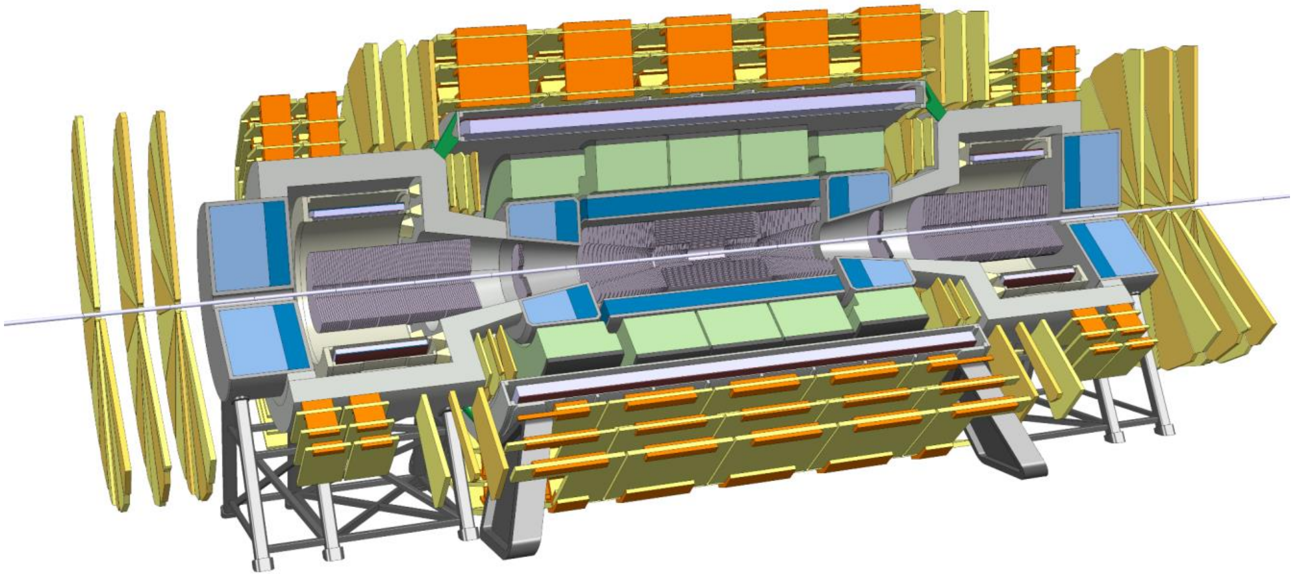
Muon System

FCC week Berlin, May 29th – June 2nd 2017

W. Riegler, CERN

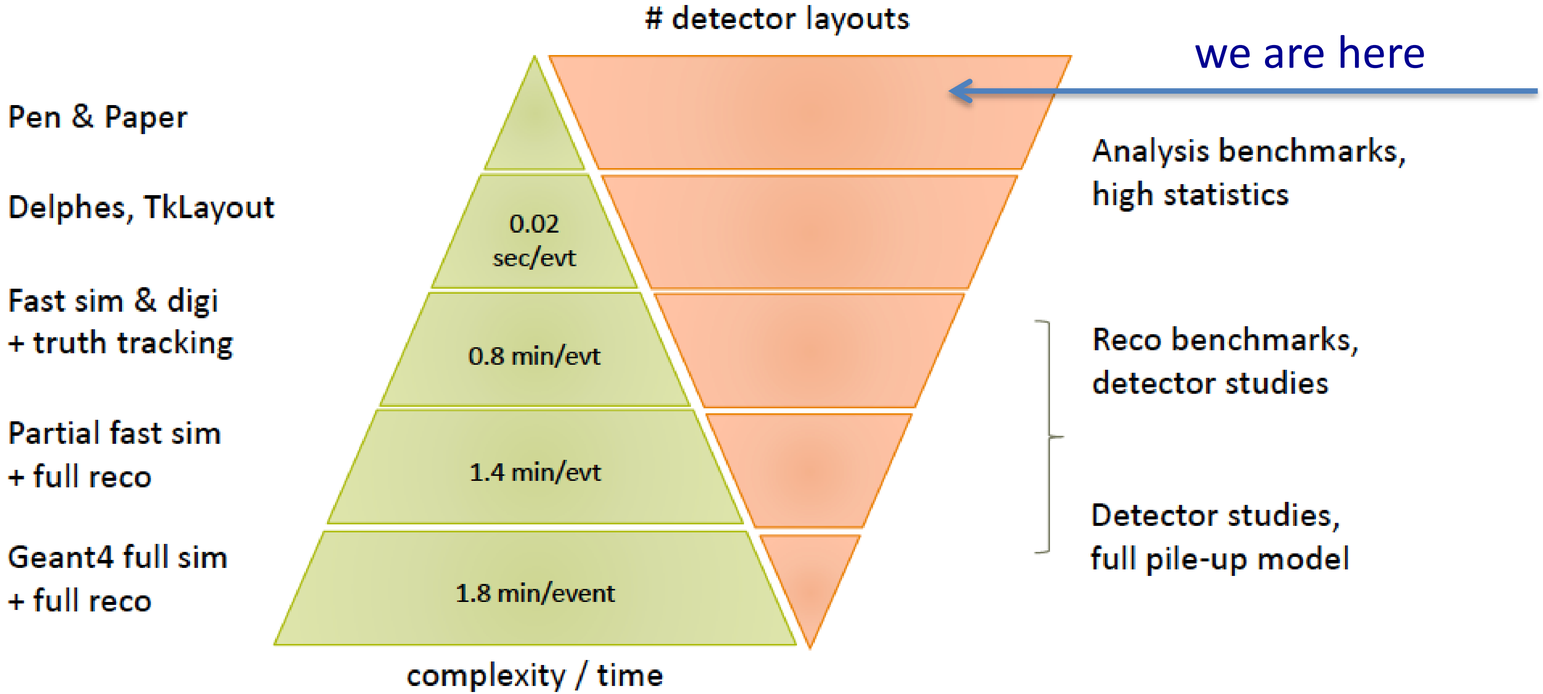
Reference detector for the CDR



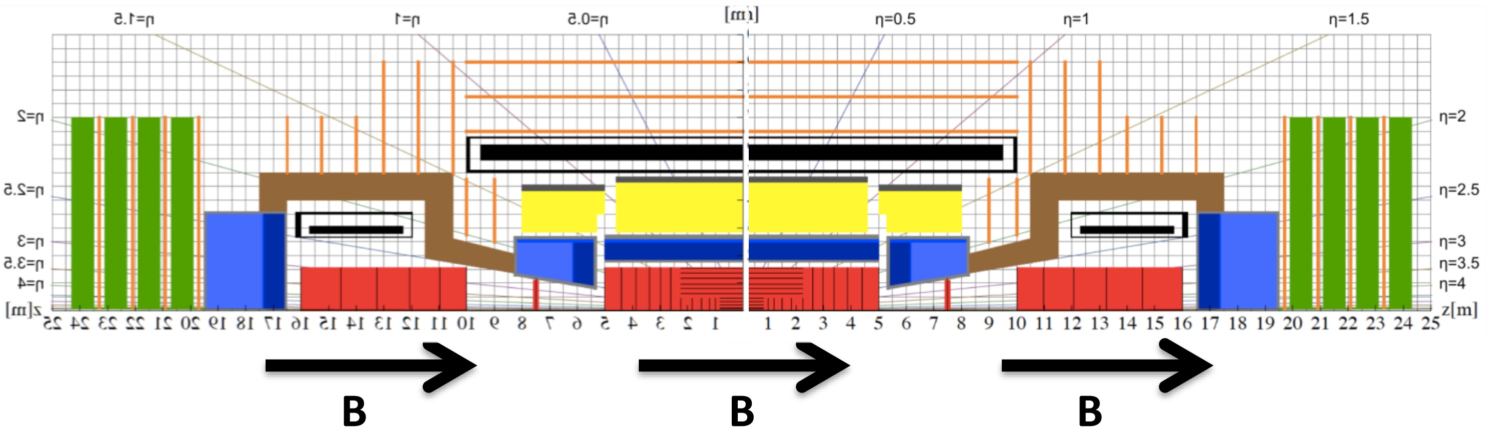
- 4T 10m solenoid
- Forward solenoids
- Silicon tracker
- Barrel ECAL LAr
- Barrel HCAL Fe/Sci
- Endcap HCAL/ECAL LAr
- Forward HCAL/ECAL LAr

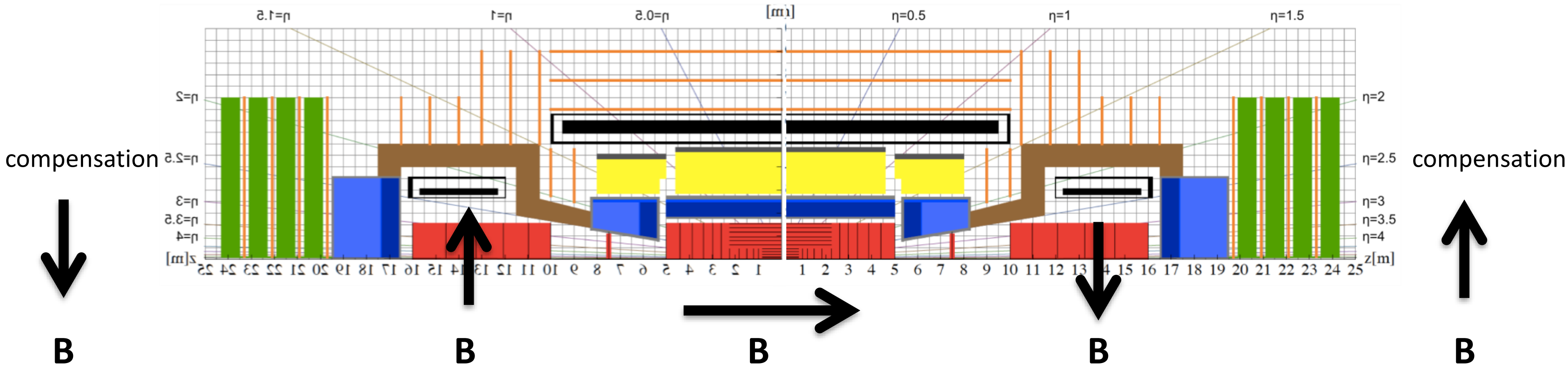
Status of Muon System Studies

The right tools for the right job

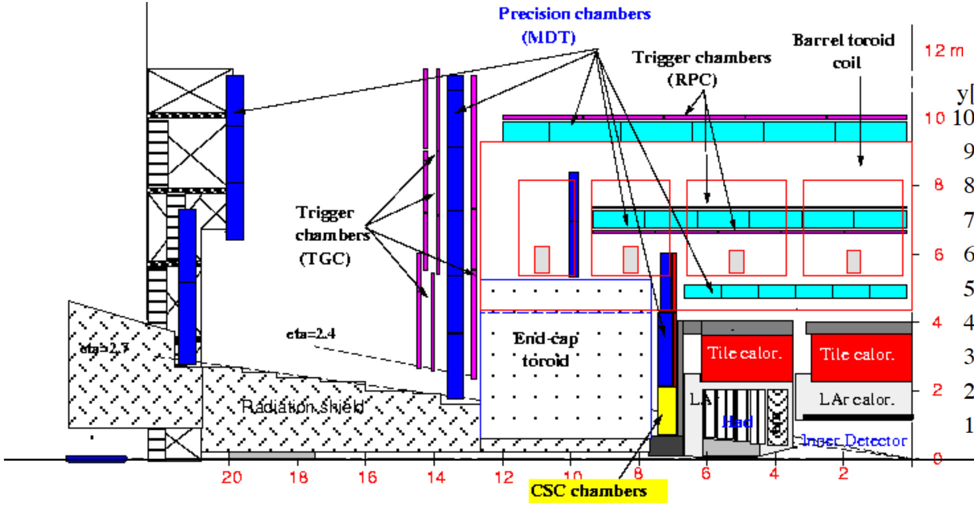


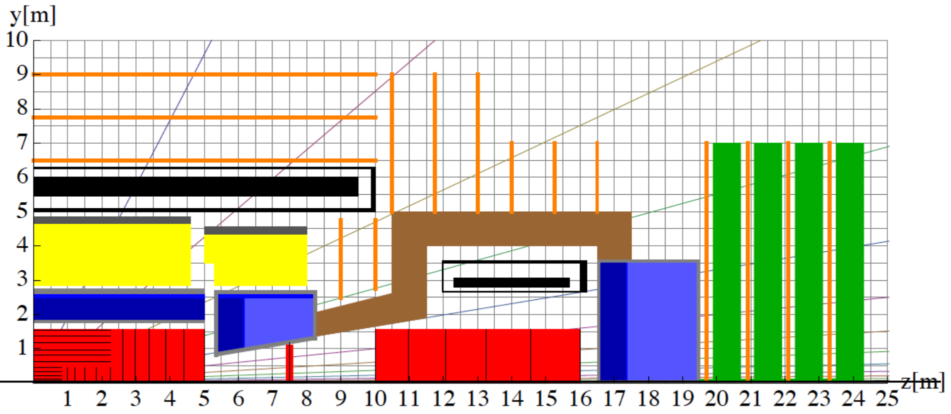
CDR will discuss performance with forward dipoles

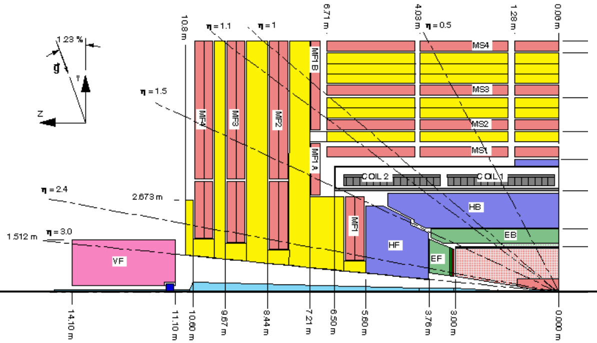


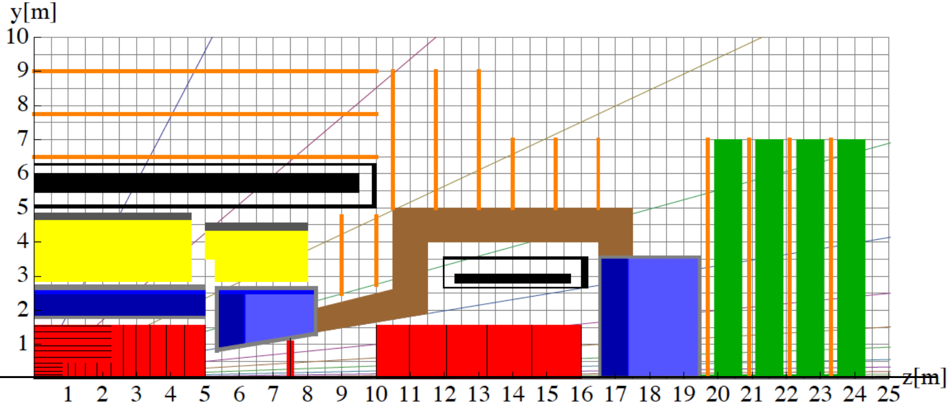


Comparison to ATLAS & CMS



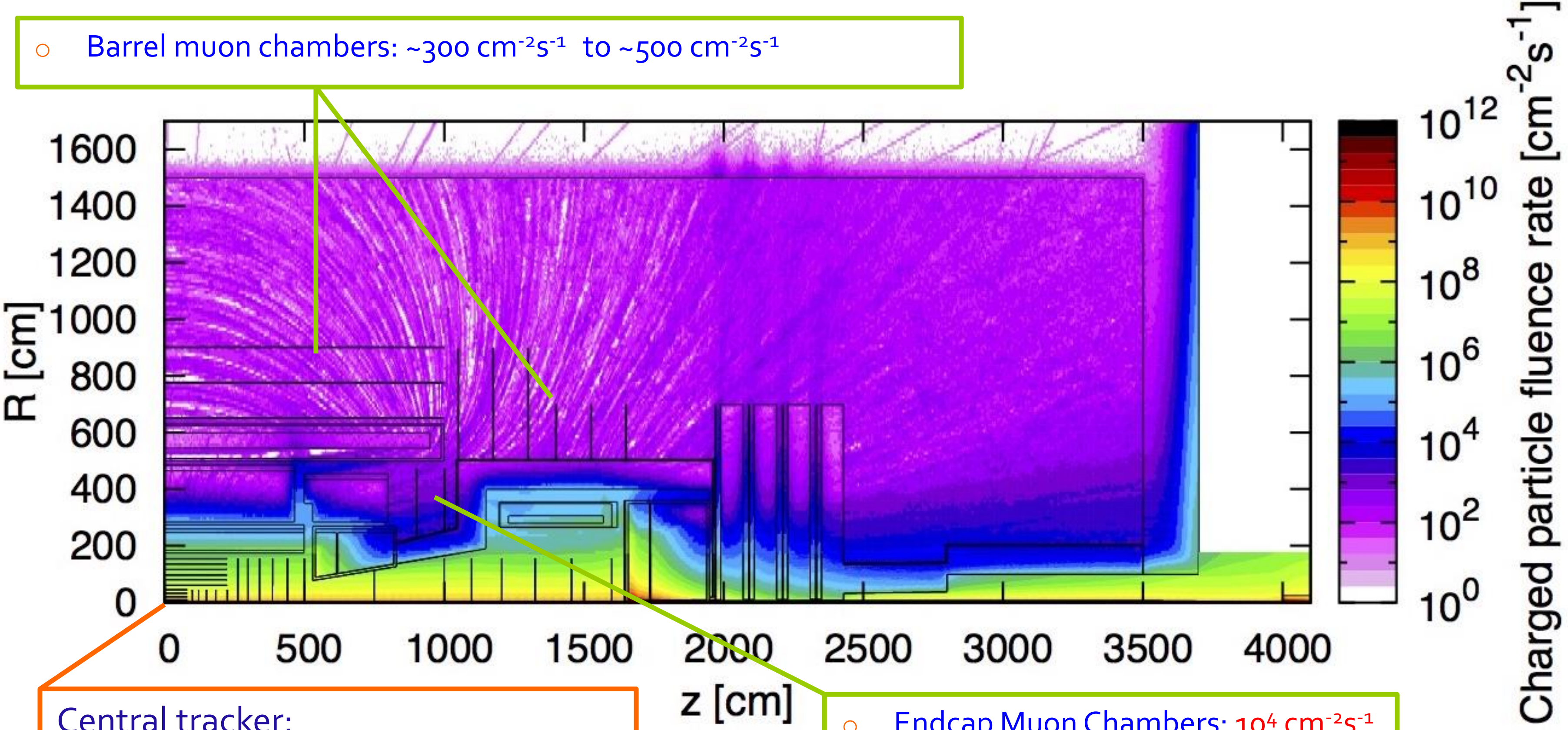






Charged Particle Fluence @ L=30x10^{34}cm^{-2}s^{-1}

- Barrel muon chambers: ~300 cm^{-2}s^{-1} to ~500 cm^{-2}s^{-1}



Central tracker:
- first IB layer (2.5 cm): ~1.2 10^{10} cm^{-2}s^{-1}
- external part: 3 10^{6} cm^{-2}s^{-1}

- Endcap Muon Chambers: 10^{4} cm^{-2}s^{-1}

Talk by I. Besana

Muon Systems

ATLAS muon system HL-LHC rates (kHz/cm^2):

MDTs barrel: 0.28
MDTs endcap: 0.42
RPCs: 0.35
TGCs: 2
Micromegas und sTGCs: 9-10

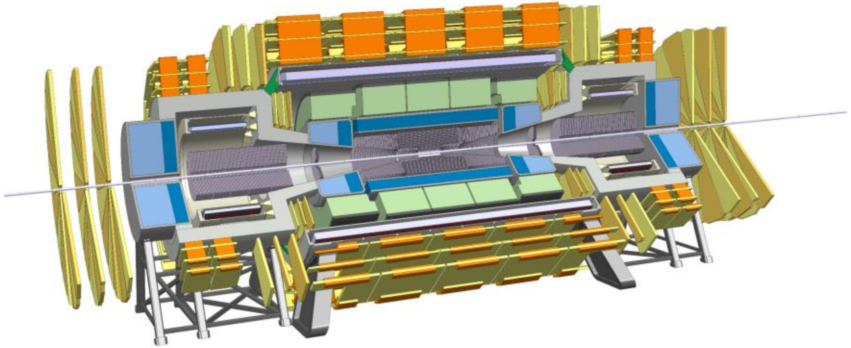
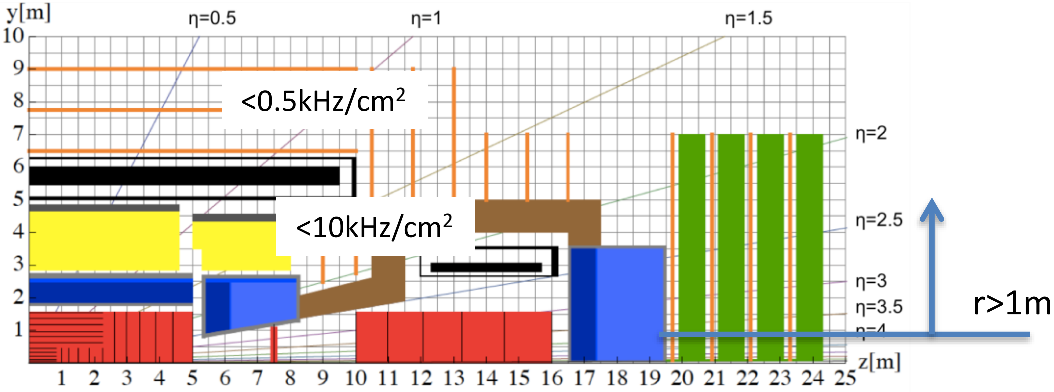


Table 4.5: Expected rates on the muon detector when operating at an instantaneous luminosity of 2×10^{33} cm^{-2}s^{-1} at a collision energy of 14 TeV. The values are averages, in kHz/cm^2, over the chamber with the minimum illumination, the whole region and the chamber with maximum illumination. The values are extrapolated from measured rates at 8 TeV.

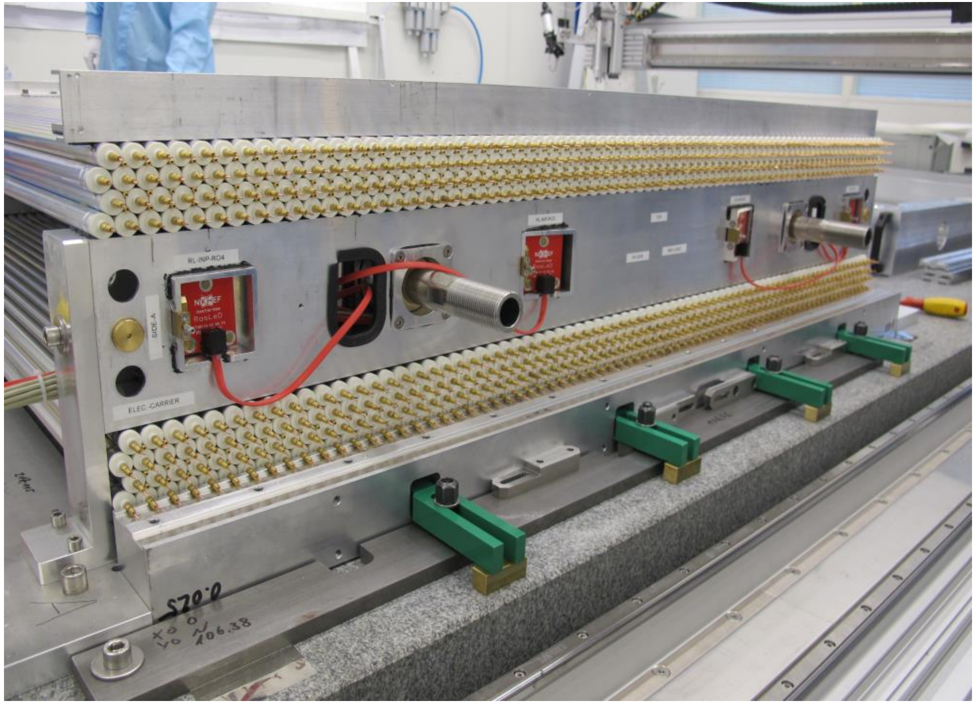
LHCb

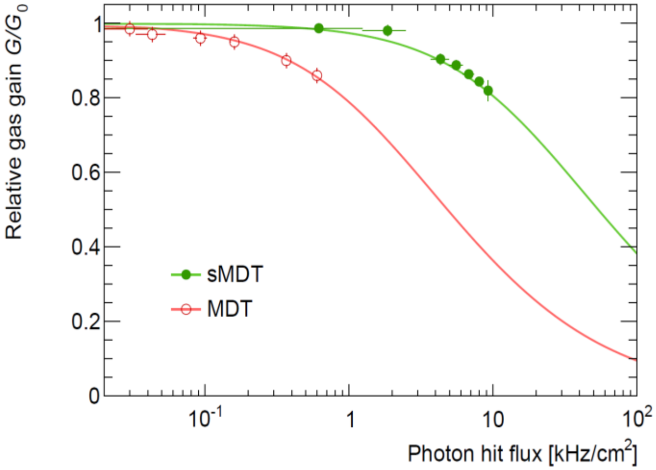
Region	Minimum	Average	Maximum
M2R1	162 ± 28	327 ± 60	590 ± 110
M2R2	15.0 ± 2.6	52 ± 8	97 ± 15
M2R3	0.90 ± 0.17	5.4 ± 0.9	13.4 ± 2.0
M2R4	0.12 ± 0.02	0.63 ± 0.10	2.6 ± 0.4
M3R1	39 ± 6	123 ± 18	216 ± 32
M3R2	3.3 ± 0.5	11.9 ± 1.7	29 ± 4
M3R3	0.17 ± 0.02	1.12 ± 0.16	2.9 ± 0.4
M3R4	0.017 ± 0.002	0.12 ± 0.02	0.63 ± 0.09
M4R1	17.5 ± 2.5	52 ± 8	86 ± 13
M4R2	1.58 ± 0.23	5.5 ± 0.8	12.6 ± 1.8
M4R3	0.096 ± 0.014	0.54 ± 0.08	1.37 ± 0.20
M4R4	0.007 ± 0.001	0.056 ± 0.008	0.31 ± 0.04
M5R1	19.7 ± 2.9	54 ± 8	91 ± 13
M5R2	1.58 ± 0.23	4.8 ± 0.7	10.8 ± 1.6
M5R3	0.29 ± 0.04	0.79 ± 0.11	1.69 ± 0.25
M5R4	0.23 ± 0.03	2.1 ± 0.3	9.0 ± 1.3

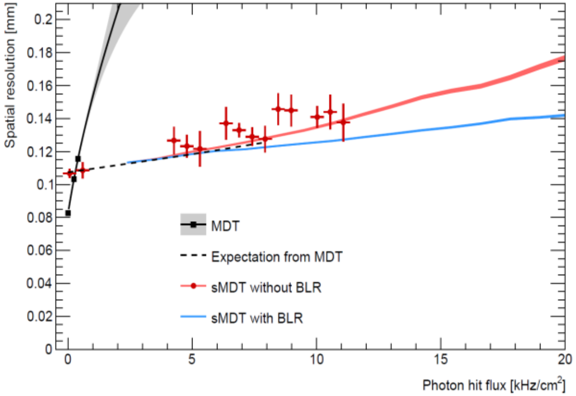


HL-LHC muon system gas detector technology will work for most of the FCC detector area

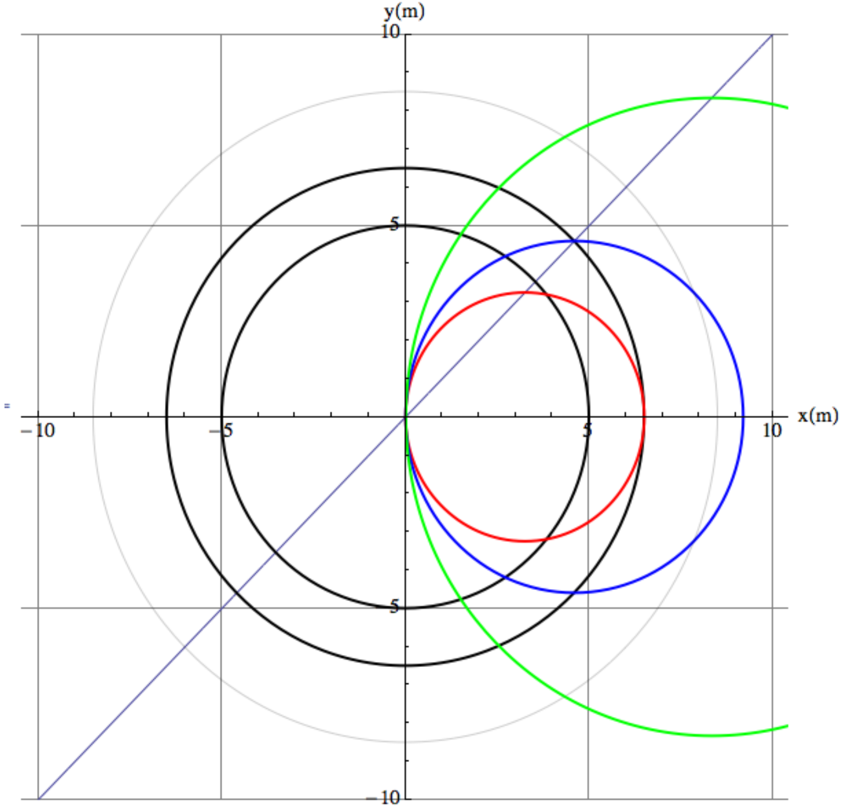
Example ATLAS MDT Drift Tubes







Muon Pt cutoff and minimum trigger threshold in the main solenoid



Pt=3.9GeV enters muon system

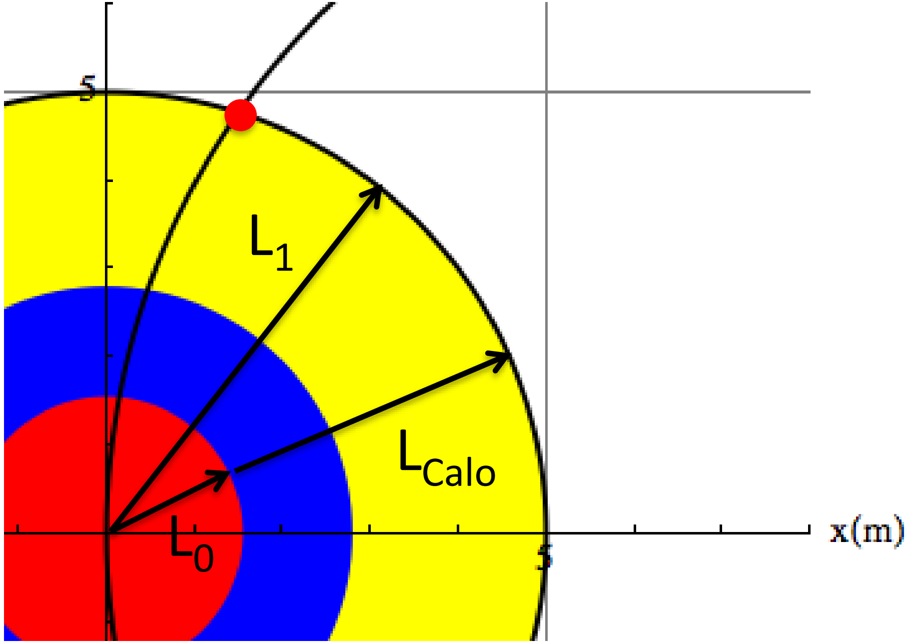
Pt=5.5GeV leaves coil at 45 degrees

Pt=10GeV

Muon system performance estimate

Three ways to measure the muon momentum

1) Tracker only with identification in the muon system
2) Muon system only by measuring the muon angle where it exits the coil
3) Tracker combined with the position of the muon where it exists the coil



We assume a constant magnetic field inside the coil radius L_1.

The measurement points in the tracker of radius L_0 are equidistant and have all the same resolution σ_0.

The measurement point at L_1 has a position error σ_1 that is given by the multiple scattering inside the calorimeters (σ_y in the following).

The formula for the momentum resolution is given in the next slide.

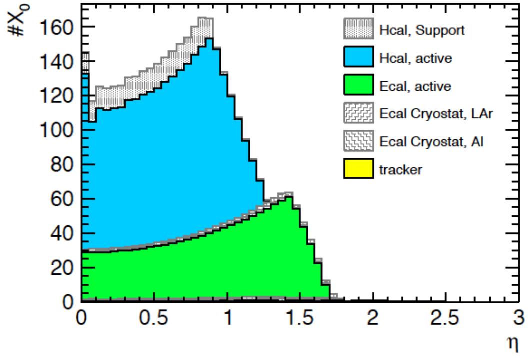
Muon system performance estimate

Muon System standalone by measuring the angle of the muon when exiting the coil

$$\frac{\Delta p}{p} = \frac{2p}{0.3 L_1 B}\sqrt{\theta_0^2 + \sigma_{theta}^2} \qquad \theta_0 = \frac{0.0136}{\beta p[GeV/c]}\sqrt{\frac{L_{Calo}}{X0_{Calo}}}\left(1 + 0.038\log\frac{L_{Calo}}{X0_{Calo}}\right)$$

Inner Tracker of radius L_0 with N+1 equidistant layers of resolution σ_0

$$\frac{\Delta p}{p} = \frac{p}{0.3B}\frac{\sigma}{L_0^2}\sqrt{\frac{720N^3}{(N-1)(N+1)(N+2)(N+3)}} \approx \frac{p}{0.3B}\frac{\sigma}{L_0^2}\sqrt{\frac{720}{N+5}} \quad N \gg 1$$



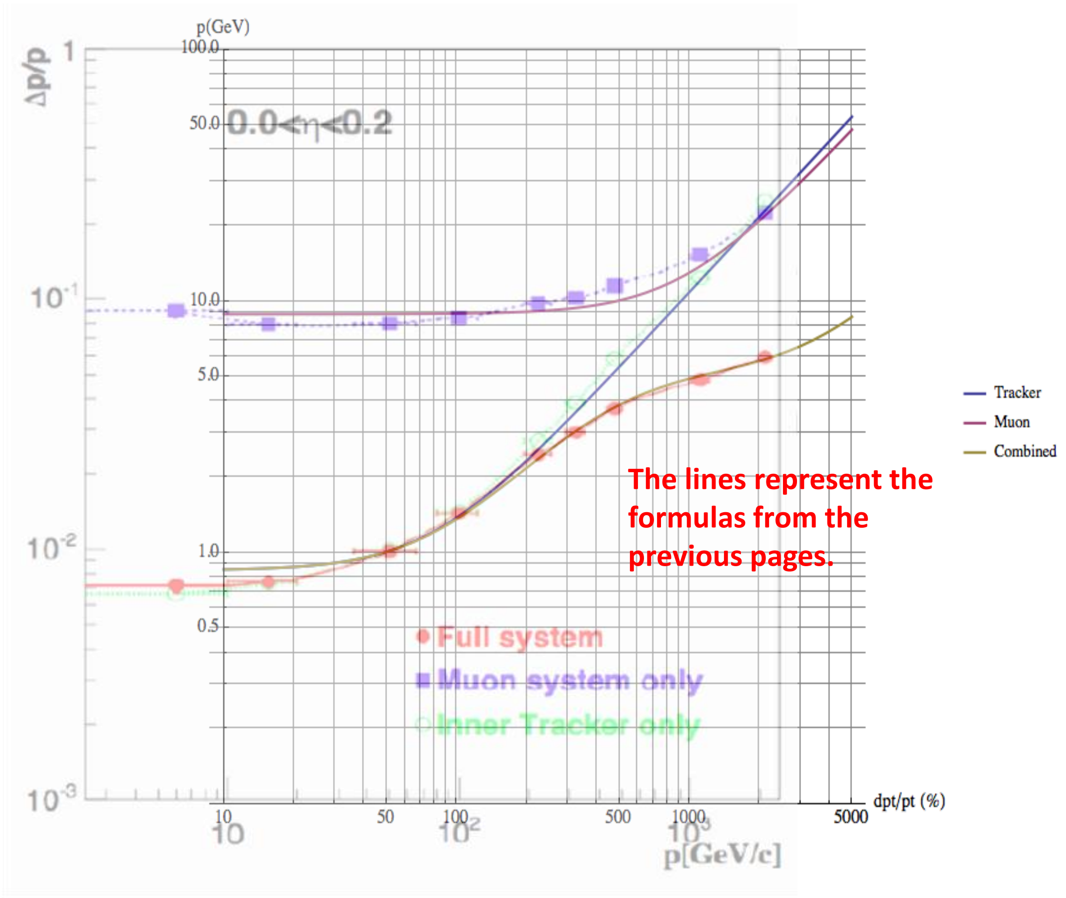
Combined

$$\frac{\Delta p}{p} = \frac{p}{0.3B}\frac{\sigma_0}{L_0^2}\sqrt{\frac{720N^3(c_1\sigma_0^2 + c_2\sigma_1^2)}{(N+1)(N+2)(c_3\sigma_0^2 + c_4\sigma_1^2)}}$$

$$\begin{aligned} c_1 &= 2[2N(L_0^2 - 3L_0L_1 + 3L_1^2) + L_0^2] \\ c_2 &= L_0^2(N+1)(N+2) \\ c_3 &= 3\left[L_0^2(3N^3 - N - 2) - 12L_0L_1(2N^3 - N^2 - N) + 12L_1^2(7N^3 - N^2 - N)\right] + 60N^3\frac{L_1^4}{L_0^2} - 120N^3\frac{L_1^3}{L_0} \\ c_4 &= L_0^2(N-1)(N+1)(N+2)(N+3) \end{aligned}$$

$$\sigma_y = \frac{1}{\sqrt{3}} L_{Calo}\,\theta_0$$

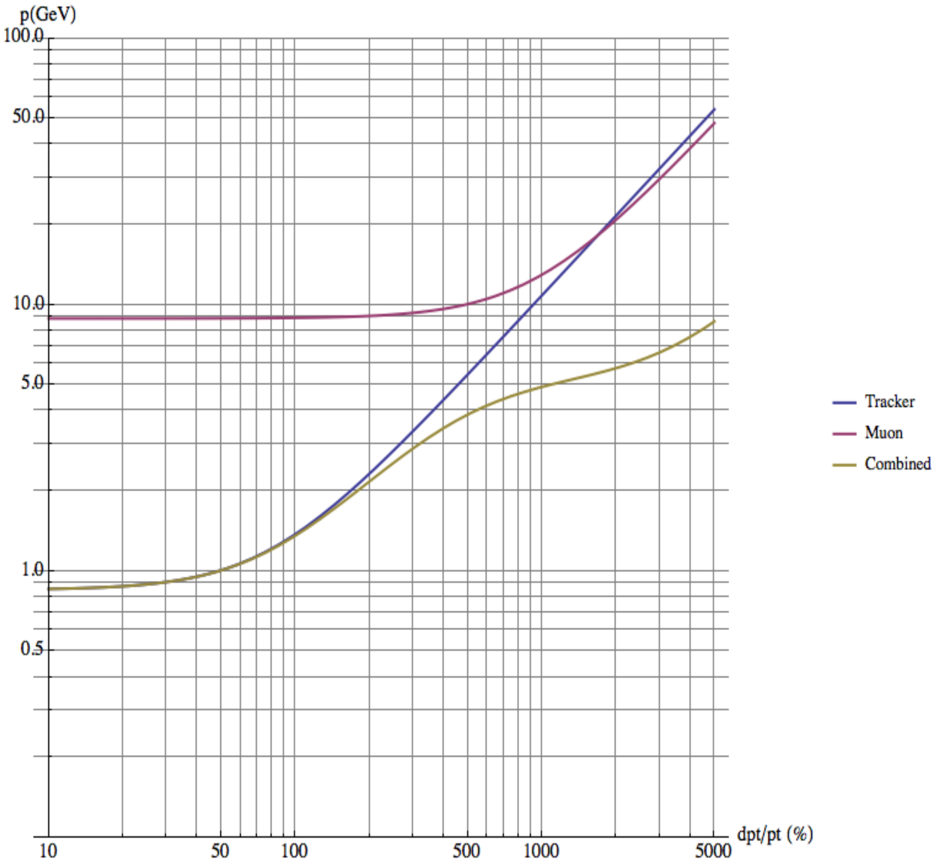
CMS muon resolution at η=0



The lines represent the formulas from the previous pages.

```
In[2]:= (* ==================== *)
In[3]:= N0 = 10;
In[4]:= L = 1.1;
In[5]:= sig0 = 23 * 10 ^ (-6);
In[6]:= L1 = 3;
In[7]:= (* sig1=50*10^(-6); *)
In[8]:= B0 = 4;
In[9]:= X0Tracker = 0.7;
In[10]:= sigtheta = 170 * 10 ^ (-6);
In[11]:= X0Calo = 100;
In[12]:= LCalo = 2.1;
```

CMS muon resolution at η=0



The CMS muon system performance is well represented by assuming:

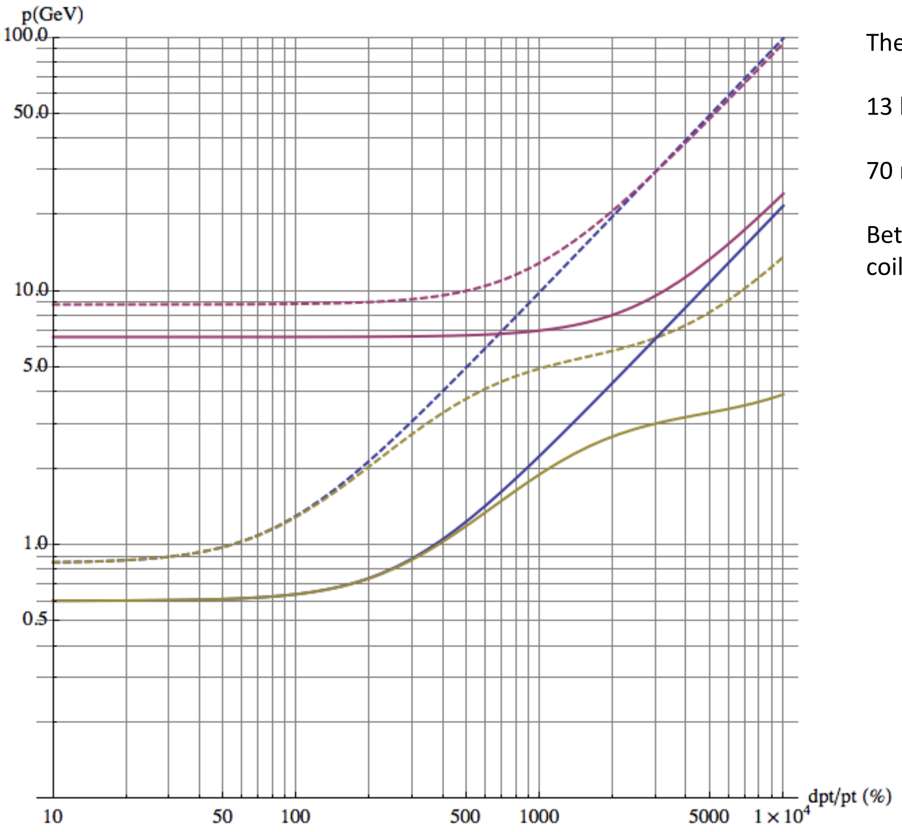
10 layers of tracker with 23um resolution.

170 microrad of angular resolution where the muon exits the coil.

Better than 100um position resolution where the muon exits the coil.

```
In[2]:= (* =================== *)
In[3]:= N0 = 10;
In[4]:= L = 1.1;
In[5]:= sig0 = 23 * 10 ^ (-6);
In[6]:= L1 = 3;
In[7]:= (* sig1=50*10^(-6); *)
In[8]:= B0 = 4;
In[9]:= X0Tracker = 0.7;
In[10]:= sigtheta = 170 * 10 ^ (-6);
In[11]:= X0Calo = 100;
In[12]:= LCalo = 2.1;
```

Comparing CMS to possible FCC resolution



The FCC muon system performance assumes:

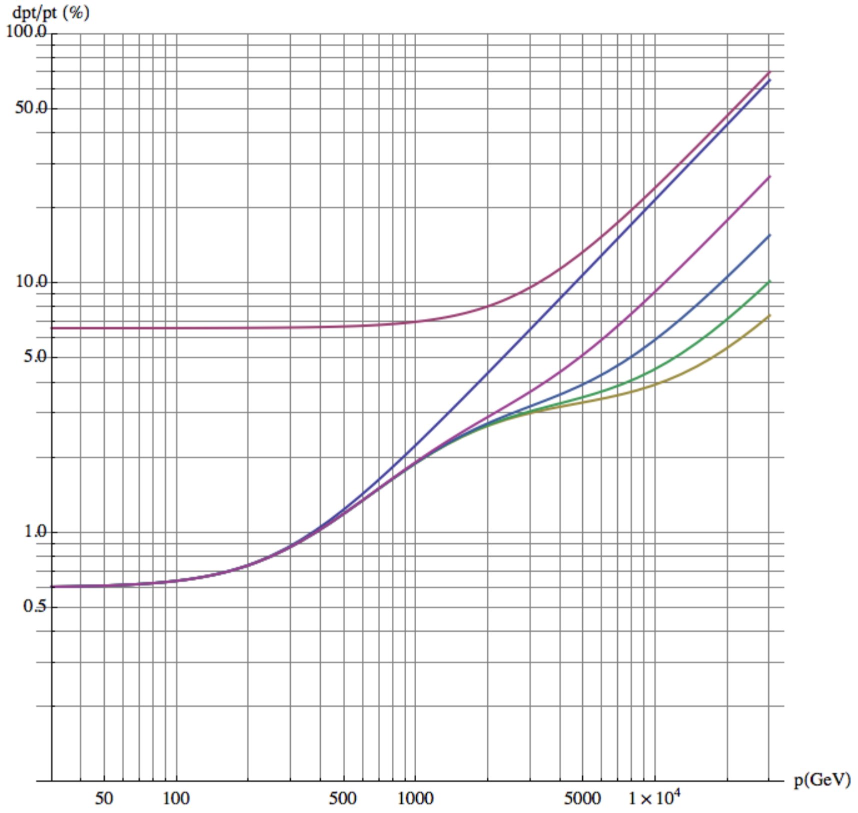
13 layers of tracker with 10um resolution and 1.55m radius.

70 microrad of angular resolution where the muon exits the coil.

Better than 25um position resolution where the muon exits the coil.

```
In[14]:= BCMS = 4;
In[15]:= BFCC = 4;
In[16]:= NCMS = 13;
In[17]:= NFCC = 13;
In[18]:= L0CMS = 1.1;
In[19]:= L0FCC = 1.55;
In[20]:= s0CMS = 23 * 10 ^ (-6);
In[21]:= s0FCC = 10 * 10 ^ (-6);
In[22]:= X0traCMS = 0.7;
In[23]:= X0traFCC = 0.7;
In[24]:= L1CMS = 3;
In[25]:= L1FCC = 5.;
In[26]:= X0calCMS = 100;
In[27]:= X0calFCC = 150;
In[28]:= sigthCMS = 170 * 10 ^ (-6);
In[29]:= sigthFCC = 70 * 10 ^ (-6);
In[30]:= LCalCMS = 2.1;
In[31]:= LCalFCC = 3.;
```

Combined performance for varying position resolution



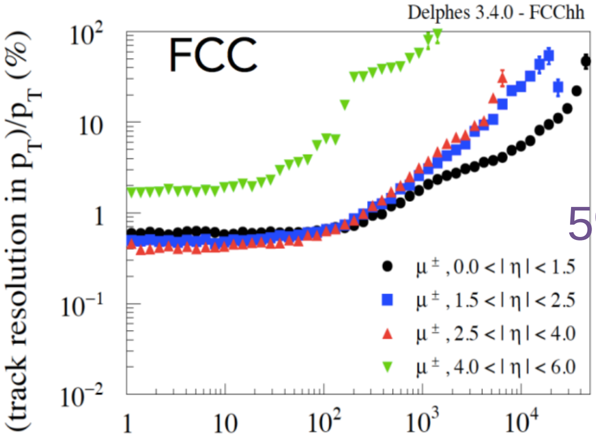
With 50µm position 70µRad angular resolution resolution we find (η=0)

<10% standalone momentum resolution up to 3TeV/c

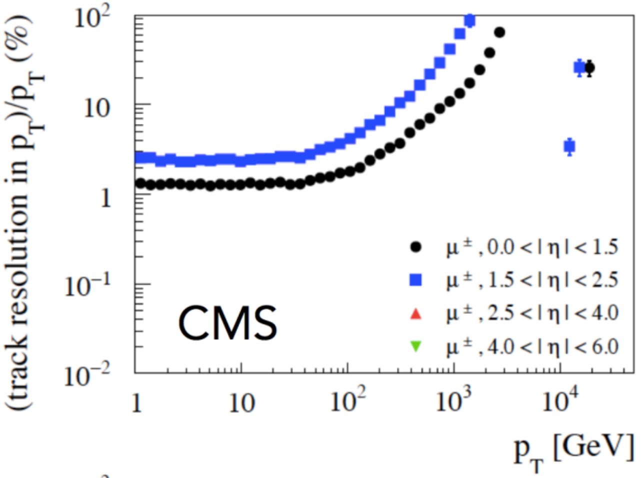
<10% combined momentum resolution up to 20TeV

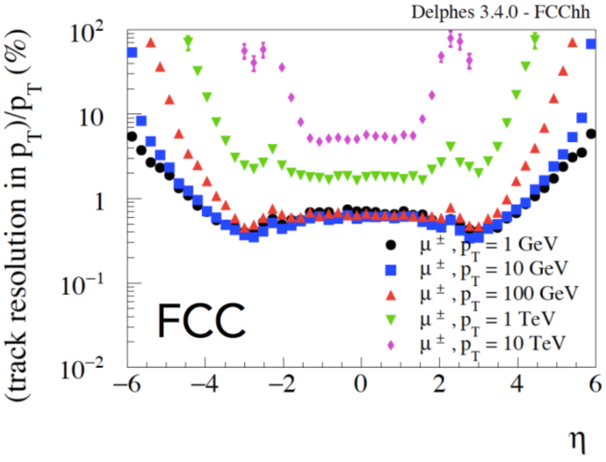
Parametrized Muon Performance

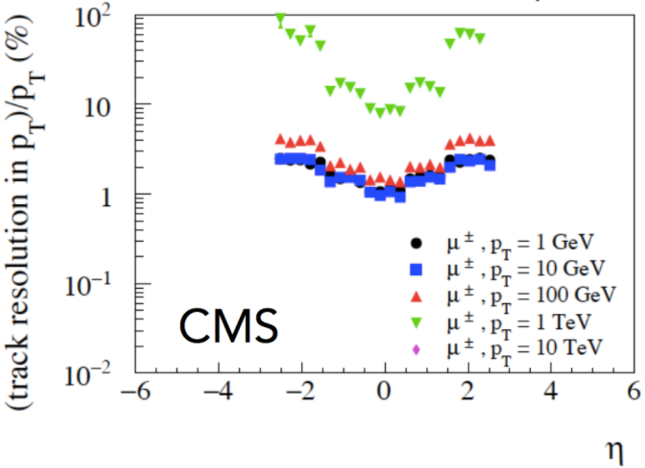
Delphes



5% @10TeV







FCC detector muon system

A 50µm position resolution and 70µRad angular resolution for muons exciting the solenoid will give excellent standalone and combined muon resolution at $\eta=0$.

E.g. Two redundant stations of detectors with 50µm position resolution at a separation of 1-2 meters will realize this requirement.

The expected charged particle rates will probably allow the use of present muon system technology.

The distance between the stations must be large enough to make sure that correlated background is eliminated.

The existing magnetic fields around 1.5Tm should be sufficient for that. Simulations have to prove this fact.

The muon trigger performance still has to be studied in detail.