Preparation of LGAD test beam at Tohoku (plus some thoughts on electronics)

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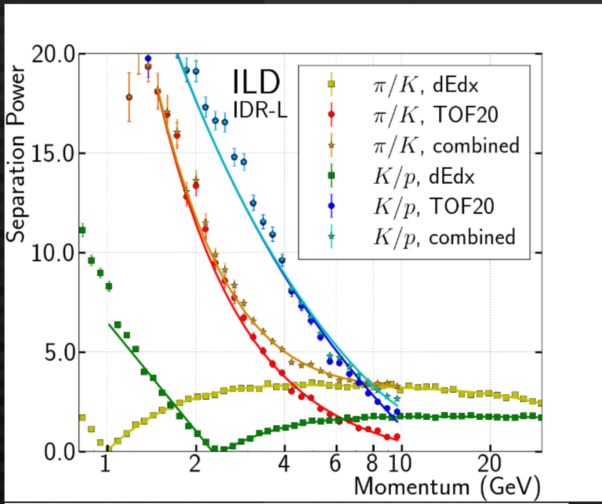
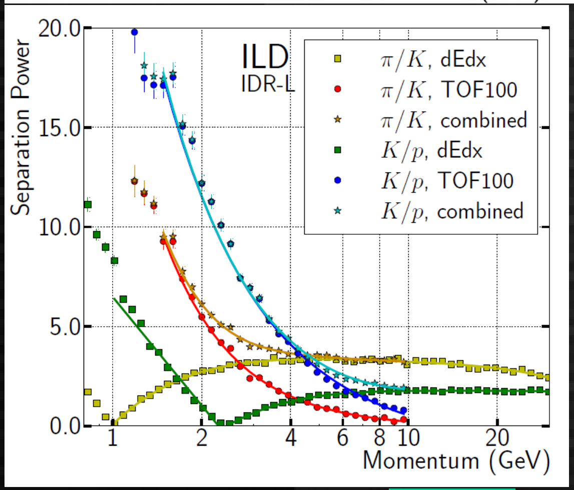
LGAD and timing resolution

- 5D calorimeter @ ILD
  - Many hits with 5D information (3D position + psec timing + Edep)
  - 5D PFA (with deep learning?)
    - Flight length different by charge/energy
  - More applications? (BSM search etc.)
- Particle ID (π, K, p)@ILD
  - dE/dx in TPC – powerful but not enough
  - ToF at calorimeters
    - Average over many hits
      - Pattern recognition of showers
    - ~10 ps resolution desired
      - 20-50 psec per hit

    → LGAD application



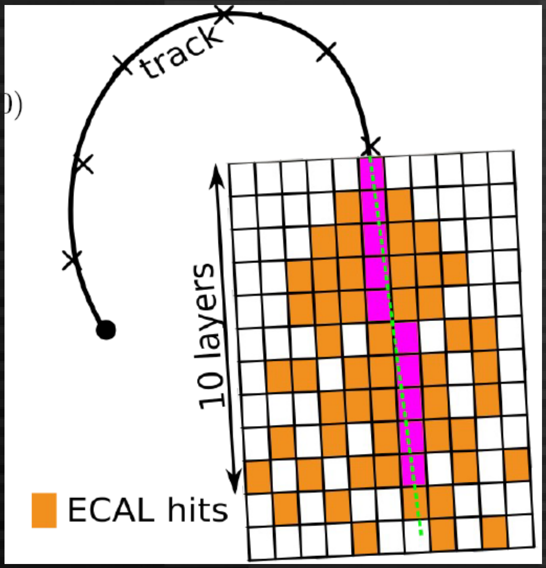


@2m

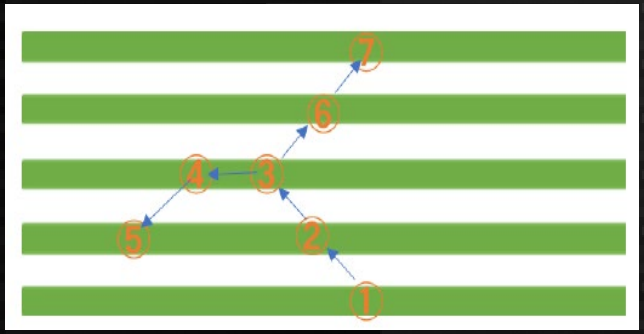
Energy	β (π)	β (K)	β (p)	Δt (π/K)	Δt (K/p)
5 GeV	0.9996	0.9951	0.9822	30 ps	88 ps
10 GeV	0.9999	0.9988	0.9956	7 ps	21 ps

Progress on timing reconstruction

- Advantage of ToF in Calo
  → Average over many hits
  (average over 100 hits → 10 x better)
- Precise "tracking" inside showers is necessary to use "all" hits
- We are working on correct "parent-daughter relation" of MC info inside calo
  - Need tuning on simulation → done
  - Reconstruction ongoing
- "Graph attention network" being investigated for reconstruction

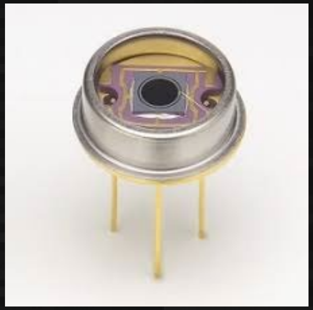


B. Dudar, LCWS21

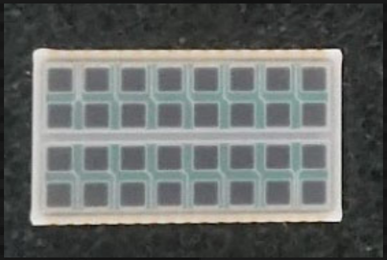


LGAD (APD) sensors

Spec no.	type	V_{BR}[V]	dimension [mm]
S8664	Inverse	400	3ϕ, 5ϕ, 5 x 5 mm
S5344/5345	Inverse	150	3ϕ, 5ϕ
S2384/2385	RS	150	3ϕ, 5ϕ
S6045	RS	200	3ϕ, 5ϕ
S8550-02	Inverse	400	32ch, 1.6 mm cells



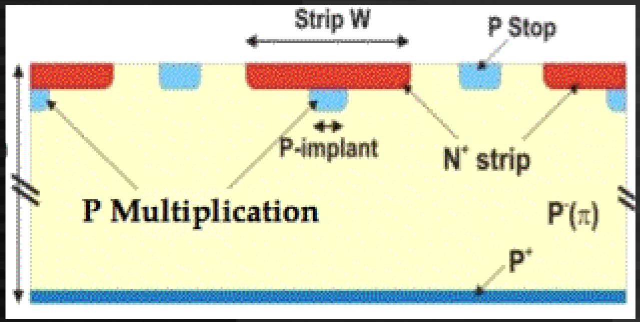
Single-cell APD



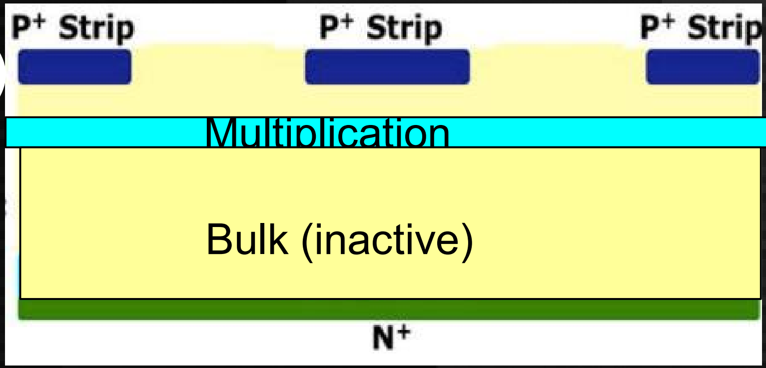
Multi-cell APD

We'd like to compare timing resolution (and gain characteristics) with those sensors

Hope for better timing resolution with inverse with thinner active thickness

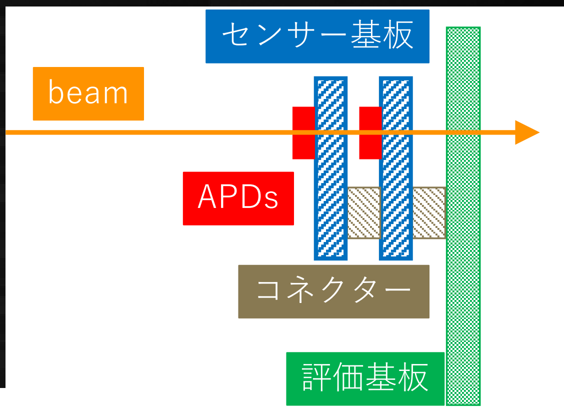


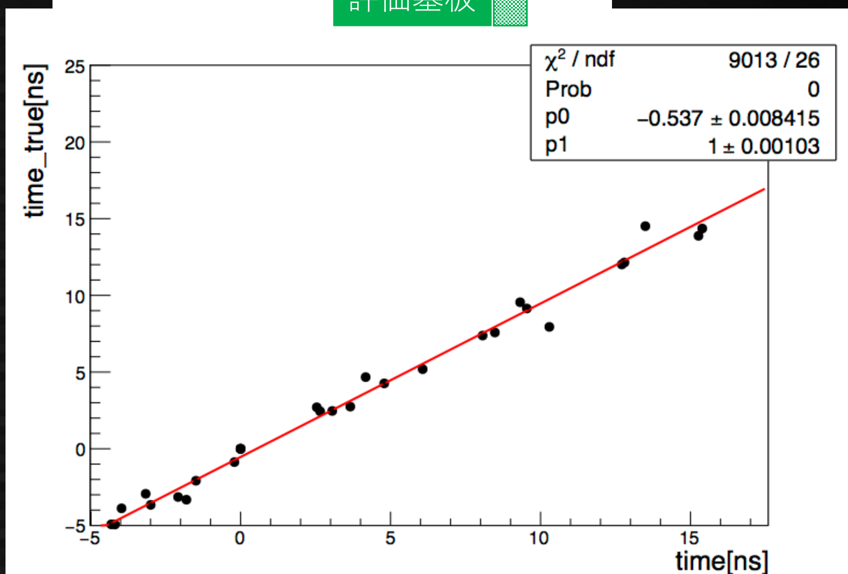
Reach-through type:
well tested on HL-LHC etc.
Gain flatness issue



Inverse type (single-sided):
Better flatness & thinner active area than double-sided one

First test beam (2019)

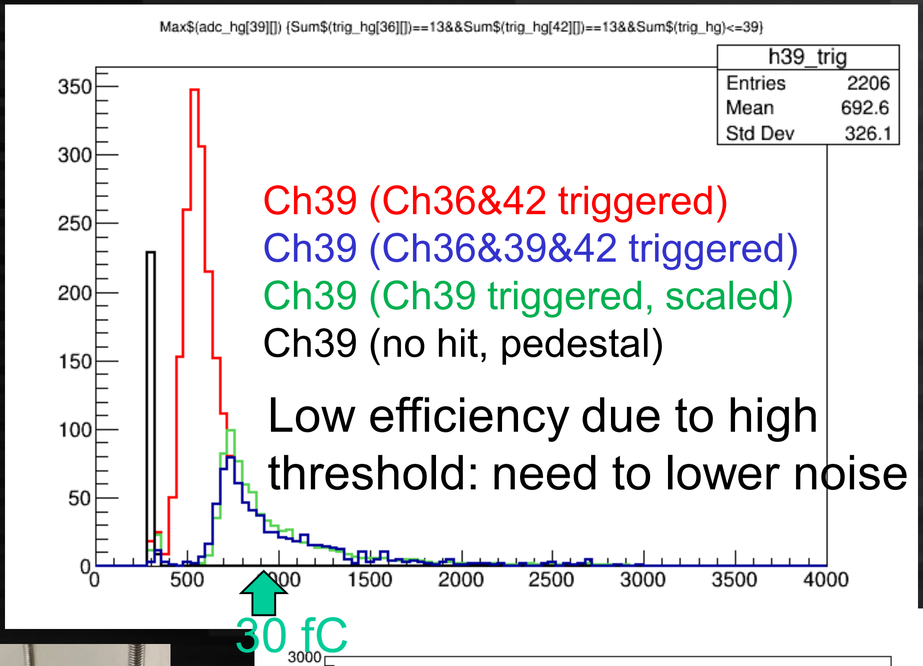


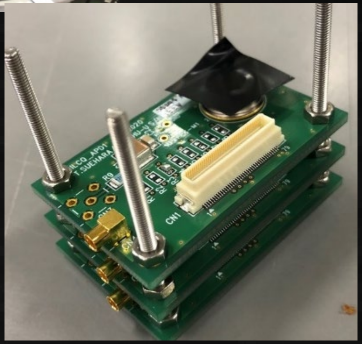


385 psec timing resolution

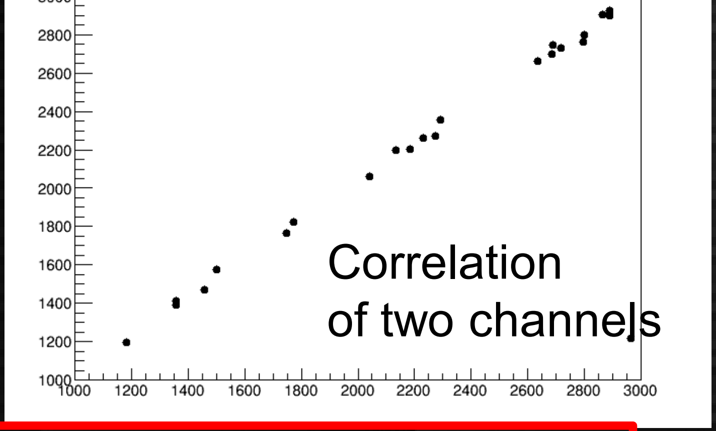
Affected by noise

2nd test beam (2021.2)





APD stack



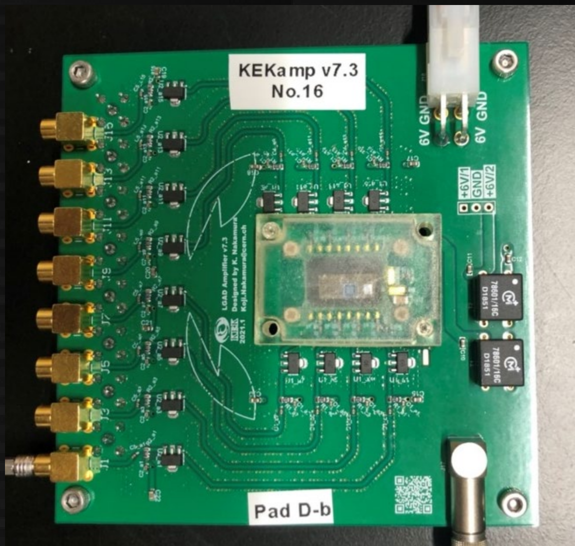
Detailed analysis talk by S. Tsumura (Friday)

For timing resolution of 20-30 psec

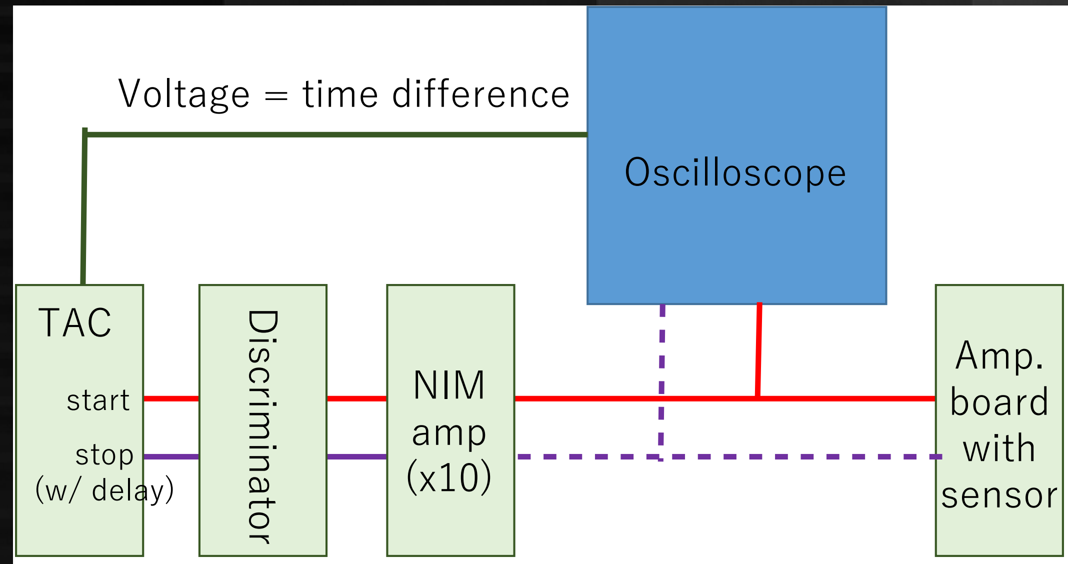
Need to reduce "electronics jitter" to see intrinsic resolution of sensors

- Jitter ~= rise time / S/N ratio + digitization jitter
  - rising time of Skiroc2-CMS fast shaper: 5 nsec
    - S/N ~ 250 required for 20 psec timing resolutiojn equivalent to 600e- noise → too difficult
    - Fast shaper can be faster, S/N degraded (need detailed study)
    - ~30 psec jitter on digitization?
- Reducing noise by better HV treatment (working)
  - Threshold 190 → 170 is possible in lab
    - Need to check with beam line environment
- Alternative electronics with discrete amplifier

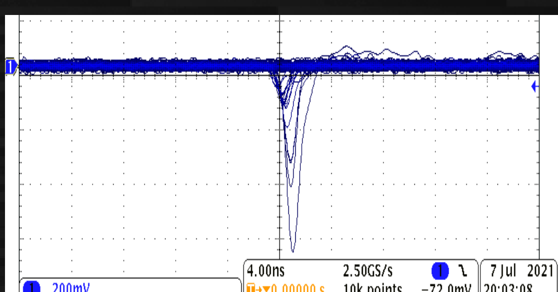
Setup with discrete amplifier



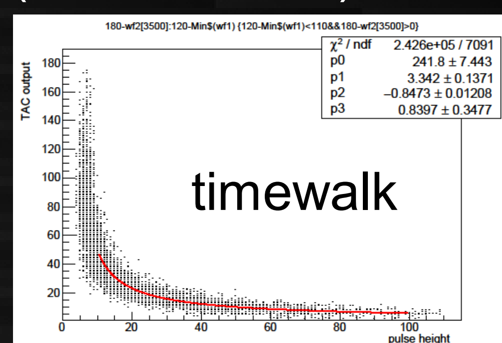
LGAD amplifier board
by K. Nakamura (KEK)
GALI-S66+ (3 GHz amp)
(2 stages, total gain 100)

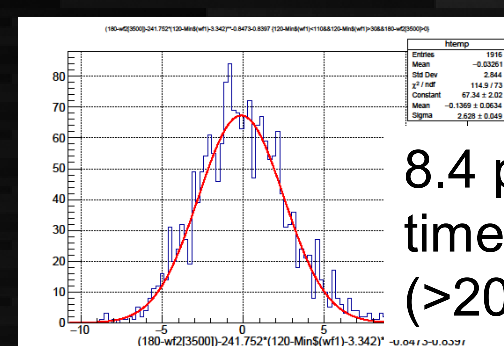


DAQ with oscilloscope: pulse height and TAC out
Test of timing resolution with single sensor using separate NIMamp output, different threshold (50 & 100 mV), timewalk correction



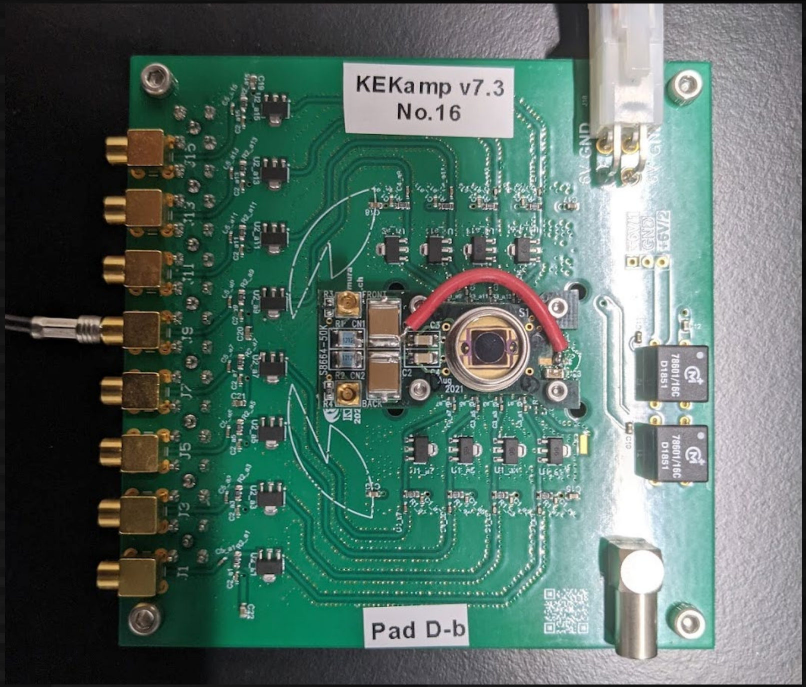
~1 ns rising time





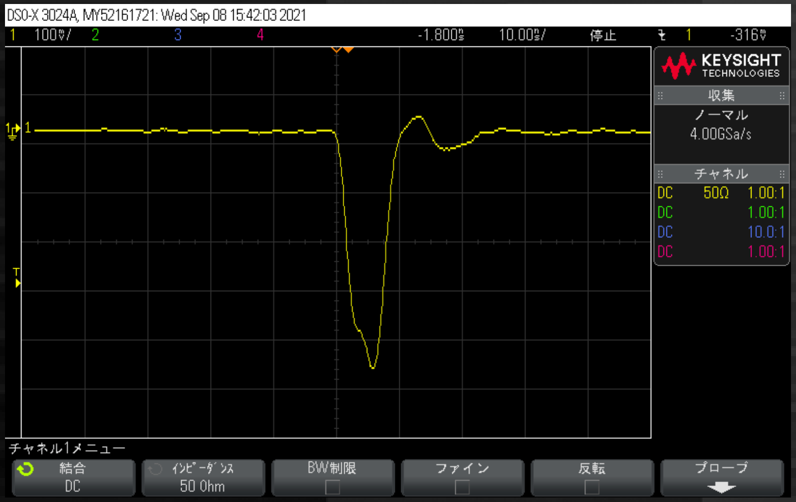
8.4 psec
time reso
(>20 fC)

Preparation

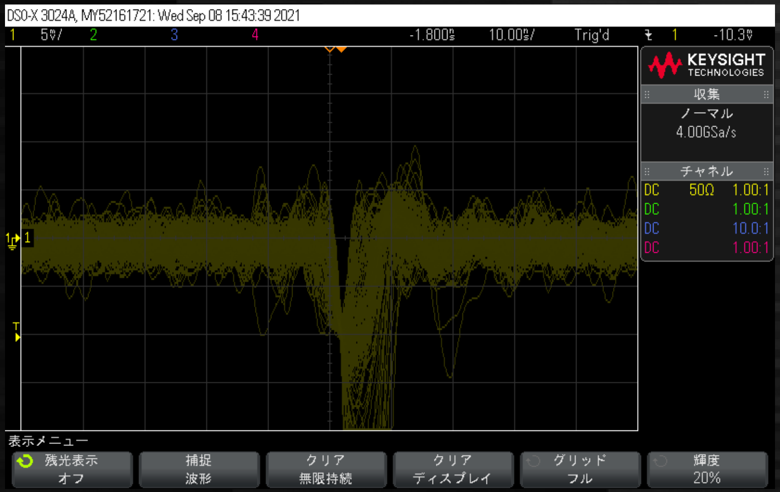


LGAD amp with adapter board
S2385 (RS) on the board

Expected jitter: ~10 psec



Pulse height ~500 mV, rise time ~ 2 ns



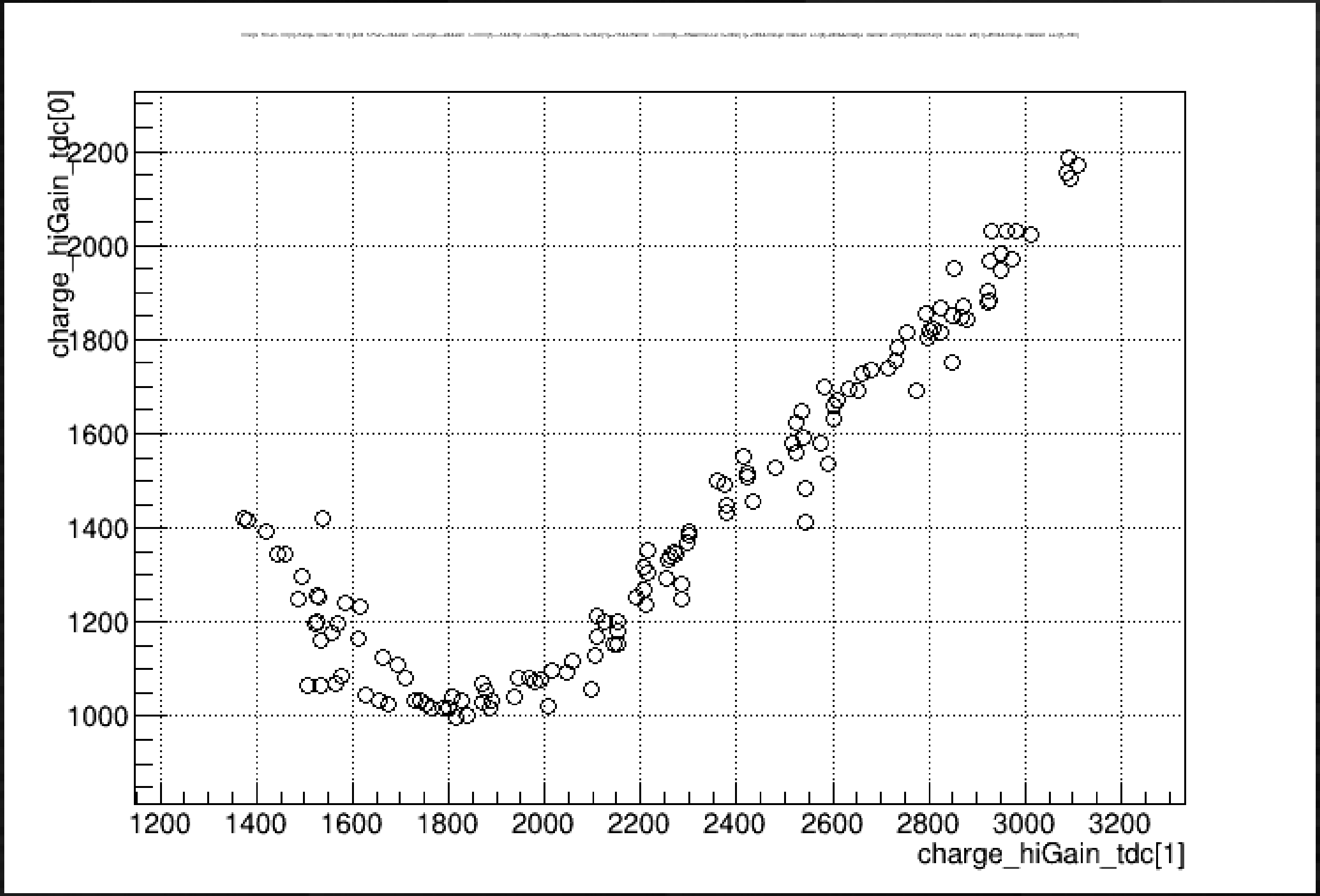
Noise ~ 2 mV (sigma)

Plans at test beam

- 3 days x 12 hours (October 6-8) 700 MeV e^+
- Timing resolution with discrete amp
  - RS and inverse sensors (4 types)
  - Several bias voltages
  - 5 mm and 3 mm sensors
    - 30 min accumulation with 5 mm, 90 min with 3 mm to get ~1000 events
- Skiroc2-CMS setup
  - Single-cell: gain-voltage calibration with MIPs
  - Multi-cell: gain variation studies

Part 2: Consideration for electronics

Timing resolution of SKIROC2A



A few ns timewalk with FEV13 (TB 2019)
1.1 ns with 21 fC injection with testboard

Consideration of timing resolution

- Jitter ~= rising time / S/N ratio + digi. jitter
- Rising time at SK2A: 30/60/90 nsec (default: 90)
- Noise at SK2A: 0.3 fC
  - Trigger S/N: 12.8 with 4.2 fC (eqv. 320 μm silicon) by S-scan with testboard
  - 90 / (21/0.3) ~ 1.3 ns: nearly consistent with 1.1 nsec
- Signal strength
  - 650 μm standard silicon: 9-10 fC?
  - LGAD: varied but 20-30 fC should be reasonable
    - Should find structure with higher gain…

Electronics for 100 psec resolution

- Skiroc2-CMS
  - Rise time (FS): < 5 nsec (cf. 90 nsec with SK2A)
  - S/N get worse with shorter rise time
    - No big dependence of timing resolution seen on rise time
  - 100 psec resolution needs 100 fC charge
    - corresponding to noise ~ 2 fC?

- Need to reduce rise time from SK2A
  or reduce noise to SK2A level from SK2CMS…

Summary on timing resolution

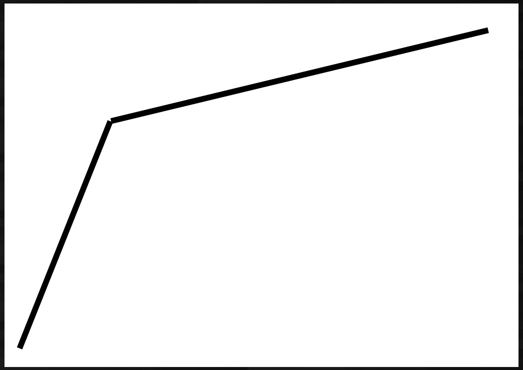
	Rise time (fast shaper)	Noise (fast shaper)	Digitization	T. Reso with 10 fC	T. Reso with 30 fC
SK2A	30-90 nsec	0.3 fC @ 90 nsec	~10 / nsec	2700 psec	900 psec
SK2CMS	-5 nsec	~2 fC @ 5 nsec	~100 / nsec	1000 psec	300 psec
Fast SK2A?	10 nsec	0.3 fC		300 psec	100 psec
Good CMS?	5 nsec	0.5 fC		250 psec	80 psec
Extreme	2.5 nsec	0.25 fC		60 psec	20 psec

Digitization noise may be more important with timing resolution of O(100 psec)

Sensor intrinsic resolution not included

Consideration on dynamic range

- Dynamic range on ADC
  - Important around shower-max
  - Less important on inner layers (fewer MIP expected)
    - Higher gain for better timing resolution on inner layers?
- Dynamic range on TDC
  - psec timing resolution needed for < 10 nsec range
  - Moderate resolution enough for 200 nsec



Steeper slope on first 5-10 nsec and moderate slope on the rest is good: but only affects resolution on digitization

Summary

- Test beam preparation
  - Previous TB: O(100 ps) due to limit of Skiroc2-CMS
  - Low-jitter electronics will be used for the next TB
- Consideration on electronics
  - 1-order-of-magnitude improvement is needed for either rising time or noise from SK2A/CMS for 100 psec with LGAD, 1.5-order for 20-30 psec
  - Dynamic range can be relaxed on the inner layers for ADC and slower timing for TDC