B0 Tracking Detector: Updates on Performance and Path Forward

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FF DWG Meeting

May 30th,2023

Updated: June 6th, 2023

Preliminaries

- Original baseline choice for B0 detector was ITS3 (3 layers) + AC-LGADs (1 layer) with 30cm spacing. **Considerations:**
  - Material thickness (ITS3 very thin < 1% X0 per layer; AC-LGADs much thicker perhaps 5% X0 for the 500um pixel configuration – AC-LGAD summary here).
  - Spatial resolution (ITS3 offers ~ 6um resolution, AC-LGADs perhaps as good as ~20um with charge sharing).
  - Fast timing (AC-LGADs) for rejection of background and removal of crab crossing effect (pT kick, dependent on z-position within bunch).

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➢ **Problems:**

1. ITS3 technology has a very long integration time ~O(10s us). Likely not going to work in the B0 given the high occupancies possible in this detector (radiation studies underway; see current results here: https://wiki.bnl.gov/EPIC/index.php?title=Radiation_Doses)
2. B0 magnet geometry has changed after the 50cm shift of the lattice back in 2021 (we have only just now begun to get updated information on it).
   - Requires reshuffle of the tracking layout to accommodate the EMCAL → shortening the lever arm of distance between the layers (30cm → 27cm provides the needed space).
3. Previous study of pixel size assumed proton momentum 80 < p < 120 GeV/c – the upper-bound was arbitrary, and likely too high. Now using 100 GeV/c as upper-bound.

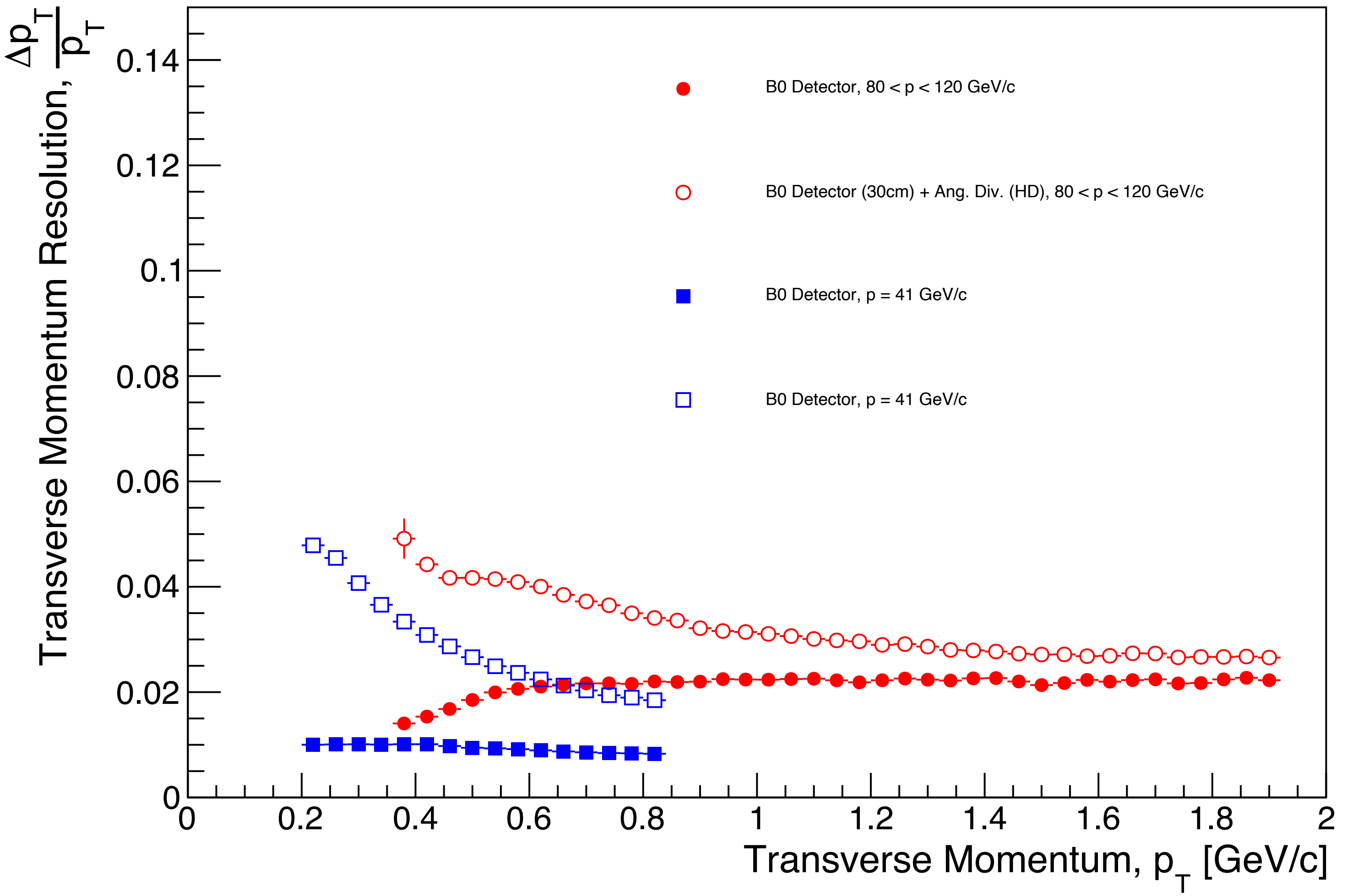
So what options do we have?

1. **<u>Fully AC-LGAD system</u> →**
   - ✓One technology, much simpler implementation.
   - ✓Precise timing information for each hit.
   - ✓In-use in RP/OMD and in the main detector – makes things cheaper.
   - ✓Thick material with ASIC, likely ~5% X0.
   - ✓20um spatial resolution relies on charge sharing, and this is barely enough to meet "physics requirement" of pT resolution ~ 5% for protons with p ~ 100 GeV/c (needs further discussion with PWG).
   - ✓Unclear how radiation damage could impact charge sharing and resolution.
2. **<u>Hybrid TimePix + AC-LGAD system (like previous ITS3/ACLGAD)</u> →**
   - ✓Slightly better spatial resolution (16um) - but doesn't require charge sharing.
   - ✓Better timing resolution than MAPS (~ 2ns for TimePix, ~ 30ps for ACLGAD).
   - ✓*Potentially t*hick material with ASIC (similar bump-bonding of ASIC to sensor, and the sensor itself is 5x thicker than the AC-LGAD: X. Llopart *et al* 2022 *JINST* **17** C01044 (2022))
   - ✓Multiple technologies for one subsystem less-optimal, but it was already part of the original plan.

Vetting the current options vs. previous baseline

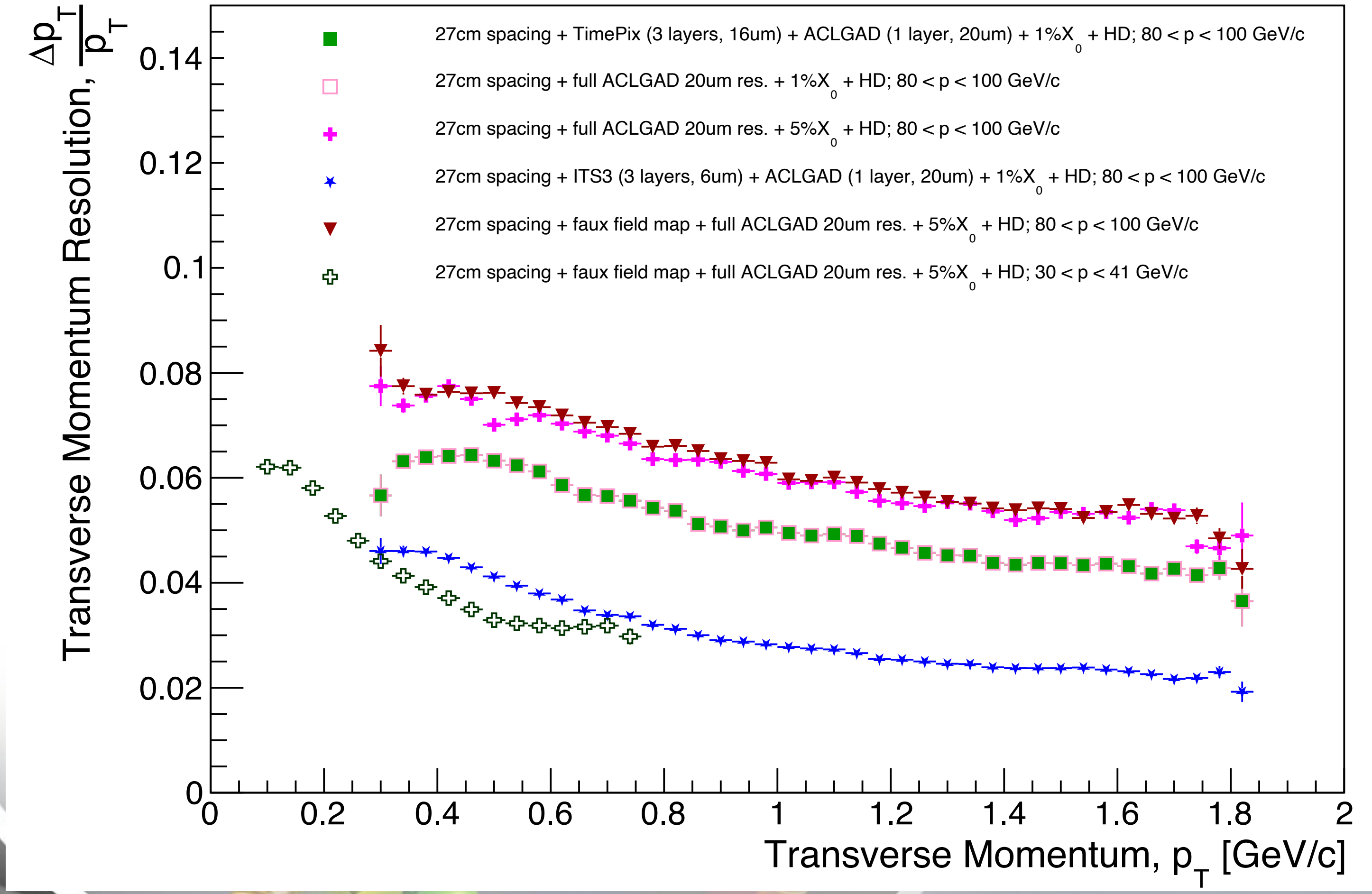
- Current DD4HEP setup doesn't allow for tracking + reconstruction with the B0 system (more on that later).
- Solution for now is to use EICROOT to compare these options, with the new tracking layer separation, to the previous baseline (ITS3 + ACLGAD).
  - The results then need to be used by the PWG to evaluate the impact.
- **<u>Major caveat:</u>** No current simulation contains the proper B0 field map + updated geometry → this will be the next step in the study (~ one week for an update).
  - Currently assume constant dipole + quadrupole field across entire tracking region.

Current baseline expectations



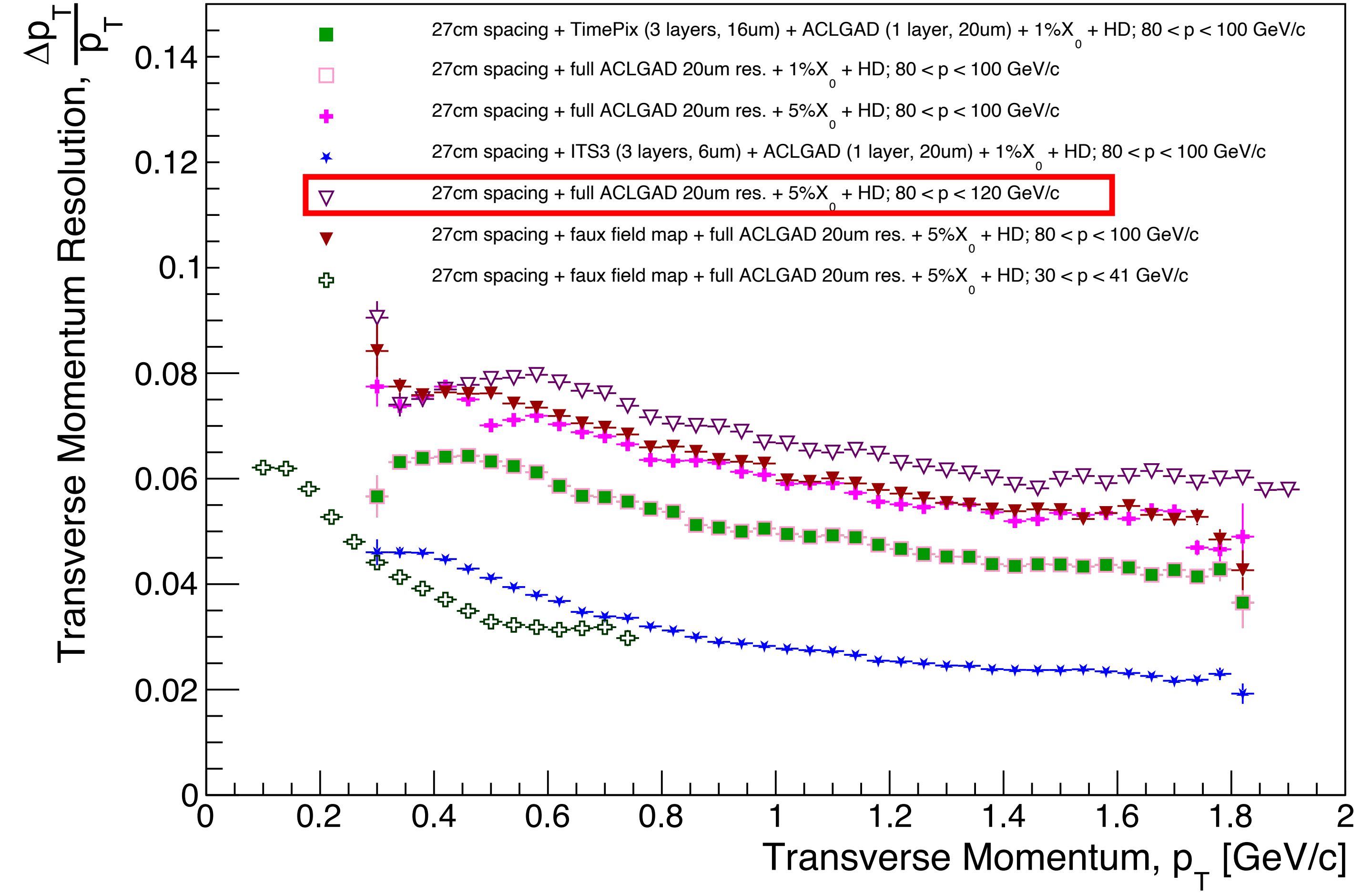
- Tracking layers separated by 30cm.
- No material consideration here.
- High Divergence angular divergence setting (worst-case).

Various settings with new technology + material assumptions



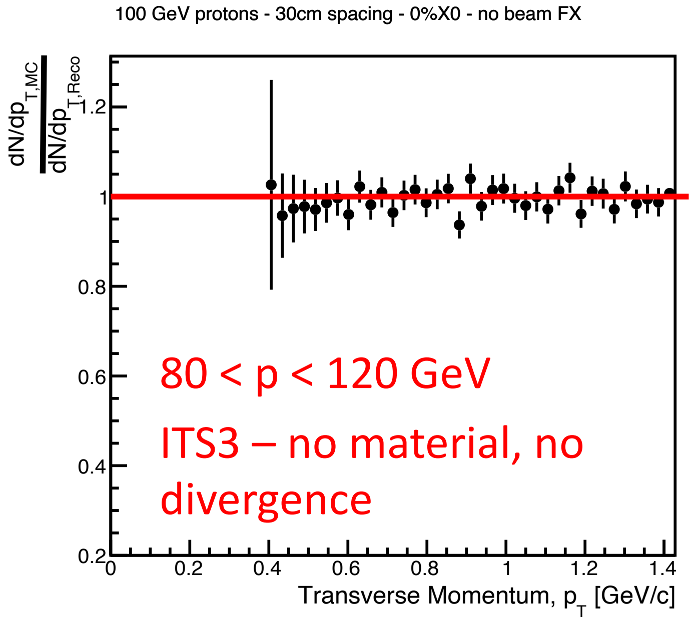
- 27cm spacing with fully AC-LGAD system and 5% radiation length may be the most-realistic option.
  - Needs to be looked at with proper field map and layout.
  - Is this resolution going to be a problem?
- **Note:** p resolution is ~ 2-4%, depending on configuration.

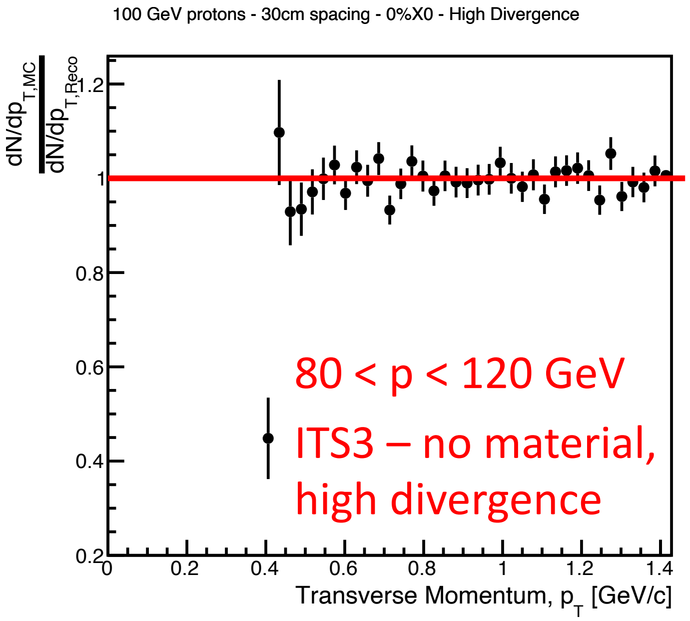
Various settings with new technology + material assumptions

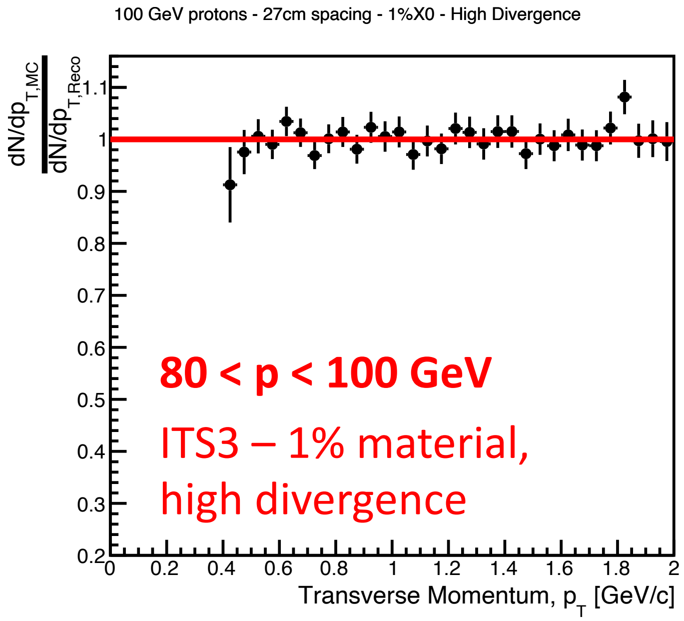


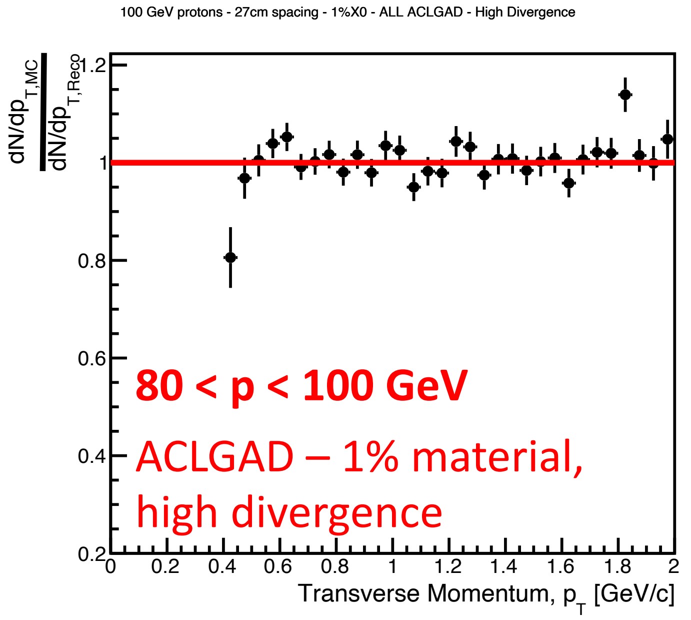
- Using the higher momentum range worsens the resolution → this was not a reasonable momentum range for study.

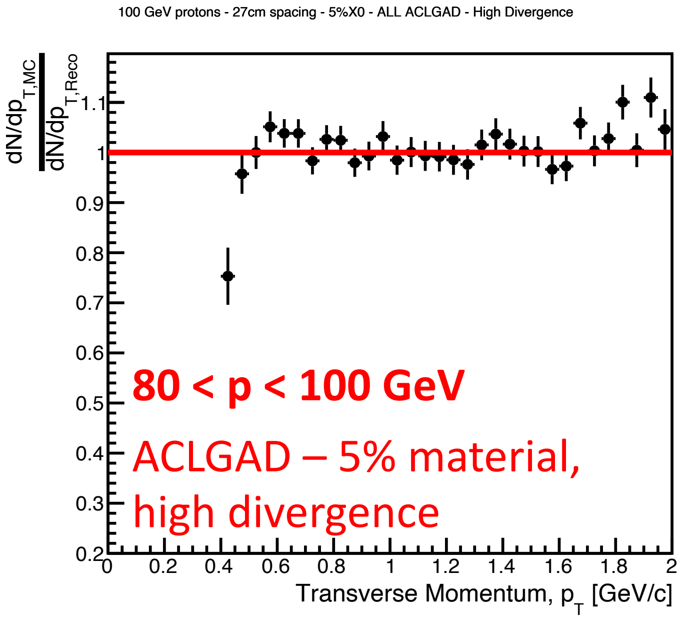
Impact on pT spectra

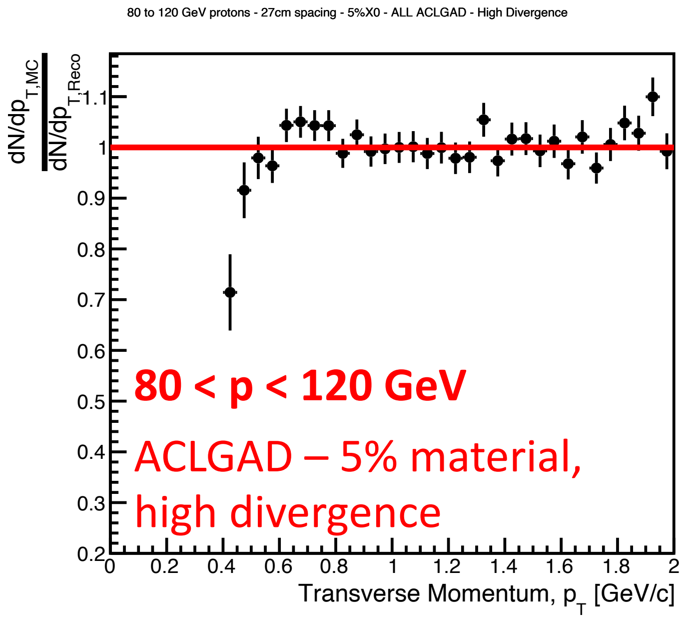












Polynomial fits for resolution curves (using ROOT/migrad)

$$\frac{\Delta p_T}{p_T} = a_0 + a_1 p_T + a_2 p_T^2$$

```
a0 =     0.0907443    +/-    0.00101056
a1 =    -0.0414639    +/-    0.00211712
a2 =      0.010735    +/-    0.00101575
```

Fully AC-LGAD system with realistic material consideration (with current knowledge).
80 < p < 100 GeV/c

```
a0 =      0.060635    +/-    0.00051283
a1 =    -0.0476607    +/-    0.00103212
a2 =     0.0151836    +/-    0.000482167
```

ITS3 + AC-LGAD hybrid system.
80 < p < 100 GeV/c

```
a0 =     0.0818078    +/-    0.000673817
a1 =     -0.162741    +/-    0.0035086
a2 =      0.131413    +/-    0.00425632
```

Fully AC-LGAD system with realistic material consideration (with current knowledge).
30 < p < 41 GeV/c

$$\frac{\Delta p}{p} = a_0 + a_1 p$$

```
a0 =     0.0263904    +/-    0.00218859
a1 =   0.000441398    +/-    2.46209e-05
```

Fully AC-LGAD system with realistic material consideration (with current knowledge).
80 < p < 100 GeV/c

ITS3 + AC-LGAD hybrid system.
80 < p < 100 GeV/c

$$\frac{\Delta p}{p} \sim 2\%$$

Fully AC-LGAD system with realistic material consideration (with current knowledge).
30 < p < 41 GeV/c

$$\frac{\Delta p}{p} \sim 3.5\%$$

Two things to note:

1) These include high divergence beam effect, effects from pixel sizes + detector spacing, and reasonable estimate for material budget.
2) The resolutions are ONLY valid within detector acceptance – the acceptance is NOT UNIFORM, so for a "fast" study, please only consider 5.5mrad < pT/p < 20mrad to assess impact.
   - Notice, the studies on **slide 8** show "3-momentum" ranges for the particle production, this is why we care about polar angle, and not pT by itself.

Next Steps

- Implement new B0 geometry into EICROOT (it's not currently in an easily-digestible form like the lattice information currently in-place).
- Input full B0 field map into simulations and assess impact on tracking performance.
- Put together reasonable set of "tests" to assess performance benchmarks for the momentum resolution.
  - Maybe just use a DVCS sample to get a realistic pT distribution to sample from.
- DD4HEP "hack" → put together "hit reader" which can take real hits from DD4HEP B0 geometry and allow user to perform tracking however they like (least squares, genFit, etc.)
  - This is the best "short term" solution for a working DD4HEP setup to ensure consistent geometry implementation + readiness for TDR.