Sensors for Roman Pots (eRD24)

E. C. Aschenauer, S. Fazio, G. Giacomini, A. Jentsch, A. Kiselev, and A. Tricoli
Brookhaven National Laboratory

1st EIC Yellow Report Workshop (Temple University)

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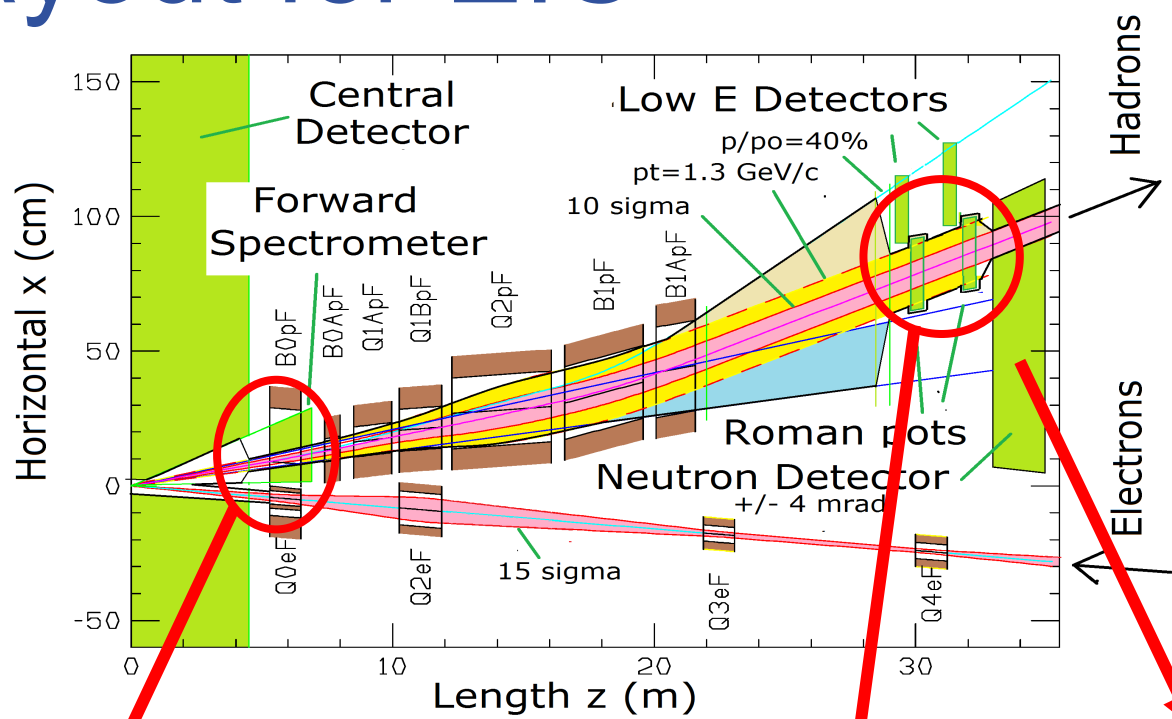
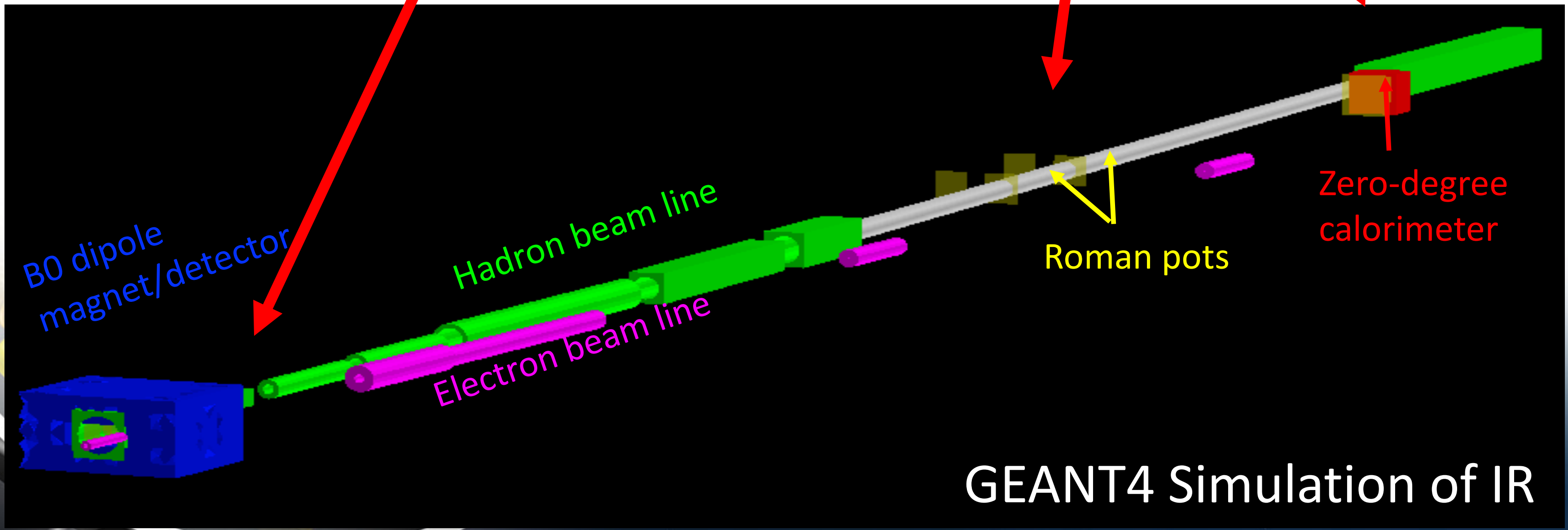
R&D Proposal Goals and Approach

- **Goals:**
  - Set performance requirements for Roman Pots at EIC
    - Focus on spatial granularity and timing resolution
  - Study application of novel silicon sensor, *AC-coupled LGAD*, in Roman Pots at EIC
  - Compare with alternative detector option: *3D detector*
- **Approach:**
  - 1st year: physics performance simulation and sensor prototype development
    - Leverage BNL expertise on physics at RHIC
    - Leverage BNL expertise on silicon R&D, LGADs, and AC-LGADs
    - Leverage collaboration with Stony Brook/Manchester on 3D detectors
  - 2nd year: prototype testing
    - Leverage RHIC resources for test-beam installation, test-beams at FNAL etc.
    - Leverage expertise in Physics Dept. and international collaborators on pixel detector readout electronics

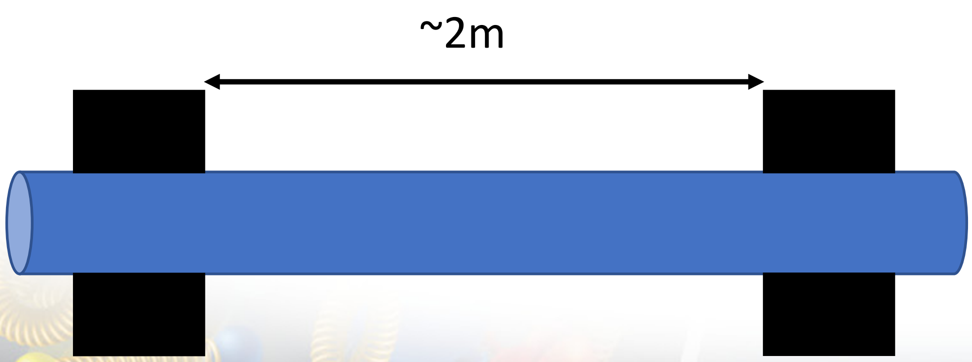
IR Layout for EIC

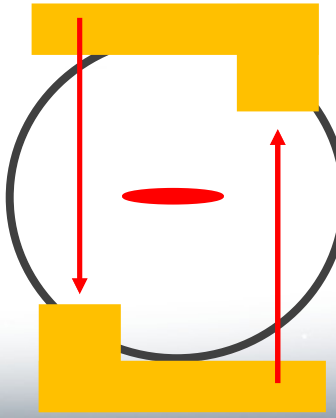




Possible (Strawman) Layout of RPs

- Two stations, separated by ~ 2 meters.
- 2-3 layers of sensors per station for redundancy – square pixels.
- L-shaped sensor pattern could allow the 2π coverage needed.
- Critical parameter for sensors is inactive area close to beam (to be minimised) ➔ slim-edges





Momentum Resolution – Summary

- The various contributions add in quadrature

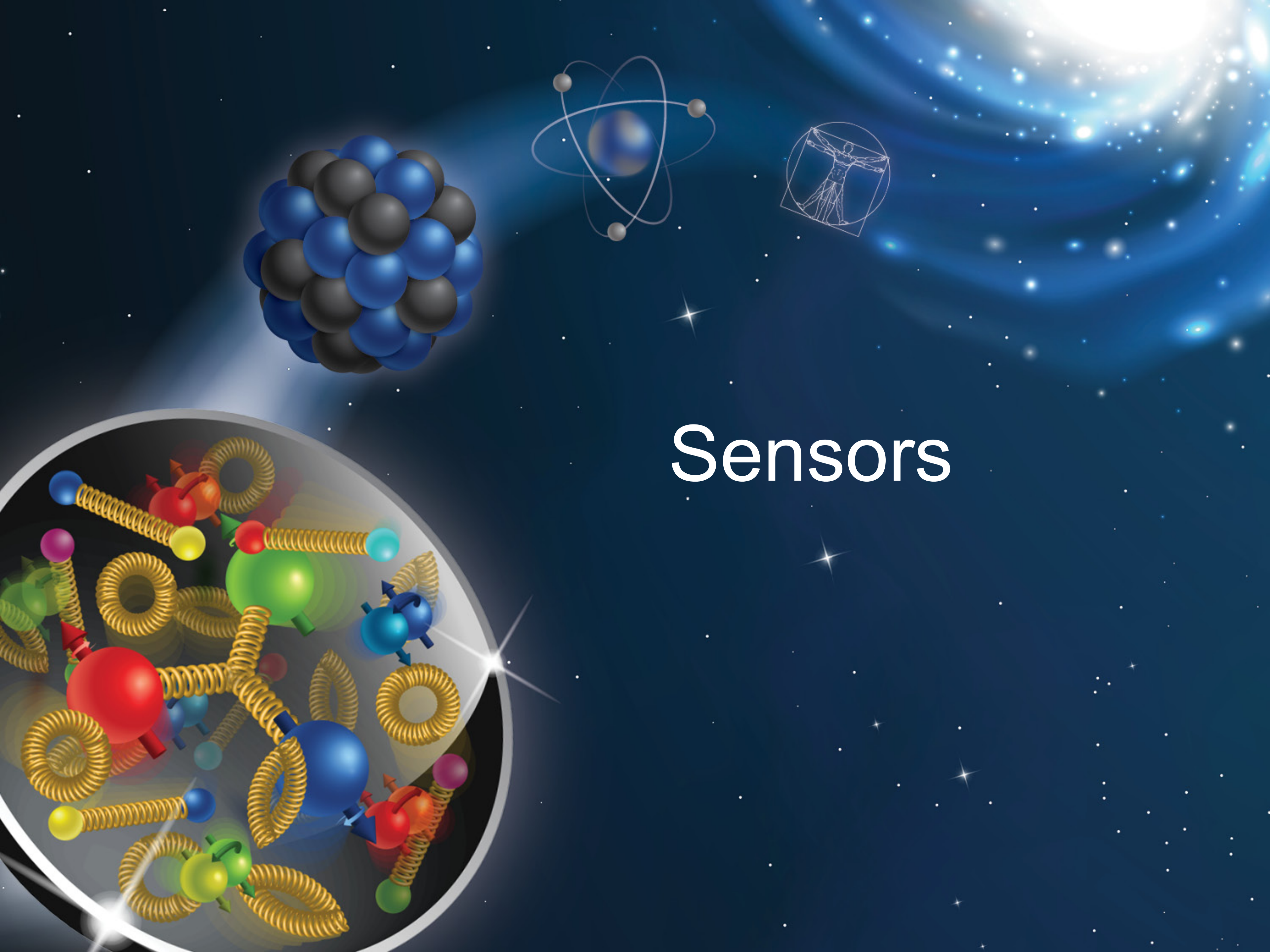
$$\Delta p_{t,total} = \sqrt{\underbrace{(\Delta p_{t,AD})^2}_{\text{Angular divergence}} + \underbrace{(\Delta p_{t,CC})^2}_{\text{Primary vertex smearing from crab cavity rotation.}} + \underbrace{(\Delta p_{t,pxl})^2}_{\text{Smearing from finite pixel size.}}}$$

	Ang Div. (HD)	Ang Div. (HA)	Vtx Smear	250um pxl	500um pxl	1.3mm pxl
$\Delta p_{t,total}$ [MeV/c] - 275 GeV (p)	40	28	20	6	11	26
$\Delta p_{t,total}$ [MeV/c] - 100 GeV (p)	22	11	9	9	11	16
$\Delta p_{t,total}$ [MeV/c] - 41 GeV (p)	14	-	10	9	10	12

- **Beam angular divergence**
  - Beam property, can't correct for it – sets the lower bound of smearing.
  - Subject to change (i.e. get better) – beam parameters not yet set in stone
- **Vertex smearing from crab rotation**
  - Correctable with good timing (~35ps)
- **Finite pixel size on sensor**
  - 1.3 mm – current pixel size of timing detectors at HL-LHC
  - 500 um is compromise between potential cost and smearing

Overview of Requirements

- The EIC Roman Pots requires an *active sensor area of ~25x10 cm^2.*
- The beam angular divergence sets the lower bound for achievable smearing – *other controllable effects should be kept well-below contribution from divergence.*
- 500 x 500 μm^2 sensor pixel is best trade-off between smearing and cost
  - Finer granularity possible on sensor (e.g. 50 x 50 μm pixels)
  - Limiting factor is readout: pixel size in ASIC and number of channels
  - 500 x 500 μm^2 seems possible to achieve with limited development in current ASIC technology for HL-LHC timing detectors (on-going discussion)
  - However, finer spatial resolution can be achieved exploiting signal sharing between pixels, at comparable cost, i.e. using current ASIC technologies (see following slides)
- Having precise timing ~35ps allows for precise determination of z-position of collision relative to the center of the bunch.



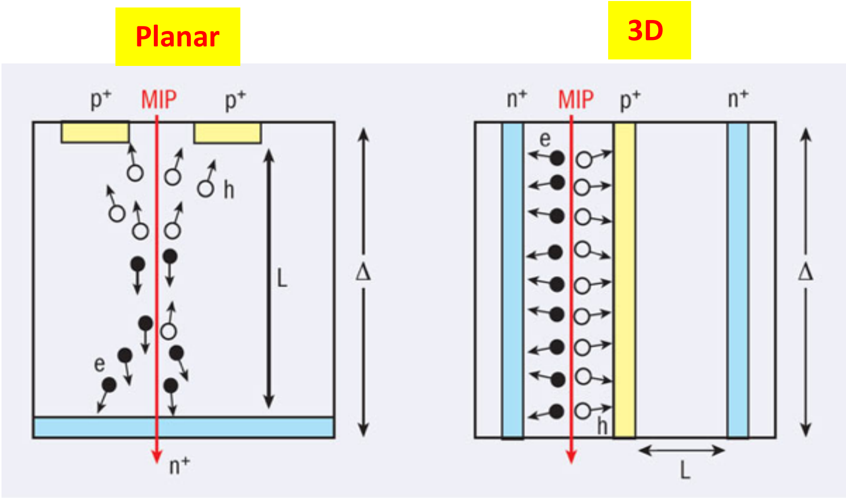
Sensors

Sensor options for RPs

- Recent developments in silicon fabrication technology show that silicon sensors can provide both tracking and timing in a single detector
- Silicon sensors can also be sufficiently radiation-hard for current levels of radiation (e.g. up to HL-LHC)
- Good candidates are 3D and LGAD-based sensors
- These technologies have undergone extensive development in recent years are are either used or will be used at (HL-)LHC experiments for tracking or timing detectors, including forward detectors
- Decision on best technology for RP depends on performance requirements, needed R&D, readout technologies, and also costs

3D sensor concept

- 3D detectors are already considered by current forward experiments, e.g. CMS CT-PPS, AFP
  - Established technology for rad-hard tracking detectors, e.g. ATLAS inner pixel (IBL), and ITK for HL-LHC
  - Fast-timing performance (~30 ps for 50x50 μm^2 pixels), active edges (by design)
- Drawbacks:
  - Complex and expensive technology with only few major vendors so far (CNM- Spain, FBK -Italy)

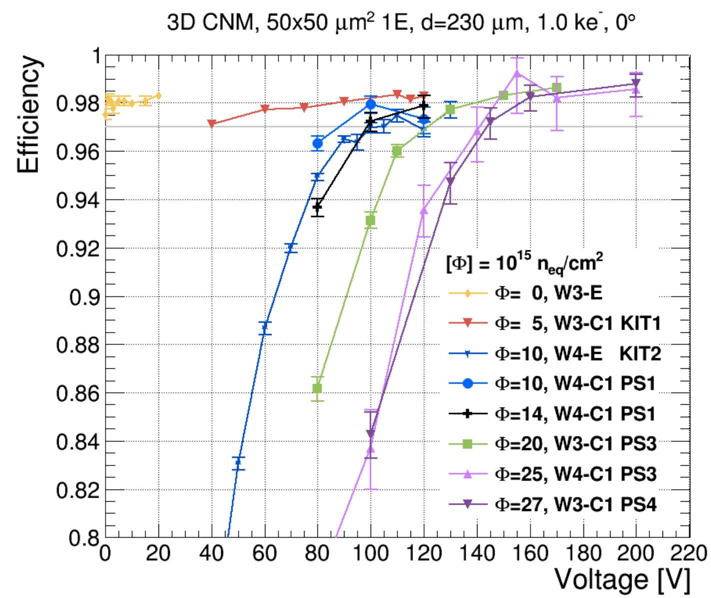


- **Main 3D detector characteristics:**
  - electric field is parallel to the wafer's surface
  - short inter-electrode distance
    - reduced collection time
    - lower trapping probability after irradiation → **rad-hard**
    - small inactive edges by design

G. Kramberger et al., *Timing performance of small cell 3D silicon detectors"*, NIMA 934 26-32
CT-PPS TDR: https://cds.cern.ch/record/1753795
AFP TDR : https://cds.cern.ch/record/2017378/

3D sensor advantages &challenges

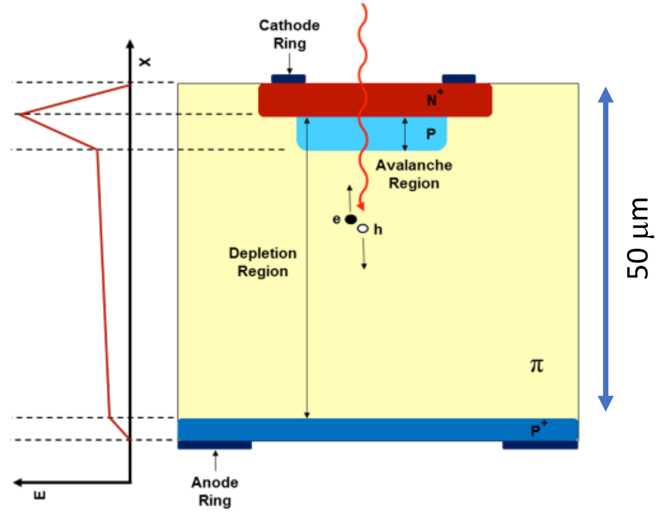
- **Advantages**
  - Established technology for pixel detectors
  - Very radiation hard
    - prototypes successfully tested to unprecedented fluences: 3 x 10^{16} n_{eq}/ cm^2 (beyond HL-LHC fluences)
  - Time resolution ~30 ps
- **Challenges**
  - **Complex production process**
    → long production time
    → lower yields
    → higher costs
  - **Higher capacitance**
    → higher noise
  - **Non-uniform response from 3D columns and low-field regions**
    → small efficiency loss at vertical incidence



J. Lange et al., 13thTrento Workshop 2018, publ. in prep.

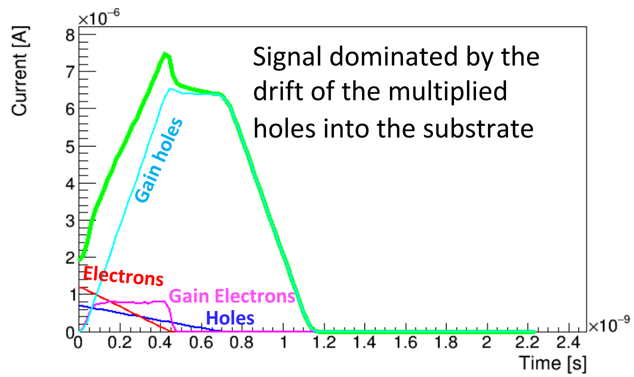
Time with LGADs

- A highly doped, thin layer of *p*-implant near the *p-n* junction in silicon creates a high electric field that accelerates electrons enough to start multiplication (*gain*).
  - **Low Gain Avalanche Detectors (LGADs)**:
    - **Gain 5-100**
    - **50 μm thickness**
    - **Large S/N ratio**
    - **Fast-timing: ~30 ps per hit**
    - **Rad-hard up to 3×10^{15} 1 MeV neutron/cm^2**
    - **To be used in forward timing det. at ATLAS and CMS at HL-LHC**

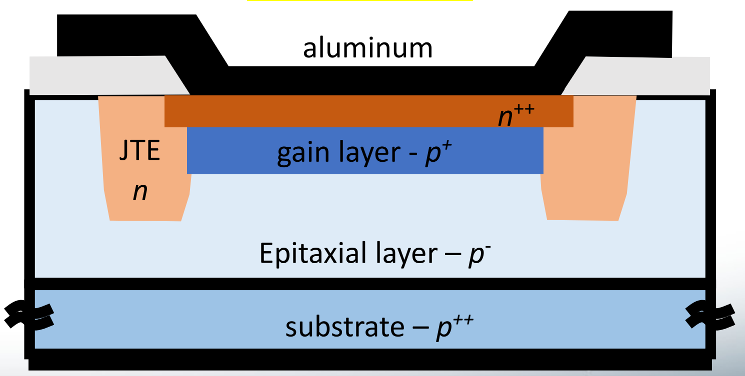


Simulation

Current pulse generated by a mip in 50-μm thick LGAD with gain=10



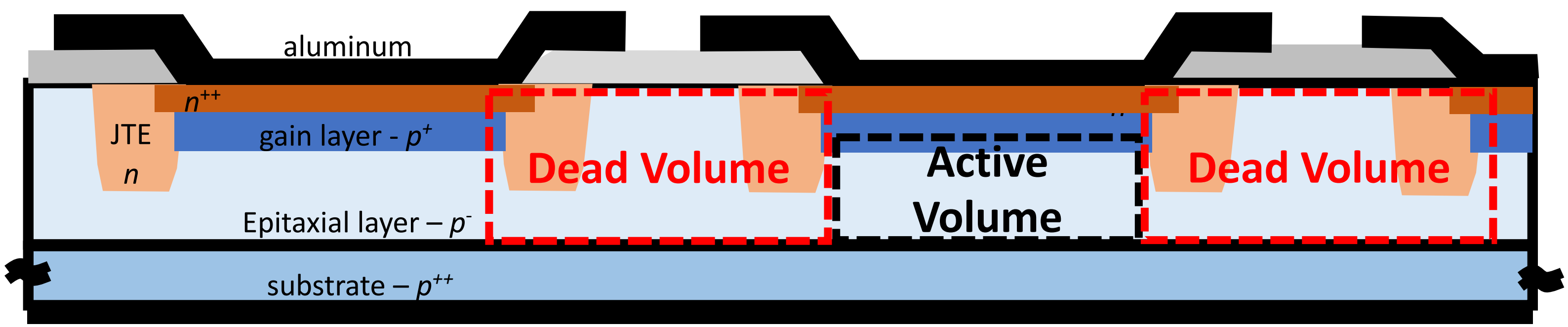
BNL designs

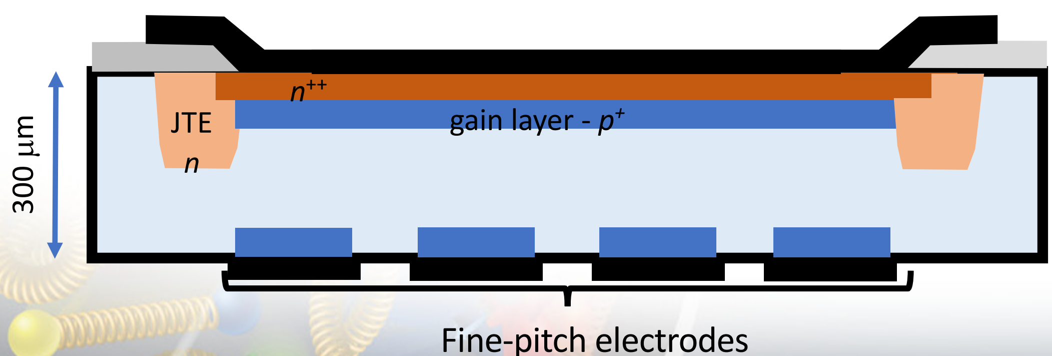


Limitations of LGADs

- **Lateral size of Gain Layer must be larger than thickness of substrate, for a uniform multiplication**
  - large pads are preferred (~ 1 mm); e.g. HGTD at ATLAS and MTD at CMS
- **Dead volume (gain ~1) extends within the implanted region of the gain layer**
  - pixels/strips with gain layer below the implant have a Fill Factor <<100% (Voltage depende)

➢ **4D detector not possible!!!**

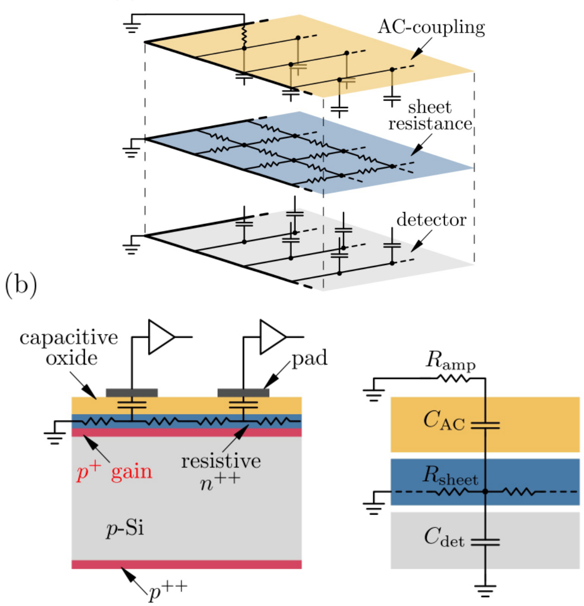




A possible Solution: Closely-spaced electrodes can be put on the opposite of the wafer (**i-LGADS**, CNM Barcelona), **but** wafers must be thick to be processed.
→ **not possible to associate fast-time information on a per-pixel level!**

Time and Space with AC-LGADs

- **Novel development: AC-coupling allows fine segmentation**
  - ➔ **Time & Space measurements**
  - ➔ **100% fill factor**



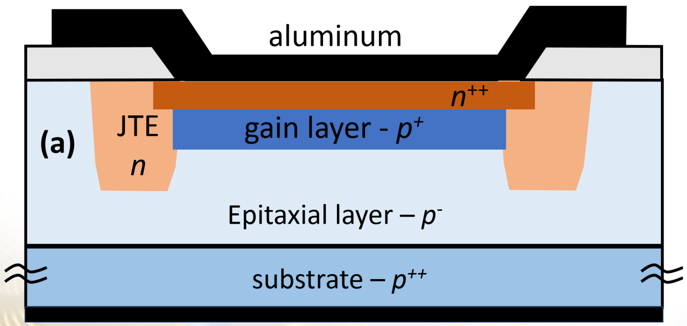
Main differences wrt LGADs:

1. one large low-doped / high-ρ n^+ implant running overall the active area, instead of a high-doped low-ρ n^{++}
1. A thin **insulator** over the n^+, where fine-pitch electrodes are placed.

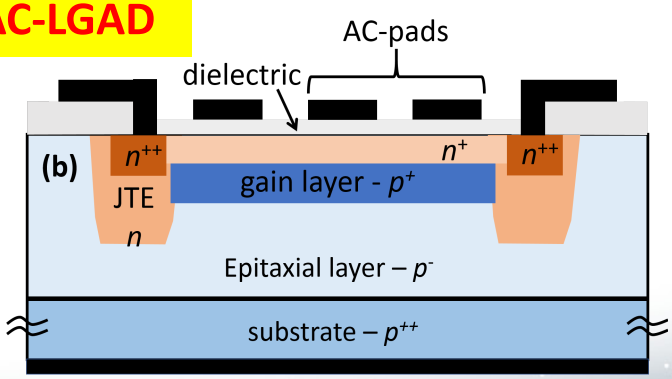
- Signal is still generated by drift of multiplied holes into the substrate and AC-coupled through dielectric
- Electrons collect at the resistive n^+ and then slowly flow to ohmic contact at the edge.
- **100% Fill Factor and fast timing information at a per-pixel level both achieved!!!**

BNL designs:

LGAD



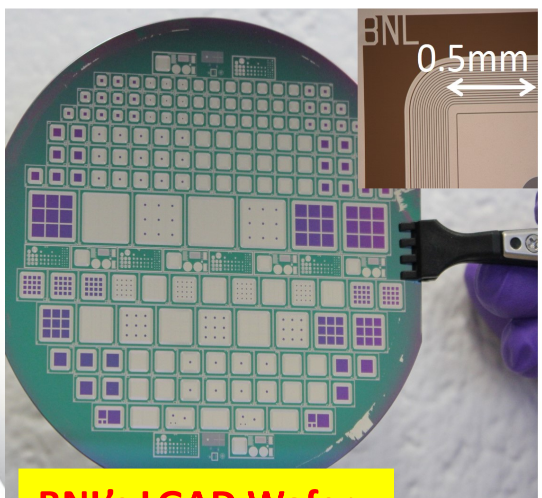
AC-LGAD



AC-LGADs Fabrication at BNL

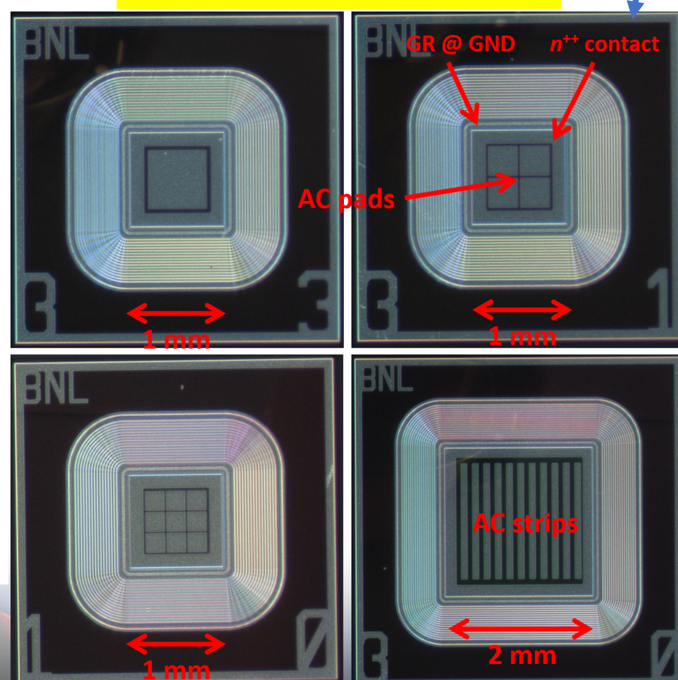
- BNL is fabricating and testing LGADs and AC-LGADs for several applications
  - G. Giacomini, A. Tricoli et al., *“Development of a technology for the fabrication of Low-Gain Avalanche Detectors at BNL”,* NIMA 62119 (2019)
  - G. Giacomini, A. Tricoli et al., *“Fabrication and performance of AC-coupled LGADs”,* arXiv:1906.11542 (2019), sub. to JINST

BNL’s LGADs show performance similar to HPK
- leakage current 1nA/cm^2
- High gain, up to ~80

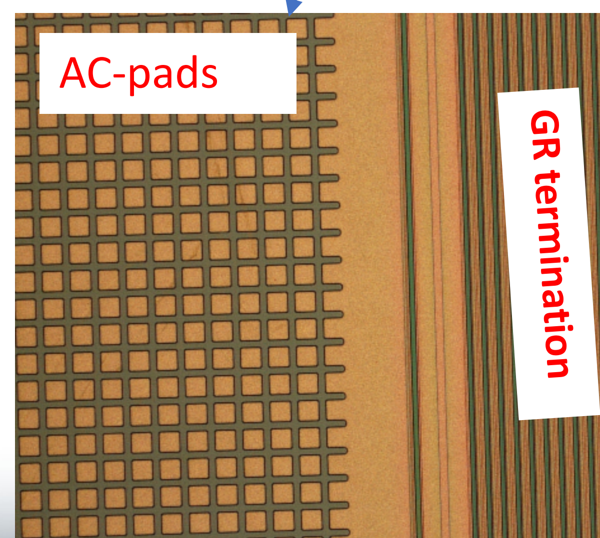


BNL’s LGAD Wafer

BNL’s AC-LGAD devices

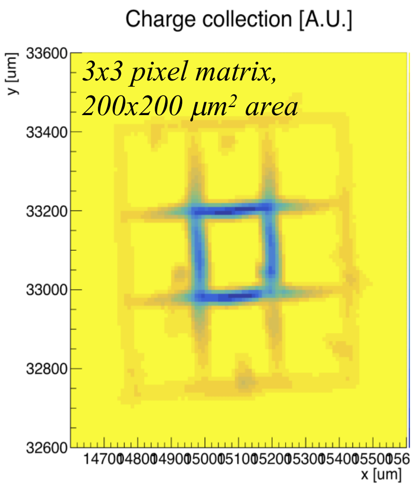


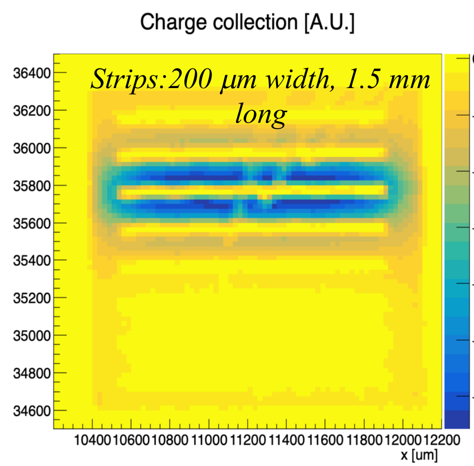
Single-pad (1x1 mm2) and **multi-strip/pixel** structures of several dimensions.
Smallest pitch: **55 um x 55 um** compatible with commercial readout Timepix3 chip



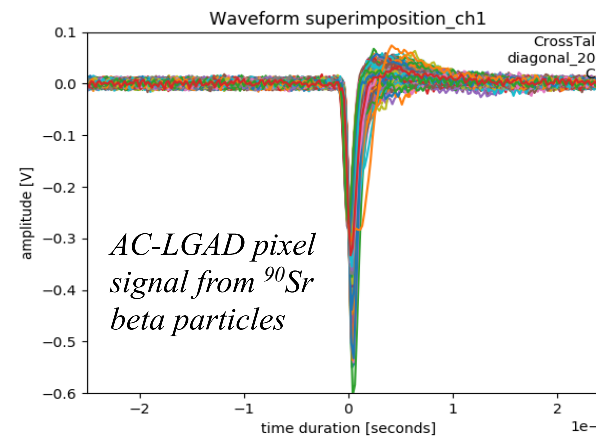
Studies of AC-LGAD performance

- Characterization of AC-LGADs of different designs, pitches and doping concentrations
  - Response to different particle beams: Beta, X/gamma rays, red/IR lasers, neutrons and protons
  - Electrical and charge collection properties
  - Signal induced on adjacent pixels/strips vs implant dose
  - **Gain ~ 80**
  - **Time resolution: ~20 ps jitter**

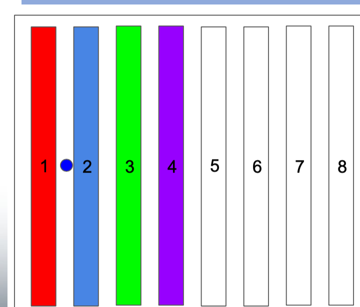




Charge collected on a strip or pixel when IR Laser is scanned over the sensor area (TCT)



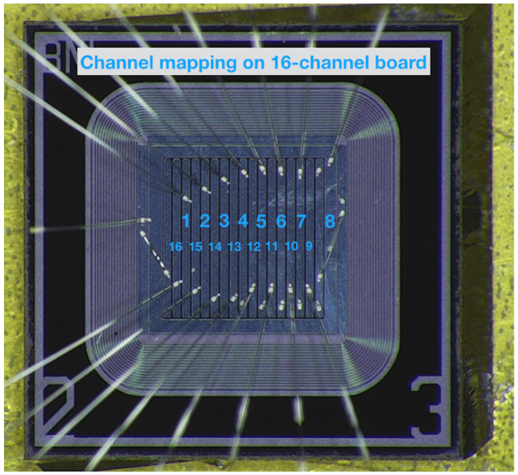
Signal sharing can help improve spatial resolution (IR laser)



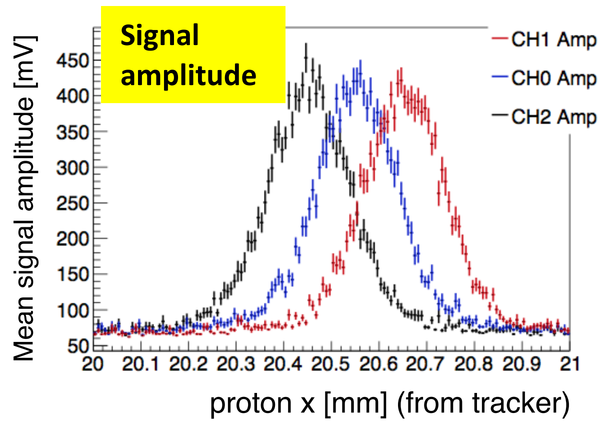
$Amplitude_2 / Amplitude_1$	100%
$Amplitude_3 / Amplitude_1$	13%
$Amplitude_4 / Amplitude_1$	6%
$Amplitude_6 / Amplitude_1$	4%

AC-LGAD Test-beam study (prelim.)

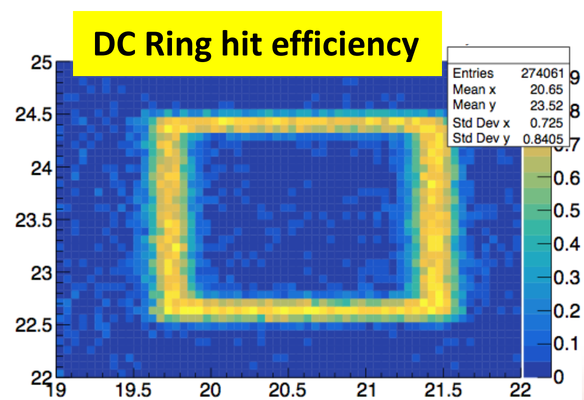
- **First characterization of AC-LGADs with 120 GeV protons at Fermilab Test Beam Facility (FTBF)**

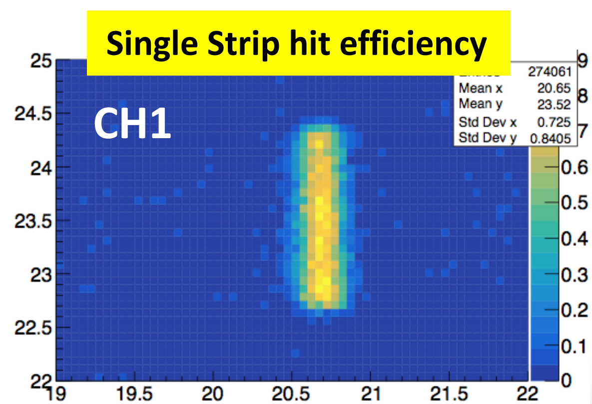


- Most data- taking focused on 3 adjacent strips (no. 4,13,12)
- Signals already very small in 2nd neighbor (dependent on doping concentration)



- Visible strip pitch 100 um (80 μm strip + 20 μm inter-pixel gap)
- Signal extends beyond strip boundaries, for ~5 strips (500 μm)
- Smearing from tracker resolution (50-70 μm)





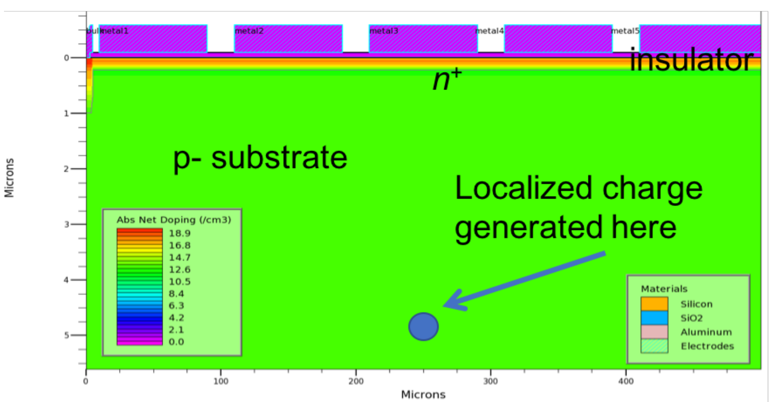
- Hit efficiency in XY plan
- Well isolated signal from DC ring
- High strip hit efficiency

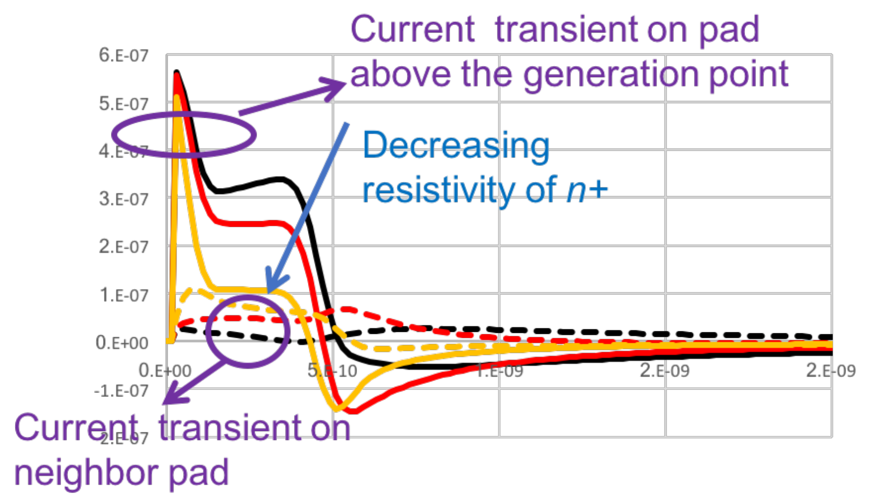
Artur Apresyan, Ryan Heller, Karri DiPetrillo (FNAL)

Optimisation for spatial resolution (I)

- Cluster centroid can be measured by induced signal on adjacent pixels/strips
- Critical parameters are geometry and fabrication details (doping, oxide thickness) that impact macroscopic quantities e.g. RC
- Ongoing studies on TCAD simulation to explore large parameter space

Simulation of AC-LGAD





Signal fed to the read-out electronics strongly depends on R(C):

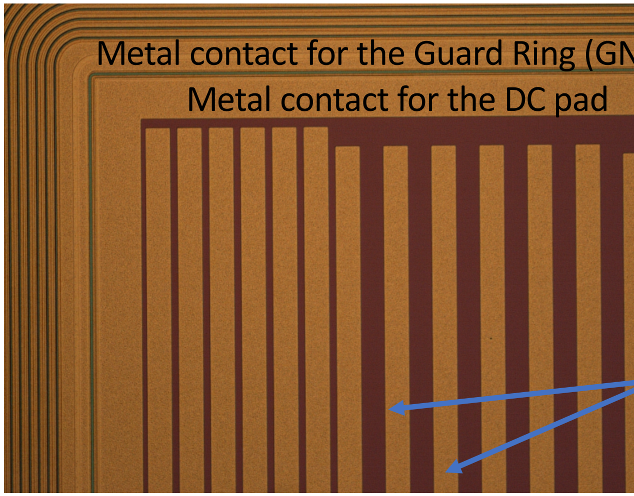
- Higher crosstalk if RC is SMALL
- Higher signal on hit pad if RC is HIGH

The RC value is being studied and tuned during fabrication to have an acceptable compromise

Gabriele Giacomini, Giovanni Pinaroli (BNL)

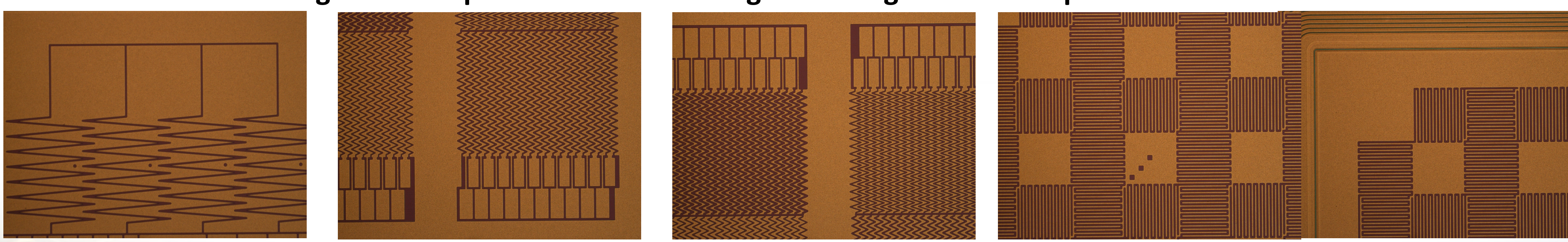
Optimisation for spatial resolution (II)

- **Alternative geometries are under study for RPs**
  - Different pixel sizes, and inter-pixel gaps
  - Zig-zag geometries to enhance information on cluster centroid, exploiting signal sharing between pixels/strips
- **Two Wafers are produced and under study**



AC pads (in this case, strips) connected to the read-out electronics.
Different gaps/width to test signal sharing between strips.

Other geometries put in a wafer to use signal sharing to enhance spatial resolution



Chevron structures (different pitches) and comb-shaped structures. All are metal patterns over an insulator (not in contact with silicon). These shapes can be arbitrary.

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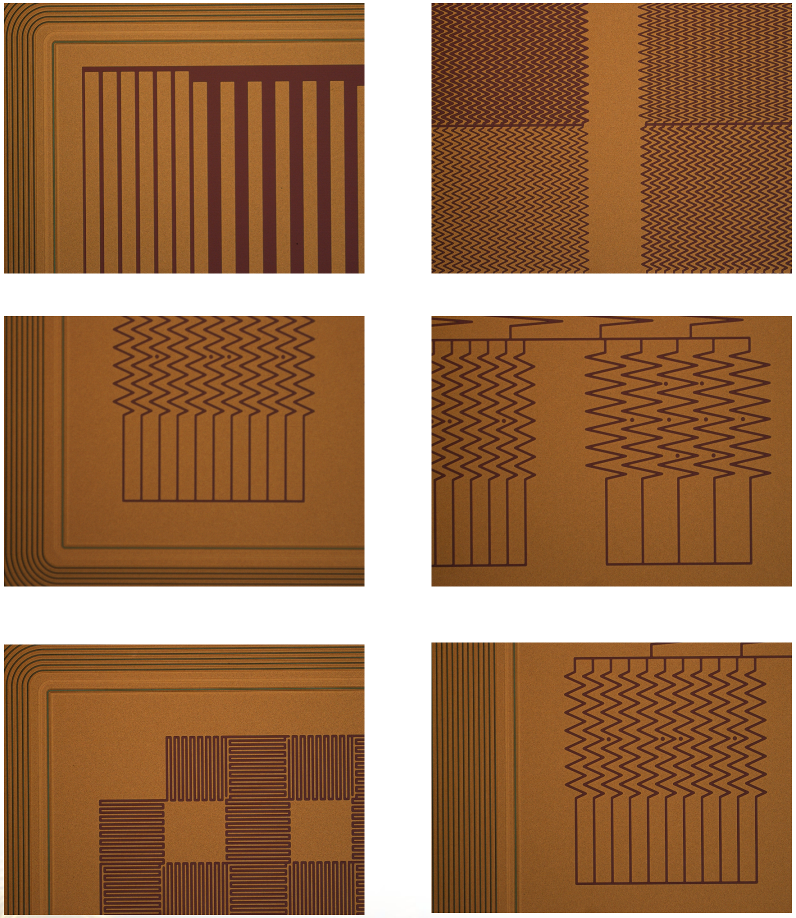
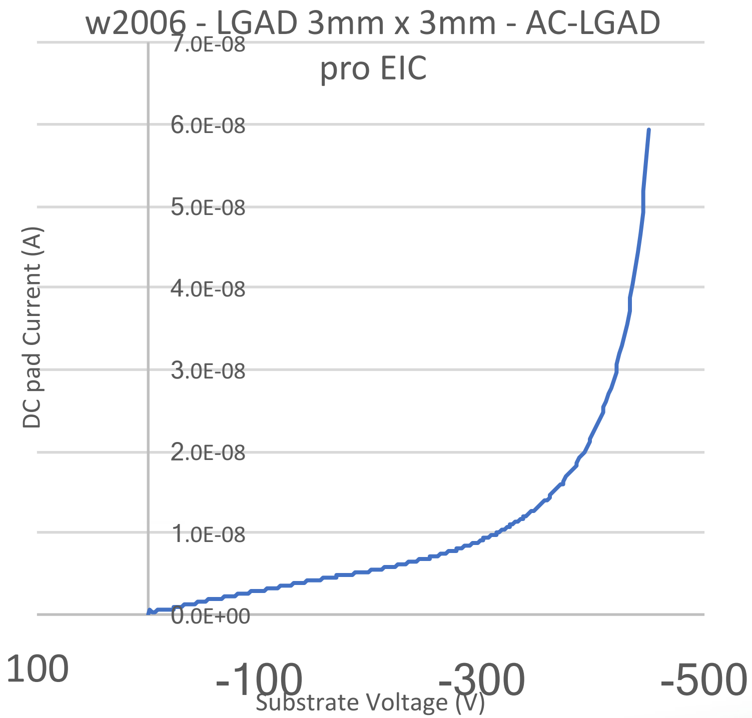
Optimisation for spatial resolution (III)



- **Performance of these new designs is on-going**
- **See Current-Voltage scan below**



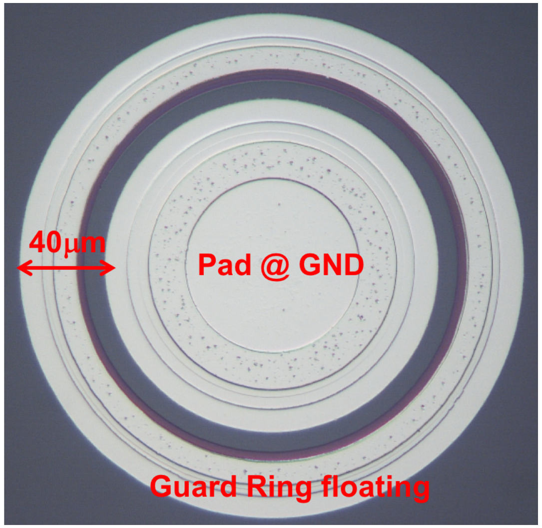
I-V are good, $V_{breakdown}$ ~ 450V,
Operational range ~ 300V-430V.

Gabriele Giacomini, Alexander Kiselev (BNL)

Slim-edge studies on AC-LGADs

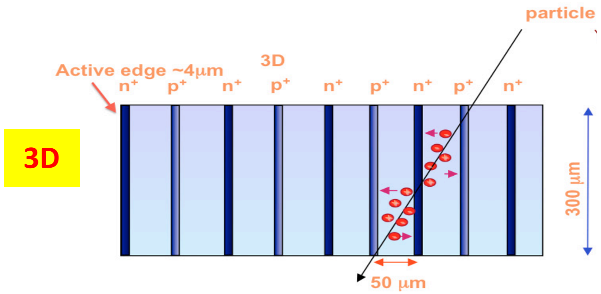
- New designs have been implemented in new wafers to address RP-specific requirements
    - Slim edge design requirement: inactive edge area to be reduced to 100 μm or less

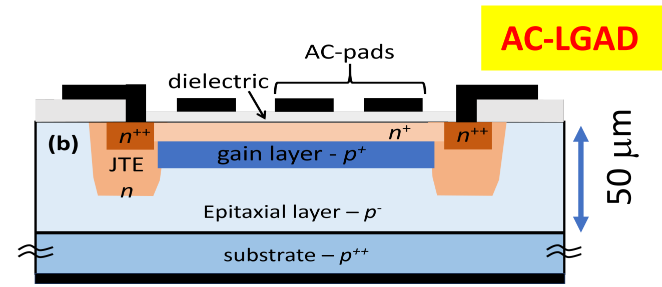
Test Structure for HV capability tests, one guard ring only for Slim Edge studies



- Prelim. Results: slim edge of 100 μm is within reach
    - 35-40 μm pad to Guard Ring
    - 50 μm Guard ring to etched trench

3D – AC-LGAD sensor comparison

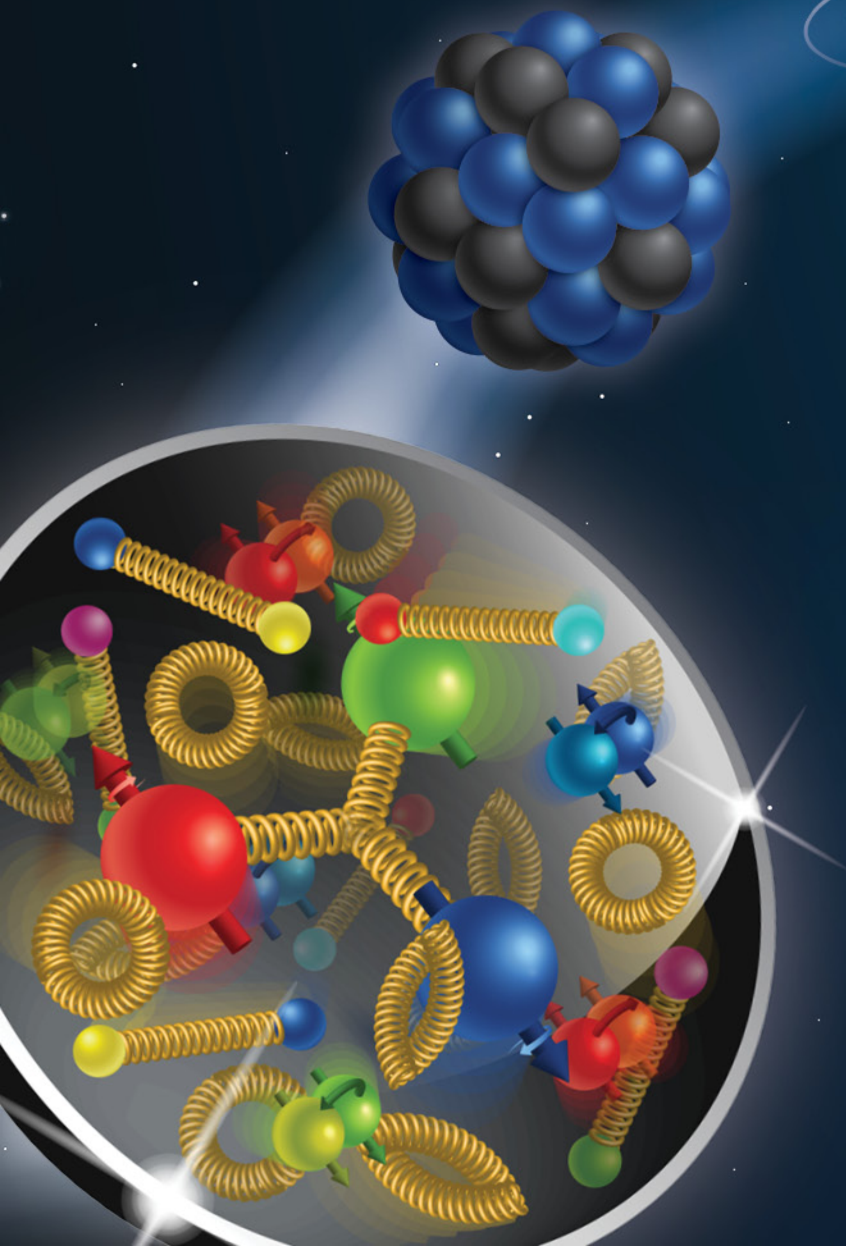




- **3D sensors are naturally with active edges**
- **3D are more rad-hard than LGADs** (unnecessary for RP at EIC)
- **3D require more complex and expensive processing with only few foundries**
- **Charge collection in LGADs and 3D:**
  - **3D** collects 80 e-/h pairs x 200/300μm ➔ ~ 16k e/h pairs
  - **LGAD** collects 80 e-/h pairs x 50μm x Gain (20) ➔ ~80k e/h pairs (Gain higher than 20 has been achieved)
  - ➢ **For a drift length of 50 μm for both, current signal is higher for LGAD**
  - ➢ **Larger pixels in 3D (e.g. 500 x 500 um^2) will induce larger jitter due to larger capacitance, while AC-LGADs are unaffected**
- **3D sensors have been used so far for tracking only as pixel detectors and need careful considerations when readout by fast amplifier and with large pixels (e.g. 500x500 um^2):**
  - Capacitance/Area is already much higher than for LGADs (~5x-10x) with 50x50 um^2
  - ➢ **Higher noise in 3D than AC-LGADs**
  - ➢ **Much higher current in preamplifier and higher power consumption in 3D than AC-LGADs**
  - ➢ **3D Timing resolution depends strongly on the cell size and track inclination (needs optimisation)**

Conclusions

- Silicon sensors can provide 4D capabilities needed by RP in a single detector
  - **Detector requirements**
    - Strawman layout: 2 stations with 2-3 layers each, active area per layer of 25x10 cm^2
    - 500x500 μm^2 pixel area allows to meet physics performance goals.
    - ~35 ps time resolution per hit is the target
  - **Detector R&D**
    - 3D and AC-LGADs can achieve ~30 ps time resolution per hit
    - Detailed comparison between AC-LGADs and 3D sensors is ongoing, however AC-LGADs seem the best match in terms of required performance and costs
      - Slim edges of 100 μm or less are possible in AC-LGADs
      - Pixel area 500x500 μm^2 or less can be fabricated with same performance as LGADs
      - Dedicated AC-LGAD designs with various geometrical layouts and different fabrication details (doping) are studied and implemented
      - Exploration of algorithms to improve spatial resolution beyond pixel size by measuring induced signal on adjacent pixels
    - Minimal pixel size is driven by ASIC development



Backup

Electronics an RP detector

- A critical aspect of the detector design is the readout electronics
  - **ASIC for ATLAS and CMS fast-timing detectors – ALTIROC and ETROC chips**
    - 225 and 256 channels, 1.3x1.3 mm^2 pixel, and 130 nm and 65 nm technology, respectively
    - TDCs for TOA and TOT, and RAMs for data buffering
    - ~25 ps jitter for 10 fC charge, power consumption 200-300 mW/ cm^2 , 1-1.2 W per ASIC
  - **Discussion has started with ALTIROC and ETROC ASIC designers**
    - Current ASIC pixel size mostly limited by TDCs and RAM
    - Possible to adapt current designs for ~500x500 μm^2 pixel size with similar performance (block rearrangements, removal/optimization of components, e.g. large RAM).
    - Slim edges of 50-100 μm on three sides (out of four) of the ASICs can be achieved
    - TOT feature in ASICs may be used to measure charge collected and shared between pixels to improve spatial resolution beyond pixel pitch size.

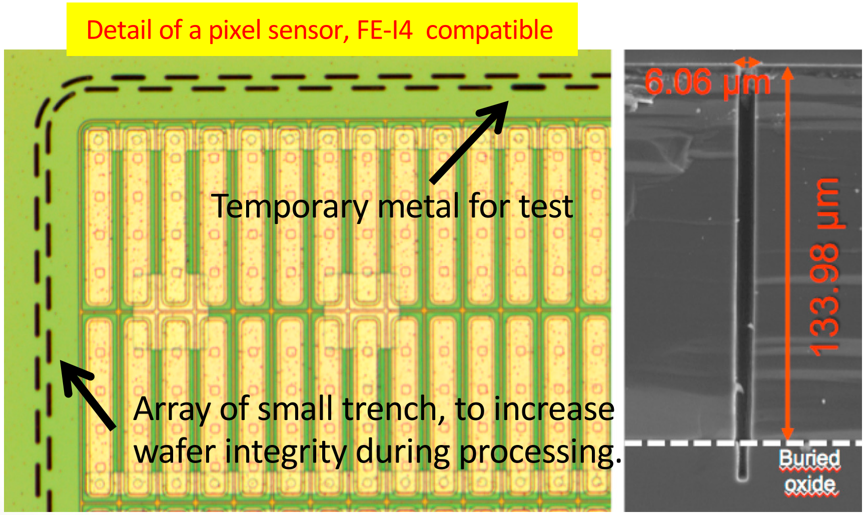
ALTIROC

TID tolerance	Inner region: 4.7 MGy Outer region: 2.0 MGy
Pad size	$1.3 \times 1.3\,\mathrm{mm}^2$
Voltage	1.2 V
Power dissipation per area (per ASIC)	$300\,\mathrm{mW\,cm^{-2}}$ (1.2 W)
e-link driver bandwidth	$320\,\mathrm{Mbit\,s^{-1}}$, $640\,\mathrm{Mbit\,s^{-1}}$, or $1.28\,\mathrm{Gbit\,s^{-1}}$
Temperature range	−40 °C to 40 °C
SEU probability	$< 5\%$/hour

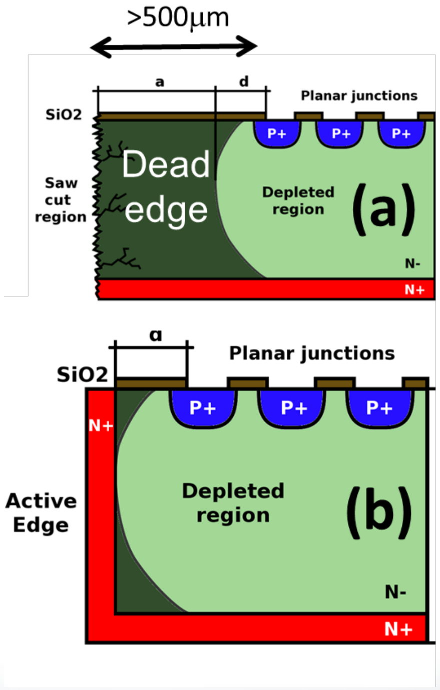
Maximum leakage current	5 µA
Single pad noise (ENC)	$< 1500\, e^- = 0.25$ fC
Cross-talk	$< 5\%$
Minimum threshold	1 fC
Threshold dispersion after tuning	10%
Maximum jitter	25 ps at 10 fC
TDC contribution	< 10 ps
Time walk contribution	< 10 ps
Dynamic range	2.5 fC–100 fC
TDC conversion time	< 25 ns
Trigger rate	1 MHz L0 or 0.8 MHz L1
Trigger latency	10 µs L0 or 35 µs L1
Clock phase adjustment	100 ps

Edge studies for Roman Pots: DRIE etching technique

- Non-sensitive area (edges) is critical for their applications in a Roman Pot
  - Current AC-LGADs have large non-active region → need optimization for application in Roman Pots
- Active edge provides a damage free interface that limits the extension of the dead silicon area, external to the sensitive area
  - To be studied for AC-LGADs and compared to 3D detectors



Calderini et al.,*"Active-edge FBK-INFN-LPNHE thin n-on-p pixel sensors for the upgrade of the ATLAS Inner Tracker"*, https://doi.org/10.1016/j.nima.2018.10.035



Deep reactive ion etching technique provides low-damage trenches or columns in silicon.
1:20 etch ratios are achievable. Any shape can be achieved.

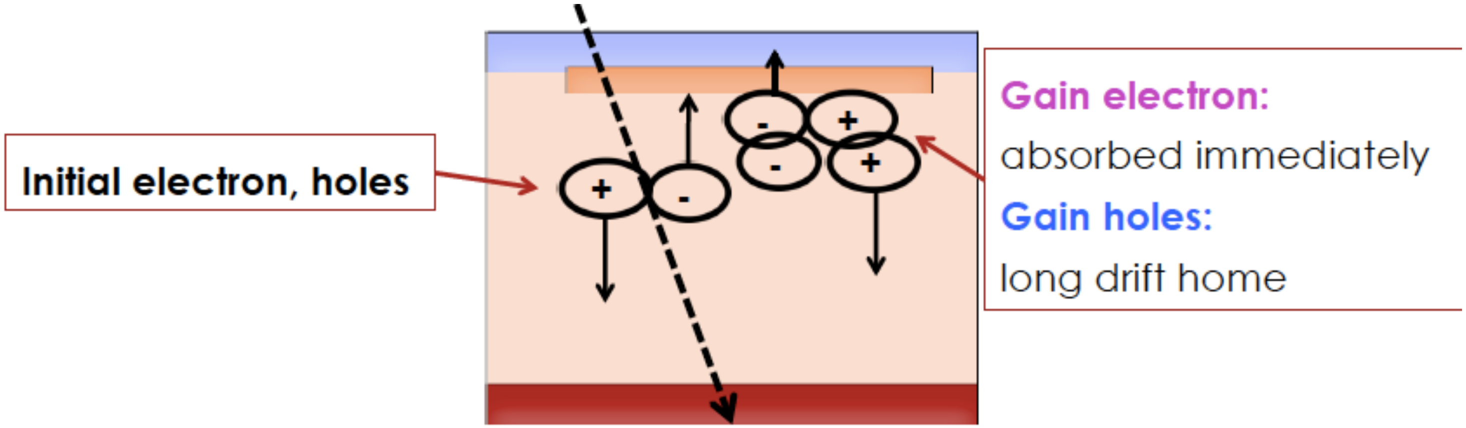
Surface needs passivation for damage removal, e.g. thermal oxidation.

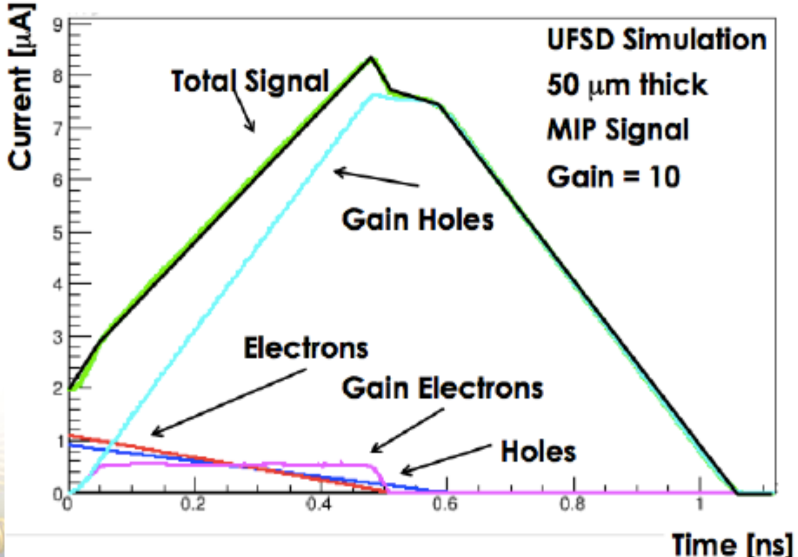
To fabricate an active edge sensor, trenches must be etched all the way through the active thickness:

- *For AC-LGADs, just 50 µm deep*
- *For 3D pixel sensors, ~ 200 µm*

Charge Multiplication in LGADs

N. Cartiglia





Electrons multiply and produce additional electrons and holes.

- **Gain electrons have almost no effect**
- **Gain holes dominate the signal**

➔ **No holes multiplications**

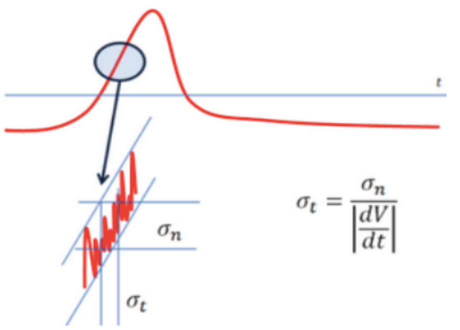
Time Resolution in LGADs

N. Cartiglia

$$\sigma_t = \left(\frac{N}{dV/dt}\right)^2 + (\text{Landau Shape})^2 + \text{TDC}$$

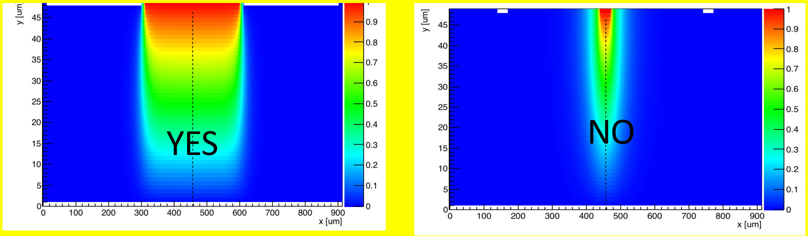
Usual "Jitter" term
Here enters everything that is "Noise" and the steepness of the signal

Time walk: Amplitude variation, corrected in electronics
Shape variations: non homogeneous energy



Signal Shape: $\mathbf{i \propto qvE_w}$

- Key to good timing is the uniformity of signals:
  - Drift velocity and field need to be as uniform as possible
  - Parallel plate geometry is optimal:
    - strip implant ~ strip pitch >> thickness



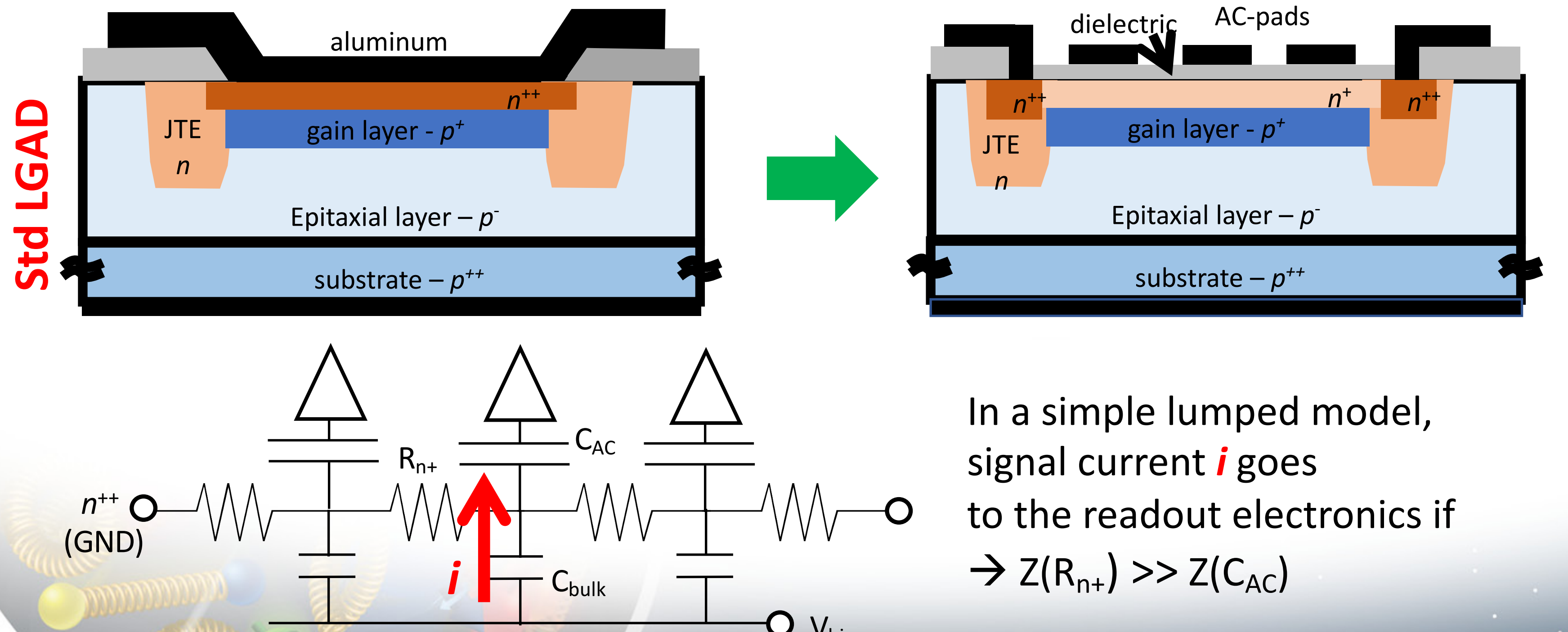
AC-LGAD concept

Two main differences:

1. one large low-doped high-ρ ***n⁺*** implant running overall the active area, instead of a high-doped low-ρ ***n⁺⁺***
2. A thin insulator over the ***n⁺***, where fine-pitch electrodes are placed.

100% Fill Factor and **fast timing information at a per-pixel level** both achieved!!!

- Signal is still generated by drift of multiplied holes into the substrate and AC-coupled through dielectric
- Electrons collect at the resistive ***n⁺*** and then slowly flow to a ohmic contact at the edge.

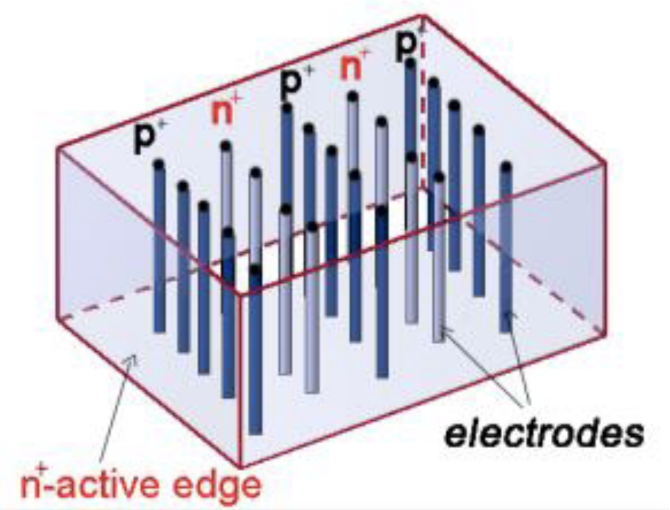


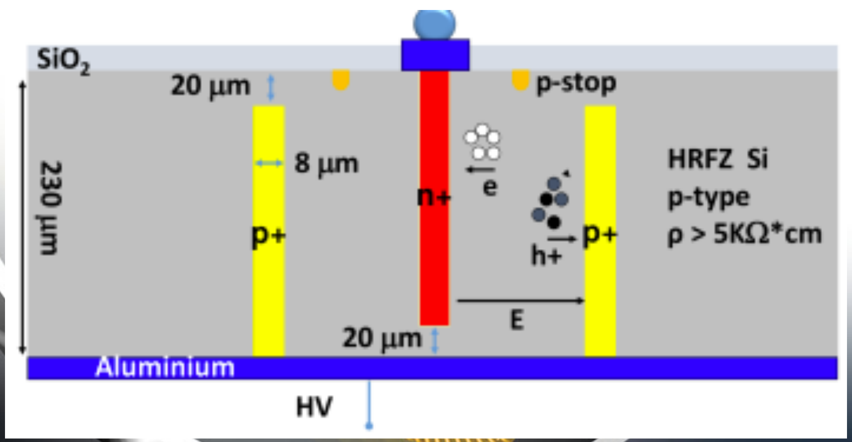
In a simple lumped model, signal current ***i*** goes to the readout electronics if

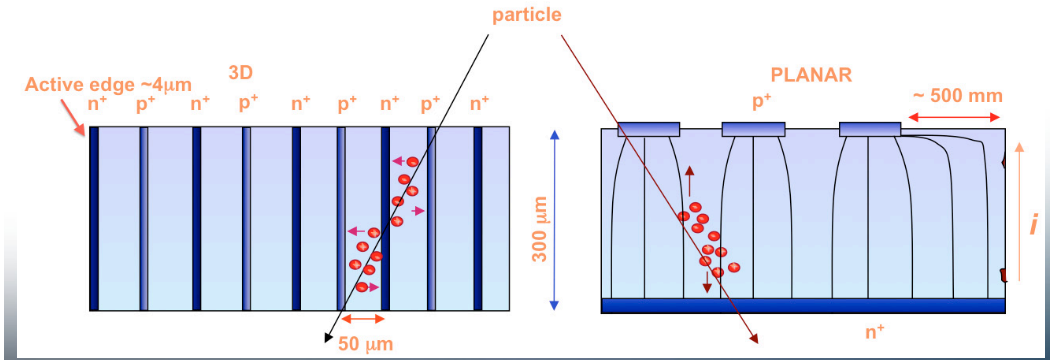
→ $Z(R_{n+}) >> Z(C_{AC})$

ITk Pixel Technologies: 3D

- **3D Silicon detectors: radiation-hard sensor technology**
  - **Electrode distance decoupled from thickness**
    - → smaller drift distance
    - → faster charge collection
    - → less trapping
    - → radiation hardness
  - **lower $V_{depletion}$ → less power dissipation, cooling**
  - **Active or slim edges are natural feature of 3D technology**





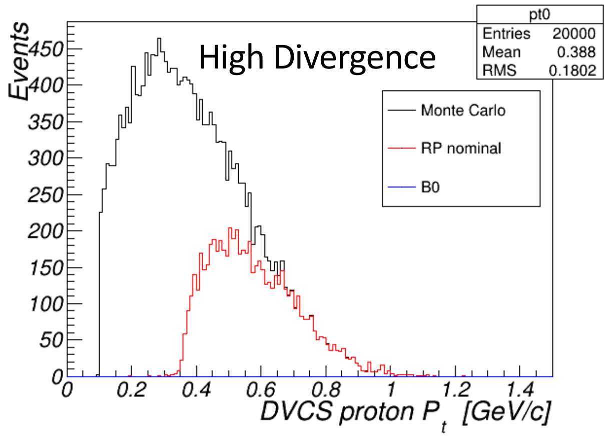


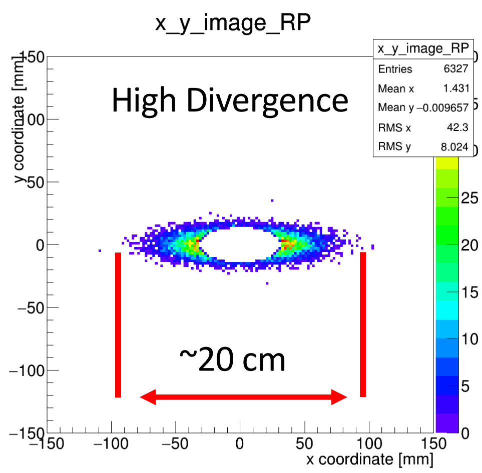
Full Simulations

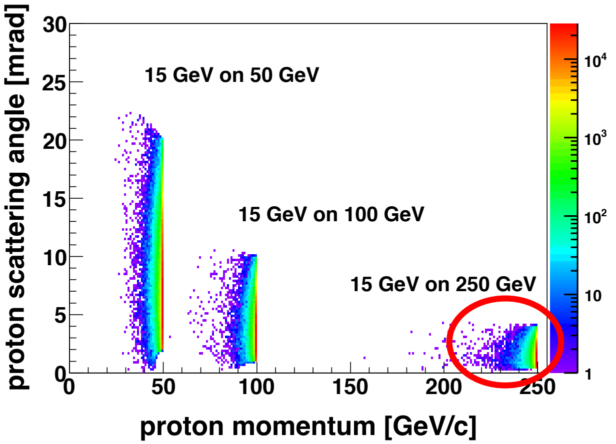
- e+p exclusive events generated using MILOU – a generator of DVCS events.
- All machine elements, magnetic fields, detectors, etc. implemented in simulation using GEANT4.
- Various beam energies considered (5(e)x41(p) GeV, 10x100 GeV, 18x275GeV)
- Effects from beam angular divergence and vertex smearing from crab cavity rotation included.

Detector Acceptance

275 GeV DVCS Proton Acceptance

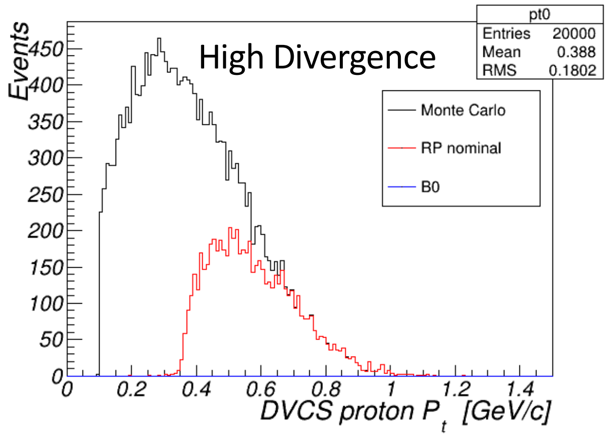


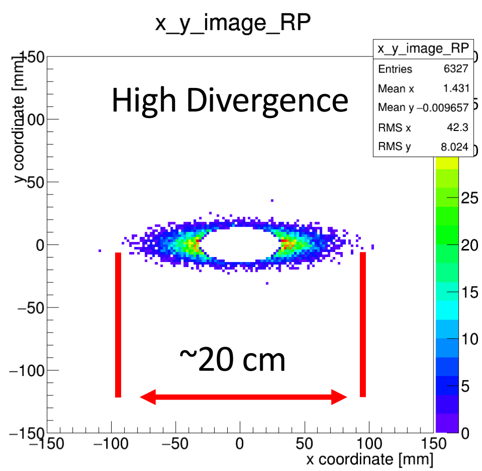


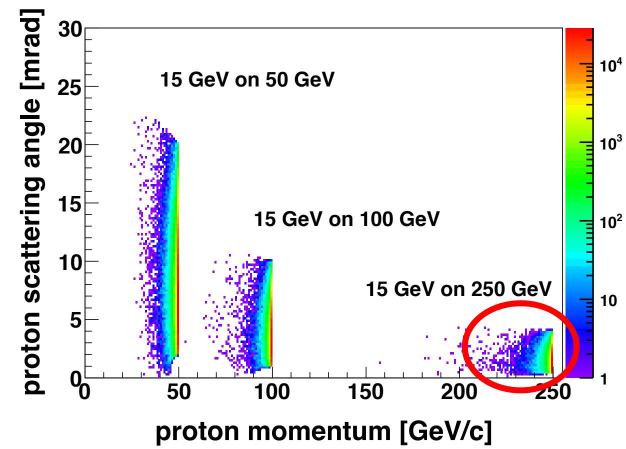


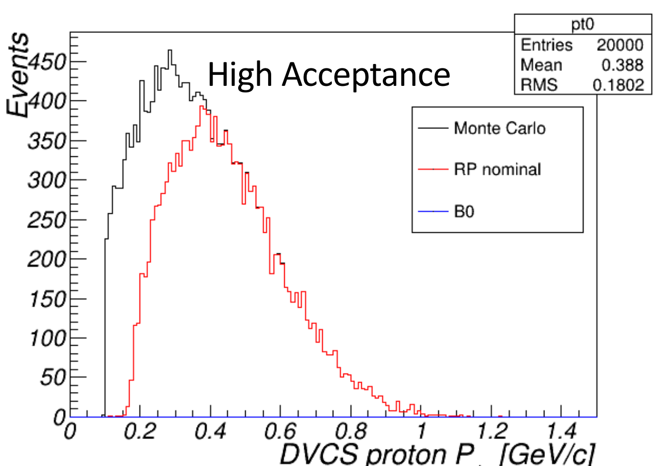
The high divergence configuration severely reduces the low p_t acceptance.

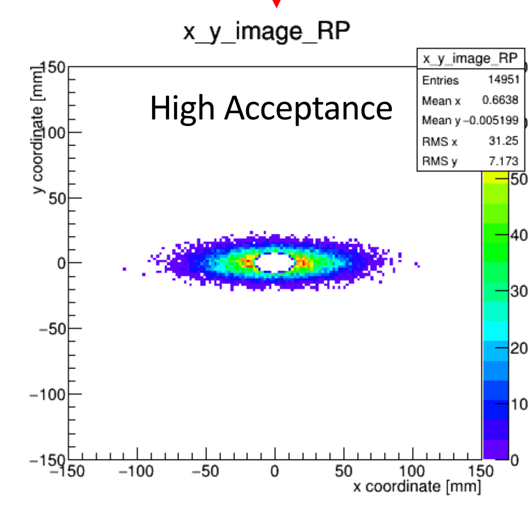
275 GeV DVCS Proton Acceptance







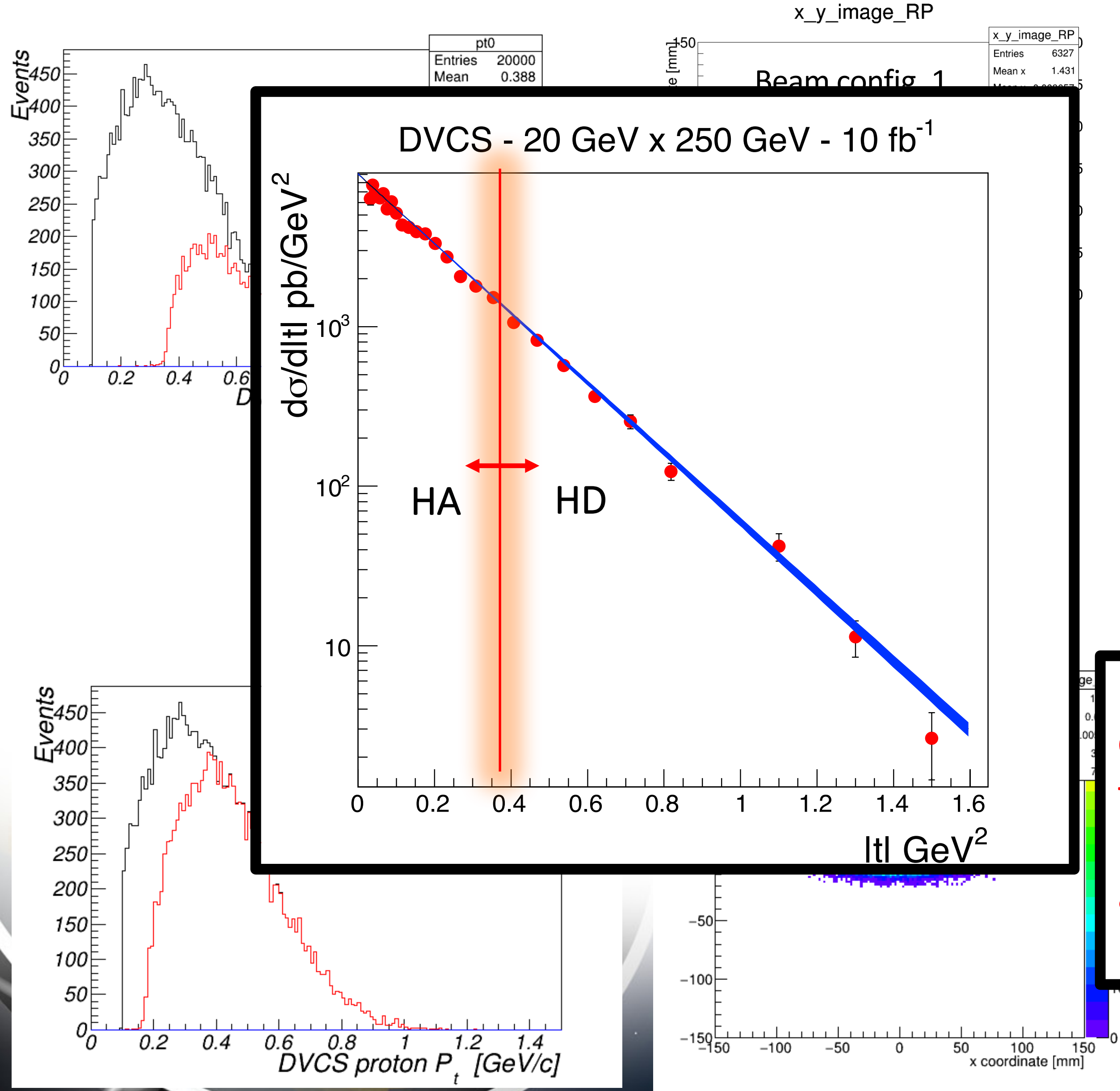


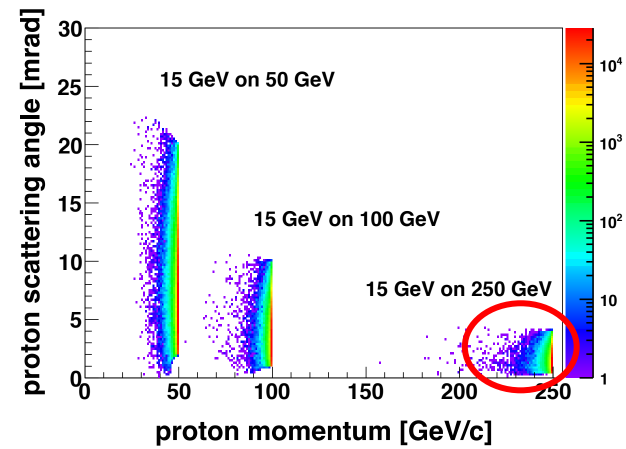


High Divergence: smaller β^* at IP, but bigger $\beta(z = 30m)$ -> higher lumi., larger beam at RP

High Acceptance: larger β^* at IP, smaller $\beta(z = 30m)$ -> lower lumi., smaller beam at RP

275 GeV DVCS Proton Acceptance





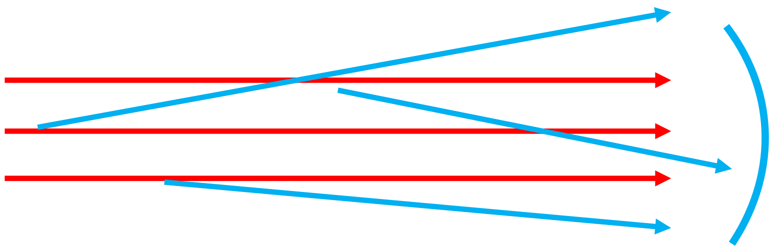
The high divergence configuration severely reduces the low p_t acceptance.

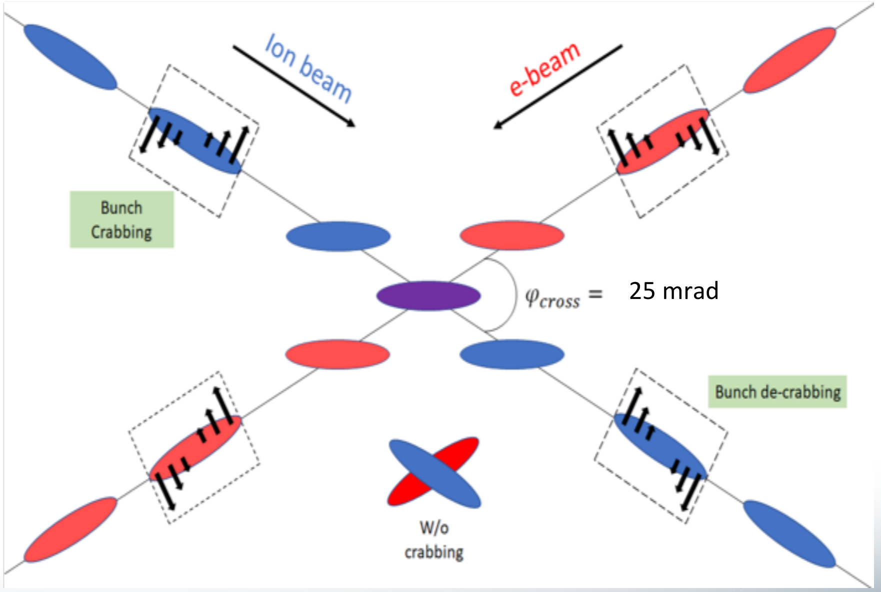
Using the two configurations, we are able to measure the low-t region (with better acceptance) and high-t tail (with higher luminosity).

Momentum Resolution

Digression: particle beams

- Angular divergence
  - Angular "spread" of the beam away from the central trajectory.
  - Gives some small initial transverse momentum to the beam particles.
- Crab cavity rotation
  - Can perform rotations of the beam bunches in 2D.
  - Used to account for the luminosity drop due to the crossing angle – allows for head-on collisions to still take place.

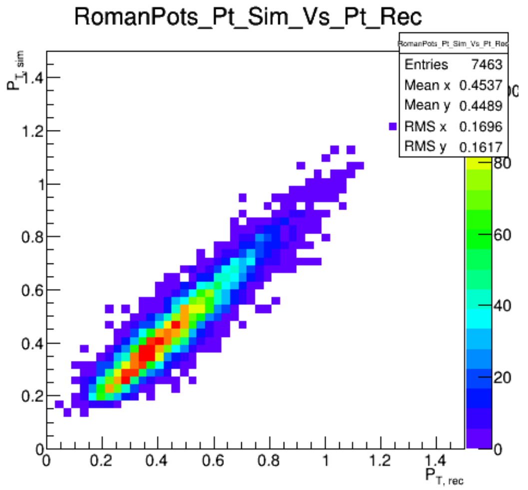


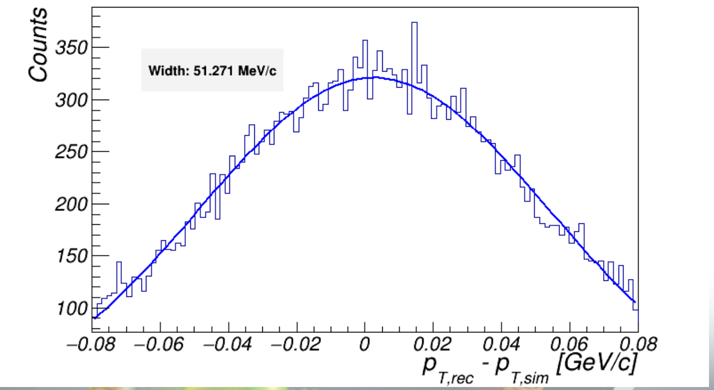


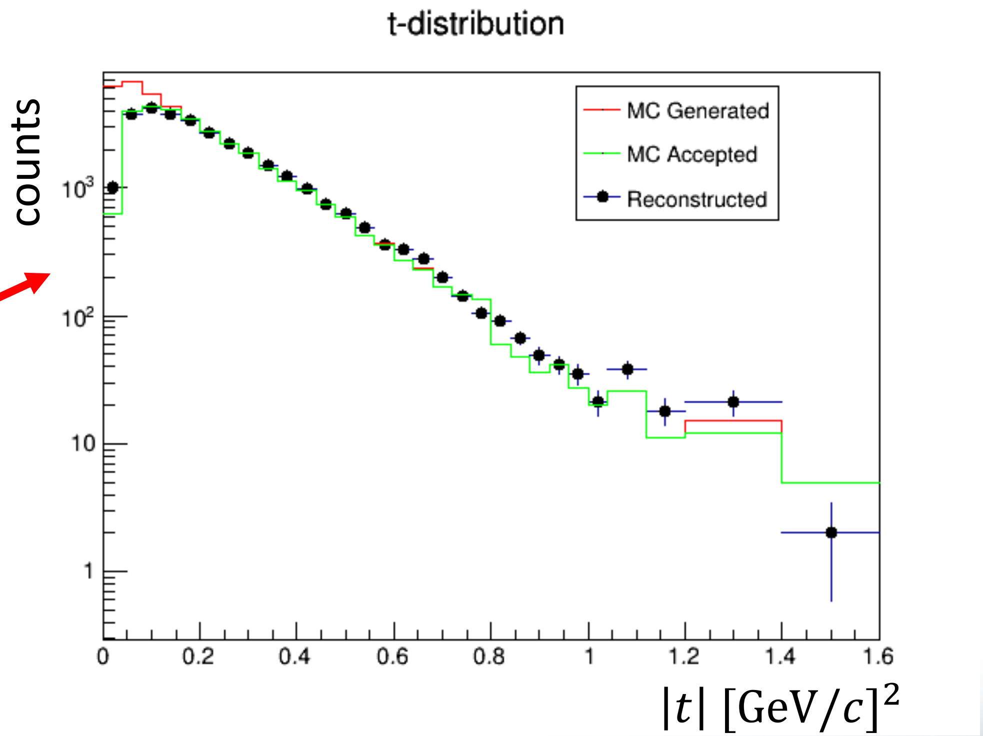
These effects introduce smearing in our momentum reconstruction.

Momentum Resolution – 275 GeV

- Beam angular divergence (HD) -> $\Delta p_t \sim 40$ MeV/c
- Finite pixel size on sensor -> $\Delta p_t \sim 3$ MeV/c to 25 MeV/c [55um x 55um to 1.3mm x 1.3mm].
- Vertex smearing from crab rotation-> $\Delta p_t \sim 20$ MeV/c – removable with precise (~35ps) timing.



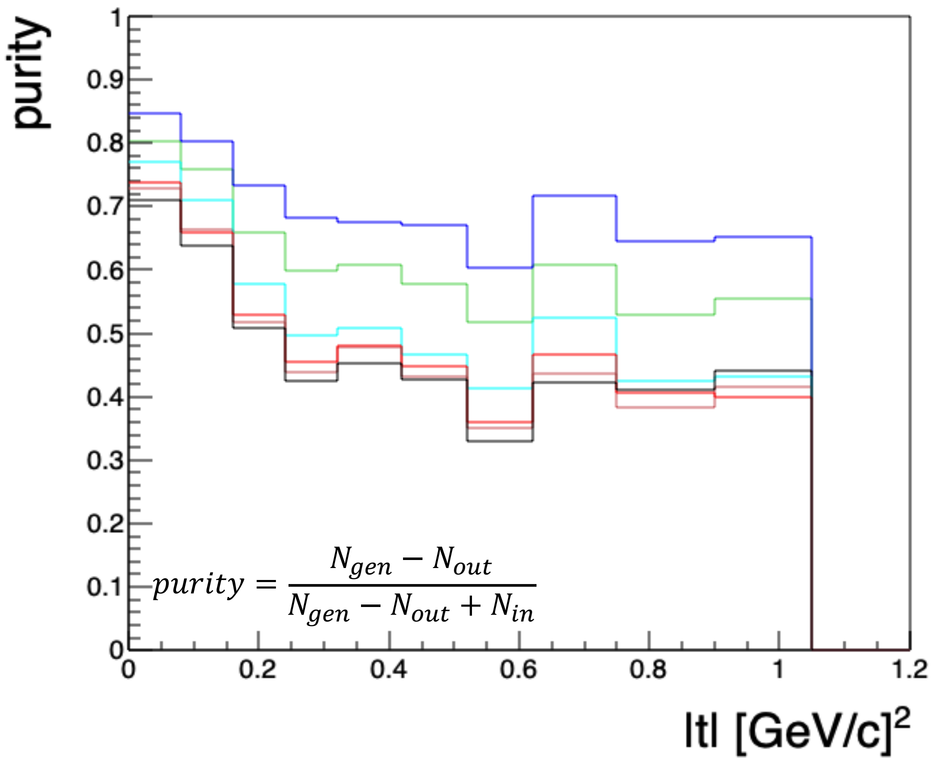




Total (worse-case): $\Delta p_t \sim 55$ MeV/c.

Momentum Resolution – 275 GeV

- Beam angular divergence (HD) -> $\Delta p_t \sim 40$ MeV/c
- Finite pixel size on sensor -> $\Delta p_t \sim 3$ MeV/c to 25 MeV/c [55um x 55um to 1.3mm x 1.3mm].
- Vertex smearing from crab rotation-> $\Delta p_t \sim$20 MeV/c – removable with precise (~35ps) timing.

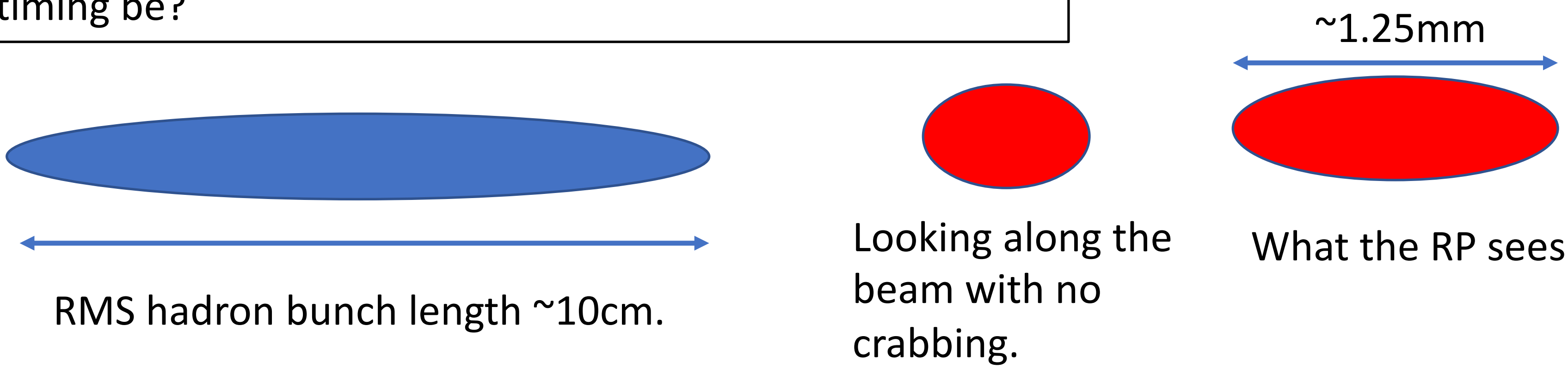


Total smearing in p_T:

- 30 MeV/c (HA + timing + 500um pxl)
- 38 MeV/c (HA + timing + 1.3mm pxl)
- 42 MeV/c (HD + timing + 500um pxl)
- 45 MeV/c (HD + no timing + 500um pxl)
- 51 MeV/c (HD + timing + 1.3mm pxl)
- 55 MeV/c (HD + no timing + 1.3mm pxl)

Momentum Resolution – Timing

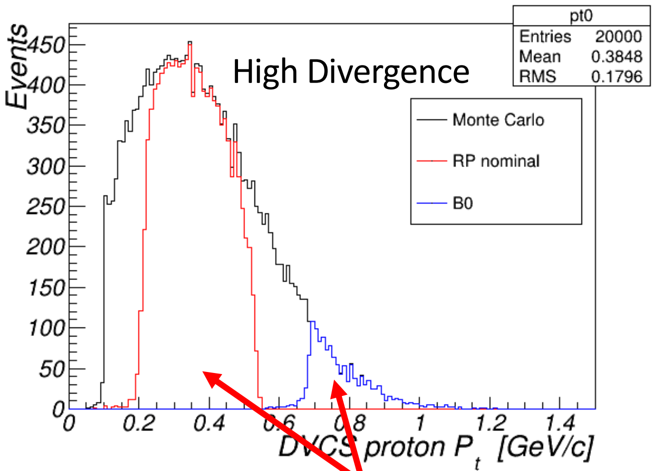
For exclusive reactions measured with the Roman Pots we need good timing to resolve the position of the interaction within the proton bunch. But what should the timing be?

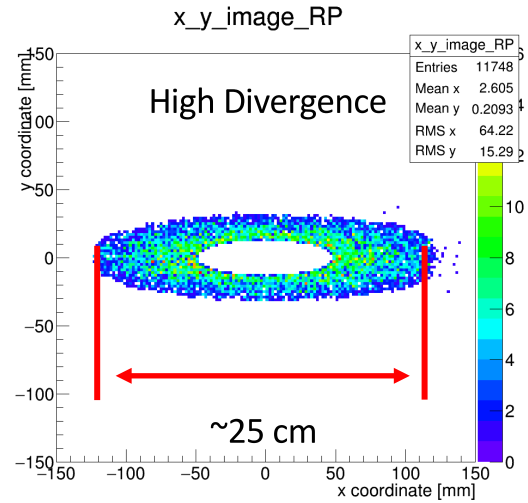


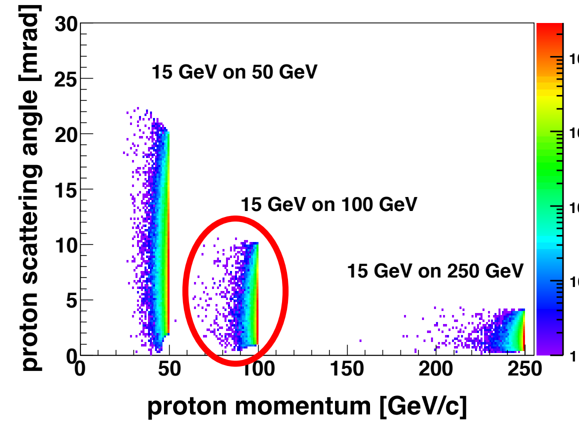
- Because of the rotation, the Roman Pots see the bunch crossing smeared in x.
- Vertex smearing = 12.5mrad (half the crossing angle) * 10cm = **1.25 mm**
- If the effective vertex smearing was **for a 1cm bunch**, we would have **.125mm** vertex smearing.
- The simulations were done with these two extrema and the results compared.

> - **From these comparisons, reducing the effective vertex smearing to that of the 1cm bunch length reduces the momentum smearing to negligible from this contribution.**
> - **This can be achieved with timing of ~ 35ps (1cm/speed of light).**

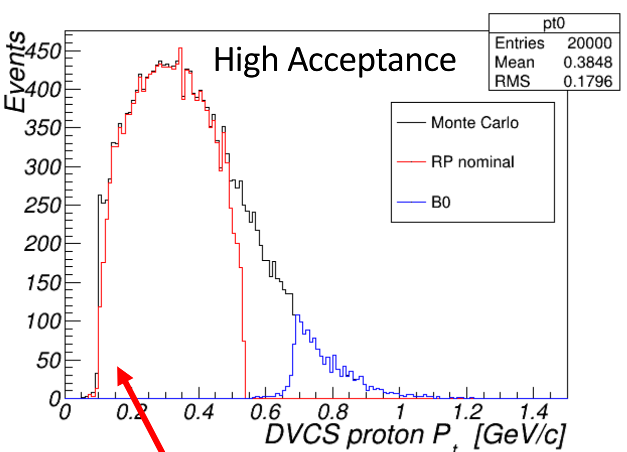
100 GeV DVCS protons

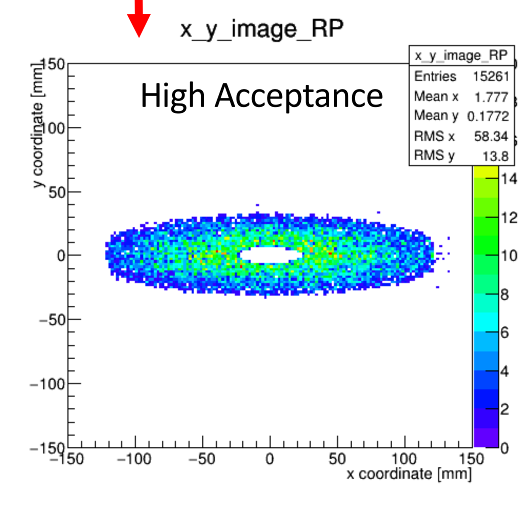






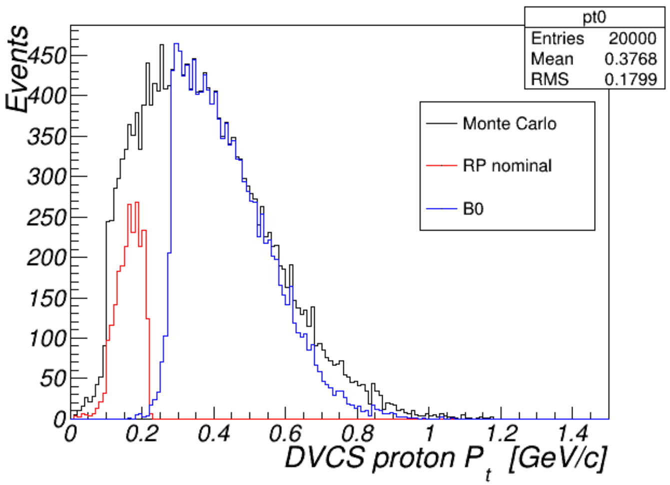
Need both detector systems together here!

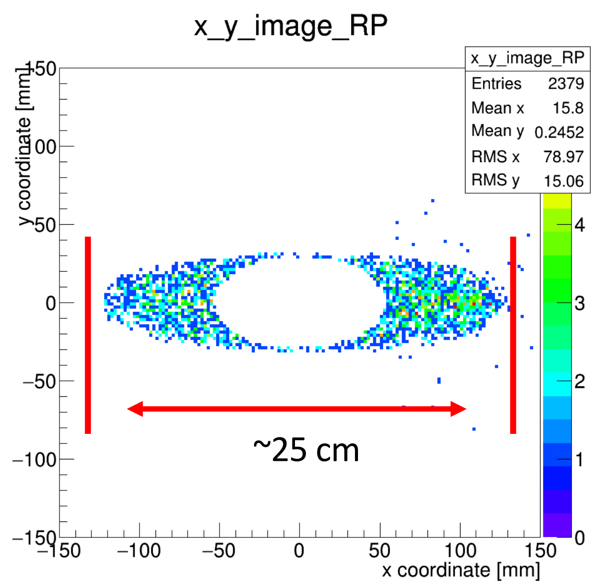


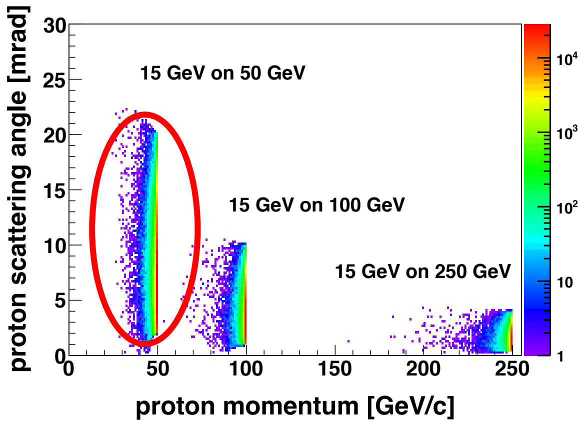


Improves low p_t acceptance.

41 GeV DVCS protons



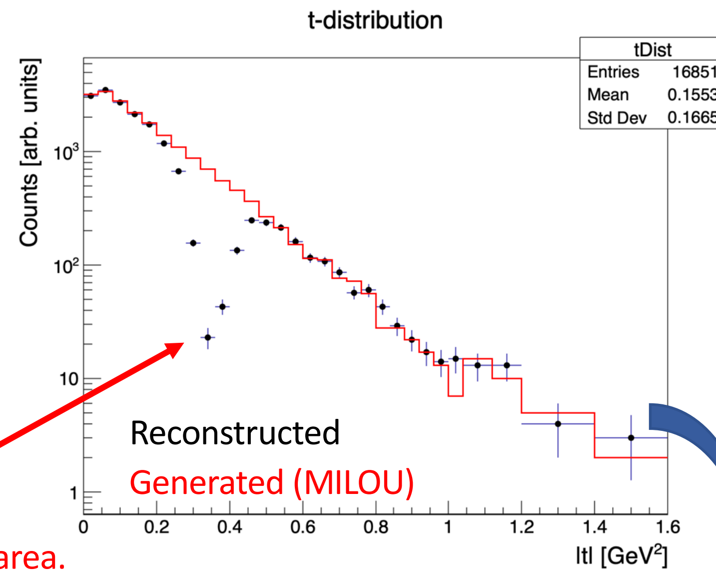




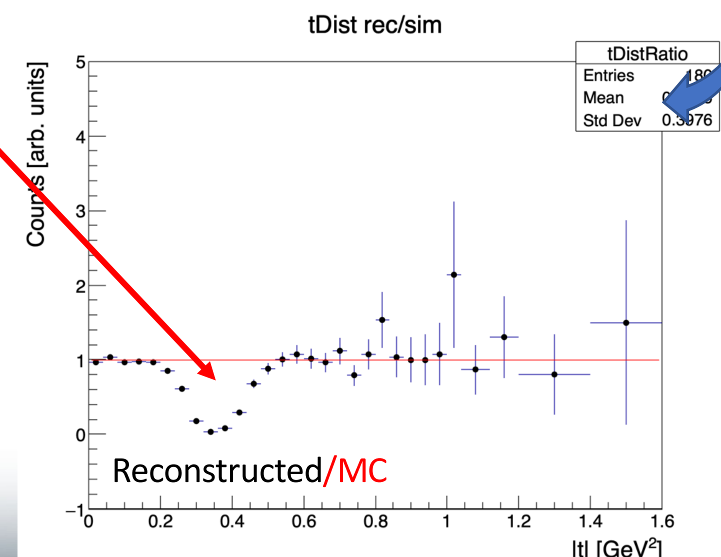
- Only one beam configuration for now.
- Acceptance gap still observed.
- Lower acceptance at high p_t.
- B0 plays largest role at this beam energy.

Momentum Resolution – 100 GeV

	Ang Div.	20um pxl	55um pxl	500um pxl	Vtx Smear
Roman Pots Δp_t [MeV/c]	22	-	-	10	9
B0 Δp_t [Mev/c]	25	17	38	-	20



Acceptance "grey" area.



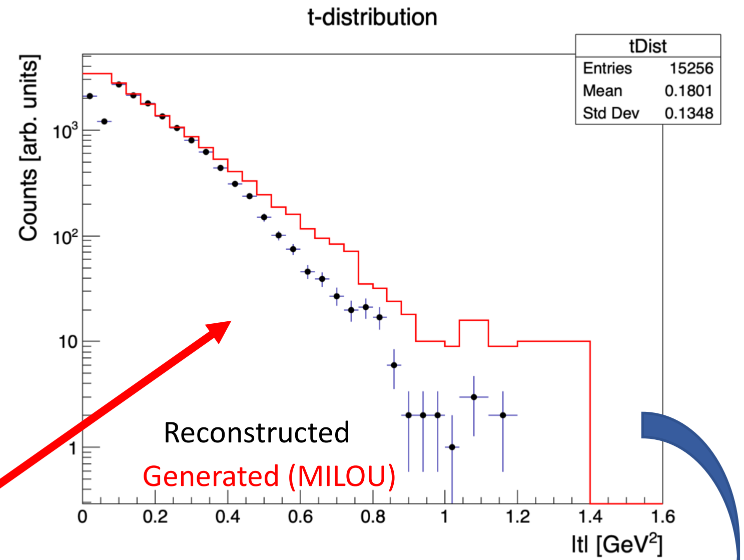
- Total:
  - RP: $\Delta p_t \sim 23$ MeV/c (worst case)
  - B0: $\Delta p_t \sim 26$ MeV/c (20 um pixels)
- |t|-reconstruction requires combined Roman Pots and B0 information.
- Still allows reconstruction of |t|-dist since data points exist on both sides of gap.

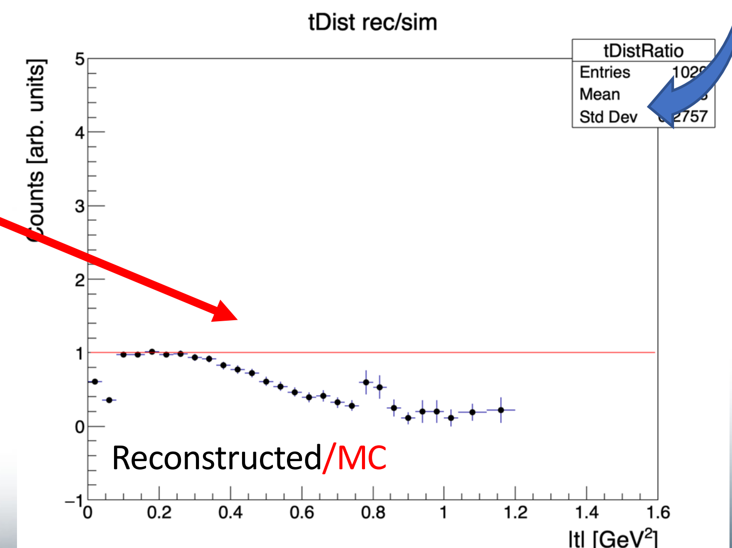
Momentum Resolution – 41 GeV

	Ang Div.	20um pxl	55um pxl	500um pxl	Vtx Smear
Roman Pots Δp_t [MeV/c]	14	N/A	N/A	10	10
B0 Δp_t [Mev/c]	17	13	25	N/A	10

- Total:
    - RP: $\Delta p_t \sim 15$ MeV/c (worse case)
    - B0: $\Delta p_t \sim 18$ MeV/c (20um pixels)
- |t|-reconstruction requires B0 for majority of reconstruction.

Some acceptance issues.
Optimization of B0 sensor layout in GEANT ongoing.





Still need to optimize the location of the detectors.