Diffractive Higgs boson production: Concept and Challenge

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Dedicated to Professor Andrzej Białas in Honour of His Birthday

Overview

Concept

Białas-Landshoff approach

Time Evolution

Plans and Challenges

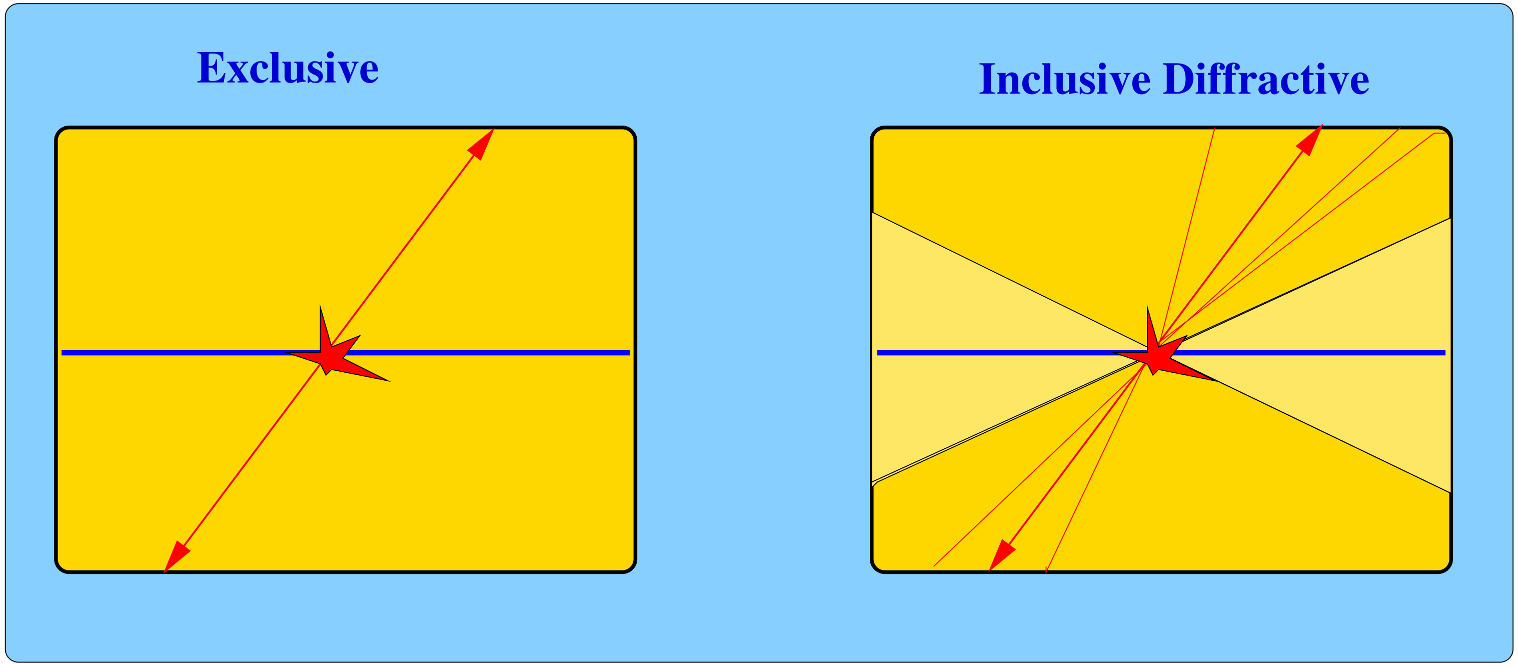
The idea – early 90ties

⟶ Many Higgs bosons were expected at the SSC and LHC but:

⟶ The background was known to be large as well

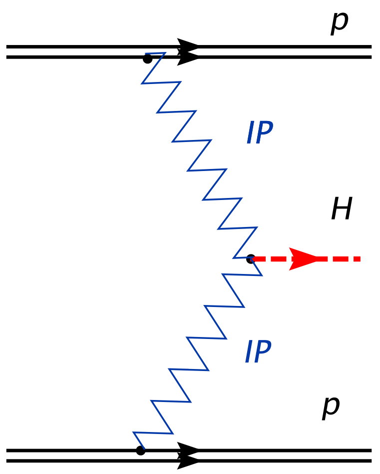
⟶ Diffractive/exclusive Higgs boson production is cleaner

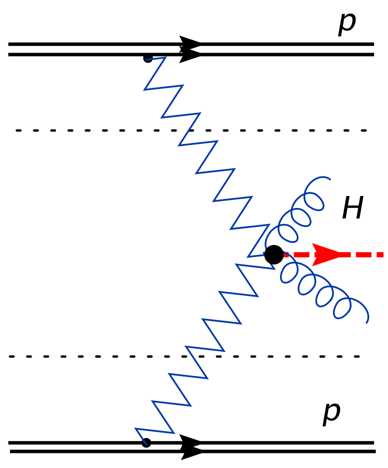
⟶ Bonus: possibility to see invisible states from outgoing pp kinematics



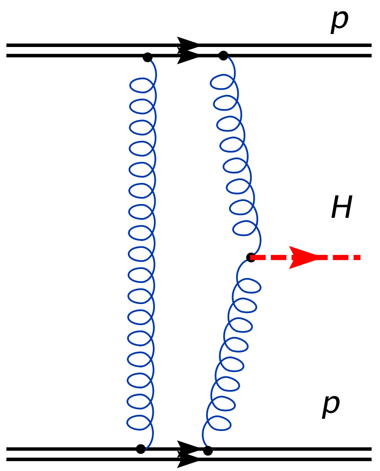
First estimates of diffractive Higgs

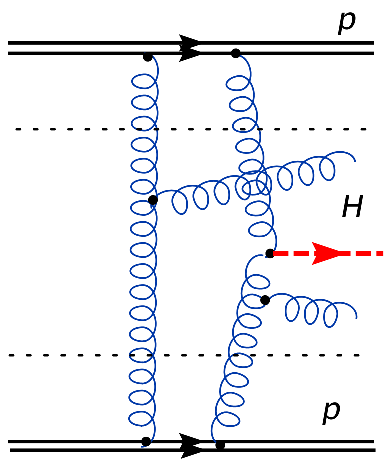
A. Schäfer, O. Nachtmann and R. Schöpf; B. Müller and A. Schramm (1990) – in Regge model





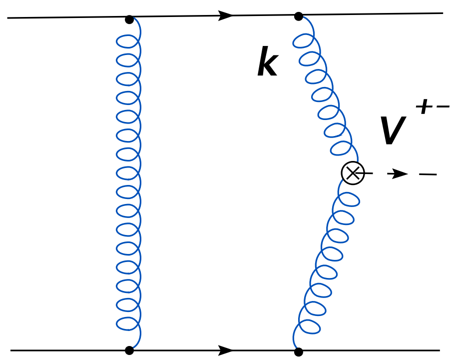
A. Białas and P.V. Landshoff (1990) – microscopic model





Białas-Landshoff approach

The lowest order diagram $qq \longrightarrow qHq$



Colour flow $\longrightarrow$ exchange of two gluons

High energy $\longrightarrow$ eikonal couplings γ^+ and γ^-

and $k^2 \sim -\boldsymbol{k}^2$

Lorentz structure and the strength of Higgs production vertex from top quark triangle for $m_t \longrightarrow \infty$

Convolution with eikonal couplings: $V^{+-} \sim V_0 \, \boldsymbol{k_1} \cdot \boldsymbol{k_2}$

Forward amplitude:

$$M \sim \int d^2\boldsymbol{k} \; \boldsymbol{k}^2 \; [\, D(-\boldsymbol{k}^2)\, D(-\boldsymbol{k}^2)\, D(-\boldsymbol{k}^2)] \;\; \Phi_q(\boldsymbol{k}) \; \Phi_q(-\boldsymbol{k})$$

$D(k^2) \sim 1/k^2$ $\longrightarrow$ Perturbative result is infra-red sensitive

Białas-Landshoff solution to accute problem of soft physics

Non-perturbative model of QCD vacuum by Nachtmann and Landshoff (1987)
based on coloured correlation functions

$$D(-\boldsymbol{k}^2) \sim \frac{1}{k^2} \quad \longrightarrow \quad D(-\boldsymbol{k}^2) \sim \exp(-\boldsymbol{k}^2/\mu^2)$$

Couplings to protons from additive quark model

Proton form-factor and energy dependence taken from Regge model

Model constrained by elastic scattering

Result

$$\sigma(pp \to p\ \text{gap}\ \ H + X\ \text{gap}\ \ p) \sim 100\ \text{fb} \qquad \sim 1\%\ \text{of events}$$

Perturbative QCD + gap = Sudakov form-factor

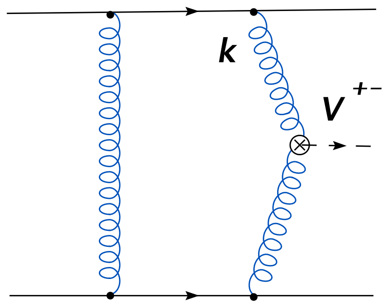
Quark impact factor $\longrightarrow$ gluon distribution

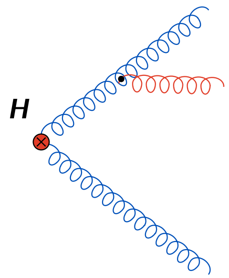
Gluon propagators $\longrightarrow$ perturbative form

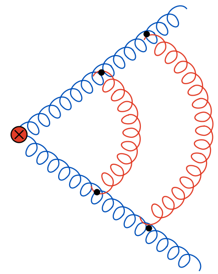
Gluon emissions from colour antenna spoil the gap

gHg vertex $\longrightarrow$ invariant mass of the gg system

Screening of hard radiated gluons by soft gluons is hard







Classical calculation of the Sudakov form-factor: **[V. Khoze, A. Martin and M. Ryskin]**

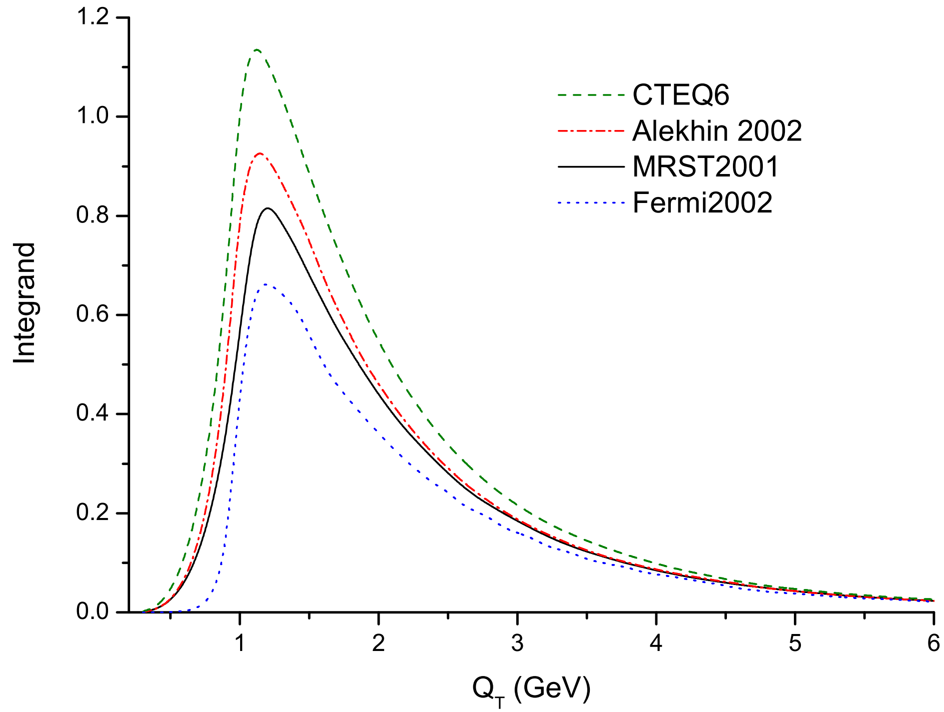
$$P(\text{no radiation}) \sim \exp(-P_1)$$

Probability to radiate single gluon

$$P_1 \;\propto\; \alpha_s \int_{k^2}^{M_H^2} \frac{dq^2}{q^2} \int_q^{M_H} \frac{d\omega}{\omega} \;\sim\; \alpha_s \log^2(M_H^2/k^2) \;\gg\; 1$$

Exclusive production is perturbative!

$$\mathrm{Im}\ M_0(y) \sim \int \frac{Q_T\, dQ_T}{Q_T^4}\, f_g(x_1, Q_T^2; \mu)\, f_g(x_2, Q_T^2; \mu)$$



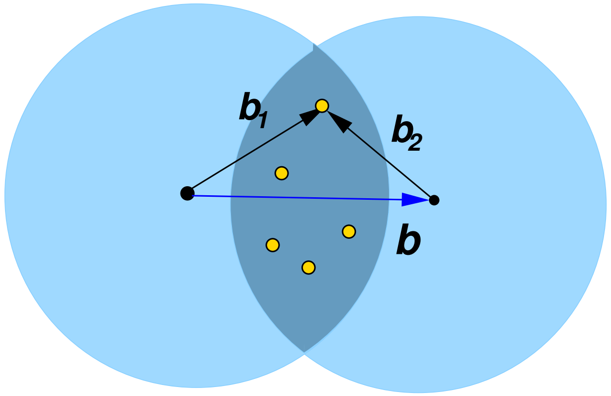
Perturbative momenta dominate

Universality $\longrightarrow$ callibration of the model possible

Sudakov form factor $\longrightarrow$ exclusive cross section reduced by two orders of magnitude

Soft rescattering

Uncorrelated independent scatters

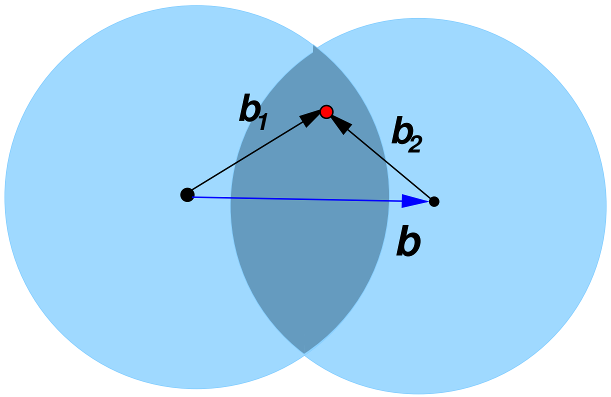


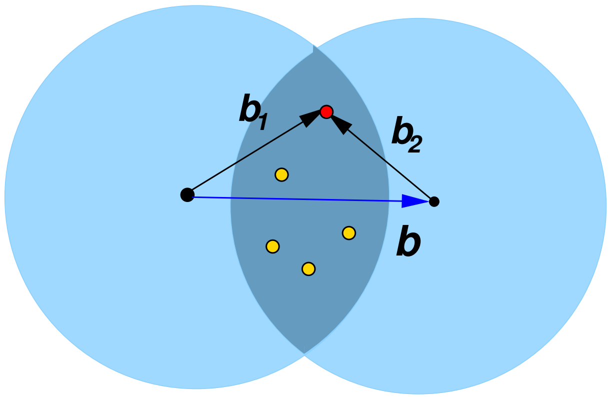
$$M_1 = \Omega/2$$

Unitarized cross section $$\Omega/2 - \frac{(\Omega/2)^2}{2!} + \frac{(\Omega/2)^3}{3!} + \ldots = 1 - \exp(-\Omega/2)$$

Soft rescattering corrections to hard exclusive production

$$M = M_{hard} \exp(-\Omega/2)$$

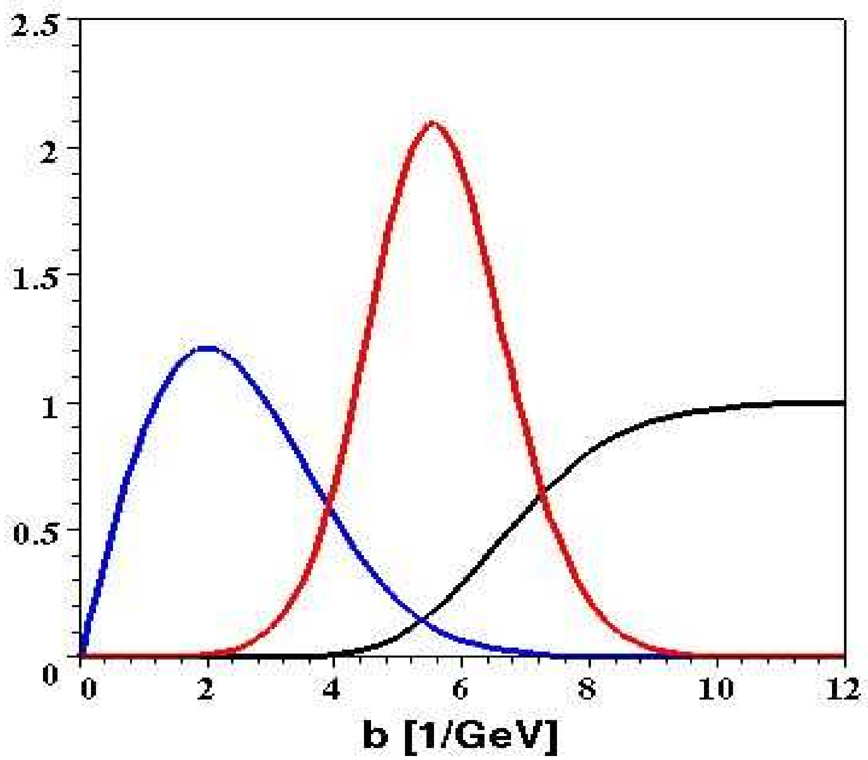


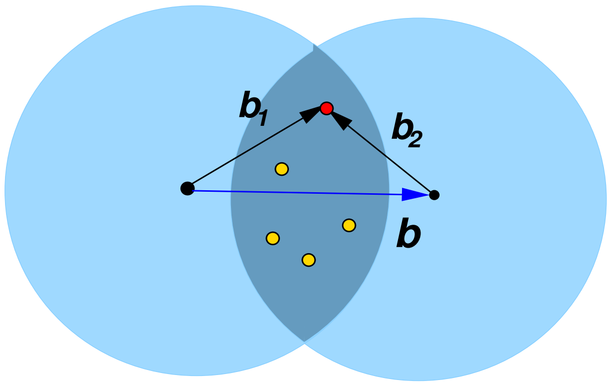


Exclusive profile

Cross section $\sigma(p+p\to p+H+p) \;=\; \int b\,db\,\exp(-\Omega(b))\,|M_{\rm hard}(b)|^2$

Production profile (red) is magnified by factor of 100





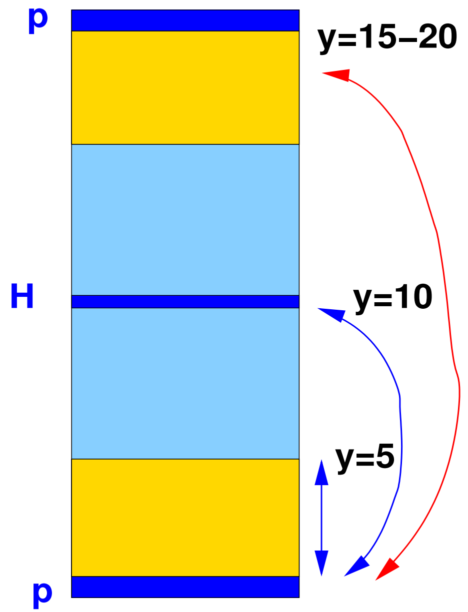
Soft gap survival factor: $S^2 = 0.1$ at the Tevatron and $S^2 = 0.03$ at the LHC

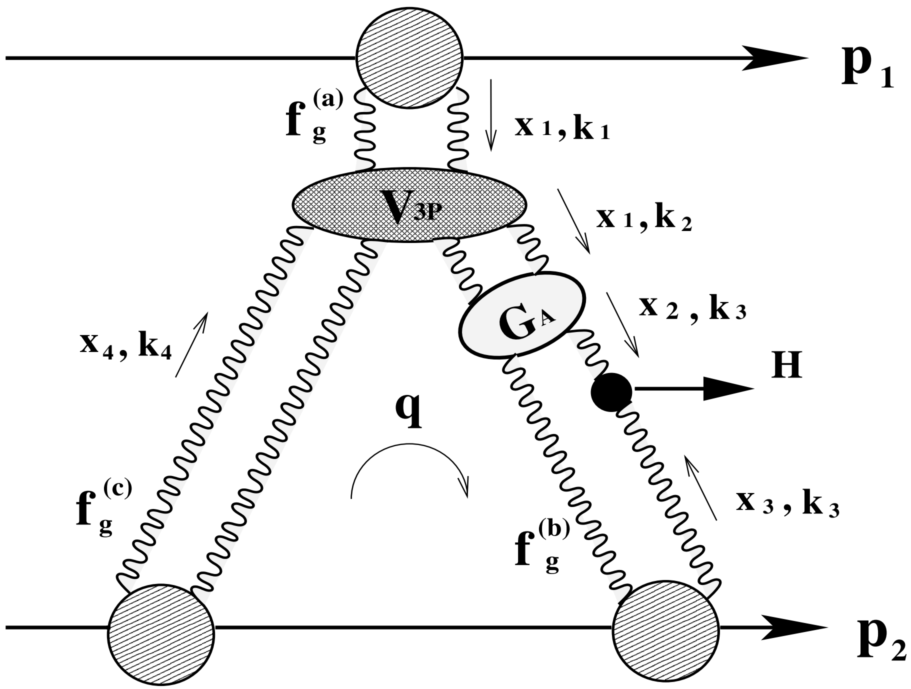
Hard rescattering of pomerons

[J. Bartels, S. Bondarenko, K. Kutak, LM]

Large rapidity $y = 15 - 20$ for hard ladder rescattering

$\longrightarrow$ long low-x evolution and enhancement





Large saturation scale $Q_s^2(y) \gg 1$ GeV^2

Absorption of hard ladder $\longrightarrow$ correction larger than leading term

Ups and downs of diffractive Higgs at LHC

Inclusive

[A. Białas and P.V. Landshoff (1990)]	~ 300 fb
[A. Schäfer, O. Nachtmann and R. Schöpf (1990)]	~ 500 fb
[V. Khoze, A. Martin and M. Ryskin (1997),(2000)]	$30 - 300$ fb
[M. Boonekamp, A. De Roeck, R. Peschanski and C. Royon (2002)]	$100 - 300$ fb
[R. Enberg, G. Ingleman and N. Timneanu (2002)]	~ 0.1 fb

Exclusive

[B. Mueller and A. Schramm (1990)]:	$10^{-2} - 10^{-3}$ fb
[Hung Jung Lu and J. Milana (1995)]:	$10^{-7} - 10^{-5}$ fb
[V. Khoze, A. Martin and M. Ryskin (1997)]:	$10^{-2} - 10^{-3}$ fb
"Exclusive double-diffractive Higgs production is thus only of academic interest"	
[E. Levin (1999)]: *"God loves the brave!!!"*	20 fb
[V. Khoze, A. Martin and M. Ryskin (2000–today)]:	3 ± 1 fb
[R. Enberg, G. Ingleman and N. Timneanu (2002)]:	$< 10^{-3}$ fb
[A. Bzdak (2005)]:	10^{-2} fb
[J. Bartels, S. Bondarenko, K. Kutak and LM (2006)]:	???
"We cannot consider our results as representing a reliable numerical final answer"	

Off-spin analyses and inspirations

Experimental tests, constraints and backgroud
Double diffractive heavy quark production
Diffractive dijets, di-photons, C-even mesons

Searches, tests of diffractive mechanisms
Single diffractive Higgs, dijets, odderon etc.

Understanding of QCD and proton structure
Studies of unintegrated gluon distributions, Transverse structure of the proton,
Hard and soft rescattering

Diffractive Higgs study of A. Białas and P. Landshoff $\longrightarrow$

key step towards understanding diffraction in QCD

Maybe there is more to come...

Higgs at LHC and road beyond Standard Model

[V. Khoze, A. Martin, M. Ryskin]

About 10 Higgs boson events in $b\bar{b}$ or W^+W^- channels with $S/B \simeq 1$

for mass between 120 GeV and 140 GeV with $\mathcal{L} = 30$ fb^{-1} at LHC

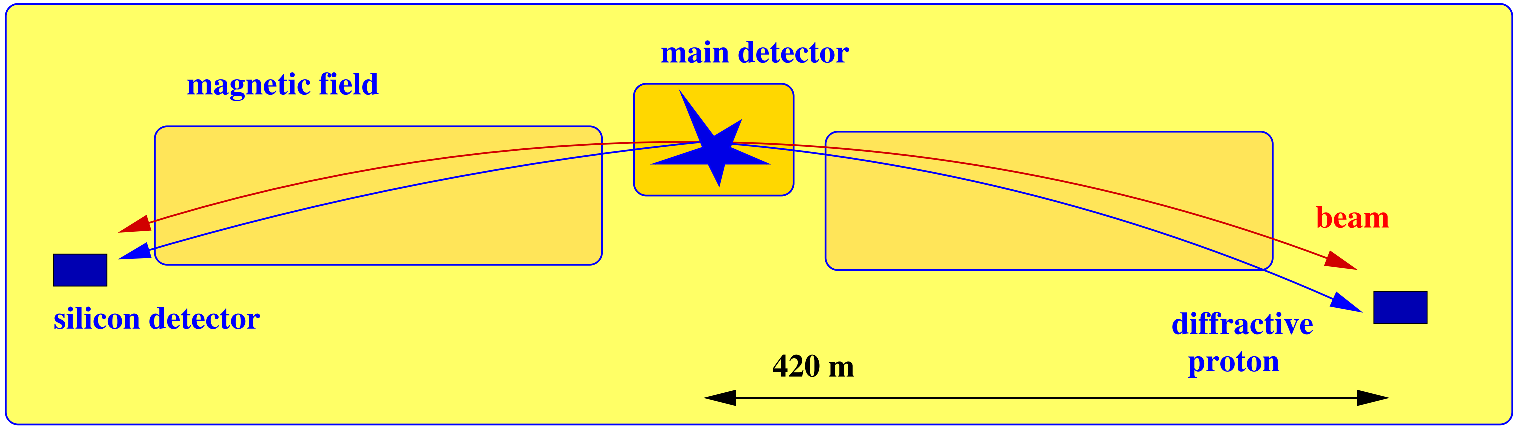
Exclusive production useful in some SUSY scenarios

$$M_A = 130 \text{ GeV}, \qquad \tan\beta = 50, \qquad \mathcal{L} = 30 \text{ fb}^{-1}$$

	Signal	Background
$M_h = 124.4$ GeV	71	3
$M_H = 135.5$ GeV	124	2
$M_A = 130$ GeV	1	2

Forward protons at LHC

FP–420



Forward Proton measurement – 420 meters downstream

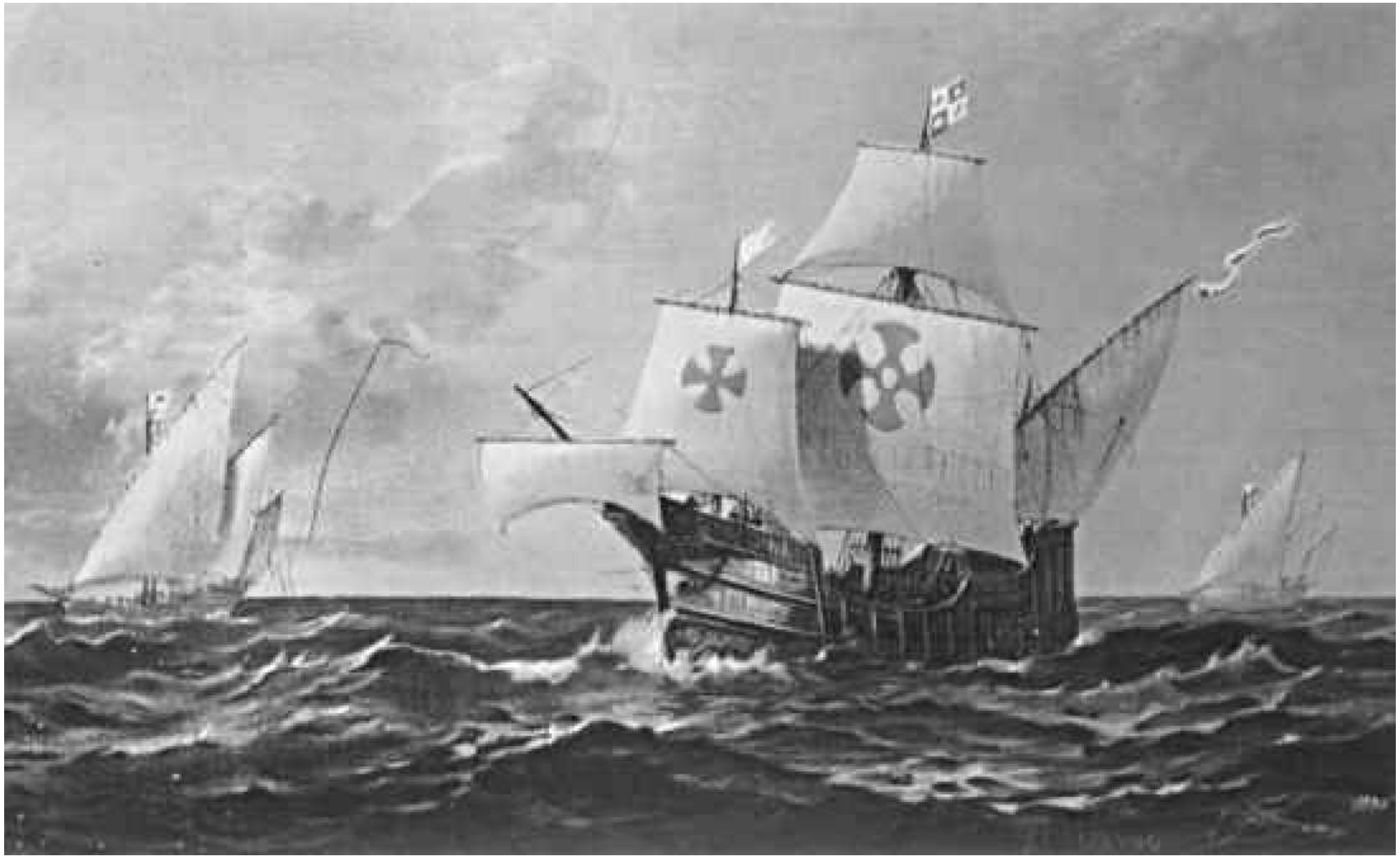
Magnetic spectrometer: small loss of energy $\longrightarrow$ drift outside the beam

Silicon trackers – milimeters from the beam

Measurement of the mass may reach $O(1\ \text{GeV})$ accuracy

Tagging of protons $\longrightarrow$ glue factory

GOLD-MINE FOR DIFFRACTIVE PHYSICS



Thank You and Happy Birthday!