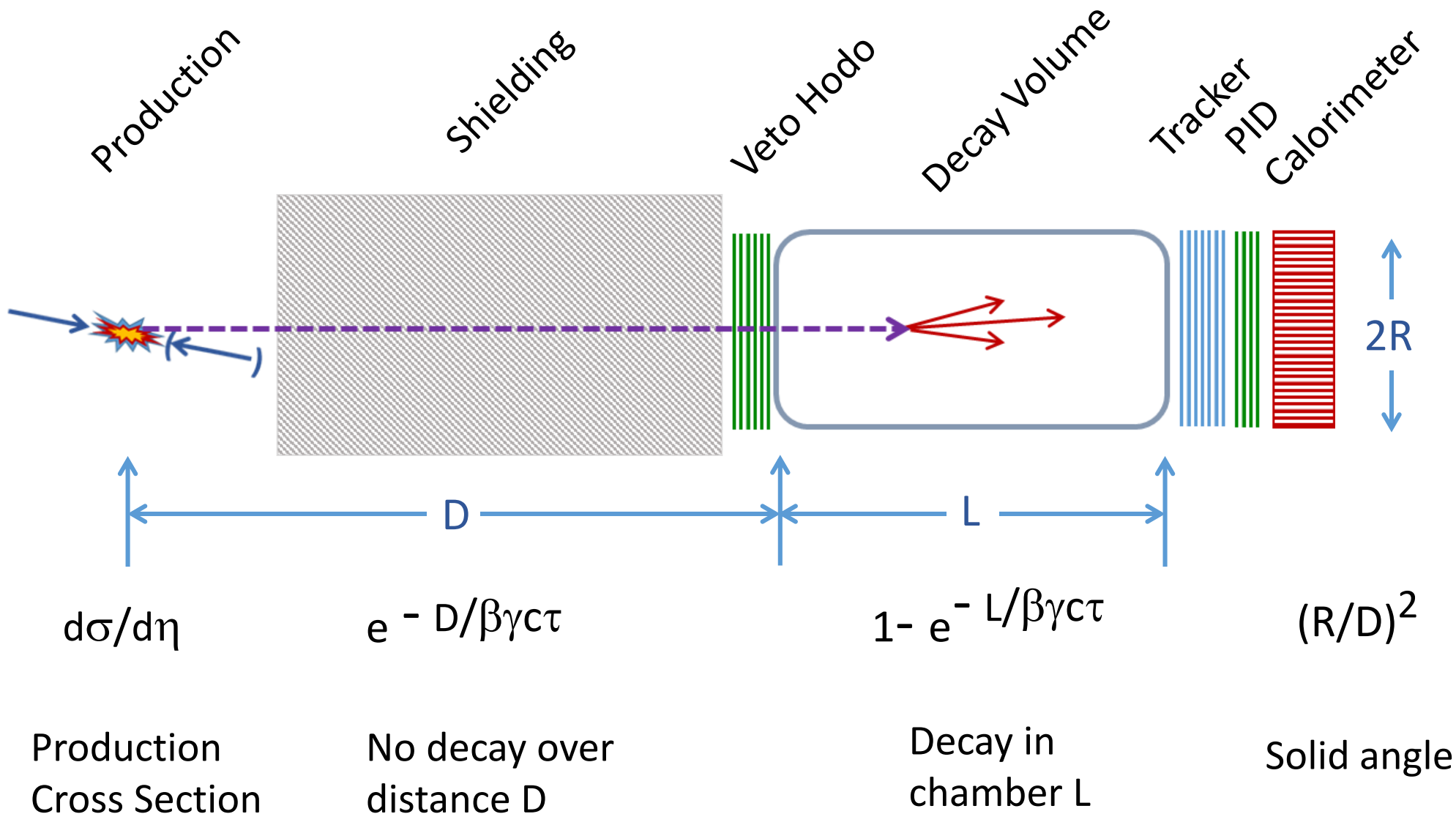
# Forward Aperture CMS ExTension: FACET SCHEMATIC (provisonal dimensions – not to scale)



Large decay volume (radius 50 cm, length = 18 m) in an expanded section of LHC beampipe

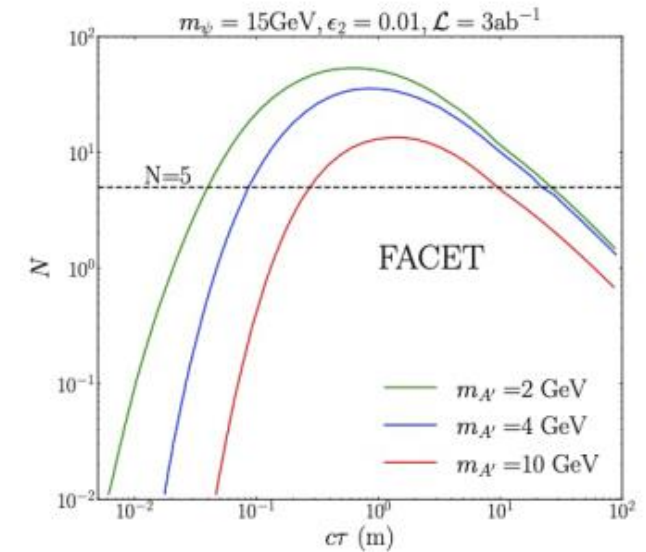
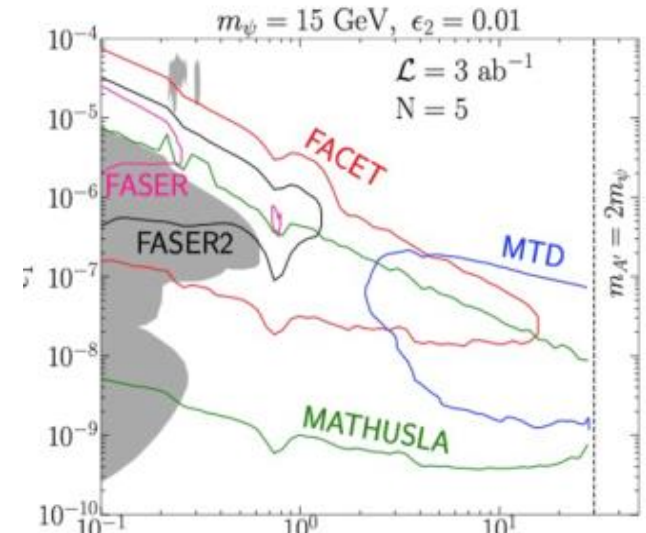
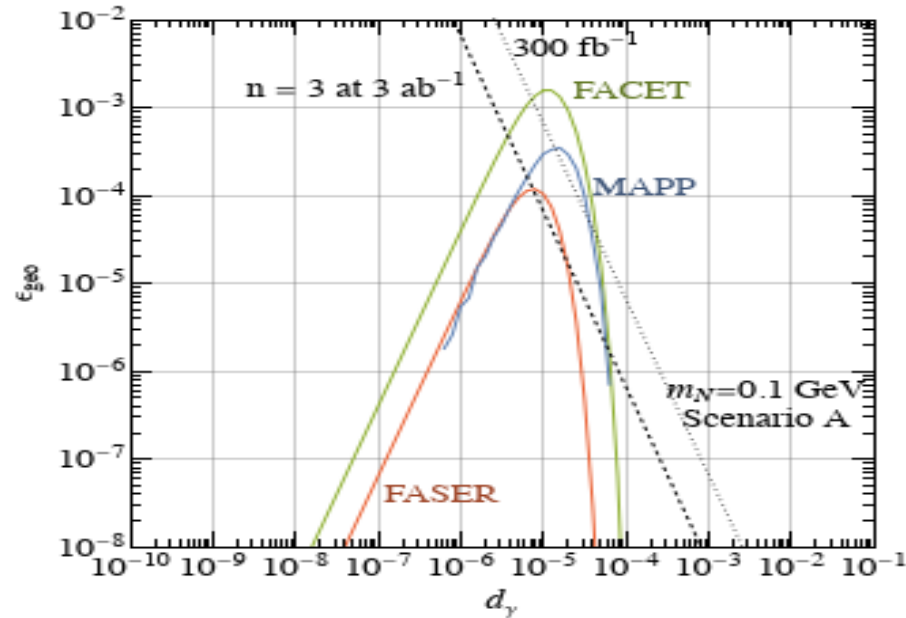


# Figure- of- Merit for LLP search projects



# Some studies of channels accessible to FACET

Dark photon production model via dark fermion bremsstrahlung (arXiv:2111.15503, M. Du et al)  
 FACET has good reach and nice complementarity with CMS Phase-2 MIP Timing Detector(MTD)



Wei Liu, Yu Zhang; aXiv:2302.02081v3 [hep-ph]  
 13 Apr 2023: production of heavy neutral leptons.

Backup



# FACET: A new long-lived particle detector in the very forward region of the CMS experiment

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S. Cerci,<sup>a,1</sup> D. Sunar Cerci,<sup>a,1</sup> D. Lazic,<sup>b</sup> G. Landsberg,<sup>c,2</sup> F. Cerutti,<sup>d</sup>  
M. Sabaté-Gilarte,<sup>d</sup> M.G. Albrow,<sup>c,2</sup> J. Berryhill,<sup>c</sup> D.R. Green,<sup>c</sup> J. Hirschauer,<sup>e</sup>  
S. Kulkarni,<sup>f</sup> J.E. Brücken,<sup>g</sup> L. Emediato,<sup>h</sup> A. Mestvirishvili,<sup>h</sup> J. Nachtman,<sup>h</sup>  
Y. Onel,<sup>h</sup> A. Penzo,<sup>h</sup> O. Aydılek,<sup>i</sup> B. Hacıahinoglu,<sup>i</sup> S. Ozkorucuklu,<sup>i,2</sup> H. Sert,<sup>i</sup>  
C. Simsek,<sup>i</sup> C. Zorbilmez,<sup>i</sup> I. Hos,<sup>j,1</sup> N. Hadley,<sup>k</sup> A. Skuja,<sup>k</sup> M. Du,<sup>l</sup> R. Fang,<sup>l</sup> Z. Liu,<sup>l</sup>  
B. Isildak<sup>m,1</sup> and V.Q. Tran<sup>n,o</sup>

<sup>a</sup>*Department of Physics, Adiyaman University, 02040, Adiyaman, Turkey*

<sup>b</sup>*Physics Department, Boston University, 590 Commonwealth Ave, Boston, MA 02215, U.S.A.*

<sup>c</sup>*Department of Physics, Brown University, 182 Hope St, Providence, RI 02912, U.S.A.*

<sup>d</sup>*CERN, 1211 Geneva 23, Switzerland*

<sup>e</sup>*Fermi National Accelerator Laboratory, PO Box 500, Batavia, IL 60510, U.S.A.*

<sup>f</sup>*Institute of Physics, NAWI Graz, University of Graz, Universitätsplatz 5, A-8010 Graz, Austria*

<sup>g</sup>*Helsinki Institute of Physics, University of Helsinki, Gustaf Hällströmin katu 2, 00560 Helsinki, Finland*

<sup>h</sup>*Department of Physics and Astronomy, University of Iowa, 203 Van Allen Hall, Iowa City, IA 52242, U.S.A.*

<sup>i</sup>*Physics Department, Istanbul University, Vezneciler Caddesi, 34134, Istanbul, Turkey*

<sup>j</sup>*Department of Engineering Sciences, Istanbul University-Cerrahpasa, 34320 Avcilar, Istanbul, Turkey*

<sup>k</sup>*Department of Physics, University of Maryland, College Park, MD 20742, U.S.A.*

<sup>l</sup>*Department of Physics, Nanjing University, Nanjing 210093, China*

<sup>m</sup>*Department of Natural and Mathematical Sciences, Ozyegin University, Orman Sk 13, 34794, Istanbul, Turkey*

<sup>n</sup>*Tsung Dao Lee Institute, Shanghai Jiao Tong University, Shanghai 200240, China*

<sup>o</sup>*Faculty of Fundamental Sciences, PHENIKAA University, Yen Nghia, Ha Dong, Hanoi 12116, Vietnam*

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<sup>1</sup>Also at the Istanbul University.

<sup>2</sup>Corresponding author.



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mainly KATOD

MCP PM UFK-5G-2D produced by KATOD (Thanks to D.Mpkrousov)

Quartz (fused silica) radiators : Specialty Glass Products; Russian  
company Alpha-TM ; Quartz fibers produced by MOLEX- Polymicro (

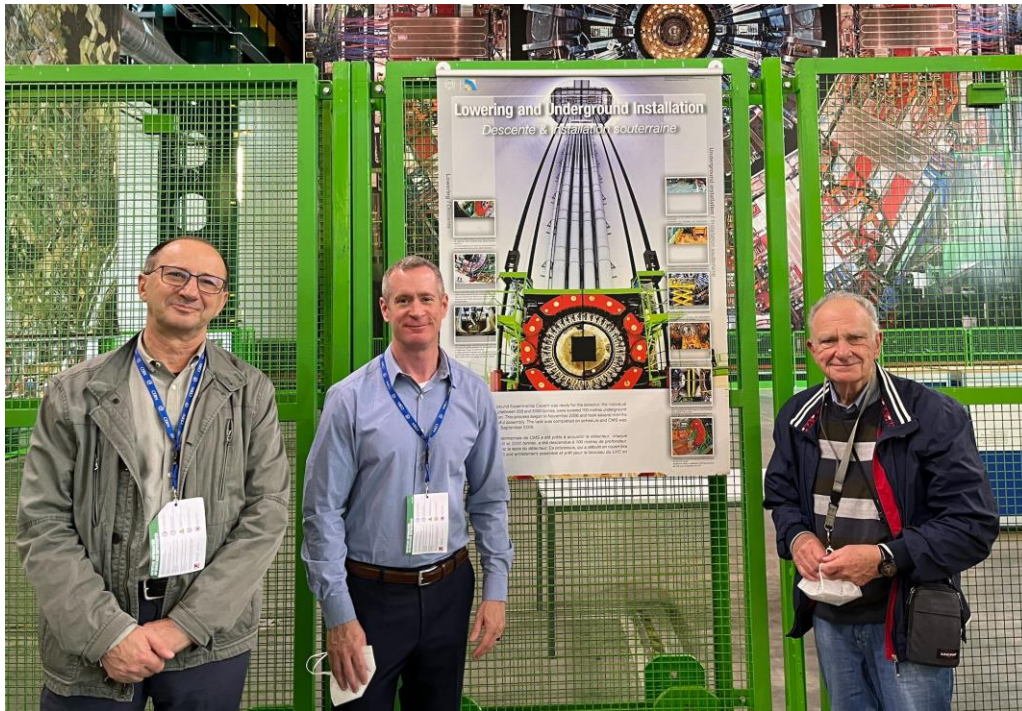
Thanks : Teo.Tichindelean and Kevin O' Connor

[1] J. Vavra et al., Beam test of a time-of-flight detector prototype, NIM-PR 299 A 606 (2009) 404

[2] M. G. Albrow et al., Quartz Cherenkov Counters for Fast Timing: QUARTIC, JINST 7 (2012) P10027

[3] K. Inami et al, A 5-ps TOF-counter with an MCP-PMT, Nucl. Instrum. Meth. A560 (2006) 303–308.

[4]<http://katodnv.com>



Our strongest option is to base our development on Quartz fibers:

Radiation resistance

Precise timing

Flexibility of handling

High level production technology

Large margins for improvement:

Visit of MOLEX-Polymicro representatives to CERN (fall 2022)

- Hollow fibers,
- Capillaries,
- Photonic band-gap fibers

More news soon....