HPS 2021 · VERTEXING

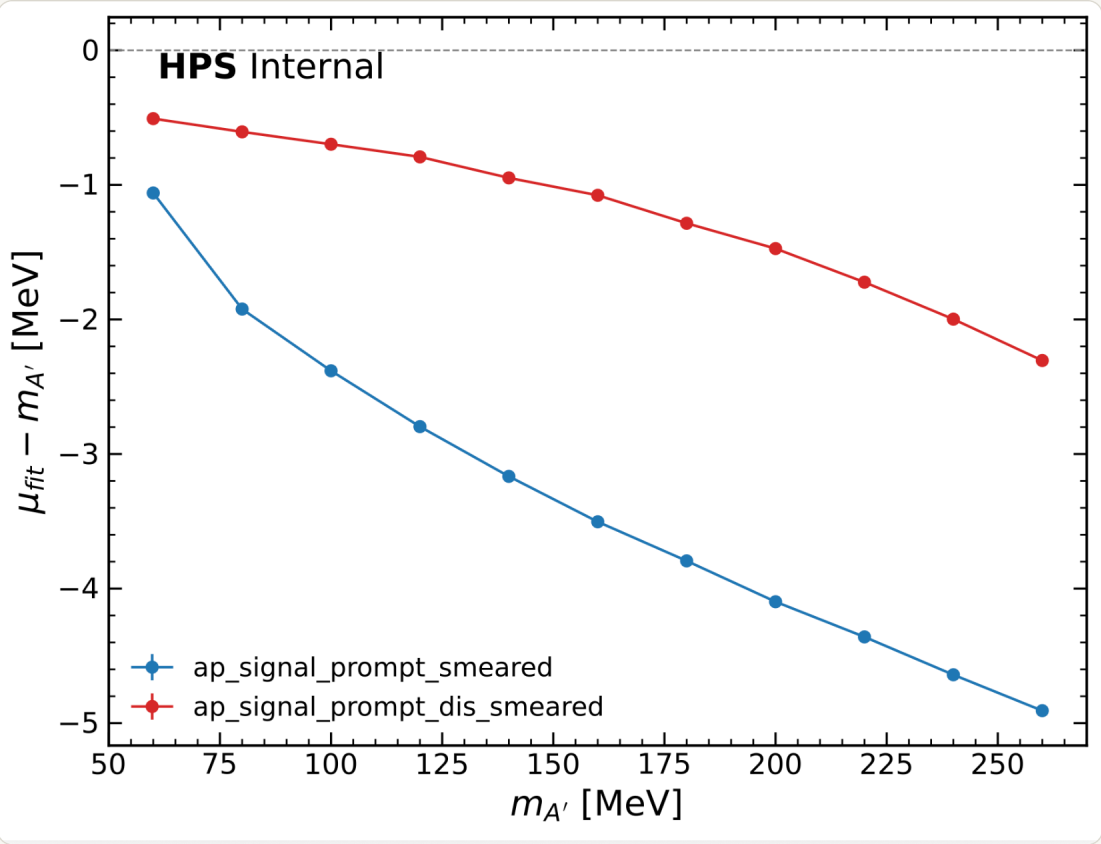
Fixing the Target-Constrained Vertex Fit Mass Bias

Why the target-constrained A′ mass came out about 2% low, and the change to BilliorVertexer and HpsReconParticleDriver that fixes it

Matthew Gignac · HPS Collaboration Meeting · October 21 2026

THE PROBLEM

Target-constrained A′ mass is biased low



−2%

Target-constrained mass bias, roughly the same fraction at every mass: −2.4 MeV at 100 MeV, −4.9 MeV at 260 MeV

The **unconstrained** mass has the same trend at less than half the size. A fixed fractional bias points to a **scale effect**.

Blue: target-constrained · **Red:** unconstrained
Prompt A′ MC (v16), run 14272 conditions, Kalman tracks

BEFORE THE CHANGE

Three vertex fits share one constraint update

Unconstrained

Free 3D vertex from the two tracks.

Refit about pass-1 vertex: yes

Beamspot-constrained

Point-back: the pair momentum must extrapolate to the beam spot. Decay length stays free.

Refit about pass-1 vertex: yes

Target-constrained

Full 3D pin to (0, 0, −1.1) mm with σ = 55 / 45 / 1 μm in x / y / z.

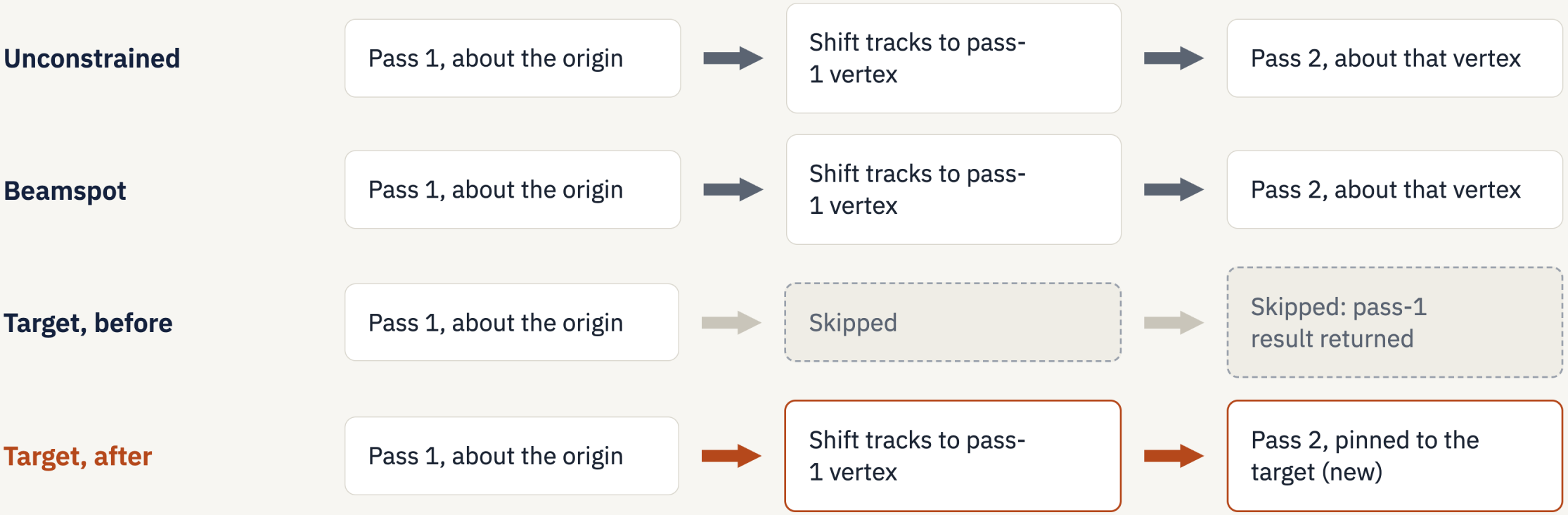
Refit about pass-1 vertex: no

$$X' = X + K \cdot r \quad K = C \cdot H \cdot (H^T \cdot C \cdot H + V_{beam})^{-1}$$

In target mode H is the identity on the vertex and zero on the momenta, so the momenta move only through their covariance with the vertex.

THE FIX IN ONE PICTURE

The target fit now gets the same second pass



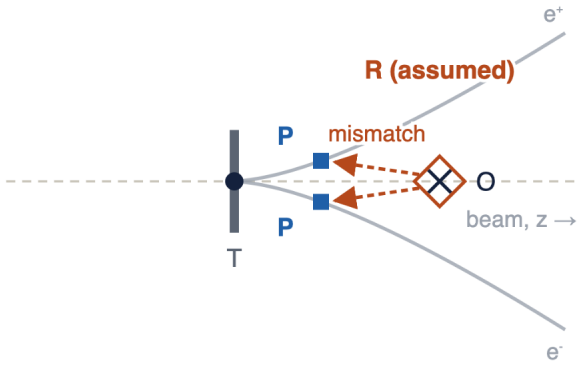
The new pass runs only with <refitTargetConstrained>true</refitTargetConstrained> in the steering.

WHY IT HAPPENED

The fit read the tracks at the wrong point

1 · Before (pass5)

Fit assumes R = origin, one pass



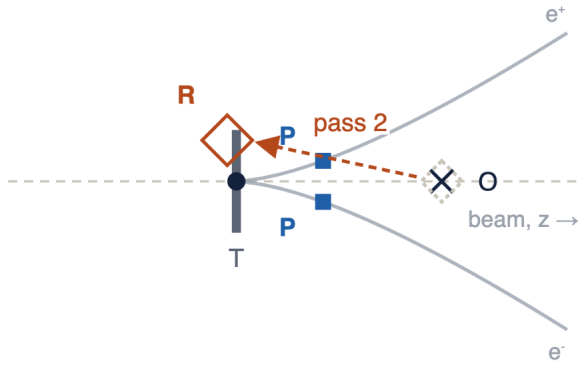
–2.36 MeV

✗ Defined at P, read as if at O

The vertex is pinned to T, so the mismatch goes into the track directions.

2 · Earlier fix: refit

R = O, then refit with R = pass-1 vertex



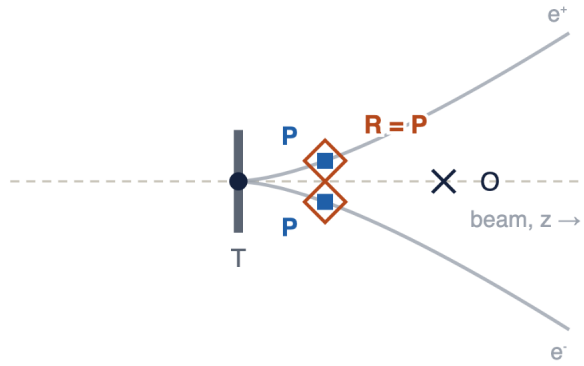
–0.49 MeV

✓ Works, at the cost of a second pass

The shift starts from the true pivot P; needs the makeRk fix once R ≠ 0.

3 · Now: track reference point

R = each track's pivot P, one pass



–0.49 MeV

✓ Same result, no refit needed

1, 2 or 20 refits on top all give –0.49 MeV.

Tell the vertexer where the track parameters are defined, and **one pass is enough**: the refit only fixed the same mismatch.

HPS 2021 · Target-constrained vertex fit mass bias · 5 · P = track pivot (AtPerigee reference point) · μ – m at 120 MeV, tc_summary.txt

WHAT WE CHANGED

Three code changes and one steering file

HpsReconParticleDriver

New steering flag **refitTargetConstrained**, off by default. When on, target-constrained vertices get the same shift-and-refit pass as the other fits.

BilliorVertexer.makeRk

Target mode compares the target with V + reference position. No effect in pass 1, where the reference is the origin; needed so pass 2 pins the right point.

ReconParticleDriver

New **beamSigmaZ** setter for the longitudinal constraint width, which was fixed at 1 μm.

Steering: 14272 fixedBeamPos

Beam position fixed at (0, 0, −1.1) mm instead of the conditions database, and the refit turned on.

WHAT WE CHANGED

The diff is small

HpsReconParticleDriver.fitVertex()

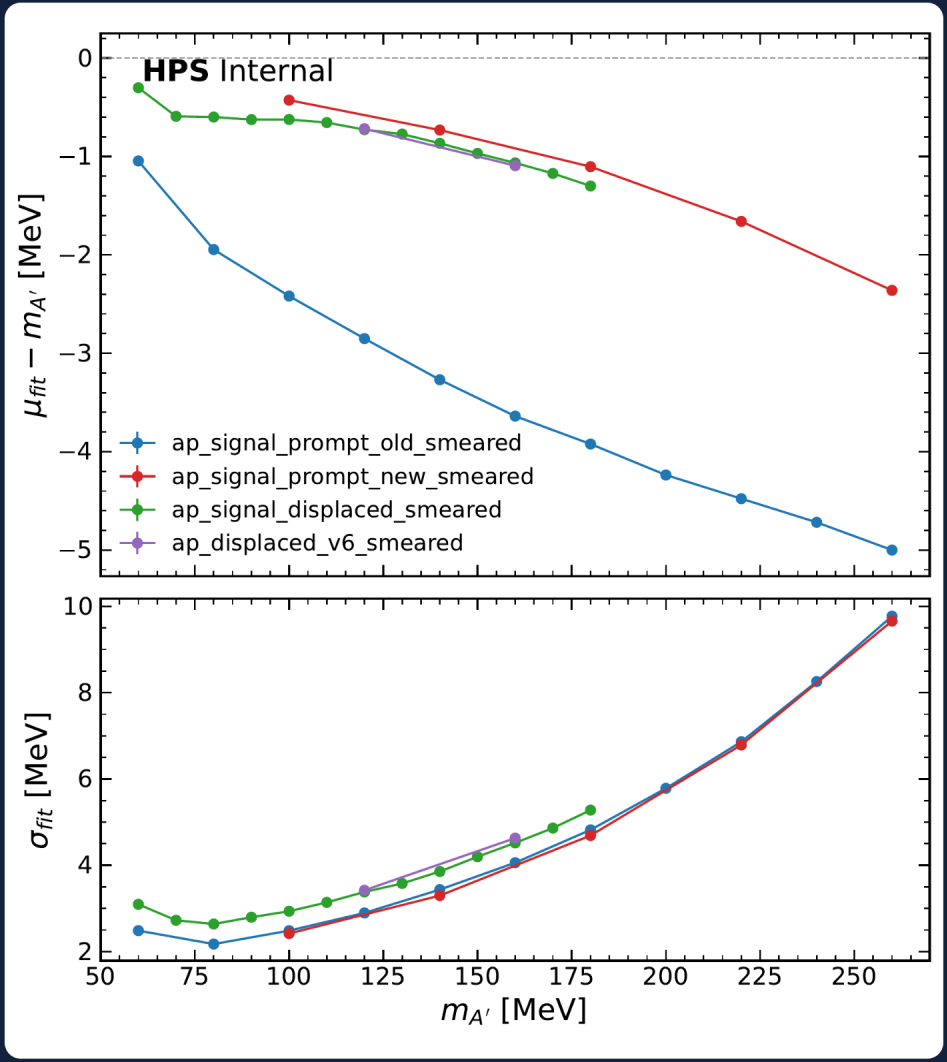
```
  if (constraint == BS_CONSTRAINED
      || constraint == UNCONSTRAINED
+     || (constraint == TARGET_CONSTRAINED
+         && refitTargetConstrained)) {
    shift tracks to pass-1 vertex
    setReferencePosition(vertex)
    refit
  }
```

BilliorVertexer.makeRk(), target mode

```
- rk = beamPosition - V;
+ rk = beamPosition - (V + referencePosition);
```

V is fitted relative to the reference point. Pass 1: reference = origin, so nothing changes. Pass 2: reference = pass-1 vertex.

Commits on mgignac-tc-refit: **44f11973a** refit option and makeRk · **345f57938** setBeamSigmaZ · **37d83cc3d** fixedBeamPos steering



IMPACT

The refit removes most of the mass bias

−3.9 → −1.1 MeV

mass bias at 180 MeV, before → after

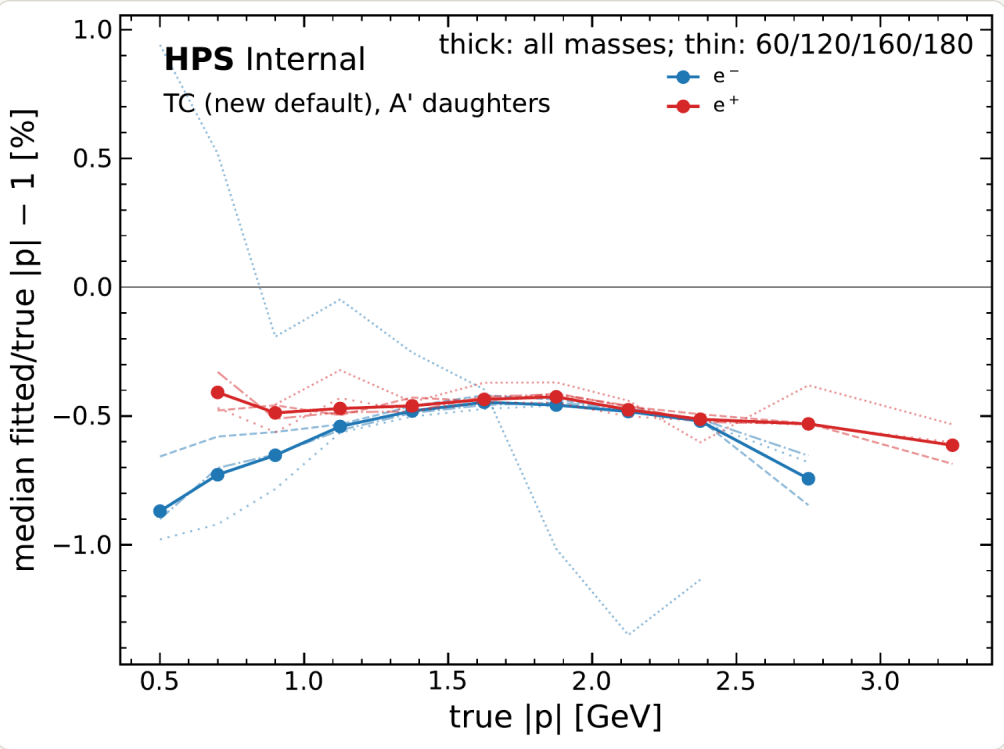
A′ mass	Before (v16)	After
100 MeV	−2.42 MeV	−0.43 MeV
140 MeV	−3.27 MeV	−0.73 MeV
180 MeV	−3.92 MeV	−1.10 MeV
220 MeV	−4.48 MeV	−1.66 MeV
260 MeV	−5.00 MeV	−2.36 MeV

The remaining bias is at the level of the **unconstrained** fit, so it is likely a **momentum bias**, not the constraint.

HPS 2021 · Target-constrained vertex fit mass bias · 8 · prompt A′ MC · blue: no TC fix, red: fixed beam pos + TC refit

REMAINING BIAS

A flat 0.5% momentum deficit explains the rest



$$m \approx \sqrt{(p_1 p_2)} \cdot \theta$$

$$\delta m/m \approx \langle \delta p/p \rangle + \delta\theta/\theta$$

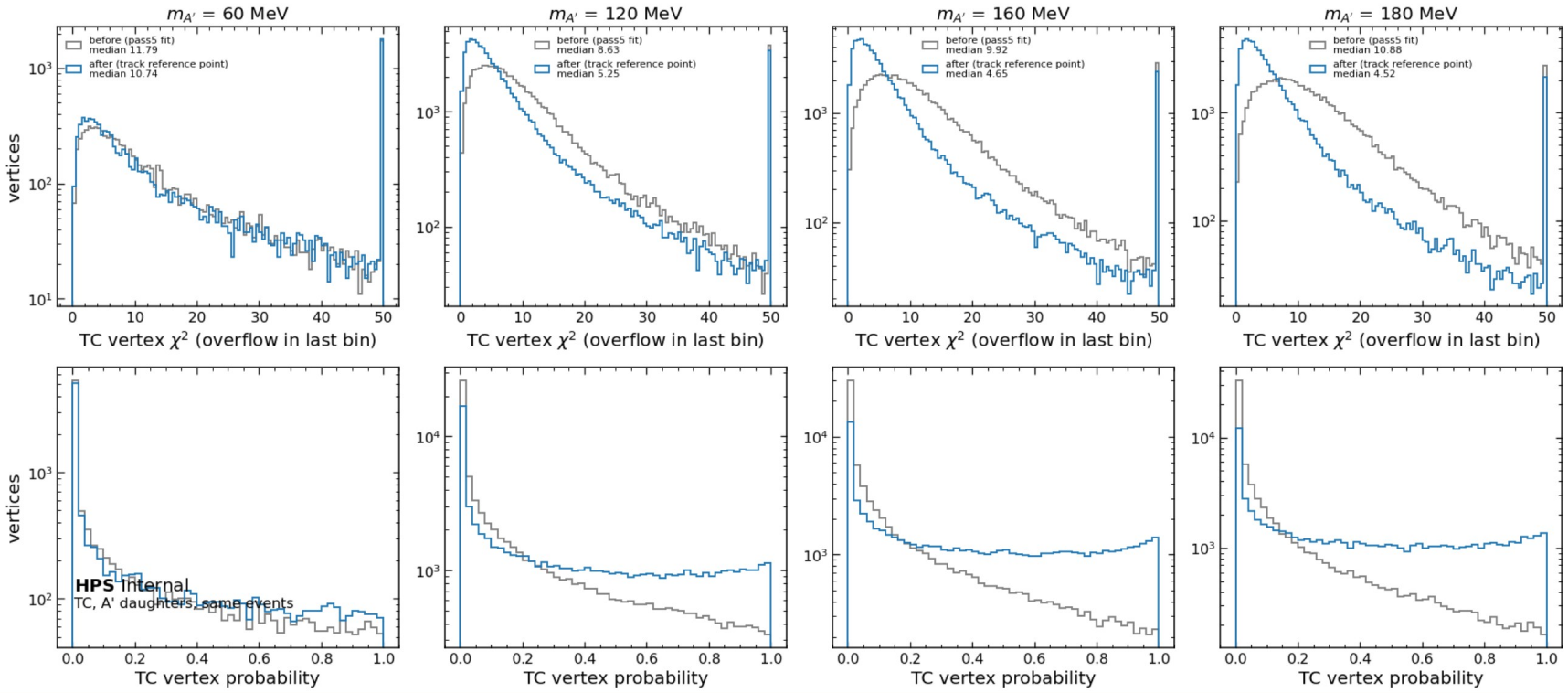
A constant fractional p bias gives a constant fractional mass bias: Δm grows with m.

m	⟨δp/p⟩	δθ/θ	Predicted	Fit μ − m
60	−0.44%	+0.60%	+0.10	+0.14
120	−0.49%	0.00%	−0.59	−0.49
160	−0.51%	−0.02%	−0.84	−0.74
180	−0.53%	−0.03%	−1.01	−0.92

Scaling p by **k = 1.005** brings μ − m to ≤ 0.1 MeV at 120–180 MeV. At 60 MeV a +0.6% wider opening angle offsets the deficit.

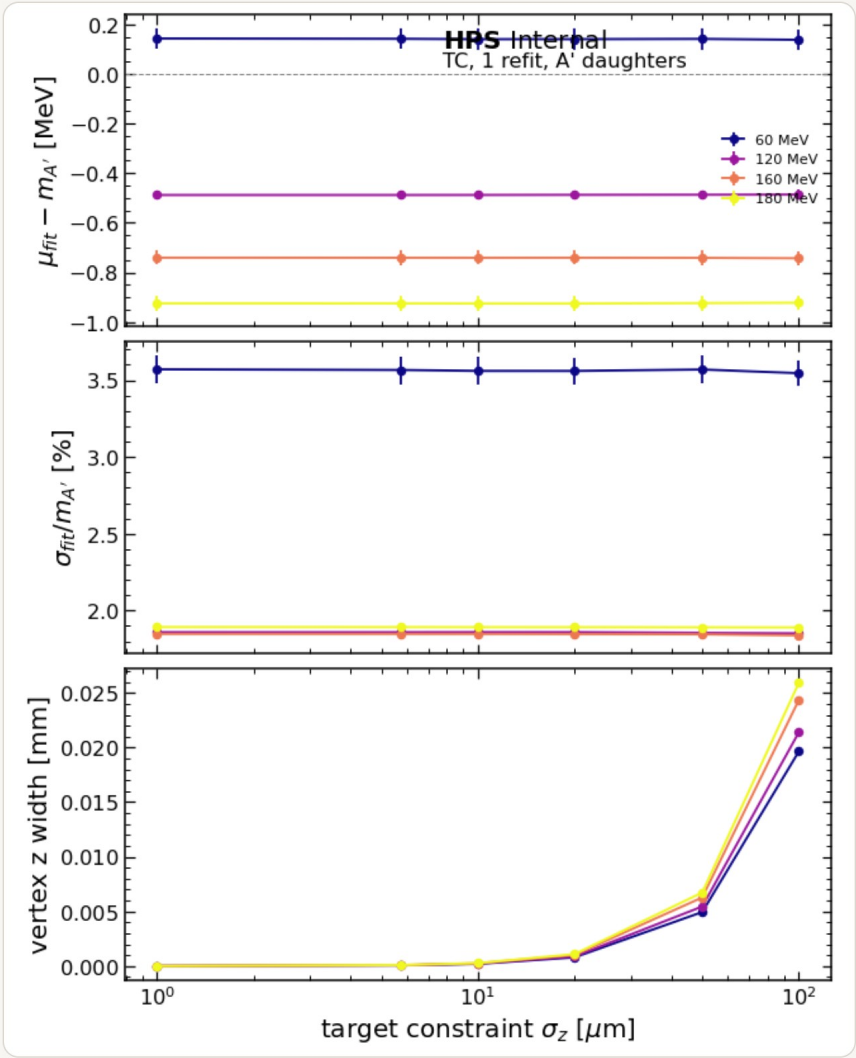
IMPACT

The vertex χ² comes down after the fix



Median χ² before → after: **11.8** → **10.7** (60 MeV) · **8.6** → **5.3** (120) · **9.9** → **4.7** (160) · **10.9** → **4.5** (180)

HPS 2021 · Target-constrained vertex fit mass bias · 10 · same events, A′ daughters



TARGET CONSTRAINT WIDTH

Loosening σz does not move the mass

At 180 MeV	σz = 1 μm	σz = 100 μm
μ − m	−0.92 MeV	−0.92 MeV
σ	3.41 MeV	3.40 MeV
Vertex z width	< 0.1 μm	25.9 μm

Same at 60, 120 and 160 MeV: bias and resolution change by 0.02 MeV or less from 1 to 100 μm. Only the vertex z width responds.

CONCLUSIONS

The constraint bias is fixed; a momentum scale remains

Cause

Track parameters are defined at each track's pivot P; the first-pass fit read them as if at the origin. With the vertex pinned, the error went into the momenta: a ~2% low mass.

Fix

Give the vertexer each track's reference point: one pass matches the refit. Bias at 180 MeV goes from **−3.9 to −1.1 MeV**; the vertex χ^2 median roughly halves.

Constraint width

Loosening σz from 1 to 100 μm leaves the mass bias and resolution unchanged. Only the vertex z width responds.

What remains

Reconstructed momenta are ~0.5% low vs truth, which accounts for the remaining bias. It is shared with the unconstrained fit and still open.