Summary of the discussion session

What can we learn/expect from the LHC experiments

Panel members:

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

Karsten Eggert

Some guidelines for the discussion

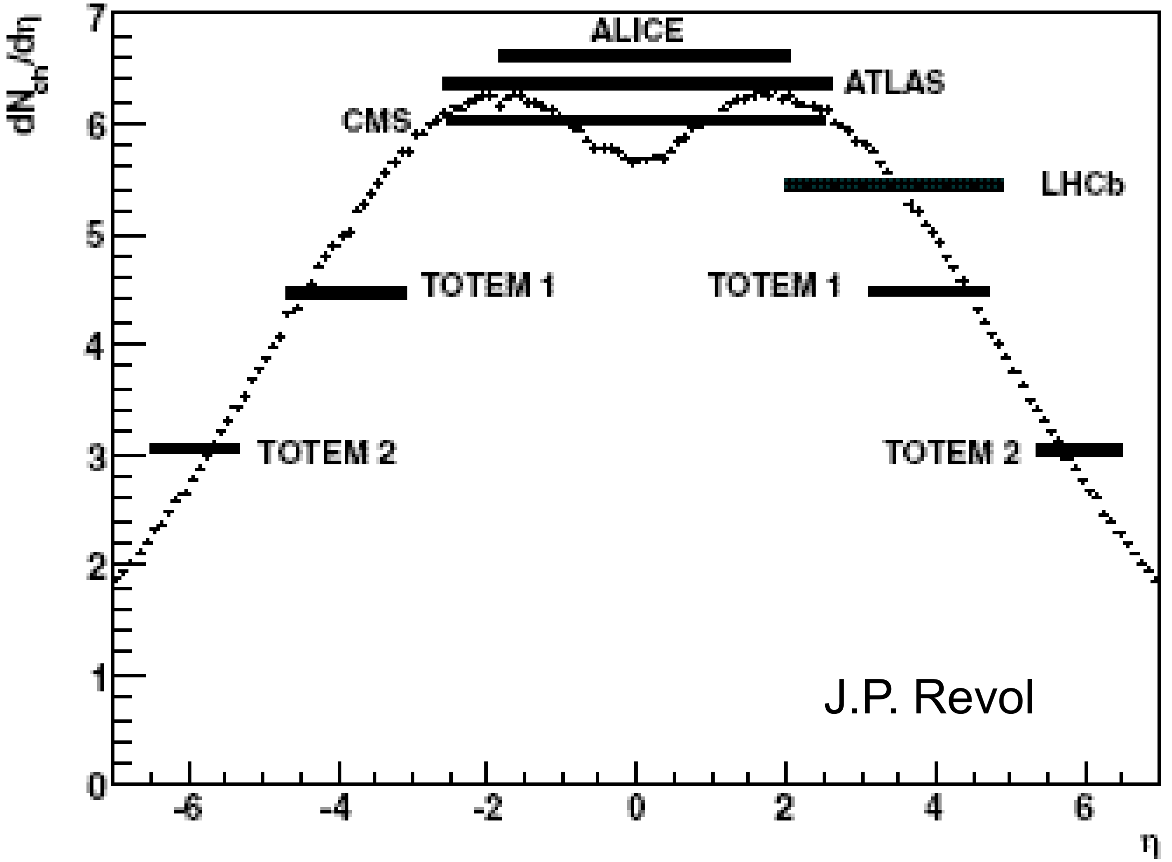
What do you consider as the most important topic to be addressed
- **at the LHC start (2010)**
- **later (>2010)**

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

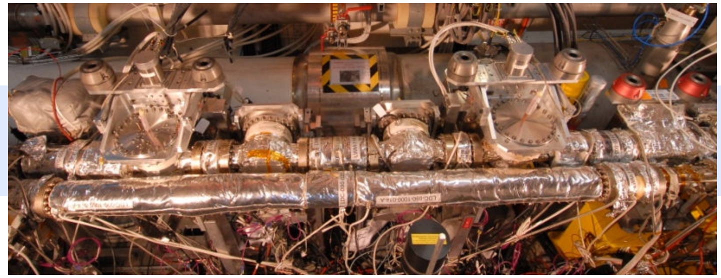
from J.P. Revol

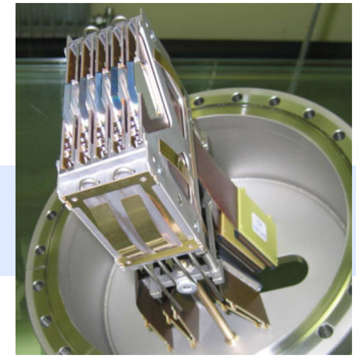


Very Forward detectors in all experiments:
LHCf, ZDC, Castor, …

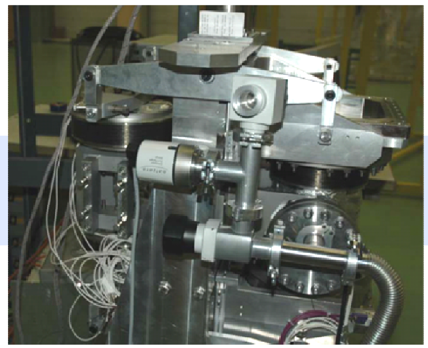
Roman Pot Forward Detectors @ LHC

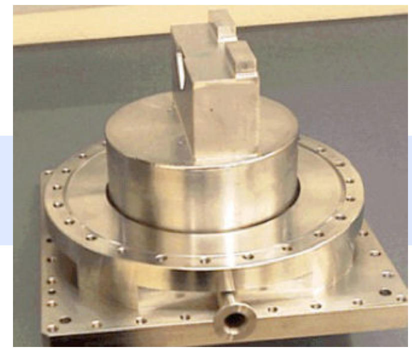
TOTEM



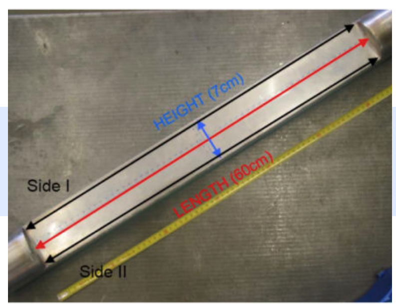


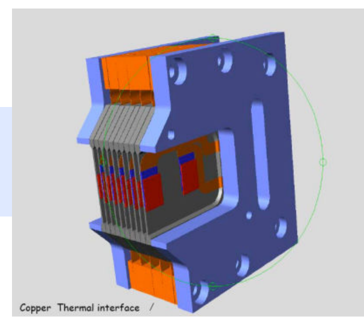
ATLAS Alfa



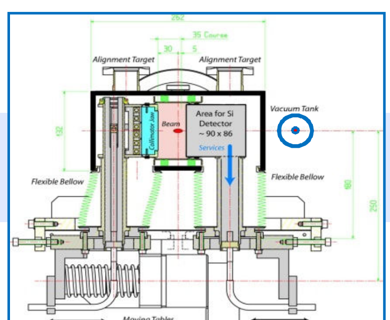


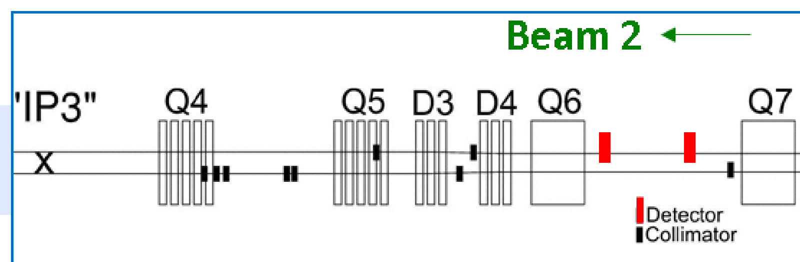
FP420





IP3





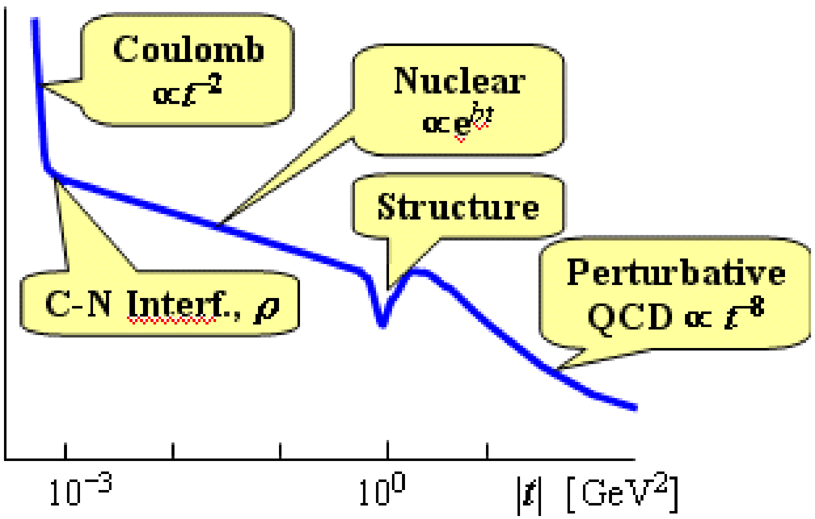
Karsten wanted me to discuss "experimental synergy" From ATLAS point of view.

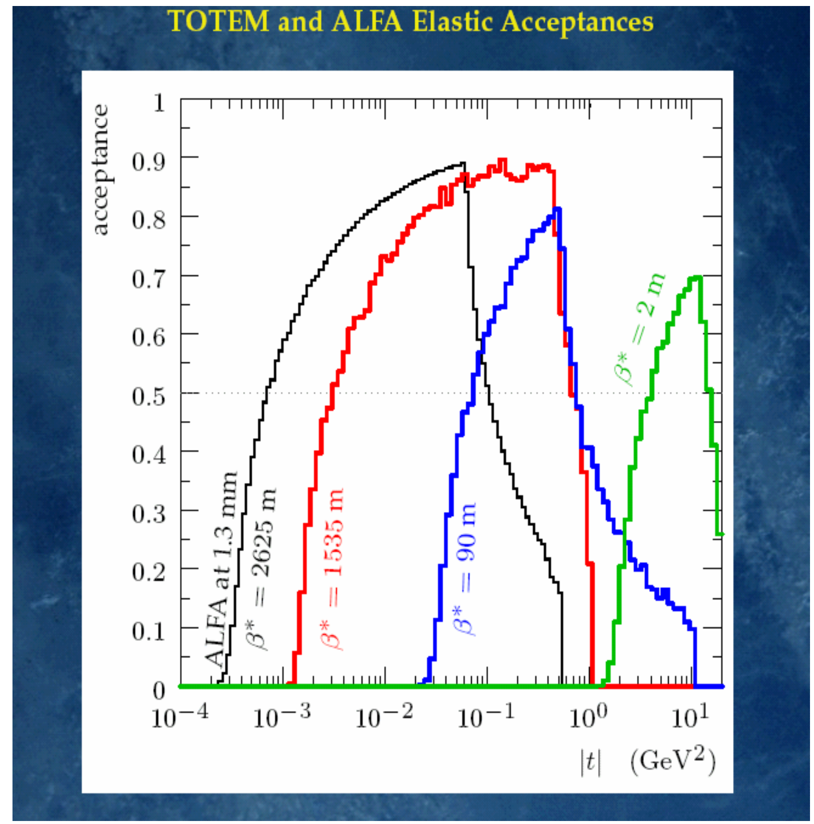
Per Grafström

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



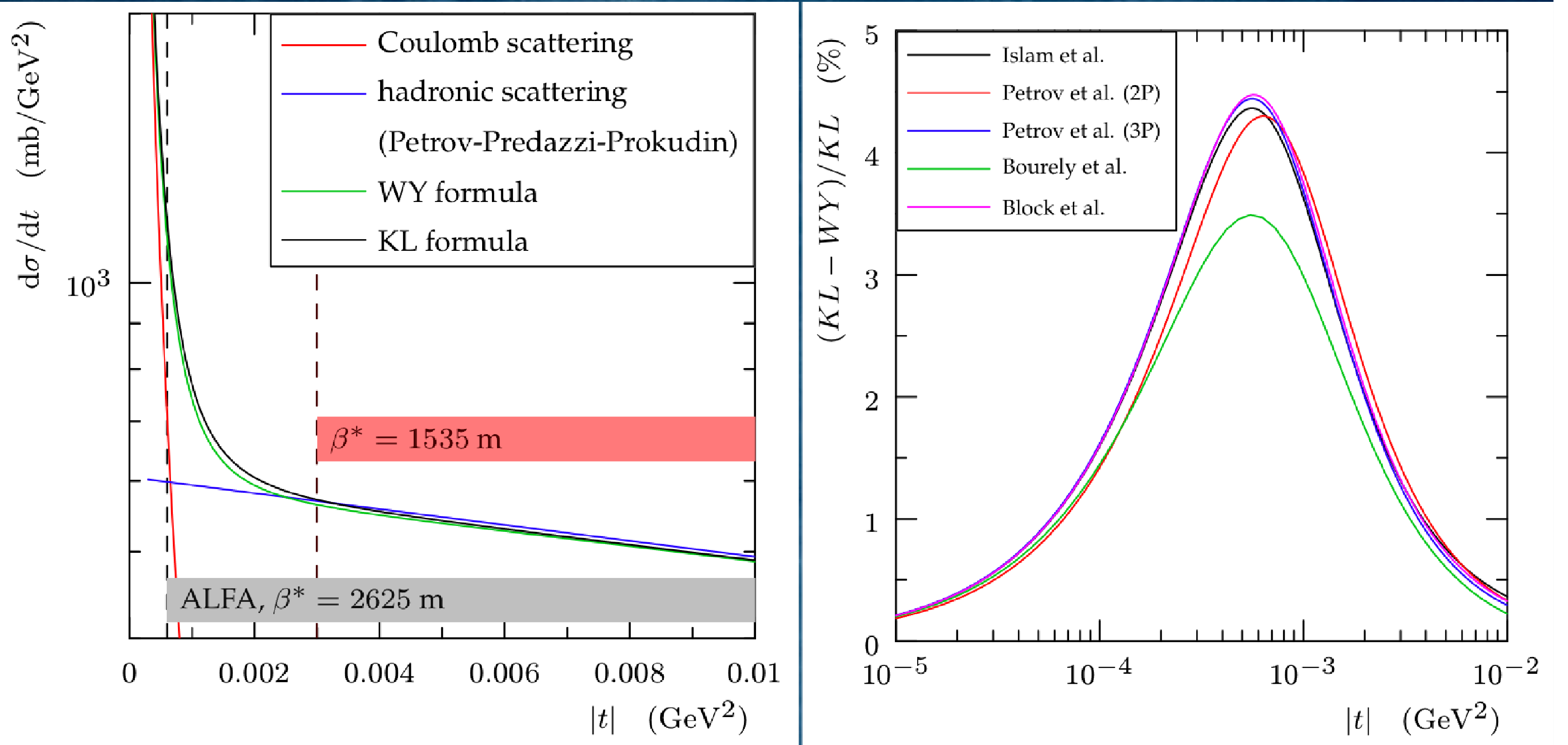


Use σ_{tot} from TOTEM
Use L from van der Meer scans

From Jan Kaspar

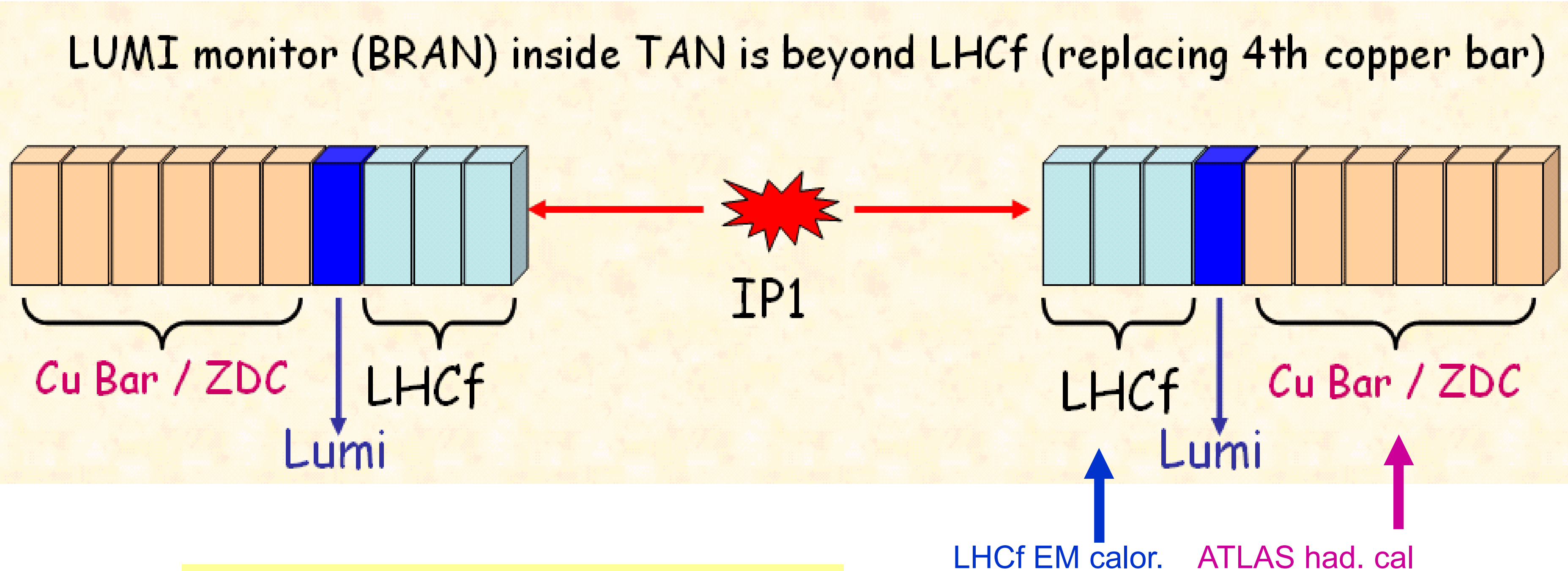
Coulomb Interference

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



Jan Kaspar

Synergy with forward calorimeters



Examples of minimal synergy:

Share Energy sums

..In trigger...

...In data....

...neutrons

More advanced:

....correlation with central system

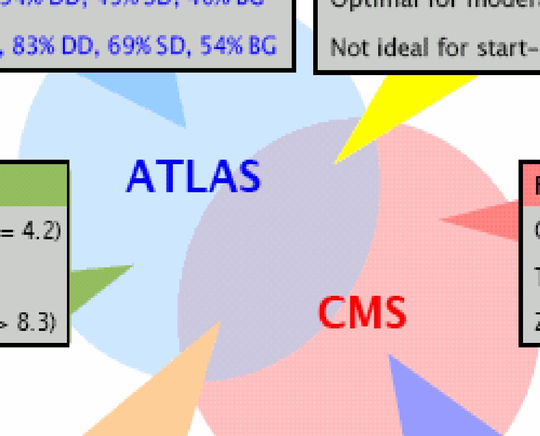
Synergy in early data-underlying event

Each experiment has its "MB" trigger –we need to combine to get the global picture

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

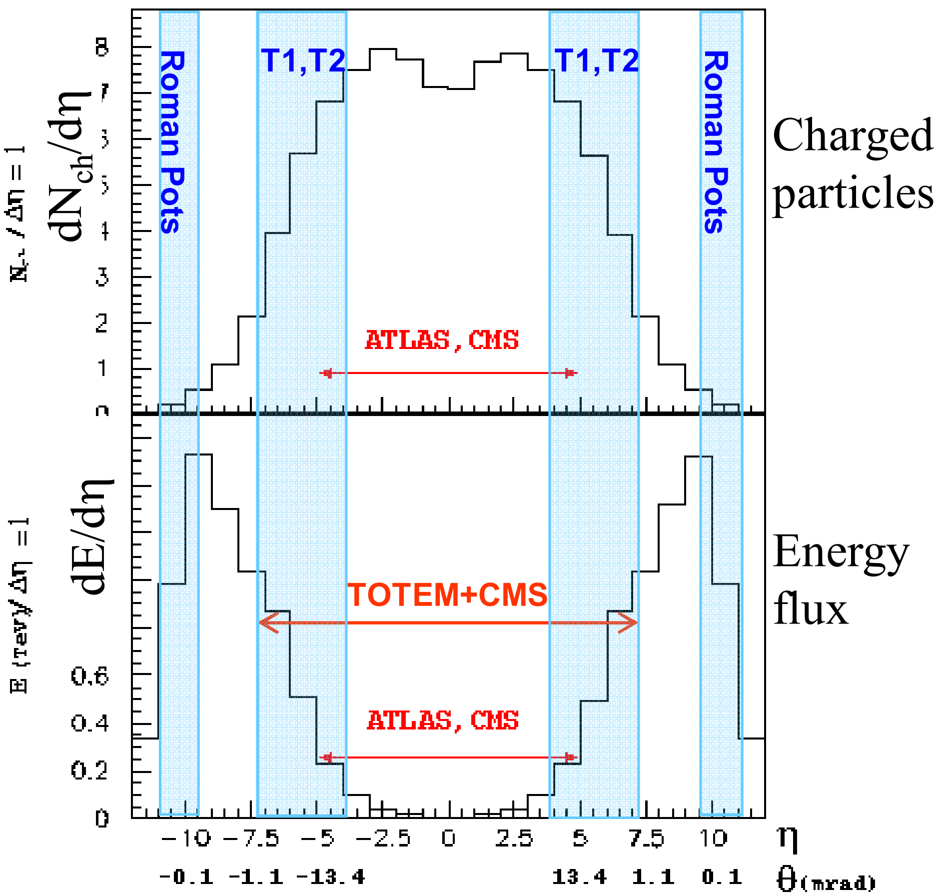
18 Mar 2009 M. Leyton, Moriond QCD 25

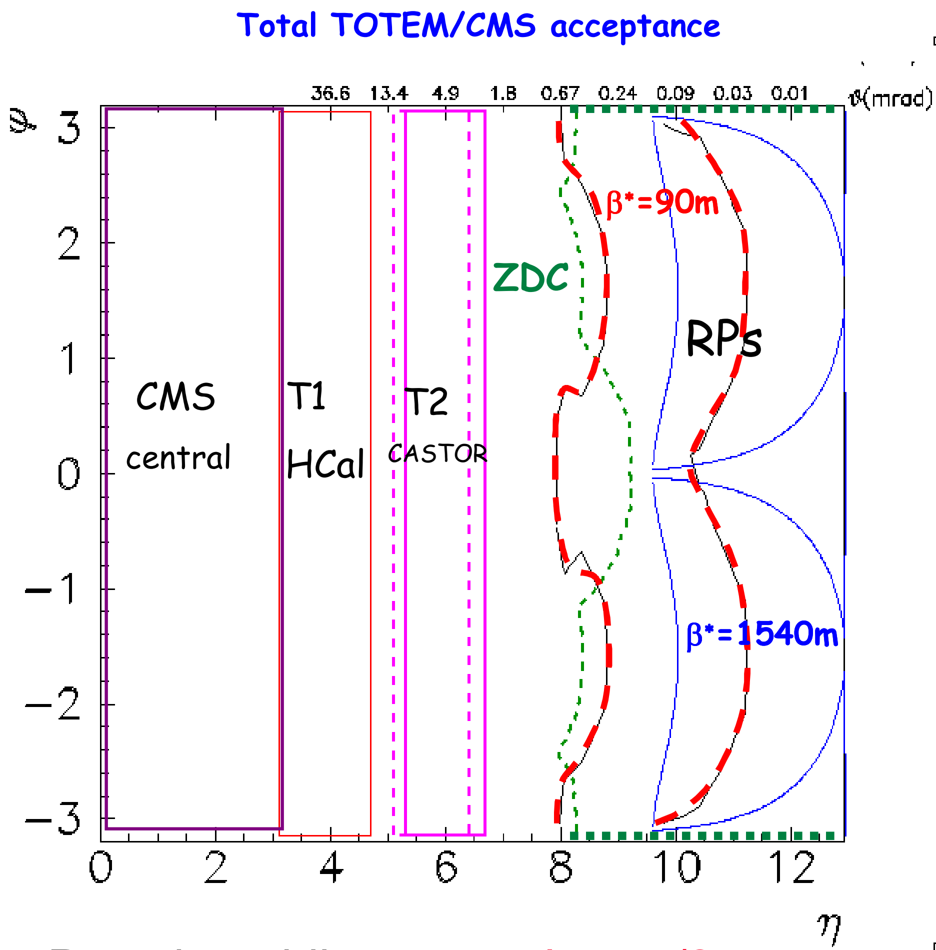
What we learn at low luminosity
Will be very useful at high luminosity

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

Karsten Eggert

what we need…

individual cross-sections and multiplicity distributions

- **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…**

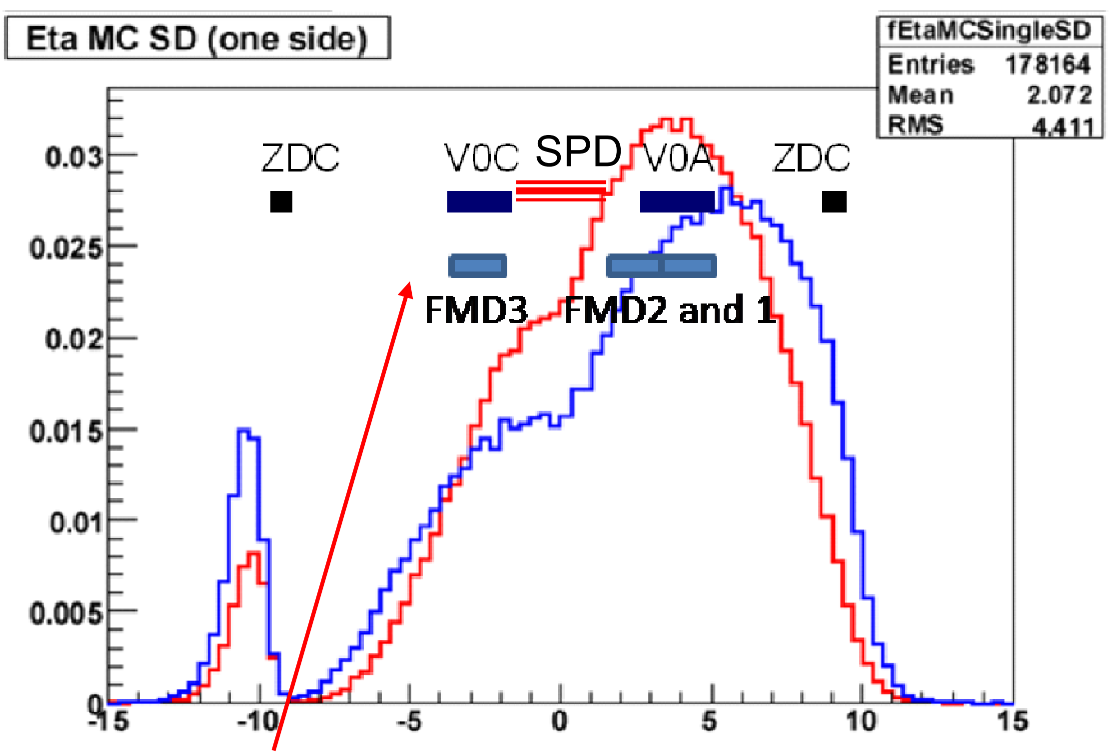
- **… and that's why we need MC event generator for diffractive collisions**

$$\frac{dN}{d\eta} = \sum_i \frac{\sigma_i}{\sigma_{tot}} \frac{dN_i}{d\eta}$$

***i* = nd, sd, dd, PP**

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**



Zoe Matthews

Add a scintillator here?

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

PHOJET PYTHIA

Going beyond inclusive x-sections

connect total x-section/diffraction with

- multi-parton interaction
- saturation

Hannes Jung

Underlying event – Multiple Interaction

- Basic partonic perturbative cross section

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

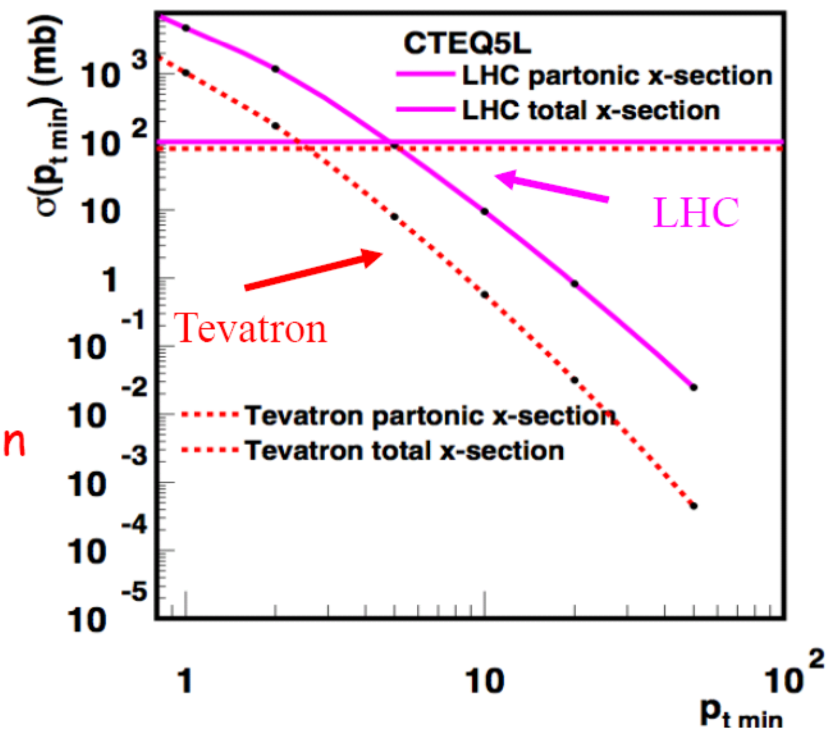
➔ diverges faster than $1/p^2_{\perp\min}$ as $p_{\perp\min} \to 0$ and exceeds eventually total inelastic (non-diffractive) cross section

- Average number of interactions per event is given by:

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

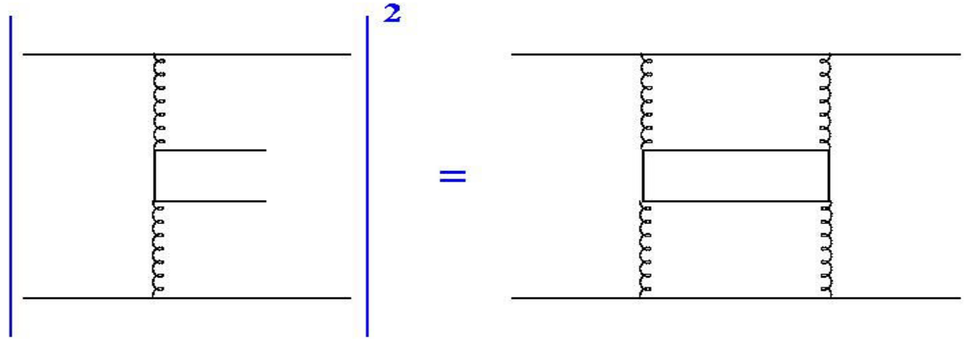
- It depends on how soft interactions are treated, ***BUT*** also on the parton densities and factorization scheme, parton evolution

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

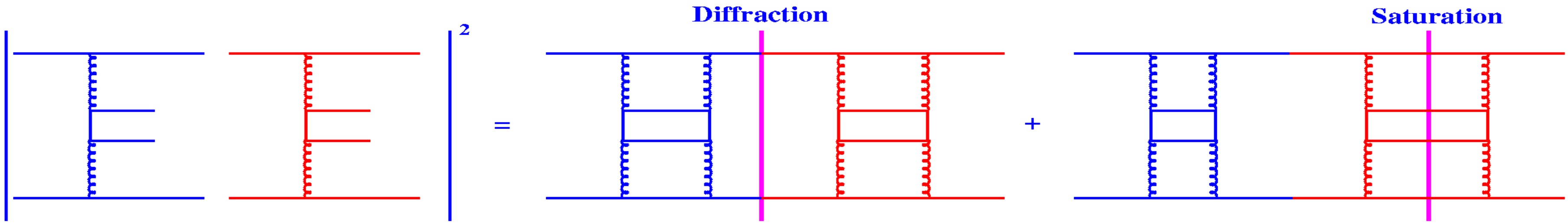


Connect diffraction with saturation and multiparton interactions

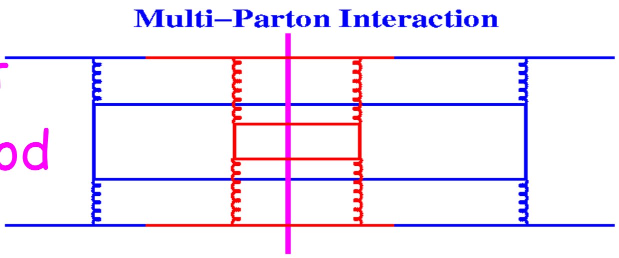
- **where is relation of diffraction – multiple scatterings – saturation coming from ?**
- **single parton exchange:**



- **2-parton exchange:**



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



Multiple Interactions and saturation

- **Multiple Interactions depend directly on parton densities at small scales and small x**
  - ➔ influence of saturation in parton densities
  - ➔ what comes from parton shower (DGALP/CCFM) and what from multiparton interaction ?
- **measurements:**
  - ➔ charged particle multiplicity vrs pt of trigger jet in central and fwd regions
  - ➔ minijet (Et>1,2,5,10 GeV) multiplicity vrs pt of trigger jet in full rapidity range
  - ➔ correlation of trigger jet with activity in forward region (charged particles, minjets), advantage of large rapidity range at LHC
- **measure minijet cross sections**
  - ➔ jet cross sections, jet – multiplicities, azimuthal and eta correlations
  - ➔ correlations of central with forward jets

Multi-Parton Interactions at LHC

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

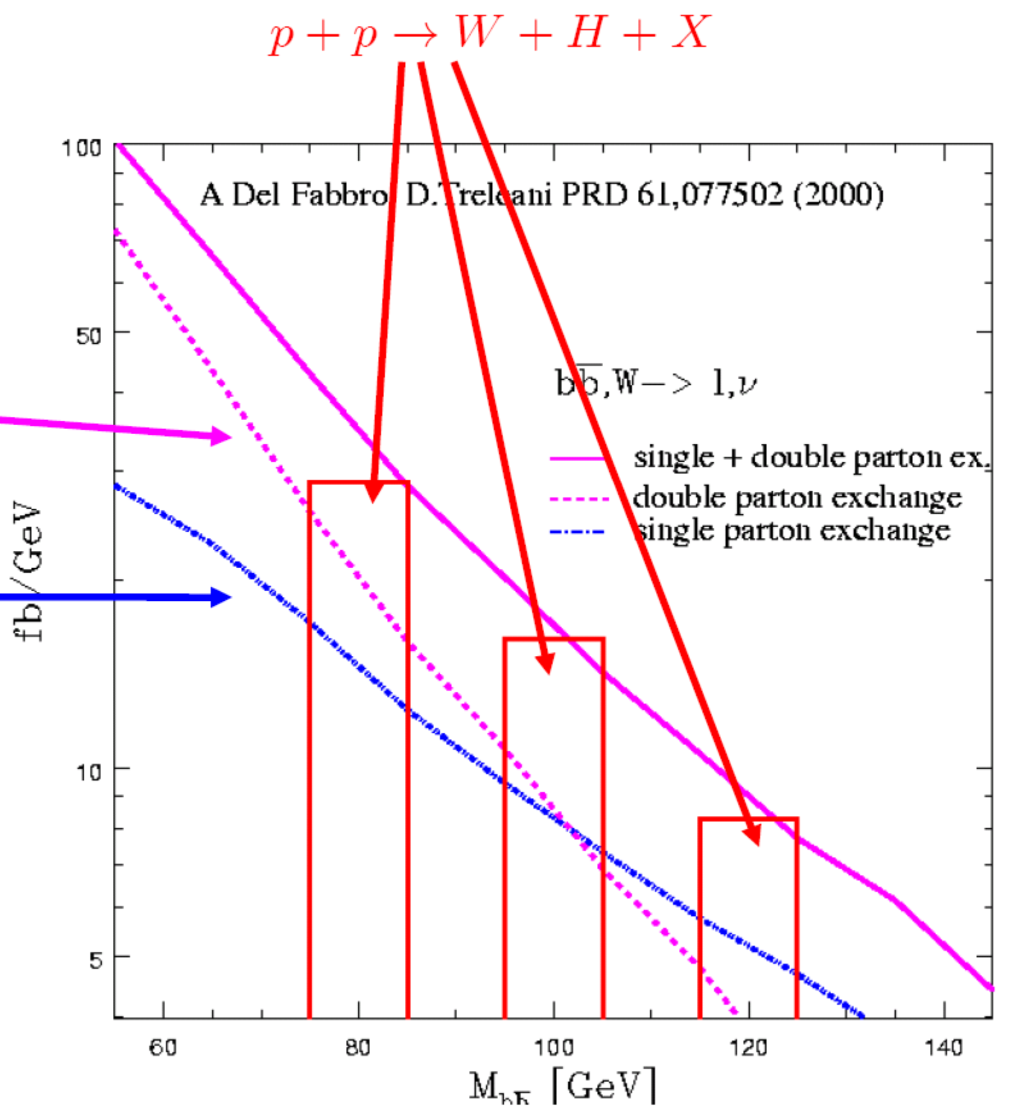
with $W \to l\nu, \quad H \to b\bar{b}$

- Double parton scattering:

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

$p + p \to W + X$

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



Lessons from HERA

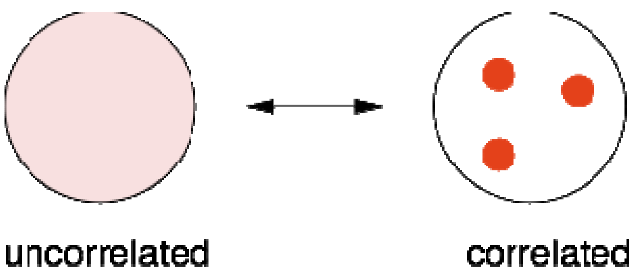
- inclusive cross sections are "relatively easy" to measure and to calculate
- the challenge is in the details of the final state:
  - still no satisfactory description of
    - forward jets, multi-jets, mini-jets etc

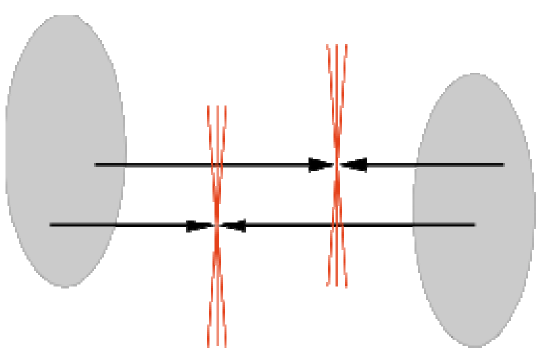
- important to understand within the same measurement and calculation:
  - total xsection
  - diffractive xsection
  - multi-jet xsection at small and medium x
  - minijet xsectons at small pt ~5 - 20 GeV

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

Mark Strikman, Penn State University

Correlations: nucleon parton structure via multiple collisions



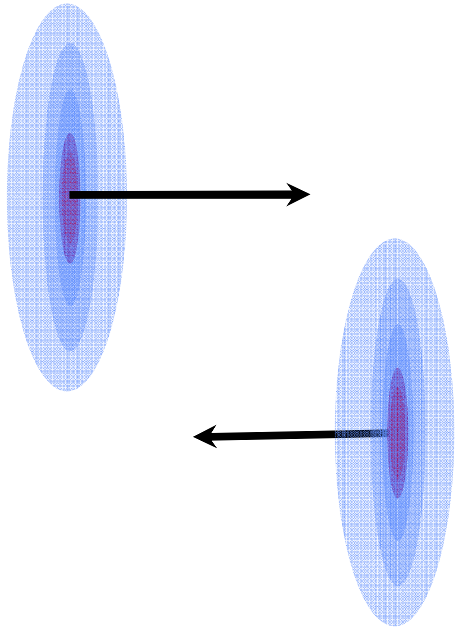


Indications of large positive transverse plane correlations from analysis of the CDF and D0 cross section pp → 3 jets + γ

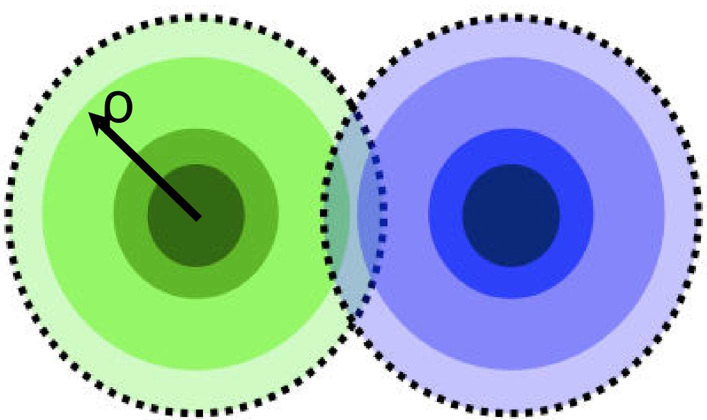
using information about nucleon GPDs

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

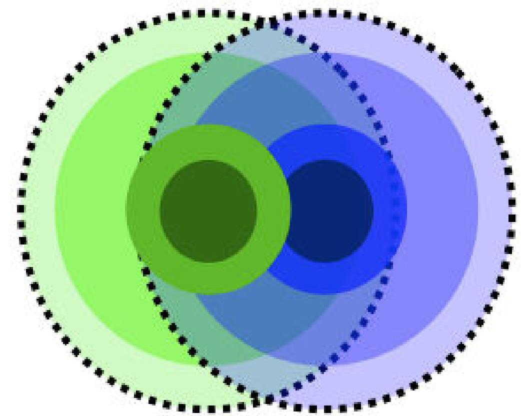
MPI are dominated by collisions at small b < 0.7 fm



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



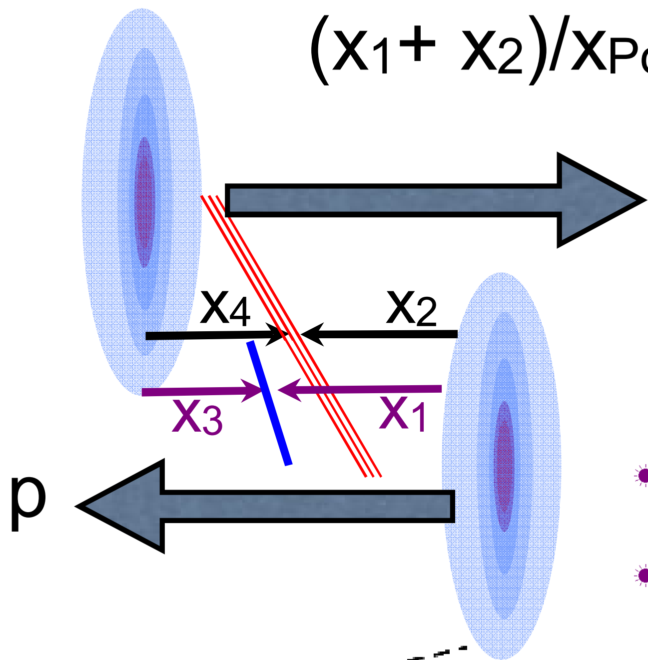
Peripheral pp



Central pp

Consider pp $\rightarrow$p + X (sd)

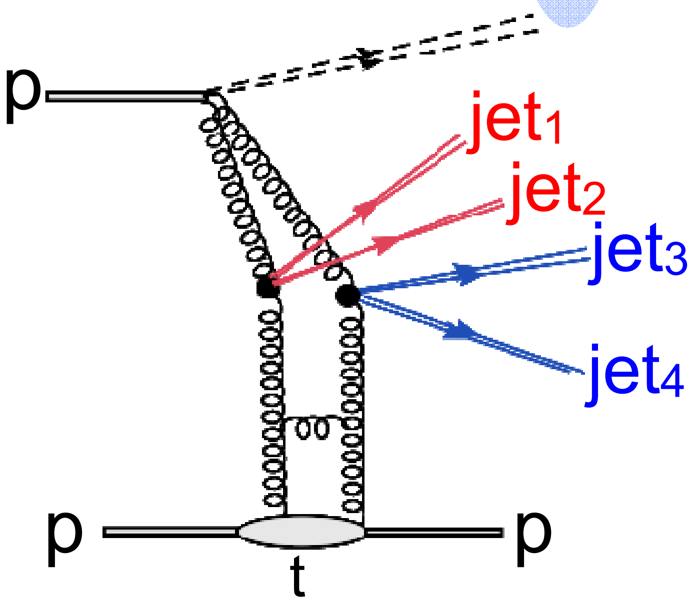
$(x_1 + x_2)/x_{Pom}$ distribution change with t



X = 4 jets + Y

Questions:

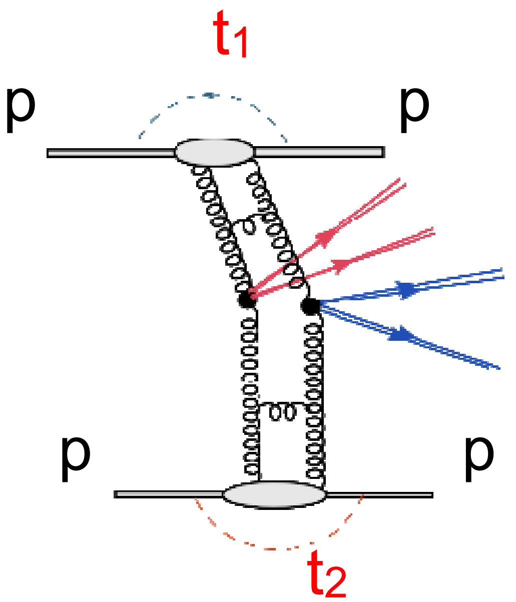
- *Is distribution in x_1, x_2 product of two GPDs*
- *Absolute rate - sensitive to transverse size of the “Pomeron” exchange - smaller size - larger cross section.*
- Is there dependence on t of x_1, x_2 *distributions:* large t closer to perturbative regime harder spectrum in x_1+x_2
- Large $-t >$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



Is there a peak near $\delta(x_1+x_2 - x_{Pom})$?

Consider double Pomeron reaction

$pp \rightarrow p\ p\ + X$



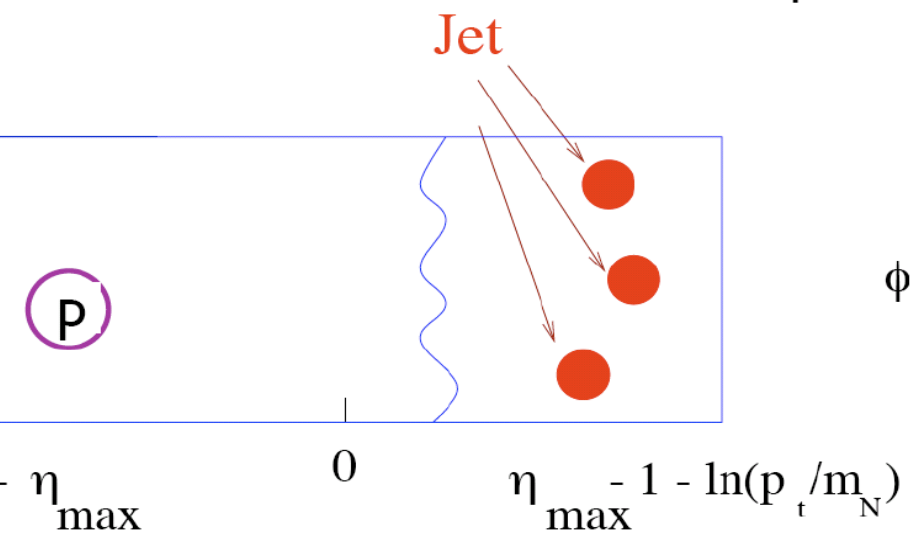
and compare with single diffraction

X=4 jets +Y; 4 jets

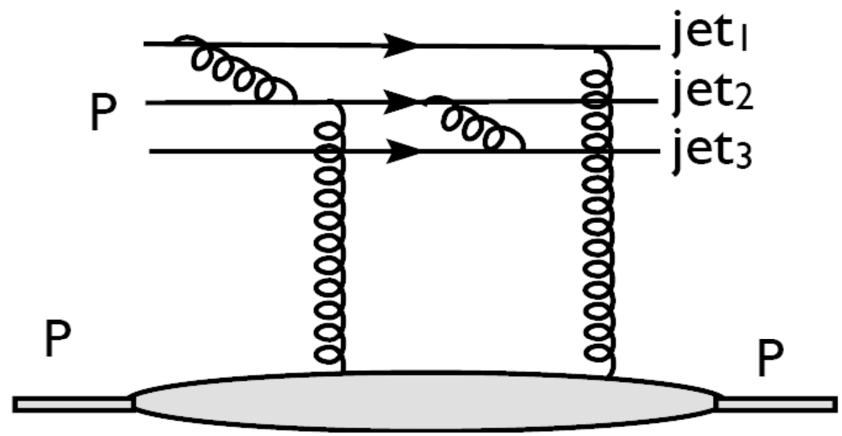
Are double diffractive PDFs the same ?

- relative rates in (1) and (2) - is gap survival becomes larger for larg 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 - $\pi A \rightarrow$ 2jets + A (good agreement with our predictions)



Lego plot for 3 jet coherent production

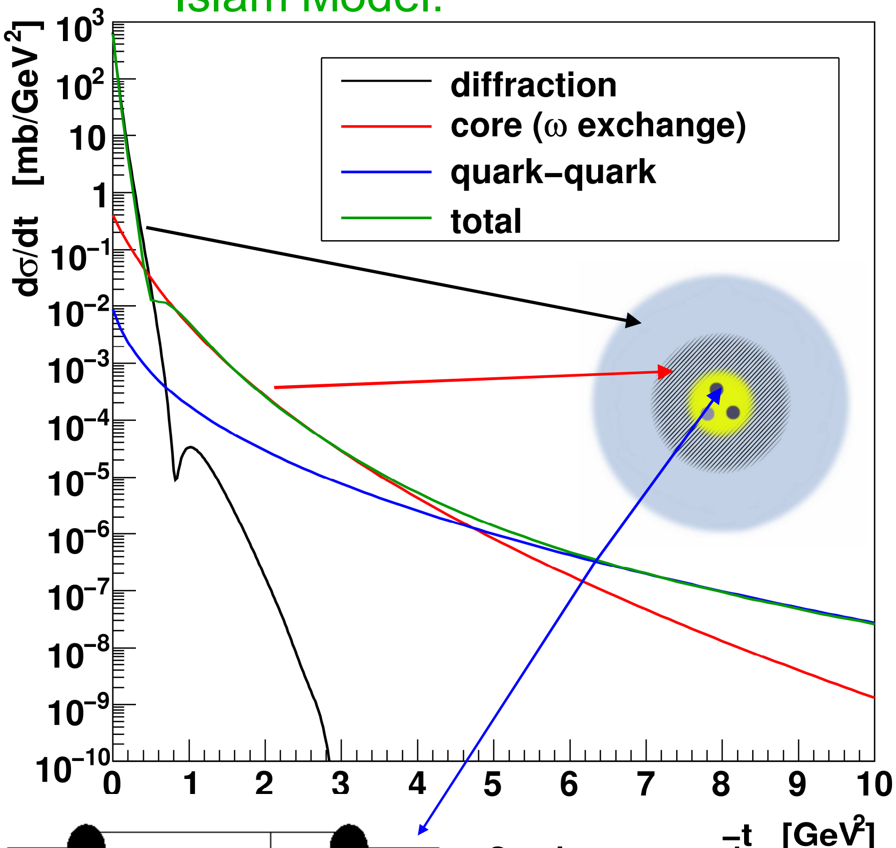


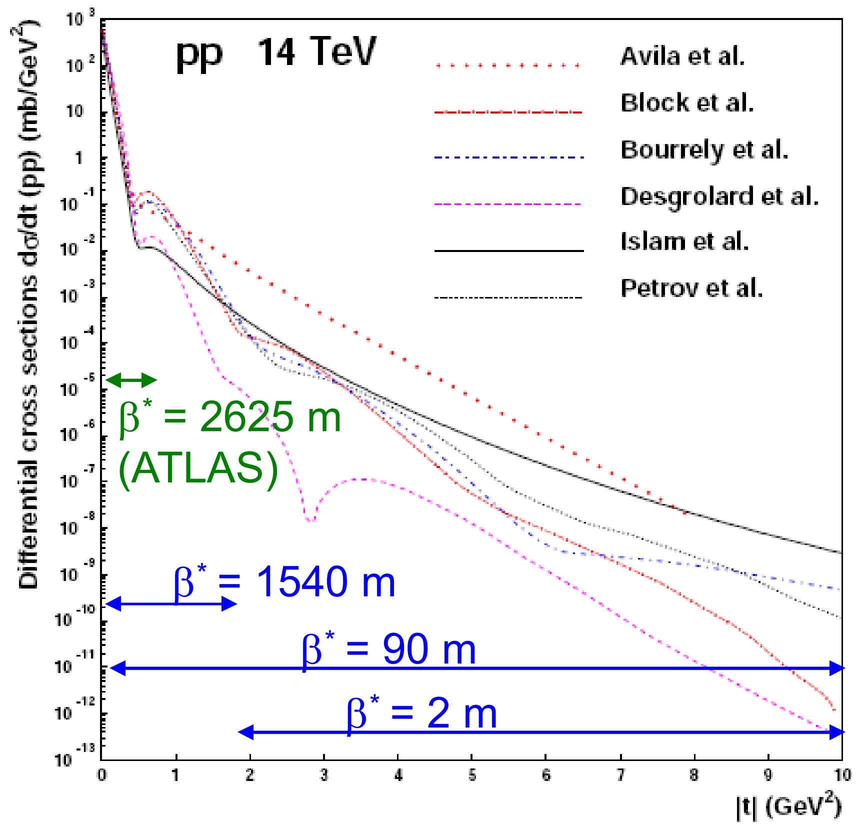
pp → leading neutron + 2 jets + p

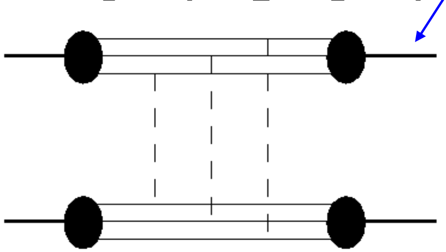
Analog of $\pi A \rightarrow$ 2jets + A   better acceptance?

Elastic pp Scattering at 14 TeV: Model Predictions

Islam Model:







3-gluon exchange at large |t|:

$$\frac{d\sigma}{dt} \sim t^{-8}$$

Big uncertainties at large |t|: Models differ by ~ 3 orders of magnitude!

TOTEM will measure the complete range with good statistics

String/Gauge Duality: (AdS/CFT Corresp.)

Pomeron in QCD associated with a reggeized Graviton is dealt in a unified single step

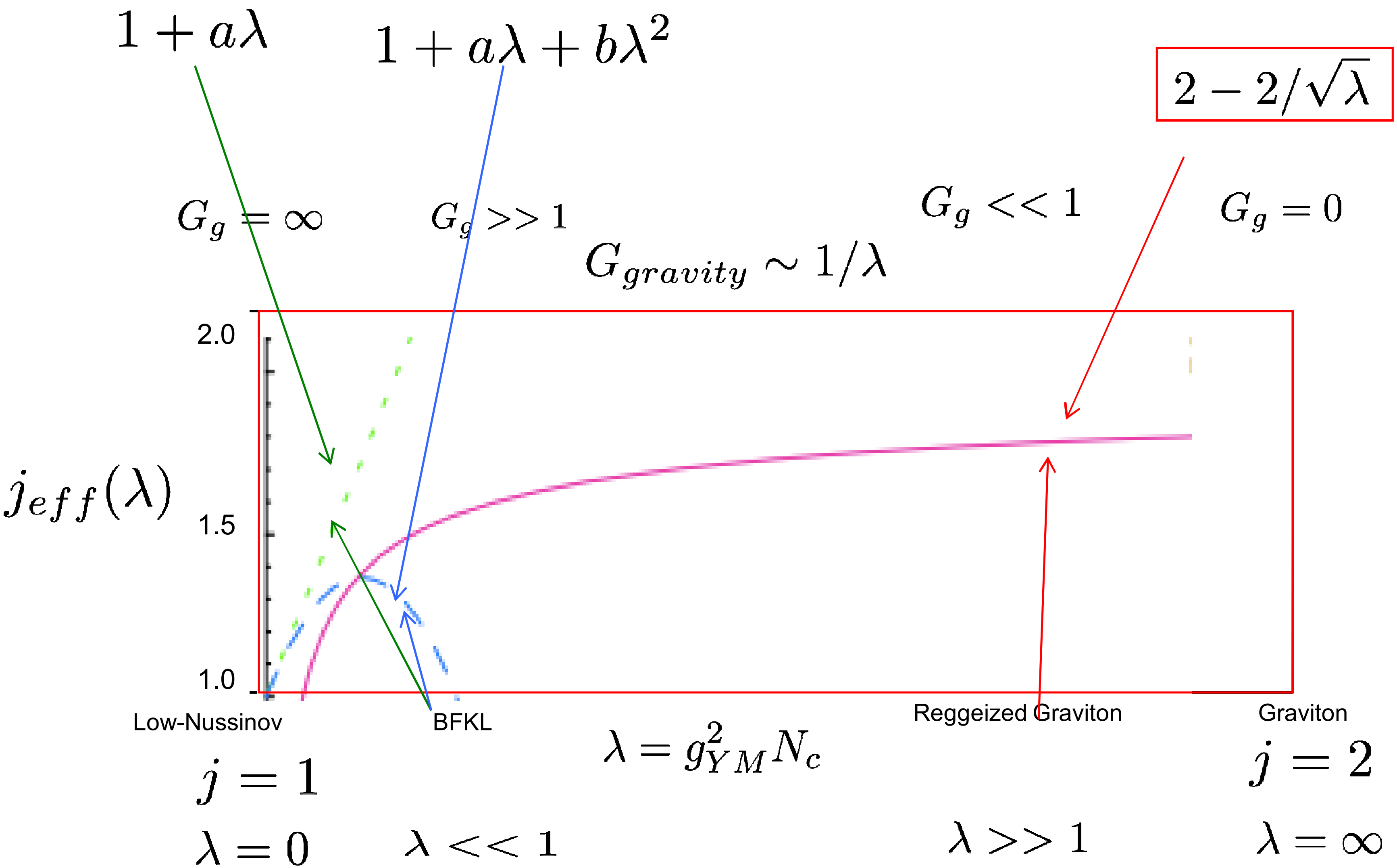
4-Dim Gauge Theory, with coupling: $\lambda = g_{YM}^2 N_c$

Duality

Gravity on 5-dim AdS space, with coupling: $G_{gravity} \sim 1/\lambda$

Weak coupling for QCD: $\lambda << 1$ ⟺ Strong coupling Gravity

Strong coupling for QCD:
Gauge theory QCD $\lambda >> 1$ ⟺ Weak coupling Gravity
Geom. theory


$1 + a\lambda$
$1 + a\lambda + b\lambda^2$
$2 - 2/\sqrt{\lambda}$
$G_g = \infty$
$G_g >> 1$
$G_g << 1$
$G_g = 0$
$G_{gravity} \sim 1/\lambda$
2.0
1.5
1.0
$j_{eff}(\lambda)$
Low-Nussinov
BFKL
Reggeized Graviton
Graviton
$\lambda = g_{YM}^2 N_c$
$j = 1$
$j = 2$
$\lambda = 0$
$\lambda << 1$
$\lambda >> 1$
$\lambda = \infty$

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.

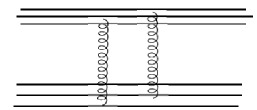
$$A(s,t) = g_s^2 A_1(s,t,\lambda) + g_s^4 A_2(s,t,\lambda) + \cdots$$

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

Perturbative QCD $\lambda \sim 0$

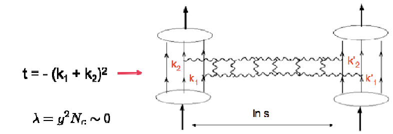
Two gluon exchange (Low-Nussinov Pomeron!)

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



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

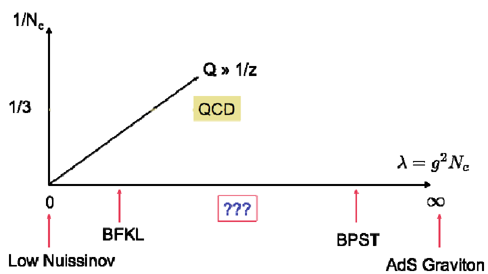
BFKL: Balitsky & Lipatov; Fadin,Kuraev,Lipatov'75



- Sum diagrams 1st order in $g^2 N_c$ & all orders $(g^2 N_c \log s)^n$
- 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

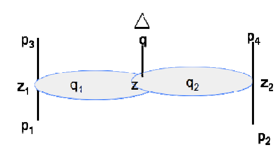
Key new results from AdS/CFT:

- A single Pomeron Propagator incorp. both Soft and Hard components,
- Eikonal summation over AdS3:

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

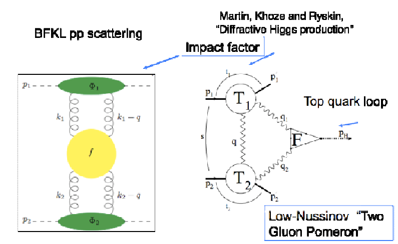
$$\chi(s, x^\perp - x'^\perp, z, z') = \frac{g_0^2 R^4}{2(zz')^2 s} \mathcal{K}(s, x^\perp - x'^\perp, z, z')$$

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)



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

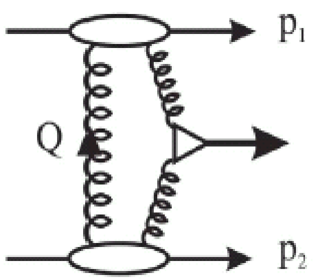
* Wait for surprises!

*Conventional wisdom all needs to be re-examined!

Discussion session EDS 09

Karsten Eggert

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

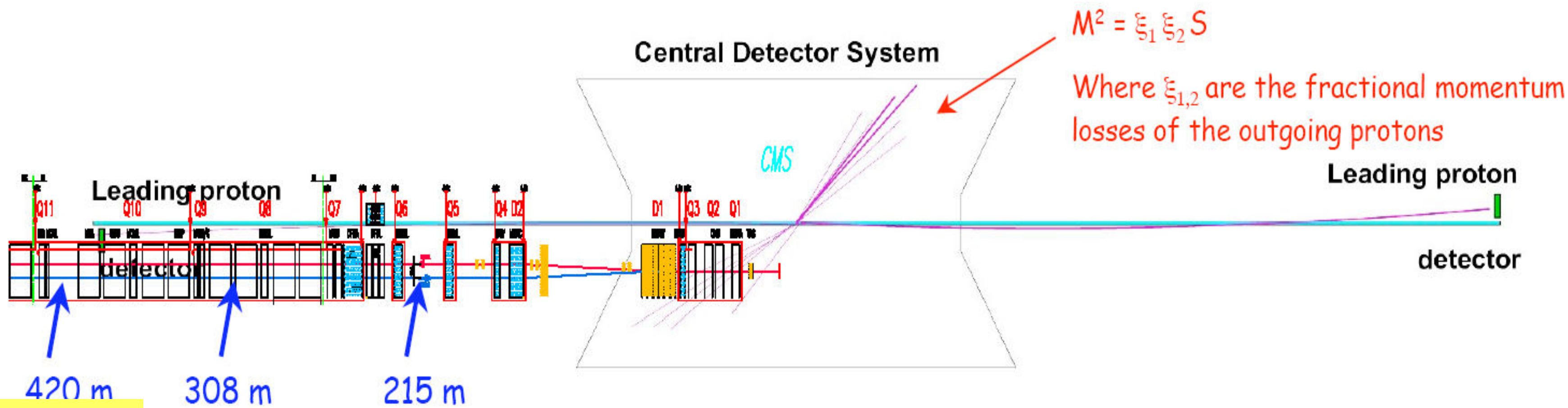
Be it FP420, Roman Pots, Hamburger Pipe, IP3
We are sweating TERRIBLY today to get it in!

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)

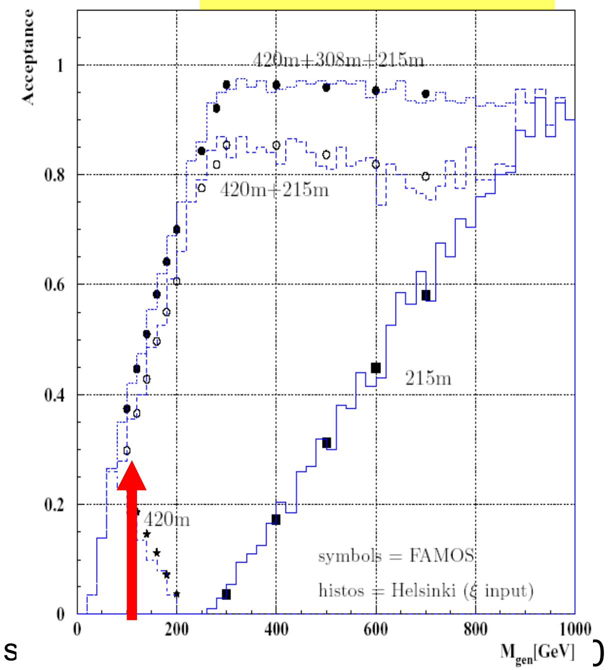
Understanding of halo
Feedback on background
combined effort , vertex,
alignement, optics....

FP420: Detectors at 420m (Albert de Roeck)



FP420

TOTEM (ATLAS/RP220)



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

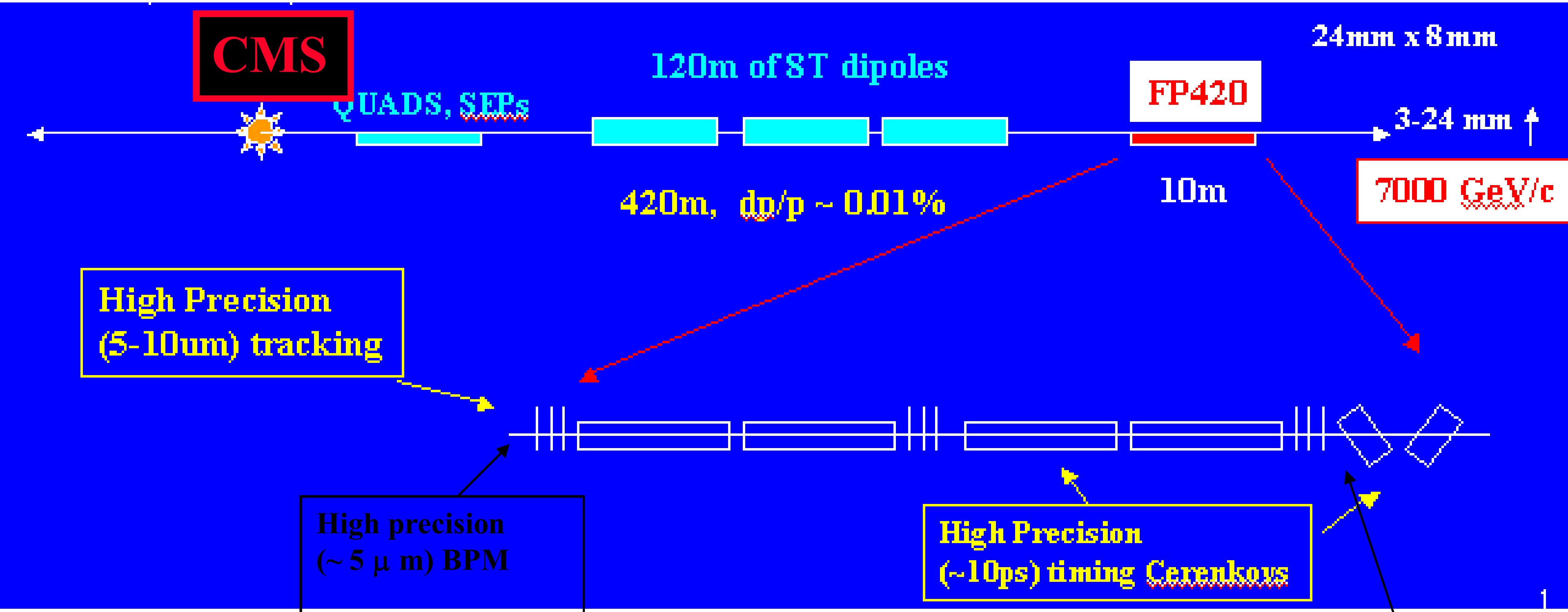
215m: $0.02 < \xi < 0.2$

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

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

FP420 R&D Study

Schematic of Extremely High Precision Proton Spectrometer

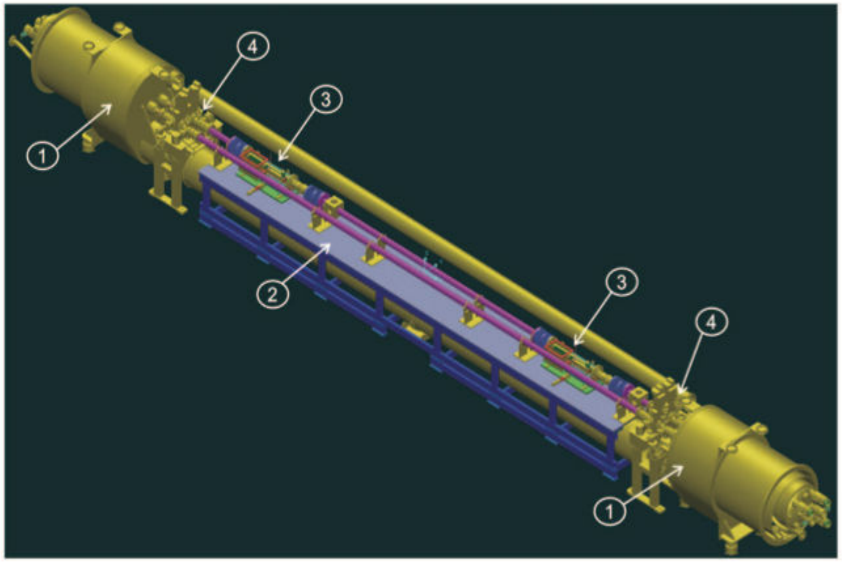


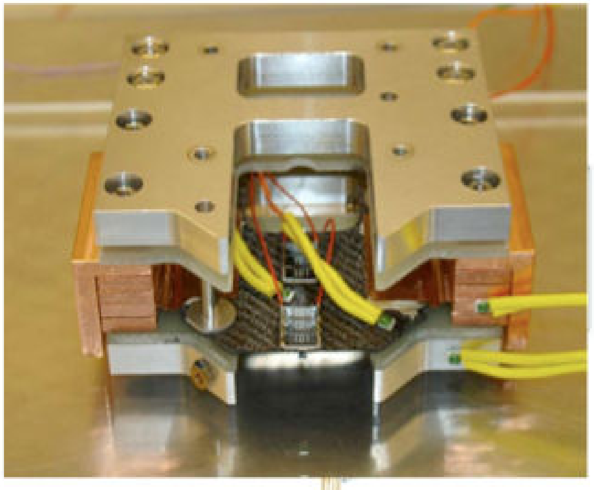
High precision
(~ 5μm) BPM

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

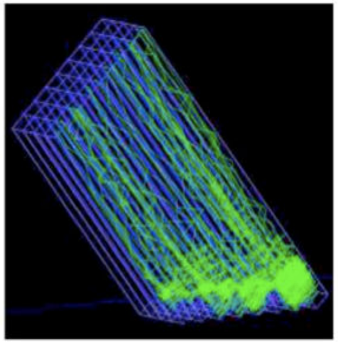
FP420 Detectors





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?

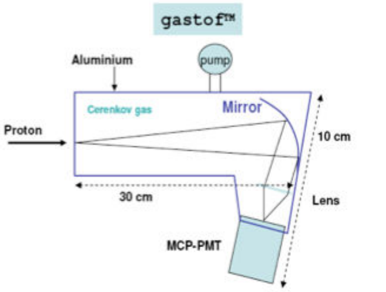
Quartic (FNAL, Alberta, UTA)



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 $\approx$ 3 ps

Hamamatsu R3809U-50 with 6 μm pores

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

Synergy

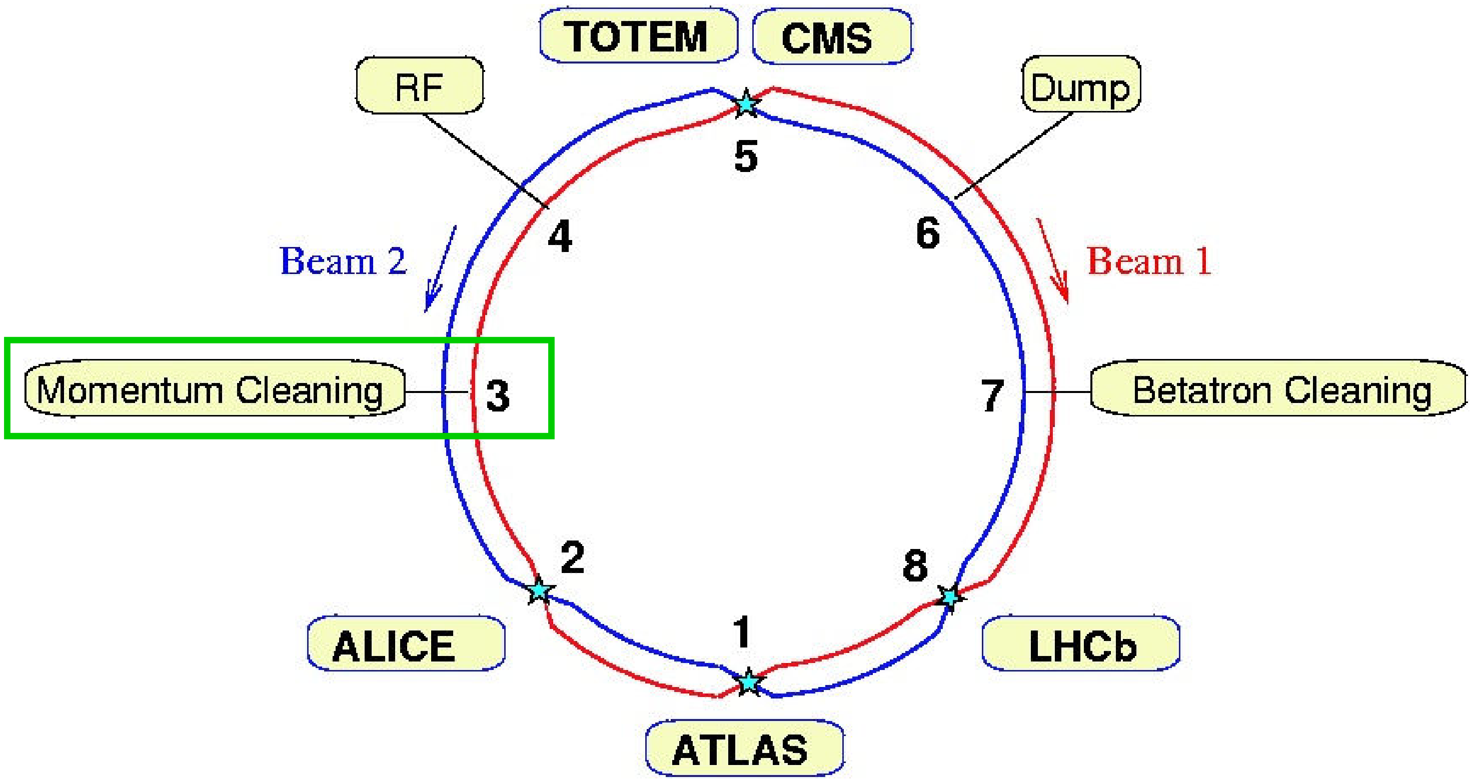
- ATLAS/CMS: common R&D, interaction with the machine, simulation studies, trigger studies,…
- TOTEM/ALFA/other near beam detectors?
  - operational experience with near beam detectors, backgrounds & calibration
  - Further detector R&D? (timing, tracker…)
  - Central detector + Forward detector studies
  - 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 lower |ξ| values (Hubert Niewiadomski)

Good acceptance and momentum resolution for diffractive protons needs:

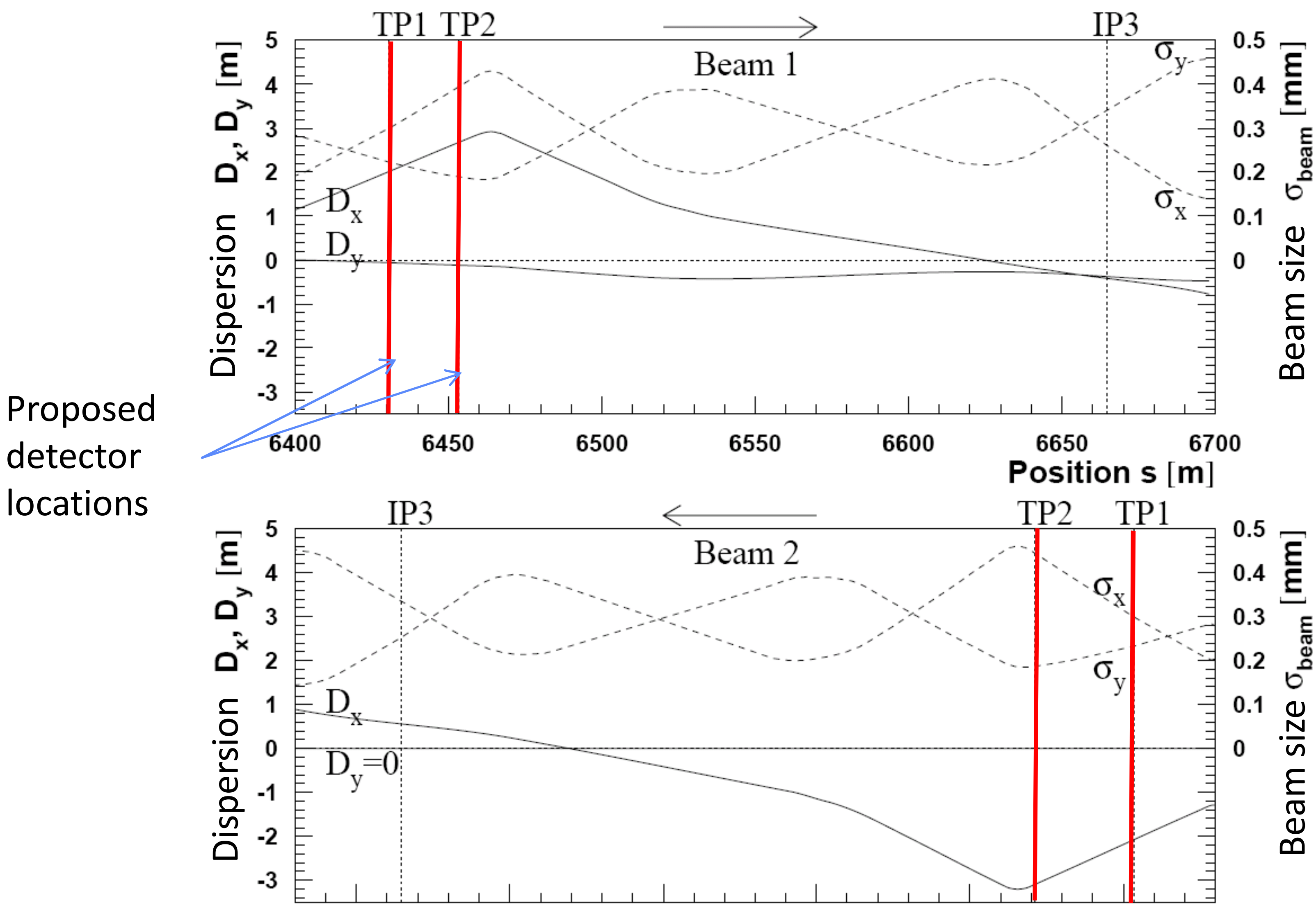
- **Large dispersion D, a few meters, $\Delta x \cong \xi \cdot D$**
- **Small beam size, beam cannot be aproached closer than ~10σ**

Where in the LHC are these requirements best fulfilled?

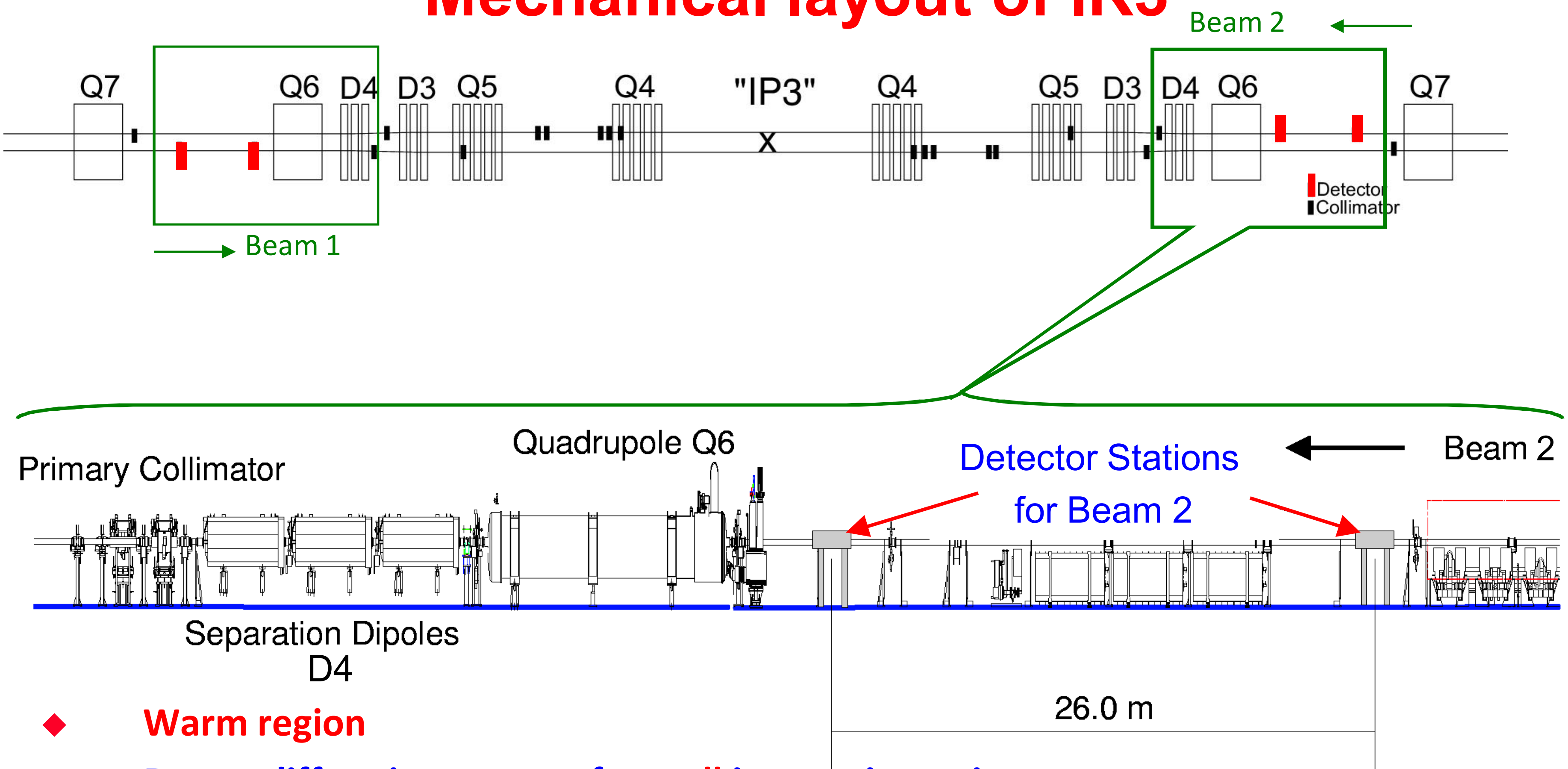


Hubert Niewiadomski, TOTEM, EDS'09

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

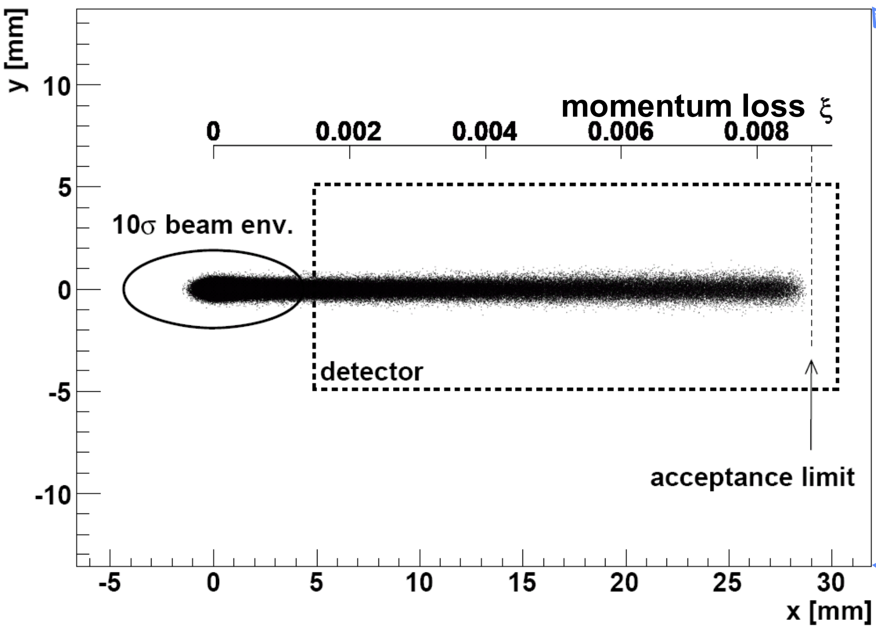


Mechanical layout of IR3

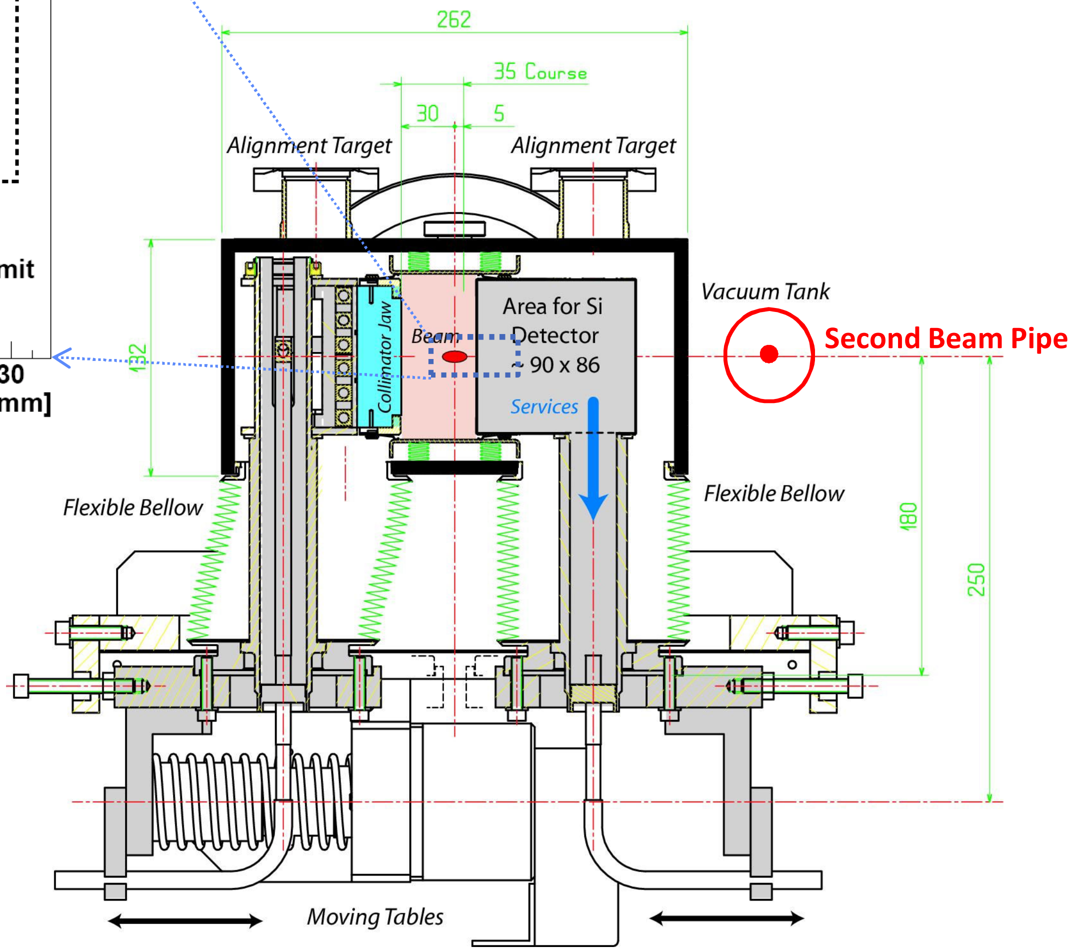


- **Warm region**
- **Detect diffractive protons from all interaction points**
- **Advantage for machine protection:**
  - **collimator downstream of detectors absorbs possible showers**
- **Diffractive proton rate of ~3 MHz @ L=10^{34} hits Q6 magnet (~5MHz quench limit)**
  - **some additional collimator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

Technical solution: combined collimator + detector



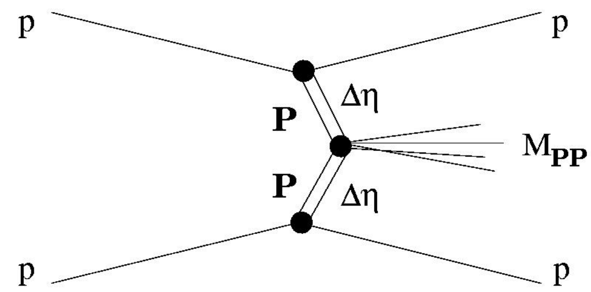
IP 3 hit distribution in a plane
transverse to Beam 2
for DPE events @ IP5



Hubert Niewiadomski, TOTEM, EDS'09

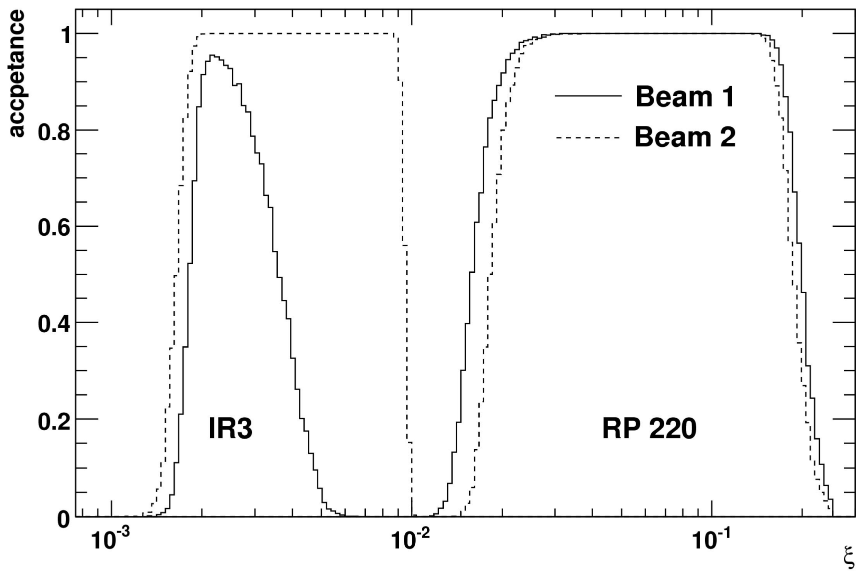
Proton acceptance of combined IR3 and RP220 insertions

Double Pomeron Exchange

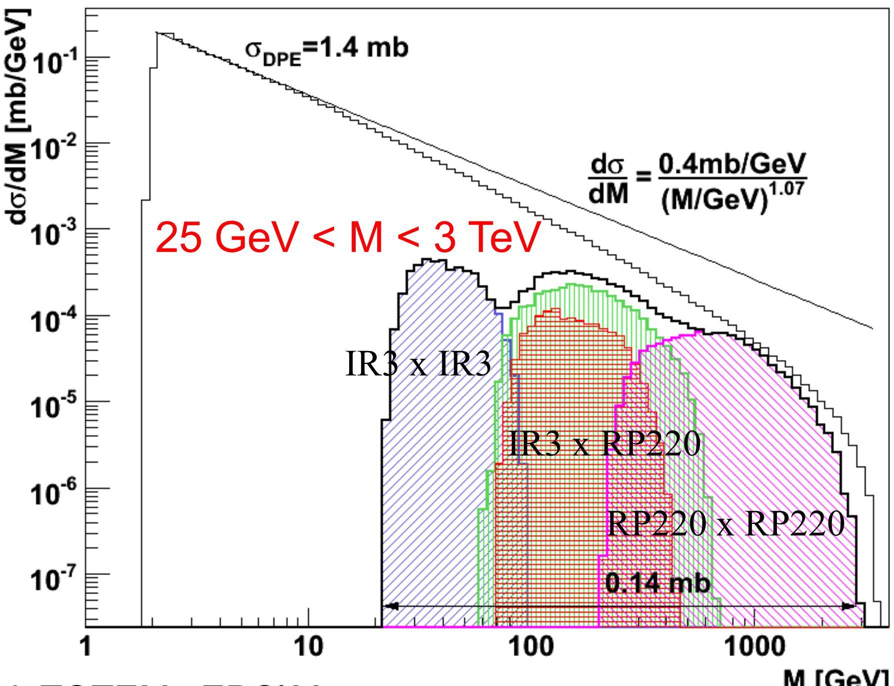


$$M_{PP}^2 = \xi_1\ \xi_2\ s$$

ξ-Acceptance, β^*=0.5 m, p=7 TeV



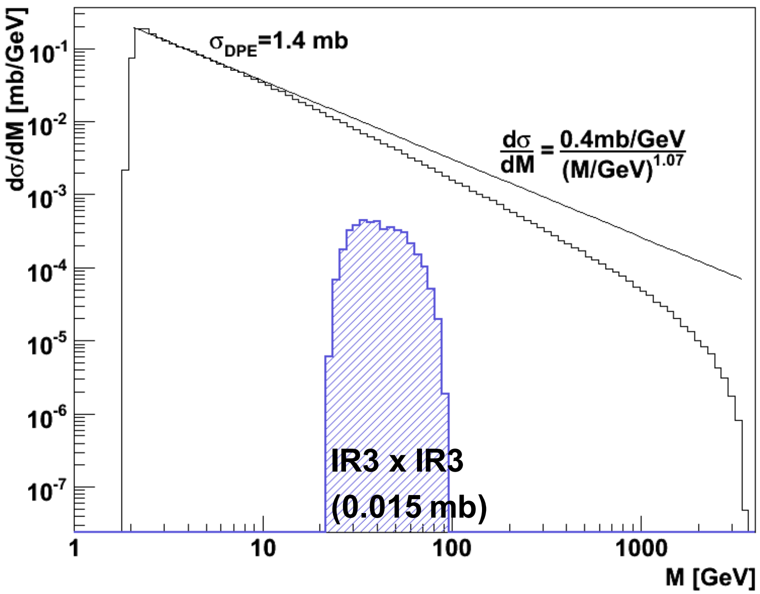
DPE Mass Spectrum with Detector Acceptance

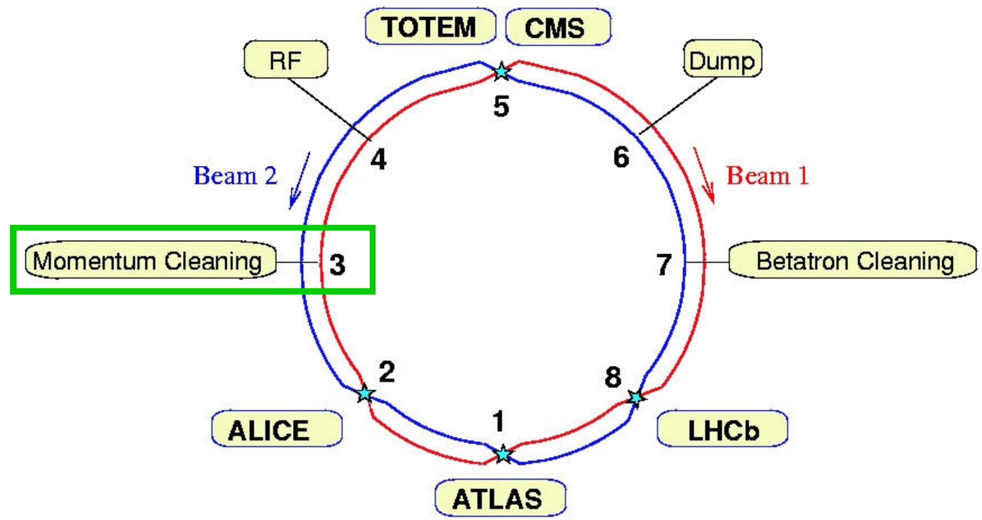


Resolution σ (ξ) ~ 10^{-4}

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

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.

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 $\sqrt{s}$ → larger σ, $\Delta\eta$ & 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 ➔ $d\sigma/d\Delta\eta$ vs. E_T^{jet}➔ BFKL, Muller-Navalet

Dark Energy

<u>Non-diffractive interactions</u>

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

<u>Diffractive interactions</u>

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?

Rapidity Gaps in Fireworks