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AMBER

Apparatus for Meson and Baryon Experimental Research

High rate capable tracking beam line detectors

Bjoern Seitz
For the AMBER Collaboration

PAW'24 Physics at AMBER International Workshop
CERN, 20 March 2024

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Apparatus for Meson and Baryon Experimental Research

	Beam	***Target***	***Additional Hardware***
Proton radius measurement	***100 GeV muons***	***high pressure Hydrogen***	***active target TPC, tracking stations (SciFi, Silicon)***
Antiproton production cross section	***50 GeV - 280 GeV protons***	***LH_2, LHe***	***Liquid He target***
Drell-Yan measurements with pions	***190 GeV charged pions***	***Carbon, Tungsten***	
Drell-Yan measurements with Kaons	***~100 GeV charged Kaons***	***Carbon, Tungsten***	***vertex detectors, 'active absorber'***
Prompt photon measurements	***> 100 GeV charged Kaon/pion beams***	***LH_2, Nickel***	***hodoscopes***
K-induced spectroscopy	***50 GeV - 100 GeV charged Kaons***	***LH_2***	***recoil ToF, forward PID***

Phase 1 (approved)

Phase 2 (in preparation)

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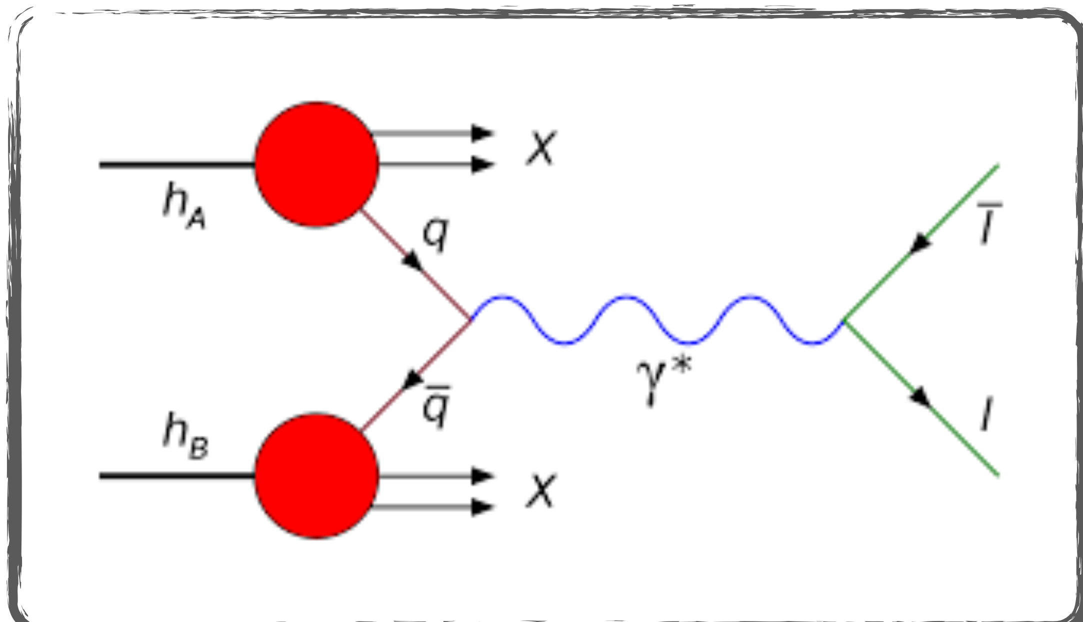

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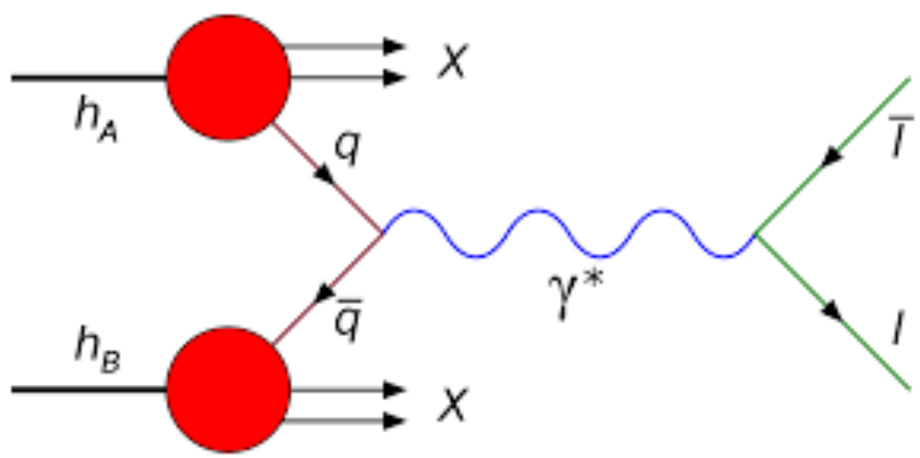

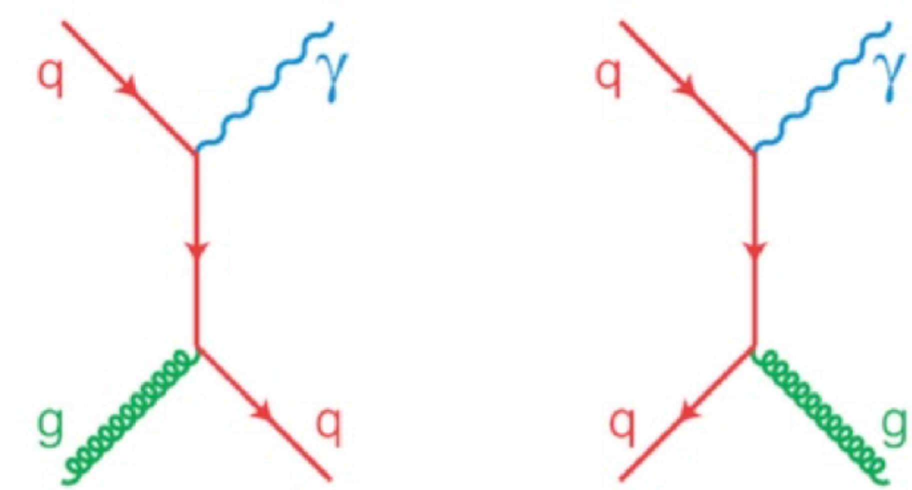

		Tar		
		hig Hy		
		LH		
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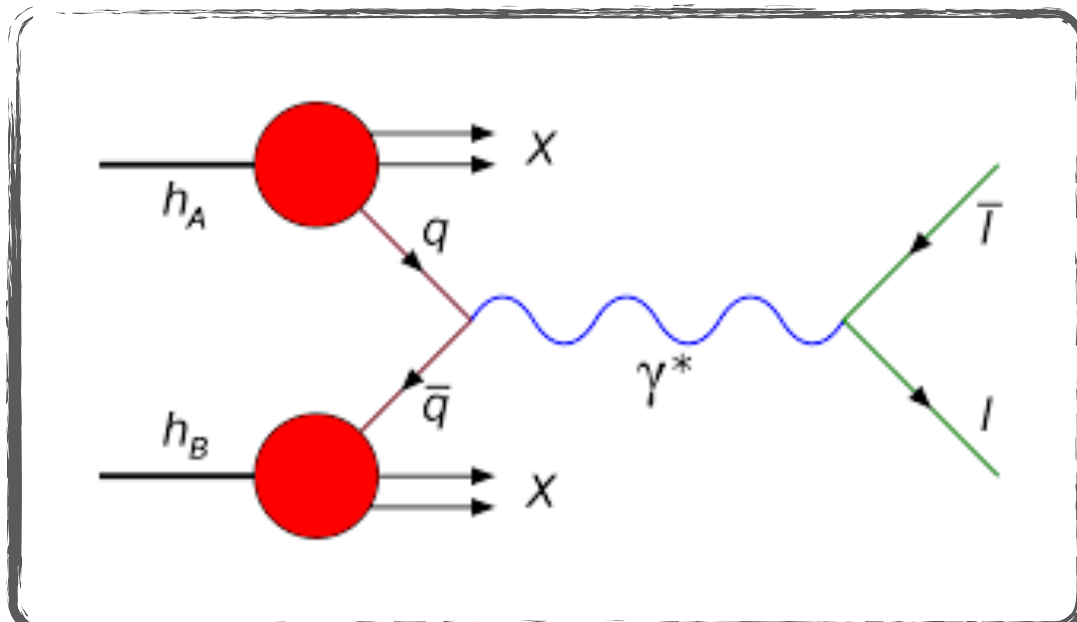

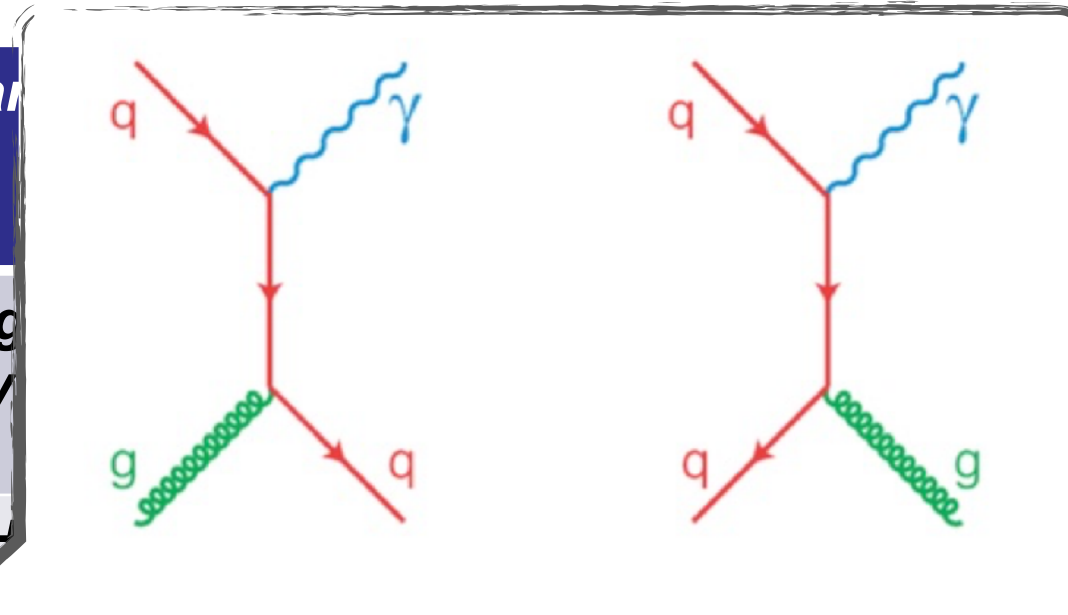

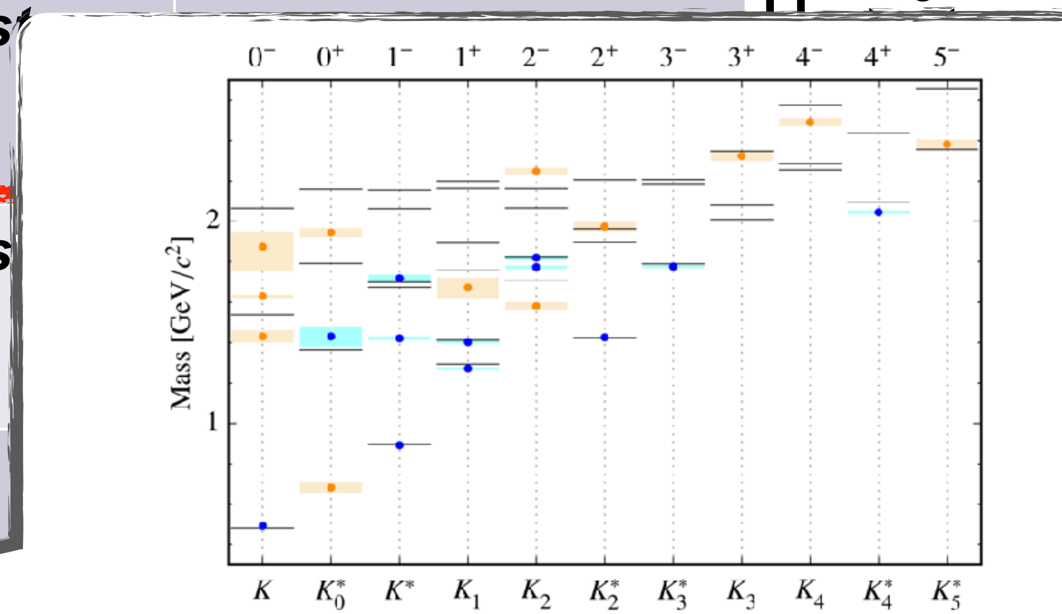

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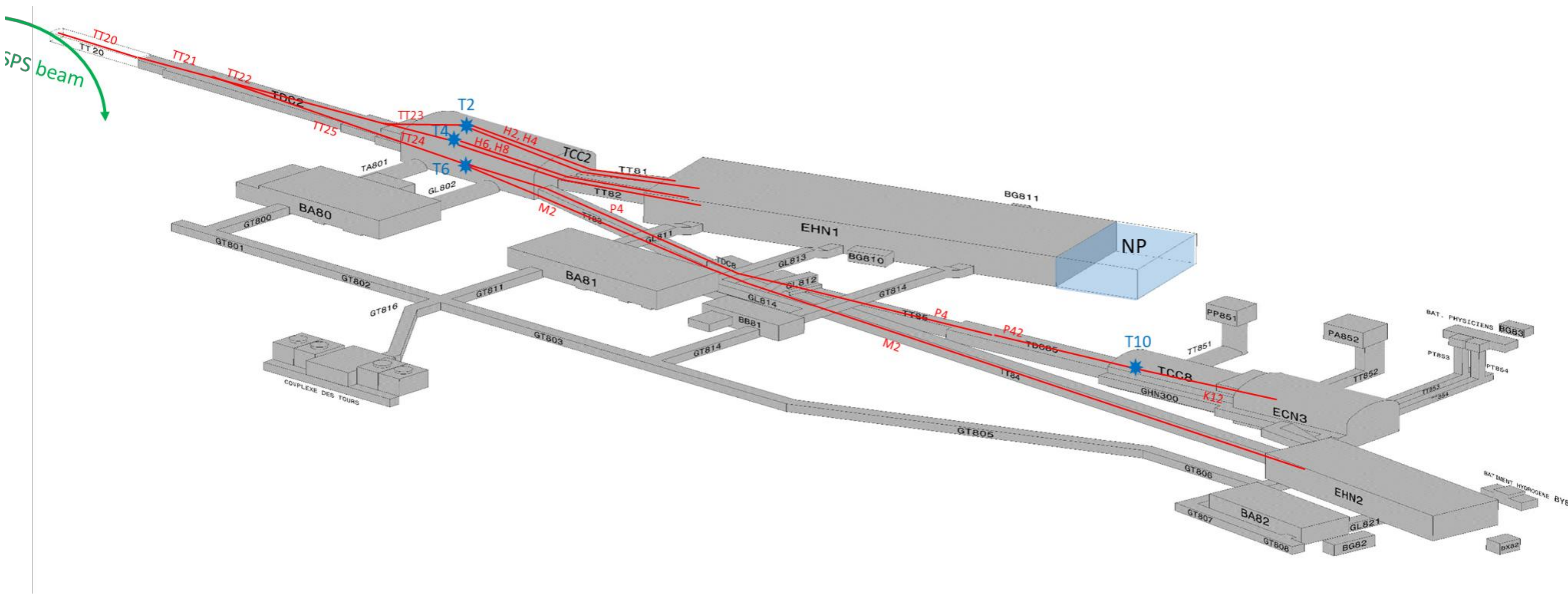
Phase 1 (in p approved)

Pha (in p

The wish: Kaon, Kaons, Kaons



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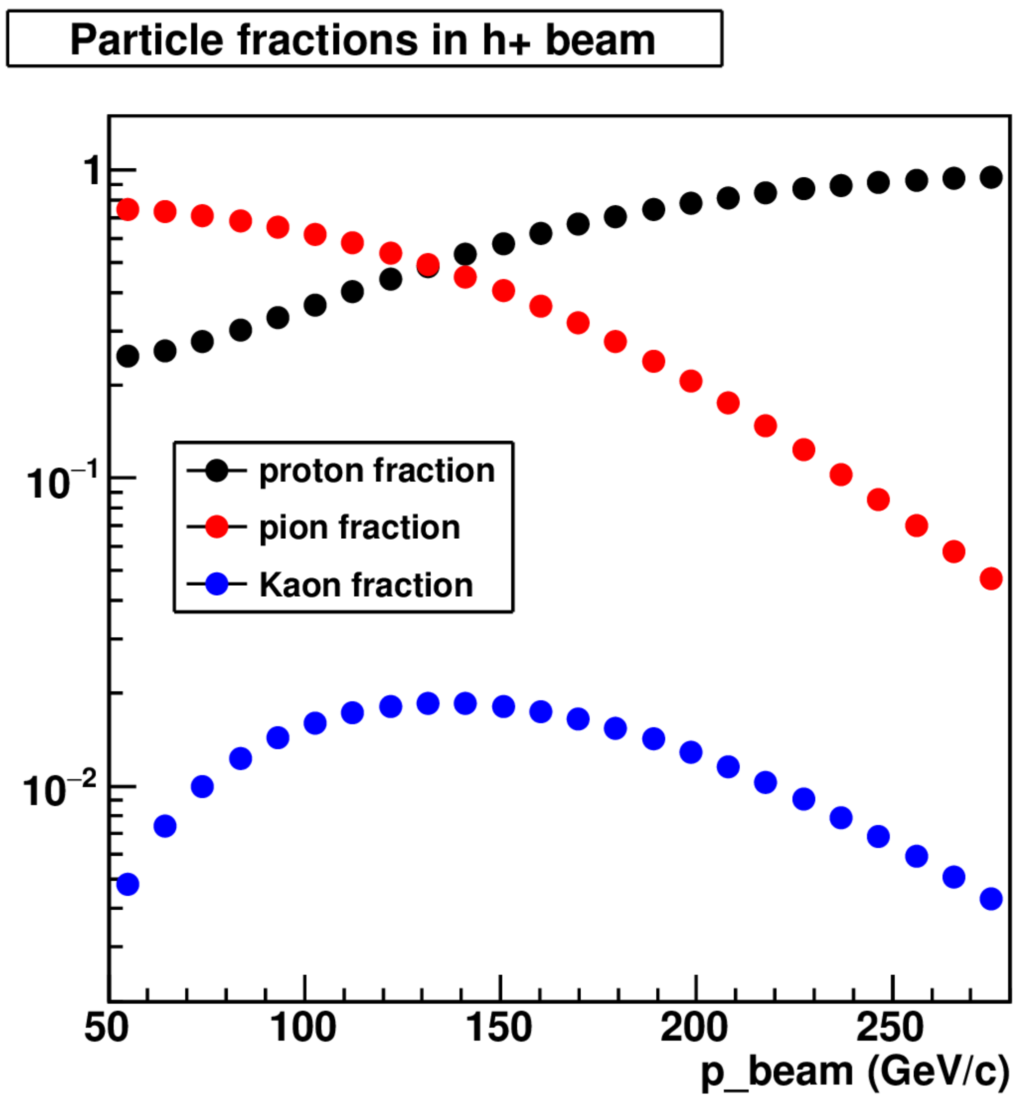
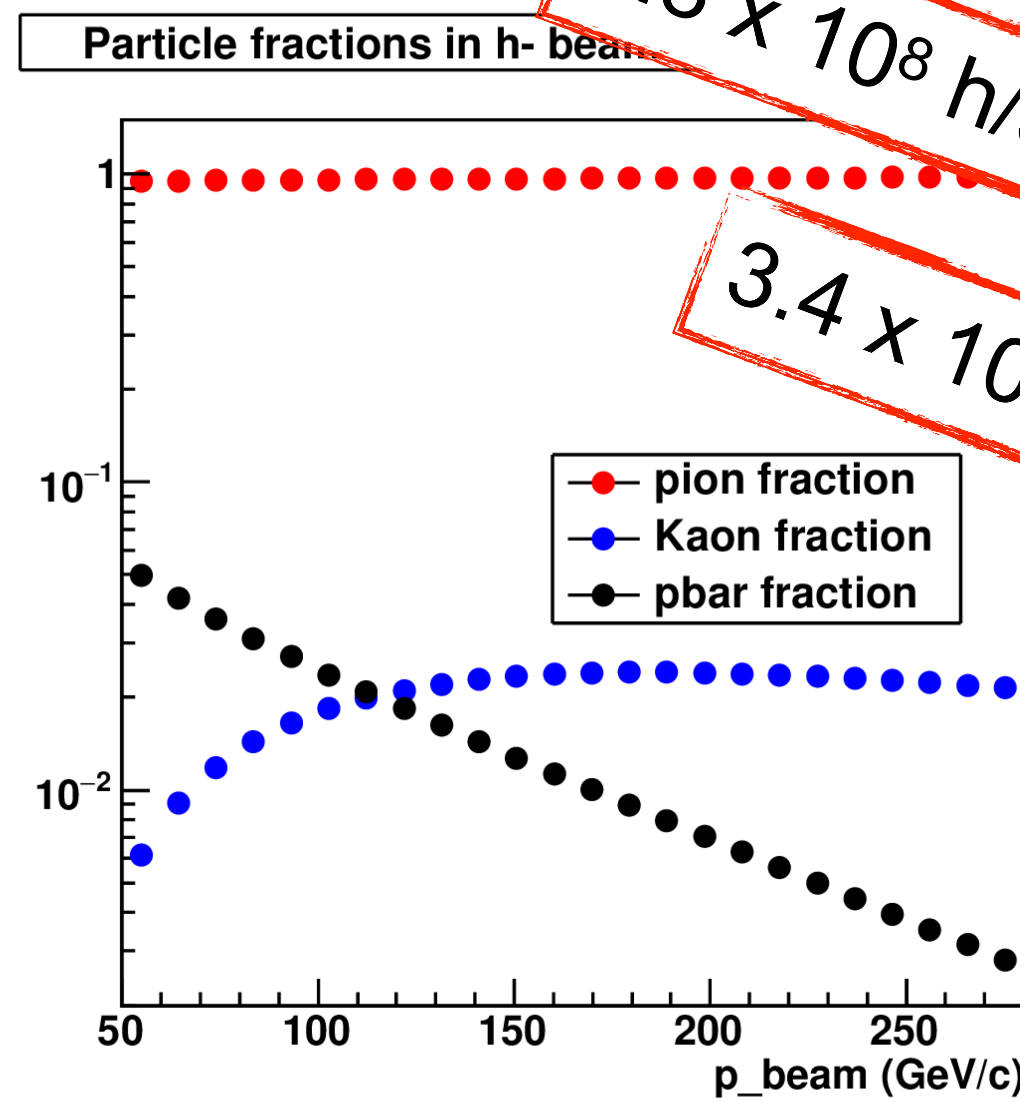
The wish: Kaon, Kaons, Kaons

4.8×10^{8} h/spill

3.4×10^{14} h/y





	π^+ fraction	K^+ fraction	p fraction	π^- fraction	K^- fraction	$\bar{p}$ fraction
p_{beam} = 160 GeV/c	0.3611	0.0175	0.6214	0.9650	0.0237	0.0113
p_{beam} = 190 GeV/c	0.2402	0.0142	0.7456	0.9680	0.0241	0.0079

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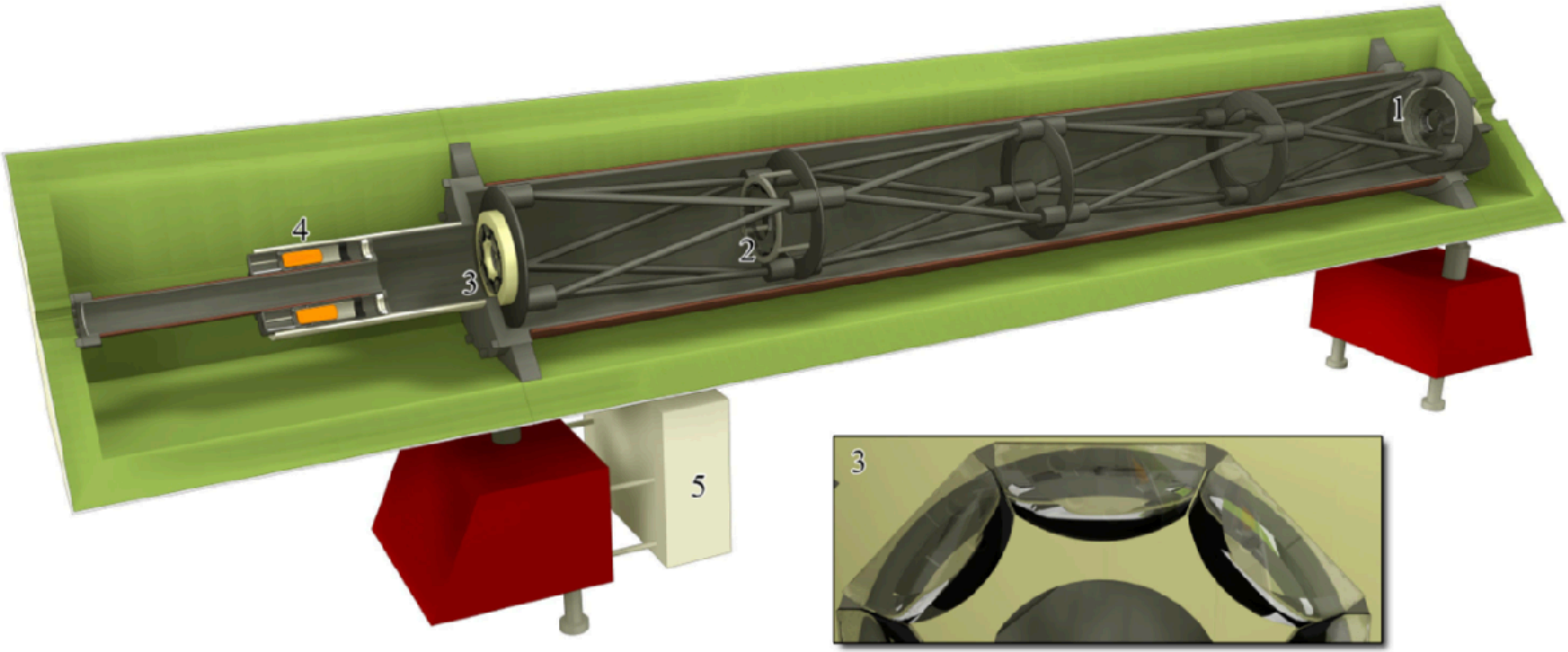
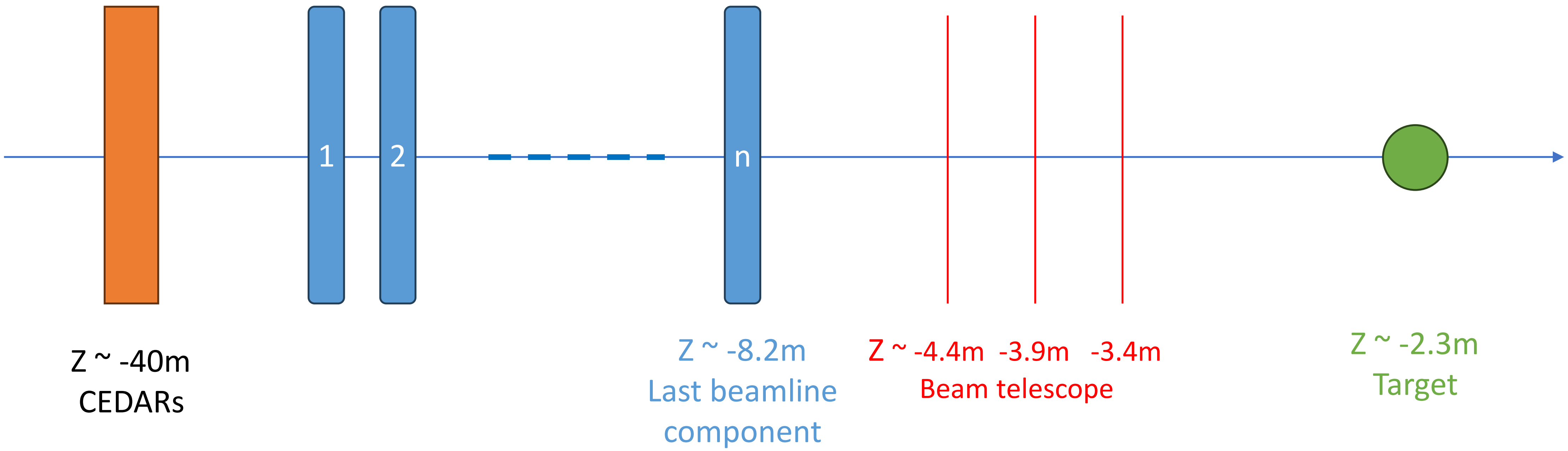
Beam particle identification: CEDARs



Differential Cherenkov counter provides π,K,p separation
Differences in Cherenkov angle are small

➜ Need parallel beam and excellent tracking

Beam line geometry and tracker position



COMPASS cold silicon: ~ 6 µm spatial resolution

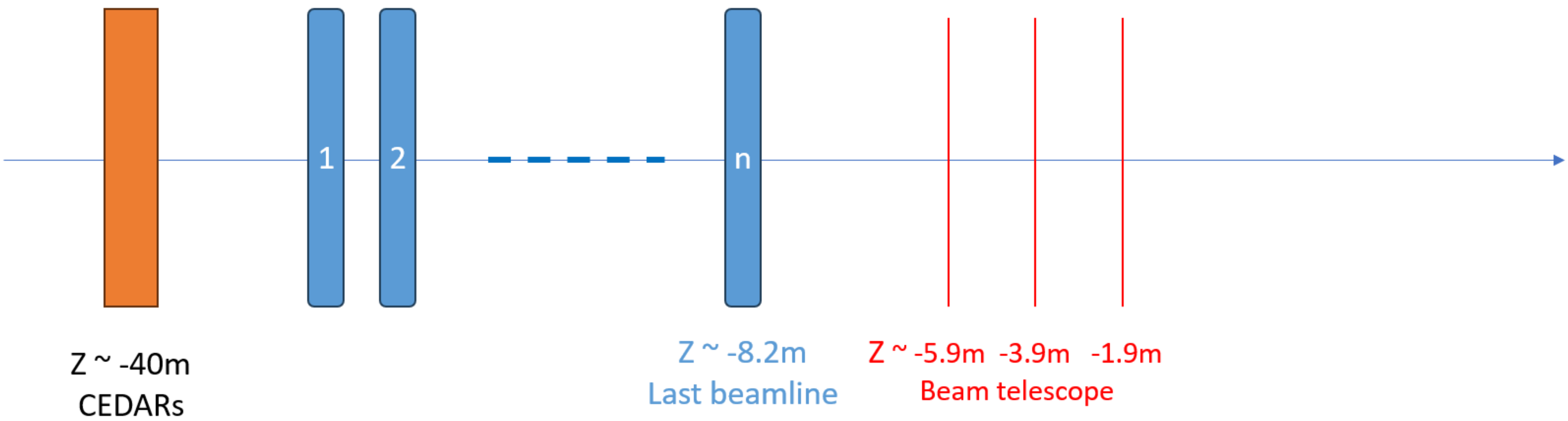
Covariance at CEDARS:

- $\sigma_x \sim 0.2\ mm$
- $\sigma_{tx} \sim 8\ \mu rad$
- $\sigma_y \sim 0.4\ mm$
- $\sigma_{ty} \sim 5\ \mu rad$

from AMBER simulation studies, Kun Liu

A new dawn

from AMBER simulation studies, Kun Liu



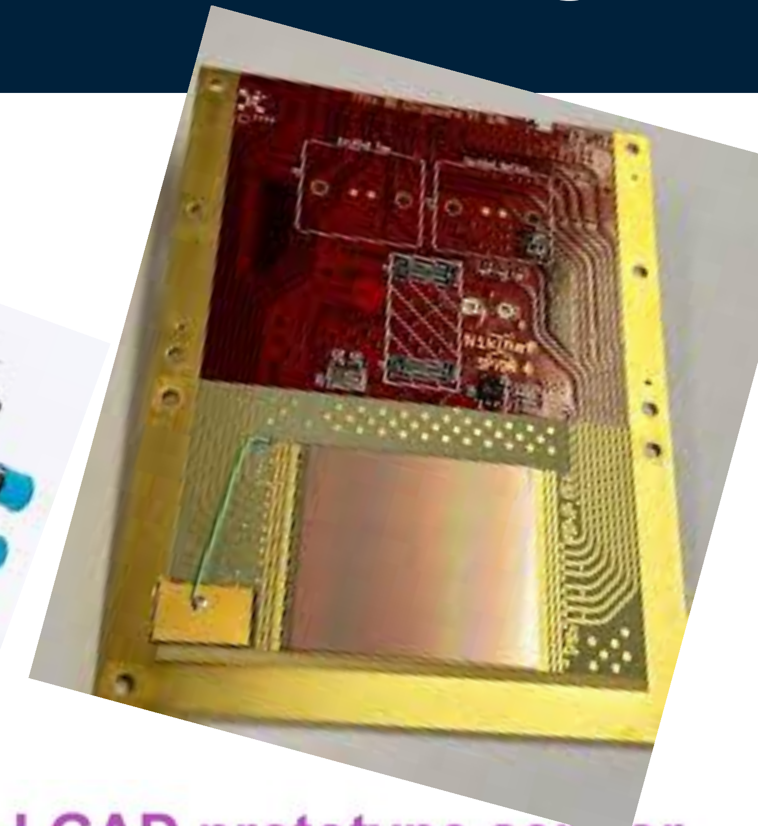
- Many new technologies have
  - 30 µm resolution
  - Much better timing
- 3 planes, 200 cm apart

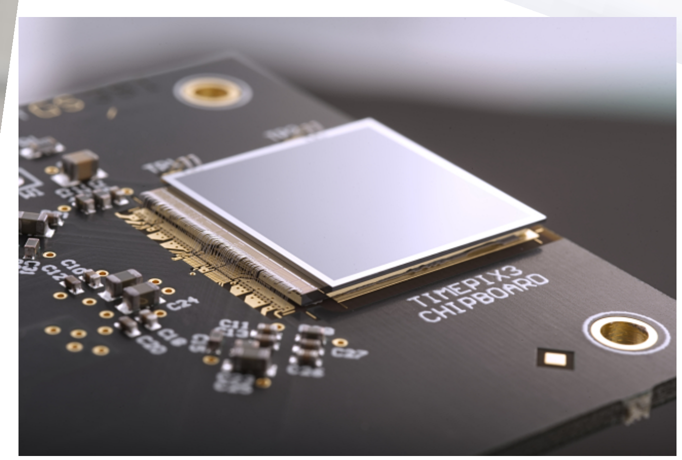
Old	New
$\sigma_x \sim 0.2\ mm$	$\sigma_x \sim 0.2\ mm$
$\sigma_{tx} \sim 8\ \mu rad$	$\sigma_{tx} \sim 9\ \mu rad$
$\sigma_y \sim 0.4\ mm$	$\sigma_y \sim 0.4\ mm$
$\sigma_{ty} \sim 5\ \mu rad$	$\sigma_{ty} \sim 6\ \mu rad$

➜ New position, similar performance, higher rates

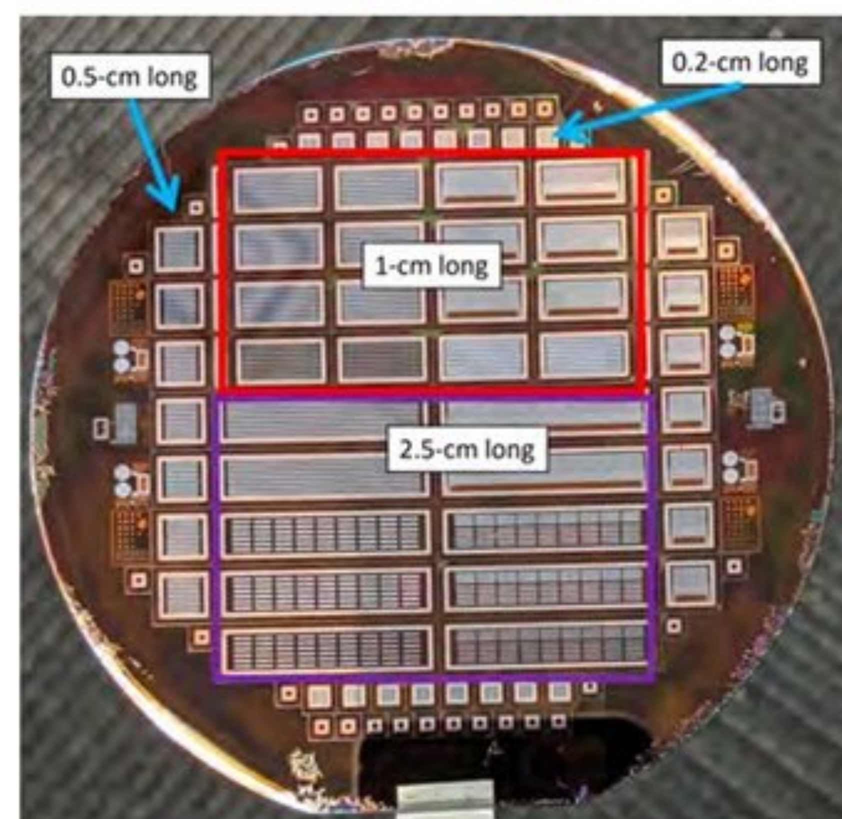
Requirements and candidate technologies

Physics case:
- 30 µm position resolution
- < 200 ps time resolution
- > 10 x 10 cm^2 active area





AC-LGAD prototype sensor



Beam properties:
- Stable, Gaussian beam
- 4.8×10^8 particles/spill, 10^7 Kaons
- ~ 10 x 10 cm^2 cross section

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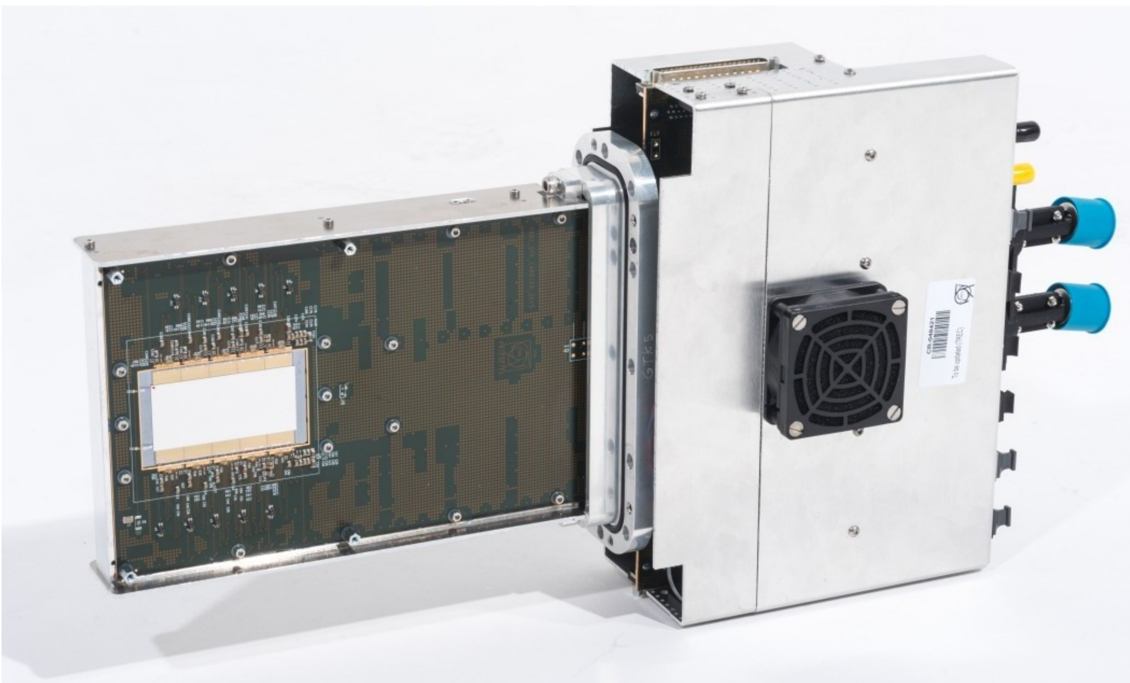
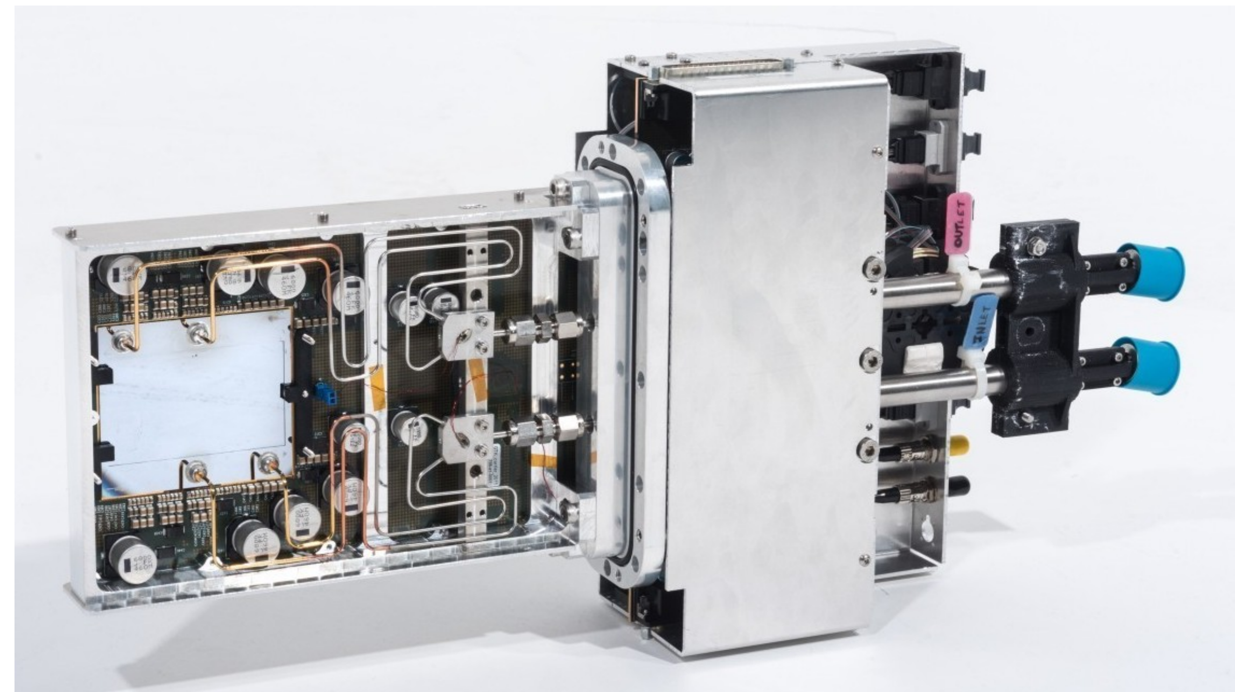
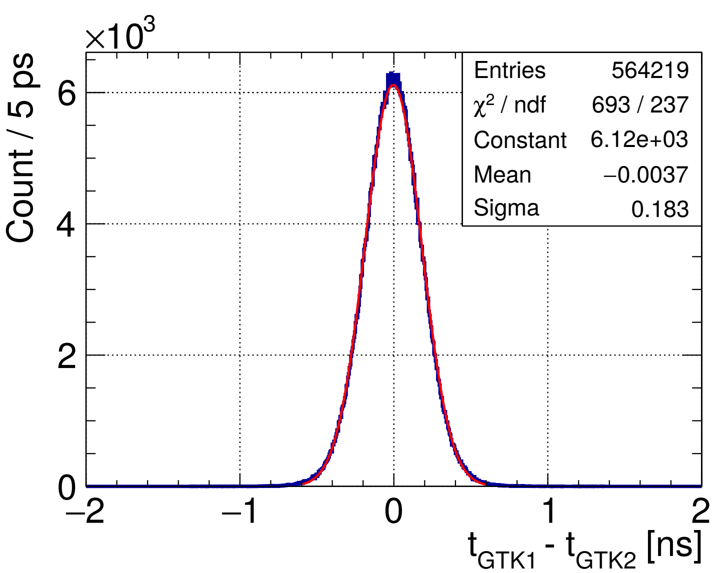
Nearest Neighbour: NA62 Gigatracker Modules







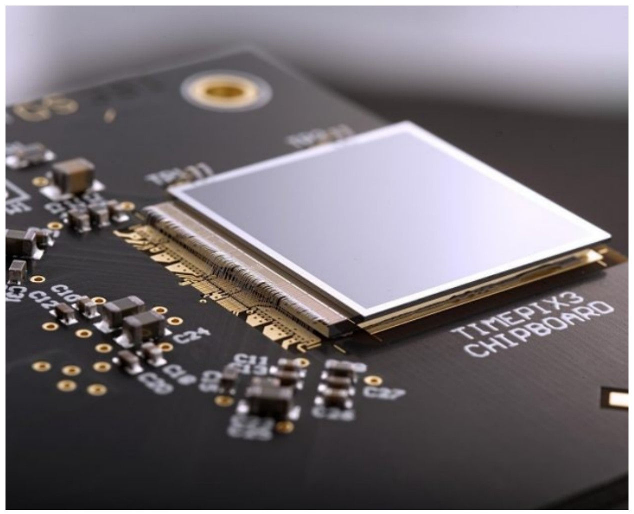
σ [ps]	
GTK1-3	181.3
GTK1-2	183.3
GTK2-3	184.7

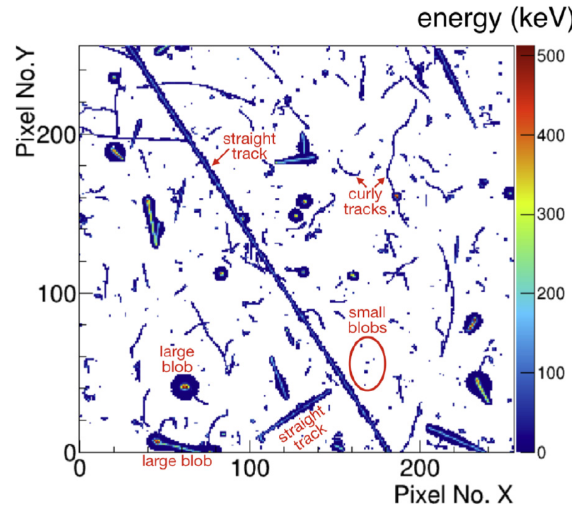
Resolution [ps]	
GTK1	132.0
GTK2	127.1
GTK3	129.2

- Similar role to AMBER needs
- Radiation hard
- Reasonable material budget (0.5%X_0)
- Good time resolution
- ~6x3cm^2

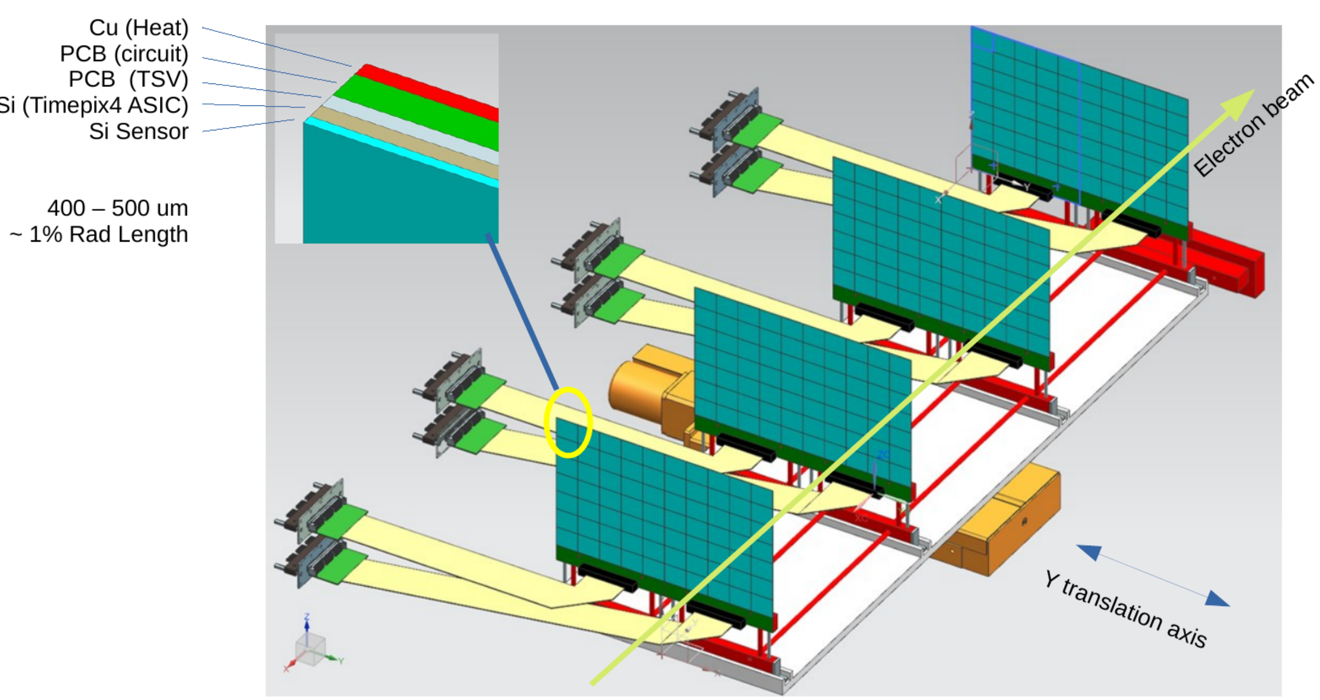
from: G. Aglieri Rinella, arXiv 1904.12837v3

Looking at EIC: Low Q^2 Tagger





	Requirement	Timepix4	AC-LGAD
Readout	—	SPIDR4	EICROC
Pixel Size (μm)	50 × 50	55 × 55	500 × 500
Sensor thickness (μm)	—	100	50
Detector size (pixels)	—	512 × 448	64 × 64
Detector area (cm^2)	—	6.94	10.24
Layer Area (cm^2)	100	83 (3x4 Timepix4)	92 (3x3)
Power consumption (W/cm^2)	As low as possible	1.0	0.4
Timing resolution (ns)	< 12	0.2	0.03
Minimum threshold (fC)	—	1.2	2.0
Individual pixel thresholds	—	Yes	Yes
Pixel hits in MIPS cluster	—	3	30

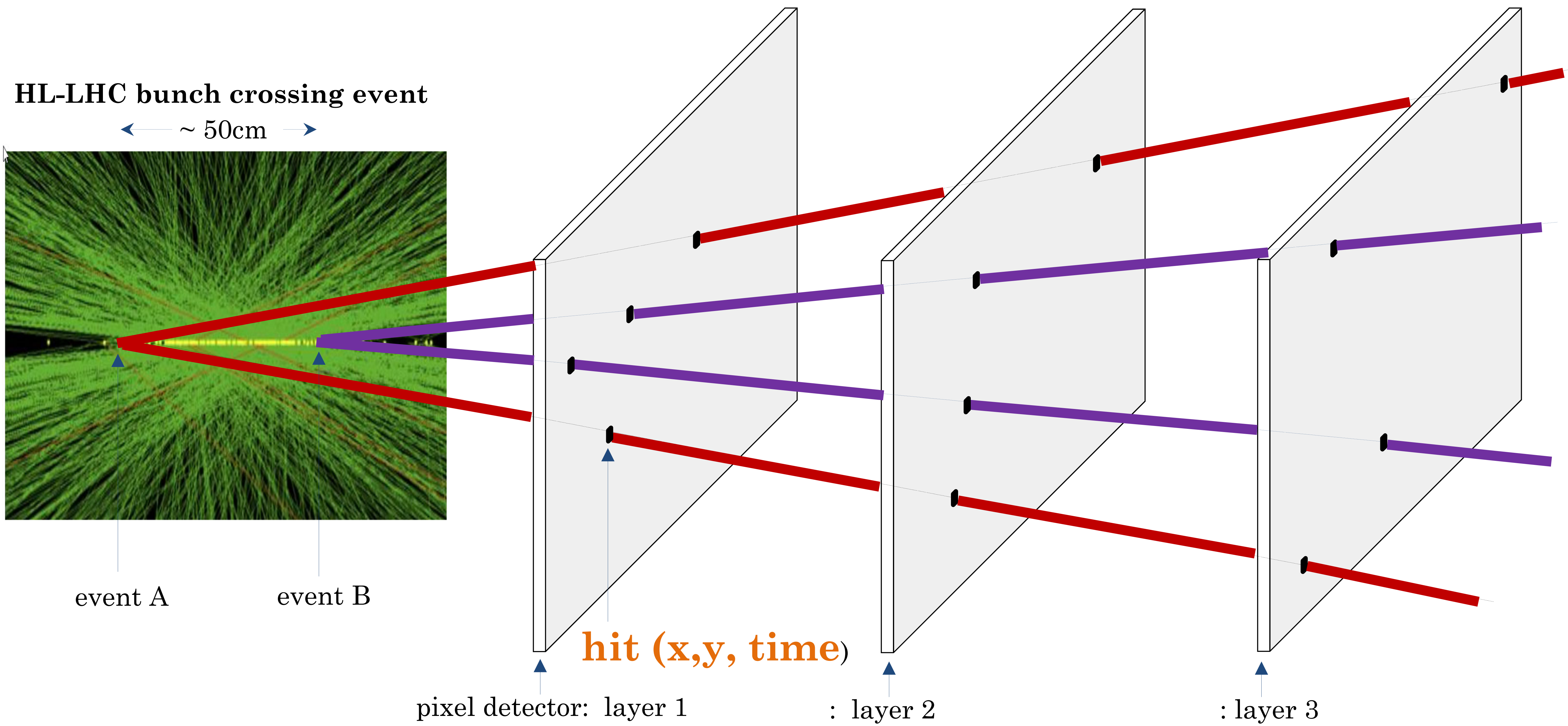


			Timepix3 (2013)	Timepix4 (2019)
Technology			130nm – 8 metal	65nm – 10 metal
Pixel Size			55 x 55 µm	55 x 55 µm
Pixel arrangement			3-side buttable 256 x 256	4-side buttable 512 x 448 **3.5x**
Sensitive area			1.98 cm²	6.94 cm²
Readout Modes	Data driven (Tracking)	Mode	TOT and TOA	
		Event Packet	48-bit	64-bit **33%**
		Max rate	0.43x10⁶ hits/mm²/s	**3.58x10⁶ hits/mm²/s**
		Max Pix rate	1.3 KHz/pixel	**10.8 KHz/pixel** **8x**
	Frame based (Imaging)	Mode	PC (10-bit) and iTOT (14-bit)	CRW: PC (8 or 16-bit) **10x**
		Frame	Zero-suppressed (with pixel addr)	Full Frame (without pixel addr) **5x**
		Max count rate	~0.82 x 10⁹ hits/mm²/s	~5 x 10⁹ hits/mm²/s **8x**
TOT energy resolution			< 2KeV	< **1Kev**
Time resolution			1.56ns	**~200ps**
Readout bandwidth			≤5.12Gb (8x SLVS@640 Mbps)	**≤163.84 Gbps (16x @10.24 Gbps)**

From: S. Gardner et al., arXiv:2305.02079v2

Round The Ring: LHCb at HL

Tracks reconstruction in High-Luminosity environment



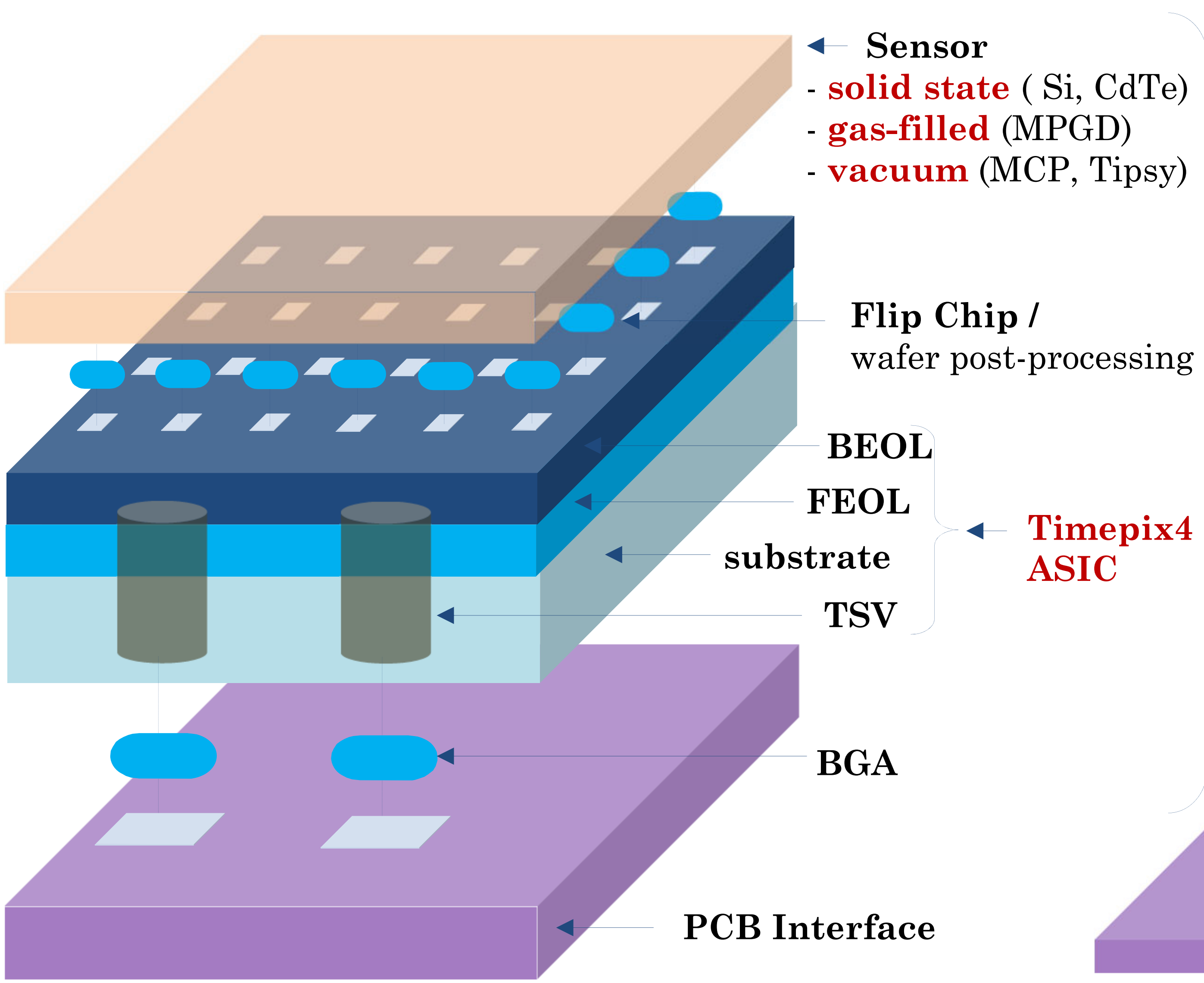
- hit time stamp gives an extra dimension in the track reconstraction
- a < 50ps time resolution is required for efficient 4D tracking in the HL-LHC environment
- the Timepix4 ASIC (195ps time of arrival bin size) will be used as a test vehicle

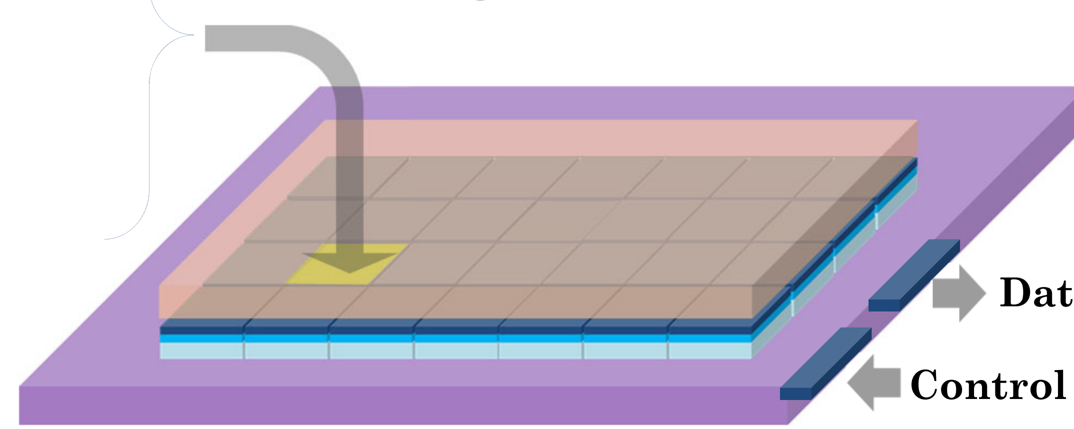
Round The Ring: LHCb at HL

From: V. Gromov (NIKHEF), DESY presentation 2020

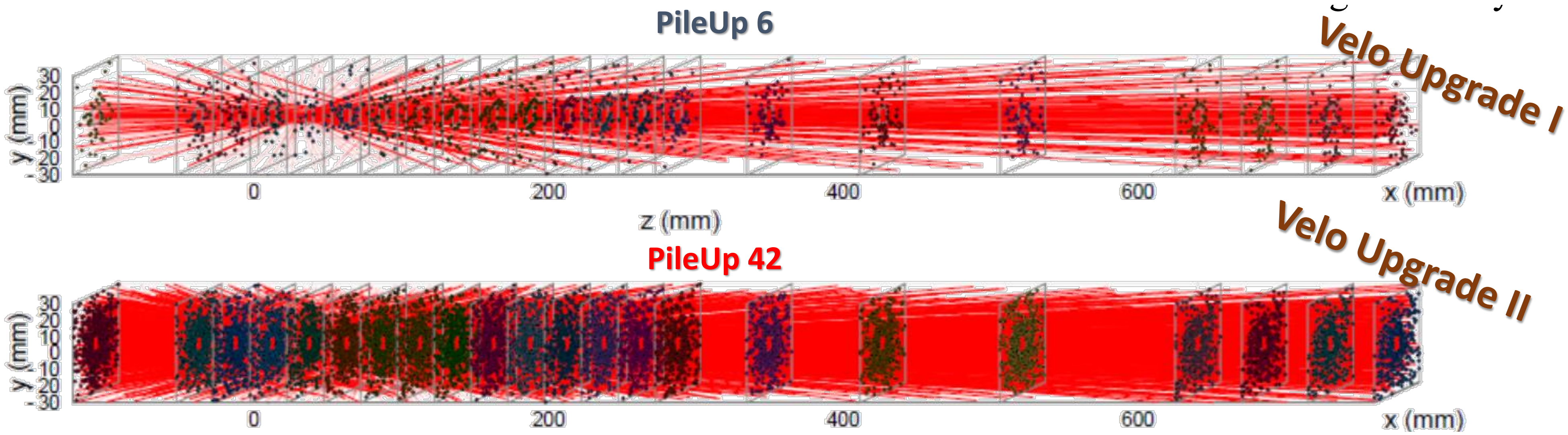
technology			TSMC 65nm - 10 metal
pixel size			55 x 55 μm
chip arrangement			**4-side buttable** 3x “hidden” periphery TSV I/O pixel matrix: 512 x 448
sensitive area			**6.94 cm²**
interface			3x 147 I/O TSV / Wirebond
Readout Modes	**Tracking** (data driven)	mode	**ToT & ToA**
		data	64-bit per hit
		max hit rate	$3.58x10^6$ hits/mm²/s (10.8 KHz / pixel)
	Imaging (frame-based)	Mode	**CRW: Pixel Counter** (8 /16-bit)
		frame rate	up to 89kFPS
		max hit rate	~ 5 x 10^9 hits/mm²/s
Energy resolution @ Si sensor			~ 1keV FWHM
ENC @ Cin = 75fF			$80e^-$ rms
minimum threshold			~ 500 e^-
hit arrival timing (ToA)			**LSB=195ps,** range: 1.638ms
charge measurement (ToT)			accuracy: $80e^-$ rms, range:$200ke^-$
data readout bandwidth			≤163.84 Gbps (16x @ **10.24 Gbps**)
Power Supply Voltage			1.2V
Power			~3.5W

Timepix4 ASIC-level Hybrid detector module



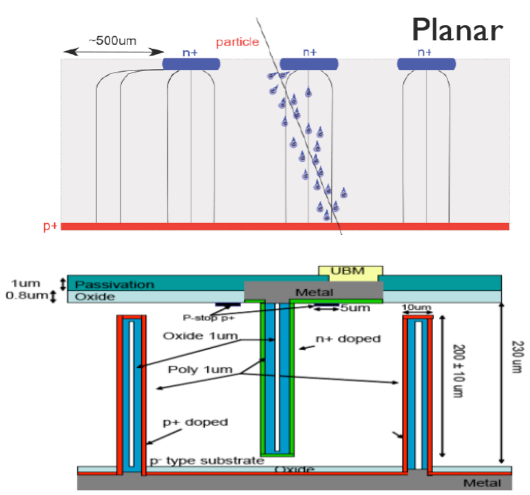


Piling up the pile-up



Need ~20 ps timing to cope with pile up

No charge amplification



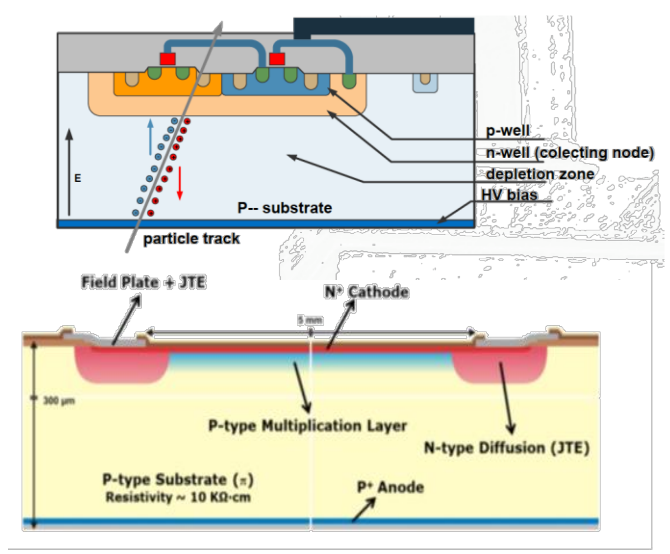
Low Gain Avalanche Diodes (LGAD)

- ✓ Signal amplification with intrinsic gain (double junction)
- ✓ High SNR and lower capacitance with 50 μm substrate
- ✓ Carbon and deep-implanted LGADs radiation hard up to ~ 3 – 4 × 10^{15} n_{eq}/cm^2
- ✓ Segmentation under investigation, Ti-LGADs & iLGADs

3D pixels

- ✓ Decoupled charge generation and drift volumes
- ✓ Proven radiation hardness at $\Phi < 10^{16}$ n_{eq}/cm^2
- ✓ Highly non-uniform field (+ gain, - jitter) with dead regions
- ✓ Higher capacitance and expensive process

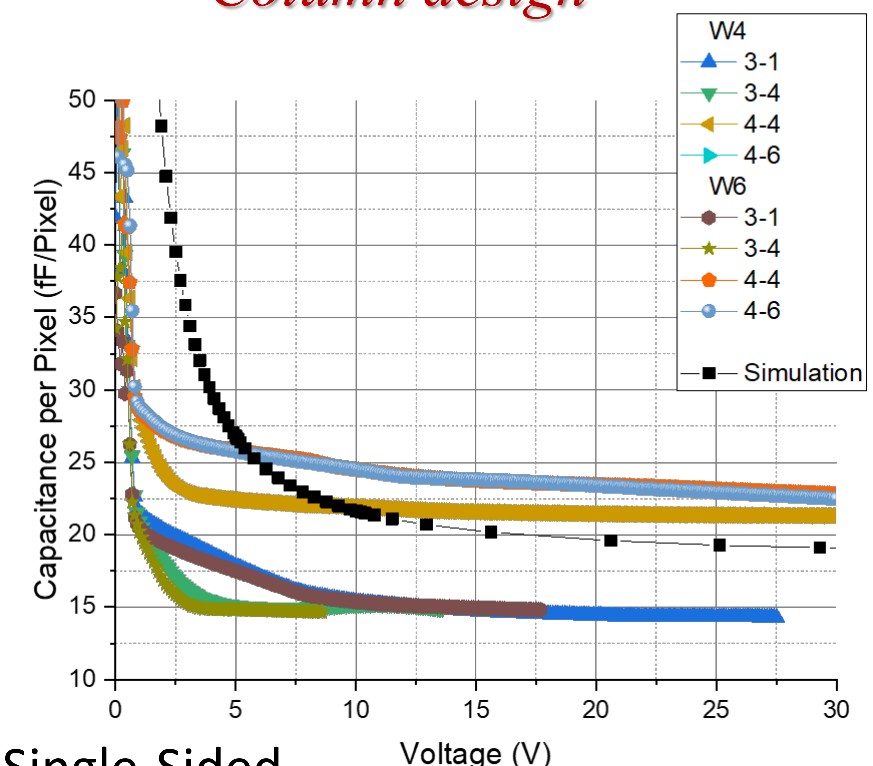
Charge amplification

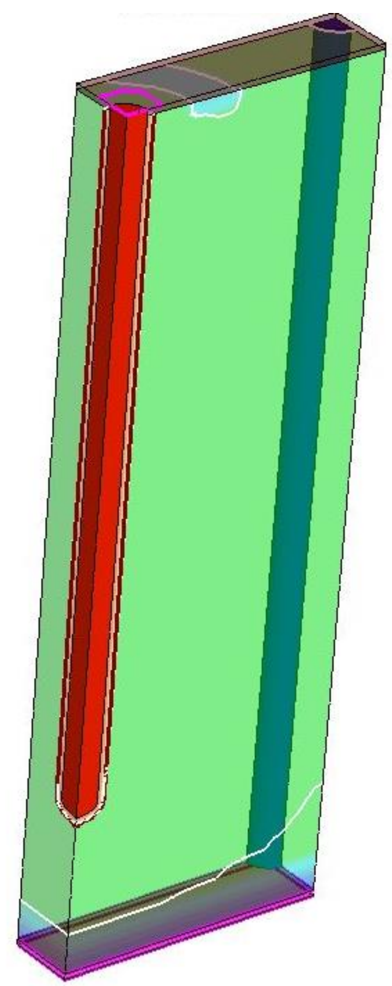


From E. Gkougkousi, Seminar Glasgow 2024

3D Pixel (Columns - Trenches)

Column design



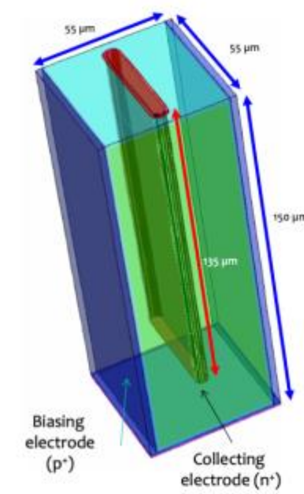


- Single-Sided
- 150µm active thickness
- 120µm deep n+ columns
- Column diameter: 8µm
- P-stop radius: 12.5µm
- ¼ column simulated → applied mirror symmetry (computational time savings)

Trench design (TimeSpot)

- ✓ More uniform field than standard 3D
- ✓ Lower distortion term in σ_{tot}
- ✓ Intransigently higher capacitance and larger inefficient regions due to tranches
- ✓ New process under development with very promising results
- ✓ Radiation studies to be performed, expecting similar results as for standard 3Ds

Presentation: TimeSpot



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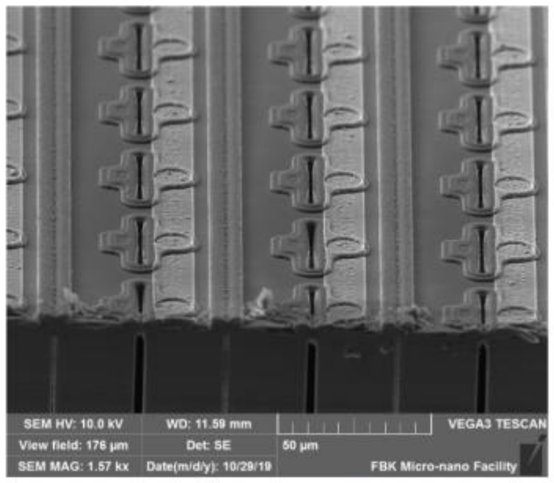
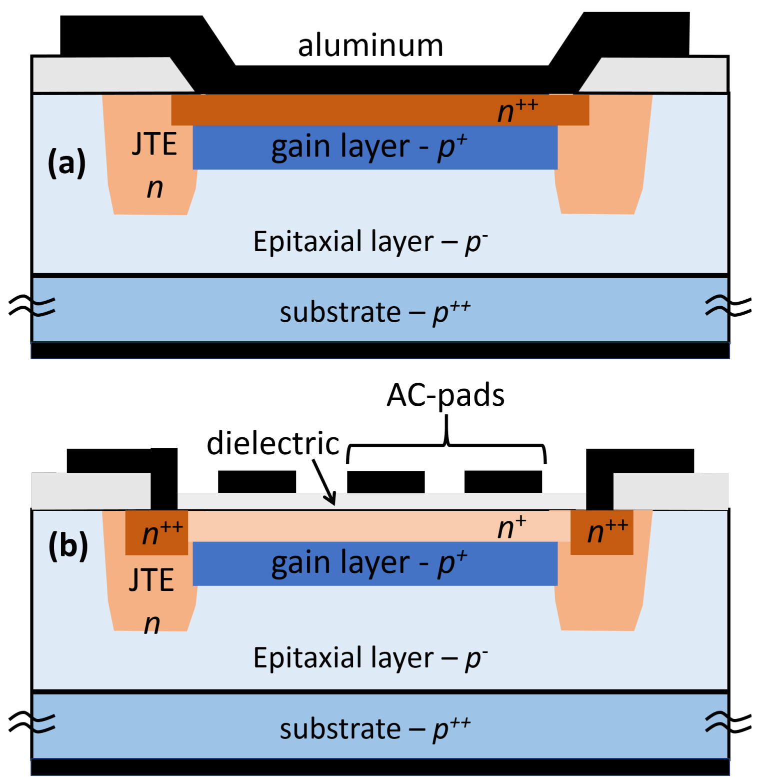


B

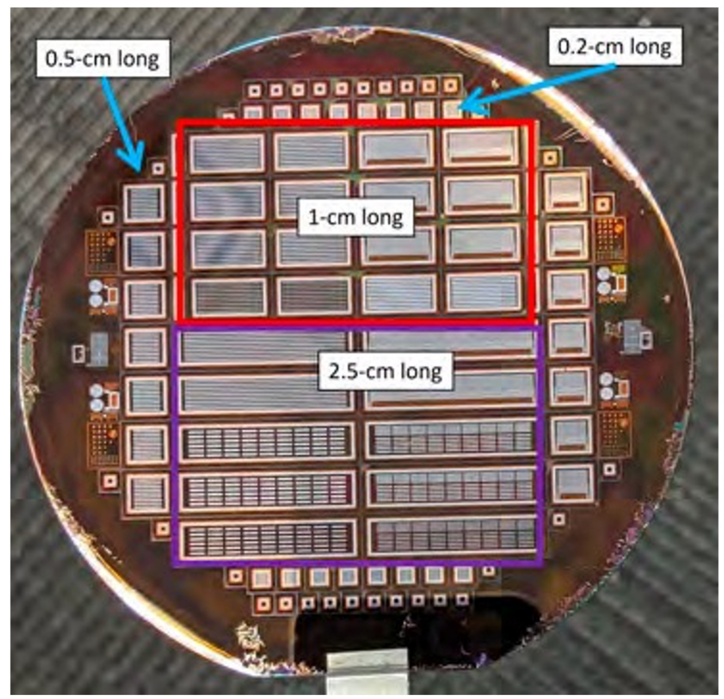
Faster then reference LGAD, < 40 ps

From E. Gkougkousi, Seminar Glasgow 2024

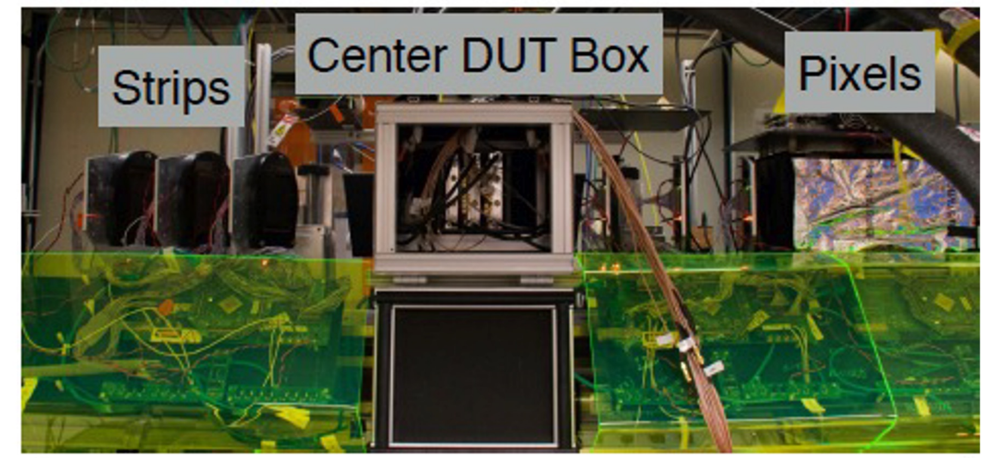
Looking at EIC: AC-LGAD for ePIC tracker

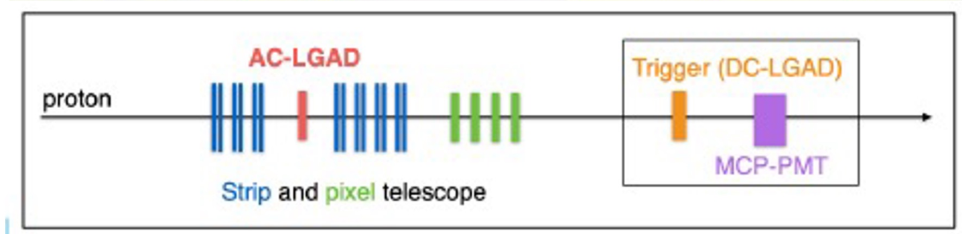


AC-LGAD prototype sensor



AC-LGAD FNAL beam test setup





- Developed for EIC ePIC tracking system by BNL and HPK
- 0.5x0.5mm² pixels and 0.5x1.0mm² strips tested at FNAL
- ~ 30 µm position resolution and ~ 30 ps time resolution
- Development ongoing, but construction expected in 2025

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Summary

- AMBER physics after LS3 needs intense $K^{\pm}$ beams
- Many physics cases need high beam momentum
- Can select momentum but not velocity ➜ mixed beam
- Need CEDAR to identify beam particle
- Need beam tracker to link to CEDAR ➜ new tracker
- High rate technologies require new position for sensor planes
- Several technology options exist to fulfil AMBER requirements

Missed out your favourite technology? Get in touch!