Straw Tube

Charlie Young

From APS Meeting @ Denver

Wire tension countered by tube wall

Successful assembly of one tube

Tube collapses if the wire tension is too high!

Gravitational Sag

Gravitational sag of wire is given by $\delta = \frac{(\rho \pi a^2) g L^2}{8T}$

where

ρ is density of wire material

a is wire radius

g is gravitational constant

L is wire length

T is tension force

Assuming

- 100 gm force = 0.981 Newton
- 50 μm diameter
- Density = 19.3 gm/cm^3 (Tungsten)

Gravitation sag ~ 75 μm for L = 4 m

Electrostatic Deflection

Deflection at mid-point is given by $\delta = \frac{(\rho \pi a^2) g}{k_e} \left[\frac{1}{cosh(\lambda L/2)} - 1 \right]$

where

ρ is density of wire material

a is wire radius

g is gravitational constant

k_e is a spring constant per unit length given by $k_e = \frac{\pi \epsilon_0 V^2}{R^2 [ln(R/a)]^2}$

R is tube radius

V is voltage

T is tension force

$\lambda = k_e / T$

Assuming

- 100 gm force = 0.981 Newton
- 50 μm diameter wire
- Density = 19.3 gm/cm^3 (Tungsten)
- 1 cm radius tube
- 2 KV

Additional deflection ~ 4 μm for L = 4 m

Euler Buckling

Minimum cylinder thickness given by: $t_{min}^{Euler} = \frac{F(KL)^2}{\pi^3 E R^3}$

where

t is cylinder thickness

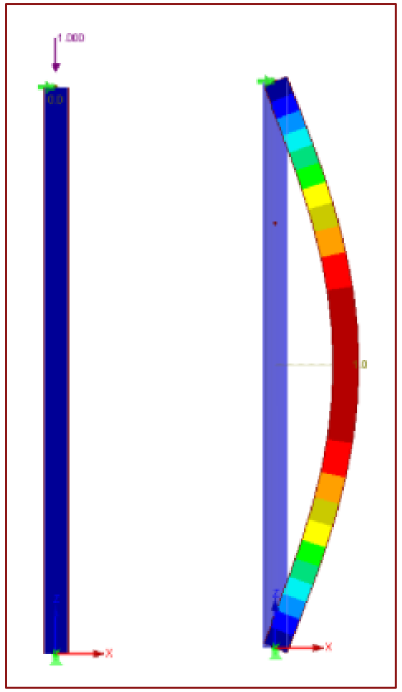
F is axial loading force

K is a scale factor for different endpoint constraints

L is cylinder length

E is Young's modulus of column material

R is radius of cylinder

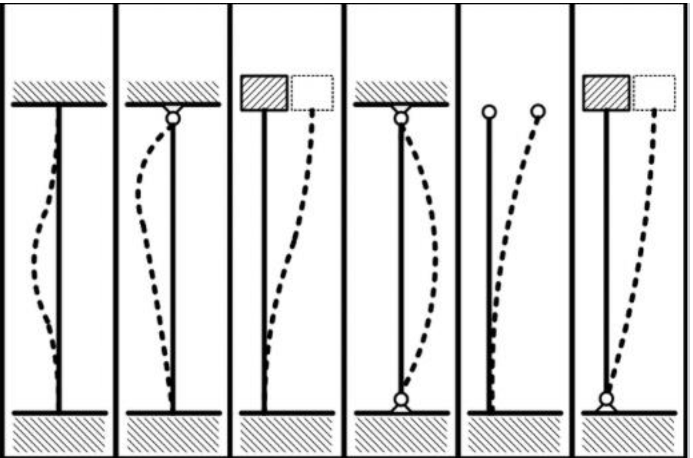


Assuming
- 100 gm force = 0.981 Newton
- K = 1 (rotation-free translation-fixed constraints both ends)
- 4 m length
- 1 cm radius
- E = 4 GPa (Mylar)

Minimum thickness ~ 185 μm
Vs short prototype ~ 12 μm
(Safety factor not included)

Effective Length

$L_{eff} = KL$

Buckled shape of column shown by dashed line						
Theoretical K value	0.5	0.7	1.0	1.0	2.0	2.0
Recommended design value K	0.65	0.80	1.2	1.0	2.10	2.0
End condition key		Rotation fixed and translation fixed Rotation free and translation fixed Rotation fixed and translation free Rotation free and translation free				

Shell (Lorenz-Timoshenko) Buckling

Minimum cylinder thickness given by: $t_{min}^{shell} \approx \sqrt{\frac{FK}{0.61 \times 2\pi E}}$

Where

t is cylinder thickness

F is axial loading force

K is a scale factor for different endpoint constraints

L is cylinder length

E is Young's modulus of column material

R is radius of cylinder

Assuming

- 100 gm force = 0.981 Newton
- K = 1 (rotation-free translation-fixed constraints both ends)
- 4 m length
- 1 cm radius
- E = 4 GPa (Mylar)

Minimum wall thickness ~ 10 μm (Safety factor not included. Large factor for extreme thickness to length ratio)

Transverse Momentum Resolution

IDEA-like layout

```
# IDEA
#
# beam pipe
#   thickness from https://repository.cern/records/p44x1-18z28 Table 2
#   position per email from Fabrizio Palla
0.0061    1.0e+3  1.0e+3  0.015
#
# vertex detector
#   thickness per email from Franco Bedeschi and https://arxiv.org/pdf/2502.21223
#   hit resolutions per email from Franco and Fabrizio Palla
#   position from above paper
0.0030    3.0e-6  3.0e-6  0.0137
0.0030    3.0e-6  3.0e-6  0.0237
0.0030    3.0e-6  3.0e-6  0.0348
0.0040    7.0e-6  7.0e-6  0.130
0.0040    7.0e-6  7.0e-6  0.315
#
# Vertex detector support tube
#   thickness per email from Manuella Boscolo
#   position is chosen randomly between last vertex layer and drift chamber inner wall
0.008     1.0E+3  1.0E+3  0.340
# drift chamber inner wall
0.0008    1.0E+3  1.0E+3  0.350
# drift chamber volume
1.03E-05        1.00E-04        2.00E-03        0.365
1.03E-05        1.00E-04        2.00E-03        0.379
1.03E-05        1.00E-04        2.00E-03        0.394
```

```
1.03E-05        1.00E-04        2.00E-03        1.956
1.03E-05        1.00E-04        2.00E-03        1.971
1.03E-05        1.00E-04        2.00E-03        1.985
# drift chamber outer wall
0.012     1.0E+3  1.0E+3  2.00
#
# silicon wrapper -
#   hit resolution per email from Franco
0.007     7.0E-6  9.0E-5  2.04
0.007     7.0E-6  9.0E-5  2.08
```

112 drift chamber layers

The four numbers in each detector plane are:

- Thickness (X0)
- R-phi hit resolution (m)
- Z hit resolution (m)
- Radial position (m)

Hit resolutions set to 10^3 m for non-measurement planes such as support tube.

Transverse Momentum Resolution

straw-like layout

Remove drift chamber inner and outer walls
Change thickness to 1.32E-04 X0 for 12-μm Mylar straw
Everything else unchanged

```
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0.0030    3.0e-6  3.0e-6  0.0237
0.0030    3.0e-6  3.0e-6  0.0348
0.0040    7.0e-6  7.0e-6  0.130
0.0040    7.0e-6  7.0e-6  0.315
#
# Vertex detector support tube
#   thickness per email from Manuella Boscolo
#   position is chosen randomly between last vertex layer and drift chamber inner wall
0.008     1.0E+3  1.0E+3  0.340
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0.0008    1.0E+3  1.0E+3  0.350
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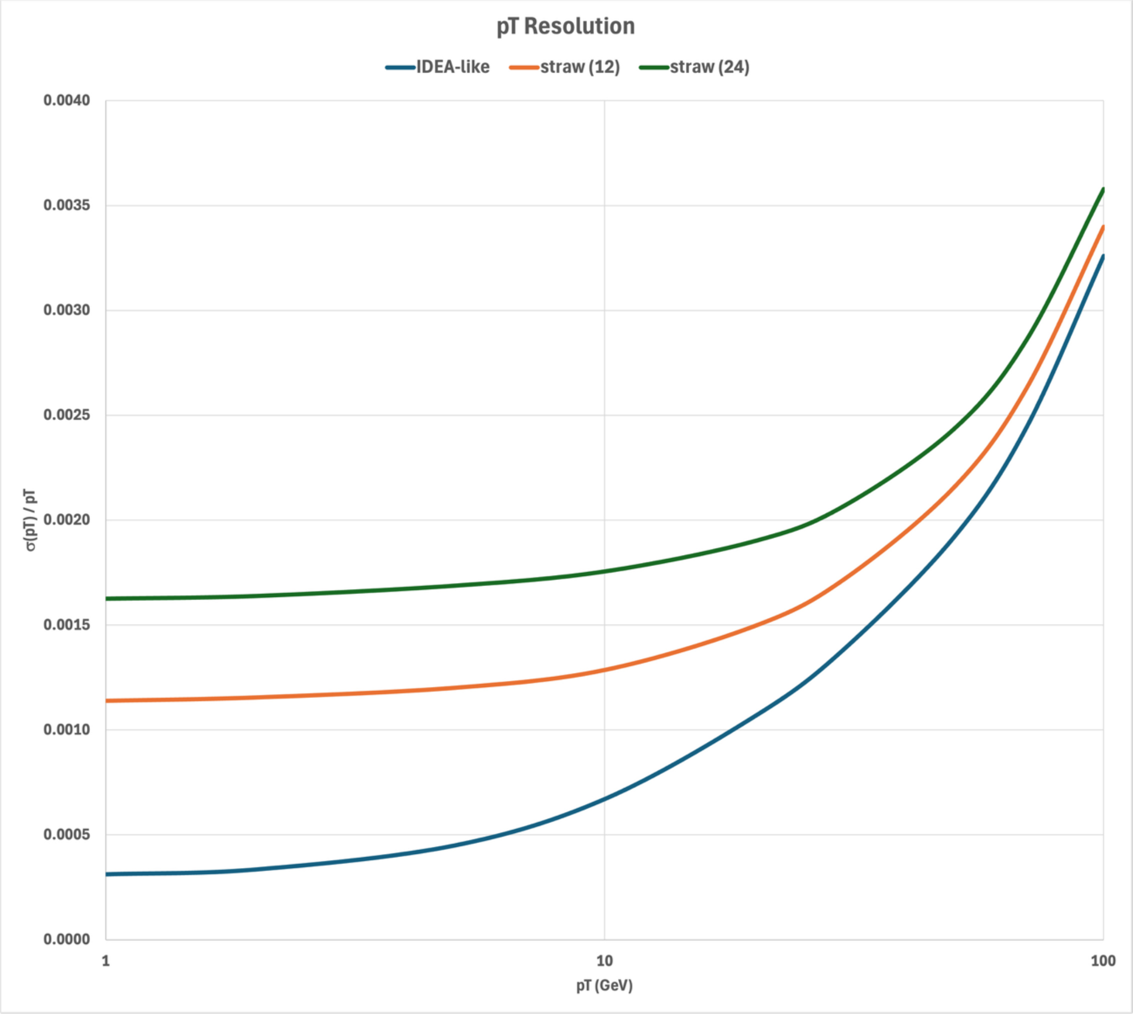
- Radial position (m)

Hit resolutions set to 10^3 m for non-measurement planes such as support tube.

Transverse Momentum Resolution

https://github.com/slaclab/TrackingResolution/tree/master



Straw (24 μm)

Straw (12 μm)

IDEA

Transverse Momentum Resolution

IDEA-like layout w/o wrapper

```
# IDEA
#
# beam pipe
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#   position per email from Fabrizio Palla
0.0061    1.0e+3  1.0e+3  0.015
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1.03E-05        1.00E-04        2.00E-03        0.365
1.03E-05        1.00E-04        2.00E-03        0.379
1.03E-05        1.00E-04        2.00E-03        0.394
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# drift chamber outer wall
0.012     1.0E+3  1.0E+3  2.00
#
# silicon wrapper -
#   hit resolution per email from Franco
0.007     7.0E-6  9.0E-5  2.04
0.007     7.0E-6  9.0E-5  2.08
```

Remove siliscon wrapper
Everything else unchanged

112 drift chamber layers

The four numbers in each detector plane are:

- Thickness (X0)
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- Z hit resolution (m)
- Radial position (m)

Hit resolutions set to 10^3 m for non-measurement planes such as support tube.

Transverse Momentum Resolution

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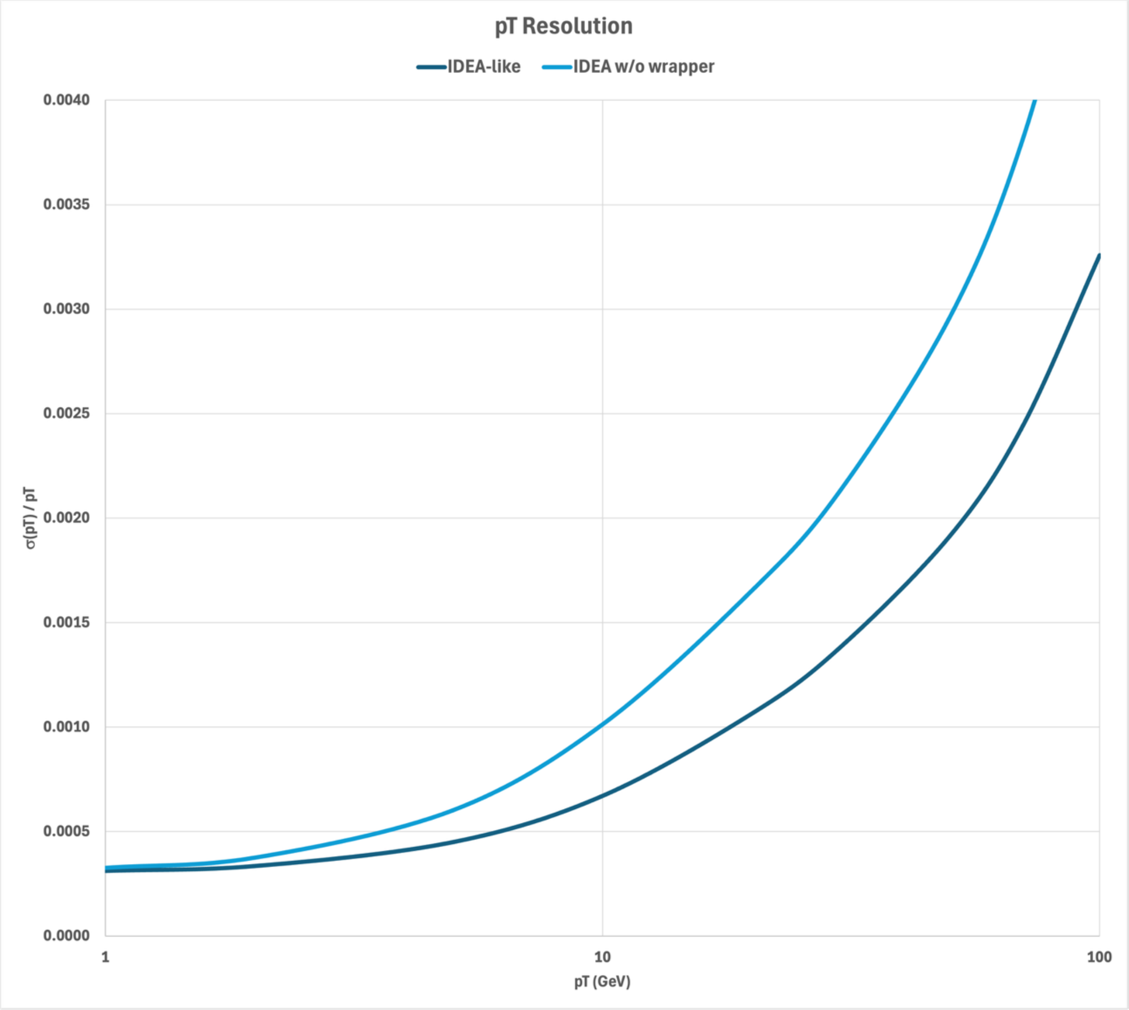
IDEA w/o wrapper

IDEA



Conclusion

Straw tube with 12-μm thick walls (default)

- σ(pT) / pT ~ 0.001 at low momentum, approximately 3x worse than IDEA
- Far exceeds buckling limit from wire tension

Options:

- Thicker tube walls but even worse momentum resolution
- Transfer load to external support
  - Still need to thin down straw tubes for competitive resolution

Silicon wrapper crucial for high-momentum performance