Discussion session

What can we learn/expect from the LHC experiments

Panel members:

Chung-I Tan	Brown University
Mark Strikman	Penn State University
Hannes Jung	DESY/University Antwerp
Dino Goulianos	Rockefeller University / CDF, CMS
Albert de Roeck	CERN / CMS and FP 420
Per Grafström	CERN / ATLAS
Karel Safarik	CERN / ALICE
Hubert Niewiadomski	Penn State University / TOTEM

Some guidelines for the discussion

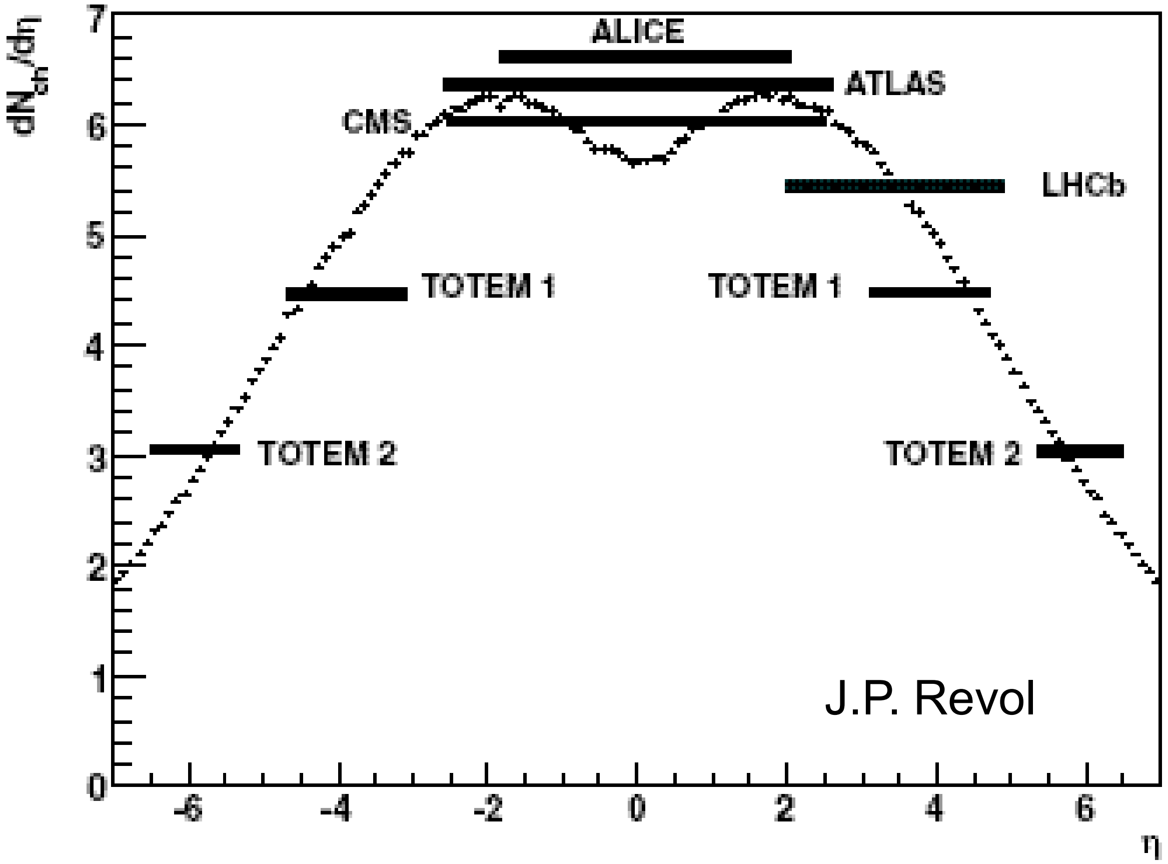
What do you consider as the most important topic to be addressed
- **at the LHC start (2010)**
- **later (>2010)**

Collaborations between the LHC experiments (synergy effects)
- **common Monte Carlos**
- **common analysis and combination of data**
- **common run strategies**
- **trigger strategies**

What kind of upgrades do you consider useful for the future

Charged particle acceptances

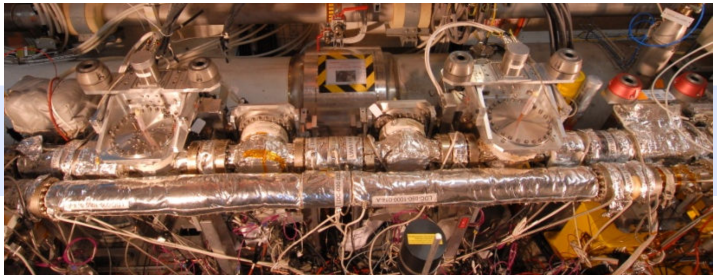
from J.P. Revol

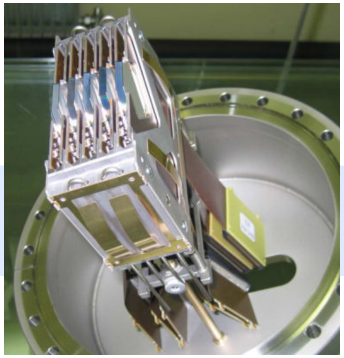


Very Forward detectors in all experiments:
LHCf, ZDC, Castor, …

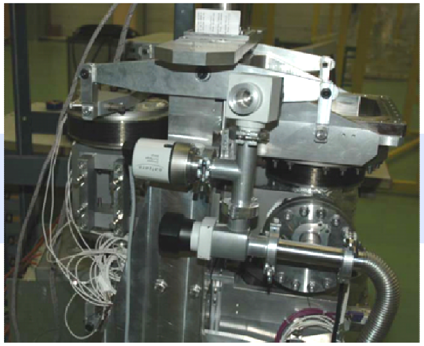
Roman Pot Forward Detectors @ LHC

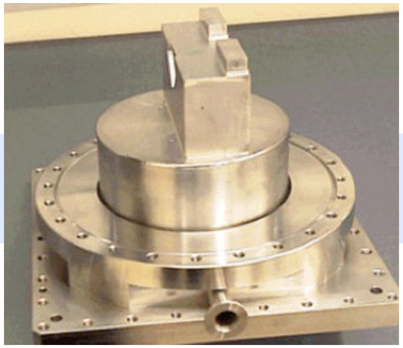
TOTEM



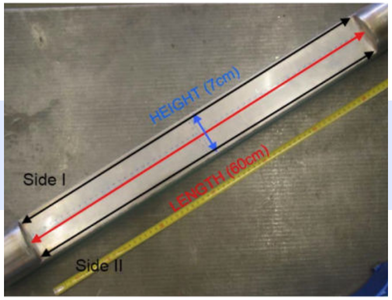


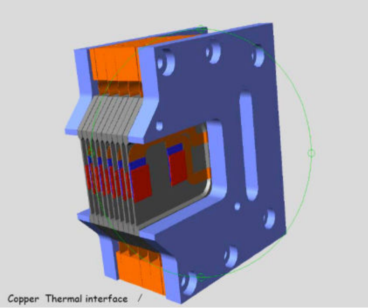
ATLAS Alfa



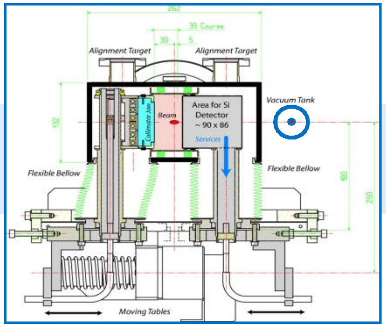


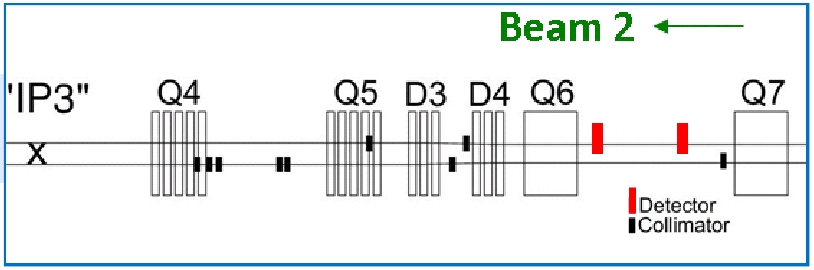
FP420





IP3





Optics and Beam Parameters

Parameters	β^* = 2 m (standard step in LHC start-up)	β^* = 90 m (early TOTEM optics)	β^* = 1540 m (final optics)
Crossing angle	0.0	0.0	0.0
N of bunches	156	156	43
N of part./bunch	$(4 - 9) \times 10^{10}$	$(4 - 9) \times 10^{10}$	3×10^{10}
Emittance ε_n [μm · rad]	3.75	3.75	1
10 σ_y beam width at RP220 [mm]	~ 3	6.25	0.8
Luminosity [cm^{-2} s^{-1}]	$(2 - 11) \times 10^{31}$	$(5 - 25) \times 10^{29}$	1.6×10^{28}

$$\sigma(\theta^*) = \sqrt{\frac{\varepsilon}{\beta^*}} \qquad L \propto \frac{1}{\beta^*}$$

β^* = 90 m ideal for early running:

- fits well into the LHC start-up running scenario;
- uses standard injection (β^* = 11m) → easier to commission than 1540 m optics
- wide beam → ideal for training the RP operation (less sensitive to alignment)

β^* = 90 m optics proposal submitted to the LHCC and well received.

what we need…

Karel Safarik

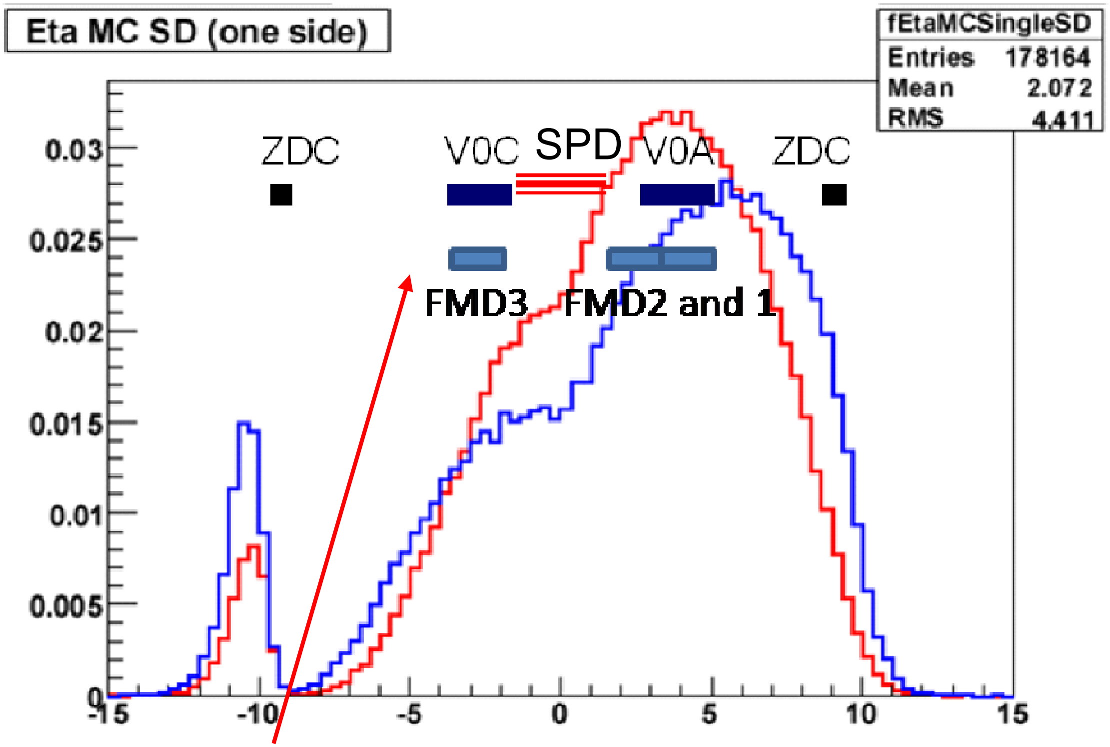
- how to correct the normalization of the first measurements (multiplicity density, multiplicity distribution), to the inelastic events, to the non-single-diffractive events and to the non-diffractive events
- estimates show that the systematic connected with this correction can be among the largest contribution to the systematic error

- some suggestions: don't correct – use just triggered events
- problem: it's not very useful
  - trigger acceptance cannot be described just as some "rectangle"
  - is quite complicated integral convoluted with the physics distributions of the produced particles (it does not factorize…)
  - that's why we use monstrous MC descriptions of detectors…

- … and that's why we need MC event generator for diffractive collisions

Detector coverage in pseudorapidity
Event selection

- We want offline triggers which will select many of one process whilst selecting very few of the others
- To distinguish between an SD and a DD event, not only do we need asymmetric triggers, but they need to be in the rapidity region most sensitive to the asymmetry



Add a scintillator here?

•The asymmetric ZDC triggers would be more sensitive to Single Diffractive events than Double – more stable fit

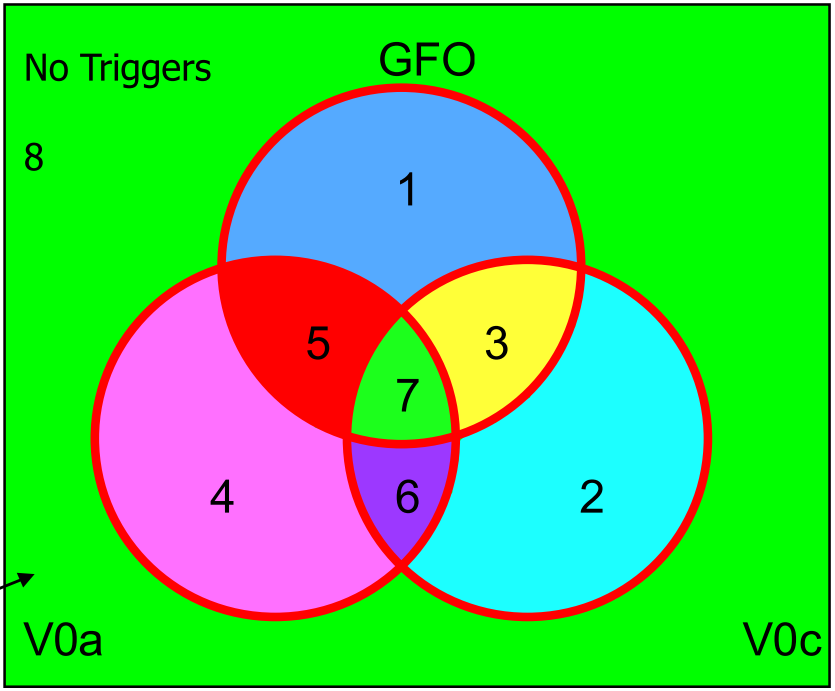
PHOJET PYTHIA

Uncorrelated offline triggers

- Here, we assume only 3 elements: V0 detectors and Global Fast Or (GFO – SPD Trigger) – can be easily extended to more detectors
- Initially, we will trigger on bunch crossings, so “no triggers” is possible
- Uncorrelated triggers should be more sensitive to the differences than a set of min-bias triggers:
  - E.g. Asymmetric triggers should be more efficient in Single Diffractive events than Non Diffractive

Tr	V0a	GFO	V0c
1	0	1	0
2	0	0	1
3	0	1	1
4	1	0	0
5	1	1	0
6	1	0	1
7	1	1	1
8	0	0	0

No overlaps - uncorrelated



Prospects for ALICE measurements of central diffraction: light states, J/ψ, (maybe χ_c) production

- Diffractive gap trigger in ALICE
- light states
- J/ψ measurement for hunting the Odderon
- maybe χ_c measurement with identifcation of different states… (needs selective trigger)

Zoe Matthews

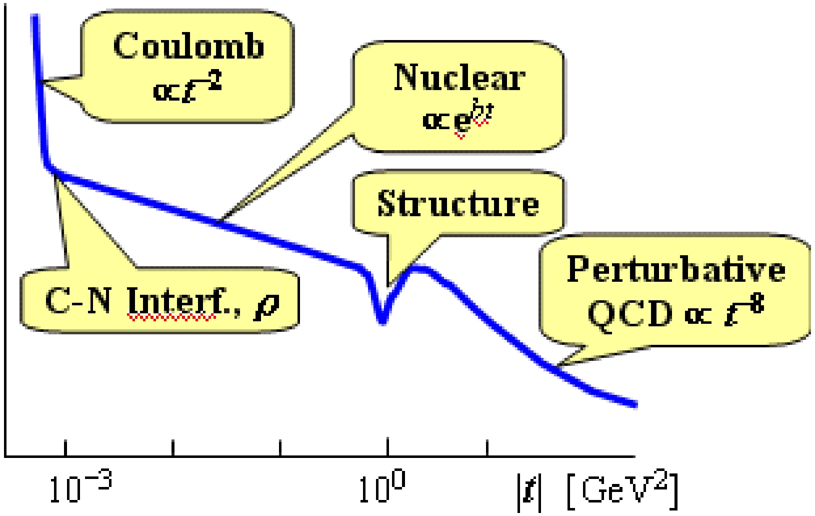
Karsten wanted me to discuss “experimental synergy” From ATLAS point of view .

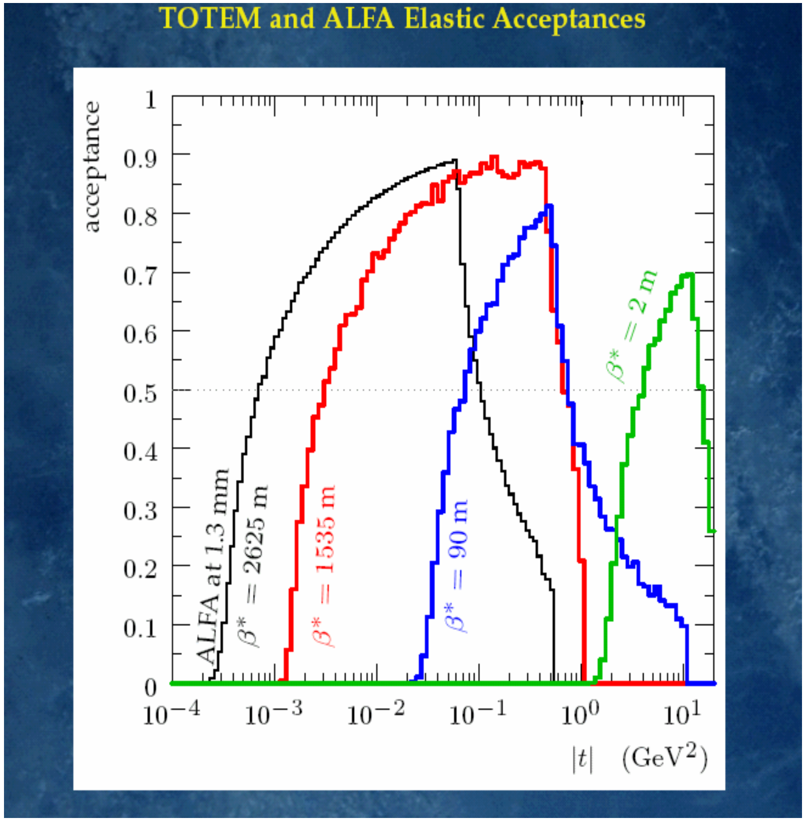
Per Grafström

Synergy (from the Greek *syn-ergos*, *συνεργός* meaning working together) is the term used to describe a situation where different entities cooperate advantageously for a final outcome. Simply defined, it means that the whole is greater than the *sum* of the individual parts. Although the whole will be greater than each individual part, this is not the concept of synergy. If used in a business application it means that teamwork will produce an overall better result than if each person was working toward the same goal individually.

Elastic scattering

Overlapping t-scales in a theoretical uncertain region





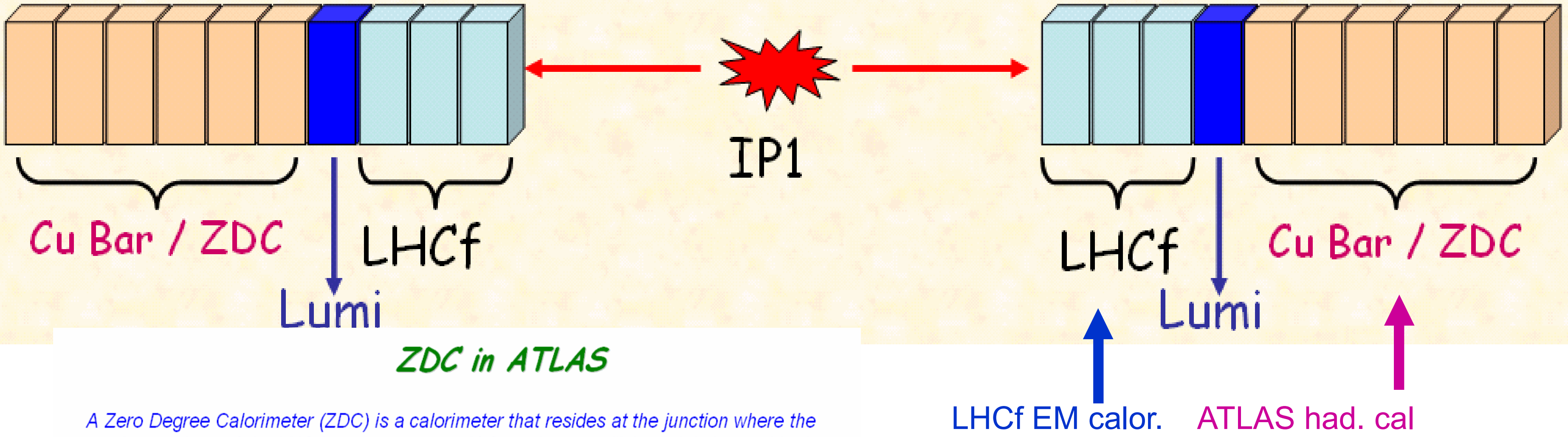
Use σ_{tot} from TOTEM

Use L from van der Meer scans

From Jan Kaspar

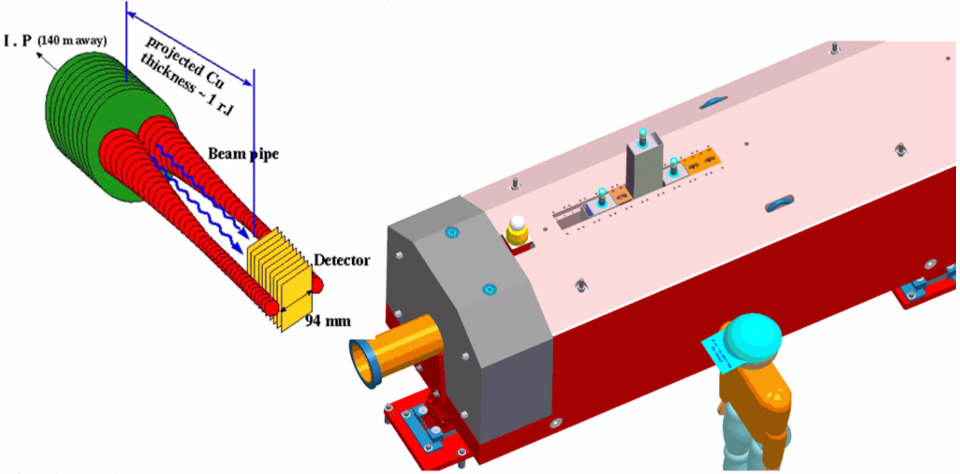
Synergy with forward calorimeters

LUMI monitor (BRAN) inside TAN is beyond LHCf (replacing 4th copper bar)



ZDC in ATLAS

A Zero Degree Calorimeter (ZDC) is a calorimeter that resides at the junction where the two beam pipes of the LHC become one – at 0° from the pp collisions. It is housed in the shielding unit that protects the S.C magnets from radiation, and measures neutral particle production at 0°. It can play many roles.



Examples of minimal synergy:

Share Energy sums

..In trigger...

...In data....

...neutrons

More advanced:

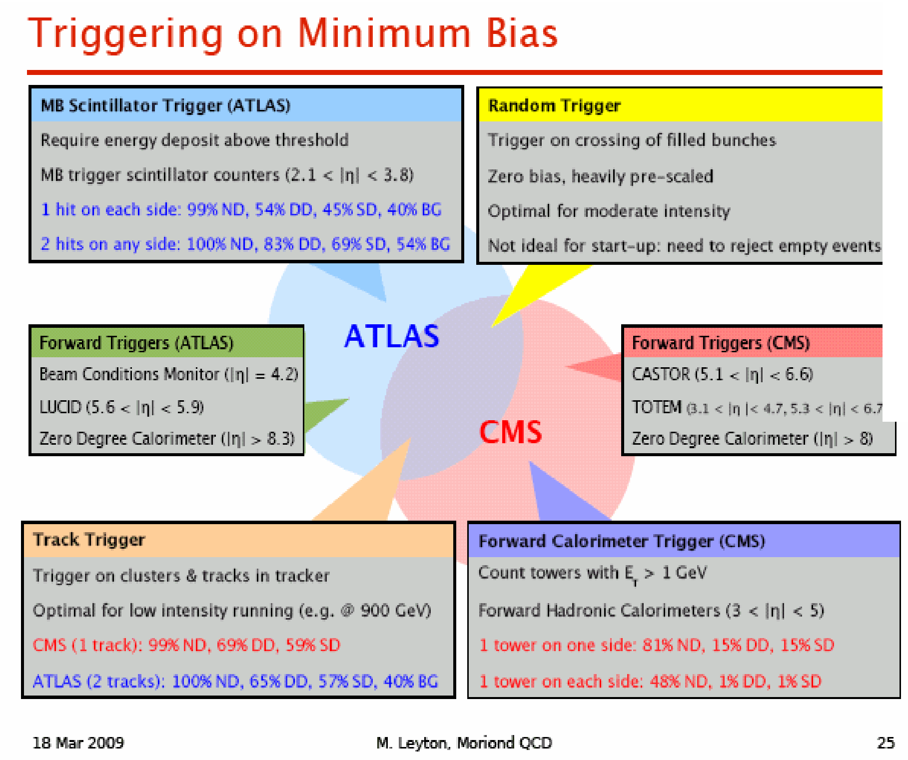
....correlation with central system

Synergy in early data-underlying event

Each experiment has its "MB" trigger –we need to combine to get the global picture – see recent KMR paper on MB effects at the LHC

◆ Understand minimum bias events

- Key observables $<N_{chg}>$, $dn_{chg}/d\eta$, $<p_t>$
- Will be major background at high luminosities and high p_t



Triggering on Minimum Bias

MB Scintillator Trigger (ATLAS)
Require energy deposit above threshold
MB trigger scintillator counters (2.1 < |η| < 3.8)
1 hit on each side: 99% ND, 54% DD, 45% SD, 40% BG
2 hits on any side: 100% ND, 83% DD, 69% SD, 54% BG

Random Trigger
Trigger on crossing of filled bunches
Zero bias, heavily pre-scaled
Optimal for moderate intensity
Not ideal for start-up: need to reject empty events

Forward Triggers (ATLAS)
Beam Conditions Monitor (|η| = 4.2)
LUCID (5.6 < |η| < 5.9)
Zero Degree Calorimeter (|η| > 8.3)

Forward Triggers (CMS)
CASTOR (5.1 < |η| < 6.6)
TOTEM (3.1 < |η |< 4.7, 5.3 < |η| < 6.7
Zero Degree Calorimeter (|η| > 8)

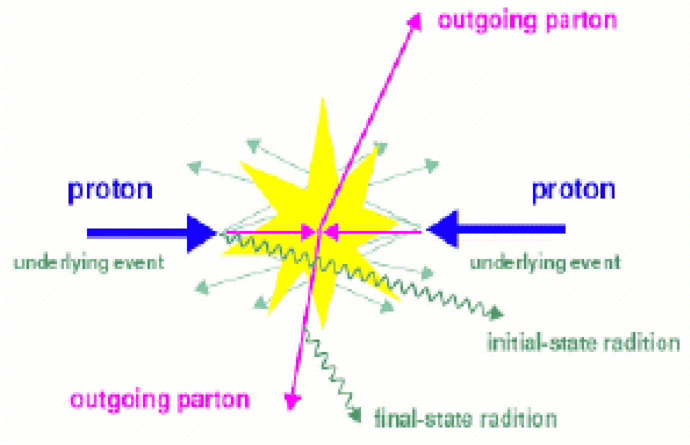
Track Trigger
Trigger on clusters & tracks in tracker
Optimal for low intensity running (e.g. @ 900 GeV)
CMS (1 track): 99% ND, 69% DD, 59% SD
ATLAS (2 tracks): 100% ND, 65% DD, 57% SD, 40% BG

Forward Calorimeter Trigger (CMS)
Count towers with E_T > 1 GeV
Forward Hadronic Calorimeters (3 < |η| < 5)
1 tower on one side: 81% ND, 15% DD, 15% SD
1 tower on each side: 48% ND, 1% DD, 1% SD

18 Mar 2009 M. Leyton, Moriond QCD 25

◆ Understand underlying event

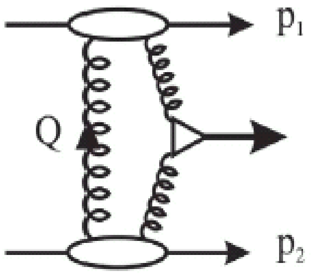
What is the UE?



Pedestal to high p_t events

What we learn at low luminosity
Will be very useful at high luminosity

Advice to next generation..........(just a dream)



Proton Tagging
Protons intact-all energy to central system
Need to detect protons in the lattice after the IP

Be it FP420, Roman Pots, Hamburger Pipe, IP3
We are sweating TERRIBLY today to get it in!

Just think about how it would be if
Roman Pots or Hamburger pipes or other detector pockets
would have been part of the accelerator installation
from the beginning.....!!
- standard pockets in strategic places...

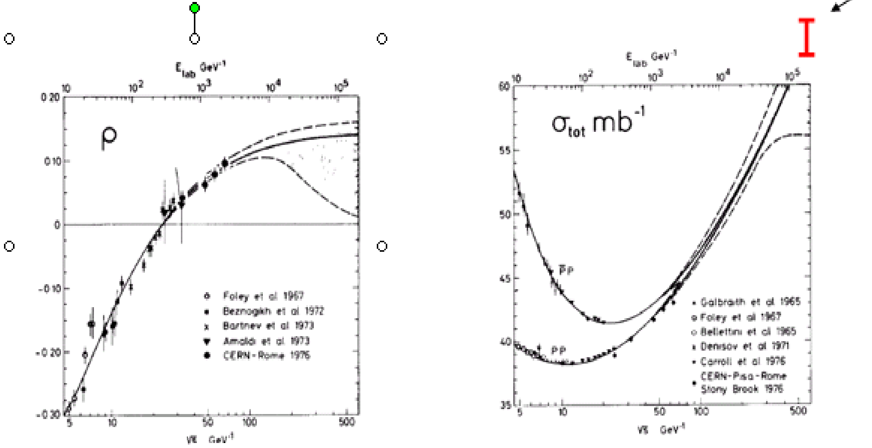
There is a lot of
Forward Detector Synergy
with the machine:
(Cf Helmut Burkhard talk)

Understanding of halo
Feedback on background
combined effort , vertex,
alignement, optics....

Predictions from ISR measurements

SPS collider

Predictions from Collider and Tevatron measurements



$$\mathrm{Re}\, f_+(E) = C + \frac{E}{4\pi^2} \int_m dE' p' \left(\frac{\sigma_+(E')}{E'(E'-E)} - \frac{\sigma_-(E')}{E'(E'+E)} \right)$$

11

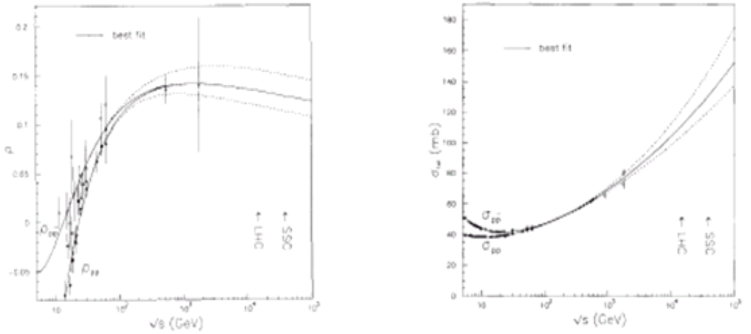


Fig. 2. The result of the fit is shown together with the experimental data on the parameter ρ. Solid and dashed lines have the same meaning as in fig. 1.

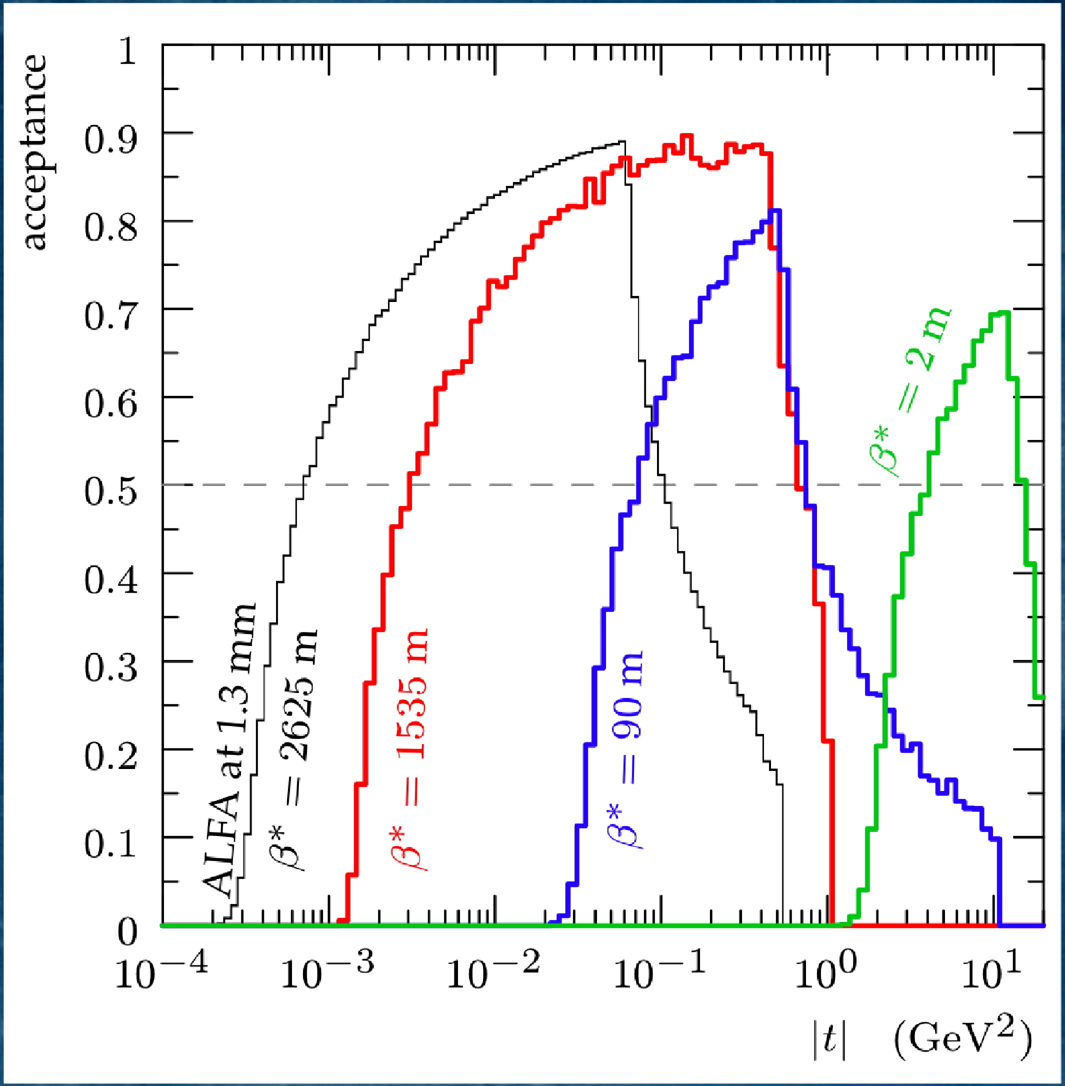
Fig. 1. The result of our fit is shown together with the experimental data on σ_{pp} and $\sigma_{\bar{p}p}$ from accelerators. The best fit is represented by the solid line while the region of uncertainty corresponding to one standard deviation is delimited by the two dashed lines.

12

- May be we will be confronted with saturation effects in elastic scattering! A new regime?
- t dependence of ρ and of b
- New behavior of ρ and of b will influence the procedure to extract the parameters
- Important to measure very accurately dσ/dt
- May be the LHC halo will not permit us to go as close to the beam as we want

Measure ρ at LHC
and predict σ_{tot} at energies
well above LHC energies

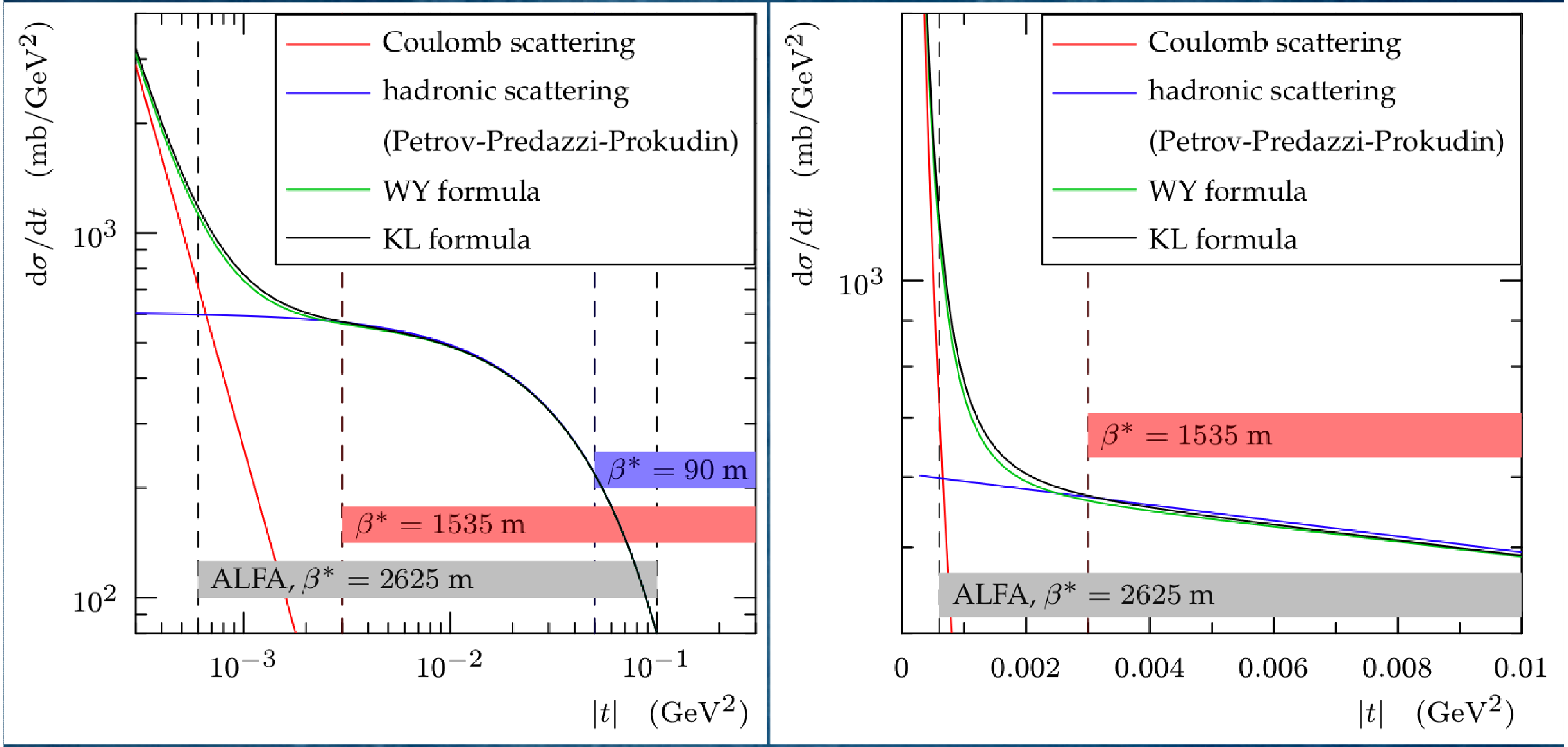
TOTEM and ALFA Elastic Acceptances



Jan Kaspar

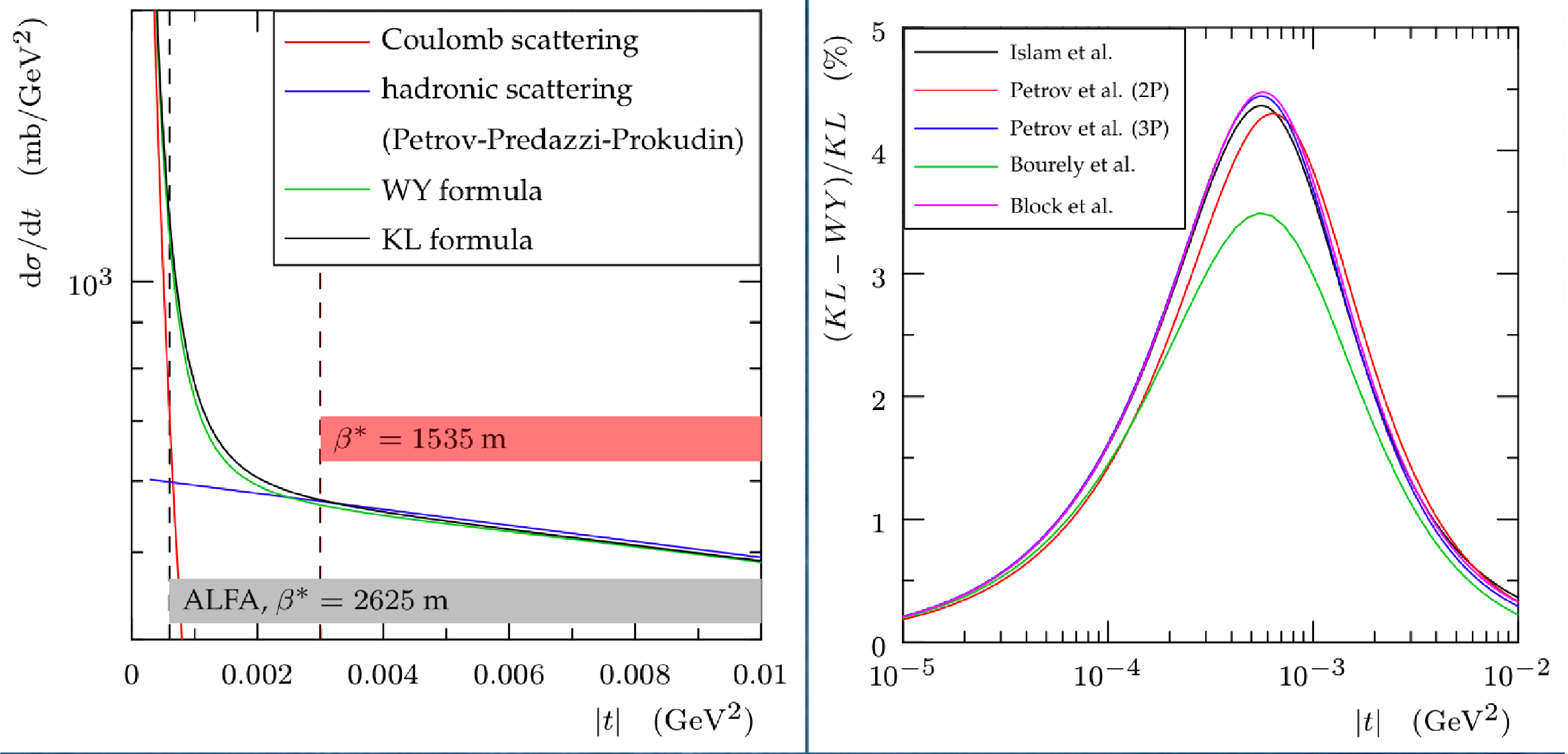
Contributions to Elastic Differential Cross Section

- identical plots, left: logarithmic, right: linear $|t|$ scale.
- colorful bands: 50% acceptance ranges



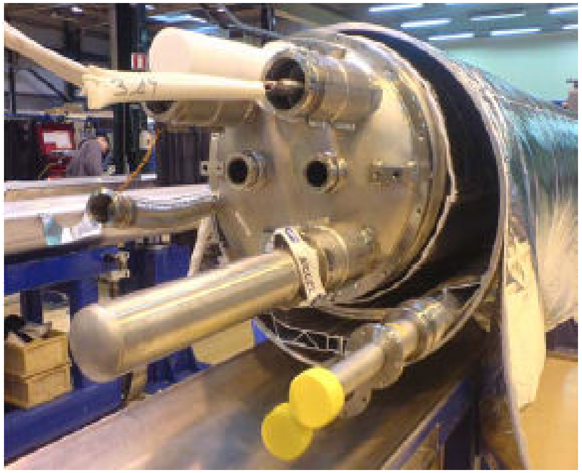
Coulomb Interference

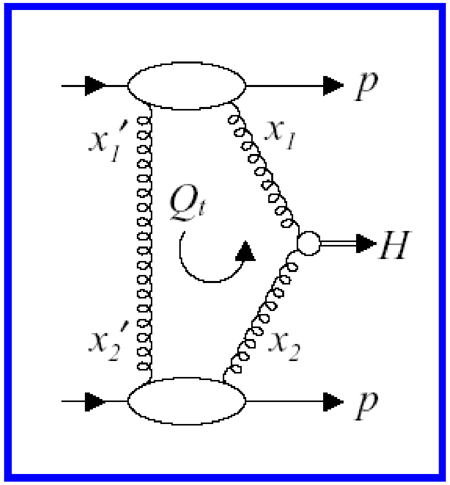
- comparison of West-Yennie (WY) and Kundrát-Lokajíček (KL) interference formulae



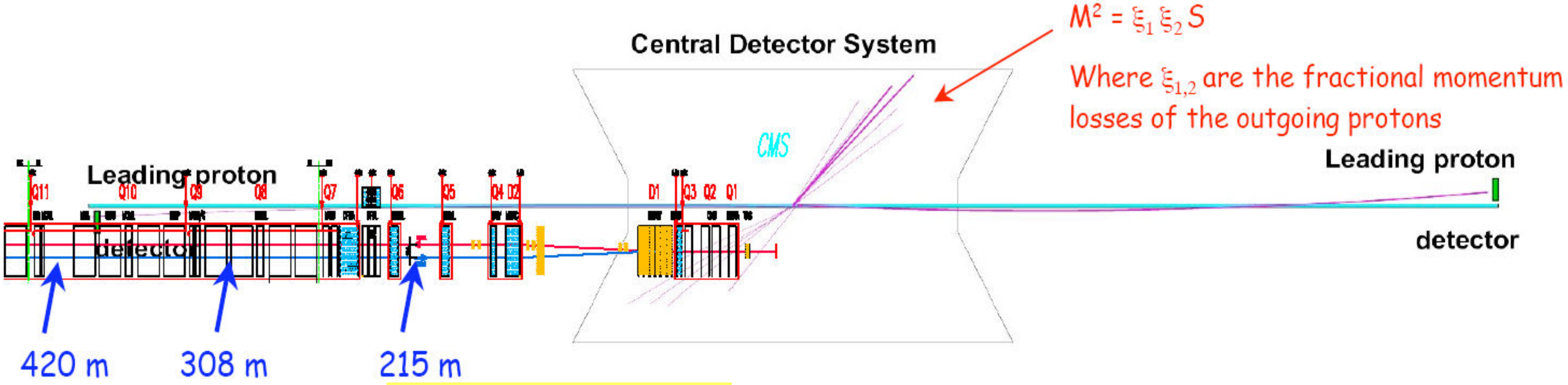
The FP420 Project

Albert De Roeck
CERN





FP420: Detectors at 420m

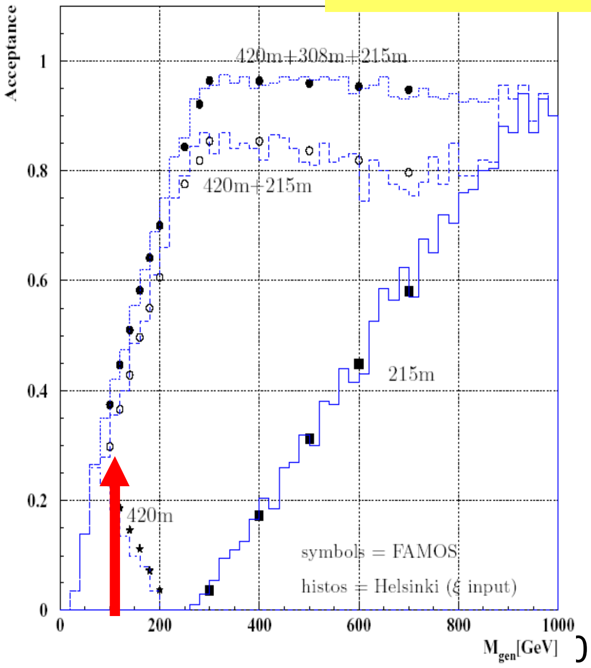


$M^2 = \xi_1 \xi_2 S$

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

FP420

TOTEM
(ATLAS/RP220)



Low β^*: (0.5m): Lumi 10^{33}-$10^{34}$$cm^{-2}s^{-1}$

215m: $0.02 < \xi < 0.2$

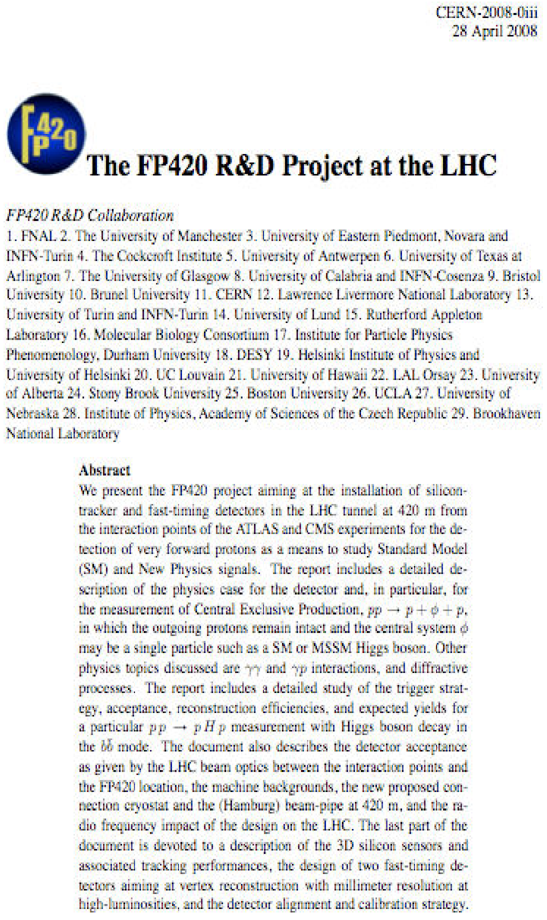
300/400m: $0.002 < \xi < 0.02$

Detectors in the cold region are needed to access the low ξ values

FP420 R&D Study

FP420

- **History on the FP420detector studies**
  - **Start at Manchester Dec 2003, formation of FP420 collaboration in 2004**
  - **Expression of interest to the LHCC in 2005**
  - **R&D physics and detector report submitted Spring 2008**
  - **Discussion within the collaborations ongoing in ATLAS and CMS**



CERN-2008-0iii
28 April 2008

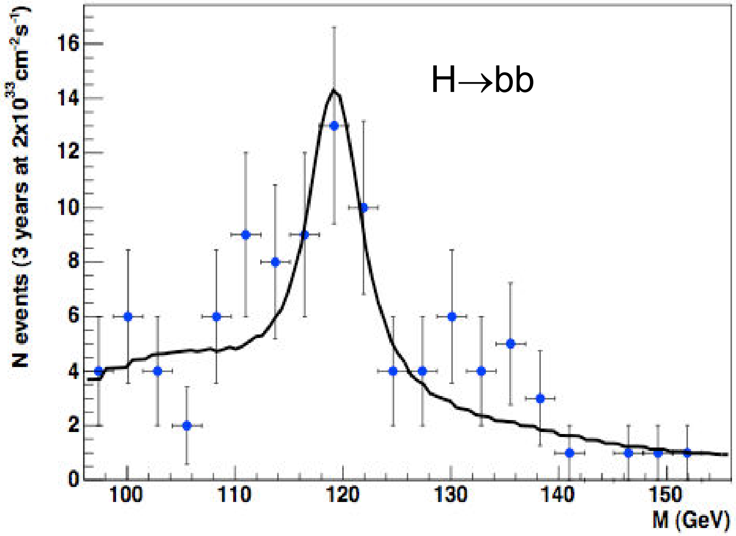
The FP420 R&D Project at the LHC

FP420 R&D Collaboration
1. FNAL 2. The University of Manchester 3. University of Eastern Piedmont, Novara and INFN-Turin 4. The Cockcroft Institute 5. University of Antwerpen 6. University of Texas at Arlington 7. The University of Glasgow 8. University of Calabria and INFN-Cosenza 9. Bristol University 10. Brunel University 11. CERN 12. Lawrence Livermore National Laboratory 13. University of Turin and INFN-Turin 14. University of Lund 15. Rutherford Appleton Laboratory 16. Molecular Biology Consortium 17. Institute for Particle Physics Phenomenology, Durham University 18. DESY 19. Helsinki Institute of Physics and University of Helsinki 20. UC Louvain 21. University of Hawaii 22. LAL Orsay 23. University of Alberta 24. Stony Brook University 25. Boston University 26. UCLA 27. University of Nebraska 28. Institute of Physics, Academy of Sciences of the Czech Republic 29. Brookhaven National Laboratory

Abstract

We present the FP420 project aiming at the installation of silicon-tracker and fast-timing detectors in the LHC tunnel at 420 m from the interaction points of the ATLAS and CMS experiments for the detection of very forward protons as a means to study Standard Model (SM) and New Physics signals. The report includes a detailed description of the physics case for the detector and, in particular, for the measurement of Central Exclusive Production, $pp \to p + \phi + p$, in which the outgoing protons remain intact and the central system ϕ may be a single particle such as a SM or MSSM Higgs boson. Other physics topics discussed are $\gamma\gamma$ and γp interactions, and diffractive processes. The report includes a detailed study of the trigger strategy, acceptance, reconstruction efficiencies, and expected yields for a particular $p\,p \to p\,H\,p$ measurement with Higgs boson decay in the $b\bar{b}$ mode. The document also describes the detector acceptance as given by the LHC beam optics between the interaction points and the FP420 location, the machine backgrounds, the new proposed connection cryostat and the (Hamburg) beam-pipe at 420 m, and the radio frequency impact of the design on the LHC. The last part of the document is devoted to a description of the 3D silicon sensors and associated tracking performances, the design of two fast-timing detectors aiming at vertex reconstruction with millimeter resolution at high-luminosities, and the detector alignment and calibration strategy.

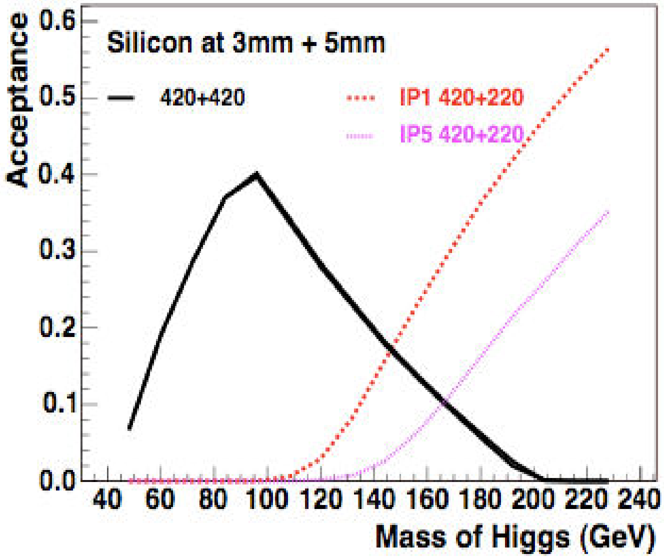
FP420/220-240 Physics



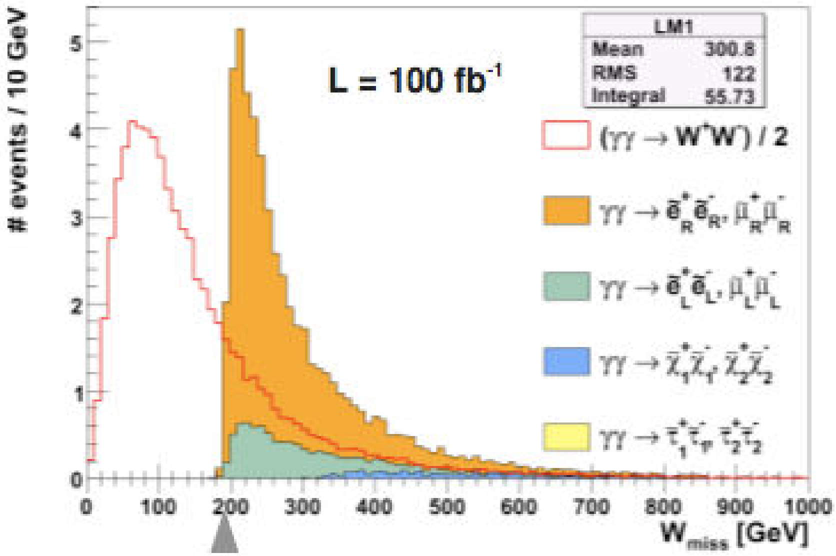
Light Higgs

M_h^{max} MSSM scenario: H→bb

(m_A=120 GeV, tanβ = 40, 60 fb^{-1}) σ= 20 fb

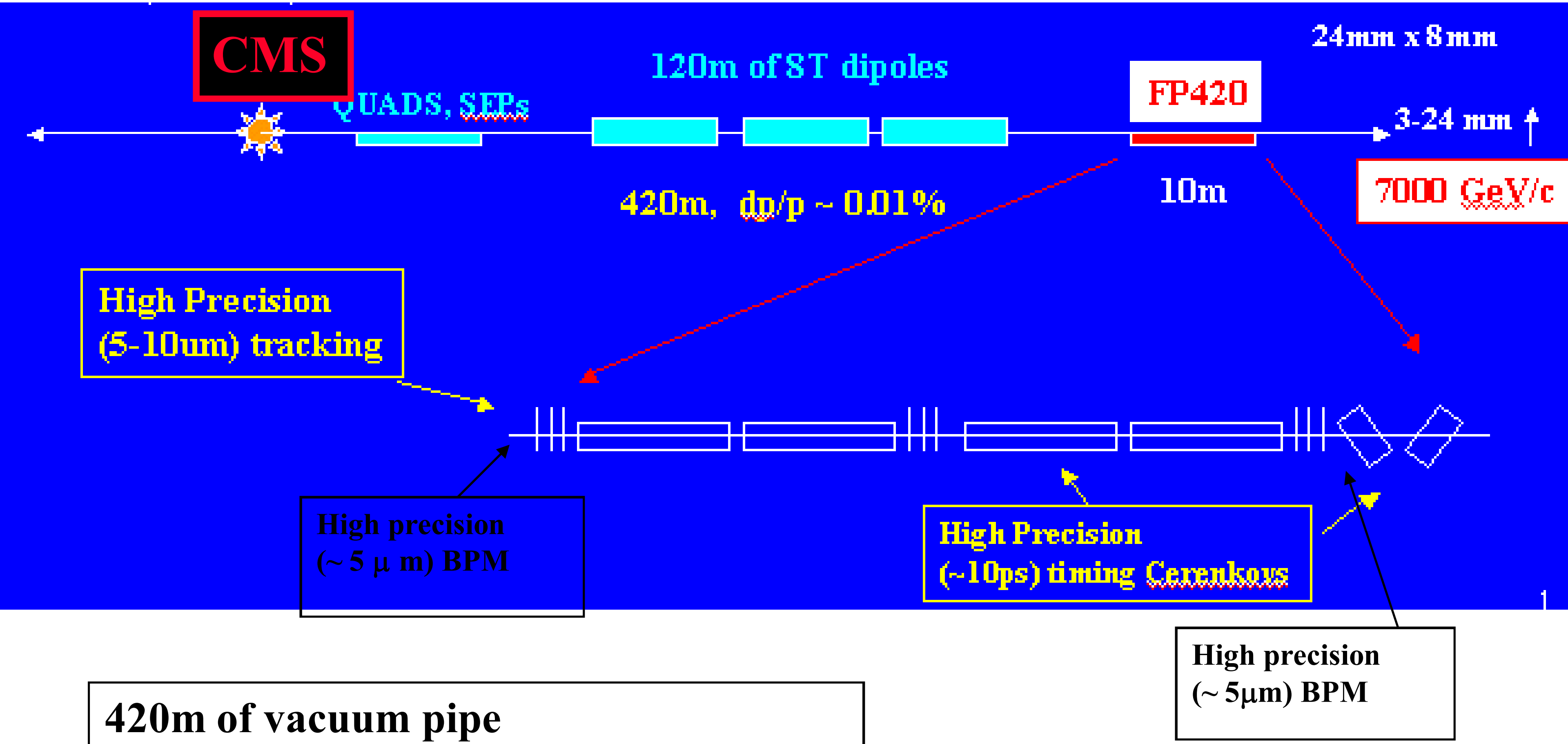


Low mass SUSY



Diffraction,…

Schematic of Extremely High Precision Proton Spectrometer



CMS

QUADS, SEPs

120m of 8T dipoles

FP420

24mm x 8mm

3-24 mm

420m, dp/p ~ 0.01%

10m

7000 GeV/c

High Precision
(5-10um) tracking

High precision
(~ 5 μ m) BPM

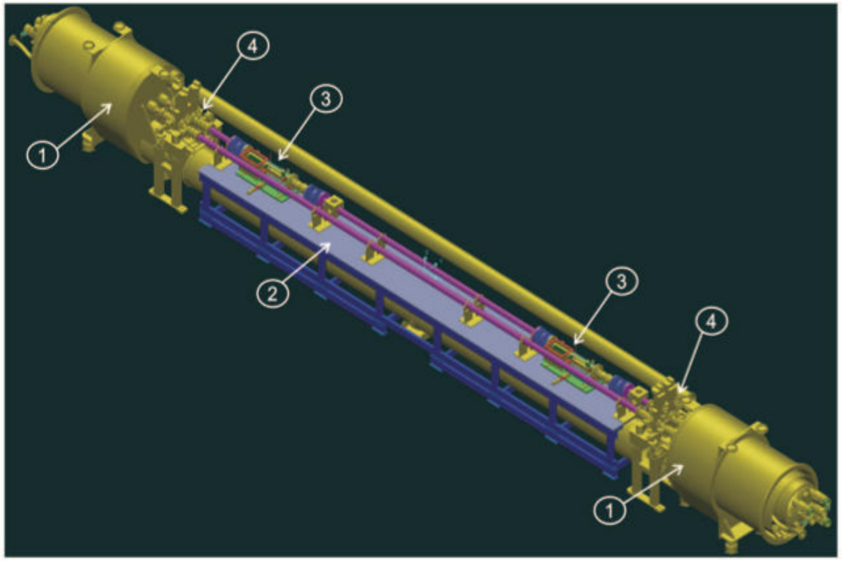
High Precision
(~10ps) timing Cerenkovs

High precision
(~ 5μm) BPM

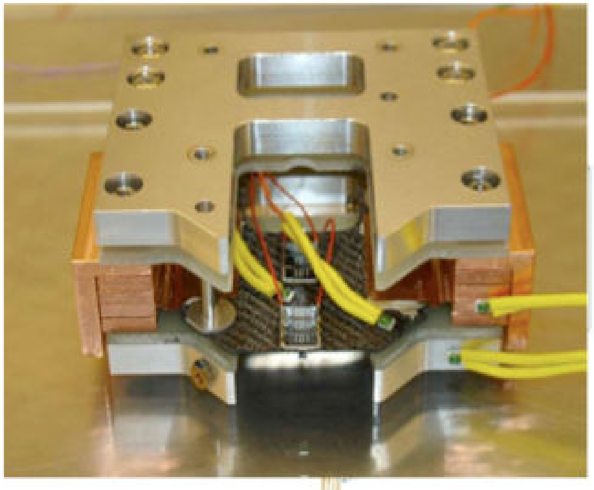
420m of vacuum pipe
120m of 8T dipoles
Precision ~ 5 μ m on track displacement
and ~ 1 μ rad on angle w.r.t. beam.

Layout schematic ...
Still being optimized

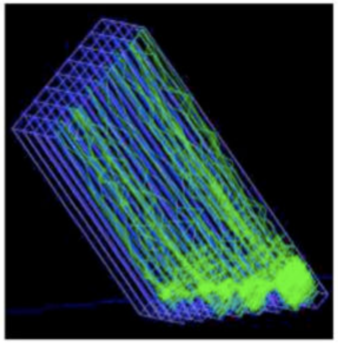
FP420 Detectors



Two stations per position/arm
Each station contains
-Tracking
Eg. 3D Silicon but other technologies feasible
-Fast timing detectors ~ 10 ps
Quartic and GASTOF
Silica-aerogel?



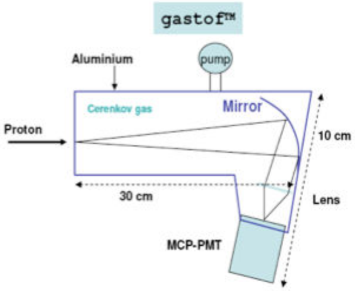
Quartic (FNAL, Alberta, UTA)



More than 50% of the photons arrive within the first 5 ps.

Burle 85011-501 with 25 μm pores

GASTOF (Louvain)



all the photons arrive within ≈ 3 ps

Hamamatsu R3809U-50 with 6 μm pores

Test beams 2008/9 $\Rightarrow$10 psec basically achieved

FP420 ⇔ATLAS/CMS

- FP420 (B. Cox, A. De Roeck) ⇒ now discussed in the ATLAS and CMS collaborations
- ATLAS: FP420+RP220 use the same type of stations (AFP: S. Watts, C. Royon)
  - Interested groups: Alberta, Arlington, CEA Saclay Cockroft Institute, Giessen, Glasgow, Cracow, Prague, Manchester, Stony Brook, UC-London
- CMS: FP at 420 + 220m (K. Piotrzkowski, A De Roeck)
  - Interested groups: Antwerp, BU-Boston, FNAL, Helsinki, Iowa, ITEP, LLNL, UCL-Louvain, Protvino, Rio, Rockefeller, Torino/Novara
- Are such stations of use for other experiments?

Synergy

- ATLAS/CMS: common R&D, interaction with the machine, simulation studies, trigger studies,…
- TOTEM/ALFA/other near beam detectors?
  - operational experience with near beam detectors, backgrounds & calibration
  - Further detector R&D? (timing, tracker…)
  - Central detector + Forward detector studies
  - Use of the 220/240 m region of the machine
- Early event + gap studies (gap survival and other model parameters)
- Tevatron: the first tests of the exclusive models

Proton Detection at IR3

How to extend diffractive proton accpetance down to $|\Delta p/p| \cong 10^{-3}$?

Hubert Niewiadomski
Penn State Univeristy / TOTEM / CERN

EDS'09

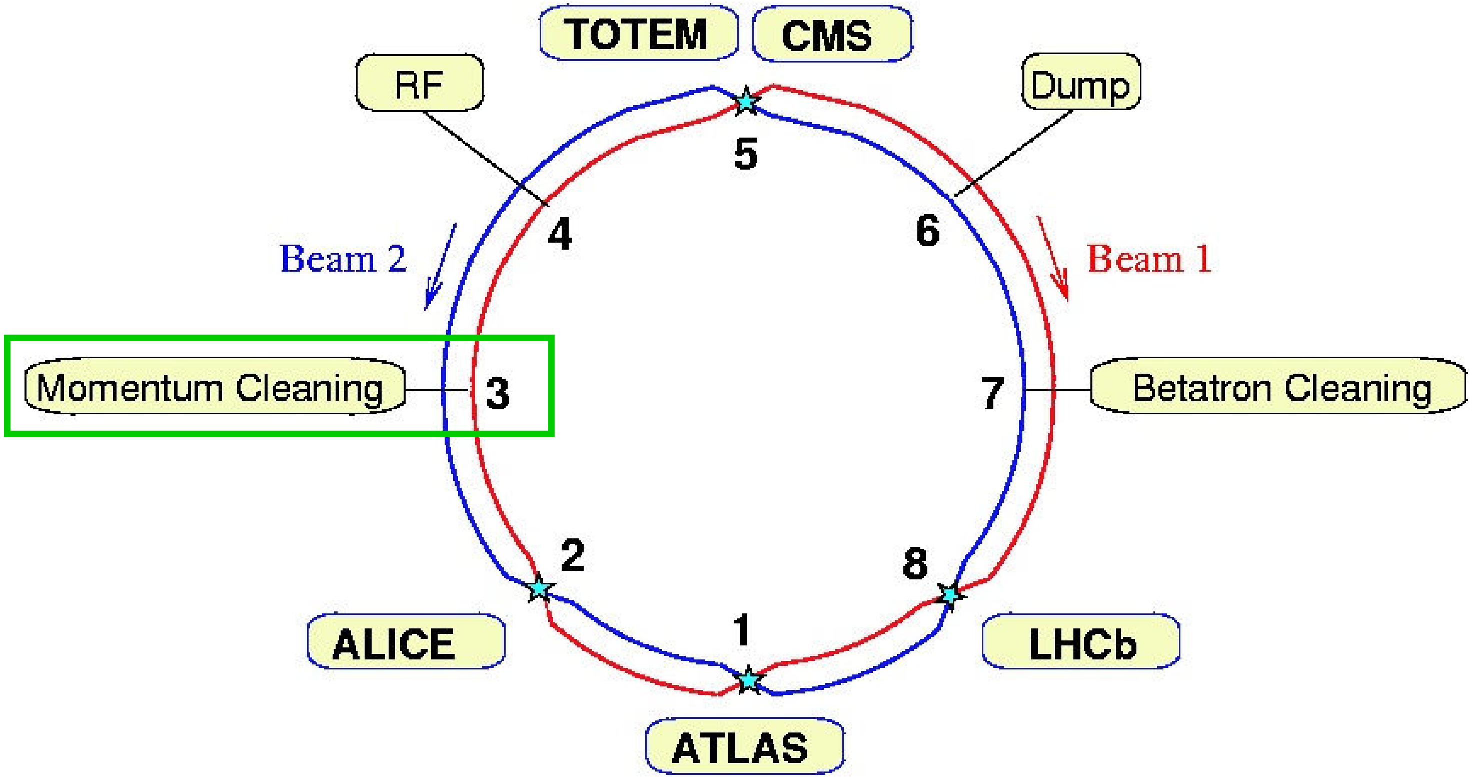
CERN, 30 June 2009

Proton detection at lower |ξ| values

Good acceptance and momentum resolution for diffractive protons needs:

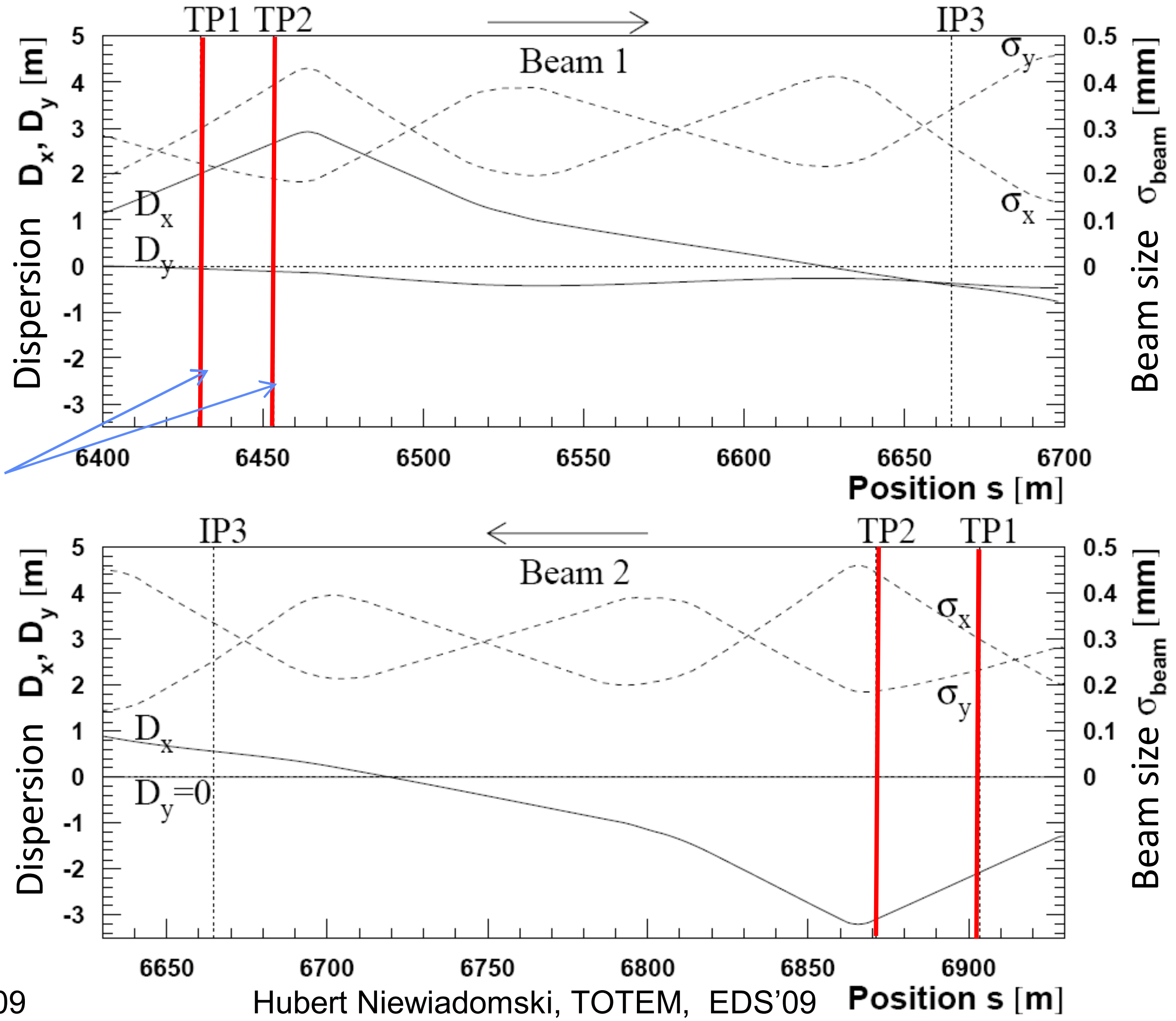
- **Large dispersion D, a few meters, $\Delta x \cong \xi \cdot D$**
- **Small beam size, beam cannot be aproached closer than ~10σ**

Where in the LHC are these requirements best fulfilled?



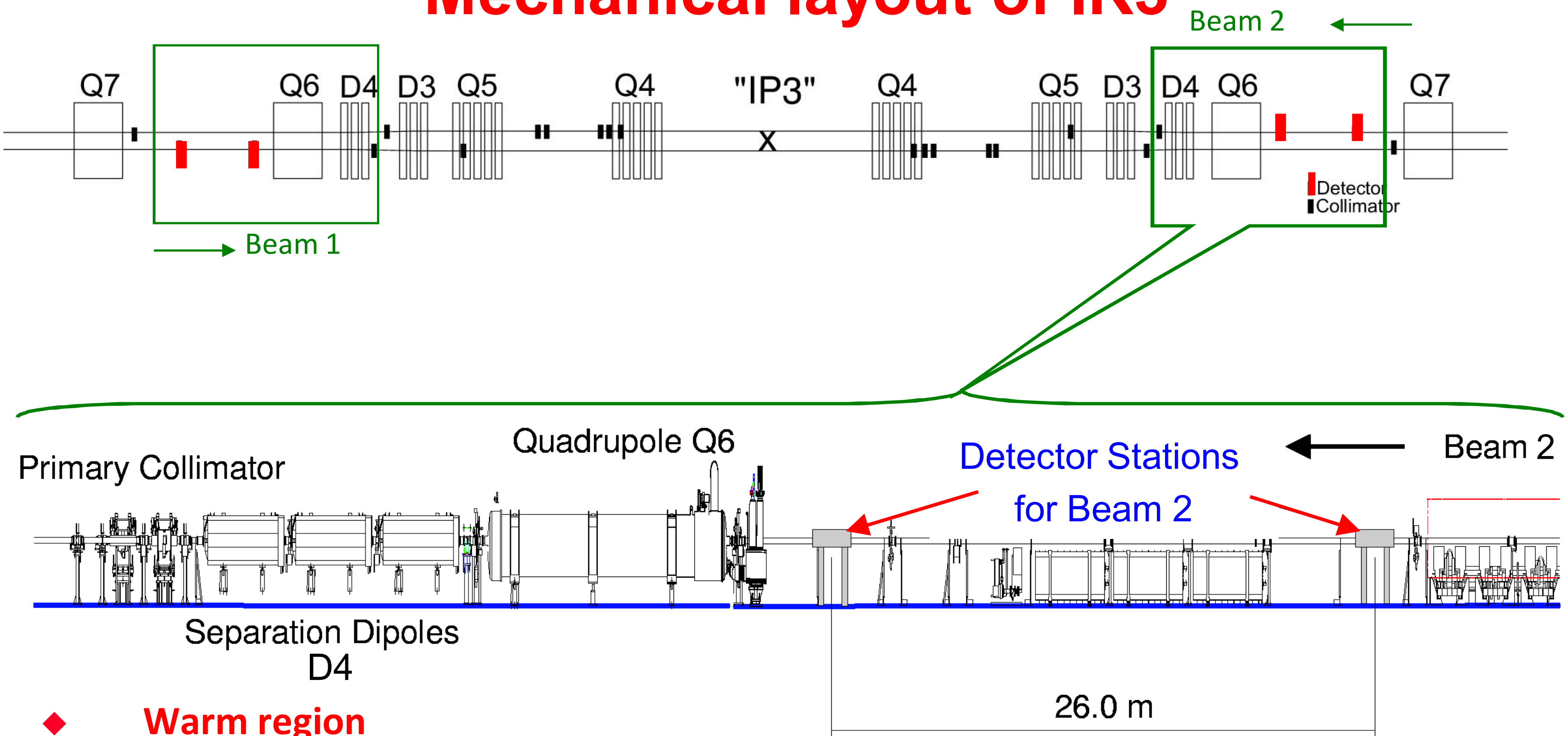
Hubert Niewiadomski, TOTEM, EDS'09

The IR3 optics ($\Delta x \cong \Delta p/p \bullet D$)



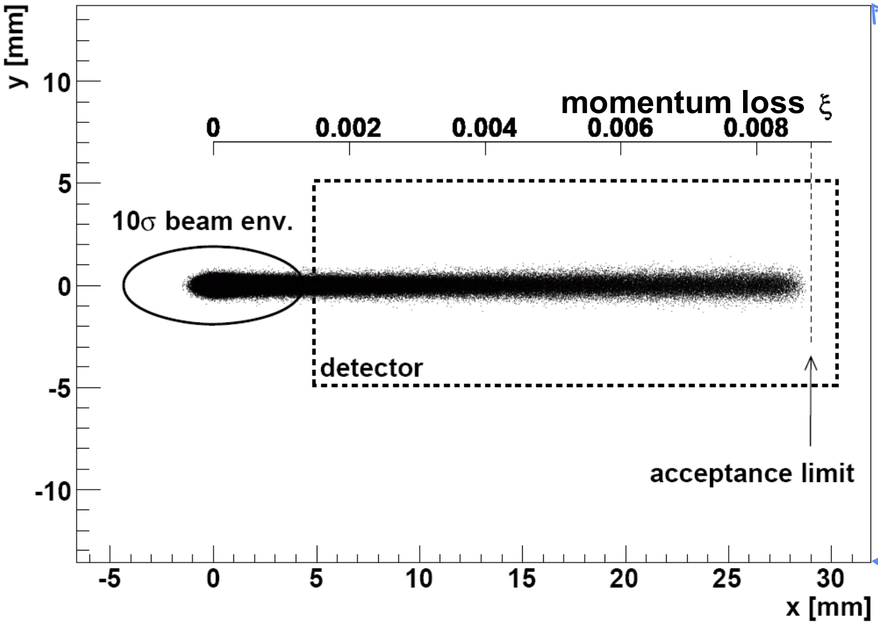
Proposed detector locations

Mechanical layout of IR3

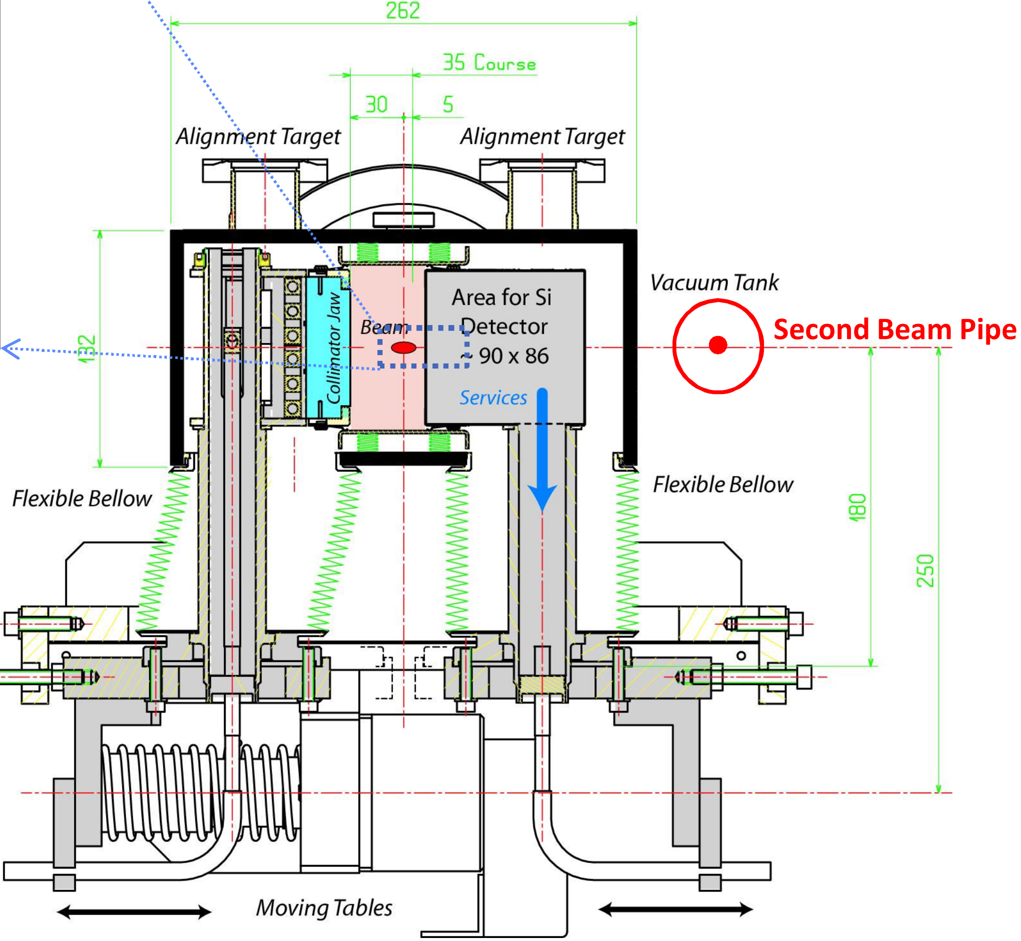


- **Warm region**
- **Detect diffractive protons from all interaction points**
- **Advantage for machine protection:**
  - **collimator downstream of detectors absorbs possible showers**
- **Diffractive proton rate of ~3 MHz @ L=10^{34} hits Q6 magnet (~5MHz quench limit)**
  - **some additional colimator may be needed**

Technical solution: combined collimator + detector

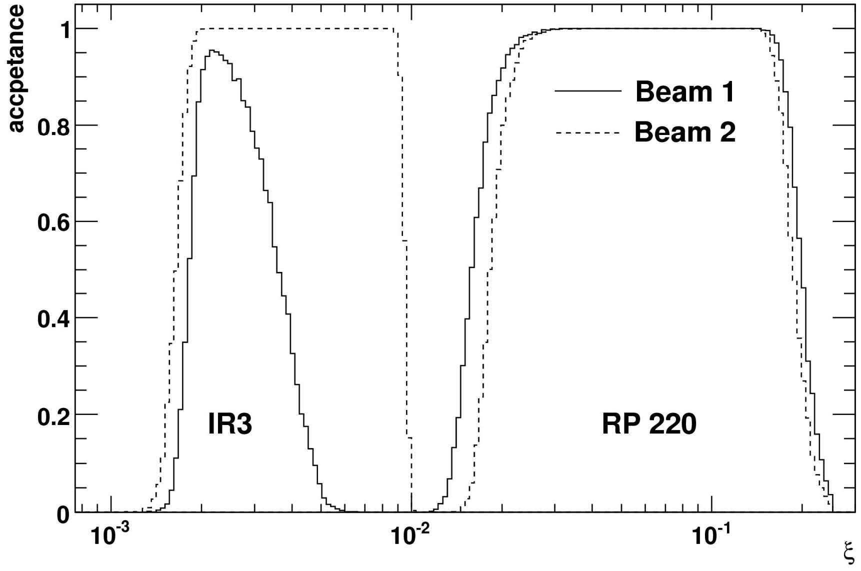


IP 3 hit distribution in a plane transverse to Beam 2 for DPE events @ IP5

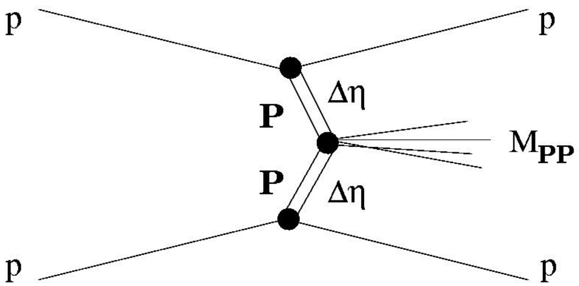


Proton acceptance of combined IR3 and RP220 insertions

ξ-Acceptance, β^*=0.5 m, p=7 TeV

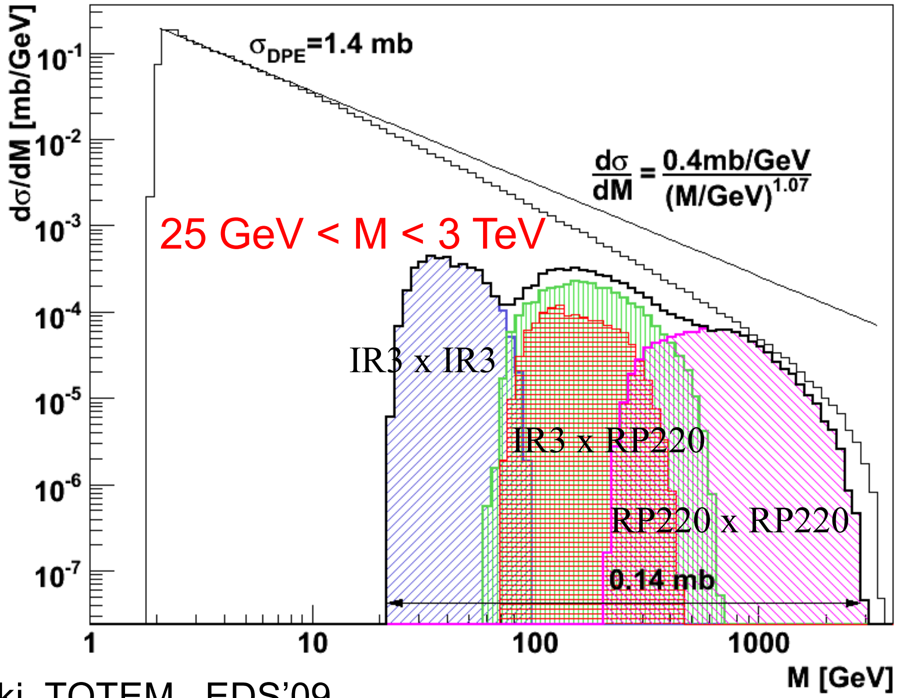


Double Pomeron Exchange



$$M_{PP}^2 = \xi_1 \xi_2 s$$

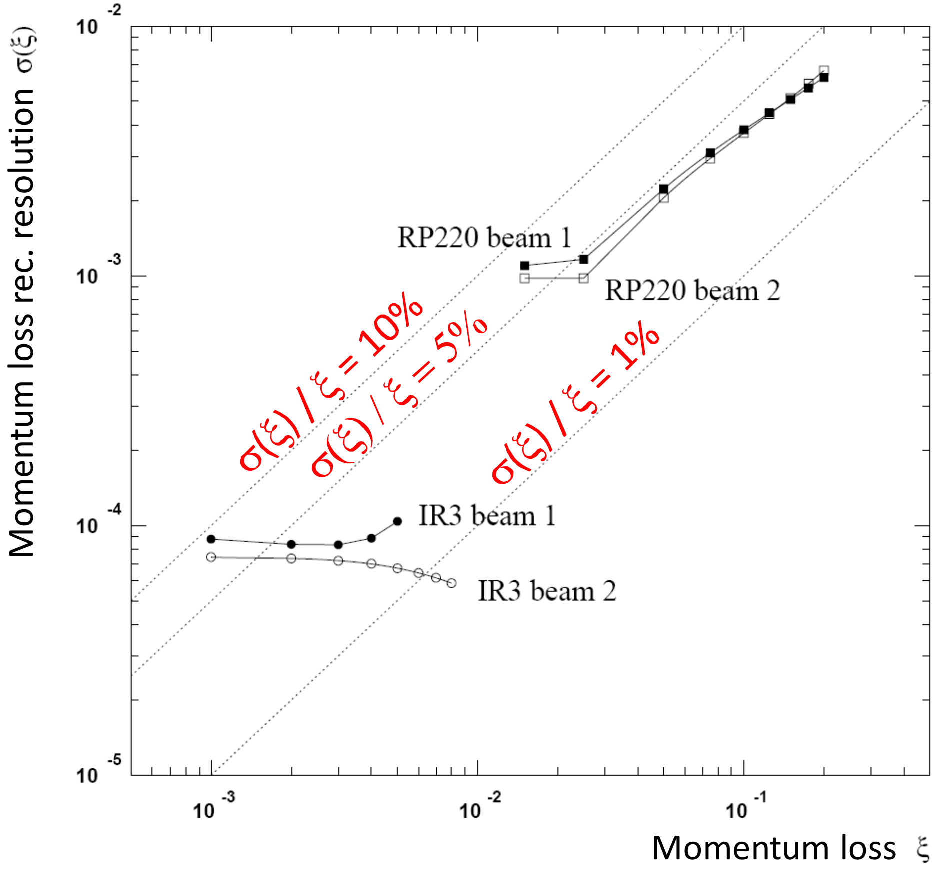
DPE Mass Spectrum with Detector Acceptance



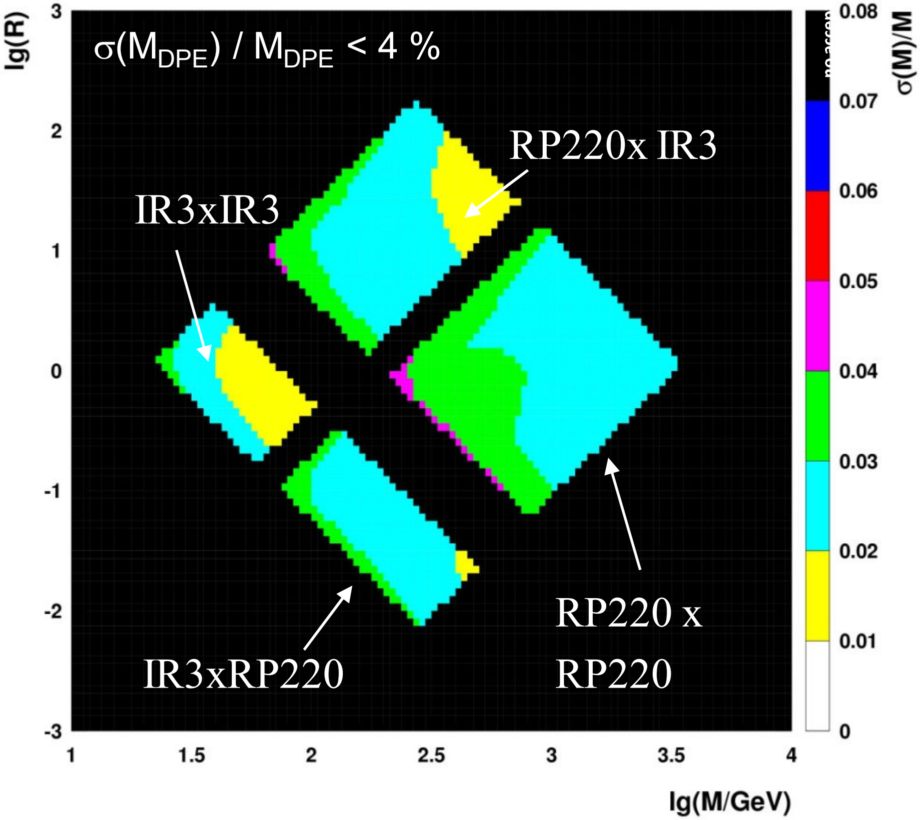
25 GeV < M < 3 TeV

Momentum / mass resolution of combined IR3 /RP220 insertions

Momentum loss resolution



Relative mass resolution

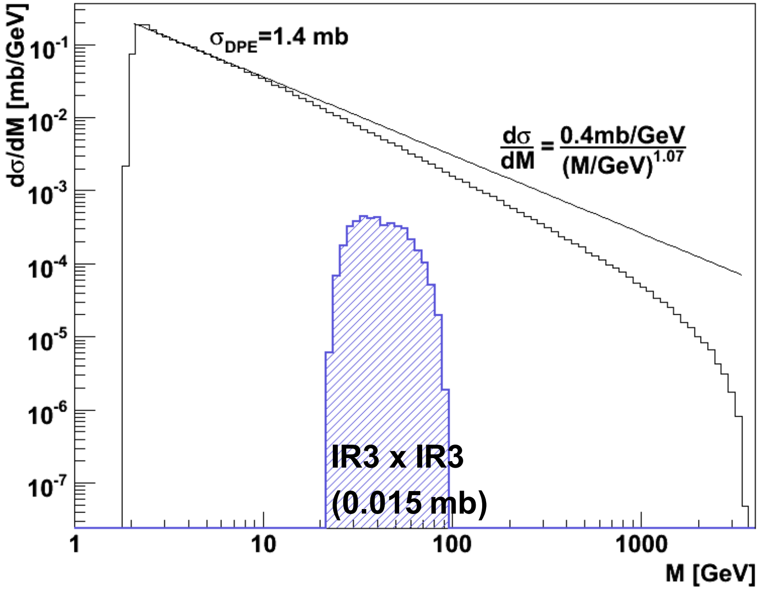


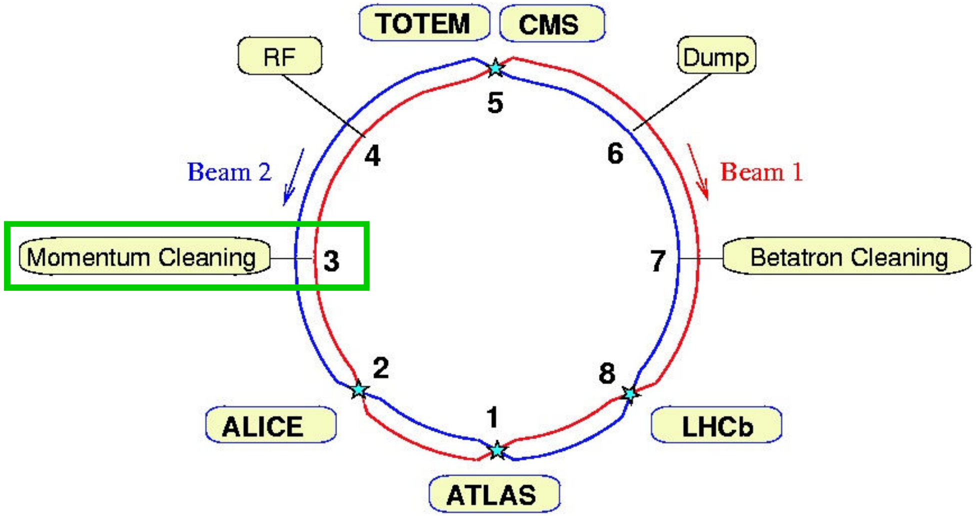
$R = \xi_1/\xi_2$

$R = 1$: symmetric event

Luminosity calibration for all LHC experiments

◆ After absolute σ_{tot} & $\mathcal{L}$ measurements with TOTEM
Use low-mass DPE with both protons detected in IR3 as a “standard candle”





Identify interaction point by time difference between the 2 protons:

Interaction point	**IP5 CMS**	**IP8 LHCb**	**IP1 ATLAS**	**IP2 ALICE**
Δt (beam 2 – beam 1)	**– 44 μs**	**+22 μs**	**+ 44 μs**	**+ 66 μs**

EDS 2009, 39 June 2009, CERN --Discussion panel

"What can we learn/expect from the LHC experiments?“ K. Goulianos

- ☐ goal…….......understand the QCD basis of diffraction & discover new physics
- ☐ TEV2LHC…confirm, extend, discover…
- ☐ Tools……….larger √s → larger σ, Δη & E_T

TODO:

- ➢ Elastic, diffractive, and total cross sections
  - ➢ Important to study partial cross section components\
    - ➔ need topology (multiplicity, E_T, …)
- ➢ Hard diffraction
  - ➢ diffrative structure function ➔dijets vs. W
  - ➢ Multigap configurations
  - ➢ Jet-gap-jet ➔ dσ/dΔη vs. E_T^{jet}➔ BFKL, Muller-Navalet

p-p Interactions

<u>Non-diffractive:</u>

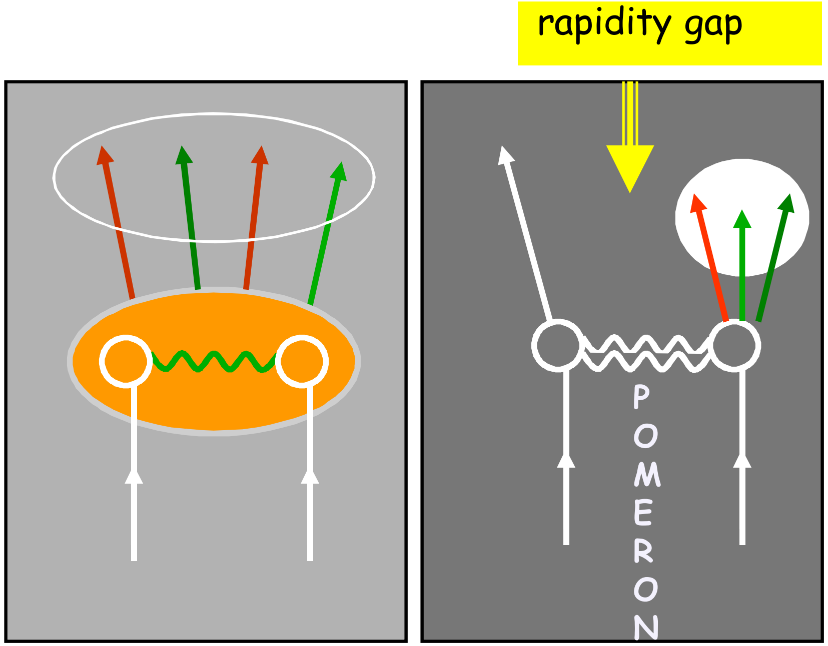
Color-exchange

<u>Diffractive:</u>

Colorless exchange with vacuum quantum numbers

Incident hadrons acquire color and break apart

CONFINEMENT

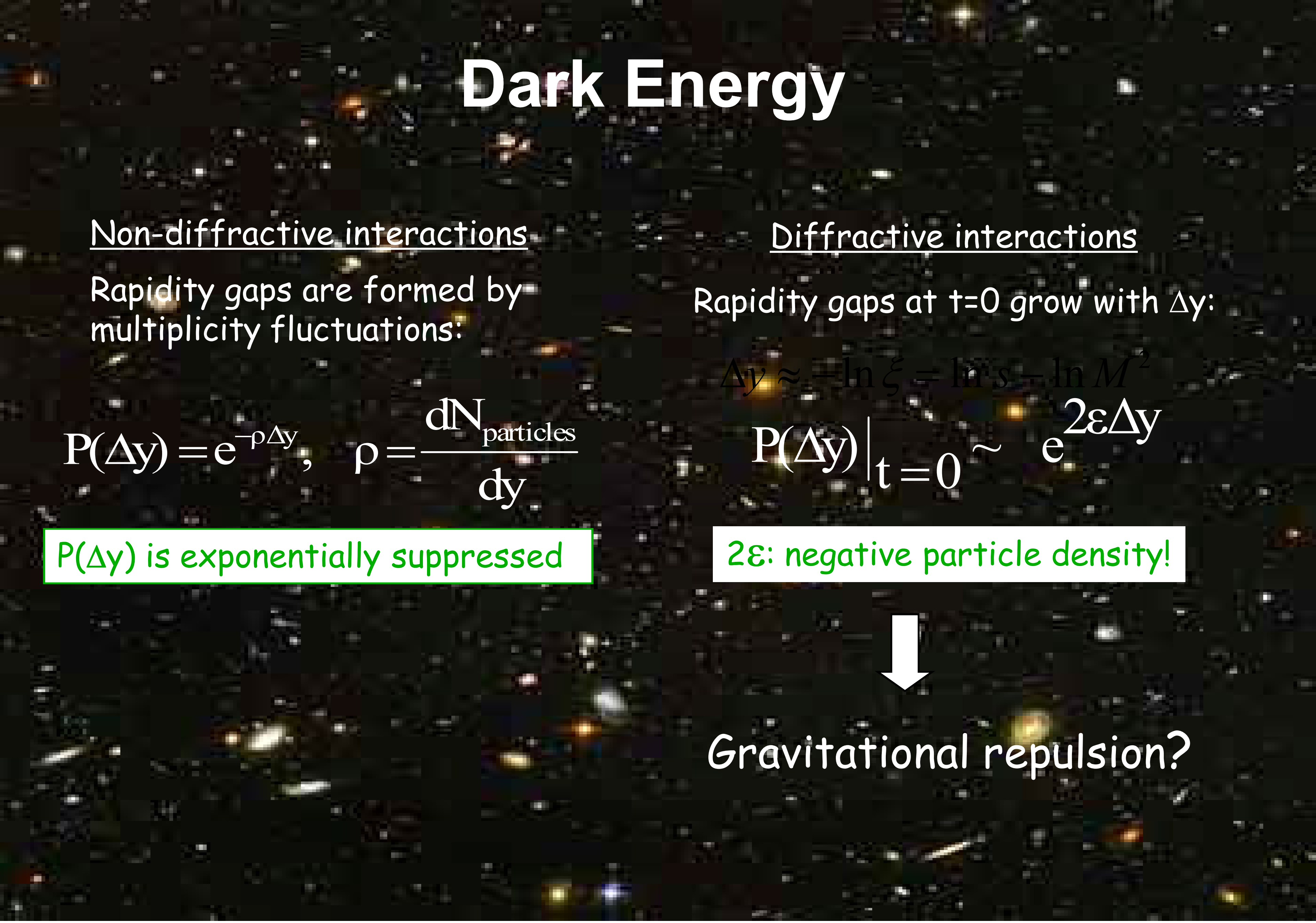


Incident hadrons retain their quantum numbers remaining colorless

pseudo-DECONFINEMENT

<u>Goal</u>: understand the QCD nature of the diffractive exchange

Rapidity Gaps in Fireworks



Dark Energy

Non-diffractive interactions

Rapidity gaps are formed by multiplicity fluctuations:

$$P(\Delta y) = e^{-\rho\Delta y}, \quad \rho = \frac{dN_{particles}}{dy}$$

P(Δy) is exponentially suppressed

Diffractive interactions

Rapidity gaps at t=0 grow with Δy:

$$\Delta y \approx -\ln\xi = \ln s - \ln M^2$$

$$P(\Delta y)\Big|_{t=0} \sim e^{2\varepsilon\Delta y}$$

2ε: negative particle density!

⬇

Gravitational repulsion?

Going beyond inclusive x-sections

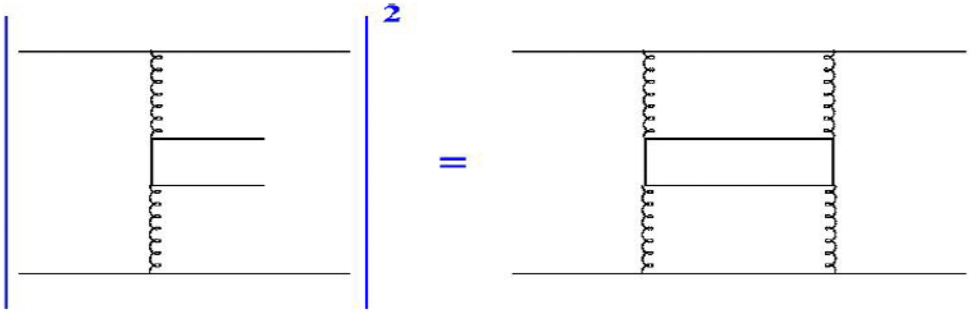
connect total x-section/diffraction with

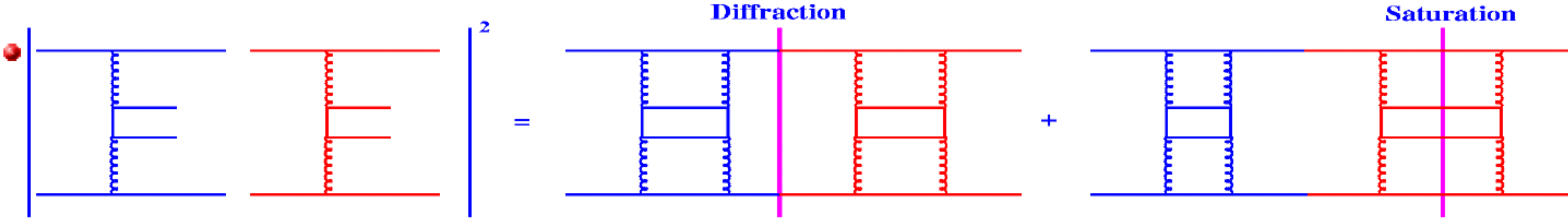
- multi-parton interaction
- saturation

Hannes Jung

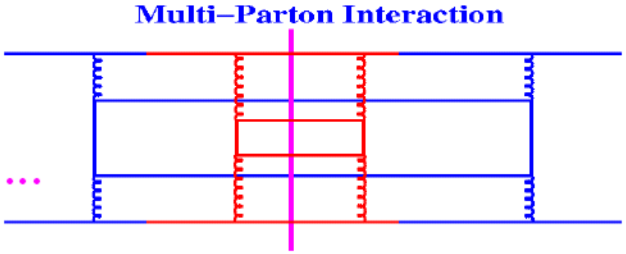
Toy Model ...

- where is relation of diffraction - multiple scatterings - saturation coming from ?
- single parton exchange:





✗ **BUT......** this is not yet really numerically understood ...



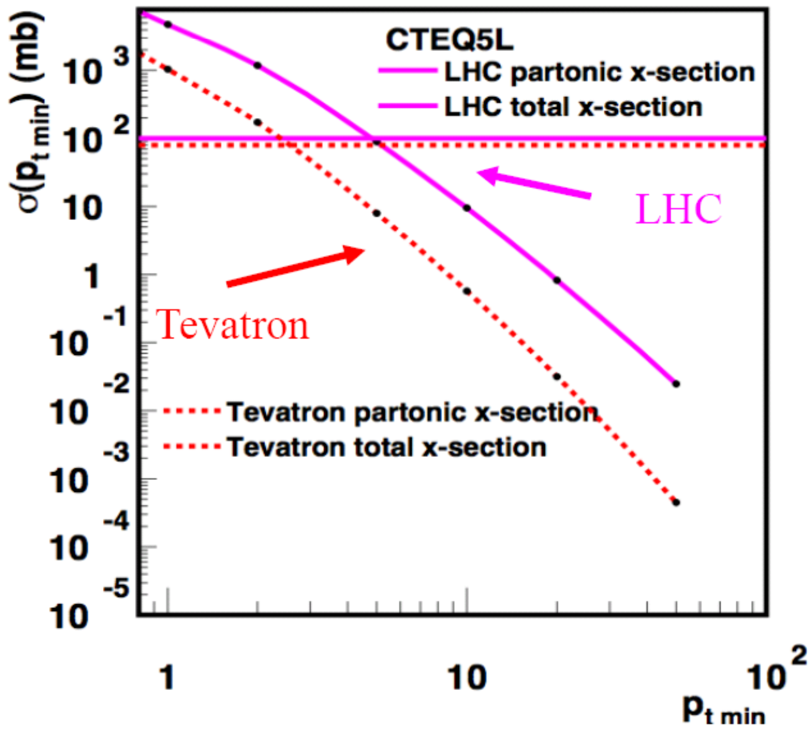
Underlying event – Multiple Interaction

- Basic partonic perturbative cross section

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

➔ diverges faster than $1/p^2_{\perp\mathrm{min}}$ as $p_{\perp\mathrm{min}} \to 0$ and exceeds eventually total inelastic (non-diffractive) cross section

- Interaction x-section exceeds total xsection
- happens well above λ_{QCD}
- in perturbative region



Underlying event – Multiple Interaction

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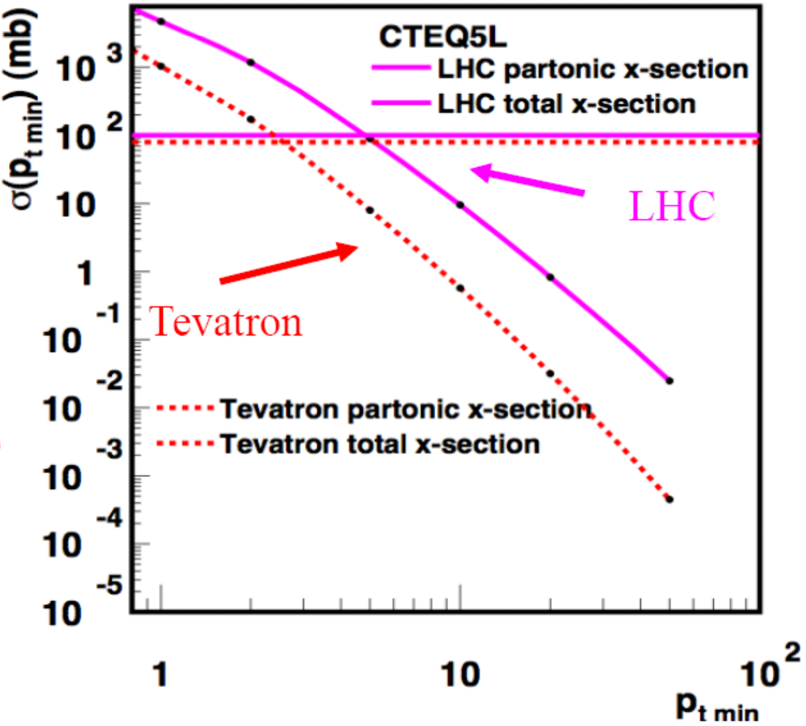
➔ diverges faster than $1/p^2_{\perp\text{min}}$ as $p_{\perp\text{min}} \to 0$ and exceeds eventually total inelastic (non-diffractive) cross section

- Average number of interactions per event is given by:

$$\langle n \rangle = \frac{\sigma_{\text{hard}}(p_{\perp\text{min}})}{\sigma_{nd}}$$

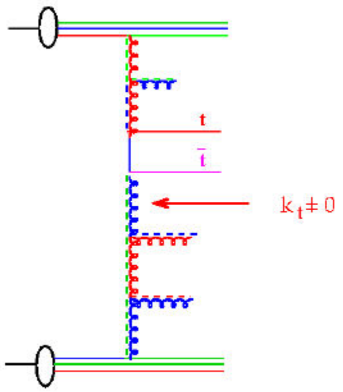
- It depends on how soft interactions are treated, ***BUT*** also on the parton densities and factorization scheme, parton evolution

(DGLAP/BFKL) !!!!!!!!!

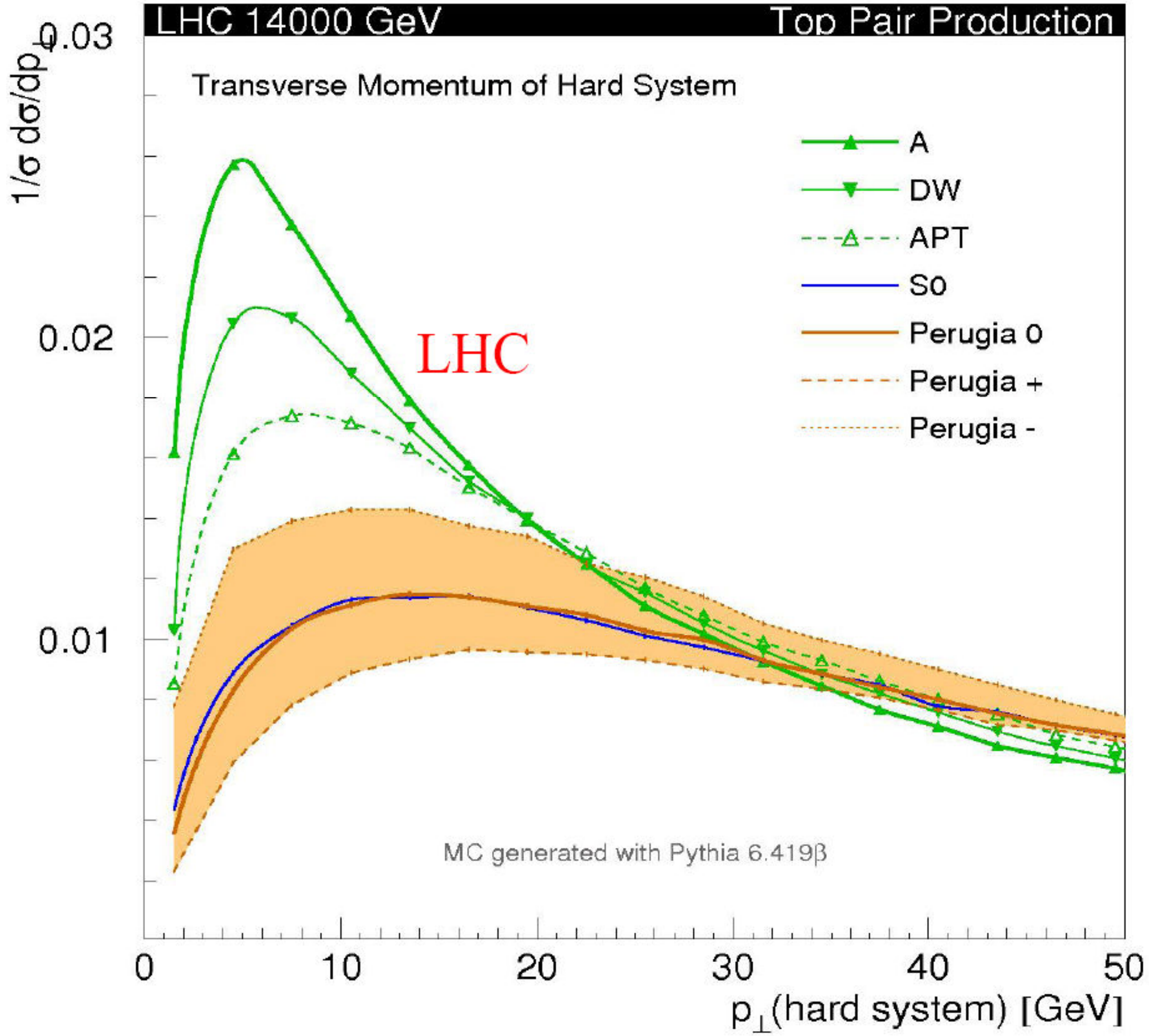


ttbar is affected ...

- P_t of $t\bar{t}$ is affected by parton shower BUT also by the underlying events ....



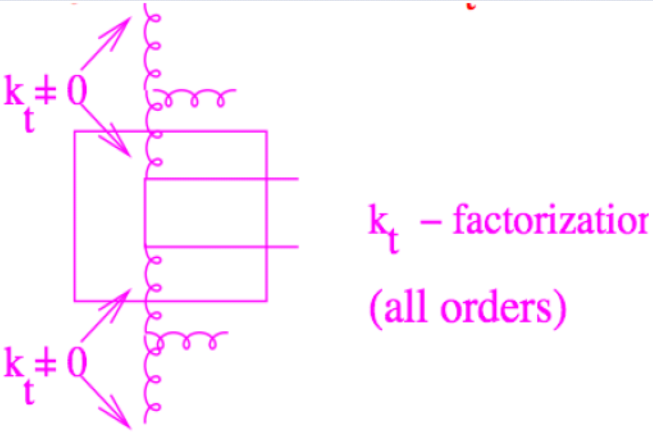
- note: pt of the pair is plotted !!!
- **HUGE effects**

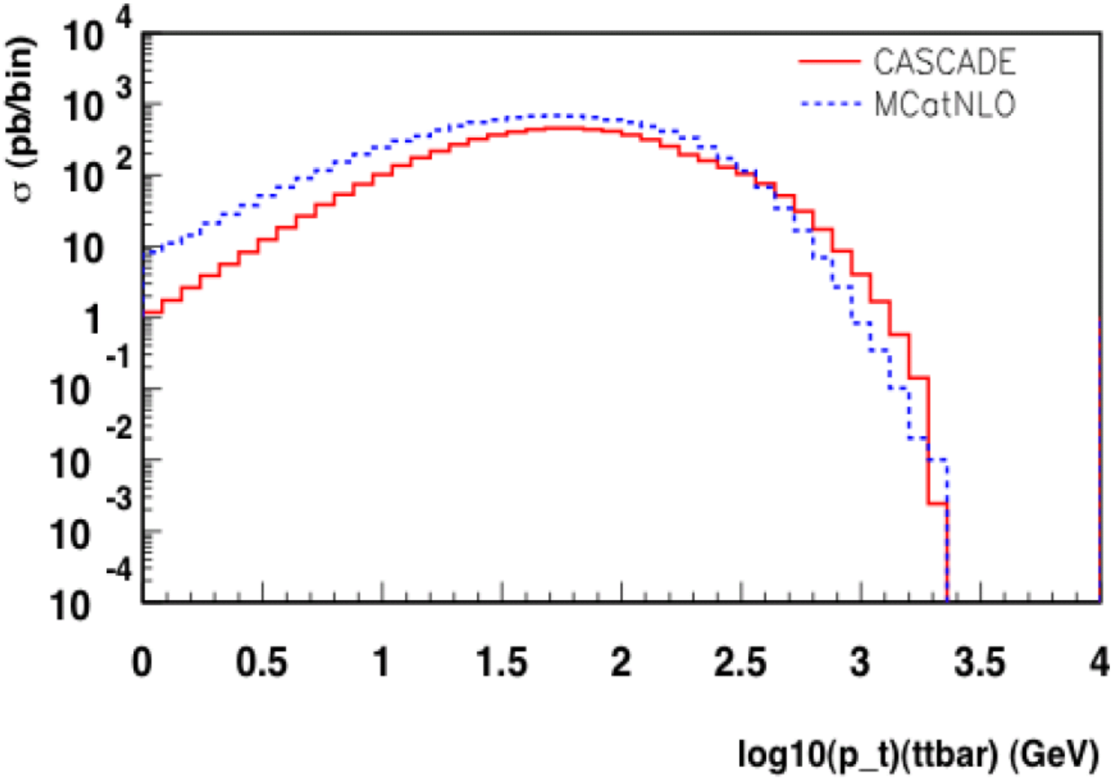


P. Skands, MPI@LHC, Perugia 2008

But … also from uPDFs

- compare CASCADE with MC@NLO for ttbar production at LHC

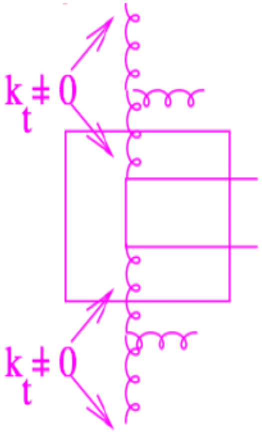




➔ small pt region of pair is coming from uPDF
  ➔ Sudakov suppression
  ➔ saturation

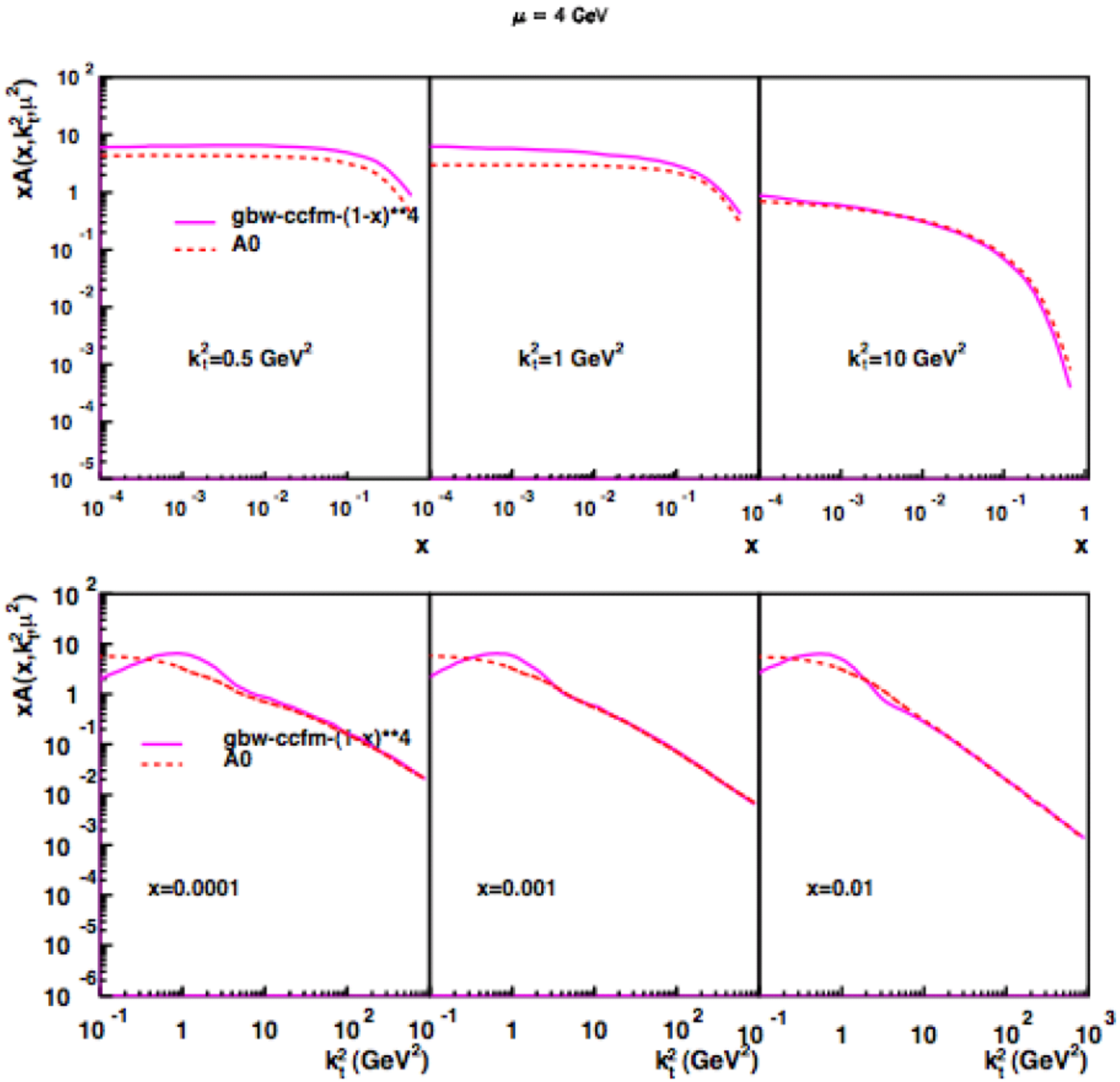
➔ Howto disentangle both ?

uPDFs - saturation



k_t – factorizatior

(all orders)



Saturation happens at

- small x
- small kt

➔ measure x-section as function of x and kt or delta phi

Multiple Interactions and saturation

- Multiple Interactions depend directly on parton densities at small scales and small x
  - ➔ influence of saturation in parton densities
- need to separate different regions:
  - ➔ measurement of correlations in central region: pt of pairs, delta phi, etc
- measure minijet cross sections
  - ➔ jet cross sections, jet - multiplicities, angular correlations
  - ➔ correlations of central with forward jets

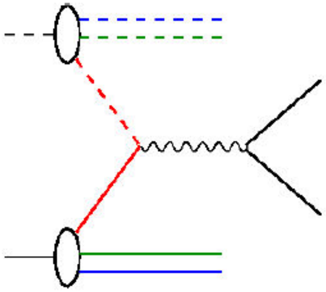
Lessons from HERA

- inclusive cross sections are "relatively easy" to measure and to calculate
- the challenge is in the details of the final state:
  - still no satisfactory description of
    - forward jets, multi-jets, mini-jets etc

- important to understand within the same measurement and calculation:
  - total xsection
  - diffractive xsection
  - multi-jet xsection at small and medium x
  - minijet xsectons at small pt ~5 - 20 GeV

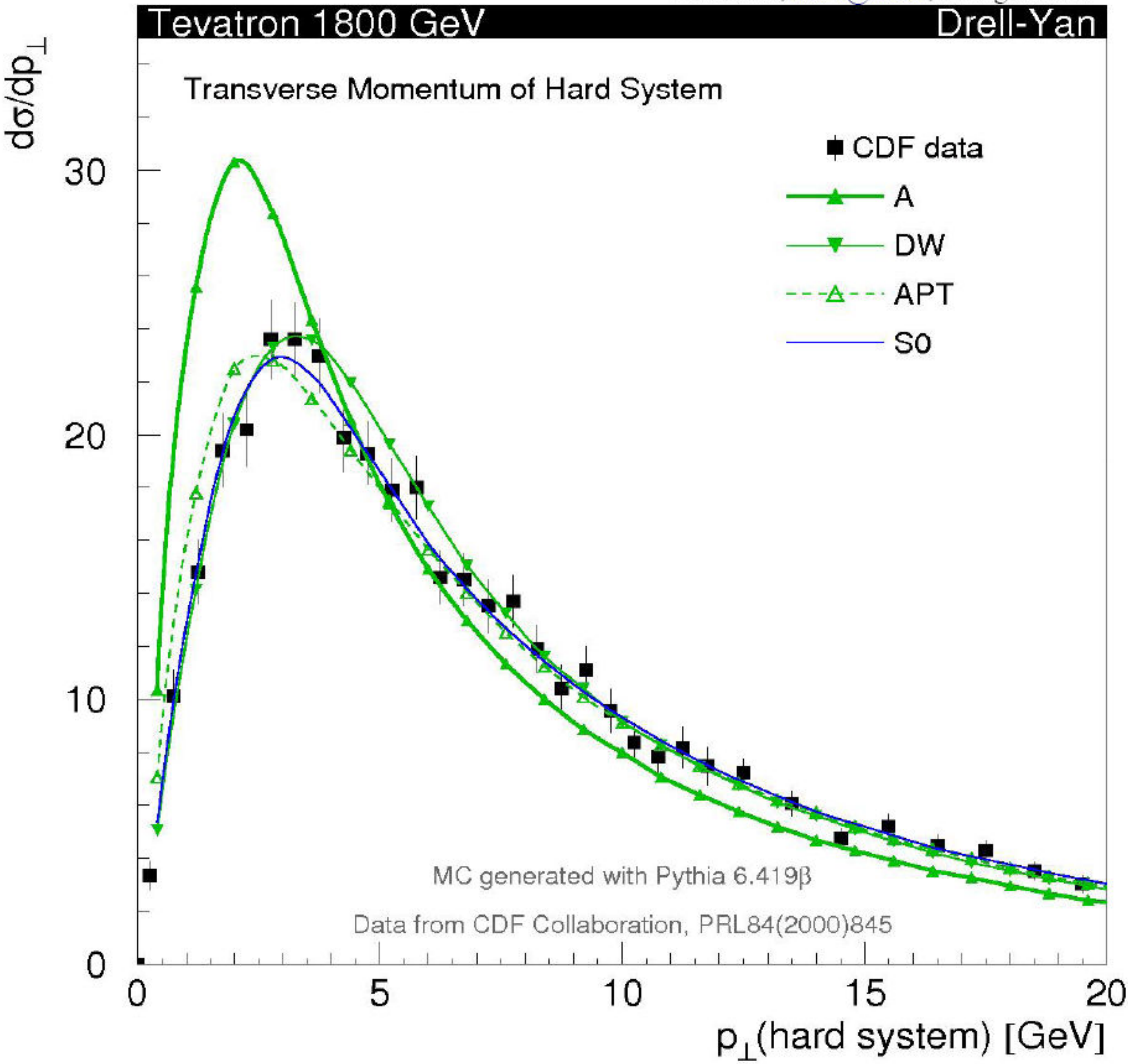
Backup Slides

Drell Yan process is affected ...



- P_t of Drell Yan is affected by parton shower BUT also by the underlying events ....
- significant effects
- how to tune the truth ?

P. Skands, MPI@LHC, Perugia 2008



Double-Parton Interactions at LHC

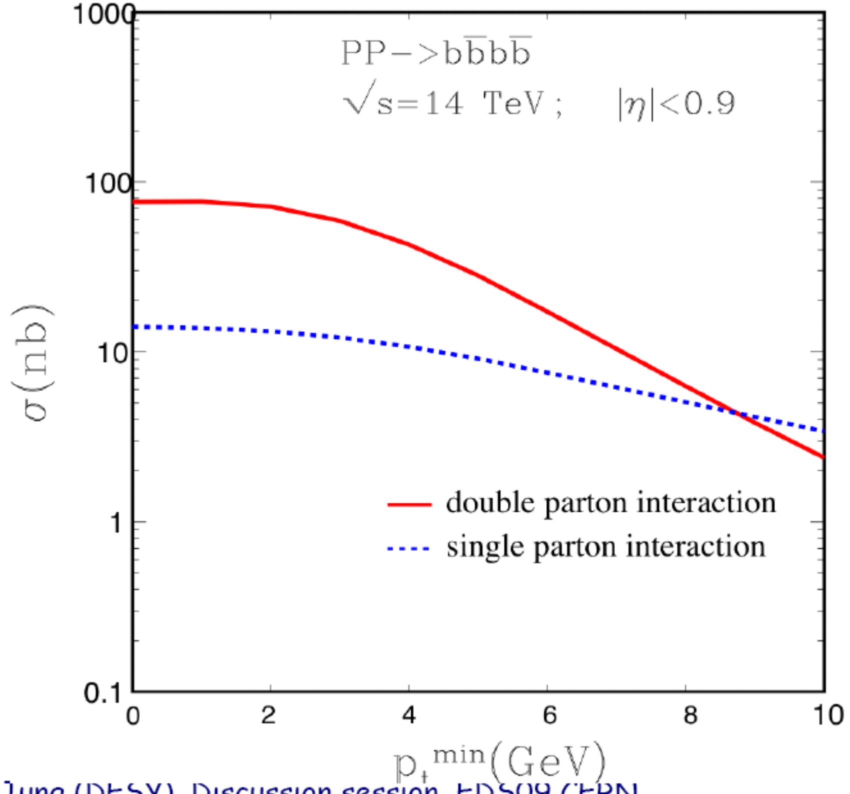
- xsection for $p + p \rightarrow b\bar{b}b\bar{b}$

single parton exchange (SP)

$$\sigma^{SP} \sim f^2 \hat{\sigma}(2 \rightarrow 4)$$

double parton exchange (DP)

$$\sigma^{DP} \sim f^4 \hat{\sigma}^2(2 \rightarrow 2)$$



- PYTHIA predictions:

$$\sigma^{DP} = 0.8 \cdots 11.1 \ \ \mu b$$

➔ Depending on model for underlying event/multi-parton interactions...

Multi-Parton Interactions at LHC

- Higgs: $p+p \to W+H+X$

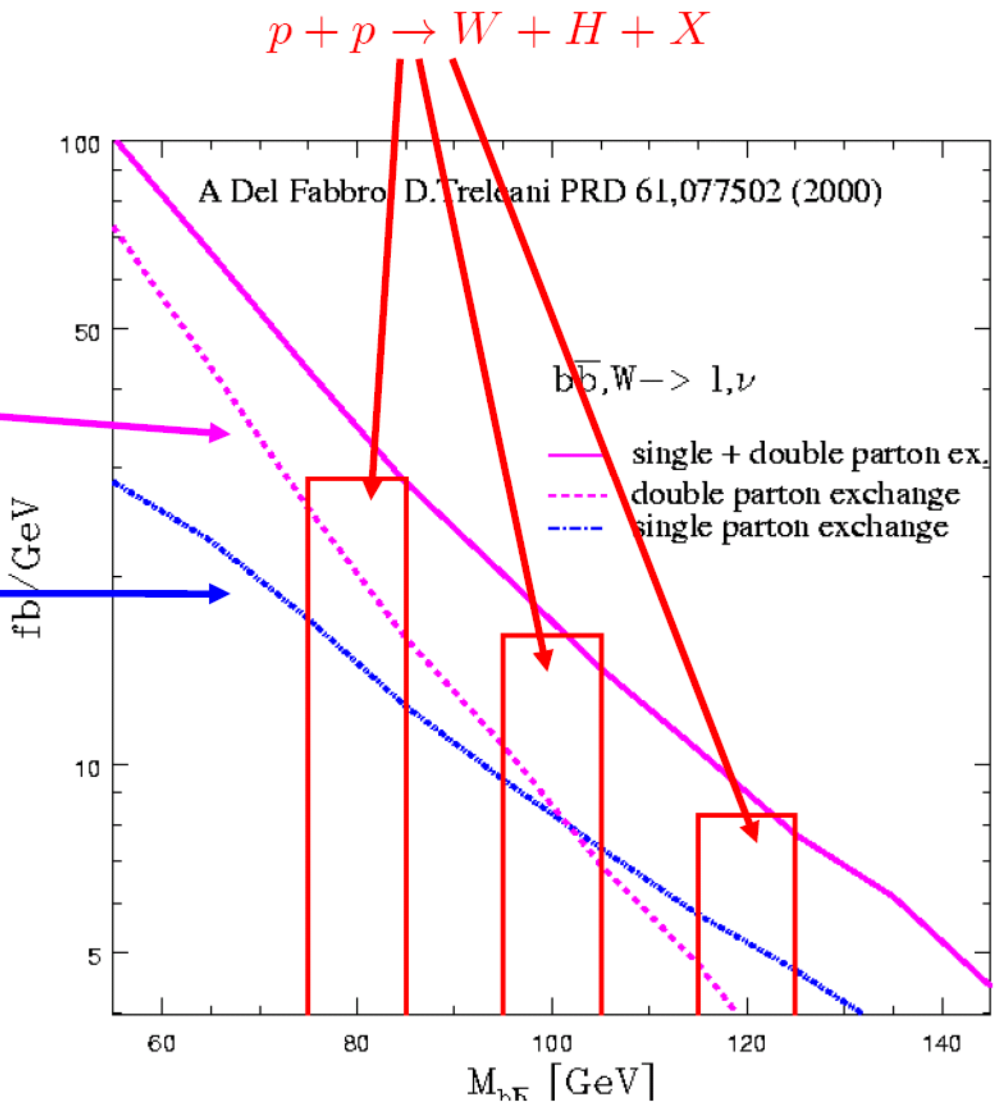
with $W \to l\nu,\ \ H \to b\bar{b}$

- Double parton scattering:

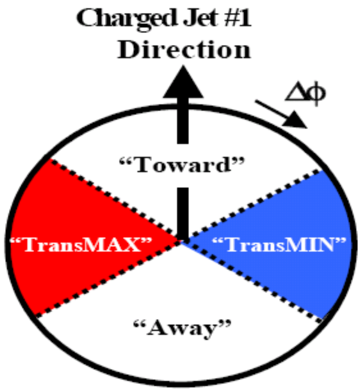
  $p+p \to b\bar{b}X$

  $p+p \to W+X$

  $p+p \to W+b\bar{b}+X$



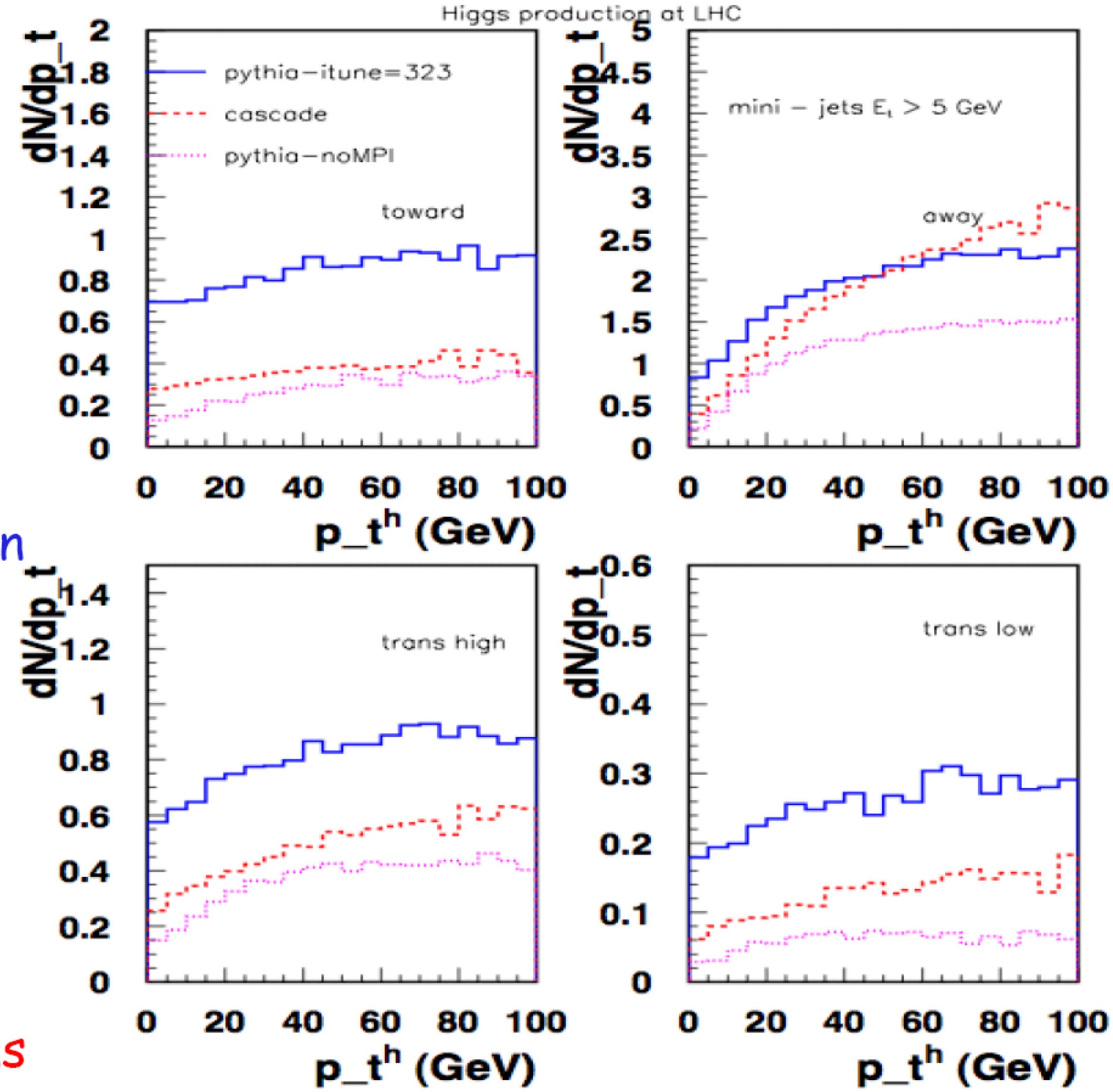
The underlying event in pp → h X



Mini-jets E_t > 5 GeV

- study underlying event in gluon processes
- check $\langle N_{minjet} \rangle$ vrs p_t^h

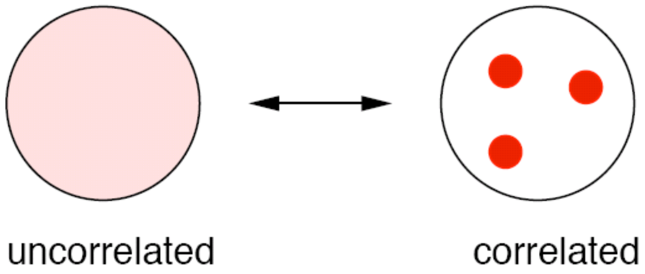
➔ CCFM parton shower produces higher multiplicity w/o Multiparton Interactions



Probing correlations of partons near nucleon edge (nucleon periphery) in Multi Parton Interactions (MPI)

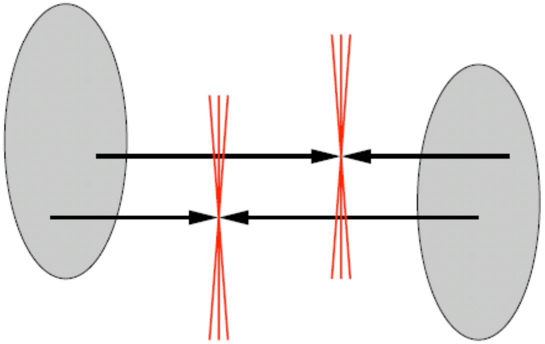
Mark Strikman, PSU

Correlations: nucleon parton structure



Indications of large positive transverse plane correlations from analysis of the CDF and D0 cross section $p\bar{p} \to$ 3 jets $+\gamma$ using information about nucleon GPDs

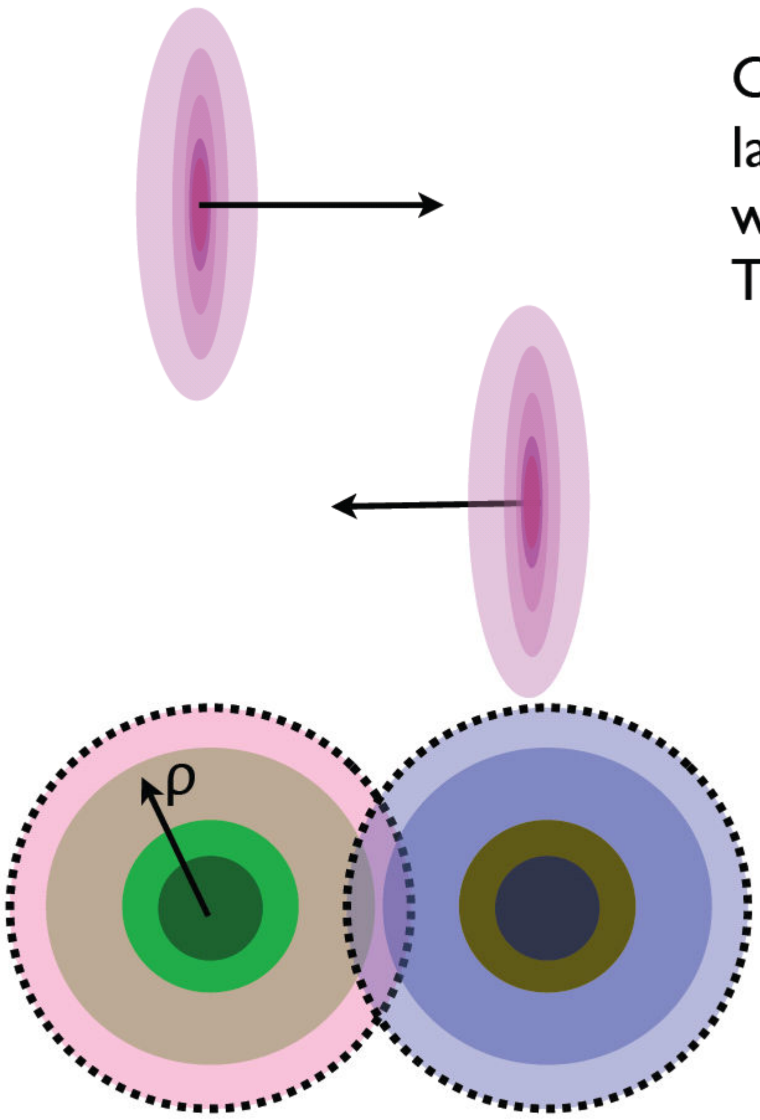
FSW03



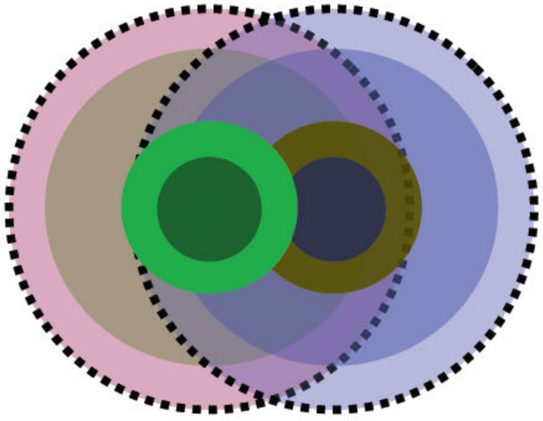
``Constituent quarks" of size r ~ 0.3 fm from chiral symmetry breaking in QCD cf. Instanton vacuum [Diakonov, Petrov 86]

MPI are dominated by collisions at small b < 0.7 fm

Correlations between partons at large ρ - would help to solve problem with S-channel unitarity at large b - T.Rogers et al 09

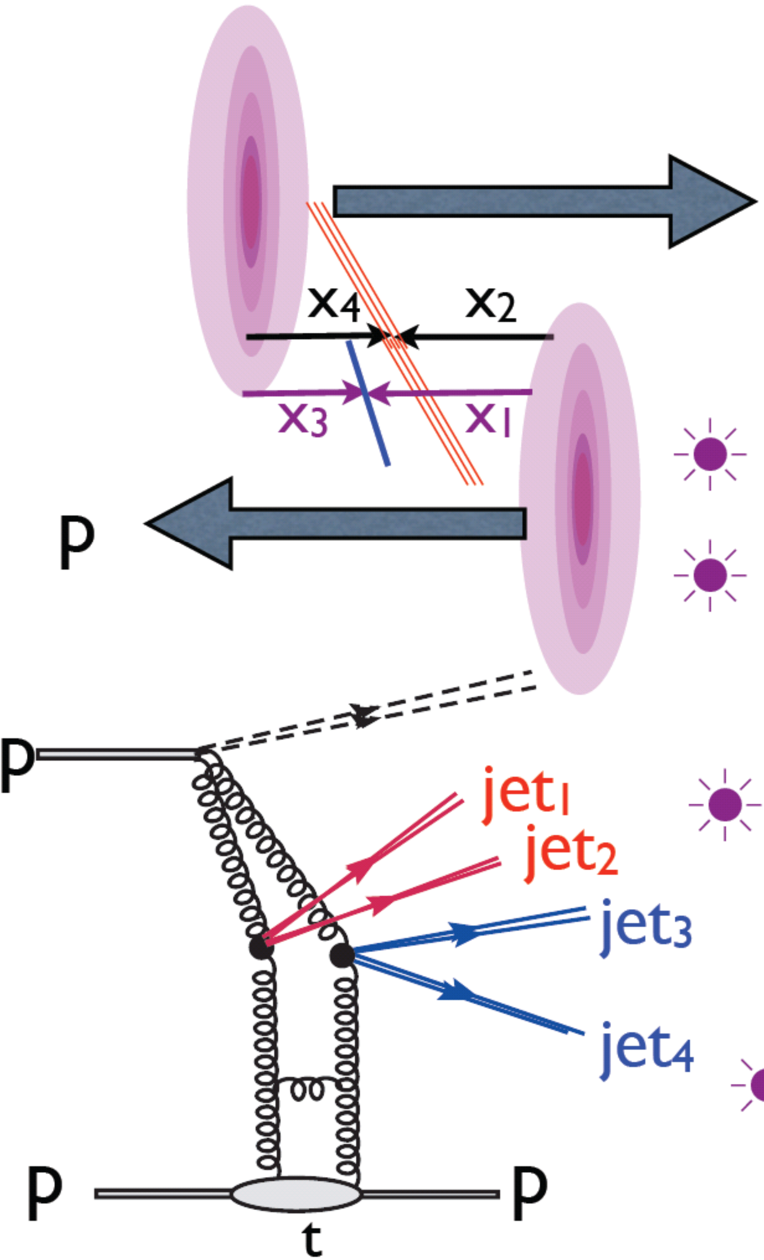


Peripheral pp



Central pp

Consider pp → p + X

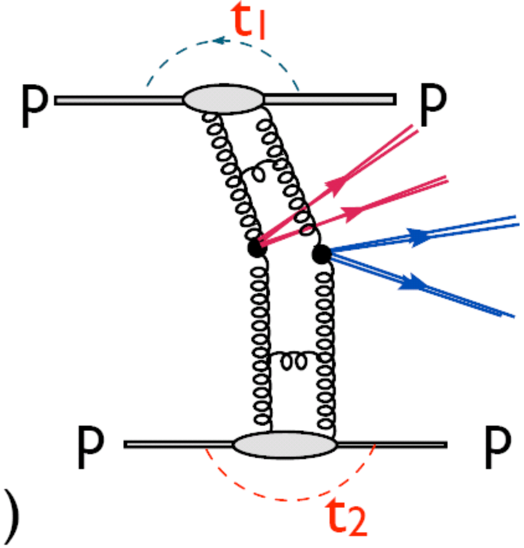


Questions:

- *Is distribution in x_1, x_2 product of two GPDs*
- *Absolute rate - sensitive to transverse size of the "Pomeron" exchange - smaller size - larger cross section.*
- Is there dependence on t of x_1, x_2 *distributions*: large t closer to perturbativ regime harder spectrum in x_1+x_2
- Large -t > few GeV^2

Is there a peak near $\delta(x_1+x_2 - 1)$?

Consider reaction (2) pp → p p + X



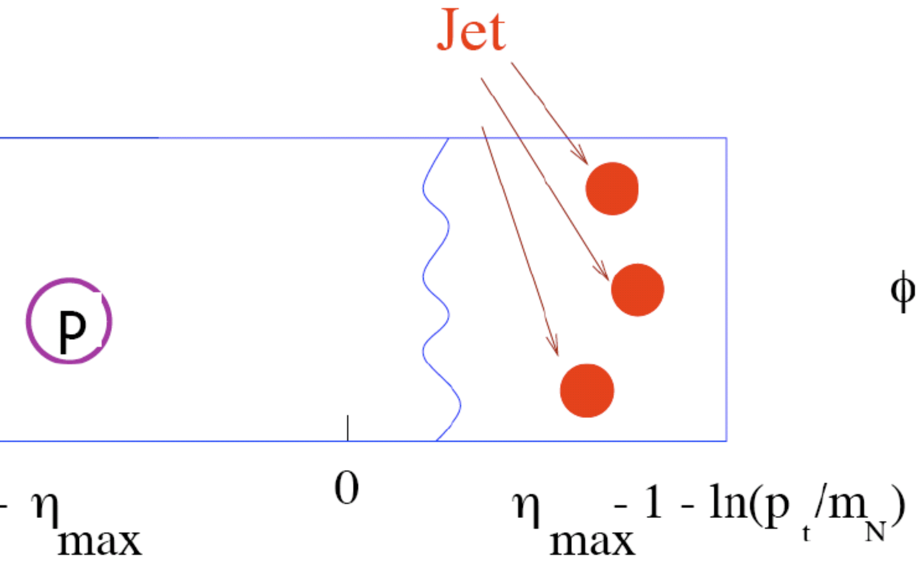
repeat the study of the pp → p + X (reaction 1)

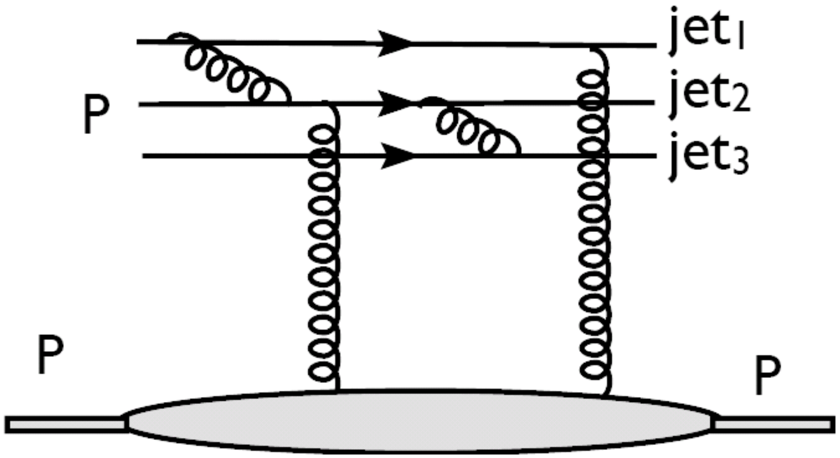
X=4 jets +Y; 4 jets

Are double diffractive PDFs the same ?

- relative rates in (1) and (2) - is gap survival becomes larger for large t?
- would gap survival changes with t_2 when t_1 is already large?

Proton dissociation into three high p_t jets measures high energy color transparency and proton 3 quark wave function - similar process was observed in the pion - nucleus scattering - πA→ 2jets + A (good agreement with our predictions)





Lego plot for 3 jet coherent production

pp → leading neutron + 2 jets + p

Analog of πA→ 2jets + A   better acceptance?

$$\frac{d\sigma(pA \to (jet_1 + jet_2 + jet_3) + A)}{dt \prod_{i=1}^{3} dx_i d^2 p_{ti}} \propto \left[\alpha_s x_A G_A(x_A, p_t^2)\right]^2 \cdot$$

$$\cdot \frac{\phi_N^2(x_1, x_2, x_3)}{\prod_{i=1}^{3} p_i^4} \delta^2(\sum_{i=1}^{3} \vec{p_{ti}} - q_t)\delta(\sum_{i=1}^{3} x_i - 1) G_N^2(t) F_A^2(t),$$

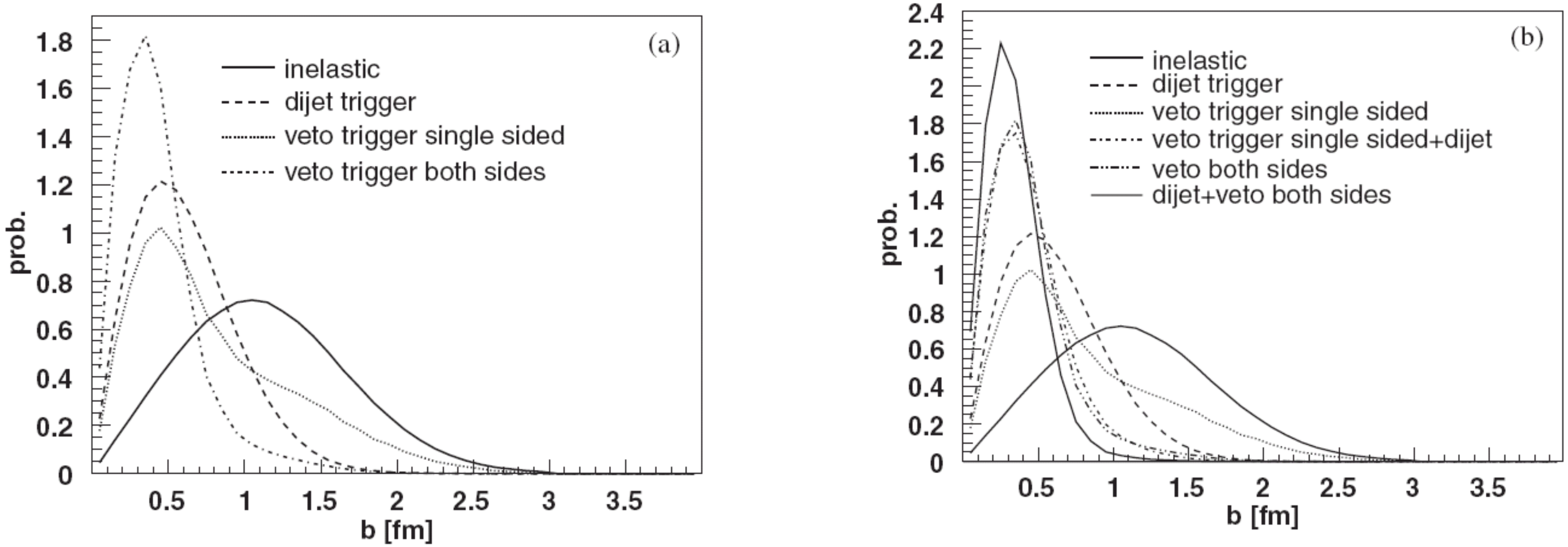
where $t = -q_t^2, x_A = M_{3jet}^2/2s$. Coefficient is also calculable in pQCD. $\phi_N(x_1, x_2, x_3)$ is relevant for calculation of proton decay.

$xG_N(x, Q^2 \sim 100\ \mathrm{GeV}^2) \propto x^{-1/2}$ $\Rightarrow$ $\sigma_{3jet} \propto s$!!!

☞ *Need to develop a effective trigger for central pp collisions at LHC.*

- *QCD interactions at gluon densities similar to those for AA collisions at LHC*
- *more realistic modeling of QCD environment for new particle production*
- *Useful information for CR at GZK*

LF, MS, C.Weiss 04, Dreshel +MS 08



0.1 veto single sided = no baryons with x>0.1

TOTEM (x>0.8)+ ZDC

0.1 veto single sided ≈ 0.1 veto both sides no neutrons with x>0.1

One can trigger on <b>=0.4 fm - collisions with gluon field at <ρ> ~ 0.6 fm where gluon density 2- 3 times smaller than in AA at LHC but at higher pp energy where $G_p(x)$ is higher by a factor of two. Encounted densities much larger than densities at RHIC. However dispersion is much larger than in AA.

What is the (bare) Pomeron anyway?

Definition:

The Pomeron ´ the vacuum exchange contribution to scattering at high energies at leading order in $1/N_c$ expansion.

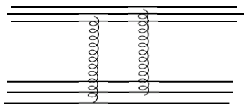
$$A(s,t) = g_s^2 A_1(s,t,\lambda) + g_s^4 A_2(s,t,\lambda) + \cdots$$

Where $\lambda = g^2 N_c$ & $g_s = 1/N_c$

Perturbative QCD $\lambda \sim 0$

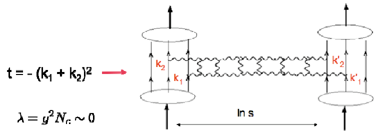
Two gluon exchange
(Low-Nussinov Pomeron!)

- $J_{cut} = 2\,(J-1) + 1 = 1$



F.E. Low. Phys. Rev. D 12 (1975), p. 163.
S. Nussinov. Phys. Rev. Lett. 34 (1975), p. 1286.

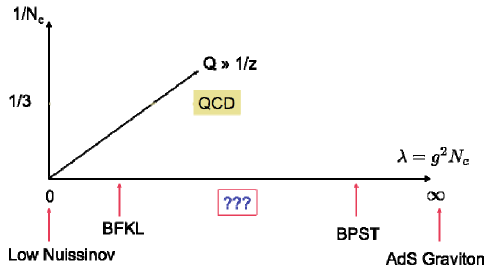
BFKL: Balitsky & Lipatov; Fadin,Kuraev,Lipatov'75



- ☐ Sum diagrams 1st order in $g^2 N_c$ & all orders $(g^2 N_c \text{ logs})^n$
- ☐ BKFL equation for 2 “reggized” gluon ladder is L = 2 SL(2,C) spin chain to one loop order.
- ☐ Accidentally “planar” diagrams (e.g. $N_c = 1$) and conformal.

Chung-I Tan

Pomeron Parameter Space



Gauge/String Duality $\lambda >> 1$

The QCD Pomeron
In gauge theories with string-theoretical dual descriptions, the Pomeron emerges unambiguously.

Pomeron can be associated with a Reggeized Massive Graviton. Both the IR (soft) Pomeron and the UV (BFKL) Pomeron are dealt in a unified single step.

BPST: Brower, Polchinski, Strassler, Tan, 2006

Key new results from AdS/CFT:

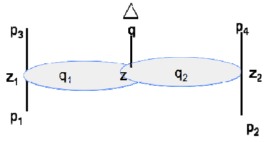
•A single Pomeron Propagator incorp. both Soft and Hard components,

• Eikonal summation over AdS_3:

$$A_{2\to 2}(s,t) \simeq -2is \int d^2b\, e^{-ib^\perp q_\perp} \int dz dz' P_{13}(z) P_{24}(z') \left[e^{i\chi(s,b^\perp,z,z')} - 1 \right]$$

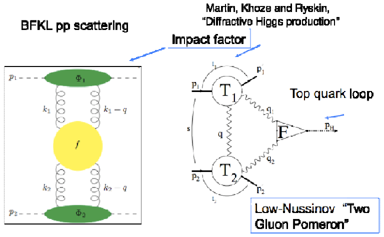
$$\chi(s, x^\perp - x'^\perp, z, z') = \frac{g_0^2 R^4}{2(zz')^2 s} \mathcal{K}(s, x^\perp - x'^\perp, z, z')$$

Double Regge (Pomeron) exchange



☐ New issues:
- Pomeron-Pomeron Glueball vertex: $V(q_1^\perp, q_2^\perp, q^\perp, z, z')$
- Top quark loop: $F^2(x)$ source at $z = 0$;
- Bulk to boundary prop from Pomeron-Pomeron vertex to $F^2(x)$

Diffractive Higgs Production (Building Blocks)



$$\alpha(0) - 1 \sim O(1)$$

* Wait for surprises!

*Conventional wisdom all needs to be re-examined!

BFKL vs Soft Pomeron

- **Perturbative QCD**
- **Short-Distance**
- **$\langle_{\mathrm{BFKL}}(0) \sim 1.4$**
- **Increasing Virtuality**
- **No Shrinkage of elastic peak**
- **Fixed-cut in t**
- **Diffusion in Virtuality**

- Non-Perturbative
- Long-distance: Confinement
- $\langle_{\mathrm{P}}(0) \sim 1.08$
- Fixed trans. Momenta
- Shrinkage of Elastic Peak: $<|t|> \sim 1/\log s$
- $\langle'(0) \sim 0.3\ \mathrm{Gev}^{-2}$
- Diffusion in impact space

UV Pomeron (BFKL): Scale Invariance

IR Pomeron (Soft Pomeron): Confinement

IIb: Geometry of AdS/CFT and Scale Invariance

What is the curved space?

Maldacena: UV (large r) is (almost) an $AdS_5 \times X$ space

$$ds^2 = r^2 dx_\mu dx^\mu + \frac{dr^2}{r^2} + ds^2_X$$

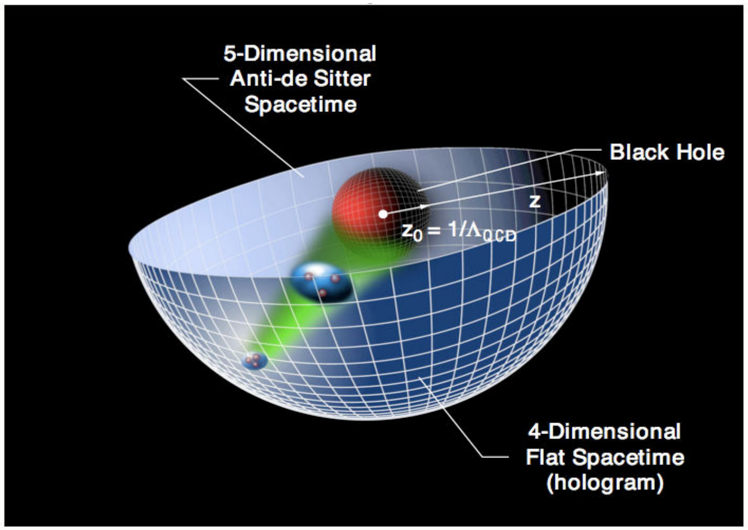
Captures QCD's approximate UV conformal invariance

$$x \to \zeta x \;,\; r \to \frac{r}{\zeta} \qquad \text{(recall } r \sim \mu\text{)}$$

Confinement: IR (small r) is cut off in some way

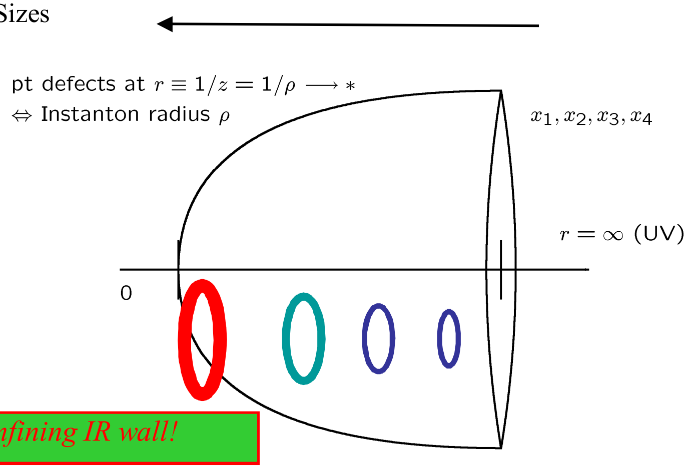
$$r \sim \mu > r_{min} \sim \Lambda_{QCD}$$

For Pomeron: *string theory* on cut-off AdS_5 (X plays no role)



Cutoff AdS_5

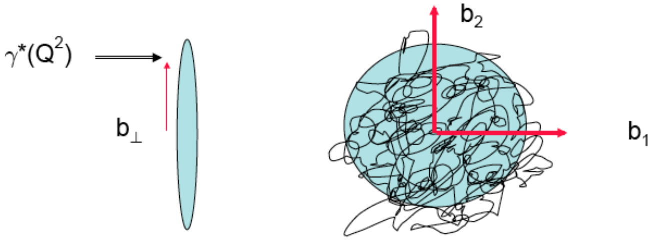
Large Sizes



Add Confining IR wall!

z=1/r,

"Fifth" co-ordinate is size z / z' of proj/target



5 kinematical Parameters:

2-d Longitudinal	$p^\pm = p^0 \pm p^3 \simeq \exp[\pm \log(s/\Lambda_{qcd})]$
2-d Transverse space:	$x'_\perp - x_\perp = b_\perp$
1-d Resolution:	$z = 1/Q$ (or $z' = 1/Q'$)

Gauge/String Duality: Conformal Limit

◆ **C=+1: Pomeron <===> Graviton**

$$j_0^{(+)} = 2 - 2/\sqrt{\lambda} + O(1/\lambda)\ .$$

◆ **C=-1: Odderon <===> Kalb-Ramond Field**

$$j_0^{(-)} = 1 - m_{AdS}^2/2\sqrt{\lambda} + O(1/\lambda)\ .$$

	Weak Coupling	Strong Coupling
$C=+1$	$j_0^{(+)} = 1 + (\ln 2)\ \lambda/\pi^2 + O(\lambda^2)$	$j_0^{(+)} = 2 - 2/\sqrt{\lambda} + O(1/\lambda)$
$C=-1$	$j_{0,(1)}^{(-)} \simeq 1 - 0.24717\ \lambda/\pi + O(\lambda^2)$ $j_{0,(2)}^{(-)} = 1 + O(\lambda^3)$	$j_{0,(1)}^{(-)} = 1 - 8/\sqrt{\lambda} + O(1/\lambda)$ $j_{0,(2)}^{(-)} = 1 + O(1/\lambda)$

Table 1: Pomeron and Odderon intercepts at weak and strong coupling.

Analyticity:

- Amplitude is crossing even.

$$\begin{aligned}\mathcal{K}(s,b^{\perp},z,z') &= -(zz'/R^4)G_3(j_0,v)\\ &\times\ \widehat{s}^{j_0}\int_{-\infty}^{j_0}\frac{dj}{\pi}\,\frac{(1+e^{-i\pi j})}{\sin\pi j}\,\widehat{s}^{(j-j_0)}\,\sin\left[\xi(v)\sqrt{2\sqrt{\lambda}(j_0-j)}\,\right]\end{aligned}$$

$$\cosh\xi = v+1 \qquad\qquad e^{\xi} = 1+v+\sqrt{v(2+v)}$$

- With λ large, Amplitude has a Large Real Part. Purely real at λ →∞.

- Need to know both Re [K] and Im [K] for all s>0.

- Im [K] can be found more easily. Re [K] can be found by Derivative Dispersion Relation.

Remarks on AdS3 Propagator:

$$\boxed{G_3(j; x^\perp - x'^\perp, z, z') \sim \langle x^\perp, z \,|\frac{1}{2\sqrt{\lambda}(j-2) + H_{+,-}}|\, x'^\perp, z' \rangle}$$

- Conformal Invariance, a function of a single AdS3 invariant.

$$\boxed{v = \frac{(x_\perp - x'_\perp)^2 + (z - z')^2}{2zz'}}$$

- Large λ ⇒ j ~ 2.
- λ infinite, s large and fixed ⇒ j=2, and Graviton exchange
- λ and s infinite, $\log s = O(\sqrt{\lambda})$ ⇒ Pomeron exchange, in order to resolve "fine structure", with

$$j \simeq j_0 = 2 - \frac{2}{\sqrt{\lambda}}$$

Strong Coupling Pomeron Propagator--Conformal Limit

- **AdS-3 propagator:**

$$K(j, x_\perp - x'_\perp, z, z') = \frac{1}{4\pi z z'} \frac{\left[y + \sqrt{y^2 - 1}\right]^{(2-\Delta_+(j))}}{\sqrt{y^2 - 1}} ,$$

- **BFKL kernel:** $y \pm 1 = \frac{(z \mp z')^2 - (x_\perp - x'_\perp)^2}{2zz'}$

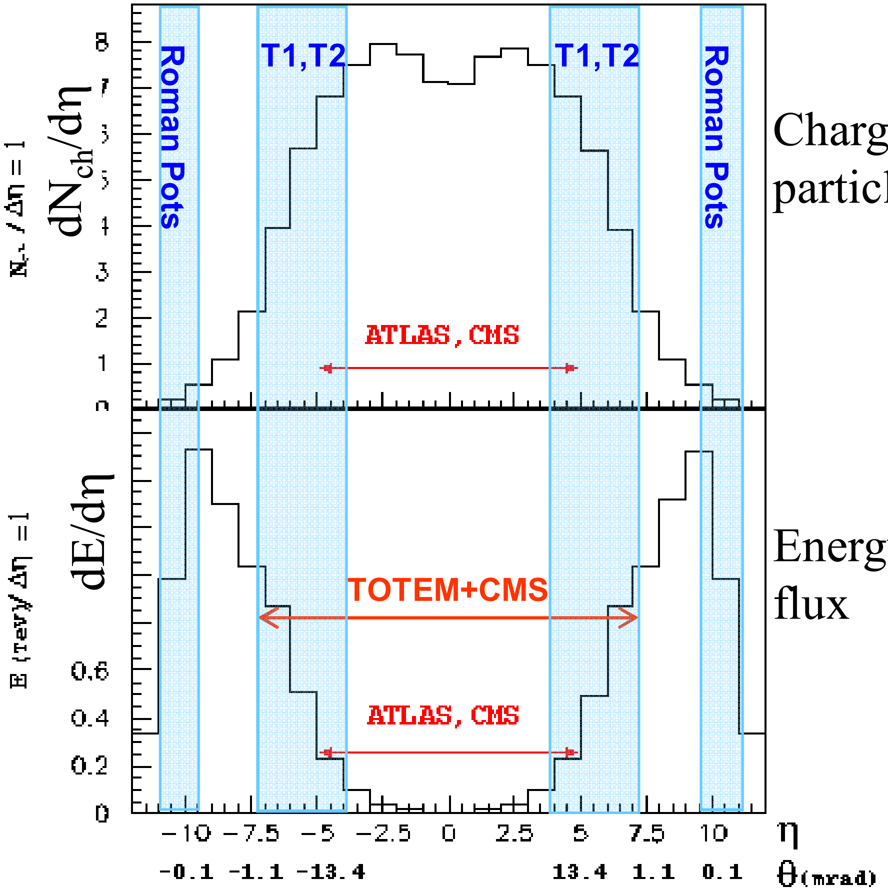
$$\Phi_{n,\nu}(b_1 - b_0, b_2 - b_0) = \left[\frac{b_1 - b_2}{(b_1 - b_0)(b_2 - b_0)}\right]^{-i\nu + (1+n)/2} \left[\frac{\bar{b}_1 - \bar{b}_2}{(\bar{b}_1 - \bar{b}_0)(\bar{b}_2 - \bar{b}_0)}\right]^{i\nu + (1-n)/2}$$

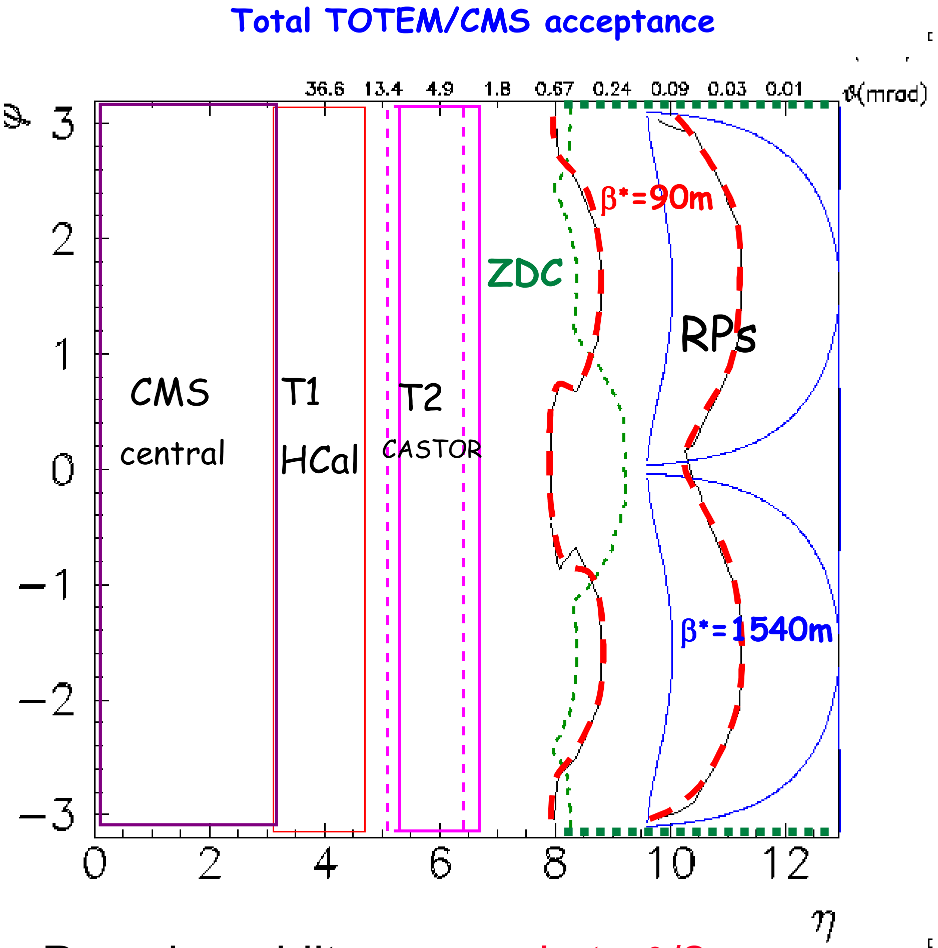
Back-up

CMS + TOTEM: Acceptance

largest acceptance detector ever built at a hadron collider

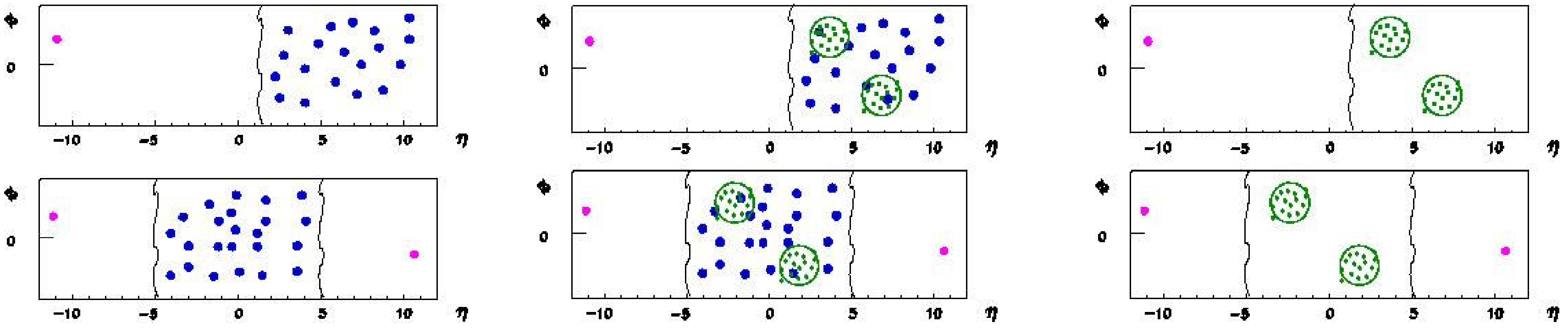
90% (65%) of all diffractive protons are detected for β^* = 1540 (90) m





Pseudorapidity: $\eta = -\ln \mathrm{tg}\, \theta/2$

Running scenarios



pp->pX
pp->pXp

soft diffraction

pp->pjjX
pp->pjjXp

(semi)-hard diffraction

pp->pjj (bosons, heavy
pp->pjjp quarks,Higgs...)

hard diffraction

Cross section

Luminosity

β (m) **1540** **90**
2 **0.5**

L (cm^{-2} s^{-1}) **10^{29}** **10^{30}** **10^{32}** **10^{34}**

TOTEM runs **Standard runs**

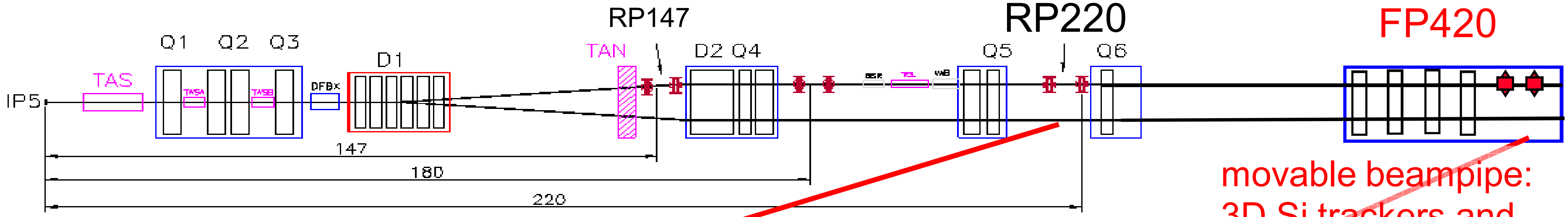
Accessible physics depends on luminosity & β*

Summary: Questions on diffraction addressed by the LHC

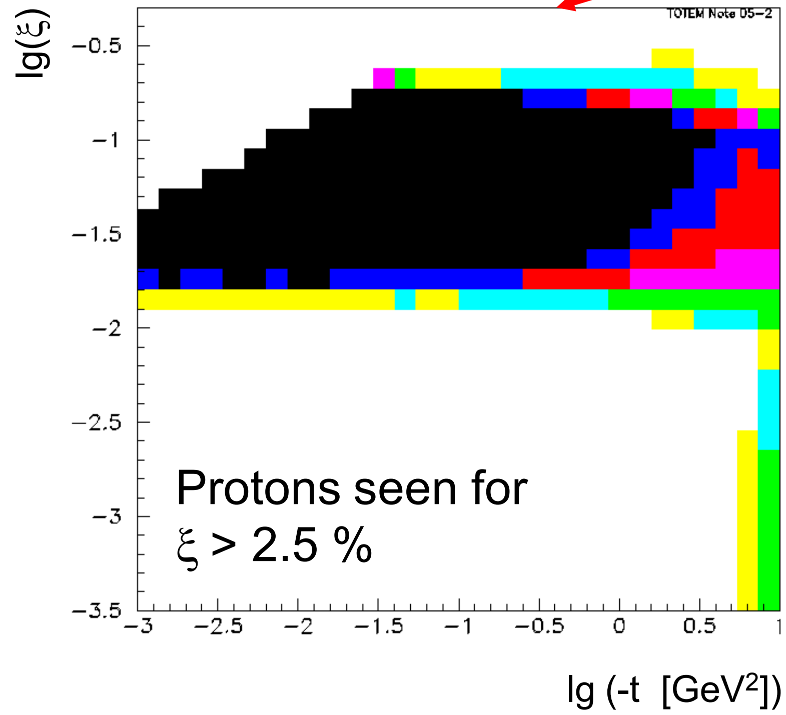
- Total p-p cross-section measurement on the ~1% level (different methods)
- Differential elastic cross-section measured over 4 orders of magnitude in t
  with very different scattering mechanisms
- Event topologies and differential cross-sections of diffractive processes
  (Tools: leading proton detectors, different specially designed beam optics, good rapidity coverage)
- Rapidity gap studies with and without proton tagging
- Study of central production with search for resonances: inclusive vs exclusive processes
- Forward physics (cosmic relation)

Diffraction at $\beta^* = 0.5 – 2$ m with high Luminosity

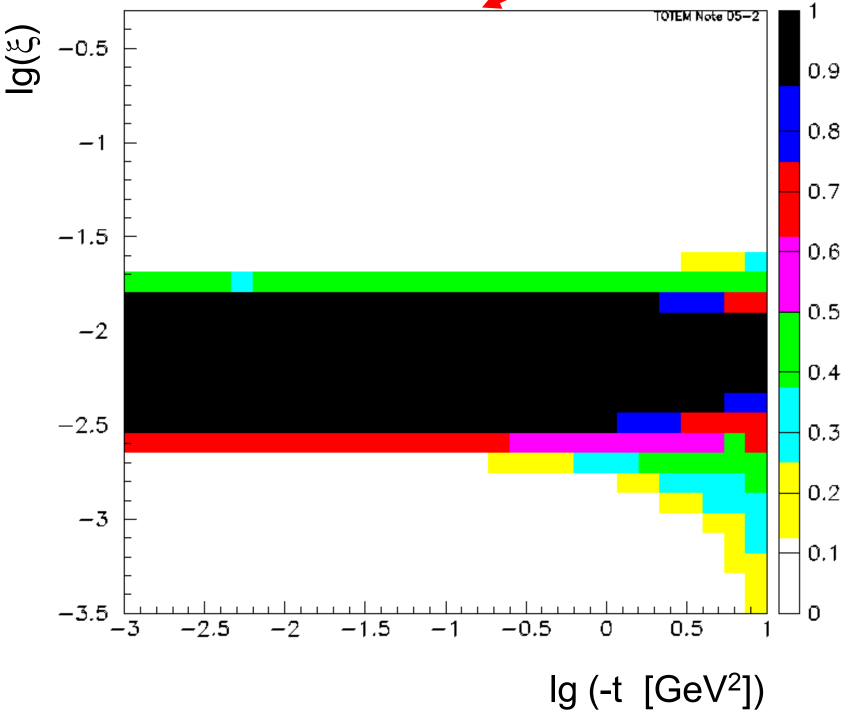
FP420 Project (IP1 and IP5)



movable beampipe:
3D Si trackers and
timing detectors

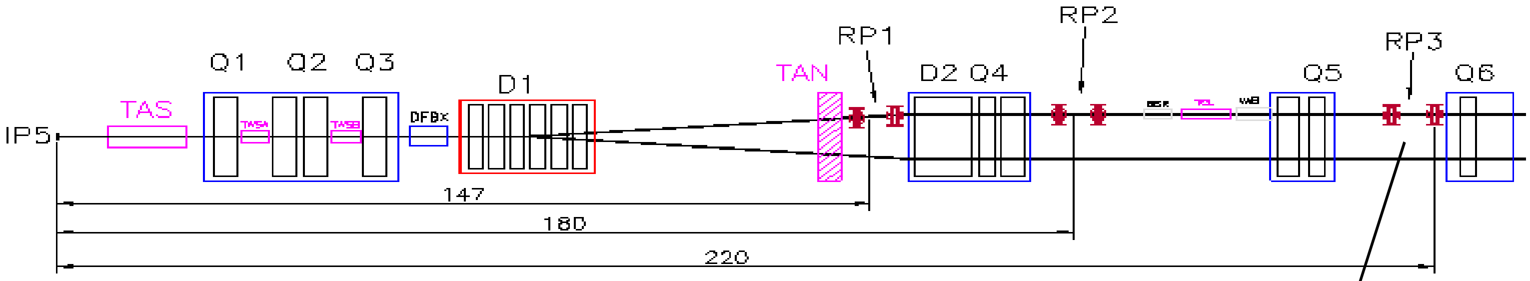


Protons seen for
$\xi > 2.5$ %

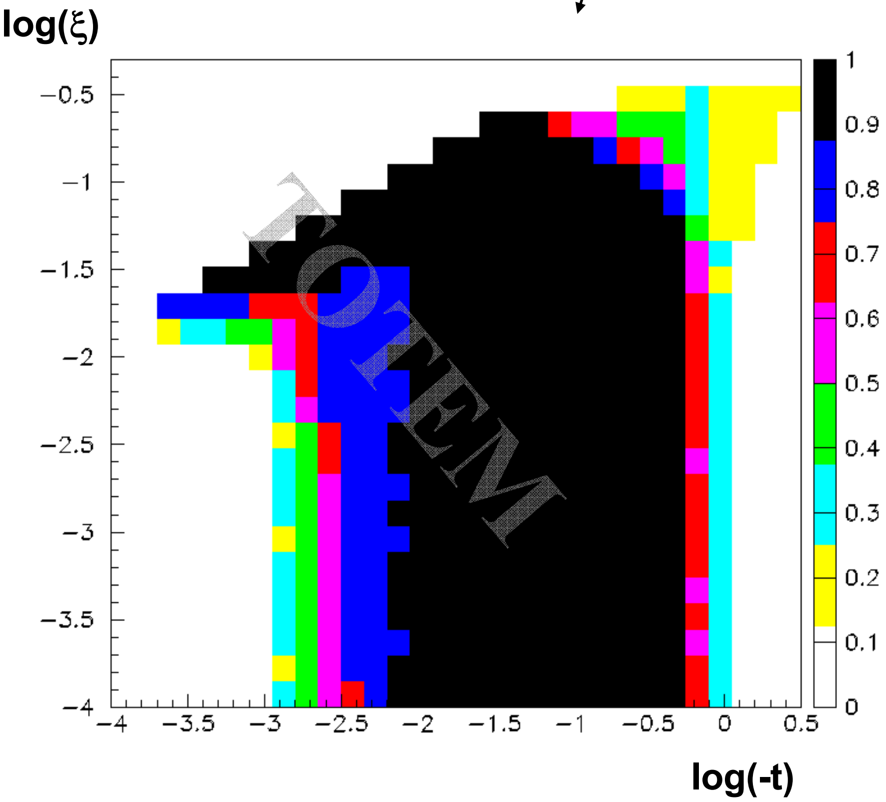


Alternative idea: put detectors in momentum cleaning region IR3 (→ talk by K. Eggert)

Diffractive protons at β^*=1540 m



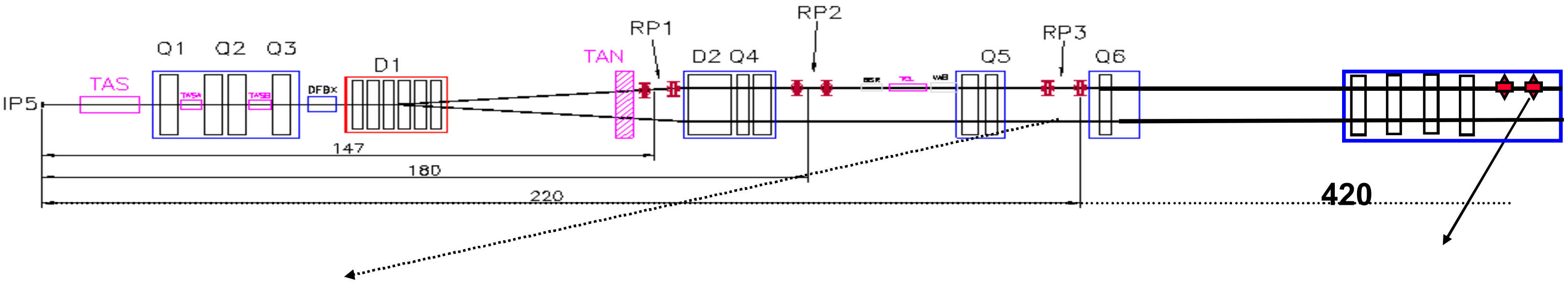
Diffractive protons are observed in a large ξ-t range > 90% are detected

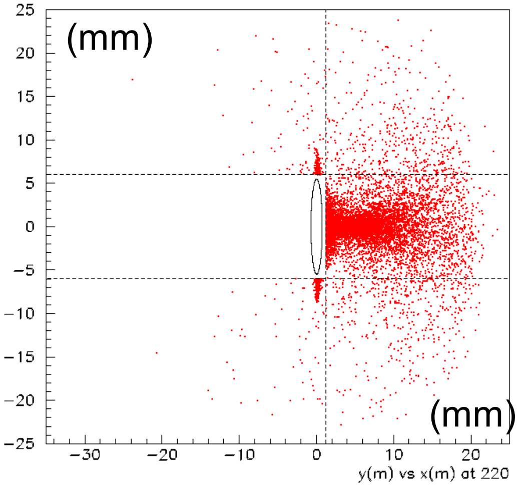


$-t > 2.5\ 10^{-3}$ GeV^2

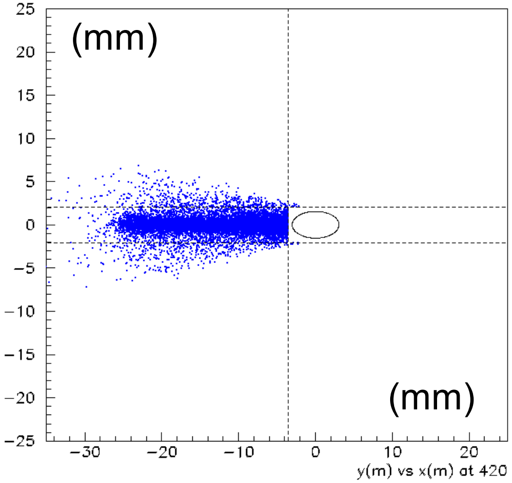
$10^{-8} < \xi < 0.1$

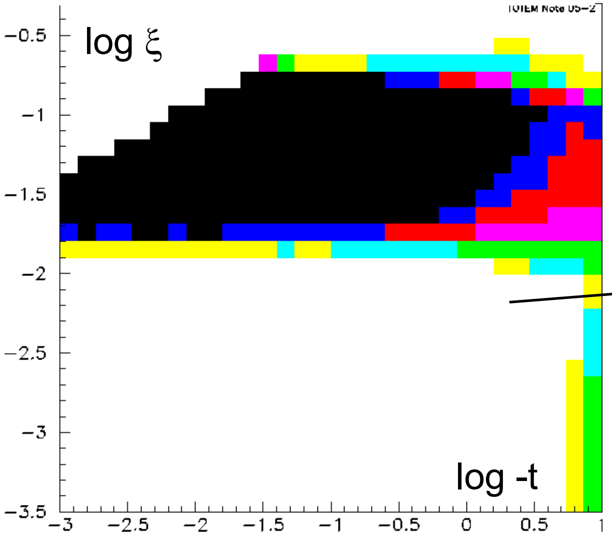
ξ resolution ~ few ‰

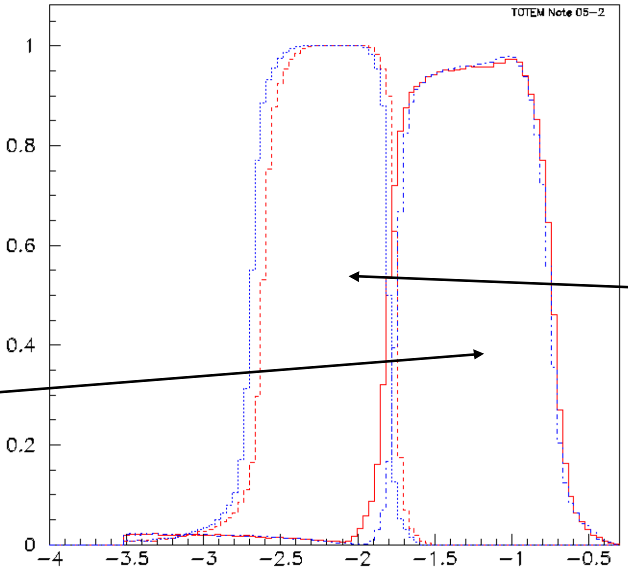


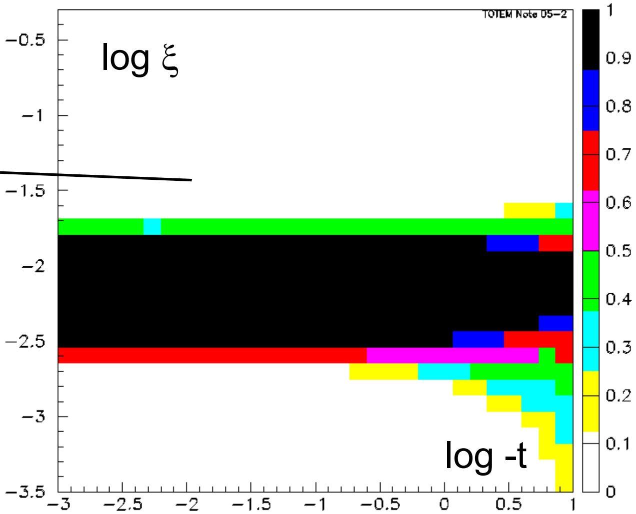


Diffractive proton detection
at $\beta^* = 0.5$ m
$\xi > 2.5$ %

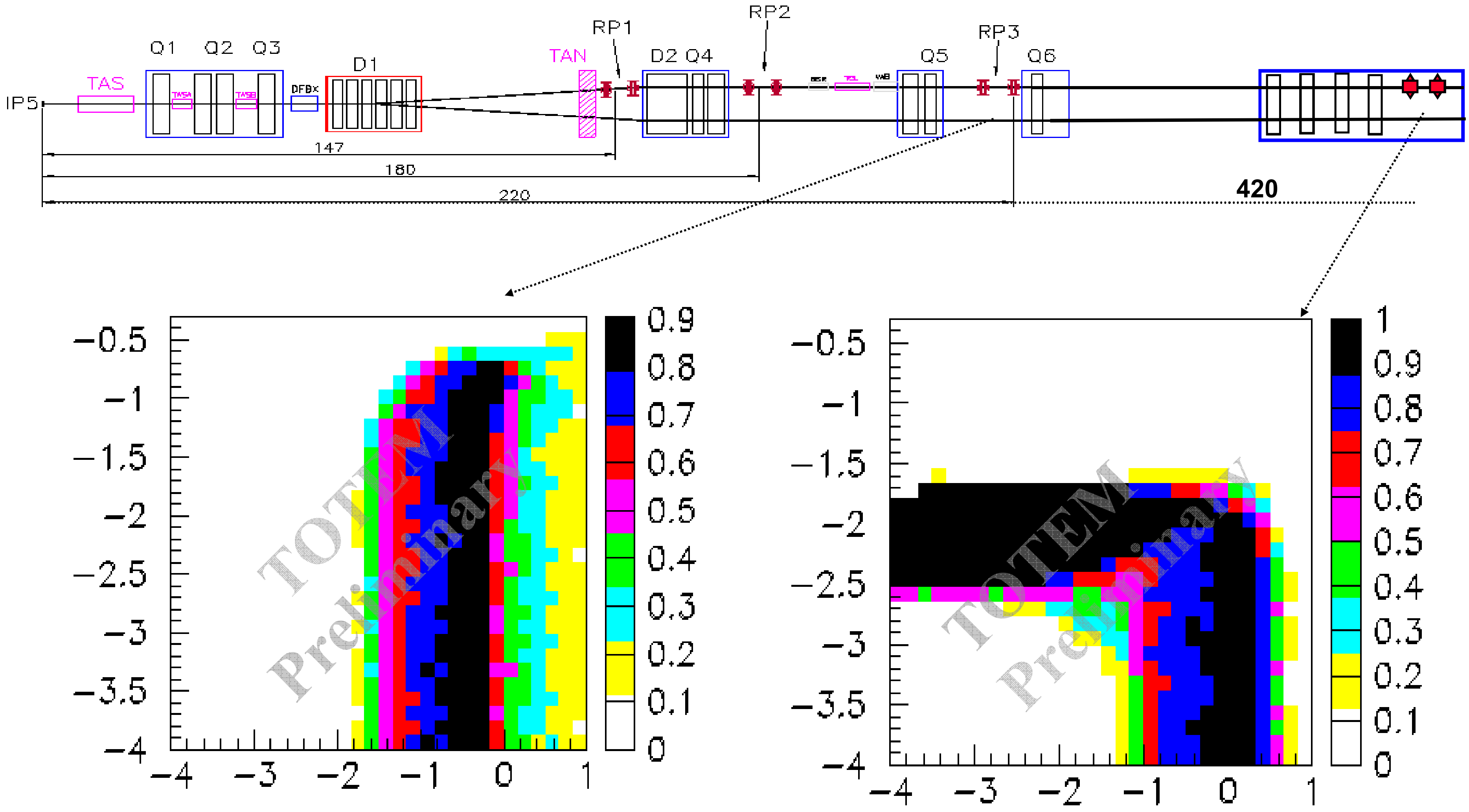








Diffractive protons at β^*=90 m



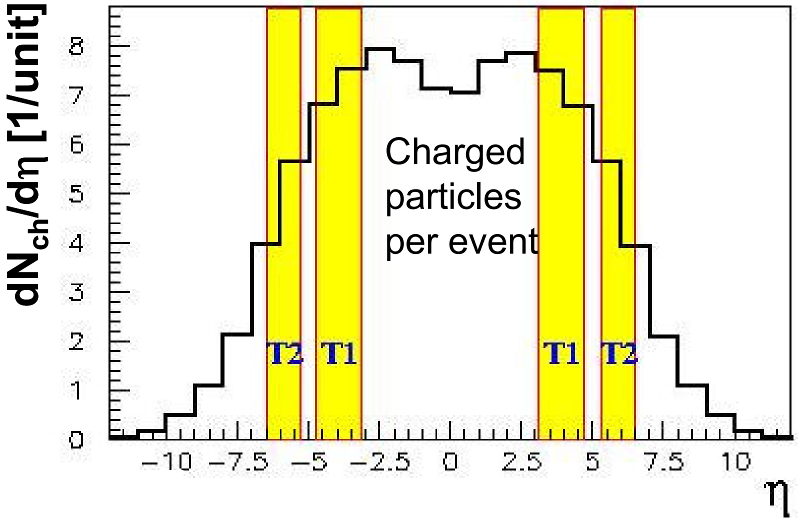
Log(ξ) vs Log(-t (GeV²))

Log(ξ) vs Log(-t)

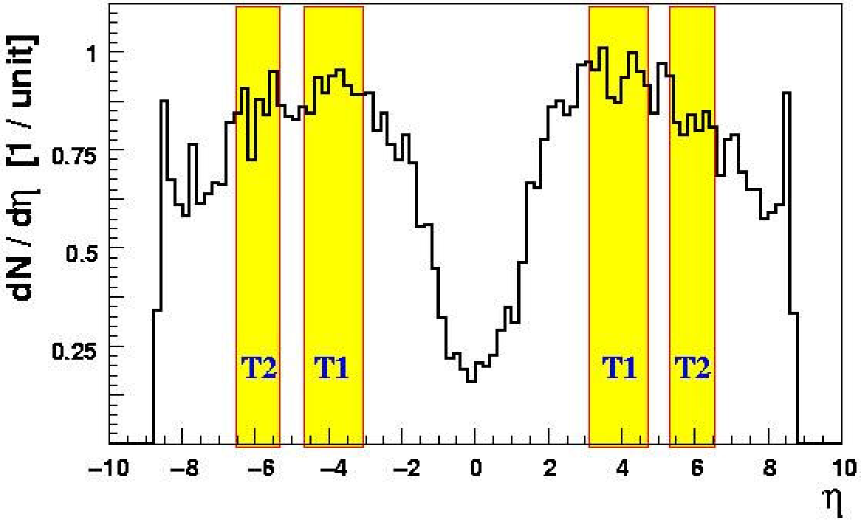
Discussion session EDS 09

TOTEM: Acceptance

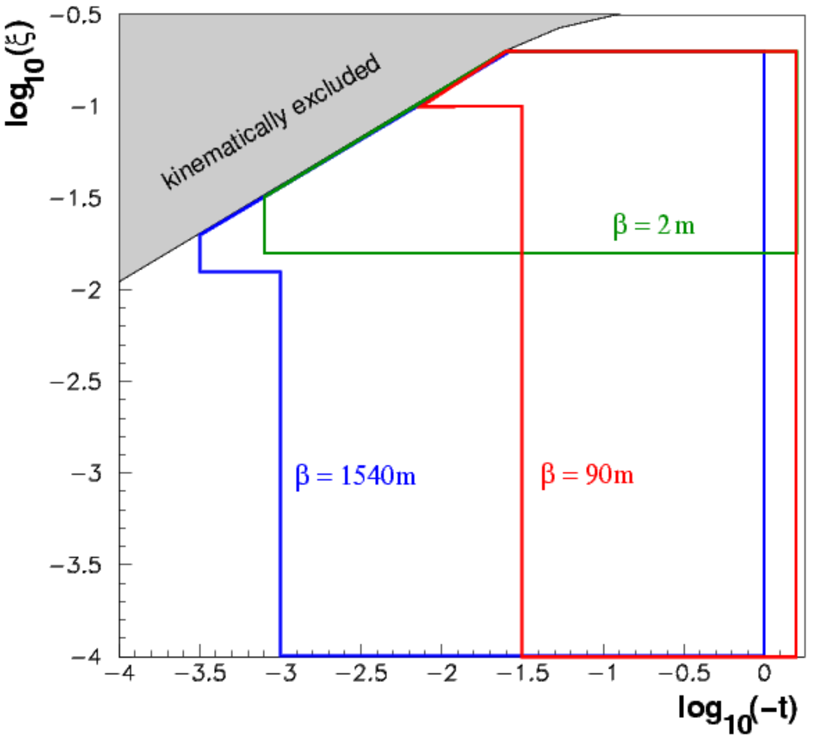
Inelastic Acceptance in η:
non-diffractive minimum bias events:



single-diffractive events:



Proton Acceptance in (t, ξ): (ξ = Δp/p)
(contour lines at A = 10 %)

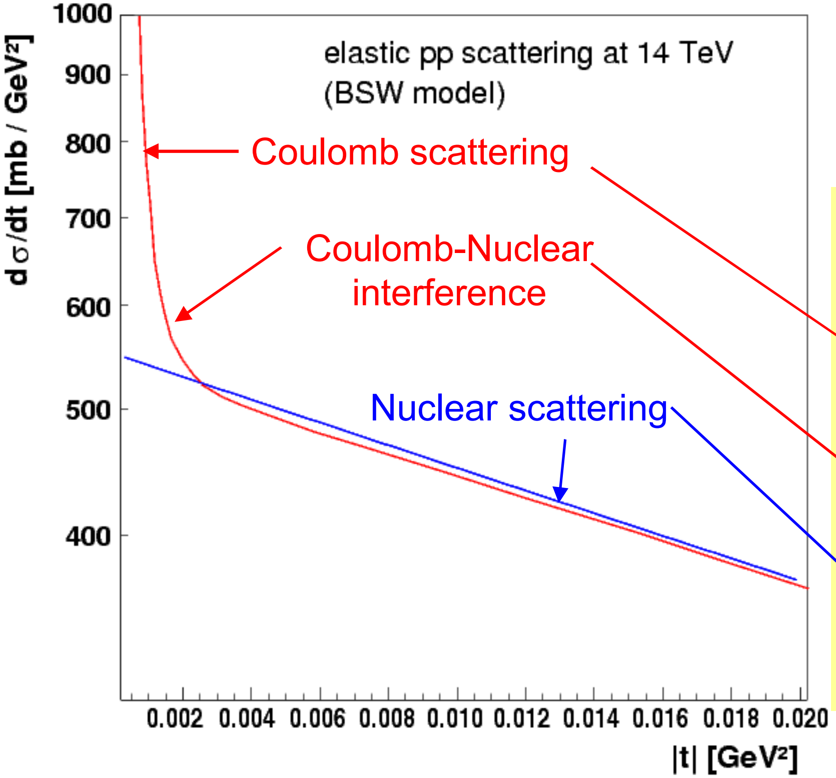


$t = p^2 \delta^2$

$\xi = \Delta / p$

All TOTEM detectors have trigger capability.

Total Cross-Section and Elastic Scattering at low |t|



Optical Theorem:

$$\sigma_{tot} = \frac{4\pi}{s} \Im\left(T_{elastic,nuclear}(t=0)\right)$$

$$\frac{d\sigma}{dt} = \frac{4\pi\alpha^2 (\hbar c)^2 G^4(t)}{|t|^2} + \frac{\alpha(\rho - \alpha\phi)\sigma_{tot} G^2(t)}{|t|} e^{-B|t|/2} + \frac{\sigma_{tot}{}^2 (1+\rho^2)}{16\pi(\hbar c)^2} e^{-B|t|}$$

α = fine structure constant

ϕ = relative Coulomb-nuclear phase

G(t) = nucleon el.-mag. form factor = $(1 + |t| / 0.71)^{-2}$

ρ = Re / Im $T_{elastic,nuclear}(t = 0)$