Galileo Galilei Institute - Firenze

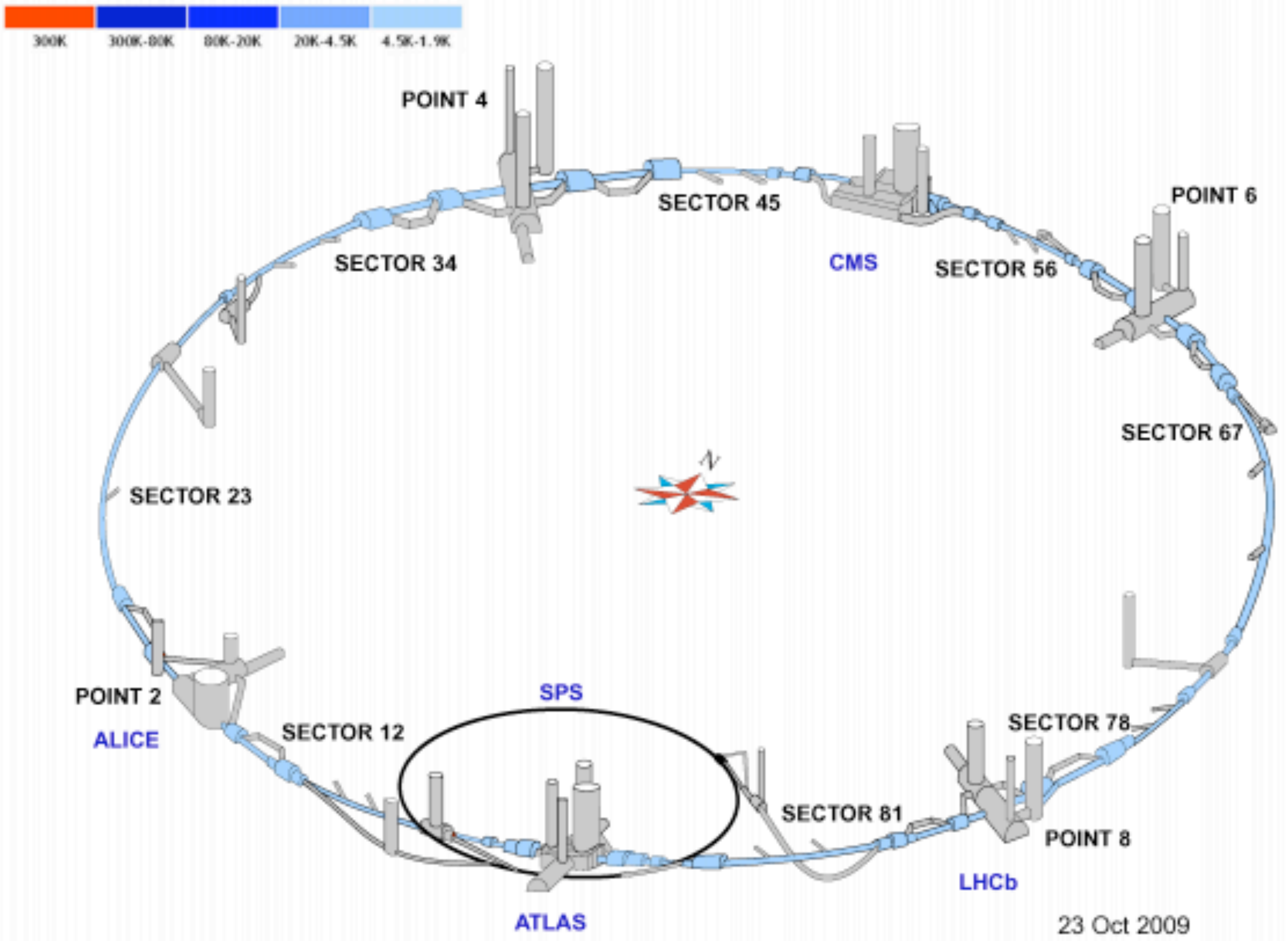
The present LHC roadmap

Firenze, 26th October 2009

Roberto Tenchini

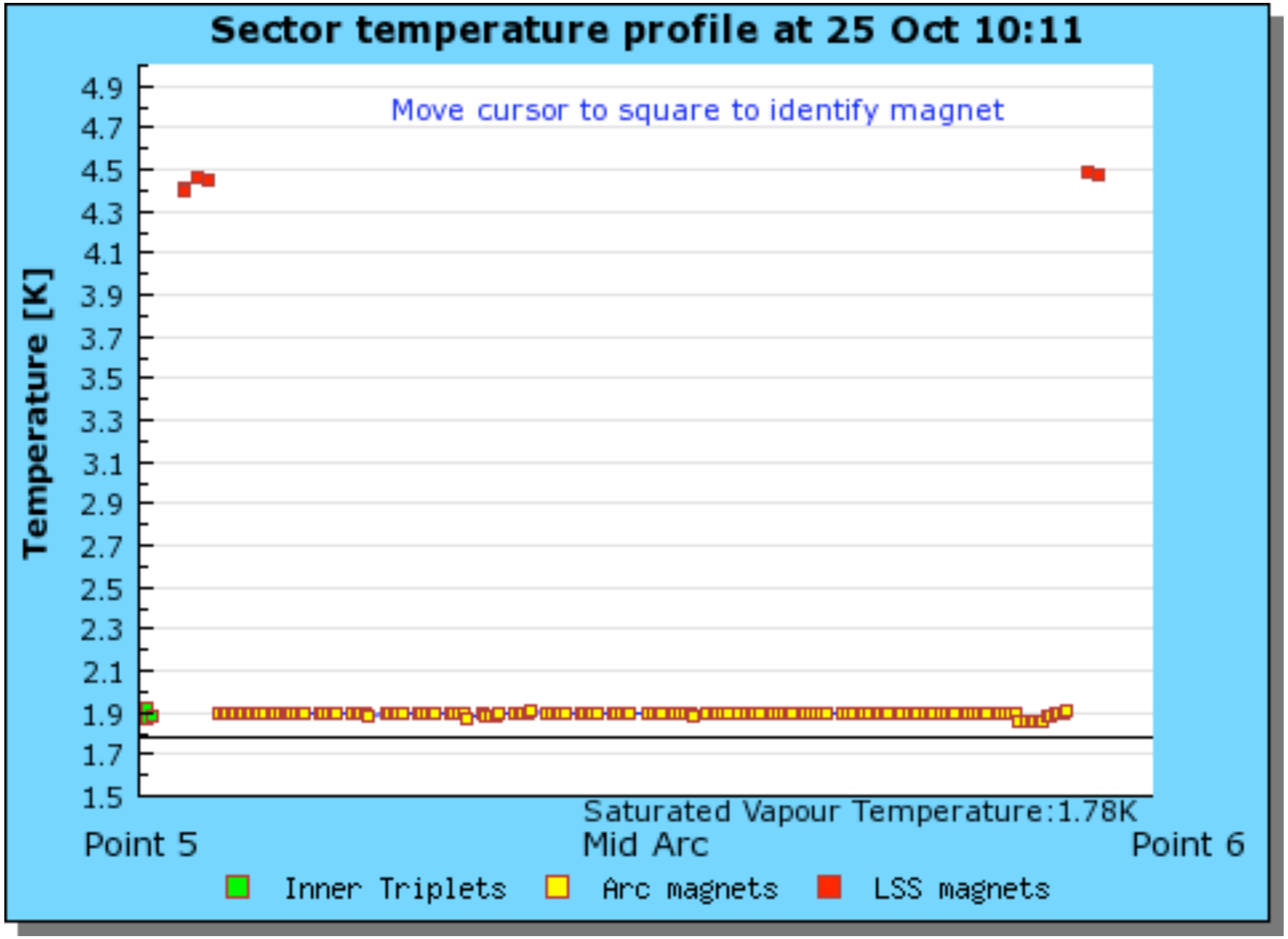
[redacted]

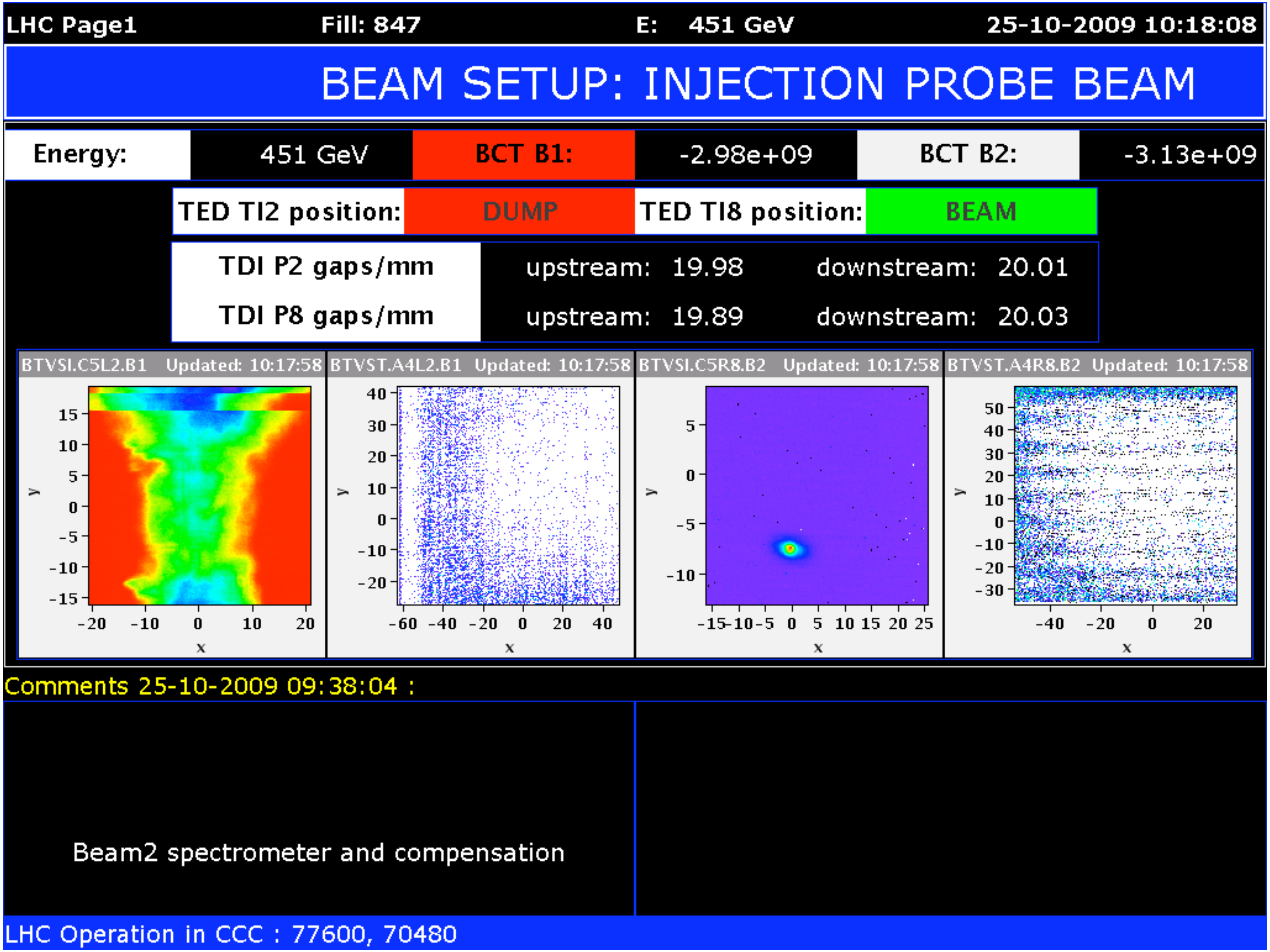
mid October 2009 : LHC is cold (again)



First attempt to inject beam: **yesterday**

All octants at 1.9 Kelvin





LHC Page1 Fill: 847 E: 451 GeV 25-10-2009 10:18:08

BEAM SETUP: INJECTION PROBE BEAM

Energy:	451 GeV	BCT B1:	-2.98e+09	BCT B2:	-3.13e+09

TED TI2 position:	DUMP	TED TI8 position:	BEAM

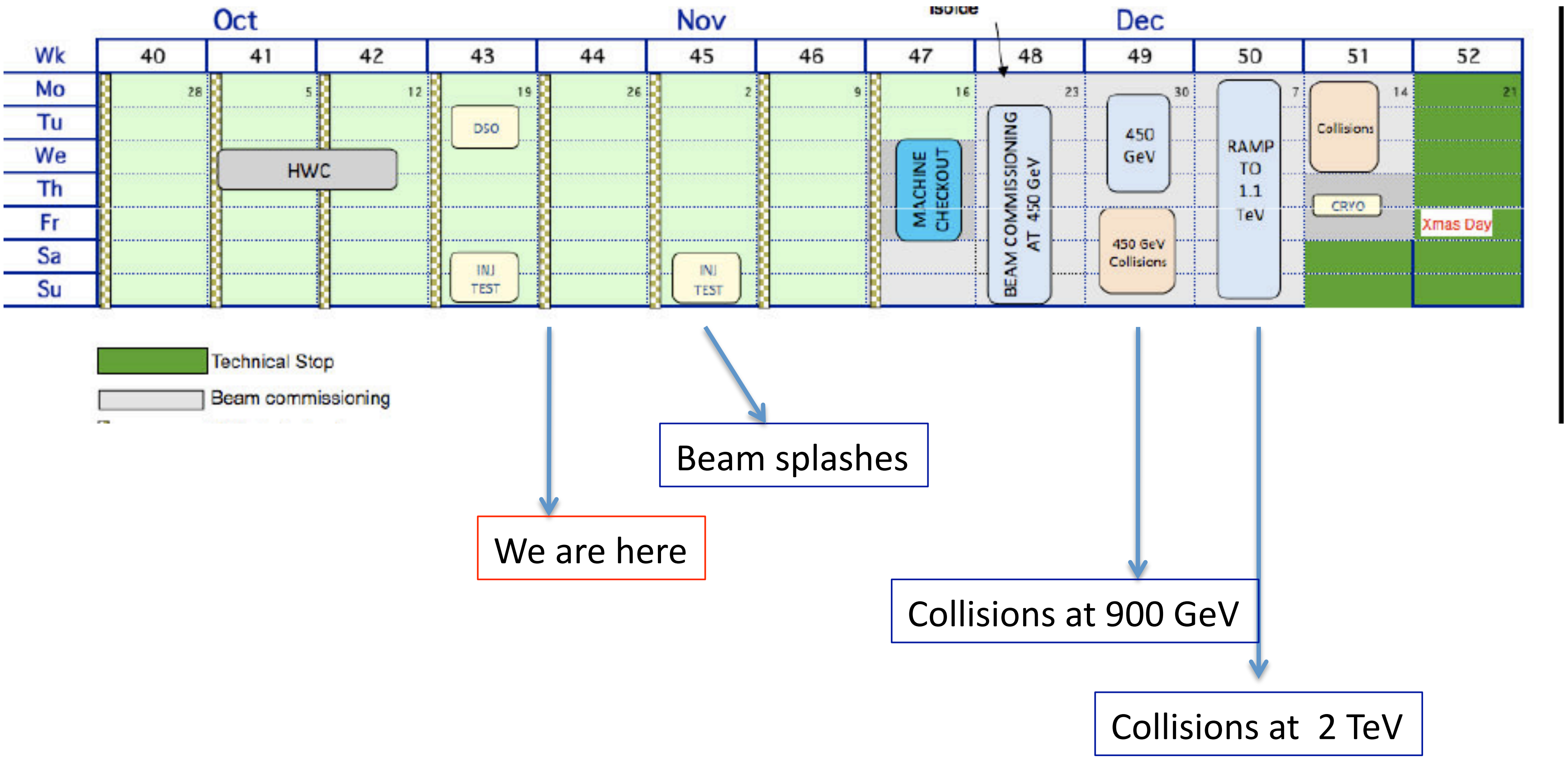
TDI P2 gaps/mm	upstream:	19.98	downstream:	20.01
TDI P8 gaps/mm	upstream:	19.89	downstream:	20.03

Comments 25-10-2009 09:38:04 :

Beam2 spectrometer and compensation

LHC Operation in CCC : 77600, 70480

The schedule before the end of the year



Isolde

		Oct				Nov				Dec			
Wk	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**
Mo	28	5	12	19	26	2	9	16	23	30 450 GeV	7 RAMP TO 1.1 TeV	14 Collisions	21
Tu				DSO					BEAM COMMISSIONING AT 450 GeV				
We		HWC						MACHINE CHECKOUT					
Th												CRYO	
Fr										450 GeV Collisions			Xmas Day
Sa				INJ TEST		INJ TEST							
Su													

🟩 Technical Stop

⬜ Beam commissioning

Beam splashes

We are here

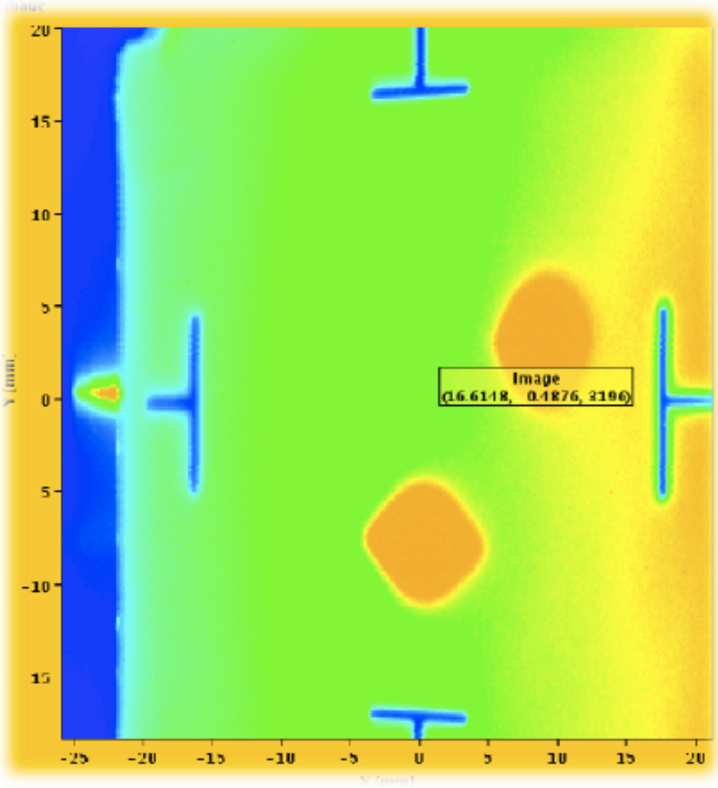
Collisions at 900 GeV

Collisions at 2 TeV

Flash back: the last 14th months

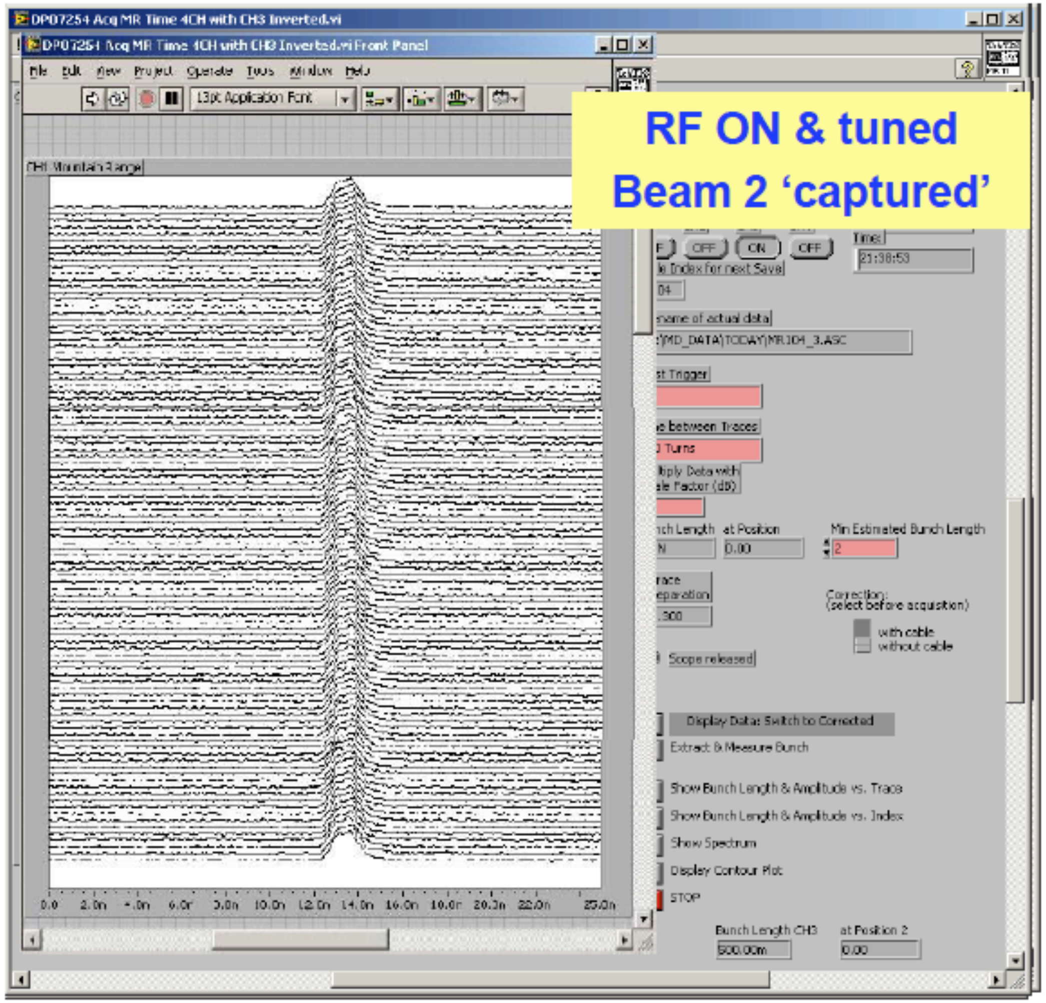
First Beam Around

Sept 10th 10:30 : two beam spots on a screen near ALICE indicate that the beam has made 1 turn.



Beam 2 captured by RF system

Evening/Night of September 11th



RF ON & tuned

Beam 2 ‘captured’

DPO7254 Acq MR Time 4CH with CH3 Inverted.vi

DPO7254 Acq MR Time 4CH with CH3 Inverted.vi Front Panel

Time: 21:38:53

ame of actual data: :\MD_DATA\TODAY\MR104_3.ASC

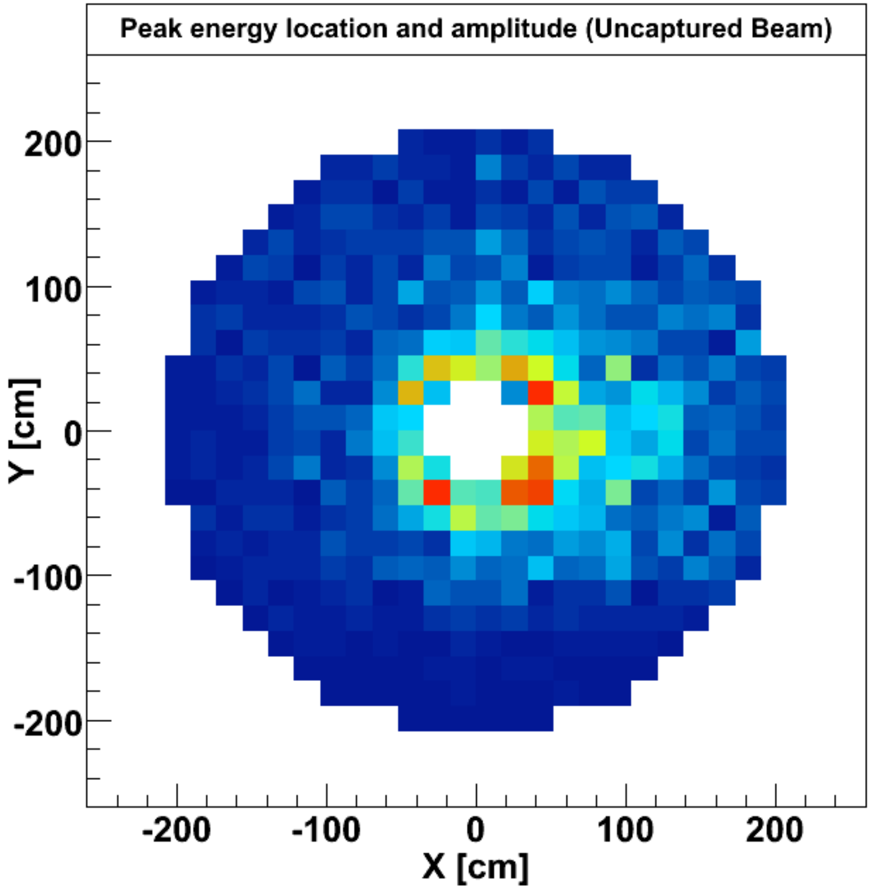
Min Estimated Bunch Length: 2

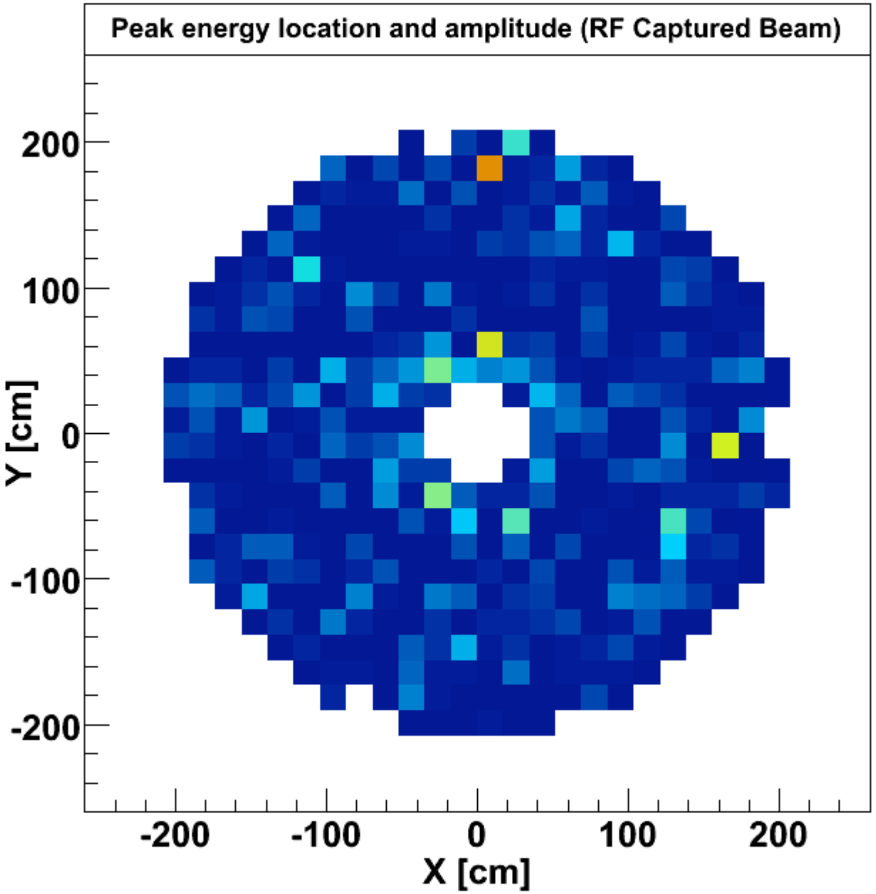
at Position: 0.00

Bunch Length CH3: 500.00m

at Position 2: 0.00

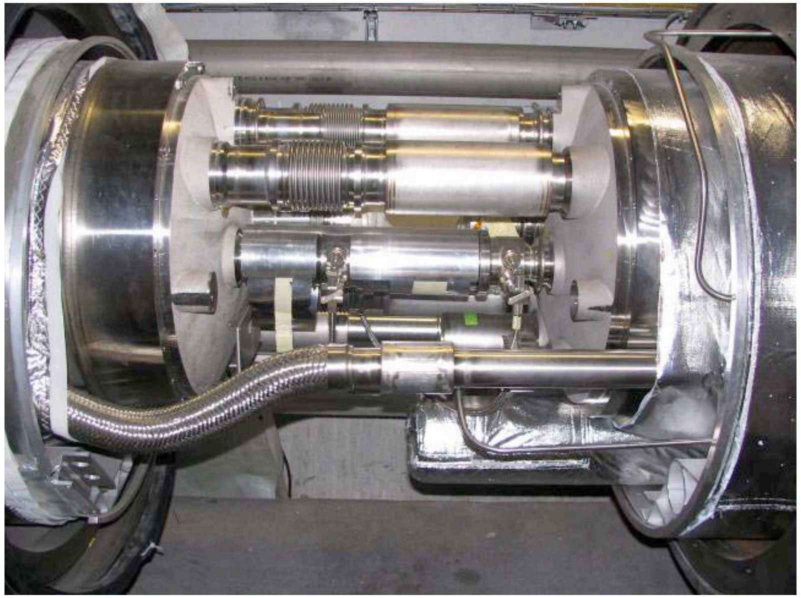
CMS HCAL Endcap Energy Before/After Capture





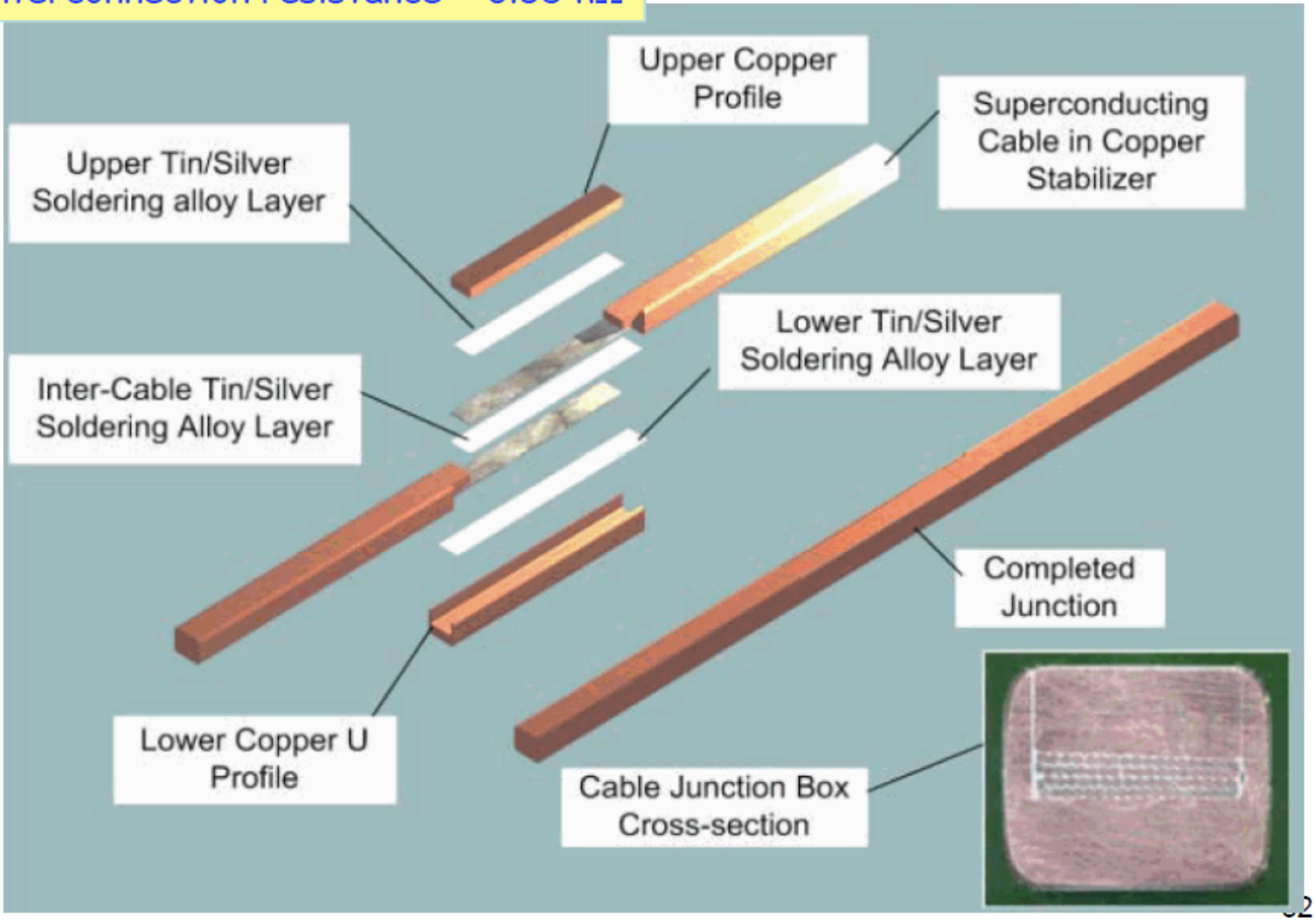
Interconnections of LHC dipoles

19 Sept. ’08, incident during hardware commissioning of sector 3/4 , at 8.7 kA or ~ 5.2 TeV, of the 600 MJ stored energy about 2/3 dissipated into the cold-mass



Busbar interconnection

Interconnection resistance ~ 0.35 nΩ



Impressive work to recover

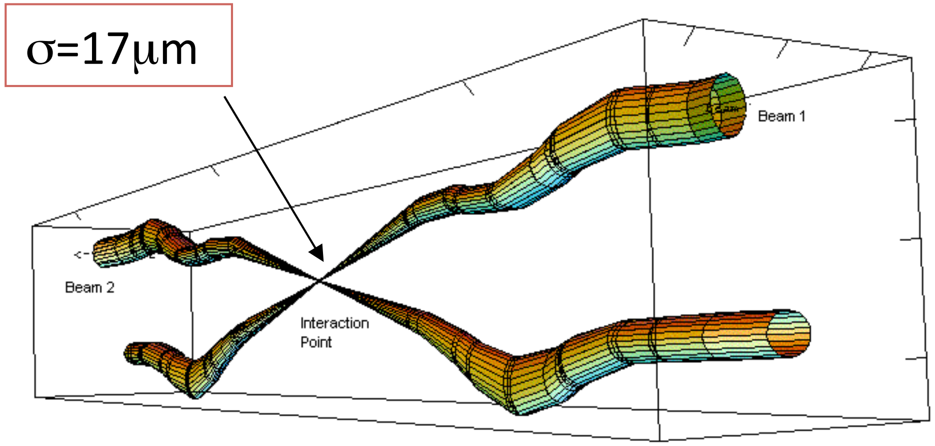
- **39 dipoles and 14 quadrupoles** removed - and re-installed. Last magnet back in tunnel on 30/04/2009, electrical connections finished 2nd June. Cleaned the beam pipe.
- **Improved diagnostics**, measurements of magnet interconnects - splice resistance
- > 50 % of machine (sectors, 1-2, 3-4, 5-6, 6-7, all standalone magnets) with fast pressure release valves
- Enhanced Quench Protection System (X2 faster)
- Improved anchoring between vacuum barrier

The LHC programme, for 2010 and next …

LHC Nominal Parameters, Beam Crossing, Luminosity

Nominal LHC parameters	
Beam energy (TeV)	7.0
Number of particles per bunch	1.15×10^{11}
Number of bunches per beam	2808
Stored beam energy (MJ)	362
Bunch spacing (ns)	25
Bunch length (cm)	7.55

σ=17μm



Relative beam sizes around IP1 (Atlas) in collision

- Crossing angle = **285 μrad**

-Luminosity = **10^{34} cm^{-2} s^{-1}**

-Integrated Luminosity per year = **100 fb^{-1}**

cross sections and rates at 14 TeV

At High Luminosity (10^{34} cm^{-2} s^{-1})

SM Higgs (115 GeV/c^2): →0.1 Hz

t t production: →10 Hz

W→ ℓ ν: →10^2 Hz

Z→ ℓ ℓ : →10 Hz

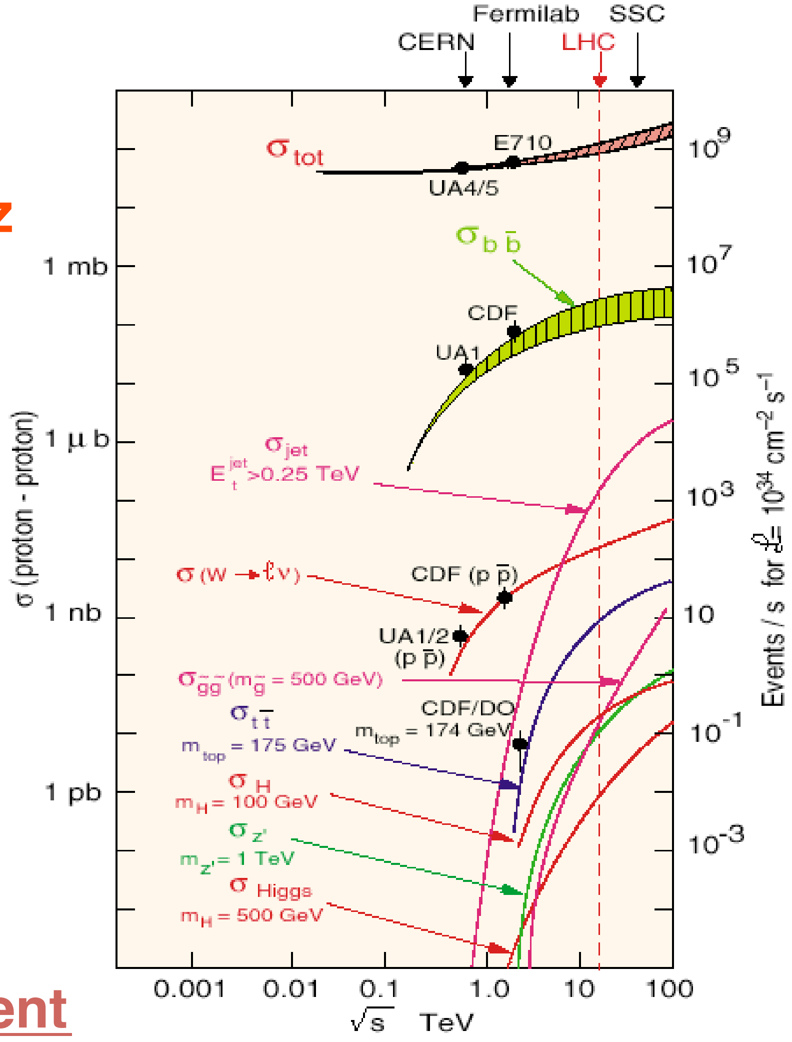
bb production: → 10^6 Hz

Inelastic: →10^9 Hz

Beam crossing every 25 ns

25 pileup event / beam crossing

(at High Luminosity)



<u>**Experiments: need stringent and efficient online selection criteria (trigger)**</u>

The first LHC physics run

Three steps

1. collisions at injection energy, 2 beams ~ 0.45 TeV = 0.9 TeV

2. physics run at 2 beams ~ 3.5 TeV = 7 TeV

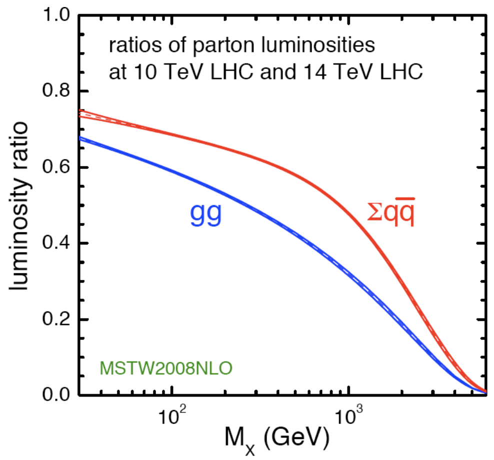
3. physics run at increased energy, max. 2 beams ~ 5 TeV = 10 TeV

Likely programme for the LHC first run

(Courtesy Mike Lamont)

Month	OP scenario	Max number bunch	Protons per bunch	Min beta*	Peak Lumi	Integrated	% nominal	events/X
1	Beam commissioning							
2	Pilot physics combined with commissioning	43	3 x 10^{10}	4	8.6 x 10^{29}	~200 nb^{-1}	3.5 TeV Per BEAM	
3		43	5 x 10^{10}	4	2.4 x 10^{30}	~1 pb^{-1}		
4		156	5 x 10^{10}	2	1.7 x 10^{31}	~9 pb^{-1}		
5a	No crossing angle	156	7 x 10^{10}	2	3.4 x 10^{31}	~18 pb^{-1}		
5b	No crossing angle – pushing bunch intensity	156	1 x 10^{11}	2	6.9 x 10^{31}	~36 pb^{-1}		
6	Shift to higher energy: approx 4 weeks	Would aim for physics without crossing angle in the first instance with a gentle ramp back up in intensity						
7	4 – 5 TeV (5 TeV luminosity numbers quoted)	156	7 x 10^{10}	2	4.9 x 10^{31}	~26 pb^{-1}	4 - 5 TeV Per BEAM	
8	50 ns – nominal crossing angle	144	7 x 10^{10}	2	4.4 x 10^{31}	~23 pb^{-1}		
9	50 ns	288	7 x 10^{10}	2	8.8 x 10^{31}	~46 pb^{-1}		
10	50 ns	432	7 x 10^{10}	2	1.3 x 10^{32}	~69 pb^{-1}		
11	50 ns	432	9 x 10^{10}	2	2.1 x 10^{32}	~110 pb^{-1}		

14, 10, 7 TeV cross section ratios



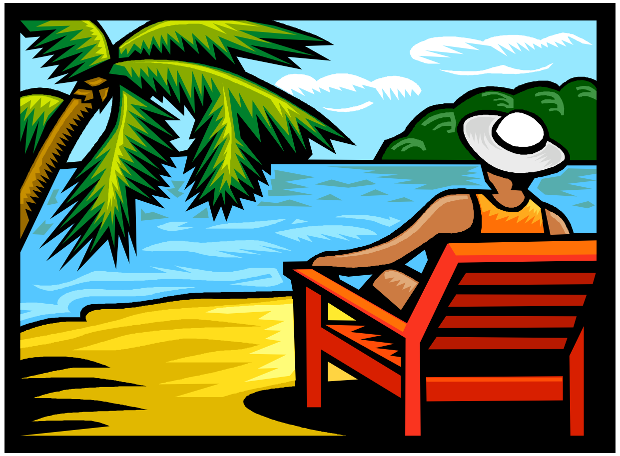
Process	σ(10TeV)/σ(14TeV)	σ(7TeV)/σ(10TeV)
H (m=160)	0.54	0.50
WW, ZZ, WZ	0.65	0.62
tt	0.45	0.39
tW	0.45	0.39
W, Z	0.68	0.66

Typical statistics for the 7 TeV run

- Assume 20 pb-1, include acceptance, initial reconstruction and id efficiency
- Can establish Standard Model cross sections and distributions
- Can use to calibrate, align detectors

min bias	10^{12}
Jet Et>25	$3.\ 10^{10}$
Jet Et>100	$3.\ 10^{6}$
γ+Jet Et>20	$3.\ 10^{6}$
W ->$l\nu$	40000
Z -> ll	4000
tt-> $l\nu$4q	100

The experiments: we didn’t spend the last year in vacation …

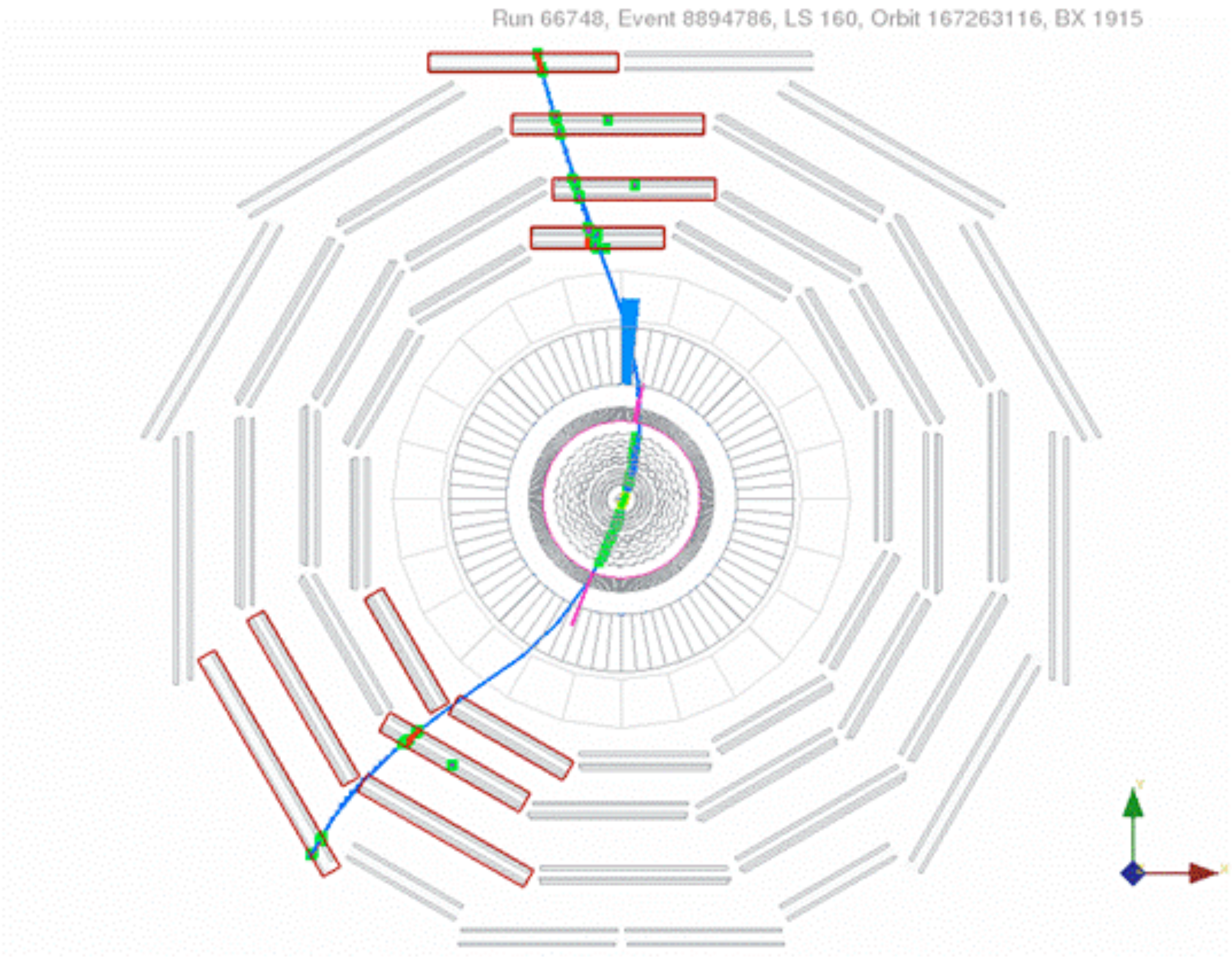


Physics Commissioning: two main phases

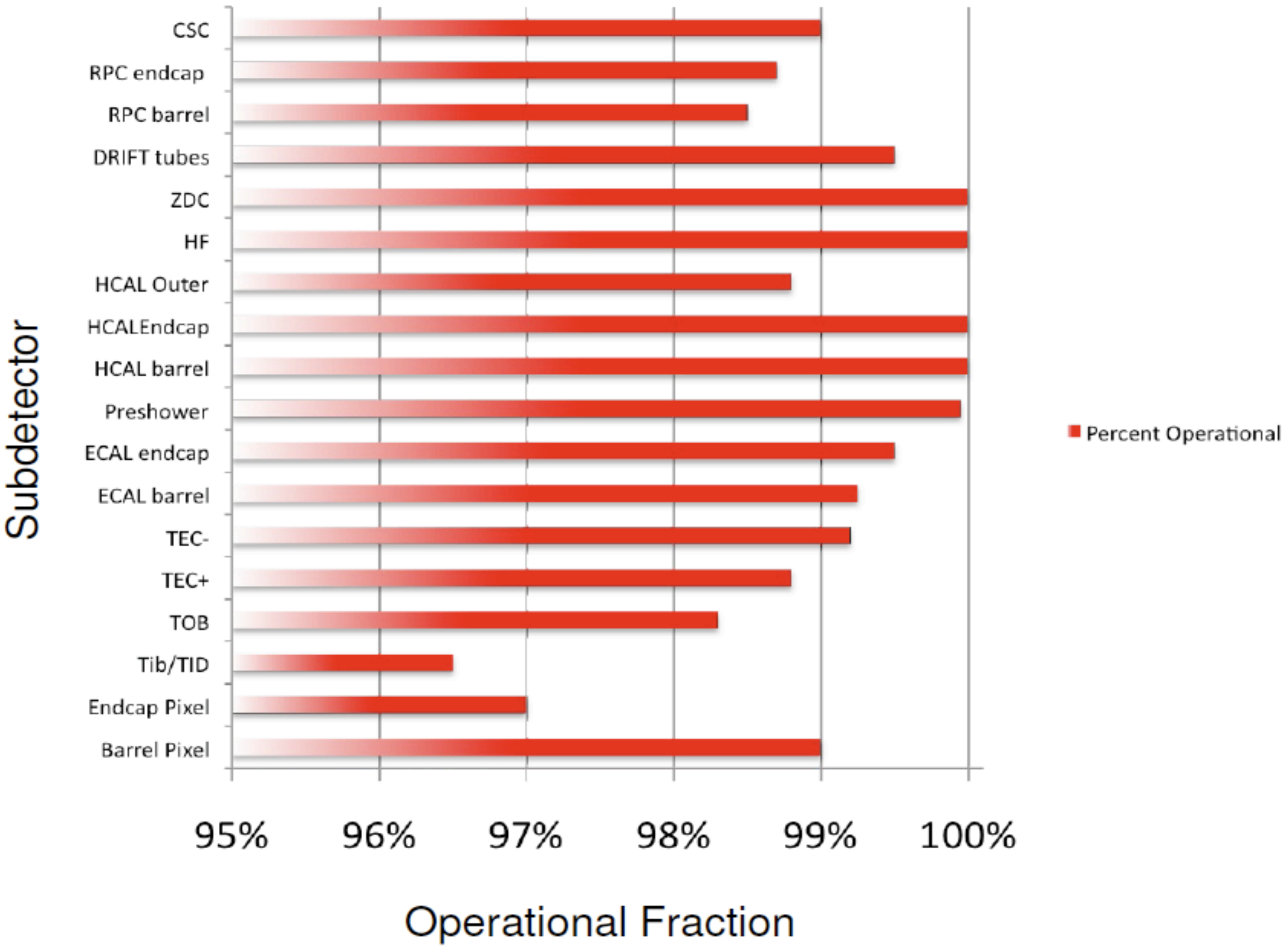
- Before data taking starts:
  - Understand and calibrate the detectors with test beams, cosmics, surveys, B-field measurements, etc.
  - Prepare software tools: simulation, reconstruction, calibration and alignment procedures
- With the initial LHC data:
  - Commission and calibrate in situ detector and trigger with physics samples
  - Understand Standard Model physics at 7, 10 and 14 TeV
  - Measure background to New Physics

→ **Prepare the road to discoveries**

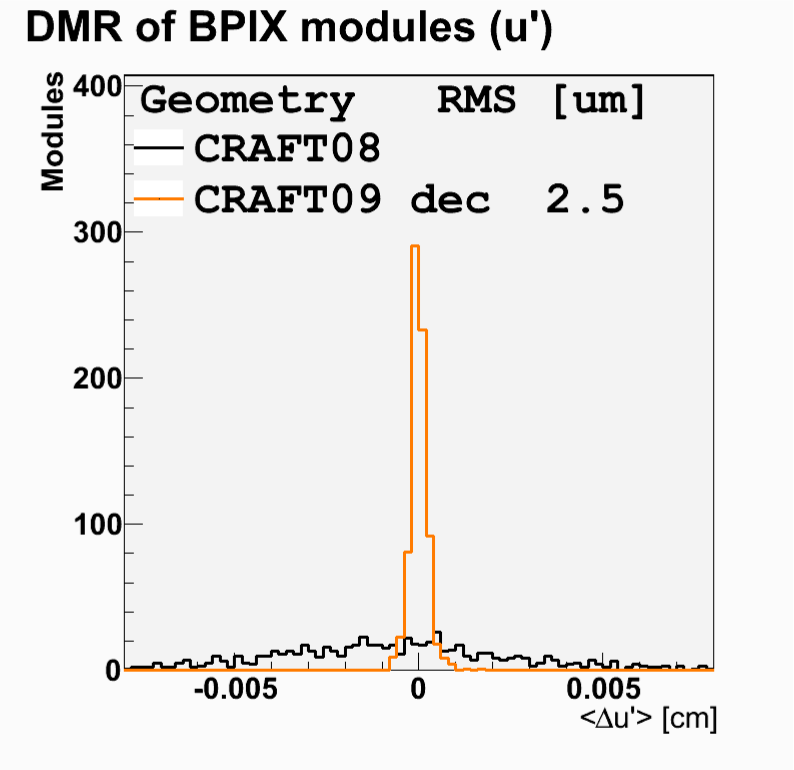
Collected huge statistics of cosmic rays
proven invaluable to understand apparatus



Detector Status in CRAFT09



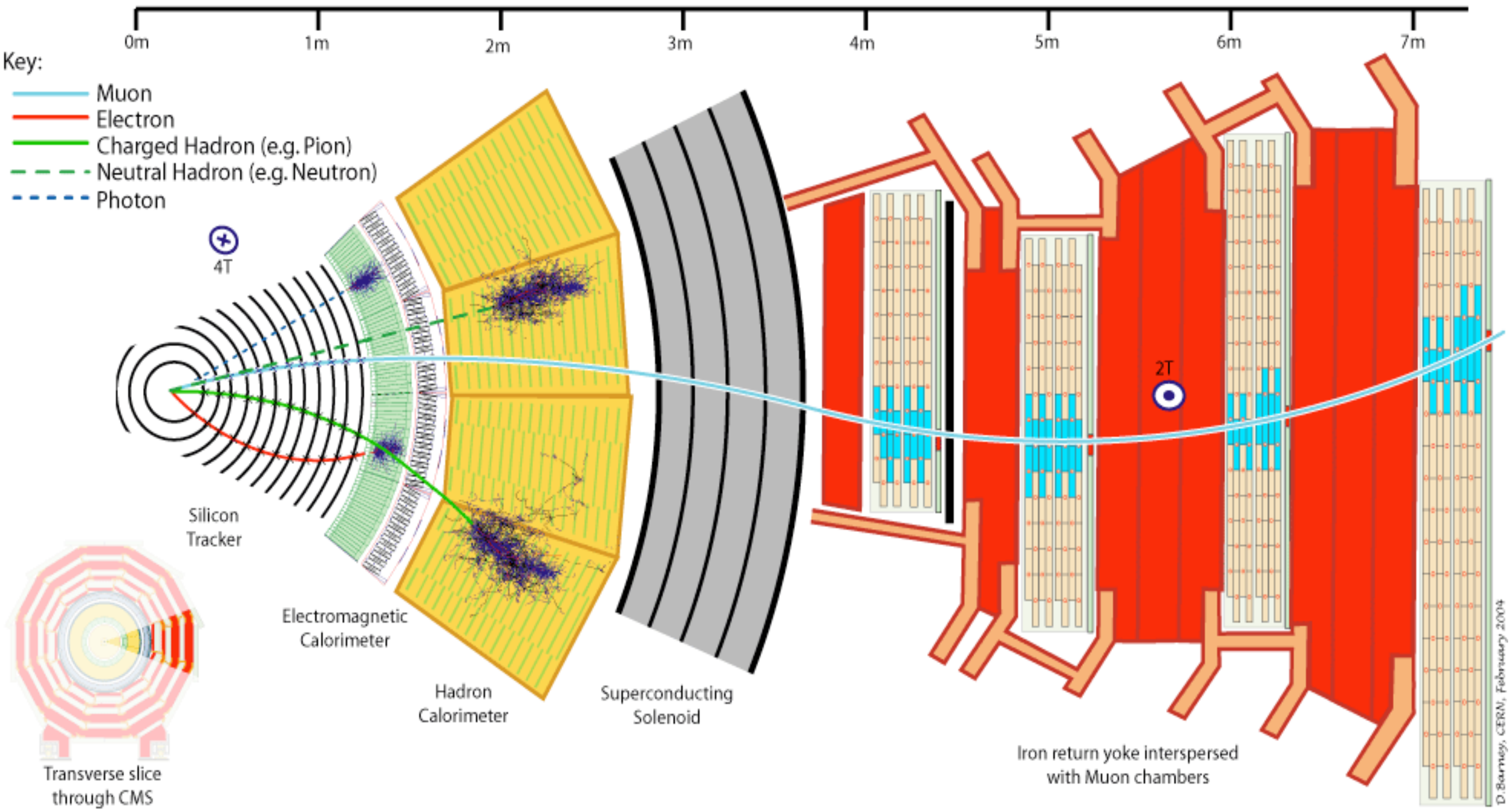
Achieved Tracker alignment similar to the one initially expected after tenth of pb-1



RMS of DMR (µm)		# of aligned modules
BPIX (x)	2.5	761/768
BPIX (y)	4	
FPIX (x)	13	539/672
FPIX (y)	13	
TIB	3	2555/2724
TOB	3	5102/5208
TID	4	808/816
TEC	8	6346/6400

Example: Distribution of the Median of Residuals for barrel pixels

Measuring the field in the return yoke



Probing the B field with Cosmic muons

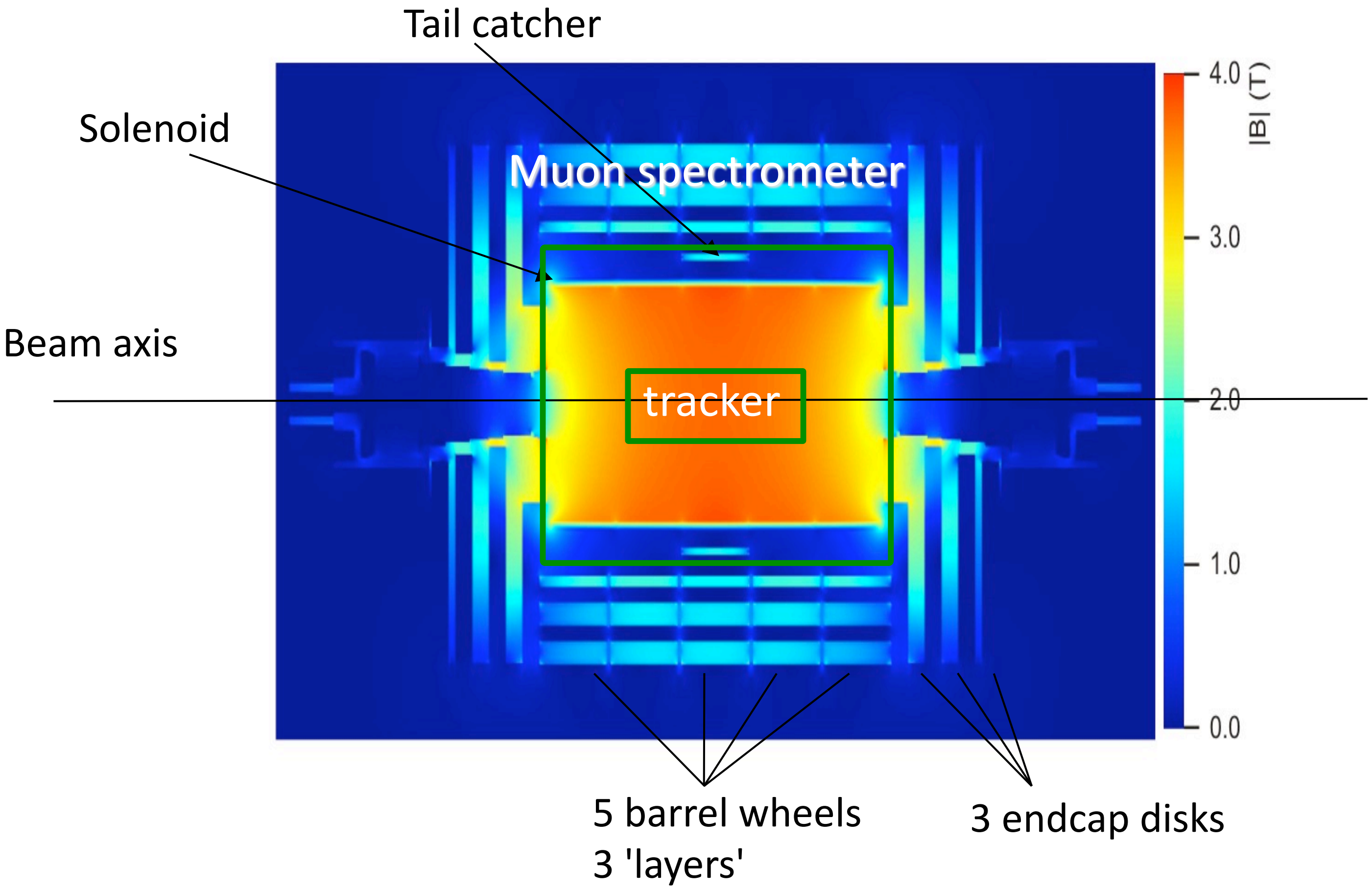
1. The field in the tracker region is known with great precision (<0.1%), thanks to field mapper measurements (MTCC) and NMR probes, see e.g.

“Measurement of the CMS Magnetic Field”, V. I. Klyukhin et al, IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 18, NO. 2, JUNE 2008 http://klyukhi.web.cern.ch/klyukhi/conferences/IEEE_ASC_18_2_2008_295_298.pdf

2. The field in the iron layers of the return yoke (muon spectrometer) is

a) more complex
b) harder to measure
c) harder to model

3. With cosmic muon tracks from CRAFT we could probe for the first time the B field in the iron of the yoke directly and with great precision, by comparing the bending of muon tracks In the muon spectrometer with the momentum measured in the tracker



Tail catcher

Solenoid

Beam axis

5 barrel wheels
3 'layers'

3 endcap disks

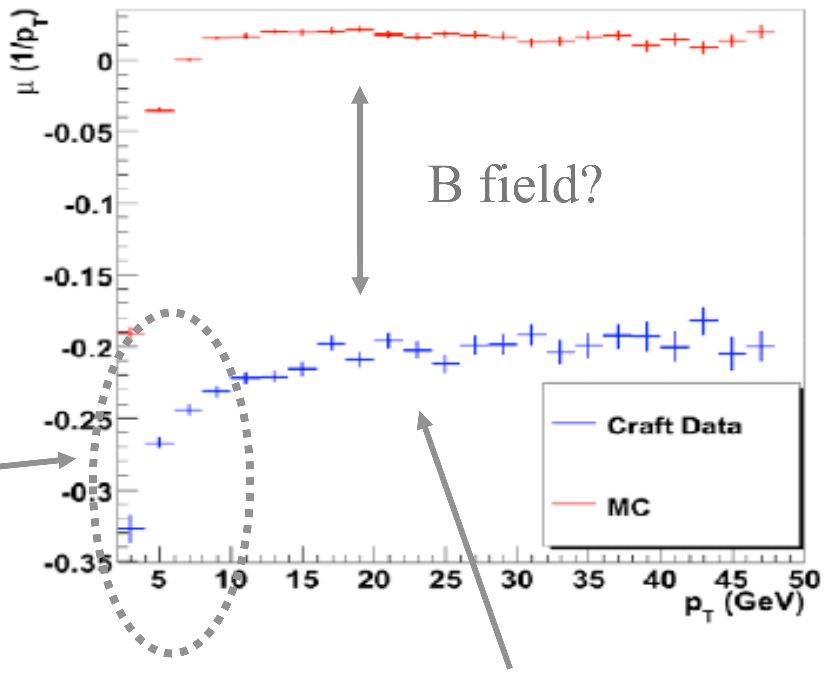
First Indications during CRAFT

Plotted is the mean value of Gaussian fit to R (vs tracker track pT):

$$R = \frac{1/p_T^{STA} - 1/p_T^{TT}}{1/p_T^{TT}}$$

Structure at low pT probably related to material effects not fully corrected for in this preliminary plot

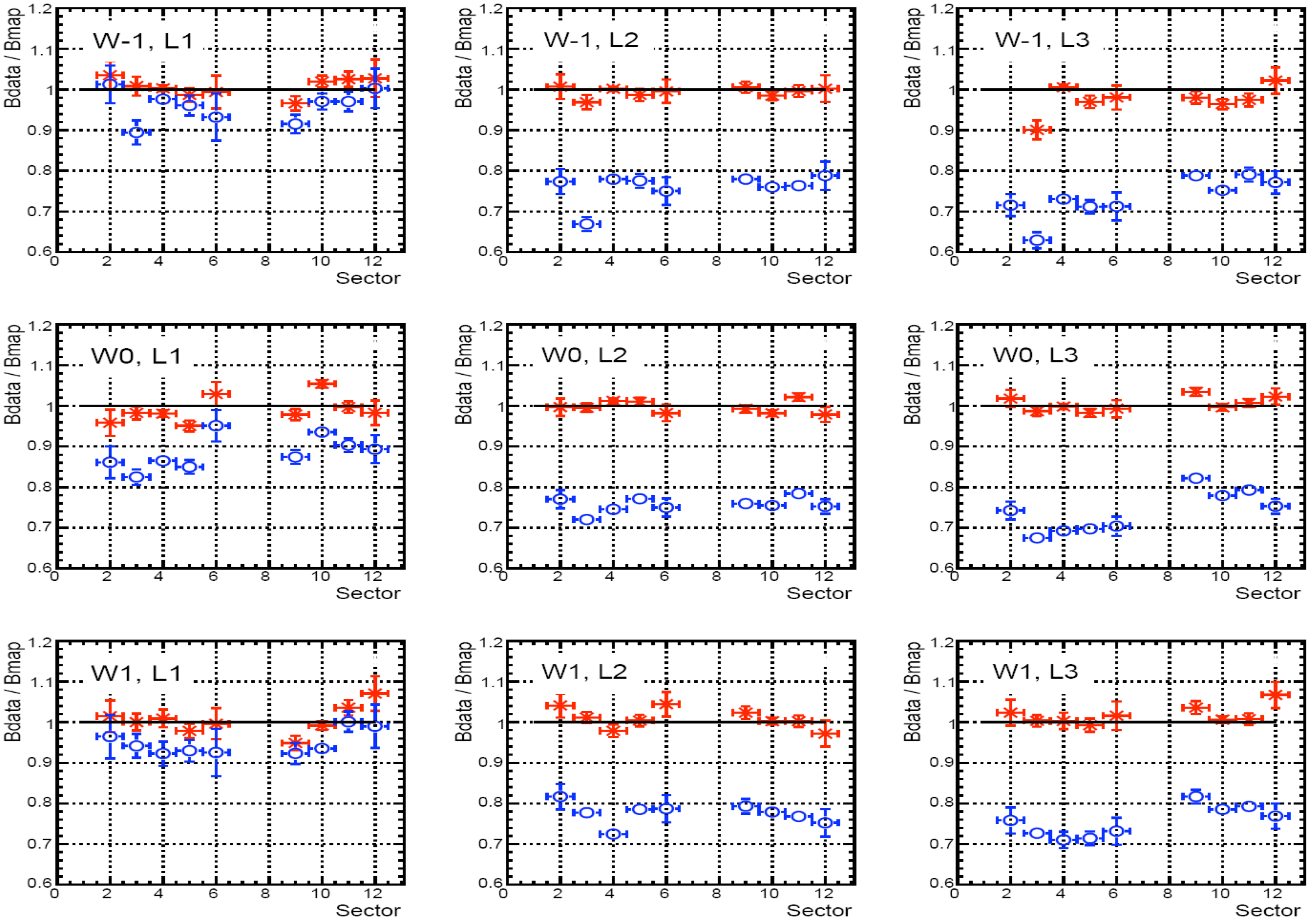
Observed during CRAFT (Oct-Nov 2008)



~20% difference in momentum scale between Stand-alone muon (STA) and tracker-track (TT) fit ~constant from 10 to 50 GeV indicates a possible difference in B scale of the order of 20% (!)

Improvement from OLD to NEW B field

B_{data}/B_{map}



Cosmic Track Finding Efficiency

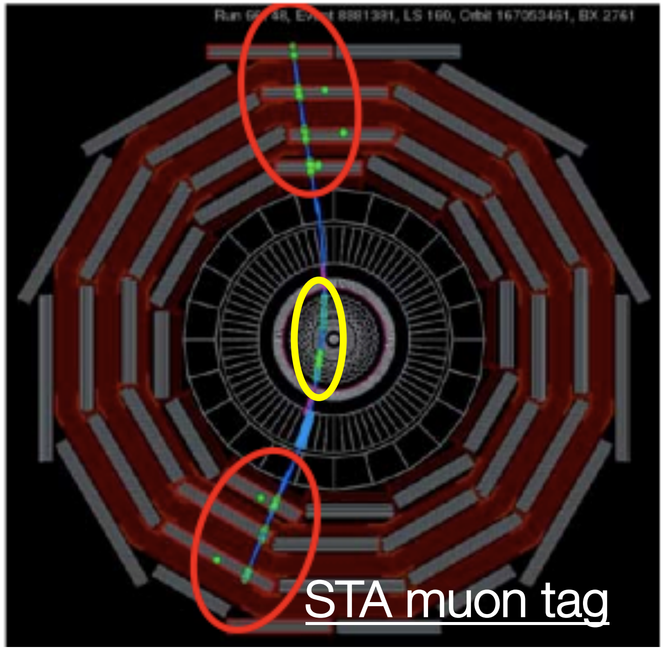
Tag and Probe method

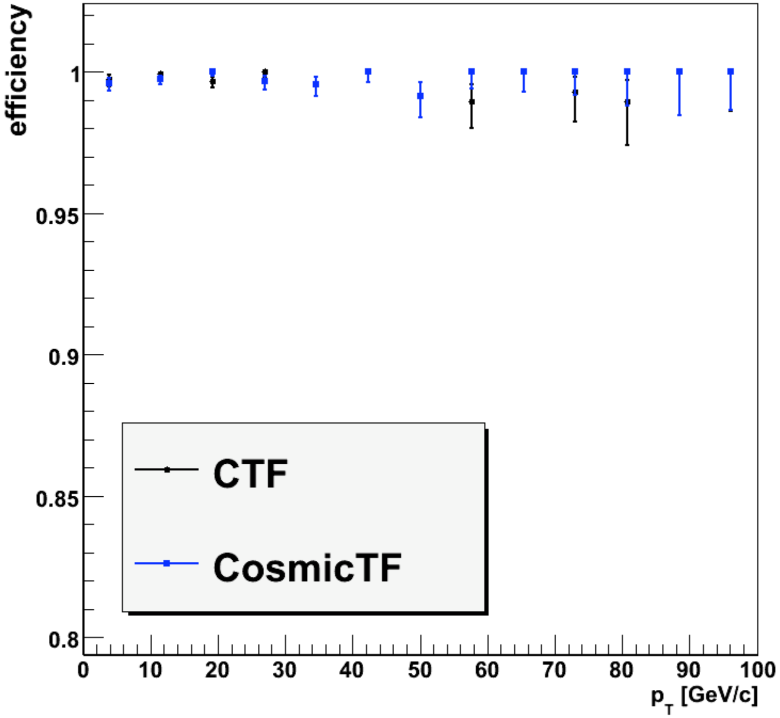
- Tag : Stand alone muons

|dz| < 30cm, |dxy| < 30cm, |eta| < 1, 0.5 < |phi| < 2.5
(at point of closest approach)

- Probe : Tracker reconstructed muons

Combinatorial Track Finder (collision algorithm with special outside-in seeding)
Cosmic Track Finder dedicated algorithm





Efficiency (%)	CRAFT 09
CTF	99.8±0.1
CosmicTF	99.8±0.1

Hcal Noise in CRAFT09

HPD noise reduced by factor ~2 in CRAFT09 vs. CRAFT08 *(for a 50 fC 10 GeV threshold)*

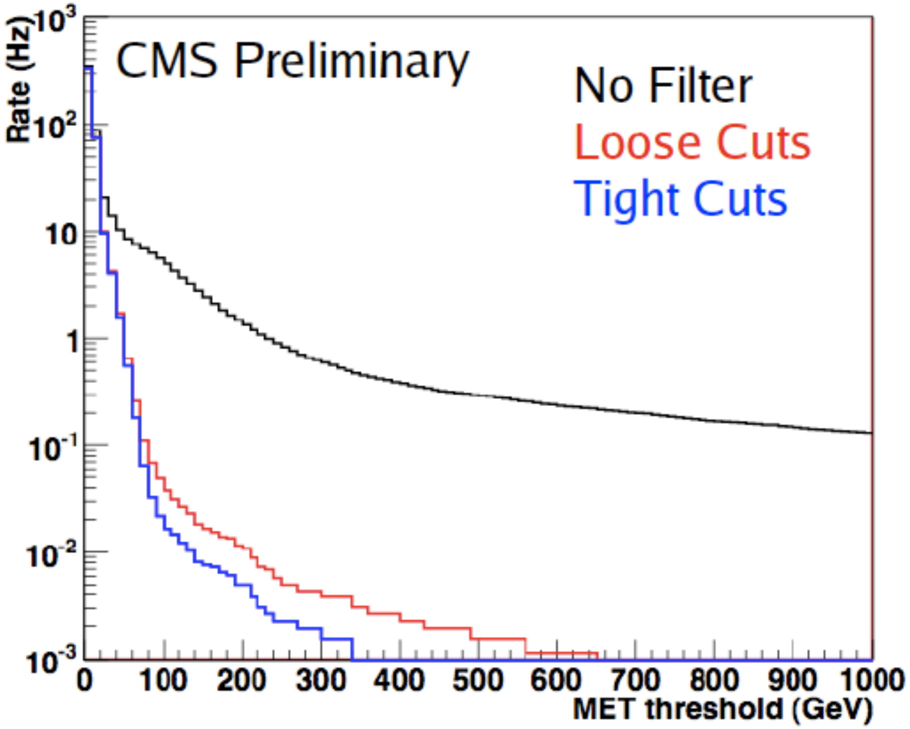
- *Replaced noisiest HPDs during shutdown*
- *HB/HE HV lowered from 7.5 kV to 7.0 kV (decreasing gain by ~12%)*

HPD Noise Rates*	0 T	3.8 T
CRAFT 08†	0.27 Hz	0.29 Hz
CRAFT 09	0.14 Hz	0.16 Hz

* HPD mean noise rate in HB/HE for a 50 fC threshold

† 7 noisiest HPDs are not included, and were replaced during shutdown

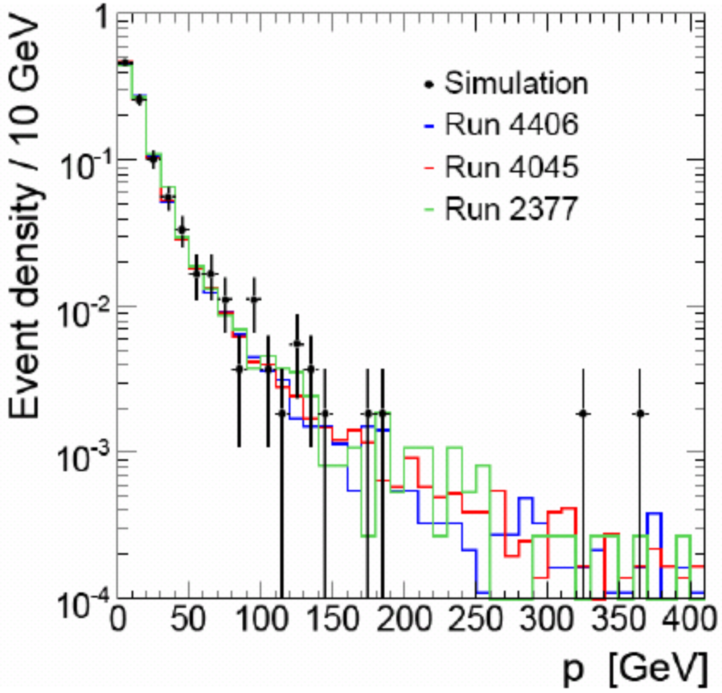
Noise-induced missing E_T rate



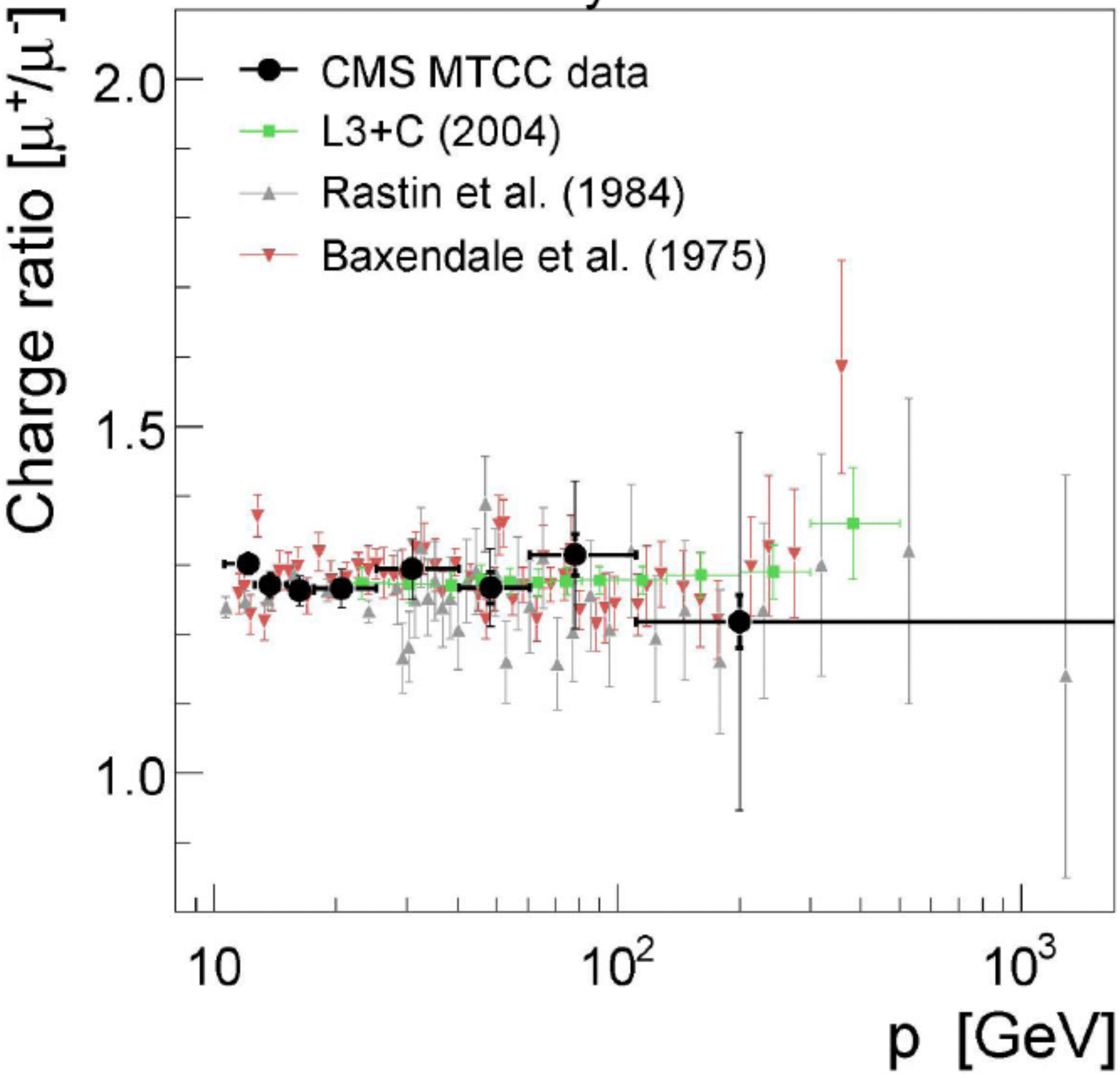
Noise filter uses:

- *Pulse shape*
- *Hit multiplicity*
- *Timing*

MTCC: Cosmic Charge Ratio Measurement



CMS NOTE-2008/016
DT Muon system measurement



Such measurements push on getting calibration and alignment correct

Conclusion from Cosmic campaign

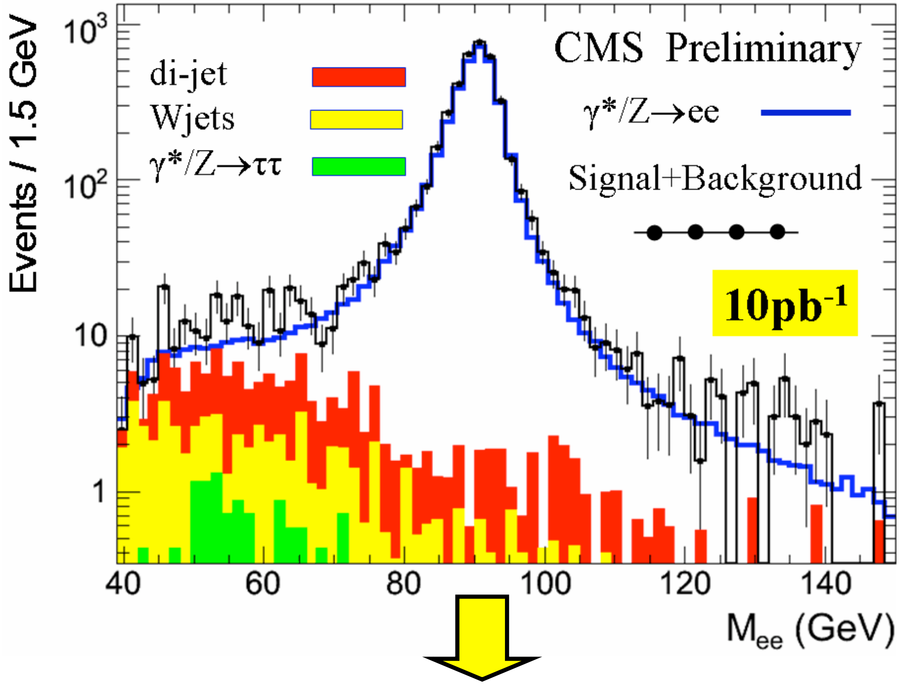
- The detectors are in excellent shape
  - Achieved calibration <u>sufficient for first physics</u>
- Integration of various subsystems
  - Global runs regularly taking place
  - Pre-synchronization
  - Trigger commissioning with cosmics

→ Collisions are next step !

Stategy for Initial Physics

- A. Identify Standard Model process and measure Cross Section
- B. Utilize Standard Model Signal to measure efficiencies and background from data
- C. Search for New Physics with similar signature

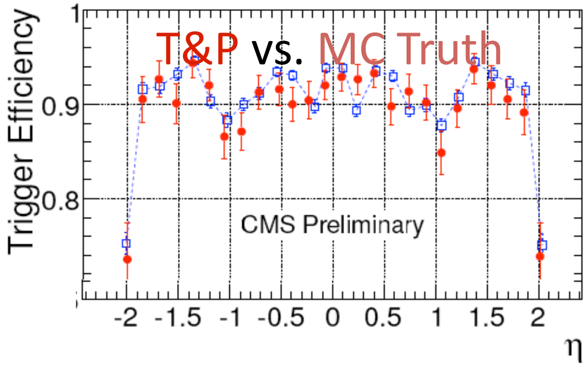
$Z \rightarrow ee/\mu\mu$ and $W \rightarrow e\nu/\mu\nu$

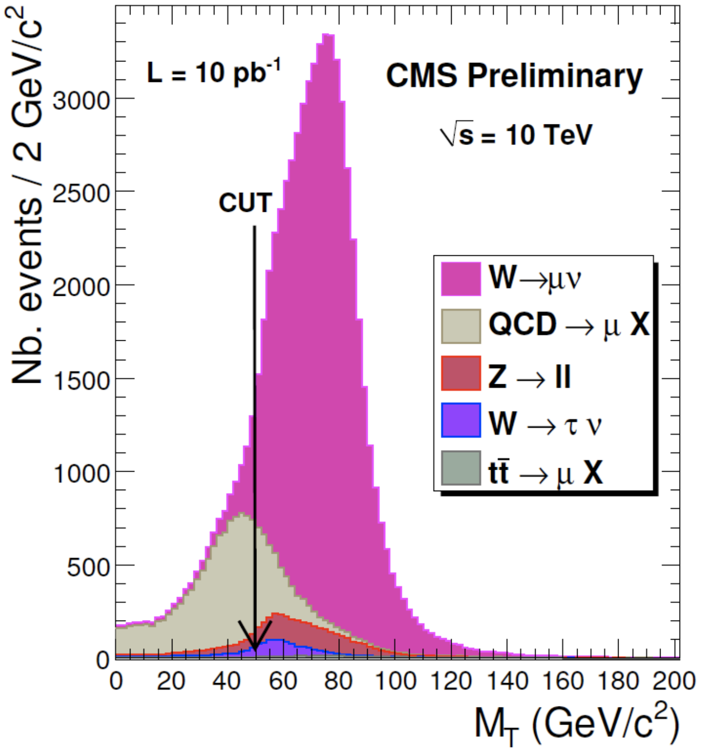


A. The Z and W cross sections are predicted to ~ 5%
   - Can be used to check luminosity
   - Z, W production properties useful to constraint the PDF

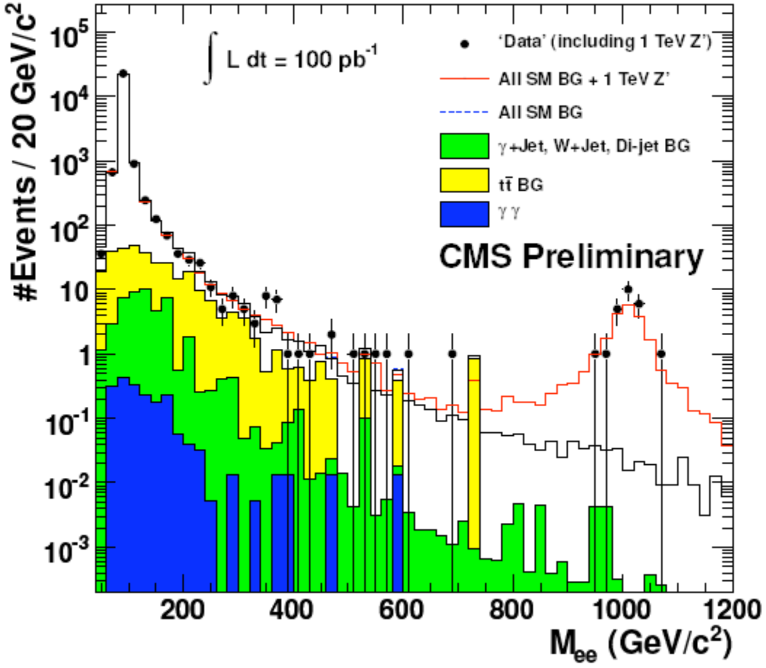
B. Powerful tools for lepton id commissioning
   - Tag & probe methods to determine efficiency from data

Also background determined from data, e.g. inverting isolation criteria

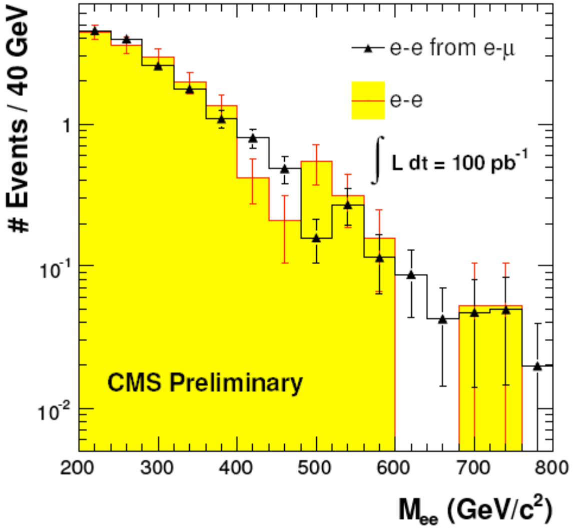




Same Topology: Search for high mass dilepton resonances



- Lepton id efficiency from tag&probe
- Irreducible Drell Yan background can be fitted
- ttbar background can be estimated from data using b-tagging or different-flavour dileptons

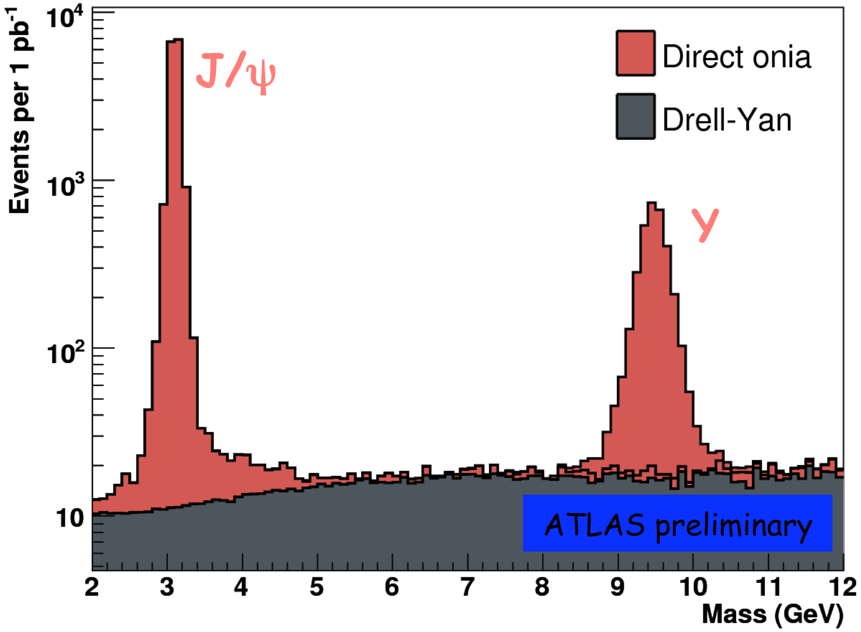


J/psi and Y are also on the list

Atlas example, after all cuts:
~ 4200 (800) J/ψ (Y) → μμ evts per day at L = 10^{31}
(for 30% machine x detector data taking efficiency)
~ 15600 (3100) events per pb^{-1}

→ tracker momentum scale, trigger performance,
detector efficiency,
sanity checks, …

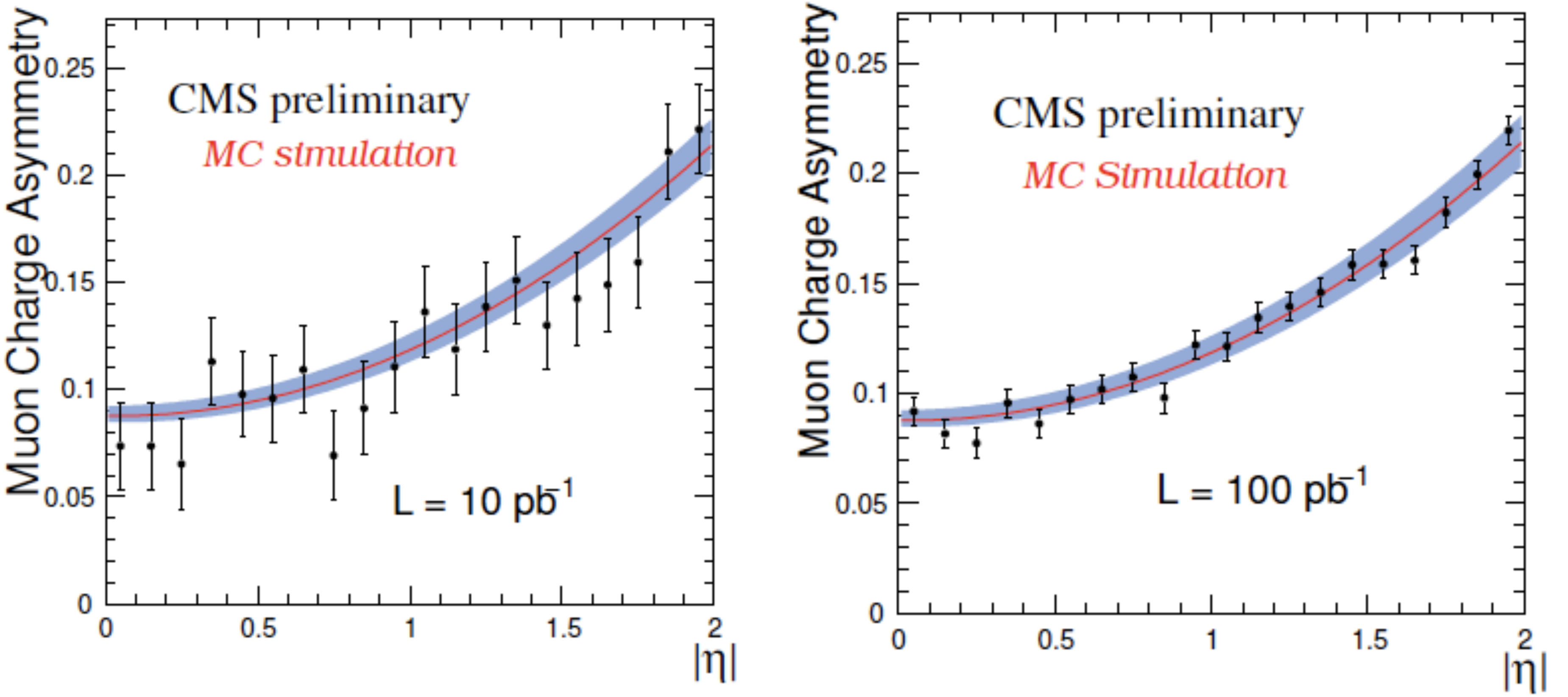
1 pb^{-1}≡3 days at 10^{31} at 30% efficiency



Need to establish Heavy Quark cross section at 7, 10, 14 TeV from first data !

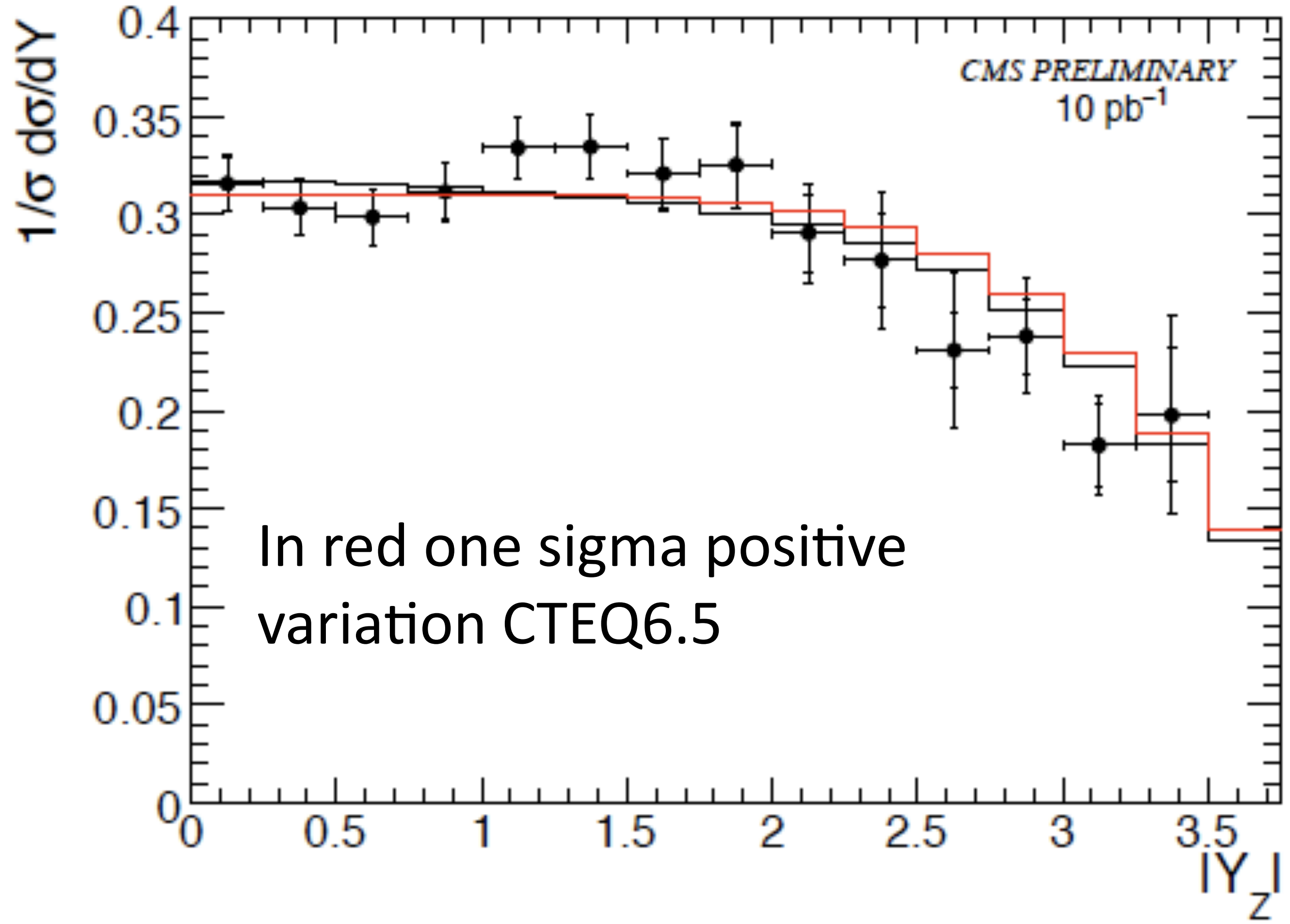
Constraining the pdf: W charge asymmetry

Plots for 10 TeV



Constraining the pdf:
Z rapidity distribution

Plot for 10 TeV

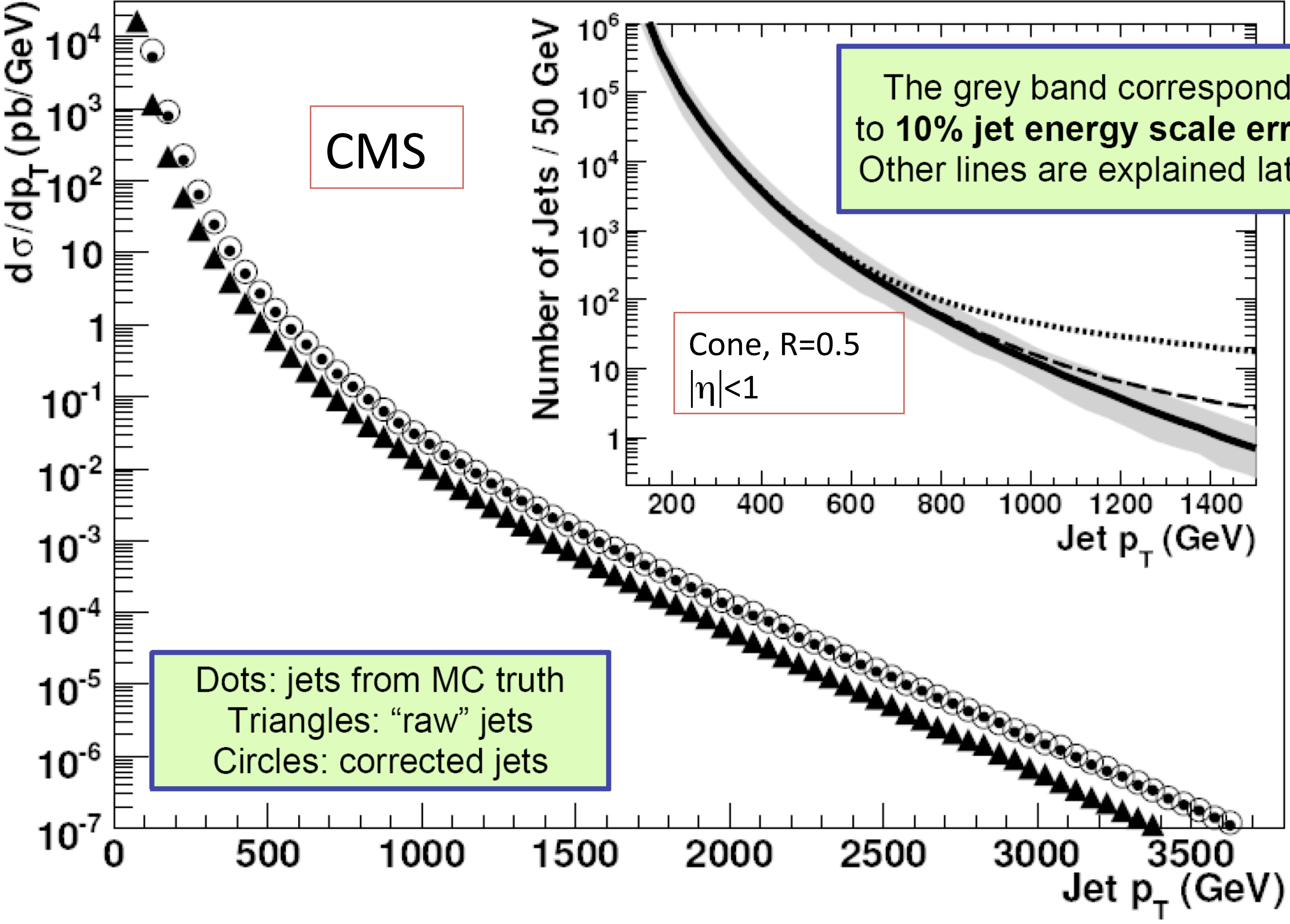


In red one sigma positive variation CTEQ6.5

Jets, 10/pb

Plots for 14 TeV

Measure inclusive jet cross section



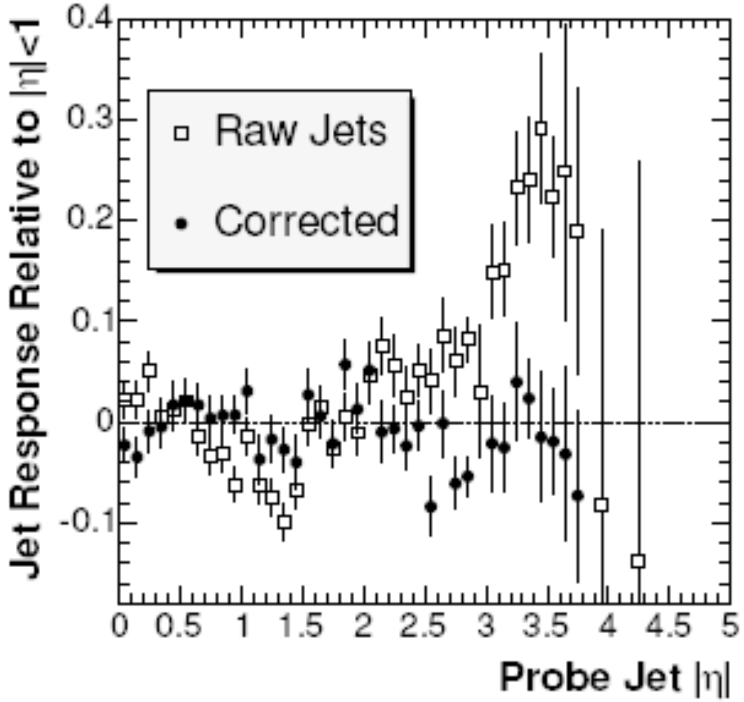
CMS

The grey band corresponds to **10% jet energy scale error**. Other lines are explained later.

Cone, R=0.5
$|\eta|<1$

Dots: jets from MC truth
Triangles: “raw” jets
Circles: corrected jets

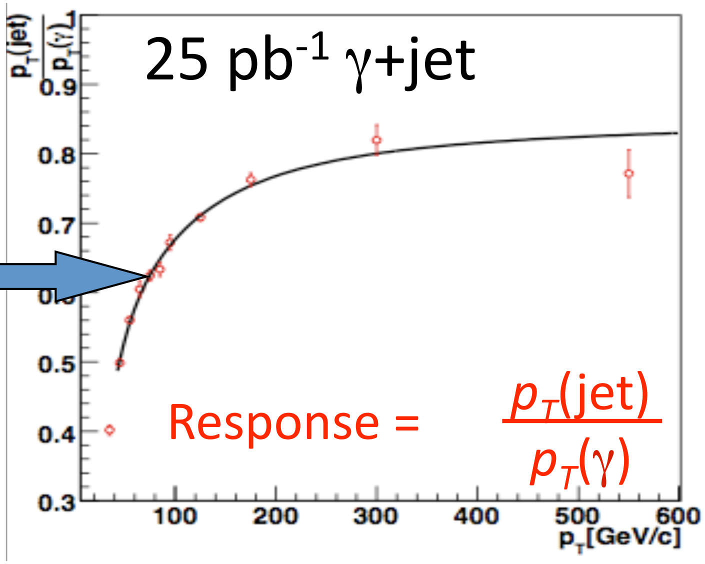
Jet Equalization with dijet balancing



- •We can quickly equalize at " low Et" until we run out of statistics
- One must assume equalization holds at higher energy (but data vs MC needed for this)

Absolute energy scale:

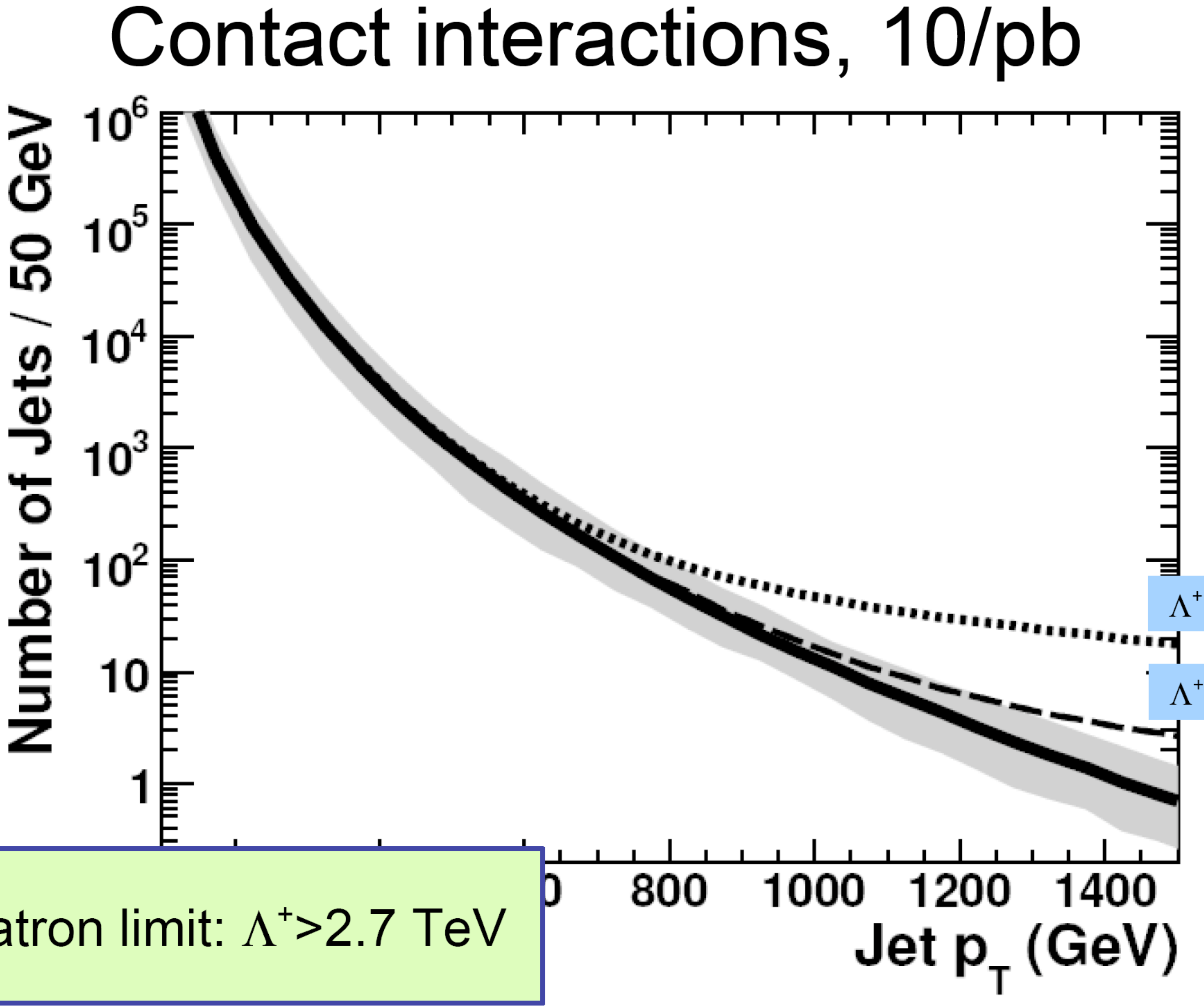
- we start with a ~ 10% uncertainty
- γ+jet, W's from ttbar will help constraining further and further



25 pb^{-1} γ+jet

Response = $\frac{p_T(\text{jet})}{p_T(\gamma)}$

Search for New Physics with di-jets:

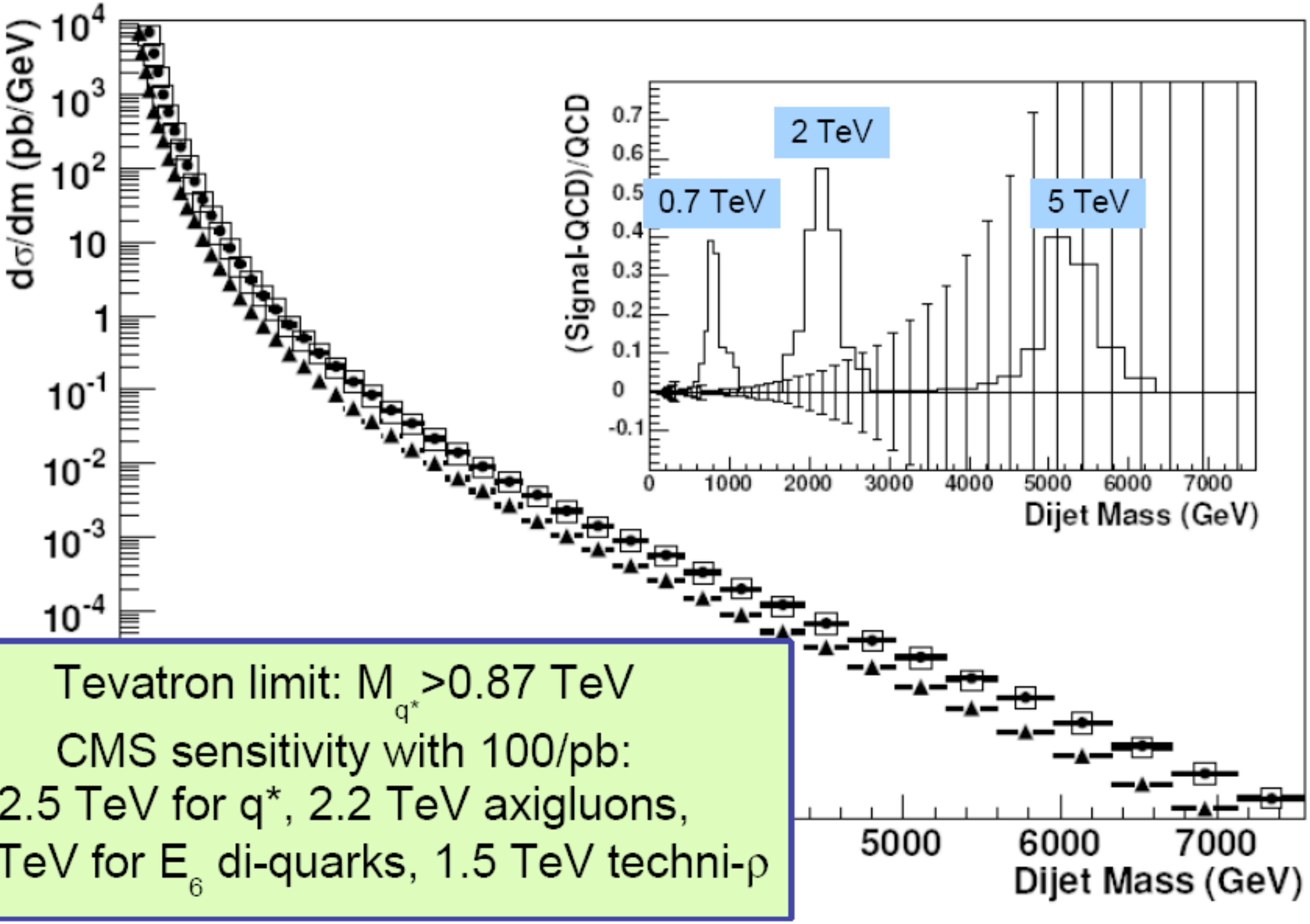


Λ^{+}=3 TeV

Λ^{+}=5 TeV

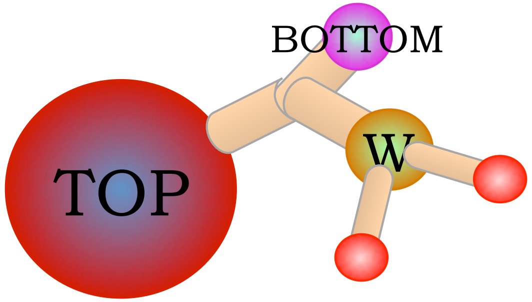
Tevatron limit: Λ^{+}>2.7 TeV

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



Early Top at LHC

Plots for 10 TeV

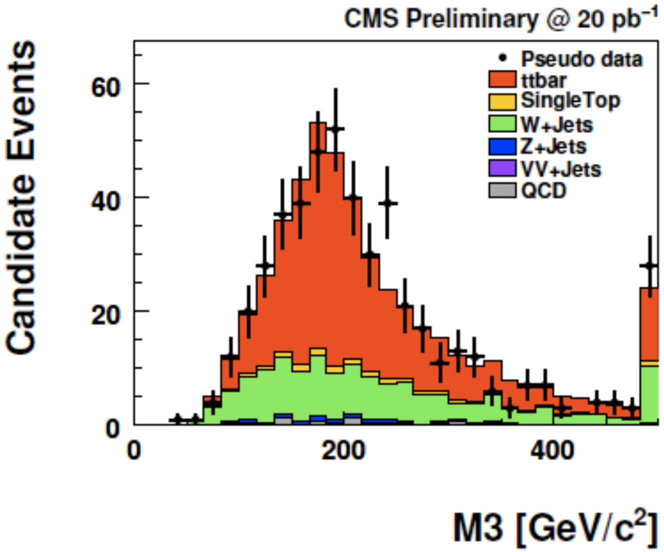
Early measurement

- Establish the ttbar cross section at 7, 10, 14 TeV
  →Check the gluon PDF !

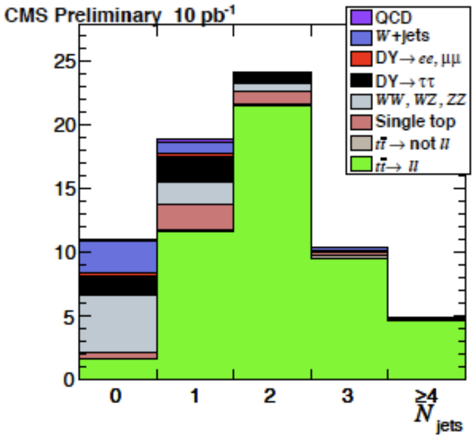
With more luminosity and understood detectors expect a rich program of top physics al LHC

- single top production
- ttbar resonances
- top rare decays
- single top and ttbar spin measurement
- …. eventually precision mass measurement

Semileptonic decays without b-tag

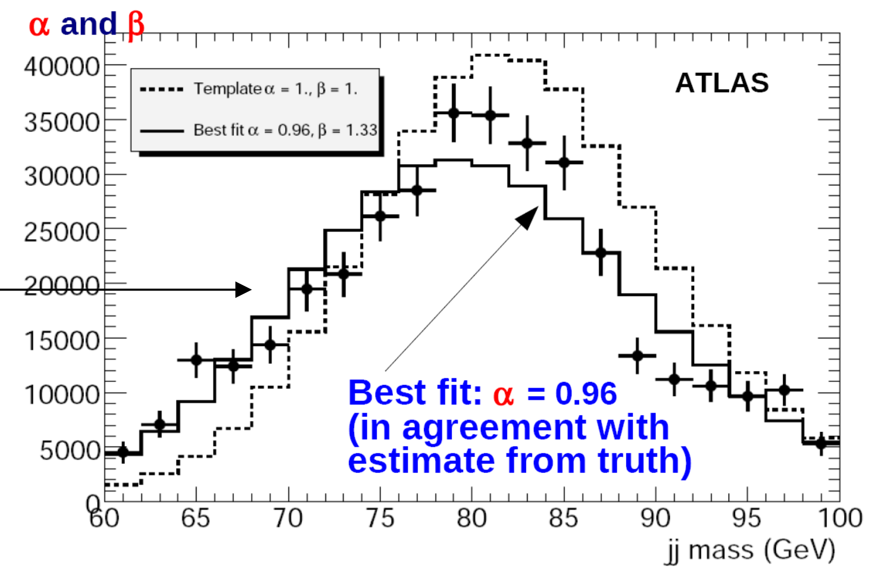


Dileptonic decays without b-tag



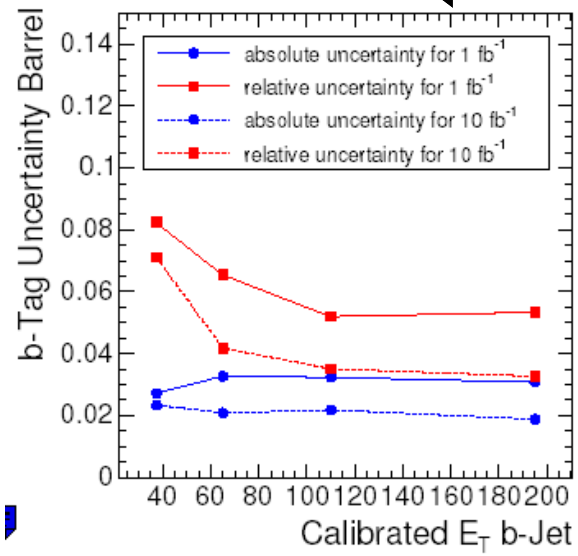
Top as a tool for calibrations

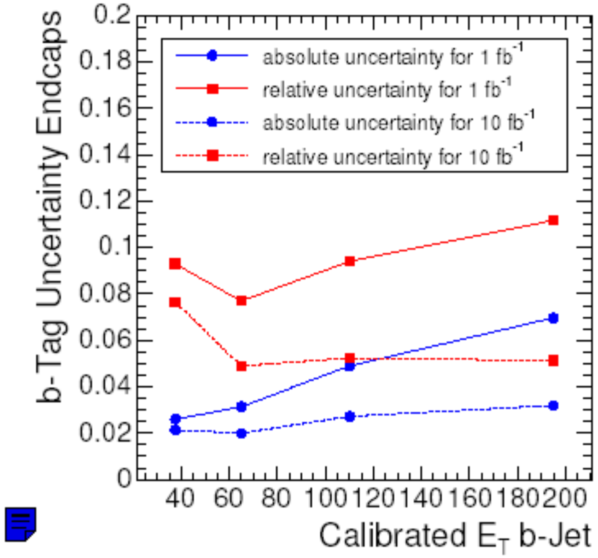
Determine light jet energy scale from W → jj coming from semileptonic top decays



Best fit: α = 0.96 (in agreement with estimate from truth)

Determine b-tagging efficiencies from b-jets coming from semileptonic top decays

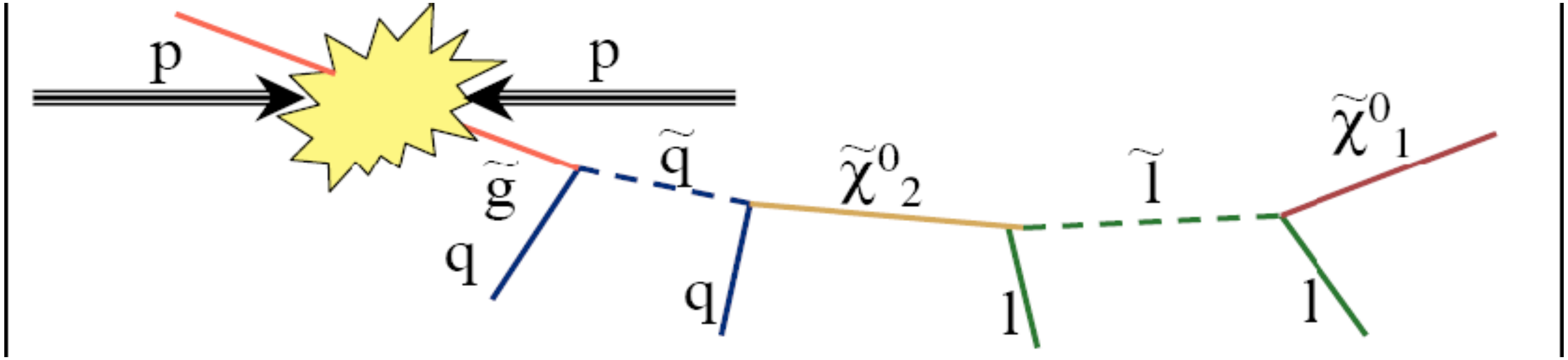




When the Standard Model is established, we can start to be brave …
…………this is just an example

Direct Search for SUSY particles

- Production of Susy Particles at LHC is dominated by gluinos and squarks
- The production is followed by a SUSY+SM cascade.

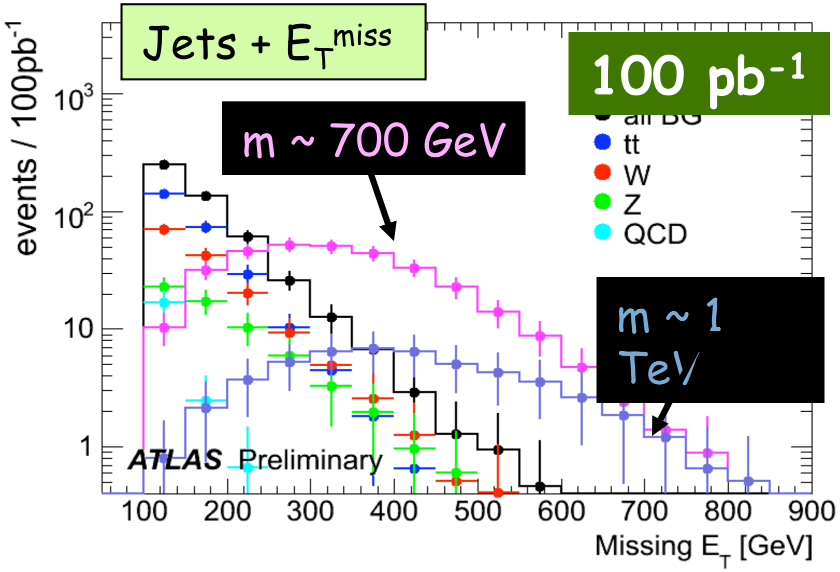


Studying Jets and Missing E_T

for Low Mass SUSY

Missing ET :

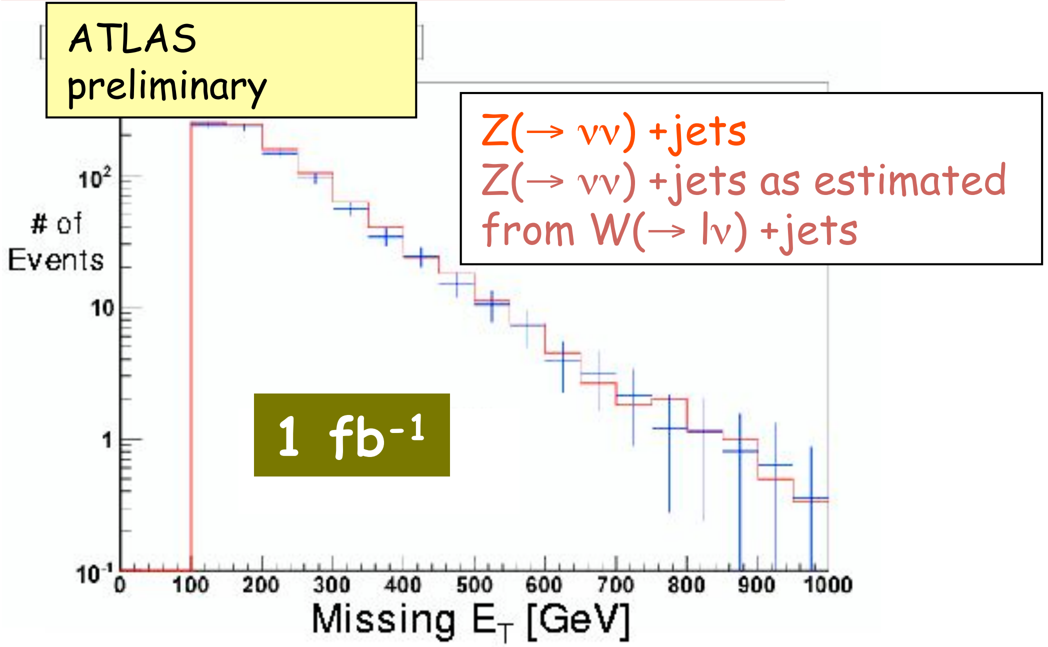
- Important to monitor instrumental effects (dead channels, non-gaussian tails)
- Important to monitor Standard Model background (e.g Z → νν accompanied by jets)


Jets + E_T^{miss}

100 pb^{-1}

m ~ 700 GeV

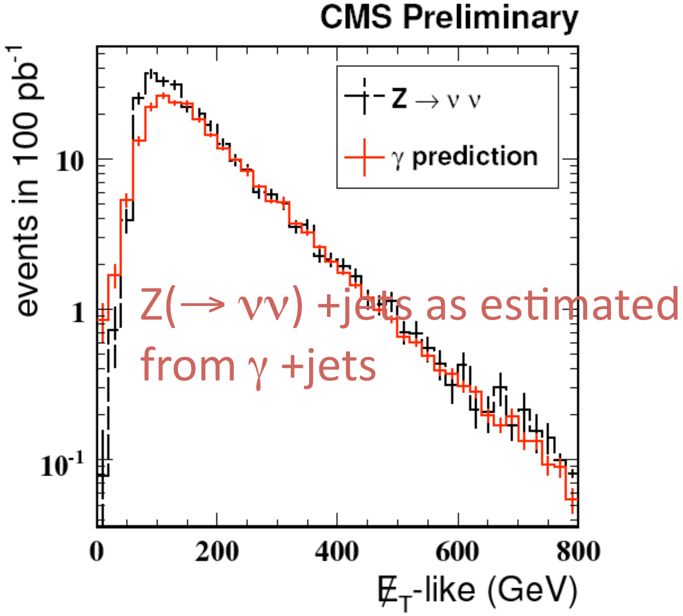
m ~ 1 TeV


ATLAS preliminary

Z(→ νν) +jets

Z(→ νν) +jets as estimated from W(→ lν) +jets

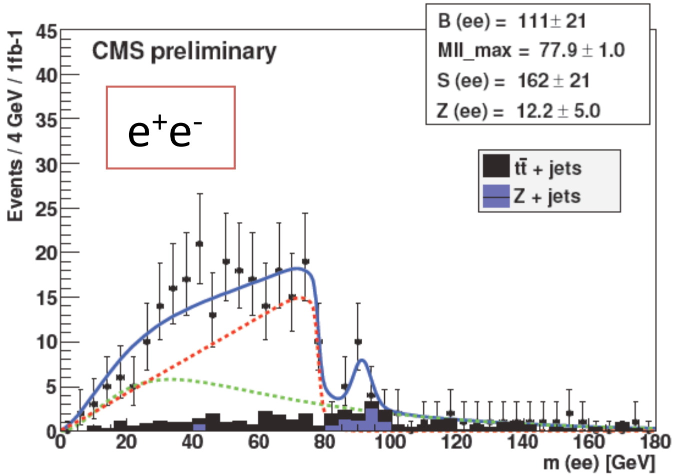
1 fb^{-1}


Z(→ νν) +jets as estimated from γ +jets

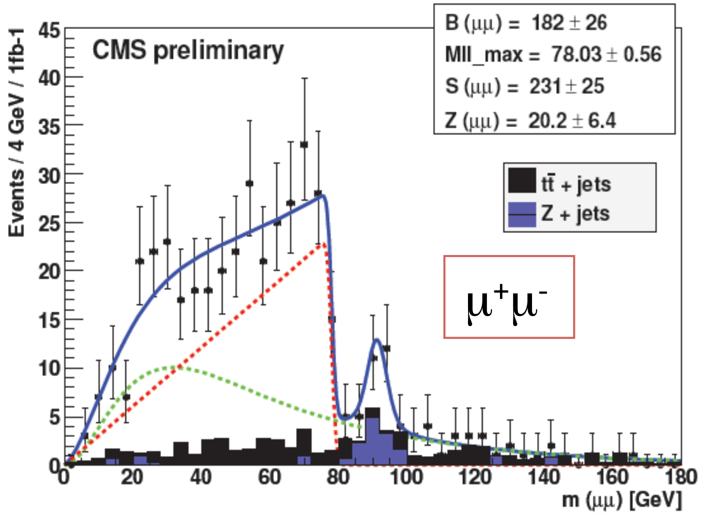
Plots for 14 TeV

Di-leptonic edges

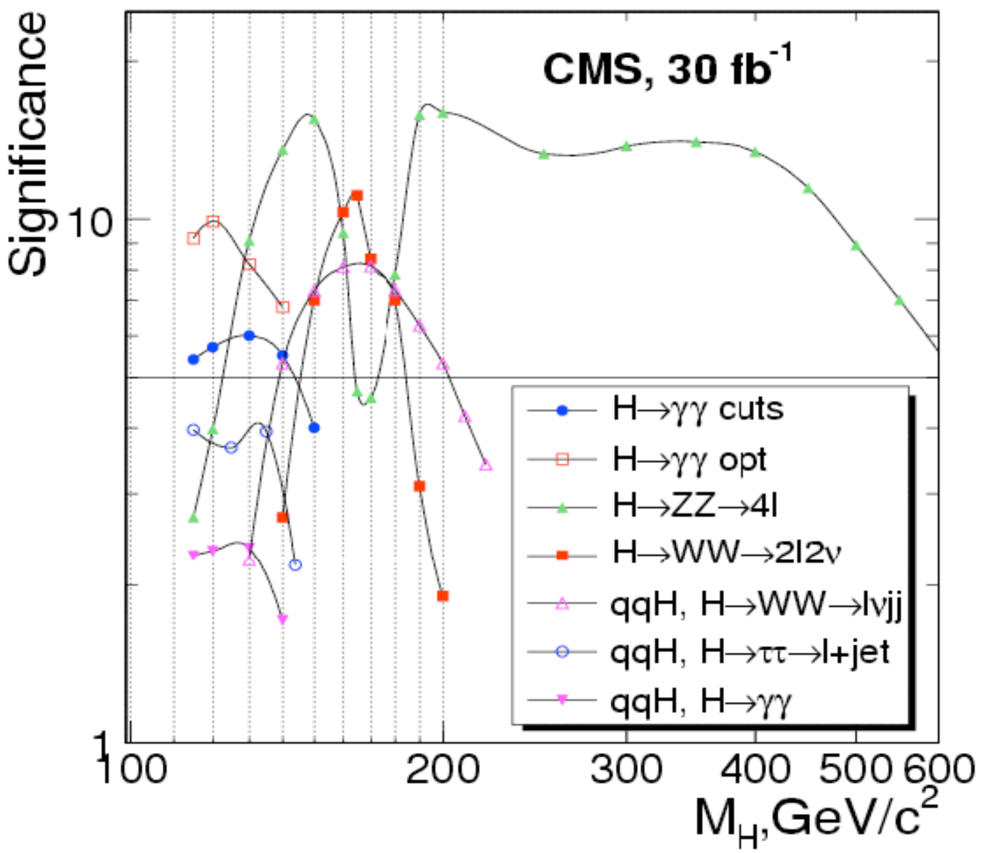
- M_{ll} distrib. in decays $\chi_2^0 \to \tilde{\ell}^+\ell^- \to \chi_1^0\ell^+\ell^-$
  - SUSY's smoking gun!
  - From edges, information on masses
- Same Flavour, Opposite Sign (SFOS)
  - Lepton flavour uncorrelated in bkg from SM and from SUSY itself
    - Estimated from OFOS leptons ($e^+\mu^-$)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

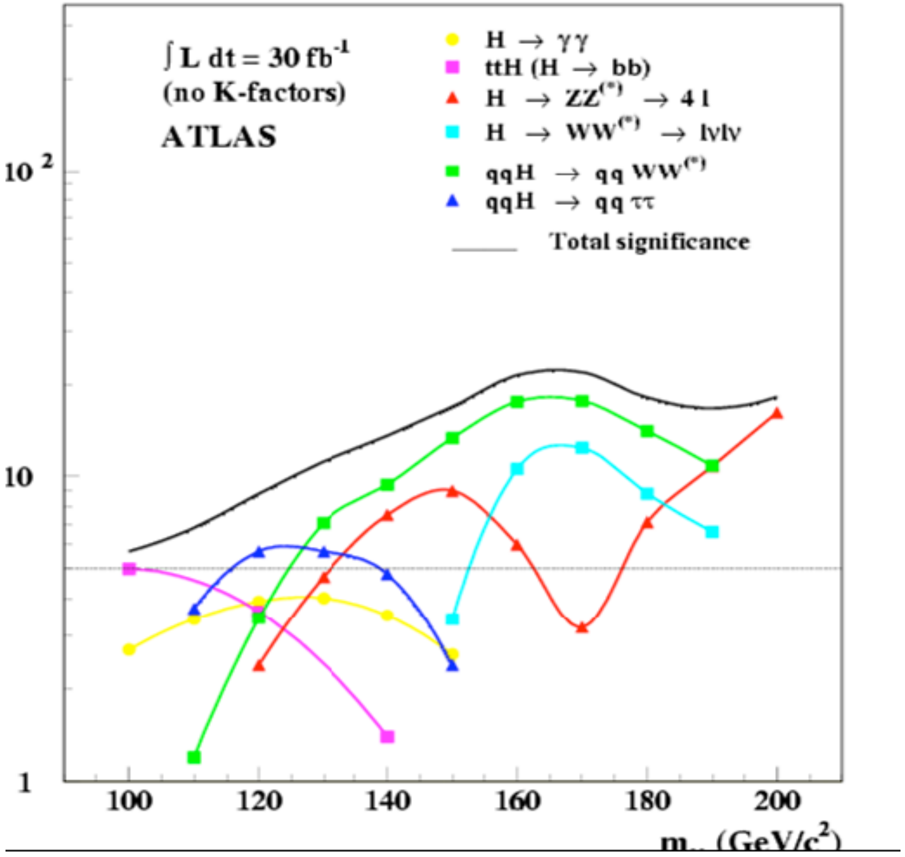


1/fb, LM1 point



The SM Higgs Boson
at LHC (14 TeV)



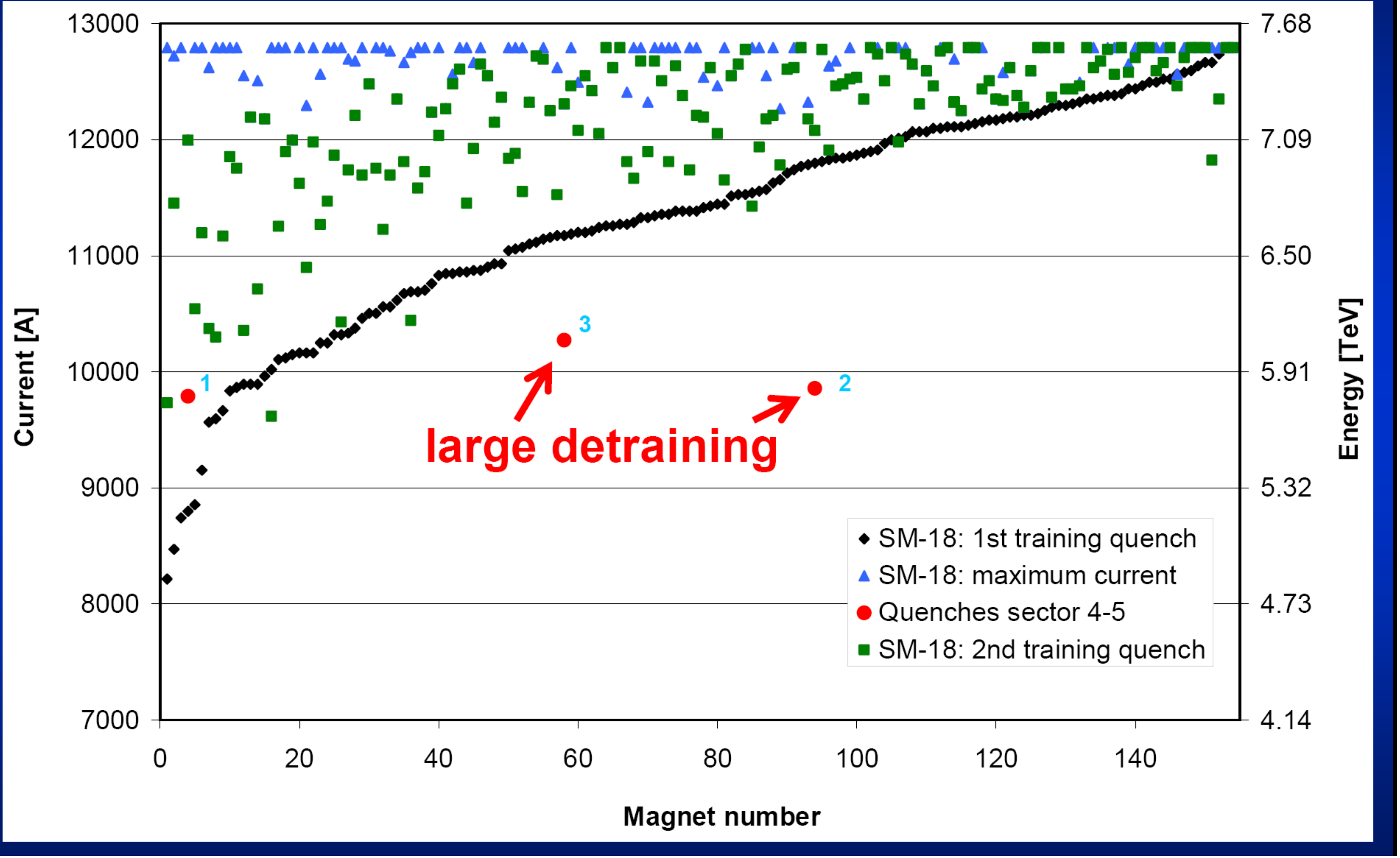


Initial goals for the LHC

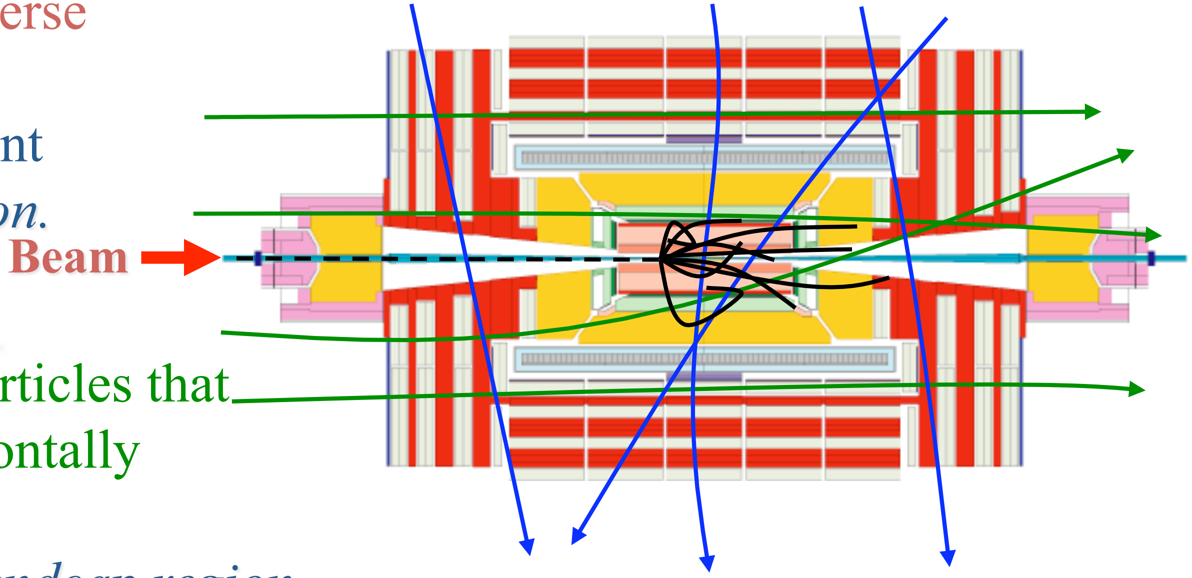
- **At LHC startup (7 and 10 TeV)**
  - Understand the apparatus (efficiencies, instrumental backgrounds)
  - Understand the initial state (Parton Density Functions) and the Luminosity
  - Understand the Underlying Event (and Pileup)
  - Measure important backgrounds to searches (multijets, multibosons, W/Z+multijets, γ+jet)
  - Develop a program of measurements for top physics
- Don't get discouraged, the die hard are always rewarded … !

backup

Sector 45 – Powering towards nominal



“Pre-Collision Physics Structures”



Cosmic Muons

High energetic muons that traverse the detector vertically

→particular useful for alignment
and calibration - *barrel region.*

Beam Halo Muons (Hadrons)

Machine induced secondary particles that cross the detector almost horizontally

→particular useful for
alignment and calibration - *endcap region.*

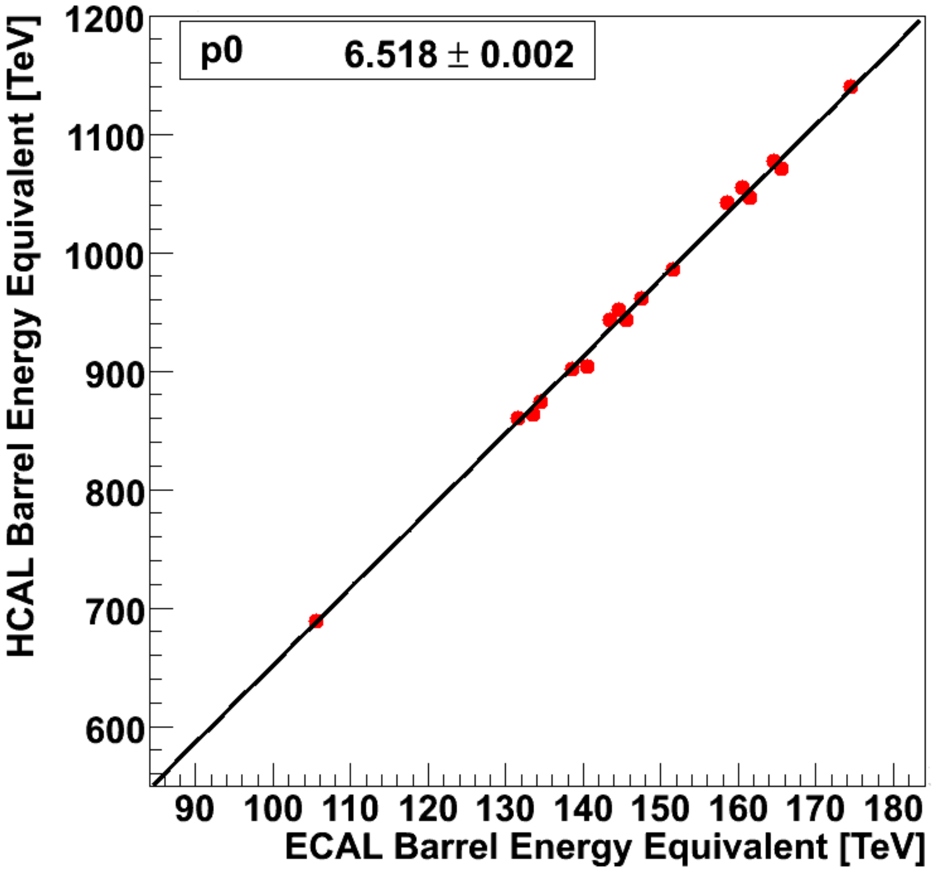
Beam Gas Interactions

Proton-nucleon interaction in the active detector volume (7TeV→E_{cm}=115 GeV)

→resemble collision events but with a rather soft p_T spectrum (p_T<2 GeV)

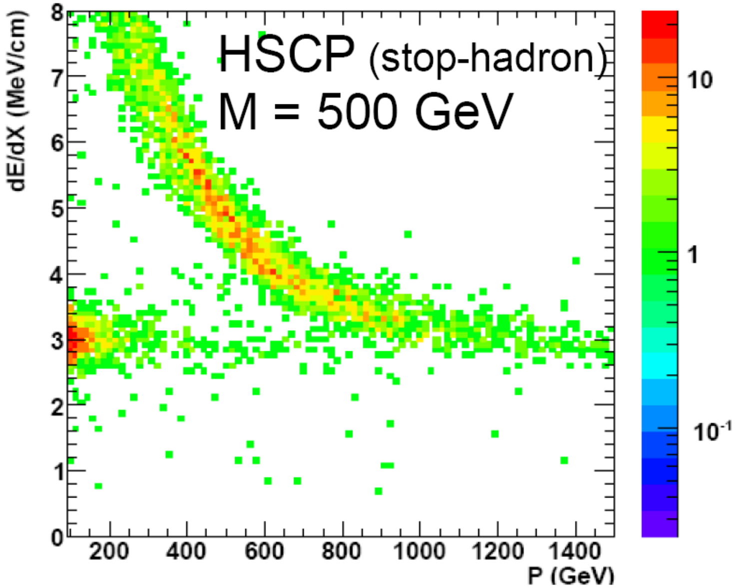
All three physics structures are interesting for alignment, calibration, gain operational experience, dead channels, debug readout, etc …

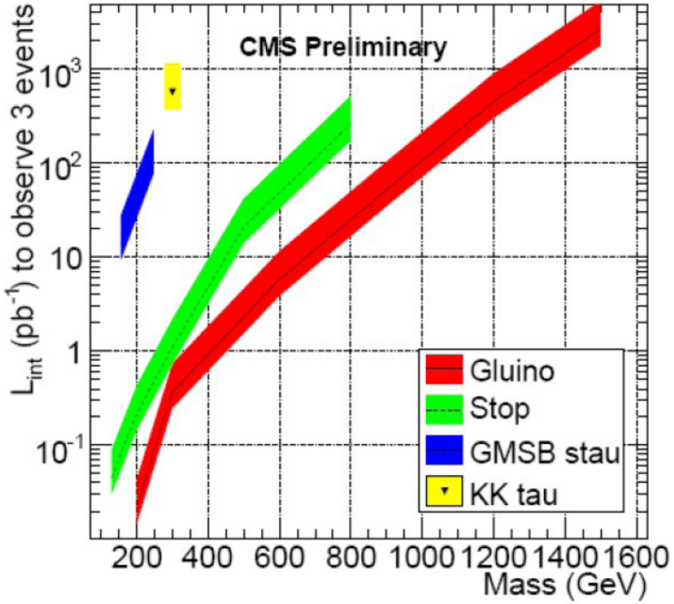
Correlation of ECAL and HCAL Barrel in beam splashes



Heavy Stable Charged Particles (HSCP)

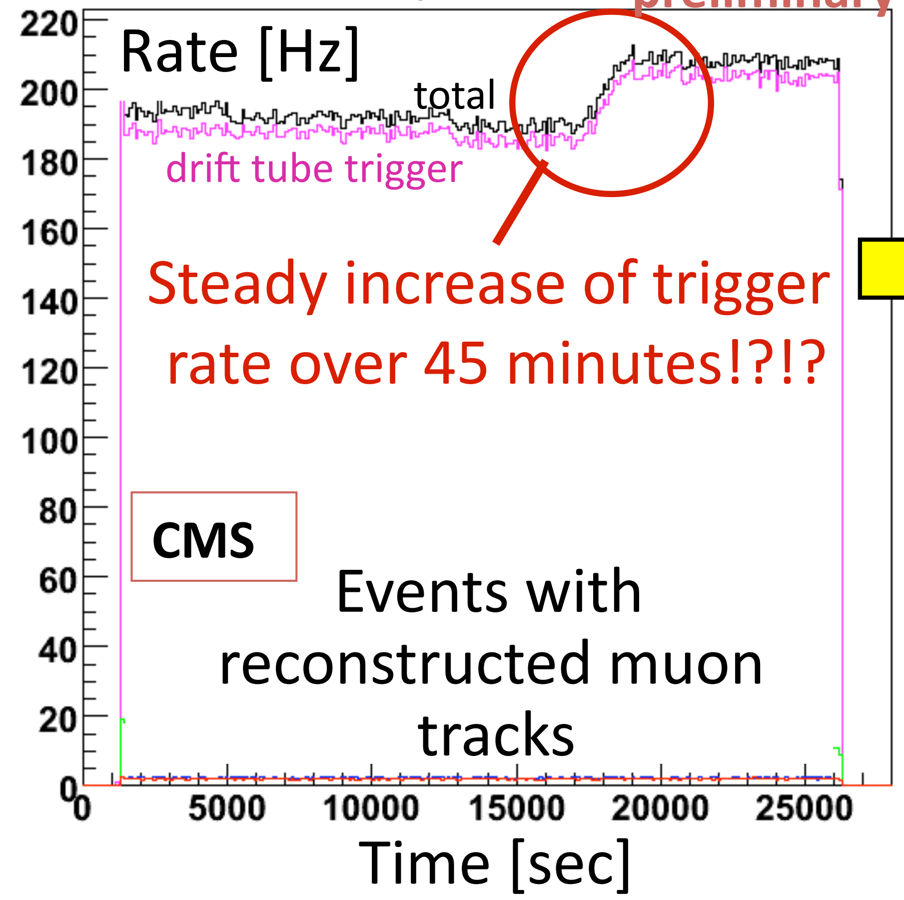
- Several SUSY variants predict metastable or stable charged particles
  - Slepton: “heavy muons”
  - Gluino, squark: “R-hadrons”
    - nuclear interactions!
- Signatures: dE/dx, Time Of Flight
- dE/dx: Tracker
  - >10 independent samplings in Si
  - Estimate the Most Probable Value
- TOF: Muon Chambers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





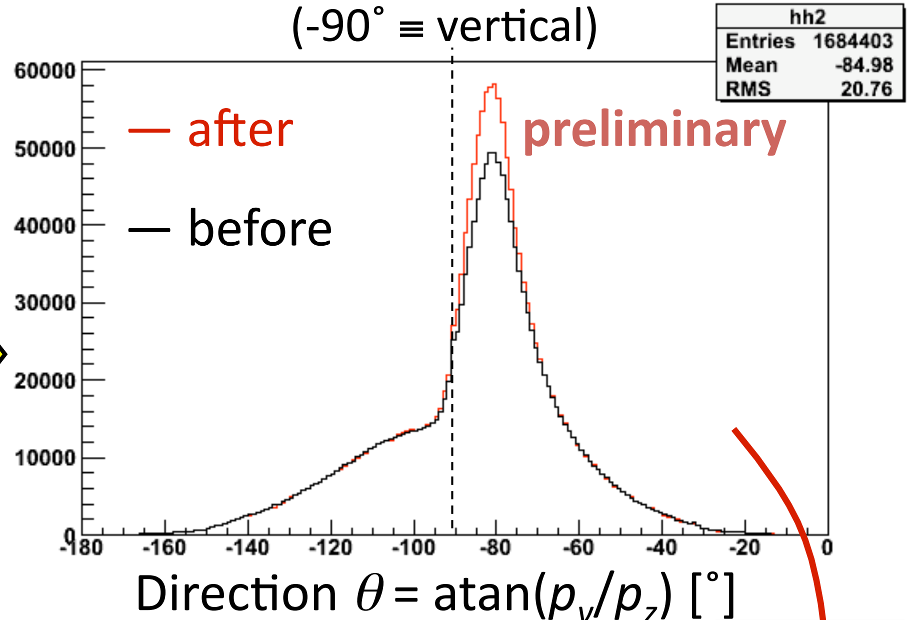
A sofisticated house alarm system

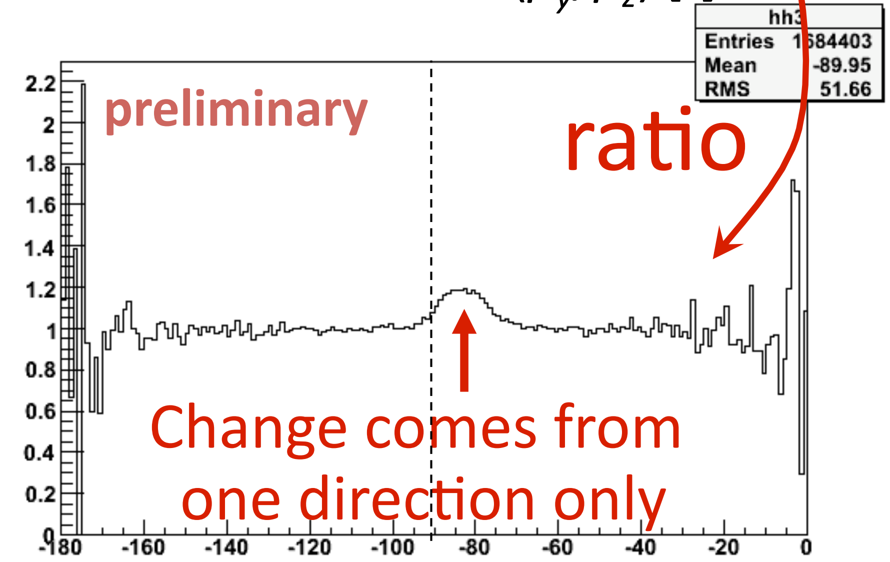
Run 43439, May ‘08



Steady increase of trigger rate over 45 minutes!?!?

Indeed, increase of cosmic rate correlated with shaft opening!





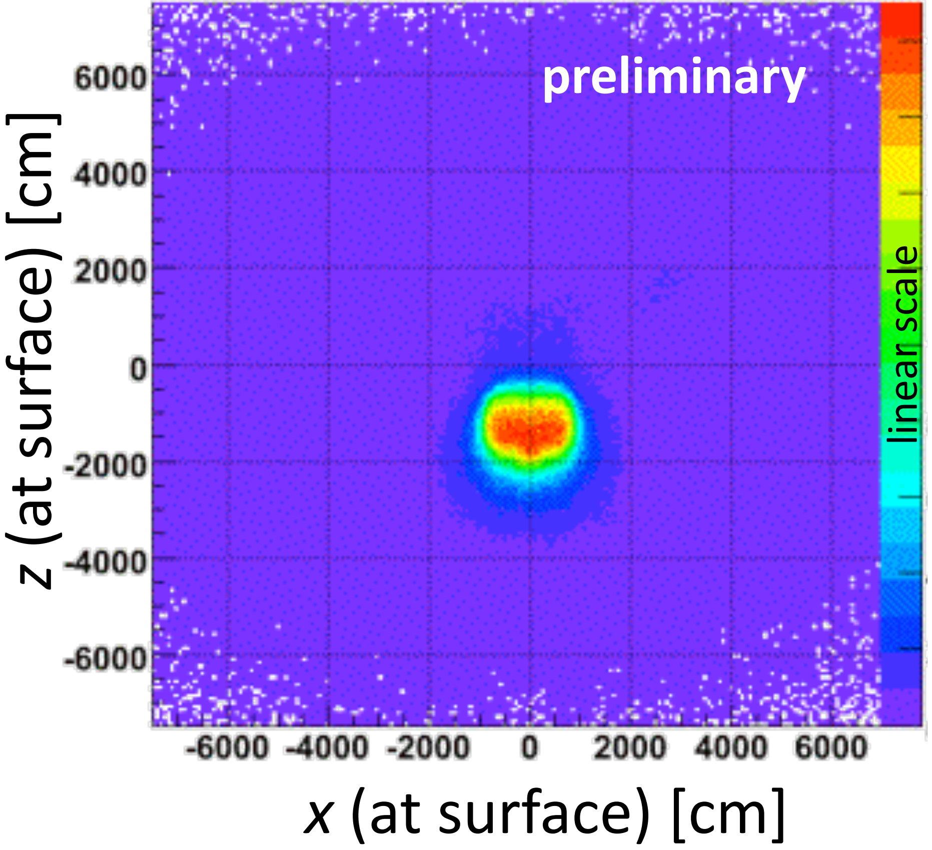
Change comes from one direction only

Muon Tag & Probe on Cosmics Data

For cosmics: top muon sectors are timed-in (delayed) w.r.t. bottom sectors → “di-muon”-like signal (here: Drift Tubes)

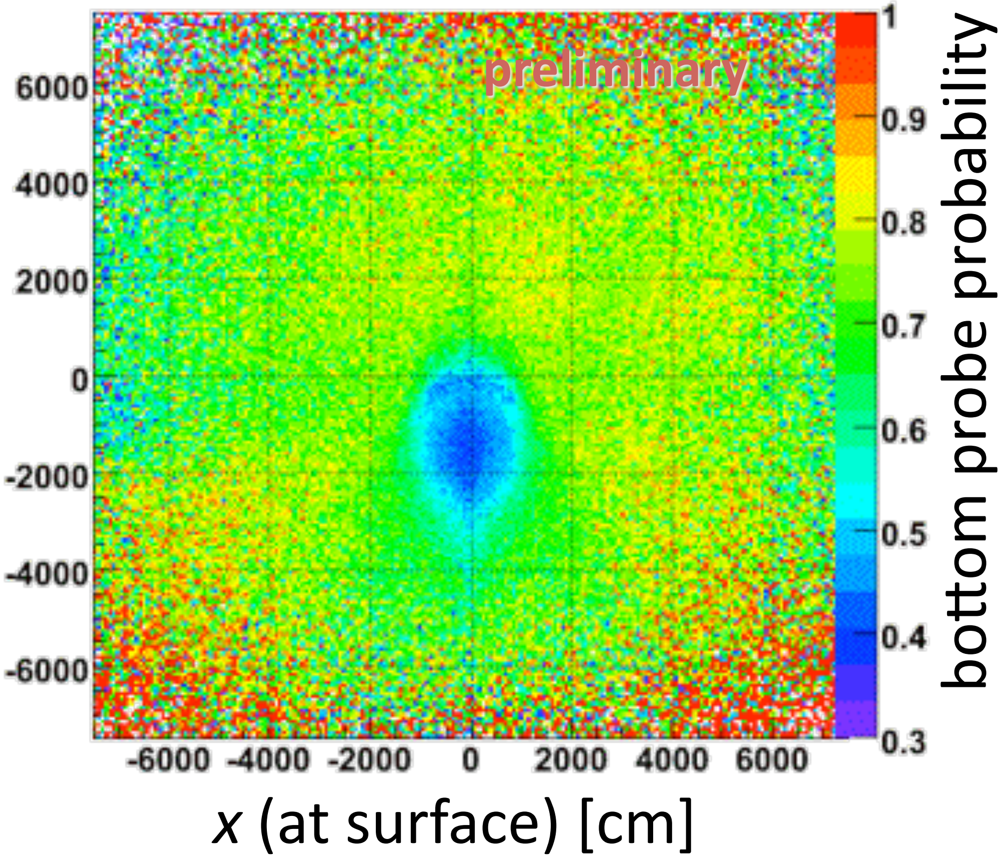
May/June data: muon origin extrapolated to the surface:

“X-ray” image of the shaft



Avg. prob. to find ≥1 segment in bottom sectors - tag (top) & probe (bottom):

Shaft-muons are softer



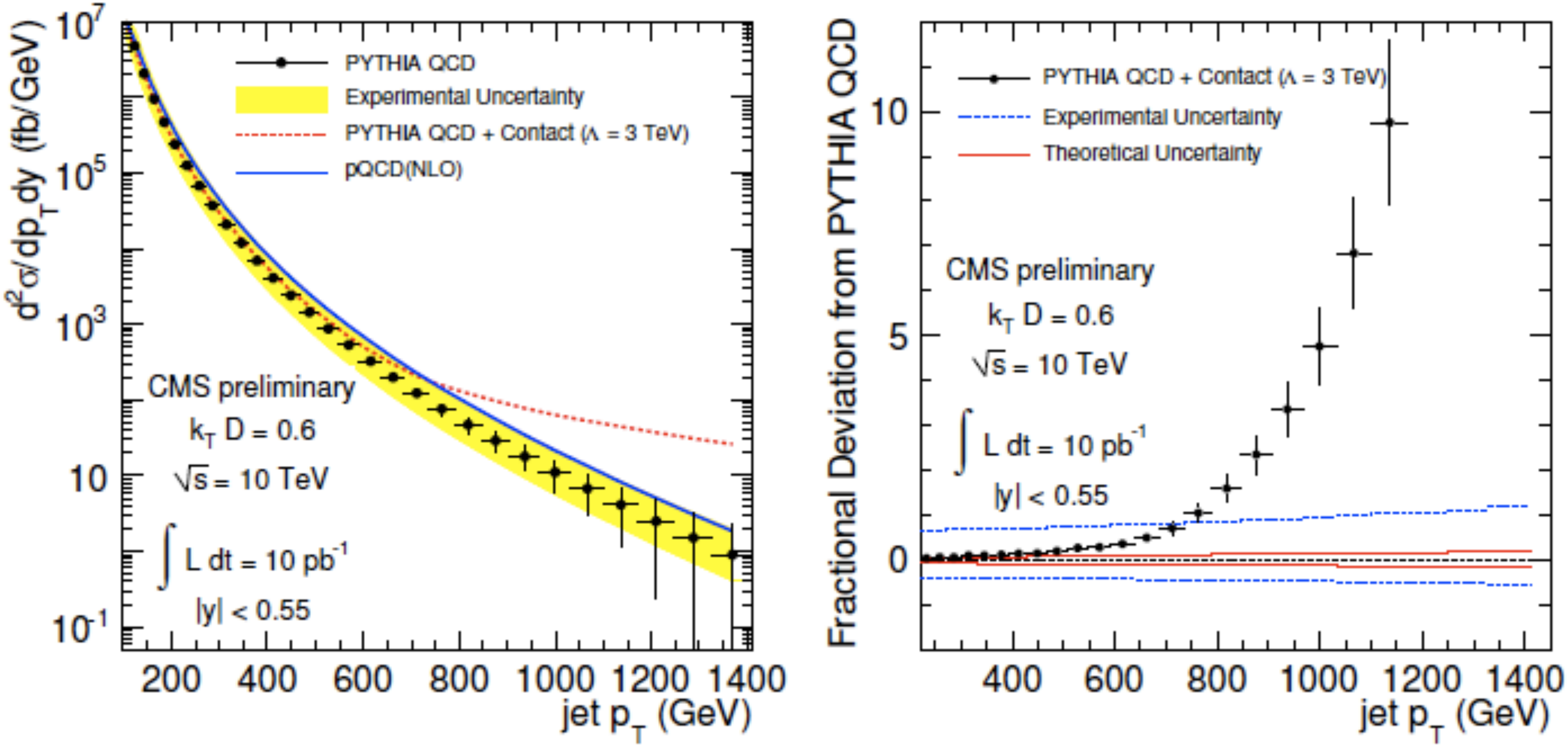


Figure 12: Measured QCD spectrum (*K* factors times PYTHIA with CMS simulation) with experimental systematic uncertainty compared with theory (NLO times non-perturbative corrections) and PYTHIA QCD+3 TeV contact interaction term (left). Fractional difference of the QCD+contact interaction term and pure PYTHIA QCD is shown in comparison to the experimental and theoretical uncertainties (right).