Logbook for YR Studies

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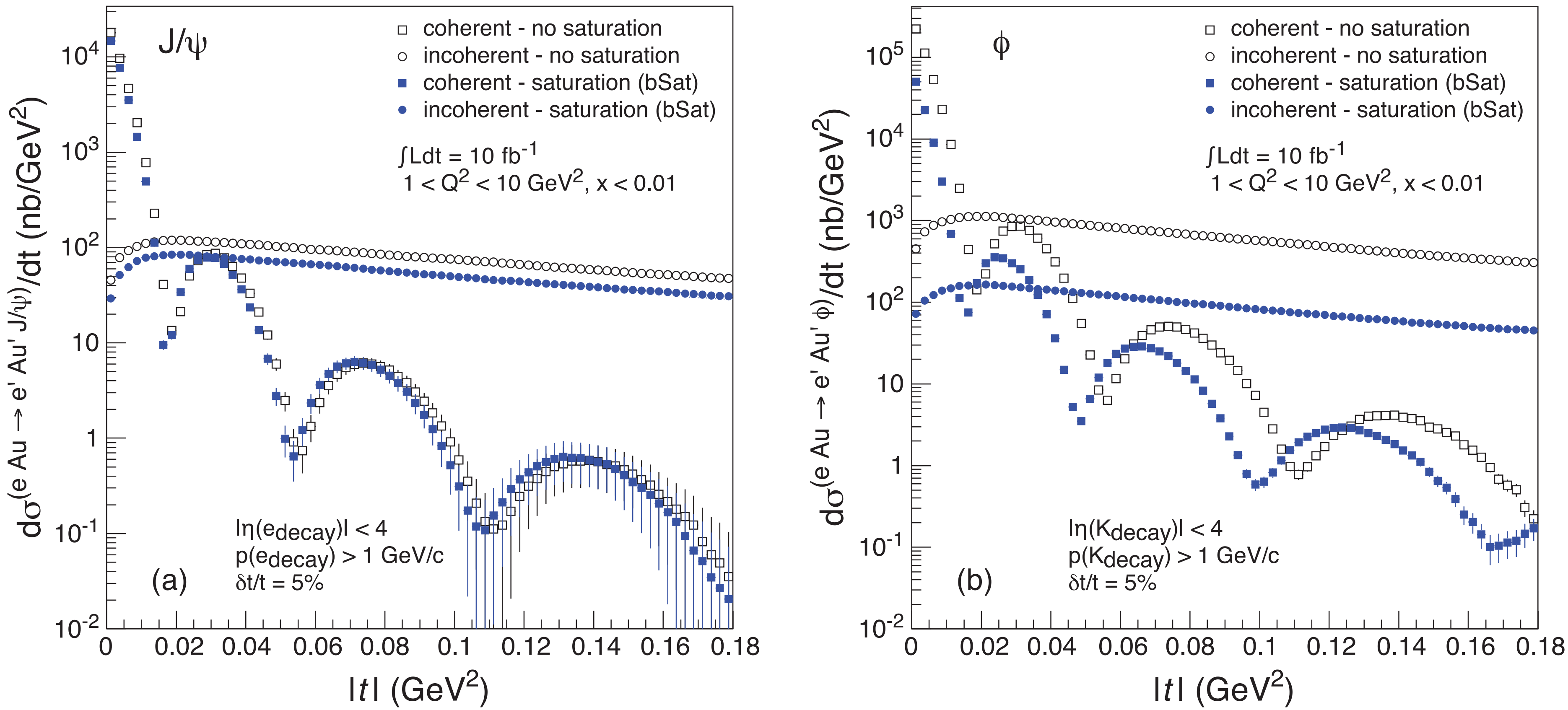
BROOKHAVEN NATIONAL LABORATORY

Vector Meson Production: dσ/dt



Assumed: dt/t ~ 5% (taken from HERA)

T. Toll and TU,
PRC 87 (2013) 024913

Measuring t in $e + A \rightarrow e' + A' + V$

Note: A' cannot be measured directly

Exact Method (E):

- $t = (p_A - p_{A'})^2 = (p_V + p_{e'} - p_e)^2$
- recovers original t used to generate Sartre event
- Note for later: details of A and A' are not relevant in this method

Measuring t in $e + A \rightarrow e' + A' + V$

Approximative Method (A):

- $t = \left[\overrightarrow{p}_T(e') + \overrightarrow{p}_T(V)\right]^2$
- Ignores any longitudinal momenta
- Method used often in HERA

Method A without any smearing

Method A appears to underestimate *t*

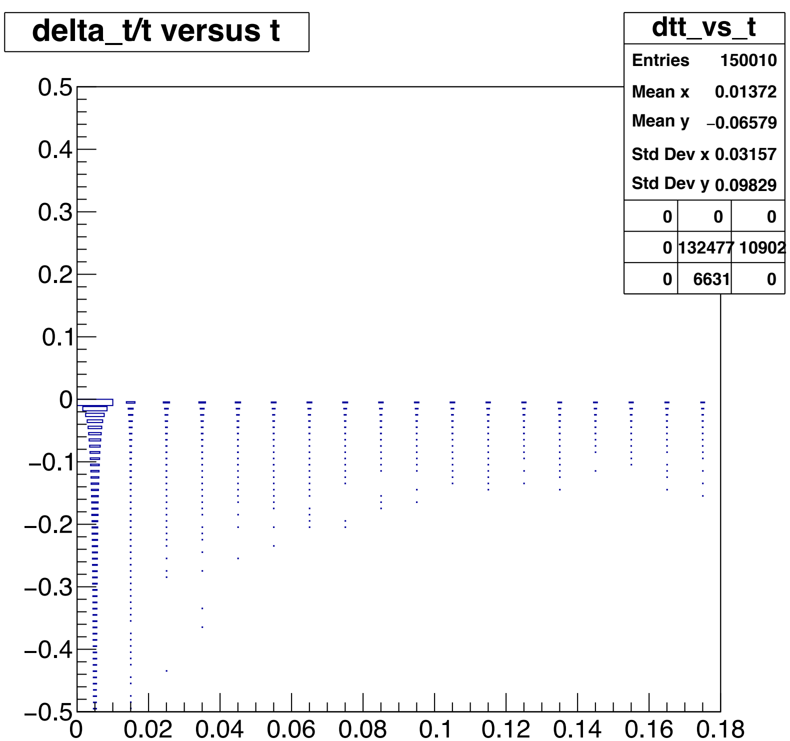
here x < 0.01 and 1 < Q^2 < 10 GeV^2

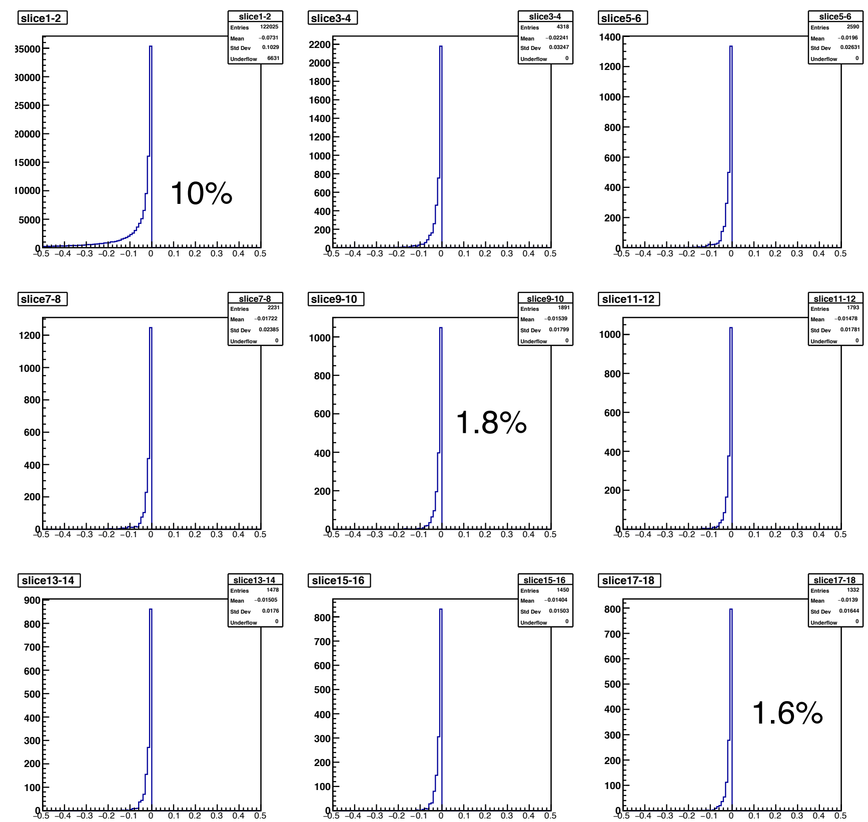
dt = |t(from A) - |t(Sartre)|

t < 0.01   dt/t ~ 10%

t ~0.16   dt/t ~ 1.6%

Here and in what follows:
Slices from left to right edge
of left side 2D histo





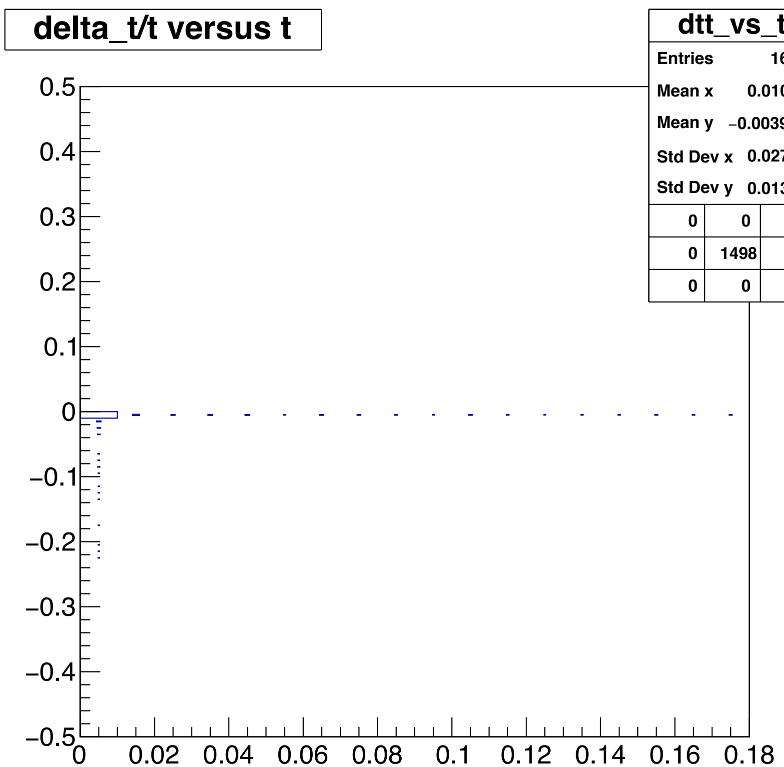
Method A without any smearing

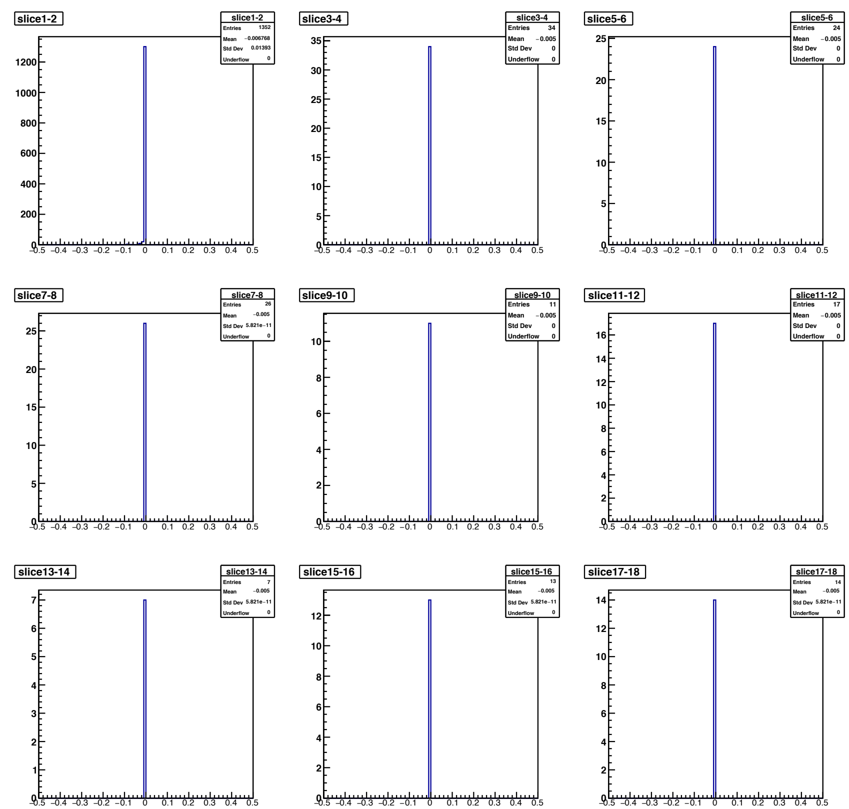
Method A with x < 0.01 and $Q^2 < 0.01$ GeV^2

more for less photo production

t < 0.01 dt/t ~ 1.3%

t ~0.16 dt/t ~ 0%

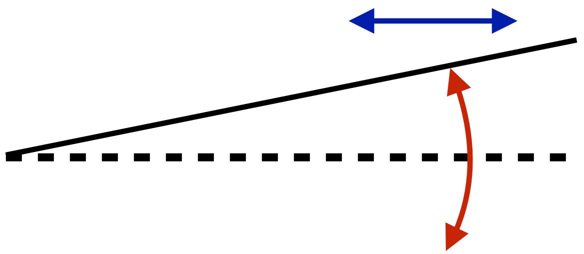




Beam Smearing

Two effects to take into account

- Spread of beam momentum dp/p
  - electron beam: 6.8e-4
  - Au beam: 7.7e-4



- Divergence $\sigma = \sqrt{\epsilon / \beta^*}$
  - electron beam: $\sigma = \sqrt{20 \times 10^{-9} / 43 \times 10^{-2}} = 216\ \mu\text{rad}$
  - Au beam: $\sigma = \sqrt{9.6 \times 10^{-9} / 90 \times 10^{-2}} = 103\ \mu\text{rad}$
- Divergence adds p_T to the beams. In the following we call this k_T. The only way to minimize k_T is to increase β^* (and lose lumi as $\mathscr{L} \propto 1/\beta^*$)
- These effects are event by event. In any calculation we have to assume the mean. This leads to a smearing of *t*, i.e. the measured one is not the actual one.

N.B. What is β^* and ϵ? (I)

The beam size can be expressed in terms of two quantities, one termed the transverse emittance, ε , and the other, the amplitude function, β.

The **transverse emittance** is a beam quality concept reflecting the process of bunch preparation (the injector chain), extending all the way back to the source for hadrons. A **low emittance particle beam is a beam where the particles are confined to a small distance and have nearly the same momentum.** A beam transport system will only allow particles that are close to its design momentum, and of course they have to fit through the beam pipe and magnets that make up the system. In a colliding beam accelerator, **keeping the emittance small** means that the likelihood of particle interactions will be greater resulting in **higher luminosity.**

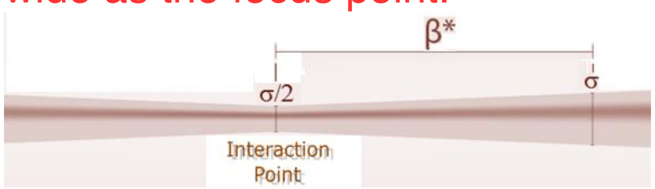
Emittance can be defined as the smallest opening you can squeeze the beam through, and can also be considered as a measurement of the parallelism of a beam.
It has units of length, but is usually referred to as "length x angle", for example, "millimeter x milli-radians". It can be measured in all three spatial dimensions. The dimension parallel to the motion of the particle is called the **longitudinal emittance**. The other two dimensions are referred to as the **transverse emittances**.
The emittance changes as a function of the beam momentum; increasing the energy of the beam reduces the emittance. It is often more useful to consider the ***normalised emittance,*** ε_n, which express the cross-sectional speeds in terms of a small angle regarding the direction of the beam and is proportional to the squared root of the energy (so the physical size of the beam will vary inversely to the square root of the energy).

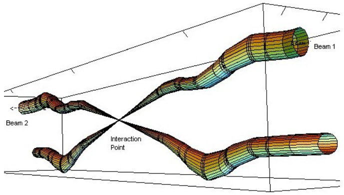
N.B. What is β* and ϵ? (II)

The amplitude function, ***β*** , is determined by the accelerator magnet configuration (basically, the quadrupole magnet arrangement) and powering. When expressed in terms of **σ** (cross-sectional size of the bunch) and the transverse emittance, the ***amplitude function β*** **becomes**(see here)**:**

$\beta = \pi \; \sigma^2/\epsilon$ **(**Note that CAD usually folds the π into ϵ)

So, **beta is roughly the width of the beam squared divided by the emittance.** If **beta is low, the beam is narrower, "squeezed". If Beta is high, the beam is wide and straight.**
Beta has units of length.
Sometimes **Beta** is referred as the distance from the focus point that the beam width is twice as wide as the focus point.





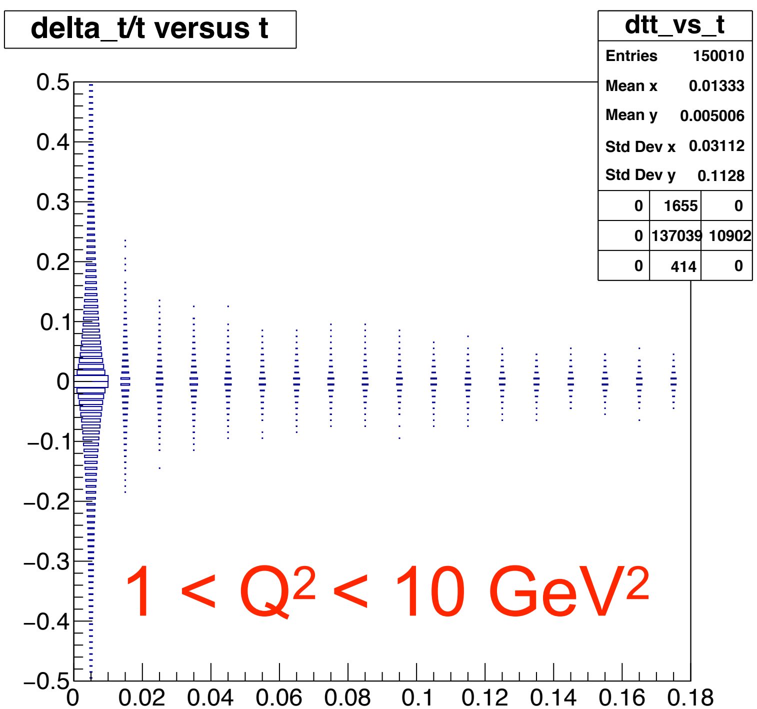
In the experiments (detectors), the beam will be "squeezed" as much as possible, to increase the number of collisions, so at a distance of beta before the focus point, the beam is also twice as wide.
Of particular significance is the value of the **amplitude function at the interaction point, *β**.Clearly one wants to be as small as possible; how small depends on the capability of the hardware to make a near-focus at the interaction point.

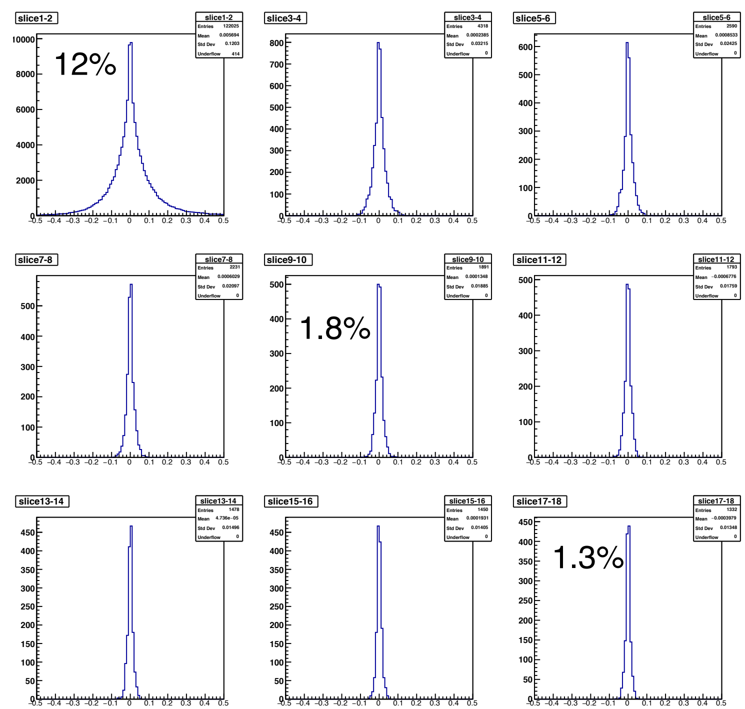
Effect of beam smearing on method E

- $t = (p_A - p_{A'})^2 = (p_V + p_{e'} - p_e)^2$
- Au/hadron beam effects do not matter here - all contained in t
- p_e matters
- Here divergence effects only:

t < 0.01 dt/t ~ 12%

t ~0.16 dt/t ~ 2%





Effect of beam smearing on method E

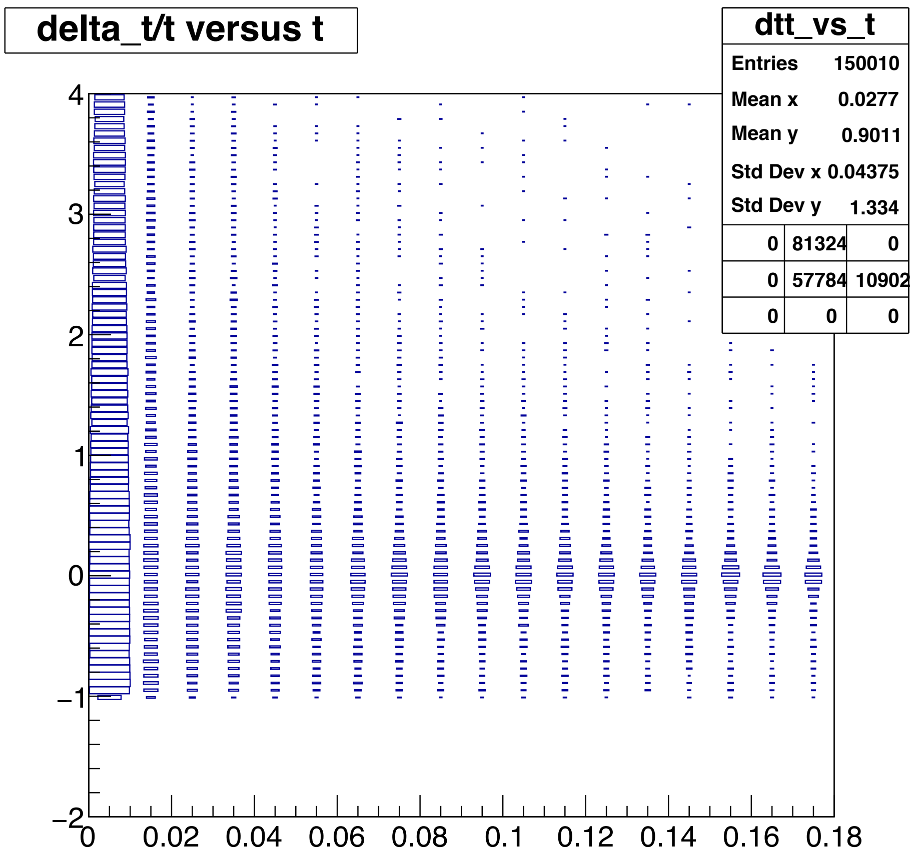
- Here momentum smearing only:

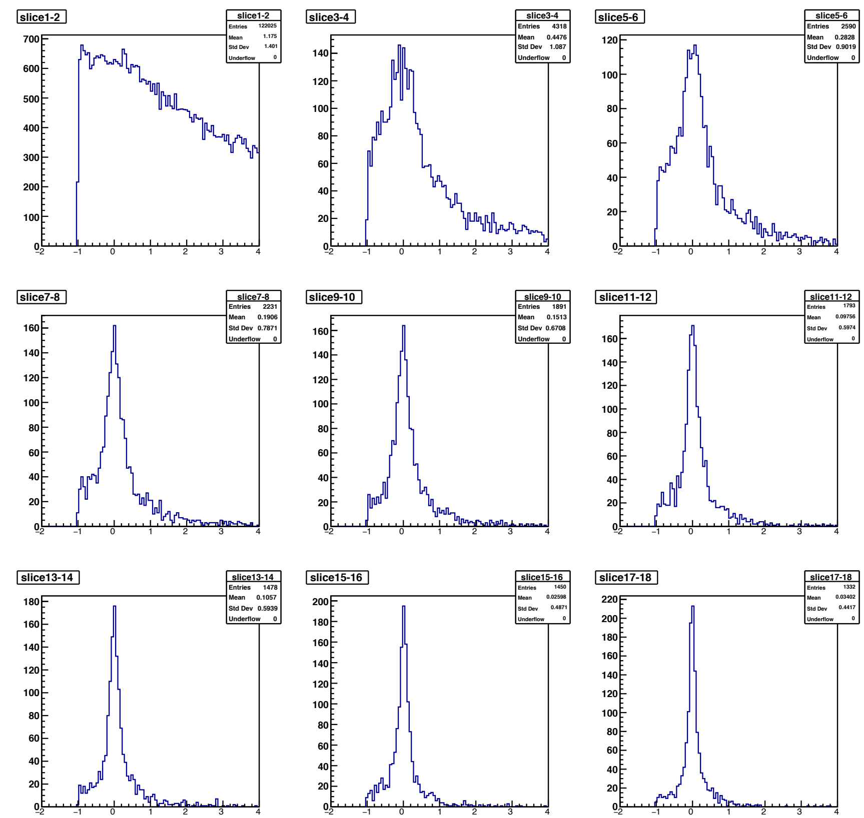
1 < Q^2 < 10 GeV^2

t < 0.01 dt/t >> 100%

t ~0.16 dt/t ~ 48%

Method E totally fails!



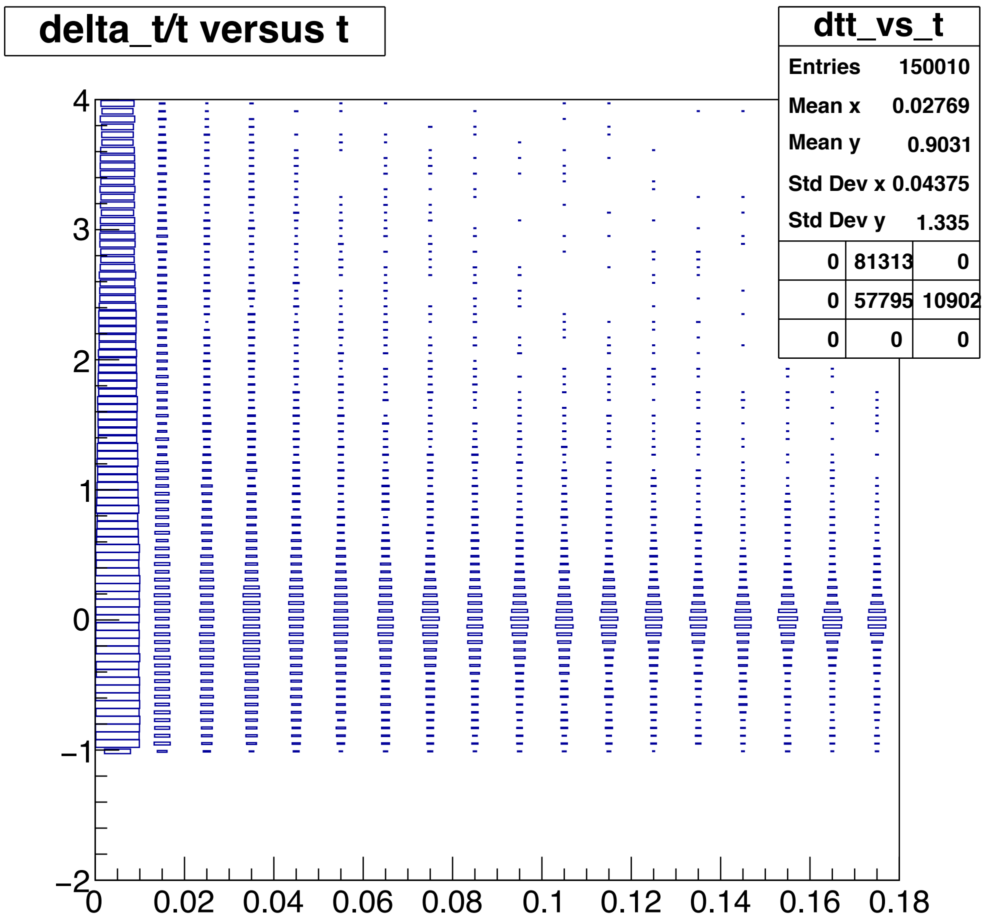


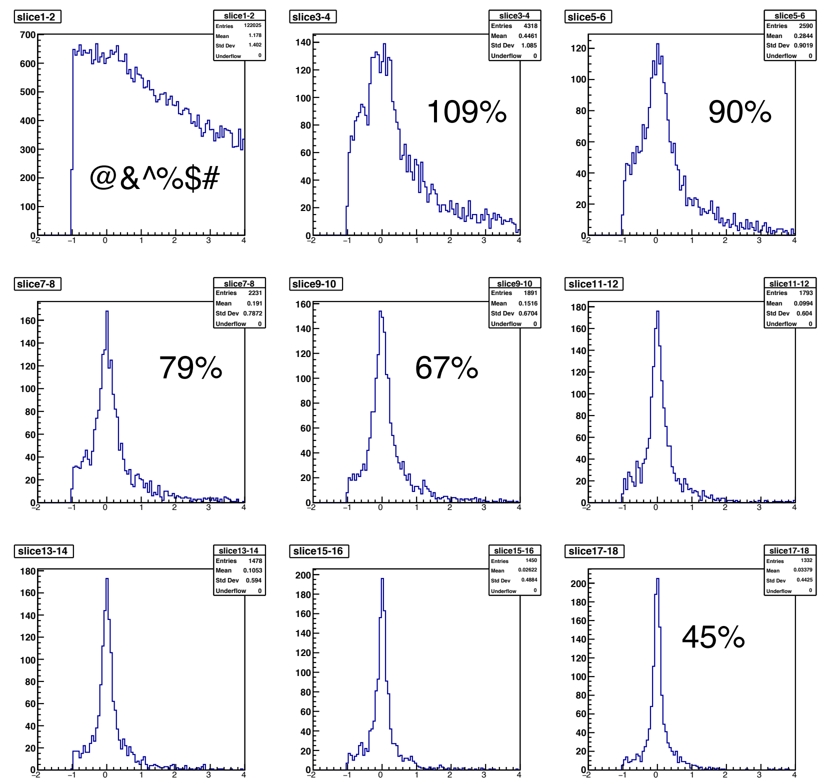
Effect of beam smearing on method E

- Both effects:

1 < Q^2 < 10 GeV^2

We are sooooo dead (and we haven't touched tracking yet)



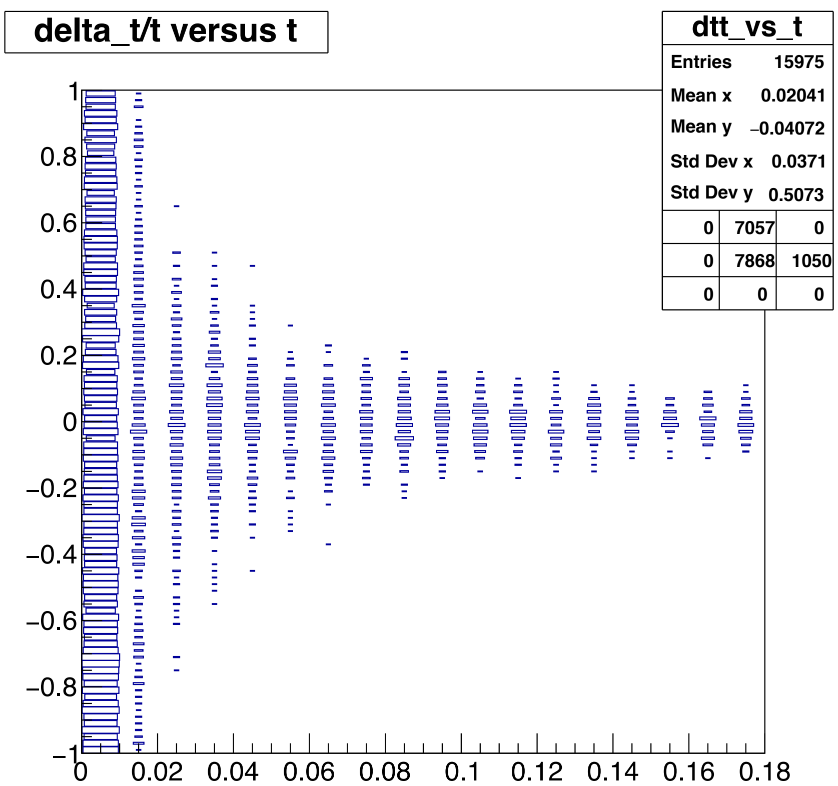


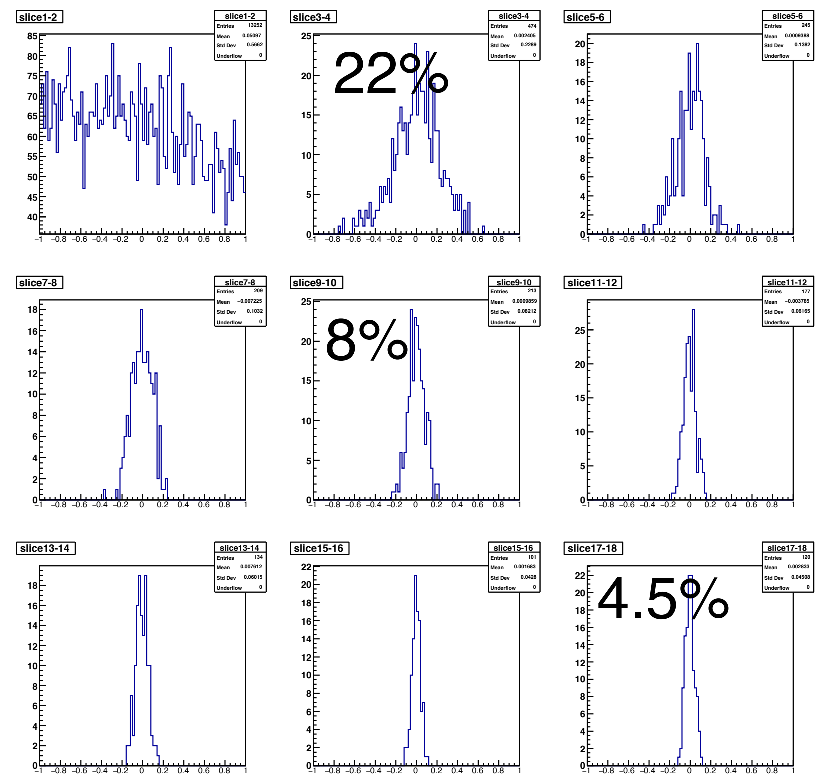
Effect of beam smearing on method E

- Both effects:

$Q^2 < 0.01\ GeV^2$

Somewhat better - still bad





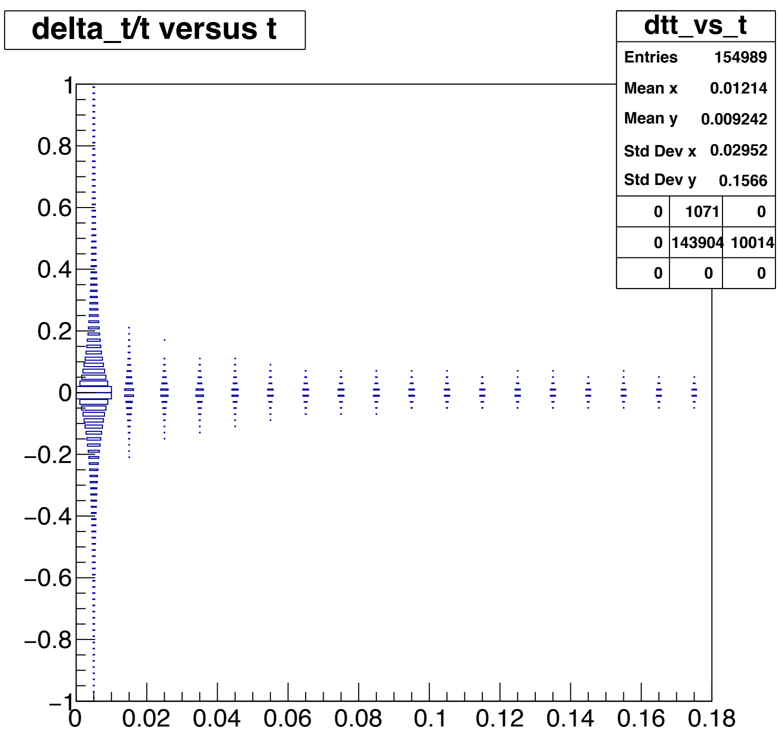
Effect of beam smearing on method E

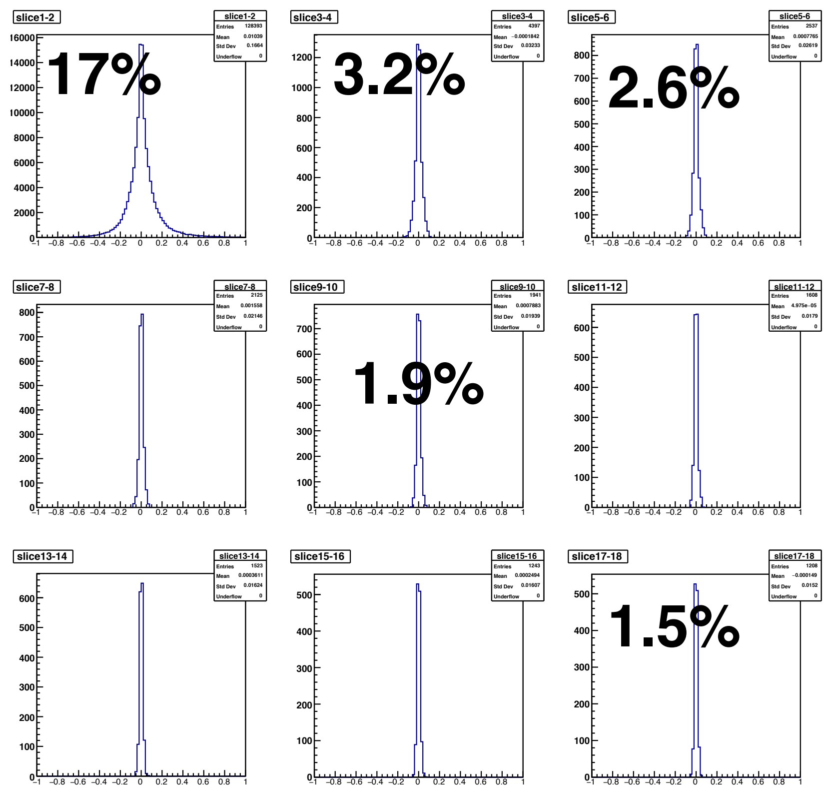
- Divergence only:

$Q^2 < 0.01\ \mathrm{GeV}^2$

Better - could live with that

… but momentum smearing is present so this is wishful thinking





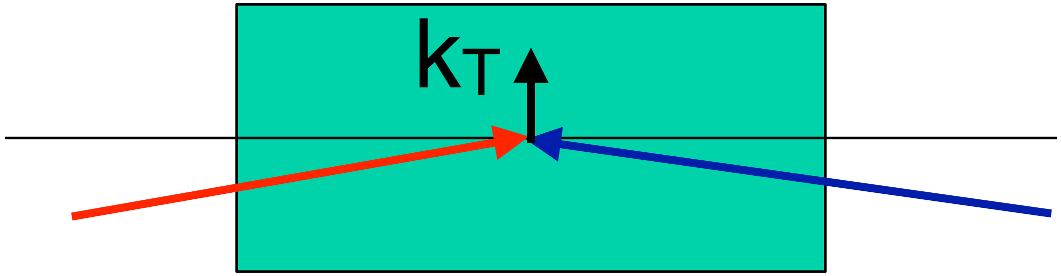
What's the issue with the Exact method?

- $t = (p_A - p_{A'})^2 = (p_V + p_{e'} - p_e)^2$
- we are subtracting large numbers
- even little fluctuations on p_e have large effects since t is small
- The divergence seems to matter less than the momentum spread which is a huge problem

Which brings method A on the table

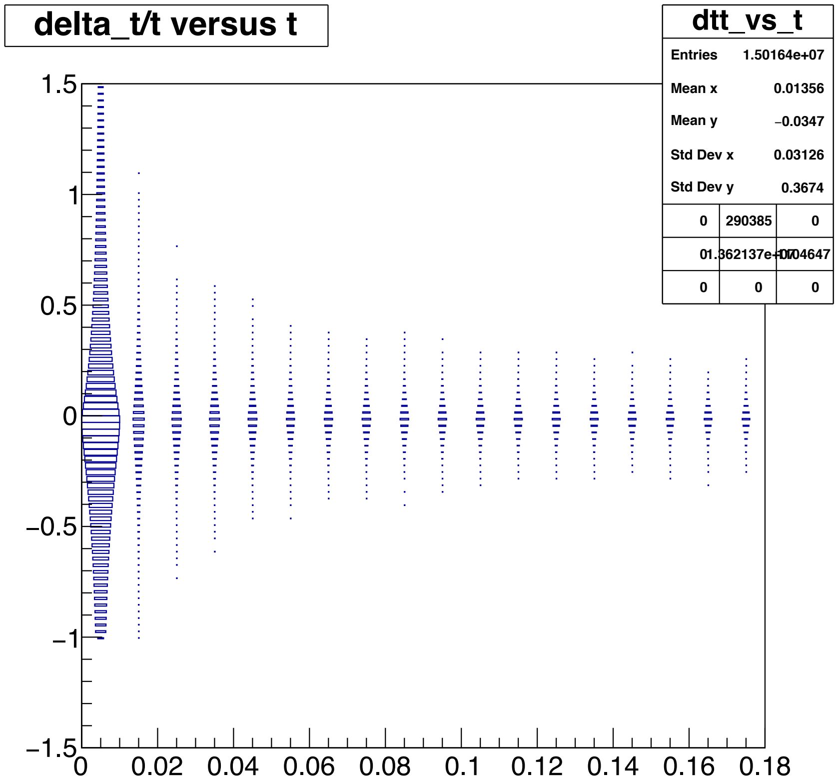
Effect of beam smearing on method A

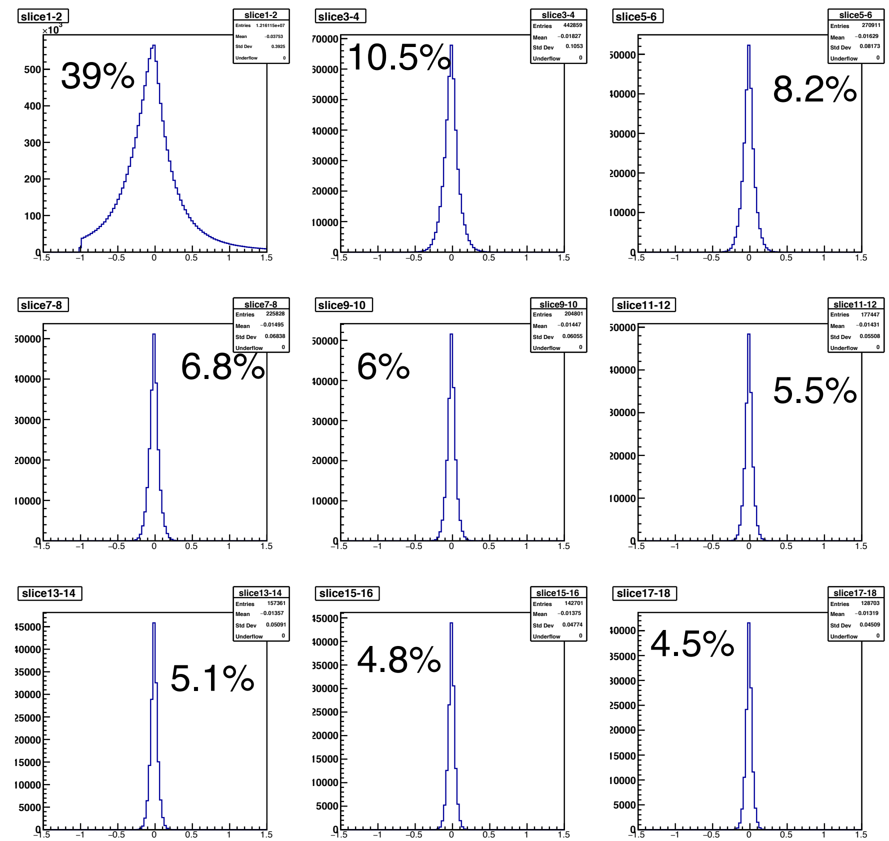
- No smearing $t = \left[\overrightarrow{p}_T(e') + \overrightarrow{p}_T(V)\right]^2$
- Beam momentum spread is less relevant here
- Divergence matters since it gives the collision system a transverse momentum kick - call it k_T
- Fluctuates around $k_T = 0$ on EbyE basis
- Cannot add this effect to Sartre (initial state) but can add it to final state. Same in terms of "error/resolution".
- $t = \left[\overrightarrow{p}_T(e') + \overrightarrow{p}_T(V) + \overrightarrow{k}_T\right]^2$ where $\overrightarrow{k}_T = \overrightarrow{k}_T^e + \overrightarrow{k}_T^h$



Effect of beam smearing on method A

1 < Q^2 < 10 GeV^2





- OK at larger t but bad at low-t. Recall the first minima in $d\sigma/dt$ matter

Christoph Montag on β*

Hi Thomas,

We have to match the beam sizes of electrons and hadrons at the IP, otherwise the larger beam gets blown up.
Larger beta* is generally easier because it reduces the beam size in the low-beta focusing magnets. The detector beam pipe diameter is large compared to the actual beam sizes because it has to accommodate the large synchrotron radiation fan, not just the beams. A couple of meters for beta* should definitely be possible; I cannot promise that 20m would still be OK.

Christoph

Note: Nominal β*

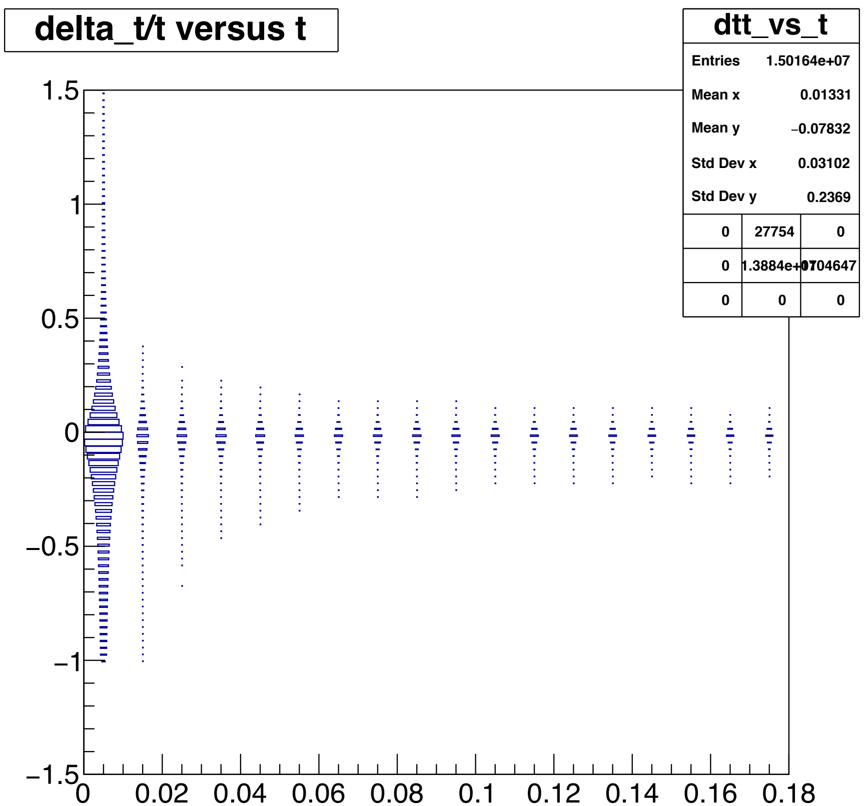
electrons: 43 cm

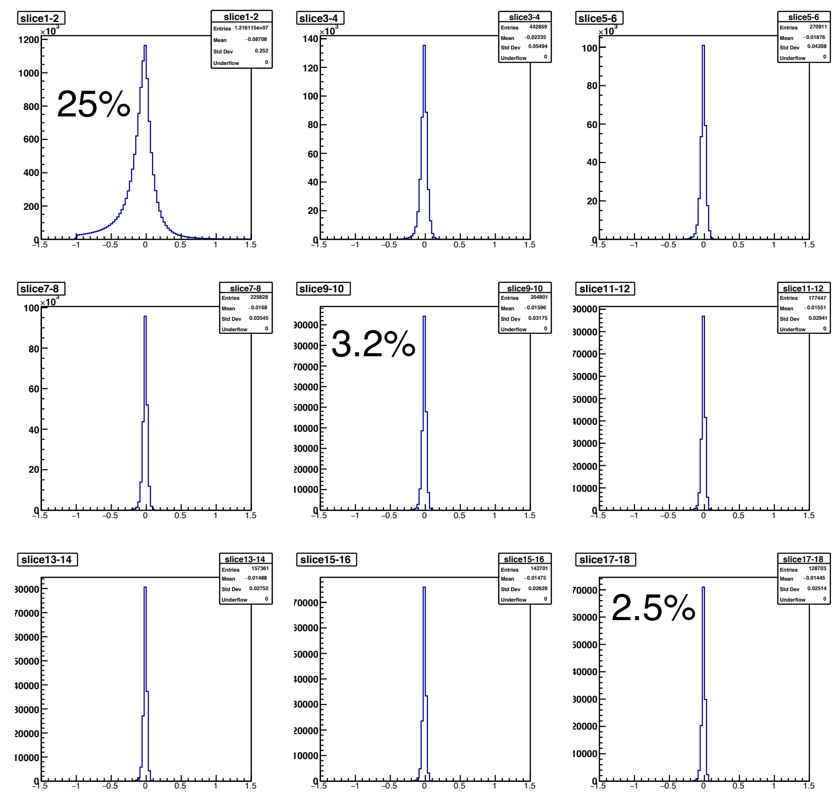
hadrons: 90 cm

Effect of beam smearing on method A

$1 < Q^2 < 10$ GeV^2

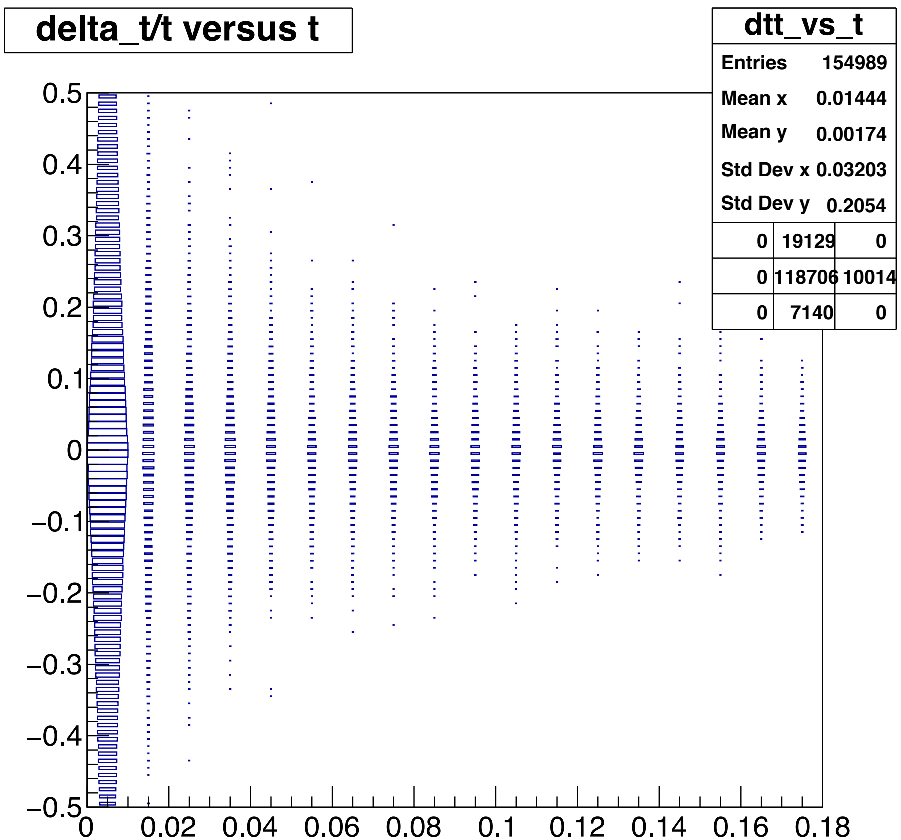
- Check: Increase β^* by factor 6 (e ~ 258 cm and h~ 540 cm), That would decrease L by 6!
- Note $\beta^* \rightarrow \infty$ does not give dt = 0 but values on page 5

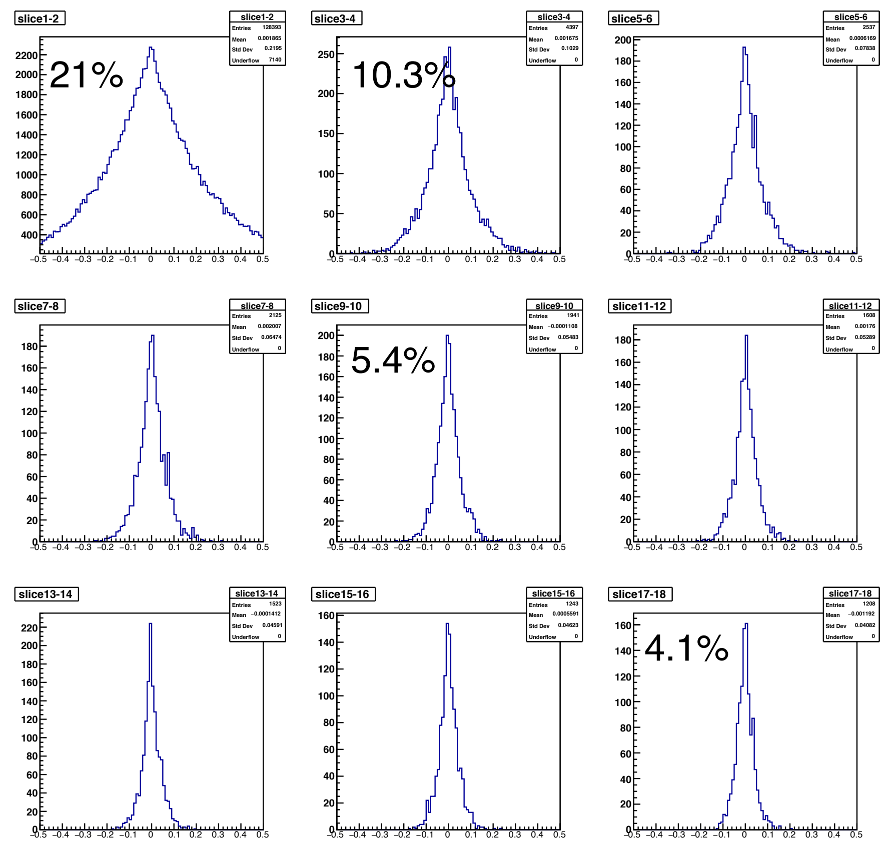




Effect of beam smearing on method A

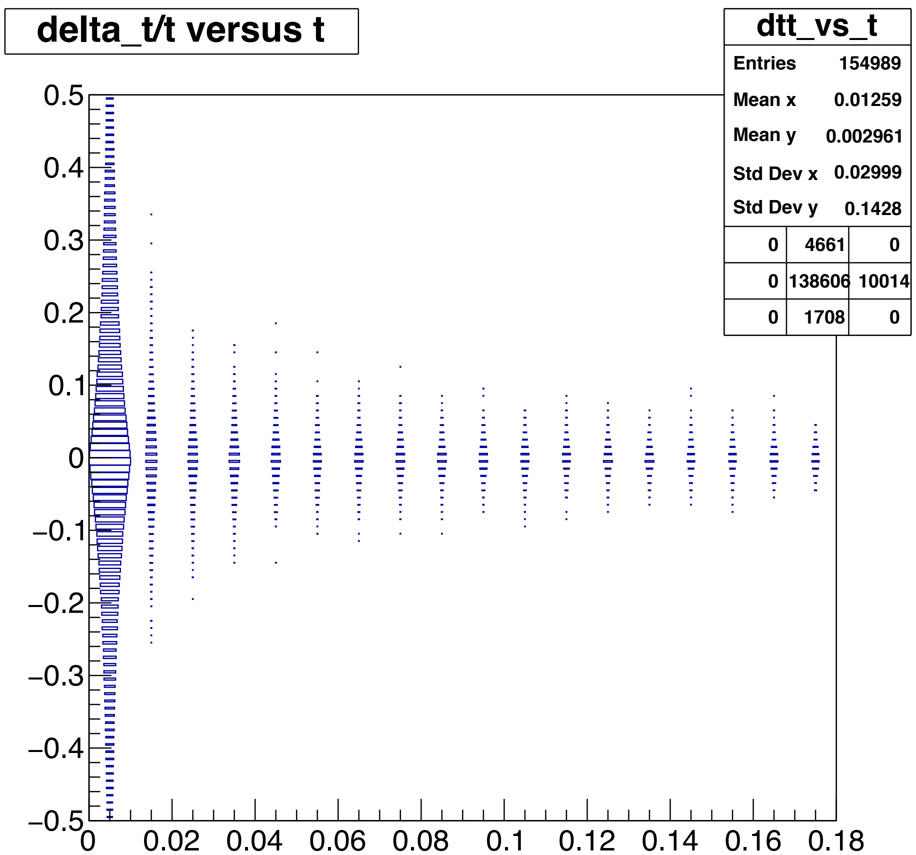
- Photoproduction $Q^2 < 0.01$
- Nominal β^*

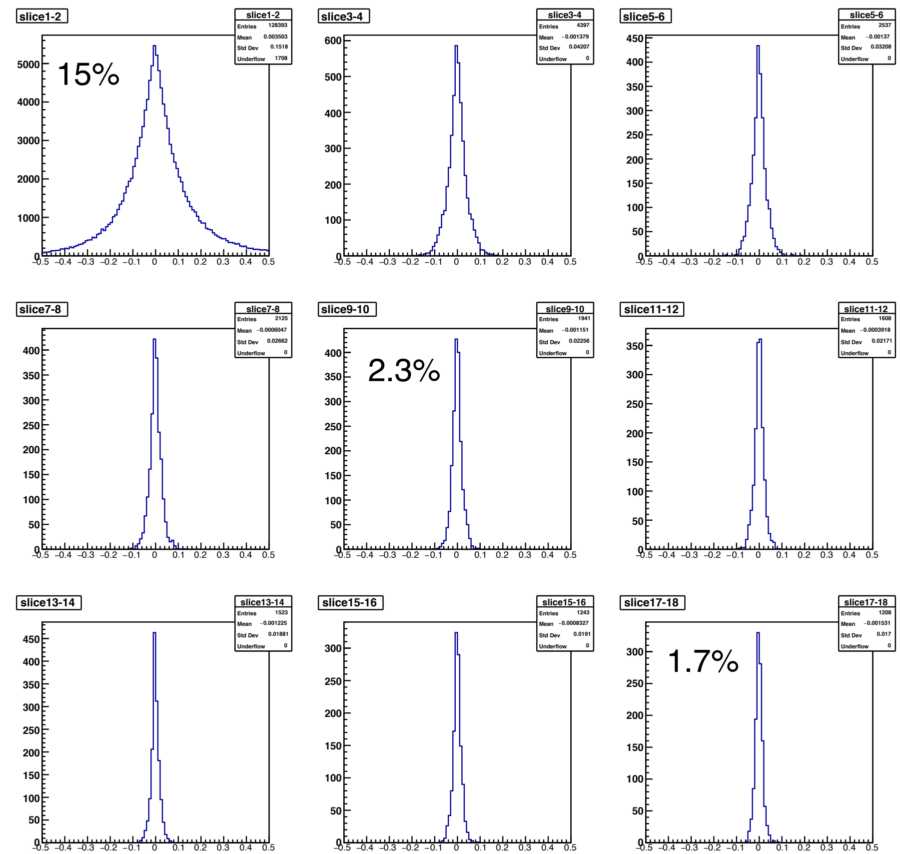




Effect of beam smearing on method A

- Photoproduction $Q^2 < 0.01$ and 6 x β^*
- Increasing β^* has more impact in improving resolution in photo production than at larger Q^2





Tracking Resolution

Precision term: $$\left.\frac{\sigma_{p_T}}{p_T}\right|_{\text{meas}} = \frac{p_T\ \sigma_{r_{\phi r}}}{0.3\ L^2\ B}\sqrt{\frac{720}{N+4}}$$

MS term: $$\left.\frac{\sigma_{p_T}}{p_T}\right|_{\text{MS}} = \frac{0.05}{L\ B\ \beta}\sqrt{1.43\frac{L}{X_0}}\left[1+0.038\ \log\frac{L}{X_0}\right]$$

where

$\sigma_{r_{\phi r}}$ is point resolution in meter

L is lever arm in meter

B is magnetic field in Tesla

N are number of measurements (hits)

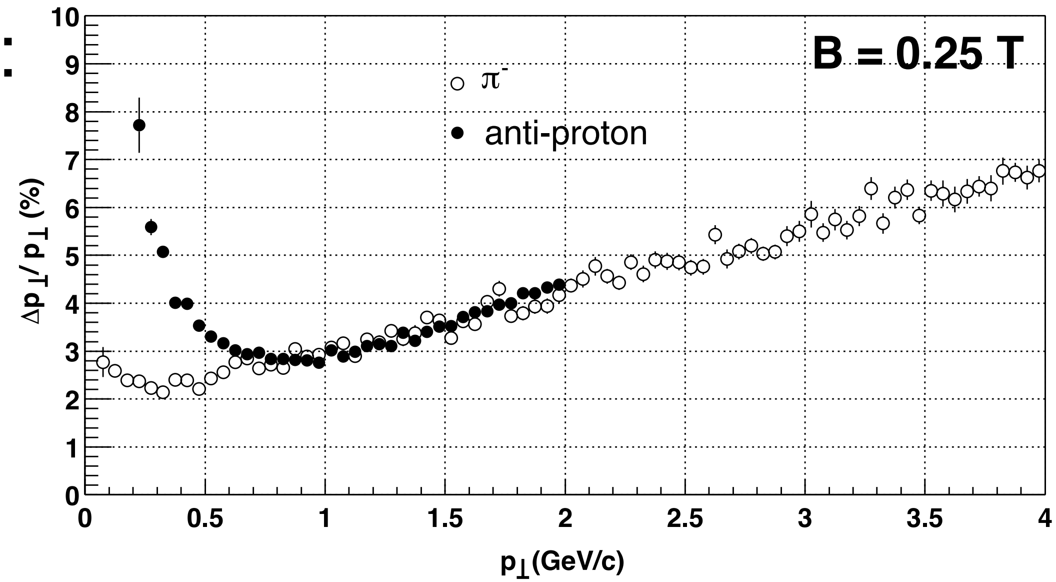
β velocity of particle

X_0 is gas/material density in meter

Track momentum resolution: $$\frac{\sigma_{p_T}}{p_T} = \left.\frac{\sigma_{p_T}}{p_T}\right|_{\text{meas}} \oplus \left.\frac{\sigma_{p_T}}{p_T}\right|_{\text{MS}}$$

Start value for simulations

STAR TPC:



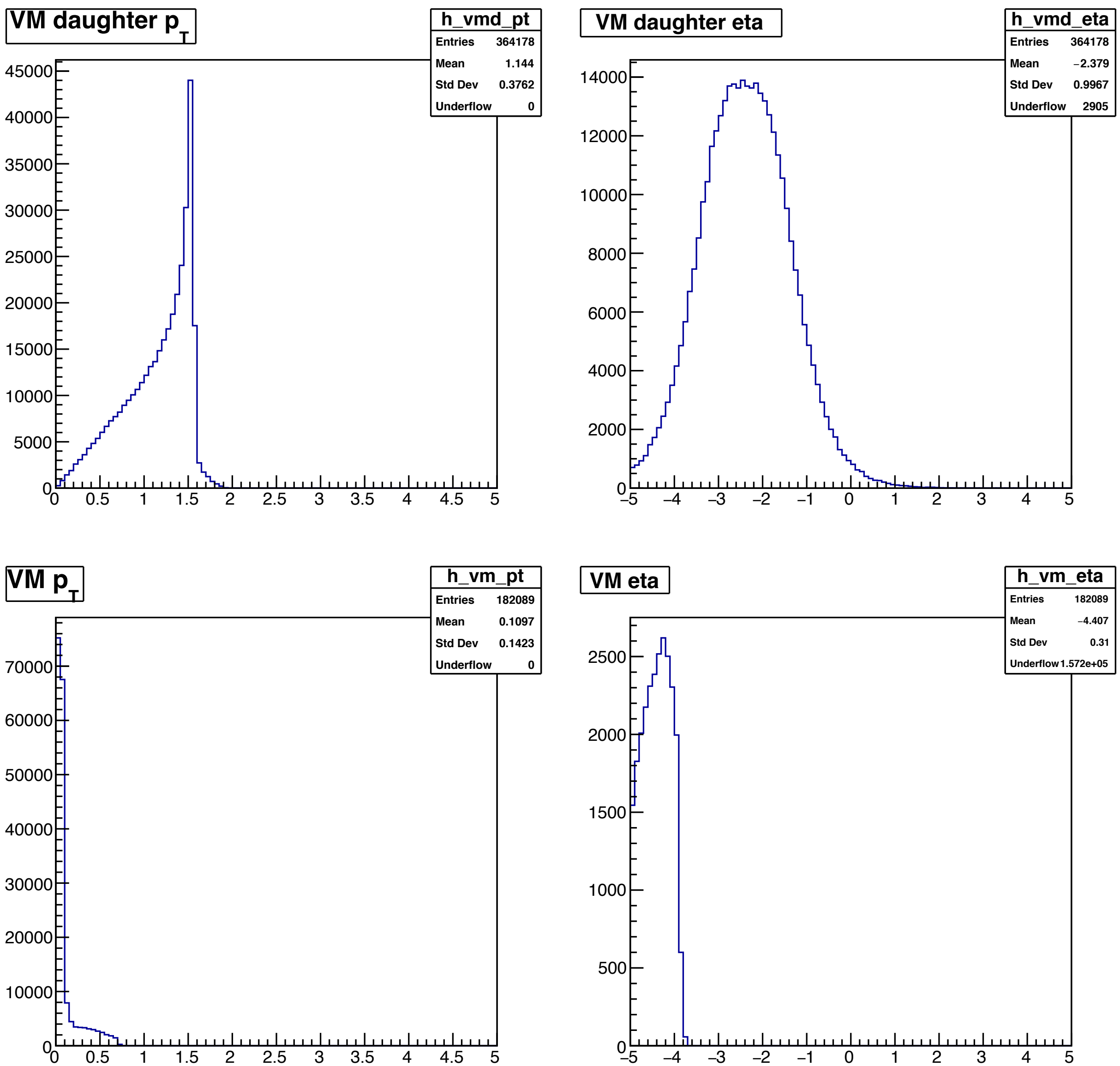
N.B.
Important to consider if vertex is included or not (primary vs. global tracks)

STAR TPC: $\frac{\sigma_{p_T}}{p_T}(\%) = 1.56\ p_T \oplus 2.74$ B=0.25 T (half field)

STAR TPC: $\frac{\sigma_{p_T}}{p_T}(\%) = 0.78\ p_T \oplus 1.37$ B=0.5 T (full field)

EIC Handbook: $\frac{\sigma_{p_T}}{p_T}(\%) = 0.05\ p_T \oplus 0.5$ B=3 T (full field)

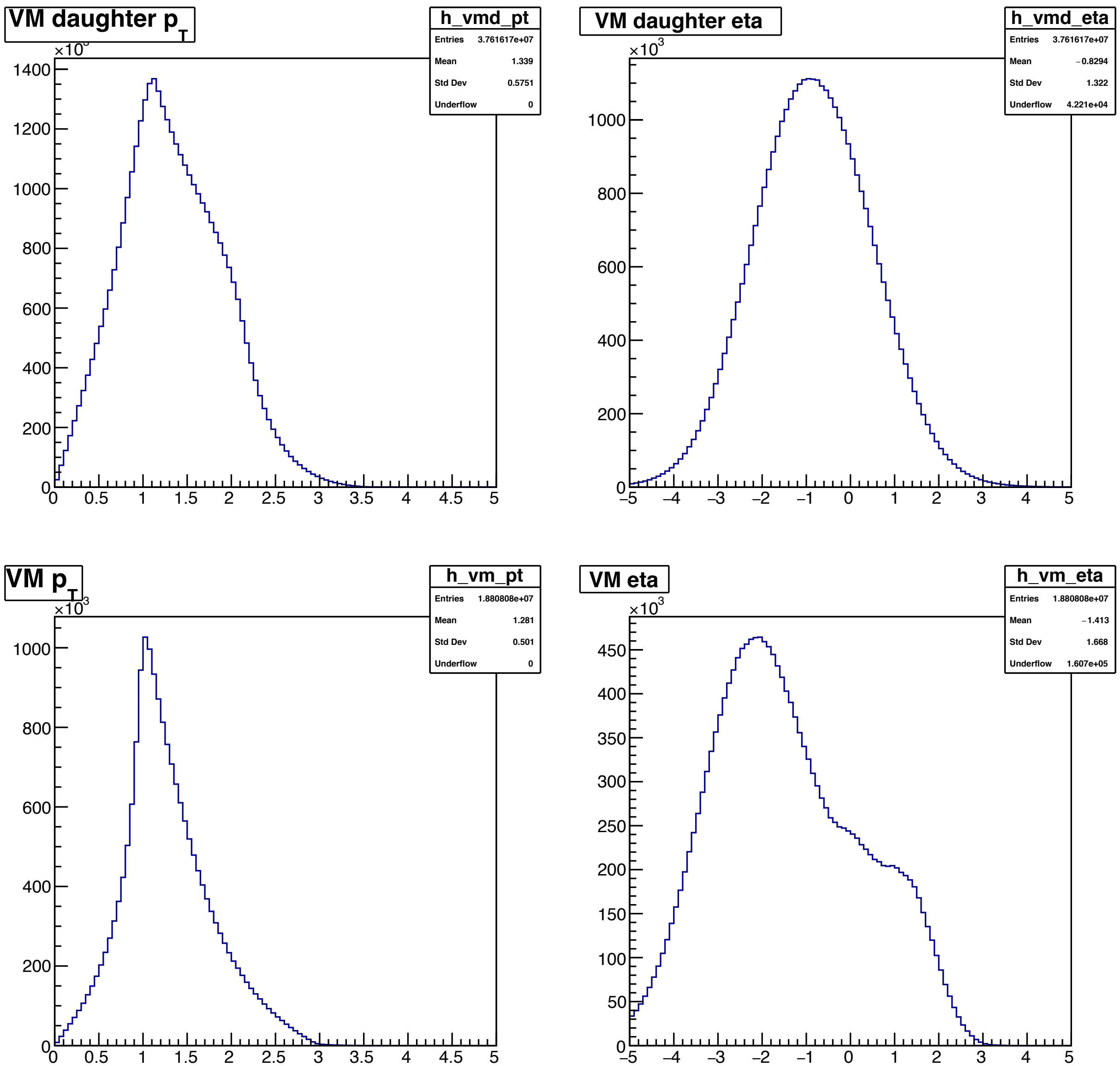
Kinematics J/ψ



$Q^2 < 0.01$ GeV^2

Note that this includes coherent & incoherent & bSat and & bNoSat

Kinematics J/ψ



$1 < Q^2 < 10$ GeV^2

Focus on barrel from now on.

Assume:

$|\eta| < 1.5$

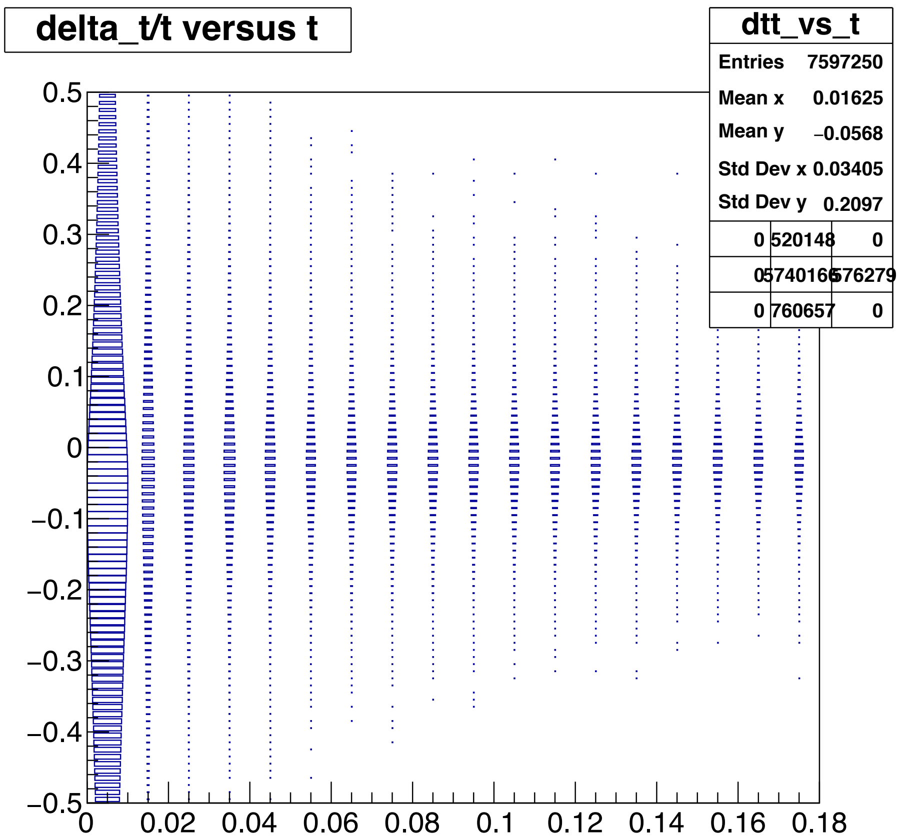
$p_T > 0.5$ GeV/c

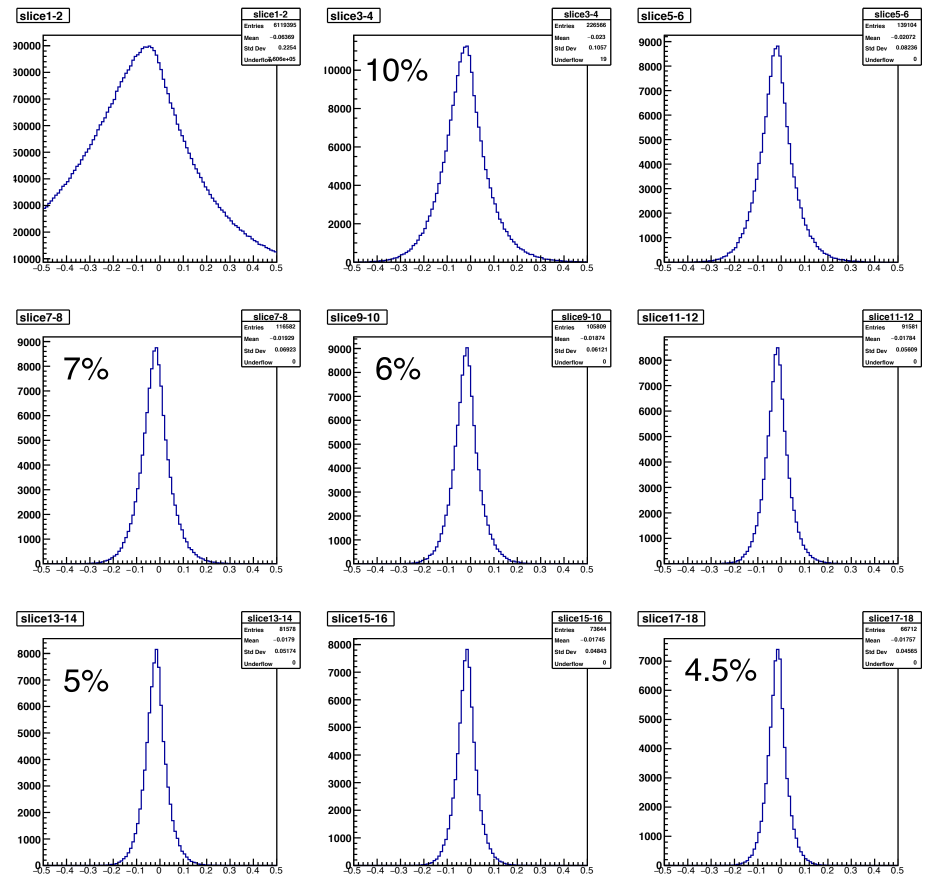
Impact of tracking on t resolution

Start with: $$\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 0.5$$

$1 < Q^2 < 10\ GeV^2$

Method A





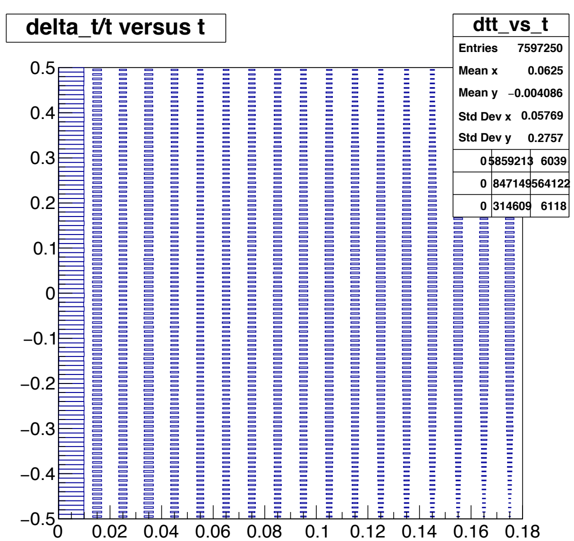
Impact of tracking on t resolution

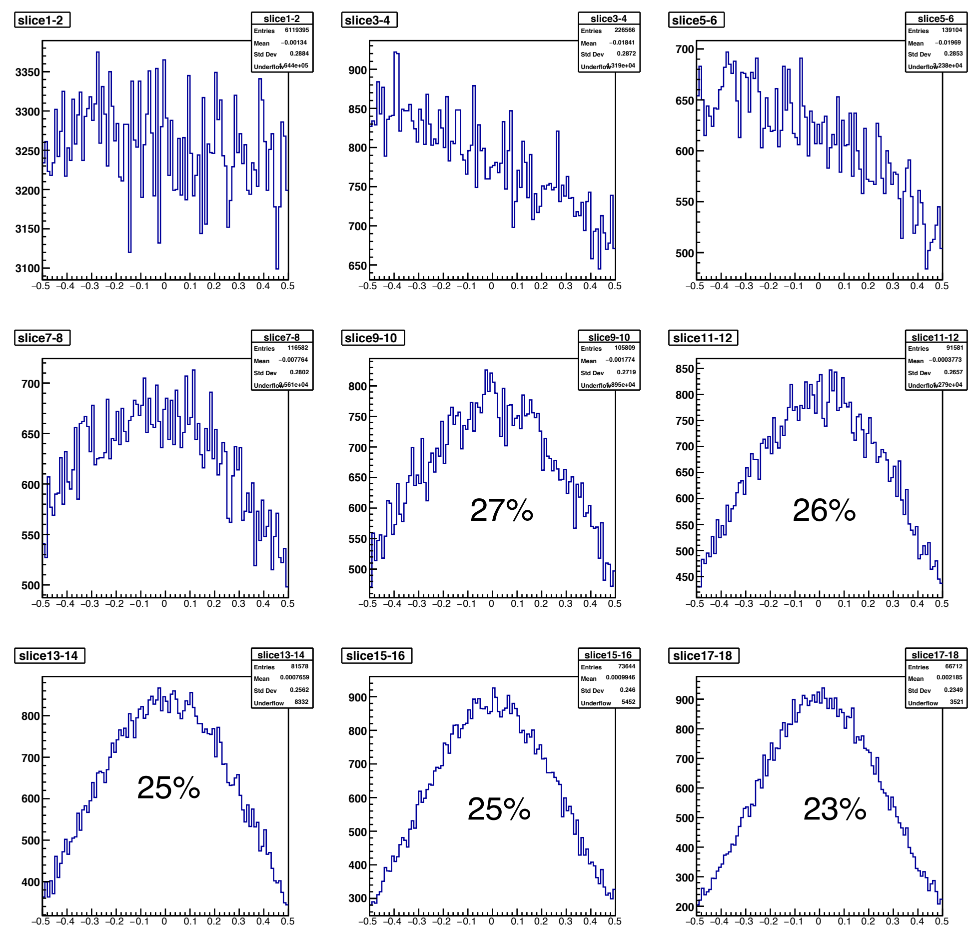
Start with: $$\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 0.5$$

1 < Q^2 < 10 GeV^2

Method **E**

Confirming that the exact (E) method is not robust enough for this kind of study





The End