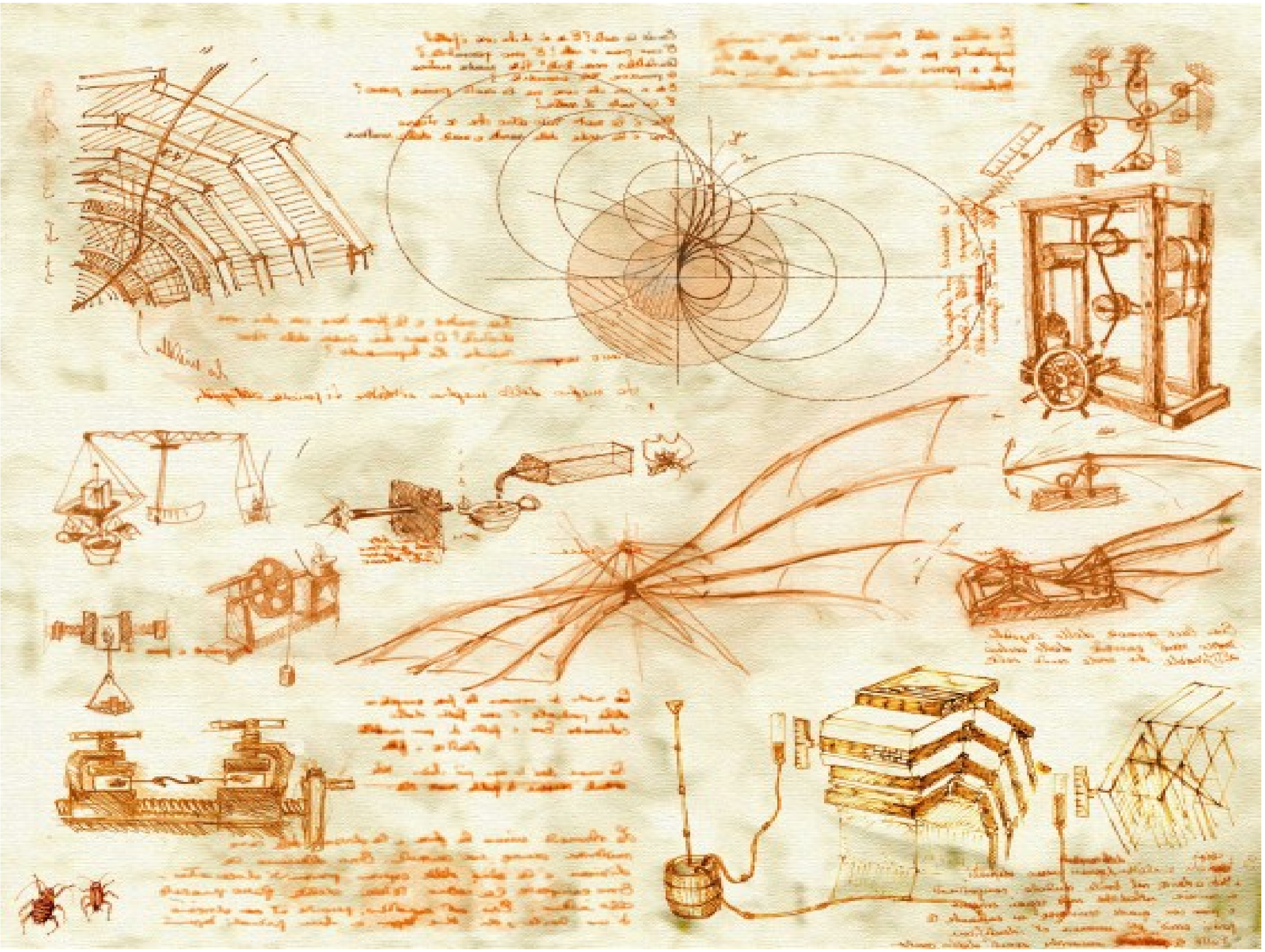
Status and expectations for the first physics in CMS



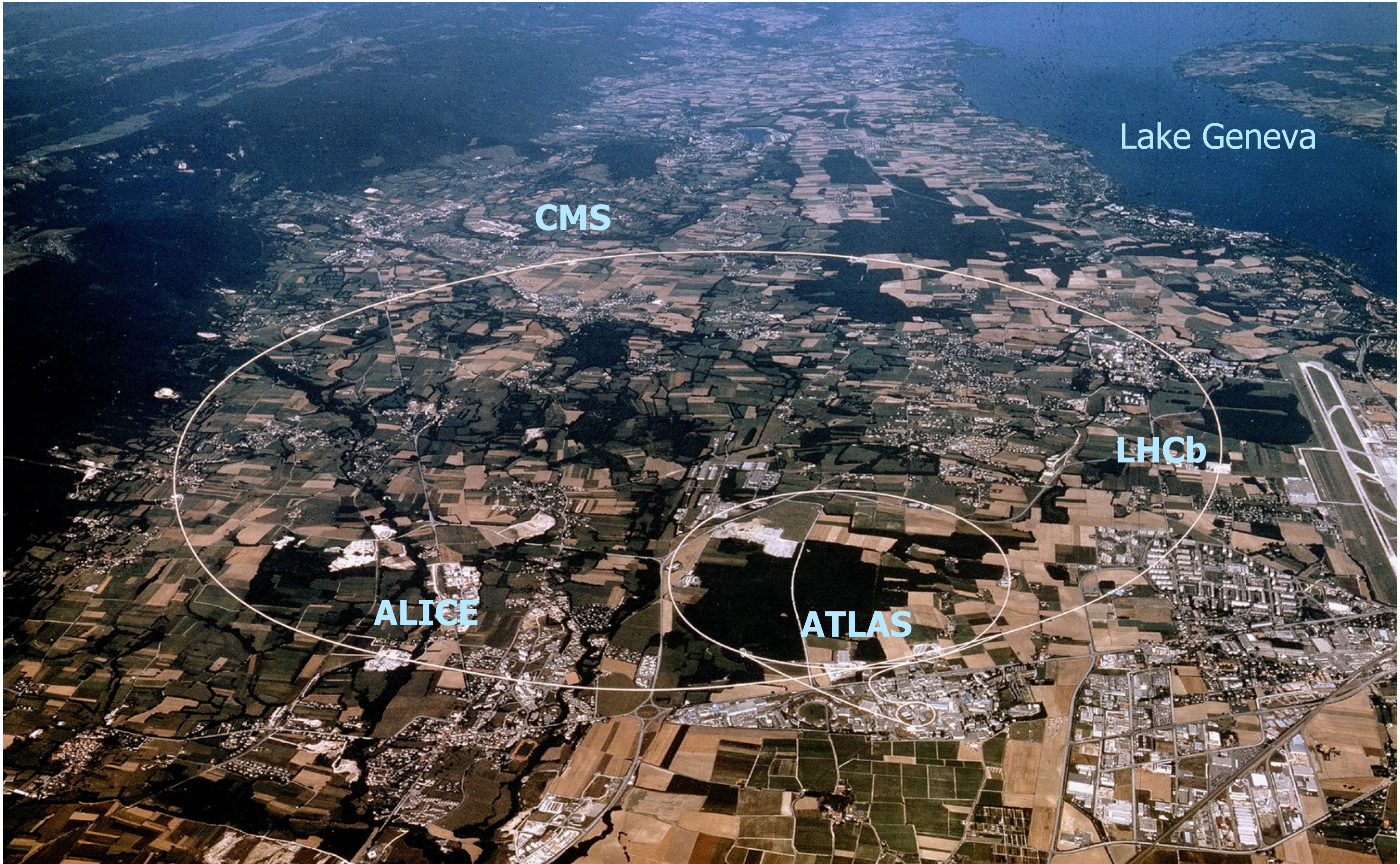
Prague, 21 july 2008

Andrea Giammanco
CP3 / UCL & FNRS, Louvain-la-Neuve, Belgium

Outline

- **Part I: LHC startup**
- **Part II: CMS commissioning**
- **Part III: prospects for physics with first data**
  - “rediscovering” the Standard Model
  - the very first searches

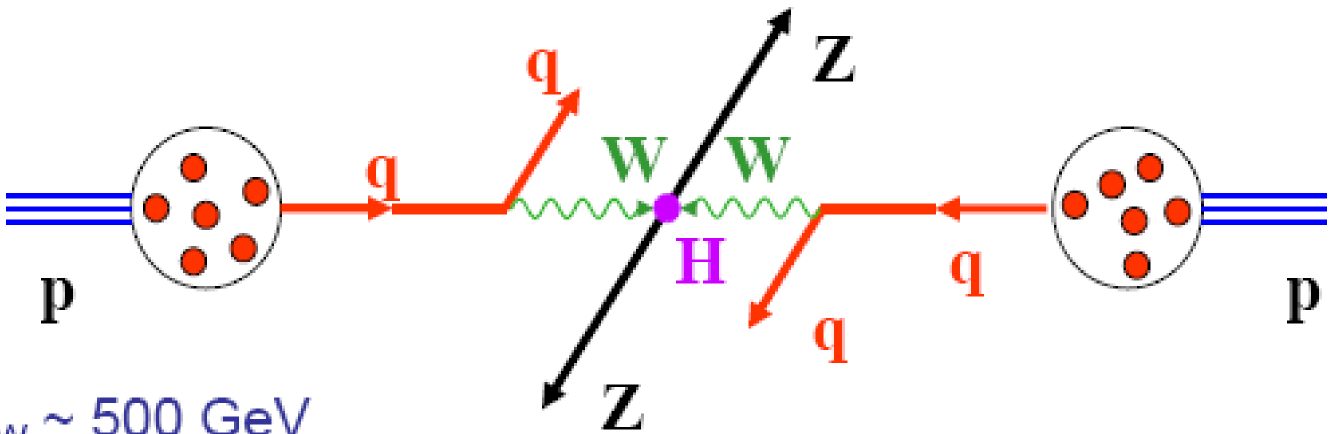
The Large Hadron Collider



Nominal settings for *pp* runs

- **7 + 7 TeV beams**
  - 1232 superconducting magnets, B = 8.4 T
- Collision rate: 40 MHz
- 1.15 x 10^{11} particles per beam
- **L = 10^{34} cm^{-2}s^{-1}**
  - “Low-lumi phase”: **L = 2x10^{33} cm^{-2}s^{-1}** for the first ~30/fb; 10/fb accumulated per year
    - Most Physics TDR studies were in this scenario
  - Pile-up: ~5 pp collisions per bunch crossing in the “low-lumi phase”, ~25 in the “high-lumi phase”

The rationale behind these numbers

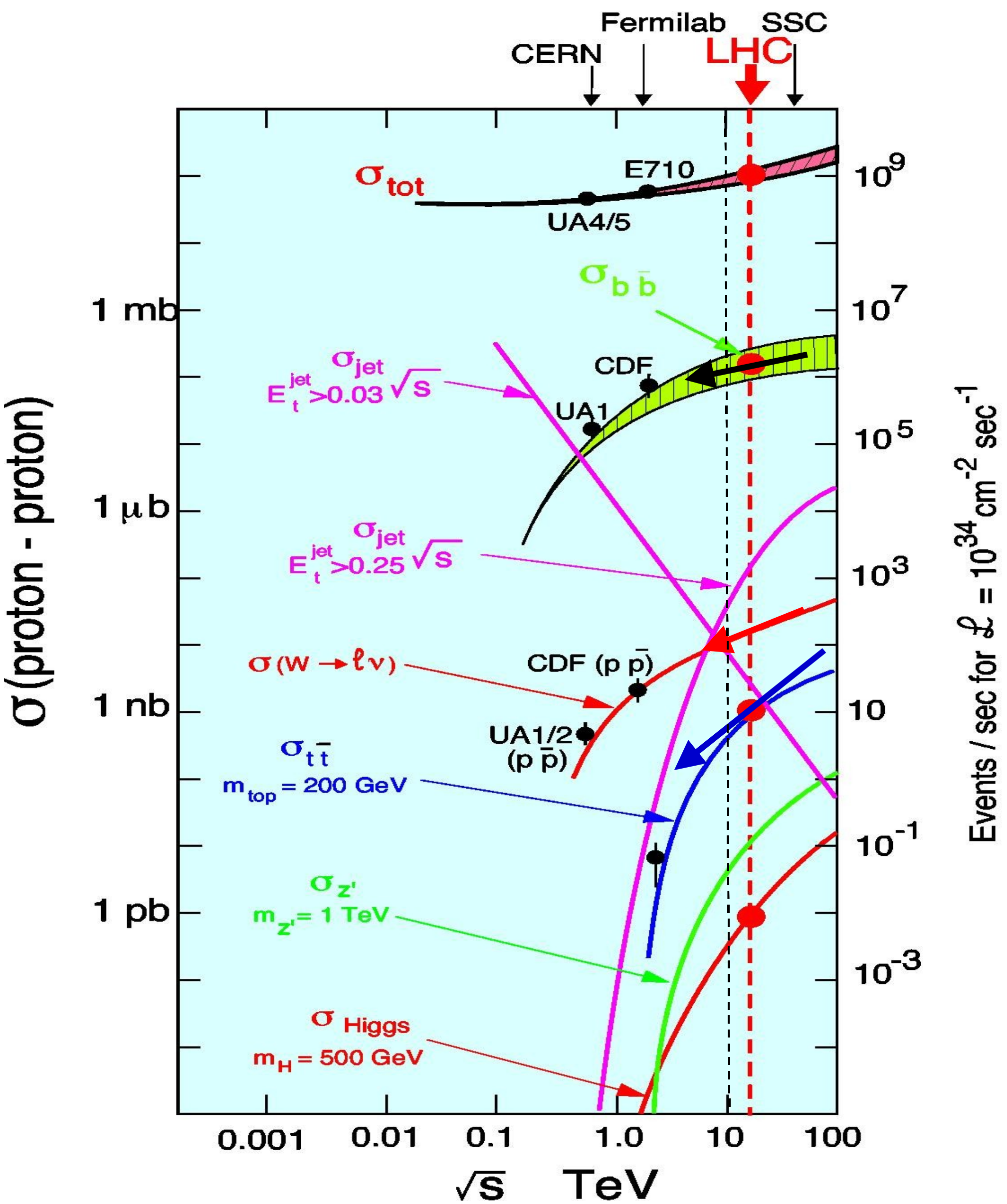


⇨ E_W ~ 500 GeV
⇨ E_{quark} ~ 1 TeV
⇨ E_{proton} ~ 6 TeV

Event Rate = L.σ.BR
e.g. H(1 TeV) → ZZ → 2e+2μ o 4e o 4μ
Per L ~10^{34} , Evts/yr = **10^{34}** $10^{-37}.10^{-3}.10^{7}$ ~ 10 /yr

- LHC can falsify the SM by excluding the Higgs for M_H<1 TeV
  - With M_H>1 TeV, it would have strong dynamics

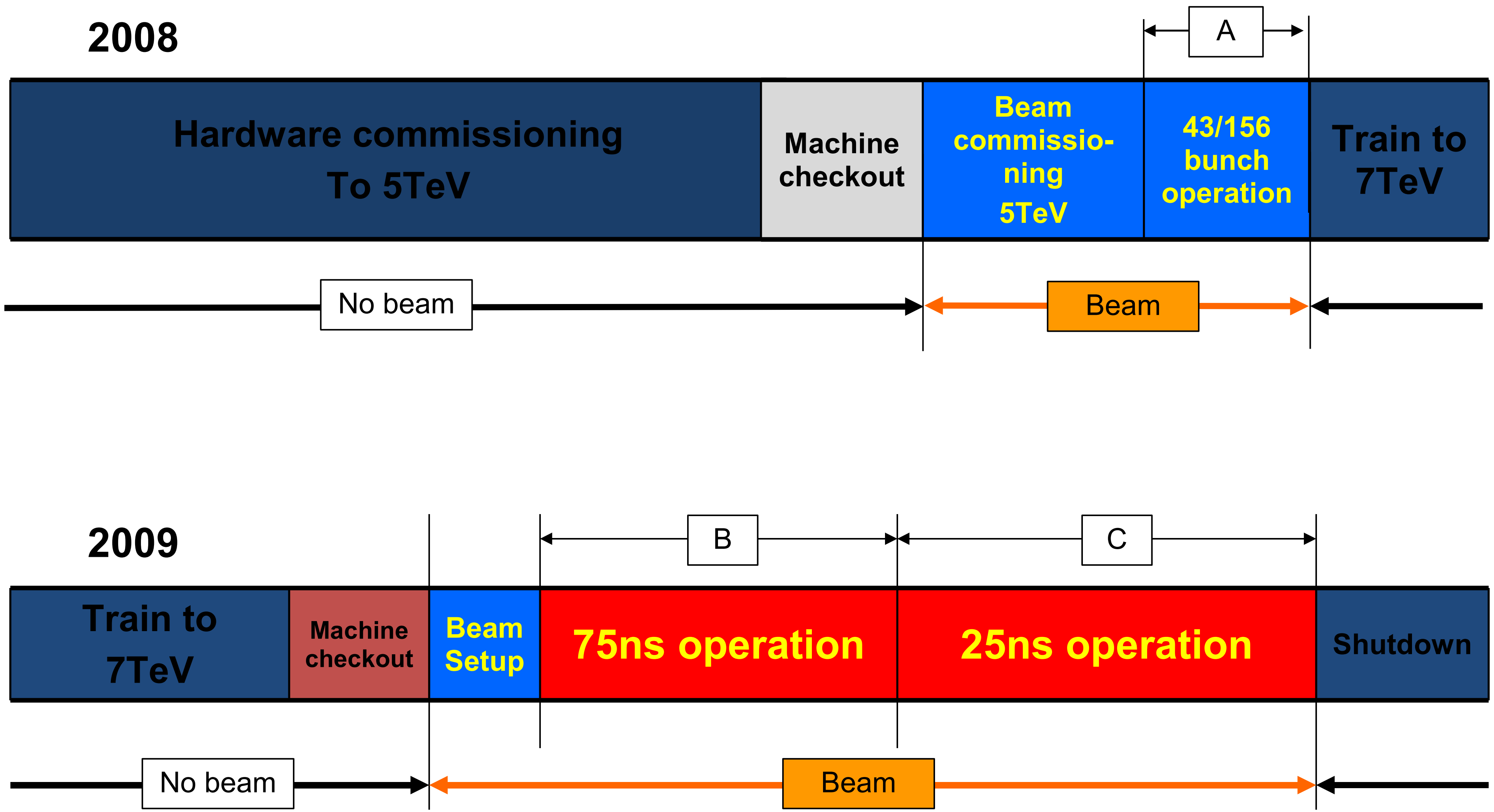
2008: expect to run at 10 TeV



	10 TeV σ_{LO}MadGraph	14 TeV σ_{LO}MadGraph
Top pairs	**317 pb**	**750 pb**
W+jets	**40 nb**	**61 nb**

- Lower reach for searches:
  - Higgs(200 GeV) reduced to ~50%
  - Z'(2 TeV) to ~30%
  - sensitivity to new physics reduced by one order of magnitude for scales >4 TeV
- Almost universal rule: bkg scales less than signal
  - (whatever you call “signal”)

LHC in 2008 and 2009

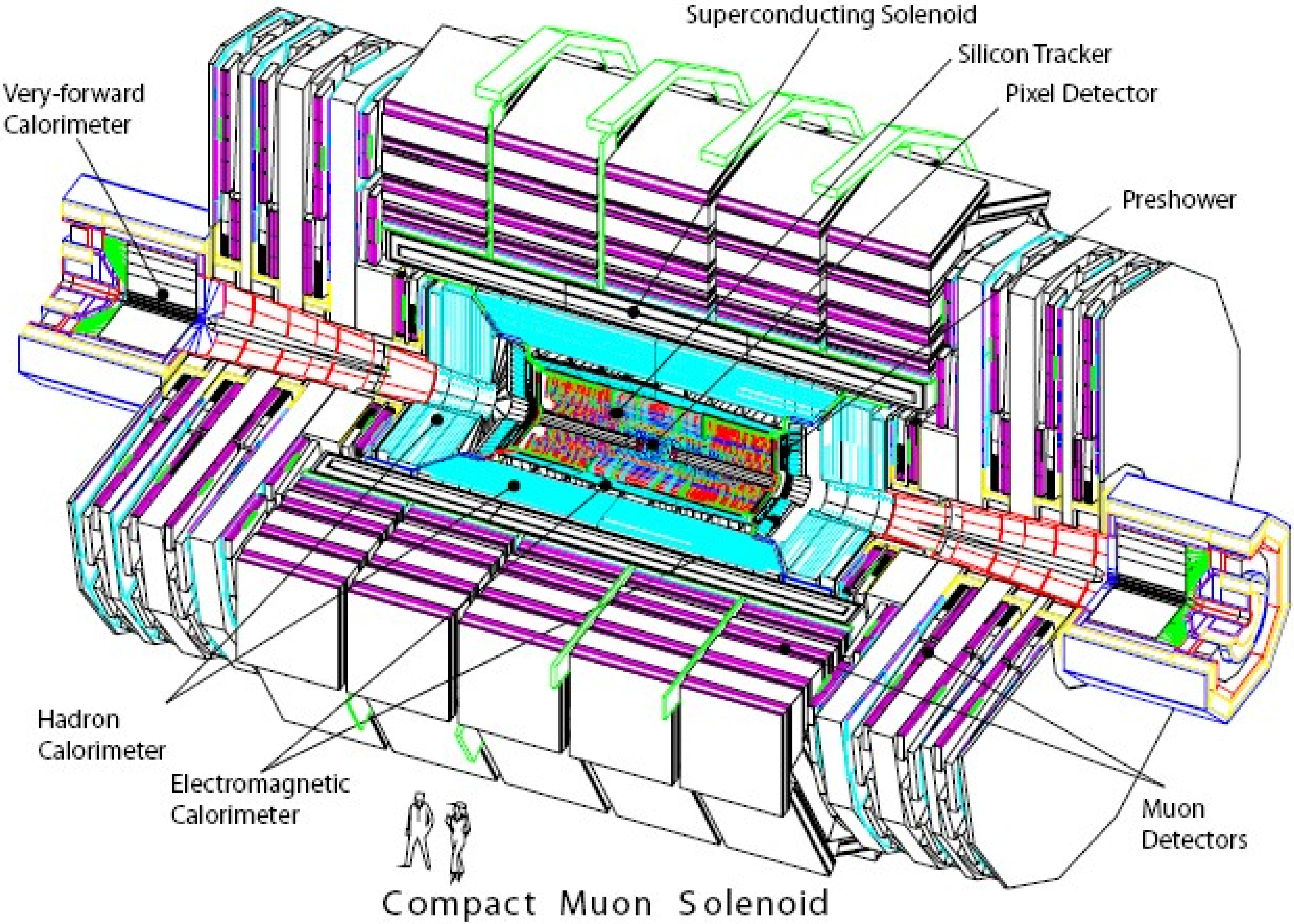


R. Bailey

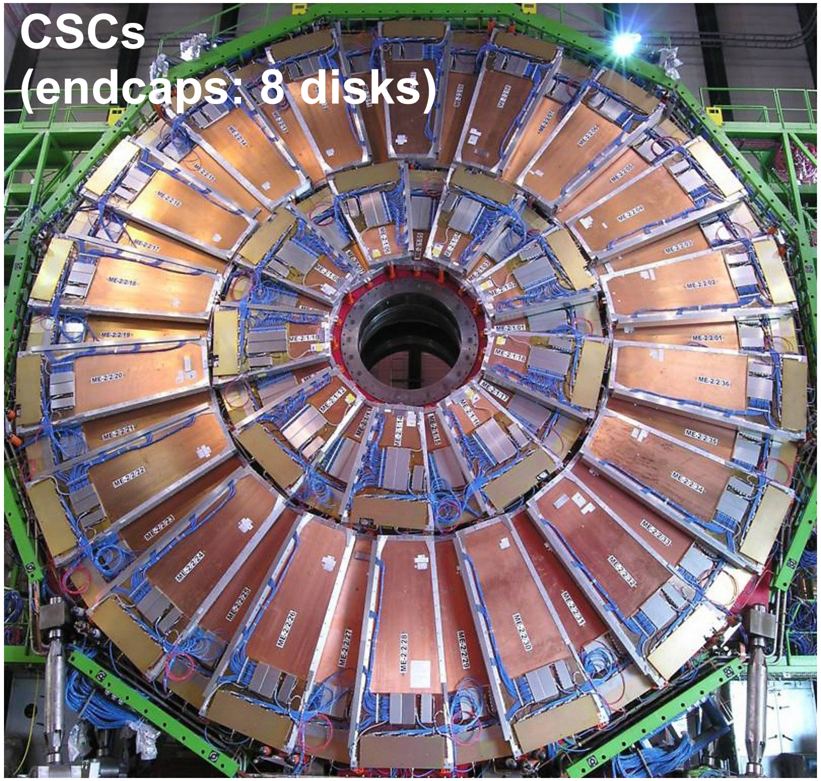
Month	Phase	Days physics	Efficiency factor	Peak luminosity	Delivered luminosity
Jan	Cooldown and Hardware Commissioning and Machine checkout				
Feb					
Mar					
Apr					
May					
June					
Jul					
Aug	Beam Commissioning				
Sep					
Oct	Physics run				
Nov		40	0.1	$5\ 10^{31}$	20 pb^{-1}
Dec	Shutdown				
Jan					
Feb					
Mar	Machine checkout				
Apr	75ns Commissioning				
May	Physics run	150	0.2	10^{33}	2.5 fb^{-1}
June					
Jul					
Aug					
Sep					
Oct					
Nov					
Dec					

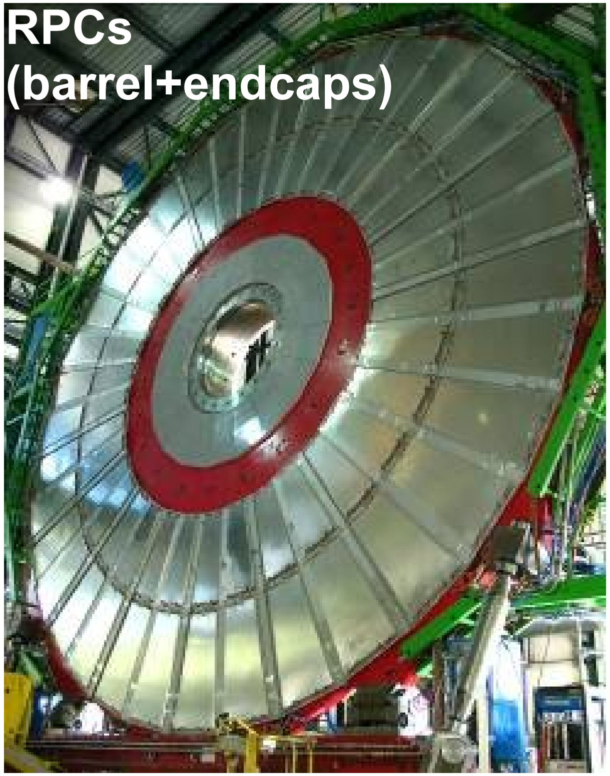
R. Bailey

The CMS detector



Muon Chambers

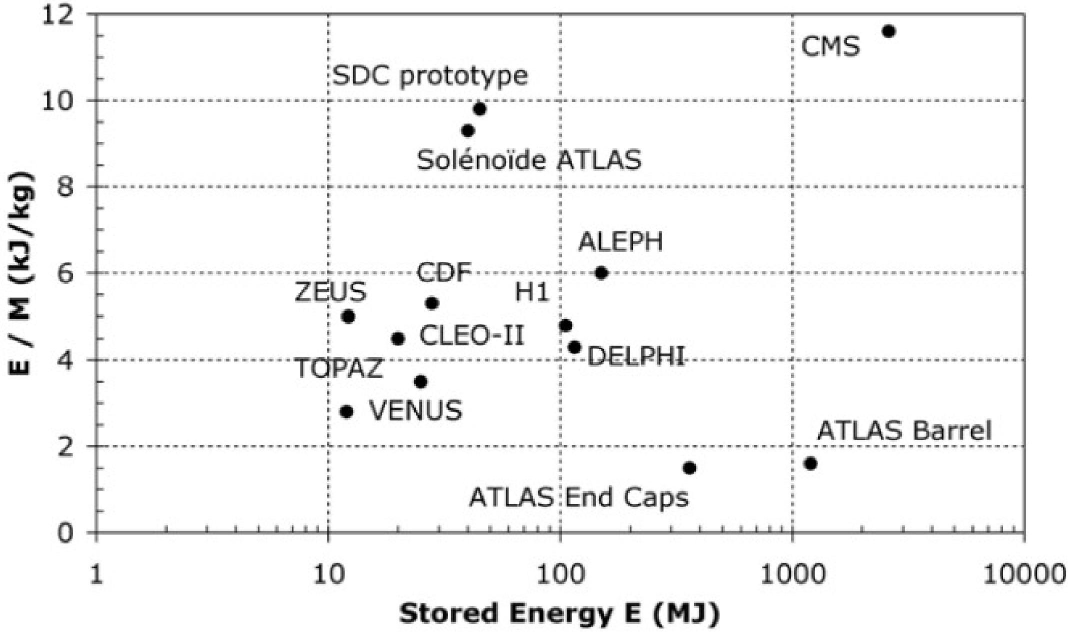


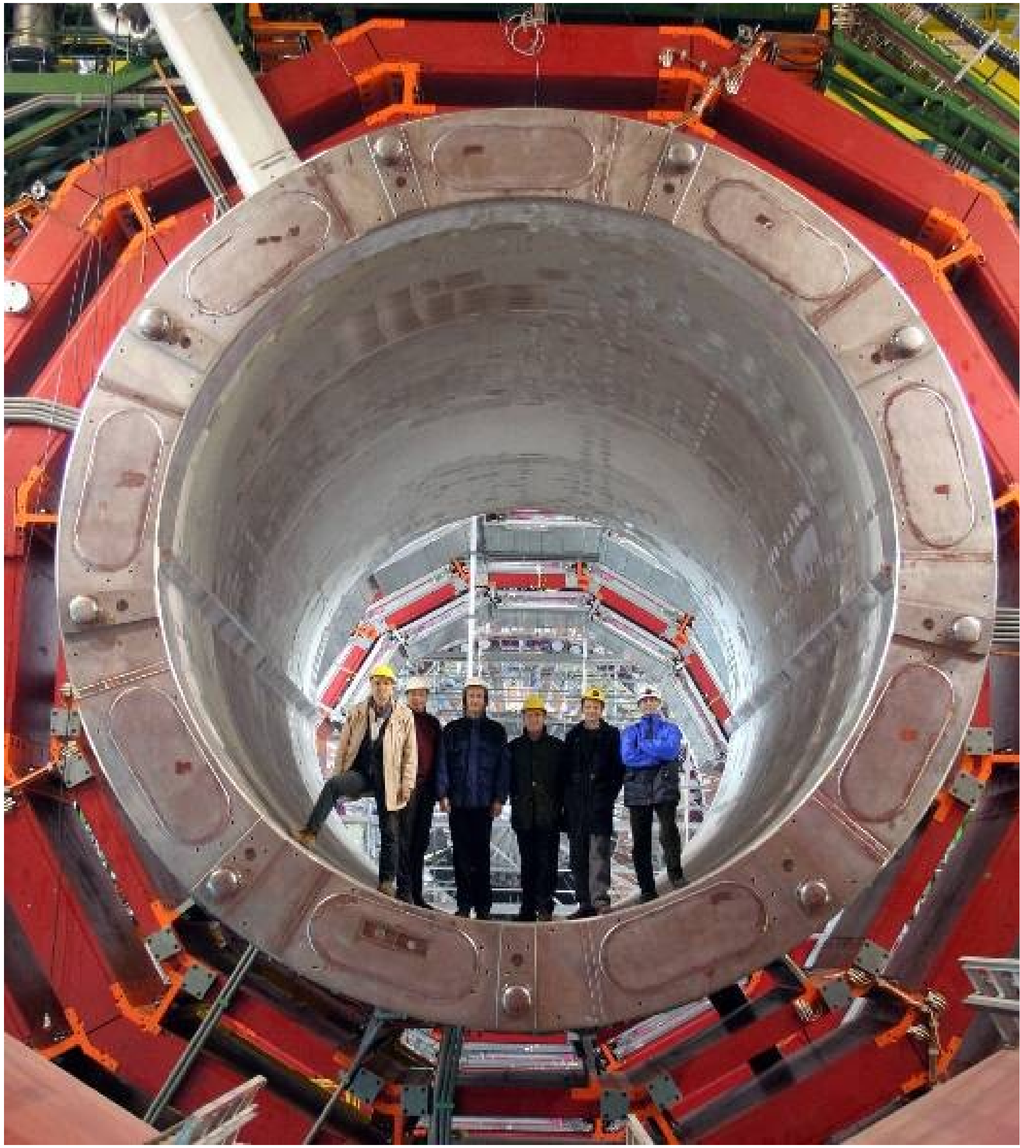


- **Barrel ($|\eta|<1.2$): Drift Tubes, $\sigma_x \sim 200\ \mu m$/layer**
- **Endcap ($|\eta|<2.4$): Cathode Strip Chambers, $\sigma_x \sim 100\text{-}240\ \mu m$/layer**
- **Barrel+Endcap: Resistive Plate Chambers, $\sigma_t \sim 2$ ns**

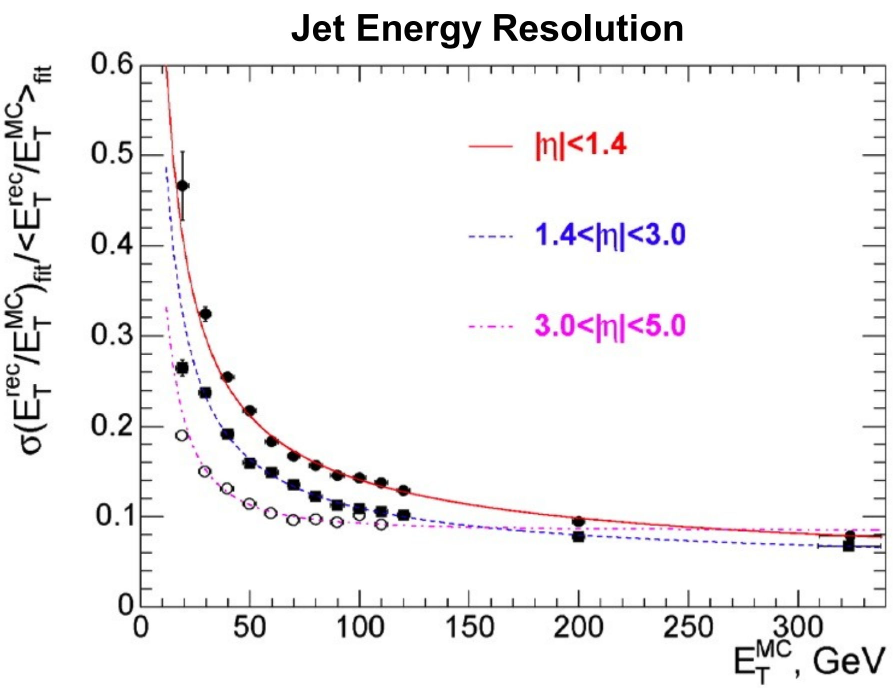
Superconducting Solenoid

- Length 13 m, diameter 6 m
- 4 Tesla





Hadronic Calorimeter (HCAL)



$\sigma(E)/E = 120\%/\sqrt{E} \oplus 5\%$

Inside the magnet: this imposes a compromise on resolution.
Main features: **~10** interaction lengths; **hermeticity**

Central Hadronic |η| < 1.7 :

Cu(70%)+Zn(30%)/scintillator+WLS

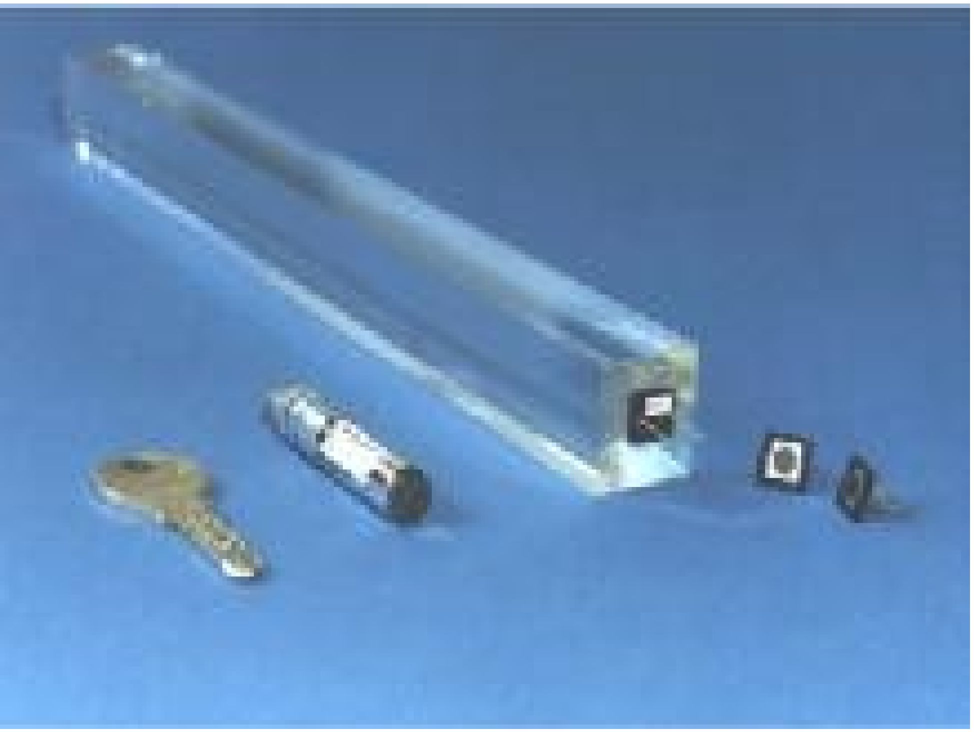
Endcap Hadronic 1.3< |η| < 3 :

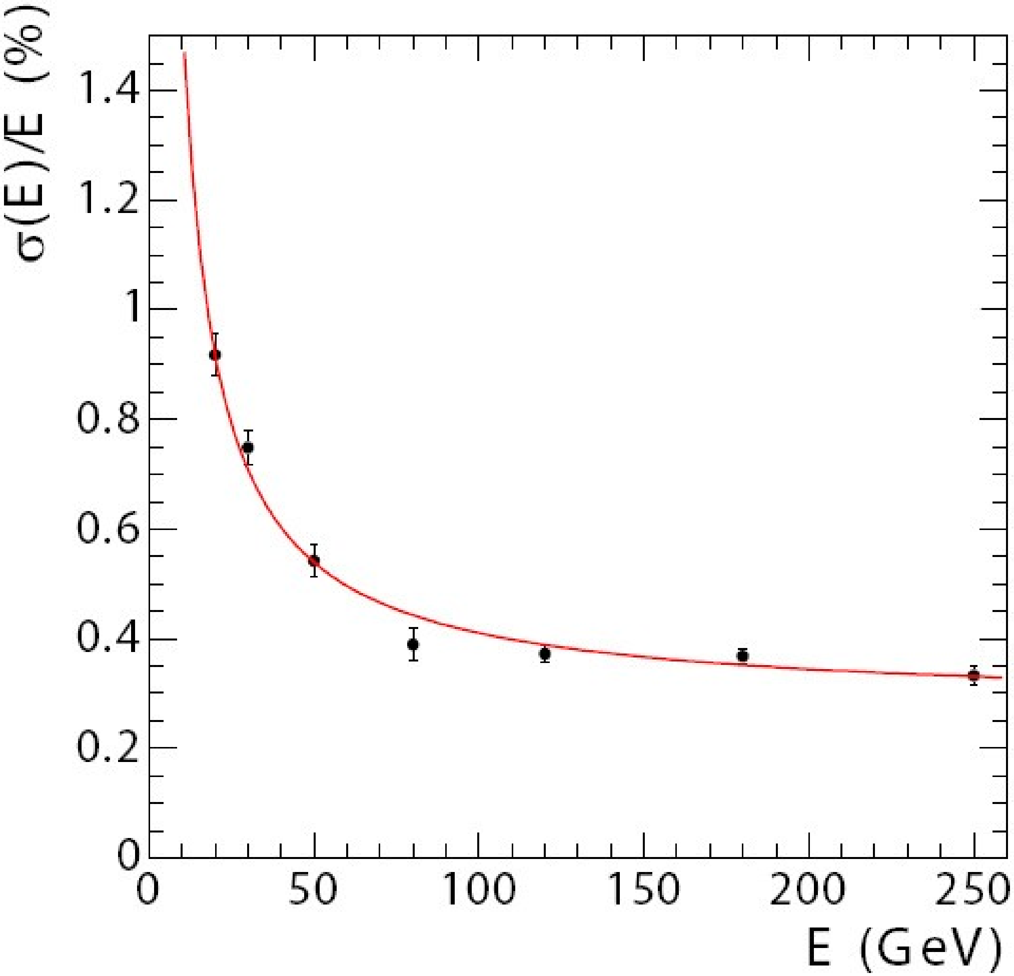
Cu(70%)+Zn(30%)/scintillator+WLS

Forward calorimeter 2.85 < η < 5.19:

Iron/quartz

Electromagnetic Calorimeter (ECAL)





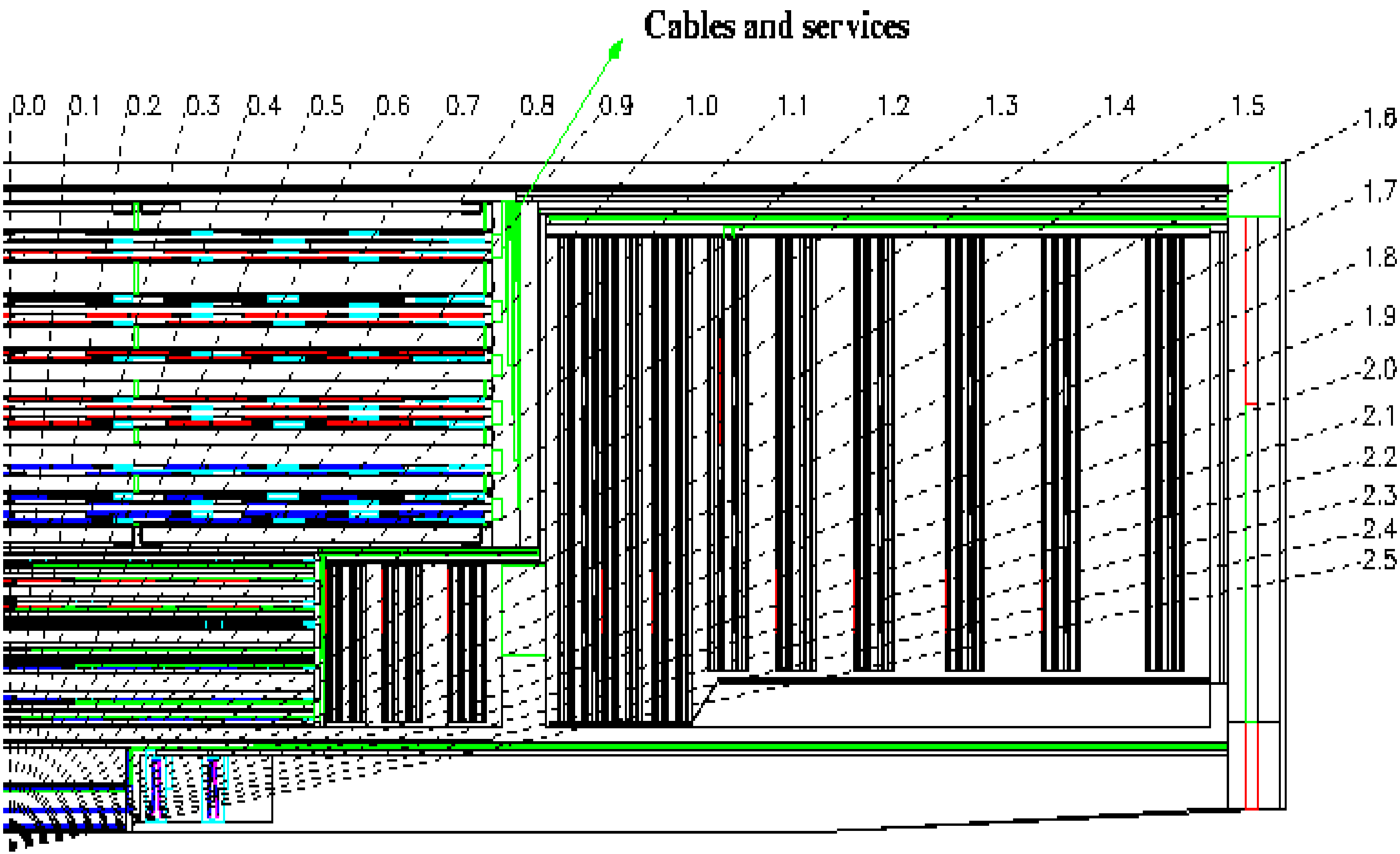
$PbWO_4$ crystals, 32x32 mm^2

61000 barrel, 15000 endcap

More crystal (in volume and number) than any HEP experiment so far

$\sigma(E)/E = 2.7\%/\sqrt{E} \oplus 0.5\%$

Tracker

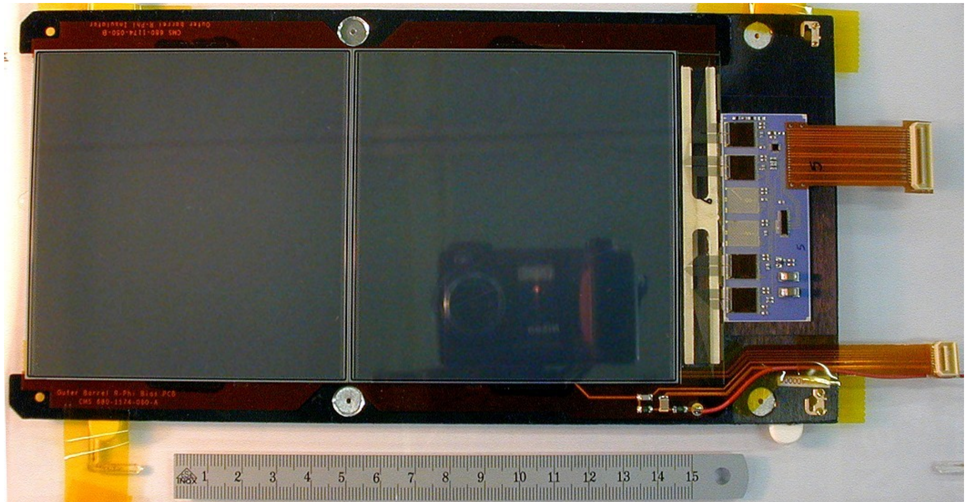


200 m^2 of Silicon

More than all HEP experiments so far

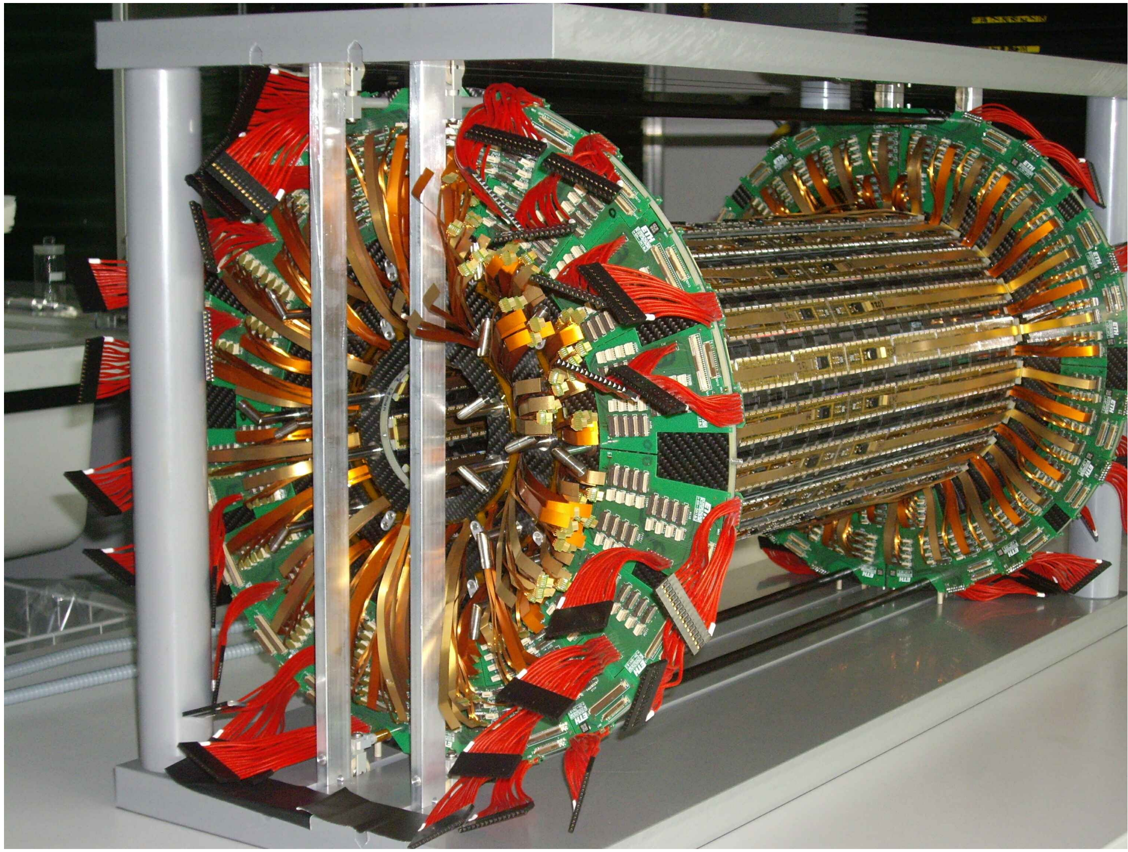
Silicon Strip Tracker (SST)

- Length 6m, diameter 2.2m
- Single- and double-sided modules (24k in total)
  - width/pitch = 0.25
  - Pitches range from 80 to 205 μm
  - Thicknesses: 320 / 500 μm
- Hit resolutions from 20 to 60 μm for high-p_T tracks
- 11M channels
  - cf. CDF <1M

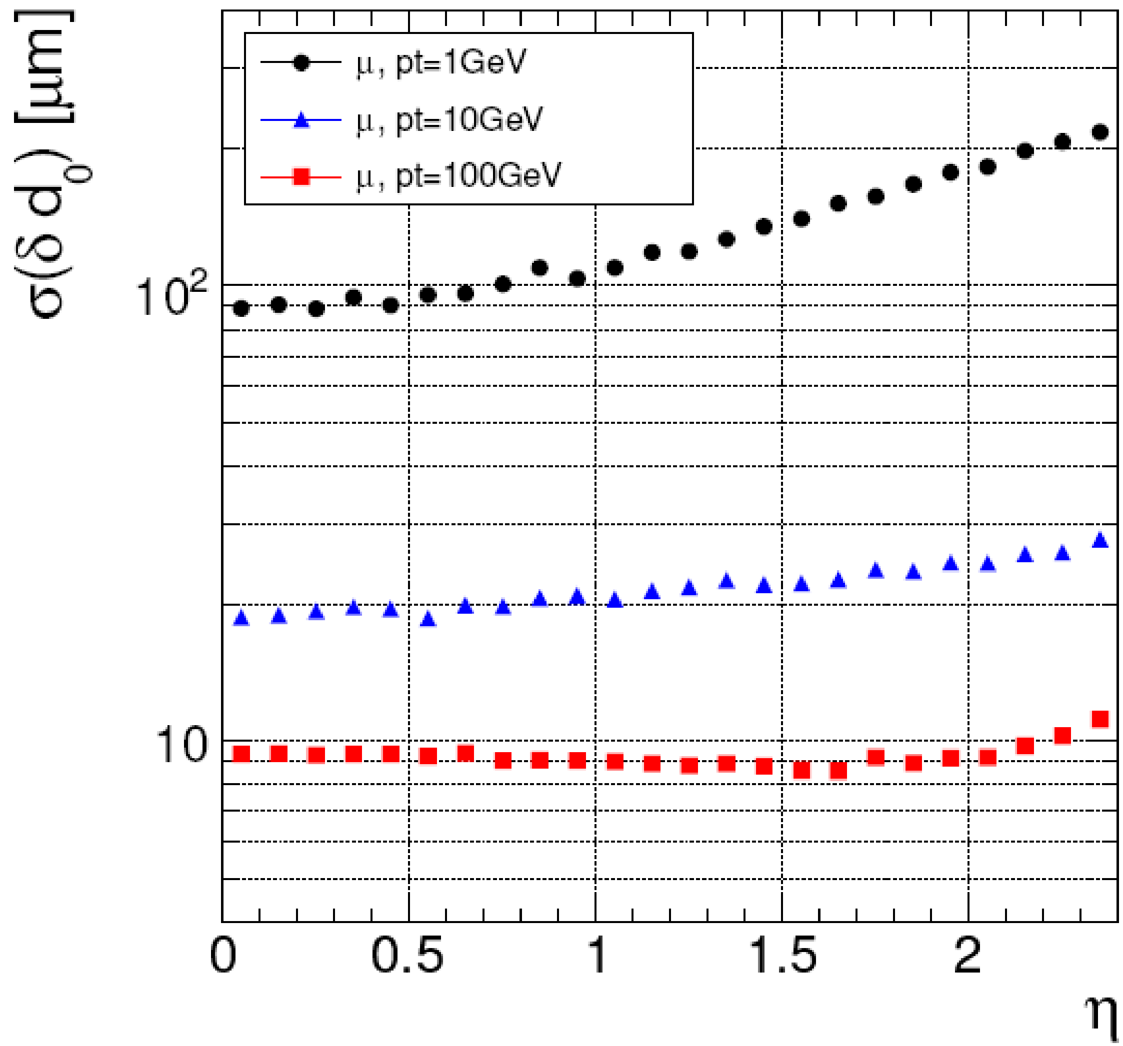


Pixel Tracker

- Essential device for vertexing and b-tagging
  - Pixel cell size: 100x150 μm^2
  - 3 barrel layers, at 4-7-10 cm from the beam axis
  - 4 endcap disks cover a radius from 6 to 15 cm
- Hit resolutions range from 10 to 20 μm
- 66M channels

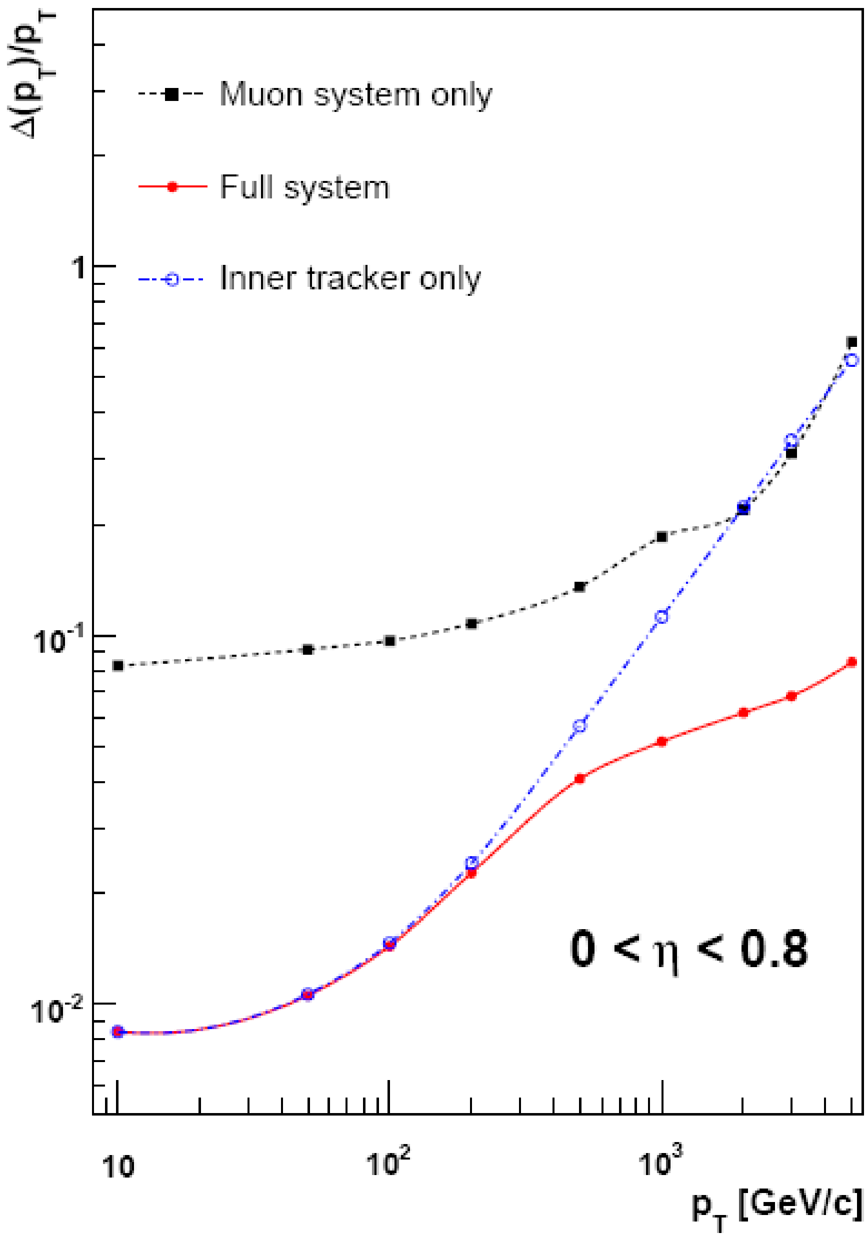


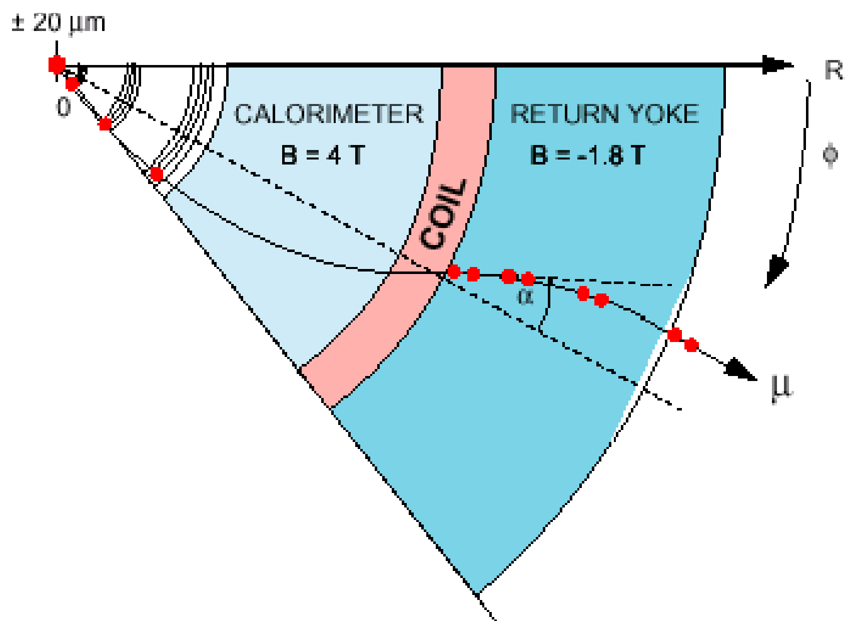
Whole Tracker (SST+PB): impact parameter resolution



Impact parameter resolution < 30 μm @ P_T>10 GeV

Tracker + Muon Chambers: transverse momentum

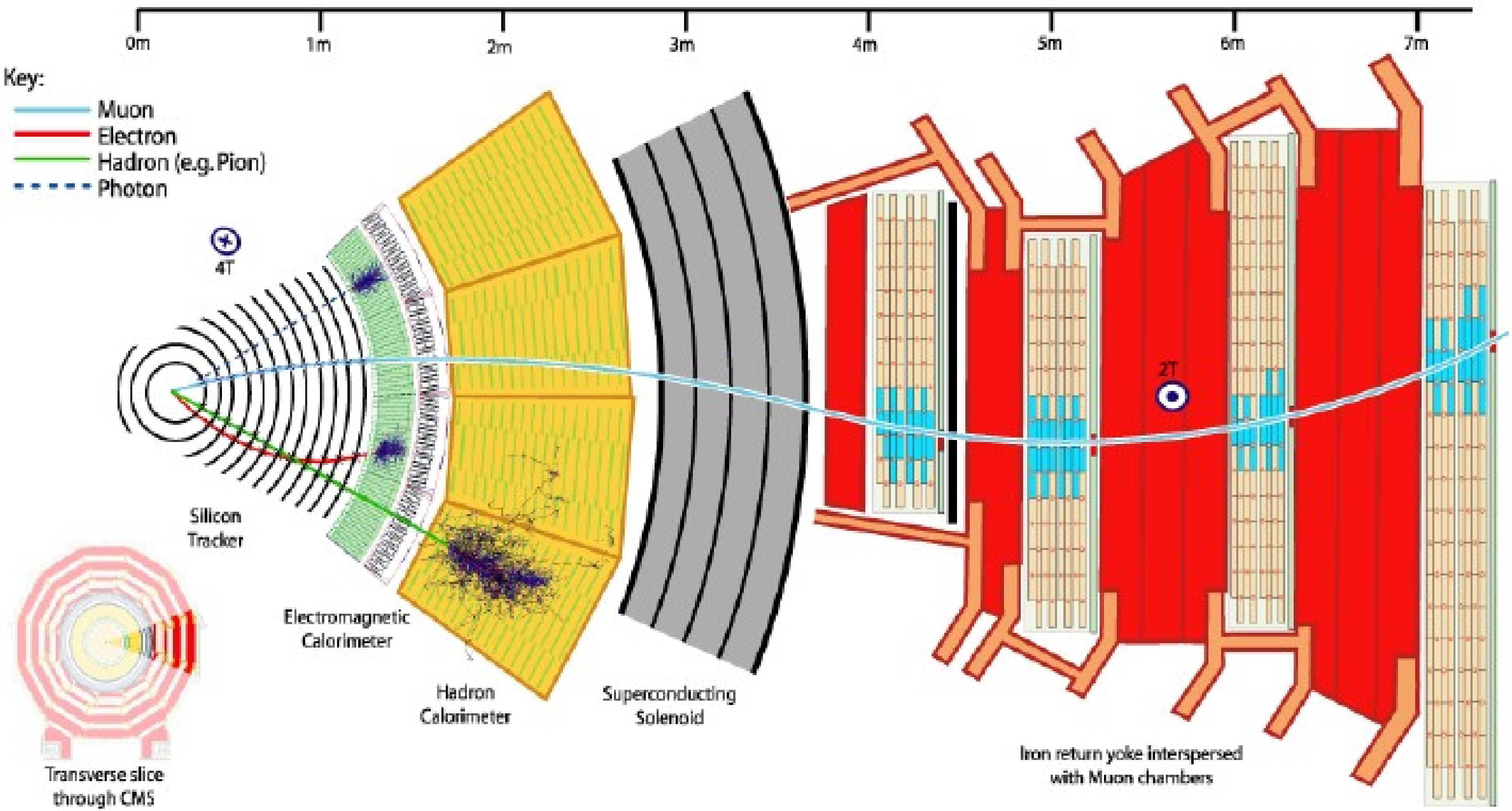




For p_T<200 GeV, precision is dominated by Tracker

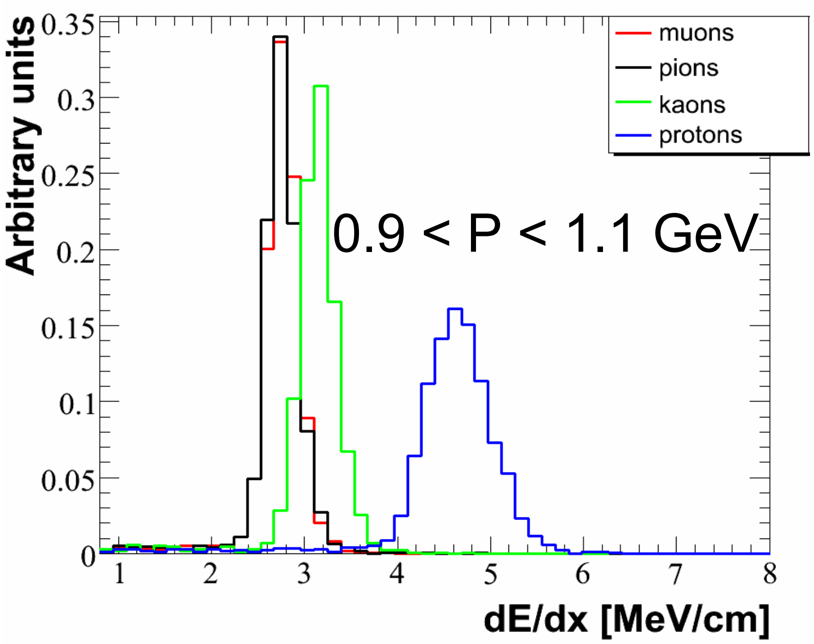
($\Delta p_T/p_T \sim O(\%)$ @ $p_T \sim 20$ GeV)

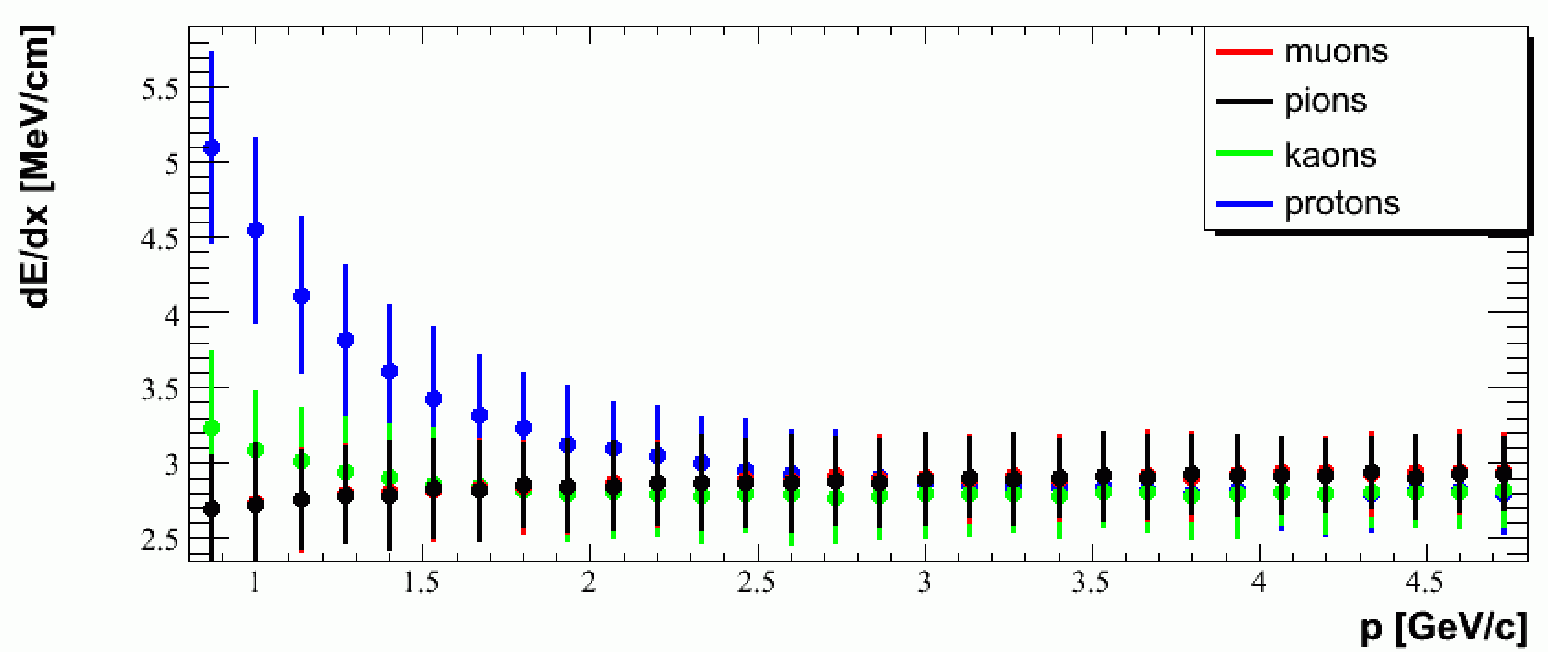
Particle-Id in CMS



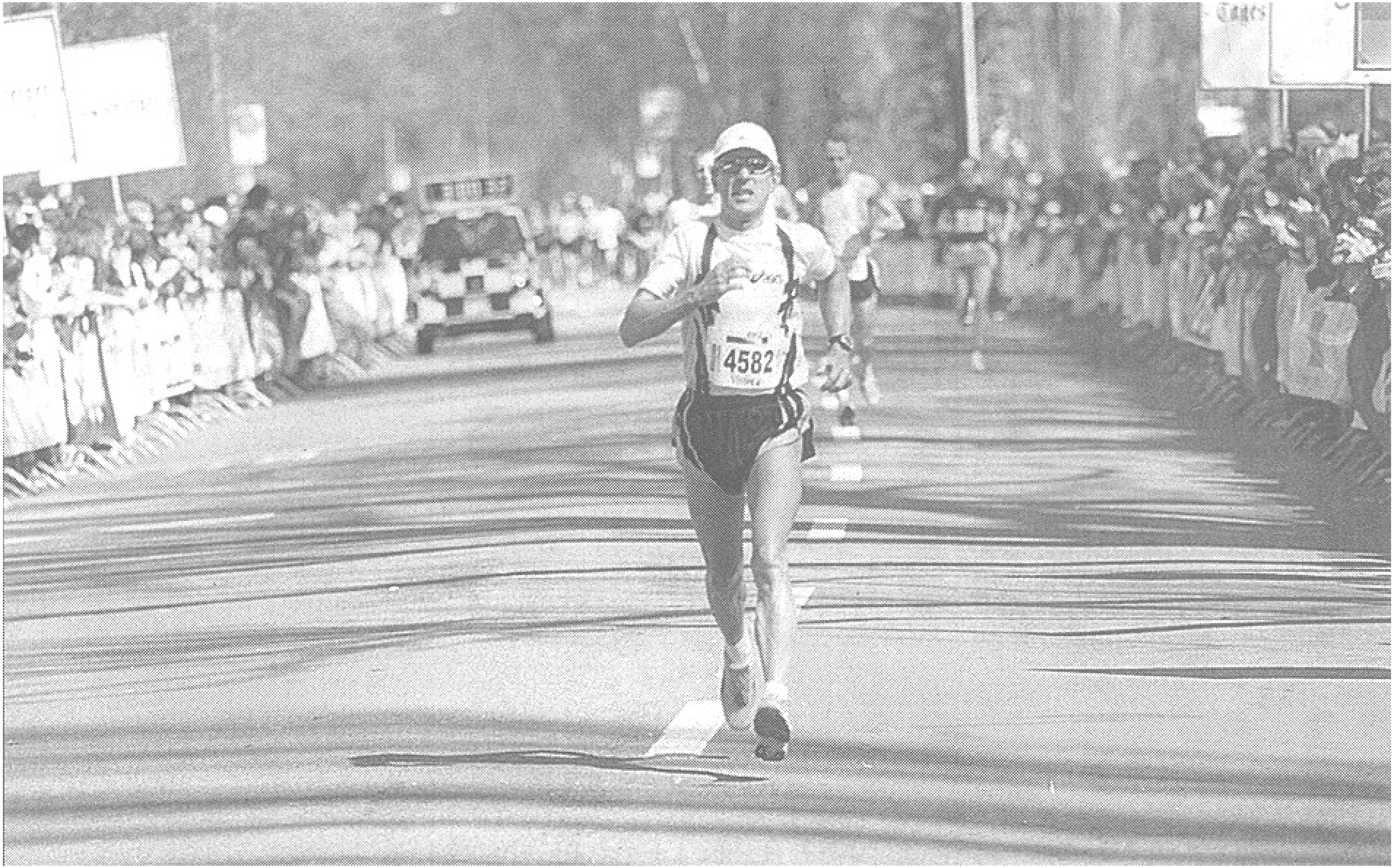
Some more Particle-Id

- Tracker was never designed for dE/dx
- Nevertheless, it can do that too
- A track typically traverses 3 pixel layers and more than 10 modules in SST
- Here shown for SST only, possible even with pixels only
- Not useful for high-P standard particles
- Useful for soft QCD studies, and exotic searches; I will give details later



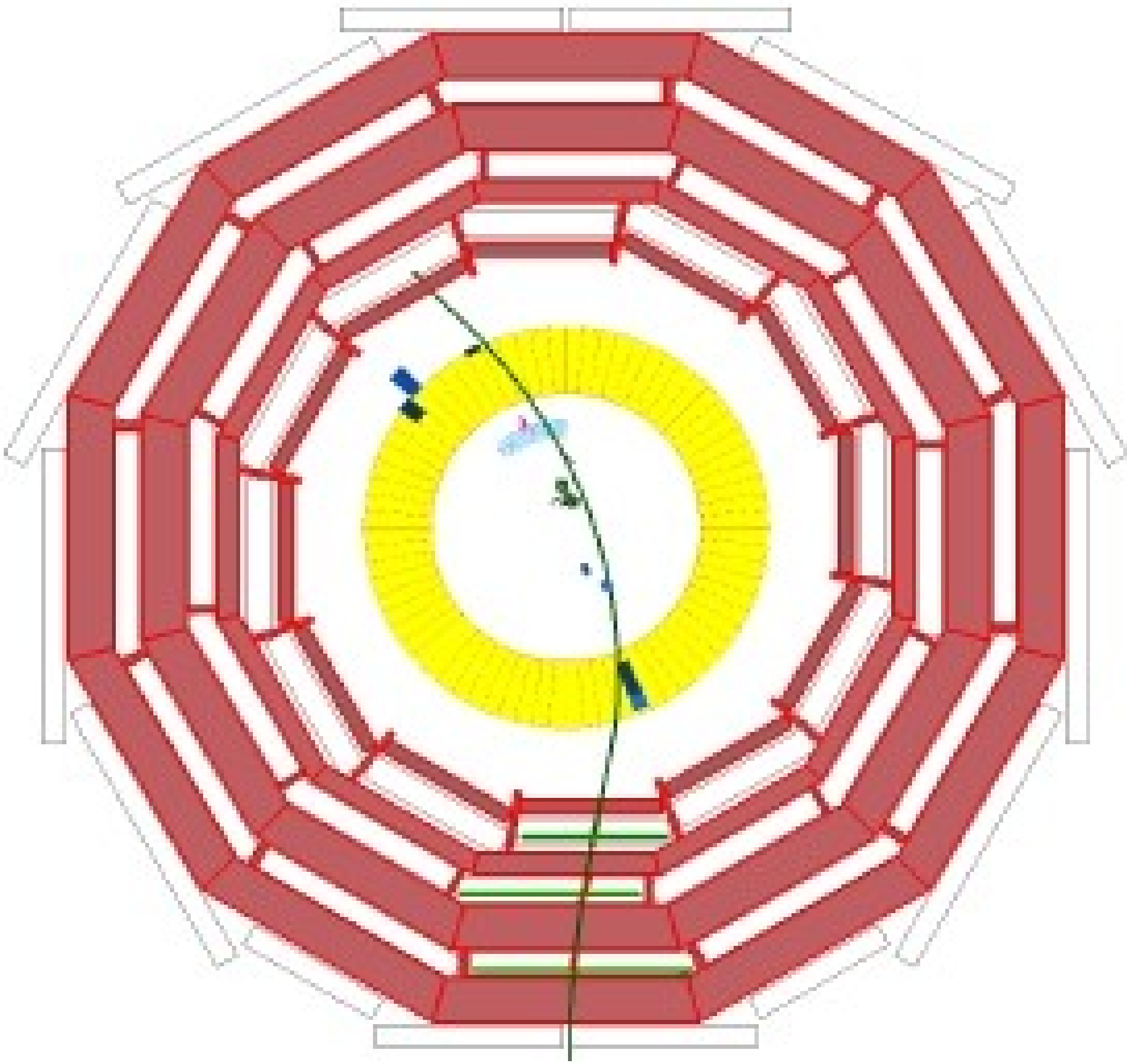


Getting ready with CMS...

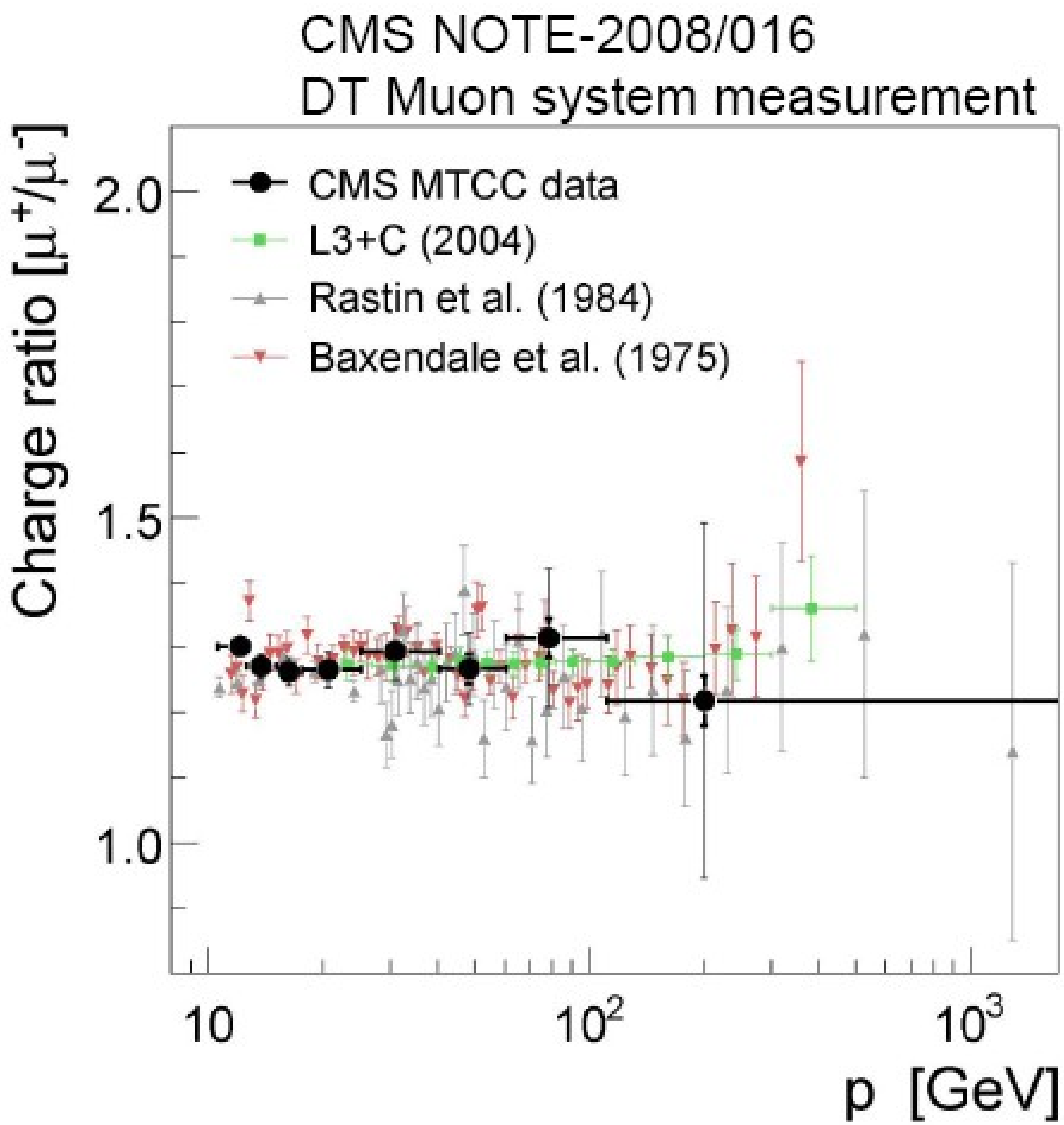


...the end of a long marathon

MTCC (2006)
(Magnet Test / Cosmic Challenge)



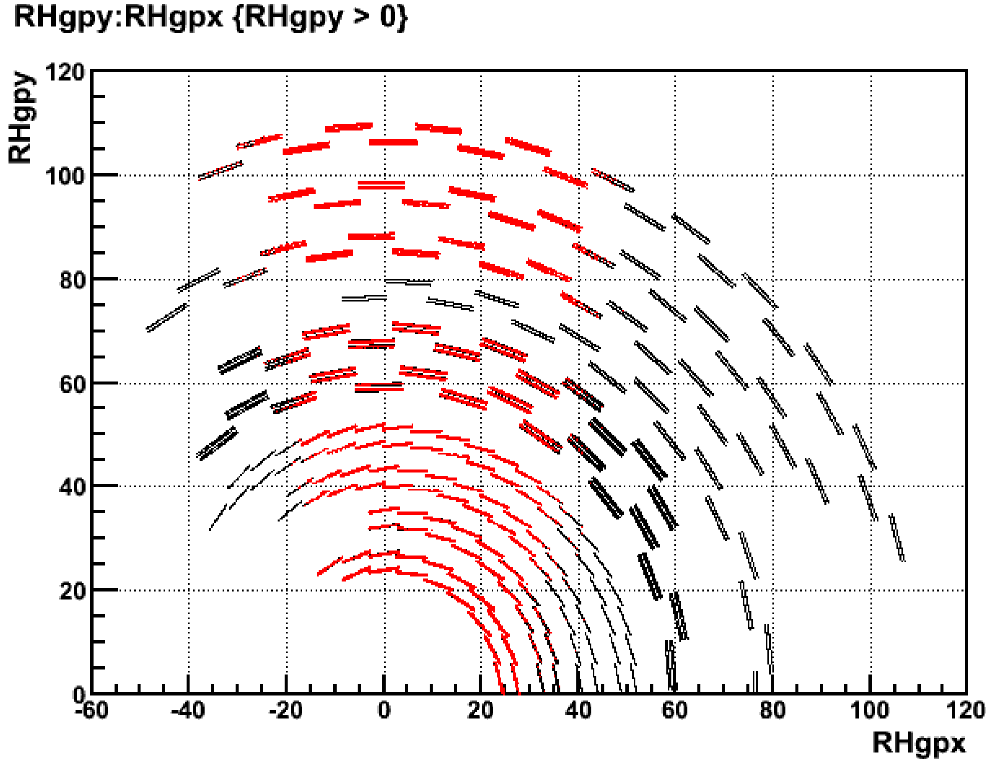
- A **test of the solenoid** (smooth operation up to 4T) plus use of cosmics for **detector commissioning**
- Phase I: combined DAQ (Tracker + ECAL + HCAL + Muon chambers)
- Phase II: mapping of the field (no Tracker/ECAL), cosmics in muon chambers only

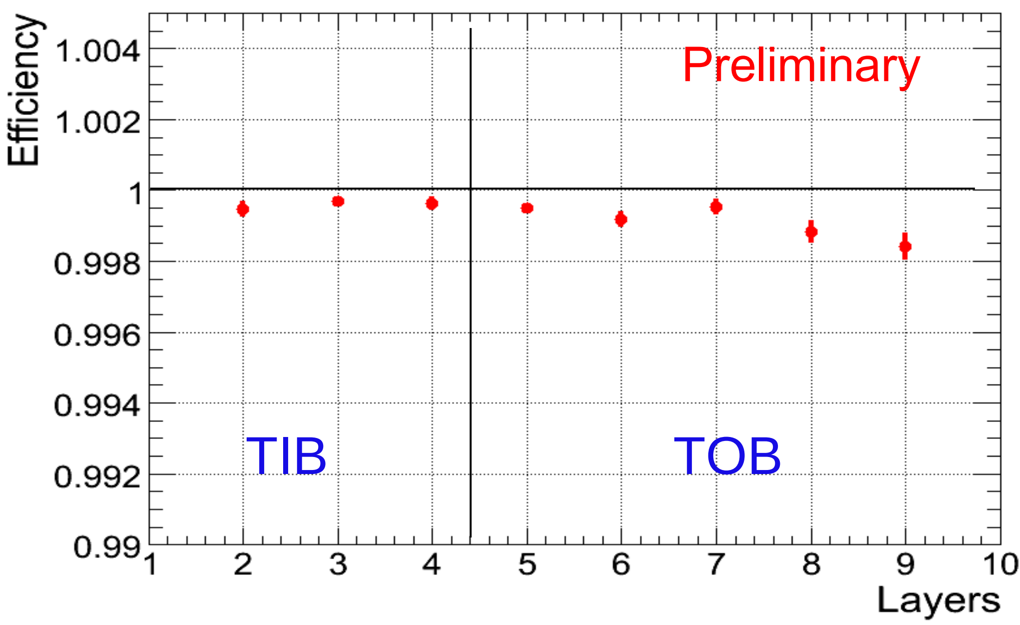


The first physics paper of CMS!

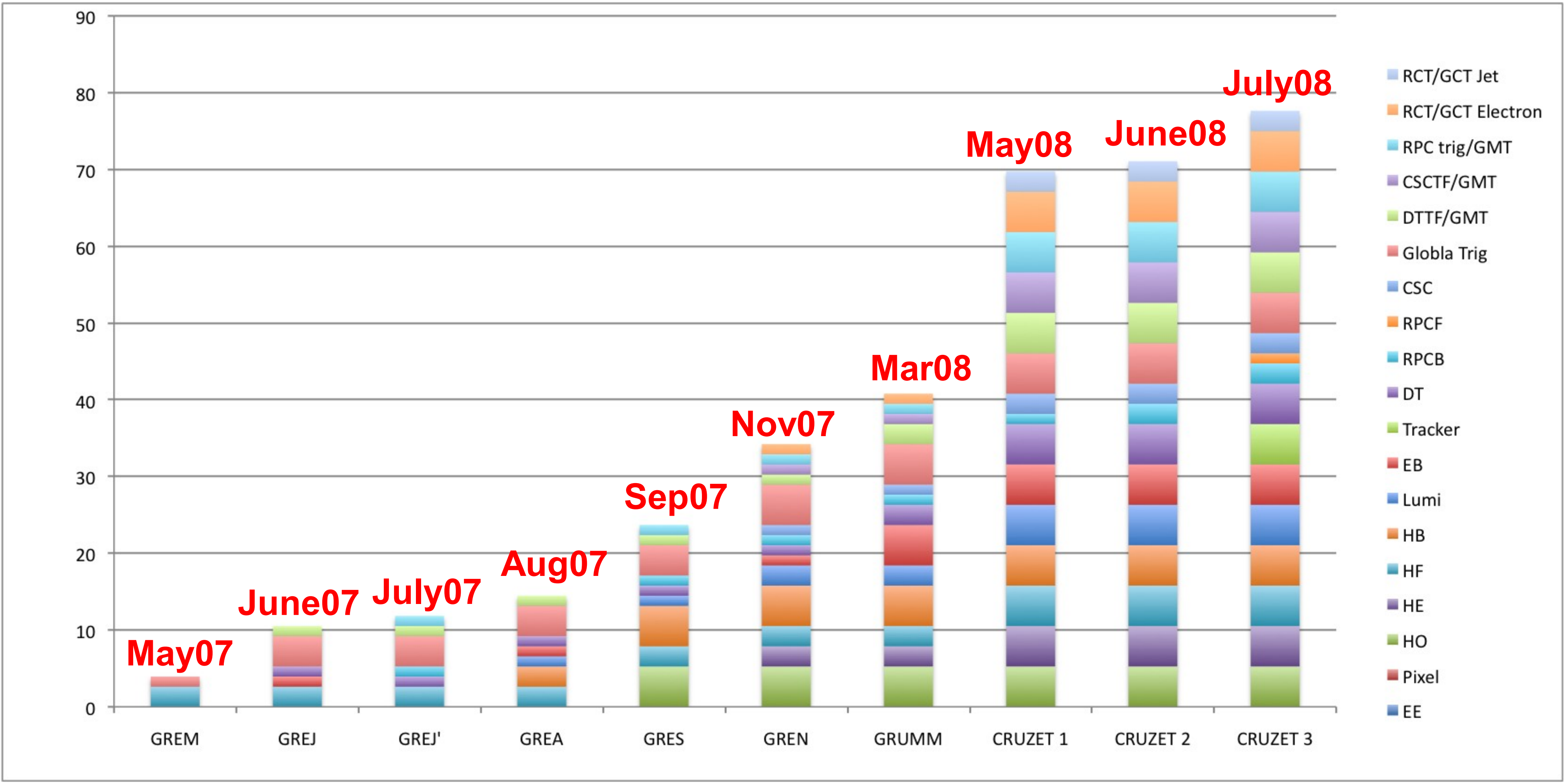
SST Slice Test (2007)

- ~20% of the Silicon Strip Tracker instrumented and read out
- Trigger from dedicated scintillators
- Several useful measurements: alignment, gain calibration, Lorentz angle, cross-talk, module efficiency, ...
- Big step forward in MC tuning



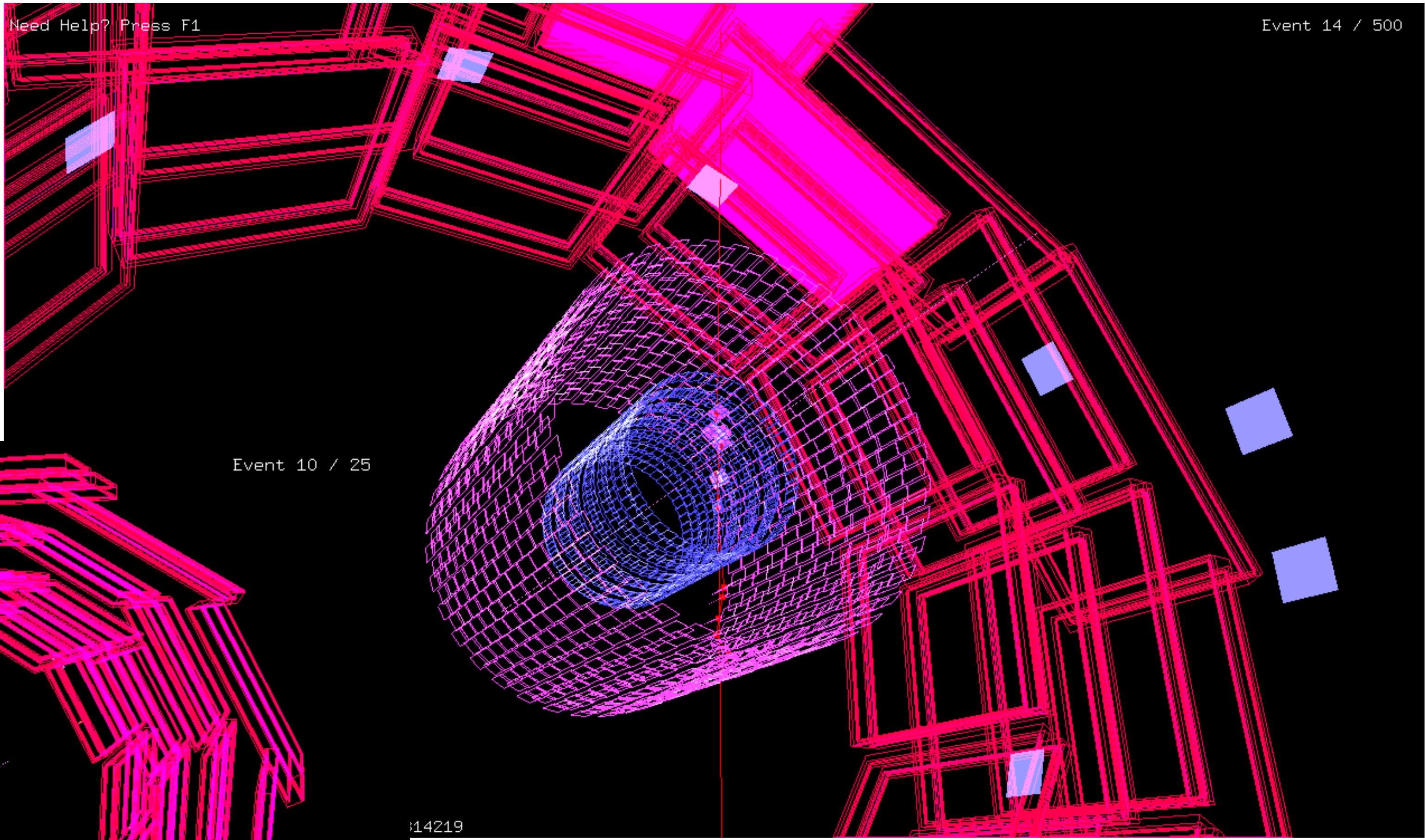


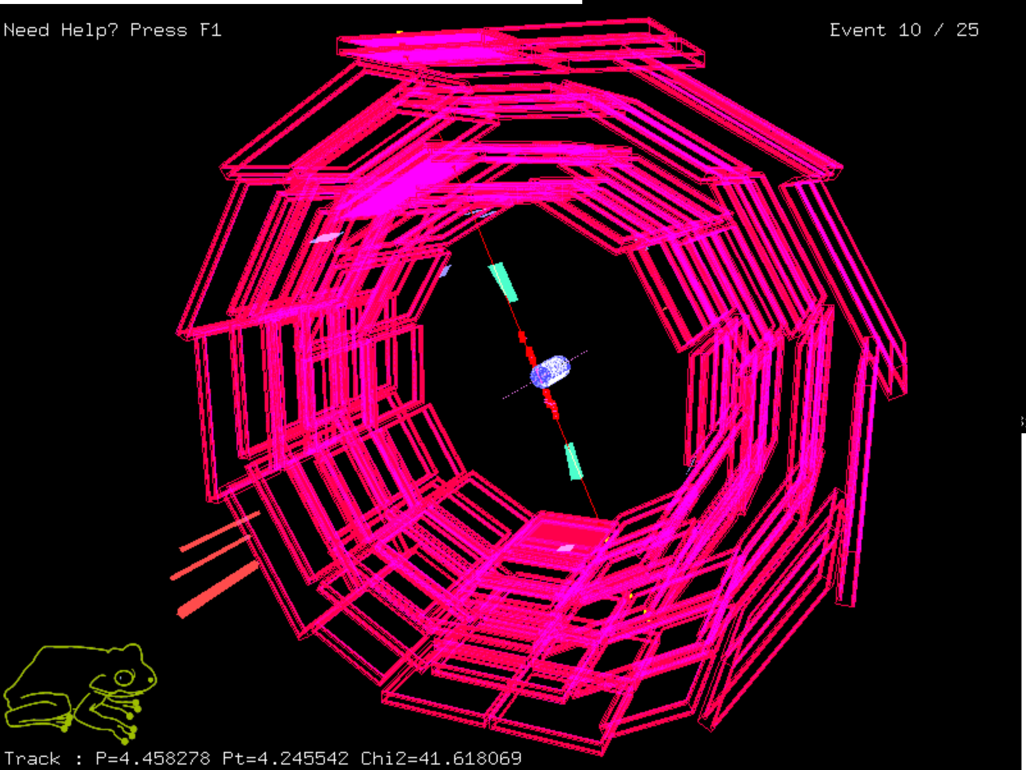
Global Runs 2007-2008
subdetectors participating



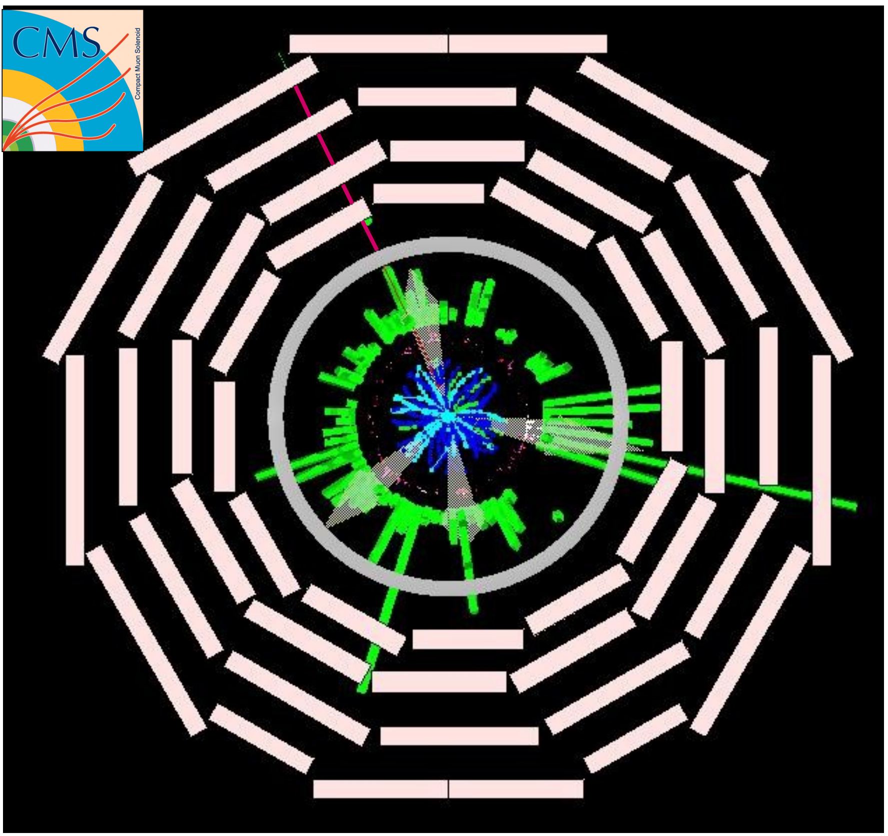
Subsystems -detector and trigger separately- are added as they came in; size of the box represents which fraction was included (0, 25%,50%,75%, 100%)

CRUZET3, july 2008
(CRUZET: Cosmic RUn at ZEro Tesla)





Prospects for CMS physics

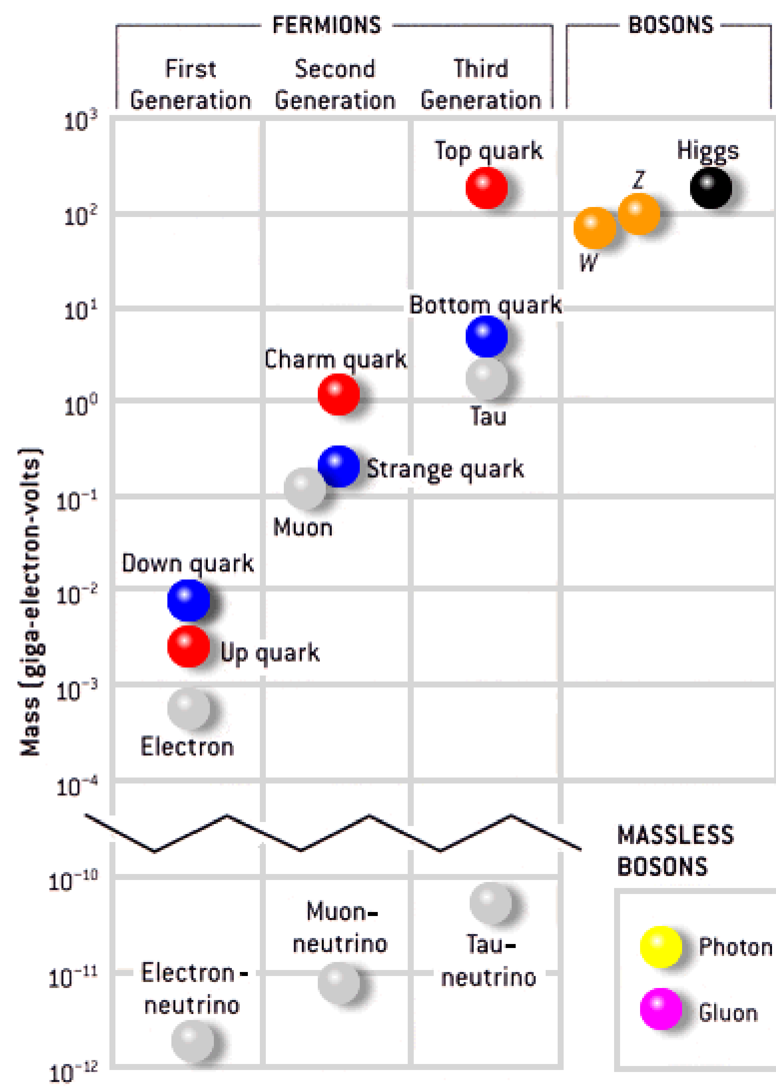


A simulated top quark event

- The Physics TDR (2006) contains several MC studies with realistic detector simulation and different luminosity scenarios (1-100/fb) with corresponding systematics
- Since then, we focused on "start-up" analyses (0-100/pb) with expected misalignments and miscalibrations
  - 0-10/pb: "pre-beam" misal/miscal
  - ~100/pb: "10/pb" misal/miscal
  - ~1/fb: "100/pb" misal/miscal
- But all public results are for 14 TeV!
  - producing MC @ 10 TeV right now

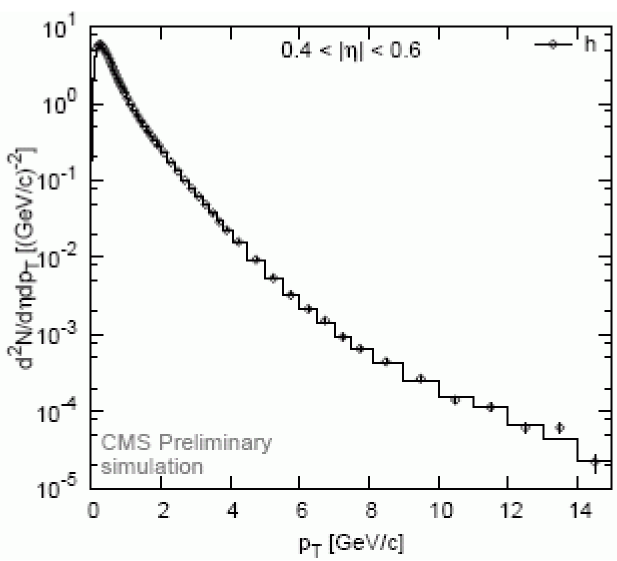
Rediscovering the Standard Model

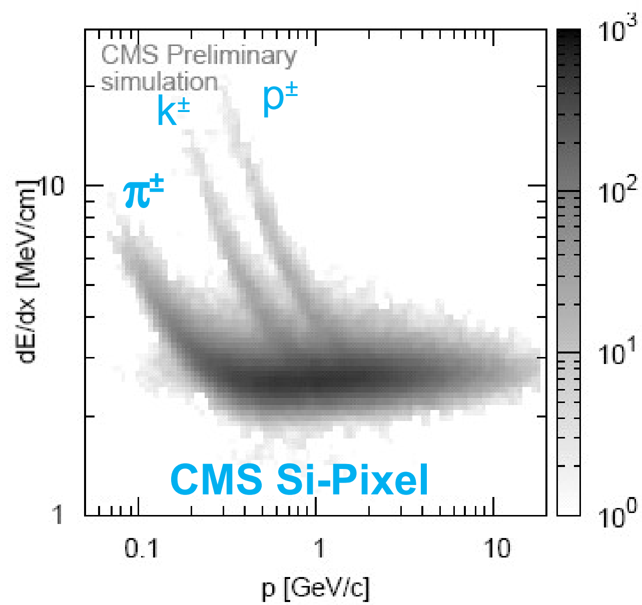
- The "re-discovery" of the SM will be an important benchmark
  - If you see a Z peak, your lepton-ID works; in order to see a top peak, several subsystems have to work
- Known particles are very useful "standard candles" for calibration
- And not everything is so well known
  - Extrapolations with large uncertainty to 14 TeV pp interactions
- Some SM physics interesting *per se*
  - e.g., top physics

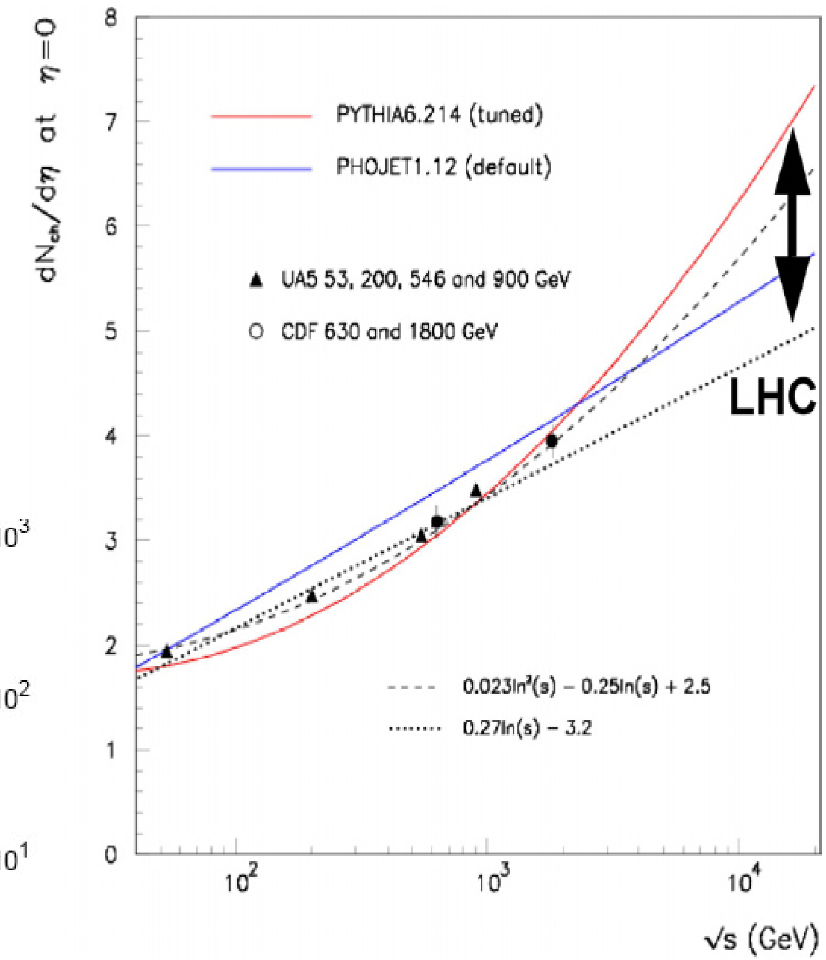


Soft hadronic physics

- "Minimum Bias" events: soft pp interactions. Important: pile-up!
- Never measured for $\sqrt{s}$ > 1.96 TeV
- MB trigger: activity in HF
  - bandwidth limited: "prescaled"
  - Plots below: 1 month @ 1 Hz
- Inclusive (all hadr.) and exclusive (π/K/p)



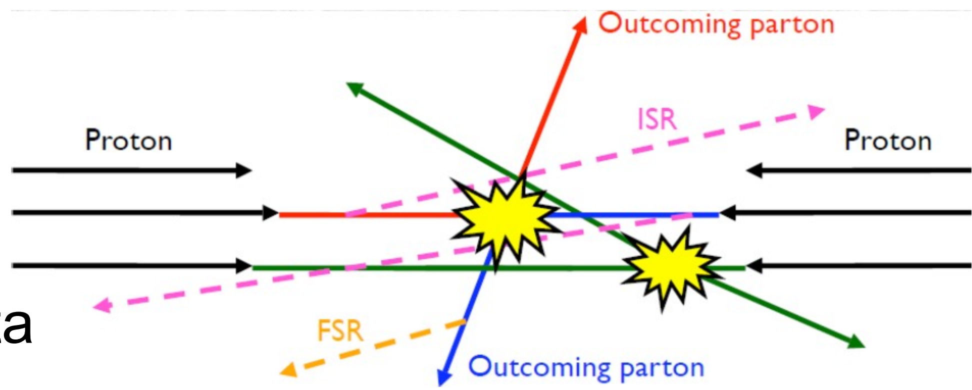


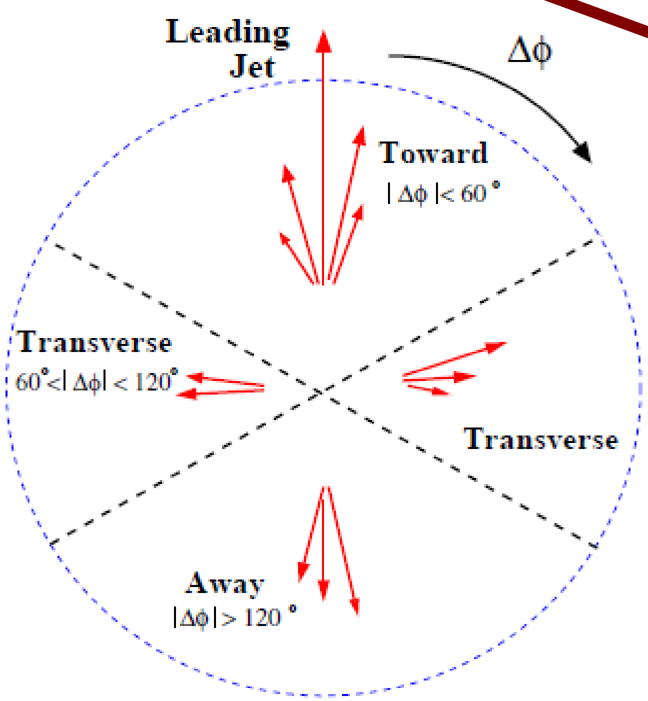


Models tuned to SppS and Tevatron

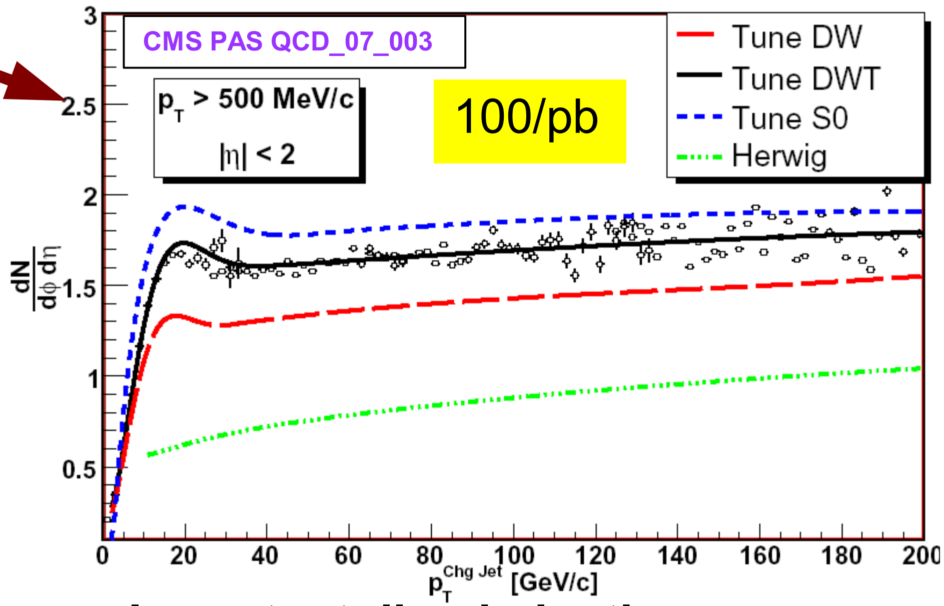
Underlying Event

- Defined as everything in the pp collision but the leading hard scattering
- Important ingredient to understand jets, lepton isolation, missing energy, etc.
- UE models tuned so far with Tevatron data
- **Widely different predictions when extrapolated to 14 TeV**





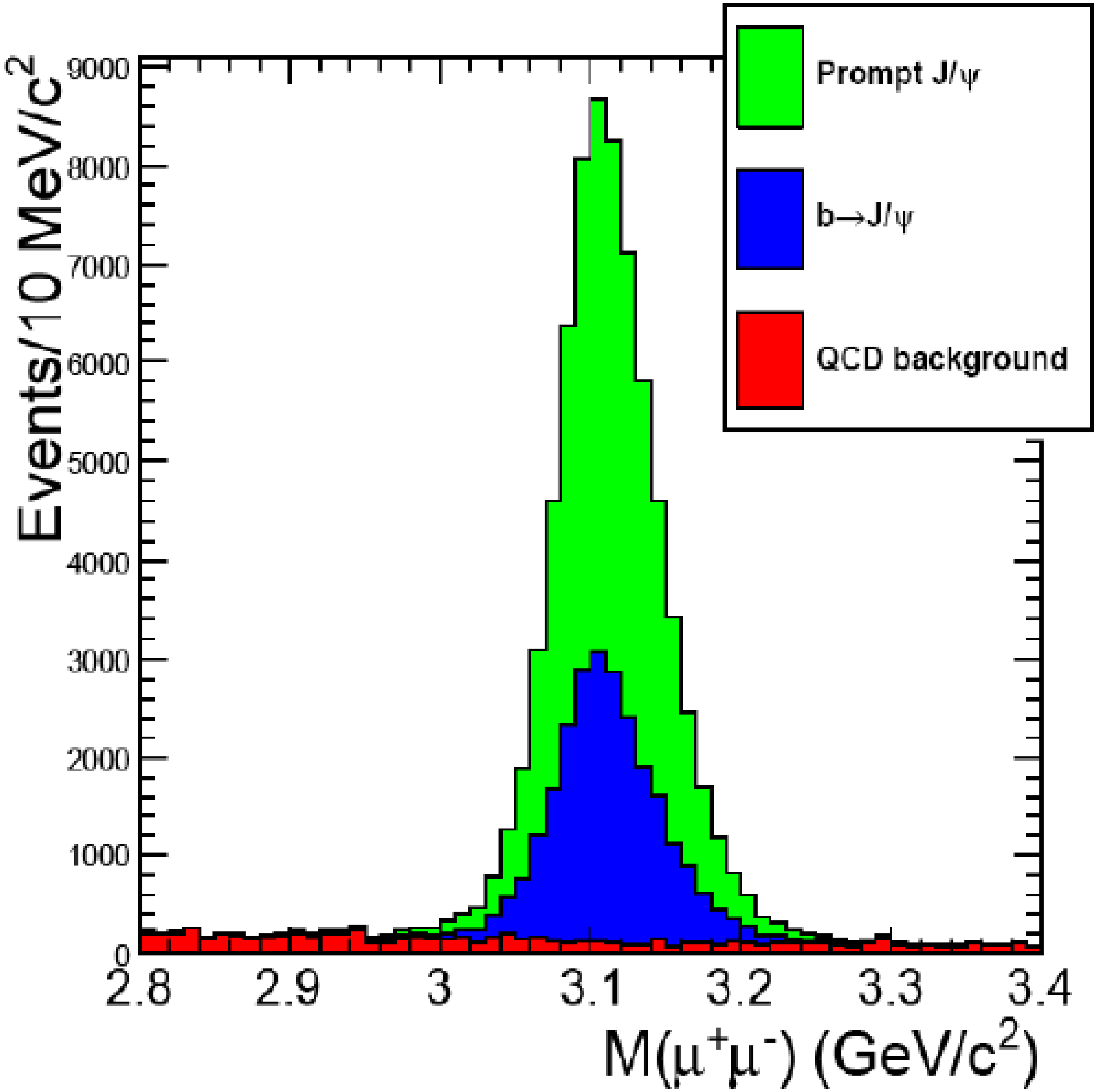
Regions transverse to the leading jet are very sensitive to the UE



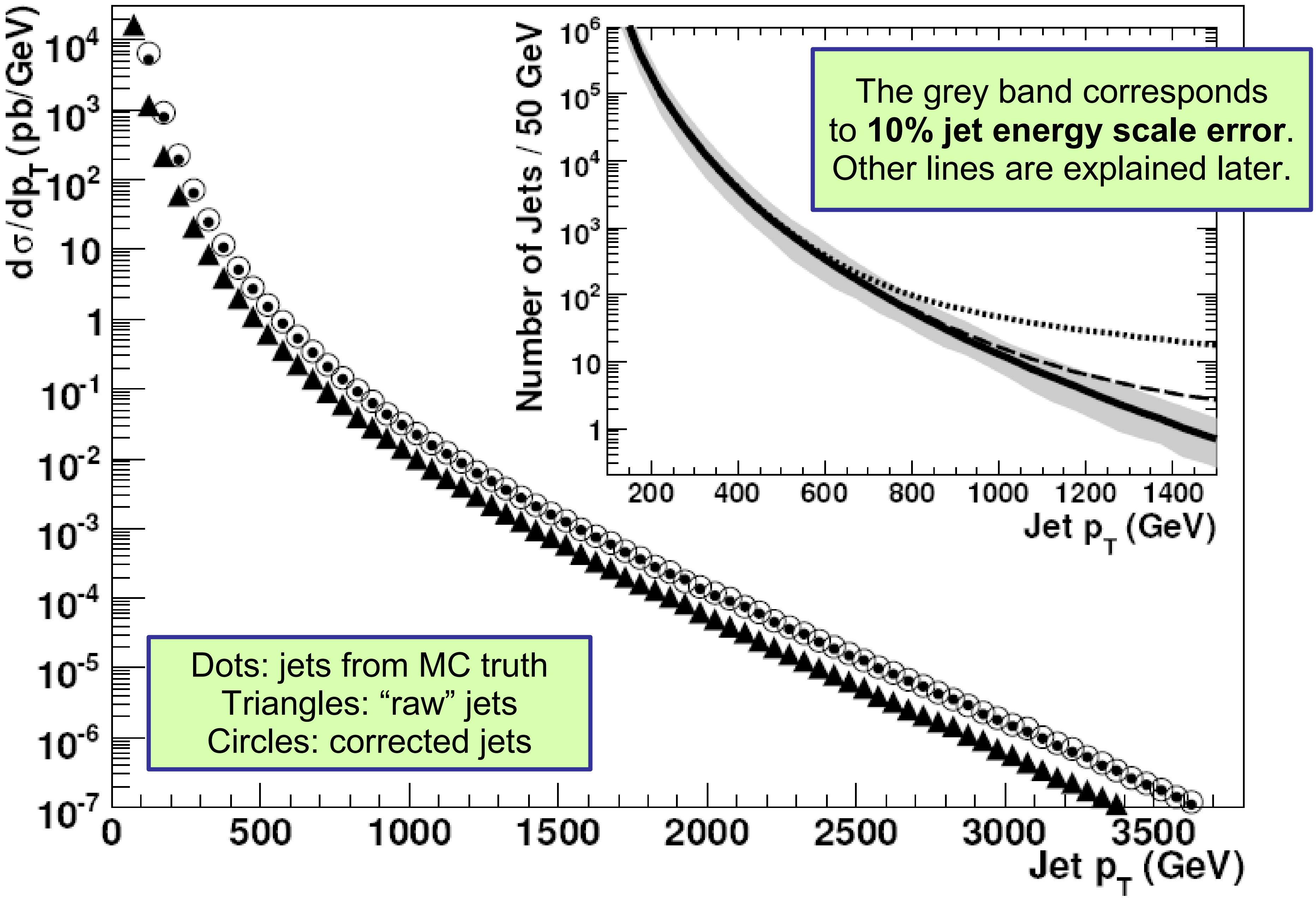
Important discrimination power between models; some tuning already possible with 1/pb

J/ψ

- Physics motivations:
  - QCD tests (cross section, polarization)
  - Production mechanism (singlet/octet)
- Detector motivations:
  - Alignment
  - Efficiency (tag-and-probe)
  - Magnetic field
- In this plot, stat. 3/pb
  - σ = 34.2 MeV @ "10/pb"
  - σ = 30.5 MeV @ "100/pb"
  - σ = 29.5 MeV w/ ideal det.

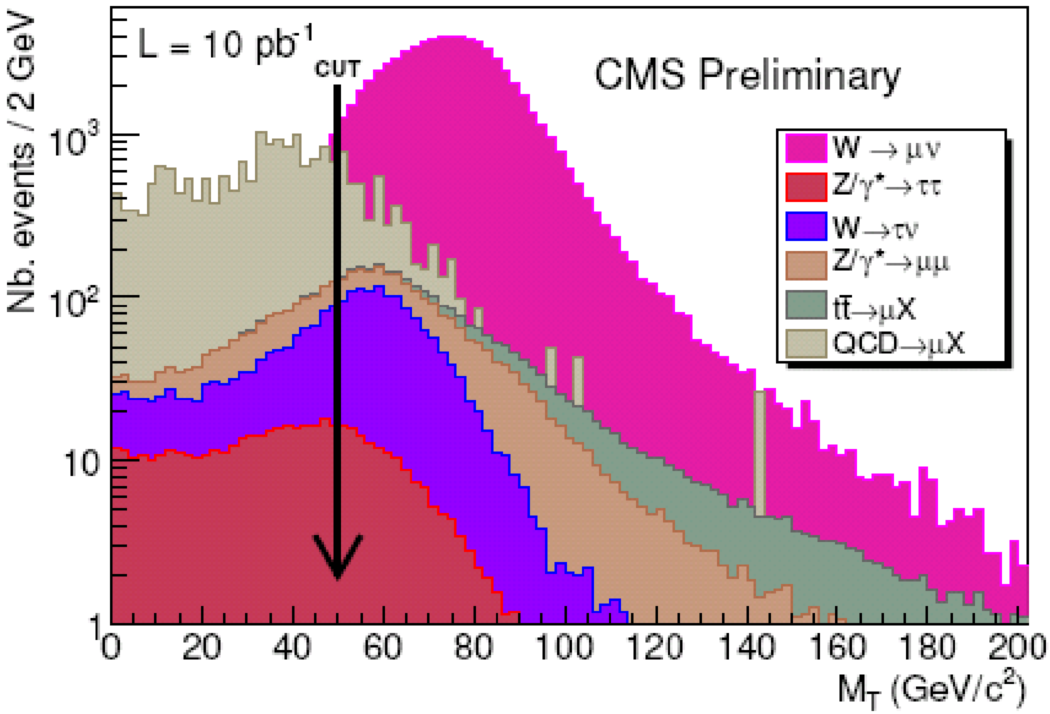


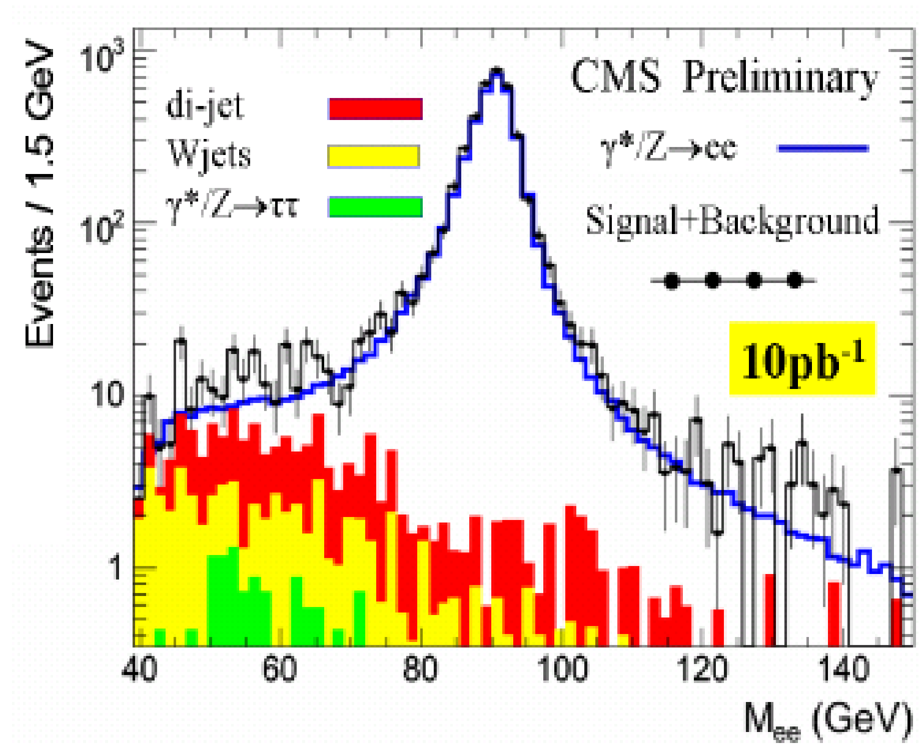
Jets, 10/pb



dσ/dp_T (pb/GeV)
Jet p_T (GeV)
Number of Jets / 50 GeV
Jet p_T (GeV)
The grey band corresponds
to **10% jet energy scale error**.
Other lines are explained later.
Dots: jets from MC truth
Triangles: “raw” jets
Circles: corrected jets

W and Z, 10/pb

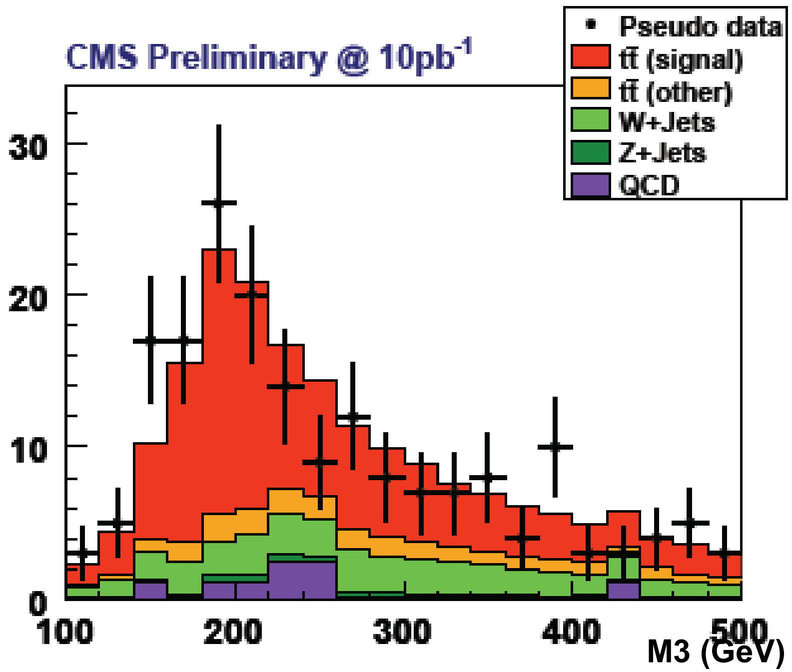




- σ(W→lν)~15 nb, σ(Z→ll)~1.5 nb
- <10% precision with 10/pb
- Muon channels: useful for alignments (Tracker, Muon Ch.)
- Electron channels: ECAL calib.
- Lepton-ID efficiencies from Z decay, using tag-and-probe
- Luminosity measurement (limited by PDF uncertainty)
- Improving PDFs: η distributions and W^+/W^- ratio, ~100/pb needed

The first european top quarks, 10/pb

Single-leptonic (μ+jets)



Requiring at least 4 jets and tight μ isolation:

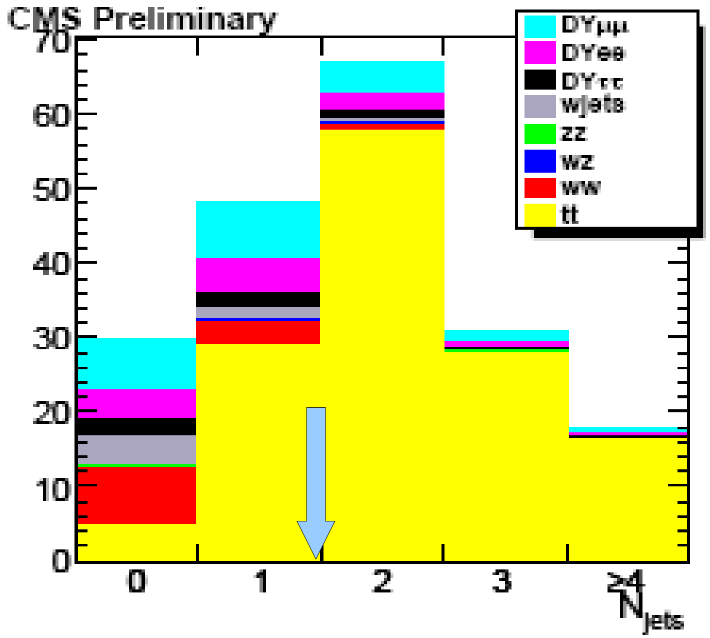
S/N ~ 1.5

S/N (m_t window) ~ 3

signal ~ 128

Δσ/σ (stat) ~ 15-20%

Di-leptonic (μμ,ee,eμ)



Requiring at least 2 jets:

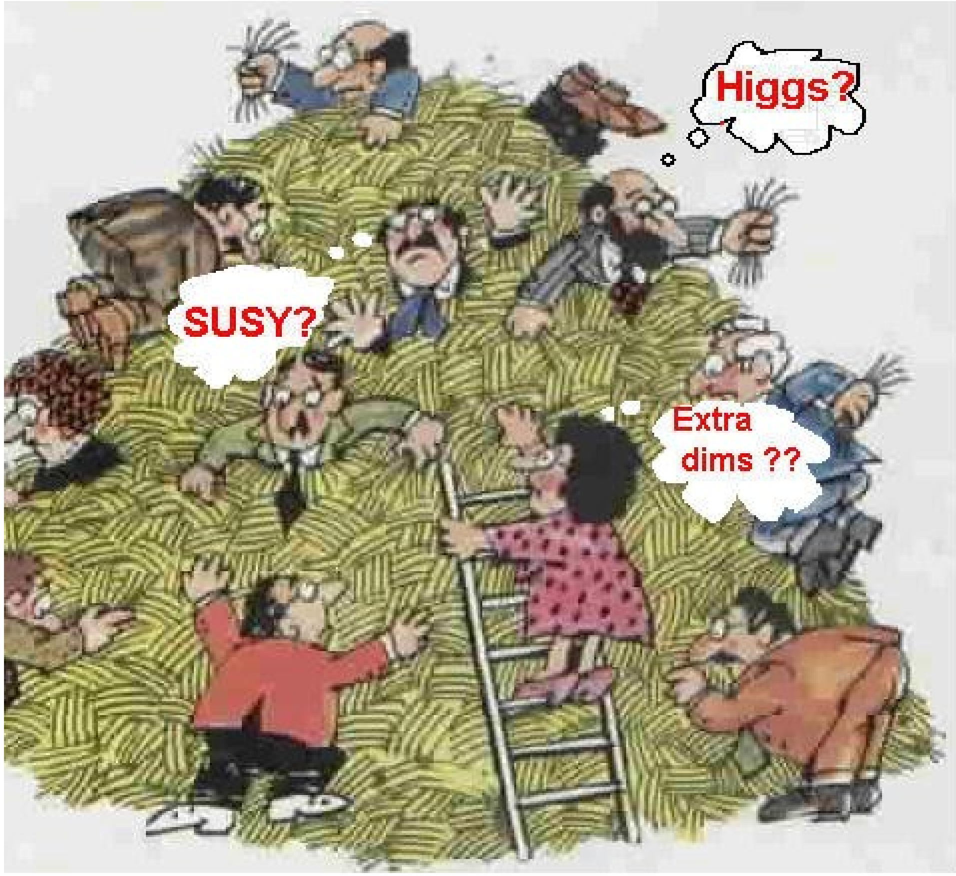
S/N ~ 8

signal ~ 100

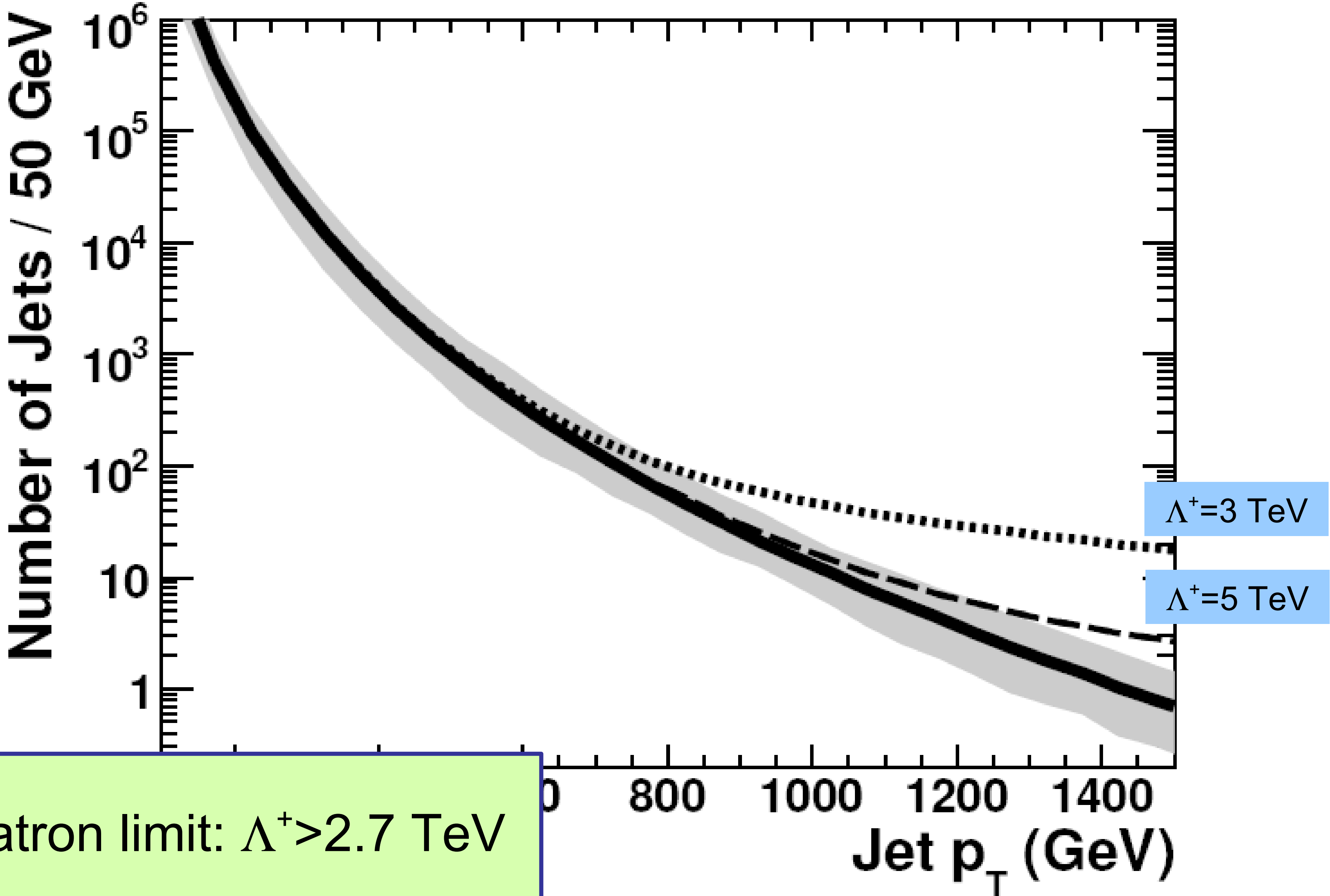
Δσ/σ (stat) ~ 10%

Very early searches

- We never forget that LHC is a **discovery machine**
- But most searches are not for the early data:
  - Clear signatures but small rates
  - Or huge backgrounds, to be estimated with dedicated measurements (which also need some statistics)
  - Or very sensitive to detector conditions (e.g., misalignment)
- Nevertheless, ...

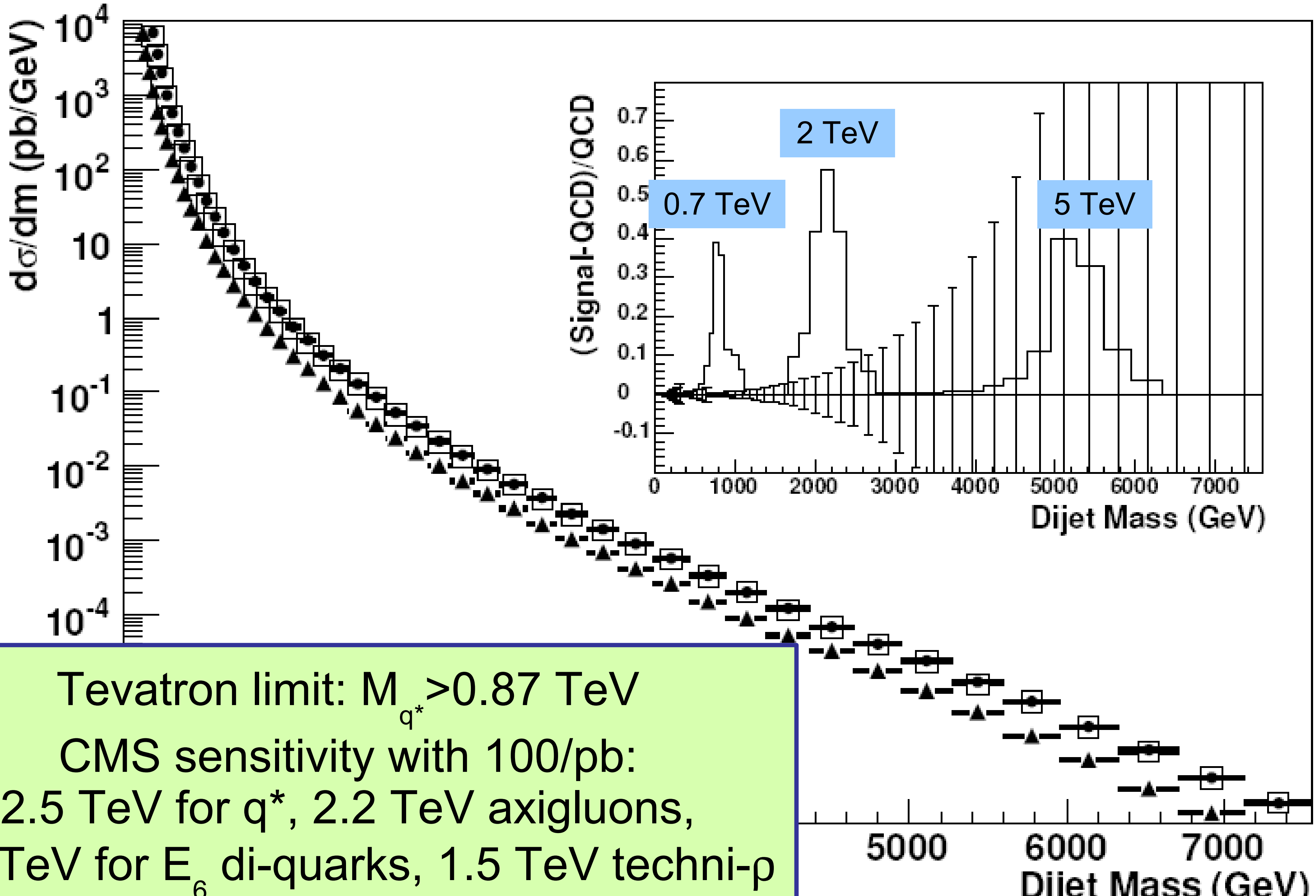


Contact interactions, 10/pb



Tevatron limit: Λ^+>2.7 TeV

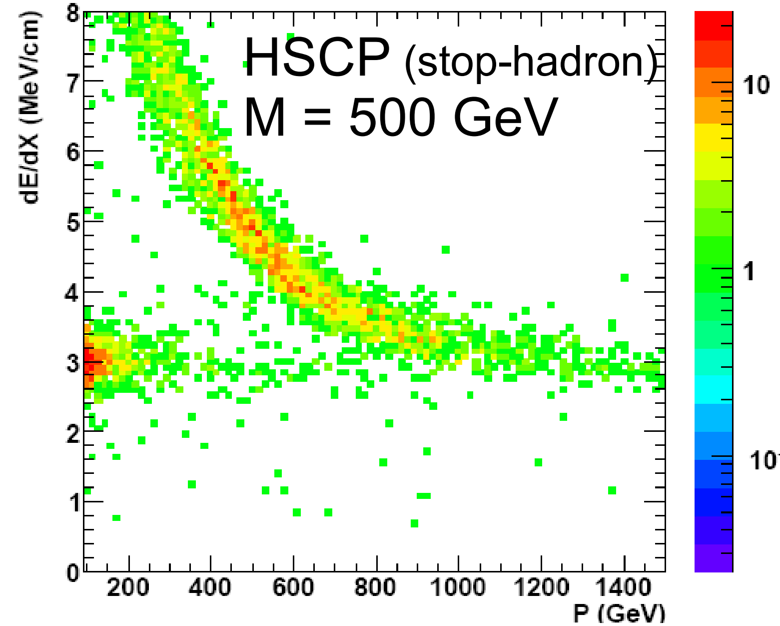
Di-jet resonances, 100/pb

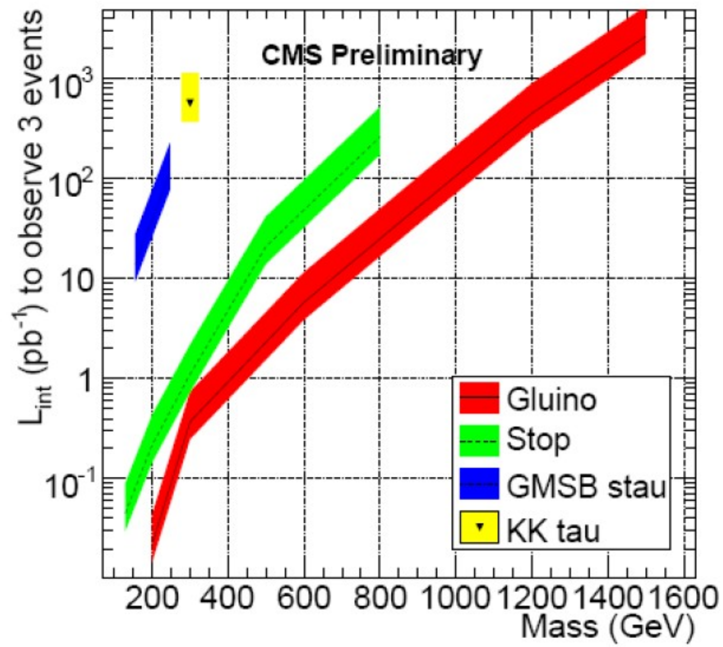


Tevatron limit: M_{q^*}>0.87 TeV
CMS sensitivity with 100/pb:
2.5 TeV for q*, 2.2 TeV axigluons,
2.0 TeV for E_6 di-quarks, 1.5 TeV techni-ρ

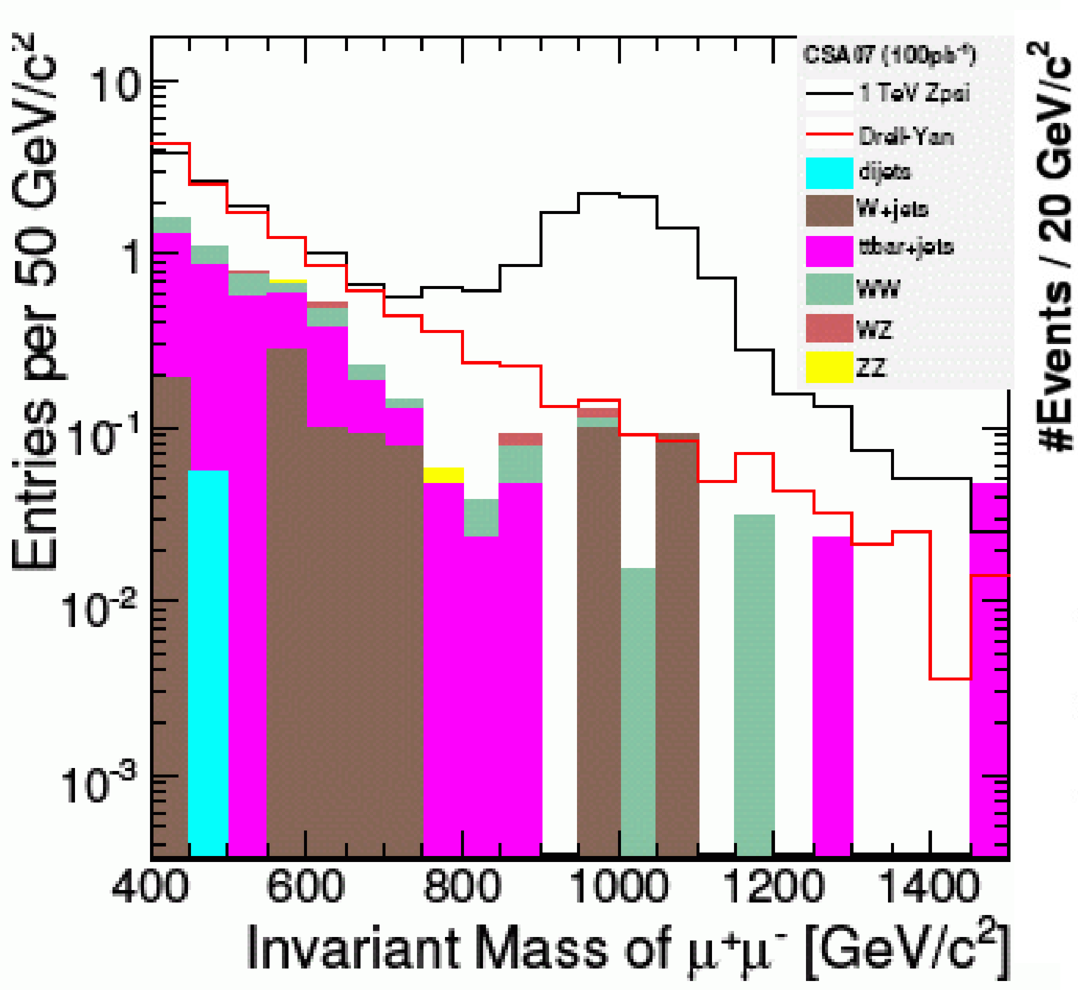
Heavy Stable Charged Particles (HSCP)

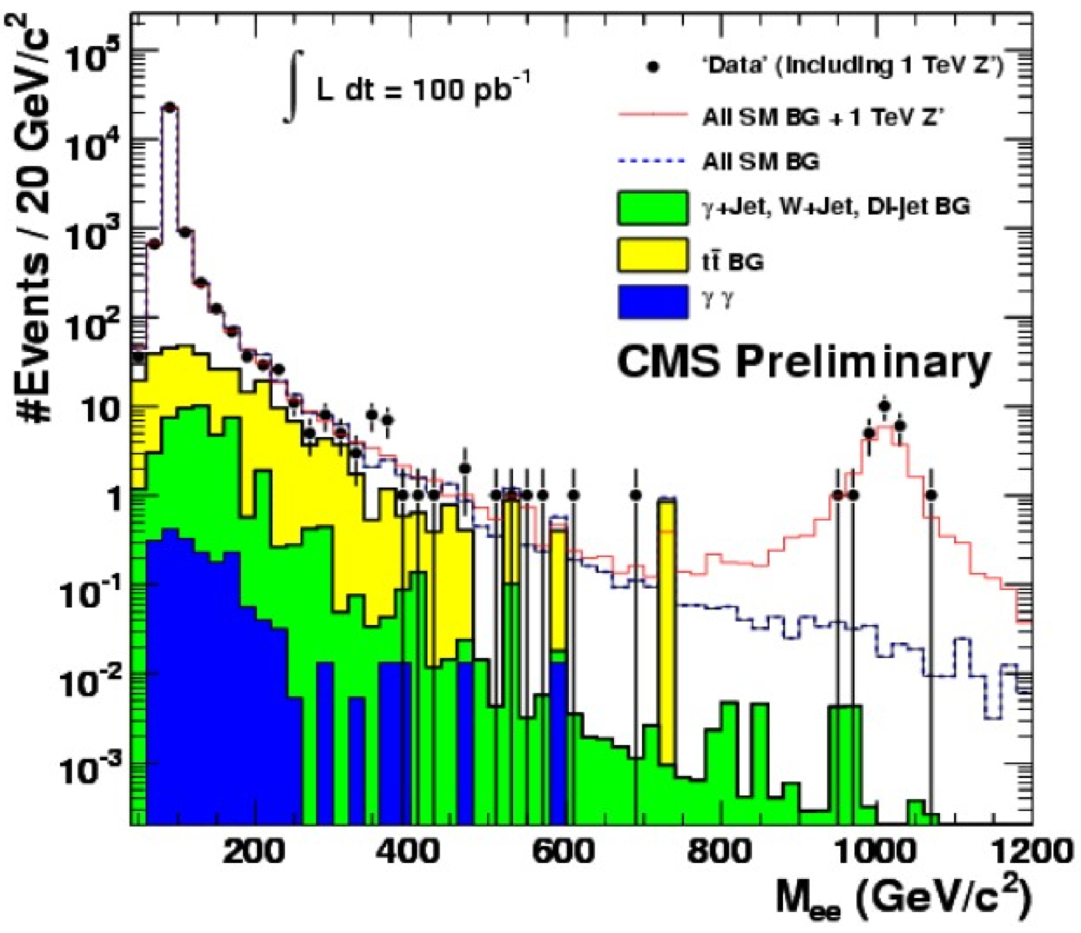
- Several SUSY variants predict metastable or stable charged particles
  - Slepton: “heavy muons”
  - Gluino, squark: “R-hadrons”
    - nuclear interactions!
- Signatures: dE/dx, Time Of Flight
- dE/dx: Tracker
  - >10 independent samplings in Si
  - Estimate the Most Probable Value
- TOF: Muon Chambers
  - δt additional parameter in the track fit
  - Main bkg: cosmics





Z'→μμ,ee, 100/pb

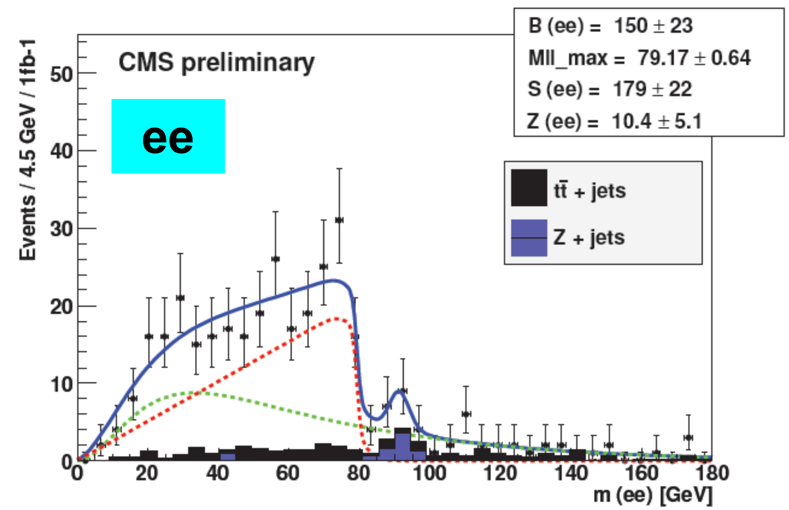




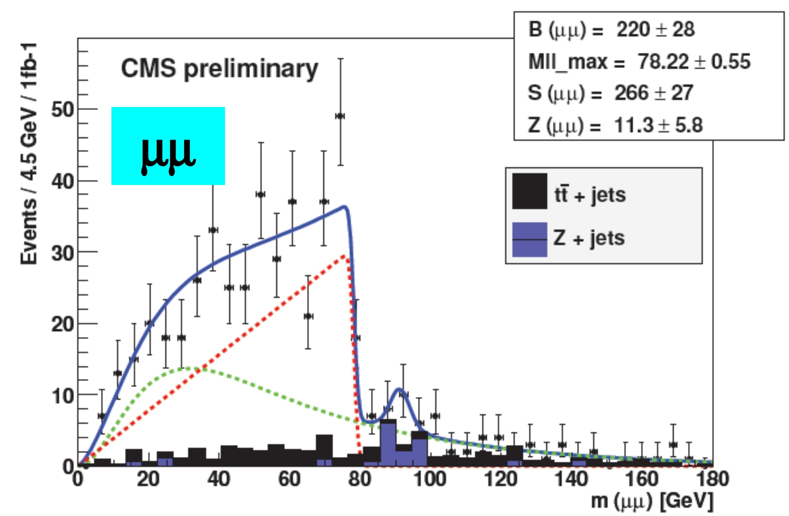
- Despite misal/miscal, 100/pb sufficient for discovery up to 1 TeV
  - But more data would be needed to discriminate between models
- Current Tevatron limit ~700 GeV

Di-leptonic edges

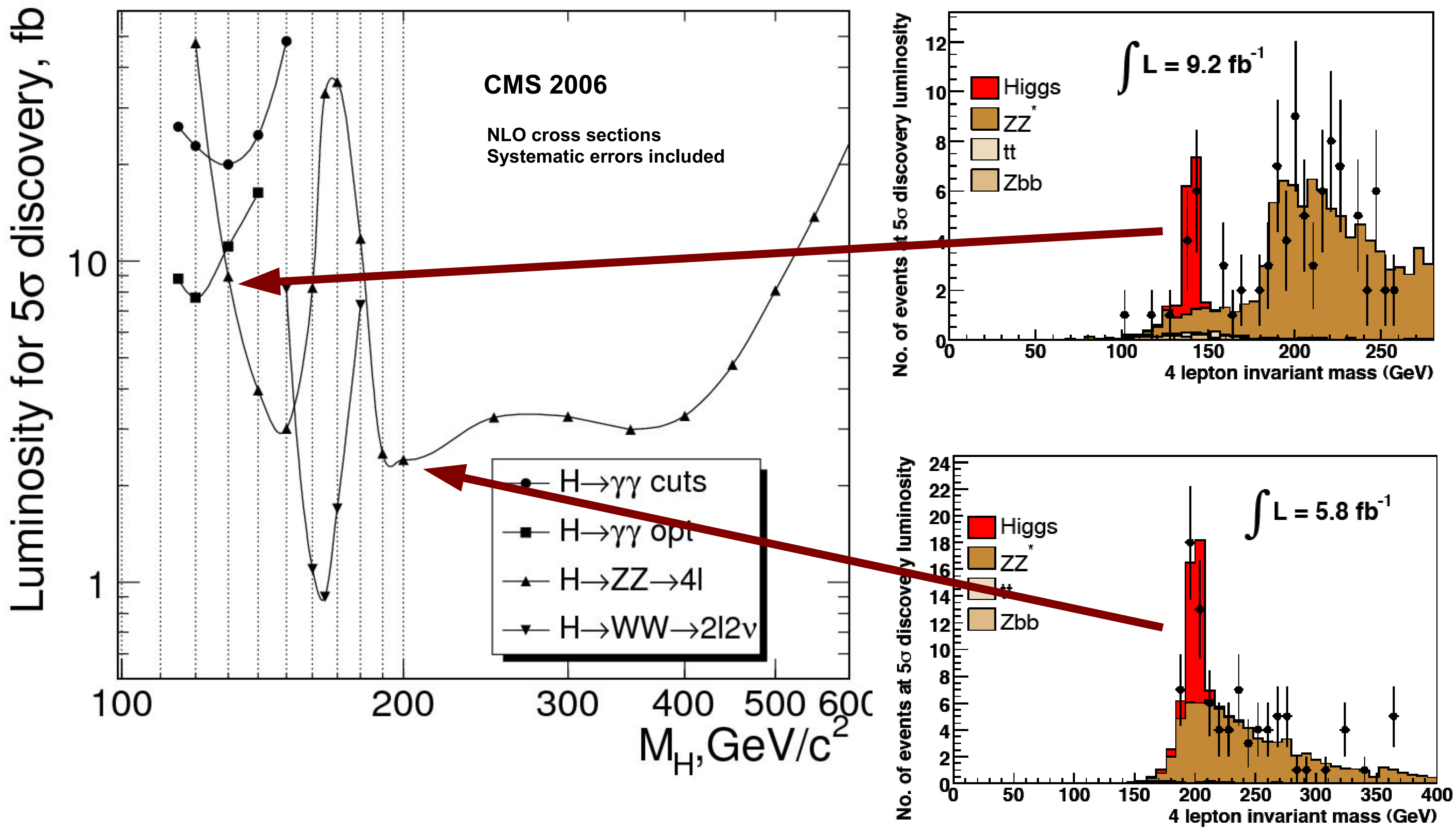
- M_{ll} distrib. in decays $\chi_2^0 \to (\tilde{l}^+ l^-) \to \chi_1^0 l^+ l^-$
  - SUSY's smoking gun!
  - From edges, information on masses
- Same Flavour, Opposite Sign (SFOS)
  - Lepton flavour uncorrelated in bkg from SM and from SUSY itself
    - Estimated from OFOS leptons ($e^+\mu^-$)
  - Background from fake leptons; “e” > “μ
    - Estimated from SFSS leptons
- ΔM_{ll}^{max} ~ 0.5 GeV @ 1/fb
  - 5σ (w/ syst) @ 17/pb at LM1 point



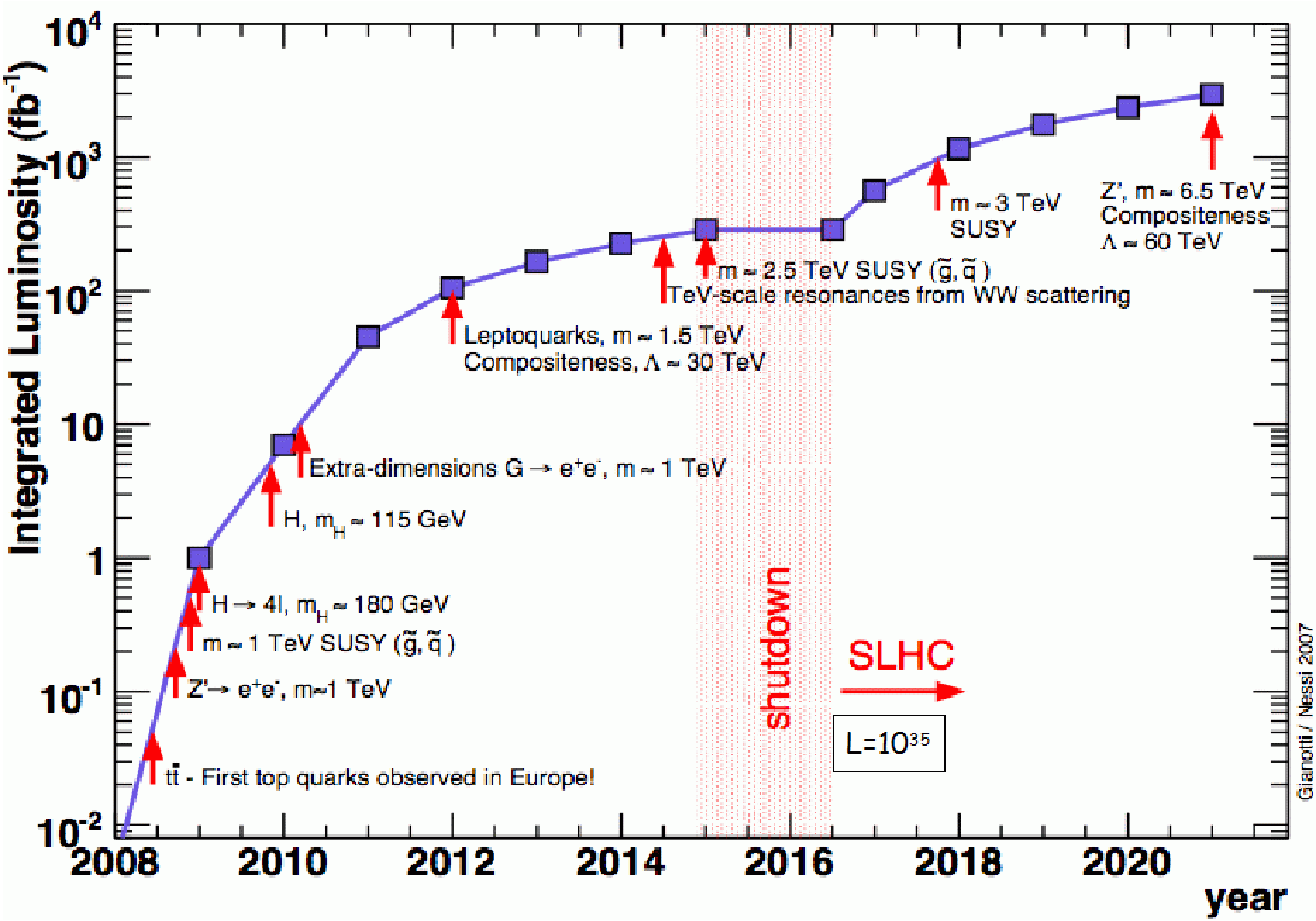
1/fb, LM1 point



And the Higgs?



And then...

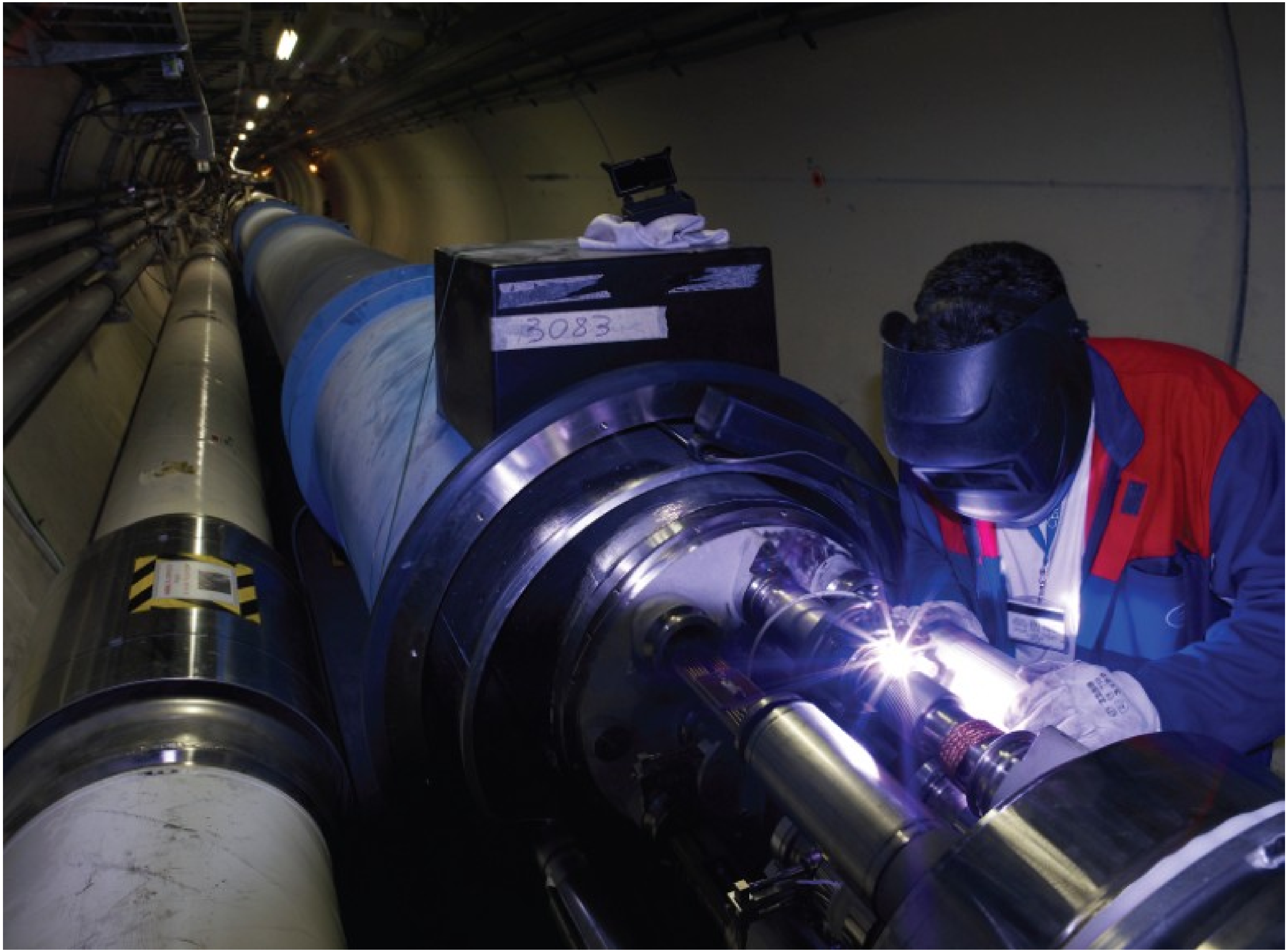


Integrated Luminosity (fb^{-1})
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
2008
2010
2012
2014
2016
2018
2020
year
$t\bar{t}$ - First top quarks observed in Europe!
Z'→ e$^+$e$^-$, m~1 TeV
m ~ 1 TeV SUSY ($\tilde{g}$, $\tilde{q}$)
H → 4l, m$_H$ ~ 180 GeV
H, m$_H$ ~ 115 GeV
Extra-dimensions G → e$^+$e$^-$, m ~ 1 TeV
Leptoquarks, m ~ 1.5 TeV
Compositeness, Λ ~ 30 TeV
TeV-scale resonances from WW scattering
m ~ 2.5 TeV SUSY ($\tilde{g}$, $\tilde{q}$)
shutdown
m ~ 3 TeV
SUSY
Z', m ~ 6.5 TeV
Compositeness
Λ ~ 60 TeV
SLHC
L=10^{35}
Gianotti / Nessi 2007

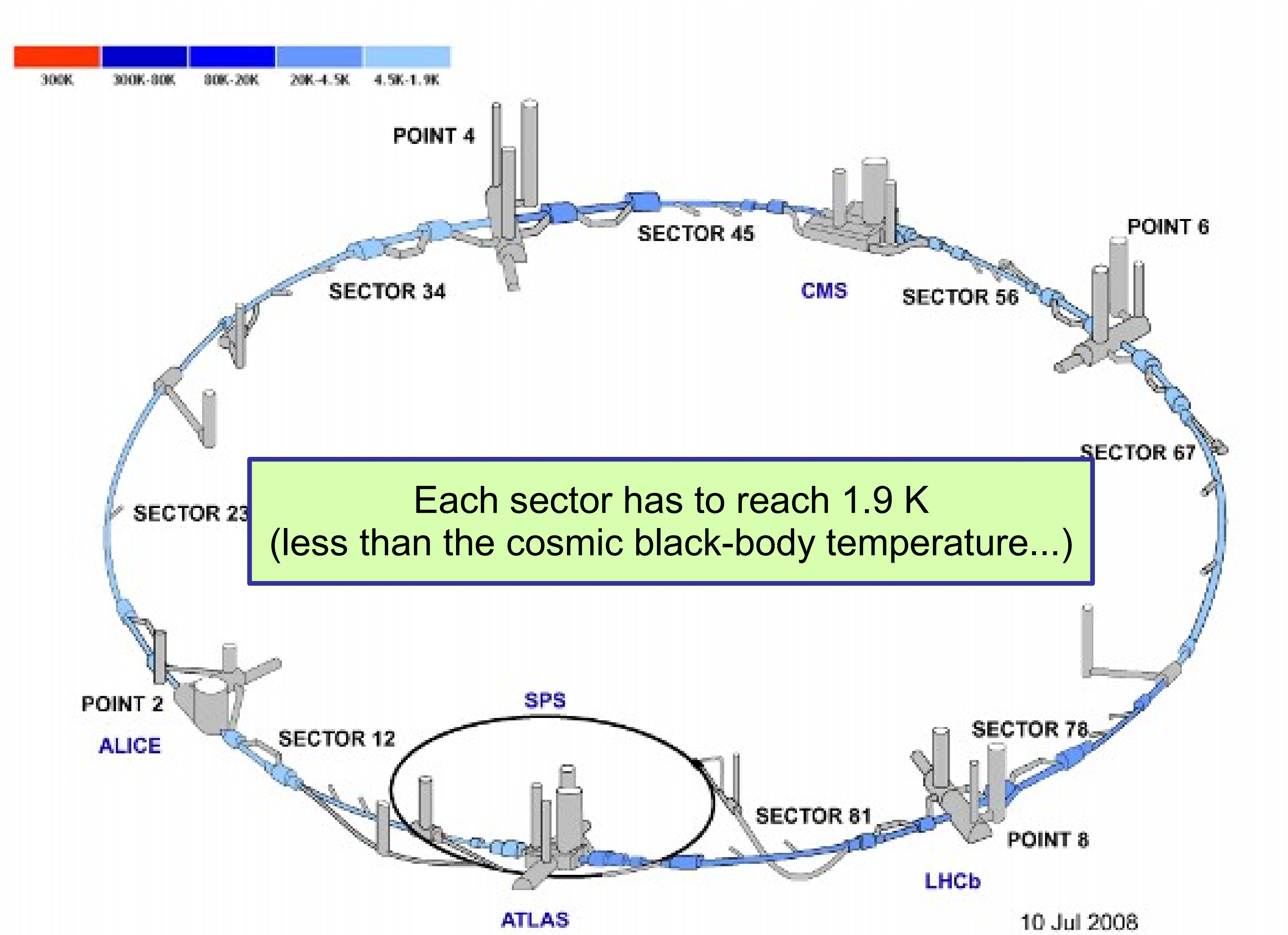
Conclusions

- LHC is a discovery machine
- CMS analyses will have first to re-establish the "known knowns", then measure the "known unknowns" (e.g., PDFs, UE), and at last quest for the Unknown
  - Examples of this path:
    - Z → Z(μμ)+Nj → Z(νν)+Nj → bkg for many SUSY channels
    - tt → tt+Nj → infer tt+bb in SM → bkg for tt+H
  - The 2008 run at ~10 TeV will be mostly used for detector understanding and MC tuning
- Nevertheless, a few examples exist of **low-background high-rate** signals, not excluded yet by lower-energy accelerators, which could be found very soon

BACKUP SLIDES



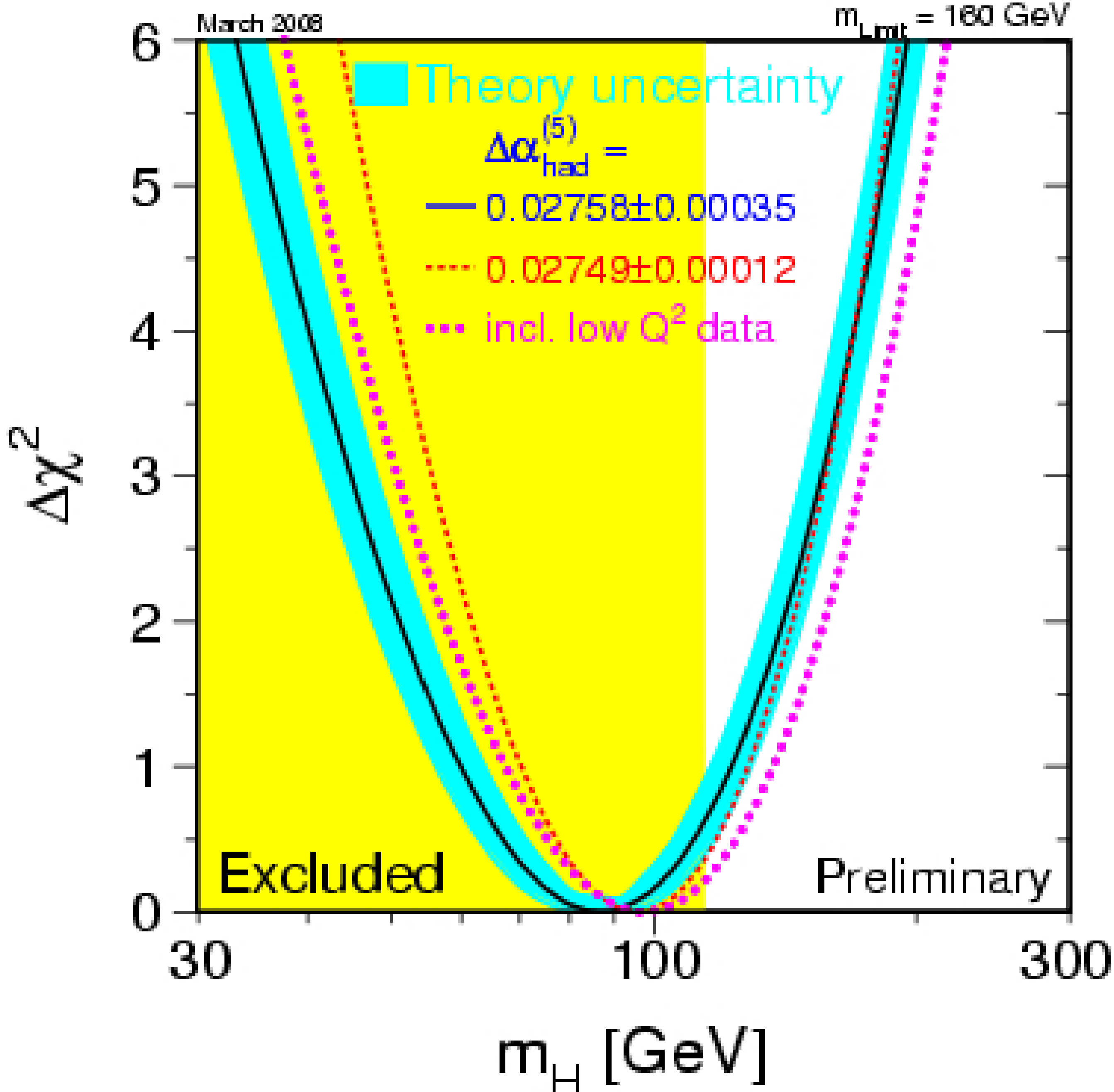
Cooldown status



Each sector has to reach 1.9 K
(less than the cosmic black-body temperature...)

Constantly updated at http://lhc.web.cern.ch/lhc/

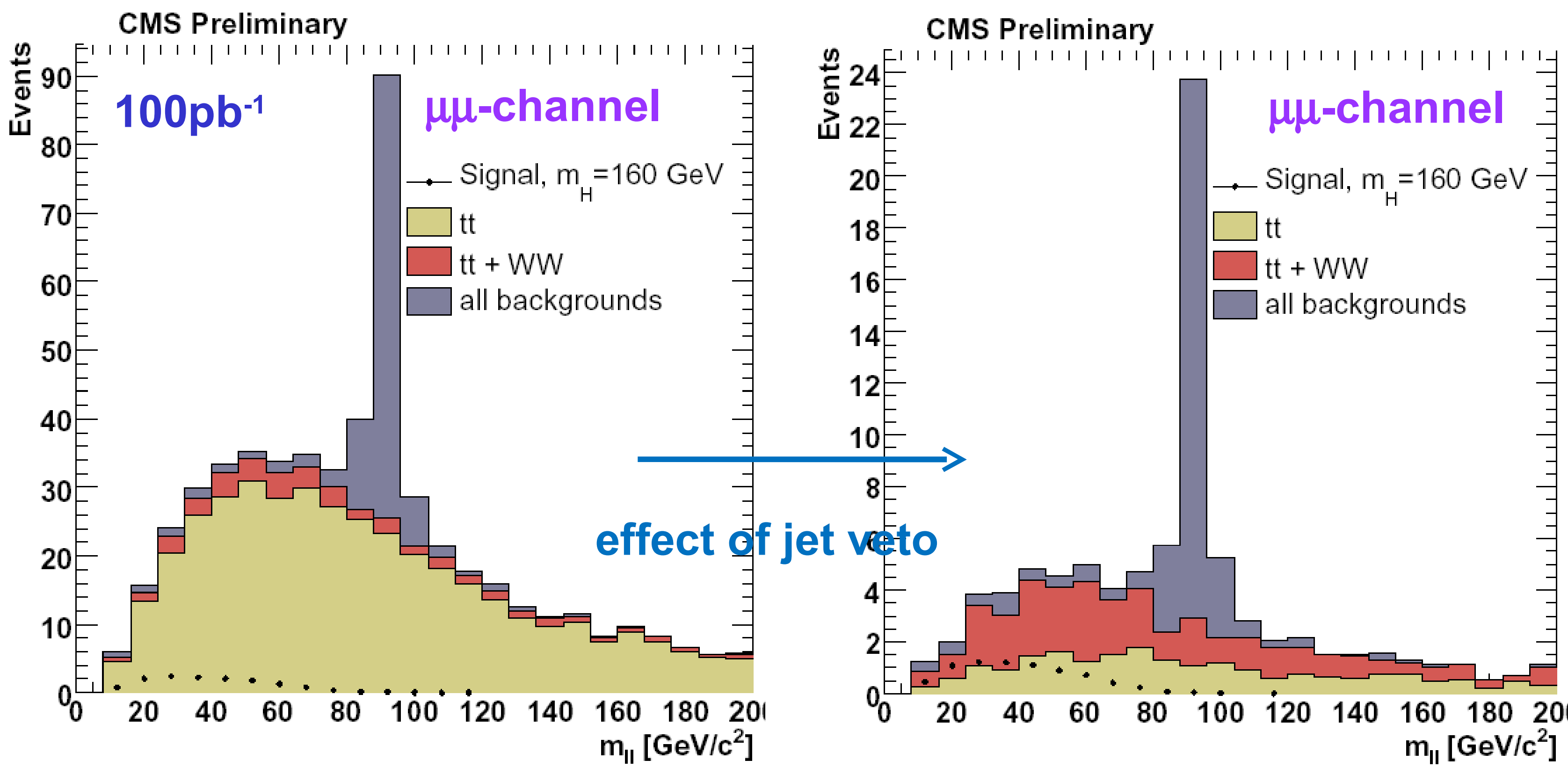
Assuming the SM correct:



M_H < 190 GeV @95%CL

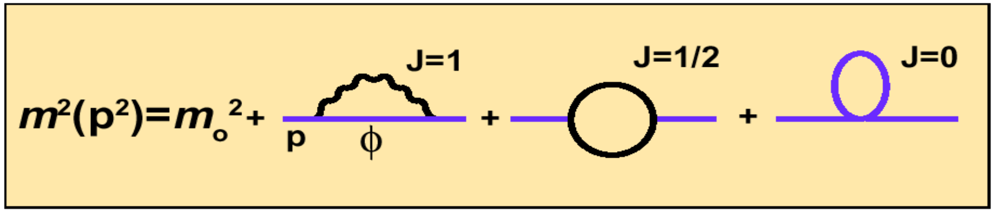
$H\rightarrow WW^{(*)}$

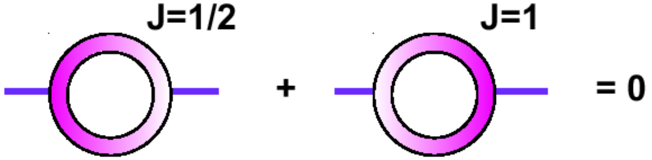
- Most promising channel at start-up ($W\rightarrow e,\mu$) for M_H~160 GeV
- Tight lepton-ID, Z-veto in the same-flavour channels, jet veto
- WW is an irreducible background (discrimination from angle); early discovery limited by uncertainty on WW and tt modeling



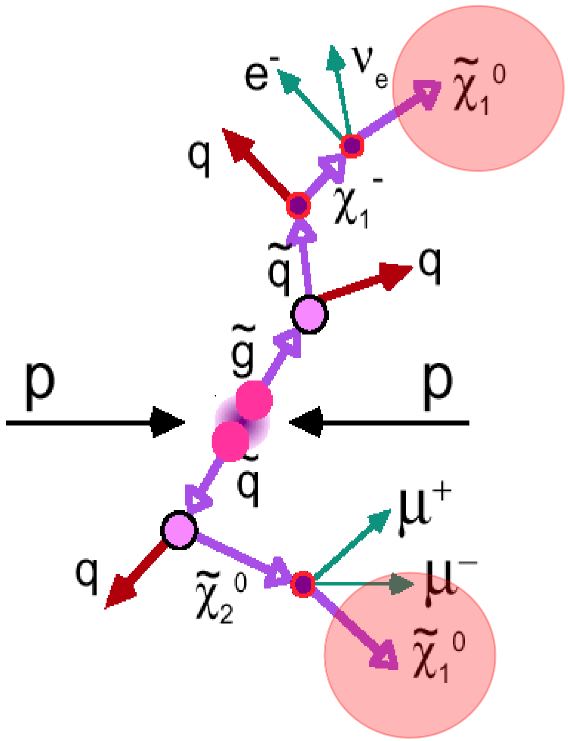
Main problem of the SM

- Fine tuning of the Higgs mass: why is it so light?
  - SUSY solves it naturally, providing a cancellation
  - The extent of non-cancellation (=M_H) tells us the scale of SUSY breaking: ~TeV
  - And some particles ~100 GeV



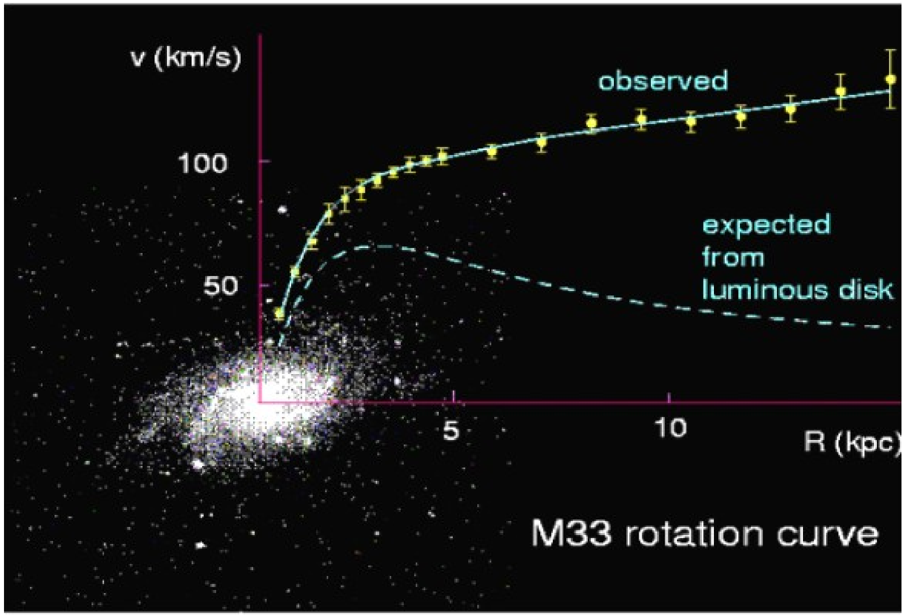


SUSY is the archetypal "new physics at sub-TeV" tested by LHC



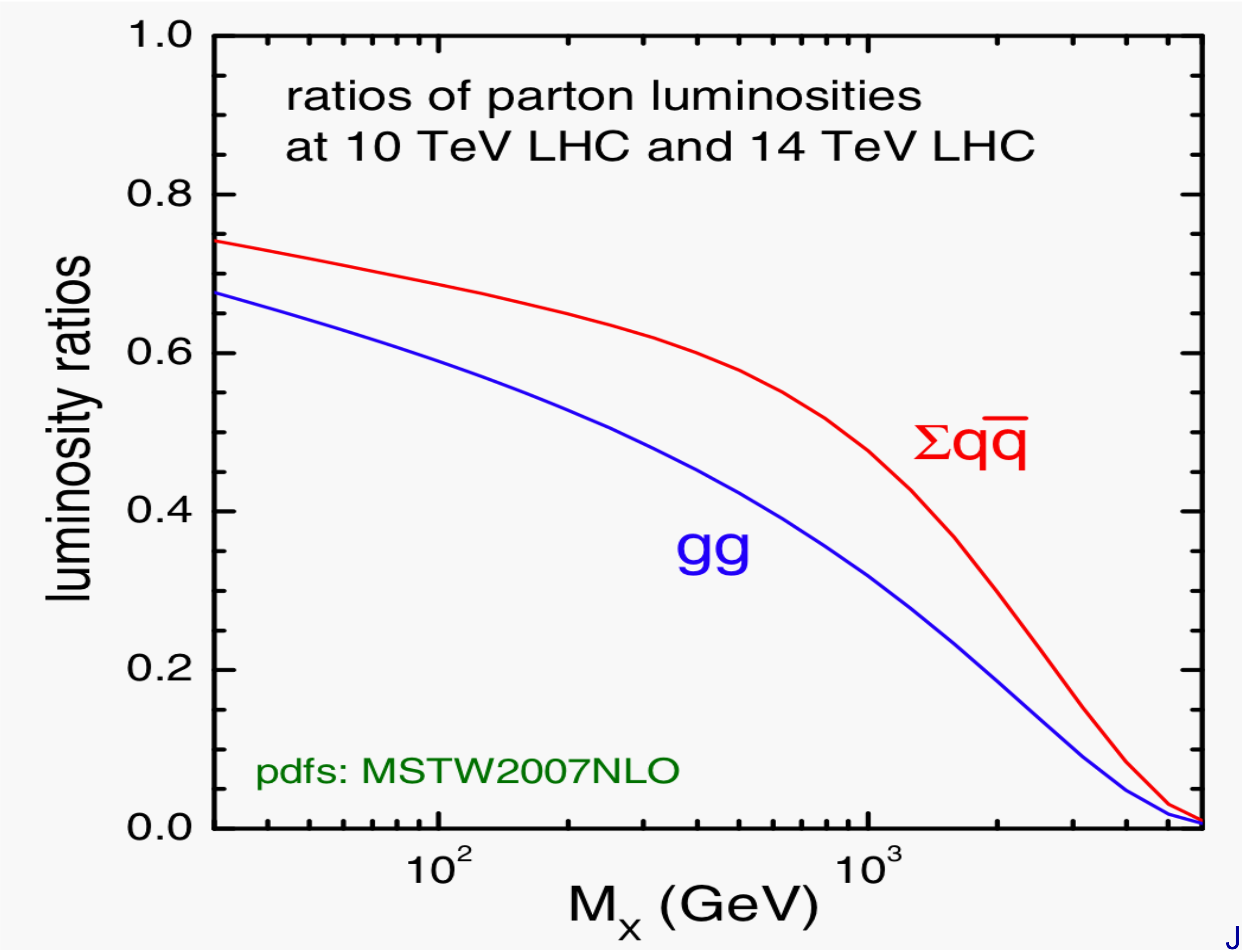
It could also solve the Dark Matter problem...

Inter-breeding of particle physics and cosmology



- But not only SUSY is on the market
  - Popular alternatives: extra-dimensional theories, new wave of technicolor, ...
  - Since they are all designed to explain fine tuning, they all predict new phenomena at the same scale (<~ TeV)
  - And some have a candidate for Dark Matter too...

10 vs 14 TeV



J. Stirling

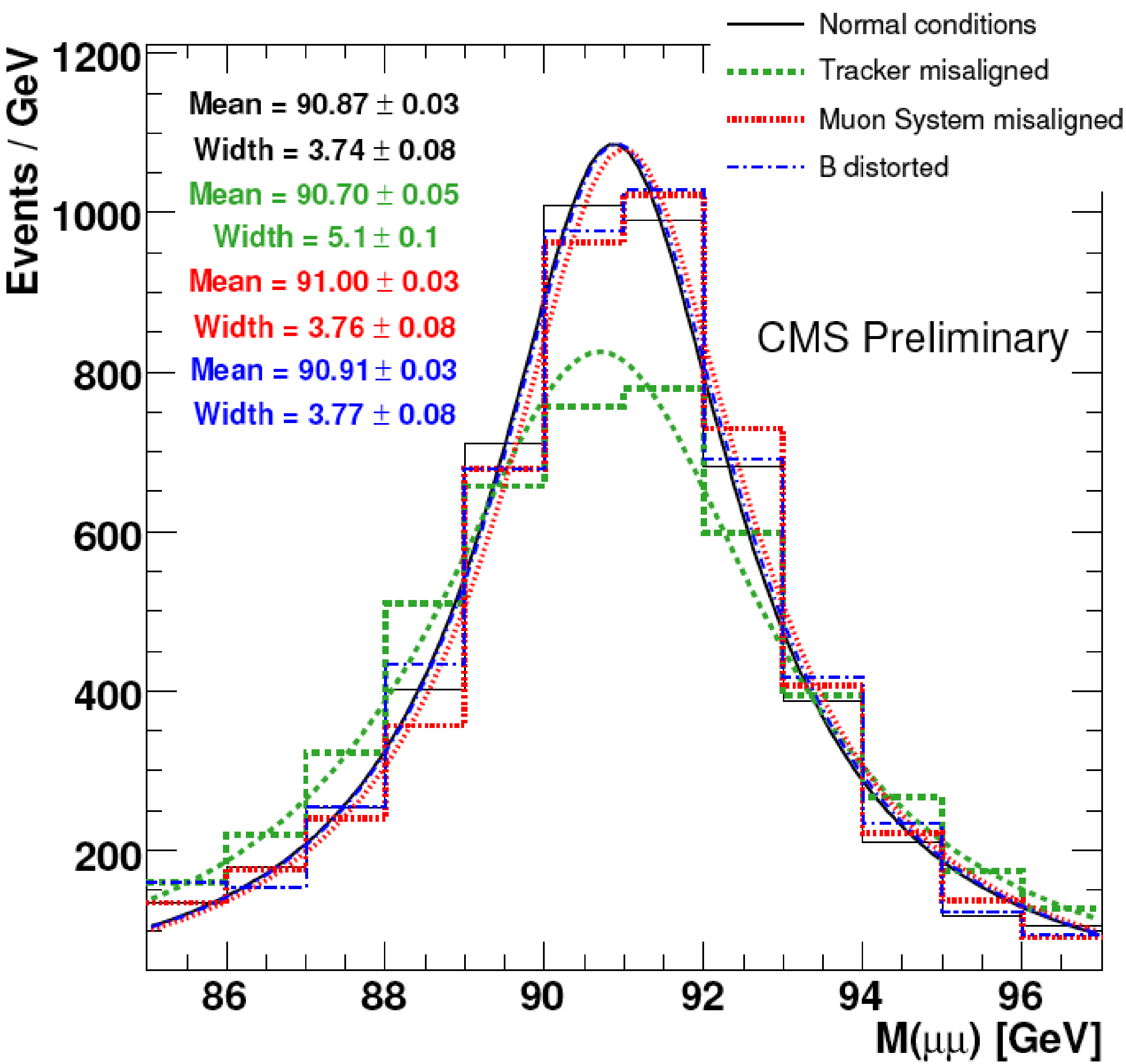
Events in 1/pb at 14 TeV

Process	# events in 1 pb^{-1}
QCD jets with p_T > 150 GeV	1000 (10% trigger bandwidth)
$J/\Psi \rightarrow \mu^+\mu^-$	15000
$Y \rightarrow \mu^+\mu^-$	3000
$W \rightarrow \mu\nu$	6000
$Z \rightarrow \mu^+\mu^-$	600
Top-antitop $\rightarrow \mu\nu$ + jets	20
Jets with p_T > 1 TeV	10

Data foreseen in 2008

- 40 days of physics running end of the year at $\sqrt{s}$ = 10 TeV
  - Peak luminosity: $5 \cdot 10^{31}$ $cm^{-2}s^{-1}$ (with 156 bunches in ring, 1.8 interaction per bunch crossing)
  - Efficiency of LHC running: 10%
  - Integrated lumi per experiment: ~20/pb
- This implies
  - At least a million minimum bias events
  - 50k W's with leptonic decays
  - 5k Z's with leptonic decays
  - > 2k low mass Drell-Yan lepton pairs
  - 20M triggered jet
  - $O(10^6)$ direct photons with p_T > 20 GeV
- Important samples to understand detector and its performance and first glimpse at SM physics

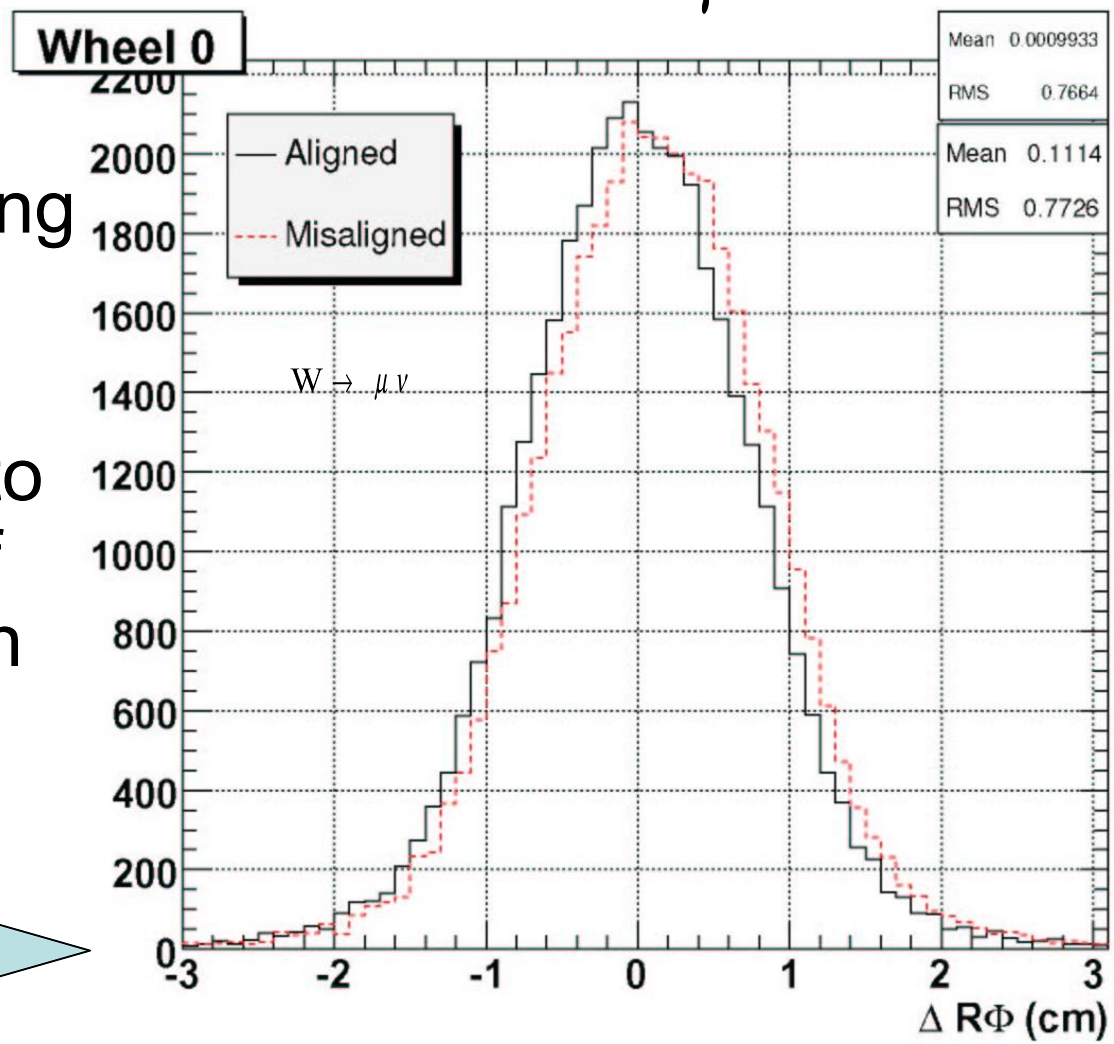
Misalignment



The plentiful production of W and Z bosons are main tools for Detector Commissioning

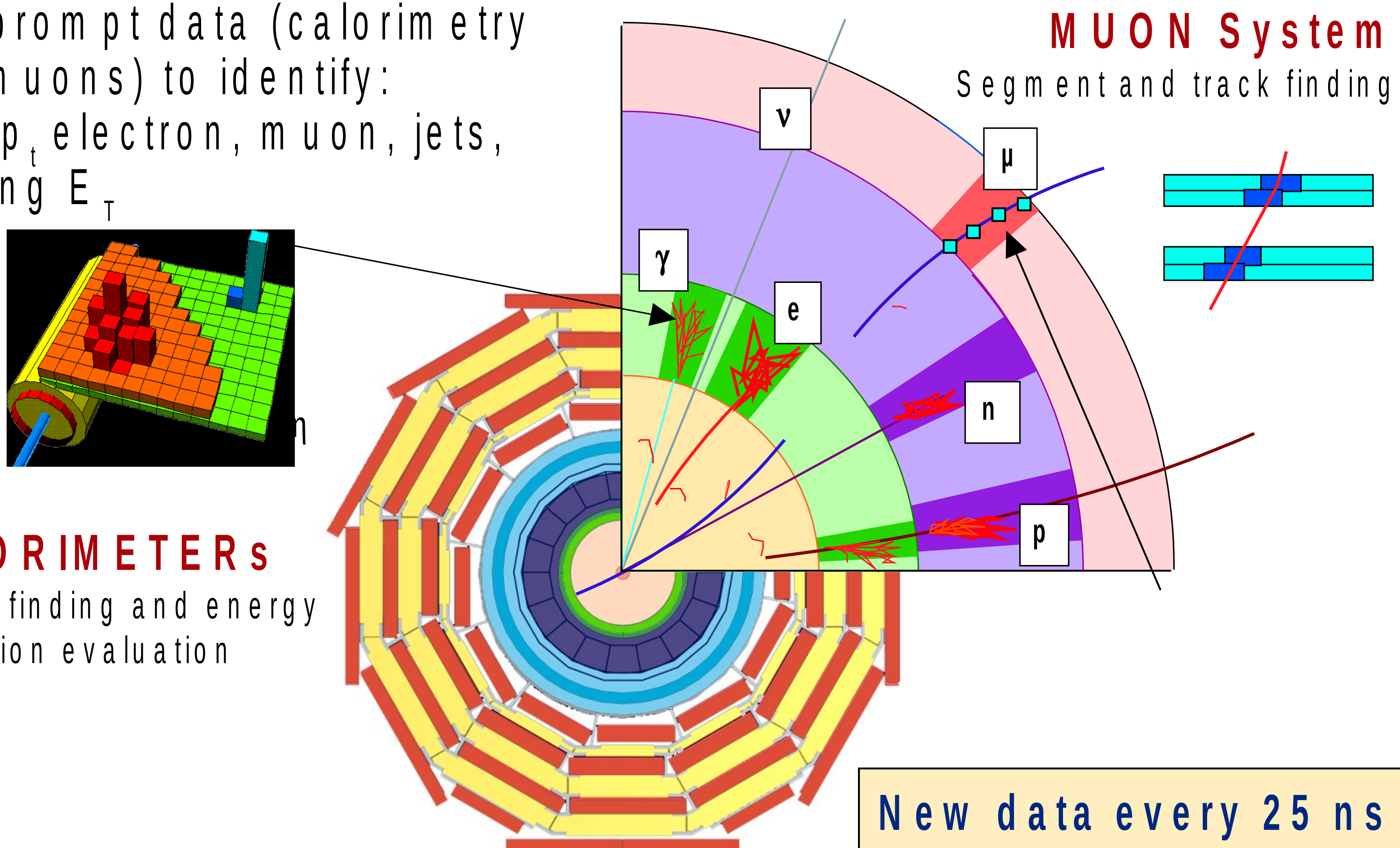
$W \rightarrow \mu \nu$

- Example: CMS Muon System alignment using real tracks
- One day at low luminosity is enough to show misalignment of the order of one fourth of mrad



Level-1 Trigger

Use prompt data (calorimetry and muons) to identify:
High p_t electron, muon, jets, missing E_T



CALORIMETERs
Cluster finding and energy deposition evaluation

New data every 25 ns
Decision latency ~ µs

SUSY models with HSCP

- AMSB: chargino (muon-like)
  - (mass difference with LSP may be <150 MeV)
- GMSB: stop (R-hadrons), stau (muon-like)
- SUSY-5D: stop (R-hadrons)
- Split SUSY: gluino (R-hadrons)

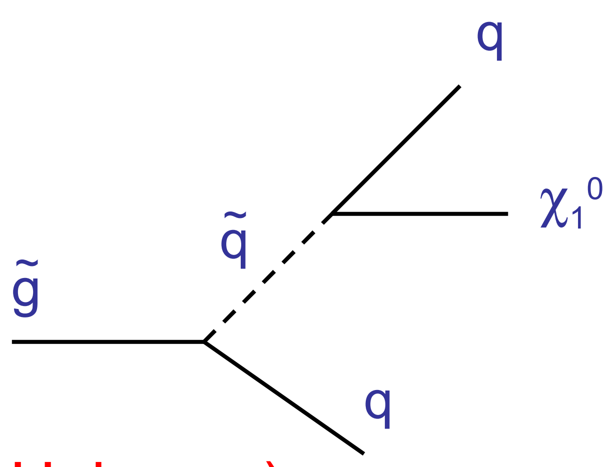
The next slide will explain the Split-SUSY case

- considered very promising by many theorists
- it tries to solve the "big" hierarchical problem (i.e. the fine tuning of the cosmological constant), by allowing a %-level fine tuning of the Higgs mass

Split SUSY

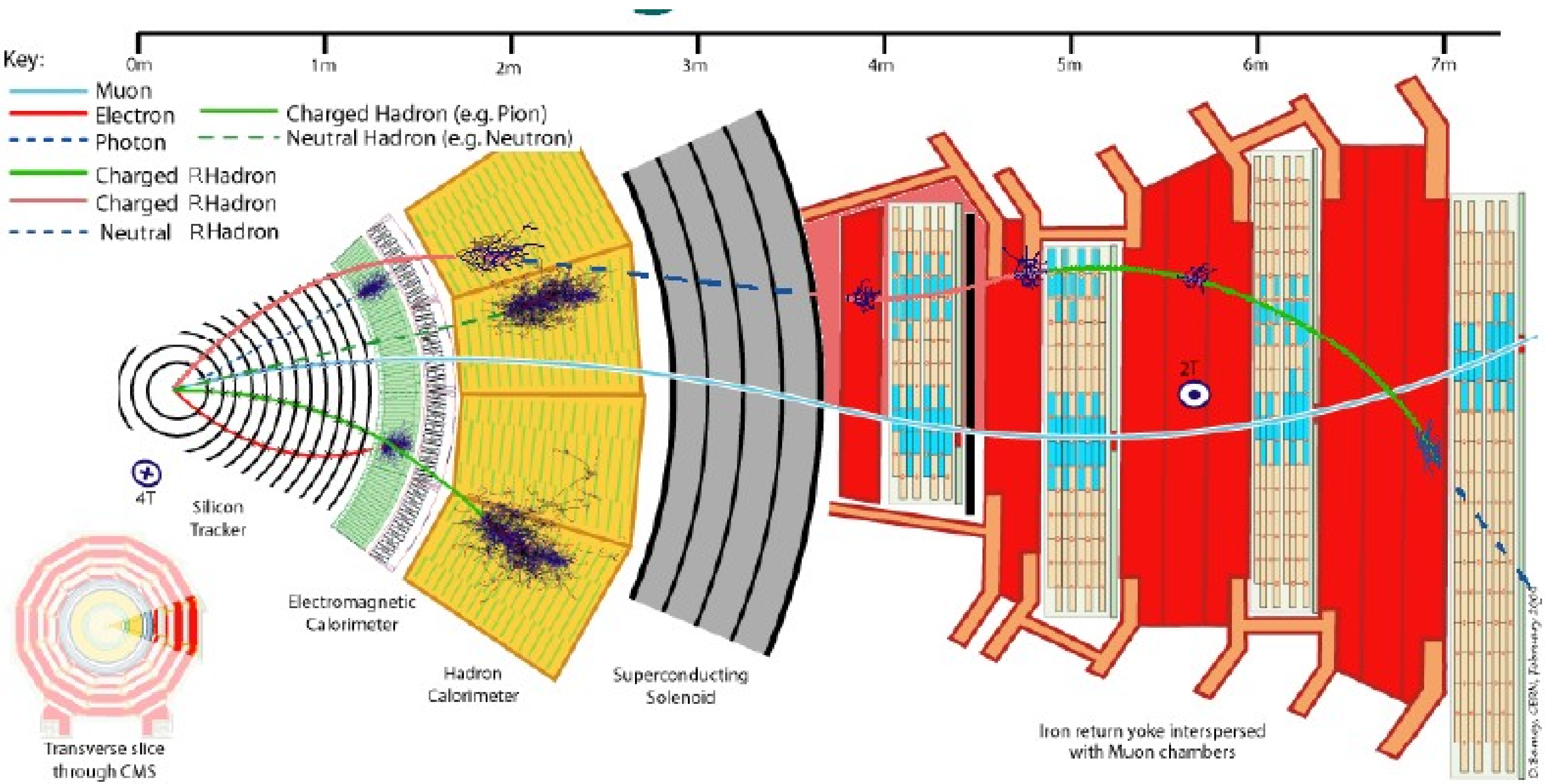
- Gauginos at TeV scale, sfermions higher (e.g., at GUT scale)
- The gluino is colored, so it has to decay to colored particles
- (If R-parity holds) it has to couple to a super-particle and a particle
- The only other colored super-particles are the squarks, but they are much heavier!
- So, it decays through a virtual squark:

$$\tau \simeq 8 \left(\frac{m_S}{10^9\ \mathrm{GeV}}\right)^4 \left(\frac{1\ \mathrm{TeV}}{m_{\tilde{g}}}\right)^5 \mathrm{s}$$



- Long lifetime: from O(ps) to O(age of the Universe)
- Slow: Time-of-Flight technique (in CMS: use Muon Chambers)
- Colored: it hadronizes ($\tilde{g}g$, $\tilde{g}q\bar{q}$), and its “hadrons” have nuclear interactions! By exchanging quarks, they can give $R^{+/-} \rightarrow R^0 \rightarrow R^{+/-}$

R-hadrons in CMS



SUSY early discovery potential