Design Considerations for a FCC Muon System at $\sqrt{s}$ = 100 TeV

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MIT

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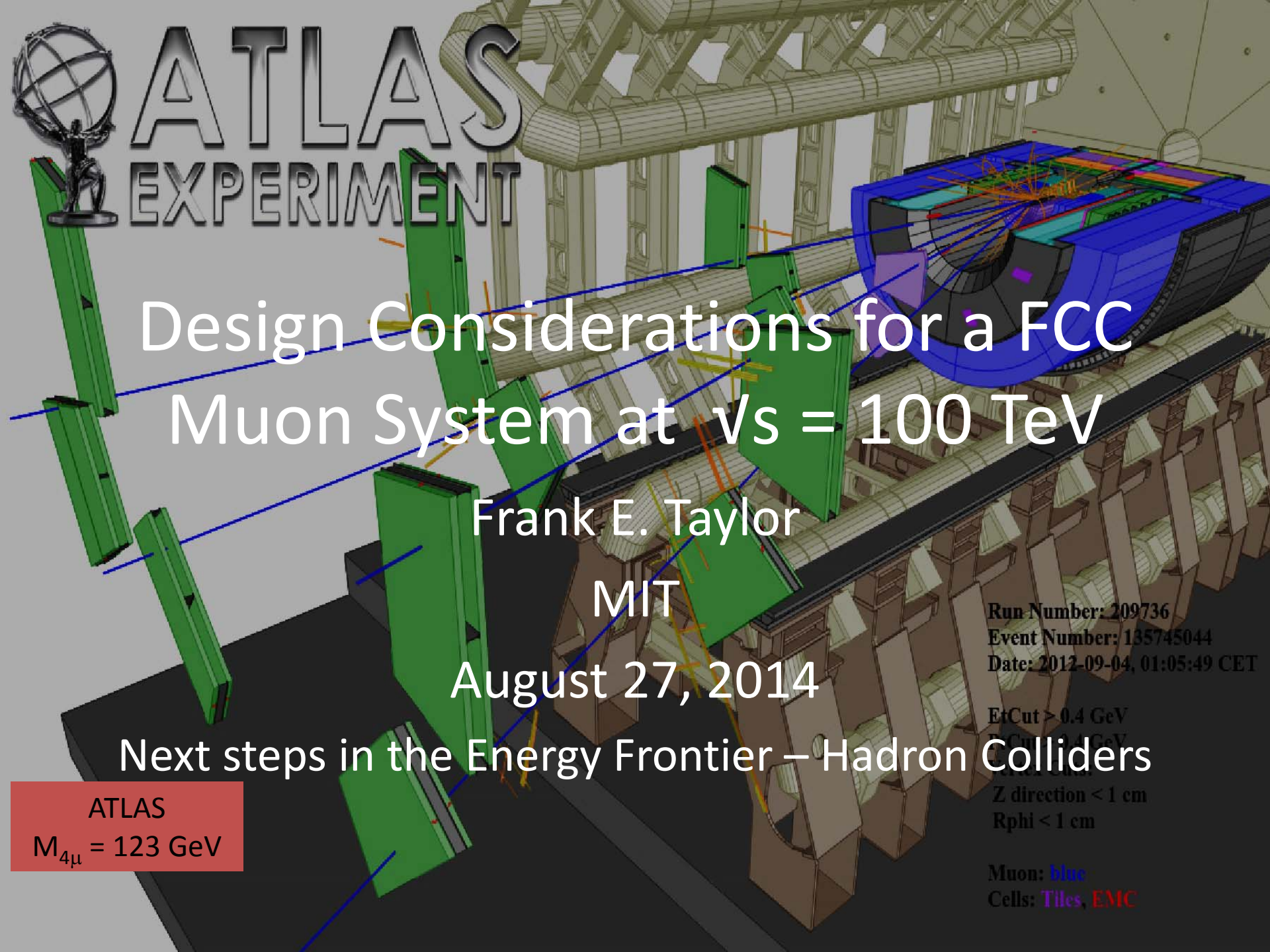
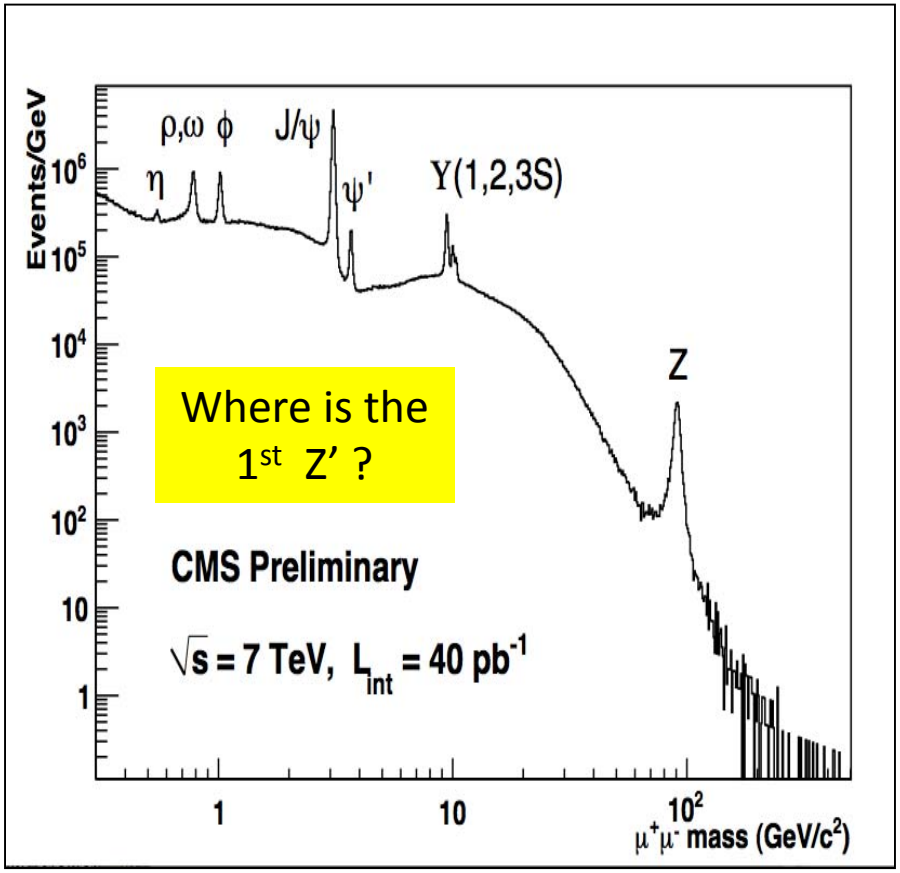
Next steps in the Energy Frontier – Hadron Colliders



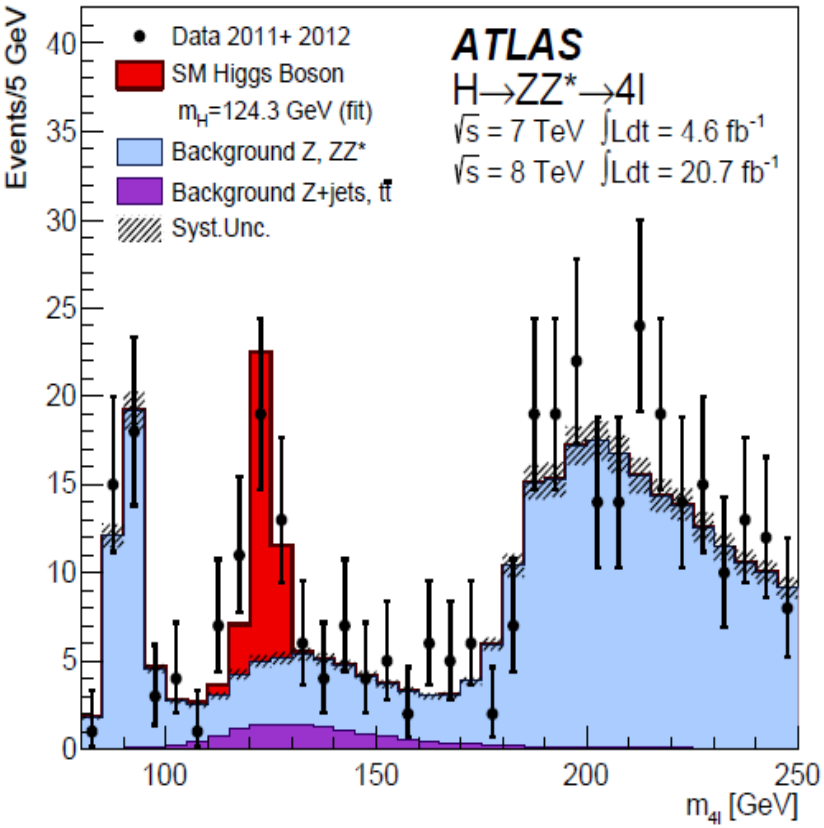
ATLAS
$M_{4\mu}$ = 123 GeV

Muons – Window to Physics

CMS (Solenoid)



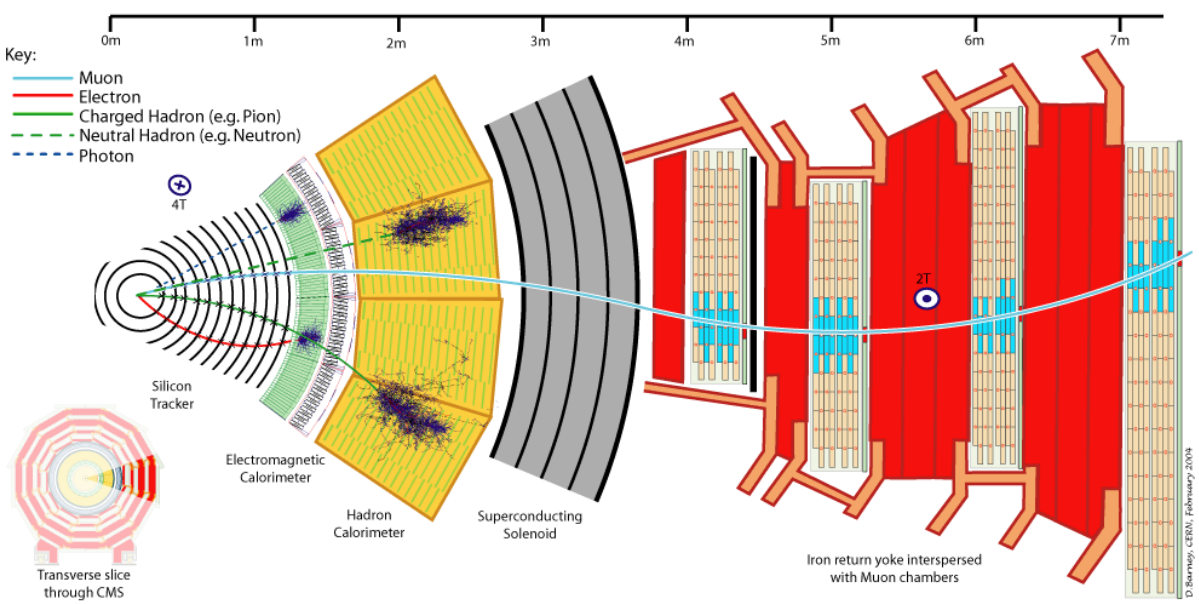
ATLAS(Solenoid & Toroids)



Parts of a Muon System

- Central Tracker with Vertex Determination
- EM/Hadron Calorimeter & Muon Filter
- Magnetic Field(s)
- Trigger and Tracking Chamber System
- DAQ & Environmental Monitoring

CMS @ LHC



Approach to Design

- Design of muon system concomitant with full detector integration
  - The muon system design requirements influence most parts of detector design
    - Magnet System Configuration (Solenoid or Toroid), Size and Cost
    - Calorimeter/muon filter thickness required
    - Access, Services and Integration
    - Shielding to control backgrounds
- Develop scaling rules using LHC & SSC detectors as benchmarks
  - Design requirements for η and pT ranges
  - Performance requirements for muon triggering and tracking technologies
  - Alignment requirements
  - Cost of magnet system
  - R&D program for muon chamber technology choice

Designer's Tool Kit - Resolution

- Resolution for momentum p
  - Momentum dispersion in B-field - sagitta
    - Field Strength B
    - Length of measured track L

$$s \sim \frac{0.3\ B\ L^2}{8\ p}$$

  - Chamber spatial resolution
    - Constant a
    - Resolution of chamber $\sigma(X_{ch})$

$$\frac{\delta s_{ch}}{s} \sim \frac{a\ \sigma(x_{ch})\ p}{B\ L^2}$$

  - Multiple scattering in system
    - Constant α
    - Thickness of middle layer X_m

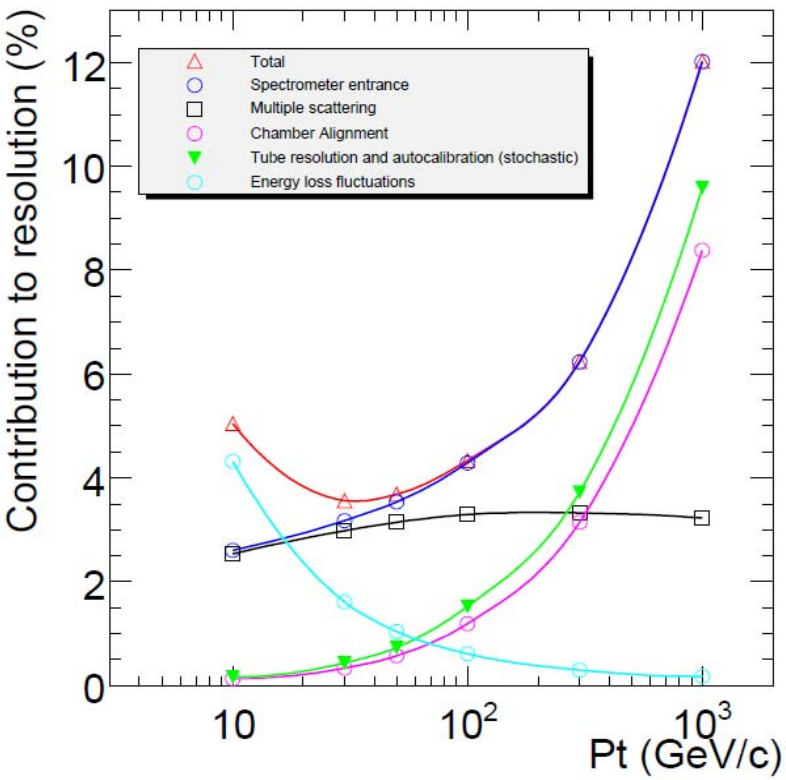
$$\frac{\delta s_{ms}}{s} \sim \frac{\alpha \sqrt{\frac{X_m}{X_0}}}{B\ L^2}$$

  - Energy loss fluctuations
    - Constant b ~ 15%
    - $dE/dx \approx 1.6E^{0.0572} + 0.0034E^{1.0897}$
    - Thickness of dead mat'l X

$$\frac{\delta s_{\Delta E}}{s} \sim \frac{\delta p_{\Delta E}}{p} \sim \frac{b \Delta E(p, X)}{p}$$

ATLAS Design vs. Toy Model (η~0)

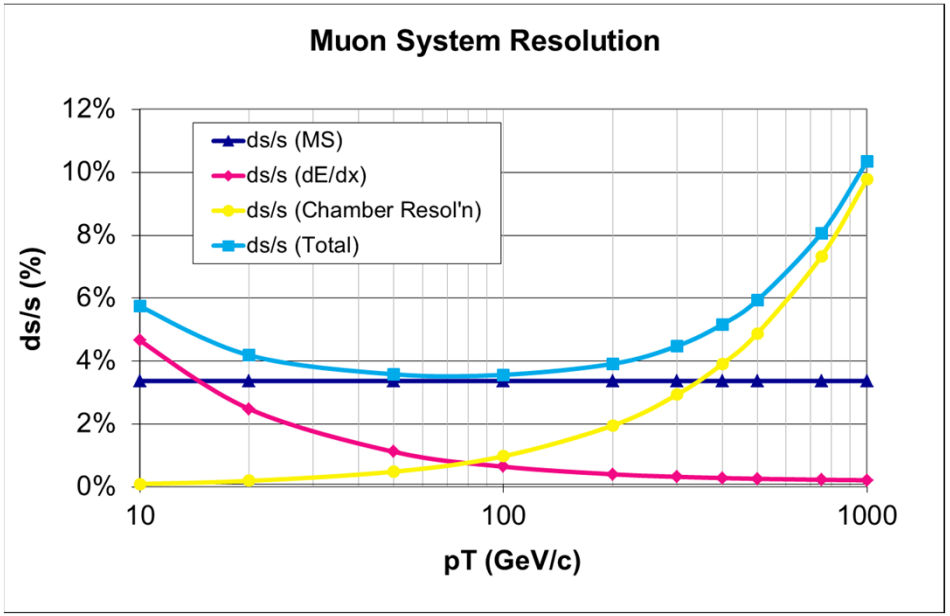
- Multiple Scattering in middle station
- Chamber alignment $\oplus$ resolution
- Energy loss compensation



Standard ATLAS

B (T)	L (m)	BL^2 (Tm^2)	BL (Tm)
0.50	6.00	18.00	3.00
$X_{Middle}/X0$	Station Resol'n (μm)	Alignment (μm)	SR $\sqrt{1.5}$ (μm)
34.0%	50.00	20.00	65.95
Calorimeter ($n\lambda$)	λ (g/cm^2)	g/cm^2	$\delta(\Delta E)/\Delta E$
12.50$\oplus$	132.00	1650.00	15.0%

s ~ 675 μm @ pT = 1 TeV/c



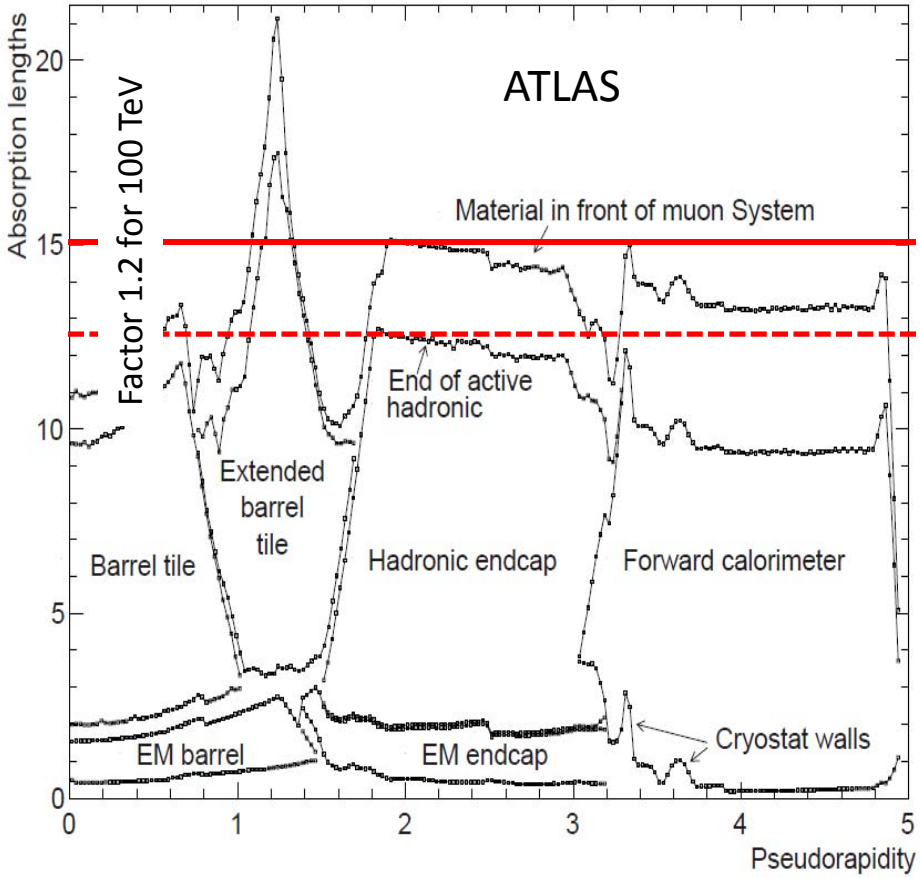
Design Criteria

- LHC @ $\sqrt{s}$ = 14 TeV or SSC @ $\sqrt{s}$ = 40 TeV
  - $|\eta|$ range < 2.7
  - Momentum Resolution $\sigma(pT)/pT \sim 10\%$ @ pT = 1 TeV
  - Beam Cross Tagging $\tau \ll 25$ ns
  - Trigger 1 MU pT > 20 GeV/c, 2 MU pT > 10 GeV/c, 3 MU pT > 6 GeV/c
  - Highest detector hit rate ~ 15 kHz/cm^2

- Scaling factors for same chamber resolution
  - $\sqrt{s}$ ratio ~ 7 for LHC or 2.5 for SSC required increase in BL^2
  - $|y_{max}|$ ratio ~ $\ln[(\sqrt{s}=100)/M_p]/[(\sqrt{s}=14)/M_p] \sim 11.5/9.5 \sim 1.2$

- FCC @ $\sqrt{s}$ = 100 TeV
  - $|\eta|$ range < 2.7 x $y_{max}(100)/y_{max}(14) \sim 3.2 \Rightarrow \theta > 4.7^o$
  - Momentum resolution $\sigma(pT)/pT \sim 10\%$ @ pT = 7 TeV/c
  - Beam Cross Tagging $\tau \ll 25$ ns
  - Trigger 1 MU pT > 20 GeV/c, 2 MU pT > 10 GeV/c, 3 MU etc.
    - With BL^2 ~ 7X or 2.5X could raise threshold to higher value but threshold will be determined by bkg. suppression, trigger bandwidth & physics
  - Highest detector hit rate ~ 30 kHz/cm^2

Calorimeter & Muon Filter



Calorimeter thickness for 100 TeV detector

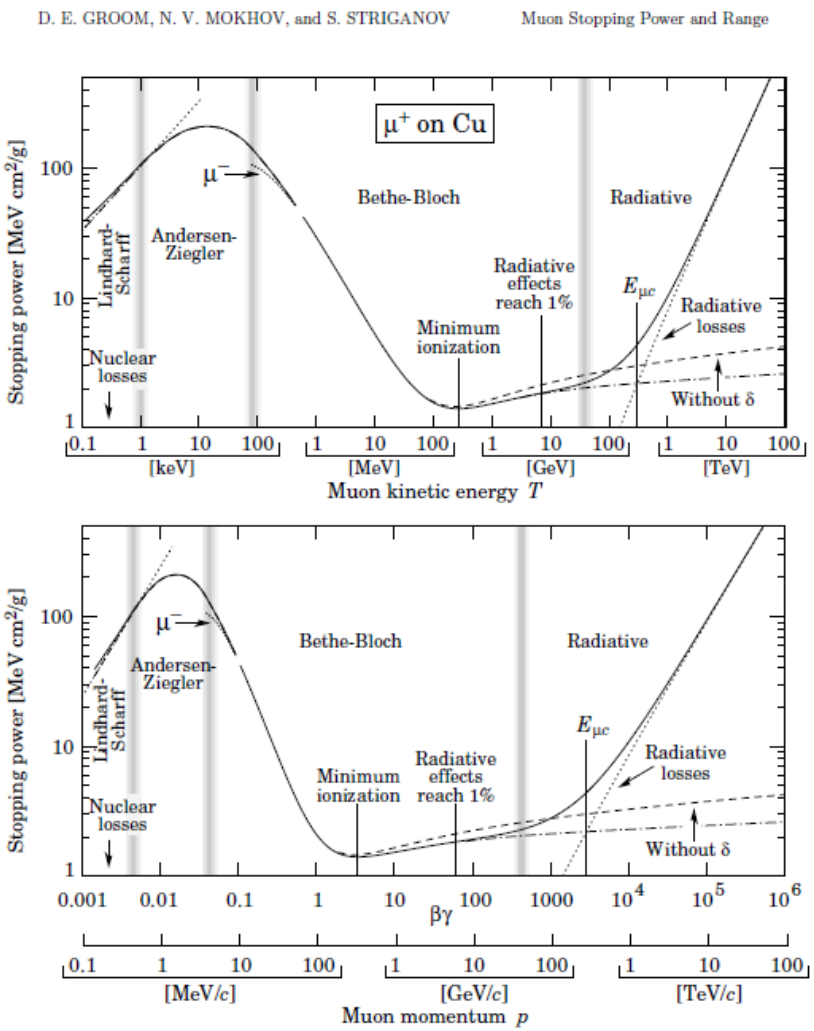
Compare E = 50 TeV vs. E = 7 TeV
Womersley et. al parameterization
λ (99%) ~ 0.64+1.063 ln(E(GeV))

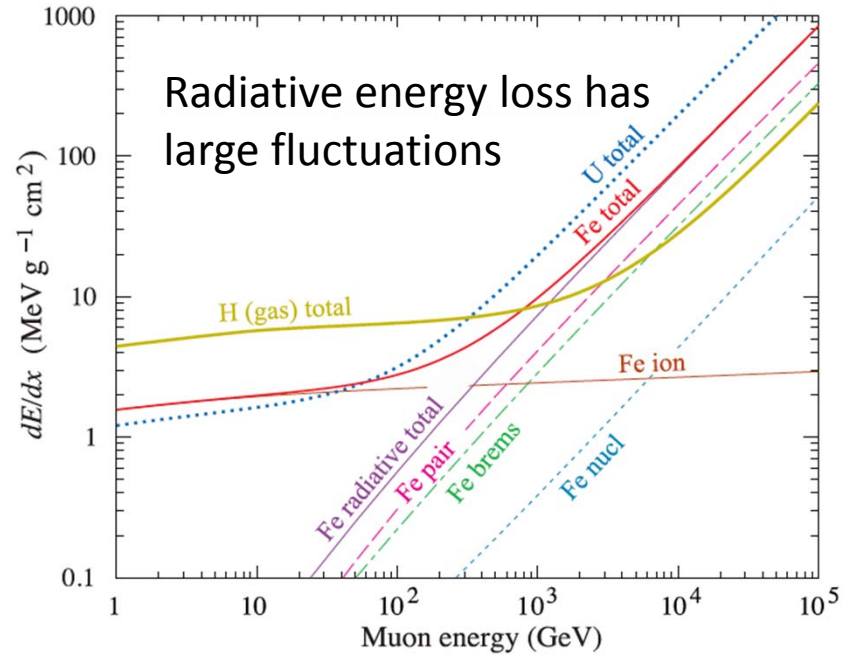
Predicts ratio of thickness for same shower containment (99%):
λ(50 TeV)/λ(7 TeV) ~ 1.2

Thus:
LHC 11 to 14 λ -> FCC 13 to 17 λ

Highly segmented calorimeter useful for isolation cuts around muon in $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$

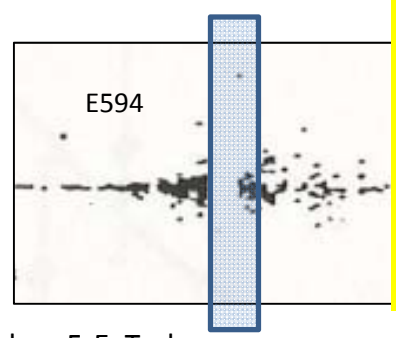
dE/dx correction & Co-traveling BKG





$dE/dx \approx 1.6E^{0.0572} + 0.0034E^{1.0897}$

Muon Station

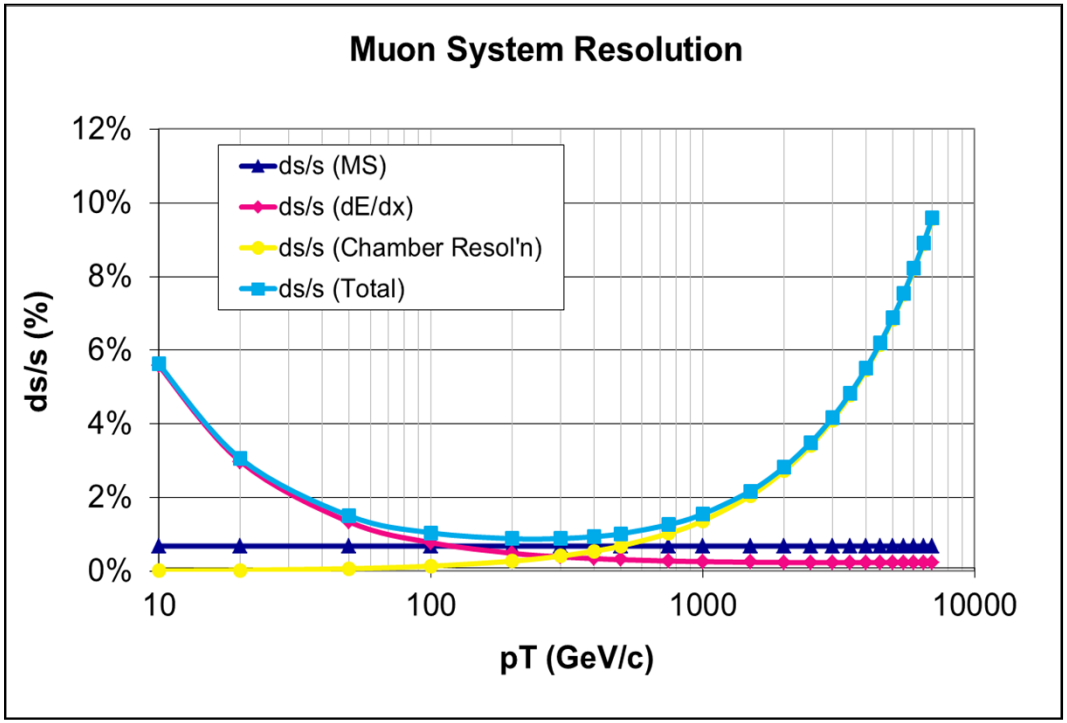


Muon radiation before Tracking station -> air gap and B-field needed as well as good double track capability

Achieving Goal Performance ($\eta \sim 0$)

Option 3

B (T)	L (m)	BL^2 (Tm^2)	BL (Tm)
1.70	8.70	128.67	14.79
$X_{Middle}/X0$	Station Resol'n (μm)	Alignment (μm)	SR $\sqrt{1.5}$ (μm)
34.0%	50.00	20.00	65.95
Calorimeter ($n\lambda$)	λ (g/cm^2)	g/cm^2	$\delta(\Delta E)/\Delta E$
15.00	132.00	1980.00	15.0%



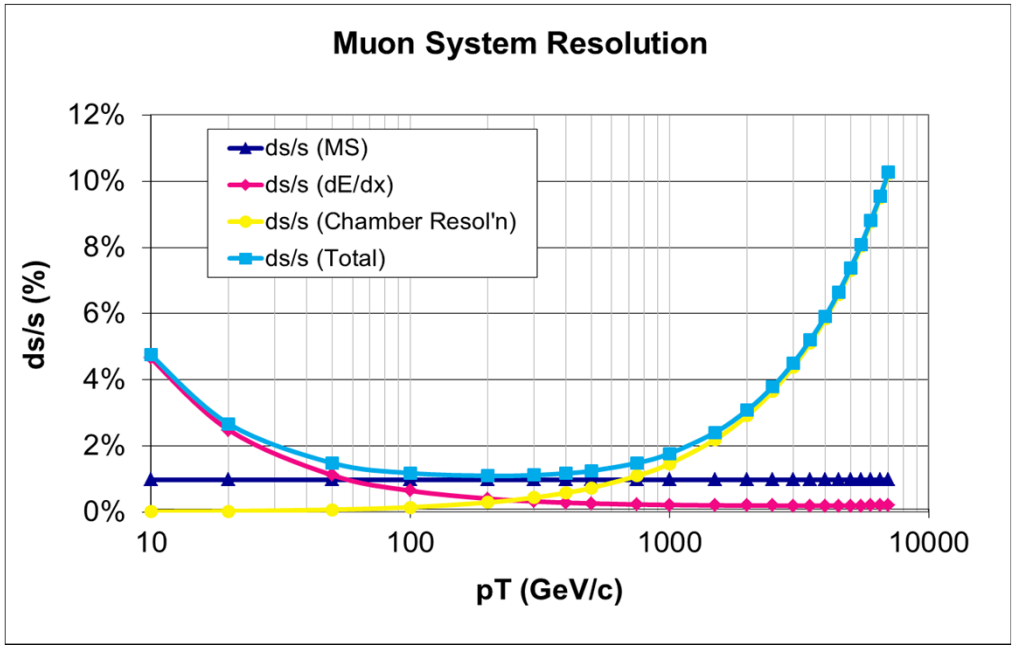
- Increase BL^2 by 7/LHC
- Increase calorimeter thickness by 1.2 to have same containment

s ~ 690 μm @ pT = 7 TeV/c
In order to meet design criterion must measure this to 10%

‘Super’ Chamber Resolution

Option 3 with super-chamber resol'n

B (T)	L (m)	BL^2 (Tm^2)	BL (Tm)
1.70	6.10	63.26	10.37
$X_{Middle}/X0$	Station Resol'n (μm)	Alignment (μm)	SR √1.5 (μm)
34.0%	20.00	20.00	34.64
Calorimeter (nλ)	λ (g/cm^2)	g/cm^2	δ(ΔE)/ΔE
15.00	132.00	1980.00	15.0%



- Assume ‘super’ chamber resolution of 20 μm (Coffee break discussion with Marcello Mannelli)
- BL^2 required decreases and cost of magnet system decreases
- But is it possible to achieve this chamber resolution ?

s ~ 340 μm @ pT = 7 TeV/c
In order to meet design criterion must measure this to 10%

B-Field Configuration

- Option 1A: Single Solenoid Design – GEM Inspired
  - Add 2 Fe field shaper cones in endcap
- Option 1B: Solenoid with iron barrel and endcap toroids – SDC Inspired
- Option 1*: Single 6T Solenoid Design – CMS Inspired
  - Add 2 endcap dipoles and Fe return Yoke
- Option 2*: Twin Solenoid – MRI Inspired
  - 6 T inner solenoid, 3T shielding coil, 2 endcap 2T dipoles
- Option 3*: Central 3.5 T solenoid and 1.7 T External Toroid – ATLAS Inspired
  - Add 2 internal 2T dipoles

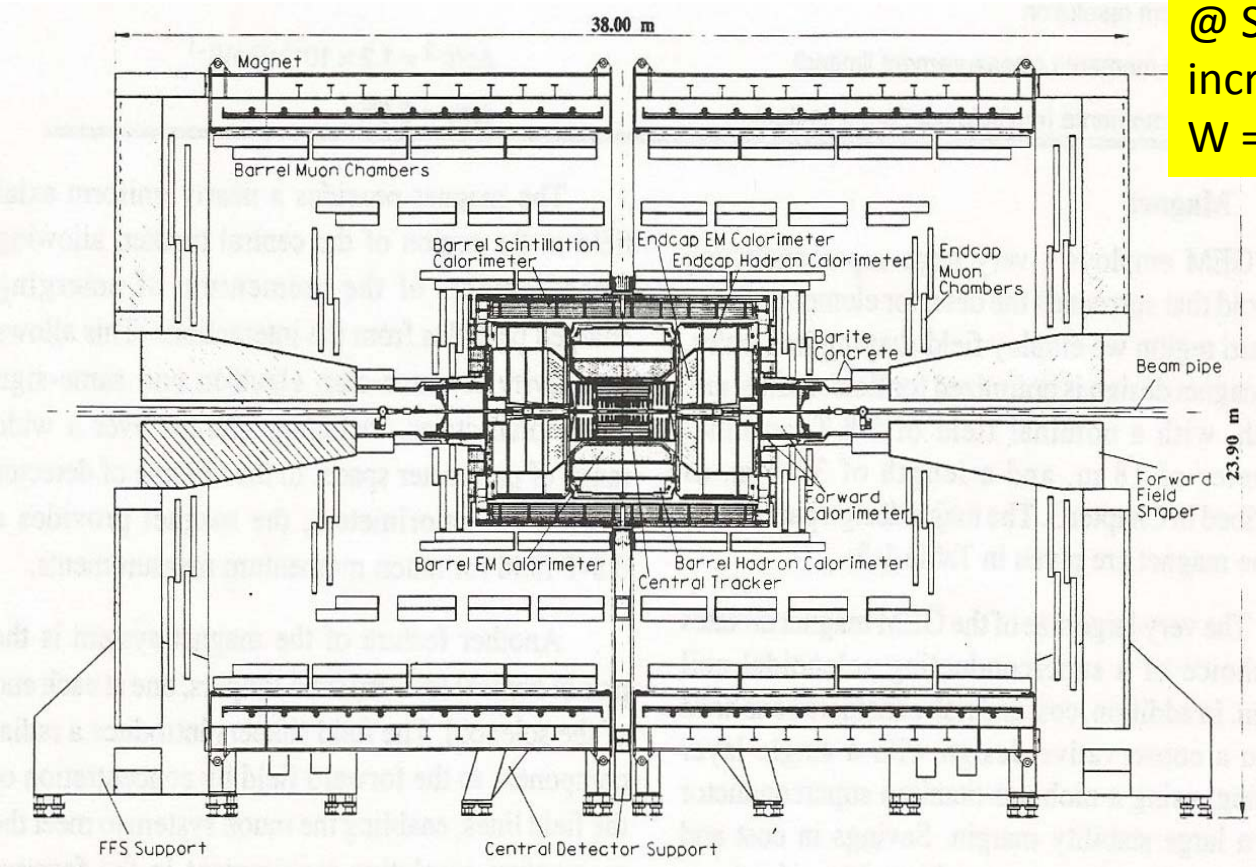
All options make an effort to enhance high $|\eta|$ performance

*Follow Herman ten Kate and Jeroen van Nugteren, CERN, 14 February 2014
Following discussions with D. Fournier, F. Gianotti, A. Henriques, L. Pontecorvo
https://indico.cern.ch/event/282344/session/13/contribution/87/material/slides/0.pdf

GEM-SSC Inspired Design – Option 1A

- GEM @ SSC √s = 40 TeV B = 0.8 T, W = 2.5 GJ

Assume performance adequate @ SSC then BL^2 is scaled 2.5 by increasing L by $(2.5)^{1/2} = 1.58$. $W = 2.5 \times (1.58)^3 = 9.9$ GJ



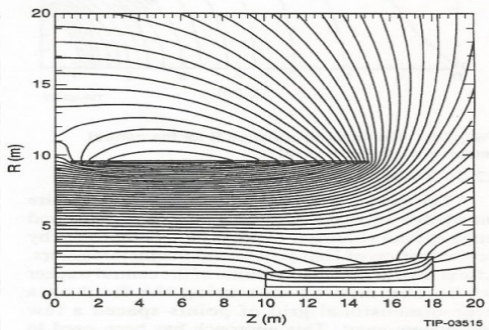


FIG. 3-4. Contours of constant flux.

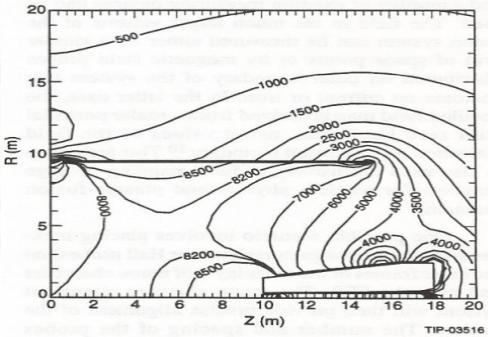
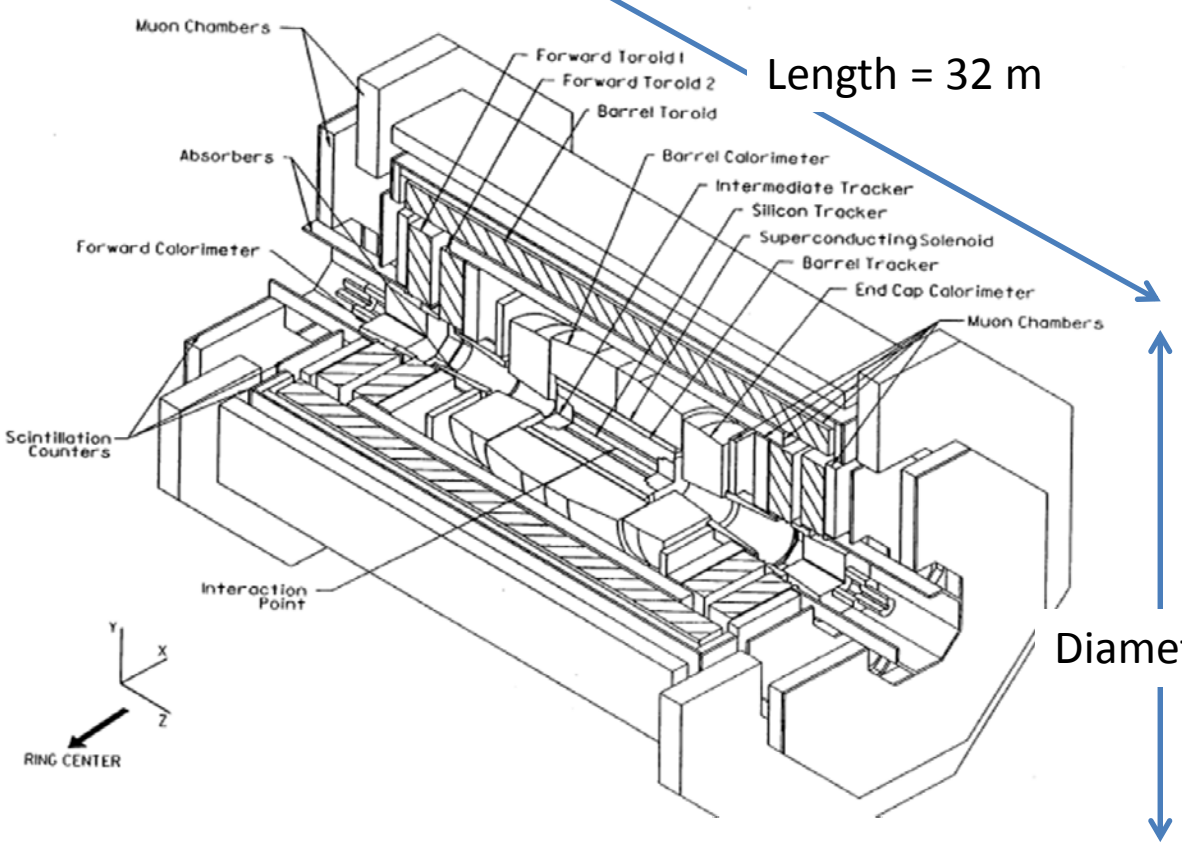


FIG. 3-5. Contours of constant B labeled in gauss.

Forward Fe B-field shaper for more bending at high |η|

SDC-SSC Inspired Design – Option 1B

- SDC @ SSC √s = 40 TeV (roughly same size as GEM but with Fe)
  - Central solenoid B= 2 T (3.4 m) and barrel B = 1.8 T + endcap iron toroids



Length = 32 m

Diameter = 22 m

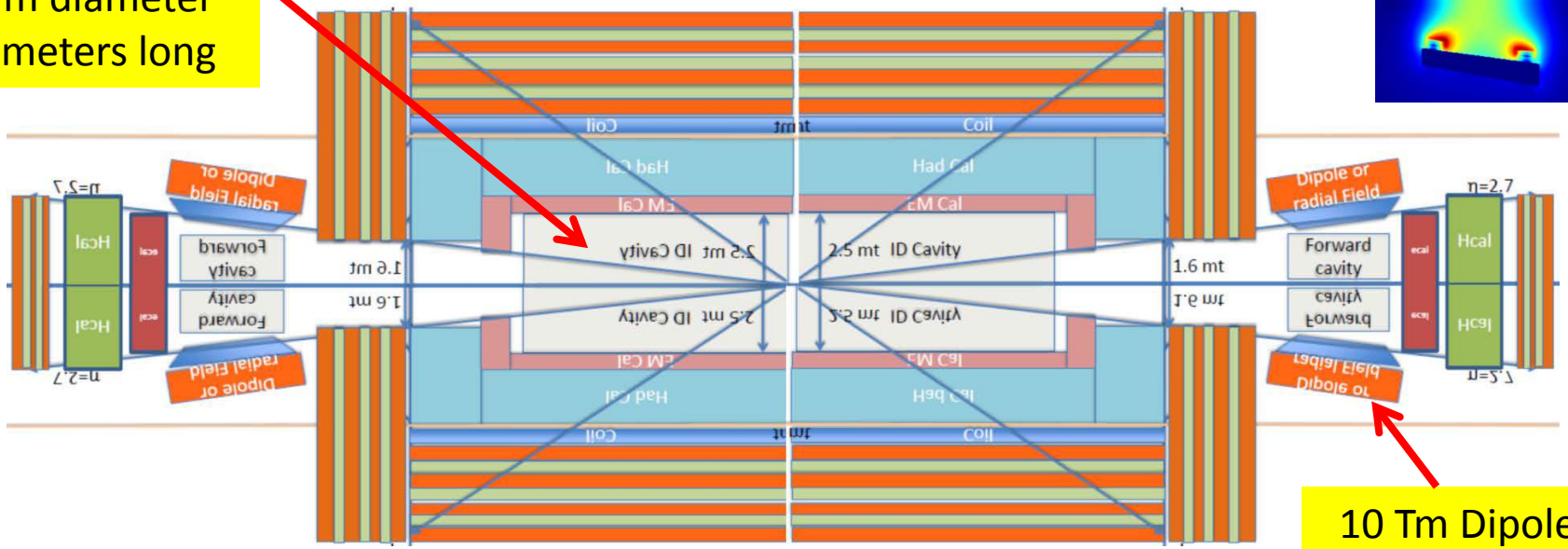
Because of iron in design scale to 100 TeV by keeping B values ~ the same and extending dimensions by $(2.5)^{1/2} = 1.58$

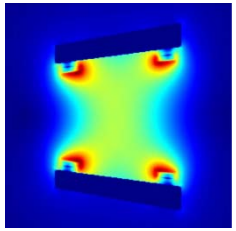
Length ~ 51 m

Diameter ~ 35 m

Option 1: Solenoid-Yoke + Dipoles (CMS inspired)

5-6 T Solenoid
12 m diameter
23 meters long

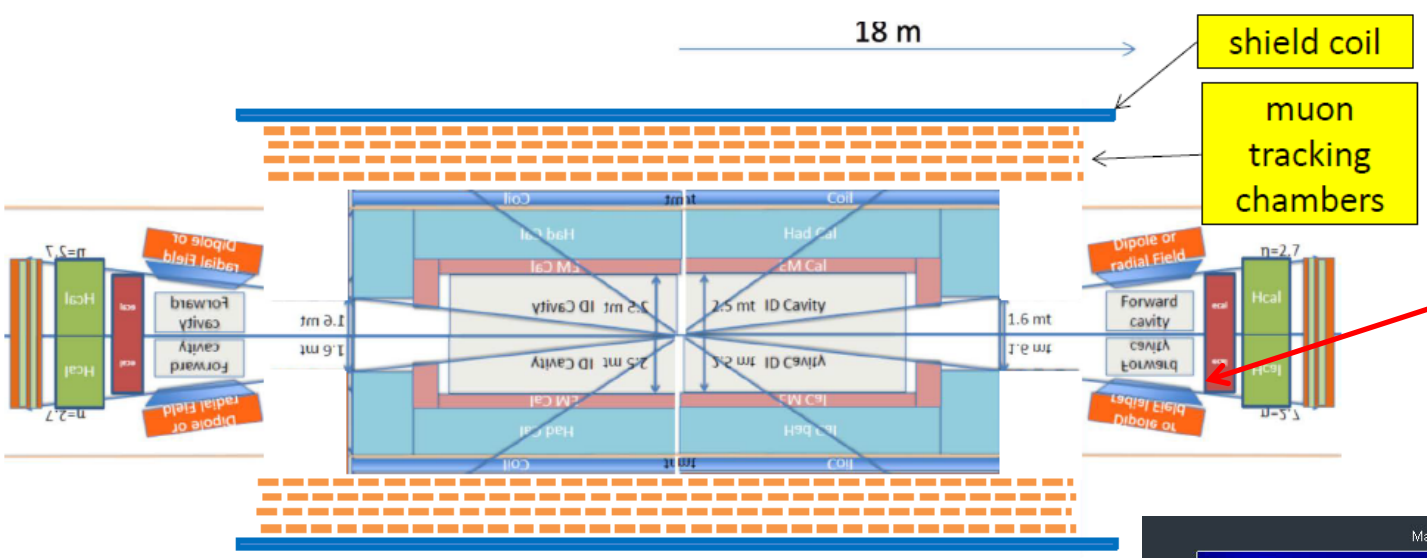


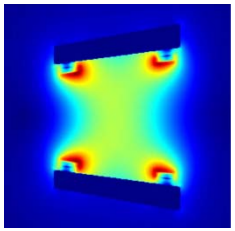


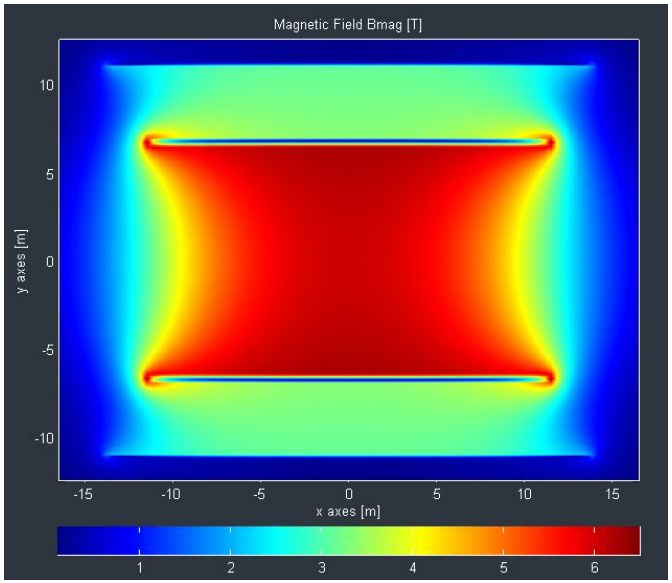
10 Tm Dipole

- Stored magnetic energy 54 GJ in solenoid
- Dipole or radial field in high rapidity region for enhanced bending power
- Iron Flux return makes design massive
  - mass ≈120 k tons (>200 M€ raw material) in comparison to CMS 12.5 k tons
  - Large mechanical engineering challenge – design impractical

Option2: Double Solenoid Design – MRI Inspired



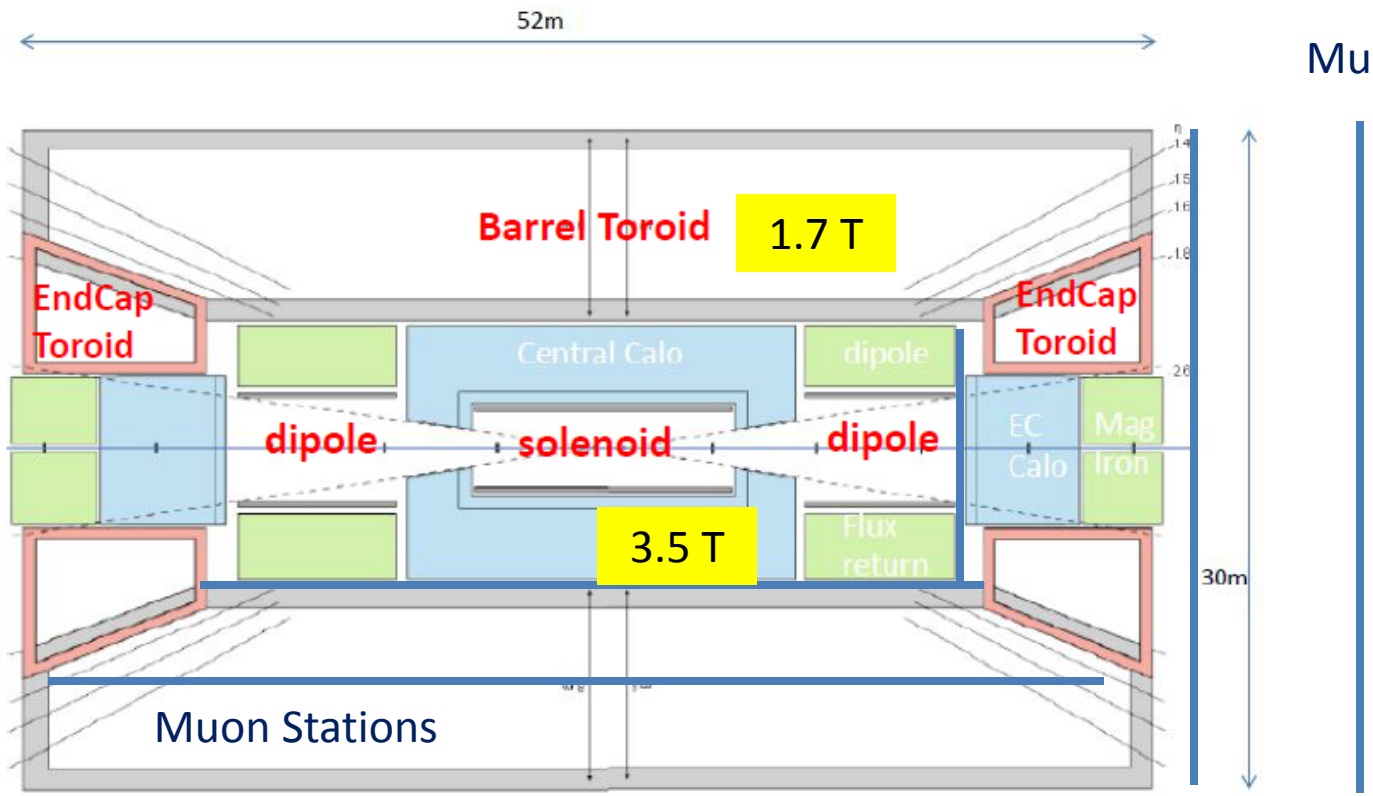




- Resultant Fields – vector sum of inner & outer coils (inner has 8.3 T windings)
  - 6 T central solenoid – inner tracker
  - - 3 T outer solenoid – muon system
  - Magnetic circuit $\Phi_{outer} = - \Phi_{inner}$
- Low mass construction
- Stored energy W = 65 GJ

P > 12 GeV/c to get out of inner solenoid

Option 3: Solenoid + Toroids + Dipoles – ATLAS Inspired

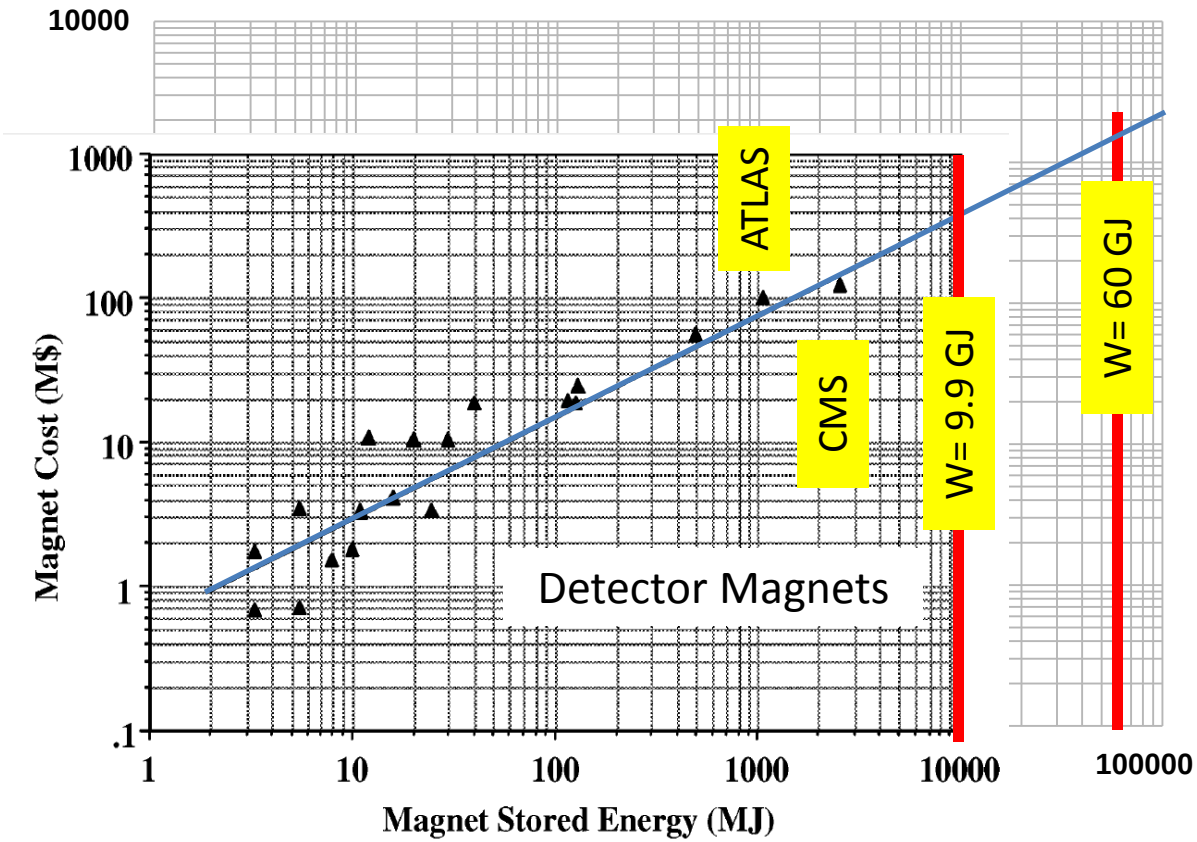


- Air core Barrel Toroid with 7 x muon bending power BL^2.
- 2 End Cap Toroids to cover medium angle forward direction.
- 2 Dipoles to cover low-angle forward direction.
- Overall dimensions: 30 m diameter x 51 m length (36,000 m^3).

W=55 GJ

Cost of Magnet System

- M. A. Green & B. P. Strauss
  - IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 18, NO. 2, JUNE 2008



Cost 2007 US$

$$C(M\$) = 0.58\,[E(MJ)]^{0.69},$$
$$C(M\$) = 0.55\,[\Omega(T\text{-}m^{3})]^{0.65}$$
$$C(M\$) = 0.75\,[M(tons)]^{0.80}$$

Cost(W(60 GJ)) ~ 1,150 M$
(no cryogenics)
~ 10X CMS
Cost(W(9.9 GJ) ~ 331 M$

$$\frac{BL^2}{\left(B^2L^3\right)^{2/3}} \sim B^{-1/3}$$

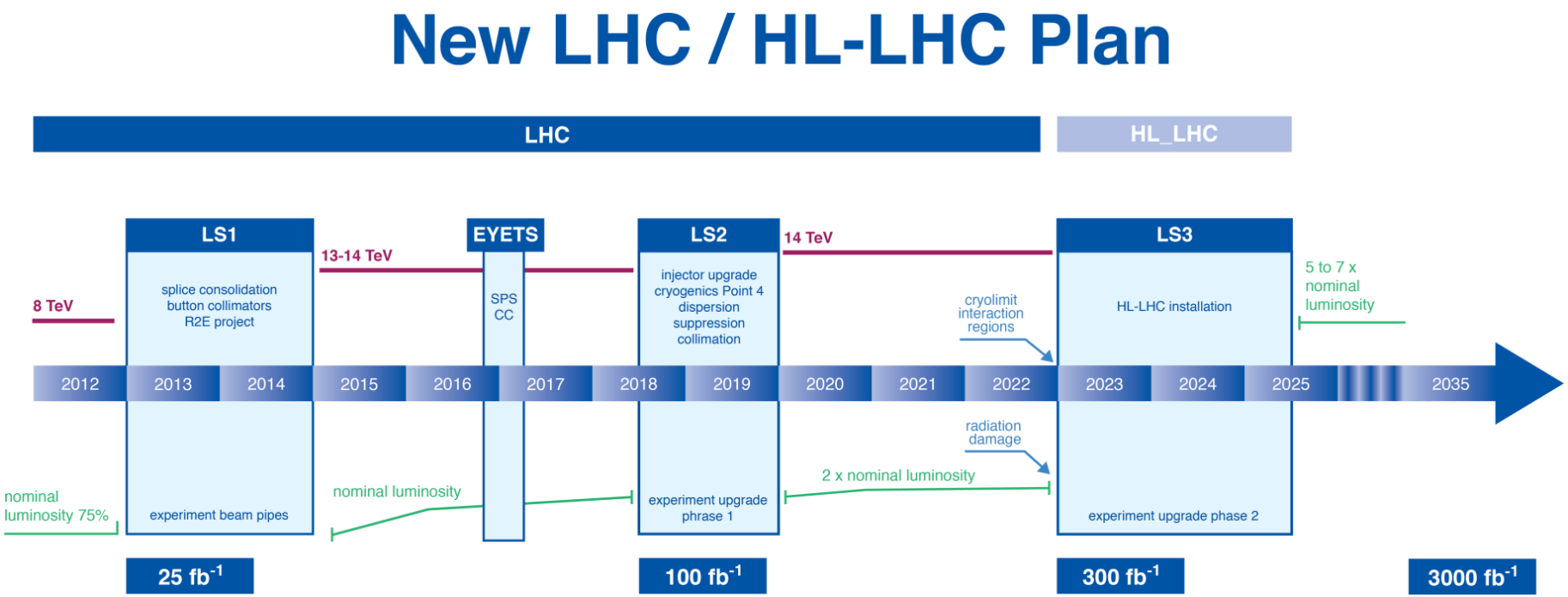
Cost considerations favor lower B-field but should be evaluated for each design

Appraisal of Designs

- Option 1A GEM-SSC: Single solenoid + Fe shaper, W=9.9 GJ
  - Least stored energy but forward B-flux shaper has limitation $\sigma pT/pT \sim 20\%$ @ pT=7TeV/c and $|\eta| = 2.5$
  - Muon system and calorimeter all within solenoid
  - Laissez-faire Flux return
- Option 1B SCD-SSC: Central solenoid, Fe barrel & endcap toroids
  - Because of Fe in design BL^2 scaling results in large size & a lot of Fe
- Option 1: Single solenoid with Fe Yoke + EC, W=54 GJ
  - Expensive and heavy construction – large mechanical engineering
  - But attraction is good resol'n by inner tracker so muon system can be less precise
- Option 2: Double Solenoid + EC, W=65 GJ
  - Elegant and lighter design
  - Worry about getting enough bending at high $|\eta|$
- Option 3: Central solenoid and toroids + EC, W=55 GJ
  - Complicated magnet designs but good performance at high $|\eta|$ and large BL^2

(Bending power/Cost) favors smaller B but iron mass, if used, has to be considered

R&D Program – Time Frame



- Mandate is to fully exploit LHC < 2035
- FCC TDR around 2030 -> 16 years of R&D for chamber technology development
- Phase I and Phase II LHC Upgrades will provide important R&D lessons and should be used as test bed for chamber R&D

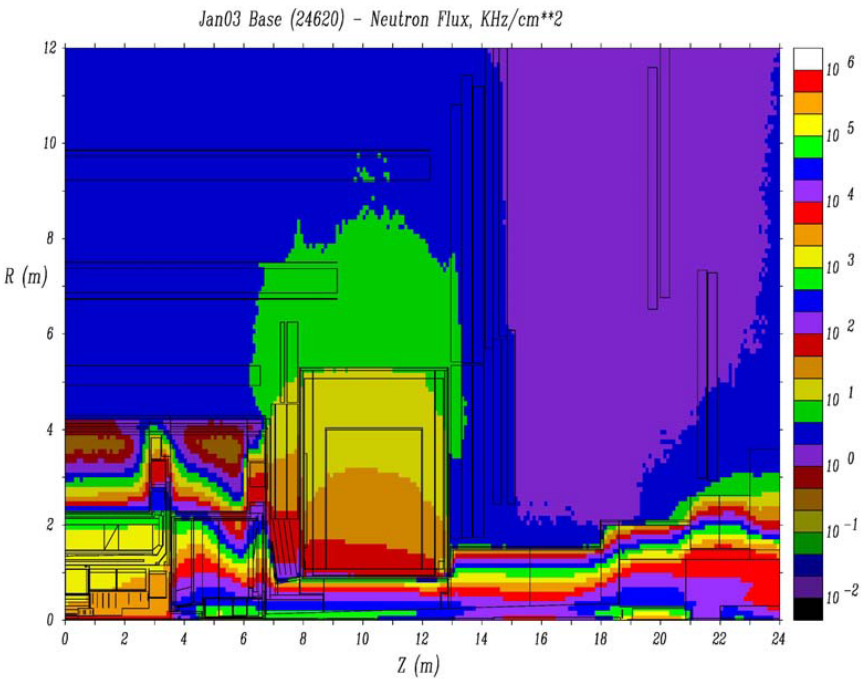
Chamber Technologies

- Choice should be 'conservative' with test experience in a hadron collider environment
  - Drift-based technologies relatively inexpensive way of covering large areas with precision – hence may be suitable for barrel region
  - Technology with highly-segmented readout would be more suitable for endcap where bkg. expected to be higher
  - Should strive for at least 100 μm single layer resolution and expect station resolution to improve by ~ $1/\sqrt{N_{layers}}$ perhaps
  - Is it possible to develop a 'super' resolution chamber technology $\sigma \sim 20\ \mu m$?
  - Integrated design to provide both the 1st (bending) & 2nd coordinates

- R&D advantage to use the <u>same</u> technology for both triggering and tracking in both barrel & endcap
  - However technology choice tends to become highly political and 'Balkan' with individual factions offering their technology for a specific region backed up by their funding agency
  - But may not be optimal in terms of performance

Backgrounds of neutrons & γs

- Most of backgrounds originate from energy deposited in detector by p-p collisions ~ ½ comes from beam line small θ
  - Preliminary ATLAS shielding study predicts a 20% increase from √s = 8 TeV to √s = 14 TeV per p-p collision would predict 3X increase
  - Assuming scaling by √s would predict ~ 10X bkg. of 14 TeV at 100 TeV

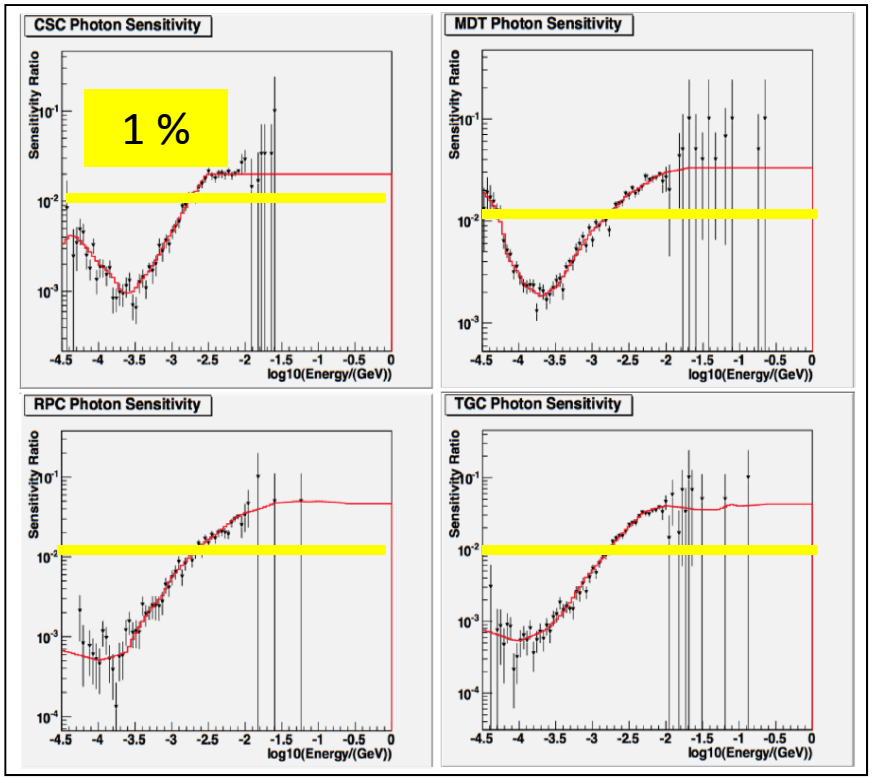


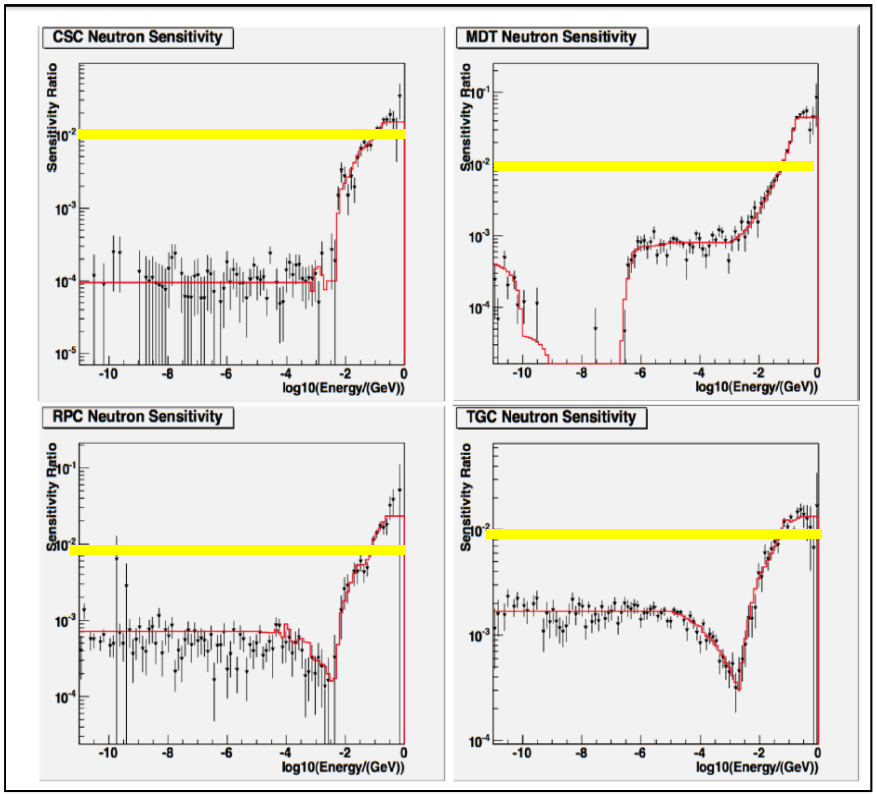
Likely an issue and has to be considered carefully when integrated detector, beam pipe and shielding become realistic.

See talk by Nikolai Mokhov on **Machine-Detector Interface**

Background Sensitivity

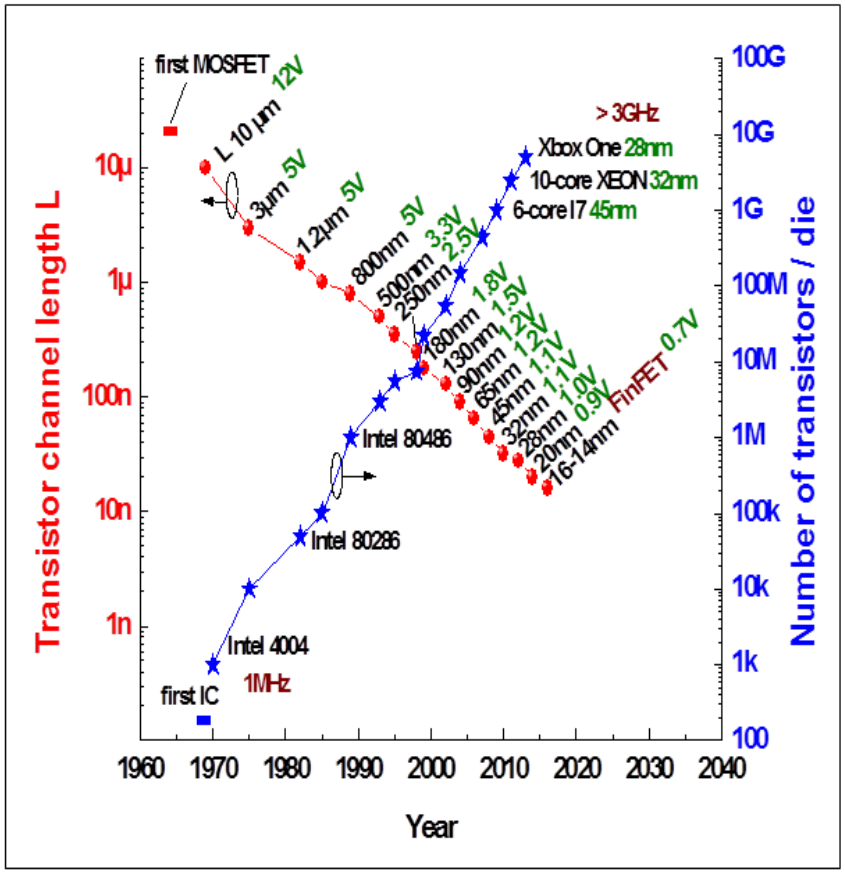
- Important that tracking/triggering technologies have low sensitivity to background neutrons and gammas
  - Requires Low Z and minimum material (ATLAS BKG Study)





Likely Design Principles

- Technology will be light weight, low Z and non-hydrogenous material and be inexpensive/m^2
  - Based on gas amplifier with gain ~ 10^4
- Large areas will have to be covered
  - ATLAS 5,800 m^2 Tracking, 9,300 m^2 Triggering
  - FCC 100 TeV could be larger by √7=2.6 implying a chamber area ~ 15k m^2
- Precision alignment system required ~ 20 μm
- Station Resolution ~ 100/√4 = 50 μm position
- Local vector determination δθ ~ 0.5 mrad
- Front-end ASICS will have more functionality
  - Multiple inputs, ASD, ADC, data flow through fiber optic links
  - High density 3D/2.5 D interconnects
- Have ~ 15 to 20 years for R&D



Gianluigi De Geronimo, TIPP 2014

Consideration-1

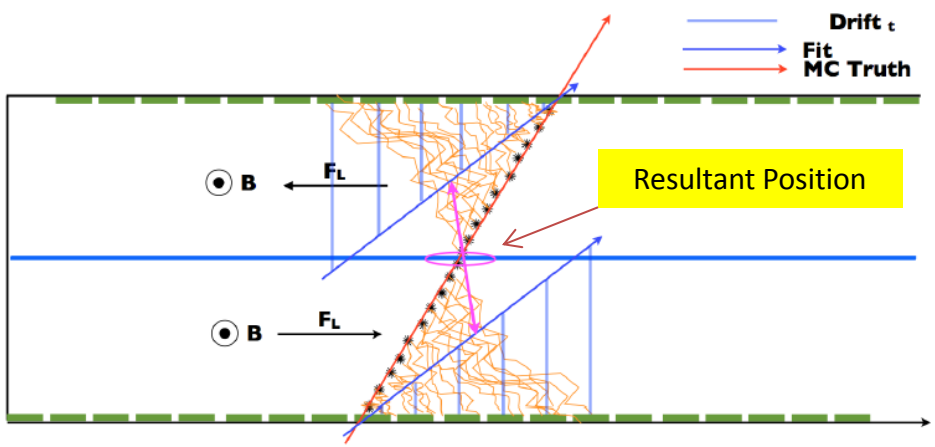
- Lorentz angle
  - Deployment in large B-field will result in a large L-angle depending on gas and E-operating point
    - Drift vector $\mathbf{V_D}$ rotates away from **E**
  - Naive configuration is to make the wires || to B but serious consideration of effect needed for any gas technology in the large B-field options

$$\omega = \frac{eB}{m} = 17.6 MHz / G$$

$$Tan\alpha = \omega\tau$$

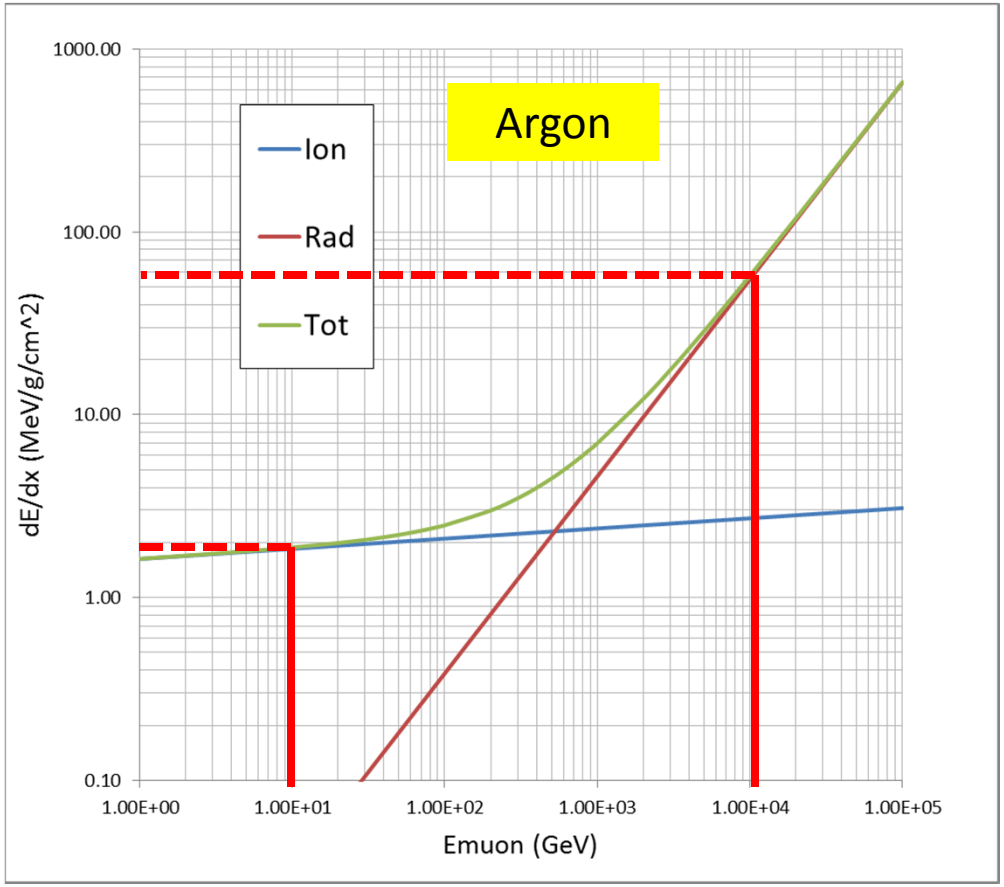
$$V_D = \left(\frac{e\tau}{m}\right) E \frac{1}{\sqrt{1+\omega^2\tau^2}}$$

Example of compensation by using back-to-back HV planes in a Micromega



Consideration-2

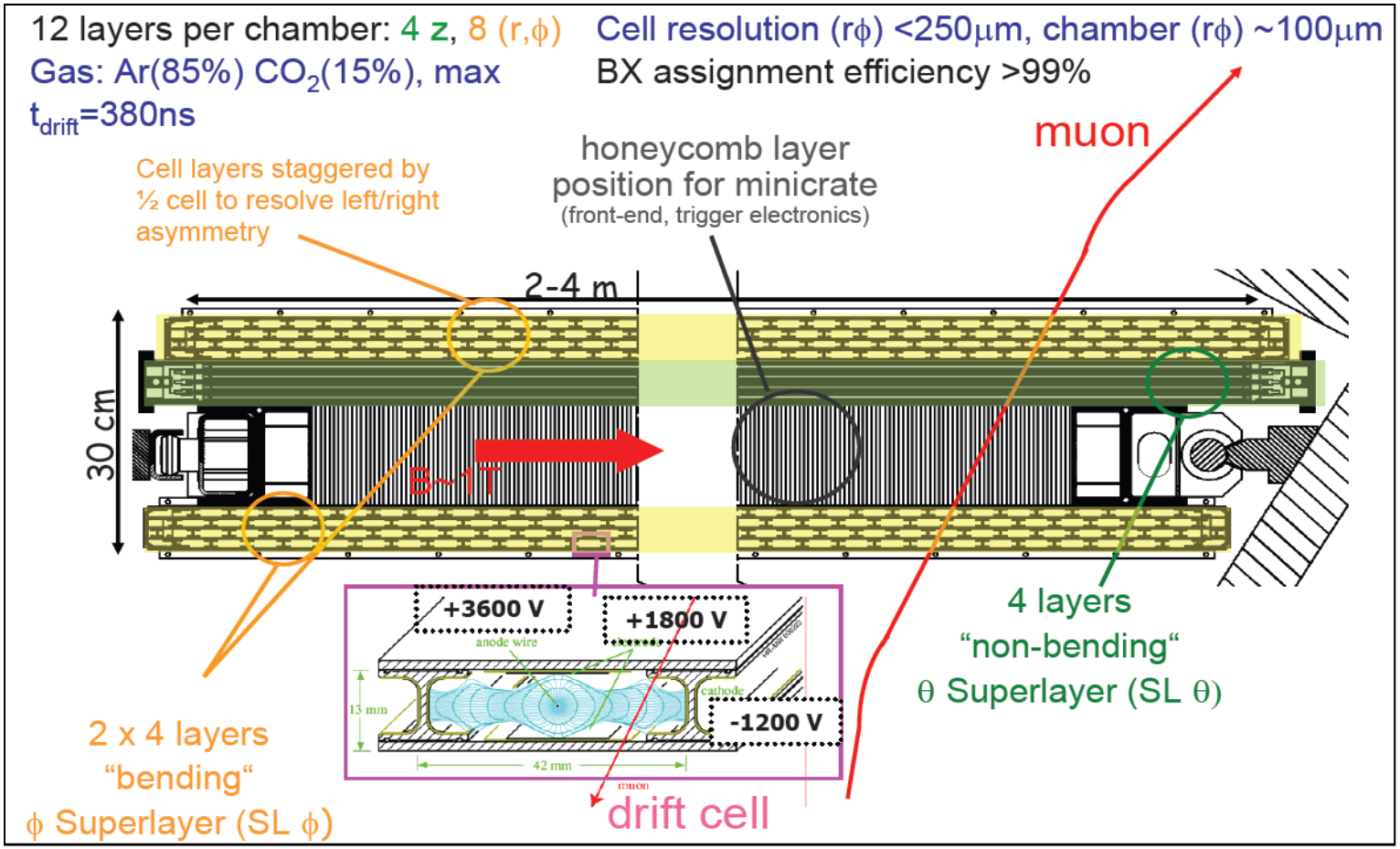
- dE/dx
  - Larger dynamic range needs to be accommodated as muon ionizes gas in chamber
  - Roughly a factor of 25 N_T = 94 x 25 = 2,350 ion pairs/cm
  - Frontend electronics has to have a larger dynamic range
  - Chamber HV system has to be 'stiff' enough not to saturate
  - Perhaps operate at ~ 10^3 gain
- Effect needs a more definitive calculation with realistic gas mixtures and chamber design



dE/dx in gaseous Argon estimated by scaling critical energy to 565 GeV

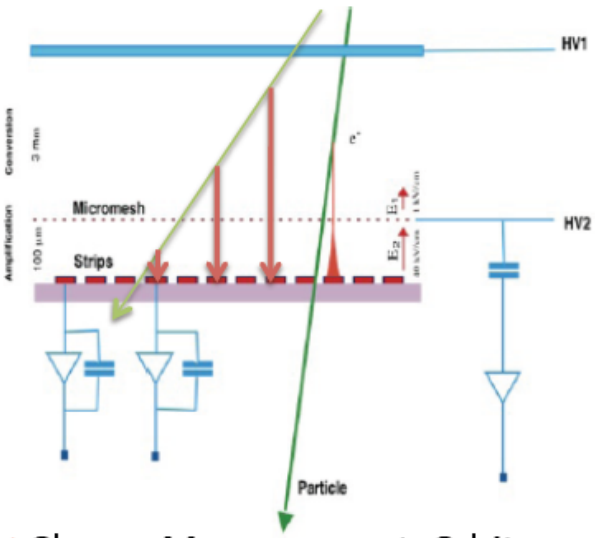
Drift Based Technologies

- Such as CMS barrel deployment
  - Inexpensive way to cover large area with smaller channel count – watch L-angle



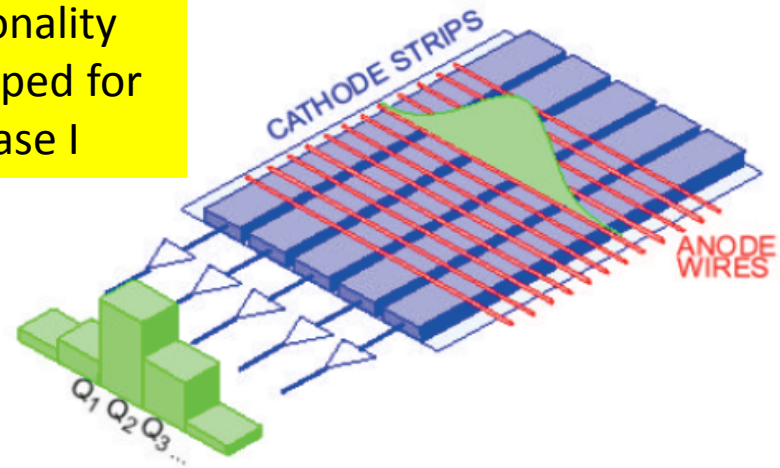
Charge Interpolation Technologies

ATLAS Micromegas – CMS GEM



FE ASIC (VMM) has high functionality being developed for ATLAS Phase I

ATLAS sTGC



- Charge Measurement: 8-bit resolution
- Negative Input
- Micro-TPC mode for inclined tracks 2 ns time resolution
- Large strip capacitance ~ 200 pF
- Trigger primitive: Mmegas Address of first arrival above threshold in a given IC and Bunch crossing
- Shaping time: 50-100 ns

- Charge Interpolation: 8-bit resolution
- Positive Input
- Trigger prompt (at BC clock)) 6-bit amplitude from each strip
- Large strip capacitance ~ 200 pF
- Shaping time: 25 ns

V. Polychronakos, US Workshop on IC Design for High Energy Physics HEPIC2013

Triggering

- Large B fields will make a natural filter blocking low p from muon system
  - For double solenoid design (Option 2) p > 13 GeV/c to get out of inner solenoid
  - Level 1 Threshold value determined by trigger bandwidth
- Design the trigger to measure the actual 3-station track-sagitta
  - In ATLAS, due to cost control, the first layer of barrel was not instrumented with RPC trigger planes
    - Improvements to the barrel trigger using the MDTs are being studied for Phase II
  - And the first layer of the endcap was only minimally instrumented
    - The endcap trigger is being upgraded in Phase I with New Small Wheel
- Ideal would be to have a dual function technology that does both triggering and tracking
  - Fast enough to label beam crossing $\tau \sim$ few ns
  - Develop FE ASIC to generate trigger signal as well as precision hit signal for tracking
  - Fiber optics, fast communications, multiplexing will make more complicated Level 1 triggering feasible
  - Build sufficient trigger latency to form first Level trigger easily
    - Latency 10 to 20 μs (ATLAS presently has 2.5 μs but will be extended to ~ 6 μs in Phase II)

sTGC, MM, CSC, RPC

Table of Muon Technologies

Muon Chamber Technology	Deployment	Comments
Drift Tubes with field shaper electrodes	Barrel Tracking & Triggering Cell resol'n ($r\phi$) < 250 μm	CMS
MDT (Monitored Drift Tubes) 3 cm dia.	Barrel Tracking Tube resol'n ($r\theta$) ~ 150 μm resolution	ATLAS
Small Diameter MDT 1.5 cm dia.	Tracking in some special regions of barrel	ATLAS
Cathode Strip Chambers (CSC)	Endcaps Tracking & CMS Triggering ATLAS: η strip pitch 5.5 mm, ϕ strip pitch 13 - 21 mm	CMS and ATLAS ($2<\|\eta\|<2.7$)
Micromegas	Endcaps Tracking & Triggering Readout pitch ~ 0.4 mm	ATLAS Phase I Upgrade New Small Wheel
Thin Gap Chambers (TGC)	Endcaps Triggering & Tracking 2nd coordinate	ATLAS 1st and 2nd stations Endcap
Small-strip Thin Gap Chambers (sTGC)	Endcaps Triggering & Tracking Fast enough for BC tagging 95% τ < 25 ns; 3 mm strip-pitch	ATLAS Phase I Upgrade New Small Wheel
Resistive Plate Chambers (RPC)	Barrel and Endcaps Triggering Fast τ ~ 3ns ATLAS: η strip pitch ~ 30 mm, ϕ strip pitch ~ 30 mm	ATLAS and CMS
Low Resistivity RPC	Higher rate capability 10^{10} Ωcm	R&D
Multi-gap Resistive Plate Chamber	Very fast τ ~ 50 ps	ALICE and R&D
GEMs (3 layer)	Endcaps Rate ~ 10^5Hz/cm^2 Fast τ ~ 4-5 ns	CMS Phase I Test & Phase II

John Sealy Townsend Circa 1900

Discussion & Summary

- Cost of B-field is likely quite high – but of order of √s ratio 7
  - Follow SMES development in power industry
  - Lower B-field options favored (Bending Power/Cost) ~ $B^{-1/3}$
- Neutron and γ background may be troublesome
  - Crude scaling from 14 TeV to 100 TeV is factor of 10
- Co-traveling EM bkg. around muon track following muon calorimeter/filter may be problematic
  - Design an air gap with B-field sweeping and deploy fine-grained multiple layers
  - Design chamber for large dE/dx up to ~ 50 MeV/(g/cm^2)
- Tracking and Triggering chamber technologies will develop over the next ~20 years – especially the readout and DAQ electronics
  - Strive for an integrated design: trigger and track, 1st and 2nd coordinates
  - Do not compromise on Trigger design – base it on 3-station sagitta
  - Is it possible to make a chamber with ~ 20 μm resolution

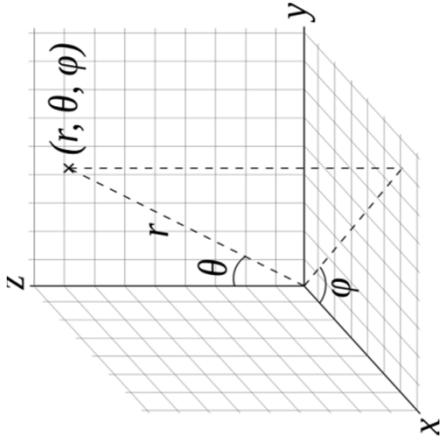
References

- 1st CFHEP Symposium on circular collider physics 23-25 February 2014
  - http://indico.ihep.ac.cn/conferenceDisplay.py?confId=4068
- BSM physics opportunities at 100 TeV, 10-11 February 2014
  - http://indico.cern.ch/event/284800/other-view?view=standard
- Workshop on Physics at a 100 TeV Collider, 23-25 April 2014
  - https://indico.fnal.gov/conferenceDisplay.py?confId=7633
- Large Hadron Collider Physics (LHCP) Conference, 2-7 June 2014
  - https://indico.cern.ch/event/279518/
- Future Circular Collider Study Kickoff Meeting, 12-15 February 2014
  - https://indico.cern.ch/event/282344/
- International Conference on Technology and Instrumentation in Particle Physics
  - http://www.tipp2014.nl/
- XII workshop on Resistive Plate Chamber and Related Detectors
  - http://166.111.32.59/indico/conferenceProgram.py?confId=1
- D. E. Groom, N. V. Mokhov and S. Striganov Muon Stopping Power and Range; Atomic Data and Nuclear Data Tables, Vol. 76, No. 2, July 2001, LBNL-44742
- HADRON SHOWERS IN A LOW-DENSITY FINE-GRAINED FLASH CHAMBER CALORIMETER, W.J. Womersley et al. NIM A267 (1988) 49-68

Additional Slides

General Considerations

- Design Driver is momentum dispersion $BL^2|_{100\ TeV} \sim 7\ BL^2|_{14\ TeV}$
  - Obviously increasing B increases mechanical stresses through magnetic pressure $\sim B^2/2\mu_0$ and by a factor of 7 is untenable
  - More practicable is to increase L with modest increase in B
- Solenoidal Configuration
  - First coordinate (bending) ϕ, second θ
    - Advantage of good vertex constraint in bending
- Toroidal Configuration
  - First coordinate (bending) θ, second ϕ
    - Advantage of higher bending power at larger $|\eta|$

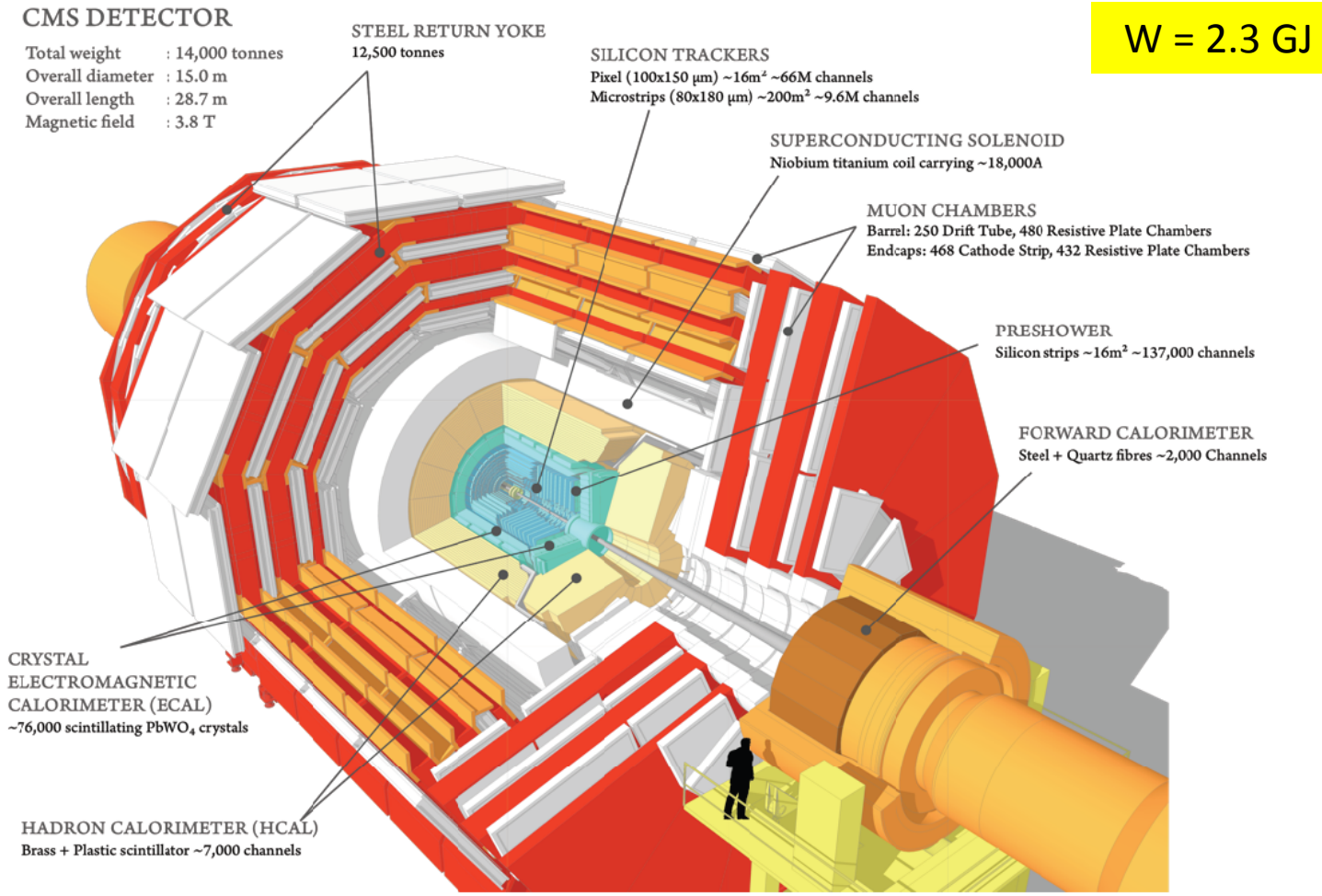


beam

- Muon Chamber system must determine both first and second coordinate
  - High precision required for first coordinate
  - Second coordinate needed for vector ***p*** as well as a pattern recognition invariant

CMS Muon System

W = 2.3 GJ



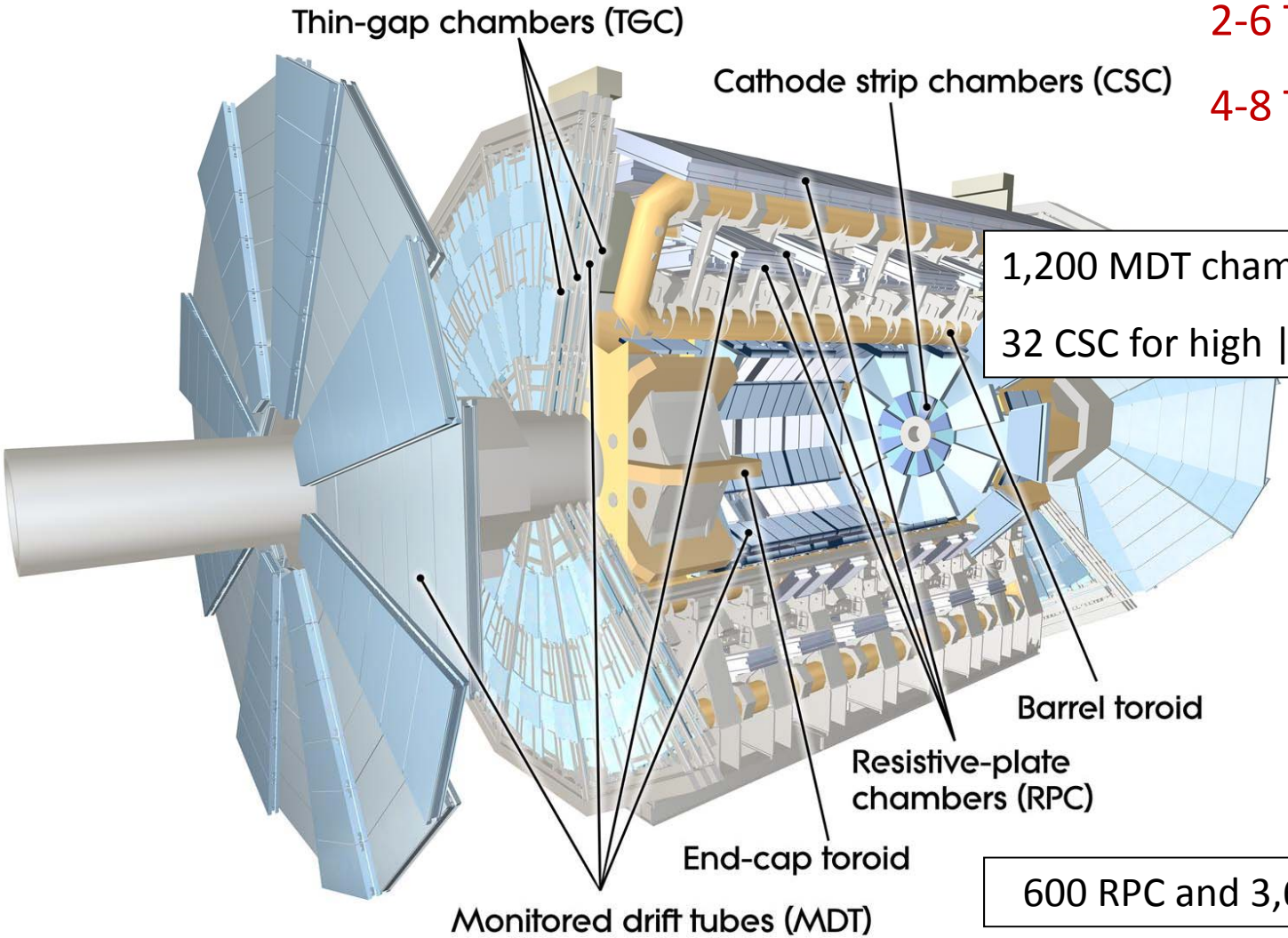
ICHEP2014 - Valencia CMS Muon System L. Guiducci - Università di Bologna & INFN 3

ATLAS Muon System

ΔpT/pT < 10% up to 1 TeV

2-6 Tm $|\eta|<1.3$

4-8 Tm $1.6<|\eta|<2.7$



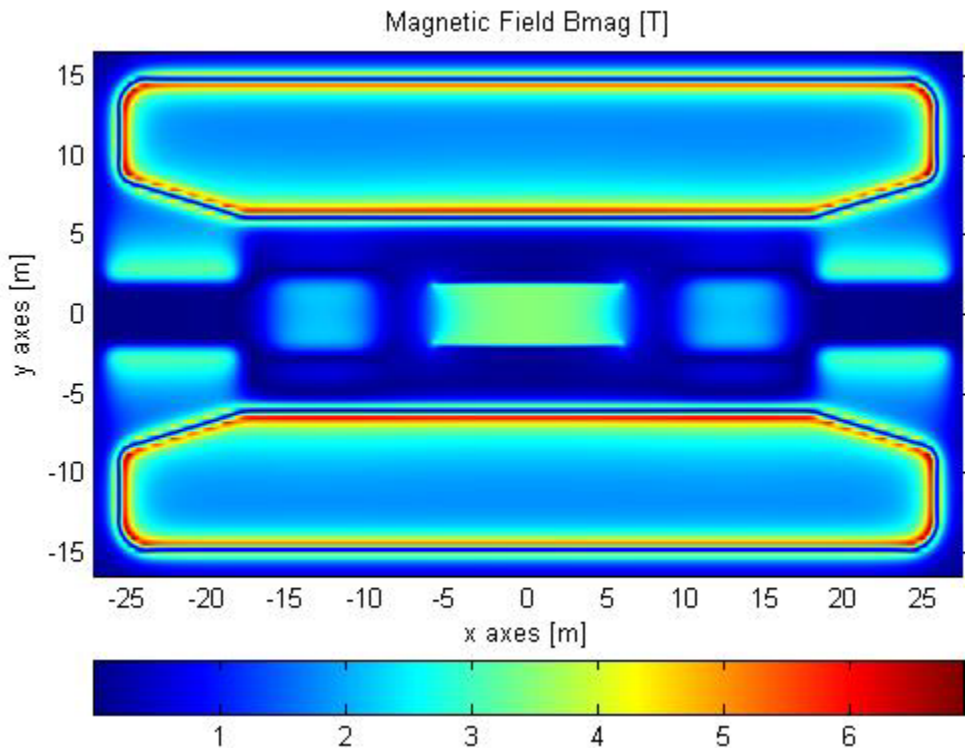
1,200 MDT chambers for tracking

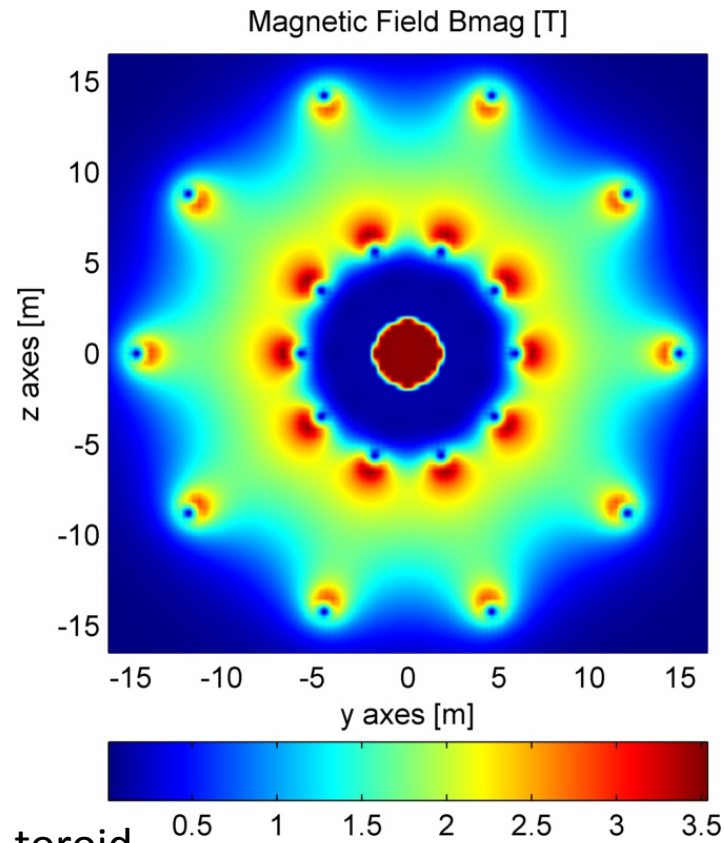
32 CSC for high $|\eta|$ region

Diameter 24 m
Length 45 m
W(B) = 1.0 GJ

600 RPC and 3,600 TGC trigger

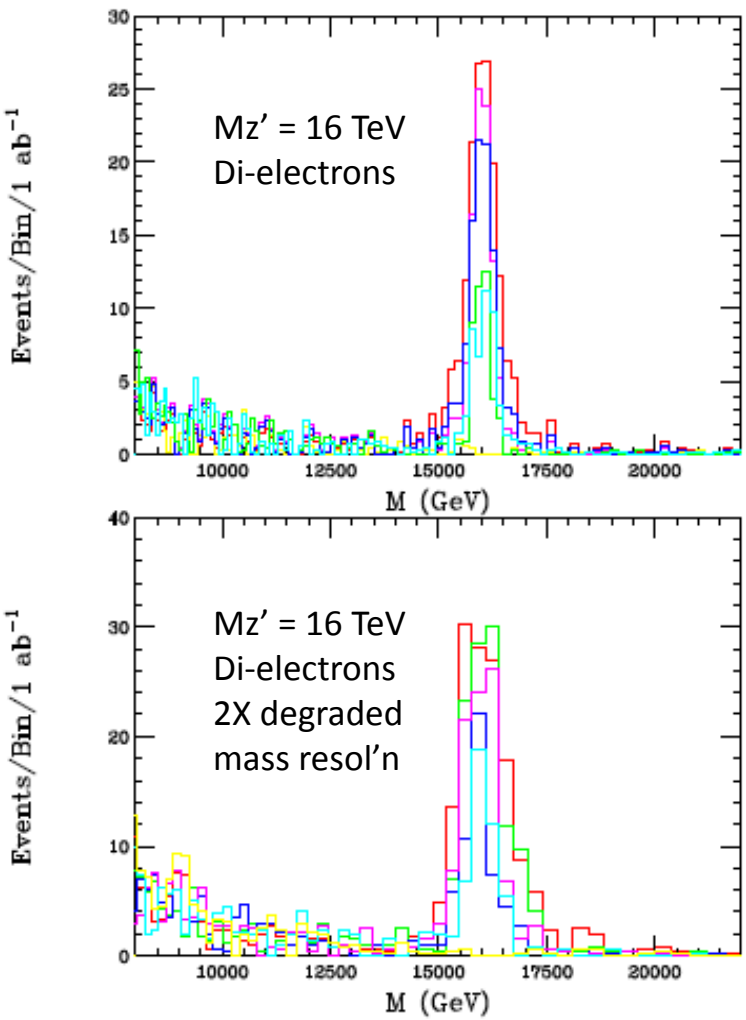
Toroidal Design – ATLAS inspired





- 3.5 T in Solenoid, 2 T - 10 Tm in dipoles and ≈ 1.7 T in toroid
- 55 GJ stored energy (for 16 Tm; 130 Tm^2)
- Complicated and non-uniform B-field
  - Will require high instrumentation
  - Lorentz angle corrections if drift chamber technology used

Search for Massive Gauge Bosons



- Search for massive objects will be a major focus with a 100 TeV Collider
  - Assume $\mathcal{L} \sim 1$ ab^{-1} by Rizzo* $\mathcal{L}\sigma B_l$

Model	10 TeV	15 TeV	20 TeV	Disc.	Excl.
SSM	2021.	232.6	36.65	23.8	27.3
LRM	1353.	156.1	24.62	22.6	26.1
ψ	573.7	65.93	10.37	20.1	23.6
χ	1372.	159.0	25.18	22.7	26.2
η	626.8	71.82	11.38	20.3	23.8
I	1241.	144.4	22.94	22.4	25.7

  - Di-electron mass resolution is better but di-muons may be cleaner
  - A challenge is to design a muon system with sufficient resolution
    - If $\delta p/p \sim 10\%$ for $p \sim 10$ TeV then $\delta m \sim 2$ TeV for $m \sim 20$ TeV

*Rizzo arXiv:1403.5465v3 [hep-ph] 7 May 2014

Dealing with ΔE_μ

- The ΔE_μ correction is unimportant in CMS-like detector (central tracker)
- In muon system stand-alone operation the ΔE_μ correction is important

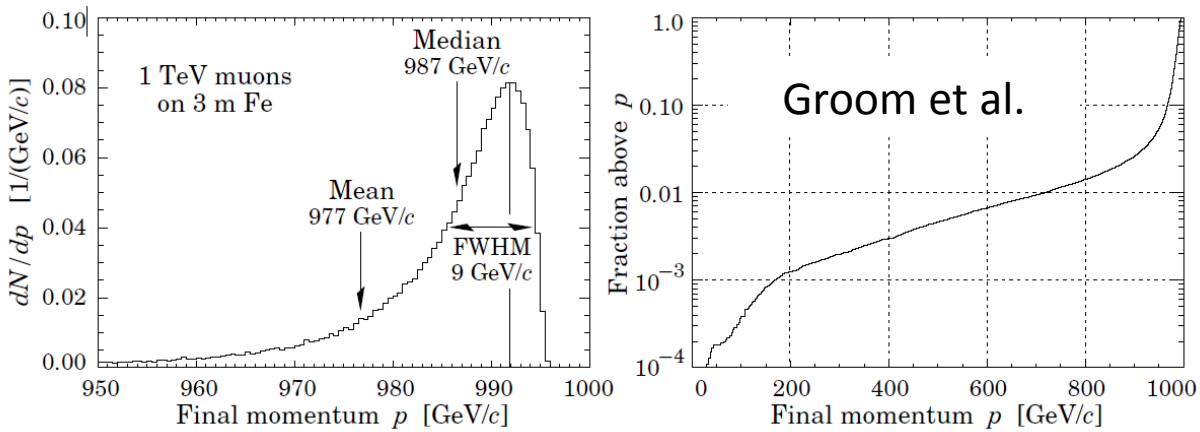


Figure 8: The momentum distribution of 1 TeV/c muons after traversing 3 m of iron, as obtained with the MARS14 Monte Carlo code [59]. The comparative rarity of very low final momenta follows from the approach of the cross sections to zero as $\nu \to 0$.

$$\frac{\delta s_{\Delta E}}{s} \sim \frac{\delta p_{\Delta E}}{p} \sim \frac{b\Delta E(p,X)}{p}$$

<u>Reality check of b =15%</u>

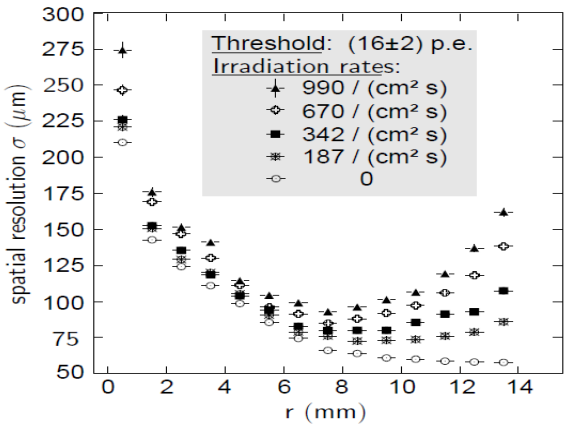
ΔE=23 GeV, FWHM = 9 GeV

σ=3.8 GeV

$\sigma/\Delta E$ = 3.8/23 = 16.5%

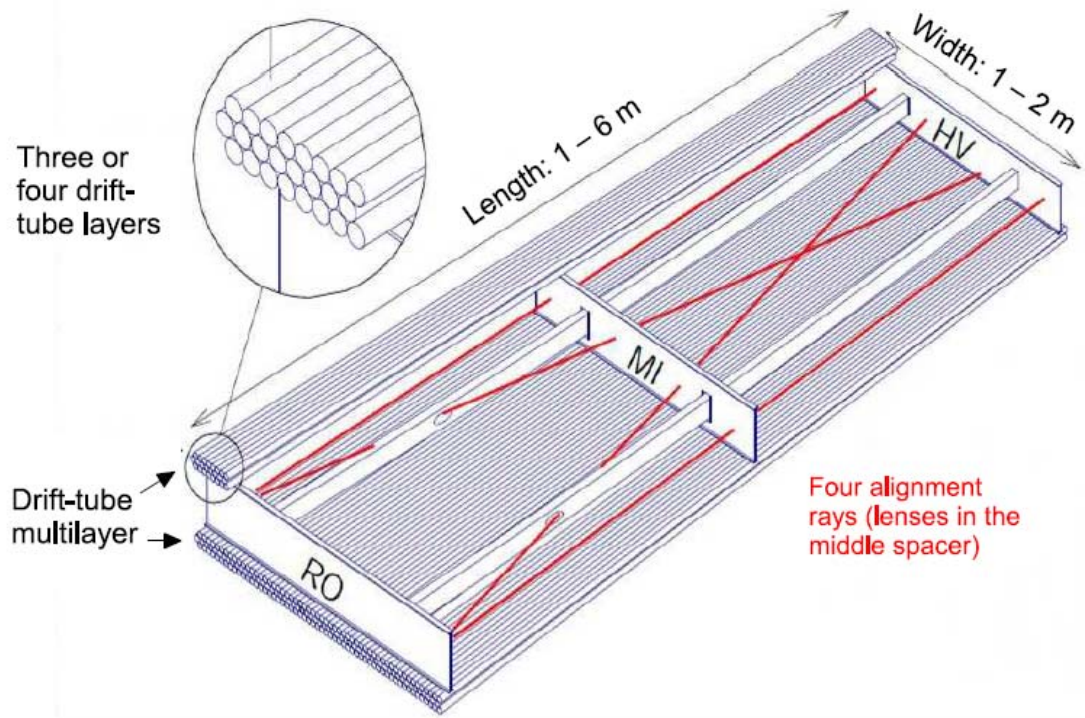
Drift Technologies – Barrel Deployment

- ATLAS – Monitored Drift Tubes



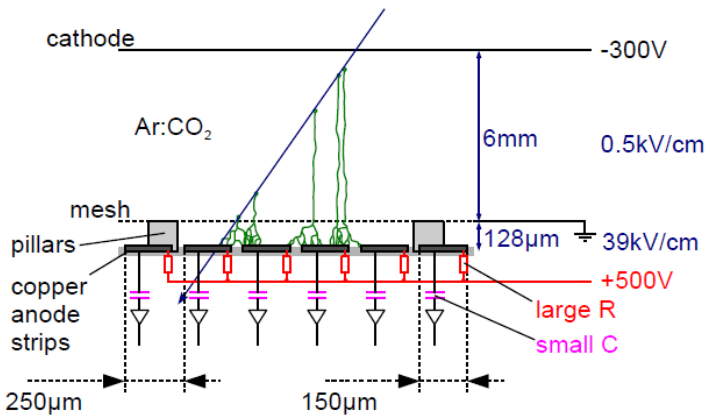
Parameter	Design value
Tube material	Al
Outer tube diameter	29.970 mm
Tube wall thickness	0.4 mm
Wire material	gold-plated W/Re (97/3)
Wire diameter	50 μm
Gas mixture	$Ar/CO_2/H_2O$ (93/7/$\leq$ 1000 ppm)
Gas pressure	3 bar (absolute)
Gas gain	2 x 10^4
Wire potential	3080 V
Maximum drift time	$\sim$ 700 ns
Average resolution per tube	$\sim$ 80 μm

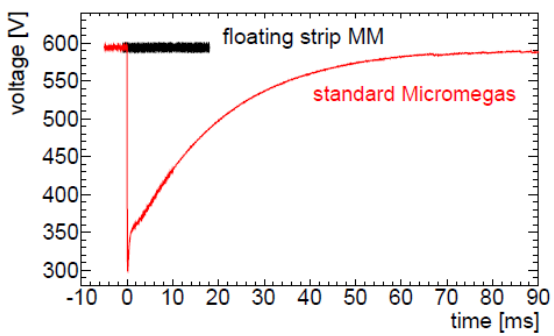
A drift-based technology is an efficient way to cover large areas without high channel counts. Resolution degrades in high backgrounds.



High Rate Micromega

Floating Strip Micromegas





challenge: discharges

- charge density $\geq 2 \times 10^6\,\mathrm{e}/0.01\,\mathrm{mm}^2$
- conductive connection → potentials equalize
- non-destructive, but dead time → efficiency drop

idea: minimize the affected region

- "floating" copper strips:
  - strip can "float" in a discharge
  - individually connected to HV via 22MΩ
  - capacitively coupled to readout electronics via pF HV capacitor
  - only two or three strips need to be recharged

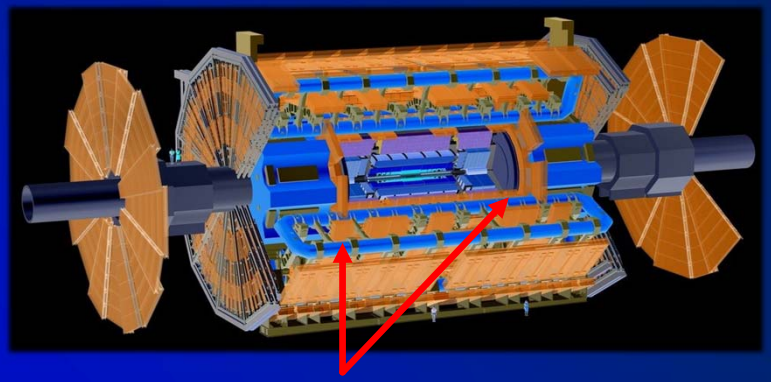
→ dedicated measurements & detailed simulation

VMM (2015-16?)

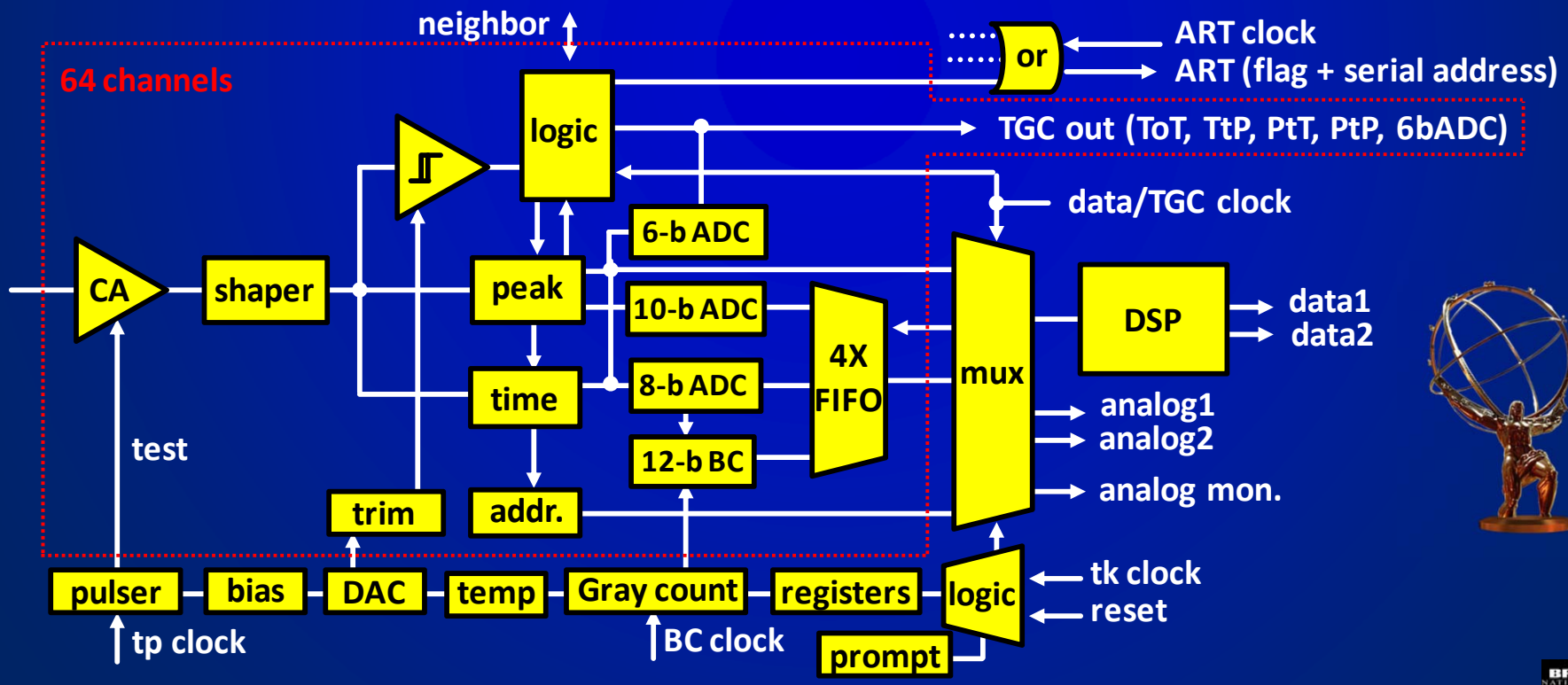
Gianluigi De Geronimo, TIPP 2014

64 channels, >6M MOSFETs (<u>>80k/ch</u>)
130nm, 1.2V, 0.4 W/cm², >110mm²
high complexity/functionality w/DSP
for ATLAS muon spectrometer/tracker

V. Polychronakos



New Small Wheels
sTGC , MicroMegas, 2.3M channels

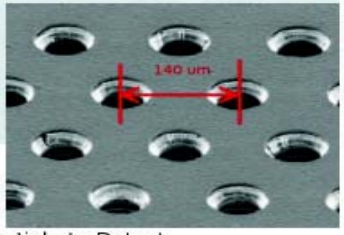


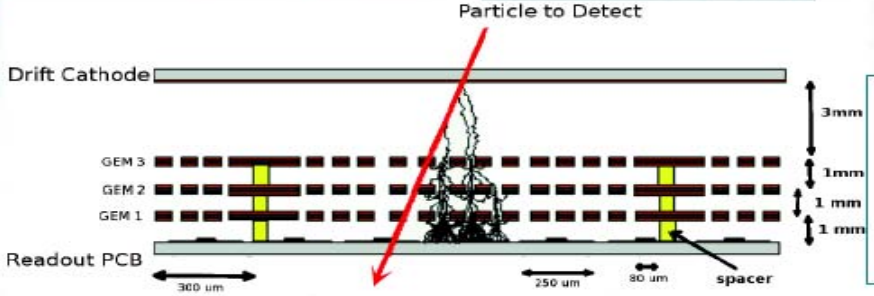
CMS Gas Electron Multipliers

- Phase II Upgrade – Forward Trigger

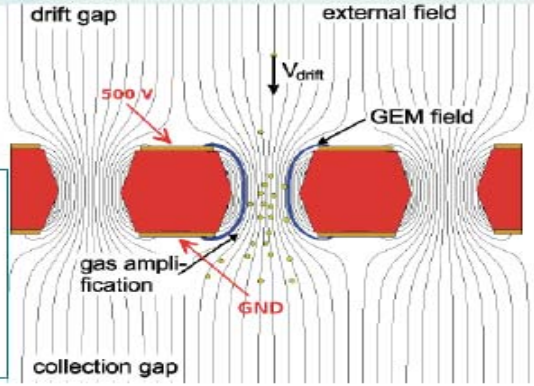
- **Rate capability:** 10^5Hz/cm2
- **Spatial/Time resolution:** ~ 100 μm / ~ 4-5 ns
- **Efficiency:** > 98%
- **Gas Mixture:** Ar/CO2/CF4 (45/15/40), non flammable
- **Typical Gas gain:** >10^4
- Radiation hardened

- GEM foils developed using PCB manufacturing techniques
- **Large areas:** ~ 1m x 2m with industrial processes (cost eff.)
- Each foil (perforated with holes) is 50μm kapton sheet with copper coated sides (5μm)
- **Typical hole dimensions:** Diameter = 70μm, Pitch = 140μm





GAIN
~ 20
~ 20
~ 20
~ 8000



Cesare Calabria – ICHEP2014 - "Large-size triple GEM detectors for the CMS forward muon upgrade"

Outline

- Examples of muon systems/physics discovery
  - J/Psi
  - Upsilon
  - W/Z
  - Higgs
- Measurement problem – emulate the present LHC detector performance
  - Size of point-like cross section vs. sqrt s
  - Luminosity needed and backgrounds
  - Designer's toolkit
    - Bending
    - MS
    - Rad loss
    - Filtering/punch-through
    - Chamber resolution
- Basic configuration
  - Toroid vs. Solenoid – strong central tracker vs. strong stand-alone muon system
    - Comparison of ATLAS vs. CMS
    - How will these configurations scale?
- Triggering & Tracking
  - Gas amplification
  - Strip & pad vs. Pixels (pixel possible?)
  - Costs & channel count
  - Combined function the best – example micromega and the ATLAS New Small Wheel project