Hard diffraction at the LHC

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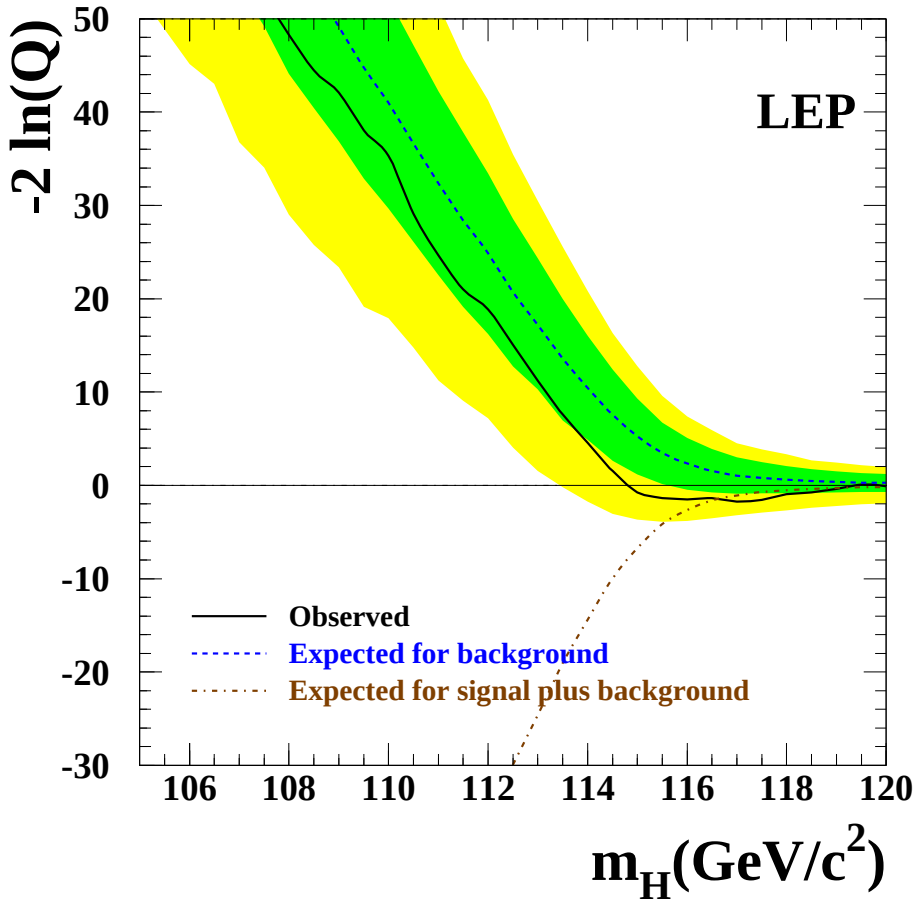
Contents:

- Standard Higgs physics at the LHC
- What is diffraction (HERA and Tevatron)?
- Inclusive diffraction at the LHC
- Diffractive Higgs production at the LHC: exclusive and inclusive production
- Background studies: How to measure the high β gluon?
- Exclusive top and stop production

Work done in collaboration with M. Boonekamp. J. Cammin, O. Kepka, A. Kupco, R. Peschanski, L. Schoeffel
NB: Many results coming from the "Saclay" group, see also results from Durham group in particular (A. Martin, V. Khoze, M. Ryskin)

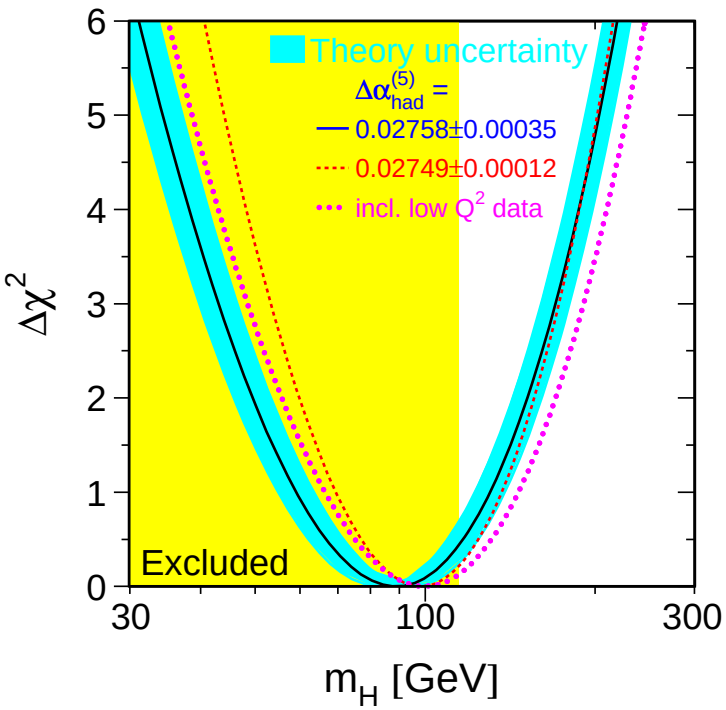
LEP experiments limits on Higgs mass

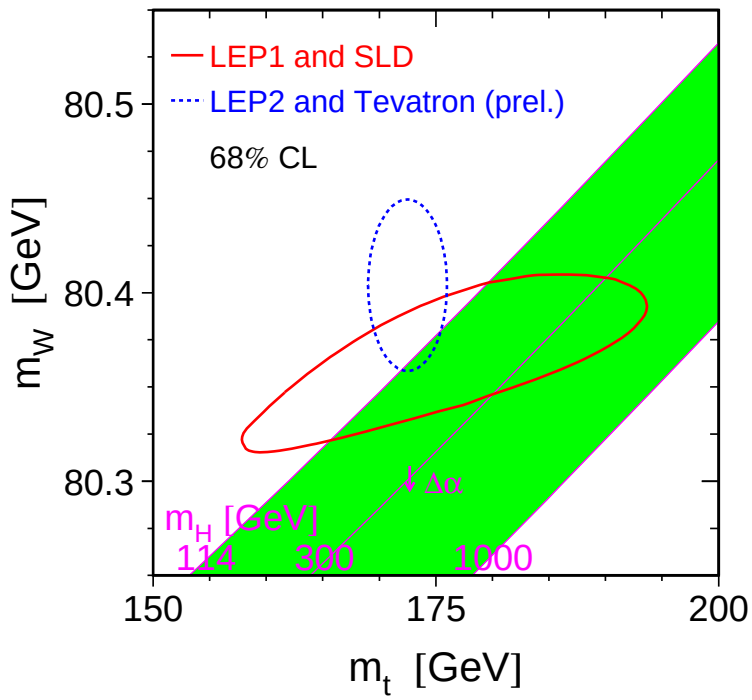
- Q: ratio of the probability to observe what has been seen if it is a Higgs signal by the probability to observe the same if it is only background
- Limit on Higgs mass: 114.4 GeV



Electroweak fits and mass of Higgs boson

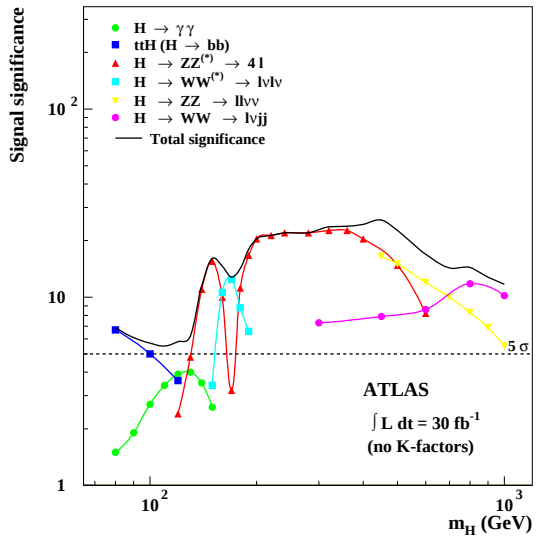
- Use new M_{top}, width of W boson from Tevatron and LEP, and mass of W from LEP
- $M_{Higgs} = 89 + 42 - 30$ GeV (68% CL), and < 175 GeV at 95% CL

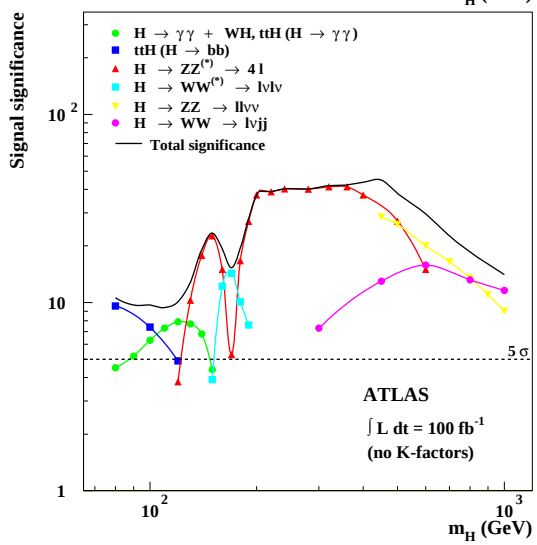




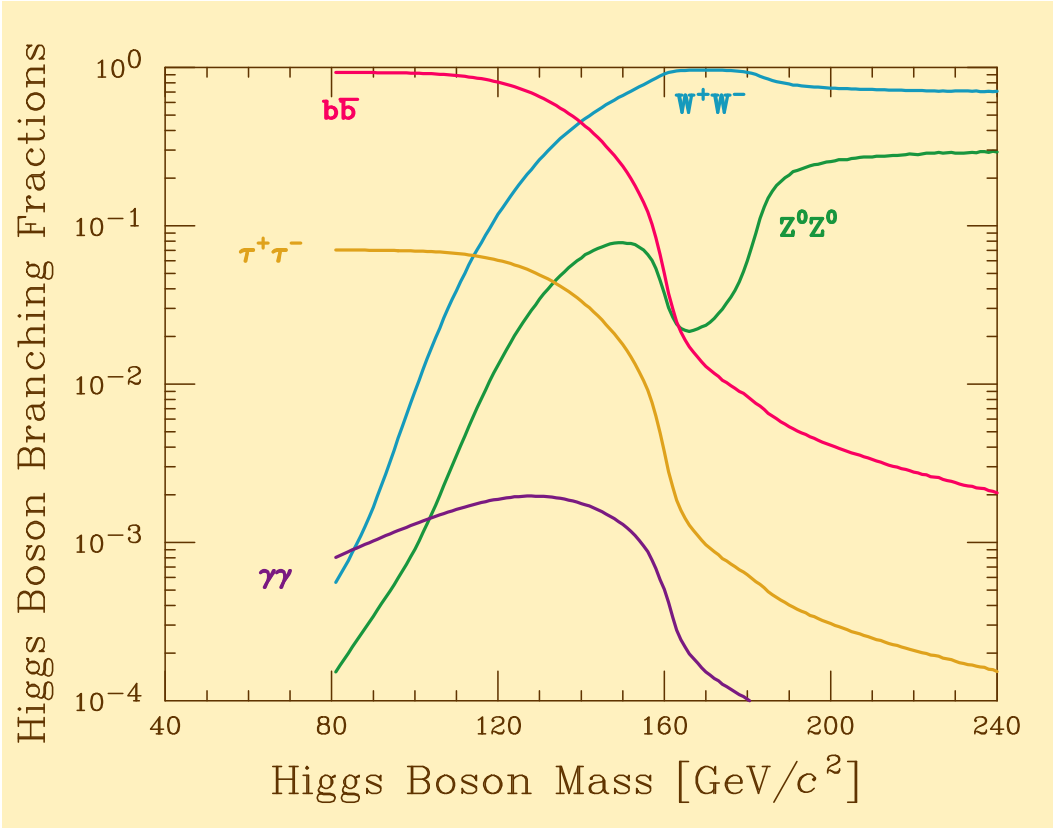
Standard search for Higgs boson at the LHC

- Low masses: difficult region at the LHC: other ways of finding the Higgs boson
- Properties of Higgs boson difficult to be analysed





SM Higgs decay



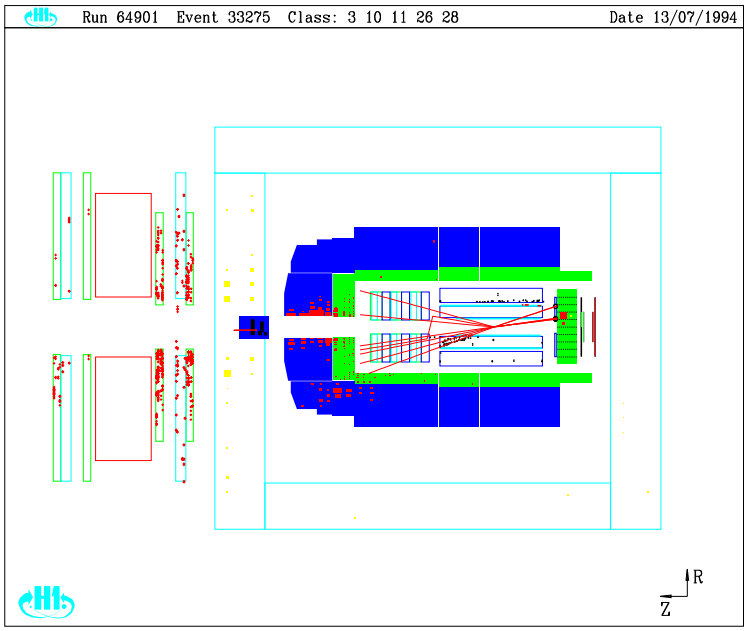
Low masses: $b\bar{b}$ and $\tau\tau$ dominate

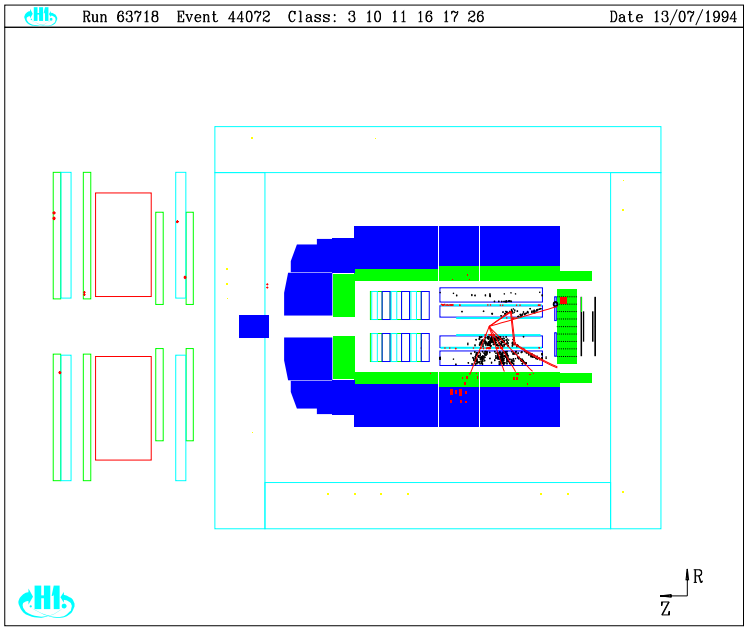
High masses: WW dominates

Definition of diffraction: example of HERA

- Typical DIS event: part of proton remnants seens in detectors in forward region (calorimeter, forward muon...)
- HERA observation: in some events, no energy in forward region, or in other words no colour exchange between proton and jets produced in the hard interaction
- Leads to the first experimental method to detect diffractive events: rapidity gap in calorimeter
- Second method to find diffractive events: Tag the proton in the final state

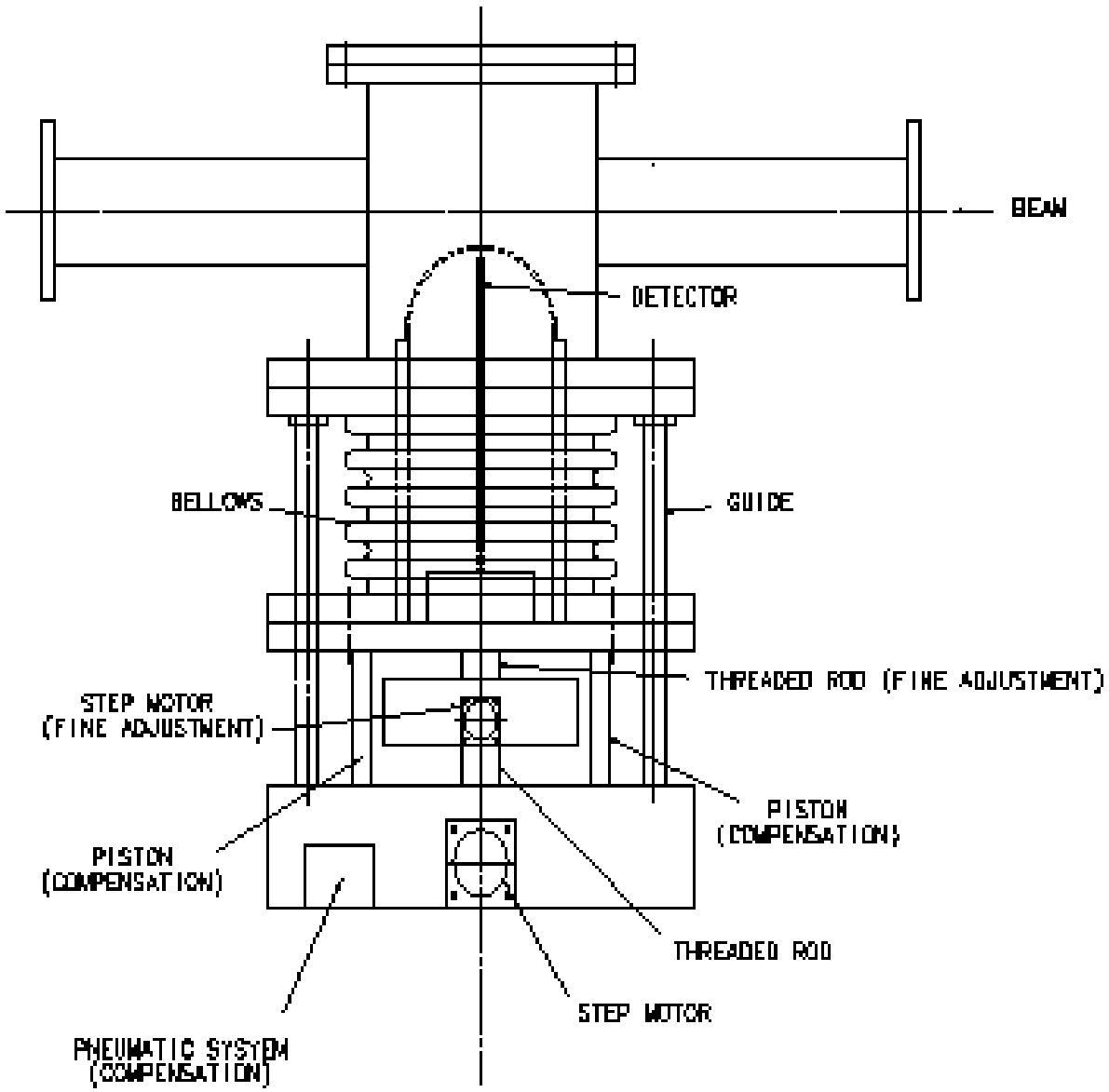
DIS and Diffractive event at HERA





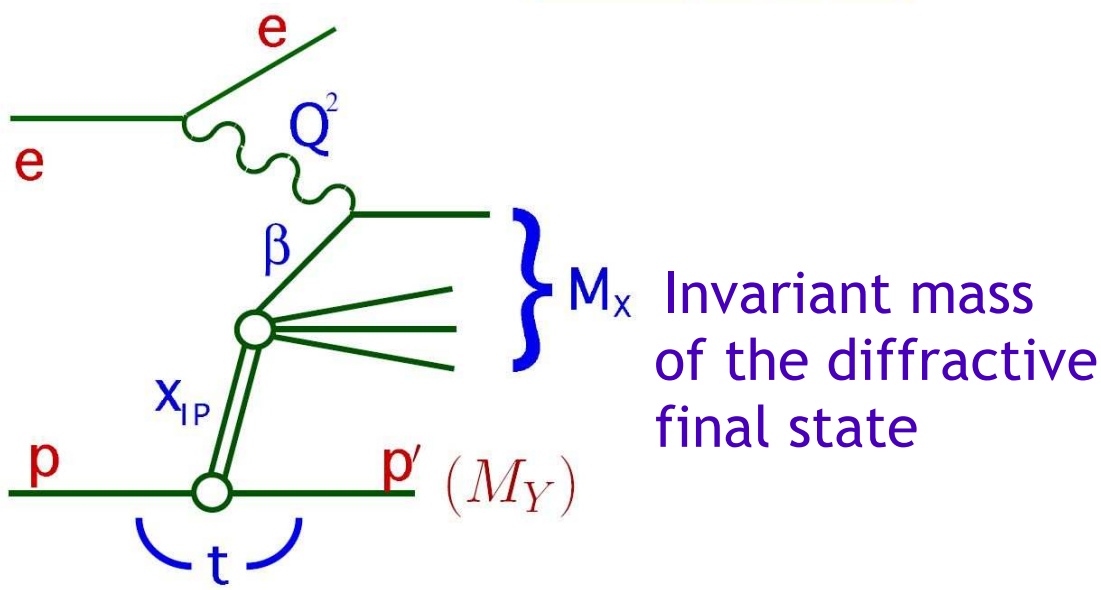
Scheme of a roman pot detector

Scheme of roman pot detector



Forward Detectors (DØ)

Diffractive kinematical variables



- Momentum fraction of the proton carried by the colourless object (pomeron): $x_p = \xi = \frac{Q^2+M_X^2}{Q^2+W^2}$
- Momentum fraction of the pomeron carried by the interacting parton if we assume the colourless object to be made of quarks and gluons: $\beta = \frac{Q^2}{Q^2+M_X^2} = \frac{x_{Bj}}{x_P}$
- 4-momentum squared transferred: $t = (p - p')^2$

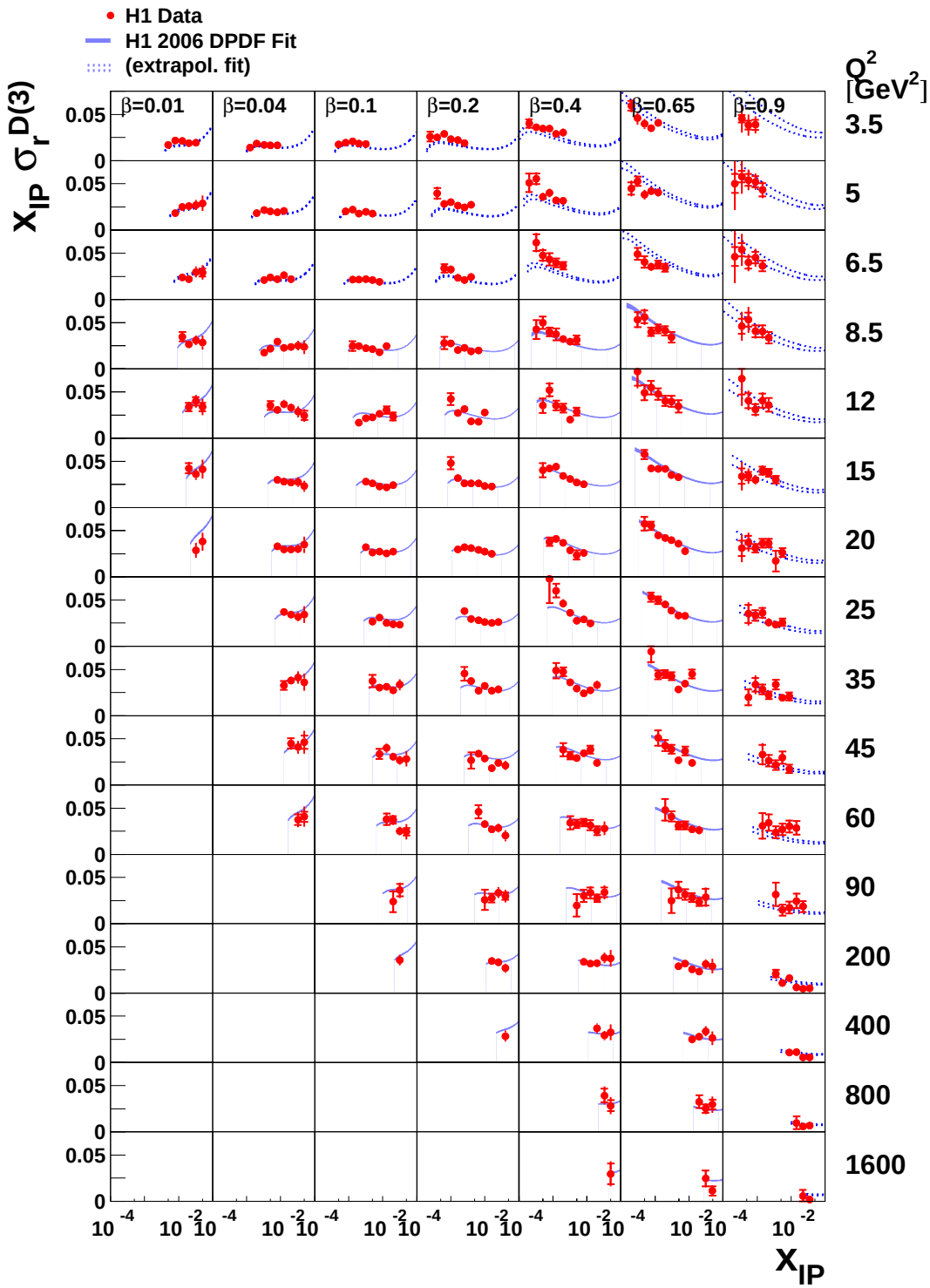
Measurement of the diffractive structure function F_2^D

- Measurement of the diffractive cross section using the rapidity gap selection over a wide kinematical domain in (x_P, β, Q^2)
- Definition of the reduced cross section:

$$\frac{d^3\sigma^D}{dx_P dQ^2 d\beta} = \frac{2\pi\alpha_{em}^2}{\beta Q^4}\left(1 - y + \frac{y^2}{2}\right)\sigma_r^D(x_P, Q^2, \beta)$$

- As an example: H1 data

Measurement of the diffractive structure function F_2^D



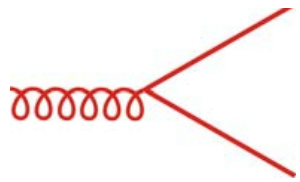
Extraction of the parton densities in the pomeron (H1)

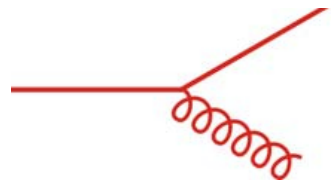
- Assume pomeron made of quarks and gluons: perform QCD DGLAP fits as for the proton structure function starting from xG and xq distributions at a given Q_0^2, and evolve in Q^2 (the form of the distributions is MRS like)

$$\begin{aligned} \beta q &= A_q \beta^{B_q} (1-\beta)^{C_q} \\ \beta G &= A_g (1-\beta)^{C_g} \end{aligned}$$

- At low β: evolution driven by $g \to q\bar{q}$, at high β, $q \to qg$ becomes important
- Take all data for $Q^2 > 8.5$ GeV^2, $\beta <$ 0.8 to be in the perturbative QCD region and avoid the low mass region (vector meson resonances)

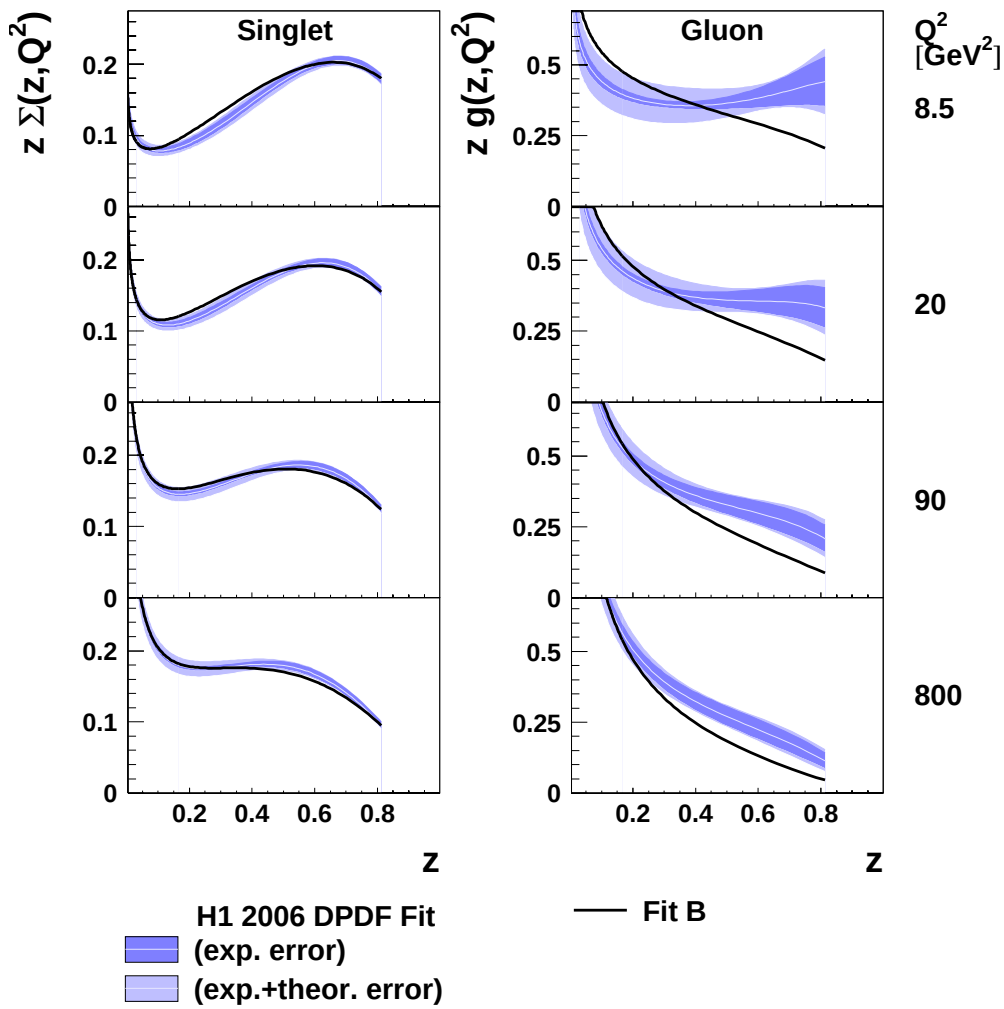
$$\frac{dF_2^D}{d\log Q^2} \sim \frac{\alpha_S}{2\pi} \left[P_{qg} \otimes g + P_{qq} \otimes \Sigma \right]$$



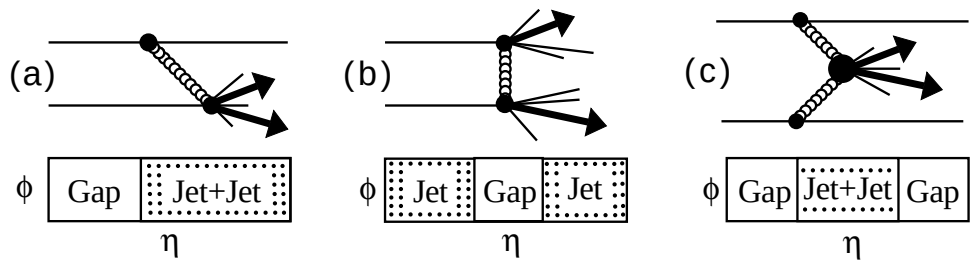


Parton densities in the pomeron (H1)

- Extraction of gluon and quarks densities in pomeron: gluon dominated
- Gluon density poorly constrained at high β (imposing $C_g = 0$ leads to a good fit as well, Fit B)
- Good description of final states



Diffraction at Tevatron/LHC

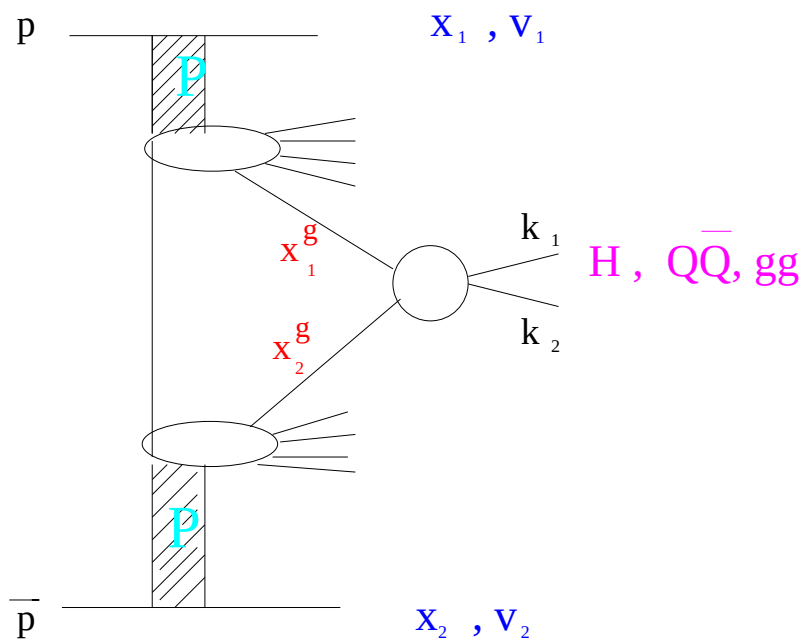


Kinematic variables

- t: 4-momentum transfer squared
- ξ_1, ξ_2: proton fractional momentum loss (momentum fraction of the proton carried by the pomeron)
- $\beta_{1,2} = x_{Bj,1,2}/\xi_{1,2}$: Bjorken-x of parton inside the pomeron
- $M^2 = s\xi_1\xi_2$: diffractive mass produced
- $\Delta y_{1,2} \sim \Delta\eta \sim \log 1/\xi_{1,2}$: rapidity gap

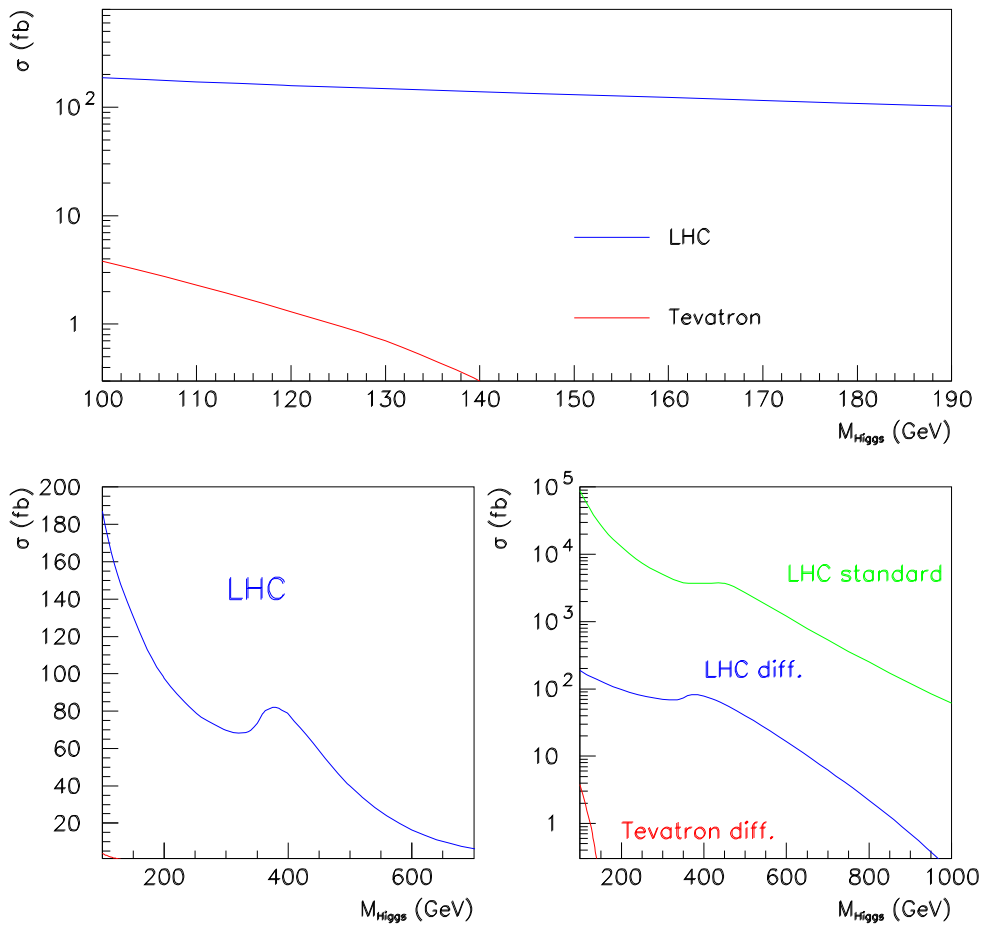
"Inclusive" models

- "Inclusive" models: Take the hadron-hadron "usual" cross section convoluted with the parton distributions in the pomeron
- Take shape of H1 measurement of gluon density
- Normalisation coming from CDF run I cross section measurement
- Inclusive cross sections need to be known in detail since it is a direct background to search for exclusive events

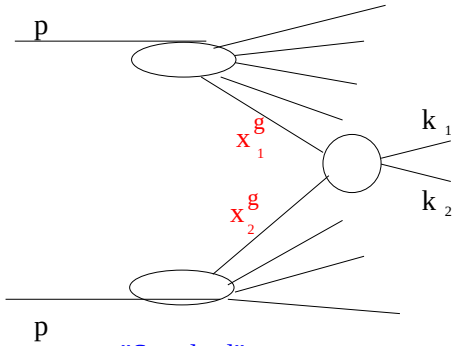


Inclusive Higgs mass production

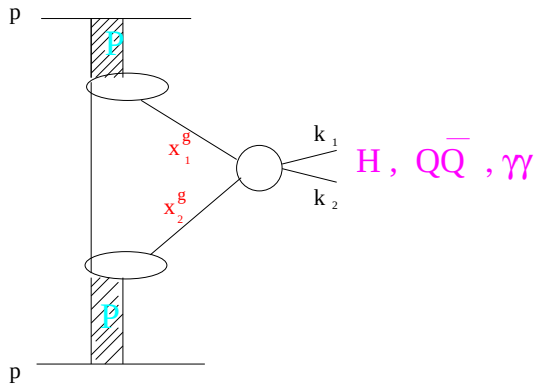
Large cross section, but mass poorly reconstructed since part of the energy lost in pomeron remnants
($M = \sqrt{\xi_1 \xi_2 S}$ ~Higgs + remnant mass)



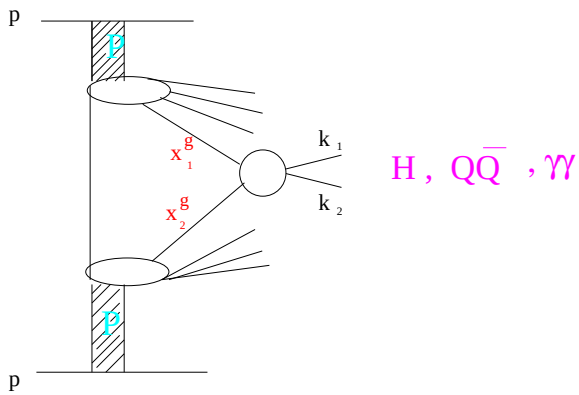
"Exclusive models"



"Standard"



"Exclusive "

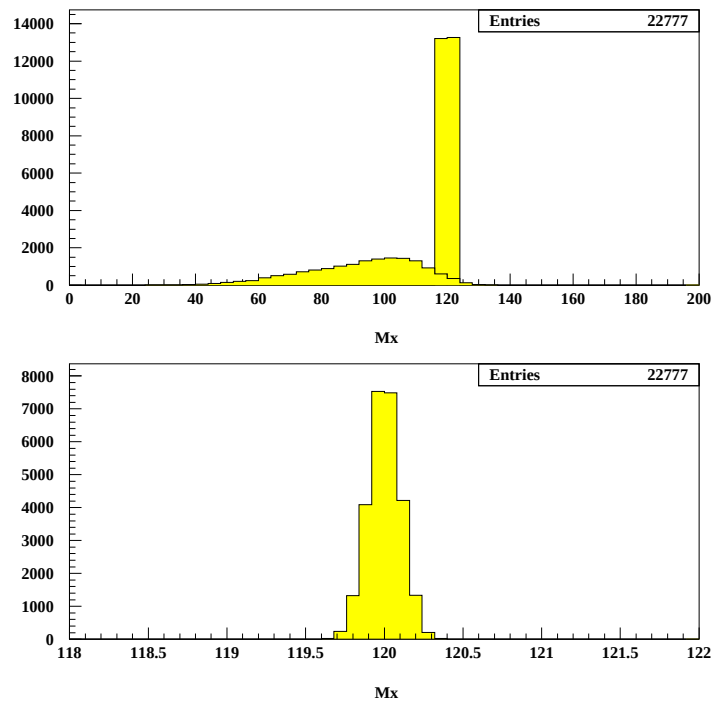


"Inclusive"

All the energy is used to produce the Higgs (or the dijets), namely $xG \sim \delta$ (See in particular "Saclay model (R. Peschanski, M. Boonekamp, J. Cammin, A. Kupco, O. Kepka, C. R.) (coupling via a pomeron), and Durham model (A. Martin, V. Khoze, M. Ryskin) (direct coupling to the proton)

Advantage of exclusive Higgs production?

- Good Higgs mass reconstruction: fully constrained system, Higgs mass reconstructed using both tagged protons in the final state ($pp \to pHp$)
- $M_H = \sqrt{\xi_p \xi_{\bar{p}} S}$
- No energy loss in pomeron "remnants"



DPEMC Monte Carlo

- DPEMC (Double Pomeron Exchange Monte Carlo): New generator to produce events with double pomeron exchange (both "Durham" and "Saclay" models) http://boonekam.home.cern.ch/boonekam /dpemc.htm, hep-ph/0312273
- Interface with Herwig: for hadronisation
- Exclusive and inclusive processes included: Higgs, dijets, diphotons, dileptons, SUSY, QED, Z, W...
- DPEMC generator interfaced with a fast simulation of LHC detector (as an example CMS, same for ATLAS), and a detailled simulation of roman pot acceptance
- Gap survival probability of 0.03 put for the LHC: is it possible to check this at the Tevatron?
- Another available MC: "Exhume" for Durham model

"Exclusive" production at the LHC

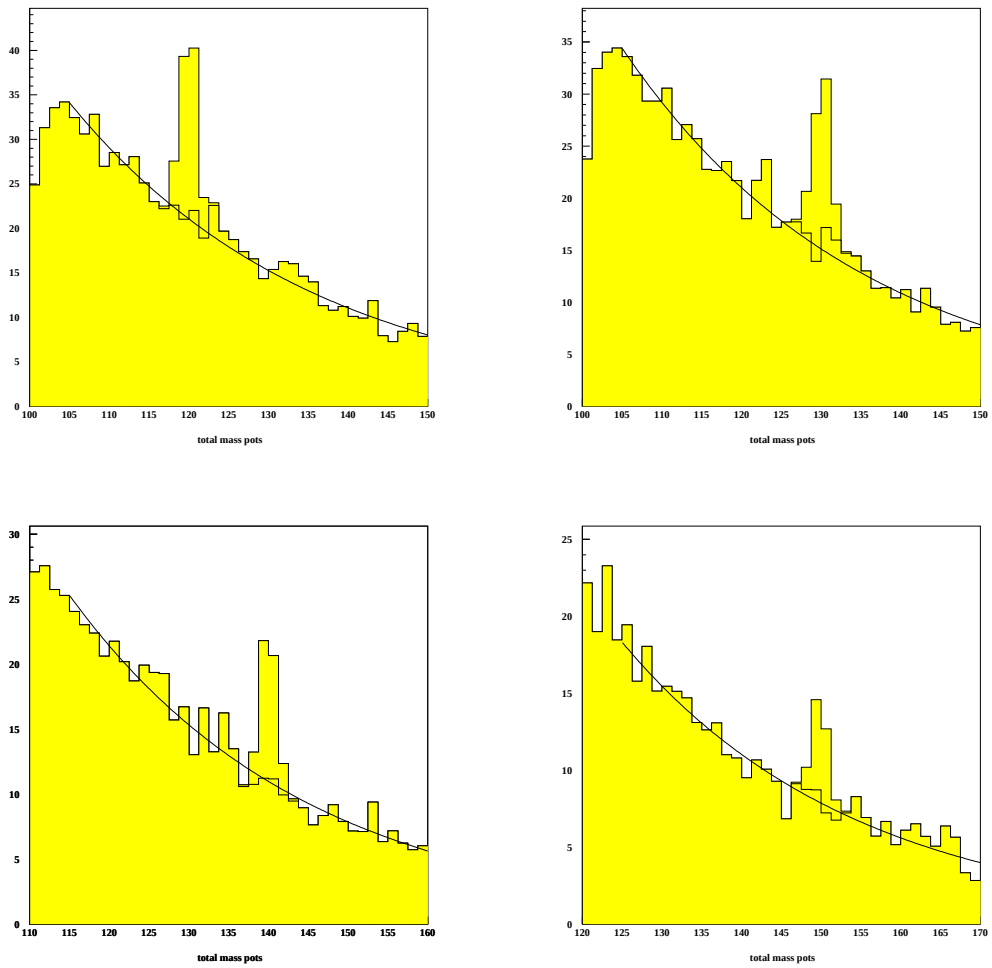
- As an example: Saclay model (For Durham model, similar results at 120 GeV with a stronger mass dependence)
- Higgs decaying into $b\bar{b}$: study S/B
- Exclusive $b\bar{b}$ cross section (for jets with $p_T > 25$ GeV): 2.1 pb
- Exclusive Higgs production (in fb)

M_{Higgs}	σ (fb)
120	3.9
125	3.5
130	3.1
135	2.5
140	2.0

- NB: a survival probability of 0.03 was applied to all cross sections

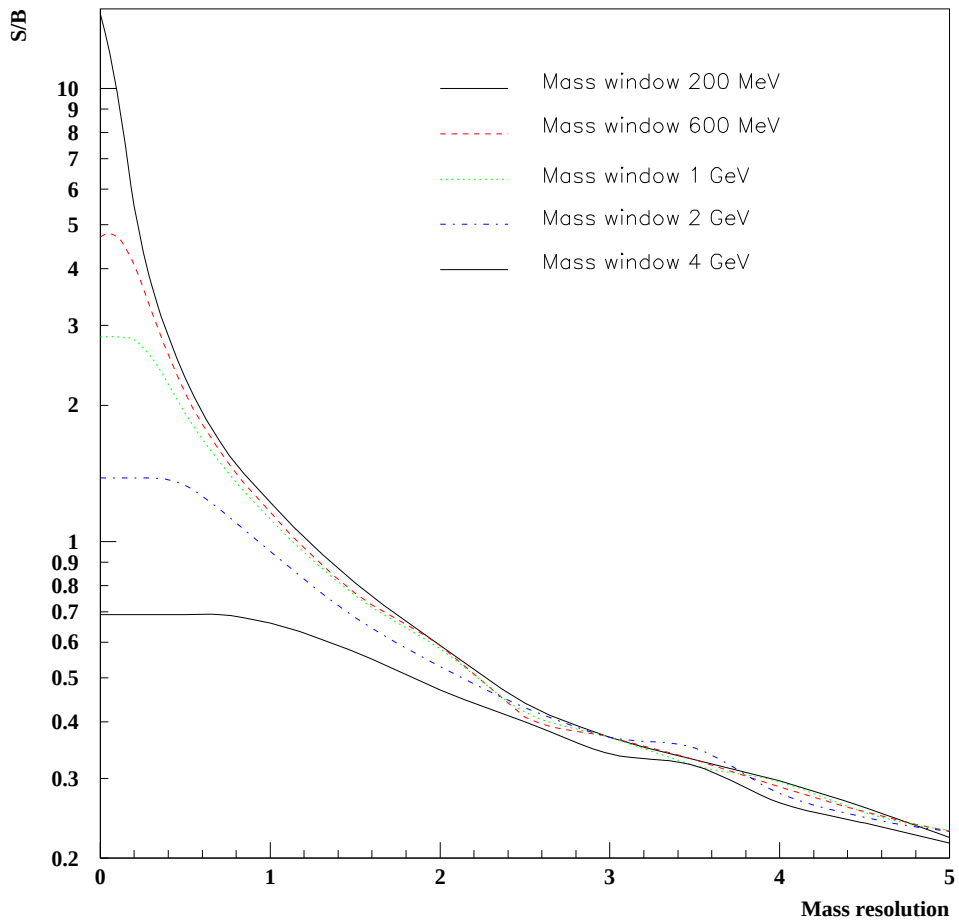
Signal and background

Signal and background for different Higgs masses for 100 fb^{-1}



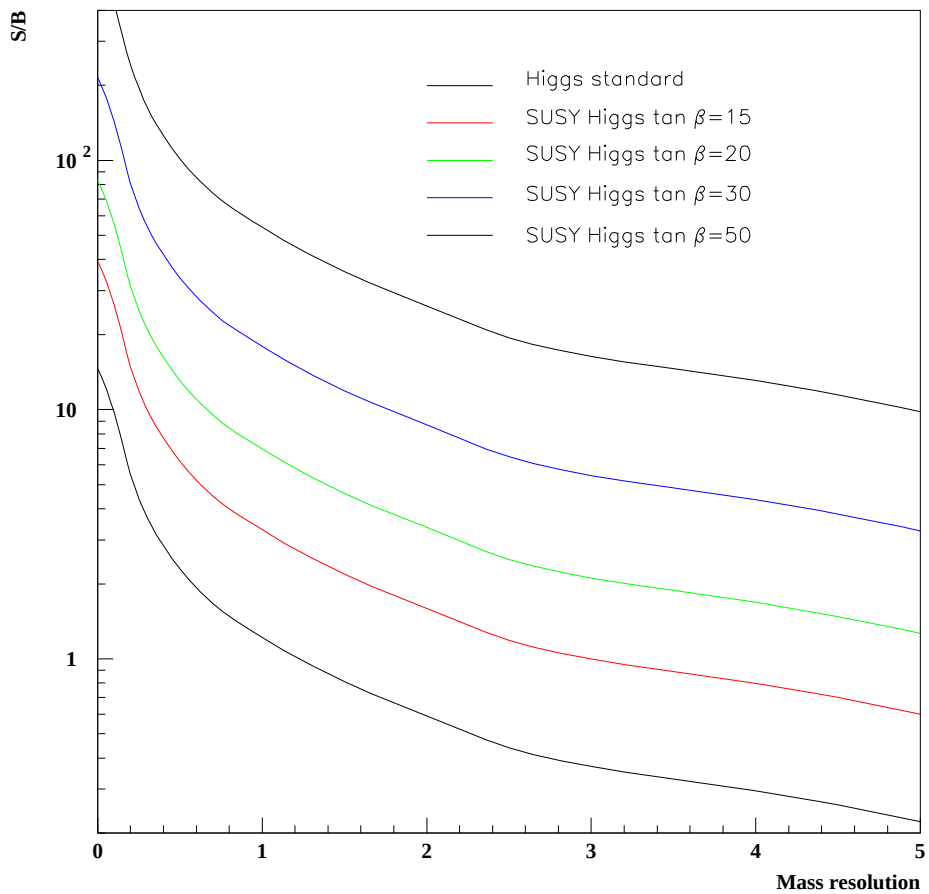
Signal over background: standard model Higgs

For a Higgs mass of 120 GeV and for different mass windows as a function of the Higgs mass resolution



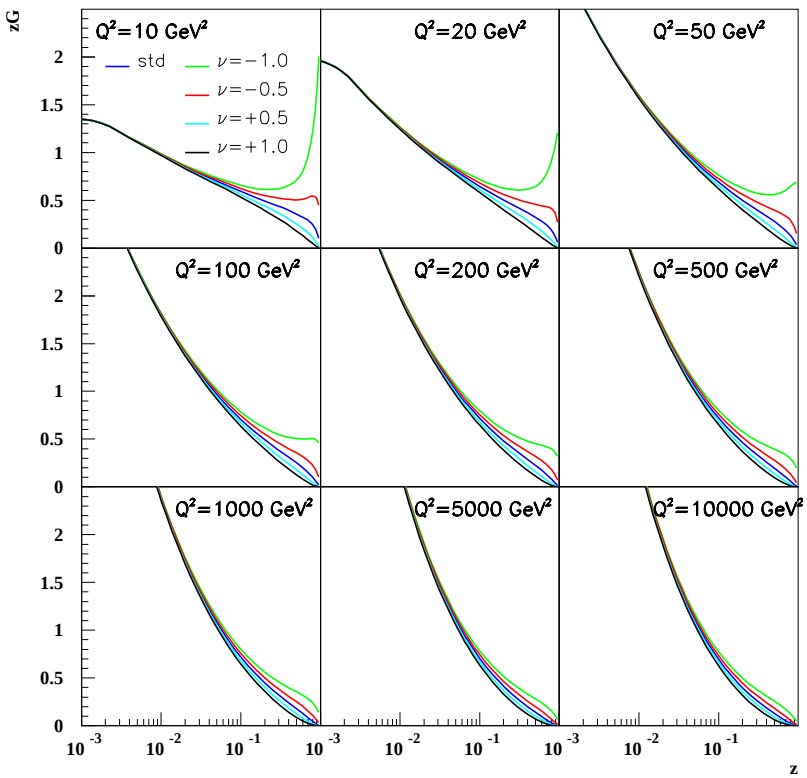
Diffractive SUSY Higgs production

At high $\tan\beta$, possibility to get a S/B over 50 (resp. 5.) for 100 (resp.10) fb^{-1}!



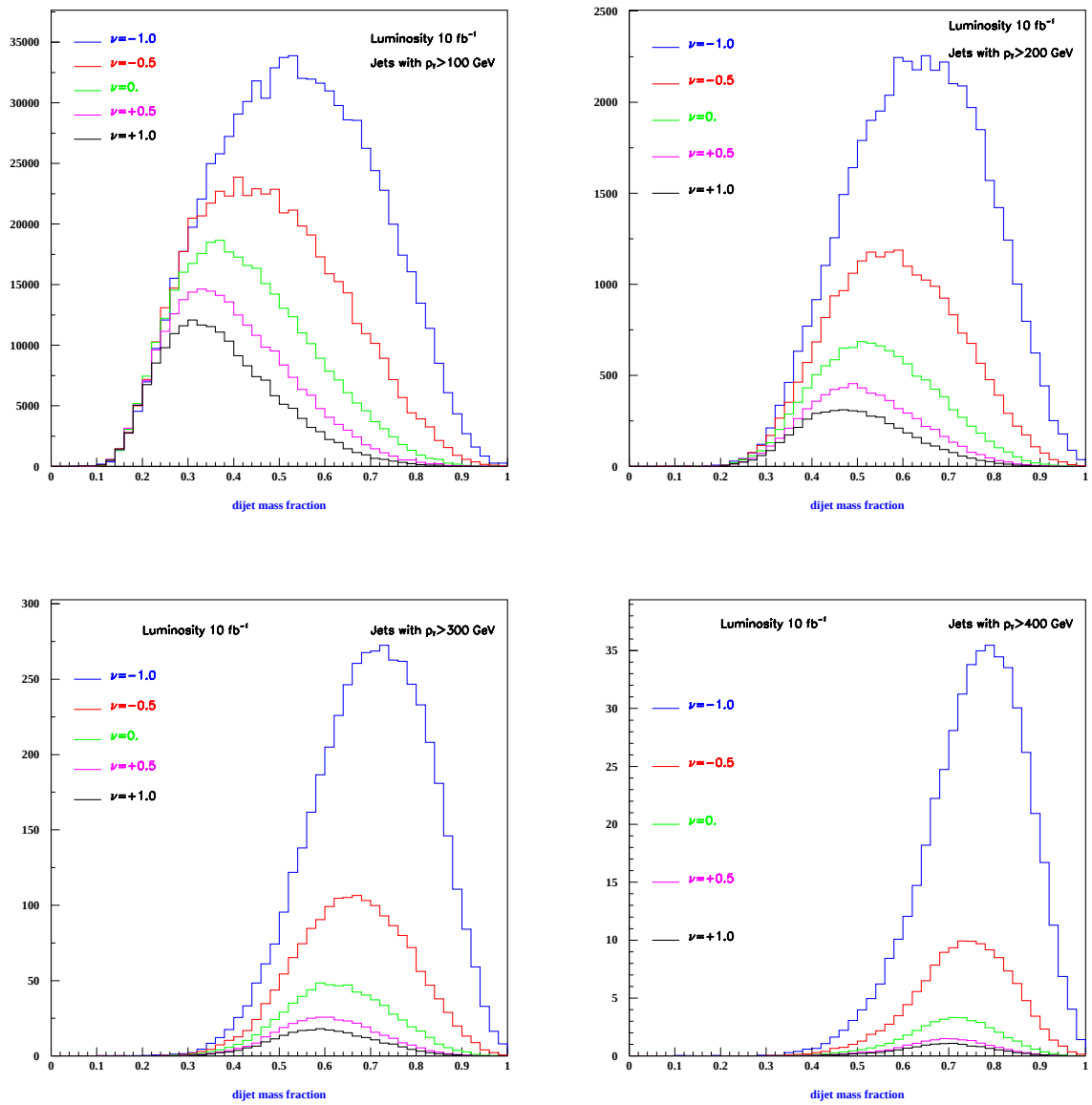
Uncertainty on high β gluon

- Important to know the high β gluon since it is a contamination to exclusive events
- Experimentally, quasi-exclusive events indistinguishable from purely exclusive ones
- Uncertainty on gluon density at high β: multiply the gluon density by $(1-\beta)^{\nu}$ (fit: $\nu = 0.0 \pm 0.6$)



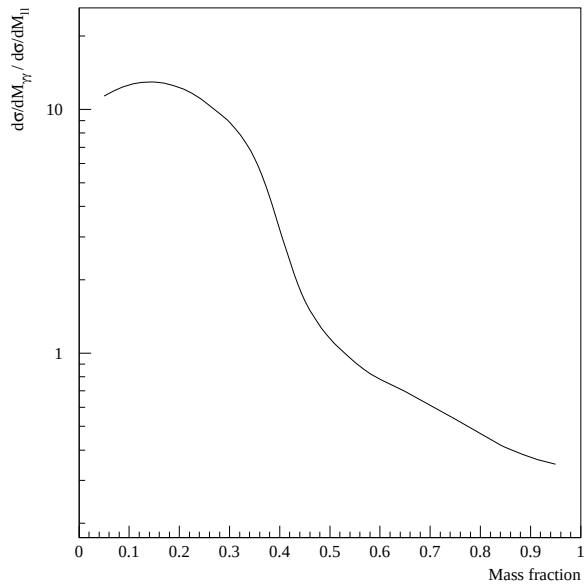
Dijet mass fraction measurement at the LHC

Dependence on high-β gluon



Existence of exclusive events

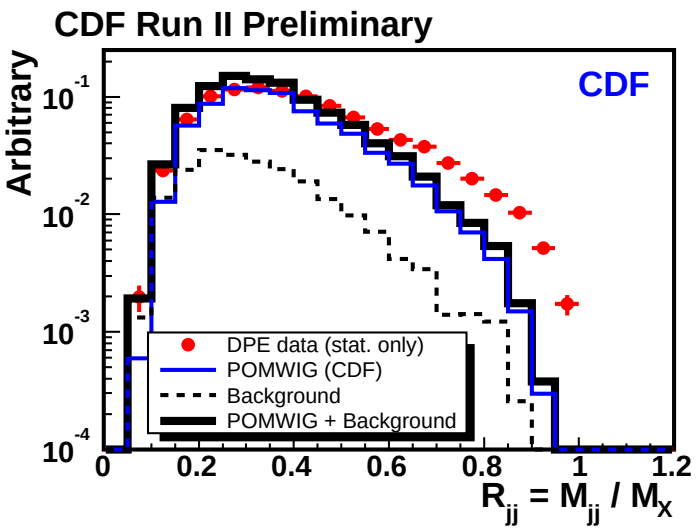
Test of the existence of exclusive events

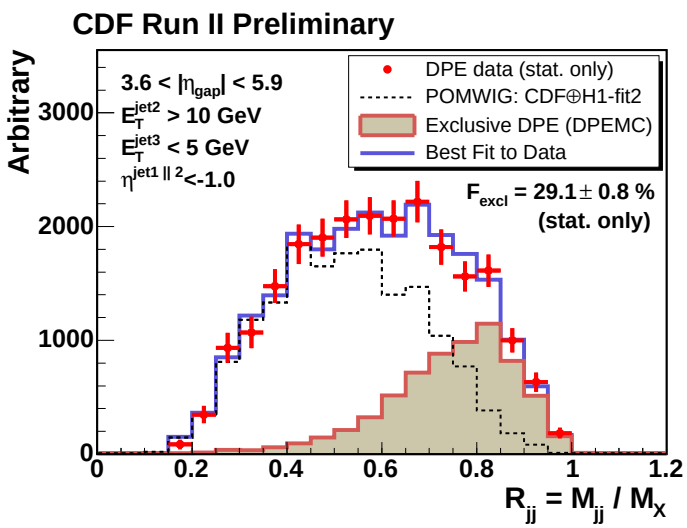


- Dilepton and diphoton cross section ratio as a function of the diphoton/dilepton mass: no dilepton event for exclusive models ($gg \to \gamma\gamma$ ok, $gg \to l^+l^-$ direct: impossible)
- Change of slope of ratio if exclusive events exist
- Other method: ratio b-jets / all jets,

Look for exclusive events at the Tevatron

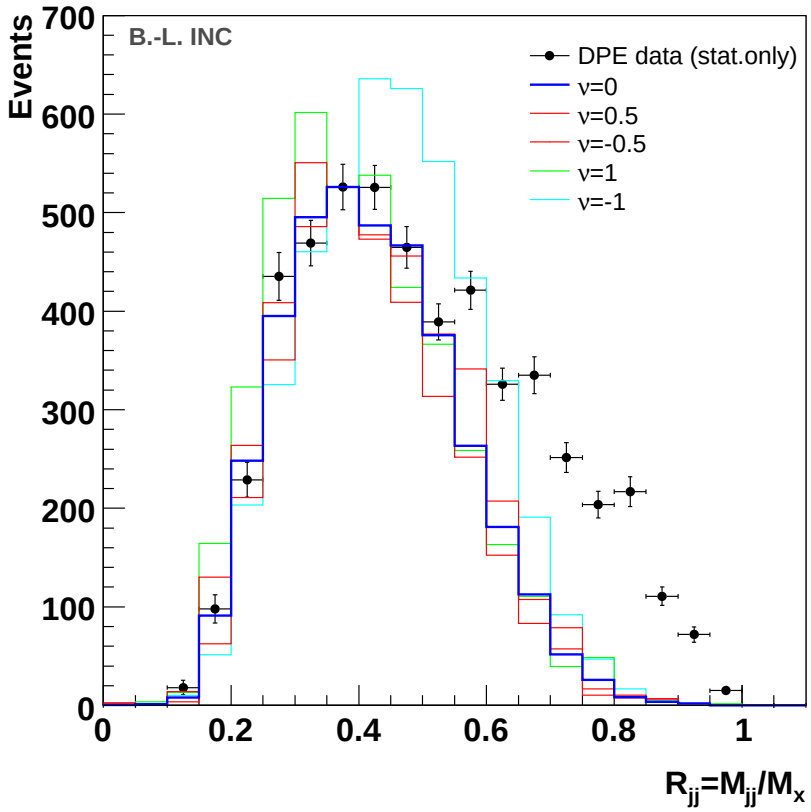
- Look for exclusive events (events where there is no pomeron remnants or when the full energy available is used to produce diffractively the high mass object)
- Select events with two jets only, one proton tagged in roman pot detector and a rapidity gap on the other side
- Comparison with POMWIG Monte Carlo using H1 gluon density in pomeron and DPEMC for exclusive signal
- Will be necessary to see the effect of new H1/ZEUS PDFs in pomeron on these results since gluon density changed by a lot; a direct Tevatron measurement would be also interesting

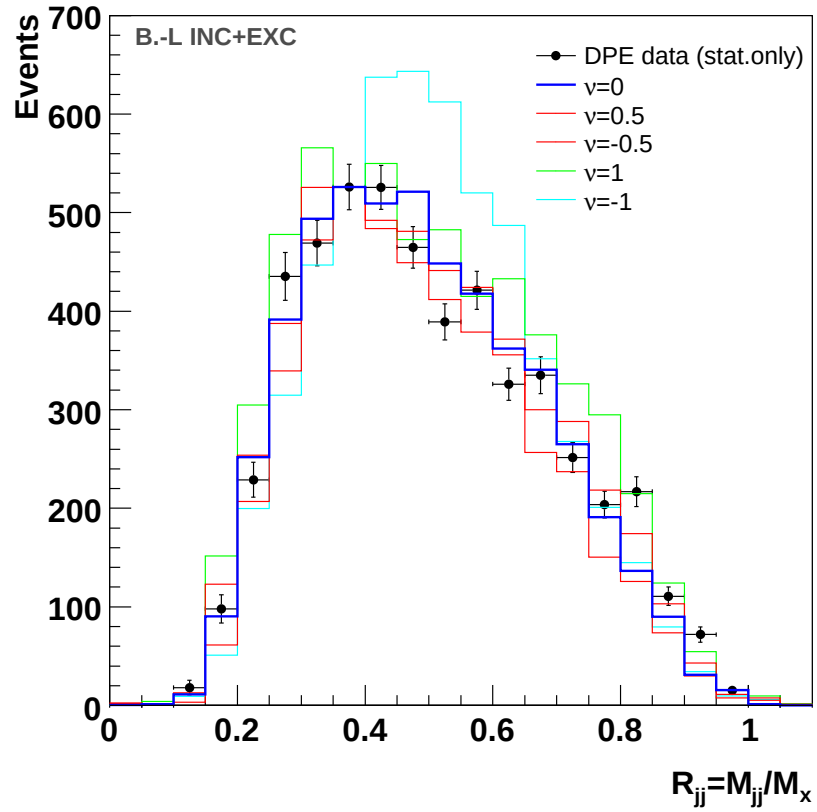




Exclusive production at the Tevatron?

Look at the dijet mass fraction: exclusive events are supposed to appear around 1





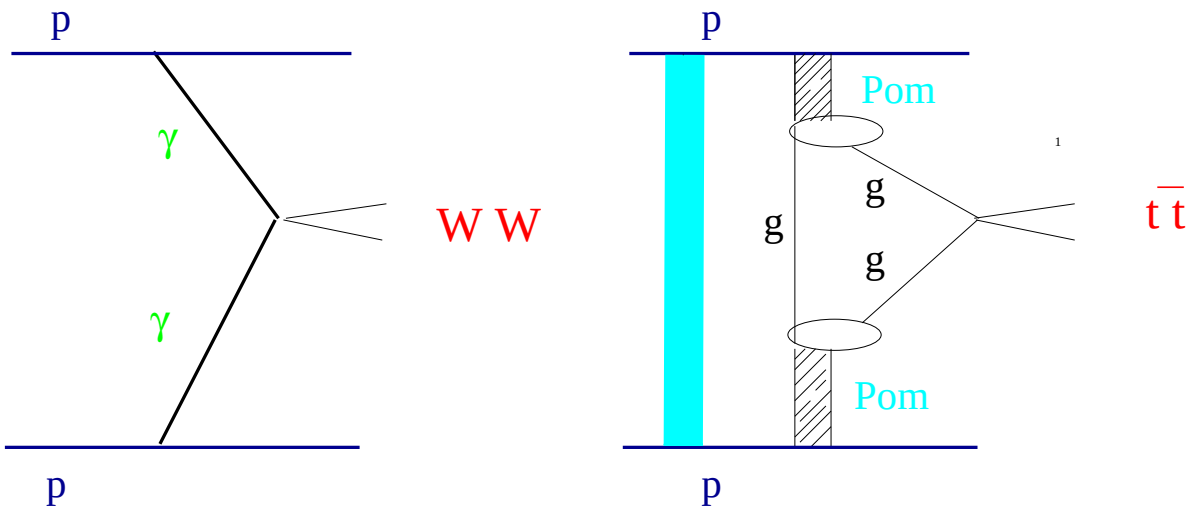
χ_C exclusive production at the Tevatron?

- CDF observation: Upper limit of χ_C exclusive production at the Tevatron in the $J/\Psi\gamma$ channel $\sigma \sim 49$ pb $\pm 18 \pm$ 39 pb for $y < 0.6$ (result not corrected for cosmics, χ_2 contamination)
- Exclusive prediction: 59 pb
- Quasi-exclusive contamination:

mass fraction	$\nu = 0$	$\nu = -1$	$\nu = -0.5$	$\nu = +0.5$	$\nu = +1.0$
≥ 0.8	5.4	119.1	27.2	0.9	0.2
≥ 0.85	2.0	62.0	11.2	0.2	0.0
≥ 0.9	0.3	19.6	2.9	0.0	0.0
≥ 0.95	0.8	1.7	0.8	0.0	0.0

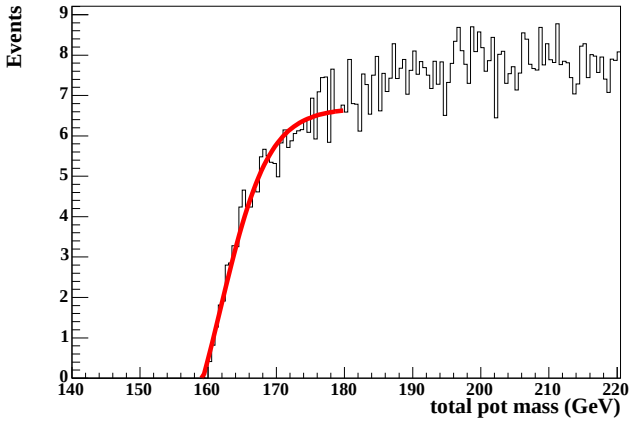
- Contamination of quasi-exclusive events strongly dependent on assumption on high-β gluon density in pomeron (completely unknown...), and also on precision and smearing of dijet mass distribution (a cut at 0.9 at generator level corresponds to ??? at reconstructed level), true also for jet studies...

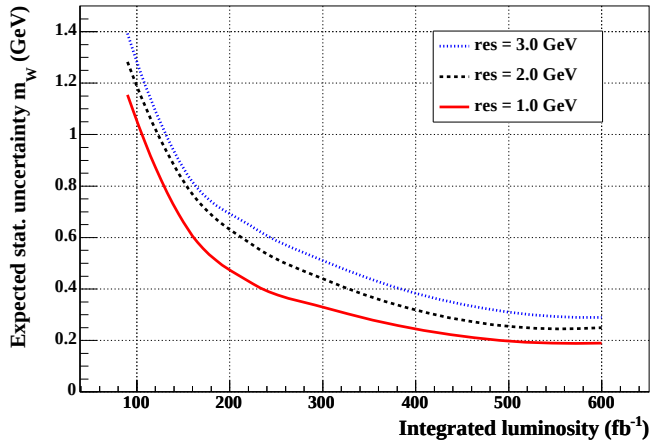
W, top and stops



All the energy is used to produce the W, top (stop) pairs: W: QED process, cross section perfectly known, top: QCD diffractive process

Top and W events

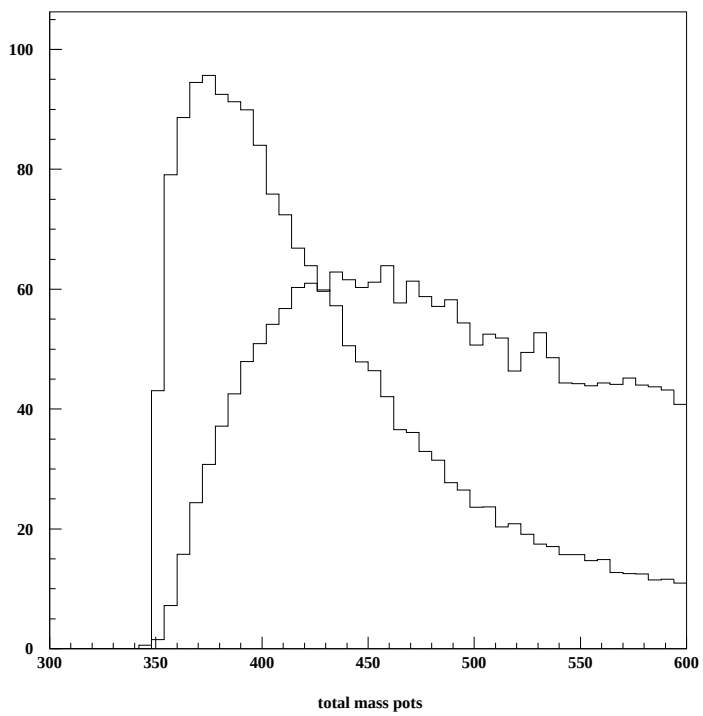


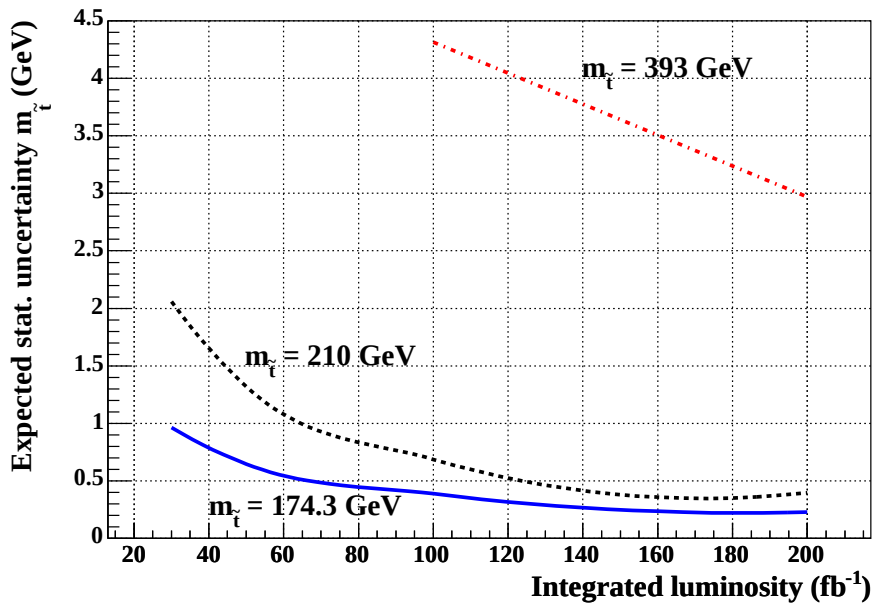


- Turn-on fits: fit missing mass distribution at threshold (events appearing when $M > 2M_W$)
- W boson cross section and acceptance: $\sigma \sim$ 56 fb, about 60% acceptance from pots, W mass resolution: $\sim$ 400 MeV, not competitive, check the roman pot alignment
- Top quark cross section and acceptance: $\sigma \sim$ 40 fb, pots at 220 m, about 85% acceptance, Top mass resolution: $\sim$ 1 GeV, competitive measurement
- WARNING: WW cross section certain (QED process), whereas $t\bar{t}$ cross section uncertain and model dependent (to be tested at the LHC)

Top and stops

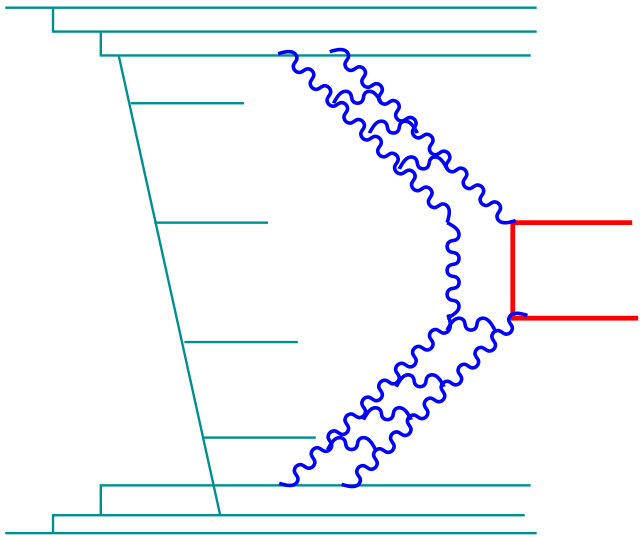
- Cross section for a stop mass of 250 GeV: $\sigma_{tot} = 8$ fb, $\sigma_{acc} = 6$ fb
- Possibility to distinguish between top and stop even if they have about the same mass: using the differences in spin (as an example: $m_{\tilde{t}} = m_{top}$) Very fast turn-on for stops
- Resolution on stop mass measurement $\sim$ 1 GeV at high lumi, if cross section high enough (model dependent)



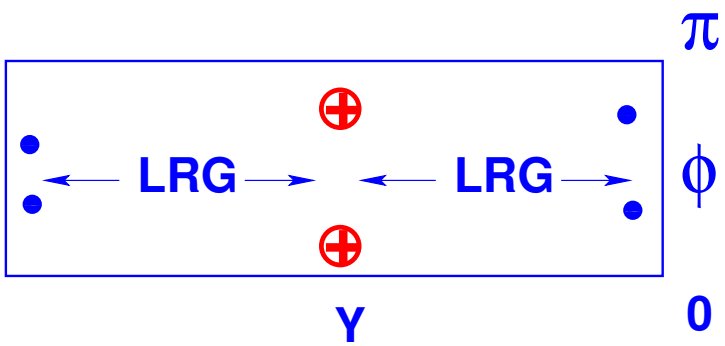


Concept of survival probability

- Survival probability: Probability that there is no soft additional interaction, that the diffractive event is kept
- Important to measure the survival probability in data: estimated to be of the order of 0.1 at the Tevatron



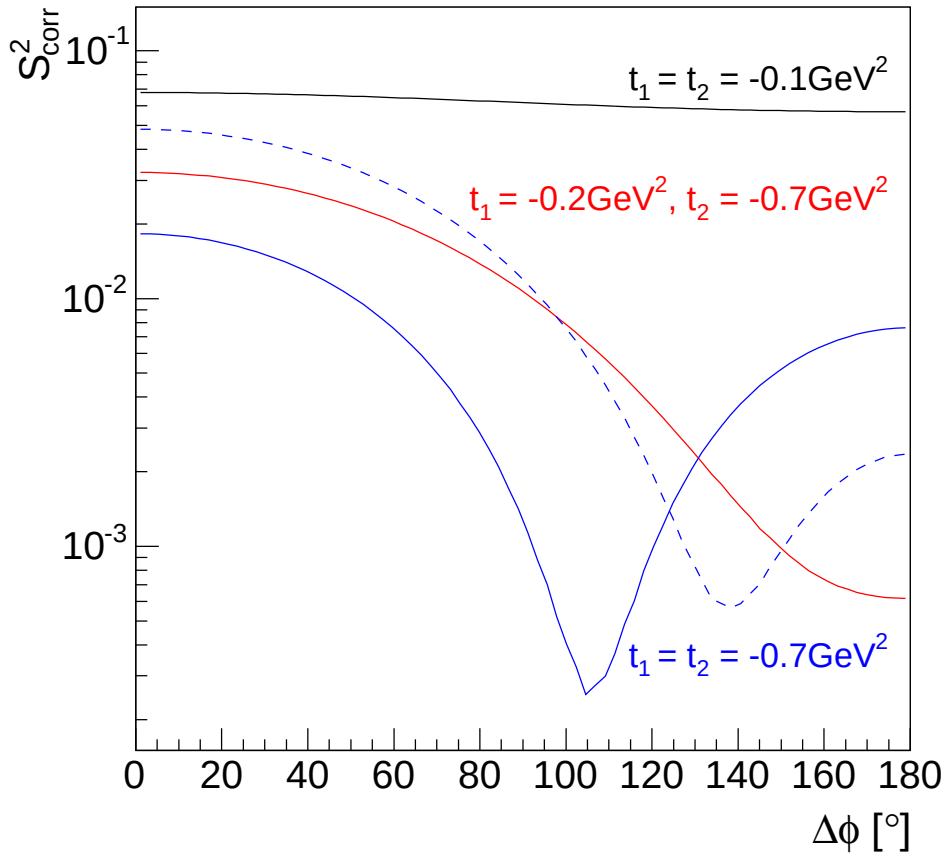
a)



b)

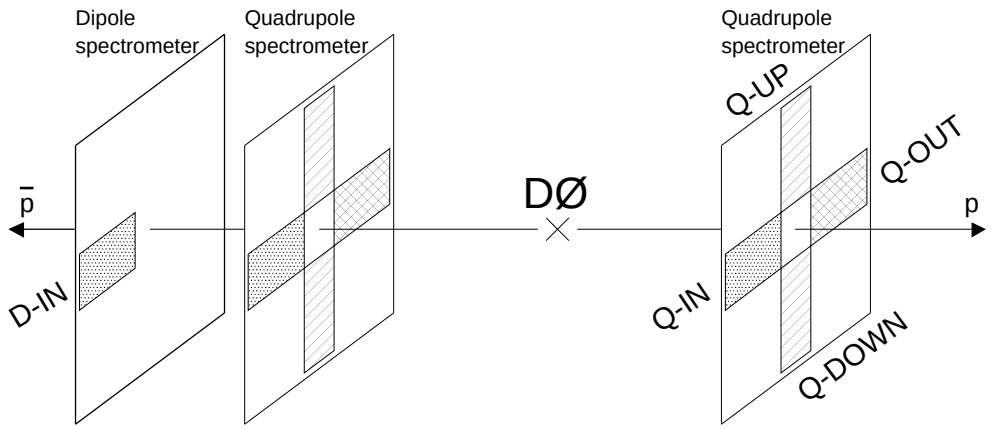
$\Delta\Phi$ dependence of survival probabilities

Survival probability strongly $\Delta\Phi$-dependent where $\Delta\Phi$ is the difference in azimuthal angles between p and $\bar{p}$



Forward Proton Detector in DØ

Forward Proton Detector (FPD) installed by DØ allowing to measure directly $\Delta\Phi$



Possibility to combine D-IN with quadrupole on the other side, or two quadrupole detectors (Q-UP and Q-UP, or Q-UP and Q-DOWN...)

Possible measurement at DØ

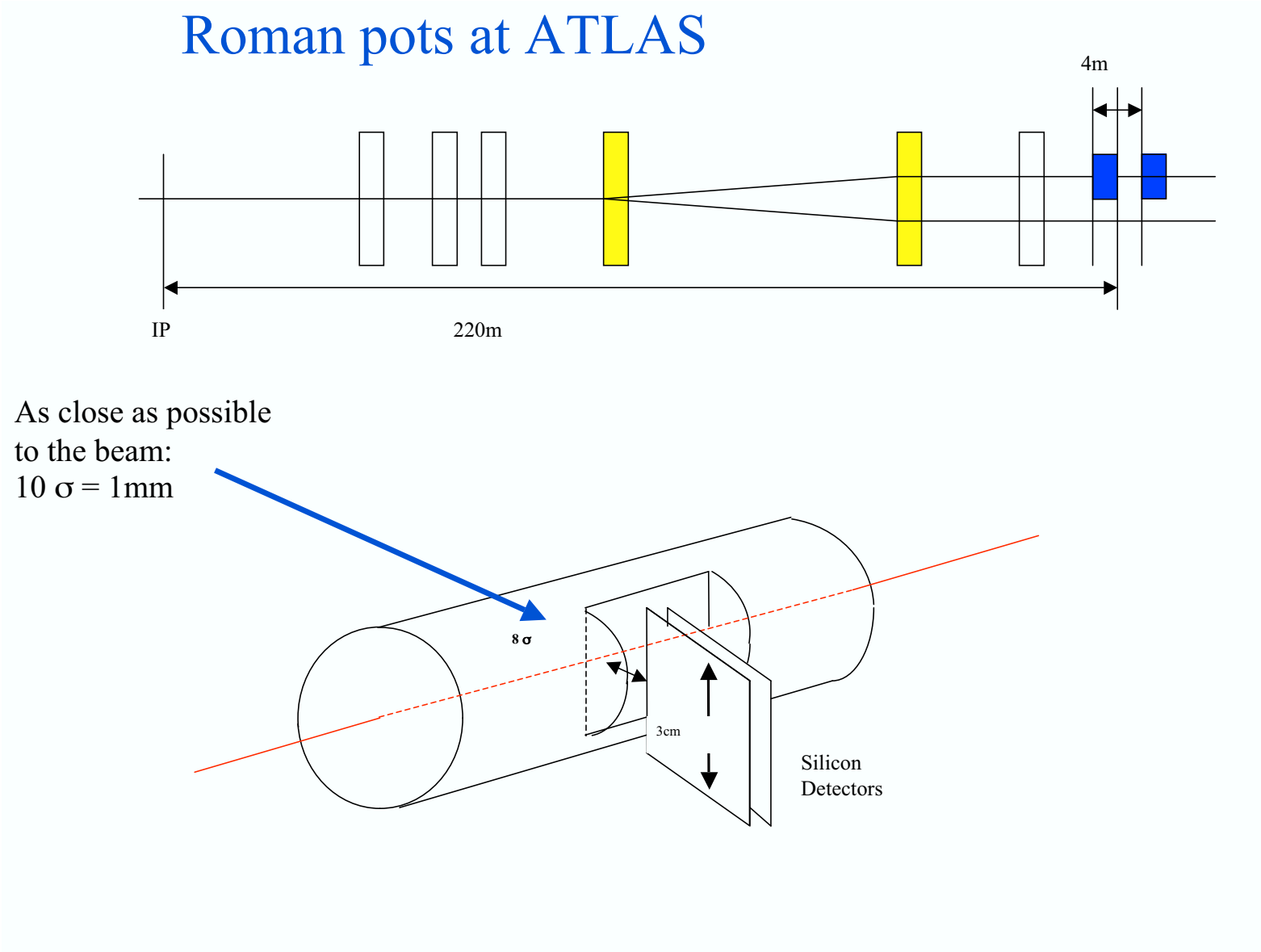
- Diffractive cross section ratios in different regions of $\Delta\Phi$ at the Tevatron
- same side: $\Delta\Phi < 45$ degrees, opposite side: $\Delta\Phi > 135$, middle: $45 < \Delta\Phi < 135$ degrees;
- 1st measurement: asymmetric cuts on t (dipole and quadrupole), 2nd measurement: symmetric cuts on t (quadrupole on both sides)
- Possible to distinguish between SCI and pomeron-based models, and test the survival probabilities

Configuration	model	middle/same	opp./same
Quad.	SCI	1.3	1.1
+ Dip.	Pom.	0.36	0.18
Quad.	SCI	1.4	1.2
+ Quad.	Pom.	0.14	0.31

Roman pot projects

- TOTEM project accepted, close to CMS
- FP420: Project of installing roman pot detectors at 420 m both in ATLAS, CMS; collaboration being built
- Roman pot detectors at 220 m in ATLAS:
  - Natural follow-up of the ATLAS luminosity project at 240 m to measure total cross section
  - Complete nicely the FP420 m project
  - Collaboration between Saclay. Prague, Cracow and Stony Brook (so far) being pursued
  - Collaboration with the FP420 m project concerning detectors, triggers, simulation...
- For more information, see the web pages of FP420, CMS, TOTEM, ATLAS

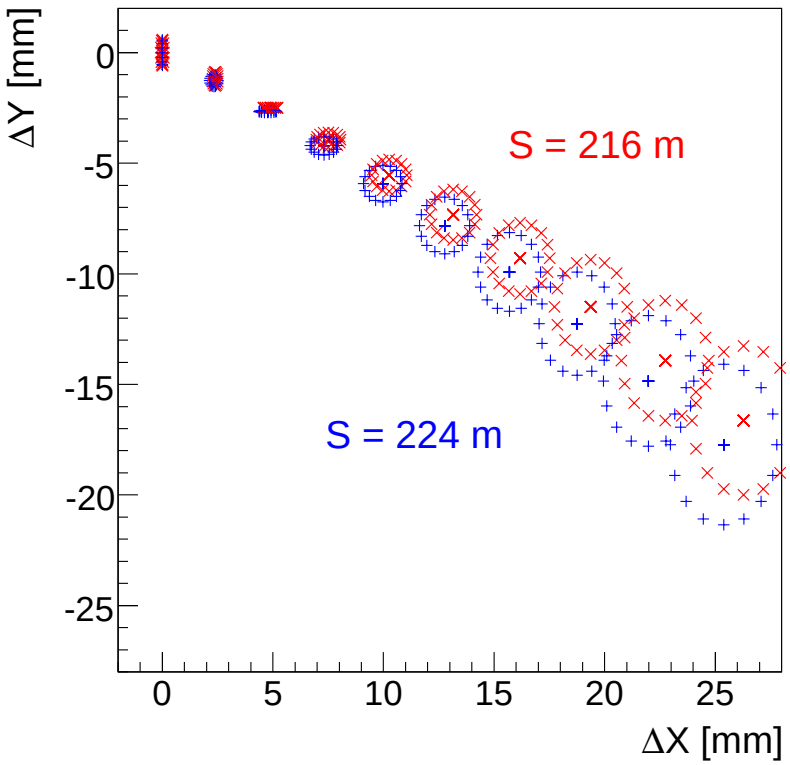
Scheme of roman pot detectors

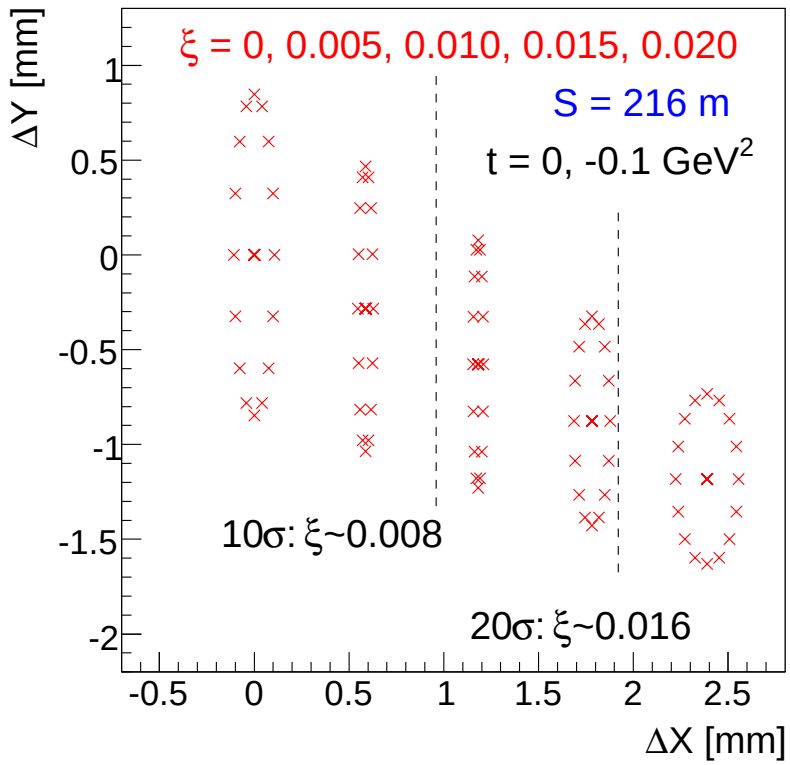


Assume roman pots located at 216 and 224 m

Acceptance for 220 m pots

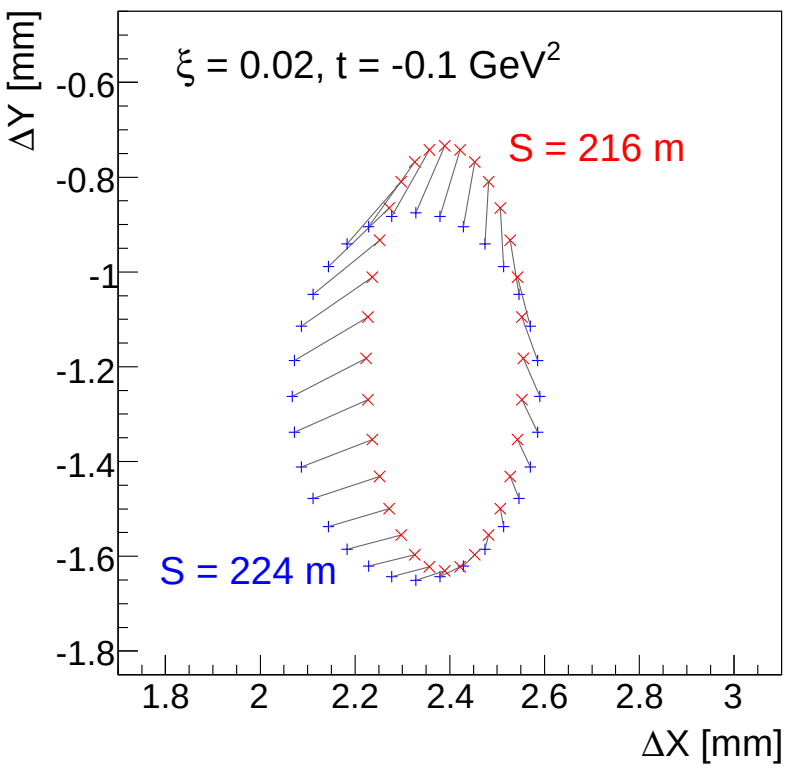
- Steps in ξ: 0.02 (left), 0.005 (right), $|t|$=0 or 0.05 GeV^2
- Detector of 2 cm $\times$ 2 cm will have an acceptance up to $\xi \sim 0.16$, down to 0.008 at 10 σ, 0.016 at 20 σ
- As an example Higgs mass acceptance using 220 m pots down to 135 GeV and upper limit due to cross section and not kinematics

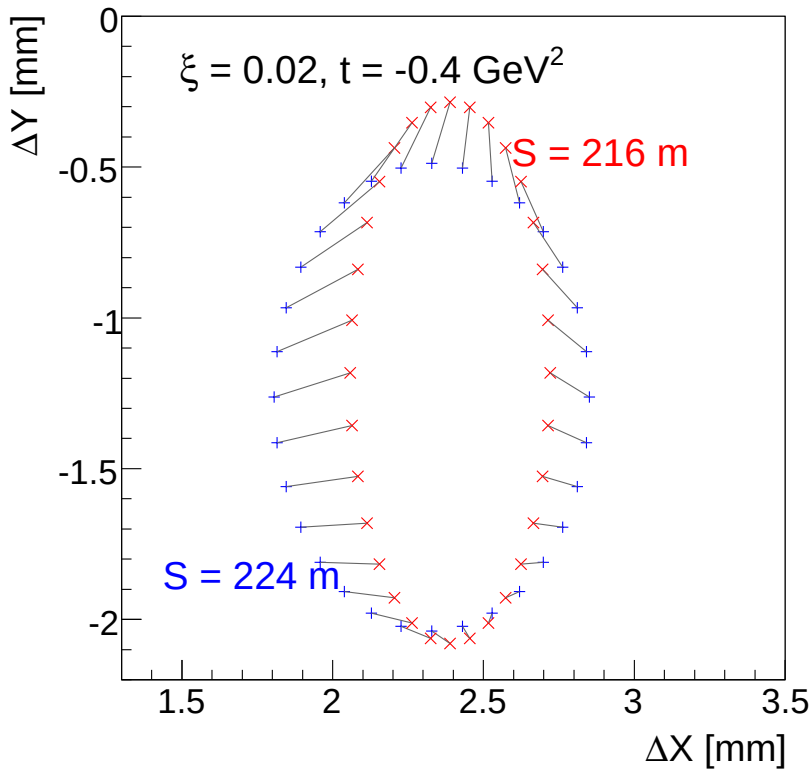




Hit maps at 216 and 224 m

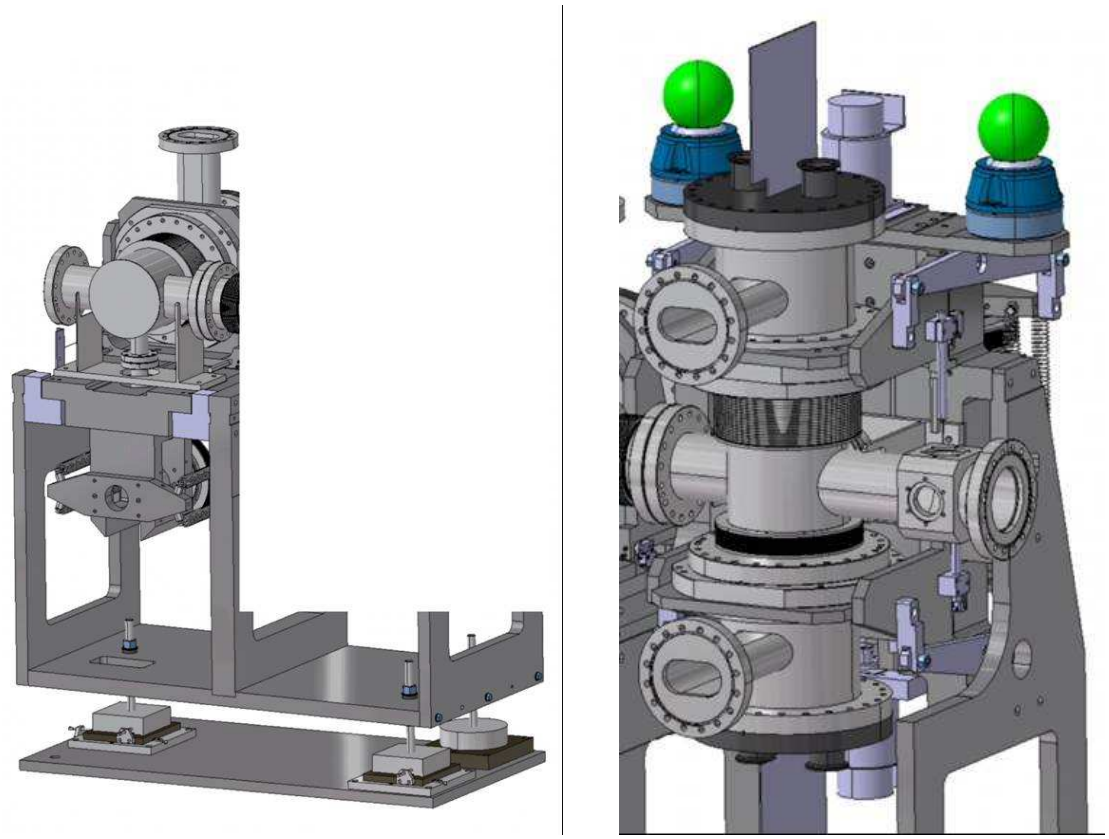
- Study difference between hit maps at 216 and 224 m: test the idea of using displacement at the trigger level to distinguish with halo
- No unique shift direction between 216 and 224 m





Roman pots at 220 m

Schematic view of 220 m pots: keep horizontal pots only from the TOTEM pots



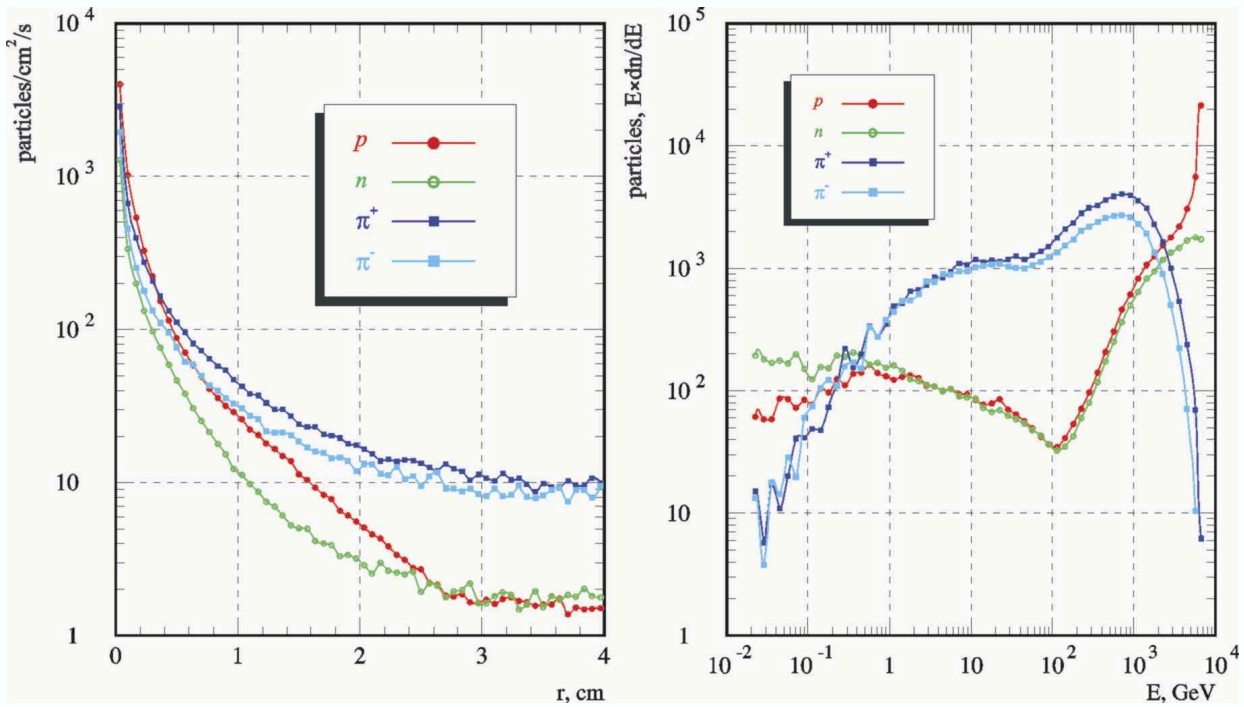
Fluxes in roman pot detectors (from Vadim Talanov)

Fluxes at 220 m at high lumi (10^{34}) (plots for 2.10^{29})

RATE EVOLUTION WITH CUTS [MD2005]

Particle flux in [Hz]

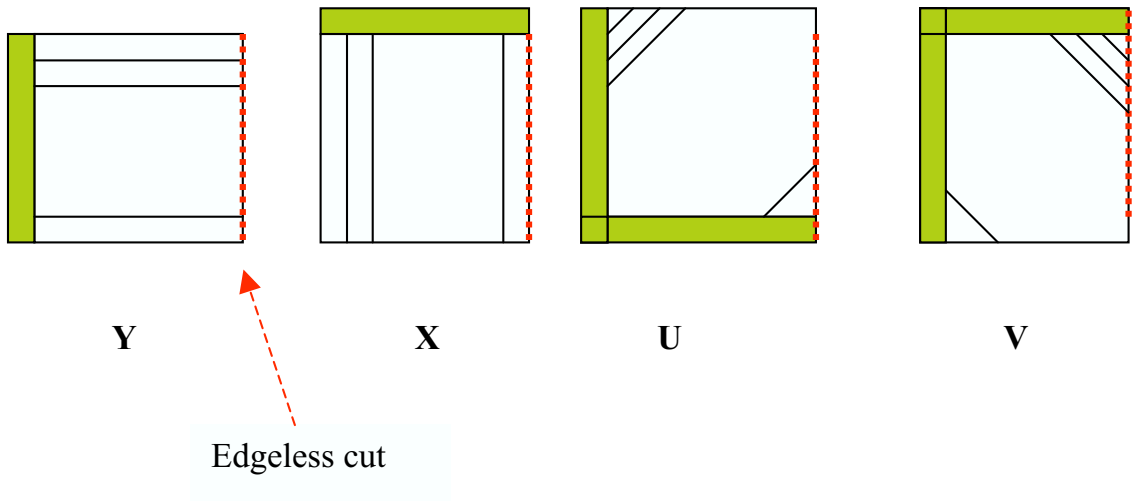
	p	n	π^+	π^-	e^+	e^-	γ
Pot at 220m	344	174	616	406	4630	3361	9.4×10^4



Si strip detectors specifications

- Size: 2cm $\times$ 2cm
- Spatial resolution of the order of 10-15 μm: Si strip detectors of 50 μm, as a first proposal: 9 layers, 3 vertical, 2 horizontal, 2 U, 2 V (45 degrees)
- Edgeless detectors: Between 30 to 60 μm
- First prototype of detector to be sent by CANBERRA by the end of December: test-stand (laser and radioactive source) to be installed in Saclay following the Paris 6, Prague, Cracow, CERN experience
- Readout: ABCD chip for test, ABCNext chip for final detectors (needs longer latency since needs as an input L1 ATLAS trigger and distance to be covered: $2 \times 220 = 440$ m)
- 2 layers used for the trigger: Strip detectors of 100-200 μm (to be optimised given the fact that we have 1 μs to send the trigger to ATLAS)
- Timing from the Si strip detector: 5-10 ns required to identify from which bunch crossing the event is coming, implies a fast shaping time of 20-30 ns

Different kinds of detectors



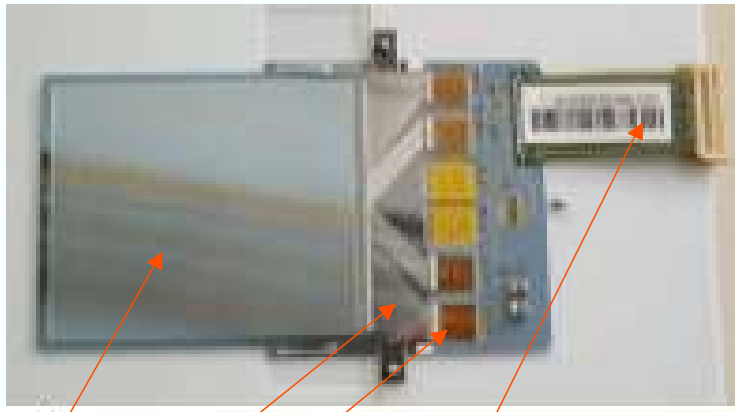
- 5 detectors to be used in readout per pot
- 2 additional detectors to be used for triggering (larger strips)

Test stand

- Installation of a test stand for Si strip detectors
- Tests performed using a laser and radioactive source
- Needs a precise table and labview software to control the motion of the laser (benefitting from the experience of Paris 6 to test Si strip detectors at the ILC)
- DAQ using ABCD chip: to be obtained from CERN, Cracow, Prague...
- Tests should be starting next December when the first prototype from Canberra is coming

Connection to the readout chips: Hybrids

As a start, obtain hybrids from CERN for test purposes



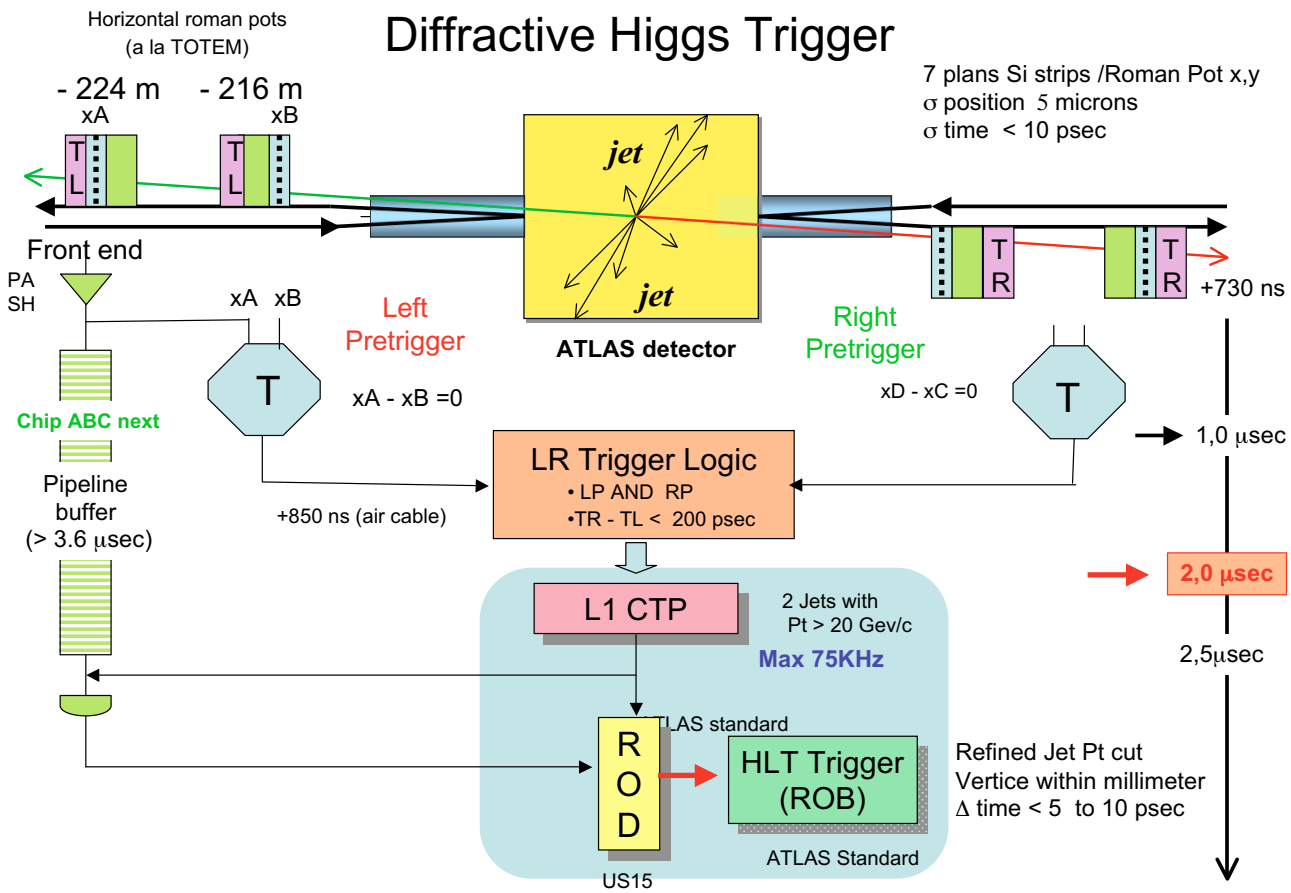
Picture 4:
Silicon detector module tested at
CERN RD39 Programme

Silicon detector
Pitch adapter
Readout chips
Output to DAQ

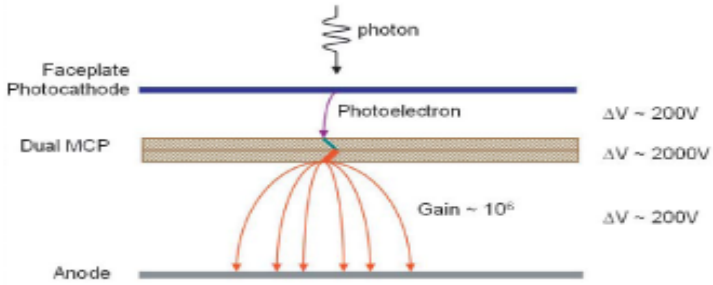
Trigger and timing: principle

- Roman pot trigger to be transmitted to L1: compatibility of hit strips between 2 different planes and 2 different roman pots (local L1 roman pot trigger), and timing information
- L1 positive trigger sent back to the pots: starts the readout of the Si strip detector
- FP420 and 220 m pot trigger: In ATLAS, there is a large overlap between FP420 and 220 m pot kinematical domain (220 m pots sensitive down to $M_H \sim 130$ GeV, allows FP420 trigger to be given by 220 m tags (offline, the 420 m information will be used)
- Timing with a precision of the order of 5 ps needed to identify from which vertex the protons are coming: 1 mm resolution, up to 25 interactions by bunch crossing
- Collaboration in progress with the University of Chicago, Argonne National Laboratory, Stony Brook, Saclay: test and develop new timing detectors specially for medical applications and linear collider, roman pots
- New 2×2 inch multi anode phototubes developped by Burle and Photonis
- Use of timing/Si strip detectors needed for future developments: ILC, CLIC, medical applications

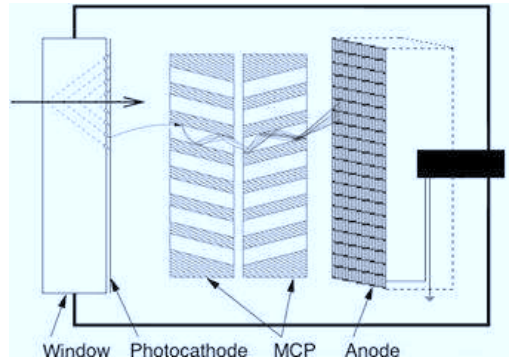
Trigger: principle

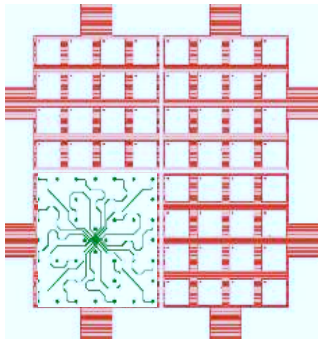


Timing detectors

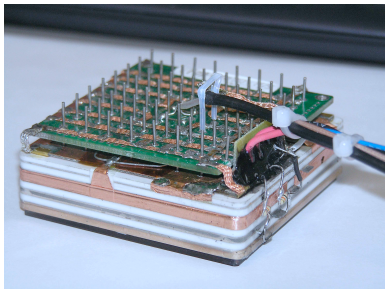


MCP Principle





Anode pads and equal read out design



Photonis Prototype

Conclusion

- Study of inclusive events (the only events which are existing for sure): determination of gluon at high β, search for SUSY events (or any resonance) when dijet background is known
- Exclusive events still to be observed in particular at the Tevatron
- Exclusive Higgs: Signal over background: ~ 1 if one gets a very good resolution using roman pots (better than 1 GeV), enhanced by a factor up to 50 for SUSY Higgs at high $tan\beta$
- QED WW pair production: cross section known precisely, allow to calibrate prescisely the roman pot detectors
- Diffractive top, stop pair production: possibility to measure top and stop masses by performing a threshold scan with a precision better than 1 GeV if cross section high enough (same idea as linear collider, without ISR problem)
- Project of installing roman pot detectors in ATLAS well started: collaboration between Prague, Cracow, Saclay, Stony Brook,...
- Collaboration about timing detectors (and medical applications): University of Chicago, Argonne, Saclay