Summary of EDS Blois 2013

Michael Albrow, Fermilab

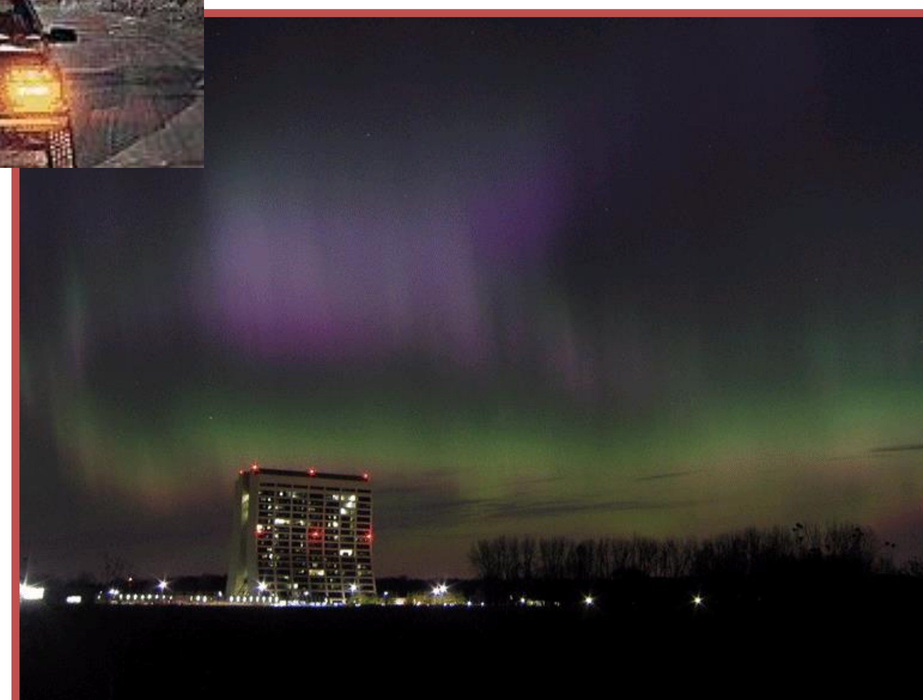
[redacted]

Highlights of EDS Blois 2013

Highlights of EDS Blois 2013

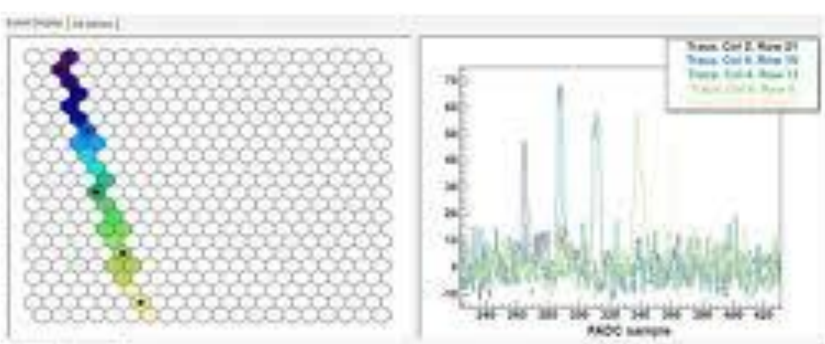
Gzillions of very low energy particles

Aurora over Fermilab



One very high energy particle
make a shower

Cosmic ray shower in Auger fluorescence



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What little I remember (+ some)

Risto Orava to me: Don’t say the word “Pomeron”
Don’t say “rapidity gap”

This week:

	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	**Total and elastic scattering**	**Soft diffraction**	**CEP and new physics with rapidity gaps**	**Ultra-peripheral physics**	**Cosmic rays**
Afternoon	**Low-x QCD**	**Hard diffraction**		**Heavy ions**	

By here I got saturated, apologies to the heavy ion gang

And I cannot cover everything, apologies for not mentioning you

Emphasis on new(ish) experimental results
No cosmic rays (this morning's talks)

The REAL Strong Interaction

extended, strong coupling
non-perturbative

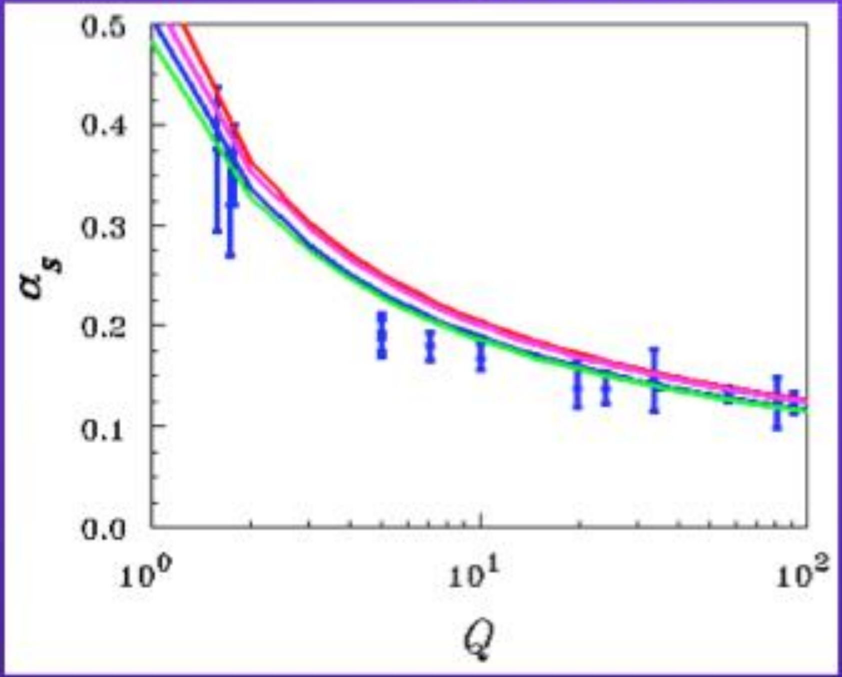
point-like, weak coupling
perturbative

Many approaches, none complete:

→ Lattice Gauge Theory
Small volume, hadron size

→ Regge Theory: Analyticity + Unitarity + Crossing Symmetry + Complex angular momenta

→ String models

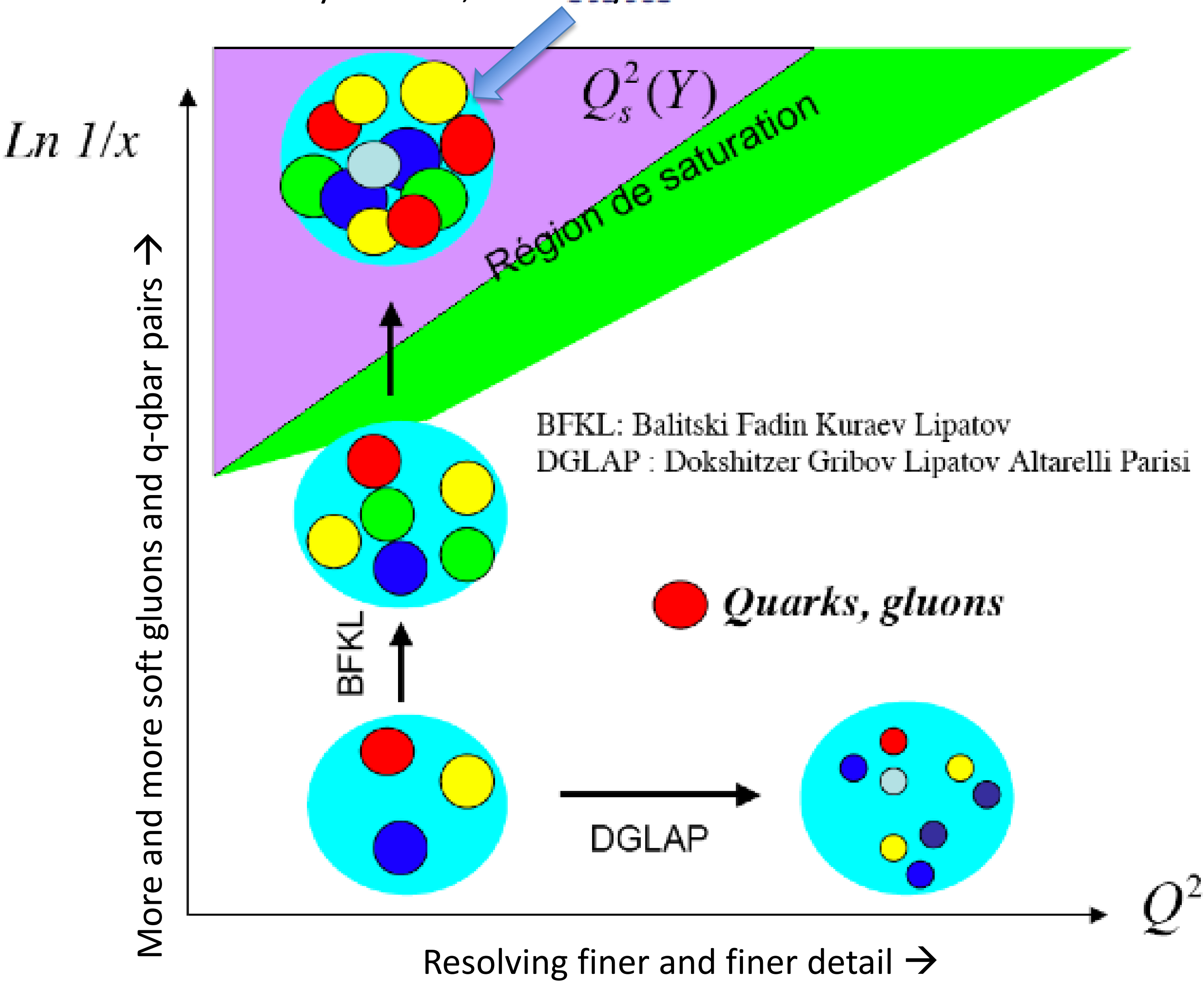


Want a complete understanding of S.I.

$Q^2 = 0 \rightarrow \infty$

Non-perturbative – perturbative transition

Funny cartoon, not really like that!



Bjorken: Low p_T is the frontier of QCD

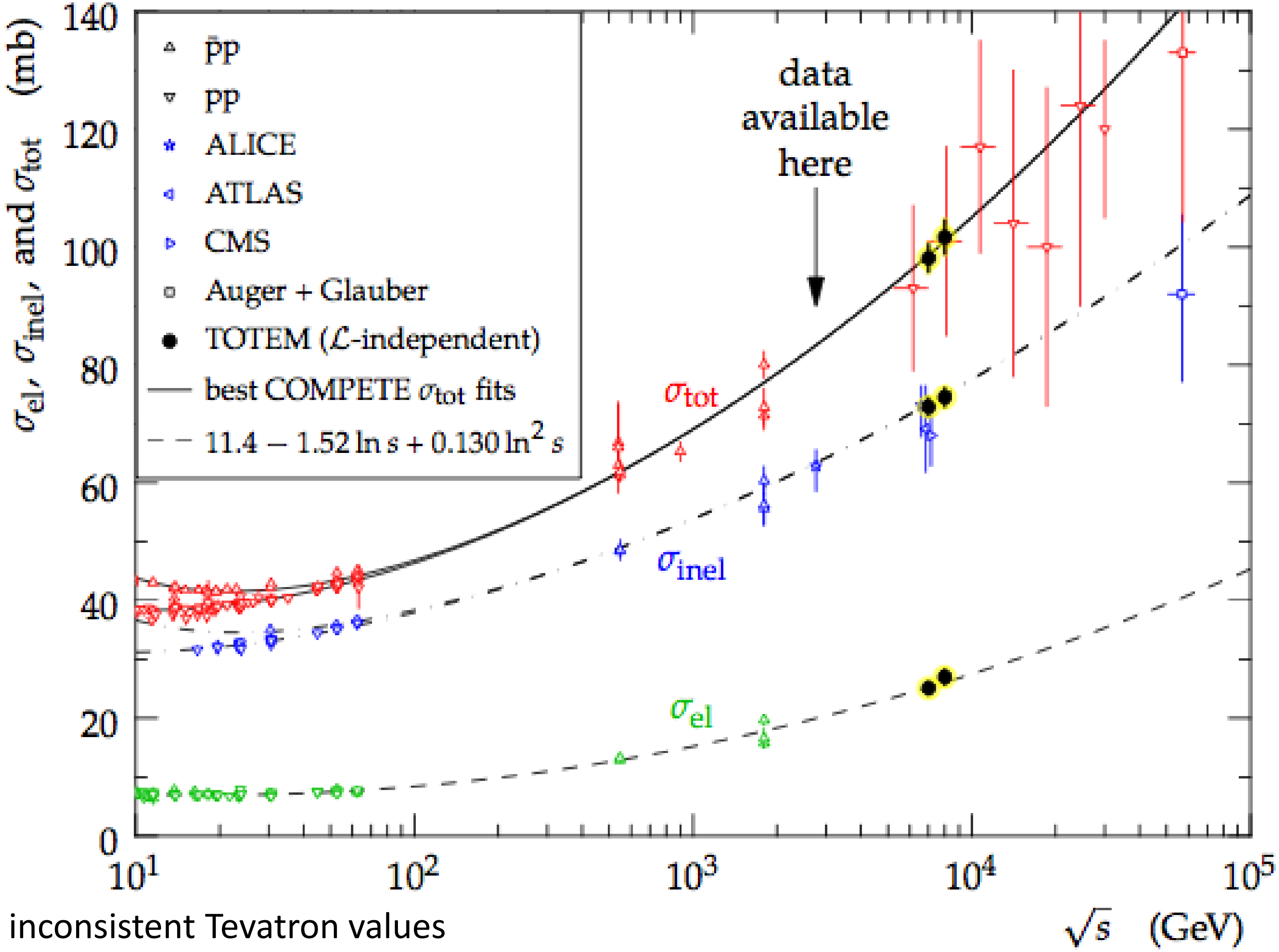
As p_T drops from 200 → 100 → 50 MeV what happens?
Larger distances: 1 fm → 4 fm
How do gluon fields in protons "cut off" ?

Multiplicity distributions of very low p_T particles, correlations, ...
Low-p_T cloud in special events

[Runs with reduced field, Si-only tracking, etc
..................absorption and multiple scattering is the limit]

Large impact parameter, b collisions

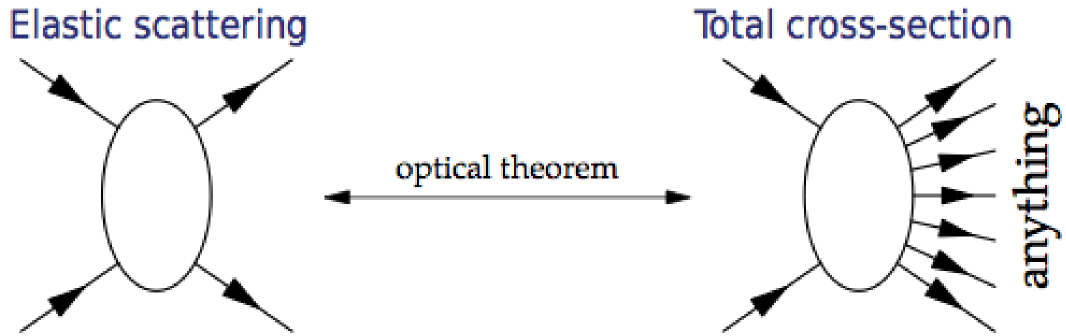
RHIC AA can measure b, how can we? Diffraction at small t pp and ppbar TOTAL CROSS SECTION with new LHC/TOTEM values



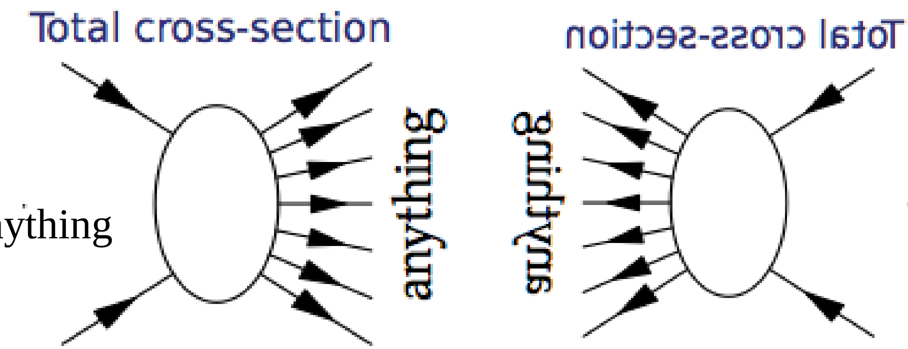
Fit splits inconsistent Tevatron values

Rise because α(t-channel exchange) > 1.0 (=pomeron dominance)

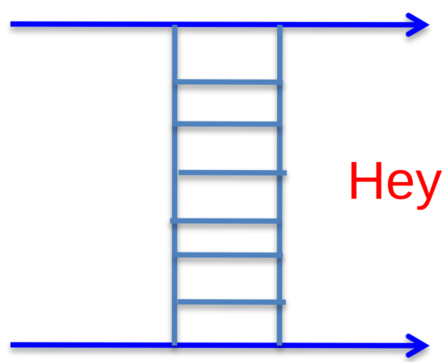
Laszlo Jenkovsky + showed good fit



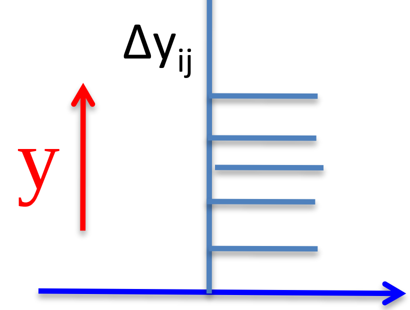
$T \quad \Sigma_{\text{anything}}$



CONTRACT



Hey Presto!

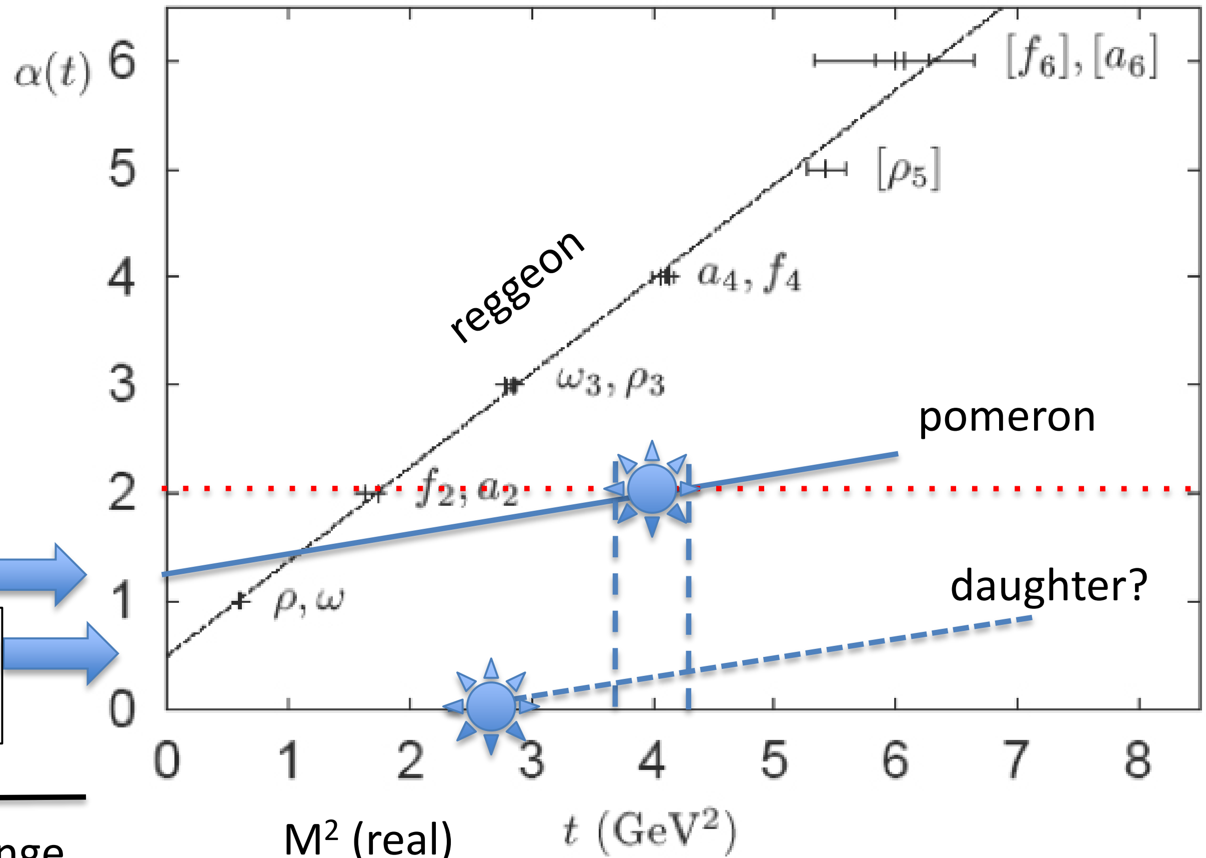


Multiperipheral Diagram

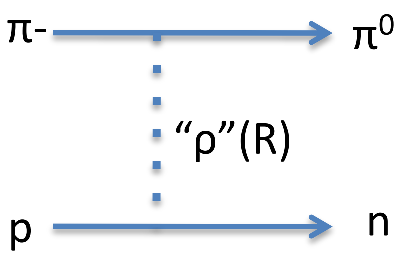
Reggeon shown
by Laszlo Jenkovsky,
pomeron added (me)

$\alpha_P(t=0) > 1.0$
σ's rising with Δy, s

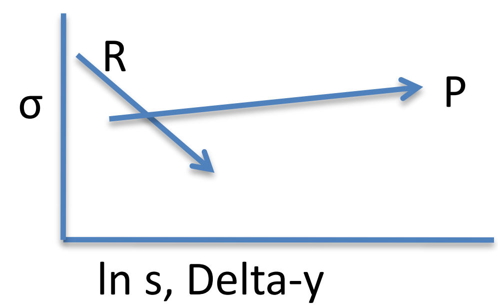
$\alpha_R(t=0) < 1.0$
σ's falling with Δy, s



t-channel exchange
t is negative



Expect a J = 2 glueball with M ~ 2 GeV
Scalar (J=0) glueball not on P trajectory.
"daughter trajectory" ?

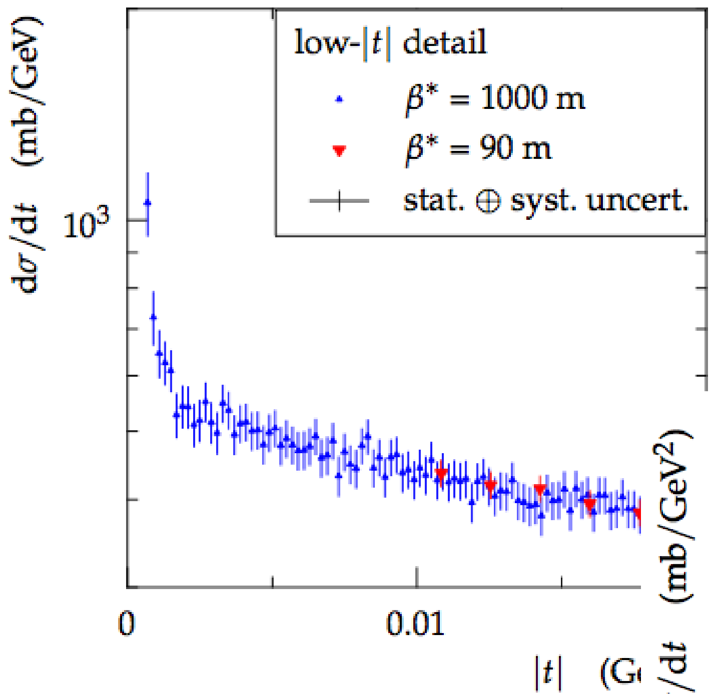


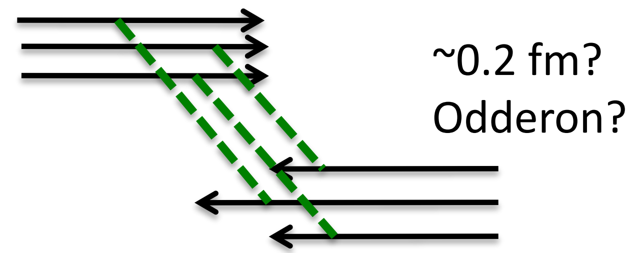
Jan Kaspar for TOTEM

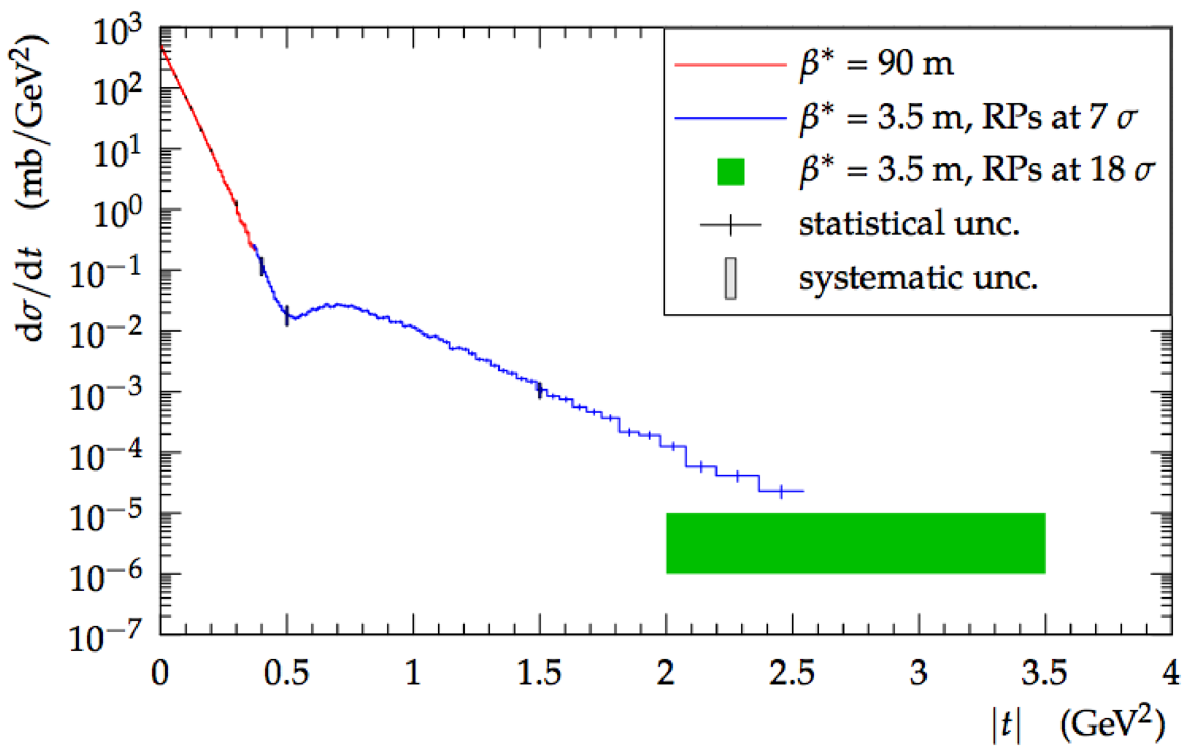
EDS

ELASTIC **FANTASTIC**

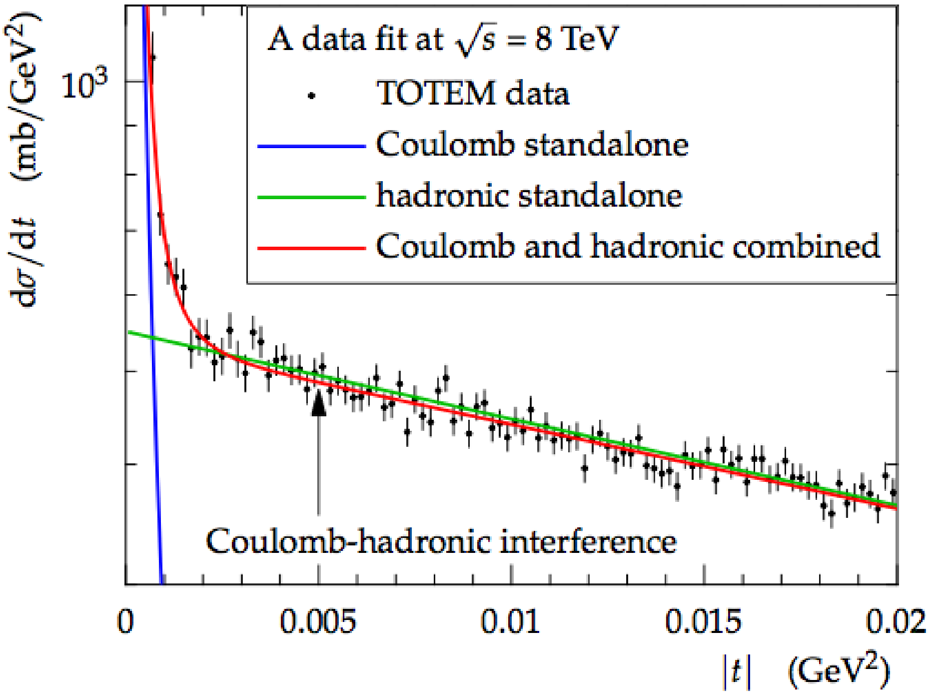
Into the Coulomb region
(large distances)
Out to the hard – t region
small distances : the “core”

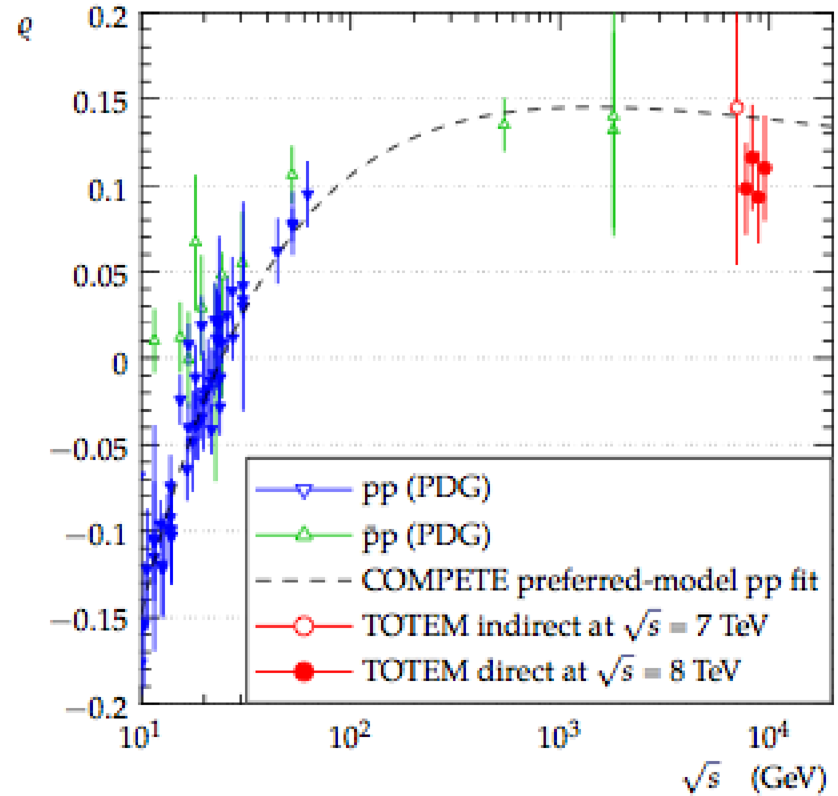






Jan Kaspar for TOTEM



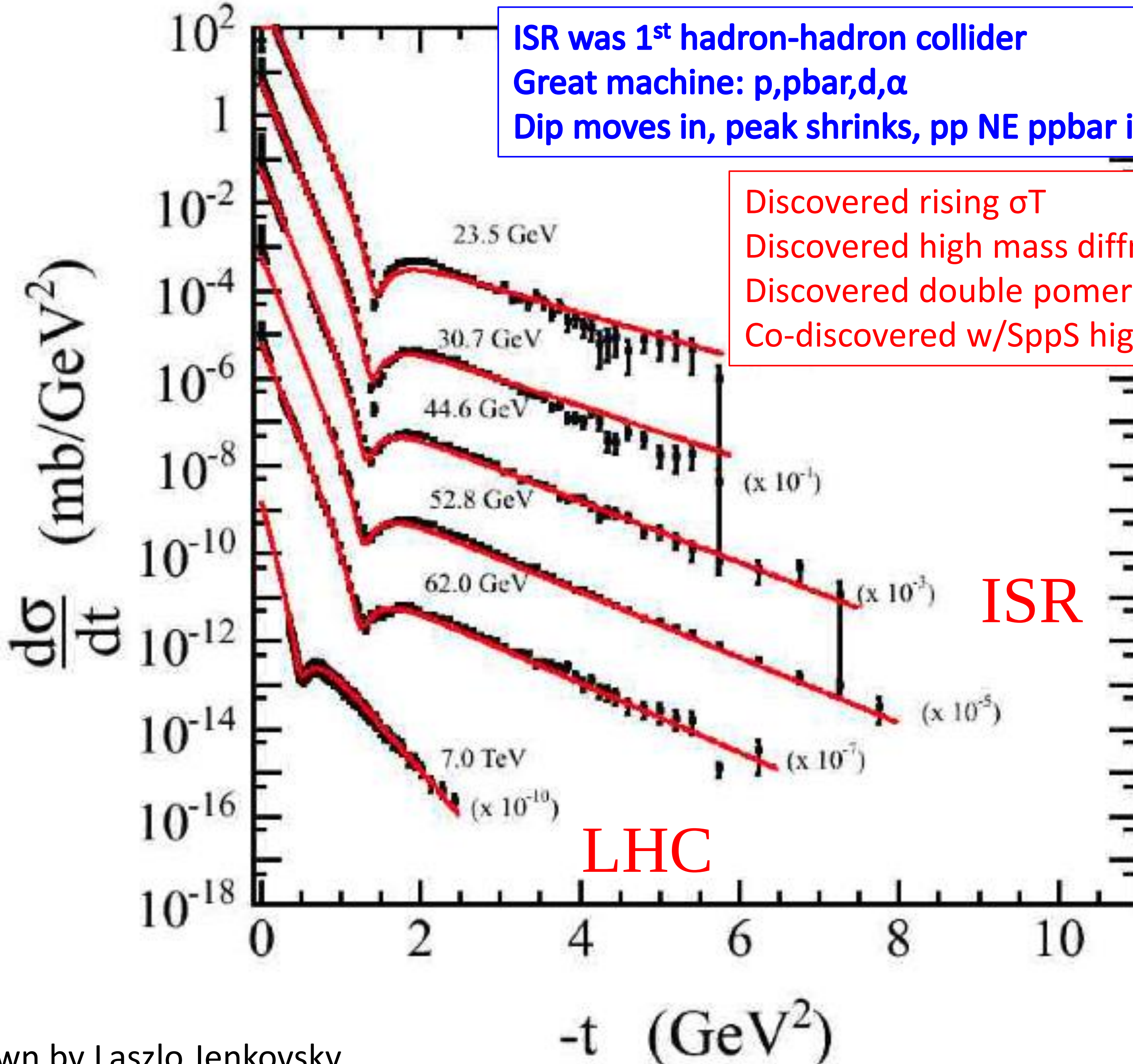


Through dispersion relations ρ = Re/Im tells you about the behaviour of σ_{TOT} at higher energies! It is constrained by analyticity of scattering amplitudes S(s,t).

First sign of ρ ➔ 0 at much higher s ?
Purely imaginary : saturation?

ISR was 1st hadron-hadron collider
Great machine: p,pbar,d,α
Dip moves in, peak shrinks, pp NE ppbar in dip region

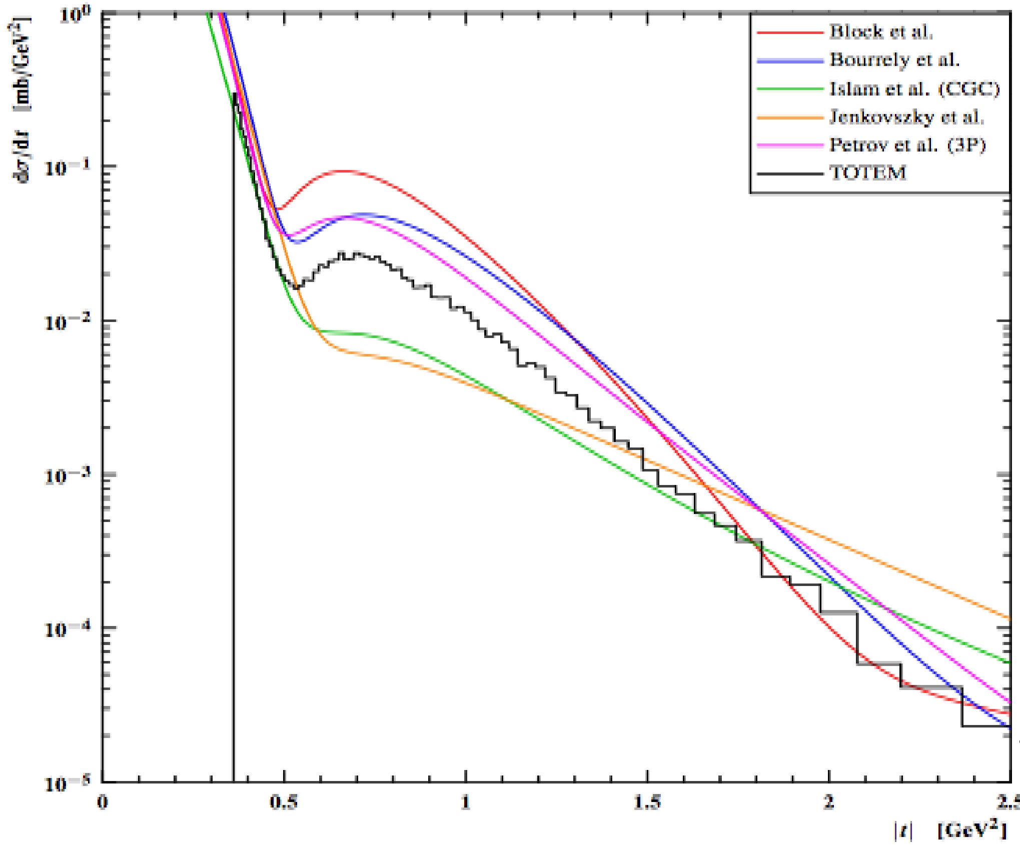
Discovered rising σT
Discovered high mass diffraction (>2 GeV)
Discovered double pomeron exchange
Co-discovered w/SppS high E_T jets



(Schopper)

Shown by Laszlo Jenkovsky

Shown many times:



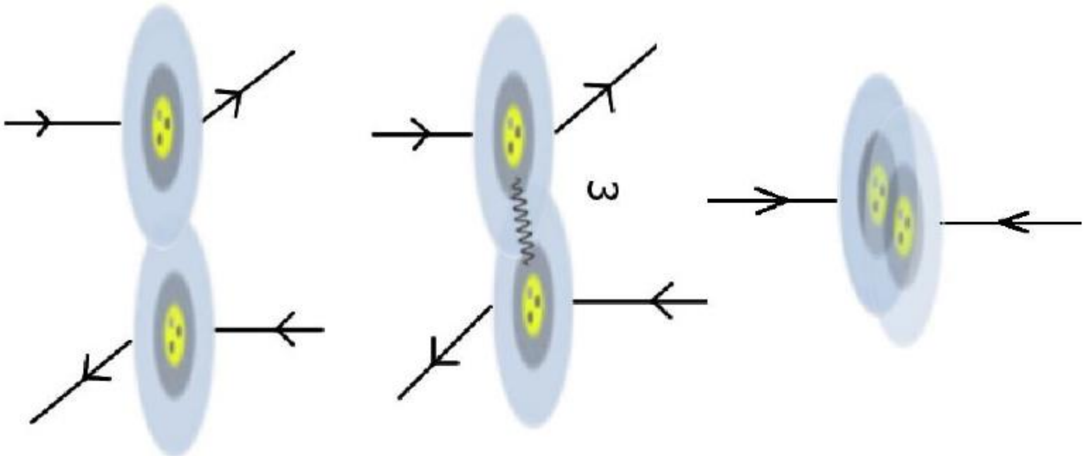
TOTEM, ALFA to extend this range

Nobody gets full marks especially around |t| = 0.5 – 2.0 GeV^2
... except the TOTEM experiment (we hope!)

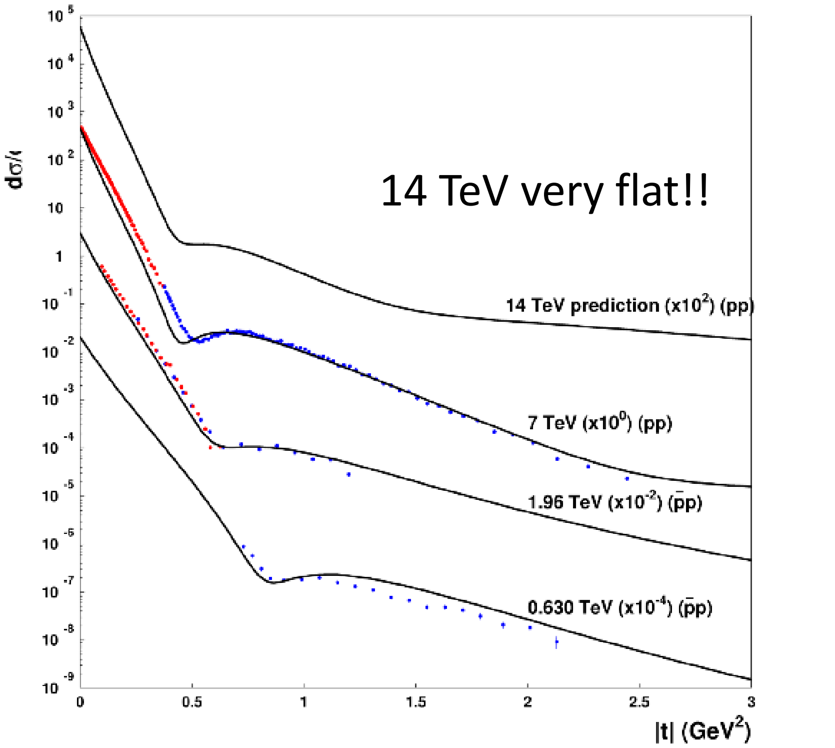
“Elastic scattering is the grandfather of all exclusive processes.”

Munir Islam:
Condensate enclosed chiral bag model

Michael Albrow
(Munir Islam told me to quote myself)



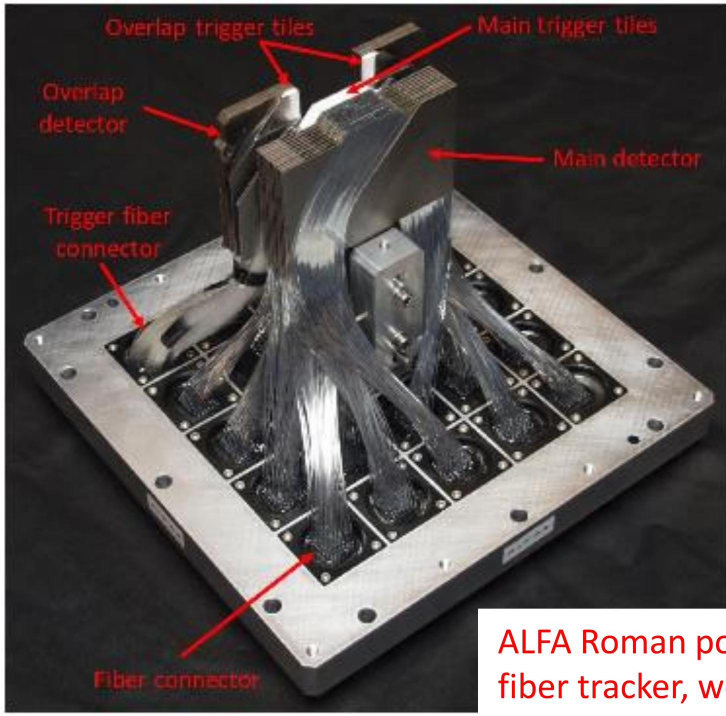
3 valence quarks in ~0.2 fm core
Shell of “baryonic charge”
Outer q-qbar condensate



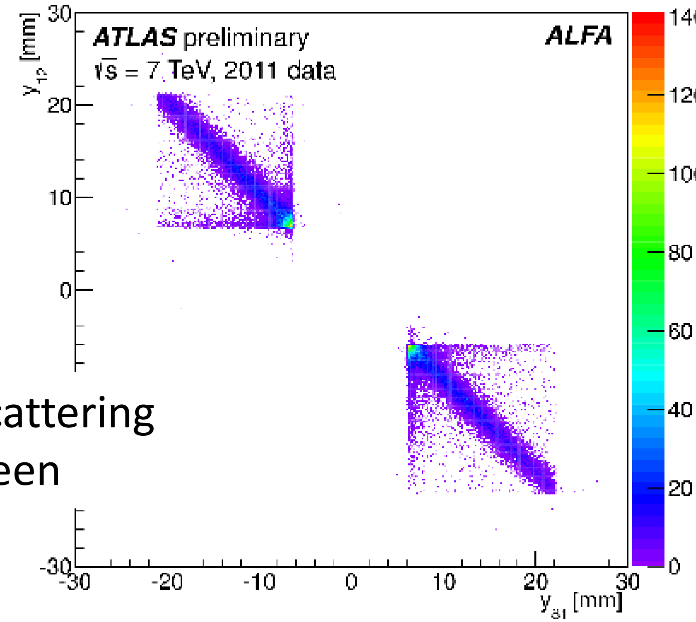
Can q-core be tested another way?
Drell-Yan only happens at small impact parameter
→ highest multiplicity events.
Double Drell-Yan enhanced, depends on core size.
Double parton scattering also, but jets from gg too

Samah Abdel Khalek: ALFA in ATLAS

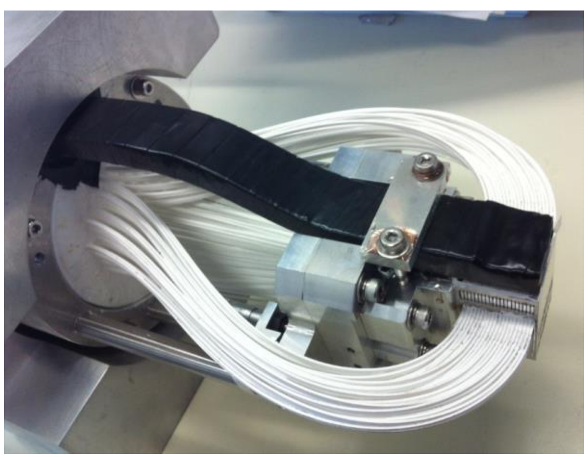
Small t elastics for luminosity measurement (calibrate L monitors)



ALFA Roman pot
fiber tracker, welcome!

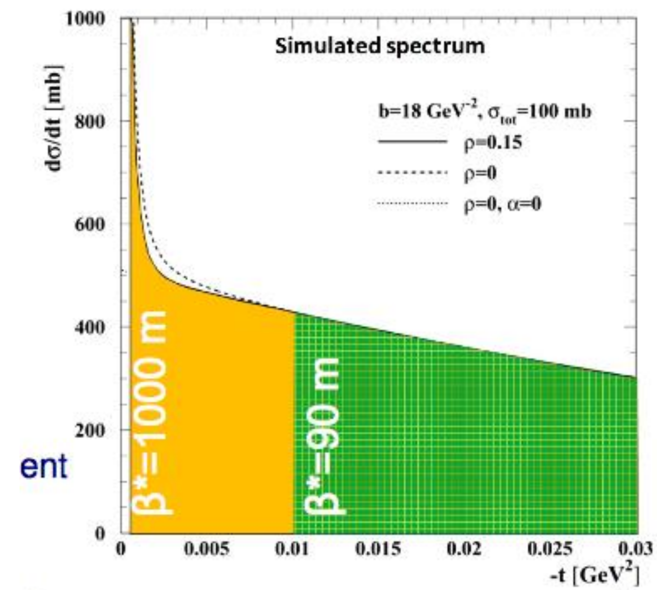


Elastic scattering
events seen

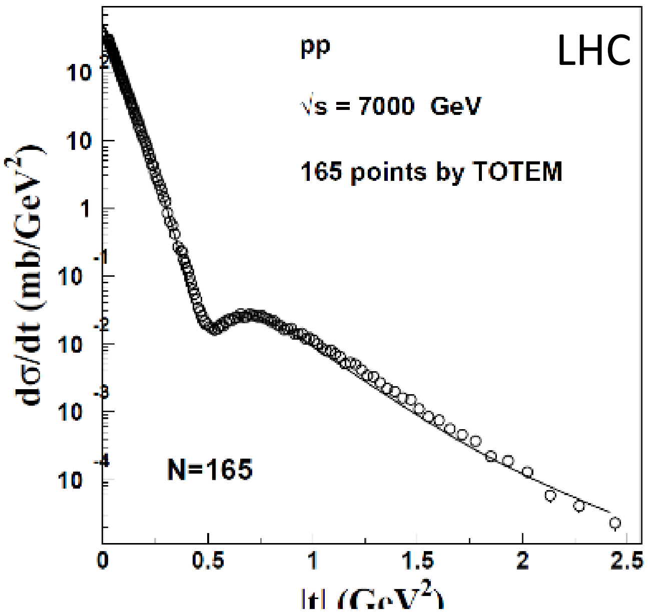


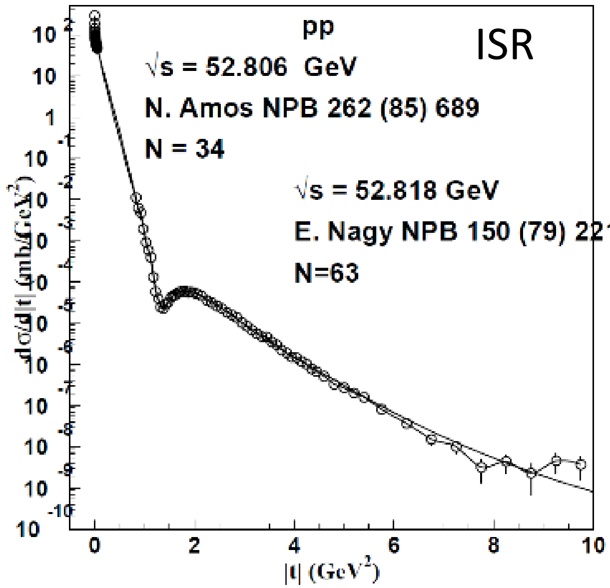
CDF Roman pot
fiber tracker, RIP

Ambition:
(not data!)



A.K.Kohara : Elastic scattering amplitudes in t and b space





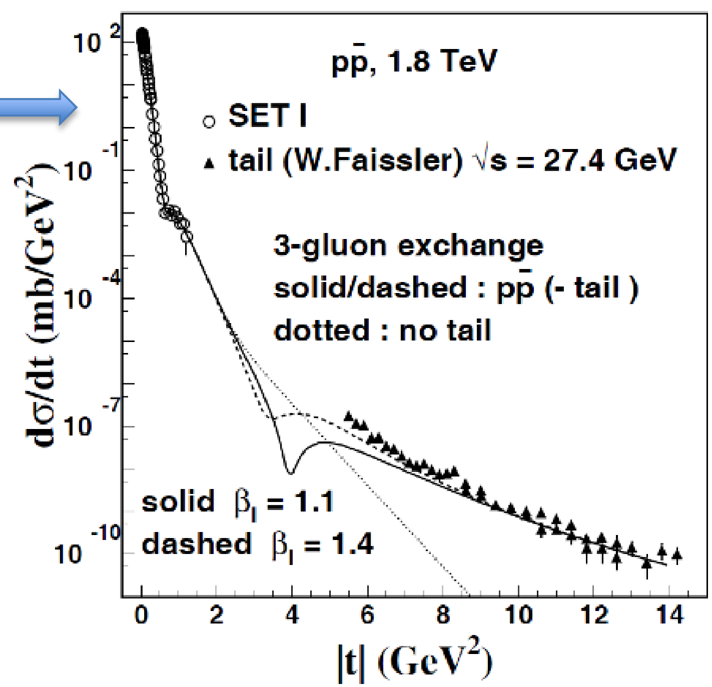
Note different scales:
old ISR at 53 GeV → 10 GeV^2

LHC at 7 TeV → 2.5 GeV2

Dip moves way in, 1.5 – 0.6
Growth of interaction radius.

Small |t| data from Tevatron
Large |t| data from Fixed Target Fermilab (200/400 GeV/c)

Predicted second dip around -4 GeV^2 missed?



From Igor Demin

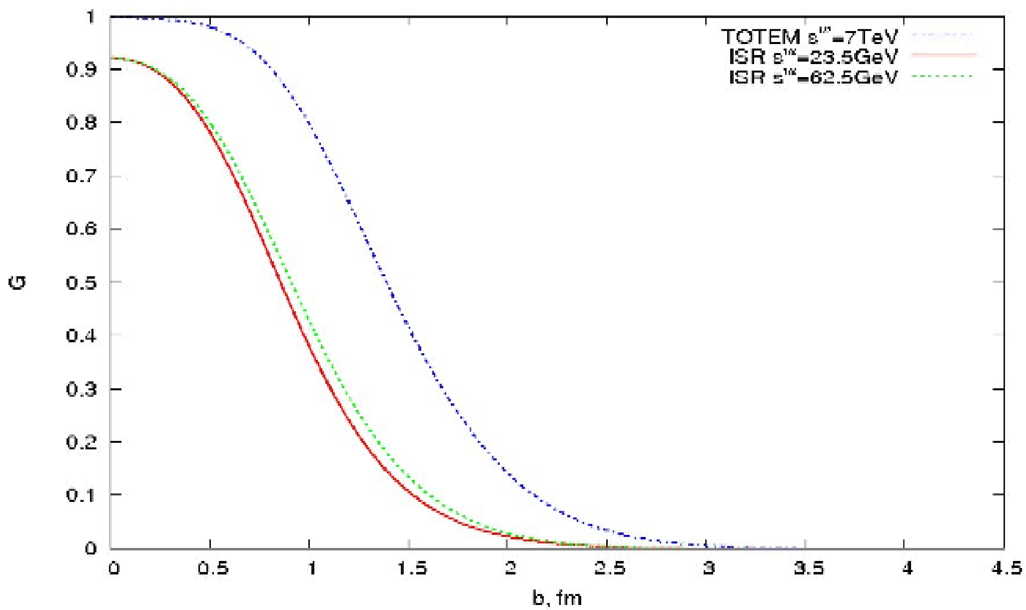
OUR GUESSES ABOUT ASYMPTOTICS

$$\sigma_t(s) \leq \frac{\pi}{2m_\pi^2} \ln^2(s/s_0)$$

THE BLACK DISK: $\sigma_t = 2\pi R^2$; $R = R_0 \ln s$; $\frac{\sigma_{el}}{\sigma_t} = \frac{\sigma_{in}}{\sigma_t} = 0.5$

$B(s) = \frac{R^2}{4}$; $\rho(s, t = 0) = \frac{\pi}{\ln s}$ None observed in experiment!

THE GRAY DISKS: two parameters - radius+opacity

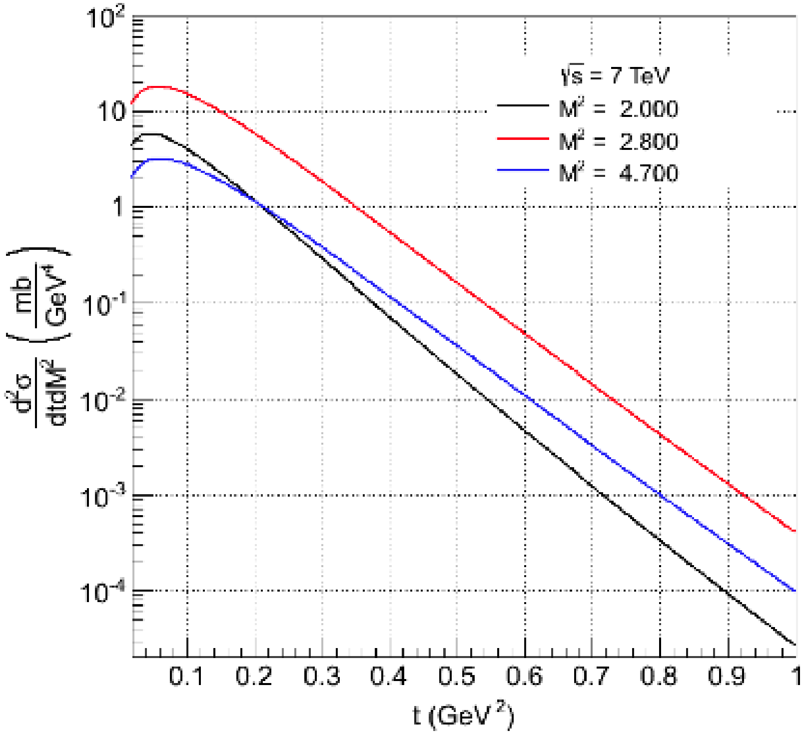


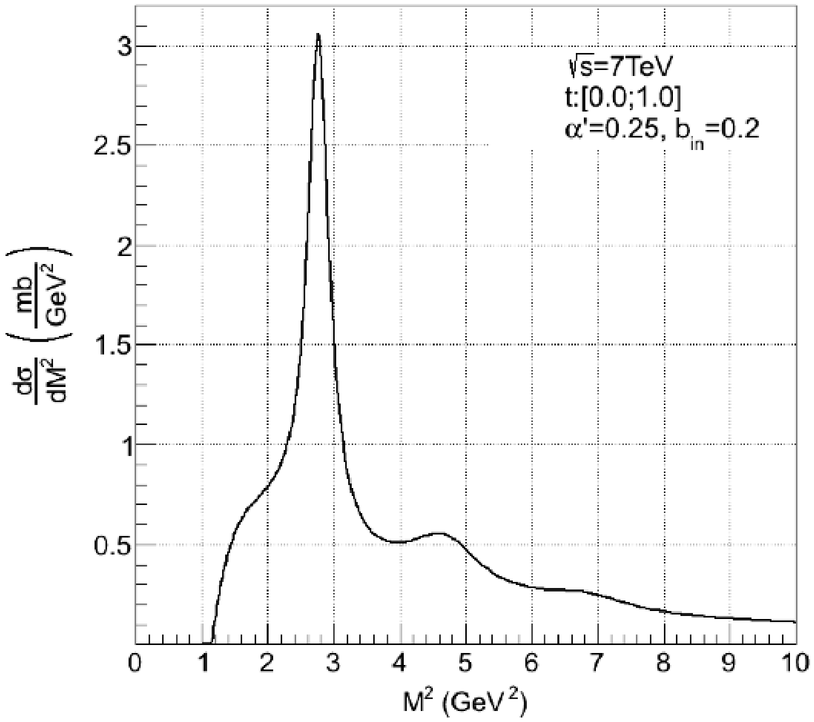
The overlap functions at 23.5 GeV (solid curve), 62.5 GeV (dotted curve) and 7 TeV (dash-dotted curve)

The parton density in the peripheral region increases with s; geometrical scaling does not apply.

ρ(t) away from t = 0 (Orear regime):
ID finds (from experimental data +)
<ρ> ~ -2.1 !
Unsolved problem.

Laszlo Jenkovsky: Reggeized dual Breit-Wigner single diffraction



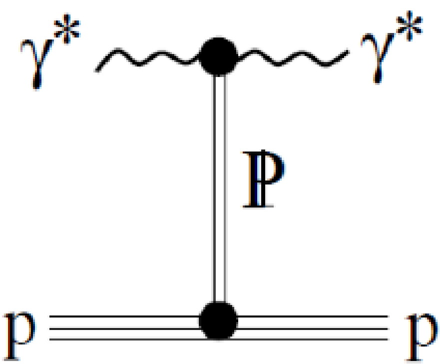


LJ expects turn-down of SD cross sections at |t| < 0.1 GeV2

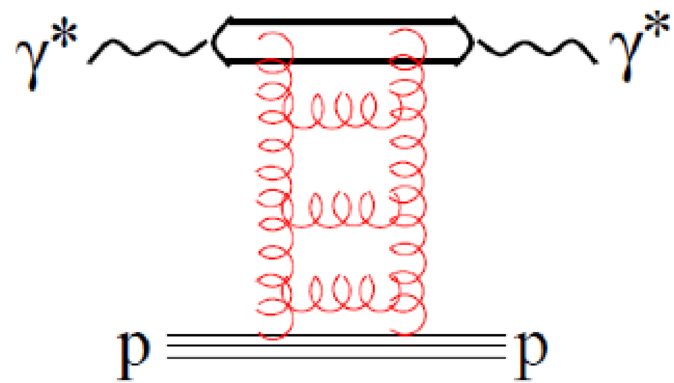
Integrated over t = 0.0 – 1.0
Resonances N* give big contributions.
→ Careful if extrapolating to unseen forward regions!
FSC counters can give information here.

Hadronic diffraction ⟺ **predominantly soft phenomenon**

<u>Regge theory approach</u> ⟺ ??? ⟺ <u>Perturbative QCD approach</u>



A. Donnachie, P.V. Landshoff, Nucl. Phys. **B231** (1984) 189.

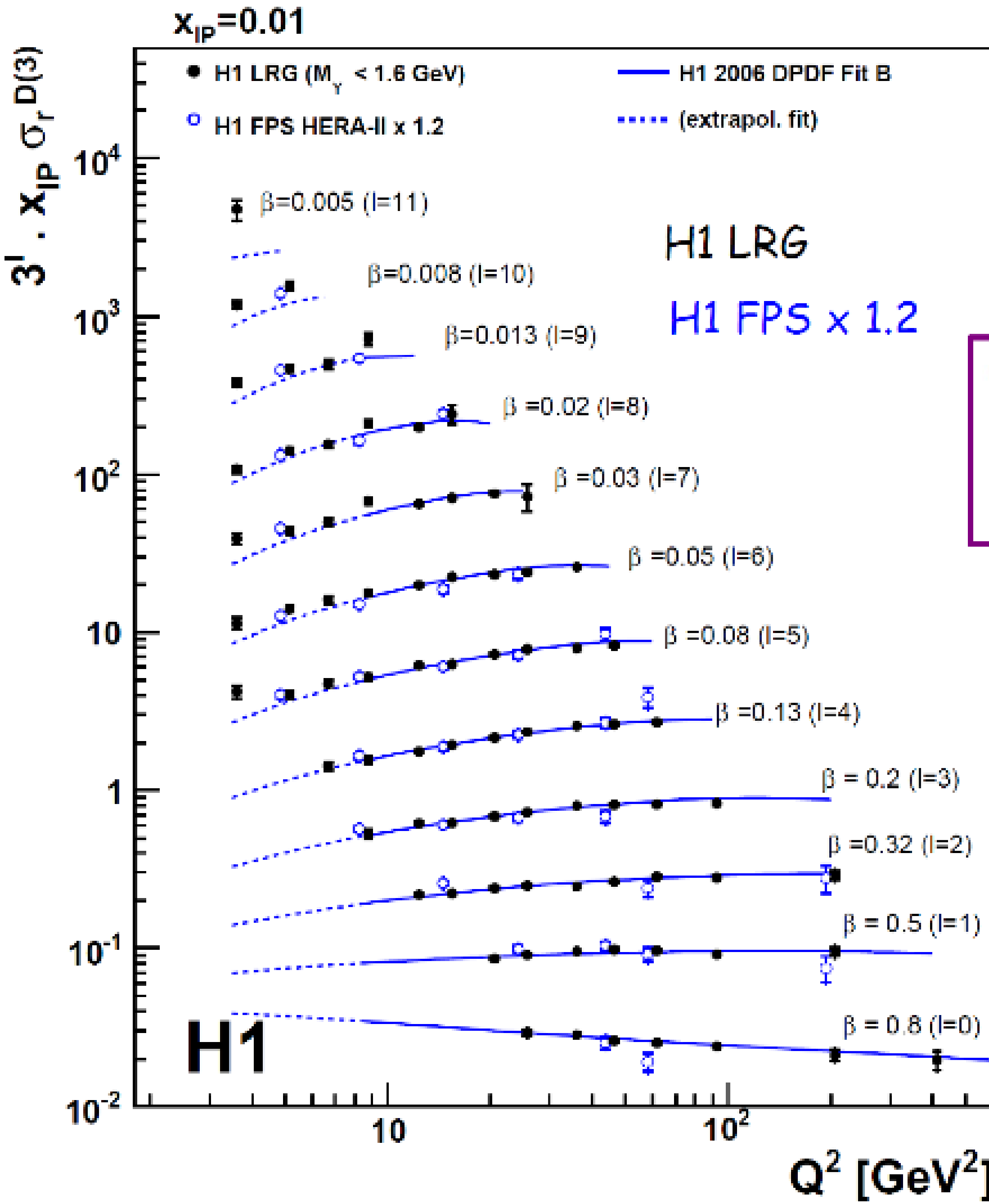


Pomeron structure is still a mystery!

pQCD motivated models:

- **Durham QCD mechanism**
- **Color Dipole Approach**
- **Color Reconnections**

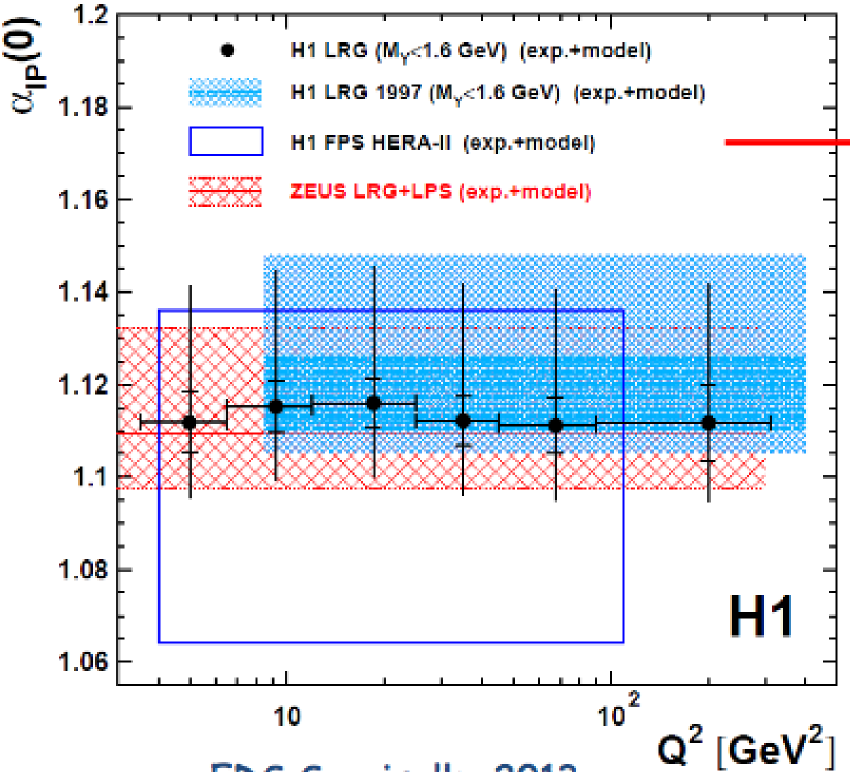
Alice Valkarova (H1 + ZEUS)   e-p collisions at HERA



$$\frac{\sigma\,(M_Y < 1.6\,\mathrm{GeV})}{\sigma\,(Y = p)} = 1.203 \pm 0.019(\mathrm{exp.}) \pm 0.087(\mathrm{norm.})$$

(1.6%)   (7.2%)

Alice Valkarova (H1 + ZEUS)



The mean value of pomeron intercept

$$\alpha_{I\!P}(0) = 1.113 \pm 0.002\,(\text{exp.})\,^{+0.029}_{-0.015}\,(\text{model})$$

- no Q^2 dependence observed
- consistent with other measurements
- supports the hypothesis of the proton vertex factorization

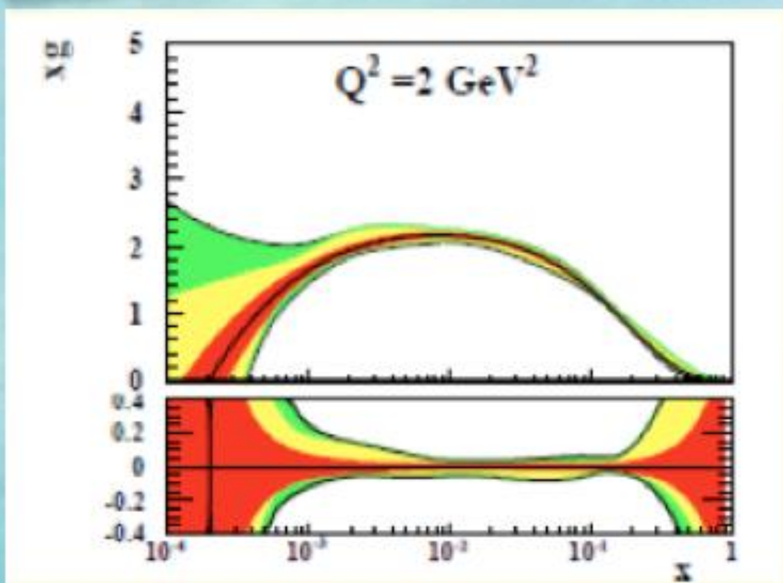
$\alpha_{I\!P}(0)$ – consistent with 'soft $I\!P$'

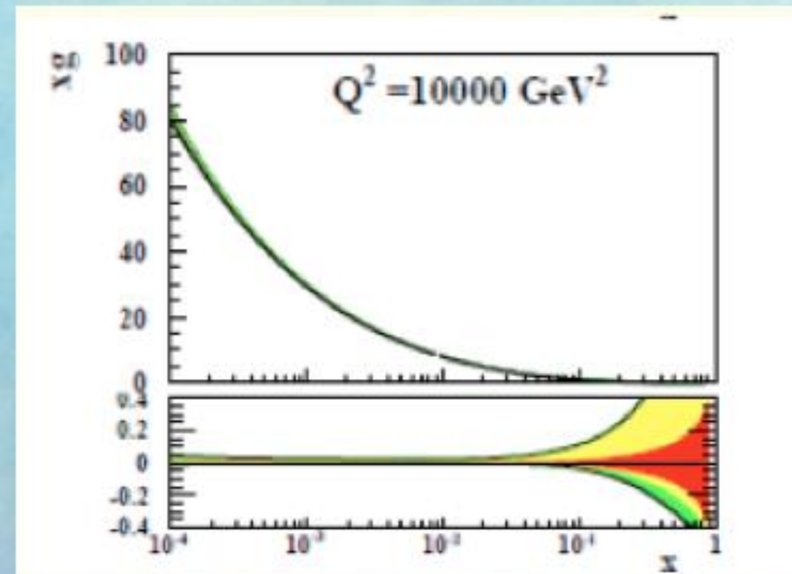
Henry Kowalski: HERA Low-x physics

from a recent talk of M. Cooper-Sarkar (DESY QCD Workshop, 2nd of Sep. 2013)

Study of uncertainties

- st. and sys. errors of data (red)
- variation of Q_0^2, range - 1.9 to 2.5 GeV^2 (green)

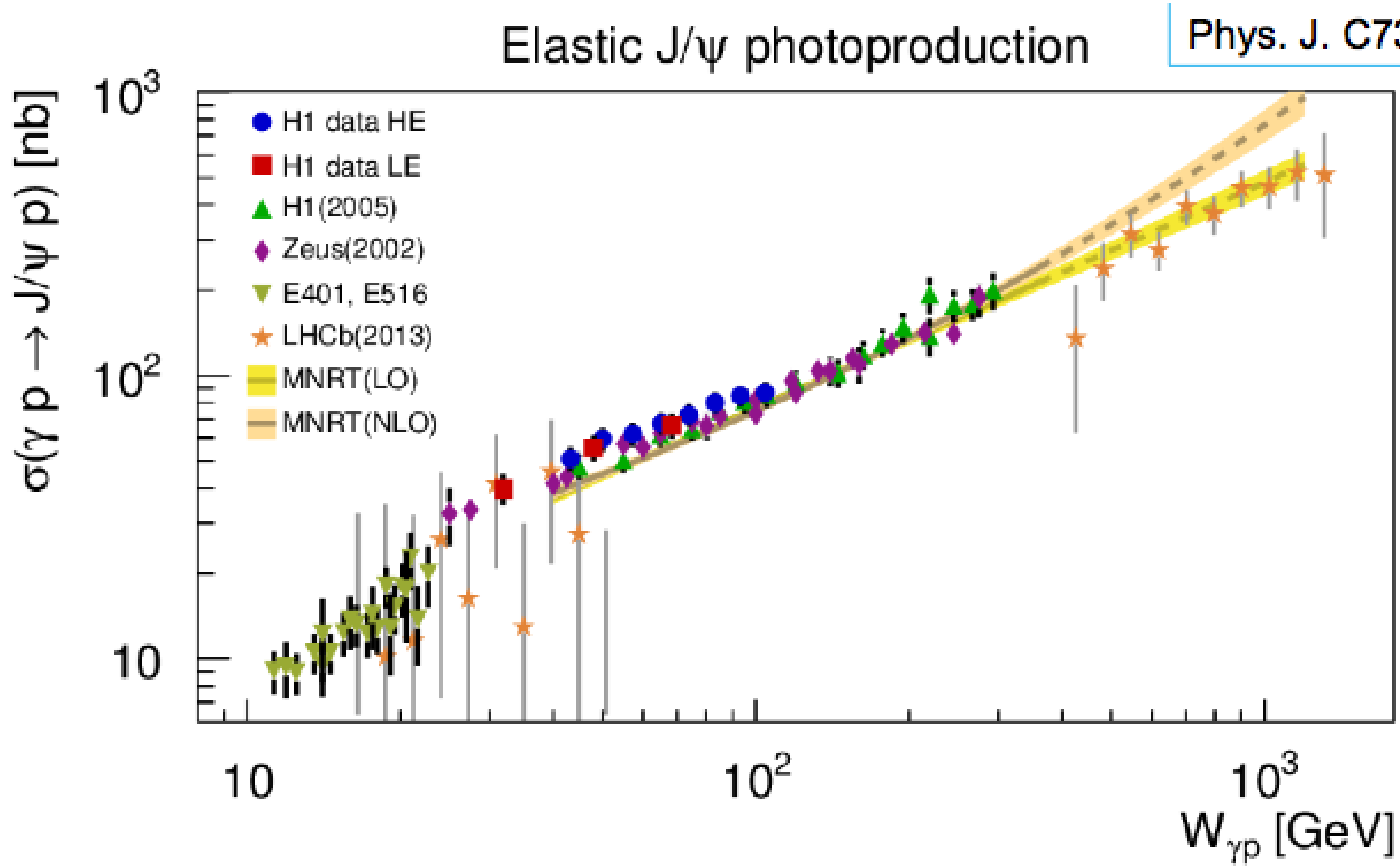




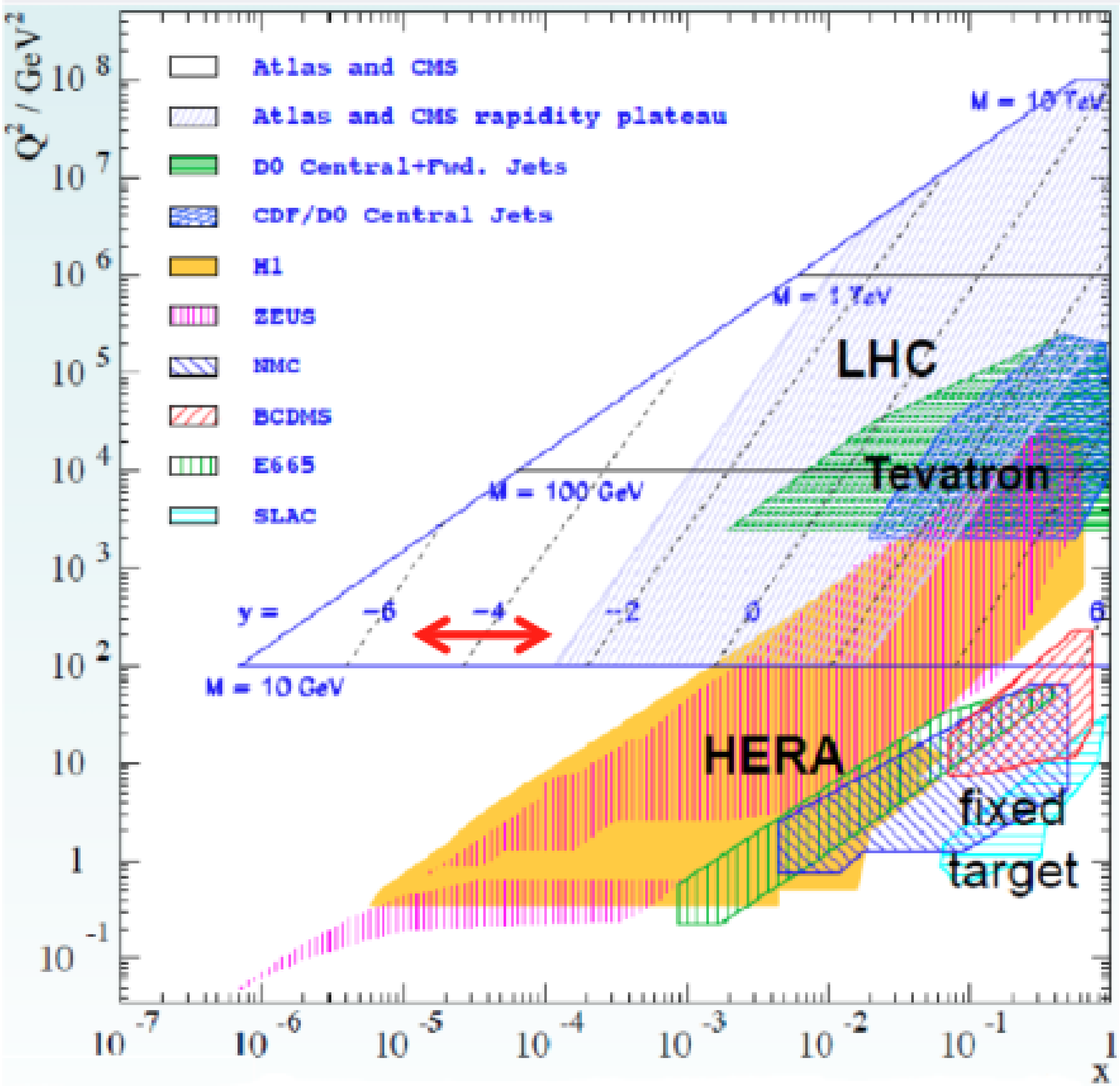
▶ behaviour of gluon density at large x and/or large Q^2's is strongly correlated with its behaviour at small x and small Q^2's

Janusz Malka: HERA exclusive production, and LHCb data

Phys. J. C73 (2013) 2466



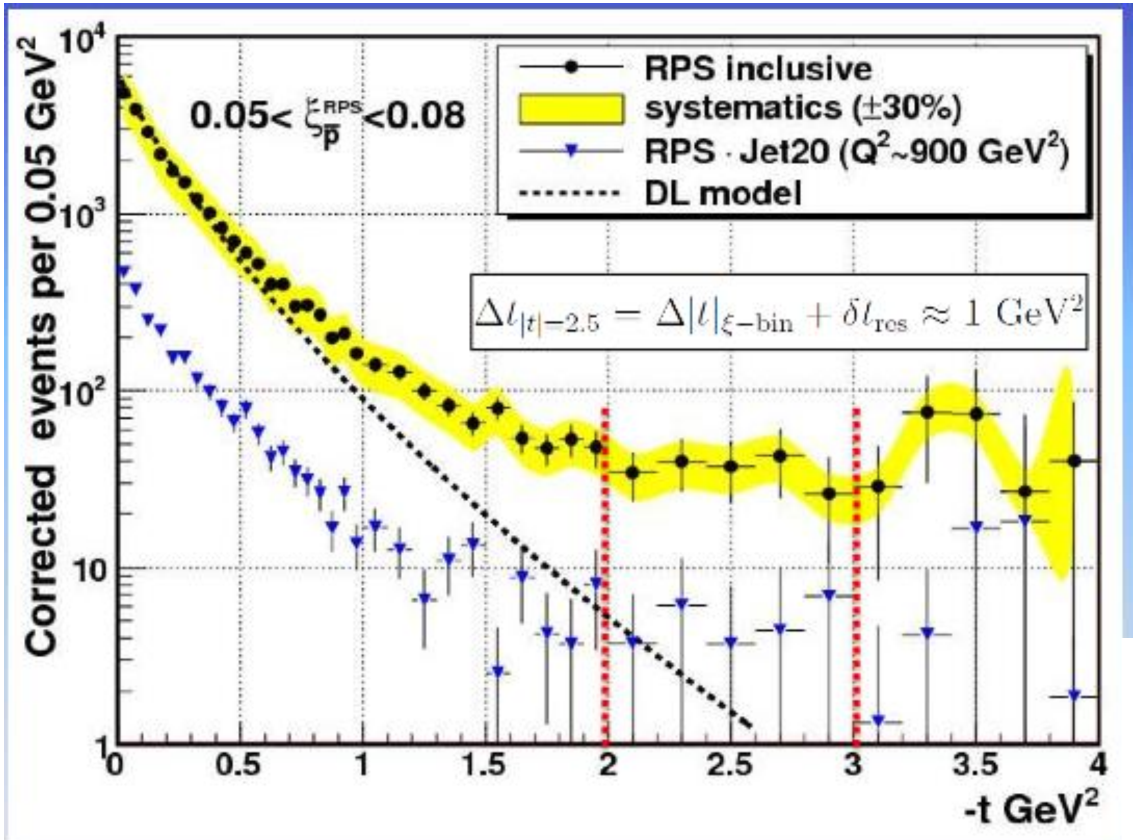
- LO and NLO fit to previous J/ψ data and extrapolated to higher Wγp.
- LO fit describes the LHCb data.



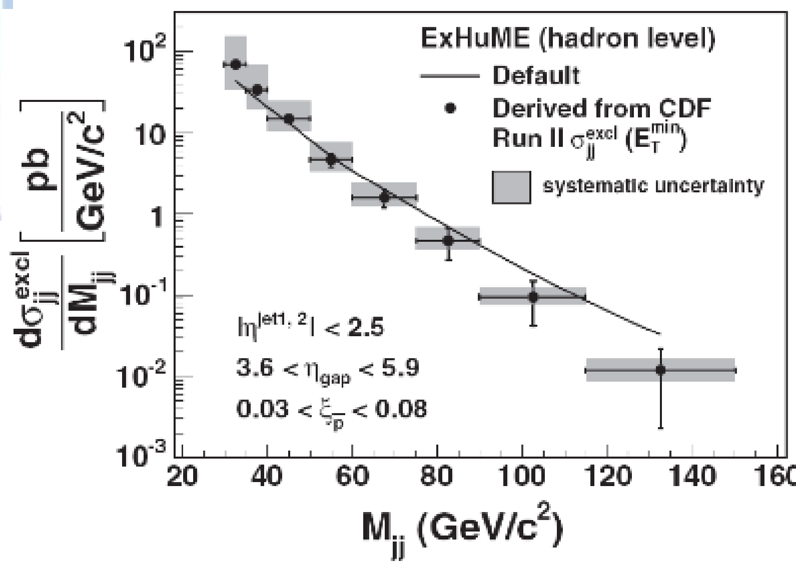
Atlas and CMS
Atlas and CMS rapidity plateau
D0 Central+Fwd. Jets
CDF/D0 Central Jets
H1
ZEUS
NMC
BCDMS
E665
SLAC
LHC
Tevatron
HERA
fixed target
M = 10 GeV
M = 100 GeV
M = 1 TeV
M = 10 TeV
y = -6 -4 -2 0 2 4 6
Q^2 / GeV^2
x

Konstantin (Dino) Goulianos High mass SDE

Remarkably flat t distributions for high mass diffraction at CDF



"Exclusive" dijets:
p-bar detected,
M(JJ) > 0.8 M(X)



Simone Monzani: ATLAS

Rapidity gap cross section

Assuming the triple pomeron phenomenology, data are sensitive to pomeron trajectory intercept $\alpha_{IP}(0)$

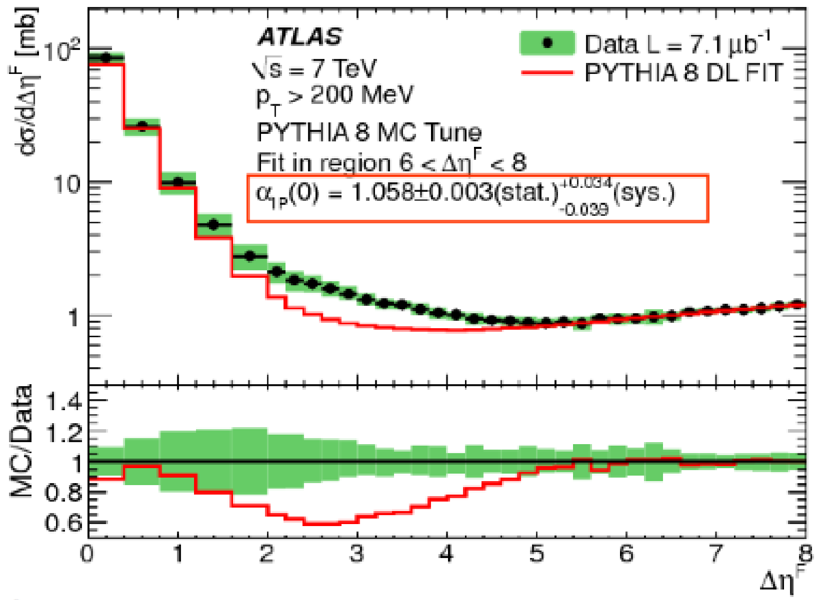
$$\frac{d\sigma}{d\xi dt} \propto \left(\frac{1}{\xi_X}\right)^{2\alpha(t)-\alpha(0)} e^{bt}$$

$$\alpha(t) = \alpha(0) + \alpha' t$$

$$\frac{d\sigma}{d\xi_X} \propto \frac{1}{\xi_X}$$

$s \gg M_X \gg t$

Pythia8 model with Donnachie and Landshoff flux parametrization



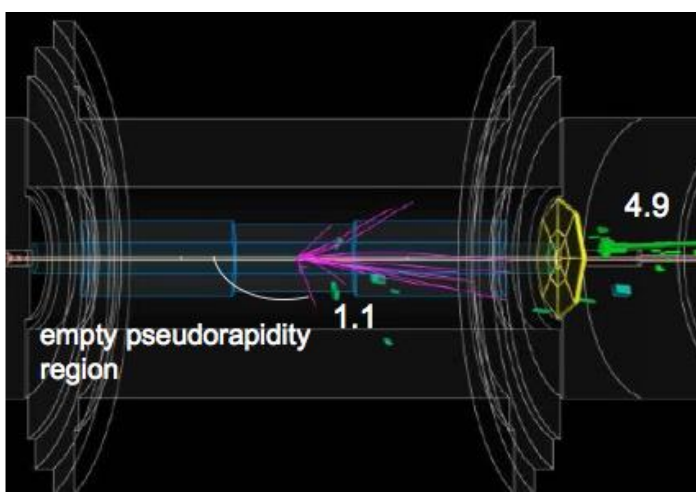
Cross section
σ(gap ~ 8) >
σ(gap ~ 5) !
IP exchange α > 1.0

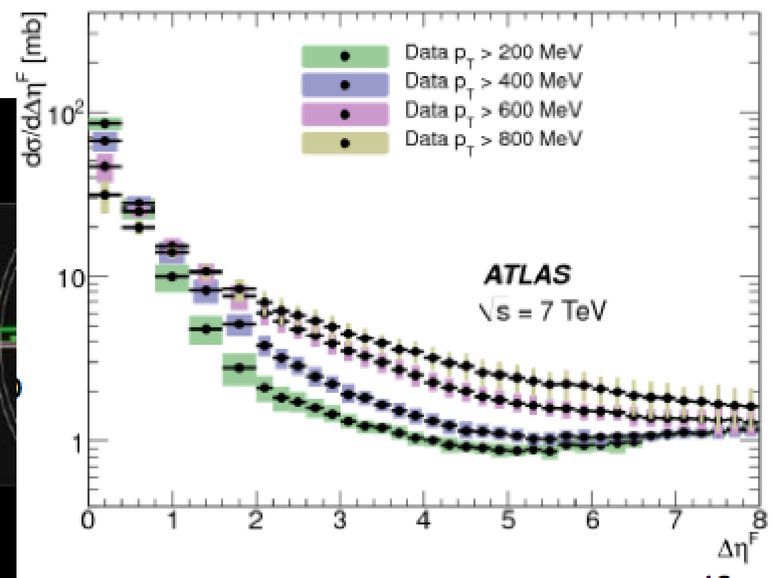
Gap really should be no hadrons. Sometimes use "no jets" but not same. With p_T(cut) at 400(200) MeV still not pure.

ND region

Diffractive region

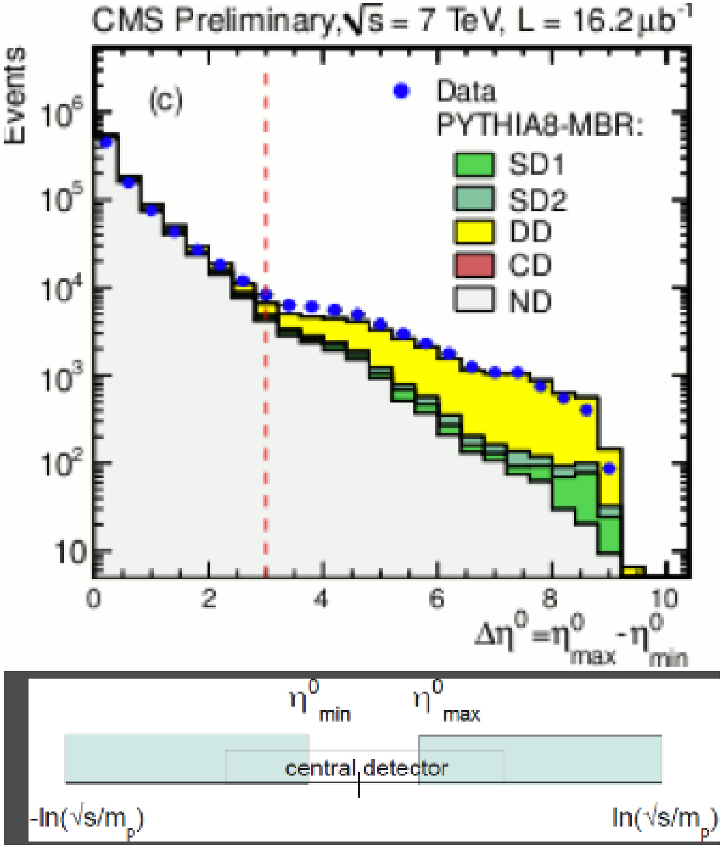
The extracted $\alpha_{IP}(0)$ relative to the whole range is obtained from the best χ^2 on the fit on MC simulation varying $\alpha_{IP}(0)$ for $\Delta\eta>6$





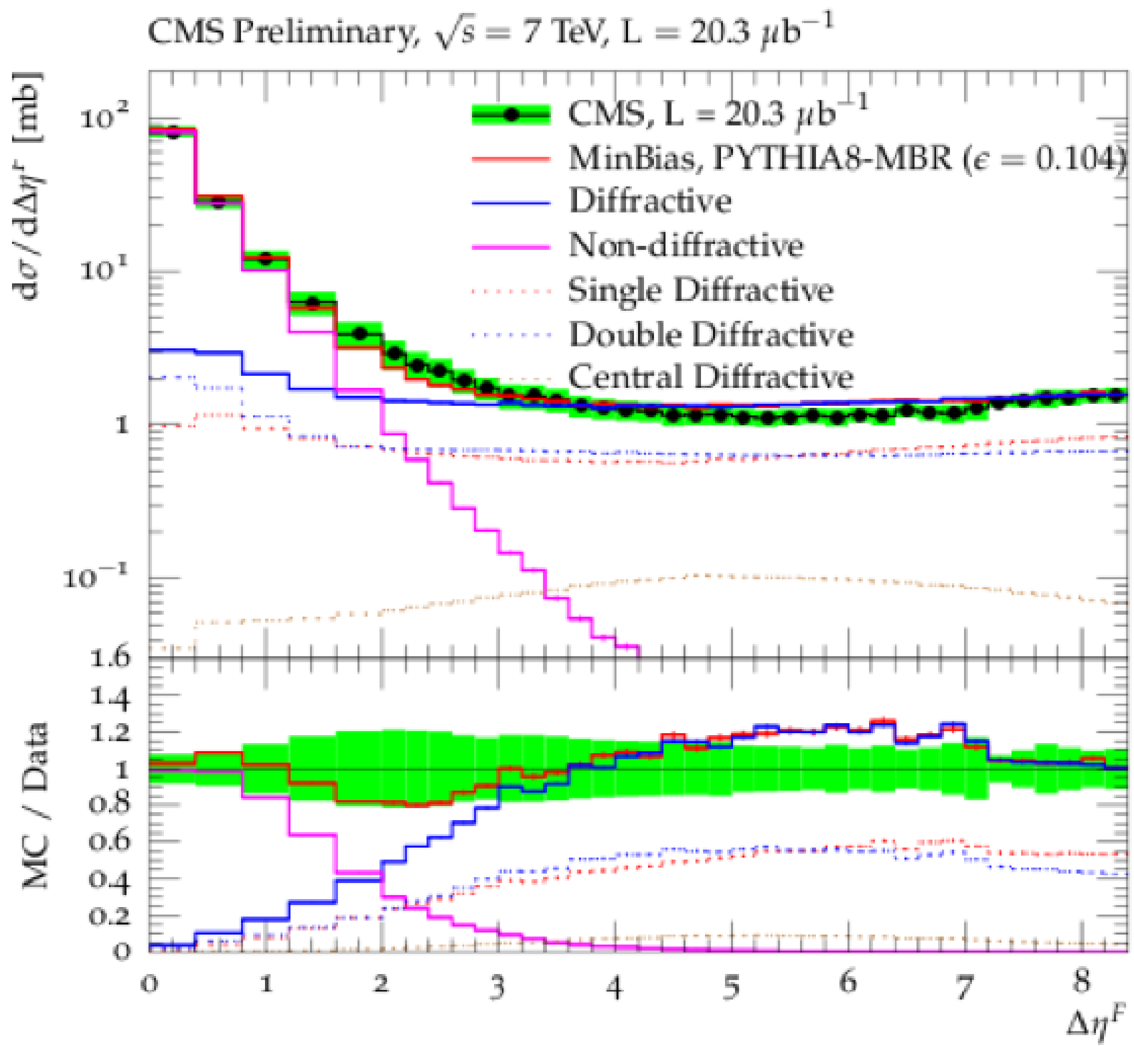
Konstantin (Dino) Goulianos : CMS

Double Diffraction = central gaps



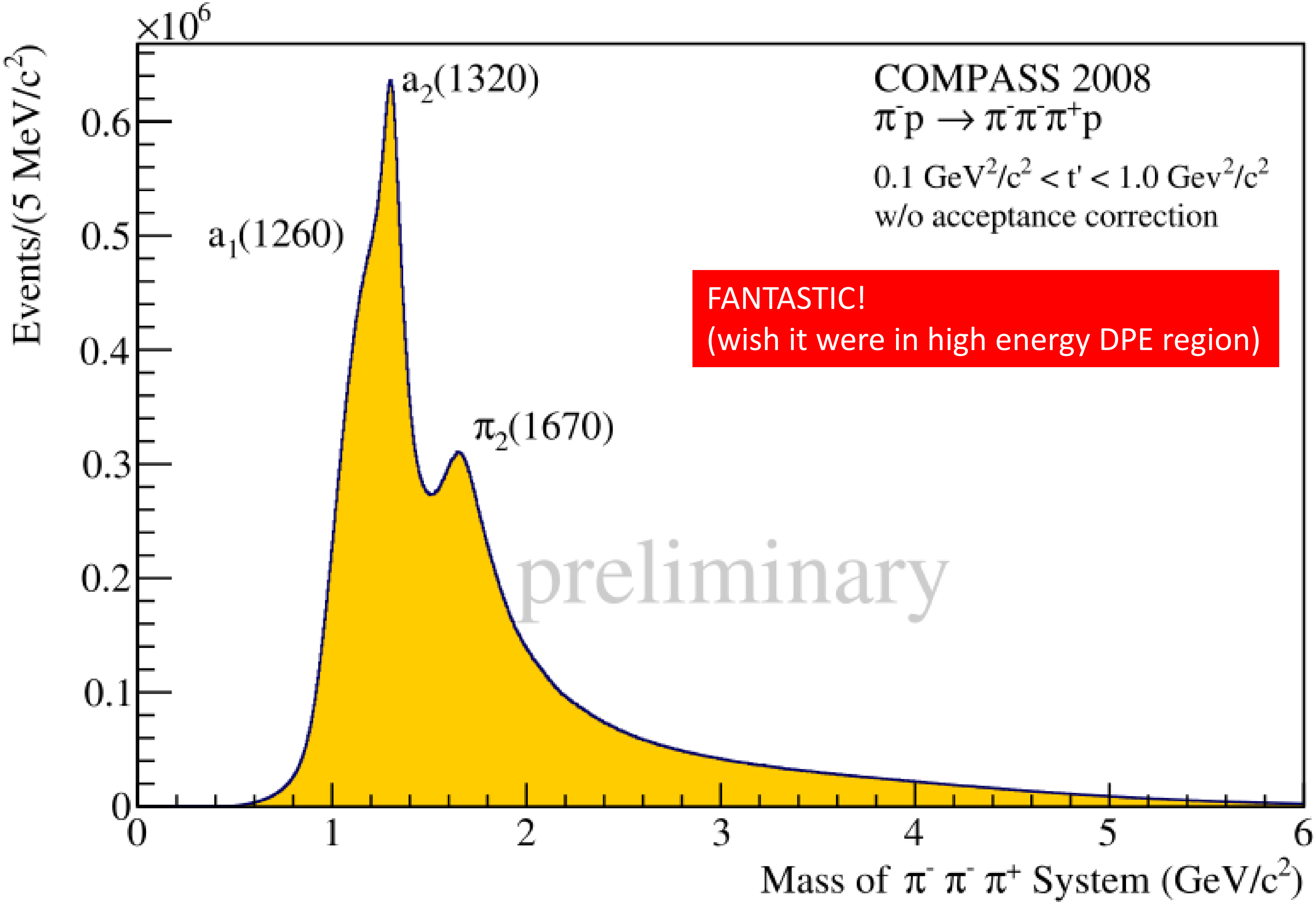
As Δη exceeds 3 separate class of DD events grows and becomes dominant

Agreement with ATLAS on rise at high Δη



Su-Urk Chung and Alex Austregesilo : Compass, SPS fixed target π- beam

$\pi^- \pi^+ \pi^-$ invariant mass distribution

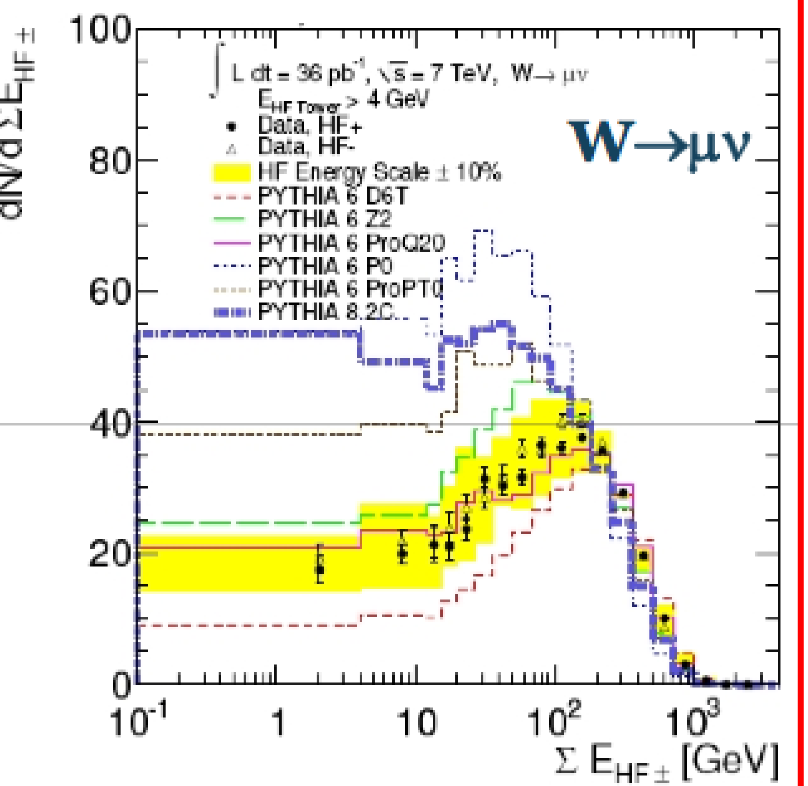


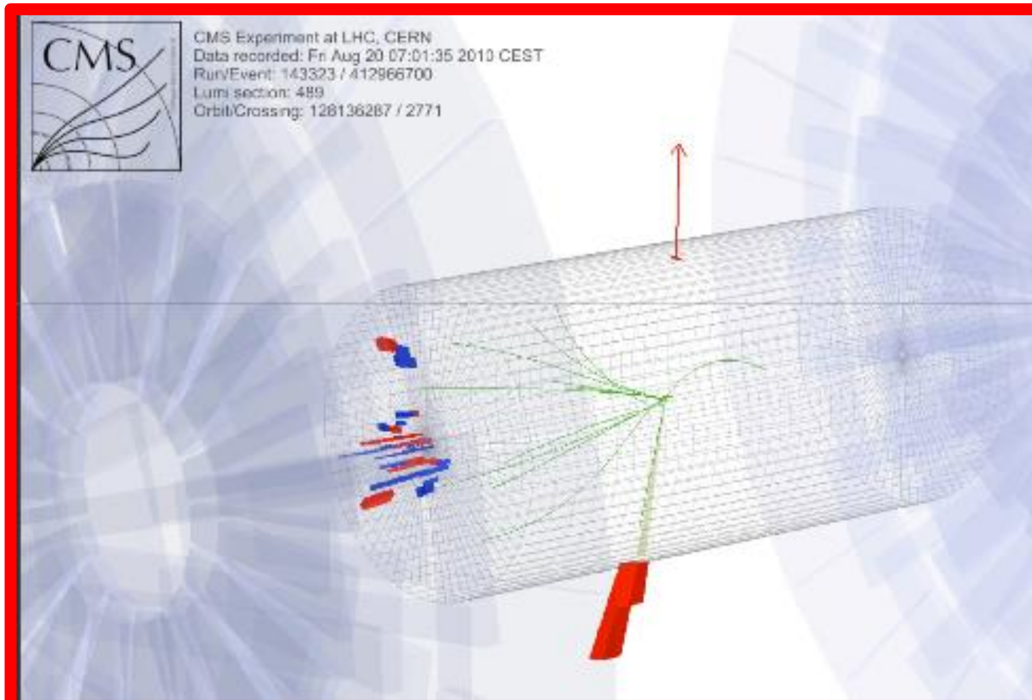
FANTASTIC!
(wish it were in high energy DPE region)

Christina Mesropian CMS

Diffractive W & Z production (rapidity gaps)
Compare to models: range of predictions:
More gap events than PYTHIA D6T, less than PYTHIA 6Z2, 8

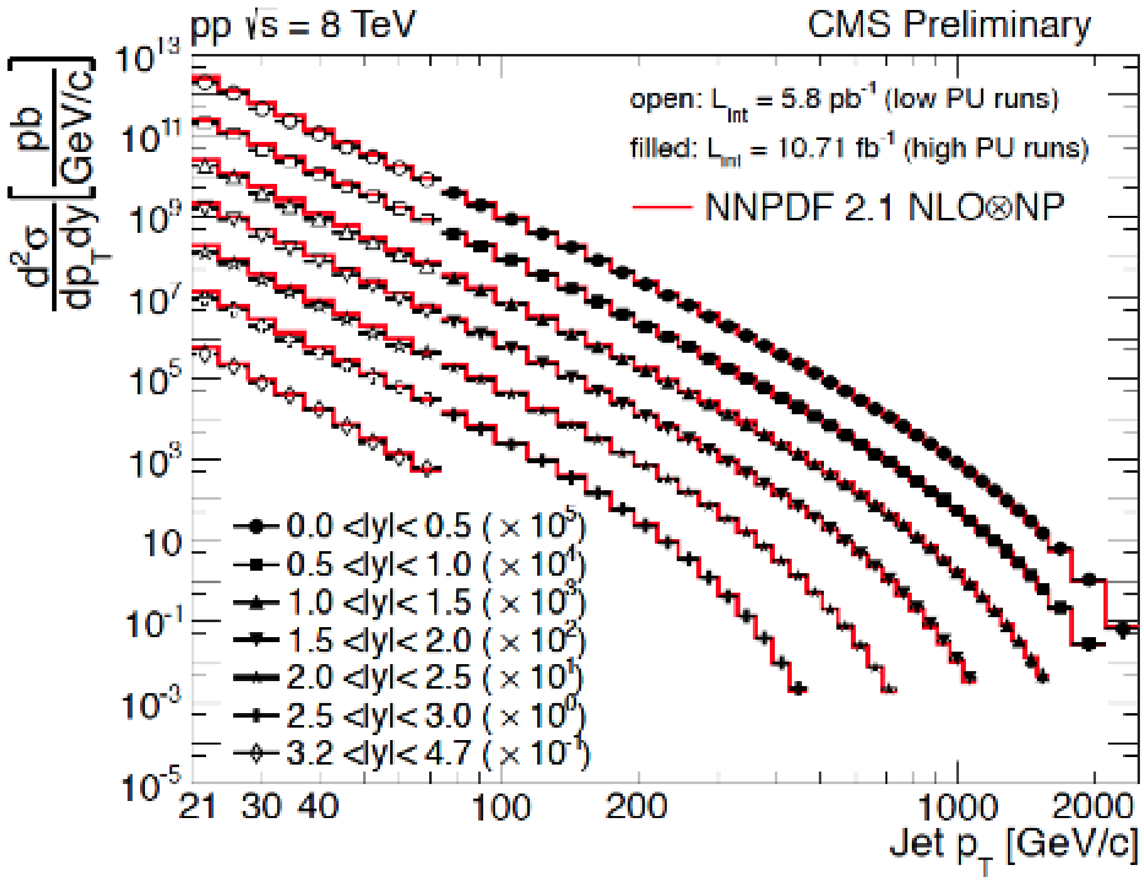
Fraction of W/Z events with a forward gap:
$W \rightarrow l\nu$: 1.46 ± 0.09(stat.) ± 0.38(syst.) %
$Z \rightarrow ll$: 1.60 ± 0.25(stat.) ± 0.42(syst.) %





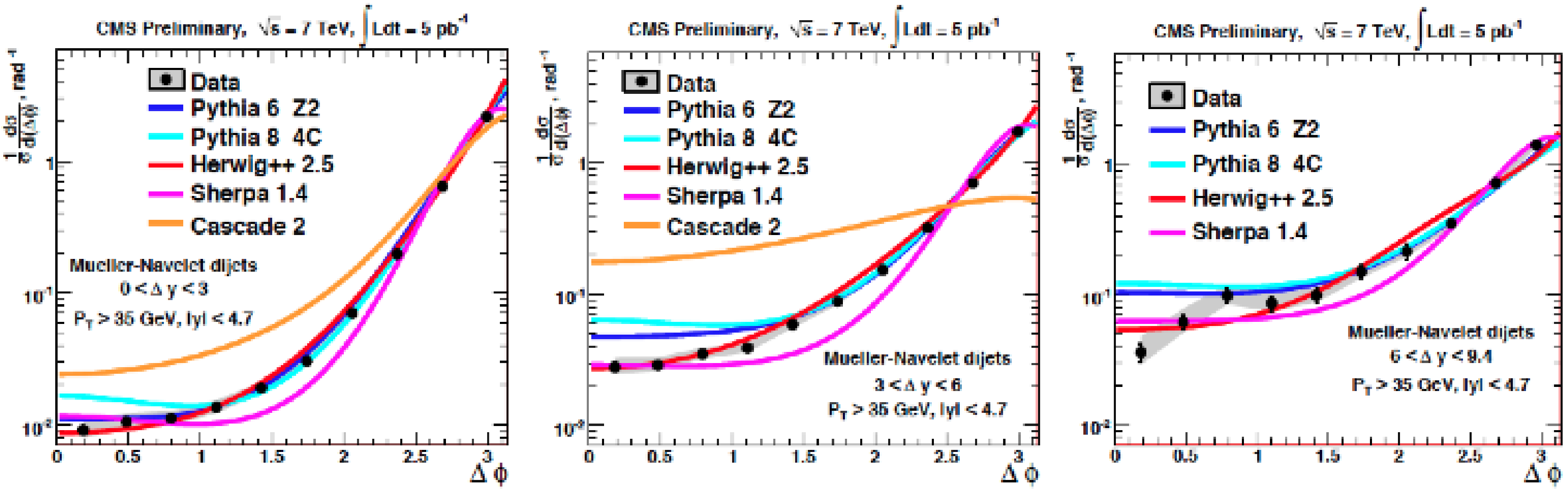
Roman Pasechnik : Soft color interaction SCI and reconnection models applied to Diff W

- Combined jet spectrum (with CMS-PAS-SMP-12-012) with NLO predictions at 8 TeV.
- Cross-section: 15 orders of magnitude!



M.Misiura: CMS jets and BFKL (no sign of it)

- CCFM Cascade predicts large too strong decorrelation.



More forward jet pairs →

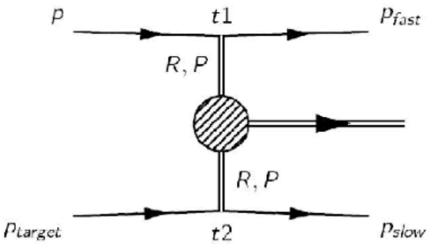
Central Exclusive Production

... or, diffractive excitation of the vacuum

"It is contrary to reason to say that there is a vacuum or a space in which there is absolutely nothing." ***Descartes***

→ Virtual states in the vacuum can be promoted to real states by the glancing passage of two particles.

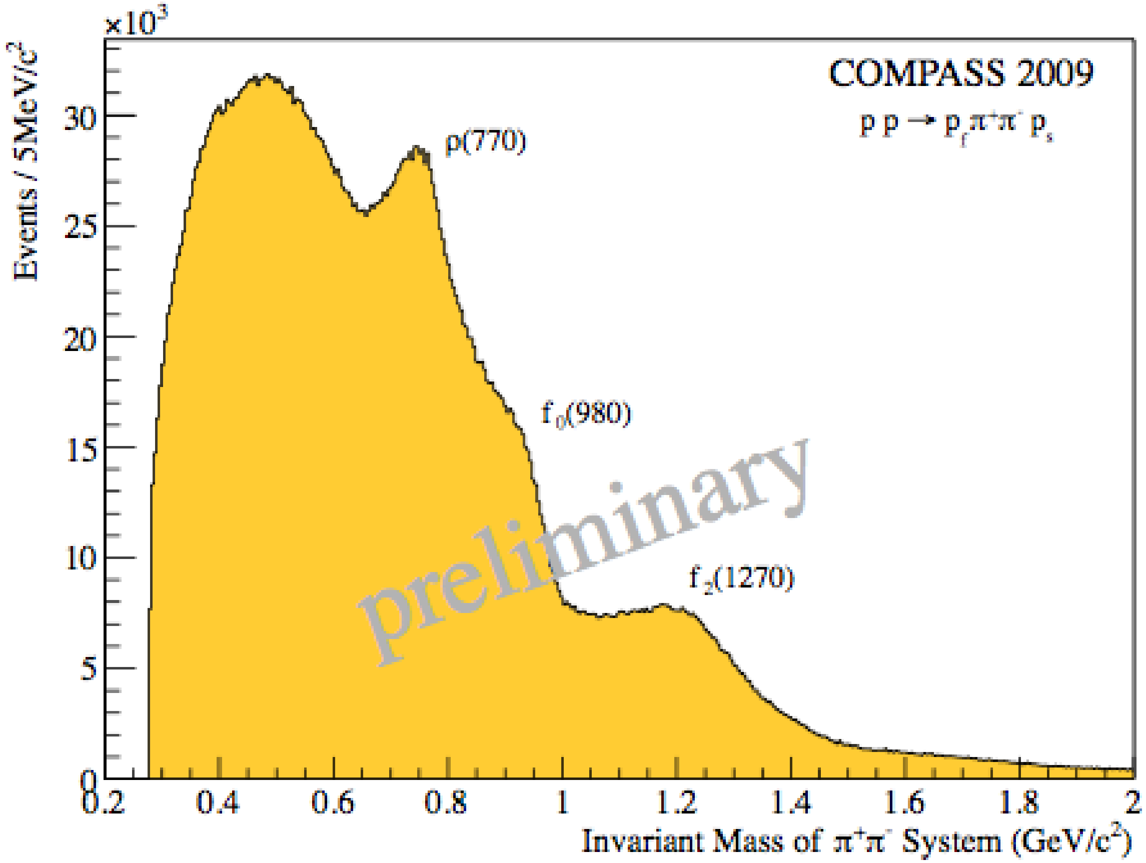
Alex Austregesilo : Compass, SPS fixed target



Kinematic Selection

- $M(p\pi) > 1.5\,\text{GeV}/c^2$
- $x_F(p_f) > .9$
- $Z_{A,B} > 2.3$
- $|y(\pi)| < 1$
- ...

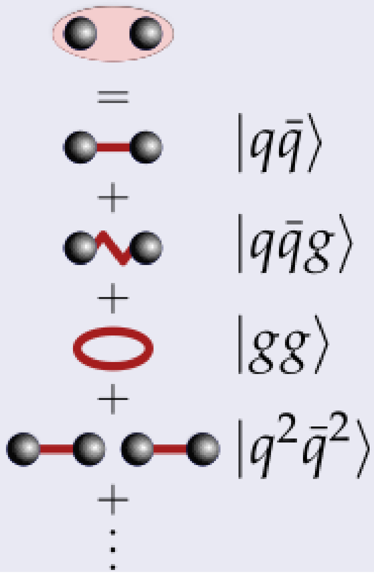
190 GeV/c p beam on hydrogen target
√s ~ 17 GeV so Δy(p-p) ~ 5.8 too low for DPE
Hence large ρ signal (Regge exchange)



Su-Urk Chung : Compass, Multiparticle forward spectrometer at SPS fixed target

Finding states beyond the CQM is difficult

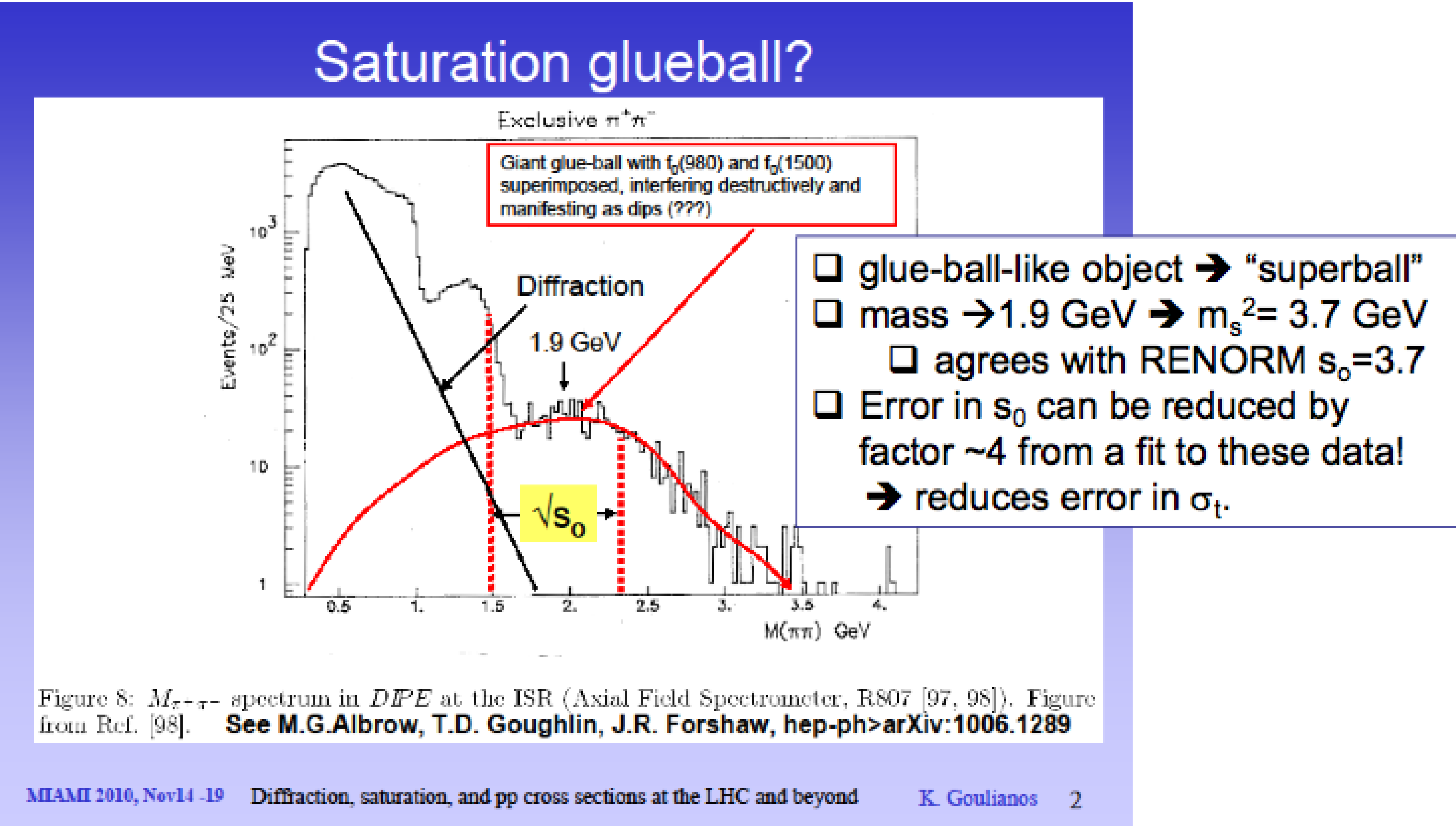
- Physical mesons = linear superpositions of *all* allowed basis states: $|q\bar{q}\rangle, |q\bar{q}g\rangle, |gg\rangle, |q^2\bar{q}^2\rangle, \ldots$
  - Amplitudes determined by QCD interactions
- Resonance classification in quarkonia, hybrids, glueballs, tetraquarks, etc. assumes dominance of *one* basis state
  - In general "configuration mixing"
  - Disentanglement of contributions difficult



- Data described by model consisting of 52 waves + incoherent isotropic background
- Isobars:
  - $(\pi\pi)_{S-\text{wave}}$
  - $f_0(980)$
  - $\rho(770)$
  - $f_2(1270)$
  - $f_0(1500)$
  - $\rho_3(1690)$

Konstantin (Dino) Goulianos

I cannot resist showing this slide of Dino's, showing "my" AFS glueball search spectrum

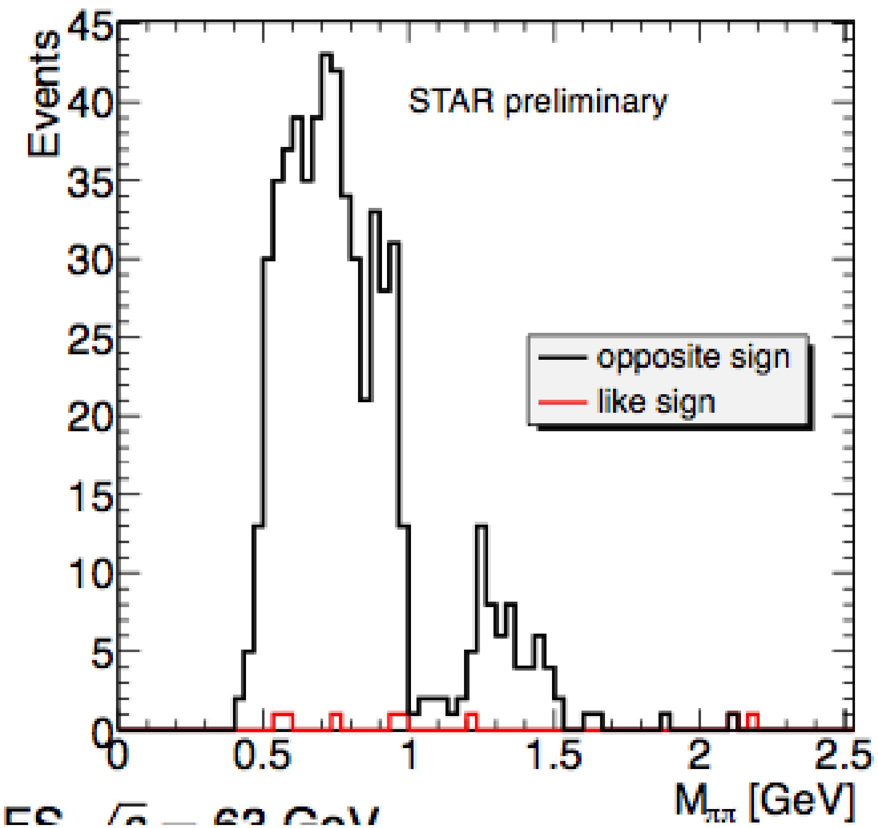


The spectrum above 1.5 GeV has not been properly explained, but new data is arriving!

Recent Results and Future Prospects in Central Exclusive Production at STAR

Leszek Adamczyk

CEP in pp collisions 2009 data, $\sqrt{s} = 200$ GeV

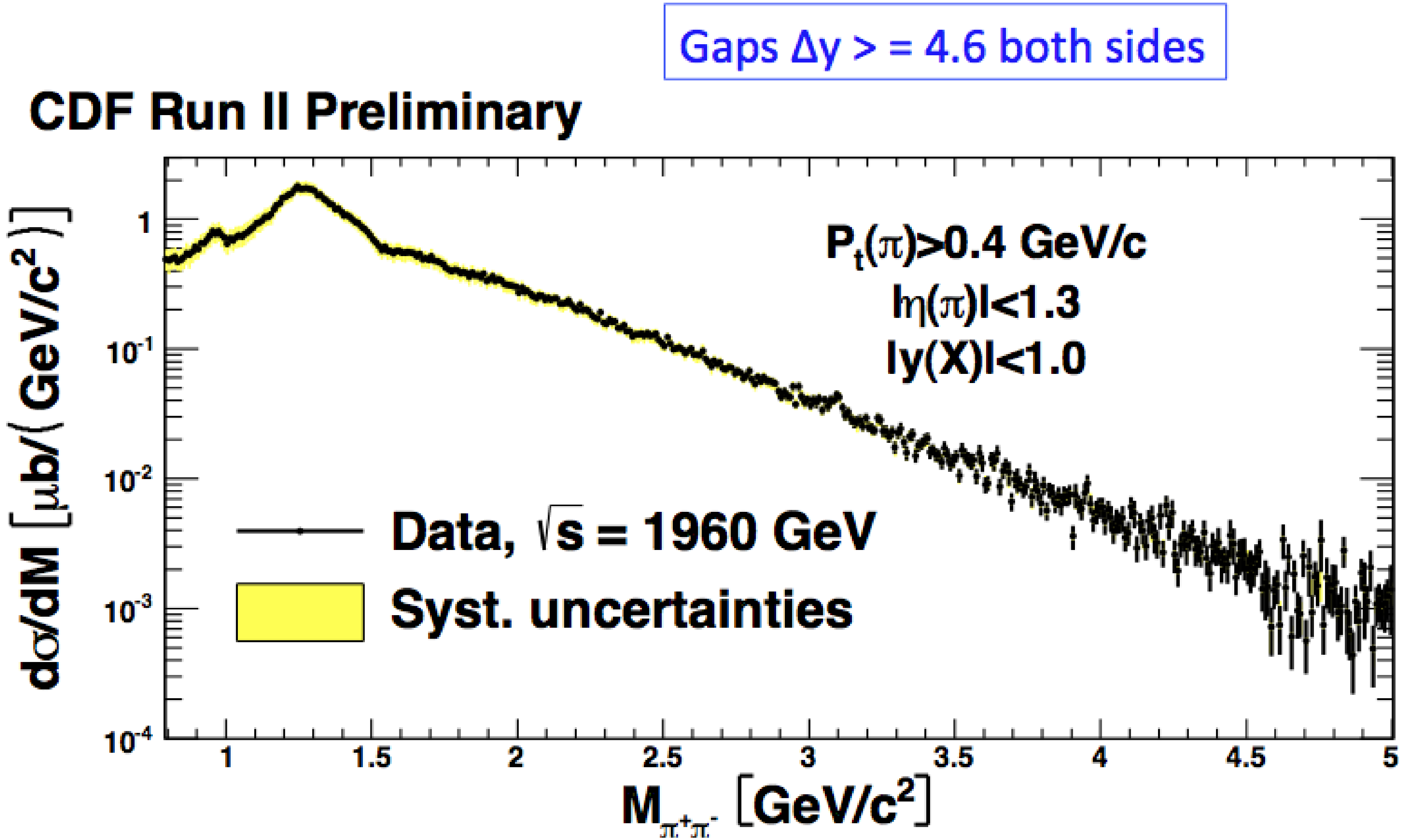


AFS $\sqrt{s} = 63$ GeV

- two TPC tracks from primary vertex:
  - $p_T > 150$ MeV
  - $|\eta| < 1.0$
- $p_T^{miss} < 0.02$ GeV
- $\Delta\Theta > 0.15$ mrad
- $|dE/dx - (dE/dx)_\pi| < 3\sigma$

A good start, more to come ...

Mike Albrow for CDF: Exclusive central π+π- production (double pomeron exchange)



fo(980), f2(1270), f0(1370)?, ...

Scott Stevenson, LHCb

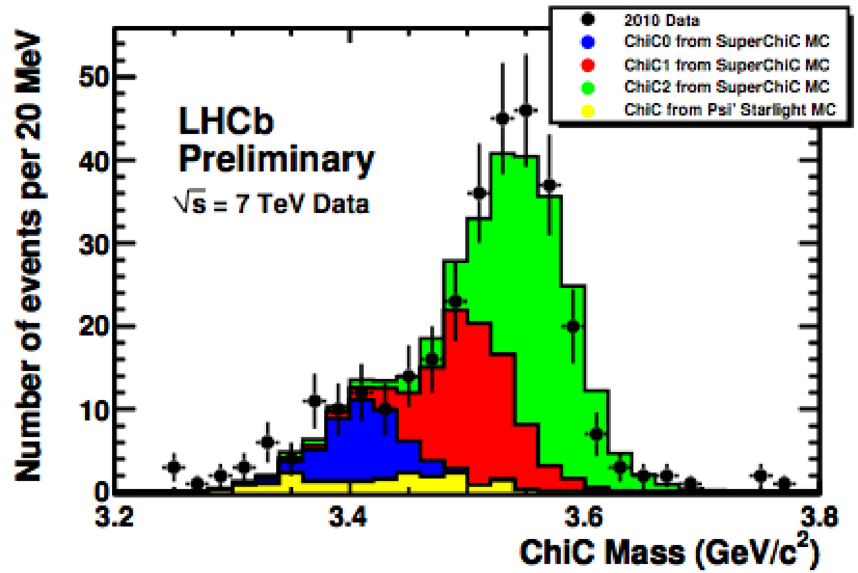
[LHCb-CONF-2011-022]

Selection

Dimuon, γ with $E_\perp > 200$ MeV, no extra tracks: 194 events.

Backgrounds

Inelastic contribution from dimuon $p_\perp$ fit, $\psi(2S)$ feed down from STARlight: (39 ± 13) % purity for $p_\perp < 900$ MeV$/c$



Results

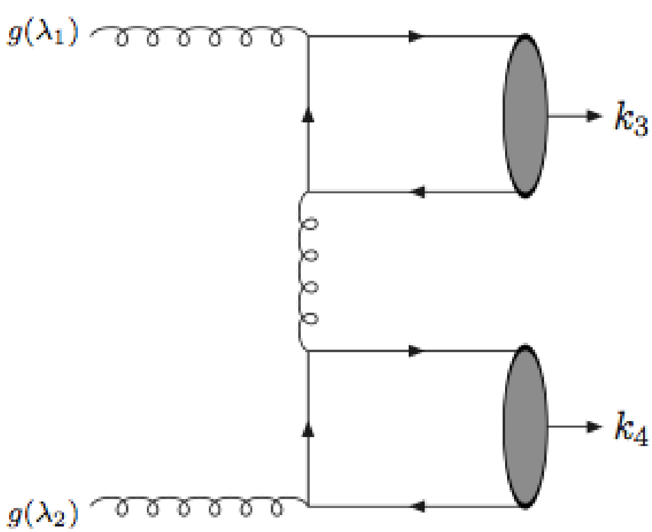
Mode	LHCb measured (pb)	SuperCHIC (pb)
$\sigma_{\chi_{c0}\to J/\psi\gamma\to\mu\mu}$	$9.3 \pm 2.2 \pm 3.5 \pm 1.8$	14
$\sigma_{\chi_{c1}\to J/\psi\gamma\to\mu\mu}$	$16.4 \pm 5.3 \pm 5.8 \pm 3.2$	10
$\sigma_{\chi_{c2}\to J/\psi\gamma\to\mu\mu}$	$28.0 \pm 5.4 \pm 9.7 \pm 5.4$	3

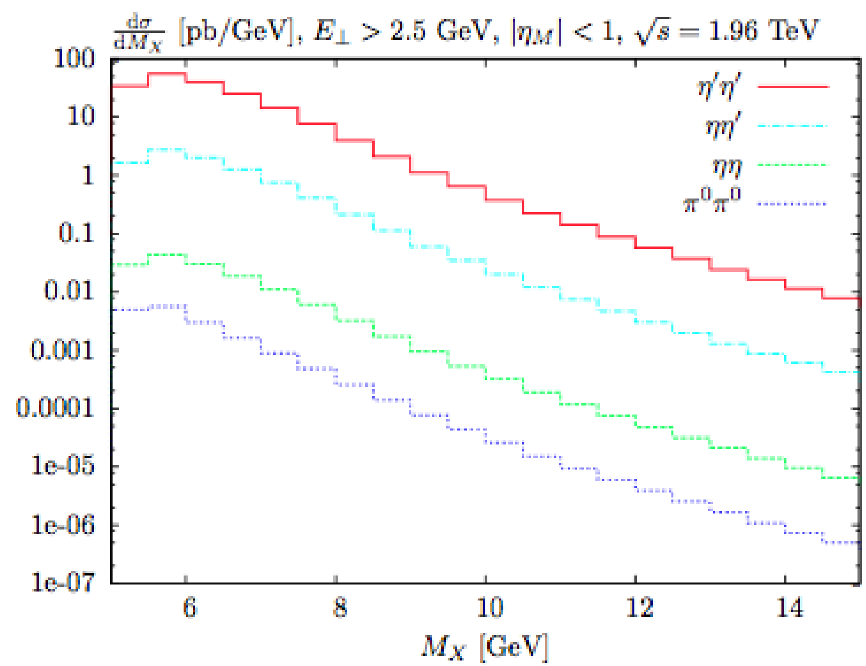
Lucien Harland-Lang with Valery Khoze, Durham group. CEP of meson pairs at Tevatron

Flavour singlet mesons

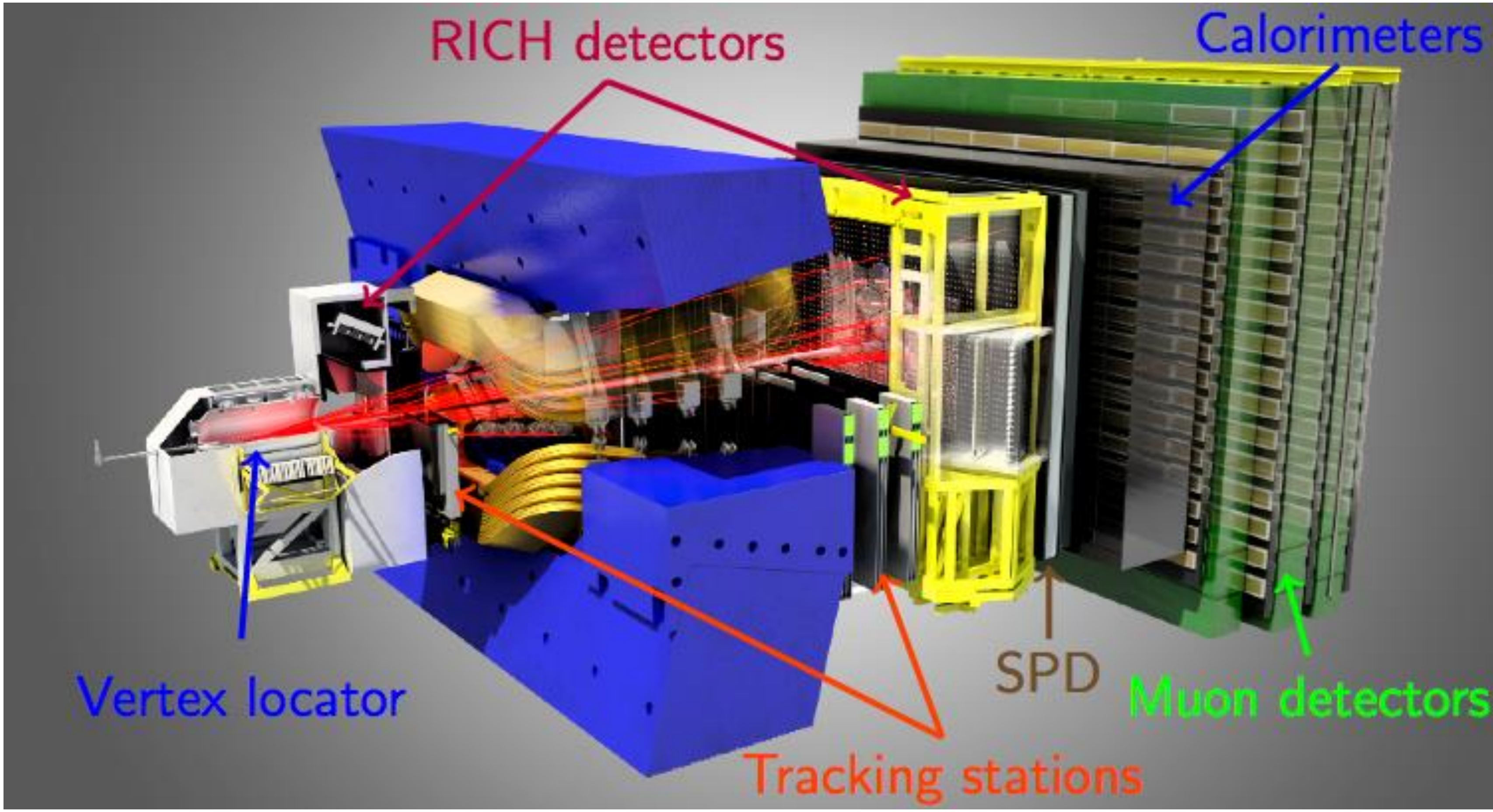
HKRS: arXiv:1105.1626

- For flavour singlet mesons a second set of diagrams can contribute, where $q\bar{q}$ pair is connected by a quark line.
- For flavour non-singlets vanishes from isospin conservation ($\pi^{\pm}$ is clear, for π^0 the $u\bar{u}$ and $d\bar{d}$ Fock components interfere destructively).
- In this case the $J_z = 0$ amplitude does not vanish (see later) $\Rightarrow$ expect strong enhancement in $\eta'\eta'$ CEP and (through $\eta - \eta'$ mixing) some enhancement to $\eta\eta'$, $\eta\eta$ CEP. The $\eta'\eta'$ rate is predicted to be large!





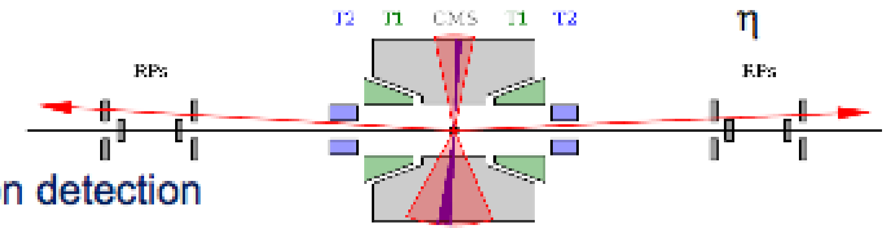
Marco Meissner, Scott Stevenson, LHCb



Excellent multi-particle forward spectrometer, very good particle identification.
Plans for HERSCHEL : forward shower counters (gap detectors) on other side.
SD: p + p → p + X, with p (or p*) inferred from empty HERSCHEL, X studied in "MPS" !
Also Central Exclusive Production in $2 < |\eta| < 4.5$

Central Diffraction: TOTEM + CMS

CD (aka DPE):



Large η-coverage:

- CMS: $-5.5<\eta<5.5$
- T1: $3.1 < |\eta| < 4.7$
- T2: $5.3 < |\eta| < 6.5$
- FSC: $6 < |\eta| < 8$

Double-arm proton detection

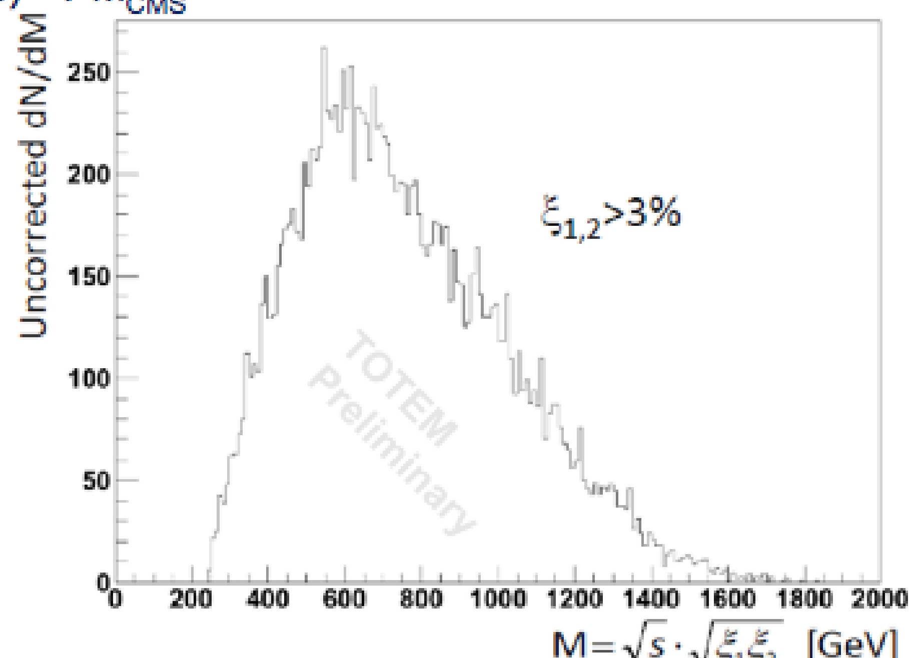
Prediction of mass to be seen in CMS from reconstructed protons: $M^2 = s\, \xi_1 \xi_2$

Initial vs. final state comparison: M_{TOTEM} (pp) =? M_{CMS}

Prediction of central particle flow topology from proton ξ's (rapidity gaps):
$\Delta\eta_{1,2} = -\ln\xi_{1,2}$

Masses up to 1.8 TeV with pp survival!

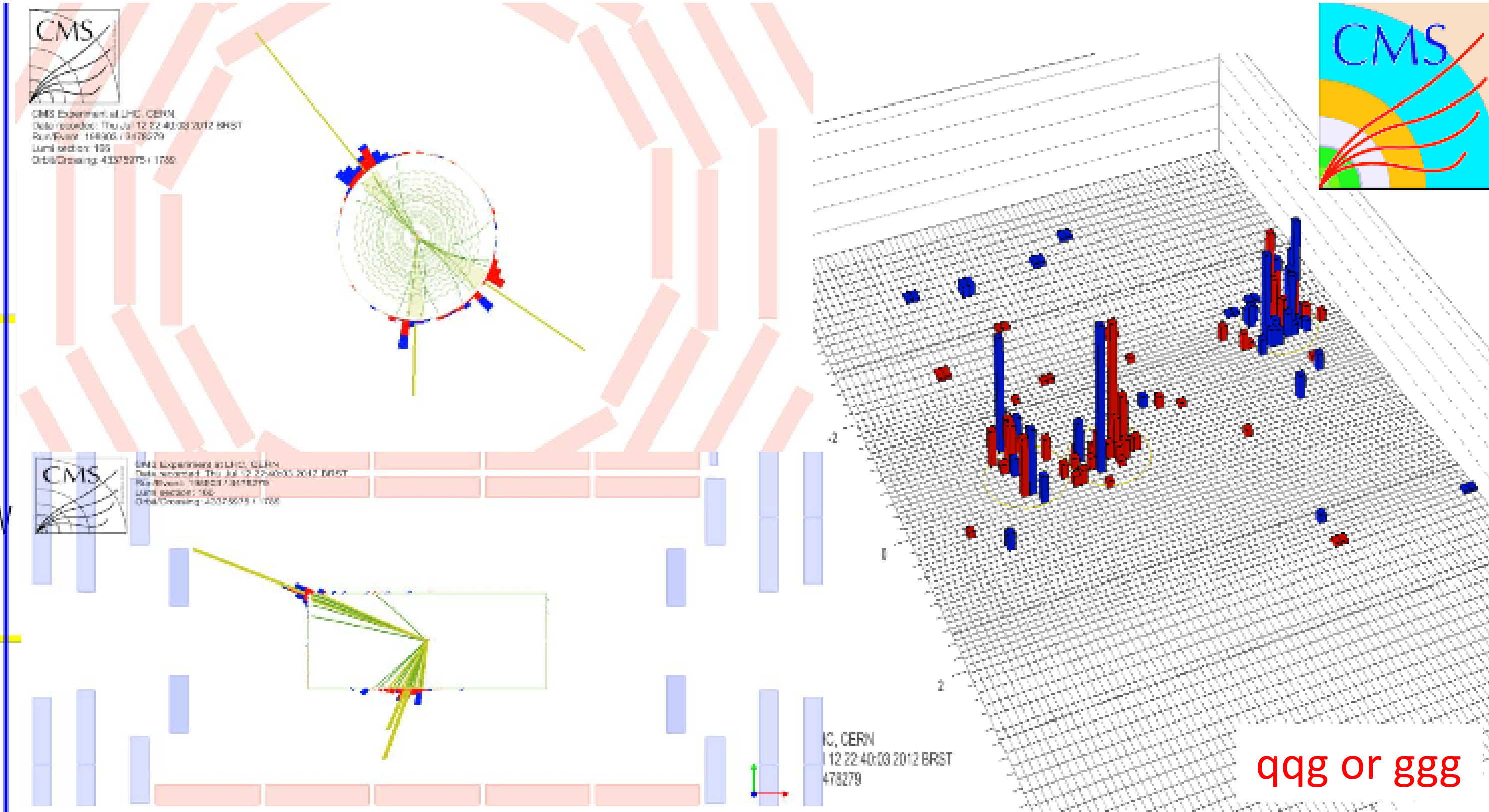
Analysis ongoing.
Good statistics for soft central diffraction & single diffractive dijets; limited for hard central diffraction



Fedrik Oljemark, TOTEM + CMS

CMS + TOTEM 90m β*
Run/Event 198903/3478279
Jets E_T = 65,45,27 GeV

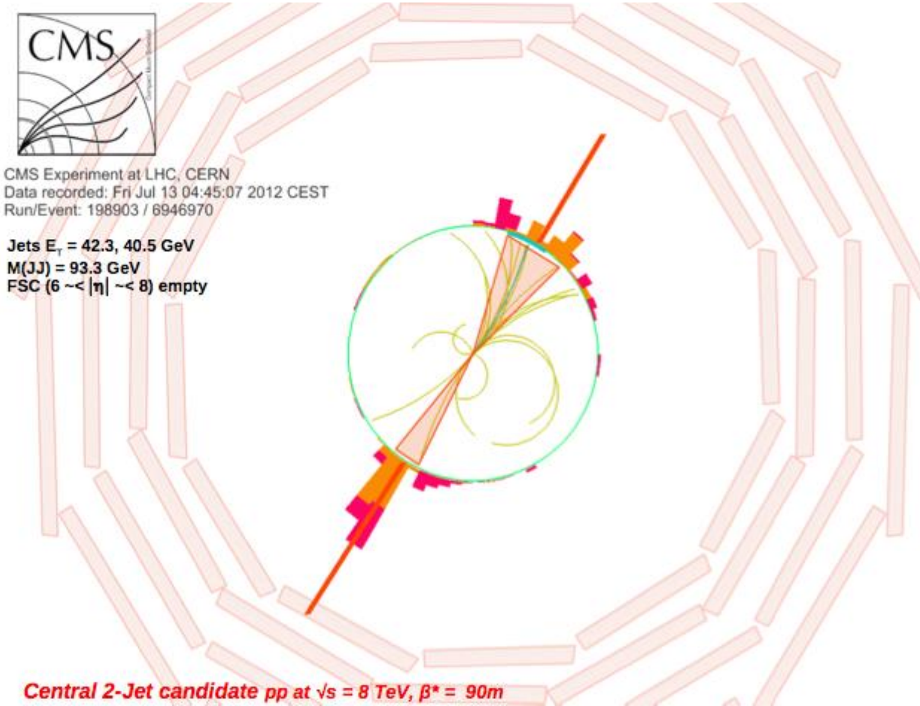
MM(pp) = 244 GeV; M(CMS) = 219 GeV
Σp_T(CMS) = 3.4 GeV
FSC empty both sides

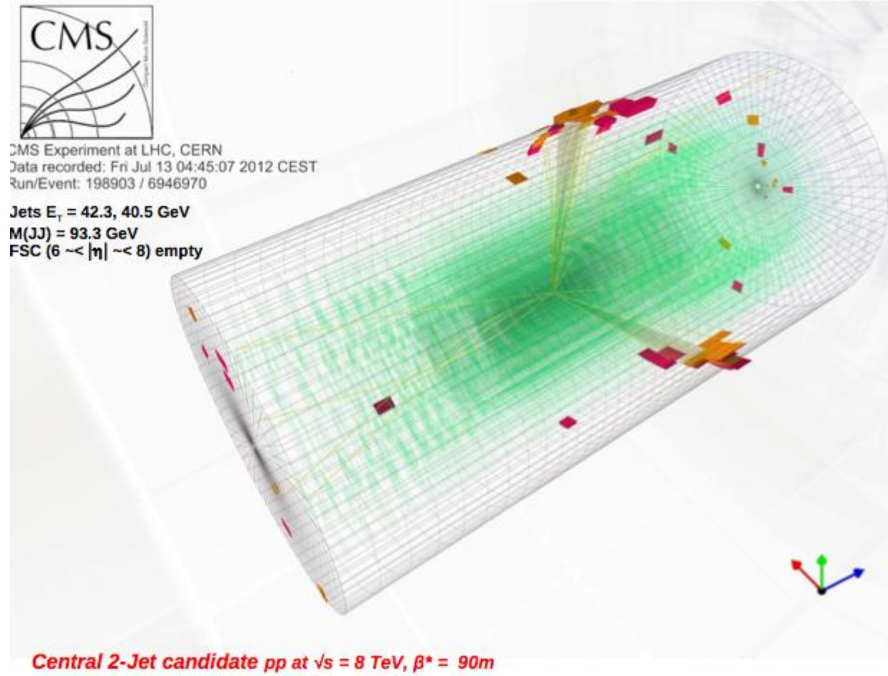


M(pp) ~ 244 GeV
(TOTEM & CMS compatible)
ξ_-=0.1 ξ=0.01

Note Forward Shower Counters
FSC, gaps requred 6 < |η| < 8

Events from July 2012 90m β* run
CMS: >= 2 jets ET > 20 GeV. Short low-pile-up run with ~ 100 bunches.
Large sample of p + JJ SD data. + some p + JJ(J) + p events.

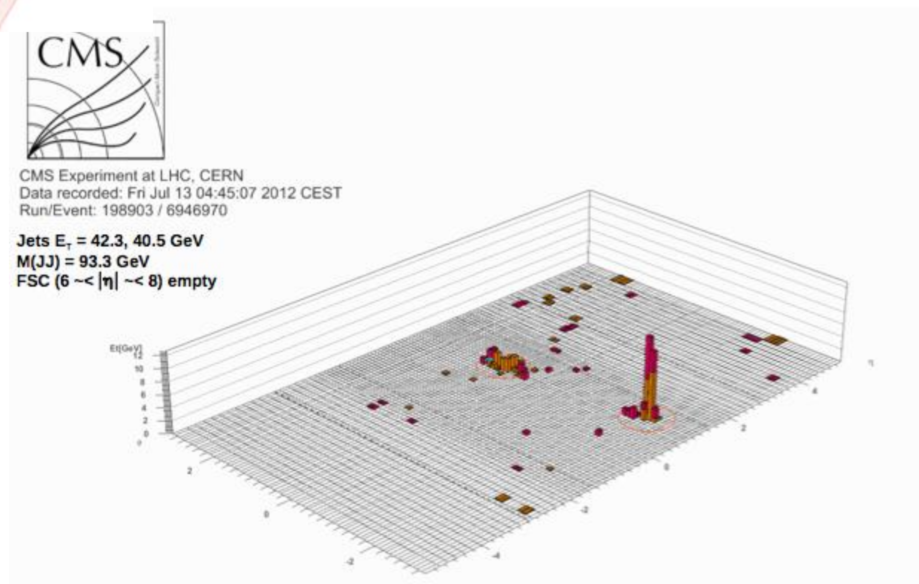




Event from 90m β* run, low PU, with TOTEM:

p + JetJet + p

with FSC empty both sides



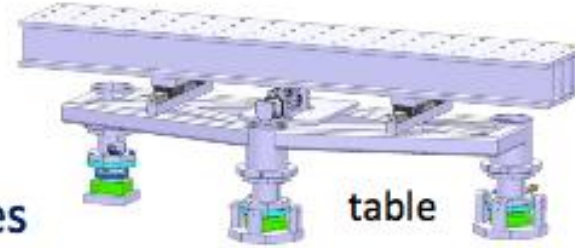
Precision Proton Spectrometer

z = 240-250 m region

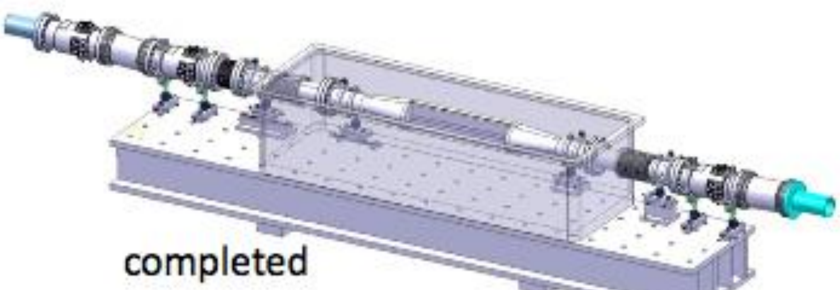
Just asking for detectors to be put there!

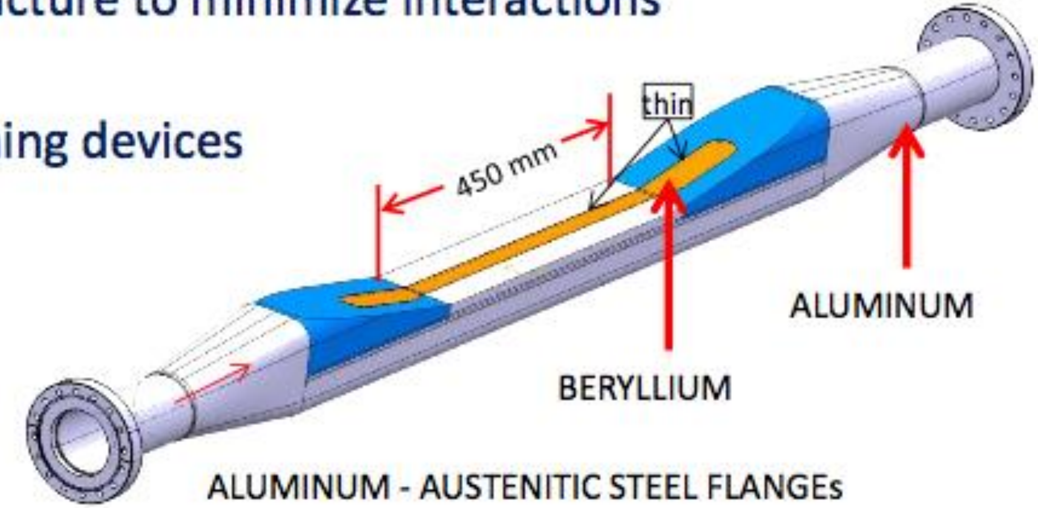
Looking down from an alcove balcony

AFP Hamburg Beam Pipe (HBP) solution



- tilted windows (11°) minimize beam coupling and losses
- Be windows and floor, and Al structure to minimize interactions and multiple scattering
- ample space for tracking and timing devices



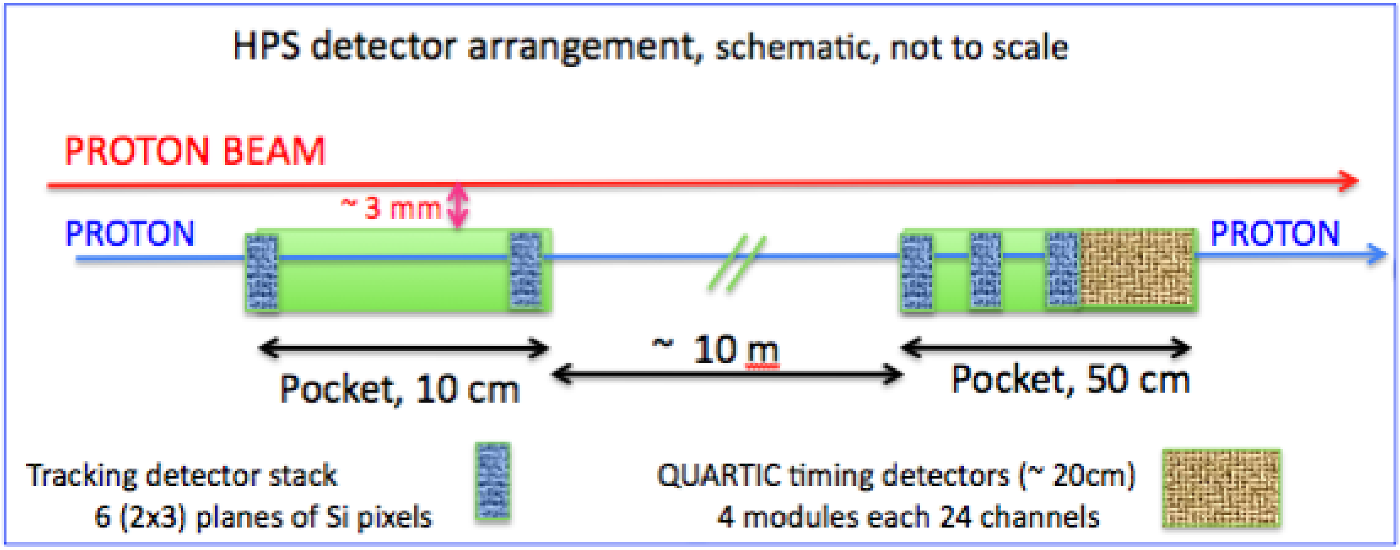


results of detailed RF simulations:

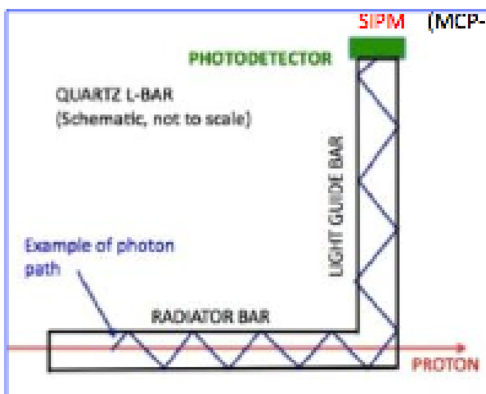
- impedance Z_{long} is at the level of 0.5%/station at 1 mm from the beam ☺
- similar for Z_{trans} ☺
- power loss (heating) is manageable ~ 30 W, mostly in conical sections
- bellows are not yet included, but we are confident we can minimize their effect

M.Albrow

The future: very forward proton spectrometers for CMS(PPS) and ATLAS(AFP) for high luminosity running, 100 fb-1/year: Jets, WW, etc



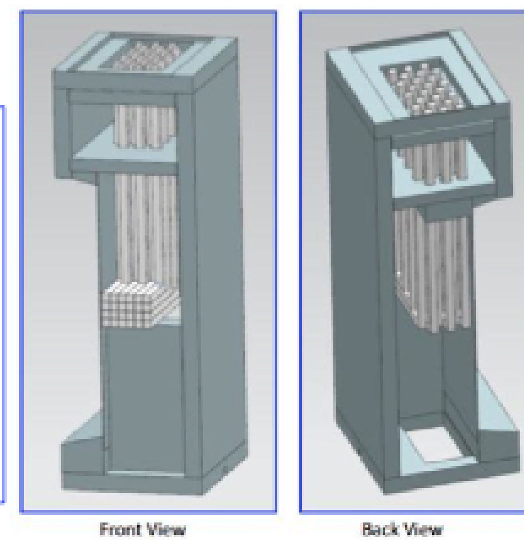
Timing essential for PU rejection:
MGA+Rostovtsev in p+H+p (2000)



L-BAR QUARTIC: LBQ

Principle: All Cherenkov light is totally internally reflected to back of radiator bar. ~ 2/3 goes up light guide bar promptly, rest folllows.

Total Internal Reflection:
Bars separated by fine wire (100 um)



One L-bar QUARTIC module
15mm x 12mm, 20 3x3mm^2 elements

$\sigma(t)$ = 30ps demonstrated (Fermilab test beam)
4 modules in line → 15 ps; $\sigma(z_{vtx})$ = 3.2 mm

Oldrich Kepka: **LHC Forward physics working group**

Physics interest

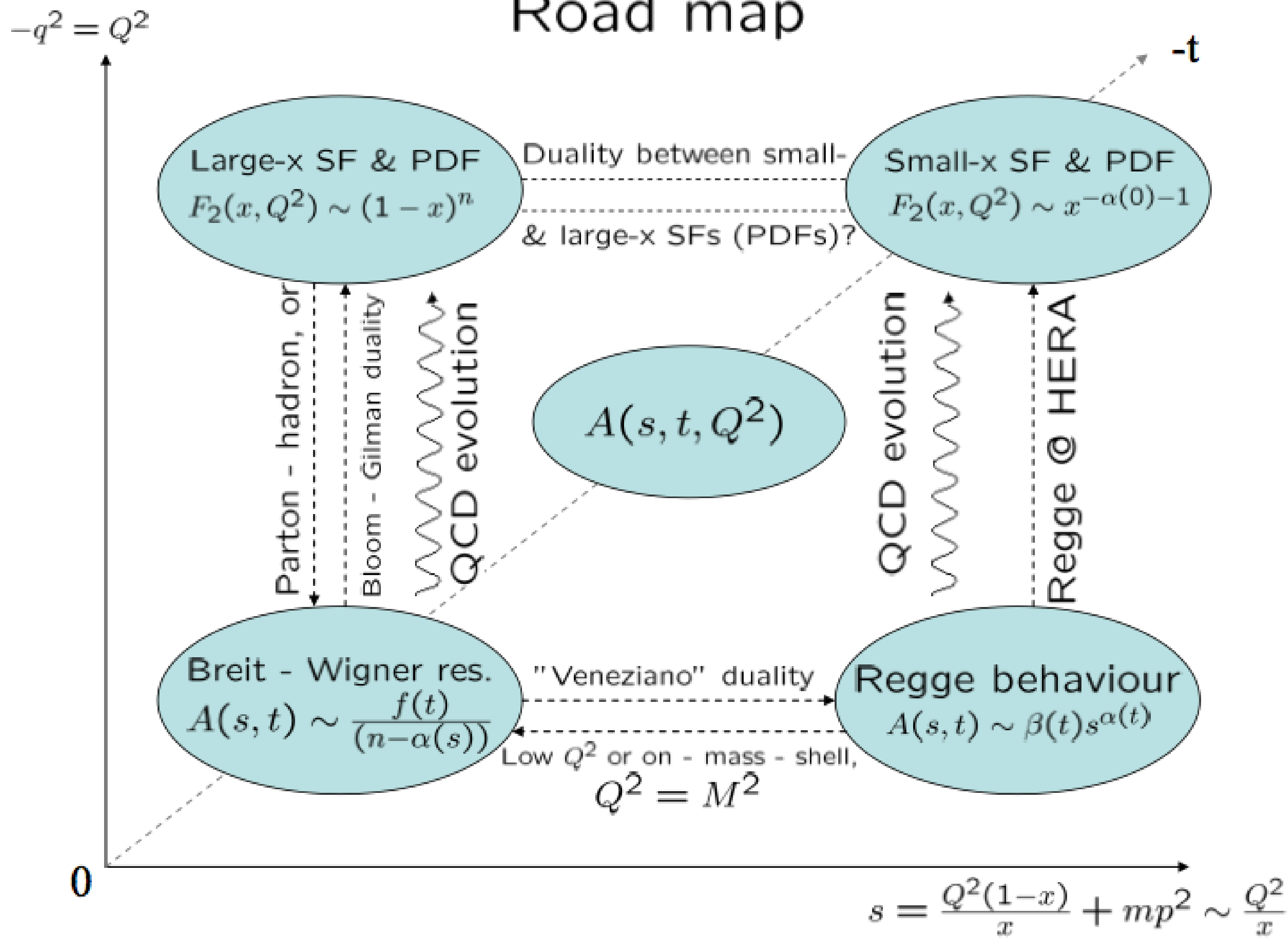
- Modeling of hadron-hadron, p-ion, ion-ion (?) interactions
  - Development of models merging soft and hard production
  - Survival probability factor
  - Multi-parton interactions
  - Measurements with gaps or proton tags
  - Low-x dynamics, saturation
- Diffractive measurements
  - Soft & hard diffraction, structure of pomeron
- Exclusive processes
  - vector meson production, photon-photon interactions, anomalous couplings, exclusive due to gluon-gluon
- Cosmic ray physics
  - LHC measurement can improve modeling of primary and secondary interactions in cosmic ray showers → more precise conclusions on CR shower composition

Oldrich Kepka: LHC Forward physics working group
Frequent meetings, all experiments + theorists/phenomenologists.
Goals:

- Produce CERN Yellow Report
  - "… includes the proceedings of schools and of workshops having a large impact on the future of CERN, the series also includes reports on detectors and technical papers from individual CERN divisions, again the criteria being that the audience should be large and the duration of interest long."

- Demonstrate the physics interest of forward physics, summarize the current results
- Define common strategy for running conditions optimal for forward physics (low-luminosity, special optics)
  - Increase chances that such runs will be delivered
- Provide clearer picture of limitations & overlaps of different experiments
  - Acceptance & resolution, new detector proposals
- Engage theorists to help to bring ideas of new forward physics studies at the LHC

Road map



Shown by Laszlo Jenkovsky

Getting to Low-x in pp

Simple kinematics:

Mapping of partons' x_1, x_2 to jets (objects) $p_{T1} = p_{T2}$ and $y_1 = y_2$ for Tevatron √s = 2 TeV.

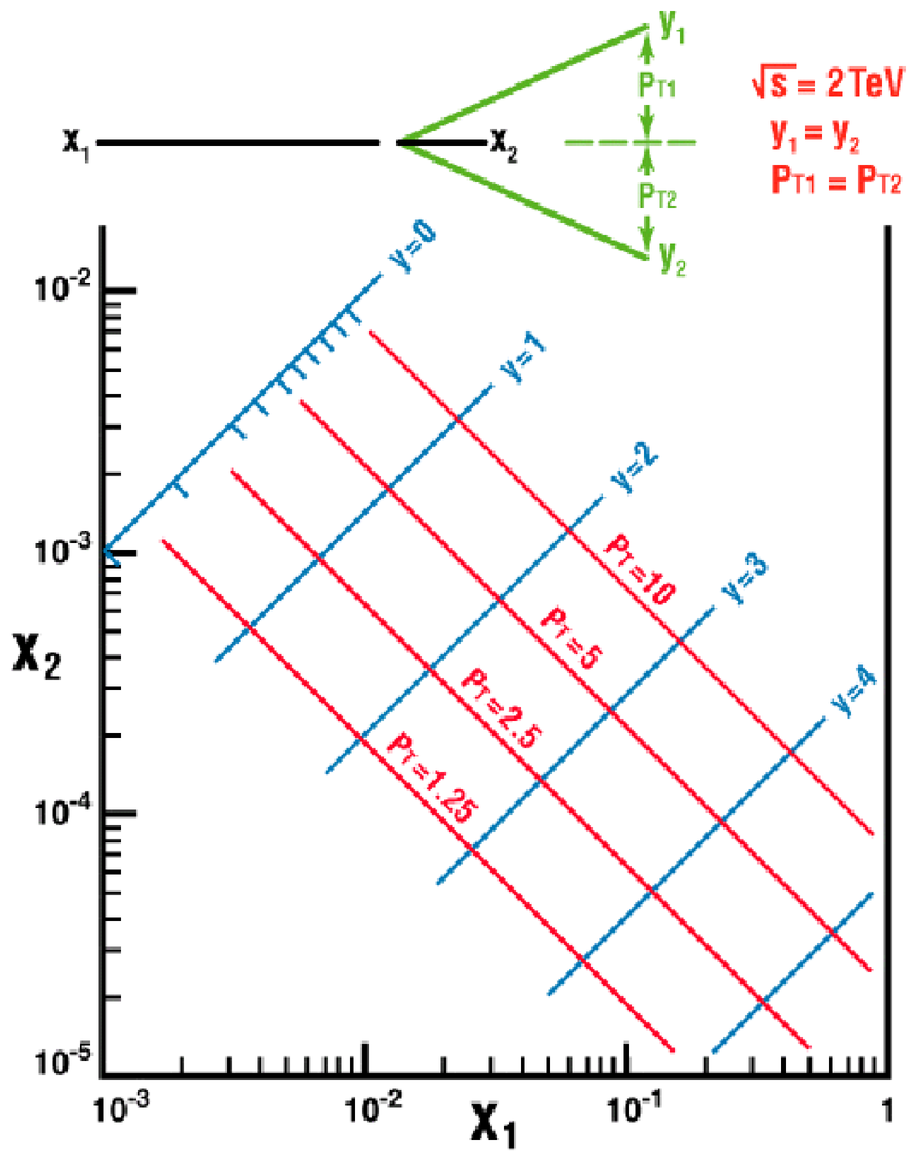
For LHC-13 multiply x-axes by 2/13 = 0.15

Good:

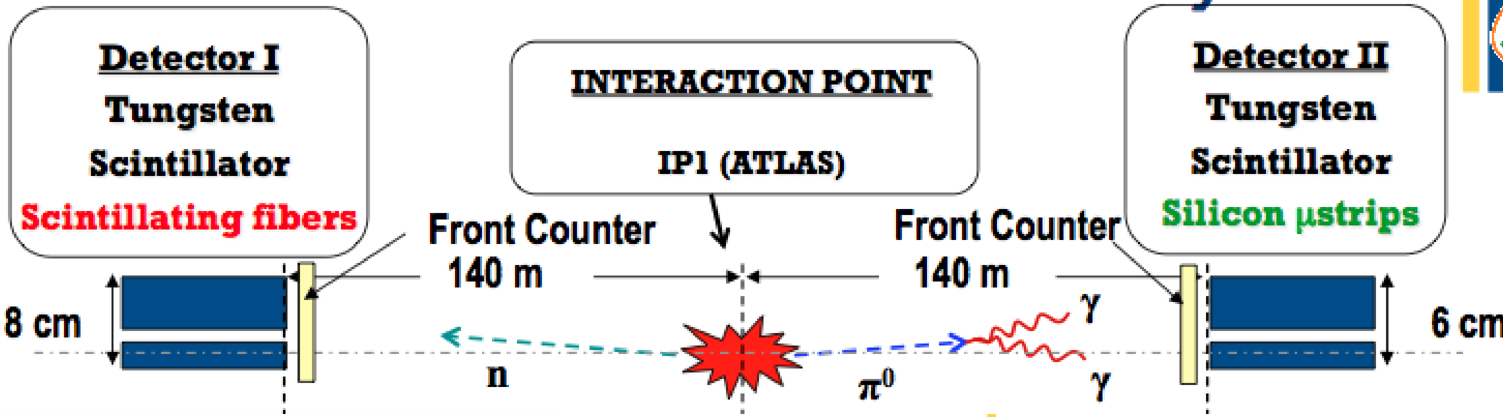
D-Dbar pairs in LHCb, both large y and low pT.

A) Inclusive

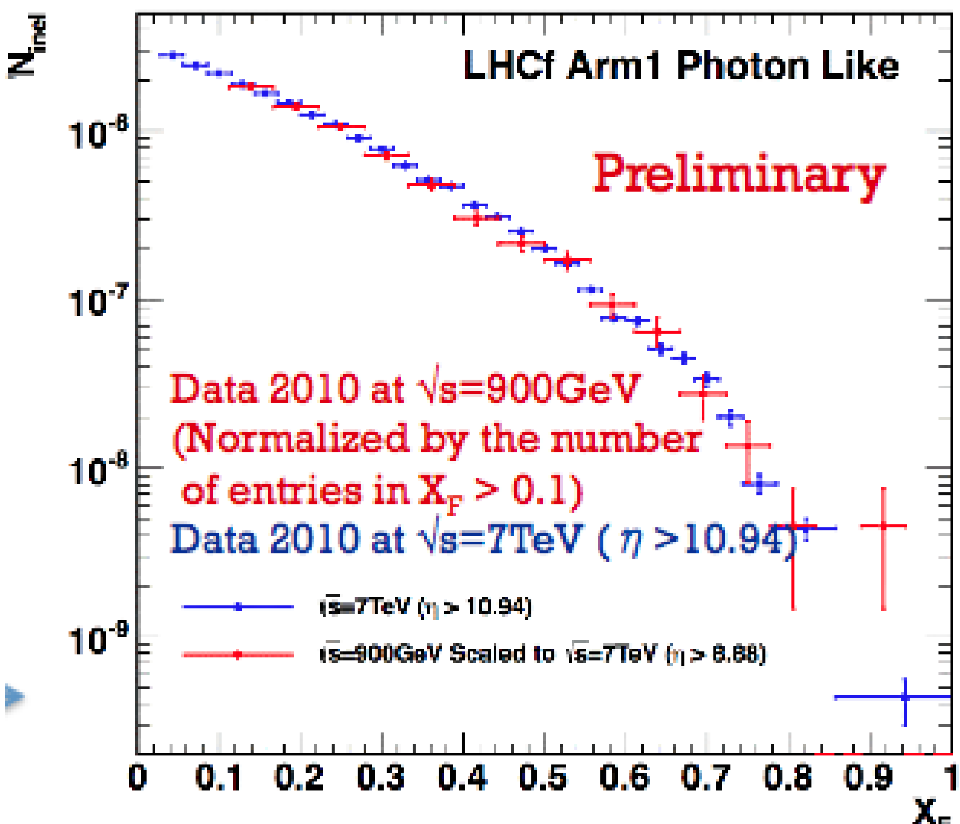
B) Exclusive



LHCf: location and detector layout



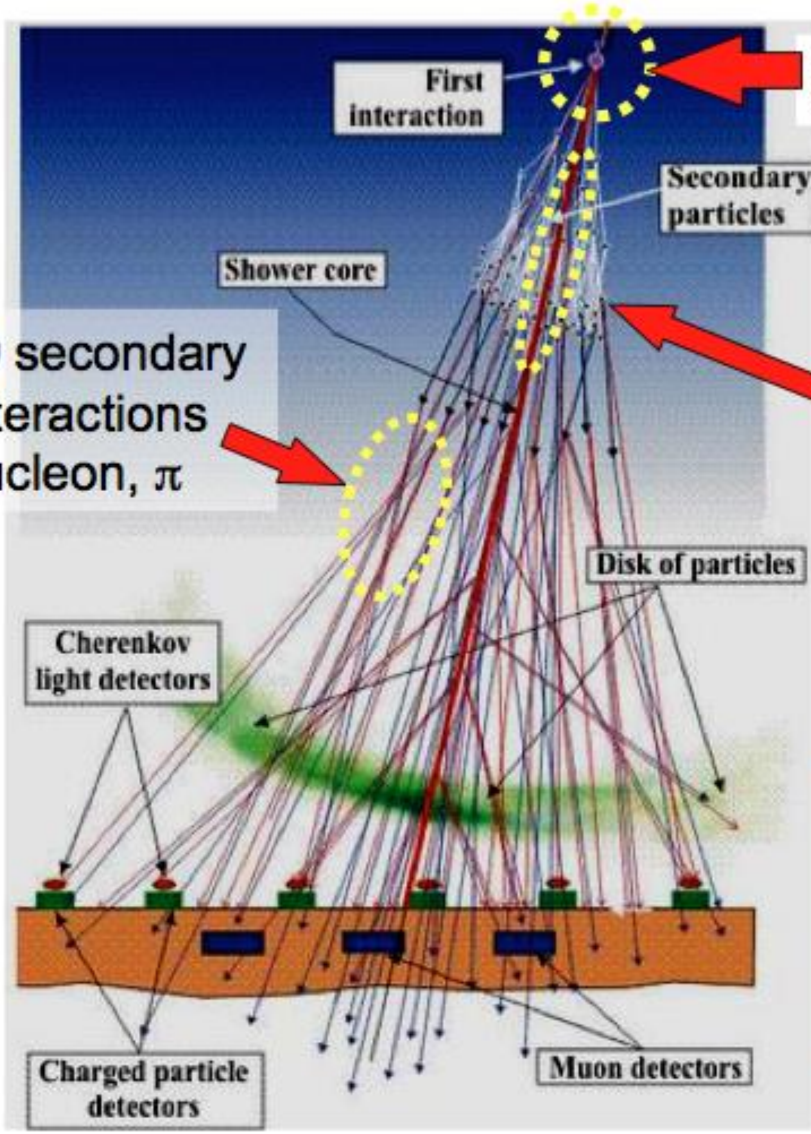
X_F spectra : 900GeV data vs. 7TeV data



Can we measure identified
π+-, K+-, p, pbar over all Feynman x_F ?

Bent crystal channelling
Good hadron calorimeter: E
Transition radiation detector: γ
Hence M
Bending magnet + precision tracker: Q

How accelerator experiments can contribute?



④ secondary interactions nucleon, π

① Inelastic cross section

If large σ: rapid development
If small σ: deep penetrating

② Forward energy spectrum

If softer shallow development
If harder deep penetrating

③ Inelasticity $k=1-E_{lead}/E_{avail}$

If large k (π^0s carry more energy)
rapid development
If small k (baryons carry more energy)
deep penetrating

We had some lively discussions!

Our field has a golden future, and Tuula found some!

Enough for the Au + Au collisions in the LHC for a decade!

Thanks Tuula and Risto and all organisers for a great conference!

Discussion Session

What do you mean by a pomeron?

What do you mean by a rapidity gap?

What do you mean by diffraction?

Risto left already

Thank you