Aurore Courtoy -INFN Pavia
with
Alessandro Bacchetta
Marco Radici

Flavor decomposition of Dihadron Fragmentation Function and its relevance for Transversity

Probing Strangeness in Hard Processes

LNF- Frascati

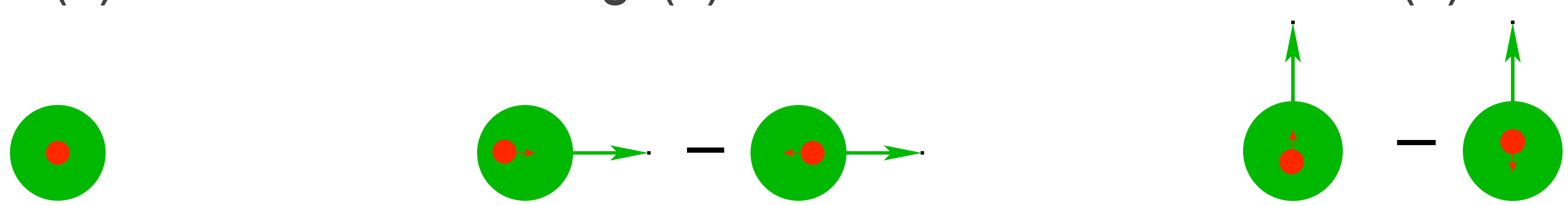
19th of October 2010

Transverse Spin & TMDs

From DIS to Semi-Inclusive DIS

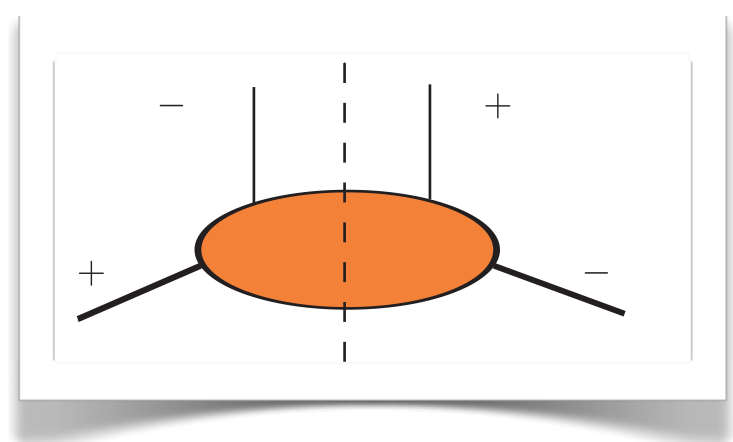
- 3 leading-twist PDFs:

$f_1(x)$ $g_1(x)$ $h_1(x)$



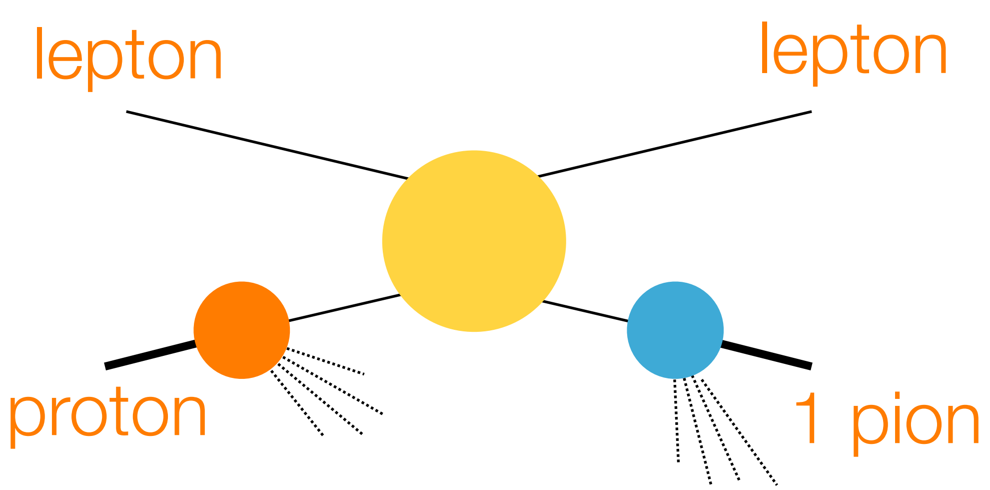
- *Transversity* not accessible through inclusive DIS
  - chiral-odd

- we go to Semi Inclusive DIS
  - one more variable $\mathbf{k}_\perp$
  - Lorentz expansion of all the possible functions
  - birth of TMDs



Ways to Transversity

SIDIS on p↑



Collins FF

$$d\sigma \propto \sum_q [h_1^q \otimes H_1^{\perp q}](x, z, P_{h\perp}^2)$$

TMD factorization

- Convolution
- Soft factors
- Evolution
- Complex universality

chiral-odd partner

Ways to Transversity

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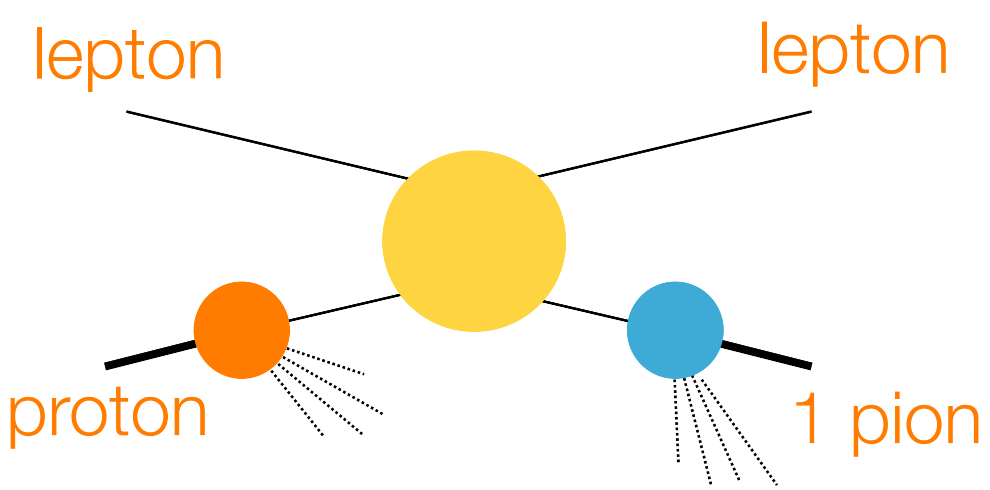

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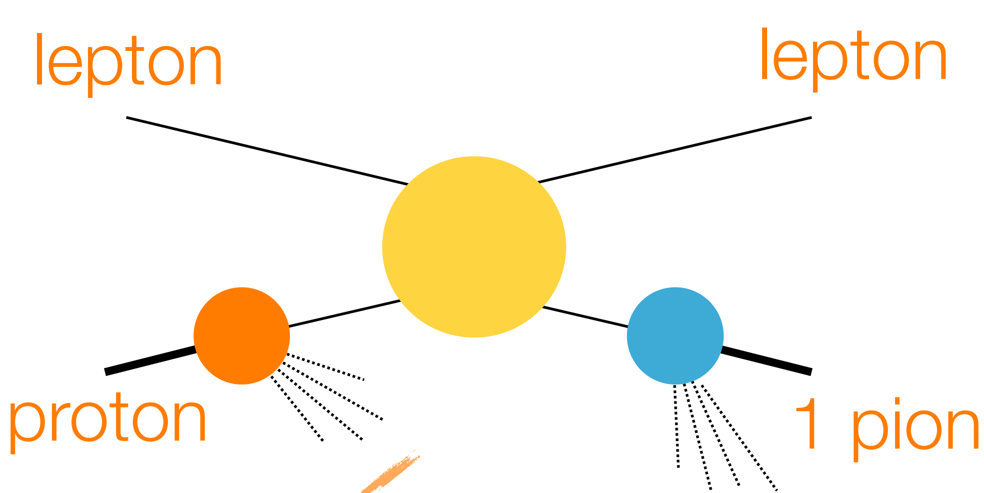
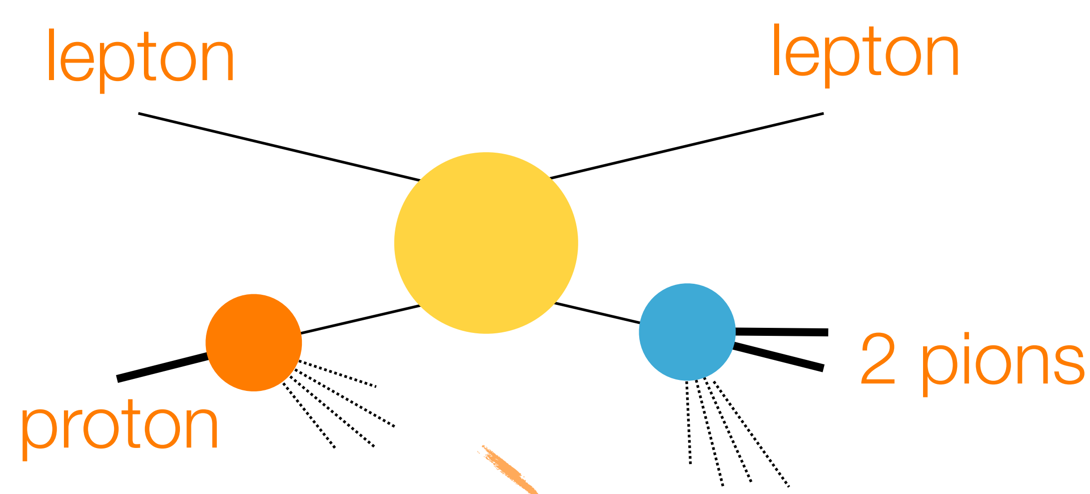




Collins FF

DiFF

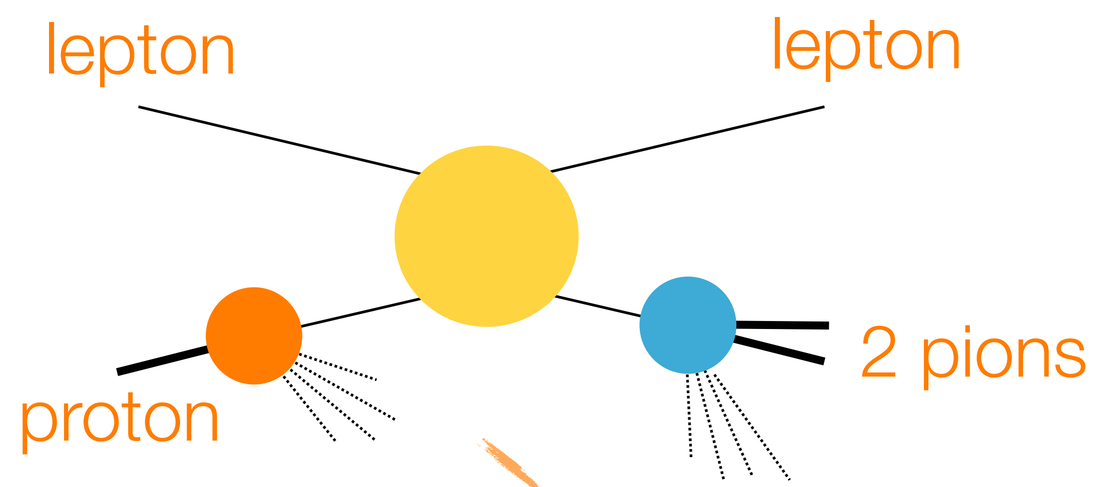
$$d\sigma \propto \sum_q [h_1^q \otimes H_1^{\perp q}](x, z, P_{h\perp}^2)$$

$$d\sigma \propto \sum_q h_1^q(x) H_1^{\sphericalangle q}(z, M_h^2)$$

chiral-odd partner

Ways to Transversity

SIDIS on p↑



DiFF

$$d\sigma \propto \sum_q h_1^q(x) H_1^{\sphericalangle q}(z, M_h^2)$$

chiral-odd partner

Transverse Spin from Fragmentation Functions

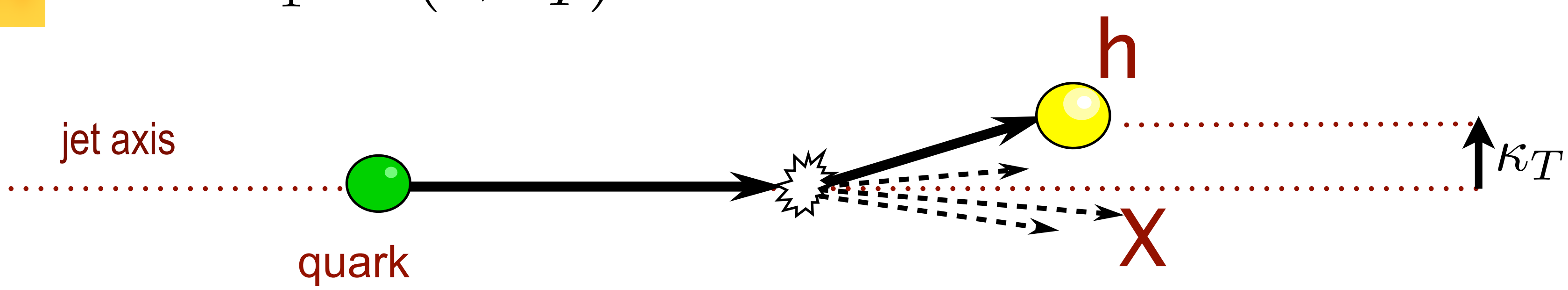
Distribution of hadrons inside the jet

→ Direction of the transverse polarization of the fragmenting quarks

Also unpolarized

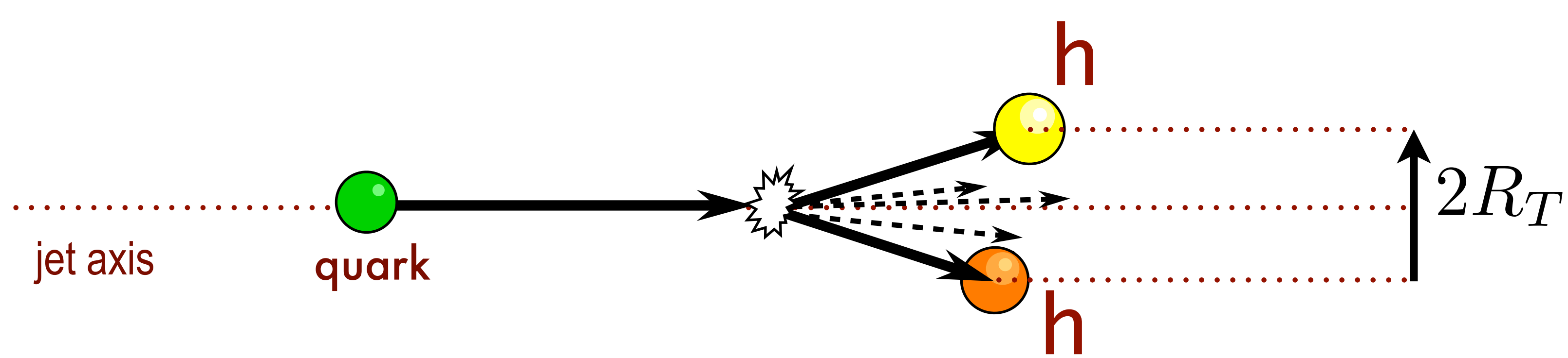
- TMD FF

$$D_1^{q\to h}\left(z,\kappa_T^2\right)$$



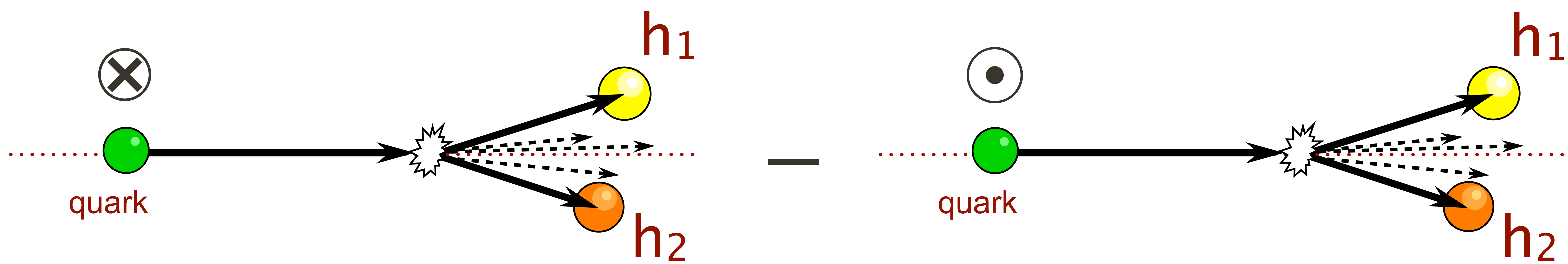
- DiFF

$$D_1^{q\to h_1 h_2}\left(z_1,z_2,R_T^2\right)$$



Transverse Spin from Fragmentation Functions

Interference Fragmentation Functions



$H^{\sphericalangle}_{1,q\to h_1 h_2}(z_1, z_2, R_T^2)$

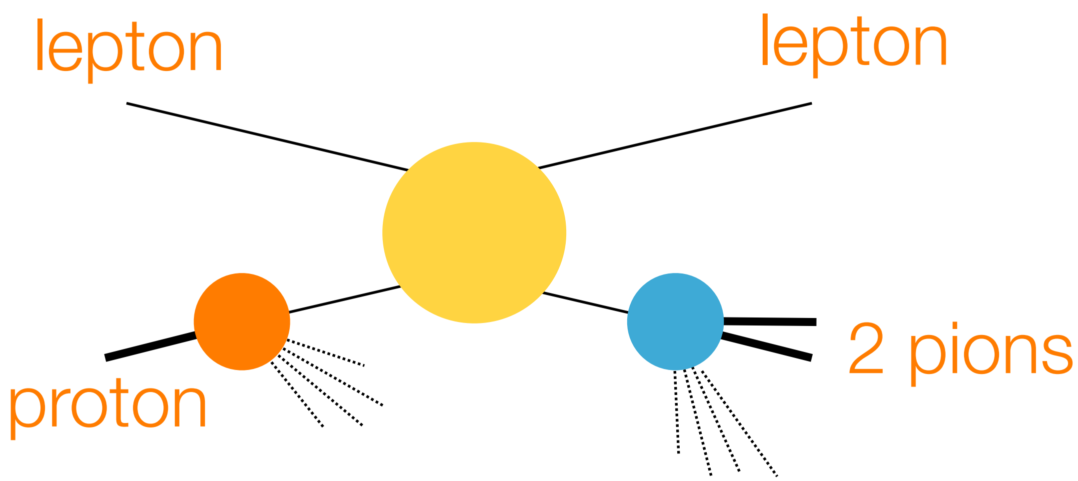
relates transverse polarization of the fragmenting quark to angular distribution of the hadron pairs in the transverse plane

- ✓ Naive T-odd ; chiral-odd
- ✓ Does not vanish if integrated over transverse momentum $\mathbf{k}_\perp$
- ✓ The two hadrons must be distinguishable

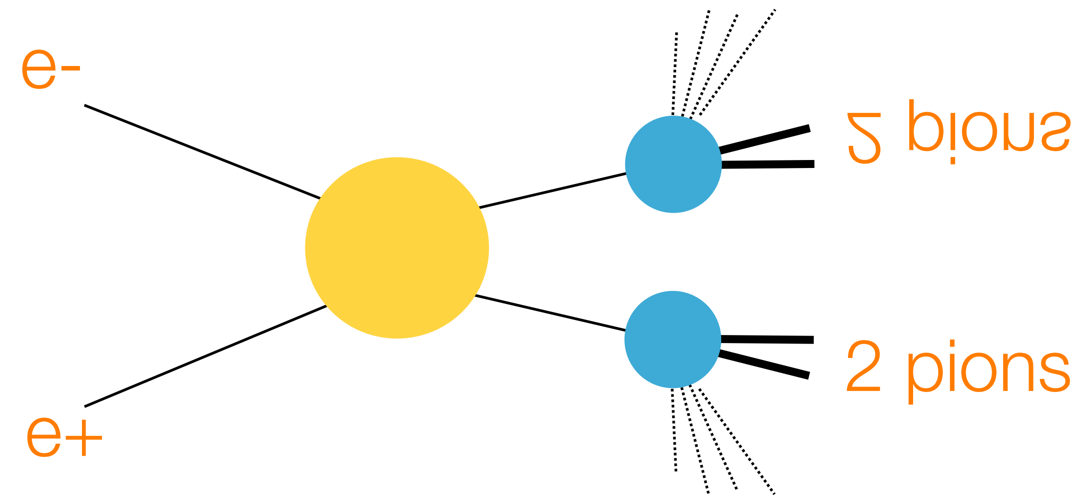
Collins, Heppelman, Ladinsky, NPB420 (94)

Framework for DiFF

SIDIS on p↑



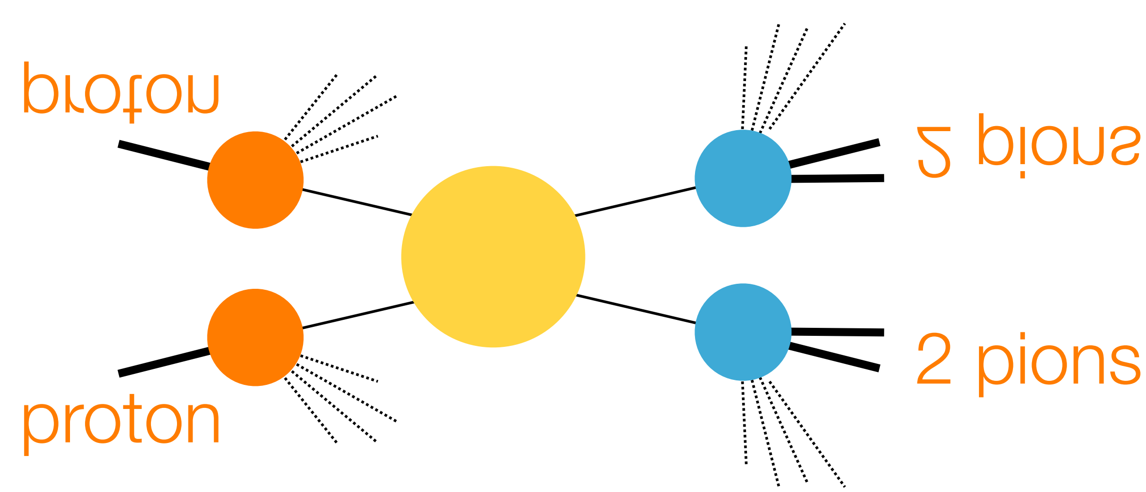
e+e- to pions



- Collinear factorization
- Universality
- No convolution
- Evolution understood

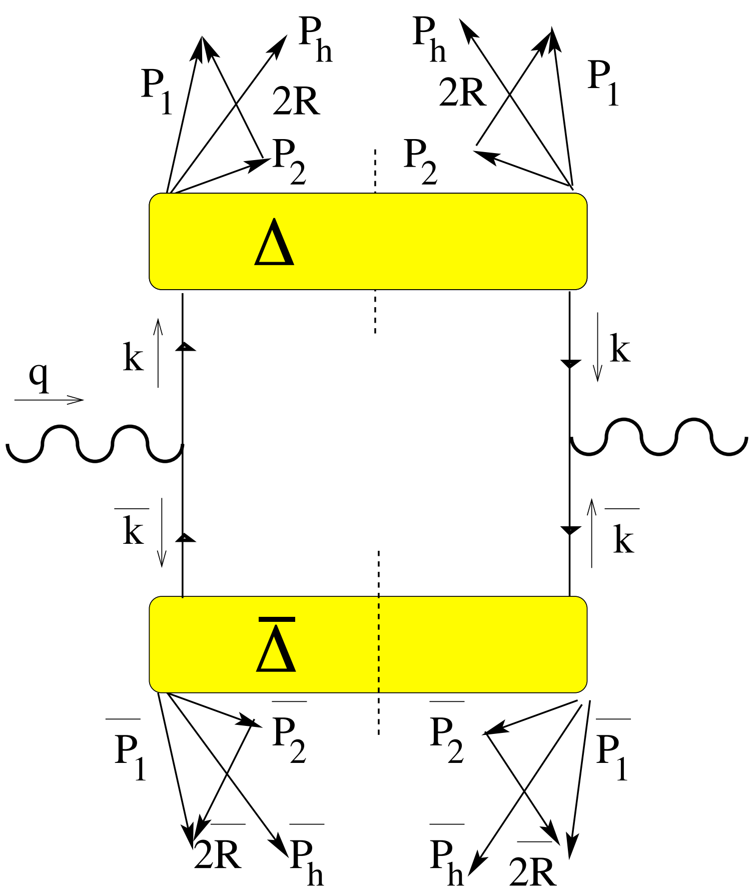
Bacchetta, Ceccopieri, Mukherjee, Radici, PRD79 (09)

pp↑ to pions



e+e- : qq correlator for DiFF

Boer, Jakob, Radici, PRD 67 (03)
Bacchetta, Radici , PRD 67(03)



$$d\sigma \propto \frac{\alpha^2}{Q^6} L_{\mu\nu} W_{4h}^{\mu\nu}$$

$$W_{4h}^{\mu\nu} \propto \sum_a \int d\mathbf{k}_T d\bar{\mathbf{k}}_T \, \delta^2() \mathrm{Tr}\left[\int d\bar{k}^- \bar{\Delta}|_{\bar{k}^+ \ldots} \gamma^\mu \int dk^+ \Delta|_{k^- \ldots} \gamma^\nu\right]$$

e+e- : qq correlator for DiFF

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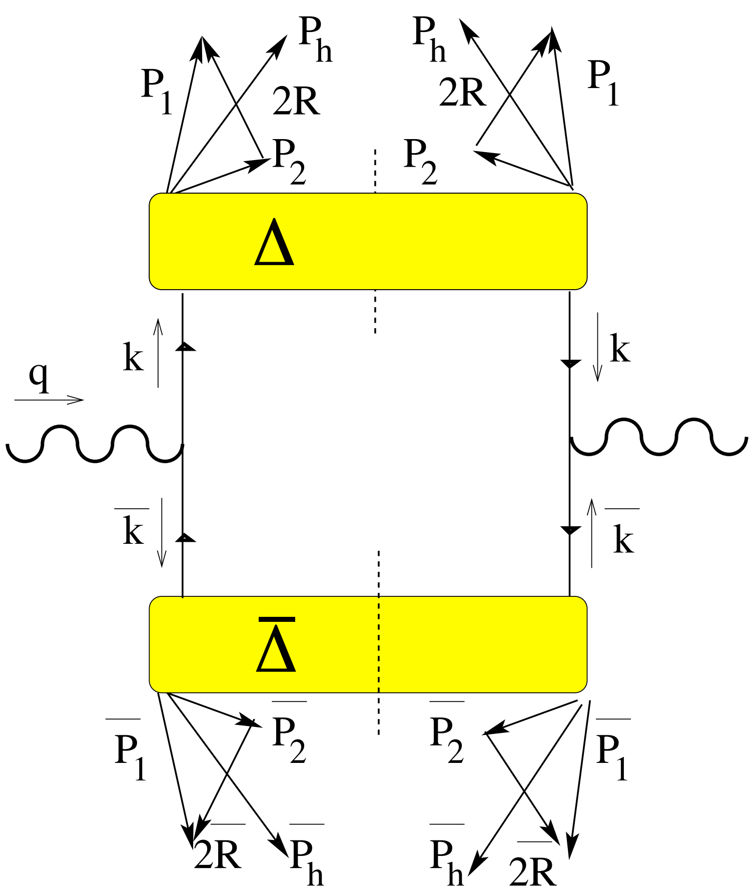

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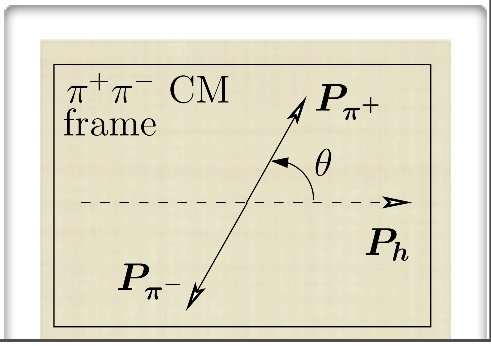
Integrated over kT

$$\mathcal{P}_- \Delta_a(z, \cos\theta, M_h^2, \phi_R) \gamma^-$$
$$= \frac{2|\vec{R}|}{8\pi M_h} \left(D_1^a(z, \zeta(\cos\theta), M_h^2) + i\, H_1^{\sphericalangle\, a}(z, \zeta(\cos\theta), M_h^2) \frac{|\vec{R}|}{M_h} \sin\theta \gamma^\mu n_\mu \right) \mathcal{P}_-$$



e+e- : qq correlator for DiFF

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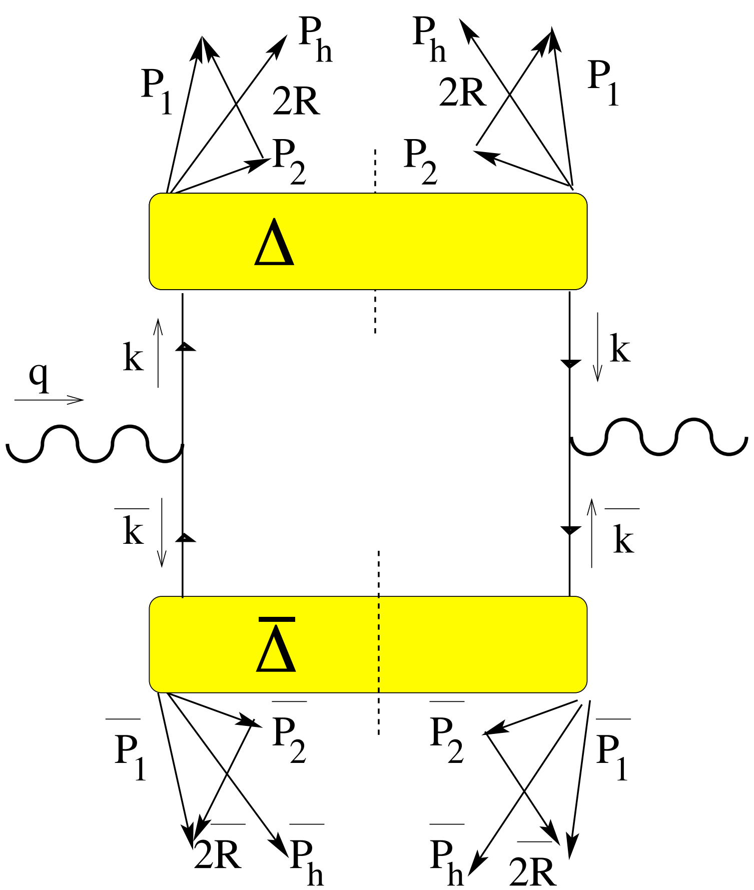

$$W^{\mu\nu}_{4h} \propto \sum_a \int d\mathbf{k}_T d\bar{\mathbf{k}}_T\, \delta^2()\mathrm{Tr}\left[\int d\bar{k}^- \bar{\Delta}|_{\bar{k}^+\dots}\, \gamma^\mu \int dk^+ \Delta|_{k^-\dots}\, \gamma^\nu\right]$$

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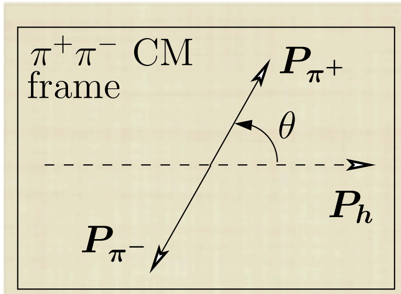
Partial Wave decomposition

$$\frac{2|\vec{R}|}{M_h} F_1\left(z, \zeta(\cos\theta), M_h^2\right) = \sum_n F_{1,n}\left(z, M_h^2\right) P_n(\cos\theta)$$

n≤2



Physics of the DiFF

Main approximation:
truncation of the partial wave analysis up to 2nd order

➡ L=0, 1 relative partial waves

➡ terms ∝ 1, cos ϑ, sinϑ, cosϑsinϑ

s-wave → unpolarized

interference b/w unpolarized pair (s-wave) and longitudinally pol. pair (p-wave)

interference b/w unpolarized pair (s-wave) and transversely pol. pair (p-wave)

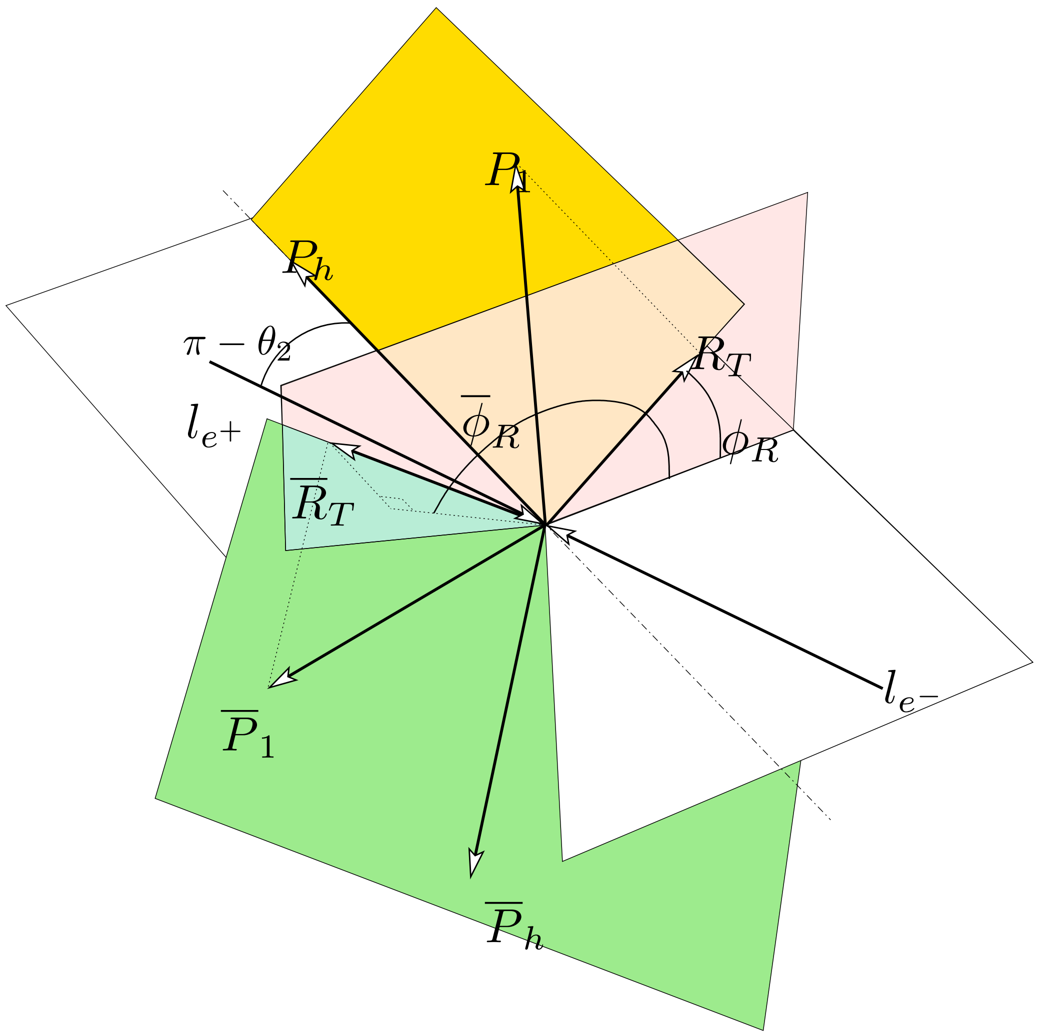
interference b/w longitudinally polarized pair (p-wave) and transversely pol. pair (p-wave)

$D_1^{q\to h_1 h_2}\left(z_1, z_2, R_T^2\right)$ → **s or p waves**

$H_{1,q\to h_1 h_2}^{\sphericalangle}(z_1, z_2, R_T^2)$ → **interf. s & p waves**

The Asymmetry in e+e-

Artru, Collins, ZPC 69 (96)
Boer, Jakob, Radici, PRD 67 (03)



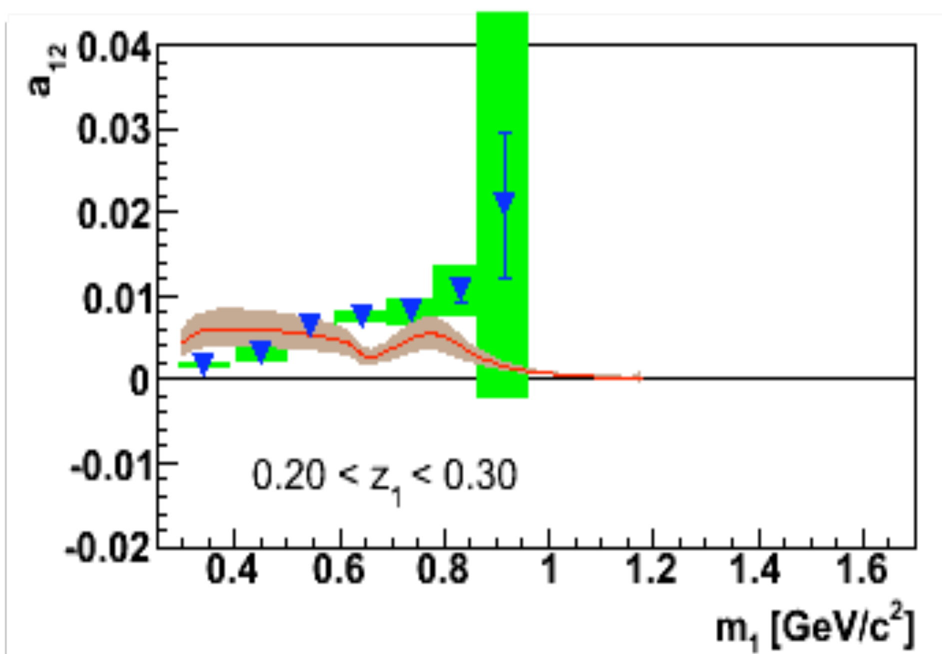
$$A(\cos\theta_2, z, M_h^2, \bar{z}, \bar{M}_h^2) = \frac{\langle \cos(\phi_R + \phi_{\bar{R}}) \rangle}{\langle 1 \rangle}$$

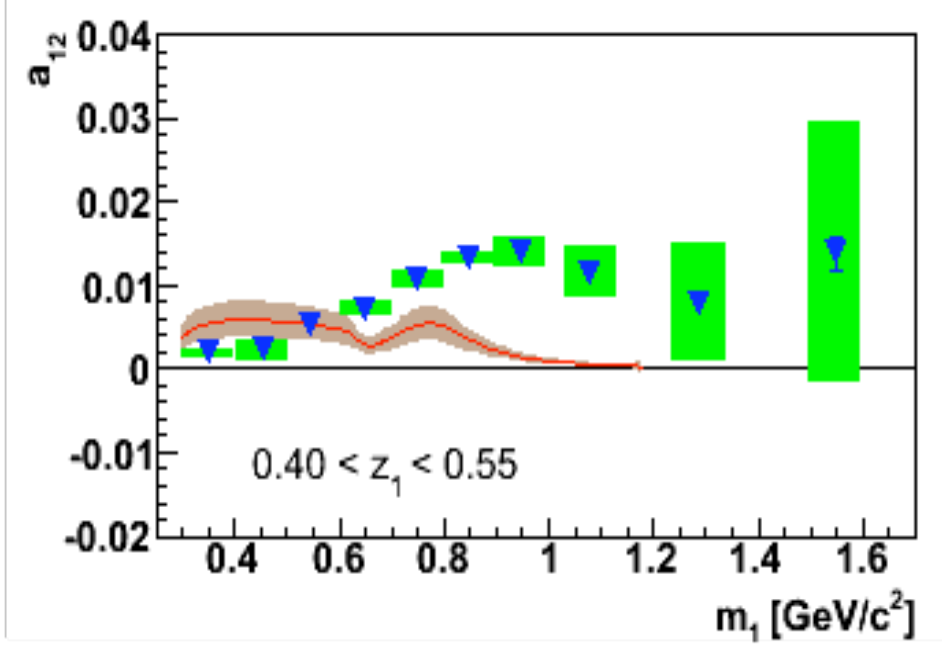
$$|\vec{R}| = \frac{M_h}{2}\sqrt{1 - \frac{4m_\pi^2}{M_h^2}}$$

$$A^{\cos(\phi_R+\phi_{\bar{R}})}(\cos\theta_2, z, M_h^2, \bar{z}, \bar{M}_h^2) \propto \frac{\sum_q e_q^2 \; H_{1,q}^{\sphericalangle}(z, M_h^2)\, \bar{H}_{1,q}^{\sphericalangle}(\bar{z}, \bar{M}_h^2)}{\sum_q e_q^2 \; D_{1,q}(z, M_h^2)\, \bar{D}_{1,q}(\bar{z}, \bar{M}_h^2)}$$

a_{12} asymmetry from BELLE

courtesy of BELLE

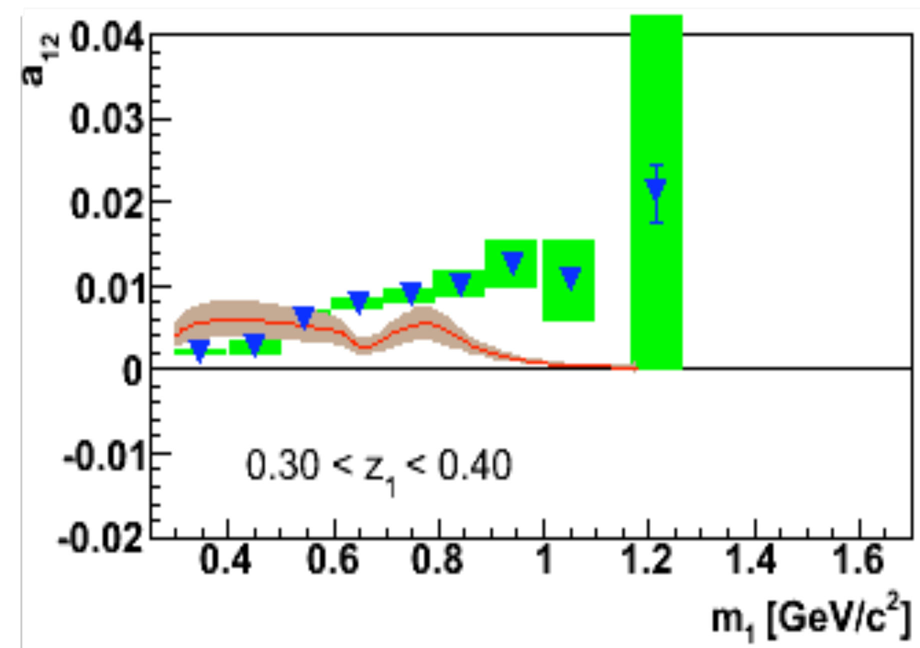


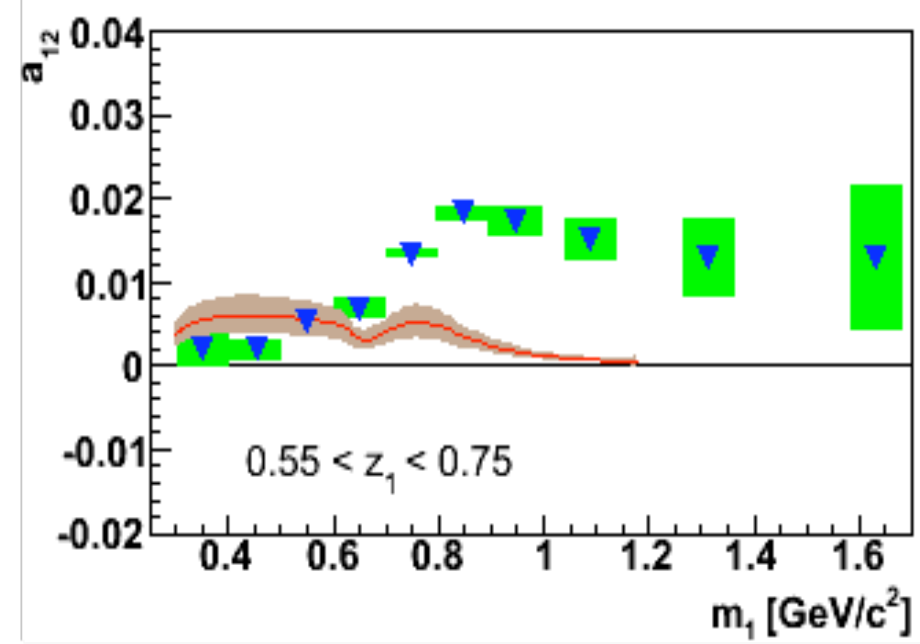


- ✓ $Q^2 \sim 100\,\mathrm{GeV}^2$
- ✓ (z, M_h) correlation
- ✓ 4 plots
  - ➡ limited range in z
- ✓ large errors
- ✓ 8x8 (Mh1, Mh2)
- ✓ 9x9 (z1,z2)

➡ red curves:

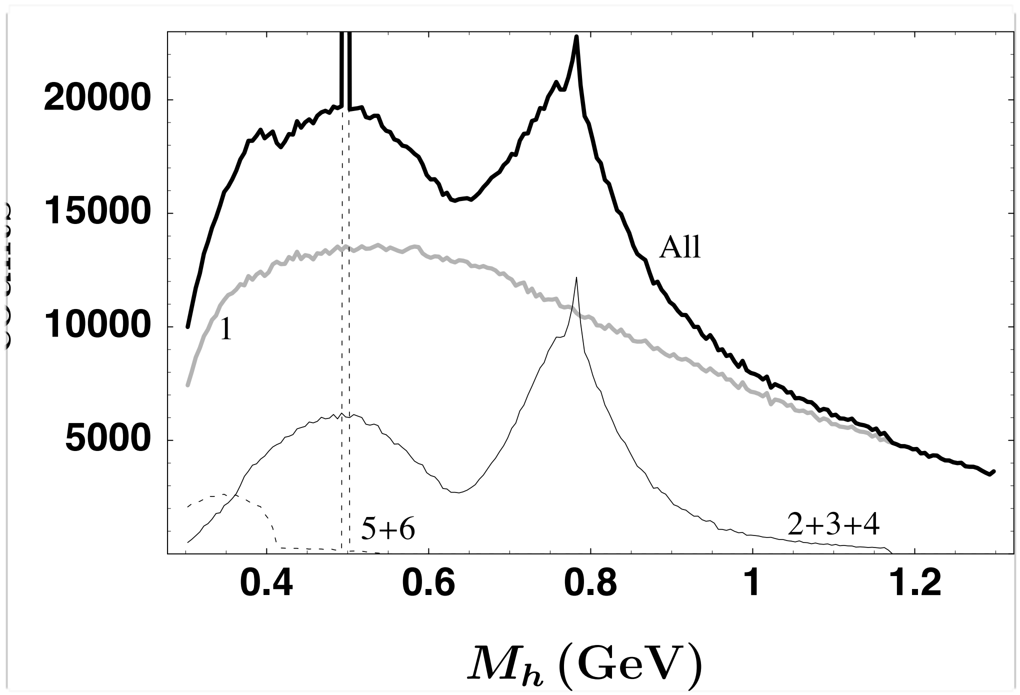
spectator model result





Data not published yet

Invariant Mass Spectrum for q→ (π+π-)X



Most prominent channels at $M_h \leq 1.8\text{GeV}^2$

1. Background

$$q \longrightarrow \pi^+\pi^- X_1$$

2. ρ production

$$q \longrightarrow \rho X_2 \longrightarrow \pi^+\pi^- X_2$$

3. ω production

$$q \longrightarrow \omega X_3 \longrightarrow \pi^+\pi^- X_3$$

$$q \longrightarrow \omega\pi^0 X_4' \longrightarrow \pi^+\pi^-\pi^0 X_4'$$

undetected π0

Peaks at

i. $M_h \sim m_\rho = 770\text{MeV}$

ii. $M_h \sim m_\omega = 782\text{MeV}$

iii. broad peak at $M_h \sim 500\text{MeV}$

I can take into account model predictions...
A. Bacchetta, M. Radici, PRD74 (06)

Monte Carlo from BELLE

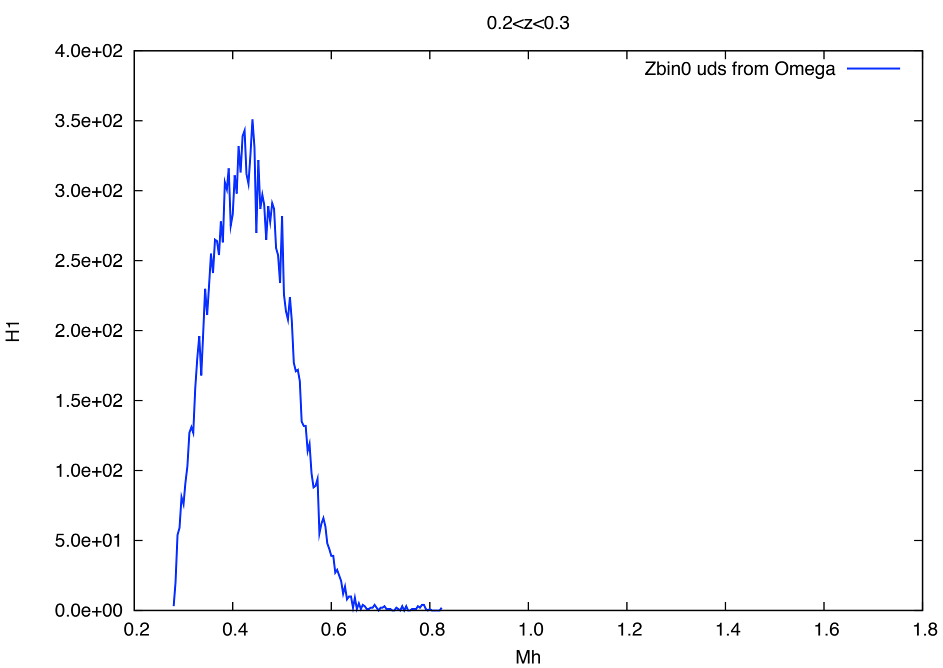
courtesy of BELLE Collaboration

Unpolarized cross section

Monte Carlo from BELLE

courtesy of BELLE Collaboration

Unpolarized cross section



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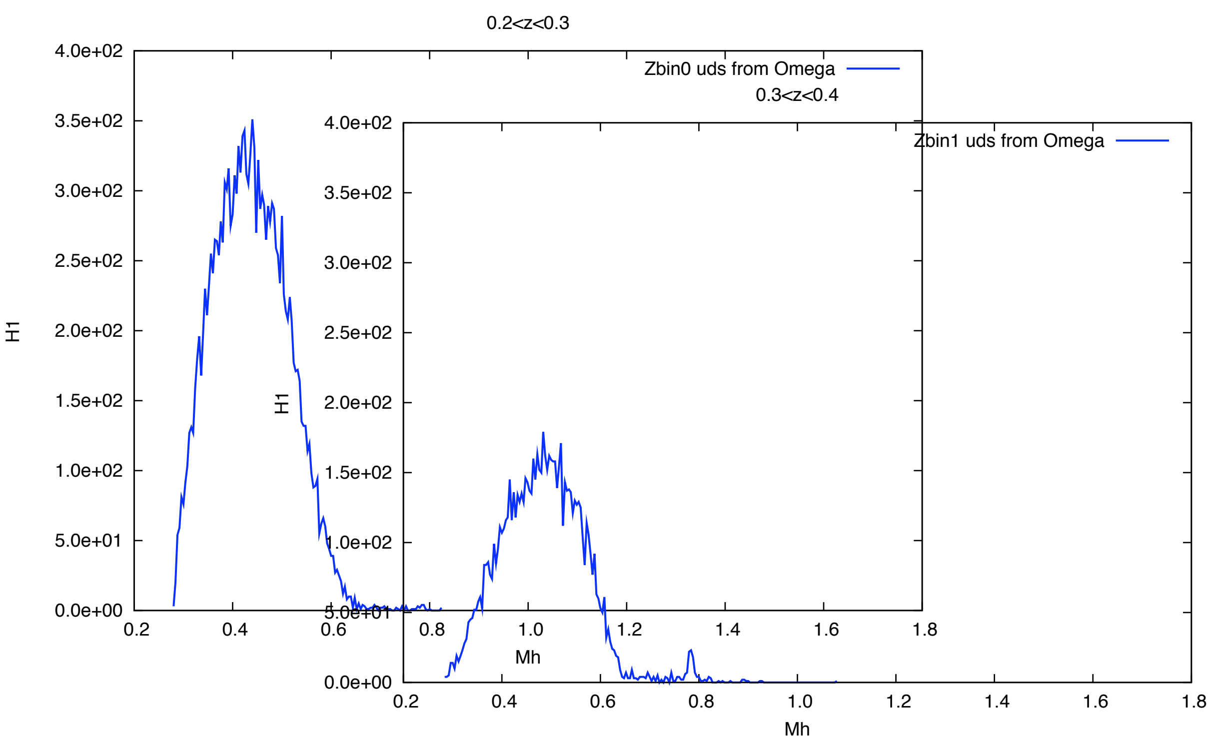

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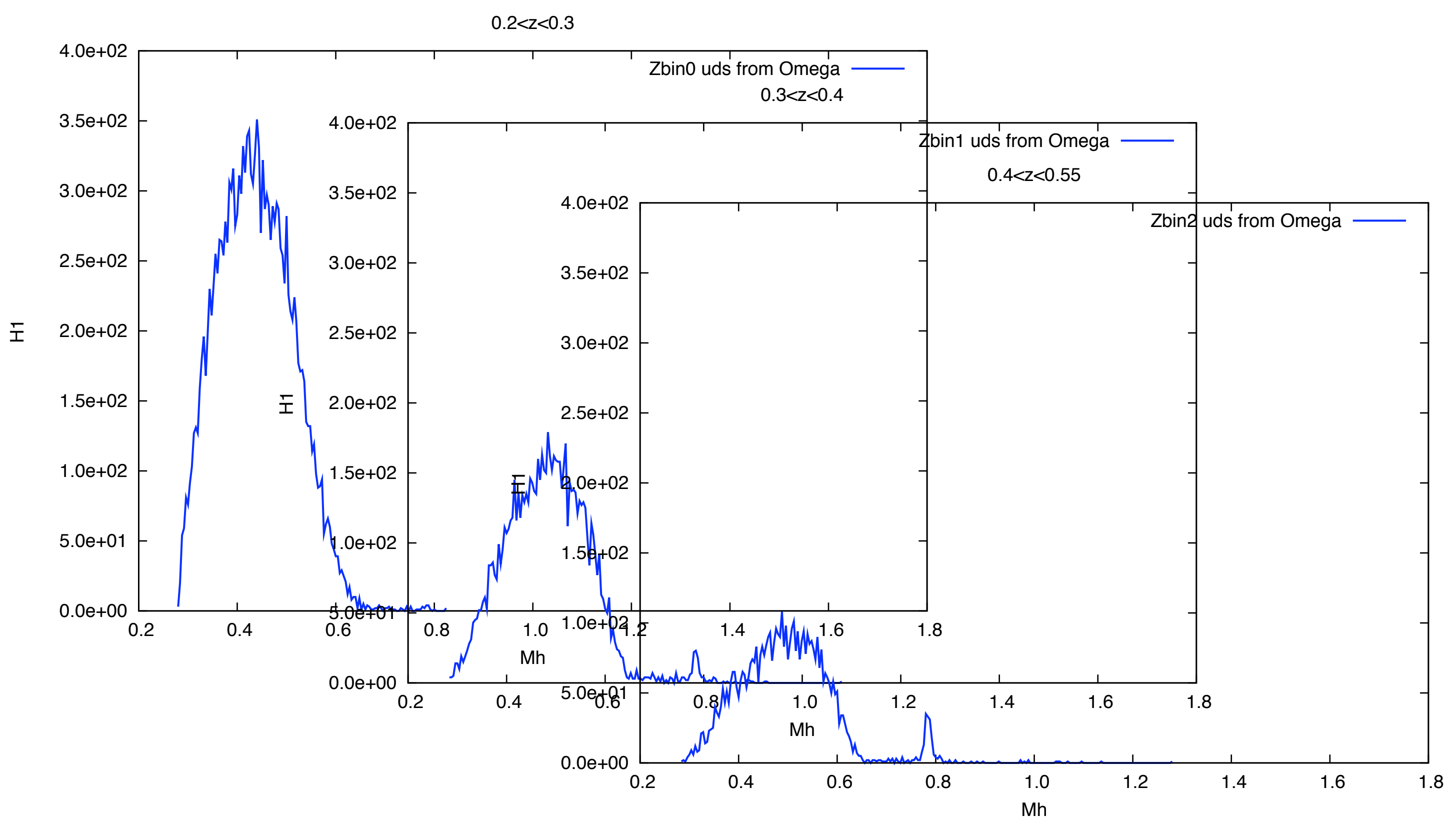

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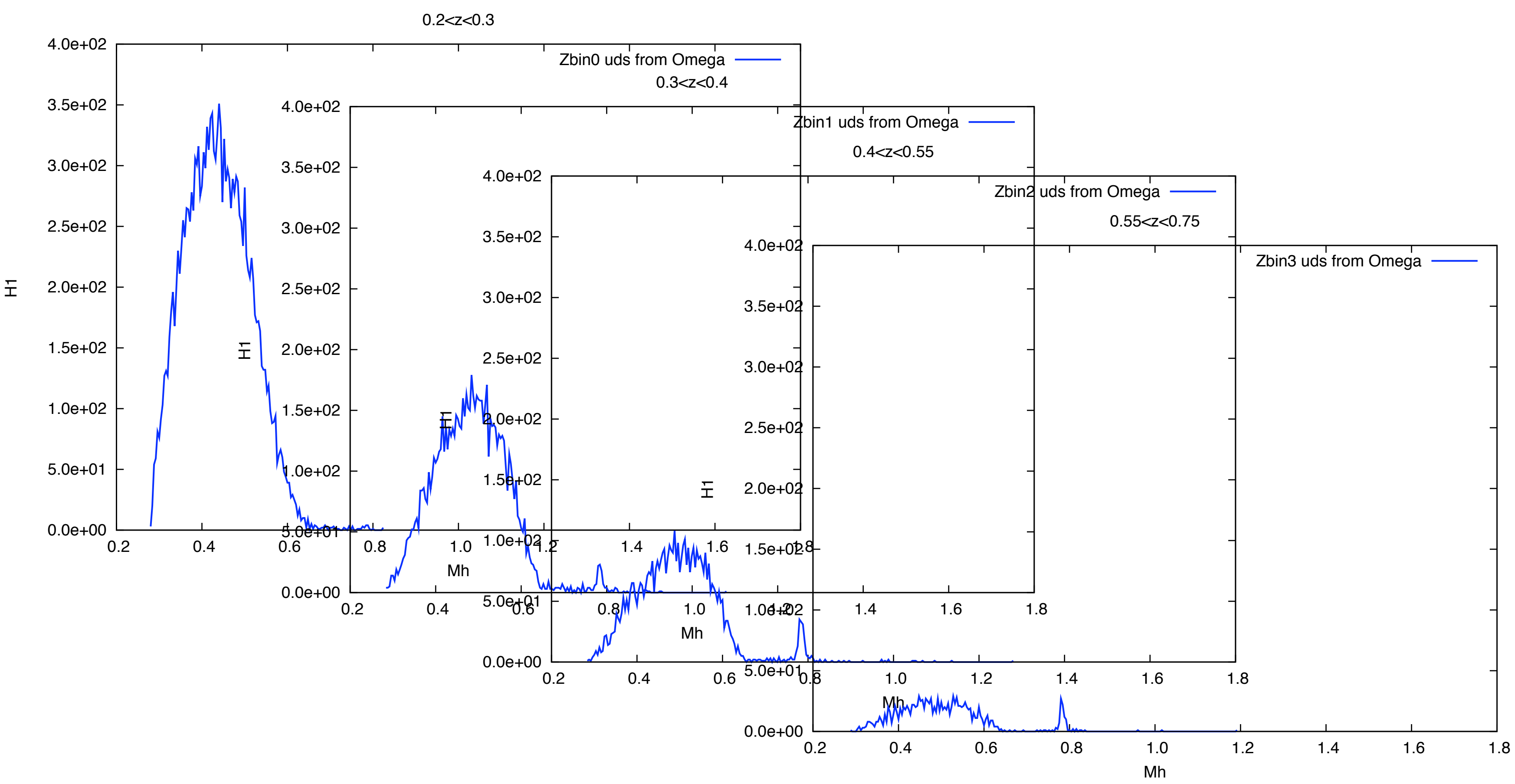

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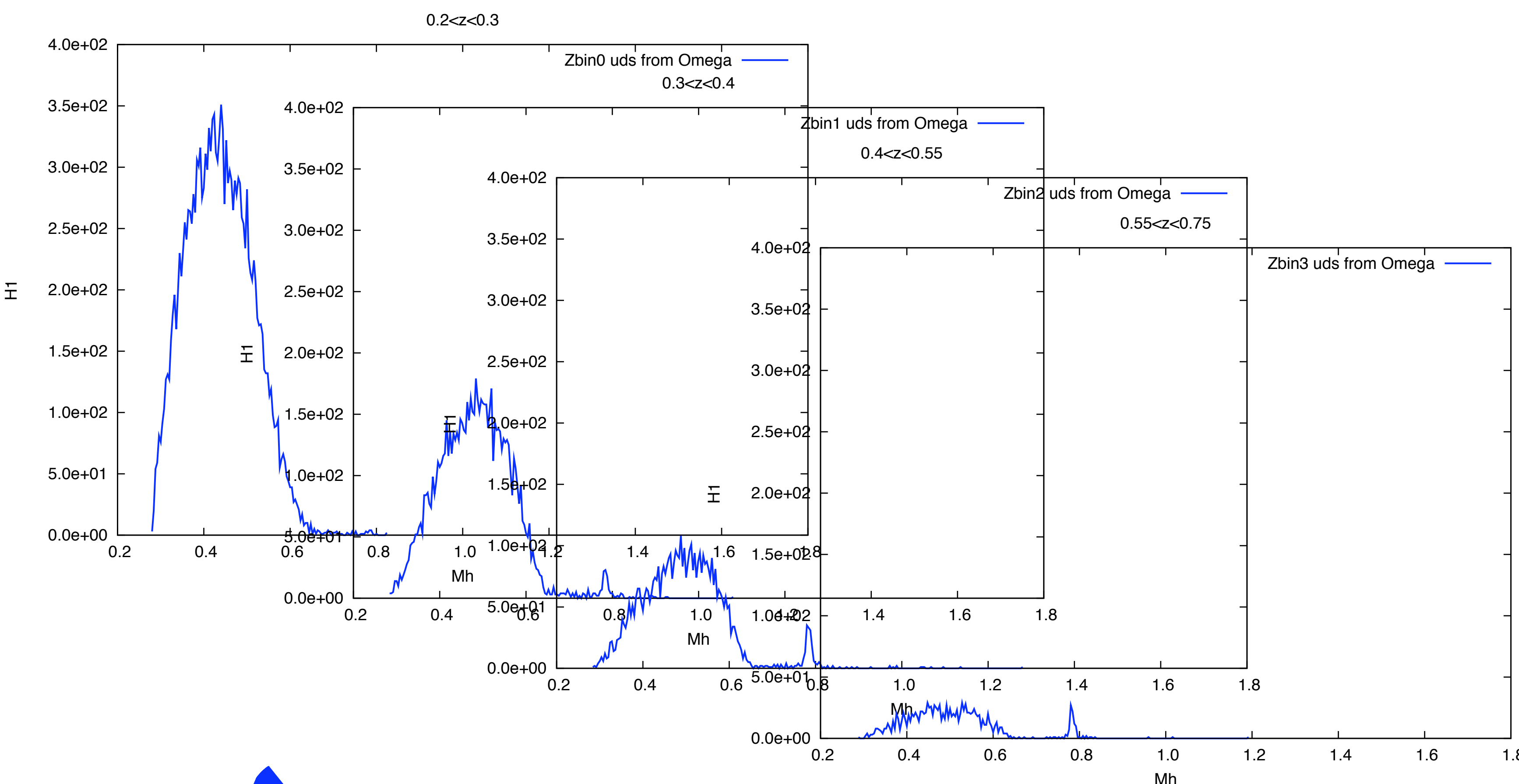


- 4 zbins
- Flavor decomposition
  - uds
  - charm
- ρ channel
- ω channels
- non resonant contrib.

e.g. uds from ω channels

NB: in our analysis, we neglect resonant channels contribution to the charm

Unpolarized Cross Section

Constraints on the Functional Form from

1. the kinematics
2. the ss and pp interference-like
3. physics model-inspired

I want to fit :

$$d\sigma \quad \propto \quad 2\frac{6\alpha^2}{Q^2}\frac{\langle 1+\cos^2\theta_2\rangle}{2M_h}\, f^a_{D_1}(z,M_h)\int_{0.2}^{1}\int_{0.28}^{2} f^{\bar{a}}_{D_1}(\bar{z},\bar{M}_h)$$

with a functional form like:

$$f^a_{D_1}(z,M_h) \quad = \quad 2M_h\, z^2\sum_a \sqrt{e_a^2\, D_{1\,a}^{ss+pp}(z,M_h^2)}$$

Error on the MC: √number of events
Functional form inside de integration routine
Propagation of errors ...

Unpolarized Cross Section

Constraints on the Functional Form from

1. the kinematics

2. the ss and pp interference-like

3. physics model-inspired

I want to fit

with a functional form

Constraints coming while determining the Functional Form

or "How it contrasts with model calculation, so far."

1. No z and Mh factorization seems possible

2. Background seems to allow both ss and pp interference-like

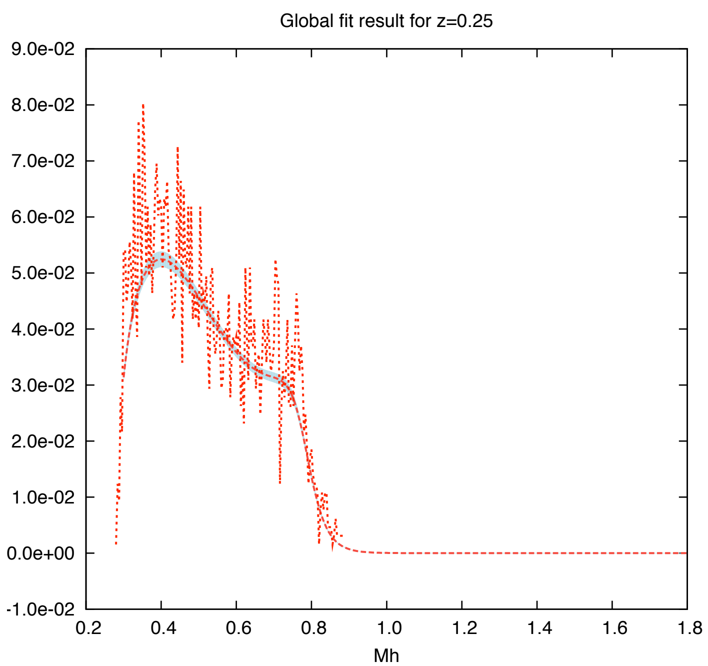
3. z-dependence of charm "background" ≠ z-dependence of uds "background"

and maybe also the Mh dpdce

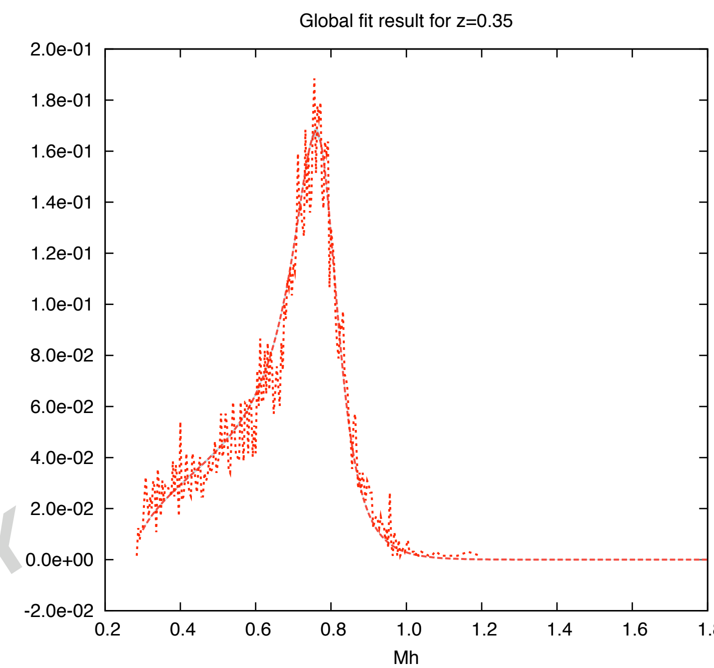
Error on the MC: √number of events
Functional form inside de integration routine
Propagation of errors ...

uds from ρ

A.C., Bacchetta and Radici, in preparation

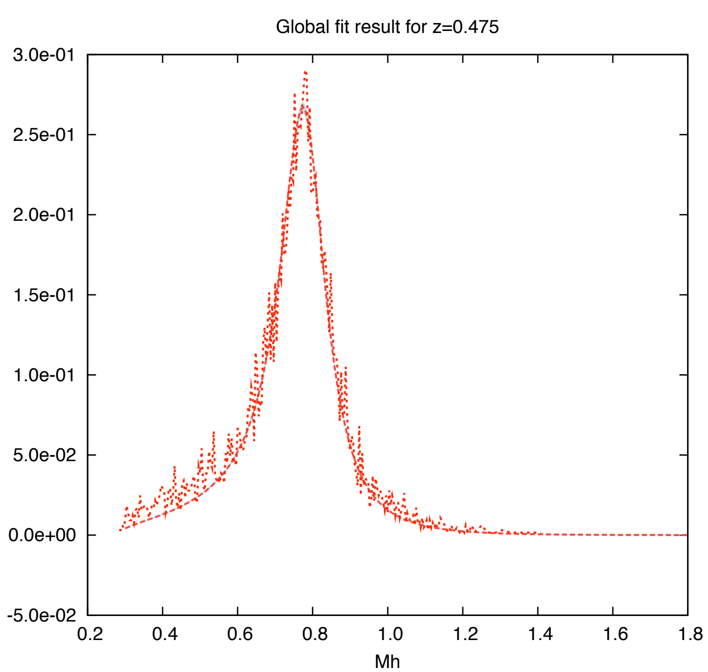


(z, M_h) fit of the 4 z-bins

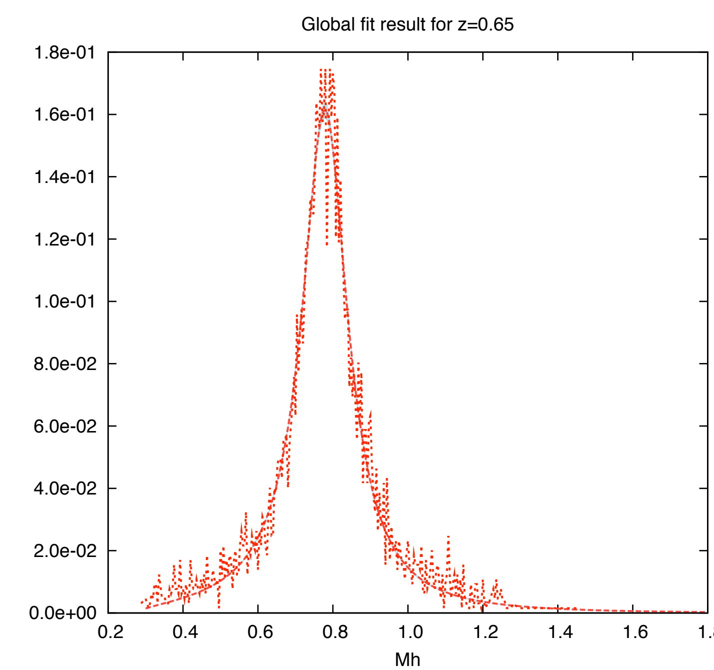


$$D_{1,\rho}^{uds}(z, M_h) \propto A\sqrt{M_h^2 - 4m_\pi^2} \times (1-z)^B z^C \times \frac{\exp f(M_h, z)}{(M_h^2 - m_\rho^2)^2 + m_\rho^2 \Gamma_\rho^2}$$

PRELIMINARY

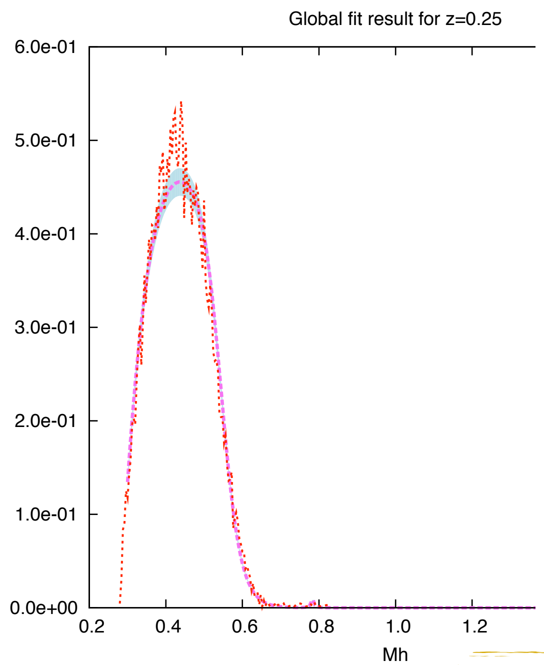


$$\chi^2/d.o.f \sim 1.3$$

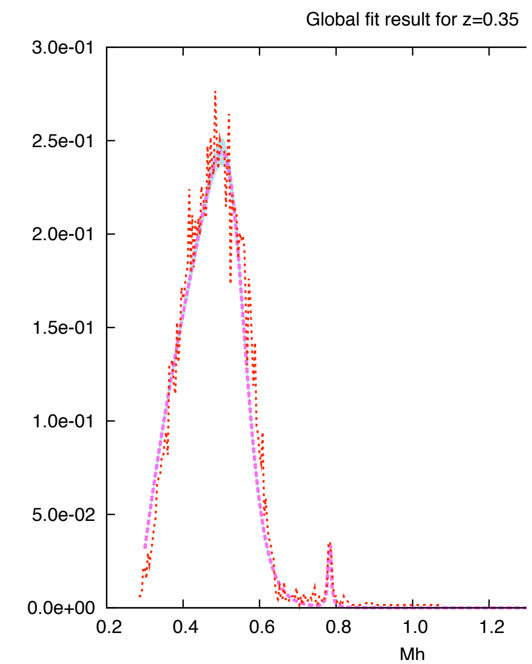


uds from ω

A.C., Bacchetta and Radici, in preparation

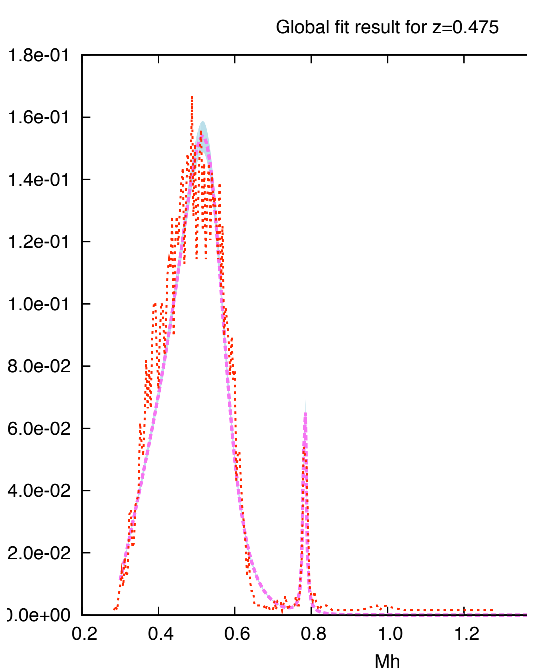


(z, M_h) fit of the 4 z-bins

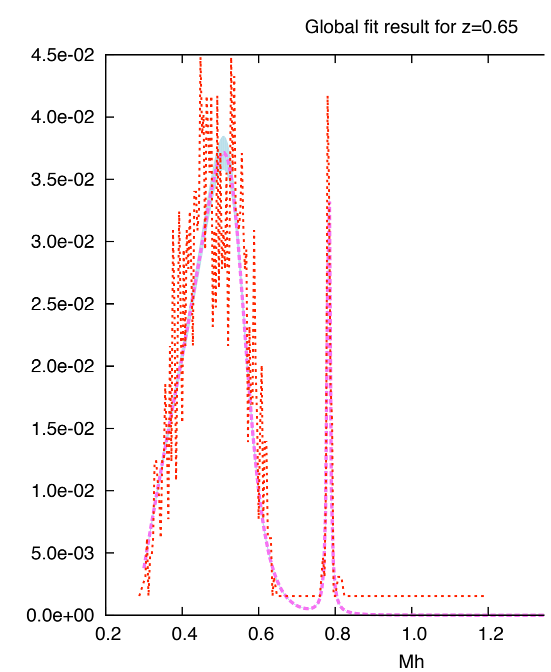


$$D_{1,\omega}^{uds}(z, M_h) \quad \propto \quad \sqrt{M_h^2 - 4m_\pi^2}\left(A\frac{(1-z)^B z^C}{(M_h - m_\omega^2)^2 + m_\omega^2\Gamma_\omega^2} + D\sqrt{M_h^2 - 4m_\pi^2}\,(1-z)^E z^F \times \frac{\exp f(z, M_h)\ \exp f'(z)}{(M_h^2 - G^2)^2 + H^2}\right)$$

PRELIMINARY

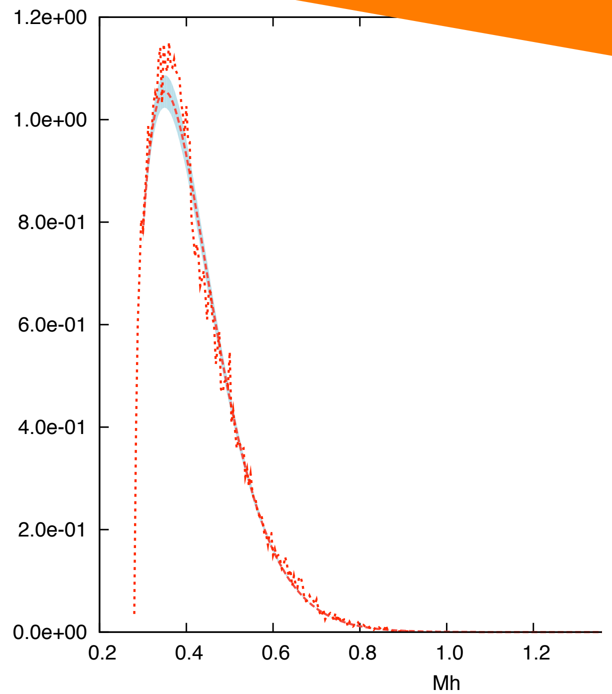


$$\chi^2/d.o.f \sim 1.3$$

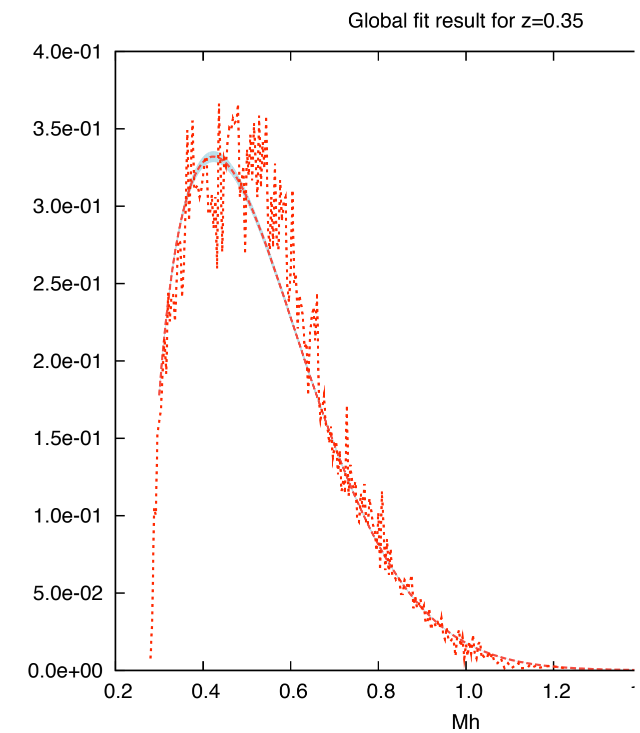


uds from background

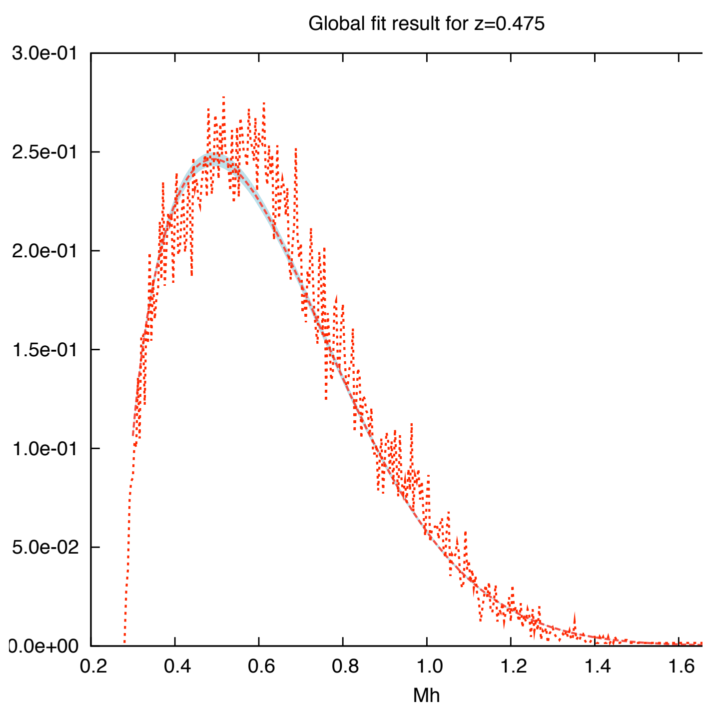
A.C., Bacchetta and Radici, in preparation



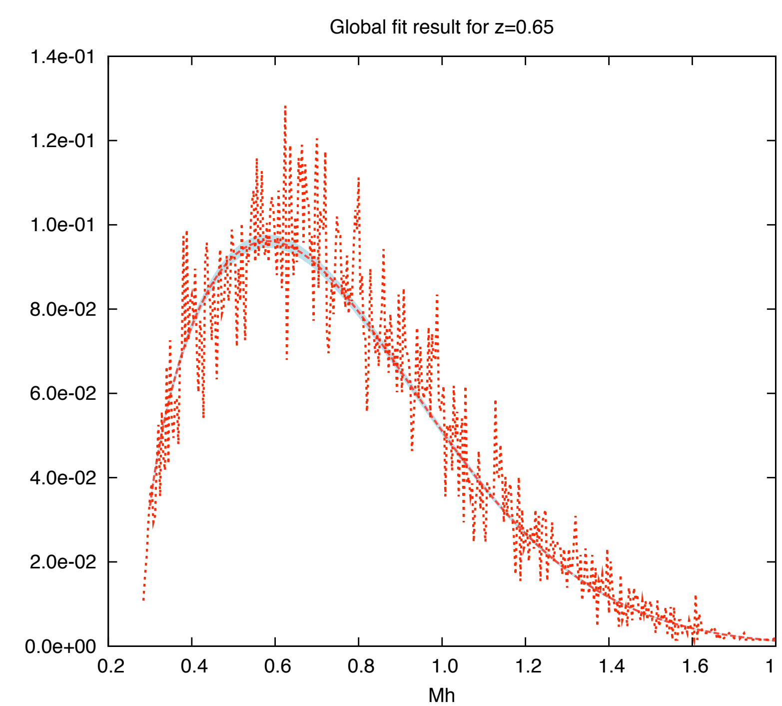
(z, M_h) fit
of the 4 z-bins



$$D^{uds}_{1,bkgd}(z, M_h) \quad \propto \quad \sqrt{M_h^2 - 4m_\pi^2}\; A\,(1-z)^B z^C e^{f(z,M_h)}\, e^{f'(z)}$$

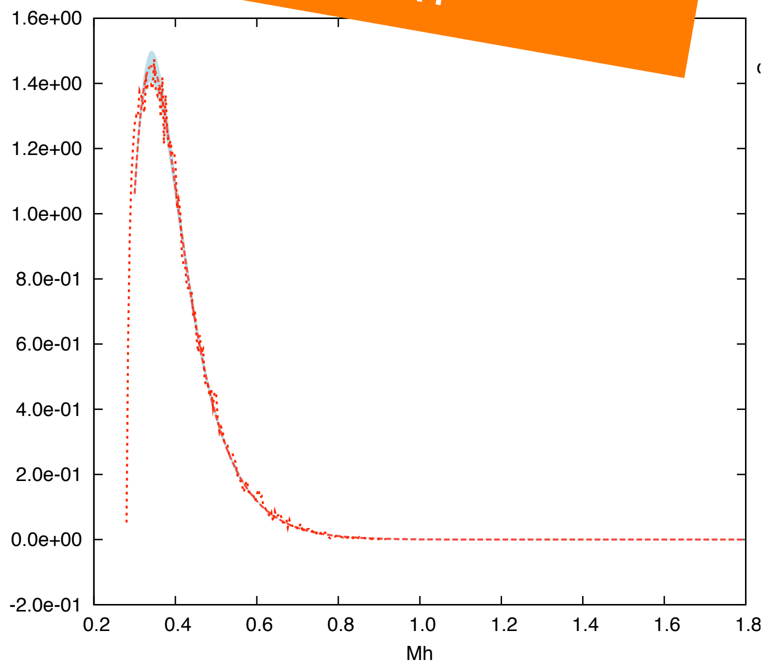


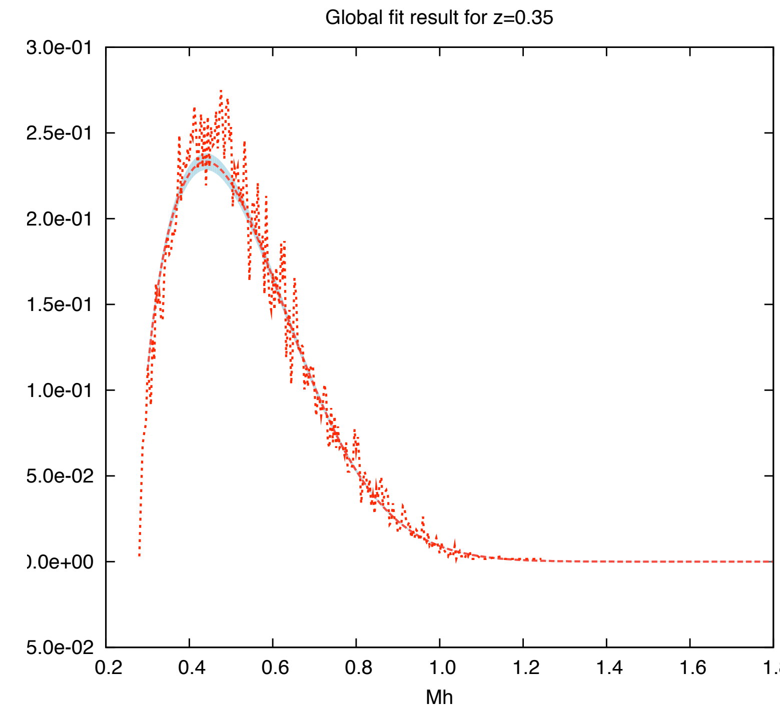
$$\chi^2/d.o.f \sim 1.3$$



charm from background

A.C., Bacchetta and Radici, in preparation

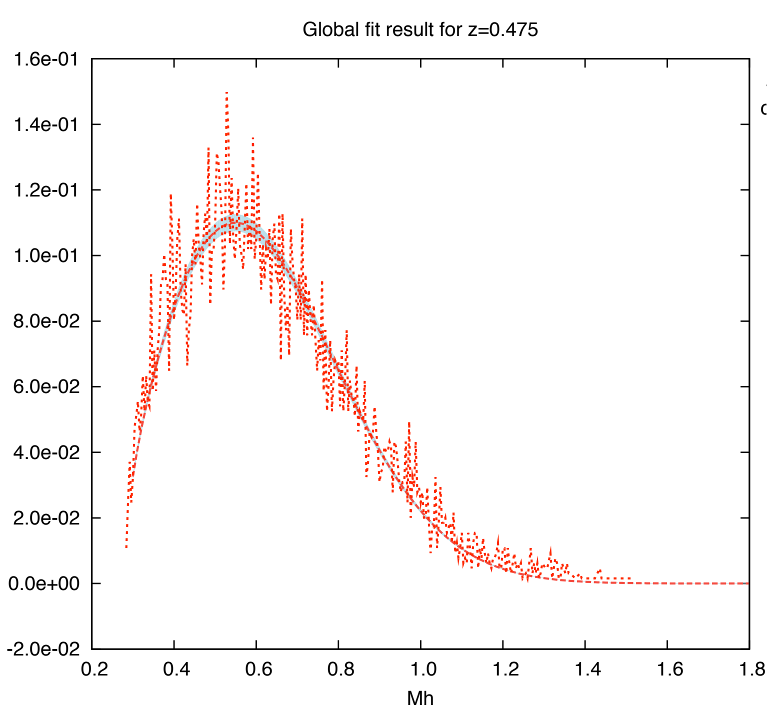




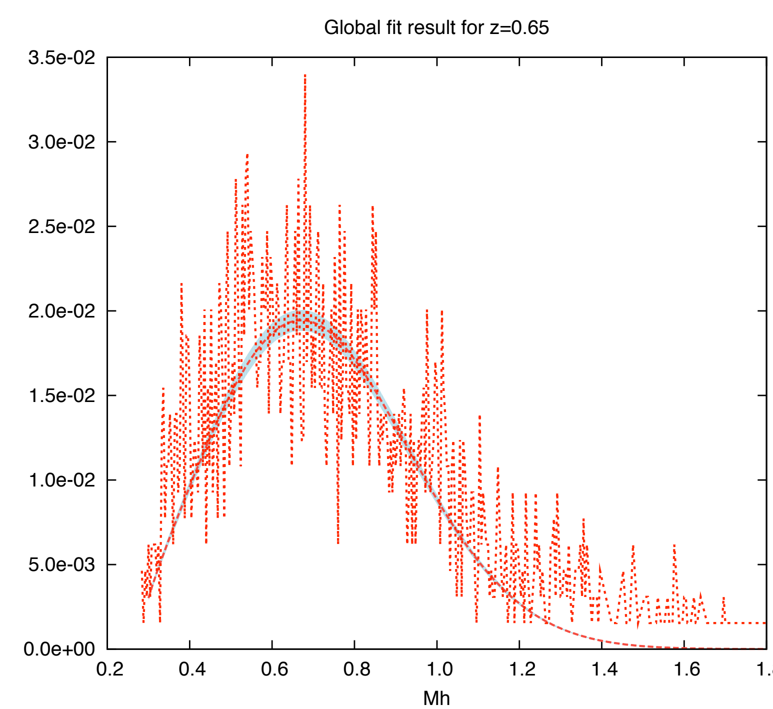
(z, M_h) fit
of the 4 z-bins

$$D^c_{1,bkgd}(z, M_h) \quad \propto \quad \sqrt{M_h^2 - 4m_\pi^2}\, A(1-z) z^B \frac{\exp g(z, M_h)}{[M_h^2 - g(z)^2]^2 - g'(z)}$$

PRELIMINARY



$\chi^2/d.o.f \sim 1.6$



Polarized Cross Section

Constraints on the Functional Form from

1. the kinematics
2. the sp interference-like
3. physics model-inspired

I want to fit :

$$d\sigma \propto \frac{6\alpha^2}{Q^2}\frac{\pi^2}{16}\frac{\langle \sin^2\theta_2\rangle}{2M_h} f^a_{H_1^{\sphericalangle}}(z,M_h)\int_{0.2}^{1}\int_{0.28}^{2} f^{\bar a}_{H_1^{\sphericalangle}}(\bar z,\bar M_h)$$

with a functional form like:

$$\begin{aligned} f^a_{H_1^{\sphericalangle}}(z,M_h) &= 2\,M_h\,z^2\,\frac{|\vec R|}{M_h}\sum_a e_a^2\,H_{1\,a}^{sp}(z,\xi,M_h^2) \\ &= z^2\sqrt{M_h^2-4m_\pi^2}\sum_a e_a^2\,H_{1\,a}^{sp}(z,M_h^2) \end{aligned},$$

Error on σ : error on the data & error on the fit of unpol. σ

1st step: no integration but bin value from experiment.

Propagation of errors ...

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further assumption

$$H_1^{\sphericalangle\,u}(z,M_h) = f(z,M_h)\,D_1^u(z,M_h)$$

Error on σ : error on the data & error on the fit of unpol. σ

1st step: no integration but bin value from experiment.

Propagation of errors ...

IFF from the Asymmetry

Fit of the sum over flavors of

$$\sum_a e_a^2 \, H_{1\,a}^{\sphericalangle\, sp}(z, M_h^2)\, \bar{H}_{1\,\bar{a}}^{\sphericalangle\, sp}(\langle \bar{z}\rangle, \langle \bar{M}_h^2\rangle)$$

Assumptions

- role of flavor decomposition from UNPOLARIZED FF

MonteCarlo uds-c

$$D_1^u(z, M_h) = D_1^{\bar{u}}(z, M_h) = D_1^d(z, M_h) = D_1^d(z, M_h)$$
$$D_1^s(z, M_h) = D_1^{\bar{s}}(z, M_h)$$
$$D_1^c(z, M_h) = D_1^{\bar{c}}(z, M_h)$$

- Two (or more) scenarios

I. . $D_1^s(z, M_h) = 0$

II. . $D_1^s(z, M_h) = D_1^u(z, M_h)$

Rôle of strange

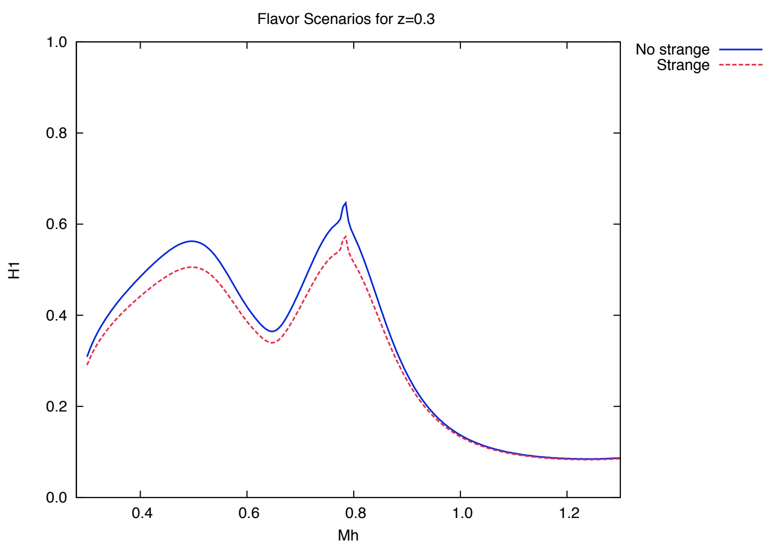
H1<

- flavor decomposition

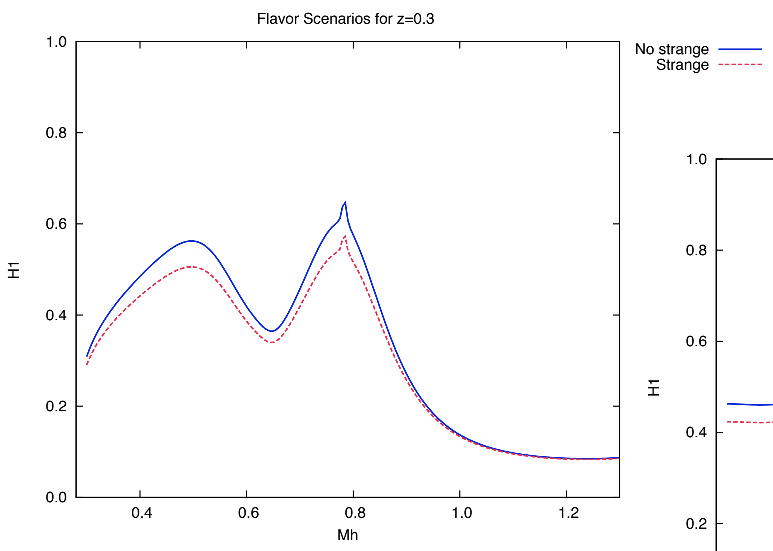
$$H_1^{\sphericalangle\, u}(z, M_h) = H_1^{\sphericalangle\, \bar{d}}(z, M_h) = -H_1^{\sphericalangle\, d}(z, M_h) = -H_1^{\sphericalangle\, \bar{u}}(z, M_h)$$
$$H_1^{\sphericalangle\, s}(z, M_h) = H_1^{\sphericalangle\, \bar{s}}(z, M_h) = 0$$
$$H_1^{\sphericalangle\, c}(z, M_h) = H_1^{\sphericalangle\, \bar{c}}(z, M_h) = 0$$

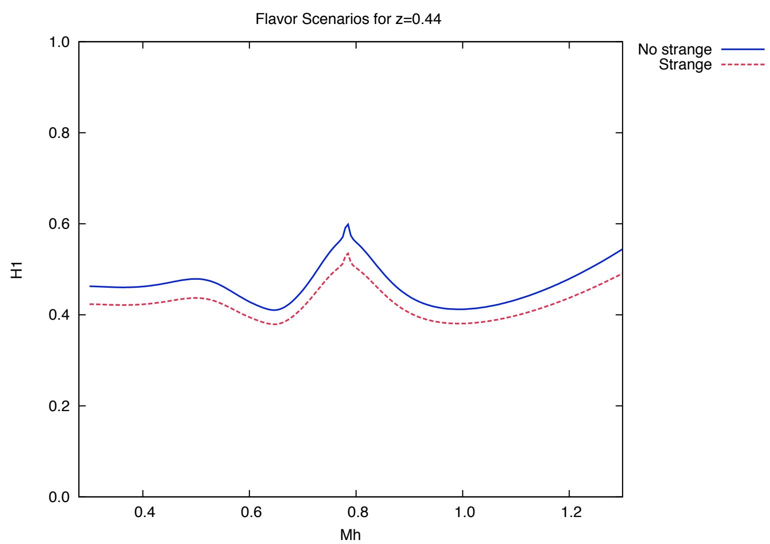
Flavor Decomposition: The Scenarios

Flavor Decomposition: The Scenarios

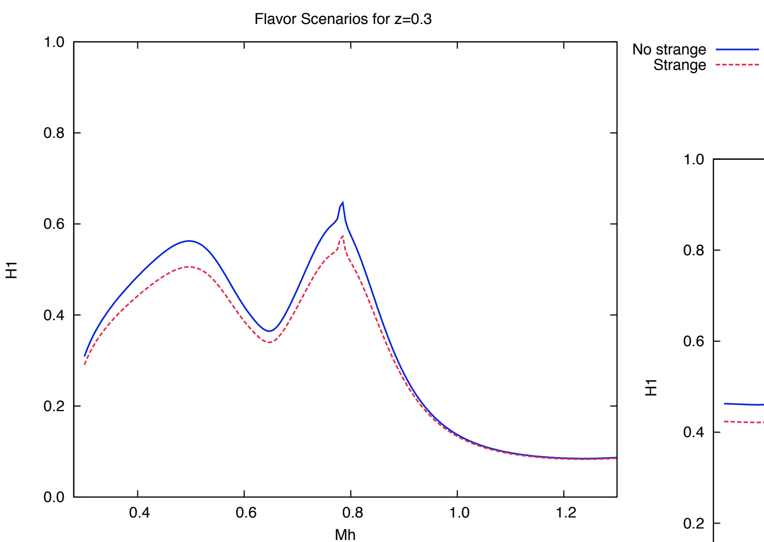


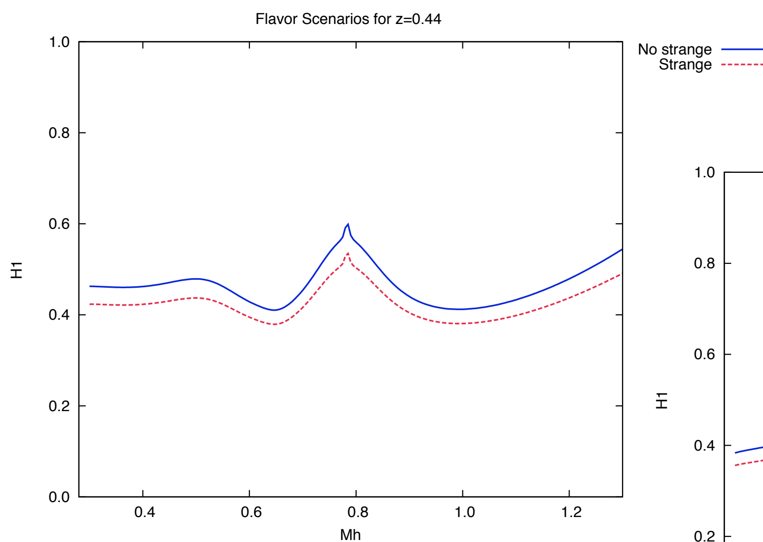
Flavor Decomposition: The Scenarios

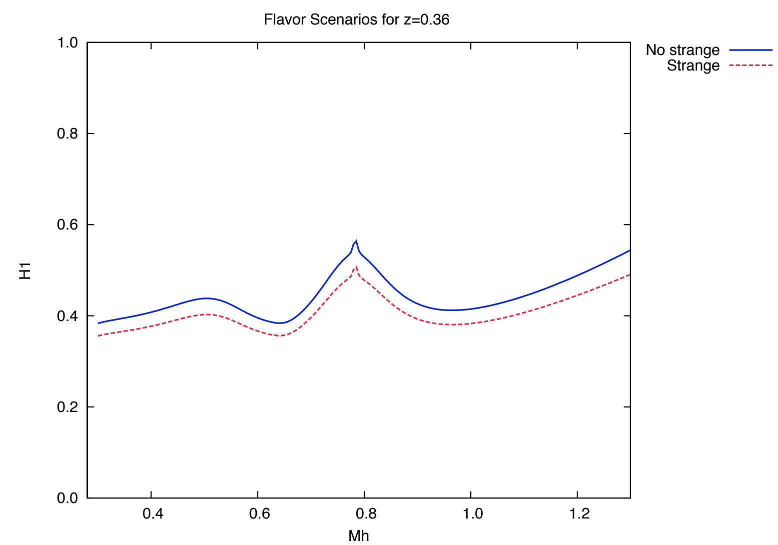




Flavor Decomposition: The Scenarios







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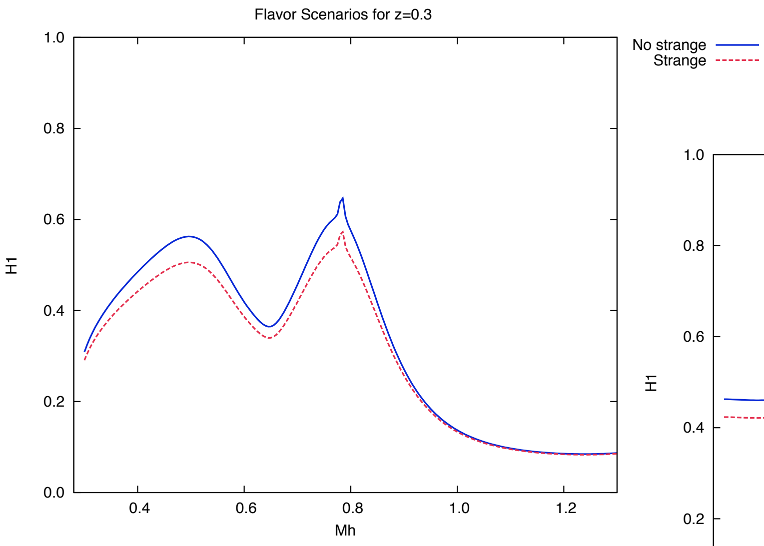
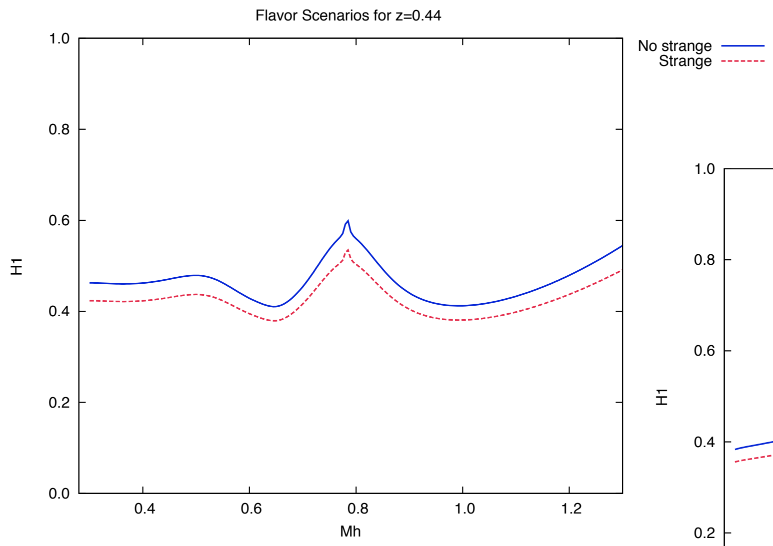
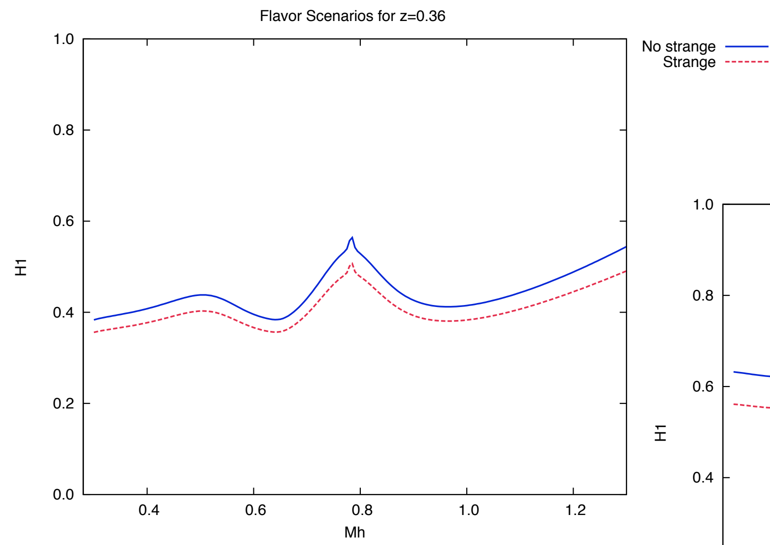
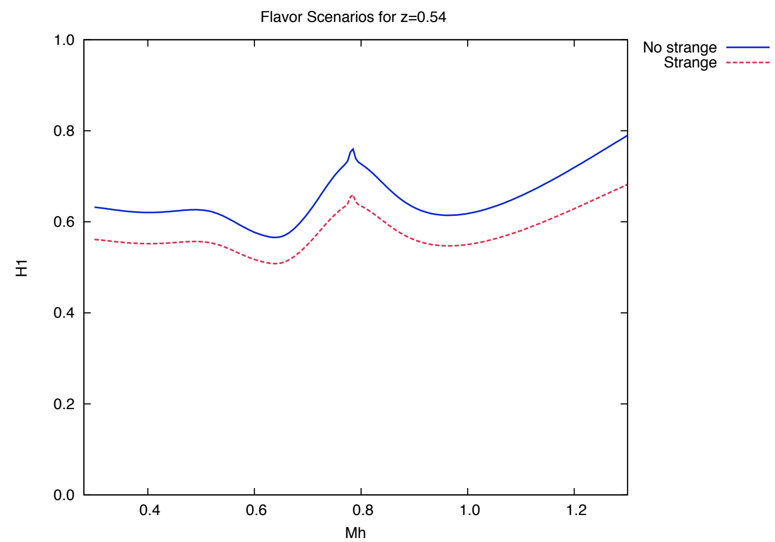
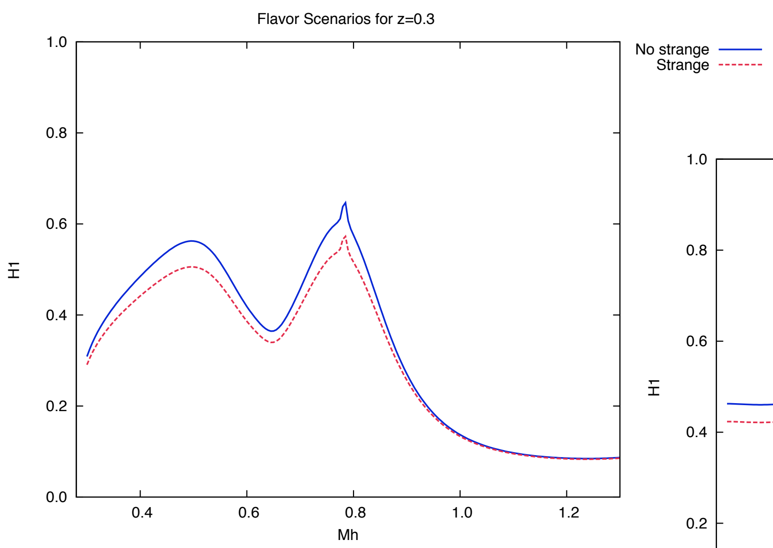


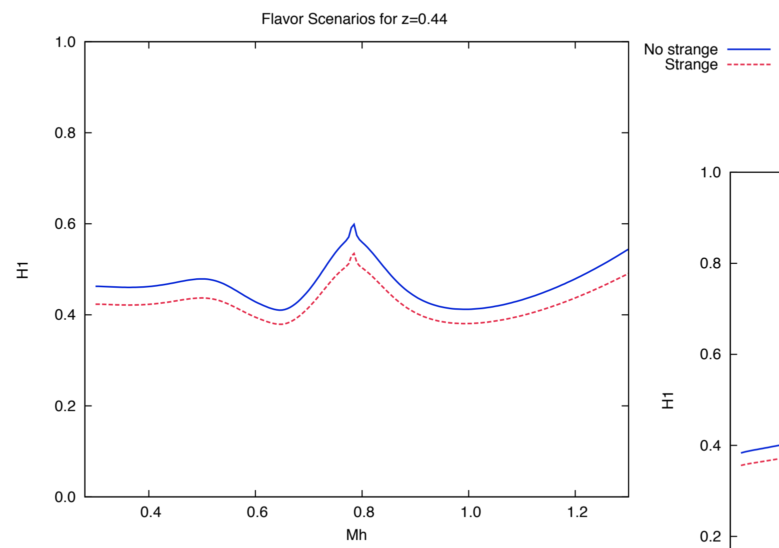


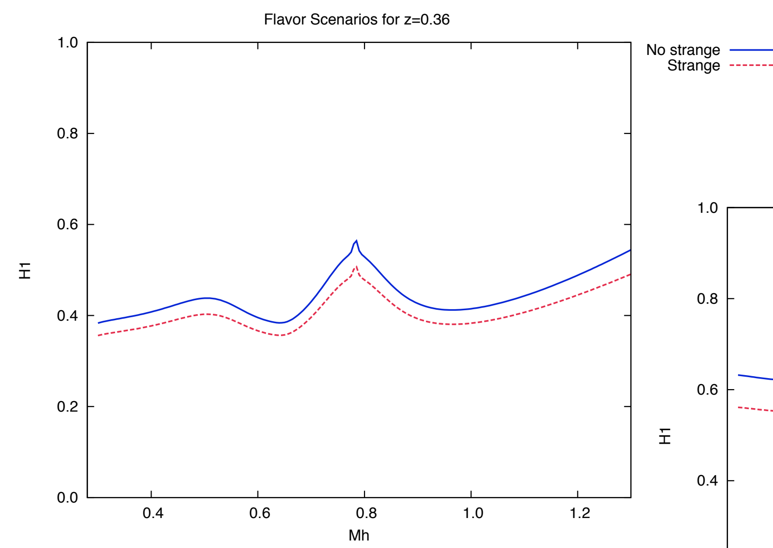


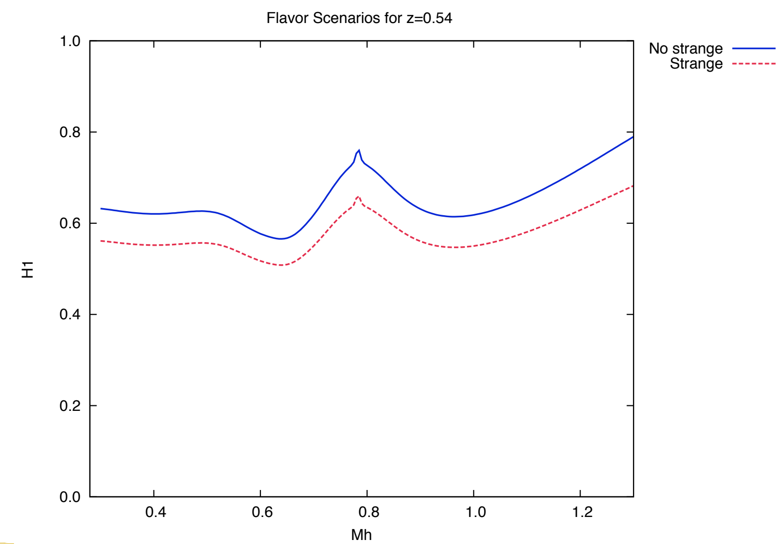


Flavor Decomposition: The Scenarios







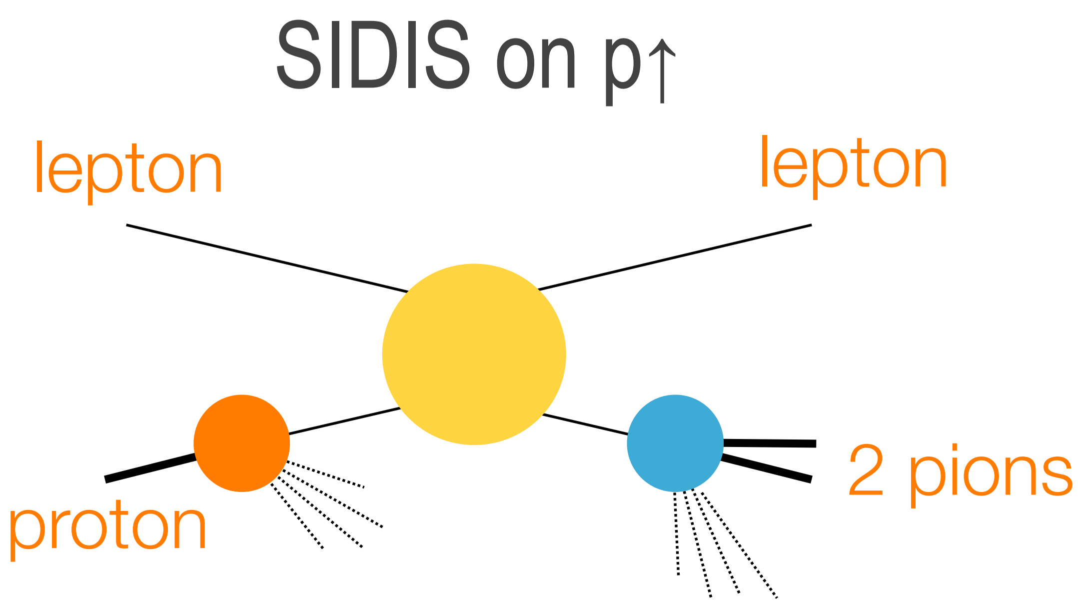


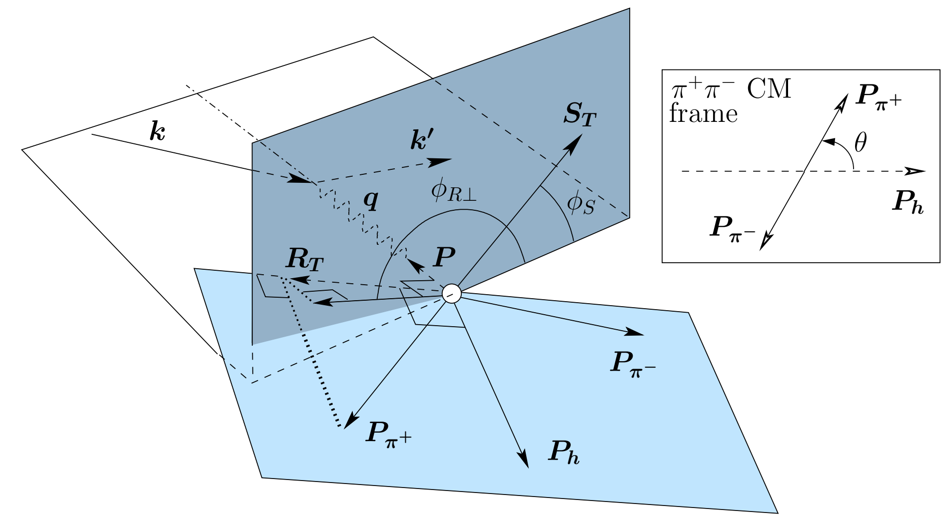
$$A^{\cos(\phi_R+\phi_{\bar{R}})} \propto -f(z,M_h)\, f(\bar{z},\bar{M}_h) \frac{D_{1,u}(z,M_h^2)\ \ D_{1,u}(\bar{z},M_h^2)}{\sum_q e_q^2\ D_{1,q}(z,M_h^2)\ \bar{D}_{1,q}(\bar{z},\bar{M}_h^2)}$$

Scenarios I & II

Flavor decomposition influences f(z, Mh)

Strange and Transversity...

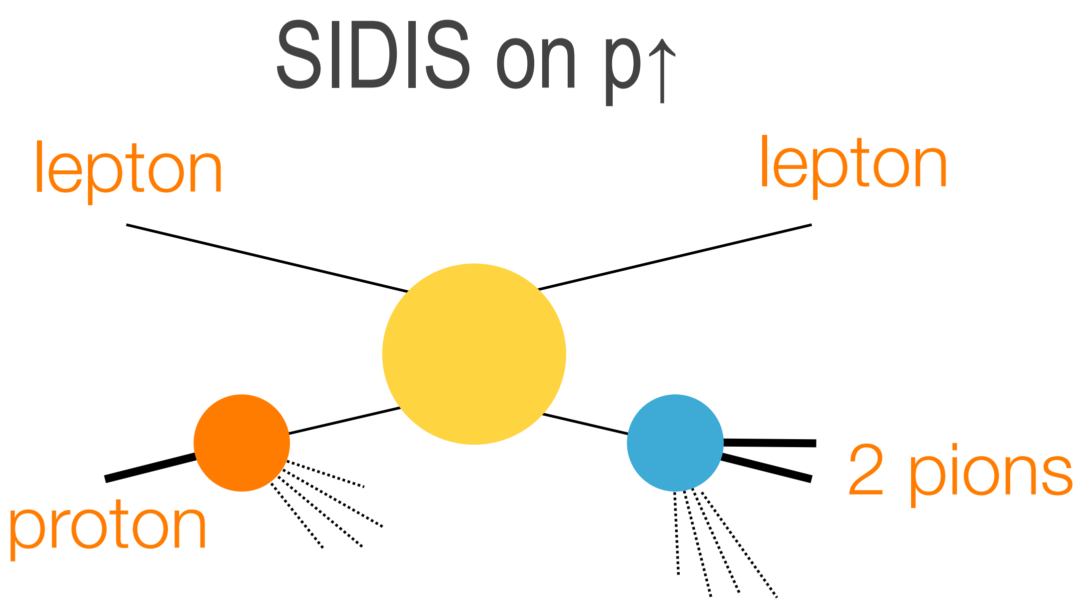


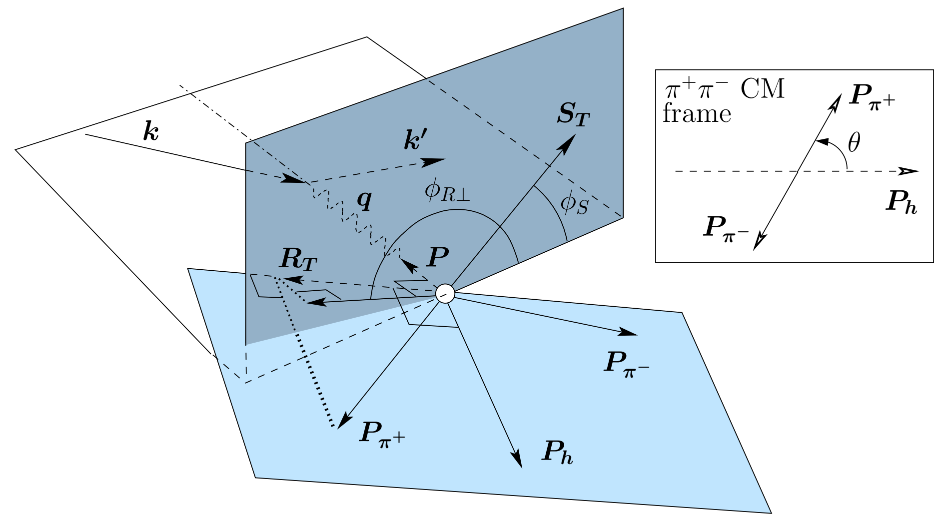


$$A_{UT}^{\sin(\phi_R+\phi_S)\sin\theta}(x,y,z,M_h^2) \propto f(y)\, \frac{\sum_q e_q^2\, h_1^q(x)}{\sum_q e_q^2\, f_1^q(x)} \times \frac{H_1^{\sphericalangle,u}(z,M_h)}{D_1^u(z,M_h)}$$

- then we are left with a **one variable** fit

Strange and Transversity...





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Flavor decomposition
Scenario I. and II.

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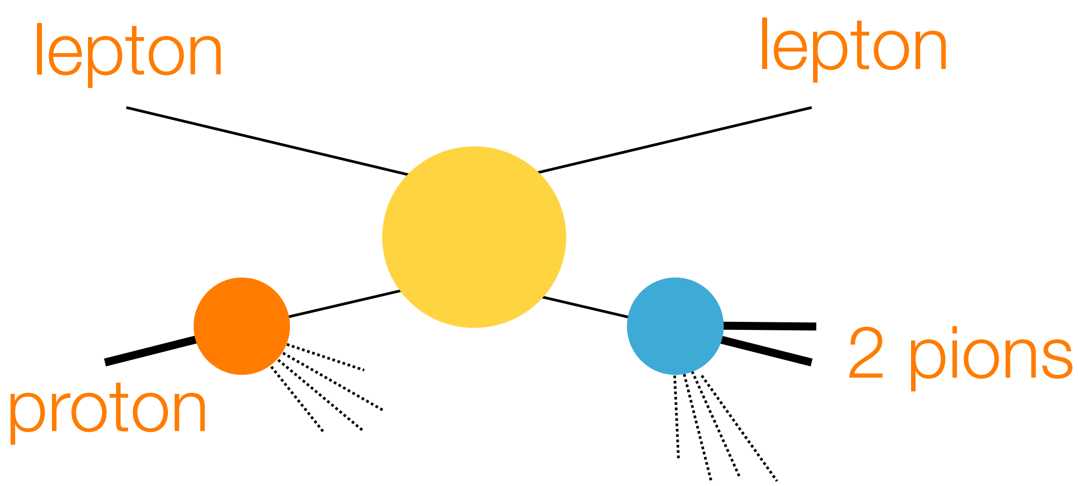
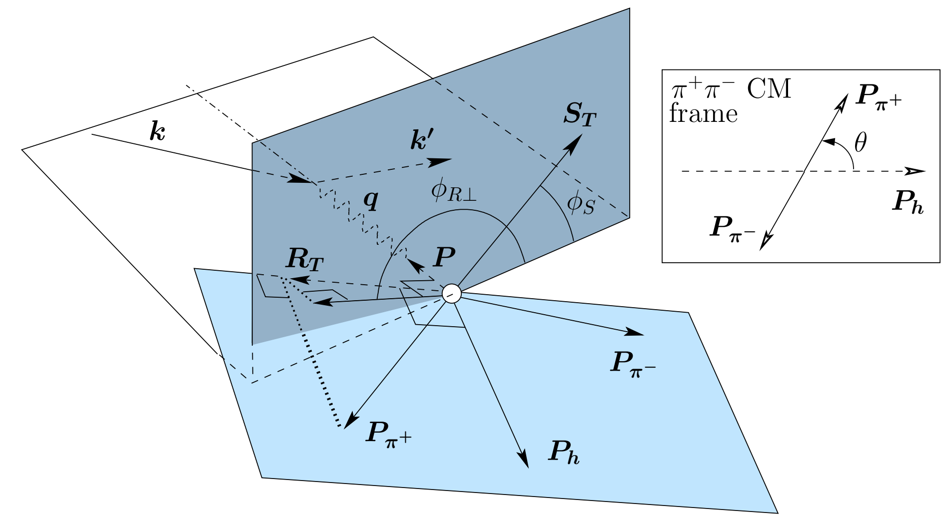
Strange and Transversity...

SIDIS on p↑





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Flavor decomposition of f1 (x)
Depends on the parametrization we use
To be studied...

Flavor decomposition
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Strange and Transversity...

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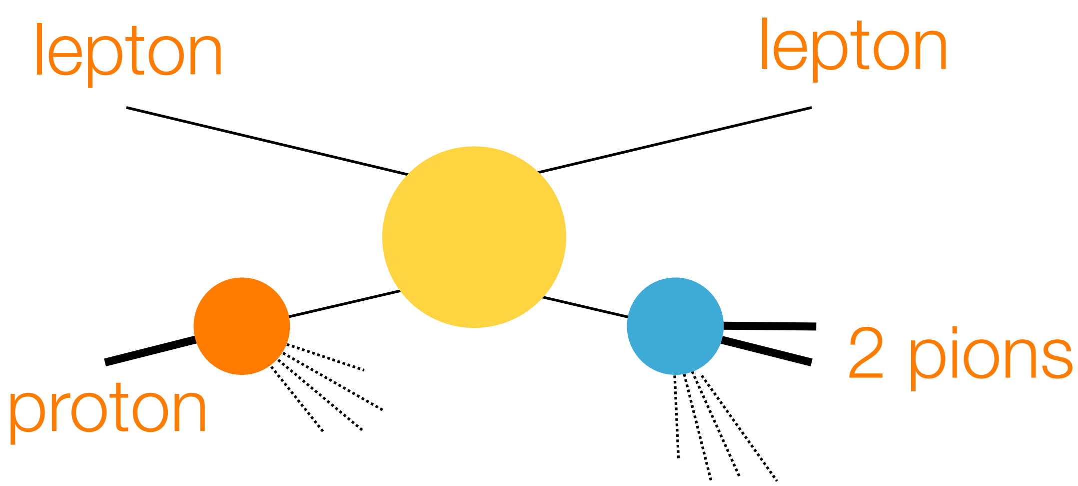

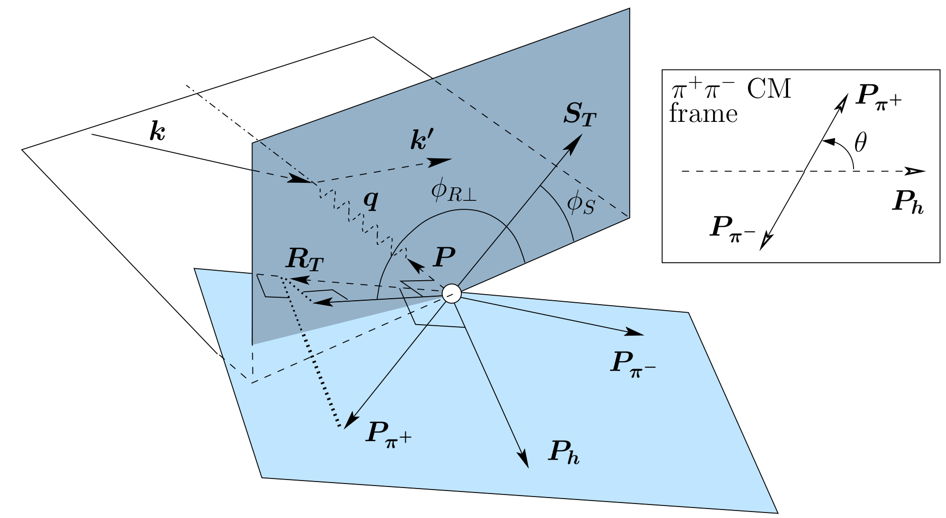

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Back to the Transversity...

HERMES

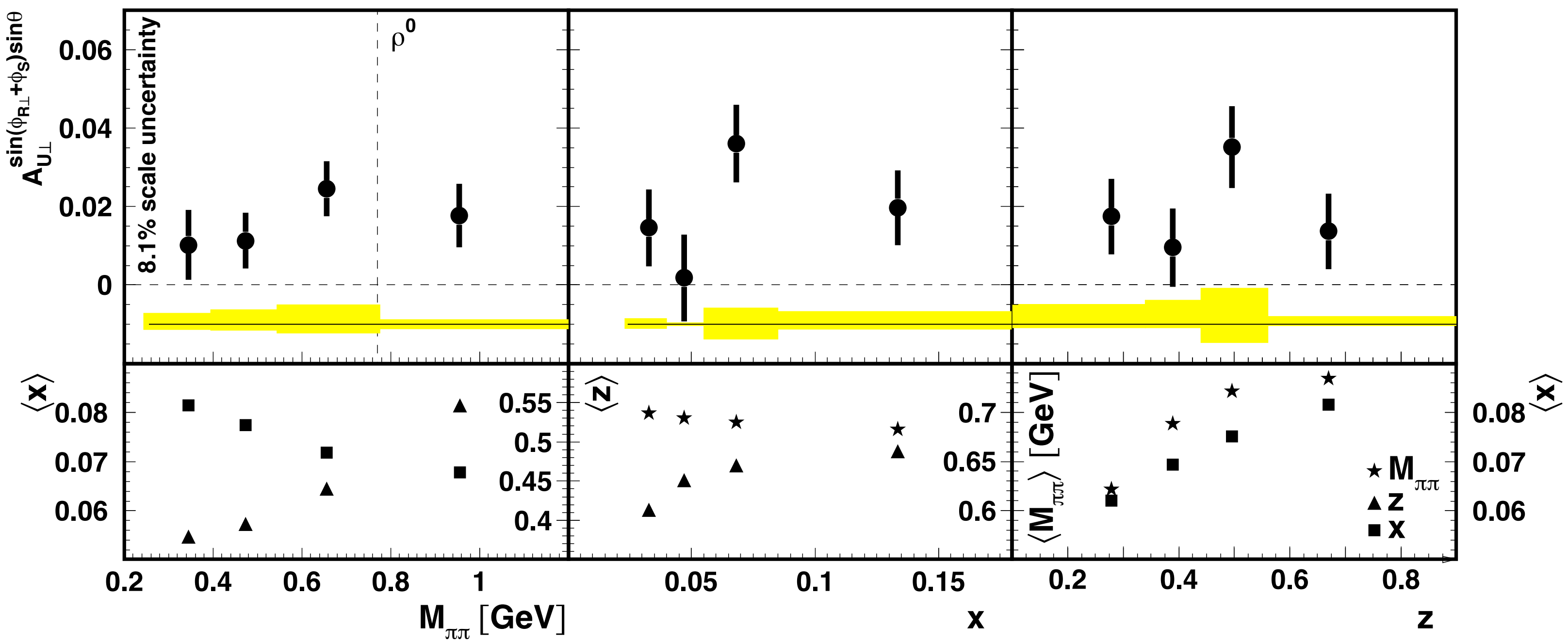

Figure 2: The top panels show $A_{U\perp}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta}$ versus $M_{\pi\pi}$, x, and z. The bottom panels show the average values of the variables that were integrated over. For the dependence on x and z, $M_{\pi\pi}$ was constrained to the range 0.5 GeV $< M_{\pi\pi} <$ 1.0 GeV, where the signal is expected to be largest. The error bars show the statistical uncertainty. A scale uncertainty of 8.1% arises from the uncertainty in the target polarization. Other contributions to the systematic uncertainty are summed in quadrature and represented by the asymmetric error band.

COMPASS not published but ¿normalization factor? w.r.t HERMES data

Di-hadron Fragmentation Functions

probability for (un-)polarized quarks to fragment into the hadron pair (h1 h2)

In particular, IFF

relates transverse polarization of the fragmenting quark to angular distribution of the hadron pairs in the transverse plane

- Collinear factorization
- Universality
- No convolution
- Evolution understood

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CONCLUSIONS

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Flavor Decomposition

- Rôle on the param of $H_1^{\triangleleft}$
- Monte Carlo input
- Data for Kaons
- BaBar data

CONCLUSIONS

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Flavor Decomposition

- Rôle on the param of $H_1^{\sphericalangle}$
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DiFF way to Transversity

- We have fitted the D_1 DiFF from the BELLE experiment
- We have almost extracted $H_1^{\sphericalangle}$ from the BELLE data
- Next step: *Go down to SIDIS and extract **Transversity***