Plans for Diffractive and Forward Physics Studies at LHC

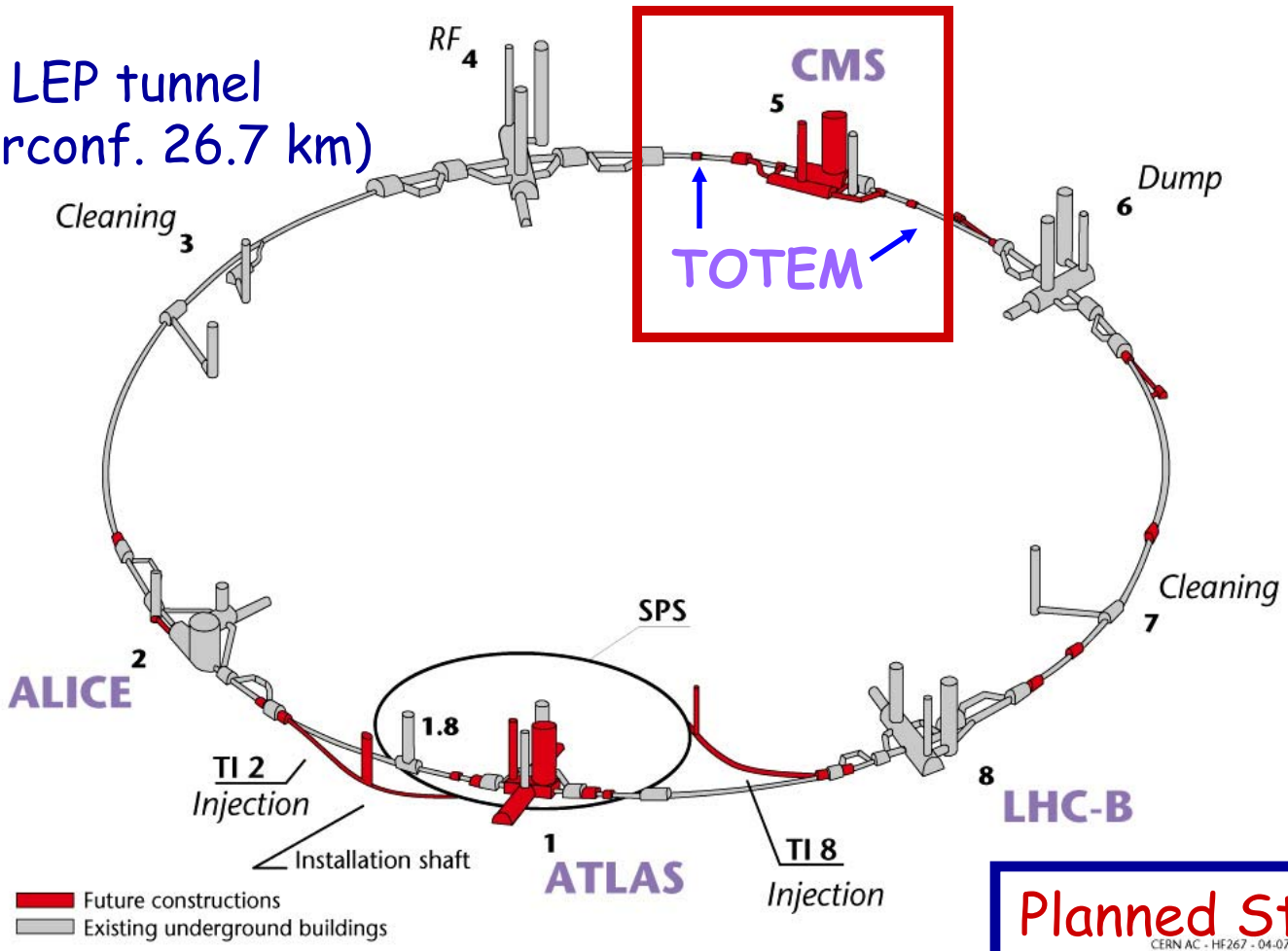
Albert De Roeck (CERN)

Introduction: LHC & experiments

Detectors

Physics

The Large Hadron Collider (LHC)



In LEP tunnel (circonf. 26.7 km)

PP collisions at $\sqrt{s}$ = 14 TeV

5 experiments

25 ns bunch spacing
$\Rightarrow$ 2835 bunches
10^{11} p/bunch

Design Luminosity:
$10^{33}cm^{-2}s^{-1}$ - $10^{34}cm^{-2}s$
$\Rightarrow$100 fb^{-1}/year

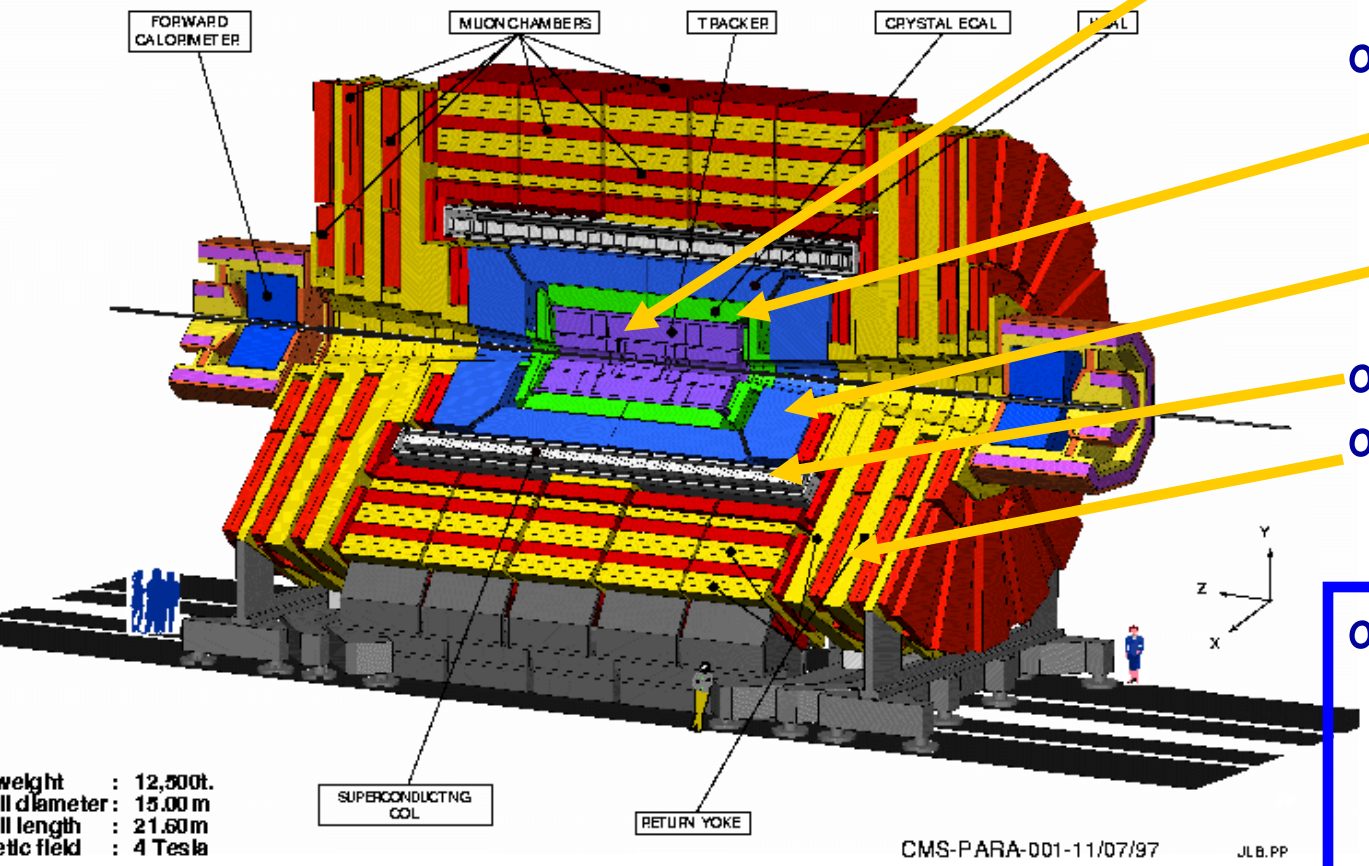
23 inelastic events per bunch crossing

Planned Startup: April 2007

CERN AC - HF267 - 04-07-1997

The CMS experiment

A Huge enterprise !



- Tracking
  - Silicon pixels
  - Silicon strips
- Calorimeters
  - PbW04 crystals for Electro-magn
  - Scintillator/steel for hadronic part
- 4T solenoid
- Instrumented iron for muon detection

- Coverage
  - Tracking
    $0 < |\eta| < 2.5$
  - Calorimetry
    $0 < |\eta| < 5$

Main program: EWSB, Beyond SM physics…

Detector Coverage

S. Tapprogge/Blois03

- ATLAS, CMS
  - → Tracking and muon system $|\eta| < 2.5$
  - → Calorimetry $|\eta| < 5$
- ALICE
  - → Tracking (TPC, vertexing) $|\eta| < 0.9$
    - and several other specialized detectors
  - → Muon spectrometer $2.4 < \eta < 4$
  - → Zero-Degree Calorimeter (ZDC)
- LHCb
  - → Forward spectrometer $1.9 < \eta < 4.9$
- TOTEM
  - → Roman Pots for leading protons
  - → Tracking for charged particles $3 < |\eta| < 7$

Diffraction and Forward Physics

TOTEM:

- TDR submitted in January 2004/ in the process of approval
- TOTEM stand alone
  - Elastic scattering, Total pp cross section and soft diffraction. Totem has no central detector
- TOTEM together with CMS:
  - Full diffractive program with central activity. TOTEM will be included as a subdetector in CMS (trigger/data stream)

CMS:

- EOI submitted in January 2004:
  - Diffractive and low-x physics part of CMS physics program
  - Diffraction with TOTEM Roman Pots and/or rapidity gaps
- LOI in preparation for new forward detectors (CASTOR, ZDC)
  - Additional options being studied

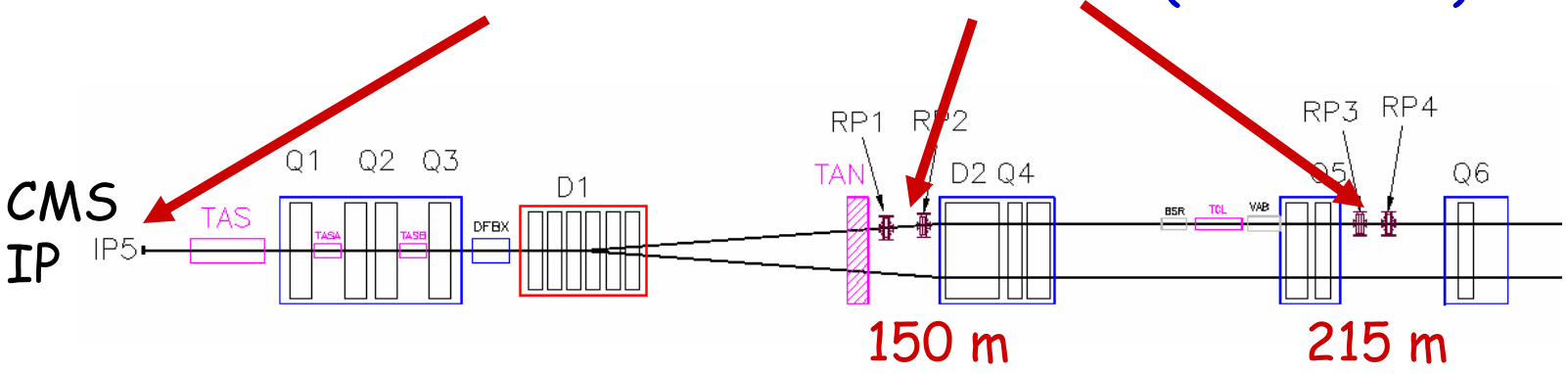
ATLAS:

- LOI submitted (March) for RP detectors to measure elastic scattering/ total cross sections/luminosity. Diffraction will be looked at later

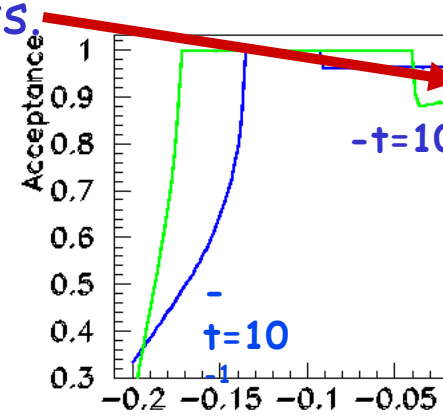
ALICE, LHCb: no direct forward projects plans but keeping eyes open.

The TOTEM Experiment

TOTEM physics program: total pp, elastic & diffractive cross sectior
Apparatus: Inelastic Detectors & Roman Pots (2 stations)



High β^* (1540m): Lumi 10^{28}-10^{31}cm^{-2}s^{-1} (few days or weeks)
>90% of all diffractive protons are seen in the Roman Pots
Proton momentum measured with a resolution ~10^{-3}



Low β^*: (0.5m): Lumi 10^{33}-10^{34}cm^{-2}s^{-1}
215m: $0.02 < \xi < 0.2$
300/400m: $0.002 < \xi < 0.2$ (RPs in the cold region)

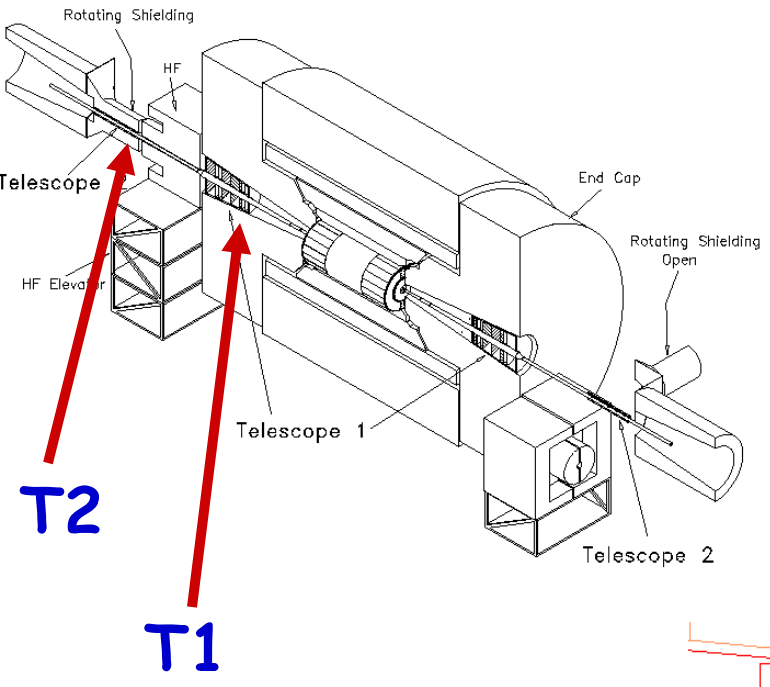
More on TOTEM & acceptance by F. Ferro

Possible Running scenarios (TOTEM TDR)

Scenario (goal)	1 low |t| elastic, σ_{tot} , min. bias	2 diffr. phys., large p_T phen.		3 intermediate |t|, hard diffract.	4 large |t| elastic
β^* [m]	1540	1540		200 - 400	18
N of bunches	43	156		936	2808
Half crossing angle [μrad]	0	0		100 - 200	160
Transv. norm. emitt. [μm rad]	1	1	3.75	3.75	3.75
N of part. per bunch	0.3×10^{11}	0.6×10^{11}	1.15×10^{11}	1.15×10^{11}	1.15×10^{11}
RMS beam size at IP [μm]	454	454	880	317 - 448	95
RMS beam diverg. [μrad]	0.29	0.29	0.57	1.6 - 1.1	5.28
Peak luminos. [$cm^{-2}s^{-1}$]	1.6×10^{28}	2.4×10^{29}		$(1 - 0.5) \times 10^{31}$	3.6×10^{32}

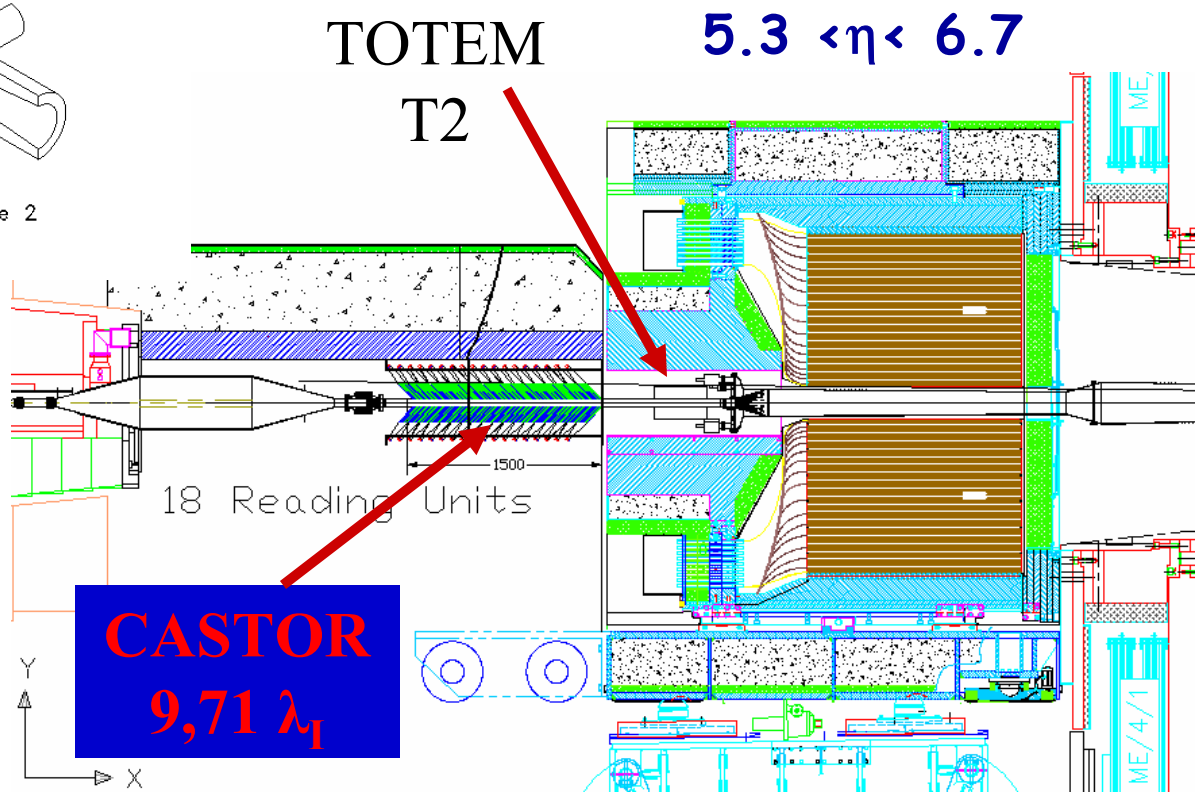
HERA experience Q: can this really work with few days/year only? (calibration…)

TOTEM/CMS forward detectors plans



T1/T2 inelastic event taggers
- T1 CSC/RPC tracker (TOTEM)
- T2 GEM or Silicon tracker (TOTEM/New)
- CASTOR Calorimeter (CMS/New)

T1	$3 < \eta < 5$
T2	$5.3 < \eta < 6.5$



CMS interests under discussion/LOI projects

- CMS central detector
  - Diffractive Gap Trigger (being studied (Nebraska,Wisconsin))
- T2 region
  - Calorimeter (CASTOR)
    - Add θ granularity (silicon, PPAC,…): needs simulation studies
    - Castor trigger
    - So far: one side of CMS (500 kCHF), additional funds requested
  - T2 tracker (part of TOTEM, see TDR, GEM is baseline choice)
    - May need participation from CMS if silicon option would be chosen
    - May need new tracker by CMS depends on TOTEM prototype results
- Roman pot detectors up to 220 m
  - Use TOTEM RPs, available as a CMS subdetector
- Roman pot detectors at 300/400 m
  - Completely new project
  - Needs new resources (there are interested parties in CMS & ATLAS)
- ZDC small project but funding not yet guaranteed part of the LOI
- New detectors in the range $7<\eta<9$??? (20 m from IP) no CMS activity now

$\Rightarrow$ Certainly help welcome on simulation tools, detailed physics studies…

CMS/TOTEM Study

Common working group to study diffraction and forward physics at full LHC luminosity approved by CMS and TOTEM (spring 2002)

(ADR/ K. Eggert organizing so far)

Use synergy for e.g. simulation, physics studies & forward detector option studies.

Common DAQ/Trigger for CMS & TOTEM

Discussions on T2

Common simulation etc…

Share physics studies

CMS/TOTEM is the largest acceptance detector ever built at a hadron collider

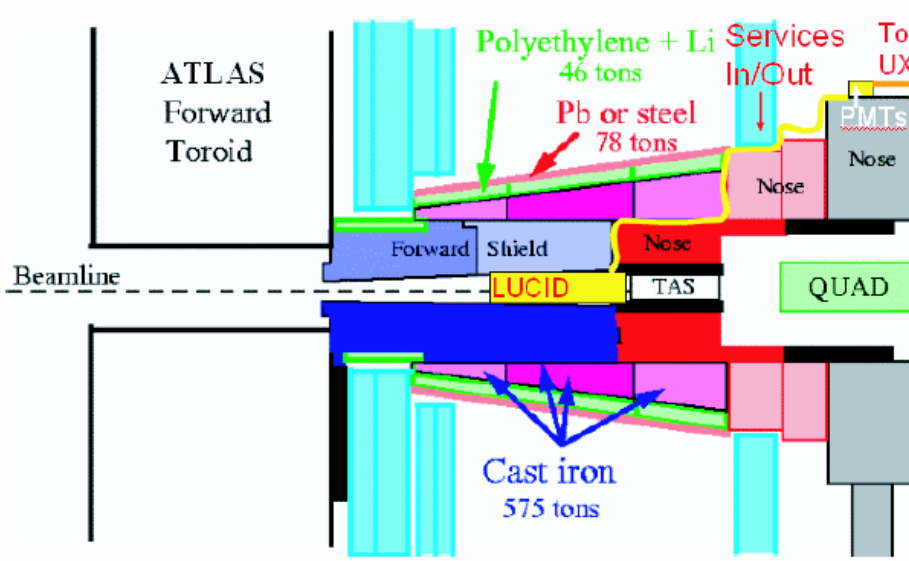
Common LOI on diffractive physics (pending LHCC approval)

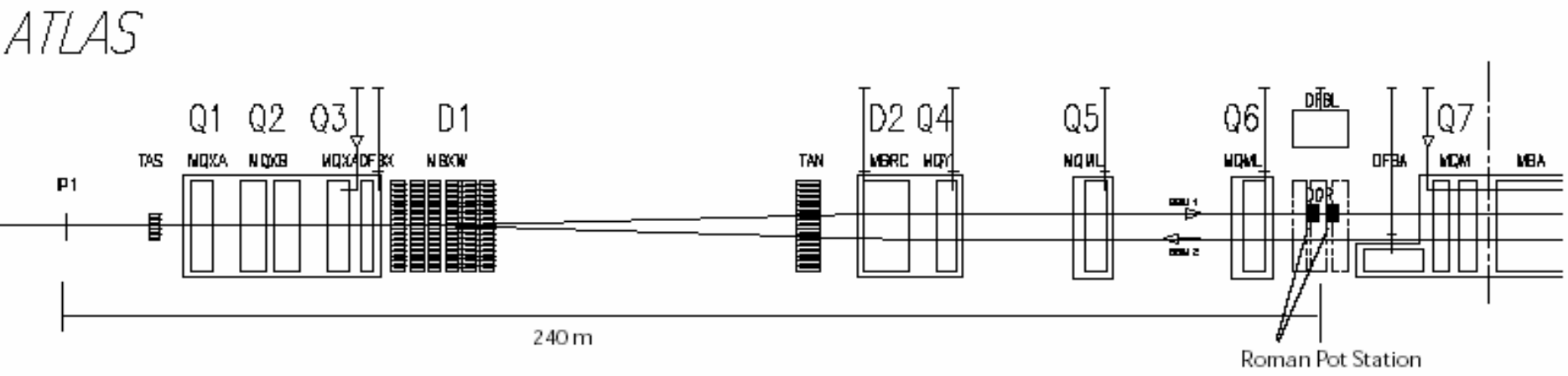
on the time scale of ~1 year

ATLAS LOI

ATLAS submitted a LOI on forward detectors for luminosity measurement and monitoring

Roman Pots at 240 m
Cerenkov Counter (LUCID) 5.4 <η< 6.1



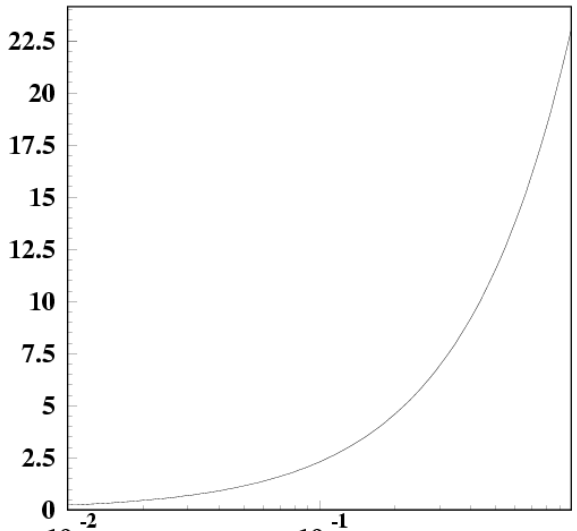


Rapidity Gaps at LHC

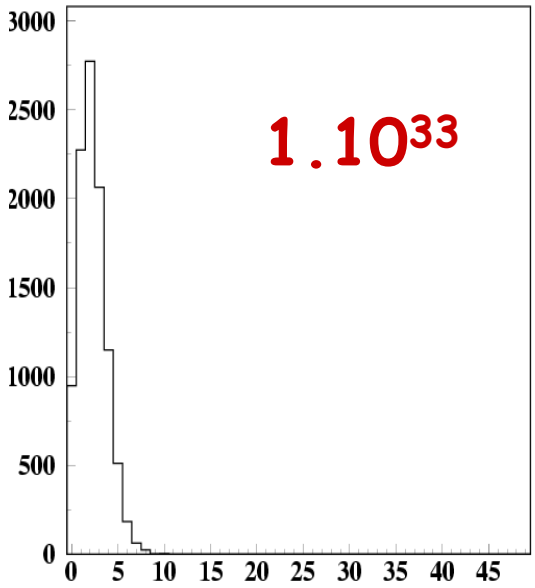
Number of overlap events versus LHC luminosity

distribution of number of interactions

Doable at startup luminosity!

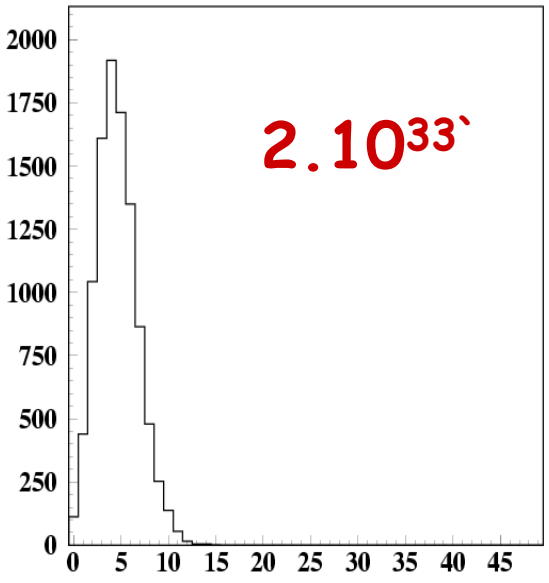


10^{32} 10^{33} 10^{34}



1.10^{33}

1 int. 22%

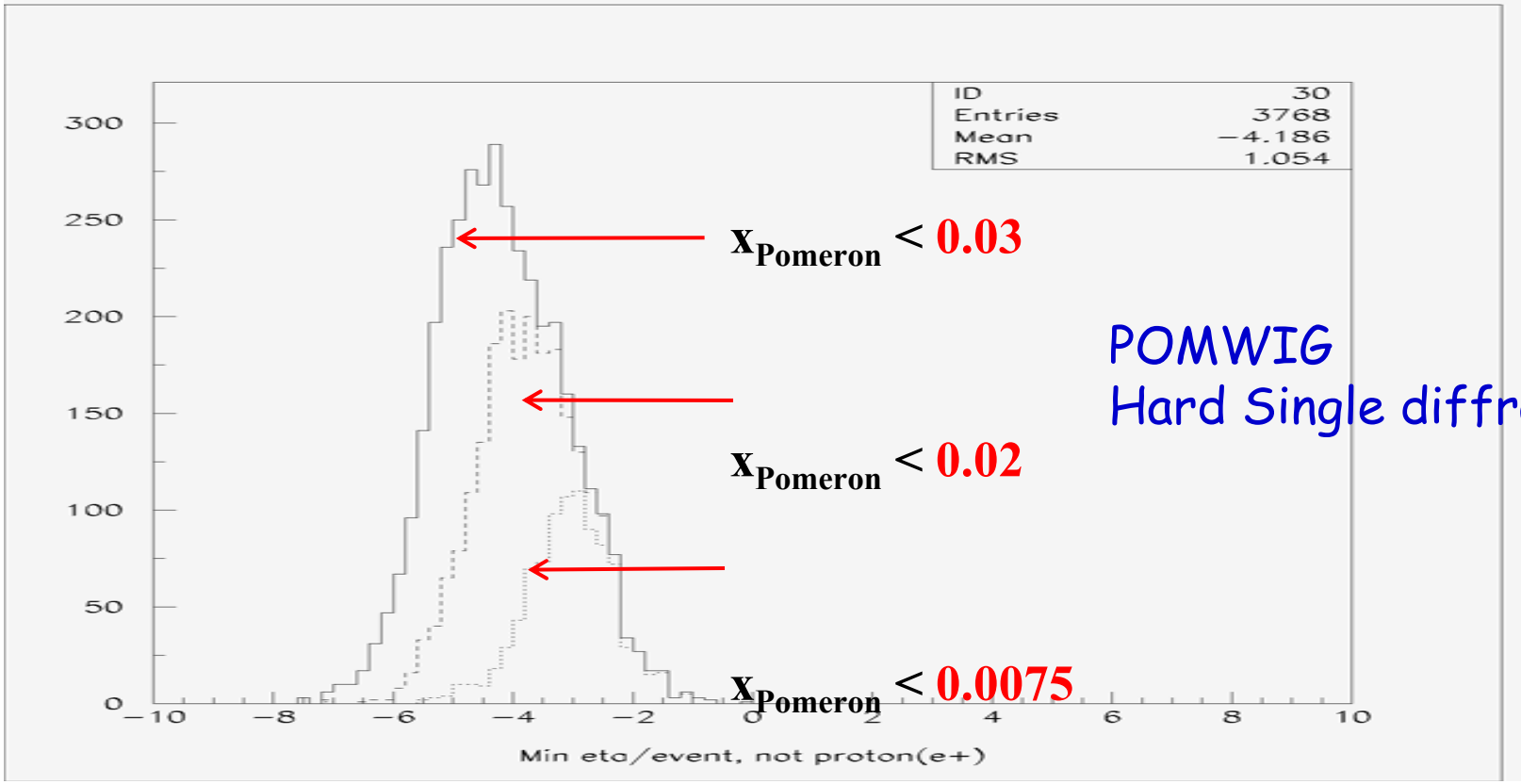


2.10^{33}`

4%

Benefit from experience of HERA experiments !!

Gap moves farther from outgoing proton for smaller x_{POM}



η of minimum-η particle per event

rapidity gap trigger study

⇒ G. Snow

Forward Physics Program

Soft & Hard diffraction

- Total cross section and elastic scattering
- Gap survival dynamics, multi-gap events, proton light cone ($pp \rightarrow 3jets+p$)
- Diffractive structure: Production of jets, W, J/ψ, b, t, hard photons
- Double Pomeron exchange events as a gluon factory (anomalous W,Z production?)
- Diffractive Higgs production, (diffractive Radion production?)
- SUSY & other (low mass) exotics & exclusive processes

Low-x Dynamics

- Parton saturation, BFKL/CCFM dynamics, proton structure, multi-parton scatteri

New Forward Physics phenomena

- New phenomena such as DCCs, incoherent pion emission, Centauro's

Strong interest from cosmic rays community

- Forward energy and particle flows/minimum bias event structure

Two-photon interactions and peripheral collisions

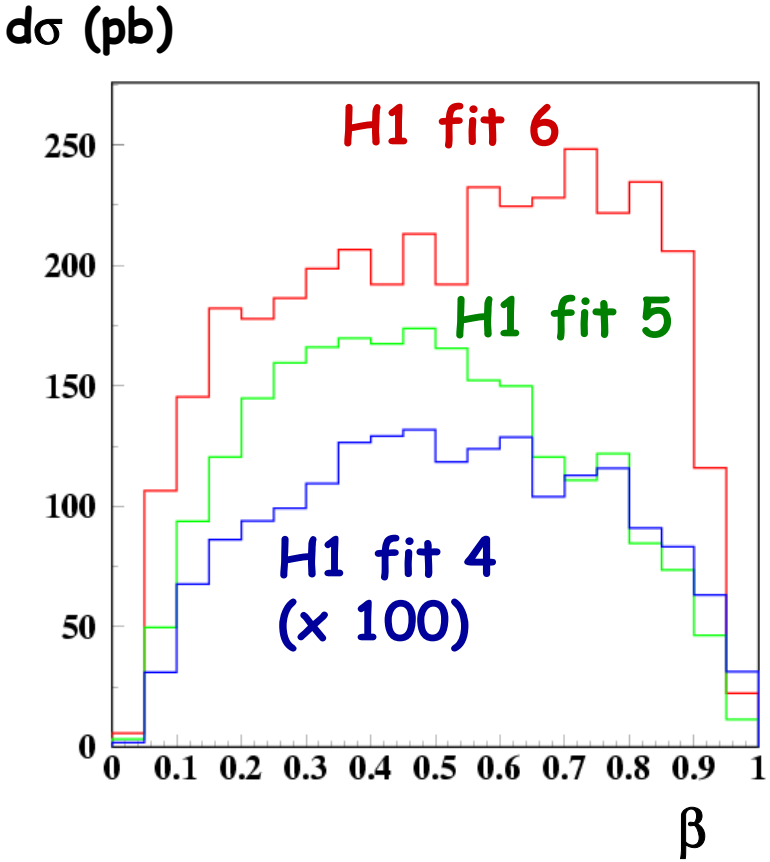
Forward physics in pA and AA collisions

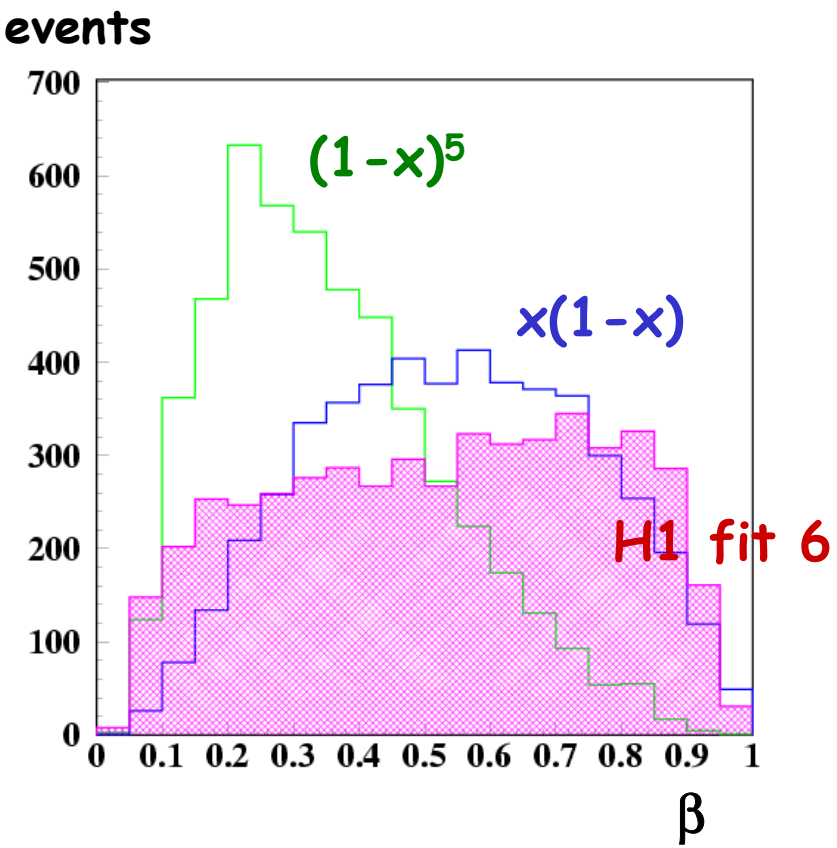
Use QED processes to determine the luminosity to 1% ($pp \rightarrow ppee$, $pp \rightarrow pp\mu\mu$)

Many of these studies can be done best with L ~10^{33} (or lower)

DPE: β from Di-jet events

P_t>100 GeV/c for different structure functions



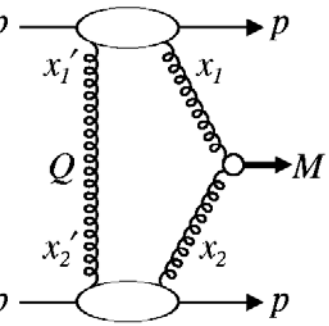


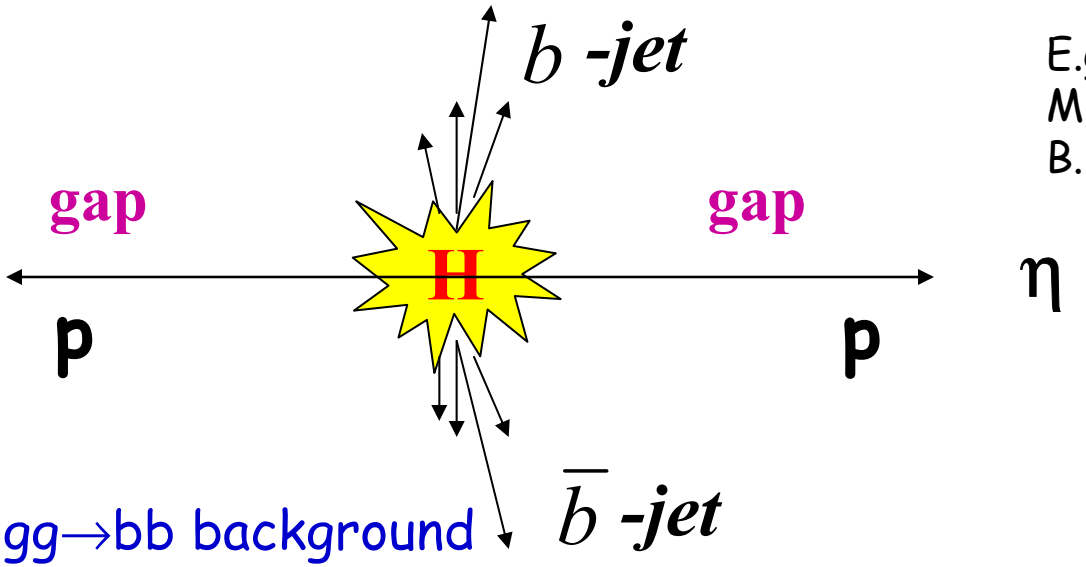
$\beta=\Sigma_{jets}\ E_T\ e^{-\eta}/(\sqrt{s}\ \xi)$: ξ from Roman Pots; E_T and η from CMS

High β region probed/ clear differences between different SFs

Diffractive Higgs Production

Exclusive diffractive Higgs production pp→ p H p : 3-10 fb
Inclusive diffractive Higgs production pp → p+X+H+Y+p : 50-200 fb

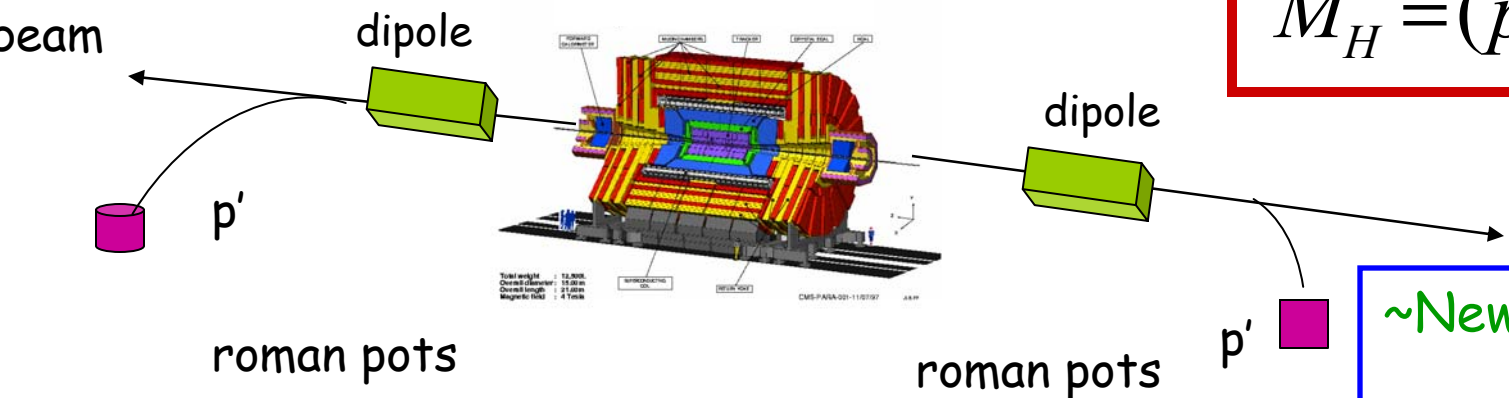




E.g. V. Khoze et a
M. Boonekamp et
B. Cox et al. …

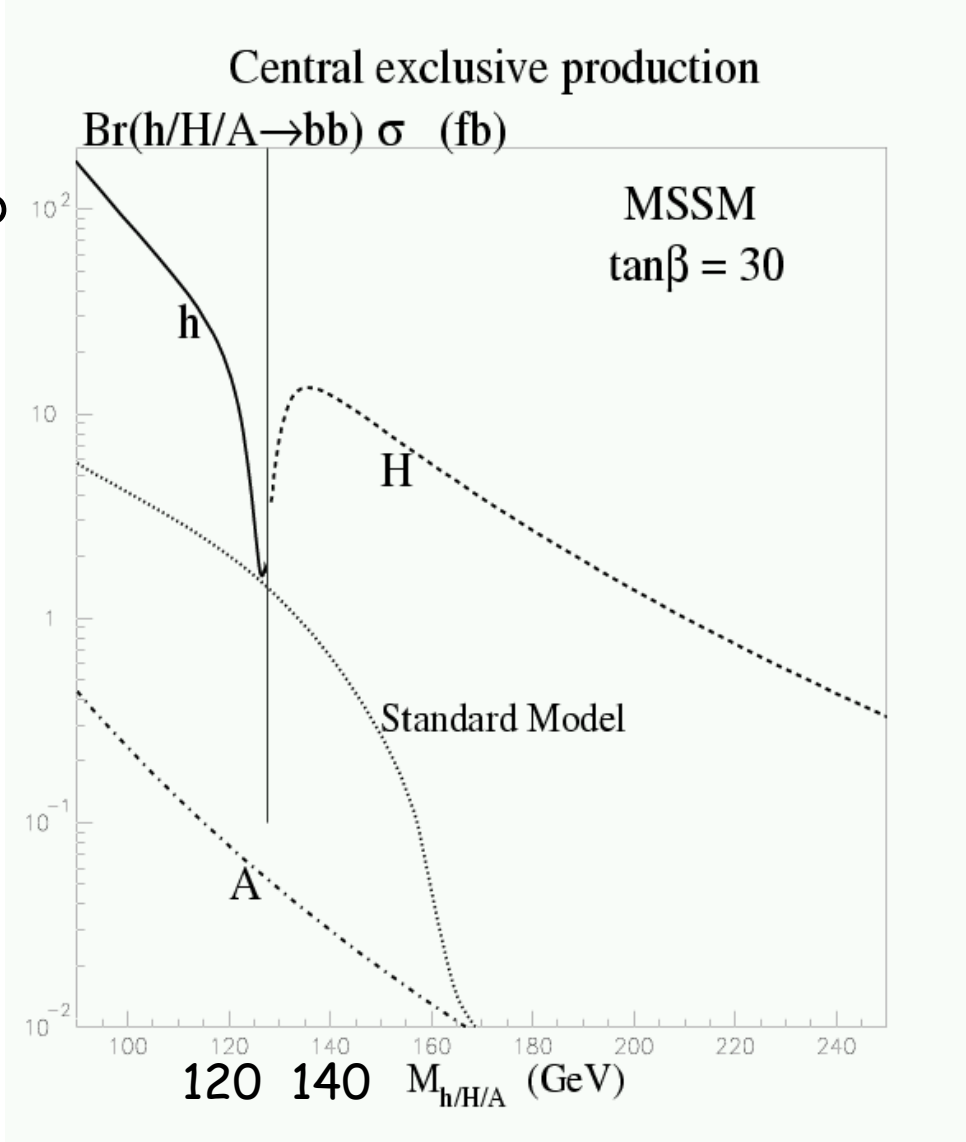
Advantages Exclusive:
- Jz=0 suppression of gg→bb background
- Mass measurement via missing mass

$$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$$



~New: Under study by many groups

MSSM Higgs



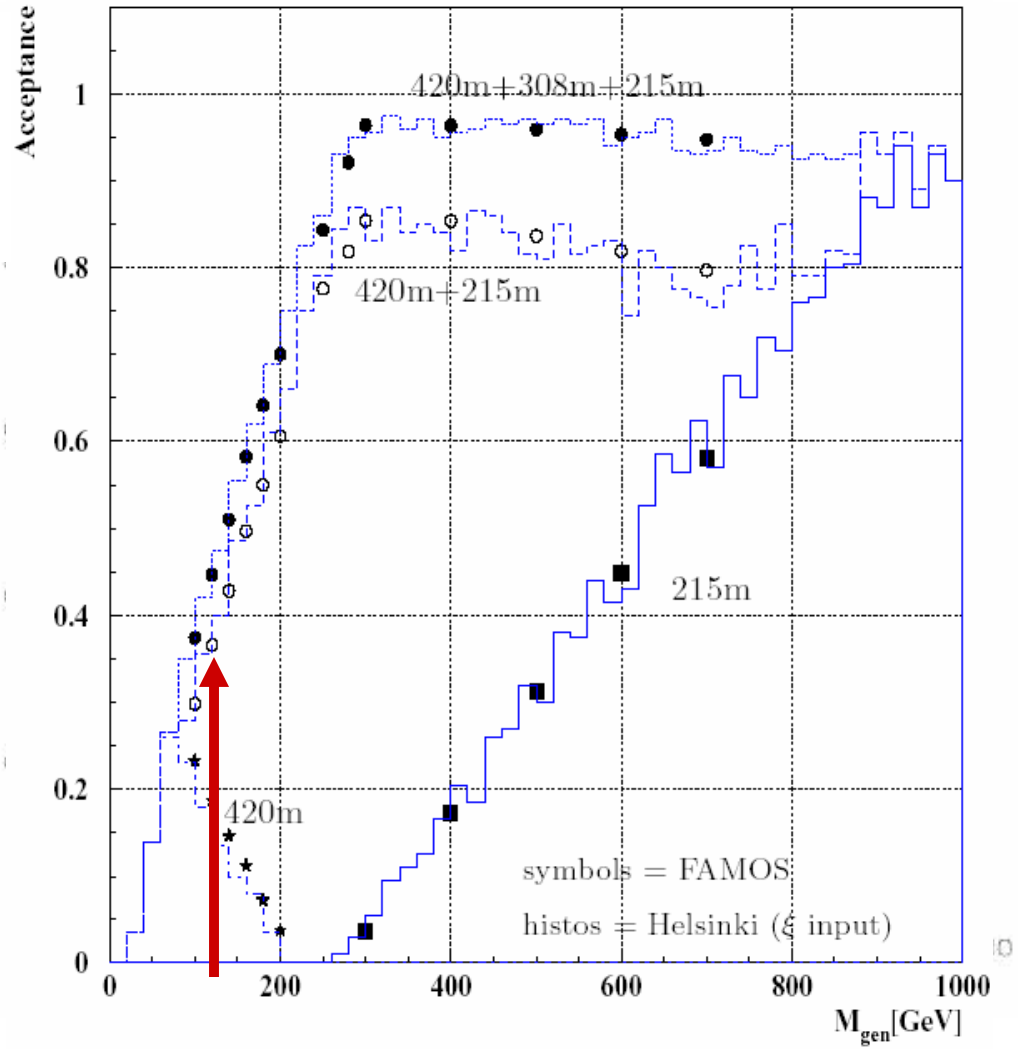
Kaidalov et al.,
hep-ph/0307064

Cross section factor ~ 10 larger in MSSM (high tanβ)

Also:
Study correlations between the outgoing protons to analyse the spin-parity structure of the produced boson

SM Higgs Studies

Needs Roman Pots at new positions 320 and/or 420 m
Technical challenge: "cold" region of the machine, Trigger signals…



- Combined acceptance of
  - → All detectors
    - Dotted line
  - → 420 m + 215 m
    - Dashed line
  - → 215 m alone
    - Solid line
  - → 420 m alone
    - Dash-dotted line
- without 308 / 338 m location
  - → 10-15 % loss in acceptance

Curves: Helsinki Group

Dots FAMOS simulati

Detectors at 300m/400m

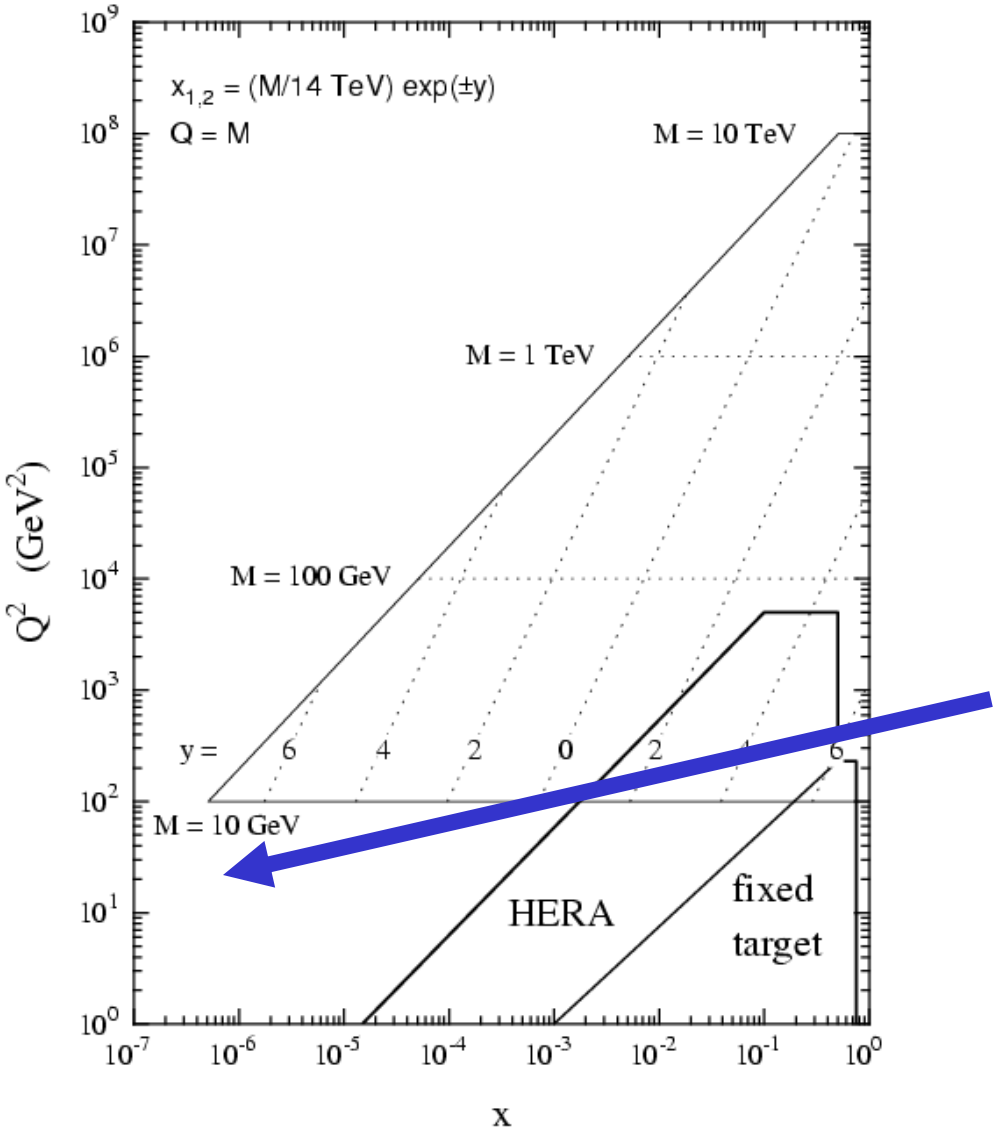
Detectors in this region requires changes in the machine

Some Major Concerns:

- Physics Case
  - Can we expect to see a good signal over background?
    - ⇒ Signal understood (cross section)
    - ⇒ Needs good understanding of the background (inclusive!)
    - ⇒ Needs more complete simulations (resolutions, etc.)
- Trigger
  - 300m/400m signals of RPs arrive too late for the trigger
    - ⇒ Can we trigger with the central detector only for L1?
      Note: L1 2-jet thresholds E_T > ~150 GeV
- Machine
  - Can detectors (RPs or microstations) be integrated with the machine? Technically there is place available at 330 and 420 m

Of interest for both ATLAS and CMS

Low-x at the LHC



LHC: due to the high energy can reach small values of Bjorken-x in structure of the proton $F(x,Q^2)$

Processes:

- Drell-Yan
- Prompt photon production
- Jet production
- W production

If rapidities below 5 and masses below 10 GeV can be covered ⇒ x down to 10^{-6}-10^{-7}

Possible with T2 upgrade in TOTEM (calorimeter, tracker) $5<\eta<6.7$!

Proton structure at low-x !!

Parton saturation effects?

Summary

- Diffraction and forward physics getting on the physics program of LHC experiments (in particular CMS/TOTEM)
  - Physics Interest
    - Hard (& soft) diffraction, QCD and EWSB (Higgs), New Physics
    - Low-x dynamics and proton structure
    - Two-photon physics: QCD and New Physics
    - Special exotics (centauro's, DCC's in the forward region)
    - Cosmic Rays, Luminosity measurement, (pA, AA…)
  - Probably initial run at high β^* (few days/weeks $\Rightarrow$ 0.1-1 pb^{-1})
  - Runs at low β^* (10-100 fb^{-1})

- Opportunities for present/new collaborators to join
  $\Rightarrow$ complete forward detectors for initial LHC lumi