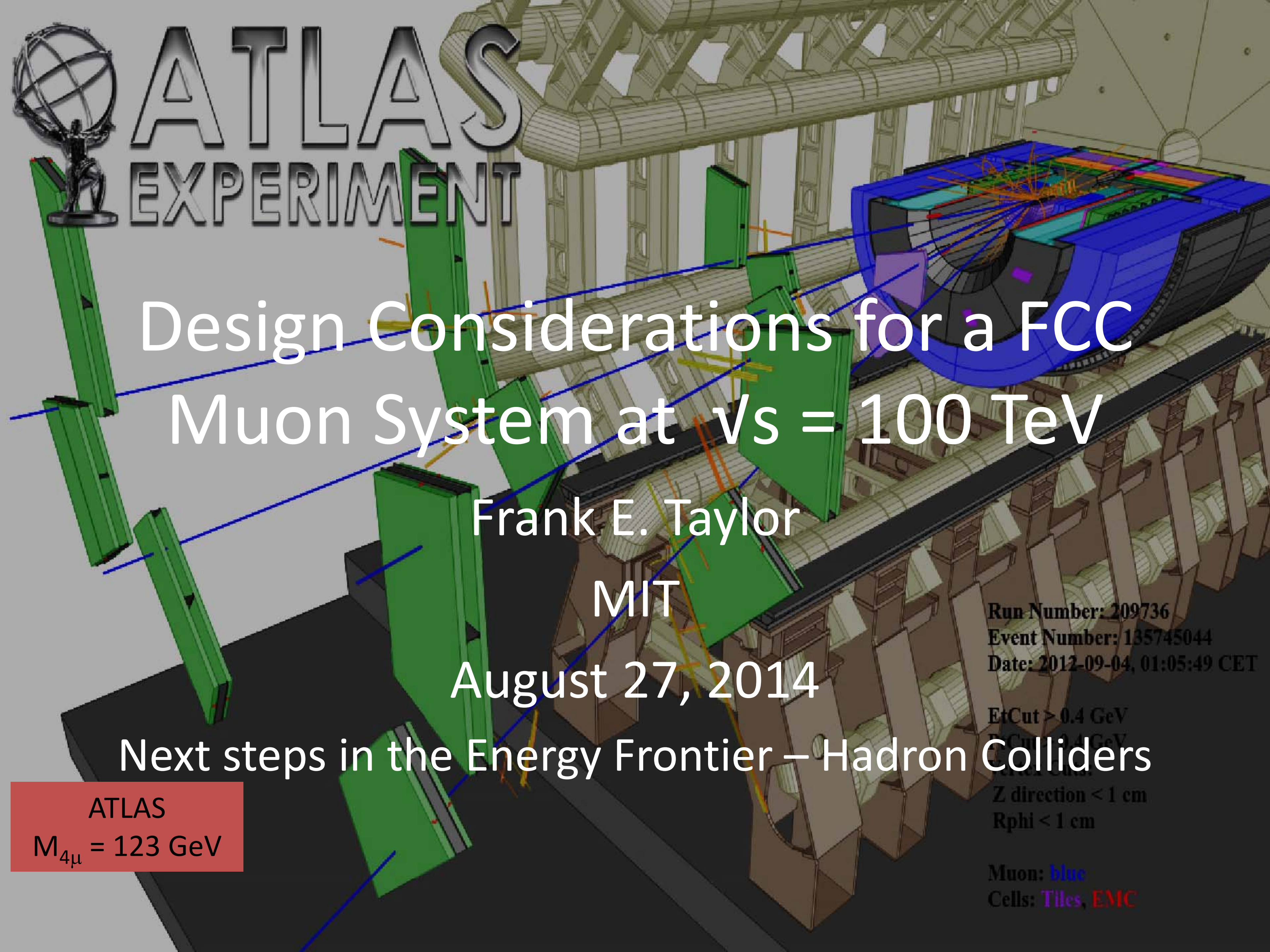


Design Considerations for a FCC Muon System at $\sqrt{s}$ = 100 TeV

Frank E. Taylor

MIT

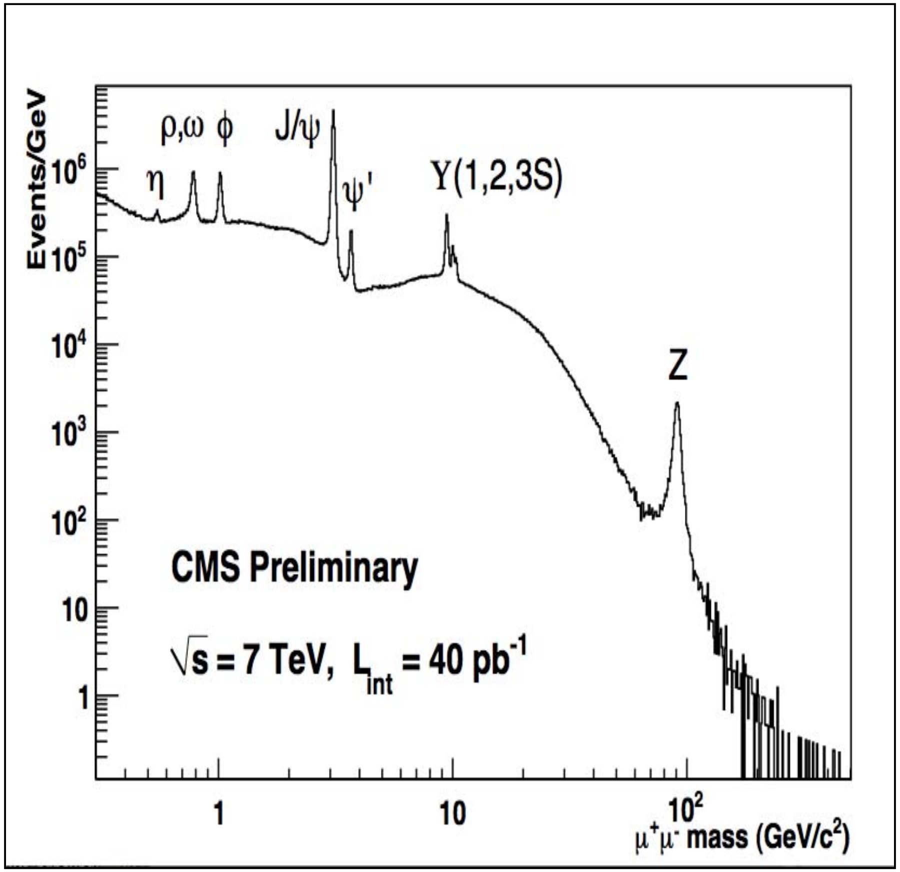
August 27, 2014

Next steps in the Energy Frontier – Hadron Colliders

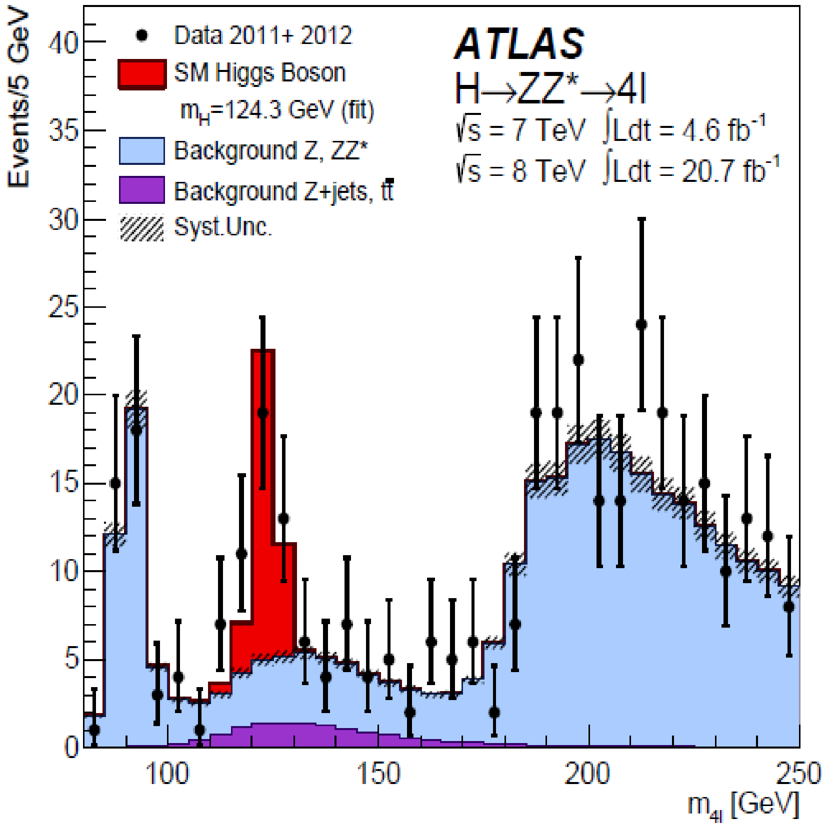
ATLAS
$M_{4\mu}$ = 123 GeV

Muons – Window to Physics

CMS



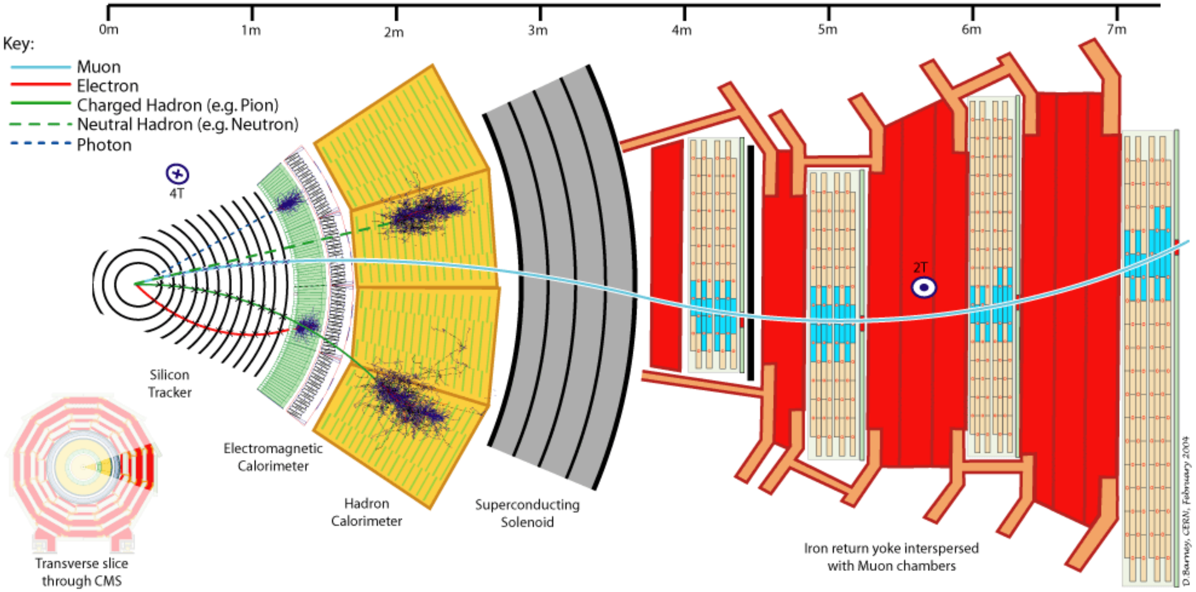
ATLAS



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

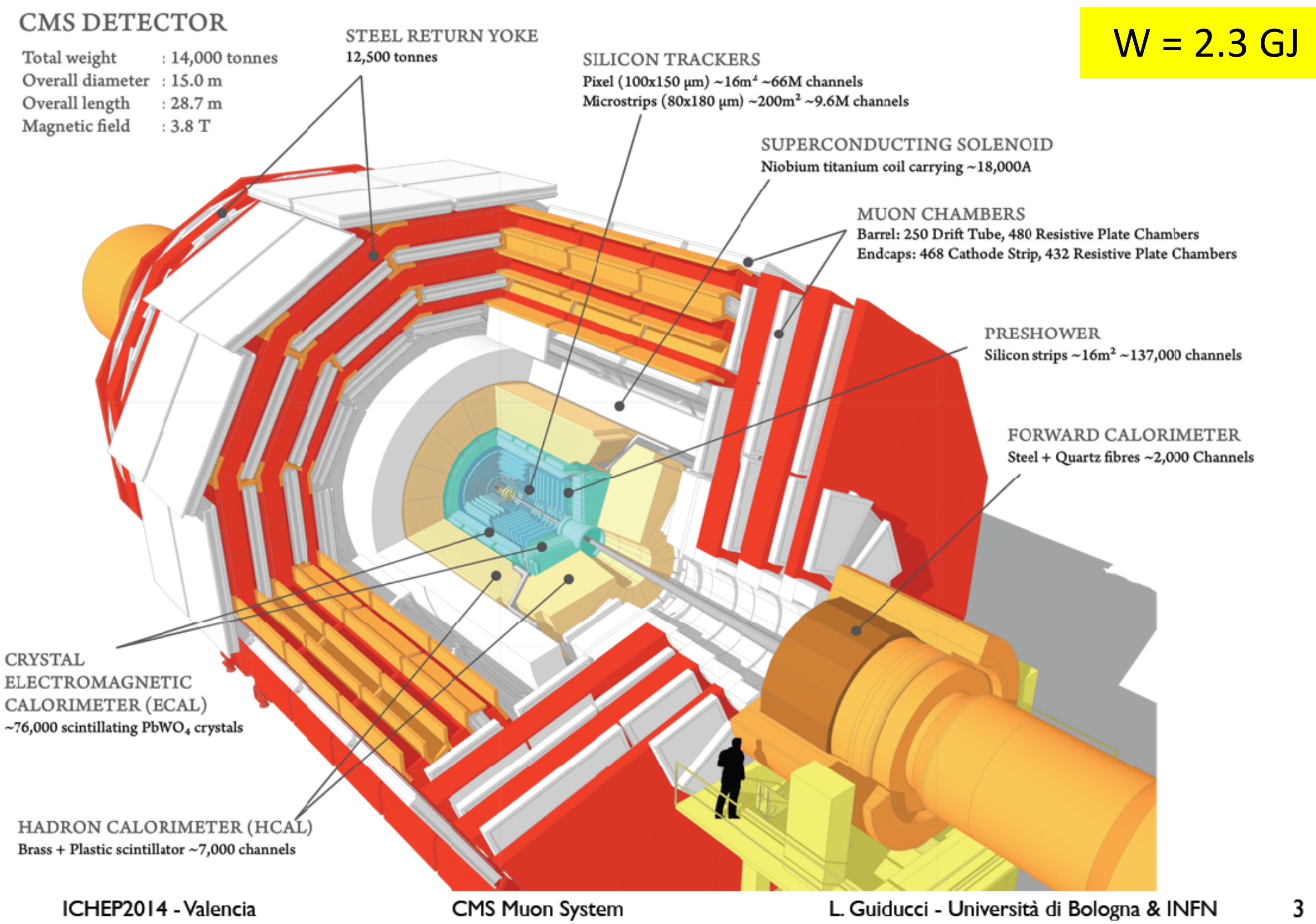
CMS @ LHC



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
    - Shielding to control backgrounds
- Develop scaling rules using LHC & SSC detectors as benchmarks
  - Design requirements for η and pT range
  - Performance requirements for muon triggering and tracking technologies
  - Alignment requirements
  - Cost of muon system
  - R&D program for muon chamber technology choice

CMS Muon System



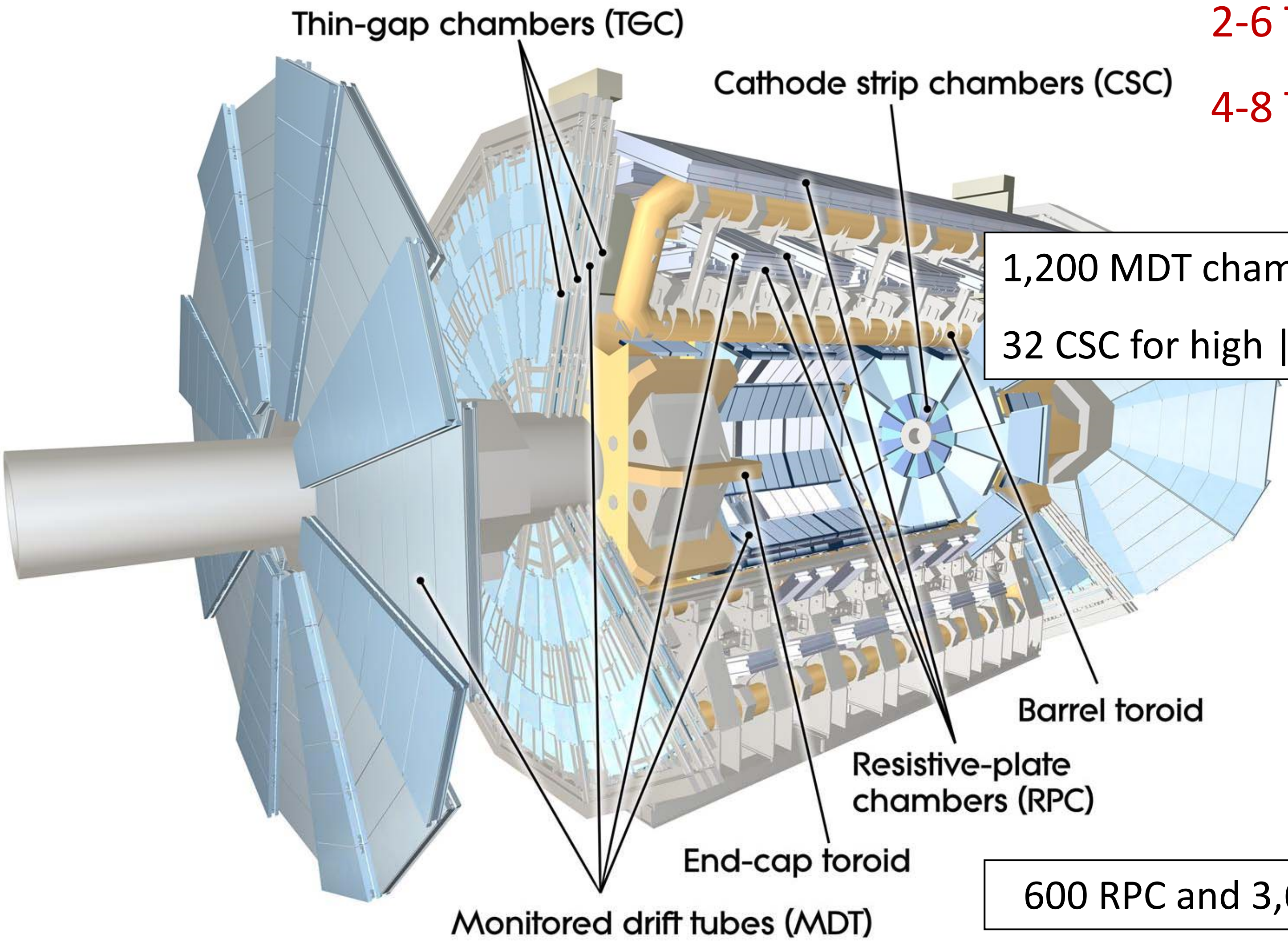
W = 2.3 GJ

ATLAS Muon System

$\Delta p_T/p_T < 10\%$ 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

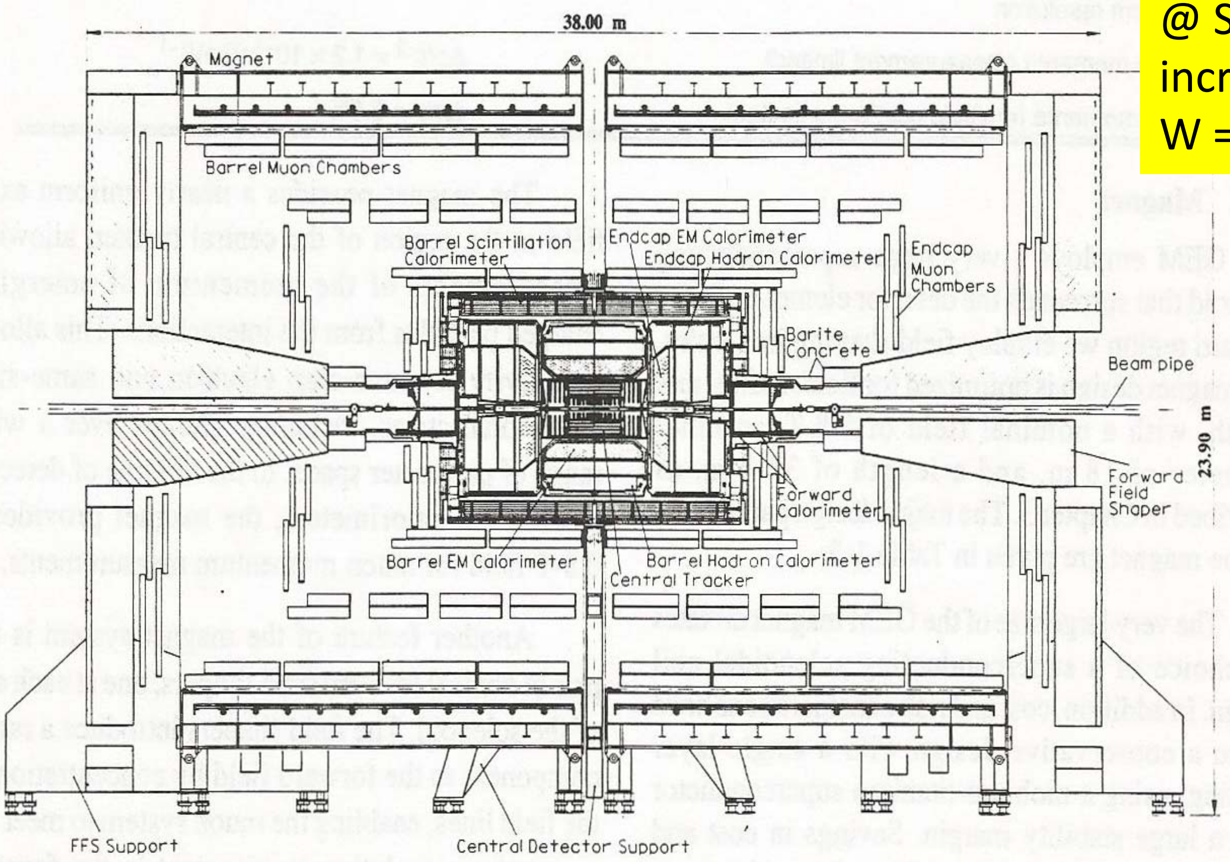
Diameter 24 m
Length 45 m
W(B) = 1.0 GJ

600 RPC and 3,600 TGC trigger

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 $(2.5)^{1/2} = 1.58$. $W = 2.5 x(1.58)^3 = 9.9$ GJ



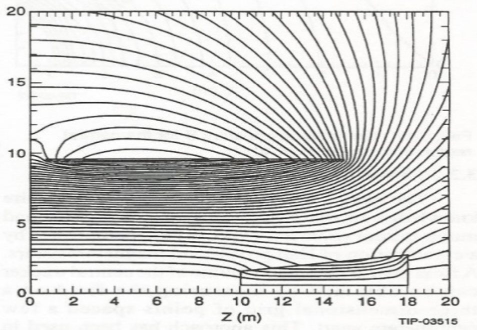


FIG. 3-4. Contours of constant flux.

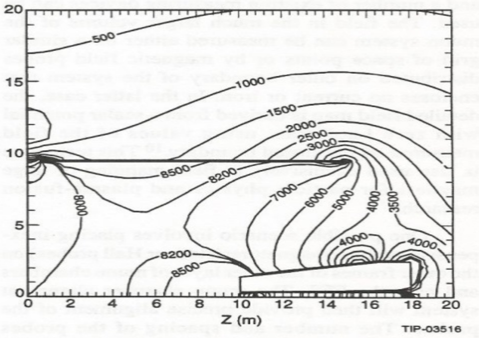


FIG. 3-5. Contours of constant B labeled in gauss.

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

Designer's Tool Kit - Resolution

- Resolution for momentum p
  - Momentum dispersion in B-field
    - 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

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

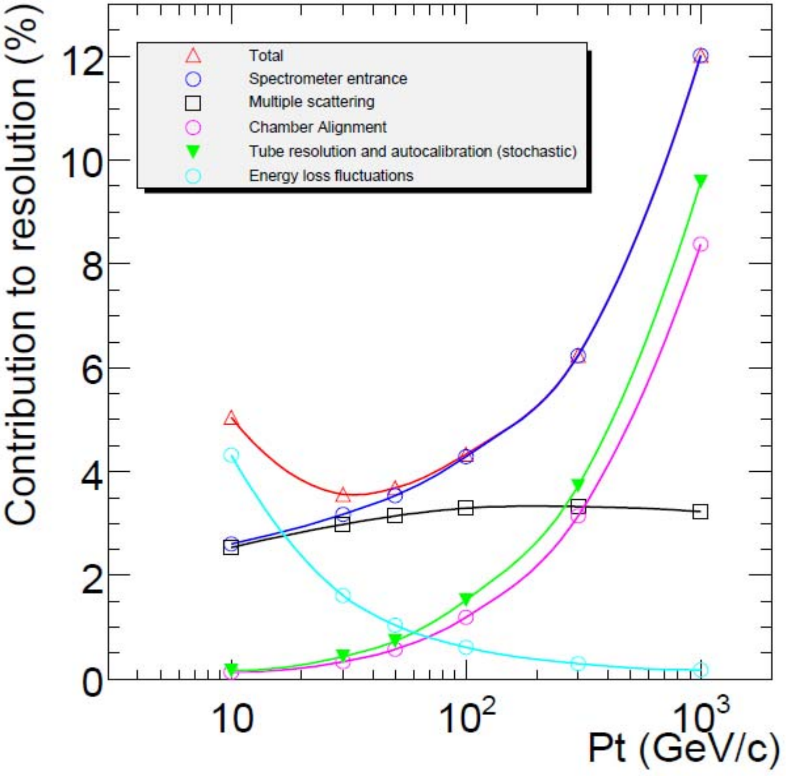
ATLAS Design vs. Toy Model ($\eta \sim 0$)

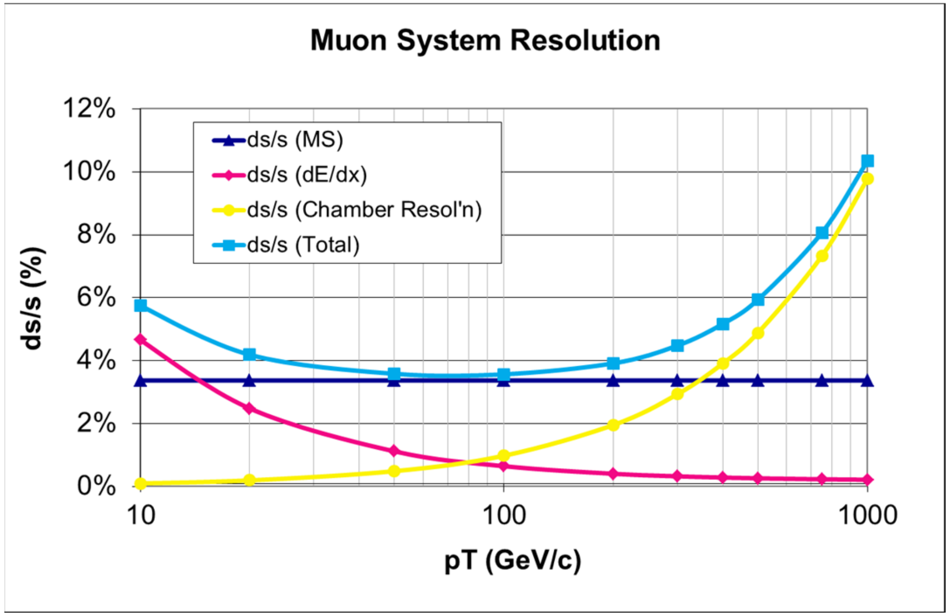
- MS in middle station
- Chamber alignment + resolution
- Energy loss compensation

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 (nλ)	λ (g/cm^2)	g/cm^2	δ(ΔE)/ΔE
12.50	132.00	1650.00	15.0%

s ~ 675 μm @ pT = 1 TeV/c





Design Criterion

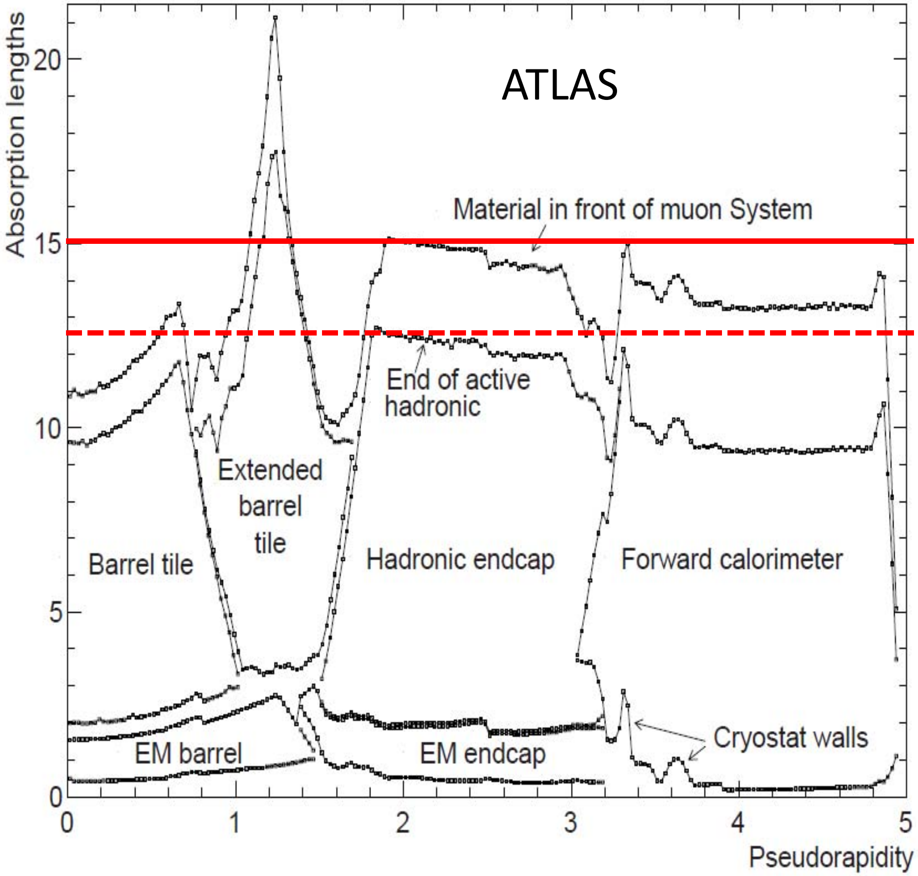
- LHC @ √s = 14 TeV
  - $|\eta|$ range < 2.7
  - Momentum Resolution $\sigma(pT)/pT \sim 10\%$ @ pT = 1 TeV
  - Beam Cross Tagging $\tau \ll 25$ ns
  - Trigger 1 MU pT > 20 GeV/c, 2 MU pT > 10 GeV/c, 3 MU pT > 6 GeV/c
  - Highest detector hit rate ~ 15 kHz/cm^2

- Scaling factors
  - √s ratio ~ 7
  - $|y_{max}|$ratio ~ ln[(√s=100)/M_p]/ [(√s=14)/M_p] ~ 11.5/9.5 ~ 1.2

$$BL^2|_{100\ TeV} \sim 7\ BL^2|_{14\ TeV}$$

- FCC @ √s = 100 TeV
  - $|\eta|$ range < 2.7 x $y_{max}(100)/y_{max}(14) \sim 3.2$
  - 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 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

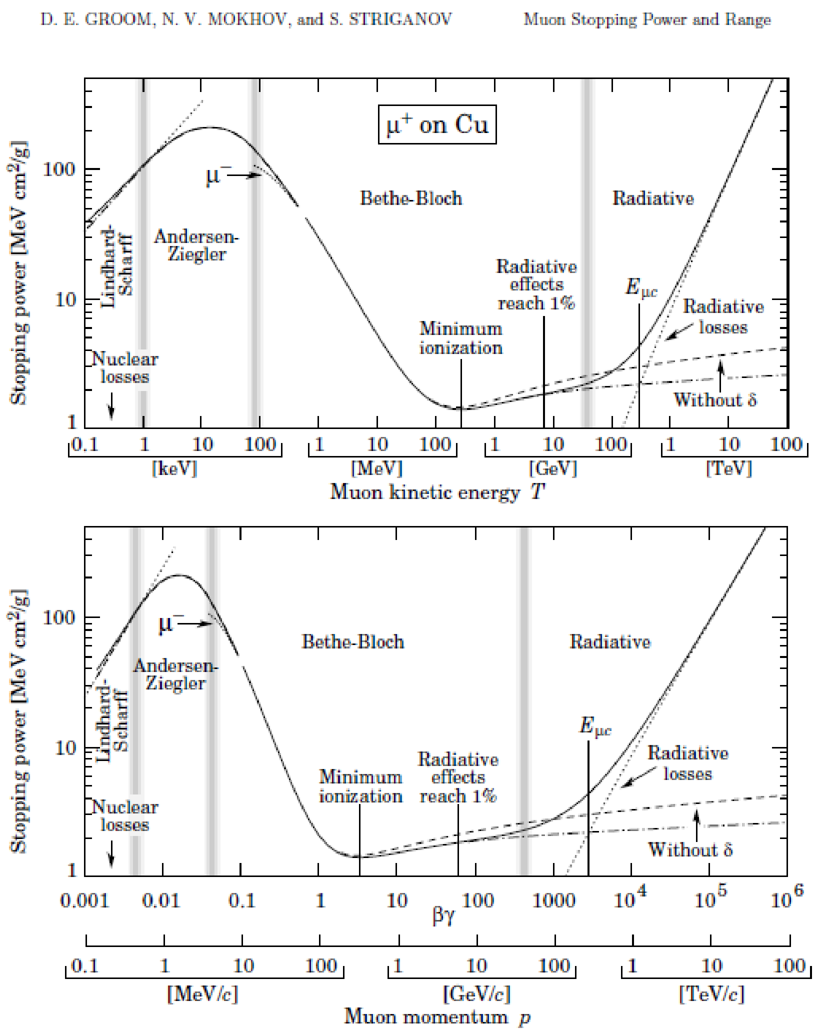
Womersley et. al
λ (99%) ~ 0.64+1.063 ln(E(GeV))

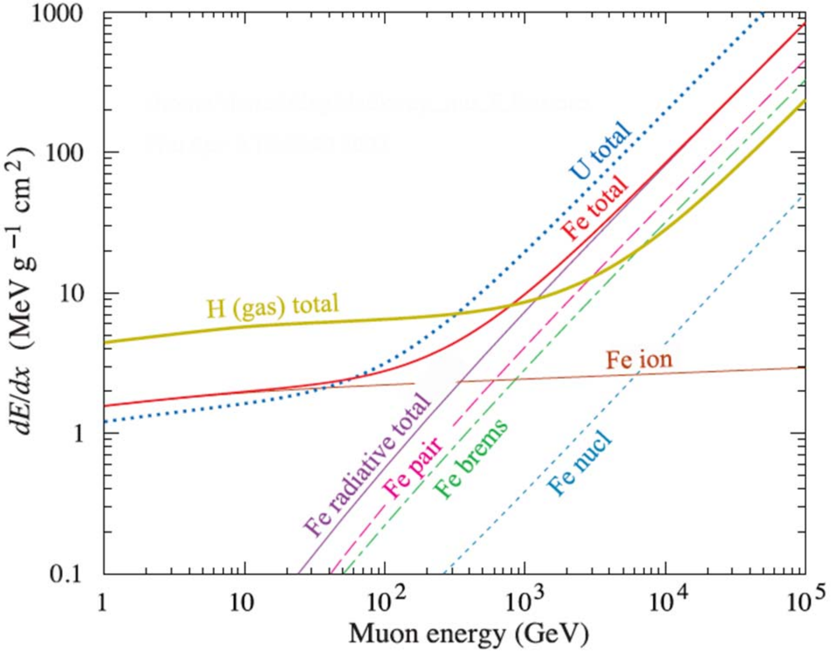
Ratio of thickness for same shower containment (99%):
λ(50 TeV)/λ(7 TeV) ~ 1.2

LHC 11 to 14 λ -> FCC 13 to 17 λ

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

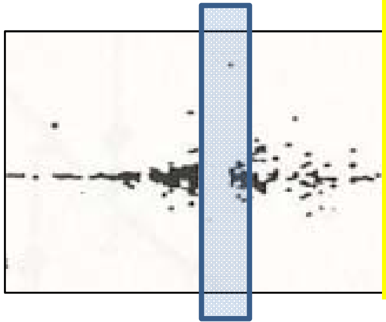
dE/dx correction & Co-traveling BKG


D. E. GROOM, N. V. MOKHOV, and S. STRIGANOV Muon Stopping Power and Range



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

Muon Station

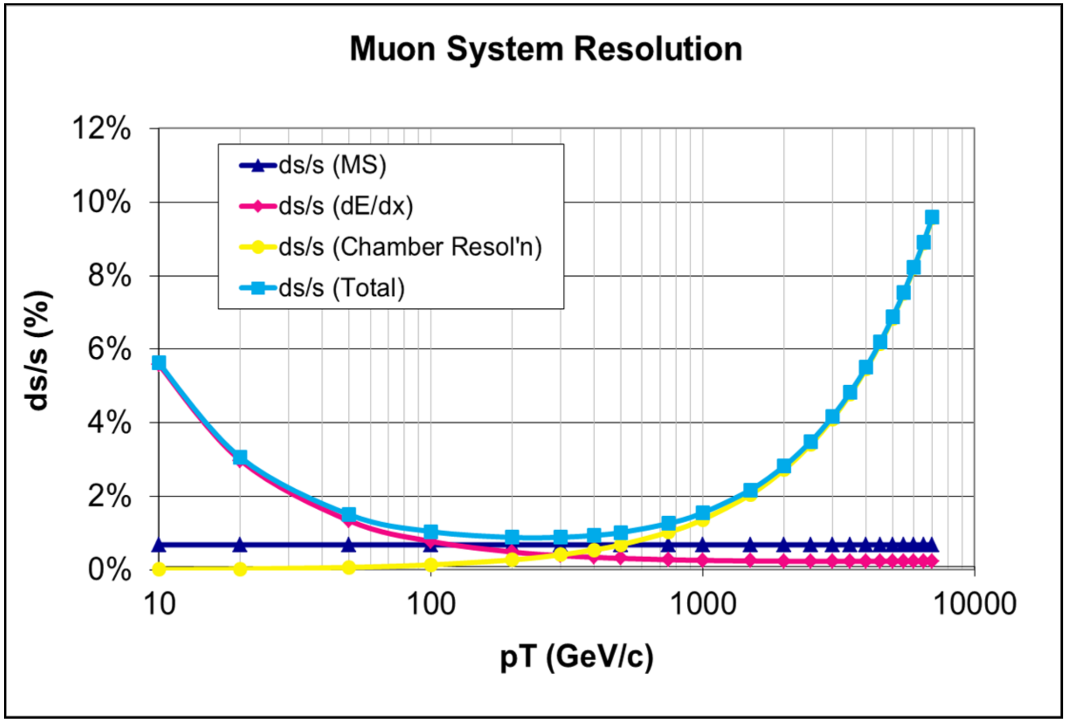


Muon radiation before Tracking station -> <u>air gap</u> and <u>B-field</u> needed as well as <u>good double track capability</u>

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%

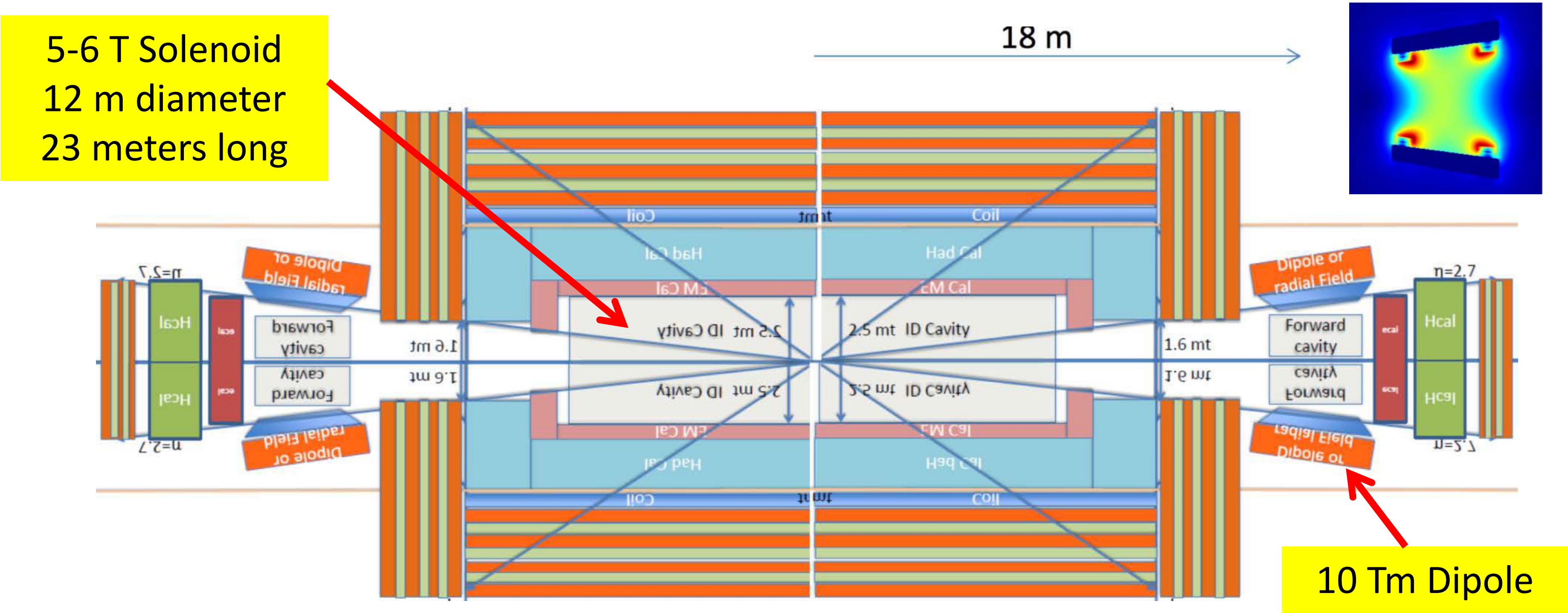
B-Field Configuration*

- Option 1: Single 6T Solenoid Design – CMS Inspired
  - Add 2 endcap dipoles and Fe return Yoke
- Option 1A: Single Solenoid Design – GEM Inspired
  - Add 2 Fe field shaper cones in endcap
- 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 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

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

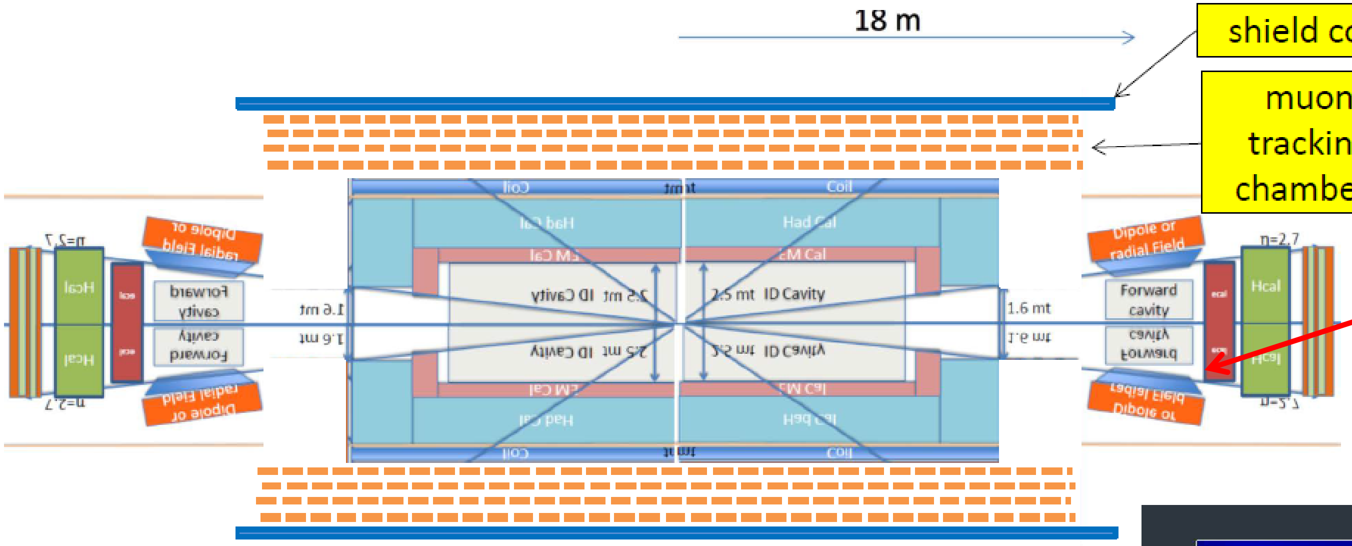


5-6 T Solenoid
12 m diameter
23 meters long

10 Tm Dipole

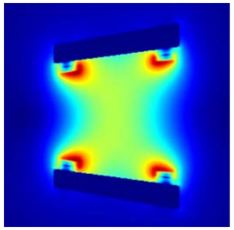
- Stored magnetic energy 54 GJ
- Dipole or radial field in high rapidity region for enhanced bending power
- Iron Flux return makes design massive
  - mass ≈120 k tons (>200 M€ raw material) in comparison to CMS 12.5 k tons
  - Large mechanical engineering challenge – design impractical

Option2: Double Solenoid Design – MRI Inspired



shield coil

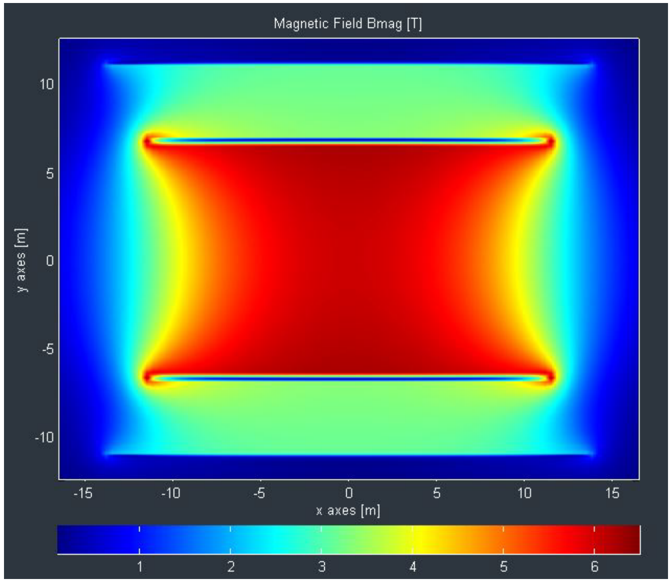
muon tracking chambers



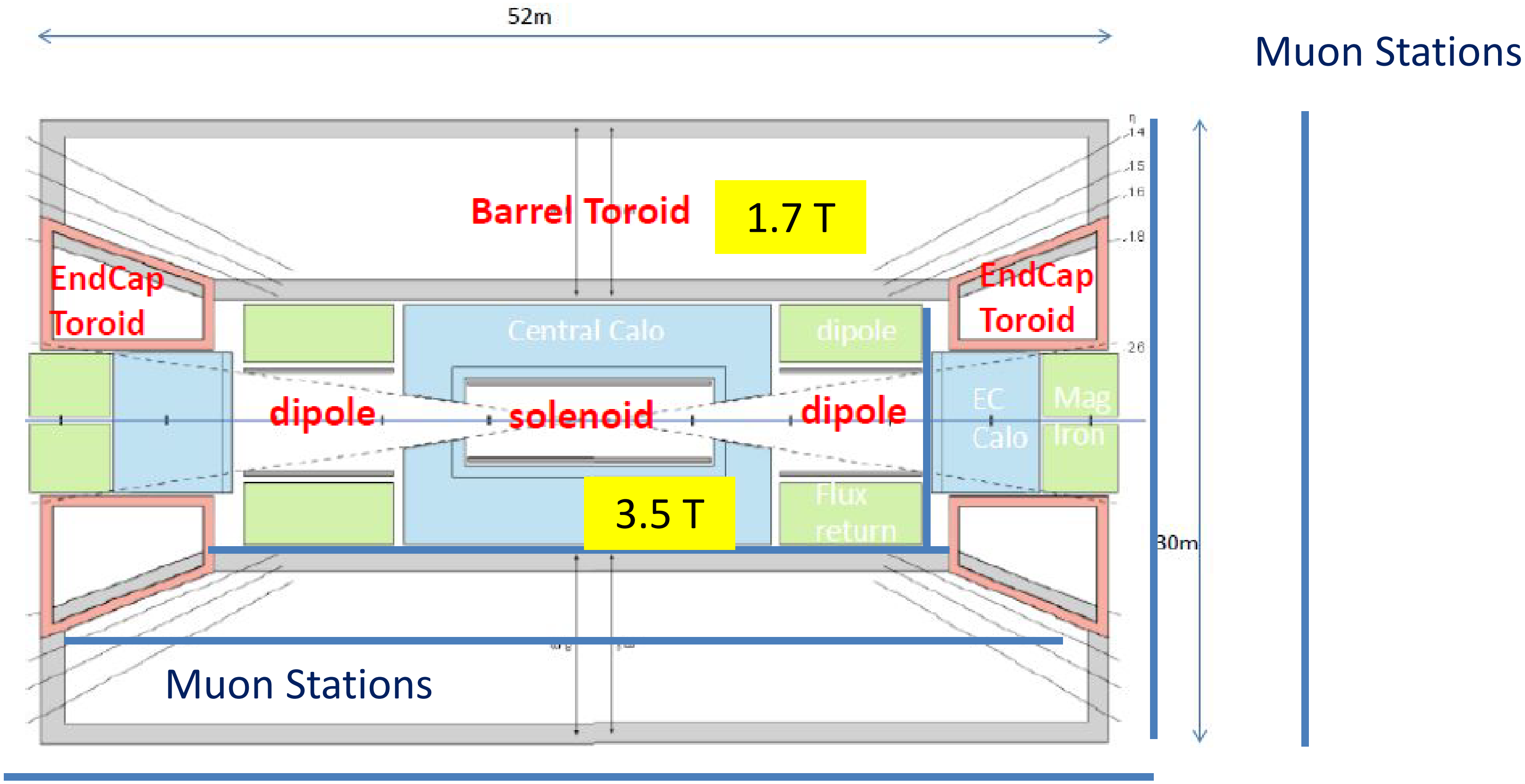
10 Tm Dipole

- 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

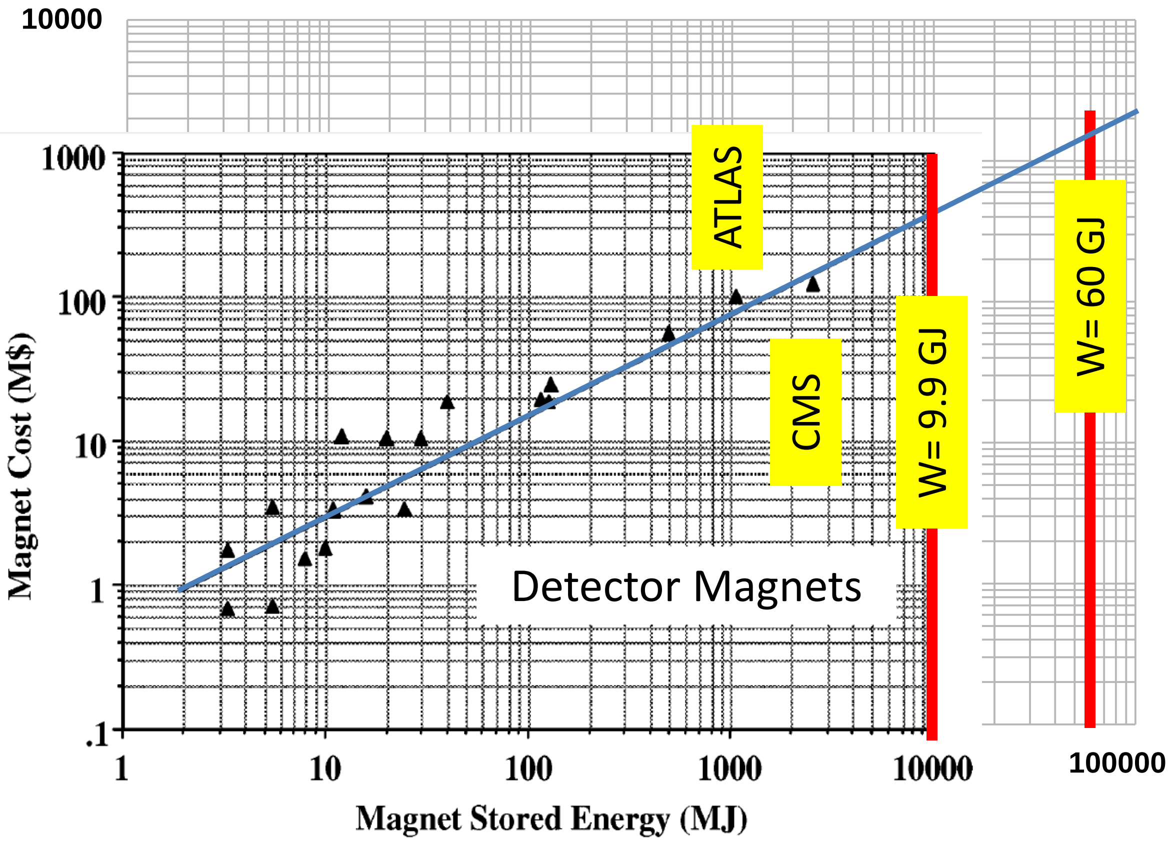


- Air core Barrel Toroid with 7 x muon bending power BL^2.
- 2 End Cap Toroids to cover medium angle forward direction.
- 2 Dipoles to cover low-angle forward direction.
- Overall dimensions: 30 m diameter x 51 m length (36,000 m^3).

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$

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

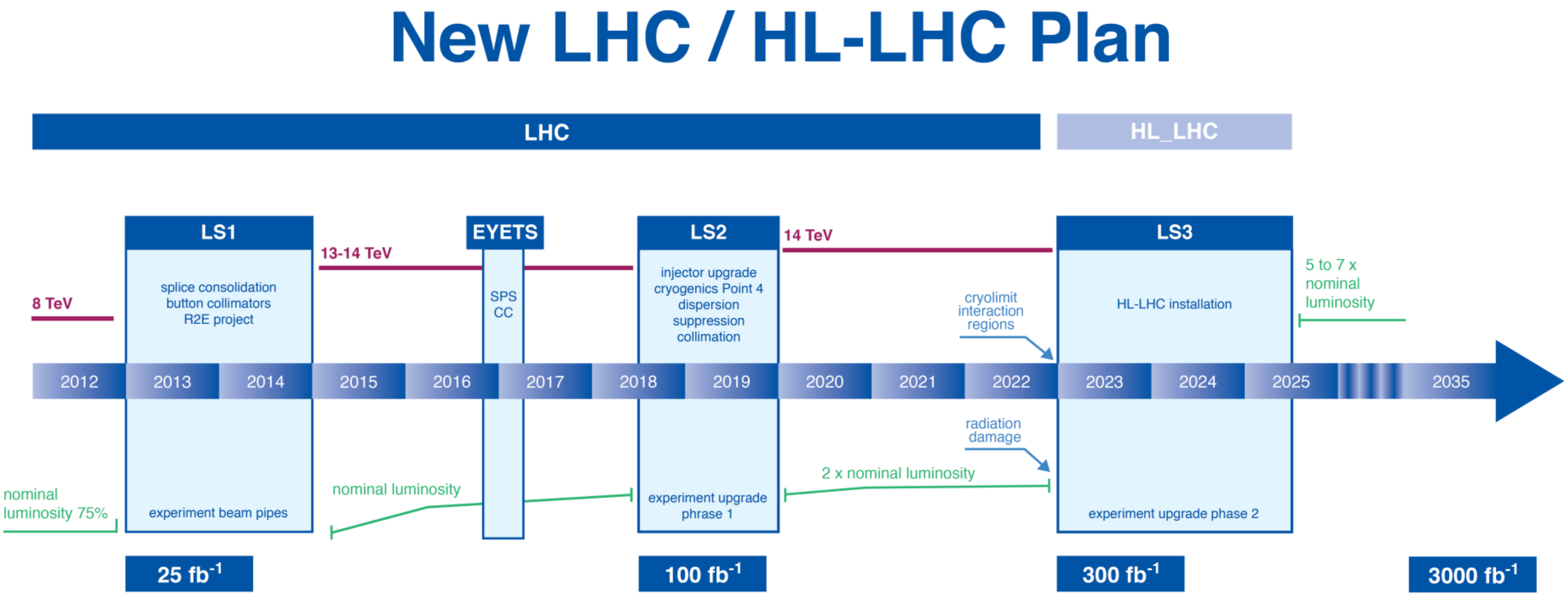
Cost considerations favor lower B-field and larger size

Appraisal of Designs

- GEM-SSC Design: Single solenoid with field shaper, W = 9.9 GJ
  - Least stored energy but may fall short in high |η| performance limited by iron saturation
  - Muon system and calorimeter all within solenoid
  - Laissez-faire Flux return
- Option 1: Single solenoid with Fe Yoke + EC, W = 54 GJ
  - Expensive and heavy construction ≈ disfavored
- Option 2: Double Solenoid + EC, W = 65 GJ
  - Elegant and lighter design
  - Worry about getting enough bending at high |η|
- Option 3: Central solenoid and toroids + EC, W = 55 GJ
  - Complicated magnet designs but good performance at high |η| and large BL^2

(Bending power/Cost) favors smaller B

R&D Program – Time Frame



New LHC / HL-LHC Plan

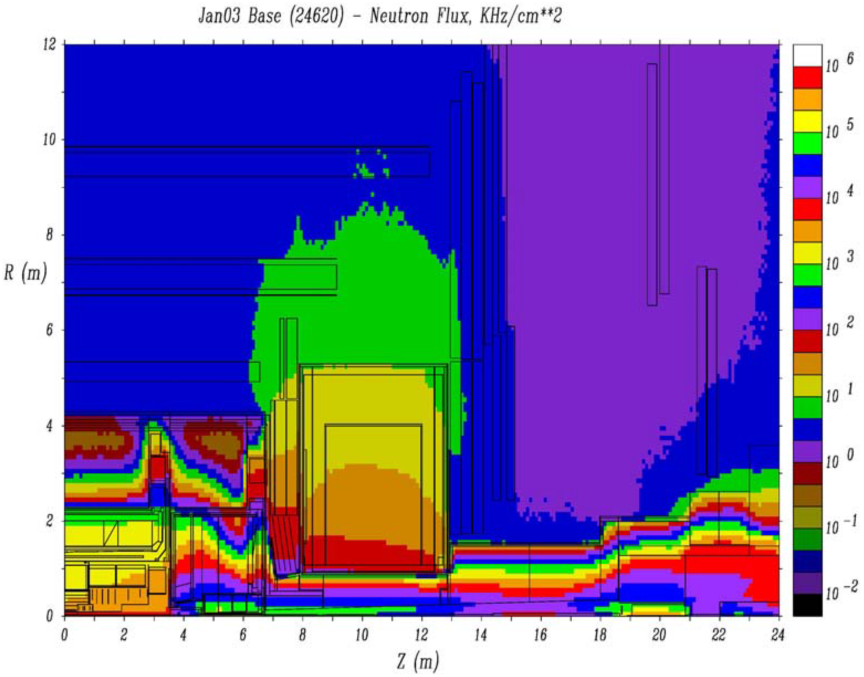
- Mandate is to fully exploit LHC < 2035
- FCC TDR around 2030 -> 16 years of R&D for chamber technology development
- Phase I and Phase II LHC Upgrades will provide important R&D lessons

Chamber Technologies

- Choice should be ‘conservative’ with test experience in a hadron collider environment
  - Will be a result of a long period of development
  - 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 ~ $1/\sqrt{N_{layers}}$
  - Integrated design to provide both the 1st & 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

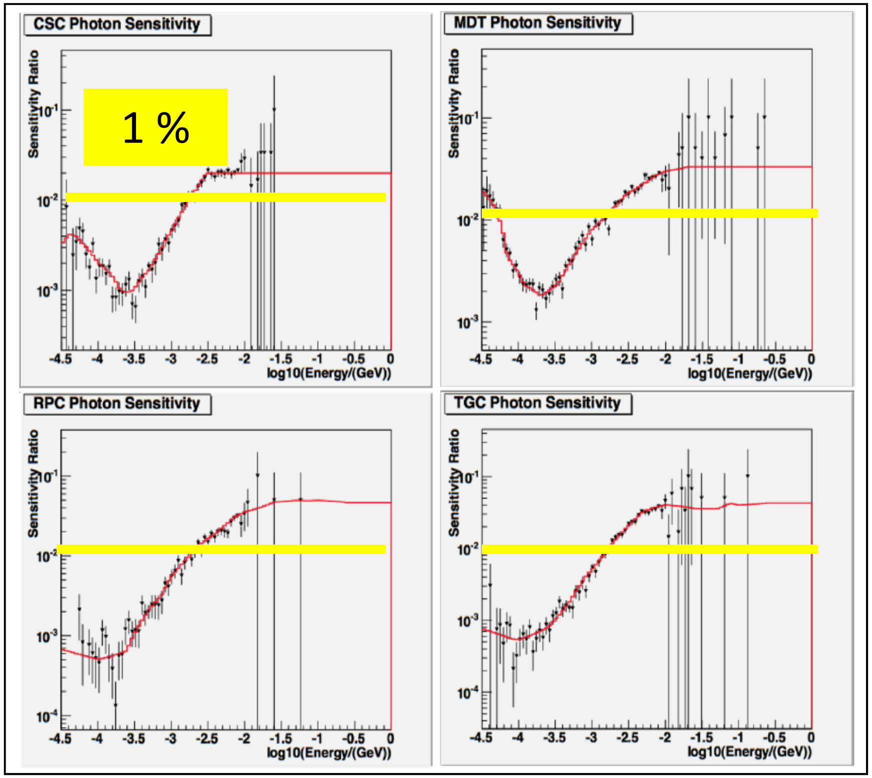
- Most of backgrounds originate from energy deposited in detector by p-p collisions ~ ½ comes from beam line small θ
  - Preliminary ATLAS shielding study predicts a 20% increase from √s = 8 TeV to √s = 14 TeV per p-p collision
  - Assuming scaling by √s would predict ~ 10X bkg. of 14 TeV at 100 TeV

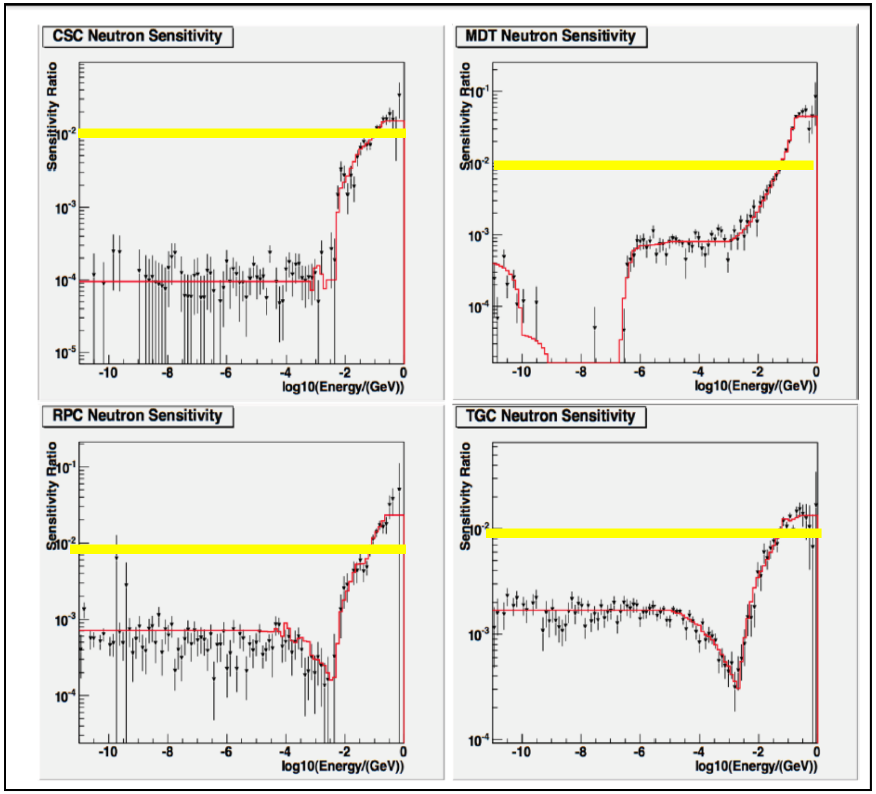


Likely an issue and has to be considered carefully when integrated detector, beam pipe and shielding become realistic.

Background Sensitivity

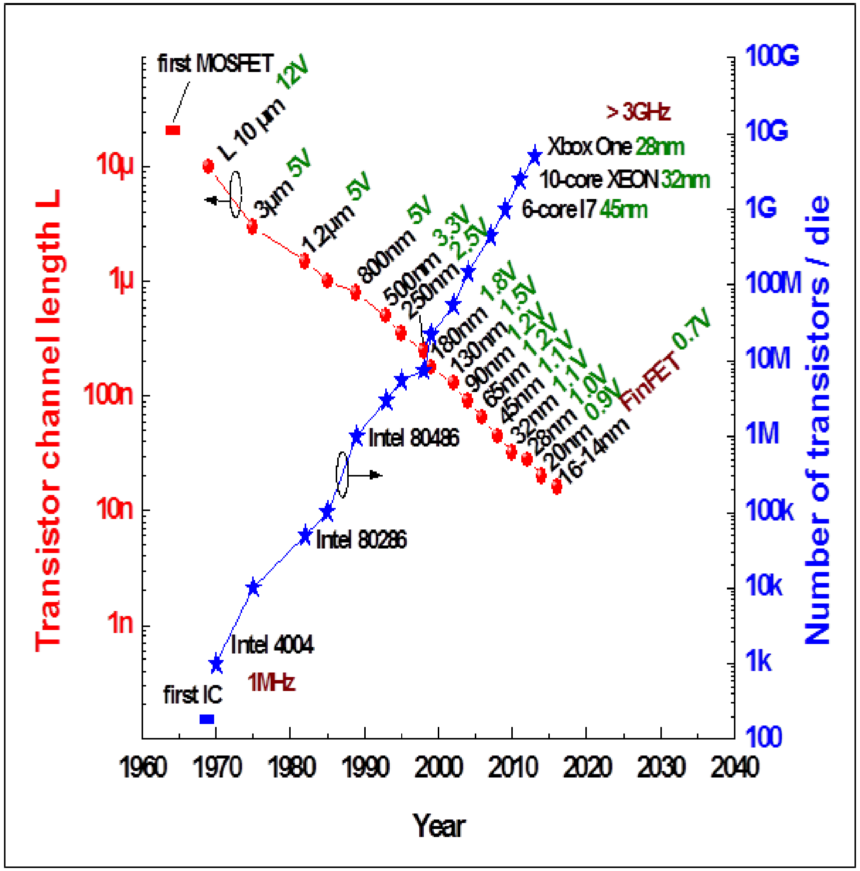
- Important that tracking/triggering technologies have low sensitivity to background neutrons and gammas
  - Requires Low Z and minimum material (ATLAS BKG Study)





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 would be larger by √7
- Precision chamber 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 16 years for R&D



Gianluigi De Geronimo, TIPP 2014

Consideration-I

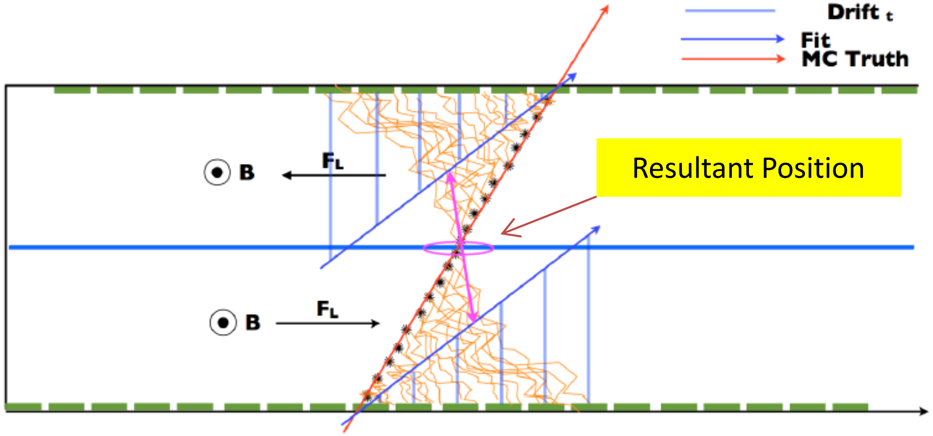
- Lorentz angle
  - Deployment in large B-field will result in a large L-angle depending on gas and E-operating point
    - Drift vector $\mathbf{V_D}$ rotates away from $\mathbf{E}$
  - Naive configuration is to make the wires || to B but serious consideration of effect needed for any gas technology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

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

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

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

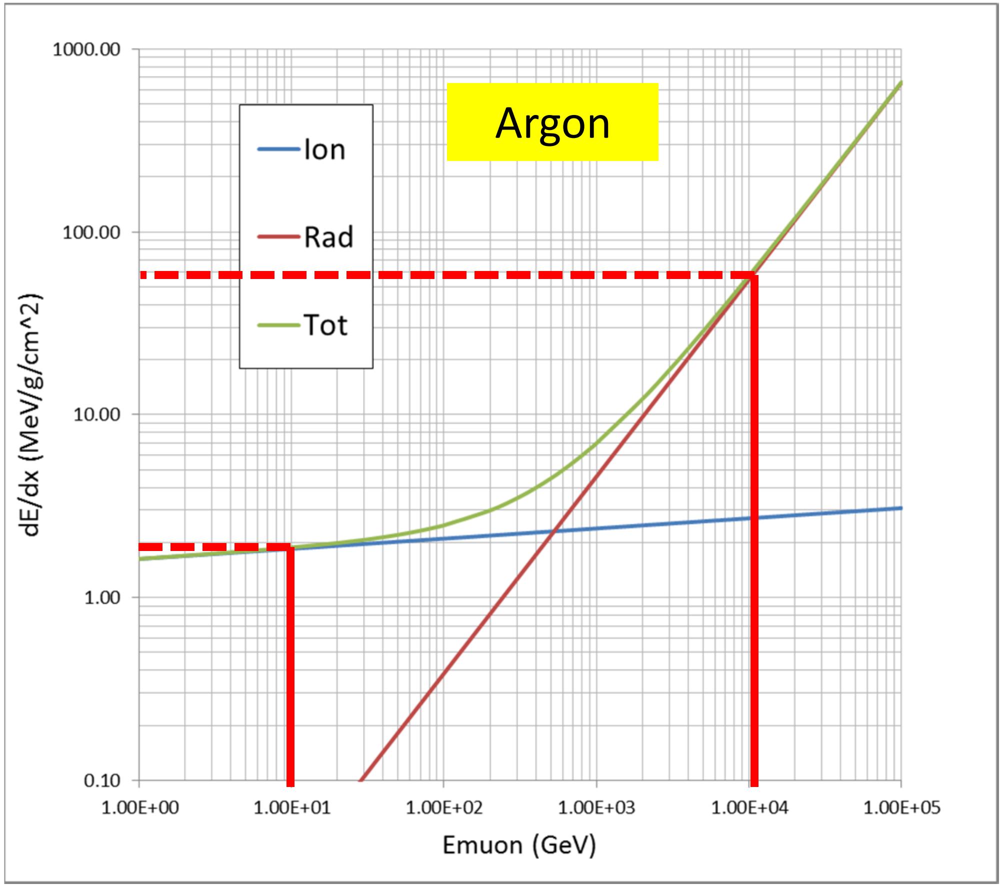
Example of compensation by using back-to-back HV planes in a Micromega



Resultant Position

Consideration-II

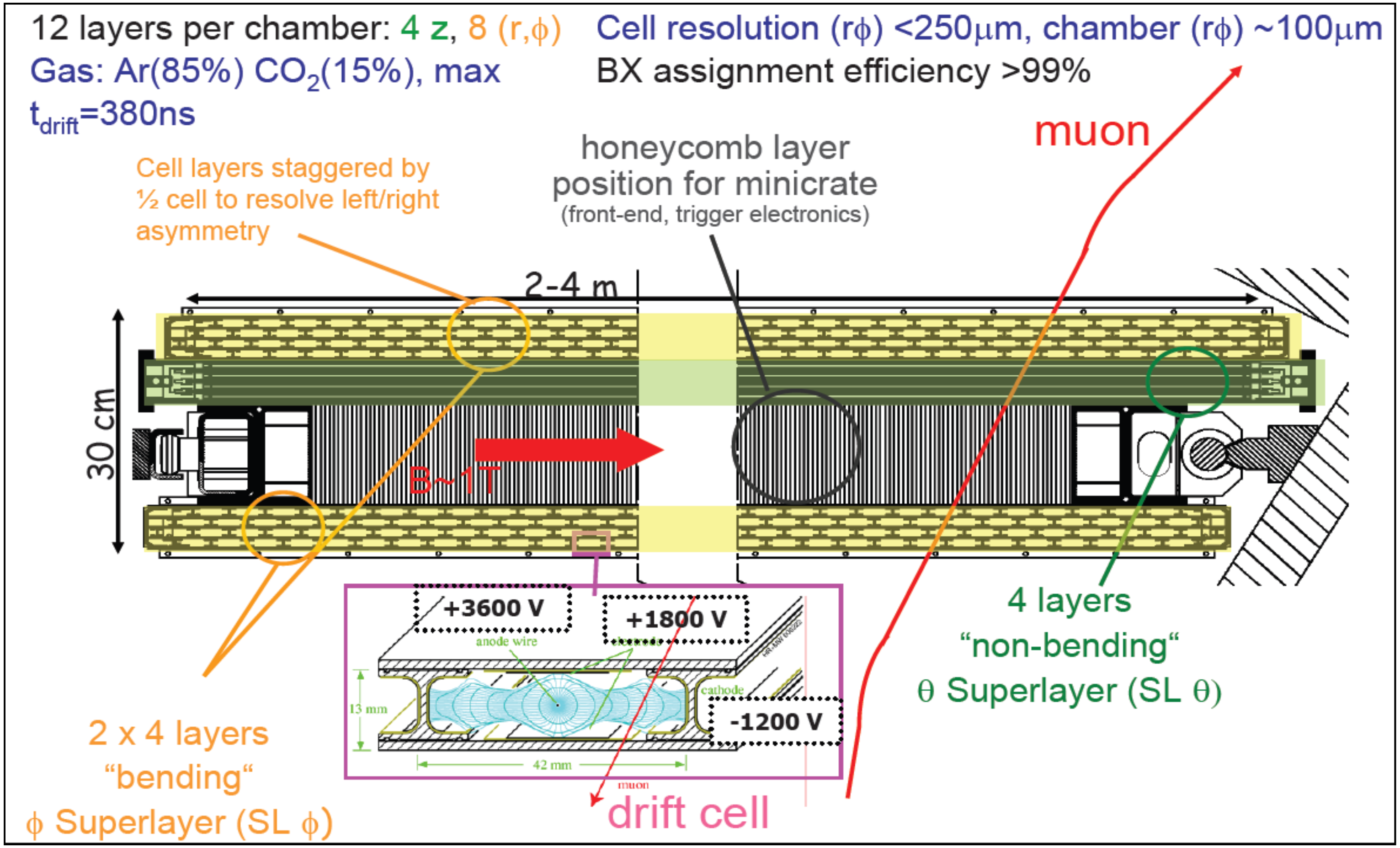
- dE/dx
  - Larger dynamic range needs to be accommodated as muon ionizes gas in chamber
  - Roughly a factor of 25 N_T = 94 x 25 = 2,350 ion pairs/cm
  - Frontend electronics has to have a larger dynamic range
  - Chamber HV system has to be ‘stiff’ enough not to saturate
  - Perhaps operate at ~ 10^3 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



12 layers per chamber: 4 z, 8 (r,ϕ)

Gas: Ar(85%) CO_2(15%), max t_{drift}=380ns

Cell resolution $(r\phi)$ $<250\mu m$, chamber $(r\phi)$ $\sim 100\mu m$

BX assignment efficiency >99%

Cell layers staggered by ½ cell to resolve left/right asymmetry

honeycomb layer position for minicrate (front-end, trigger electronics)

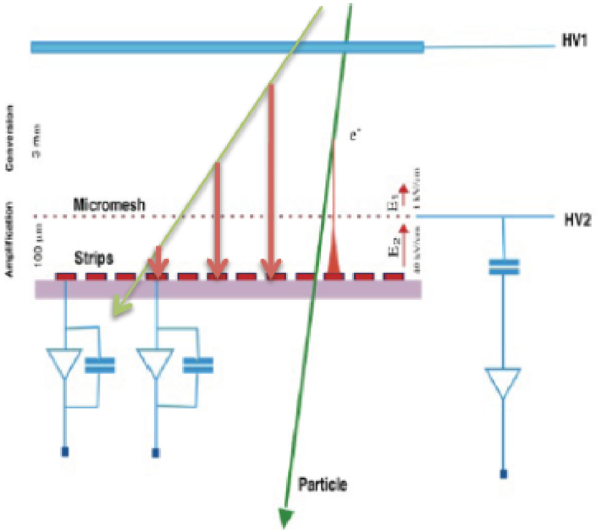
2 x 4 layers “bending“ ϕ Superlayer (SL ϕ)

4 layers “non-bending“ θ Superlayer (SL θ)

drift cell

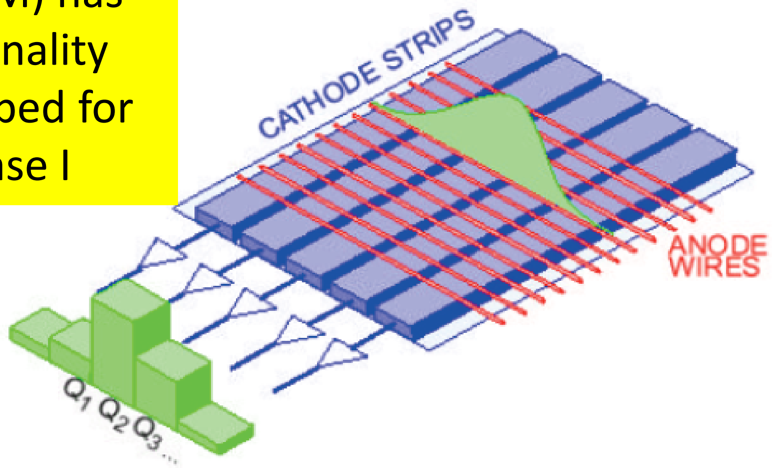
Charge Interpolation Technologies

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
    - SMES = Superconducting Magnetic Energy Storage and note that large SMES favor toroidal geometry
  - Lower B-field options favored (Bending Power/Cost) ~

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

- Neutron and γ background may be troublesome
  - Crude scaling from 14 TeV to 100 TeV is factor of 10
    - Should be done much more carefully
- 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 for 1st muon station
- Tracking and Triggering chamber technologies will develop over the next ~20 years – especially the readout and DAQ electronics
  - Gas amplifiers likely to provide the foundation operating principle
  - How will they work when dE/dx ~ 50 MeV/(g/cm^2) for high p muons?
  - How will they work in large B-field?

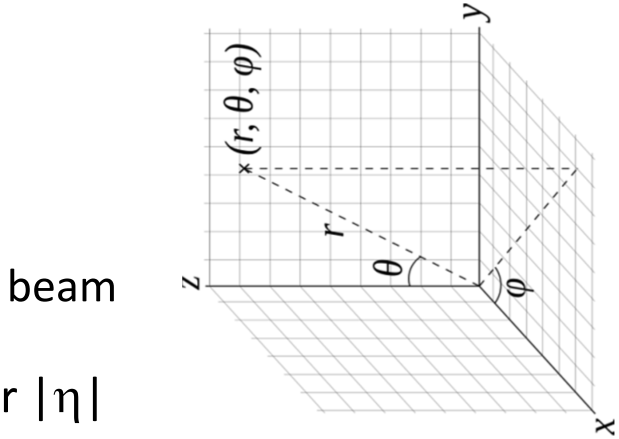
References

- 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

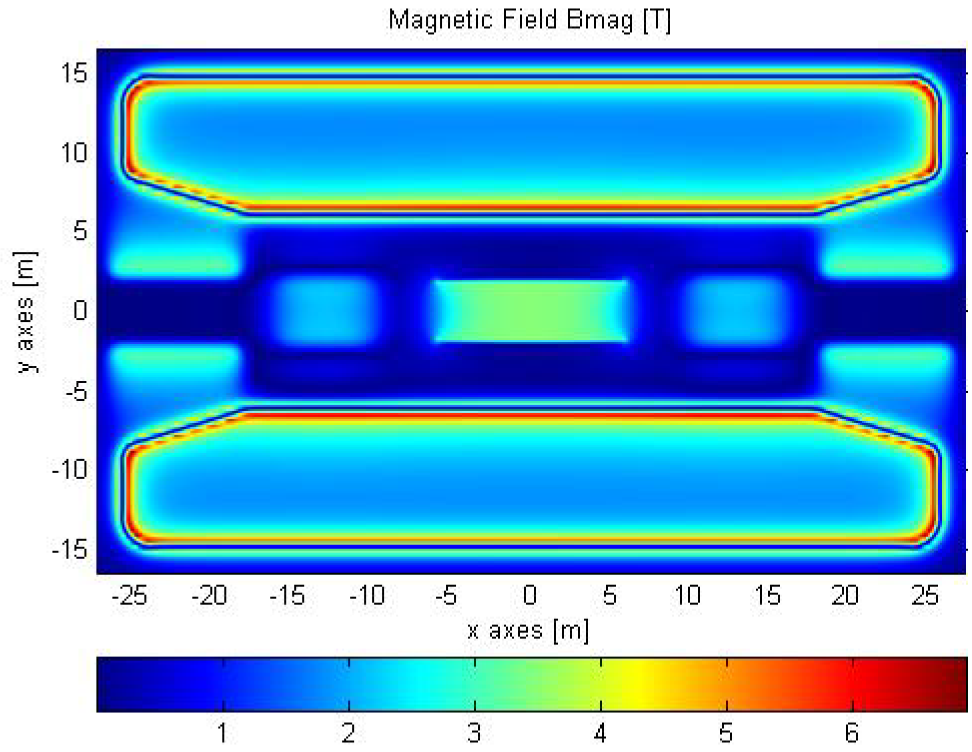
General Considerations

- Design Driver is momentum dispersion $BL^2|_{100\ \mathrm{TeV}} \sim 7\ BL^2|_{14\ \mathrm{TeV}}$
  - Obviously increasing B increases mechanical stresses through magnetic pressure ~ $B^2/2\mu_0$ 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 determination
- Toroidal Configuration
  - First coordinate (bending) θ, second ϕ
    - Advantage of higher bending power at larger $|\eta|$

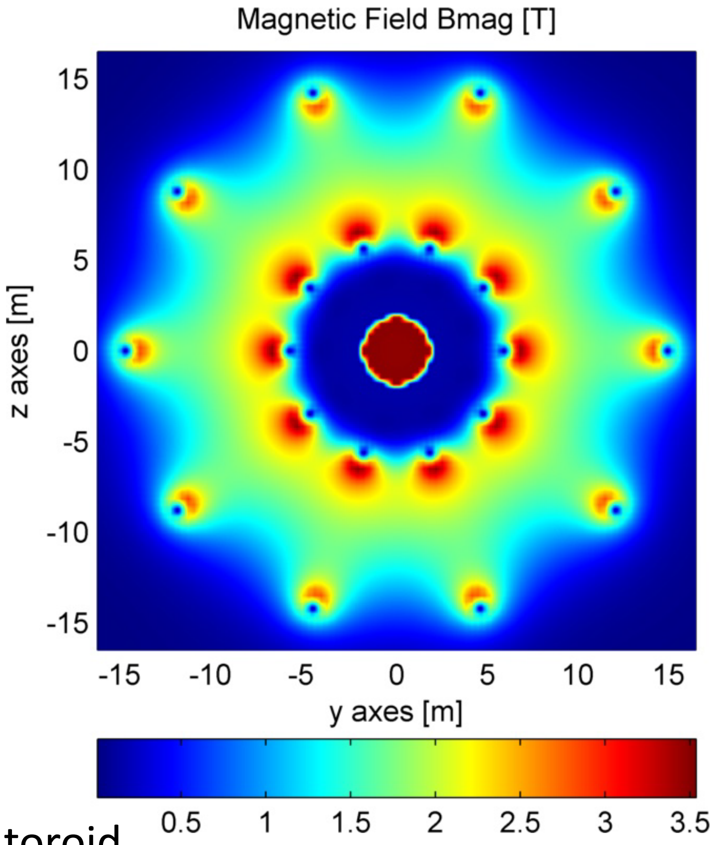


- Muon Chamber system must determine both first and second coordinate
  - High precision required for first coordinate
  - Second coordinate needed for vector ***p*** as well as a pattern recognition invariant

Toroidal Design – ATLAS inspired



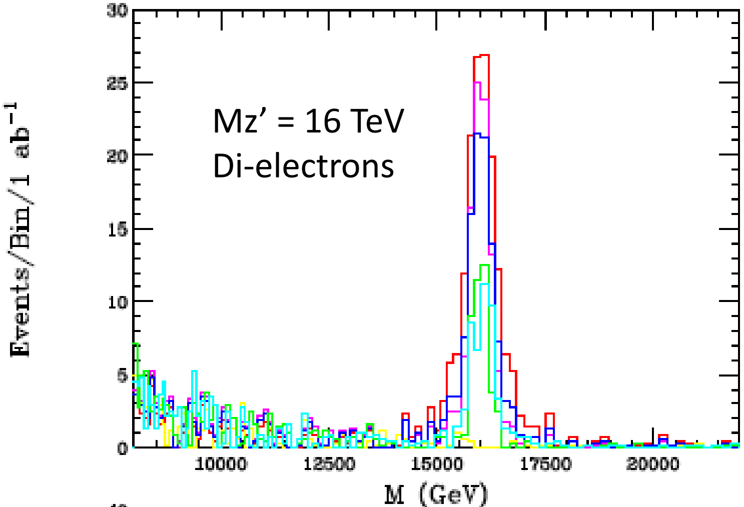
Magnetic Field Bmag [T]

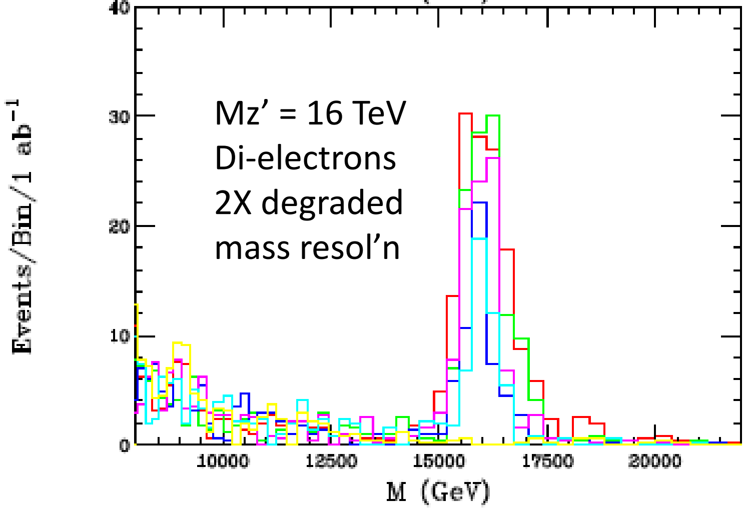


Magnetic Field Bmag [T]

- 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* $\mathcal{L}\sigma B_l$

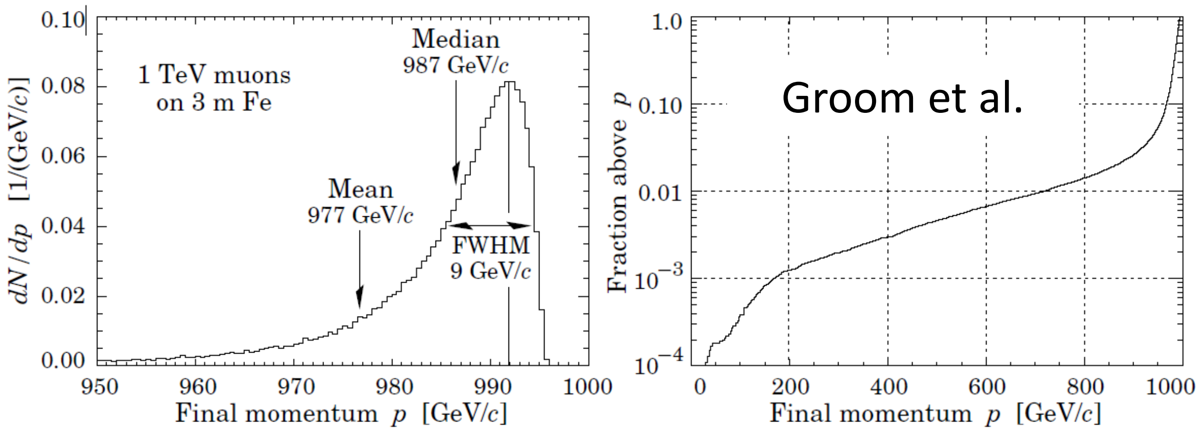
Model	10 TeV	15 TeV	20 TeV	Disc.	Excl.
SSM	2021.	232.6	36.65	23.8	27.3
LRM	1353.	156.1	24.62	22.6	26.1
ψ	573.7	65.93	10.37	20.1	23.6
χ	1372.	159.0	25.18	22.7	26.2
η	626.8	71.82	11.38	20.3	23.8
I	1241.	144.4	22.94	22.4	25.7

  - 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



Groom et al.

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 $\nu \to 0$.

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

Reality check of b =15%

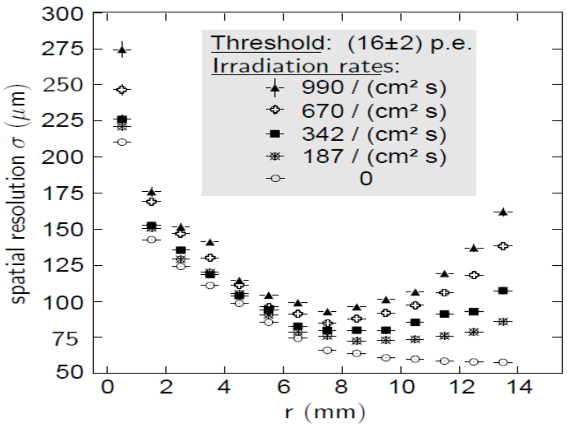
ΔE=23 GeV, FWHM = 9 GeV

σ=3.8 GeV

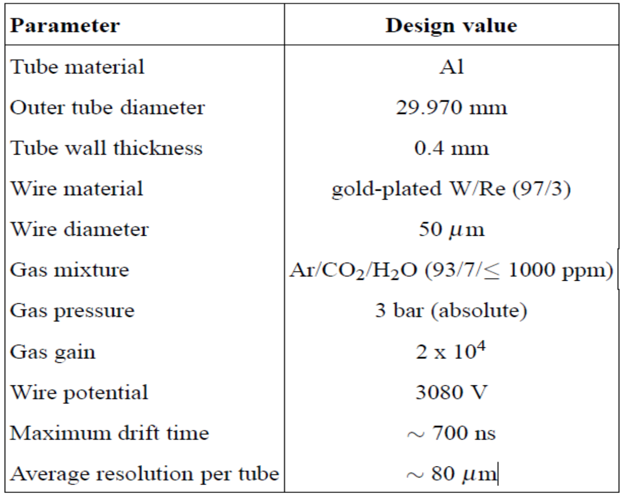
σ/ΔE = 3.8/23 = 16.5%

Drift Technologies – Barrel Deployment

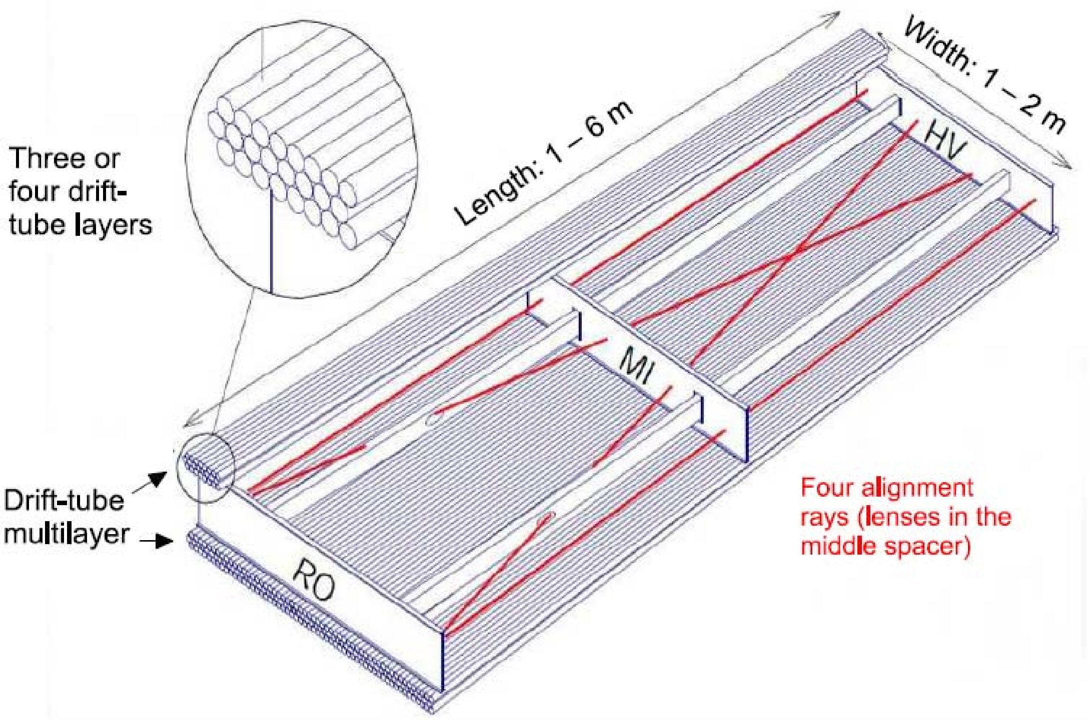
- ATLAS – Monitored Drift Tubes



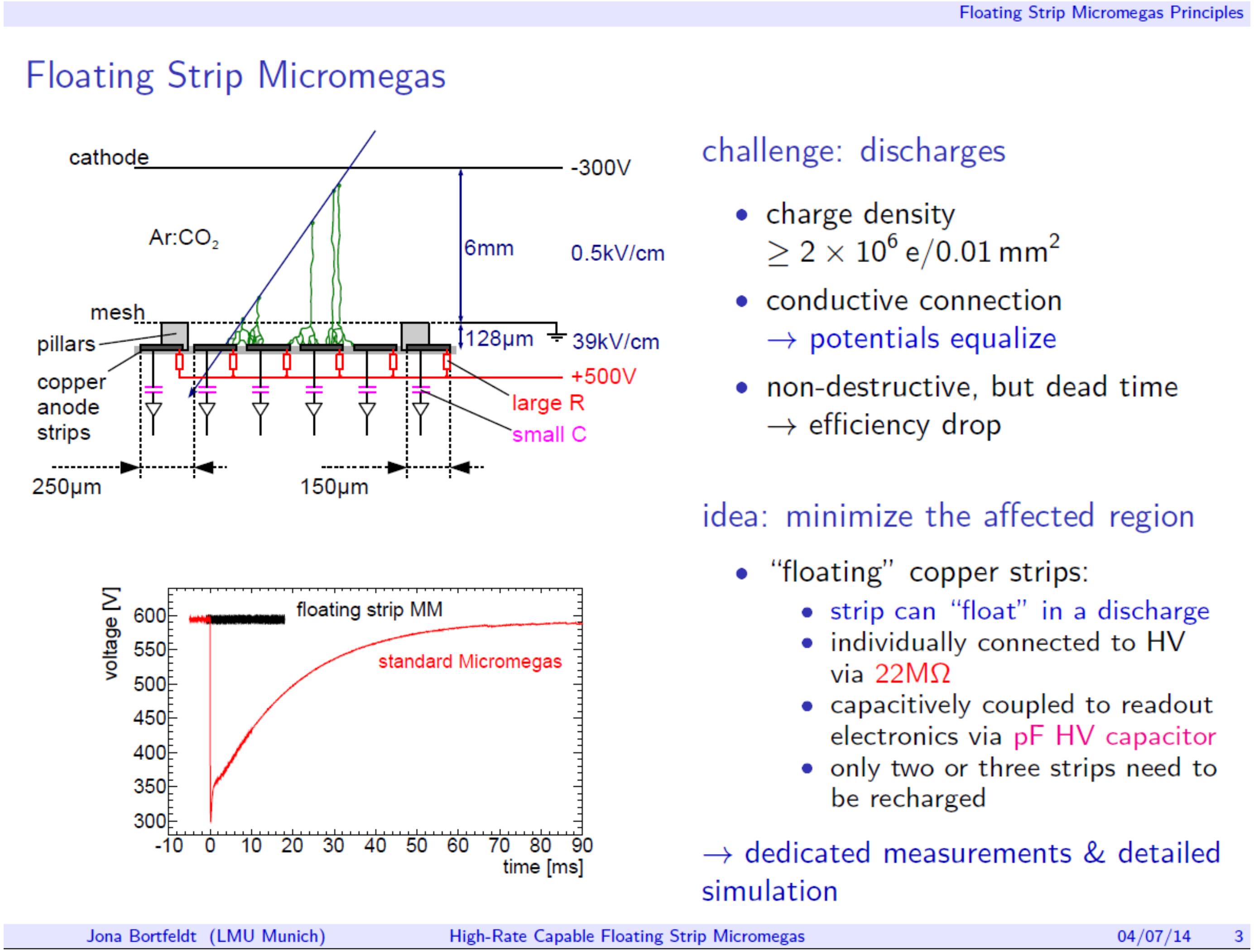
A drift-based technology is an efficient way to cover large areas without high channel counts. <u>Resolution degrades in high backgrounds.</u>



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$_2$O (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



High Rate Micromega



Floating Strip Micromegas Principles

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

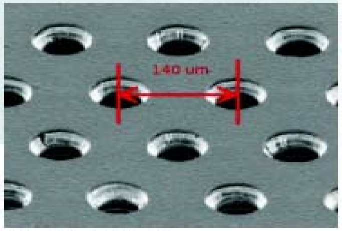
Jona Bortfeldt (LMU Munich) High-Rate Capable Floating Strip Micromegas 04/07/14 3

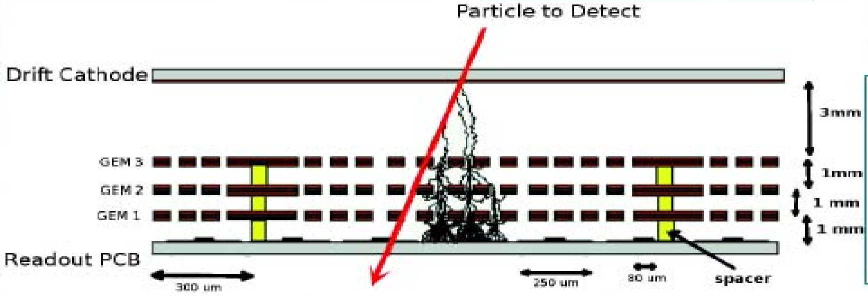
CMS Gas Electron Multipliers

- 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

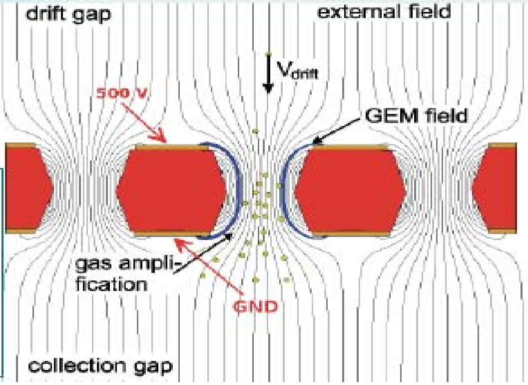
- GEM foils developed using PCB manufacturing techniques
- **Large areas:** ~ 1m x 2m with industrial processes (cost eff.)
- Each foil (perforated with holes) is 50μm kapton sheet with copper coated sides (5μm)
- **Typical hole dimensions:** Diameter = 70μm, Pitch = 140μm





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