The SLHC Program and Detector Upgrades

2008 Aspen Winter Conference

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U. Wisconsin - Madison

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Outline:

SLHC Upgrade

Mature LHC → SLHC Discovery Physics examples

ATLAS & CMS Detector Upgrades

This talk is available on:

http://www.hep.wisc.edu/wsmith/cms/doc08/smith_slhc_aspen_jan08.pdf

Mature LHC Program

If Higgs observed:

- Measure parameters (mass, couplings), need up to 300 fb^{-1}
- Self-coupling not accessible with LHC alone

If we think we observe SUSY:

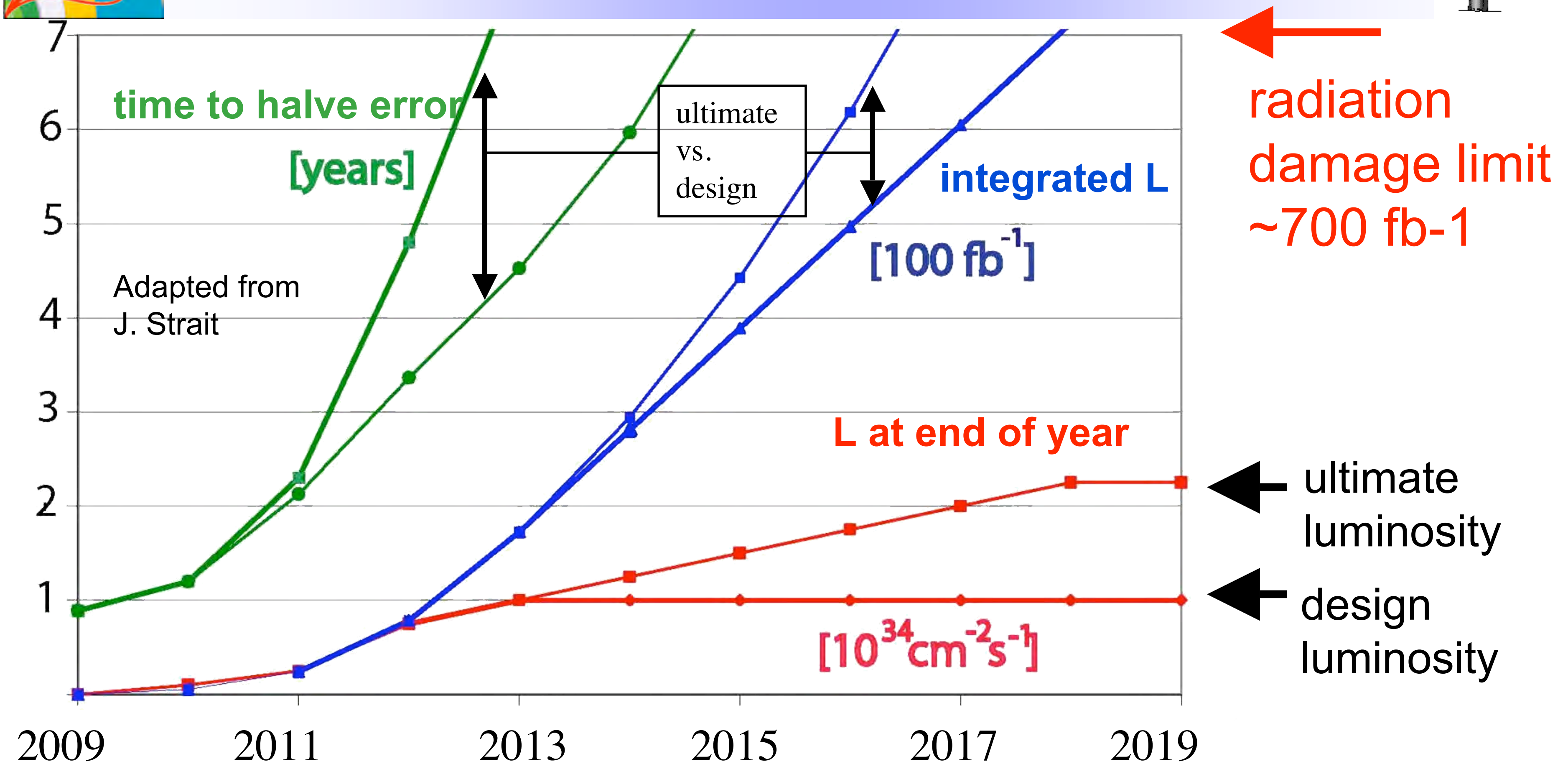
- Try to measure mass (study cascades, end-points, …)
- Try to determine the model: MSSM, NMSSM, …
- Establish connection to cosmology (dark matter candidate?)
- Understand impact on Higgs phenomenology
- Try to determine the SUSY breaking mechanism

If neither or something else:

- Strong $W_L W_L$ scattering? Other EWSB mechanisms?
- Extra dimensions, Little Higgs, Technicolor ?
- Do we have to accept fine-tuning (e.g. Split Supersymmetry)

Next: SLHC

Time Scale of LHC Upgrade



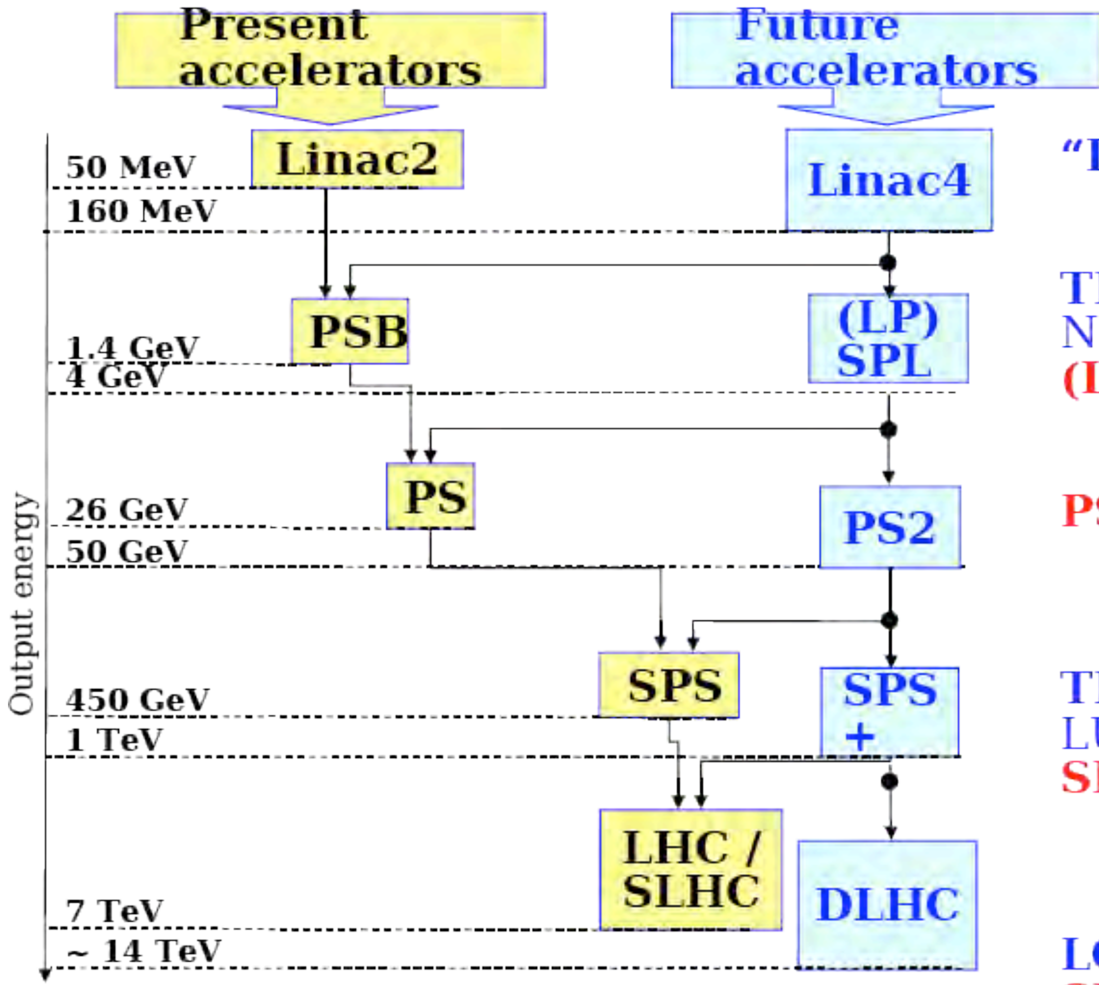
(1) ***LHC IR quads life expectancy*** estimated <10 years from radiation dose

(2) the ***statistical error halving time*** will exceed 5 years by 2013-2014

(3) therefore, it is reasonable to plan a ***machine luminosity upgrade based on new low-β IR magnets by ~2018***

LHC upgrade options

Themes 1 (2012) & 3 (2016)



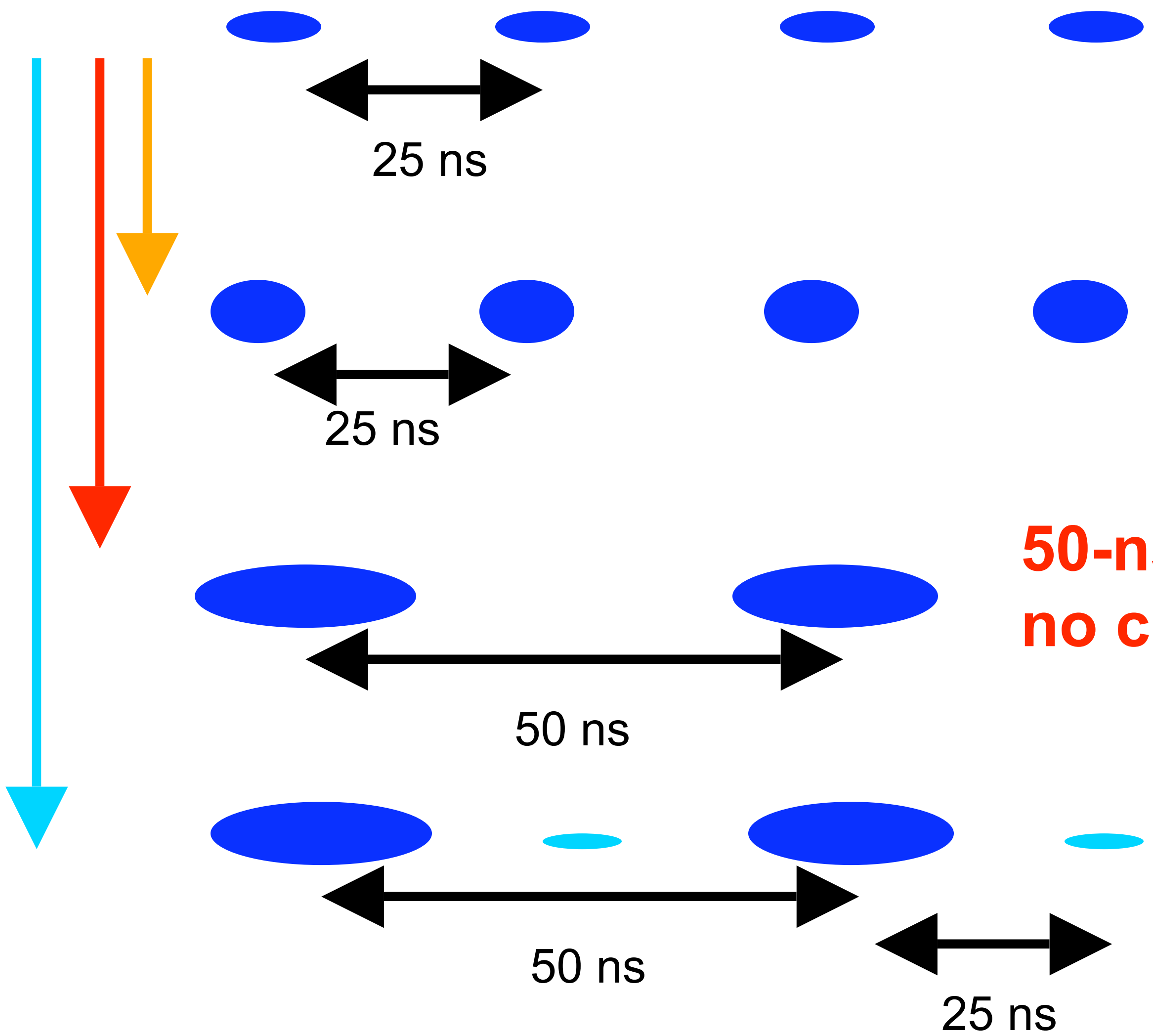
"DONE" DEAL Linac4

THEME 1
NEAR TERM FOCUS ~2012
(LP)SPL (Low Power) Superconducting Proton Linac (4-5 GeV)
PS2 High Energy PS (~ 5 to 50 GeV – 0.3 Hz)

THEME 3
LUMI UPGRADE ~2016
SLHC "Superlumi" LHC (up to 10^{35} $cm^{-2}s^{-1}$)

LONG TERM FANTASY
Not discussed → **SPS+** Superconducting SPS
DLHC "Double energy" LHC

SLHC Bunch Structure Options



Nominal LHC

new alternative

ultimate
& 25-ns upgrade

50-ns upgrade,
no collisions @S-LHCb

new baseline

50-ns upgrade
with 25-ns
collisions
in LHCb

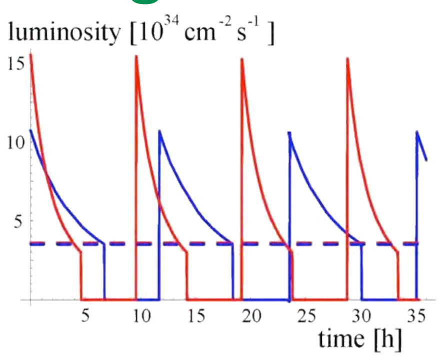
LHC Upgrade Scenarios

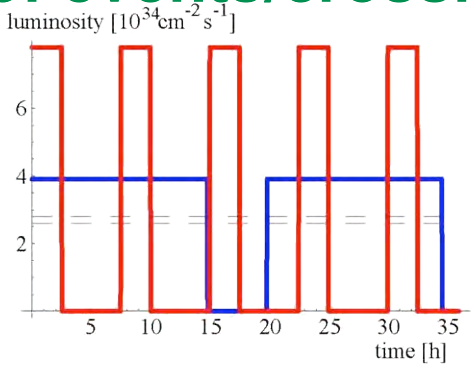
Two scenarios of L~10^{35} $cm^{-2}s^{-1}$ for which heat load and #events/crossing are acceptable

25-ns option: pushes β*; requires slim magnets inside detector, crab cavities, & Nb_3Sn quadrupoles and/or Q0 doublet; attractive if total beam current is limited; Peak events/crossing ~ 200.

50-ns option: has fewer longer bunches of higher charge ; can be realized with NbTi technology if needed ; compatible with LHCb ; open issues are SPS & beam-beam effects at large Piwinski angle; Peak events/crossing ~ 400

Luminosity leveling may be done via bunch length and via β*, resulting in reduced number of events/crossing ~ 100.





Two upgrade scenarios

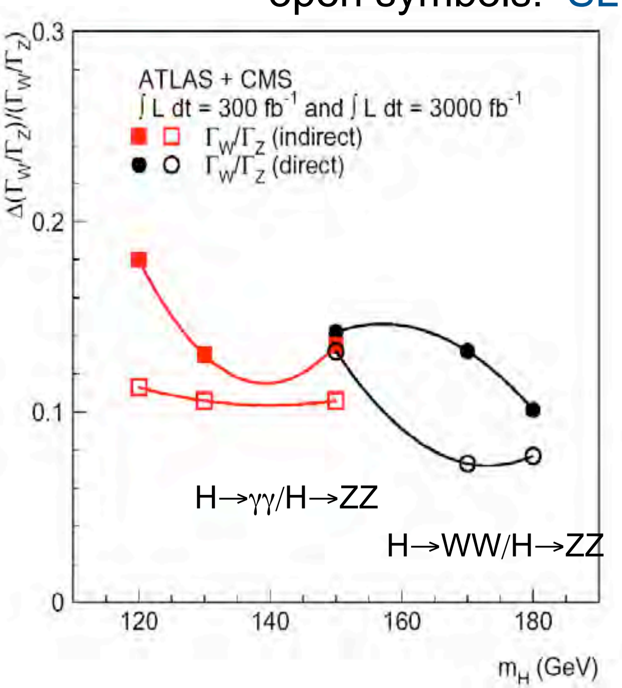
parameter	symbol	25 ns, small β^*	50 ns, long
transverse emittance	ε [μm]	3.75	3.75
protons per bunch	N_b [10^{11}]	1.7	4.9
bunch spacing	Δt [ns]	25	50
beam current	I [A]	0.86	1.22
longitudinal profile		Gauss	Flat
rms bunch length	σ_z [cm]	7.55	11.8
beta* at IP1&5	$\beta*$ [m]	0.08	0.25
full crossing angle	θ_c [μrad]	0	381
Piwinski parameter	$\phi=\theta_c\sigma_z/(2*\sigma_x*)$	0	2.0
hourglass reduction		0.86	0.99
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	15.5	10.7
peak events per crossing		294	403
initial lumi lifetime	τ_L [h]	2.2	4.5
effective luminosity ($T_{turnaround}$=10 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	2.4	2.5
	$T_{run,opt}$ [h]	6.6	9.5
effective luminosity ($T_{turnaround}$=5 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	3.6	3.5
	$T_{run,opt}$ [h]	4.6	6.7
e-c heat SEY=1.4(1.3)	P [W/m]	1.04 (0.59)	0.36 (0.1)
SR heat load 4.6-20 K	P_{SR} [W/m]	0.25	0.36
image current heat	P_{IC} [W/m]	0.33	0.78
gas-s. 100 h (10 h) τ_b	P_{gas} [W/m]	0.06 (0.56)	0.09 (0.9)
extent luminous region	σ_l [cm]	3.7	5.3
comment		D0 + crab (+ Q0)	wire comp.

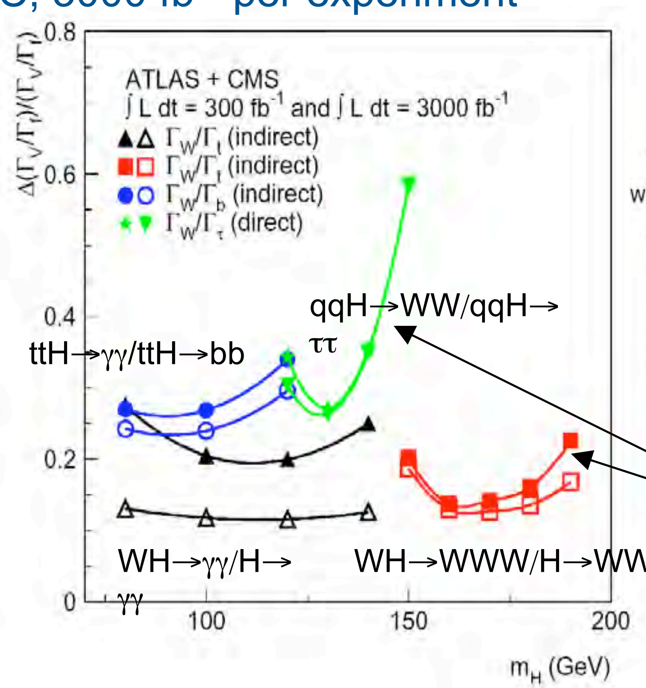
SM Higgs Couplings

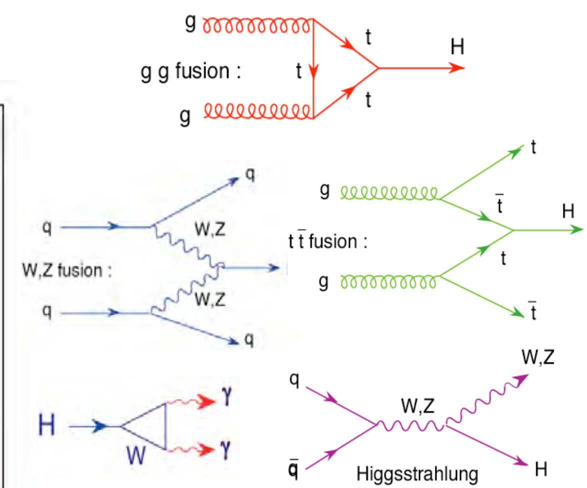
Combine different production & decay modes
→ ratios of Higgs couplings to bosons & fermions

- **Independent of uncertainties on σ^{tot}_{Higgs}, Γ_{H}, $\int L dt$ → stat. limited**
- **Benefit from LHC → SLHC (assuming similar detector capabilities)**

full symbols: LHC, 300 fb^{-1} per experiment
open symbols: SLHC, 3000 fb^{-1} per experiment





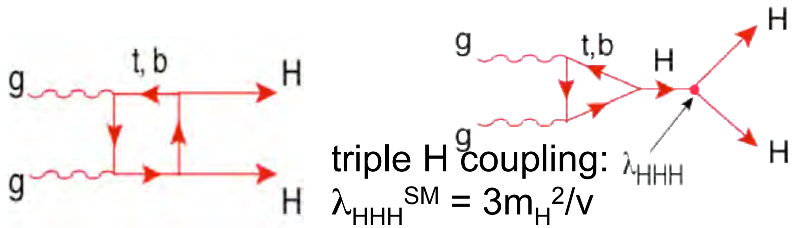


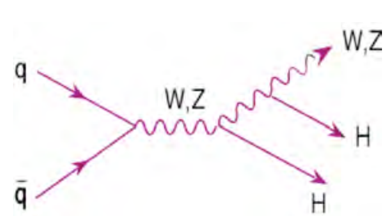
syst.- limited at LHC (σ_{th}),
~ no improvement at SLHC

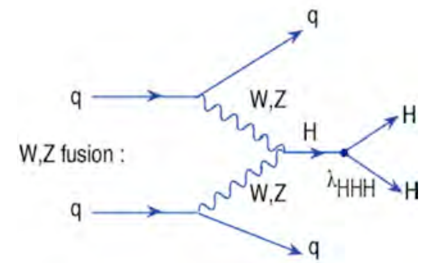
➡ SLHC ratios of Higgs couplings should be measurable with a ~ 10% precision

Higgs pair prod. & self coupling

Higgs pair production through two Higgs bosons radiated independently (from VB, top) & from trilinear self-coupling terms proportional to λ_{HHH}^{SM}







+…

$\sigma(pp \rightarrow HH) < 40$ fb, $M_H > 110$ GeV

Small BR for clean final states →no sensitivity at LHC (10^{34}), but some hope at SLHC:

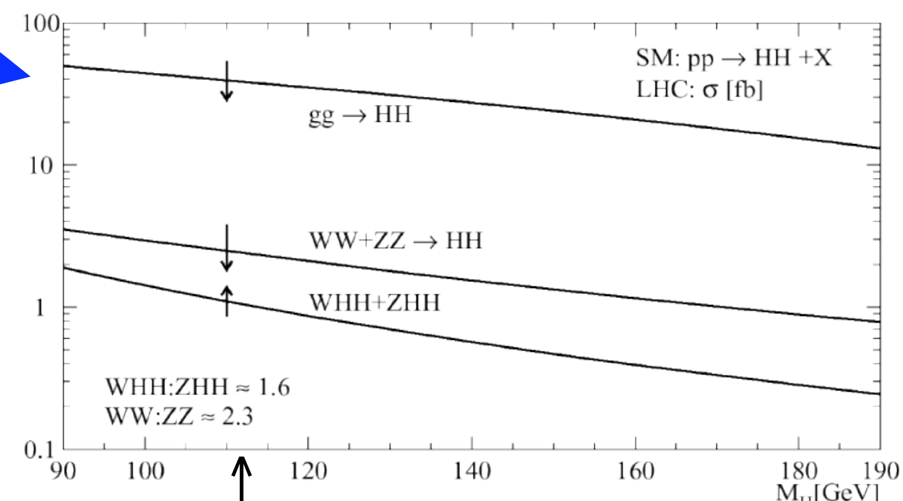
channel investigated:

$170 < m_H < 200$ GeV (ATLAS):

$gg \rightarrow HH \rightarrow W^+ W^- W^+ W^- \rightarrow l^\pm \nu jj \; l^\pm \nu jj$

with same-sign dileptons - difficult!

cross sections for Higgs boson pair production in various production mechanisms and sensitivity to λ_{HHH} variations



arrows correspond to variations of λ_{HHH} from 1/2 to 3/2 of its SM value

More optimistic study by Baur, Plehn, Rainwater:

$HH \rightarrow W^+ W^- W^+ W^- \rightarrow \lambda^\pm \nu jj \;\; \lambda^\pm \nu jj$

Limits @ 95% CL. for $\Delta\lambda = (\lambda - \lambda_{SM})/\lambda_{SM}$

LHC: $\lambda = 0$ can be excluded at 95% CL.

SLHC: λ can be determined to 20-30% (95% CL)

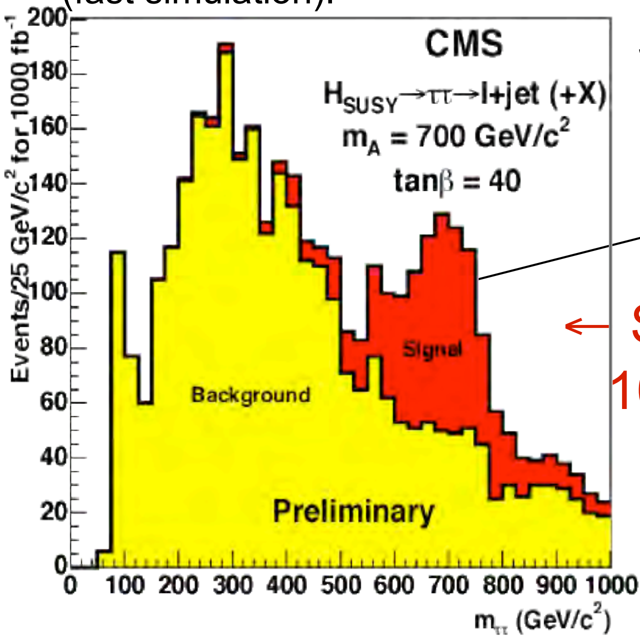
Improved reach for Heavy MSSM Higgs bosons

Order of magnitude increase in statistics with SLHC should allow

Extension of discovery domain for massive MSSM Higgs bosons A,H,$H^{\pm}$

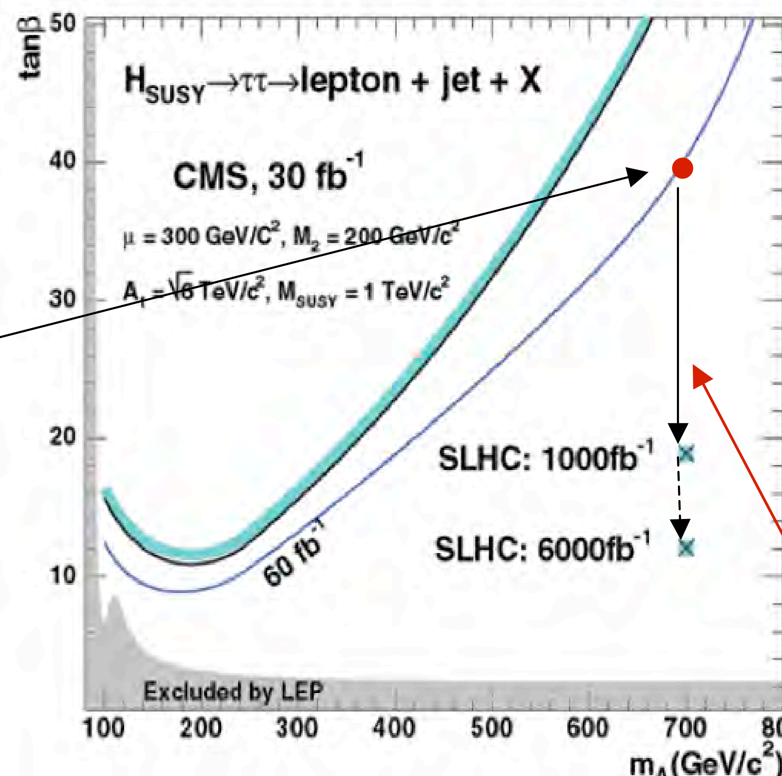
e.g.: A/H → ττ → lepton + τ-jet, produced in bbA/H

Peak at 5σ limit of observability at LHC greatly improves at SLHC, (fast simulation):



S. Lehti

← SLHC 1000 fb^{-1}



←LHC 60 fb^{-1}

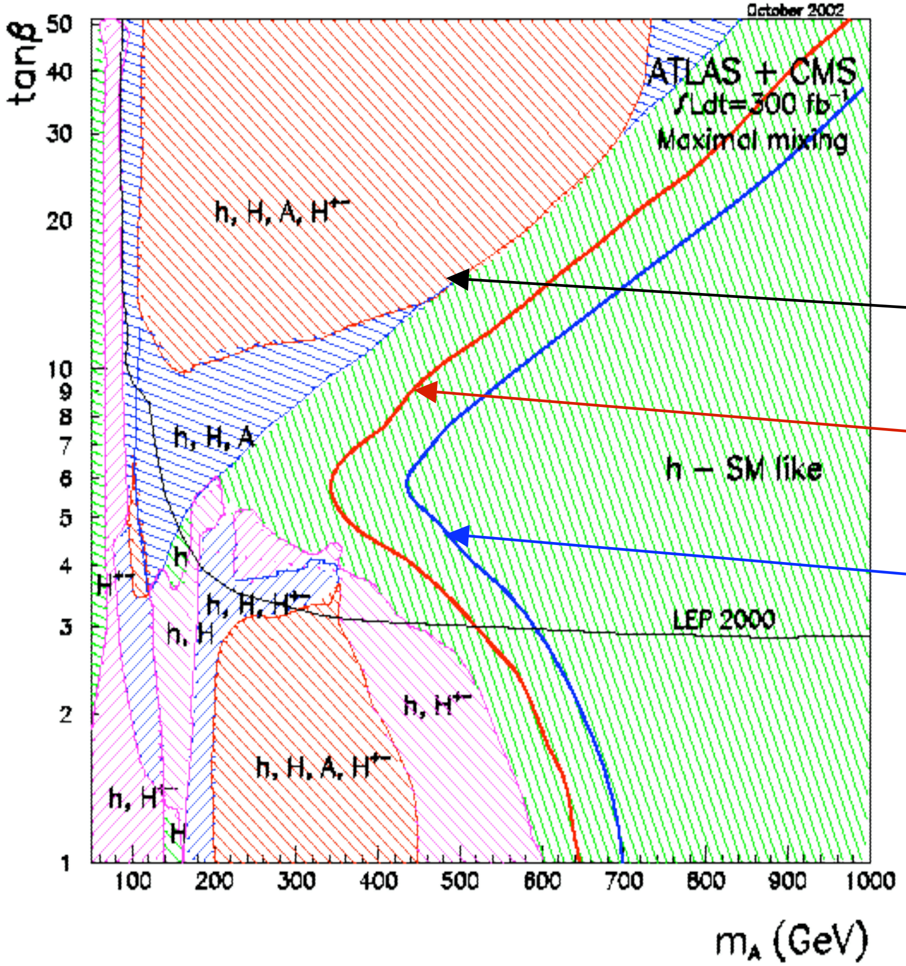
←SLHC 1000 fb^{-1}

gain in reach

b-tagging performance comparable to present LHC detectors required

Improved reach for MSSM Higgs bosons

MSSM parameter space regions for > 5σ discovery for the various Higgs bosons, 300 fb^{-1} (LHC), and expected improvement - at least two discoverable Higgs bosons - with 3000 fb^{-1} (SLHC) per experiment, ATLAS & CMS combined.



green area: region where only one (the h, ~ SM-like) among the 5 MSSM Higgs bosons can be found (assuming only SM decay modes)

LHC contour, 300 fb^{-1}/exp

SLHC contour, 3000 fb^{-1}/exp at least one heavy Higgs discoverable up to here

SLHC contour, 3000 fb^{-1}/exp at least one heavy Higgs Excludable (95% CL) up to here

Heavy Higgs observable region increased by ~ 100 GeV

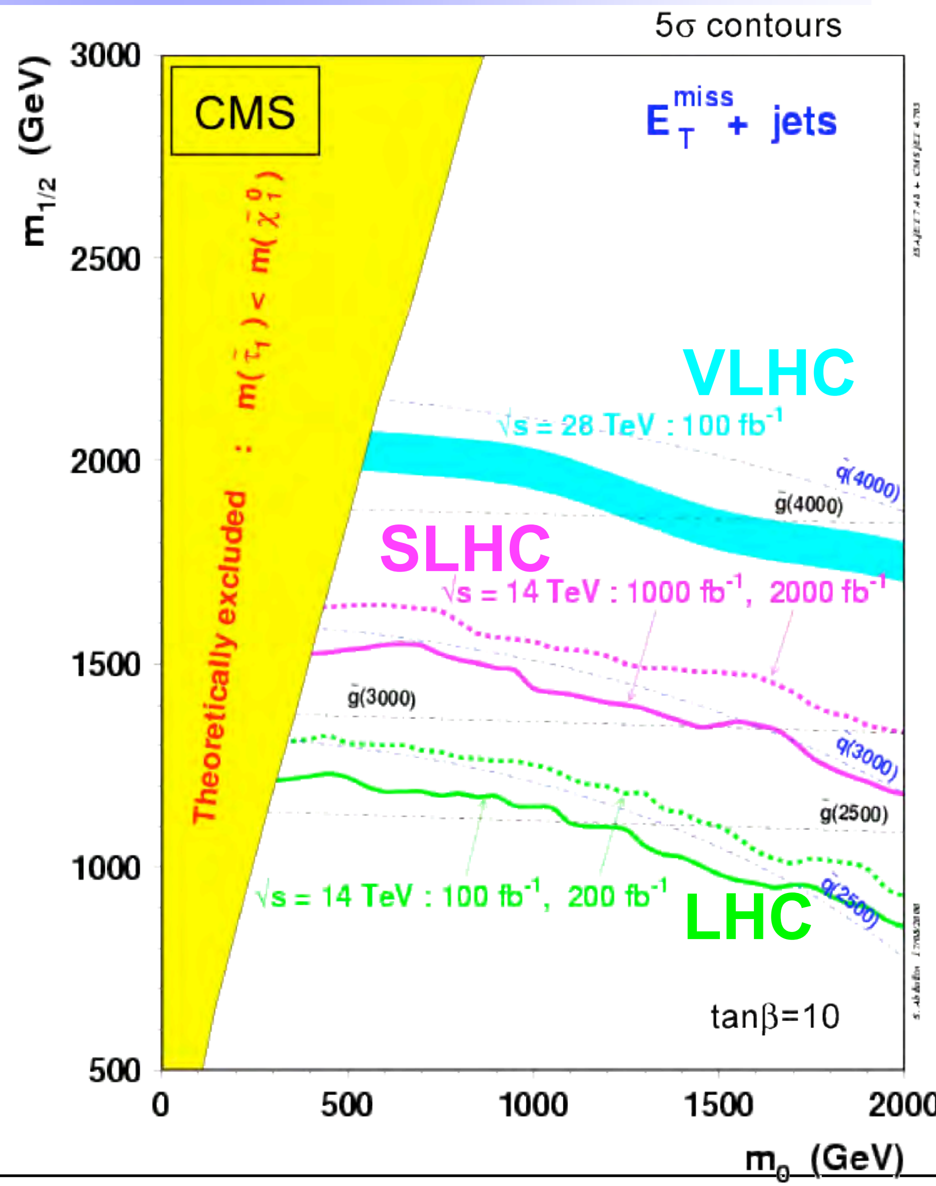
Supersymmetry

Use high E_T jets, leptons & missing E_T

- Not hurt by increased pile-up at SLHC

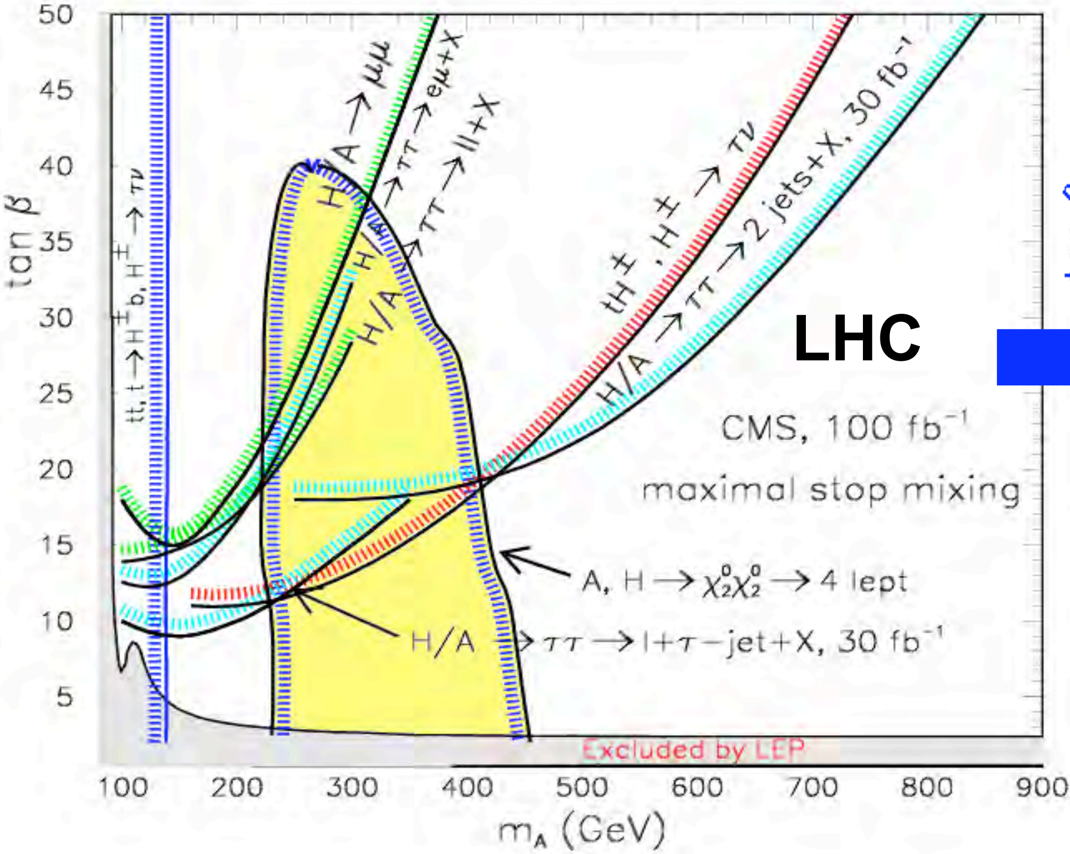
Extends discovery region by ~ 0.5 TeV

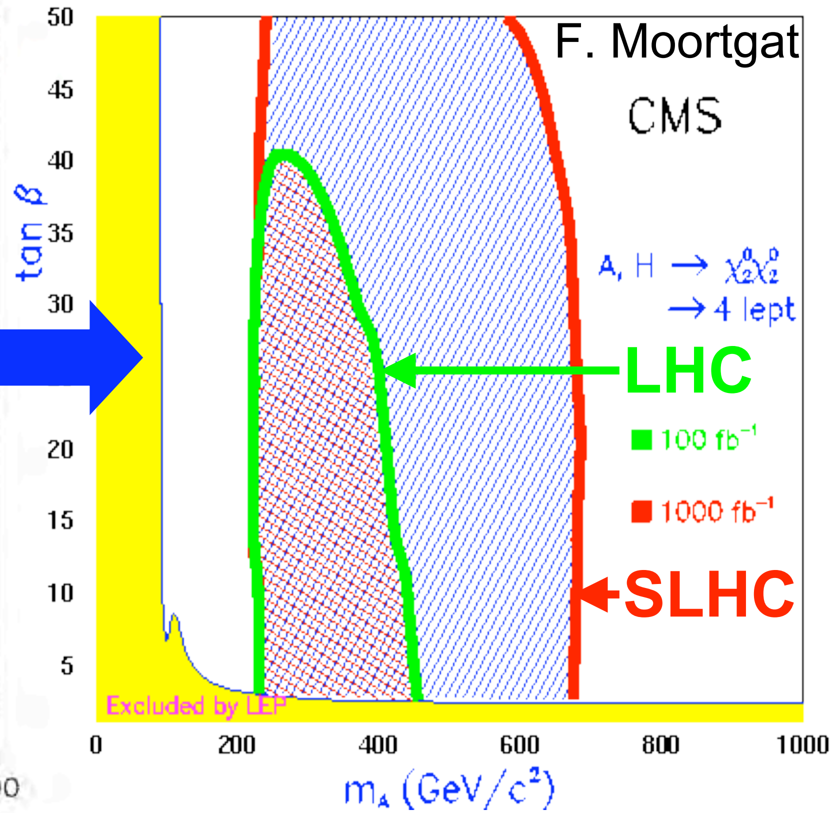
- ~ 2.5 TeV → 3 TeV
- (4 TeV for VLHC)
- Discovery means > 5σ excess of events over known (SM) backgrounds



Improved coverage of A/H decays to neutralinos, 4 isolated leptons

Use decays of H,A into SUSY particles, where kinematically allowed





$A/H \rightarrow \chi\chi \rightarrow 4$ iso. leptons

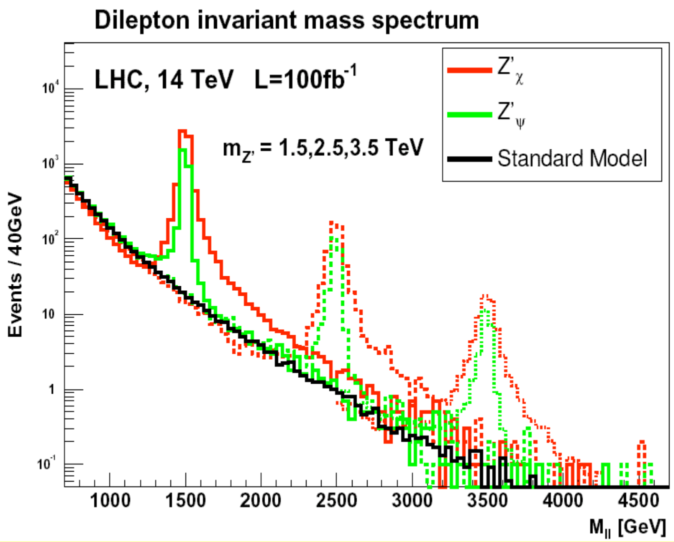
Strongly model/MSSM parameter dependent:
M_2 = 120 GeV, μ= -500 GeV,
$M_{sleptons}$ = 2500 GeV, $M_{squark, gluino}$ = 1TeV

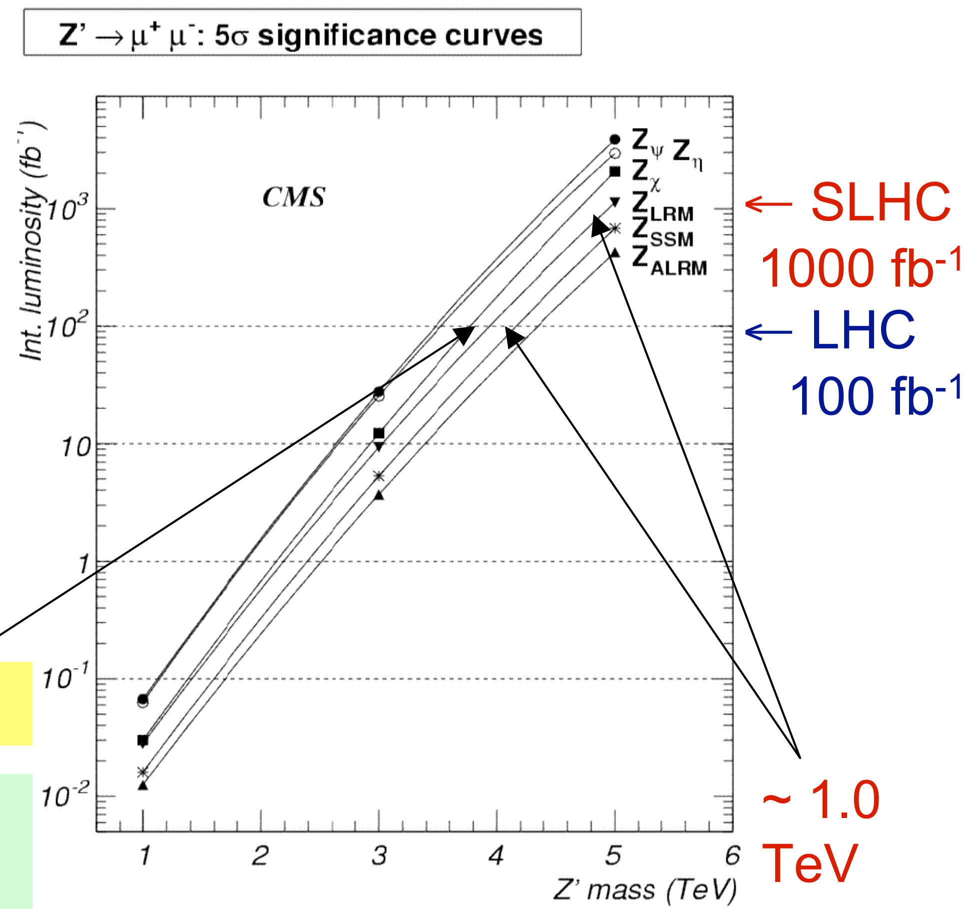
New gauge bosons

sequential Z' model, Z' production (assuming same BR as for SM Z) and Z' width:

Z' mass (TeV)	1	2	3	4	5	6
$\sigma(Z' \to e^+e^-)(fb)$	512	23.9	2.5	0.38	0.08	0.026
$\Gamma_{Z'}$ (GeV)	30.6	62.4	94.2	126.1	158.0	190.0

Acceptance, e/μ reconstruction eff., resolution, effects of pile-up noise at 10^{35}, ECAL saturation included. (CMS study)



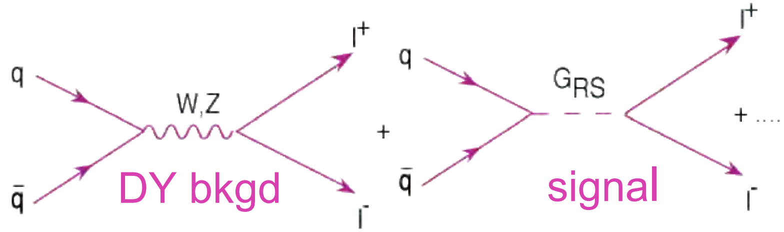


LHC reach ~ 4.0 TeV with 100 fb^{-1}

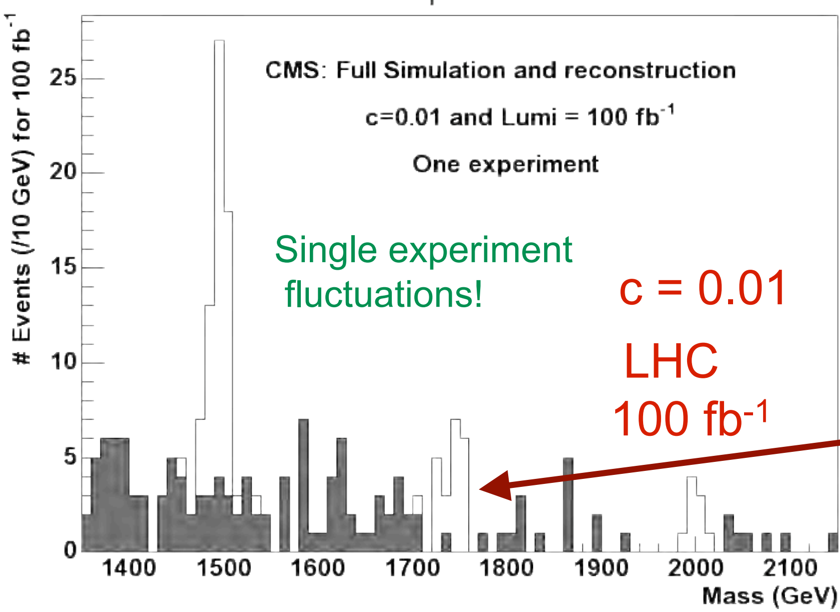
Gain in reach ~ 1.0 TeV i.e. 25-30% in going from LHC to SLHC

Extra Dimensions: Randall-Sundrum model

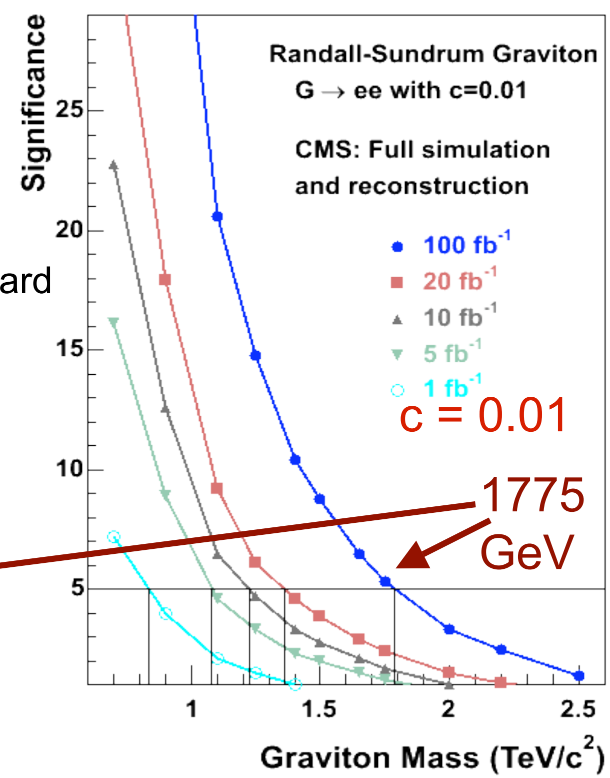
$pp \rightarrow G_{RS} \rightarrow ee$ full simulation and reconstruction chain in CMS,
2 electron clusters, $p_t > 100$ GeV, $|\eta| < 1.44$ and $1.56 < |\eta| < 2.5$, el. isolation, H/E < 0.1, corrected for saturation from ECAL electronics (big effect on high mass resonances!)



$$S = 2(\sqrt{N_S + N_B} - \sqrt{N_B}).$$



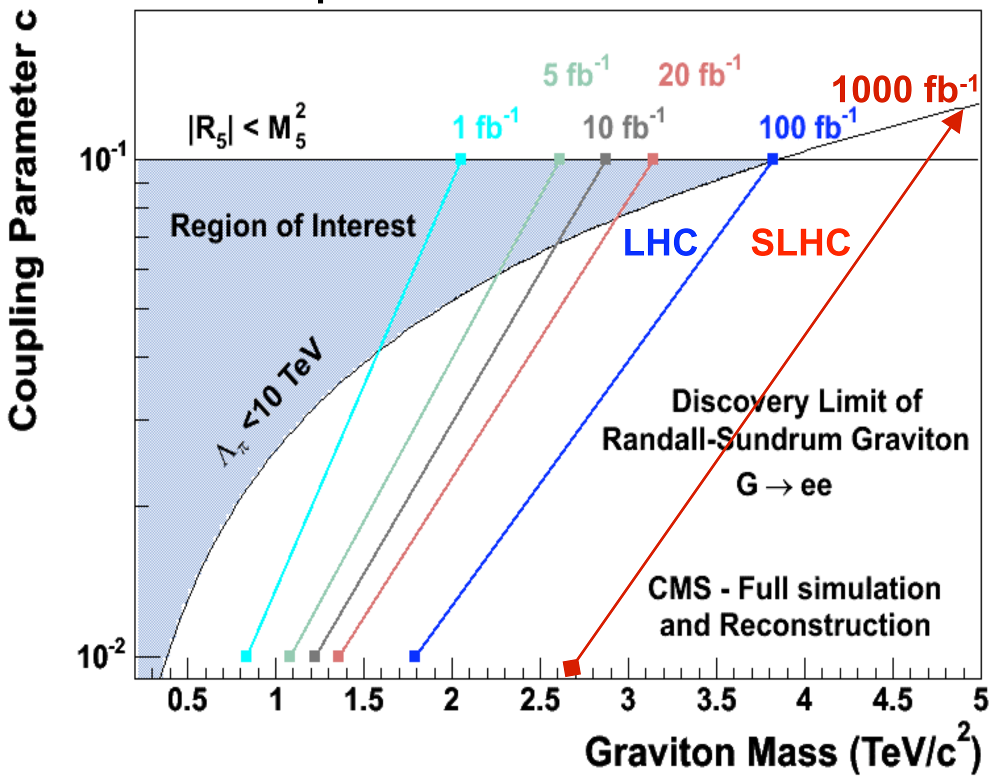
C. Collard



LHC: statistics limited. SLHC: ~ 10 increase in luminosity→ mass reach - increased by ~ 25% - & differentiate a Z' (spin = 1) from G_{RS} (spin = 2)

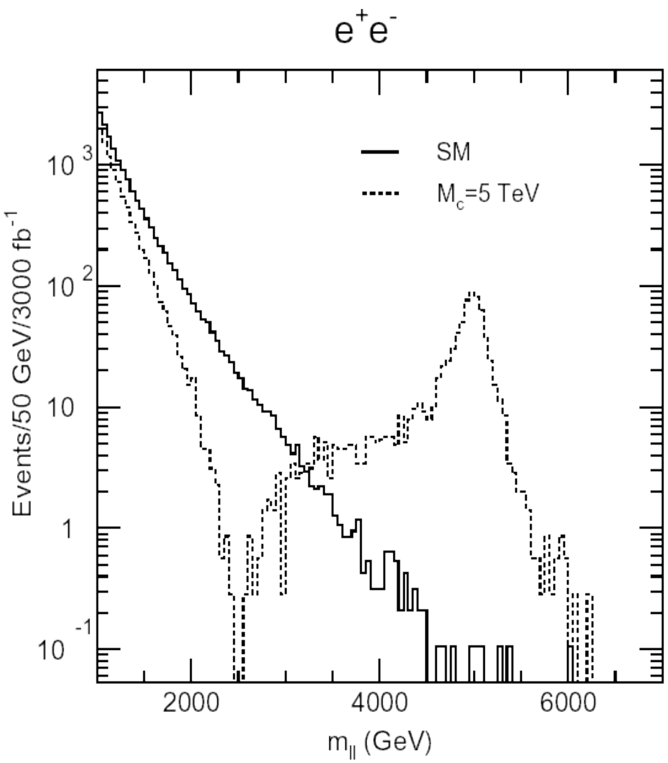
Gravitons

whole plane theoretically allowed,
shaded part favored:



TeV scale Extra Dimensions

- KK excitations of the γ,Z

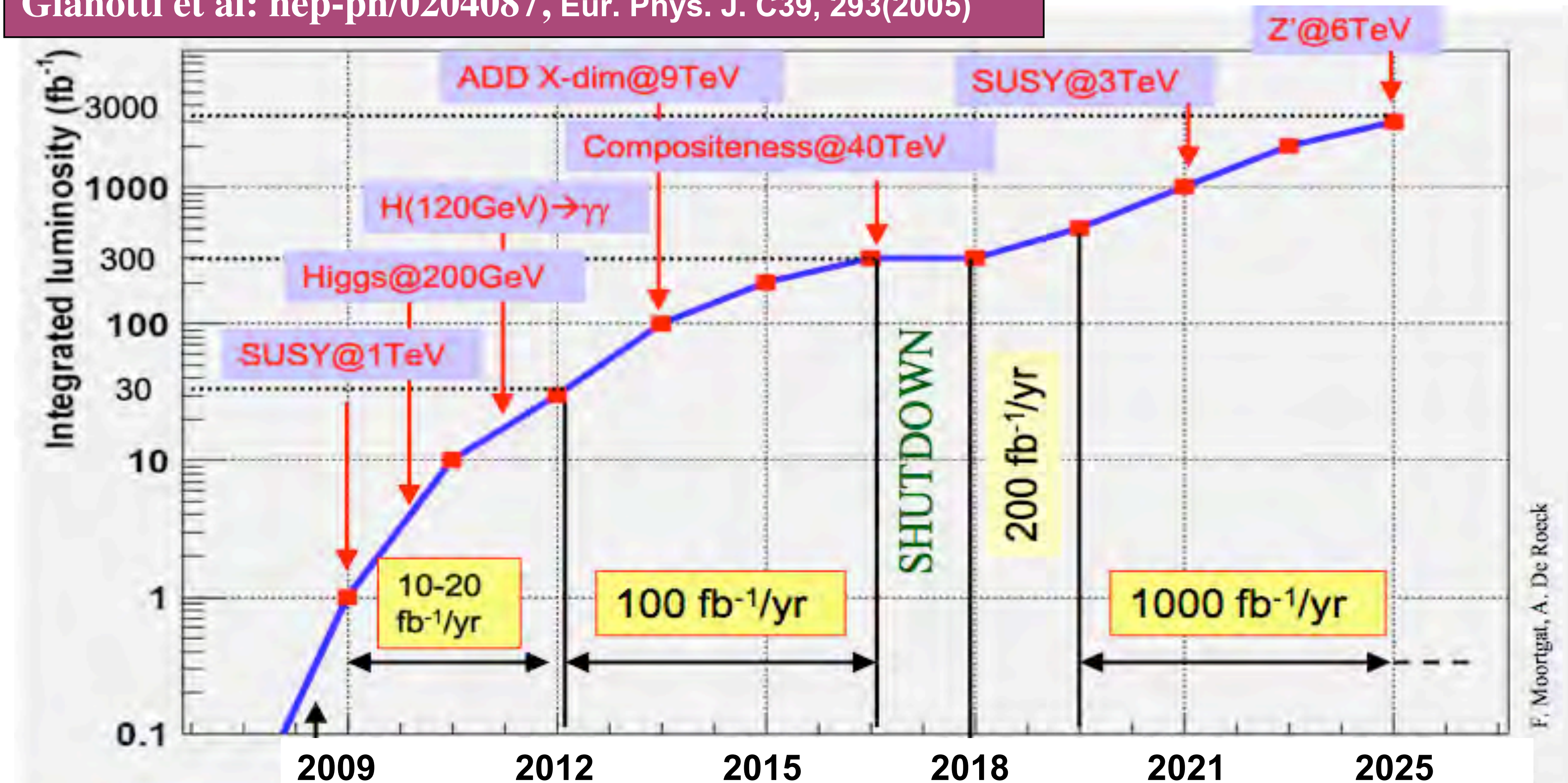


LHC→ SLHC: (100→1000 fb^{-1}):
Increase in reach by ~ 1 TeV

Direct:	LHC/600 fb^{-1}	6 TeV
	SLHC/6000 fb^{-1}	7.7 TeV
Interf:	SLHC/6000 fb^{-1}	20 TeV

LHC → SLHC physics evolution

De Roeck, Ellis, Gianotti: hep-ph/0112004
Gianotti et al: hep-ph/0204087, Eur. Phys. J. C39, 293(2005)



Timescale adjusted

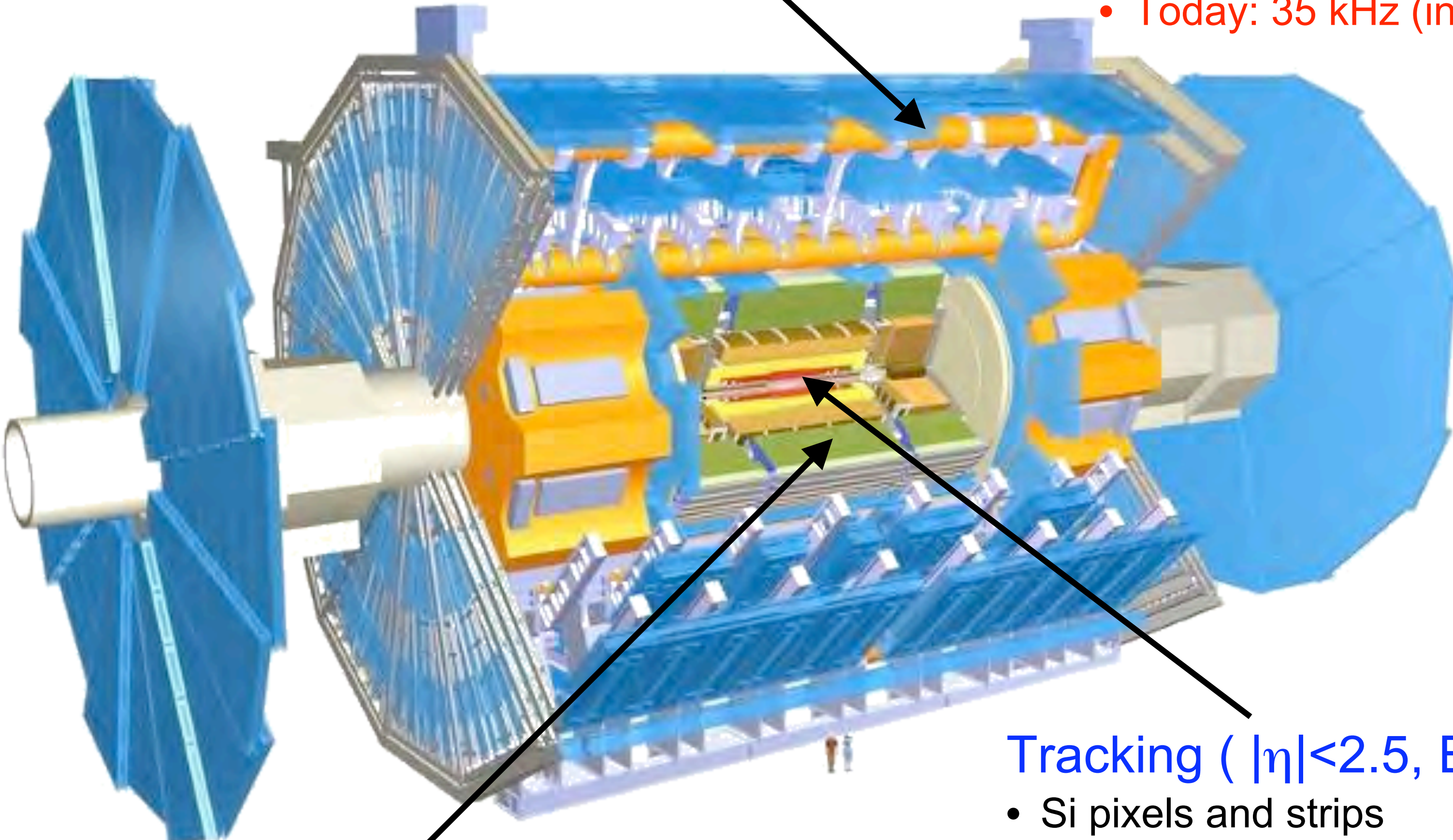
ATLAS Detector Design

Muon Spectrometer ($|\eta|<2.7$)

- air-core toroids with muon chambers

Level-1 Trigger Output

- Today: 35 kHz (instead of 75)



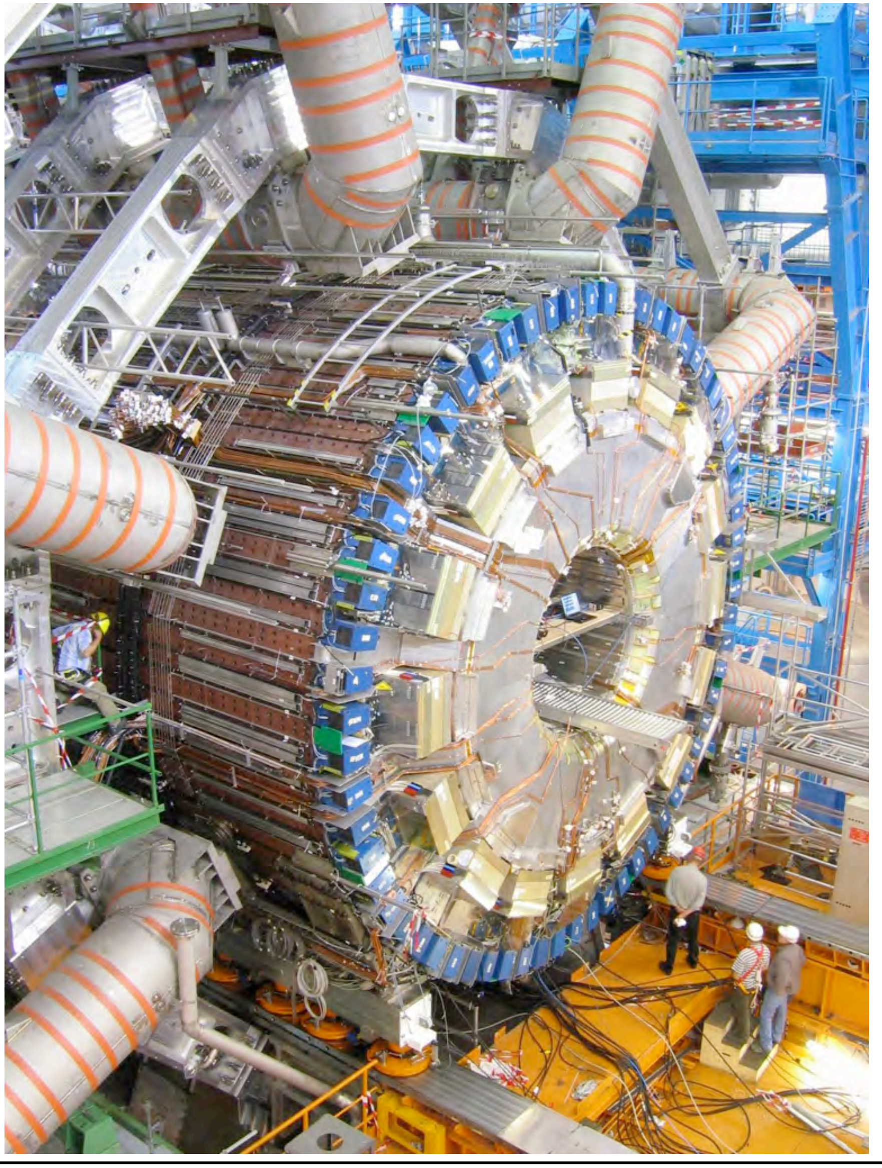
Tracking ($|\eta|<2.5$, B=2T)

- Si pixels and strips
- TRD (e/π separation)
- Today: TRT $|\eta| < 2$ (instead of 2.4)

Calorimetry ($|\eta|<5$)

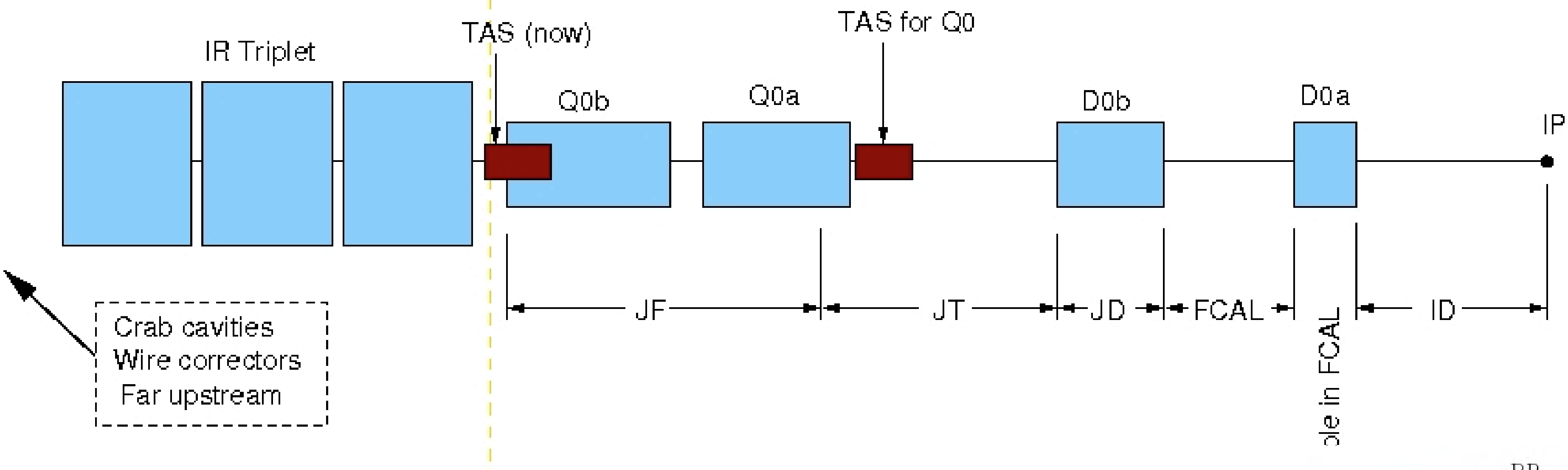
- EM : Pb-LAr
- HAD : Fe/scintillator (central), Cu/W-Lar (fwd)

ATLAS Today



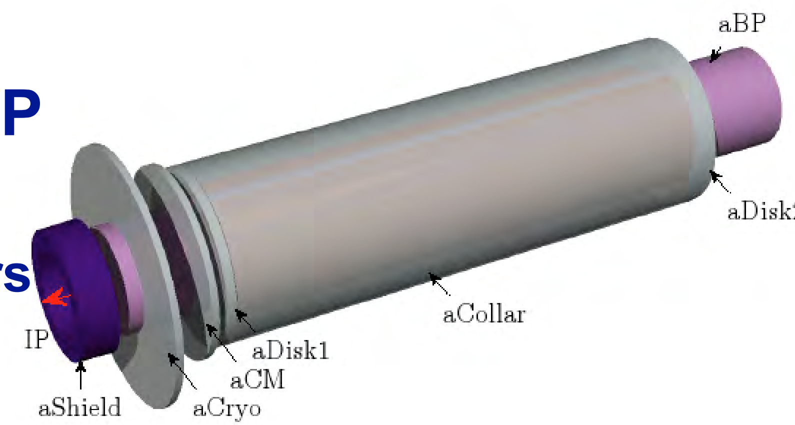
ATLAS at the SLHC

Add quads & dipoles (for 25 ns) plus new shielding (TAS)

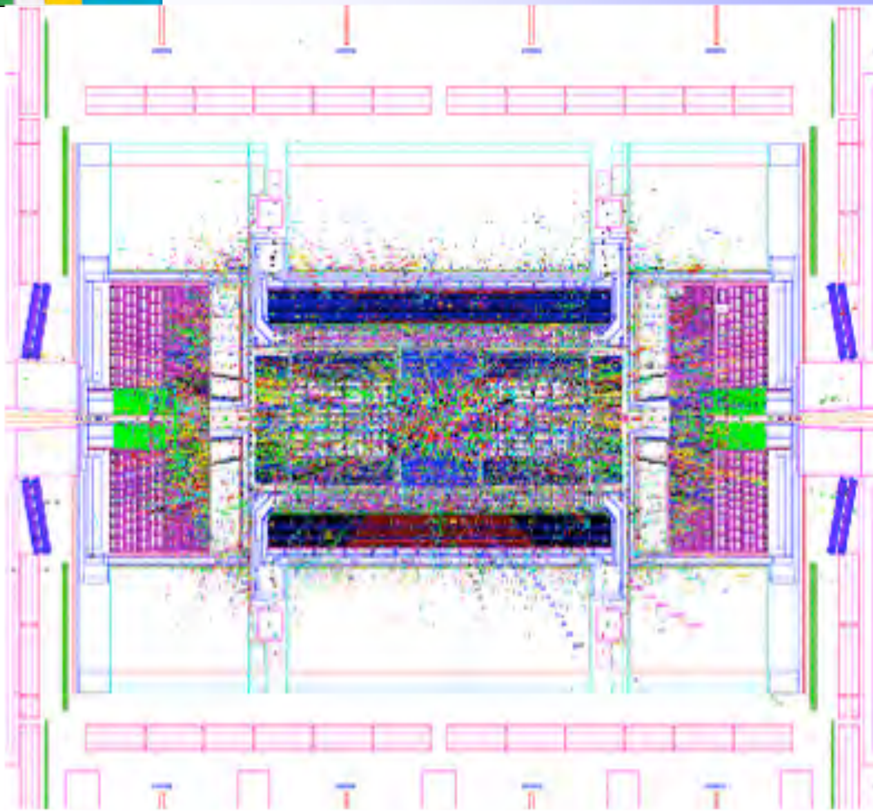


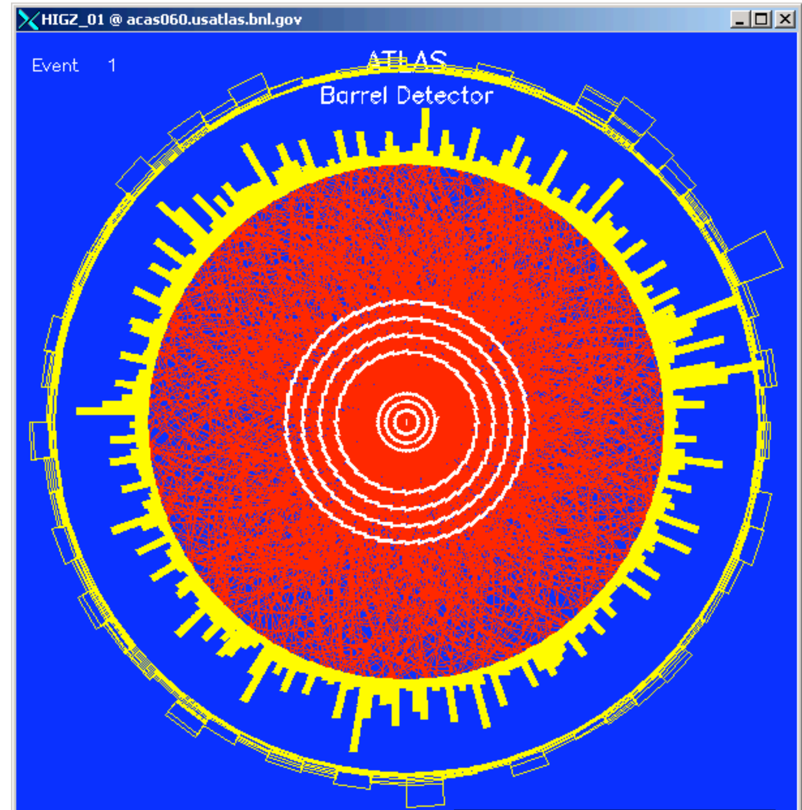
All Be beampipe: radius 21 mm at IP

- x 2-3 reduction in muon bkgd.
- Cheaper than replacing muon chambers
- Allows new pixel b-layer (innermost) at 30 mm



Expected Pile-up at Super LHC
in ATLAS at 10^{35}





$N_{ch}(|y|\leq 0.5)$

- 230 min.bias collisions per 25 ns. crossing
- ~ 10000 particles in $|\eta| \leq 3.2$
- mostly low p_T tracks
- requires upgrades to detectors

ATLAS Tracker Upgrade

ATLAS is considering a B-layer (innermost) replacement after ~3 year of integrated full LHC luminosity and replace completely the Inner Tracker with a fully silicon version for SLHC.

The B-layer replacement can be seen as an intermediate step towards the full upgrade. Performance improvements for the detector (mostly for to FE chip):

- Reduce radius → Improve radiation hardness (→ 3D sensors, or possibly, thin planar detectors, diamond, gas, …?)
- Reduce pixel cell size and architecture related dead time
- (→ design FE for higher luminosity, use 0.13 μm 8 metal CMOS)
- Reduce material budget of the b-layer (~3% X_0 → 2.0-2.5% X_0)
- increase the module live fraction (→ increase chip size, > 12 × 14 mm^2)
- possibly use "active edge" technology for sensor.
- Use faster R/O links, move MCC at the end of stave

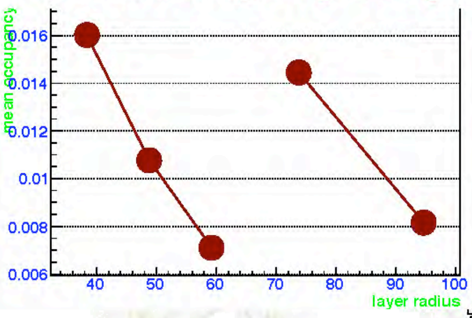
B-layer for upgrade will need radiation hardness (10^{15}→10^{16} n_{eq}/cm^2) and cope with detector occupancies up to (×15)

ATLAS SLHC Tracker "strawman" design

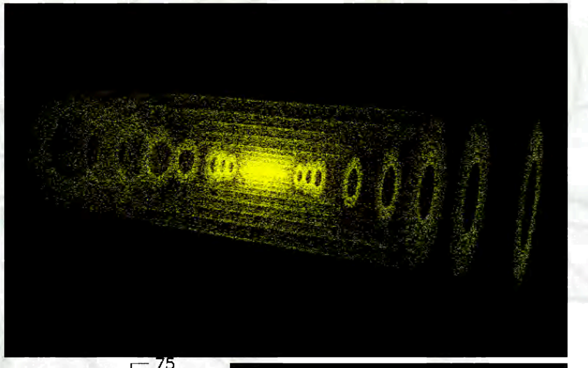
Strawman 4+3+2

Pixels:	**r=5cm, 12cm, 18cm, 27cm**	**z=±40cm**
Short (2.4 cm) μ-strips (stereo layers):	**r=38cm, 49cm, 60cm**	**z=±100cm**
Long (9.6 cm) μ-strips (stereo layers):	**r=75cm, 95cm**	**z=±190cm**

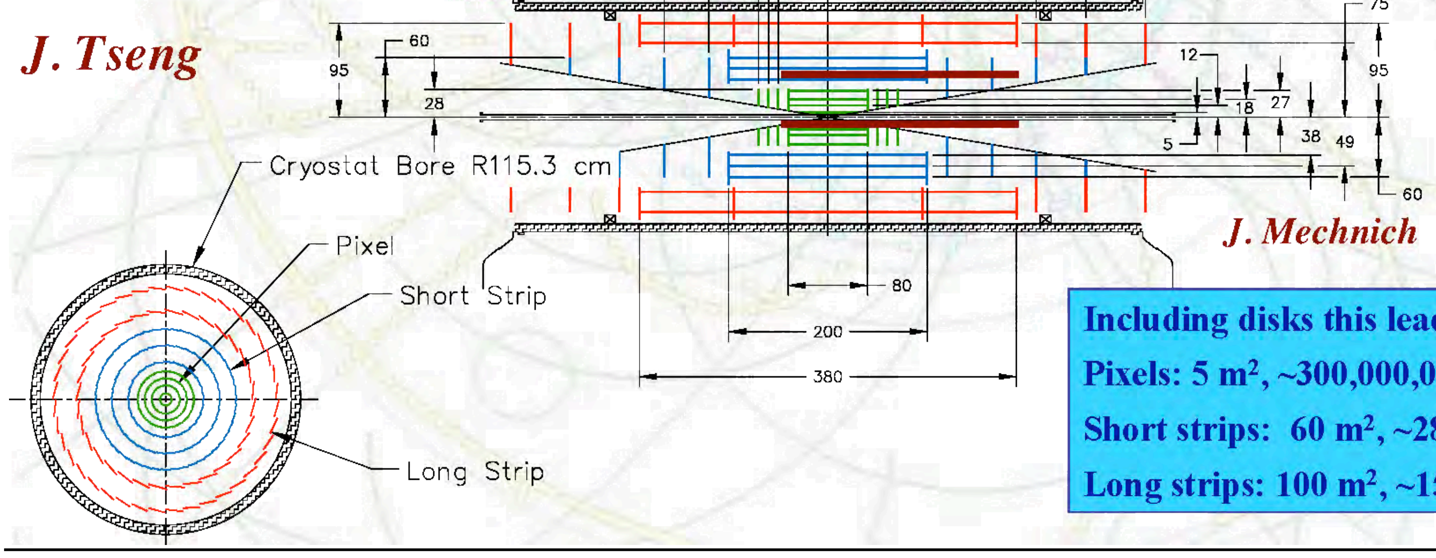
Short and Long Strip Occupancy

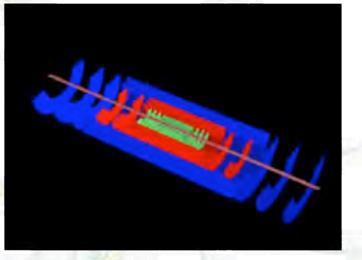


Only LO MC (Pythia) . May need to include ×2 safety factor?



J. Tseng





J. Mechnich

Including disks this leads to:

Pixels: 5 m², ~300,000,000 channels

Short strips: 60 m², ~28,000,000 channels

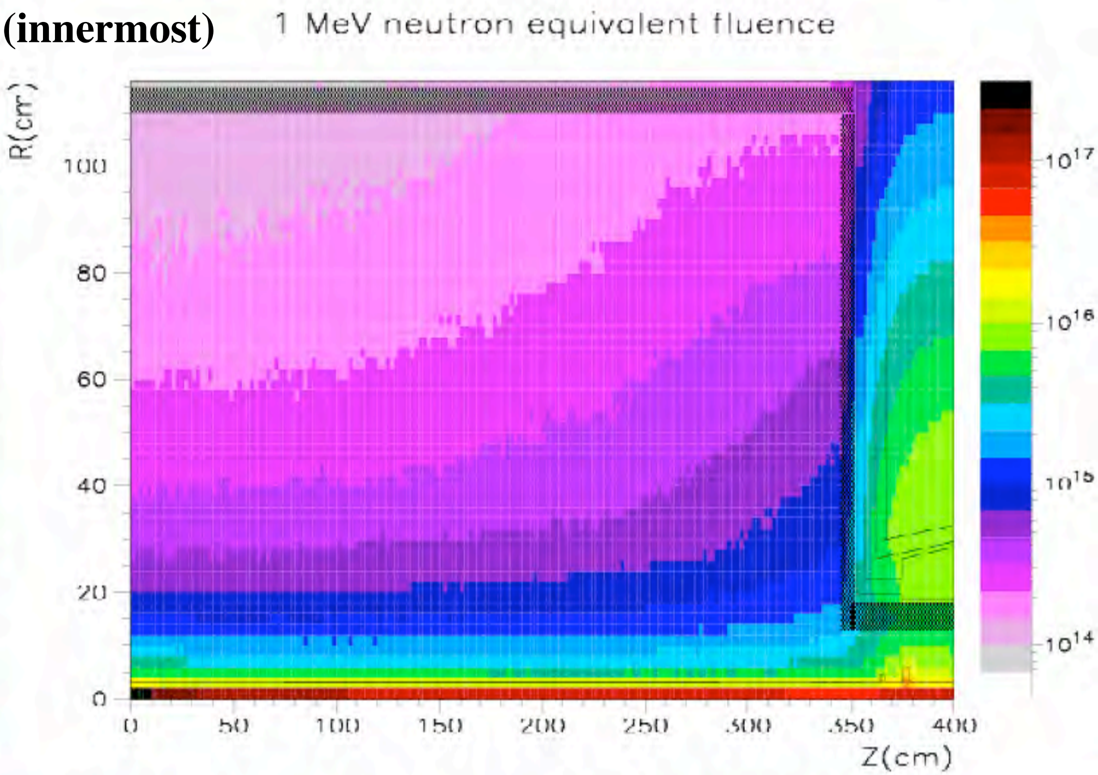
Long strips: 100 m², ~15,000,000 channels

ATLAS Tracker Region Charged Hadron Irradiation

- With safety factor of two, need pixel (innermost) b-layer to survive up to $10^{16} n_{eq}/cm^2$
- Short microstrip layers to withstand $9 \times 10^{14} n_{eq}/cm^2$ (50% neutrons)
- Outer layers up to $4 \times 10^{14} n_{eq}/cm^2$ (and mostly neutrons)

→ Issues of thermal management and shot noise. Silicon looks to need to be at ~ -25°C (depending on details of module design).

→ High levels of activation will require careful consideration for access and maintenance.



Quarter slice through ATLAS inner tracker Region, with 5cm moderator lining calorimeters. Fluences obtained using FLUKA2006, assuming an integrated luminosity of 3000fb⁻¹.

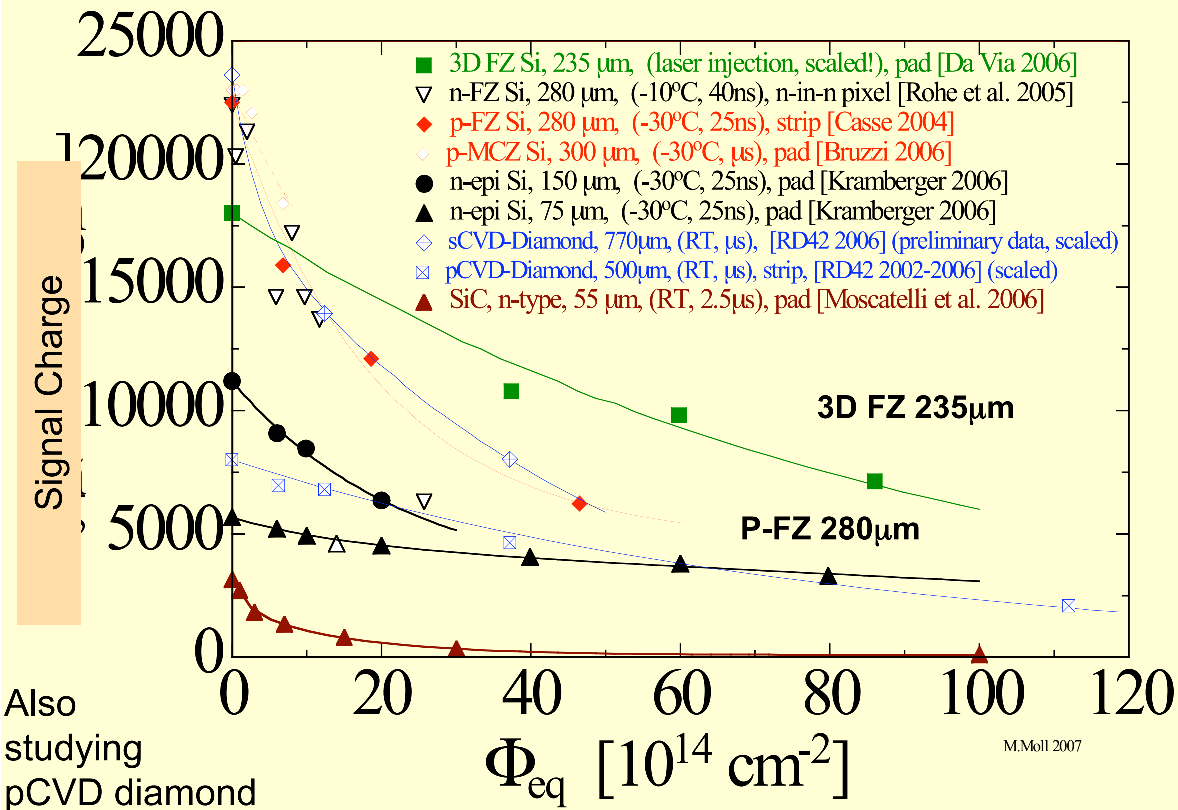
Issues of coolant temperature, module design, sensor geometry, radiation length, etc etc all heavily interdependent.

ATLAS Sensor R&D

Pixel and Strips: n-in-p (planar technology)

- No type inversion, full depletion is on structured side
- Collection of electrons (faster than p-in-n)

Still ~15000e$^-$ at 1.10^{15} cm^{-2}s^{-1}

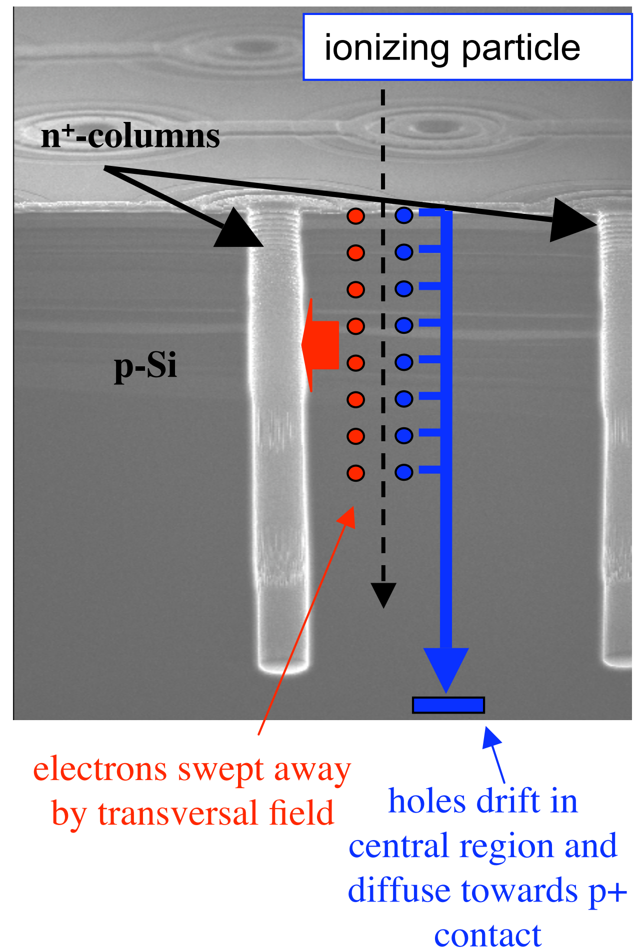


Also studying pCVD diamond

Pixel b-layer: 3D technology is an option

(should be ready for b-layer replacement in 20012)

Exist in single and double column type



CMS is also doing R&D on this

SLHC: ATLAS Calorimeter

LAr: Pileup will be ~ 3.2 X higher @ 10^{35}

- Electronics shaping time may need change to optimize noise response

LAr Forward:

- Space charge effects present for $|\eta|>2$ in EM LAr calorimeter
- High rates give high currents, heating of LAr
- Some intervention will be necessary -- next slide

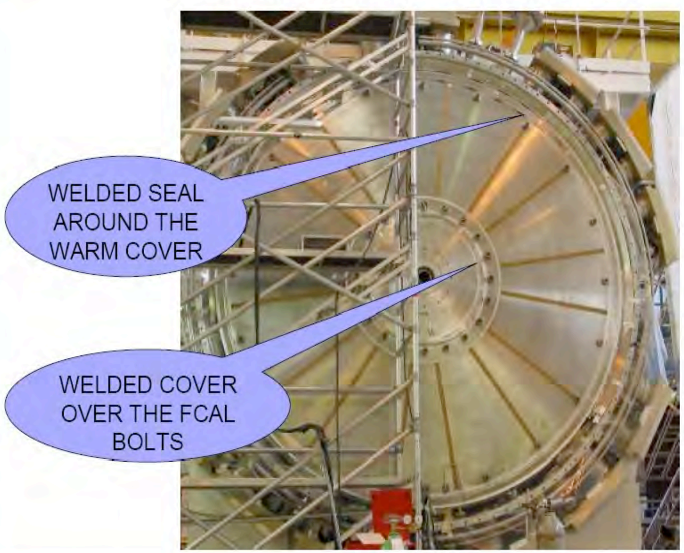
Tilecal mostly OK

- Will suffer some radiation damage ΔLY< 20%
- Calibration & correction – may be difficult to see Min-I signal amidst pileup

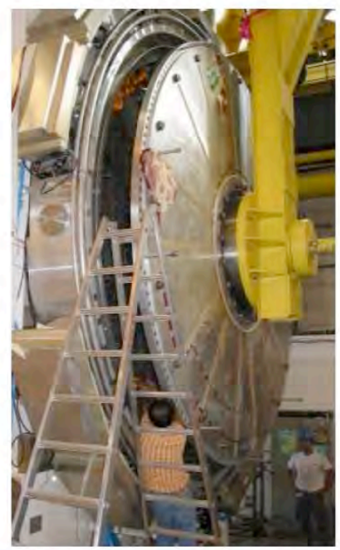
ATLAS LAr Endcap Upgrade
(one scenario)

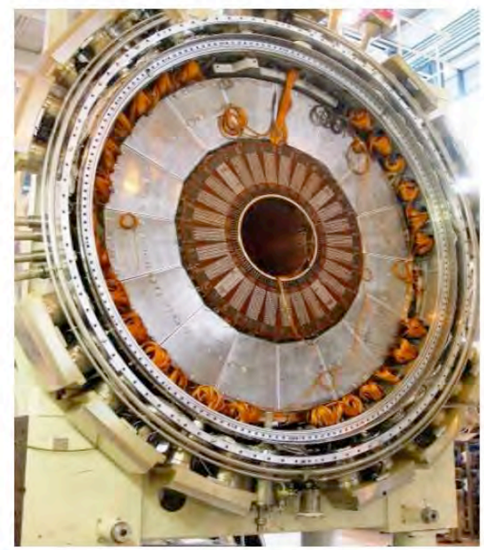
- Probably need to open up the endcaps to upgrade FCAL etc.
- Time taken to bring to surface, dismantle, upgrade and return >~2 y
- Instead, lots of progress on understanding option to work in pit
- Favoured scenario:
  - Build replacement FCAL ready for upgrade.
  - Remove old FCAL in pit and put in brand new one.

END CAP WITH WARM COVER REMOVED



REMOVE COLD COVER TO EXPOSE REAR FACE OF HEC2





SLHC: ATLAS Muons

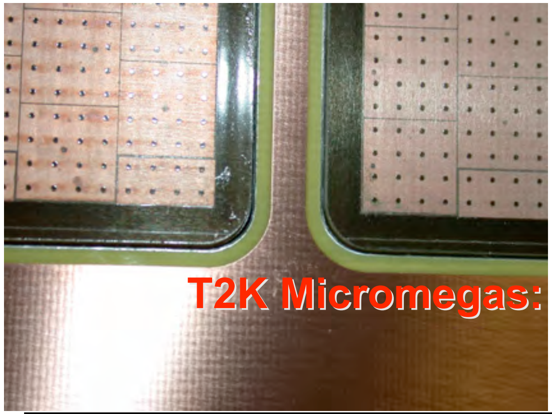
Some or many chambers will have to be replaced - N. Hessey

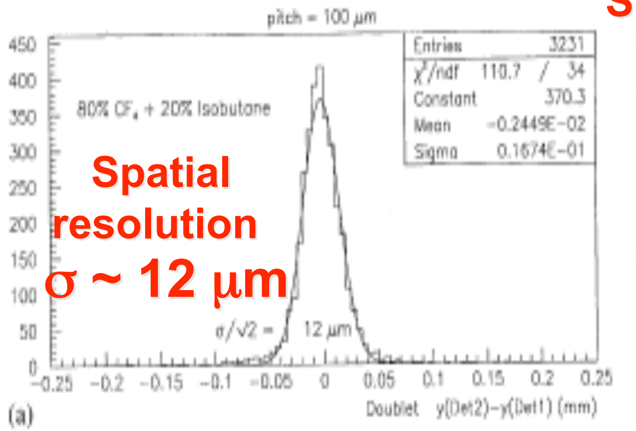
- depends on actual background rates

R&D proposals for electronics, gases, new chambers

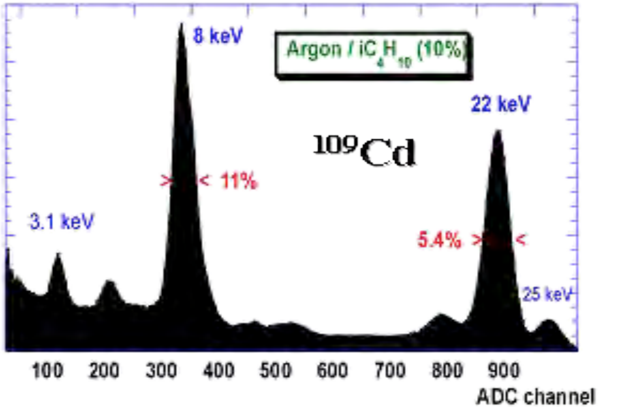
Particularly micromegas is making progress

- MICROMEsh GAseous Structure (Micromegas)
  - Parallel plate multiplication in thin gaps btw fine mesh & anode plate
- can be used for both precision and triggering
- challenge is to make large area (few m^2) chambers

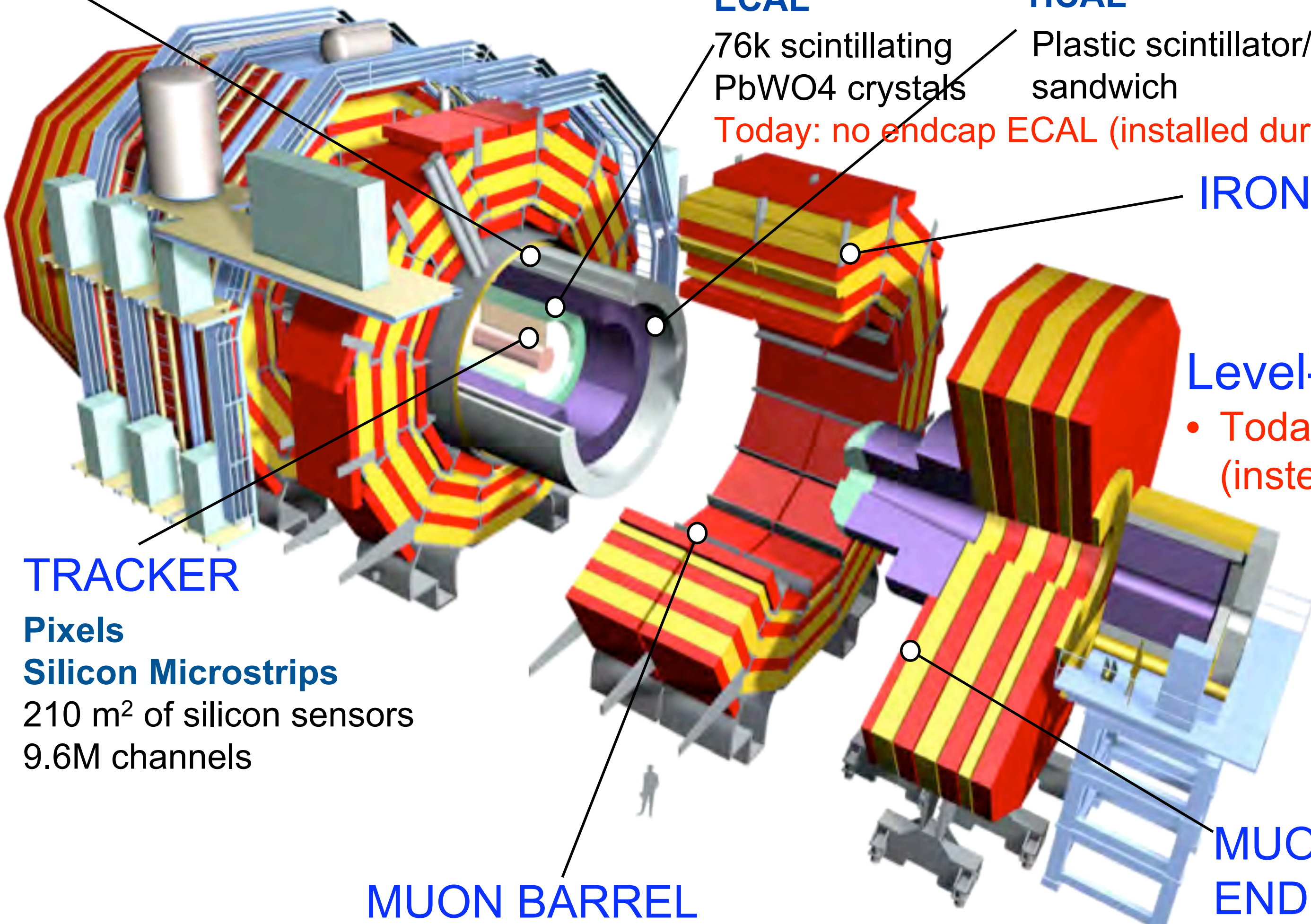




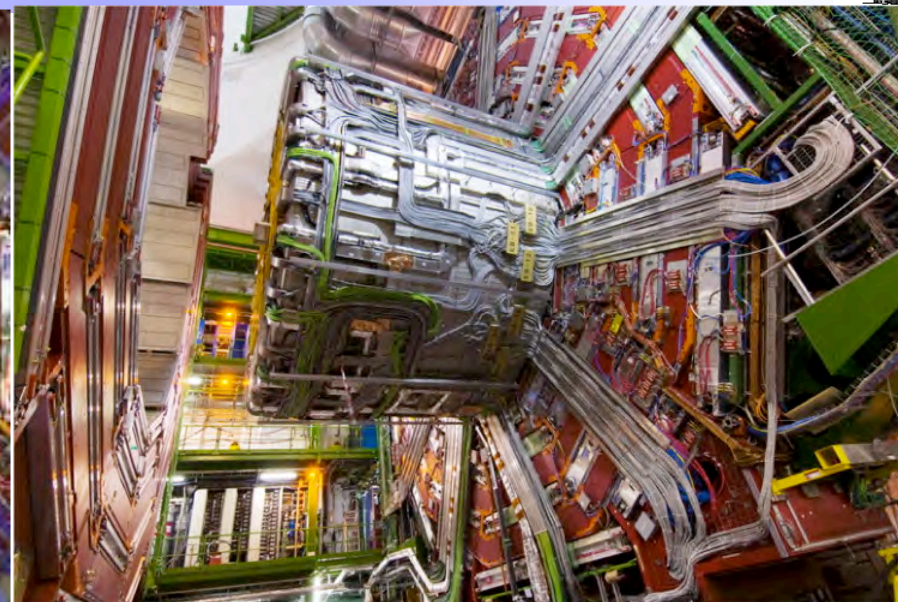
Small gap→ good energy resolution



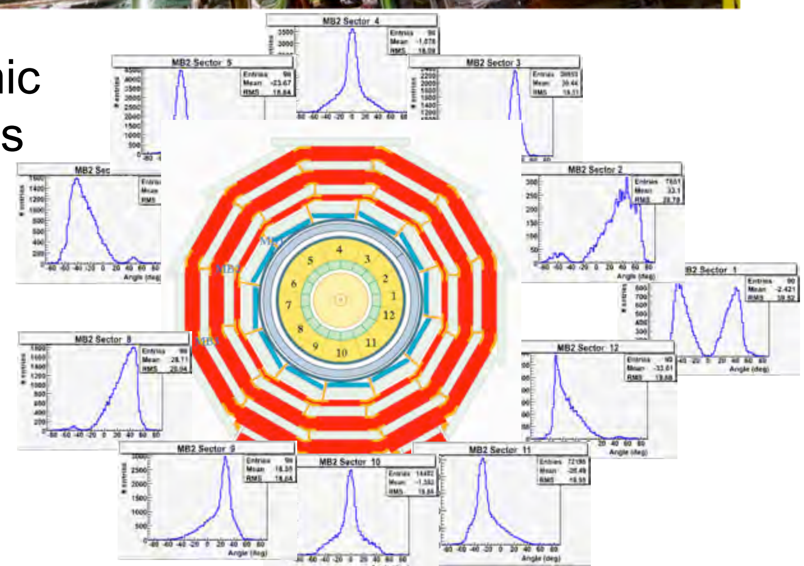
CMS Detector Design



CMS Today



Cosmic muons thru drift tubes

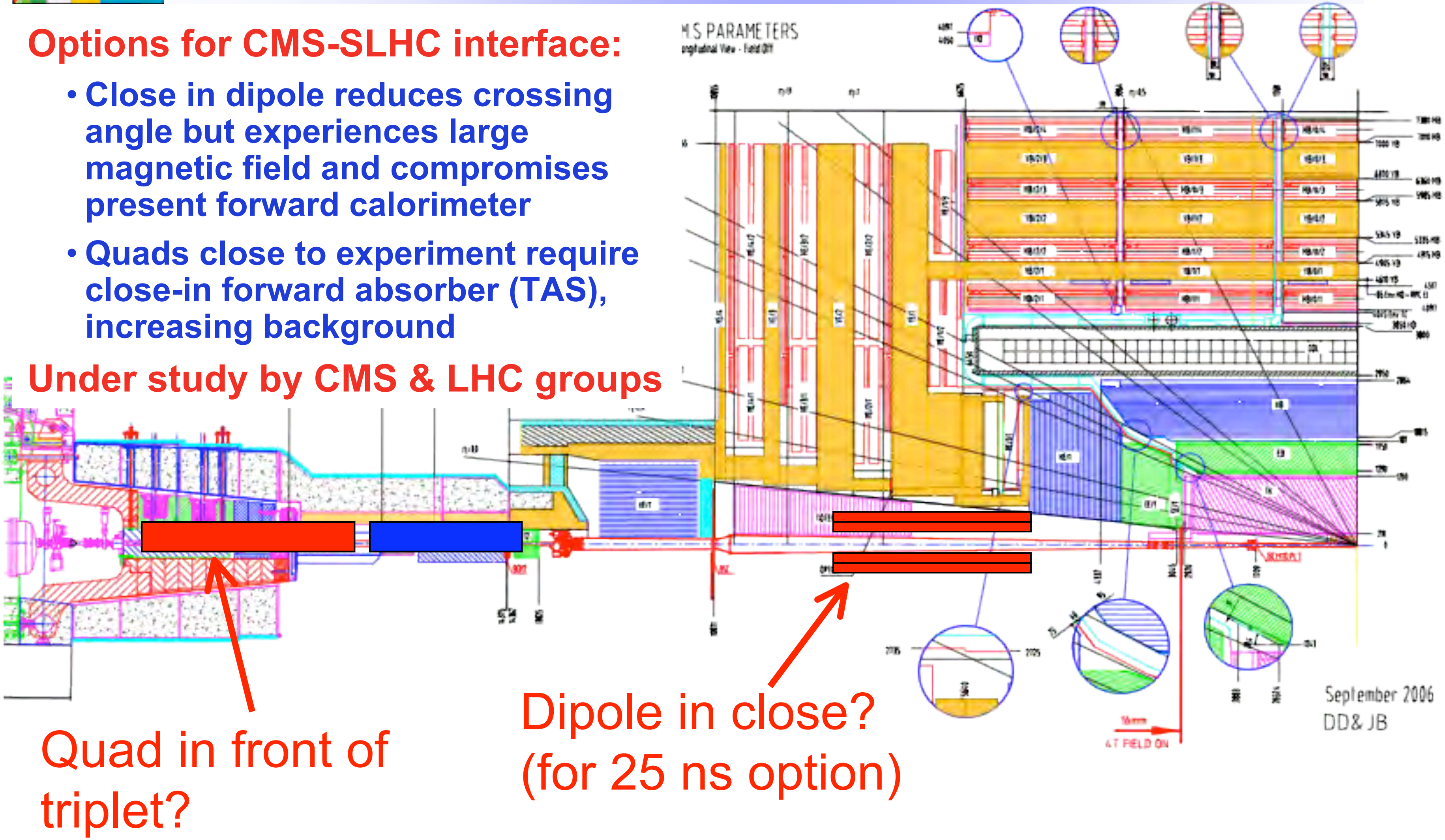


CMS at the SLHC

Options for CMS-SLHC interface:

- Close in dipole reduces crossing angle but experiences large magnetic field and compromises present forward calorimeter
- Quads close to experiment require close-in forward absorber (TAS), increasing background

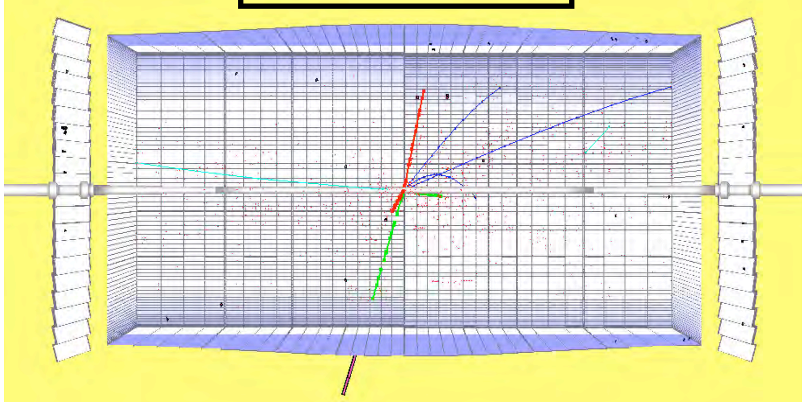
Under study by CMS & LHC groups



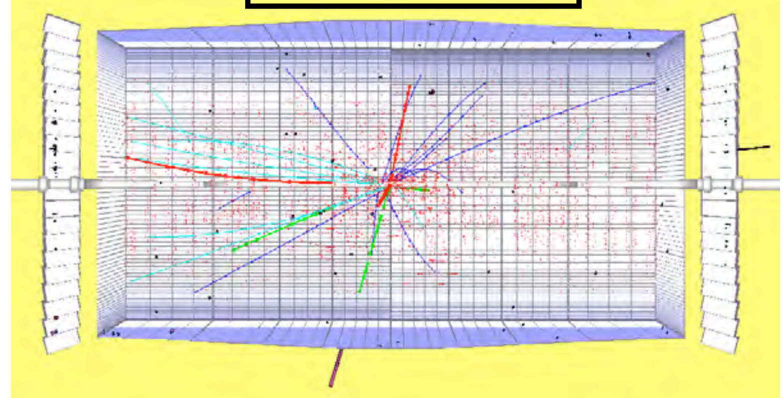
Detector Luminosity Effects

$H \rightarrow ZZ \rightarrow \mu\mu ee$, M_H= 300 GeV for different luminosities in CMS

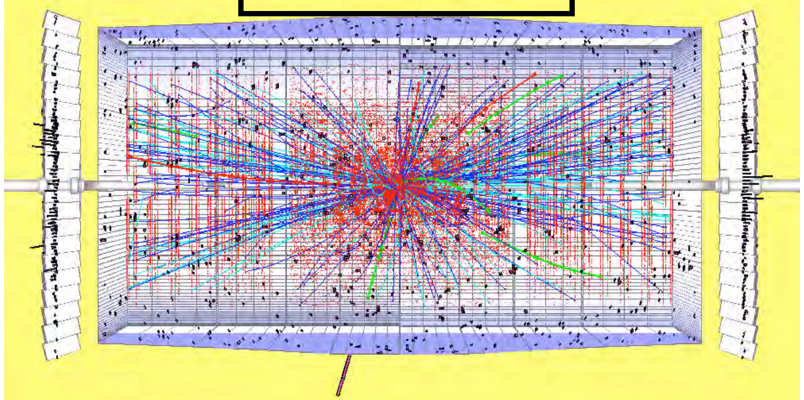
10^{32} cm^{-2}s^{-1}



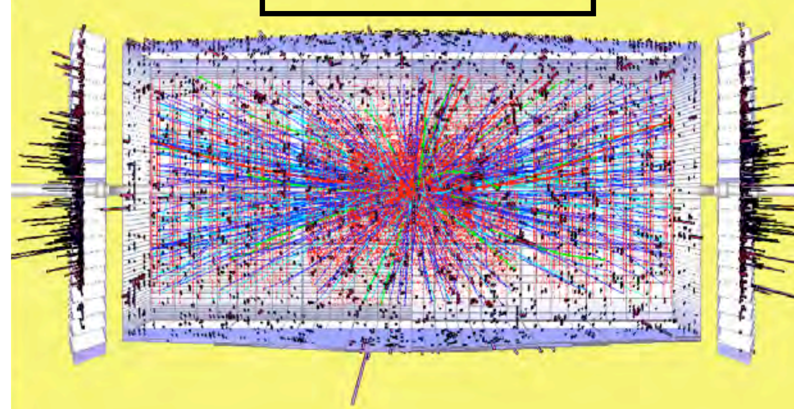
10^{33} cm^{-2}s^{-1}



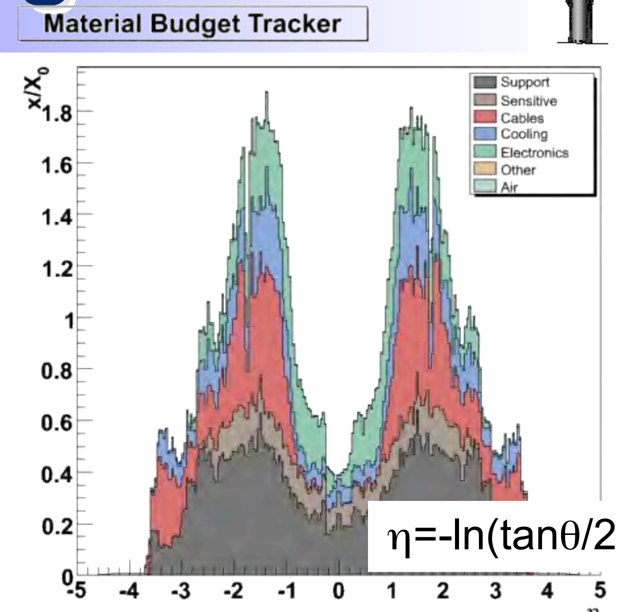
10^{34} cm^{-2}s^{-1}



10^{35} cm^{-2}s^{-1}



CMS Tracker Upgrade

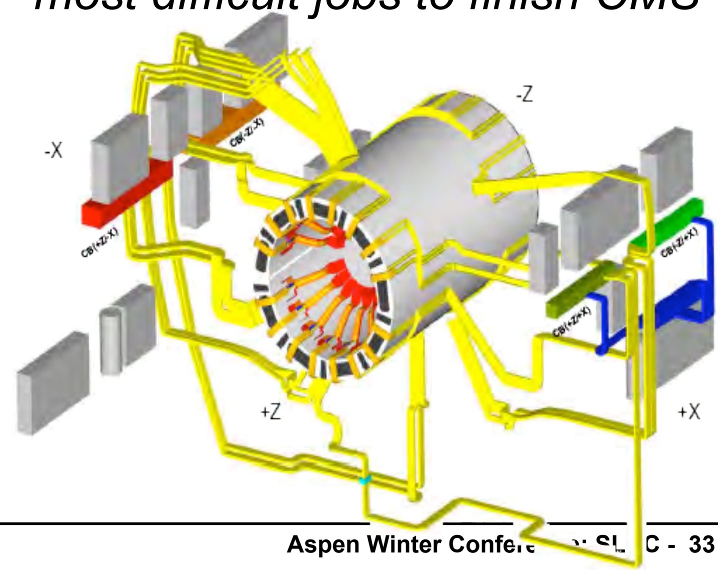


Challenge Facing CMS & ATLAS: Build a replacement tracker for $L = 10^{35}$ cm^{-2}s^{-1} with equal or better performance

To do so, CMS & ATLAS need to solve several <u>very</u> difficult problems

- **deliver power - probably requiring greater currents**
- **develop sensors to tolerate radiation fluences ~10x larger than LHC**
- **reduce material in the tracker**
- ***CMS needs to construct readout systems to contribute to the L1 trigger using tracker data -- next slides***

Installation of services one of the most difficult jobs to finish CMS



It is probably <u>at least</u> as difficult a challenge as the original LHC detectors were in 1990

CMS SLHC Tracker R&D

Ultra Rad-hard sensors

- Magnetic Czochralski (MCz) growth technology produces Si devices which are intrinsically highly oxygenated & high resistivity
- Using p-type MCz Si wafers instead of n-type ones, has the further advantage of not encountering type inversion at high fluences

Thin Sensors

- For fluences > 10^{15} p/cm^2, sensors dissipate a lot of power
- Thinner sensors → less volume → less current

3D or SOI Detectors

Large area low cost interconnections

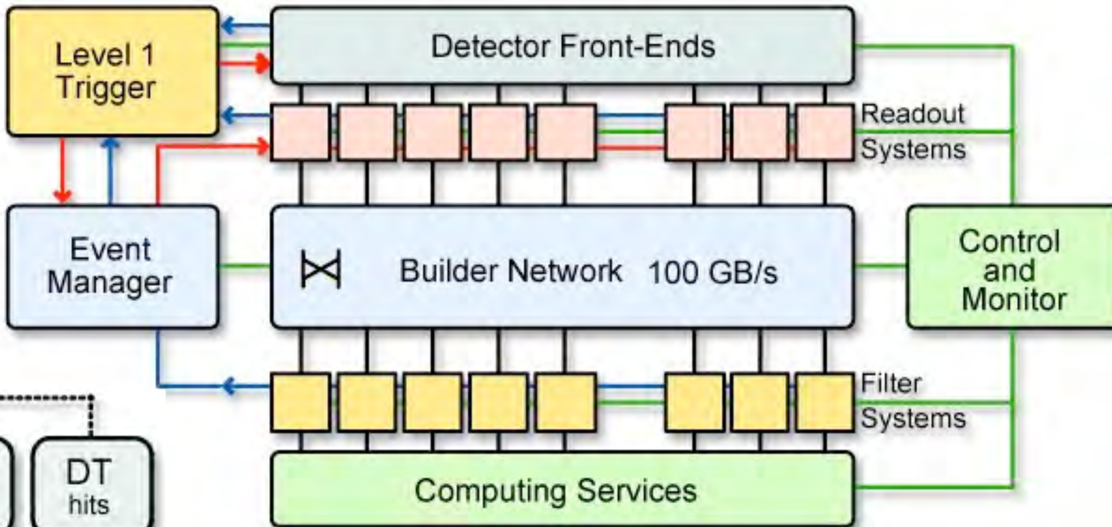
Low mass components & cooling methods

New Pixel Front End ASIC

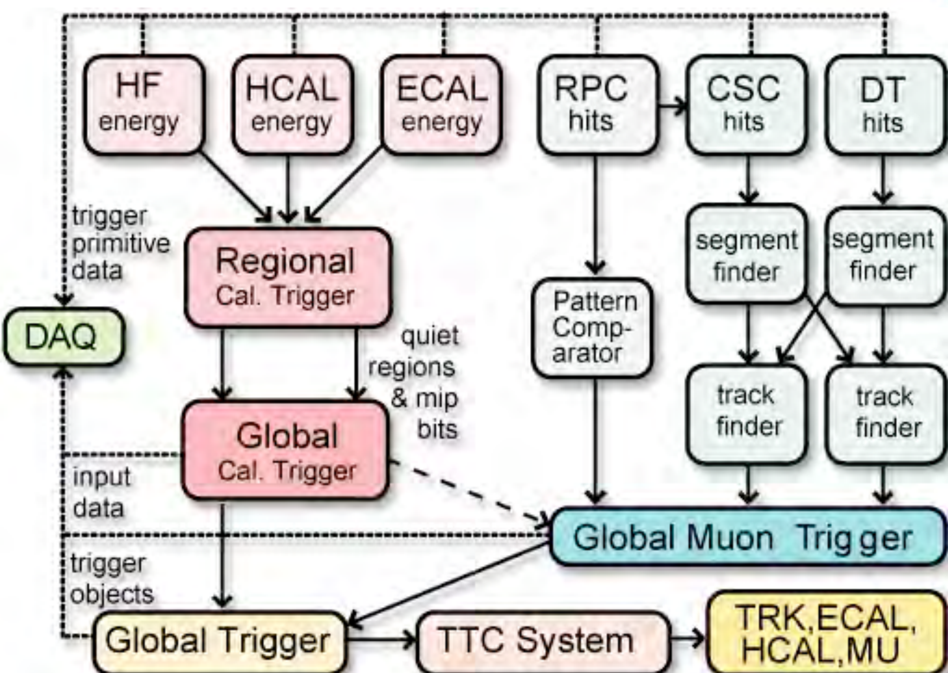
- Reduced power -- switch from 250 to 130 nm technology helps
- Increased radiation tolerance

CMS Trig & DAQ for LHC

Overall Trigger & DAQ Architecture: 2 Levels:



Level-1 Trigger:



Interaction rate: 1 GHz

Bunch Crossing rate: 40 MHz

Level 1 Output: 100 kHz (50 initial)

Output to Storage: 100 Hz

Average Event Size: 1 MB

Data production 1 TB/day

SLHC Level-1 Trigger @ 10^{35}

Occupancy

- **Degraded performance of algorithms**
  - Electrons: reduced rejection at fixed efficiency from isolation
  - Muons: increased background rates from accidental coincidences
- **Larger event size to be read out**
  - New Tracker: higher channel count & occupancy → large factor
  - Reduces the max level-1 rate for fixed bandwidth readout.

Trigger Rates

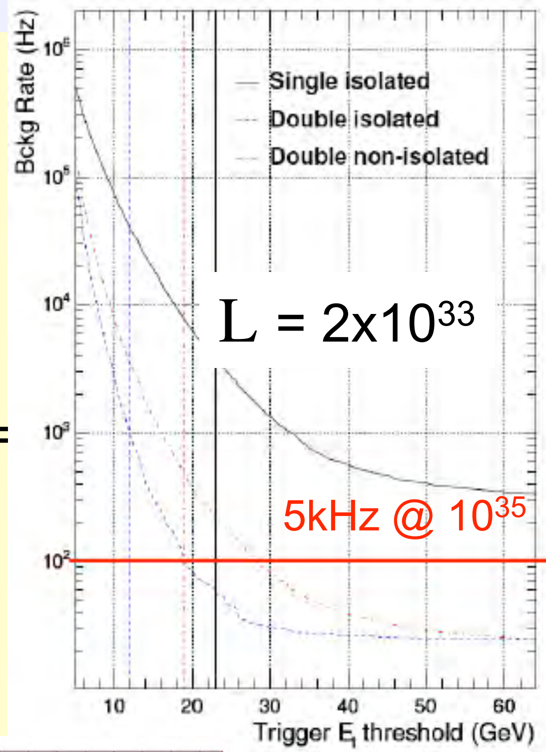
- **Try to hold max L1 rate at 100 kHz by increasing readout bandwidth**
  - Avoid rebuilding front end electronics/readouts where possible
    - **Limits: ⟨readout time⟩ (< 10 μs) and data size (total now 1 MB)**
  - Use buffers for increased latency for processing, not post-L1A
  - May need to increase L1 rate even with all improvements
    - **Greater burden on DAQ**
- **Implies raising E_T thresholds on electrons, photons, muons, jets and use of multi-object triggers, unless we have new information ⇒Tracker at L1**
  - Need to compensate for larger interaction rate & degradation in algorithm performance due to occupancy

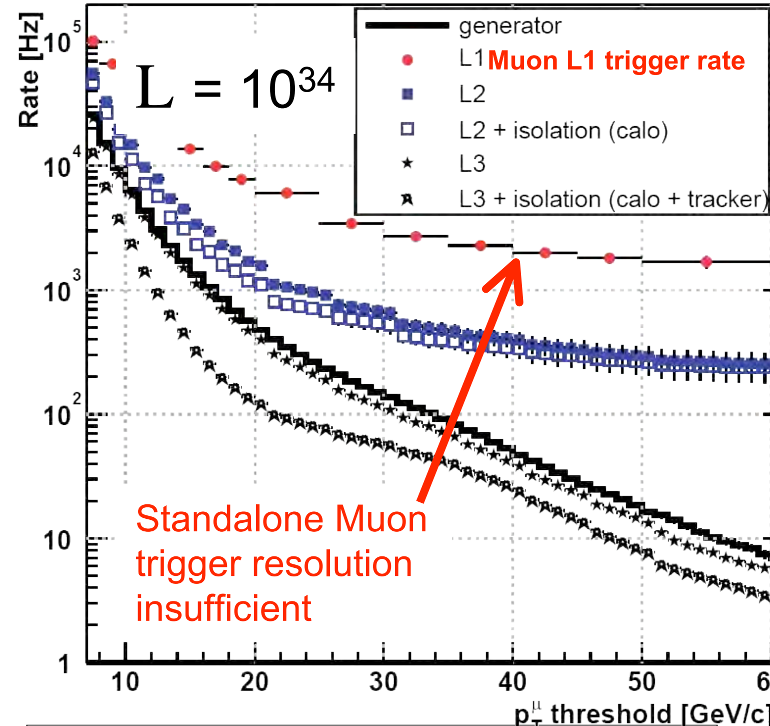
Radiation damage **-- Increases for part of level-1 trigger located on detector**

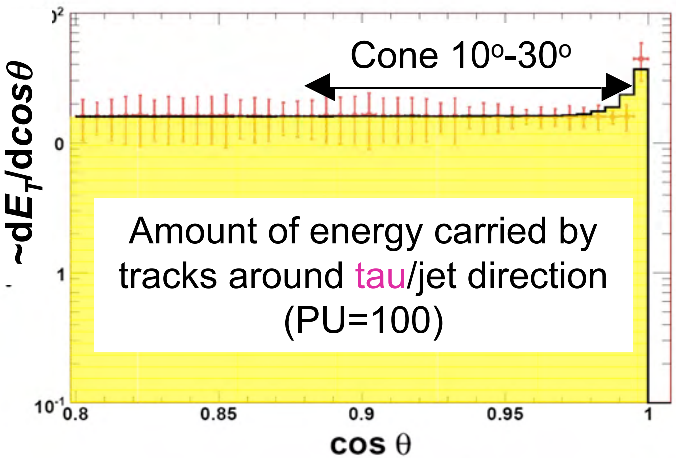
Tracking needed for L1 trigger

Single electron trigger rate

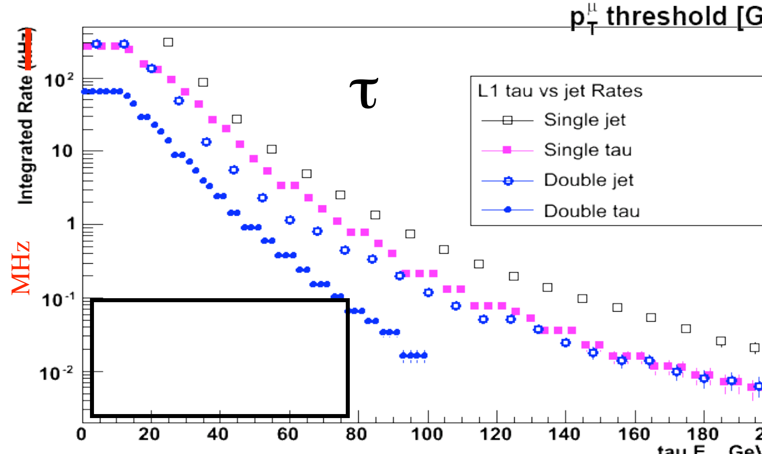
Isolation criteria are insufficient to reduce rate at L = 10^{35} $cm^{-2}.s^{-1}$







We need to get another x200 (x20) reduction for single (double) tau rate!



Use of CMS L1 Tracking Trigger

Combine with L1 μ trigger as is now done at HLT:

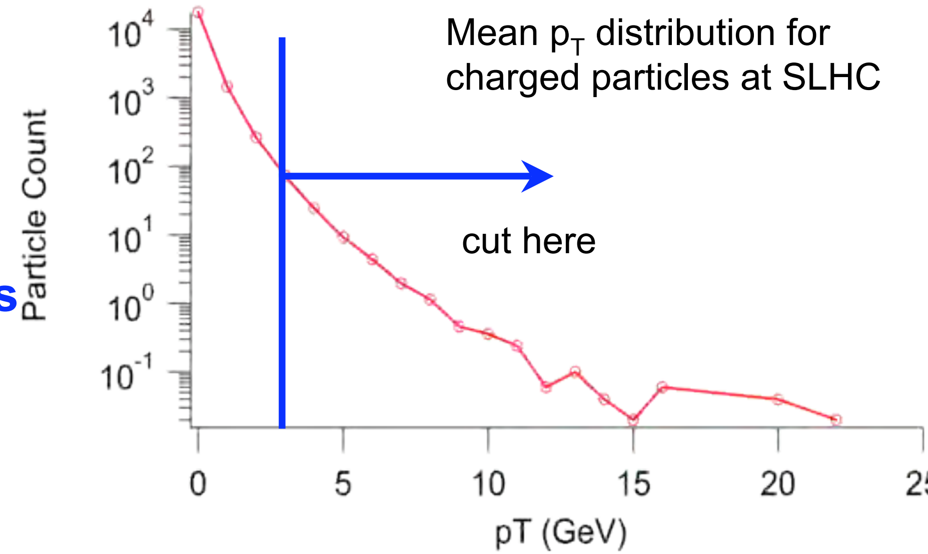
- **Attach tracker hits to improve P_T assignment precision from 15% standalone muon measurement to 1.5% with the tracker**
  - Improves sign determination & provides vertex constraints
- **Find pixel tracks within cone around muon track and compute sum P_T as an isolation criterion**
  - Less sensitive to pile-up than calorimetric information *if* primary vertex of hard-scattering can be determined (~100 vertices total at SLHC!)

To do this requires η–ϕ information on muons finer than the current 0.05–2.5°

- **No problem, since both are already available at 0.0125 and 0.015°**

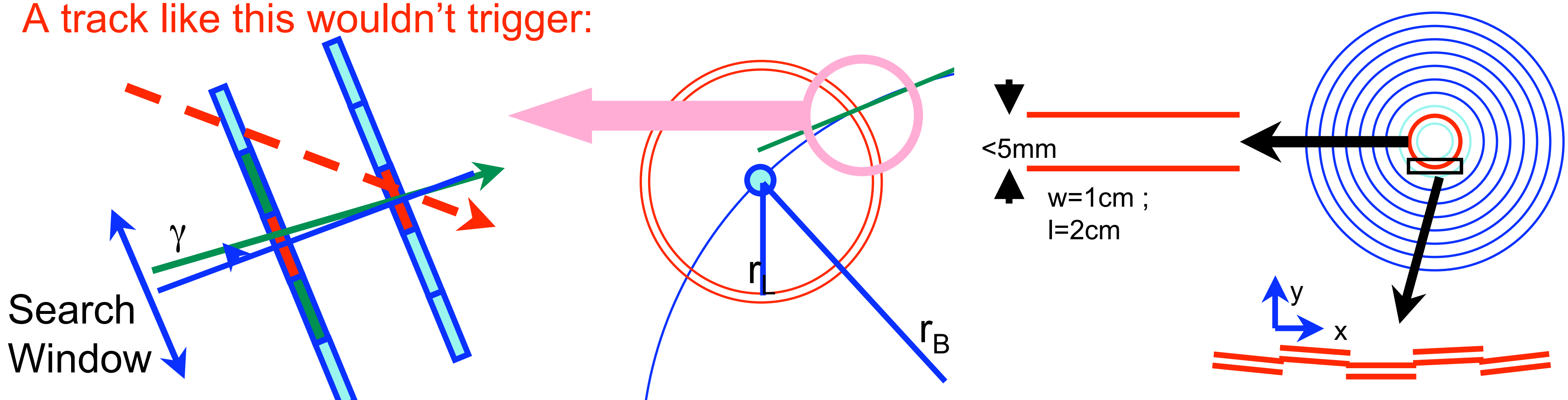
CMS ideas for trigger-capable tracker modules -- very preliminary

- Use close spaced stacked pixel layers
- Geometrical p_T cut on data (e.g. ~ GeV):
- Angle (γ) of track bisecting sensor layers defines p_T ($\Rightarrow$ window)
- For a stacked system (sepn. ~1mm), this is ~1 pixel
- Use simple coincidence in stacked sensor pair to find tracklets
- More details & implementation next slides



-- C. Foudas & J. Jones

A track like this wouldn't trigger:



p_T Cuts in a Stacked Tracker – p_T Cut Probabilities

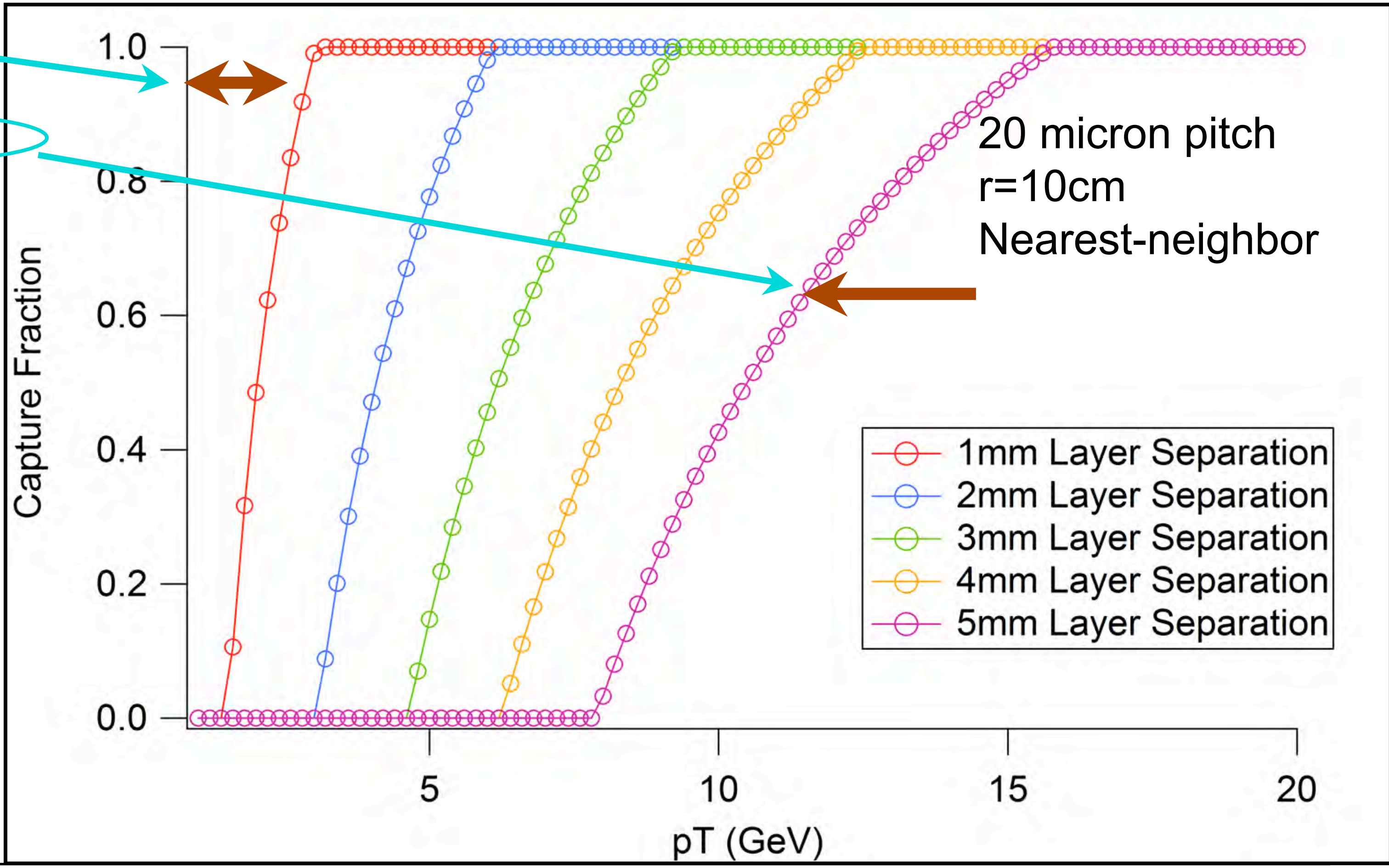
- J. Jones

- **Depends on:**

Layer Sepn. & Radius

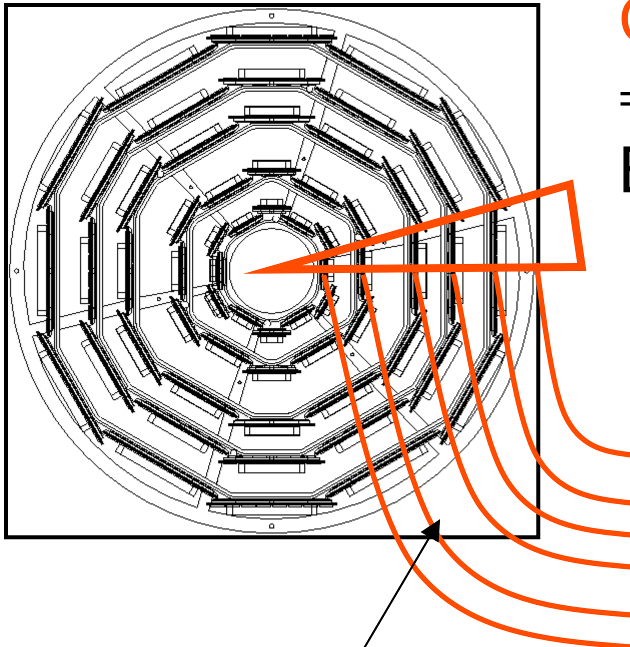
Pixel Size

Search Window



There is an additional 'blurring' caused by charge sharing…

Alternative Tracking Trigger: Associative Memories (from CDF SVX)



Challenge: input Bandwidth
$\Rightarrow$divide the detector in thin ϕ sectors.
Each AM searches in a small $\Delta\phi$

OFF DETECTOR

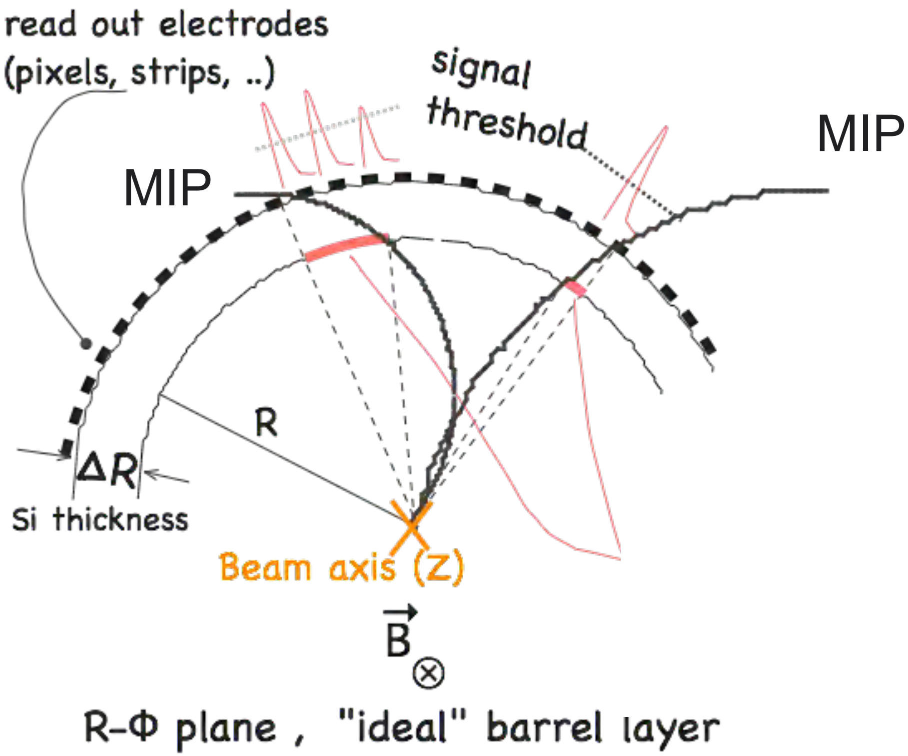
1 AM for each enough-small $\Delta\phi$
Patterns
Hits: position+time stamp
All patterns inside a single chip
N chips for N overlapping events identified by the time stamp

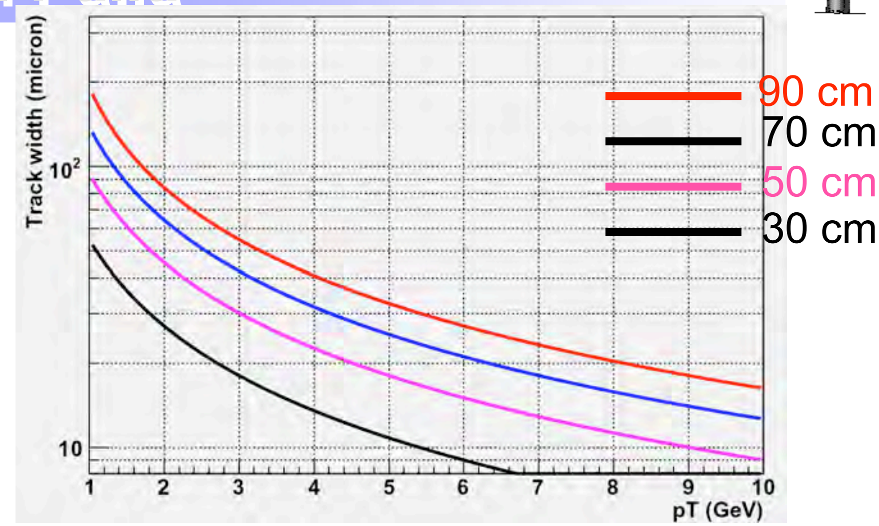
Data links

-- F. Palla, A. Annovi, *et al.*

Event1 AMchip1	Event2 AMchip2	Event3 AMchip3	• • • • •	EventN AMchipN

Cluster width discrimination
-- F. Palla





Discrimination of low p_T tracks made directly on the strip detector by choosing suitable pitch values in the usual range for strip sensors.

(Needed because 25M channels x 4% occupancy would require 6000 2.8 Gbps links at 100 kHz.)

In the region above 50 cm, using 50µm pitch, about 5% of the total particles leave cluster sizes with ≤2 strips

- No. of links (2.5Gbps) ~300 for whole tracker (assuming 95% hit rejection)

Once reduced to ~100 KHz, it would only need few fast readout links to readout the entire Tracker

SLHC: CMS Calorimeter

Forward Calorimeter: Quartz Fiber

- **Radiation tolerant**
- **Very fast**
- **Modify logic to provide finer-grain information**
  - Improves forward jet-tagging

Hadron Barrel & Endcap Calorimeters

- **Plastic scintillator tiles and wavelength shifting fiber is radiation hard up to 2.5 MRad while at SLHC, expect 25MRad in HE.**
  - R&D new scintillators and waveshifters in liquids, paints, and solids, and Cerenkov radiation emitting materials e.g. Quartz
- **Study silicon photomultipliers (SiPMs) to replace Hybrid Photodiodes (HPDs)**
  - Less noise, more amplification, magnetic, radiation tolerance under study

ECAL: PBWO4 Crystal: Stays

- **Sufficiently radiation tolerant**
- **Exclude on-detector electronics modifications for now -- difficult:**
  - Regroup crystals to reduce $\Delta\eta$ tower size -- minor improvement
  - Additional fine-grain analysis of individual crystal data -- minor improvement

CMS SLHC Muon

Drift Tubes (barrel):

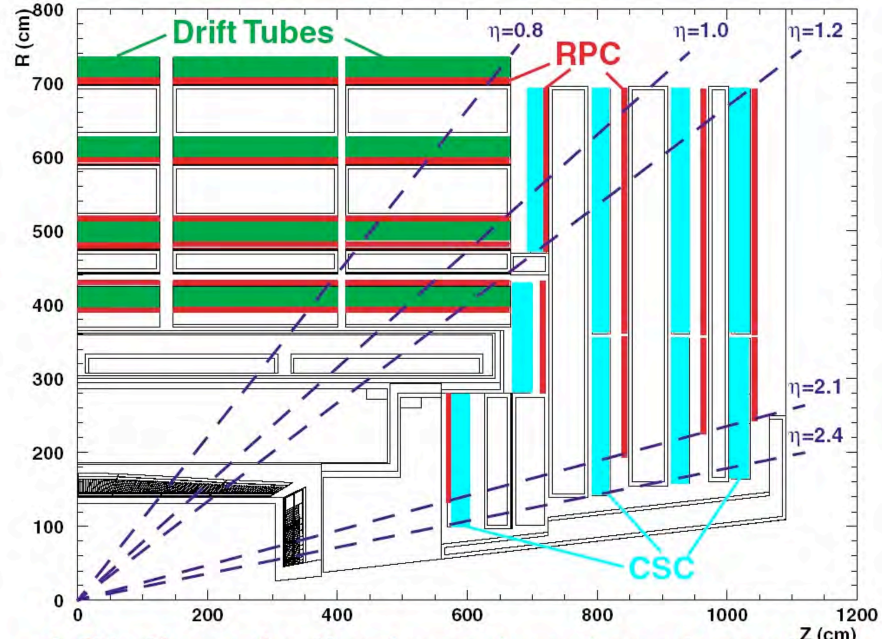
- Electronics might sustain rad. damage
- Increase x 10 in muon rates will cause dead time & errors in BTI algorithm, due to long drift times.
- # two tracks per station/bx could limit due to ghosts.

RPC (barrel & endcap):

- Operate in low η region with same FE
- Detector & FE upgrade is needed for η > 1.6 region
- Trigger Electronics can operate with some modifications
- Some front-end electronics may not be sufficiently radiation tolerant

CSCs (endcap):

- CSCs in endcaps have demonstrated required radiation tolerance
- Need ME4/2 layer recovered
- Parts of trigger & DAQ may need replacement to cope with high rates
- Some front-end electronics may not be sufficiently radiation tolerant



4 Stations in the barrel and each endcap

- Initial coverage of RPC is staged to η<1.6 and 3 disks
- Initial trigger coverage of CSC 1st station is staged to η<2.1
- Fourth CSC disk staged to η<1.8

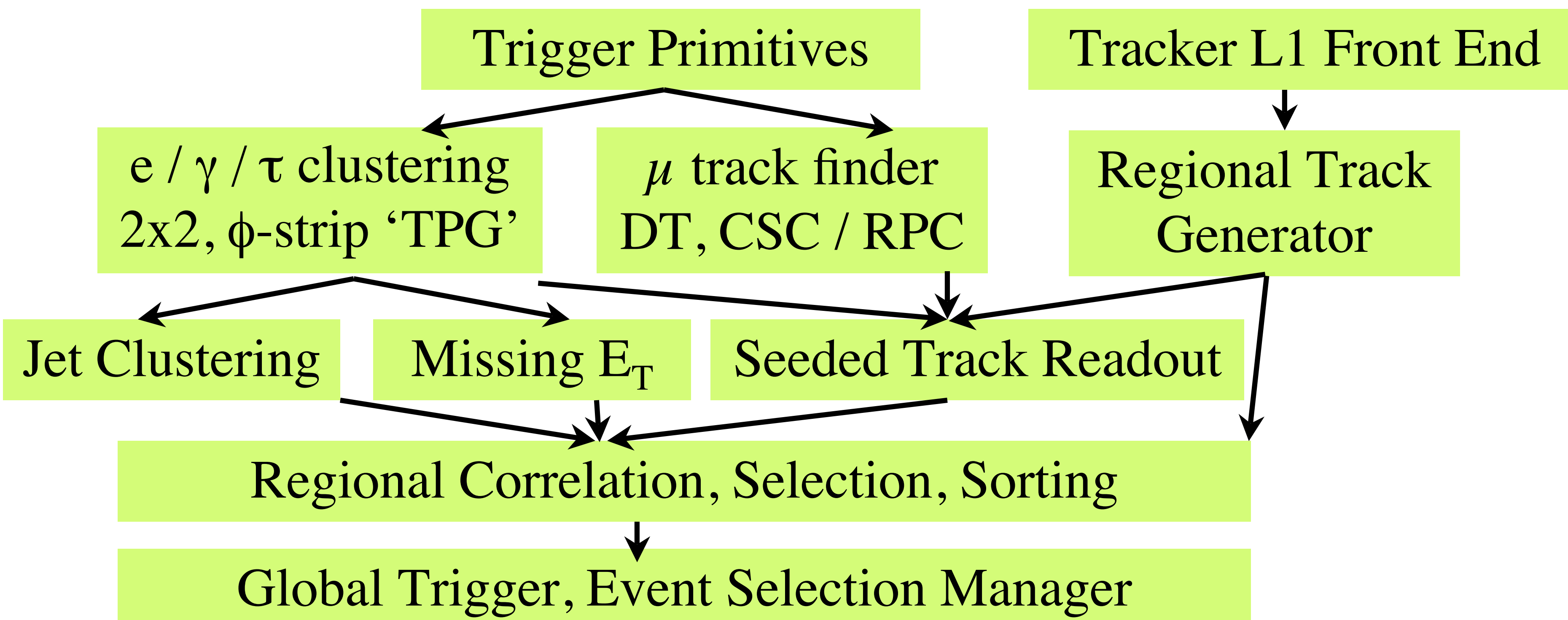
CMS L1 Trigger Stages

Current for LHC:

TPG ⇒ RCT ⇒ GCT ⇒ GT

Proposed for SLHC (with tracking added):

TPG ⇒ Clustering ⇒ Correlator ⇒ Selector



CMS Level-1 Latency

Present CMS Latency of 3.2 μsec = 128 crossings @ 40MHz

- Limitation from post-L1 buffer size of tracker & preshower
- Assume rebuild of tracking & preshower electronics will store more than this number of samples

Do we need more?

- Not all crossings used for trigger processing (70/128)
  - It's the cables!
- Parts of trigger already using higher frequency

How much more? Justification?

- Combination with tracking logic
- Increased algorithm complexity
- Asynchronous links or FPGA-integrated deserialization require more latency
- Finer result granularity may require more processing time
- ECAL digital pipeline memory is 256 40 MHz samples = 6.4 μsec
  - Propose this as CMS SLHC Level-1 Latency baseline

Conclusions

The LHC will initiate a new era in colliders, detectors & physics.

- Searches for Higgs, SUSY, ED, Z' will commence
  - Exploring the TeV scale
- Serious challenges for the machine, experiments & theorists will commence

The SLHC will extend the program of the LHC

- Extend the discovery mass/scale range by 25-30%
- Could provide first measurement of Higgs self-coupling
- Reasonable upgrade of LHC IR optics
- Rebuilding of experiment tracking & trigger systems and parts of calorimetry, muon systems
- Need to start now on R&D to prepare