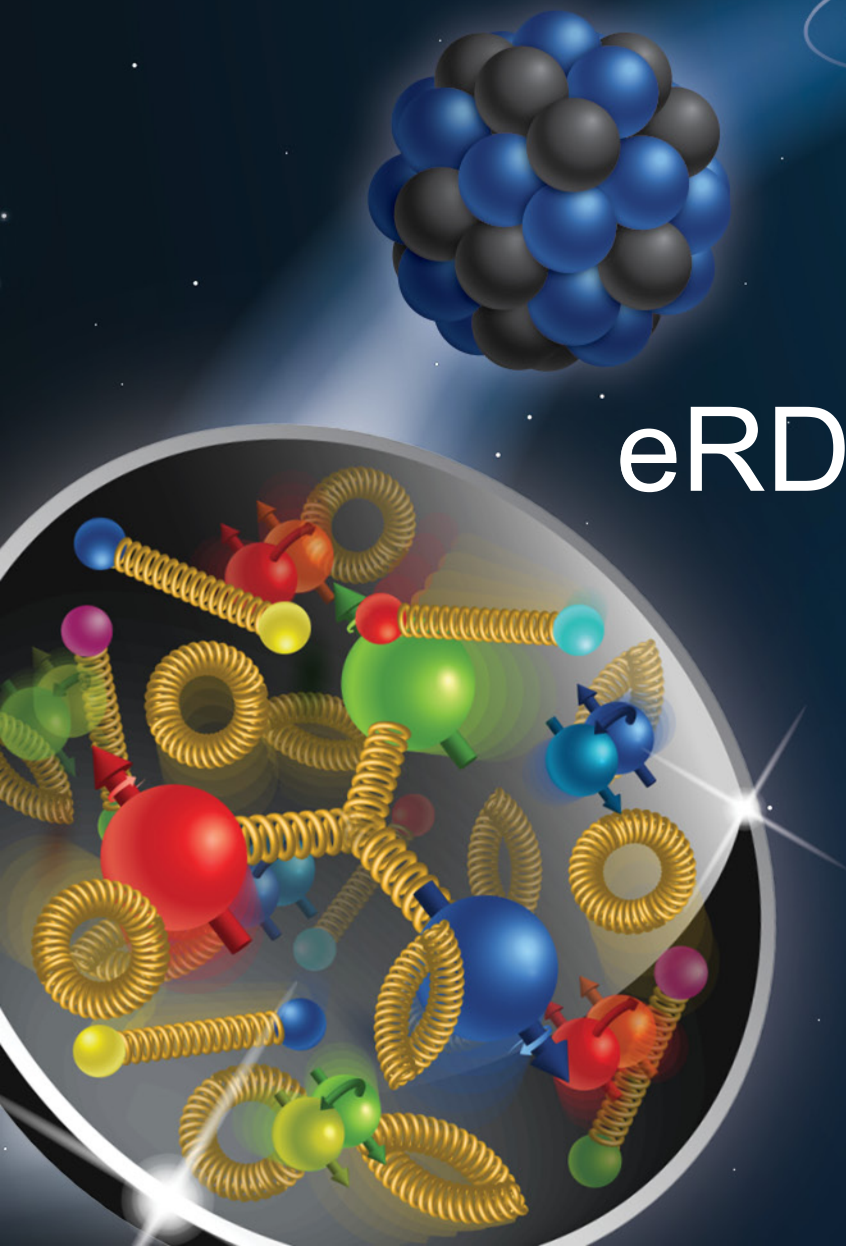


eRD24 Progress Report

EIC R&D Meeting, 7/24/2020

A. Jentsch and G. Giacomini
on behalf of eRD24

Electron Ion Collider

BROOKHAVEN NATIONAL LABORATORY

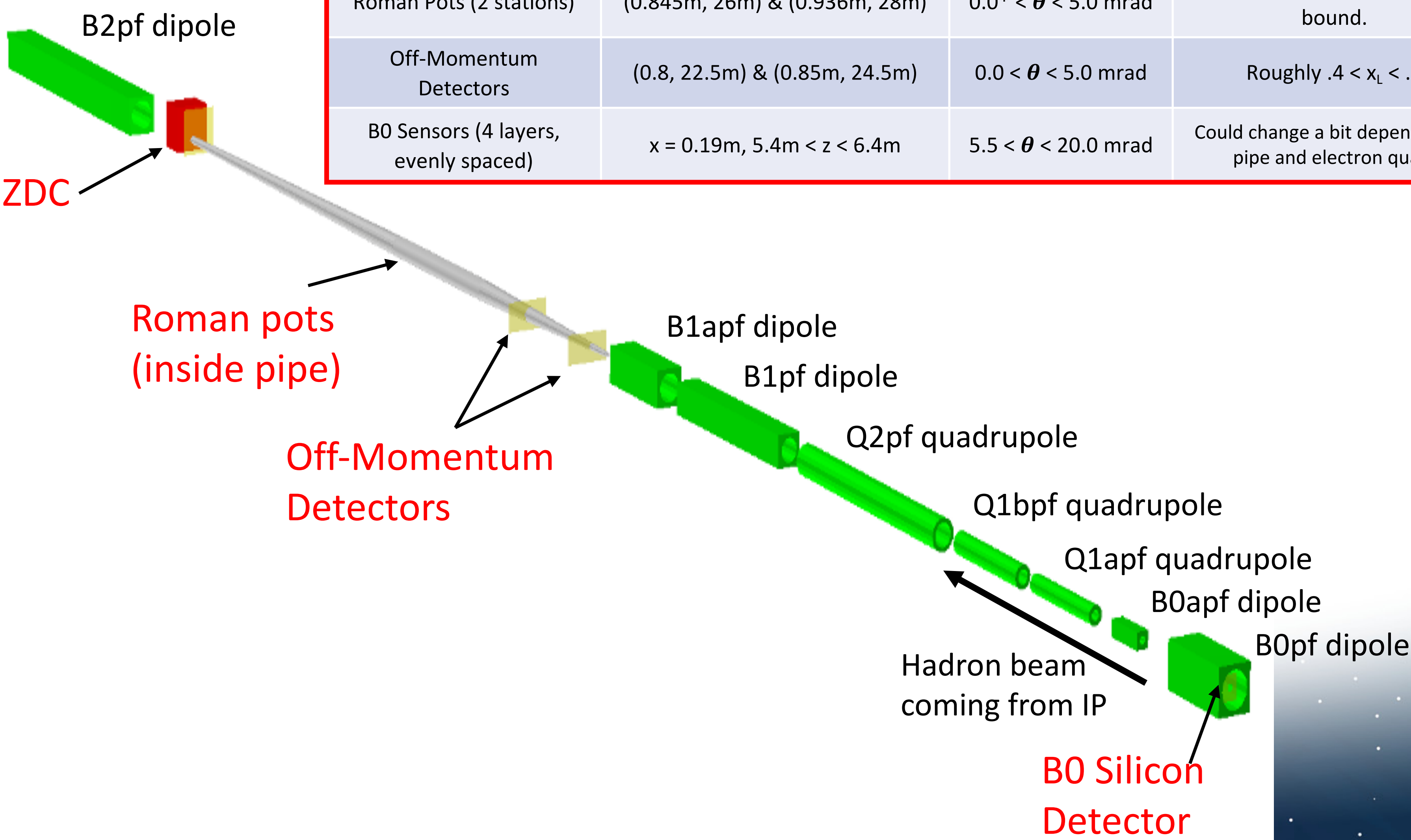
U.S. DEPARTMENT OF ENERGY | Office of Science

Simulations

Layout of Far-Forward Region

$$x_L = \frac{p_{z,nucleon}}{p_{z,beam}}$$

Detector	Detector Position (x,z)	Angular Acceptance	Notes
ZDC	(0.96m, 37.5m)	θ < 5.5 mrad	About 4.0 mrad at $\varphi \sim \pi$
Roman Pots (2 stations)	(0.845m, 26m) & (0.936m, 28m)	0.0* < θ < 5.0 mrad	*10σ cut determines lower bound.
Off-Momentum Detectors	(0.8, 22.5m) & (0.85m, 24.5m)	0.0 < θ < 5.0 mrad	Roughly .4 < x_L < .6
B0 Sensors (4 layers, evenly spaced)	x = 0.19m, 5.4m < z < 6.4m	5.5 < θ < 20.0 mrad	Could change a bit depending on pipe and electron quad.

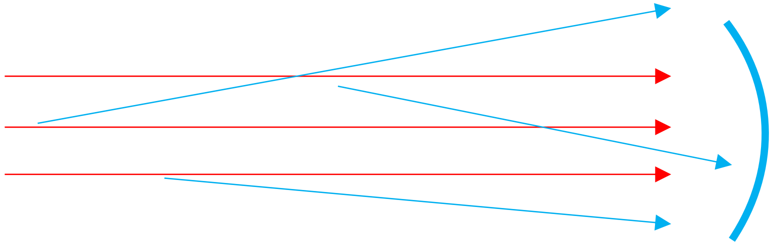


Open questions from last report and new study

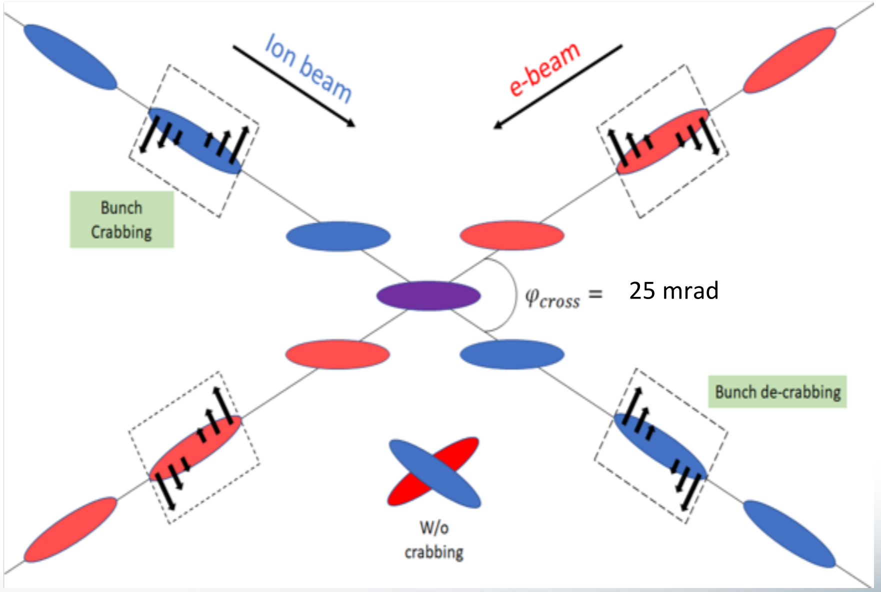
- How do we justify the timing need?
  - It seems like the angular divergence dominates the smearing – why does the crab smearing need to be removed with such precise timing?
- Do we really need edgeless sensors?
  - Imposes extra challenge on sensor design – is it necessary?
- Addition of “off-momentum detectors” for proton tagging from incoherent e+A collisions (see backup).

Reminder: Smearing Contributions

- 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.

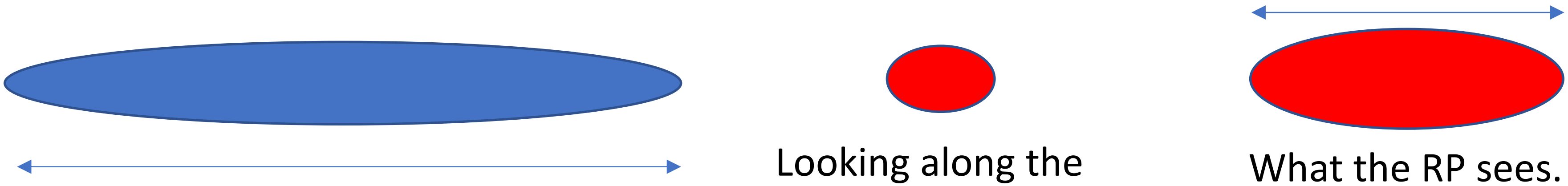


These effects introduce smearing in our momentum reconstruction.

Reminder: 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?

~1.25mm



RMS hadron bunch length ~10cm*.
*based on "ultimate" machine performance.

Looking along the beam with no crabbing.

What the RP sees.

- 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 **0.125mm** vertex smearing.
- The simulations were done with these two extrema and the results compared.

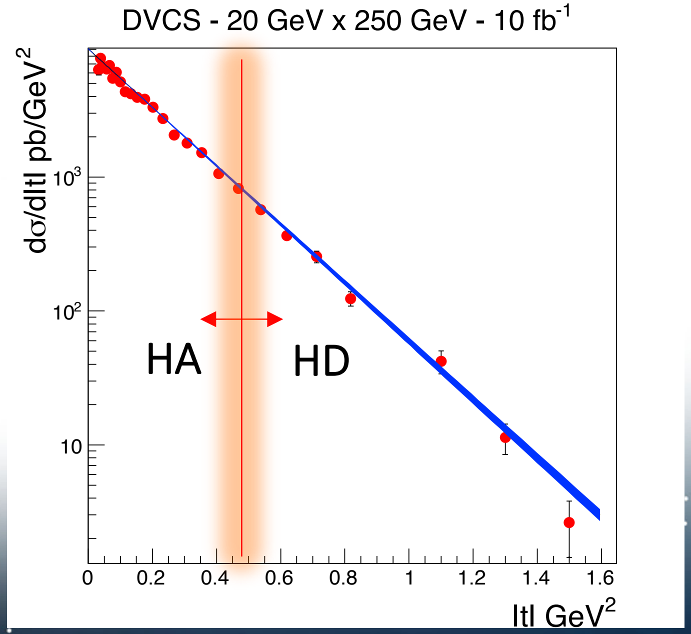
> - **From these comparisons, reducing the effective vertex smearing to that of the 1cm bunch length reduces the momentum smearing to a negligible amount from this contribution.**
> - **This can be achieved with timing of ~ 35ps (1cm/speed of light).**

Reminder: Divergences and Optics Parameters

- Two configurations
  - **High divergence (HD)** – beta functions tuned such that small beam at IP (higher luminosity), at the cost of larger beam at Roman Pots (meaning worse low-pt acceptance).
  - **High acceptance (HA)** – Larger beam at IP, lower luminosity, better low-pt acceptance at the Roman Pots.

	18x275 GeV		10x100 GeV	
	HA	HD	HA	HD
RMS $\Delta\theta_H$, (urad)	65	133	180	203
RMS $\Delta\theta_V$, (urad)	277	251	243	227
Luminosity 10^{33} $cm^{-2}s^{-1}$	0.94	1.93	4.07	4.35

Note: there are ongoing discussions with C-AD about different configurations that significantly reduce divergence. One of those test cases was used previously to see what it did to the smearing.



Reminder: Comparison

- The various contributions add in quadrature (this was checked empirically, measuring each effect independently).

$$\Delta p_{t,total} = \sqrt{(\Delta p_{t,AD})^2 + (\Delta p_{t,CC})^2 + (\Delta p_{t,pxl})^2}$$

Angular divergence

Primary vertex smearing from crab cavity rotation.

Smearing from finite pixel size.

These studies based on the "ultimate" machine performance with strong hadron cooling.

	Ang Div. (HD)	Ang Div. (HA)	Vtx Smear	250um pxl	500um pxl	1.3mm pxl
$\Delta p_{t,total}$ [MeV/c] - 275 GeV	40	28*	20	6	11	26
$\Delta p_{t,total}$ [MeV/c] - 100 GeV	22	11	9	9	11	16
$\Delta p_{t,total}$ [MeV/c] - 41 GeV	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
    - *using symmetric divergence parameters in x and y at 100urad.
- **Vertex smearing from crab rotation**
  - Correctable with good timing (~35ps).
  - With timing of ~70ps, effective bunch length is 2cm ->.25mm vertex smearing (~7 MeV/c)
- **Finite pixel size on sensor**
  - 500um seems like the best compromise between potential cost and smearing

Current Parameters in Use

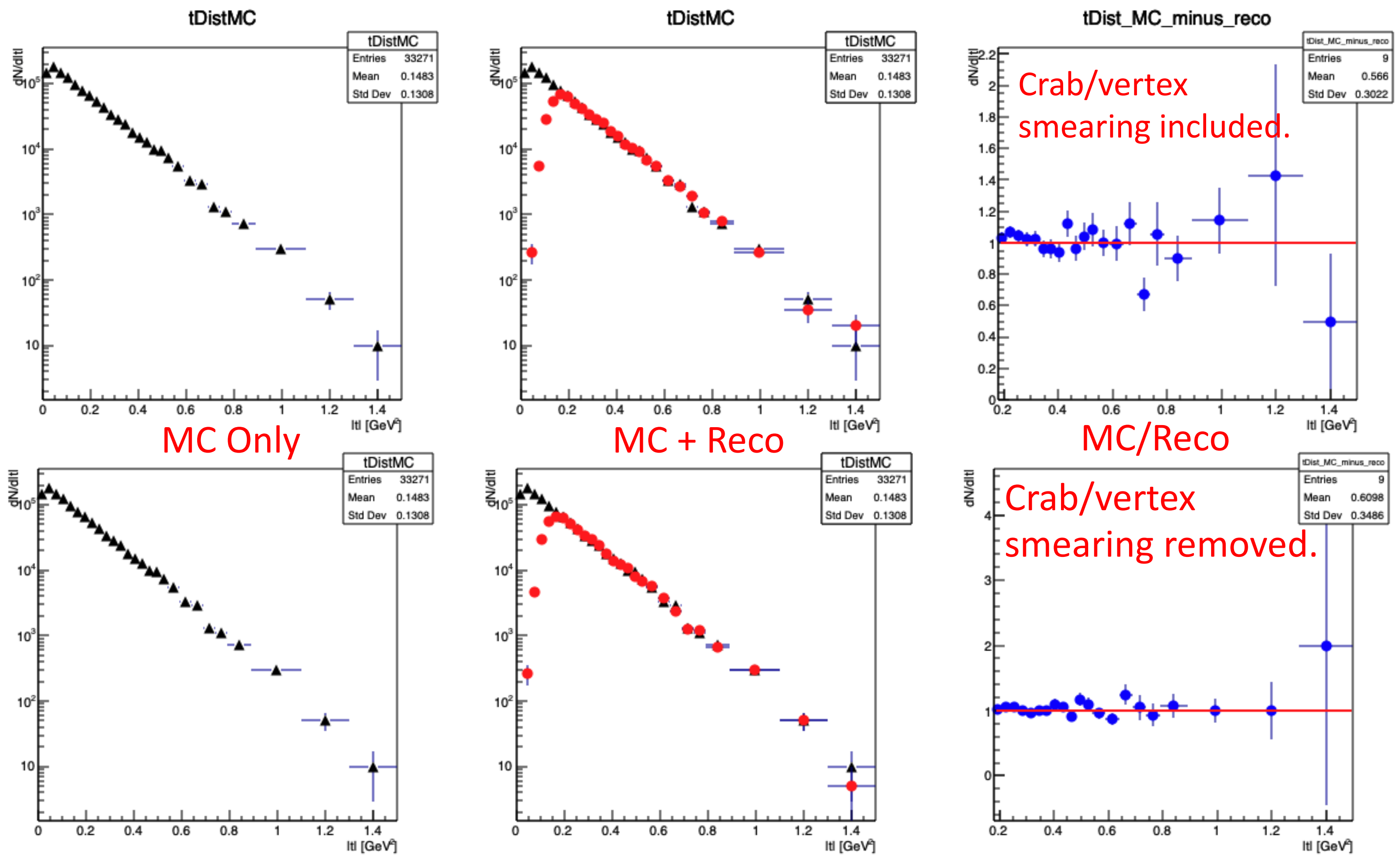
	275GeV	275GeV	275GeV	100GeV	100GeV
Configuration	**HA**	**HD**	**HD v2**	**HA**	**HD**
RMS $\Delta\theta_H$, (urad)	65	132	119	180	203
RMS $\Delta\theta_V$, (urad)	229	253	119	243	227

Angular Divergence

- The above divergences are essentially unchanged compared to what was studied previously.
  - ”HD v2” is a new set of parameters we are using to evaluate the effect of symmetric divergences, and smaller divergences.
- 500um x 500um pixels used for the Roman Pots.
- 20um x 20um pixels used for the B0 sensors (in backup).
- The smaller angular divergence configuration(s) cause the overall smearing contribution from divergences and crab cavity/vertex smearing to be comparable in magnitude.

How does the crab smearing affect reconstruction of t?

18x275 GeV
$0.9 < Q^2 < 50\ GeV^2$
$0.0016 < x < 0.0025$
HD (v2) – new parameters from C-AD



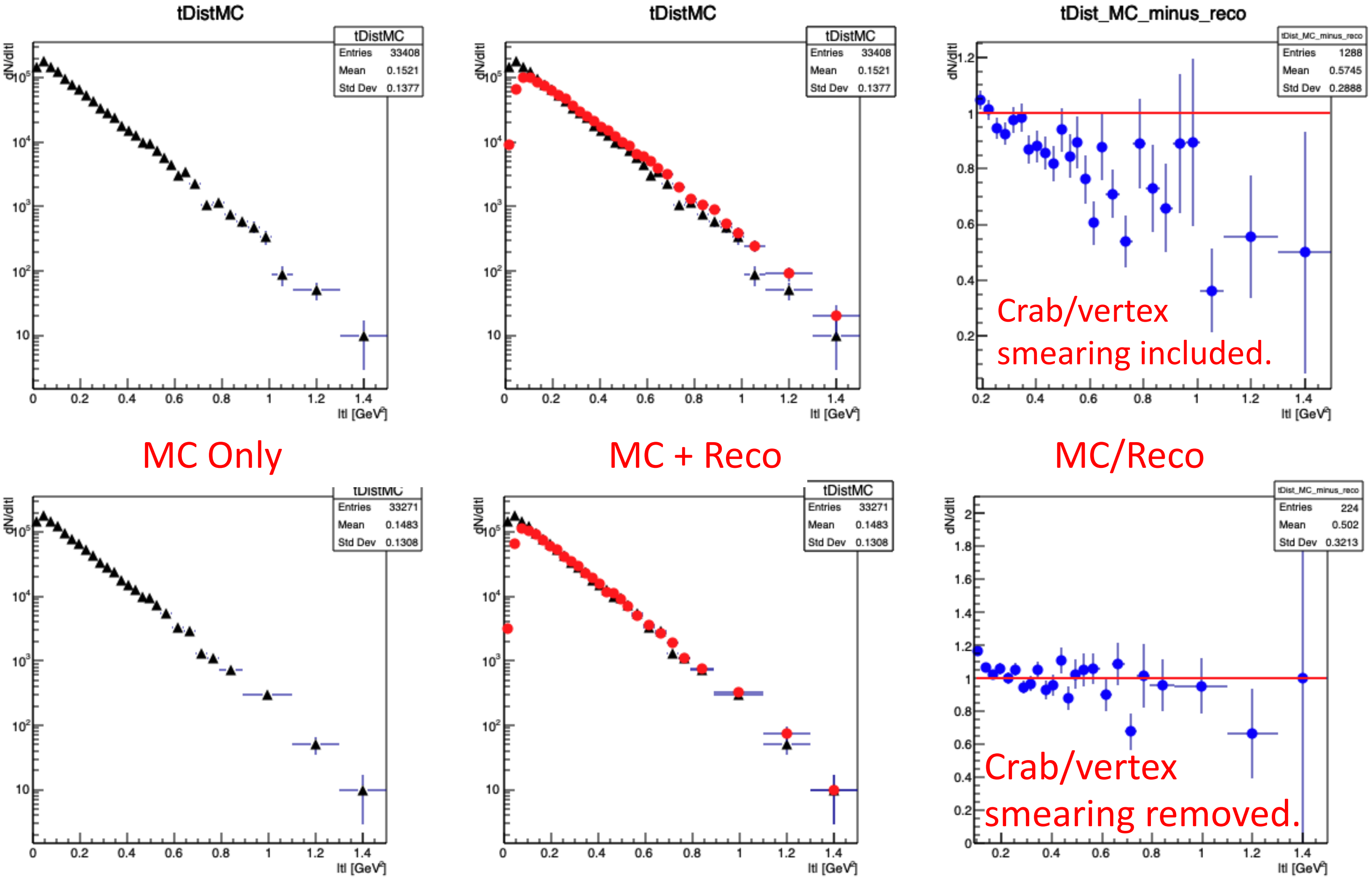
Note: The first few bins are cutoff, where the ratio is dominated by acceptance.

Further Optimization of the Collider Luminosity

- Double the number of bunches in the machine.
  - Less space between bunches, and more background (beam+gas, beam+machine) events.
- Will lead to a bigger crossing angle to avoid parasitic collisions.
  - Potentially up to 50 mrad.

How does the crab smearing affect reconstruction of t?

18x275 GeV
$0.9 < Q^2 < 50$ GeV^2
$0.0016 < x < 0.0025$
HD (v2) – new parameters from C-AD
crossing angle = 50 mrad

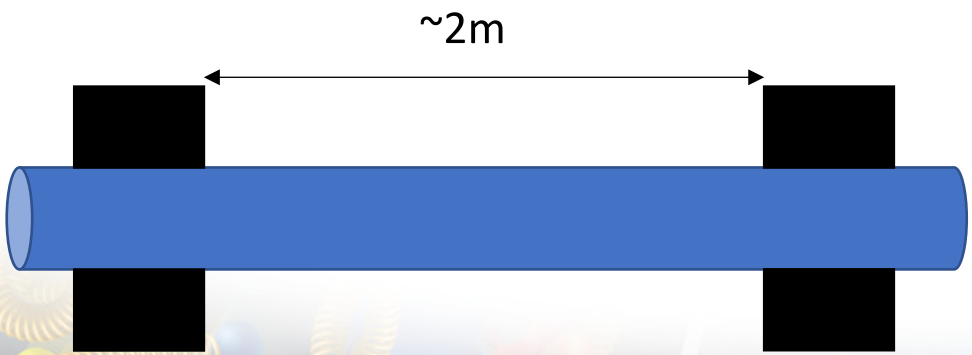


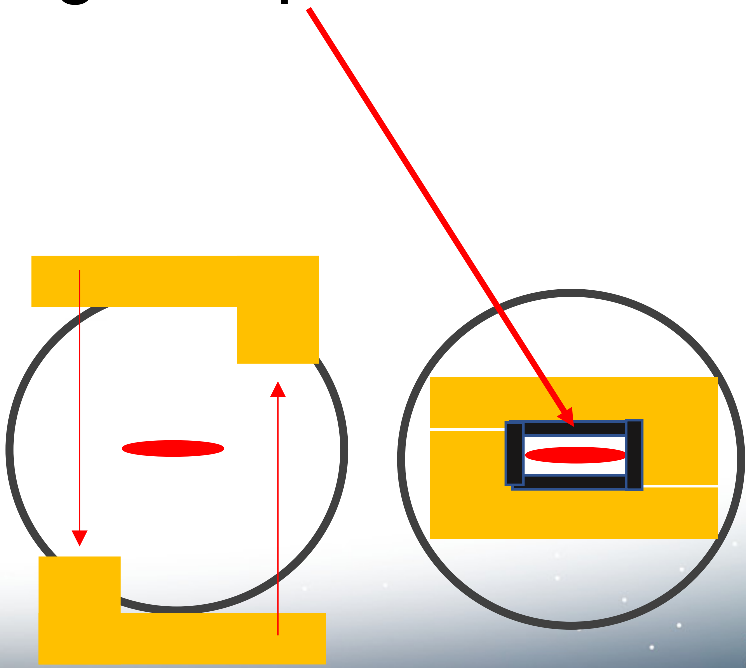
Conclusions from Timing

- With improved optics, the angular divergence and vertex smearing contributions become comparable.
  - Note: we expect improved optics for the Roman Pots for both the HD and HA configurations – we need the resolution to be good for both since the HD configuration helps populate the tails.
- A larger crossing angle (up to 50 mrad) is under consideration.
  - This would make the vertex smearing the dominant contribution, and it has a clear effect on the t-resolution.
- Timing will also be required for background rejection, which is being investigated now.

Sensor Dead Area

- Since Roman Pots are placed very close to the beam, limiting dead area at the sensor edge can be important for improving acceptance at low-pt.





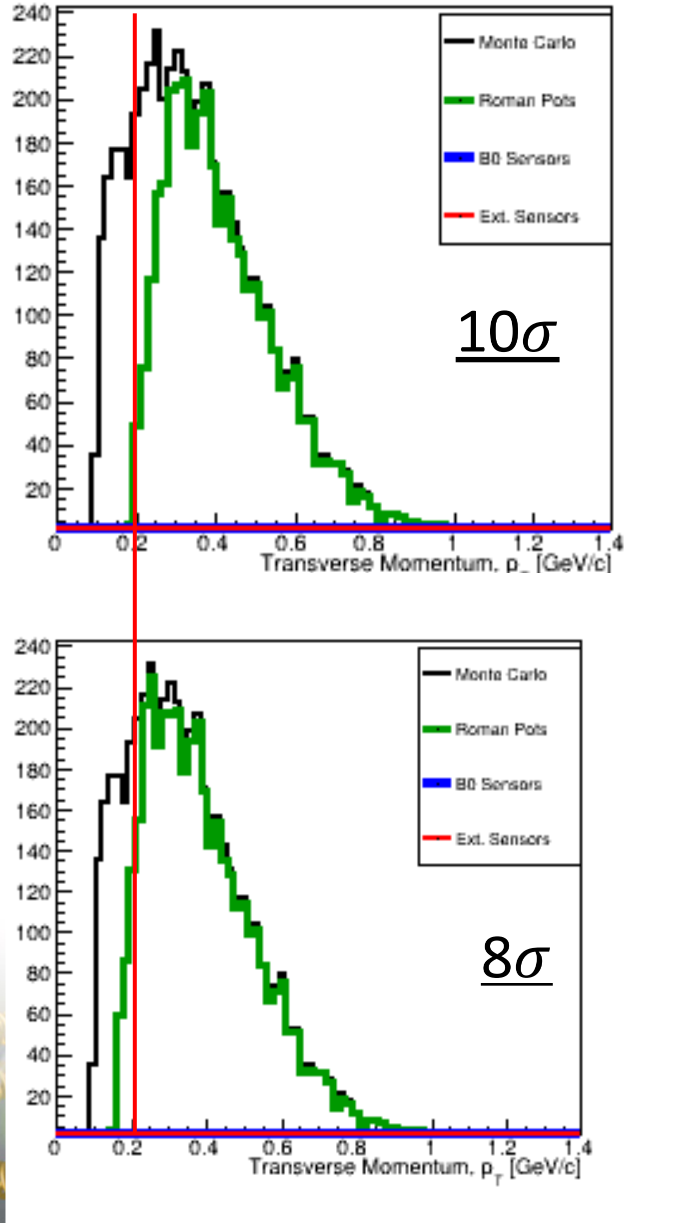
Digression: What is a "σ" cut?

$$\sigma(z) = \sqrt{\varepsilon \cdot \beta(z))}$$

- $\beta(z)$ is the RMS transverse beam size.
  - $\sigma(z)$ is the Gaussian width of the beam, ε is the emittance.
- General rule of thumb is to keep Roman Pot sensors at $\sim 10\sigma$ distance from beam to limit exposure.
  - 275 GeV – 1σ = 1.79 mm (HA) / 3.58 mm (HD)
  - 100 GeV – 1σ = 2.45 mm (HA) / 5.13mm (HD)
  - 41 GeV – 1σ = 6.14 mm

> **What is the effect of moving the sensors closer to the beam?**
> **How does 1σ (~2-6mm) relate to pt-acceptance?**

High Acceptance Case



Move sensors closer to beam in increments of “1σ”.

<u>1σ = 1.79 mm</u>
(for the high acceptance optics)

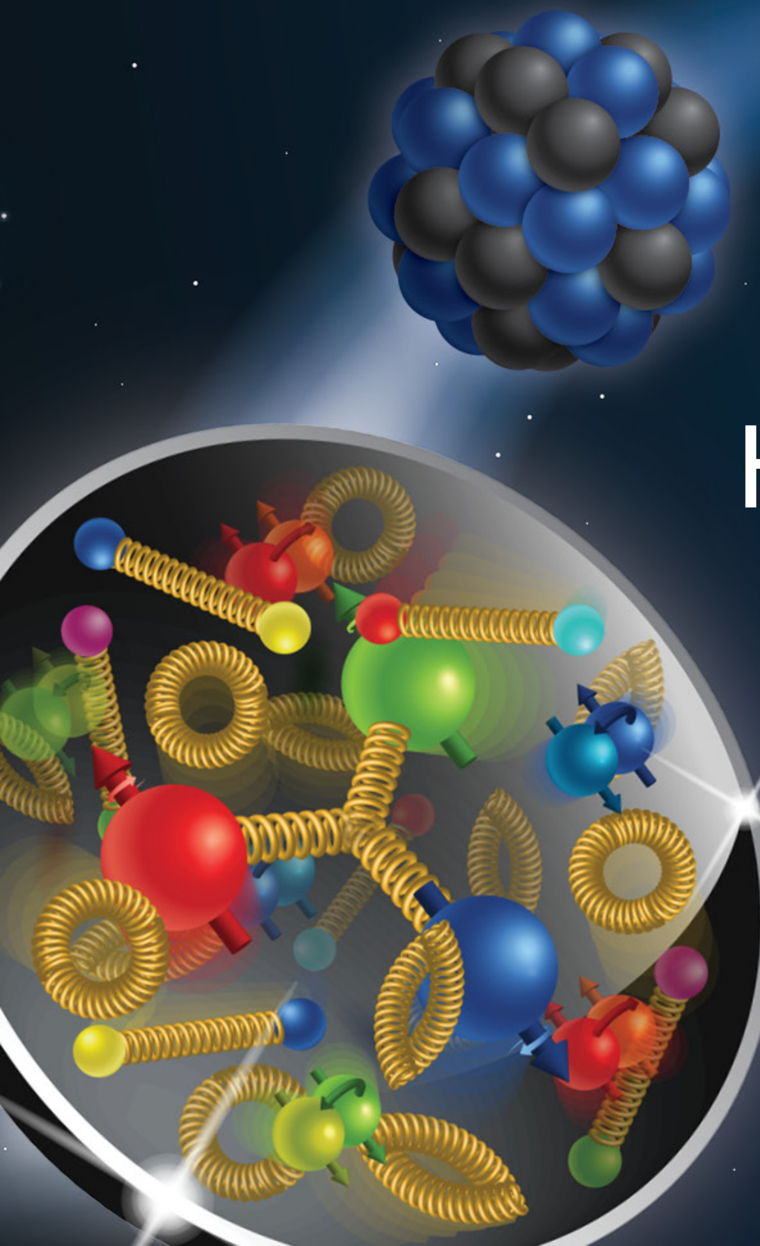
Moving the sensors ~3.6 mm closer (from 10 to 8σ) gains about 50 MeV in pt-acceptance.

Conclusion on Edgeless Requirement

- Every 3.6 mm of additional active area yields ~ 50 MeV more pt-acceptance.
- From this, a dead area (edge) of 0.5mm to 1.0mm is sufficient to not significantly reduce the pt-acceptance.

Simulation Conclusions

- We have a better understanding for the timing needs and justification.
  - We need to be prepared for some changes to machine design that could exacerbate machine backgrounds and smearing effects from crab rotation.
- Having an edgeless sensor is nice, but potentially not a stringent need.
- The sensor requirements for the Roman Pots can be used for Off-Momentum Detectors (see backup), and also potentially for a timing layer in the B0.
- The simulations serve as a guide for the further hardware development (presented next).



Hardware: Roman Pot sensors and read-out ASICs

Our collaboration is expanding:
New members:

- University of California Santa Cruz and SCIPP:
  Bruce Schumm, Hartmut Sadrozinski, Abe Seiden
  They bring their expertise in LGADs/AC-LGADs (inventors of AC-LGAD concept)

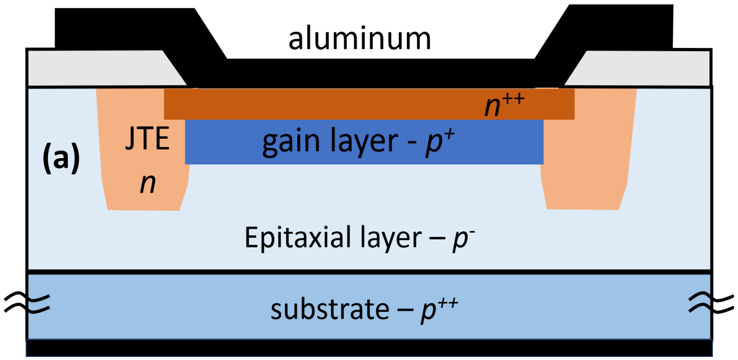
- Omega/Orsay (France), Christophe De La Taille, Laurent Serin – developers of the ALTIROC chip, to be used as fast read-out of LGADs in ATLAS HGTD

- Mathieu Benoit recently joined BNL, with expertise on readout electronics, sensor testing and simulations

- We are aware of the proposal ToF-LGAD by Wei Li (Rice) and we are willing to closely cooperate.

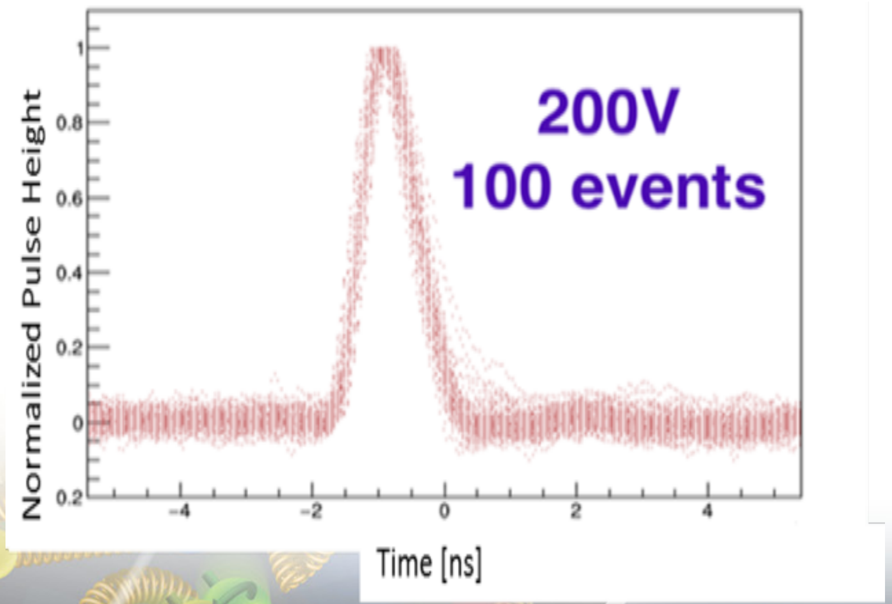
Timing with LGADs

LGAD (BNL) design:



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**
  - **30-50 μm thickness**
  - **Large S/N ratio**
  - **Fast-timing: ~30-50 ps per hit, dominated by Landau fluctuations**

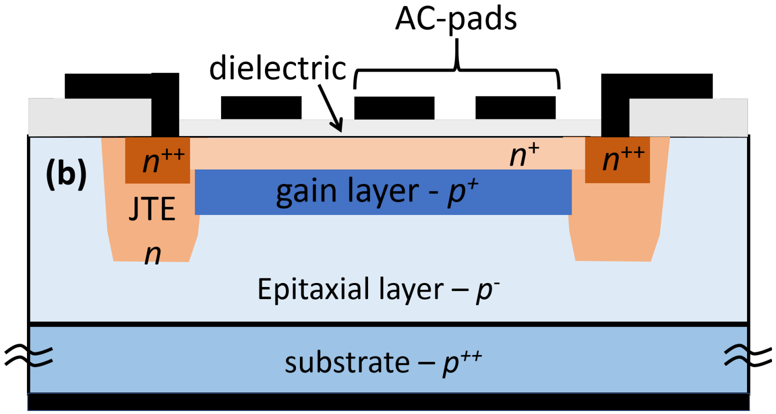


50um thick LGAD, gain=20
Very constant shape!

- 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

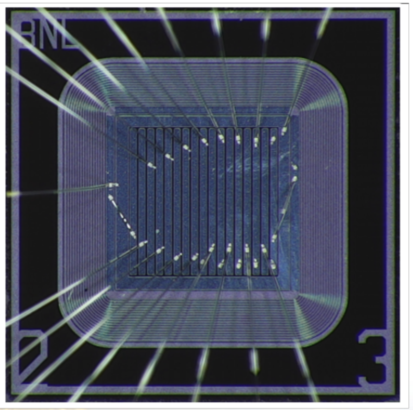
Timing and space with AC-LGADs

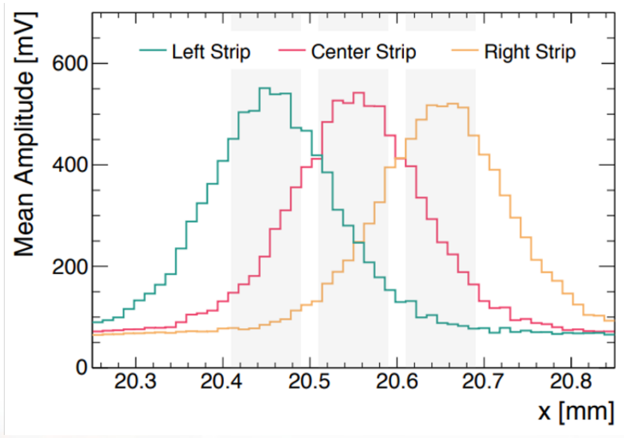
Problem: LGADs do not allow fine segmentation. Another concept is required:



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

Beam Test at FNAL





AC-LGAD 2mmx2mm strip sensor.

- Strip pitch = 100um
- Wire bonded to a multichannel TA board (FNAL)

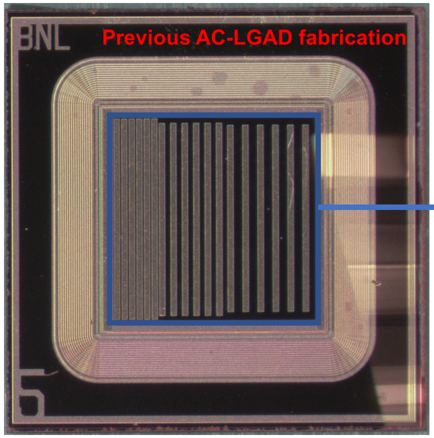
Confirmed:

- 100% fill factor
- Good spatial resolution (limited by the telescope resolution), better than 50um
- Good timing resolution, comparable to LGAD

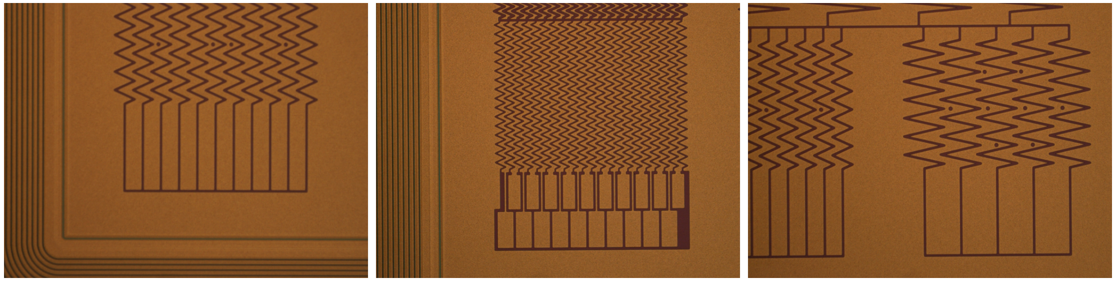
"Measurements of an AC-LGAD strip sensor with a 120 GeV proton beam," arXiv:2006.01999

AC-LGAD design and production for RPs

- New designs in upcoming wafer productions to address RP-specific requirements
  - Optimized configurations to study induced signal on adjacent pixels/strips

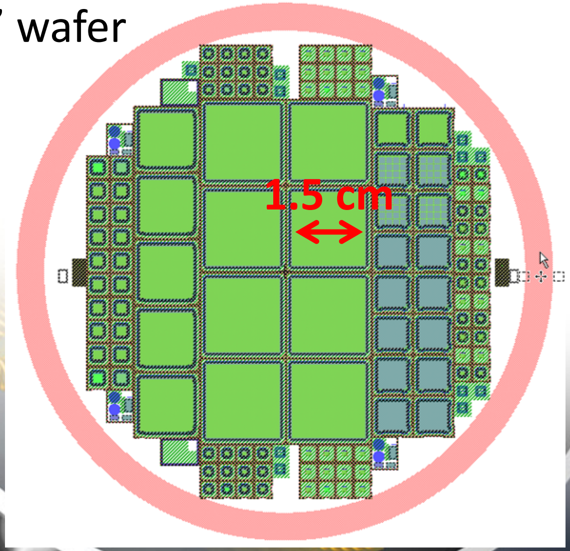


Several chips in a few wafers with different configurations, including zig-zag strips to improve spatial resolution.



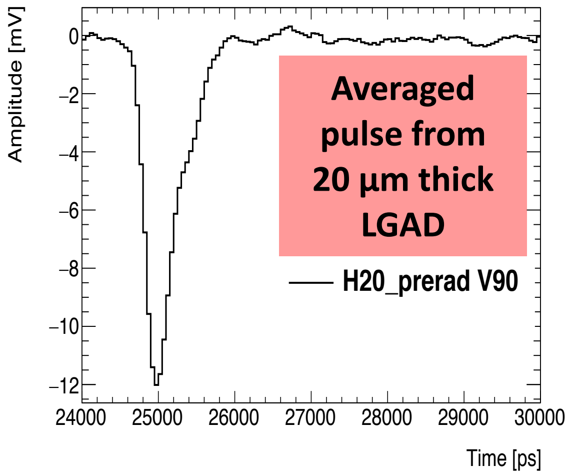
➢ Performance of such structures will be compared with standard designs

4” wafer



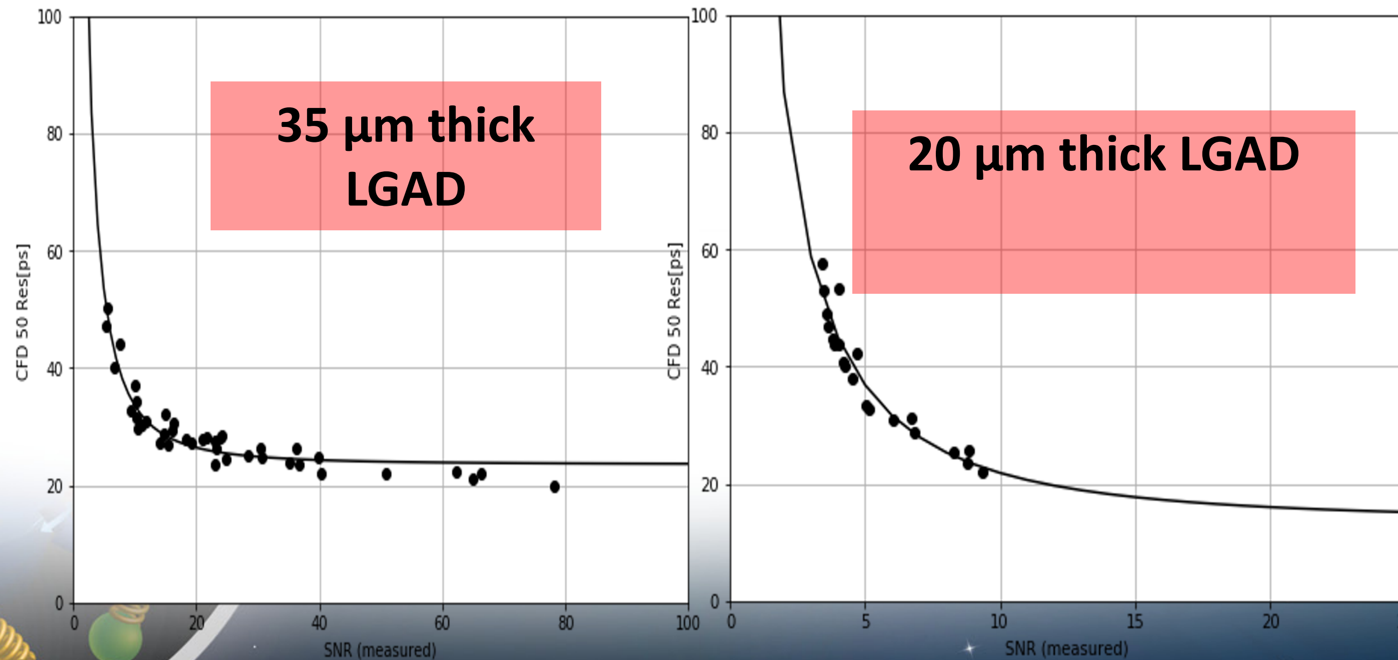
New wafer layout designed; process started.
Metal yet to be designed: electrodes are independent from the rest of the geometry. We’ll optimize configurations to study induced signal on adjacent pixels/strips.
The design features devices with larger area, slim edges that can accommodate a trench termination.
objective: reduce the inactive area below 100um.

THIN LGAD: Measured time resolution versus S/N ratio



- **Signal much larger than baseline fluctuations**
  ➔ very good S/N even with a gain of only 8.
- **Rise-time (10-90%) about 150 picoseconds compared to about 500 picoseconds for the 50um sensor in earlier slide.**
- **Contribution to the time resolution from Landau fluctuations is roughly proportional to the detector thickness so smaller for thinner detectors (expected to be ~ 10 picoseconds for the 20 micron thick sensor).**

Time resolution for minimum ionizing particles measured for thin detectors versus the signal-to-noise ratio.



Proposed working plan

New fabrication of AC-LGAD:

- Devices with larger active area (up to 1.5cm x 1.5 cm), towards more realistic dimension of the final sensor
- New shapes of AC-coupled electrodes (zig-zag, etc)
- Double metal to allow a variety of AC-coupled electrodes
- Thinner substrates: 20um and 30um wafers already ordered

Continuation of tests:

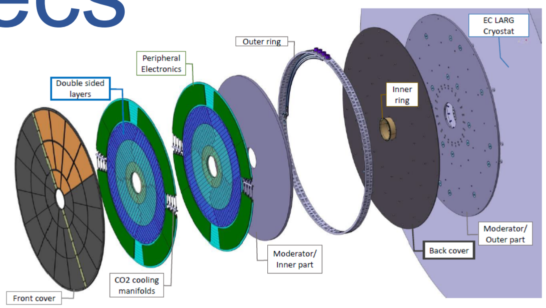
- lab tests: response to betas, gain, TCT, timing resolution
- beam tests

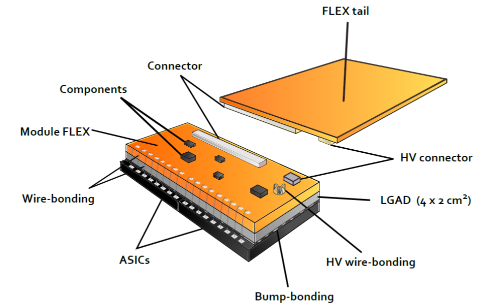
Continuation of TCAD numerical simulations:

- Insight of process parameters (doping of resistive layers, oxide thickness)

ALTIROC ASIC specs

ALTIROC to be used in ATLAS HGTD, as read-out of DC-coupled LGADs





(Coloured area most relevant for a use in Roman pots)

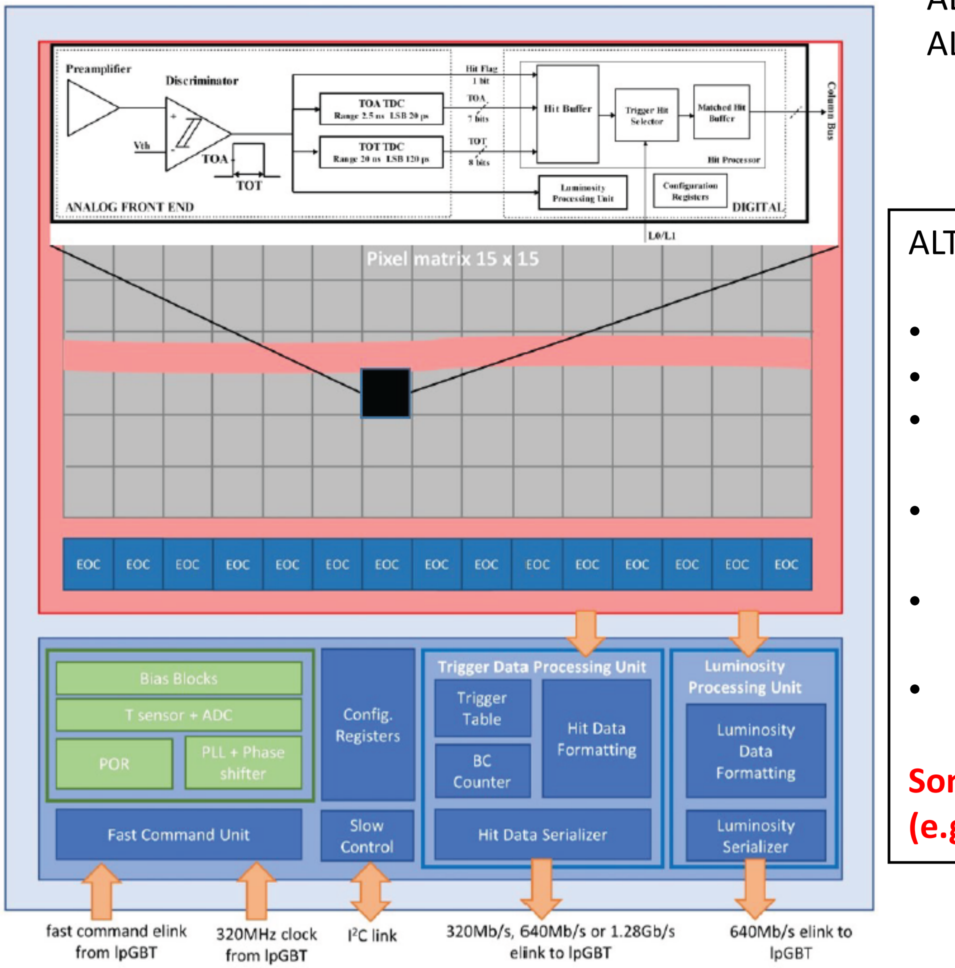
Pad size	$1.3 \times 1.3\,\mathrm{mm}^2$
Voltage	1.2 V
Power dissipation per area (per ASIC)	$300\,\mathrm{mW\,cm}^{-2}$ (Total: 1.2 W)
e-link driver bandwidth	$320\,\mathrm{Mbit\,s}^{-1}$, $640\,\mathrm{Mbit\,s}^{-1}$, or $1.28\,\mathrm{Gbit\,s}^{-1}$
Temperature range	−40 °C to 40 °C
TID tolerance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

- 130 nm CMOS TSMC technology
- Limited power consumption and operation at -30°C with CO2 cooling (10 % improvement in the jitter w.r.t. room temperature)
- ASIC bandwidth selected by slow control

Maximum leakage current	5 µA
Single pad noise (ENC)	$<3000\,e^- = 0.5$ fC
Cross-talk	< *2.5 %*
Threshold dispersion after tuning	< 10%
Maximum jitter	25 ps at 10 fC 70 ps at 4 fC
TDC contribution	< 10 ps
Time walk contribution	< 10 ps
Minimum threshold	2 fC
Dynamic range	4 fC–50 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

- Noise < 3000 e- for 4 pF
- Time measurement :
  - ❑ Time of Arrival (ToA) measured wrt to Bunch Crossing clock over +/- 1.25 ns
  - ❑ Time over Threshold (TOT) measured for amplitude estimate and Time Walk correction offline
- Threshold as low as 2 fC
- Reference clock of each ASIC can be phase adjusted to take into account time of flight/cable…. But still some skew in ASIC

ALTIROC architecture



ALTIROC0 (2018): 4ch, preamp + discriminator (no TDC)
ALTIROC1 (2019): 25ch, preamp + discriminator
+ TDC and SRAM

ALTIROC2 (November 2020): full size ASIC

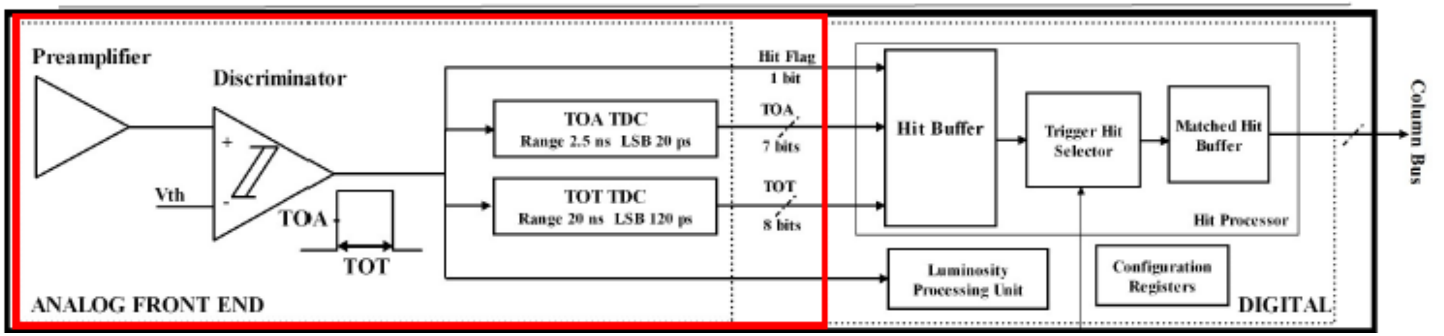
- Matrix of 15x15 pixels
- ASIC size 20x22 mm^2
- On pixel electronics mostly tested with prototypes

- First implementation of digital part of the periphery on-going
- End of Column logic for data processing

- Interfaced to lpGBT, with e-link speed selected in ASIC

Some digital part not needed for Roman Pots (e.g. Luminosity counter)

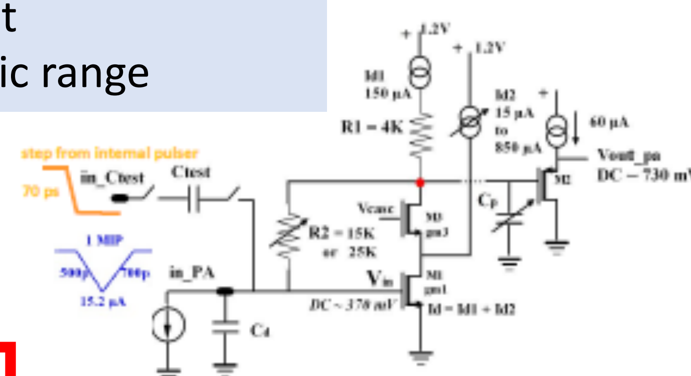
Single pixel architecture



PREAMPLIFIER :

- Voltage configuration
  → Amplitude given by Q/Cd
- Tuneable current from 0.15 to 1 mA
- Tuneable bandwidth from 200 MHz to 1 GHz
- R2 adjustable for DC Bias and pulse falling time
- Noise independent < 3000 e-@4pF

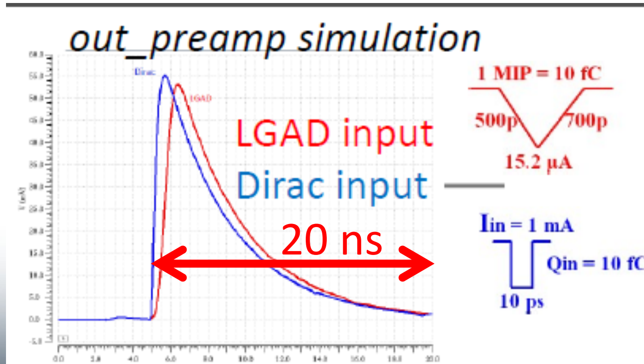
For Roman pots, might need to revisit dynamic range



Jitter given by

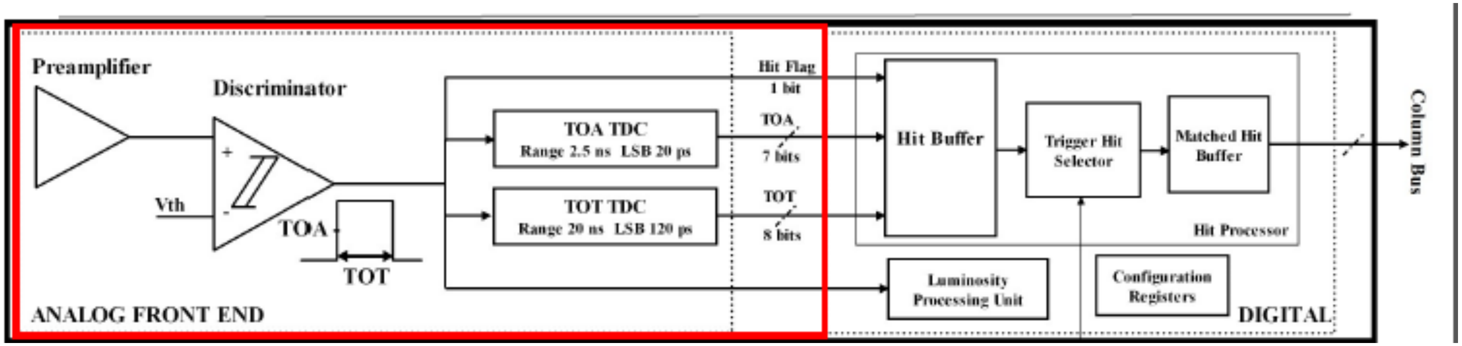
$$\sigma_t^{J} = \frac{e_n C_d}{Q_{in}} \sqrt{t_d}$$

t_d given by quadratic sim of preamplifier rise time and LGAD duration (dominated by LGAD duration ~1 ns)



Tested in ALTIROC0 as well as a pseudo TZ preamplifier (https://iopscience.iop.org/article/10.1088/1748-0221/15/07/P07007/pdf)

Single pixel architecture



DISCRIMINATOR:

- large gain and bandwidth (jitter < 10 ps)
- Threshold : one common to all pixels + individual per pixel : accuracy of 0.8 mV (~0.2 fC @ 4pF) over 100 mV range
- Stable within +/- 2 mV with PVT corners
- Hysteresis system against re triggering.

For Roman pots, might need to revisit
- TOA range
- TOT range and accuracy

TDC (developed by SLAC) :

- Vernier delay lines for TOA to achieve 20 ps lsb with measurement window of 2.5 ns
  - use rising edge of discriminator as START and 40 MHz for STOP to save power when no hit.
- Simple delay line for TOT (lsb of 120 ps)

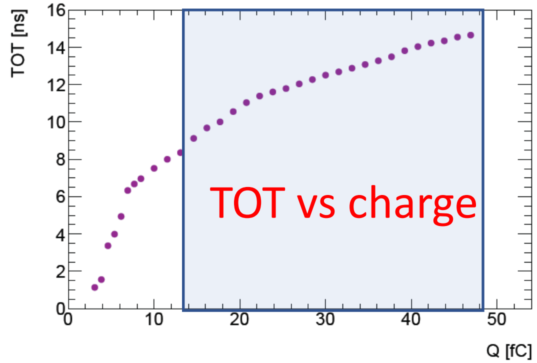
DIGITAL PART :

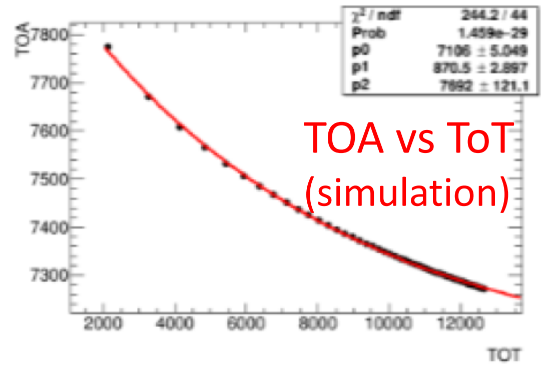
- Read out in ATLAS after L0 or L1 trigger at ~1 MHz with latency up to 35 µs
- Hit buffer with a circular big SRAM as occupancy up to 10 %, transferred to a matched hit buffer upon trigger reception . Use a large fraction of pixel area

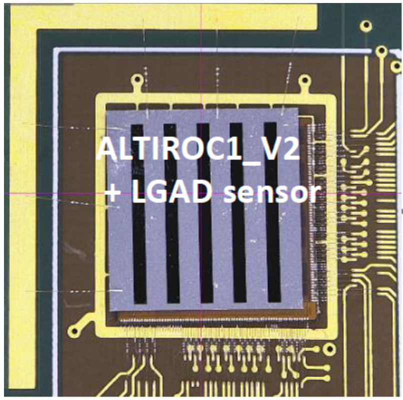
For Roman pots, should redesign to have a trigger-less architecture and store only hit pixels with a BCID.

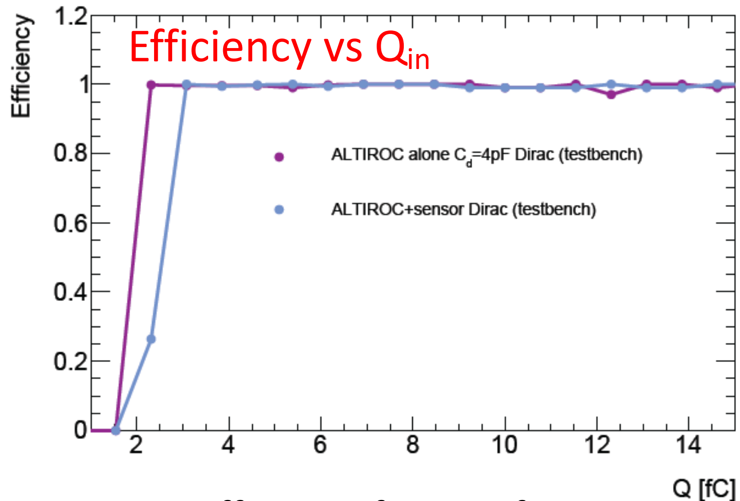
Performance

TDCs are working properly

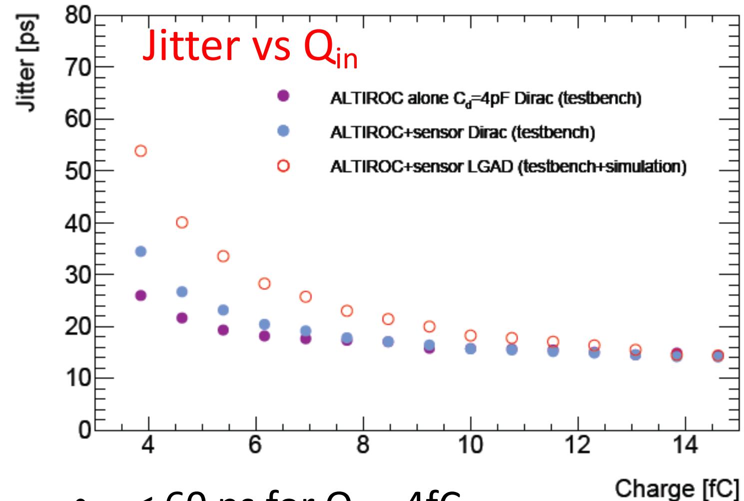








100 % efficiency for Q=4 fC
(with threshold around 2 fC)



- < 60 ps for Q = 4fC
- ~16 ps constant term, for Q > 10 fC
- ~8 ps from TDC, remaining contribution is due to clock and charge injection.

TestBeam with LGAD gain of 20 :

- achieved 39 ps jitter but not using the proper interface board to filter noise (35 % noise reduction) and TOT distorted due to coupling to TOA busy
- Next test beam in October (?) to demonstrate ~30 ps resolution with sensor

Proposed working plan

1) Establish specification for ASIC use in Roman Pots at EIC
   - Check if same Front End as ALTIROC can be used
   - Study pixel hit storage/processing
   - Evaluate surface needed (0.25 mm^2 vs 1.69 mm^2 : in ALTIROC2 SRAM is using 50 % of pixel area and TDC about 20 %)
   - Link to Back-End (Input/output)

2) Use ALTIROC1 (to evaluate Front End performance)

- Re-evaluating current amplifier vs voltage amplifier with AC-coupled LGAD
- Tests with low detector capacitance (~ 1 pF)
- Tests with AC-LGAD of 0.5mm x 0.5mm (side to side ASIC and sensor with wire bonding even if it can induce coupling through long inductance wire)

Back Up

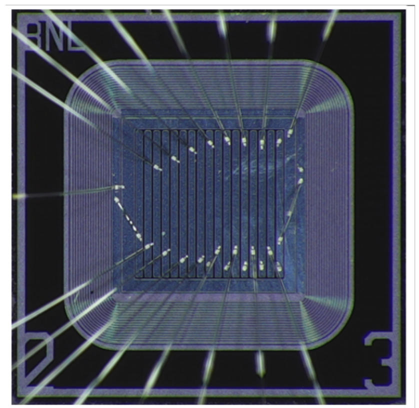
Beam Test at FNL with AC-LGADs

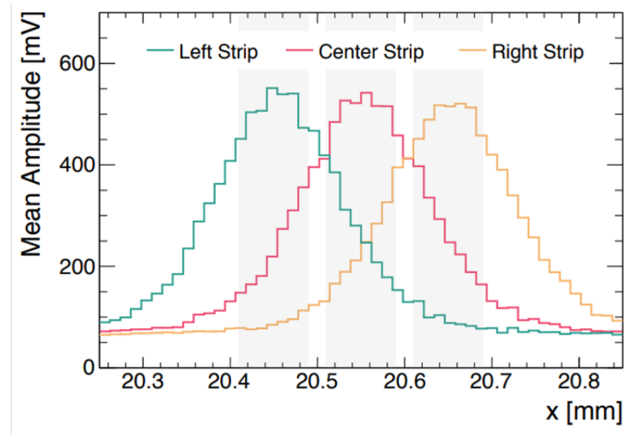
AC-LGAD 2mmx2mm strip sensor.

- Strip pitch = 100um
- Wire bonded to a multichannel TA board (FNL)

Confirmed:

- 100% fill factor
- Good spatial resolution (limited by the telescope resolution)
- Good timing resolution



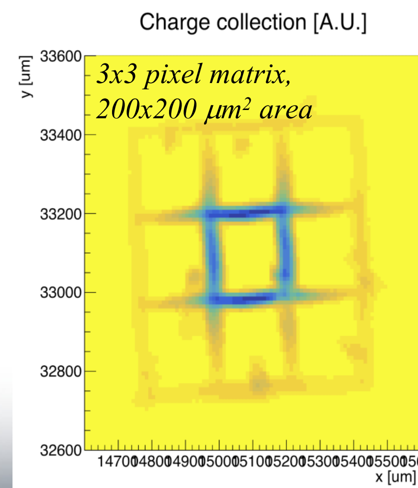


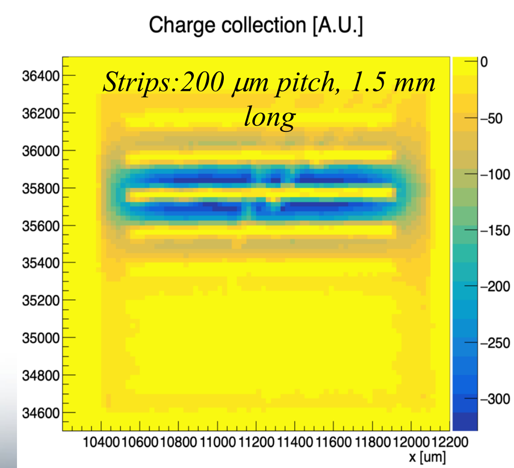
"Measurements of an AC-LGAD strip sensor with a 120 GeV proton beam,"

arXiv:2006.01999

In lab, we routinely perform IR laser scans (TCT), to measure sharing and crosstalk among neighbor strips.

Induced signals on a cluster of strips depend on geometry and fabrication details: TCAD simulations on-going

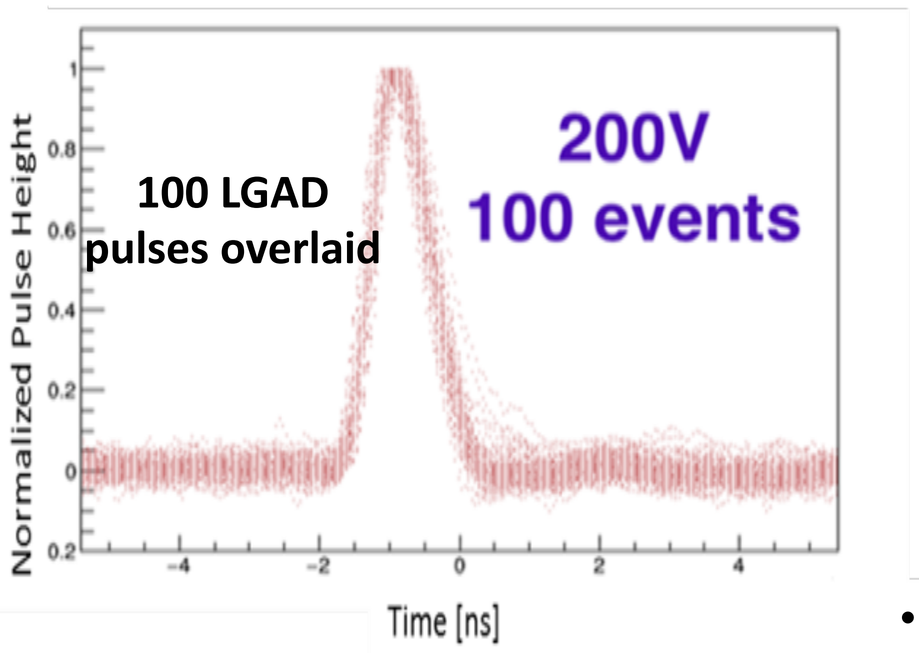




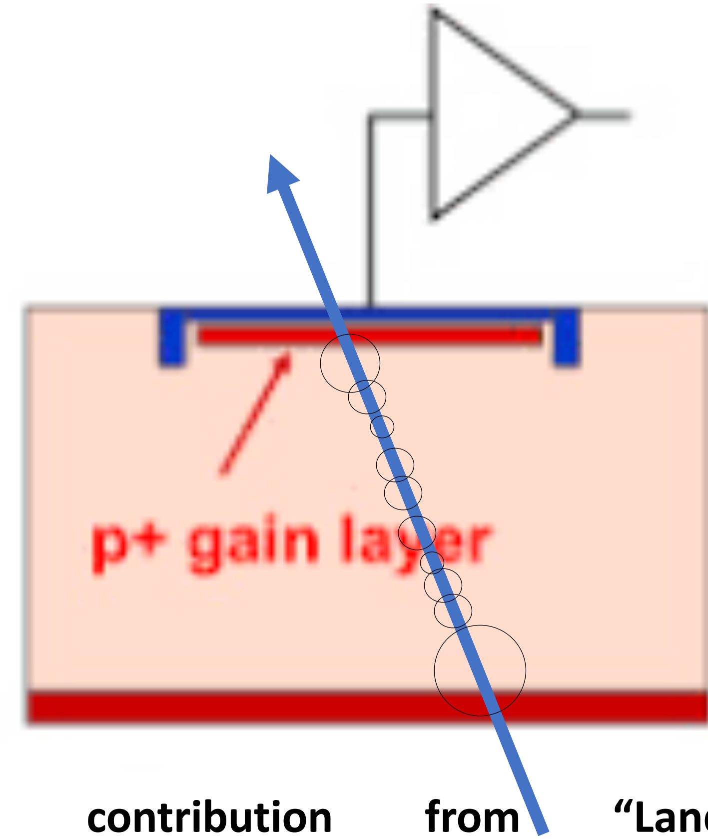
Also, double-sided PCB (modified version of the UCSC SCIPP board) with fast electronics (TA) for timing measurements (acquisition of coincidence).

Precise Timing with LGADs: Status and Prospects

LGAD Signals – 50 micron thick sensor, gain of 20

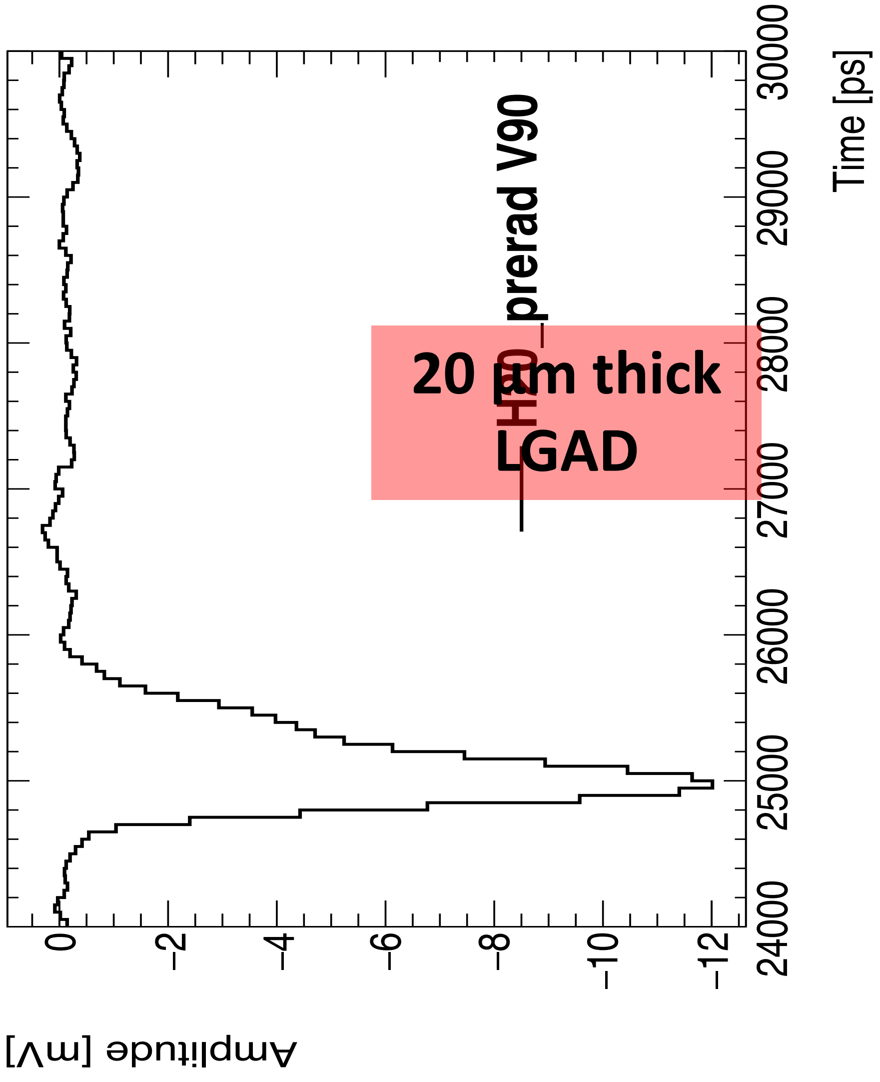


- Very constant shape
- Low electronic noise achieved
- Allows excellent timing
- Measured timing resolution ~30 ps
- Dominated by Landau fluctuations



- σ_t contribution from "Landau fluctuations" arises from fluctuating charge deposition profile coupled to finite signal propagation time (~100µm per nsec)
- Of order ± 20-25 ps for 50 µm bulk sensor

Thinner detectors offer potential for even better timing resolution



Averaged Pulse for 20 micron thick LGAD at Gain = 8.

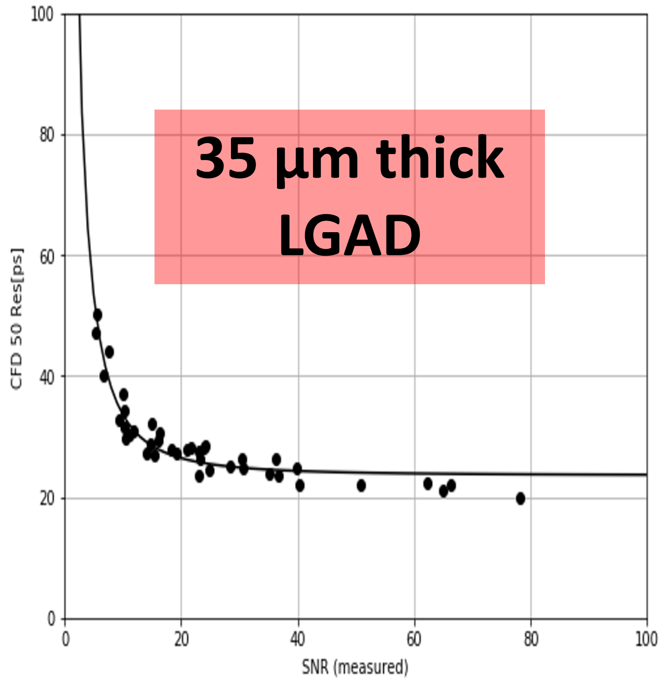
Signal much larger than baseline fluctuations ➔ very good signal-to-noise even with a gain of only 8.

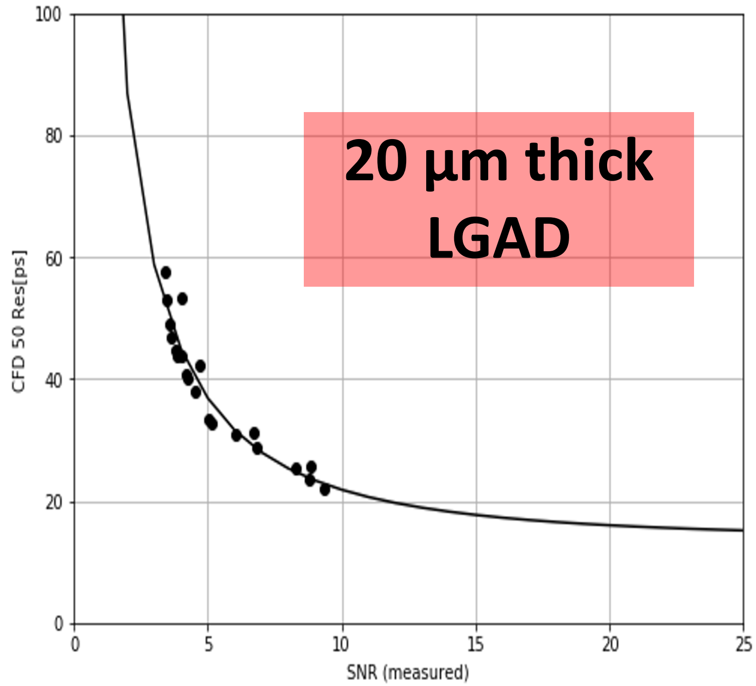
Rise-time (10-90%) about 150 picoseconds compared to about 500 picoseconds for the 50 micron sensor in earlier slide.

Contribution to the time resolution from Landau fluctuations is roughly proportional to the detector thickness so smaller for thinner detectors (expected to be ~ 10 picoseconds for the 20 micron thick sensor).

Measured time resolution versus signal-to-noise ratio for thin detectors

Time resolution for minimum ionizing particles measured for thin detectors versus the signal-to-noise ratio.

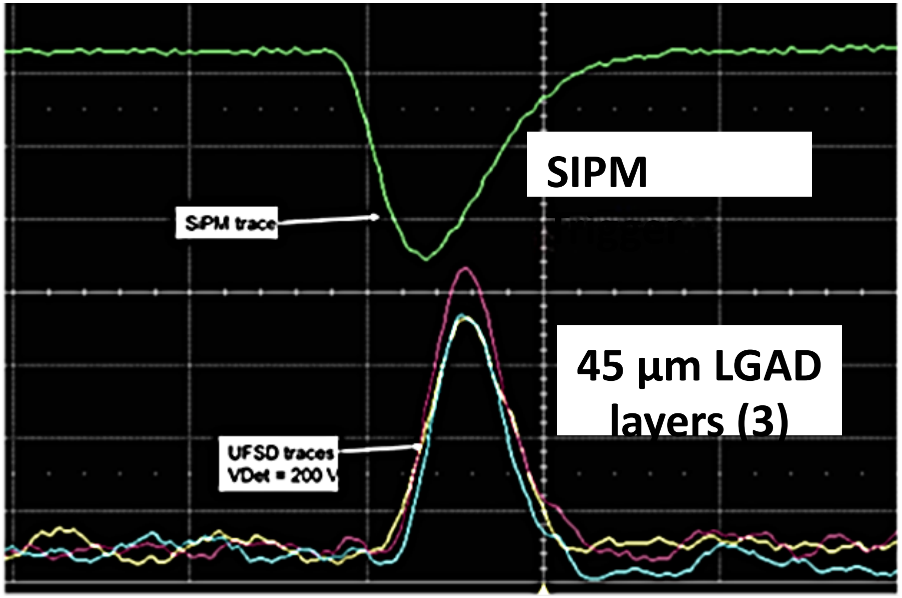




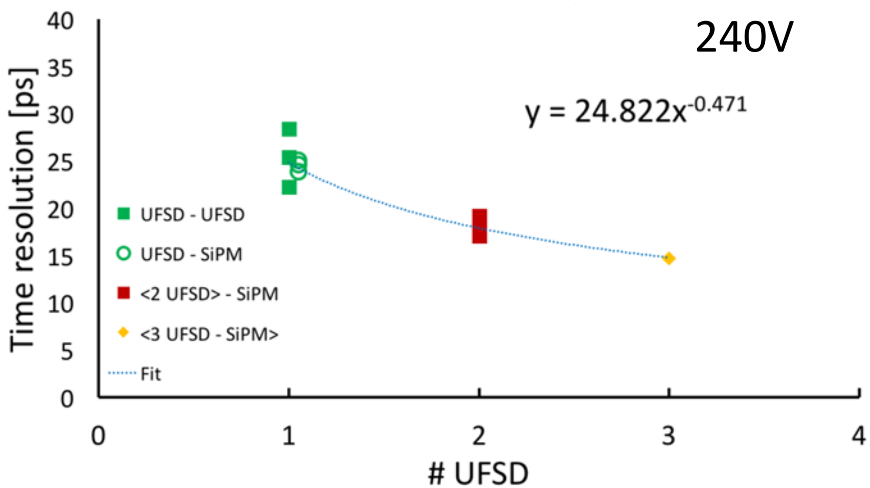
Left: for 35 micron thick detector. Right: for 20 micron thick detector. Note the modest value of signal-to-noise required to get to about 20 picosecond time resolution for the 20 micron thick sensor.

Multiple Layer Systems: In Pursuit of σ_t < 10 ps

N. Cartiglia et al., “Beam test results of a 16 ps timing system based on ultra-fast silicon detectors”, NIM. A850, (2017), 83–88.



Timing resolution vs. # of UFSD averaged



3 identical 45 µm thick 1.3x1.3 mm^2 LGAD produced by CNM

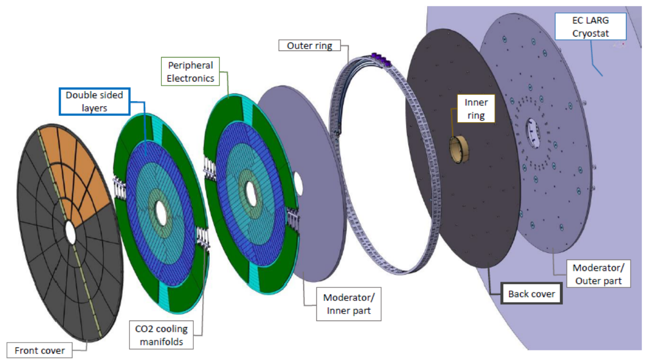
SiPM trigger (14 ps resolution)

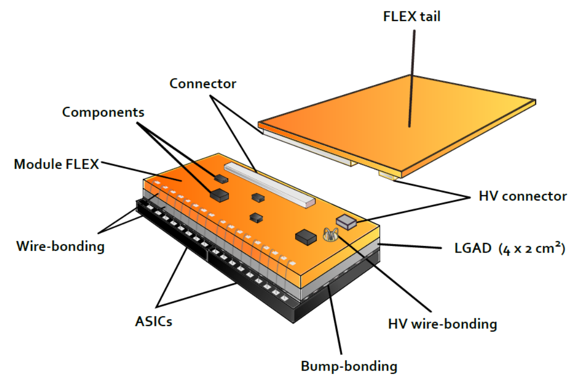
- **Good matching of three LGADs**
- **Time resolution of single UFSD: ~ 25 ps (240V)**
- **Time resolution of average of 3 UFSD: 16 ps (240V)**
- **Timing resolution agrees with expectation $\sigma(N) = \sigma(1)/N^{0.5}$**

4 layers of sub-20 ps LGADs expected to yield σ_t< 10 ps

ATLAS HGTD

- ASIC designed to read LGAD(-DC) sensors for ATLAS High Granularity Detector in the forward region made of two double sided LGAD layers





8043 4x2 cm^2 modules made of a LGAD sensor flip-chipped to two ASICs
Pixel size 1.3x1.3 mm^2 (Cd ~4 pF)
225 channels / ASIC
ASICs signals are wire bonded to a module flex.

- Detector requirements :

1) Provide a track time measurement combining 2 or 3 hits of 30 ps (non irradiated) and 50 ps (after 2.5 10^{15} n_{eq}/cm^2) for triggered events (L0 or L1)

→ Resolution per hit : < 35 ps for Q > 10 fC (non irradiated)
< 70 ps for Q = 4 fC (smallest MIP charge form sensor)

2) Provide a bunch by bunch luminosity measurement counting the number of hits per ASIC in time with bunch crossing (time spread of 260 ps) and out of time .

ALTIROC ASIC requirements

Colored area most relevant for a use in Roman pots

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

130 nm CMOS TSMC technology
Limited power consumption and operation at -30°c with CO2 cooling (improve a bit jitter by 10 % room temperature)
ASIC bandwidth selected by slow control

Maximum leakage current	5 µA
Single pad noise (ENC)	$< 3000\ e^{-} = 0.5$ fC
Cross-talk	< 2.5 %
Threshold dispersion after tuning	< 10%
Maximum jitter	25 ps at 10 fC 70 ps at 4 fC
TDC contribution	< 10 ps
Time walk contribution	< 10 ps
Minimum threshold	2 fC
Dynamic range	4 fC–50 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

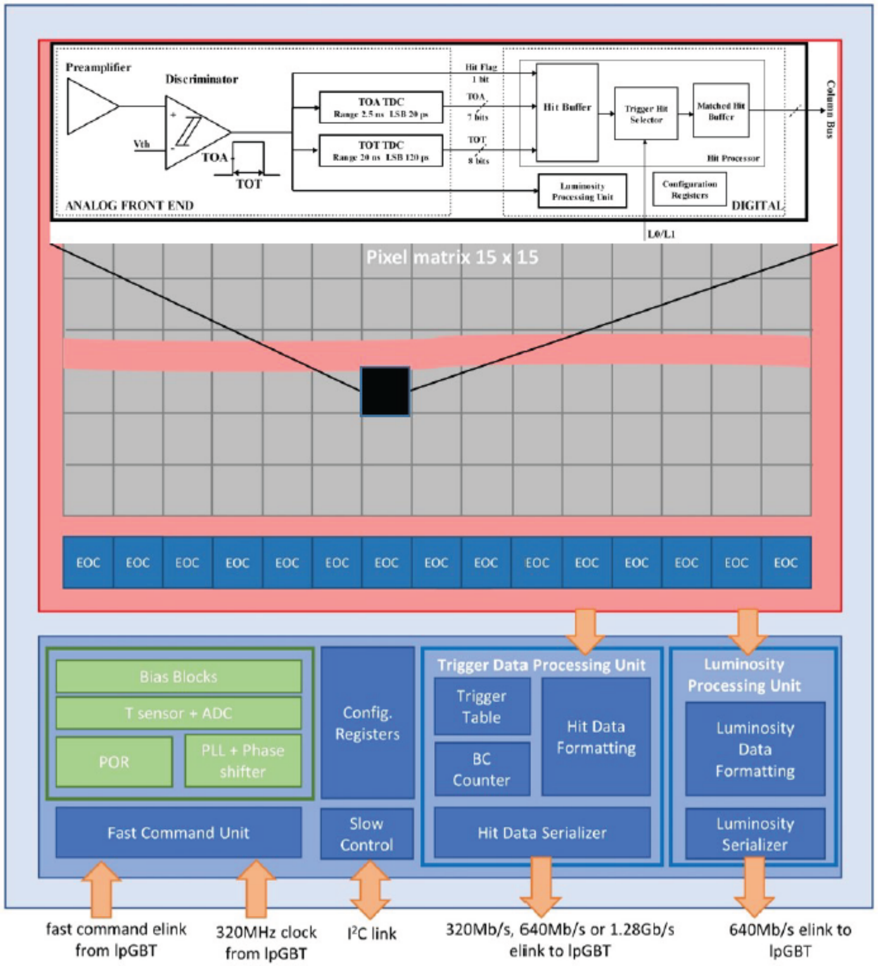
Noise < 3000 e- for 4 pF

Time measurement :

- Time of Arrival measured wrt to Bunch Crossing clock over +/- 1.25 ns TOA
- Time over threshold measured for amplitude estimate and Time Walk correction offline : TOT
- Threshold as low as 2 fC

- Reference clock of each ASIC can be phase adjusted to take into account time of flight/cable…. But still some skew in ASIC

ALTIROC architecture



Matrix of 15x15 pixels, ASIC size 20x22 mm^2
On pixel electronics mostly tested with prototypes ALTIROC1 (Preamplifier, discri + TDC and SRAM)
Discussed in next slides

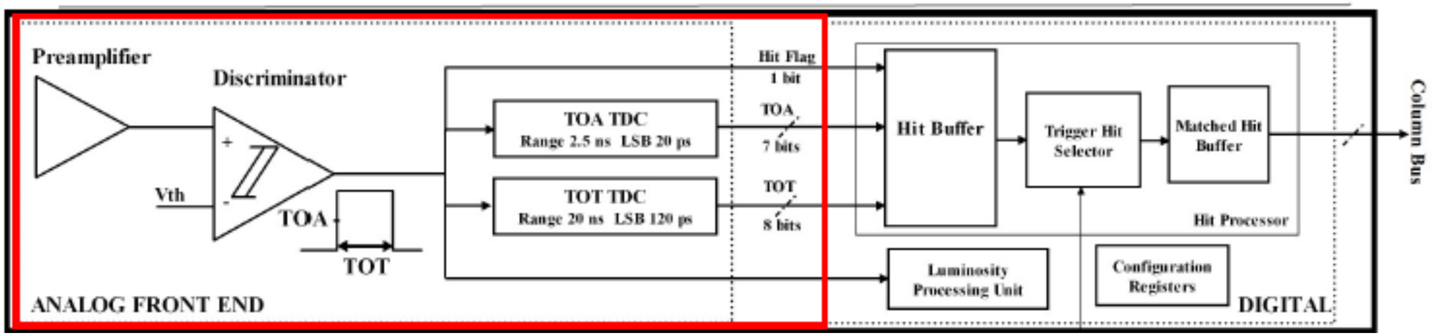
First implementation of digital part of the periphery on going : submission of ALTIROC2, full size ASIC, in November

End of Column logic for data processing

Interfaced to lpGBT, with e-link speed selected in ASIC

Some digital part not needed for Roman Pots (Luminosity counter

Single pixel architecture



For Roman pots, might need to revisit dynamic range

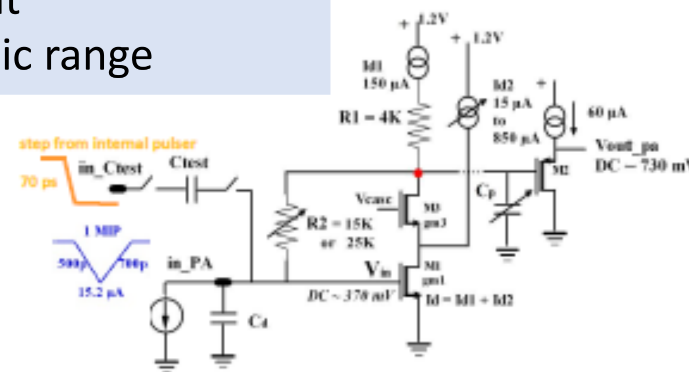
PREAMPLIFIER : Voltage configuration

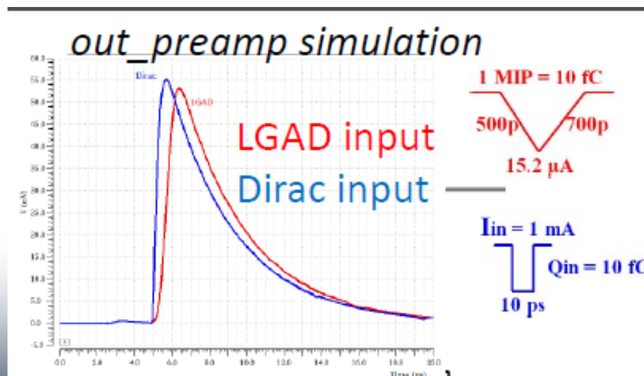
- Tuneable current from 0.15 to 1 mA
- Tuneable bandwidth from 200 MHz to 1 GHz
- R2 adjustable for DC Bias and pulse falling time
- Noise independent < 3000 e-@4pF
- Amplitude given by Q/Cd
- Jitter given by

$$\sigma_t^J = \frac{e_n C_d}{Q_{in}} \sqrt{t_d}$$

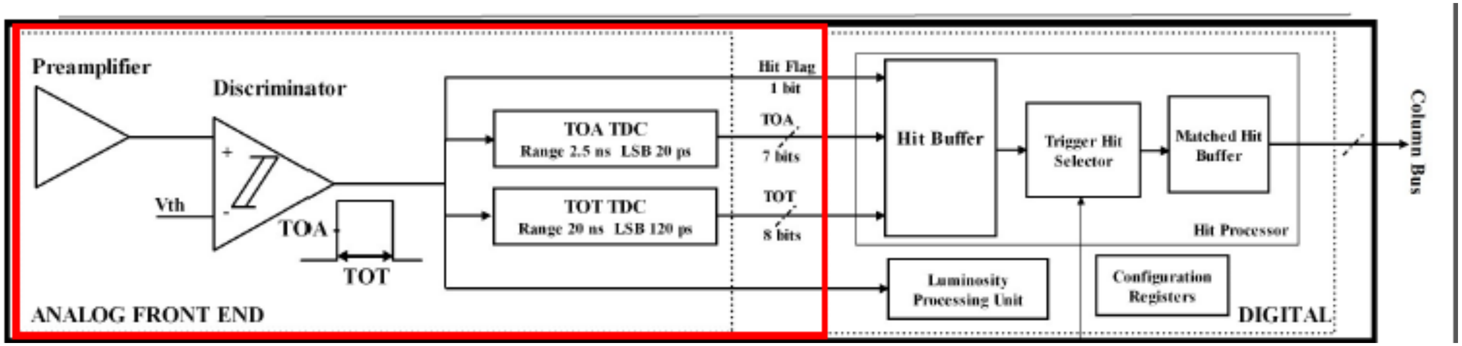
- td (given by quadratic sim of preamplifier rise time and LGAD duration) dominated by LGAD duration (~1 ns)

Tested in ALTIROC0 as well as a pseudo TZ preamplifier (https://iopscience.iop.org/article/10.1088/1748-0221/15/07/P07007/pdf)





Single pixel architecture



DISCRIMINATOR:

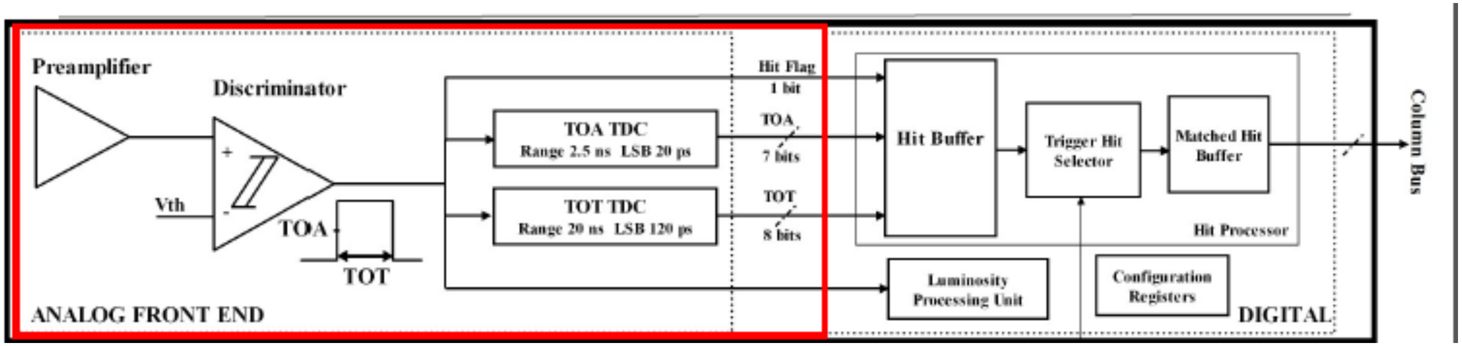
- large gain and bandwidth (jitter < 10 ps)
- Threshold : one common to all pixels + individual per pixel : accuracy of 0.8 mV (~0.2 fC @ 4pF) over 100 mV range
- Stable within +/- 2 mV with PVT corners
- Hysterisis system against re triggering.

TDC (developed by SLAC) :

- Vernier delay lines for TOA to achieve 20 ps lsb with measurement window of 2.5 ns : use rising edge
- of discriminator as START and 40 MHz for STOP to save power when no hit.
- Simple delay line for TOT (lsb of 120 ps)

For Roman pots, might need to revisit
- TOA range
- TOT range and accuracy

Single pixel architecture



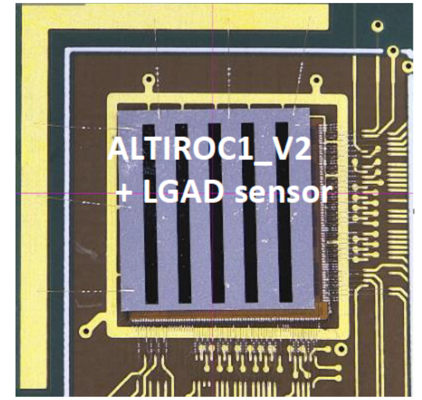
DIGITAL PART :

- Read out in ATLAS after L0 or L1 trigger at ~1 MHz with latency up to 35 µs
- Hit buffer with a circular big SRAM as occupancy up to 10 %, transferred to a matched hit buffer upon trigger reception . Use a large fraction of pixel area

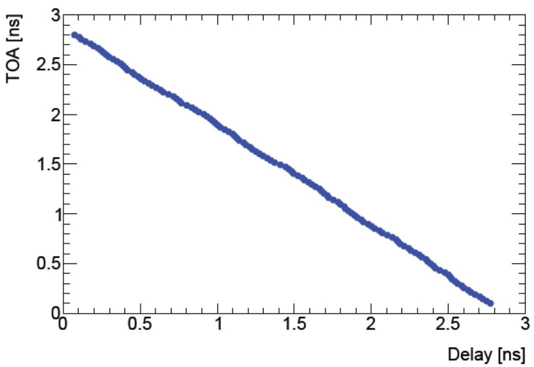
For Roman pots, should redesign to have a trigger-less architecture and store only hit pixels with a BCID.

Performance (1)

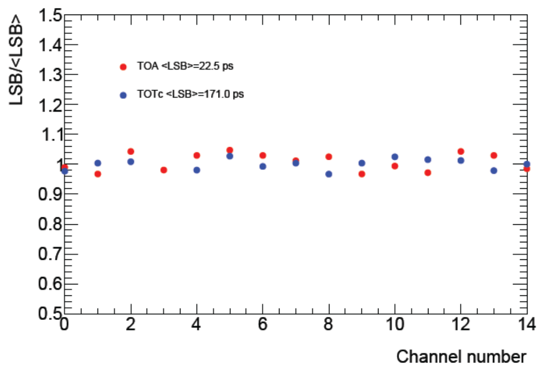
ALTIROC1 : 5x5 pixels prototype, bump bonded to LGAD sensor



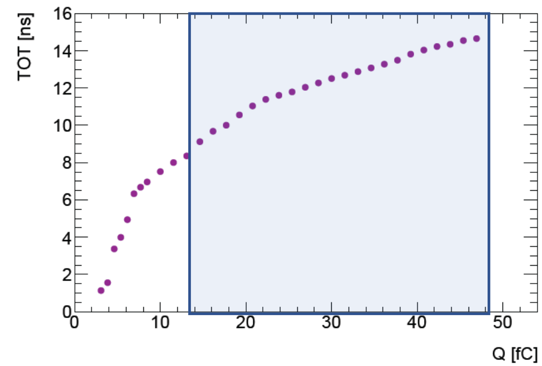
TDC performance



TOA range of 2.5 ns
DNL not corrected
Estimated contribution to jitter : 8 ps

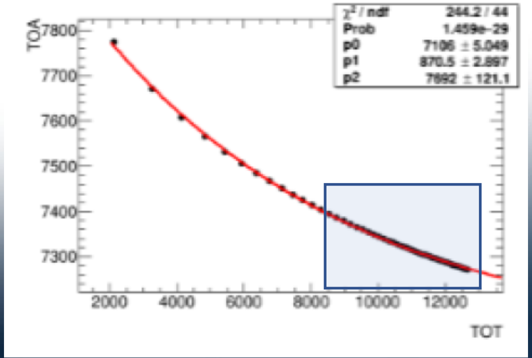


TOA and TOT LSB can be adjusted to 20 ps/160 ps .
Dispersion < 10 %

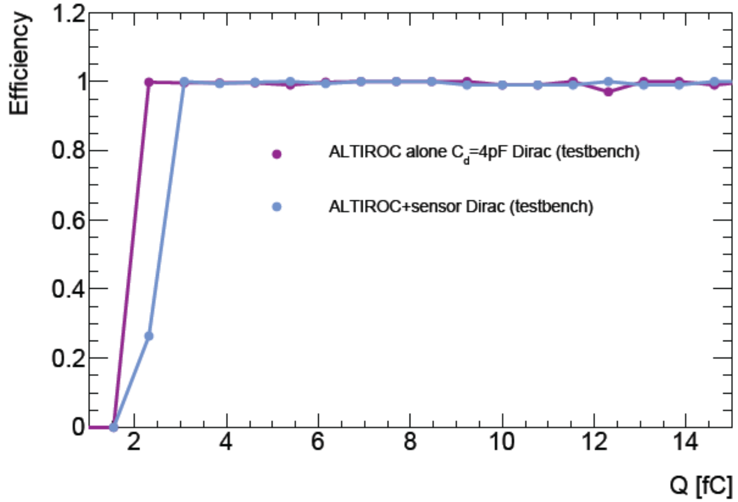


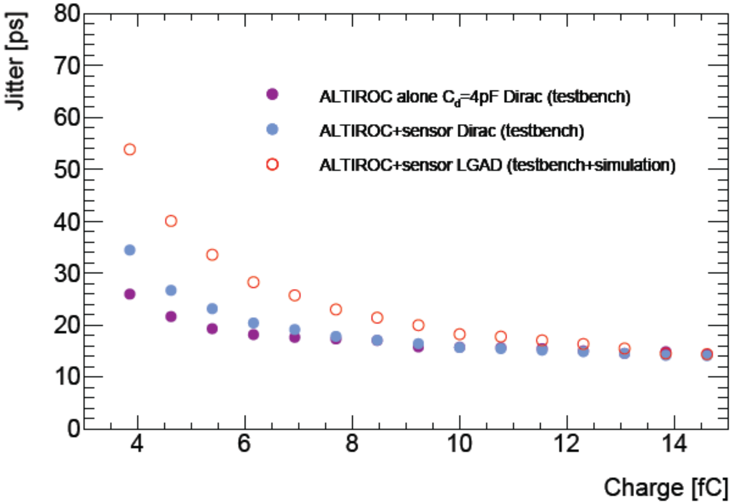
TOT vs charge.
Most difficult issue as very sensitive to any coupling to the preamp input

Range > 15 fC for EiC roman pots



Performance (2)





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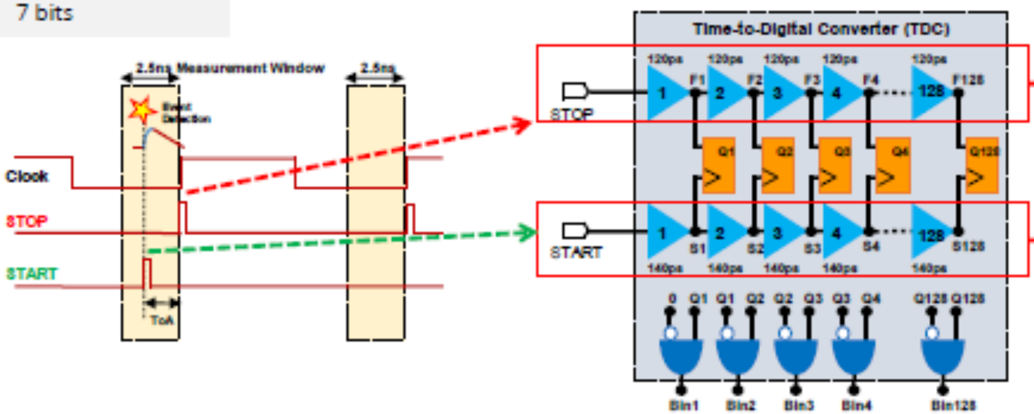
2) Use ALTIROC1 to evaluate Very Front End performance
- With low detector capacitance (1 pF ?)
- with LGAD-AC of 0.5x0.5 mm^2 (side to side ASIC and sensor with wire bonding even if it can induce coupling through long inductance wire)

TOA TDC Architecture (Simplified): Vernier Delay Line

TOA TDC
- Resolution: 20 ps
- Range: 2.5 ns
- 7 bits

TDC Power consumption 0.4 mA *1.2 V = 0,5 mW @ 10% occupancy

Simplified Block Diagram



Differential shunt capacitor voltage-controlled delay cells

STOP (rising edge of signal of 40 MHz) propagates in the **Fast Delay Line**
Delay of one cell = 120 ps

START (rising edge of the discriminator) signal propagates in the **Slow Delay Line**
Delay of one cell = 140 ps

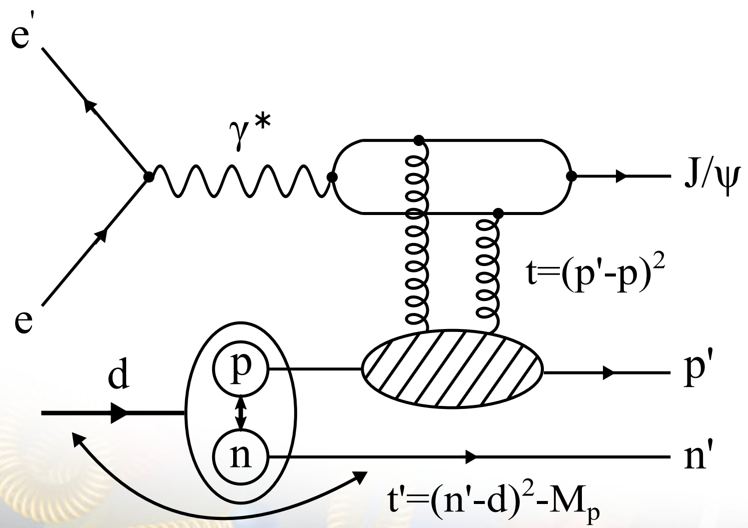
- START pulse comes first and initializes the TDC operation. STOP pulse follows the START with a delay that represents the time interval to be digitalized.
- At each tap of the Delay Line, STOP signal catches up to the START signal by the difference of the propagation delays of cells in Slow and Fast branches: i.e. 140ps – 120ps = 20ps (LSB).
- The number of cells necessary for STOP signal to surpass the START signal represents the result of TDC conversion
- Cycling configuration used in order to reduce the total number of Delay Cells.
- TDC range is equal to 128 * 20 ps = 2.56 ns

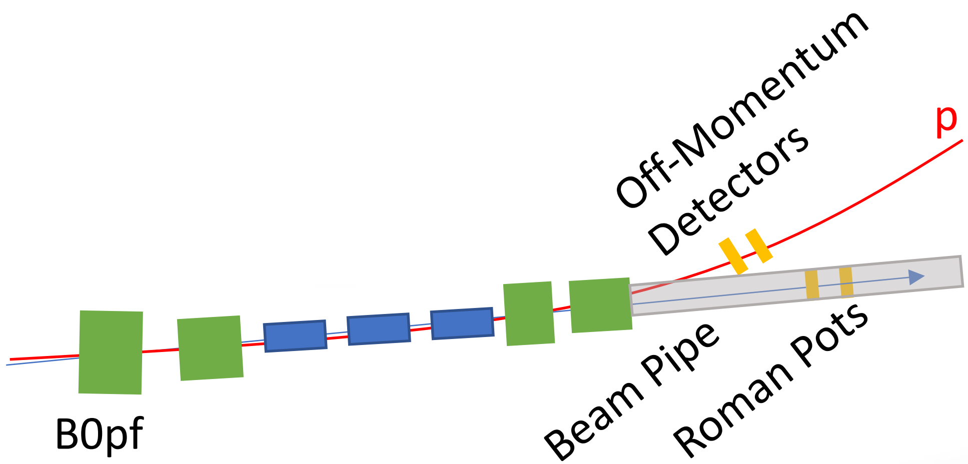
New Study – Off-Momentum Detectors

- Protons that come from nuclear breakup have a different magnetic rigidity than their respective nuclear beam.
  - This means the protons experience more bending in the dipoles.
- As a result, small angle (θ < 5mrad) protons from these events will not make it to the Roman Pots, and will instead exit the beam pipe after the last dipole.
  - Detecting these requires “off-momentum detectors”.

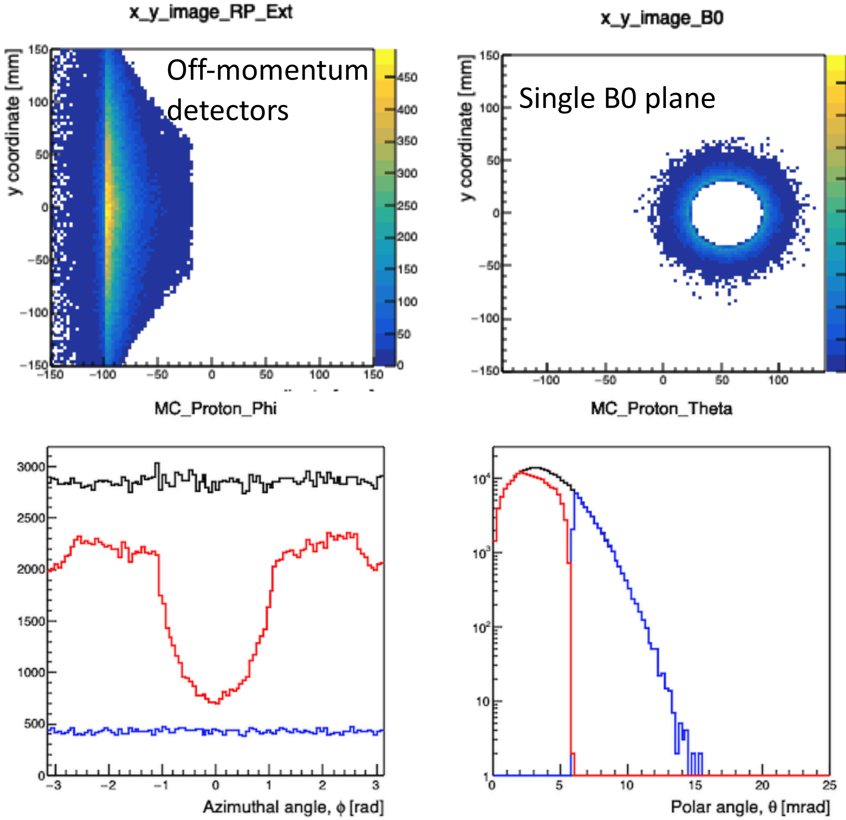
Short Overview of Study

- Used BeAGLE (eRD17) to generate e+d -> J/ψ + p + n events.
  - Goal is to tag the protons and neutrons in the final state.
  - We only show the proton results here.
  - Written up in a paper submitted to PLB (https://arxiv.org/abs/2005.14706)

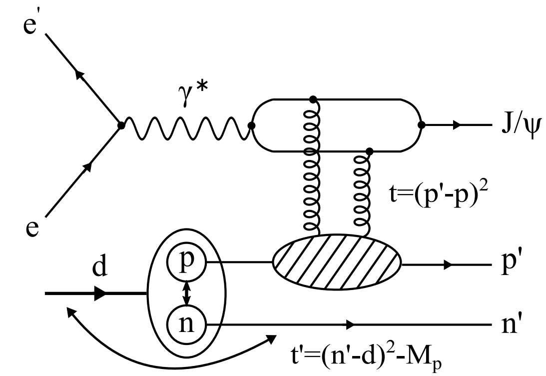




Short Overview of Study

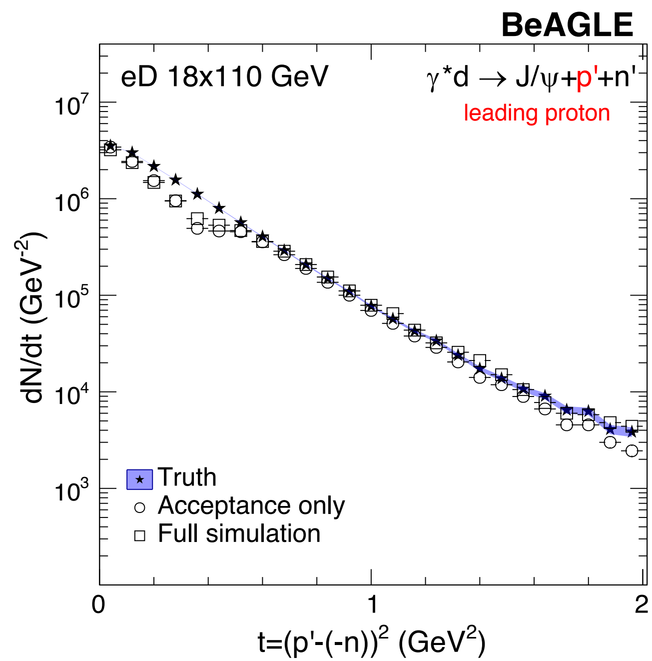


Particular process in BeAGLE: incoherent diffractive J/psi production off bounded nucleons.



18x110GeV

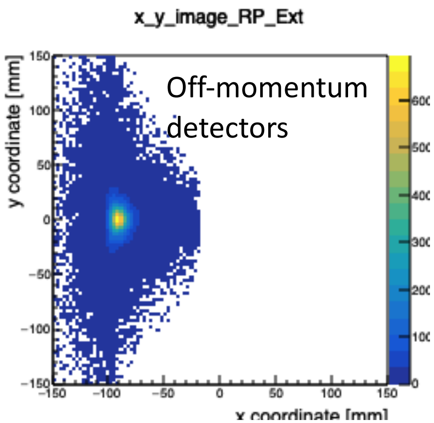
Neutron spectator/leading proton case.

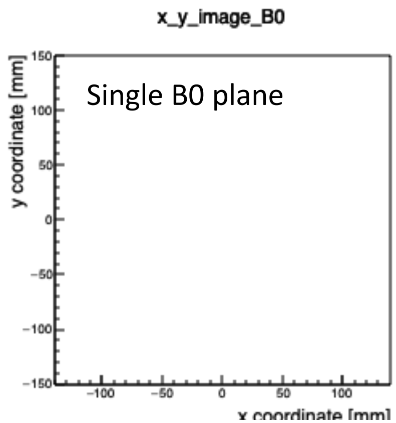


Good timing is assumed here (i.e. vertex smearing removed). If this contribution was not removed, the slope would be distorted.

t-reconstruction using double-tagging (both proton and neutron). Takes advantage of combined B0 + off-momentum detector coverage.

Short Overview of Study





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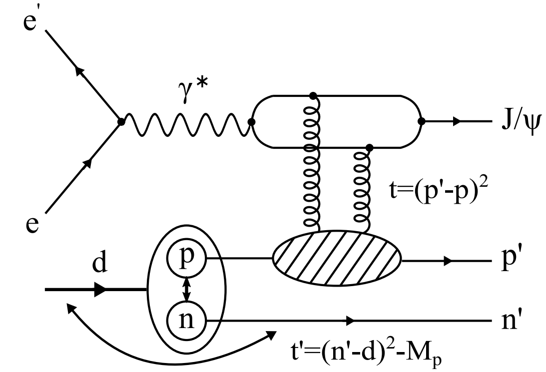
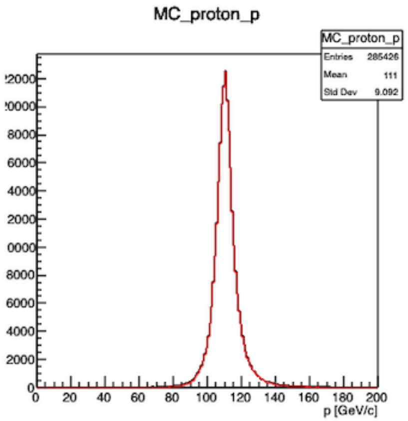
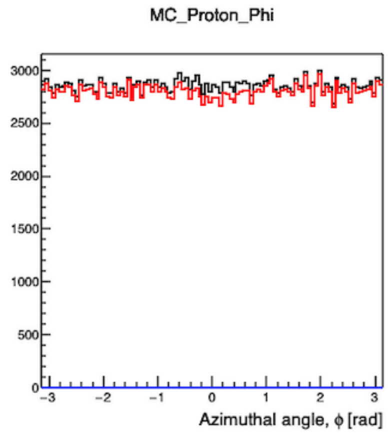
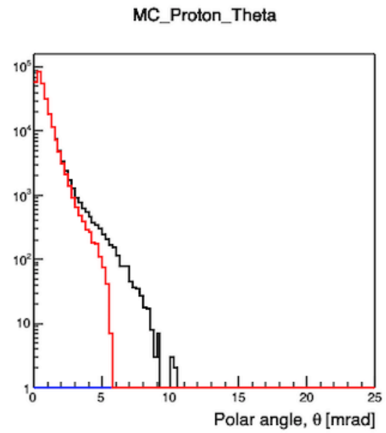


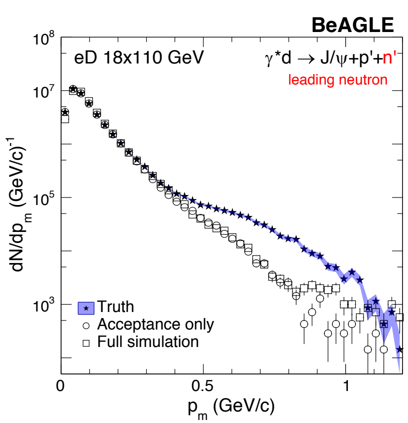
18x110GeV

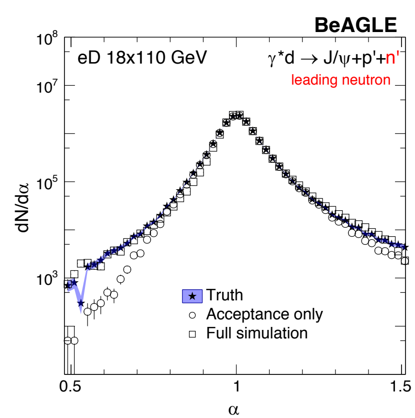






Proton spectator case.

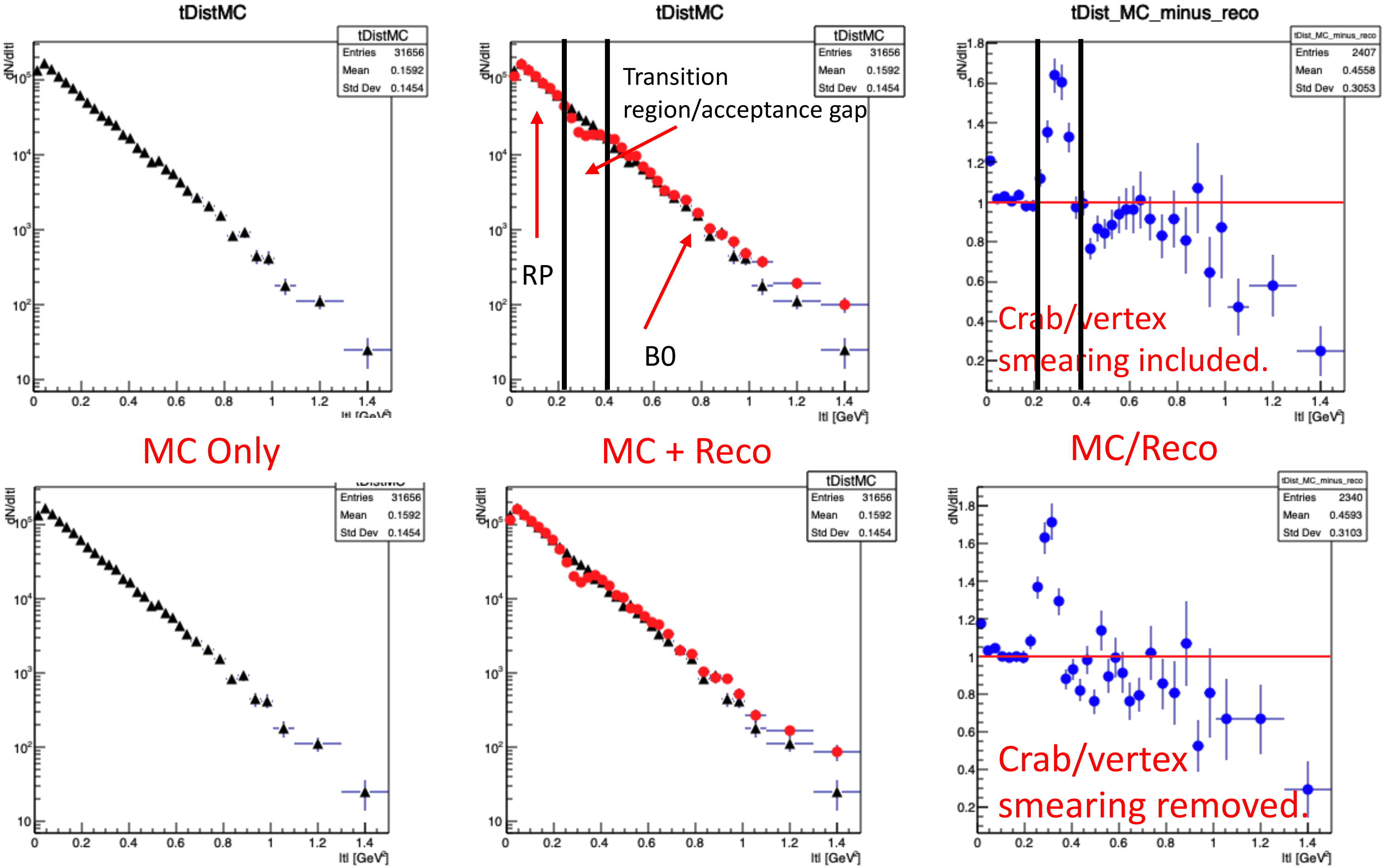




Some examples of observables (light-cone momentum fraction, α), and missing-momentum (p_m).

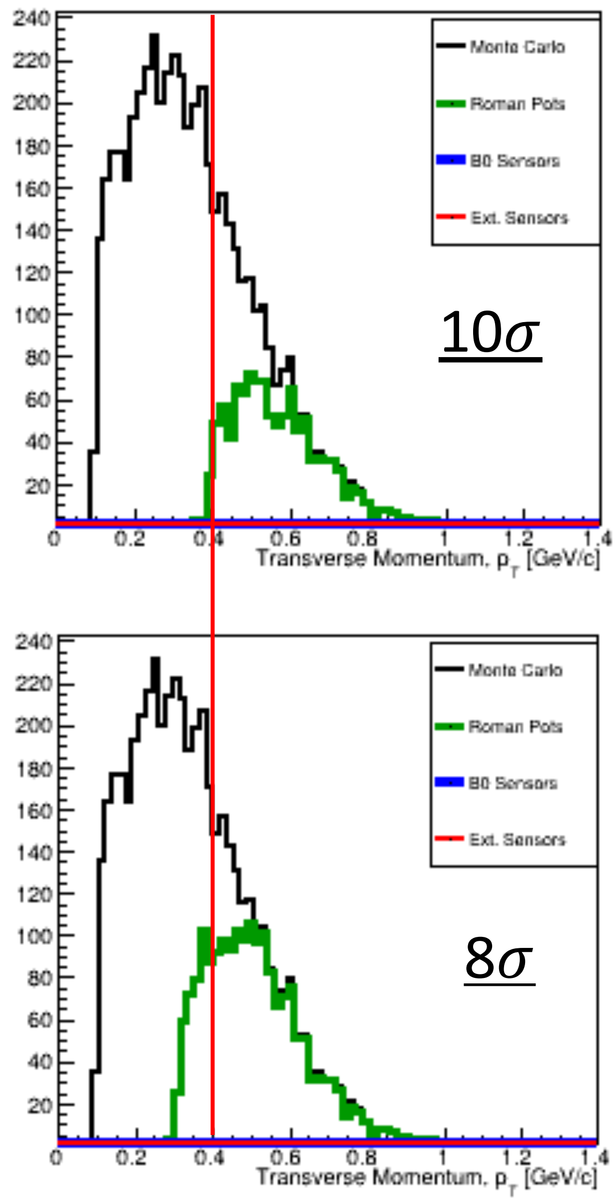
How does the crab smearing affect reconstruction of t?

5x100 GeV
0.016 < x < 0.025
HA



Notes: 1) Above |t|= 0.2, B0 begins to be mainly used. 2) the peak at 0.35 is due to the acceptance gap between the Roman Pots and B0.

Some Comparisons – High Divergence



Move sensors closer to beam in increments of "1σ".

$1\sigma = 3.58$ mm
(for the high divergence optics)

Moving the sensors ~7.2 mm closer (from 10 to 8σ) gains about 100 MeV in pt-acceptance.