# Preparation for forward jet measurements in Atlas

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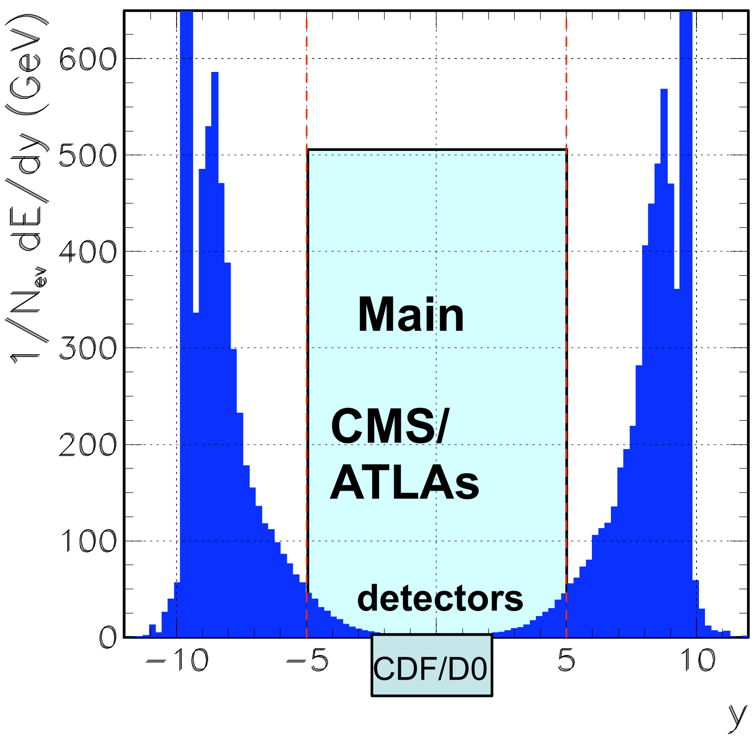
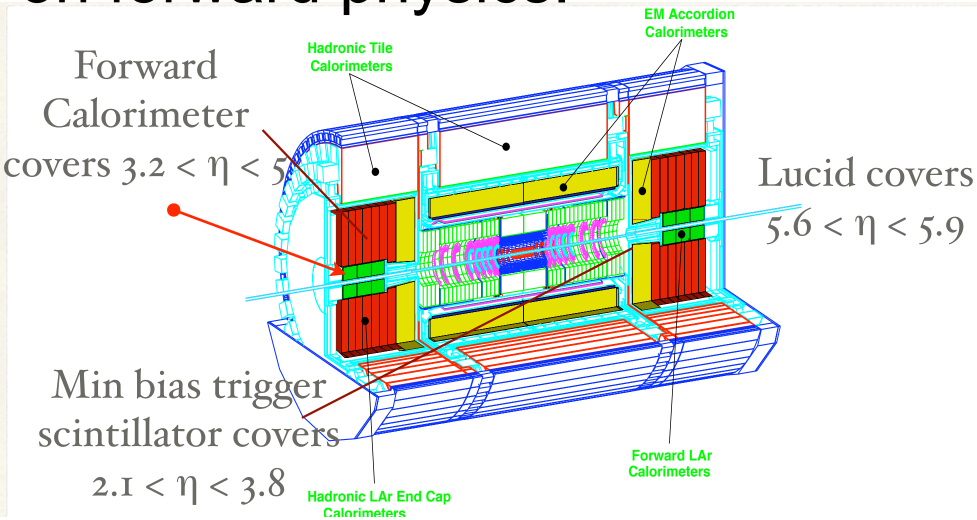
- Motivations
- First measurement:
  Jet-gap-jet
  QCD evolution
  Central diffraction
- Trigger issues
- Future of forward physics in ATLAS

# Forward physics at the LHC

The first LHC data will mainly be used for commissioning and calibration, but even with small luminosity a large number of events with forward jets will be recorded.

Due to the unprecedented η coverage of LHC detectors, we can say something really new on forward physics.



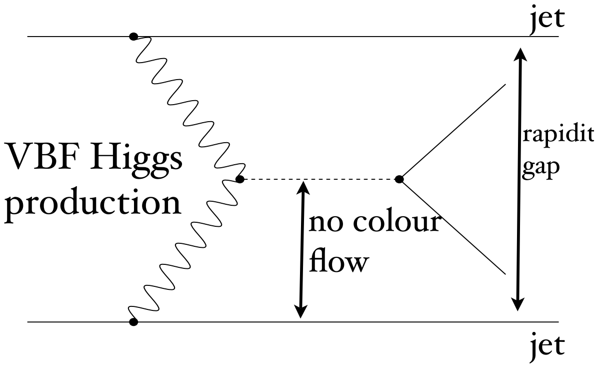




Still, most of the particles are produced in the very forward region, and a vast program is under way to extend the coverage as forward as a rapidity of 10 or more

# Forward jets

Most of the LHC interactions will involve forward jets final states

Mainly produced by exchange of coloured objects,
-> hadronic activity in the central region
very common topology



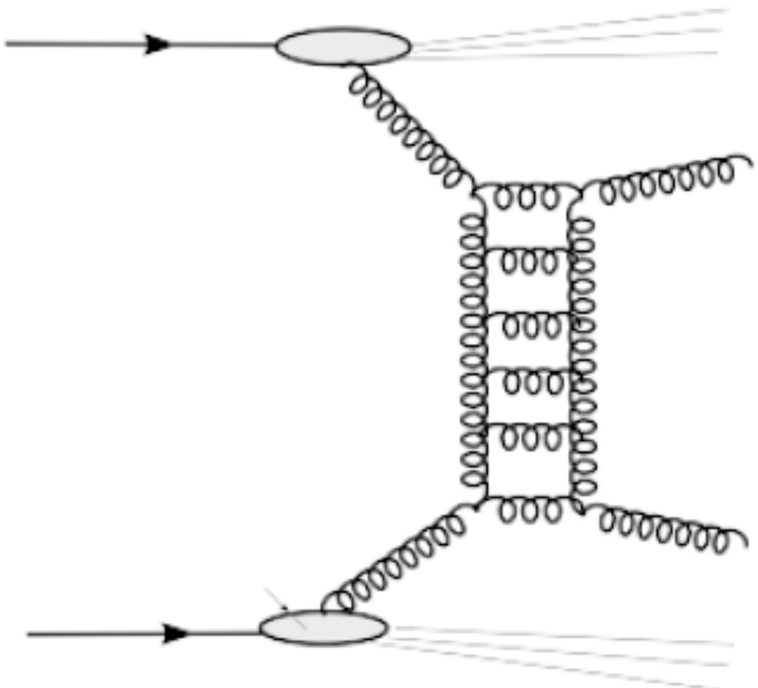

Color-singlet (vector boson or pomeron) exchange can also be responsible for forward jet production, albeit with much smaller cross section

Single-color exchange cross section decreases exponentially with Δη between the most forward and most backward jet

---> “extreme” forward-backward events often the most interesting

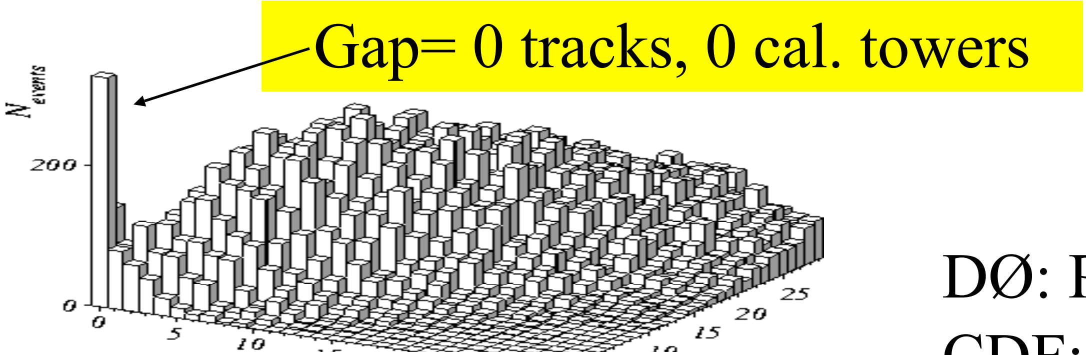
# BFKL ladder

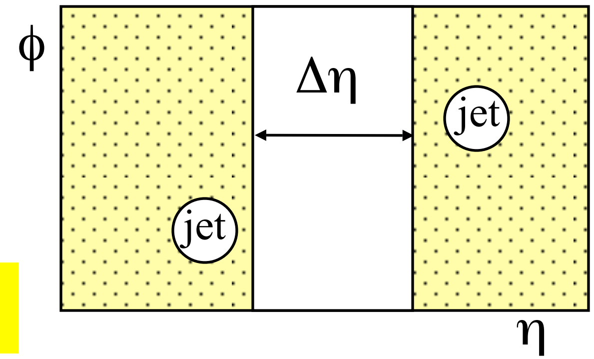
- QCD evolution from the matrix element is usually done for central events using the DGLAP equation, that orders gluon splitting in kt and x, and sums on ln $Q^2$
- The BFKL equation performs ln 1/x resummation, performs orderinf in x (random walk in kt) and is more suitable for low-x processes like forward-backward jets
- The resulting description often described as a gluon ladder, that can lead to central rapidity gaps or "jetlets" spoiling correlations between the two main jets



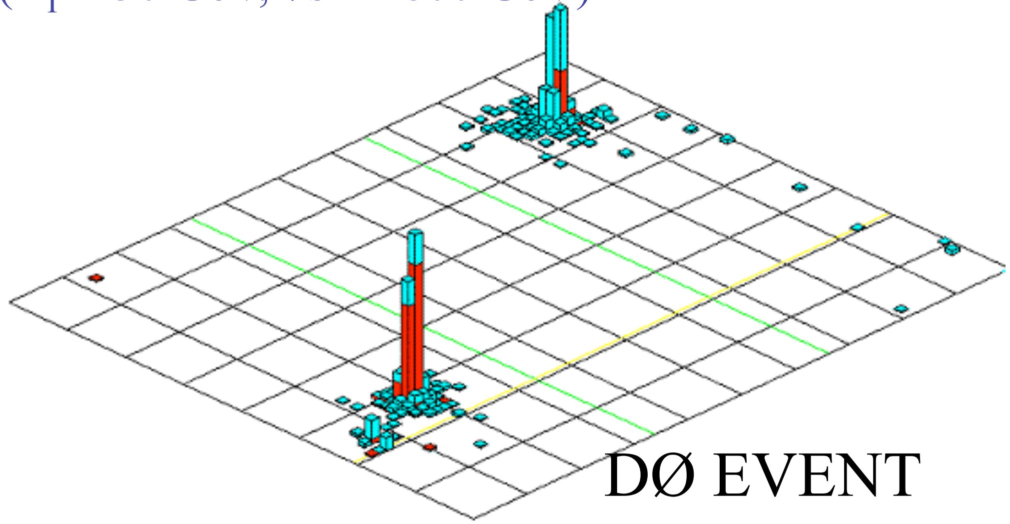
# Previous Hard Color-Singlet Mesurements

**QCD color-singlet signal observed in ~ 1 % opposite-side events (ppbar )**




(E$_T$ > 30 GeV, √s = 1800 GeV)



DØ EVENT

## Publications

DØ: PRL 72, 2332(1994)

CDF: PRL 74, 885 (1995)

DØ: PRL 76, 734 (1996)

Zeus: PLB369, 55 (1996)

CDF: PRL 80, 1156 (1998)

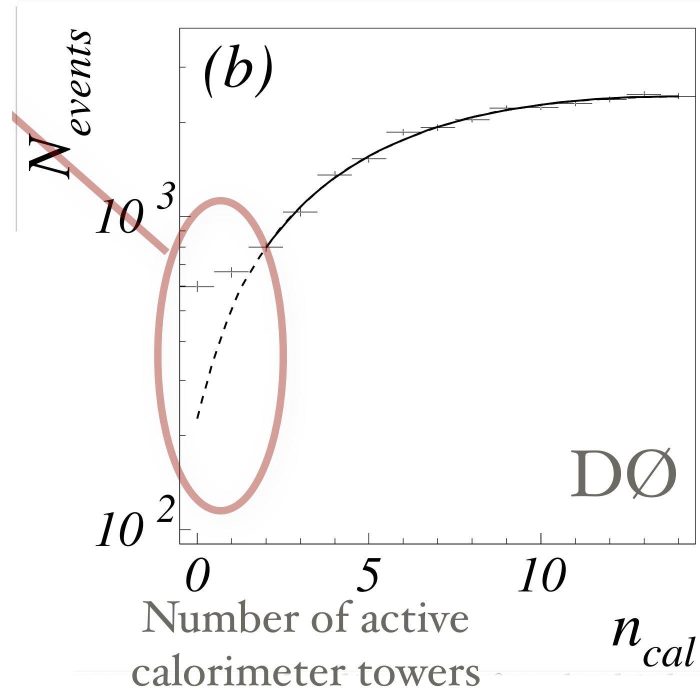
**DØ: PLB 440, 189 (1998)**

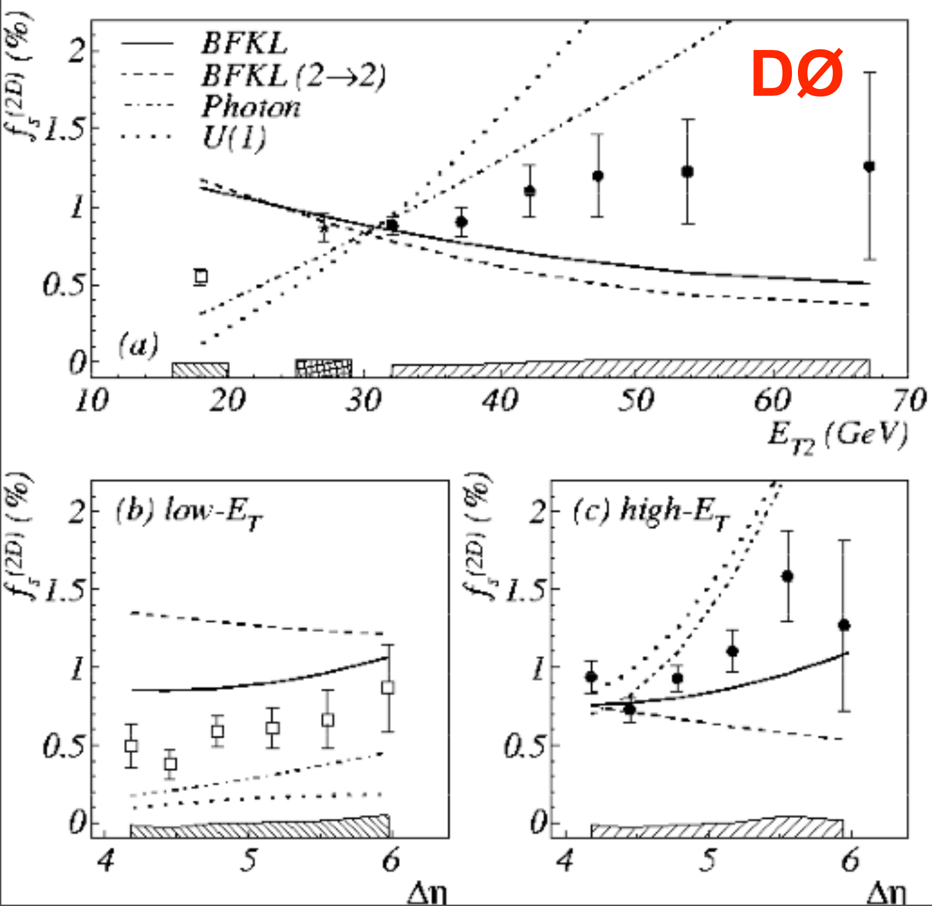
CDF: PRL 81, 5278 (1998)

**H1: Eur.Phys.J. C24 517 (2002)**

# Gap fraction evolution

D0 measured an excess of “empty” events then gap fraction up to rapidity interval of 6



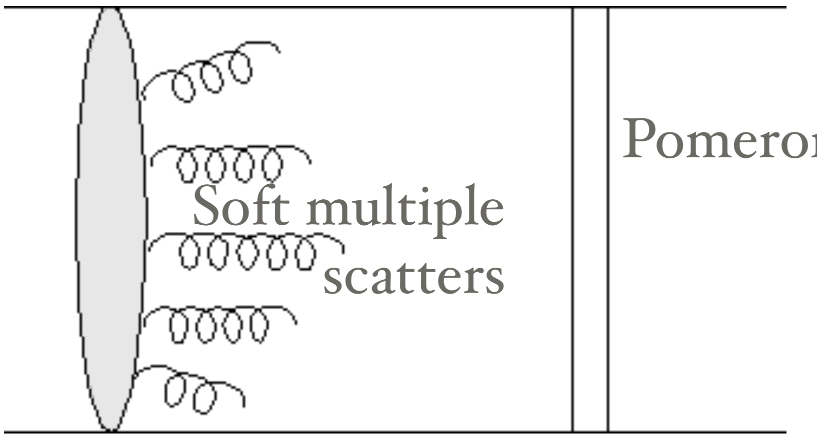




**Herwig (BFKL) did not describe observed DØ $E_T$ dependence**

**B. Cox et al JHEP9910:023,1999** suggested fixing $\alpha_s$ at pomeron-quark vertex to fit the data

**Need more precise data, larger Δη coverage**

# Soft survival fraction




Of course, singlet exchange is not alone in the event!

Soft interactions typically emit radiation in the gap

Only a small fraction of gap event survive the attack of soft radiation!

Effect requires interplay between MonteCarlo and underlying event studies

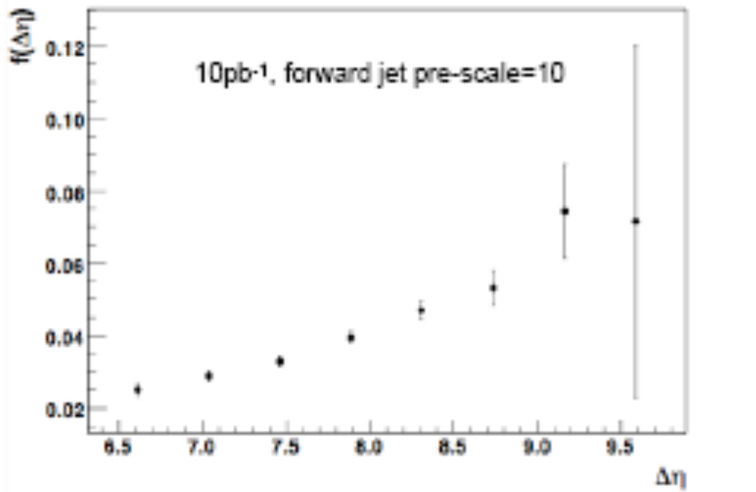
Additional effects to study on data:

- calorimeter noise
- pileup
- proper gap definition

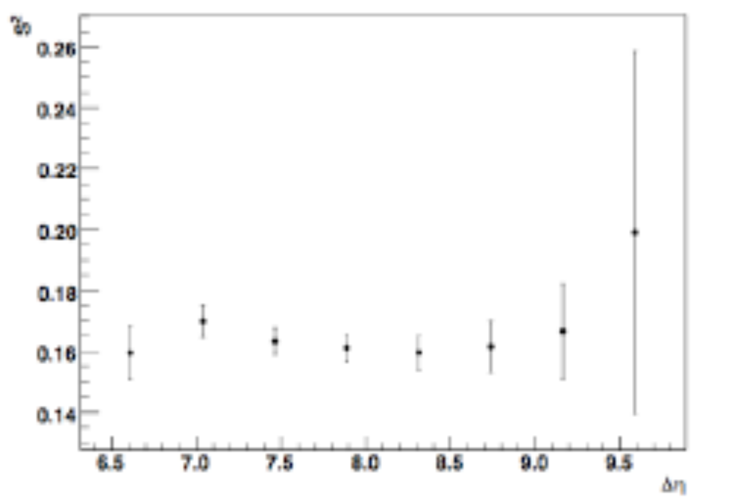
a lot of work to do with gap studies on diffractive events before attacking VBF Higgs!

# Rise of the Gap Fraction - Hadron Level Prediction for the LHC

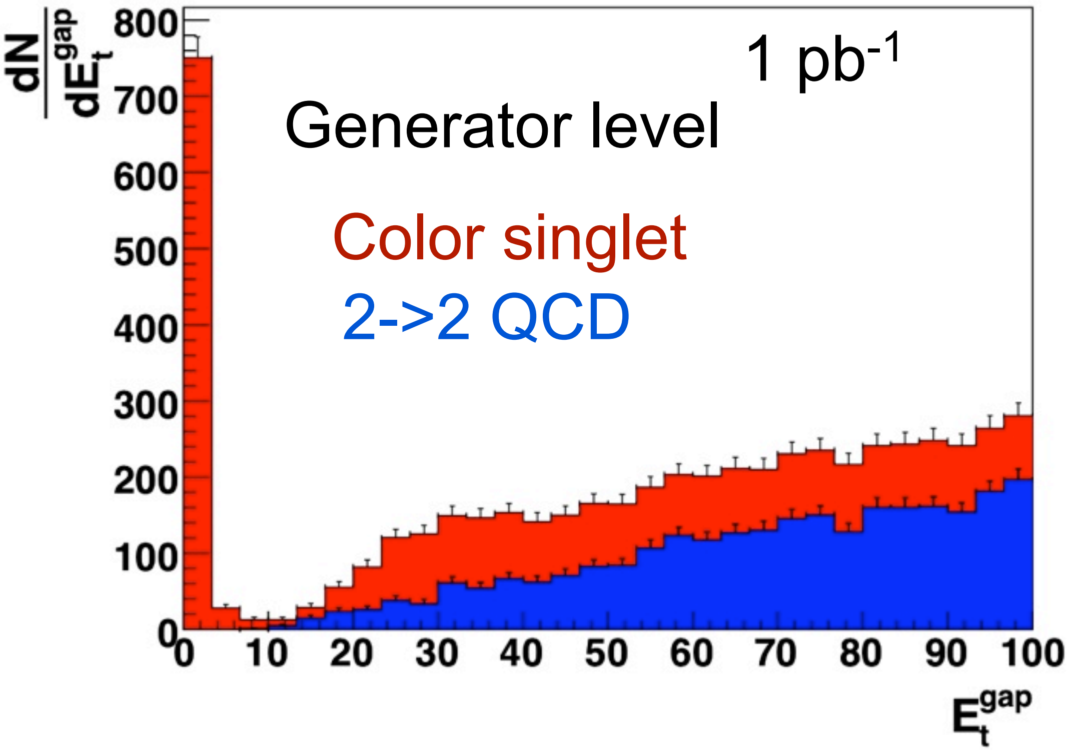
- Hadron level feasibility study performed using HERWIG+JIMMY for QCD and CSE events.
- Stable particles restricted to calorimeter coverage ($|\eta|<4.9$). Basic smearing of particle energy given by ATLAS parameters.
- Forward jet trigger approximated for particles in forward calorimeters. Events kept if 2 jets with $E_T>30$GeV. Assume jet prescale=10.




- Analysis defines gap by using KT algorithm, sum transverse energy of mini-jets in the interval between the two leading jets. Define CSE to have $\Sigma E_T<10$GeV.



# Jet-gap-jet in Atlas (very preliminary)




- Hadron level analysis defined CSE as less than 10 GeV of transverse energy in the interval between the jets. (Basic smearing of particle energy applied)
  - How does noise and real detector affect this?
  - How does the crack region affect this?
  - Can tracking information improve gap definition (a la D0)?

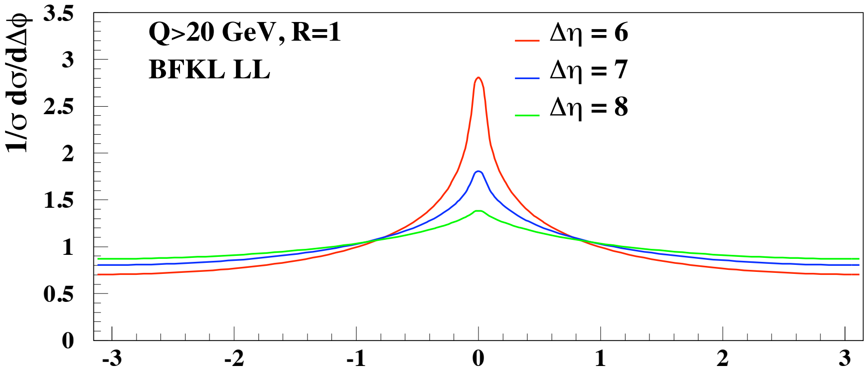
# Mueller-Navelet jets: not only gaps

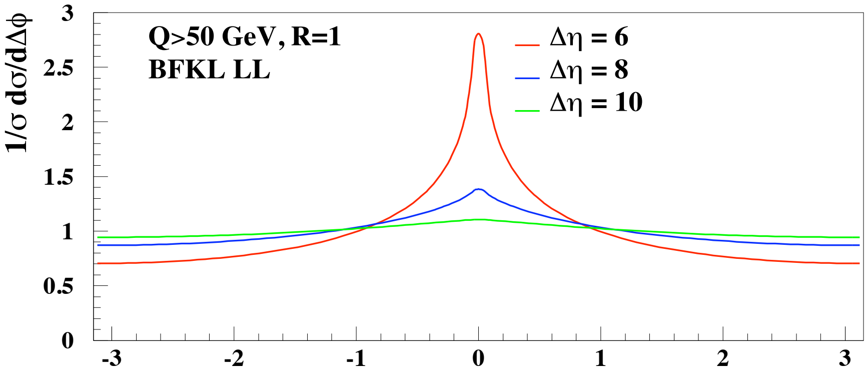
The BFKL ladder does not only predict an increase of events with large rapidity gaps.

An “open ladder” leads to an enhancement of jets in the central region of similar Et to the forward-backward ones, and de-correlation of the ΔΦ between the jets.

ΔΦ dependence on Δη is another indicator of BFKL behaviour:

Marquet, Royon, arXiv:0704.3409

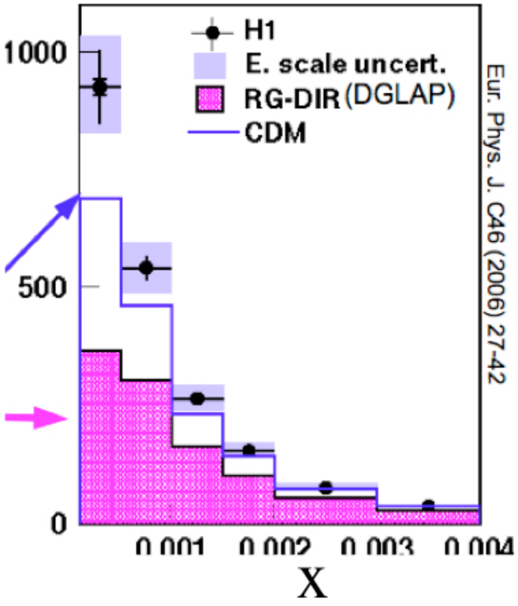


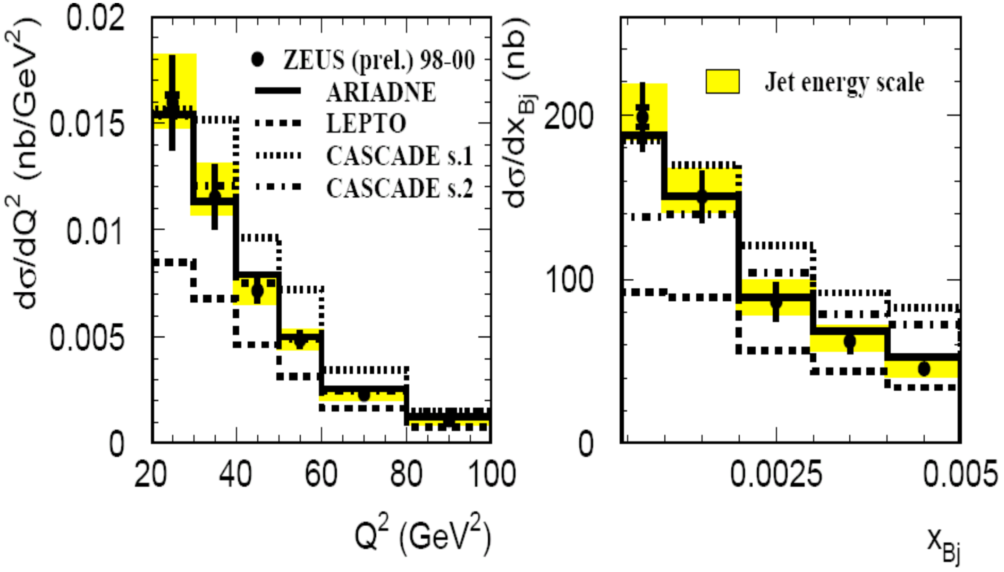




Other observables, depending on jet energies, may not be available from day 0 due to calibration, but certainly for later analysis

# Various models and Hera measurement

- BFKL approximation with Color Dipole Model (CDM) available since some years in the ARIADNE code
- CCFM evolution based on kt factorisation, with angular (instead of kt) ordering is similar to DGLAP at high $Q^2$, to BFKL at low x. Implemented in CASCADE
- Both models have been tested at HERA, results not fully conclusive, waiting for the LHC!



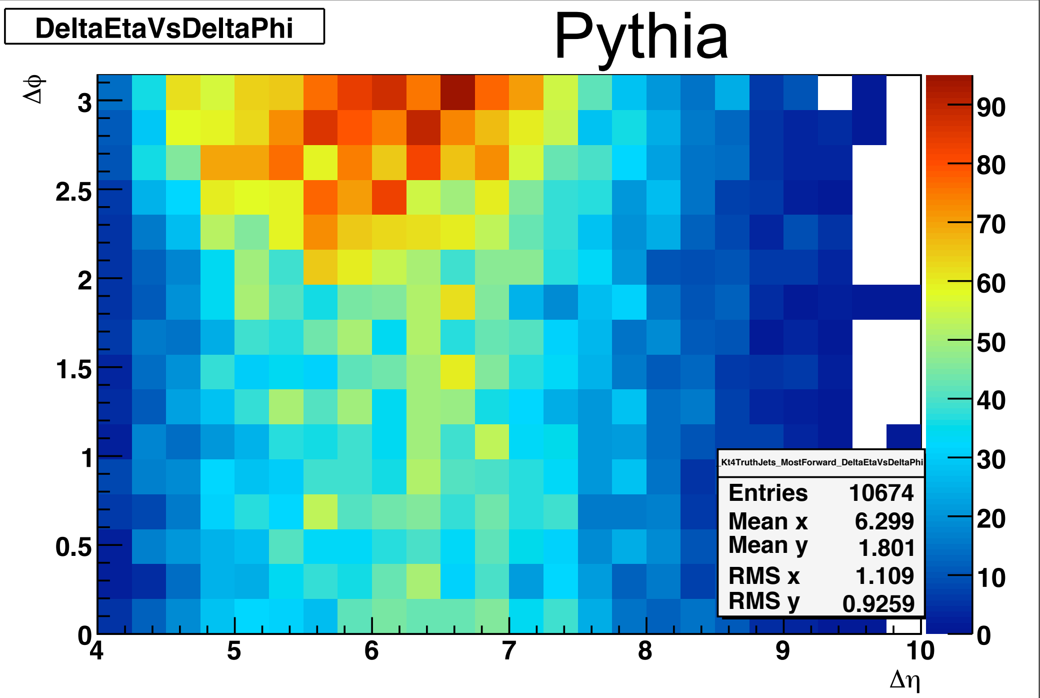
# De-correlation studies on parton level Monte Carlo

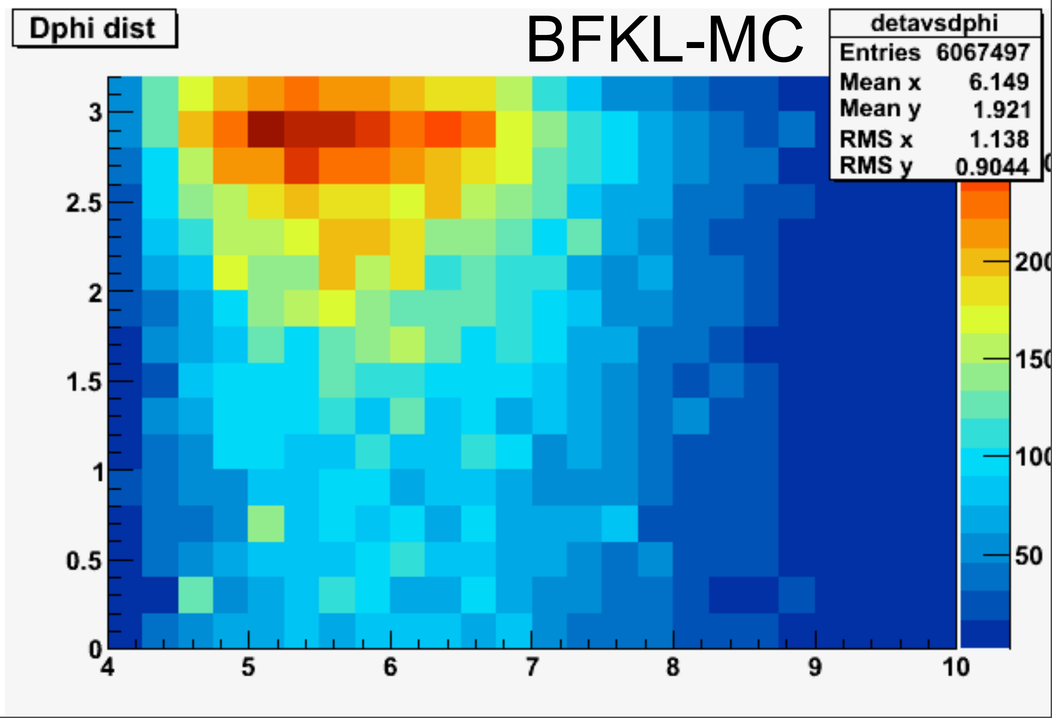
Jeppe R. Andersen ([hep-ph/0602182](hep-ph/0602182) etc.) developed a MonteCarlo implementation of jet production in the BFKL framework.

Also a full numerical integration of the FKL limit (without approximations to get analitical form) will be available soon (as well as matching with PS)

Ex: 2 opposite jets with Et>10 GeV, |η| >2; different behaviour for Δη ~ 7

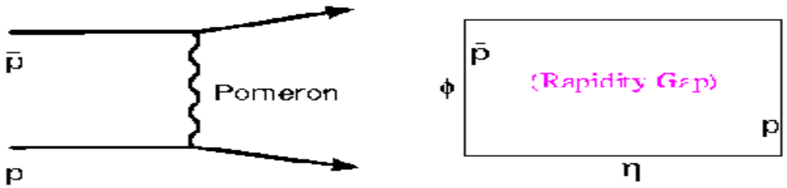
~ 1 interesting event per μb!



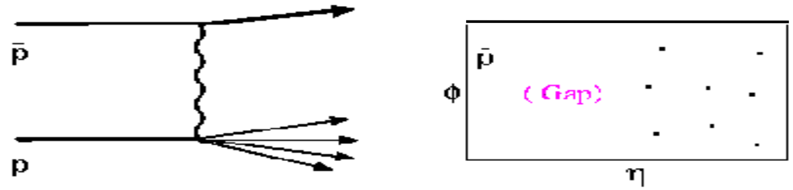
# More Diffractive Topologies

## Soft Processes:




**Elastic Scattering**

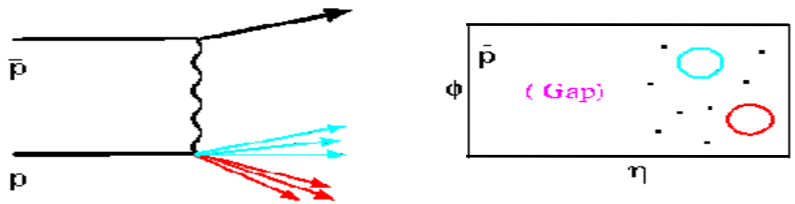
$$p\,\bar{p} \rightarrow p\,\bar{p}$$




**Single Diffraction**

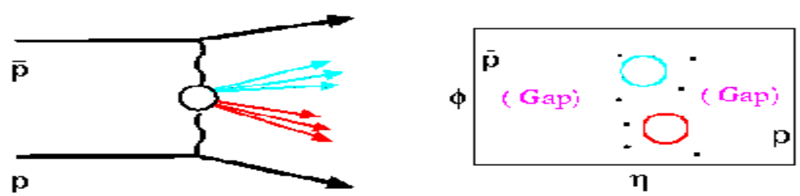
$$p\,\bar{p} \rightarrow p\,(\bar{p}) + X$$

## Hard Processes (jet production):



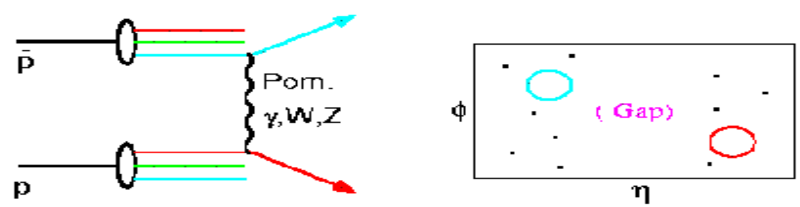

**Hard Single Diffraction**

$$p\,\bar{p} \rightarrow p\,(\bar{p}) + j\,j$$




**Hard Double Pomeron**

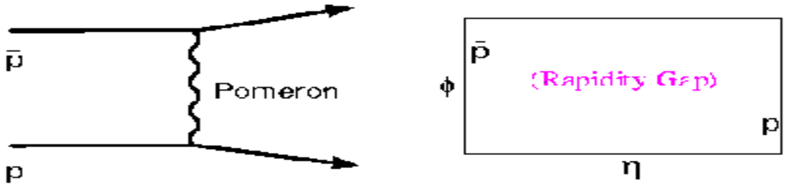
$$p\,\bar{p} \rightarrow p\;\;\bar{p} + j\,j$$




**Hard Color Singlet**

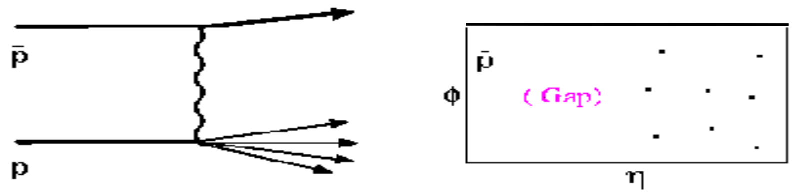
# More Diffractive Topologies

***Soft Processes:***




**Elastic Scattering**

$$p\,\bar{p} \to p\,\bar{p}$$




**Single Diffraction**

$$p\,\bar{p} \to p\,(\bar{p}) + X$$

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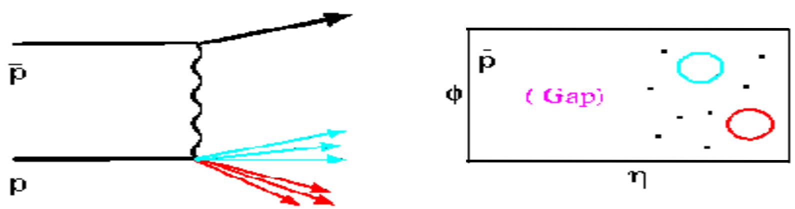


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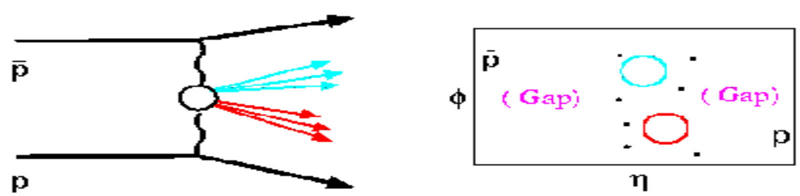


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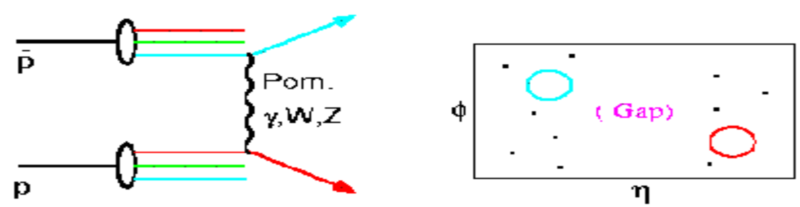
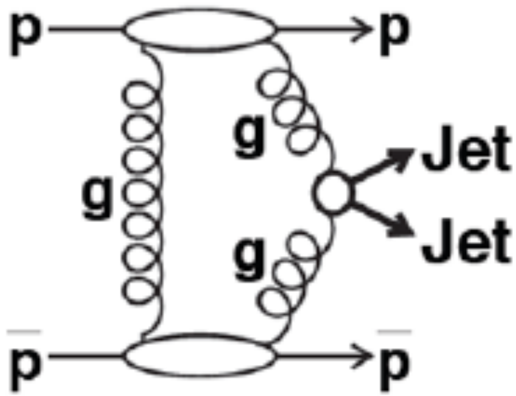



**Hard Color Singlet**

**Triggering: diffraction has gap(s) and/or protons; high cross section hard diffraction has jets too**

# Central Exclusive Di-jet Production

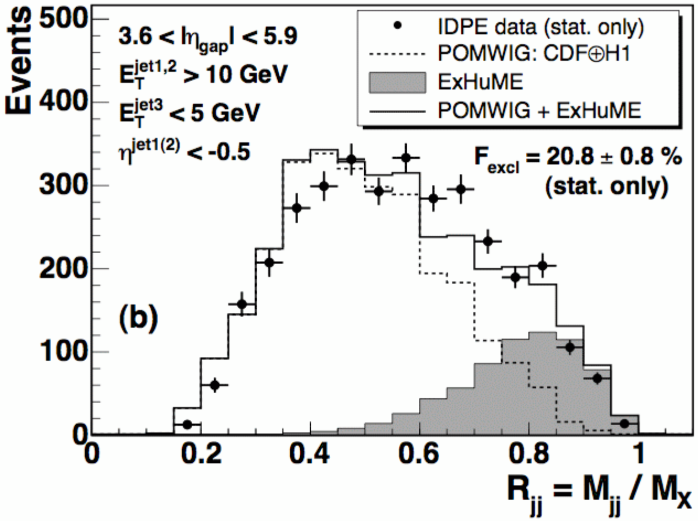


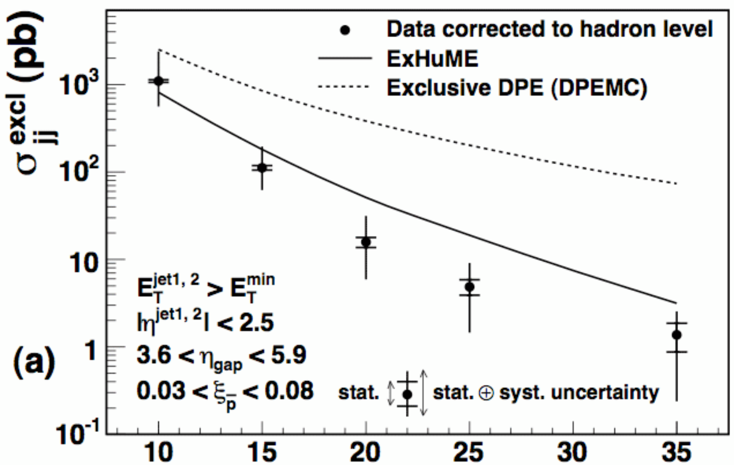

- Protons remain intact.
- All of the energy lost by protons goes into the production of central system.
  (for protons losing 1% of momentum, effective center-of-mass energy is 140 GeV—Higgs measurements possible with proton spectrometers)
  - Measure central jets and no activity in forward region
- Fraction of b-jets in di-jet sample is reduced with respect to standard production.
- Measuring CEP dijet rate allows us to test the theoretical framework - generalised parton distributions, sudakov suppression, soft-survival.
  - Constrains model, important for proposed forward proton detector upgrade.

# CEP observation at CDF

- **Di-jets:**
  - **CDF observed an excess of events at high values of the dijet mass fraction (mass of dijets / mass in calorimeter)**
  - **6σ deviation from background.**
  - **Excess is consistent with CEP theory predictions.**

- **Di-photons:**
  - **Observed 3 candidate γγ events.**
  - **Cross section consistent with theory (within theoretical error of factor 2-3)**



# ATLAS Gap Trigger Strategy

| Jet Trigger | Prescale (L1) | Rate (Hz) |
|---|---|---|
| J10 | 42000 | 3.9 |
| J18 | 6000 | 1.02 |
| J35 | 500 | 1.37 |
| J42 | 100 | 3.73 |

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Standard jet thresholds too highly prescaled for CEP studies.

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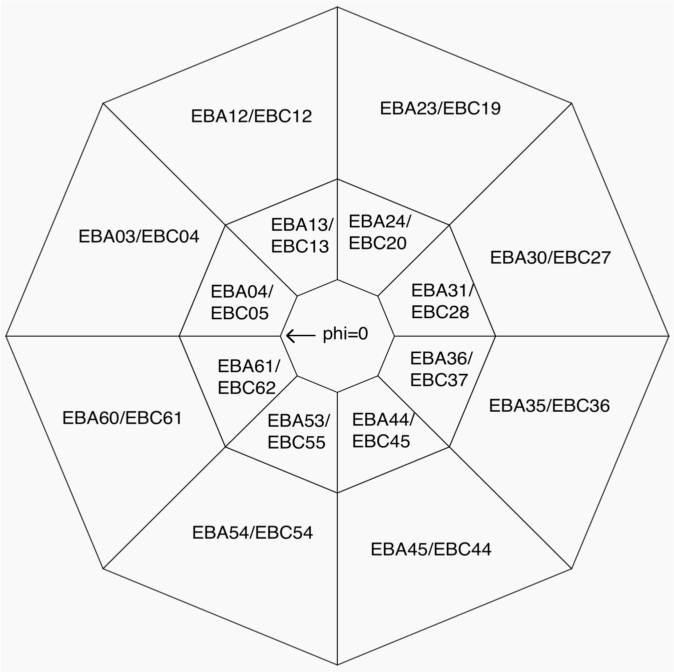

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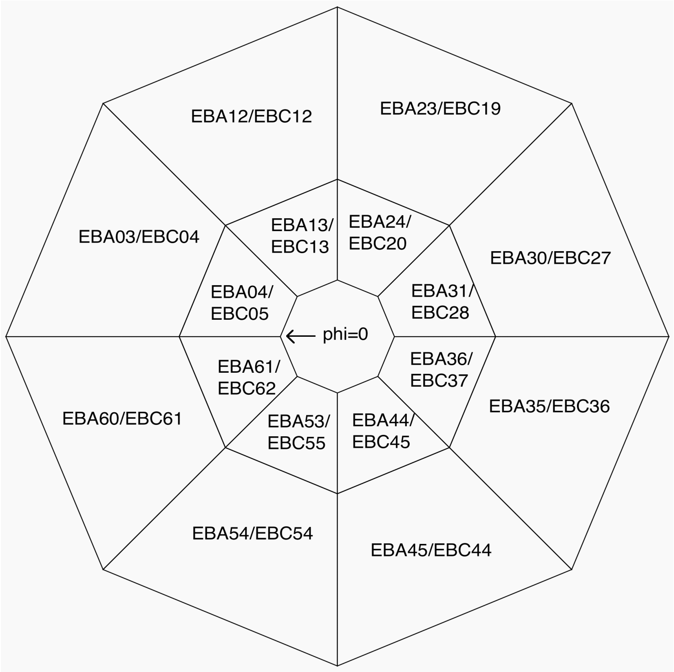

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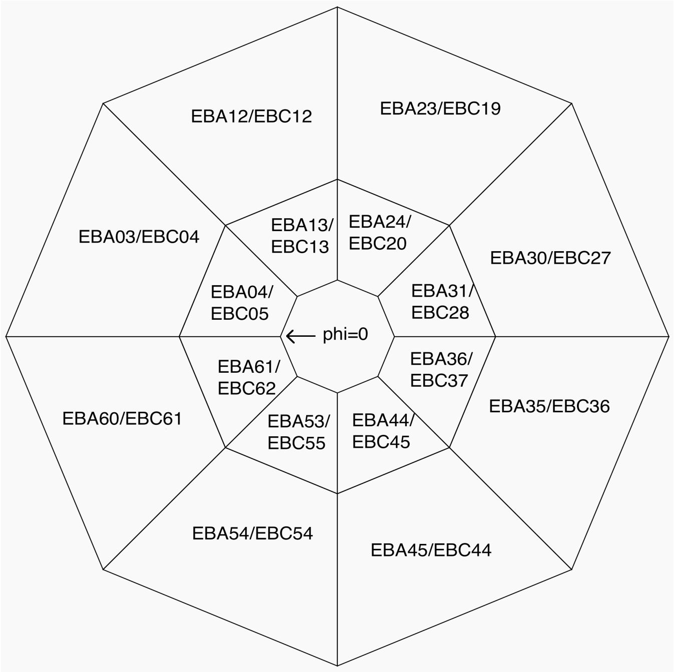

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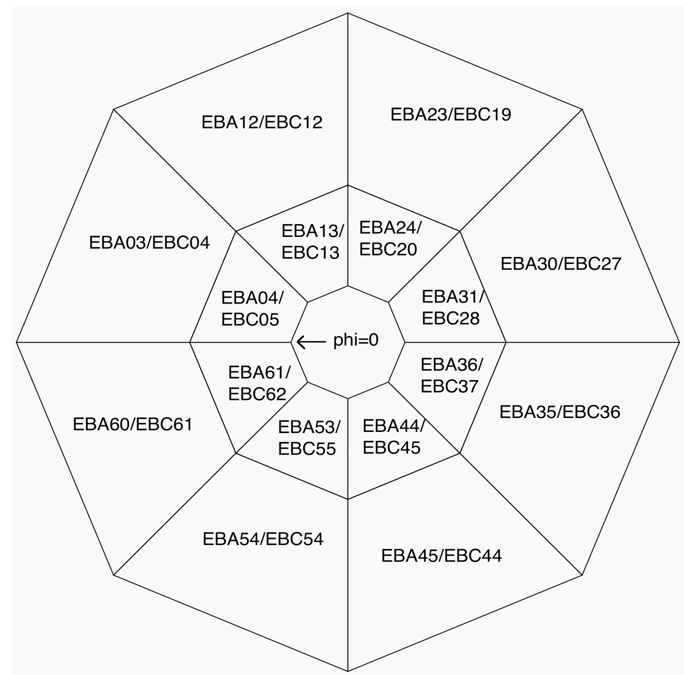

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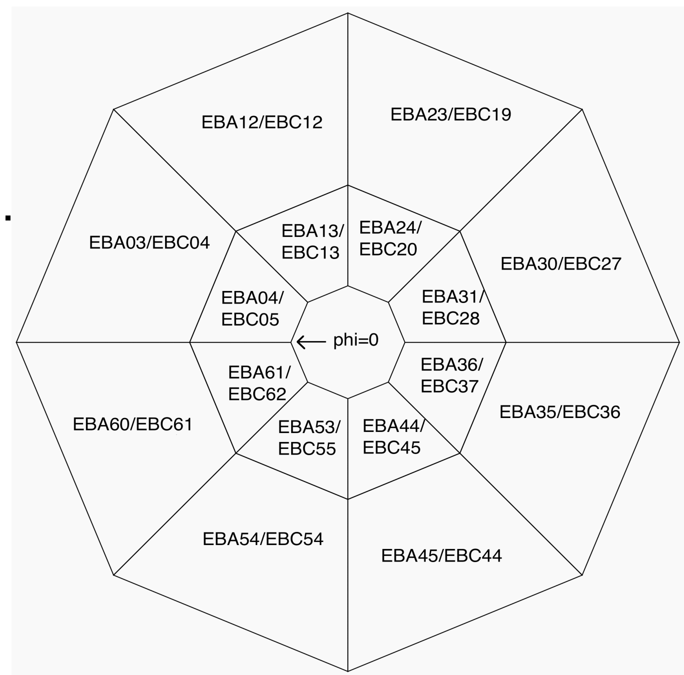

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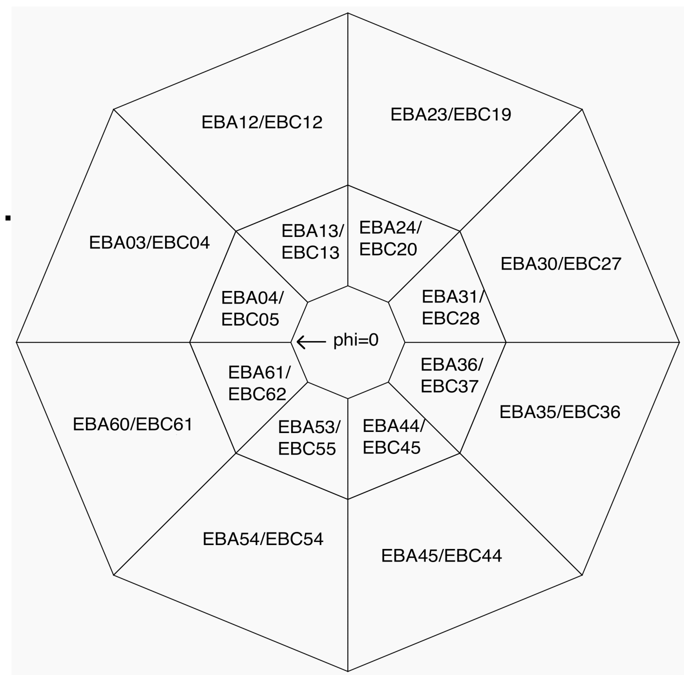
**Possible gap triggers in 2009:**

- Require one jet passing J18 + veto on MBTS (veto of hits on both sides means no hits on one side or no hits on either side)
- Investigating other MBTS terms such as inner ring veto on one side + outer ring coincidence on other
- Number of tracker hits at L2 could be used to suppress L1Calo noise



# Gap Trigger Expectations: Signal Efficiency

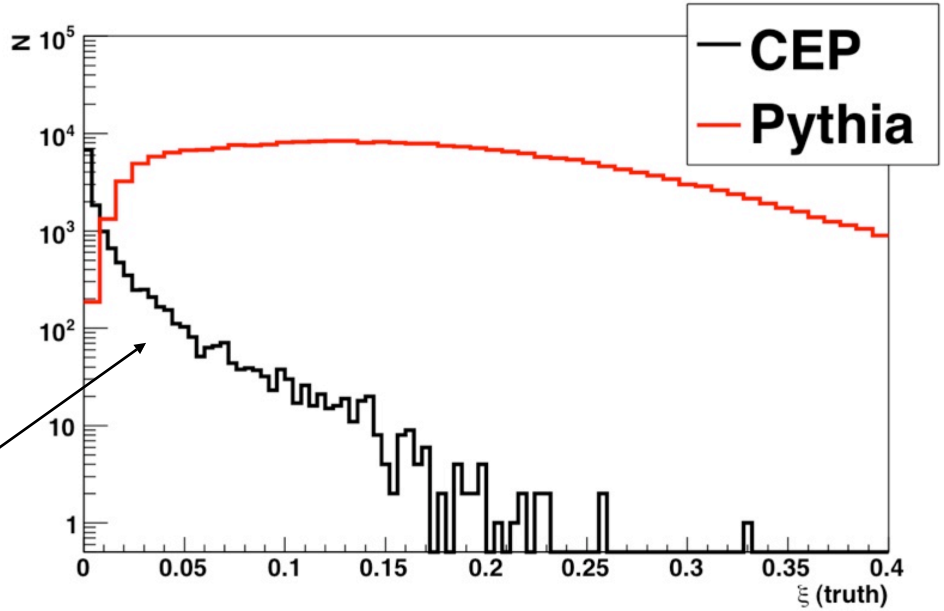
- A veto on MBTS (both sides) reduces Minimum Bias rate by a factor 10000 bringing it to level acceptable for an unprescaled trigger
- Efficiency reaches a plateau of ~65% for EXHUME CED signal sample ($p_T$>35 GeV)
  - Hadron Level expect nearly 90% efficient
  - Losses probably due to secondary particles produced via particle interactions with detector

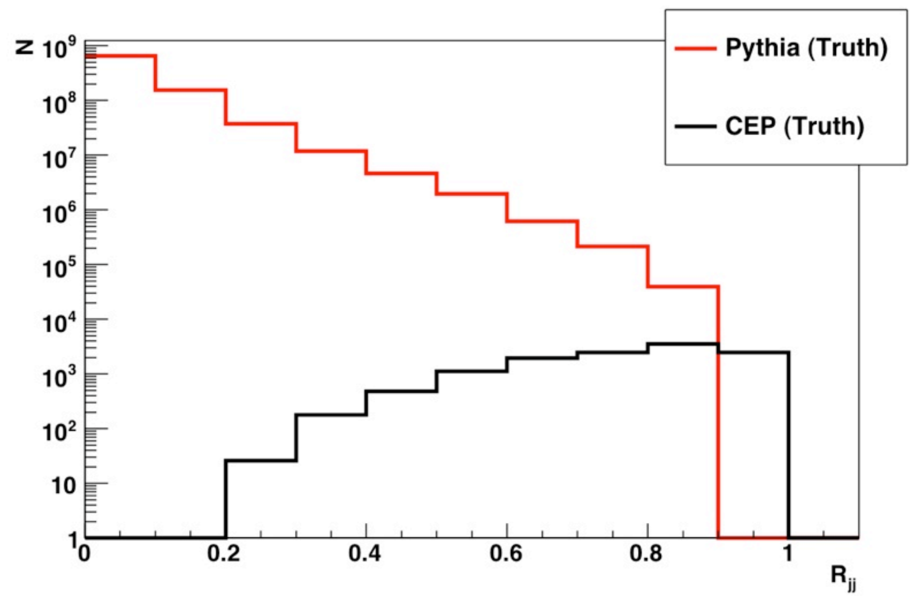
So, we can trigger on these events.
But what about measuring the mass?

# Diffractive Observables: $\xi$

- Usually specify diffractive processes by the fractional momentum loss of proton during interaction, $\xi$.
- Diffraction and CEP have $\xi$<<0.1 (hadron level studies)
- If no proton detector $\xi$ can be estimated from calorimeter energy, with 10% precision (not sufficient for Higgs)
- However, the steeply falling distribution introduces a ~5% shift, not seen in the flatter QCD distribution.

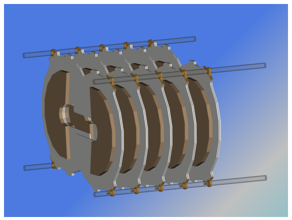
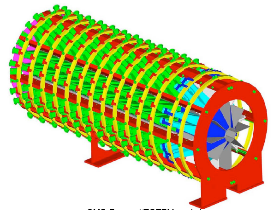
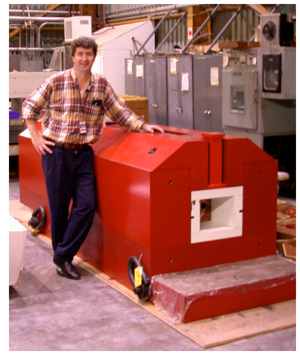
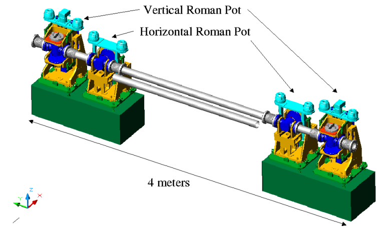
For precision measurements we need a dedicated detector!

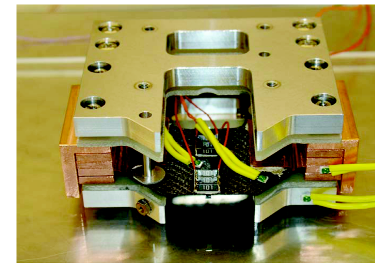


# Forward detectors at LHC

**TOTEM -T2 | CASTOR | ZDC/FwdCal | TOTEM-RP | FP420**

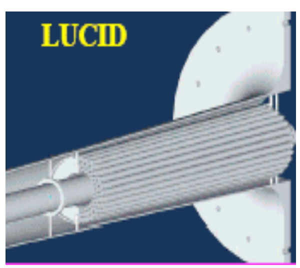





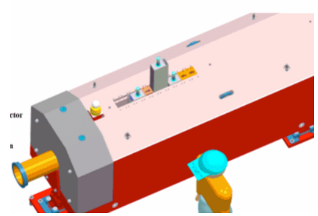
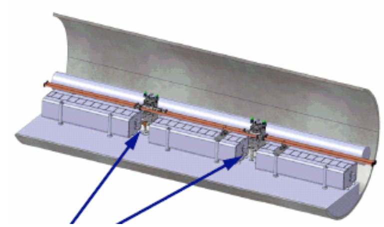
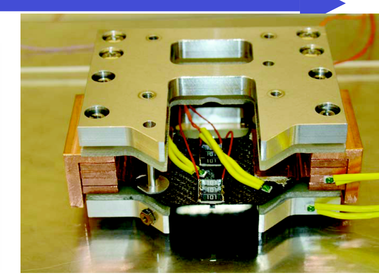


**I P 5**

14 m | 16 m | 140 m | 147m – 220 m | 420 m

**I P 1**

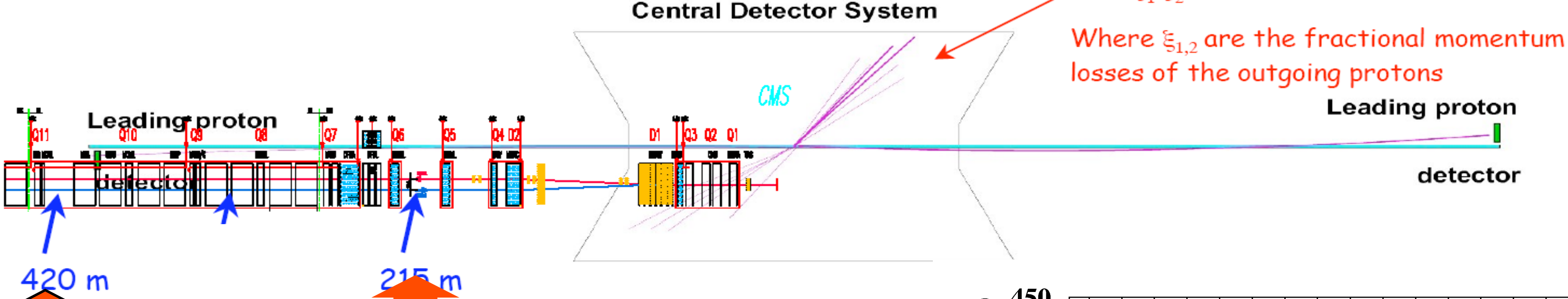


ATLAS

**LUCID | ZDC | ALFA/RP220 | FP420**

# How to measure the protons

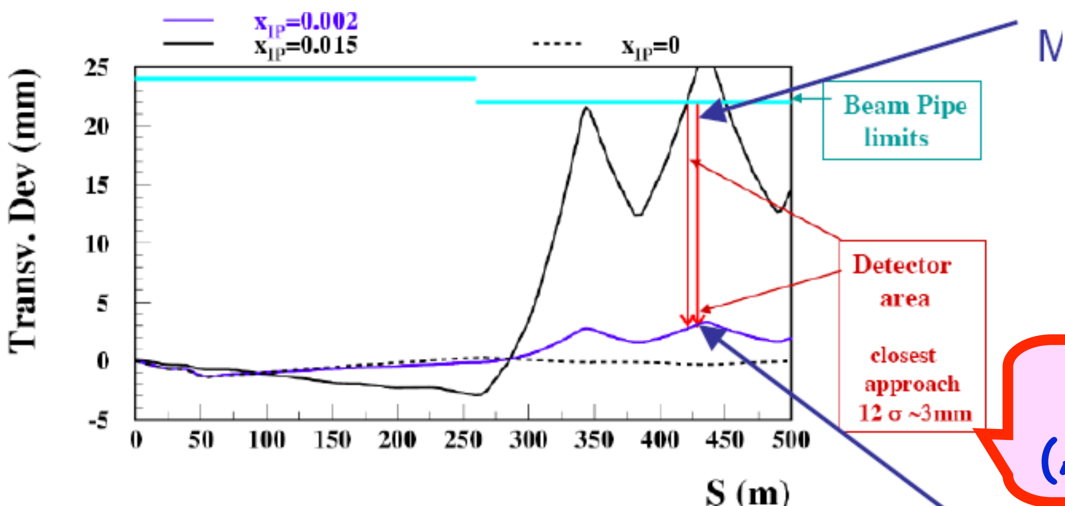



$M^2 = \xi_1 \xi_2 S$

Where $\xi_{1,2}$ are the fractional momentum losses of the outgoing protons

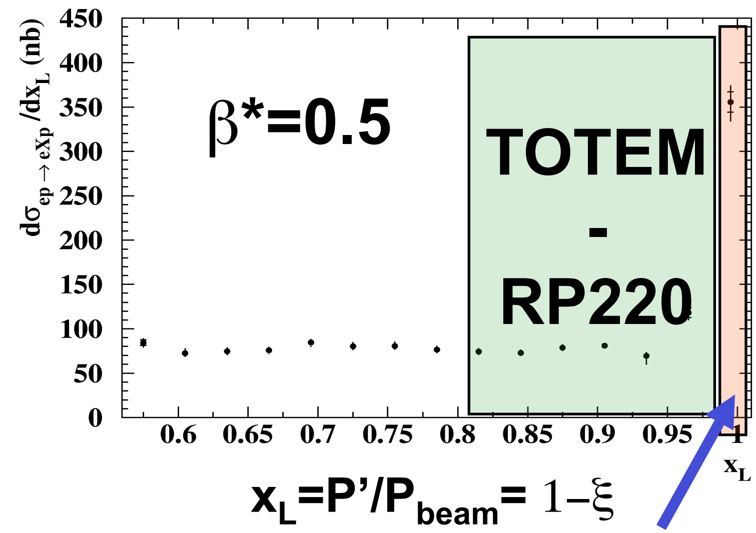
FP420

TOTEM on CMS side
RP220 on ATLAS side




FP420
(ATLAS)

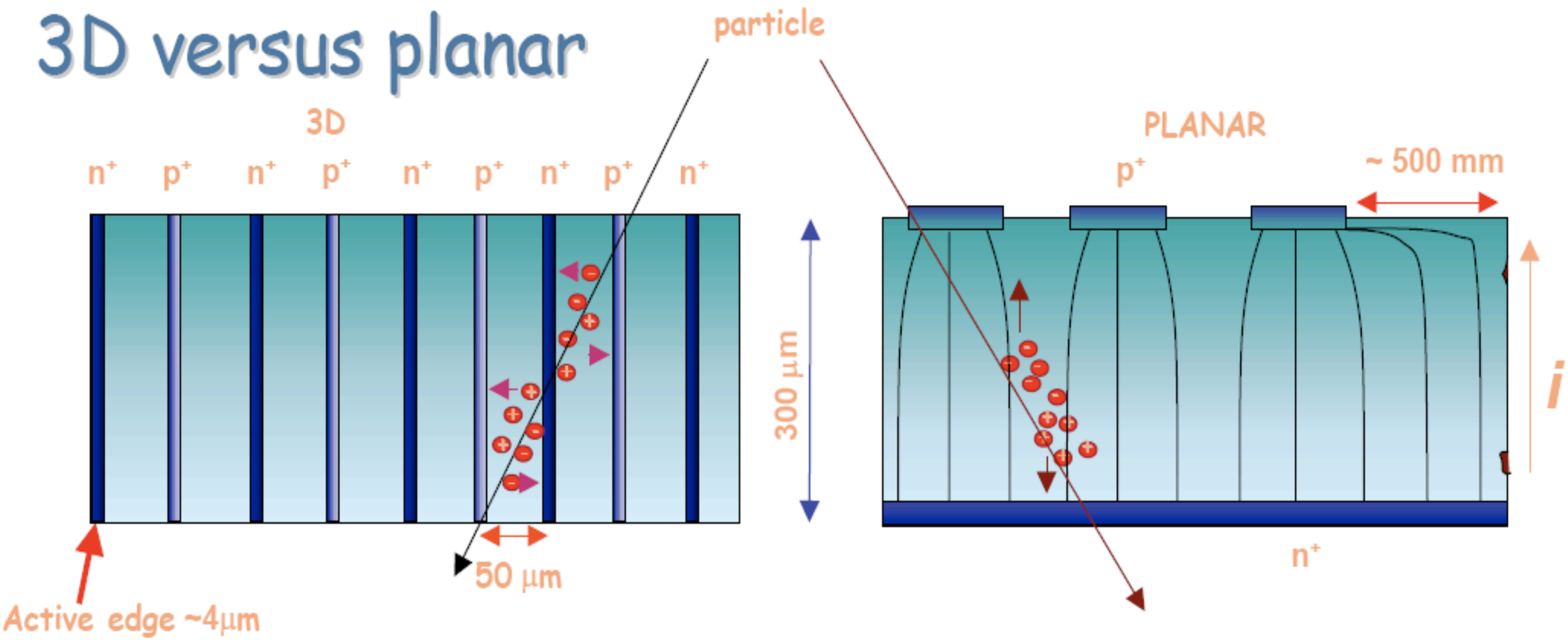
M ~ 30 GeV




$x_L = P'/P_{beam} = 1-\xi$

FP420

# 3D Silicon Detector Development




Manchester/Stanford/MBC

3DC Collaboration

Transfer to Industry in

progress – SINTEF

Also support from Bonn/LBL/Prague

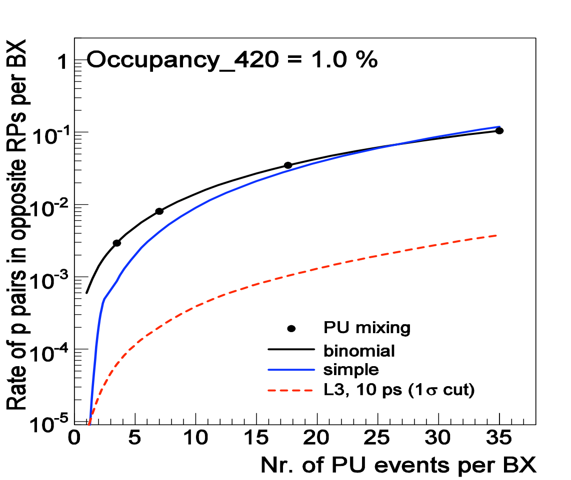
Note: 3D ATLAS R&D Collaboration forming

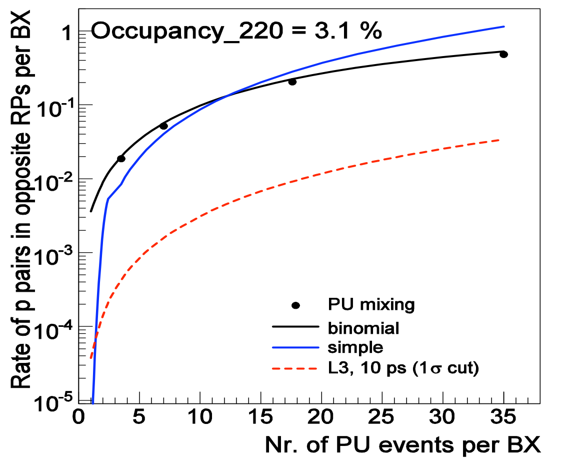
| | 3D | planar |
|---|---|---|
| $V_{dep}$ | < 5-10 V | 50-70 V |
| $Q_{1mip}$ | 24000e$^-$ | 24000e$^-$ |
| $C$ | 40-80fF | 50-200fF |

# Fast timing detectors

**Diffraction makes up 20-30% of $\sigma_{TOT}$: diffractive p's from pile-up fake signal diffr. p's**

Example of H->bb:overlay of 3 events (2 SD + non-diffr. dijets) fakes signal perfectly and with prob. $10^{10}$ x higher than signal. Can be reduced by fast timing det.



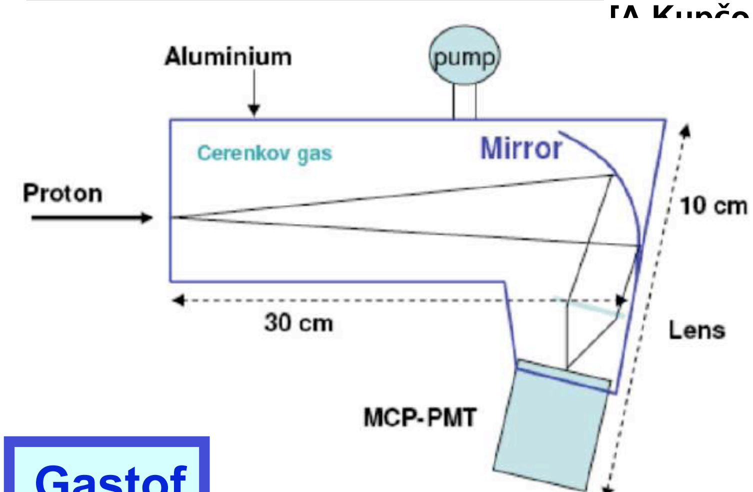




**[A Kupčo and M.T]**

**10ps (2-3mm) resol. may separate different vertices**

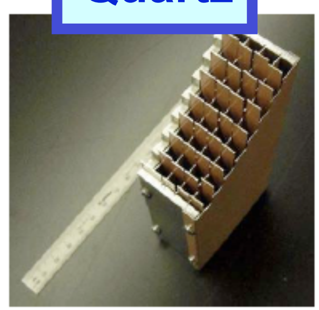
**BG Rejection up to**

UTA, Louvain, Fermilab, Saclay, Stony Brook, Chicago, Alberta, Argonne




**Gastof**

**Quartz**



Test beams indicate:
10-20 ps by Gastof
20-30 ps by Quartz

Disadvantage of Gastof: no space resol

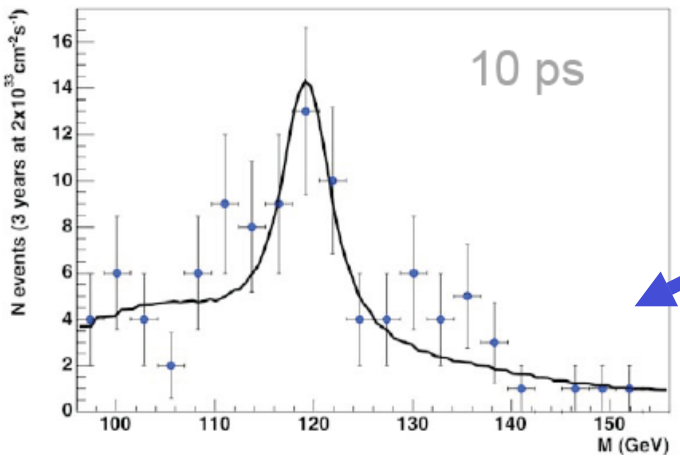
Future: 1-2 ps? Space resolution?
Combination of Gas and Quartz

Key point: yield of photoelectrons

# CED H→bb using Forward Proton Tagging

**h→bb, mhmax scenario, ATLAS L1 triggers, 420m only, 5 mm from beam**

Huge Pile-up bg for diffractive processes: overlap of three events (2*SD+non-diffr. Dijets). Reduced by Fast Timing detectors: t-resol. required: 2 ps for high lumi!




**JHEP 0710:090,2007**

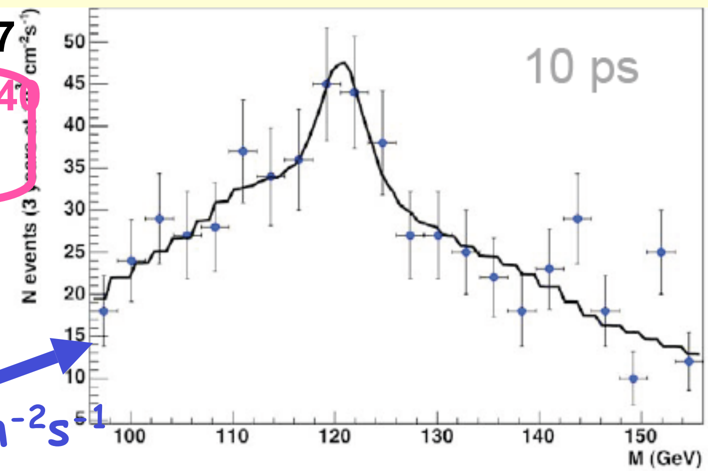
$m_A$=120 GeV, tan$\beta$=40

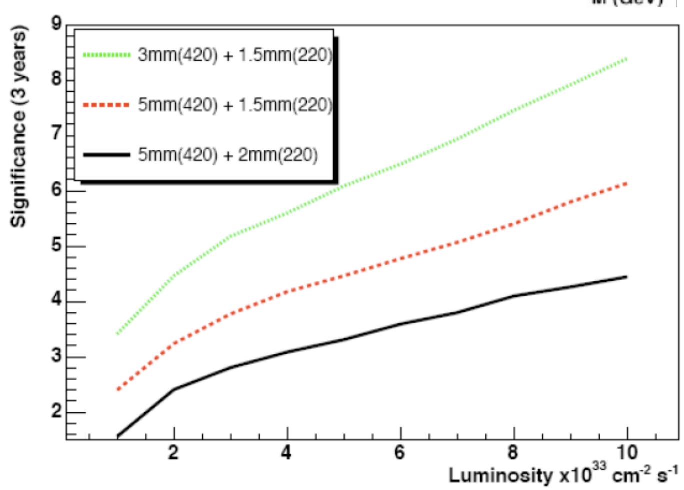
$\sigma_{h\rightarrow bb}$=17.9 fb

3 years at

2x10$^{33}$cm$^{-2}$s$^{-1}$

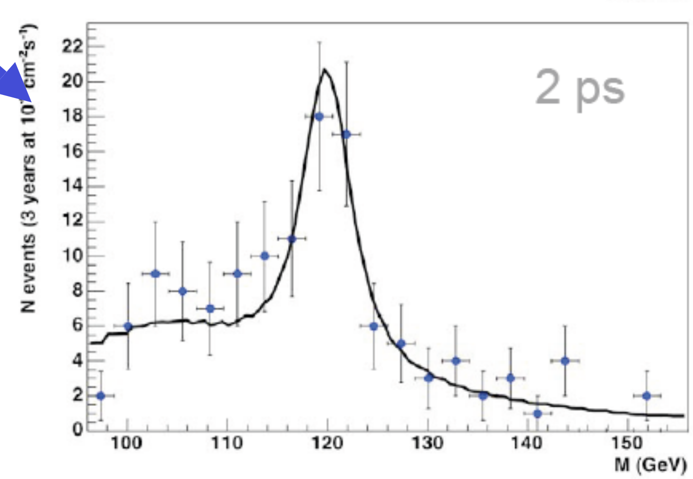
3 yrs at 10$^{34}$cm$^{-2}$s$^{-1}$




**Assume 220m**

**Pots at L1**



# Summary

Forward physics will play a large role in the LHC startup studies
Main topics with present detectors:

- Forward jets (BFKL evolution, rapidity gaps).
  - Only needs ~10 $pb^{-1}$ of data.
  - Helps understand forward jets for VBF studies
- Central exclusive production (10-100$pb^{-1}$ of data).
  - Helps to understand underlying event, parton distributions, Sudakov suppression
  - Constraints theoretical models

R&D for forward detectors over, approval process started on both experiments. Install in 2010 shutdown?

- Precision CEP
- Higgs quantum number determination?