Challenges for SLHC Detector Sensors
2.4≤η≤6

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Thank you to the organizers,
to colleagues on CMS,
especially the Forward Calorimetry groups,
and apologies to ATLAS for likely mistakes in discussing their publicly available information.

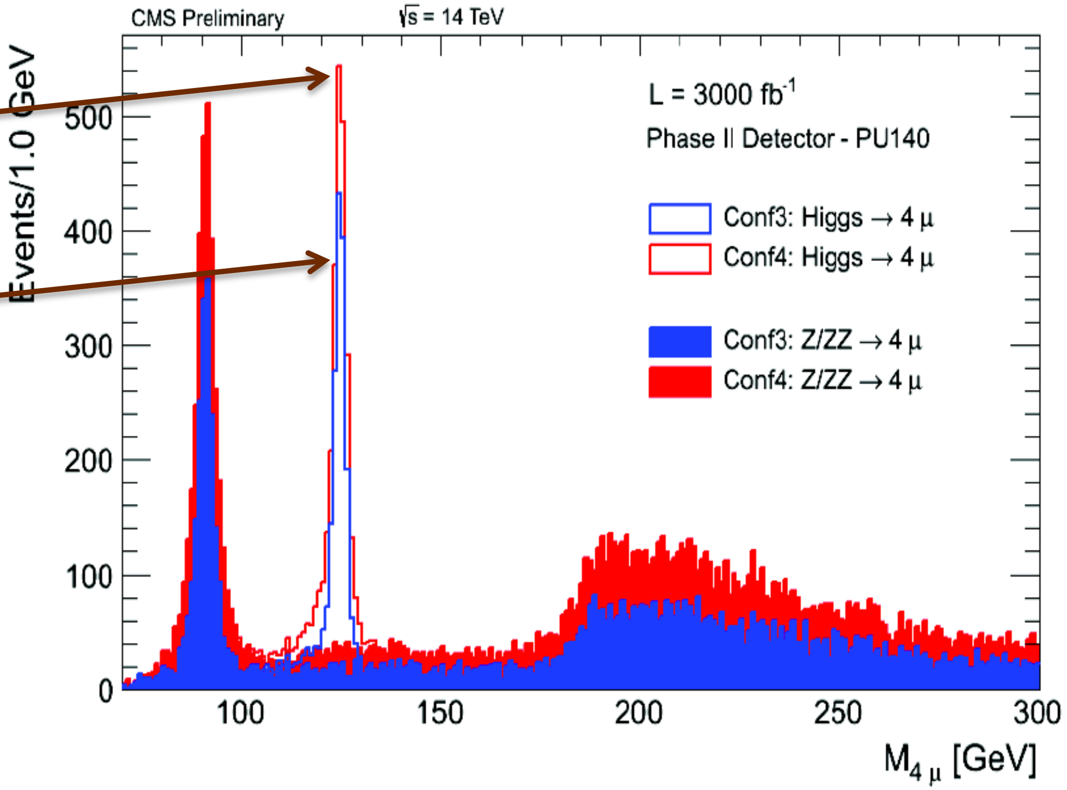
Forward $2.5\leq\eta<6$ μ, jet,[e,γ] Physics <-14 TeV

An Example - MET: 1 TeV muon @ $\eta=3$: ***$E_T \sim 100$ GeV*** ***->> CMS/ATLAS: N.A.!***

"Processes"where forward detectors may enhance physics reach:

- Z/W Forward/Backward Asymmetries/BSM physics
- SuSY: MET(->smaller); F/B & Same Sign Asymmetries;
- 125 GeV Higgs: Acceptance; H->$\mu\mu\mu\mu$, H -> $\mu\mu$
- Vector Boson collisions: $\gamma\gamma$, γW, WZ, W^+W^-, $W^\pm W^\pm$, ZW
    - ***Color not exchanged*** -> E-W bosons collide ~ headon -> ***forward tag-jets***
    - Boson Fusion – 3,4… boson vertices.
    - Inverse decay: $\gamma\gamma$->H
    - Is H consistent with damping strong boson interactions?
- **PDF's at low x** – consistency; calibrations; acceptance J/Ψ,Y…
- **$F_2(x_1, x_2,..x_n)$:** multiple D-Y, Z/W – Correlation Fn's
- b_x jets, W, Z -> **jet-jet ID**
- **Rare Decays** - B_s-> $\mu\mu$ (μ's: LHCb $2<\eta<5$; CMS $0\leq\eta<\pm2.4$)

Exotica– Heavy resonance/Z'/W'; heavy quasi-stable charged, neutral…



Muons up to|η|=4

Muons up to|η|=2.4

Tracking and muon system coverage extension from |η|=2.4 to |η|=4 under study

Sizable impact on H->ZZ->4μ acceptance: +45%!

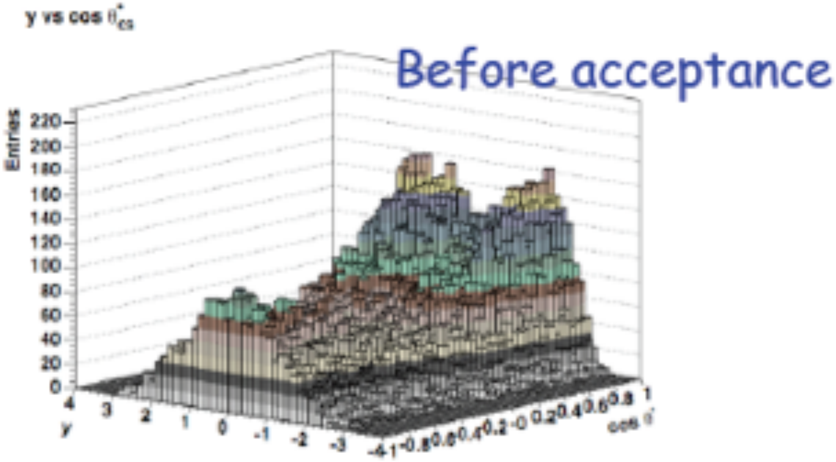
H->μμ similar gains

Muon Pair F/B Asymmetries – $A_{FB}=(\sigma_F - \sigma_B)/(\sigma_F + \sigma_B)$

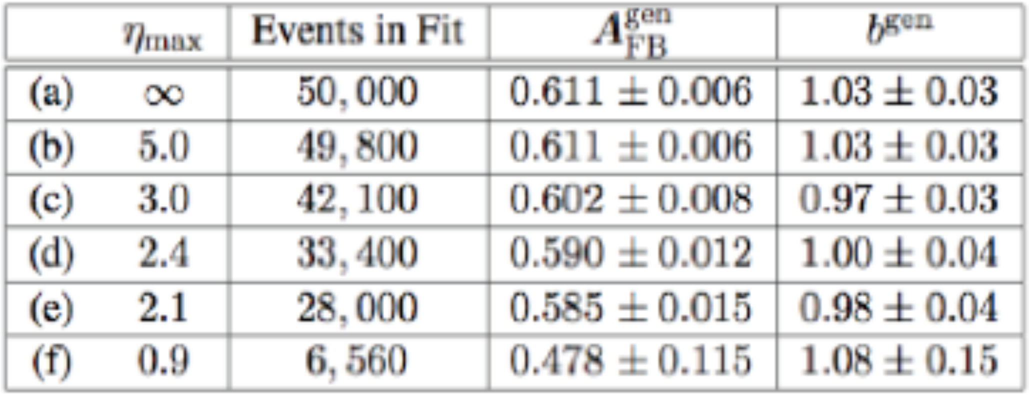
$\sigma_{F,B}$: dσ (qq->μμ), integrated over hemispheres.

A_{FB} tests V-A in the SM; deviations: new physics BSM.

Add μ's $2.5 \le \eta \le 5$: ~50% more events, x2 smaller error, 4% larger A_{FB}.



Before acceptance

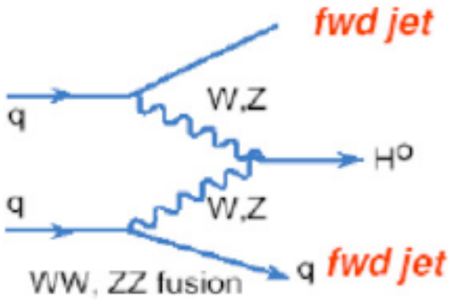


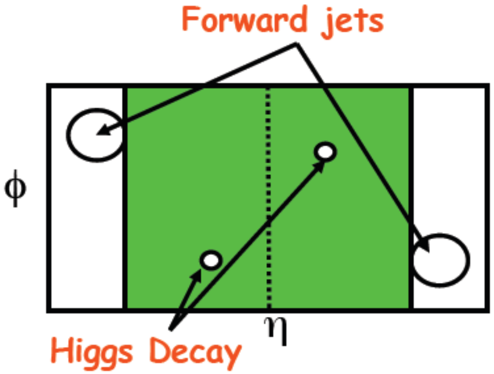
	η_{max}	Events in Fit	A_{FB}^{gen}	b^{gen}
(a)	∞	50,000	0.611 ± 0.006	1.03 ± 0.03
(b)	5.0	49,800	0.611 ± 0.006	1.03 ± 0.03
(c)	3.0	42,100	0.602 ± 0.008	0.97 ± 0.03
(d)	2.4	33,400	0.590 ± 0.012	1.00 ± 0.04
(e)	2.1	28,000	0.585 ± 0.015	0.98 ± 0.04
(f)	0.9	6,560	0.478 ± 0.115	1.08 ± 0.15

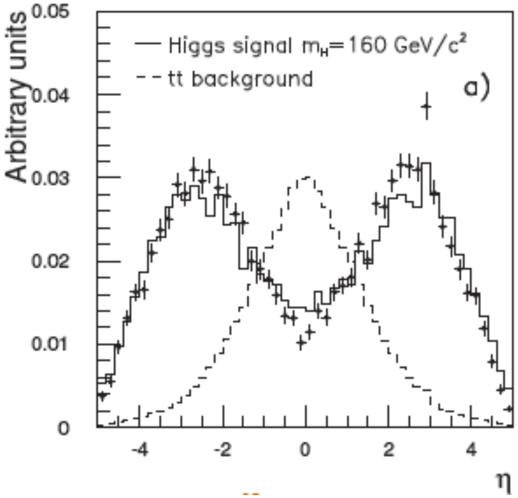
$$P(\cos\theta^*; A_{FB}, b) = \frac{3}{2(3+b)}(1 + b\cos^2\theta^*) + A_{FB}\cos\theta^*$$

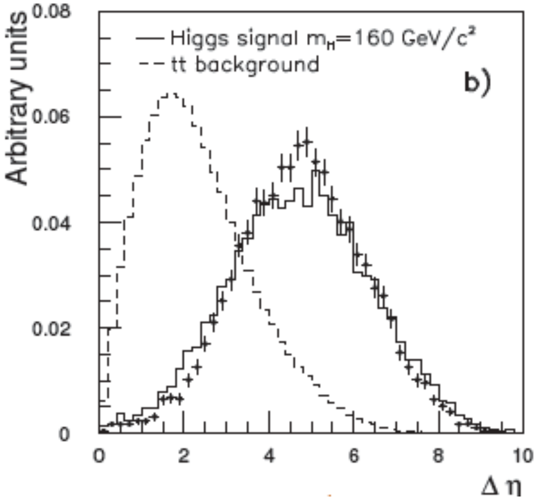
http://www.pha.jhu.edu/~ntran/cms/papers/note05_022.pdf

Vector Boson Scattering, Fusion From $\sqrt{s_{eff}} \sim M_H$ -> few TeV









S/LHC is an electroweak Boson-Boson Collider.

Checking Strong Boson Scattering/Higgs Unitary Requires>500 fb^{-1}

Tag Jets of~equal E, η; ΔΦ~π, then heavy object fusion central-η~0

Whither & Whether SLHC…..?
Start ~10 Years Hence…
Ends >20 Years Hence ….

- How will the LHC perform till its end? When will S/LHC finish?

- Will the experiments be capable of facing the challenges set by high luminosity/radiation and age in the forward region?

- Is there time and funds for major upgrades 2021-23?

- To which level will we be able to fulfill precision Higgs physics?

- What BSM physics needs forward region μ, jet, [e,γ] measures?

- Some Answers elaborated in the last year in the context of ESG, Snowmass and ECFA

Beyond (2021) 2024

LHC:replace ~1.2km: IR-quads(inner triplets),11T short dipoles Nb_3Sn

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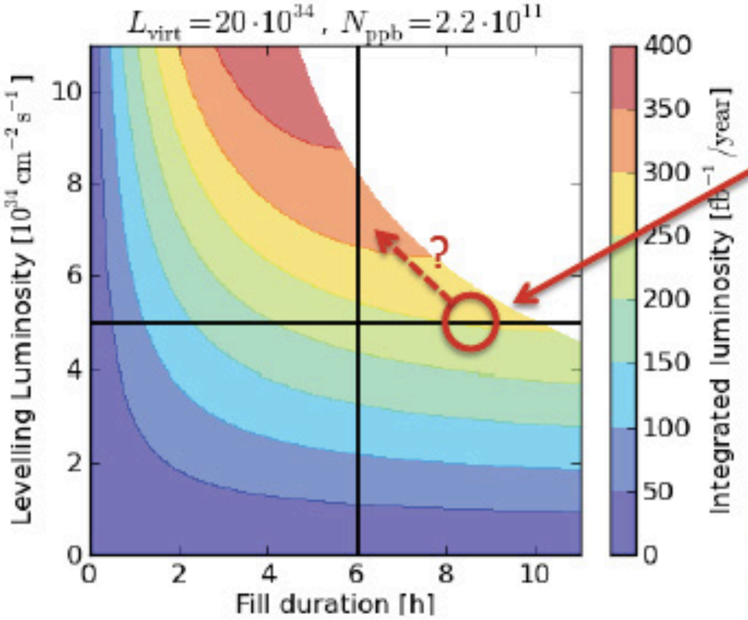
Phase 2: High Luminosity LHC upgrades at Interaction Regions

- New low-β quadrupoles - improve beam focus - allows ~ 70 fb^{-1}/year
- & Beam-Beam Wire Compensation - reduce long range beam-beam effects ~ 170 fb^{-1}/year
- & Matching sections & Crab Cavities - compensate crossing angle
- & New options: CC kissing scheme - reduce PU density, 200 MHz RF in LHC - longer & more intense bunches

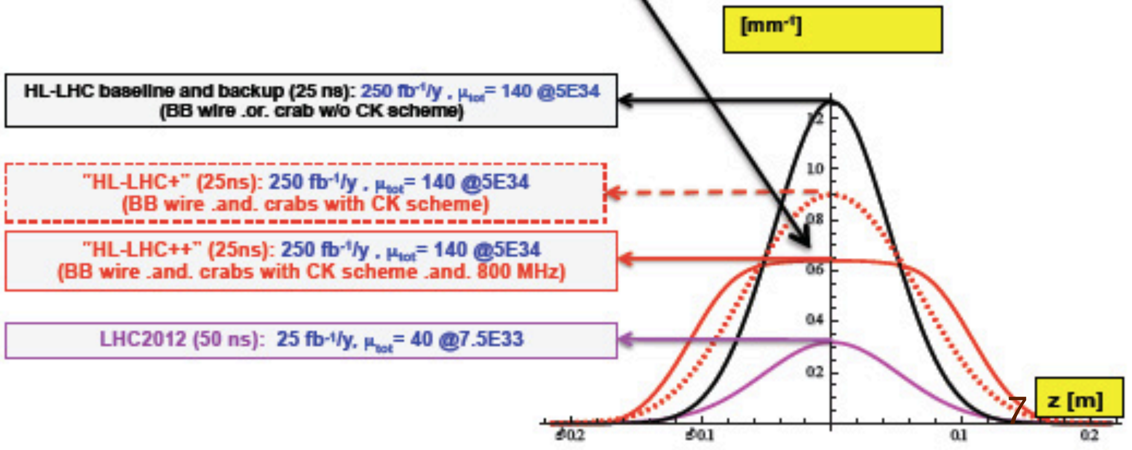


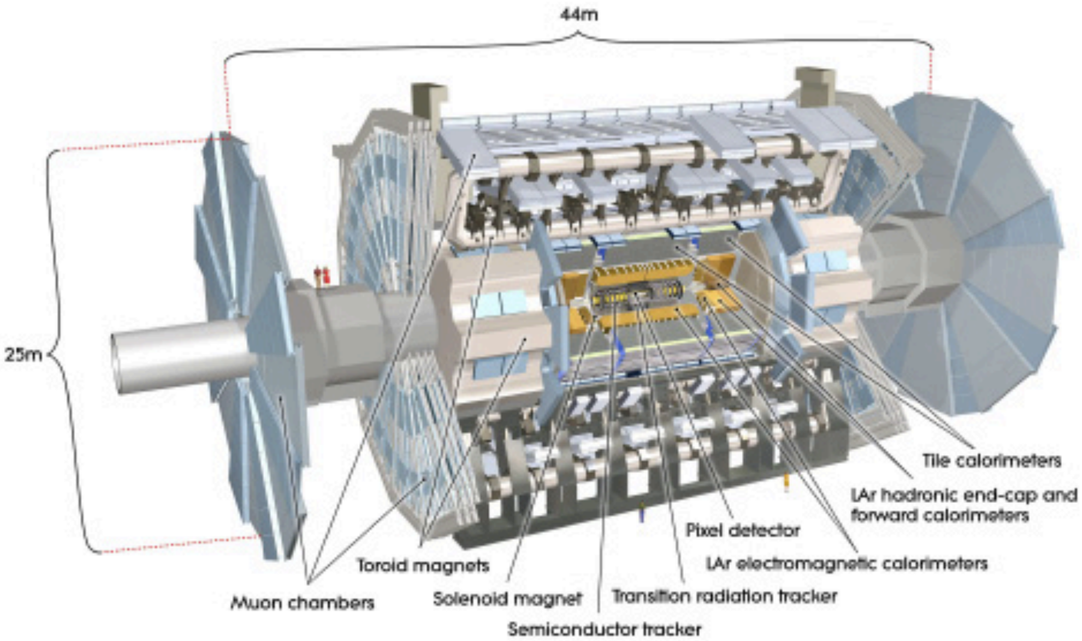
Integrated luminosity will be limited to 250 fb^{-1}/year by leveling at 5 x 10^{34} Hz/cm^2

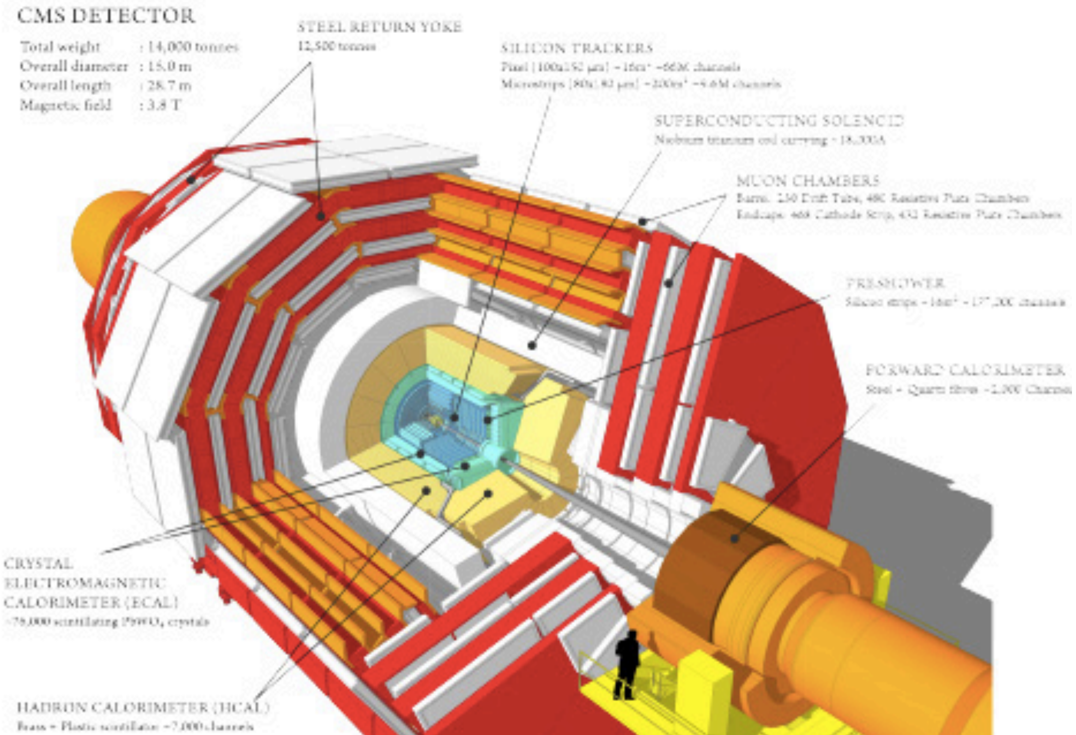
- Target performance at 125-140 PU

Can we do better? using Crab Cavity kissing scheme? (reduce PU density by a factor 2)

It will be challenging to reach 3000 fb^{-1} by 2035







Forward Region?

Muons:
$-2.4 \leq \eta \leq 2.4$
Passive shielding
$\eta > 2.4$

Calorimeters:
Performance $\eta > 3$?

Trackers?
$\eta > 2.5$?

Taking 2012 as a Reference:

T= 6.5×10^{6} s, $\mathcal{L}=23\,\mathrm{fb}^{-1}$ $\langle\mathcal{L}\rangle=3.7\,\mathrm{nb}^{-1}\mathrm{s}^{-1}$
10 years @ $\langle\mathcal{L}\rangle=50\,\mathrm{nb}^{-1}\mathrm{s}^{-1}$ -> **$\mathcal{L}=3000\,\mathrm{fb}^{-1}$**
Pileup: ($\sigma_{\mathrm{Inel}}=81$mb, n=2808, 25 ns spacing)
$130<\mu<150$

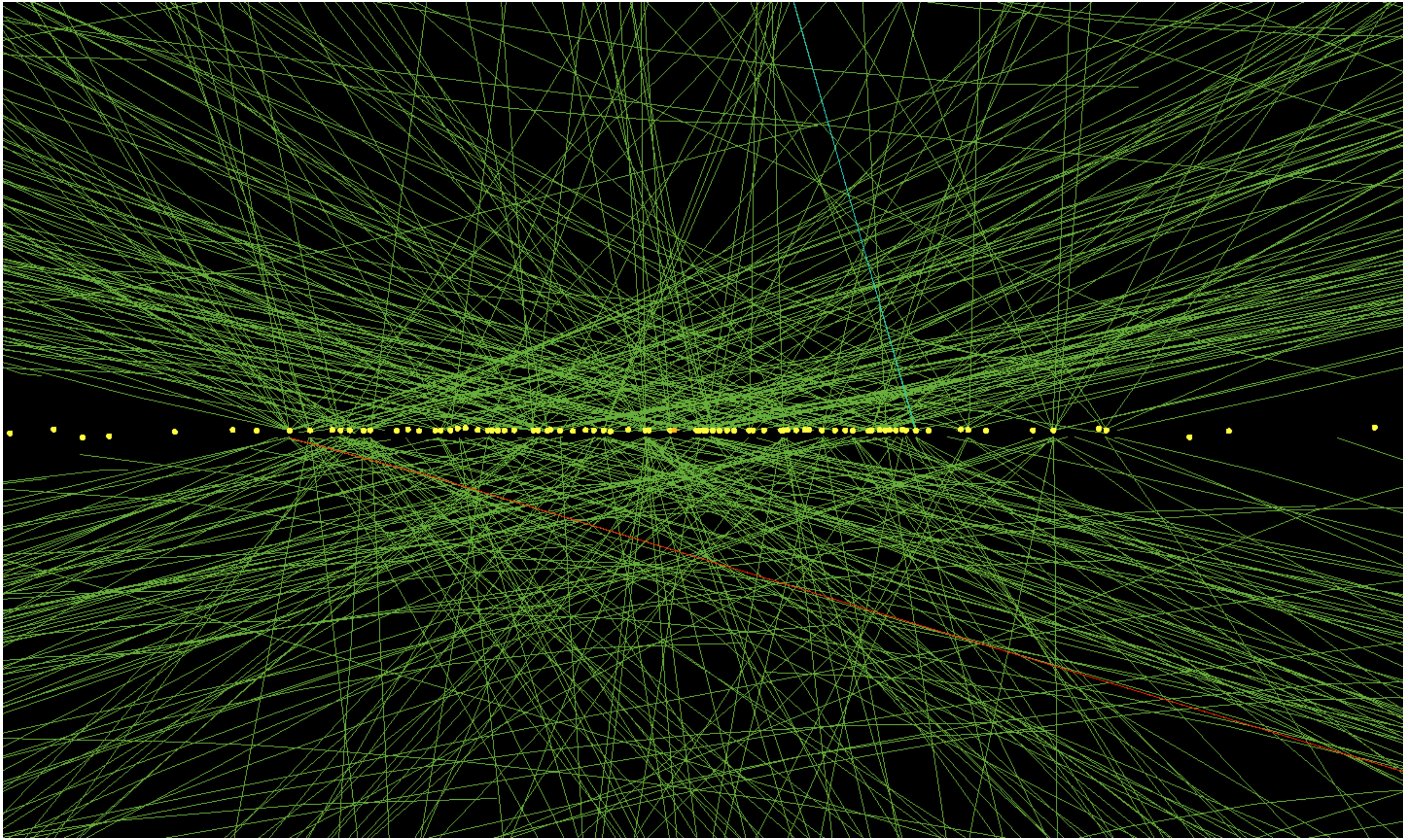
CMS, ATLAS designed for relatively low pileup, $\mu\sim24$:

- **NB! BUT Excellent performance with μ up to 35!**

Is precision Physics possible with $\mu\sim140$?

- Primary Vertex identification (e.g. for H->$\gamma\gamma$)
- Secondary vertex and b-tagging
- Tracking needs to cope with much higher occupancy
- Huge energy flow ($\Sigma E_T\sim60$ GeV per pileup event), MET resolution and tails
- Forward jets association to vertex (pivotal for VBS)

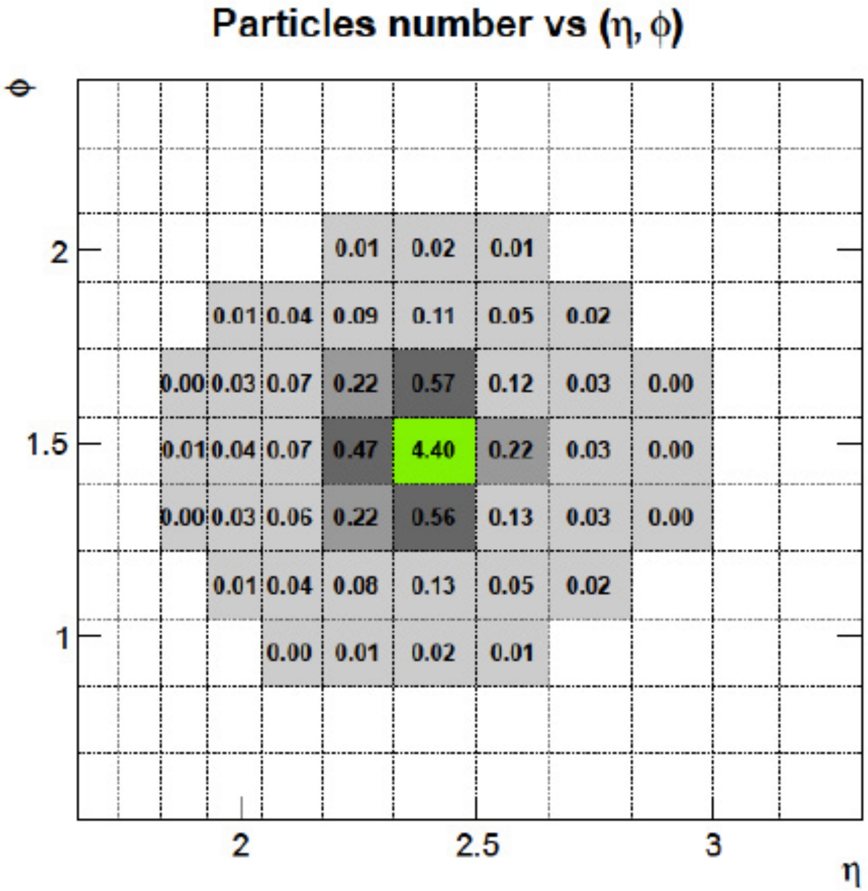
PileUp!



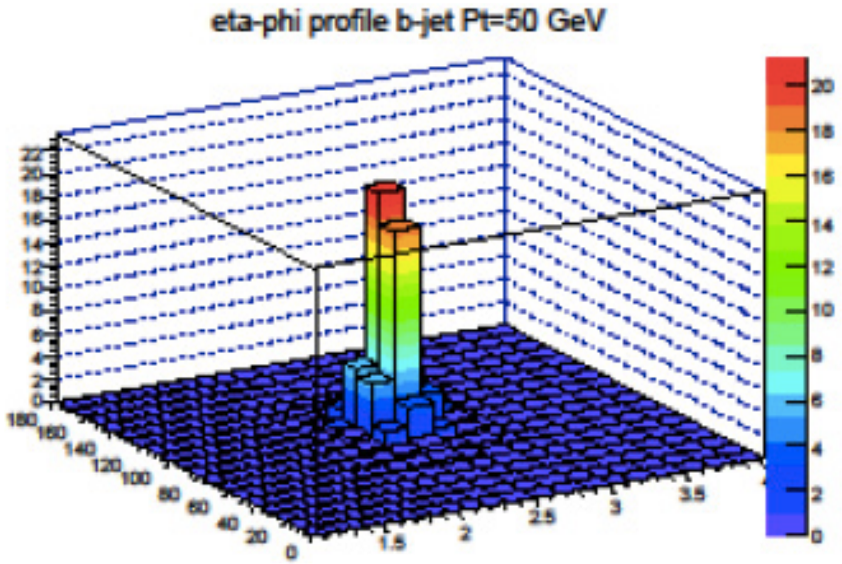
78 primary vertices

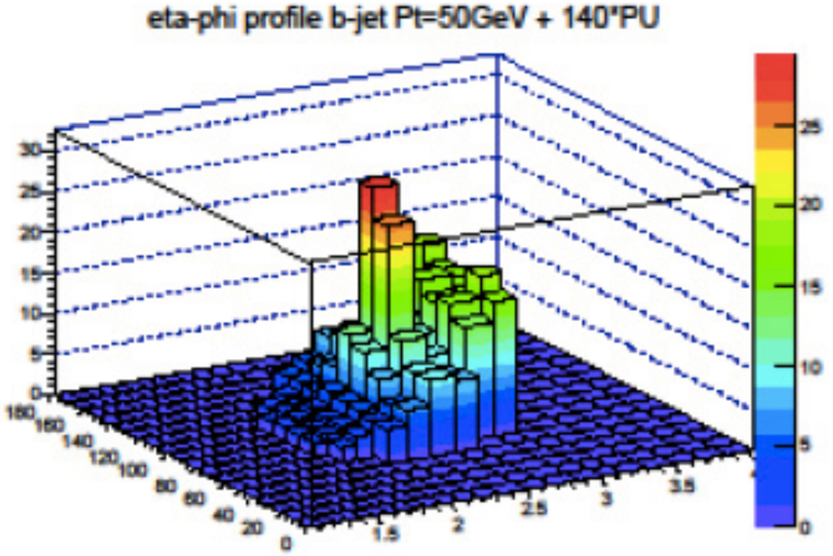
~Double this all too often….

quark jet pT=50 GeV, η=2.4
transverse jet size ~ single hadron shower


Particles number vs (η, ϕ)

			0.01	0.02	0.01		
	0.01	0.04	0.09	0.11	0.05	0.02	
0.00	0.03	0.07	0.22	0.57	0.12	0.03	0.00
0.01	0.04	0.07	0.47	4.40	0.22	0.03	0.00
0.00	0.03	0.06	0.22	0.56	0.13	0.03	0.00
	0.01	0.04	0.08	0.13	0.05	0.02	
		0.00	0.01	0.02	0.01		


eta-phi profile b-jet Pt=50 GeV


eta-phi profile b-jet Pt=50GeV + 140*PU

Pile-Up Mitigation Rules-of-Thumb for Sensors
(ROTs may apply to all regions)

Tracker:

- pixels -> 25-50 μm
- non-hydrogenous (neutron bad bongoes)

Calorimeters: **FOM: Can *Your* Calorimeter resolve/tag a muon to ~5σ? Within a jet?**

- $\Delta\eta \times \Delta\phi$ increased by ***at least*** 2x2
- Transverse segmentation: ½-1/3 shower diameter (conflict with above?)
- $T_{integration}$ < 25ns; rate 40 Mhz; σ_t <0.5ns –> Waveform Analysis? Hysteresis?
- $\sigma E_h/E_h$ -> ~30%/$\sqrt{E}$ + 1-2% [Compensation]*
- $\sigma E_{em}/E_{em}$-> <10%/$\sqrt{E}$ + 1% AND Compensated*
- Low background/fake signal generation from punchthru, neutrons,…
- Denser** (and/or Increase distance to crossing)
- Thicker to beam: 10 L_{int}: ~1 per 1000 π,K go whistling right through/μ-like

Muons:

- Increase η up to ~5
- Pixellate in high rate regions
- Non-hydrogenous – the gas of neutrons is a problem
- $T_{integration}$ < 25 ns; rate 40 MHz

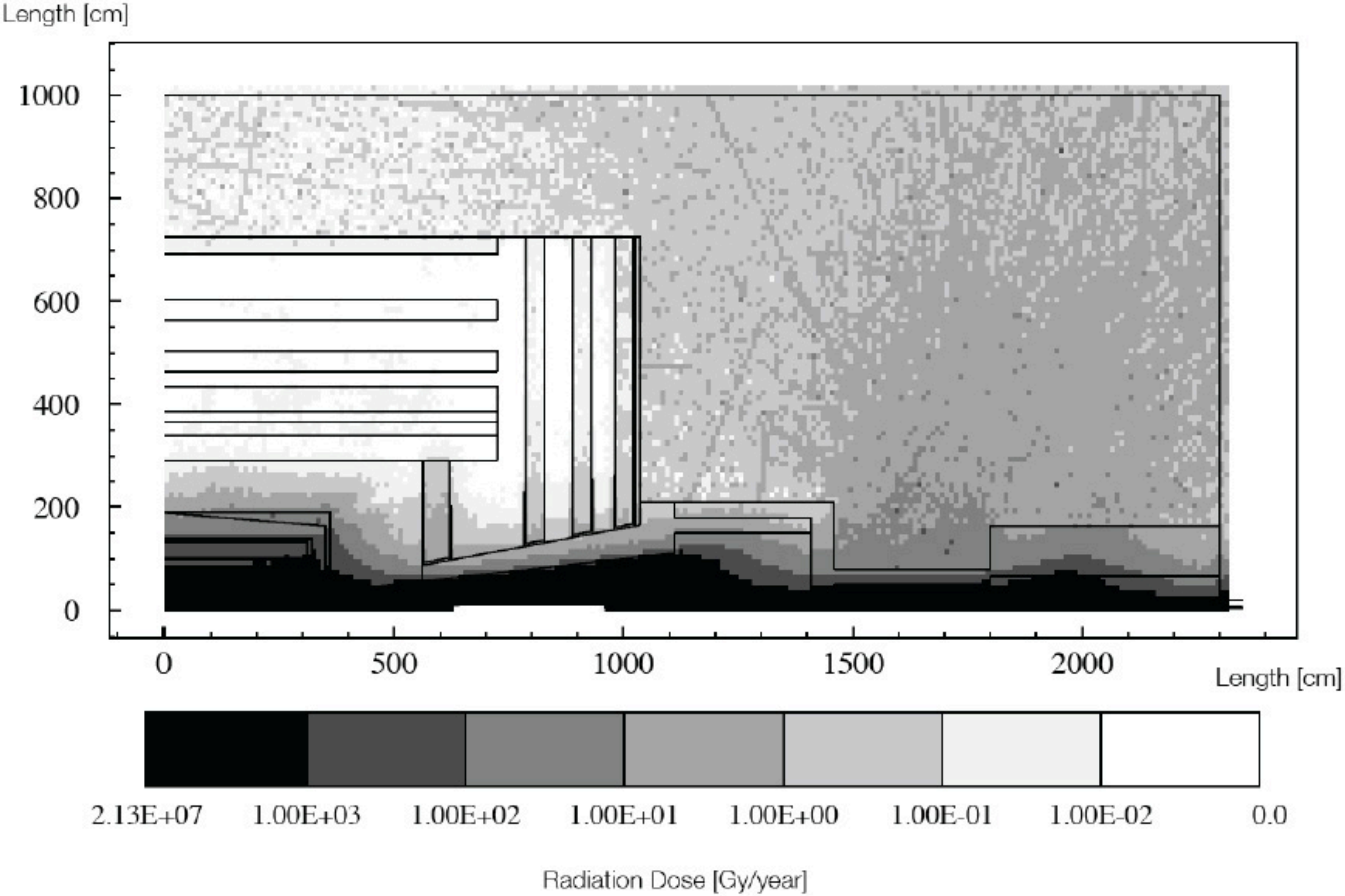
Neutrons: - Methods to reduce the flux – absorbers

* - Top tags via jet-jet require excellent jet resolution – some jets in forward region…

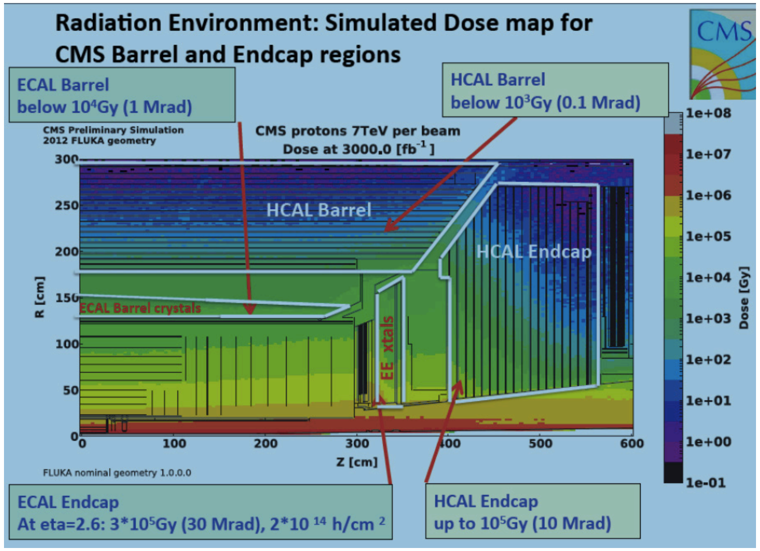
** - *ACHTUNG!* Pb, W produce ~4-5 more neutrons per hadron than Cu, and they spill out over ~ 100 ns. W absorber excellent for an e-m compartment, as long as it is compensated.

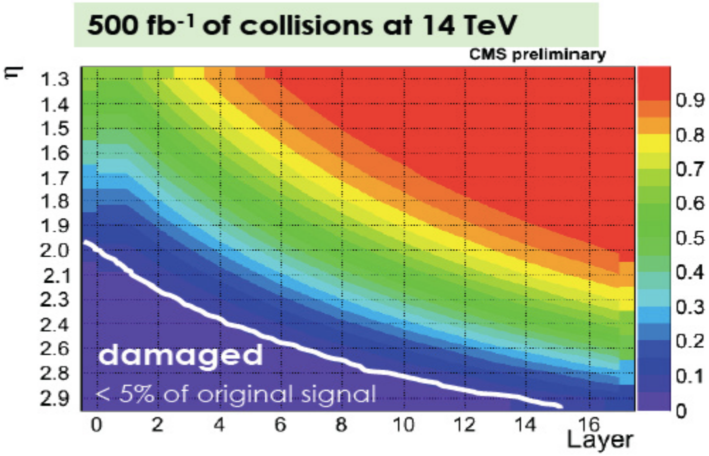
3000 fb^{-1} - 10+ years of $4\times10^{34} < L \leq 10^{35}$

- ***Radiation Damage! 0.1-2 GigaRads $\eta>3$***



Ex: CMS Forward Calorimeter – Quartz Fibers embedded in Fe $3 \leq \eta \leq 5$
$-5 \leq \eta \leq 3$ Survives 2 GRad – signal loss in highest η ~40-60%
- Damn Fast – Signal over in ~12ns + Visible hadron “tube”~ 9cm Diameter
- BUT Needs much better $\sigma E/E$ <-> compensation – PhotoStat. Ltd.
- Needs thicker absorber





CMS Scintillator Endcaps

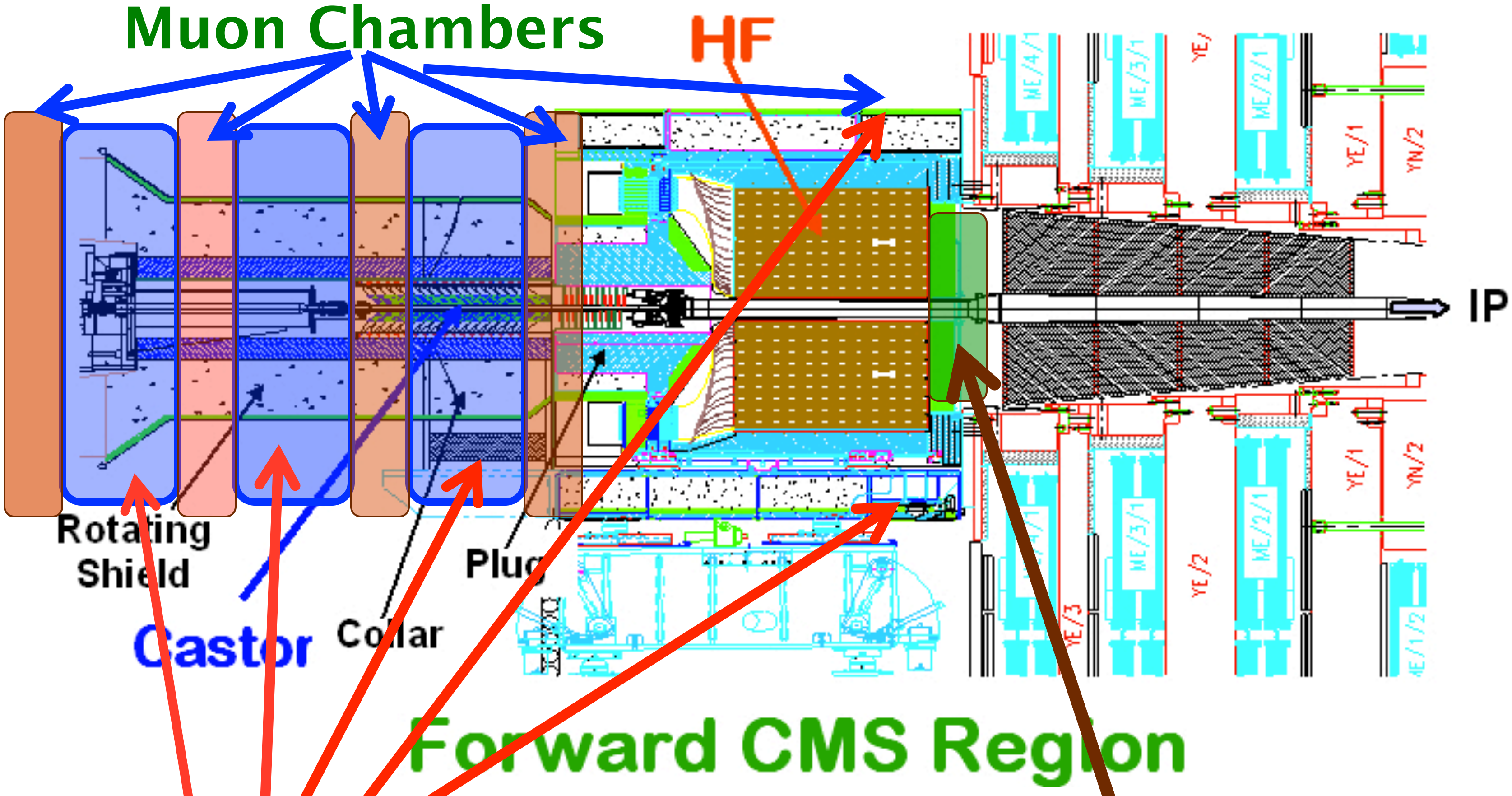
ATLAS LArgon Forward Calorimetry – Cu rods embedded in LAr survives;
~ x2 Better Resolution than CMS
- in-LAr electronics may need work(?)
- Ion current, potential for bubbles/cooling problematic at 5 x 10^{34}.
- Even smaller drift gaps?

Calorimeter Raddam Mitigation

Many plastics -> Dust! ***Require Low Activation***

- noble elements
- metal & semi-conductor oxides [scintillation, ionization, Cerenkov, Secondary Emission(SE)] Examples:
  - ZnO:Ga; SiC; Al_2O_3(alumina/sapphire), BeO, WO_2; Quartz (epi Si fails $\eta>3$)
- PMT dynodes, Accelerator Beam monitors (CERN BLM's: 10^{21} p/cm^2 no loss of signal) (Metal Oxides & Fluorides)
- III-V semiconductors & semiconductor alloys with large bandgaps: GaAs, GaInP, InGaAs...(Lower Signals, $$-yet common digital radios)
- Diamond (doping) [Aside: SE Gain -> 3000! Xmission dynode films]
- Scint/WLS: Thin films, nanocrystals embedded, coated on quartz, metal,.. . *(+ALD, MOCVD, Flood MBE, Large flat-panel tooling….)*
- Rapid Periodic Replacement: robotics, liquids, gasses
- Annealing – liquids, soft materials, thermal/optical Ex: BaF_2 anneals fully with ~1 day of UV ….

Forward μ System?



Muon Fe Toroids
eplace Rot. Shield/Collar

Stub Tracker, Pre-radiator, e-m Cal
–replaces inert poly shield

Muon Toroid System

- ~2-3 m of Fe Toroids: in 4 ***or many more*** Segments
  ~1.8 T Saturation. Superferric? $H_{TC}LN_2$ –2.2-2.5T inner radius; SC Toroids B>3T
- ~1-1.5 m max radius chambers, 50 μm *pixels* – non-hydrogenous –> Si trackers!
- ~0.5 m wide chamber stacks (100 μrad per stage)
- σ_p/p ~11-12% MS limit @ 1.5 TeV (6 Toroid, 2.5m Fe)
  - p term in dp (B^2L) ~10^{-4} p (GeV)
- ->low Z Toroids: Al(ρ=2.7), Alumina(ρ=4 -> Porous Al_2O_3)
  ~1 L_{int} thick toroids + Energy “harps” for Brem ID

Compensation via Cerenkov Light*

Tile Dual Readout – use to tune e/h->1

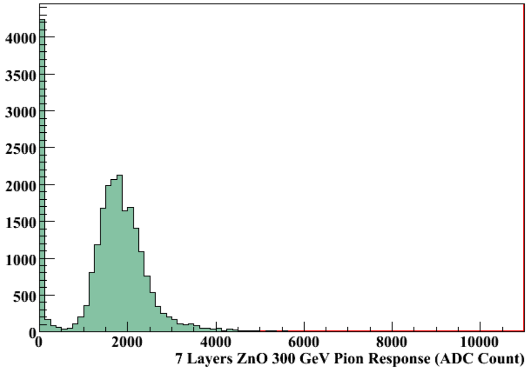
A Toy Example: Back-Back Quartz Tile + Rad-Hard Scintillator Tile:

Scintillator Tiles: Lscint boxes; BaF2+UV anneal; ZnO:Ga coated Quartz, ….

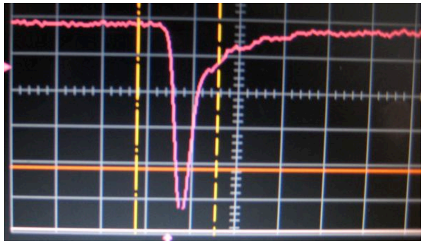
ReadOut by WLS fibers:

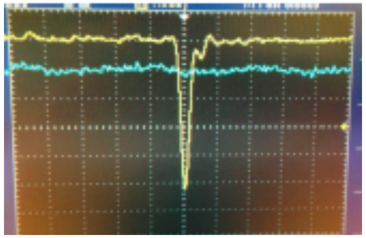
Robotic-Replaceable plastic; LiqWLS or soft WLS material (pTP) in quartz capillary cores or on quartz cores; annealable materials; …..

E-M compartment – 0.5Lrad W plates
Hadron Compartment: – 0.5 Lint Cu plates



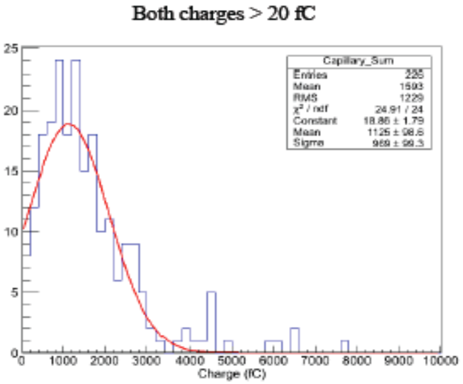
0.2μm ZnO(4%Ga) film on
100μm thick quartz tile
x 7 tile stack < 0.8mm tile
Exposed MIPs (300 GeV π)
ZnO:Ga <2ns; 10-20% NaI

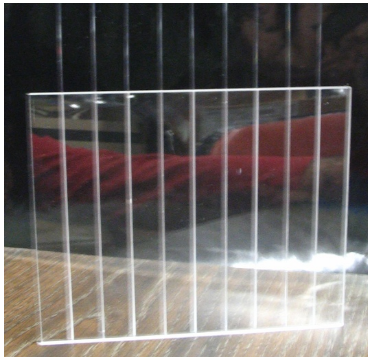


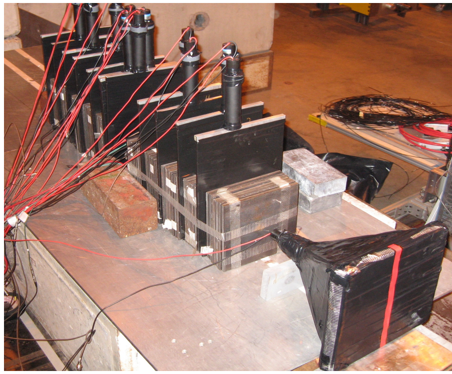


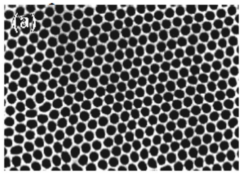
700μmx25 cm Quartz
Capillary Anthracene Core
Via vacuum melt imbibition
MIP-10 mV/div x 10ns/div

8 p.e./end









Bonus!

Porous Al_2O_3 Cladding
n~1.25 – TIR w/H_2O!
On quartz: NA~0.9

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*D.R.Winn and W.A.Worstell, Compensating Hadron Calorimeters with Cerenkov Light, IEEE Trans.Nuc.Sci 36,334(1989)

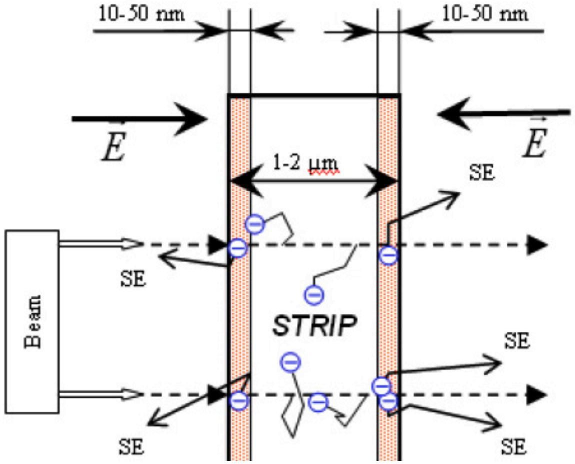
Secondary Emission Ionization Calorimeters?

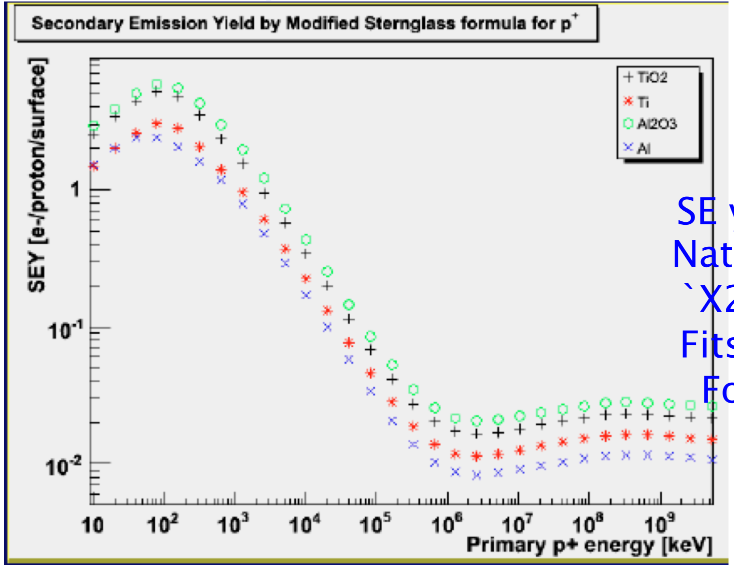
- Secondary Emission(SE): Rad-Hard + Fast *(Damn Fast!)*
  - *a) Metal-Oxide SE PMT Dynodes survive > 100 GigaRad*
  - *b) SE Beam Monitors survive 10^{21} mip/cm^2*
- ***SEe signal:** SE surfaces inside em/had Showers:*
  - SE yield δ: Scales with particle momentum ~dE/dx
  - e^-: $3 < \delta < 100$, per $0.05 < e^- < 100$ KeV (material depnt)
  - δ~1.05 -1.3 (0.05-0.1 SEe^- per MIP)

BUT SEe Must be Amplified – do this exactly like p.e….

NB: an SEe is statistically exactly like a p.e.

g >10^4e/SEe which are generated by shower particles)
(just like a p.e. is defined from a photoelectron)

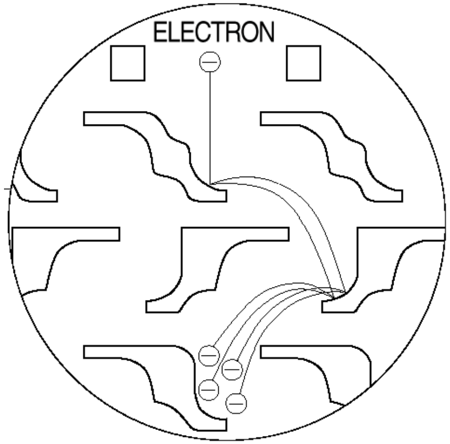


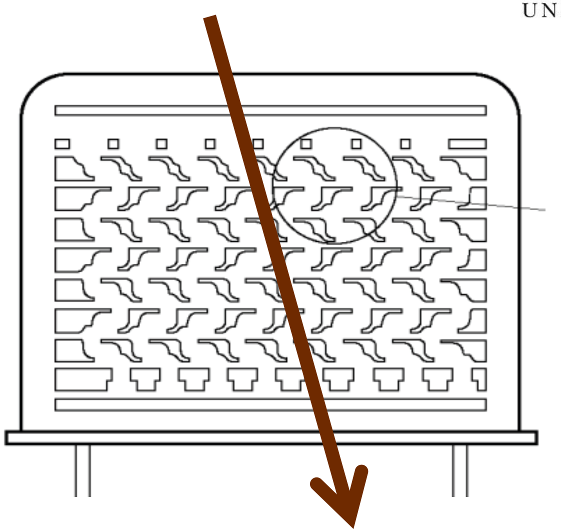


SE yield vs Eproton
Native oxides Ti, Al
`X200 peak-valley
Fits the Sternglass
Formula ~dE/dx

SEe Dynodes: *Etched Metal Sheets, Mesh*

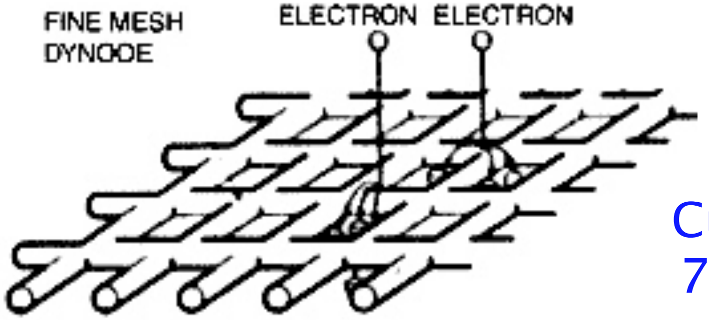
Hamamatsu Sheet Dynodes
15 cm now -> ~50 cm





Use dynodes as aborber & detector
– quasi heterogeneous

D_n–D_{n+1}: 0.5 mm
C-C mesh: 13 µm
Wire diameter: 2 µm
15D: $g \sim 10^5$, $B_z \sim 2$ T
B(20°)~10%

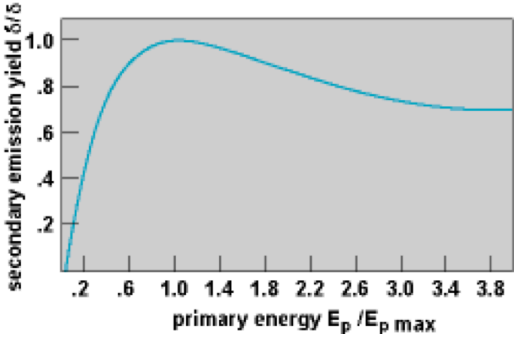


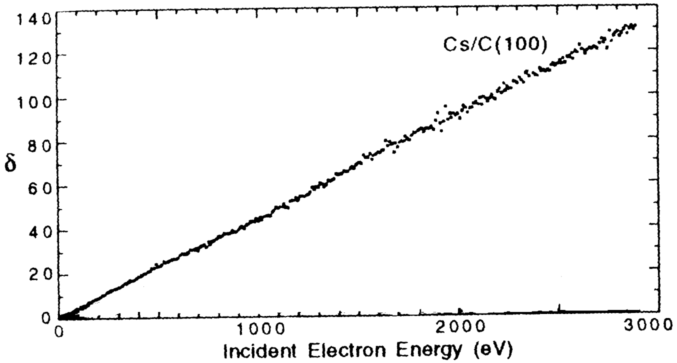
CuBe Mesh 37% transparent,
75 µm apertures– <\$15/m^2

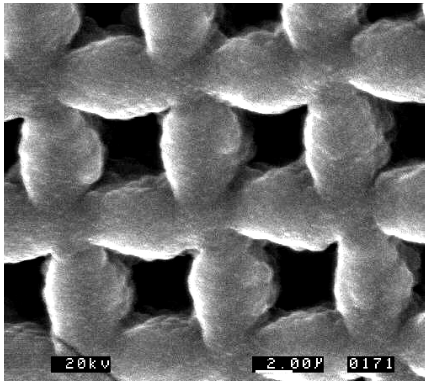
Low Cost High SE Yield Materials

Peak Yields~5-10+; Alumina Easy

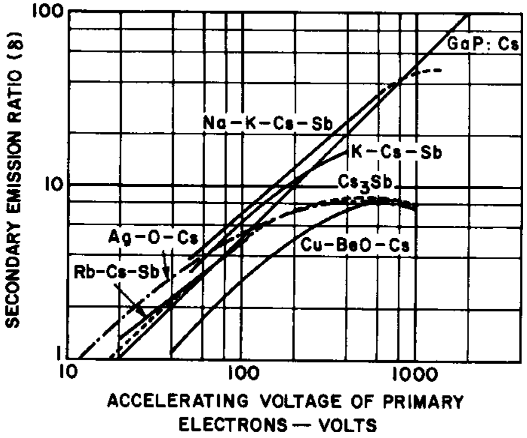
Universal curve of SE

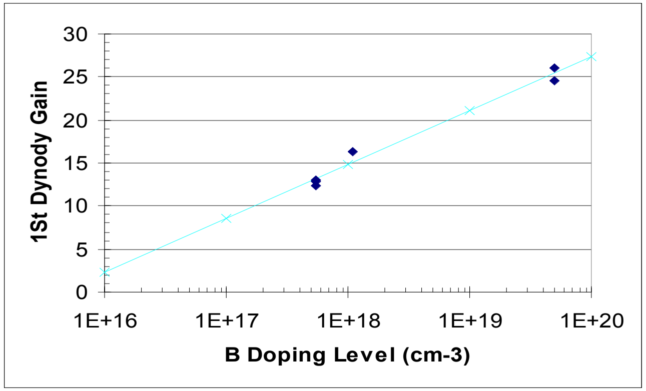






Diamond nucleated
on Si MCP
12μm centers

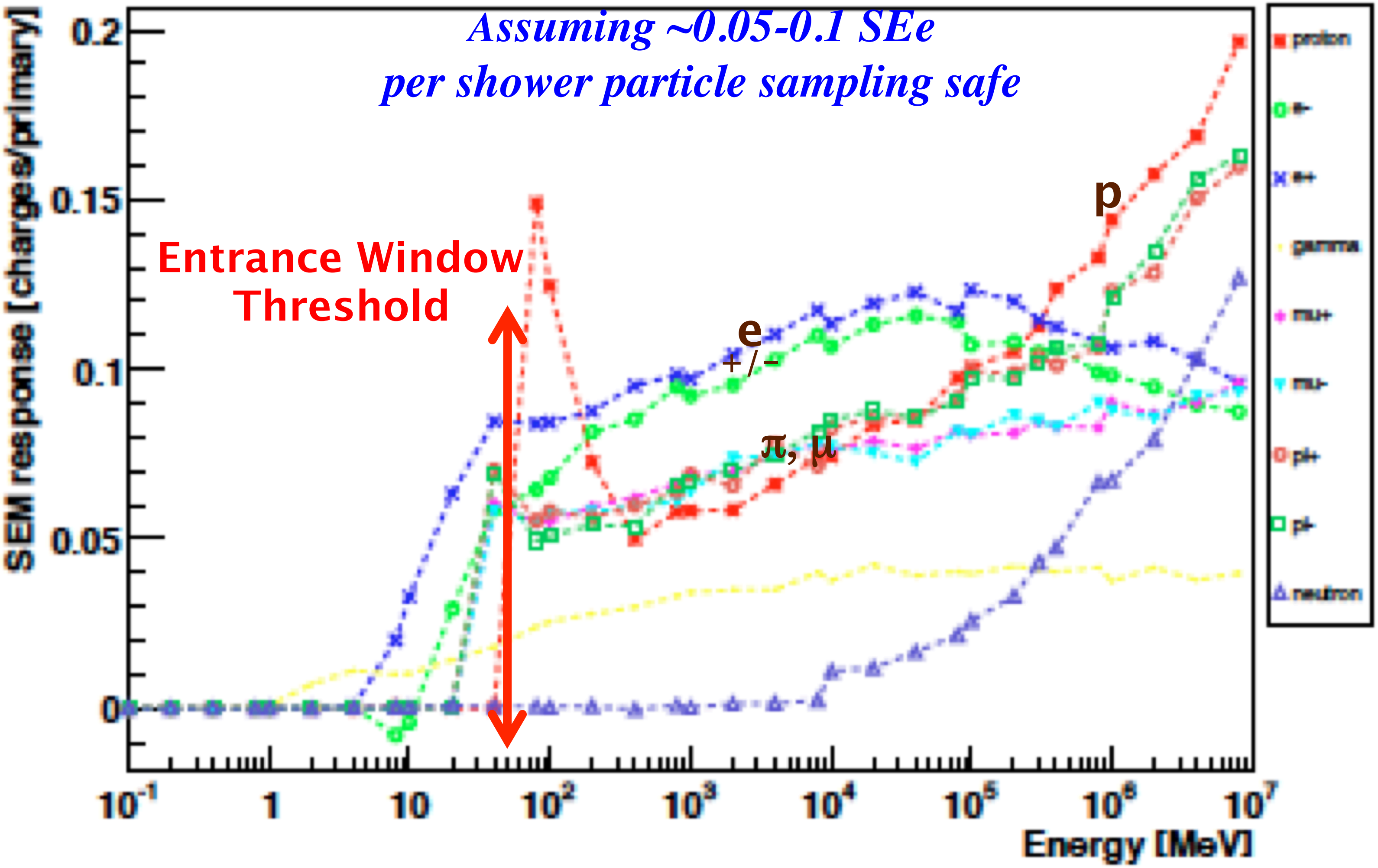




B-doped Synthetic Diamond - 100 nm poly film nucleated on W – 300V @ 1KVe: δ = 40!

Transmission Dynodes -

Sensitivity of SEM detector



Assuming ~0.05-0.1 SEe per shower particle sampling safe

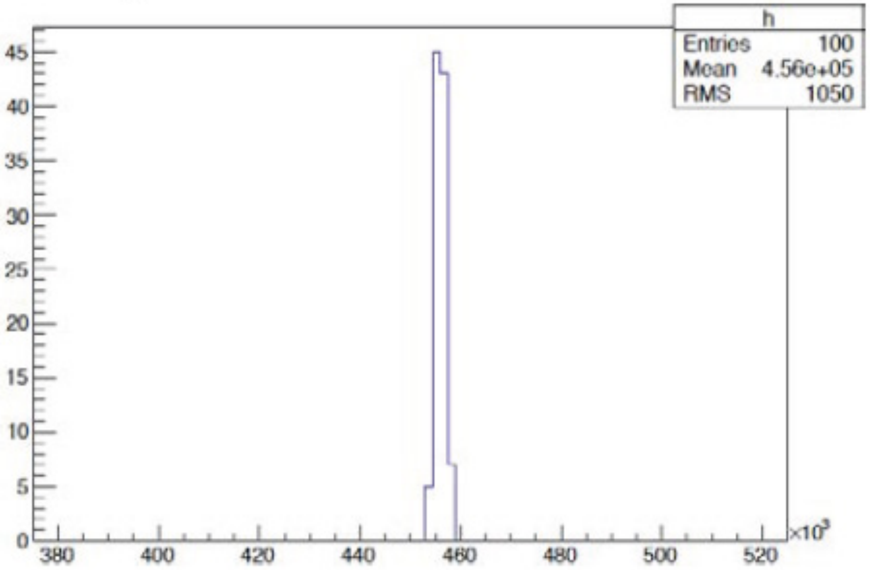
Entrance Window Threshold

#SEe per primary (CERN SEM BLMS Al_2O_3) vs $E_{primary}$:

p, e^-, e^+, μ^+, μ-, π^+, π^-, γ, n - ***Yield: ~0.05-0.15/MIP for Showers***

(no energy < 10 MeV - threshold from the thick entrance window)

Secondary Emission Ionization Calorimeters



GEANT4 MC

Monotonous 10μm W mesh 20% open

10μm spacing; ~40% density of W;150 V

100 GeV e Generates ~450k SE

Implies $\sigma E/E<3\%/\sqrt{E}$

If 50μm/50μm Cu -> $3\%/\sqrt{E}$

(but no gain spread, electronics)

SE Modules CERN Test Beam

COMMMMMENTS:

- **Scintillator Cal:** – *Lots of Photons, but ~1% converted to p.e.*
- SE Cal: – *Few SEe, but >90% collected and amplified.*

-A Dynode amplified SEe directly comparable to Dynode amplified p.e.

- Fine Segmentation, Arbitrary shapes, Tileable. ->energy flow

NO ACTIVATION. ASSEMBLE IN AIR.

No Photocathode processing (few hours).

Bakeout (Refractory T)/Evacuate

Vacuum 100 times worse than PMT ok.

Alternative gain mechanism – MCP et al.

E-M Calorimeter/Preshower/Stub Tracker Options

- Liquid Scintillator Sampling: Organic or LXe under E-field
- Quartz Plates+Films:0.5-5 μm ZnO:Ga, pTP, nanophosphors, YAP:Ce, …
- Quartz SciFi/WLS fibers: Ext. Films ZnO:Zn
- Quartz-Capillaries SciFi/WLS sub-Cores:
  - Lscint/WLS Liquid Core Fibers
  - pTP, Anthracene, ZnO:Ga, ZnO:Zn Core
- Fluorphosphate:Eu, Germania (GeO_2) Cerenkov Glasses
- ***Gaseous-Based non-hydrogenous pixels?***
- ***Secondary Emission Modules?****
- ***Assume Compensation via Cerenkov.***

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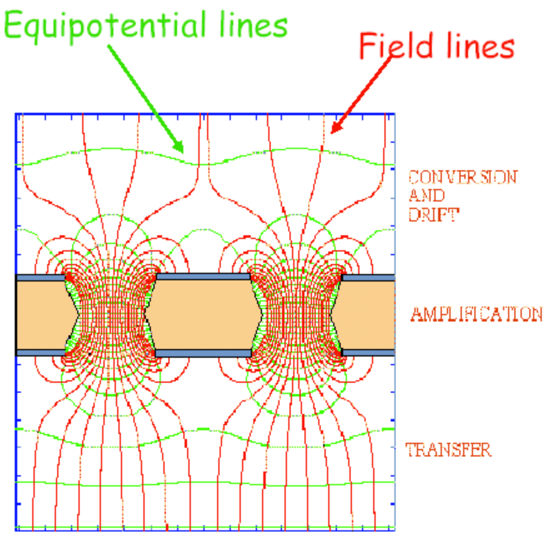
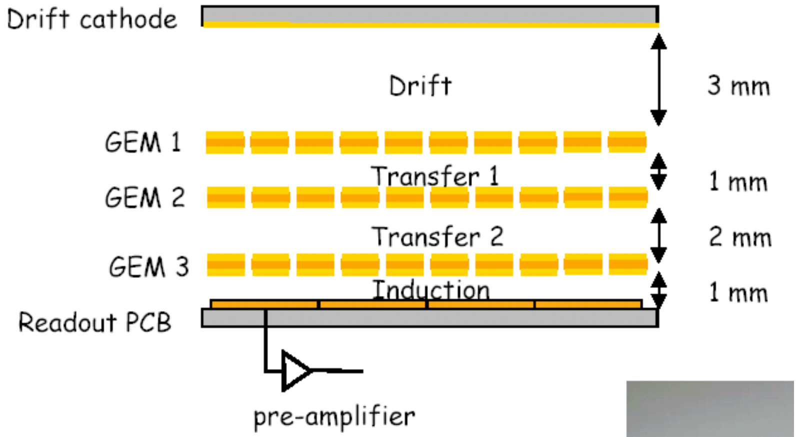
Stub Tracker/Preradiator+Muon Option

MPGD’s – CMS Studies

- Spatial resolution ~ 100 μm
- Time resolution ~ 2-3 ns
- Efficiency > 98%
- Rate capability > 5 kHz/cm^2
- Track capability – 10^4/mm^2
- A/CO$_2$ – OK????





Stub-Tracker Pre-Radiator

- PMT: Excellent Direct e, μ , π Detectors!

  - Turning a Problem into a Feature….

  - Cerenkov light Gaussianly distributed…

- PMT: Rad-hard up to window transmission

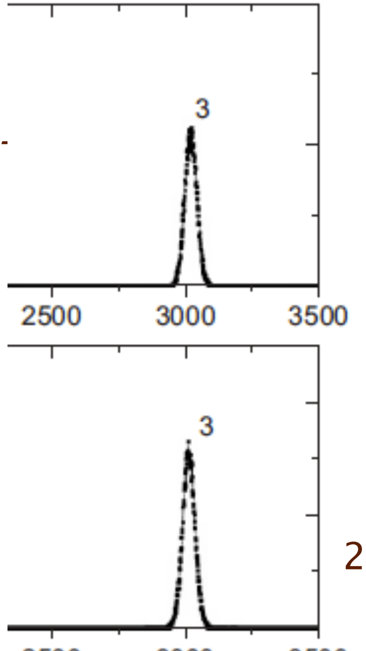
Quartz, Sapphire Xmission: >90%/mm, ~500 Mrad (400-500 nm)

Nuclear Instruments and Methods in Physics Research A 581 (2007) 438-442 **Radiation-hard photodetectors based on fine-mesh phototubes for calorimetry in very forward rapidity** Y. Gusev et al.

10^{16} n/cm^{2} (0.95MeV), gamma ray 5 MRad on FEU-187 mesh PMT

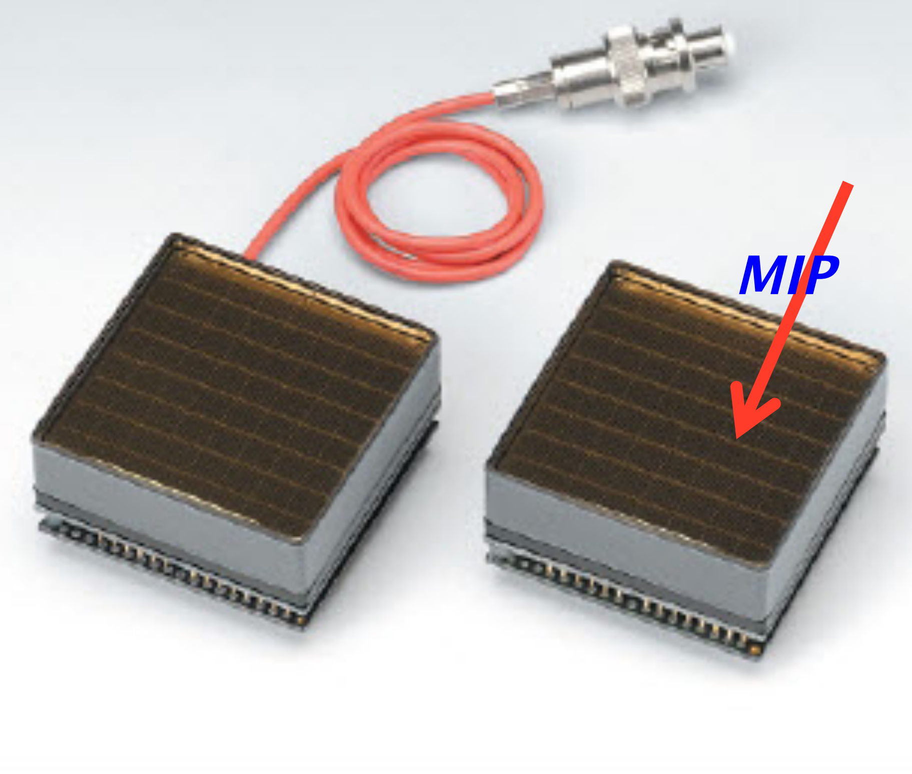
Gain shift consistent w/7% UV-glass transmission loss +/-2%

Operates ~8-10% gain at 1 T (0^{o}–20^{o})



Anode Sensitivity Before/After Raddam
BlueLED: Number/Ch vs Channel Count

Stub-Tracker/Pre-Radiator



Left: H10966A (HV cable input type), Right: H10966B (HV pin in

H10966 Series (c.2010)

52 mm (2”) x 15 mm thick

Active area 49mm

Packing Density: 89%

Risetime 0.4 ns – 200 ps σ_T

Transit: 4 ns (!)

Rate: ~1/8ns = 125 MHz

Pixel: 5.8 mm pitch->2.9mm

Window: 1.5 mm thick

pe/MIP: ~20 *(Gaussian!)*

Gain: 3 x 10^5

Cross Talk: 2-3%

$\Delta\theta$ ~ 2.9mm/11.1m ~ 250 µm pixel at 1m = 0.5 mRad

-> Tile front of E-M with layers of pixel PMT

Summary Forward System

- Lepton-Photon-Jet System at $3 \leq \eta \leq 5$ Feasible?
- Need Mechanical/Assy/B issues for Muon System
- Need Proofs of em cal, preradiator (cabling,…)
- Need Physics MC motivations using Target Perf:
  - *$\sigma_E/E \sim 10\%$ for +/- 1 TeV μ; $<10\%/\sqrt{E}$ for e,γ (No Sign)*
  - *Electron/Photon discrim.: ~90%,~1 cm*
  - *Electron Track: ~6mm box + geometric unsharpness from interaction diamond*
  - *$\sigma_E/E \sim 30\%/\sqrt{E}$ for jets via compensation*
  - *Time resolution ~200 ps*

SUMMARY: SE Calorimeter R&D
Secondary Emission Sensors for Calorimeters

- **Basic Idea:** *Dynode Stack:High Gain Radiation Sensor*
  - ε ~0.1-0.2 SEe/mip/SE Surface Sample
  - Signal g >10^4/SEe (15 Mesh Dynodes -> 1 SEe ~ 1pe ~10^5e)
  - σ_{Eem}/E_{em} ~ SEe/GeV <5%/√E(GeV)
  - Eh – no information – some indication of compensation
  - Rad-Hard (PMT dynodes>100 GRads)
  - Uber-Fast: signal ~cotemporal w/shower ~ PMT impulse
  - Compact (dynodes <0.1mm thick/stage)
  - Rugged/Structural Element/Non-Crit./NoActivation Assy
  - Arbitrary Shapes/Integrate into large calorimeters
  - Minimal Dead Areas or Services needed.

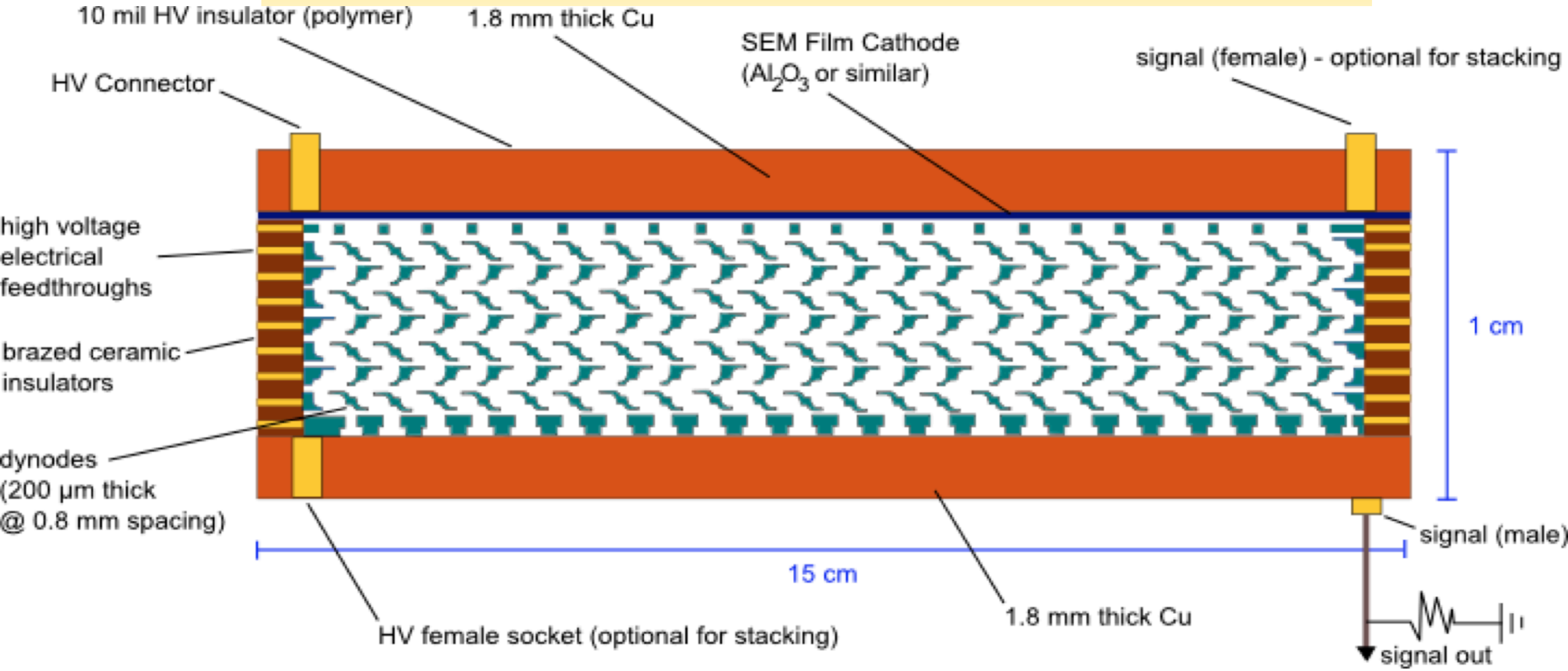
- Energy-Flow Calorimeters (e+e-, μC, SLHC,….)

- Forward HiRad HiRate Calorimeters

- Compensation

Extra/Back-up Slides

SEe Detector Module Concept -HCal



3D Stackable x,y,z

Secondary Emission Calorimeter Sensor:

1. **Top Metal Oxide/C SE Cathode, thin film SE inner Surface**

   Square/Hex/Rectangle/etc –can be thick!

2. **Edge Wall: ceramic, or metal w/ceramic HV insulators; HV feedthrus; vacuum metal tip-off: ~1cm high**
3. **Dynode Stack – mesh, slats ~5-10 mm thick;**
4. **Bottom Metal Anode – thick ~Cathode; Vacuum pump tip;**

   Seal – e-beam seam, braze, etc

5. **Evacuate/Bake (Refractory T!), and Pinch-off tip.**

NO ACTIVATION! ASSEMBLE IN AIR!

No Photocathode processing (few hours).

Vacuum 100 times higher than PMT ok.

NOTE: Alternative gain – MCP et al.

Technologies to make SE Calorimeters: Cheap Mesh!

CuBe Mesh 37% transparent 75 µm apertures– <$18/m^2

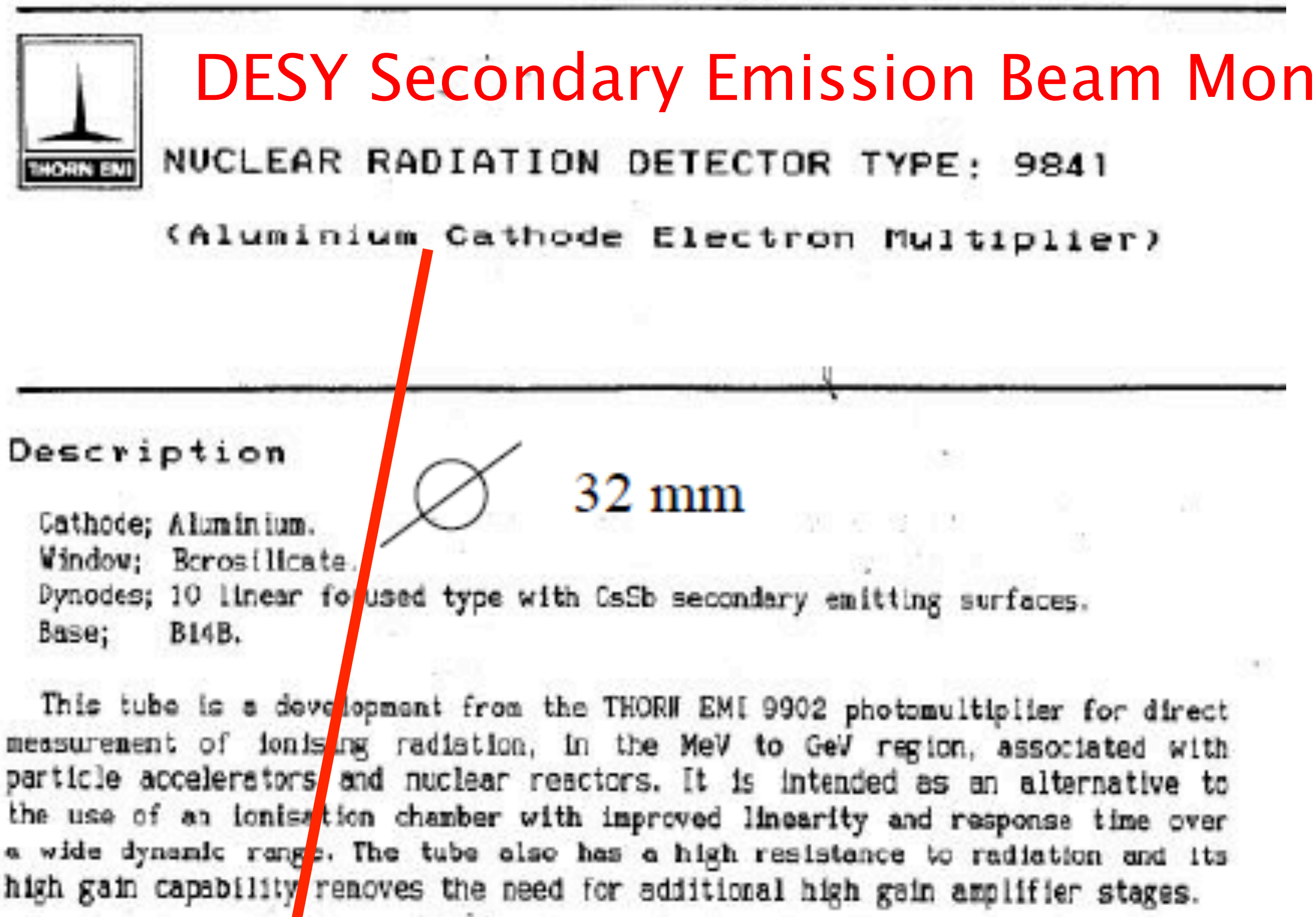
15 mesh/Lrad x 25 Lrad x 3m^2 x 2 arms x $18/m^2 ~ $40k

SE MIP Detector w/ 5 x 10^7 Gain!

SEe- Already In Vacuum

Use Dynodes To Amplify!

DESY Secondary Emission Beam Monitor



THORN EMI

NUCLEAR RADIATION DETECTOR TYPE: 9841

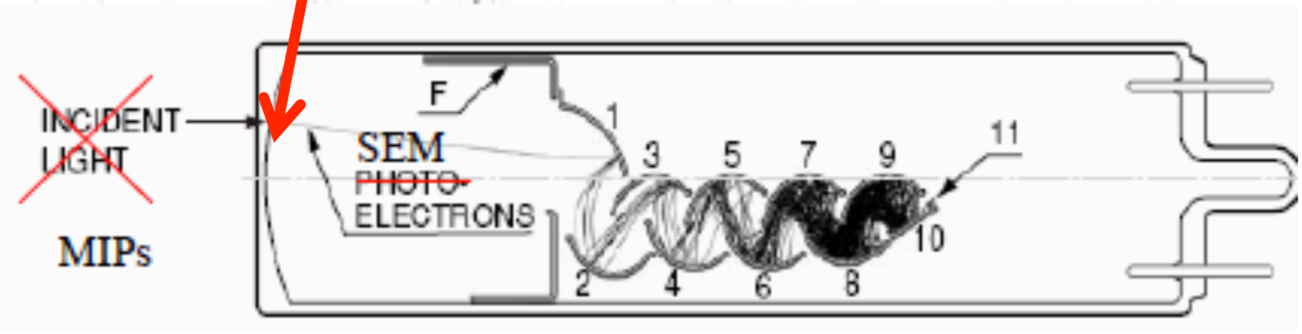
(Aluminium Cathode Electron Multiplier)

Description

⌀ 32 mm

Cathode; Aluminium.
Window; Borosilicate.
Dynodes; 10 linear focused type with CsSb secondary emitting surfaces.
Base; B14B.

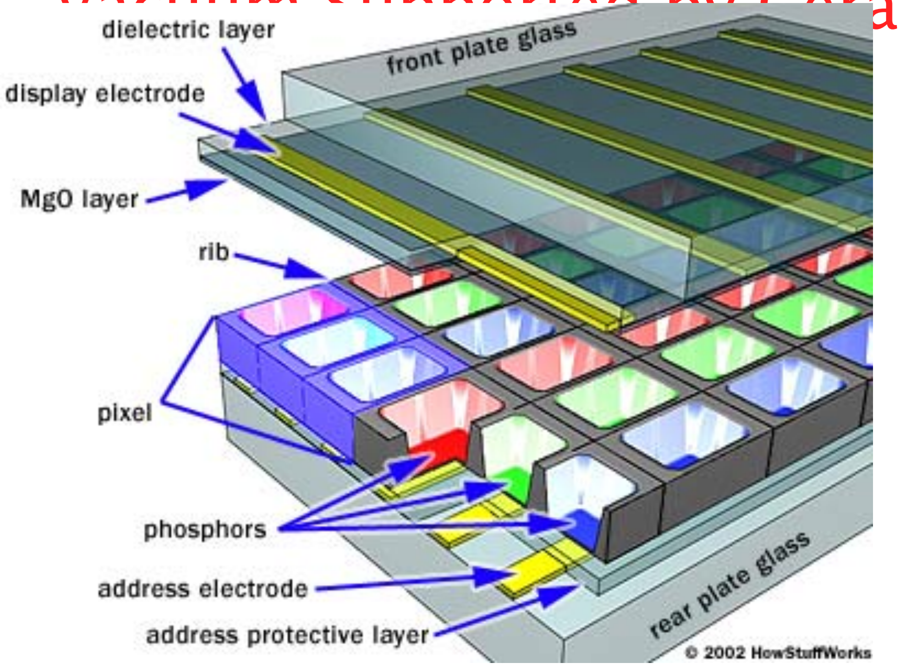
This tube is a development from the THORN EMI 9902 photomultiplier for direct measurement of ionising radiation, in the MeV to GeV region, associated with particle accelerators and nuclear reactors. It is intended as an alternative to the use of an ionisation chamber with improved linearity and response time over a wide dynamic range. The tube also has a high resistance to radiation and its high gain capability removes the need for additional high gain amplifier stages.

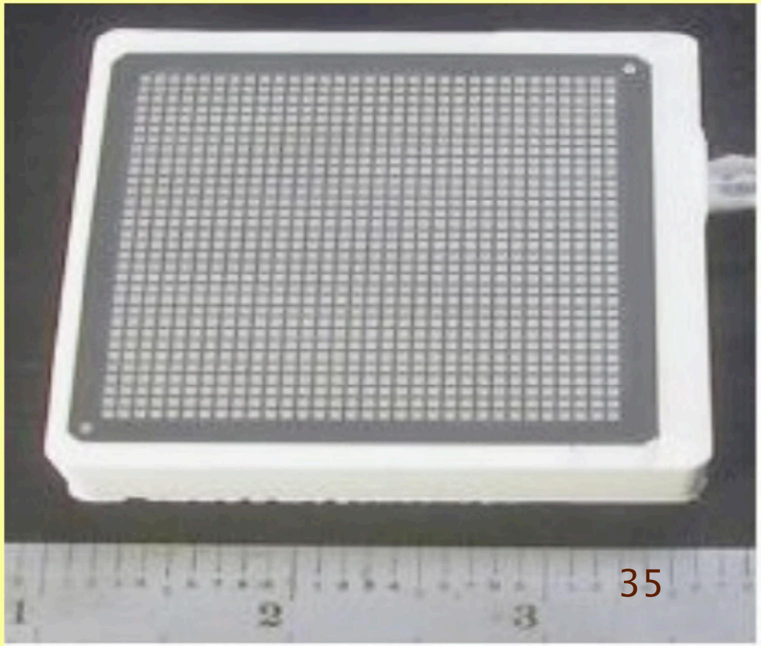


SE Calorimeter Sensors: Can Be Manufactured!

- Similar to m^2 Low Pressure Gas Plasma Display Technology
- Proof Principle/Manufacture BUT SE Calo sensor far simpler
- Hermetic + Voltages similar to dynodes
- Vacuum Supported by Ceramic walls or posts

Ceramic Body 2.5" MCP-PMT – em!



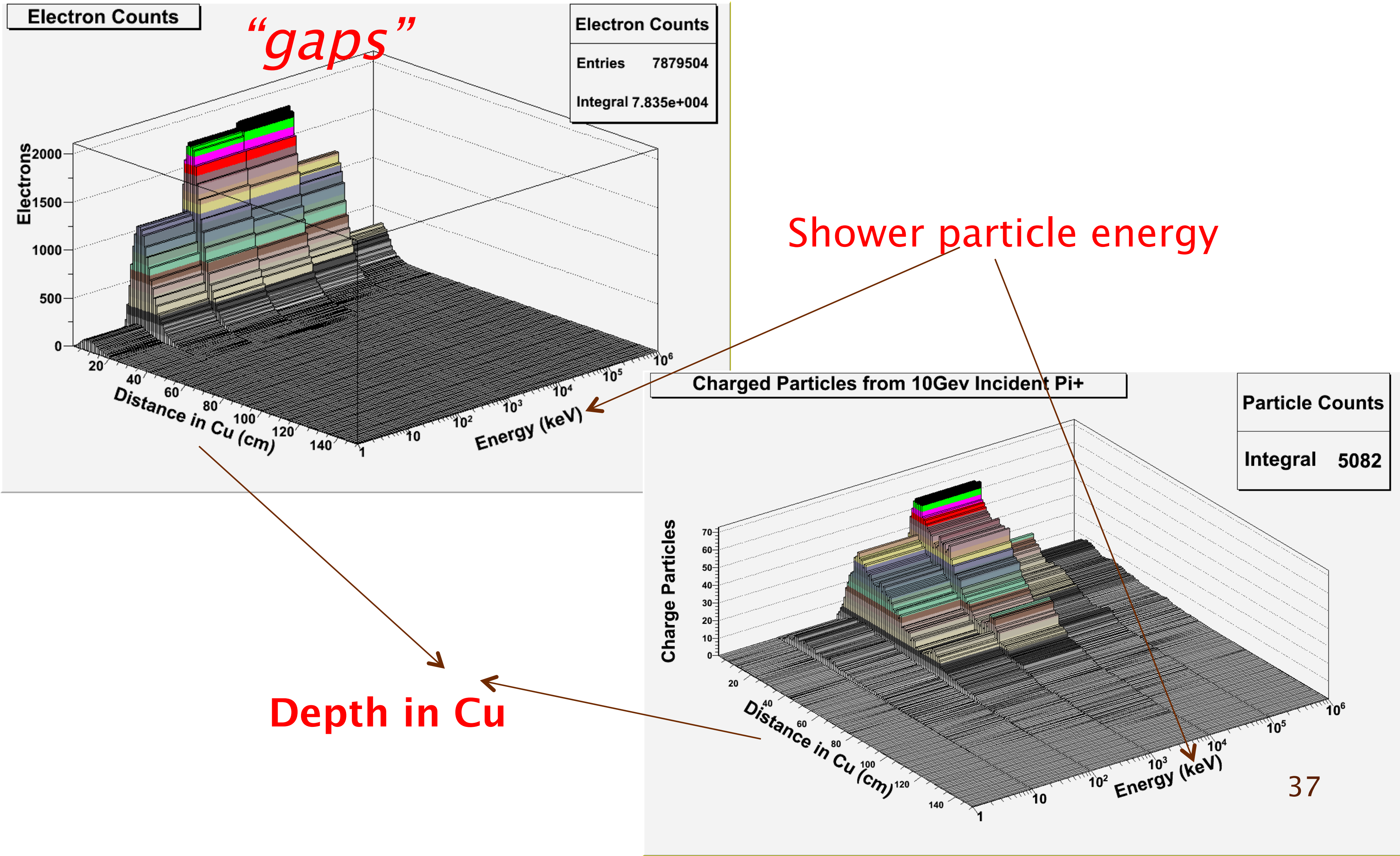


Stub-Tracker/Pre-Radiator Option

- 1 Layer Tile of both arms with H10966:

  2,400 PMT =155K Channels
- 4 Layer tracker/pre-radiator: 10k PMT
- Base – Ceramic Board, Individ.Dynode HV Bus
  - No active elements, multilayer strip-line readouts to outside of detector
- Edges covered by stripe prisms: 89% ->100%
- Alternating Layers displaced ½ cell
- 5” development PMT -> 2.5k PMT (pack eff)

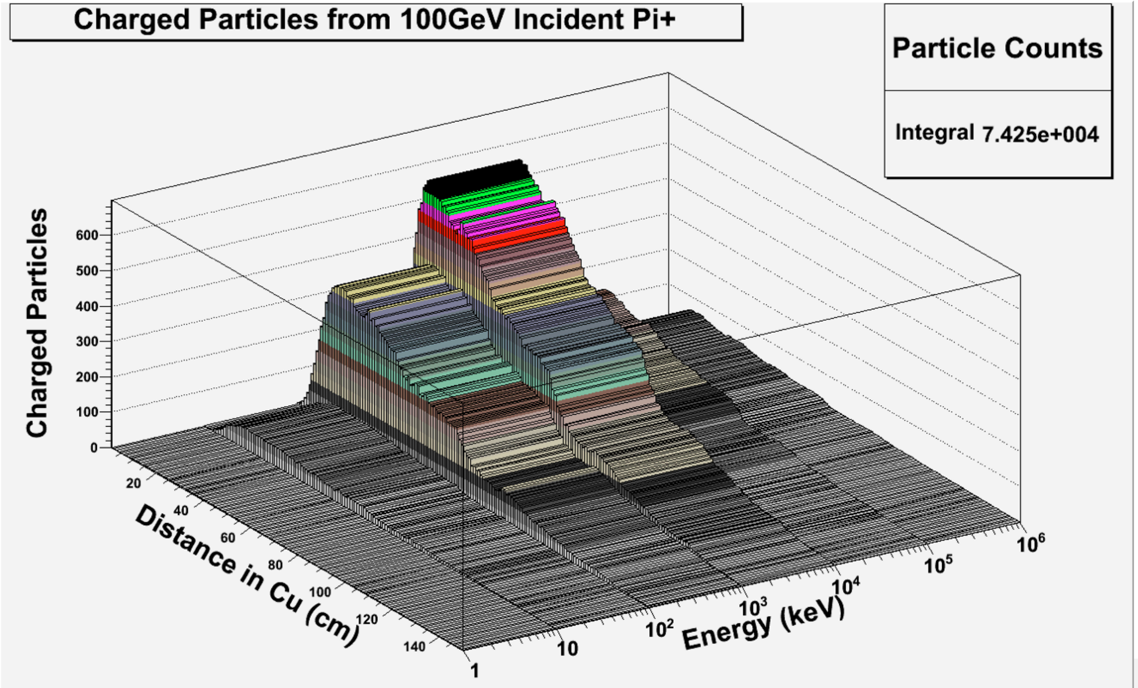
GEANT4: Cu Block, 1cm "plates" 10 GeV e, π incident. Charged Particles binned as cross 1cm "gaps"

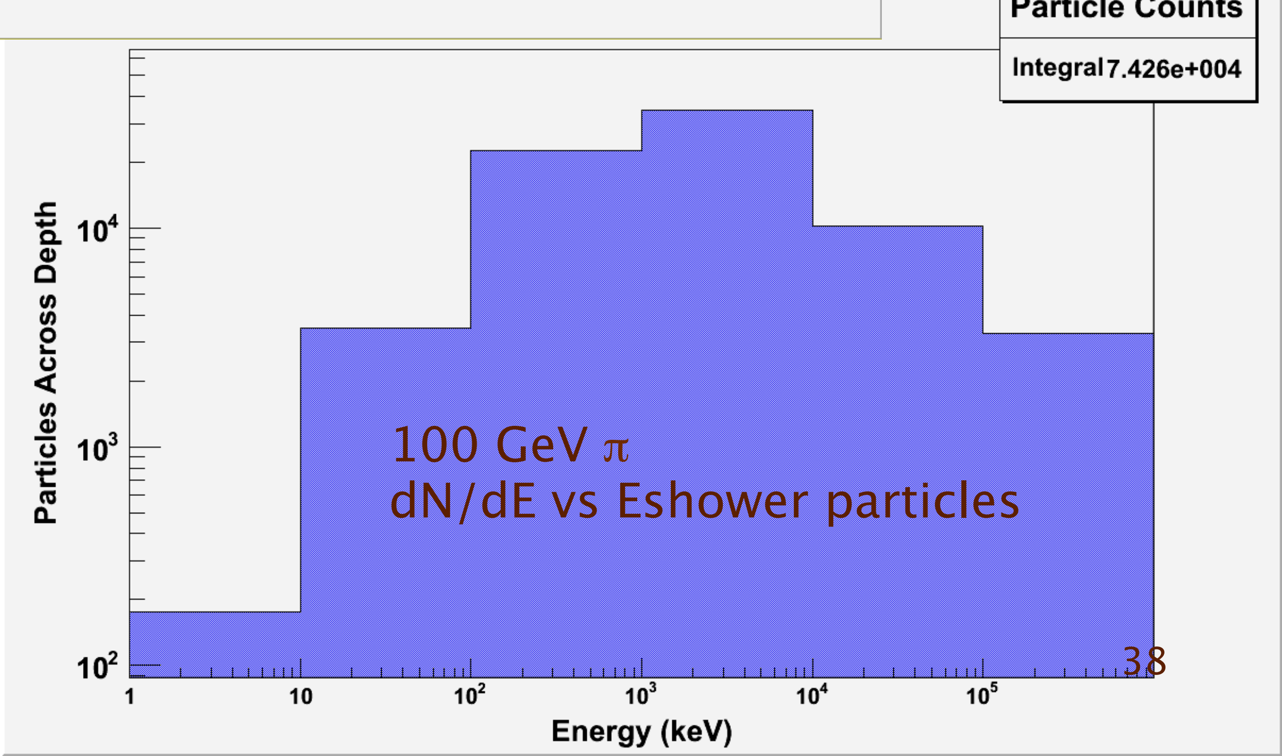


Shower particle energy

Depth in Cu

Hadron Showers





100 GeV π
dN/dE vs Eshower particles

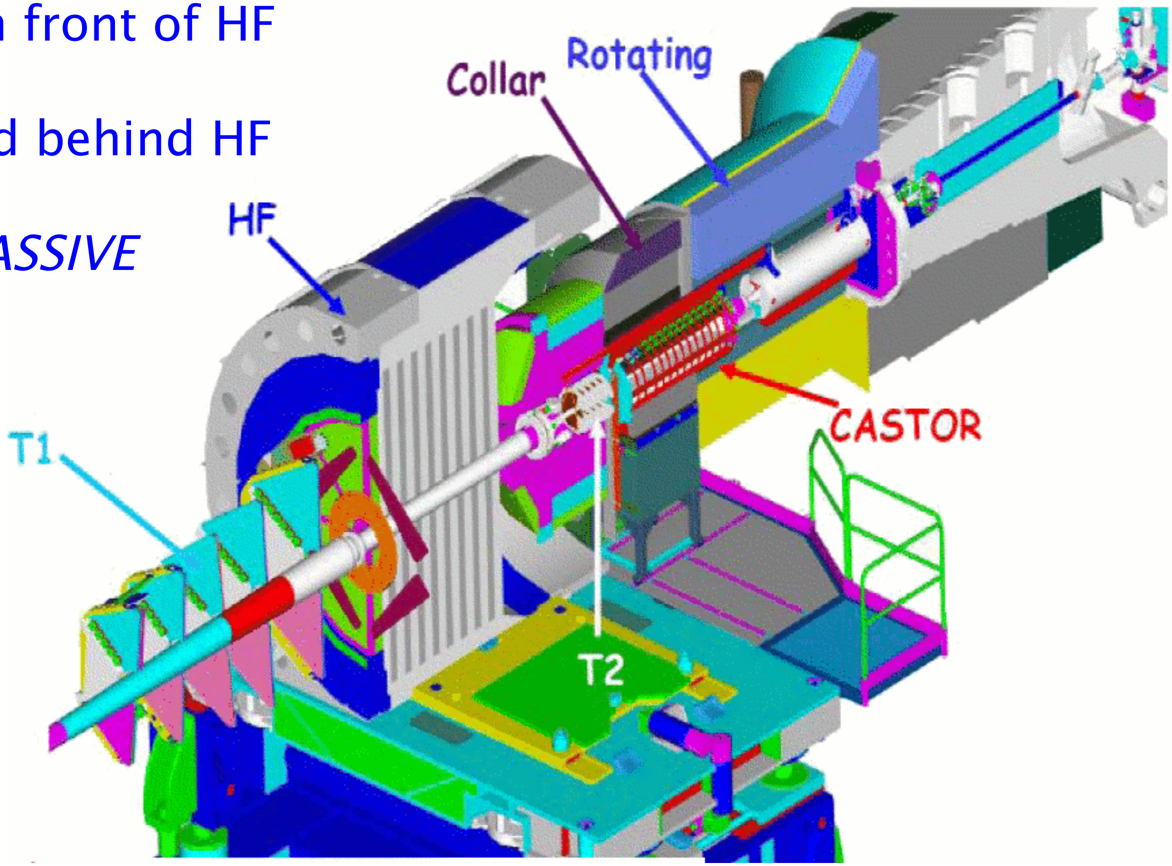
~740 Charged Particles/π-GeV

~35-80 SEe/π-GeV!

NB: *% low E 2ndries vs e-m showers – ØLow Estimate…*

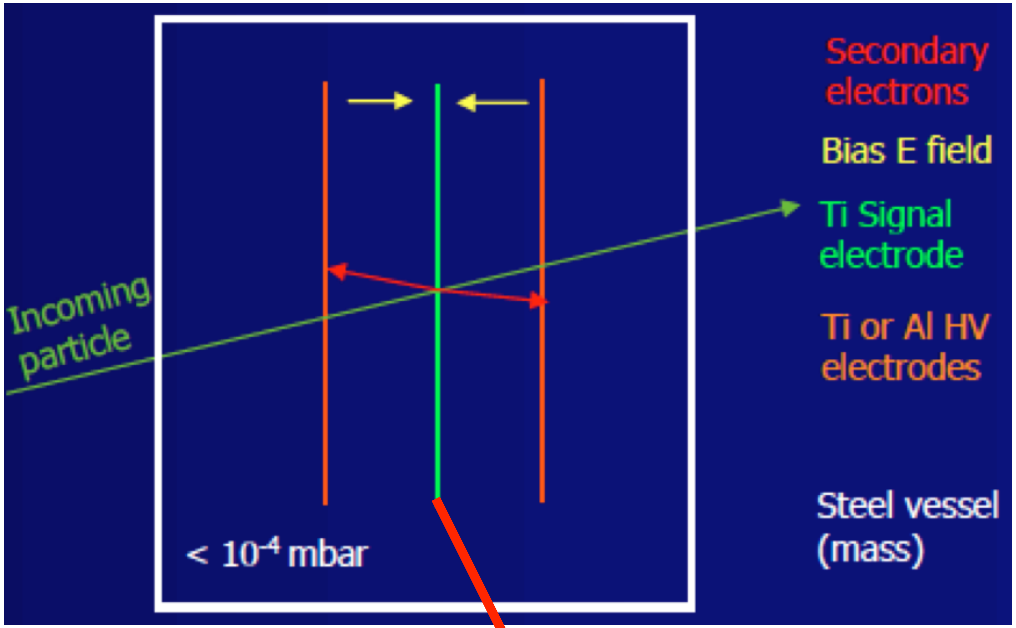
Forward Muon Systems?

Polyethylene Shield in front of HF
and
Collar, Rotating Shield behind HF
are
COMPLETELY PASSIVE



Replace:
Passive Poly Shield w/ PreRadiator/e-m Calorimeter
Passive Collar/Rot. Shield w/Muon Toroids and Chambers

Example SE: CERN LHC Beam Loss Monitor



Secondary electrons

Bias E field

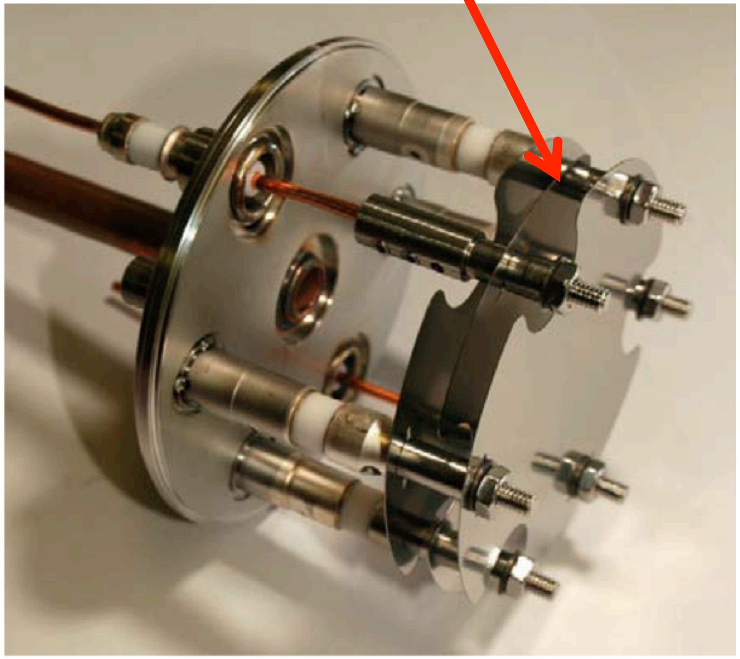
Ti Signal electrode

Ti or Al HV electrodes

Steel vessel (mass)

Incoming particle

$< 10^{-4}$ mbar



Signal Generation from protons – DESY *BPM*

SEM Sensitivity (MIPs) :

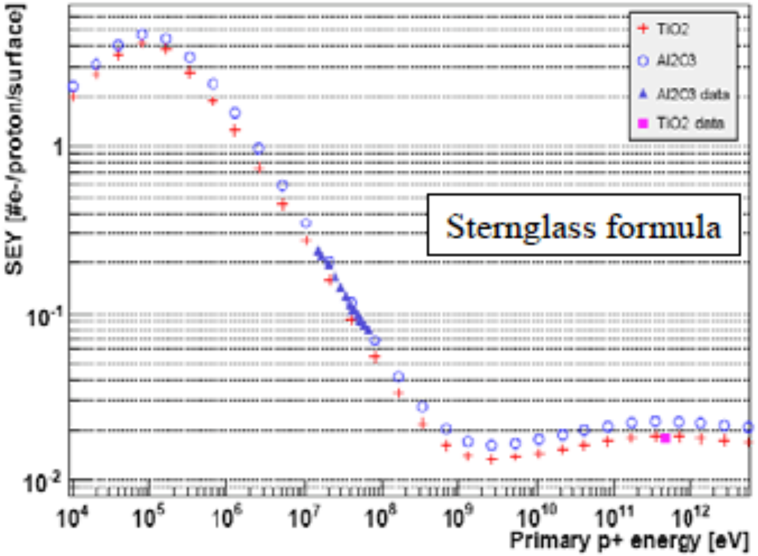
$$1\,rad = \frac{100\,ergs}{gram} \cdot \frac{MeV}{1.6 \cdot 10^{-6}\,ergs} \cdot \frac{MIP \cdot gram}{2\,MeV \cdot cm^2} = 3.1 \cdot 10^7\ MIPs\ per\ cm^2$$

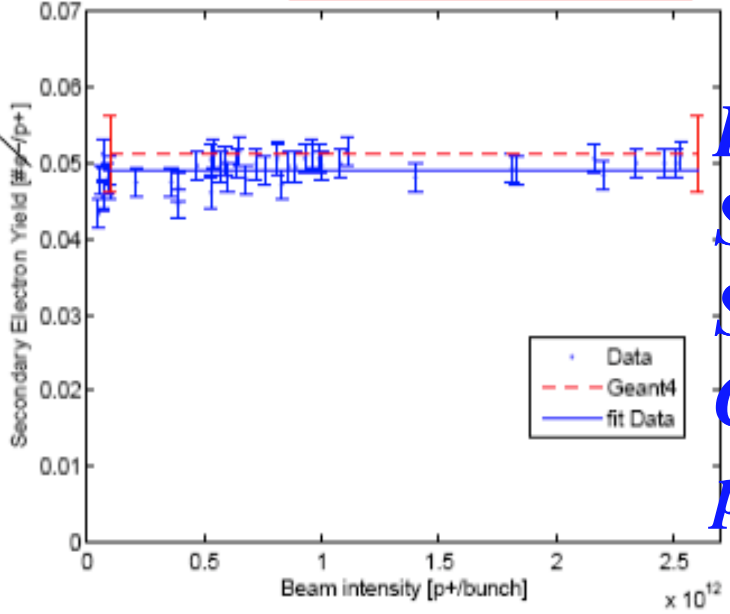
sensitive surface Ø = 3.2 cm = 8cm^2

=> $S_{SEM} = 2.5 \cdot 10^8$ MIPs/rad · 0.05 e$^-$/MIP · 1.6 ·10^{-19} C/ e$^-$ = 2 pC/rad (· **PMT**$_{gain}$)

Al_2O_3,TiO_2 ~0.05 e$^-$ per *MIP.*

Yet used as beam monitors: Rad Hard!





Hadron Showers: Sub-mip Charged particles

Beyond 2021 (2024)

LHC (replace more than 1.2 km):

- IR-quads (inner triplets), 11 T (short) dipoles->Nb3Sn
- Collimation upgrade
- Cryogenics upgrade
- Crab Crossing Cavities, ….
- Instantaneous luminosity limited by beam-beam
- lifetime level luminosity, $\langle L \rangle \sim 5\times10^{34}\ \mathrm{cm^{-2}s^{-1}}$.
- 2012 as ref: $T=6.5\times10^{6}$ s, $L=23\mathrm{fb^{-1}}$ $\langle L \rangle=3.7\ \mathrm{nb^{-1}s^{-1}}$

  10 years @ $\langle L \rangle=50\mathrm{nb^{-1}s^{-1}}$ -> **$L=3000\ \mathrm{fb^{-1}}$**

Pileup: ($\sigma_{\mathrm{Inel}}=81\mathrm{mb}$, $n_b=2808$ (25 ns bunch spacing) **$\mu>130$**