“Forward” Physics at the LHC

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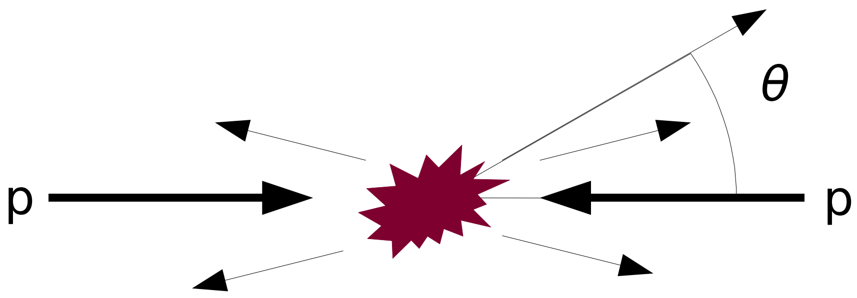
Outline/Aim of this talk

- The interest in “Forward” Physics
- Overview of forward detectors
  in ATLAS and CMS/TOTEM
- Some experimental signatures

The interest in “Forward” Physics

Experimental definition:

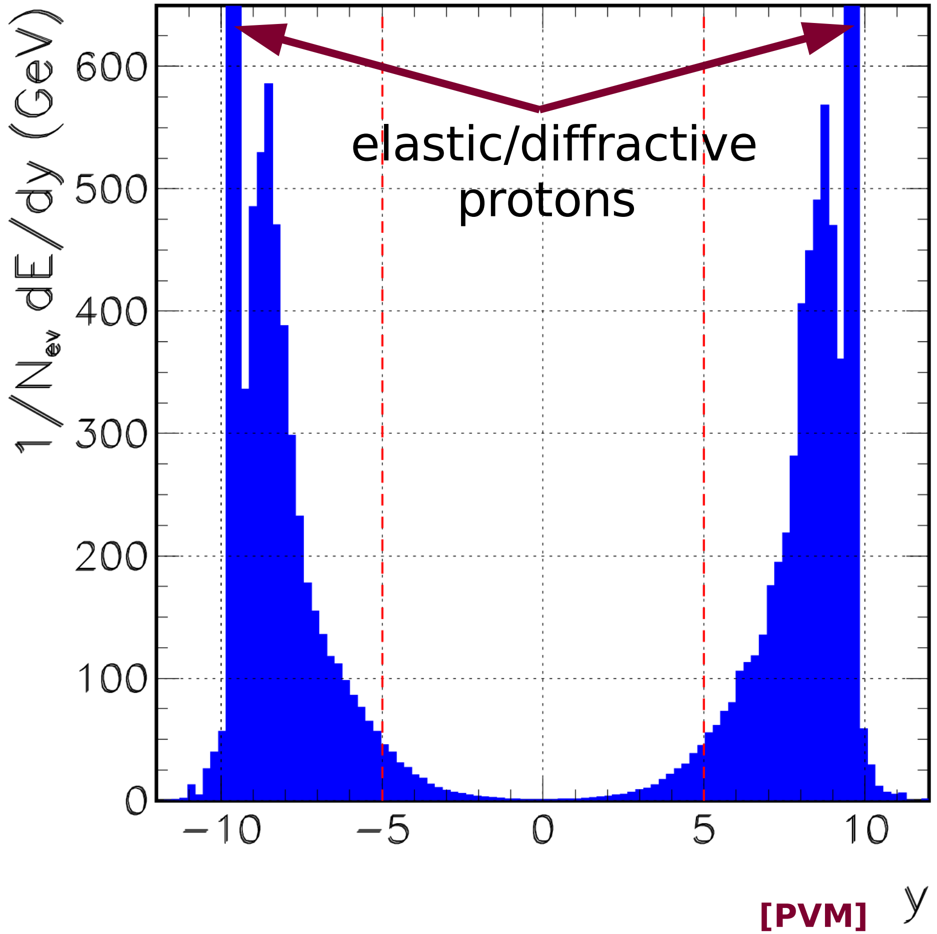


All processes in which particles are produced at small polar angles (i.e. large rapidities).

Maximal rapidity at the LHC given by:

$$y_{max} = \ln \frac{\sqrt{s}}{m} \approx 11.5$$

Energy flow at the LHC



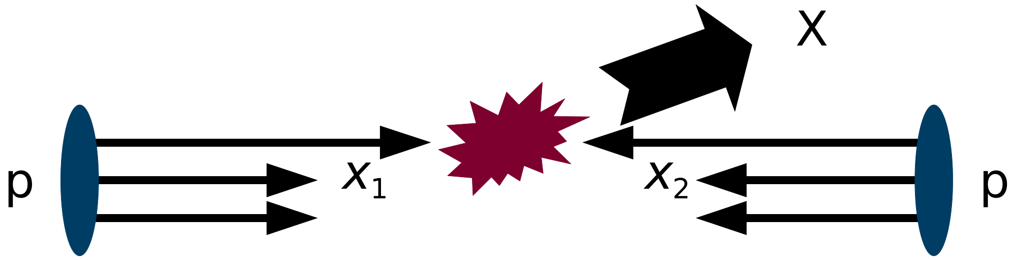
[PVM]

- most energy is deposited between: $8 < |y| < 9$
- main ATLAS/CMS calorimeters: $|\eta| < 5$

Low x saturation

How to get interesting physics at small polar angles?

1. parton-parton scattering: qq → X



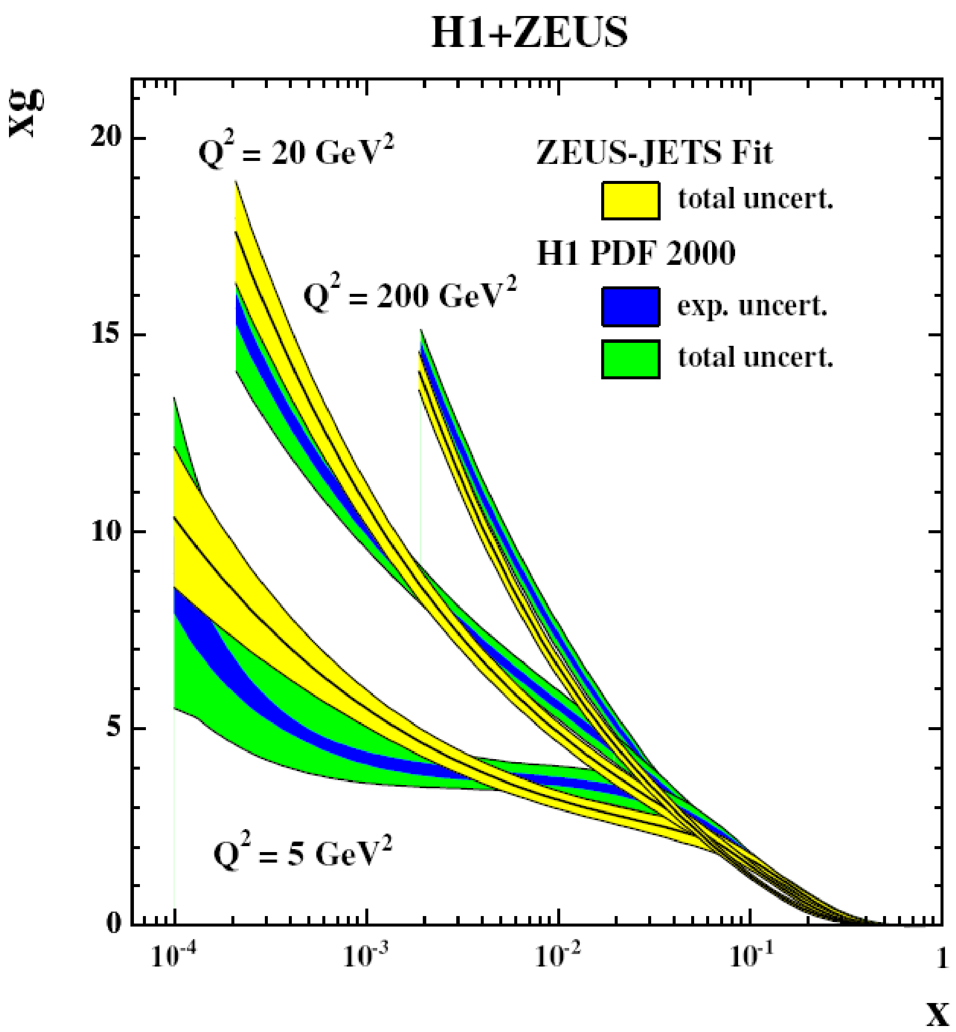
- X can be jets, Drell-Yan pairs, prompt photons, heavy quark pairs, ...
- X goes forward if $x_2 \ll x_1$ → access to low-x_{Bjorken} proton structure:

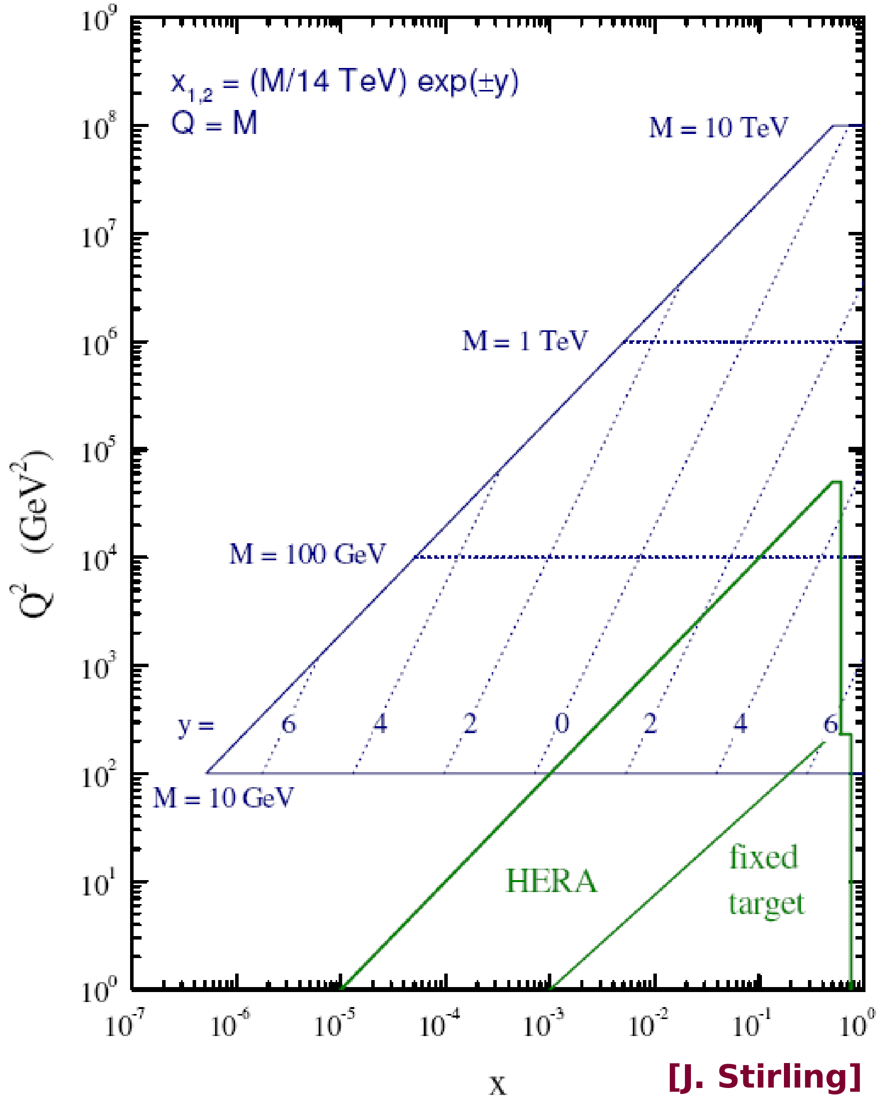
$$x_{Bj} = \frac{Q}{\sqrt{s}} e^{-\eta}, \qquad Q = p_T, M, \ldots$$

→ at LHC (for $Q \gtrsim 1$ GeV and $\eta = 8$): $x_{\text{Bjorken}} \gtrsim 10^{-8}$

→ x_{Bjorken} decreases by factor 10 for each 2 units in rapidity

Proton structure at low x





[J. Stirling]

→ strong rise of $F_2(x,Q^2)$ at low x observed at HERA

→ extrapolation to LHC?

Multiple interactions

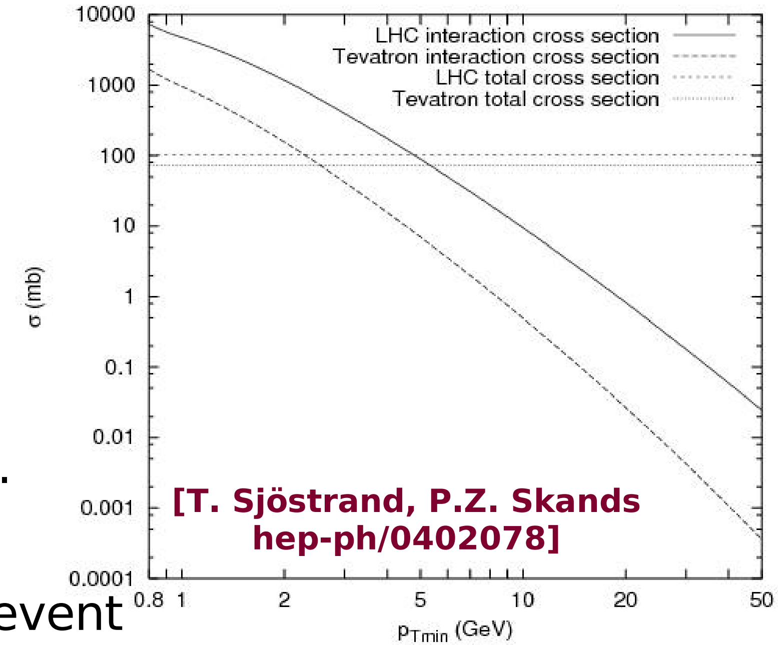
2. Multiple interactions/underlying events

- Basic partonic cross section

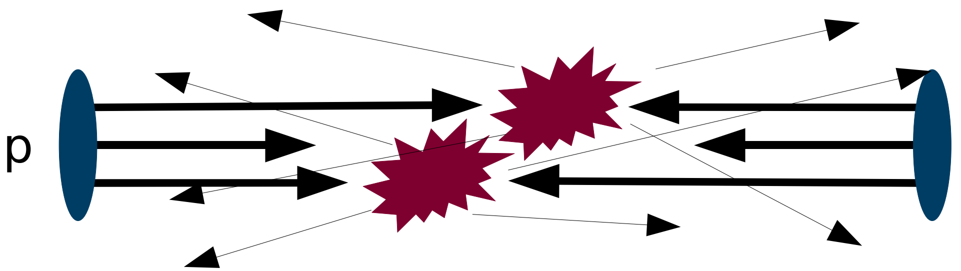
$$\sigma_{hard}(p^2_{\perp min}) = \int_{p^2_{\perp min}} \frac{d\sigma(p^2_\perp)}{dp^2_\perp}\, dp^2_\perp$$

→ diverges faster than $1/p^4_{\perp min}$ as $p_{\perp min} \to 0$

→ eventually exceeds σ_{tot}(even for $p_{\perp min} > \Lambda_{QCD}$).



- Consequence: Multiple parton interactions per event



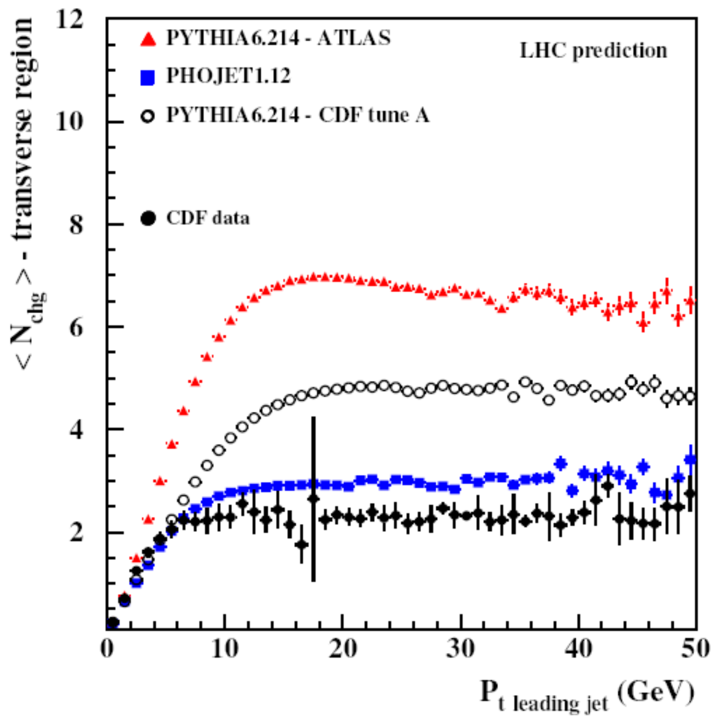
→ higher particle multiplicity (additional energy offset in jet profiles)

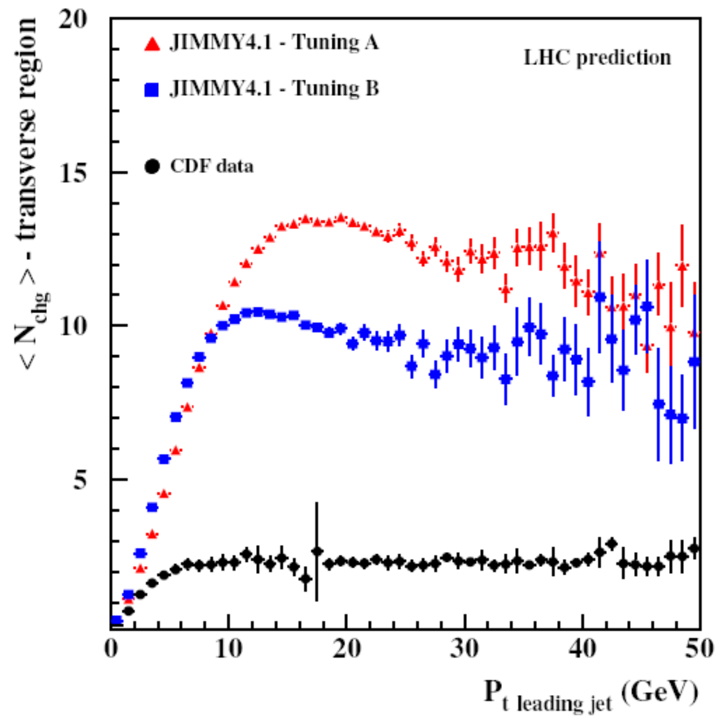
→ long distance correlations in rapidity (need to cover forward region!)

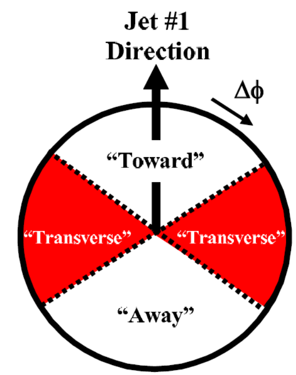
→ additional hard interactions may fake a discovery signal !
(e.g. pp → W H X with H → bb vs. pp → W bb X)

Multiple interactions: MC tuning

LHC prediction for average multiplicity transverse to the leading jet:







[C. Buttar et al., HERA-LHC Workshop proc.]

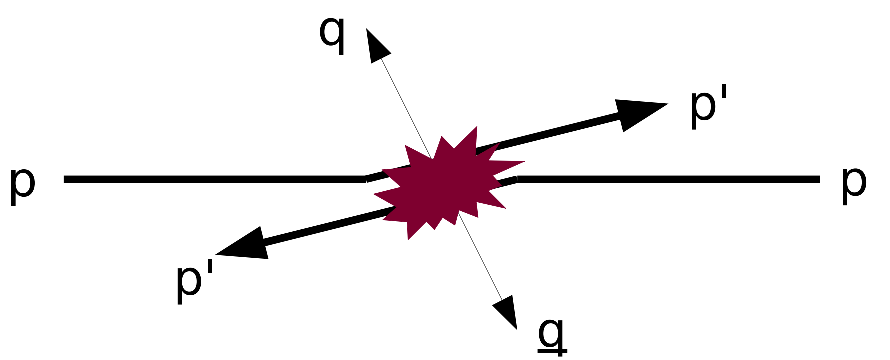
→ huge differences for the different generators and tunes

→ better understanding of multiple interactions is needed for MC tuning!

Diffraction

3. Hard diffractive scattering

- One or both protons survive hard interaction (yielding jets, heavy quarks, ...)

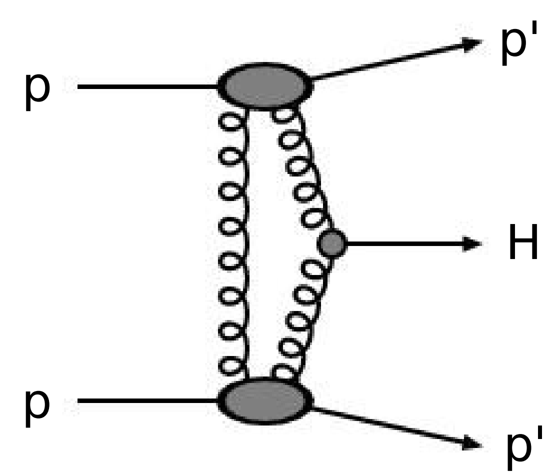


→ diffraction (including soft diffraction) makes up 25% of σ_{tot}!

→ tool to study (perturbative) QCD and the structure of hadrons

- Diffractive Higgs production pp -> p H p

→ particularly clean channel for the study (or discovery) of the Higgs boson



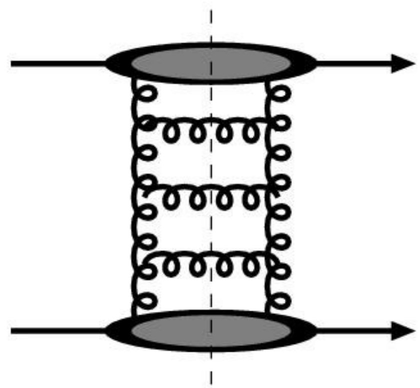
AGK cutting rules

Relation between diffraction – multiple interactions – low x saturation:

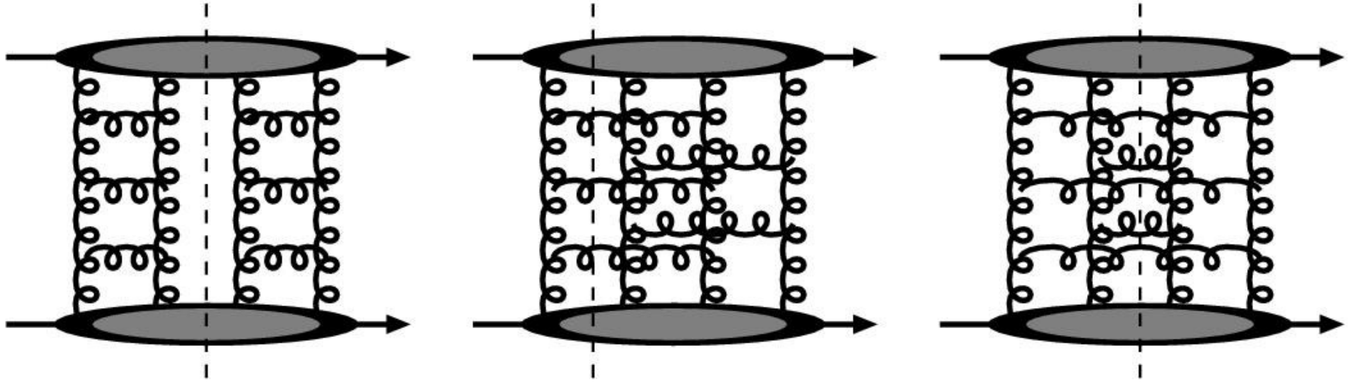
Optical theorem:

$$\frac{1}{s} Im\ T_{2\to 2} = \sigma_{tot}^{pp} = \sum_f \int d\Omega_f |T_{i\to f}|^2$$

- single parton exchange:



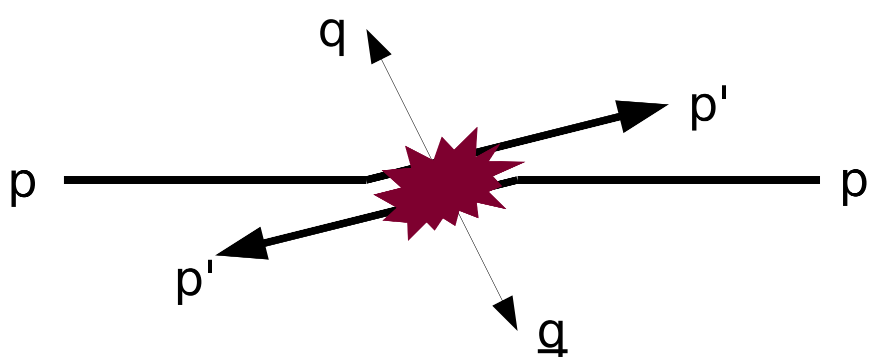
- double parton exchange:



diffraction saturation multiple interaction

4. Photon-induced processes

- pp → p $\gamma^{(*)}\gamma^{(*)}$ p → p X p



→ Similar to diffraction, but smaller $|t|$

→ X = e^+e^-, $\mu^+\mu^-$, $\gamma\gamma$, W^+W^-, Z^0Z^0, H, t $\underline{t}$, SUSY-pairs, ...

- Physics programme:

→ absolute luminosity calibration (using very well known QED cross sections)

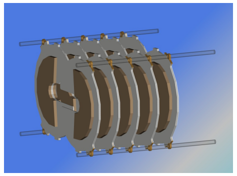
→ calibration and resolution measurement of forward proton spectrometers

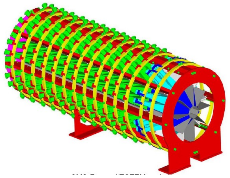
→ factorisation breaking in hard diffraction

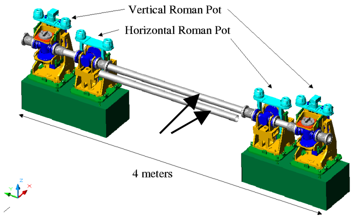
Forward detectors at the LHC

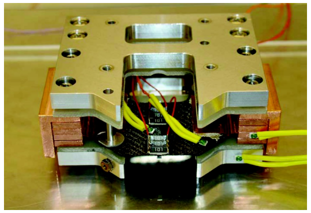
Forward detectors: Overview

IP5









TOTEM-T2 — 14m

CASTOR — 16m

ZDC/FwdCal — 140m

TOTEM-RP — 147-(180)-220m

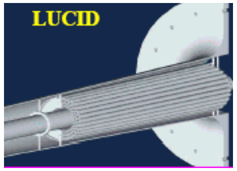
FP420 — 420m

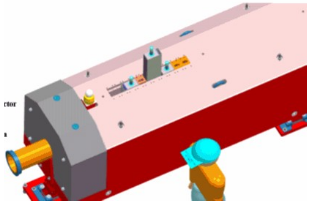
LUCID

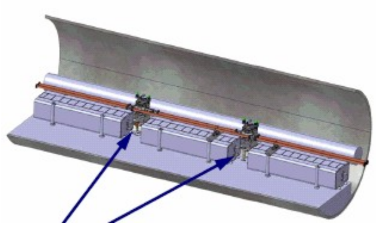
ZDC

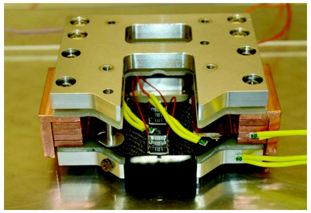
ALFA/FP220

FP420





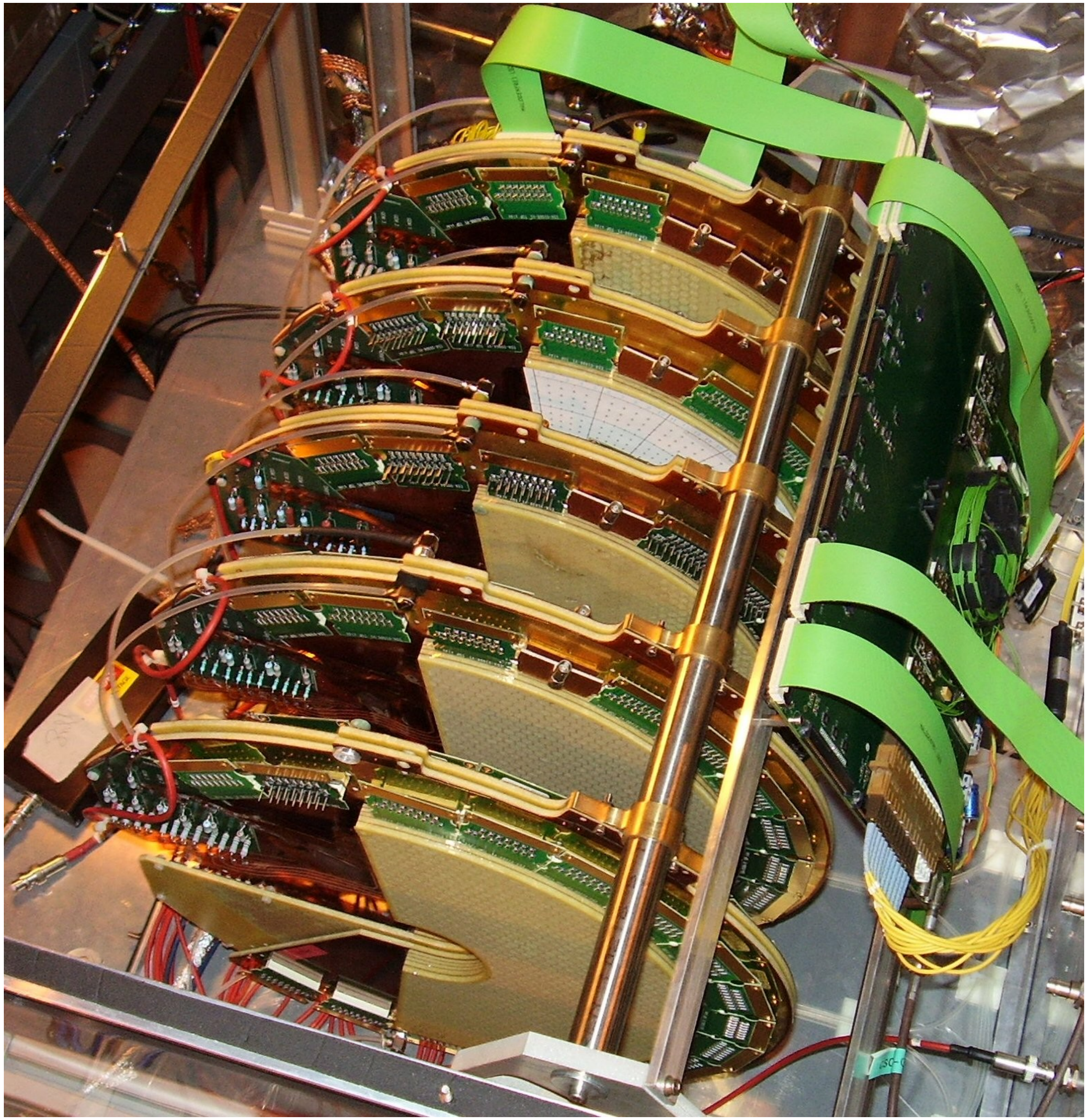




IP1

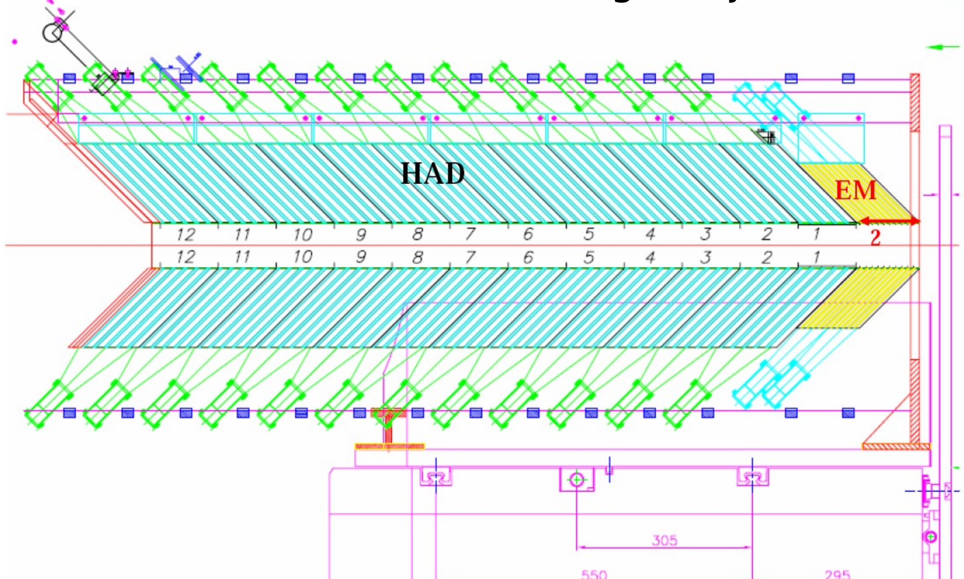
TOTEM-T2

- GEM tracking detectors (Ar/CO_2) with 10 aligned detector half-planes
- 512 strips (width 80 µm, pitch of 400 µm); 65 x 24=1560 pads
- Acceptance: $5.2 < |\eta| < 6.5$
- Resolution:
  $\Delta\varphi \times \Delta\eta = 0.06 \times 0.017\pi$
- Installation 2007



CASTOR/LUCID

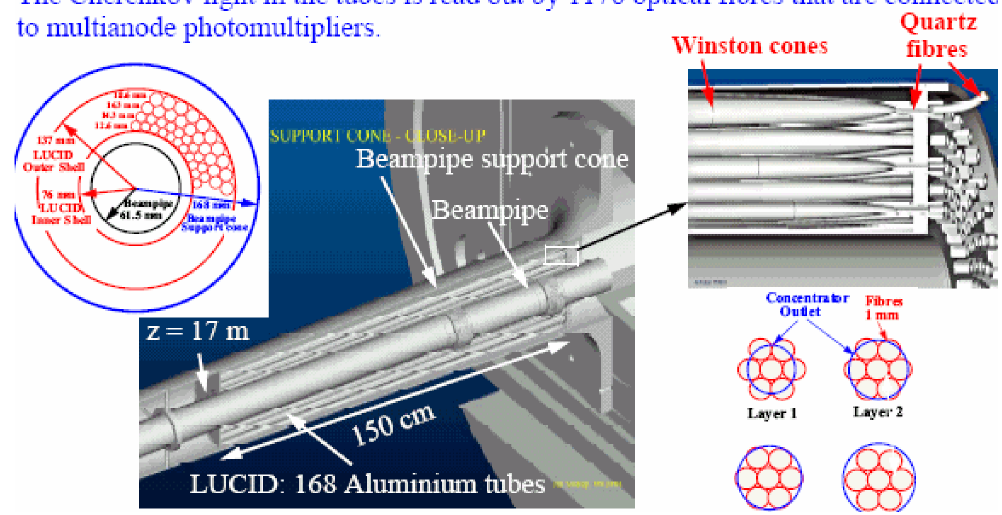
CASTOR: Centauros And Strange Object Research



- Thungsten/quartz calorimeter using Čerenkov radiation as measuring principle with separate e.m. (20.1 X_0) and had.(9.5 λ_I) sections
- Octagonal cylinder (length: 1.5m, diameter: 36 cm) with 16-fold segmentation in φ and 14-fold segmentation in z
- Acceptance: $5.2 < \eta < 6.6$
- Staged construction: 1 CASTOR in 2008, 2 CASTORs in 2009

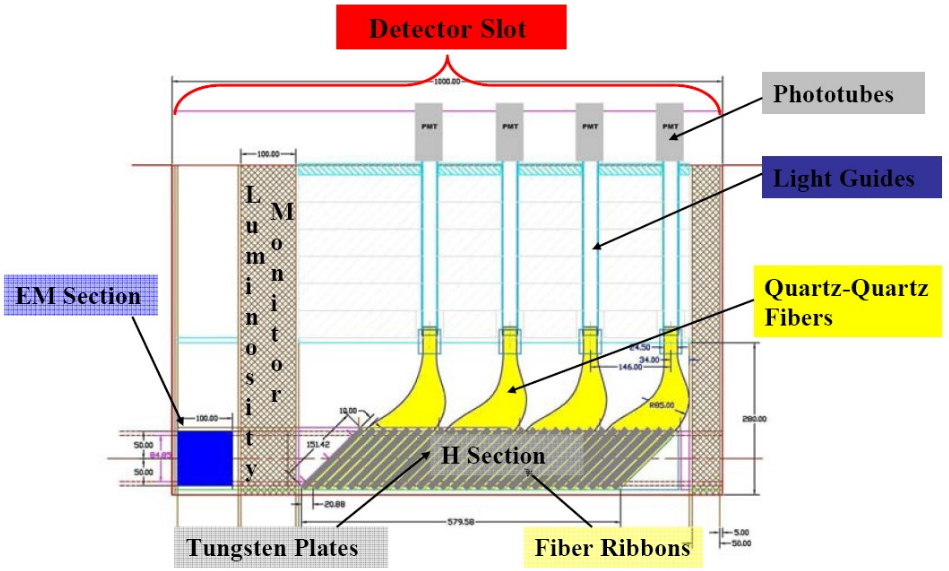
LUCID: LUminosity measurement using a Cherenkov Integrating Detector

The two LUCID detectors consist each of 168 gasfilled (isobutane) aluminium tubes. The Cherenkov light in the tubes is read out by 1176 optical fibres that are connected to multianode photomultipliers.



- Gasfilled (isobutane) aluminium tubes with Čerenkov radiation as measuring principle
- Cylinder (length 1.5, diameter: 13.7 cm) with 168 tubes and 1176 fibres
- Acceptance: $5.5 < \eta < 6.2$
- Staged construction: partial detector in 2007, full detector later

CMS ZDC

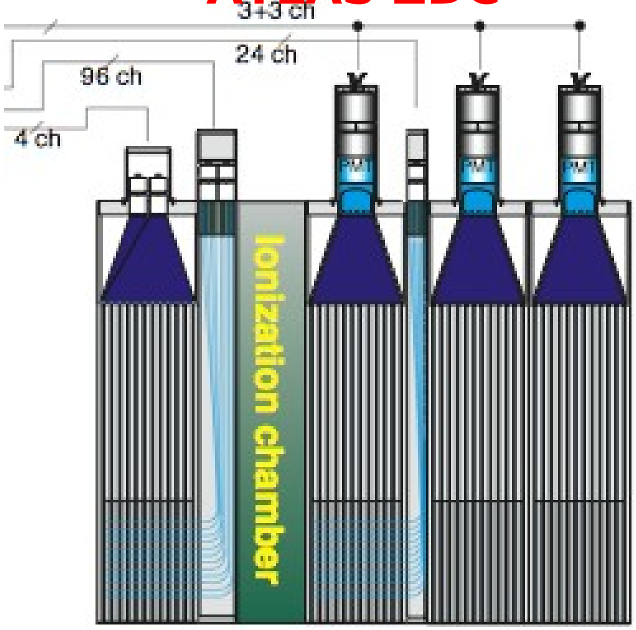


- Thungsten/quartz Čerenkov calorimeter with separate e.m. (19 X_0) and had.(5.6 λ_I) sections
- Acceptance for neutral particles (γ, π^0, n) from $\eta > 8.1$ (100% from $\eta > 9.3$)
- Installation in 2007

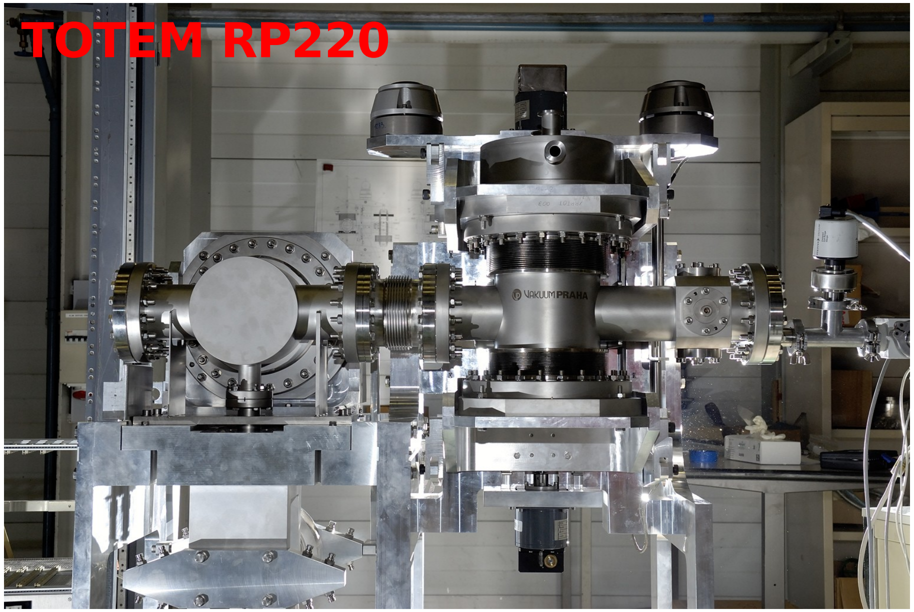
FwdCal proposal:

- Use hadronic SPACAL from H1
- Acceptance for charged particles: $8 < \eta < 12$ for $2 < E < 5.5$ TeV

ATLAS ZDC

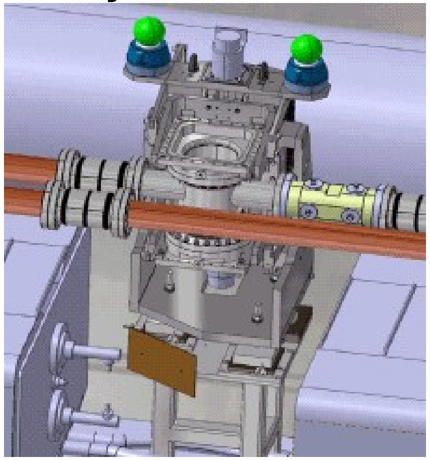


- Thungsten/quartz Čerenkov calorimeter with separate e.m. (29 X_0) and had. (4.6 λ_I) modules
- 3-fold segmentation in *z* for had. section; quartz rods in e.m. and first had. module provide transverse coordinate measurement
- Acceptance for neutral particles $\eta \gtrsim 8$
- Installation in 2007/2008 (phased with LHCf detector)



- 2 units at 220m from IP5 separated by 4 m and each consisting of 2 vertical and one horizontal Roman Pot approaching the beam up to 10σ + 0.5 mm = 1.5 mm
- Each pot has 5+5 planes of "edgeless" silicon detectors
- Spatial resolution 20 μm per plane
- Acceptance varying with beam optics; for nominal low β^* optics (highest luminosity): $0.02 < \xi < 0.2$
- Installation end of 2007

ALFA: Absolute Luminosity For ATLAS



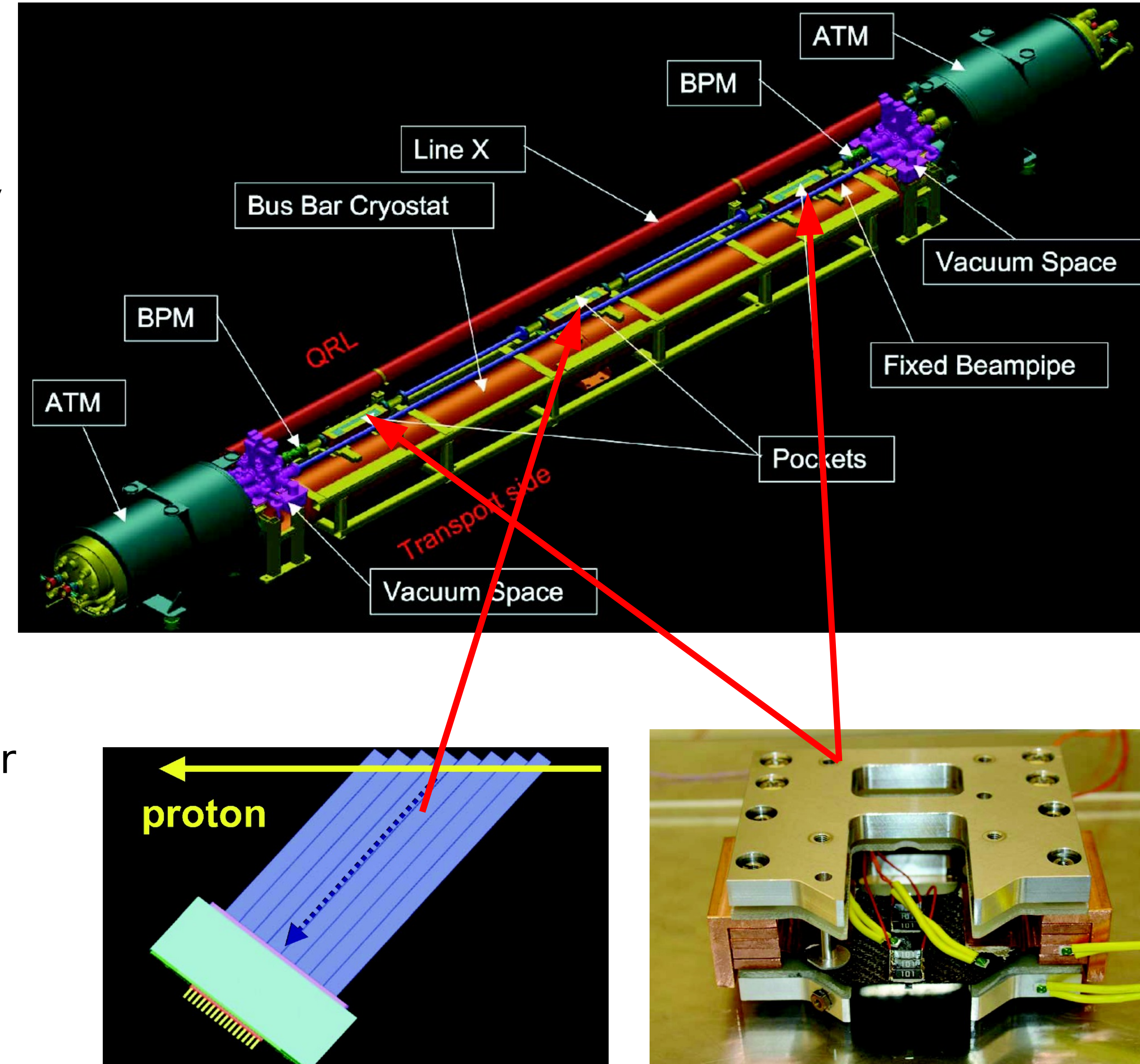
- 2 stations at 240m from IP1 approaching the beam up to 1.5 mm
- 10+10 planes of scintillating fibre detectors
  → spatial resolution 30 μm (goal)
  → edge < 100 μm (goal)
- Installation of detectors during 2008-2009 shutdown

FP220

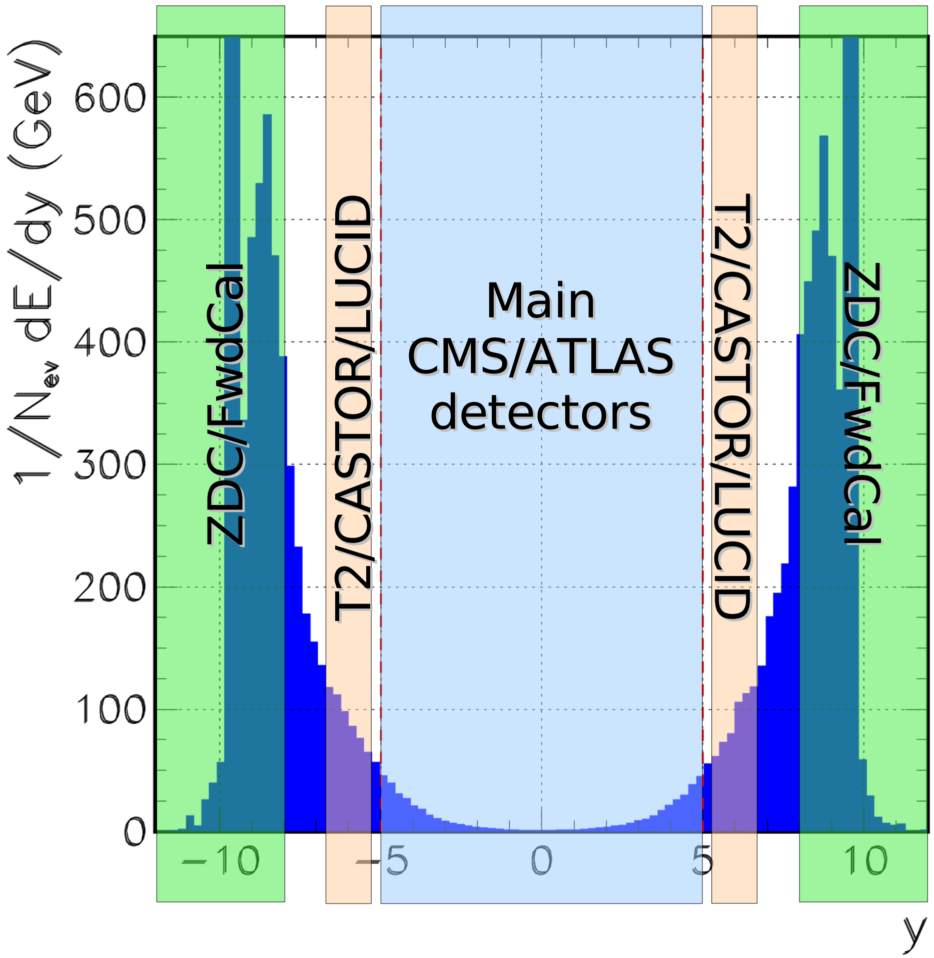
- horizontal stations at 220m from IP1
- Si or 3DSi detector + TOF detector
  → spatial resolution 10-15 μm
  → edge < 30-60 μm
- Installation foreseen 2009-2010

FP420

- Cryostat adaptation using moving beam pipe
- Will operate with standard high luminosity optics.
- Acceptance:
  $0.002 < \xi < 0.02$
  → exclusive central system in mass range $30 < M < 200$ GeV
- 3DSi detectors yielding $\Delta p/p \approx 10^{-4}$
  → $\delta M \approx 1$ GeV
- Čerenkov timing detector yielding 10 ps resolution
  → to sort out pile-up
- Installation (if approved) foreseen during 2008/2009 shutdown

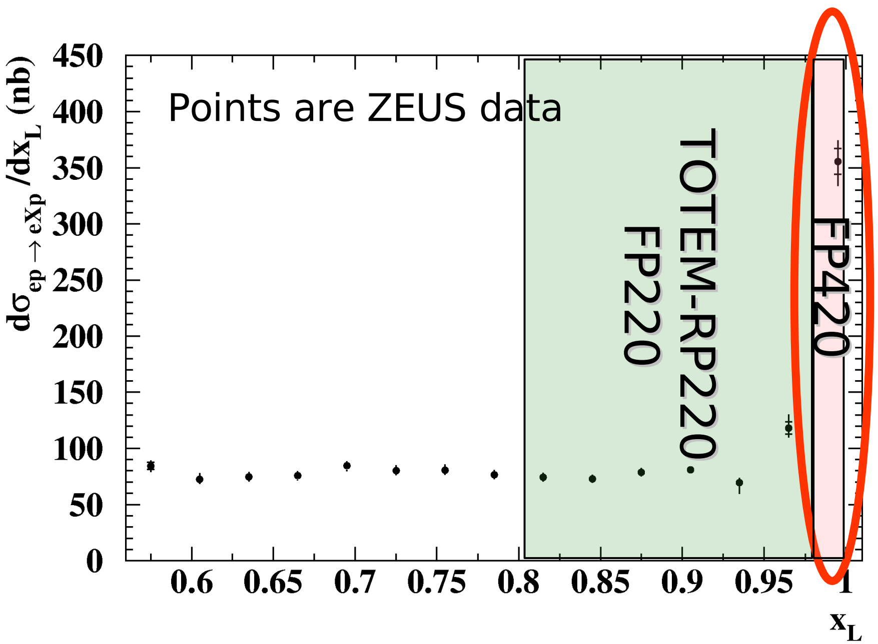


Forward calorimeters:



Forward proton spectrometers:

At nominal LHC optics, $\beta^* = 0.5$ m

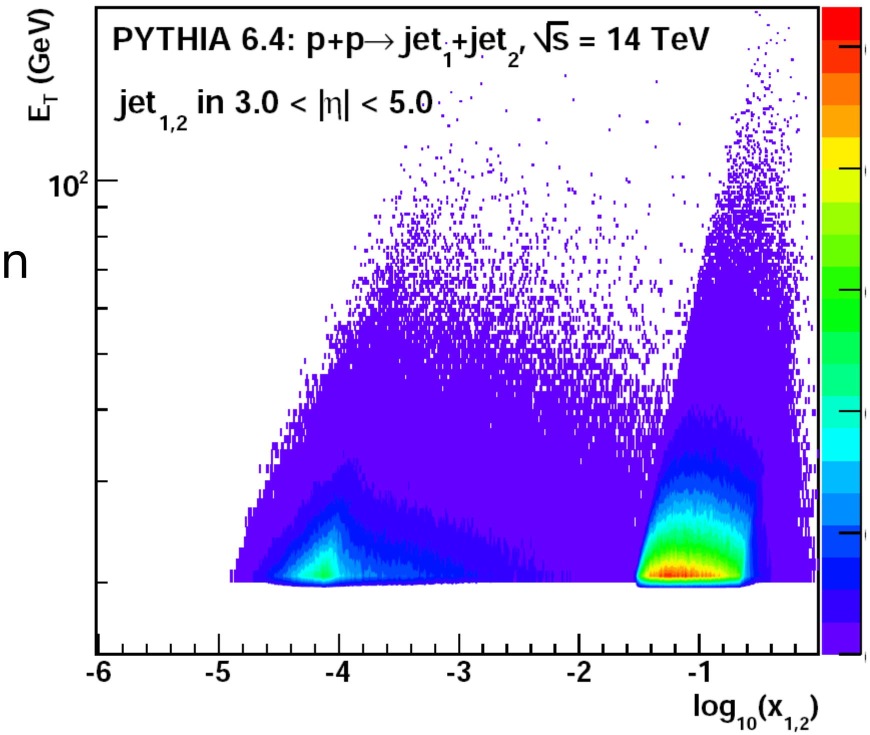


Some experimental signatures

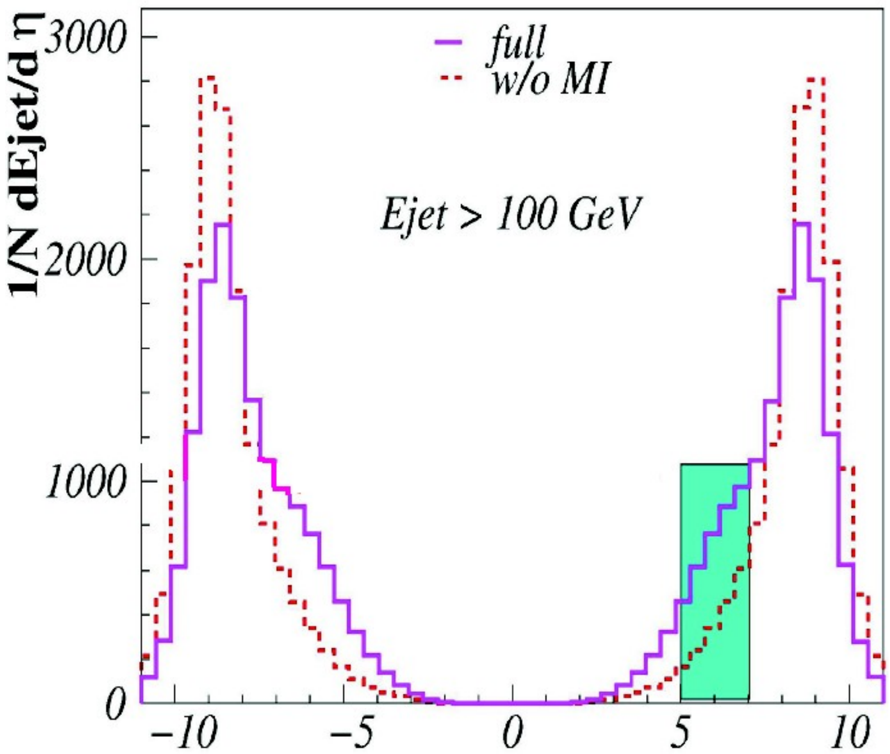
Single inclusive forward jets

- Single inclusive forward jets probe the low-x structure of the proton

  → saturation will reduce the jet cross section



[D. d'Enterria, CMS-note 2007/002]



[M. Deak]

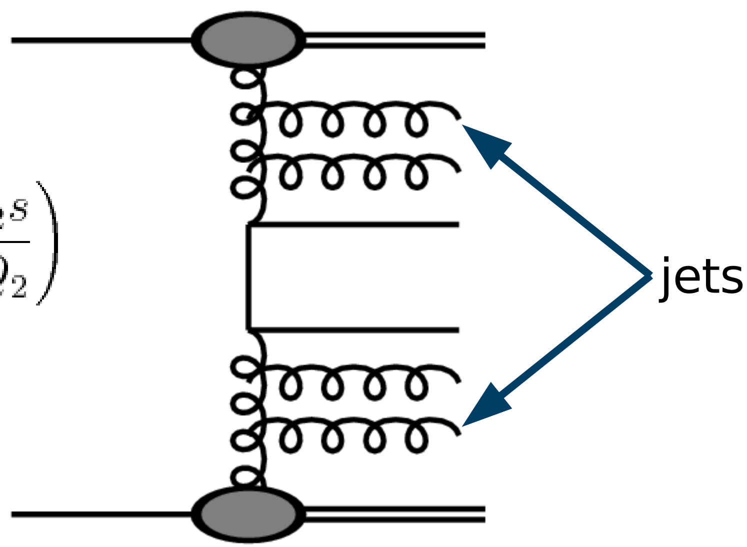
- Depending on the multiple interaction ansatz more or less energy is taken from the beam remnants

  → M.I. will increase the jet energy

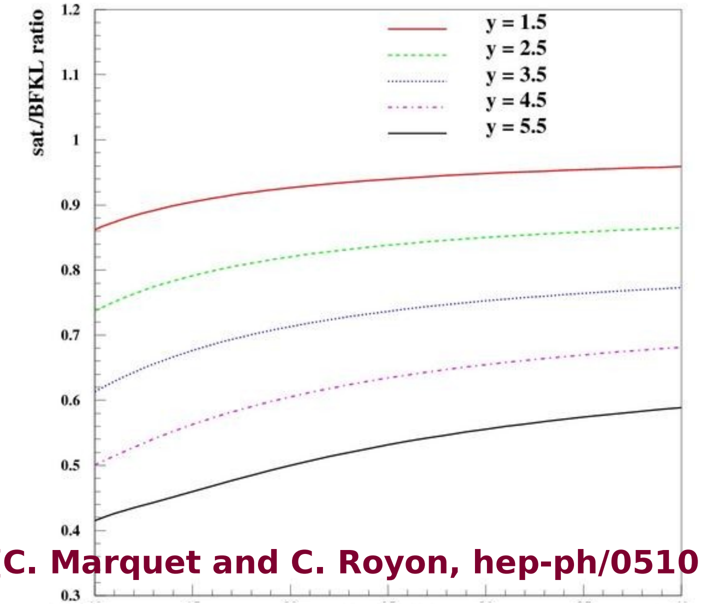
Jets at large $\Delta\eta$

$$\Delta y = \log\left(\frac{x_1 x_2 s}{Q_1 Q_2}\right)$$

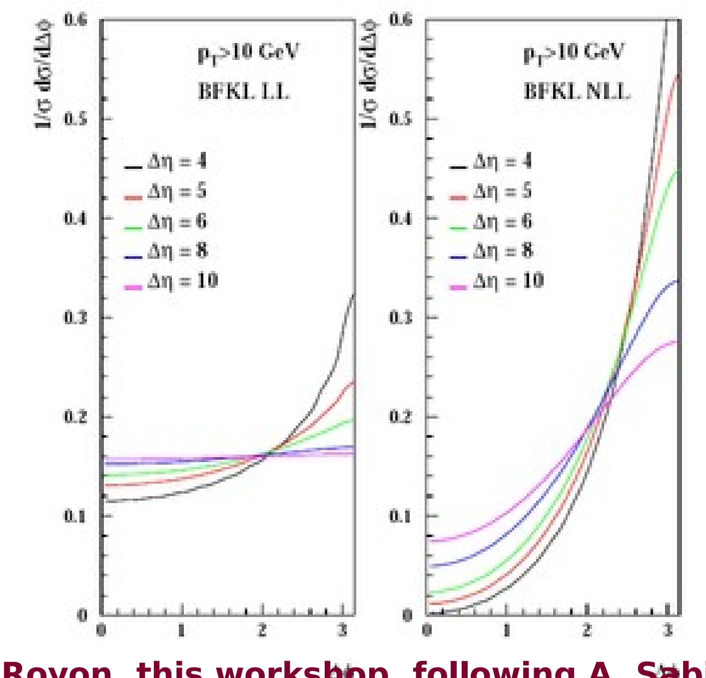
$$Q_i \approx E_{T,i}$$



- Large rapidity separation enhances phase space for BFKL
- BFKL predicts de-correlations in azimuthal angles from jets for increasing $\Delta\eta$
- Low x saturation effects in BFKL ladder? → biggest reduction for largest rapidity separations



[C. Marquet and C. Royon, hep-ph/0510266]



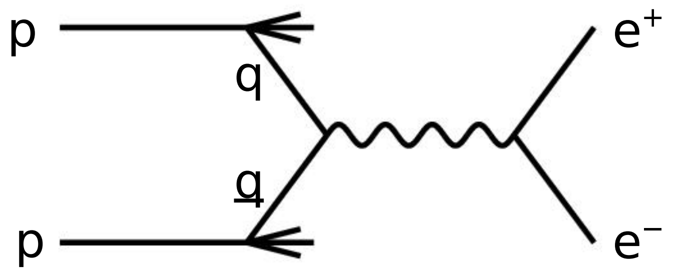
[C. Royon, this workshop, following A. Sabio Vera and F. Schwenssen, hep-ph/0702158 and hep/ph0602250]

Forward Drell-Yan pairs

- Kinematics of pp → e^+e^-X:

$$M^2 = s x^+ x^- \qquad x^\pm = \frac{M}{\sqrt{s}} \exp^{\pm y}$$

$$x_F = \frac{p_z^+ + p_z^-}{\sqrt{s}/2} = x^+ - x^-$$



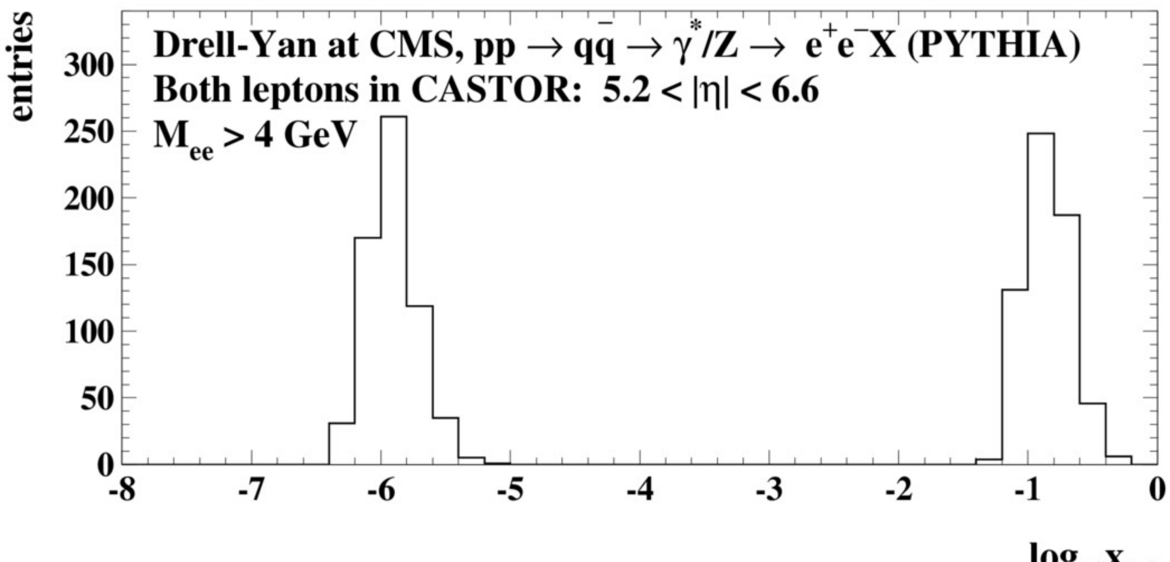
→ asymmetric x_{Bj} values ($x^- \ll x^+$) will boost the leptons to large rapidity

→ pdf known at high x^+ ⇒ extract pdf at low x^-

- CASTOR acceptance:

  → low mass DY in CASTOR probes the proton down to $x_{Bj} = 10^{-6} - 10^{-7}$

  → constraint of global parton density fits!



[E. Sarkisyan-Grinbaum, CMS-note 2007/002]

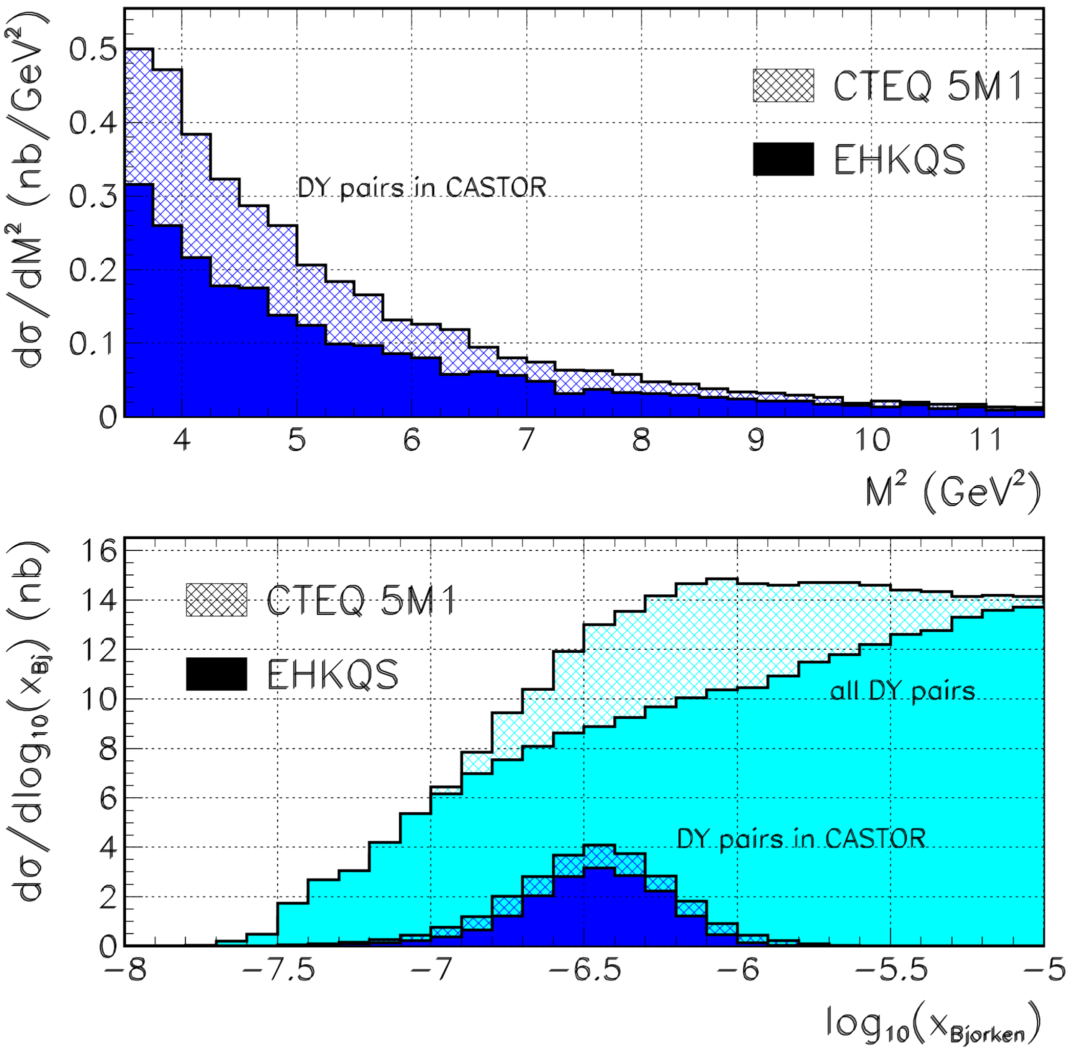
Forward DY and saturation

Rise of F_2 tamed by saturation?

- CTEQ 5M1: standard, "non-saturated" pdf
- EHKQS: "saturated" pdf with nonlinear terms in gluon evolution

[A. Dainese et al., HERA-LHC Workshop proc.]

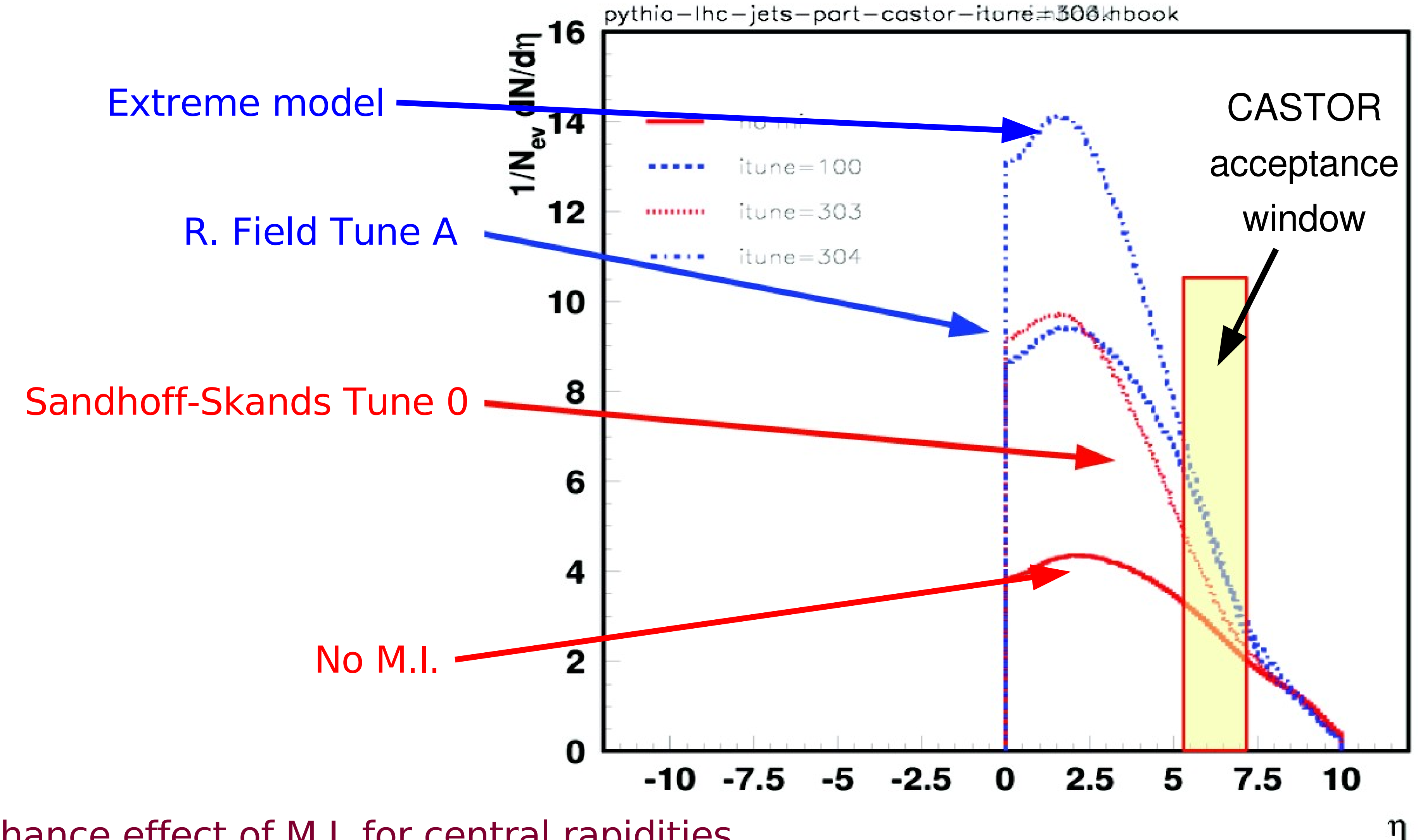
→ Saturation effects cause a 30% decrease in the DY cross section!



[PVM, CMS-note 2007/002]

Event yield: ~2 million events/fb^{-1} in CASTOR

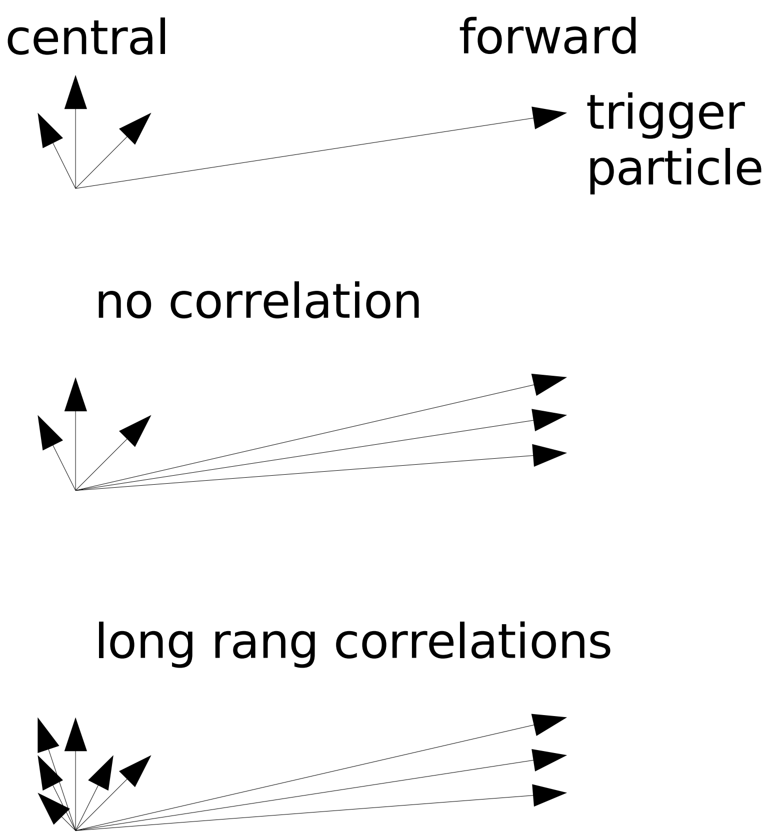
Effect of M.I. on particle flow vs. rapidity:

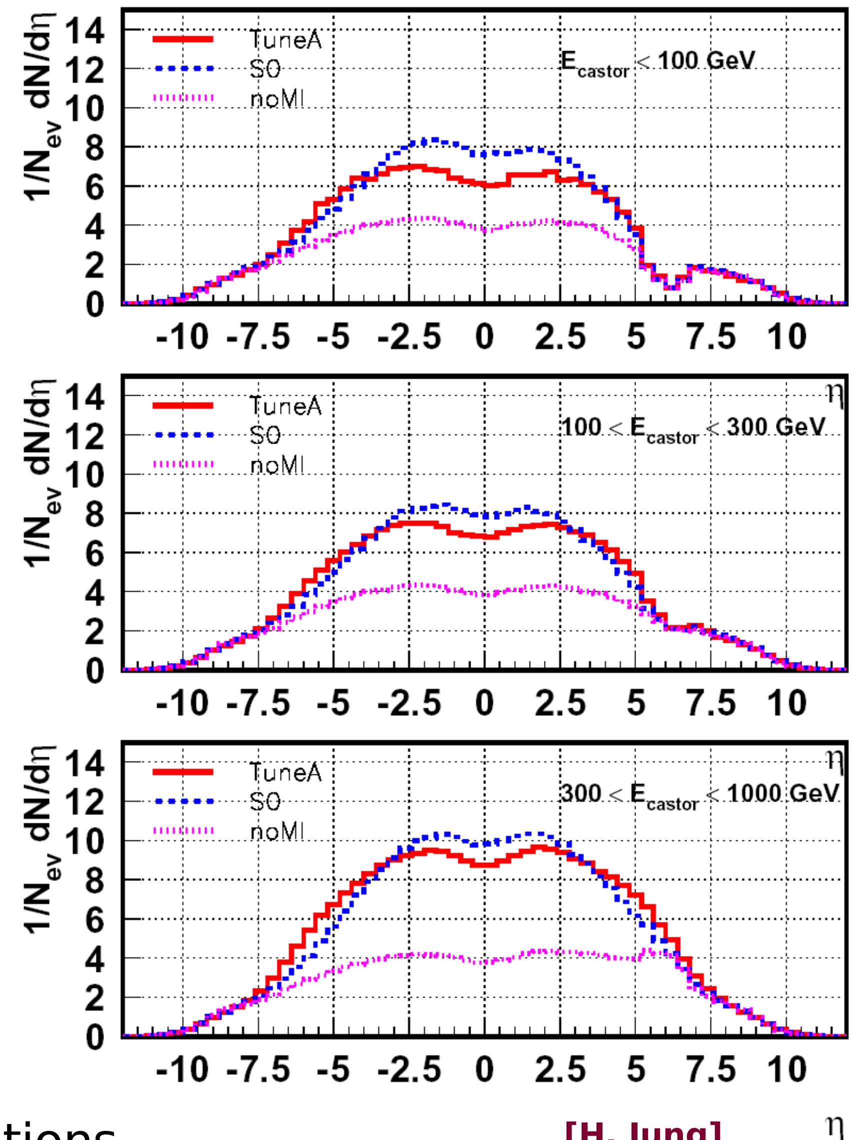


→ Enhance effect of M.I. for central rapidities by condition on forward region?

[H. Jung]

Central-forward correlations





[H. Jung]

→ forward condition uncovers long range correlations

→ discriminative power for different M.I. tunes

Conclusion and summary

Conclusion and summary

- “Forward” Physics covers many aspects, not all “discovery” physics but:
  - → FP is a convenient tools to study SM physics
  - → FP will provide important input to discovery/precision measurements at the LHC
- Many detector initiatives exist in both ATLAS and CMS
  - → most of them are well on track to be realised for the start-up phase of the LHC

Many thanks to

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for information and discussions.