Diffraction at LHC

(How to turn LHC into a 14 TeV Gluon Factory ?)

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LISHEP 2002

Workshop on Diffractive Physics
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What it takes to cover forward physics at LHC?

(1) Introduction to the machine (LHC) and the 'base line' general purpose experiments (ATLAS & CMS)

(2) Forward physics at LHC:

- Physics motivation
- How to provide the required extended acceptance of *inelastic activity*?
- How to detect and measure the *leading protons*?

Diffraction is mostly beyond the reach of the large baseline experiments at LHC (ATLAS & CMS).[1] How to extend them for the benefit of forward physics?

(3) Leading proton measurement

(4) Upgrade scenarios & Forward detectors:

- ATLAS + A Foward Spectrometer
- CMS + TOTEM (TOTEM is accepted to go for a TDR)
- Roman Pots and MicroStations©

(5) Physics Performance:

- Diffractive Scattering & Exclusive DPE

(6) Outlook

1 See presentation of Albert DeRoeck...

Diffraction and Low-x at the LHC

Albert De Roeck
CERN

LISHEP

Diffraction at the LHC
Low-x QCD at the LHC
2-photon physics at the LHC?
Running the LHC at lower energies

LHC will be a 14 TeV proton-proton collider with a record luminosity

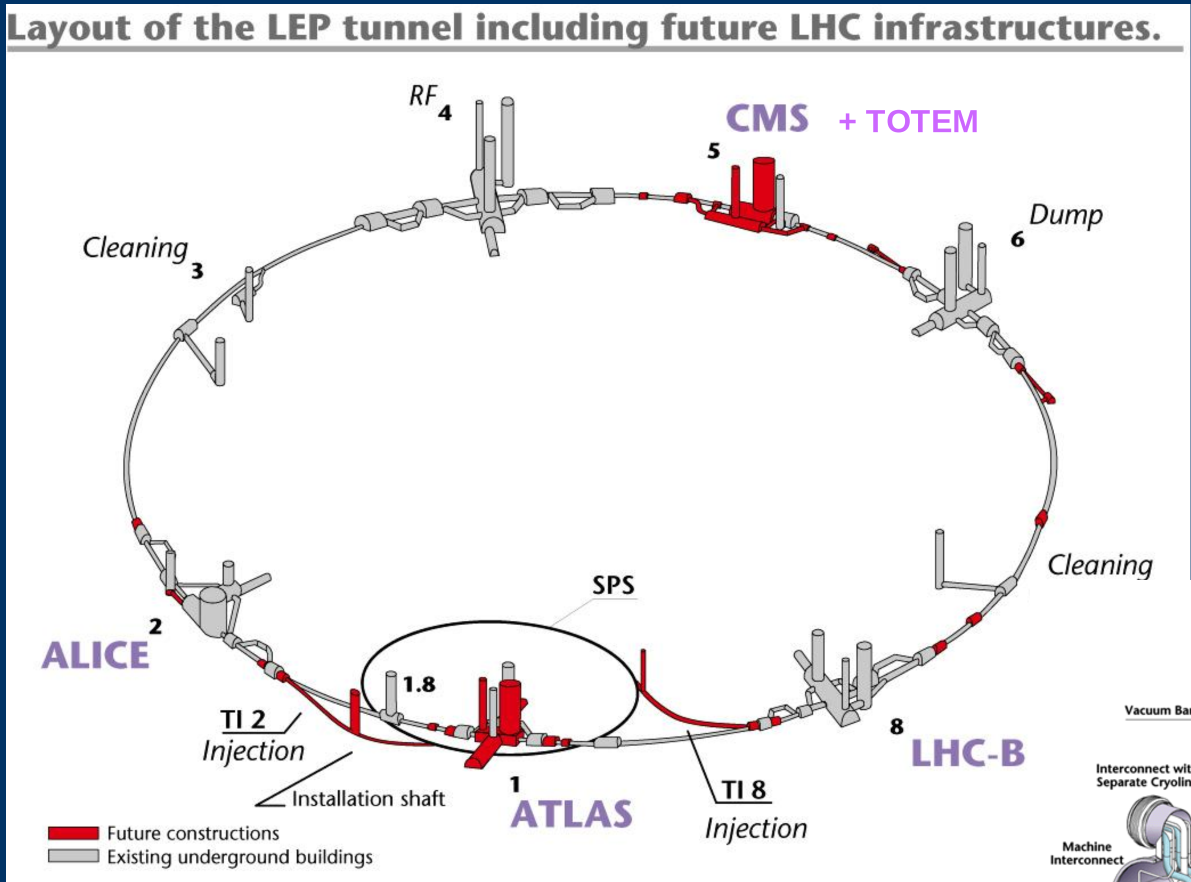
- proton-proton collisions @ 14TeV
  1104 dipoles with B = 8.3T (NbTi @ 1.9K)

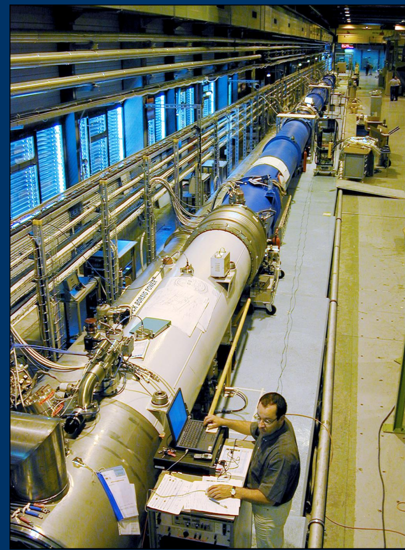
- 25ns bunch spacing
  2835 bunches (10^{11} protons per bunch)

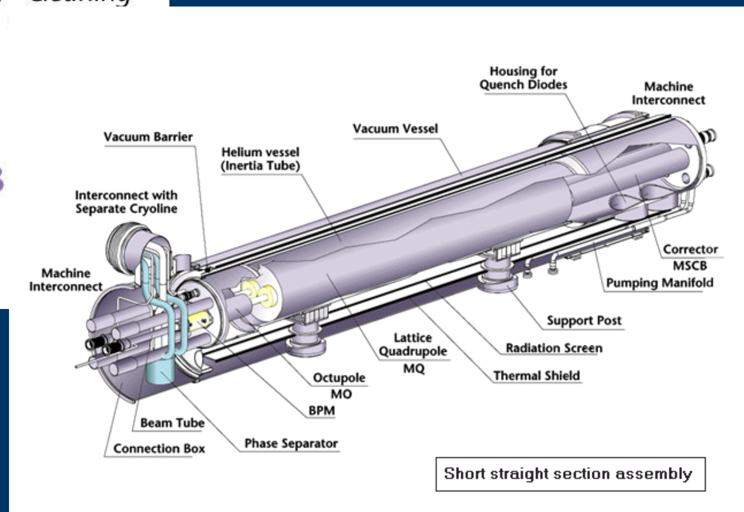
- $L_{design} = 10^{34}$ cm^{-2} s^{-1} (100 fb^{-1} per year)
  23 inelastic events per bunch crossing

LHC will have 4+ experiments

1.2







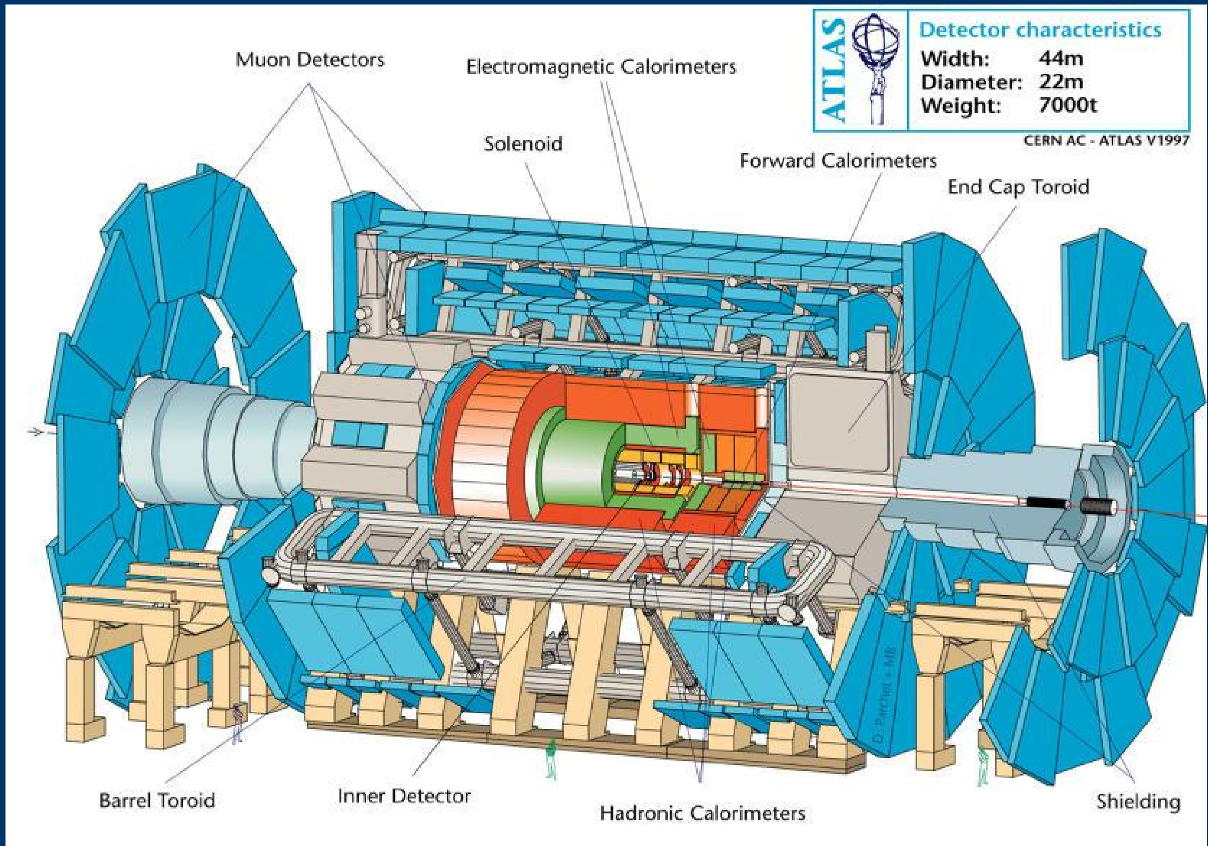
- construction of the infrastructure well under way

LHC will produce its first collisions in 2006...[1]

Date:	Milestone:
• April – September 2004	sector tests with a pilot beam
• February 2006	first beam
• April 2006	first collisions ($L = 5\text{-}10 \cdot 10^{32}$ cm^{-2} s^{-1})
• May – July 2006	shut down
• August 2006 – February 2007	physics run ($L = 2 \cdot 10^{33}$ cm^{-2} s^{-1} $\Rightarrow$ 10fb^{-1})
• March 2007 – April 2007	heavy ion run

1 Revised schedule given in March

LHC will have two 'general purpose' experiments: ATLAS



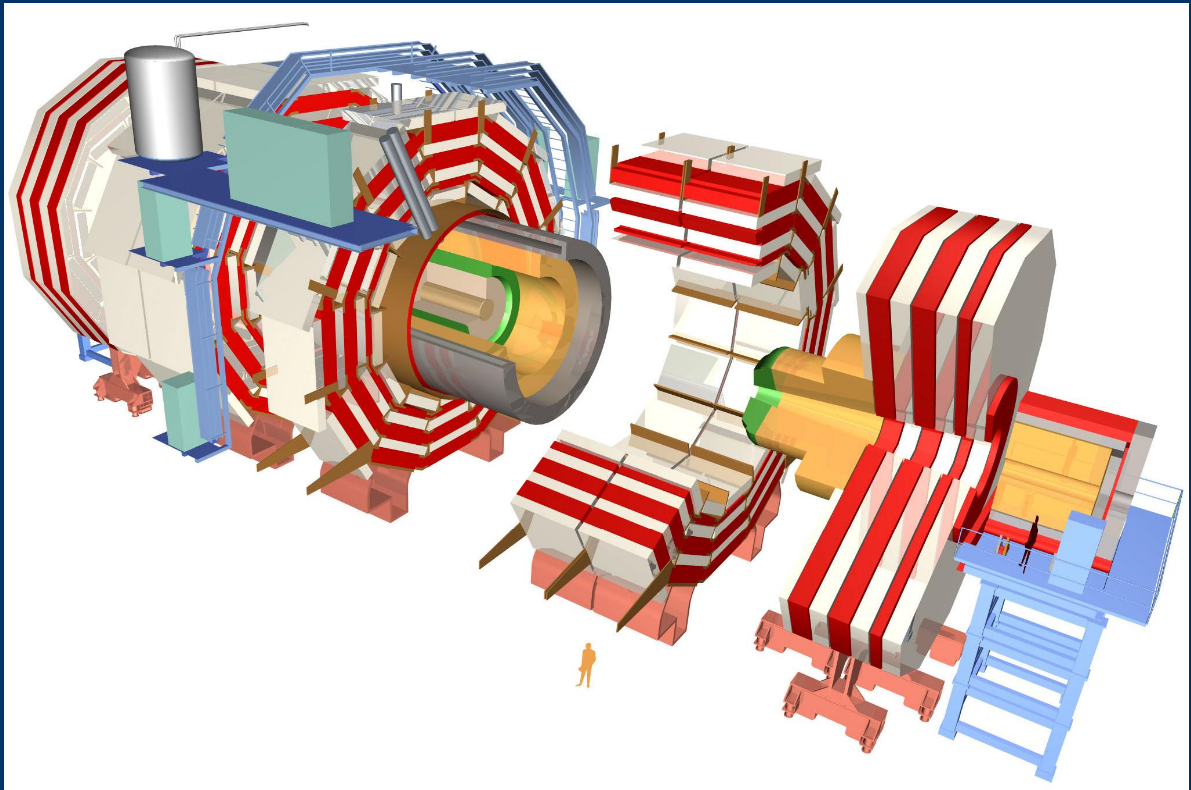
Inner Detector:
Si strip & pixel detectors, TRT
$\sigma/p_T \approx 5 \cdot 10^{-4}\ p_T \oplus 0.01$

Solenoid:
2T s.c. solenoid

Calorimetry:
LAr and scintillating tile based em $\sigma/E \approx 10\%/\sqrt{E}$ and had cal (10λ)
$\sigma/E \approx 50\%/\sqrt{E} \oplus 0.03$

Air Core Toroids & Muon Detectors
$\sigma/p_T \approx 7\%$ at 1 TeV

and CMS



Tracking:
Si strip & pixel detectors
$\sigma/p_T \approx 1.5 \cdot 10^{-4}\ p_T \oplus 0.005$

Calorimetry:
em $PbWO_4$ crystals
$\sigma/E \approx 2\text{-}5\%/\sqrt{E}$, had Cu-scintillator (>5.8λ + catcher)
$\sigma/E \approx 65\%/\sqrt{E} \oplus 0.05$

Solenoid:
4T s.c. solenoid

Return yoke:
Fe with muon chambers
$\sigma/p_T \approx 5\%$ at 1 TeV

The Base Line LHC Physics programme aims at discovering the SM Higgs at all possible masses. Moreover, LHC:

- Allows precision measurements:
  m_W to 15MeV, m_{top} to 1.5 GeV
  $\sin^2\Theta_{eff}$,...

- Covers physics beyond the SM:
  SUSY: squarks & gluinos up to 2.5 TeV
  W' (Z') bosons up to 4.5 (6) TeV
  compositeness up to 40 TeV

Design Criteria of ATLAS & CMS are based on:

- Detection of High p_T Objects:
  Higgs, SUSY,...
- Precise measurement of e, γ, μ, τ, and b-jets:
  tracking: $|\eta| < 2.5$
  calorimetry with fine granularity: $|\eta| < 2.5$
  muon system: $|\eta| < 2.7$
- Measurement of jets, E_T^{miss}:
  calorimetry extension: $|\eta| < 5$
- Precision physics (cross sections...):
  energy scale: e & μ 0.1%, jets 1%
  absolute luminosity vs. parton-parton luminosity via "well known" processes such as W/Z production?

LHC experiments can be extended to cover forward physics.

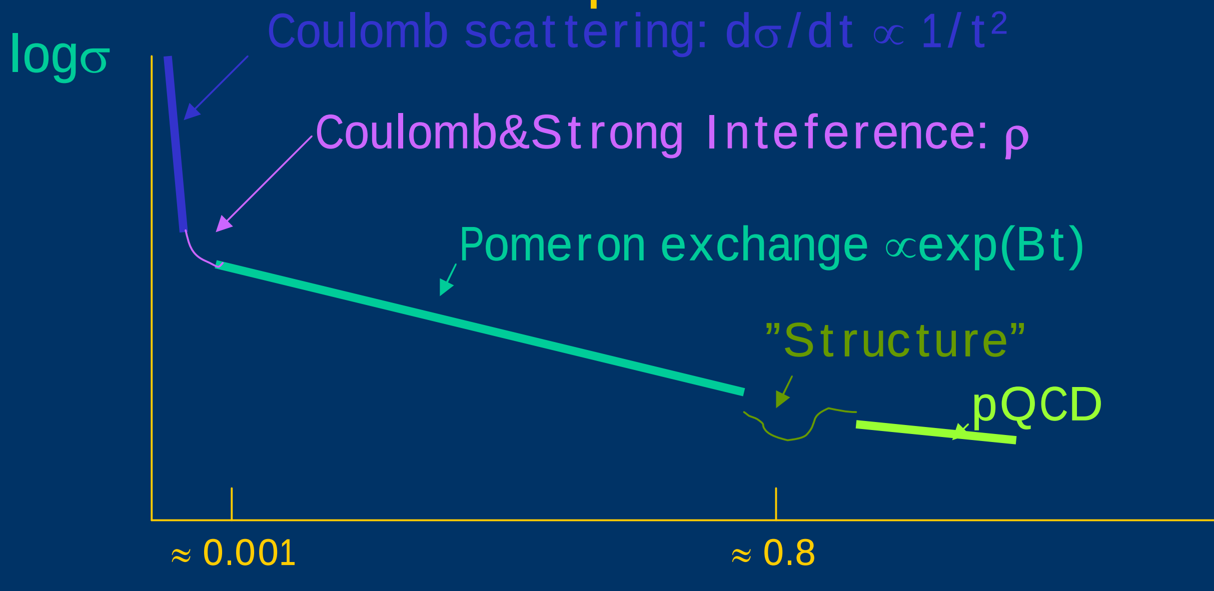
2.1

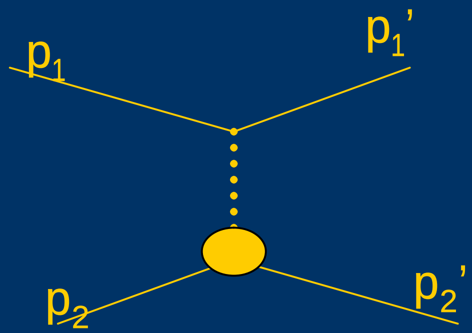
- Search for signals of new physics using fwd protons + rapidity gaps $\Rightarrow$Threshold scan for new massive states in: $pp \rightarrow p+X+p$ [1]
- Extension of the 'standard' physics reach of present LHC experiments into the forward region (CMS/Totem,ATLAS)
- Luminosity measurement with $\leq$ 5 % [2]
- Investigate QCD: σ_{tot}, elastic scattering, soft & hard diffraction, multi rapidity gap events (see: Hera, Tevatron, RHIC...)

$\Rightarrow$ Possible extension to a full acceptance detector. [3]

[1] Albrow&Rostovsev, DeRoeck, Khoze & RO [2] F. Gianotti, M. Pepe Altarelli, hep/ex/0006016
[3] Felix-proposal, K.Eggert et al.

Forward physics processes range from Coulomb scattering to hard diffractive processes

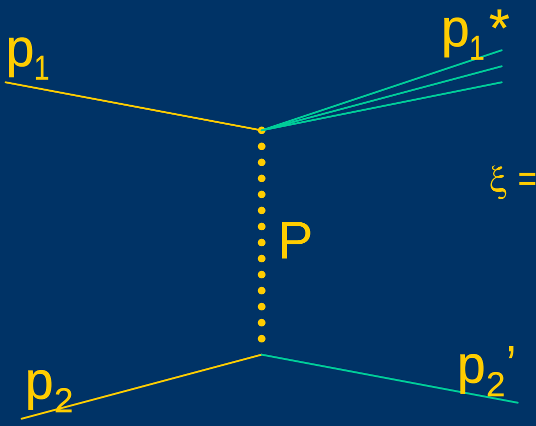




Region	Characteristic –t $(GeV/c)^2$	Run type[1]
Coulomb region	$\leq 10^{-4}$	super β^*
Coulomb –Strong Interference	$\approx 10^{-3}$	high β^*
Pomeron – Diffraction	$\geq 10^{-3}$	high/low β^*
Structure – Peaks & Bumps	≈ 0.8	low/high β^*
Large –t – Perturbative QCD	≥ 5	low β^*

[1]The official LHC optics is based on low β^*=0.5m and high β^* =1100m.

In Single Diffractive Excitation mass of the diffractive system depends on the momentum loss, ξ, of the incident proton. The size of a rapidity gap is $\propto \ln\xi$.

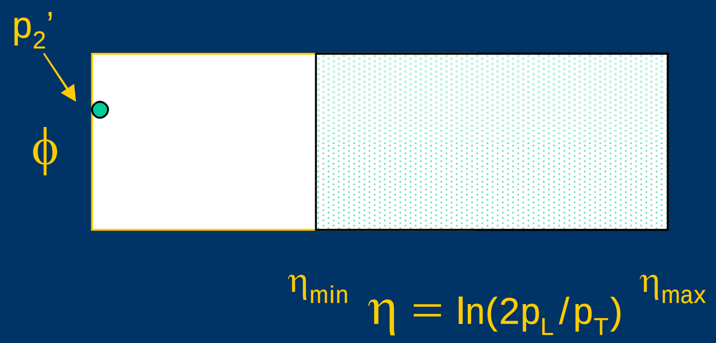


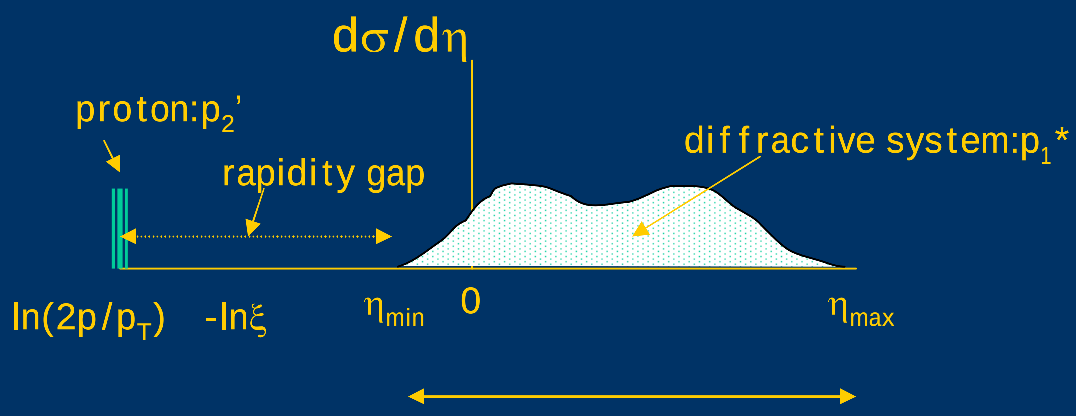
$\xi = 1 - x_F = M^2/s$

Rapidity Gap Survival Probability[1]

	Tevatron	LHC
SD	10-24%	6-21%

[1] V.A.Khoze,A.D.Martin and M.G.Ryskin, hep-ph/0007359





Cross section: $d^2\sigma_{sd}/d\xi dt = (A/\xi)b\exp(-bt)$ $\Delta\eta \propto \ln M_{diff}^2$

with $b \sim 10\ GeV^{-2}$, $t \sim \theta^2 p^2$

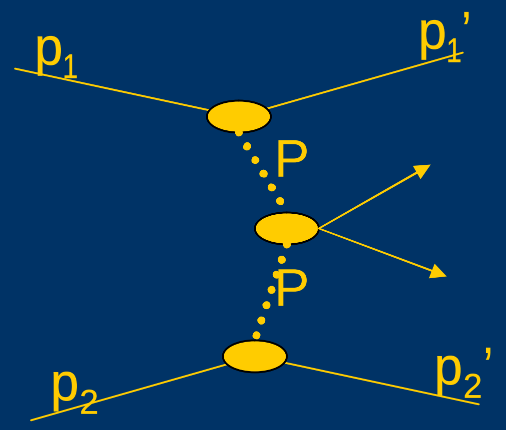
Hard single diffractive excitation is used to learn more about the Pomeron structure.

- Diffractive production of heavy objects: W, Higgs, heavy flavour,...and di-jets
- σ_{SD} vs. $\xi = 1 - x_p = 1 - p/p_{beam}$ and $-t = (p_{beam} - p)^2$
- 3rd jet activity in jet production (probing the q/g nature of Pomeron)
- Extraction of Pomeron structure function

- "Hard" refers to large p_t's, Ingelman & Schlein consider a composite P within a proton with a flux of P's (f P) and P structure function $F_2^P \sim \beta(1-\beta)$ (hard) and $F_2^P \sim (1-\beta)^5$ (soft)

Double Pomeron Exchange: exclusive channels with leading protons and rapidity gaps.

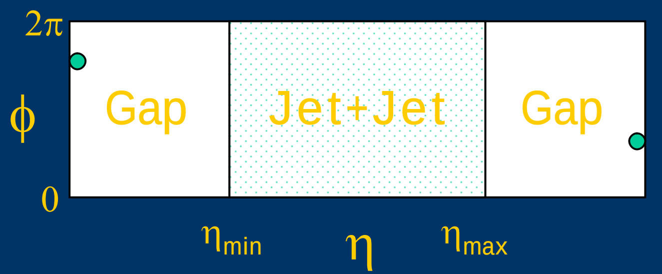
The Pomeron has the internal quantum numbers of vacuum.



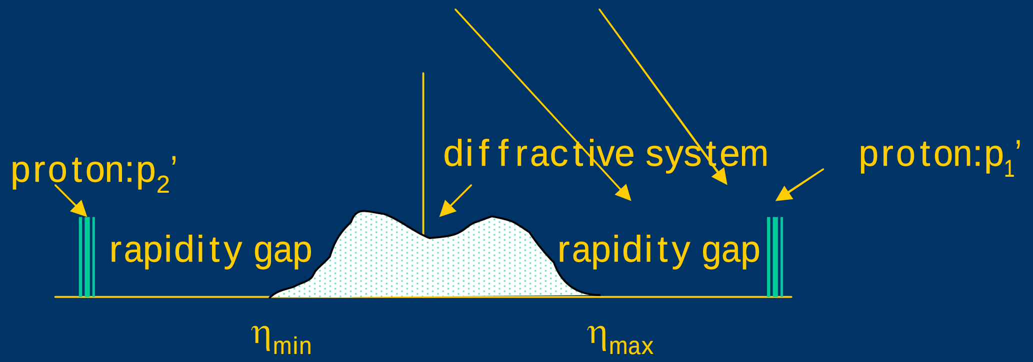
PP: C = +, I=0,...

P: $J^{PC} = 0^{++}, 2^{++}, 4^{++},\ldots$ (not 1^{++} etc.)

$\Rightarrow$ gg vs. $u\bar{u}$, $d\bar{d}$, $s\bar{s}$, $c\bar{c}$, $b\bar{b}$?



Two types of signatures



Rapidity Gap Survival Probability[1]

	Tevatron	LHC
CD	5-14%	2-11%

[1] Khoze, Martin, Ryskin/Levin/Block et al

As a Gluon Factory LHC could deliver...

- 100,000 high purity (q/g = 1/3000) gluon jets with E_T > 50 GeV in 1 year; gg-events as "Pomeron-Pomeron" luminosity monitor

- Possible new resonant states, e.g. *Higgs* (250 H $\rightarrow$ b$\underline{\text{b}}$ events per year with m_H = 120 GeV, L=10^{34})*, *glueballs, quarkonia* 0^{++} (χ_b), *gluinoballs* - background free environment (b$\underline{\text{b}}$, WW & $\tau+\tau-$ decays)

- *Squark & gluino* thresholds
  - thresholds are well separated
  - practically background free signature: multijets & missing transverse energy
  - model independence (missing mass!)
  - expect 10-15 events for gluino/squark masses of 250 GeV
  - interesting scenario: gluino as the LSP with mass window 25-35 GeV (S.Raby et al.)

*V.Khoze, Martin & Ryskin, Boonekamp, Peschanski, Royon,...

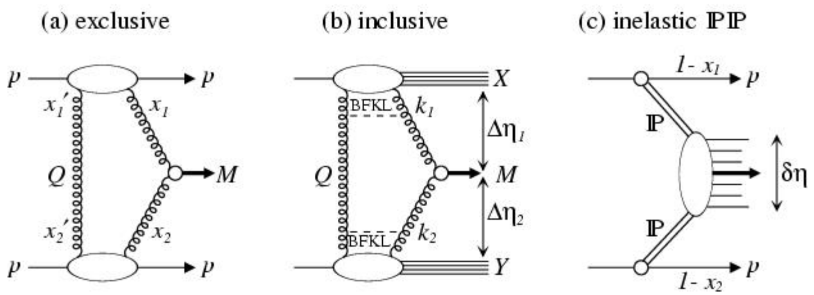
- Several events with isolated *high mass* $\gamma\gamma$ *pairs, extra dimensions*

Exclusive central diffraction is experimentally distinctive - inclusive has higher rate...

In *exclusive* process: pp → p + X + p:

- only J_z = 0, P=+1 contribute[1]
- signature: forward-backward pair of protons separated by two rapidity gaps from the central pair of jets

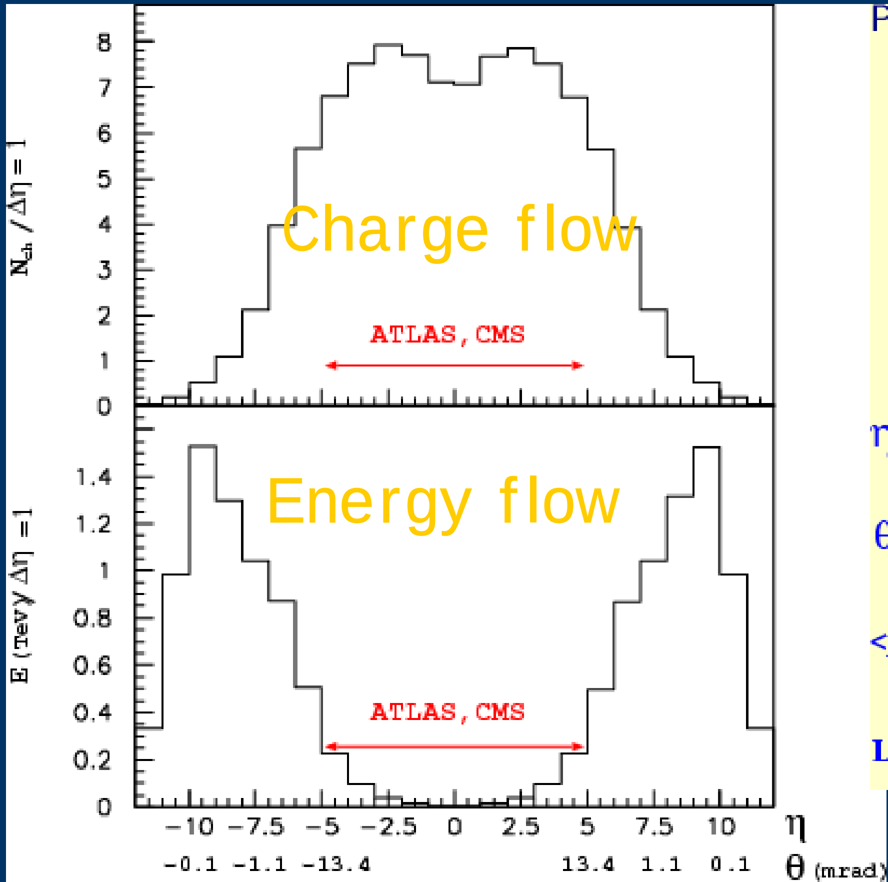
In *inclusive* process: pp → p X p extra particles emitted in the central region. (see:Ch. Royon)

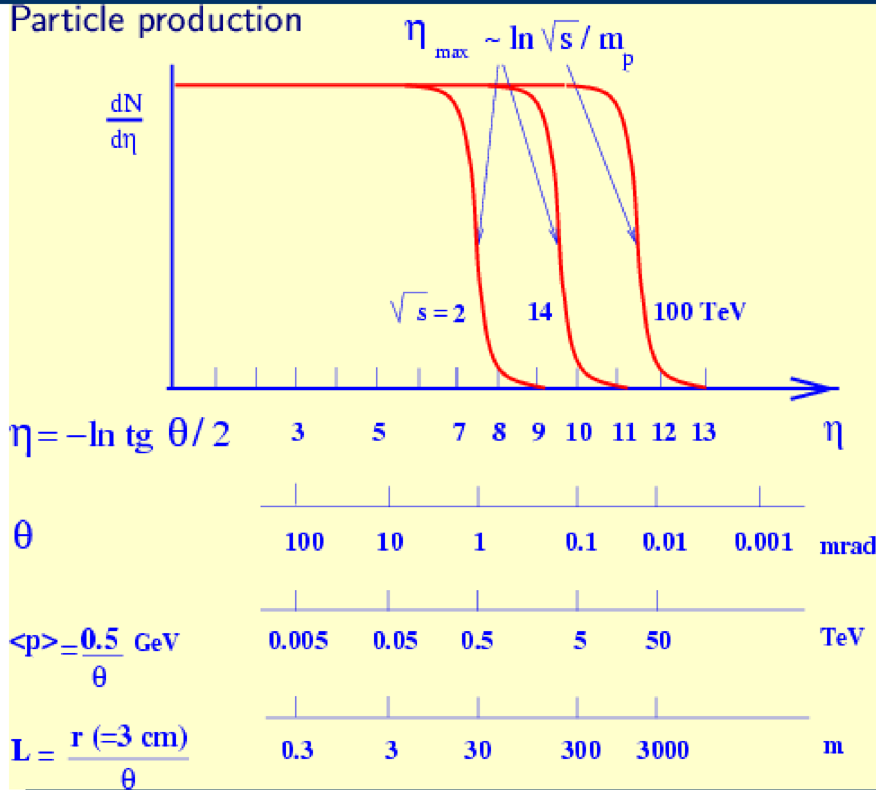


Khoze, Martin, Ryskin
Boonekamp, Peschanski, Royon
Cox, Lonnblad,...

[1] Amplitude averaged over the two transverse polarisations of the incoming gluons

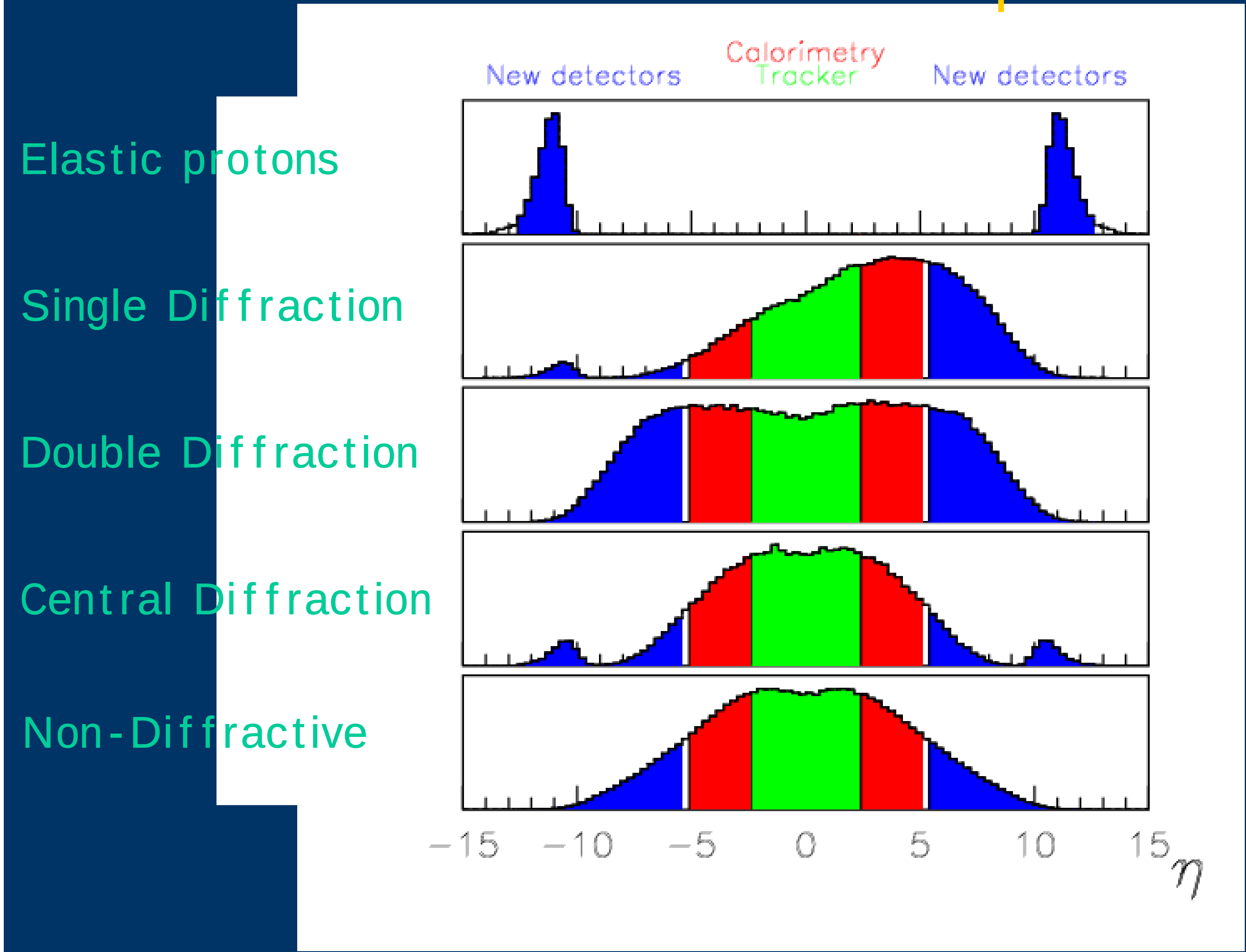
Important part of the phase space is not covered by the baseline designs. Much of the large energy, small transverse energy particles are missed.





In the forward region (|η| > 5) few particles with large energies/small transverse momenta.

As a conclusion: For forward physics processes need to extend the base line experiments.



Diffraction is mostly beyond the reach of large baseline experiments at LHC (ATLAS & CMS). What should be done to increase their coverage in the forward region?

(3) Leading proton measurement

(4) Upgrade scenarios & Forward detectors:

- ATLAS + A Foward Spectrometer
- CMS + TOTEM
- Roman Pots and MicroStations

(5) Physics Performance:

- Diffractive Scattering & Exclusive DPE

(6) Outlook

Forward physics processes have two distinctive signatures: (1) leading protons and (2) rapidity gaps.

- Additional coverage of *inelastic activity* can be achieved with a modest extension of these experiments beyond their base line acceptance limit of $|\eta|=5$.

- Detection and measurement of *leading protons* can be arranged by using Roman Pots/MicroStations far from the interaction point

For detecting and measuring the leading protons, need to consider the layout and optics of the LHC.

Relevant LHC machine parameters:

- nominal beam energy 7 TeV
- uncertainty in beam momentum $\xi_o = \Delta p/p = 10^{-4}$
- bunch spacing at 40 MHz: 25 ns
- design luminosity: 10^{-34} cm^{-2} s^{-1} with $\beta^* = 0.5$m (vs. injection, special runs)

At the interaction point:

- crossing angle: 300 μrad
- beam transverse divergence: 31.7 μrad
- normal transverse emittance: 3.75 μm (during the commissioning phase: 1μm!)

Leading proton measurement is closely linked to the machine parameters

Consider the trajectory of a proton in the transverse plane:

$$y(s) = v_y(s) \bullet y^* + L_y^{eff}(s) \bullet \theta_y^*$$

$$x(s) = v_x(s) \bullet x^* + L_x^{eff}(s) \bullet \theta_x^* + \xi \bullet D(s),$$

x^* and y^* = position in the transverse plane
θ_x^*, θ_y^* = scattering angles
$\xi = 1 - p'/p$ = the longitudinal momentum loss
$L_{x,y}^{eff}(s) = \sqrt{(\beta_{x,y}(s)\beta^*)} \sin\Delta\mu(s)$ the effective length with $\Delta\mu(s) = \int\beta^{-1}(s)ds$ the betatron phase advance
$v_{x,y}(s) = \sqrt{(\beta_{x,y}(s)/\beta^*)} \cos\Delta\mu(s)$ the magnification
$D(s)$ = the dispersion
$\beta_{x,y}(s)$ = the value of the β-function along the beam line
$\beta^* = \beta_x(s=0) = \beta_y(s=0)$ is the value of the β function at the interaction point

Acceptance and precision depend on...

The measured proton momentum:

$$p' = (1-\xi)\bullet p$$

$$t = -(1-\xi)^2[\sin^2\theta_x^* + \sin^2\theta_y^*]$$

Uncertainties:

- dispersion, magnification, effective length of position i
- transverse position of the event at the IP
- position resolution of the detectors
- beam momentum spread: $\xi_o \approx 10^{-4}$
- angular divergence at the IP: $\sigma_{\theta x*} = \sigma_{\theta y*}$ = 32 mrad.

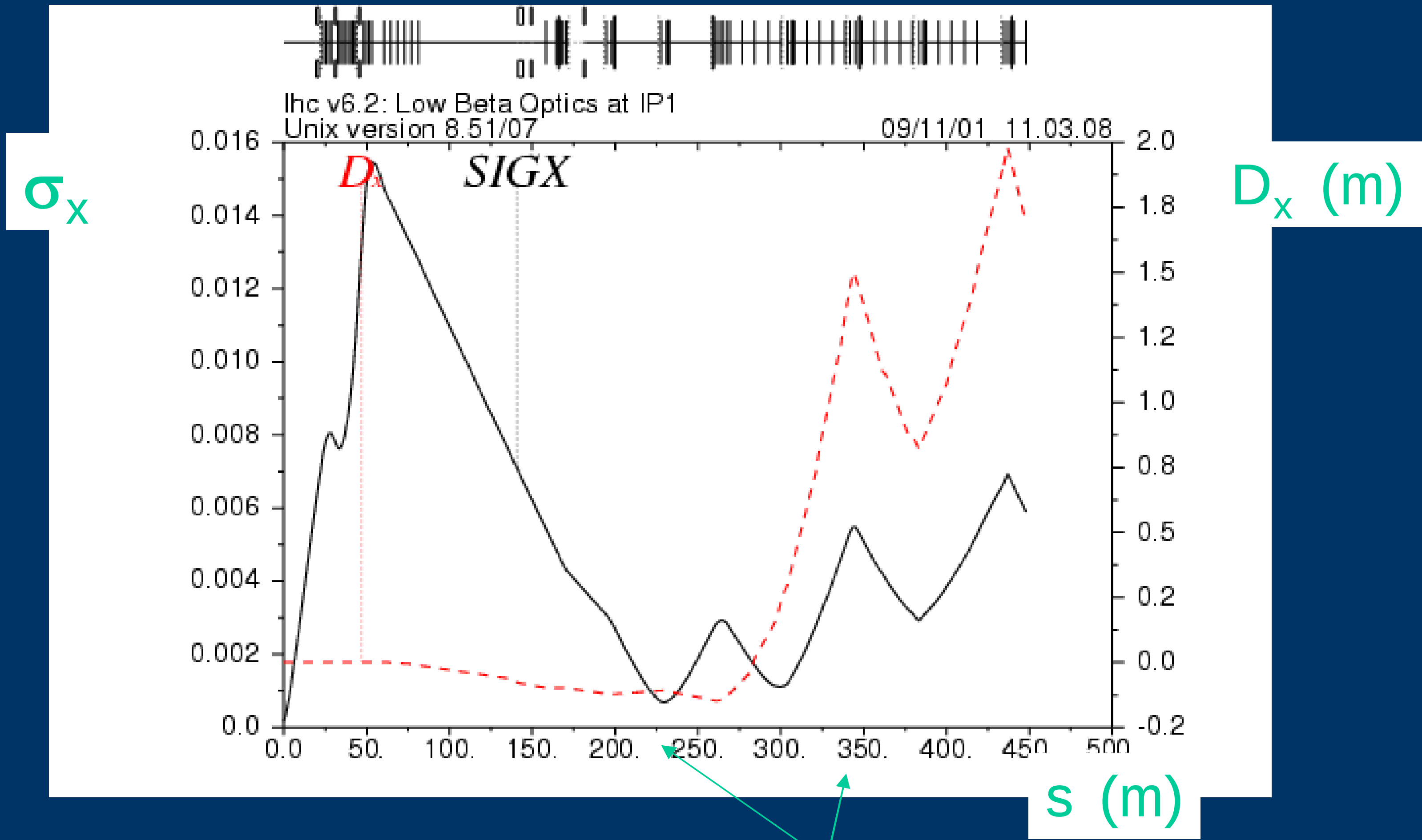
Estimated accuracy: $\Delta\xi/\xi \approx 10^{-4}$, $\Delta t/t$ = 10% for $-t$ = 0.01 GeV^2

Detecting leading protons in high β^* (β^* =1100m) or injection β^* (β^* =18m) conditions require dedicated runs. These are needed for reaching lower -t values in studies of elastic scattering and soft diffraction.

Optimize detector locations & machine optics in order to achieve:

- Principle of *parallell-to-point* focusing to allow a measurement independent of the position of the initial interaction - in the transverse plane- at high β^*, the beam size is large ($\sigma_{x,y}$ = 740μm)
- Small beam size at the chosen detector locations - at high β^*, σ_y = 0.1mm at z = 150m
- TOTEM optics (z=150m) reaches $-t_{min} = 10^{-2}$ GeV^2
- A.Faus-Glolfe, J.Velasco & M.Haguenauer (z=240m) $-t_{min} = 6{\cdot}10^{-4}$ GeV^2
    - Measurements in the vertical (σ_{tot}) and in the horizontal (Coulomb scattering) planes.
    - Super β^* (β^* = 3500m)

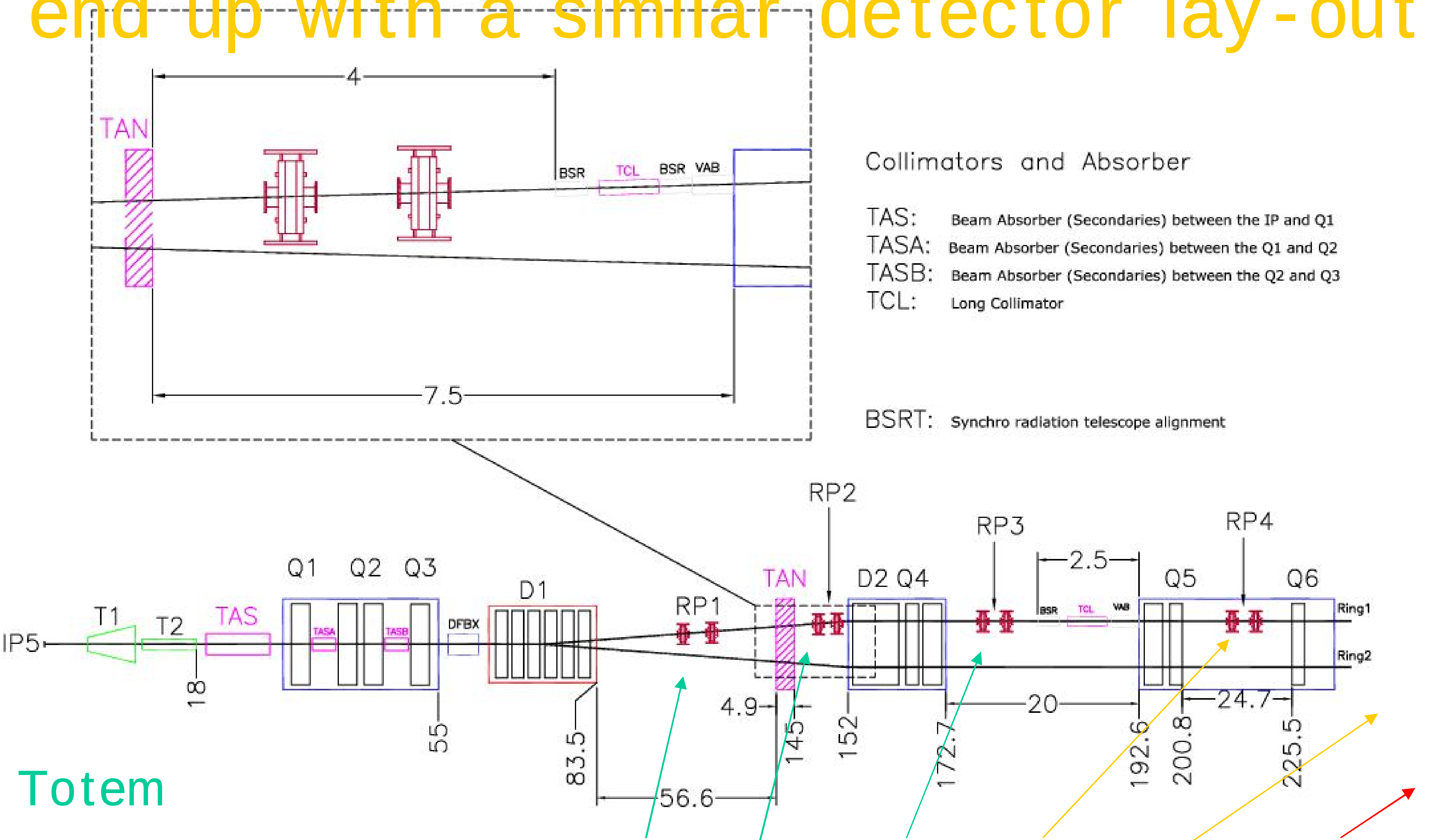
LHC low β* optics (β* = 0.5m, v6.3) 3.6



Beam size is small between s=200-250m.

Beam dispersion (D_x) large at s>300m: horizontal deviation from the nominal beam position given as: $\Delta x = \xi D_x$

LHC optics (v6.3) layout: Two studies end up with a similar detector lay-out



Optimized detector locations: 90m, 150m, 180m, 210m, 240m, >400m?

Beam sizes and effective distances at detector locations define the acceptance.

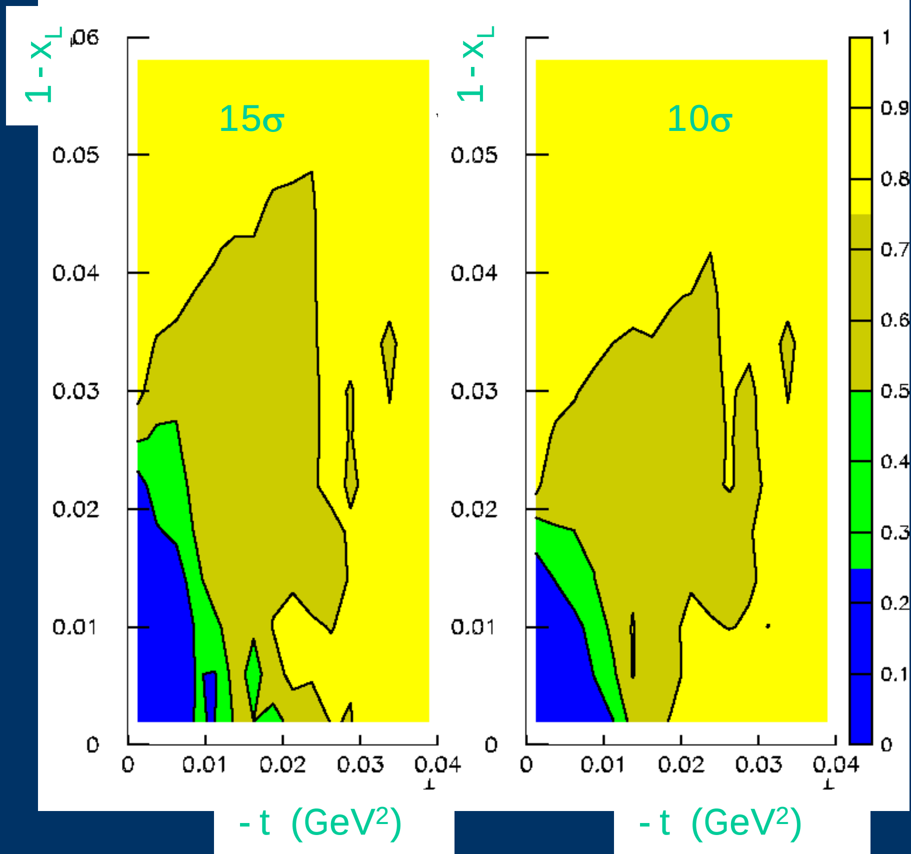
Location s(m)	Beam size σ_x(mm)	Effective distance Δ_{eff} (mm)
150	0.6	7 (13)
180	0.4	5 (9)
210	0.2	3 (5)
240	0.07	1.7 (2.4)
425	0.3	4 (7)

In defining Δ_{eff}, we assume: $10\sigma_x$ ($20\sigma_x$)

- Note: beam halo rates difficult to predict at 240m's
- For the RF shielding & guard ring add 1mm dead space

Leading Proton Acceptance

- High β*(=1100m)



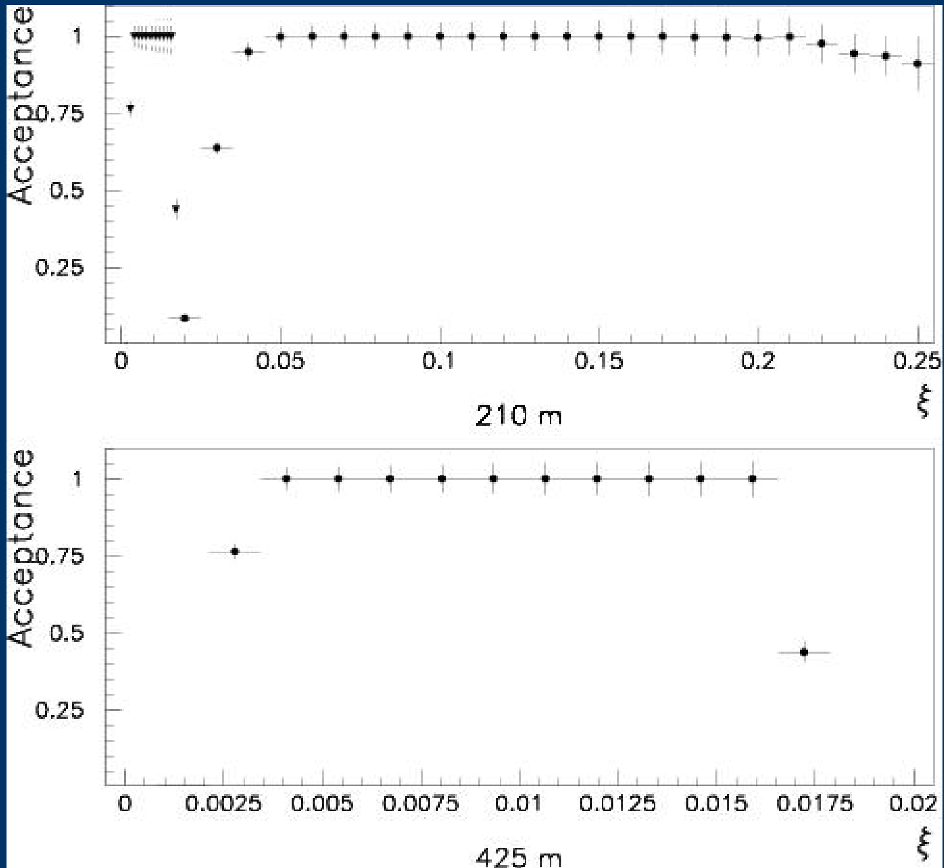
Acceptance > 50%
for all values of -t:
ξ > 0.03 (0.02)

Acceptance > 50%
for all values of ξ:
-t > 0.02 GeV^2

Helsinki group/L.Salmi et al.

Proton acceptances at 210 & 425m

low β^* (β^* = 0.5m)



Acceptance limited to $\xi > 0.03$

Acceptance to $\xi > 0.003$

- for 20σ downgrade by a factor of two

Helsinki group/ S. Tapprogge, K.Österberg et al.

Upgrade scenarios and Forward detectors - ATLAS & A Fwd Detector

For enabling the rapidity gap tagging and studies of the inelastic final states, the forward coverage of inelastic activity has to be extended beyond the baseline limit of $|\eta| \sim 5$.

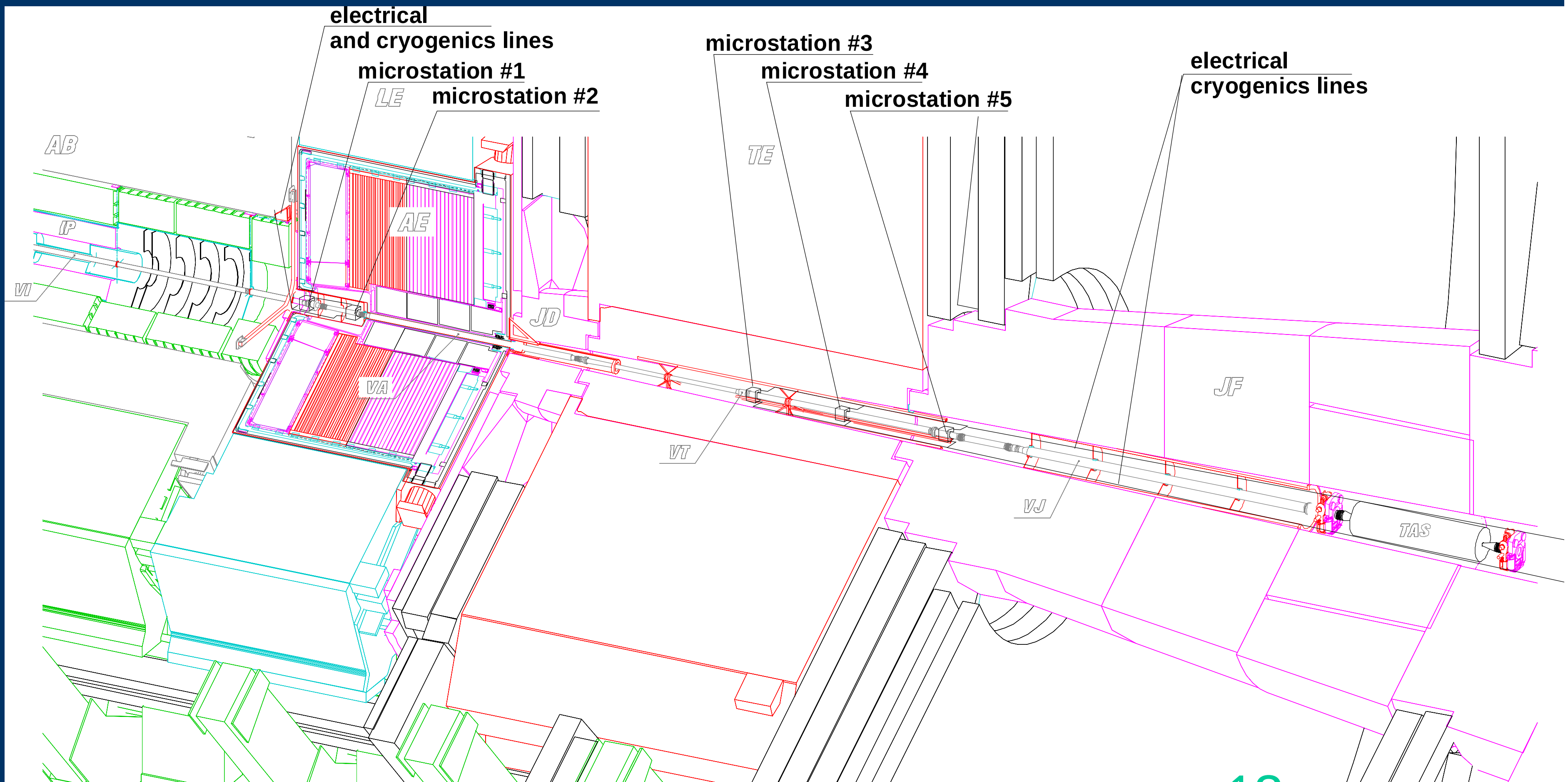
This is also needed for the luminosity measurement and monitoring.

The Microstation© concept was developed to provide a solution.

Design of the Forward Spectrometer is Challenging since one has to:

- operate close to the beam in *intense radiation* environment
- meet the constraints due to *limited amount of space* available
- integrate the detectors with the *machine requirements* (vacuum, RF,...)
- adapt to changing machine conditions (injection, special runs) require *movable* detectors

Additional detectors are needed to extend the acceptance close to the collision point - space is limited (forward region of ATLAS)



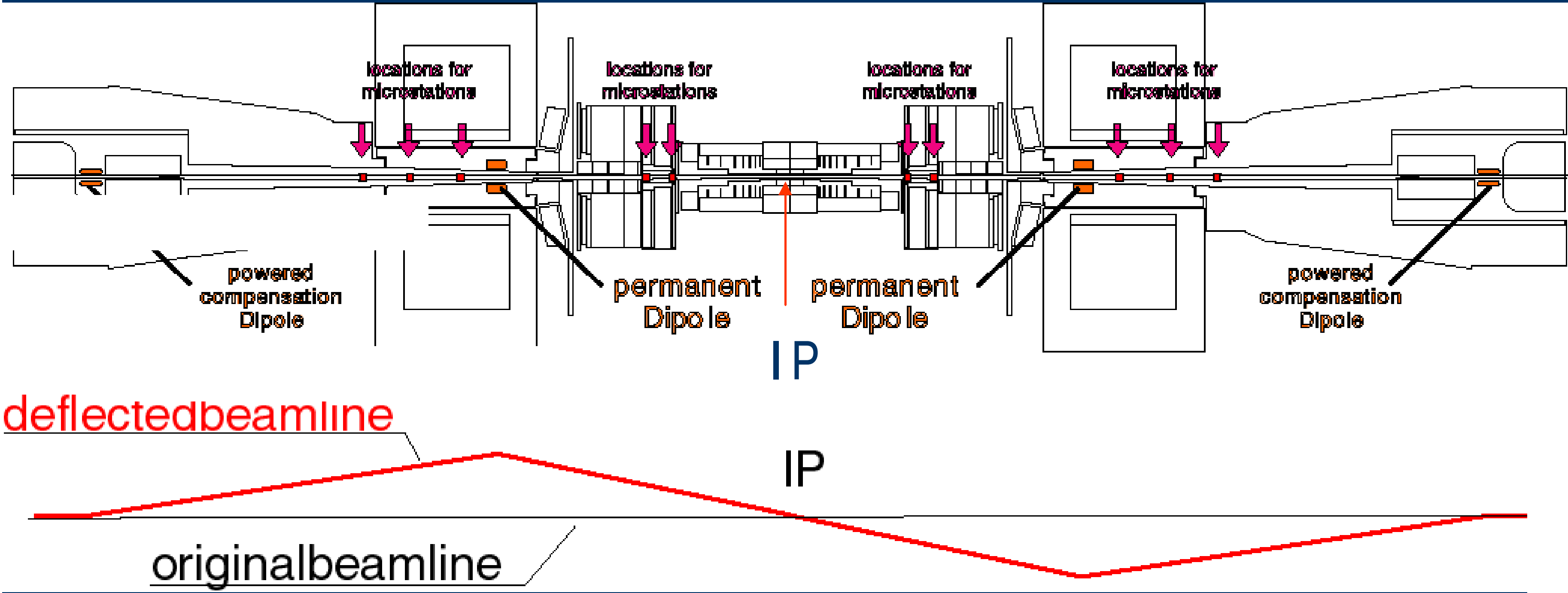
z = 3- 4m

z = 10- 13m

z = 18m

Risto Orava

In addition, need to detect and measure the leading protons close to the beam - further locations are the same in case of ATLAS & CMS



For optimal detector locations consider: beam optics, ”warm” sections, available space & services, access, acceptance (η & ϕ), radiation background, trigger latency...

A novel detector for measuring the leading protons - the Microstation© - is designed to comply with the LHC requirements.

- a compact and light detector system (secondary particle emission, dimensions < 20cm, weight < 2kg)
- integrated with the beam vacuum chamber (acceptance)
- geometry and materials compatible with the machine requirements (dynamic vacuum (outgassing 10^{-11} atm, bake-out to 180 C), RF impedance (< 0.6mΩ/ms), em pick-up)
- μm accurcay in sensor movements (alignment)
- robust and reliable to operate (access limitations)
- Si strip or pixel detector technology (heat dissipation (< 50 mW), simplicity & radiation hardness (n flux 10^5 kHz/cm^2, 0.25μm CMOS read-out chips fully functional up to 30Mrad))

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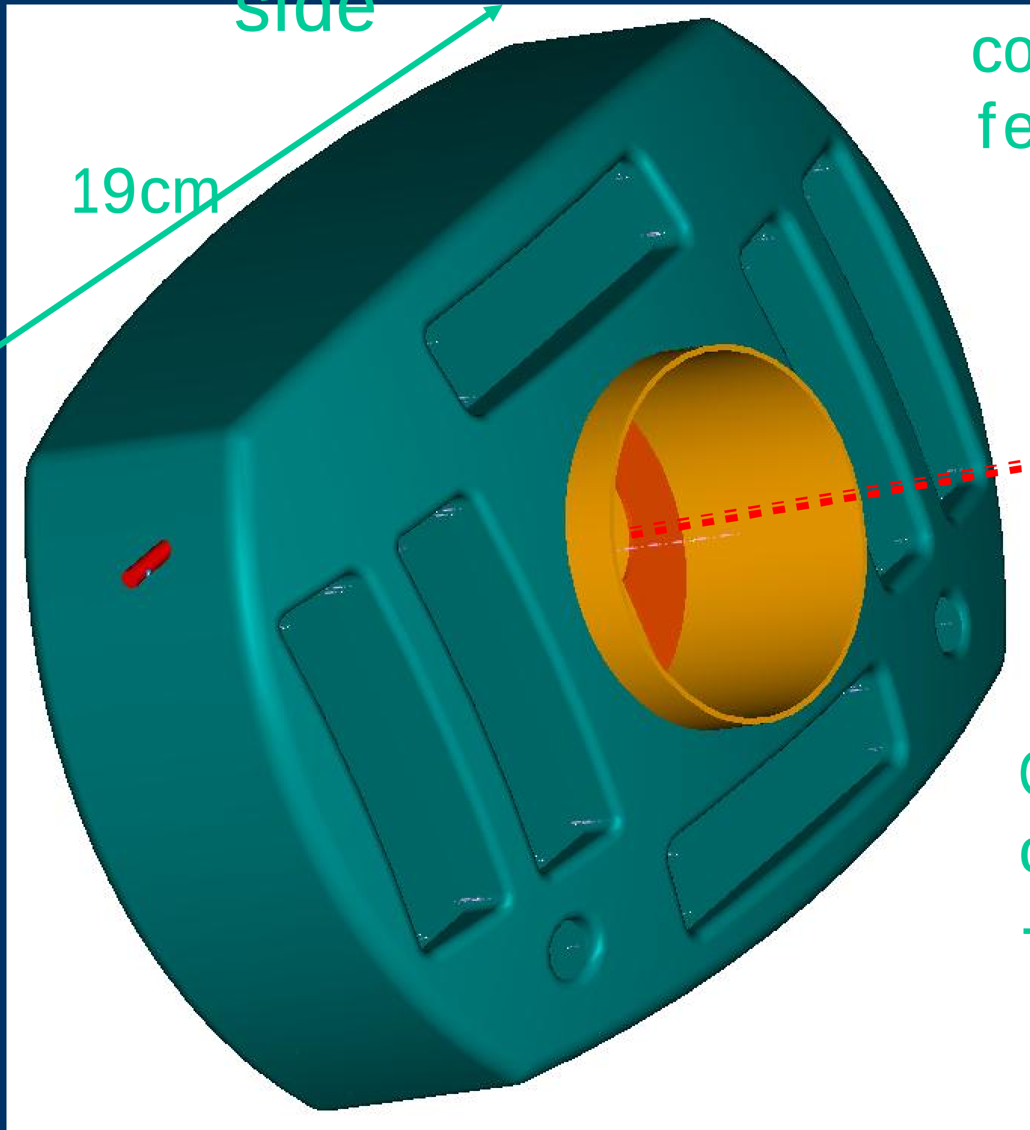
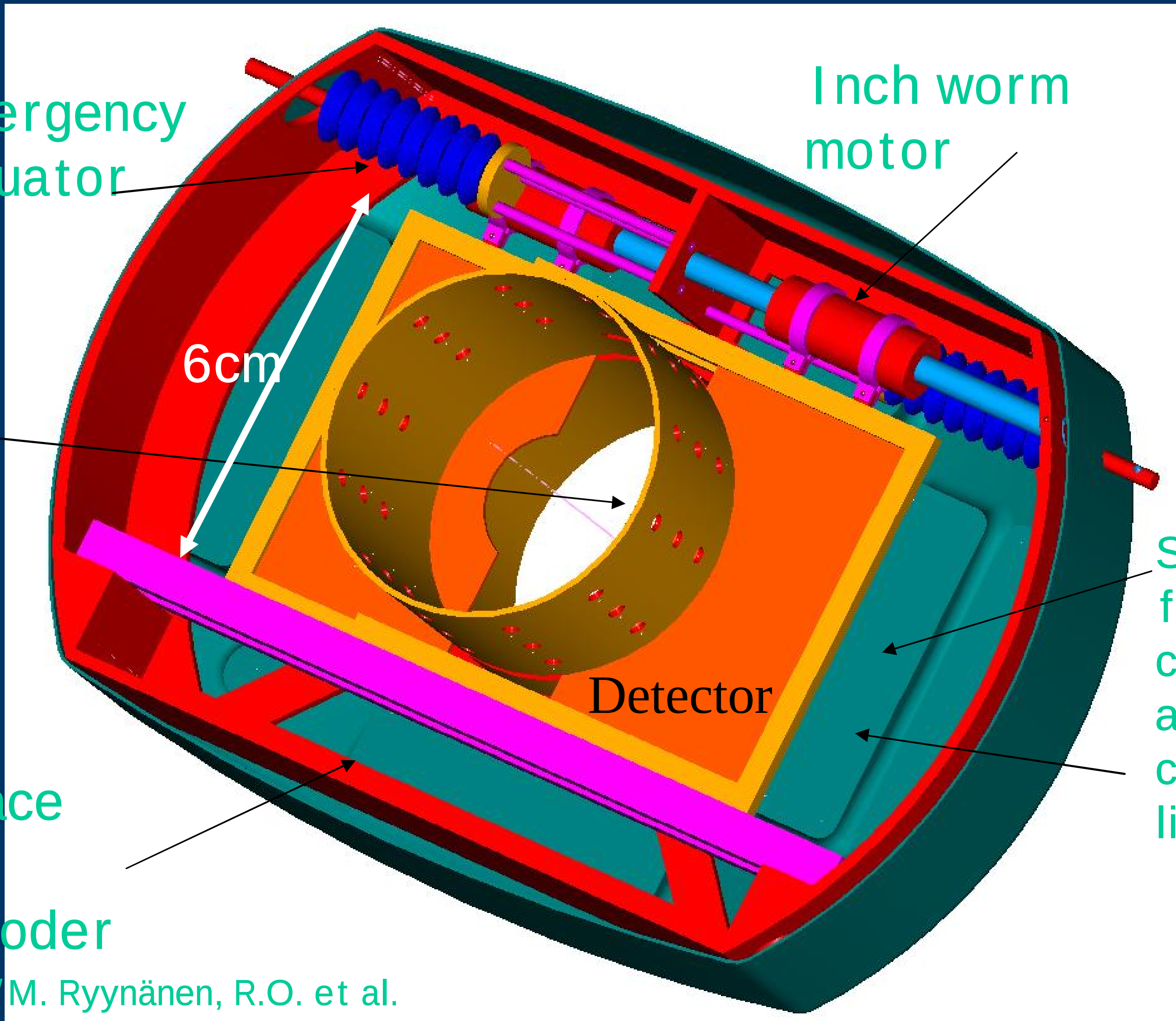
Micro-Station



Microstation

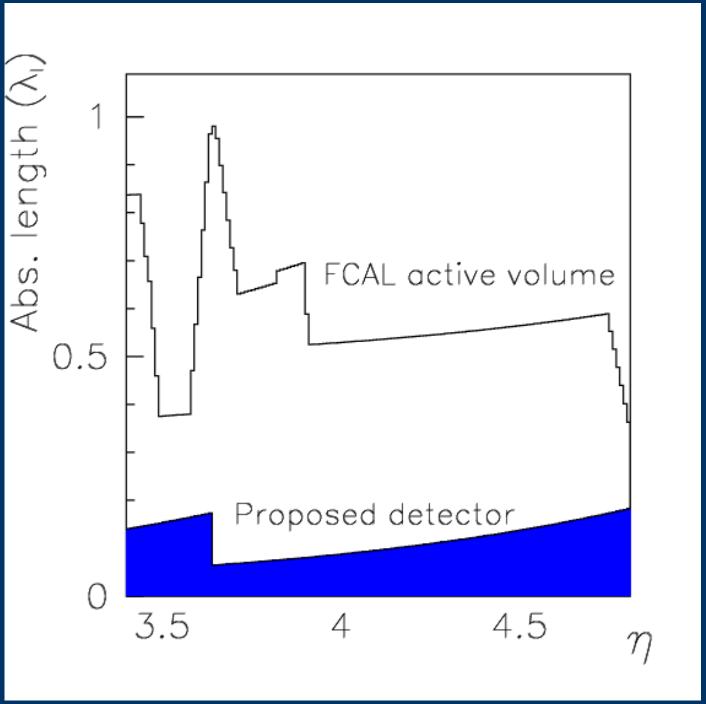


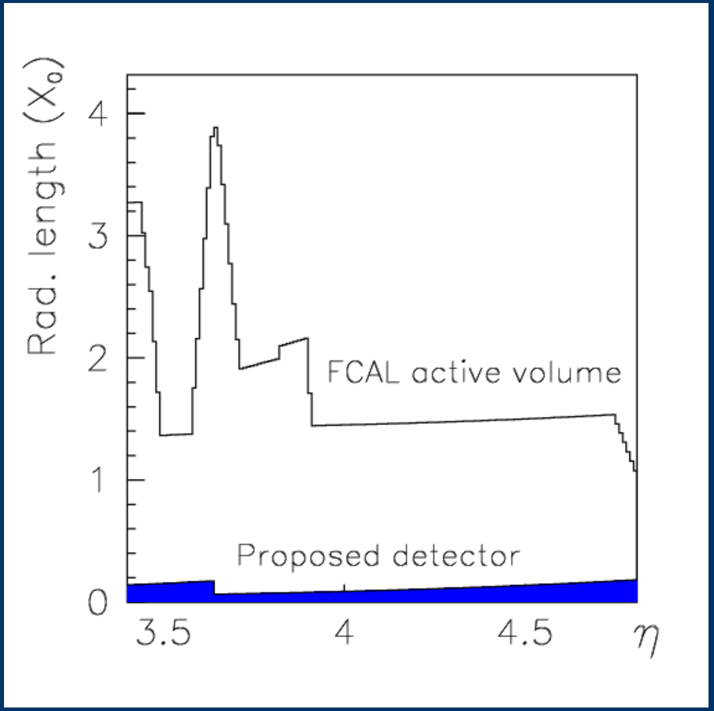
Helsinki group/M. Ryynänen, R.O. et al.

Research and Development: *μstations*

- Beam impedance, electromagnetic pick-up bench measurements, shielding.
- Alignment, mechanical stability and reliability, emergency detector retraction from the beam.
- Cooling and cryogenic system studies.
- Bakeout tests, outgassing and vacuum tests.
- Study of radiation hardness of the critical components:
  - motors,
  - connectors and feedthroughs,
  - flexible connections at cryogenic temperatures in vacuum.

The forward spectrometer introduces a minor increase for the material budget





Helsinki group/V.Nomokonov et al.

Detector occupancies are well under control.

1) Primary tracks/physics events
2) Secondary particles (γ,e,p) from interactions with the beam pipe etc.
3) Beam background

Detector size: 300 × 50 μm^2

Item	Minimum bias events	+ Bkg at low lumi	+ Bkg at high lumi
Detector occupancy	4.0 10^{-5}	6.5 10^{-4}	6.5 10^{-3}
Fraction of merged hits	1.2 10^{-3}	8.0 10^{-3}	1.2 10^{-2}

Helsinki group/V.Nomokonov et al.

Upgrade scenarios and Forward detectors - CMS & TOTEM

- The Technical Proposal submitted in 1999
- The Technical Design Report (TRD) to be completed by Fall 2002
- Designed to co-exist with CMS and to run with large or intermediate β^* (1100m & 18m &...)
- Aims at:
  - Precision measurement of σ_{tot} ($\Delta\sigma_{tot}$ ~ 1mb)
  - Elastic scattering down to $-t_{min} \sim 10^{-3}$
  - Inclusive (soft) diffractive scattering
- Forward spectrometer:
  - T1 & T2 for inelastics ($3 < |\eta| < 7$)

TOTEM @ CMS

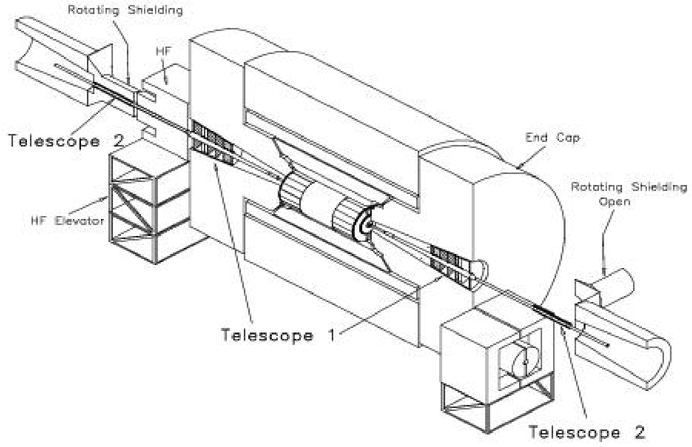


Figure 16: Sketch of the CMS / TOTEM layout.

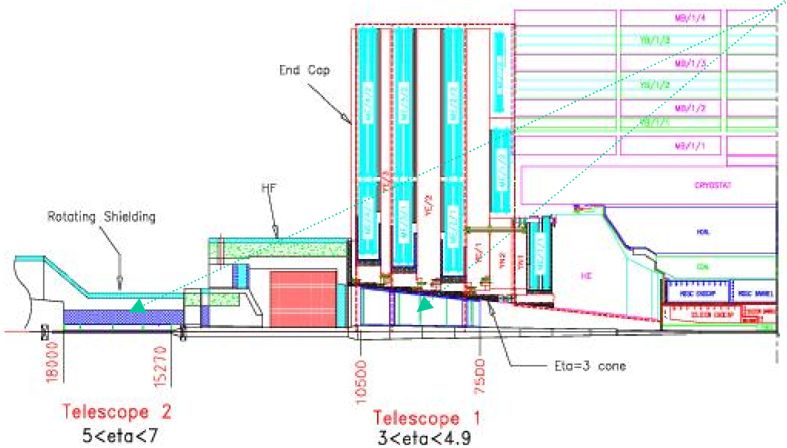


Figure 17: Section of the CMS experimental apparatus showing the integration of the TOTEM telescopes T1 and T2.

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CMS has reserved space for the forward detectors in T1 and T2 regions

TOTEM T1: 5 MWPC planes

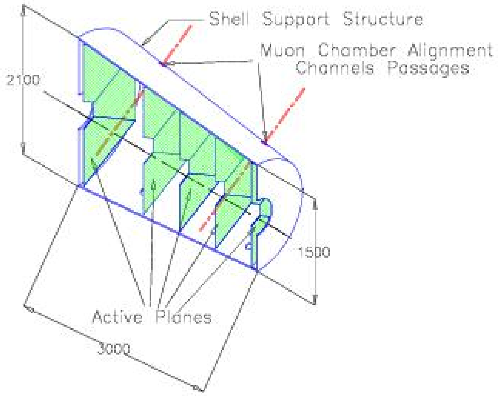

Figure 19: Sketch of the telescope T1.

- $3 \leq \eta \leq 4.9$
- installed in two halves

TOTEM T2 ?

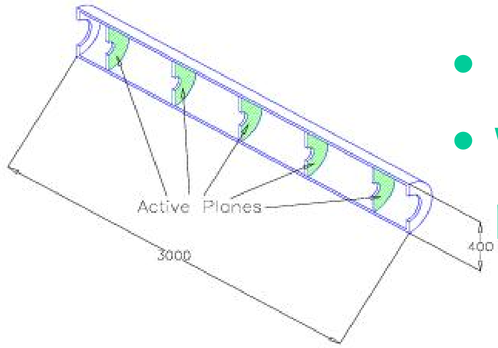

Figure 20: Sketch of the telescope T2.

- $5 \leq \eta \leq 7$
- within the rotating shield

the vacuum chamber in T2
to be specified further

+ a lumi monitor behind T2

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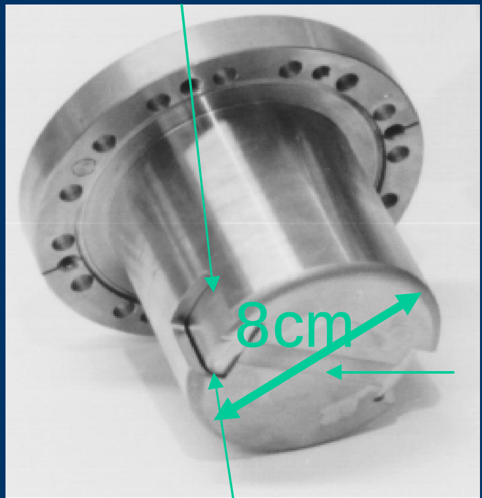
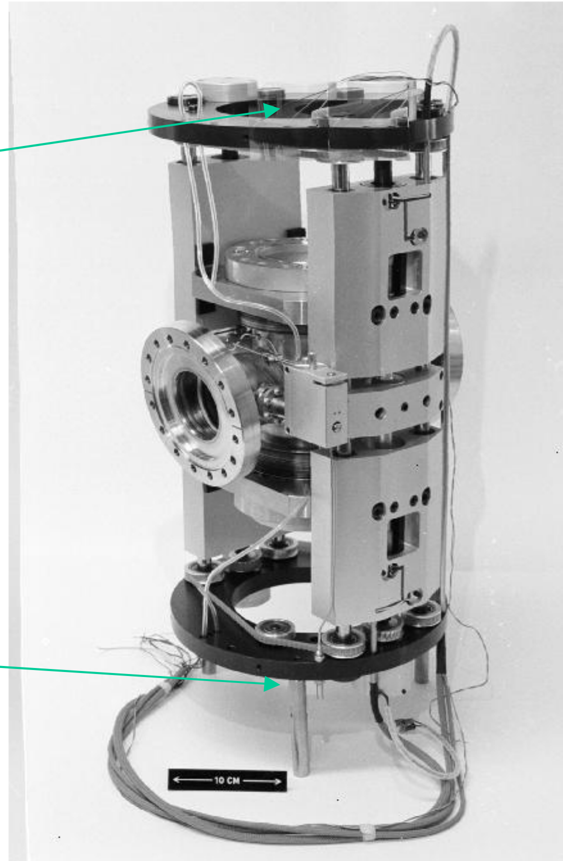
TOTEM : Roman Pots for leading protons[1]

Cryogenic Si-detectors located here (RD39)



Concave bottom

Thin window (3 x 2 cm^2)



The detectors approach the beam vertically (step motor)

Si-detectors operated at 130K (where the Lazarus effect (V.Palmieri et al.) optimizes charge collection efficiency, reduces noise and provides radiation hardness.)

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 For a state-of-the art example: see the display!

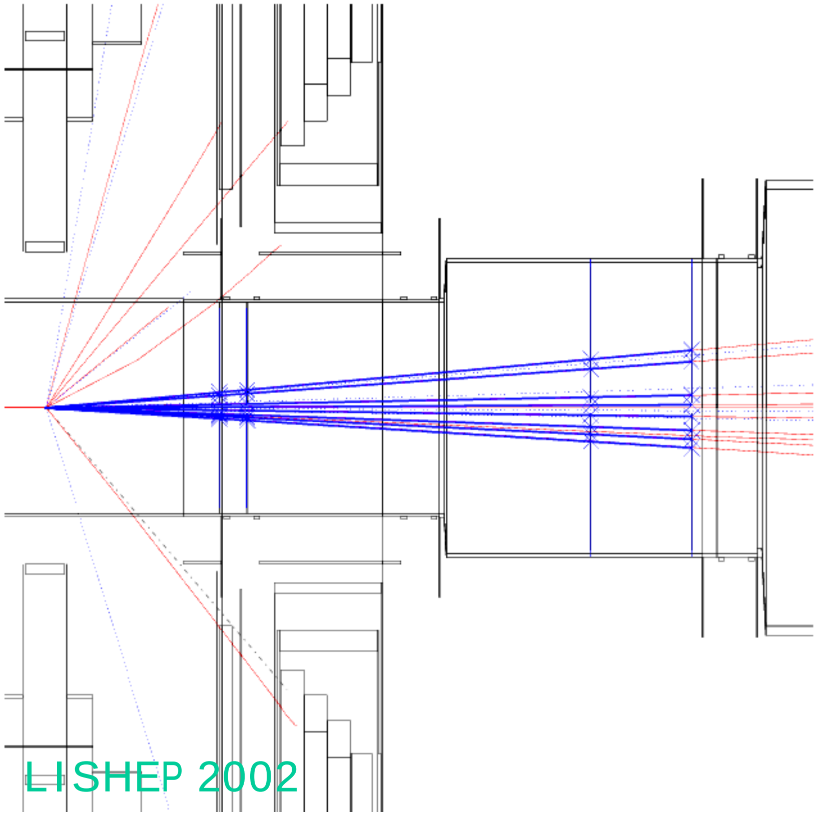
Expected Performance - Observables

- Charged particles from inelastic events:
  - Pseudorapidities: $3 < \eta < 7$ ($5.7 < \eta < 8.4$)
    - with nominal LHC optics
- Leading protons:

Detector location	Leading p (β*=1100m)	Leading p (β*=0.5m)
180 m	$-t > 7.0 \times 10^{-3}$ GeV^2	$\xi > 0.03$ (0.02)
240 m	$-t > 3.5 \times 10^{-4}$ GeV^2	$\xi > 0.01$
425 m	$-t >$	$\xi > 0.003$ (0.002)

- Missing mass in $pp \rightarrow p + M_X + p$?

Track reconstruction by Microstations



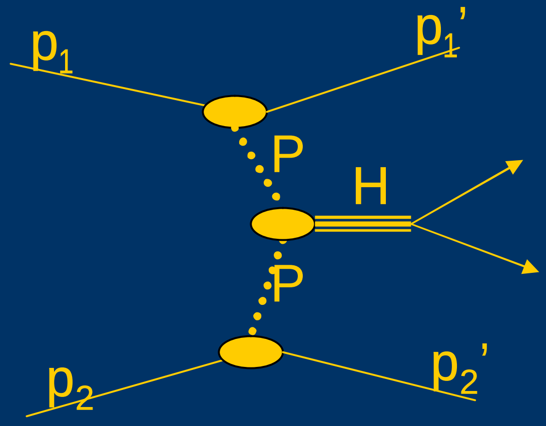
Simulation study with GEANT:

- include signal hits by PYTHIA minimum bias events
- hits from secondaries due to backgrounds
- beam related background: 5 MHz for > 15σ at design luminosity (flux vs. R param.)

Track reconstruction code

- pattern recognition with beam spot constraint

Double Pomeron Exchange and Higgs



$M_H^2 = \xi_1 \xi_2 s$

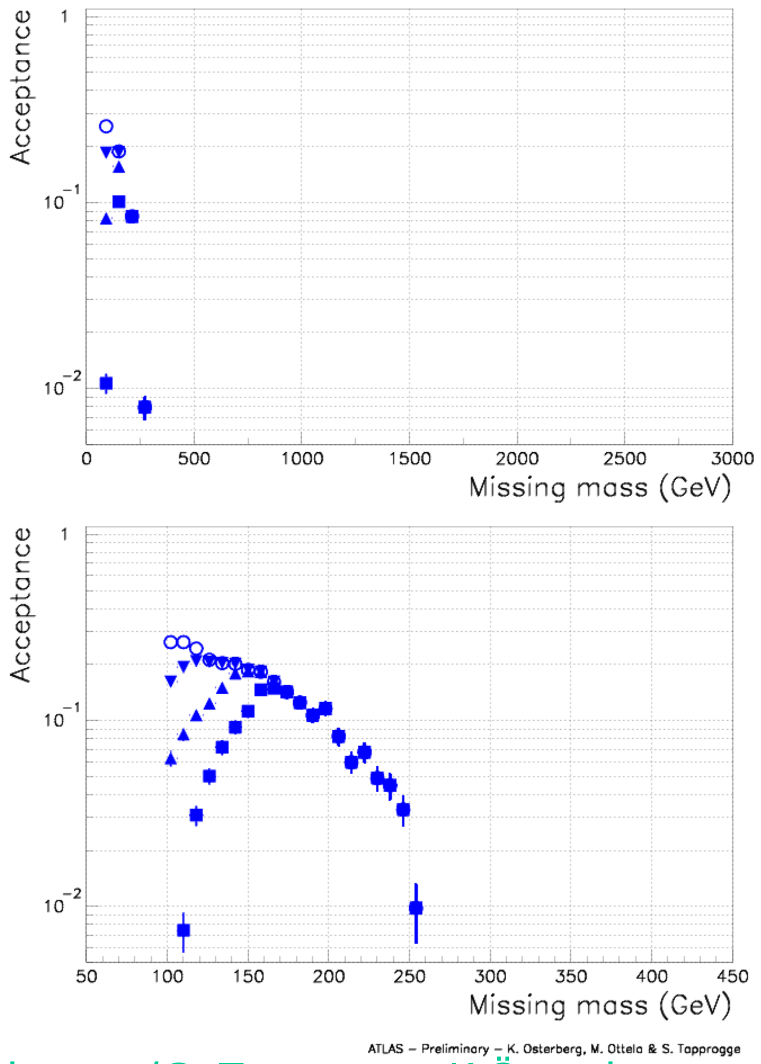
In symmetric case ($\xi_1 = \xi_2 = \xi$) for
M_H = 140 GeV: ξ = 0.01 (ε = 40%)

$\sigma(pp \rightarrow p+H+p)$ = 2 - 4 fb at $\sqrt{s}$ = 14TeV

$\Delta M \leq 3.0$ GeV achievable

Helsinki group/ J.Lamsa, R.O.

Missing Mass Acceptance, low β* = 0.5m, z=425m



Helsinki group/S. Tapprogge, K.Österberg et al.

Mass acceptance cross checked with a full MAD beam optics calculation.

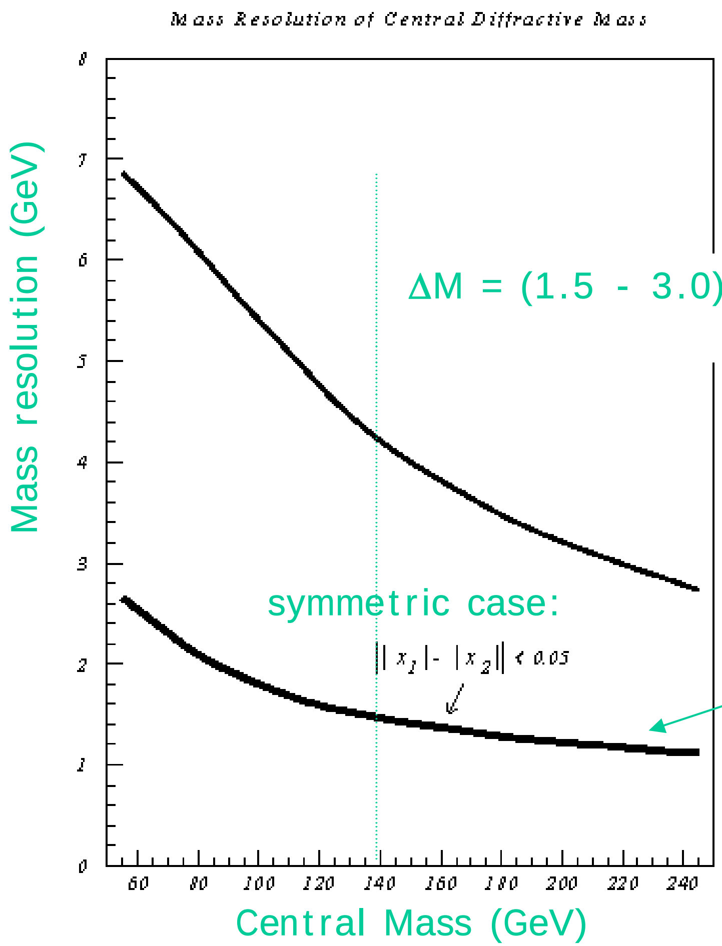
Note: Proton hits at 425m cannot arrive within the trigger latencies of ATLAS or CMS.

Possible ways to reduce event rates:

(1) Rapidity gaps

(2) Large E_T jet pairs

DPE Mass Measurement at 400m



Mass resolution vs. central mass assuming $\Delta x_F / x_F = 10^{-4}$

ΔM = (1.5 - 3.0) GeV ($\Delta x_F/x_F$ = (1-2)×10^{-4})

≈ 65% of the data

20 GeV < M_X < 160 GeV

(M_{Xmax} determined by the aperture of the last dipole,B11,
M_{Xmin} by the minimum deflection = 5mm)

Helsinki group/ J.Lamsa, R.O.

Outlook(1): LHC Running Scenarios

LHC is likely to be commissioned with small initial beam currents (first superconducting machine designed for large beam currents, control of beam halo particles, collimation...)

=> 2-3 years of "running-in" at 10^{33} cm^{-2} s^{-1} ?

Perfect for forward physics!

Short dedicated runs (1-2 days) at nominal & Tevatron energies with high(1100m) /initial (18m) /intermediate (160m) β^*, luminosities of 10^{28} to 3 x 10^{33} cm^{-2} s^{-1} (large -t), bunches 36 to 2835 (10^{28} cm^{-2} s^{-1} = 8.6 10^5 mb^{-1} day^{-1})

Outlook (2): Running Scenarios

Dedicated runs (2 one week runs/year)
High β^* (β^* = 1100 m, 5nb^{-1}):

- Measure elastic & inelastic rates, extrapolate to -t = 0
  ⇒ Luminosity calibration, calibration of the luminosity monitor
- Measure σ_{tot}
- Measure elastic scattering
- Measure soft diffraction
- Measure minimum bias event structures

During the nominal running conditions
Low β^* (β^* = 0.5 m, 10 fb^{-1}):

- Measure inelastic rate on-line by the dedicated luminosity monitor
- Measure elastic & inelastic rates extrapolate to -t = 0 (use dσ/dt dependence measured at high β^*)
  ⇒ Luminosity calibration cross check
- Measure elastic scattering
- Measure soft diffraction
- Measure hard diffraction
- Measure minimum bias event structures
- Measure diffractive jet production

Outlook (2'): Running Scenarios

- Other possible LHC running modes?
  - √s = 8 TeV is possible without modifications
  - √s = 2 TeV is - in principle - possible, as well

- Running at Tevatron energies would enable comparison of
  - σ_{tot} (p$\underline{p}$) and σ_{tot} (pp)
  - W, Z, jet production

- Energy dependence di-jet production at large rapidities...

- Energy dependence of rapidity gap suppression effects

Outlook (2”): Running Scenarios

- Luminosity upgrade - Super-LHC ?
  - increase bunch intensity
  - new focusing quadrupoles with larger apertures, low β^*
  - reduce bunch spacing to 12.5ns

  $\Rightarrow$ get up to 10^{35} cm^{-2} s^{-1} luminosities with minor new investments with the machine, experiments will need a major upgrade...

- Upgraded energy?
  - presently $B_{th}^{dipole} \leq 11$ T limits the $\sqrt{s}_{max}$ to 18 TeV
  - at LHC: $B_{LHC}^{dipole} \leq 9$ T limits the $\sqrt{s}_{max}$ to 15 TeV
    - 1st industrial pre-series dipole reached 9 T without a quench
  - synchrotron radiation may pose a problem
    - beam screening requirements may limit to $B_{LHC}^{dipole} \leq 10.5$ T?
  - further optimization and R&D required

Outlook (3):

- What it takes to turn LHC into a Gluon Factory?

- Optimized leading proton detection (z = 425m?)

  - Extended coverage for inelastic activity ($|\eta|>5$)

  - Upgrade scenarios & Forward detectors:
    - ATLAS + A Foward Spectrometer
    - CMS + TOTEM - the Forwrd Physics Facility at LHC?
    - Roman Pots with cryogenic Si-detectors
    - MicroStations as compact acceptance enhancers

- New particle thresholds, forward physics from Coulomb scattering to hard diffractive processes, and more...

Outlook (4)

- Physics Performance Figures

Inelastic activity can be extended to cover (low β^*)

- Charged particles within $3(5.7) < |\eta| < 7(8.4)$
- Luminosity monitoring for $5.2 < |\eta| < 6.6$

Leading protons can be detected (low β^*, >50% efficiency):

- $\xi > 4\times10^{-2}$ (180m), $\xi > 2.5\times10^{-2}$ (210m), $\xi > 10^{-2}$ (240m), $\xi > 2.0\times10^{-3}$ (425m) ($10\sigma_x$ approach, for $20\sigma_x$, factor 2 downgrade)

Missing mass:

- For 20 GeV < M_X < 160 GeV achieve ≈1% mass resolution

Dedicated runs with β^* = 1100m (3500m):

- Measure elastic protons down to $-t = 4\times10^{-3}$ GeV^2 (240m assumed)
- Measure diffractive protons down to $\xi > 0.03$ (180m)

Outlook - Final

- Existing LHC experiments can be extended to cover exiting new physics by adding a *forward spectrometer* to their base line designs

- A forward spectrometer could turn LHC into a *gluon factory*

- The new physics potential can be achieved with a very *modest additional effort*

LET's START WITH AT LEAST ONE OF THE LHC EXPERIMENTS!