Logbook for YR Studies

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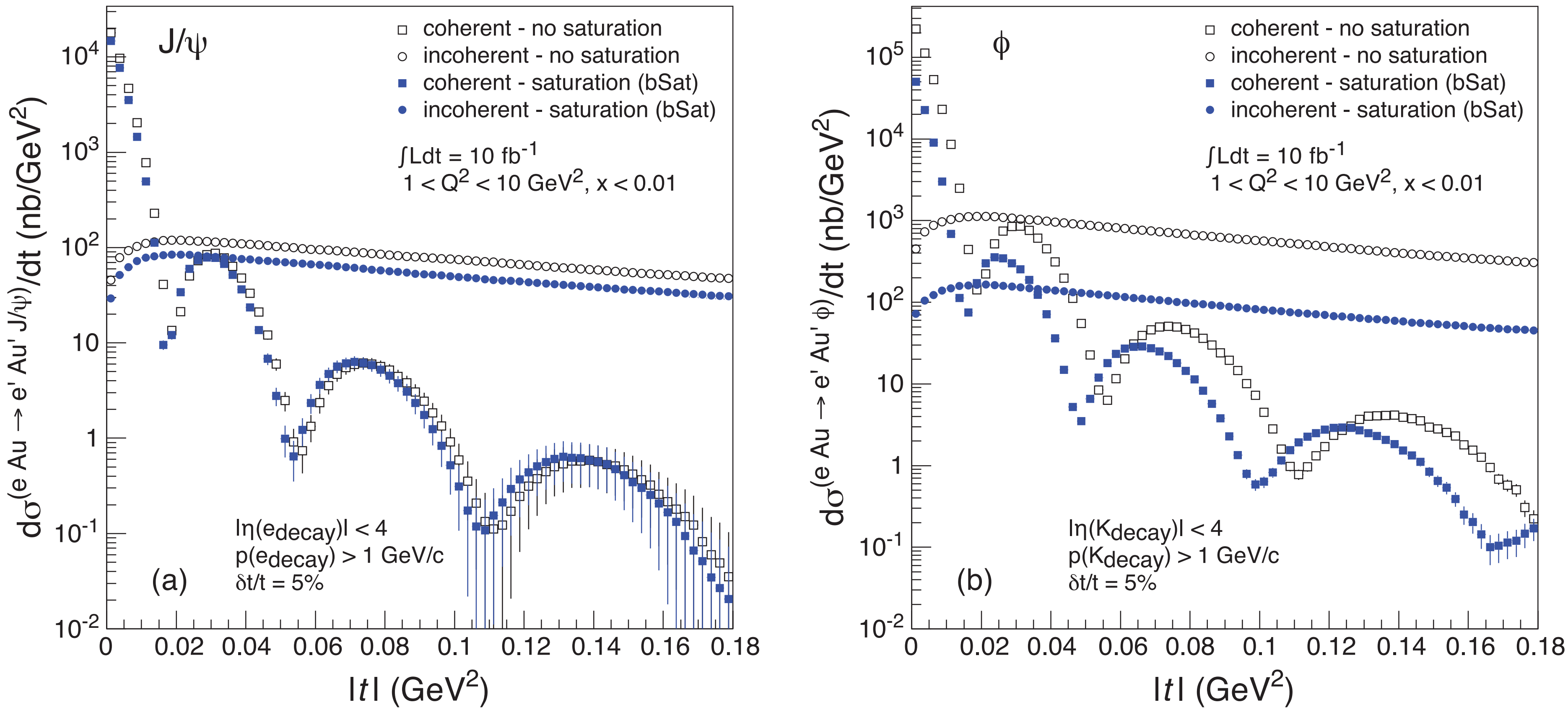
Vector Meson Production: dσ/d*t*



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
- This formula is valid for small t and for small Q^2

Method A without any smearing

Method A appears to underestimate *t*

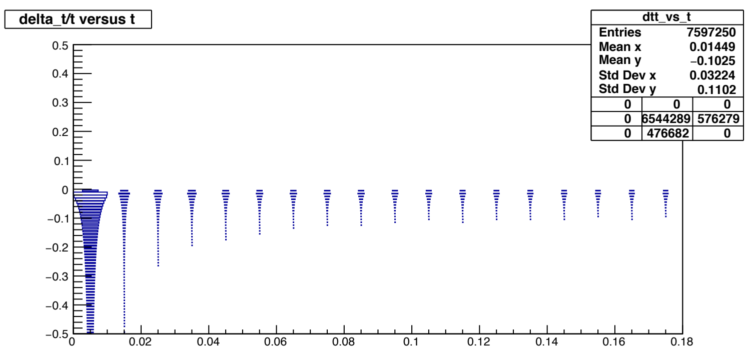
here x < 0.01 and 1 < Q^2 < 10 GeV^2

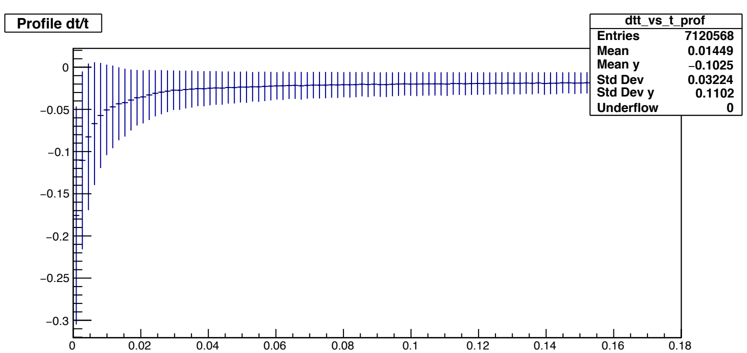
dt = |t(from A) - |t(Sartre)|

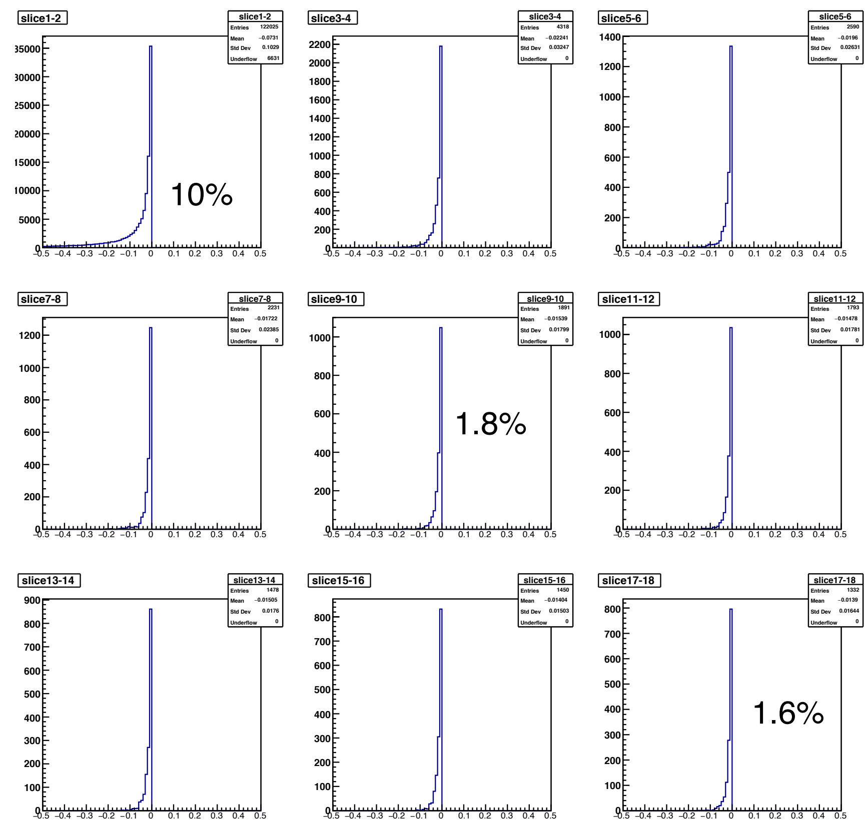
t < 0.01 dt/t ~ 10%

t ~0.16 dt/t ~ 1.6%

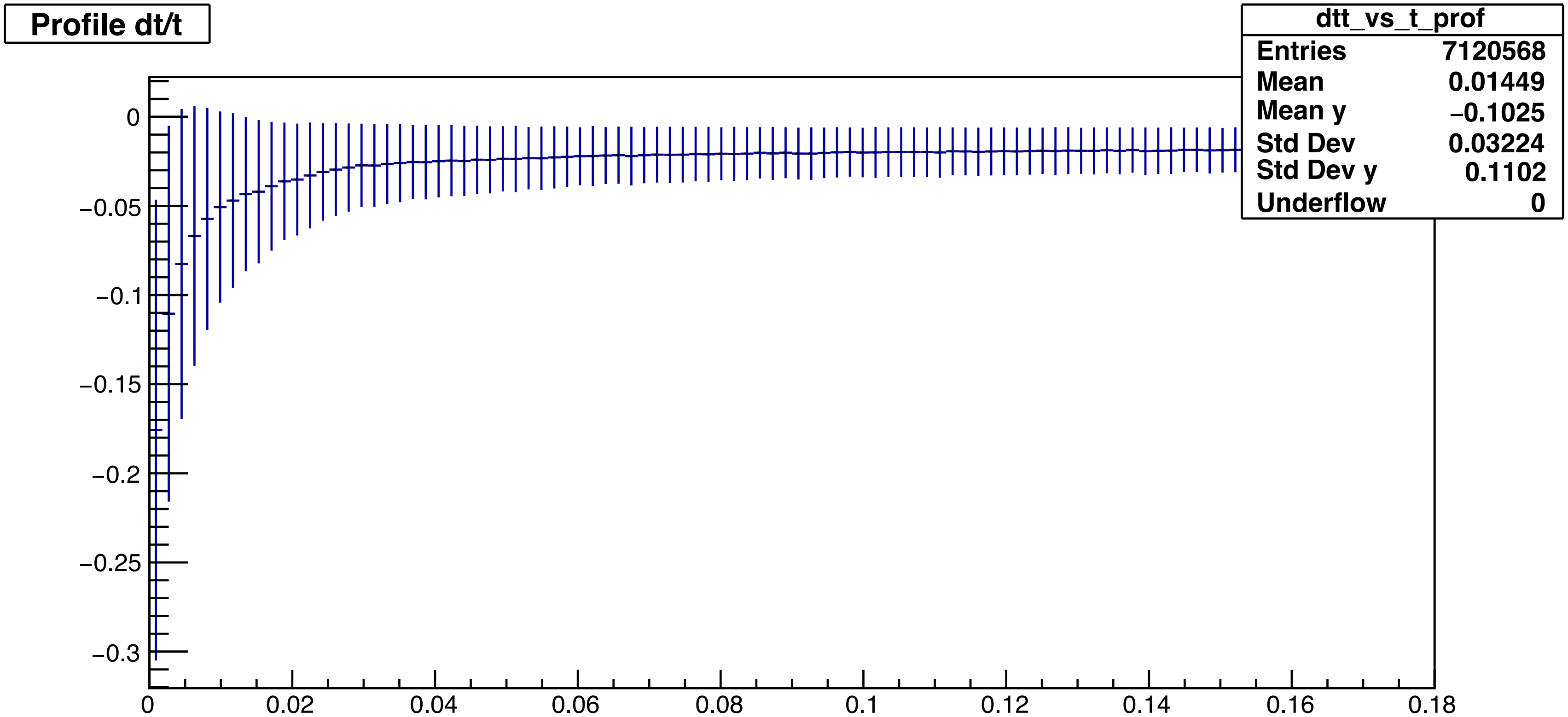
Here and in what follows:
Slices from left to right edge
of left side 2D histo







Q^2 dependent correction for Method A?



- This offset is Q^2 dependent - vanishes at $Q^2 \sim 0$ (see next slide)
- Can this be corrected for? Unfolding, Monte Carlo?
- HERA - couldn't find any attempts to do so
- Is there an analytic way to calculate a simple corrections?

Q^2 Dependence of Offset in dt/t

Q^2 range (GeV)	offset	error
< 0.01	-0.00135311	9.03428E-06
1-2	-0.018309	0.00288668
2-3	-0.0148724	0.00182143
3-4	-0.0130223	0.00140125
4-5	-0.0117659	0.0011486
5-6	-0.0110839	0.000993935
6-7	-0.0105928	0.000887688
7-8	-0.010177	0.000800267
8-9	-0.00990677	0.000734945
9-10	-0.00976082	0.000687827

In the ranges looked at here:
Highest at low Q^2 and then gets less for larger Q^2 but disappears for photo production $Q^2 \to 0$

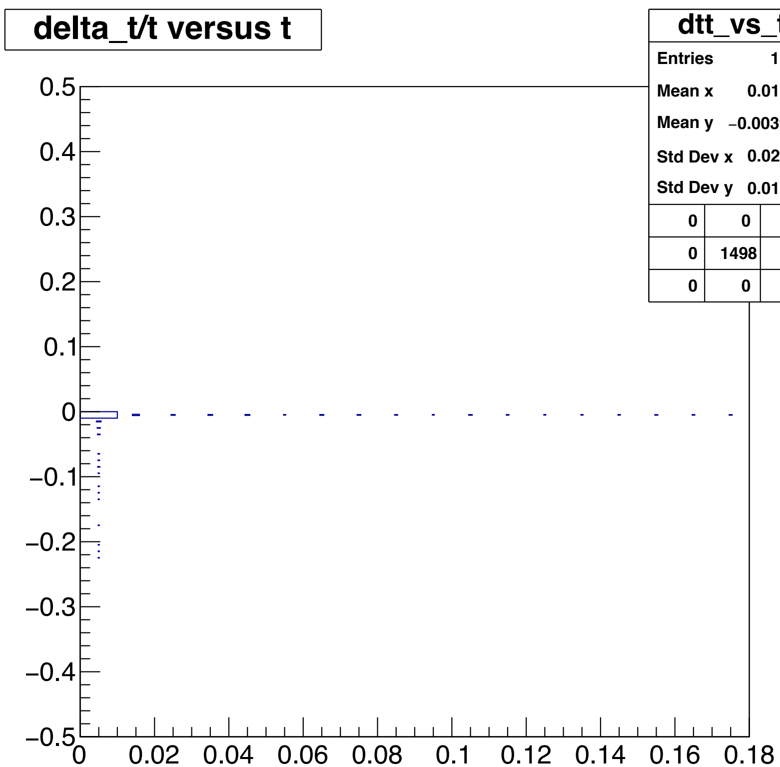
Method A without any smearing

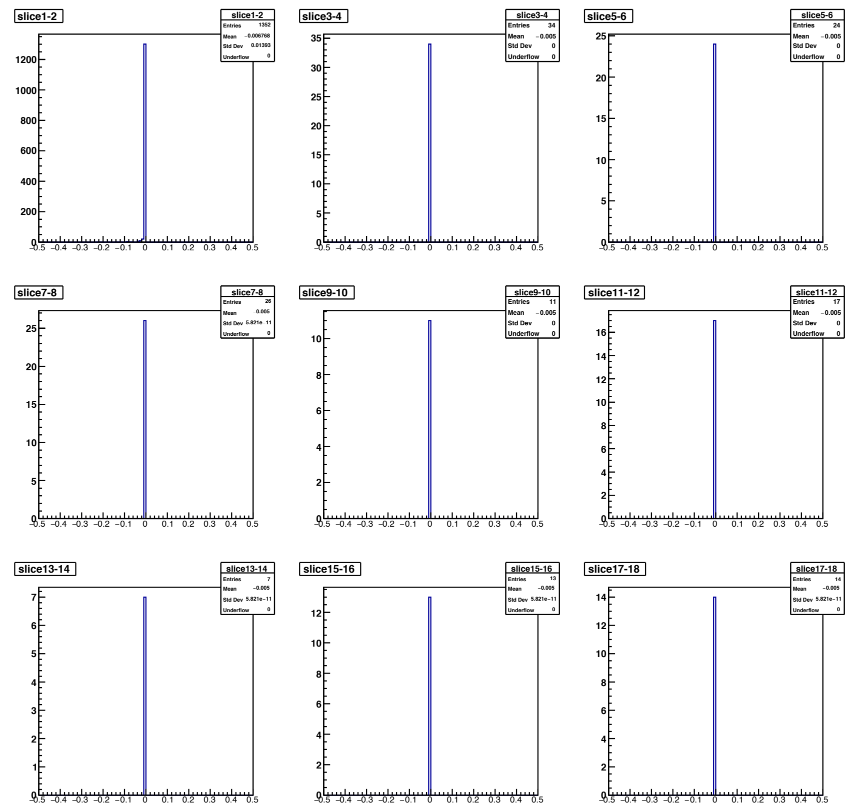
Method A with x < 0.01 and $Q^2 < 0.01$ GeV^2

more for less photo production

t < 0.01   dt/t ~ 1.3%

t ~0.16   dt/t ~ 0%

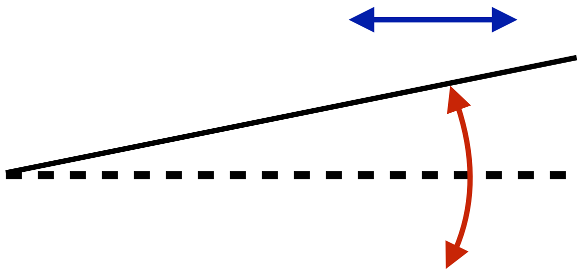




Beam Smearing

Two effects to take into account

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



- Divergence $\sigma_x = \sqrt{\epsilon_x/\beta^*_x}$
  - Note that σ_x and σ_y are different so the beam profile and divergence is an ellipse
  - e+Au: $\sigma_x = 109\ \mu\mathrm{rad}$ and $\sigma_y = 38\ \mu\mathrm{rad}$
- Divergence adds p_T to the beams and a possible p_z. The only way to minimize p_T is to increase β^* (and lose lumi as $\mathscr{L} \propto 1/\beta^*$)

Table 3.3: eRHIC beam parameters for different center-of-mass energies $\sqrt{s}$, with strong hadron cooling. High divergence configuration.

Species	proton	electron	proton	electron	proton	electron	proton	electron	proton	electron
Energy [GeV]	275	18	275	10	100	10	100	5	41	5
CM energy [GeV]	140.7		104.9		63.2		44.7		28.6	
Bunch intensity [10^{10}]	20.5	6.2	6.9	17.2	6.9	17.2	4.7	17.2	2.6	13.3
No. of bunches	290		1160		1160		1160		1160	
Beam current [A]	0.74	0.227	1	2.5	1	2.5	0.68	2.5	0.38	1.93
RMS norm. emit., h/v [μm]	4.6/0.75	845/72	2.8/0.45	391/24	4.0/0.22	391/25	2.7/0.27	196/20	1.9/0.45	196/34
RMS emittance, h/v [nm]	16/2.6	24/2.0	9.6/1.5	20/1.2	37/2.1	20/1.3	25/2.6	20/2.0	44/10	20/3.5
β^*, h/v [cm]]	90/4.0	59/5.0	90/4.0	43/5.0	90/4.0	167/6.4	90/4.0	113/5.0	90/7.1	196/21.0
IP RMS beam size, h/v [μm]	119/10		93/7.8		183/9.1		150/10		198/27	
K_x	11.8		11.9		20.0		14.9		7.3	
RMS $\Delta\theta$, h/v [μrad]	132/253	202/202	103/195	215/156	203/227	109/143	167/253	133/202	220/380	101/129
BB parameter, h/v [10^{-3}]	3/2	100/100	14/7	73/100	10/9	75/57	15/10	100/66	15/9	53/42
RMS long. emittance [10^{-3}, eV·sec]	36		36		21		21		11	
RMS bunch length [cm]	6	0.9	6	2	7	2	7	2	7.5	2
RMS $\Delta p/p$ [10^{-4}]	6.8	10.9	6.8	5.8	9.7	5.8	9.7	6.8	10.3	6.8
Max. space charge	0.006	neglig.	0.003	neglig.	0.028	neglig.	0.019	neglig.	0.05	neglig.
Piwinski angle [rad]	5.6	0.8	7.1	2.4	4.2	1.2	5.1	1.5	4.2	1.1
Long. IBS time [h]	2.1		3.4		2		2.6		3.8	
Transv. IBS time [h]	2		2		2.3/2.4		2/4.8		3.4/2.1	
Hourglass factor H	0.86		0.86		0.85		0.83		0.93	
Luminosity [10^{33}cm^{-2}sec^{-1}]	1.65		10.05		4.35		3.16		0.44	

Table 3.4: eRHIC beam parameters for different center-of-mass energies $\sqrt{s}$, with strong hadron cooling. High acceptance configuration.

Species	proton	electron	proton	electron	proton	electron	proton	electron	proton	electron
Energy [GeV]	275	18	275	10	100	10	100	5	41	5
CM energy [GeV]	140.7		104.9		63.2		44.7		28.6	
Bunch intensity [10^{10}]	19.53	6.248	6.9	17.2	6.9	17.2	4.7	17.2	2.6	13.3
No. of bunches	290		1160		1160		1160		1160	
Beam current [A]	0.71	0.227	1	2.5	1	2.5	0.68	2.5	0.38	1.93
RMS norm. emit., h/v [μm]	4.9/0.62	845/42.3	2.8/0.45	391/22	3.5/0.25	391/27	2.7/0.27	196/20	1.9/0.45	196/34
RMS emittance, h/v [nm]	16.7/2.1	24.0/1.2	9.6/1.5	20/1.1	33/2.4	20/1.4	25/2.6	20/2.0	44/10	20/3.5
β^*, h/v [cm]]	395/4.0	274/7.0	227/4.0	109/5.5	102/4.0	169/6.8	90/4.0	113/5.0	90/7.1	196/21
IP RMS beam size, h/v [μm]	256/9.2		148/7.8		184/9.7		150/10		198/27	
K_x	0.036		18.9		18.9		14.9		7.3	
RMS $\Delta\theta$, h/v [μrad]	65/229	94/131	65/196	135/143	180/243	109/143	167/253	133/202	220/380	101/129
BB parameter, h/v [10^{-3}]	3/1	100/71	14/5	75/71	11/8	75/57	15/10	100/66	15/9	53/42
RMS long. emittance [10^{-3}, eV·sec]	36		36		21		21		11	
RMS bunch length [cm]	6	0.9	6	2	7	2	7	2	7.5	2
RMS $\Delta p/p$ [10^{-4}]	6.8	10.9	6.8	5.8	9.7	5.8	9.7	6.8	10.3	6.8
Max. space charge	0.006	neglig.	0.003	neglig.	0.027	neglig.	0.019	neglig.	0.05	neglig.
Piwinski angle [rad]	2.6	0.4	4.5	1.5	4.2	1.2	5.1	1.5	4.2	1.1
Long. IBS time [h]	2		3.4		2		2.6		3.8	
Transv. IBS time [h]	2		2		2.0/3.0		2/4.8		3.4/2.1	
Hourglass factor H	0.88		0.87		0.85		0.83		0.93	
Luminosity [10^{33}cm^{-2}sec^{-1}]	0.83		6.4		4.07		3.16		0.44	

Table 3.5: eRHIC beam parameters for e-Au operation for different center-of-mass energies $\sqrt{s}$, with strong hadron cooling.

Species	Au ion	electron	Au ion	electron	Au ion	electron	Au ion	electron
Energy [GeV]	110	18	110	10	110	5	41	5
CM energy [GeV]	89.0		66.3		46.9		28.6	
Bunch intensity [10^{10}]	0.08	7.29	0.05	17.2	0.05	17.2	0.036	17.2
No. of bunches	290		1160		1160		1160	
Beam current [A]	0.23	0.26	0.57	2.50	0.57	2.50	0.41	2.50
RMS norm. emit., h/v [μm]	5.1/0.7	705/20	5.0/0.4	391/20	5.0/0.4	196/20	3.0/0.3	196/20
RMS emittance, h/v [nm]	43.2/5.8	20.0/0.6	42.3/3.0	20.0/1.0	42.3/3.0	20.0/2.0	68.1/5.7	20.0/2.0
β^*, h/v [cm]]	91/4	196/41	91/4	193/12	91/4	193/6	90/4	307/11
IP RMS beam size, h/v [μm]	198/15		196/11		197/11		248/15	
K_x	0.077		0.057		0.056		0.061	
RMS $\Delta\theta$, h/v [μrad]	218/379	101/37	216/274	102/92	215/275	102/185	275/377	81/136
BB parameter, h/v [10^{-3}]	1/1	37/100	3/3	43/47	3/2	86/47	5/4	61/37
RMS long. emittance [10^{-3}, eV·sec]	16		16		16		16	
RMS bunch length [cm]	7	0.9	7	2	7	2	11.6	2
RMS $\Delta p/p$ [10^{-4}]	6.2	10.9	6.2	5.8	6.2	6.8	10	6.8
Max. space charge	0.007	neglig.	0.008	neglig.	0.008	neglig.	0.038	neglig.
Piwinski angle [rad]	4.4	1.1	4.5	1.2	4.5	1.5	5.8	1.2
Long. IBS time [h]	0.33		0.36		0.36		0.85	
Transv. IBS time [h]	0.81		0.89		0.89		0.16	
Hourglass factor H	0.85		0.85		0.85		0.71	
Luminosity [10^{33}cm^{-2}sec^{-1}]	0.59		4.76		4.77		1.67	

Table 3.6: eRHIC beam parameters for e-Au operation for different center-of-mass energies $\sqrt{s}$, with stochastic cooling.

Species	Au ion	electron	Au ion	electron	Au ion	electron	Au ion	electron
Energy [GeV]	110	18	110	10	110	5	41	5
CM energy [GeV]	89.0		66.3		46.9		28.6	
Bunch intensity [10^{10}]	0.10	7.29	0.10	30	0.08	30	0.09	30
No. of bunches	290		580		580		580	
Beam current [A]	0.29	0.26	0.57	2.18	0.44	2.18	0.50	2.18
RMS norm. emit., h/v [μm]	2.0/2.0	845/60	2.0/2.0	391/102	2.0/2.0	196/63	2.0/2.0	196/113
RMS emittance, h/v [nm]	16.9/16.9	24.0/1.7	16.9/16.9	20.0/5.2	16.9/16.9	20.0/6.4	45.4/45.4	20.0/11.5
β^*, h/v [cm]]	288/12	203/116	91/12	77/39	146/12	113/31	149/50	339/196
IP RMS beam size, h/v [μm]	221/45		124/45		157/45		261/150	
K_x	0.202		0.363		0.284		0.577	
RMS $\Delta\theta$, h/v [μrad]	77/380	109/38	136/376	161/116	108/380	127/144	174/302	77/77
BB parameter, h/v [10^{-3}]	3/1	35/100	11/4	66/93	11/3	100/96	9/5	100/100
RMS long. emittance [10^{-3}, eV·sec]	64		64		64		64	
RMS bunch length [cm]	15	0.9	18	2	18	2	18	2
RMS $\Delta p/p$ [10^{-4}]	10	10.9	10	5.8	10	6.8	13	6.8
Max. space charge	0.001	neglig.	0.001	neglig.	0.001	neglig.	0.007	neglig.
Piwinski angle [rad]	8.5	0.5	18.1	2.0	14.3	1.6	8.6	1.0
Long. IBS time [h]	2.65		2.65		3.39		2.02	
Transv. IBS time [h]	1.02		0.80		1.32		0.93	
Hourglass factor H	0.54		0.54		0.54		0.65	
Luminosity [10^{33}cm^{-2}sec^{-1}]	0.14		2.06		1.27		0.31	

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.**

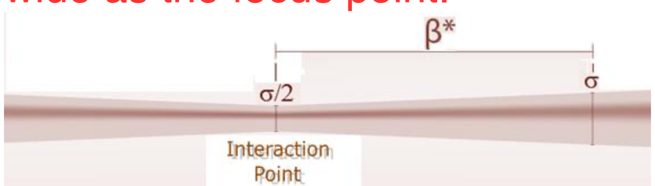
Emittance can be defined as the smallest opening you can squeeze the beam through, and can also be considered as a measurement of the parallelism of a beam.
It has units of length, but is usually referred to as "length x angle", for example, "millimeter x milli-radians". It can be measured in all three 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).

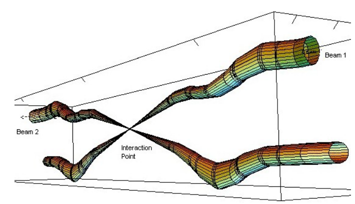
N.B. What is β^* and ϵ? (II)

The amplitude function, $\boldsymbol{\beta}$, 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.

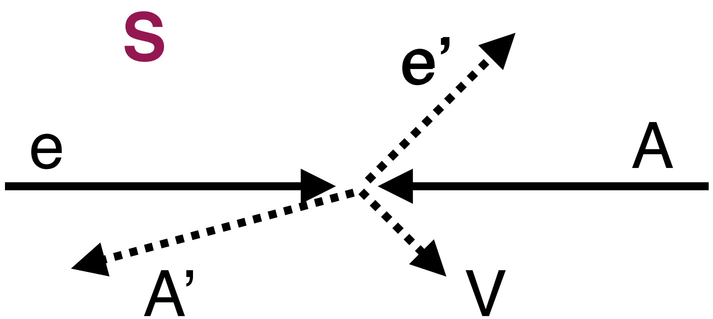




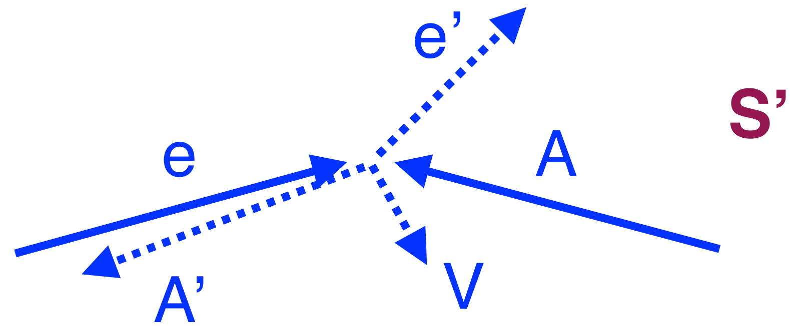
In the experiments (detectors), the beam will be "squeezed" as much as possible, to increase the number of collisions, so at a distance of beta before the focus point, the beam is also twice as wide.
Of particular significance is the value of the **amplitude function at the interaction point, $\boldsymbol{\beta^*}$**.Clearly 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.

How to simulate (I)

- Most generators, including Sartre, have only beams with 0 crossing angle

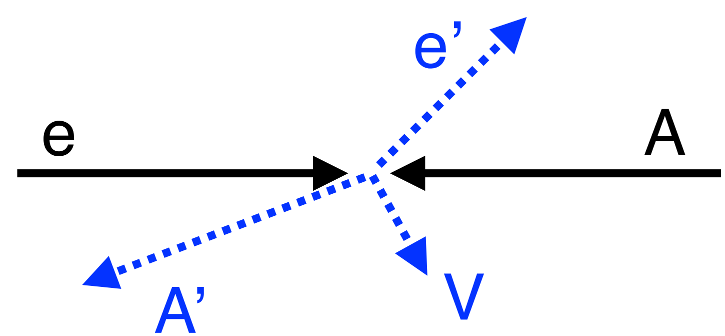


Ideal case
Generator does this



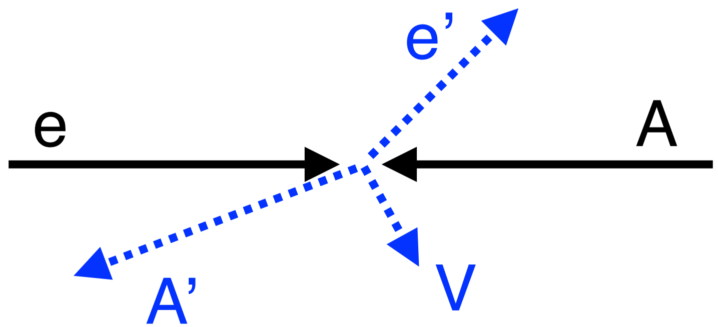
Nature & collider do this but we don't know the details and assume it looks like this:

In the experiment this affects the way we calculate t. We can only assume nominal beam energy and 0 divergence. Depending on method this smears *t*.

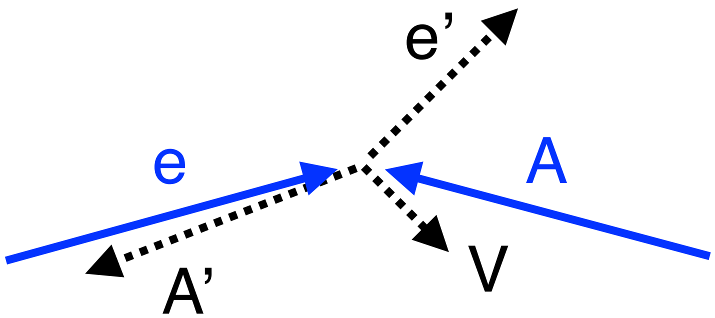


How to simulate (II)

- Issue
  - Cannot transform (via Lorentz boost) S → S'
  - The two system have different (Lorentz invariant) features, e.g. $\sqrt{s}$ and t
- Strategy:



Instead of this



we use this scenario

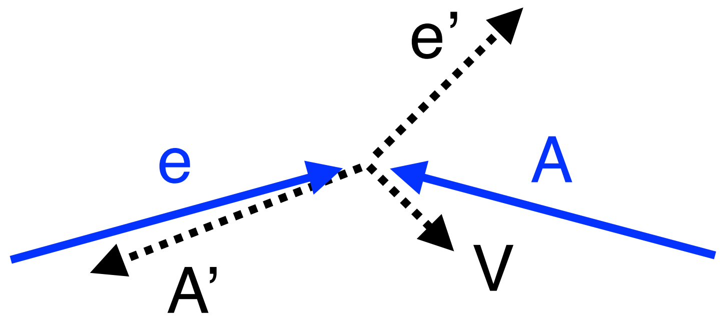
Instead of using the "*wrong*" *initial state* and the correct final state we are using the *correct initial state* but the "*wrong*" *final state*

- **Pros:** can use final state from generator which gives coherent physics picture and all variables are known
- **Cons:** does not give the most precise smearing numbers

How to simulate (III)

How are the different methods affected?

- <u>Method E</u>
  - $t = (p_V + p_{e'} - p_e)^2$
  - p_V is taken from generator
  - $p_{e'}$ is staken from generator
  - p_e is smeared using divergence and beam momentum spread

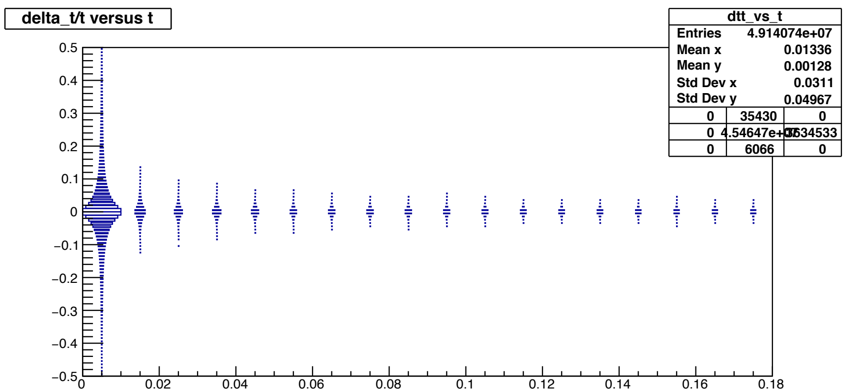


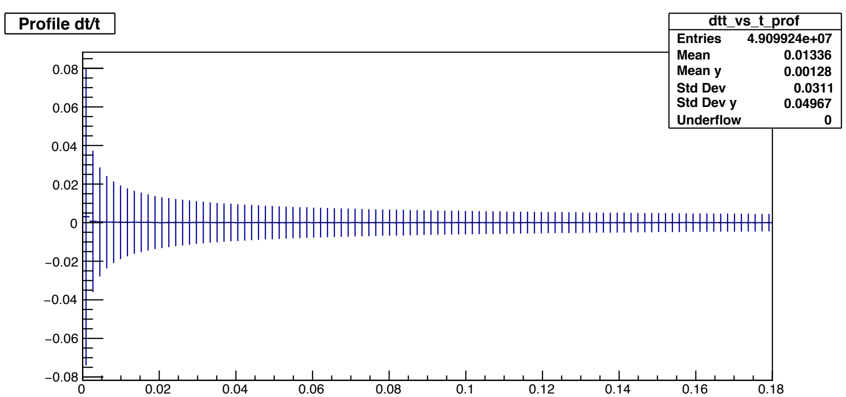
- <u>Method A</u>
  - $t = \left[\vec{p}_T(e') + \vec{p}_T(V)\right]^2$
  - $\vec{p}_T(e')$ is taken from generator
  - $\vec{p}_T(V)$ is taken from generator
  - In **S** and **S'** this method is *not* affected by smearing
  - Despite it's shortcoming it is more robust

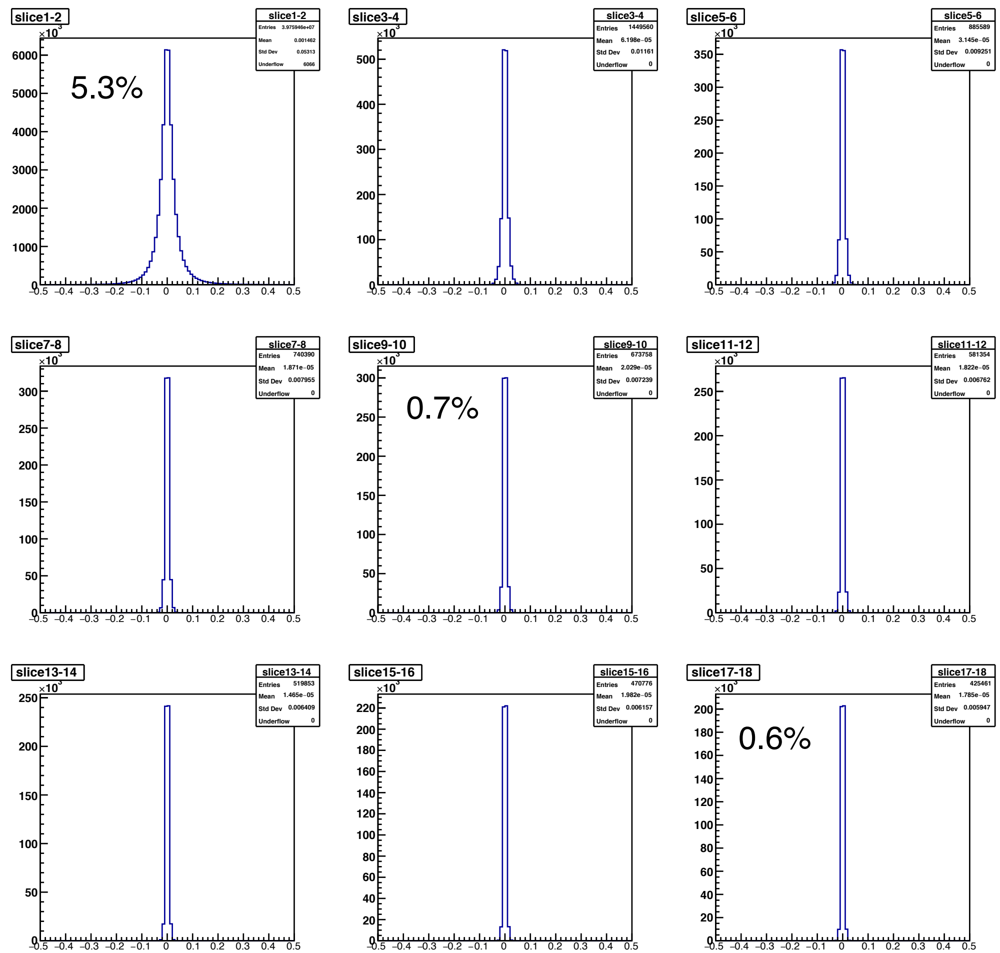
Effect of beam smearing on method E

- $t = (p_V + p_{e'} - p_e)^2$
- Here divergence effects only
- Small/moderate effect

$1 < Q^2 < 10\ \mathrm{GeV}^2$

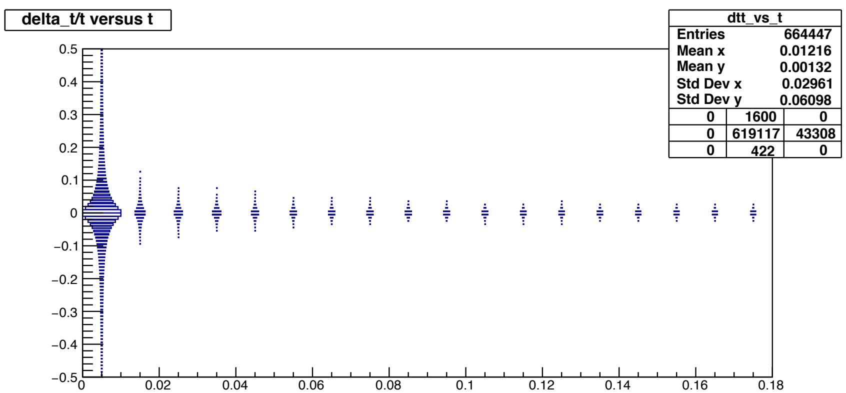


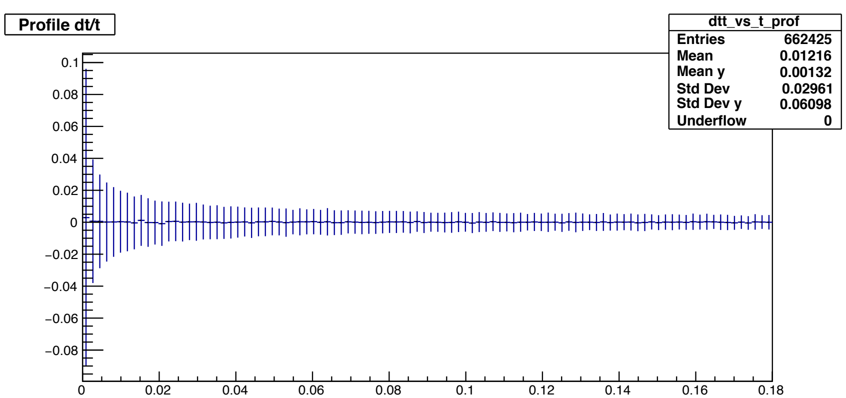


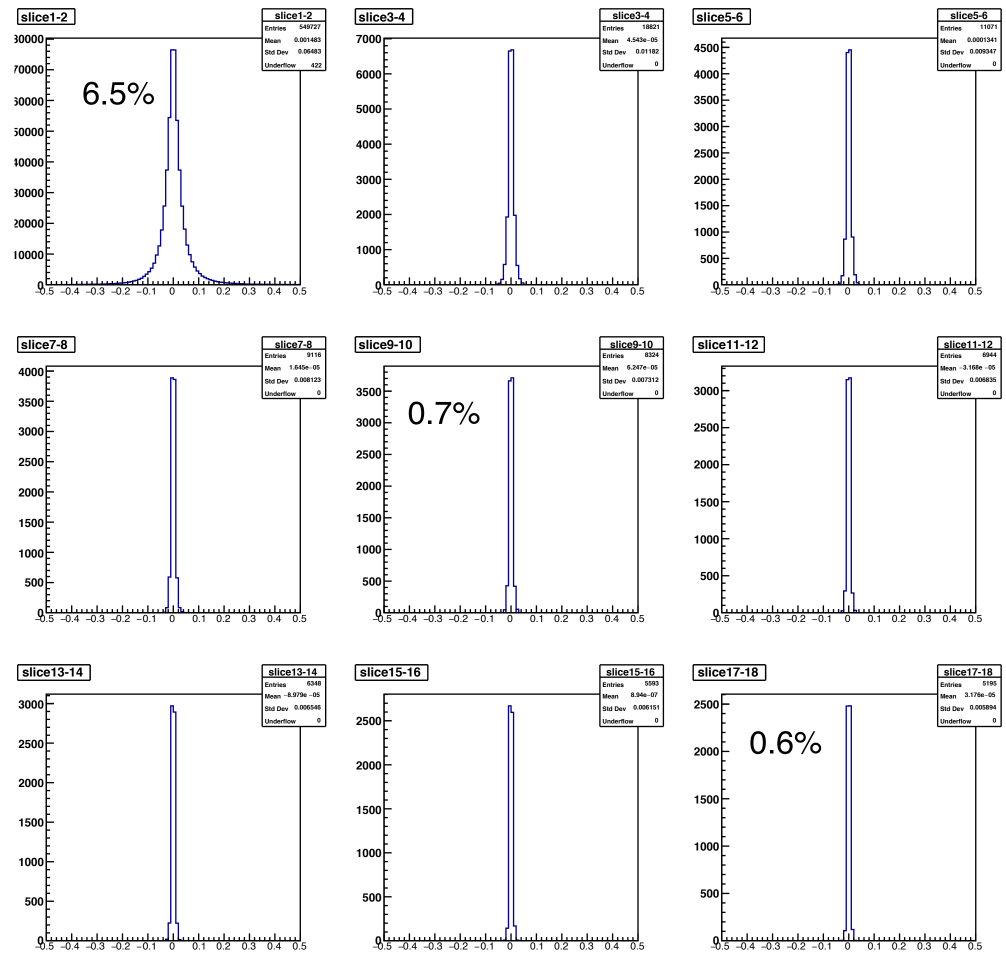


Effect of beam smearing on method E

- Divergence only: $Q^2 < 0.01\ GeV^2$
- Similar to larger Q^2
- Small/moderate effect





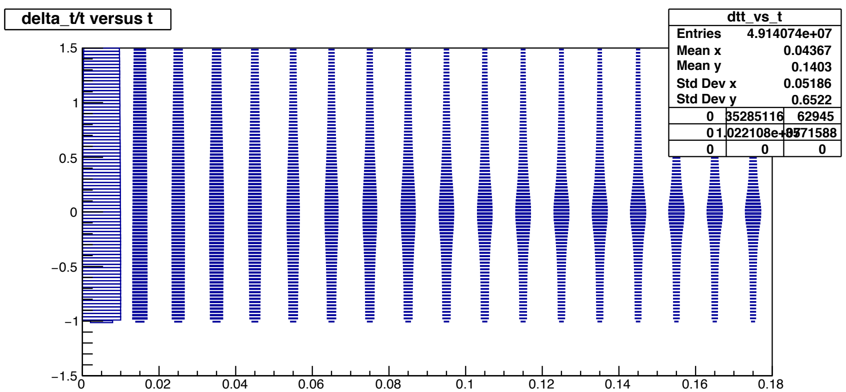


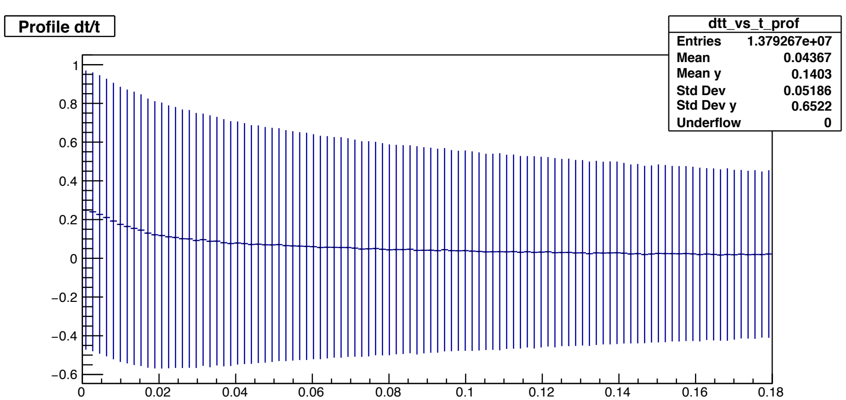
Effect of beam smearing on method E

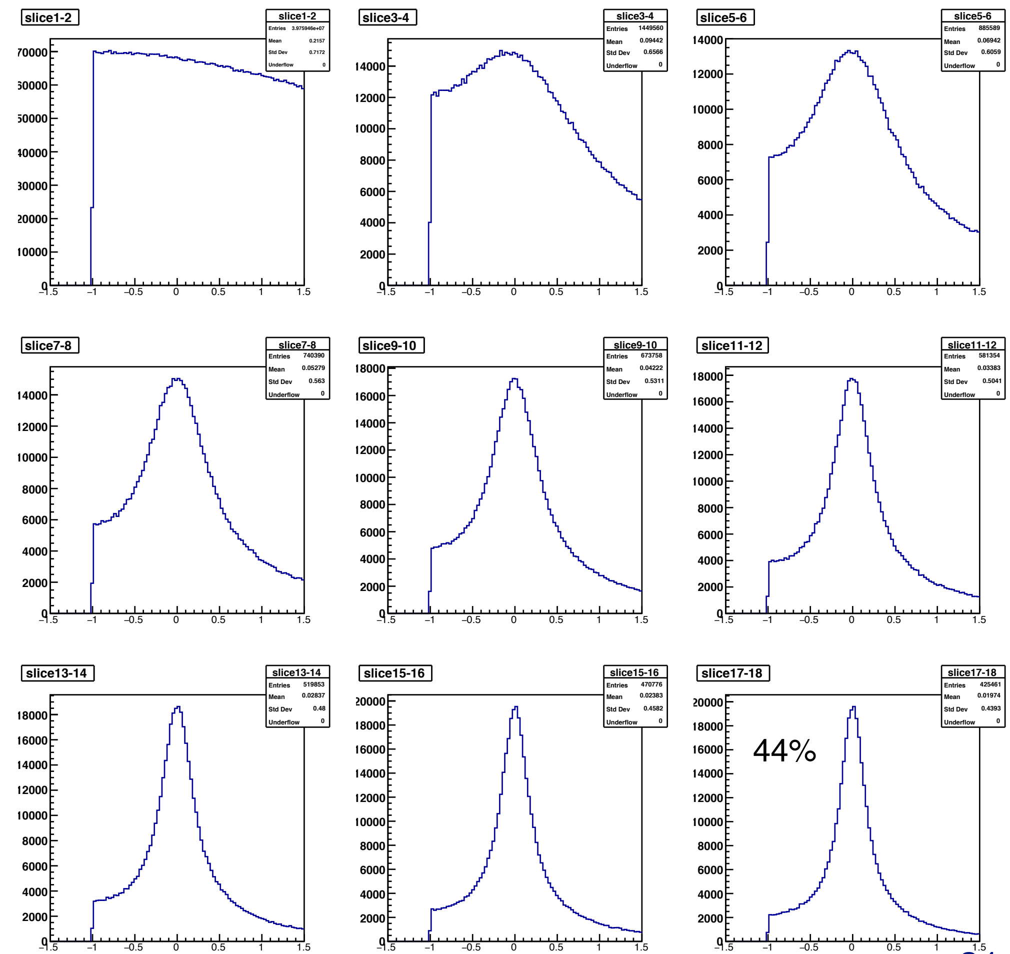
- Here momentum smearing only:

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

Method E totally fails!



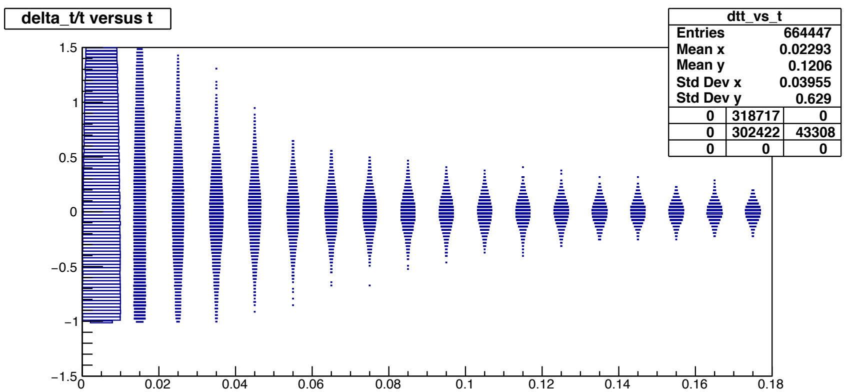


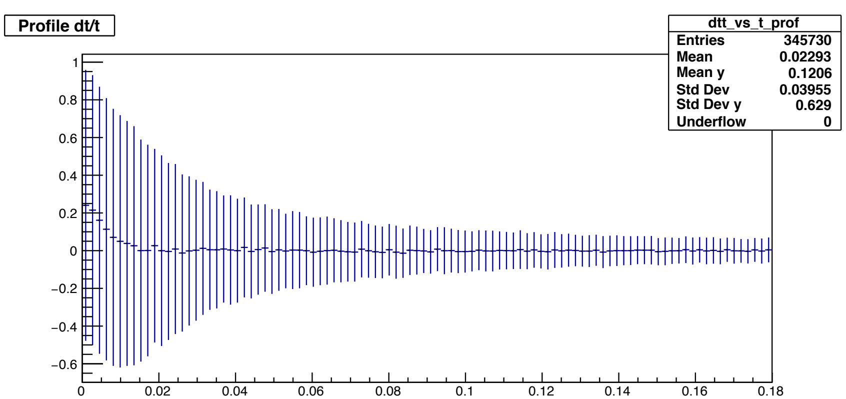


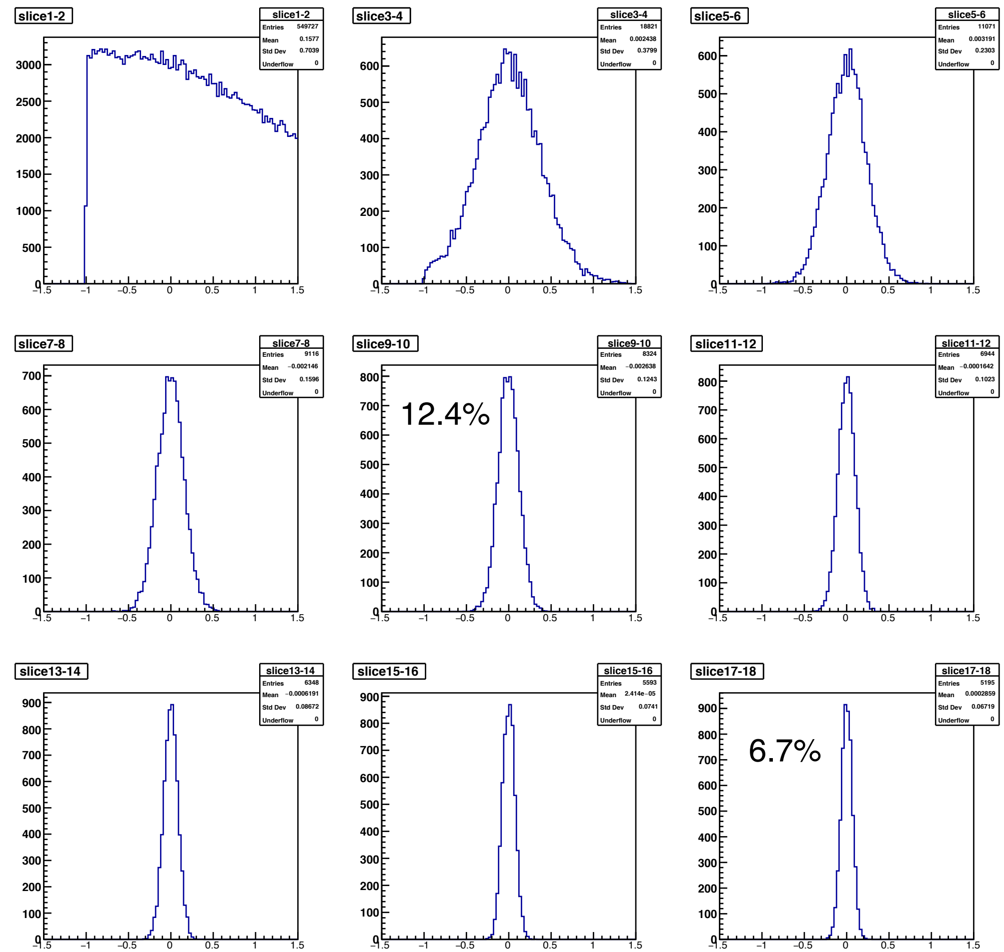
Effect of beam smearing on method E

- Here momentum smearing only: $Q^2 < 0.01$ GeV^2

Somewhat better than $1 < Q^2 < 10$ but still quite sensitive and bad.



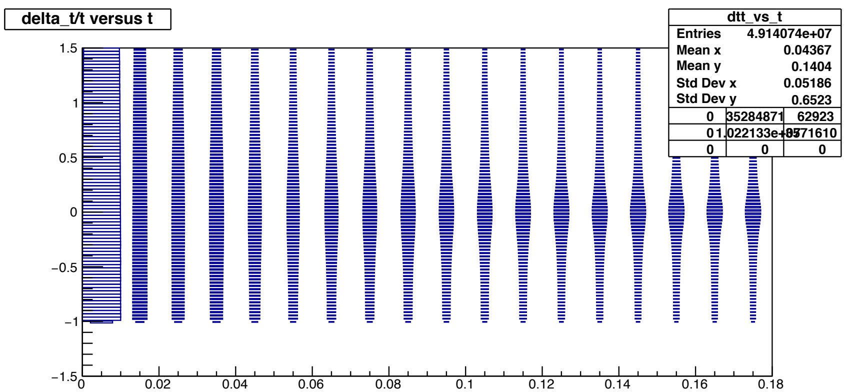


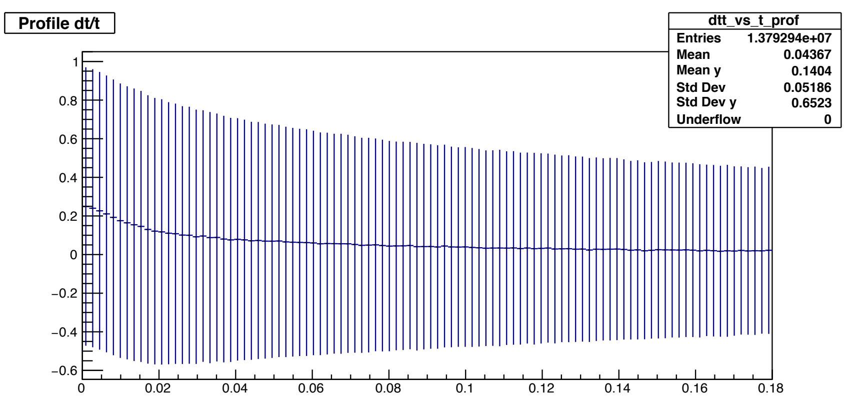


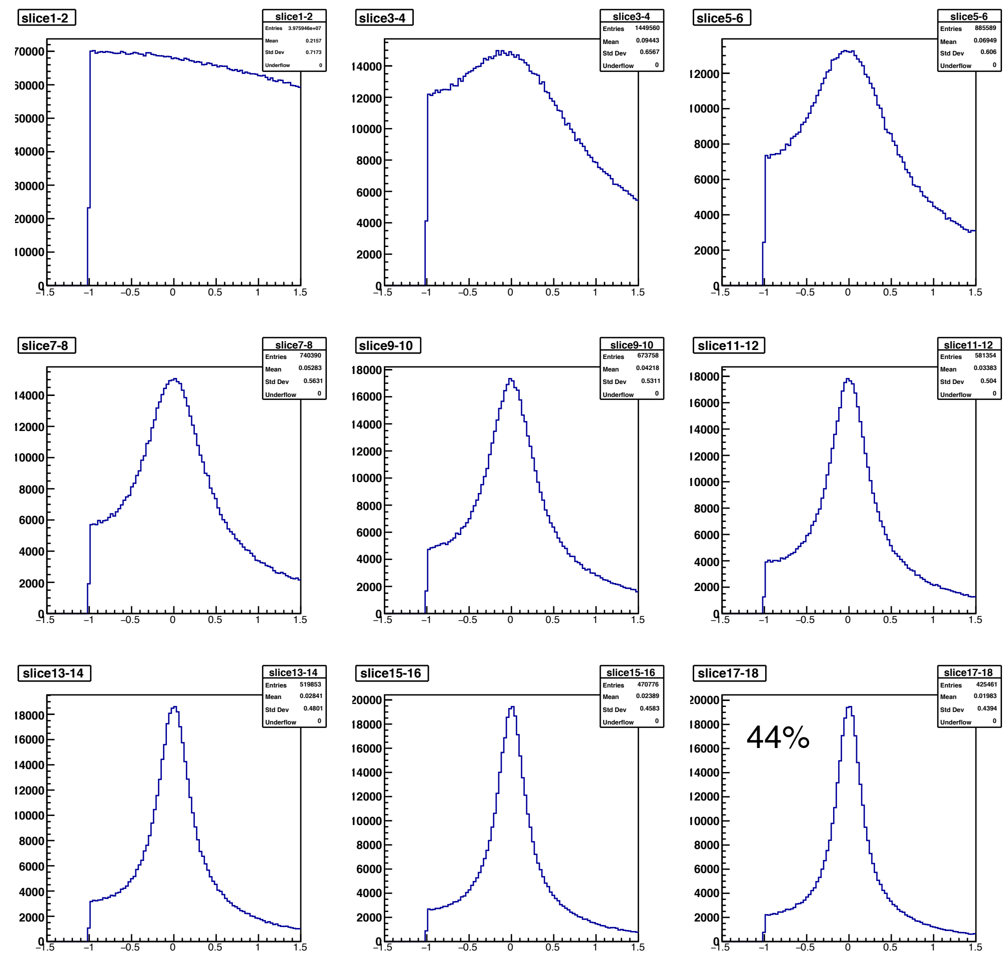
Effect of beam smearing on method E

- Both p smearing and divergence: 1 < Q^2 < 10 GeV^2

Results are so bad it takes method E off the table





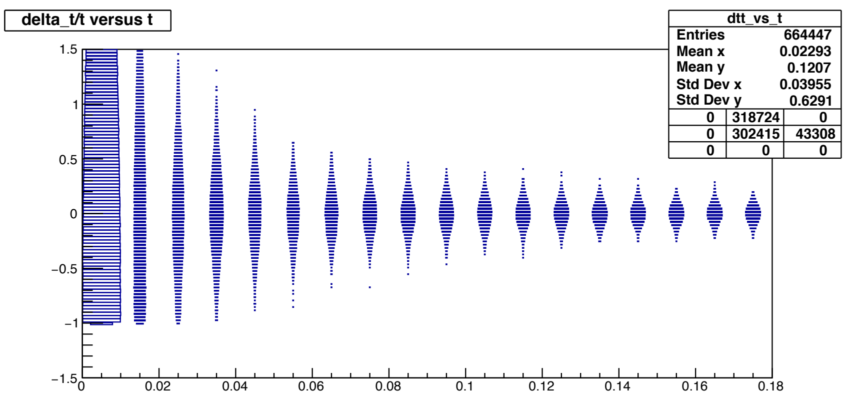


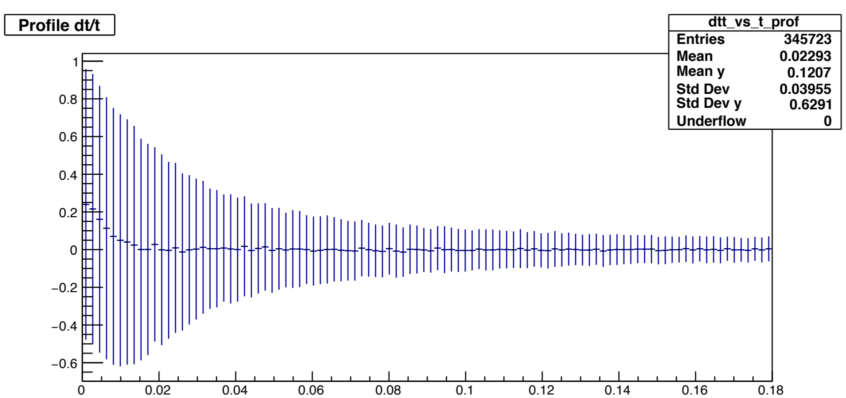
Effect of beam smearing on method E

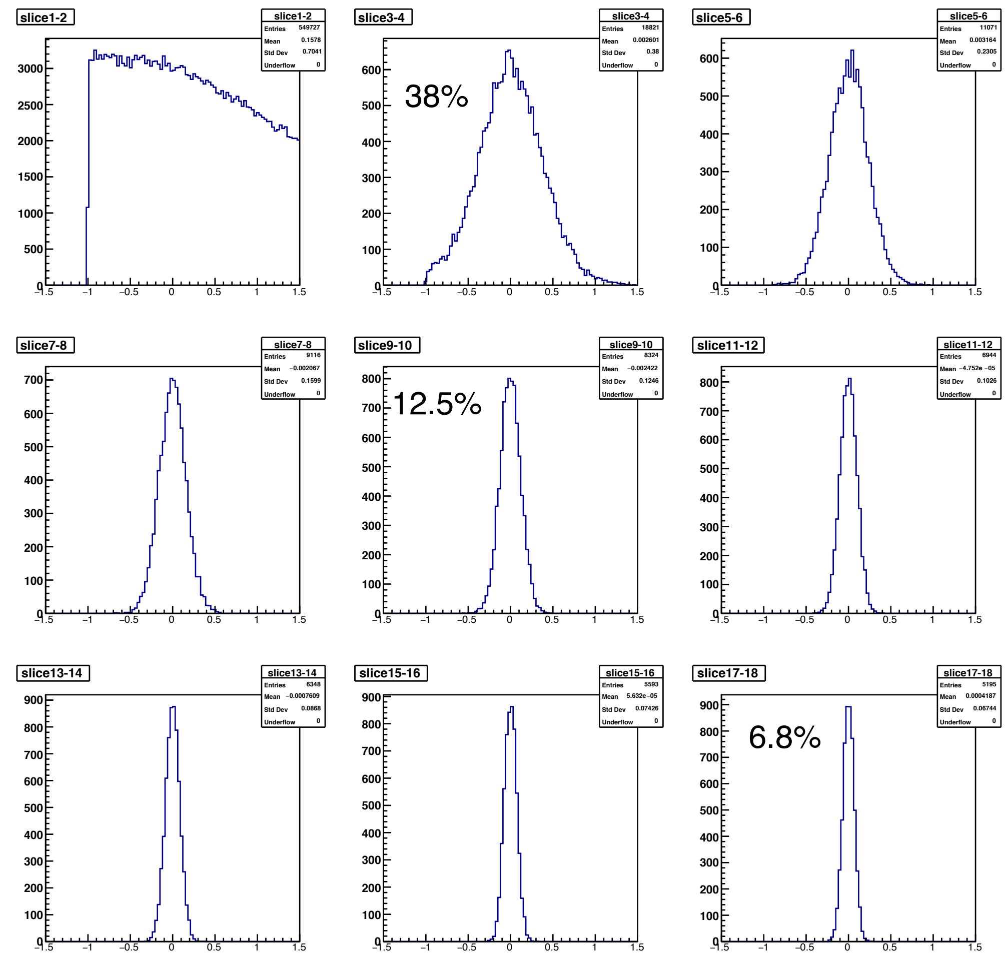
- Both effects:

$Q^2 < 0.01$ GeV^2

Somewhat better - still a killer







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 have large effects since *t* is small
- The effect of the momentum spread is the overwhelming cause of the devastating t resolution. Divergence is a minor problem for *t* with method E.

at $|t| = 0.18$ GeV^2

	$Q^2 < 0.01$ GeV^2	$1 < Q^2 < 10$ GeV^2
beam divergence	0.6%	0.6%
beam momentum spread	6.7%	44%
both	6.8%	44%

Increasing 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

See Tables on page 9-11

Unfortunately increasing β^* does not help method E since divergence is a negligible effect.

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)

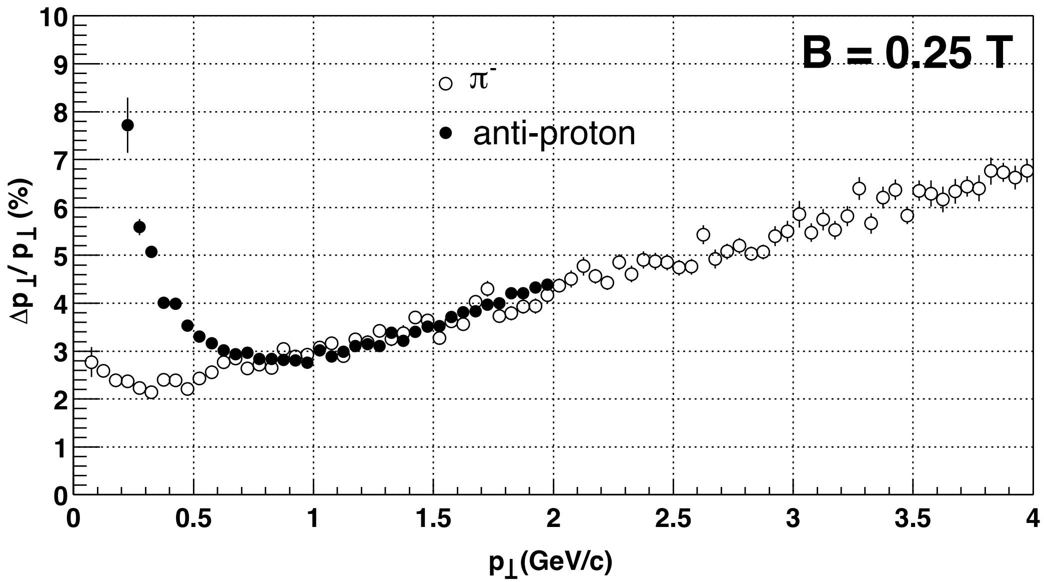
β velocity of particle

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:



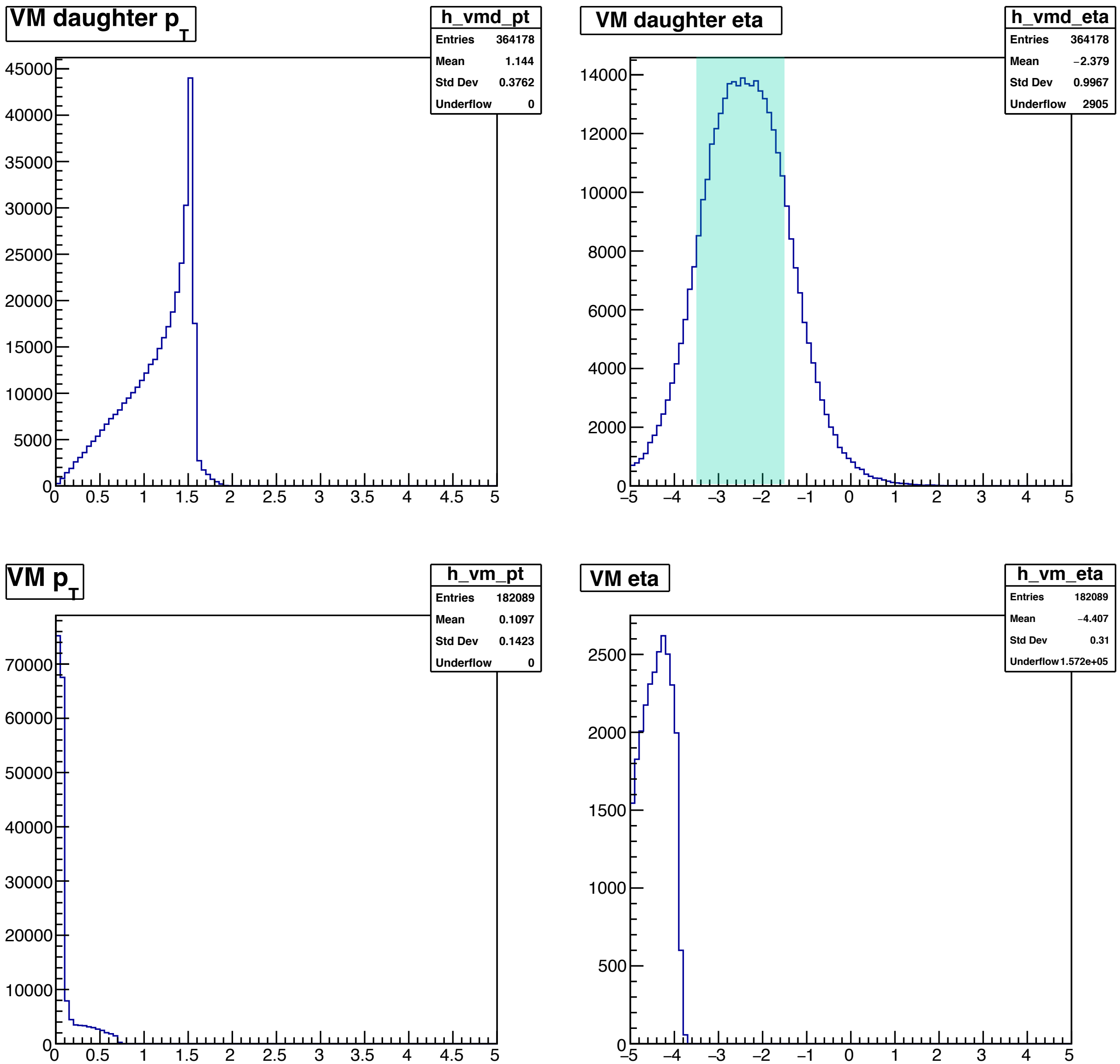
N.B.
Important to consider if vertex is included or not (primary vs. global tracks)

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)

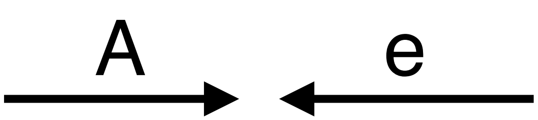
EIC Handbook: $\frac{\sigma_{p_T}}{p_T}(\,\%\,) = 0.05\ p_T \oplus 0.5$ B=3 T (full field)

Kinematics J/ψ



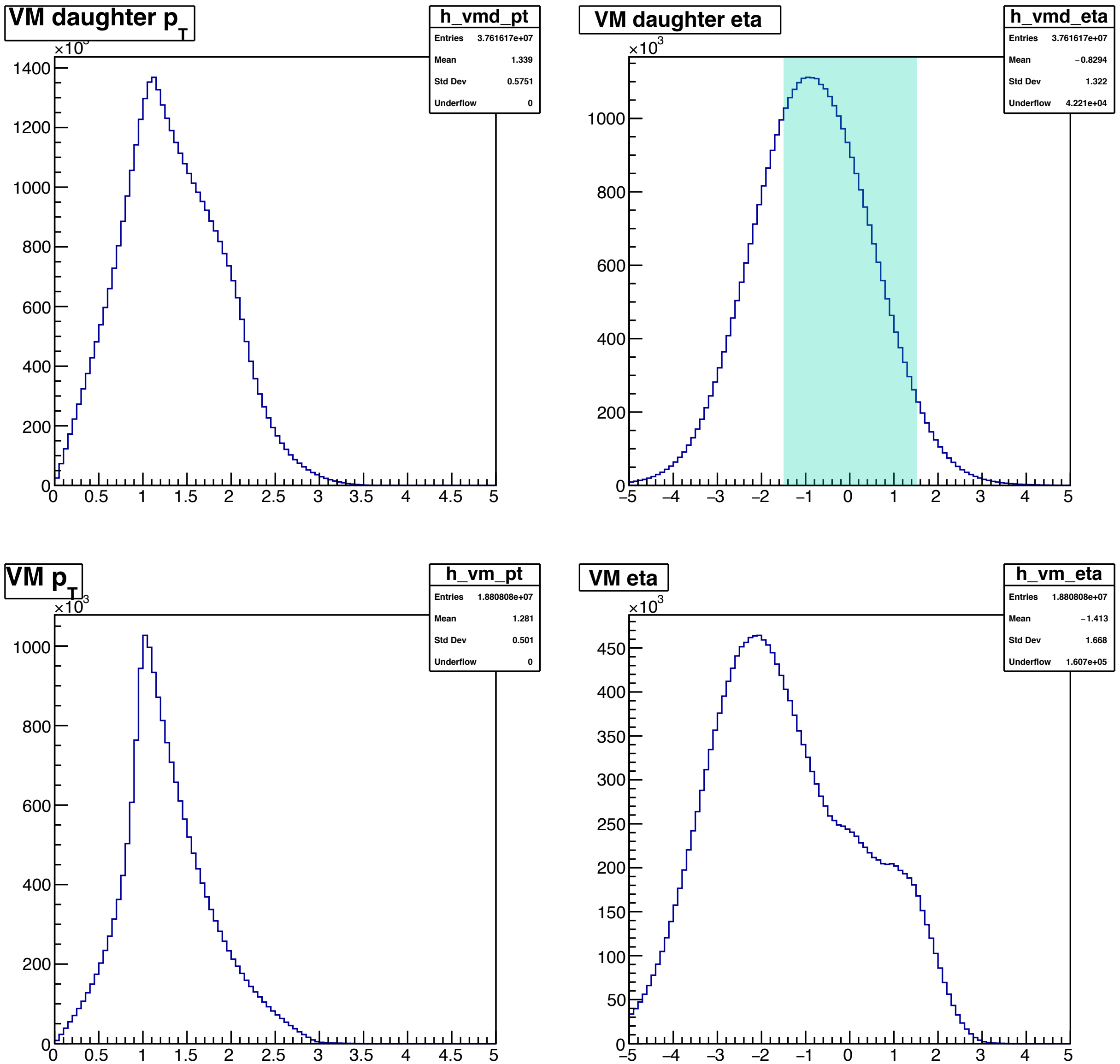
$Q^2 < 0.01$ GeV^2

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



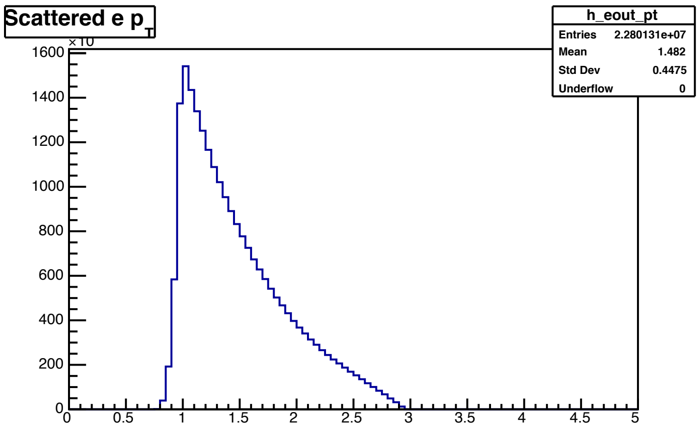
Kinematics J/ψ

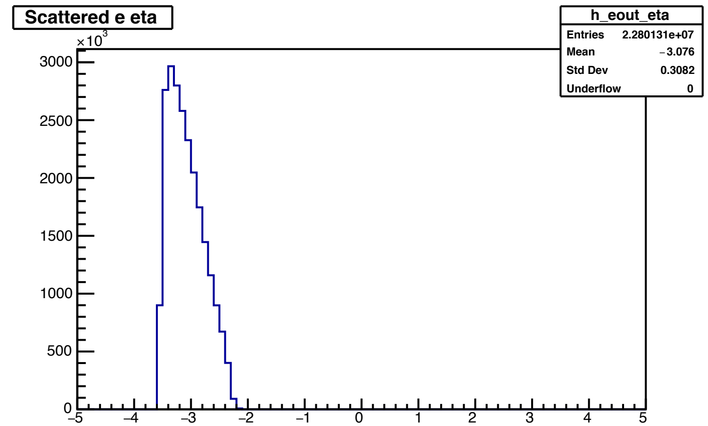
$1 < Q^2 < 10$ GeV^2



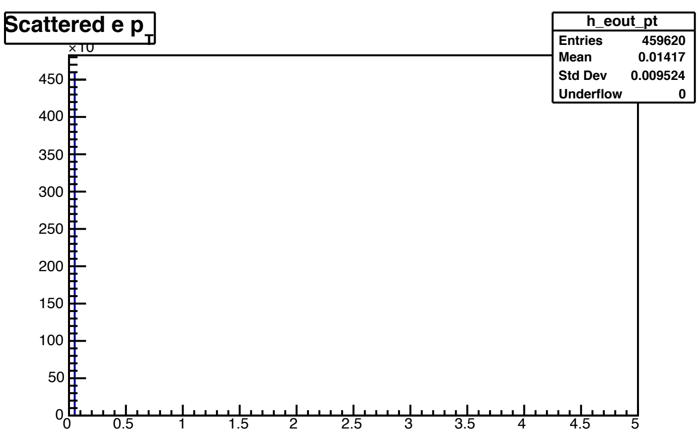
Where do the scattered electrons go?

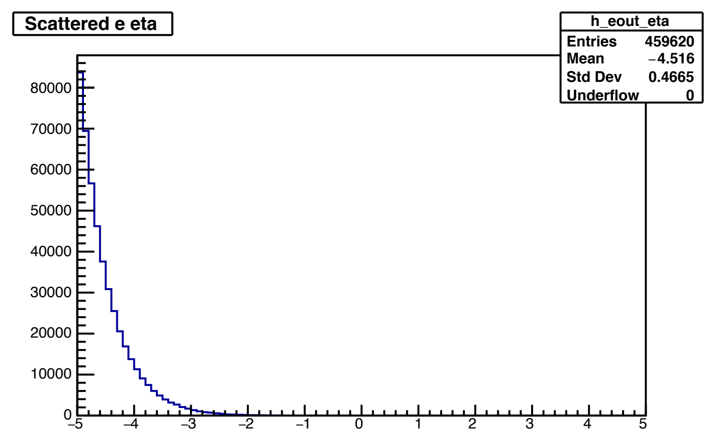
- $1 < Q^2 < 10$ GeV^2





- $Q^2 < 0.01$ GeV^2





Detector Constraints - Directions

- $Q^2 < 0.01$ GeV^2
  - Constraints tracking in the backward (e-going) region
  - $-3.5 < \eta < -1.5$
  - $p_T > 0.5$
  - Smearing of scattered electron does not matter since $p_T \sim 0$
- $1 < Q^2 < 10$ GeV^2
  - Constraints tracking in the central (barrel) region
  - $|\eta| < 1.5,$
  - $p_T > 0.5$
  - Smearing of scattered electron *does* matter
    - $-3.5 < \eta < -2$
    - $p_T > 1$ GeV/c

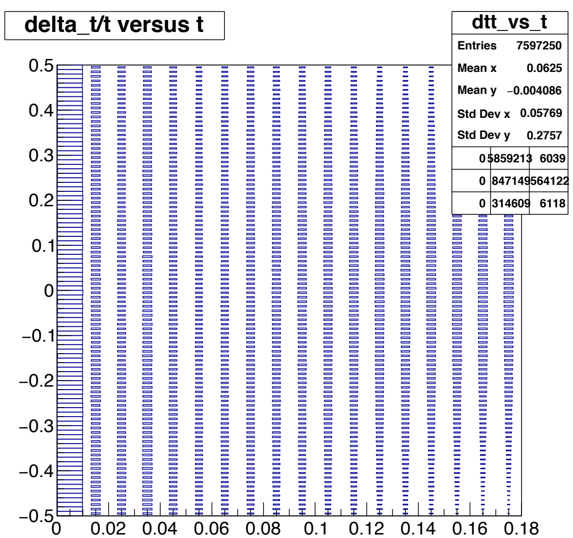
Impact of tracking on *t* resolution (barrel)

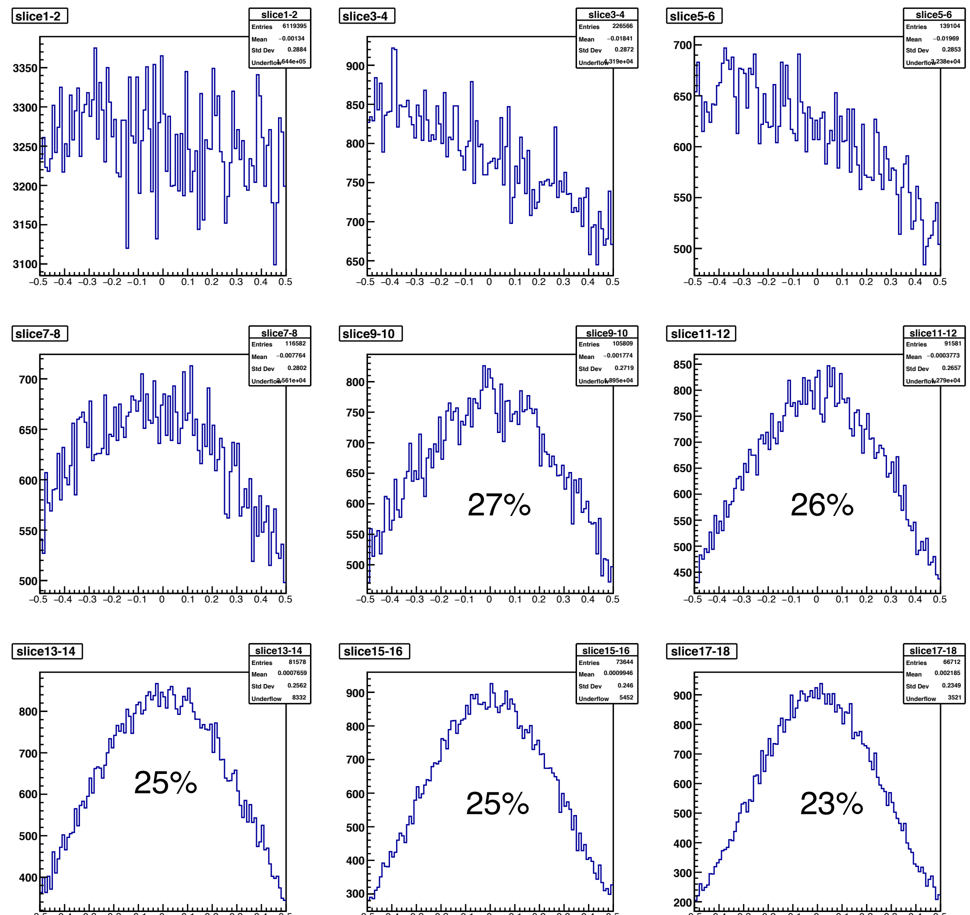
Start with: $\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 0.5$

1 < Q^2 < 10 GeV^2

Method **E,** no beam effects

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



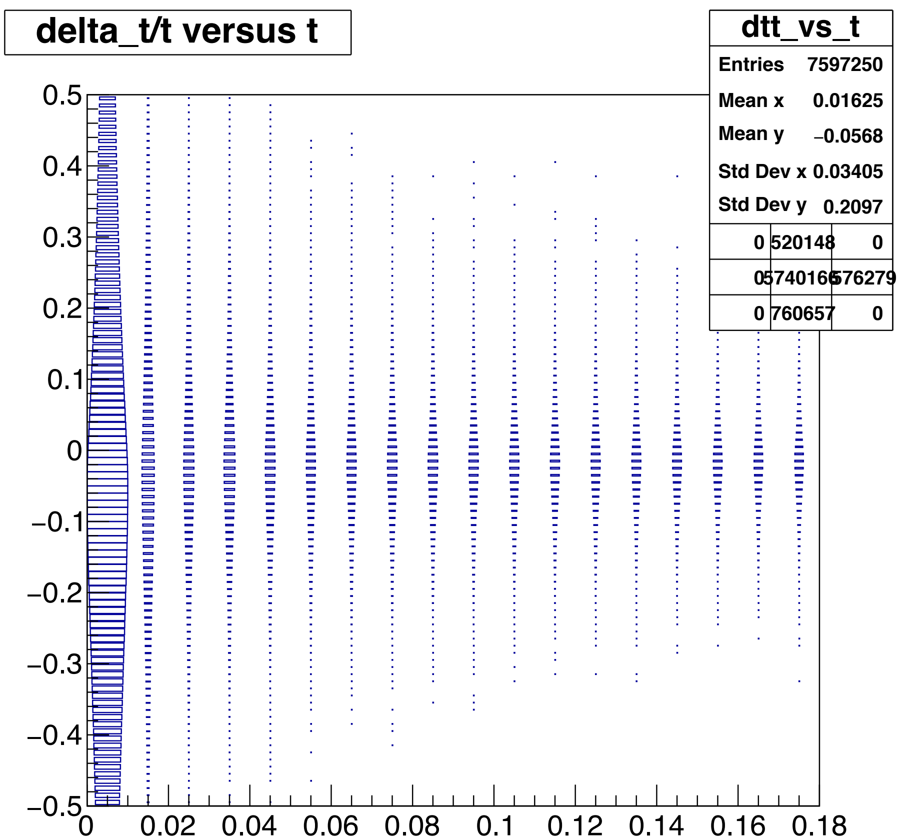


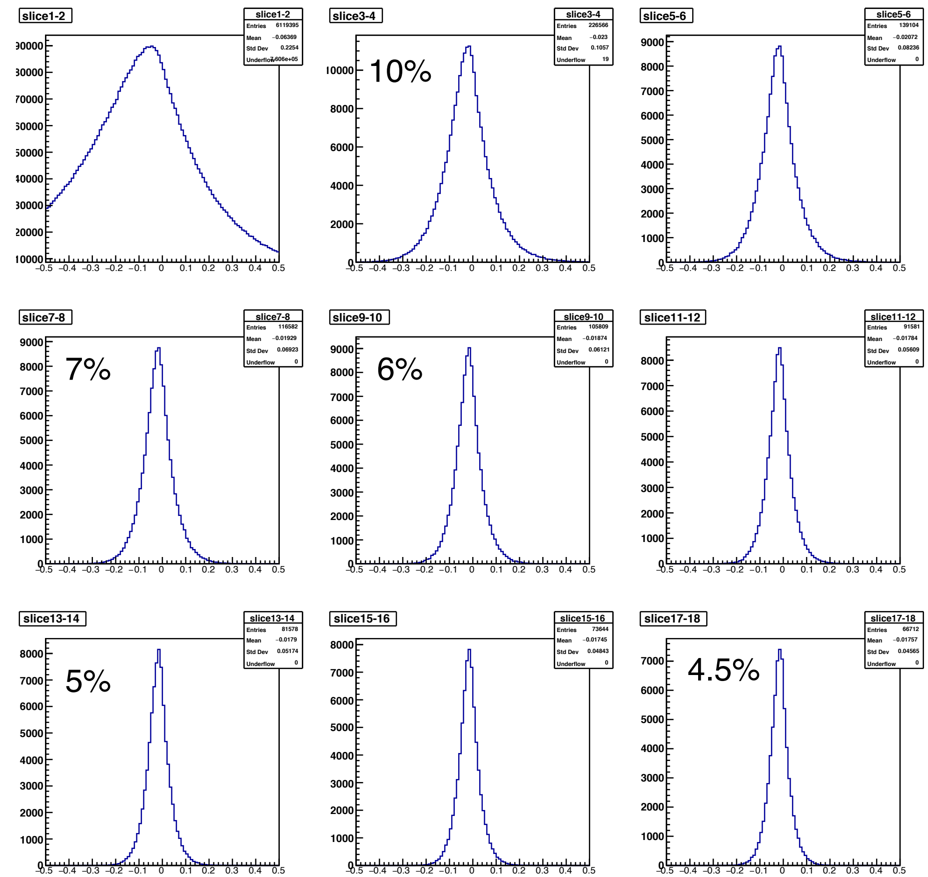
Impact of tracking on t resolution (barrel)

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

1 < Q^2 < 10 GeV^2

Method A, no beam effects





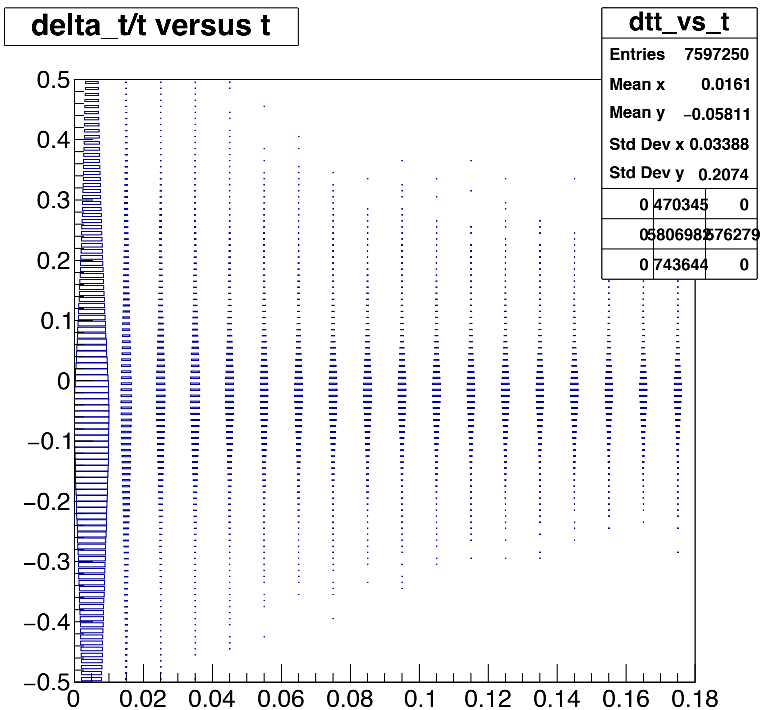
Impact of tracking on *t* resolution (barrel)

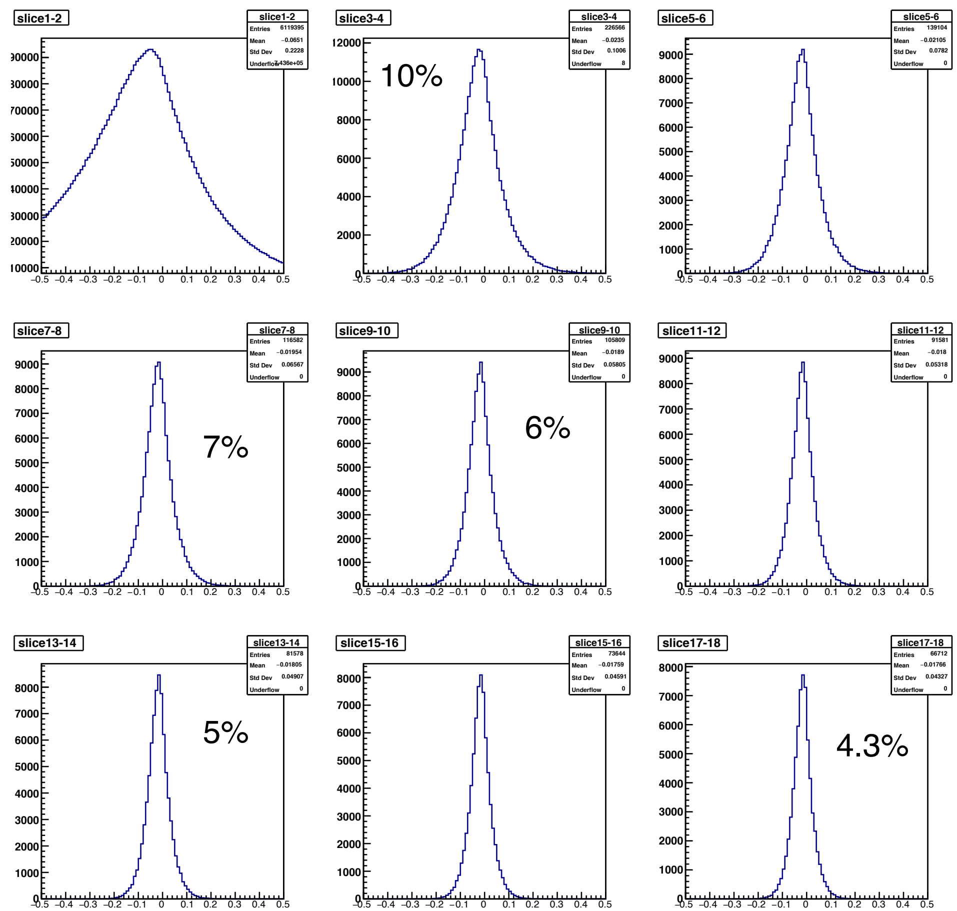
1 < Q² < 10 GeV²

Start with: $\frac{\sigma_{p_T}}{p_T}(\%) = 0.05\ p_T \oplus 0.5$

Method A, no beam effects

Precision term seem not matter too much





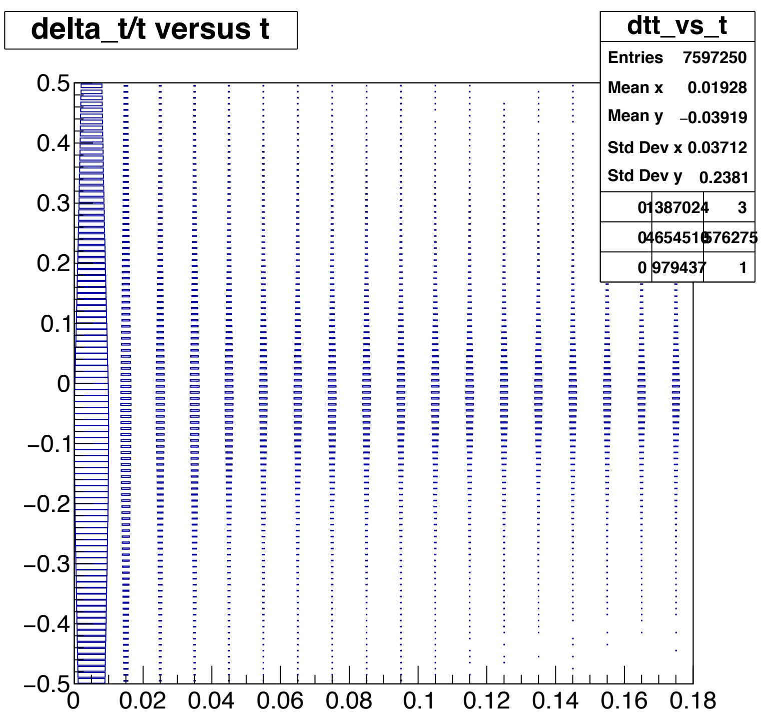
Impact of tracking on t resolution (barrel)

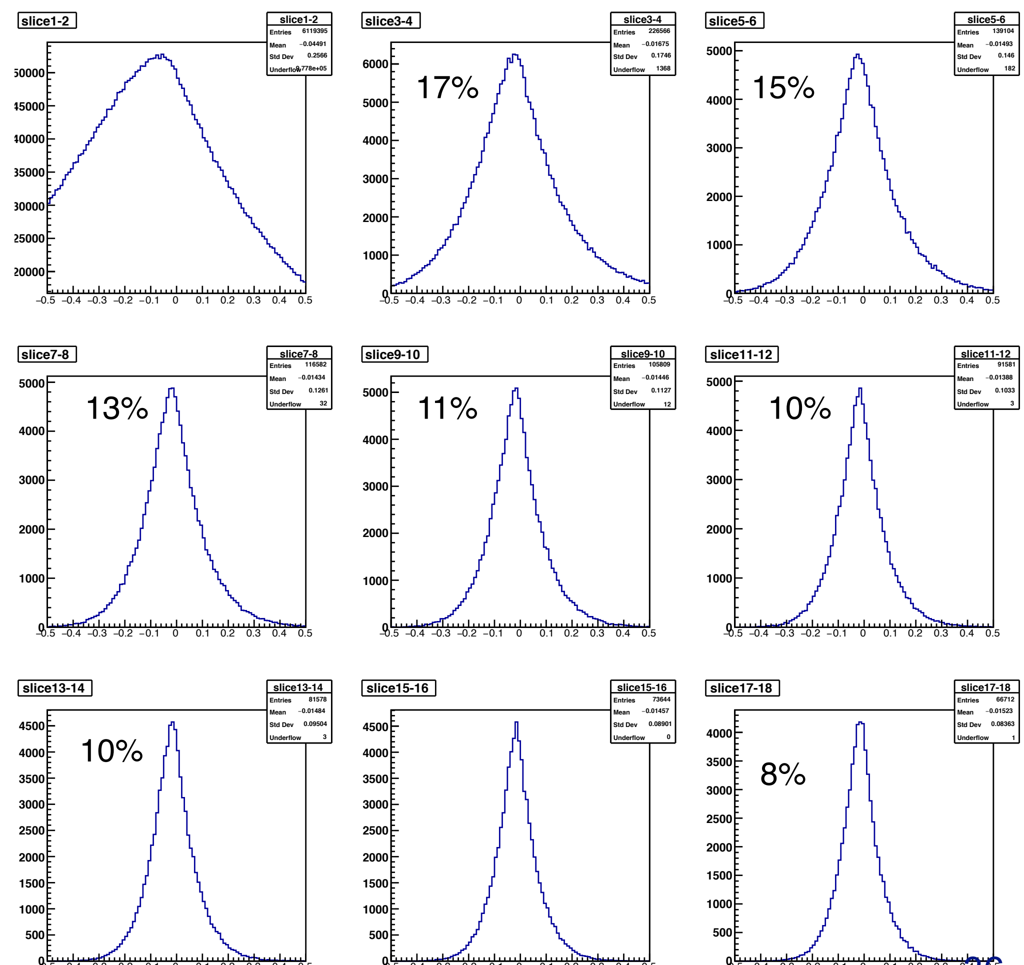
Start with: $$\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 1.0$$

1 < Q^2 < 10 GeV^2

Method A, no beam effects

MS term matters!
$dpt/pt|_{MS} \sim dt/t$



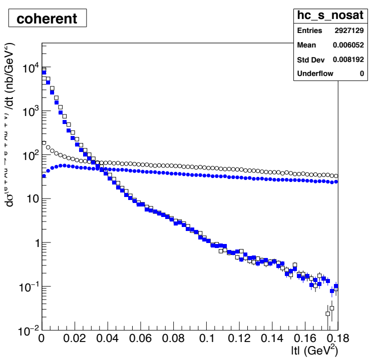


Impact of tracking on t resolution (barrel)

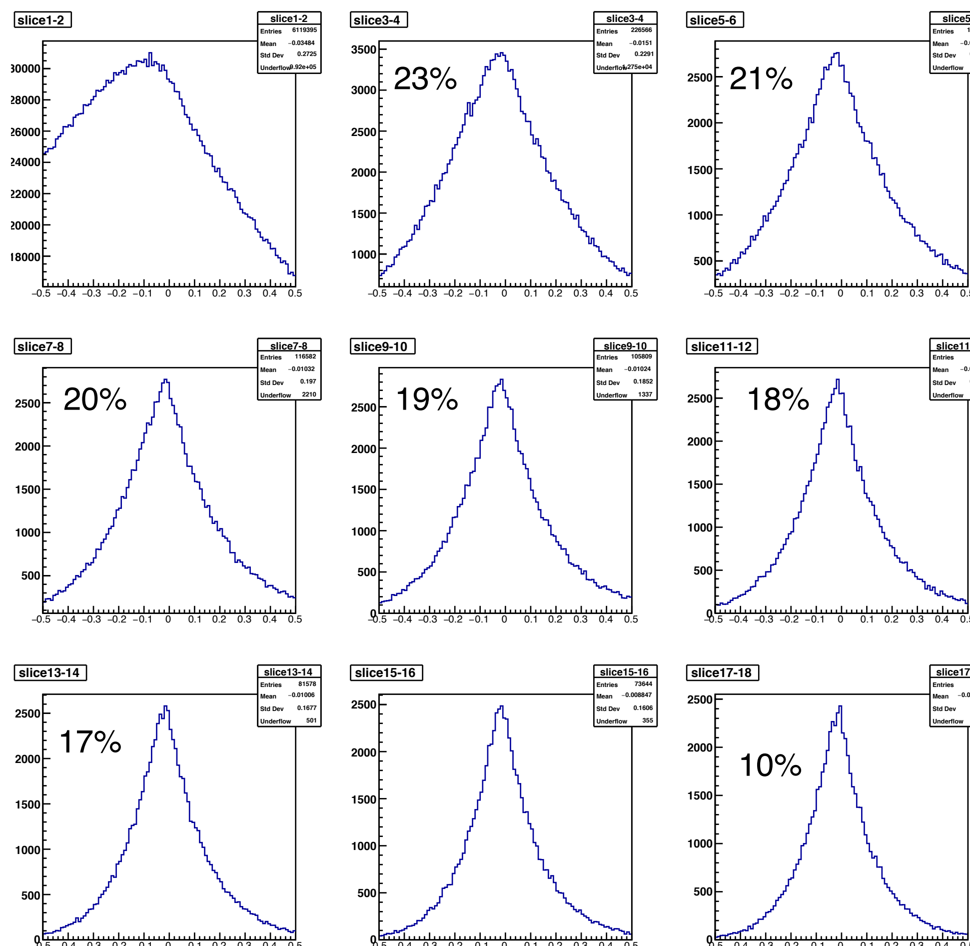
STAR TPC: $$\frac{\sigma_{p_T}}{p_T}(\%) = 0.78\ p_T \oplus 1.37$$

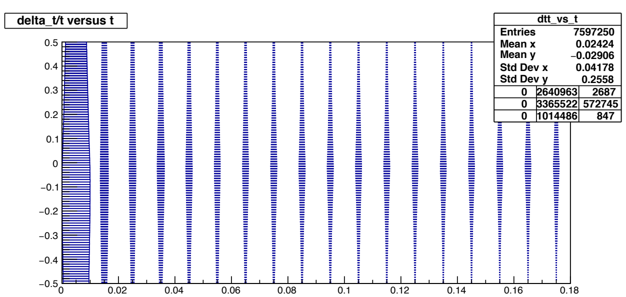
1 < Q^2 < 10 GeV^2

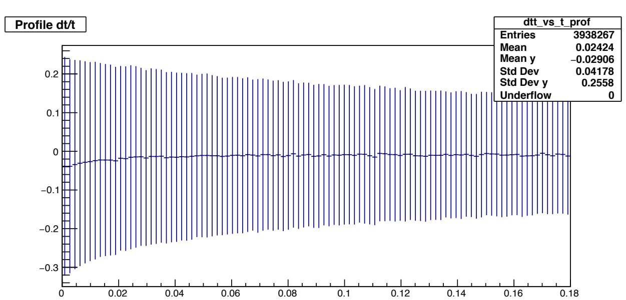
Method A, no beam effects



STAR TPC like resolution
is NOT an option.
Minima gone







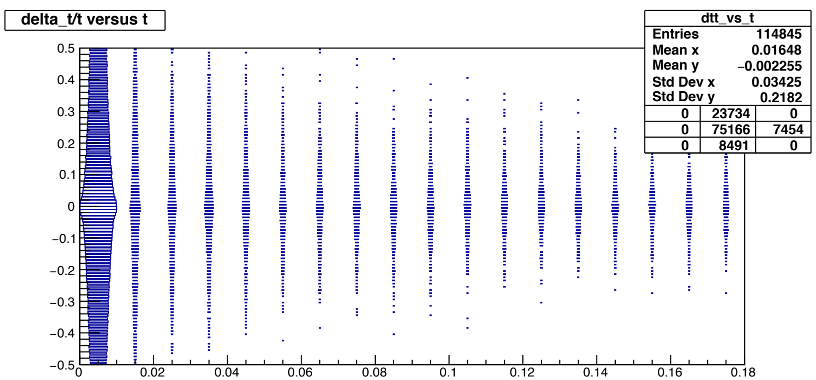
Impact of tracking on t resolution (bkwd)

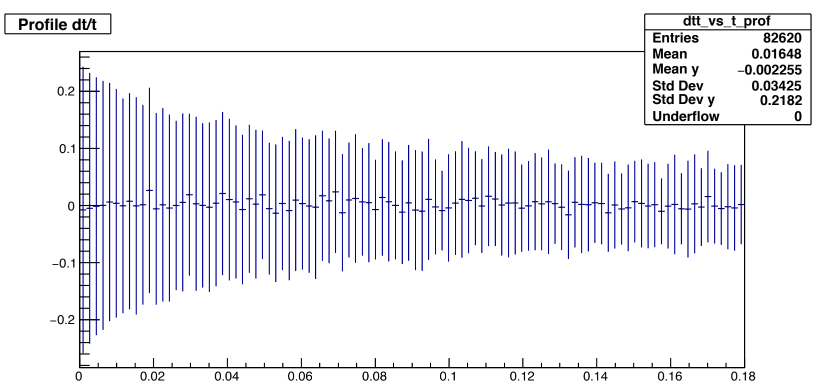
Method A, no beam effects

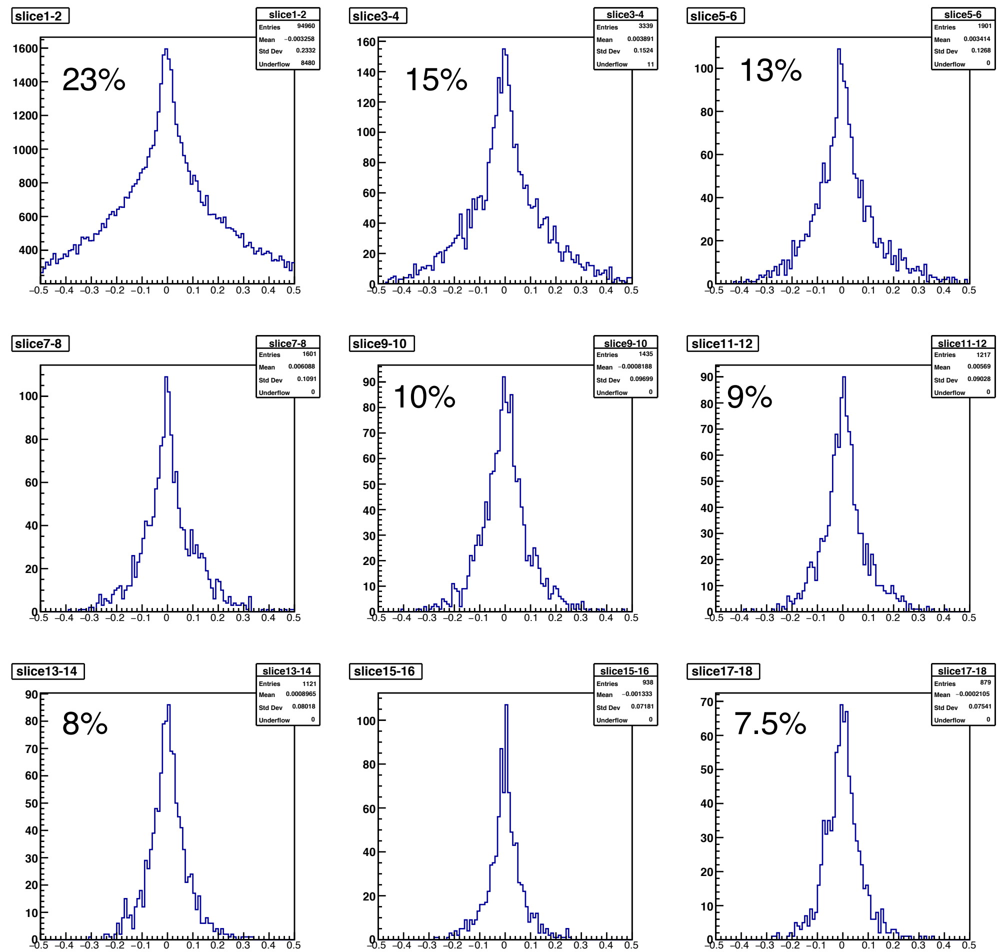
$Q^2 < 0.01$ GeV^2

Start with (: $\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 1.0$

Same ballpark as large Q^2







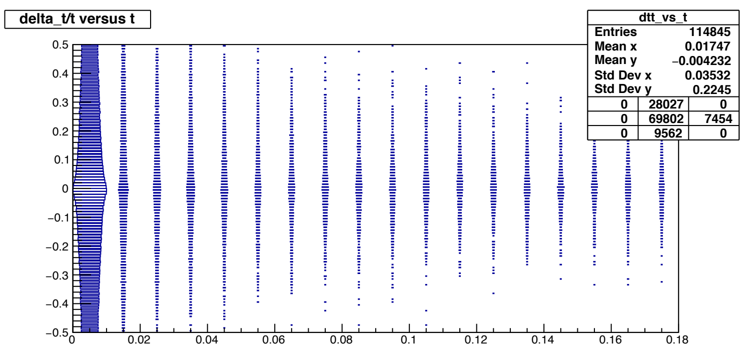
Impact of tracking on *t* resolution (bkwd)

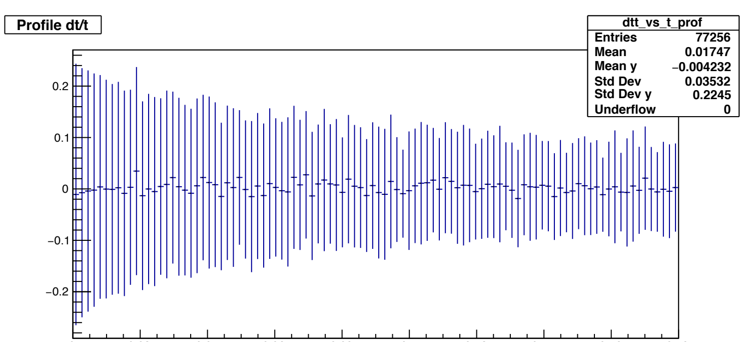
Method A, no beam effects

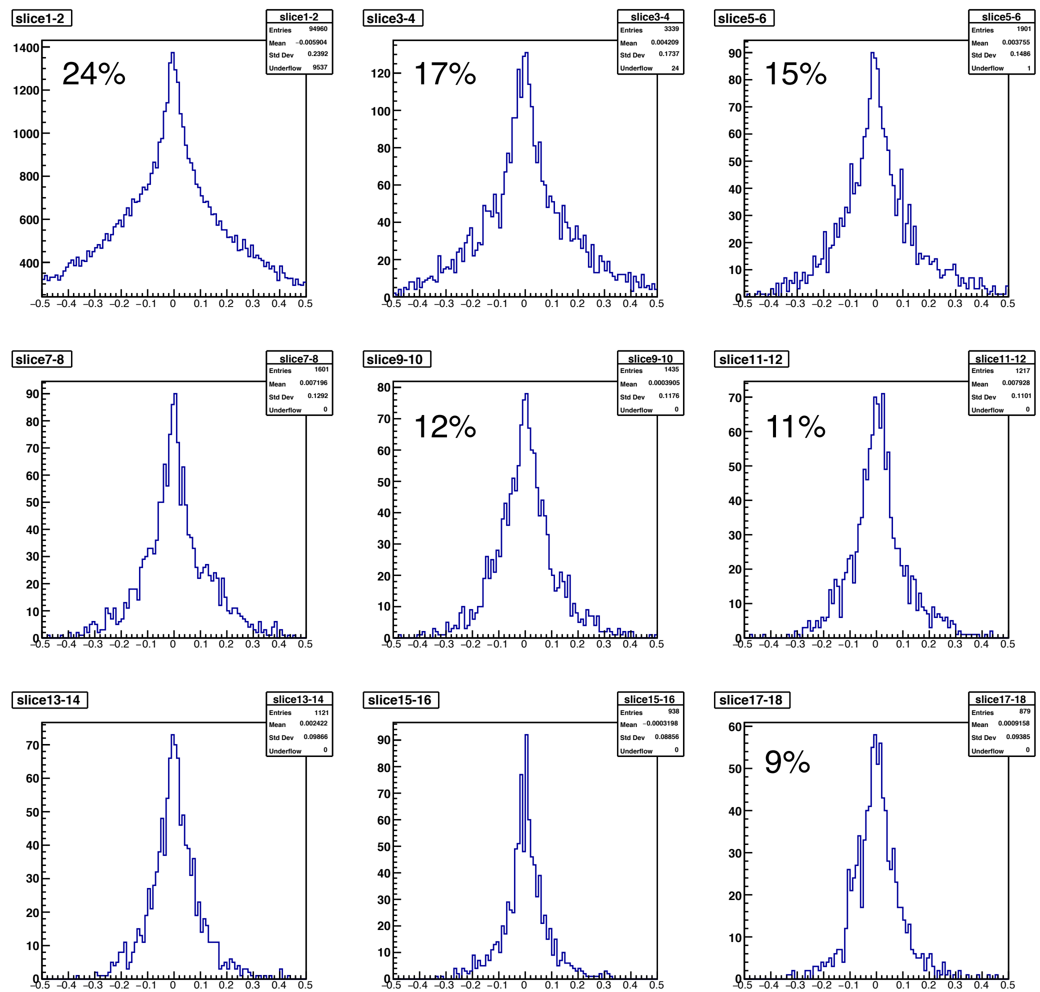
$Q^2 < 0.01$ GeV^2

Start with (: $\frac{\sigma_{p_T}}{p_T}(\,\%\,) = 0.5\ p_T \oplus 1.0$

Again weak impact of precisions term







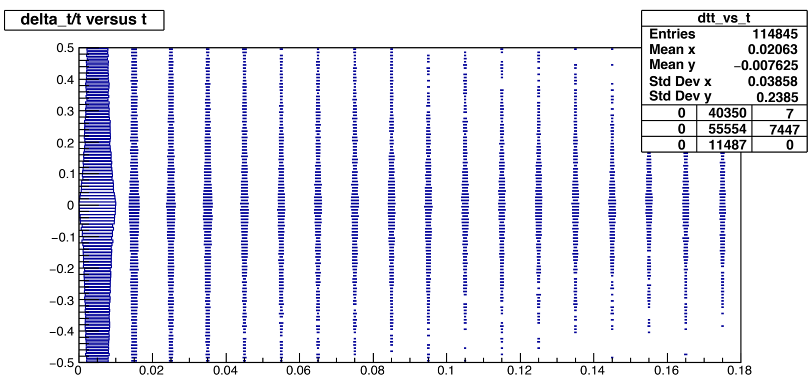
Impact of tracking on t resolution (bkwd)

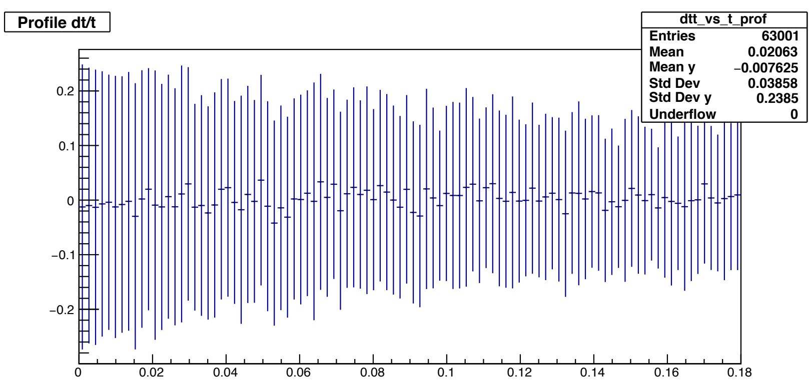
Method A, no beam effects

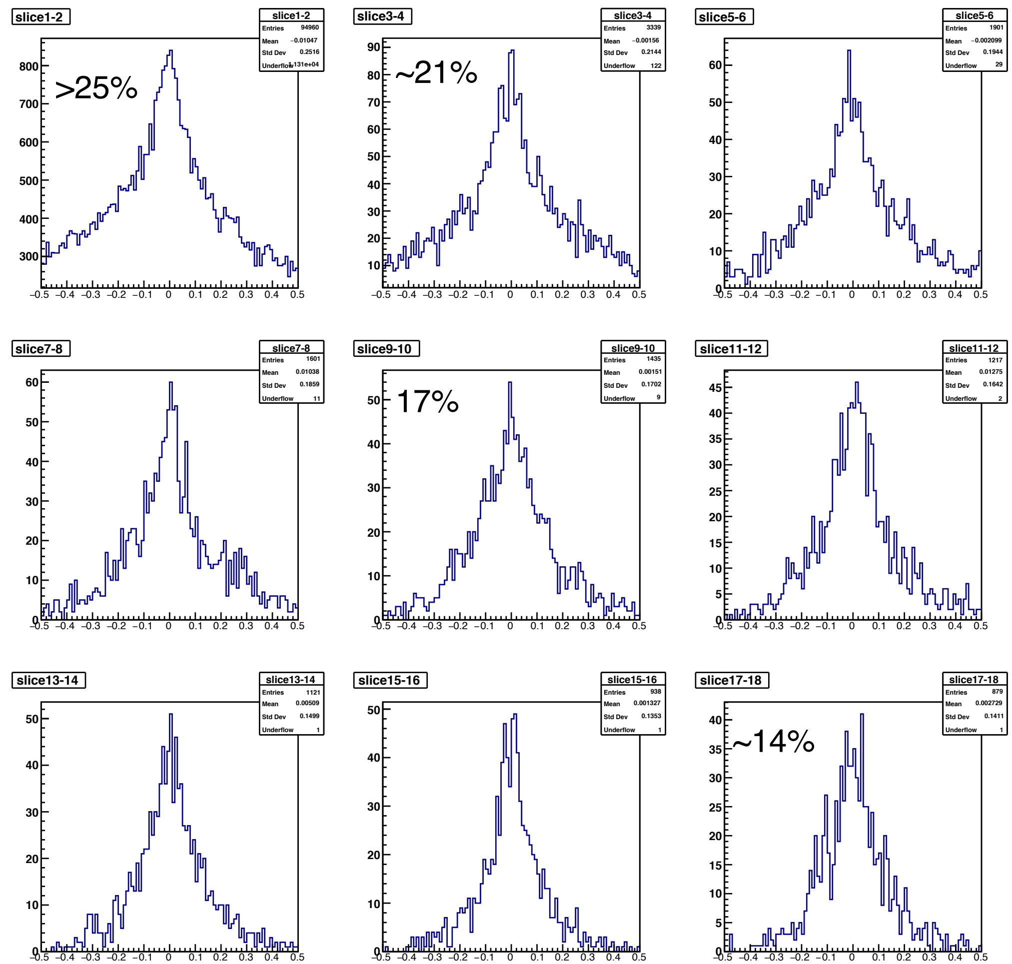
$Q^2 < 0.01$ GeV^2

Start with (: $\frac{\sigma_{p_T}}{p_T}(\,\%\,) = 0.1\ p_T \oplus 2.0$

MS term will be key



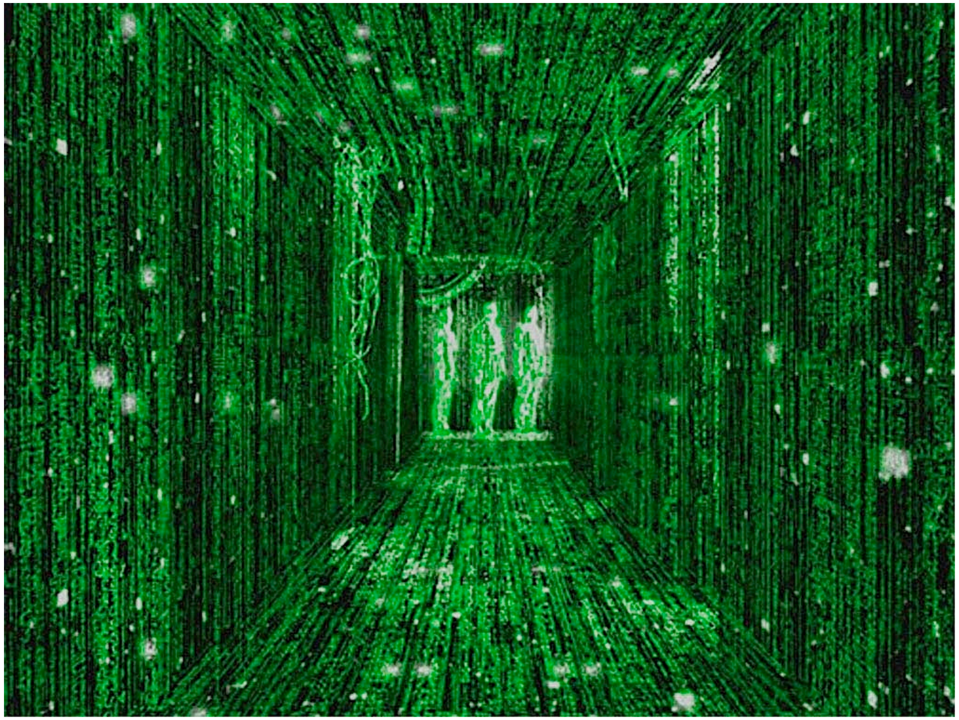




The Raison d'etre for $d\sigma/dt$

Finding the Source

- Sartre used Wood-Saxon as input distribution
- Basic Idea: Comparison of extracted WS with input is key to establishing when *t* resolution is not good enough



Getting Source Distribution from dσ/dt

Markus Diehl (INT '10):

http://www.int.washington.edu/talks/WorkShops/int_10_3/People/Diehl_M/Diehl1.pdf

$$F(b) \sim \frac{1}{2\pi} \int_0^\infty d\Delta\, \Delta\, J_0(\Delta b) \sqrt{\frac{d\sigma}{dt}}$$

$t = \Delta^2/(1-x) \approx \Delta^2$ (for small x)

Issues (ep):

- Measured range in Δ
- Statistical errors on data

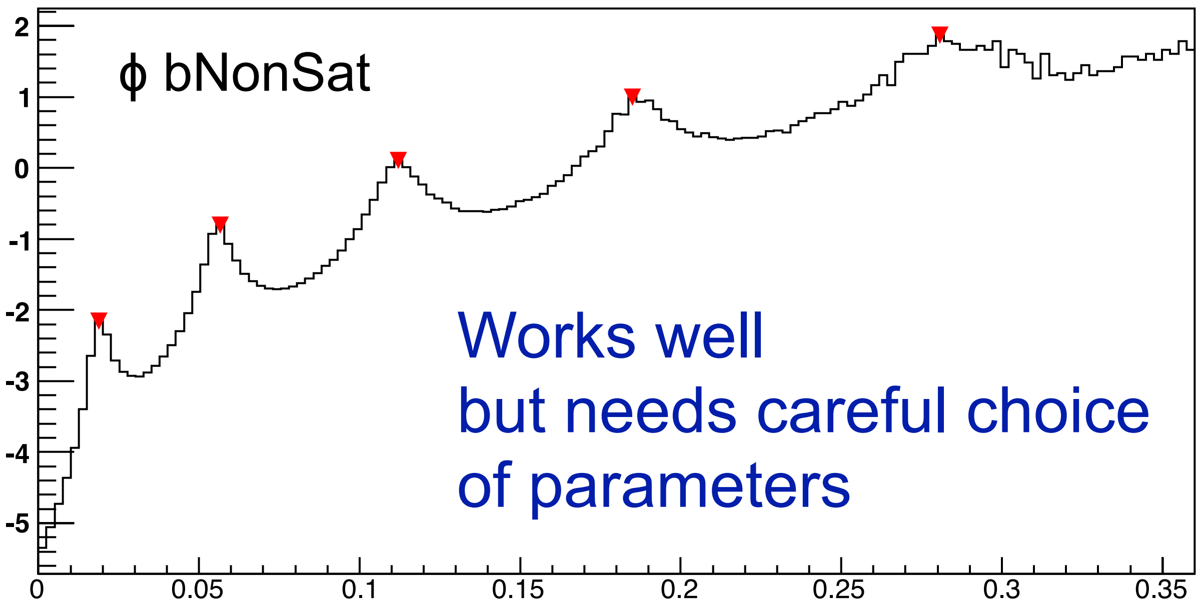
What about eA?

- So far dσ/dt for $t<0.18$ GeV^2
- Can extend to $t=0.36$ GeV^2 but need lots of statistics
- Good enough for first studies

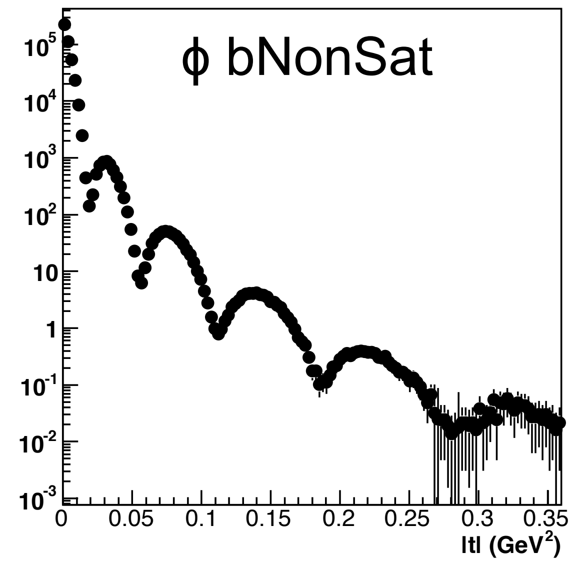
Practical Issues

For integration: Sign flip in $J_0(\Delta b)$?

Use ROOT::TSpectrum::Search package:



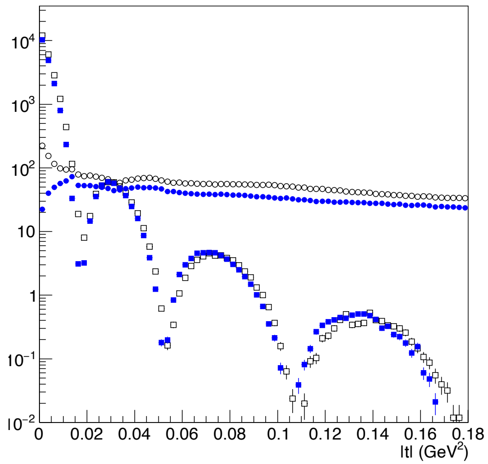
Works well
but needs careful choice
of parameters



Integration routines have their issues with Bessel functions

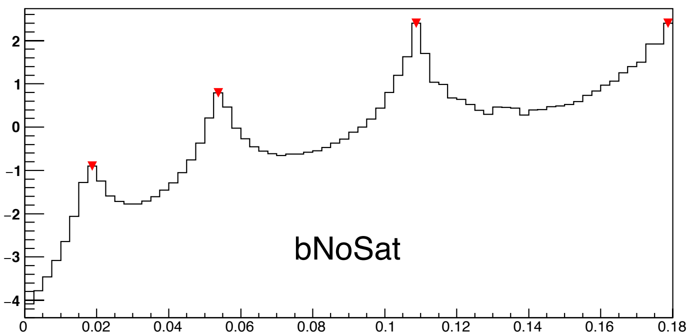
Use GSLIntegration (best available) - makes a difference!

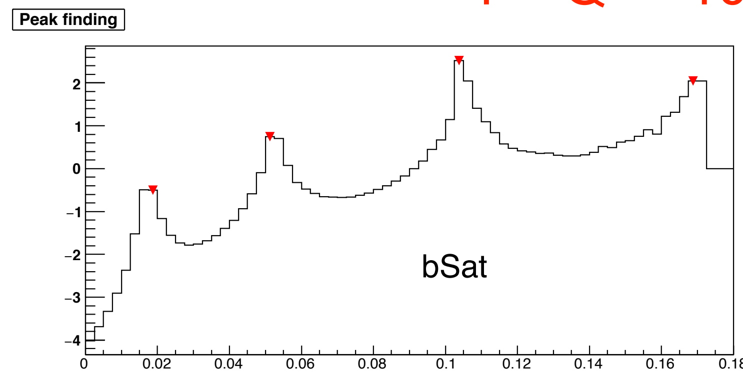
Method A: $F(b)$ without any smearing

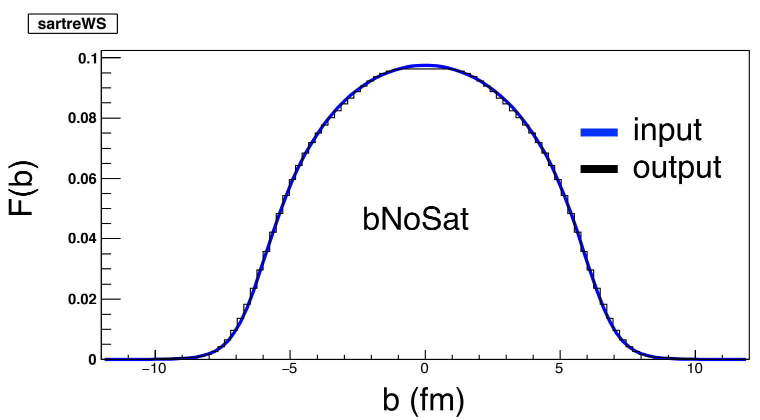


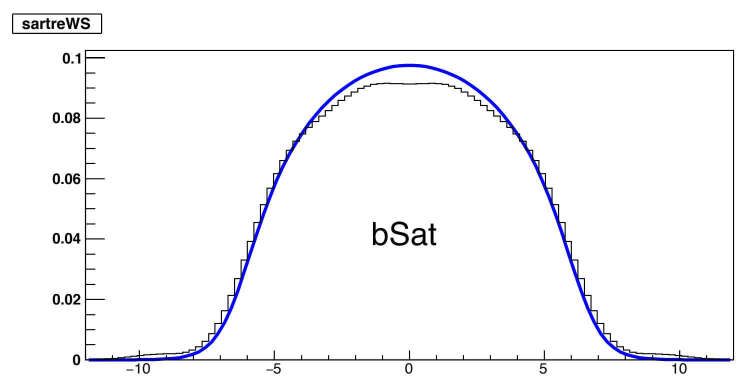
- bSat: method A seem good enough
- bNonSat: as usual slight indication of saturation around b ~0
- Use bSat only from now on

1 < Q^2 < 10 GeV^2





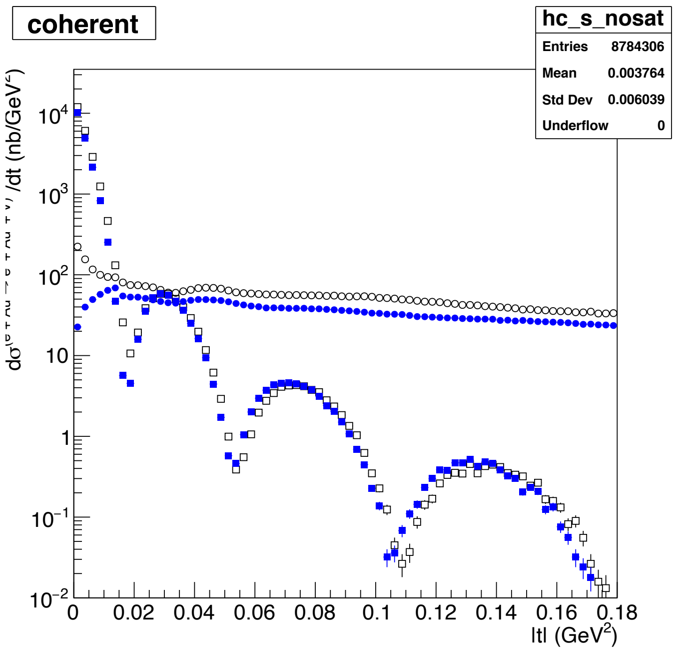


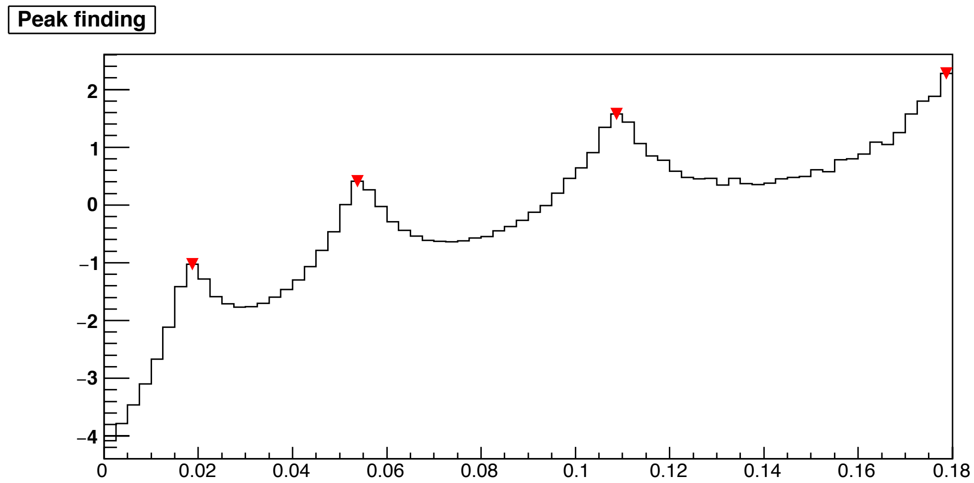


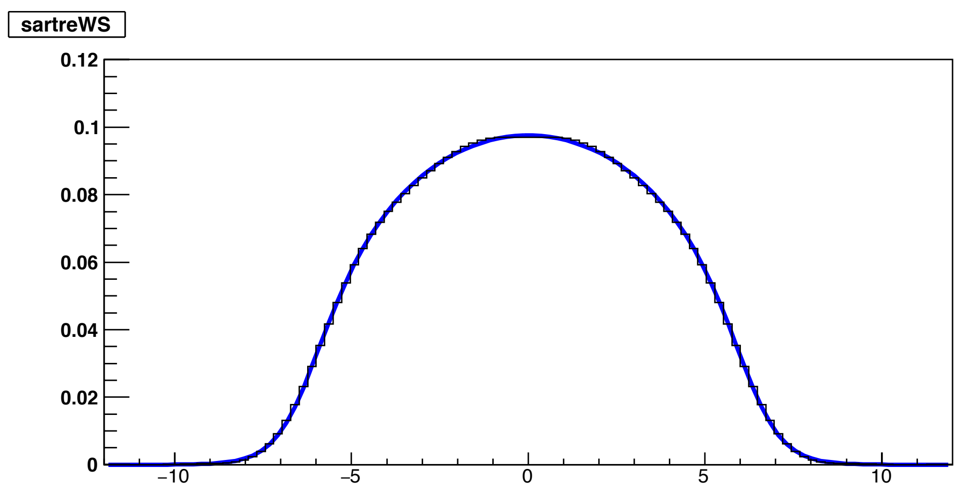
Method A: $F(b)$

$$\frac{\sigma_{p_T}}{p_T}(\%) = 0.05\ p_T \oplus 0.25$$

- e from J/ψ p_T smearing
- $1 < Q^2 < 10$ GeV^2





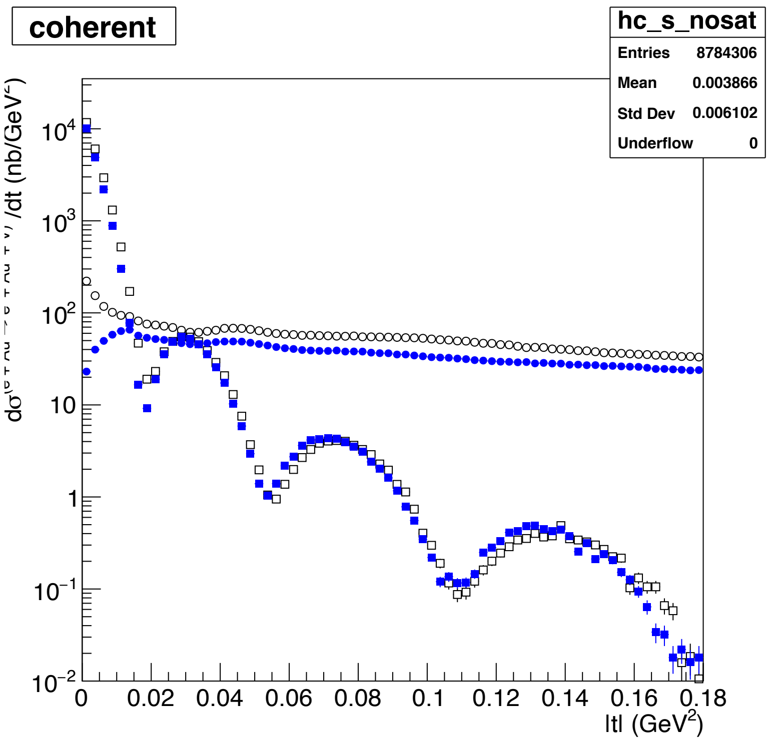


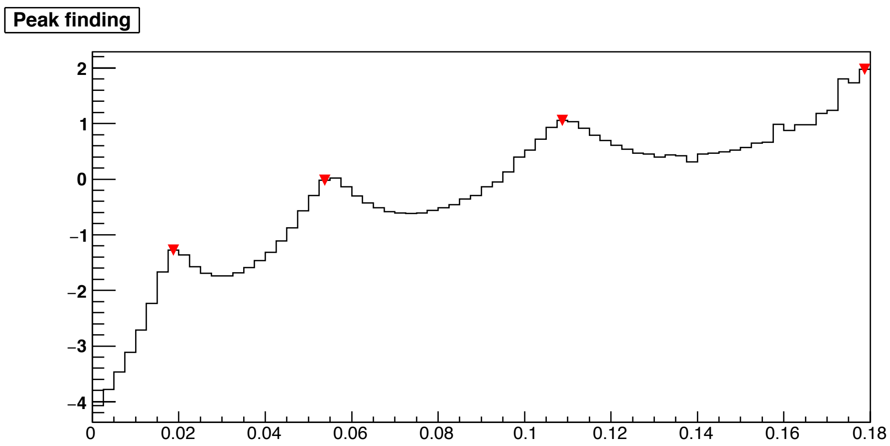
Hardly any effect
Still OK

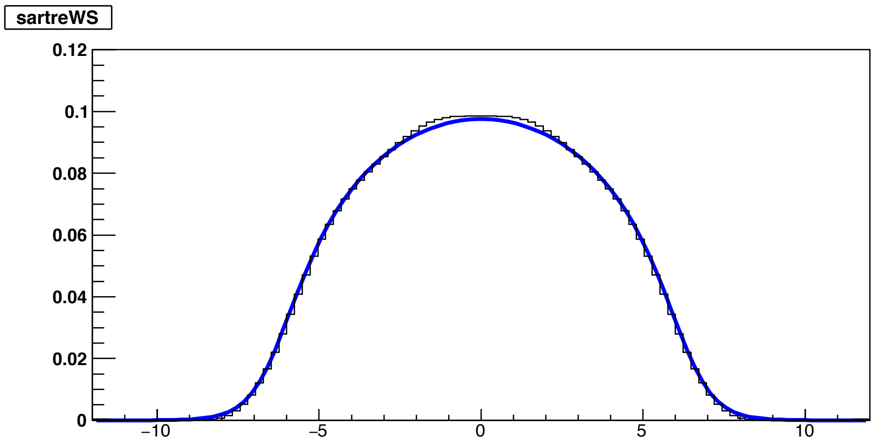
Method A: $F(b)$

$$\frac{\sigma_{p_T}}{p_T}(\,\%\,) = 0.05\ p_T \oplus 0.5$$

- e from J/ψ p_T smearing
- $1 < Q^2 < 10$ GeV^2





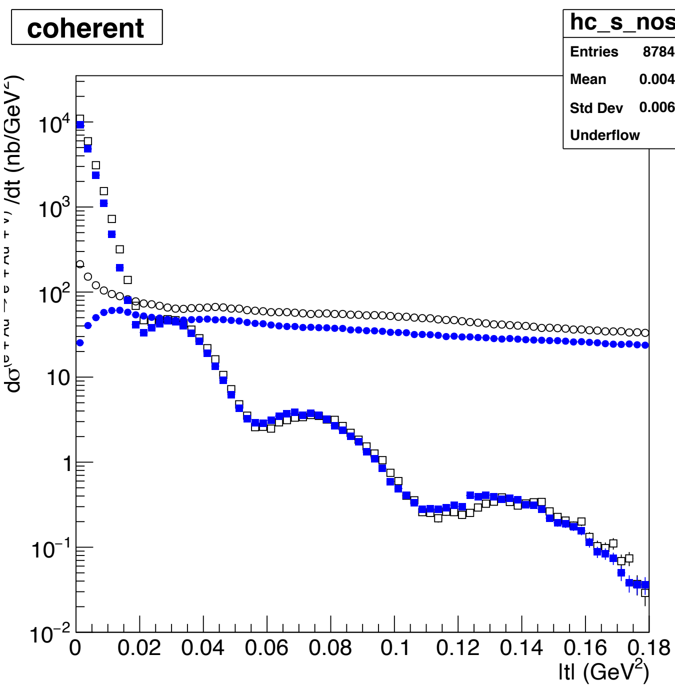


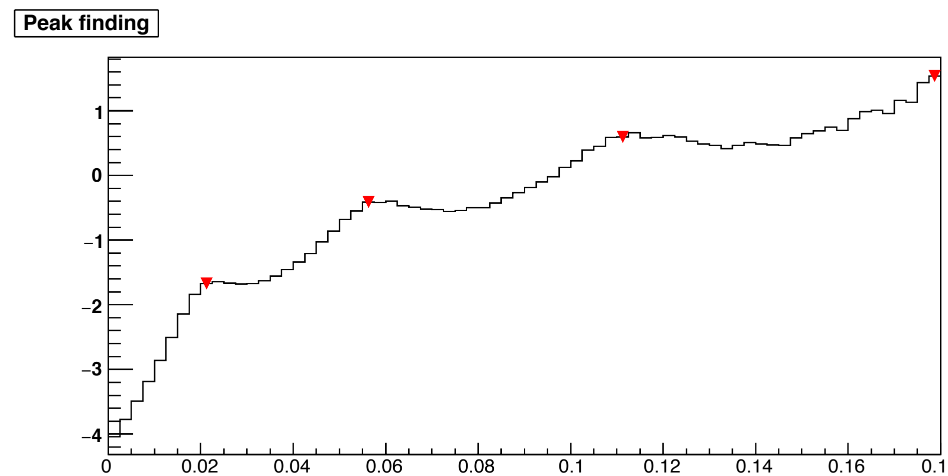
Slight softening of the peak, hardly affecting the source distribution.

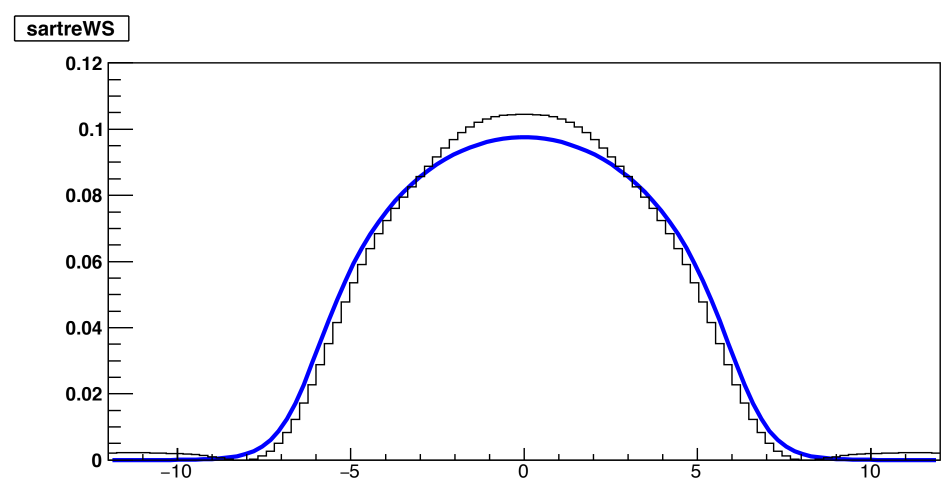
Method A: $F(b)$

$$\frac{\sigma_{p_T}}{p_T}(\,\%\,) = 0.05\; p_T \oplus 1.0$$

- e from J/ψ p_T smearing
- $1 < Q^2 < 10$ GeV^2





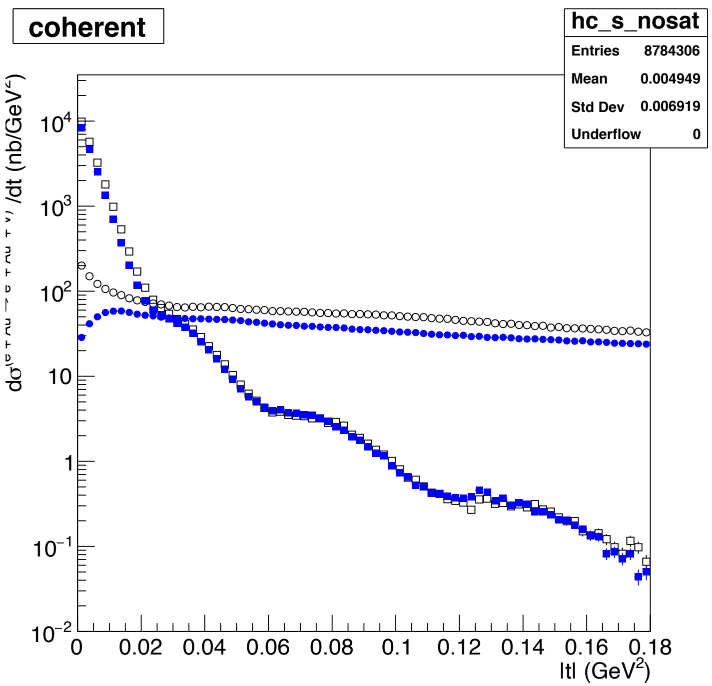


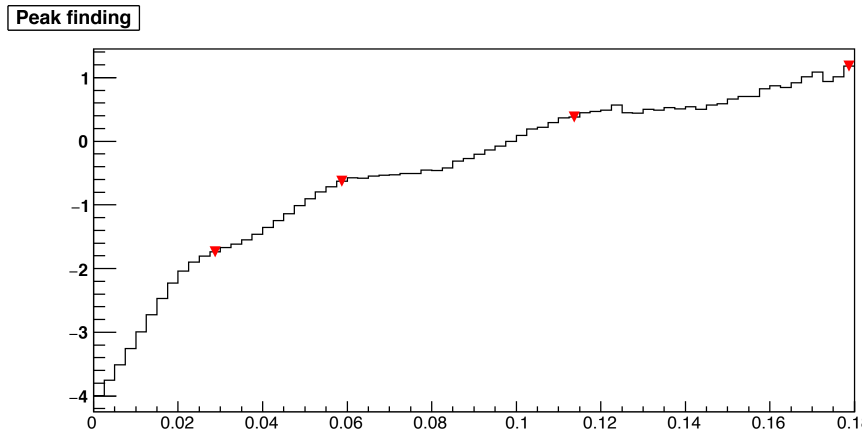
Substantial broadening
Distinct minima are almost gone.

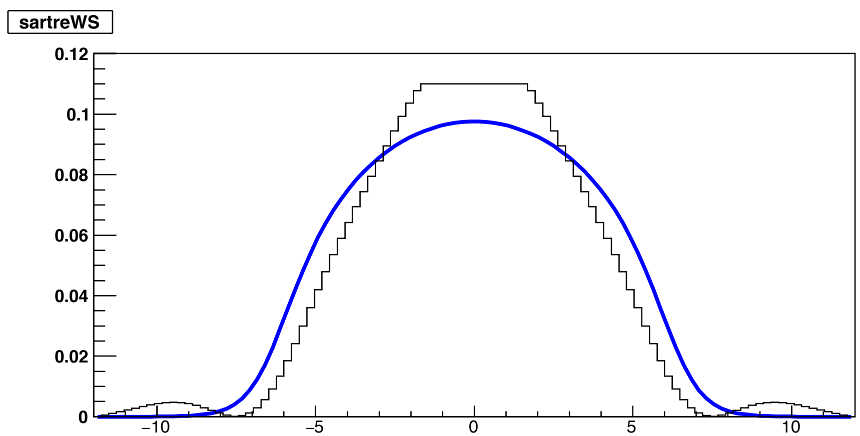
Method A: $F(b)$

$$\frac{\sigma_{p_T}}{p_T}(\%) = 0.05\ p_T \oplus 1.5$$

- e from J/ψ p_T smearing
- $1 < Q^2 < 10$ GeV^2





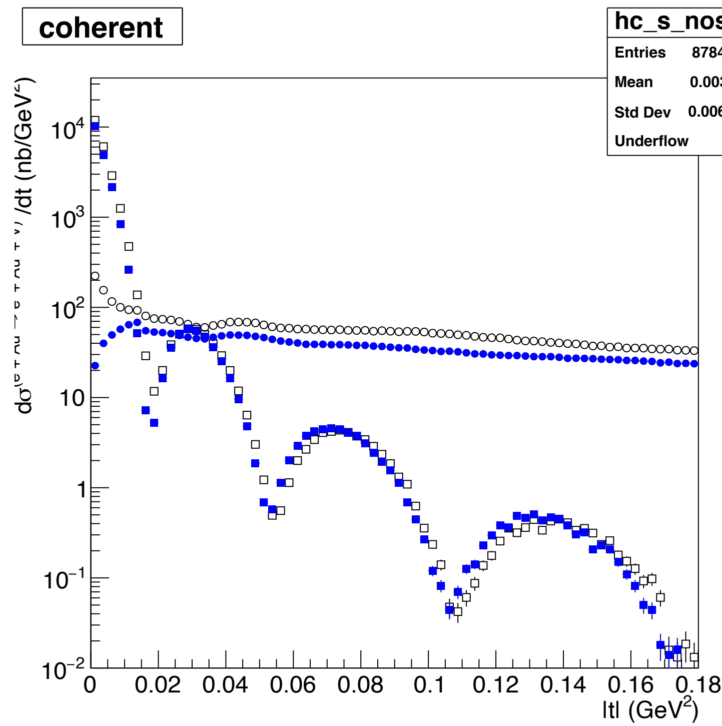


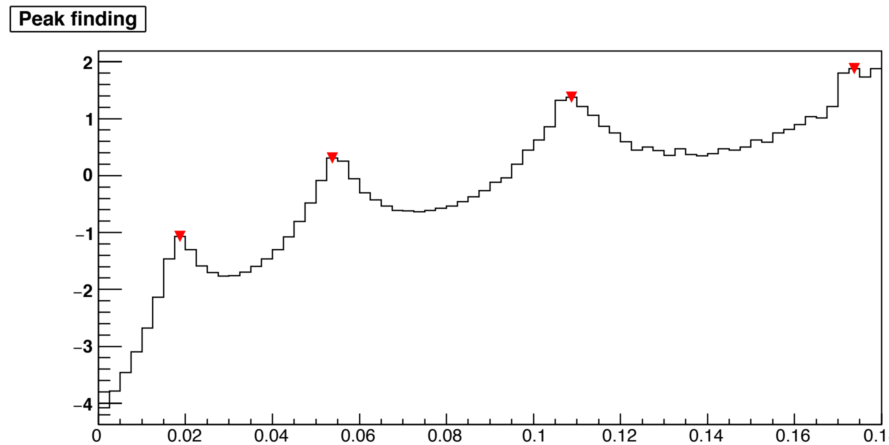
Clearly reached the end.
Even unfolding will not
help any more

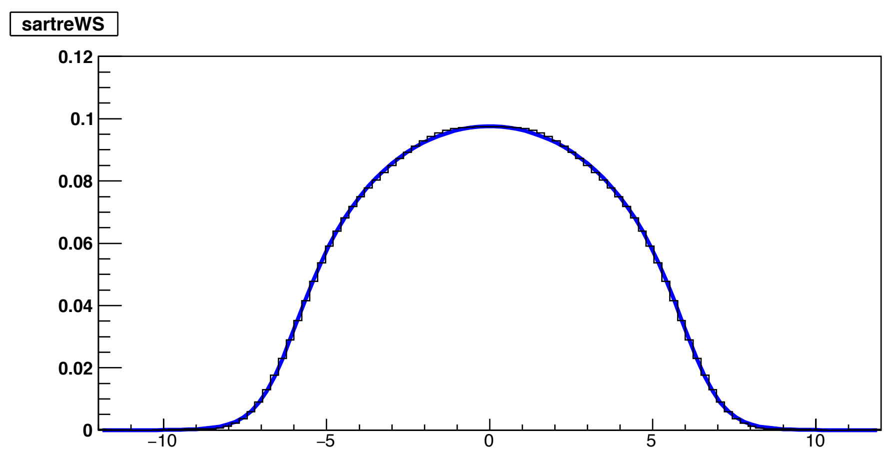
Method A: $F(b)$

$$\frac{\sigma_{p_T}}{p_T}(\,\%\,) = 0.1\; p_T \oplus 0.25$$

- e from J/ψ p_T smearing
- $1 < Q^2 < 10$ GeV^2





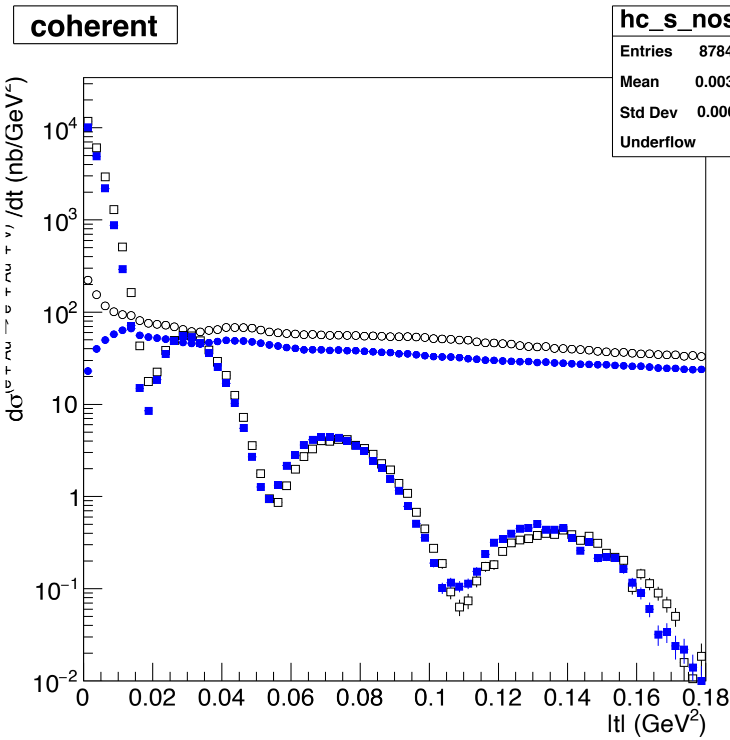


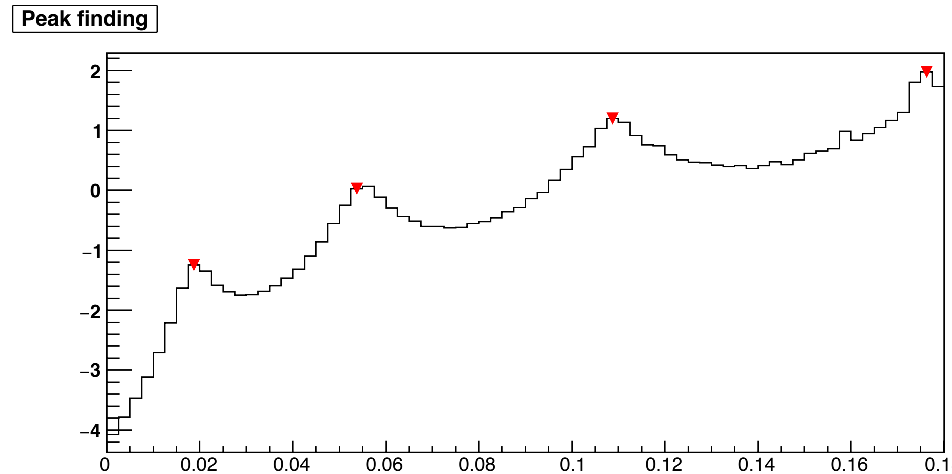
Precision term has little to no effect as expected

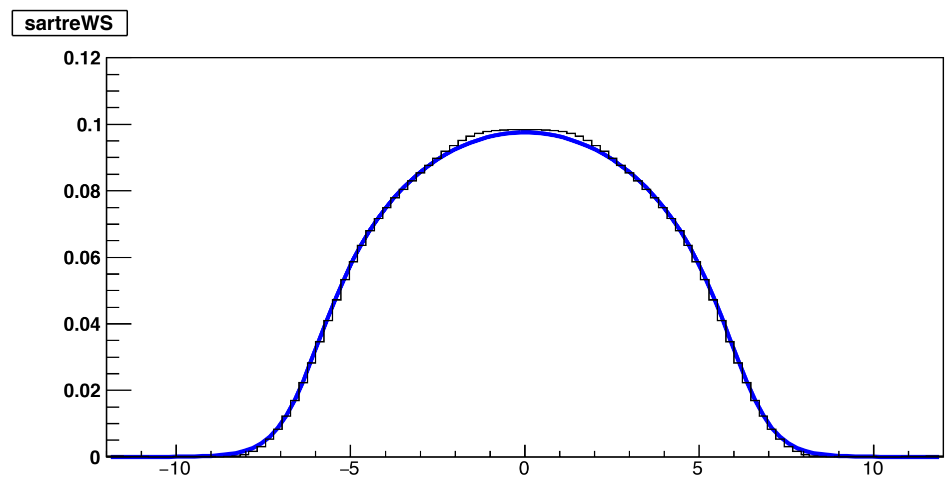
Method A: $F(b)$

$$\frac{\sigma_{p_T}}{p_T}(\%) = 0.2\ p_T \oplus 0.25$$

- e from J/ψ p_T smearing
- $1 < Q^2 < 10$ GeV^2





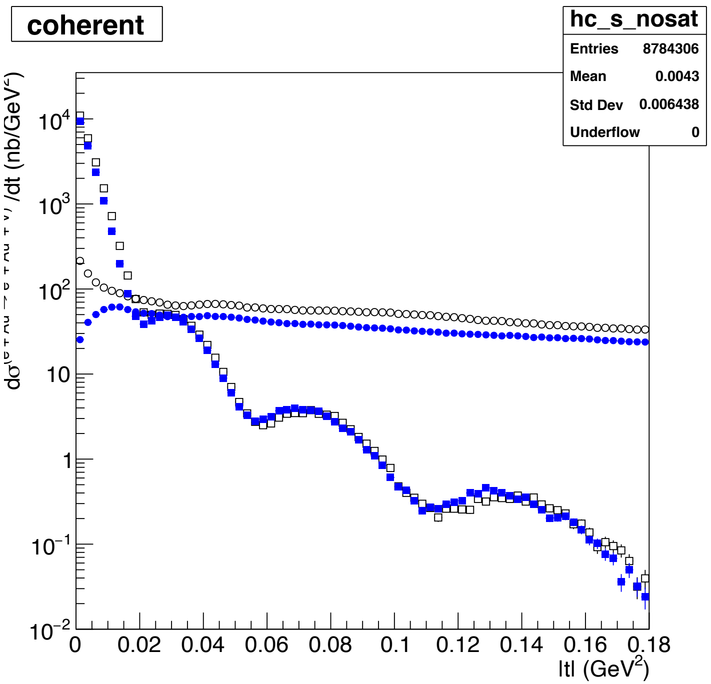


Precision term still OK

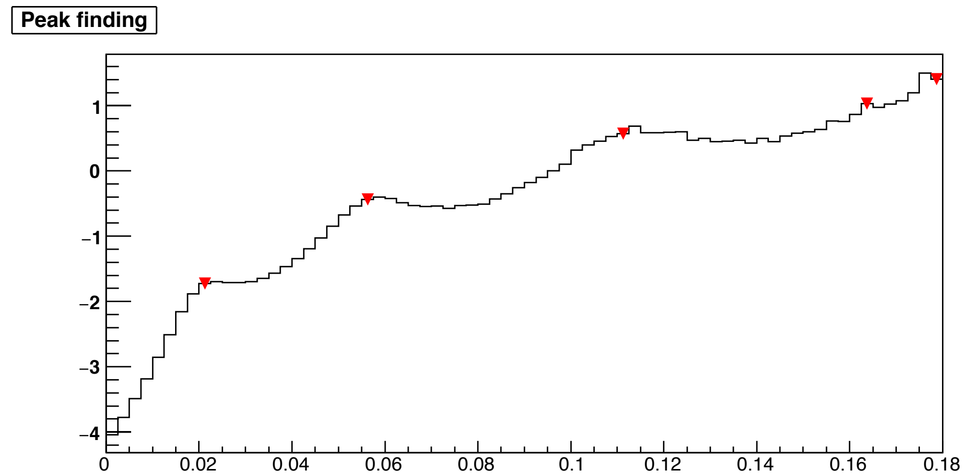
Method A: $F(b)$

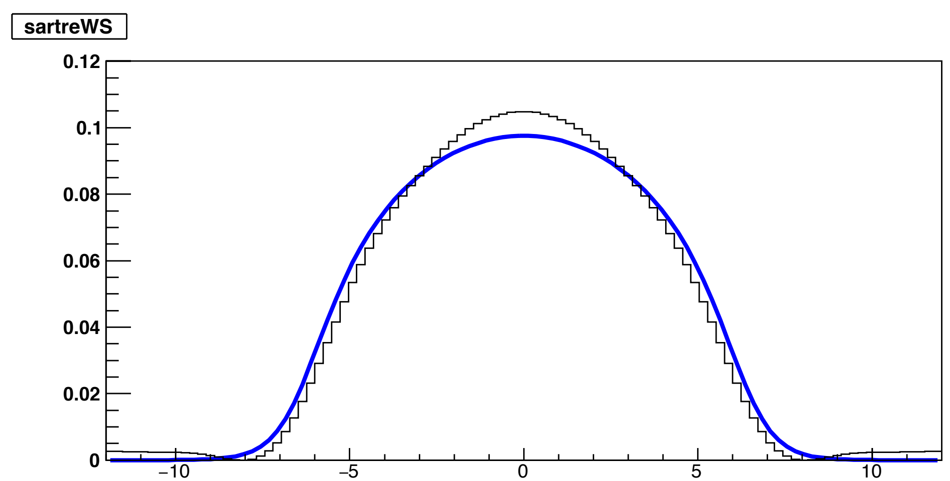
$$\frac{\sigma_{p_T}}{p_T}(\%) = 0.5\, p_T \oplus 0.25$$

- e from J/ψ p_T smearing
- $1 < Q^2 < 10$ GeV^2



Starts to wash out

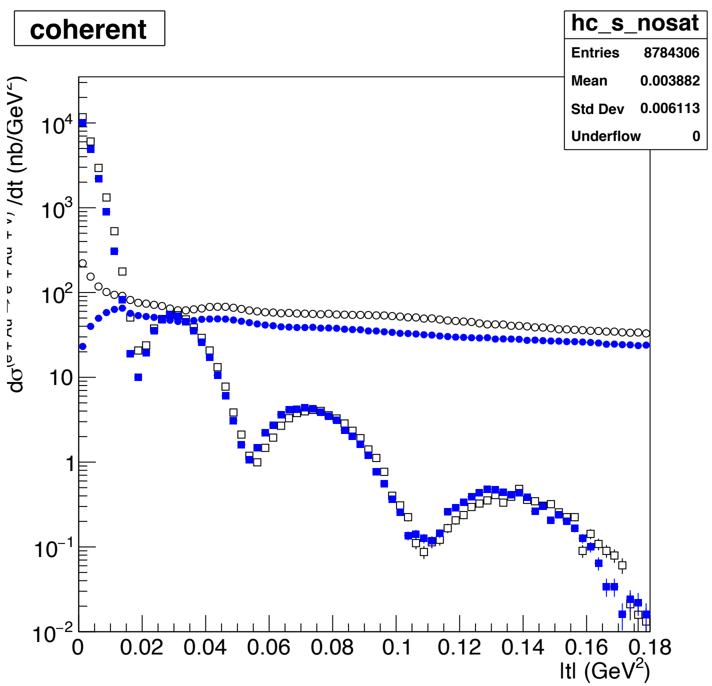


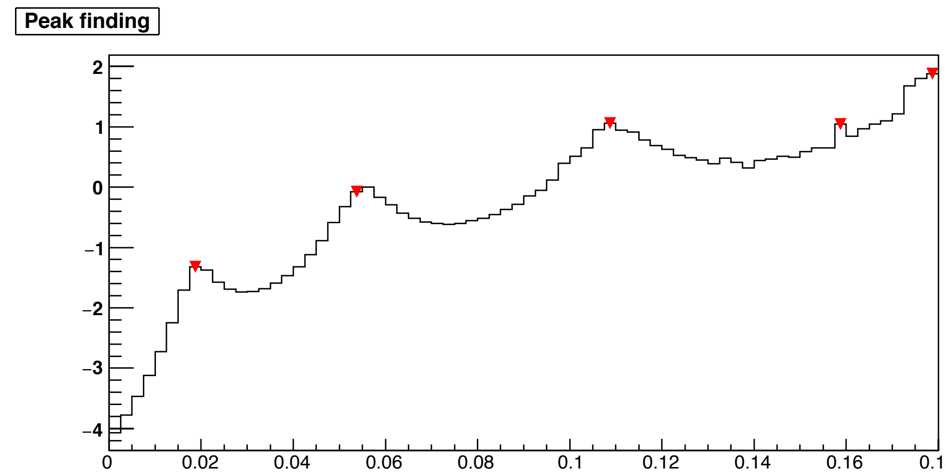


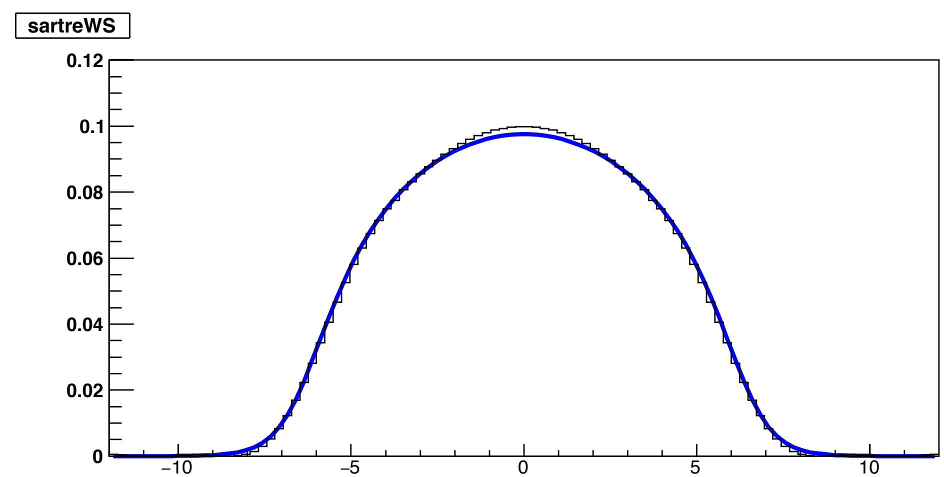
Method A: $F(b)$

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

- e from J/ψ p_T smearing
- $1 < Q^2 < 10$ GeV^2







That is roughly the edge of being OK

Conclusion: Barrel ($Q^2 > 1$) J/ψ Smearing

$$\frac{\sigma_{p_T}}{p_T}(\%) = a\, p_T \oplus b$$

- MS term (b) needs to be ≤ 0.5, 0.25 is clearly enough
- Precision term (a) should be < 0.1
  - not so important unless >> 0.1

What matters for $\delta t / t$

- $Q^2 < 0.01$ GeV^2

$$\frac{\delta t}{t} \approx \frac{\delta p_T^{e^-}}{p_T^{e^-}} \oplus \frac{\delta p_T^{e^+}}{p_T^{e^+}}$$

$$-3.5 < \eta < -1.5$$

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

$$\frac{\delta t}{t} \approx \frac{\delta p_T^{e^-}}{p_T^{e^-}} \oplus \frac{\delta p_T^{e^-}}{p_T^{e^-}} \oplus \frac{\delta p_T^{e^+}}{p_T^{e^+}}$$

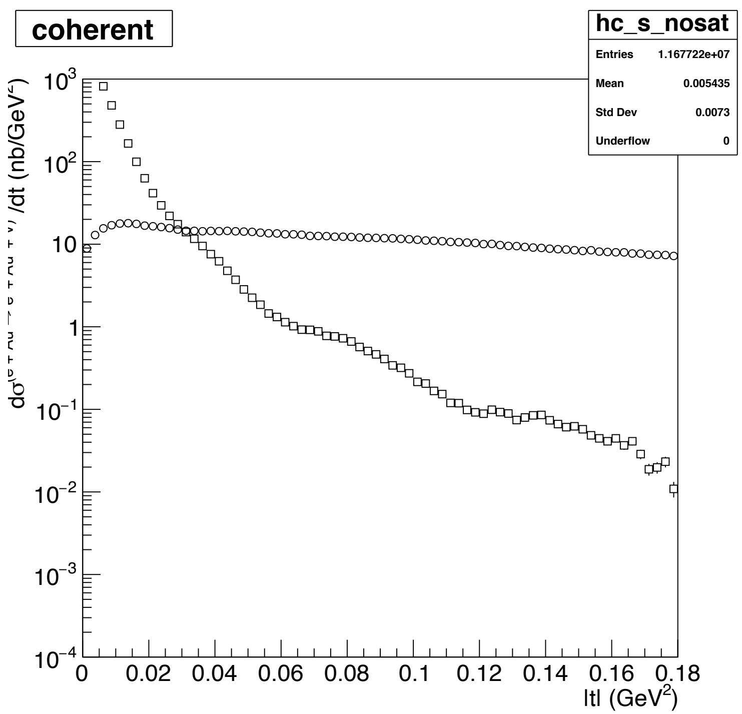
$$-3.5 < \eta < -2 \qquad |\eta| < 1.5$$

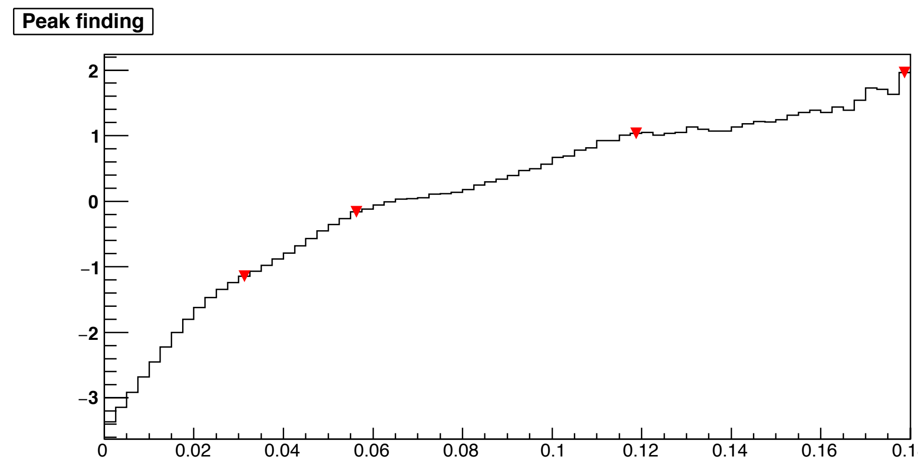
Method A: $F(b)$

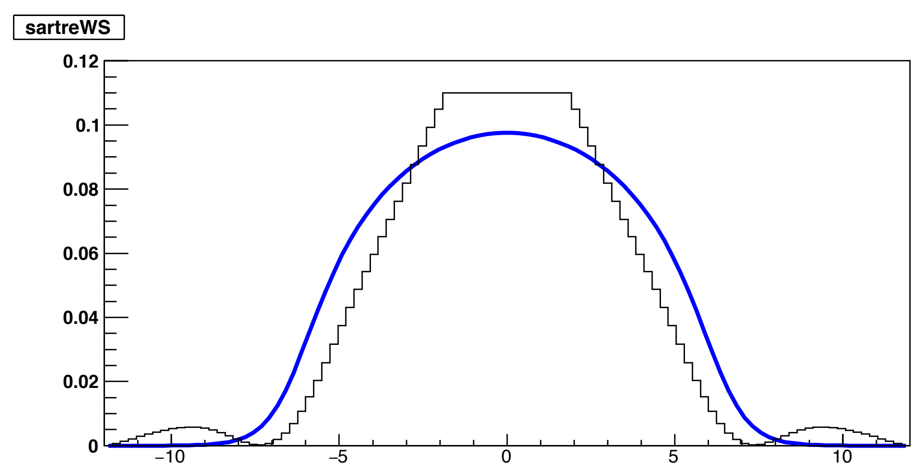
$$\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 2.0$$

- e from J/ψ p_T smearing
- $Q^2 < 0.01\ GeV^2$

Handbook value for $-3.5 < \eta < -2.5$







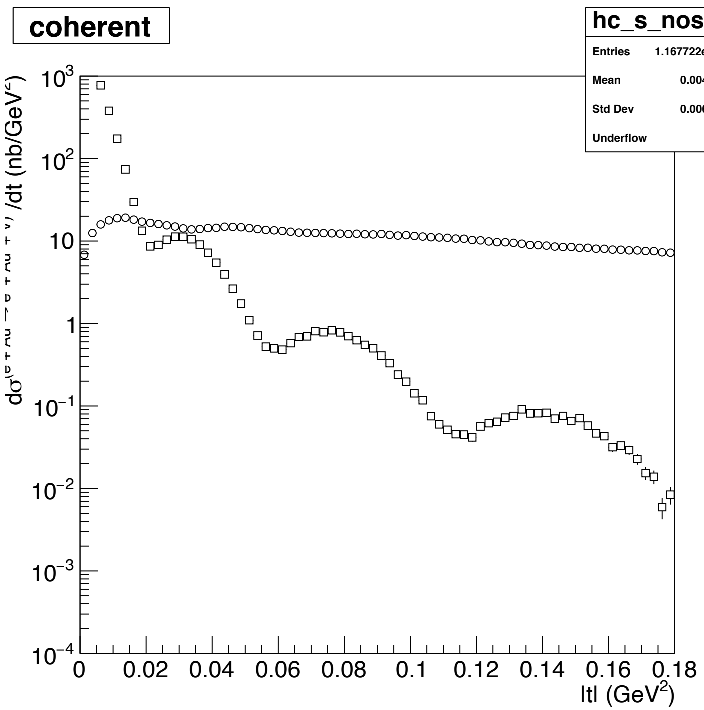
Not working

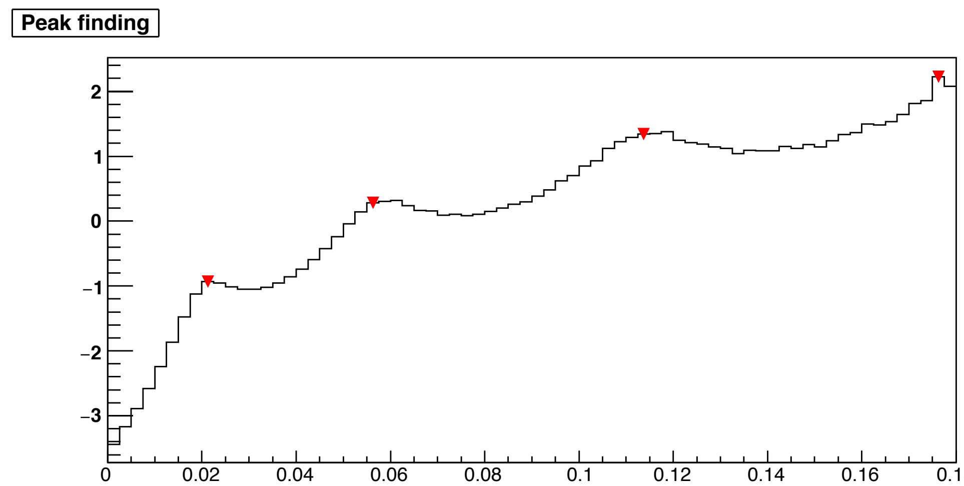
Method A: $F(b)$

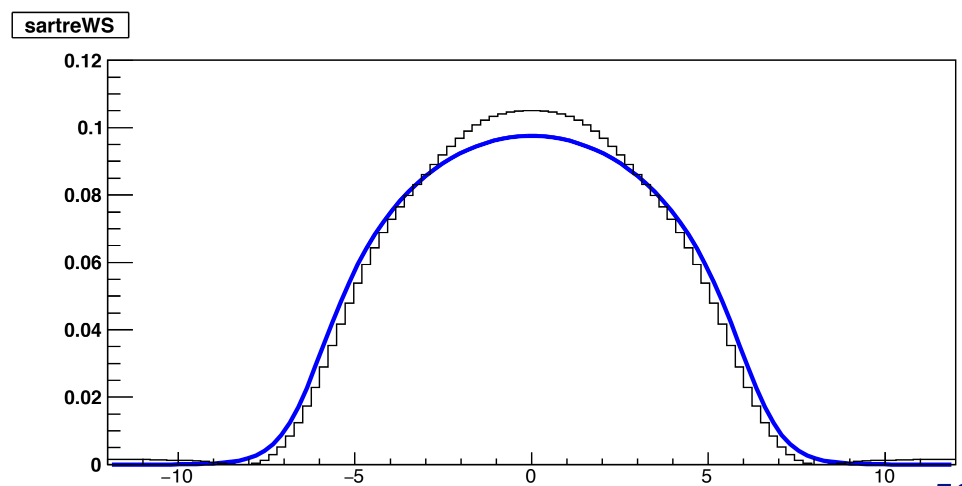
$$\frac{\sigma_{p_T}}{p_T}(\%) = 0.05\ p_T \oplus 1.0$$

Handbook value for -2.5 < η < -1.5

- e from J/ψ p_T smearing
- $Q^2 < 0.01$ GeV^2





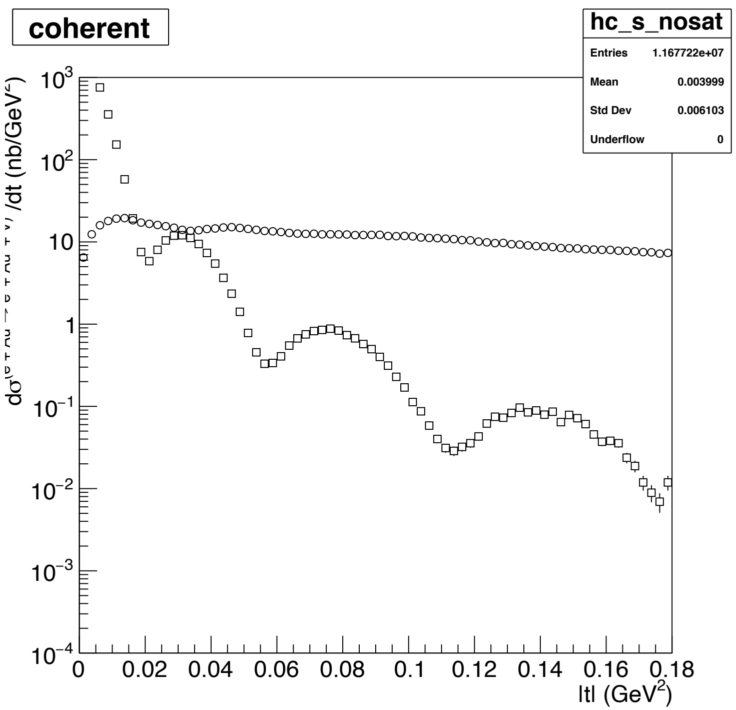


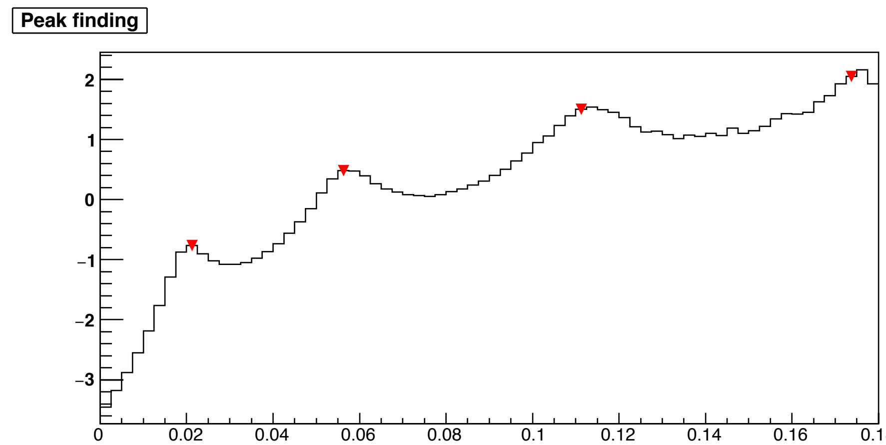
Broadening of peaks
affects extraction of shape

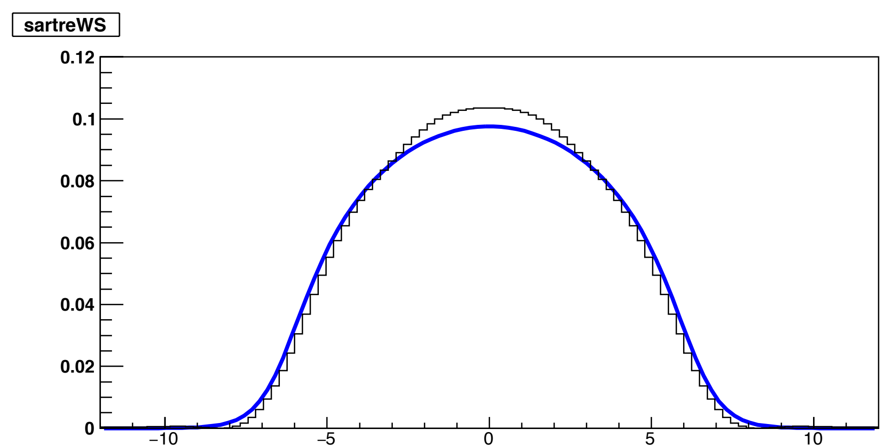
Method A: $F(b)$

$$\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 0.75$$

- e from J/ψ p_T smearing
- $Q^2 < 0.01\ GeV^2$





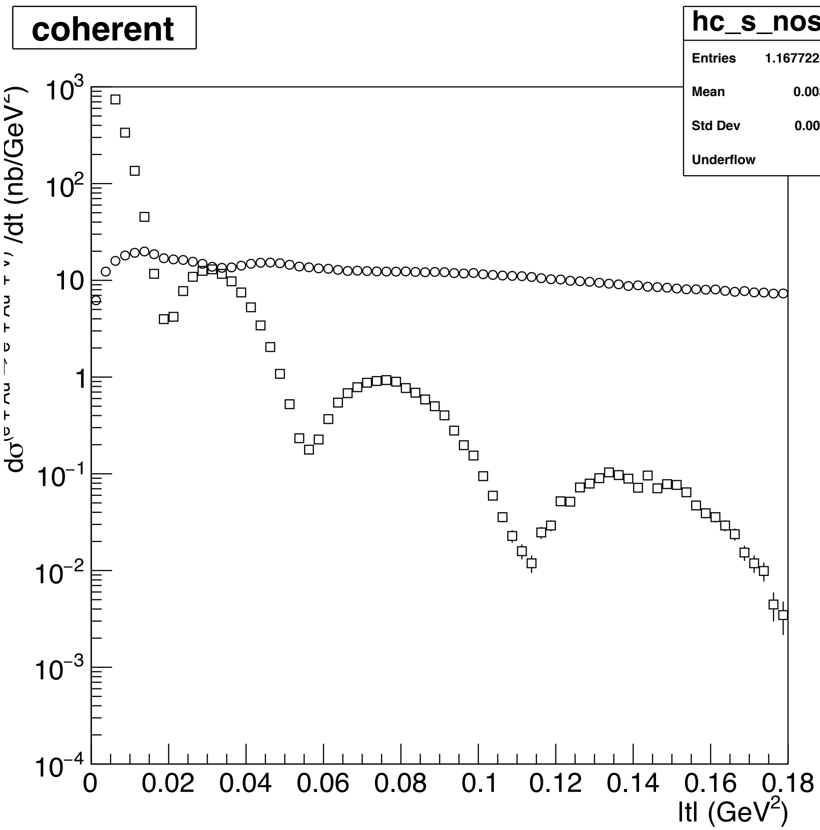


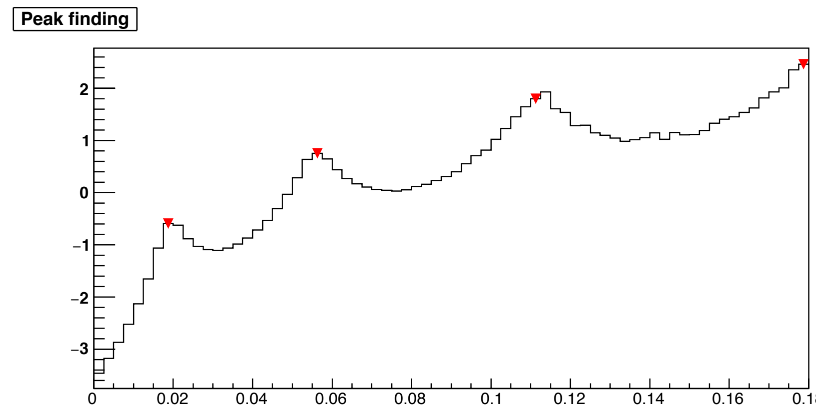
Slightly better but still not okay

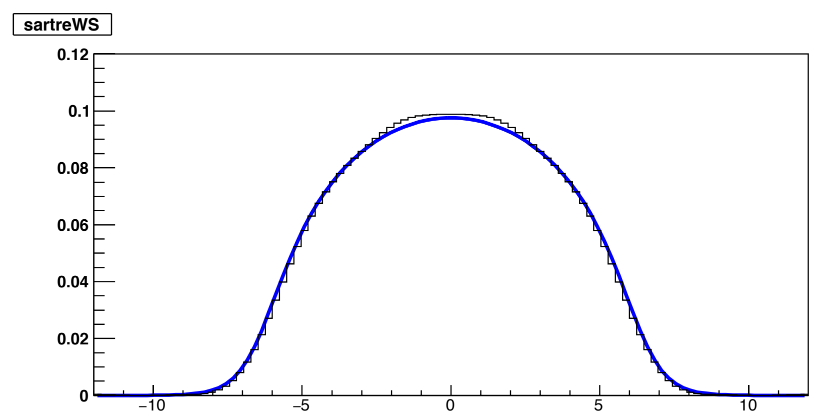
Method A: $F(b)$

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

- e from J/ψ p_T smearing
- $Q^2 < 0.01$ GeV^2







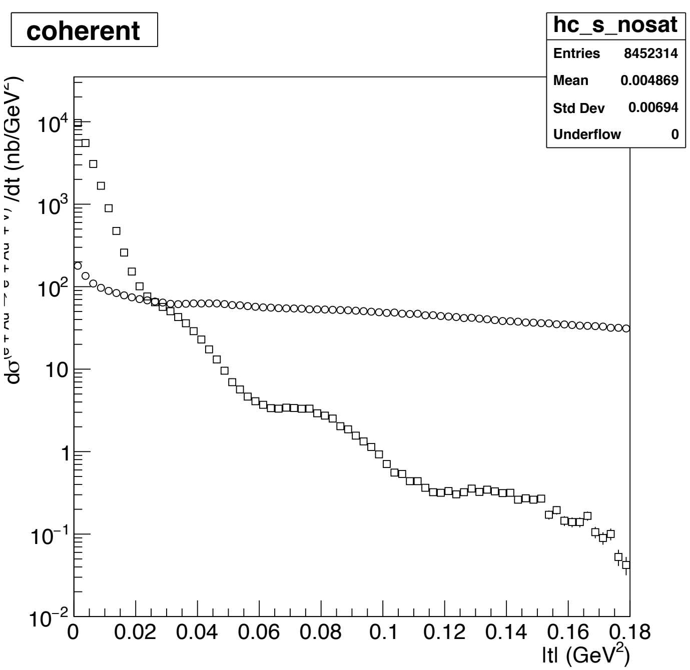
That seems to do!

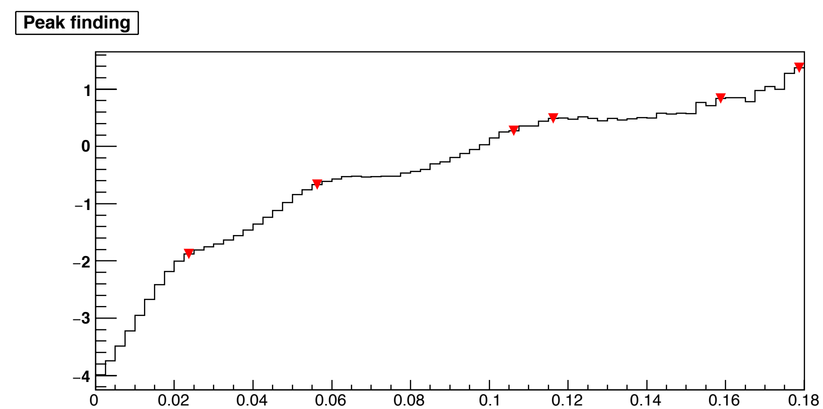
Method A: $F(b)$

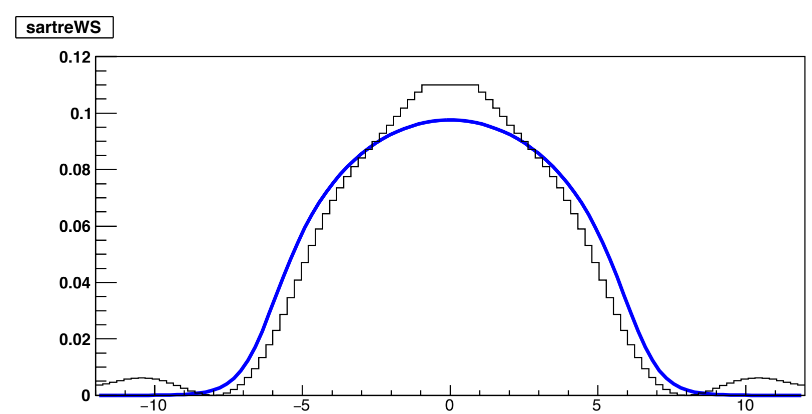
e from J/ψ: $$\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 0.5$$

scattered e': $$\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 2.0$$

- $1 < Q^2 < 10\ \mathrm{GeV}^2$







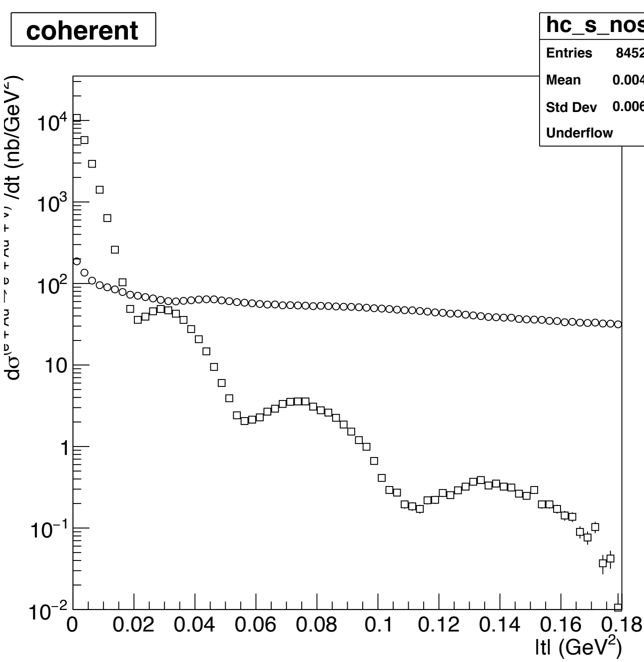
e' MS kills measurement

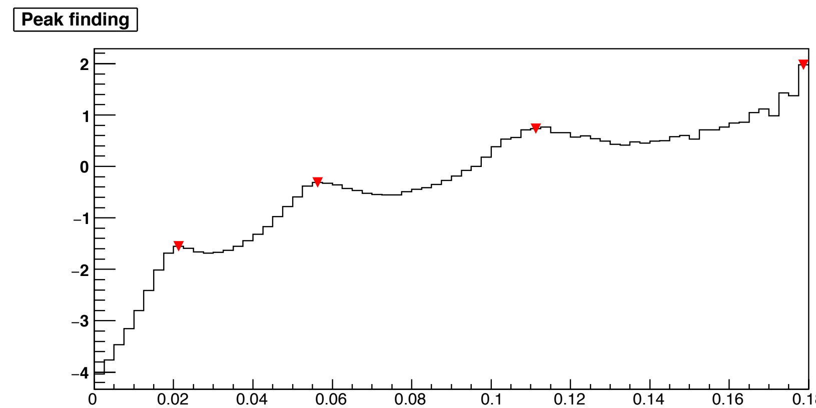
Method A: $F(b)$

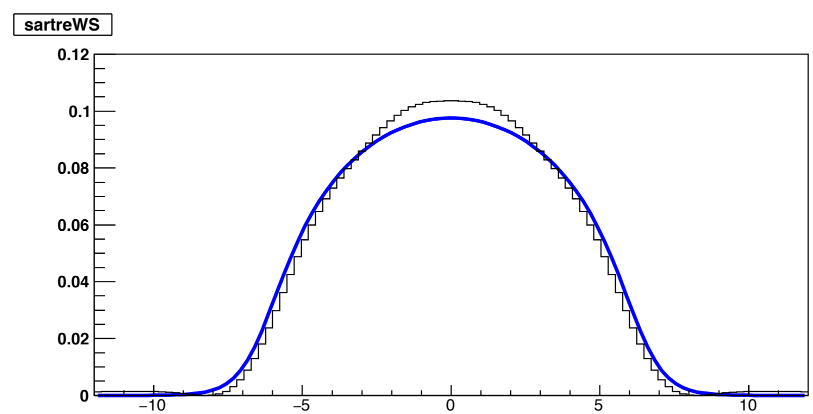
- 1 < Q^2 < 10 GeV^2

e from J/ψ: $$\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 0.5$$

scattered e': $$\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 1.0$$







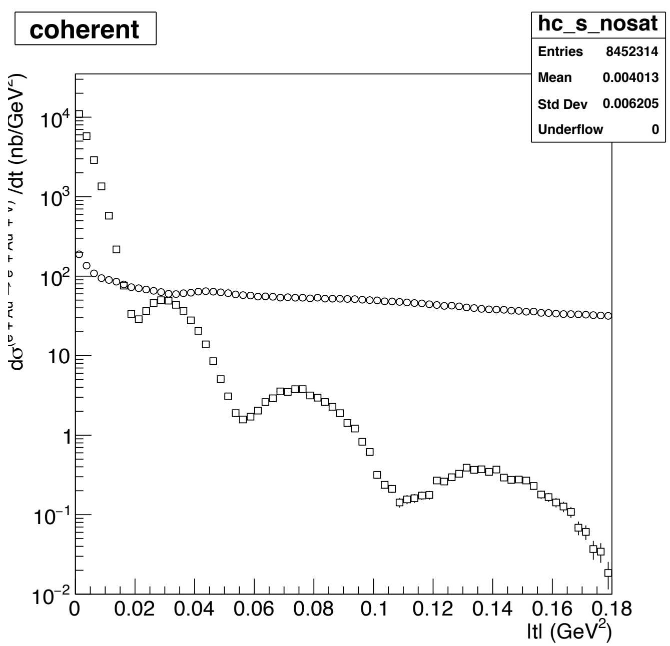
e' MS term starts to matter!

Method A: $F(b)$

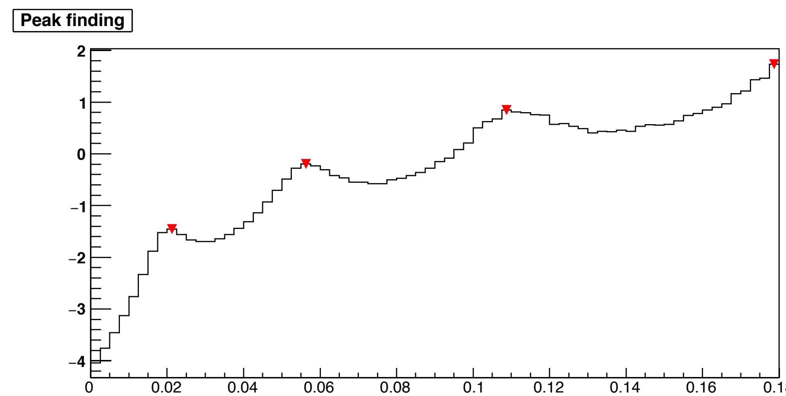
e from J/ψ: $$\frac{\sigma_{p_T}}{p_T}(\%) = 0.05\ p_T \oplus 0.5$$

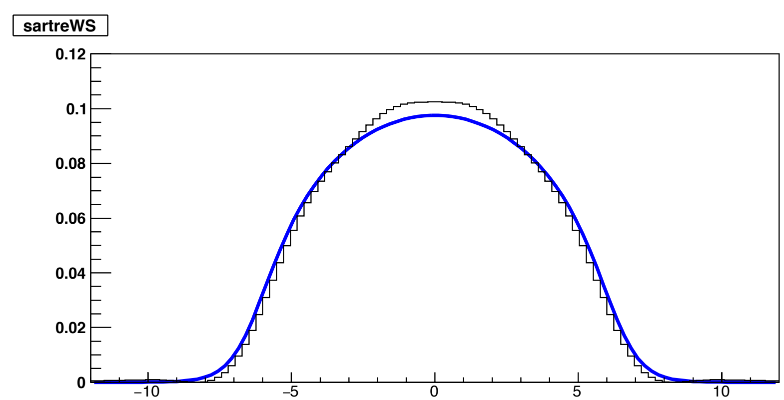
scattered e': $$\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 0.75$$

- $1 < Q^2 < 10\ \mathrm{GeV}^2$



at/over the edge



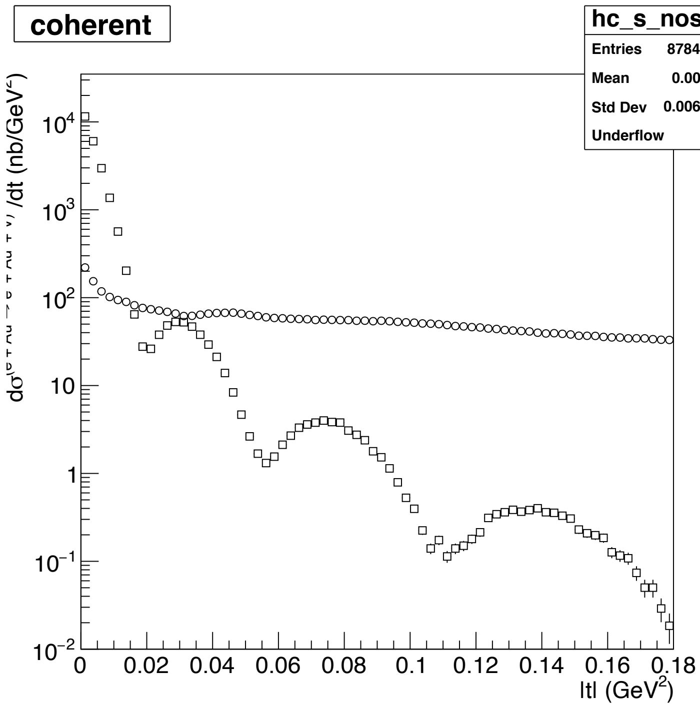


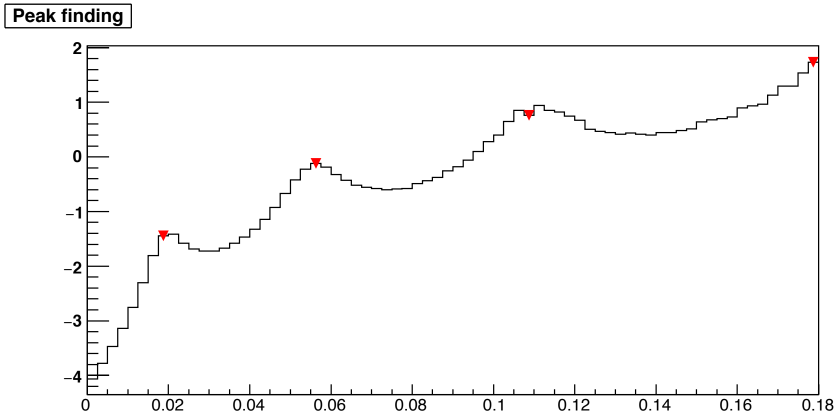
Method A: $F(b)$

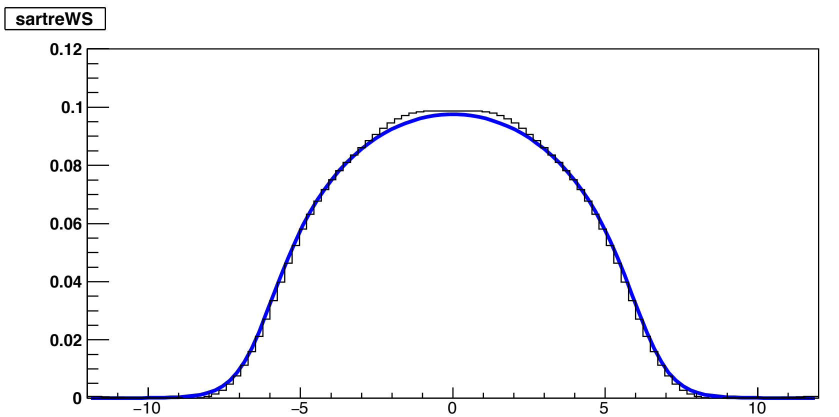
e from J/ψ: $$\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 0.5$$

scattered e': $$\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 0.5$$

- $1 < Q^2 < 10$ GeV²







That seems to do!

View Matrix | View Model | View Help | Login to Edit

η	Nomenclature			Tracking			Electrons		π/K/p		HCAL	Muons
				Resolution	Allowed X/X_0	Si-Vertex	Resolution σ_E/E	PID	p-Range (GeV/c)	Separation	Resolution σ_E/E	
-6.9 to -5.8			low-Q2 tagger	σθ/θ < 1.5%; 10-6 < Q2 < 10-2 GeV2								
...												
-4.5 to -4.0	↓ p/A	Auxiliary Detectors	Instrumentation to separate charged particles from photons									
-4.0 to -3.5							2%/√E					
-3.5 to -3.0				σ_p/p ~ 0.1%⊕0.5%								
-3.0 to -2.5												
-2.5 to -2.0			Backward Detector	σ_p/p 0.1%⊕0.5%		TBD	2%/√E		≤ 7 GeV/c		~50%/√E	
-2.0 to -1.5				σ_p/p 0.05%⊕0.5%			7%/√E					
-1.5 to -1.0							7%/√E	π suppression up to 1:10^4				
-1.0 to -0.5												
-0.5 to 0.0		Central Detector	Barrel	σ_p/p ~0.05%×p+0.5%	~5% or less X	σ_{xyz} ~ 20 μm, $d_0(z)$ ~$d_0(r\Phi)$ ~ 20/p_TGeV μm + 5 μm			≤ 5 GeV/c	≥ 3 σ		TBD
0.0 to 0.5												
0.5 to 1.0												
1.0 to 1.5									≤ 8 GeV/c			
1.5 to 2.0				σ_p/p ~0.05%×p+1.0%			(10-12)%/√E					
2.0 to 2.5			Forward Detectors			TBD			≤ 20 GeV/c		~50%/√E	
2.5 to 3.0				σ_p/p ~ 0.1%×p+2.0%								
3.0 to 3.5									≤ 45 GeV/c			
3.5 to 4.0												
4.0 to 4.5			Instrumentation to separate charged particles from photons									
...	↑ e	Auxiliary Detectors	Neutron Detection									
> 6.2			Proton Spectrometer	$\sigma_{intrinsic}(\lvert t\rvert)/\lvert t\rvert$ < 1%; Acceptance: 0.2 < p_t < 1.2 GeV/c								

https://physdiv.jlab.org/DetectorMatrix/

$$e + A \rightarrow e' + A' + \phi$$

Studies

m_ϕ = 1019.461 ± 0.016 MeV

m_K = 493.677 ± 0.016 MeV

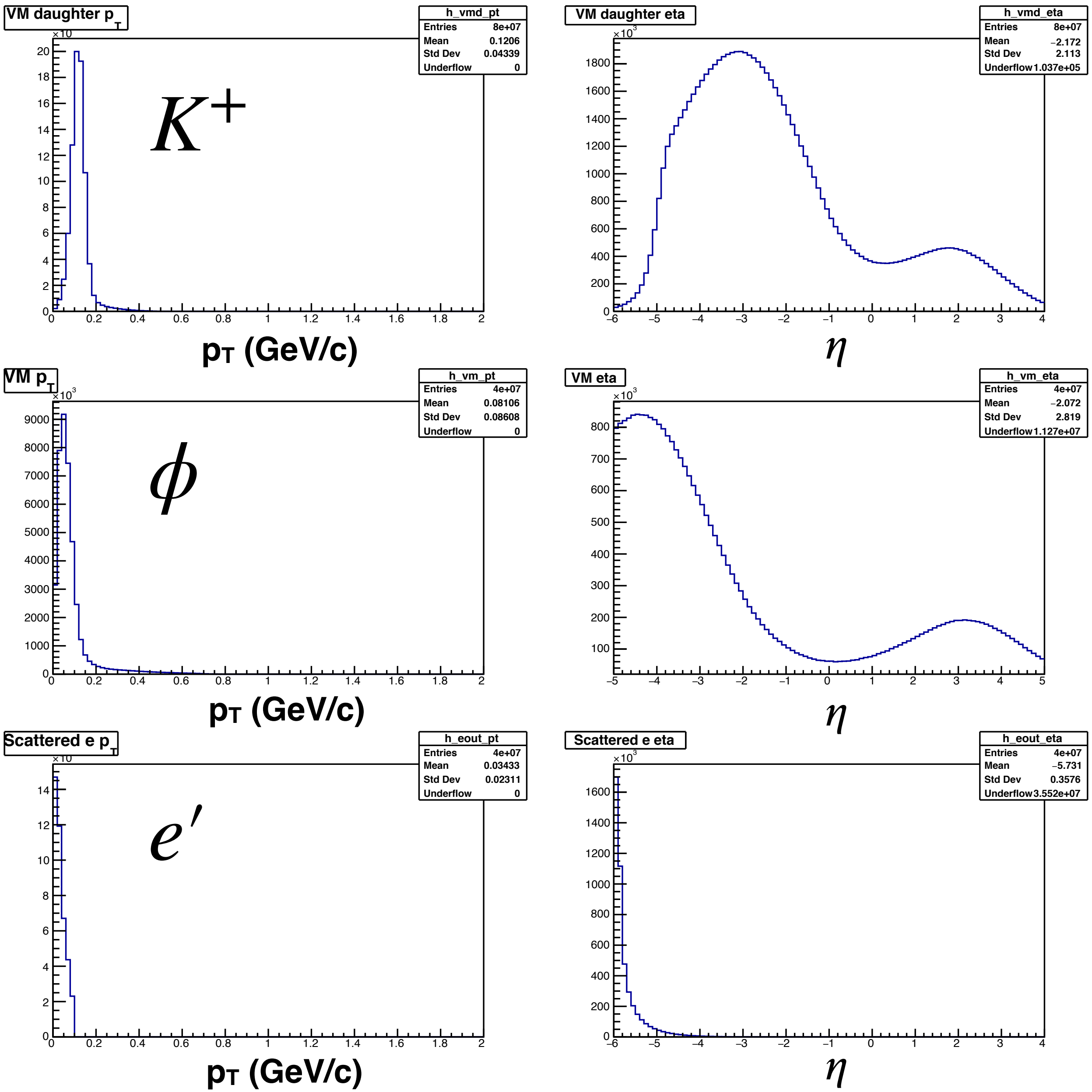
m_ϕ - 2 × m_K = 32.107 MeV

BR(KK) = 49.2 ± 0.5 %

BR(ee) = 2.973 × 10^{-4}

BR($\mu\mu$) = 2.86 × 10^{-4}

Kinematics: Photoproduction $Q^2 < 0.01$

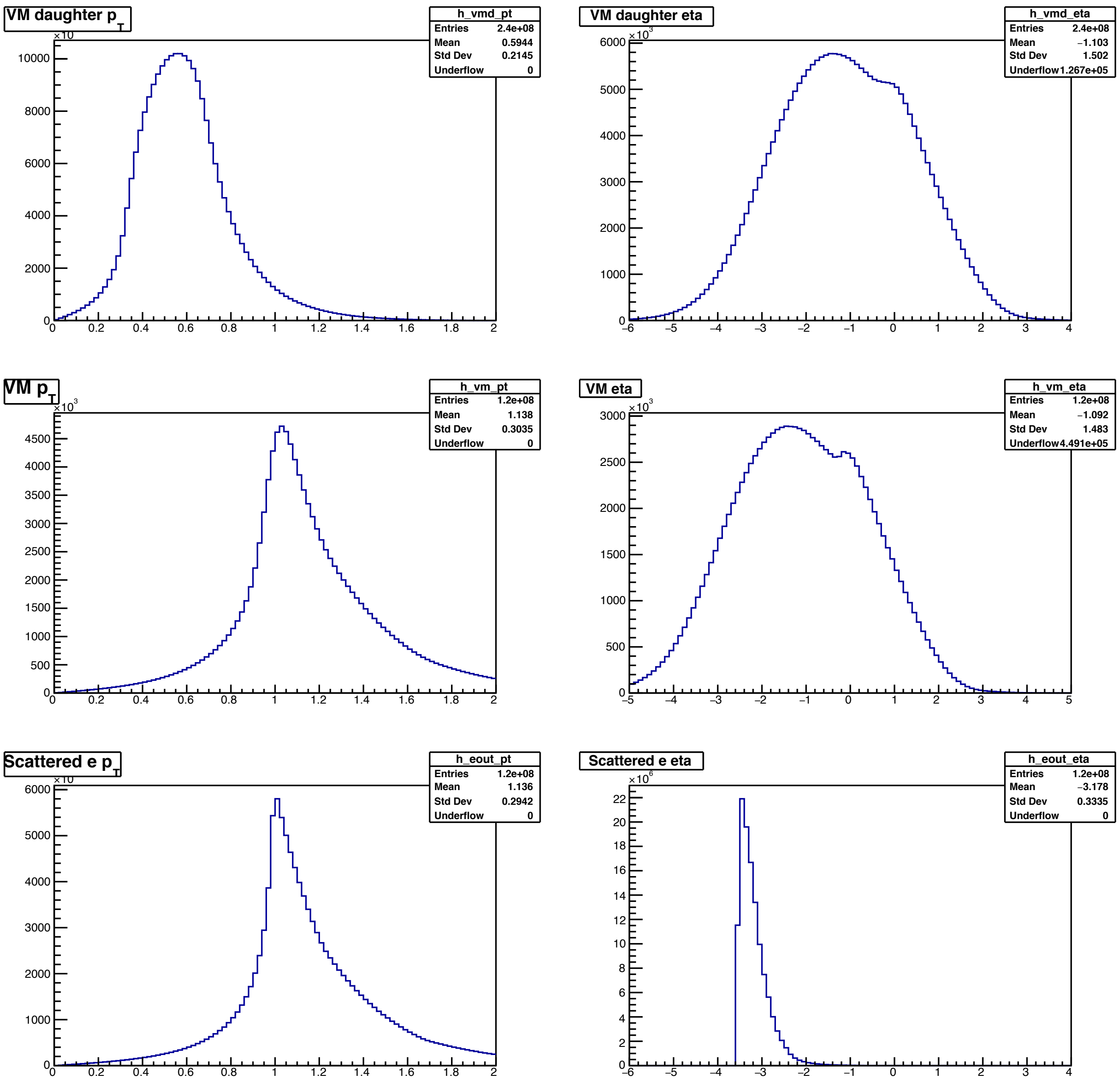


As expected the p_T of the decay kaons is so small that they likely would fall below the tracking threshold (also never reach any PI detector)

BR(*KK*)/BR(*ee*) = 1655

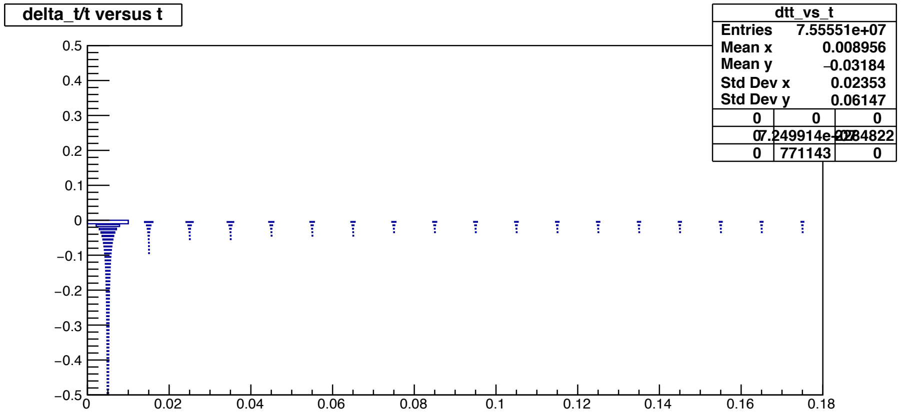
Going to *ee* we lose 3 orders of magnitude compared to *KK*

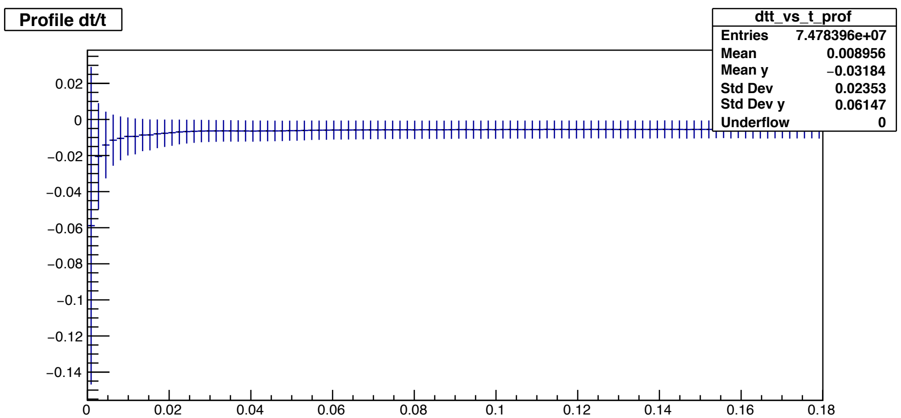
Kinematics: $1 < Q^2 < 10$

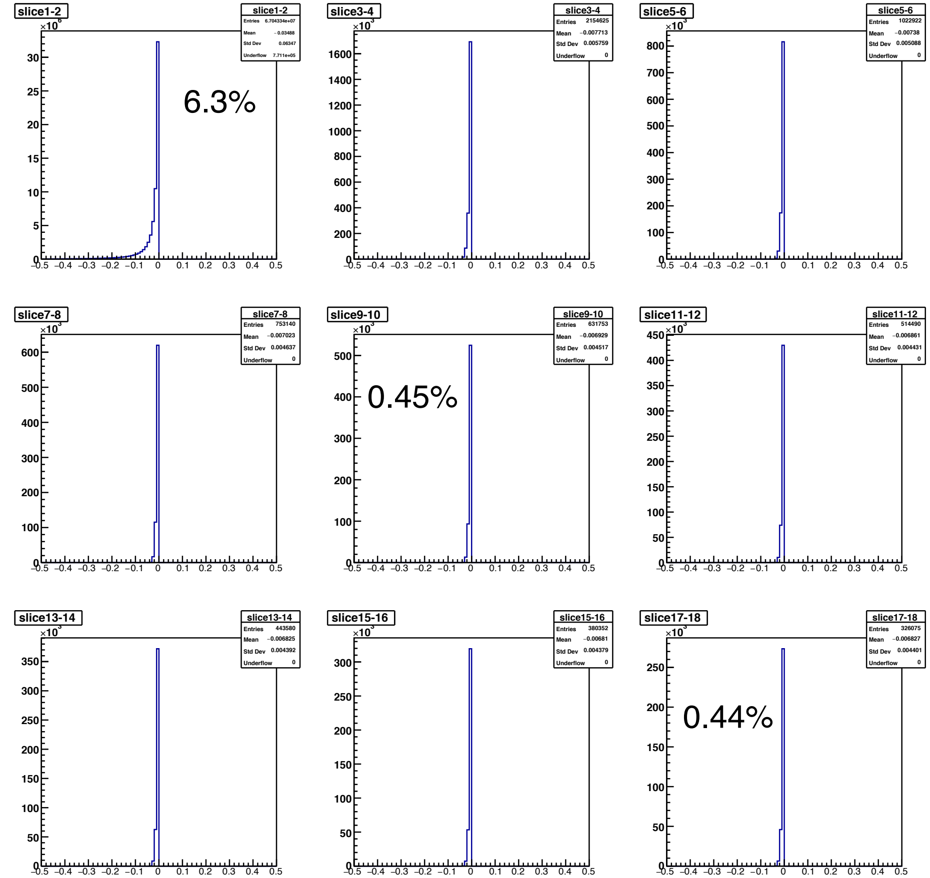


- For larger Q^2 things look much better.
- $p_T^K \sim 0.3 - 2$ GeV/c
- Wide rapidity range $-3.5 < \eta_K < 2$
- Barrel fully covered but stats can be increased by going wider
- e' very much like for J/ψ, $-3.5 < \eta_{e'} < -2$

Method A - no smearing







Same issue as with J/ψ. Method A underestimates t.

However, offset is much smaller than for the J/ψ.

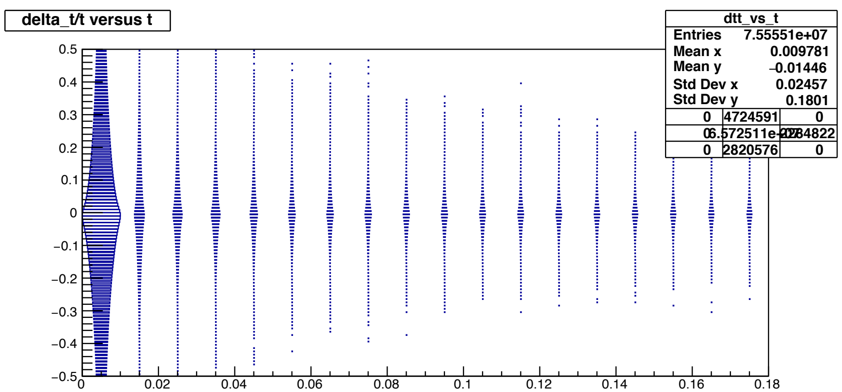
Almost irrelevant.

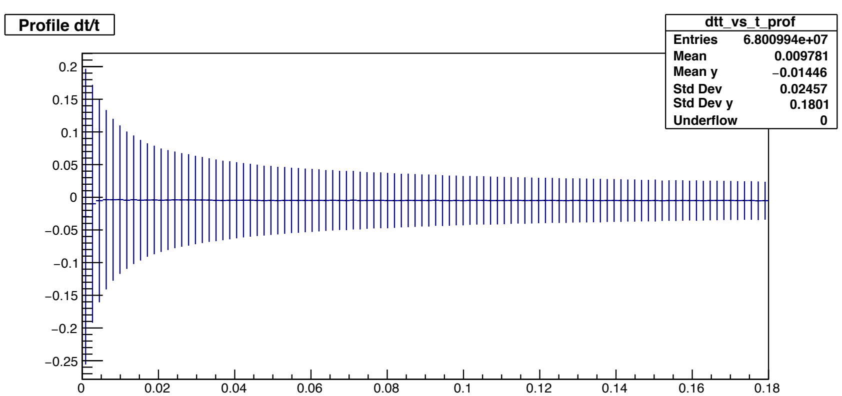
Method A: $F(b)$ extraction (I)

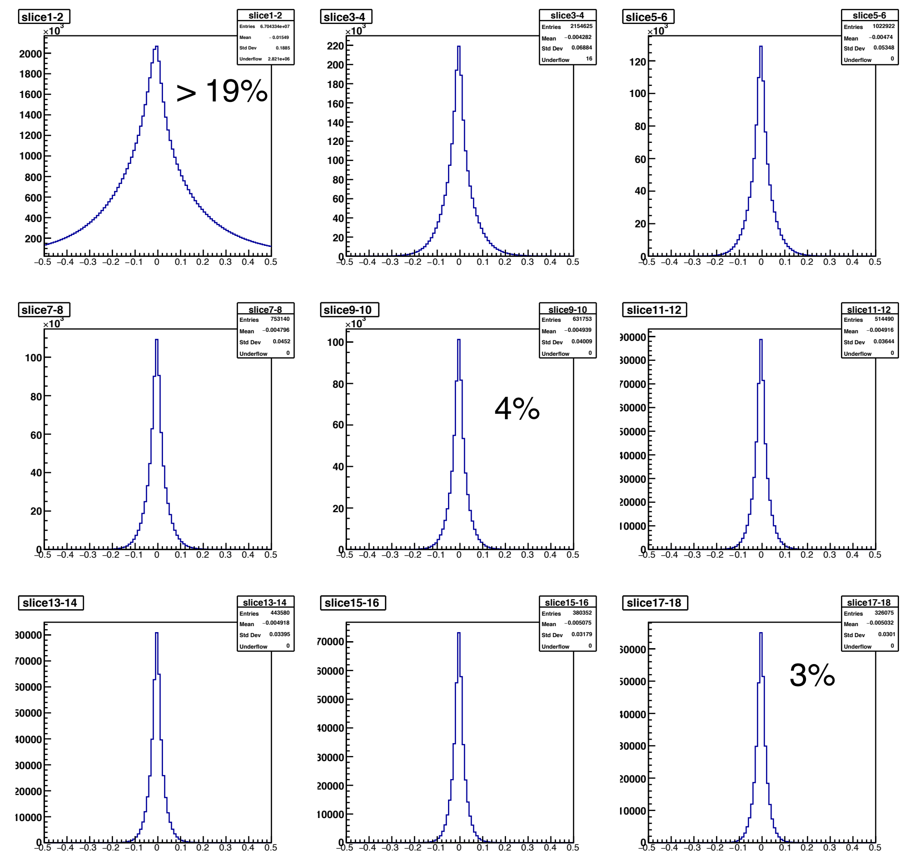
K from ϕ: $$\frac{\sigma_{p_T}}{p_T}(\,\%\,) = 0.05\ p_T \oplus 0.5$$

scattered e': $$\frac{\sigma_{p_T}}{p_T}(\,\%\,) = 0.1\ p_T \oplus 0.5$$

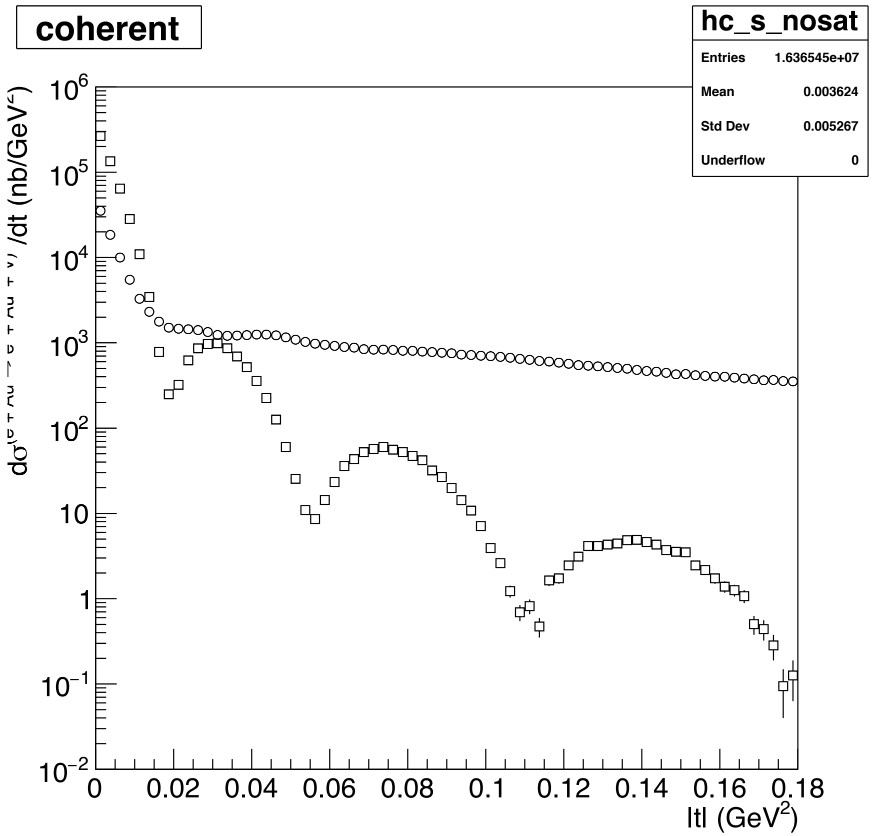
Parameters from https://physdiv.jlab.org/DetectorMatrix/ as of Mar 25, 2020

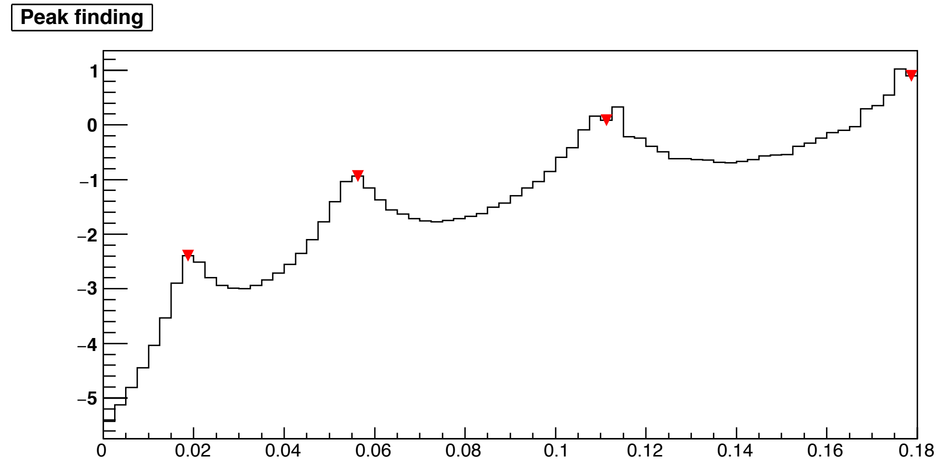


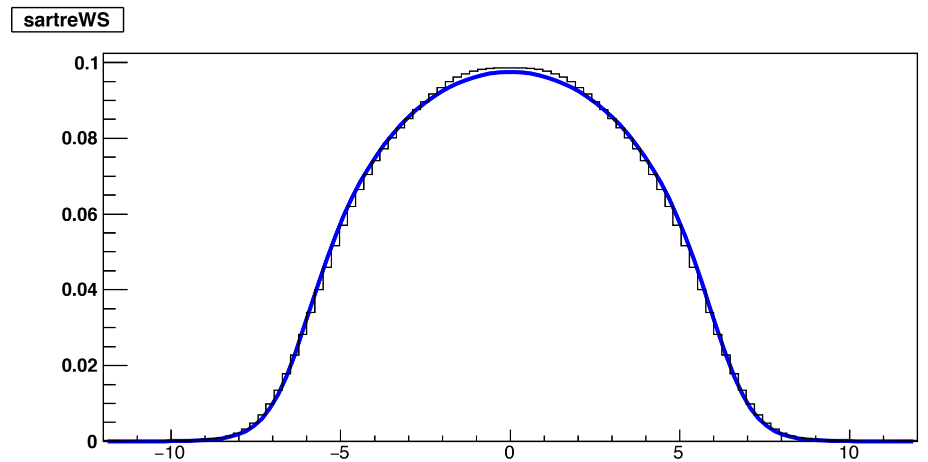




Method A: $F(b)$ extraction (II)





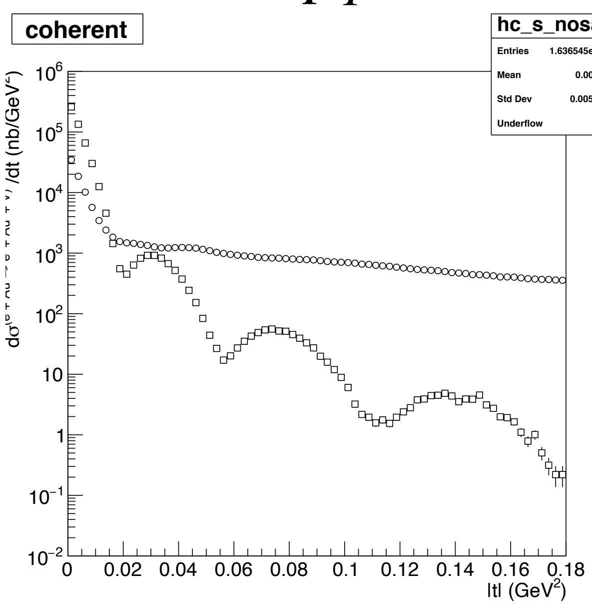


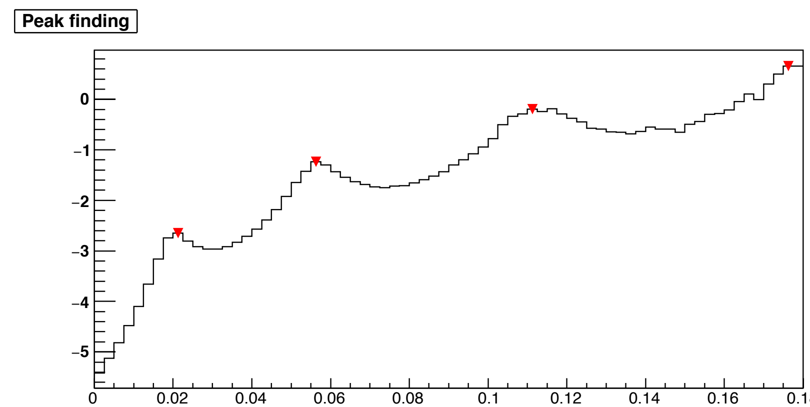
- Looks good - so far seems ϕ will not supersede any J/ψ results - see how much one can relax requirements.

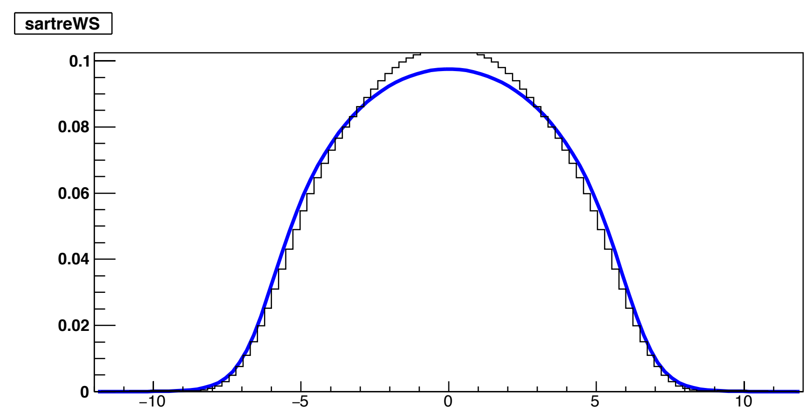
Method A: $F(b)$ extraction

K from ϕ: $$\frac{\sigma_{p_T}}{p_T}(\,\%\,) = 0.05\;p_T \oplus 0.5$$

scattered e': $$\frac{\sigma_{p_T}}{p_T}(\,\%\,) = 0.1\;p_T \oplus 1.0$$







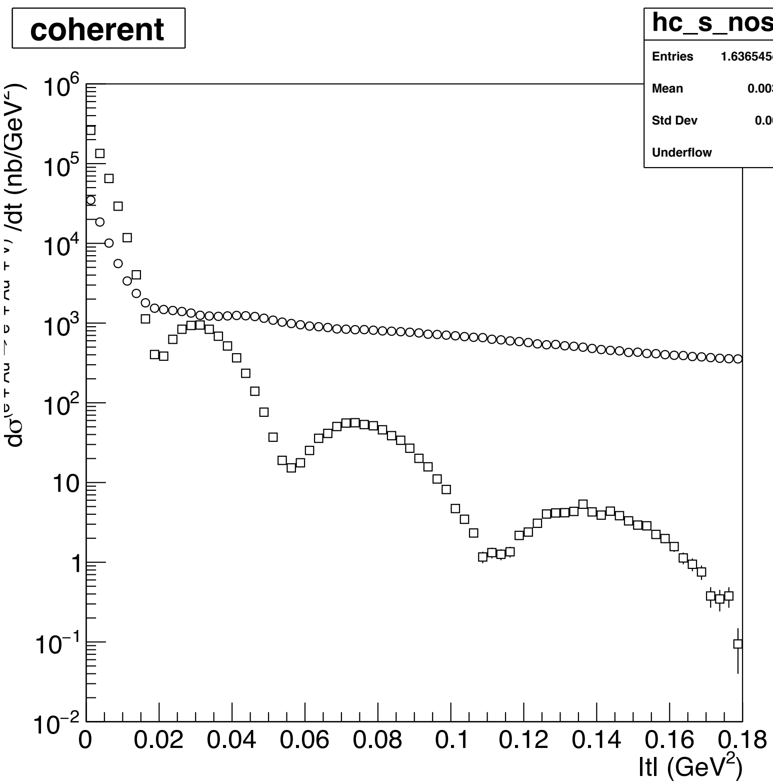
- Nope as for J/ψ. e' needs 0.5 MS term

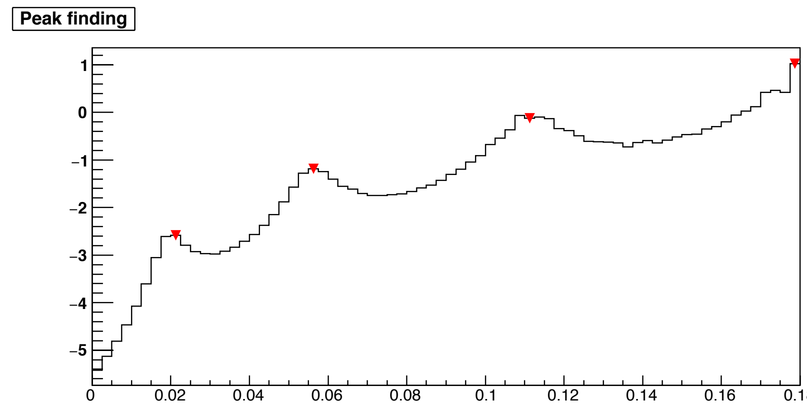
Method A: $F(b)$ extraction (I)

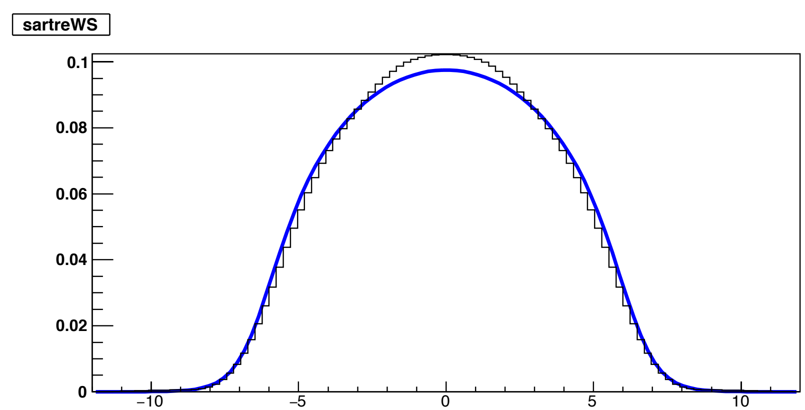
K from ϕ: $$\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 1.0$$

scattered e': $$\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 0.5$$

- More or less as for J/ψ. Cannot deviate much from J/ψ constraints.







Saving Photoproduction (I)

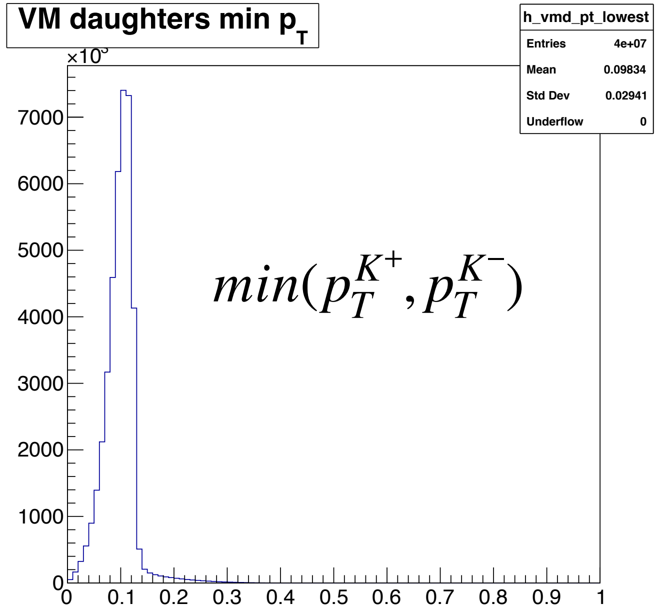
Assume we could decrease B so we could track 100 MeV/c kaons (just hypothetically…).

- Note that p_T resolution ~ 1/B
- Sims: p_T > 0.1 GeV and desired resolution * 1/3

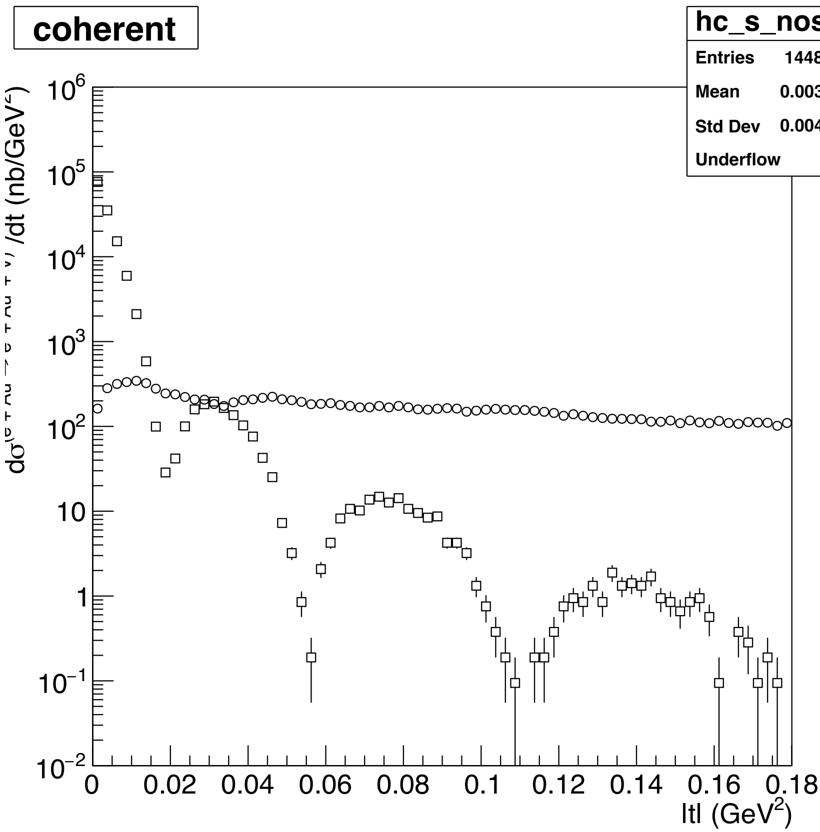
K from ϕ: $$\frac{\sigma_{p_T}}{p_T}(\%) = 0.05 \times 3 \; p_T \oplus 0.5 \times 3$$

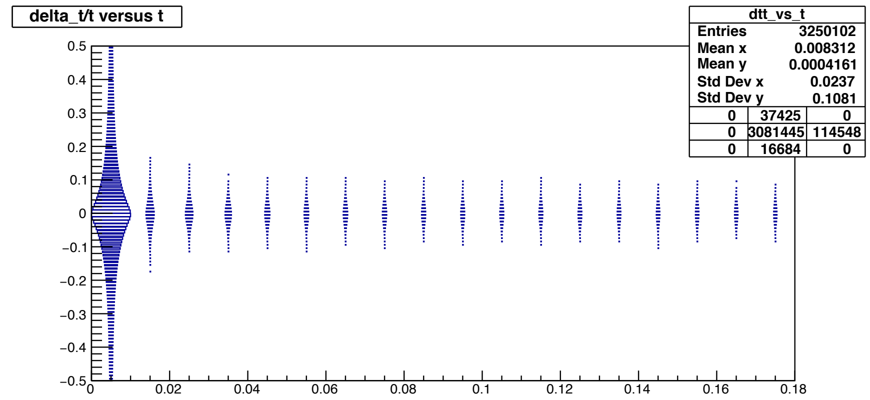
Recall that the scattered e' doesn't matter in photo production

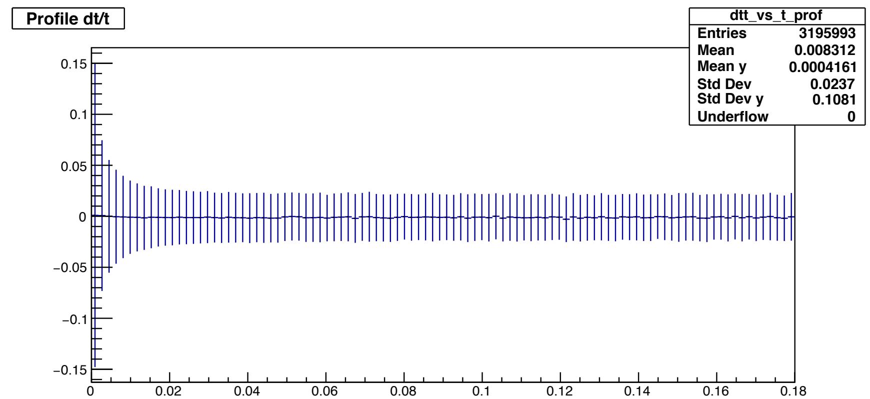
Also p_T of kaons is so low that precision term is negligible



Saving Photoproduction (II)







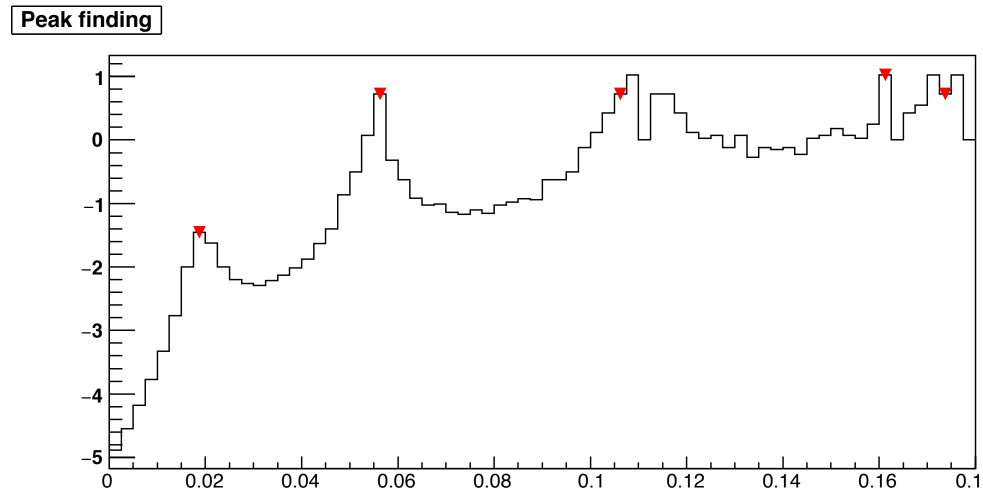
Looks good. Recall that method A is more precise in photo production.

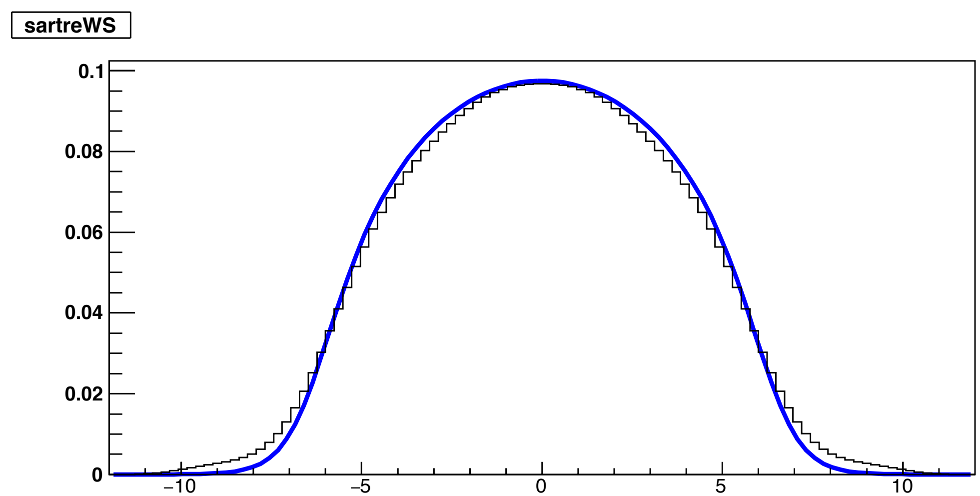
Saving Photoproduction (III)

Seems to work

- method A more precise
- precision term ~ 0
- e' uncertainty gone

What about relaxing the p_T cut a bit and say $p_T >$ 0.2 GeV?

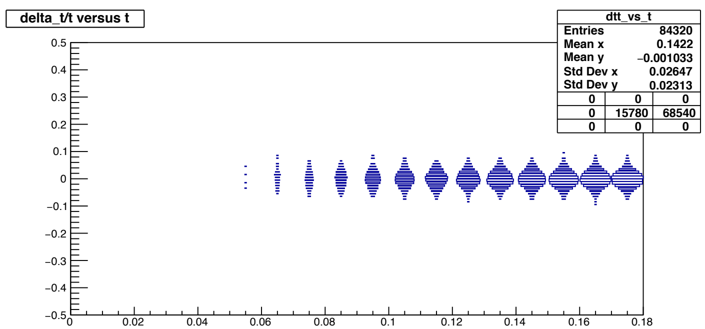


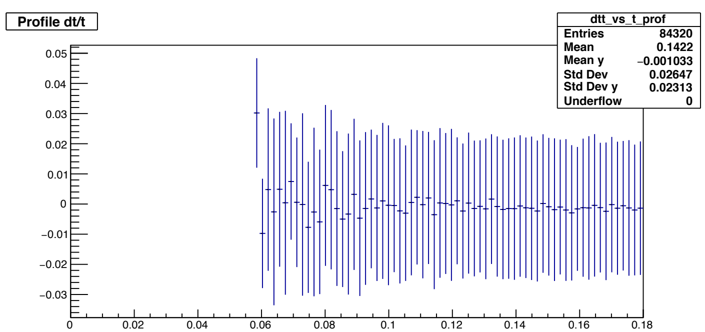


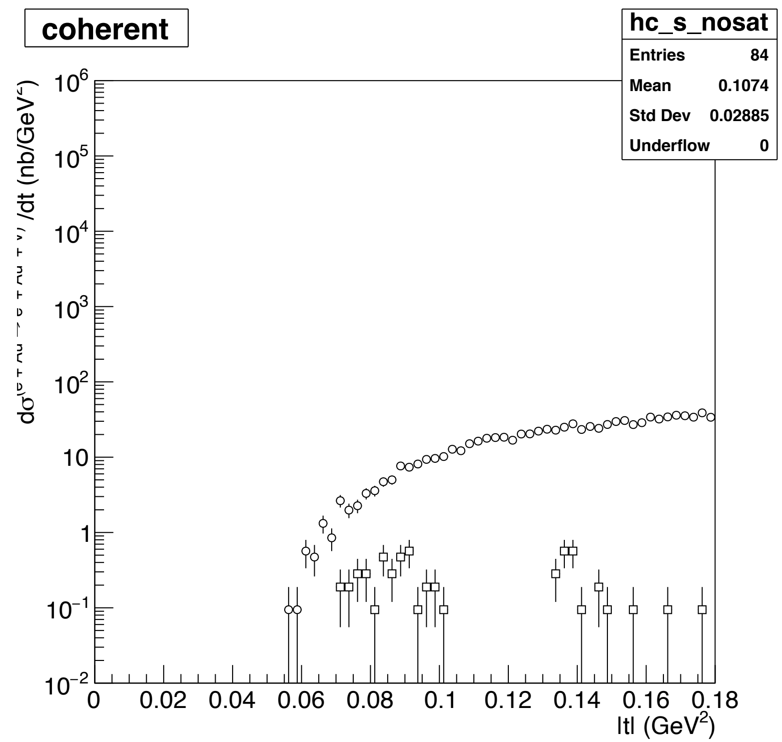
Saving Photoproduction (IV)

- Sims: p_T > 0.2 GeV and desired resolution * 1/3

K from ϕ: $$\frac{\sigma_{p_T}}{p_T}(\,\%\,) = 0.05 \times 3\ p_T \oplus 0.5 \times 3$$







Nope. Cuts away low *t* and kills measurement

Photoproduction $e + A \rightarrow e' + A' + \phi$

A measurement on the edge

$\phi \rightarrow KK$: only if we can set the B field low enough to track down to 100 MeV/c and be a bit relaxed what we call "photoproduction" (here we used $Q^2 < 0.01$ GeV^2). Already 200 MeV/c is too large of a cut. We can take the hit in the deterioration of the tracking precision. This looks like a neat special run a couple of years into the program.

Is this a detector constraint one should put forward?

$\phi \rightarrow \ell\ell$: factor 1600 smaler BR. Even with the greater luminosity and a long EIC lifetime this seems a stretch

$$e + A \rightarrow e' + A' + \rho$$

Studies

m_ρ = 775.49 MeV

m_π = 139.57 MeV

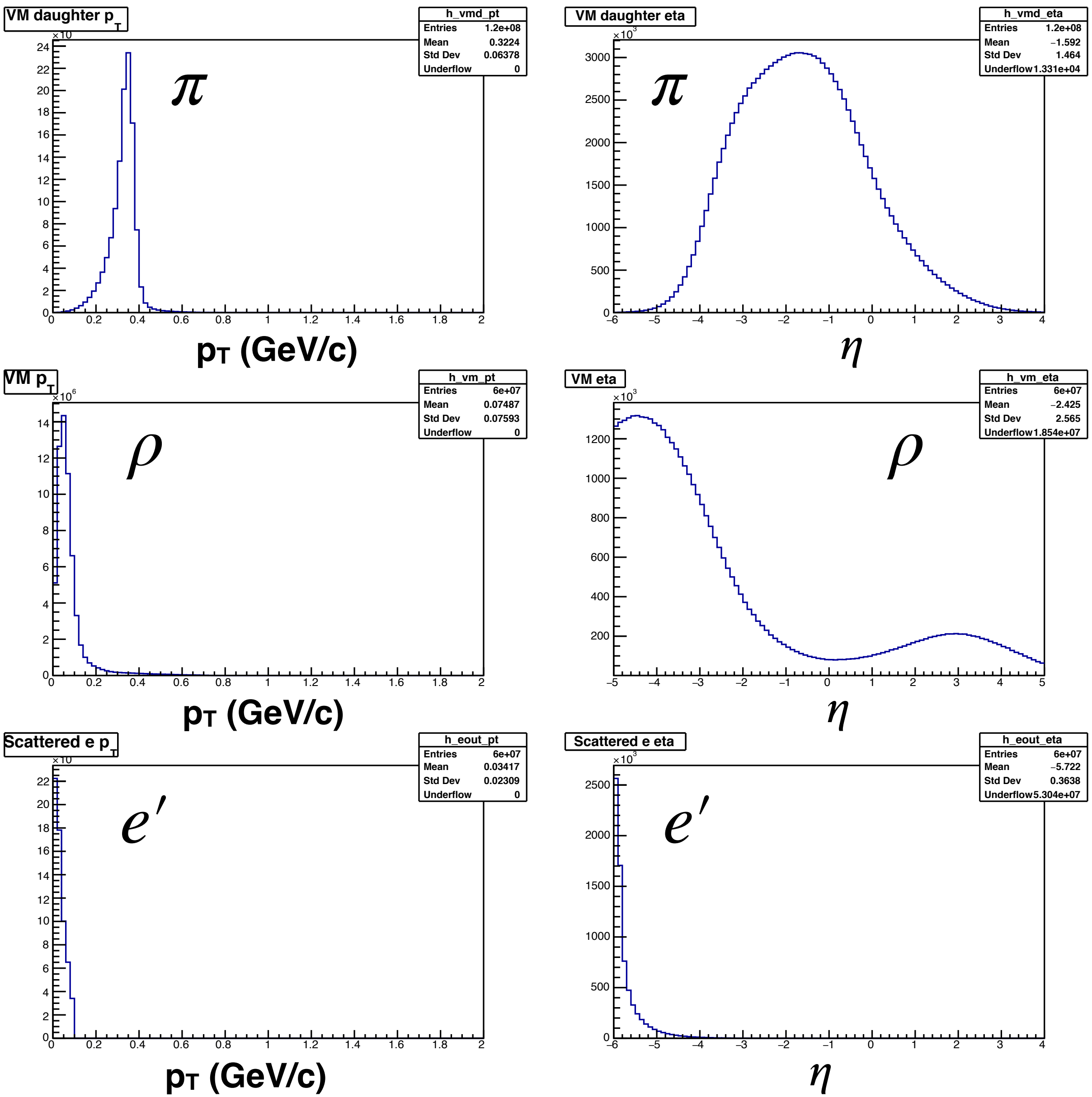
m_ρ - 2 × m_π = 496.35 MeV

BR($\pi\pi$) = ~100%

BR(ee) = 4.72 × 10^{-5}

BR($\mu\mu$) = 4.55 × 10^{-5}

Kinematics: Photoproduction $Q^2 < 0.01$



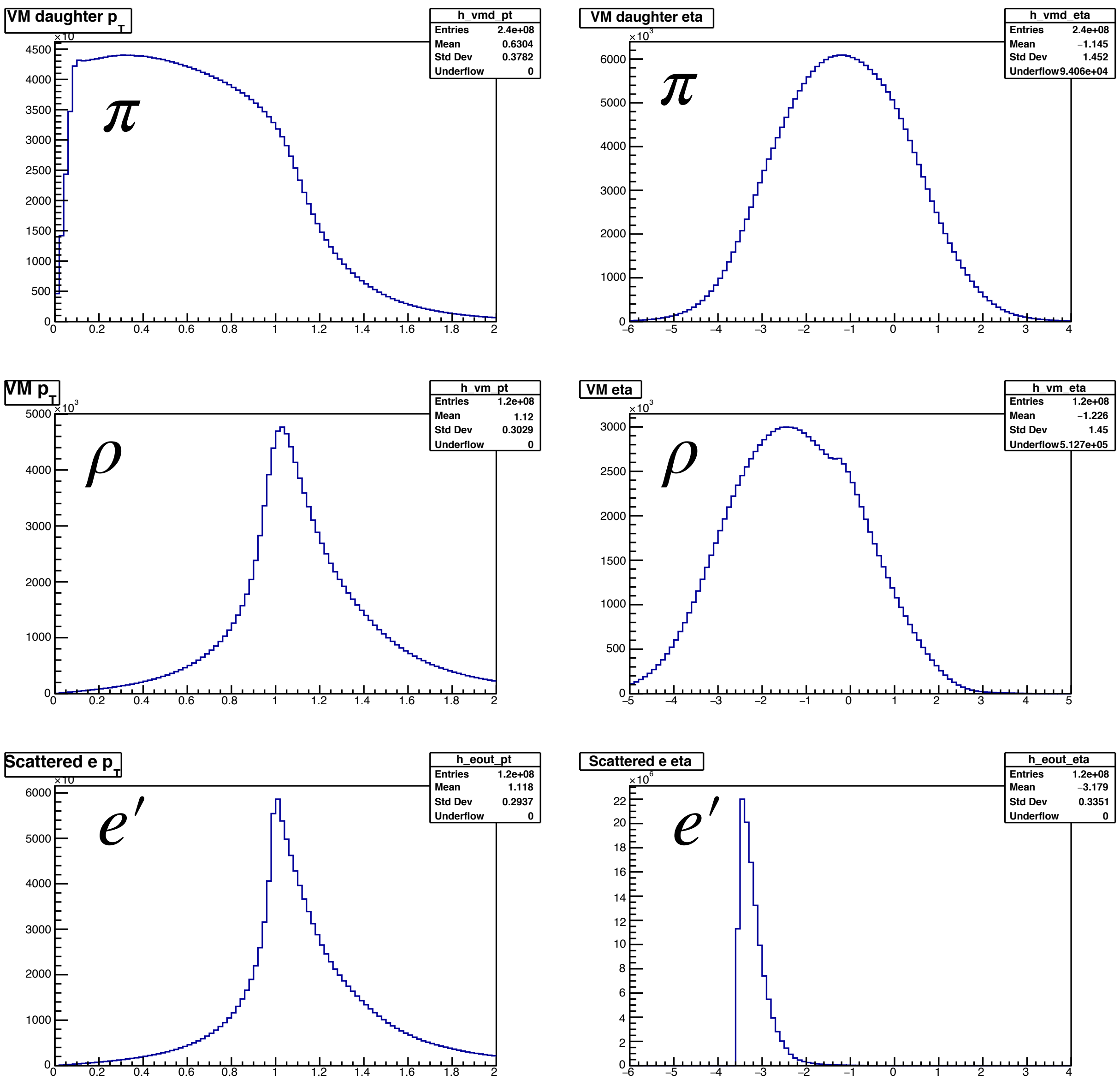
As expected the p_T of the decay pions is not large: 0.2-0.4 GeV. Depending on field this is likely also at the edge.

Other than for J/psi there's some yield at mid-rapidity.

BR($\pi\pi$)/BR(ee) = 21,276

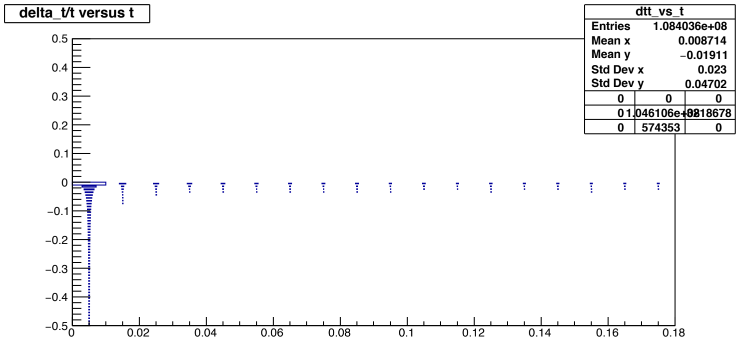
Going to ee we lose 4 orders of magnitude compared to $\pi\pi$

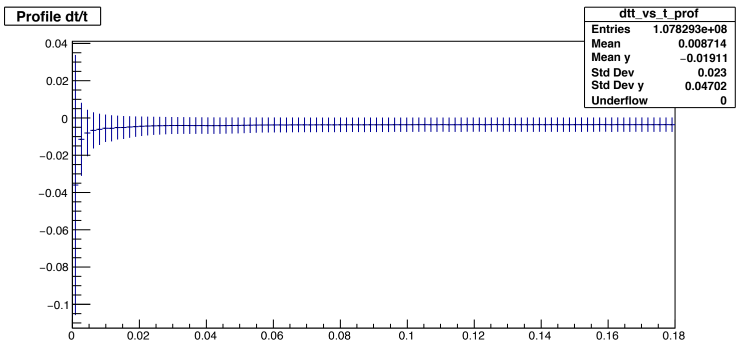
Kinematics: $1 < Q^2 < 10$



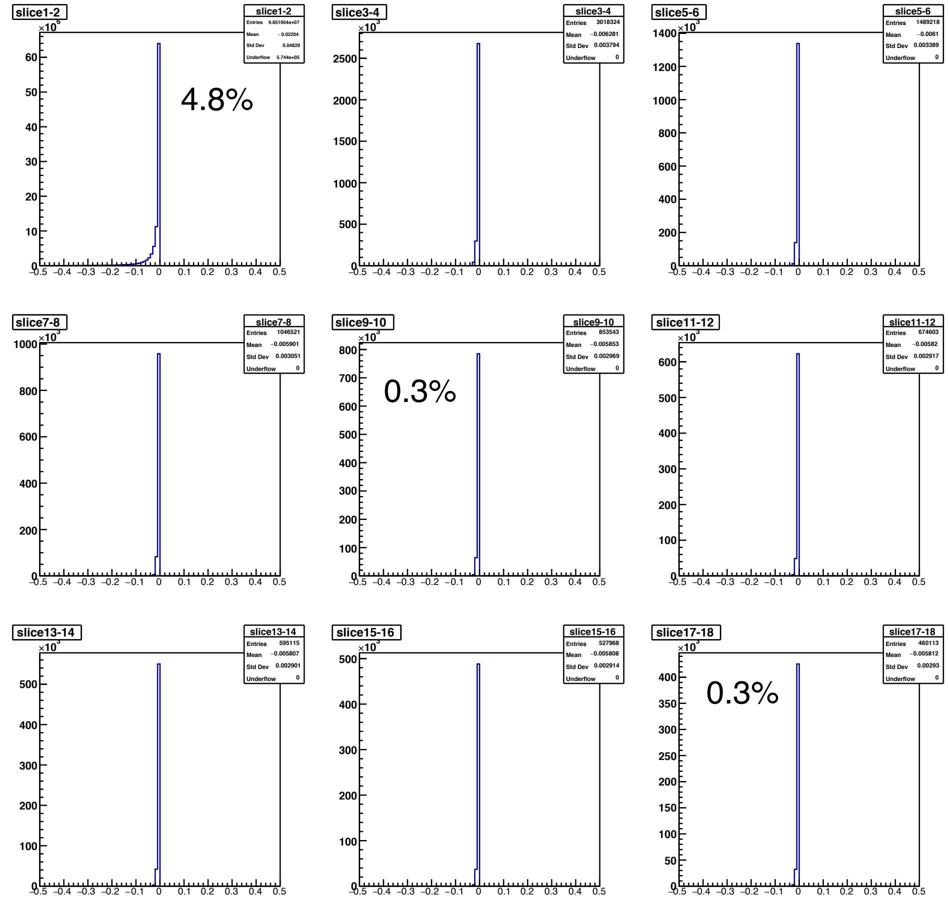
- As always for larger Q^2 things look much better.
- $p_T^\pi \sim 0.2 - 1.6\ \mathrm{GeV}/c$
- Wide rapidity range $-4 < \eta_\pi < 3$
- Barrel fully covered but stats can be increased by going wider
- e' very much like for J/ψ, $-3.5 < \eta_{e'} < -2$

Method A - no smearing





$$1 < Q^2 < 10 \text{ GeV}^2$$



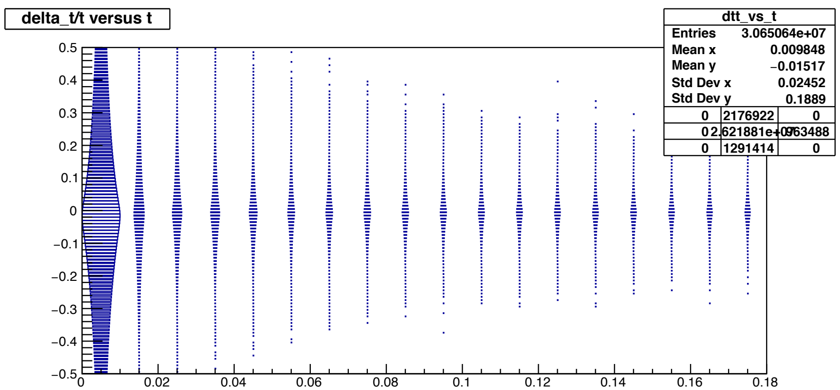
- Trend observed in ϕ continues: Method A becomes more accurate for lower mass vector mesons

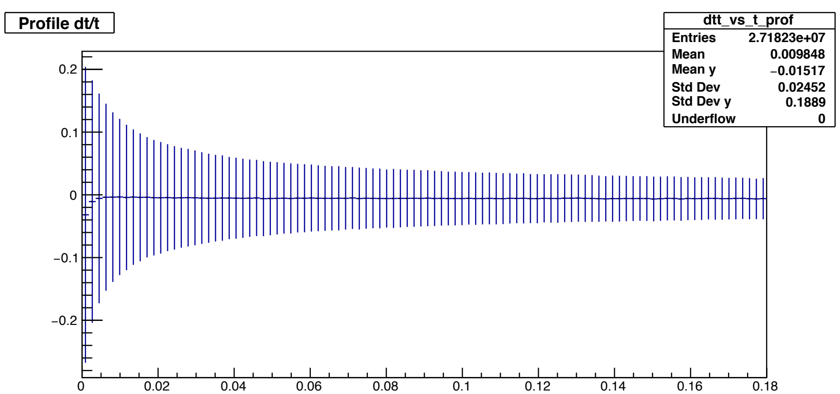
Method A: $F(b)$ extraction (I)

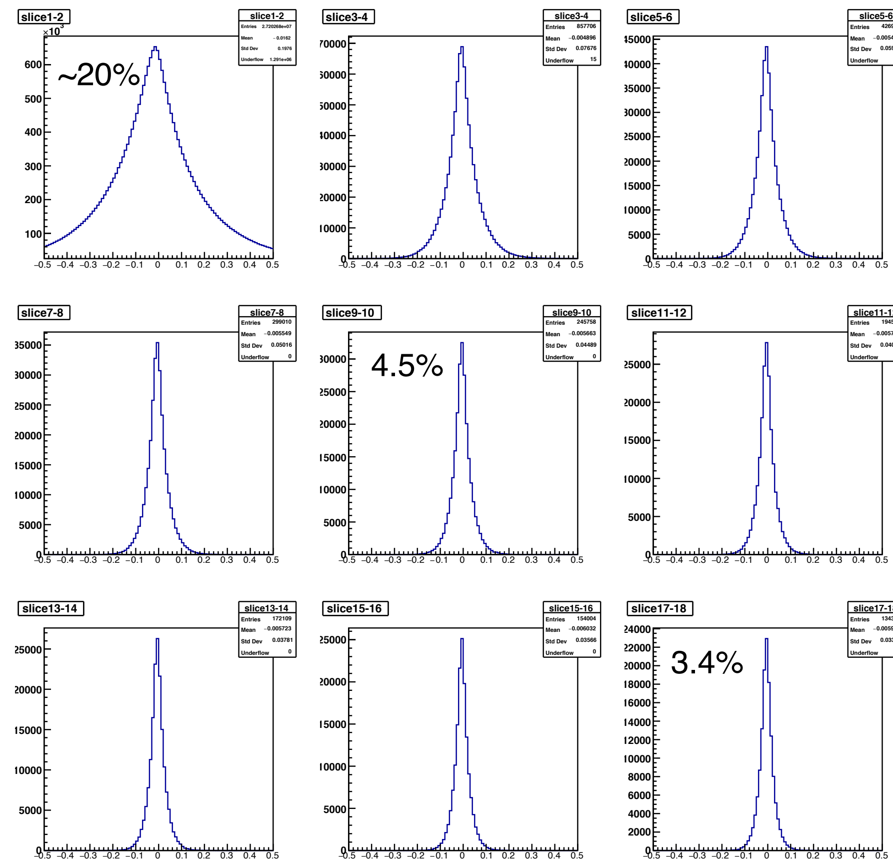
π from ρ: $$\frac{\sigma_{p_T}}{p_T}(\,\%\,) = 0.05\ p_T \oplus 0.5$$

scattered e': $$\frac{\sigma_{p_T}}{p_T}(\,\%\,) = 0.1\ p_T \oplus 0.5$$

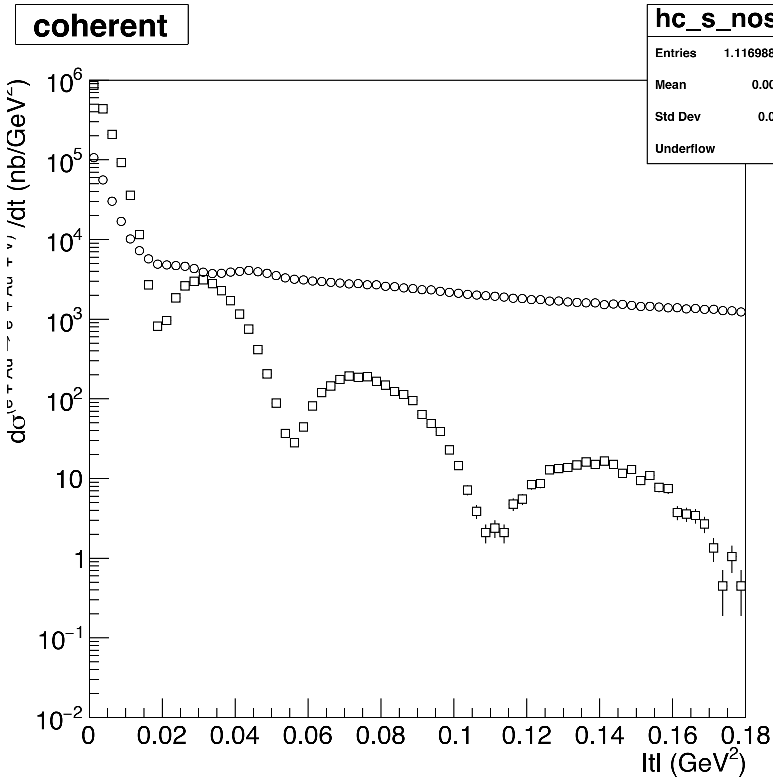
Parameters from https://physdiv.jlab.org/DetectorMatrix/ as of Mar 25, 2020

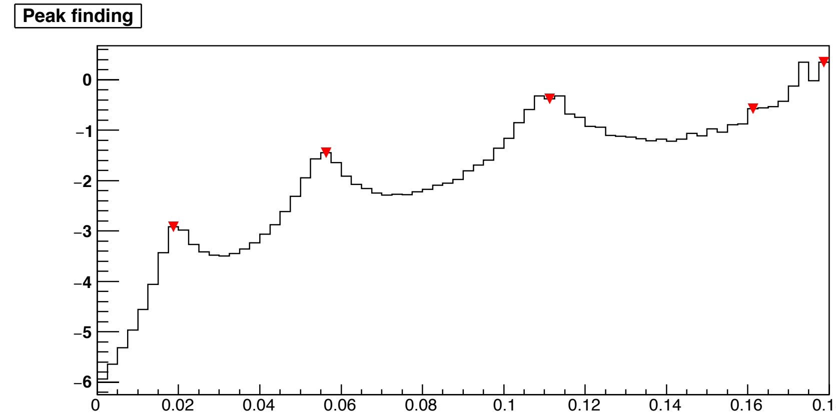


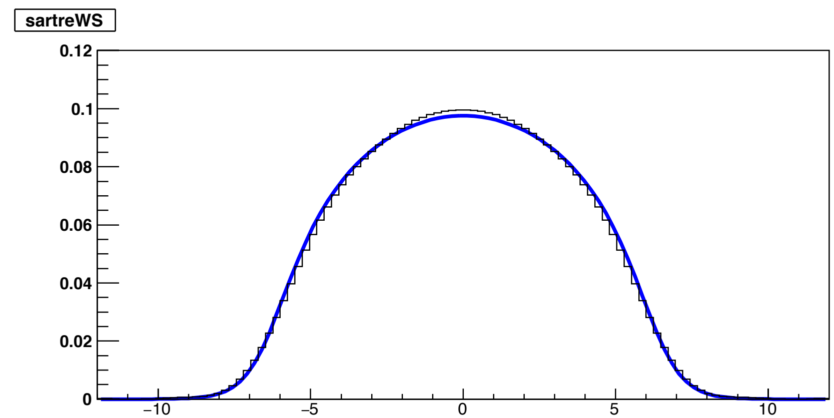




Method A: $F(b)$ extraction (II)





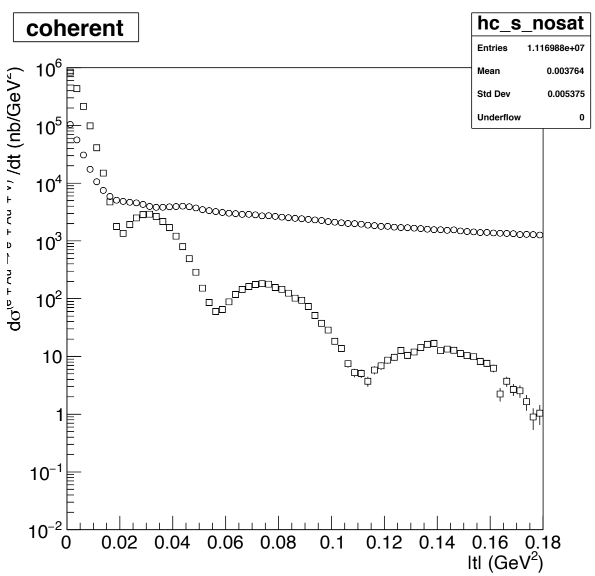


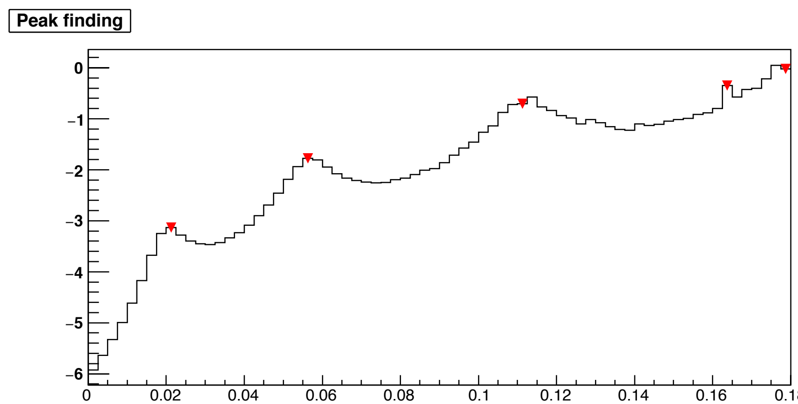
- Looks good - so far seems ρ will not supersede any J/ψ or ϕ results - see how much one can relax requirements.

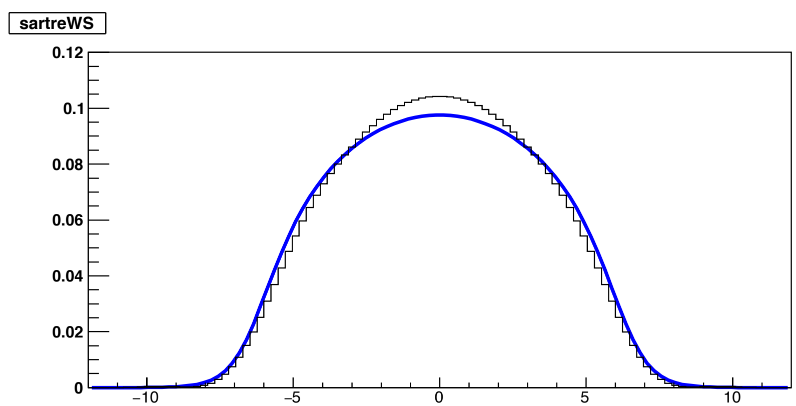
Method A: $F(b)$ extraction

π from ρ: $$\frac{\sigma_{p_T}}{p_T}(\,\%\,) = 0.05\ p_T \oplus 0.5$$

scattered e': $$\frac{\sigma_{p_T}}{p_T}(\,\%\,) = 0.1\ p_T \oplus 1.0$$







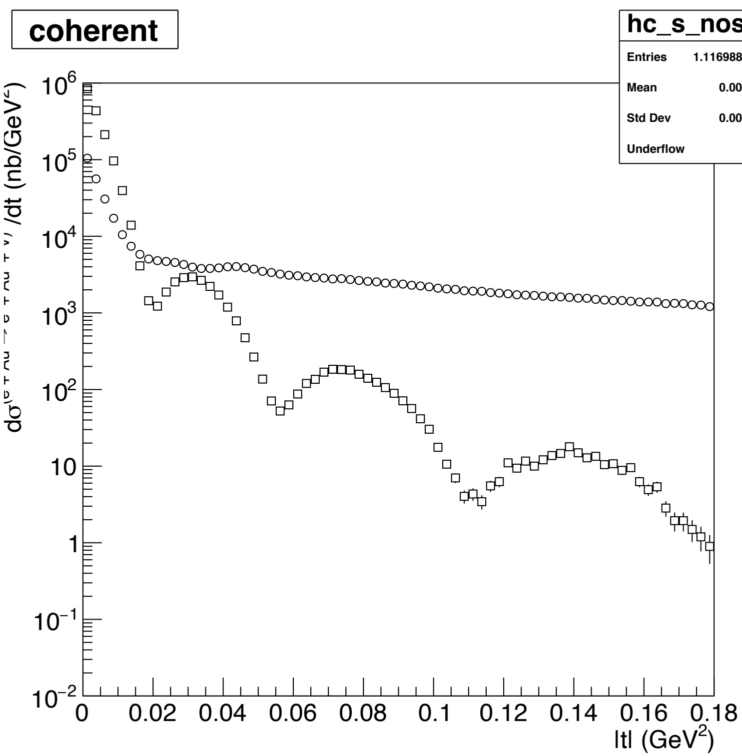
Nope, as for J/ψ and ϕ, e' seems to need smaller MS term

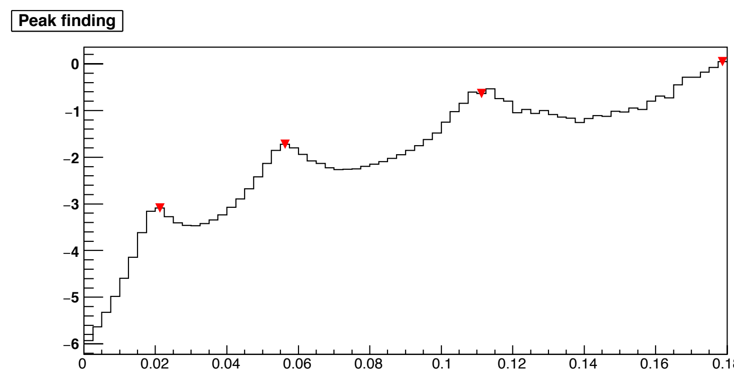
Method A: $F(b)$ extraction

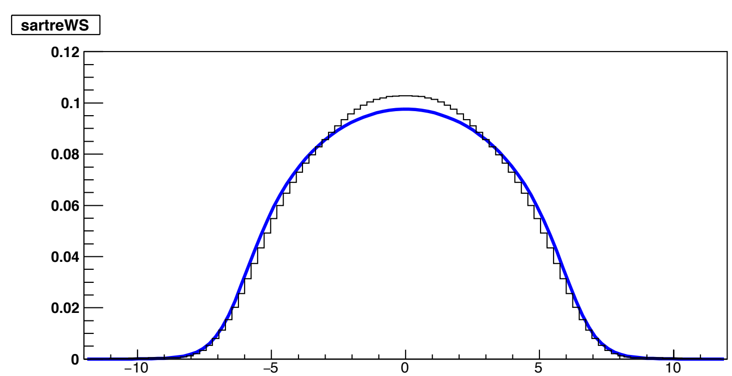
K from ϕ: $$\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 1.0$$

scattered e’: $$\frac{\sigma_{p_T}}{p_T}(\%) = 0.1\ p_T \oplus 0.5$$

- More or less as for J/ψ and ϕ. Cannot deviate much from J/ψ constraints, although ρ looks a tic more flexible

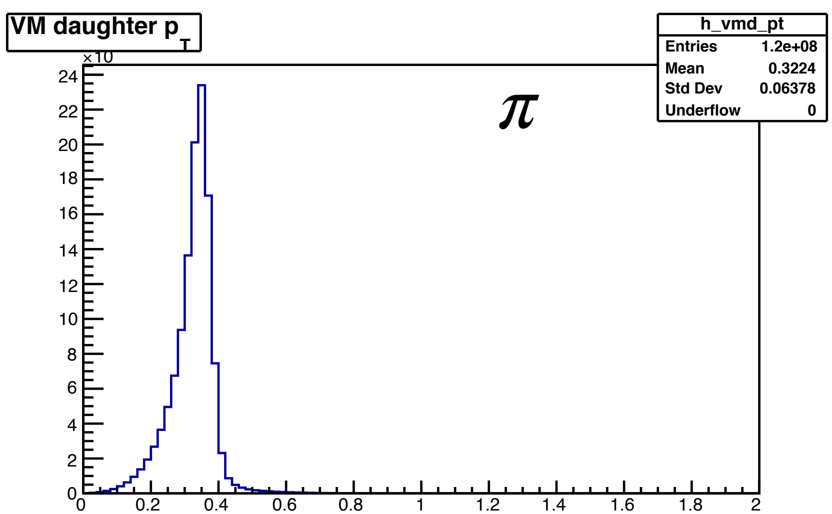


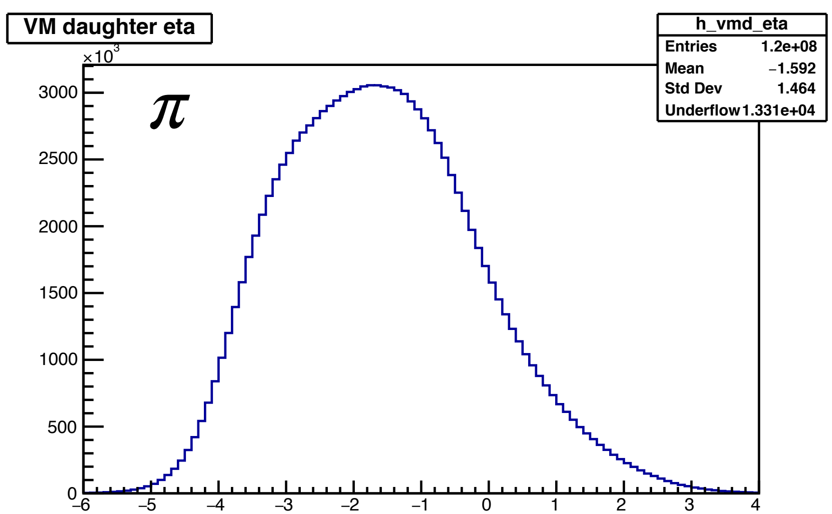




Photoproduction Q2 < 0.01 GeV2

- Do not have non-saturation data since amplitudes table only go to Q ~ 0.01 GeV2. Saturation data is available but has the issue that saturation distorts the the WS anyway.
- However, the clear challenge is the low p_T of the π. Slightly better than the K from the ϕ so is not so grim.
- On the upside the η distribution is wide which helps.





Summary

- The tracking requirement for $e + Au \rightarrow e' + Au' + V$ for $V = J/\psi, \phi, \rho$ were studied.
- A successful measurement, i.e. extraction of the source distribution, of all 3 mesons requires a smaller MS term (0.5%) in the forward region to capture the e’ as well as the V decay particle for photo production.
- This is now put in the current requirement table
- Measuring photo production of the ϕ is a challenge since we have to track down to p_T ~ 100 MeV.

That’s it for me on this

Next I plan to establish requirements on how well we have to suppress/detect/tag the incoherent vector meson production. I will use only the J/ψ for this.

The End